Astrophysique Instrumentation Modélisation

Unité Mixte de Recherche N° 7158

Report 2007 – mid 2012
Project 2014 - 2018

Cover legend:
Herschel image of the Aquila region
where the filamentary structure
has been extracted thanks to the *xfilaments*
algorithm, used by the *getsources* extraction
software package (Menshchikov et al. 2012).

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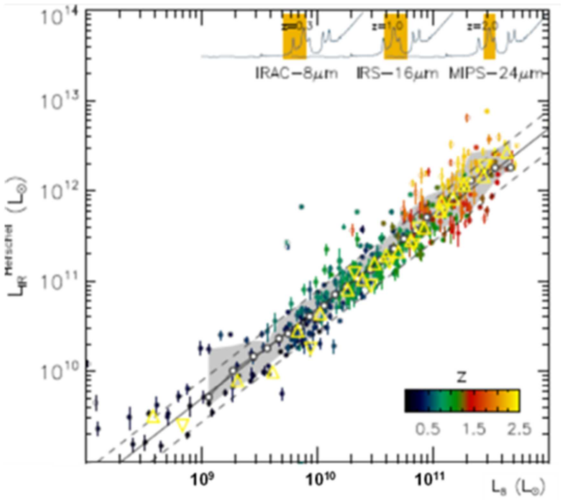
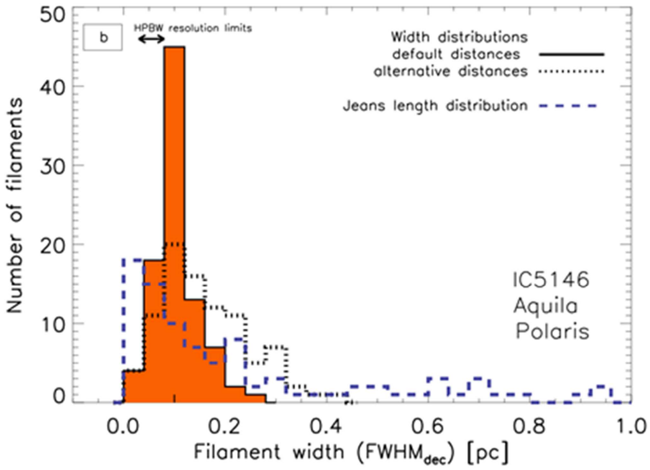
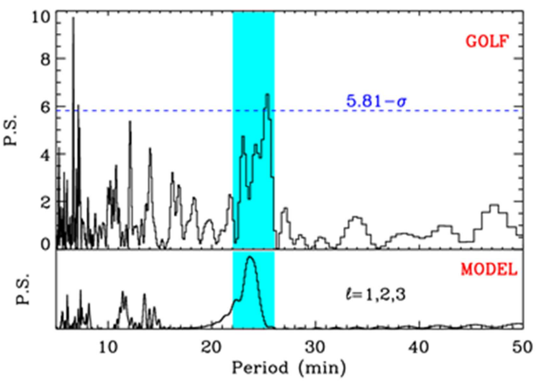
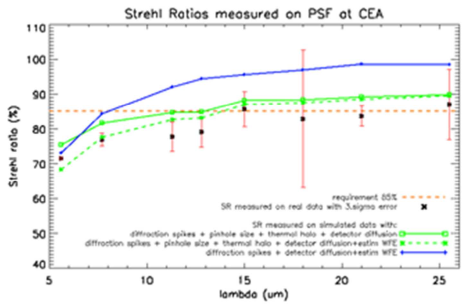


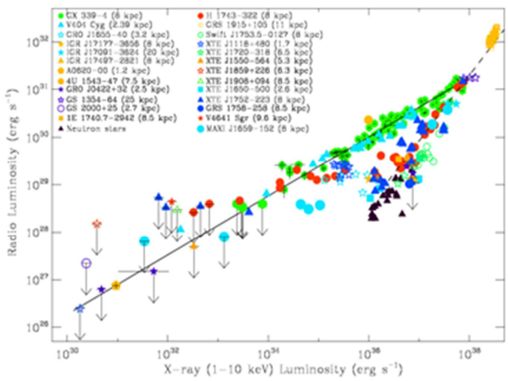


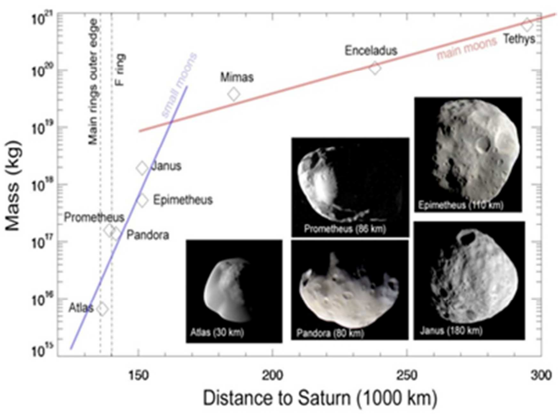
FIRST PART

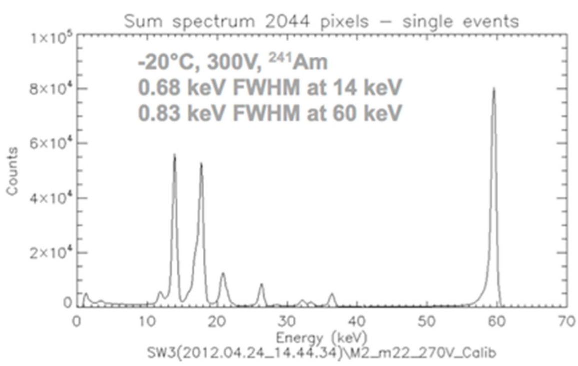
Report











The AIM Laboratory (Astrophysics Instrumentation Modelling) is a joint research unit (UMR) supervised by CEA-Irfu[1], Paris-Diderot University, and CNRS-INSU[2].

Created on the 1st of January 2005, the research unit results from a long collaboration between SAp (the CEA's Astrophysics Department) and CNRS (1979-2004, in the administrative form of an associated research unit), and between SAp and Paris-Diderot University (1997-2004, in the administrative form of a research team: the γ-Gravitation team).

Following the only major recommendation of the AERES visiting committee in 2008, the engineers and technicians from SAp have now been included in AIM. On the 30th of June 2012, AIM consisted of **110 permanent** employees: 52 researchers (39 CEA, 8 Paris-Diderot, and 5 CNRS), 13 instrumentalists (12 CEA, 1 CNRS), 40 engineers and technicians (CEA), 5 support staff (4 CEA, 1 CNRS), and **88** people under a **temporary** contract: 32 PhD students, 46 post-docs, 9 engineers, 1 apprentice.

AIM is located at the Saclay CEA site. Four offices at the Tolbiac campus of the Paris-Diderot University have recently been attributed to AIM research-lecturers.

The missions of the unit are twofold:

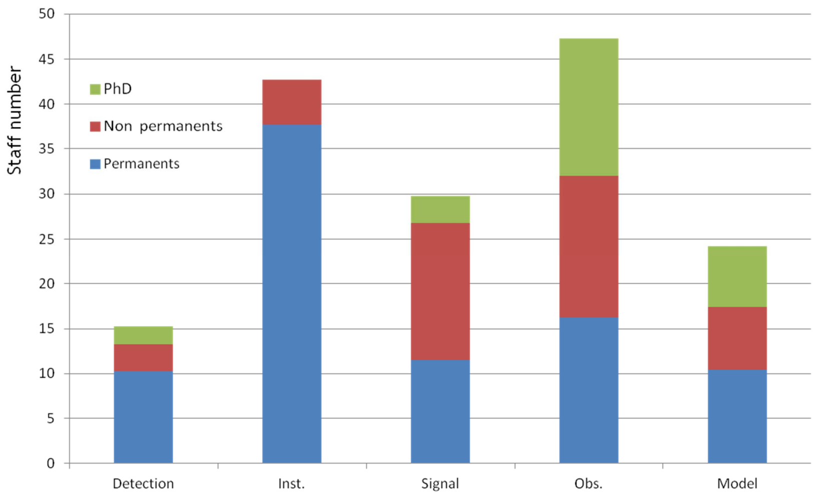
- first, to acquire new knowledge about the Universe and its constituents by :
  - developing research programs in Astrophysics at the best international level,
  - developing state of the art instruments required for this research, mainly for space missions, but also for large ground-based telescopes;
- second, to disseminate the new knowledge by training PhD students, lecturing, and making the results accessible to the general public.

A. Activities and Results

1. Acquisition of New Knowledge

a) Activities, Themes, Results

AIM is active along the whole chain of new knowledge acquisition from instrumental Research & Development (R&T) to astrophysical discoveries in a coordinated way such that the various activities reinforce each other. The activities and staff are balanced between **detector R&T, space instrumentation, signal processing, multi-wavelength observations/interpretation, and multi-scale modelling**, especially with numerical simulations (see Figure just below). AIM is one of the very few laboratories in Europe simultaneously conducting large observing programs at the best international level, developing innovative data processing methods, state of the art space and ground-based instrumentation, front line numerical simulations on massively parallel computers. Note that many tasks are done **as a service to the community ("tâche de service"),** such as releasing numerical codes and data analysis software as open sources, or releasing scientific material essential for data analyses (instrument performances, source catalogues, etc.).



Number of staff devoted to the various activities carried out at AIM along the chain of new knowledge acquisition (Detection, Instrumentation, Signal Processing, Observation-Interpretation, and Modeling).

[1] Institute of Research into the Fundamental Laws of the Universe at the French Alternative Energies and Atomic Energy Commission
[2] National Institute for Earth Science and Astronomy of the French National Centre for Scientific Research

We study the constituents of the Universe following an original strategy combining multi-wavelength observations (from radio to γ-rays) and multi-scale modelling.

The themes developed in the unit are divided in three wide sections, according to scale:

- Galaxies – galaxy clusters. Via observations of galaxies (gas, dust, morphology, etc.) and galaxy clusters (temperature, mass, etc.), we study **galaxy evolution** by looking for **underlying laws** describing the observed properties. In parallel, we conduct large numerical simulations to isolate the **main physical mechanisms at work**. We moreover use observations of galaxy clusters and galaxies (weak lensing) as **cosmology tools** to constraint **"dark energy"** properties.
- Milky Way and nearby galaxies. Via observations of specific galactic constituents (interstellar medium, supernova remnants, microquasars) and large numerical simulations, we study key physical processes responsible for the evolution of galaxies, such as **star formation, accretion-ejection of matter** around black holes, acceleration/propagation of cosmic rays.
- Sun – Stars and planetary systems. Via observation of the **Sun and the Saturn system** (planet, rings, and satellites) as well as other stars, we make detailed studies of physical processes at work in stellar evolution and dynamics, planet formation, and star-planet interactions.

All the objectives that were planned in the 2007 AIM project have been achieved and even exceeded in some cases. A few examples of the results are briefly discussed below, while additional results can be found in the report from the teams.

All our research themes are fully in line with the 2007 ASTRONET prospective report (www.astronet-eu.org/FP6/astronet/www.astronet-eu.org/spipef16.html?article115). We took part in this prospective exercise in particular by emphasizing the importance of studying dark energy.

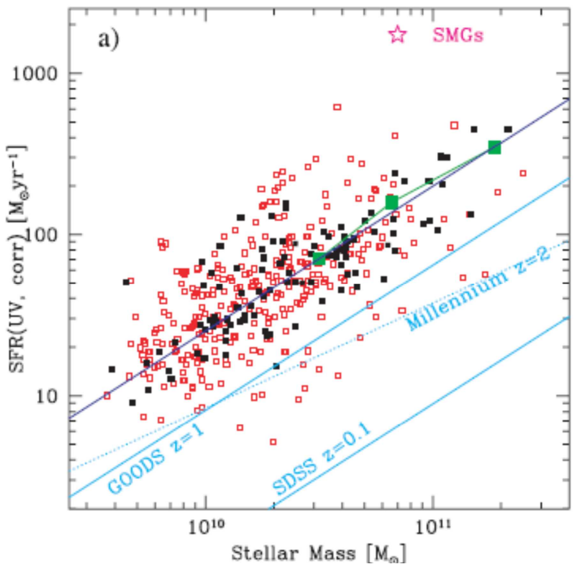
Observations/Interpretation

Galaxies – galaxy clusters

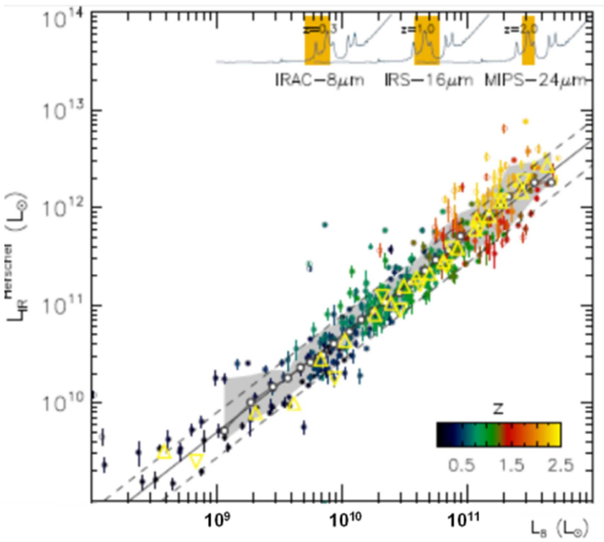
Large catalogues of clusters of galaxies are powerful cosmological probes, provided cluster properties are well understood. We have led several ***XMM-Newton*** surveys (such as the XXL survey, the largest XMM program ever attributed) and co-led the construction of the ***Planck*** Sunyaev-Zeldovich **catalogue of clusters.** Exploiting X-ray/SZ synergy, our emphasis has been on r**igorous measurement of the structural and scaling properties** of clusters using *representative* samples, as a probe of the interplay between gravitational and non-gravitational processes in structure formation.

Leading large international key programs with ***Herschel***, ***IRAM***, ***CFHT-MEGACAM***, we have gained key insight into galaxy evolution in terms of **mass growth**, **star formation rate history** (e.g. discovery of the correlation between stellar mass and star formation rate, demonstrating the existence of a "main infrared sequence" for galaxies), **central black-hole growth** (dynamical disk instabilities), etc…, securing our position **of essential international playe**r in that field.

Finding the underlying laws describing the observational properties



*Discovery of a correlation between the stellar mass and the Star Formation rate ; E. Daddi et al. "Multiwavelength study of massive galaxies at z = 2; I. star formation and galaxy growth", **ApJ 670**, 156 (2007).*

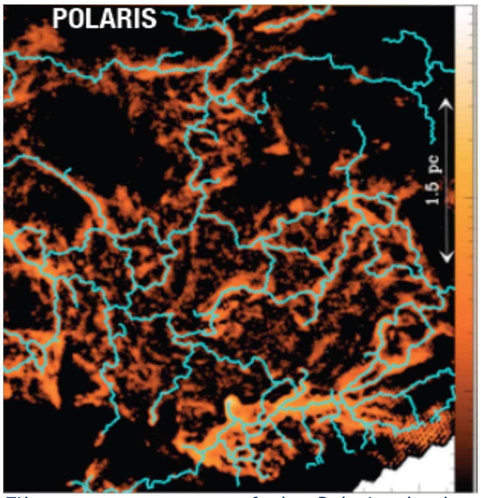


*Discovery of an IR "main sequence" for star forming galaxies; D. Elbaz et al., "Goods Herschel: an infrared main sequence for star forming galaxies", **A&A 523,** A119 (2011).*

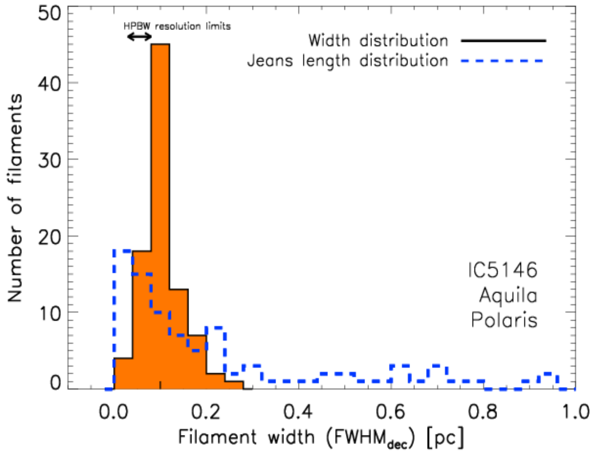
Milky Way and nearby galaxies

Since the 90's, we have been specialized in the **earliest phases of star formation** for which we have acquired an international leadership (e.g. introducing a new class of young stellar objects: the class 0; Ph. André et al. **ApJ 406**, 122 (1993)). Over the 2007-2011 period, leading large international ***Herschel and IRAM programs***, we have reinforced our leadership, in particular making a step forward in the **link between star formation and the intimate structure of the InterStellar Medium** (ISM), showing that filaments are ubiquitous, have a typical width of 0.1 pc and, when dense enough, are the place where stars form.

Breakthrough in the earliest stages of star formation with Herschel



*Filamentary structure of the Polaris cloud as observed with Herschel (Men'shchikov et al., **A&A 518**, L103 (2010)).*



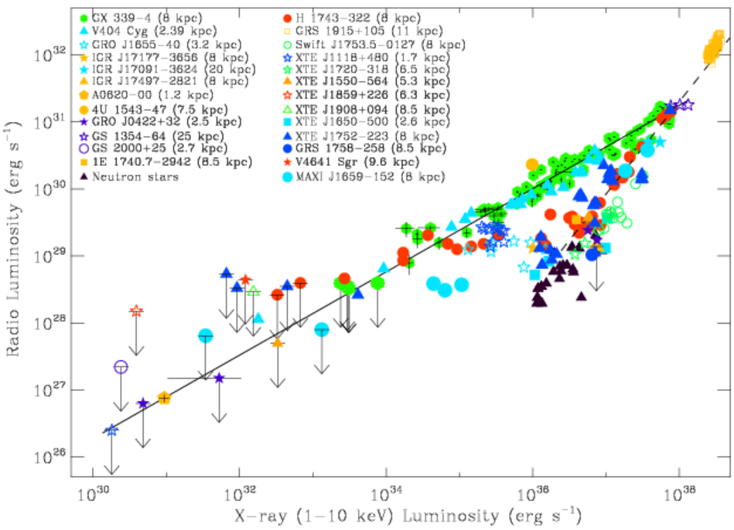
*The width of the filaments exhibits a typical size of 0.1 pc (Arzoumanian et al., **A&A 529**, L6 (2011)).*

Leading large international Herschel and Fermi programs, we have studied how dust and cosmic rays can trace the total amount of interstellar gas in different cloud environments in the Milky Way and nearby galaxies.

From the first resolved GeV images of supernova remnants and of a starburst region (Cygnus X) obtained with Fermi, we have found key constraints on how cosmic rays are released into interstellar space and how they are confined in the turbulent environment of massive stellar clusters (Abdo et al., **Science 327**, 1103 (2010); Ackermann et al. (correspondent author: I. Grenier), **Science 334**, 1103 (2011)). Beyond attesting the long advocated assumption that OB associations host cosmic-ray factories (pioneered by our laboratory in the eighties, Montmerle 1979 Ap.J 231, 95, Cesarsky and Montmerle 1983, Space Science Rev. 36, 173), these findings deeply question our current ideas on cosmic-ray propagation inside galaxies.

Leading multi-wavelength observation campaigns of **microquasars** (a concept invented in the unit; F. Mirabel et al., **Nature 371**, 46 (1994)), we have pursued and developed the study of the connection between accretion and ejection around stellar-mass black holes. We have discovered a population of "outliers" to the "universal" radio/X-ray correlation, probably corresponding to radiatively more efficient accretion flows (Coriat et al., **MNRAS 414**, 677 (2011); Corbel et al. in press).

Discovery of an outlier population to the "universal" radio/X-ray correlation

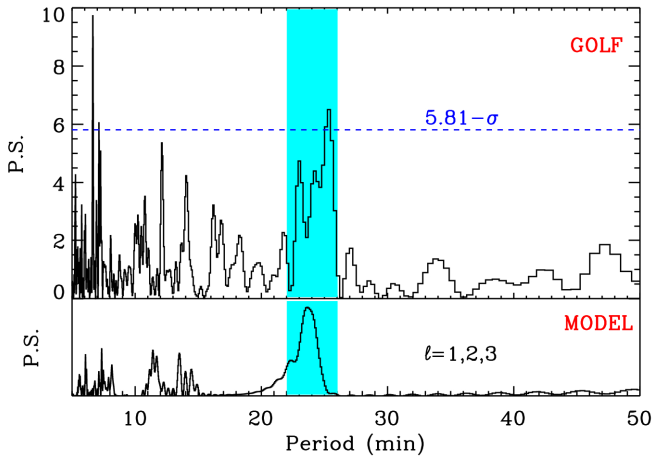


Radio and X-ray (1-10 keV) luminosities for Galactic accreting binary black Holes in the hard and quiescence states. It illustrates the standard correlation, with index 0.6, and the new correlation for the outliers with index 1.4. (Corbel et al. in press).

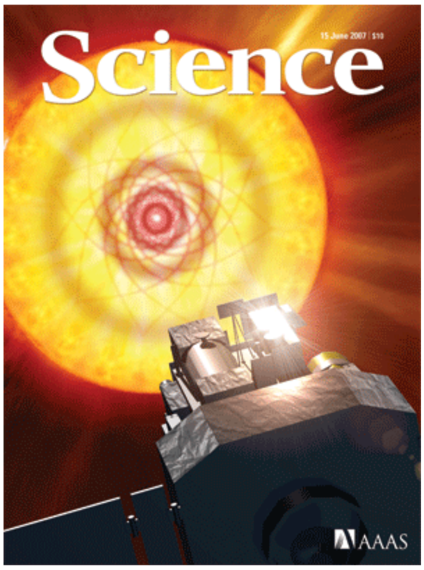
Sun – Stars and planetary systems

We are also studying how stars work, the Sun first of all. We have deepened our knowledge of the Sun via **helioseismology** observations (discovery of **global gravity modes** with SOHO-GOLF (Garcia et al., **Science 316**, 1591 (2007)) and large magneto-hydrodynamics simulations on massively parallel computers. The link between the Sun and other stars has been made through our participation in the exploitation of **asteroseismology** data obtained by the ***Kepler*** and ***Corot*** missions and state-of-the art simulations of stellar dynamos, activity and cycles. We are developing the field of interactions (magnetic, tidal forces) between the stars and their environment (planet, wind, circumstellar envelope).

Tracking Solar Gravity Modes



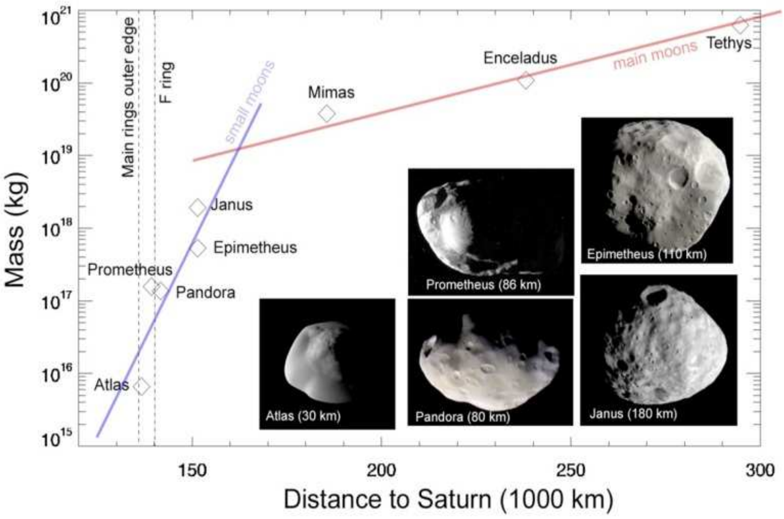
Power spectrum of the GOLF real data (Top) and a simulation (bottom) showing the peak corresponding to the separation between the dipole gravity modes (blue shaded region). (Garcia et al. **Science 316, 1591** *2007)*



Cover of Science for Garcia et al 2007 paper; Artist's view of the Sun's core, showing gravity waves inferred from observations with SOHO-Golf.

The Saturn system serves as a detailed laboratory to study the gravitational processes at work in planet formation and circumstellar discs. Exploiting **Cassini** observations, we have developed an original theory of **formation and evolution of Saturn satellites** (Charnoz et al. **Nature 465**, 752 (2010)), which only works if the tidal force between Saturn and its satellite is 10 times higher than usually considered. Confirmation of the strong tidal force has been obtained through precise astrometric measurements of the motion of Saturn satellites (Lainey et al., **ApJ 752**, 19 (2012)). Such a strong tidal force can be reproduce by the new model of Remus et al. (**A&A 541**, A165 (2012)).

A new model to the formation of Saturn satellites



Mass of Saturn's moons versus distance. The moon diameters are indicated in the insets. The vertical dashed lines show the locations of the F ring and the outer edge of the A ring. The mass-distance evolution can be explained as a time series of satellite formations within the ring and their subsequent dynamical escape and recoil from the ring. Images from the Cassini mission, courtesy of NASA/JPL/SSI). Charnoz et al. ***Nature 465****, 752 (2010).*

Numerical simulations

In the AIM project of 2007, we had fully anticipated the increasing importance of the numerical simulations and decided to strongly support the activity along different lines:

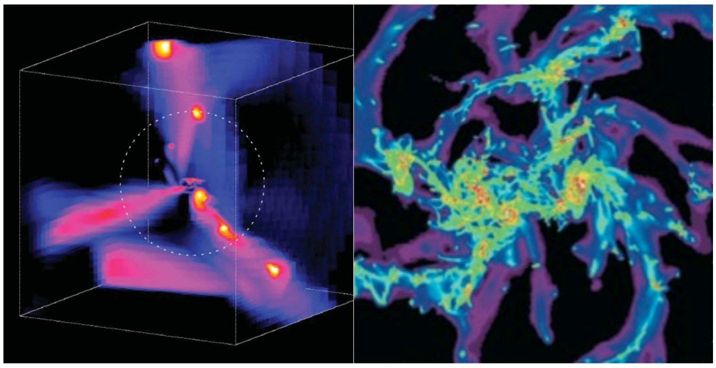
- developing **original numerical codes** for massively parallel computers, such as the RAMSES adaptive mesh code, and making them available to the community. Note that improving codes contributes as much to the global performance increase as the hardware improvement;
- participating in **Grand challenges** during the commissioning of new machines, (Mare Nostrum, CCRT, CINES);
- using the codes in relation to observations, either to **interpret or predict the result of observations**;
- using them standalone to **discover the main mechanisms at work** in the structuration of the Universe (e.g. cold flows, disk instabilities, disc/planet interactions, planetesimal accretion,…), or the inner dynamics of stars (convection, rotation, turbulence, magnetism, waves);
- using them to predict or **optimize the performances of future space missions**, such as Euclid.

The way to obtain computing time on a super computer is now similar to the way to obtain time on a telescope: proposals evaluated by a peer review committee. In 2011, we have obtained, as Principal Investigator (PI), 25 million hours of computing time (galaxy evolution, star formation, magnetism of the stars, turbulence in protoplanetary disks). **This is 55% of the total computing time distributed for Astrophysics by the French Agency for computing (GENCI).** In addition, we have obtained 9 million hours of time in the Framework of the European Prace Agency.

Important discoveries are now made thanks to numerical simulations:

- At the large structures scale, a major discovery has been obtained with the RAMSES code developed at AIM; indeed, the Mare-Nostrum simulation with the code has revealed the importance in the galaxy evolution of the continuous accretion of cold pristine gas in the form of filaments towards the core of dark matter halos (Dekel et al., **Nature 457**, 451 (2009)).
- At the scale of galaxies, the growth of the supermassive black hole at the center of galaxies is an unsolved problem. The mechanism usually considered was the merging of galaxies. Numerical simulations at high resolution have identified a new process to feed the central black hole at high redshift: disk instabilities. This process also contributes to the building of galactic bulges, through the migration and merging of massive clumps formed in unstable gas disks (Bournaud et al., **ApJL 741**, L33 (2011)).
- At the scale of stars, the mechanism responsible for supernova explosions is a long-standing theoretical puzzle. That there is a need for 3D numerical simulations was made clear when simplified models of supernova explosions showed the presence of a Standing Accretion Shock Instability (SASI), asymmetric by nature. It is not yet possible to perform realistic 3-D numerical simulations and this re-enforces the need to understand the instability mechanism at work. The mechanism responsible for SASI, the Advective Acoustic Cycle (Foglizzo et al., **ApJ 654**, 1006 (2007)) has been identified. This identification is now used as a guide to understand and validate the results of the numerical simulations being developed in the field.

Discoveries with numerical simulations



*Left: Numerical simulations revealing that Cold flows feed galaxies (Dekel et al., **Nature 457**, 451 (2009)).*
*Middle: Numerical simulation revealing the role of disk instabilities to feed the central black hole of galaxies (Bournaud et al., **ApJL 741**, L33 (2011)).*
*Right: The standing accretion shock instability (SASI) is responsible for breaking the spherical symmetry during the first second of a supernova explosion. A shallow water analogue of SASI has been developed and patented. This experiment is used for public outreach and as a research tool complementary to numerical simulations (Foglizzo et al., **PRL 108**, 051103 (2012)).*

Signal processing

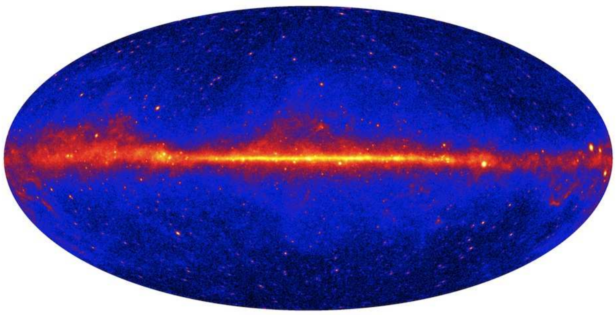
We have produced numerous data analysis tools for various facilities (Herschel, Planck, XMM, Fermi, KEPLER, CFHT…), most often based on original methods – one of them requires the use of massive parallel computers.

Participating in Fermi thanks to signal processing

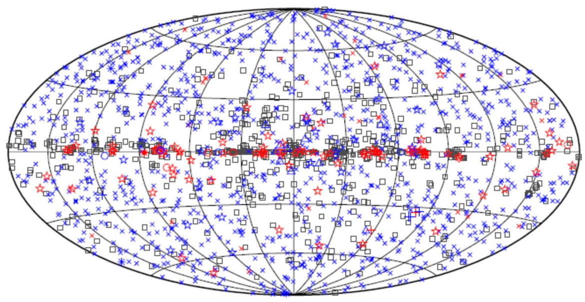
Our competence in signal processing and component separation in the ISM has enabled us to maintain our participation in the GLAST mission (gamma-ray observations in the energy range from 30 MeV to 300 GeV), renamed the Fermi Gamma-ray Space Telescope after its launch in 2008. Cosmic rays have long been studied at SAp, since the mid 60's. As a natural continuation, we took part in the GLAST consortium around the main telescope (LAT) as early as 1998. Our hardware participation was stopped in 2004 when CNES, in a situation of over-programming, had to cut funding. We kept on contributing to the ground segment on high visibility tasks: source extraction and catalogue building (co-lead and manager), and modelling the diffuse emission from cosmic rays interacting with the ISM (which is the dominant background for source extraction) (co-lead and manager).

An intensive pre-launch preparation with several data challenges has allowed for an efficient data analysis after launch. Source catalogues have been published after 3 months, 11 months, and 2 years of data acquisition. The rich harvest of new information (1873 sources in 2011) has revealed new classes of gamma-ray emitters in the Universe and has ten-folded the sparse samples of gamma-ray pulsars and active galactic nuclei to study how they accelerate particles to extreme energies. New methods for the separation of interstellar components have been developed jointly for the Planck and Fermi foreground/background studies and are being tested to further improve all science analyses in both these large international collaborations.

Signal processing to remain part of the Fermi-LAT Consortium



*Full sky gamma-ray count map as observed by Fermi LAT after 2 years at energies above 1 GeV; (Nolan et al., **ApJS 199**, 31 (2012)).*

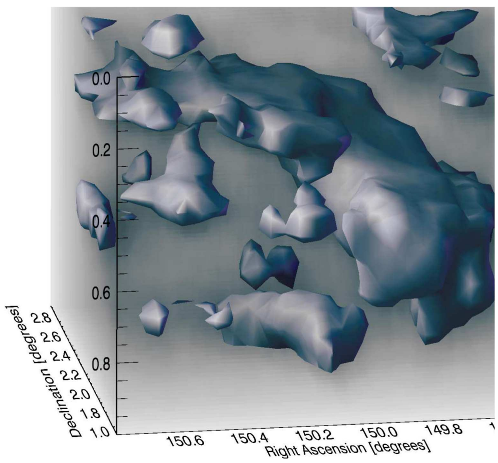


*Full sky map showing the 1873 Fermi LAT sources by class. Firmly identified sources are shown in red, sources with an associated counterpart at lower waveband in blue; (Nolan et al., **ApJS 199**, 31 (2012)).*

Signal processing for cosmology

A special effort has been made in **statistical methods** (especially sparse representation of signals) and their **application to cosmology**. A team dedicated to this activity has been set up. We have organized three **international conferences** on astronomical data analysis, two international workshops and 3 sessions in international conferences.

Sophisticated signal processing methods have been developed for cosmology



*Three-dimensional reconstruction of the dark matter distribution. The three axes correspond to right ascension, declination and redshift: with distance from the Earth increasing towards the bottom. The redshift scale is highly compressed, and the survey volume is really an elongated cone. An isodensity contour has been drawn arbitrarily to highlight the filamentary structure. The faint background shows the full distribution, with the level of the greyscale corresponding to the local density. From Massey et al., **Nature 445**, 286 (2007).*

Instrumentation

Space Instrumentation

We are one of the few (5) French Space laboratories that have a **proven record in the mastering of space instruments**. Our space projects are developed in **partnership with CNES** according to the agreement signed between CNES and CEA (sharing the full cost on a fifty/filty basis). Given the long duration of a space project (of the order of 10 years from the initial idea to the beginning of the scientific exploitation), we have to work in parallel on several instruments at different phases in the development.

During the 2007 - mid 2012 period, we have achieved the construction of a major instrument: the ***JWST-MIRI*** imager (French Co-Principal Investigator level (Co-PI)), and participated in the construction of the instrument of the ***Pilot balloon*** by providing the sub-mm focal planes (Co-I level). The first flight of Pilot is scheduled in 2014; the JWST launch is now scheduled in 2018.

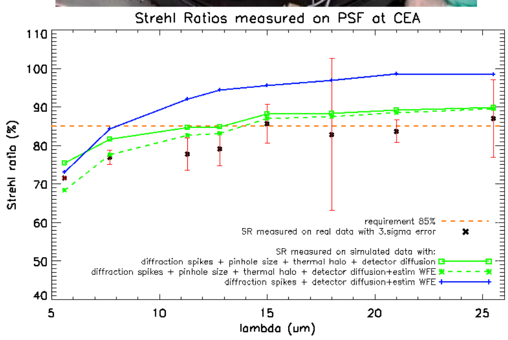
In parallel to the construction of the JWST-MIRI camera, we had to study projects that will enter the science exploitation phase in the 2019-2024 timeframe or even beyond. Furthermore, given the ESA policy to have competing studies for several missions in the definition and assessment phases, and given our broad technical and scientific coverage, we had to participate in numerous instrumental studies, heavily loading our technical staff. Our participation is always twofold: science definition and instrumental definition. The level of participation varies according to the project, ranging from leading role to an expertise role.

We have played a ***leading role*** in three space missions: the ***ESA DUNE-EUCLID*** mission, which has been selected in October 2011 as the M2 ESA cosmic-vision 2015-2025 mission; the **French-Chinese *SVOM*** mission, which has been in a “frozen” state since early 2012, waiting for the Chinese decision about the platform; and the French-Italian ***SIMBOL-X*** mission, which was stopped in 2009 due to lack of funding by CNES and **ASI**, the Italian Space Agency.

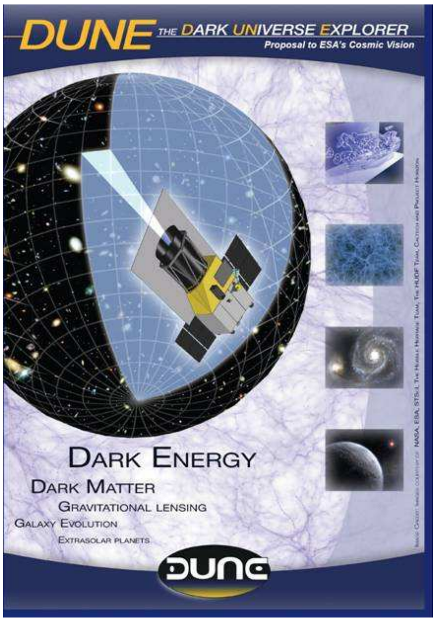
We have had a key role in the study of the **STIX instrument** of the ESA Solar Orbiter M1-mission by studying the **detection unit**. It consists in 32 detection modules derived from the MACSI concept that we have developed in our R&T programs (see R&T paragraph, this section).

We have also contributed to the definition phase of ***SPICA***, ***Plato***, ***IXO***, ***ATHENA***, ***ECHO***, ***LOFT***, and recently participated in the Echoes proposal by **NASA JPL** for the ***JUICE*** ESA L1 mission; (see section “Instrumental projects”). We have also participated to several proposals for future missions (ESA M3: NEAT, SPICES, COSPIX, …; ESA Small missions: PLAVI, microNeat, A-Star…; …), which have not been selected.

Two major achievements: realization of the imager of the MIRI instrument for the JWST and the proposal to ESA of the DUNE mission, which has evolved into EUCLID.



Top: the imager of MIRI being integrated and checked in the AIM clean room at Saclay before delivery to RAL; Bottom: measurements of the strehl ratio are shown (Ronayette et al., MIRI-RP-00919-CEA (2011)). We have been responsible for this sub-instrument. The imager has been integrated to the spectro-imager MIRI and delivered to the NASA Goddard Space Flight Centre in May 2012.

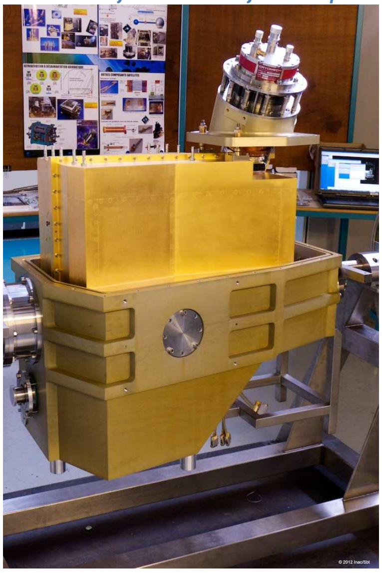


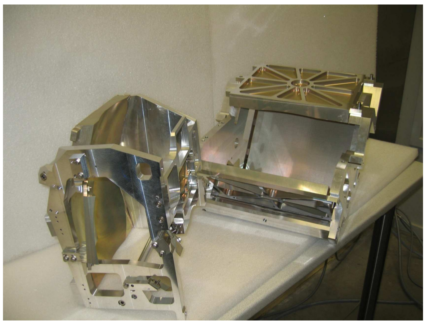
*After having played a key role in introducing the dark-energy theme for the call of ideas by ESA in 2004, we have led a consortium of laboratories answering to the ESA call for a dark energy mission (Refregier et al. **EA 23**, 17 (2009)) and then played a crucial role in the development of Euclid (Refregier et al. “Euclid Imaging Consortium Science Book.”, arXiv: 1001.0061(2010)).*

Ground-based Instrumentation

Concerning ground-based projects, we have conducted the building of the ***APEX-ArTeMiS*** camera (PI), which will enter in full scientific exploitation in 2014 on the APEX telescope in Chile. We have also designed and realized a submillimetric camera named Camistic to be operated at Concordia in Dome-C, Antarctica. We are participating in the preparatory phase of the ***CTA*** project (site selection, ground-segment), in the definition phase of the ***IRAM-NIKA*** large field camera (polarisation channel). We have also participated in the phase A study of the ***METIS*** instrument for the European Extremely Large Telescope (***E-ELT***) planned to be installed in 2024. The time scale for developing ground-based instrumentation on large telescopes can now be similar to that for space projects.

A Key instrument for Herschel follow-up : the ArTeMiS large field camera for the APEX telescope





The ArTeMiS cryostat (left) and part of the fore and internal optics (above).

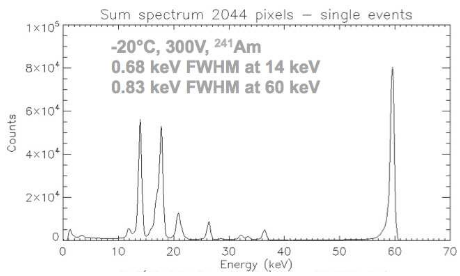
Research & Technology

At the level of R&T and demonstrators, we have concentrated our activity on focal plane arrays from hard X-rays to mm wavelengths.

- We have developed with Irfu-SEDI (ASICS skills) and with the know-how of the 3D+ company, a novel 2048-pixel fine-pitch **camera for hard X rays** (MACSI modules, see figure below).
- We have passed crucial steps in the development of **novel ultra-high resolution X-ray imaging spectrometer** realized at the INAC Grenoble technological Platform.
- We have collaborated with the Léti at Grenoble to define the **future generation of sub-mm bolometer arrays**, capitalizing on the very successful development of the novel PACS bolometer arrays.
- We have developed cryogenic (50 mK) electronics for these arrays under an **FP7 contract we are leading**.
- We are **characterizing IR detectors** under ESA contracts.

We are presently co-coordinating with the IPAG laboratory in Grenoble, the **FOCUS LabEx (Laboratoire d'Excellence)**, **FOC**al plane arrays for **U**niverse **S**ensing. The proposal has been funded at the level of 9.3 M€ over 8 years.

Developing demonstrators to enter a space mission.



MACSI Module: novel 2048-pixel fine-pitch ***camera for hard X rays*** *in collaboration with* ***Irfu-SEDI*** *and the* ***3D+ company; a threshold as low as 1.2 keV has been reached (Limousin et al., IEEE conference 2012).***

Our participation in the **STIX** instrument of the ***Solar-Orbiter*** ESA M1 mission directly results from the development of CdTe-based hard-X-ray spectro-imagers, thanks to an R&T program with CNES and to studies in the framework of the Simbol-X mission (after the CNES and ASI decision to stop the Simbol-X project, Irfu/Dir decided to keep on with the developments). These developments have also led to a collaboration with the **Berkeley Space Lab** around the "Cinema" nanosatellites program and to a participation in the ***ASTRO-H*** **Japanese** mission at the level of expertise.

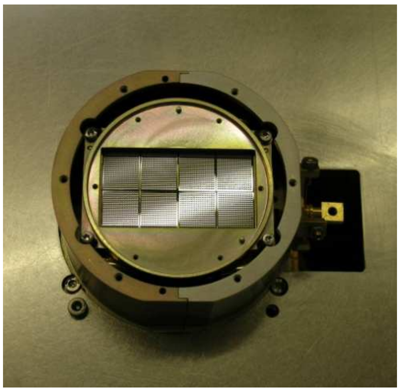
__All along the chain of acquisition of new knowledge with Herschel__

Our implication in the ESA Herschel mission is an excellent illustration of the link between the various AIM activities and of the global strategy followed by AIM.

The scientific potential is the first criterion for us to enter a project; technical implication in an instrument is always coupled with a scientific counterpart. Scientifically, we were fully convinced of the need for a space observatory in the far-IR, especially to study the **earliest stages of star formation** (Ph. André in "The Far Infrared and Submillimetre Universe", edited by A. Wilson, Noordwijk, The Netherlands, ESA, p.51 (1997)), which is **a field of excellence of AIM**. The bulk emission from these embedded objects indeed emerges in the far-IR. Understanding star formation is a major goal in modern astronomy and we have shown that the earliest phases are of crucial importance, for example in determining the Initial Mass Function.

*Technically, our preferred positioning is at the level of **the focal plane of detectors**, a key subsystem.* In the mid 90's, in the framework of the perspective of the FIRST space mission (now named as Herschel), we undertook, jointly with Léti at CEA Grenoble, a R&T program on novel detector arrays to detect sub-millimeter cosmic radiation (see Figure below, left). These developments allowed us to take the full responsibility for the focal plane of the Herschel-PACS photometer (including its cooling system at 300mK, developed at CEA-INAC, and its readout electronics). Note that this development illustrates our *capacity to take advantage of our inclusion within CEA*. The focal plane (see Figure below, central) has been delivered to MPIA, the PI institute, in July 2006. Our excellent knowledge of the focal plane made us a key partner for the ground segment; we have been responsible for the photometer tests/calibrations, on-sky commissioning, performance monitoring, and data pipeline. This activity has been very successful, as shown, for example, by the first PACS image out of the data reduction pipeline, soon after the launch in May 2009, which was amazingly clean (see Figure below, right).

Herschel from novel detector array to major discoveries



Novel bolometer arrays developed at Léti Grenoble for Herschel and characterized/optimized at AIM Saclay. These arrays have been a "world premiere".

Herschel-PACS photometer delivered to MPIA by AIM in July 2006. It features 2 channels; a cryo-cooler cools the bolometers from 2 K down to 300 mK.

A false-color image of the M51 galaxy combining the first observations at 70, 100 and 160 µm made with the Herschel-PACS photometer, just out of the pipeline, without further processing. It shows the great quality of the preparatory work.

Note that we have also contributed to another instrument of Herschel, SPIRE, by providing the readout electronics for its bolometers. The SPIRE spectro-imager covers the 194 - 671 micron wavelength range and complements PACS. Being in both consortia has given us a definite scientific advantage.

The scientific exploitation of the Herschel data was a major observation/interpretation axis for AIM in its 2007 project. Even if the Herschel mission is still operating (it should run out of liquid helium in early 2013) and if a lot of data have still to be analyzed, we can already claim that our participation has been tremendously successful. We are one of the most active European laboratories exploiting Herschel (> 30 AIM researchers mobilized). As of August 2012, we have co-authored 35% of the 476 refereed scientific publications from Herschel observations. We have been first author of 33 of them (7%) and one of them (Ph. André et al.) is the most widely cited Herschel paper so far. The 33 AIM first author papers have been quoted 603 times which represents 12% of the quotation of the 476 scientific Herschel papers.

We have also been very successful with open time proposals. For example, we have led the GOODS Herschel key program gathering about 60 researchers around the world to study the evolution of galaxies, especially the star formation rate history. Note that this is the only Herschel key program lead by a French scientist. In the selection of key programs, the capability to reduce the data at high level and to make them available to the community is an important criterion; the fact of having a recognized activity in ground segments is a definite advantage.

b) Production, Awards

Publications

We have been very productive with 1650 peer-reviewed publications, including 50 in Science or Nature, and about the same number of non-refereed publications. The average rate of 300 publications a year is 3 times higher than the one over the years 2005-2006. The total citation number from ADS amounts to more than 45 000. **A study of the 2011 publication rate of the French Astronomy laboratories has shown that AIM was the French laboratory with the largest number of first author papers (D. Egret, SF2A poster June 2012).** A lot of high impact results have been obtained; 264 papers published during the period 2007-2012 have been quoted more than 50 times; 91 papers more than 100 times (see list in Appendix). Out of the 264 papers, 46 have a first author from AIM. The H_{index} of the unit is of 96. The table hereafter shows that our papers are ranked above average; indeed, in 2011 41% of the papers we are co-authoring were in the 10% most quoted papers.

Evolution of the % of AIM articles ranked in top 1% or top 10%, in the field of Space science					
Top ranked most quoted papers	**2007**	**2008**	**2009**	**2010**	**2011**
Top 1%	8,3%	4,9%	8,9%	10,8%	14,3%
Top 10%	**33,2%**	**32,8%**	**36,5%**	**40,7%**	**41,4%**

Over the same period, **a comparable amount of technical documents** (more than a thousand, for a total amount of more than 30 000 pages) have been written **in the framework of instrumental developments reviews either by CNES or ESA**.

A lot of technical documents

Set of documents provided to ESA in the framework of the definition phase of the Euclid mission by the Euclid consortium; we have been leading the study in terms of science, technique and management.

Awards

Besides the high number of invitations in international conferences, an indicator about the visibility of AIM is the prizes or prestigious grants awarded to researchers of the unit:

- **3 prizes from the French Academy of Sciences**:
  - **one related to numerical simulations:** *Grand Prix Cino del Duca* 2011 awarded to *R. Teyssier and his team,*
  - **one related to signal processing:** Prix *EADS 2011* awarded to *J.-L. Starck,*
  - **one related to observations/interpretation:** *Grand Prix Deslandres* 2011 awarded to *F. Mirabel*;
- **F. Mirabel was also awarded the 2010 "Consecration" prize** of the Argentina Academy of Sciences and has become a member of the Argentina Academy of Exact Sciences, Physical, and Natural Sciences in 2011
- **2 CNRS medals**:
  - 2010 CNRS *silver medal* awarded to *M. Arnaud* **for her work in the field of galaxies clusters**
  - 2011 CNRS *bronze medal* awarded to *E. Daddi* **for his work in the field of galaxy evolution***;*

- **2 prizes "La Recherche"**:
  - 2011 prize awarded to S. Brun and his team **for their work on the Sun modeling;**
  - 2012 prize awarded to S. Charnoz and his team **for their work on the origin of Saturn moons**.
- **Associated to two Rossi prizes in the high energy domain**:
  - 2010 prize awarded to 2010 Felix A. Aharonian, Werner Hofman, Heinrich J. Voelk and the H.E.S.S. team;
  - 2011 prize awarded to Bill Atwood, Peter Michelson, and the Fermi Gamma Ray Space Telescope LAT team;
- **7 ERC grants**:
  - **4 grants (1 consolidated, 3 juniors) based on intensive numerical simulations**
    - 2007: Junior ERC Grant awarded to S. Brun (880 k€) for the project STARS2, "Simulations of Turbulent, Active and Rotating Suns and Stars"
    - 2010: Junior ERC Grant awarded to F. Bournaud (988 k€) for the project GALISCO, "Resolving Galaxy formation: Small-scale Internal Physics in the Cosmological context";
    - 2010: Junior ERC Grant awarded to S. Fromang (1093 k€) for the project PETADISK, "Petascale numerical simulations of protoplanetary disks: setting the stage for planet formation";
    - 2012: Consolidated ERC Grant awarded to P. Hennebelle[3] (1312 k€) for the project MAGMIST, "From the Magnetized Interstellar Medium to the Stars";
  - **1 advanced grant in the domain of signal processing**
    - 2008: Advanced ERC Grant awarded to J-L Starck (2270 k€) for the project SPARSE ASTRO, "Sparse Representation of Multivalued Images: Application in Astrophysics";
  - **2 grants (1 advanced, 1 junior) in the domain of observation/interpretation**
    - 2009: Junior ERC Grant awarded to E. Daddi (939 k€) for the project UPGAL, "Understanding the Physics of Galaxy Formation and Evolution at High Redshift";
    - 2011: Advanced ERC Grant awarded to Ph. André (2268 k€) for the project ORISTARS, "Toward a Complete View of Star Formation: The Origin of Molecular Clouds, Prestellar Cores, and Star Clusters";
- **2 Grant/Prizes to Students**:
  - 2008 Prix de la Chancellerie (Prix Perrissin - Pirasset / Schneider) awarded to Joel Bergé for his thesis « *Les lentilles gravitationnelles faibles vers la cosmologie de haute precision.* »
  - 2012 Grant *L'Oréal France - Unesco - Académie of Sciences "Pour les Femmes et la Science"* (15000€) awarded to Françoise Remus (PhD Student co-supervised by AIM and LUTH at the observatoire de Paris) ;
- **4 members of Institut Universitaire de France (IUF)**:
  - 2009 Stephane Corbel: membre Junior;
  - 2010 Isabelle Grenier: membre senior;
  - 2011 Sébastien Charnoz: membre Junior;
  - 2012 Sylvain Chaty: membre Junior
- **Participation in 3 LabEx**:
  - FOCUS (co-direction), detection
  - UnivEarthS (in the board of direction), high energies, planetology
  - P2IO, Physics of the 2 Infinities and of the Origins
- **Patents:** 5 international**.**
- **4 Prizes for popularizing science :**
  - three awarded to R. Lehoucq (2010 Diderot-Curien Prize from AMCSTI (Association des Musées et centres pour le développement de la Culture Scientifique, Technique et Industrielle; 2008 Prix SF2A (French Society of Astronomy)/ACO pour la diffusion scientifique en astronomie; 2008 Prix du Festival d'astronomie de Haute-Maurienne for his book « Le Grand récit de l'Univers »)
  - and one to A. Brahic (Prix 2011 du Festival d'astronomie de Haute-Maurienne).

As can be seen, the **various activities** (R&T, signal processing, observation/interpretation, modelling) and the **various themes** (galaxy clusters, galaxy evolution, high energy cosmic phenomena, star formation, solar system) have **all been awarded**.

[3] Even if P. Hennebelle has joined Aim on the 1st of October, his ERC was planned to be operated in AIM.

2. Dissemination of knowledge

a) Training master students, PhD students

Students are an important component of the unit. 73 PhD students have been in the unit during the 2007-mid 2012 period; 41 have passed their PhD and 32 PhD students are presently hosted in the unit. This is 15% more than the number of PhD student in 2007 (which the 2008 AERES committee considered as at the high end relative to French standard) and not far from the maximum we can supervise, taking into account the recommendation of a single PhD student per supervisor. Five of the 32 PhD Students are in co-supervision, (one with the University of Herdforshire (UK), one with the University of Conception (Chile), one with the Purple Mountain Observatory (China), one with CEA Cadarache, one with the Observatoire de Paris). About half of the funding is from CEA under a general competitive call at the global level of CEA, taking as first criterion the student academic results; the other half comes from various sources: University, Europe (ITN, ERC), Ile de France region, CNRS, Chile and Portugal grant, CNES…

The PhD students come in a large part from the Ile de France master in Astrophysics-Astronomy; a significant part comes from other masters such as plasma or numerical simulations.

We make sure that the students are working in good conditions: scientifically ensuring they are working on very interesting subjects at the international forefront of research, materially providing them with a laptop computer upon their arrival and financing their participation in at least one conference or summer school per year.

We follow their progress at the level of the unit. Indeed, on a yearly basis, we organize internal seminars dedicated to the presentation by the PhD students; these internal seminars increase the visibility of the students and sharpen their presentation skills. In addition, since 2009, a member of the Unit (J. Rodriguez) has been appointed "as PhD correspondent". A PhD student who experiences problems at any point can discuss with the PhD correspondent. In any case, the correspondent discusses with each PhD student once a year.

One PhD student is an elected member of the "conseil de laboratoire"; this is another way for the students to participate in the life of the unit.

Almost all our PhD students are registered with the "école doctorale d'astrophysique d'Ile de France" (ED127). Their work is also yearly followed by the ED127. UMR AIM is one of 21 laboratories associated with ED 127. One member of the board is a scientist from AIM (J.-P. Chieze) and the director of AIM has been elected as one of the two representatives of the 21 directors at the scientific advisory body of ED127.

To be able to supervise a PhD student, a researcher must pass an accreditation ("habilitation"). We have been encouraging AIM researchers to do so; fifteen AIM researchers have obtained such an accreditation between 2007 and mid-2012.

b) Lecturing

In addition to the 8 professors or assistant professors from the Paris-Diderot University, 30 members of AIM give lectures. Over 5 years, 4144 hours of lectures at master and PhD level have been provided (see Appendix). 80% of these lectures are given by AIM staff other than the 8 Paris-Diderot professors or assistant professors. The professors or assistant professors provide most of the lectures at the "licence" level. Note that "licence" level is very important to attract students towards science. The lecturers participate in the evolution of the educational content of the Master and Doctoral programs, in the visibility of the unit within the University Paris Diderot thanks to their active participation to various Councils (UFR, Scientist, Education (Teaching), Spatial Campus, Labex UnivEarths,) as well as at the Commission of Specialists or experts.

The 506 hours provided annually (on average) at the level of master 2 "Research" (417 h a year) and "Professional" (89 h a year) are shared over eight different masters, with a major contribution to the Master "Astronomy and Astrophysics" and "Tools and Systems for Astronomy and Space." Lecturers for engineers (150 h a year) are provided to prestigious "grandes écoles" (Polytechnique, Centrale Paris, ENSTA, Telecom Bretagne). The AIM contribution to various master programs reflects the great diversity of expertise in the unit.

These lectures, in addition to the training aspect, increase the visibility of AIM among students from diverse backgrounds and thus contribute to our capacity to attract talented PhD students. AIM has attracted more than 60 students for Master 1 or 2 training over the last five years.

UMR contributed 85h a year in the ED 127 post-master courses by training students in project management, data analysis, and numerical simulation of stellar dynamics; showing once more the diversity of skills at AIM.

c) Schools

We have initiated specific programs geared toward students and teachers of secondary schools. This has involved several one-day meetings with classes each year. During these meetings, the laboratory activities are presented by scientists and coupled with visits to the technical facilities. To follow this pedagogical approach, specific trainings are also proposed to the teachers by way of 2-3 day training courses in which specific exercises are developed based on real astronomical data. Several pedagogical booklets for the young public were also produced (The Calendars (2009), The Galaxy (2010), “What is astrophysics?” (2011)).

d) Public Outreach

We have a long tradition of scientific popularization, starting with Hubert Reeves who arrived in the lab from Canada in the mid seventies’ and remained connected to the lab until his retirement. Almost everybody in the unit has contributed one way or another to disseminate knowledge, from commenting attractive astronomy pictures in a primary school to being interviewed during the 8 pm newscast (millions of viewers)! A few (André Brahic, Roland Lehoucq, Jean-Marc Bonnet-Bidaud) devote a large fraction of their time to this activity, while others give on average one public conference a year. Original ways to attract the public interest have been developed such as discussing the scientific context of cartoons or films (Roland Lehoucq) or participating in shows with a magician (David Elbaz).

At the level of the unit, the communication group chaired by Jean-Marc Bonnet-Bidaud is in charge of collecting and highlighting new scientific results. One hundred “faits marquants” have been posted on our website (see Appendix). We regularly have visitors coming and seeing the **3D-film** that we have developed from our multi-scale numerical simulations of the Universe, which can be now shown in our new seminar room (85 seats) built in 2010. A successful press conference has been organized about new discoveries in the field of stars. We have been responsible of the French Web site of Herschel (www.Herschel.fr) with videos, interviews, and more.

The year of astronomy in 2009 has triggered a large amount of activities. We took more than our share. We are at the origin of the exhibition “A journey to the center of the galaxy” at the Palais de la Découverte in Paris during 3 months, with support from CEA general communication and CNES (Jean-Marc Bonnet-Bidaud curator). This has been a great success. A reduced version of 10 large posters in French, English, Spanish and Chinese, has been travelling in France and around the world (Chile, Argentina, Spain, South Korea, China, Vietnam).

The multiscale numerical simulations shown at the “Palais de la découverte museum”during the exhibition “Journey to the center of our Galaxy” was broadcasted on the regional News of the France 3 TV channel.

The itinerant version of the exhibition “Journey to the center of our Galaxy conceived by AIM, shown here at the Beijing planetarium (China) in October 2009.

With CNRS, we co-realized the exhibition “The Mysteries of the Universe” at Paris Trocadéro with an attendance of 50 000 visitors and the photographic exposition “Did you say Universe?” at Montparnasse, one of the major Paris subway station. We also took a major part in designing the content of the permanent exhibition “Le grand Récit de l’Univers” at the Museum of Science and Industry (La Villette, Paris) with R. Lehoucq and M. Lachieze-Rey as curators.

We embarked on the production of an original documentary film “Des étoiles et des hommes” (47 minutes-Pierre-Francois Didek and Samuel Albaric film directors, AIM- Goyave Production) that relates the story of the building of the Herschel camera at AIM and involved a nine month shooting with contributions of numerous AIM members. The film was shown in numerous festivals and TV-broadcasted on the cinema channel of the Canal+ group.

Other audiovisual productions have covered wide scopes including the realization of two 3D-films (Cosmos-3D and Galaxies-3D) based on the advanced numerical simulations done at AIM and authoring or realization of documentary films (The Sirius enigma 2008, The Dunhuang celestial chart 2009). 30 members of the laboratory have also participated to more than 100 scientific podcasts in collaboration with the Ciel & Espace magazine and numerous individual contributions were also brought to diverse national radio broadcasts (France-inter, France-Culture, RFI, etc…).

In collaboration with the Palais de la Découverte Museum of Science, the conception of the largest sundial in the world has been realized, covering an area of about 13000 square meters on the EDF hydro electrical dam at Castillon (supervision R. Lehoucq, D. Savoie).

Top: The film “Des Etoiles et des Hommes” (47 min - 2009), a nine-month story relating the building of the Herschel camera at AIM.

Right: The largest world sundial, built at the Castillon dam, showing here the shadow marking the 9 a.m hour. Covering approximately 13 000 square meters, this giant solar clock has been computed by R. Lehoucq (AIM) and D. Savoie (Palais de la Découverte) and was set up at the occasion of the 2009 International Year of Astronomy.

In association with the Museum of Science and Industry (La Villette, Paris), we organized all-day meetings with the general public, on the theme "Universe deep virtual world: from giant telescopes to numerical simulations” (October 2009) and “Nano, Astro and Brain” (November 2010). The program for these days included round-table discussions, 3D movie projections; such days are also opportunities to present the instruments made by AIM and the latest results of research in astrophysics.

AIM took a large part in different open days organized at CEA as well as in additional events such as “Journées du Patrimoine”, “50 ans du CNES” and “Nuit des Musées” by displaying different technical space artefacts built at AIM.

A theorist, T. Foglizzo, has found a simple way to explain the hydrodynamic instabilities responsible for asymmetric supernova explosions, using the analogy between hydraulic jumps in shallow water and accretion shocks in the collapsing stellar core (see also section Activities, Themes, results). This patented experiment will be widely distributed to research institutes (e.g. Caltech USA, Australian National University) and science museums (e.g. Palais de la Découverte Paris).

Numerous AIM members have also chosen to disseminate scientific knowledge via books for the general public amounting to more than 35 between 2007 and mid-2012.

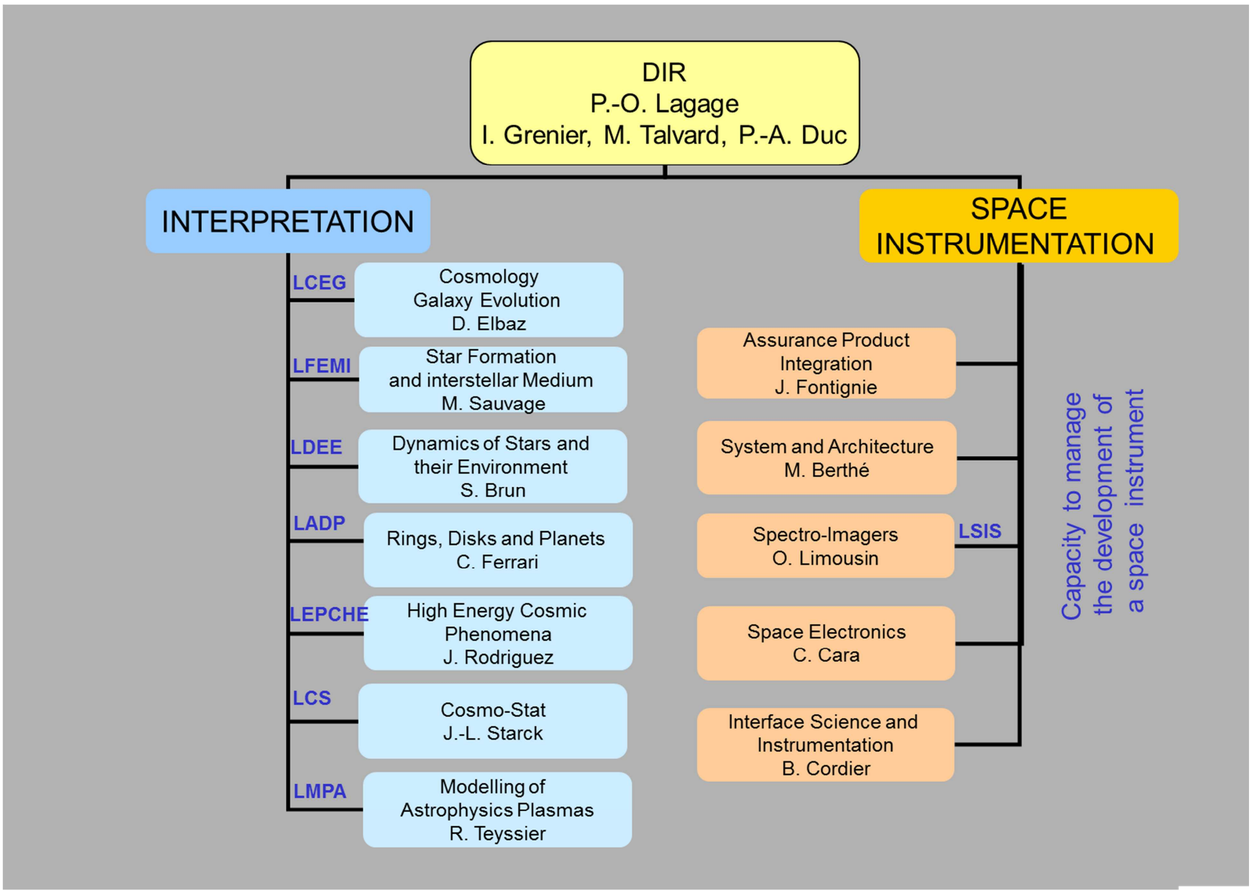
B. Organisation, staff, Fundings, Collaborations

The ambitious strategy that we have developed relies upon a well-motivated and competent staff organized in teams, a network of national and international collaborations and an active search for funding.

1. Organisation

At the head of the unit are a director (P.-O. Lagage from CEA), 2 deputy directors (I. Grenier, professor at Paris-Diderot University and P.-A. Duc, directeur de recherche at CNRS), and a technical director (M. Talvard from CEA). M. Talvard is also the security officer, assisted by a security engineer (P. Marlet). Three secretaries are in charge of administrative matters (temporary contracts, missions, orders, etc...); additional support (budget, Human Resources) is provided at the level of CEA-Irfu. IT support is provided by two technicians, at the unit level, and by the general support of Irfu.

AIM is organized into teams (see the organization chart just below); each team has a leader, who is in charge of the scientific or technical animation and of human management aspects (for example annual performance evaluation). There are regular meetings (about every other month) between the direction and the team leaders.

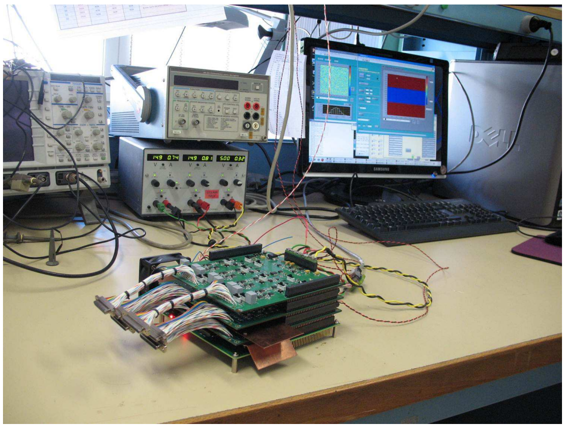


a) Teams, skills, facilities, instrumental projects organisation

Five teams have been organized according to astrophysical themes: Cosmology and Galaxy Evolution (LCEG), Star Formation and Interstellar Medium (LFEMI), Star Dynamics and Environment (LDEE), Disks, Rings and Planets (LADP), Cosmic Phenomena at High Energy (LEPCHE). The organization has slightly evolved since 2007; indeed, to take into account the lack of scientific interaction between the star formation component and the planet formation component of the "Star and planet formation" team, as noted by the 2008 AERES visiting committee, we have split the previous team into two teams: one devoted to star formation and one to planet formation. In addition, researchers working on the ISM of nearby galaxies, and formerly attached to the Cosmology and Galaxy Evolution team, have joined the star formation team. They pursue complementary scientific objectives, namely understanding star formation processes at different physical scales. Several team leaders (J.-P. Chieze, S. Turck-Chieze, Ph. André), who had served since a long time, have left their position. This organization is close to the organization of INSU in terms of national programs: Cosmology and Galaxy Evolution (PNCG), Physics and Chemistry of the Interstellar Medium (PCMI), Stellar Physics (PNPS), Planetology (PNP), high energies (PNHE), and Sun-Earth (PNST); the team LFEMI is at the interface between PNPS and PCMI and the team LDEE is at the interface between PNPS and PNST.

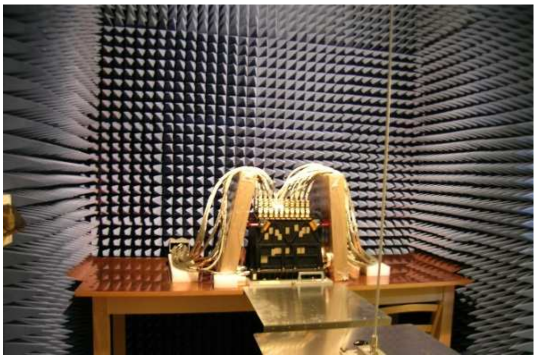
One team is devoted to modelling. Although there is modelling activity within the thematic teams, there is also a need for modelling activity to take place independently to ensure the development of transverse tools such as codes for numerical simulations which can be of interest to several teams. The numerical simulations users/developers from various teams meet regularly in the framework of the COAST project (COmputationnal ASTrophysics) (see http://irfu.cea.fr/Projets/COAST/). During the 2007-2011 period, we have benefited for this activity from an "in house" opteron cluster with 256 cores to be soon upgraded (cost: 500 k€ funded by ERC grants and the Del Duca prize).

Recognizing the need to develop new methods to analyze astronomical data, especially in cosmology which requires powerful statistical methods (PLANCK, EUCLID, etc.), and taking the opportunity of the advanced European Research Council Grant obtained by Jean-Luc Starck, we created in 2010 a pluri-disciplinary team in Computational Cosmology, which has been strongly supported by CEA-Irfu (hiring of 2 permanent staff).



As already mentioned, following the major recommendation from the AERES committee in 2008, engineers and technicians are now part of AIM. The technical teams are organized according to expertise: space project management, system, architecture (LSAS); space product assurance, integration (LQIS); space spectro-imager (LSIS); space electronics (LEDES); interface science-instrumentation (LISIS). The LSAS and LQSI teams ensure our ability to conduct the realization of a space instrument; we are the only French space astrophysics unit which has been able to keep four permanent staff working in space product assurance. In terms of system engineering, we have supported ESA in the Euclid Mission Definition task by introducing systematic methodology for requirements engineering. This is crucial for a mission as complex as Euclid where ultimate performance is only relevant when taking together space segment, instruments, ground segment, calibration, data processing, and survey operation. The LSIS and LEDES teams are at the heart of our R&T effort, namely, by developing novel focal planes with front-end electronics (see figure). The space constraints are taken at the early stages of our R&T developments accelerating the space readiness.

The LQIS team is responsible for the clean room maintenance (class 100 000, 10 000 with spots at a class 100). The LEDES team has maintained competences in electromagnetic compatibility and is responsible for the maintenance of the AIM anechoic chamber, which allows easy compatibility tests (see Fig. below). The LISIS has developed a rare skill in radiation effects on detectors and is co-responsible for the radiation facility at Irfu premises on the main Saclay CEA center; it is also leading regular meetings of about 25 radiation experts from several divisions inside Irfu, in strong collaboration with experts of space agencies (CNES, ESA) or other research institutes (ONERA). The radiation group aims at establishing a complete record of space radiation effects on space instruments. Records are fed all along the life of the project, from the early development phase until the end of the scientific exploitation. Studies address successively: the space environment, allowing to optimize the orbital parameters and to derive the constraints on the reliability of electronics; numerical simulations, allowing to adapt the overall design; irradiation tests, performed for qualification purposes (total dose, singular effects and instrumental response), and radiation monitoring during the scientific exploitation in order to compare the predictions made before launch with actual measurements. This feedback is crucial because microelectronics is increasingly sensitive to space radiations and the required performances are increasingly more difficult to guarantee. For example, the feedback about the dark current evolution of the infrared camera ISOCAM was put forward in order to convince space agencies to put the Euclid project on an orbit far from the Earth, instead of their preferred option (geosynchronous orbit). Such expertise at system level is likely to be unique in Space laboratories.



Above :Electronics being tested in the AIM anechoic chamber
On the right : Clean room

The technical staff is allocated to instrumental projects following a classical matrix organization. Engineers and technicians most often work on more than one project, which is one of the arguments in favor of a vertical organization in terms of skill. Note that we have been able to keep a strong team in product Assurance, which is a guarantee of success. Regular meetings between the technical team leaders, the technical director and the projects manager have been established to monitor the progress of each project and to compare the resource allocation to the needs.

The organization of the projects is the classical organization of space projects: a project scientist (PI, Co-PI or Co-I at the level of the international project), a project manager, an instrument scientist, a system engineer leading a system group with various architects (mechanics, optics, electronics, etc…)

Note that most of our projects beneficiate from technical support by engineers in the technical departments of Irfu (SIS and SEDI). This is the reason why the non-permanent technical staff is reduced compared to other French space laboratories. A global monitoring of the projects is performed at Irfu level during monthly meetings, which is attended by the AIM director or technical director.

In addition, the AIM director participates to monthly management meetings at Irfu level.

b) Life in the units, scientific animation, senior staff visiting program

At the beginning of each year, the director presents the highlights of the previous year and the prospects and strategy for the coming year during a general assembly.

On a 3-month basis, day-to-day life issues as well as strategic choices for the unit are discussed within the « Conseil de laboratoire ». The members of the "Conseil de laboratoire" are members of the Unit, partly elected and partly chosen by the director (see list of members in Appendix).

Since May 2012, following a suggestion made during our prospective days in March 2012, an AIM breakfast is organized every Tuesday at 9h30 followed by a talk from a post-doc. This event is very successful with about 50 persons regularly participating, and it helps to trigger additional informal discussions.

With the regular increase in the number of post-docs (see the Funding Section), we have a chronic problem of lack of space. We have been able to get a few additional offices (+8), but we have most often been at the limit or even behind the needs. To anticipate problems and to optimize the office space occupancy, we have set up a group of 5 people chaired by Michel Talvard, which meets regularly; this group has been able to smooth the problems so far. By early 2013, we will have a new temporary building ready, which will relieve some of the pressure. A more permanent solution would be to have a new building.

Another group of people, chaired by H. Aussel, discusses the optimization of the computing resources and the trend for future. The group then makes recommendations to the direction team for improvements.

AIM has established a group, chaired by Jean-Marc Bonnet-Bidaud, who is in charge of communication aspects, such as collecting and selecting news to be disseminated to a large public via our web site (see also section 2.d).

Another advisory body, composed of both members from the unit and members outside the unit, is the CSTS (Conseil Scientifique and Technique de Service), chaired by Monique Arnaud. It provides advices on the scientific strategy of the unit, on the opportunity for the unit to enter new projects. The CSTS members from the unit are partly elected, partly chosen by the director (see list in the Appendix). It meets on a yearly basis.

In terms of scientific animation, there are regular seminars of general interest on Thursday. In addition there are seminars or internal meetings at the initiative of the teams; for example there is a weekly pizza lunch in the field of galaxy evolution, a monthly meeting dedicated to Supernovae...

Following the recommendation of the AERES 2008 committee, we have started a senior staff visiting program. We have hosted, during their sabbatical year, Mark Dickinson (NOAO, Tucson US) during 4 months (2009) and Margaret Mexnier (STSCI Baltimore US) during 6 months (2011); Vassilis Charmandaris (Crete University, Greece) has visited us 8 times from 2008 to 2011 (1 month per visit), Linda Spilker (JPL Caltech, USA) 1 month (July 2010), Phil Kaaret (USA, Univ Iowa) 2 months, Michael Elad (Technion, Israel) 1 month, P. Pallé (IAC, Spain) 1 month, J. Toomre (Univ Colorado) 3 weeks, E. Spiegel (Univ Colombia) 2 weeks. Peter Eisenhardt (Wise project scientist) is interested in coming to Saclay for up to 6 months during his Sabbatical year in 2013 and David Clarke in interested in coming to Saclay for his sabbatical year in 2014.

c) Quality Assurance

Hosted at CEA/Saclay, the AIM Laboratory has been operating for many years with a strong project-based methodology within a culture of quality assurance. Recently (2007), we obtained the ISO 14000 certification. A document describing the Environment Management System (SME) has been written for all the facilities used in the AIM laboratory. Follow-up audits are regularly planned.

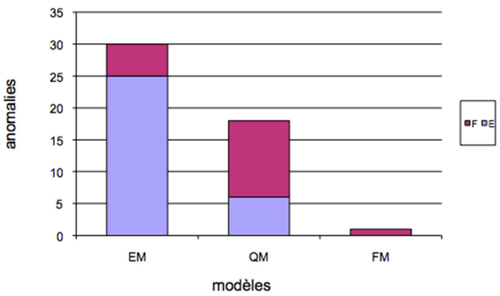
The quality approach at AIM is also strongly driven by the methodology used for space projects. Space projects are operational processes for which several “support” processes such as Training, Hiring, Purchases, Selling, Intellectual property, and “management” processes such as Communication, Security, Human resources, Finances have been identified.

Regarding management aspects, periodic reviews are planned by Irfu (in average twice a month). The Institute Project Reviews (RPI) alternates with the Institute Management Reviews (RMI). The corresponding reports are uploaded on the internal website.

Risk analysis and product assurance for space developments

AIM has set a quality system for space instrument projects, based on the ECSS standards of the European Space Agency. For each space instrument, this system is tailored in a dedicated plan that relies on a set of internal procedures which capitalize on the teams’ knowledge and skills. These procedures integrate risk analysis (both technical and organizational), requirements analysis, product reliability, a control procedure during manufacture and tests, and the application of specific standards and processes. Space instruments projects are structured according to:

- **Product breakdown structure**: as long as its definition is refined, the instrument is split into a hierarchical set of systems, subsystems and parts. Each element is associated with a set of specifications, drawings, assembly and verification procedures.
- **Project phasing**: the project is split in time according to different phases with defined objectives (goals) for each phase. Reviews are organized periodically to verify that objectives are met and to validate both the output documentation of the current phase and the input documentation of the next phase.
- **Model philosophy**: a model development philosophy is established in order to limit the risk analysis. A set of intermediate and representative models is manufactured and allows us to gain knowledge when changes are still possible at a reasonable cost. The figure below shows the efficiency of this strategy on the SCU electronic box for the SPIRE instrument on board the Herschel mission: most changes concern the least expensive model (Engineering Model) and very few changes concern the most expensive model (Flight Model).



Number of operational and functional anomalies observed on the engineering, qualification and flight models.

d) “Réglement intérieur”

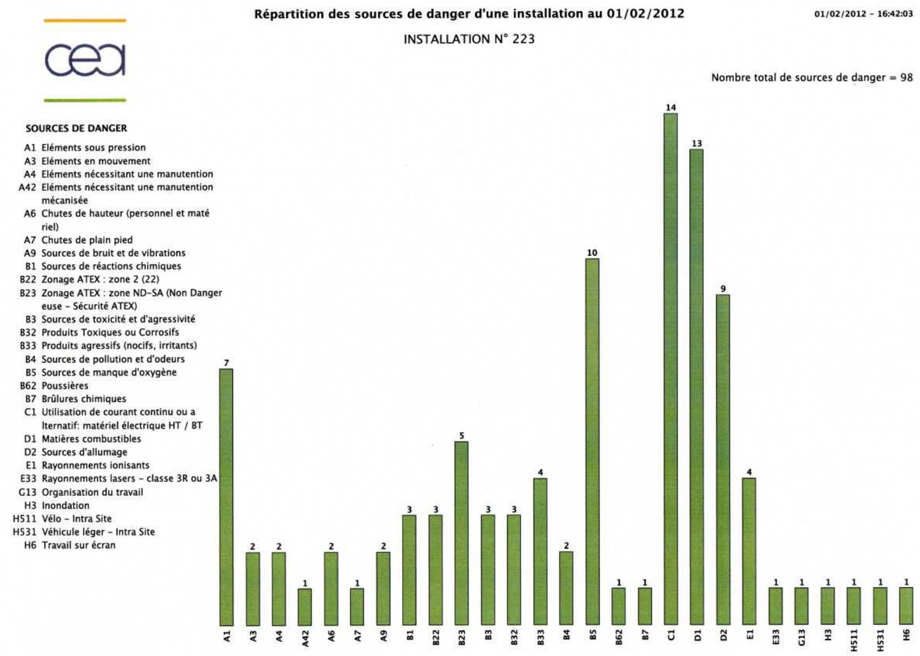
Given that AIM is located in a CEA-site, the internal rules of CEA apply, except those concerning the number of working hours for the CNRS staff. The CEA internal rules are posted in the laboratory and can be made available upon request. We have written specific internal rules to AIM to take into account CNRS staff specificities in terms of working hours a week. The Paris-Diderot research-lecturers have no administrative constrains related to the number of working hours at Saclay.

e) “Hygiène et sécurité”

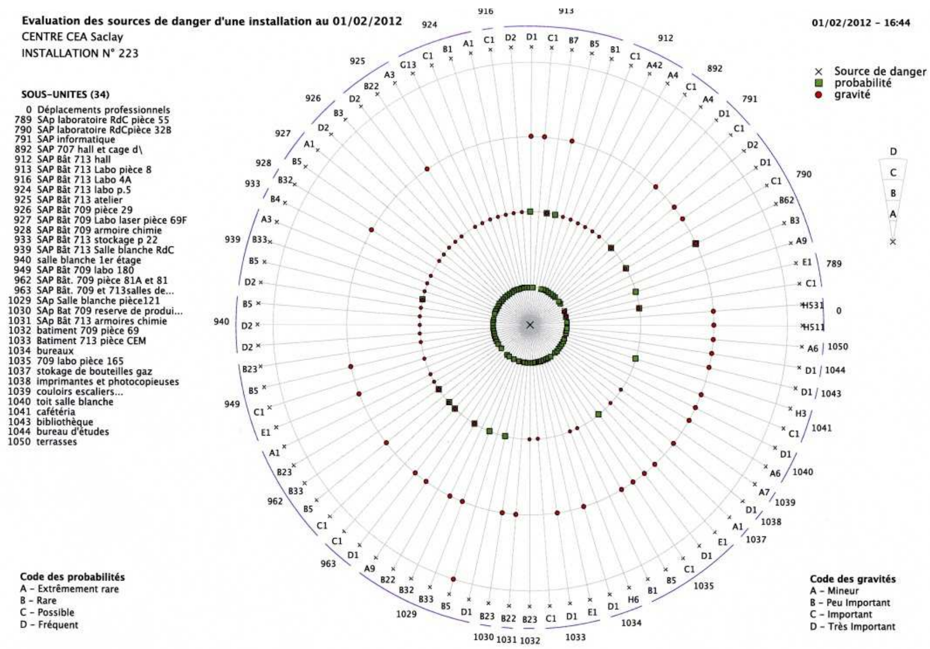
Hosted at the CEA/Saclay, AIM staff is submitted to the stringent safety rules of CEA. For example among others, a special training for every new comer is organized by the center at the beginning of each contract. The access badge is delivered once this training has been completed. In addition, for the AIM staff, we have written a “welcome booklet” which includes some recommendations and the specific risks encountered in AIM facilities. A team is in charge of security at AIM. It is composed of the head of installation, a deputy, a security engineer and two security agents, one of them managing radiation health and hygiene.

Specific risk

A cartography obtained on the basis of the MIPS software developed for CEA centers is used as a management tool. It views all kinds of risks and indicates, for each of them, the occurrence weighted by the total exposed population. Two risks are emerging for AIM: the risk of fire and the electrical risk (see figure below). Additional risks such as Anoxia risk for laboratory people working with liquid Nitrogen and Helium, Chemical risk, Radiological risk for people in charge of radiation tests for space developments, Laser risk are rather low.



The probability and the impact of those risks are controlled in any part of the installation (figure below).



Specific actions

Two visits of the installation are planned every year. These involve the security team, one person representing the medical and health service of CEA/Saclay and the security engineer of CEA-Irfu. As a result, prevention actions are regularly undertaken so as to reduce the risks as much as possible.

Risk assessment at work (EvRP) is prepared and signed by anyone working at the laboratory. Two security exercises are organized a year. Trainings are also proposed for people in charge of specific activities e.g., using radio sources, cryogenic tanks, cranes, chemicals, alignment lasers, etc. Habilitations are signed by the head of installation.

General instructions are displayed, including hazardous points, first aid instructions, useful telephone numbers and alarms. Fire extinguishers are available and visible everywhere in the buildings and laboratories.

Accident at work

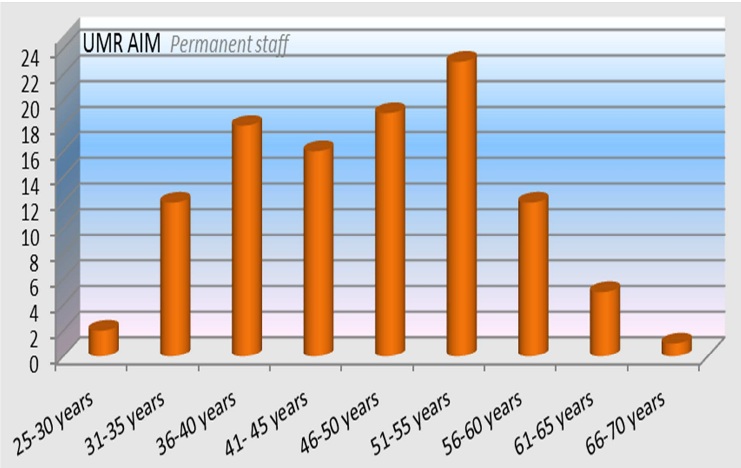
Very few accidents are occurring each year regarding the total population of 200; 2007: 1; 2008: 2; 2009: 1; 2010: 4; 2011: 1; 2012: 2. These are minor accidents, e.g., ankle and foot injuries due to slithering, falls on stairs.

2. Permanent staff and post-docs

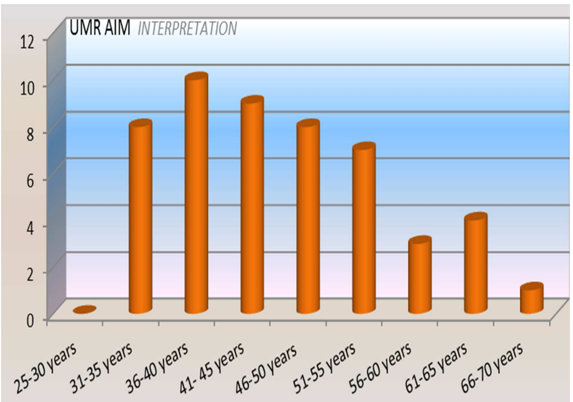
Between the 1st of January 2007 and the 30th of June 2012, the staff number has grown from 159 to 198, mostly by an increase in the non-permanent staff (students: +10 and post-docs: +24). Indeed, while the unit was composed of 7 professors or assistant professors, 38 researchers, 11 instrumentalists, 59 engineers, technicians, administrative, 22 PhD students and 22 post docs, on the 1st of January 2007, it was composed of 8 professors or assistant professors, 42 researchers, 13 instrumentalists, 57 engineers, technicians, administrative, 32 PhD students and 46 post docs on the 30th of June (see AIM organigram on page 24).

Note that we have separately listed instrumentalists, who are physicists with a PhD but whose main task is in relation with instrumentation. Although these are not required to be "publiant" in the AERES sense (a mean publication rate of one refereed paper per year), most of them are, and all of them when considering SPIE papers.

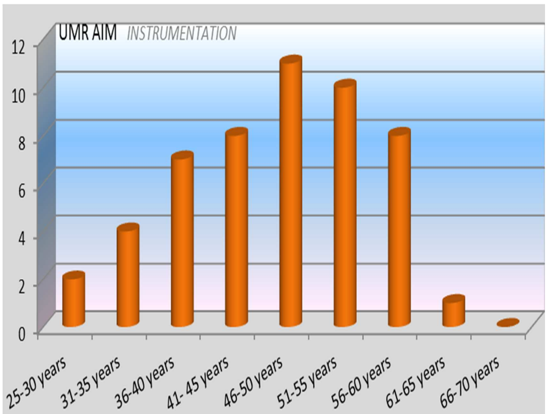
The mean age of the permanent staff is 47 years. When splitting the staff in terms of interpretation and instrumentation, the mean age of the instrumentation staff is slightly higher (47 years) than the one of the interpretation part (45 years) (see below). The age histograms are shown below.



Age histogram of AIM



Age histogram for the interpretation part of AIM



Age histogram for the instrumentation part of AIM.

The strategy announced in the 2007 AIM prospective document to increase the interpretation staff especially for the scientific exploitation of the space missions (starting with Herschel) and to develop the numerical simulation, while maintaining the instrumental staff at its 2007 level, has been followed. This is reflected in the histograms.

In terms of permanent research positions, 9 astrophysicists have been hired (7 CEA, 1 P7 and 1 CNRS) from January 2007 to June 2012 and 3 hires are scheduled before the end of 2012 (2 CEA, 1P7) (see table next page). In addition, we have benefited from the hiring at CEA-Irfu/SEDI of two specialists of signal processing to develop this activity and from one internal CEA transfer (D. Gilles to work on opacities). The ambitious goal to promote 3 assistant professors as professor has been achieved. In the meantime, 3 astrophysicists have retired (2 CEA, 1 CNRS); 2 have an emeritus status (including a retired CNRS researcher who has got an CEA emeritus status); 4 astrophysicists (CEA) have left the unit.

Scientific exploitation	
Star formation (Herschel)	A. Menshchikov (CEA, 2007)
Nearby galaxies modelling (Herschel)	F. Galliano (CNRS, 2008)
High energy Cosmic Phenomena (Hess)	K. Kosack (CEA, 2008)
Galaxy evolution (Herschel)	E. Le Flo'ch (CEA, 2009)
SN + French expertise data center JWST/MIRI	P. Bouchet (CEA, 2012)
Interstellar medium, High Energy	D. Marshall (P7, Sep 2012)
High-z galaxy diagnostics	S. Juneau (CEA, Nov 2012)
Numerical simulation-modelling	
Turbulence in disk	S. Fromang (CEA, 2007)
Link between observations and numerical simulations of galaxy evolution	F. Bournaud (CEA, 2007)
Radiative transfert	M. Gonzalez (P7, 2009)
Replacement of the unexpected departure of 2 key scientists	
A. Refregier (ETH Zurich) : cosmology weak lensing	M. Kilbinger (CEA, 2011)
E. Audit (head of « maison de la simulation ») numerical simulations	P. Hennebelle (CEA, Oct 2012)
Development of the activity in signal processing (opportunity given the advanced ERC grant of J-L Starck, Irfu-SEDI)	J. Bobin (CEA-SEDI, 2010) F. Sureau (CEA-SEDI, 2011)
3 Promotions from assistant professor to professor	S. Corbel, S. Chaty, S. Charnoz

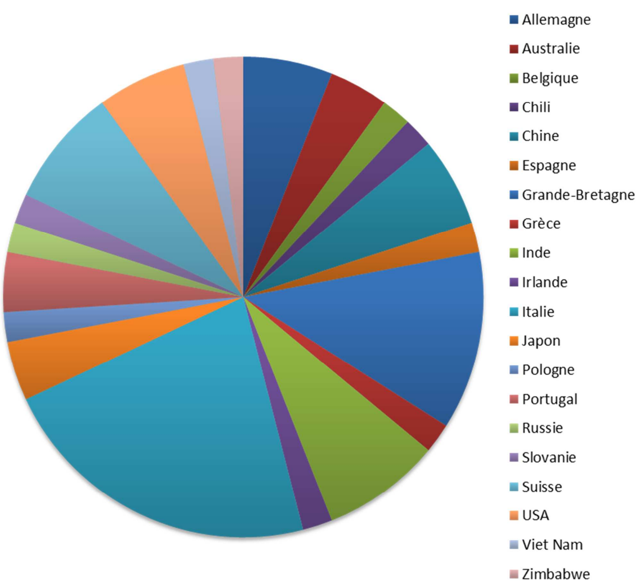
Table of the researchers hiring and thematic

All the astrophysicists are hired following an international call. For CNRS positions, a national committee is in charge of the hiring. For CEA and P7 hirings, a local committee is set up. At each CEA call, about fifty answers have been received (from various countries); a short list of 4 to 8 candidates was established. Each selected candidate has been interviewed at Saclay during about 1h30 by an advisory body, made of people from the unit, including the direction team. The candidate selected at the level of the unit is then interviewed by the head of Irfu and by the responsible of human resources at Irfu. The selection criteria are: scientific achievements and potential, contributions to the unit in terms of expertise and collaborations, and capacity to be well integrated in the unit. Among the 14 researchers who have been hired, 9 are French and 5 are foreigners (Swiss, American, Canadian, Russian, German). All have spent several years as a postdoc; four have obtained their PhD in the unit; four others have been postdoc in the unit.

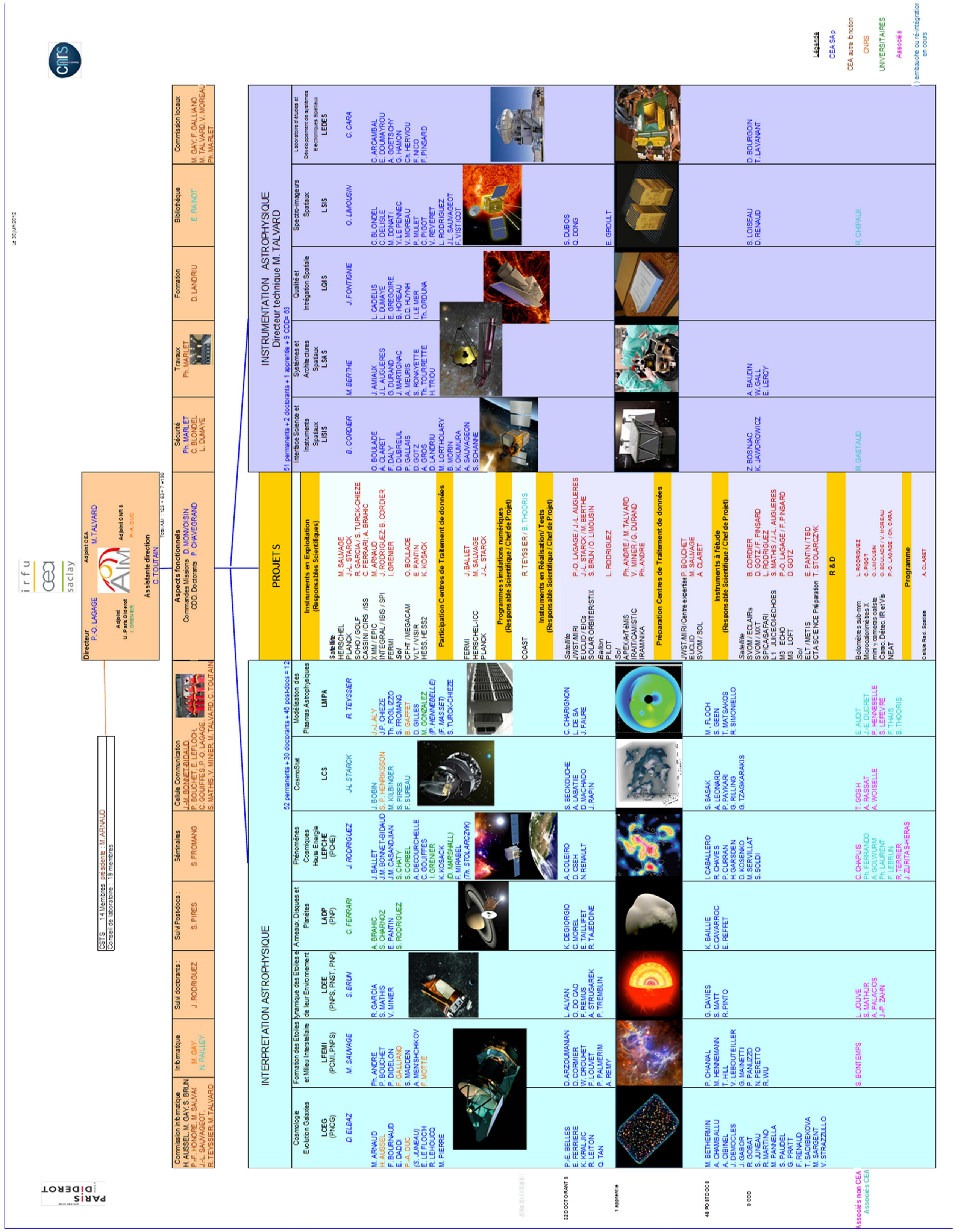
Given the size of the laboratory and the high number of candidates (15 in 2012), we were expecting more than one position from CNRS. We had put substantial effort in preparing the candidates (comments on their application, rehearsal of the oral presentation).

In terms of instrumentation we have stayed constant (8 departures, 8 hires).

The postdocs are also hired following an international call, most often in the AAS job register. We are very attractive and have hired 50 postdocs with non-French citizenship (see diagram just below).



Various countries of origin for the 50 non-French postdocs hired by AIM.



AIM Organigram end of June 2012

3. Collaborations

a) National level

We are collaborating with almost all the French laboratories of Astrophysics. In the framework of space projects we are collaborating with the 4 other French space laboratories: IAS, LESIA, IRAP and LAM. For example, we have initiated collaborations with LESIA, IAS, and LAM for the JWST-MIRI instrument, and we are collaborating with IRAP in the framework of the SVOM mission. In the framework of scientific exploitation, in addition to informal collaboration between scientists, formal collaborations have been established via ANR projects; (ANR stands for Agence Nationale pour la Recherche). Numerous collaborations with IAS, IAP, Observatoire de Paris (LUTH, LERMA, GEPI), Institut Néel at Grenoble, LAM at Marseille, CRAL at Lyon, Bordeaux Observatory, were established in this framework. Note that we have initiated collaboration beyond astrophysics laboratories: with Celia Bordeaux (Plasmas), IPN Orsay for Supernovae (Nuclear Physics), LPGN, LGL, LATMOS, MSC, IPGP, LMD for planetology. In R&T we are collaborating with CSNSM in Orsay, and LPN in Marcoussis (electronics), among others.

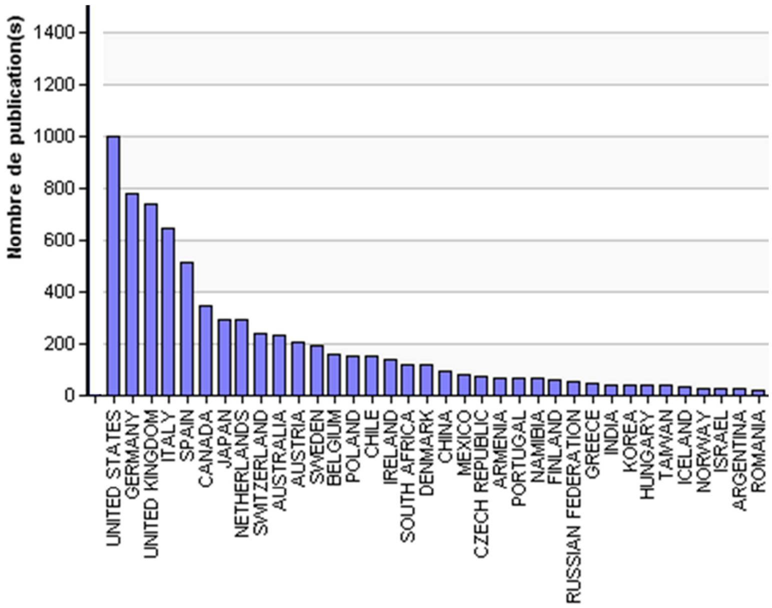
At the unit level, we have established a GIS (“Groupement d’Interet Scientifique”) between IAS, LESIA and us to co-ordinate the use of the facilities to test space instruments. We have been one of the four laboratories who have written the proposal to have astrophysics as a major interest for the Ile-de-France Region: the ACAV proposal, which has been successful.

We have been co-coordinating the FOCUS LabEx proposal including nine laboratories, and the UnivEarths LabEx (AIM, APC, IPGP).

b) International level

In the framework of the space projects we are developing, we are collaborating with about all the astrophysics space laboratories in Europe (UK, Germany, Spain, Netherlands, Sweden, Belgium, Denmark, Italy, Switzerland, Austria). We are also collaborating with US colleagues (NASA Goddard, NASA JPL, Berkeley Space Laboratory; Stanford) in the framework of the Fermi, JWST, EUCLID or JUICE missions and with Japanese colleagues (ASTRO-H, SPICA) and Chinese colleagues (SVOM).

In terms of scientific exploitation, we can assess the extent of our collaborations by gathering information on the countries and affiliations of our co-publishers. The table below shows that we have collaborators in multiple countries, more importantly in the USA, within Europe (Germany, UK, Italy, Spain, etc.), in Canada, and in Japan. The Appendix furthermore shows the affiliations of our collaborators.



f) Participation in committees

We are participating in many committees of the Paris-Diderot University, of National Agencies (INSU scientific council, ANR proposal selection committee, AERES visiting committees (7, including 2 as chairman), in numerous Time Allocation Committees (IRAM, CFHT, ESO, HST, XMM, Chandra, Suzaku, Integral, Hess, Spitzer, GENCI), users group (XMM, INTEGRAL), in CNRS committees, in laboratory scientific committees (Observatoire de Paris, CDS, IRAP, LAPP, OAMP) CFHT, IRAM). The full list is given in the Appendix.

4. Funding

a) Recurrent Funding

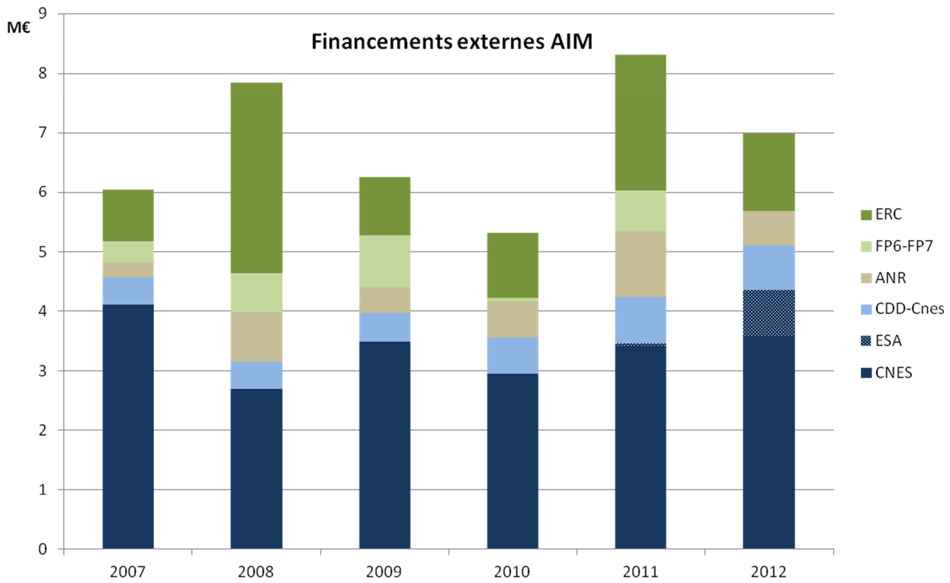
The salary is paid by the institutes, as well as the expenses related to the premises. In addition we receive some funds for the functioning. These funds have decreased a lot at CEA from 1300 k€ to 800 k€, at CNRS from 50k€ to 0; it has increased at the University from 30 k€ to 50 k€.

We are no longer in a position to fund new investments on projects or R&T within our recurrent funding.

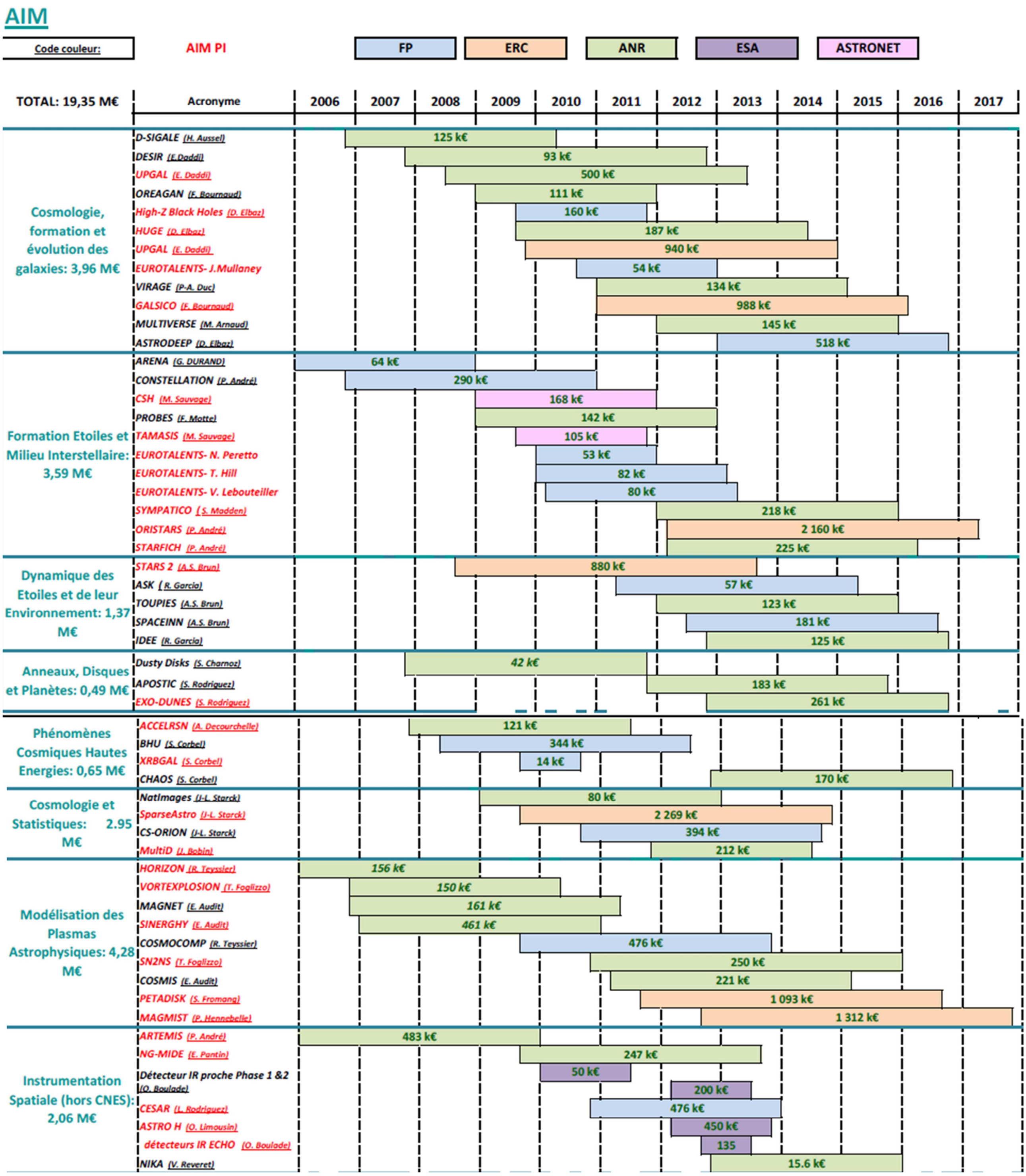
b) Projects Funding

All our projects now have to be funded by external funding. We have been very successful in applying for funds. A total of about 20 M€ has been obtained in 6 years, mainly from ANR and ERC (see detail in the table next page). For R&T, we have started to apply to ESA funding. Most of these external resources are used to hire postdocs. This explains the large increase in the number of postdocs from 22 in 2007 to 45 in 2012.

In addition, the space projects to which we are participating, are funded withi a partnership with CNES. On average about 4 M€ per year comes from CNES.



Projects funding obtained by AIM per year from 2007 to 2012. The CNES funding corresponds to the money spent in a given year. The other funds are those obtained for the whole duration of a project. This indicates that in stationary state we could rely on a total budget of about 7 M€.



List of projects funded during the 2007- mid 2012 period

C. Summary and Conclusion

Staff number on the 1st of January 2007

159: 3 professors and 4 assistant professors; 38 researchers; 11 instrumentalists; 59 engineers, technicians, administrative; 22 PhD students and 22 post docs.

Number of months of presence for the staff who have left the unit during the period

Permanent: 144 months; PhD: 1298 months; post-doc: 1360 months.

Number of permanent research staff hired during the period (origin of the staff)

11 researchers on a permanent position; (PhD AIM and Post-Doc US (NASA); PhD AIM and post-doc US (University Arizona and then Hawaii); PhD AIM and post-doc (Madrid); PhD AIM and then post doc US (Caltech); PhD ENS and then post doc UK (Cambridge); PhD Paris Observatory and then postdoc AIM; PhD CEA, postdoc Belgium; PhD US and then post-doc Germany (Heidelberg); ESO & CDD AIM; PhD Germany (Bonn), Post Doc IAP and then Cambridge; PhD Russia, Post-doc US, CDD AIM).

Staff number on the 30th of June 2012

198: 6 professors and 2 assistant professors; 42 researchers; 13 instrumentalists; 48 engineers, technicians, administrative; 32 PhD students and 48 post docs.

Scientific production during the period (1st January 2007 – 30 June 2012):

- Breakthrough in our understanding of galaxy growth thanks to the synergy of observations (IRAM, Spitzer, Herschel) and simulations: unveiling the dominance of gas-rich disks (main sequence mode of star-formation) versus merger-driven starbursts, key role of disk instabilities to feed bulges and black hole growth (Daddi et al. 2007, ApJ; Daddi et al. 2010, ApJ; Elbaz et al. 2007, A&A; Bournaud et al. 2011).
- Discovery with Herschel that filaments are ubiquitous in the cold ISM, have a characteristic width of 0.1 pc and that low-mass stars form in those filaments with a high enough gas density so that gravitational instabilities can be at work (André et al. 2010, A&A; Men'shchikov et al. 2010, A&A; Arzoumanian et al. 2011, A&A).
- Unveiling solar g-modes amplitude envelope via state-of-the-art data analysis/calibration of SoHO-Golf data (García et al. 2007, Science; Mathur et al. 2007, ApJ) and modeling them via 3-D whole Sun high resolution simulations with self-consistent tachocline, g-waves excitation and propagation (Brun et al. 2011, ApJ).
- New paradigm for Saturn's satellite formation from the rings : rings may give birth to several mid-sized satellites by viscous spreading through the Roche limit (Charnoz et al. 2010, Nature; Charnoz et al. 2011, ICARUS).
- Successful development, fabrication and tests of a novel 2048 pixel, CdTe based, fine pitch imaging spectrometers for hard X-ray Space science (Limousin et al. 2011, NIM-A). This concludes a 7 years R&D effort. The detectors have been selected as the focal plane detector for the STIX instrument of Solar Orbiter.

Quantitative report on the publications of the unit:

- 1650 articles in refereed journals, including 50 in Nature or Science.
- 45 000 citations; 264 publications with more than 50 citations, 91 with more than 100 citations.
- More than a thousand of technical documents written in the context of our participation in space instrumentation, and reviewed by ESA or CNES.

Indicate **5 major publication of the unit**:

- Daddi, E. et al. "Multiwavelength Study of Massive Galaxies at z~2. I. Star Formation and Galaxy Growth", 2007, ApJ 670, 156 *(349 citations)*.
- Abdo et al. (2010, ApJS, 188, 405) (J. Ballet, I. Grenier): Fermi Large Area Telescope First Source Catalog (*402 citations*). The production of Fermi γ-ray catalogues is managed by J. Ballet (AIM).
- Ocvirk, P., Pichon, C. & Teyssier, R., 2008, MNRAS, 390, 1326, « Bimodal gas accretion in the Horizon-MareNostrum galaxy formation simulation » *(142 citations)*
- Arnaud, M., Pratt, G.W., Piffaretti, R., 2010, A&A **517**, 92 "The universal galaxy cluster pressure profile from a representative sample of nearby systems and the Y_{SZ} - M_{500} relation", *(118 citations)*
- André P., Men'shchikov A., Bontemps S. et al., 2010, A&A **518,** L102, "From filamentary clouds to prestellar cores to the stellar IMF: Initial highlights from the Herschel Gould Belt Survey" (*123 citations*).

Indicate **5 major documents:**

- Data package for the delivery to the Rutherford Appelton Laboratory (UK) of the camera of the mid-InfraRed Instrument (MIRI) for the JWST (PI-ship of this sub-instrument by AIM; co-PI-ship at the level of MIRI).
- Proposal of the DUNE mission to ESA (2007); data pack for the assessment phase review of the DUNE instrument of the Euclid mission (2009); Proposal to answer to the Euclid Instrument Definition phase AO released by ESA (2010); data pack for the definition phase of Euclid (2011). (All the activities have been conducted under the scientific, managerial and technical lead by AIM staff).
- Review Data Pack for the phase A and phase B studies of the Eclairs instrument of the French-Chinese SVOM mission (All the activities have been conducted under the scientific and technical lead by AIM staff).

- RAMSES and HERACLES codes for numerical simulations (open source access).
- FASTLens, MR/Lens, MR/Sphere, SparsePol data reduction codes (open source access).

Indicate **5 facts illustrating the academic impact and attractiveness of the unit**:

- 3 prizes from the French Academy of Sciences; 2 CNRS medals; 7 ERC grants; 5 international Patents.
- More than 200 invitations to international conferences, including the “invited discourse” of Ph. André at the 2012 IAU General Assembly (Beijing). Organizer or co-Organizer of 15 international conferences.
- Coordinator of the CESAR FP7 program devoted to cryogenics electronics for the future. This collaborative project involves 6 institutes from 5 European countries.
- International Framework Agreement with UC Berkeley Space Sciences Lab, allowing the use of microelectronics devices designed along the CdTe R&D (AIM and Irfu-SEDI), in CINEMA TRIO nano-satellite program.
- Participation in three LabEx: FOCUS (co-direction) : Focal plane array for Universe Sensing; UnivEarthS (in the excecutive board) : Earth, Planets, Universe; P2IO : “Physique des 2 Infinis et des Origines”. Leading 11 projects funded by the National Agency for Research (ANR) + participation in 12 other projects

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Indicate **5 facts illustrating the interactions of the unit with its socio-economic or cultural environment:**

- Partnership with the “Palais de la découverte” Museum in Paris for the exhibition « A journey to the center of the galaxy» 3 months: February, March, April 2009 (curator J-M Bonnet-Bidaud, AIM). Reduced version of 10 large posters in French, English, Spanish and Chinese, exposed in various places in France (Air and Space museum at Le Bourget…) and around the world (Chile, Argentina, Spain, South Korea, China, Vietnam).
- Partnership with “La cité des Sciences” Museum in Paris on a special day dedicated to conferences given by AIM members, dealing with the theme: "Deep Universe, virtual Universe: from giant telescopes to numerical simulations". Co-Curator (R. Lehoucq AIM) of the permanent exhibition “Le grand récit de l’Univers” at “La cité des Sciences” Museum.
- Partnership with the Canal+ group to broadcast on the cinema channel the Film “des étoiles et des hommes” (45 min.), Pierre-Francois Didek and Samuel Albaric film directors, Goyave Production; the film directors have followed the work of AIM staff during almost a year.
- Partnership with EDF to realize the largest sundial in the world covering an area of about 13 000 square meters on the hydro electrical dam at Castillon (R. Lehoucq, D. Savoie).
- 1.1 M€ contract with the 3D+ company (Buc, France) to realize the hard-X rays CdTe caliste modules for the STIX instrument of the Solar Orbiter ESA M1 mission.

Indicate **the main contributions of the unit to teaching**

- 41 PhD students have passed their thesis; 32 PhD students hosted presently.
- 1100 hours of lectures per year.
- Conception and coordination of three PhD Formation Modules: “project management” (1 week); “numerical simulations in astrophysics” (1 week); “data analysis methods and application”.
- Organization of 5 summer schools (4 as Principal Organizer; 1 as co-organizer).
- Strong implication in CLEA (Chairwoman 2009-2012) for permanent formation in Astronomy of teachers.

In conclusion, AIM has reached or maintained its top level leading international role in several scientific topics (early phases of star formation, galaxy evolution, galaxy clusters, microquasars, cosmic-ray interactions with the ISM, sophisticated signal processing, numerical simulations) and is at the international forefront of several other research fields. Furthermore, AIM has a leading expertise in the design and high-level management of instruments, and in conducting large observing programs. It has been very successful in securing funding and attracting talented young researchers from various countries. Therefore, AIM has proved to be an essential astrophysical laboratory at both the national and international levels.

LCEG - Laboratoire Cosmologie et Evolution des Galaxies

1. Scientific report

LCEG team : The scientific report of the LCEG team concerns a total of 65 researchers who have worked in this group over the period 01/07-06/12 including in total 11 staff members (3 CNRS, 8 CEA), 31 postdocs, 16 PhD students, 5 masters M1 and 7 masters M2 (5 of which continued with a PhD). It is **presently composed of** :
9 staff members : M. Arnaud, F. Bournaud, E. Daddi, D. Elbaz (*head*), E. Le Floc'h, R. Lehoucq, M. Pierre from CEA and H. Aussel, P.-A. Duc from CNRS
15 postdocs : M. Béthermin (ANR), A. Chamballu (P2IO), A. Cibinel (Switzerland+ERC), J. Democles (CNES), J. Gabor (ERC), R. Gobat (ERC), S. Juneau (ITN), R. Martino (CNES), M. Pannella (ANR), S. Paudel (ANR), G. Pratt (CEA), F. Renaud (ERC), T. Sadibekova (CNES), M. Sargent (ERC), V. Strazzullo (ERC)
6 PhD students : P.-E. Belles (CFR+UK), E. Ferrière (Un. Paris-Diderot), K .Kraljic (CFR), R. Leiton (CONYCIT), F. Salmi (MENRT), Q. Tan (Chinese Academy of Science and CNRS/co-lead China)
Past team members *(2007-12)*: *staff members:* D. Alloin (CNRS, retired 2010), A. Réfrégier (CEA, left for ETH in 2011). *16 postdocs:* H. Chen (CNES), H. Dannerbauer (ANR), K. Dasyra (Marie Curie), C. Feruglio (ANR), H. Gosh (CNES), H.S. Hwang (CNES), N. Jetha (CNES), D. Le Borgne (CNES), K. Libbrecht (CNES), G. Magdis (CNRS), C. Mastropietro (ANR), J. Mullaney (Eurotalents), M. Onodera(ANR), R. Piffaretti (P2I/CNES), L. Powell (ANR), S. Temporin (CEA).
10 PhD students : S. Anokhin (CFR), M. Boquien (CFR), N. Clerc (CFR), Y. Debono (Malte grant), B. Magnelli (CFR), C. Mancini (Egide/co-lead Italy), M. Martig (CFR), D. Miralles (Spain), F. Pacaud (CFR), L. Riguccini (MENRT)

Main research interests: The research activities of the LCEG group are primarily related to understanding :

- the main physical mechanisms responsible for the growth of galaxies in stellar and black hole mass,
- what controls the mass assembly of galaxies at cosmological scales from a statistical perspective and in their environment,
- the dominant physics governing large-scale structure formation, accounting for the roles of dark matter and dark energy.

Main instrumentation/observational perspective:

- Space far-infrared (Spitzer, Herschel) / "sub-mm" (Planck) / X-ray (XMM, Chandra) / optical (HST) astronomy.
- Ground-based sub-mm/mm/radio (IRAM, JVLA), optical imaging and spectroscopy (CFHT, Keck & VLT).

Main modeling perspective:

- High-resolution numerical simulations from Mpc to sub-pc scale.
- Spectral energy distribution of galaxies, luminosity functions, galaxy counts, scaling laws of star-formation.
- Structural and scaling properties of the galaxy cluster population across cosmic time.

Broad picture and scientific identity of the LCEG team:
During the last 5 years, the members of the LCEG group have been actively involved in the observation and modeling of the formation/evolution of galaxies and galaxy clusters. Specific emphasis was put on the determination of the fundamental scaling laws describing the observational properties of star-forming galaxies and present-day galaxy clusters. This may be seen as the main achievement of the team over this period. For galaxy formation, extending these fundamental relations to z>2 and understanding their physical origin has now become a major source of investigation worldwide. For galaxy clusters, scaling law evolution, selection effects and precision cosmological applications represent the next challenges. These will represent the central research interest of our future activities. These findings were made possible thanks to major observational programs that we have led as PI over this period, and our recognized expertise in the fields of mid to far-infrared/sub-mm and X-ray observations. These important results build on the involvement of AIM in the construction of *Herschel* and XMM instruments, on our participation in the *Planck* consortium and ground-based observations with IRAM in particular. Bridging the multi-scale physics from Mpc to sub-pc scales, our interpretation of these results has strongly beneficiated from our numerical simulations of the sub-pc-scale physics regulating star-formation at galaxy scales. They have revealed the key role of dynamical instabilities driven by cosmological infall of matter onto galaxies in explaining scaling laws at galactic scales.

LCEG resources : we list below the major funding resources and large observational/simulation programs that helped the team members carrying out their research activities from 2007 to 2012.

funding
2 ERC starting grants (Daddi 2008, Bournaud 2010), 2 ANR grants as PI E. (Daddi 2007, D. Elbaz 2009), node coordinators of 5 ANRs (M. Arnaud, H. Aussel, F. Bournaud, E. Daddi, P.-A. Duc) and 1 FP7 SPACE (D. Elbaz)

large programs (PI-ship in bold letters)
The LCEG team members are leaders of major international collaborations involved in the collaborative projects listed below with e.g. 39 astronomers from 8 different countries, ESO and ESA in GOODS-*Herschel* (PI D. Elbaz), 30 European researchers in the XMM-LSS project (PI M. Pierre),…

Herschel : open time key programs **GOODS-Herschel** (PI D. Elbaz), **CANDELS-Herschel** (PI M. Dickinson, co-PI D. Elbaz), guaranteed time key programs PEP (steering group Elbaz, co-I Aussel, Daddi), HerMES (co-I H. Aussel, D. Elbaz)

Spitzer : GOODS-Spitzer (PI M. Dickinson, co-I D. Elbaz, E. Daddi), S-COSMOS (co-I E. Le Floc'h, H. Aussel, E. Daddi)
IRAM : molecular gas in local to distant galaxies (PIs E. Daddi, F. Bournaud)
HST : CANDELS (co-I F. Bournaud, E. Daddi, D. Elbaz)
XMM : **XMM-LSS** (11 sq.deg, PI M. Pierre), **XXL** (50 sq.deg., 3 Msec, PI M. Pierre), **Dark Matter distribution in high z clusters** (370 ksec, PI M. Arnaud); REXCESS (representative sample of local clusters, 900 ksec, co-I & scaling law study lead: M. Arnaud, G. Pratt); **XMM Follow-up of Planck clusters:** DDT validation program (lead M. Arnaud), Large Programs on disturbed local clusters (PI G. Pratt) and Large Program on z>0.5 clusters with additional VLT lensing (PI M. Arnaud) for 1.5 Msec in total.
Planck (All Sky Sunyaev-Zeldovich identification of massive clusters): Major involvement in Planck Working Group 5 « Clusters and secondary anisotropies ». Co-leads of catalog construction/validation (M. Arnaud) and X-ray data assembly (G. Pratt) working groups; 3/6 of Planck Cluster early papers led by AIM members (M. Arnaud, R. Piffaretti, G. Pratt).
EVLA (atomic gas : **Chaotic THINGS**, PI P.A. Duc) ; *CFHT - MEGACAM* (diffuse stellar light, **MATLAS**, PI P.A. Duc)
*ESO - **VLT*** spectroscopic follow-ups in optical and near-IR + **SINFONI** (dynamics) (F. Bournaud, E. Daddi, D. Elbaz, M. Pierre)
PI-ship of several computing programs on supercomputers (**GENCI**) + Grand challenges (**PRACE**, **GPU**...) (F. Bournaud)

Participation of LCEG staff members to major committees in the field of astronomy :
Presidency of PNCG (Programme National Cosmologie et Galaxies) Science Council (Arnaud), of CFHT Time Allocation Committee (TAC) (Duc, Elbaz) & Science Advisory Committee (Duc) and of XMM-Newton user Group (Arnaud)
Members of TACs for IRAM (Duc)/Spitzer (Aussel, Daddi, Duc, Elbaz, Le Floc'h)/XMM (Pierre, Pratt)/Chandra (Arnaud, Pratt)/ESO (Arnaud, Aussel, Bournaud)/HST (Daddi)/Suzaku (Arnaud) / GMRT (Bournaud) / Opticon (Aussel), member of ASI Grant evaluation committee (Pratt)
Members of INSU CSA (comité spécialiste astrophysique et astronomie, Arnaud) & CSI (conseil scientifique de l'INSU)
TAC supercomputers TGR (grands équipements de recherche) GENCI (France, Bournaud) & PRACE (Europe, Bournaud)
Users groups : ESO (Pierre), GENCI & TGCC (très grand centre de calcul, Bournaud)
Member of visiting committee of AERES (Arnaud), of the scientific councils of OAMP (Duc), IRAP (Arnaud), Paris Observatory (HCS, Arnaud), Pytheas (Aussel), of the expert committee for the Ministry of Research (Duc).

Training : training of 14 PhD students, 12 master students and 28 postdocs. High-level teaching activities in masters and post-graduate classes. Invited lectures in several international Physics Schools.

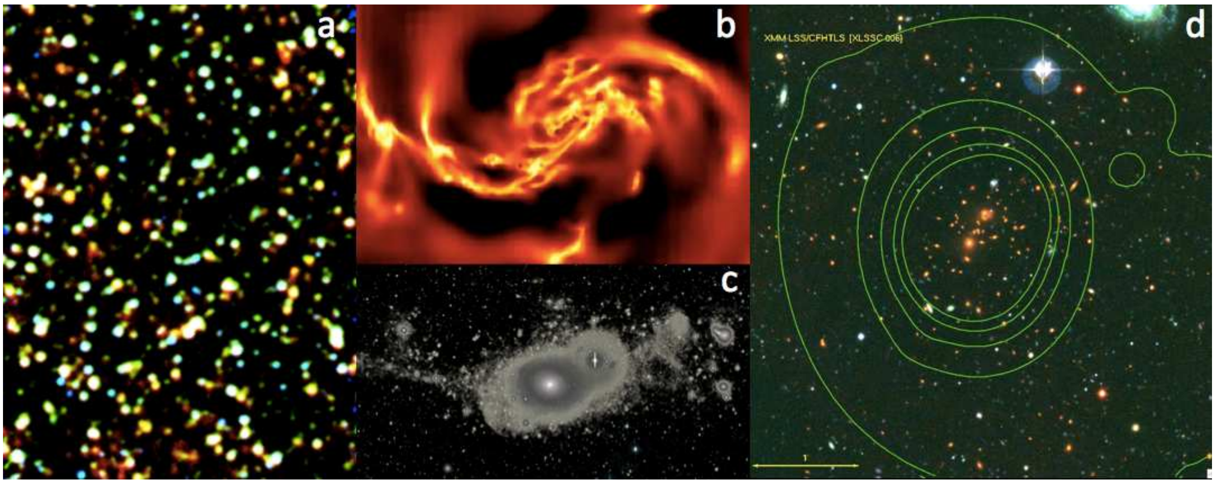


Figure 1 : (a) *3 color (100-160-250 microns) Herschel image from GOODS-Herschel of the GOODS-North field (10'x15', deepest far-IR imaging survey).* ***(b)*** *sub-pc scale numerical simulation of a Milky-Way like galaxy.* ***(c)*** *NGC 5557, a local elliptical with tidal tails signing a past merger (CFHT-MEGACAM, Duc).* ***(d)*** *An XMM-LSS cluster of galaxies at a redshift of 0.43 (X-ray contours overlaid on a CFHTLS color composite image).*

Scientific report :

I) Quantification of the star-formation and black-hole growth rate in galaxies: a modest contribution of galaxy mergers to the cosmic history of galaxies

"Paradigm" before 2007
Until the middle of the last decade, mergers of galaxies and the star formation episodes triggered by these phenomena had been considered as a major, even dominant, phase in the cosmic history of the formation of stars. This view of galaxy evolution stemmed from the increasing (i) fraction of interacting galaxies as a function of redshift (measured by the density of galaxy pairs or morphological analysis) and (ii) bolometric luminosity of distant galaxies whereas, in the local Universe, such high luminosities are only observed in merging systems. The latest progress in this field of astrophysics, particularly by our group, however, have led to a real breakthrough in this vision of cosmic evolution and our understanding of which physical processes dominate the star formation at high redshift :

Discovery of the stellar mass - star formation rate relation: ***the SFR-Mstar scaling law***

We showed that at z=0, 1 and 2, most star-forming galaxies follow a tight correlation (0.3 rms) between their star formation rate (SFR) and stellar mass, the so-called "main sequence" of star-formation (Elbaz +07, Daddi +07, see also Noeske +07). This suggests that episodic events such as mergers of galaxies that trigger a "starburst" (sharp increase of the SFR for a given stellar mass) must contribute relatively little to the global history of star formation, since they would otherwise broaden this relation. The normalization of this SFR-Mstar main sequence rises with increasing redshift up to z ~ 2, but appears to remain flat at higher redshifts. While this main sequence may be explained by the fact that Mstar traces the dark matter halo mass of galaxies, hence their attractive power over extragalactic fuel to further star formation, the plateau at high redshift contradicts this explanation that would instead require a continuous rise in specific SFR (sSFR=SFR/Mstar) with increasing redshift.

As a result of the main sequence and of its rise up to z~2, the most luminous galaxies that are systematically merging systems at z~0, fall in the main sequence mode at z~1 and z~2, hence appear to be normal star-forming systems, suggesting that the role of merger-driven starbursts has been overestimated in the past. According to recent measurements obtained with the *Herschel* satellite, the contribution of the star formation events taking place in a starburst mode to the density of star formation would be about 5-15% at z ~ 2, hence similar to the fraction measured in the local Universe, where merging galaxies are very rare (Rodighiero +11, Sargent +12, Elbaz +11).

A puzzling universality of infrared galaxies energy distributions

Thanks to the deepest far-IR image of the Universe obtained from the Open Time Key Program GOODS-Herschel, we were able to identify a puzzling universality of the properties of star-forming galaxies from z~0 to 2.5. The infrared spectral energy distribution of distant highly star-forming galaxies appears to be scaled up versions of the local ones of moderately star-forming disks. The ratio of far-IR over mid-IR luminosity in star-forming galaxies has been shown to rise with increasing star-formation compactness, ranging from low value in normal disks to high values in merger-driven starbursts. This ratio traces the relative emission of big dust grains over fragile dust such a PAH (polycyclic aromatic hydrocarbon) molecules in the mid-IR, easily destroyed in compact star-formation regions (Elbaz +11). This segregation between extended and compact/clumpy star-formation, offers a new tool to separate isolated galaxies from merger-driven starbursts.

Gas content: ***the SFR-Mgas scaling law***

Observations of molecular gas in typical distant galaxies showed that their gas fraction may reach 50% at z ~ 2 (Daddi 10) and that their star-formation efficiency (star-formation rate per unit gas mass) was comparable to that of disks in the local Universe even though their absolute SFR may be tens or hundreds time higher. The much higher star-formation efficiency measured in present-day starbursts is not observed in equivalently luminous galaxies but only found in a minor fraction of galaxies - identified by their excess submillimeter emission for their carbon monoxide line luminosity, tracing the amount of available molecular gas - showing evidence of being triggered by merger events. This work has led to a revision of the local Schmidt-Kennicutt law and its extension to z~2.

Effects of environment on star formation: ***the SFR-density relation***

We also played a key role in the study of the dependence of star-formation activity with the environment in which galaxies evolve. In the local universe, it is established that the average SFR drops sharply in denser environments. We now know that this effect disappears with increasing redshift, and that the relationship between SFR and local density of galaxies becomes even reversed beyond z ~ 1 (Elbaz +07). The origin of this reversal continues to be debated since galaxies living in denser environments are also more massive and the SFR-stellar mass relation alone may explain their excess star-formation in large part (Feruglio 10).

bibliography: Rodighiero, Daddi et al. 2011, ApJ 739, L40; Sargent, Béthermin, Daddi, Elbaz 2012, ApJS 747, L31; Feruglio, Aussel, Le Floc'h et al. 2010, ApJ 721, 607 + references listed below.

II) Morphological transformation of galaxies over cosmic history: a much larger range of mechanisms than previously envisioned

Signs of recent mergers around local ellipticals

if the overall contribution of galaxy mergers in the history of star formation appears to have been fairly small, interaction phenomena have yet played a fundamental role in the mass growth of galaxies, including their morphological transformation in the course of cosmic evolution. Very deep images of local elliptical galaxies have revealed the presence around them of signatures typical of interaction (e.g., tidal tails, "shells",...; Duc +11). If the stellar populations of massive ellipticals seem to have been mostly formed at very high redshift, these signatures, however, show that these objects have experienced interactions over the last few billion years (minor mergers and / or major). These interactions, even of minor type (mass ratio greater than four), may have a role in the growth of the characteristic radius of elliptical galaxies over time (ellipticals at high redshift are more compact than their analogues in the local Universe, at fixed stellar mass). One can also note that over the last 8 billion years (0 <z <1), the density of star formation has fallen sharply on cosmological scales and galaxy interactions must have played a role in their morphological evolution.

The cold-flow paradigm: were galaxy bulges produced by dynamical instabilities driven by external infall ?

Numerical simulations revealed the importance of continuous accretion of filaments of cold gas toward the heart of dark matter halos, and how this could help building disks of gas, and later one stars, around spheroids at lower redshift. This accretion of cold gas therefore appears to have played a significant role in the evolution of the morphology and properties of galaxies, with the possibility for them to evolve from an early-type stage to a star-forming phase.

A high redshift (z> 1), numerical simulations revealed that in addition to interaction phenomena, internal processes have also played a role in the formation and evolution of galaxies (e.g., gravitational instabilities triggered with gas rich discs, Bournaud +07b,08,09). For example, while mergers of galaxies were long considered as the only mechanism to lead to the formation of spheroids, simulations have recently shown that an isolated disk galaxy may as well transform itself into a spheroid through the migration of large clumps of star-formation triggered by these internal disc instabilities toward their center.

bibliography: Duc et al. 2011, MNRAS 417, 863+ references listed below.

III) Understanding of the statistical properties of galaxy clusters and their implication on cosmology

Context

Galaxy clusters form through hierarchical gravitational collapse driven by the merging of dark matter haloes. They are excellent laboratories for the study of dark matter and baryonic physics in structure formation, and are potentially powerful cosmological probes because they are sensitive to both geometry (luminosity distance) and the rate of expansion of the Universe (growth of structure). As clusters are dark matter dominated objects, and since gravity is a scale-free process, the galaxy cluster population is expected to exhibit structural similarity and scaling laws in mass and redshift. These scaling laws are fundamental to constrain the physics of cluster formation and for exploitation of the cluster population as a cosmological probe. By 2007, regularity was well established from X-ray observations of the intra-cluster medium (ICM), but with significant, poorly understood, departures from purely gravitation based models. However this was based on biased and heterogeneous sampling of the underlying cluster population, limiting the constraining power of the observations both for astrophysics and cosmology. A major observational advance in the post 2007 period has been the advent of Sunyaev-Zeldovich (SZ) surveys, with the first blind SZ detection of a cluster occurring in 2009. The SZ signal of galaxy clusters, due to the inverse Compton scattering of CMB photons by the ICM, is expected to correlate tightly with cluster mass and its surface brightness is independent of redshift. SZ surveys can thus provide cluster samples that are as close as possible to unbiased, thus particularly well-suited for statistical studies of the galaxy cluster population up to high redshifts.
Since 2007 our emphasis has been on rigorous measurement of structural and scaling properties using *representative* samples in X-rays, and more recently in SZ, as a probe of the interplay between gravitational and non-gravitational processes in cluster formation; construction of new contiguous area X-ray surveys for cosmology; optimum exploitation of new generation X-ray and SZ surveys.

Scaling laws in galaxy clusters

With the XMM-Newton Large Program REXCESS (X-ray scientific exploitation led by G. Pratt & M. Arnaud), we were able to robustly calibrate the structural and scaling properties of the ICM in the local (z < 0.2) cluster population. REXCESS is fully representative of an X-ray-selected cluster sample, with no *a posteriori* bias on dynamical state, thus is uniquely suited to measurement of statistical properties including intrinsic scatter. In particular, we measured the radial and mass-dependent behavior of the ICM entropy, showing that the entropy excess above the prediction from pure gravitational collapse is centrally concentrated and extends to larger radius in lower mass systems (Pratt, Arnaud et al. 2010), and is likely connected to heating by the central AGN. We also measured a *universal* pressure profile from the REXCESS clusters (Arnaud, Pratt et al. 2010) showing that the pressure is little affected by the complex formation physics. When combined with numerical simulations, this allowed us to make definitive predictions for the "M-Y_{SZ}" relation - linking the total mass of a cluster with the intensity of the SZ signal as parameterized by the Y_{SZ} parameter. The universal pressure profile has since become the *de facto* community standard for SZ cluster studies, including for blind detection of new clusters in SZ maps, and for parameterization of the SZ signal once a cluster has been identified.

The X-ray-SZ synergy with Planck and XMM: massive galaxy clusters as probes of physics and cosmology

The Planck all-sky survey is the first-ever all-sky blind SZ search for clusters, and the first all-sky cluster search since the ROSAT X-ray survey in the early 1990s. This allows detection of the rarest clusters, the most massive objects lying in the exponential tail of the mass function. However, multi-wavelength data are needed to scientifically exploit *Planck* cluster candidate data. Due to their differing ICM density dependencies, the X-ray emission from the ICM and the SZ cluster signal are complementary probes of the hot gas in galaxy clusters. Indeed, X-ray observations have made substantial contributions to the early scientific results on galaxy clusters from the Planck mission. Validation and exploitation of the Planck cluster catalogue was optimized thanks to the construction of *The MCXC: a meta-catalogue of x-ray detected clusters of galaxies* (Piffaretti, Arnaud, Pratt et al. 2011). XMM-Newton has also made important contributions : notably, through an agreement between the XMM-Newton and Planck project scientists, 500 ksec of Director's Discretionary Time was awarded to validate newly-detected Planck galaxy cluster candidates. This program (coordinated by M. Arnaud) yielded the confirmation and first characterization of the physical properties of a total of fifty-one previously unknown clusters, lying at redshifts 0.2 to 0.9, revealing a non-negligible population of massive, dynamically perturbed objects, likely under-represented in X-ray surveys. The program has led to two press releases and 4 publications. In parallel, we made extensive use of the XMM-Newton archive to make a precise calibration of the mass/SZ observable relation in the local Universe (project coordinated by G. Pratt), a pre-requisite for the on-going cosmological exploitation of the Planck cluster sample. The MCXC was used to measure the bin-averaged SZ signal down to unprecedentedly low masses (project coordinated by R. Piffaretti). These studies resolved the longstanding controversy concerning the possible missing hot baryons in clusters, by showing the excellent consistency between X-ray and SZ gas census. Exploitation of the Planck cluster catalogue has been further supported by the award of two ongoing XMM-Newton large Programs (PIs G. Pratt and M. Arnaud) consisting of a total of more than 1 Msec XMM observing time, some with complementary VLT time.

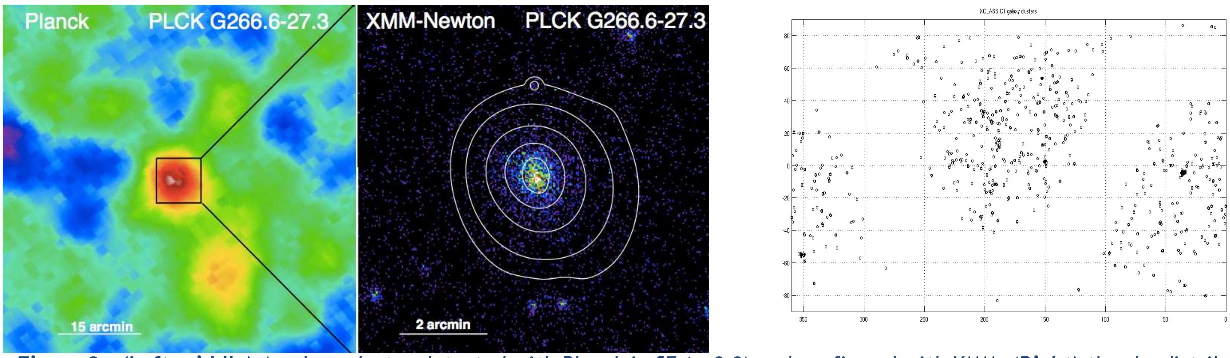


Figure 2 ***: (Left-middle)*** *A galaxy cluster detected with Planck in SZ (z=0.9) and confirmed with XMM.* ***(Right)*** *the sky distribution of the XCLASS cluster catalogue (851 objects).*

Surveying large-scale structure formation/evolution with galaxy clusters: the XMM-LSS survey

XMM-LSS (PI M. Pierre) is a survey of 11 square degrees with the main goal of studying the population of low mass galaxy clusters outside the local Universe up to redshifts of about 1 or more with peculiar emphasis on systematics, selection effects. This pilot project is aimed to better understand the process of cosmic structure formation and thus set up constraints on cosmological models. This work is the result of a collaboration of about 30 researchers from Europe and has been accompanied by numerous series of ground-based follow-up observations (ESO). It has led to the development of sophisticated techniques of analysis of extended sources in X-ray imaging (limited by Poisson noise) resulting in the definition of new criteria to build reliable samples of galaxy clusters with controlled degrees of purity, a necessity prior to any cosmological study with peculiar emphasis on selection effects related to apparent sizes. This helped demonstrating that the concept of flux limit was not reliable for extended sources, while instead an efficient selection of galaxy clusters must happen in a 2D manifold accounting both for apparent size and flux. Such selection effects were demonstrated to be critical in the determination of scaling laws of clusters and their evolution (Pacaud et al 2007) ; consequently, cosmology, evolutionary scaling relations (including scatter) and selection effects must always be simultaneously worked out, whatever the cluster sample. The XMM-LSS survey allowed us to also identify and study the population of galaxy groups at z~0.3-0.5 (Pacaud et al. 2007).

From clusters to cosmology

Tools (pipeline and database) developed for the XMM-LSS project were applied to the entire archive XMM allowing us to extract a catalog of 851 clusters (XCLASS project). In parallel, we developed a novel method for the analysis of cosmological surveys of clusters, based not on the mass function, but on color-X-ray magnitude diagrams. The method allows a simultaneous analysis of cosmology, selection effects and scaling laws. We were able to carry out the first cosmological analysis of archival XMM deriving constraints on σ_8 and Ω_m and highlight that clusters exhibit a tendency to evolve in a non-self-similar way (Clerc et al. 2012 a,b). The XCLASS catalog was integrated into a multifunctional database, developed by an engineer of IRFU and is available online (http://xmm-lss.in2p3.fr:8080/l4sdb/). Our expertise in the detection of X-ray clusters allowed us to undertake the most realistic to date calculation of cosmological predictions (Pierre et al 2011), which led to the award of the XXL project: a survey of 50 square degrees with XMM to constrain the equation of state of dark energy using the counts and the correlation function of clusters (3 Msec, PI Pierre).

bibliography : Piffaretti, R., Arnaud, M., Pratt, G. W., Pointecouteau, E., Melin, J.-B., 2011, *A&A*, 534,109 ; Pacaud, F., Pierre, M. et al., 2007, MNRAS 382, 1289 ; Pierre, M., Pacaud, F.et al., 2011 MNRAS, 4141, 1732 ; Clerc, Pierre, Pacaud, Sadibekova 2012a, MNRAS 423, 3345 ; Clerc, Sadibekova, Pierre et al. 2012b, MNRAS 423, 3561 + refs. below

2. List of publications

The scientific achievements of the team have been presented in 473 peer-reviewed articles (20212 citations, *h*-index 69 since 2007), including 144 first author papers (4583 citations), 6 papers in Nature and 3 in Science. 11 first-authored papers received more than 100 citations and 23 more than 50 over the considered period.

Peer-reviewed first author papers with >50 citations published in the period 2007-06/2012:

1. Arnaud, M., E. Pointecouteau, and G. W. Pratt (2007), "Calibration of the galaxy cluster M{500}-Y{X} relation with XMM-Newton." , A&A 474, L37– L40 (71 citations)
2. Arnaud, M., G. W. Pratt, R. Piffaretti, H. Böhringer, J. H. Croston, and E. Pointecouteau (2010), "The universal galaxy cluster pressure profile from a representative sample of nearby systems (REXCESS) and the YSZ - M500 relation." , A&A 517, A92 (136 citations)
3. Bournaud, F., E. Daddi, B. G. Elmegreen, D. M. Elmegreen, N. Nesvadba, E. Vanzella, P. Di Matteo, L. Le Tiran, M. Lehnert, and D. Elbaz (2008), "Observations and modeling of a clumpy galaxy at z = 1.6. Spectroscopic clues to the

origin and evolution of chain galaxies." , A&A 486, 741–753 (66 citations)
4. Bournaud, F., P.-A. Duc, E. Brinks, M. Boquien, P. Amram, U. Lisenfeld, B. S. Koribalski, F. Walter, and V. Charmandaris (2007a), "Missing Mass in Collisional Debris from Galaxies." Science, 316, 1166 (61 citations)
5. Bournaud, F., Elmegreen, B.G., Elmegreen, D.M. (2007b), "Rapid Formation of Exponential Disks and Bulges at High Redshift from the Dynamical Evolution of Clump-Cluster and Chain Galaxies", ApJ 670, 237–248 (147 citations)
6. Bournaud, F., B. G. Elmegreen, and M. Martig (2009), "The Thick Disks of Spiral Galaxies as Relics from Gas-rich, Turbulent, Clumpy Disks at High Redshift." , ApJ 707, L1–L5 (65 citations)
7. Bournaud, F., C. J. Jog, and F. Combes (2007c), "Multiple minor mergers: formation of elliptical galaxies and constraints for the growth of spiral disks." , A&A 476, 1179–1190 (119 citations)
8. Daddi, E., D. M. Alexander, M. Dickinson, R. Gilli, A. Renzini, D. Elbaz, et al. (2007a), "Multiwavelength Study of Massive Galaxies at z~2. II. Widespread Compton-thick Active Galactic Nuclei and the Concurrent Growth of Black Holes and Bulges." , ApJ 670, 173–189 (230 citations)
9. Daddi, E., F. Bournaud, F. Walter, H. Dannerbauer, C. L. Carilli, M. Dickinson, D. Elbaz, et al. (2010), "Very High Gas Fractions and Extended Gas Reservoirs in z = 1.5 Disk Galaxies." , ApJ 713, 686–707 (174 citations)
10. Daddi, E., H. Dannerbauer, D. Elbaz, M. Dickinson, G. Morrison, D. Stern, and S. Ravindranath (2008), "Vigorous Star Formation with Low Efficiency in Massive Disk Galaxies at z = 1.5." , ApJ 673, L21–L24 (113 citations)
11. Daddi, E., H. Dannerbauer, M. Krips, F. Walter, M. Dickinson, D. Elbaz, and G. E. Morrison (2009a), "A CO Emission Line from the Optical and Near-IR Undetected Submillimeter Galaxy GN10." , ApJ 695, L176–L180 (60 citations)
12. Daddi, E., H. Dannerbauer, D. Stern, M. Dickinson, G. Morrison, D. Elbaz, M. Giavalisco, C. Mancini, A. Pope, and H. Spinrad (2009b), "Two Bright Submillimeter Galaxies in a z = 4.05 Protocluster in Goods-North, and Accurate Radio-Infrared Photometric Redshifts.", ApJ 694, 1517–1538 (118 citations)
13. Daddi, E., M. Dickinson, G. Morrison, R. Chary, A. Cimatti, D. Elbaz, D. Frayer, A. Renzini, A. Pope, D. M. Alexander, F. E. Bauer, M. Giavalisco, M. Huynh, J. Kurk, and M. Mignoli (2007b), "Multiwavelength Study of Massive Galaxies at z~2. I. Star Formation and Galaxy Growth.", ApJ 670, 156–172 (366 citations)
14. Daddi, E., D. Elbaz, F. Walter, F. Bournaud, F. Salmi, et al. (2010b), "Different Star Formation Laws for Disks Versus Starbursts at Low and High Redshifts." , ApJ 714, L118–L122 (114 citations)
15. Elbaz, D., E. Daddi, D. Le Borgne, M. Dickinson, D. M. Alexander, R.-R. Chary, J.-L. Starck, W. N. Brandt, M. Kitzbichler, E. MacDonald, M. Nonino, P. Popesso, D. Stern, and E. Vanzella (2007), "The reversal of the star formation-density relation in the distant universe." , A&A 468, 33–48 (309 citations)
16. Elbaz, D., M. Dickinson, H. S. Hwang, T. Diaz-Santos, G. Magdis, B. Magnelli, D. Le Borgne, F. Galliano, M. Pannella, P. Chanial, L. Armus, V. Charmandaris, E. Daddi, H. Aussel, et al. (2011), "GOODS-Herschel: an infrared main sequence for star-forming galaxies." , A&A 533, A119 (93 citations)
17. Elbaz, D., H. S. Hwang, B. Magnelli, E. Daddi, H. Aussel, B. Altieri, et al. (2010), "Herschel unveils a puzzling uniformity of distant dusty galaxies." , A&A 518, L29 (88 citations)
18. Feruglio, C., R. Maiolino, E. Piconcelli, N. Menci, H. Aussel, A. Lamastra, and F. Fiore (2010), "Quasar feedback revealed by giant molecular outflows." , A&A 518, L155 (63 citations)
19. Magnelli, B., D. Elbaz, R. R. Chary, M. Dickinson, D. Le Borgne, D. T. Frayer, and C. N. A. Willmer (2009), "The 0.4 z 1.3 star formation history of the Universe as viewed in the far-infrared." , A&A 496, 57–75 (161 citations)
20. Magnelli, B., D. Elbaz, R. R. Chary, et al. (2011), "Evolution of the dusty infrared luminosity function from z = 0 to z = 2.3 using observations from Spitzer", A&A 528, 35
21. Mancini, C., E. Daddi, A. Renzini, F. Salmi, H. J. McCracken, A. Cimatti, M. Onodera, M. Salvato, A. M. Koekemoer, H. Aussel, E. Le Floc'h, C. Willott, and P. Capak (2010), "High-redshift elliptical galaxies: are they (all) really compact?" , MNRAS 401, 933–940 (59 citations)
22. Martig, M., F. Bournaud, R. Teyssier, and A. Dekel (2009), "Morphological Quenching of Star Formation: Making Early-Type Galaxies Red." , ApJ 707, 250–267 (64 citations)
23. Planck Collaboration [R. Piffaretti, contact author] (2011), "*Planck Early Results X: Statistical analysis of SZ scaling relations for X-ray galaxy clusters*", A&A, 536, A10 (65 citations)
24. Pratt, G. W., M. Arnaud, R. Piffaretti, H. B ̈ohringer, T. J. Ponman, J. H. Croston, G. M. Voit, S. Borgani, and R. G. Bower (2010), "Gas entropy in a representative sample of nearby X-ray galaxy clusters (REXCESS): relationship to gas mass fraction." , A&A 511, A85 (66 citations)

LFEMI - Laboratoire Formation des Etoiles et Milieu Interstellaire

1. Scientific report

In the interstellar medium and star formation fields, there is an increasing need to bridge local studies made in the Milky Way to global measurements made across galaxies. LFEMI was built in this spirit by bringing together experts of Galactic star formation (P. André, A. Men'shchikov, F. Motte) and specialists of the interstellar medium in nearby galaxies (M. Sauvage, S. Madden, F. Galliano). Over the reviewed period, we have been primarily concerned with the initial conditions for star formation, the origin of the initial mass function, the interplay between young massive stars and their surroundings, and how this affects the tracers that are used in extragalactic studies. We have combined ambitious observational programs with the development of state-of-the-art modeling and data processing codes to make the most of the data we have acquired. Our targets go from the nearby star forming clouds of the Gould Belt to the star forming regions of galaxies in the Local Group and beyond, providing us with a vast range of physical conditions, and with the opportunity to witness the impact of star formation on a wide range of physical scales.

a. Activities and Results

The physics of star formation

Understanding star formation from large to small scales is a major unsolved problem of modern astrophysics, fundamental in its own right and having a profound bearing on both galaxies and planet formation. Recognizing that the earliest evolutionary stages (e.g., pre-stellar cores and protostars) are crucially important, the LFEMI programs have revolved around the exploitation of large-scale submillimeter surveys of nearby star-forming regions. We for instance led large multi-wavelength surveys, using e.g. the IRAM/PdBI or Spitzer, over prototypical Galactic star forming regions such as Cygnus X and W43 (Motte et al. 2007, Schneider et al. 2010).

Thanks to our role in building these surveys and in elucidating fundamental steps in the early stages of the star formation scenario, we obtained key responsibilities in the Herschel Guaranteed Time Key Programs of the SPIRE instrument: **P. André was nominated chairman of the Star Formation Specialist Astronomy Group, and P. André and F. Motte acted as PIs of two of the programs, the Gould Belt Survey and HOBYS**. The Gould Belt Survey probes the link between interstellar cloud structures and compact cores with the main goal of understanding the physical mechanisms of the formation of pre-stellar cores out of the diffuse medium, a crucial step for understanding the origin of stellar masses. HOBYS allows, for the first time, to statistically study the formation of 10-20 $M_\odot$ stars in 100 pc molecular complexes in the nearest portion of the first Galactic arm towards us, providing accurate bolometric luminosities and envelope masses for homogeneous and complete samples of the progenitors of massive stars.

The first images from the Gould Belt survey revealed a profusion of long (> pc scale) filaments in nearby cloud complexes (Men'shchikov et al. 2010) and suggested a tight connection between the filamentary structure of the ISM and the formation process of pre-stellar cores (André et al. 2010). While molecular clouds were known to exhibit large-scale filamentary structures long before Herschel, our new observations demonstrated that these filaments are truly ubiquitous in the cold ISM throughout the Galactic Plane (Molinari et al. 2010) and provided an unprecedented large-scale view of the role of filaments in the formation of pre-stellar cores. In any given cloud complex, Herschel imaging revealed networks of filaments (Arzoumanian et al. 2011), which we endeavored to characterize in a proper statistical manner. In particular, detailed analysis of the radial column density profiles derived from Herschel data showed that **interstellar filaments are characterized by a very narrow distribution of central widths with a typical FWHM value ~ 0.1 pc** (Figure 1, Arzoumanian et al. 2011). A plausible interpretation of this characteristic thickness of interstellar filaments is that it corresponds to the sonic scale below which interstellar turbulence becomes subsonic in diffuse, non-star-forming gas (e.g. Arzoumanian et al. 2011).

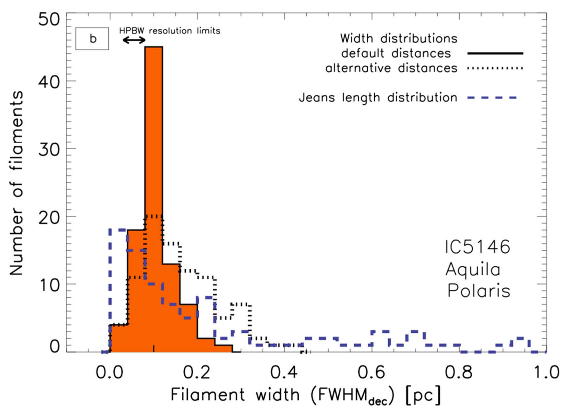


Figure 1: The distribution of filament's width in three ISM clouds with vastly different star formation activity (Arzoumanian et al. 2011).

With our submillimeter continuum observations, **we showed that the pre-stellar core mass function (CMF) resembles the IMF** (e.g. Motte et al. 1998, 2001; Könyves et al. 2010; André et al. 2010), suggesting that the stellar IMF is at least partly determined at the pre-stellar core stage. This finding is consistent with theoretical models for the IMF based on the « gravo-turbulent » concept (e.g. Hennebelle & Chabrier 2008). **We also discovered a threshold for the formation of self-gravitating pre-stellar cores in molecular clouds**. In the Aquila Rift complex, for instance, the Gould Belt survey has revealed a complete sample of 341 bound pre-stellar cores (Könyves et al. 2010), ~ 90% of which are found above a background gas surface density Σ_{back} ~ 150 $M_\odot/pc^2$, corresponding to a background visual extinction A_V ~ 7. In contrast, in the non-star-forming Polaris Flare complex where the surface density of the background cloud is below Σ_{back} ~ 100 $M_\odot/pc^2$ everywhere, only unbound starless cores are detected with Herschel but no pre-stellar cores or proto-stars (André et al. 2010). Interestingly, this threshold value for the column density is at the right location to explain the threshold for star formation that occurs in the Schmidt-Kennicutt law observed in galaxies.

We explored the link between Galactic and extragalactic star formation regions more thoroughly by focusing on one of the most massive star-forming regions in the Galaxy, Cygnus X. This multiwavelength study, using molecular lines, continuum (Motte et al. 2007), and Herschel in the context of HOBYS (Hennemann et al. 2012), clearly confirmed the concept of dynamic star-formation. It emphasized the importance of supersonic flows on large scales (Schneider et al. 2010) and small scales (Csengeri et al. 2011 and PhD thesis, Bontemps et al. 2010).

Similarly, in Q. Nguyen-Luong's PhD thesis, W43 was characterized as a mini-starburst region, presenting strong analogies with external starburst galaxies. We showed that the strong concentration of its high-density gas and the high number of massive pre-stellar cores can be explained by the location of the W43 complex at the tip of the long bar of the Milky Way. Indeed, this crowded zone of Galactic orbits can accumulate atomic gas that will become molecular and efficiently form stars. HOBYS also revealed thousands of burgeoning Young Stellar Objects in these new molecular complexes, which make it possible to measure, simply by counting sources, the present-day star formation rate (SFR) on 1-100 pc scales. We were thus able directly plot the Schmidt-Kennicutt relation at the scale of the cloud. This study is among the first ones performed on an entire molecular cloud complex of the Milky Way, with tracers and angular resolution (< 0.1 pc) perfectly suited to study proto-stars and their parental high-density cloud, that is at the same time directly comparable with approaches applicable to galaxies as a whole.

Still with HOBYS, **we showed that high-mass stars form only in high-column density (A_v > 100 mag, see Figure 2), elongated (several pc) cloud structures concentrating the mass of their surroundings, that we named "ridges"** (Hill et al. 2011). While turbulence could have formed most cloud filaments in e.g. Gould Belt fields, more dynamic scenarios such as converging flows and/or filaments merging (e.g. Heitsch et al. 2006) are advocated to form ridges (Hill et al. 2011; Hennemann et al. 2012). This interpretation is in complete agreement with IRAM observations of short timescales for high-mass star-forming clouds (Motte et al. 2007) and supersonic global infall towards ridges (Schneider et al. 2010; Csengeri et al. 2010). Ridges are the privileged sites for the formation of high-mass stars clusters with star formation rate densities (Σ_{SFR} ~ 10-100 $M_{\odot}$/yr/kpc^2 on 1-10 pc^2 areas) worthy of starburst galaxies (usually defined by Σ_{SFR} > 1) and therefore called mini-starburst regions (Nguyen-Luong et al. 2011b). Short mini-bursts of star formation are to be expected after a fast episode of cloud formation (e.g. Vazquez-Semadeni et al. 2008).

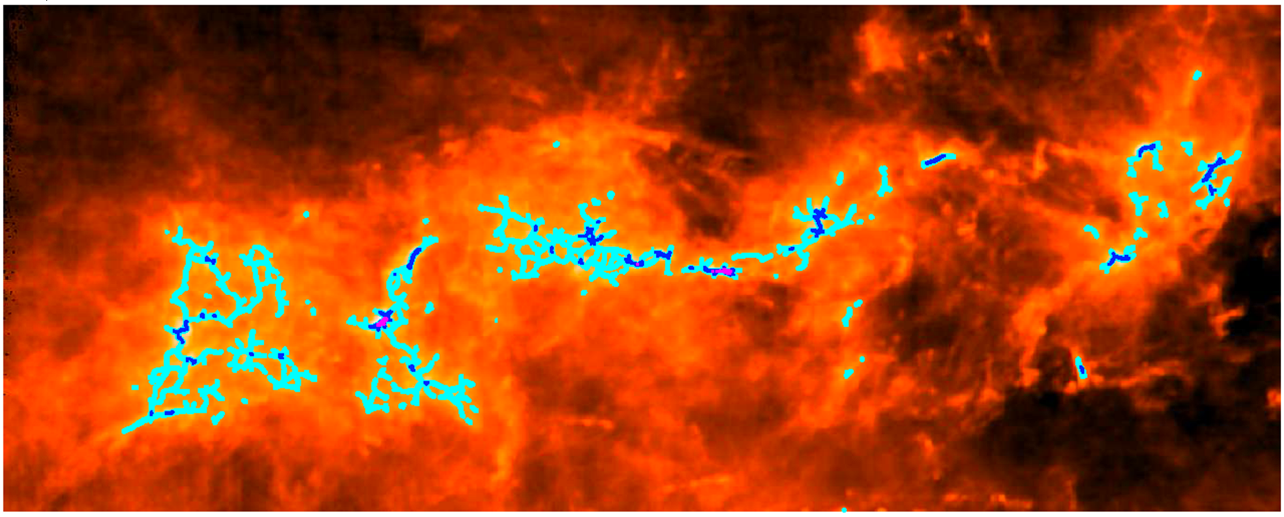


Figure 2: The filament structure in Vela C. Filaments coded cyan, blue and magenta correspond to A_V > 25, 50, and 100 mag (Hill et al. 2011).

Deciphering interstellar medium tracers

When individual newly-formed stars can no longer be resolved, the star formation process is observed through indirect tracers that result from the interaction of massive stars with the interstellar medium. As star formation is a key ingredient in the evolution of galaxies, it is crucial that we establish the interpretation of ISM tracers on a firm basis. These tracers can broadly be categorized in two classes: spectral lines coming from various phases of the gas, and the dust continuum that carries most of the energy emitted by the ISM. Our laboratory inherits from a long tradition of infrared studies, that started in the 90's with the ISOCAM camera on-board ISO, and thus has been focusing on issues pertaining to the nature of interstellar dust (components, spectral features), its relation to the heating sources, and the build-up of the mid to far-infrared (MIR to FIR) spectral energy distribution on galactic scales. Over the period however, we have seized the opportunity presented by the spectroscopic instruments on-board Herschel to integrate in our studies the rich family of submillimeter lines, and we developed a comprehensive approach of the interpretation of the infrared to submillimeter spectral energy distribution (SED) of galaxies.

One of the particular aspects of the science we develop, and for which we are quite unique, is our focus on dwarf low-metallicity galaxies. Although these galaxies contribute a small amount to the star formation rate density of the universe at any time, they occupy a special place in the local universe in that they provide us with a glimpse of the conditions that could have be the norm in the early universe: high energy density due to strong local star formation, but low metal and dust content. More generally, they extend the range of physical conditions that can be explored, which offers an opportunity to truly test any model of the ISM.

Our first line of research focused on the PAH emission of these galaxies, which has been known to be deficient with respect to large more metal-rich star-forming galaxies. We were the first to present evidence that the hardness of the radiation field on full global scales is the reason low metallicity galaxies show a deficit of PAHs (Madden et al. 2006). In addition, we presented the first detailed comparison between the masses of dust and PAHs observed in a large sample of galaxies, and those predicted by a model of evolution of the elements and dust grains (Galliano et al. 2008a). This study revealed the evolution of the abundances of **large** grains and PAHs as a function of metallicity**.** In particular**, we demonstrated** that there was a differential evolution between these two components**,** and that their origin could be linked to the history of star formation.

We also performed in Galliano et al (2008) a systematic study of PAHs in many environments (HII and Photo-Dissociation Regions, spirals, starbursts, dwarfs, …). We established that relations between the different PAH bands followed a small number of universal correlations that can be explained by a systematic variation of the electrical charge of these molecules through different environments. We thus created an empirical diagnostic tool relating these PAH band ratios to the fundamental PDR parameter: G_0/n_e (the UV energy density over the electron density).

This work was fundamental for the elaboration of the Galliano dust model, which, in turn, is now at the basis of the studies we developed on the FIR to submillimeter dust continuum, using ISO, then Spitzer and now Herschel.

With this dust model, our group was the first to develop a comprehensive model of the dust properties of dwarf galaxies, linking the FIR emission to the stellar heating input. **We first found the dust properties to be very different from those of our Galaxy and other dusty spirals or starbursts, in particular requiring in general that amorphous carbon grains replace classical graphite grains in order to provide more emissivity per unit mass at a given temperature**. We then made the first discovery of a submillimeter continuum excess found to date (convincingly) in low metallicity galaxies (Galliano et al 2003; 2005; Galametz et al 2009; 2011). A systematic study of this excess is in progress with Herschel and shows that **50% of dwarf galaxies present a 500 µm excess reaching in a few cases 150% of the value expected from a detailed spectral energy distribution modeling**. In our work in the Herschel/Heritage program, we have finally isolated this submillimeter excess in the Large Magellanic Cloud (LMC) and have associated it with the low dust column density regions. This will be a critical piece of the puzzle to unveil the origin of the submillimeter excess.

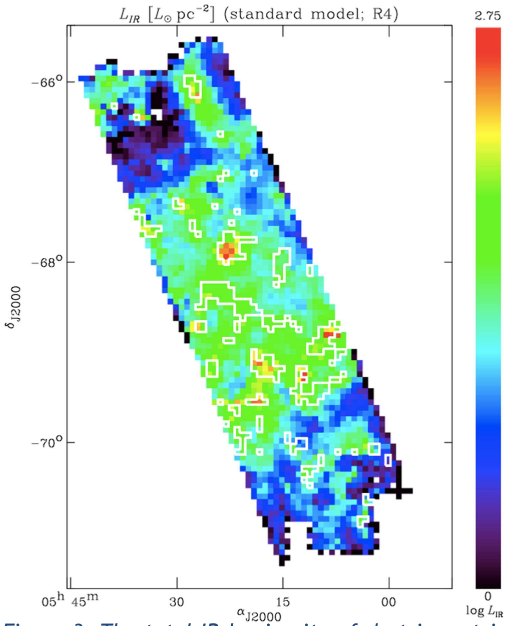


Figure 3: The total IR luminosity of dust in a strip through the LMC as deduced from the Galliano model fit to the PACS+SPIRE data. White contours encircle regions containing 90% of the CO mass, revealing a large amount of gas, associated with the dust, but not detected through CO emission (Galliano et al., 2011).

One of the most intriguing issues in low metallicity galaxies is the well-known dearth of CO and the anemic reservoir of molecular gas, even using reasonable CO-to-H_2 conversion factors, despite flourishing star formation. We have investigated this paradox with the now available FIR fine-structure lines, in particular the [CII] and [OI] lines that arise from the photodissociation envelopes of molecular clouds in the vicinity of star formation. From our Herschel survey of 50 low metallicity galaxies, we find that the [CII]/CO is always brighter (up to 10 times) in low metallicity galaxies than in the dustier, globally more vigorous, star-forming galaxies (Madden et al 2011 - IAU284 review, EAS). Due to lower dust attenuation, the UV photons photodissociate CO and ionize a larger envelope of photodissociated gas, leaving a much smaller CO core. A significant amount of H_2 can exist outside of the CO core since H_2 is more efficient at self-shielding from photodissociation than CO. **We show that the [CII] line traces the reservoir of this 'dark' molecular gas, sometimes revealing 10 to 100 times more H2 than that traced by CO alone** (see also Figure 3).

The difference in the structure of the ISM of low metallicity galaxies compared to their dustier counterparts has been demonstrated for the first time with our complex modeling of the photoionization and photodissociation regions. Modeling 17 MIR and FIR fine structure lines, Cormier et al (2012) find the ISM of Haro 11 (1/3 $Z_\odot$ metallicity starburst galaxy) to be unusually porous, with a diffuse low density ISM component occupying at least 90% of the ISM volume, and the dense PDRs, harboring the fuel for the massive star-forming regions, residing in small dense clumps. In the LMC, Lebouteiller et al (2012) show the effect of the massive star-forming region, N11B, on the surrounding ISM is far-reaching, confirming the remarkably porous nature of the low metallicity regions. The strong correlation between [CII] and [OI] and PAH emission over the whole star formation region, illustrates that [CII] and [OI] provide the total cooling in these low metallicity ISM.

Fostering science activities in the laboratory

These results rest no only on our long-standing research efforts but also on the development of tools that are at the basis of our analyses:

- In order to quantitatively analyze the images of molecular clouds, we have been exploring objectives methods to characterize their structure (see e.g. Motte et al 2007). In the reviewed period we created 3 high performance source and filament extraction codes: P. Didelon adapted the DisPerSe algorithm (T. Sousbie, IAP), as well as developed the Morphological Component Analysis, A. Men'shchikov built the *getsources* program. *getsources* is a multi-scale, multi-wavelength code that was adopted after comprehensive benchmarking by the whole SPIRE Specialist Astronomy Group for the analysis of their surveys.
- Since most of our observations consist of far-infrared and submillimeter SEDs, we needed a tool to relate this observable to intrinsic properties of the sources, such as the radiation field intensity, or the dust mass and properties. To this aim, F. Galliano developed a fully-fledged and state-of-the-art dust model that has shed

significant light on the necessity to modify the dust spectral properties to avoid dust-to-gas mass ratio crisis in low-metallicity galaxies.

- As participants to the most challenging PACS mapping program (Heritage), we were faced with significant data-processing challenges. To meet those, P. Chanial developed Tamasis, a multi-purpose massively-parallel inverse problem solver. In this concept we model the signal acquisition by the instrument, and inverse the model to obtain the sky. This code is the only one that has been able to process the large (8°x8°) LMC complete maps with no need for priors (e.g. the lower resolution Spitzer maps).

These general purposes tools have now reached full maturity and are being used well beyond their "birth" circles.

Still at the heart of our science activities, we maintain a significant level of informal group meetings. We have weekly meetings around the Gould Belt, HOBYS, and ISM science projects where ideas are exchanged and latest results commented. We also organize the "Galaxy Lunch", a weekly lunch talk with the LCEG (cosmology and galaxy evolution laboratory). For the first years of Herschel operations, we held a weekly meeting to maintain the whole team up-to-date with our progress in data processing and instrument calibration. Finally we have hosted more focused one-day or more meetings, with guests from collaborating laboratories, on issues that interest the whole group. The last one of these meetings brought us together with colleagues from Manchester (thanks to a CNRS/Royal Astronomical Society grant won by N. Peretto) to discuss star-formation from small Galactic scales to the LMC.

Instrumental activities

One of our particular aspects is our strong involvement in instrumentation. Although we do not effectively develop instruments, we have been very active in their definition, during their study phases, in their calibration (on ground or in space), and in their operations.

This is obviously the case for Herschel, carrying PACS and SPIRE, our flagship instruments. The 2007-2012 period has seen their ground-based calibration and tests, their launch, commissioning and transition to routine phase exploitation. We have been involved in all these periods, with M. Sauvage carrying the main scientific responsibilities for the commissioning of the PACS bolometer camera, and P. Panuzzo managing the development of the pipeline for the SPIRE instrument. The success of these facilities on the international stage owes in part to our dedication in bringing them on-line at the best of their capacities.

The laboratory has also played a crucial part in the definition of the science program for the camera ArTéMiS, which will be installed at APEX and inherits its detectors from PACS (see André et al. 2008, and Minier et al. 2009 for publication of p-ArTéMiS data). It is worth noting that this ground-based instrument will benefit from our investment in data-processing software development, as the Tamasis code by P. Chanial is fully applicable to these data.

Finally, through the ORISTARs ERC AdG we will provide support for the development of the polarization channel of NIKA, a bolometric camera for IRAM.

b. Analyse des moyens de l'unité

Staff

At the start of the period, the laboratory was comprised of 5 permanent staff (4 with CEA positions, and 1 with a CNRS position), 1 associated CNRS scientist, and 6 post-docs and PhD students.

Our scientific focus and our involvement in the Herschel programs initially showed weaknesses in the structure of our personnel in the areas of radiation transfer, structure characterization, and dust models. To gain strength in these areas, we managed to hire A. Men'shchikov in 2007, through a CEA position, and F. Galliano on a CNRS position. Early 2012, P. Bouchet joined us, following his hire by CEA, bringing to the lab his expertise on supernovae and their interaction with the ISM. Over the period considered here, our lab demonstrated the high interest generated in the international community by its research program, as we managed to attract 18 post-docs and PhD students.

At the end of the period, considering the post-docs and PhD students that left the lab to pursue their careers, the laboratory is now comprised of 8 permanent staff (6 with CEA positions, 2 with CNRS positions), 1 associated scientist, and 13 post-docs and PhD students.

Focusing more on our post-docs and students, the period under review has seen us hosting 11 PhD Students (with 4 from 4 different foreign countries), 4 of which have completed their PhDs, while the remaining 7 are at various stages of completion. We have hosted 13 post-docs, with 9 of them originating from 8 different foreign countries.

Programs and grants

Given the involvement of AIM and of LFEMI personnel in the development of the Herschel mission, we have been in capacity to lead key projects on the guaranteed time. These are (1) The Gould Belt survey of solar-mass star forming regions (P. André), (2) HOBYS a survey of regions forming massive stars in the Galaxy (F. Motte), and (3) The Dwarf galaxy survey (S. Madden).

Thanks to our expertise on Herschel, both technical and scientific, we have also been able to participate in a large number of open-time key projects (KINGFISH, HERITAGE, Hi-GAL, to name the three largest programs). These programs have allowed us to expand the observational database on which our investigations can be deployed.

We also invested ourselves significantly in the support of the Herschel mission for the ground segment of the PACS and SPIRE ICC, which generated support from the CNES for both our instrumental and scientific endeavors with Herschel. Combined with the attractive science program outlined above, we have been able to attract a large number of talented scientists to work in our unit.

Thanks to a vigorous fund-raising policy, we managed to secure, as principal investigators, a number of proposals, which helped us obtained significant support for post-docs and PhD students. These are:

- Astronet Proposal CSH (PI M. Sauvage) aimed at testing the applicability of compressed sensing to the Herschel data processing pipeline (Barbey et al. 2011). This project, made in cooperation with the Vienna Observatory (Austria), funded the three-year post-doc position of N. Barbey.
- Astronet Proposal TAMASIS (PI M. Sauvage) focused on developing advanced data-processing techniques for submillimeter facilities. This project is a collaboration with ESO-Garching, Leiden Observatory, and Institut d'Astrophysique Spatiale and supported the position of P. Chanial.
- ANR project PROBES (PI F. Motte & S. Bontemps) dedicated to the exploitation of the HOBYS program, this project funded the post-doc contract of M. Hennemann.
- ANR project SYMPATICO (PI S. Madden) concentrates on the realization of advanced modeling tools to interpret the FIR spectral energy distribution of galaxies. This project has started in September 2011 and will fund one post-doc position.
- ERC Advanced Grant ORISTARS (selected in October 2011, started in April 2012) with PI Ph. André, aiming at understanding the origin of the filamentary structure in the ISM and it relation to star formation physics, at small and large scale, as well as participating to the development of a polarization channel for NIKA on the IRAM 30m telescope. This project will fund up to 5 post-doc positions in the lab.
- ANR project STARFICH (selected in June 2011, started in April 2012) with PI Ph. André, aiming at exploring the (extra)galactic implications of the results obtained with Herschel in nearby Galactic clouds on the filamentary structure of the ISM. This project will fund 1 additional post-doc position in the lab.

The high-level of our science programs also resulted in the fact that we could obtain post-doc and PhD funding from CNES around our participation to the Spitzer SAGE program (a precursor to HERITAGE), from the CEA-FP7 joint program Eurotalents, and from the Constellation FP6 training program.

Finally, and even-though Herschel was our main source of observational data, we have been very active in obtaining telescope time for our science programs, either in preparation, or in follow-up, using a vast array of facilities: over the period we were PIs of 34 observing proposals using, in order of decreasing usage IRAM/30m, JCMT, IRAM/PdBI, APEX, ESO/VLT, ALMA, CSO, MOPRA, SOFIA and Effelsberg. We have also secured, as PI, 400000 hr of computing time through the GENCI to run the Tamasis processing of HERITAGE maps.

LDEE - Laboratoire Dynamique des Etoiles et de leur Environnement

1. Scientific Report

a) Activities and Report

Summary table

Publications	240	Science & Nature	8	In conferences	245
ERC	1	ANR	2	Invited talks	> 40
Prize	2	Int. Conference Chair + SOC	6+10	Committee	8

The Laboratory Dynamics of Stars and their Environment (LDEE) focuses on the study of the inner and outer (magnetohydro)-dynamics of the Sun, stars and their interactions with their environment (planets, wind, and circumstellar envelope). It is indeed crucial these days to move beyond a static description of stars and their interactions with their environment, this is the main objective of LDEE.
The central question of our laboratory over 2007-2012 was: ***How do stars wor ?***
This can be broken down into a number of questions such as (partial list): how stars evolve on short and long temporal scales, what is the history of their rotation and angular momentum and how the later is distributed in their interior and exchanged/coupled to the outside, how are they structured, how are they shaping and influencing their surroundings through their activity, wind, tidal effect and multi wavelength radiation? Why does the Sun have an 11 +/- 3 yr cycle? What is the origin of the 2-year magnetic modulation? Can other stars have several cycles at different time scales?
To achieve this goal of developing a dynamical view of stars and their environment and to seek answers to these fundamental questions, the LDEE focuses on three complementary activities: observations, theory and simulations and is actively involved in providing scientific expertise on ongoing or new instrumentation projects.
This complementary approach was conducted on four major themes of stellar physics during 2007-2012: a) *stellar magnetism*, b) *wave physics and asteroseismology*, c) *the rotation of stars and the redistribution of angular momentum* and d) by the increasing role taken in our research studies by *the influence of stars on their environment*. We develop in more details these four themes in the remainder of the document.

a.1) Origin & properties of stellar magnetism

Stellar magnetism is a fast developing field thanks to the recent upraise of high-quality observations such as spectropolarimetry, asteroseismology, CaII H&K lines, X-ray emissions, to cite only a few. It is key to note that depending on their mass, stars display a strikingly different magnetic activity. Solar-like stars possess, spots, hot corona and, often, magnetic cycles and large range of magnetic features on their convective surface, whereas more massive stars (A-type stars and earlier spectral types, e.g. M >~ 2 Msol) possess for 10 to 15% of a given population a very stable and strong magnetic field in their radiative envelope. In order to draw a coherent picture regarding stellar magnetism and unravel what physical processes are at the origin of this large diversity of magnetic manifestations, our laboratory has studied from a theoretical, numerical and observational point of view stellar magnetism in convective and radiative envelopes/interiors, with a special emphasis on stellar dynamos and magnetic instabilities.

- Solar and Solar-like stellar magnetism

Over 2007-2012, both through the ERC STARS2 project and the MoU on Stellar Dynamo with Prof J. Toomre real advances on solar/stellar dynamos have been achieved. In Browning et al. (2007), we have demonstrated that in 3-D global convective model of the solar dynamo the presence of a tachocline of shear indeed leads to the formation of coherent toroidal (horizontal) magnetic structures. This work has been extended to solar-like stars. In the series of paper Brown et al. (2008, 2010, 2011) *magnetic wreaths* have been identified and shown to survive within turbulent convective zone. This is a major result as it was thought until then that this was not possible due to so called flux expulsion. These simulations also make good contact with current spectropolarimetric observations of fastly rotating Suns, which exhibits a dominant toroidal field topology. Further such self-consistently generated magnetic wreaths were found to become buoyant and to form emerging W-loops (e.g. star spots) if the diffusivities were low enough (Nelson et al. (2011)), thus getting for the first time coherent emerging structures in a global dynamo simulations. Activity cycles have also been obtained with regular reversals of field polarity found to exist in turbulent conditions.

Another important study has been to model in 3-D flux emergence in global rotating nonlinear convective models. This is key to understand sunspot emergence and observed properties such as Joy's (tilting) law. In Jouve & Brun (2007, 2009) we studied how convection, rotation, large scale flows, geometry influence the emergence, validating thresholds for field amplitude and twist, how convection modulates, eases/delays the structure's rising time and how large scale flows impact & transport magnetic flux. In Pinto & Brun (2012) we took into consideration the influence of a self-consistent dynamo magnetic field and how handeness of the structure is influenced by and influence the global mean magnetic field, while in Jouve, Brun, Aulanier (2012), we looked at W-loop emergence and identified/explained the existence of *magnetic necklaces*. Flux emergence may lead to flares and CME's, with their associated high energy particles and X ray radiations. This comes in support of our Solar-Orbiter STIX scientific interpretation and support activity.

We also developed a series of 2-D mean field dynamo models in order to study the impact of various physical processes on the 11-yr cycle (Jouve & Brun 2007), guided by our 3-D numerical simulations. We showed that multi celled meridonal flows, turbulent pumping have a significant impact on the cycle and the butterfly diagram and extended this work to others stars to interpret the observed scaling law linking the star's cycle period to its rotation rate (Jouve, Brown, Brun 2010, DoCao & Brun 2011).

On the observational side, major breakthroughs were obtained thanks to seismology. The observed frequency shifts of acoustic/mixed modes in stars is found to depend on the magnetic activity level, hence allowing to probe stellar magnetic fields and cycles by observing their numerous vibrations. In Garcia et al. (2010), such technique was applied and revealed the presence of a stellar activity cycle in HD49933. In Fletcher et al. (2010) a shorter activity cycle (2 yr) in the solar data has been identified. It may be linked to the presence of magnetic layer at the base of the surface shear layer (0.96 R). In Salabert et al. (2009), the seismic study revealed that during the extended low activity level of the last stretch of cycle 23, the 11 yr cycle near the polar region seemed to go on unchanged, whereas near the equator it was delayed. This is key to anticipate the next solar maximum and comes in complement of our physically based solar prediction model. Indeed we recently developed the first variational data assimilation a-w dynamo model (Jouve, Brun, Talagrand 2011) demonstrating the power of such novel methods to perform solar activity forecasting.

- Massive stars and magnetic field in radiative interiors

In Zahn, Brun, Mathis (2007) we have studied the stability criteria of toroidal structures within stellar radiation zones, following the pioneering work of Tayler. We have further corrected the radiative dynamo loop proposed by Spruit, showing that it could only work via an a-effect involving non axisymmetric fluctuations of the flow and field and thanks to 3-D high resolution numerical simulations that it is difficult to actually trigger. This has serious implications for 1-D stellar evolution model and angular momentum redistribution and chemical mixing. In Duez & Mathis (2010), we have identified the MHD relaxation mechanism that drives the birth of fossil magnetic fields in stably stratified stellar radiation zones after star formation and PMS phases. The obtained magnetic configurations are in stable non-force free equilibria and constitute a generalization of relaxed configurations known in laboratory plasma physics taking here the gravity into account. Moreover, their properties matches with fossil fields observed at the surface of massive stars by the observational LPs MiMeS (ESPaDONs@CFHT, NARVAL@TBL, HARPSpol@ESO). The results also apply to compact objects (WD & NS). In Duez, Braithwaite & Mathis (2010), we demonstrate using 3D numerical simulations that relaxed configurations identified theoretically are stable and corresponds to those previously obtained by direct numerical simulations (cf Fig 1)

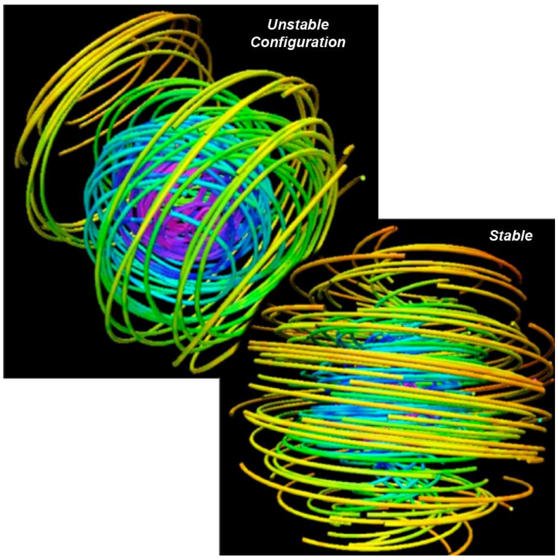


Fig 1 : 3-D magnetic field lines rendering of unstable and stable magnetic field configuration in stellar radiative interior (Duez et al. 2011).

In Strugarek, Brun, Zahn (2011a,b), we computed in 3-D the interaction of a deeply buried fossil field with a differentially rotating convection zone, allowing for instance to study the solar tachocline dynamics and evolution. We showed that unless the inner field is purely perpendicular to the axis of rotation, any field would establish Ferraro's law of isorotation in the radiative interior, which is not observed (inverted by seismology), thus casting doubt on the possibility to confine magnetically the solar tachocline.

Similarly in Featherstone et al. (2009) we computed the interaction of a convective core with various field topology in its surrounding radiative envelope. We demonstrated that such interaction (if the external field possesses a poloidal component) can lead to a strong dynamo branch (i.e. superequipartion field) in the core with B reaching the megaGauss level. The flows adapt/change such as to mitigate the Lorentz force.

Finally we also contributed to the definition of PLATO workpackages being for instance in charge of the dynamo and differential rotation one.

<u>Funded project :</u> ERC STARS2

a.2) Asteroseimology revolution and waves physics

Seismic studies are the only way to extract stratified information of the interior of stars. Trapped waves are modified by the structure and dynamics of the environment in which they propagate modifying their properties. Therefore, their characterization would give us invaluable information of the stellar interiors. There are two different classes of modes: the acoustic modes (the restoring force is the pressure) and gravity modes (the restoring force is buoyancy). While the first can propagate all along the star, the gravity waves are evanescent in the convective regions and they can only bring information on the radiative layers. In stars like the Sun, they are very sensitive to the core in which the nuclear reactions take place. The LDEE is a unique laboratory in which we study these waves from an analytical, numerical and observational point of view.

-Excitation and propagation of waves:

The detailed physical mechanisms associated with the excitation of the waves are not fully understood yet. Using 3D simulations we were able to show that the statistics of the convective movements in a high-resolution simulation of the deep convective layers of the Sun (Miesch et al. 2008) follows a Lorentzian distribution instead of a Gaussian one (Belkacem et al. 2009). This has a direct impact on the excitation of the g modes in the Sun. Indeed, their surface amplitudes were increased when compared to previous works. An extension to this work was done for massive stars in which the g modes are excited by a convective core (Samadi et al. 2010). Moreover, we produced the first 3-D solar simulation between 0.07 and 0.97 solar radius by coupling the radiative interior simulation with a 3-D

ASH simulation of the convective zone. By doing so, we were able to study the excitation and propagation of waves and gravity modes in the solar interior (Brun, Miesch Toomre 2011). This is the starting of L. Alvan's PhD. From this simulation, she will analyze the sensitivity to the different parameters (e.g. diffusivity, rotation rate, etc) and she will produce, at each stage, the spectrum of the propagating waves. Moreover, when stars are fast rotators, the action of the Coriolis and of the centrifugal accelerations become important. Then, the excitation by turbulent convection is modified. In this context, we considered the case of a uniform rotation and we studied the influence of the Coriolis acceleration on the stochastic excitation of oscillation modes (p modes and gravito-inertial modes) by convective regions (Belkacem, Mathis et al. 2009). These results extended the formalism previously derived (Samadi & Goupil 2001; Belkacem et al. 2008) by including the effect of the Coriolis acceleration. Finally, we have studied the modification of the propagation of gravity waves by the combined action of the Coriolis acceleration and the Lorentz force associated to a toroidal magnetic field. Gravity waves then become magneto-gravito-inertial and trapping phenomena, both in the vertical and in the horizontal directions, occur that are different for prograde and retrograde waves. This has been for the first time studied by Mathis & de Brye (2011).

-Detecting and Characterizing, mixed and gravity modes in solar-like stars.

A breakthrough was done in 2007 by the detection of the solar asymptotic g-mode period spacing of the dipole gravity modes (García et al. 2007; Fig2). This allowed putting new constraints on the solar core structure and dynamics (the Solar core may spinning around 3-5 times faster in average than the part of the radiative zone between 0.2 and 0.7 $R_\odot$). Moreover, g-mode period spacings were first detected in red giants stars through mixed-modes (that have the behavior of a p mode in the deep convective envelope and of a g mode in the core (Beck et al. 2011) thanks to the *Kepler* satellite. This allowed disentangling between stars burning hydrogen in a shell or also burning Helium in the core (Bedding et al. 2011). Furthermore, Beck et al. (2012) and Deheuvels, García et al. (2012) have been able to show that the core of 3 red giant stars and of a subgiant one observed by *Kepler* are rotating faster that the surface (10 times for the red giant stars and 5 times for the subgiant). Those results open new windows for the study of the internal differential rotation of stars during their evolution. Using state of the art stellar evolution codes including rotation, it has been shown that this is impossible to obtain a similar profile without evoking new physical processes that are not yet included in the models. To progress in this topic, we have hired a new PhD student, T. Ceillier that will study in detail how the angular moment is transported in such stars (see the rotation section).

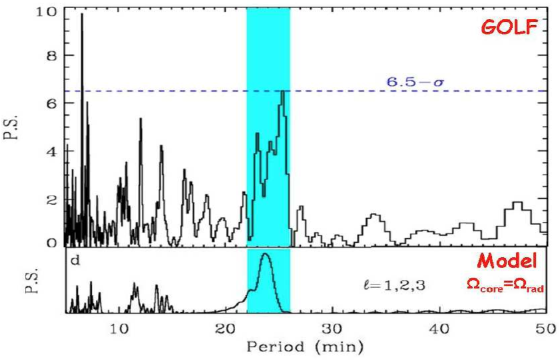


Fig 2 : Power spectrum of GOLF power spectrum (top) and a simulation (bottom) in the region where the dipolar gravity modes are expected. The shadded vertical region shows the place of the dipolar periodicity (Garcia et al. 2007).

Finally, we have also tested the validity of thermal wind balance in the solar convection zone using helioseismic inversions in order to validate the results from simulations in which thermal wind (baroclinic effect) influences the differential rotation yielding a conical instead of cylindrical profile (Brun, Antia & Chitre 2010).

Funded projects: FP7 IRSES, FP7 SPACEINN, CNES-GOLF

a.3) History of angular momentum and stellar rotation

Rotation deeply influences stars evolution from their formation to their death. Moreover, rotation, with turbulent flows, drives the magnetic activity of stars that strongly impacts their environment. From 2007 to 2012, the LDEE laboratory members have been leaders to unravel which constraints can be obtained from solar and stellar seismology and to build complete models both on dynamical and on secular time-scales of the rotational dynamics.

From the observational point of view, R.A. García and his collaborators have studied the sensitivity of solar oscillation modes to rotation to identify which ones are the most powerful to constrain the angular velocity distribution in the Solar core using inversion technics. First, Mathur et al. (2008) have studied the influence of low-degree low-order g-mode splittings in the inferred rotation profile in the radiative core. They demonstrated that the introduction of some g-mode candidates improves the constraints in the solar core rotation. Higher accuracy --and a more stable solution-- is obtained in the inversions when more g modes are used. Moreover, Eff-Darwich et al. (2008) showed that the level of uncertainty that is needed to infer the dynamical conditions in the core when only acoustic modes (p modes) are included is unlikely to be reached in the near future, and hence that sustained efforts are needed toward the detection and characterization of g modes in the Sun. Moreover, García et al. (2008) demonstrated that p modes that penetrate deeper into the solar core (until $0.2R_\odot$) are necessary to better constrain the rotation there. Modes with higher radial orders for a given latitudinal degree are required but they are more difficult to observe because their lifetimes are small and the split components of the same mode are blended. Strong efforts have also been undertaken to improve rotation 2D-inversions (Eff-Darwich et al. 2010). Finally, R.A. García and his collaborators have developed data analysis tools to be able to determine, with a good precision, the surface rotation of solar-type and red giant stars using asteroseismology.

All these observational constraints have encouraged theoretical studies to understand differential rotation distribution in stars and their rotational history. First, on dynamical time-scales, we have studied with numerical simulations performed with the ASH code solar and stellar rotating convection. In Miesch et al. (2008) and Brun et al. (2011) we studied the highly non-linear dynamics of the solar convective envelope at the highest spatial resolution to date to unravel the interaction between convection, the associated meridional flows (see also Brun & Rempel 2009) and the differential rotation they sustain with or without a tachocline (Fig 3). They also studied the convection properties and the associated differential rotation in young Suns as a function of their rotation rate (Ballot et al. 2007, Brown et al. 2008), in T-Tauri (Bessolaz & Brun 2011), in G & K stars (Matt et al. 2011), in F stars (Augustson et al. 2012) and in RGB (Brun & Palacios 2009). These has lead to the establishment of scaling laws for the differential rotation, its properties (pro or retrograde at the equator) and the associated thermal imbalance, the meridional flow properties, etc. in the whole Hertzsprung-Russel Diagram.

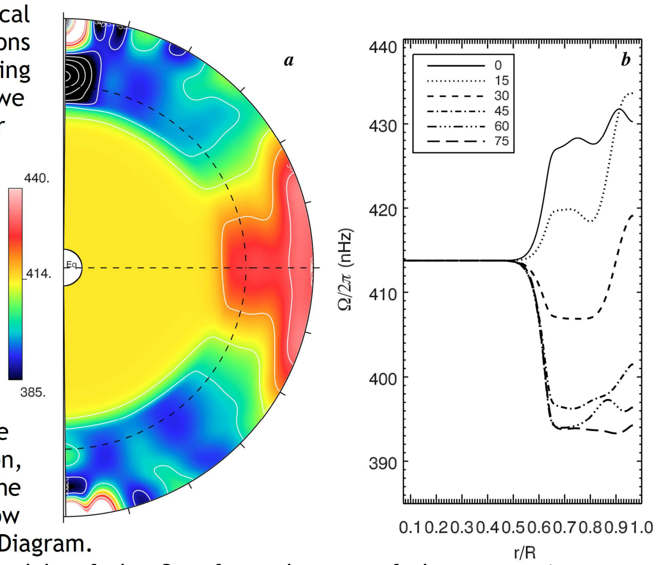


Fig 3 : Angular velocity in a 3-D nonlinear whole Sun model (Brun et al. 2011). Left : Meridional cut using colour contours, Right : radial profiles at indicated latitudes.

Furthermore, the first complete 3-D hydrodynamical models of the Sun from the top of the convective envelope to the radiative core have been computed using ASH showing the consistent establishment of the tachocline, and the profile of the large-scale flows, i.e. the differential rotation that matches with helioseismic inversions and the meridional circulation. Simultaneously, S. Mathis and his collaborators have studied the transport of angular momentum on secular time-scales and its seismic signatures. First, Decressin, Mathis et al. (2009) identified each step of the highly non-linear interaction between the differential rotation and the associated shear-induced turbulence and secular meridional flows in stellar interiors for low-mass and massive stars. Then, since other processes must be taken into account to reproduce the rotation profile in the radiative cores of solar-type stars, subgiants and red giant stars and since stellar radiation regions can host fossil magnetic fields, the impact of magnetism and of internal waves (hereafter IWs) was examined. Concerning, fossil magnetic fields, obtained results are described in the section concerning magnetism. For IWs, the transport of angular momentum by gravito-inertial waves (i.e. IWs modified by the Coriolis acceleration) was studied, first in the case of a weak differential rotation (Mathis et al. 2008), and then in the one of a general differential rotation (2009). The next step to evaluate the impact of the combined action of rotation and a given toroidal magnetic field on transport by IWs was treated for the first time by Mathis & de Brye (2012) showing the effects of the different trappings that have been identified by Mathis & de Brye (2011). The net result of these three works is that, even if the amplitude of the transport by IWs is affected by rotation and magnetic field, the extraction of angular momentum obtained by Talon & Charbonnel (2005) is robust. Finally, we have studied the coupling of IWs transport with large-scale meridional currents, differential rotation and the shear-induced turbulence that shows, as in Decressin et al. (2009), the importance of the applied torques at the surface of stars on the internal transport (see the section on Environment).
Funded project : ANR Toupies, FP7-IRSES

a.4) Stellar environment: radiations, wind and tidal effects

Environments of planets and stars are dynamical zones where interaction at various levels plays a physically important role in shaping astronomical bodies and defining their kinematics. These include massive star cluster and interstellar medium interaction at early phase, star and planetary disk interaction, planet and moons interaction, and star and planet interaction. Star and planet environment study is one of the main research activities at LDEE using observational, analytical and numerical approaches, making LDEE a unique interdisciplinary laboratory.

- Massive stars and ISM interaction

Stars rarely form isolated, but more generally in clusters. Molecular clouds do not deliver stars in one shot, but following multi-generation sequences. This implies a strong interaction between massive stars of previous generations and residual interstellar medium. Using observations (APEX, ATNF, Herschel, IRAM), Minier et al. (2007, 2009, 2012) and Purcell, Minier et al. (2009) have studied in depths many giant molecular clouds (Fig 4). They revealed the role of massive stars in pressuring interstellar gas filaments or sheets, in forcing infall of gas and triggering new star formation. Numerical simulations (Tremblin et al. 2011, 2012) have been dedicated to characterize the ionization impact on interstellar medium due to strong UV radiation from massive stars. In less of one million year, ionization would be able to reshape and form dense clumps at the border of molecular clouds in the shock/ionization front. This is Pascal Tremblin's PhD thesis under Vincent Minier (LDEE) and Edouard Audit's (LSNPA) supervision. Current work focuses in assessing the role of stellar winds.

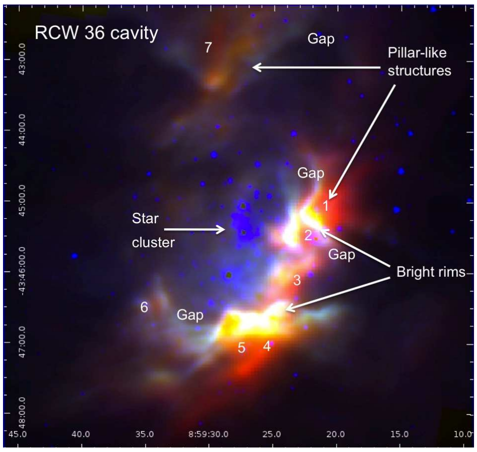


Fig 4 : Three-color image (Herschel+Spitzer) of the RCW 36 HII region showing the interaction between a star cluster (in blue) and the interstellar environment (Minier et al. 2012).

- Planet and moon interaction

Earth-like planets have viscoelastic mantles, whereas giant planets may have viscoelastic cores. Modeling tidal interactions provides constraints on planets' properties and helps us to understand their history and evolution, in either our solar system or exoplanetary systems. Remus, Mathis et al. (2012) have brought a new vision. Tidal dissipation in icy and rocky nuclei of giant planets is a major component in the transfer of kinematical momentum to moons. This was applied to understand Saturn moon acceleration. Further work demonstrates that strong tidal dissipation is required in Saturn to form icy moons from its rings (Charnoz…Mathis et al. 2011). This study in collaboration with S. Charnoz (LAPD) and Observatoire de Paris (Lainey…Charnoz…Mathis, Remus, et al. 2012) was confronted to astrometry measurements that reveal moon deceleration ten times more important than expected, implying a greater tidal dissipation in Saturn. The new model of Remus et al. (2012) was then able to explain this strong tidal dissipation, and furthermore this work led to explain the geysers located at Enceladus poles. In the future, these results could apply to extrasolar planets.

- Star and planet interaction

With the discovery during the past decade of a large number of extrasolar planets orbiting their parent stars, with the position of inner natural satellites around giant planets in our Solar System and with the existence of very close but separated binary stars, tidal interaction has to be studied carefully. Mathis & Le Poncin-Lafitte (2009) have proposed a general theory that includes MHD modelling and anelastic tidal dissipation effects. In particular, Remus, Mathis et al. (2012) refine the theory of the equilibrium tide in fluid bodies that are partly or entirely convective, to predict the dynamical evolution of the systems.

In Pinto et al. (2011) we computed the temporal evolution of the solar wind during an 11-yr cycle, by coupling 2-D wind and dynamo models, hence going beyond usual simple background dipolar configurations to take into account more complex field topology and polarity reversals. Angular momentum, mass loss and Alfven radius all show significant temporal variations that can impact star-planet systems.

<u>Funded project</u>: ANR IDEE, Univ P6 ENCELADE

b. Analyse des moyens de l'unité

During 2007-2012, we have answered to various calls of opportunity with a very good success rate (ERC STARS2 (2008-2013), ANR Toupies (2011), ANR IDEES (2012), also obtained support by INSU via PNPS, PNST and PNP, by CNES for GOLF, PLATO, SOLAR ORBITER, and through EC for FP7-IRSES and FP7-SPACEINN. This has given us the opportunity to hire PhD students, postdocs and CDDs. Yet no tenure researcher in stellar physics was hired to reinforce our activity.

LADP - Laboratoire Anneaux, Disques et Planètes

1. Scientific Report

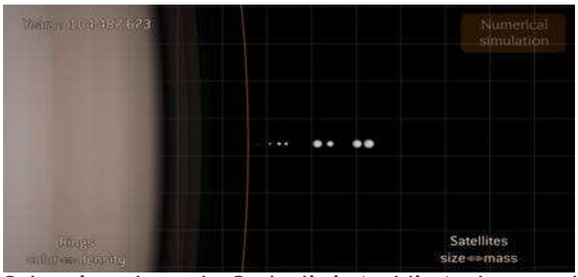
Team created in 2010.
5 staff members: A. Brahic (PREX), C. Ferrari (PR1C), S. Charnoz (MCF), S. Rodriguez (MCF), E. Pantin (CEA)
7 PhD students : J. Salmon, E. Taillifet, K. Degiorgio, C. Morel, E. Déau, R. Tajeddine, C. Doucet
4 post-docs : E. di Folco, E. Reffet, C. Cavarroc, K. Baillie
20 Master-level students
83 publications ranked A, 983 citations
Science responsibilities:
- **CASSINI space mission: ISS:** 1 Team member + 1 associated scientist ISS, **CIRS:** 1 co-I, **VIMS**: 1 associated scientist
- **Ground-based telescopes:** science leader on **VLT-VISIR**, 1 co-I **ELT-METIS**,
- **ANR programme blanc** : « NG-MIDE » (PI E. Pantin, 2009-2012), « EXODUNES » (PI S. Rodriguez, 2012-2016)
- **Labex Univearths :** S. Rodriguez PI Exploratory WP « Dunes et climat de Titan » (2011-2021), C. Ferrari co-PI du WP K1: Inter-University Diploma "Terre-Planètes-Univers", S. Charnoz, PI WP Interface Project 1 « *Formation and early evolution of planetary systems* ».

a. Activities et results

The broad picture. The quest for origins has gained major interest since the discovery of the first exoplanets in the mid 90s. The way done since may be illustrated by the improved knowledge on the circumstellar disk of β Pictoris, first imaged in 1984 and now known to shelter at least one planet, which has been imaged too. Amazing steps have been cleared theoretically or by numerical simulation to understand the diversity of exoplanets and their interactions with the mother disk. But describing the complex chain of processes that build up planets from grains remains a major challenge. The group is first deeply involved in the detection and characterization of circumstellar disks in the mid-infrared domain to address the question of the dust content and spatial distribution in protoplanetary disks. Its continuous involvement in instrumental development of mid-infrared spectro-imagers, such as VISIR/VLT and the future MIRI/JWST is a definite asset to insure its leadership in this field. The circumplanetary disks, i.e. planetary rings, offer a comfortable, nearby laboratory to understand accretion/disruption processes at work in viscous disks, both at smaller time and space scales. Understanding the relationship between rings and mid-sized satellites give clues to the complex interaction between disks and accreted bodies. Who are the parents? rings or the satellites ? The CASSINI mission has been offering since 2004 a huge opportunity to scrutinize these interactions, characterize the current dynamical state of rings and develop dynamical models to tentatively describe them. The team has focused most of its activity on these questions during the 2007-2012 quadrennial. The group is recognized internationally for its competence in this field and is unique in France. Dynamical modelling of Saturn's rings and their relationship with satellites has led to a new paradigm of mid-satellites formed from rings. It has definitely inspired new models to describe both dynamical and thermodynamical evolutions of circumstellar grains in their sedimenting path to the disk mid-plane. Also thermal models, developed to constrain the vertical structure of Saturn's rings, and blocks within, are currently exported to exoplanets to estimate the detectability of exo-rings. Finally Saturn largest satellite, Titan, is a prior target of the CASSINI mission because of the enigma raised by its pertaining thick atmosphere. Beyond understanding what is its source, how it interacts with the surface and what its climate looks like are questions specifically addressed by the team. The Laboratoire « Anneaux Disques Planètes » then questions the origin and evolution of rings, satellites or planets and the accretion and erosion processes at play in circumstellar or circumplanetary discs in which satellites and planets form. Studies are driven both theoretically via intensive use of numerical simulation or analytical modelling and observationally via multi-wavelength observations to characterize the current disks or surfaces structures. The major results of the Team to date are:

1. **A new model for the formation of satellites** (S. Charnoz, A. Brahic, J. Salmon, Collaboration: A. Crida & ISS-CASSINI Science Team; C. Ferrari, K. Degiorgio, S. Rodriguez)

Thanks to a new numerical simulation that couples an hydrodynamics code for simulating the rings and a simplified N-body code to simulate the evolution of satellites under both the rings and planet's tidal torques, we have shown that the small and mid-sized Saturn satellites may have formed from the ring material about the Roche limit and have migrated outwards (Charnoz et al., 2010). This opens a new way of understanding the origin of satellites in the Solar System by creating a new link with ring disks. All mid-sized satellites beyond Rhea (included) have most probably formed this way (Charnoz et al., 2011). We have successfully extended this work to Uranus and Neptune systems (Crida et Charnoz, 2012) or to Mars (Rosenblatt et Charnoz 2012).

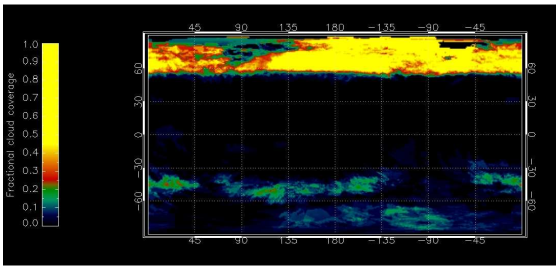


Polar view above the Roche limit (red line) where small satellites are generated from ring material (Animation S. Charnoz et al.)

To understand what might have been the degree of evolution of icy satellites in the first billion year of the Solar System, we have built tools to derive the rheological properties of the surface at the epoch of the Late Heavy

Bombardment from the shape of craters. A new multiscale photometric model, which can treat fast a large number of craters as seen in ISS images at any spatial resolution, helps deriving the transition diameter and the regolith properties. On Enceladus surface, it has been shown that terrains out of the Tiger stripes regions are similar to what is observed on other satellites in the Solar System and were already differentiated at the time of the bombardment (Degiorgio et al. 2012). This is compatible with the new scenario of satellite formation from rings.

2. **Long-term follow-up of Titan clouds with the VIMS-CASSINI NIR spectro-imager.** Collaborations A. Brahic (AIM), C. Sotin, S. Le Mouélic, O. Bourgeois, T. Cornet et G. Tobie (LPG Nantes et JPL), A. Coustenis (LESIA), S. Douté (IPAG), R.H. Brown et C.A. Griffith (LPL, Arizona), J.W. Barnes (University of Idaho), T.B. McCord et J.P. Combe (Bear Fight Institute, Winthrop), R. Jauman et K. Stephan (DLR, Berlin))

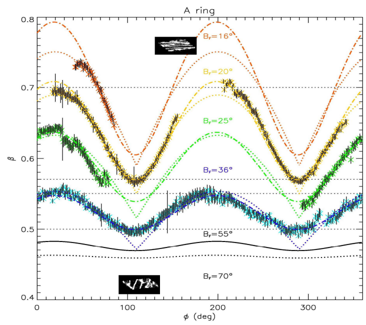


Cloud coverage map of Titan as determined by our Team and collaborators with the VIMS-CASSINI instrument.

Saturn largest moon Titan has been focusing major efforts in research since the discovery of its huge atmosphere. Understanding how it is continuously replenished requires elucidating the links between its internal structure, its surface and the interaction between surface and atmosphere. Understanding this complex system has required since the beginning of the CASSINI mission a multi-instrumental synergy with VIMS, ISS and RADAR-CASSINI which can see the surface in Titan narrow atmospheric windows. We participate in the discoveries of cryo-volcanic structures, of mountains and canals, dunes fields or erosion deltas (Barnes et al. 2007, 2008, 2011a, 2011b). We have achieved the first long-term follow-up of the meteorological activity of Titan (Rodriguez et al. 2009b, 2010, 2011). Radiative transfer methods including scattering by the haze layer and absorption by atmospheric gases have been developed to correct from atmospheric effects and tentatively derive the chemical composition of the surface (Rodriguez et al. 2009a).

3. **Evidence for current accretion in Saturn's rings.** (S. Charnoz, A. Brahic, Collaboration: ISS-CASSINI Science Team; C. Ferrari, collaboration: CIRS-CASSINI Ring Team)

Newly discovered accretion and erosion processes, similar to the ones observed in some exo-planetary systems, are at play in Saturn's rings (Charnoz 2009b). We were able to build a new numerical model of planetary rings that could explain a certain number of structures by combining tidal effects and add the physics that takes place in proto-planetary disks like self-gravity wakes or viscous spreading, but at very different scales. The model predictions have been verified in the ISS-CASSINI images (Charnoz et al., 2009b, Charnoz et al., 2010). This work yields a better understanding of interactions between disks and close satellites or planets. It led to two Press releases. Thanks to the ISS instrument, it was also demonstrate how Saturn moonlets accrete material form the rings (Charnoz et al., 2007). Charnoz et al. also proposed a new model of Saturn's rings formation, compatible with the actual scenario of the formation of the planet (Charnoz et al.,2009a). This work has been presented in invited talks and book chapter « Saturn's rings origin» (Charnoz et al. 2009, OS, Elsevier Verlag). Temporary accretion in Saturn's rings in the A ring has been observed and characterized in details by the CIRS-CASSINI infrared spectrometer (Ferrari et al. 2009). The azimuthal variation of the ring filling factor with its FOV has put into evidence self-gravity wakes and yield a detailed determination of their aspect ratio at a distance of 129,000 km form Saturn. The wakes are very flat (<10m), close to quasi-monolayers of the largest particles.



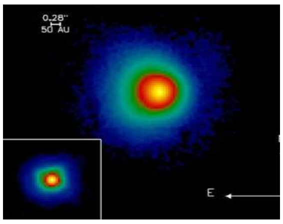
Azimuthal asymmetries of the A ring volume filling factor as detected by CIRS at different spacecraft elevations. These data highly constrain the aspect ratio of self-gravity wakes (Ferrari et al. 2009)

4. **Characterization of ring disk properties** (C. Ferrari, E. Reffet, collaboration: CIRS-CASSINI Ring Team)

Currently estimated ring-satellite interactions and erosive flux from meteroids push for a young age of Saturn's rings. Ring mass is estimated to be that of Mimas. Providing such a mass every 0.8 Gyr within the Roche limit remains difficult. Were rings more massive and the meteoroid flux less intense, rings may resist over the age of the Solar System and nurture new generations of mid-sized satellites (Charnoz et al. 2011). The surface mass density is usually derived from the damping of density waves driven in the rings by satellites. Such waves are scarce in the most opaque and largest ring of Saturn, the B ring. We have proposed a new model to derive the surface mass density of this ring from the seasonal change of its unlit side temperature as observed by the CIRS-CASSINI spectrometer (Ferrari and Reffet, Reffet and Ferrari, 2011, 2012). It relies on a packed-bed formalism and takes into account heat transfer by conduction, radiation and contacts at both the scale of ring particles and the scale of particle regoliths. The B ring might be as thin as 2-3m with a surface mass density of about 47 g/cm^2. Also the anisotropy in thermal emission of Saturn's C ring was observed with the VISIR/VLT instrument prior to CASSINI mission and compared to a new model that takes into account the spin of ring particles (Ferrari et Leyrat 2006). It confirms the low thermal inertia of particles and that a significant fraction comes from a reduced population of hot slowly rotating particles (Leyrat et al. 2008b). This model is currently the only one being able to reproduce well the azimuthal asymmetries in the thermal emission of the ring during equinox as Saturn only is heating up the rings (Spilker et al. 2010, 2011).

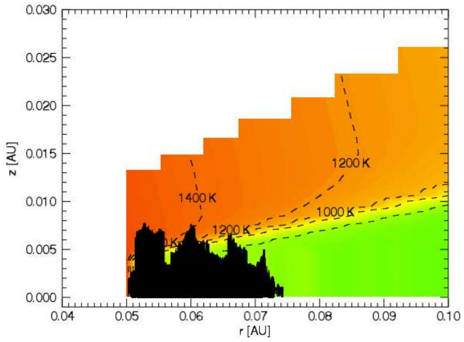
5. **Characterization of protoplanetary disks and planetary formation** (E. Pantin, C. Doucet, S. Charnoz, IPAG, IPGP, Collaboration VLT-VISIR)

The Team is involved both in theoretical modelling of the evolution of dust grains within circumstellar discs and in observations to characterize their actual structural and chemical properties. The timescales of planetary formation from the oligarchic accretion of circum-stellar grains are still very uncertain. Constraining the different steps of this process requires multi-wavelength observations on proto-planetary disks over hundreds of AU. The recent discovery of exo-planets far away from the star raises questions the spatial distribution of primordial material and how it evolves with time via dust sedimentation, radial migration or coagulation. The spatial distribution of dust can be best constrained nowadays in the mid-infrared thanks to a favorable contrast and sufficient resolution to reach discs zones in-between 50 and 300 AU. We have benefited of a key-program on the VISIR/VLT instrument to image a selection of proto-planetary disks with the goals of deriving geometrical parameters and constrain the dust content as a function of the stellar distance. First results have been published (Lagage et al., 2006, Doucet et al. 2007). Two new studies (HD169142 and HD97048) are about to be published. Besides, several collaborations based on VISIR observations have led to the geometrical characterization of the HD142527 and HD95881 disks (Verhoeff et al. 2010 and Verhoeff et al. 2011). Finally, some parallel work in the field of debris disks has been conducted, based on observations with the HERSCHEL satellite (Sibthorpe et al. 2010, Vandenbusche et al. 2010).



Protoplanetary disk around HD97048 star as observed by the VLT-VISIR spectro-imager. The image reveals a flared 3D structure of the disk. (Doucet et al. 2007)

On the theoretical field, we have first studied debris disks to study the coupled effects of coagulation, fragmentation and dynamics to constrain the initial size distribution of planetesimals in the Kuiper belt (Charnoz et al., 2007). This new numerical model allowed us for the first time to reconcile in a same frame the size distributions of both comets and TNO populations. S. Charnoz has then transposed this model to the planet formation in the context of the ANR project « DustyDisk » (PI F. Ménard, IPAG, 2008-2011), to model the growth and dynamics of grains in a turbulent nebula, populated or not with planets. The code is named LIDT3D for *Lagrangian Implicit Dust Transport in 3D* (Charnoz et al., 2011b, 2012). This physical model will be directly fitted to observations, as the coupling of this code with the radiative transfer code of C. Pinte G. Duchêne (IPAG) will be effective. The formation of first solids (CAI and chondrites) in the proto-planetary disks is being included in collaboration with Pr. M. Moreira (IPGP), E. Taillifet (Thèse IdF) and J. Aléon (CSNSM, Univ. Paris 11).



Trajectory (black) of a 1μm grain in a turbulent protoplanetary disk calculated over 1000 years with the LIDT3D code. Coagulation is not included here. The thermal profile of the nebula is color-coded. (Charnoz and Taillifet 2012)

6. **Conception and installation of new high-angular resolution imaging modes on VISIR-upgrade** (E. Pantin)

In 2009 was launched the VISIR-upgrade project aiming at refurbishing the VLT/VISIR instrument in order to improve its performances. In this context, we have proposed to implement new high-resolution modes (coronagraphic and sparse aperture masking modes) that will allow to closely reach the theoretical angular resolution performances and image faint objects around bright stars. The upgrade version was commissioned successfully in August 2012 and operations should start in September 2012. These prototypal high angular resolution modes will also serve as pathfinder for the future ELT/METIS instrument. E. Pantin acts as the PI of the ANR Project «NG-MIDE » for the development, in partnership with R&T Division of Thales, of a new generation of infrared detectors (8-13 μm) optimized for astronomical observations using QWIP (Quantum Well Infrared Photoconductor). These detectors allow on-chip multi-spectral differential imaging. They are designed to increase the performances in the detection of giant exo-planets very close to their star because of a larger stellar light rejection rate (an order of magnitude). Finally we are involved in a European consortium with Netherlands, Germany, Belgium, Switzerland and France to build the ELT/METIS instrument cited above. E. Pantin is co-investigator of the project, coordinating the French contribution (AIM, Irfu/SIS) to the project. We have proposed and are in charge of the implementation of coronagraphic modes with high contrast to characterize giant exo-planets.

These researches translate into 83 articles in ranked-A reviews, with 4 articles in Nature and 2 in Science. Team members are regularly invited in international meetings (15 invited talks). Science in progress and results are regularly communicated in main meetings of the AAS Division of Planetary Science meeting, of the General Assemblies of the American or European Geophysical Unions or in the LPSC conferences. The total number of communications is 97, 51 of which are published with acts. The involvement in ELT/METIS project translates into two phase-A reports.

Research is collaborative within the team and mainly turned towards international collaboration with US research institutions within the CASSINI project or large consortia using ground-based facilities. The Team is highly invested in the CASSINI mission with 2 collaborators as Team member (A. Brahic) and associated scientist (S. Charnoz) for the ISS cameras, 1 co-investigator (C. Ferrari) in the CIRS infrared spectrometer and one associated scientist of the VIMS near-infrared spectrometer (S. Rodriguez). The involvement in the ELT-METIS design and construction is also recognized by a co-I-ship (E. Pantin).

The research related to the CASSINI exploration of the Saturn system (rings and satellites) is support by the CNES and partially by CEA for the CIRS experiment. The other scientific projects are largely recognized and supported by ANR funding for instrumental development (E. Pantin - Project « NG-MIDE » ANR-blanc (2009-2012) with THALES/TRT: « Développement de nouveaux détecteurs multi- spectraux pour l'imagerie en infrarouge moyen à haut contraste et haute-résolution angulaire»), and for the modelling of Titan atmosphere through co-ship or collaboration in two ANR projects (S. Rodriguez), i.e. « APOSTIC » (2011-2015) and « EXOCLIMATS » (2007-2011). The starting research program on dunes morphodynamics as tracers of interface between surface and atmosphere (Project « Exodunes » PI : S. Rodriguez) is both supported by ANR funding and LabEx UnivEarths via an exploratory WP « Dunes et climat de Titan » starting in 2011. The research program on the evolution of grains in protoplanetary disks is also funded by this LABEX in the Workpackage Interface Project « Formation and early evolution of planetary systems ».

S. Charnoz has been distinguished for his work on satellite formation as a Junior member of the IUF for 4 years (2011-2014). He was involved in the SOC of the international workshop on « Formation of satellites » (ESTEC- ESA June 2012). Team members and co-Is of the CIRS and ISS instruments have also organized Team meetings in Paris. C. Ferrari has been organizing for years (2002-2009) the « Rings and satellites » session of the General Assembly of the EGU.

All members of the Team are regularly invited to give conferences to the public, among which « la fête de la Science » or to informed audience. A. Brahic's activity is highly exceptional in this field. S. Rodriguez has largely supported the organization of the exhibition on the exploration in the Solar System at La cité des congrès de Nantes during the PSC-DPS meeting in October 2012. More than 15,000 visitors attended the exhibition that week. Numerous press releases, interviews or films have been delivered, related to the scientific activity of the Team. C. Ferrari has written articles and chronicles to relate news from the Solar System in the monthly magazine « l'Astronomie » published by the "Société Astronomique de France" in 2010 & 2011.

Most of the Team members act as "enseignant-chercheurs" at University Paris-Diderot and are then fully involved in the initial formation of students in science at all levels. More than 20 undergraduate students (4 from Master 1 and more than 16 in Master 2) have followed a training course in the Team during research activities. Seven PhD students will have been formed in 7 years (2007-2013). Members of the Team also deliver courses at the M2 level in remote sensing applications in planetary exploration or detectors for astronomy and signal processing. C. Ferrari, as president of the "Comité de Liaison Enseignants Astronomes" (CLEA), is also involved in the in-service training of teachers of primary and secondary schools. This non-profit national organization has more than 500 members and publishes a trimestral magazine « Les Cahiers Clairaut » and thematic special issues. A summer school is also organized every year to welcome and form teacher to astronomy and related activities in the classroom. She is also co-PI of a workpackage in the LabEx UnivEarths which is aimed at creating an Inter-University Diploma "Terre-Planètes-Univers" for the next quadrennial most probably.

LEPCHE - Laboratoire d'Etudes des Phénomènes Cosmiques de Haute Energie

1. Scientific Report

Table 1 provides a schematic view of the main characteristics of LEPCHE (Laboratoire d'Etudes des Phénomènes Cosmiques de Haute Energie), summarizing the number of researchers and the main achievements.

Staff	11 permanents / 7 HDR	Post-docs: 18 (2007-2012)/ 7(2012)	PhDs: 9 (2007-2012)/ 3 (2012)
Publications	419 (18 Science, 2 Nature)	1st author: 65	Citations: ~13400
Grants	ANR: 1 PI/ 2 CoI	LabEx UnivEarths: 2 project PIs	Marie Curie ITN: 1 Co-I
Missions	4 current: XMM-Newton, INTEGRAL, HESS, Fermi	4 projects under development: Astro-H, (SVOM)	4 studies: CTA, Loft (Simbol-X, Cospix, Athena)
Symposia	Meetings: 4 LOC, > 30 SOC	Schools: 3 LOC / 4 SOC	Invited talks: >70
Recognition	IUF: 2 junior + 1 senior	CNU:4, CNRS:1, AERES:2, CNES:2, ESA:1	Scientific Prizes: 4

Table 1: LEPCHE main data

a. Activities and Results

LEPCHE: summary and synthetic view

The objectives of LEPCHE (Laboratoire d'Etudes des Phénomènes Cosmiques de Haute Energie) are to shed light on astrophysical phenomena related to high-energy processes. Activities of the team include the production of source catalogues, population studies from surveys, detailed observational characterization of prototype sources, and modelling and numerical simulations of these high-energy sources.

A strong point of LEPCHE is its contribution (past and future, Table 1) to high-energy telescopes in space and from the ground (TeV), through hardware and software developments and maintenance. Our team has an excellent record with space agencies (CNES, ESA) and large international consortia.

The topics studied by the LEPCHE are related to the physics of the extreme: extreme gravitational and magnetic fields, extremely dense matter, extremely accelerated particles. These are, in many cases, associated to the explosive death of the most massive stars (supernovae, gamma-ray bursts) and their diffuse and compact (neutron star or black hole) remnants. The core questions concern the validity of fundamental physics in strong fields, the nature of the processes of particles acceleration, the origin and composition of cosmic rays, the physics of the accretion of matter onto compact objects, and that of the related production of jets, the nucleosynthesis processes in our Galaxy and the galactic diffuse emission, the formation and evolution of neutron stars and black holes.

These questions are tackled via observational and theoretical studies of compact objects (isolated or in binary systems) and supernova remnants (SNR), as well as their immediate surroundings. Compact objects (white dwarfs, neutron stars and black holes) appear as very variable emitters over the whole electromagnetic spectrum. They are the primary targets of multi-wavelength campaigns involving ground-based and space telescopes. The study of particle acceleration is conducted via the observation and the modelling of the strong shocks generated by the SNRs in the interstellar medium, the wind of particles produced by pulsars, and the ejection of matter close to compact objects. These approaches have permitted the LEPCHE to obtain several breakthroughs in the understanding of high-energy phenomena, and some of the main results are summarized hereafter.

These research programs make full use of the observational facilities, to which we have contributed.

LEPCHE also contributes greatly to the dissemination of knowledge through the direct organization (Local organizing committees, LOC) of international symposia and schools (Table 1). Our team also aims at forming young researchers by mentoring students through their Master thesis and PhD thesis. The correspondent of the PhD student of UMR AIM is a member of the LEPCHE and about 75% of the permanent are habilitated and thus can be thesis advisors. This therefore indicates a specific interest of our team in the formation of young researchers. Teaching is a fundamental aspect since 3 of our members are professors at Université Paris Diderot. Finally two of our members belong to the AIM's public outreach cell. This particular aspect of public dissemination corresponds to the main part of their activity and duty. They actively participate to the dissemination of science in a more general context via the maintenance of the web site, but also the organization of public exhibitions, including abroad as for "Voyage au Centre de la Galaxie" that was « exported » in Asia (Vietnam, Korea, China) and South America (Argentina and Chile).

The team is composed of two main scientific poles: compact objects (accretion-ejection processes) and supernova remnants (particle acceleration). We have tried to make sure that these two poles were not disconnected and have organized internal meeting to favor exchanges. Scientific meetings and presentations are organized around each of these poles with short recurrence times. Participation to one or the other is never restricted. These 'sub-team' meetings are also an excellent place to check the evolution of the students' work all along their thesis. General meeting and seminars of the whole team usually occur every second month. More general meetings, with discussion on the scientific policy (scientific breakthrough, recruitments, instruments) are organized about twice a year.

Major scientific productions and breakthroughs
High energy astronomy, catalogues of sources and population studies

Unveiling the content of the high-energy Universe, statistical studies of source populations.

A fundamental aspect of our activities resides in a characterization of the high-energy sky, hence the establishment of catalogues of sources. These have an enormous impact on the international community, besides allowing breakthrough in the understanding of the content of the Universe. By multiplying the number of sources at a given wavelength, one can also access the physics of given populations through the statistical study of large samples. LEPCHE has lead/participated to the most recent catalogues of the high-energy sky.

The INTEGRAL (20-500 keV) sky

The INTEGRAL satellite was launched on October 17, 2002. In addition to the monitoring of the evolution of the IBIS/ISGRI camera, its calibration, the development and testing of the data reduction software, LEPCHE has significantly participated to the scientific analysis of the data collected for almost 10 years. Our team is particularly involved in the production of the IBIS (20-500 keV) source catalogue. The last version of the latter (Bird et al. 2010) contained 723 sources of which 400 were previously unknown. Our team maintains a dedicated web site (http://irfu.cea.fr/Sap/IGR-Sources), regularly updated. In the 2010 catalogue, the sources are divided as follows: Active Galactic Nuclei (AGN, 35%), Low Mass X-ray Binaries (LMXB, 13%), High Mass X-ray Binaries (HMXB, 13%), Cataclysmic Variable (CV, 5%), other types (SNR, PWN,…, 5%), and 29% are unclassified. Further studies of some of these are developed hereafter (e.g. below).

The Fermi (0.1-100 GeV) sky

Before the launch of the Fermi satellite, and in a view to prepare the forthcoming Fermi catalogues, Casandjian & Grenier (2008) completely reanalyzed data from the previous very high-energy mission EGRET. Thanks to a new modelling of the diffuse emission, they could show that most of the previously unidentified sources were in fact due to giant clouds of gas. That diffuse emission model continued to improve and is now the baseline for Fermi.

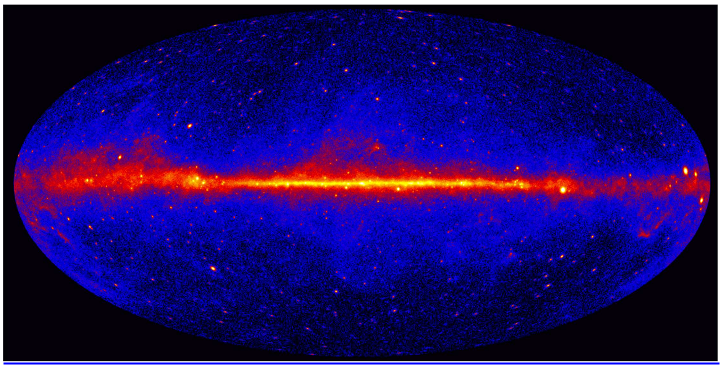


Fig. 1: Fermi-LAT all-sky map in galactic coordinates, covering the energy range 1 to 100 GeV. It integrates 3 years of data, selecting the events with best spatial resolution (Front). The color scale is in log scale from dark blue to light yellow.

The Fermi satellite (NASA) was launched in June 2008. The main instrument (LAT) surveys the sky between 30 MeV and 300 GeV. Our team shares the responsibility of the main source catalogues with the PI institute at Stanford (J. Ballet is Catalogue manager and I. Grenier is co-lead of the Catalogs science group).

The Fermi/LAT collaboration committed to release source catalogues after 1, 2 and 5 years. The readiness of the instrument and the quality of the data justified an early one after 3 months (Abdo et al. 2009; 2010; Nolan et al. 2012). The Fermi/LAT catalogue is a large improvement over the earlier CGRO/EGRET catalogue (**1873 sources in 2FGL vs 271 in 3EG**). The LAT catalogue is 10 times deeper, extends to beyond 10 GeV and provides improved localization (10' vs. 1° for EGRET at the detection limit). The catalogue contains different classes of AGN (58.3%), external galaxies, pulsars (5.8%), SNRs (3.6%), globular clusters, gamma-ray binaries. Even though the Fermi sources are fainter, the fraction of sources associated to a known counterpart is larger than with EGRET (69% in 2FGL vs 37% in 3EG).

The TeV sky seen with HESS

The HESS (High-Energy Stereoscopic System) telescope array went into operation in 2002 and has since been a revolution in the field of gamma-ray astronomy. HESS is sensitive to gamma rays in the "very-high-energy" (VHE) range, from 100 GeV to 100 TeV; while 10 years ago only a few isolated sources were known in that energy range, the number is now close to 100. This range is a window to sites of non-thermal particle acceleration in the universe, the study of which may someday answer the question of the origin of the highest energy cosmic rays.

The LEPCHE group is involved in the operation of HESS and in particular the ongoing HESS Galactic Plane Survey, which presently covers -70 to +90 degrees in galactic latitude (+/- 3 degrees longitude). The survey has revealed a large number of high-energy objects, many of which were previously unknown (e.g. Aharonian et al. 2008a). Some highlights include the discovery of new gamma-ray emitting shell-type supernova remnants (Abramowski et al. 2011), cosmic-ray illuminated molecular clouds (Aharonian et al. 2008b), gamma-ray binaries, and a bright source coincident with the galactic central black hole Sgr A*.

In addition to the scientific analysis of extended Galactic sources (including but not limited to SNRs, PWNs, and unidentified sources), the LEPCHE currently organizes the analysis/calibration and survey working groups within the HESS collaboration. It is also responsible for the HESS online analysis and web-monitoring interface.

Neutron stars in binary systems: High mass X-ray binaries and Galactic evolution

The Identification of the cradle and the characterization of the immediate surroundings of HMXBs is a new way to approach stellar and Galactic evolution.

Most of the new INTEGRAL HMXBs contain a supergiant star (Sg-HMXB). They are, usually, highly absorbed, which explains their non-detection with previous X-ray scans. Infrared observations have secured their spectral classification and also shown the presence of a significant infrared excess in their spectra (Chaty et al. 2008). The novelty shown by scientists from LEPCHE was to attribute this excess to a cocoon of gas that absorbs radiations over most of the electromagnetic spectrum (Rahoui et al. 2008). This cocoon is specific to some sources, and may, actually, be a direct signature of the supernova that gave birth to the compact object.

HMXBs are young objects and should therefore somehow testify of the recent Galactic history of star formation. Although expected the link to star forming regions had never been completely established. Scientists of the LEPCHE, by following two different and independent approaches, have clearly shown, for the first time in an undisputable manner, that Galactic HMXBs reside at an average of 0.4 kpc from a, their therefore parent, OB association (Bodaghee, et al. 2012; Coleiro et al. 2012). This offset further implies an average natal kick of ~100 km/s for the neutron star at the supernova explosion, impacting thus on the mechanism of supernova explosion.

OB associations and cosmic-rays

The discovery of freshly accelerated cosmic rays opens a new era and new possibilities in the studies of cosmic rays and their interaction with the interstellar medium. Massive stars and Wolf-Rayet stars undergo extreme mass loss through an active wind. These stars are therefore natural sources of energetic particles. Furthermore, and especially when found in clusters, the combined action of the winds from different stars creates cavities and super-bubbles. The intra-bubble medium is highly turbulent and perturbed by the shocks due to the winds. Any particle crossing through such a medium will be highly affected.

The Cygnus X region in the Cygnus constellation is a region of active star formation. It contains several clusters of massive young stars and Wolf-Rayet objects. A team led by I. Grenier, from LEPCHE, has discovered an excess of gamma-ray radiation with Fermi from one of these clusters, the Cyg OB2 region. This gamma-ray radiation is the signature of particles with energies greater than 1 GeV. These are particle propagating in the bubbles that gain energies through an interaction with this very turbulent medium (Ackerman et al. 2011). It is a young population of Galactic cosmic rays which can be studied when freshly accelerated before they escape in the interstellar medium.

Acceleration in SNR

The strong shocks due to supernova explosions are an important energy input to the interstellar medium. Our team has focused on diagnostics of particle acceleration at those shocks. This is thought to be the dominant mechanism for maintaining the pool of Galactic cosmic rays.

An important diagnostic is the gas compression at the shock, which is larger if a sizable fraction of energy goes into cosmic rays. It is difficult to measure the density directly, but it is possible to measure the associated volume reduction in young supernova remnants, by looking at the width of the shell of shocked gas surrounding the supernova ejecta (characterized by strong metal lines in X-rays). Quantitatively, the interpretation is complicated by the Rayleigh-Taylor instability at the interface, which makes the limit fuzzy. We have used the capacities of the AIM-laboratory to apply ***3D simulations*** to that problem, ***resulting in the most realistic representation of SNRs to this day*** (Fig. 2; Fraschetti et al. 2010, Ferrand et al. 2010).

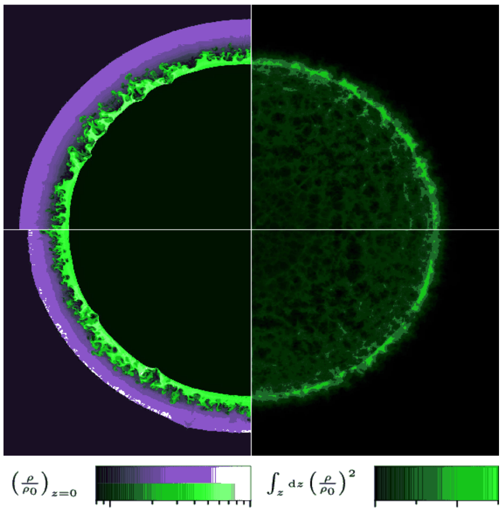


***Fig. 2**: 3D simulation of a young supernova remnant (Ferrand et al. 2010). The left side is a density slice with shocked ejecta in green and shocked ambient gas in purple. The right side approximates X-ray emission of the ejecta integrated along the line of sight. The bottom half includes back-reaction from accelerated particles at the blast wave. The ejecta emission is affected only slightly.*

In parallel, we have looked at particular SNRs. At the end of his thesis, using XMM-Newton, F. Acero has published the best X-ray map of the brightest TeV SNR, RX J1713.7-3946 (Acero et al. 2009). He has performed a detailed comparison of X-ray and TeV emission, indicating that the contrast between faint and bright regions is larger in X-rays, something that can be understood if the TeV emission is inverse Compton (IC) by the same electrons that emit synchrotron X-rays. Using our models, we studied in detail the Chandra X-ray emission associated to the shock in the remnant of Tycho, revealing notably a low ambient density (Cassam-Chenaï et al. 2007). More recently, we have studied SNRs with Fermi and we have shown that the GeV emission of the Tycho SNR is detected at exactly the right level to be π^0 decay due to interaction of the cosmic rays accelerated at the shock with the shocked gas (Giordano et al 2012). That hadronic component is not as strong in RX J1713.7-3946 because of the lower density. A large program of observations of SN1006 with XMM-Newton has been obtained to characterize the properties of the acceleration and shock-heated gas.

Stellar mass black holes and microquasars

Microquasars are accreting black holes (BH) or neutron stars in binary systems with associated relativistic jets. During periods of outbursts, they transit through several 'spectral states'. The so-called 'hard state' (HS) is associated to a cold (~0.1 keV) accretion disc truncated far from the compact object, with a strong and persistent 'compact' radio-jet. In this state a strong correlation (a.k.a the fundamental plane), extending over several orders of magnitude, exists between the radio flux and the X-ray flux. This fundamental plane has been shown to also be valid for super-massive BHs. When the disc becomes warmer (typically kT~1 keV) and brighter, a 'soft state' (SS) is reached. Massive and 'superluminal' radio-ejections occur somewhere in transition from the HS to the SS.

Accretion ejection connections

Radio/X-ray monitoring of GRS 1915+105 allowed our team (Rodriguez et al. 2008b) to discover a systematic trend (an 'ejection signal') in the X-ray light curves. Through X-ray spectral and temporal studies of this pattern we could pinpoint the exact moment of the ejection and the origin of ejected matter (Rodriguez et al. 2008c). By unveiling a correlation between the time spent in HS before the ejection and the amplitude of the latter (Prat et al. 2009), our team could understand that matter (and energy) are slowly stored near the BH (hard state), and suddenly ejected at the state transition. This opens ***new perspectives for the modelling of the HS*** and may point toward ***magnetic instabilities as the origin of these effects***.

A population of "outliers" to the universal radio/X-ray correlation have been discovered thanks to long-term multi-wavelengths studies of microquasars during their HS (e.g. Coriat et al. 2011). We demonstrated that the steeper correlation for these "outliers" in the HS could be explained by a radiatively efficient accretion flow during the HS, in contrast to for the standard interpretation of BH X-ray binaries in this spectral state. The observations of more BH sources following the radiatively efficient path (e.g. Corbel et al. 2012) have permitted us to ***open an entirely new paradigm for the understanding of BH accretion***.

Discovery of jet emission over the whole electromagnetic spectrum

LEPCHE has been involved in several multi-wavelengths observing campaigns of microquasars with a view to characterize their different emitting media. Simultaneous infrared and X-ray bands have shown that the compact jet has a significant emission in the infrared and clearly extends into the X-ray domain (Chaty et al. 2011). This allowed constraints on the size ($2\ 10^8$ cm), and upper limit on the magnetic field at the base of the jet (<5 T) to be obtained.
Members of our team have discovered polarized emission from Cyg X-1 at energies above ~450 keV (Laurent et al. 2011). By cross-correlating this finding with a precise spectral analysis, we could show that the origin of the polarized emission necessarily came from a compact jet. This is the ***first direct emission of a jet in the MeV*** gamma-ray domain. An estimate of the energy of the electrons composing the jet was also given.
At even higher energy, an international team led by S. Corbel has detected for the first time a variable high-energy source coinciding with the position of the microquasar Cygnus X-3. In a more recent work, Corbel et al. (2012) have further shown that gamma-ray emission is not exclusively related to the rare giant radio flares, but can also be seen during periods of weak radio flaring activity. They suggest that transitions into and out of the ultra-soft state trigger the gamma-ray emission, strengthening the connection of relativistic jets to the accretion processes. This opens ***new areas to study the formation of relativistic jets with associated particles acceleration***.

Intermediate mass BH and ultra luminous X-ray sources

Ultra-luminous X-ray sources (ULXs) are variable non-nuclear X-ray sources in external galaxies with luminosities greatly exceeding the (isotropic) Eddington luminosity of a stellar-mass compact object. ULXs are thought to be binary systems containing a compact object that is either a stellar-mass BH (with beamed or super-Eddington emission), or an intermediate-mass black hole (IMBH) with mass in excess of $100M_\odot$. IMBHs have been invoked in contexts ranging from the remnants of Population III stars to the formation of super-massive black holes (SMBHs). Probing the nature of the compact object in ULXs (and thus the existence of IMBHs) is therefore a key question that scientists from LEPCHE are trying to solve by following different paths.
An important piece of information for our understanding of ULXs comes from the discovery of huge ionized bubble nebulae around a significant fraction of un-obscured ULXs in nearby galaxies (Kaaret & Corbel 2009). This allowed an independent measure of the (ionizing) X-ray luminosity to be estimated. D. Cseh and S. Corbel discovered an energetic radio nebula in the ULX IC342 X-1 (Cseh et al. 2012), possibly inflated by a powerful undetected jet in a way similar to microquasars. By measuring the radio and X-ray fluxes of the central core, they conclude that the BH in IC342 X-1 has a mass smaller than 1000 $M_\odot$ using the fundamental plane of black hole activity.

Following a similar approach, they had already showed that if a BH existed at the center of the globular cluster NGC 6388 (one strong candidate for an IMBH) in our Galaxy, it necessarily had a mass smaller than 1500 $M_{\odot}$ (Cseh et al. 2010). Although none of these studies completely refute the existence of IMBH, they bring stronger constraints on their existence in a few sources. They, in particular, show, that if IMBH exist, they could be lighter than first thought, or be extremely inefficient accretors.

Gamma-ray bursts

Gamma-ray bursts (GRBs) are the most violent and energetic phenomena in the Universe (after the Big Bang). They are thought to either originate from the collapse of an extremely massive star into a BH, or to result from the merger of two compact objects (NS-NS, BH-BH, or NS-BH). These sources are at the crossroads of all the core topics studied in LEPCHE since they imply the physics of accretion, the physics of ejection and particle acceleration in the shocked jets, their interaction with the intergalactic medium, and finally the formation of extremely dense objects.
Götz et al. (2009) discovered polarized emission in the gamma-ray burst (GRB) GRB 041219A with INTEGRAL. The polarization fraction is extremely high and variable, and indicates Synchrotron radiation as the most probable radiation process from the jet. Götz et al. could further constrain the jet geometry with a novel approach. They deduced that the jet was formed by several layers, each having a different Lorentz factor. This object was also used in a test of fundamental physics. The quantum nature of space-time may lead to the violation of the Lorentz invariant. One effect of which would be a differential rotation of the polarization plan with the energy during the propagation of the wave. This effect is proportional to the distance to the source, therefore GRBs, lying at cosmological distances, are perfect sources for this. Using the measured polarized flux from GRB 041219A, it was therefore possible to improve the constraint on the Lorentz invariant violation by four orders of magnitudes (Laurent et al. 2011).

LCS - Laboratoire CosmoStat

1. Scientific Report

The scientific field of the CosmoStat interdisciplinary entity, created in February 2010, is **Computational Cosmology**. CosmoStat goals are:

- **Statistics & Signal Processing:** Develop new methods for analyzing astronomical data, and especially in cosmology (PLANCK, EUCLID, etc) where the needs of powerful statistical methods are very important.
- **Cosmology**: Analyze and interpret data.
- **Projects:** Participation to important astronomical projects: PLANCK, FERMI, HERSCHEL, EUCLID, etc
- **Education:** teach students and young researchers how to analyze astronomical data.
- **Dissemination:** take opportunity to disseminate our idea and tools in and outside the astronomical field (CEA, CNRS, University, Industry...).

CosmoStat is composed of:

- 5 permanent researchers: J. Bobin, S. Pires, M. Kilbinger, F. Sureau, J.-L. Starck
- 1 Engineer : S. Paulin-Henriksson + 2 associated researchers (A. Woiselle, SAGEM and A. Rassat, EPFL)
- 6 postdocs : A. Leonard, P. Paykari, S. Basak, G. Tsagkarakis, H. Garsden, T. Gosh
- 4 PhD students : A. Labatie, S. Beckouche, D. Machado, J. Rapin

Former PhD students since 2007 are: J. Schmitt (ATER Supelec), A. Woiselle (SAGEM), P. Abrial (ITLink LtD), J. Bobin (Caltech postdoc) and S. Pires (CEA).
Former Postdoc students since 2007 are: A. Rassat (24m, EPFL), F.X. Dupe (18m, Maitre de conf. at Université d'Aix-Marseille, O. Fourt (24 m, Postdoc at Clermont Ferrand), E. Deriaz (12m, researcher at CNRS).
Former and current master students: F. Lanusse, A. Balavoine, B. Leistedt, N. Clerc, Y. Zheng, P. Gay, and C. Delestre.

A) Statistical Methods

Sparse Representation of signals:
A signal is said to be sparse if it can be represented in a basis or frame (Fourier, Wavelets, Curvelets, etc.) in which the curve obtained by plotting the obtained coefficients, sorted by their decreasing absolute values, exhibits a polynomial decay. The basis or frame is called the dictionary. Note that most natural signals and images are compressible in an appropriate dictionary. Faster is the decay, better it is, since a very good approximation of the signal can be obtained from a few coefficients. For instance, for a signal composed of a sine, the Fourier dictionary is optimal from a sparse point of view since all information is contained in a single coefficient. Wavelets have been extremely successful to represent images, most natural images present a sparse behavior in the wavelet domain, and this explains why wavelets have been chosen in the JPG2000 image compression norm. Other representations such as curvelet are more adequate when the data contains filaments. We have been working on several ill posed inverse problems where we have shown that sparsity is a very efficient way to regularize the problem in order to get a unique and stable solution (**Starck** al, *Cambridge University Press*, book, 2010):

- Blind Source Separation (BSS): Exceptional results were obtained (**Bobin, Starck** et al, IEEE Trans. on Image Processing, 2007), (**Bobin**, **Starck**, et al. *Journal of Mathematical Imaging and Vision*, 2009) when sparsity is used to recover sources from a set of multichannel observations, each channel containing a mixture of the different sources (classic BSS problem).
- Inpainting: we have shown that missing data could be interpolated in very efficient way using sparsity (Fadili, **Starck**, Murtagh, *Computer Journal,* 2009).
- Deconvolution: We have studied the recent proximal theory in optimization theory, and shown that it provides very elegant solutions for image restoration (Dupé, **Starck**, et al, *IEEE Trans. on Image Processing*, 2009).
- Structure Sparsity: using a sparse representation such as wavelet or curvelet decomposition, there are some correlations between neighbor pixels that can be captured and used to improve denoising results. (Chesneau, Fadili, and **Starck**, *Applied and Computational Harmonic Analysis*, 2010).
- 3D Sparse Representations: we have extended to the third dimension recent sparse 2D decompositions such as ridgelet or curvelet (**Woiselle**, **Starck** and Fadili, *Applied and Computational Harmonic Analysis*, 2010), (**Woiselle**, **Starck**, Fadili, *J. of Mathematical Imaging and Vision*, 2011).
- Compressed Sensing (CS): CS is a theorem which links the data acquisition principle to the sparsity concept. We have investigated how this kind of new idea could be useful for the transfer of astronomical data from satellite such as Herschel (**Bobin, Starck**, and R. Ottensamer, *IEEE Journal of Selected Topics in Signal Processing*, 2008), and we have developed algorithms to recover the solution from compressed sensing data (Donoho, Tsaig, Drori, **Starck**, *IEEE Transactions on Information Theory,* 2012). We have shown using a Herschel data set, especially acquired to test the CS approach, that CS could indeed be a very practical solution for astronomical data transfer from a satellite to earth (Barbey, Sauvage, **Starck**, Ottensamer, *A&A*, 2011).

B) Cosmology

While band limited signals, 2nd-order statistics, l2-norm regularization (i.e. energy) have been the main ingredients of the data processing during the last century, sparse signal, higher-order statistics and compressed sensing are becoming the key for modern data analysis in the beginning of this twenty one century. Our pioneer work has been to study how this sparsity concept could change and improve our way to manipulate and interpret cosmological data set. We now present how the idea and methods described in the previous section impact cosmological data analysis.

Cosmic Microwave Background (CMB):

We have been working on several aspects relative to CMB data:

- **CMB map reconstruction** from multichannel observations obtained by instrument such as WMAP or PLANCK. We have shown that our sparse component separation, called GMCA, can be used to recover both CMB and SZ maps (**Bobin** et al, *Statistical Methodology,* 2008). We have also shown that a post-processing using sparse representation could be very useful for noise and foreground removal (**Bobin, Starck, Sureau**, Fadili, *A&A*, 2012).
- **Sparse Representation of Polarized Spherical Data**: we have developed new decompositions (wavelet and curvelet) on the sphere for polarized data (**Starck** et al, *A&A*, 2009; **Paykari and Starck**, *A&A*, 2012). The software SparsePol (Polarized Spherical Wavelets and Curvelets) has been developed, documented, and is available since June 2010 at: http://jstarck.free.fr/mrsp.html. Any astronomer can now very easily apply a wavelet transform or a curvelet transform on spherical polarized data. Our toolbox has already been downloaded more than 1500 times.
- **Integrated Sachs-Wolfe effect detection (ISW):** ISW detection consists in detecting a very weak signature of the matter in the CMB, due to the passage of CMB photons through the gravitational potential. This is done by cross-correlating a galactic survey, which traces the matter and a CMB map. We have proposed a new method to make this detection, based on sparse representations in order to take into account missing values and a parametric bootstrap techniques allowing us to properly estimate the detection level. This method has been applied on WMAP and 2MASS (**Dupe, Rassat, Starck**, *A&A*, 2012). Our results (2sigma detection) is compatible with the expected signal in the standard cosmological model, and do not confirm high detection levels (> 4sigma) claimed by few other groups.

Weak Lensing

- **2D Convergence Mass Map:** we have applied to the COSMOS data our mass map reconstruction method and we have shown a good spatial correlation between visible and dark matter (Massey et al, *Nature*, 2007; **Pires, Starck** and A. Refregier, *IEEE Signal Processing Magazine*, 2010). We have also shown that there is a clear relation between the Helmholtz decomposition of a vector field and the E and B modes reconstruction from weak lensing data, and we have derived a new Wavelet Helmholtz decomposition to reconstruct the dark matter mass map. Using this idea, we can design very specific curl-free and divergence-free wavelets which allow to better recover the information on the border of the field (**Deriaz, Starck, Pires** *A&A*, 2012).
- **High-Order Statistics:** we have shown that i) sparse representation could help to discriminate cosmological models (**Pires, Starck** et al, *MNRAS*, 2009) (**Pires, Starck**, et al, *A&A*, 2009), ii) high-order statistics should be performed on the wavelet decomposition of the convergence map rather than on the aperture mass map (**Leonard, Pires, Starck**, *MNRAS*, 2012), and iii) that the best cosmological constraint are obtained using a wavelet peak counting statistic on the sparse denoised convergence map (**Pires, Leonard, Starck**, *MNRAS*, 2012).
- **3D Density Mass**: we have worked on the extension of the weak lensing reconstruction operator to the third dimension (i.e. tomographic weak lensing), and we have found a very interesting behavior of this operator. It acts in fact as a Compressed Sensing operator (i.e. it spreads out any localized information over all measurements). Then l1 sparse recovery is an interesting approach to reconstruct the 3D mass distribution. We have proposed a new sparse non-linear approach for 3D density mass map reconstruction, and we have shown that it outperforms significantly all existing methods (**Leonard, Dupe, Starck**, Fadili, *A&A*, 2012b). In particular, we have seen using simulations that we can reconstruct two clusters on the same light of sight, which was impossible with previous methods. The method has also the great advantage to solve the underdetermined problem, i.e. we have a solution with more redshift bins than the input shear measurements.

Spatial Distribution of Galaxies:

- **Two point correlation function (2PCF):** we have investigated whether Labini's group claim, that the 2PCF at large scales behavior in galaxy surveys (BAO, Universe homogenization) cannot be trusted due to the limited volume effect, is correct. We have demonstrated that all 2PCF estimators verifies a relation called integral constraint, which is not necessary by the real 2PCF, which biases correlation function estimators. But we showed using simulations of the Sloan Digital Sky Survey Data Release 7 (SDSS DR7) that the effect of the constraint is very small for current galaxy surveys (**Labatie, Starck**, Lachieze-Rey, *Statistical Methodology,* 2011).
- **Baryonic Acoustic Oscillation (BAO):** We have designed a specific wavelet adapted to search for shells, and exploit the physics of the process by making use of two different mass tracers, introducing a specific statistic to detect the BAO features. We have applied our method to the detection of BAO in a galaxy sample drawn from the Sloan Digital Sky Survey (SDSS). We have used the "main" catalogue to trace the shells, and the luminous red galaxies (LRG) as tracers of the high density central regions. Using this new method, we detect, with a high significance, that the LRG in our sample are preferentially located close to the centers of shell-like structures in the density field, with characteristics similar to those expected from BAO (Arnalte-Mur, **Labatie, Clerc**, Martínez, **Starck** et al, *A&A*, 2012). Then we have studied the classical method for detecting BAOs and the assumptions that the method requires. We

have also found that the approximation of a constant covariance matrix in the classical BAO analysis method can affect non negligibly both the BAO detection and cosmological parameter constraints (**Labatie, Starck**, Lachieze-Rey, *ApJ*, 2012).

- **Multiscale morphology of the galaxy distribution:** we have shown how to calculate the Minkowski Functionals (MFs) taking into account border effects of complex observational sample volumes. We have proposed a multi-scale extension of the MF, which gives us more information about how the galaxies are spatially distributed. This method has been applied to the 2dF Galaxy Redshift Survey data. The MMF clearly indicates an evolution of morphology with scale. We also compare the 2dF real catalogue with mock catalogues and found that Λ cold dark matter simulations roughly fit the data, except at the finest scale (Saar, Martinez, **Starck** and Donoho, *MNRAS*, 2007).
- **Galaxy clustering and the changing relationship between galaxies and haloes since z=1.2:** We measured the galaxy spatial correlation function in multi-band optical data over 133 square degree in the CFHTLS-Wide survey, from z=0.2 to 1.2 (**Coupon, Kilbinger et al.**, *A&A*, 2012). Comparing these observations to a semi-analytical model of the matter distribution in the Universe, including a prescription how galaxies populate halos, a so-called halo occupation distribution (HOD) model, we determine the evolution of the luminosity-to-mass (L/M) ratios for stellar-mass selected galaxy samples. A maximum L/M is reached at halo masses of 6.3×10^{11} at low redshift. This mass increases with redshift, indicating “anti-hierarchical” evolution or “down-sizing”, where galaxies formed more efficiently in larger halos in the past.

C) Projects

PLANCK: We are highly involved in the PLANCK project. We run our tools (component separation, inpainting, ISW detection, non-Gaussianity tests based on sparsity, etc) on PLANCK data. We have also shown on simulations that the CMB lensing effect can be recovered even in the presence of missing data, thanks to sparse representations (Perotto, **Bobin** et al, *A&A*, 2010; Plaszczynski et al, *A&A*, 2012). Finally, we have investigated how the theoretical power spectrum can be estimated from the reconstructed CMB map using sparsity (**Paykari, Starck** et al, *A&A*, 2012).

EUCLID: Euclid will require that we manipulate 3D spherical data. We have developed a 3D spherical harmonic analysis decomposition (**Leistedt, Rassat, Refregier, Starck** et al, *A&A*, 2012) and a 3D isotropic wavelet decomposition on the sphere (**Lanusse, Starck, Rassat,** *A&A*, 2012). The two related packages were released in October 2011. The software is available from the web page http://jstarck.free.fr/mrs3d.html. We have also taken several responsibility positions in the Euclid consortium ((OULE3 lead, and several OULE3 work packages leads).

Fermi: We have developed a new method for denoising and deconvolution of multichannel data on the sphere contaminated with Poisson noise (**Schmitt, Starck** et al, *A&A*, 2010; **Schmitt, Starck** et al, *A&A*, 2012). A toolbox for Multichannel Spherical Image Debluring has been release in March 2012. The Fermi sources catalog has been derived using our wavelet code (Abdo et al. (**Starck**), *ApJS*, 2010).

HERSCHEL: We have realized a study on Compressed Sensing for Herschel (see above). One of our sparsity based algorithms, which decomposes one image into two components, has provided one of the strongest results of Herschel (Andre et al, *A&A*, 2010). Philippe Andre will present his results at the next IAU meeting (August, 2012) as a Keynote speaker.

XMM: The XMM-LSS catalog has being derived using our wavelet code (Pierre, et al (**Starck**), MNRAS, 2007).

CFHTLenS: We are involved in the Canada-France-Hawaii Telescope (CFHT) lensing survey (CFHTLenS). Several analysis (PSF treatment, systematics testing, shape measurement) will be submitted soon, as well as several science publications on cosmological constraints for LCDM models, dark energy and modified gravity. This work is a continuation from publications using previous data releases (**Fu, Semboloni, Hoekstra, Kilbinger et al**., *A&A* 2008; **Kilbinger et al.**, *A&A* 2009). Preliminary results were presented at a special CFHTLenS parallel session and press release at the AAS meeting in Austin, Texas, 2012. For systematics testing and to produce the science results, public software developed by M. Kilbinger (athena, nicaea, cosmo_pmc, available atwww2.iap.fr/users/kilbinge) has been used.

D) Education

We have been involved in the following education activities:

- Master 2, MVA, ENS-Cachan (24h per year).
- Post-master class of the Ecole Doctorale d’Astronomie d’Ile de France (20h per year).
- Tutorial during the ADA6 conference, May 2010.
- Organization of the Summer school on advanced data processing and reproducible research, Cargese, May 2012.
- 5 PhD + 4 PhD in preparation + 9 postdocs + 7 internship students.

E) Dissemination:

CEA:
- One PhD with DRT (CEA Technical Research Department) on mass spectroscopic imaging.

Industry:
- Two projects (European CS-Orion project and ANR MultID) are realized in collaboration with private companies, SAGEM and VTRID Ltd (Greek company).
- One PhD (Contract CIFRE with SAGEM), defense in 2008.

F) Scientific Visibility

Prize:

- ★ EADS Prize (2011) from the French National Academia of Science.
- ★ ERC Senior (2009): SparseAstro project (ERC-228261), in the interdisciplinary panel.

Conferences: we have organized three international conferences on astronomical data analysis in 2008 (Heraklion, Crete), 2010 (Monastir, Tunisia) and 2012 (Cargese, France), an international workshop on Sparsity in Cosmology in May 2011 (Nice) and an international workshop on Image Processing for Random Shapes: Applications to Brain Mapping, Geophysics and Astrophysics in 2007 (UCLA, USA). We have also organized several sessions in international conferences (ICIP, Cairo, 2009; CMA V, Pennsylvania State University, 2011; 6th PICOF Conference, Polytechnique, 2012).

Scientific Organizing Committee: SOC Member of seven conferences, Editorial board for the Springer Series on Astrostatistics, project reviewers for many Science Foundations, Executive member of the ISI International Astrostatistics Network.

Invited Talks:
48 invited talks (see list below) including:

- Plenary lecture, Statistical Challenges in Modern Astronomy V, State College, USA, June 15, 2011.
- Plenary lecture, ENS-Cachan, Conference en l'honneur d'Yves Meyer, Prix Gauss, Cachan, Nov. 4, 2010.
- Special Astrophysics Colloquium, SLAC, Stanford, July 22, 2010.
- Plenary lecture, SIAM Conference on Imaging Science, April 14, 2010.
- Australia Telescope National Facility, November 27, 2009.
- Plenary lecture, IEEE International Conference on Image Processing, Brussels, Sept. 11-14, 2011.
- Plenary lecture, SIAM Conference on Imaging Science, Chicago, April 14, 2010.
- Plenary lecture, Kapteyn Institute, Groningen, June 15, 2009.
- Plenary lecture, I-science workshop on data mining, distributed computing and visualization for astronomy, Lorentz Center, Leiden, Oct 13, 2008.
- IMI Distinguished lecture Series, University of South Carolina, Columbia, November 7, 2007.

Funding:

- ANR DESIR, Deep galaxy evolution survey in the near infra-red, 2007-2010, team member, 346000 Euros.
- ANR NatImages. Adaptivity for Natural Images and Texture Representations, CO-I, 2009-2012, 307278 Euros.
- Compressed Sensing for Herschel, European Astronet Funding, team member, 2009-1011, 183000 Euros.
- SparseAstro, Senior ERC, 2009-1014, P.I., 2360000 Euros.
- CS-Orion, Marie Curie Industry-Academia Partnership and Pathways (IAPP), 2010-1014, CO-I., 1280000 Euros.
- ANR MultID, Robust Multispectral data analysis for target detection and IDentification, P.I., 297 838 Euros.

LMPA - Laboratoire de Modélisation des Plasmas Astrophysiques

1. Scientific Report

Human resources:

The LMPA team is presently composed of 12 permanent staff, 3 post docs and 4 PhD students. The team members are:
10 CEA researchers: E. Audit, J-P. Chièze, J.-E. Ducret, T. Foglizzo, S. Fromang, D. Gilles, P. Hennebelle, F. Masset, R. Teyssier (head), S. Turck-Chièze
1 CNRS researchers: J-J. Aly
1 researcher retired from CNRS in 2010 and with an emeritus CEA status: B. Gaffet
1 Paris 7 lecturer: M. Gonzalez
3 Post docs: T. Matsakos (ANR), R. Simoniello (CNES), M. Flock (ERC)
5 PhD students: L. de Sa (ED), C. Charignon (CFR), P. Tremblin (CFR), M. Labadens (CFR), J. Faure (ERC)
11 Post docs that left the team after 2007: D. Aubert (ANR), P. Ocvirk (ANR), E. Tescari (PF7), S. Dib (ANR), F. Delahaye (ANR), A. Palacios (CEA), L. Piau (CNES), S. Lefèvre (CNES), T. Yamasaki (CEA), J. Sato (ANR) , N. Veytet (ANR)
10 PhD students that left the team after 2007: Y. Dubois (CFR), T. Guillet (CFR), D. Chapon (CFR), J. Guilet (CFR), C. Baruteau (CFR), J. Casoli (AMN), B. Commerçon (AMN), S. Mathur (CFR), V. Duez (CFR), G. Loisel (CFR)
S. Fromang was recruited in 2007 after a post doc in Cambridge, **M. Gonzalez** was recruited in 2009 after a post doc in Madrid and **P. Hennebelle** (formerly Astronome Adjoint in LERMA) was recruited in 2012. **F. Masset** is on a long-term leave of absence in Mexico. **E. Audit** has departed in January 2012 for his new appointment as head of "Maison de la Simulation".

Main research interests:
Our team is interested in solving fundamental problems in astrophysics that are transversal to many other teams in our laboratory. These questions are mostly related to the physics of astrophysical plasmas, which are quite specific to our field. We are trying to understand the fundamental role played by gravity, fluid dynamics, magnetic fields and radiation fields in astrophysical objects as diverse as the large-scale structure in the universe, high-redshift galaxies, the Milky Way, star-forming molecular clouds, young stars and their planet, and the Sun. Our methodology is based on the transverse nature of these fundamental physical processes, as opposed to a more traditional "per-object" break-down. To achieve our goals, our team uses 3 types of tools: computer simulations, analytical methods and laboratory experiments.

Scientific identity:
Our team is composed of world-expert in computational astrophysics, with a strong expertise in magnetized and radiative fluids and parallel computing. We have developed our own computational tools, with general-purpose codes such as RAMSES, FARGO and HERACLES. In term of fluid dynamics numerical techniques, we make extensive use of grid-based schemes, especially the Godunov techniques. We have developed completely original Godunov schemes for solving the equations of ideal MHD and radiation hydrodynamics. When developing numerical techniques, it is mandatory to have also a strong analytical background. We have in our group several members who developed very powerful methodologies to derive fundamental analytical results, with a very general applicability, far beyond just testing numerical codes. Finally, one original aspect of our research is to make extensive use of laboratory experiments to study astrophysical plasmas, from high-energy lasers (radiative shocks and opacity measurements) to complex fluid experiments (SWASI experiment for supernovae hydrodynamics).

Community codes development:
Our team has invested a large amount of time and effort in the development of freely available codes to study self-gravitating fluid dynamics. In the period 2007-2012, we have added 2 important physical modules to our existing codes, namely a Godunov-like solver for ideal MHD (Fromang+2006, Teyssier+2007) and a Godunov-like solver for radiation hydrodynamics (Gonzalez+2007, Aubert+2008). These 2 solvers are now part of the RAMSES and HERACLES codes, and are used for galaxy formation and star formation studies.

COAST project:
We have created in 2007 a transverse project inside IRFU to rationalize activities in computer simulations. This project, named after "COmputational ASTrophysics", gather members of the LMPA team but also members of other teams that use our tools, our computer equipment and participate to our meetings. A small group from the Computer Science department at IRFU is also part of the project, providing support for data visualization, parallel computing and code development, web page and movie editing. The COAST project is a sustained effort within IRFU to optimize the scientific exploitation of our various codes.

Maison de la Simulation:
During the period 2007-2012, E. Audit has decided to apply and expand our methodology to a much broader scope. He has created a new structure, called the "House of Computing", whose objectives are to provide support to scientific teams in various fields (astrophysics, climate modeling, material science…) in term of code optimization, new hardware and data visualization. This new institute, a joint initiative of CEA, CNRS and INRIA, has been officially created in 2011 with E Audit as the new director.

Funding:
We describe the sources of external funding during the years 2007-2012.
Our members have been PIs in 5 projects funded by ANR: HORIZON (R. Teyssier), SYNERGHY (E. Audit), VORTEXPLOSION (T. Foglizzo), SN2SN (T. Foglizzo), COSMIS (P. Hennebelle).
Space experiments COROT and PICARD + participation to GOLF (S. Turck-Chièze).
We have participated as node coordinator for 4 other ANR projects (MANET, BINGO, DUSTYDISK, MAPP).
R. Teyssier was the French node coordinator for 2 European networks: COSMOCOMP (FP7) and ASTROSIM (ESF).
S. Fromang has been awarded in 2010 an ERC starting grant for his project PETADISK.
R. Teyssier has been awarded in 2011 the Cino and Simone Del Duca Prize by the French academy of science.
P. Hennebelle has been awarded in 2012 an ERC starting grant for his project MAGMIST.

Computer support:
Using various sources of funding, we have acquired in 2011-2012 a cluster of 1024 cores with Infiniband interconnect and a fast 52 TB file system. This computer is available to our team and to the members of the COAST project. We have also continued access to national and international supercomputing centers, with a cumulative computing time allocation of 40 millions CU hours per year.

Training:
We have trained 12 PhD students during the years 2007-2012 and half a dozen Master students. This is significantly more than other teams of AIM. Our members are teaching at Paris 7 and Paris 11 Universities at the Master and post-Master level. We have also teaching activities at the CEA training center (INSTN), at the University of Zürich, at the University of Bordeaux and at ENSTA engineering school.

Conferences:
We have organized many international conferences during the years 2007-2012, including the ASTRONUM conference, organized each year since 2007 with more than 100 participants and the ASTROSIM conferences (2008 in Ascona and 2012 in Davos) with more than 100 participants.

Scientific report:

We now describe 5 main scientific achievements accomplished by our team in the period 2007-2012. They start from the largest scale with cosmology and galaxy formation and then we focus on the study of star forming regions in the interstellar medium. We continue with the physics of circum-stellar and proto-planetary disks, reaching finally the scale of individual stars, with the physics of the Sun and core-collapse supernovae.

I) Accretion flows and galaxy fromation:
The field of galaxy formation and cosmological simulations has expanded quite dramatically in France (as in the rest of the world) after 2007 thanks to the collective effort of the French community within the HORIZON project. This period has seen the development of the massively parallel version of the RAMSES code, as well as the cosmological initial condition generator MPGRAFIC and the power spectrum analysis tool POWMES. In 2007, the HORIZON project has performed the largest N-body simulation of its time with 70 billion particles in a 2 Gpc box (Teyssier+2009). The legacy of the HORIZON project is still quite strong, since a new world record was obtained in 2012 with these same 3 codes with half a trillion particles in a 20 Gpc box (Alimi+2012). Beyond pure N-body simulations, a very spectacular result was obtained with the RAMSES code using the MareNostrum super-computer in Barcelona. This simulation, now referred to as the MareNostrum simulation, allowed us to follow the complex gas dynamics, star formation and associated feedback of hundred of thousands of galaxies in a 50 Mpc box (Ocvirk+2008, Devriendt+2010). Although the spatial resolution was quite coarse (1 kpc), making the detailed study of galaxy properties quite challenging, we were able to resolve quite nicely the accretion flows around these high-redshift, star-forming galaxies. The simulation was revealing for the first time cold accretion streams of pristine gas, feeding directly the central 10 kpc of their parent halo. Although the idea of “cold streams” was not new at that time, we were able for the first time to quantify statistically the accretion rate and relate it to the star formation rate of high-redshift galaxies (Ocvirk+2008, Dekel+2009). This idea of cold stream accretion has immediately triggered considerable interest as an alternative model for galactic disk formation, as opposed to the traditional view of a hot, quasi-spherical cooling halo. We have performed with the RAMSES code additional simulations at much higher resolution, using the so-called “zoom-in” technique. We were able to model in much greater details the formation of a Milky Way disk, highlighting the importance of unresolved, sub-grid physics in determining the final properties of the model galaxies (Agertz+2009, Agertz+2011, Scannapieco+2012). After this intense period of effort in galaxy formation, we are now convinced that violent feedback processes drive galaxy formation, with stellar feedback and gas fragmentation acting on small scales (Teyssier+2010, Teyssier+2012) and super-massive black holes and AGN feedback dominating on large scale (Teyssier+2011). This work has triggered many interactions with the LCEG team.

2) Interstellar turbulence and star formation:
Star formation is still an unsolved problem in astrophysics. Although infrared and sub-millimeter observations have considerably improved our understanding of the dynamics of the turbulent interstellar medium, and the formation of molecular cores within, we still don’t understand the origin of this turbulence within molecular clouds, and we don’t have a clear picture of the star formation process itself. In this complicated framework, P. Hennebelle and E. Audit have revisited the role played by the thermal instability in colliding galactic flows in triggering the formation of molecular clouds and the associated turbulence. Our team has re-examined this old idea using high-resolution 2D and

3D simulations (Hennebelle+2007, Audit+2010). These results have triggered considerable interest in the community of star formation, opening the possibility of a self-consistent origin for turbulent molecular cores. Using self-gravitating, ideal MHD follow-up simulations, P. Hennebelle has explored further the formation of proto-stellar cores in this well-posed framework (Hennebelle+2011). Our team has also explored the collapse of molecular cores into proto-stars in 3D, using for the first time MHD and radiation hydrodynamics (Commercon+2010, Commercon+2011), but also in 1D following the collapse all the way down to the second Larson core (Commercon+2011). These results, obtained in collaboration with G. Chabrier, have profound consequences on our understanding of the stellar Initial Mass Function. Both magnetic and radiation fields have a direct impact on the mass of proto-stellar fragments, and regulate the formation of massive stars. Using a different approach, P. Hennebelle and G. Chabrier have used the Press-Schechter theory of Gaussian random fields to derive analytically the stellar IMF. This purely analytical approach is complementary to our numerical investigations, and offers an explicit dependence of the IMF to structural parameters of the interstellar turbulence (Mach number, power law…). This work has many connections with the observational effort led by P. André in the LFEMI team.

3) Accretion disks and magnetized turbulence:
Accretion disks are ubiquitous in the universe. Yet the mechanism extracting angular momentum from the disk and thus enabling accretion to proceed remains poorly understood. The most likely candidate is believed to be MHD turbulence mediated by the magnetorotational instability (MRI, Balbus & Hawley 1991). While the saturation amplitude of the MRI was believed to be well understood in the early 2000's, we found using a local model of disks, the so-called shearing box, that many of the published simulations suffered from a numerical artifact (Fromang & Papaloizou 2007) and that the saturation amplitude of the MRI was in fact a strong function of the magnetic Prandtl number, the ratio between microscopic viscosity and resistivity (Fromang+2007). These results have generated a lot of interest in the MRI community. They have since been confirmed by several teams and have generated significant follow-up work, some of which in our group (Fromang 2010). The focus is now to find asymptotic properties of the turbulence in the astrophysical regime of interest (large Reynolds number, small Prandtl number). In parallel, our team has developed global simulations of turbulent protoplanetary disks to study the consequences of MHD turbulence on various aspects of planet formation, including dust dynamics (Fromang & Nelson 2009), large scale flow (Fromang+2011) and planet migration (Baruteau+2011). All of these papers have highlighted a subtle yet important interplay between MHD turbulence and planet formation.

4) Gravity modes and the internal structure of the Sun:
Solar seismology has revealed unsolved problems in the understanding of the interior of solar-like stars. The solar radiative sound speed and rotation profiles, obtained with great accuracy down to the core thanks to both detected acoustic and first gravity modes aboard SOHO, disagrees with the predictions coming from a classical representation of stars, even when the transport of momentum by rotation is included (Garcia et al. 2007, 2010, Mathur et al. 2007, 2008, Turck-Chièze, Palacios et al. 2010). On the other end, the solar seismic model predicts extremely well all the detected neutrino fluxes, in contrast with the SSM predictions. The coherent picture of the solar core that emerges from these independent probes demonstrates that the energetic of the Sun is not yet under control (Turck-Chièze and Couvidat 2011). Different hypotheses are explored: a bad description of the transfer of energy by photons, the presence of a deep fossil field (Duez et al. 2010), a complex redistribution of energy in the radiative zone due to dynamical motions that are in action since the early stage (Turck-Chièze, Piau and Couvidat 2011). This transition period has produced three complementary activities. 1) An instrument 10 times more performing than GOLF has been built and qualified at IRFU to amplify the detection of solar gravity modes (Turck-Chièze et al. 2008, 2012) and a new concept of formation flying mission called DynaMICCS (Turck-Chièze et al. 2009) has been proposed to ESA to improve our knowledge of the Sun-Earth dynamical relationship. 2) An international consortium (CEA-Los Alamos-Aldermaston) has been created in 2009 to study the photon interaction with plasma in X and XUV both theoretically and in laboratory (Loisel et al. 2009, Turck-Chièze et al. 2009, Gilles et al. 2011). 3) Theoretical 3D simulations with the STAGGER code and observational studies have been pursued on the emergence of the magnetic field and its role in producing variable activity (Simoniello et al. 2012, Piau et al. in preparation). Central temperature and density of the solar core have been also used to put astrophysical constraints on WIMP dark matter properties (Turck-Chièze et al. 2012, Turck-Chièze and Lopes 2012). Our theoretical work will now benefit from interaction with the Saclay members who work on young stars and with the 3D simulations of young objects. These activities will find natural extension with the development of asteroseismology and with the solar projects in observation (SDO Stanford and PICARD).

5) The SASI mechanism in core-collapse supernovae:
The explosion of massive stars as supernovae is still a theoretical mystery. The neutrino-driven mechanism proposed by Bethe & Wilson (1985) has been revived over the last decade by the discovery of the importance of SASI (Standing Accretion Shock Instability, Blondin+2003), a hydrodynamical instability that breaks the spherical symmetry and generates convective oscillatory motions on a large angular scale. Crucial to the success of the explosion, these transverse motions can account for the natal kick of the residual pulsar. The mechanism of SASI relies on the linear interplay of acoustic and vorticity waves in the shocked accretion flow. The LMPA team played a historical role by introducing this physical mechanism into astrophysics in the early 2000s and identifying it in the context of core-collapse supernovae (Foglizzo+2007, 2009, Scheck+2008, Guilet & Foglizzo 2012). These theoretical studies used the complementarity of perturbative methods and numerical simulations, and a long lasting collaboration with the supernova team at MPA Garching. This deep analytical understanding of the SASI mechanism has been fruitful for guiding the interpretation of complex numerical simulations, predicting the nonlinear amplitude of these asymmetries (Guilet et al. 2010) and anticipating the consequences of MHD effects (Guilet & Foglizzo 2010, Guilet+2011). In 2012 the LMPA team proposed the first experimental approach of stellar core-collapse, based on the analogy between shock waves in the stellar gas and hydraulic jumps in a shallow water liquid (Foglizzo+2012). The SWASI experiment

has been constructed and patented at CEA, benefiting from the technical facilities at AIM. A new version of this experiment is now being developed at CEA/IRFU to further investigate the effects of stellar rotation on the development of SASI and assess its consequences on the pulsar spin, predicted by Yamasaki & Foglizzo (2008). A simpler experimental device, developed for public outreach, aims at a large distribution in science museums and universities.

2. List of publications

The team has produced 234 peer-reviewed articles (5529 citations since 2007), including 3 papers in Nature and Science. 8 papers received more than 100 citations and 27 between 50 and 100 citations over the considered period. This statistics was performed using individual data from ADS.

T. Foglizzo has produced a CEA patent in 2011 (ref. SP 39712 JCI / BD 12547 MP) for a “Device and design process for the formation of an hydraulic jump”.

R. Teyssier has produced the RAMSES code under the Open Source CeCill license. The code is now widely used by a large community in cosmology, galaxy formation and star formation. The code’s papers have received more than 376 citations, which compares favorably with the other community codes in astrophysics like GADGET (1398 citations), FLASH (512 citations) and ENZO (195 citations).

S. Turck-Chièze and the IRFU team have produced the prototype GOLF-NG in 2010. All the required performances have been achieved to continue the detection of solar gravity modes in a future space mission.

Peer-reviewed papers with >50 citations published in years 2007-2012:

25. Dekel A., et al., 2009, Nature, 457, 451 (376 citations)
26. Agertz O., et al., 2007, MNRAS, 380, 963 (203 citations)
27. Ocvirk P., Pichon C., Teyssier R., 2008, MNRAS, 390, 1326 (141 citations)
28. Hennebelle P., Chabrier G., 2008, ApJ, 684, 395 (133 citations)
29. Fromang S., Papaloizou J., Lesur G., Heinemann T., 2007, A&A, 476, 1123 (123 citations)
30. Fromang S., Papaloizou J., 2007, A&A, 476, 1113 (115 citations)
31. Michel E., et al., 2008, Science, 322, 558 (107 citations)
32. Garcia R., Turck-Chièze S., et al., 2007, Science, 316, 1591 (91 citations)
33. Chaplin W., et al., 2010, ApJ, 713, L169 (88 citations)
34. Hennebelle P., Fromang S., 2008, A&A, 477, 9 (85 citations)
35. Agertz O., Teyssier R., Moore B., 2009, MNRAS, 397, L64 (83 citations)
36. Papaloizou J., Nelson R., Kley W., Masset F., Artymowicz P., 2007, Protostars and Planets V, 655 (81 citations)
37. Hennebelle P., Teyssier R., 2008, A&A, 477, 25 (81 citations)
38. Hennebelle P., Audit E., 2007, A&A, 465, 431 (79 citations)
39. Hennebelle P., Banerjee R., Vazquez-Semadeni E., Klessen R.~S., Audit E., 2008, A&A, 486, L43 (72 citations)
40. Laureijs R., et al., 2011, arXiv, arXiv:1110.3193 (70 citations)
41. Agertz O., Teyssier R., Moore B., 2011, MNRAS, 410, 1391 (70 citations)
42. Banerjee R., Vazquez-Semadeni E., Hennebelle P., Klessen R., 2009, MNRAS, 398, 1082 (69 citations)
43. Dubois Y., Teyssier R., 2008, A&A, 477, 79 (69 citations)
44. Foglizzo T., Galletti P., Scheck L., Janka H.-T., 2007, ApJ, 654, 1006 (68 citations)
45. Scheck L., Janka H.-T., Foglizzo T., Kifonidis K., 2008, A&A, 477, 931 (65 citations)
46. Martig M., Bournaud F., Teyssier R., Dekel A., 2009, ApJ, 707, 250 (64 citations)
47. Baruteau C., Masset F., 2008, ApJ, 672, 1054 (63 citations)
48. Teyssier R., Chapon D., Bournaud F., 2010, ApJ, 720, L149 (54 citations)
49. Arentoft T., et al., 2008, ApJ, 687, 1180 (53 citations)
50. Hennebelle P., Chabrier G., 2009, ApJ, 702, 1428 (52 citations)
51. Goerdt T., Dekel A., Sternberg A., Ceverino D., Teyssier R., Primack J.~R., 2010, MNRAS, 407, 613 (52 citations)
52. Cattaneo A., Teyssier R., 2007, MNRAS, 376, 1547 (52 citations)
53. Pato M., Agertz O., Bertone G., Moore B., Teyssier R., 2010, PhRvD, 82, 023531 (51 citations)

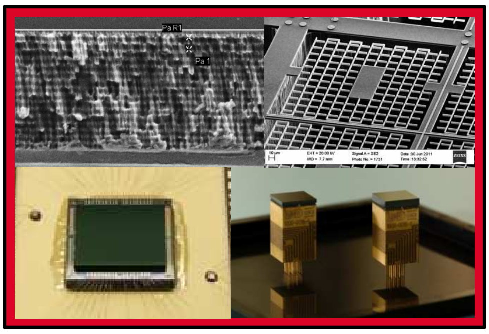
LSIS - Laboratoire Spectro-Imageurs Spatiaux

1. Scientific Report

LSIS is a R&T laboratory of AIM, focused on the design of advanced imaging spectrometers for astrophysical observations from space. It is part of the instrumentation branch of AIM. Its main task is to realize the Research and Development programs for instrumentation, in a broad range of energy starting from the far infrared (meV range) to the gamma rays (MeV range). LSIS benefits of an advantageous environment and position at three levels:, inside AIM thanks to other associated space labs: LISIS - Interface to science , LQIS- Quality and AIT , LSAS - System , LEDES-electronic office; inside Irfu connections with Sédi and Sis, and inside CEA with Léti in Grenoble. It allows LSIS considering any branch of innovation from material technologies to TRL 9 instrumentation including microelectronics or advanced process and hybridization technologies.

LSIS strategy is based on the realization of devices at different levels of technological maturity, as the development of new technologies may last typically 10 to 15 years. The R&T targets are jointly agreed with main science topics inside AIM, emphasizing our skills and history. Low maturity activities involve researches in basic material properties and characterizations (superconducting material properties, material interfaces, polymers, semiconductor physics…), front-end electronics and cryogenics electronics (noise, readout strategy, specs and design…), systems in-pixel (innovative designs, …). More advanced detectors are managed as projects and deal with design and realization of prototypes including full-functional detector chains (performances and proof of concept…), imaging spectrometer assembly and process (with industry) as well as specific test benches (ultra-low temperature means, …) and pre-qualification activities follow-up (space requirements, radiation hardness…). When a sufficient maturity is reached, complex systems and technological demonstrators are built, proposed to science missions or valorized in other science fields.

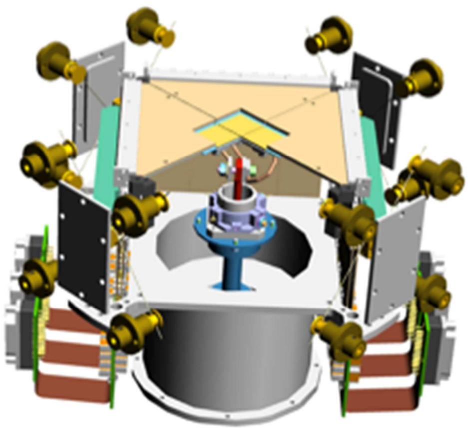
On the picture below, illustrating LSIS devices at different level of maturity: top left is a cross section view of a cryogenics multilayer thermally insulated electrincal internaconnection, top right is a close-up view of a sub-millimeter range bolometer, bottom left is a HgCdTe middle infrared prototype bump bonded to its CMOS readout chip and bottom left are two pixelated CdTe based prototypes.



LSIS skills are wide, from photon/particle interaction with matter, semiconductor and superconductor physics, semiconductor technologies and micro machining on silicon, materials physics, hybridization technologies, vacuum and cryogenics, space techniques, measurements, electronics, radiation damage on electronics and detectors, spectrometry, data analysis and software applications.
LSIS imaging spectrometers are direct ionization systems (semiconductor devices, mostly CdTe based for hard X-ray and gamma rays and HgCdTe sensors for Mid Infra-red imagers) on one hand and cryogenic detector arrays (sub millimeter arrays and X ray micro calorimeters) on the other hand. Major outputs for micro-calorimeter illustrating activities for early research and building blocks activities, CdTe based imaging spectrometer as advanced detector prototype example and Sub-millimeter range bolometers as high maturity systems are proposed below to illustrate our most relevant results. Mid infrared devices joined the lab more recently and we will describe in more detail in the project or the next contract.

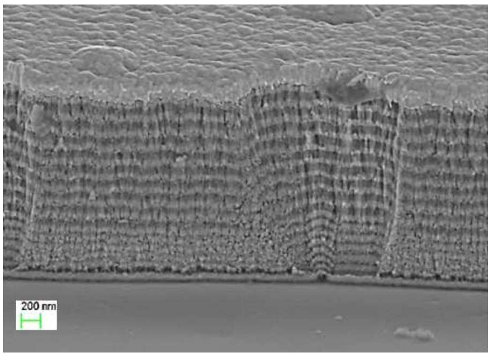
a. X-ray micro-calorimeters – MIS technology

Ultra high spectral resolution X-ray micro-calorimeter imager is currently the most challenging R&T program that LSIS is leading. This activity is inheriting from prestigious realization for the XMM-Newton X-ray CCD cameras, in flight since 1999. From XMM science feedback, LSIS pushed an entirely new concept of micro-calorimeter imaging spectrometer to reach the highest achievable energy resolution ever, far beyond the physical limits of semiconductors: ~2-5 eV full width half maximum at 6 keV, the iron line.



The final goal is to produce a 32x32 (see top right figure), 500-micron pixel pitch array for space application. In this peculiar technique, a single X-ray photon is efficiently stopped into the Ta absorber and releases its energy heating up the medium, previously cooled down between 30 and 50 mK. The rise of temperature of the absorber is measured using a Si thermometer hybridized underneath the Ta pixel. The temperature curve is sampled and acquired to determine both the pixel address and the energy value with unprecedented accuracy. The main advantages of this technique with regard to TES design from Godard Space Flight Center (USA) or SRON (The Netherlands) competitors in this field, is to allow collective fabrication of the sensor (no need to install manually each individual pixels), to take advantage of multiplexing in the time domain instead of frequency domain and to guarantee a uniform response of an unprecedented large number of pixels. Moreover, the system is buttable on 2 sides to build up to 4 cm^2 focal plane. The main drawback comes from the fact that it is almost impossible to come up with spectrometry results until the program is over.

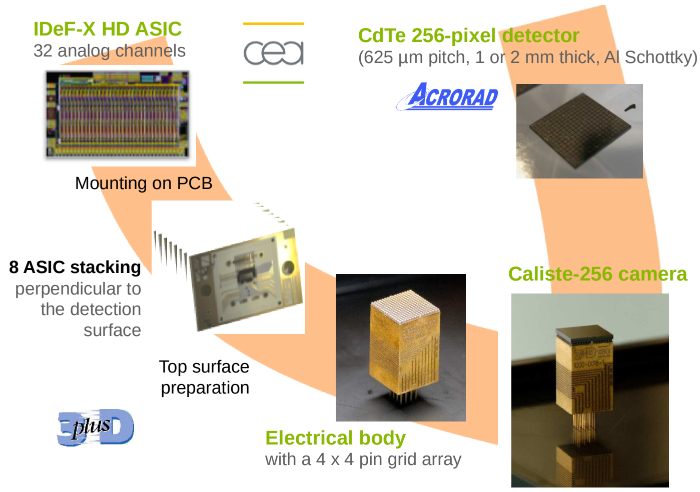
During the contract, LSIS successfully led a large scientific collaboration involving CEA/Léti, CEA/PTA, CNRS/CSNSM, IAS, UNIPA Palermo, LPN, Irfu/Sédi. The team realized a set of building blocks solving many challenging interface problems due to the fact that 2048 wires are brought out of the focal plane, eventually breaking the thermal insulation. First we built an ultra low temperature test bench to characterize materials, assemblies and electronics prototypes. The team also prototyped each part of the puzzle: Tantalum absorbers and their hybridization process, low impedance MIS thermometers, ultra low noise HEMPT amplifiers, ultra low power cryogenic multiplexing ASIC. The most recent achievement of this research activity is an innovative technology (patent pending) for bringing the signals through thermally insulated links using superconducting multilayer mirrors (see bottom right figure). This result is a major step forward for the integration of the focal plane array with the cryo-electronics around.



The micro-calorimeter team is funded by CEA, CNES and FP7 framework program CESAR. It also has the support of P2IO LabEx. Most significant results have been published in 7 peer-reviewed journal papers or peer-reviewed proceedings articles and two proceedings [LSIS-ACL24-30, LSIS-ASCL9-10, LSIS-BRE3-4]. The team produced heavy sets of documentation for ESA/ATHENA former IXO for the assessment studies, proposing this technology to the community for future missions. Team leaders were members of the IXO and ATHENA International Working Groups.

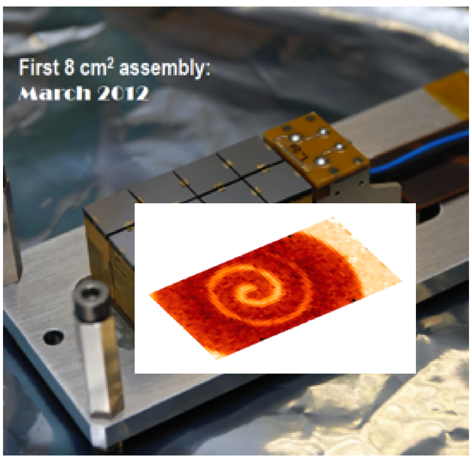
b. CdTe based imaging spectrometers – 3D hybrids

Early 2007, LSIS reached a high enough maturity on CdTe based imaging spectrometers R&T program, to start the fabrication of real prototypes; basic research on materials, building block, front-end micro-electronics were ready; feasibility of a 64 pixels, 1 mm pitch hybrid has been demonstrated. Consequently, the goal of the 2007-2012 period of time was to develop, realize, characterize and qualify a set of CdTe pixel hybrids prototypes, namely Caliste and to pursue the development towards higher pixel density, lower power consumption and assembly into a prototype of focal plane called MACSI (Modular Assembly of Caliste Spectro Imager).



As good quality CdTe single crystals are limited in volume while at the same time, focal plane demand for hard X-ray astronomy is pretty large (up to 64 cm^2), we invented a new concept of pixelated CdTe hybrid, buttable on 4 sides enabling the assembly of a mosaic focal plane of any size and any shape. To do so, LSIS developed together with a French private company, 3D plus, a technology to stack readout front-end ASICs (IDeF-X chips) and install them perpendicularly to the detection surface (see figure on the left). Apart the uniformity of the imager, it also enables excellent spectral performances and good yield of fabrication, which are the main advantages of this technology with regard to our main competitors Caltech (USA) who develops a CdZnTe on-chip device buttable on 2 sides and JAXA/ISAS (Japan) who develops a double-sided strip detector. Our technology is very flexible and allows fast design adaptation to fit any pixel size and shape from 500 µm up to 4 mm. This technology has been emphasized in various programs as Simbol-X (Fly in formation – Cnes) and IXO/HXI (ESA Cosmic Vision).

LSIS completed this R&T program in 2010 producing a 580 µm pitch imager called Caliste-256 and decided to go ahead manufacturing a MACSI prototype. It required designing the final and most advanced version of the hybrid: Caliste-HD. The latter has a high maturity level (TRL5) thanks to successful qualification tests, including radiation hardness evaluation in addition to its excellent spectral performances: ~750 eV fwhm at 60 keV. The team reached this final goal in 2012 showing up a spectacular 2048 pixel imager offering a 800 eV fwhm energy resolution at 60 keV. This technology is now ready to fly. After this successful R&T program, LSIS CdTe team ends with a complete product line enabling space applications.

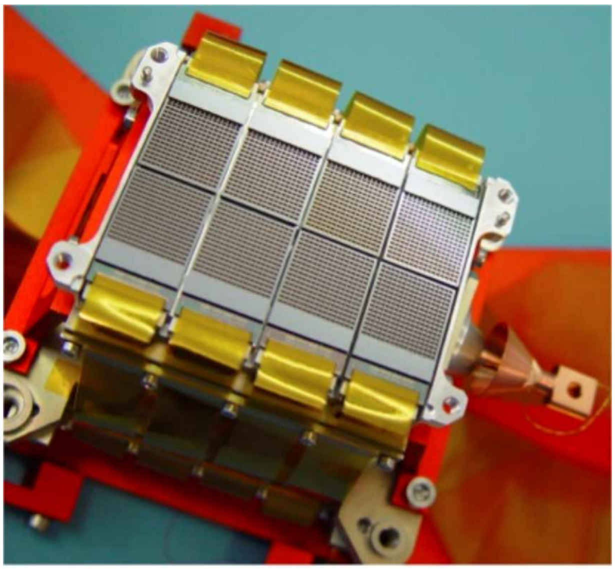


LSIS successfully joined the Solar Orbiter ESA mission to the sun, promoting Caliste-SO, a derived version of Caliste-HD that shall populate the focal plane of the STIX instrument, a hard X-ray imaging spectrometer to study solar flares. Caliste-SO passed Preliminary Design Review easily after only 6 months development. On the other hand, this R&T work gave us the opportunity to set new prestigious international collaborations with JAXA/ISAS for ASTRO-H mission where we contribute to the radiation damage analysis on CdTe based systems, and with UC Berkeley/Space Science Lab where we procure IDeF-X ASICs to be used with LBNL high performance Si diodes, for a supra-thermal energetic particle instrument to fly on CINEMA Trio nanosatellite program, summer 2012. Otherwise, another international collaboration with INFN Bologna, Universty of Coimbra and ESRF has been set for the science performance of CdTe pixel detectors as gamma ray polarimeters. Finally, we are involved in the LabEx UnivEarths together with APC for the development of a gamma camera based on strip Si detectors using IDeF-X chip.
Caliste CdTe pixel detectors are supported by Cnes and CEA/Irfu has funded MACSI.
We published our most important results in 23 Peer-Reviewed Journal papers or Peer-reviewed proceedings [LSIS-ACL1-23] and 8 proceedings papers [LSIS-ASCL1-8]. We patented some innovative technologies twice in the period of the contract [LSIS-BRE1-2]. In addition we contributed to document packages for phase 0, A and B in different space mission like SIMBOL-X, ECLAIRs, COSPIX, IXO, STIX, …Team leader is member of the ASTRO-H team, and contributed to IXO International Working Group.

c. Sub-millimeter range activities – Large arrays

LSIS sub-millimeter team has concluded in the period of the contract a major milestone, illustrating the most advanced stage of a detector development in our lab: tests, calibration and integration of the largest sub-mm bolometer array in space ever - the Herschel/PACS photometer instrument. PACS is an instrument suite containing 2560 bolometer pixels operated at 300 mK. The instrument is split in two focal planes tuned to be sensitive in three bands from 60 microns to 210 microns wavelength. The pixel pitch of 750 microns is small enough to produce diffraction-limited images, and the sensitivity enables almost background-limited observations in the 3 bands. The instrument has been launched in 2009 and performs very well since that time.

To develop the bolometers, we have used technologies on the edge of innovation from CEA/Léti, like silicon micromachining (deep etching of crystalline silicon to produce ultra-thin membranes for high sensitivity and low susceptibility to cosmic rays), low temperature CMOS multiplexing circuits, resonant absorption cavity and indium bump hybridization techniques. Traditionally, each individual bolometer was assembled by hand in the focal plane, resulting in a natural limitation in size and performances. The new way of assembling bolometers developed in our group is a breakthrough in the field, enabling building large focal planes. Our design shows a high yield, good performance uniformity over the array and very high quality image sampling.



The success of this development has paved the way to other ambitious instruments like the PILOT balloon-borne experiment for the measurement of the polarization of the interstellar medium (first flight in 2013), and the ARTEMIS camera at the APEX telescope in Chile (commissioning due during the first half of 2013). ARTEMIS is a camera that will operate simultaneously in 3 bands (200, 350 and 450 microns) with a large field of view (5800 pixels in total). Its performances will be limited by atmospheric fluctuations. ARTEMIS is unique. This camera is the only ground-based instrument working in the 200 microns atmospheric band. It will be complementary to Herschel observations (better spatial resolution) and to ALMA (better mapping speed).

The bolometer development has been supported by CNES and the ARTEMIS project has benefited from an ANR grant started in 2006. In parallel to the detector development, our group has started the development of high performance cryogenic electronics through a FP7 grant (collaborative project CESAR), started in 2010.

We published our most important results in 11 Peer-Reviewed Journal papers or Peer-reviewed proceedings [LSIS-ACL31-42] and 3 proceedings papers [LSIS-ASCL11-13]. In addition we contributed to document package for phase 0, A and B in different space mission like PILOT, ARTEMIS and SPICA.

d. Infrared semiconductor detectors

Infrared activity joined the lab in 2012 after successful completion of the MIRIM project, a Mid Infrared Imager to be flown on JWST in 2018. This development project gave AIM a world-class visibility in this field of IR detector characterization and space technology program development.

This activity is directly inherited from several major past contributions to the field like ISO or VISIR. Prospecting future European technologies in this field, the R&T activity has been therefore recently reinforced at LSIS with new

fundings opportunities from ESA and CNES. This activity is in the landscape for LSIS future, in collaboration with other AIM labs, LISIS in particular and CEA/Léti. Most of outputs in this activity were not performed in LSIS during the reference period, but recently attached to the lab. Main results were published in reviewed proceedings [LSIS-ACL-43-52]. Principal documents out of this activity were contribution to the Euclid Phase 0 doc package and response to ESA Invitation To Tender.
Recently, ESA has initiated a number of R&T program to support the development IR detectors in Europe for present and future astrophysics an Earth observation missions where challenging low dark current, high quantum efficiency, good operability, low intrinsic noise are required in large format sensors. These last two years, CEA has won two ITTs such as Near IR at 2.1 µm and MidIR and 12 µm, where our main contribution is related to our expertise on detector characterization at very low flux level (dark current, linearity, responsitivity, noise measurement). These projects are essentially oriented to push the French IR Mercuric Cadmium Telluride technology (MCT) to its ultimate performances. Our partners are CEA/Léti and Sofradir. On a p/n MCT photodiode technology, we demonstrated a 0.06 el/sec dark current level for a 384 x288 pixel hybridized MCT, cutting at 2.1 µm [LSIS-ACL-46].

CNES is also funding a R&T program at CEA to characterize NIR detectors at high temperatures, with the aim of reducing as much as possible the complexity of the thermal/cooling system of the focal planes.

All these ESA and CNES programs are tied together in the global exploration of the 2D space parameters of wavelength range and operating temperature of MCT detectors.

e. LSIS contributions, communications, training, committees, jury,

Besides R&T, technical realization and associated documentation, LSIS plays its role of knowledge spreading by training PhD students, apprentices or young engineers and technicians. In addition, LSIS member occasionally give lectures (124 hours mostly at M2 level).

Every year, since 2002, we are involved in “Project initiation” training activities given to thesis level students.
LSIS staff have published 79 articles including 31 published in peer review journals, 33 published in peer reviewed proceedings, 15 published in a conference proceedings, 2 books contributions, 8 grand-public papers, 4 patents. Contributing to publication in the field of instrumentation, LSIS researchers have been solicited 110 times for peer review (in IEEE TNS, NIM-A, A&A, Experimental Astronomy, ApJ, Radiation Measurement and Journal of Low temperatures). LSIS was guest editor for 85 of these papers (NIM-A and Journal of Low Temperature).

At international conferences, our staff presented 18 posters [LSIS-C-AFF1-18] and 14 talks [LSIS-C-ACTI1-14] in addition to 25 communications in important international meeting or workshops [LSIS-C-COM1-25].
Communication is also directed to the wide public and LSIS contributed to the 2009 World Year of Astronomy by exhibition, seminars and grand-public articles [LSIS-PV1-9].

LSIS members have participated to the organization of six conferences or colloquium (NDIP08 – exhibition chairman, 219 pers. international; NDIP11, conference co-chair – 219 pers., international; LTD12, Local organizing Committee, 250 pers., international; DRTBT, Local Organizing committee, 50 pers. National, R&T Insu Grenoble-2011, Scientific committee (100 pers); national, Astrophysics Detector Workshop Scientific committee 2008 Nice (120 pers); …).

Staff

LSIS has been created in 2010 from the Space Detector Lab, having the same people, management and missions. The size of the crew grew up from 13.5 FTE up to 18.5 people from 2007 to 2012. The number of permanent staff grew from 9 to 13 along the contract. In 2007, the crew was: 13.5 FTE, 10 permanent people, 3.5 researchers, 4 technicians, 4 engineers or other, 2 PhD students or postdocs. In 2012, the crew is: 18,5 FTE, 13 permanent people, 6.5 Researchers, 3 technicians, 4.5 engineers or other, 4.5 PhD students or postdocs.

1 permanent technician quitted after spending 36 months in the lab, 3 apprentices quitted after spending 54 months in total, 2 PhD students ended after 60 months in total in the contract and one postdoc spent 24 months with us.
In the same period of time, 1 new apprentice, 3 PhD students, 2 postdocs joined us. Two researchers were hired (one from another lab of the entity and one from a previous non-permanent position in our lab, working in the same field. In addition, 1 non-permanent position engineer has been hired.

Instrumental Projects

1. Instrumental Realisation

Delivery of the imager of the JWST-MIRI instrument

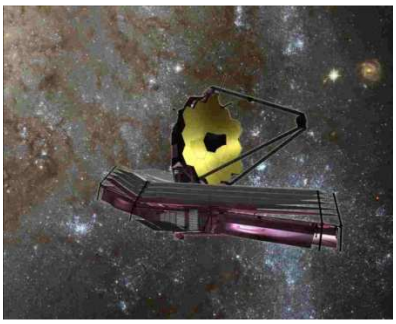
The JWST is the next flagship mission of NASA. With a telescope of 6.5 meters working in the infrared, the JWST is the successor of both the HST and Spitzer. Four main themes have been identified: the End of the Dark Ages: First Light and Reionization; Assembly of Galaxies; the Birth of Stars and Protoplanetary Systems; Planetary Systems and the Origins of Life. Three main instruments will be positioned at its focus:

- NIRCAM, a camera for the near infrared (1–5 micrometers), designed, and constructed in the US;
- NIRSPEC, a spectrometer dedicated to the near infrared, designed, and constructed by European manufacturers, under project leadership, and with funding, from the ESA;
- MIRI, an imaging spectrometer for the mid-infrared (5–27 micrometers), designed, and constructed by a collaboration, one half being accounted for by the US (Jet Propulsion Laboratory/NASA), the other half by a consortium of European space laboratories, from 10 countries (by decreasing rank, in terms of funds contributed: the United Kingdom, France, Belgium, the Netherlands, Germany, Spain, Switzerland, Sweden, Denmark, Ireland), led by the UK's Royal Observatory, Edinburgh (ROE), and funded by the respective national agencies.

Given our technical expertise in mid-InfraRed (ISO-ISOCAM, VLT-VISIR) and our scientific interest to further develop our fields of expertise (galaxy evolution, star formation), but also to open new themes, in particular exoplanets, we have started to work on preliminaries studies of a mid-IR instrument for the JWST as soon as 1998. It should be pointed out that, at that time, the JWST program had made no provisions for a dedicated instrument for mid-infrared observations. We were only a small number of US and European astrophysicists advocating for the presence of such an instrument, in the proposed space telescope. We have succeeded in having such an instrument on board of the JWST. Being in the initial discussions, we were able to have a "place de choix": the scientific and technical leadership for the realization of the MIRI imager, which features 3 observing modes: imaging, coronagraphy and low resolution spectroscopy. We have involved three other French space laboratories in the project – namely, LESIA at the Paris–Meudon Observatory (coronagraphy), IAS at Orsay (star simulator optics; tests), LAM at Marseille (test facility) et have made the CNES accepting to fund the project.

During the 2007-mid 2012 period, we have led the realization of the flight model of the camera, fully tested it at Saclay, participated in the testing at the Rutherford Appelton Laboratory (UK) and of course in data analysis. We have also started to discuss the scientific programs which will be conducted in the framework of the Guaranteed Time Observations attributed to instrument builders (900 hours shared 50-50 between Europe and US). We are chairing the large program of exoplanet characterization (150 hours) and we are responsible for the observation of SN1987A. We are also preparing a French expertise data center.

After some trouble at the level of the JWST project (cost increase, delays), the project is again on track with a 2018 launch date, five years later than expected in the 2007 prospective report. Such a delay is not a real issue in terms of science; science objectives of MIRI are unique and we have a lot to do otherwise in terms of scientific exploitation. The delay could be an issue in terms of keeping expertise. Given the hiring of Patrice Bouchet at CEA and the permanent position of coronagraph specialists at Meudon, we are confident that the expertise will be kept.



Artist view of the JWST, the successor of both Hubble and Spitzer, a NASA led mission to be launched in 2018.

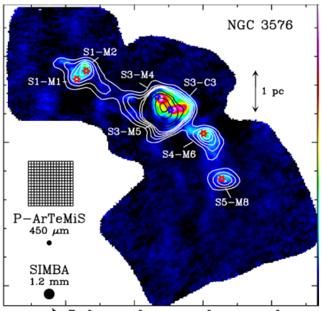
The imager of MIRI being integrated and checked in the AIM clean room at Saclay.

View of the Saclay test bench used to fully test the imager.

Development of the ArTeMiS large field submm camera for APEX

About 8 years ago, we analyzed that, on the one hand, there was a great scientific potential for a large field camera on the 12m APEX antenna observing in the 350 and 450 micrometers atmospheric windows (beating the Herschel angular resolution and then the sensitivity because the Herschel sensitivity is confusion limited), and that, on the other hand, the novel bolometer arrays developed for Herschel by Léti could, via minor changes, be adapted for ground-based observations. That is the reason why, in 2005, we applied for funding by the newly created French National Research Agency, and successfully obtained funding at the level of 700k€, one of the highest amounts distributed at that time. We managed to get the rest of the funding from CEA (which would no longer be possible today, given the budget restrictions at the level of French Research organisms; see Funding Section). In 2007 and 2010, we have demonstrated on sky the feasibility of the project and started to produce science with a prototype of ArTeMiS (see Figure below). The development of ArTeMiS was more difficult than anticipated, especially in terms of developing the bolometer arrays at Léti, the Silicon laboratory of CEA; one of the reasons being the change in technology from the 100 mm wafer platform to the 200 mm one. All pieces, except arrays, are being integrated at Saclay and the commissioning on sky is scheduled in March-April 2013.

The 12m APEX Antenna, in the Chajnantor plateau at an altitude of 5000 m.



Observation of a star-forming region with the prototype of ArTeMiS: the P-ArTeMiS mounted on APEX.

The ArTeMiS cryostat, conceived and realized at CEA Inac-SBT during its reception test at Saclay.

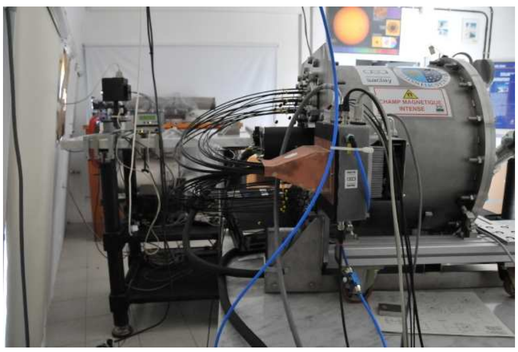
Development of the CAMISTIC camera for Antarctica

We have also designed and realized a full submillimetric camera named Camistic with its thermalized electronics to be operated at Concordia in Dome-C, Antarctica. It will be mounted on the Italian IRAIT 80 cm telescope in December 2012 and will be run during the 2013 winter period in the Southern hemisphere.

Development of the GolfNG instrument for helioseismology

We have prepared the successor of GOLF/SoHO, through the building under the scientific leadership of S. Turck-Chieze (AIM) and the technical management by P.-H. Carton (Irfu/SEDI), of the GOLF-NG (Global Oscillations at Low Frequencies - New Generation) prototype. The tests done have shown the ability of such an instrument to measure properly the time variation of the Doppler velocity on at least 6 heights in the atmosphere, which aims at eliminating part of the granulation noise and measuring quicker the small amplitude of gravity modes (Turck-Chieze et al. *J. Phys.: Conf. Ser.* **271** 012044 2011).

Testing the Antarctica CONCORDIA site in the sub-mm with CAMISTIC



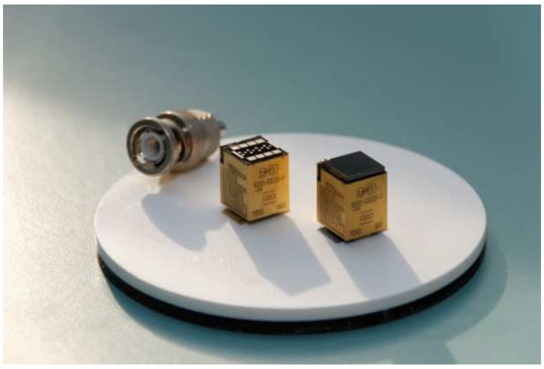
The GolfNG instrument

Solar Orbiter / STIX (M1-ESA mission)

Solar Orbiter is the first Medium class mission selected by ESA for its Cosmic Vision program. Its main goal is to explore the Sun-Heliosphere connection. Its originality lies on the proximity, i.e. 0.28 AU of the Sun, and up to 34° above the ecliptic hence providing an unique view point of the Sun and its heliosphere. The Scientific contribution of AIM is to develop 3-D models of particle acceleration in realistic magnetic field configurations deduced from numerical simulations of flux emergence. This is part of a scientific collaboration with N. Vilmer (Co-I of the STIX instrument), head of the solar pole at LESIA and A.S. Brun, head of AIM/LDEE, for which CNES has provided a 2-year postdoc and travel funds.

The payload is made of both in-situ and remote sensing instruments for an overall total of 10 experiments. AIM is involved directly in the SO/STIX (Spectrometer/Telescope for Imaging X-rays). STIX will provide imaging spectroscopy of solar thermal and non-thermal X-ray emission from ~4 to 150 keV mostly associated to flares and/or microflares. It will do so by giving information on the timing, location, intensity and spectra of accelerated electrons and of high temperature thermal plasmas. STIX is based on a Fourier-transform imaging technique similar to that of RHESSI.

The hardware contribution of AIM is to deliver the detection units of the STIX spectrometer focal plane. It consists of 32 Caliste-SO devices, the latest version of Caliste product line, a space qualified technology for CdTe based sensors inherited from AIM/LSIS R&T efforts. Caliste-SO is a hybrid, low weight, low power and radiation hard pixelated spectrometer operating in the hard X-ray range from 4 keV to 200 keV with 1 keV spectral resolution at 14 keV. Its mature technology was an essential contribution to the successful completion of the STIX Phase B in 2012.



The Picture illustrates the Caliste-SO spectrometer first prototypes – the left device has no sensor on top and unique STIX electrode pattern is visible – the right device is equipped with its CdTe sensor and ready for integration into the focal plane.

2. Assessment and Definition phases

The Euclid M2-ESA mission

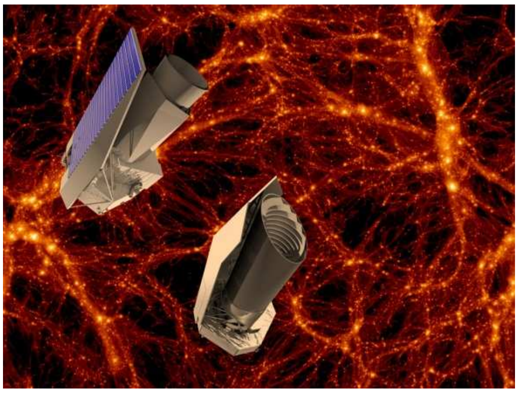
Euclid is an ESA medium class mission selected for launch in 2020 in the Cosmic Vision 2015-2025 program. The main goal of Euclid is to understand the origin of the accelerating expansion of the Universe. To achieve this, it is proposed to build a satellite equipped with a 1.2 m telescope and two imaging and spectroscopic instruments working in the visible and near-infrared wavelength domains. These instruments will explore the expansion history of the Universe and the evolution of cosmic structures with look back in time by measuring shapes and red-shifts of galaxies as well as the distribution of clusters of galaxies as function of redshift over a very large fraction of the sky. The satellite will be launched by a Soyuz ST-2.1B rocket and transferred to the L2 Lagrange point for a 6 years mission.

In 2002, following an international call for job and candidates interviews, we have hired Alexandre Réfrégier to participate in the scientific exploitation of MEGACAM, the large field (1 square degree) camera built by Irfu-SEDI under scientific management from AIM and just delivered to CFHT. Alexandre Réfrégier is a specialist of cosmology and was interested in constraining dark energy via the weak lensing technique, which was one of the MEGACAM large programs. One of his motivations to come at AIM was its space technical expertise.

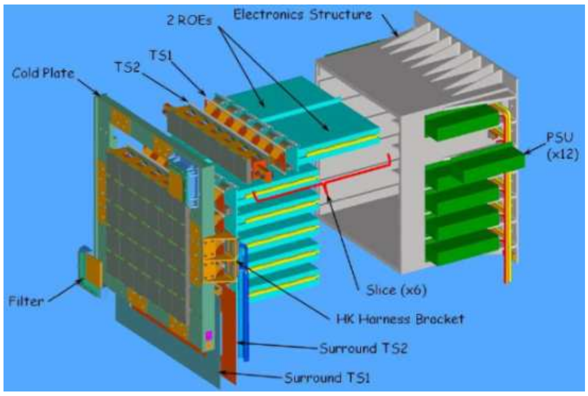
In 2004 he answered to the call for ideas from ESA, proposing a Dark Energy mission as a *Theme* to ESA's Cosmic Vision program. In June 2007, DUNE (Dark UNiverse Explorer) was proposed to ESA's Cosmic Vision program as M-class mission (with about 50 other proposals). In Oct 2007, the DUNE and SPACE concepts were jointly selected for an ESA Assessment Phase (among 5 selected). In May 2008, the Euclid mission has been validated by the ESA AWG as a merged mission between DUNE and SPACE. After an assessment study phase from Sept 2008 to Sept 2009, Euclid has been definitely selected for a definition study phase in Feb. 2010.

The merging of the IR spectrometer and the IR photometer, meant merging the two consortia; this was done and A. Réfrégier took the leadership of the merged consortium and lead the answer to the call for the definition phase.
This was difficult and in the middle of the study, he left, having been proposed a position at Eth Zurich. Since then, Y. Mellier from IAP, Paris, has been accepted as the new leading scientist of the Euclid mission. Y. Mellier has been partly affiliated to CEA to achieve these objectives. In October 2011, the Euclid mission has been selected as the second M-class Cosmic vision, this program been fully adopted by ESA in June 2012.

We are presently actively involved at the Euclid Consortium level (Coordination and Management support, Mission System lead, Ground segment scientist lead) together with key hardware responsibilities for the Visible (VIS) namely and for the Infrared (NISP) instruments, as well in the Science Ground Segment. The CEA contribution to the VIS instrument consists in the delivery of the Focal Plane Area (36 CCD, totalizing ~500 000 000 pixels) and the instrument's Power and Mechanism Control Unit. The CEA contribution to the NISP instrument consists in the delivery of two cryo-mechanisms, that will rotate the filter wheel and the grism wheel, with extremely high accuracy and in cold temperature. As for the Science Ground Segment, we have concentrated our efforts along the data-processing steps associated with the weak-lensing analysis. We participate in the development of instrument simulation for the VIS instrument, in the shape-measurement data challenges, and the algorithmic developments for the high-level science data products. We are also co-leading the cosmological simulations needed for Euclid.



Two concepts for EUCLID Satellite - © ESA



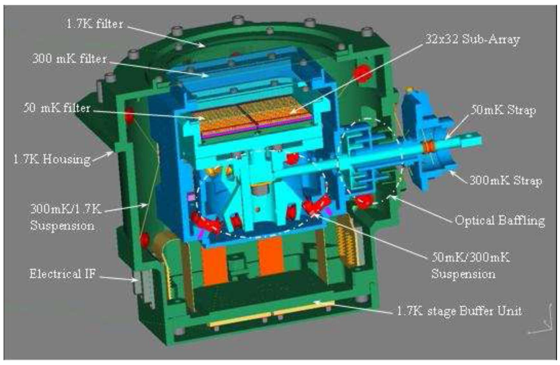
Conceptual view of the Euclid VIS Focal Plane Assembly (CEA responsibility)

The SPICA JAXA/ESA mission

SPICA, a space infrared telescope proposed to be launched in 2018 by the JAXA with a participation of ESA, is expected to reveal the origins of the planets and galaxies with its unprecedented infrared sensitivity. The SPICA telescope will be cooled below 6K. SPICA employs a completely new cooling system which utilizes effective mechanical cryocoolers. This technology enables large cooled telescopes in space and allows reducing the self-emitted infrared radiation by a factor of 1 million, then achieving much higher sensitivities. The high sensitivity of SPICA will enable photometric surveys beyond z ~4 that will resolve more than 90% of the Cosmic Infrared Background. SPICA will also observe Milky Way type galaxies in the far infrared out to z ~1, where the Star Formation Rate peaks.

We have participated in the assessment phase of the focal plane of SAFARI, one of the 4 instruments planned for SPICA. SAFARI is an imaging Fourier Transform Spectrometer designed to provide continuous coverage in photometry and spectroscopy from 34 to 210 µm, with a field of view of 2’ × 2’. The picture on the right shows the proposed design of the detector focal plane submitted in 2009.

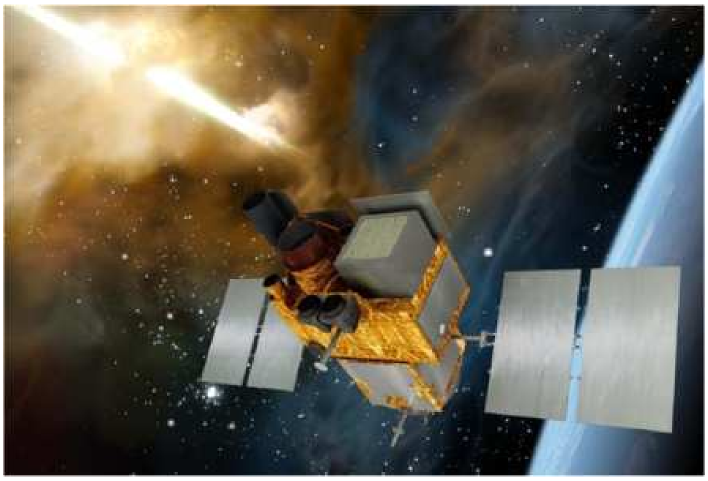
The ESA consortium chose a different detector technology which makes this proposal apart for the moment. We have pushed forward this detector alternative in the frame of our R&T programs. In parallel, we are in charge at the consortium level, of the electric architecture of the telescope cryocoolers.



Mechanical and thermal architecture of the 50 mK focal plane of SAFARI

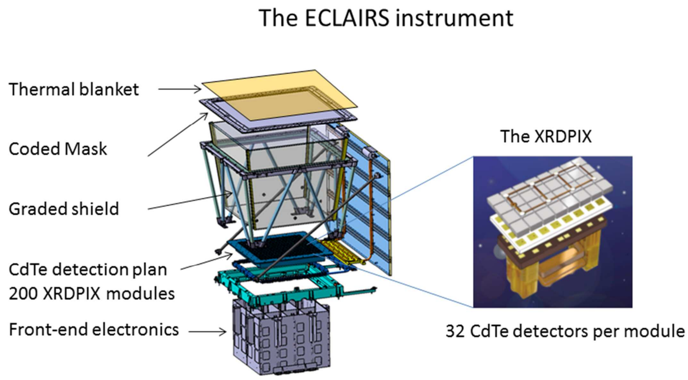
The French-Chinese SVOM mission

CNES contributes to ESA projects but has also the possibility to conduct bilateral collaborations. The Space based Variable Objects Monitor (SVOM) is the first Sino-French scientific space mission (developed with CNES, CAS and CNSA). It aims at studying Gamma-Ray Bursts (GRB) and related astrophysical subjects such as relativistic jets, GRB progenitors, star formation rate in the early universe, cosmology through GRBs, origins of cosmic rays, etc.
While current GRB missions, such as Swift and INTEGRAL (sensitive above 15 keV), have studied a few GRBs at high redshift, the SVOM mission (sensitive above 4 keV) will be particularly suited to detect those most distant GRBs and X-ray rich GRBs, in addition to classical GRBs.

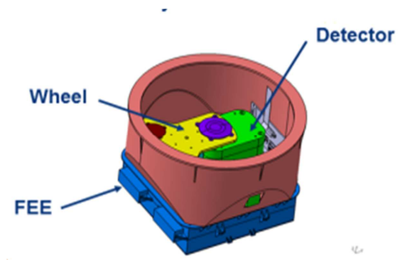


Artist view of the SVOM mission

SVOM will transmit in near real-time GRB localizations to robotic telescopes on ground and will permit an optimized follow-up thanks to its pointing strategy towards the night sky. SVOM will also observe the afterglow of GRBs in X-rays and visible band, which enhances their localization up to 1 arcsec for many GRBs. Onboard SVOM, the first detection and localization of a GRB is performed by the ECLAIRs instrument (developed by CEA Saclay/IRFU and AIM, IRAP Toulouse and APC Paris). ECLAIRs is an X/gamma-ray telescope with coded-mask imaging (in the 4-120 keV energy band) offering a large field-of-view (2 sr), coupled to an onboard Science and Trigger Unit (UTS, developed at CEA-Irfu) in charge of the real-time detection and localization of GRBs. A gamma-ray monitor without localization capability (GRM, by IHEP Beijing) expands the energy band to 5 MeV. A GRB localization by UTS initiates a spacecraft slew to place the event into the field of view of two narrow-field instruments: (a) the X-ray focusing telescope MXT (developed by CEA-Irfu and AIM, IRAP, LAM Marseille, University Leicester and MPE Garching) using micro-channel optics and a low noise CCD, and (b) the visible-band telescope VT (of NAOC Beijing and XIOPM Xi'an) sensitive to magnitude Mv=23. Ground based telescopes complement the SVOM mission: (a) two visible band ground follow-up telescopes (GFTs) and (b) a ground-based wide-angle camera (GWAC) for the search for visible prompt emission of a fraction of SVOM GRBs. The low-Earth orbit SVOM satellite will be operational after 2018.



Design of ECLAIRs



Design of the MXT camera

In addition to the scientific PI ship of the SVOM mission, AIM has the scientific responsibility of the two French instruments: the ECLAIRS telescope and the X-ray camera MXT.

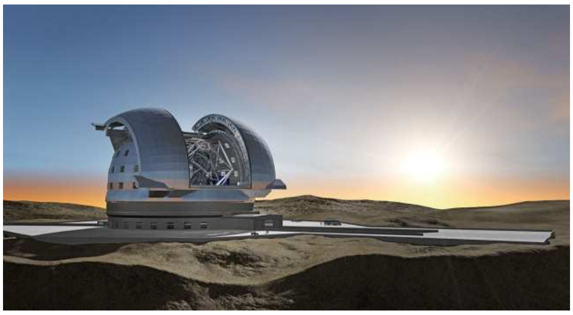
Note that CEA-IRFU is master of work of the ECLAIRs telescope and pilots a consortium of French laboratories. AIM is also master of the French center of scientific data.

The METIS instrument for ESO-ELT

The METIS instrument, working in the mid-IR, is in direct scientific and technical interest of the unit (ESO 3.6m-TIMMI; ISO/ISOCAM; VLT/VISIR; JWST/MIRI). The PI is B. Brandl from Leiden (Netherlands); we are "head of Nation" and have 2 members in the scientific team.

We have participated during the 2008-2009 period in the phase A studies of the ELT-METIS project, aiming at mounting a mid-infrared (3.5-13 µm) on the future E-ELT telescope. We are in charge of the cryomechanisms, calibration, long-wave coronography, and detectors testing workpackages.

The project's phase B (preliminary design) should start during year 2014 with a final design review end of 2017 and a delivery to Cerro Armazones in 2022-2023.

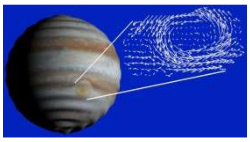


Artist view of the E-ELT 39 meters telescope

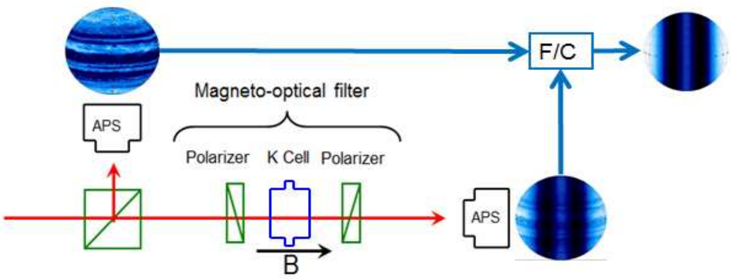
Novel cryomechanisms developed in the framework of the VLT/VISIR

The JUICE L1-ESA mission

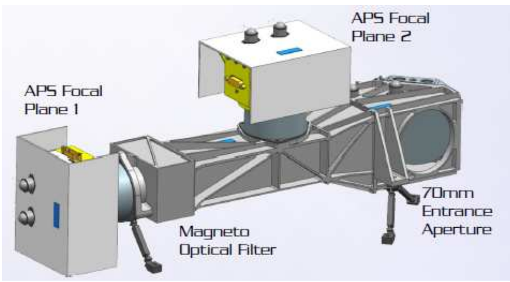
Selected in May 2012, JUICE is the first Large-class mission chosen as part of ESA's Cosmic Vision 2015-2025 program. It will be launched in 2022 from Europe's spaceport in Kourou, French Guiana, on an Ariane 5, arriving in the Jovian system in 2030 to spend at least three years making detailed observations of Jupiter and of its moons (Ganymède, Europa and Callisto). The two principal scientific objectives are the exploration of the potential emergence of habitable worlds around gas giants (under the icy crust of their natural satellites) and of the Jupiter system as an archetype for gas giants. For the second objective, the main goals are to characterize and to improve our understanding of the Jovian atmosphere, magnetosphere, ring systems, and interactions with the moons. Moreover, for each of this topics, a detailed understanding of the internal structure of Jupiter is needed that will give strong clues on the origin of the highly complex atmospheric dynamics and on the generation of the very strong magnetosphere. Furthermore, the knowledge of the deep internal structure, and more specifically, of the presence or not of a heavy elements core is crucial to understand the Jovian system formation and the tidal interactions between the planet and the moons. In this context, AIM collaborates to the proposal for the instrument ECHOES with a strong scientific implication of the LDEE laboratory.



ECHOES is an US led instrument (JPL) candidate for the JUICE payload with French deputy PI and leader of the Science team. ECHOES main objective is the characterization of Jupiter's atmospheric dynamics and deep internal structure. **AIM** foreseen contributions to ECHOES encompass Science (global seismology; modeling and simulation of the Jovian internal structure, atmospheric dynamics and of tidal and magnetic interactions in the Jovian system), Instrumentation and Ground segment.



ECHOES measurement principle.



ECHOES implementation.

The **ECHOES** Instrument *(Figure, right)* is designed to produce maps of line-of-sight velocity in Jupiter's troposphere. It is a Doppler Imager based on a magneto-optical filter to measure the Doppler shift in the Potassium absorption line of the reflected sunlight *(Figure, left)*.

The **AIM** laboratory instrumental contribution consists in the delivery of the 2 APS (Active Pixel Sensor) detector Focal Planes, these Focal Planes being based on HYDRA Star tracker heads manufactured by the SODERN Company. Moreover, AIM has key responsibilities in the management of the French hardware part of the project.

3. The future M3-ESA mission (contribution to PLATO, ECHO, LOFT projects)

We have been active in answering the ESA M3 call. Namely, we proposed hardware contributions to SPICES (Spectro-Polarimetric Imaging and Characterization of Exoplanetary Systems), NEAT (Nearby Earth Astrometric Telescope), CAPSITT (Compton Large Area Silicon Timing Tracker), COSPIX (a focussed hard-X ray telescope with an extensible optical bench), ECHO, PLATO and LOFT. We detail hereafter our contributions to the preselected mission to date.

PLATO

Plato (PLAnetary Transits and Oscillations of stars) is a proposed ESA medium-class M3 mission scheduled for a launch at the 2024 horizon as part of the Cosmic Vision program. The selection will be done in 2013 among the 5 candidates that were preselected in 2010. The main scientific objective is to understand the formation and evolution of planetary systems as a whole (planets + host stars) and how the conditions of life (as known on Earth) could develop. To do so, PLATO will observe 50% of the brightest stars in the sky down to magnitude 11, complementing the stellar parameters obtained by GAIA through asteroseismology. Two of the 38 telescopes will be operating with a fast camera allowing the study of a few thousands of stars between magnitudes 4 and 8.

AIM is in charge of the front-end electronics of these two cameras taking advantage of the synergies with other projects such as EUCLID, R&T ESA, as well as the reading electronics developed for SVOM/MXT. We expect to make the full integration (electronics + focal plane) of these FAST cameras.

On the software/pipeline side, our laboratory is responsible of two working packages of the PLATO Data Center (PDC): Ensemble FIT (to characterize the oscillation modes of stars on clusters), and the Rotation & Activity analysis Tools.

ECHO

Echo is one of the five ESA candidate M3 missions (selection end of 2013, launch 2022-2024). Echo is dedicated to the characterization of a large sample of exoplanets, through spectroscopic observations of their atmosphere.

The French laboratories involved in the project (LESIA, AIM, IAP, IAS) have decided to combine their effort and to take the responsibility of the mid-IR channel (MWIR) of the ECHO payload. AIM is responsible for the "Detection Assembly" of the MWIR channel. It includes 2 focal planes and a proximity electronic box. When the nominal detector arrays are Si:AS BIB American detectors, operated at 7K, we are developing an alternative based on HgCdTe detectors realized by the Léti at Grenoble, which have the great system advantage of working at 30-40 K. Funding has been obtained from CNES, Focus and ESA. The first results are encouraging.

LOFT

LOFT is one of the five ESA candidate M3 missions (selection end of 2013, launch 2022-2024). It is a mission dedicated to fast timing and spectral studies of compact objects, whose main goals are the study of matter in strong-field gravity conditions, i.e. the measure of black hole masses and spins, and the equation of state of ultra-dense matter, i.e. neutron stars. In addition, LOFT will provide real-time alerts for variable X-ray sources over a large fraction of the sky.

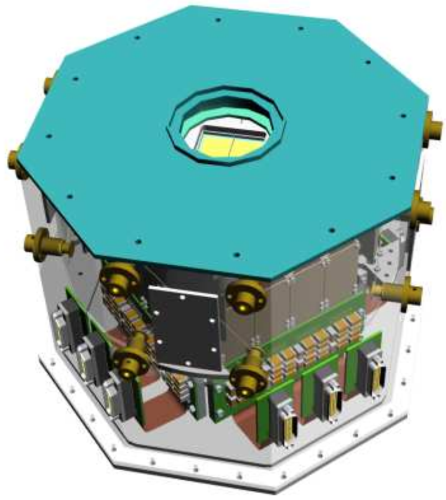
Irfu (SAp-AIM, SEDI, SIS) is involved in the transients real-time triggering system (LBAS for Loft Burst Alert System), providing its on-board firmware and software.

4. The future L2-ESA mission

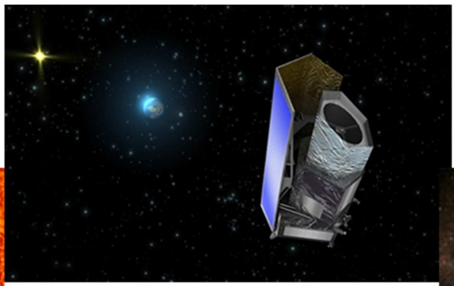
Athena is an X-ray observatory-class mission, developed from April to December 2011 as a result of the reformulation exercise for Large class mission proposals, requested by ESA in the framework of Cosmic Vision 2015-2025. The science case of Athena addresses the Universe of extremes, from Black Holes to Large-scale structure, to answer some of the most important questions envisaged for Astrophysics in the 2020's. The specific science goals are structured around three main pillars: “Black Holes and accretion physics”, “Cosmic feedback” and “Large-scale structure of the Universe”. Underpinning these pillars, the study of hot astrophysical plasmas offered by Athena broadens its scope to virtually all corners of Astronomy. The revolutionary instrument onboard Athena is the X-ray Microcalorimeter Spectrometer (XMS), a cryogenic instrument based on superconducting sensors, offering a spectral resolution of 3 eV over a field of view of 2.3’ × 2.3’. With a spatial resolution better than 10”, the XMS will provide the highest capability for spatially resolved high spectral resolution spectroscopy.

Complete System Study of a camera based on 4 quadrants composed by a 32x32 microcalorimeters array each with its associated Front-End Electronics has been performed by AIM staff. Such a system, inheriting from the Herschel PACS design, has been optimized for Thermal Load reduction, compactness and weight. This system could be an alternative to the official TES based XMS camera onboard Athena.

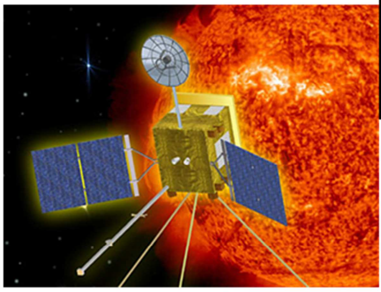
At its meeting on May 2, 2012, ESA's Science Programme Committee decided not to select Athena as the L1 mission for Cosmic Vision 2015-2025. It however decided to continue with technological developments that will further enhance the scientific performance of the Athena payload. Both the science goals and the concept of Athena, developed as a true X-ray observatory-class mission, remain very valid and confort the basis of the next proposal to ESA as a flagship L2 mission for the benefit of Astrophysics at large.



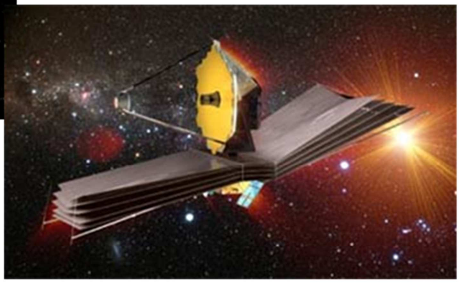
MIS Detector system for XMS



EUCLID
VIS focal plane
Ground segment



Solar Orbiter
Participation in STIX
(Caliste)



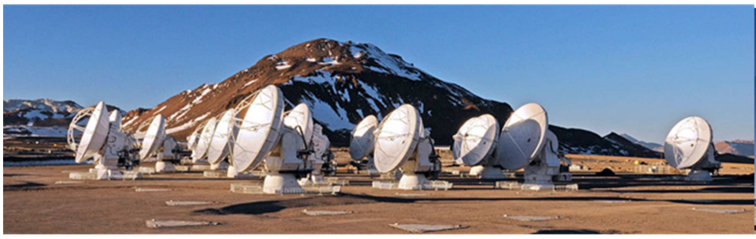
JWST
MIRI

Second PART Project

JUICE
Participation in ECHOES
(if selected)

Pilot
Providing focal plane

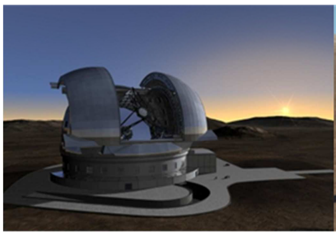
Massively parallel computers
Scientific exploitation



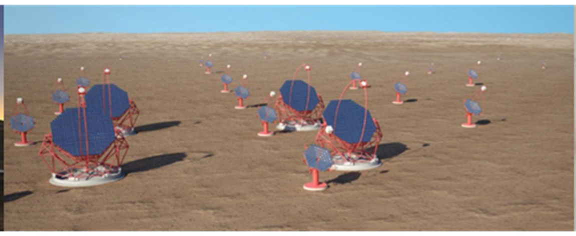
ALMA
Scientific exploitation

APEX
Providing ArTéMiS

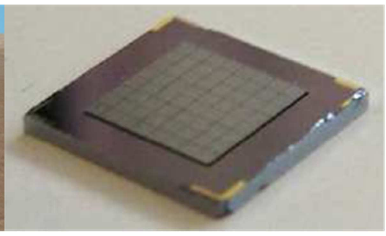
IRAM
Participation in NIKA
(polarimetry)



E-ELT
Participation in METIS



CTA
Participation ground segment

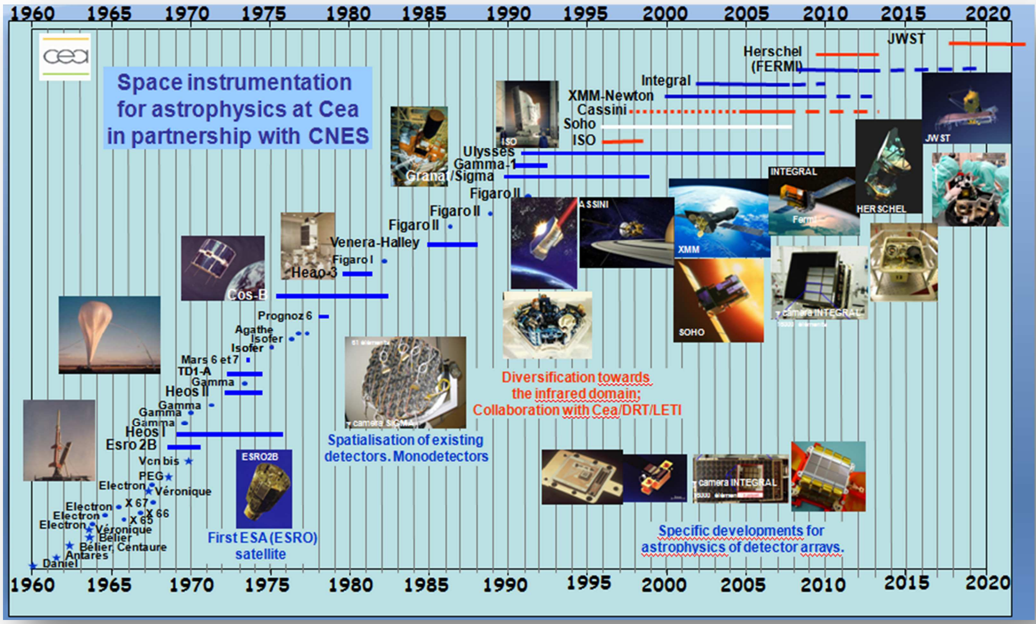


Novel detectors
Detector characterisation platform

A. Introduction

1. Historical background

AIM benefits from the long tradition of space projects at SAp (the CEA's Astrophysics Department) (see Figure below).



Since the early 60's, SAp/AIM has been participating in most of the major astrophysics space missions.

The presence of astrophysics within the CEA has always benefited astrophysics and has been beneficial to CEA. Research in astrophysics at CEA began in the 1960s and built upon the wide experience in X-ray and γ-ray detectors and instrumentation. At the same time, space studies were starting to develop with the foundation of CNES in 1961. Since X and γ radiations from space are absorbed by the atmosphere, it was natural to combine the expertise of the CEA and CNES to develop high-energy astrophysics. Thus SAp became one of the first French space laboratories dedicated to astronomy and, in partnership with CNES, it went on participating in most of the major astronomy projects investigating cosmic radiation (HEAO, Ulysses), γ radiation (Cos-B, Sigma, Integral) and X rays (XMM).

Since the 1980s, the CEA has diversified and developed a high-technology center. Astrophysics is a driver of technological developments ripe for industrial use because its instruments require exceptionally high performances in order to observe the faintest objects in the Universe. Astrophysics also required new observing windows across the electromagnetic spectrum. SAp kept up with these evolutions and diversified into a new sphere of excellence: the detection of infrared radiation, based on technological developments in detectors made at Léti, CEA Grenoble. SAp consequently took charge of the development of the ISOCAM camera on board the ISO satellite (1995 – 1998), and participated in the CIRS instrument for the Cassini mission (launch 1997, insertion into orbit around Saturn in 2004). Development at Léti of new types of detectors for astrophysical applications has continued with the production of bolometer arrays for the PACS instrument for the Herschel mission and, now, with the production of bolometers arrays for the APEX/ArTeMiS large-field camera and the development of near-InfraRed (IR) and mid-IR HgCdTe arrays in the context of the ECHO M3 mission candidate.

Until the end of 2001, SAp was organized into groups of engineers and researchers according to the wavelength being studied (X, γ, IR, etc.), plus a «theoretical» group and a space experiments group (GERES). At the start of 2002, SAp was reorganized into nine teams, five bringing physicists together around a science topic, and four space instrumentation teams – including a detection team combining physicists, engineers and technicians. This structure also took account of the fact that, since SAp became part of Irfu in 1992, it has worked with Irfu's technical services, particularly for ground-based projects. As a result, SAp and now AIM has been able to focus most of its technical activities on aspects specific to space. The potential of numerical simulations was fully recognized and a dedicated transverse program, the COAST program, was set up in 2005.

Since the late 70's, SAp has hosted CNRS researchers and since the 90's, research-lecturers from the Paris Diderot University. On 2005 January 1st, a joint research unit, AIM, supervised by CEA-Irfu[4], Paris-Diderot University and CNRS-INSU[5], has been created; at that time, only researchers were part of the unit. Following the only major recommendation of the AERES visiting committee in 2008, the engineers and technicians from SAp have now been included in AIM.

[4] Institute of Research into the Fundamental Laws of the Universe at the French Alternative Energies and Atomic Energy Commission
[5] National Institute for Earth Science and Astronomy of the French National Centre for Scientific Research

2. Characterization of the research

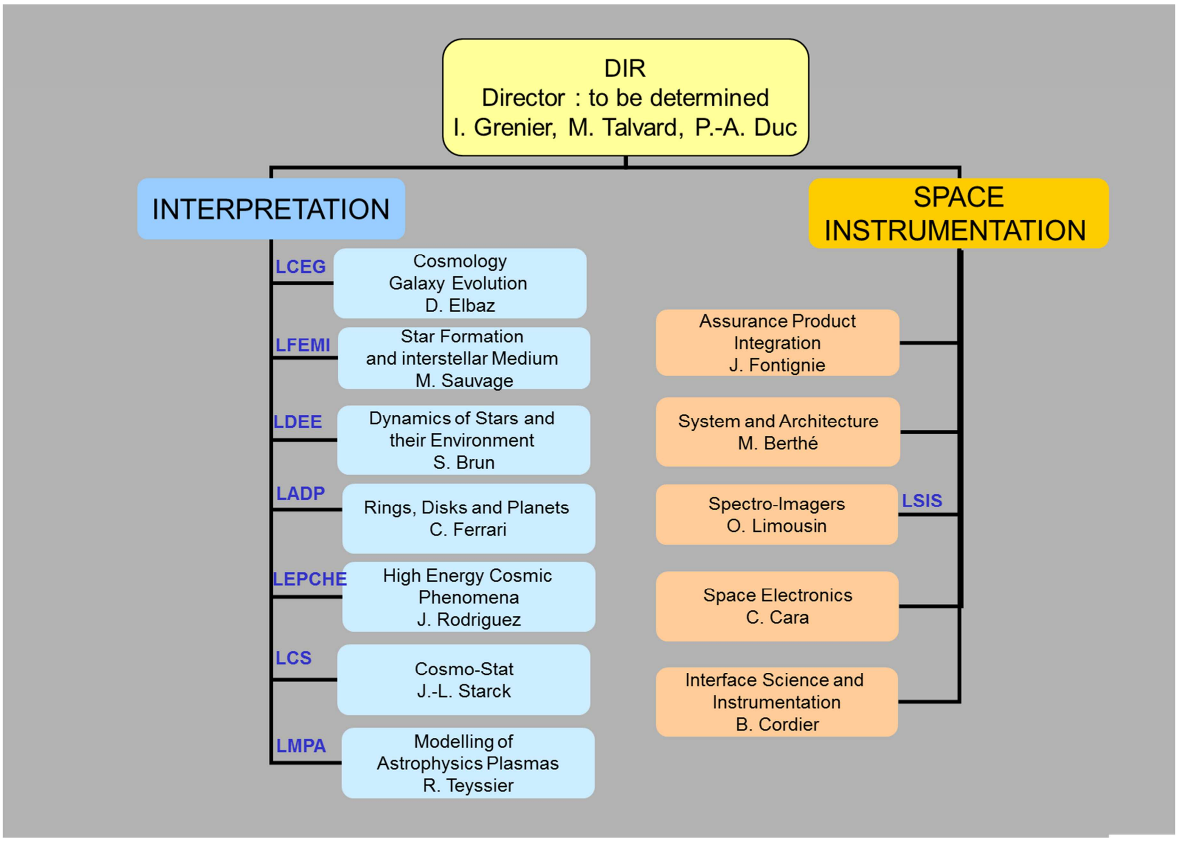
AIM is a fundamental research unit. The missions of the unit are twofold:

- first, to acquire new knowledge about the Universe and its constituents by :
  - o developing research programs in Astrophysics at the best international level,
  - o developing the state of the art instrumentation required for this research, mainly for space missions, but also for large ground-based telescopes;
- second, to disseminate new knowledge by training PhD students, lecturing, and making the results accessible to the general public.

Thus, the unit interacts, in a first place, with the research world and students, and, in a second place, with a large public to participate in the dissemination of the scientific culture.

3. Organization chart

Below is the organization chart. It is similar to that in the result report; the only change being the director. Indeed, after 12 years of directorship, the current director will step down and a new director will be appointed starting his job on January 1st, 2014. The deputy directors and technical director can provide continuity.



Organization chart

There is no need to change the present organization. Future adjustments will follow the needs, as done in the past, for example with the set-up of the CosmoStat team in 2009.

At the level of the unit, we will continue fostering many interactions between the teams (e.g., regular meetings, journal clubs). Particular attention will be given to transverse studies across teams. For instance:

- studies related to “dark energy” will strongly develop during the next period using galaxy clusters as a cosmological tool (LCEG team), developing signal processing for weak lensing (LCS) and cosmological numerical simulations (LMPA), designing, manufacturing, and testing the Euclid VIS focal plane (instrumental teams);
- comparative studies of the star formation rate in our galaxy and nearby galaxies (LFEMI and LMPA) with its history at low to high redshifts (LCEG);
- improving our understanding of the gas and dust tracers in the interstellar medium from observations, numerical simulations, and taking into account the role of cosmic-rays (LFEMI, LPCHE, and LMPA);
- studies of star and planets interactions (LDEE and LADP) and formation of planetary systems (LADP, LMPA).

B. SWOT analysis

1. Strengths

- The unit is present all along the chain of new knowledge acquisition and has developed synergies between the various activities. The size of the unit (200 staff, including PhD students and post-docs), the high capacity to raise funds and to attract young talented scientists or engineers, the numerous national and international partnerships, allow us to hold such an ambition.
- The unit has built an international leadership in several fields, such as galaxy clusters, galaxy evolution, star formation, Sun studies, microquasars, cosmic rays, statistical methods for cosmology, computational astrophysics, space spectro-imagers… and has a high profile in managing large observing programs or instrumental projects. This is well recognized by prizes, invitations to conferences, …. The publication rate is excellent with about 300 publications a year, including about 10 per year in Nature and Science.
- Covering a broad range of expertise in themes and wavelengths (from γ-rays to mm) is a definite advantage when there are increasingly longer delays between two projects in a given field or at a given wavelength (for example the launch of the SPICA mission is expected 10 years after the end of Herschel). We also have rare expertise, such as space radiation effects on detectors.
- The technical and scientific staff is very professional, experienced, and strongly motivated. It has demonstrated a strong reactivity that is essential to rapidly evaluate and answer to solicitations to participate in instrument or ground-segment proposals; (e.g. see our recent implication in the JUICE Echoes proposal with the NASA Jet Propulsion Laboratory and the Nice Observatory).
- The unit has a remarkable and reliable instrumental road map, with, in particular, two flagship space missions: the JWST, to be launched in 2018, and Euclid to be launched in 2020, and on ground–based telescopes: APEX-ARTEMIS to be fully operational in 2014 and E-ELT-METIS expected to operate in 2024.
- The unit is involved in three Laboratories of Excellence “LabEx” (FOCUS, UnivEarthS, P2IO).
- We have built a very good partnership with technical departments of Irfu that provide additional expertise (for example ASICS), with the Paris-Diderot University and the “Institut de Physique du Globe de Paris” (IPGP), with several national and international astrophysics laboratories.
- For the CEA staff, we can fully recognize the investment of scientists in the development of large codes or instruments because the career management is evaluated first at the level of the unit and because the career path at CEA is the same for scientists and engineers.
- A long tradition in popularizing science in France and abroad.
- A good connection with various Masters in astrophysics, physics, signal processing, numerical modelling; numerous lecturers (40).

2. Weaknesses

- In a few cases, there is a single expert in a field; (for example, following the recent departure of an architect in space instrumentation assembly, integration and tests, we have now a single one left, which will not be sufficient in the near future.
- There is a risk for the technical staff to be overloaded (for example if the SVOM mission eventually goes ahead); but given that space projects are selected after parallel competitive studies with a relatively low rate of success, we must take this risk to mitigate the even higher risk of being underloaded. In that respect, we benefit from the technical support of Irfu which brings flexibility in addition to their expertise.
- Strong dependence on the CNES funding, mitigated by our participation in ground-based projects (ESO E-ELT) and our recent contracts with ESA (detector development/characterization) or in the framework of the European FP7 (e.g. cryogenic electronics).
- Because in the past we have been able to develop novel detectors arrays (for ISO-ISOCAM, CASSINI-CIRS, INTEGRAL-IBIS and recently HERSCHEL-PACS) and because of the lack of funding for such costly developments out of an approved project, we have not been able to build a strong enough R&T and demonstrator program especially in the sub-mm (for example for SPICA/SAFARI). This is one of the reasons why we have co-lead the proposal for the FOCUS LabEx, which has been successful.
- With the strong growth and visibility of the “Observation/Signal-Processing/Interpretation/Modelling” activities in the unit (ERC grants, ANRs…), there is a mid-term risk to lose the good balance (for example in terms of hiring) between science activities linked to “Interpretation” and science activities directly linked to “instrumentation” (Instrument scientist, calibration scientist…) and a long term risk of a decoupling between the scientific exploitation of instruments built at home and other facilities.

3. Opportunities

- Onset of new observing facilities matching well the need for several of our research themes: APEX/ARTEMIS, ALMA, NOEMA in the sub-mm/mm, for the evolution of galaxies and star formation themes; LOFAR, MeerKAT, ASKAP, in the radio wavelength range for the accretion-ejection theme...
- Development of massively parallel computing facilities in the framework of GENCI and PRACE, collaboration with the “maison de la simulation”.
- CEA-Irfu hiring on a permanent position in the framework of ERC (3 years funded by ERC), which allows to hire in a tight funding situation and with few expected retirements (retirement age recently extended from 60 to 70 years old at CEA); this is also a way to alleviate the potential problems at the end of an ERC contract.

- Forthcoming ESA calls: second Large mission (L2), fourth medium size mission (M4), small missions (new concept), R&T.
- CNES call for ideas in the framework of the CNES prospective exercise.
- The creation of a department of Earth and Universe Sciences in the framework of the new Sorbonne-Paris-Cité University, with IPGP, AIM, and APC and with new opportunities to develop inter-disciplinary collaborations and teaching courses within a multidisciplinary university.
- Development of the Paris-Saclay Idex with new opportunities to develop collaborations, for example in the framework of space activities, with engineering schools, to benefit from new facilities (a large conference room, researcher and student apartments…) making the Saclay plateau even more attractive.

4. Threats

- Loss of the opportunity to hire new staff after the departure of key staff. High-profile astrophysicists or engineers may be presented with important responsibilities elsewhere (for example E. Audit has recently become director of the "maison de la simulation"; F. Mirabel was director of ESO Chile for several years). So far, we have been able to keep those positions; if it were no longer the case, we would have to substantially revise the strategy of the unit.
- Due to the large increase of post docs and students (+40 since January 2007), we have reached our limit in terms of office space; a short-term solution has been proposed with a set of "algeco" pre-fabricated buildings to be in place beginning of 2013. Alternative solutions for the long term should still be investigated.
- Further decrease in the recurrent funding (mainly CEA for us) will force us to apply to even more external sources and to spend even more time filling forms and proposals, at the significant expense of a potential decrease of our research productivity.
- Continuation of the ESA politics to maintain competition through the labor-intensive assessment and definition phase studies, as it was done for the M1, M2 missions. It seems that a reorientation is underway with the decision to select a single M3 mission at the end of 2013 for the definition phase study, and with discussions about a cornerstone approach for the L missions.
- The Technical Readiness Level now required by ESA at the end of the assessment and definition phase of an instrument is much higher than before. We would not have passed this level to get selected for the focal plane of ISO-ISOCAM, INTEGRAL-IBIS or HERSCHEL-PACS.
- Increase in the size of the consortia around space missions (more than 500 astrophysicists-cosmologists for Euclid), with the risk of making the discipline less attractive to young people and of increasing the organization burden in the consortium.
- Development of a "mercato" for astrophysicists.

C. Strategy and projects

1. Strategy

All along the chain of new knowledge

The strategy developped so far, i.e. to be present all along the chain of acquisition of new knowledge (detector R&T, space instrumentation, observations/interpretation, signal processing, modelisation) in a co-ordinated way and at the best international level, appears to be more relevant than ever.

Interplay between observations, signal processing and numerical simulations

The interplay between observations, signal processing and numerical simulations is becoming essential. As shown in the AIM report, surveys with various observatories now provide large databases which require sophisticated data mining and signal processing tools, especially in cosmology (see the project by the LCS team). We have well anticipated this evolution by creating the Cosmo-Stat team in 2009; a handful of similar teams have been created around the world. Thanks to the analysis of these large databases, the underlying laws describing the properties of the astrophysical objects can be discovered. Detailed numerical simulations are often needed to find the main physical mechanisms at work behind these laws; thanks to the GENCI agency in France and PRACE at the European level, we have access to internationally competitive massively parallel computers, which are regularly updated. Standalone numerical simulations are also very useful as they can pin point specific processes at work in given objects and then trigger new observations (for example the search for cold flows feeding galaxies). Note that numerical simulations generate a large amount of data that require, as for large observational datasets, dedicated analysis and visualisation tools. The forthcoming computational power increase will open new avenues to the astrophysical computing (see the project by the LMPA team).

When applying for observing time, it is a definite advantage to present a so-called "dream team", i.e. composed of specialists in observations/interpretation, signal proceessing, numerical simulations. This advantage will be of particular importance for us during the next period with the reduction of guaranteed time from space missions and our greater dependence on the success of observing proposals; the next guaranteed time observations are expected from the JWST in 2019. National and international collaborations are of course another way to combine expertises, and we have indeed developped numerous collaborations, but having the three types of activities within AIM is a definite advantage in terms of cross fertilization and to set up collaborations in full knowledge of facts.

Instrumentation: mastering the scientific performances

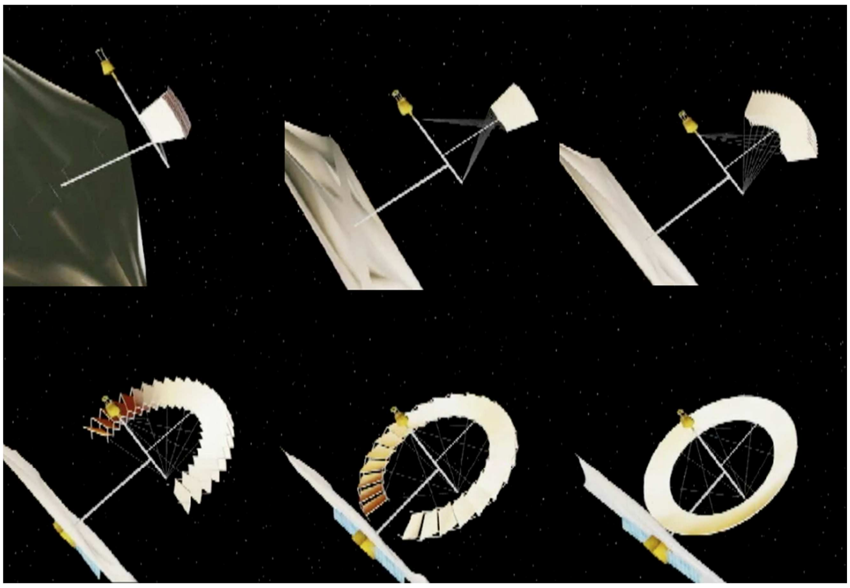
To achieve the scientific performances of future missions, the demand in terms of instrumental characterization and calibration in order to build performant data reduction pipelines will keep increasing, especially at the level of the detector focal plane. An example is given in Euclid, which requires an exquisite knowledge of the optical CCDs transfer function, response to cosmic rays, etc., in order to be able to measure faint changes in the ellipticity of the galaxies due to weak lensing effects. Another example is the 10^{-5} precision requirement to measure a photocenter in a future astrometric mission to detect Earth-like exoplanets around nearby Sun-like stars, such as the NEAT mission (F. Malbet et al. 2012).

The focal plane system is the part we concentrate our construction and characterization efforts on, for which we have the needed competence, and for which we take advantage of our links inside CEA, (ASICS expertise at Irfu/SEDI, collaboration with Léti, INAC, etc.) and of the CEA staff status (same career path for researcher and engineers (see SWOT section). Our system team provides essential knowledge at the system level (cooling if any, electronics…) to really control the focal plane performance. Our “radiation team” has the rare competence needed to secure the performance against the effect of radiation. Note that an intimate knowledge of the focal plane is a definite advantage to participate in the ground segment and to the best scientific exploitation of an instrument.

Enhanced R&T activities

Our participation in the development of the focal plane of future space missions must be anticipated well in advance. As shown in the SWOT section, given the change in the Technical Readiness Level requested at the selection of a space mission, we can no longer develop novel focal planes within an approved project or even a project under study. The recent concept of a new class of small ESA missions, to be launched 4-5 years after the call, also goes in the direction of anticipating the development of instrumentation. Thus during the next period, we plan to increase the amount of upstream activities in R&T and demonstrators. To be successful, a system approach and the constraints of a space mission must be followed from the start. We have the two teams (product assurance team, and system and architecture team) to follow this mandatory approach.

Note that the increase in R&T driven by astrophysical needs fits quite well the general trend to increase technological developpements in France and in Europe (FP8), so that we expect to be able to raise R&T funds. The labex FOCUS, which we are co-coordinating with the IPAG laboratory, will provide seed money for the R&T, will increase our credibility when applying for funds, and will provide a forum to discuss the future needs for novel detectors. For example, in the LabEx proposal, we have clearly identified a need for much higher performances sub-mm arrays, for example for the next cosmology mission that should aim at measuring the polarisation of the Cosmic Microwave Background (CMB), or for future sub-mm missions that aims at improving the angular resolution, which is still in its infancy. Indeed, with a diameter of 3.5 Meters, Herschel is the largest telescope dedicated to astronomy in space. But, used in the sub-mm wavelength range, its angular resolution is not better than the one of the small (5 cm) Galileo telescope. After the first discoveries by Galileo, many discoveries have been made thanks to the increased size of the optical telescope. We can predict a brillant future to the sub-mm. We are developping a novel concept of a 20 meters deployable annual mirrors for sub-mm observations, as the next step to get enhanced angular resoltion, before the interferometric missions, such as FIRI.



Concept of deployable annular 20 meters telescope for sub-mm observations (G. Durand, A. Bonnet et al. 2012); This concept will be proposed to CNES in the framework of the CNES prospective (2013).

Multi-wavelengths strategy?
The 2014-2018 period will see new large observatories, such as ALMA, GAIA, Solar Orbiter, entering in operation, and the extension of the operations of many others (XMM, INTEGRAL, Fermi, CASSINI, KEPLER, HESS, HESS 2 LOFAR and SKA precursors), so that we will be able to keep on our multi-wavelength strategy.

On a longer time scale, the prospectives are good for many wavelengths, except for the X-ray domain. Indeed, when the visible, near- and mid-IR domains are well covered with the JWST in space and the ELTs on the ground, when LOFAR, MeerKat and ASKAP pave the road towards SKA in the radio, when CTA, the Hess successor at TeV energies, is underway, there is no plan for the X-ray domain. And, it is not due to the lack of proposals and studies (XEUS → IXO → ATHENA).

During the next period, we will keep lobbying for the great scientific value of a large X-ray space observatory, participating to new proposals (e.g. answering an L2 call by ESA), and we will keep developing R&T on micro-calorimeters for spectro-imagers.

2. Themes and questions

Dark dominated Universe and Euclid

Constraining theorigin of the re-acceleration of the Universe is a prime objective, recognized as such in all the prospective exercises (Europe, US…). In the previous period, we had prepared the ground for results in the coming period with weak lensing and galaxy clusters (Planck, XMM, CFHT-MEGACAM observations), and later on with Euclid. We have made the right choice proposing and studying Euclid, as it has been selected and is now "THE" dark Universe space mission. We are very well positionned in terms of instrumentation and ground segment; we have to keep increasing our scientific visibility.

Weak lensing and "dark energy"
One of the two main EUCLID probes for dark energy is weak lensing; we have partipated in the weak lensing program with the HST, developing sophisticated signal processing tools (e.g. Berger et al. 2008). The study was done over a two-square-degree field. The larger the field, the more stringent the constraint on "dark energy" is. We are part of the large consortium associated to the CFHTLens program, a 155 square degree multi-color optical survey in *u, g, r, I, and z made* with the MEGACAM camera (built at Irfu). Space measurements have a definite advantage in terms of point spread function (PSF) stability, which is a key requirement for weak lensing. That is why we have proposed the DUNE mission to ESA: a full extragalactic sky survey (15 000 square degrees) with a 1.2 meter telescope in space, which has become the EUCLID mission.

The Euclid mission is our first priority. We have major responsibilities at the level of:

- project management (project coordinator for the consortium, system engineer of the consortium, ground-segment scientist) in direct interface with ESA,
- hardware (responsible of the visible focal plane),
- ground-segment (responsible of the level 3 data reduction algorithms),
- cosmological simulations (co-responsible),
- science legacy (co-leading the distant galaxy legacy science group).

Our strategy has been to occupy key positions related with weak lensing, one of the two key probes of Euclid. The 2014–2018 period will be very active with the development and test of the hardware (VIS focal plane), the development of our contribution to the ground segment (level 3), and preparation of the scientific exploitation. After the departure of A. Refregier, former PI of Euclid, from CEA to ETH Zurich, we have hired M. Kilbinger, a specialist in weak lensing. Y. Mellier, the new Euclid PI from IAP, has accepted to be formally associated to AIM (by CEA contract), and collaboration with IAP has started with regular meetings. On January 2014, Jean-Charles Cuillandre (astronomer from CNAP, resident for 10 years at CFHT, mainly working on MEGACAM data reduction) will work on Euclid and has decided to join AIM and its scientific, instrumental and data reduction activities for Euclid. In the next period, efforts to hire or attract two other scientists for Euclid will continue (see our hiring plan).

Galaxy clusters in a dark dominated Universe.
The statistical properties of galaxy clusters (structure and scaling laws, mass function, and their evolution) are uniquely sensitive *both* to cosmology and to the physics of structure formation. We will pursue both avenues, building on the Planck All Sky survey and the 50 square degrees XMM XXL survey. These will provide largely complementary cluster data sets: Planck is detecting through the SZ effect essentially all the rare, massive clusters in the Universe up to z=1, while the dominant population at the XXL sensitivity will be group scale objects at z~0.5 detected in X-ray.

A very large effort will be devoted to catalogue construction with the new surveys, and in understanding their selection function and the mass-observable relations. The Planck cluster catalogue is well suited for the study of dark matter profiles as a probe of the LCDM paradigm as well as the dynamical evolution of baryons. This will be conducted in synergy with other major surveys (RASS, WISE, LOFAR/ASKAP), together with intensive follow-up (XMM including the two recently granted Large Programs, VLT, Subaru) and numerical simulations. The XXL population will be privileged targets for the understanding of galaxy feedback effects. Constraints on cosmology from each catalogue will be extracted and compared. It is also important to have different methods to probe "dark energy" to control the systematics.

Euclid will provide a full sky catalogue of galaxy clusters in the optical, not only through galaxy overdensity but also directly as dark matter concentration via their lensing signal. We will prepare the science exploitation of its cluster catalogues. For instance, we intend to explore stacking methods to constrain dark matter profile as cosmology probes.

Structuration of the Universe and ArTeMiS, ALMA, IRAM, CFHT, then EUCLID, JWST, then E-ELT

As seen in the report, we have made major discoveries during the last period on galaxy evolution and star formation. We have a leading role in these fields, well recognized at the international level. We have to capitalize on these results and lead the programs that will bring answers the new questions raised by our discoveries.

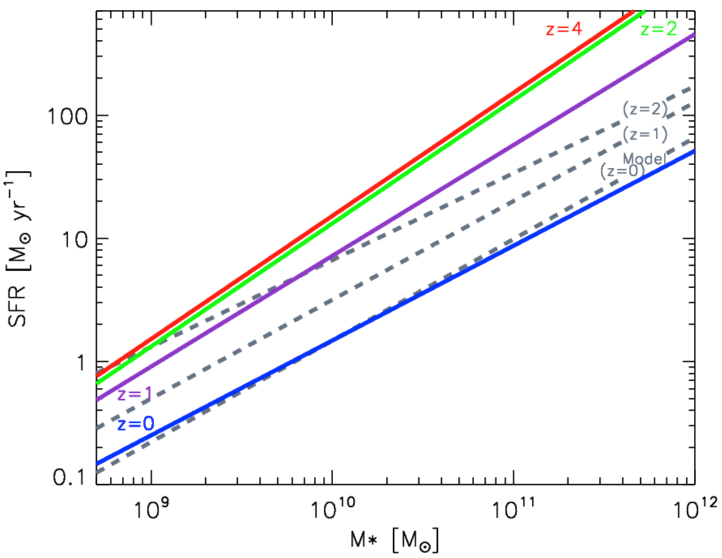
Galaxy evolution: mass growth and star formation history

Collecting large samples of galaxies from surveys with current facilities such as Herschel or IRAM, we have been very successful at finding laws describing the star formation rate in galaxies, such as a so-called "main sequence" dominant mode of long-lasting rather than starbursting star-formation. The phenomenological correlations between the star formation rate and stellar mass in galaxies for redshifts $0 < z < 1$ (Elbaz et al. 2007, 309 cit.), $z = 2$ (Daddi et al. 2007, 366 cit.), and $z = 4$ (Daddi et al. 2009, 118 cit.) have been confirmed and extended to higher redshifts by our team (Elbaz et al. 2011, 93 cit.) and others (see figure below).

At the same time, numerical simulations have been developed and have reached a point where discoveries of the main mechanisms governing the evolution of galaxies can be studied. Bridging the observed and numerical worlds, a new scenario has emerged in which galaxies are continuously, rather than stochastically, fed through infall of extragalactic matter, in large part consisting of collimated cold flows. However, this qualitative agreement fails quantitatively, with simulations predicting too inefficient star formation at $z<2$ (figure below) as compared to observations, as a result of a possibly too rapid gas consumption at higher redshifts leaving not enough gas reservoirs for more recent star formation.

A prime goal for the next period is to quantitatively reconcile simulations and observations by linking small-scale gas and star formation physics to scaling relations on galactic scales and cosmic inflows and outflows. Two ways will be followed in parallel:

- Using the increasing power of massively parallel computers (GENCI, PRACE) to enrich the simulations by increasing their resolution – by, e.g., making them capable of resolving the formation of molecular clouds - and adding physics so far treated at a sub-grid level, such as the effect of feedback (supernovae, radiative pressure, central black hole jets, winds) on the efficiency of star formation.
- Observationally, we will, in particular, dedicate a large effort to access the gas content of galaxies, derive directly their star formation efficiency and study the parallel growth in stars and black holes taking advantage of new facilities such as Alma, ARTEMIS, as well as IRAM PdBI + NOEMA, JVLA, KMOS, MUSE for optical/near-infrared IFU spectroscopy. We will use refined stacking and deblending methods to combine *Herschel* with multi-wavelength surveys of the deepest extragalactic fields. Exploring these multi-parameter scaling laws linking the gas, stellar, metal and black hole content of galaxies will require very large samples, hence will be first explored on limited samples paving the way for later, statistically significant, studies with Euclid.



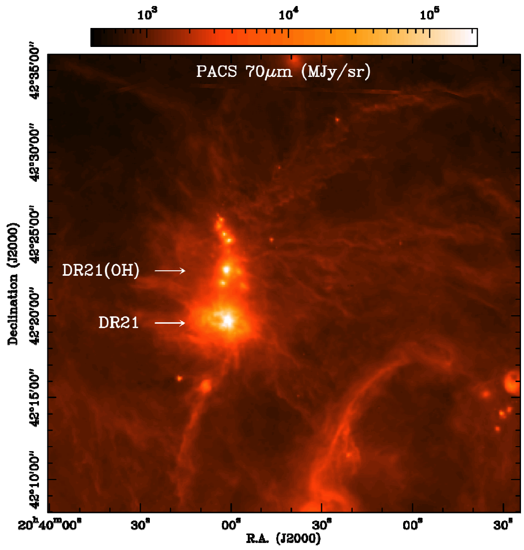
SFR-M relation or scaling law from observations (solid lanes) at z~0, 1 (Elbaz et al. 2007), 2 (Daddi et al. 2007) and 4 (Daddi et al. 2009) as compared to model expectations (dashed line) at cosmological scales from the Millennium simulations, based on the mock light cones of Kitzbichler & White (2007).*

For more details, see the section about the LCEG team project.

Star formation: filamentary structure, IMF

With Herschel, we have revealed the deep connection between the structure of the cold molecular clouds, and the star formation process. We have evidenced the role of turbulence in the generation of a characteristic thickness in interstellar filaments, and that of gravity in the onset of infall inside the filaments. Very recently we have seen that structure of the magnetic field is ordered in cold molecular clouds and could both provide a mechanism for the growth of mass inside filaments and support against collapse (see figure below). Thus the key question for the coming years is to understand the interplay of dynamics, magnetic field and gravity in the formation of the observed structures in the ISM, and how these contribute in building up a dense core mass function that is parallel to the initial mass function. We can address this difficult question thanks to the combination of talents assembled in AIM:

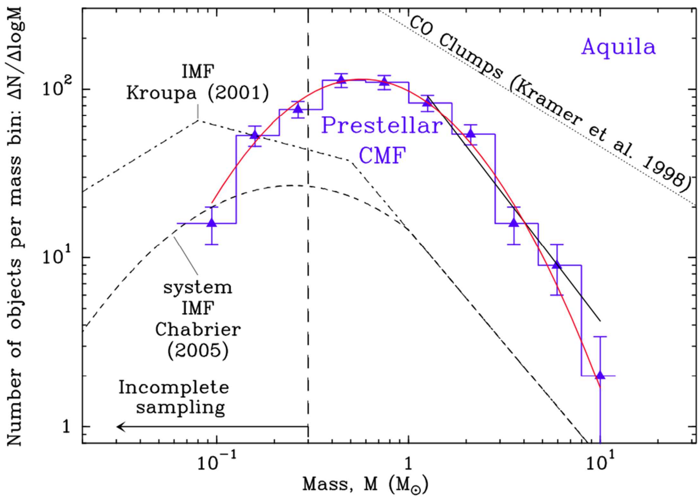
- We will develop new simulations which, for the first time, will be able to treat in a consistent way the issue of structure formation in the cold ISM, incorporating the aspect of turbulence decay and magnetic support.
- Thanks to the development of polarization capacities on new submillimeter cameras (e.g. our involvement on IRAM-NIKA), we will have access to the organization of the magnetic field in star-forming clouds, thus complementing the set of constraints needed by the numerical simulations.



How does the filament mass grow? This Herschel image of Cygnus X shows a central filament connected to a rich network of adjacent fainter filaments, suggesting a possible "feeding" mechanism. Polarization and dynamical measurements with forthcoming facilities (e.g. Alma, IRAM-NIKA…) will make possible to test this scenario (from Hennemann et al., 2012).

Herschel has also robustly confirmed the fact that the initial mass function is imprinted in the ISM when dense cores are formed. The question which has now to be tackled is how this footprint is kept at later stages of star formation and what reduces the efficiency of the process that turns these cores into stars (corresponding to the shift between the mass functions on figure below). The combination of complex numerical simulations and observations at higher resolution that can be performed with Herschel (using e.g. ALMA to focus on individual star-forming cores) will be deployed to address the issue.

The core mass function (blue histogram with error bars) derived from the Herschel mapping of the Aquila region. The IMF of single stars (corrected for binaries) and multiple systems, as well as the typical mass spectrum of CO clumps are shown for comparison (From André et al., 2011).



At larger scales, we have also shown that regions of massive star formation in our own galaxy can reach a star-formation rate surface density that is comparable to that measured in starburst galaxies. Exploitation of the Herschel surveys of these regions, as well as higher resolution studies with newly developed facilities (e.g. Artemis) will bring new light on the physical conditions require for intense high-mass star formation, and will be used to address the question of the universality of the high-mass end of the IMF.

For more details, see the section about the LFEMI team project.

Interstellar tracers : a transverse teaser

From star formation to galaxy evolution and to cosmic-ray physics, several teams across AIM are working on complementary probes of the interstellar medium (ISM). Reliably quantifying the mass, physical state, spatial distribution, and dynamics of the different gas phases is key to understanding the matter cycle from cloud to filaments, and conversely from clouds to galactic scales. The body of ISM tracers has recently expanded to atomic and molecular lines and ladders in the sub-mm, to the full sub-mm to infrared thermal dust emission, and to gamma rays from cosmic-ray interactions with gas (Planck, Herschel, Fermi). It will further expand with follow-up observations (SOFIA, ALMA, APEX, Fermi, …) and with stellar reddening and DIBs from dust (2Mass, Gaia). Our studies have revealed significant non-linearities in the gas and dust tracers and that an entire phase (dark gas), albeit as massive as the CO-bright molecular phase, easily escapes detection. This rich panel of observational data and the joint expertise present within AIM strongly calls for an in-depth study of the ISM tracer diagnostics at different cloud scales and in a variety of irradiation and metallicity environments in the Milky Way and nearby galaxies. Confronting observations with realistic ISM simulations will help sort out how faithfully different sets of tracers can account for the total gas in the turbulent multi-phase structure of clouds. To this aim, simulation work will proceed toward two goals : implementing more precise photoionization physics on one hand, and implementing MHD turbulence and cosmic rays on the other hand. Understanding the limitations of ISM tracers in a comprehensive way will directly serve the interpretation of distant galaxies and reduce the large uncertainties in the current derivation of star formation efficiencies in main-sequence and starburst galaxies.

Cosmic phenomena at high energy and Fermi, HESS2, CTA, LOFAR and SKA precursors

Cosmic-ray acceleration and transport in the Galaxy remain largely unknown. In the last period, our teams have contributed novel results both observationally and numerically. We plan to further build on these strengths to study the acceleration and youth of cosmic rays. Studying their youth represents a novel step in linking the cosmic-ray properties at the sources and at large in the ISM. Several paths will be followed in parallel:

- multi-wavelength images of specific supernova remnants will be used to probe the efficiency of shock acceleration by studying the cosmic-ray feedback on the shock compression and magnetic field amplification. The data will be confronted to new MHD simulations coupled to a kinetic model for particle acceleration and feedback to model the complex stratification in a remnant.
- the known GeV and TeV emitting remnants span a large enough range of ages and interstellar environments to start and study how the acceleration efficiency and particle release into the ISM evolve with age.
- 1-100 GeV observations and numerical modeling will be combined to study the emergence of cosmic rays into surrounding clouds and to search for new examples of fresh cosmic-ray cocoons in bright stellar clusters to constrain their early propagation inside turbulent superbubbles.
- TeV data can probe young cosmic rays at high energies, but the current background subtraction methods in the Cherenkov data prevent an efficient detection of diffuse or broadly extended emission. We will take advantage of our expertise in HESS and HESS-2 data to try and lower this methodological barrier in preparation for the next major CTA observatory.

Accretion of matter onto a compact object is the most efficient way to transform gavitationnal energy into radiative and kinetic energy transported to large scales. We want to probe the possible origin of the different modes of accretion we have just found in the fundamental plane of microquasars. We also want to constrain the associated emission processes and to study how these different paths impact the physics of jets (type, power, ...).

- One way to do so is to follow the evolution of a complete black-hole outburst from the radio to gamma rays, in order to connect the jet non-thermal emission to the evolution of the thermal pool in the accretion disc and its potential oscillations and instabilities. To carefully model this interplay, we have created, in collaboration with IPAG and IRAP colleagues, the ANR program CHAOS that has just started. Its goal is to bring theoreticians and observers together to provide a unified picture of black holes properties along the course of their outburst.
- We will also develop new imaging tools to search for transient sources in the massive data flows of the next generation of radio arrays (in preparation for SKA). This will open a new window on the rapid variability of jets and accretion disc coronae, to be tested with LOFAR, ASKAP and MeerKat.

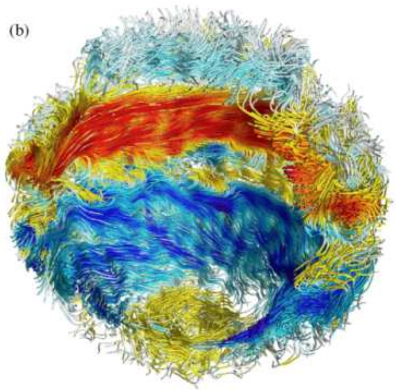
For more details, see the section about the LEPCHE team project.

Stars and their environment; Kepler, Solar Orbiter, JWST and then E-ELT

Over the last decade two majors advances have been realized in stars and planet research: the outcome of asteroseismology in one hand and the detection of exo-planets on the other hand. New exo-planetary systems are discovered almost every day and need to be characterized. One key aspect is to know several global parameters of the host star as well as its intrinsic variability in order to help disentangling the presence of planets from the stellar variability. Among the most frequent stellar variabilities we are leaders in the observational, theoretical, 1-D modeling and multi-D high performance numerical simulations study of stellar oscillations and magnetic activity. We intend to reinforce and develop further this activity over the next 5 years period by developing a global view of how do stars, planets and their environment work and interact. This will take the following form:

- improve our ability at modeling stellar dynamos and the associated cycles, using the Sun as a guide and the Sun-star relationship as a way of adapting current dynamo models to the various conditions existing in stars with different age, mass, chemical composition and rotation rates;
- develop an operational solar activity models based on modern data assimilation techniques and dynamo models;

- analyze thousands of Kepler's stars and strengthen our ensemble asteroseismology pipeline in order to give improved constraints to both the stellar and planetary communities;
- improve our theoretical modeling and high performance multi-D numerical simulations of stars and planets, with a special emphasis on their internal structure and large scale dynamics on short (of order few cycles or rotations) and secular time scales;
- develop the first steps towards an integrated model of star-planet interactions taking into account both magnetic (wind, spectral luminosity variability) and tidal effects in order to determine how host stars and planets influence their surrounding;
- characterize with such models the habitable zones for various configurations of stars and planets, using the solar system as a guide;
- develop models of particle acceleration in realistic magnetic topologies in support of Solar Orbiter and the STIX instruments as well as a seismology pipeline in support of Juice/Echoes.



Recent 3-D numerical simulations with the ASH code of fastly rotating Suns (Brown, Browning, Brun et al 2010, 2011) have revealed the existence of large-scale magnetic wreaths. Such horizontal (toroidal) magnetic structures were not anticipated within turbulent convection zones, as one would have expected flux expulsion to act and to push them outside of the convection zone (likely in a tachocline below). ASH simulations actually demonstrate that by acquiring a fibril, non-axisymmetric nature, they can accommodate such expulsion phenomena, yielding intense localized magnetic concentration that can then rise buoyantly to the surface (Nelson, Brown, Brun et al. 2011) and contribute to the establishment of a cyclic magnetic activity and stellar butterfly diagram (Nelson, Brown, Brun et al. 2012).

We also intend to keep on working on Cassini data to understand the Saturn system and to increase our implication in the characterisation of the atmosphere of exoplanets, coordinating the large program (130 hours) to be conducted in the framework of JWST-MIRI guaranteed observing time. We are also investing in future exoplanets missions, participating in the studies of the ECHO M3 mission candidate (G. Tinetti et al. 2012), in the METIS instrument for the E-ELT project (B. Brandl et al.) and in the R&T for an astrometric space mission dedicated to the dedection of exoplanets systems (including Earth like) around nearby stars, such as the NEAT mission proposal to the M3 (F. Malbet et al. 2012).

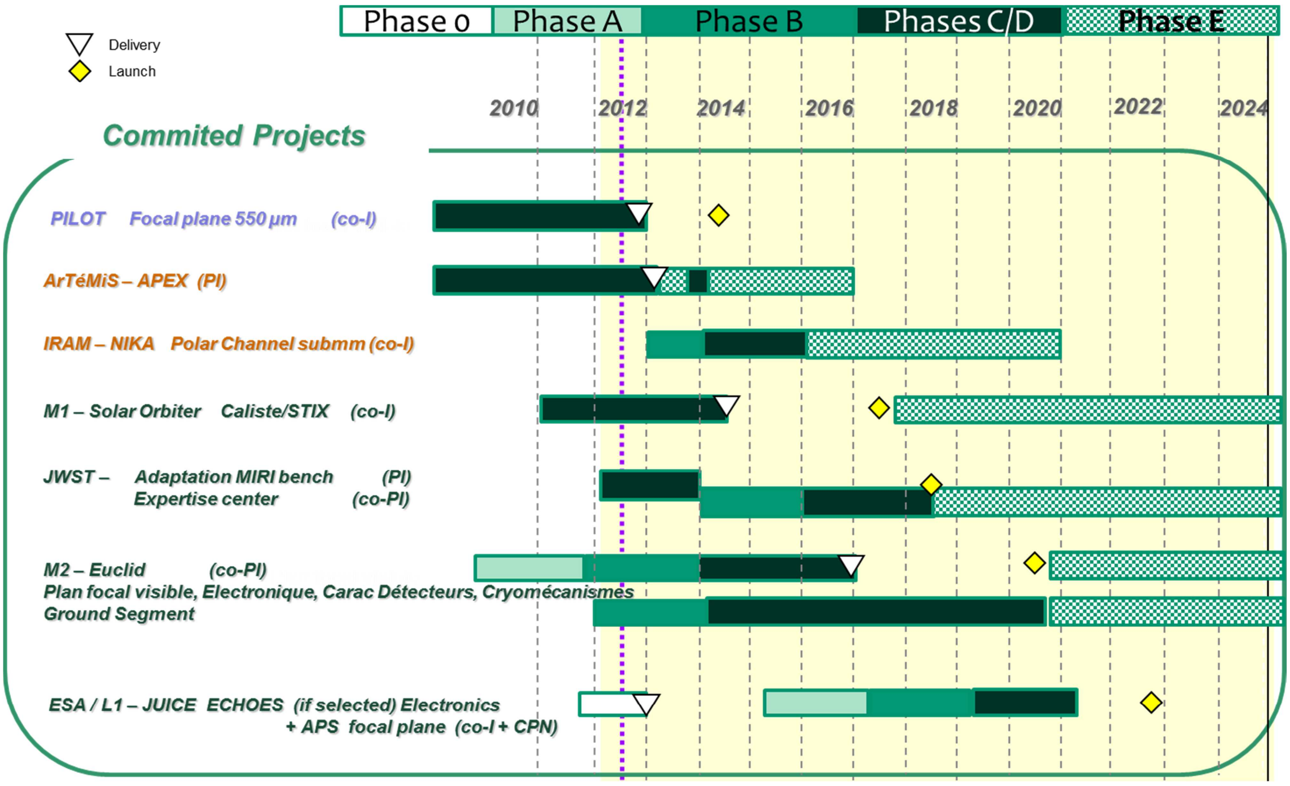
For more details, see the section about the projects of the LDEE and LADP teams.

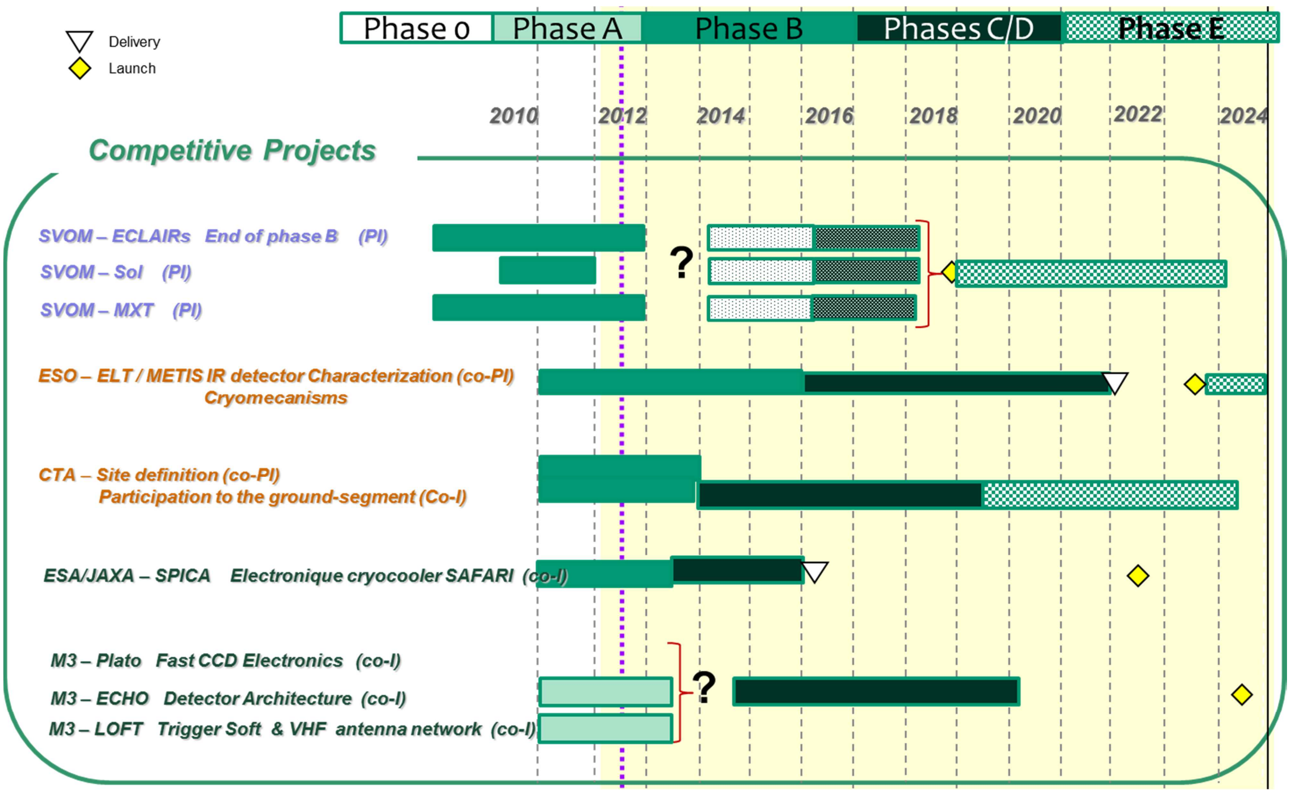
3. Instrumentation

Strategy considerations lead us to work on several projects at different phases of their development:

- scientific exploitation of available facilities and on-going monitoring the behaviour of the instruments we have provided (for example, still monitoring the ISGRI detector INTEGRAl)
- hardware design and construction for mid-term future facilities and preparing their science exploitation (ground segment, science) (JWST, Euclid, Solar orbiter),
- anticipating the emergence of important fields and the associated R&T, answering calls for missions, assessment phase, definition phase (JUICE instrumentation, M3, L2, E-ELT…).

The following figure shows the instrumental roadmap, distinguishing between the committed projects and those which are still in a competitive phase.

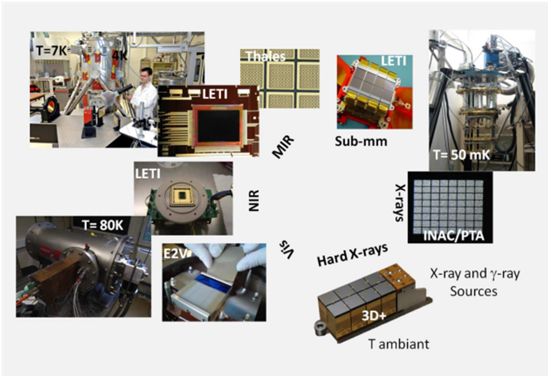

Phase 0
Phase A
Phase B
Phases C/D
Phase E
Delivery
Launch
2010
2012
2014
2016
2018
2020
2022
2024
Commited Projects
PILOT Focal plane 550 µm (co-I)
ArTéMiS – APEX (PI)
IRAM – NIKA Polar Channel submm (co-I)
M1 – Solar Orbiter Caliste/STIX (co-I)
JWST – Adaptation MIRI bench (PI)
Expertise center (co-PI)
M2 – Euclid (co-PI)
Plan focal visible, Electronique, Carac Détecteurs, Cryomécanismes
Ground Segment
ESA / L1 – JUICE ECHOES (if selected) Electronics
+ APS focal plane (co-I + CPN)


Phase 0
Phase A
Phase B
Phases C/D
Phase E
Delivery
Launch
2010
2012
2014
2016
2018
2020
2022
2024
Competitive Projects
SVOM – ECLAIRs End of phase B (PI)
SVOM – SoI (PI)
SVOM – MXT (PI)
?
ESO – ELT / METIS IR detector Characterization (co-PI)
Cryomecanisms
CTA – Site definition (co-PI)
Participation to the ground-segment (Co-I)
ESA/JAXA – SPICA Electronique cryocooler SAFARI (co-I)
M3 – Plato Fast CCD Electronics (co-I)
M3 – ECHO Detector Architecture (co-I)
M3 – LOFT Trigger Soft & VHF antenna network (co-I)
?

4. Research and Technology

One of our key objectives is to anticipate the development of novel focal planes, but they can be very costly and cannot enter in the usual R&T CNES funding. That is one of the reasons why we have co-led with IPAG the FOCUS laboratory of excellence (LabEx) proposal devoted to sensors for astrophysics. It has been accepted and will get a budget of 1.2 M€ per year during 8 years. This is not enough for all the developments, but the LabEx is a helpful label to get additional funding, for example in the framework of Horizon 2020. Moreover, we have sucessfully started to answer ITT calls from ESA and plan to continue answering future calls.

We also plan to coordinate our various test benches in a “detector characterization platform”, to increase the visibility of the detector characterization and development activities.



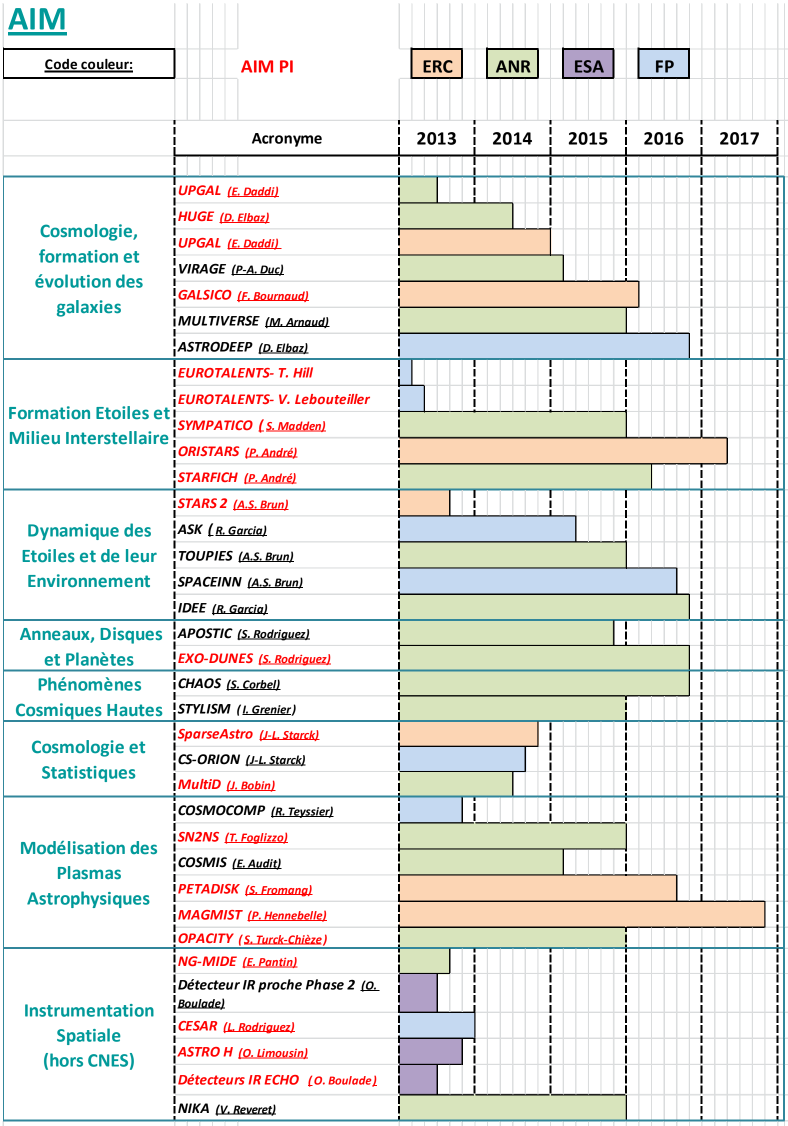
Different detectors characterized at AIM (from visible to hard X-ray) and the associated test benches (from ambient temperature to 50 mK).

5. Resources

A lot of projects funded by the ANR or ERC are ongoing (see Figure beside); we are also part of 3 LabEx funded for 8-10 years, and we are part of the Ile de France ‘’Domaine d’Intérêt Majeur’’ ACAV.

We are an important partner of a large European space project that is accepted (Euclid) and can be considered as funded (with the caveat that we have to wait for the endorsement by the CNES board at the beginning of 2013). We are part of a pre-selected E-ELT instrument (METIS) whose hardware cost will be funded by ESO. We have also started to get funding from ESA via successful answers to call to tender.

We suffer from the absence of margin to initiate projects or to fund any post-doc on internal resources. We will of course continue to answer the various calls to fund our projects.



6. Hiring plan

While our internal funds are very limited, we have a great richness : the permanent staff. Given our dynamism, our capacity to raise funding, and our attractiveness, we hope for a slight increase in permanent positions, as it has been the case during the previous period. Our permanent position hiring plan is an immediate consequence of the SWOT analysis and of our objectives. It is difficult to estimate the number of retirements as we have the new possibility to work until 70 years old at CEA; it can vary from 2 to 8 if everyone leaves at 70 or 62.

Regarding the space instrumentation, we should rapidly hire a space AIV expert for Euclid (replacement of a departure in 2010; need in 2013) and replace any unexpected departure because, most often, there is only one specialist per domain. If possible, we should decrease the risk by having two experts in a given domain (for example an additional space mechanical architect). A strategic line for the future is R&T; we should reinforce this activity by hiring one specialist of detection and by replacing any departure. Given the age histogram (see report), we do not have immediate retirement problems, but we have to anticipate the large number of retirements over the following period (2019 – 2024), especially in terms of technicians.

For astrophysicists, the situation is slightly different in the sense that we need both to reinforce our fields of excellence with new expertise and to evolve in our themes. The first priority is to hire a specialist in ALMA interferometric observations which will be beneficial to both fields of star formation and galaxy evolution. Then we must prepare the cosmological exploitation of Euclid by hiring, at least, a weak-lensing expert and a galaxy cluster expert; we also have to prepare the exploitation of the Euclid Legacy science. The field of the Sun, stars, planets and exoplanets is in full expansion and we have several cards to play (Solar Orbiter, JWST, E-ELT), but at least two hires are needed to reach a critical size. With the development of LOFAR, SKA precursors and, on the long term, SKA, the radio domain will have an important impact in many fields of astrophysics; we aim at hiring a specialist in observations with these upcoming facilities. In terms of numerical simulations, the unit is barely at a critical size (a single specialist per field), so that any departure should be replaced. There is one field of research for which the synergy between observations and simulations should be improved: the cosmic phenomena at high energies. The hiring of a specialist of numerical simulations in that domain would therefore be highly valuable.

D. Conclusions

New facilities such as ALMA and massively parallel computers are just in time to follow-up the discoveries that we have made in the fields of galaxy evolution, star and planet formation, and stellar evolution.

We are deeply involved in future major space missions such as JWST and Euclid, which will be key missions to study most of our fields of research, including exoplanets and dark energy.

We are preparing the long-term future by developing a solid R&T, especially concerning sensors, with extensive discussions between engineers and astrophysicists.

LCEG - Laboratoire Cosmologie et Evolution des Galaxies

1. Présentation de l'unité

The LCEG team involved in the 2014-2018 period will consist of 10 staff members: M. Arnaud, F. Bournaud, E. Daddi, D. Elbaz (*head*), E. Le Floc'h, R.Lehoucq, M. Pierre (CEA), H.Aussel, P.-A. Duc (CNRS), and S. Juneau (since Nov. 2012).

2. Analyse SWOT et objectifs scientifiques de l'unité

SWOT analysis for the LCEG team

Strengths: A key asset of the LCEG team is the existence *within* the group of a synergy between observations, theoretical data modelling and numerical simulations, naturally benefitting from the complementary expertise of team members. This synergy covers a wide range of spatial scales and physical processes (from interstellar gas physics to large-scale cosmological structures) and wavelength areas (from far infrared to X-rays). Complementary scientific skills converge to target well-defined scientific objectives as described in the scientific report.
On a practical level, the team has benefitted from: (i) a strong implication in proprietary time for space observatories (*Herschel*, *Planck*), (ii) a unique set of large programs of observations (centered on but not limited to *Herschel*, XMM, CFHT) and simulation programs (PRACE & GENCI, 37 Mhours since mid-2010 on Curie and Supermuc Petaflopic computers and the new CNRS Blue Gene), (iii) a strong success rate in prestigious grants (2 ERC, 7 ANR, 1 FP7 SPACE), (iv) tight perennial connections with researchers providing complementary expertise from external (e.g. IRFU-SPP/IAS/IRAP for Planck) and internal institutes within the SAp (for e.g. the cosmological context/LSPNA, modelling of dust emission/LFEMI).

Weaknesses: On the observational side, interferometry plays an increasing role for extragalactic studies but the team will need to adapt its local expertise accordingly. On the modeling side, the present numerical simulations of our group lack a proper treatment of the role of black hole growth and feedback, and only include a marginal connection with the global cosmological framework and associated large-scale physical ingredients such as the merger rate. We also note a pending challenge to sustain the broad range of expertise through which our group has reached a leading position in the field of galaxy formation: this is a potential weakness because an increasing part of this expertise has been developed through the contribution of non-permanent researchers. The ratio of non-permanent over permanent staff researchers is now greater than three, and our current scientific success can be maintained only through the new hiring of outstanding researchers.

Opportunities: A new generation of powerful instrumentation will provide us with tools to extend our investigation on dust-obscured star formation and black hole growth in distant star-forming galaxies with the advent of ALMA, JVLA and later on NOEMA at IRAM and APEX/ARTEMIS, followed by the mid-infrared spectro-imaging capabilities of JWST scheduled for 2018. Our leadership in the field places our group in a unique position to fully exploit these facilities, from the successful access to observing time to the theoretical interpretation and modelling. These facilities will provide much larger samples and extend to higher redshifts the measurements obtained for moderately distant galaxies. More importantly for our group, they will enable us to resolve the actual physics of star-formation and black hole growth in distant galaxies. The new generation of wide-field and multi-object IFU spectrographs (such as KMOS and MUSE on the VLT) will offer an unprecedented possibility to distinguish star formation and nuclei activity when they occur jointly in high-redshift galaxies (using new diagnostics such as the mass-excitation diagram: Juneau et al.2011, ApJ 736, 104), which puts us in excellent position to obtain a much more complete census of black hole growth and its interplay with star formation in all types of galaxies. We have already been very successful in obtaining open observing time on this topic over the past 12 months (several regular programs and two DDTs on JVLA, IRAM/PdBI, VLT/XSHOOTER, VLT/SINFONI). This opportunity on the observational side is perfectly matched on the simulation side with the rapid growth of computation facilities at the European scales. Our group is perfectly positioned to maximize their use with high-resolution simulations ideally suited to compare to deep spectroscopic data from such IFUs.
At larger, cosmological scales, we are entering a true panchromatic era in the study of galaxy cluster populations up to high redshifts thanks to the combination of the Planck survey legacy, the extension of XMM potentially up to 2018, the e-Rosita X-ray survey, recent or upcoming radio and high energy facilities (LOFAR, ASKAP/EMU, nuSTAR, CTA) and ultimately, the Euclid mission. We will also investigate a possible participation in the CCAT project of a 25m sub-mm telescope at Chajnantor led by JPL and Cornell University. Altogether, this offers a truly unique opportunity to reveal the full properties of an unbiased cluster population, which is essential for a precise understanding of cluster astrophysics as well as for cosmological applications.
Several team members are strongly involved in the preparation of the Euclid scientific exploitation, especially regarding the Legacy Science on galaxy evolution and AGN (D.Elbaz is co-coordinator of the Euclid Galaxy Science Working Group and other team members are assigned to scientific work packages). This will lead to new and strategic

collaborations extending our expertise in the field, and furthermore placing our team in good position for the scientific exploitation of Euclid and related simulations, when it is launched soon after the coming five-year period.

Threats: In the coming years, we will become increasingly dependent on accessing time on new facilities such as 2nd generation instruments at VLT (KMOS, MUSE) or ALMA because we do not hold guaranteed time and we are not currently part of major surveys like Pan-Stars, DES, LSST and e-Rosita. With the increasing complexity of astronomical instrumentation and project sizes, the coming era will likely involve teams of greater sizes making it more challenging to develop new projects that are managed *in-house*. The foreseen competition will be stronger with facilities expected to be central in the field of galaxy formation/evolution, such as ALMA. However, the expertise and leadership of our team associated with the comprehensive study of the most observed fields of the sky such as the GOODS fields, and our recognized forefront position in topics such as molecular gas reservoirs (Daddi et al) among others, should represent an asset for our group. Therefore, we need to capitalize on this strength in order to mitigate against the threat of reduced guaranteed access to world-class facilities. The expertise of the team has grown thanks to our strong success rate in obtaining a rich financial support but with no definitive guarantee that future proposals will bring a similar success rate. Also, part of our success is a result of our involvement in the building of new instrumentation for e.g. *Herschel* and XMM. The next major instrument with similar local involvement is Euclid. To secure our leadership, we therefore need to maintain a critical threshold in size and expertise.

Scientific objectives of the LCEG team

(1) Unveiling the main physical mechanisms responsible for the growth of galaxies in stellar and black hole mass: can theory and observations be reconciled?

Context: a series of observational and theoretical results in which our team have played a leading role have concomitantly converged towards a scenario of galaxy growth dominated by continuous mass accretion and star formation rather than stochastic bursts of star-formation resulting from merging events. This is supported by:
(i) the phenomenological correlations between a galaxy star formation rate and stellar mass found for redshifts z~0 to 1 (Elbaz et al. 2007), 2 (Daddi et al. 2007, Elbaz et al. 2011), 4 (Daddi et al. 2009) which has been confirmed and extended to higher redshifts by others,
(ii) the finding that diffuse gas accretion dominates the fueling of galaxies (perhaps in collimated cold flows) responsible for the bulk of the star formation history of galaxies and for a large part of the growth of their supermassive black holes as we have started to argue,
(iii) the existence of large clumps of star formation in distant galaxies seen in high-resolution HST images and expected from numerical simulations developed by our team; these clumps arise when high gas fractions together with a rapid gas supply lead to violent dynamical instabilities.
This emerging scenario offers a new starting point in our understanding of galaxy evolution but in details it fails when comparing quantitatively model expectations with observations. In particular, models are far too efficient in forming stars at early epochs compared to the observed Universe. As a result, model galaxies use their gas reservoirs sooner and produce fewer stars at fixed stellar mass at intermediate redshifts (z~1). Although affecting all redshifts, this issue is particularly relevant at the still weakly explored z>2 epoch, a peak era in galaxy and black hole growth. Thus, a major goal of our team for the coming years is to better quantify the still incomplete observational picture at z>2 and to investigate numerical/theoretical solutions to remaining disagreements with these improved observations.

Challenge: The central question here is to understand the balance between the cosmological supply of gas and its conversion into stellar mass and supermassive black holes.

Prospective for 2014-2018:
• ***Linking small-scale gas and star formation physics to scaling relations on galactic scales and cosmic inflows and outflows***. The violent dynamical instabilities specific to distant galaxies with large gas supplies are likely accompanied with feedback mechanisms different in strength and possibly nature, compared to local star-forming regions. Strong supernova rates likely involve outflows that can expel as much as half of the gas infall, while AGN radiative and/or jet feedback may compress or expel the ISM and lead to either a diminution or possibly an enhancement of star formation. These mechanisms can now be investigated owing to new generations of numerical simulations, capable of resolving molecular clouds with sub-parsec resolution. In the next few years, our team will couple these detailed models to the full cosmological context in order to study samples of galaxies with initial conditions reproducing realistic cosmological galaxy populations.
The “broadly Universal” Schmidt-Kennicutt law is now thought to describe complex star formation processes encompassing different modes: (i) galaxies presenting an excess SFR given their gas surface density as compared to most "normally" star-forming galaxies, (ii) distant gas-dense galaxies showing a reduced star-formation efficiency (SFR/Mgas) as compared to a pure Schmidt law possibly due to negative feedback, and (iii) low-efficiency systems which, surprisingly, can be either dwarf galaxies or massive early-type galaxies. Fundamental questions have emerged from these findings that we will address in the coming years by perfecting a better control on systematic uncertainties in existing data and by taking advantage of new facilities offered to the community such as ALMA. In particular, these various observed modes contrast with the puzzling homogeneity of Main Sequence galaxies. Does this homogeneity still hold at the scale of their star-forming regions (the well-known « giant SF clumps » of high redshift galaxies), or can the clump be “local starbursts” with efficiencies higher than their host galaxies? What is the response to feedback from newly formed stars? What causes starbursts in galaxies, i.e. enhanced SFR per unit stellar mass or gas mass and oppositely reduce strongly their star-formation efficiency? A major step forward in understanding star formation scaling laws from redshift 0 to z~2 can now be done by resolving and mapping the ISM properties in moderately distant

galaxies, to link small-scale star formation physics to galaxy-scale properties.

• ***Build a new picture of gas properties and star formation at z>2***. The cosmic evolution of the specific SFR (sSFR=SFR/M*) of galaxies above redshift 2-3 is still misunderstood, and even poorly constrained in current observations. Current, sparse data seem to indicate that the sSFR cosmic density stops increasing with redshift above z=2, which may be in conflict with theoretical models (e.g. Davé et al. 2011). Using various and complementary tracers of star formation activity within galaxies, we will refine the existing constraints on the sSFR evolution above redshift two and seek for dependence on galaxy mass. We will also constrain the evolution of the relative contribution of Main Sequence and Starbursts galaxies to the cosmic-averaged sSFR toward the highest redshifts.

• ***Understanding the concurrent growth of stellar and black hole mass***. Central Black Holes have grown in proportions tightly connected to the stellar mass growth of galaxies, but the physics driving this concurrent growth is unknown. The census of active BHs in the distance Universe is far from being complete, as standard selections are sensitive mostly to the brightest and less obscured AGN and QSOs (which may dominate the BH mass budget, but may not include important phases of feedback). Yet there is growing evidence that many high-redshift AGN reside in normally star-forming galaxies (not only in spheroids or starbursting mergers). Once we are able to thoroughly identify these AGN+SF systems, we will study the link between the nuclear activity and star formation: is star formation triggered/quenched in AGN regions or even in entire galaxies, are outflows triggered by the AGN or does the gas continue to flow toward the central BH over long duty cycles?

Tools:

• Exploitation of **multi-wavelength** surveys: we benefit from the deepest *Herschel* extragalactic surveys GOODS-*Herschel* (PI D.Elbaz) and CANDELS-*Herschel* (co-PI D.Elbaz, observations mid-2012) in the 4 best-studied extragalactic survey fields (GOODS-N, GOODS-S, COSMOS, UDS). Simulations using *a priori* knowledge of the typical IR SED and redshift distribution of galaxies will be used to quantify the local impact of source confusion due to the large beam size and dig deeper into these far-IR images. Refined prior source extraction techniques will be used to combine in a consistent manner survey data at all wavelengths from the radio, sub-mm, far-IR to the optical, UV, X-ray in these fields. Extension to deeper levels will be obtained from **stacking** images from various selection techniques including **NIR-selected high-z population** using **HST-WFC3**. This effort is strongly supported by a European network (ASTRODEEP, EC FP7 SPACE, 0.5 M€ for our group to hire postdocs), in collaboration with U.Bologna, U.Edinburgh and the CDS Strasbourg. Forthcoming *Herschel* data will be used in particular to search for z>2 rare analogues to local ULIRGs, i.e. extreme starbursts, so as to probe high-redshift star formation in extreme conditions.

• Intensive follow-up campaigns with **ALMA, APEX/ARTEMIS** as well as **IRAM PdBI+NOEMA and JVLA** will be performed. Access to ALMA time will not only beneficiate from the strength of our team to obtain open observing time but will also be facilitated thanks to our connection with Universidad de Concepcion, Chile (one co-advised thesis in 2009-12, starting program for long-term visiting students in the next years, and on-going preparation of a formal cooperation agreement between AIM and U. Concepcion). The bimodal distribution of galaxies depending on their star-formation efficiency between Main Sequence and Starburst galaxies remains to be firmly established by using more thorough studies of the molecular gas content of galaxies from the CO line as well as by probing the amount of high-density gas (e.g., using HCN). These will be compared to predictions of numerical and theoretical models of starburst galaxies (models that we now start to use for quantitative predictions of molecular line observations – based on a new coupling that we have developed between the **AMR hydro-simulations and LVG models**).

• Exploring these multi-parameter scaling laws linking the gas, stellar, metal and black hole content of galaxies will require very large samples, hence will be first explored on limited samples paving the way for later on statistically significant studies with **Euclid**.

• The interpretation of these observational results will intensively use our **in-house numerical models**, which as of mid-2012 are able to resolve the turbulence cascade in interstellar gas clouds over five decades of volume density, and include predictive prescription for stellar feedback processes (photoionization, stellar winds and radiative pressure, supernovae). A major development in these numerical models will be the inclusion of high-resolution recipes to model the accretion of mass by supermassive black holes and the re-injection of energy in the interstellar medium. We will develop a detailed physical understanding of the gathering of gas in proto-galaxies (observations of ionized and atomic gas), its conversion into cold and dense clouds (observations of various molecular transitions), the structure of these cold gas clouds (through high-resolution modeling down to the sub-parsec scale), and the effect of feedback from young stars and accreting black holes (in simulations and observations). As for black hole growth and AGN feedback, we will exploit a new "Grand Challenge" simulation program (recently awarded on the new CNRS Blue Gene, P.I. Gabor) to model self-consistently the dynamics of entire galaxies at ~2pc resolution and the formation of accretion disks around their central supermassive black hole up to ~0.02pc resolution using AMR zoom techniques. We will use these news models to study the link between large-scale gas flows and real black hole accretion/feedback.

• Our **simulations** can resolve the main scales of ISM turbulence, hence they can predict the chemical enrichment of gas reservoirs through turbulent mixing, when these have low star formation efficiencies. This will be used to propose **observational diagnostics** on the gas reservoirs in early galaxies at z>2, with ALMA and other instruments. We will also use other tracers of gaseous reservoirs than the usual CO molecule in order to better probe low-metallicity gas in galaxies that have merely started to assemble their stellar mass (e.g., [CII], CH^+, etc.).

• **Optical+near-infrared IFU spectroscopy and radio interferometry** will be extensively used to resolve galaxies, separate AGN signatures from star-forming regions, and study their mutual properties. We will use more complete selections in observational dataset, including moderate/obscured AGN from studies of their infrared SEDs, or novel in-house expertise on emission line diagnostics (e.g. MEx, Juneau+11). **High-resolution simulations** (to describe the ISM structure, SF efficiency, and gas flows in detail) and prescriptions of the BH accretion rate (standard Bondi-Hoyle prescription, viscous/turbulent disk models, etc) will be compared to determine the most realistic solutions, interpret the observed gas motions and search for the main source of AGN feeding (merger-driven, secular modes and disk instabilities, stochastic processes) as well as mechanisms of black hole seed formation. IFU and interferometric observations will be used to determine when and where such BH activity occurs, in galaxies that have a mass-deficient SMBH, or conversely in active galaxies that have not formed a central stellar bulge yet.

(2) Morphological evolution of galaxies and the cause of their star-formation quenching

Context: the "death" of star formation in galaxies remains a major mystery both from the observational and theoretical perspectives. At cosmic scales, star formation has declined steeply since z~1-2 and a dominant fraction in mass among present-day galaxies exhibit red colors typical of systems that stopped forming stars long ago. Massive galaxies appear to have died first, possibly through internal negative feedback processes emptying their gas reservoirs and/or preventing further gas infall, as well as environment effects. Forming Red-and-Dead spheroids may require energy injection by active nuclei but a better understanding of this mechanism requires (i) a more complete census and detailed studies of the interplay between active nuclei and the interstellar medium and (ii) more realistic modeling of feedback in high-resolution simulations in a cosmological context, to resolve accurately the dynamical and stochastic interactions between AGN and surrounding gas, and study the resulting effects on gas ouflows/inflows.

Challenge: to establish the relative roles of galaxy mergers, large-scale environment, internal galaxy dynamics and feedback in shaping the morphology of galaxies, triggering and/or quenching star-formation and black hole growth.

Prospective for 2014-2018
• **MATLAS**: probe of galaxy evolution with extremely deep optical images (**CFHT-MEGACAM** g=29 AB)
New observational techniques and data processing can now achieve unprecedented levels of surface brightness in the optical imaging of nearby galaxies allow us to study the stellar populations in the outermost regions. Their properties (color, morphology) provide information about their growth in mass over the last billion years. A CFHT Large Program has just been accepted (2013-2016) to image the closest 260 early-type galaxies in five bands, completing a set of data that has started to be achieved through the international collaborations Atlas3D and NGVS. Expertise in the detection and identification of structures of lower surface brightness (e.g. tidal tails) is in the process of being acquired. Results will be compared to predictions of cosmological models and simulations in cosmological context already available as part of the Atlas3D collaboration (and largely developed in the LCEG laboratory).

• Exploitation of **numerical simulations of galaxies at cosmological scales**: our objective will be to strengthen the use of our numerical simulations with the adaptive mesh refinement code RAMSES to cosmological scales. So far, the focus was on the analysis of "dedicated" simulations or simulations in cosmological context; we want to bring these simulations to a more global scale in the cosmological context. Developing accurate models of baryonic processes (AGN and stellar feedback, outflows…), as proposed in part (1) above, is of fundamental importance for cosmological simulations, in particular in the context of EUCLID: these processes can significantly affect both the baryonic distribution and the dark structure of the Universe at relatively large scales and may affect cosmological parameters estimates. However the effect of baryonic processes on dark matter structures remains poorly understood because of the lack of accurate, predictive models, in particular for accretion and feedback processes. Our high-resolution simulations (idealized galaxy-sized models with accurate ISM modeling + cosmological zoom-in techniques) are ideal tools to study these multi-scale effects.

• We are extending our expertise on **quantitative morphological analysis of distant galaxies**, in order to better quantify the contribution at cosmological scale of the various mechanisms that govern the evolution of galaxies and in the prospect of preparing the **Euclid** mission (start of a new postdoc, A. Cibinel with E. Le Floc'h). Technically: we will produce maps of stellar mass density and star-formation density from WFC3 and ACS images. Scientific goal: study of the morphology of galaxies in the "starburst" mode of star-formation, identification of interacting systems among galaxies following the SFR–Mstar fundamental relation, identification of stellar bars, evolution of the bulge-to-disk ratio and comparison with simulations obtained in our laboratory.

• We plan to dedicate substantial effort to link the properties of galaxies (stellar mass, SFR, nuclear activity) to those of their **dark matter haloes using clustering** and abundance matching techniques in order to characterize the effects of **environment** and the role of the phases of "**quenching**" in the formation of elliptical galaxies. This project will also enable us to position ourselves in the scientific exploitation of **Euclid** data, particularly on the link of "Legacy" and "cosmology" type analysis (e.g., tomography of the distribution of dark matter halos). In parallel, we will lead zoomed cosmological re-simulations (with our in-house multi-scale techniques e.g. Martig & Bournaud 2010 or other techniques) with high-resolution capturing the details of interstellar gas physics, star formation and AGN feeding. We will study the interaction between AGN outflows (and star-formation outflows) and infalling baryons to better understand the conditions that can lead to quenching of fresh gas infall and star formation.

(3) Unveiling the physics of large-scale structure formation in the dark-dominated universe

Context: The statistical properties of galaxy clusters (structure and scaling laws, mass function, and their evolution) are uniquely sensitive to cosmology and the physics of structure formation. The properties of local clusters ($z<0.2$) are now well established. Excellent quantitative agreement between X-ray derived dark matter profiles on relaxed clusters and theoretical prediction is observed. However there is not yet perfect convergence between X-ray and lensing studies and the critical test on the full population, and its evolution is a severe bottleneck. Similarly while the present-day gas entropy is well measured, pointing out the importance of AGN heating, the entropy evolution is critical to disentangle the effect of the various non-gravitational energy inputs. Finally the understanding of non-thermal component is in its infancy.
Current best cosmological constraints from clusters on the equation of state of the Dark Energy are from the X-ray observations with typical precision of $\delta w=\pm0.2$ (Vikhlinin et al. 2009; Mantz et al. 2010). Constraints are still limited by systematics due to selection and uncertainties on the mass-observable relations.

Challenge: Limited redshift leverage and selection bias have reduced the pertinence of our understanding until now.

Prospective for 2014-2018: Our work will build on the Planck survey and the XMM Very Large Program XXL, which will provide largely complementary cluster data sets. The Planck catalogue, based on the full mission, is expected to contain essentially all the rare, massive ($M > 7 \times 10^{14} M_{\odot}$) clusters in the Universe up to z=1, while the dominant population at the XXL sensitivity will be group scale objects at z~0.5. The former population is ideally suited for the study of dark matter collapse, as well as the dynamical evolution of baryons in the dark matter potential well, as it is the least affected by complex non-gravitational physics. The latter population is sensitive to such non-gravitational processes like galaxy feedback and are privileged targets for the understanding of these effects. Both samples have the necessary redshift leverage and size for competitive assessment of evolution, a key diagnostic to distinguish between various theoretical models. Both samples are relevant for cosmological studies and again are complementary in that respect as they probe different regime of the mass function and selection techniques.

Exploitation of the *Planck* survey
This will be conducted in synergy with other major surveys (**RASS, WISE, LOFAR/ASKAP**), together with intensive follow-up (**XMM** including the two recently granted Large Programs, **VLT, HST**) and numerical simulations to test the standard ΛCDM scenario and understand gravity driven structure formation (M. Arnaud, G. Pratt, H. Aussel, R. Teyssier and J.B. Melin (SPP) in coordination with Planck Working Group 5):
Continue active involvement in **Planck** collaboration to build unbiased mass-selected samples of massive galaxy clusters up to z~1. The Planck catalogue for the extended mission is expected to contain about ~1500 clusters detected at S/N>4. It will be published early 2014, but full validation and scientific follow-up (e.g. redshift estimate) will continue much beyond that date. We also envisage to develop novel detection techniques based on a simultaneous SZ and X-ray search, to extend the catalogue, with potential application to upcoming surveys like **e-Rosita** and as a pathfinder for other multi-wavelength cluster searches.
Provide a decisive **test of the ΛCDM model** of the dark matter gravitational collapse from full statistical analysis of the dark matter profiles of massive clusters, and of their evolution. Extension of the X-ray mass profile estimate to the full cluster population made possible from systematic confrontation of observations with tailor-made numerical simulations.
Assess the **dynamics of baryons** within the evolving dark matter potential: 1) provide the first census of the dark matter and hot and cold baryonic phases up to z~1, 2) measure the dynamical state, entropy and pressure profiles as probe of hierarchical formation and gravitational heating, 3) probe the redistribution of energy between the thermal gas and non-thermal components (relativistic particles and magnetic fields)
This work will provide inputs for the **cosmological exploitation of the Planck cluster sample** (e.g. evolution of $M\text{-}Y_{SZ}$ relation, of pressure profiles), to which we will continue to participate.

XXL: The Ultimate XMM extragalactic survey
End of 2010, a Very Large XMM program – the XXL survey - has been allocated to the SAP to perform a medium-deep survey of 50 deg2 (M. Pierre, PI). This will yield some 500 clusters of galaxies out to z~1.5 and provide constraints on the Dark Energy equation of state at the Stage III level (last step before missions to cover very large fractions of the sky), as advocated by the Dark Energy Task Force. The XXL survey, with numerous associated surveys in radio, IR, optical and UV, will enable truly innovative extragalactic studies:
-The cosmological analysis along with a careful modelling of the survey selection function will unveil the evolution of the **scaling relations** for the cluster mass-range pertaining to the survey. The associated STP-pol, ACT-pol (S-Z) and Subaru-HSC(lensing) guaranteed time surveys will allow us to pinpoint cluster masses and the properties of the ICM.
- A census of the **cluster population** in the 1<z<1.5 range.
- A detailed study of the **z~0.5 groups**, which constitute the dominant population at the XXL sensitivity
- Some **10 000 AGNs** will be detected in the survey; for the first time, we will be in a position to compute the X-ray AGN correlation function on very large scales.
- The **legacy aspect** is very important: by the completion of the survey, the consortium will deliver the full X-ray source lists and images, an online catalogue of clusters (http://xmm-lss.in2p3.fr:8080/xxldb/index.html) as well as a multi-wavelength source catalogue (http://cosmosdb.iasf-milano.inaf.it/XXL/)
- In parallel to the science analysis, four independent teams are performing **real-size XXL numerical simulations**. The comparison with the observed cluster and AGN populations will help interpreting the physical processes at work in structure formation. The four virtual XXL surveys will be made public under the same format as the real data.

LFEMI - Laboratoire Formation des Etoiles et Milieu Interstellaire

1. Présentation de l'unité

a. Historique

The LFEMI results from the fusion of the Galactic star formation group with the nearby galaxies and interstellar medium group. This occurred around the exploitation of the Herschel programs, as both groups were poised to exploit similar observations, large maps of similarly extended and sub-structured objects, i.e. dust clouds of various sizes and temperatures, and with complementary scientific objectives, namely understanding star formation processes on different physical scales.

b. Caractérisation de la recherche

The LFEMI is essentially a fundamental research laboratory, as its principle aim is to work at the frontier of knowledge in its areas of expertise (i.e. star formation processes and the physics of the interstellar medium). However, as a part of AIM and CEA, the LFEMI also has an implicit mission to provide momentum to the instrumental research and development at AIM. It does so by continuously identifying the key questions in its fields and participating in the different prospective exercises aimed at defining which future facilities the community will need. This is clearly demonstrated by the constant involvement of our members in instrument consortia at various maturity stages, as well as by the fact that a significant number of the grants we have received contain an instrument development part.

Even-though LFEMI is primarily connected with the academic research community, we devote a fraction of our activities to the public at large, given the strong appeal that our research fields have. We regularly volunteer to participate in science-related events, on a large range of audiences, from the local to the national ones.

2. Analyse SWOT et objectifs scientifiques de l'unité

Strengths

- Our research themes (initial conditions for star formation and the origin of the IMF, massive stars and the interstellar medium in galaxies) have led us to significant discoveries that gave us a high visibility. This is demonstrated through our success with national and international funding agencies: as PI, the LFEMI secured 1 Advanced ERC grant, 3 ANR projects, and 2 ASTRONET proposals. Not counting Herschel programs, we also obtained, as PI, about 34 observing proposals (including large programs on facilities such as IRAM PdBI).
- We gather in the laboratory comprehensive competences regarding Herschel, from the instrumental expertise, to the development of innovative data processing techniques (map-making, source extraction, large-scale structure identification).
- Our in-house general-use tools have reached maturity level: the dust emission model by F. Galliano, the multi-scale and multi-wavelength source extraction and structure detection algorithm of A. Men'shchikov, and the massively parallel inverse problem solver of P. Chanial are now used beyond their creators' circle. These tools will not only strengthen our own projects, but open new possibilities of collaborations.
- We attracted a significant number of PhD students and post-docs, 18 in total. Particular emphasis was placed on training for ALMA-related science and techniques, as well as physical modeling tools, in order to prepare for the future.
- We have significant stakes in future projects for large submillimeter focal plane arrays (ArTéMiS, NIKA) that offer interesting perspectives for our research themes.

Weaknesses

- No young scientist was recruited since F. Galliano in 2008. With the increased pressure from management responsibilities (M. Sauvage is Euclid Ground Segment Scientist, ERC and ANR PI-ships for P. André and S. Madden), our permanent staff has a reduced capacity to steer the science activities. With respect to our future initiatives on gas+dust modeling or interferometric observations, our inability to recruit some of our efficiently trained temporary staff is worrying.
- As the laboratory was formed from two entities, one concentrating on star formation in the Galaxy and one concentrating on the interstellar medium of galaxies, a risk exists of evolving toward a structure made of two unconnected groups within the same laboratory. A number of internal initiatives have been taken to steer us away from this risk, and the new generation of instruments offers clear opportunities as well (cf. Opportunities section).

Opportunities

- With the recruiting of P. Hennebelle in the numerical simulation laboratory (now Laboratoire de Simulation des Plasmas Astrophysiques, with which we have a long term collaboration), AIM is in a position to realize simulations of the star formation process from the smallest scales of the pre-stellar core to the large scale of galaxies themselves. Strong collaborations with this part of AIM can help us understand better key questions raised by the Herschel observations.
- Large submillimeter interferometric arrays (ALMA, NOEMA) are coming on-line. Thanks to their high spatial resolution, star-forming regions of nearby galaxies can be studied with as much details as what was offered by Herschel on Galactic high-mass star-forming regions. This is an opportunity to truly join the main science themes of the laboratory, as nearby galaxies enlarge the spectrum of interstellar physical conditions.
- The airborne SOFIA observatory is now operating. This telescope is well adapted to prolong our studies on the physical conditions around massive star clusters in nearby galaxies, a theme on which we have gained significant expertise with Herschel.
- P2IO LabEx: this structure gathers many local laboratories among which the Institut d'Astrophysique Spatiale. We have numerous individual collaborations with the IAS (in the framework of the Herschel programs for instance), but the LabEx offers the opportunity to reach a higher level.
- FOCUS LabEx: this program is geared toward the development of new detectors for the IR and sub-mm domains and has star formation as one its main scientific themes.

Threats

- The next period will see the transition to a post-Herschel era. We have now a demonstrated scientific track record that should allow us to fare well in the competition for time on international facilities, but the mode of access to new data will effectively radically change. This combines to the fact that the submillimeter projects in which we are actively participating (ArTéMis on Apex, NIKA for IRAM through the ORISTARS ERC) imply a change in our methods (e.g. no science exploitation support from CNES for instance) or are in the very distant future (SPICA).
- For a laboratory, and science themes, that relied heavily on space-borne submillimeter observations, the long-term European future is worrisome: there is no selected mission, or projects about to be submitted to future calls in the coming decade, and development of ground-based instrumentation is focused toward the optical and mid-IR domains for the ELT.

The main features of the LFEMI project

Looking at the principal milestones that lay in our future, it is quite clear that on a five-year term the Herschel data will feature prominently in our activities. However the period will offer many opportunities to expand on our research themes (using e.g. ALMA, SOFIA, and the new generations of large submillimeter cameras). This expansion beyond the Herschel-supported science will be necessary to prepare ourselves for the longer term, when facilities such as SPICA/Safari, and the JWST will become available.

To detail our project for the next reviewed period, we must realize that we have now reached a state where we understand the properties of the Herschel instruments, we have the tools needed to interpret the data and the fundamental questions raised by these new observations have been clearly laid out. We thus plan to devote most of our energy to the optimal exploitation of this very rich database, obviously along the lines of the two ANR projects (SYMPATICO and STARFICH) and the ERC AdG ORISTARS as their time spans will cover an important fraction of the period envisioned in this report. In their broad lines we describe here the main topics that our project will address and we will provide more details in section 3:

- Dynamical processes in star-forming regions. With the large and sensitive submillimeter interferometers ALMA and NOEMA, we shall investigate issues related to the mass accretion on filaments, pre-stellar cores and protostars. Indeed Herschel has revolutionized our view of the structure of star-forming regions, and the relations of this structure with the star formation process itself, but the dynamical information is severely lacking. Numerical simulations will be called upon to disentangle the complex dynamical signatures we will unveil.
- Massive stars near and far. Both through the identification of a critical column density threshold for massive dense core formation, and through the source-per-source estimation of the star formation rate in Galactic clouds, we can now directly compare Galactic and extragalactic star-forming processes. We will pursue this activity by identifying more regions that can bridge the divide between our Galaxy and its more distant neighbors, and by validating the consistency of the different tracers used on these vastly different scales.
- Accounting for all the ISM phases. As we developed our understanding of the ISM tracers, it has also become clear that very significant biases still exist in the dust and gas mass tracers, and that significant phases of the ISM have escaped detections, e.g. the so-called "dark gas" phase. We have demonstrated how important a precise accounting of the structure of the ISM is in interpreting the information from the physical tracers. We have developed a number of investigative tools for this purpose (e.g. FIR lines, Density-Temperature diagrams), and through modeling work and new observations (ArTéMis, SOFIA, ALMA), we plan on tackling this issue on a wide range of galactic environments.

3. Mise en œuvre du projet

Dynamical processes in star-forming regions

Altogether, the early results from Herschel imaging surveys have led us to build a scenario in which interstellar filaments and pre-stellar cores represent two fundamental steps in the star formation process: first, large-scale MHD turbulence generates filamentary clouds in the ISM; second, the densest filaments fragment into pre-stellar cores (and ultimately protostars) through gravitational instability. A number of critical issues are however still open that we intend to tackle during the next period, all related to the issue of the universality of this scenario for all mass scales.

The first of these deals with the formation of the filament network itself. For instance, in the turbulent formation picture, we would need to evidence low-velocity interstellar shocks associated to the filaments. In the same line of thought, the static picture revealed by the Herschel observations raises many questions regarding its evolution and we can wonder whether the thermally-subcritical filaments observed with Herschel are long-lived structures with thermally-dominated velocity dispersions or transient, highly-turbulent structures. This is connected to the fate of this subcritical filaments, namely whether they evolve into supercritical filaments by gaining mass or disperse in the diffuse ISM? Given that we have identified that the filamentary structure is the first stage in the star formation process, understanding its formation and evolution is key to understanding the formation of stars themselves and particularly the efficiency of the process.

On the theoretical front, we will perform magneto-hydrodynamic (MHD) numerical simulations with the RAMSES code including cooling, self-gravity, and magnetic fields. These simulations will be used to investigate the properties of MHD turbulence in a thermally bi-stable flow (such as atomic hydrogen), as well as the properties of the filaments and clumps formed in such a flow. We will compare the statistical distributions of properties such as filament thickness in the simulations with the observed distributions. We expect these quantitative comparisons to yield much insight into the mechanism responsible for the formation of filamentary molecular clouds.

On the observational front, we have an approved Herschel project (OT1_pandre_4, 58.3 hr of priority 1 time) to test the hypothesis that filaments are formed behind low-velocity interstellar shock waves, by searching for shock signatures in the form of CII, CI, CO emission lines from the post-shock gas. We also plan to use the NRAO Green Bank telescope (GBT) and the Nançay radio telescope to carry out wide-field mapping of atomic gas in several cloud complexes of the Gould Belt. These telescopes can map fields of linear sizes ~ 10-30 pc, at a spatial resolution ~ 0.4 pc at the distance of the nearest molecular clouds (d = 140 pc). This is well matched to the size of the above-mentioned numerical simulations and will therefore allow us to test the theoretical view of molecular cloud formation from atomic gas.

On the instrumental front, in collaboration with the NIKA consortium as part of the ORISTARS project, we will take advantage the polarization channel that we are developing for the next generation large-format bolometer array planned by IRAM for the 30m telescope. This will allow polarized 1.2 mm dust continuum emission to be mapped on scales ranging from individual cores to cluster-forming clouds, revealing the morphology of the magnetic field lines in molecular clouds, thereby helping to clarify the role of magnetic fields in generating filaments and forming pre-stellar cores.

The second aspect of this theme deals with the onset of gravitational instabilities in filaments, as this is the key step leading to the formation of pre-stellar cores. To confirm/refine the picture of core formation by gravitational instability within filaments, it is crucial to characterize the velocity field of the filaments seen in the Herschel dust continuum images. In particular, the simple gravitational stability criterion used in André et al. (2010) assumes that the filaments have thermally-dominated velocity dispersions when they approach the verge of instability. However, the non-thermal (turbulent) velocity dispersion may not always be small compared to the thermal velocity dispersion, in which case the critical mass per unit length at which filaments become unstable can significantly change. For a proper gravitational stability assessment, the 1-dimensional velocity dispersion within the filaments should thus be measured. This can be done by mapping lines such as ^{12}CO(1-0), ^{13}CO(1-0), and C^{18}O(1-0) to probe the low-density outer envelopes of molecular filaments, and dense gas tracers such as N_2H^+(1-0) to probe the inner crest of the densest filaments.

If the picture of the star formation process outlined here is even approximately correct, we also expect a significant fraction of the thermally supercritical filaments seen with Herschel to be globally gravitationally unstable and to undergo large-scale collapse/contraction motions, eventually leading to the formation of proto-clusters. We thus plan to use ground-based (sub-) millimeter radio telescopes, such as the IRAM 30m or the APEX 12m telescopes, to carry out follow-up molecular line studies of a representative sub-sample of the filaments identified with Herschel in a wide range of star-forming clouds, in order to set constraints on the dynamics of filament fragmentation and core formation. The methodology we propose to follow is directly inspired from our successful study of the NGC 2264-C cluster-forming clump (Peretto et al. 2006, 2007). We will use the Herschel submillimeter dust continuum maps to trace the spatial distribution of mass, molecular line mapping in both optically thick and optically thin tracers to set constraints on the velocity fields, radiative transfer calculations to derive quantitative properties of the velocity fields, and numerical MHD simulations to derive self-consistent physical models. We note that, while quite successful, the simulations of Peretto et al. (2007) did not include magnetic fields. Using the MHD version of the AMR code RAMSES, we intend to perform new, dedicated simulations of several cluster-forming clumps, such as the densest filaments revealed by the Herschel Gould Belt survey, which will include magnetic support self-consistently.

Massive stars near and far

With the HOBYS survey, we have been able for the first time to statistically study the formation of 10-20 $M_{\odot}$ stars in 100 pc molecular complexes in nearest portion of the first Galactic arm towards us (Motte et al. 2010). Exploitation of the survey is far from over; furthermore, other surveys by Herschel such as the Hi-GAL have mapped more star-forming regions of the Galaxy containing massive protostars. Thus a substantial amount of work in the next period will be dedicated to a proper and as complete as possible accounting of massive proto-stars in large Galactic complexes. This emphasis on massive stars in our galaxy is quite natural in the LFEMI given that it is that fraction of the IMF that has the most detectable impact on the ISM properties of galaxies, and thus on their FIR and submillimeter SEDs. Therefore it is through the study of massive star formation that the laboratory truly finds its unity.

A first aspect of this work will be a natural extension of the investigations detailed above. Indeed the question still remains whether ridges, the high column density counterparts of the ubiquitous filaments, in which massive proto-stars are found, require a different mass accretion mechanism or not. The scenario that is developing for low column density filaments has turbulence and gravity slowly concentrating matter on and along the filaments. Yet ridges are most probably forming and growing through a more dynamical process such as free-fall or converging flows on the most massive structures. Given the physical size of the structure, we wish to obtain dynamical information on scales from 10 to 0.1 pc, i.e. comparable to the characteristic widths of filaments. This is possible, using instruments such as HERA and EMIR on the IRAM 30m, and as of today we have indeed shown that the DR21 and W43 are globally free-falling (Schneider et al. 2011, Motte et al. in prep.) and display shocked gas (Nguyen Luong et al. in prep.). We intend to use the Herschel surveys to focus on the many-more interesting ridges for these dynamical studies, in order to identify whether the formation of massive dense cores involves another physical threshold in gas density.

A second important aspect of this work is that these massive star-forming regions allow an in-situ study of the star-formation process in its "high-state", i.e. close to the so-called starburst regime encountered in galaxies. Given that the regions have been surveyed at high spatial resolution with Spitzer and Herschel, it is now possible to directly count the number of sources at different stages of the formation process, and thus measure past, present and future star formation rates. We will perform these counts in a systematic way over a large number of Galactic regions that we have surveyed (e.g. Cygnus X, W43). This opens very interesting perspectives both toward extragalactic studies and simulation studies, with an ultimate prospect of closing the loop between these two fields, i.e. providing a physically-based recipe for computing the star formation rate in simulated galaxies.

On the simulation side, the interest of these Galactic regions is that we can estimate the star formation rate as well as measure the properties of the molecular cloud in which this is taking place (e.g. total mass and mass distribution as a function of physical scale). This allows the computation of quantities that can directly be related to the simulation such as the star-formation rate per free-fall time. Another such "observable" is the mass transfer of gas from pre-stellar cores to massive stars: comparing the evolution of the star formation rate as a function of time or total mass involved can reveal how cores fragment or merge as they evolve. Thus we plan to interact tightly with the numerical simulation laboratory to define which features can be extracted from our observations that provide the strongest constraints on the simulation free parameters.

On the extragalactic side, we have already shown that we observe in Galactic star-forming regions a relation between the star formation rate surface density and the gas column density that is very similar to the Schmidt-Kennicutt law observed in galaxies. Given the practical importance of the Schmidt-Kennicutt law (i.e. it is the foundation on which almost all numerical recipes for star formation rest) this observation needs to be studied in many more details to certify that it is not coincidental. Indeed there are large differences between the way the star formation rate can be measured in Galactic molecular clouds and on the scale of galaxies, and the beam dilution that occurs when molecular clouds are observed in external galaxies significantly affect what we measure as a column density. However once again, we now have in our possession a broad sample of Galactic star forming regions where these investigations can be done. In the coming period we shall also benefit from large ground-based submillimeter cameras (e.g. ArTéMiS) that we shall use to obtain higher resolution maps of our regions. This will be quite important to identify possible substructure in the massive cores, which can bias our estimation of the star formation rate.

Accounting for all the ISM phases

In order to preserve our originality among our competitors and partners, our project will favor very detailed studies of nearby objects, with high sensitivity and spatial resolution. Our goal is to refine our physical diagnostics, and remove the various degeneracies (e.g. between the ISM structure and the physical conditions or between the dark gas and exotic grains), which are currently limiting our interpretations. The body of experimental data that we plan to exploit will consist in the rich archive of Herschel spectroscopic and photometric data that we have accumulated thanks to our participation to a wide range of programs (augmented when needed by the publicly available Herschel archive), while follow-up with new ground-based and air-born telescopes will expand on sensitivity, wavelength range and spatial resolution (e.g. SOFIA, CCAT, ALMA, LMT and APEX, etc.). The overall plan is to use the period to enhance our expertise and participate in the emergence of research themes that will be hot topics for SPICA/SAFARI, an instrument dedicated to FIR and submillimeter spectroscopy that should fly at the end of the decade.

The SPIRE FTS and the PACS spectrometer gave us access to the full rotational ladder of CO along with the highest quality FIR and submillimeter fine structure and molecular transitions. These can be turned into valuable diagnostics of density, temperature and column density, and trace the energy sources in the molecular, atomic and ionized ISM. In particular, we have shown (Lebouteiller et al. 2012, accepted by A&A, Cormier at al. 2012, submitted to A&A) how the combination of [NII] (122 and 205 µm), [OI] 63 µm and [CII] 158 µm can be used to trace a wide range of ISM phases, from the Warm Ionized Medium to the Cold Neutral Medium and the PDRs, revealing the ambiguities associated with the broadly used [CII] line. We are also investigating how the Temperature-Column Density diagrams of star-forming clouds can reveal the different phases in the clouds (Didelon et al., in preparation), providing further constraints to the line-only diagnostics. This broad observational basis will make for a more realistic approach to the structure of the ISM of galaxies, in the sense that it will capture more of its intrinsic complexity. Our group has already made significant steps toward complex multi-phase models of galaxies: we produced the general dust model of Galliano et al. (2011) and we are now implementing this model in a multipurpose tool to provide Bayesian SED fitting, continuum radiation transfer, and computation of non-thermal grain emission (Galliano et al., in preparation). To complete our capacities to decipher the FIR-submillimeter spectral energy distribution we need to also treat the line emission and to this aim we will link the excellent photoionization physics of CLOUDY to a better-suited PDR model that has more predictability for the molecular gas physics and can deal with the PDR geometry issues: i.e. include 3D geometry in PDR codes. This will allow the generation of clumpy ISM models, which we know are essential to represent the multiphase ISM of real galaxies. This is the aim of the efforts we will develop in the SYMPATICO ANR project, in collaboration with the LUTH (Observatoire de Paris). By linking IR to mm dust and gas observations, we will be able to study the heating and cooling of all ISM phases and explore how this is related to the star formation, ISM structure, and the propagation of the ISRF in galaxies.

In particular, we plan to use this comprehensive approach to move beyond the famous X_{CO} obstacle (i.e. the extremely uncertain relation between the CO luminosity and the H_2 mass). This will be beneficial for the interpretations deployed on global scales of galaxies where different assumptions on the X_{CO} value can possibly lead to, or blur, the identification of different regimes of star formation. This work will be part of the interface we intend to keep active with the LCEG at AIM.

We will, however, keep the emphasis on nearby objects, as it is especially well suited to the expertise present in the LFEMI. It will open areas of fruitful collaborations on Galactic and extragalactic star-forming regions: for instance, we can study on a wide range of physical scales the impact of the past, present and future star formation activity in the traces it leaves on turbulence, cosmic rays, or magnetic fields (that we can access through velocity information, high-energy gamma-rays, and polarization studies).

Application of this suite of tools to our rich observational database that will provide several well-constrained empirical diagnostics of the physical conditions in galaxies, as well as qualitative understanding of the nature (composition and physical conditions) of the ISM in galaxies of different masses and evolutionary stages.

In future development, these studies will also connect to the issues of the evolution of galaxies. In particular, we will study dust production and destruction mechanisms, as these processes are crucial to explain the evolution of the gas-to-dust ratio as a function of metallicity, another highly uncertain ISM parameter. We plan on studying these mechanisms both through the modeling of the Herschel observations of low-metallicity object as well as through a dedicated network (called SUNDANCE for "SUperNovae, Dust, And its Cosmic Evolution: observations and theory) that P. Bouchet will submit to the Marie Curie Actions. In this way, we will understand the first stages of dust production at low metallicity, and explore the deviation from the trend of metal-to-dust mass ratio vary as a function of metallicity.

The further developments of our ISM modeling tools will also let us test the nature of the mysterious submillimeter excess in dwarf galaxies that we were the first to unveil. Theoretical modeling of spinning grains, as well as grain cross-sections varying with the physical conditions (temperature, metallicity, UV field, etc.) are currently advocated to explain the excess. Combining our rich observations, with an increase capacity to disentangle the phases giving rise to the emission, and the possibility to perform high-resolution continuum follow-up observations will definitely enable us to progress in our understanding of this regime.

LDEE - Laboratoire Dynamique des Etoile et de leur Environnement

1. Présentation de l'unité

LDEE is a fundamental astrophysics research laboratory seeking to better understand stars and their environment. As in most academic research entity, the permanent members of LDEE supervise masters & PhD students, postdocs and CDD's who are actively participating to the research activity. It also regularly participates and organizes public outreach events. LDEE will contribute to societal challenges via its project of developing solar activity forecasting tools. Through various projects (SO/STIX, Herschel/ISM, COAST/Simulations, Tidal effects, etc…) LDEE is exchanging regularly with other AIM laboratories contributing to its overall scientific goals. Through its numerous international collaborations LDEE is developing state-of-the-art research in stellar dynamics and interactions with their surroundings.

2. Analyse SWOT et objectifs scientifiques de l'unité

Strength: -3 Complementary & Synergistic approaches: Theory, Observations/Analysis (ground and space) and Simulations/Models
-High citation publications count (240+ ref papers, 4600+ citations) for a team of 4 tenure researchers
-Several funded projects via grants/networks: ERC-STARS2, ANR-Toupies & IDEE, FP7 networks IRSES, SPACE-INN
-Various national funding sources: PNST, PNPS, PNP, CNES, Campus Spatial
-High Attractivity: Many high quality PhD students + experienced postdocs from US, Japan, EU
-Strong links between inner and outer stellar dynamics, between astero/sismo/magnetism/planet search, between evolved and massive stars, between star-planet/disk/MIS interactions
-World-leading simulation programs & tools (ASH, PLUTO, STELEM, STAREVOL); new ASH-FD scaling beyond 10,000+ cores, simulations > 2 billions cells – Prize La Recherche 2011 in Astrophysics
Potentially leads to discovery or observation confirmation via direct simulations
- Leader for two international code benchmarks (dynamo & convection)
-World-leading data analysis pipelines (light curves treatment for Kepler-KASC & calibration – analysis of SOHO/Golf)
- World-leading theoretical results and prescriptions for stellar and multi-layers giant planets, implemented in most stellar evolution and planetary codes
- Our involvement in various teaching programs (M2S, Master Fusion, ENSTA, PostMaster IdF,…) help us find bright/motivated students
- Many keynote lectures and invited reviews, high visibility in international conferences; Several « faits marquants »
- We have an established strong national network via various key large observation programs: MAGIC, Mimes/Binamics/Matysse, satellites CoRoT, SoHO-GOLF and institutes LESIA, IAS, IRAP, IPAG, IPGP, IRFM- Fusion,
- Likewise, we have many international scientific links via SoHO, *Kepler* KASC, Herschel, our MOUs with CU Boulder and STAREVOL consortium, HAO, JAXA/NAOJ, LMSAL, St Andrews, IAC, Obs Genève, U. Birmingham, U. Sydney, ….
-Links within CEA/AIM: Cosmostat: wavelet/MRE; ADP: tides dissipation/Moon formation; COAST: Simulations; LFEMI: formation/MIS
-Active participation in STIX and Solar Orbiter – Lien LSIS – Lesia (N. Vilmer)

Weakness: Overbooked tenure scientists: Need to reinforce Laboratory following recent Cosmic Vision selection (SO) in order to prepare science return
-Fundings post STARS2/Toupies era
-Fundings post GOLF, Herschel, CoRoT
-Possibility (time-wise) of maintaining – developing 3-D codes and analysis pipelines
-Difficulty of most committee to fund real innovative/risky projects

Opportunity:
- Our direct involvement in Solar Orbiter via STIX will give us direct access to top of the line solar data and constraints, likewise with our participation to Jaxa/Solar C selection panel and our link to NAOJ and Kyoto University.
- The fast development and (competitive) access to supercomputing infrastructure at the national and European level CEA TGCC-GENCI-PRACE allow us to answer key scientific questions and to push the realism of our simulations to the forefront thanks to our state-of-the-art parallel codes.
- Development of new collaborations within LabEx P2IO/UnivEarthS, Idex Paris-Sorbonne-Cité, Campus Spatial, DIM ACAV, FP7 Network, ERC. Our main research themes centered on Stars-environment dynamic and interaction and habitability conditions are among the main objectives of many of these funding bodies.
- The European Space Situation Awareness (SSA) program puts forward the need for an integrated solar vision and model and to the development of tools that can serve the civil society via solar activity predictions program using modern data assimilation techniques such as the ones developed in LDEE
- The selection of JUICE/Echoes, or PLATO, or PLAVI will reinforce our leading position in analysis/calibration of seismic data, 3-D simulations of large scale flows and dynamos in star and planets and theoretical prescriptions for stars and planets.
- Main research topics of LDEE (coupling in a common view observations, simulations and theoretical development of stars, planets and their interactions) is in line with ESA's Cosmic Vision and open new opportunities in space research

Threat :
- Access to supercomputing time due to higher Pressure factor

- Radical change in parallel supercomputing Infrastructures – survival of simulations codes
- Multiplicity of funding bodies – time spent on proposal vs science/research
- Lost of key postdocs to higher bidder
- Continuity of research team (knowledge) due to the multiplication of soft money/non tenured position
- Non selection of PLATO as M3 or PLAVI as S1 or Di-Echoes as part of JUICE payload

3. Mise en œuvre du projet

Over 2014-2018, LDEE's main scientific objective is to answer the central question :

How do stars and their environment work and interact ?

To answer this fundamental astrophysical question we have divided our research efforts into two main themes : *A) Dynamics of stars* and *B) Physics of stellar environment*. This project rest on the strong scientific results to understand and characterize the dynamics of stars of various types that we have published over the 2007-2012 period, with the clear objective of consolidating our current leading position in that field as well as to expand our blossoming research activity on the interactions between stars and their environment bringing this more recent activity to a similar level of maturity than task A.

A) Dynamics of stars

We seek to answer the following two major questions:

- How can we explain the history of stellar rotation and their abundances?
- What triggers magnetic activity and cycles in stars?

A.1) Simulations and models of the Sun and stars

In order to model stellar structure, evolution and dynamics on short (minutes to centuries) and secular (millenia to billion years) time scales one must take into account macroscopic physical processes that redistribute heat, chemical species, magnetic field and angular momentum. Processes such as convection, turbulence, rotation, waves, magnetic field and their associated instabilites are key to study and model and LDEE has largely contributed to the latest progress made in that domain. Over 2014-2018 we will consolidate our efforts by modeling and simulating stars of various masses and ages in 1-D, 2-D and 3-D thanks to our theoretical work and set of modern state-of-the-art numerical tools (STAREVOL, STELEM, ASH).

We will:
- Extend our analytical prescriptions of MHD processes to include a full description of angular-momentum history and waves transport in radiative interior; providing scaling laws and formulations for stellar evolution codes
- Develop 2-D solar and stellar dynamo models with nonlinear feedback (of the Malkus-Proctor type) and applied external torques (wind, tides) to model over long time scales stellar magnetism and activity
- Compute 3-D nonlinear high-resolution models of stellar convection, rotation and dynamo, seeking to determine what set their rotation profiles, stellar cycles and periods, the role of tachoclines and gravito-internial-Alfven waves
- Obtain self-consistent magnetic flux emergence in dynamo simulations and study the link between cycles, polar field reversals and flux transport and cancellation in full 3-D global nonlinear settings
- Model high-energy particles acceleration in solar flares in support of SO/STIX from 3-D MHD configurations of turbulent magnetic current sheets using the PLUTO code
- Develop and seek collaborations to post process our simulations to model UV, X fluxes, g waves detectability levels

We anticipate delivering the following milestones:
- 2yr: STELEM dynamo models with Lorentz force feedback and wind torque; G-K stars rotation and activity study; 3-D models of selected Kepler target stars; analytical theory and prescriptions for G-waves excitation and propagation in the presence of magnetic field
- 5 yr: 1-D MHD secular STAREVOL solar and stellar models; 1-D data grid portal of Omega(r) profile deduced from 3-D ASH models of various mass and rotation rates; Full gravito-inertial-Alfven waves theoretical treatment; Solar-like stars dynamo simulations with self-consistent flux emergence; High resolution simulation of the Sun (6,000^3) down to supergranulation; 11 yr solar cycle prediction/forecasting ; Post treatment pipeline of stellar numerical simulations (X, UV, etc…) ; Preparation of SO/STIX simulations and data analysis post processing ; 2 International meetings
- 10 yr: Grand challenge 3-D whole Sun models (12,000^3 resolution) in order to model convective scales down to granulation and small magnetic features (pores) and its nonlinear coupling to a deep radiative interior in a global spherical code; Interpretation SO/STIX data by state-of-the-art particle acceleration simulations in realistic 3-D magnetic field topology; Derive a complete MHD+waves framework for stellar evolution.

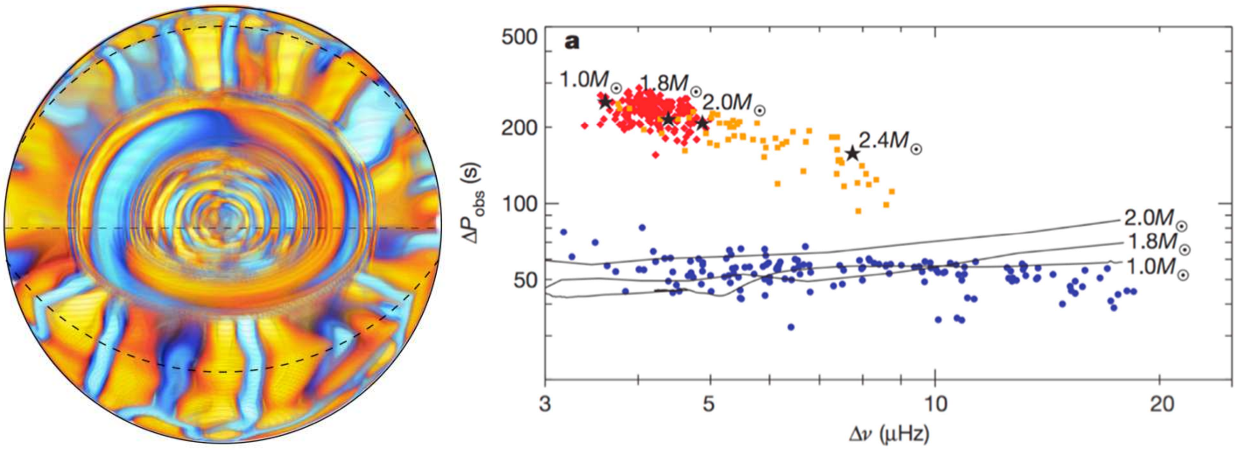


Fig 1: Left: Color rendering of the normalized radial velocity in a 3-D whole Sun model from which we have omitted one quadrant in order to see the internal waves propagating in the deep radiative interior (Brun et al. 2011). Right: Seismic H-R diagram showing how seismology can help distinguishing between RGB stars burning H or He in their core (Bedding,…, Garcia et al. 2011).

A.2) Observations and new constraints

Over 2014-2018, the extension of both the NASA's *Kepler* mission till 2016 and the French-led CoRoT satellite for 3.5 more years will provide an unprecedented set of data never obtained before in asteroseismology. On the one hand, more than seven years of continuous high-precision photometry on the *Kepler* targets will be available reaching a frequency resolution never obtained in a star other than the Sun, for hundreds of solar-like stars and even thousands of red giants. On the other hand, CoRoT --with its ability to observe bright stars in different regions in the galaxy-- will allow the study of particular stars for which we will have a much better ground-based follow up because they will be brighter than the *Kepler* ones, as well as several thousands of red giants in several directions of the galaxy outside the solar neighbourhood.

We expect to:

-Progress on the understanding of the physical mechanisms driving stellar magnetic activity cycles and dynamos by measuring activity cycles of *Kepler* stars thanks to the long datasets available. Indeed, with asteroseismology we will be able to measure, at the same time, the surface and the internal (differential) rotation, the properties of the convection zones (sizes and characteristic time scales) and the periods of the magnetic cycles (both surface and internal activity).

-Put new constraints on the temporal distribution of magnetic activity cycles as well as be able to establish the frequency in which two magnetic activity cycles (a short and a long one) are present in solar-like stars.

-Progress on the study of the chemical evolution of Galactic stellar populations by coupling the asteroseismic measurements providing masses, radius and ages with spectroscopic measurements done by the APOGEE survey (APOKAS survey).

-Study if there any statistical differences in the intrinsic properties of stars depending if they are isolated or if they are harboring planets

- with BinaMICS, we will obtain constraints on magnetism of all classes of stars in binary and multiple systems. Obtained results will give important information on the impact of gravitational interactions on stellar magnetism and also on MHD interactions in such systems.

- Participate to the development of a data analysis pipeline for SO/STIX in link with our colleagues in Lesia while developing turbulent MHD numerical simulations with the MHD PLUTO code.

- Continue the development of a physically based solar dynamo 11-yr cycle forecast model, working on various proxies

The expected deliverables would be:

-2yr: to create catalogues of seismic observables -including surface and internal (differential) rotation-, and inferred global stellar properties for *Kepler* and CoRoT solar-like and red giant stars

-2yr: provide the length of the stellar cycles, surface rotation, depth of the convection zone, and characteristic time of the granulation for the stars in which stellar cycles could be measured.

-5yr: to produce all the necessary hardware and scientific pipelines in support of the PLANET-VISION mission If it is selected by ESA.

-5yr: to produce a merged spectroscopic and seismic catalogue inside the APOKAS (APOGEE + KEPLER) consortium

- 5yr: Operational solar data assimilation (variational method) based on a Babcock-Leigthon dynamo model to forecast solar activity

-10yr: For those asteroseismic targets observed by GAIA, we will be able to infer a mass estimation down to a few per cent by combining the seismic variables with the radius obtained from GAIA's distances and a good estimation of Teff, and everything being approximately model independent.

-10yr: to provide, if PLATO is selected as a M3 mission, the software and the required management necessary to accomplish with our commitments within the consortium.

B) Physics of stellar environment

We seek to answer the following two major questions:

- How do stars interact with their environment and which processes are dominant?
- What is the impact of these interactions on habitability?

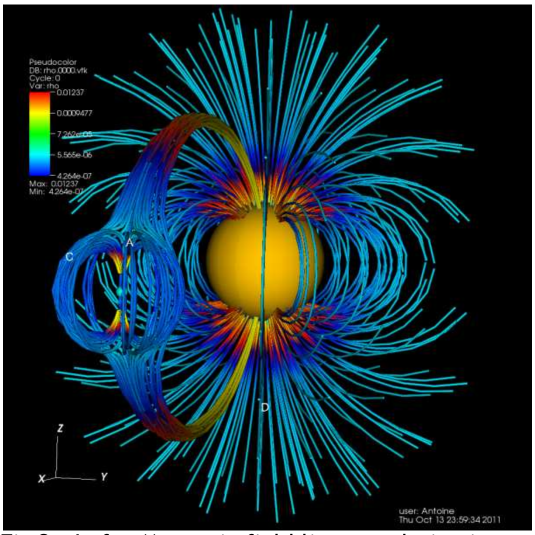
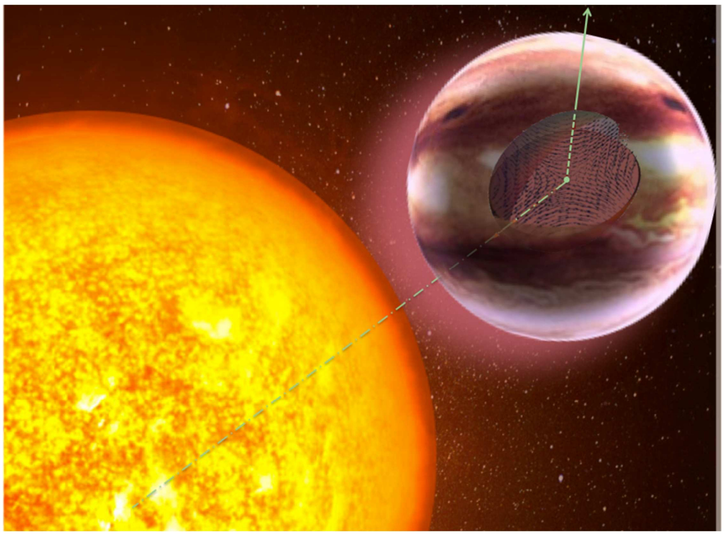



Fig 2 : Left : Magnetic field lines rendering in a star-planet interaction (SPI) configurations, in which both the star and the planet are magnetized (Strugarek et al. 2012). Right : Rendering of the elastic deformation of a Hot Jupiter's core due to the host star tidal interaction (Remus et al. 2012).

B.1) Star-Environment Interactions (tides, MHD, radiations)

As a continuity of what has been achieved during the period 2007-2012, the general study of the interactions of stars with their environment will be strengthen. The key questions on which we want to answer are: what are the physical processes that drive the Star Interstellar Medium Interactions (SISMI), the Star Planet Interactions (SPI), the Star Star Interactions (SSI) and the Planet Satellite Interactions (PSI). To answer this question, LDEE members will continue to develop coherent dynamical models of gravitational and MHD interactions in such systems. Then, strong efforts will be devoted to improve the modeling of stellar winds and of their interactions with their surrounding media (other stellar or planetary magnetospheres, region of stellar and planetary formation) and of tidal interactions.

To reach these scientific objectives, we will:

- Develop MHD models and simulations of stellar winds for all classes of stars using the PLUTO code taking into account realistic stellar magnetic configurations obtained in A.1. with 2D and 3D simulations or observed through spectropolarimetric observations (end of MAPP/MiMeS, BinaMICS and Matysse).
- Develop complete simulations of the interactions of stellar winds with planetary magnetospheres (SPI, preparation and exploitation of SPIROU) or stellar magnetospheres in the case of binary (multiple) stars (SSI, BinaMICs) and with the regions of formation of stellar and planetary systems (SISMI).
- Develop integrated models of tidal dissipation in stellar and in planetary interiors and of their consequences on stellar and planetary evolution (tidal heating, spins and internal redistribution of angular momentum) and on systems architecture (orbital evolution).
- Develop models of dynamical evolution of systems, taking into account simultaneously the obtained models of gravitational and MHD interactions.

We anticipate delivering the following milestones:

- 2yr: stellar wind models for various classes of stars; model of the interaction between massive star winds and stellar formation regions; advanced models of magnetospheric interactions in star-planet systems and in binary stars; first integrated models of tidal dissipation in stellar and planetary interiors.
- 5 yr: Deliver to the community complete grids of the value of the efficiency of tidal dissipation as a function of the stellar and planetary types and related applications to the Solar system bodies and to exoplanets; models of dynamical evolution of systems taking simultaneously into account realistic tidal torques and those related to MHD interactions (stellar winds and magnetospheric interactions);
- 10 yr: Global treatment of angular momentum exchanges in planetary systems taking into account both gravitational and MHD interactions and the internal exchanges of angular momentum both in stellar and in planetary interiors; obtain a comprehension of the impact of such interactions on the systems architecture (and their stability) and of their global impact on habitability conditions. Obtained results will be applied to systems studied by CoRoT, KEPLER and JWST and by PLAVI, PLATO, ECHO, etc. if they are selected. Moreover, systems of giant planets hosting moons like the Jovian one will be studied for their possible habitability (JUICE).

B.2) Habitability

Planet habitability obeys to various definitions. It is linked to the presence of liquid water on the planetary (or moon) surface in a thermodynamic state between the water triple point (273 K) and the critical temperature point (647 K). This led to define a *circumstellar habitable zone* in function of the star luminosity (or mass) and its distance to the planets. Habitability is actually a complex and dynamic concept and can be defined as the relation between a planet (or a moon) and its environments, and their co-evolution. Habitability is first a property of a planet-star system, and then becomes the property of its internal and external environments. This includes the relation between the star and its galactic environment, the relation between the planets and the central star, between the planets and their moon.

Based on LDEE growing expertises in Star Interstellar Medium Interactions, Star Planet Interactions, the Star Star Interactions and the Planet Satellite Interactions, we aim to tackle the complex concept of habitability. In particular, we will characterize the importance of a given interacting mode in shaping the conditions for habitability. Habitability will be studied under two angles:

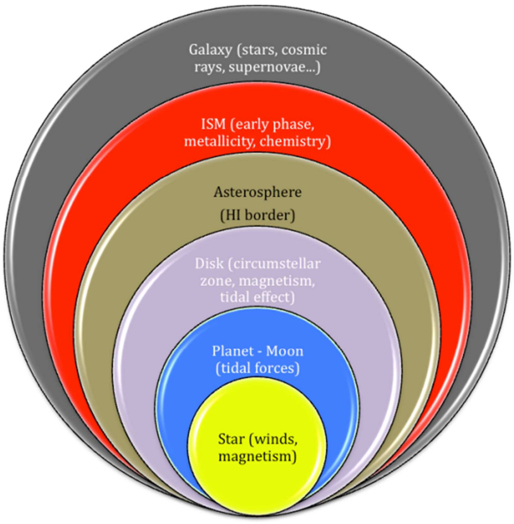


Fig 3 : Star environment and interactions between the internal zone (planet, moon, disk, astrosphere) and the external zone (interstellar medium, galactic).

- Internal impact on habitability: planet – moon interaction (tidal effects, energy balance, water phase state, magnetic field), star – planet interaction (energy balance, UV, magnetism, green-house effect)
- External impact on habitability: star – galaxy interaction (metallicity, chemistry, cosmic rays, impact of early phase of star formation in the metallicity and chemistry).

Methodology: simulation, theory, observation (SKA for radio search in HI, ELT for visible/IR imaging, JWST for search for early phases, Herschel archives for interstellar medium).

We anticipate delivering the following milestones:

- 2 yr: prospective on habitability, research of astronomical factors in which LDEE can bring values to the debate.
- 5 yr: application of LDEE expertise to habitability and proposition of criteria to exoplanets.
- 10 yr: search for habitable zones under new criteria.

Facilities useful in habitability and interaction studies:

SKA (radio detection, ionization, HI) will image the thermal emission from dust in the habitable zone in unprecedented detail and will show where dust evolves from micron sized interstellar particles to centimeter sized “pebbles”, the first step in assembling Earth-like planets. Other facilities will contribute such as ELT: Direct imaging of habitable planets; ALMA, APEX, and NOEMA/IRAM: Astrochemistry; Herschel: Early phase of star and planet formation in the interstellar environment; JWST: Early phase of star and planet formation; Cassini, JUICE: Habitability in icy moons of giant planets.

Factual Summary:

Methodology: We intend to manage the existing programs and grants we are PI or CO-I of such as: SO/STIX; ANR Toupies/IDEE; FP7 networks IRSES, Space-Inn ; LP Binamics/Matysse), contribute to driving science via the various committees we are members of (PNST, IAU WG on solar-stellar connections, Kepler-KASK, MoU on stellar dynamo and on 1-D stellar evolution (STAREVOL)) and search for new fundings reinforcing our main scientific objectives.

Hiring policy: 1) Solar dynamics in support of Solar-Orbiter/STIX; 2) Asteroseismology in support of Plato/Plavi

Publication policies: We will maintain our high publication rates by publishing articles in major astrophysical journal, aiming for Nature/Science when appropriate or by coordinating books and reviews (ISSI, CUP, etc…)

Public outreach: Continue our efforts to organize general public conference, interviews/articles in popular science magazines, Herschel-App and Astrophysical-TV on daily motions

Teaching/Supervising: We will continue being involve in PhDs and postdocs supervision, having between 1 and 2 PhD students per year and as many postdocs that our present and future grants will afford us. We will continue teaching in various Master (graduate) courses, as this is key to find the best students and to pass on to the young generation our passion for research and astrophysics.

Grants/time allocations: We will seek financial support through for instance FP8, ANR, IDEX to bridge the gap between the end of the quinquennal (Dec 2018) and our existing fundings (most would be over by the end of 2016). Since many tasks require HPC supercomputing time allocation we will continue requesting of order 20 Million node hours, amount we have been securing through Genci and now Prace over the last few years. Likewise we will compete for telescope time, having already secured our participation in two large programs at CFHT.

LADP - Laboratoire Anneaux, Disques et Planètes

1. Présentation de l'unité

a. Team history

The LADP has been created in 2010 with the aim of offering a new visibility to planetology and exo-planetology research within the AIM Laboratory. This has effectively boosted its attractiveness to students and post-docs, who have definitely contributed to science results and to the development of transversal collaborations within the team. The group, originally composed of 2 permanent members (A. Brahic, C. Ferrari) took roots in the SAp in 1996 to insure the scientific return of the CIRS-CASSINI instrument. The collaboration was further extended to the exploration of the Saturn system by the ISS cameras. The main research theme has long been the dynamics and properties of planetary rings, as driven by Pr. A. Brahic (ISS-CASSINI Team member) and supported by the unrivalled Voyager and Cassini missions data. To this regard, the team is unique at the international level for its competences, knowledge and excellence in planetary rings research. The group has grown up in the early 2000s with 2 more permanent members (S. Charnoz & E. Pantin) to address the question of planetary formation by coupling its competence in disk dynamics with the search and characterization of new circumstellar disks and the development of infrared instruments (VLT/VISIR, JWST/MIRI). In 2006, S. Rodriguez joined the Team and brought his experience in studying planetary surfaces and atmospheres in the near-IR with the VIMS-CASSINI spectrometer.

2. Analyse SWOT et objectifs scientifiques de l'unité

- **Strengths.** The LADP has the ability to address the questions on the evolution of planetary rings, satellites and of grains in circumstellar disks (proto-planetary or debris) through theory, simulation, modelling and multi-wavelength observations. Most members share a common culture in disks or in radiative transfer and are able to work together on very diverse objects. A major asset of the Team is its large implication in the CASSINI mission on 3 different remote sensing instruments, allowing a multi-wavelength approach that provides independent diagnostics and observables of a same object. The Team has a definite expertise in dynamics of disks and related numerical simulation, in radiative transfer, in multi-wavelength data analysis and processing, or in the development and exploitation of infrared spectro-imagers. The Team has the expertise to handle a large multi-instrumental and multi-object database, both from ground-based telescopes or space missions. The Team is also fitted to address multi-scale problems, from the size of a grain to that of a large terrestrial body with an atmosphere. Team members have demonstrated their ability to get substantial financial support for their project from LABEXs or ANRs.
- **Weaknesses.** The group of planetology, formerly embedded in a larger Team of the AIM lab, had lost visibility to PhD and post-doc students. The recent creation of the Team has had highly positive effects to this regard. No member has full dedication to science in its activity and the science return from instruments may not be completely satisfying. This is particularly critical for VISIR key program analysis, not completely published yet, when VISIR-upgrade and ALMA are ready to operate. This might raise a difficulty to obtain observing time on these new installations. Finally, the group chronically suffers from a lack of engineering support to maintain its databases and analysis software.
- **Opportunities.** The instrumental context at short and mid-term is highly favorable to support the research of the Team. As far as circumstellar disks are concerned, the conjunction is very favorable to constrain their structure and properties thanks to Herschel data on debris disks, ALMA and VISIR-II coming on-line to collect new and more precise data on disks and with the perspective offered by our implication within the ELT/METIS and JWST/MIRI projects. As far as ring questions are concerned, the CASSINI mission will come to an end in 2017 and science analysis will still be supported by the CNES. The Solstice mission (2013-2017) is dedicated to seasonal effects, which are central in our research plan for the next 5 years plan (see below). The structural context of research is also most favorable for the Team. The creation of the LABEX UnivEarths for the ten coming years (2011-2021) at University Paris Diderot offers new vectors for science development and synergies around planetology with the IPGP (Institut de Physique du Globe de Paris). Team members are already deeply involved in this structure, both at research and educational levels, with financed workpackages.
- **Threats.** The context of the AIM lab within the University Paris Diderot has changed significantly recently with the creation of the LABEX UnivEarths and of the IDEX. Those big opportunities also generate threats for the LADP as mainly composed of "enseignants-chercheurs", in front of very time-consuming administrative or pedagogical tasks that will add up inevitably and may entail subsequent loss in science productivity. The project of moving the AIM Lab from the Physics Department to a new department for Earth and Universe Sciences may generate collateral effects like preventing new hiring of university staff. If all teams of the AIM lab are impacted, the LADP Team is all the more sensible to it in that its recruitment mostly comes from University. The Team is exposed to enduring lack of recruitment since 2006 despite high level science results and productivity. Positive signals have to be sent to PhD and post-docs of the Team by pushing hard for new permanent position to be opened in this field both at University and at CEA.

2.2 Scientific objectives

The big picture. Grains collide, stick, accrete and grow to form large ensembles driven by forces at play. The processes that give birth to kilometer-sized planetary embryos from sub-micron grains in proto-planetary disks and their characteristic timescales stay weakly constrained by observations. Accretion and fragmentation of grains also happen in planetary ring disks, which offer close laboratories in our Solar System to observe accretion at smaller spatial and temporal scales. Temporary accretion indeed happens in ring disks, showing gravitational accretion and tides struggling to form self-gravity wakes (Jeans-Toomre instabilities). These wakes give clues to the ring surface mass density and thickness. Determining the ring mass from its thickness gives insights on its origin, considered as the result from the break-up of a large satellite. The question of the origin of rings, their genetic link with regular small satellites is still in debate. As rings spread out of the Roche limit, they may form new low-density satellites younger than the Solar System. The rheological properties of Enceladus support this idea of young satellites, suffering impact cratering as they are already partially differentiated, i.e. later than the LHB. The origin and evolution of the complex world of Saturn largest moon Titan are still puzzling. Its surface, as an interface between its internal structure and its dense atmosphere, is a clue to its history but remains difficult to read and analyze. On Titan and terrestrial surfaces, grains stick up in dunes and are transported by winds, if any. Their morphogenesis and dynamics reveal both the properties of grains and the history of the climate as resulting from the interactions of soil with atmospheres. Properties of regolith grains are clues to their chemical composition and evolution over ages.

2.2.1 How did the satellites of giant & terrestrial planets form and evolve?

Context: We have explored the complex links between a circumplanetary ring and nearby satellites for the case of Saturn both with numerical simulations and observations with the CASSINI spacecraft. Spontaneous processes of gravitational accretion conflicting with tides yield to the formation of self-gravity wakes (Porco et al. 2005; Ferrari et al. 2009), of a spiral structure in the F ring (Charnoz et al. 2005) attesting collisional processes between rings and satellites. Satellites were also shown to accrete ring material in an equatorial bulge (Charnoz et al. 2007). A new process has been proposed to form new generations of low-density satellites from rings (Charnoz et al. 2010). We have also shown that Saturn mid-size satellite like Enceladus would already been partially differentiated at the epoch of their bombardment, supporting this new scenario (Degiorgio et al. 2012).

Challenges: Explain the close isotopic ratios of the Earth and Moon when it should have been formed from the material of the impactor, accreted far away or the equatorial orbits of Mars satellites Phobos and Deimos / Lead a consistent analysis of rheological parameters for all satellites of giant planets and confirm (or not) the singular behavior of Mimas against the empirical law for craterisation / Determine the surface composition of Titan and reveal the nature of the sediment/ Disclose information on the past or present climate contained in the morphology, size and orientation of Titan dunes.

Prospective for 2014-2018:

- The accretion process proposed for Saturn satellites, may have also forged the Moon from a debris disc after a large impact. This explaination may hold if the proto-lunar disc has survived 1000 years, which requires the disc to stay hot to prevent rapid accretion. We propose to include the thermodynamical evolution of the disk in our current code HYDRORINGS to tentatively solve this paradox. The origin of Mars satellites Phobos and Deimos is still controversial as an asteroid capture can hardly explain their equatorial orbits. Accretion in a tidal disc may naturally explain the Phobos circulation below synchronous orbit. This research on the origin of terrestrial planets satellites is supported by the LabEx UnivEarths (Workpackage “Origin and evolution of the first solids and of the moon”, PI S. Charnoz). It involves collaboration with S. Mathis (AIM/CEA, LDEEP team), A. Crida (Nice Observatory), and V. Lainey (IMCCE).
- The photometric model, built to analyze wide data sets of poorly resolved impact craters of satellites surfaces and derive their rheological parameters, will be improved to take into account more realistic craters shapes and the method will be extended to all mid-sized satellites of the giant planets. This will yield a consistent analysis among satellite systems. Also the currently singular behavior of Mimas against the empirical law for craterisation, which may reveal a new craterisation regime at very low surface gravity and/or special ground properties, will be re-examined. This research involves K. Degiorgio, S. Rodriguez, C. Ferrari in collaboration with the ISS-CASSINI Science Team (C. Porco, A. Brahic).
- Saturn largest moon Titan is already a target of major interest of several new projects proposed to pursue its exploration at the 2025 horizon (TSSM, TAE, JET, TIME, AVIATR). Understanding how its atmosphere is continuously replenished requires elucidating the links between internal structure, surface and atmosphere. However the CASSINI mission will be providing until 2017 always more constraints on the seasonal evolution of its climate and these interactions (formation of lakes, clouds, winds). Characterizing the present dynamics of the system is required. The determination of the surface composition is highly challenging due to the few narrow spectral windows opened in the atmosphere. We’ll lead the task of retrieving the surface albedo and composition in the context of the ANR “Apostic” project (2012-1015) with the development of a new fast forward radiative transfer model and a new inversion scheme to massively retrieve both atmosphere and surface composition from a large volume of spectroscopy data. S. Rodriguez will also lead the ANR “Exodunes” project (2013-2016) which objective is to develop new quantitative methods to disclose the fundamental information about the nature of the sediment and the links between the past or present climate and the morphology, size and orientation of dunes. Three questions will be addressed: what’s the role of inter-grain cohesion? What is the role of topography and of the variability of winds intensity and orientation? Images and topography of dunes in different environments will yield quantitative characterization of their morphodynamics, which will be completed by experiments in granular physics and numerical simulations. This research is supported by ANR and by an exploratory workpackage of the LabEx “UniverEarthS” (2011-2021). It involves collaboration with the VIMS Science Team.

2.2.2 What is the mass of Saturn's rings?

Context: Currently estimated ring-satellite interactions and erosive flux from meteroids push for a young age of Saturn's rings. Ring mass is estimated to be that of Mimas. Providing such a mass every 0.8 Gyr within the Roche limit remains difficult. Were rings more massive and the meteoroid flux less intense, rings may resist over the age of the Solar System and nurture new generations of mid-sized satellites (Charnoz et al. 2011).
Challenge: Determine the mass of the most opaque of Saturn's rings, the B ring.
Prospective for 2014-2018. The surface mass density is usually derived from the damping of density waves driven in the rings by satellites. Such waves are scarce in the most opaque and largest ring of Saturn, the B ring. We have proposed a new method to derive the surface mass density of a thick ring from the seasonal change of its unlit side temperature (Ferrari and Reffet 2012). The heat diffusion time from one side to the other and the transient thermal regime within the planetary shadow are both key factors to estimate its thickness, controlled by self-gravity instabilities and then directly related to surface mass density. We plan to analyze the seasonal temperature variations of the B ring in this densest part over two seasons (2004-2017) to constrain its thickness and surface mass density as a function of distance. We also plan to independently constrain the ring porosity and thickness from the opposition effect. The different contributions to this effect can be separated by a multi-wavelength study. We will benefit from our various competences in data analysis of the ISS and VIMS-CASSINI instruments. This research involves C. Ferrari, E. Reffet, K. Degiorgio, S. Rodriguez, collaboration with the ISS-CASSINI Science Team (C. Porco, A. Brahic, et al.), the CIRS-CASSINI Ring Team at JPL (L. Spilker et al.) and the VIMS-CASSINI collaboration.

2.2.3 Detect and characterize exorings.

Context: The origin and age of rings around giant planets are still uncertain. The multiplicity of detection methods of exoplanets has yielded a marvelous diversity of planetary systems. Numerous exoplanets are expected to have a Roche limit that might shelter rings. The detection of exorings will help understanding planet and ring formation. Numerous projects focus on the characterization of exoplanets at the 2020 horizon, like JWST/NIRCAM, JWST/MIRI, the ELT/METIS, ECHO…
Challenge: Establish the detectability of exorings with future instruments as a function of wavelength.
Prospective for 2014-2018. A PhD student currently dedicates her activity to establish this detectability in the near- and mid-infrared domains, both in stellar diffuse light and thermal infrared emission. Radiometric ring models as developed by C. Ferrari and colleagues are exported to exoplanet observing configurations. This work is in direct link with E. Pantin co-I ship for the ELT-METIS instrument and related to the upstream ANR NG-MIDE project.

2.2.4 Transport, erosion and coagulation of grains in protoplanetary discs.

Context: The early stages of planetary formation within the first few million years are complex to clarify. This requires a multi-physics approach (celestial mechanics, hydrodynamics, radiative transfer and geophysics), numerical simulations, observational constraints from known circumstellar discs and from the chemical composition of meteorites.
Challenge: Study the spatial distribution and transport of dust grains at large scale in 3D, coupling dynamics, coagulation, fragmentation.
Prospective for 2014-2018: The LIT3D code (Charnoz et al. 2011, Charnoz and Taillifet 2012) is currently the only one able to individually follow dust grains trajectories in turbulent discs and include coagulation and fragmentation processes. We aim to study their spatial distribution and transport at large scale in 3D, coupling dynamics, coagulation and fragmentation. Grains, as a function of their size, suffer different thermal and chemical alterations and settle in diverse regions of the disc. Coupling modelled spatial distribution of sizes, chemical or isotopic compositions with the radiative transfer code MCFOST developed by C. Pinte (IPAG; former collaboration within the ANR DUSTYDISK) will allow direct comparison with proto-planetary discs as observed by VISIR/VLT or JWST/MIRI, the first candidate being HD97048. We will benefit for this study of the new "High Angular Resolution" modes of the VISIR/VLT instrument. The coronagraphic and SAM modes will provide disc probing in the 30-100 AU region with much higher contrast compared to the previous VISIR version. We also plan to compare models with millimetre ALMA observations that will focus on the larger grains settling in the disc median plane, looking at the very early stages of planetary accretion. This will be done in collaboration with Bordeaux and Grenoble observatories.

2.2.5. Methodology: Multiscale Radiative & Heat transfer in grains ensembles.

Context: Planetary surfaces and rings are all but flat and regular surfaces. Rugosity happens at all scales, both above and beyond the resolution of instruments. These multi-scale and irregular structures, like self-gravity wake in Saturn's rings or complex craters of satellite surfaces, condition the way stellar light is reflected and thermal radiation emitted towards the observer. A complexity in front of which current analytical models can appear trivial or not valid.
Challenge: Include the complex multi-scale structure of rings in radiative transfer models (scattering and emission) to analyze CASSINI multi-wavelength and multi-viewing data set.
Prospective for 2014-2018: We aim at developing a multi-physics and multi-scale model of Saturn's rings coupling realistic outputs of numerical simulations of the dynamics of dense rings, ray-tracing and heat transfer in complex objects. The plan is to parallelize the available code (built by S. Charnoz) to handle wide size distributions of ring particles with numerous collisions in a dense ring, together with optimized ray-tracing, wise treatment of spatial and temporal scales and coupling of scattering, absorption, radiation and conduction. A similar approach will be adopted to handle more realistic photometric modelling complex craters in the determination of rheological properties of satellites (see § formation of satellites). This tool is also intended to question the effect of multi-scale rugosities of a real surface on the scattering function about opposition (which is expected to be null in analytical theories), for example on the amplitude of the LIDAR echo of a terrestrial terrain or on a self-gravity wake in a ring. A combined

approach is chosen, comparing backscattered light from a ray-traced high-spatial resolution DEM of a real terrain with the LIDAR echo actually observed (Collaboration S. Jacquemoud IPGP).

2.2.6 Data processing

Context: Most of our scientific objectives rely on the processing of a multi-instrumental and multi-mission data set. ***Challenge:*** Maintain the CASSINI multi-instrumental databases; develop new software to handle VISIR-upgrade. ***Prospective for 2014-2018***: Restore a satisfactory archiving and accessibility of the CASSINI ISS and CIRS data thanks to a perennial engineering support. The threat is that the Team members still loose substantial time in this instead of analyzing data. The VISIR pipeline and VISIR data analysis software will have to be upgraded to be adapted to the new VISIR configuration. This is very important to insure continuity in the formation of master and graduate students.

2.2.7 Instrumental perspective

Apart from the already mentioned context of the VLT/ELT/JWST and ALMA instrumentation to fully support our activities, long-term perspectives are worked out by the Team. The ESA **JUICE** L-mission is intended to study Jupiter's satellites and their relation with the planet as well as the rings. Our team is involved in the proposal of the JIMI NAC and WAC cameras to respond to the ESA'AO (consortium led by the Applied Physics Laboratory, John Hopkins Observatory, Maryland, USA). Similarities and differences with Saturn will help us to better understand the diversity of satellite formation processes in the Solar System. The **Marco-Polo-R** mission has been elected for the assessment study phase of ESA M3 missions in 2011, with a launch opportunity in 2022-2024. Aimed at returning a sample of a primitive NEA asteroid, it will also provide crucial elements to answer the fundamental questions of interest for the Team like, 1) what were the processes occurring in the early solar system and accompanying planet formation? 2) What are the physical properties and evolution of the building blocks of terrestrial planets? C. Ferrari and S. Rodriguez are already participating Working Groups on the global characterization of the target (spectral and visible), mechanical or thermal properties and morphology, properties or craters.

3. Mise en œuvre du projet

3.1 **Recruitment plan.** The team has its specificity as being mostly composed of university personal, as the result of an understandable and coordinated strategy of the AIM Lab with the Paris Diderot. The hiring rate of this Team is about one every 5 years. The next one will not happen before 2014, at the soonest, and this is a concern. Any additional permanent position will obviously bring an efficient support to the Team. Permanent positions are desired to support projects as follows:

- One researcher (CEA, UPD, CNRS) having competences in infrared/high angular instrumentation, circumstellar disks and data processing for: 1) the exploitation of existing and future data, 2) modelling of METIS data; preparation of future METIS observation programs. At minimum, 1 post-doc position over 3 years is required to conduct the VLT/VISIR project only.
- One researcher (CEA, UPD, CNRS), having skills in radiative transfer, parallel processing, multi-physics problems and inversion of large data sets to support characterization of ring and planetary surfaces.
- One engineer with expertise in database handling and processing of huge amount of data for: 1) keeping updated on a regular basis and improving the storage efficiency of the huge volume of data gathered and to be gathered by the group, 2) helping the group to process and analyze the datasets.

3.2 **Funding Plan.** CNES will guarantee the funding on CASSINI-related research of CIRS Co-I, ISS and VIMS associated scientist and ISS Team member (most probably until 2019). Researches on Titan are funded with two ANR programs until 2016 with two 2-years postdoc (T. Appéré & A. Lucas, 2012-2014) and by an exploratory workpackage of the LabEx "UniverEarthS" (2011-2021). Funding from ANR/PNP and LABEX UnivEarthS funding will be solicited in a near future for the radiative transfer project. S. Charnoz is funded for 5 years through its nomination to IUF. In addition, through the LabEx Workpackage on the "evolution of first solids in the Solar System" a post-doc will be hired within the 4 next years. Asking for an ERC funding is also considered in the "consolidator" funding scheme. To be achieved, ground-based observational projects (VLT/VISIR; ELT/METIS) will need to find financial support from national (PNP), regional (DIM) or LABEX programs.

LEPCHE - Laboratoire d'Etude des Phénomènes Cosmiques à Haute Energie

1. Analyse SWOT et objectifs scientifiques de l'unité

Scientific objectives of the LEPCHE team

The main topics studied by our team concern the accretion/ejection processes around compact objects, supernova remnants, the acceleration and propagation of cosmic rays and their interplay with the interstellar medium

Accretion is a very efficient process in the Universe and it is often associated with the expulsion of highly energetic jets of material. Accretion/ejection processes are ubiquitous and seen at all (temporal and spatial) scales (young stellar objects to γ-ray bursts, microquasars, active galactic nuclei). Understanding the physics governing microquasars and X-ray binaries (XRB) — bright objects that evolve on human time scales and are seen with little absorption— will shed light on a wide range of cosmic phenomena.

The origin of the Galactic cosmic rays still defies our understanding 100 years after their discovery. Our team aims at answering questions regarding their acceleration, feedback on the acceleration site, and their propagation and impact on the interstellar medium (ISM). This goes from supernova remnants to star formation regions and the Galaxy as a whole. Cosmic rays are also used to trace and gauge the different gas phases in the ISM.

SWOT Analysis

<u>*Strengths:*</u>

• ***Strong experience in mission development:*** participation to a wide variety of calls for new missions, to the definition of scientific requirements, to science working groups, to the definition and development of data centers; close collaboration with AIM/LSIS and AIM/LISIS teams involved in the design/building of satellites/detectors.

• ***Direct involvement in most of the high-energy observatories in operation (XMM-Newton, INTEGRAL, Fermi, HESS):*** software development, participation in data centers, calibration, sky surveys and source catalogues. Thanks to this we beneficiate of CNES-funding which, in particular, allows us to have a rather large number of post-docs.

• ***Vast amounts of high-quality data from radio to TeV:*** at high energy, this includes guaranteed time and an extensive use of the large existing archives. We have a high success rate for obtaining observations in the X-rays, optical, infrared, sub-mm, and radio.

• ***Involvement in SVOM at multiple levels:*** involvement in the data center (together with LISIS) and responsible for the definition and management of the general program (non-gamma-ray burst science).

• ***High rate of high-impact-factor publications:*** with a large number of breakthroughs (see the summary) and numerous publications in prestigious journals.

• ***Recognition as world leaders:*** in the topics of supernova remnants, cosmic-ray sources, interstellar γ-ray emission, microquasars, and related physical processes, resulting in a large number of international collaborations, invitations to symposia, prizes, and the strong participation to the local or scientific organizations of international symposia.

• ***Strong involvement in outreach activities:*** 2 of our permanent staff dedicate most of their time to this activity. This consists of website news, press releases, organization of expositions. We also actively participate to the organization of conferences, write books, give support for teachers and students

• ***International attractiveness***: our team comprises 9 different nationalities (7 for PhD+post-doc)

<u>*Weaknesses:*</u>

• ***Weak participation to HESS and CTA at present:*** the arrival of a particle physicist in 2012 has increased our participation to 2.5 FTE (2 permanent, 0.5 post-doc) with several leadership roles in both projects. However we need to further strengthen our participation in the CTA collaboration where we could have a strong scientific impact.

• ***Weak theoretical/modelling manpower:*** theoretical modelling is under-represented in our team and we often rely on external collaborations for modelling. We need to recruit a permanent theorist to strengthen the team's work.

• ***Lack of students:*** although most LEPCHE scientists are habilitated, and 3 are full professors, we still have too few students. We need to enhance our implication in education through research, starting at master level.

• ***Mean age of the permanent staff:*** 48.5 y-old.

<u>*Opportunities:*</u>

• ***Next X-ray missions (at different stages of maturation):*** contribution to several scientific white papers for **Astro-H** (Japan), access to data through call of opportunity; possible participation to **SRG** (Russia); at longer term**,** participation to the **LOFT** (ESA) observatory science working group and all sky survey, and to the topics of g-ray bursts and transients.

• ***ESA-L2/L3 call for mission (*****foreseen in 2013)**: We will participate to the resubmission of an updated version of the Athena proposal.

• ***Development of new generations of radio telescopes:*** members of science groups for LOFAR (Europe), ASKAP (Australia) and MeerKAT (South Africa), the precursor instruments of the major international SKA facility to be developed for 2020+. We need to increase our participation at various levels (preparation to observations and data reduction)

• ***New generations of high-energy telescopes:*** CTA will image the TeV sky with unprecedented sensitivity and resolution. We are also discussing with the Russian teams preparing the Gamma-400 satellite at GeV energies (>2019).

• ***Numerical simulations in rapid progress:*** the topics studied at LEPCHE will greatly benefit from the development of dedicated programs with LNSPA on supernova remnants and cosmic-ray interactions with the interstellar medium.

• ***Creation of a new department of Earth and Universe Sciences (University P. Diderot):*** Our direct participation will allow us to increase notably the number of students.

Threats:

• ***The future of X-ray astronomy:*** No (or weak involvement in) new missions foreseen at the <2022 horizon**.** Athena was not selected as ESA L1; selection of LOFT as an M3 mission is uncertain

• ***SVOM currently frozen***: Decision pending —and dependent upon— agreement between the Chinese space agency, and its related institutes, and the French CNES. Launch is in any case postponed to > 2017.

• ***No breakthrough mission planned at MeV-GeV energies after Fermi:*** the possible Gamma-400 project provides a modest increase in performance over Fermi. No R&T program across the world has reached the level of readiness allowing the preparation of a new generation of gamma-ray telescopes.

• ***Current space missions ageing:*** XMM, INTEGRAL, and Fermi are fully functional, but already 13, 10, and 4 years old, respectively. The instruments, in a hostile environment, are subject to sudden and unpredictable degradations.

2. Mise en œuvre du projet

Scientific projects and strategy:

1. Accretion and ejection

How ejection episodes and flares relate to instabilities in the accretion flow and how persistent outflows are sustained are still largely unknown. **We need to go beyond the standard model of an □-disc to understand accretion in its integrity.** In particular we want to study **what controls the evolution of XRB during outbursts. How do we measure the initial conditions to jet launching?** Key answers lie in the study of the **differences between the different modes of accretion (efficient vs inefficient) that give two different branches in the fundamental plane of black holes**. Can a system evolve between these two modes, or are we witnessing two populations of sources with different jet properties? We want to **constrain the formation and destruction of jets and their relation to the accretion states** (spectral and rapid temporal behavior)**. How are jets collimated and what fraction of the accretion power is fuelled into them? The derivation of scaling relations between objects at different time scales provides powerful constraints to numerical models. Furthermore, we want to understand the impact of jets on the interstellar medium** (ISM)? The latter can serve as a calorimeter to measure the jet energy and momentum, and its feedback on the ambient medium. A very debated question today is whether or not **intermediate mass black holes exist.** Answering this question has a direct impact on the hierarchical evolution of galaxies and their nucleus. Accreting systems are also known to emit up to the TeV range: are these rare exceptions or **just the tip of the iceberg? Which observational signature can differentiate the three potential scenarios depicted in Figure 1?**

The current high-energy missions, the soon-to-be-launched Astro-H, and the current and future radio telescopes will be our primary tools to progress. Observations will be compared to theoretical models and simulations, notably within the ANR CHAOS (with IPAG, and IRAP) in order to test different accretion instabilities thought to trigger spectral transitions during outbursts. We will for example test the evolution of jet power and the relation with the properties of the accretion disc (temperature, size). Of particular relevance will be the comparison of the system properties (temperature, typical timescales of variability, jet luminosity,…) between the different branches of the outbursts (rise vs decay). The AIM group is in charge of the analyses of the multi-wavelength light curves and spectra spanning the different phases of outbursts of most microquasars. We have obtained several programs on major facilities (ATCA in radio, INTEGRAL, Swift, at X-ray energies), and we will make use of the archival data of RXTE. At longer term we will also access data from Astro-H for which we have submitted several scientific white papers for the study of microquasars (outburst evolution and timing).

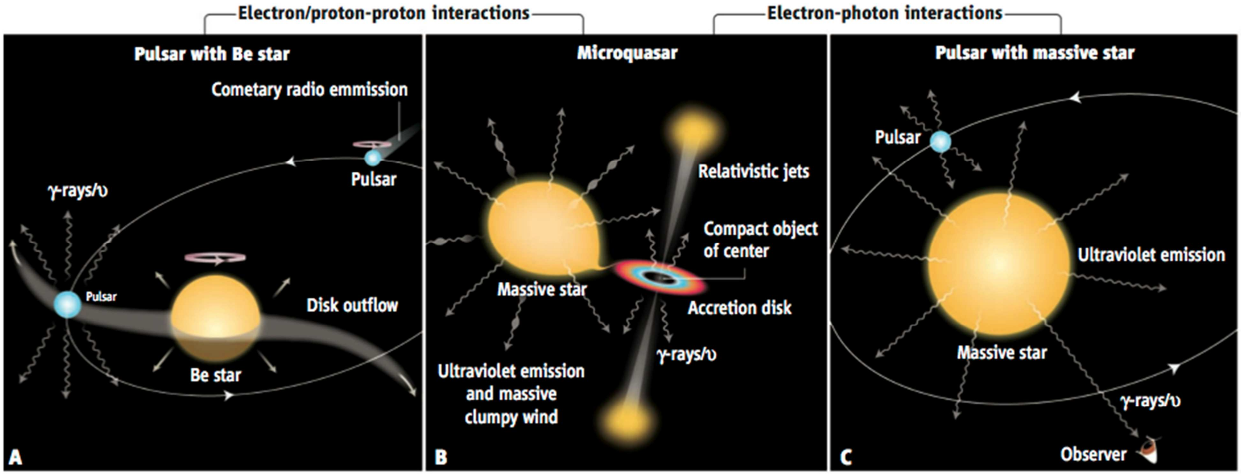


Fig. 1: Schematic representation of the three main types of accreting objects studied by our team, and possibilities for the emission of g-rays. A) Be-HMXB, B) Microquasar, C) sg-HMXB. From Mirabel (2012).

The multi-wavelength spectra of jets are also extremely important to quantify their energetic budget (for example the energy of electrons in cases of leptonic jets). This necessitates, in particular, a precise parameterization of the level of jet emission at hard X-ray and g-rays. This will be tested with the use of specific models (Comptonising 'coronae' vs. synchrotron jets) through spectral modelling, and also with the study of polarization at hard X-rays, first with INTEGRAL, and at longer term with Astro-H. We will also study these aspects within our international collaborations (in particular Berkeley, the University of Amsterdam, the Observatory of Bamberg, and the University of Southampton), which allow us access to different specialities (numerical simulations) and observational time (NuSTAR, e-Rosita).

The future generation of high-resolution spectrometers (Astro-H, then Athena) and radio arrays (ALMA, ASKAP, MeerKAT, and later SKA) will permit us to study the formation, destruction, and composition of discs winds (absorption and emission lines) and jets, and to test their feedback on the ISM. In the next decade, time domain studies in the radio will be the new terra incognita. Rapid variability of jets will be accessible, and we can expect new discoveries (as when rapid timing in X rays became available). By scaling the properties of stellar mass (galactic) objects, we can obtain constraints on the parameters of ULXs which, in conjunction with X-ray data will allow to construct a census of black hole masses in ULXs. Here again our collaborations will allow us to put together a large multiwavelength database.

The large improvement in sensitivity of HESS II, and even more for CTA, will permit a much larger number of γ-ray binaries to be detected and studied with higher precision and across a broad energy band that overlaps with Fermi.

2. Source Populations

We will continue to **characterize the high-energy sky** (keV, GeV, TeV). This involves the detection and spectral and time characterization of sources in a controlled manner (catalogues) that **allows statistical studies of their global properties, the search for specific signatures of different populations, and the confrontation of their properties with population syntheses that include the observational biases to** follow **evolutionary patterns** within **our Galaxy**. This will be applied to Fermi and HESS/HESS II datasets to study the evolution of young pulsars and their wind nebulae and to try and solve their puzzling overabundance with respect to models.

With the extension of the INTEGRAL, Fermi, and HESS/HESS II observatories and X-ray/optical/IR/radio follow-up campaigns we aim at extending the small samples of the three types of binaries depicted in Figure 1 toward very faint or dormant objects which will possibly impact the understanding of their geometries (orbital periods), evolutionary patterns (absorption/absorbers, winds, orbital evolution), their physics, and their relation to stellar evolution.

3. Cosmic rays, supernova remnants , and the high-energy side of the interstellar medium

The **origin (composition, acceleration) and propagation of cosmic rays (CRs), and their interaction with the interstellar medium (ISM)** are still highly enigmatic. Supernova remnants (SNRs) are natural places for CR acceleration. How do SNR shocks evolve when including particle acceleration, magnetic field amplification and feedback on the thermal gas? **To which energy can they accelerate particles and what fraction of the shock energy is transferred to CRs?** Our recent results have shown that star-forming regions may also act as accelerators, re-accelerators, or confinement regions. **Are the majority of star-forming regions filled with enhanced CR densities? How do shocks propagate in turbulent media, and how does this impact their acceleration capacity?** In the near future, data from Fermi, XMM-Newton, Astro-H, and HESS, together with numerical simulations, will be used to study these questions. CTA and hopefully Athena will then open studies at higher angular and spectral resolutions, respectively, both to study in-situ acceleration in SNR, their impact on shock-heating of the gas, and to follow the release and early propagation of fresh CRs into the ambient medium.

An XMM-Newton **large Program of deep observations of SN 1006** to determine consistently the energy partition between thermal gas, relativistic particles and magnetic field has been obtained by our team. A key determination is to extract the spatial width and the spectral break frequency along the synchrotron filaments of this shell-type SNR. This gives access to the **magnetic field amplitude and the maximum energy reached by electrons** for different initial orientations of the magnetic field with respect to the shock front, allowing for precision tests in an object where the distance, shock speed and ambient density are rather well known.

The comparison of the spectral breaks recently found at GeV energies for middle-aged remnants and at TeV energies for younger ones provides new clues on how CR acceleration responds to environmental effects and on the energy-dependent escape of CRs from the shock as it expands. Fermi, HESS and the future CTA data are well suited to **statistically study** SNRs over a large range of age and ambient ISM density. The starting point will be a **catalogue of γ-ray SNRs**, currently in progress. To interpret the correlations, we are improving our **global models of SNR evolution and emissions** (including both CRs and thermal gas), and of CR leakage and diffusion in collaboration with APC within the UnivEarths LabEx.

We will continue to search for CR cocoons in star-forming regions with Fermi, HESS II and CTA. The GeV-TeV data are crucial to evaluate the impact of the turbulent environment of massive stars and SNRs on the CR spectrum emerging from these regions, thus to connect the CR spectrum at the sources and in the Milky Way at large. For the present we ignore whether the spectrum hardens while diffusing through random shocks or if short diffusion lengths and severe radiation losses soften the emerging spectrum.

The Galactic center itself is a good place to look at the collective effect of shock acceleration and shock heating. We have deep X-ray observations of that region (e.g. the Arches cluster), and we participate to a Large XMM Program (lead by APC) to complement them, allowing a full characterization of individual sources and of the various components (thermal, non-thermal) of the diffuse emission. Dedicated work on the gas structure is planned to disentangle the γ-ray emission (as seen by Fermi) produced along the line of sight from CR interactions in the central molecular zone and its massive stellar clusters. On a larger scale, the CR spectrum will be extracted as a function of Galactocentric distance and in regions of different star-formation rates to infer constraints on the CR source distributions and diffusion properties in and out of spiral arms.

Enhanced CR irradiation affects chemical abundances, hence gas-density tracers and mass diagnostics in molecular clouds, because CRs are the main ionization source in the dense, UV optically thick, cloud cores. The COSMIS ANR (P. Hennebelle, AIM-LSNPA) aims at joining numerical models of CR shock acceleration and of a multi-phase turbulent ISM. We have **3D SNR simulations** in a realistic ISM to investigate how this changes their evolution and impact on the ISM. We will also study CR propagation in a realistic MHD representation of the ISM. CRs are indeed key to improving the **census of Galactic interstellar gas** by revealing, in conjunction with dust, **the large masses of dark neutral gas present at the transition between the atomic and molecular phases**. Joint Fermi, Planck, and Gaia (for interstellar extinction) studies, combined with radio-line surveys, will aim at providing a realistic **3D census of the different ISM phases within 500 pc of the Sun and in the spiral arms** with increasing difficulty. Tracing the dark-gas phase and understanding its response to environmental effects (total HI and CO mass and dynamics) is essential for the interpretation of external galaxies, and of interest to other AIM teams.

SNRs can also be used to provide constraints to SN explosion models and we are working on **3D simulations of the thermal emission from young SNRs**. X-ray calorimeters promise to give access to the velocity dimension (with a resolution of a few 100 km/s) via atomic lines of highly ionized ejecta. This will allow much more precise estimates of the amount of metals in young SNRs, and will give access to asymmetries in the explosion process. Astro-H should open the way with limited spatial resolution. A large telescope with good optics as in the Athena project will revolutionize this field.

Instrumental involvement and relevance to our activities

Table 1 and the opportunities listed in the SWOT section summaries the instrumental perspectives relevant to our team and its science objectives. Here we present a more detailed description of the few projects and the associated activities expected in the next five years. Future scientific activities and projects for the period to come are as well strongly connected to potential, innovative and unexpected developments on detectors and devices. Extensive and close collaborations with the laboratories at the front-end of detectors developments, especially AIM-LSIS will be pursued.

1. Involvement in HESS II and CTA (GeV-TeV domain)

HESS II is the upgrade of the HESS Cherenkov telescope array (with first data taken on July 26, 2012). HESS-II will be the largest atmospheric Cherenkov telescope in the world and will extend the HESS energy range down to a few tens of GeV. This will overlap well with the band covered by the Fermi satellite, but with a much larger effective detection area. Combined with multi-wavelength observations from radio, X-ray, and GeV gamma-ray telescopes, this will provide for the first time, a complete picture of the energy spectrum of many objects, in particular the spectral breaks that occur at GeV or tens of GeVs in energy: distant AGN, micro-quasars, other gamma-ray binaries, gamma-ray pulsars, globular clusters, and starburst galaxies fit into this category. Note that a Fermi synergy with HESS II and CTA will be important to constrain the maximum energies particles can achieve in these different types of accelerators and how they evolve after they leave the accelerating site.

LEPCHE and the IRFU are also strongly involved in the development of the next-generation VHE gamma-ray instrument, CTA (the Cherenkov Telescope Array), which will increase the sensitivity and angular resolution of existing instruments by an order of magnitude. The CTA project is currently in the preparation phase and is likely to begin science operation in 2016, when part of the array construction will be completed. The current involvement of the team in the project is with simulation work, data and analysis development, science definition, and site selection. An internal re-shuffling is ongoing to strengthen our participation, but will not be enough; a HESSII/CTA scientist is one of our priorities for a new permanent position.

2. The SVOM (0.1-400 keV) gamma-ray burst Franco-Chinese mission

The SVOM mission is a major project of AIM and IRFU. After a period of uncertainty concerning its continuation, it is very likely that the project will restart before the end of 2012. The instrumental baseline should be affected, but little changes with respect to our short and long-term involvement are expected.

Our team is directly involved in the definition and development of the French data center (under the supervision of LISIS). We are, in particular in charge of the definition and management of data products for non-gamma-ray-bursts observations (from the raw data to the scientific products), their production, distribution to the community, archiving and compliance with the virtual observatory. We will thus have access to all non-burst data, in particular the all-sky X-ray survey with a particular interest in accreting sources of all types (microquasars and AGNs), this in synergy with the ground based follow-up telescopes.

3. The transient radio sky with ASKAP, MeerKAT, and SKA

The capability to study transient phenomena with a continuous coverage on time scales from seconds to years is starting timidly with g-ray (Fermi) and optical monitoring surveys. It will leap forward with the radio monitors under construction. The advent of this new window opens an entirely new potential for discoveries (new types of transient objects or phenomena, key time constraints on models,…). We currently participate in the LOFAR project that has already started observations. We also have a strong involvement in a network of large and innovative radio telescopes currently under construction (MeerKAT, ASKAP) to prepare the square kilometer array (SKA) project (> 2020).

One key objective of these new facilities is the systematic search for and monitoring of sources across the sky. Of particular relevance for our science goals is the study of the radio bursts associated with explosive events that can be seen at high energies (X-ray and gamma-ray all-sky monitors). The multi-wavelength non-thermal spectra will shed light on the acceleration processes at work in these events and their characteristic timescales. The excellent sensitivity in the radio allows for the sampling of very short timescales, inaccessible at high energy.

Our strong expertise in transients of various types, their physics behavior and their multi-wavelength observations, has permitted some of us to join these international efforts to deal with on-the-fly detections and analyses and multi-wavelength follow-up campaigns. The huge data rates involved require the development of new analysis methods. The synergy with the AIM-CosmoStat team and their algorithmic developments is a strong asset for building and testing innovative analysis methods and softwares, and for building a visible role in this international endeavor.

		XMM-Newton	Integral	Fermi	HESS HESS2	Astro-H	SVOM	CTA	Athena	LOFT	LOFAR	ASKAP MeerKAT SKA
Accretion	Pulsars magnetars											
	Binaries X-Gamma											
	μ-quasars											
	γ-ray burst											
Acceleration	SNR											
	Diffuse											
	Cosmic-rays											

Table 1: List of missions (current and future) with specific involvement from LEPCHE. Green (resp. yellow) indicates a mission with direct (resp. secondary) impact on each science topic

Involvement in education: teaching, phDs and postdocs

Our involvement in the education of young researchers should increase in the near future, notably through the funding obtained with grants from ANR and LabEx UnivEarthS. The future PhD subjects, (some currently discussed in the team), will be original and notably largely based on our involvement in the new projects. These could for example concern the study of gamma-ray binaries with Fermi and HESS II, or focus on the transient radio sky with dedicated X-ray programs.

A Marie Curie/ITN proposal (HTRA: High Time Resolution Astrophysics) was submitted by some of us (selection is pending), and a Marie Curie ITN “Black Hole Universe 2” proposal is to be submitted for the 2014 call. A particular effort will be made to increase the number of PhDs.

The current AIM-PhD correspondent was recently nominated to be PhD correspondent at the institute level, which means a larger involvement in education at the level of CEA, but also a tight contact with the different doctoral schools. In addition, this will permit us (and the AIM lab) to have a more precise follow-up of the young researchers after the PhD, which in turns will permit a better advising of the PhDs.

LCS - Laboratoire CosmoStat

1. Analyse SWOT et objectifs scientifiques de l'unité

The scientific field of the CosmoStat interdisciplinary entity, created in February 2010, is **Computational Cosmology**. CosmoStat goals are:

- **Statistics & Signal Processing:** Develop new methods for analyzing astronomical data, and especially in cosmology (PLANCK, EUCLID, etc) where the needs of powerful statistical methods are very important.
- **Cosmology**: Analyze and interpret data.
- **Projects:** Participation to important astronomical projects: PLANCK, Fermi, HERSCHEL, EUCLID, CFHTLenS, XXL, etc
- **Education:** teach students and young researchers how to analyze astronomical data.
- **Dissemination:** take opportunity to disseminate our idea and tools in and outside the astronomical field (CEA, CNRS, University, Industry...).

Analyse SWOT

- Strengths
  - CosmoStat is an interdisciplinary laboratory, at the interface between cosmology, applied mathematics and signal processing. There are many collaborations between members, and most papers are written by researchers coming from different scientific fields.
  - It is clearly a very attractive laboratory, attracting young researchers from many countries (8 different nationalities in 2012).
  - The activity has a high visibility, with one Advanced ERC grand, one prize from the French Academy of Sciences, many invited talks, etc…
  - Our group has many collaborators in Europe and in US. Furthermore these collaborations are in different scientific fields.
  - We have developed many packages, that are available on the web.
  - Strong involvement in large international spatial missions, especially PLANCK and EUCLID.

- Weaknesses
  - Departure of EUCLID P.I.: Alexandre Refregier, former P.I. of Euclid, left CEA and his P.I. position in 2011, which has weakened our weak lensing group. We have hired a young promising researcher to maintain this activity, but it will obviously take time to recover from this loss of visibility.
  - Weak Lensing Manpower did not reach the critical number to have a world leading group.
  - Highly original idea based on new concepts such as sparsity or compressed sensing take time to be accepted in a given field.

- Opportunities
  - Strong involvement in large international missions (PLANCK & EUCLID): being involved in such important missions gives us the possibility to apply our ideas to the most exciting cosmological data set.
  - New mathematical concepts may change our way to understand cosmological data sets.

- Threats
  - Project policy: in large international mission, decisions relative to the choice of the methods to be used are taken by the science team. These decisions are generally based on the quality of the proposed methods, but also on more political aspects, such as the repartition between countries of the different selected methods, lobbying of some groups, etc. Therefore, we can never be sure, independently of the quality of the proposed method, that what we propose will be accepted. This is however true for any group involved in large scientific missions.

- Statistical Methods

Hyperspectral imaging: Hyperspectral imaging has emerged as an essential tool for multiwavelength observations in a very wide range of scientific and industrial areas including astronomy and astrophysics. The development and study of methods leading to better estimated components or targets in hyperspectral data is therefore extremely important. Standard analysis methods are generally based on blind source separation techniques; unfortunately, these methods are not well suited to account for some prior knowledge on the spectral content of the data. Our goals are i) understand how prior knowledge on the spectra, even only approximate, can be accounted for in a source separation process. We will focus on different settings ranging from the single target case to high dimensionality cases (i.e. high number of potentially active targets) and ii) understand how this spectral prior information can be incorporated into a blind source separation method. A typical example of application is the research of water ice on Mars, where we know the spectrum of one component (i.e. water ice), but not the others. We expect the main outputs of these methodological developments to be a novel source separation framework combining the robustness and adaptivity of blind source separation methods and informative priors on the spectra of parts of the sought after components. This new approach will be tested on Mars Express data.

Polarization: Instruments such as PLANCK provide multichannel polarization data. To analyze such multi-valued data set, we have recently proposed new multiscale decompositions such as polarized wavelets or polarized curvelets (Starck et al, *A&A*, 2009). Using these new transforms, we will develop the following applications:
• Blind Source Separation: The GMCA method that we recently developed (Bobin et al., *A&A*, 2012), entirely based on the concept of sparsity, is an efficient way to solve source separation problem. Therefore, we want to build a new blind source separation method for polarized data (GMCA-POL), by putting together our new polarized multiscale decomposition and the GMCA methodology.
• E and B mode extraction: when some data are missing (which is generally the case for Cosmic Microwave Background (CMB) observations, due to the masking of dirty area), a linkage between E and B modes may appear. Some papers have proposed a way to handle this problem (Schneider and Kilbinger, 2007; Smith and Zaldarriaga, 2007). We believe that extending the inpainting (i.e. missing data interpolation) framework proposed in (Abrial, Starck et al., 2008) using the polarized decompositions could be a very efficient way to correct the map from the missing part.
• Gaussianity test: Testing the inflationary paradigm can also be achieved through detailed study of the statistical nature of the CMB anisotropy distribution. In the simplest inflation models, the distribution of CMB map fluctuations should be Gaussian, and this Gaussian stationary field is completely determined by its power spectrum. A large number of studies have recently been devoted to the subject of the detection of non-Gaussian signatures. During the last years, wavelets have become a standard tool for searching non-Gaussian signatures in the CMB temperature map (Vielva et al., 2004; Vielva et al., 2006). It will be of importance to test Gaussianity by properly adapting to the polarized CMB data the statistical tests we previously proposed in the scalar case (Starck et al., 2004a; Jin et al., 2005). Statistical Gaussianity tests will be derived based upon our new polarized decompositions..
Dictionary Learning: The best data decomposition is the one which leads to the sparsest representation, i.e. few coefficients have a large magnitude, while most of them are close to zero. Hence, for some astronomical data sets containing edges (planetary images, cosmic strings, etc.), curvelets should be preferred to wavelets. For a signal composed of a sine, the Fourier dictionary is optimal from a sparse point of view since all information is contained in a single coefficient. Hence, the representation space, also called Dictionary, that we use in our analysis can be seen as a prior we have on our observations. Larger is the dictionary, better will be analysis of our data, but also larger will the computation time to derive the coefficients in the dictionary. For some specific dictionary limited to a given set of functions (Fourier, wavelet, etc) we however have very fast operators allowing us to compute the coefficients, which makes these dictionary very attractive. But what can we do if our data are not well represented by these fixed existing dictionary ? or if we don't know the morphology of features contained in our data ? Is there a way to optimize our data analysis by constructing a dedicated dictionary ? To answer these questions, a new field has recently emerged, called *Dictionary Learning* (DL). Dictionary learning techniques propose to learn an adaptive dictionary directly from the data (or from a set of simulations that we believe to well represent the data). DL is also related to the Learning scientific field, and establishes a bridge between harmonic analysis and the learning theory. We will study whether the concept could improve our data analysis. DL could extremely interesting for many different applications such as astronomical image restoration, detection of feature such as Cosmic Strings in PLANCK data, or Point Spread Function representation for EUCLID.

B) Cosmology

Cosmic Microwave Background (CMB):

- **CMB B-Mode Recovery:** Within the competitive field of CMB studies, the sparse component separation method GMCA has provided the best results on PLANCK FFP4 simulation. As described, previously, our goal is to extend GMCA to polarized data as well. Thanks to PLANCK data, foreground modeling will significantly improve in the next coming years, especially on the polarization emission of galactic components. Obviously, this knowledge should be very useful to separate the CMB from the galactic components. But including this knowledge in blind source separation algorithm such as GMCA is not obvious. Symmetrically, better will the component separation better, better will be our understanding of the physical mechanisms will lead to the observed polarized emission. To attack this highly difficult problem, members from the CEA-CosmoStat group (Starck, Bobin, Sureau, Basak) and Francois Boulanger group from IAS have built a common team (MISTIC Team) in order to reach necessary the expertise on both CMB component separation and galactic foregrounds. Tuhin Gosh is a join postdoc, sharing his time between IAS and CEA. Hence, **the MISTIC team has the unmatched ambition and capability to tie polarization data analysis and component separation to state-of-the-art understanding and modelling of the magnetized interstellar medium.** We will develop a new concept in sky modeling: we will discover how to express it linearly. This breakthrough will allow us to use the model to have a physically motivated estimate of the mixing matrix, which can vary spatially to account for spatial changes in the spectral dependence of the Galactic components, and thereby to introduce the relevant physics of Galactic foregrounds into the mathematical writing of the separation problem. Two recent breakthroughs, one in harmonic analysis (sparse signal recovery in case of matrix uncertainty) and one in optimization theory (proximal operator theory), open the possibility to design a new component separation method that can be coupled to a physical model of the Galactic foregrounds. i) **First Breakthrough: sparse signal recovery**

in case of matrix uncertainty. Several studies (Rosenbaum and Tsybakov 2008, Hoffmann and Reiss 2008) have considered the following equations:

$$y = Ax + \xi$$
$$B = A + \Delta$$

where the matrix A is the true mixing matrix and B is an estimate of A. In particular, it was demonstrated that it is possible to recover a sparse solution $\tilde{x}$ provided some assumptions on the original matrix A (for instance on the coherence of the matrix) and the errors ξ and Δ are made (Δ should be small). This means that we may retrieve the original components even when using an approximate (but close) mixing matrix. ii) **Second Breakthrough: proximal operator theory:** Proximal operator theory (Combettes and Pesquet 2008) allows us to solve the problem set by previous equation, with proven convergence to a unique minimum under various assumptions. Indeed, recovering the various components given an approximate mixing matrix *B* may then be written as a convex problem that belongs to the flexible framework proposed in Combettes et al. (2008):

$$\min_{x \in H} \sum_{i=1}^{m} f_i(x)$$

where *H* is a real Hilbert space, $\{f_i\}_{i=1..m}$ are proper lower-continuous convex functions (representing for example a discrepancy function and a regularization term). In this framework, the solution $\tilde{x}$ may be constrained to belong to the intersection of closed convex subsets, representing for instance some physical knowledge of the spatial support or bounds on the values of the various components. Several optimization algorithms have already been proposed to solve such problems (Combettes and Pesquet 2008). We will use these two breakthroughs to introduce an original two-stage approach in component separation. The sky model will be introduced in this new method in two ways: i) A good estimate of the mixing matrix will be obtained at each sky pixel by linearizing a parameterized description of the Galactic components, which will take into account the spatial variability of their spectral energy distribution, and ii) the sky model will also be used to define physically meaningful constraints to be included into the proximal decomposition algorithm, which will be used in solving the minimization in the last equation.

- Cosmological Parameter Estimation: In (Paniez, Starck, Fadili, A&A, 2012), it was shown on simulations that we can recover an extraordinary estimation of the underlying theoretical CMB power spectrum using sparsity. But if we can recover so well this theoretical power spectrum, maybe this estimation could be useful also for the estimation of the cosmological parameters. The main difficulty to solve will be due to the fact that we need to work with a covariance matrix which is completely full, and not diagonal at all.

- **Tomographic Integrated Sachs-Wolfe effect detection (ISW):** We have developed a new method to detect the ISW effect (Dupe, Rassat, Starck, *A&A*, 2012). We plan to extend it in order to take in account galaxies coming from different redshift bands coming from different surveys (2MASS, SDSS) or from surveys such as Euclid.

Galaxies Surveys:

- **BAO:** Apply our BAO analysis methods to the next SDSS data release (BOSS).
- **Tomographic-ISW** (see also CMB above). We want to work on better estimation of the 2D spherical galaxy density field, by taking properly the Poisson noise effect. Methods that have been developed for Fermi could also be useful for this talk.
- **Spectroscopic redshift estimation:** Accurate determination of the redshifts of galaxies comes from the identification of key lines in their spectra. Large sky surveys, and the sheer volume of data they produce, have made it necessary to tackle this identification problem in an automated and reliable fashion. Current methods attempt to do this with careful modeling of the spectral lines and the continua, or by employing a flux/magnitude or a signal-to-noise cut to the dataset in order to obtain reliable redshift estimates for the majority of galaxies in the sample. We plan to develop new methods to analyze spectroscopic data. Several problems will be studied:
    - Automatic detection of outliers in spectroscopic redshift estimation: if we are able to detect automatically outliers, we could reject them and build extremely low signal-to- noise catalogue.
    - Galaxy templates construction: similar techniques to those proposed for PLANCK component separation could help us to build more efficient Galaxy templates, and to derive more accurate redshift.
- **3D Density estimation taking into account redshift distortions:** For many applications (tomographic ISW, comparison between Weak Lensing Mass map and visible matter, etc), we want to estimate the 3D density map. This requires to properly take into account the redshift distortions. We will develop a sparsity based method, using 3D wavelets and 3D curvelets, to make this task.

Weak Lensing: We have identified three major bottlenecks in the weak lensing data processing to optimally exploit future weak lensing survey like Euclid.

1- The first point is the shear estimation that is based on the measure of the slight deformations caused by weak gravitational lensing effect on the background galaxy images. This effect is so small that it requires the control of any systematic error that can mimic the lensing signal; in particular the smearing due to atmospheric and instrumental

effects. Several methods have already been developed and have achieved an accuracy of a few percent. However, the accuracy required for future surveys will be of the order of 0.1%. Consequently, the injection of new ideas is of crucial importance to achieve this precision and extract significant results for cosmology. To develop a new method to estimate the shear with the accuracy required for future wide-field surveys, we propose to introduce stochastic geometry to the estimation of the shape of the galaxies and optimal transportation theory to the problem of estimation of the PSF across the field. Moreover, we will explore Bayesian methods for weak-lensing measurements, quantifying and accounting for the model uncertainty. This can be applied to shape measurement and PSF modeling.
2- The second point is the 2D mass inversion that consists in deriving a 2D projected mass distribution from the shear measurements of background galaxies located at a given redshift. This is a difficult inverse problem and classical methods are not optimal in presence of observational effects such as non-Gaussian noise or complex geometry of the field. To solve optimally this problem, we propose to explore the use of the Helmholtz decomposition in the wavelet domain. Our preliminary results on noise free data have already shown significant improvements in bounded domains (E. Deriaz, Starck, Pires, *A&A*, 2012). A particular emphasis will be put on the use of wavelets adapted to noise and boundary effects.
3- The last point is to develop a new method to reconstruct a 3D mass (or density) distribution, making use of the photometric redshift information. Several linear methods have been developed recently under the assumption of Gaussian noise. However, the proposed methods show a number of problematic artefacts. Notably, structures detected using these methods are strongly smeared and shifted (relative to their true positions) along the line of sight and theirs amplitudes are damped. We propose to use recent results in proximal splitting theory to explore a new way to solve optimally this inverse problem in presence of realistic noise. A first important step has already been made in this direction with the 1D method (A. Leonard et al., *A&A*, 2012). Afterwards, we expect to obtain tighter cosmological constraints from these 3D (deprojected) density distributions.
The originality of the project is that we propose to use new techniques that have emerged recently in the field of applied mathematics, such as optimal transport formalism or border divergence-free wavelets to improve significantly the current weak lensing data processing methods.

C) Project

- **PLANCK:** We are involved in the PLANCK project. We will participate to the PLANCK Consortium activity (meeting, challenges on simulation, data analysis, etc), mainly on the scientific subjects presented in the CMB section.

EUCLID: the Euclid mission is now selected, and we will continue to prepare the mission. We are strongly involved in the Weak Lensing scientific working group, the OU-SHE (shear estimation) and the management of the OU-LE3 (unit in charge of designing the algorithms to be used to derive the Euclid products).

- **CFHTLenS**: The weak-lensing data from the Canada-France Hawaii Lensing Survey (CFHTLenS) will be released in November 2012. One member of CosmoStat (M. Kilbinger) is part of this collaboration, which is finalizing a number of publications (technical and scientific results) until the release date. After that date, we plan to apply to the lensing data several methods developed in our group (mass reconstruction, peak counts to constrain cosmological models, PSF and shape measurement). We will make use of the expertise and first-hand knowledge of the data.
- **COSMOS:** The recent re-analysis of weak-lensing data in COSMOS (Schrabback, Hilbert, Joachimi, Kilbinger, Simon et al. 2010) is of excellent quality, both concerning the measured shapes as well as the 30-band photometric redshifts. This allows us to apply 2D and 3D mass reconstruction algorithms, and, for the first time quantify the statistical properties of those lensing mass maps on real data. The wealth of observations in other wavelengths allows us to compare the reconstructed total mass with other tracers of the large-scale structure, e.g. galaxy overdensity or X-ray signal.
- **XXL:** Our involvement in the XXL surveys is two-fold: First, our wavelet tools will be used for detection and classification of extended objects in very low signal-to-noise X-ray images. Second, we will use the CFHTLenS data to measure the weak-lensing signal of X-ray selected clusters, to obtain independent mass estimates. For that purpose, we will run ray-tracing analyses of several suites of N-body simulations to predict the expected lensing mass constraints including systematic effects (astrophysical and instrumental).

D) Teaching/Training

We will continue to teach at different levels:

- MASTER 2 MVA of ENS-CACHAN
- Post-master class of the Ecole Doctorale d'Astronomie d'Ile de France.
- We plane to have two PhD students.

E) Dissemination:

We will keep collaborating with non astronomical laboratories and external companies to transfer our knowledge.

F) Conferences:

We plan to organize one international conference and two international workshops during the next five years.

LMPA - Laboratoire de Modélisation des Plasmas Astrophysiques

1. Présentation de l'unité

In the 2014-2018 period during which our project is scheduled, the LMPA team will be composed of **11 staff members**. The CEA researchers will be J-P. Chièze, J-E. Ducret, T. Foglizzo, S. Fromang, D. Gilles, P. Hennebelle, F. Masset, R. Teyssier (head), S. Turck-Chièze. Only one CNRS researcher will remain: B. Gaffet. We will also have one Paris 7 lecturer: M. Gonzalez. Our intent is to hire at least 10 new PhD students and a similar number of post docs during this 5 years period. We will also try to attract a senior scientist, expert in numerical modeling of core collapse supernovae simulations.

2. Analyse SWOT et objectifs scientifiques de l'unité

SWOT analysis for the LMPA team

Strengths
The strength of our team is to be able to develop complex numerical tools from scratch. We have complete control of all aspects of the design, optimization and distribution of our 3 codes: FARGO, RAMSES and HERACLES. This requires a very specific set of skills in applied mathematics, computer science and computational astrophysics. Our expertise in developing complex analytical models is also a very strong complementary approach, especially when it comes to code validation and theoretical models design. We also benefit greatly from the support of the computer science teams in IRFU, with D. Pomarède and B. Thooris, in term of data visualization, parallel computing and outreach, within the COAST project. Our team has also a very strong scientific track record, with 5 ANR projects, 2 ERC grants and 1 prestigious prize from the French Academy of Science being awarded. We have also produced key contributions to our understanding of galaxy, star and planet formation, as well as core collapse supernovae and stellar structure. One strong aspect of our team is related to our very presence in a world-leading observational department such as AIM: cutting-edge astronomical observations have proven very valuable in the past to foster new analytical and numerical development. In return, we believe our help in interpreting observations and preparing proposals has a positive impact on the other teams of AIM.

Weaknesses
AIM has a very strong team in high-energy astrophysics and compact objects. Although the work of T. Foglizzo has been quite visible in the context of core collapse supernovae, we believe we need to strengthen our modeling abilities in the physics of compact objects, especially related to special and general relativistic aspects. Another weak point of our team is that we have to spend quite a lot of time developing and debugging our codes. Since these tools are all freely available open sources, other teams in France and abroad quite often exploit them, with sometimes minimal credit to our work. We believe this Open Source philosophy to be very important in validating our scientific methodology, since it allows other teams to check our results. It also increases our worldwide visibility and helps developing new international collaborations. On the other hand, these other teams often make interesting discoveries with our own software.

Opportunities
A great opportunity that our team will most certainly exploit is the strong strategy of France in general and CEA in particular in High Performance Computing. Our position inside CEA is a great opportunity for our developments: we have privileged access to CEA supercomputers, especially during the commissioning phases. Our reputation in code testing and benchmarking on massively parallel system is quite good, so we can benefit directly from new hardware opportunities inside CEA. In this very favorable context, E. Audit has created recently the "Maison de la Simulation", whose goal is to provide services in code optimization and algorithmic development for petascale and exascale computing. This new institute is a great opportunity for our team, since astrophysics has been identified as one "key customer" of this new service.

Threats
Computational astrophysics is a very competitive field. Being the first to reach a certain resolution or to include a certain physical process is quite often what matters in term of scientific discovery. We need to be fast, efficient and we need to have access to the largest facilities in the world. Losing our leadership in term of adaptive mesh techniques and Godunov methodology is a great threat. Another threat, that applies to astrophysics in general, is to lose our currently dominant position in term of access to massively parallel systems. Other important sciences, such as computational biology or climate modeling, might grow significantly in the next decade, limiting our time allocations on large systems. A very important tool in our every-day work is our department cluster. It will still be active in 2016, but we need to plan in advance the acquisition of a new system for 2016-2018, especially since it will depend on external sources of funding.

Scientific objectives of the LMPA team

(1) Computational astrophysics at the era of exascale computing

Context: The large supercomputing facilities that we are currently using offer usually slightly less than 100 000 compute cores. Typical state-of-the-art simulations feature a couple of 1000 cores, while extreme simulations require 10 000 cores. Only a couple of very large simulations have approached the barrier of 100 000 cores. Only a small number of codes are able to deal with such a large number of independent compute elements. Our codes, RAMSES and HERACLES, are among them. In order to maintain our leadership position in the field, we need to be ready for the next generation of supercomputers, the so-called "exaflops" machines, with probably more than 1M cores systems commonly available. These new machines will have a very different architecture than traditional present day clusters: they will feature very large compute nodes, with more than hundred cores per node, with a very heterogeneous node structure. Graphic cards (GPU) will play an essential role as accelerators within these heterogeneous nodes.

Challenge: We need to upgrade constantly our codes, so they remain at the bleeding edge of computational astrophysics. This will require significant modifications, beyond the traditional "message passing" strategy that we use now, based on the MPI library. We will have to use new hardware, probably new programming languages and we will have to exploit extremely large machines, for which the mean time to failure (MTTF) will become prohibitively small (below 1 minute).

Prospective for 2014-2018

• *Hybrid OpenMP-MPI programming strategy*

We have recently developed a new strategy based on using both MPI and the OpenMP directives. This strategy is based on the fact that compute nodes have a larger and larger number of compute-core, each core having access to the same shared memory within the node. The idea is to have one MPI processing elements for each node, with a large shared memory allowing to define larger physical domains, with less associated overheads. Within each MPI domain, parallel computations are performed by distributing the work using OpenMP directives. This allows us to perform optimization and balancing of computations at the system level. We have tried this strategy with mixed successes on both HERACLES and RAMSES. This requires a very good knowledge of both the hardware (especially the memory architecture) and the compilers. We will need help from computer scientists, both from IRFU, within the COAST project, but also from the "Maison de la Simulation", with dedicated projects to optimize our codes.

• *GPU acceleration*

The recent years have seen the advent of scientific computing based on graphic cards, especially since NVidia has made available the CUDA language, and more recently floating-point arithmetic in double precision. GPU offer a very fast memory access together with many-core parallel computing. The problem is to copy the information from the host (CPU) memory to the GPU, a very slow process funneled through by a PCI express port. The key is therefore to design science algorithms with a very large "Float to byte" ratio, in order to take advantage of the capabilities of the GPU. Radiative transfer and MHD are good examples of such floating-point intensive problems, especially if they are performed on a simple Cartesian grid structure, that can be mapped trivially on the GPU many-core architecture. We have already exploited this technology to perform cosmic reionization simulation (in collaboration with D. Aubert and P. Ocvirk at the University of Strasbourg). S. Fromang will also exploit GPU acceleration for long-term integration of magnetized turbulence. We will be working on this with P. Kestener (Maison de la Simulation).

• *Fault tolerant computing*

A supercomputer with 1.5 million cores is already available in the US, with the BlueGene/Q Sequoia machine. The number of machines with more than 1 million cores will grow significantly in the next couple of years. Although the Operating System running on these machines is robust to node and disk failures, we need to make our applications similarly robust to hardware and software failures. The methodology associated to such robust behavior is called "fault tolerant computing". It requires the design of new algorithms (for gravity and hydro for example) that can be restarted without loss of data and without unnecessary computations. The MTTF of existing hardware is quite good, although it was predicted 10 years ago to be dramatically small. Can we expect the same to happen for the next generation of supercomputers? Fault-tolerant computing is a new paradigm with a lot of interesting consequence on algorithmic developments.

• *Developing new algorithms for astrophysics*

The last activity in our project will be to design new algorithms, taking advantage of our local expertise on Godunov schemes, adaptive meshes and elliptic solvers for gravity and implicit time integration. One missing physical ingredient in our code suite is relativistic hydrodynamics. This key addition will allow us to tackle high-energy astrophysics problems, such as relativistic jets, high velocity winds, and supernovae physics. Relativistic hydrodynamics can be expressed as a hyperbolic system of conservation laws: it is therefore ideally suited for the Godunov methodology and for the AMR technique. This project will be led by S. Fromang and T. Foglizzo, in collaboration with LAOG in Grenoble. We will also continue our exploration of numerical algorithms for radiative transfer, building up on both standard diffusion solvers and our M1 moment-based techniques. One difficulty is to be able to solve the radiation diffusion equation with an implicit solver with adaptive time step for AMR. This will be done in collaboration with G. Chabrier and B. Commercon. We will also continue to extend of photo-ionization solver (with D. Aubert, J. Blaizot and J. Rosdahl) to multigroup radiation and photo-dissociation problems.

(2) Interpreting and preparing astronomical surveys in the next decade

Context: our department is involved in many important experiments in the next 10 years, such as the coming EUCLID mission, the exploitation of the Herschel satellite, ALMA and JWST. We need to upgrade our codes and plan our participation for the preparation and the scientific exploitation of these important missions.

Challenge: EUCLID will go wide, while ALMA and JWST will go deep and reach ultra-high resolution. We need to be able to deliver simulations that meet new challenging requirements: very large simulated volume with enough resolution (EUCLID) and very high-resolution simulations with the appropriate physics (JWST).

Prospective for 2014-2018

• *Preparation of the EUCLID mission*
R. Teyssier, co-lead of the Cosmological Simulation Working Group within the EUCLID collaboration, will coordinate the activity related to performing large simulations for EUCLID. This will require running large (a few trillion particles) simulations with enough resolution (1 billion solar masses per particle) to model the mass distribution in the universe. These simulations will be performed with *at least* 3 different codes, one of which will be RAMSES. We will also explore the role of baryons in re-shaping the mass distribution in the universe, and affecting the determination of the cosmological parameters by introducing a bias in the measurement.

• *Exploitation of Herschel, ALMA and JWST*
Both Herschel and ALMA will require detailed simulations of galaxy formation and star-forming regions. In collaboration with the LCEG team, we will perform high-resolution simulation of high-redshift galaxies, for which our team and the LCEG team have a strong leadership position (R. Teyssier and F. Bournaud). This will require new tools to model the sub-mm emission of these high-redshift galaxies. We will have also to develop new models to account for realistic feedback processes, regulating the formation of giant molecular clouds in these extremely star-forming objects. P. Hennebelle will also develop new tools to model the sub-mm emission of star-forming regions in the Galaxy, supporting ALMA proposals and interpreting the observations performed by the LFEMI team and P. André. Sub-mm mock observations are very hard to perform: we will need complex radiative transfer tools to model both continuum and line emission. Given our expertise in radiative transfer, as well as complementary tools developed elsewhere with AIM (both in LCEG and LFEMI), we are in a very good position to deliver competitive results for these forthcoming observations.

(3) A common theoretical approach for star formation and galaxy formation

Context: Our understanding of galaxy formation is currently limited by small-scale processes, such as star formation, stellar and AGN feedback. In order to make a significantly leap-forward and go beyond current phenomenological models, we need to address more directly the problem of star formation and feedback within the galactic context. The theory of star-formation is also limited by our poor understanding of interstellar turbulence: where does it come from? How is the turbulent energy injected so efficiently inside molecular clouds? Why doesn't it dissipate? Our team has pioneered many aspects of this problem during the last 5 years (sensitivity of galaxy morphology to star formation efficiency, formation of molecular clumps from galactic colliding flows). Our various studies all point towards the necessity to address the problem of star and galaxy formation together, in order to overcome the limitations of both fields. Fundamental questions such as the Initial Mass Function in star forming regions or the (non-) formation of bulges in galaxies will be solved only if one tackles both scales (galactic and star-forming clouds) together.

Challenge: the main challenge is obviously related to the multi-scale nature of the problem, with 10 kpc-sized discs, down to a few AU-sized molecular cores. This is also a problem of physical modeling: magnetic and radiation fields are both required to determine the chemistry of the star-forming gas, as well as the morphology of star-forming filaments. Modeling an isolated disk while forming stars one by one is a formidable task that will probably not be reached within the next 5 years: our goal is to pave the road towards this ultimate goal, identifying the main problems to solve.

Prospective for 2014-2018
Our goal is to perform first simulations of isolated Milky Way-like disk with an implementation of stellar feedback that allows us to destroy the molecular clouds. We will obviously rely on a phenomenological model of stellar feedback to reach this goal, since the disruption of molecular clouds is still an unsolved problem. These simulations will be performed in collaboration between R. Teyssier and F. Bournaud. It is worth mentioning that a simulation of an isolated Milky Way disk has been performed in 2012 with a spatial resolution of 0.1 pc, a world premiere in this context. In the same time, we will perform in parallel simulation of turbulent molecular cloud, using both the classical set-up of decaying turbulence in a box and the now traditional set-up of colliding flows. The idea is to use a proper modeling of both radiation and magnetic field to get the correct size of proto-stellar fragments, and explore in the same time the interruption of star formation by stellar winds or other feedback mechanisms (P. Hennebelle, S. Fromang and M. Gonzalez will lead this project). When these 2 types of simulations will be under control, we will try to couple them by performing an isolated disk simulation and by zooming on a collapsing giant molecular cloud, following the collapse self-consistently down to the formation of the star cluster. This will be a massive collaborative effort within our team, with the RAMSES code as the main tool.

(4) Understanding the formation of planets

Context: As uncovered by the Kepler mission, planetary systems like our own are numerous in the universe. They have diverse and sometimes unexpected properties. In order to understand their architecture, we first have to obtain an acute understanding of the environment in which they form, namely protoplanetary (PP) disks. This subclass of accretion disk is a complex beast: believed to be partially turbulent as a result of the MRI, they also feature complex radiative and chemical processes. Such highly nonlinear effects are best studied with the help of cutting edge MHD numerical simulations. Key questions that will be studied in the next five years are: 1- what is the saturation amplitude of MHD turbulence in protoplanetary disks? 2- what are the consequences on radiative processes on the disk dynamics? Do they result in any observable consequences? 3- what is the large-scale structure of PP disks (dead zone, jets, winds)?

Challenge: The main challenge is the enormous computing time required by such simulations. Millions of time steps are needed to extract meaningful statistical diagnostics of the flow from a simulation. Coupled to the high resolutions intimately associated with any turbulence simulation, this makes that project a formidable numerical challenge.

Prospective for 2014-2018: The questions outlined above will be tackled within the framework of the PETADISK project, an ERC starting grant that has just been awarded to S. Fromang (2011-2016). A group of 5 researchers (1 PhD student, 2 Postdocs, 1 engineer and the PI) will develop dedicated MHD numerical simulations. Subgrid models of MHD turbulence will help reach the parameter regime relevant for PP disks. Non-ideal MHD effects as well as the link between MHD turbulence and disks winds will be considered. On the computational side, a GPU version of our code will be developed in collaboration with P. Kestener (Maison de la Simulation). In parallel, more realistic physical modules will be included in global simulations of turbulent PP disks: temperature dependent resistivity will help study the dynamics of the dead zone while coupled MHD/radiative transfer simulations of PP disks will open a link between dynamical simulations and observations. At the dawn of he ALMA era, this should prove an exciting adventure.

(5) Towards a complete modeling of core-collapse supernovae

***Context*:**
The theory of core collapse supernova describes the interplay of gravitation, hydrodynamics, nuclear physics, neutrino interactions and transport during the first second following the formation a proto-neutron star. Most of the recent progress is related to the consequences of hydrodynamical instabilities that break the spherical symmetry, such as neutrino-driven convection and the Standing Accretion Shock Instability (SASI), but their relative roles in 3D are a subject of vivid controversy. Numerical simulations from different groups are still too different and too few to disentangle issues of numerical convergence from the possible stochastic nature of the explosion process. While the sloshing oscillations of SASI have been recognized in most 2D simulations assuming an axisymmetric evolution, the spiral asymmetry expected in 3D for rotating progenitors has not been confirmed yet (Yamasaki & Foglizzo 2008, Wongwathanarat+2012). Additional complexity concerns the structural diversity of stellar cores before collapse (Mueller+2012, Ugliano+2012), and uncertainties in the equation of state of nuclear matter (Marek & Janka 2009).

***Challenge*:**
Our goal is to develop a numerical model of core-collapse characterizing the conditions for a successful supernova explosion in 3D, depending on the properties of the stellar core such as its radial structure and rotation rate. This model will also be able to describe the birth conditions of neutron stars (mass, kick and spin), with particular attention to the threshold of black-hole formation. Direct signatures of the explosion mechanism are the time dependence of the neutrino signal and the emission of gravitational waves. Expertise in the many required topics (including condensed matter Equation-Of-State, neutrinos transport, nuclear burning and general relativity effects) is currently note present in our team. Our goal is to build the missing skills by inviting or hiring an expert in core collapse numerical modeling.

***Prospective for 2014-2018*:**
The numerical cost of simulating core-collapse in 3D precludes a direct and systematic exploration of the parameter space. The theory of core-collapse supernovae in the future 5 years will rely on a few complex simulations complemented by simplified ones. A deep understanding of the hydrodynamical processes will be necessary to evaluate the sensitivity of the explosion mechanism to the physical ingredients and approximations. This project will benefit from the expertise of the LMPA team in hydrodynamics in general (Fromang, Masset), and core-collapse hydrodynamics in particular (Foglizzo) in numerical techniques with the codes RAMSES and HERACLES (Teyssier, Fromang, Audit, Gonzalez, Hennebelle), and in transport methods (Audit, Gonzalez). A collaboration with the experts in numerical relativity and nuclear physics at Meudon Observatory (Novak, Gourgoulhon, Oertel) and IPN Orsay (Margueron, Kahn) has been initiated by the ANR project SN2NS (2011-2015). The collaboration with the team at MPA Garching will be continued (Foglizzo+2006, 2007, Scheck+2008). We also expect to attract in our team an expert in core-collapse modeling, which will increase our knowledge in this difficult science.

(6) Unveiling the structure and the internal dynamics of stars on secular timescales

Context: Previous studies on stellar interiors lead to crucial questions on the existence of magnetic field in the core of stars and on the evolution of the magnetic field of solar-like star near their surface (Turck-Chièze & Couvidat 2011, T-C, Piau, Couvidat 2011, Piau et al. 2011, Simoniello et al. 2012). These dynamical effects compete with microscopic physics that today mainly governs the theoretical evolution of stars and the pulsations of massive stars (Cepheids, Beta Cepheids…) (Turck-Chièze et al. 2009, 2010, Gilles et al. 2011). So, progress and verification of the quality of the physics describing the equation of state and opacities are also clearly useful along the HR diagram. The lack of knowledge of the respective role of these competing processes leads to the absence of prediction of the solar activity of the next decade or to its precise secular evolution during the last centuries, this fact limits our understanding of the relationship between Sun and Earth, at an epoch where more and more planets are detected and where one tries to understand how they interact with their host star. Moreover one has not a proper description of the accretion ejection phase of solar-like stars, nor of their dynamical pre-main sequence description at the period of the planet formation. This phase is a key phase to understand the whole story of the deep internal stellar magnetic field and of the dynamo actions at different periods of a stellar life.

Challenge: No direct signature of deep magnetic field topology and strength in solar-like stars is today accessible as the magnetic pressure is generally negligible in comparison with gas pressure. But indirect manifestations through the splitting of the gravity modes or the evolution of the internal rotation profile of twins of the Sun at different ages become available. The history of the internal magnetic field along the HR diagram represents a real challenge for a good understanding of the early and final stages of evolution of stars.

Prospective for 2014-2018: We shall develop two activities. The first one is to validate or improve the description of the microscopic physics used in stellar evolution in confronting detailed opacity calculations performed with the code HULLAC and other codes of the OPAC consortium to some key experiments realized with high energy lasers of LULI, LMJ and maybe ORION facilities (Turck-Chièze, Ducret, Gilles, Le Pennec). The already performed experiments push us to improve the individual opacity coefficient used in the envelopes of stars for elements of the iron group. The second activity is dedicated to the phase transition between the formation of stars and the main-sequence stage after the first contraction period. We would like to follow how the strong rotation of the stellar core can induce some magnetic field, what could be its strength and if this magnetic field is sufficiently strong to diffuse in main sequence and modify the rotation profile as the radiative region extends (Turck-Chièze, Le Pennec). Of course seismic observations of the rotation profile of different stars will be useful to constrain such models together with the understanding of the role of magnetic field in the helioseismic data (Turck-Chièze, Simoniello in collaboration with Piau, Kosovichev and Rozelot) in order to prepare the next generation of instrument like GOLD.

LSIS - Laboratoire Spectraux Imageurs Spatiaux

1. Présentation de l'unité

LSIS was created in 2010 from the Space Detector Group of a former larger Space Detection Lab., keeping the same people, management and missions. The size of the team grew from 13.5 FTE up to 18.5 people between 2007 and 2012. The creation of LSIS gave more internal visibility and permits a more flexible management. As consequence, lab activity is more active: enhancing discussion, ideas, and hardware exchange.
The number of permanent staff grew from 9 up to 13 during the contract. In 2007, the staff was: 13.5 FTE, 10 permanent people, 3.5 researchers, 4 technicians, 4 engineers or other, 2 PhD students or postdocs. In 2012, the team is: 18,5 FTE, 13 permanent people, 6.5 Researchers, 3 technicians, 4.5 engineers or other, 4.5 PhD students or postdocs.
One of our permanent technicians leaved after 36 months in the lab, three apprentices ended their contracts after spending 54 months in total and graduated either at engineer degree or technician degree. In addition, 2 PhD students defended a thesis after 60 months in total, and one postdoc spent 24 months with us.
In the same period of time, a new apprentice, 3 PhD students, 2 postdocs joined us. Two researchers were hired (one from another lab of AIM and one from a previous non-permanent position in our lab. In addition, a non-permanent position engineer was hired.
In the future, our objective is to maintain our skills and creativity by hiring a new technician, and giving training opportunities for new PhD students and postdoc (one every other year).

2. Analyse SWOT et objectifs scientifiques de l'unité

SWOT analysis for the LSIS team

Strengths
The most important strength of our R&T lab is creativity. LSIS draws its creativity of its multidisciplinary expertise, from basic material research to advanced space systems for imaging spectrometry.

LSIS strategy is consistent and durable. It relies on developments in parallel at different levels of maturity. When a R&T program concludes to a successful space proven detection system, team leaders are active to promote attractive and flexible product lines in relation with AIM astrophysicists. This benefits from space instrumentation experts to emphasize their capability to join ambitious international instrumentation programs from design to flight.

LSIS space imaging spectrometer expertise is recognized internationally and allows setting prestigious collaborations and reliable research networks in all our fields of applications from the far infrared to gamma rays.

R&T efforts enable high maturity level imaging spectrometers attractive to international instrument payload consortia in new missions. LSIS has the ability to quickly respond to new opportunities. Active participation to space mission proposals, phase 0 and A gives our lab a chance to enter into new space science projects and new collaborations (UC Berkeley CINEMA/TRIO, ASTRO-H, STIX, EChO, SPICA/safari…).

Managing new opportunities and R&T programs is achievable because LSIS permanently pays attention to get coherent programmatic and synergistic activities.

LSIS facilities are numerous, modern and often extend to clean room facilities when clean operations and tests are critical. No less than six experimental areas are currently available to receive our instrument developments. Our technical environment is a force.

Weaknesses
Whatever the skill of our lab, politics and lobbying is extremely important to raise our chances to play a major role in a space program. Even with excellent technologies, we often contributed to phase 0 and A being a back-up option while our skill are often at a very high level (SPICA, LOFT, IXO/XMS, IXO/HXI,…). The lack of leader involvement at science level in new program communities is a major weakness.

It is difficult for LSIS to be attractive to PhD students. The duration of a space project development is very different from the thesis duration. Our location into an Astrophysics division hides our technological face from universities and requires extra efforts to draw the attention. Although there are well suited sources of funding for PhD grants like CTCI (shared contract between industry and CEA), the process is complex and pretty slow, preventing us from being attractive with respect to some industries where excellent candidates showing similar profiles are also welcome.

Finally, probably the most critical weakness is that LSIS has an unbalanced configuration of the number of our technicians with respect to the number of our engineers and researchers.

Opportunities
LSIS environment is conductive to innovation and to high performance apparatus for astrophysics. As a matter of fact, LSIS works systematically with every instrumentation labs of AIM (LEDE, LSAS, LQIS and LISIS) and is well established within Irfu institute. This enables strong and sustainable cooperations, mostly with technical services and labs, SEDI/LEDEF, the detector and front-end electronics lab but also other divisions like SIS and its mechanical engineering office for instance. Moreover, implantation within CEA and more specifically direct connections with DRT/Léti DRT/LIST, DSM/INAC/PTA, … gives access to most advanced technological facilities and platforms. When innovation and skills are positioned in the industry, LSIS contracts and cooperates, sometimes on the long run.

Our R&T space programs are supported by Cnes, the French national space agency, but also more recently by ESA, the European space agency. In these frameworks either preliminary studies or payload participations studies and realizations are conducted.

Success into international collaborations is fruitful and triggers new opportunities and new perspectives (SORRENTO, SRG, ASTRO-H, …). Sometimes LSIS may contribute significantly to science missions out of the main historical science topics (SENIC, Solo/EPT…) but increasing very much our visibility and opening new horizons.

Recently, LSIS was successful in diversifying funding resources: applying to ESA calls for instance. Moreover, as the landscape of research has changed significantly in France in the last few years, especially with the creation of LabEx structure, LSIS had new opportunities. This framework is beneficial to LSIS when cooperating with other labs in related and synergistic field. LSIS is contributing actively to P2IO, UnivEarthS and Focus and answers to calls for projects from these structures. Recent proposals and funding opportunities came with FP7 or ANR. In the future, these sources may extend to Regional support for industry-institutions cooperation's for innovation and technologies (FEDER, FUI,…)

Threats
R&T and innovation relies on anticipation and risk taking which is somehow contradictory with contractual commitments, demanding schedules, set with funding agencies. How to guarantee on-time success into innovation without paying the price of performance? Similarly, it is sometimes difficult to take in our wake industrial partners who have to share the risks with us. This immediately causes the developments to be expensive.

Our resources, in particular funding, are difficult to obtain in a very competitive field. This task is therefore time consuming and solicits our experts, possibly pushing them away from their main technical skills.

LSIS cannot escape attempting to reply to many calls for new space projects. As a result, great efforts are made in vain, possibly discouraging the involved staff.

New opportunities for imaging spectrometer development could have the effect of easily overloading LSIS with projects that could be decoupled from the main scientific goals of AIM.

Participation to space programs at the moment requires a very high level of maturity, which requires anticipation: the main threat is certainly failing to anticipate a key development for future missions.

Intellectual Property is partially covered by patents. Patenting requires secret, time and anticipation, which is somehow contradictory with participation to proposals in phase 0 and A. As a matter of fact, disclosure of fresh results in innovating fields before patentability has been performed is required to reinforce space mission proposals. A R&T lab cannot anticipate every emerging technology.

3. Mise en œuvre du projet

<u>Global trends in the field of imaging spectrometers in space</u>
The permanent mission of LSIS is to raise the imaging spectrometers sensitivity as much as possible. In the case of sub-mm range bolometers, it essentially means reducing the Noise Equivalent Power by several orders of magnitudes. In the IR domain it drives to large arrays and fine pitch detectors, having ultra-low dark current and readout by bump bonded CMOS readout ASICs, while in the X or gamma ray domain, the goal is mainly to improve as much as possible the energy resolution, to Fano limit for CdTe based detectors, in small pixel arrays.
This is reflected by a systematic search for **noise reduction** in LSIS activities. The trend is to raise the pixel density, integrate electronics functions or optical functions near or inside the pixels, making more and more complex detection systems (low power, multiplexing, cryogenics, on chip real time analysis, …), without sacrificing reliability (radiation hardness, mechanical stress, …) and build large surface detectors.
On the other hand, there is a general keen interest in **polarization** measurements for astronomical purpose in addition to spectrometry and photometry resolved in time. This is an emerging parameter that most of our technologies can integrate at detector level.
In the next sections, we detail the perspective to follow the general trends in each individual LSIS activity.

LSIS Strategy 2014-2018

LSIS strategy remains valid for the next period to 2018 that is to conduct in parallel low maturity level basic research with advanced systems applications. The technological merry-go-round will probably push X-ray micro calorimeter into the prototyping stage while CdTe activities will start a new cycle of basic R&T studies as well as IR detectors.

In terms of organization, we'll reinforce and improve internal communication in LSIS for better cooperation between staff in apparently different skills. This happens when organizing periodic Science and Technical Forums where LSIS staff is invited to share and comment on new innovating ideas without any external public. This kind of forum comes in addition to periodical general-purpose lab meetings where information's are shared; opportunities are discussed and prioritized according to AIM technical director advices. Conversely, LSIS must communicate efficiently inside AIM to influence its main scientific items.

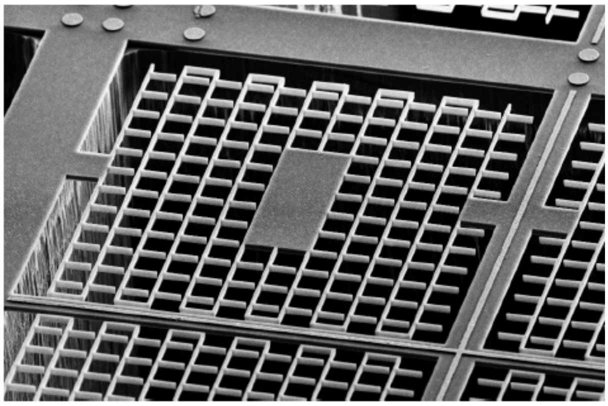
LSIS will pay attention to sustain valorization efforts to other fields than astronomy, enabling new sources of funding.

LSIS life

LSIS pays attention to staff skills and encourage participation to professional training and conference participation. It is also our role to go ahead in teaching our cutting edge knowledge, especially giving lectures. This was done previously including students training (Postdocs, PhD students and apprentices or students at any degree of technical training). The goal for each team is to incorporate at least one PhD, Postdoc and student (i.e. more than a dozen of new non-permanent positions).

LSIS shall hire at least one technician in its permanent staff during the 2014-2018 contract, while replacing retired members.

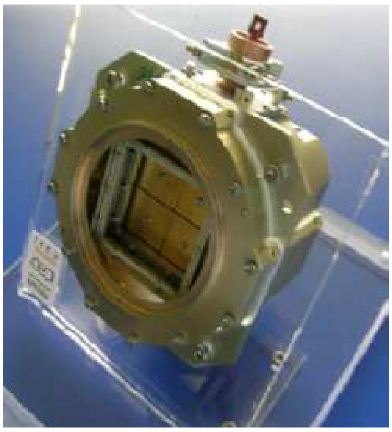
R&T prospective for sub millimeter range bolometers



Our aim is to reach a Noise Equivalent Power below 10^{-18} W/sqrt(Hz) on PACS type sub millimeter bolometers (Metal-Insulator Semiconductors – MIS). The future observatory like SPICA (Jaxa) requires an improvement by a factor of 1000, (i.e. 10^{-19} W/sqrt(Hz)) with respect to current arrays. It is a major acceleration of the typical detector improvement step (one order of magnitude par step). This goal is a real challenge and succeeding here would be a breakthrough in this field.

LSIS believes that MIS resistive bolometers are still capable to evolve this way and remains competitive with respect to Transition edge sensors or more recent KIDs arrays. Nowadays, even if TES are faster than MIS, serious limitation come from the complicated manufacturing process and high power readout electronics needed, which eventually limit the number of achievable channels in a space program. On the other hand, KIDS are very promising and easy to build, but possibly sensitive to cosmic rays. They require complex warm electronics and have a low maturity level. Improvement of MIS sensitivity relies on:

- First, detail knowledge and modeling shows that current bolometer architecture, when cooled down to 50 mK, instead of 300mK, enables to access the 10^{-18} or 5 10^{-19} W/sqrt(Hz) range. Cryogenics is obviously not sufficient to succeed as careful doping of the resistive thermometers is absolutely mandatory and a technological development is in progress. As the temperature goes down, thermal conductivity drops together with heat capacity, which improves drastically the Noise Equivalent Power as well as the bolometer response.
- Second, entirely new pixel design is foreseen to reduce the Noise Equivalent Power even more. This design called ULG from Léti (see top right figure), combines a complex shape and ultra-low thermal conductivity link to a radiation absorber in a single micro machined ~250 µm silicon pixel bringing another improvement factor of 5 or 10.
- Finally, adjusting carefully the shape of the absorber, the pixel is eventually sensitive or not to radiation polarization, on demand.



This has never been achieved up to now and is fully part of our program for 2014-2018 period.

In parallel to this ambitious noise hunting, it is planned to quadruple at least the number of channels in a bolometer module increasing the detector surface and reducing the pixel pitch (bottom right figure chose a mockup of what should be a mosaic of four 1024 pixel bolometer arrays with 650 micron pitch).

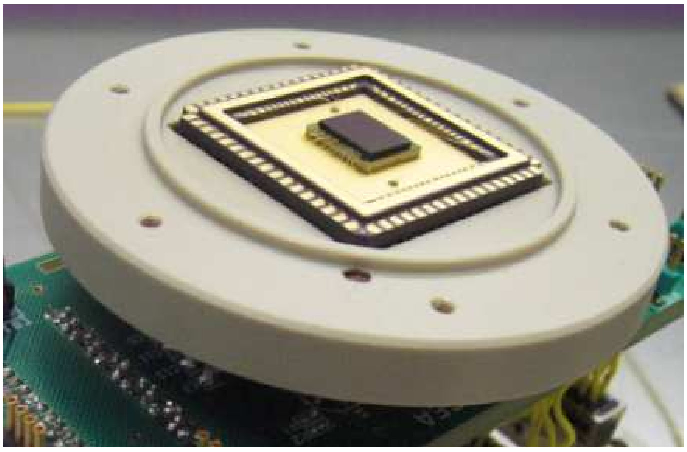
Of course, such a development is associated to a parallel effort on cryogenic electronics, as the amplification, readout, multiplexing etc. must fit these extreme noise requirements. This is the goal of CESAR program led by LSIS. The Sub-millimeter R&T coupled to CESAR cryo-electronics programs also aims also at contributing to applications in the medical imaging techniques, more precisely in magneto metric brain imaging.

Within the framework of the Focus LabEx, LSIS will investigate possible hybrid bolometers using manufacturing process of MIS together with KIDS.

In addition to this coherent program on ultra-high sensitivity bolometers, more exotic studies will be reinforced, for instance to design and model some entirely new bolometers integrating some spectrometry capabilities. This idea relies on the resonant cavity adaptation on demand, either dynamically with a cavity motion or using magnetic modulation of a dielectric absorption.

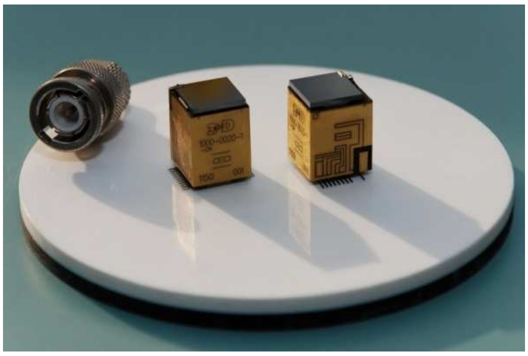
R&T prospective for IR sensors

European Space Agency has established a roadmap for the development of infrared detectors in Europe that shall be used in space both for astrophysical and Earth Observation purpose. The roadmap responds to a strategic plan to overcome the US supremacy in this field for space applications. The main goal of ESA is to support a European source of ultra-low dark current IR detectors built in a large format configuration up to 2K x 2K and operated at cryogenic temperatures and covering the whole spectrum from NIR (1-2 µm) to VLWIR (16 µm).



CEA/Léti – AIM duo and Sofradir, a French company born from CEA, are in a very good position to play a major role in this European MIR development because this consortium disposes of cutting edge technology: large scale, fine pitch MCT (HgCdTe) bump bonded to CMOS readout chips (see left picture), operated at cryogenics temperatures in the range from 30 K to 110 K and capable to meet the science requirements of most demanding missions like Euclid or EChO in several bands: SWIR, MWIR or LWIR. A single technology process is available to fine-tune MCT detectors in any of these wavelength channels. The requirements for such applications are ambitious because the source flux is extremely low, which obviously requires ultra-low dark current in the pixels: the typical range is a few tens of ato-amps. Consequently, R&T efforts are mandatory for design, fab and fine characterization of ultra-low dark current detectors. LSIS is expert in IR sensor fine characterization while CEA/Léti is expert in IR detector physics and manufacturing. This association of these competences enables challenging this R&T effort to the space qualification au CEA/Léti IR products.
The current main frame for such developments is EChO/ITT published by ESA that AIM and Léti won. On the other hand, Cnes has established its own road map and LSIS is funded for R&T program devoted to EChO activities in France. This activity is accelerating, as the IR demand is strong. LSIS is preparing answer to new ITT coming up soon, especially for earth observation in the LWIR-VLWIR range.

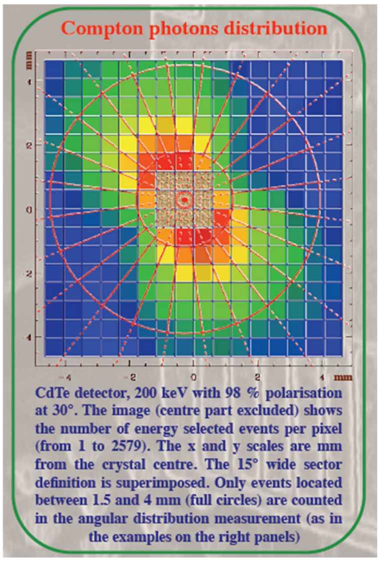
R&T prospective for semiconductor imaging spectrometers



CdTe based imaging spectrometer Caliste R&T is over and the device is ready for flight in its Caliste-SO version (see picture on the right). It will be used in the ESA Solar Orbiter mission inside the STIX X-ray spectrometer in charge of observing the solar flares in a ultra-wide domain of luminosity, with a good timing accuracy, good spectral resolution, large dynamic range down to 4 keV through a thermal shield and with an unprecedented angular resolution near perihelion, 0.22 astronomical unit from the sun. Solar orbiter will be LSIS first opportunity to fly a set Caliste but hopefully will trigger new opportunities such as Spectrum Roentgen Gamma ART-XC focal planes or Inter-Helio Probe SORRENTO focal planes Russian payloads under discussions for the period of 2014-2018. In addition, this mature technology is also ready for ground application in the industry and is proposed for valorization in programs such as ORIGAMIX, a ANR devoted to post-Fukushima activities where Caliste could act as a building block of a ultra low wright and high performance portable gamma camera (collaboration between CEA and industry).

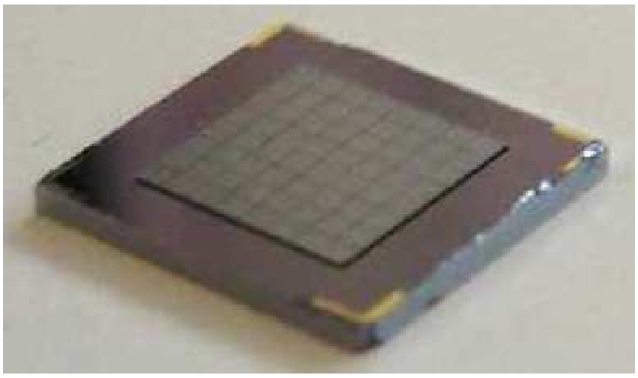
Time has come to start a new cycle of R&T for such imagers towards higher pixel density devices and lower noise. This is the goal of MC2 (Mini CdTe on Chip). This program supported by Cnes, starts with microelectronics developments and aims at designing entirely new CdTe imaging spectrometer with 300 µm pitch (instead of 580) and Fano limited spectral response, i.e. ~500 eV fwhm at 60 keV. A particular attention will be drawn on the attractive low threshold capabilities of our designs, which allows extended dynamic range down to 1 keV, in the X-ray domain. MC2 program has been triggered recently and hosts one PhD's in the field in LSIS. Another student is about to finish a microelectronics PhD at Irfu/LDEF, our main partner. Preliminary results show very promising performance that encourage us to start building prototypes and develop basic technologies for integration of a 3D hybrid, based on advanced technologies such as heterogeneous Wire-less Die on Die technology (3D plus) and/or Through silicon via's (TSV "last") techniques. Innovative funding for integration phase is under study in the prospective of getting closer relationships with industry, in a collaborative approach.

As our imager hybrid technology (but the ASICs) is in principle not limited to CdTe sensors, we now pay attention that our recent design is compatible with silicon diodes having reverse current with respect to CdTe diodes, or silicon double-sided strip detectors having connection both at the cathodes and anodes. This approach reinforces emerging collaboration with UC Berkeley - NASA/GSFC and JAXA/ISAS for space weather and solar physics or hard X-ray astronomy respectively. The latter pushes us to study double sided detector (DSD), whether they are CdTe based or Si based. In this case, LSIS will run a ESA funded program, in the frame of the European contribution to ASTRO-H, to study the stability of high spatial resolution Double sided CdTe as used in HXI instrument, and the stability of such detectors on the long run, taking into account radiation damage. On the other hand, development of DSD feeds new developments committed in the framework of the LabEx UnivearthS/WP I5, that consists of building prototypes of large area silicon based DSSD's for Compton imaging in the frame of LabEx UnivearthS.



CdTe detector, 200 keV with 98 % polarisation at 30°. The image (centre part excluded) shows the number of energy selected events per pixel (from 1 to 2579). The x and y scales are mm from the crystal centre. The 15° wide sector definition is superimposed. Only events located between 1.5 and 4 mm (full circles) are counted in the angular distribution measurement (as in the examples on the right panels)

Compton imaging is the key to access the polarization measurements of each single photon hitting the sensors in the gamma ray range. A polarimeter would count at list a pixelated or DSD CdTe camera or a stack of it, or a stack of Si DSSDs. A pixelated CdTe Caliste-256 module has been successfully experienced at the European Synchrotron Research Facility in 2011 giving promising results (see figure above). This triggered a new international collaboration, joining IAAT/Tubingen, INAF/Bologna, University of Coimbra and APC, that LSIS intend to animate for further research, new ESRF campaigns towards instrument concept development in the period 2014-2018. This Project is called ASTROPOL.



R&T prospective for X-ray microcalorimeter

The micro-calorimeter in the X-ray domain is a very challenging R&T program of LSIS. Basic research on materials, manufacturing process and collective building-up of an entire array is achieved. This includes Tantalum absorber preparation, purification and bonding, cryogenics systems and benches, radiation-hard and ultra low-power cryo-electronics, massive interconnection systems at 50 mK (see figure bottom right), multiplexing strategy, warm electronics and data acquisition. Building blocks are ready and no more technological barrier is ahead. The team will build a first full functional prototype. The goal is clearly to realize an ultra-high energy resolution spectrum in the short term and to go ahead with a demonstrator of quarter of focal plane with 32x32 pixel array, 500-micron pitch, operated at 50 mK.

The expected performances are in the range of only 2 to 5 eV fwhm at 6 keV. The system approach of the development will allow building the full assembly in the next period of 2014-2018 showing a Technological Readiness Level at 4/5. The demonstrator will be the largest X-ray micro-calorimeter array ever built and will certainly enter in a competing position with respect to Transition Edge Superconductor based micro-calorimeters of our main competitors, i.e. NASA/GSFC and SRON.

LSIS is leader of a large collaboration involved in the X-ray micro-calorimeter focal plane development, ready to face future call for large mission.

APPENDIX

List of Publications during the 2007-mid2012 period with more than 50 quotations on October 1st 2012

1	2009ApJ...697.1071A	753.000	juin-09
	Atwood, W. B.; Abdo, A. A.; Ackermann, M.; Althouse, W.; Anderson, B.; Axelsson, M.; Baldini, L.; Ballet, J.; Band, D. L.; Barbiellini, G.; and 230 coauthors	The Large Area Telescope on the Fermi Gamma-Ray Space Telescope Mission	
2	2009PhRvL.102r1101A	597.000	mai-09
	Abdo, A. A.; Ackermann, M.; Ajello, M.; Atwood, W. B.; Axelsson, M.; Baldini, L.; Ballet, J.; Barbiellini, G.; Bastieri, D.; Battelino, M.; and 179 coauthors	Measurement of the Cosmic Ray $e^{+}+e^{-}$ Spectrum from 20GeV to 1TeV with the Fermi Large Area Telescope	
3	2010ApJS..188..405A	409.000	juin-10
	Abdo, A. A.; Ackermann, M.; Ajello, M.; Allafort, A.; Antolini, E.; Atwood, W. B.; Axelsson, M.; Baldini, L.; Ballet, J.; Barbiellini, G.; and 226 coauthors	Fermi Large Area Telescope First Source Catalog	
4	2007ApJS..172....1S	403.000	sept-07
	Scoville, N.; Aussel, H.; Brusa, M.; Capak, P.; Carollo, C. M.; Elvis, M.; Giavalisco, M.; Guzzo, L.; Hasinger, G.; Impey, C.; and 12 coauthors	The Cosmic Evolution Survey (COSMOS): Overview	
5	2009Natur.457..451D	396.000	janv-09
	Dekel, A.; Birnboim, Y.; Engel, G.; Freundlich, J.; Goerdt, T.; Mumcuoglu, M.; Neistein, E.; Pichon, C.; Teyssier, R.; Zinger, E.	Cold streams in early massive hot haloes as the main mode of galaxy formation	
6	2010A&A...518L...2P	395.000	juil-10
	Poglitsch, A.; Waelkens, C.; Geis, N.; Feuchtgruber, H.; Vandenbussche, B.; Rodriguez, L.; Krause, O.; Renotte, E.; van Hoof, C.; Saraceno, P.; and 73 coauthors	The Photodetector Array Camera and Spectrometer (PACS) on the Herschel Space Observatory	
7	2010A&A...518L...3G	360.000	juil-10
	Griffin, M. J.; Abergel, A.; Abreu, A.; Ade, P. A. R.; André, P.; Augueres, J.-L.; Babbedge, T.; Bae, Y.; Baillie, T.; Baluteau, J.-P.; and 169 coauthors	The Herschel-SPIRE instrument and its in-flight performance	
8	2007ApJ...670..156D	360.000	nov-07
	Daddi, E.; Dickinson, M.; Morrison, G.; Chary, R.; Cimatti, A.; Elbaz, D.; Frayer, D.; Renzini, A.; Pope, A.; Alexander, D. M.; and 5 coauthors	Multiwavelength Study of Massive Galaxies at z~2. I. Star Formation and Galaxy Growth	
9	2009ApJS..183...46A	306.000	juil-09
	Abdo, A. A.; Ackermann, M.; Ajello, M.; Atwood, W. B.; Axelsson, M.; Baldini, L.; Ballet, J.; Band, D. L.; Barbiellini, G.; Bastieri, D.; and 200 coauthors	Fermi/Large Area Telescope Bright Gamma-Ray Source List	
10	2007A&A...468...33E	302.000	juin-07
	Elbaz, D.; Daddi, E.; Le Borgne, D.; Dickinson, M.; Alexander, D. M.; Chary, R.-R.; Starck, J.-L.; Brandt, W. N.; Kitzbichler, M.; MacDonald, E.; and 4 coauthors	The reversal of the star formation-density relation in the distant universe	
11	2009ApJ...690.1236I	298.000	janv-09
	Ilbert, O.; Capak, P.; Salvato, M.; Aussel, H.; McCracken, H. J.; Sanders, D. B.; Scoville, N.; Kartaltepe, J.; Arnouts, S.; Le Floc'h, E.; and 53 coauthors	Cosmos Photometric Redshifts with 30-Bands for 2-deg^2	

12	2007ApJS..172...70L	286.000	sept-07
	Lilly, S. J.; Le Fèvre, O.; Renzini, A.; Zamorani, G.; Scodeggio, M.; Contini, T.; Carollo, C. M.; Hasinger, G.; Kneib, J.-P.; Iovino, A.; and 67 coauthors	zCOSMOS: A Large VLT/VIMOS Redshift Survey Covering 0 < z < 3 in the COSMOS Field	
13	2008ApJ...680..246T	282.000	juin-08
	Tacconi, L. J.; Genzel, R.; Smail, I.; Neri, R.; Chapman, S. C.; Ivison, R. J.; Blain, A.; Cox, P.; Omont, A.; Bertoldi, F.; and 10 coauthors	Submillimeter Galaxies at z ~ 2: Evidence for Major Mergers and Constraints on Lifetimes, IMF, and CO-H_2 Conversion Factor	
14	2008PhRvL.101z1104A	278.000	déc-08
	Aharonian, F.; Akhperjanian, A. G.; Barres de Almeida, U.; Bazer-Bachi, A. R.; Becherini, Y.; Behera, B.; Benbow, W.; Bernlöhr, K.; Boisson, C.; Bochow, A.; and 146 coauthors	Energy Spectrum of Cosmic-Ray Electrons at TeV Energies	
15	2009Sci...323.1688A	271.000	mars-09
	Abdo, A. A.; Ackermann, M.; Arimoto, M.; Asano, K.; Atwood, W. B.; Axelsson, M.; Baldini, L.; Ballet, J.; Band, D. L.; Barbiellini, G.; and 244 coauthors	Fermi Observations of High-Energy Gamma-Ray Emission from GRB 080916C	
16	2009ApJ...700..597A	269.000	juil-09
	Abdo, A. A.; Ackermann, M.; Ajello, M.; Atwood, W. B.; Axelsson, M.; Baldini, L.; Ballet, J.; Barbiellini, G.; Bastieri, D.; Baughman, B. M.; and 183 coauthors	Bright Active Galactic Nuclei Source List from the First Three Months of the Fermi Large Area Telescope All-Sky Survey	
17	2009A&A...508..561A	260.000	déc-09
	Aharonian, F.; Akhperjanian, A. G.; Anton, G.; Barres de Almeida, U.; Bazer-Bachi, A. R.; Becherini, Y.; Behera, B.; Bernlöhr, K.; Bochow, A.; Boisson, C.; and 160 coauthors	Probing the ATIC peak in the cosmic-ray electron spectrum with H.E.S.S.	
18	2009ApJ...706.1364F	258.000	déc-09
	Förster Schreiber, N. M.; Genzel, R.; Bouché, N.; Cresci, G.; Davies, R.; Buschkamp, P.; Shapiro, K.; Tacconi, L. J.; Hicks, E. K. S.; Genel, S.; and 20 coauthors	The SINS Survey: SINFONI Integral Field Spectroscopy of z ~ 2 Star-forming Galaxies	
19	2010ApJS..187..460A	256.000	avr-10
	Abdo, A. A.; Ackermann, M.; Ajello, M.; Atwood, W. B.; Axelsson, M.; Baldini, L.; Ballet, J.; Barbiellini, G.; Baring, M. G.; Bastieri, D.; and 207 coauthors	The First Fermi Large Area Telescope Catalog of Gamma-ray Pulsars	
20	2007ApJS..172...99C	245.000	sept-07
	Capak, P.; Aussel, H.; Ajiki, M.; McCracken, H. J.; Mobasher, B.; Scoville, N.; Shopbell, P.; Taniguchi, Y.; Thompson, D.; Tribiano, S.; and 48 coauthors	The First Release COSMOS Optical and Near-IR Data and Catalog	
21	2007ApJ...664L..71A	241.000	août-07
	Aharonian, F.; Akhperjanian, A. G.; Bazer-Bachi, A. R.; Behera, B.; Beilicke, M.; Benbow, W.; Berge, D.; Bernlöhr, K.; Boisson, C.; Bolz, O.; and 128 coauthors	An Exceptional Very High Energy Gamma-Ray Flare of PKS 2155-304	
22	2008ApJ...687...59G	230.000	nov-08
	Genzel, R.; Burkert, A.; Bouché, N.; Cresci, G.; Förster Schreiber, N. M.; Shapley, A.; Shapiro, K.; Tacconi, L. J.; Buschkamp, P.; Cimatti, A.; and 15 coauthors	From Rings to Bulges: Evidence for Rapid Secular Galaxy Evolution at z ~ 2 from Integral Field Spectroscopy in the SINS Survey	
23	2007ApJ...670..173D	229.000	nov-07

	Daddi, E.; Alexander, D. M.; Dickinson, M.; Gilli, R.; Renzini, A.; Elbaz, D.; Cimatti, A.; Chary, R.; Frayer, D.; Bauer, F. E.; and 9 coauthors	Multiwavelength Study of Massive Galaxies at z~2. II. Widespread Compton-thick Active Galactic Nuclei and the Concurrent Growth of Black Holes and Bulges	
24	2010PhRvL.104j1101A	226.000	mars-10
	Abdo, A. A.; Ackermann, M.; Ajello, M.; Atwood, W. B.; Baldini, L.; Ballet, J.; Barbiellini, G.; Bastieri, D.; Baughman, B. M.; Bechtol, K.; and 174 coauthors	Spectrum of the Isotropic Diffuse Gamma-Ray Emission Derived from First-Year Fermi Large Area Telescope Data	
25	2008A&A...482...21C	219.000	avr-08
	Cimatti, A.; Cassata, P.; Pozzetti, L.; Kurk, J.; Mignoli, M.; Renzini, A.; Daddi, E.; Bolzonella, M.; Brusa, M.; Rodighiero, G.; and 6 coauthors	GMASS ultradeep spectroscopy of galaxies at z ~ 2. II. Superdense passive galaxies: how did they form and evolve?	
26	2007ApJ...663...81P	218.000	juil-07
	Polletta, M.; Tajer, M.; Maraschi, L.; Trinchieri, G.; Lonsdale, C. J.; Chiappetti, L.; Andreon, S.; Pierre, M.; Le Fèvre, O.; Zamorani, G.; and 11 coauthors	Spectral Energy Distributions of Hard X-Ray Selected Active Galactic Nuclei in the XMM-Newton Medium Deep Survey	
27	2007ApJS..170..175B	214.000	mai-07
	Bird, A. J.; Malizia, A.; Bazzano, A.; Barlow, E. J.; Bassani, L.; Hill, A. B.; Bélanger, G.; Capitanio, F.; Clark, D. J.; Dean, A. J.; and 13 coauthors	The Third IBIS/ISGRI Soft Gamma-Ray Survey Catalog	
28	2010ApJ...715..429A	210.000	mai-10
	Abdo, A. A.; Ackermann, M.; Ajello, M.; Allafort, A.; Antolini, E.; Atwood, W. B.; Axelsson, M.; Baldini, L.; Ballet, J.; Barbiellini, G.; and 198 coauthors	The First Catalog of Active Galactic Nuclei Detected by the Fermi Large Area Telescope	
29	2007MNRAS.380..963A	210.000	sept-07
	Agertz, Oscar; Moore, Ben; Stadel, Joachim; Potter, Doug; Miniati, Francesco; Read, Justin; Mayer, Lucio; Gawryszczak, Artur; Kravtsov, Andrey; Nordlund, Åke; and 9 coauthors	Fundamental differences between SPH and grid methods	
30	2009Natur.462..331A	196.000	nov-09
	Abdo, A. A.; Ackermann, M.; Ajello, M.; Asano, K.; Atwood, W. B.; Axelsson, M.; Baldini, L.; Ballet, J.; Barbiellini, G.; Baring, M. G.; and 199 coauthors	A limit on the variation of the speed of light arising from quantum gravity effects	
31	2010Natur.463..781T	193.000	févr-10
	Tacconi, L. J.; Genzel, R.; Neri, R.; Cox, P.; Cooper, M. C.; Shapiro, K.; Bolatto, A.; Bouché, N.; Bournaud, F.; Burkert, A.; and 12 coauthors	High molecular gas fractions in normal massive star-forming galaxies in the young Universe	
32	2008ApJ...675.1171P	191.000	mars-08
	Pope, Alexandra; Chary, Ranga-Ram; Alexander, David M.; Armus, Lee; Dickinson, Mark; Elbaz, David; Frayer, David; Scott, Douglas; Teplitz, Harry	Mid-Infrared Spectral Diagnosis of Submillimeter Galaxies	
33	2007ApJS..172..196K	188.000	sept-07
	Koekemoer, A. M.; Aussel, H.; Calzetti, D.; Capak, P.; Giavalisco, M.; Kneib, J.-P.; Leauthaud, A.; Le Fèvre, O.; McCracken, H. J.; Massey, R.; and 4 coauthors	The COSMOS Survey: Hubble Space Telescope Advanced Camera for Surveys Observations and Data Processing	
34	2012ApJS..199...31N	179.000	avr-12

	Nolan, P. L.; Abdo, A. A.; Ackermann, M.; Ajello, M.; Allafort, A.; Antolini, E.; Atwood, W. B.; Axelsson, M.; Baldini, L.; Ballet, J.; and 227 coauthors	Fermi Large Area Telescope Second Source Catalog	
35	2009A&A...493..339W	177.000	janv-09
	Watson, M. G.; Schröder, A. C.; Fyfe, D.; Page, C. G.; Lamer, G.; Mateos, S.; Pye, J.; Sakano, M.; Rosen, S.; Ballet, J.; and 40 coauthors	The XMM-Newton serendipitous survey. V. The Second XMM-Newton serendipitous source catalogue	
36	2007MNRAS.376...13M	170.000	mars-07
	Massey, Richard; Heymans, Catherine; Bergé, Joel; Bernstein, Gary; Bridle, Sarah; Clowe, Douglas; Dahle, Håkon; Ellis, Richard; Erben, Thomas; Hetterscheidt, Marco; and 21 coauthors	The Shear Testing Programme 2: Factors affecting high-precision weak-lensing analyses	
37	2010ApJ...713..686D	169.000	avr-10
	Daddi, E.; Bournaud, F.; Walter, F.; Dannerbauer, H.; Carilli, C. L.; Dickinson, M.; Elbaz, D.; Morrison, G. E.; Riechers, D.; Onodera, M.; and 3 coauthors	Very High Gas Fractions and Extended Gas Reservoirs in z = 1.5 Disk Galaxies	
38	2007ApJS..172...86S	169.000	sept-07
	Sanders, D. B.; Salvato, M.; Aussel, H.; Ilbert, O.; Scoville, N.; Surace, J. A.; Frayer, D. T.; Sheth, K.; Helou, G.; Brooke, T.; and 32 coauthors	S-COSMOS: The Spitzer Legacy Survey of the Hubble Space Telescope ACS 2 deg^2 COSMOS Field I: Survey Strategy and First Analysis	
39	2010ApJ...709..644I	166.000	févr-10
	Ilbert, O.; Salvato, M.; Le Floc'h, E.; Aussel, H.; Capak, P.; McCracken, H. J.; Mobasher, B.; Kartaltepe, J.; Scoville, N.; Sanders, D. B.; and 15 coauthors	Galaxy Stellar Mass Assembly Between 0.2 < z < 2 from the S-COSMOS Survey	
40	2009A&A...496...57M	161.000	mars-09
	Magnelli, B.; Elbaz, D.; Chary, R. R.; Dickinson, M.; Le Borgne, D.; Frayer, D. T.; Willmer, C. N. A.	The 0.4 < z < 1.3 star formation history of the Universe as viewed in the far-infrared	
41	2009ApJ...706L.138A	160.000	nov-09
	Abdo, A. A.; Ackermann, M.; Ajello, M.; Asano, K.; Atwood, W. B.; Axelsson, M.; Baldini, L.; Ballet, J.; Barbiellini, G.; Baring, M. G.; and 196 coauthors	Fermi Observations of GRB 090902B: A Distinct Spectral Component in the Prompt and Delayed Emission	
42	2007A&A...464..235A	160.000	mars-07
	Aharonian, F.; Akhperjanian, A. G.; Bazer-Bachi, A. R.; Beilicke, M.; Benbow, W.; Berge, D.; Bernlöhr, K.; Boisson, C.; Bolz, O.; Borrel, V.; and 115 coauthors	Primary particle acceleration above 100 TeV in the shell-type supernova remnant RX J1713.7-3946 with deep HESS observations	
43	2007ApJS..172..239M	157.000	sept-07
	Massey, Richard; Rhodes, Jason; Leauthaud, Alexie; Capak, Peter; Ellis, Richard; Koekemoer, Anton; Réfrégier, Alexandre; Scoville, Nick; Taylor, James E.; Albert, Justin; and 10 coauthors	COSMOS: Three-dimensional Weak Lensing and the Growth of Structure	
44	2007ApJS..172...38S	157.000	sept-07
	Scoville, N.; Abraham, R. G.; Aussel, H.; Barnes, J. E.; Benson, A.; Blain, A. W.; Calzetti, D.; Comastri, A.; Capak, P.; Carilli, C.; and 45 coauthors	COSMOS: Hubble Space Telescope Observations	
45	2007Natur.445..286M	150.000	janv-07

	Massey, Richard; Rhodes, Jason; Ellis, Richard; Scoville, Nick; Leauthaud, Alexie; Finoguenov, Alexis; Capak, Peter; Bacon, David; Aussel, Hervé; Kneib, Jean-Paul; and 10 coauthors	Dark matter maps reveal cosmic scaffolding	
46	2007ApJ...670..237B	147.000	nov-07
	Bournaud, Frédéric; Elmegreen, Bruce G.; Elmegreen, Debra Meloy	Rapid Formation of Exponential Disks and Bulges at High Redshift from the Dynamical Evolution of Clump-Cluster and Chain Galaxies	
47	2008MNRAS.390.1326O	143.000	nov-08
	Ocvirk, P.; Pichon, C.; Teyssier, R.	Bimodal gas accretion in the Horizon-MareNostrum galaxy formation simulation	
48	2010MNRAS.407.2091G	140.000	oct-10
	Genzel, R.; Tacconi, L. J.; Gracia-Carpio, J.; Sternberg, A.; Cooper, M. C.; Shapiro, K.; Bolatto, A.; Bouché, N.; Bournaud, F.; Burkert, A.; and 12 coauthors	A study of the gas-star formation relation over cosmic time	
49	2010A&A...517A..92A	135.000	juil-10
	Arnaud, M.; Pratt, G. W.; Piffaretti, R.; Böhringer, H.; Croston, J. H.; Pointecouteau, E.	The universal galaxy cluster pressure profile from a representative sample of nearby systems (REXCESS) and the Y_{SZ} - M_{500} relation	
50	2010ApJ...712..147A	135.000	mars-10
	Abdo, A. A.; Ackermann, M.; Ajello, M.; Atwood, W. B.; Baldini, L.; Ballet, J.; Barbiellini, G.; Bastieri, D.; Bechtol, K.; Bellazzini, R.; and 153 coauthors	Observations of Milky Way Dwarf Spheroidal Galaxies with the Fermi-Large Area Telescope Detector and Constraints on Dark Matter Models	
51	2007ApJ...671..303B	132.000	déc-07
	Bouché, N.; Cresci, G.; Davies, R.; Eisenhauer, F.; Förster Schreiber, N. M.; Genzel, R.; Gillessen, S.; Lehnert, M.; Lutz, D.; Nesvadba, N.; and 10 coauthors	Dynamical Properties of z ~ 2 Star-forming Galaxies and a Universal Star Formation Relation	
52	2011A&A...536A...1P	130.000	déc-11
	Planck Collaboration; Ade, P. A. R.; Aghanim, N.; Arnaud, M.; Ashdown, M.; Aumont, J.; Baccigalupi, C.; Baker, M.; Balbi, A.; Banday, A. J.; and 265 coauthors	Planck early results. I. The Planck mission	
53	2010A&A...518L.102A	130.000	juil-10
	André, Ph.; Men'shchikov, A.; Bontemps, S.; Könyves, V.; Motte, F.; Schneider, N.; Didelon, P.; Minier, V.; Saraceno, P.; Ward-Thompson, D.; and 47 coauthors	From filamentary clouds to prestellar cores to the stellar IMF: Initial highlights from the Herschel Gould Belt Survey	
54	2010ApJ...716...30A	130.000	juin-10
	Abdo, A. A.; Ackermann, M.; Agudo, I.; Ajello, M.; Aller, H. D.; Aller, M. F.; Angelakis, E.; Arkharov, A. A.; Axelsson, M.; Bach, U.; and 247 coauthors	The Spectral Energy Distribution of Fermi Bright Blazars	
55	2007A&A...461...71P	130.000	janv-07
	Pratt, G. W.; Böhringer, H.; Croston, J. H.; Arnaud, M.; Borgani, S.; Finoguenov, A.; Temple, R. F.	Temperature profiles of a representative sample of nearby X-ray galaxy clusters	
56	2009A&A...498..361P	129.000	mai-09
	Pratt, G. W.; Croston, J. H.; Arnaud, M.; Böhringer, H.	Galaxy cluster X-ray luminosity scaling relations from a representative local sample (REXCESS)	
57	2008A&A...488..705A	125.000	sept-08
	Appourchaux, T.; Michel, E.; Auvergne, M.; Baglin, A.; Toutain, T.; Baudin, F.; Benomar, O.; Chaplin, W. J.; Deheuvels, S.; Samadi, R.; and 12 coauthors	CoRoT sounds the stars: p-mode parameters of Sun-like oscillations on HD 49933	

58	2011ExA....32..193A	124.000	déc-11
	Actis, M.; Agnetta, G.; Aharonian, F.; Akhperjanian, A.; Aleksić, J.; Aliu, E.; Allan, D.; Allekotte, I.; Antico, F.; Antonelli, L. A.; and 662 coauthors	Design concepts for the Cherenkov Telescope Array CTA: an advanced facility for ground-based high-energy gamma-ray astronomy	
59	2011ApJS..197...35G	124.000	déc-11
	Grogin, Norman A.; Kocevski, Dale D.; Faber, S. M.; Ferguson, Henry C.; Koekemoer, Anton M.; Riess, Adam G.; Acquaviva, Viviana; Alexander, David M.; Almaini, Omar; Ashby, Matthew L. N.; and 97 coauthors	CANDELS: The Cosmic Assembly Near-infrared Deep Extragalactic Legacy Survey	
60	2011PhRvL.107x1302A	122.000	déc-11
	Ackermann, M.; Ajello, M.; Albert, A.; Atwood, W. B.; Baldini, L.; Ballet, J.; Barbiellini, G.; Bastieri, D.; Bechtol, K.; Bellazzini, R.; and 142 coauthors	Constraining Dark Matter Models from a Combined Analysis of Milky Way Satellites with the Fermi Large Area Telescope	
61	2009Sci...325..848A	119.000	août-09
	Abdo, A. A.; Ackermann, M.; Ajello, M.; Atwood, W. B.; Axelsson, M.; Baldini, L.; Ballet, J.; Barbiellini, G.; Baring, M. G.; Bastieri, D.; and 192 coauthors	A Population of Gamma-Ray Millisecond Pulsars Seen with the Fermi Large Area Telescope	
62	2007A&A...476.1179B	119.000	déc-07
	Bournaud, F.; Jog, C. J.; Combes, F.	Multiple minor mergers: formation of elliptical galaxies and constraints for the growth of spiral disks	
63	2011A&A...536A...8P	118.000	déc-11
	Planck Collaboration; Ade, P. A. R.; Aghanim, N.; Arnaud, M.; Ashdown, M.; Aumont, J.; Baccigalupi, C.; Balbi, A.; Banday, A. J.; Barreiro, R. B.; and 228 coauthors	Planck early results. VIII. The all-sky early Sunyaev-Zeldovich cluster sample	
64	2011ApJS..197...36K	116.000	déc-11
	Koekemoer, Anton M.; Faber, S. M.; Ferguson, Henry C.; Grogin, Norman A.; Kocevski, Dale D.; Koo, David C.; Lai, Kamson; Lotz, Jennifer M.; Lucas, Ray A.; McGrath, Elizabeth J.; and 114 coauthors	CANDELS: The Cosmic Assembly Near-infrared Deep Extragalactic Legacy Survey—The Hubble Space Telescope Observations, Imaging Data Products, and Mosaics	
65	2009ApJ...694.1517D	116.000	avr-09
	Daddi, E.; Dannerbauer, H.; Stern, D.; Dickinson, M.; Morrison, G.; Elbaz, D.; Giavalisco, M.; Mancini, C.; Pope, A.; Spinrad, H.	Two Bright Submillimeter Galaxies in a z = 4.05 Protocluster in Goods-North, and Accurate Radio-Infrared Photometric Redshifts	
66	2007ApJS..172..182F	115.000	sept-07
	Finoguenov, A.; Guzzo, L.; Hasinger, G.; Scoville, N. Z.; Aussel, H.; Böhringer, H.; Brusa, M.; Capak, P.; Cappelluti, N.; Comastri, A.; and 23 coauthors	The XMM-Newton Wide-Field Survey in the COSMOS Field: Statistical Properties of Clusters of Galaxies	
67	2007ApJS..172..219L	114.000	sept-07
	Leauthaud, Alexie; Massey, Richard; Kneib, Jean-Paul; Rhodes, Jason; Johnston, David E.; Capak, Peter; Heymans, Catherine; Ellis, Richard S.; Koekemoer, Anton M.; Le Fèvre, Oliver; and 7 coauthors	Weak Gravitational Lensing with COSMOS: Galaxy Selection and Shape Measurements	
68	2010PhRvL.104i1302A	112.000	mars-10
	Abdo, A. A.; Ackermann, M.; Ajello, M.; Atwood, W. B.; Baldini, L.; Ballet, J.; Barbiellini, G.; Bastieri, D.; Bechtol, K.; Bellazzini, R.; and 153 coauthors	Fermi Large Area Telescope Search for Photon Lines from 30 to 200 GeV and Dark Matter Implications	
69	2009Sci...325..840A	112.000	août-09

	Abdo, A. A.; Ackermann, M.; Ajello, M.; Anderson, B.; Atwood, W. B.; Axelsson, M.; Baldini, L.; Ballet, J.; Barbiellini, G.; Baring, M. G.; and 170 coauthors	Detection of 16 Gamma-Ray Pulsars Through Blind Frequency Searches Using the Fermi LAT	
70	2008ApJ...673L..21D	112.000	janv-08
	Daddi, E.; Dannerbauer, H.; Elbaz, D.; Dickinson, M.; Morrison, G.; Stern, D.; Ravindranath, S.	Vigorous Star Formation with Low Efficiency in Massive Disk Galaxies at z = 1.5	
71	2007ApJS..172...46S	112.000	sept-07
	Schinnerer, E.; Smolčić, V.; Carilli, C. L.; Bondi, M.; Ciliegi, P.; Jahnke, K.; Scoville, N. Z.; Aussel, H.; Bertoldi, F.; Blain, A. W.; and 4 coauthors	The VLA-COSMOS Survey. II. Source Catalog of the Large Project	
72	2010ApJ...714L.118D	111.000	mai-10
	Daddi, E.; Elbaz, D.; Walter, F.; Bournaud, F.; Salmi, F.; Carilli, C.; Dannerbauer, H.; Dickinson, M.; Monaco, P.; Riechers, D.	Different Star Formation Laws for Disks Versus Starbursts at Low and High Redshifts	
73	2010ApJS..186....1B	111.000	janv-10
	Bird, A. J.; Bazzano, A.; Bassani, L.; Capitanio, F.; Fiocchi, M.; Hill, A. B.; Malizia, A.; McBride, V. A.; Scaringi, S.; Sguera, V.; and 12 coauthors	The Fourth IBIS/ISGRI Soft Gamma-ray Survey Catalog	
74	2009A&A...494..443P	111.000	févr-09
	Popesso, P.; Dickinson, M.; Nonino, M.; Vanzella, E.; Daddi, E.; Fosbury, R. A. E.; Kuntschner, H.; Mainieri, V.; Cristiani, S.; Cesarsky, C.; and 3 coauthors	The great observatories origins deep survey. VLT/VIMOS spectroscopy in the GOODS-south field	
75	2010A&A...520A...1T	110.000	sept-10
	Tauber, J. A.; Mandolesi, N.; Puget, J.-L.; Banos, T.; Bersanelli, M.; Bouchet, F. R.; Butler, R. C.; Charra, J.; Crone, G.; Dodsworth, J.; and 490 coauthors	Planck pre-launch status: The Planck mission	
76	2010MNRAS.404.2151C	110.000	juin-10
	Ceverino, Daniel; Dekel, Avishai; Bournaud, Frederic	High-redshift clumpy discs and bulges in cosmological simulations	
77	2007prpl.conf...33W	109.000	00/2007
	Ward-Thompson, D.; André, P.; Crutcher, R.; Johnstone, D.; Onishi, T.; Wilson, C.	An Observational Perspective of Low-Mass Dense Cores II: Evolution Toward the Initial Mass Function	
78	2010PhRvD..82i2004A	108.000	nov-10
	Ackermann, M.; Ajello, M.; Atwood, W. B.; Baldini, L.; Ballet, J.; Barbiellini, G.; Bastieri, D.; Baughman, B. M.; Bechtol, K.; Bellardi, F.; and 185 coauthors	Fermi LAT observations of cosmic-ray electrons from 7 GeV to 1 TeV	
79	2008Sci...322..558M	108.000	oct-08
	Michel, Eric; Baglin, Annie; Auvergne, Michel; Catala, Claude; Samadi, Reza; Baudin, Frédéric; Appourchaux, Thierry; Barban, Caroline; Weiss, Werner W.; Berthomieu, Gabrielle; and 34 coauthors	CoRoT Measures Solar-Like Oscillations and Granulation in Stars Hotter Than the Sun	
80	2008ApJ...682..231S	107.000	juil-08
	Shapiro, Kristen L.; Genzel, Reinhard; Förster Schreiber, Natascha M.; Tacconi, Linda J.; Bouché, Nicolas; Cresci, Giovanni; Davies, Richard; Eisenhauer, Frank; Johansson, Peter H.; Krajnović, Davor; and 16 coauthors	Kinemetry of SINS High-Redshift Star-Forming Galaxies: Distinguishing Rotating Disks from Major Mergers	
81	2007A&A...476.1243M	106.000	déc-07

	Motte, F.; Bontemps, S.; Schilke, P.; Schneider, N.; Menten, K. M.; Broguière, D.	The earliest phases of high-mass star formation: a 3 square degree millimeter continuum mapping of Cygnus X	
82	2008A&A...491..597L	105.000	nov-08
	Leach, S. M.; Cardoso, J.-F.; Baccigalupi, C.; Barreiro, R. B.; Betoule, M.; Bobin, J.; Bonaldi, A.; Delabrouille, J.; de Zotti, G.; Dickinson, C.; and 20 coauthors	Component separation methods for the PLANCK mission	
83	2007ApJS..172....9T	104.000	sept-07
	Taniguchi, Y.; Scoville, N.; Murayama, T.; Sanders, D. B.; Mobasher, B.; Aussel, H.; Capak, P.; Ajiki, M.; Miyazaki, S.; Komiyama, Y.; and 20 coauthors	The Cosmic Evolution Survey (COSMOS): Subaru Observations of the HST Cosmos Field	
84	2010ApJ...716.1178A	103.000	juin-10
	Ackermann, M.; Asano, K.; Atwood, W. B.; Axelsson, M.; Baldini, L.; Ballet, J.; Barbiellini, G.; Baring, M. G.; Bastieri, D.; Bechtol, K.; and 169 coauthors	Fermi Observations of GRB 090510: A Short-Hard Gamma-ray Burst with an Additional, Hard Power-law Component from 10 keV TO GeV Energies	
85	2007ApJ...656...66Z	103.000	févr-07
	Zirm, Andrew W.; van der Wel, A.; Franx, M.; Labbé, I.; Trujillo, I.; van Dokkum, P.; Toft, S.; Daddi, E.; Rudnick, G.; Rix, H.-W.; and 2 coauthors	NICMOS Imaging of DRGs in the HDF-S: A Relation between Star Formation and Size at z ~ 2.5	
86	2010A&A...518L...4S	101.000	juil-10
	Swinyard, B. M.; Ade, P.; Baluteau, J.-P.; Aussel, H.; Barlow, M. J.; Bendo, G. J.; Benielli, D.; Bock, J.; Brisbin, D.; Conley, A.; and 48 coauthors	In-flight calibration of the Herschel-SPIRE instrument	
87	2009ApJ...690.1250S	101.000	janv-09
	Salvato, M.; Hasinger, G.; Ilbert, O.; Zamorani, G.; Brusa, M.; Scoville, N. Z.; Rau, A.; Capak, P.; Arnouts, S.; Aussel, H.; and 33 coauthors	Photometric Redshift and Classification for the XMM-COSMOS Sources	
88	2008ApJ...688...67E	101.000	nov-08
	Elmegreen, Bruce G.; Bournaud, Frédéric; Elmegreen, Debra Meloy	Bulge Formation by the Coalescence of Giant Clumps in Primordial Disk Galaxies	
89	2007ApJS..172..494S	101.000	sept-07
	Scarlata, C.; Carollo, C. M.; Lilly, S. J.; Feldmann, R.; Kampczyk, P.; Renzini, A.; Cimatti, A.; Halliday, C.; Daddi, E.; Sargent, M. T.; and 19 coauthors	The Redshift Evolution of Early-Type Galaxies in COSMOS: Do Massive Early-Type Galaxies Form by Dry Mergers?	
90	2010A&A...518L..21O	100.000	juil-10
	Oliver, S. J.; Wang, L.; Smith, A. J.; Altieri, B.; Amblard, A.; Arumugam, V.; Auld, R.; Aussel, H.; Babbedge, T.; Blain, A.; and 68 coauthors	HerMES: SPIRE galaxy number counts at 250, 350, and 500 μm	
91	2007ApJS..172..117M	100.000	sept-07
	Mobasher, B.; Capak, P.; Scoville, N. Z.; Dahlen, T.; Salvato, M.; Aussel, H.; Thompson, D. J.; Feldmann, R.; Tasca, L.; Le Fevre, O.; and 19 coauthors	Photometric Redshifts of Galaxies in COSMOS	
92	2007A&A...474..145Z	99.000	oct-07
	Zahn, J.-P.; Brun, A. S.; Mathis, S.	On magnetic instabilities and dynamo action in stellar radiation zones	
93	2007ApJ...661..236A	99.000	mai-07
	Aharonian, F.; Akhperjanian, A. G.; Bazer-Bachi, A. R.; Beilicke, M.; Benbow, W.; Berge, D.; Bernlöhr, K.; Boisson, C.; Bolz, O.; Borrel, V.; and 117 coauthors	H.E.S.S. Observations of the Supernova Remnant RX J0852.0-4622: Shell-Type Morphology and Spectrum of a Widely Extended Very High Energy Gamma-Ray	

		Source	
94	2010ApJ...708.1254A	98.000	janv-10
	Abdo, A. A.; Ackermann, M.; Ajello, M.; Atwood, W. B.; Axelsson, M.; Baldini, L.; Ballet, J.; Barbiellini, G.; Baring, M. G.; Bastieri, D.; and 182 coauthors	Fermi Large Area Telescope Observations of the Crab Pulsar And Nebula	
95	2010ApJ...713L.176B	97.000	avr-10
	Bedding, T. R.; Huber, D.; Stello, D.; Elsworth, Y. P.; Hekker, S.; Kallinger, T.; Mathur, S.; Mosser, B.; Preston, H. L.; Ballot, J.; and 40 coauthors	Solar-like Oscillations in Low-luminosity Red Giants: First Results from Kepler	
96	2009ApJ...698L.116P	97.000	juin-09
	Pannella, M.; Carilli, C. L.; Daddi, E.; McCracken, H. J.; Owen, F. N.; Renzini, A.; Strazzullo, V.; Civano, F.; Koekemoer, A. M.; Schinnerer, E.; and 10 coauthors	Star Formation and Dust Obscuration at z ≈ 2: Galaxies at the Dawn of Downsizing	
97	2010JCAP...04..014A	96.000	avr-10
	Abdo, A. A.; Ackermann, M.; Ajello, M.; Baldini, L.; Ballet, J.; Barbiellini, G.; Bastieri, D.; Bechtol, K.; Bellazzini, R.; Berenji, B.; and 139 coauthors	Constraints on cosmological dark matter annihilation from the Fermi-LAT isotropic diffuse gamma-ray measurement	
98	2009ApJ...696.1084A	96.000	mai-09
	Abdo, A. A.; Ackermann, M.; Atwood, W. B.; Bagagli, R.; Baldini, L.; Ballet, J.; Band, D. L.; Barbiellini, G.; Baring, M. G.; Bartelt, J.; and 225 coauthors	Fermi Large Area Telescope Observations of the Vela Pulsar	
99	2009ApJ...703..982G	95.000	sept-09
	Giodini, S.; Pierini, D.; Finoguenov, A.; Pratt, G. W.; Boehringer, H.; Leauthaud, A.; Guzzo, L.; Aussel, H.; Bolzonella, M.; Capak, P.; and 17 coauthors	Stellar and Total Baryon Mass Fractions in Groups and Clusters Since Redshift 1	
100	2007A&A...472..519A	95.000	sept-07
	André, Ph.; Belloche, A.; Motte, F.; Peretto, N.	The initial conditions of star formation in the Ophiuchus main cloud: Kinematics of the protocluster condensations	
101	2011ApJ...743..171A	94.000	déc-11
	Ackermann, M.; Ajello, M.; Allafort, A.; Antolini, E.; Atwood, W. B.; Axelsson, M.; Baldini, L.; Ballet, J.; Barbiellini, G.; Bastieri, D.; and 167 coauthors	The Second Catalog of Active Galactic Nuclei Detected by the Fermi Large Area Telescope	
102	2009PhRvL.103y1101A	94.000	déc-09
	Abdo, A. A.; Ackermann, M.; Ajello, M.; Anderson, B.; Atwood, W. B.; Axelsson, M.; Baldini, L.; Ballet, J.; Barbiellini, G.; Bastieri, D.; and 164 coauthors	Fermi Large Area Telescope Measurements of the Diffuse Gamma-Ray Emission at Intermediate Galactic Latitudes	
103	2008A&A...481..401A	94.000	avr-08
	Aharonian, F.; Akhperjanian, A. G.; Bazer-Bachi, A. R.; Behera, B.; Beilicke, M.; Benbow, W.; Berge, D.; Bernlöhr, K.; Boisson, C.; Bolz, O.; and 131 coauthors	Discovery of very high energy gamma-ray emission coincident with molecular clouds in the W 28 (G6.4-0.1) field	
104	2007A&A...475L...9A	94.000	nov-07
	Aharonian, F.; Akhperjanian, A. G.; Barres de Almeida, U.; Bazer-Bachi, A. R.; Behera, B.; Beilicke, M.; Benbow, W.; Bernlöhr, K.; Boisson, C.; Bolz, O.; and 134 coauthors	New constraints on the mid-IR EBL from the HESS discovery of VHE γ-rays from 1ES 0229+200	
105	2007ApJS..172..406S	94.000	sept-07

	Scarlata, C.; Carollo, C. M.; Lilly, S.; Sargent, M. T.; Feldmann, R.; Kampczyk, P.; Porciani, C.; Koekemoer, A.; Scoville, N.; Kneib, J.-P.; and 19 coauthors	COSMOS Morphological Classification with the Zurich Estimator of Structural Types (ZEST) and the Evolution Since z = 1 of the Luminosity Function of Early, Disk, and Irregular Galaxies	
106	2007Sci...316.1591G	94.000	juin-07
	García, Rafael A.; Turck-Chièze, Sylvaine; Jiménez-Reyes, Sebastian J.; Ballot, Jérôme; Pallé, Pere L.; Eff-Darwich, Antonio; Mathur, Savita; Provost, Janine	Tracking Solar Gravity Modes: The Dynamics of the Solar Core	
107	2008A&A...477..353A	93.000	janv-08
	Aharonian, F.; Akhperjanian, A. G.; Barres de Almeida, U.; Bazer-Bachi, A. R.; Behera, B.; Beilicke, M.; Benbow, W.; Bernlöhr, K.; Boisson, C.; Bolz, O.; and 134 coauthors	HESS very-high-energy gamma-ray sources without identified counterparts	
108	2010A&A...518L.100M	91.000	juil-10
	Molinari, S.; Swinyard, B.; Bally, J.; Barlow, M.; Bernard, J.-P.; Martin, P.; Moore, T.; Noriega-Crespo, A.; Plume, R.; Testi, L.; and 114 coauthors	Clouds, filaments, and protostars: The Herschel Hi-GAL Milky Way	
109	2011A&A...533A.119E	90.000	sept-11
	Elbaz, D.; Dickinson, M.; Hwang, H. S.; Díaz-Santos, T.; Magdis, G.; Magnelli, B.; Le Borgne, D.; Galliano, F.; Pannella, M.; Chanial, P.; and 45 coauthors	GOODS-Herschel: an infrared main sequence for star-forming galaxies	
110	2008Natur.451..159W	90.000	janv-08
	Weidenspointner, Georg; Skinner, Gerry; Jean, Pierre; Knödlseder, Jürgen; von Ballmoos, Peter; Bignami, Giovanni; Diehl, Roland; Strong, Andrew W.; Cordier, Bertrand; Schanne, Stéphane; Winkler, Christoph	An asymmetric distribution of positrons in the Galactic disk revealed by γ-rays	
111	2007A&A...467.1075A	90.000	juin-07
	Aharonian, F.; Akhperjanian, A. G.; Bazer-Bachi, A. R.; Beilicke, M.; Benbow, W.; Berge, D.; Bernlöhr, K.; Boisson, C.; Bolz, O.; Borrel, V.; and 117 coauthors	Detection of extended very-high-energy γ-ray emission towards the young stellar cluster Westerlund 2	
112	2010ApJ...713L.169C	89.000	avr-10
	Chaplin, W. J.; Appourchaux, T.; Elsworth, Y.; García, R. A.; Houdek, G.; Karoff, C.; Metcalfe, T. S.; Molenda-Żakowicz, J.; Monteiro, M. J. P. F. G.; Thompson, M. J.; and 99 coauthors	The Asteroseismic Potential of Kepler: First Results for Solar-Type Stars	
113	2009ApJ...695L..40A	89.000	avr-09
	Aharonian, F.; Akhperjanian, A. G.; Anton, G.; de Almeida, U. Barres; Bazer-Bachi, A. R.; Becherini, Y.; Behera, B.; Benbow, W.; Bernlöhr, K.; Boisson, C.; and 156 coauthors	Discovery of Very High Energy γ-Ray Emission from Centaurus a with H.E.S.S.	
114	2007ApJS..172..150S	88.000	sept-07
	Scoville, N.; Aussel, H.; Benson, A.; Blain, A.; Calzetti, D.; Capak, P.; Ellis, R. S.; El-Zant, A.; Finoguenov, A.; Giavalisco, M.; and 18 coauthors	Large Structures and Galaxy Evolution in COSMOS at z < 1.1	
115	2009ApJ...706L...1A	87.000	nov-09
	Abdo, A. A.; Ackermann, M.; Ajello, M.; Baldini, L.; Ballet, J.; Barbiellini, G.; Baring, M. G.; Bastieri, D.; Baughman, B. M.; Bechtol, K.; and 167 coauthors	Fermi LAT Discovery of Extended Gamma-Ray Emission in the Direction of Supernova Remnant W51C	
116	2009ApJ...693..447F	87.000	mars-09

	Fiore, F.; Puccetti, S.; Brusa, M.; Salvato, M.; Zamorani, G.; Aldcroft, T.; Aussel, H.; Brunner, H.; Capak, P.; Cappelluti, N.; and 34 coauthors	Chasing Highly Obscured QSOs in the COSMOS Field	
117	2010A&A...518L..29E	86.000	juil-10
	Elbaz, D.; Hwang, H. S.; Magnelli, B.; Daddi, E.; Aussel, H.; Altieri, B.; Amblard, A.; Andreani, P.; Arumugam, V.; Auld, R.; and 99 coauthors	Herschel unveils a puzzling uniformity of distant dusty galaxies	
118	2007Natur.447..829P	86.000	juin-07
	Pastorello, A.; Smartt, S. J.; Mattila, S.; Eldridge, J. J.; Young, D.; Itagaki, K.; Yamaoka, H.; Navasardyan, H.; Valenti, S.; Patat, F.; and 25 coauthors	A giant outburst two years before the core-collapse of a massive star	
119	2011A&A...536A...7P	84.000	déc-11
	Planck Collaboration; Ade, P. A. R.; Aghanim, N.; Arnaud, M.; Ashdown, M.; Aumont, J.; Baccigalupi, C.; Balbi, A.; Banday, A. J.; Barreiro, R. B.; and 221 coauthors	Planck early results. VII. The Early Release Compact Source Catalogue	
120	2009MNRAS.397L..64A	84.000	juil-09
	Agertz, Oscar; Teyssier, Romain; Moore, Ben	Disc formation and the origin of clumpy galaxies at high redshift	
121	2008A&A...477...25H	84.000	janv-08
	Hennebelle, P.; Teyssier, R.	Magnetic processes in a collapsing dense core. II. Fragmentation. Is there a fragmentation crisis?	
122	2008AJ....136...18W	83.000	juil-08
	Whitney, B. A.; Sewilo, M.; Indebetouw, R.; Robitaille, T. P.; Meixner, M.; Gordon, K.; Meade, M. R.; Babler, B. L.; Harris, J.; Hora, J. L.; and 45 coauthors	Spitzer Sage Survey of the Large Magellanic Cloud. III. Star Formation and ~1000 New Candidate Young Stellar Objects	
123	2008ApJ...679..310G	83.000	mai-08
	Galliano, Frédéric; Madden, Suzanne C.; Tielens, Alexander G. G. M.; Peeters, Els; Jones, Anthony P.	Variations of the Mid-IR Aromatic Features inside and among Galaxies	
124	2007A&A...476.1307S	81.000	déc-07
	Sidoli, L.; Romano, P.; Mereghetti, S.; Paizis, A.; Vercellone, S.; Mangano, V.; Götz, D.	An alternative hypothesis for the outburst mechanism in supergiant fast X-ray transients: the case of IGR J11215-5952	
125	2011arXiv1110.3193L	80.000	oct-11
	Laureijs, R.; Amiaux, J.; Arduini, S.; Augueres, J. -L.; Brinchmann, J.; Cole, R.; Cropper, M.; Dabin, C.; Duvet, L.; Ealet, A.; and 209 coauthors	Euclid Definition Study Report	
126	2009ApJ...701L.123A	80.000	août-09
	Abdo, A. A.; Ackermann, M.; Ajello, M.; Atwood, W. B.; Axelsson, M.; Baldini, L.; Ballet, J.; Barbiellini, G.; Bastieri, D.; Baughman, B. M.; and 173 coauthors	Fermi LAT Observations of LS I +61°303: First Detection of an Orbital Modulation in GeV Gamma Rays	
127	2007A&A...465..431H	80.000	avr-07
	Hennebelle, P.; Audit, E.	On the structure of the turbulent interstellar atomic hydrogen. I. Physical characteristics. Influence and nature of turbulence in a thermally bistable flow	
128	2007ApJS..172..132B	79.000	sept-07
	Bertoldi, F.; Carilli, C.; Aravena, M.; Schinnerer, E.; Voss, H.; Smolcic, V.; Jahnke, K.; Scoville, N.; Blain, A.; Menten, K. M.; and 13 coauthors	COSBO: The MAMBO 1.2 Millimeter Imaging Survey of the COSMOS Field	
129	2010JCAP...05..025A	78.000	mai-10

	Ackermann, M.; Ajello, M.; Allafort, A.; Baldini, L.; Ballet, J.; Barbiellini, G.; Bastieri, D.; Bechtol, K.; Bellazzini, R.; Blandford, R. D.; and 132 coauthors	Constraints on dark matter annihilation in clusters of galaxies with the Fermi large area telescope	
130	2009Sci...326.1512F	78.000	déc-09
	Fermi LAT Collaboration; Abdo, A. A.; Ackermann, M.; Ajello, M.; Axelsson, M.; Baldini, L.; Ballet, J.; Barbiellini, G.; Bastieri, D.; Baughman, B. M.; and 167 coauthors	Modulated High-Energy Gamma-Ray Emission from the Microquasar Cygnus X-3	
131	2009ApJ...697..115C	78.000	mai-09
	Cresci, G.; Hicks, E. K. S.; Genzel, R.; Schreiber, N. M. Förster; Davies, R.; Bouché, N.; Buschkamp, P.; Genel, S.; Shapiro, K.; Tacconi, L.; and 16 coauthors	The SINS Survey: Modeling the Dynamics of z ~ 2 Galaxies and the High-z Tully-Fisher Relation	
132	2007MNRAS.381.1018A	78.000	nov-07
	Amara, Adam; Réfrégier, Alexandre	Optimal surveys for weak-lensing tomography	
133	2007A&A...465.1099R	78.000	avr-07
	Ravikumar, C. D.; Puech, M.; Flores, H.; Proust, D.; Hammer, F.; Lehnert, M.; Rawat, A.; Amram, P.; Balkowski, C.; Burgarella, D.; and 16 coauthors	New spectroscopic redshifts from the CDFS and a test of the cosmological relevance of the GOODS-South field	
134	2011A&A...536A..10P	77.000	déc-11
	Planck Collaboration; Aghanim, N.; Arnaud, M.; Ashdown, M.; Aumont, J.; Baccigalupi, C.; Balbi, A.; Banday, A. J.; Barreiro, R. B.; Bartelmann, M.; and 190 coauthors	Planck early results. X. Statistical analysis of Sunyaev-Zeldovich scaling relations for X-ray galaxy clusters	
135	2010A&A...524A..76B	77.000	déc-10
	Bolzonella, M.; Kovač, K.; Pozzetti, L.; Zucca, E.; Cucciati, O.; Lilly, S. J.; Peng, Y.; Iovino, A.; Zamorani, G.; Vergani, D.; and 56 coauthors	Tracking the impact of environment on the galaxy stellar mass function up to z ~ 1 in the 10 k zCOSMOS sample	
136	2009A&A...504..415S	77.000	sept-09
	Schuller, F.; Menten, K. M.; Contreras, Y.; Wyrowski, F.; Schilke, P.; Bronfman, L.; Henning, T.; Walmsley, C. M.; Beuther, H.; Bontemps, S.; and 24 coauthors	ATLASGAL - The APEX telescope large area survey of the galaxy at 870 µm	
137	2008ApJS..175...97H	77.000	mars-08
	Healey, Stephen E.; Romani, Roger W.; Cotter, Garret; Michelson, Peter F.; Schlafly, Edward F.; Readhead, Anthony C. S.; Giommi, Paolo; Chaty, Sylvain; Grenier, Isabelle A.; Weintraub, Lawrence C.	CGRaBS: An All-Sky Survey of Gamma-Ray Blazar Candidates	
138	2007A&A...467..529C	77.000	mai-07
	Churazov, E.; Sunyaev, R.; Revnivtsev, M.; Sazonov, S.; Molkov, S.; Grebenev, S.; Winkler, C.; Parmar, A.; Bazzano, A.; Falanga, M.; and 25 coauthors	INTEGRAL observations of the cosmic X-ray background in the 5-100 keV range via occultation by the Earth	
139	2011MNRAS.410.1391A	76.000	janv-11
	Agertz, Oscar; Teyssier, Romain; Moore, Ben	The formation of disc galaxies in a ΛCDM universe	
140	2010Natur.463..919A	76.000	févr-10
	Abdo, A. A.; Ackermann, M.; Ajello, M.; Axelsson, M.; Baldini, L.; Ballet, J.; Barbiellini, G.; Bastieri, D.; Baughman, B. M.; Bechtol, K.; and 255 coauthors	A change in the optical polarization associated with a γ-ray flare in the blazar 3C279	
141	2008MNRAS.388.1595D	76.000	août-08
	da Cunha, Elisabete; Charlot, Stéphane; Elbaz, David	A simple model to interpret the ultraviolet, optical and infrared emission from galaxies	

142	2008A&A...484..801R	76.000	juin-08
	Rahoui, F.; Chaty, S.; Lagage, P.-O.; Pantin, E.	Multi-wavelength observations of Galactic hard X-ray sources discovered by INTEGRAL. II. The environment of the companion star	
143	2010ApJ...712..459A	75.000	mars-10
	Abdo, A. A.; Ackermann, M.; Ajello, M.; Baldini, L.; Ballet, J.; Barbiellini, G.; Bastieri, D.; Baughman, B. M.; Bechtol, K.; Bellazzini, R.; and 162 coauthors	Observation of Supernova Remnant IC 443 with the Fermi Large Area Telescope	
144	2010ApJ...708..202M	75.000	janv-10
	McCracken, H. J.; Capak, P.; Salvato, M.; Aussel, H.; Thompson, D.; Daddi, E.; Sanders, D. B.; Kneib, J.-P.; Willott, C. J.; Mancini, C.; and 11 coauthors	The COSMOS-WIRCam Near-Infrared Imaging Survey. I. BzK-Selected Passive and Star-Forming Galaxy Candidates at z gsim 1.4	
145	2010Sci...327.1103A	74.000	févr-10
	Abdo, A. A.; Ackermann, M.; Ajello, M.; Baldini, L.; Ballet, J.; Barbiellini, G.; Baring, M. G.; Bastieri, D.; Baughman, B. M.; Bechtol, K.; and 171 coauthors	Gamma-Ray Emission from the Shell of Supernova Remnant W44 Revealed by the Fermi LAT	
146	2010A&A...511A..85P	74.000	févr-10
	Pratt, G. W.; Arnaud, M.; Piffaretti, R.; Böhringer, H.; Ponman, T. J.; Croston, J. H.; Voit, G. M.; Borgani, S.; Bower, R. G.	Gas entropy in a representative sample of nearby X-ray galaxy clusters (REXCESS): relationship to gas mass fraction	
147	2010ApJ...709...97L	74.000	janv-10
	Leauthaud, Alexie; Finoguenov, Alexis; Kneib, Jean-Paul; Taylor, James E.; Massey, Richard; Rhodes, Jason; Ilbert, Olivier; Bundy, Kevin; Tinker, Jeremy; George, Matthew R.; and 20 coauthors	A Weak Lensing Study of X-ray Groups in the Cosmos Survey: Form and Evolution of the Mass-Luminosity Relation	
148	2008A&A...486L..43H	74.000	août-08
	Hennebelle, P.; Banerjee, R.; Vázquez-Semadeni, E.; Klessen, R. S.; Audit, E.	From the warm magnetized atomic medium to molecular clouds	
149	2010ApJ...709L.152A	73.000	févr-10
	Abdo, A. A.; Ackermann, M.; Ajello, M.; Atwood, W. B.; Axelsson, M.; Baldini, L.; Ballet, J.; Barbiellini, G.; Bastieri, D.; Bechtol, K.; and 161 coauthors	Detection of Gamma-Ray Emission from the Starburst Galaxies M82 and NGC 253 with the Large Area Telescope on Fermi	
150	2009ApJ...704L..34C	73.000	oct-09
	Cappellari, Michele; di Serego Alighieri, S.; Cimatti, A.; Daddi, E.; Renzini, A.; Kurk, J. D.; Cassata, P.; Dickinson, M.; Franceschini, A.; Mignoli, M.; and 4 coauthors	Dynamical Masses of Early-Type Galaxies at z ~ 2: Are they Truly Superdense?	
151	2008ApJ...673..557M	73.000	janv-08
	Miesch, Mark S.; Brun, Allan Sacha; De Rosa, Marc L.; Toomre, Juri	Structure and Evolution of Giant Cells in Global Models of Solar Convection	
152	2010MNRAS.401.1950P	72.000	janv-10
	Paardekooper, S.-J.; Baruteau, C.; Crida, A.; Kley, W.	A torque formula for non-isothermal type I planetary migration - I. Unsaturated horseshoe drag	
153	2009Sci...326.1080A	72.000	nov-09
	Acero, F.; Aharonian, F.; Akhperjanian, A. G.; Anton, G.; Barres de Almeida, U.; Bazer-Bachi, A. R.; Becherini, Y.; Behera, B.; Bernlöhr, K.; Bochow, A.; and 160 coauthors	Detection of Gamma Rays from a Starburst Galaxy	
154	2010ApJ...720..435A	71.000	sept-10

	Abdo, A. A.; Ackermann, M.; Ajello, M.; Antolini, E.; Baldini, L.; Ballet, J.; Barbiellini, G.; Bastieri, D.; Baughman, B. M.; Bechtol, K.; and 161 coauthors	The Fermi-LAT High-Latitude Survey: Source Count Distributions and the Origin of the Extragalactic Diffuse Background	
155	2010ApJ...716.1503P	71.000	juin-10
	Papovich, C.; Momcheva, I.; Willmer, C. N. A.; Finkelstein, K. D.; Finkelstein, S. L.; Tran, K.-V.; Brodwin, M.; Dunlop, J. S.; Farrah, D.; Khan, S. A.; and 8 coauthors	A Spitzer-selected Galaxy Cluster at z = 1.62	
156	2008A&A...477...79D	71.000	janv-08
	Dubois, Y.; Teyssier, R.	On the onset of galactic winds in quiescent star forming galaxies	
157	2007A&A...474L..37A	71.000	nov-07
	Arnaud, M.; Pointecouteau, E.; Pratt, G. W.	Calibration of the galaxy cluster M{500}-Y{X} relation with XMM-Newton	
158	2007ApJ...654.1006F	71.000	janv-07
	Foglizzo, T.; Galletti, P.; Scheck, L.; Janka, H.-Th.	Instability of a Stalled Accretion Shock: Evidence for the Advective-Acoustic Cycle	
159	2011A&A...536A..18P	70.000	déc-11
	Planck Collaboration; Ade, P. A. R.; Aghanim, N.; Arnaud, M.; Ashdown, M.; Aumont, J.; Baccigalupi, C.; Balbi, A.; Banday, A. J.; Barreiro, R. B.; and 195 coauthors	Planck early results. XVIII. The power spectrum of cosmic infrared background anisotropies	
160	2009ApJ...706L..56A	70.000	nov-09
	Abdo, A. A.; Ackermann, M.; Ajello, M.; Atwood, W. B.; Axelsson, M.; Baldini, L.; Ballet, J.; Barbiellini, G.; Bastieri, D.; Baughman, B. M.; and 177 coauthors	Fermi/LAT observations of LS 5039	
161	2009APh....32..193A	70.000	oct-09
	Abdo, A. A.; Ackermann, M.; Ajello, M.; Ampe, J.; Anderson, B.; Atwood, W. B.; Axelsson, M.; Bagagli, R.; Baldini, L.; Ballet, J.; and 238 coauthors	The on-orbit calibration of the Fermi Large Area Telescope	
162	2008Sci...322.1218A	70.000	nov-08
	Abdo, A. A.; Ackermann, M.; Atwood, W. B.; Baldini, L.; Ballet, J.; Barbiellini, G.; Baring, M. G.; Bastieri, D.; Baughman, B. M.; Bechtol, K.; and 175 coauthors	The Fermi Gamma-Ray Space Telescope Discovers the Pulsar in the Young Galactic Supernova Remnant CTA 1	
163	2007ApJ...657L..97K	70.000	mars-07
	Kaaret, P.; Prieskorn, Z.; in 't Zand, J. J. M.; Brandt, S.; Lund, N.; Mereghetti, S.; Götz, D.; Kuulkers, E.; Tomsick, J. A.	Evidence of 1122 Hz X-Ray Burst Oscillations from the Neutron Star X-Ray Transient XTE J1739-285	
164	2008ApJ...683.1031B	69.000	août-08
	Bozzo, E.; Falanga, M.; Stella, L.	Are There Magnetars in High-Mass X-Ray Binaries? The Case of Supergiant Fast X-Ray Transients	
165	2008A&A...477..931S	69.000	janv-08
	Scheck, L.; Janka, H.-Th.; Foglizzo, T.; Kifonidis, K.	Multidimensional supernova simulations with approximative neutrino transport. II. Convection and the advective-acoustic cycle in the supernova core	
166	2007ApJS..172..468Z	69.000	sept-07
	Zamojski, M. A.; Schiminovich, D.; Rich, R. M.; Mobasher, B.; Koekemoer, A. M.; Capak, P.; Taniguchi, Y.; Sasaki, S. S.; McCracken, H. J.; Mellier, Y.; and 27 coauthors	Deep GALEX Imaging of the COSMOS HST Field: A First Look at the Morphology of z ~ 0.7 Star-forming Galaxies	
167	2007A&A...469L...1A	69.000	juil-07

	Aharonian, F. A.; Akhperjanian, A. G.; Bazer-Bachi, A. R.; Behera, B.; Beilicke, M.; Benbow, W.; Berge, D.; Bernlöhr, K.; Boisson, C.; Bolz, O.; and 121 coauthors	Discovery of a point-like very-high-energy γ-ray source in Monoceros	
168	2010ApJ...710.1271A	68.000	févr-10
	Abdo, A. A.; Ackermann, M.; Ajello, M.; Atwood, W. B.; Axelsson, M.; Baldini, L.; Ballet, J.; Barbiellini, G.; Bastieri, D.; Bechtol, K.; and 167 coauthors	Spectral Properties of Bright Fermi-Detected Blazars in the Gamma-Ray Band	
169	2009ApJ...699...31A	68.000	juil-09
	Abdo, A. A.; Ackermann, M.; Ajello, M.; Asano, K.; Baldini, L.; Ballet, J.; Barbiellini, G.; Bastieri, D.; Baughman, B. M.; Bechtol, K.; and 160 coauthors	Fermi Discovery of Gamma-ray Emission from NGC 1275	
170	2008ApJ...672.1054B	68.000	janv-08
	Baruteau, C.; Masset, F.	On the Corotation Torque in a Radiatively Inefficient Disk	
171	2007MNRAS.382.1289P	68.000	déc-07
	Pacaud, F.; Pierre, M.; Adami, C.; Altieri, B.; Andreon, S.; Chiappetti, L.; Detal, A.; Duc, P.-A.; Galaz, G.; Gueguen, A.; and 23 coauthors	The XMM-LSS survey: the Class 1 cluster sample over the initial 5 deg^2 and its cosmological modelling	
172	2007MNRAS.376..313G	68.000	mars-07
	Groenewegen, M. A. T.; Wood, P. R.; Sloan, G. C.; Blommaert, J. A. D. L.; Cioni, M.-R. L.; Feast, M. W.; Hony, S.; Matsuura, M.; Menzies, J. W.; Olivier, E. A.; and 6 coauthors	Luminosities and mass-loss rates of carbon stars in the Magellanic Clouds	
173	2011A&A...536A..19P	67.000	déc-11
	Planck Collaboration; Ade, P. A. R.; Aghanim, N.; Arnaud, M.; Ashdown, M.; Aumont, J.; Baccigalupi, C.; Balbi, A.; Banday, A. J.; Barreiro, R. B.; and 198 coauthors	Planck early results. XIX. All-sky temperature and dust optical depth from Planck and IRAS. Constraints on the "dark gas" in our Galaxy	
174	2011MNRAS.413..813C	67.000	mai-11
	Cappellari, Michele; Emsellem, Eric; Krajnović, Davor; McDermid, Richard M.; Scott, Nicholas; Verdoes Kleijn, G. A.; Young, Lisa M.; Alatalo, Katherine; Bacon, R.; Blitz, Leo; and 16 coauthors	The $ATLAS^{3D}$ project - I. A volume-limited sample of 260 nearby early-type galaxies: science goals and selection criteria	
175	2010A&A...518L..25R	67.000	juil-10
	Rodighiero, G.; Cimatti, A.; Gruppioni, C.; Popesso, P.; Andreani, P.; Altieri, B.; Aussel, H.; Berta, S.; Bongiovanni, A.; Brisbin, D.; and 30 coauthors	The first Herschel view of the mass-SFR link in high-z galaxies	
176	2010ApJ...709L.146D	67.000	févr-10
	De Pasquale, M.; Schady, P.; Kuin, N. P. M.; Page, M. J.; Curran, P. A.; Zane, S.; Oates, S. R.; Holland, S. T.; Breeveld, A. A.; Hoversten, E. A.; and 185 coauthors	Swift and Fermi Observations of the Early Afterglow of the Short Gamma-Ray Burst 090510	
177	2010arXiv1001.0061R	67.000	janv-10
	Refregier, A.; Amara, A.; Kitching, T. D.; Rassat, A.; Scaramella, R.; Weller, J.; Euclid Imaging Consortium, for the	Euclid Imaging Consortium Science Book	
178	2009ApJ...707..250M	67.000	déc-09
	Martig, Marie; Bournaud, Frédéric; Teyssier, Romain; Dekel, Avishai	Morphological Quenching of Star Formation: Making Early-Type Galaxies Red	
179	2009ApJ...703.1249A	67.000	oct-09

	Abdo, A. A.; Ackermann, M.; Ajello, M.; Atwood, W. B.; Axelsson, M.; Baldini, L.; Ballet, J.; Barbiellini, G.; Bastieri, D.; Baughman, B. M.; and 158 coauthors	Fermi LAT Observation of Diffuse Gamma Rays Produced Through Interactions Between Local Interstellar Matter and High-energy Cosmic Rays	
180	2009ApJ...700.1589S	67.000	août-09
	Stello, Dennis; Chaplin, William J.; Bruntt, Hans; Creevey, Orlagh L.; García-Hernández, Antonio; Monteiro, Mario J. P. F. G.; Moya, Andrés; Quirion, Pierre-Olivier; Sousa, Sergio G.; Suárez, Juan-Carlos; and 15 coauthors	Radius Determination of Solar-type Stars Using Asteroseismology: What to Expect from the Kepler Mission	
181	2009ApJ...699..817A	67.000	juil-09
	Abdo, A. A.; Ackermann, M.; Ajello, M.; Atwood, W. B.; Axelsson, M.; Baldini, L.; Ballet, J.; Barbiellini, G.; Bastieri, D.; Battelino, M.; and 171 coauthors	Early Fermi Gamma-ray Space Telescope Observations of the Quasar 3C 454.3	
182	2008A&A...492...31D	67.000	déc-08
	Di Matteo, P.; Bournaud, F.; Martig, M.; Combes, F.; Melchior, A.-L.; Semelin, B.	On the frequency, intensity, and duration of starburst episodes triggered by galaxy interactions and mergers	
183	2010A&A...511A..46M	66.000	févr-10
	Mathur, S.; García, R. A.; Régulo, C.; Creevey, O. L.; Ballot, J.; Salabert, D.; Arentoft, T.; Quirion, P.-O.; Chaplin, W. J.; Kjeldsen, H.	Determining global parameters of the oscillations of solar-like stars	
184	2008A&A...486..741B	66.000	août-08
	Bournaud, F.; Daddi, E.; Elmegreen, B. G.; Elmegreen, D. M.; Nesvadba, N.; Vanzella, E.; Di Matteo, P.; Le Tiran, L.; Lehnert, M.; Elbaz, D.	Observations and modeling of a clumpy galaxy at z = 1.6. Spectroscopic clues to the origin and evolution of chain galaxies	
185	2007A&A...469..363B	66.000	juil-07
	Böhringer, H.; Schuecker, P.; Pratt, G. W.; Arnaud, M.; Ponman, T. J.; Croston, J. H.; Borgani, S.; Bower, R. G.; Briel, U. G.; Collins, C. A.; and 24 coauthors	The representative XMM-Newton cluster structure survey (REXCESS) of an X-ray luminosity selected galaxy cluster sample	
186	2009ApJ...707L...1B	65.000	déc-09
	Bournaud, Frédéric; Elmegreen, Bruce G.; Martig, Marie	The Thick Disks of Spiral Galaxies as Relics from Gas-rich, Turbulent, Clumpy Disks at High Redshift	
187	2007ApJS..172..523M	65.000	sept-07
	Murayama, T.; Taniguchi, Y.; Scoville, N. Z.; Ajiki, M.; Sanders, D. B.; Mobasher, B.; Aussel, H.; Capak, P.; Koekemoer, A.; Shioya, Y.; and 17 coauthors	Lyα Emitters at Redshift 5.7 in the COSMOS Field	
188	2007A&A...467..585B	65.000	mai-07
	Bodaghee, A.; Courvoisier, T. J.-L.; Rodriguez, J.; Beckmann, V.; Produit, N.; Hannikainen, D.; Kuulkers, E.; Willis, D. R.; Wendt, G.	A description of sources detected by INTEGRAL during the first 4 years of observations	
189	2011Sci...331..739A	64.000	févr-11
	Abdo, A. A.; Ackermann, M.; Ajello, M.; Allafort, A.; Baldini, L.; Ballet, J.; Barbiellini, G.; Bastieri, D.; Bechtol, K.; Bellazzini, R.; and 158 coauthors	Gamma-Ray Flares from the Crab Nebula	
190	2010ApJ...722..520A	64.000	oct-10
	Abdo, A. A.; Ackermann, M.; Ajello, M.; Antolini, E.; Baldini, L.; Ballet, J.; Barbiellini, G.; Bastieri, D.; Bechtol, K.; Bellazzini, R.; and 161 coauthors	Gamma-ray Light Curves and Variability of Bright Fermi-detected Blazars	

191	2010ApJ...716..348B	64.000	juin-10
	Brusa, M.; Civano, F.; Comastri, A.; Miyaji, T.; Salvato, M.; Zamorani, G.; Cappelluti, N.; Fiore, F.; Hasinger, G.; Mainieri, V.; and 57 coauthors	The XMM-Newton Wide-field Survey in the Cosmos Field (XMM-COSMOS): Demography and Multiwavelength Properties of Obscured and Unobscured Luminous Active Galactic Nuclei	
192	2008ApJ...681L..53C	64.000	juil-08
	Capak, Peter; Carilli, C. L.; Lee, N.; Aldcroft, T.; Aussel, H.; Schinnerer, E.; Wilson, G. W.; Yun, M. S.; Blain, A.; Giavalisco, M.; and 15 coauthors	Spectroscopic Confirmation of an Extreme Starburst at Redshift 4.547	
193	2009ApJ...707.1310A	63.000	déc-09
	Abdo, A. A.; Ackermann, M.; Ajello, M.; Atwood, W. B.; Axelsson, M.; Baldini, L.; Ballet, J.; Barbiellini, G.; Baring, M. G.; Bastieri, D.; and 170 coauthors	Fermi Observations of TeV-Selected Active Galactic Nuclei	
194	2009A&A...506...41G	63.000	oct-09
	García, R. A.; Régulo, C.; Samadi, R.; Ballot, J.; Barban, C.; Benomar, O.; Chaplin, W. J.; Gaulme, P.; Appourchaux, T.; Mathur, S.; and 16 coauthors	Solar-like oscillations with low amplitude in the CoRoT target HD 181906	
195	2009ApJ...703..222L	63.000	sept-09
	Le Floc'h, Emeric; Aussel, Hervé; Ilbert, Olivier; Riguccini, Laurie; Frayer, David T.; Salvato, Mara; Arnouts, Stephane; Surace, Jason; Feruglio, Chiara; Rodighiero, Giulia; and 10 coauthors	Deep Spitzer 24 μm COSMOS Imaging. I. The Evolution of Luminous Dusty Galaxies—Confronting the Models	
196	2009ApJ...696L.150A	63.000	mai-09
	Aharonian, F.; Akhperjanian, A. G.; Anton, G.; Barres de Almeida, U.; Bazer-Bachi, A. R.; Becherini, Y.; Behera, B.; Bernlöhr, K.; Boisson, C.; Bochow, A.; and 316 coauthors	Simultaneous Observations of PKS 2155-304 with HESS, Fermi, RXTE, and Atom: Spectral Energy Distributions and Variability in a Low State	
197	2008ApJ...687..835A	63.000	nov-08
	Alexander, D. M.; Chary, R.-R.; Pope, A.; Bauer, F. E.; Brandt, W. N.; Daddi, E.; Dickinson, M.; Elbaz, D.; Reddy, N. A.	Reliable Identification of Compton-thick Quasars at z ~ 2: Spitzer Mid-Infrared Spectroscopy of HDF-oMD49	
198	2008AJ....136..919B	63.000	sept-08
	Bernard, Jean-Philippe; Reach, William T.; Paradis, Deborah; Meixner, Margaret; Paladini, Roberta; Kawamura, Akiko; Onishi, Toshikazu; Vijh, Uma; Gordon, Karl; Indebetouw, Remy; and 39 coauthors	Spitzer Survey of the Large Magellanic Cloud, Surveying the Agents of a Galaxy's Evolution (sage). IV. Dust Properties in the Interstellar Medium	
199	2008APh....29...55A	63.000	févr-08
	Aharonian, F.; Akhperjanian, A. G.; Bazer-Bachi, A. R.; Beilicke, M.; Benbow, W.; Berge, D.; Bernlöhr, K.; Boisson, C.; Bolz, O.; Borrel, V.; and 117 coauthors	Observations of the Sagittarius dwarf galaxy by the HESS experiment and search for a dark matter signal	
200	2010A&A...518L.155F	62.000	juil-10
	Feruglio, C.; Maiolino, R.; Piconcelli, E.; Menci, N.; Aussel, H.; Lamastra, A.; Fiore, F.	Quasar feedback revealed by giant molecular outflows	
201	2010MNRAS.401..933M	62.000	janv-10
	Mancini, C.; Daddi, E.; Renzini, A.; Salmi, F.; McCracken, H. J.; Cimatti, A.; Onodera, M.; Salvato, M.; Koekemoer, A. M.; Aussel, H.; and 3 coauthors	High-redshift elliptical galaxies: are they (all) really compact?	
202	2010Sci...330..944R	61.000	nov-10

	Rea, N.; Esposito, P.; Turolla, R.; Israel, G. L.; Zane, S.; Stella, L.; Mereghetti, S.; Tiengo, A.; Götz, D.; Göğüş, E.; Kouveliotou, C.	A Low-Magnetic-Field Soft Gamma Repeater	
203	2010MNRAS.407..830M	61.000	sept-10
	Maraston, Claudia; Pforr, Janine; Renzini, Alvio; Daddi, Emanuele; Dickinson, Mark; Cimatti, Andrea; Tonini, Chiara	Star formation rates and masses of z ~ 2 galaxies from multicolour photometry	
204	2008MNRAS.391..228A	61.000	nov-08
	Amara, Adam; Réfrégier, Alexandre	Systematic bias in cosmic shear: extending the Fisher matrix	
205	2007Sci...316.1166B	61.000	mai-07
	Bournaud, Frédéric; Duc, Pierre-Alain; Brinks, Elias; Boquien, Médéric; Amram, Philippe; Lisenfeld, Ute; Koribalski, Bärbel S.; Walter, Fabian; Charmandaris, Vassilis	Missing Mass in Collisional Debris from Galaxies	
206	2009ApJ...707...55A	60.000	déc-09
	Abdo, A. A.; Ackermann, M.; Ajello, M.; Atwood, W. B.; Axelsson, M.; Baldini, L.; Ballet, J.; Barbiellini, G.; Bastieri, D.; Bechtol, K.; and 173 coauthors	Fermi Large Area Telescope Gamma-Ray Detection of the Radio Galaxy M87	
207	2009A&A...507L..13B	60.000	nov-09
	Benomar, O.; Baudin, F.; Campante, T. L.; Chaplin, W. J.; García, R. A.; Gaulme, P.; Toutain, T.; Verner, G. A.; Appourchaux, T.; Ballot, J.; and 11 coauthors	A fresh look at the seismic spectrum of HD49933: analysis of 180 days of CoRoT photometry	
208	2009ApJ...695L.176D	60.000	avr-09
	Daddi, E.; Dannerbauer, H.; Krips, M.; Walter, F.; Dickinson, M.; Elbaz, D.; Morrison, G. E.	A CO Emission Line from the Optical and Near-IR Undetected Submillimeter Galaxy GN10	
209	2007ApJS..172..203R	60.000	sept-07
	Rhodes, Jason D.; Massey, Richard J.; Albert, Justin; Collins, Nicholas; Ellis, Richard S.; Heymans, Catherine; Gardner, Jonathan P.; Kneib, Jean-Paul; Koekemoer, Anton; Leauthaud, Alexie; and 4 coauthors	The Stability of the Point-Spread Function of the Advanced Camera for Surveys on the Hubble Space Telescope and Implications for Weak Gravitational Lensing	
210	2011A&A...536A...9P	59.000	déc-11
	Planck Collaboration; Aghanim, N.; Arnaud, M.; Ashdown, M.; Aumont, J.; Baccigalupi, C.; Balbi, A.; Banday, A. J.; Barreiro, R. B.; Bartelmann, M.; and 194 coauthors	Planck early results. IX. XMM-Newton follow-up for validation of Planck cluster candidates	
211	2011A&A...536A...6P	59.000	déc-11
	Planck HFI Core Team; Ade, P. A. R.; Aghanim, N.; Ansari, R.; Arnaud, M.; Ashdown, M.; Aumont, J.; Banday, A. J.; Bartelmann, M.; Bartlett, J. G.; and 156 coauthors	Planck early results. VI. The High Frequency Instrument data processing	
212	2011Natur.471..608B	59.000	mars-11
	Bedding, Timothy R.; Mosser, Benoit; Huber, Daniel; Montalbán, Josefina; Beck, Paul; Christensen-Dalsgaard, Jørgen; Elsworth, Yvonne P.; García, Rafael A.; Miglio, Andrea; Stello, Dennis; and 24 coauthors	Gravity modes as a way to distinguish between hydrogen- and helium-burning red giant stars	
213	2010A&A...518L..30B	58.000	juil-10
	Berta, S.; Magnelli, B.; Lutz, D.; Altieri, B.; Aussel, H.; Andreani, P.; Bauer, O.; Bongiovanni, A.; Cava, A.; Cepa, J.; and 27 coauthors	Dissecting the cosmic infra-red background with Herschel/PEP	
214	2010A&A...515A..87D	58.000	juin-10

	Deheuvels, S.; Bruntt, H.; Michel, E.; Barban, C.; Verner, G.; Régulo, C.; Mosser, B.; Mathur, S.; Gaulme, P.; Garcia, R. A.; and 9 coauthors	Seismic and spectroscopic characterization of the solar-like pulsating CoRoT target HD 49385	
215	2010ApJ...710..133A	58.000	févr-10
	Abdo, A. A.; Ackermann, M.; Ajello, M.; Baldini, L.; Ballet, J.; Barbiellini, G.; Bastieri, D.; Baughman, B. M.; Bechtol, K.; Bellazzini, R.; and 145 coauthors	Fermi Observations of Cassiopeia and Cepheus: Diffuse Gamma-ray Emission in the Outer Galaxy	
216	2007A&A...470..475A	58.000	août-07
	Aharonian, F.; Akhperjanian, A. G.; Bazer-Bachi, A. R.; Beilicke, M.; Benbow, W.; Berge, D.; Bernlöhr, K.; Boisson, C.; Bolz, O.; Borrel, V.; and 115 coauthors	Detection of VHE gamma-ray emission from the distant blazar 1ES 1101-232 with HESS and broadband characterisation	
217	2008A&A...487..431C	57.000	août-08
	Croston, J. H.; Pratt, G. W.; Böhringer, H.; Arnaud, M.; Pointecouteau, E.; Ponman, T. J.; Sanderson, A. J. R.; Temple, R. F.; Bower, R. G.; Donahue, M.	Galaxy-cluster gas-density distributions of the representative XMM-Newton cluster structure survey (REXCESS)	
218	2008ApJS..177...14S	57.000	juil-08
	Smolčić, V.; Schinnerer, E.; Scodeggio, M.; Franzetti, P.; Aussel, H.; Bondi, M.; Brusa, M.; Carilli, C. L.; Capak, P.; Charlot, S.; and 14 coauthors	A New Method to Separate Star-forming from AGN Galaxies at Intermediate Redshift: The Submillijansky Radio Population in the VLA-COSMOS Survey	
219	2011A&A...536A...4P	56.000	déc-11
	Planck HFI Core Team; Ade, P. A. R.; Aghanim, N.; Ansari, R.; Arnaud, M.; Ashdown, M.; Aumont, J.; Banday, A. J.; Bartelmann, M.; Bartlett, J. G.; and 156 coauthors	Planck early results. IV. First assessment of the High Frequency Instrument in-flight performance	
220	2011Sci...332..213C	56.000	avr-11
	Chaplin, W. J.; Kjeldsen, H.; Christensen-Dalsgaard, J.; Basu, S.; Miglio, A.; Appourchaux, T.; Bedding, T. R.; Elsworth, Y.; García, R. A.; Gilliland, R. L.; and 49 coauthors	Ensemble Asteroseismology of Solar-Type Stars with the NASA Kepler Mission	
221	2011ApJ...729..114A	56.000	mars-11
	Ackermann, M.; Ajello, M.; Asano, K.; Axelsson, M.; Baldini, L.; Ballet, J.; Barbiellini, G.; Baring, M. G.; Bastieri, D.; Bechtol, K.; and 189 coauthors	Detection of a Spectral Break in the Extra Hard Component of GRB 090926A	
222	2010PhRvD..82b3531P	56.000	juil-10
	Pato, Miguel; Agertz, Oscar; Bertone, Gianfranco; Moore, Ben; Teyssier, Romain	Systematic uncertainties in the determination of the local dark matter density	
223	2010MNRAS.405.2044B	56.000	juil-10
	Bridle, Sarah; Balan, Sreekumar T.; Bethge, Matthias; Gentile, Marc; Harmeling, Stefan; Heymans, Catherine; Hirsch, Michael; Hosseini, Reshad; Jarvis, Mike; Kirk, Donnacha; and 24 coauthors	Results of the GREAT08 Challenge: an image analysis competition for cosmological lensing	
224	2010ApJ...718..348A	56.000	juil-10
	Abdo, A. A.; Ackermann, M.; Ajello, M.; Allafort, A.; Baldini, L.; Ballet, J.; Barbiellini, G.; Bastieri, D.; Bechtol, K.; Bellazzini, R.; and 144 coauthors	Fermi Large Area Telescope Observations of the Supernova Remnant W28 (G6.4-0.1)	
225	2010A&A...518L...5N	56.000	juil-10
	Nguyen, H. T.; Schulz, B.; Levenson, L.; Amblard, A.; Arumugam, V.; Aussel, H.; Babbedge, T.; Blain, A.; Bock, J.; Boselli, A.; and 62 coauthors	HerMES: The SPIRE confusion limit	

226	2009ApJ...694L.158B	56.000	avr-09
	Bournaud, Frédéric; Elmegreen, Bruce G.	Unstable Disks at High Redshift: Evidence for Smooth Accretion in Galaxy Formation	
227	2008ApJ...686.1245R	56.000	oct-08
	Rea, N.; Zane, S.; Turolla, R.; Lyutikov, M.; Götz, D.	Resonant Cyclotron Scattering in Magnetars' Emission	
228	2007MNRAS.377.1531P	56.000	juin-07
	Pastorello, A.; Mazzali, P. A.; Pignata, G.; Benetti, S.; Cappellaro, E.; Filippenko, A. V.; Li, W.; Meikle, W. P. S.; Arkharov, A. A.; Blanc, G.; and 24 coauthors	ESC and KAIT observations of the transitional Type Ia SN 2004eo	
229	2007MNRAS.376.1270L	56.000	avr-07
	Lagadec, Eric; Zijlstra, Albert A.; Sloan, G. C.; Matsuura, Mikako; Wood, Peter R.; van Loon, Jacco Th.; Harris, G. J.; Blommaert, J. A. D. L.; Hony, S.; Groenewegen, M. A. T.; and 4 coauthors	Spitzer spectroscopy of carbon stars in the Small Magellanic Cloud	
230	2011A&A...536A..20P	55.000	déc-11
	Planck Collaboration; Ade, P. A. R.; Aghanim, N.; Arnaud, M.; Ashdown, M.; Aumont, J.; Baccigalupi, C.; Balbi, A.; Banday, A. J.; Barreiro, R. B.; and 206 coauthors	Planck early results. XX. New light on anomalous microwave emission from spinning dust grains	
231	2011A&A...528A..35M	55.000	avr-11
	Magnelli, B.; Elbaz, D.; Chary, R. R.; Dickinson, M.; Le Borgne, D.; Frayer, D. T.; Willmer, C. N. A.	Evolution of the dusty infrared luminosity function from z = 0 to z = 2.3 using observations from Spitzer	
232	2010ApJ...725..571S	55.000	déc-10
	Saz Parkinson, P. M.; Dormody, M.; Ziegler, M.; Ray, P. S.; Abdo, A. A.; Ballet, J.; Baring, M. G.; Belfiore, A.; Burnett, T. H.; Caliandro, G. A.; and 27 coauthors	Eight γ-ray Pulsars Discovered in Blind Frequency Searches of Fermi LAT Data	
233	2010ApJ...714.1407C	55.000	mai-10
	Carilli, C. L.; Daddi, E.; Riechers, D.; Walter, F.; Weiss, A.; Dannerbauer, H.; Morrison, G. E.; Wagg, J.; Davé, Romeel; Elbaz, D.; and 4 coauthors	Imaging the Molecular Gas in a Submillimeter Galaxy at z = 4.05: Cold Mode Accretion or a Major Merger?	
234	2009ApJ...699.1660L	55.000	juil-09
	Lehnert, M. D.; Nesvadba, N. P. H.; Le Tiran, L.; Di Matteo, P.; van Driel, W.; Douglas, L. S.; Chemin, L.; Bournaud, F.	Physical Conditions in the Interstellar Medium of Intensely Star-Forming Galaxies at Redshift~2	
235	2008PhRvL.101q0402A	55.000	oct-08
	Aharonian, F.; Akhperjanian, A. G.; Barres de Almeida, U.; Bazer-Bachi, A. R.; Becherini, Y.; Behera, B.; Beilicke, M.; Benbow, W.; Bernlöhr, K.; Boisson, C.; and 145 coauthors	Limits on an Energy Dependence of the Speed of Light from a Flare of the Active Galaxy PKS 2155-304	
236	2008A&A...489..849C	55.000	oct-08
	Casandjian, J.-M.; Grenier, I. A.	A revised catalogue of EGRET γ-ray sources	
237	2010ApJ...720L.149T	54.000	sept-10
	Teyssier, Romain; Chapon, Damien; Bournaud, Frédéric	The Driving Mechanism of Starbursts in Galaxy Mergers	
238	2010A&A...518L..31I	54.000	juil-10
	Ivison, R. J.; Magnelli, B.; Ibar, E.; Andreani, P.; Elbaz, D.; Altieri, B.; Amblard, A.; Arumugam, V.; Auld, R.; Aussel, H.; and 95 coauthors	The far-infrared/radio correlation as probed by Herschel	
239	2008A&A...484..783C	54.000	juin-08
	Chaty, S.; Rahoui, F.; Foellmi, C.; Tomsick, J. A.; Rodriguez, J.; Walter, R.	Multi-wavelength observations of Galactic hard X-ray sources discovered by INTEGRAL. I. The nature of the companion star	

240	2007MNRAS.376.1547C	54.000	avr-07
	Cattaneo, A.; Teyssier, R.	AGN self-regulation in cooling flow clusters	
241	2011A&A...536A..12P	53.000	déc-11
	Planck Collaboration; Aghanim, N.; Arnaud, M.; Ashdown, M.; Aumont, J.; Baccigalupi, C.; Balbi, A.; Banday, A. J.; Barreiro, R. B.; Bartelmann, M.; and 195 coauthors	Planck early results. XII. Cluster Sunyaev-Zeldovich optical scaling relations	
242	2011ApJ...734...28A	53.000	juin-11
	Abdo, A. A.; Ackermann, M.; Ajello, M.; Allafort, A.; Baldini, L.; Ballet, J.; Barbiellini, G.; Baring, M. G.; Bastieri, D.; Bellazzini, R.; and 154 coauthors	Observations of the Young Supernova Remnant RX J1713.7-3946 with the Fermi Large Area Telescope	
243	2010MNRAS.407..613G	53.000	sept-10
	Goerdt, Tobias; Dekel, A.; Sternberg, A.; Ceverino, D.; Teyssier, R.; Primack, J. R.	Gravity-driven Lyα blobs from cold streams into galaxies	
244	2010Sci...328..725A	53.000	mai-10
	Abdo, A. A.; Ackermann, M.; Ajello, M.; Atwood, W. B.; Baldini, L.; Ballet, J.; Barbiellini, G.; Bastieri, D.; Baughman, B. M.; Bechtol, K.; and 172 coauthors	Fermi Gamma-Ray Imaging of a Radio Galaxy	
245	2009A&A...506...51B	53.000	oct-09
	Barban, C.; Deheuvels, S.; Baudin, F.; Appourchaux, T.; Auvergne, M.; Ballot, J.; Boumier, P.; Chaplin, W. J.; García, R. A.; Gaulme, P.; and 11 coauthors	Solar-like oscillations in HD 181420: data analysis of 156 days of CoRoT data	
246	2008ApJ...687.1180A	53.000	nov-08
	Arentoft, Torben; Kjeldsen, Hans; Bedding, Timothy R.; Bazot, Michaël; Christensen-Dalsgaard, Jørgen; Dall, Thomas H.; Karoff, Christoffer; Carrier, Fabien; Eggenberger, Patrick; Sosnowska, Danuta; and 38 coauthors	A Multisite Campaign to Measure Solar-like Oscillations in Procyon. I. Observations, Data Reduction, and Slow Variations	
247	2007A&A...473L..25A	53.000	oct-07
	Aharonian, F.; Akhperjanian, A. G.; Barres de Almeida, U.; Bazer-Bachi, A. R.; Behera, B.; Beilicke, M.; Benbow, W.; Bernlöhr, K.; Boisson, C.; Bolz, O.; and 134 coauthors	Discovery of VHE γ-rays from the distant BL Lacertae 1ES 0347-121	
248	2007ApJ...665..315C	53.000	août-07
	Cassam-Chenaï, Gamil; Hughes, John P.; Ballet, Jean; Decourchelle, Anne	The Blast Wave of Tycho's Supernova Remnant	
249	2011A&A...536A..11P	52.000	déc-11
	Planck Collaboration; Ade, P. A. R.; Aghanim, N.; Arnaud, M.; Ashdown, M.; Aumont, J.; Baccigalupi, C.; Balbi, A.; Banday, A. J.; Barreiro, R. B.; and 200 coauthors	Planck early results. XI. Calibration of the local galaxy cluster Sunyaev-Zeldovich scaling relations	
250	2011ApJ...730....4B	52.000	mars-11
	Bournaud, Frédéric; Chapon, Damien; Teyssier, Romain; Powell, Leila C.; Elmegreen, Bruce G.; Elmegreen, Debra Meloy; Duc, Pierre-Alain; Contini, Thierry; Epinat, Benoit; Shapiro, Kristen L.	Hydrodynamics of High-redshift Galaxy Collisions: From Gas-rich Disks to Dispersion-dominated Mergers and Compact Spheroids	
251	2010ApJ...723.1607H	52.000	nov-10
	Huber, D.; Bedding, T. R.; Stello, D.; Mosser, B.; Mathur, S.; Kallinger, T.; Hekker, S.; Elsworth, Y. P.; Buzasi, D. L.; De Ridder, J.; and 12 coauthors	Asteroseismology of Red Giants from the First Four Months of Kepler Data: Global Oscillation Parameters for 800 Stars	
252	2010A&A...518L..65B	52.000	juil-10

	Bendo, G. J.; Wilson, C. D.; Pohlen, M.; Sauvage, M.; Auld, R.; Baes, M.; Barlow, M. J.; Bock, J. J.; Boselli, A.; Bradford, M.; and 50 coauthors	The Herschel Space Observatory view of dust in M81	
253	2010A&A...518L..24N	52.000	juil-10
	Nordon, R.; Lutz, D.; Shao, L.; Magnelli, B.; Berta, S.; Altieri, B.; Andreani, P.; Aussel, H.; Bongiovanni, A.; Cava, A.; and 24 coauthors	The star-formation rates of 1.5 < z < 2.5 massive galaxies	
254	2010ApJ...711..424B	52.000	mars-10
	Brown, Benjamin P.; Browning, Matthew K.; Brun, Allan Sacha; Miesch, Mark S.; Toomre, Juri	Persistent Magnetic Wreaths in a Rapidly Rotating Sun	
255	2011A&A...536A..24P	51.000	déc-11
	Planck Collaboration; Abergel, A.; Ade, P. A. R.; Aghanim, N.; Arnaud, M.; Ashdown, M.; Aumont, J.; Baccigalupi, C.; Balbi, A.; Banday, A. J.; and 198 coauthors	Planck early results. XXIV. Dust in the diffuse interstellar medium and the Galactic halo	
256	2011A&A...536A..17P	51.000	déc-11
	Planck Collaboration; Ade, P. A. R.; Aghanim, N.; Arnaud, M.; Ashdown, M.; Aumont, J.; Baccigalupi, C.; Balbi, A.; Banday, A. J.; Barreiro, R. B.; and 191 coauthors	Planck early results. XVII. Origin of the submillimetre excess dust emission in the Magellanic Clouds	
257	2010ApJ...723.1583M	51.000	nov-10
	Metcalfe, T. S.; Monteiro, M. J. P. F. G.; Thompson, M. J.; Molenda-Żakowicz, J.; Appourchaux, T.; Chaplin, W. J.; Doğan, G.; Eggenberger, P.; Bedding, T. R.; Bruntt, H.; and 48 coauthors	A Precise Asteroseismic Age and Radius for the Evolved Sun-like Star KIC 11026764	
258	2010ApJ...723.1082A	51.000	nov-10
	Abdo, A. A.; Ackermann, M.; Ajello, M.; Allafort, A.; Atwood, W. B.; Baldini, L.; Ballet, J.; Barbiellini, G.; Baring, M. G.; Bastieri, D.; and 183 coauthors	Fermi Large Area Telescope Constraints on the Gamma-ray Opacity of the Universe	
259	2010PASP..122..314M	51.000	mars-10
	Molinari, S.; Swinyard, B.; Bally, J.; Barlow, M.; Bernard, J.-P.; Martin, P.; Moore, T.; Noriega-Crespo, A.; Plume, R.; Testi, L.; and 109 coauthors	Hi-GAL: The Herschel Infrared Galactic Plane Survey	
260	2010ApJ...710L..92A	51.000	févr-10
	Abdo, A. A.; Ackermann, M.; Ajello, M.; Allafort, A.; Baldini, L.; Ballet, J.; Barbiellini, G.; Baring, M. G.; Bastieri, D.; Baughman, B. M.; and 162 coauthors	Fermi-Lat Discovery of GeV Gamma-Ray Emission from the Young Supernova Remnant Cassiopeia A	
261	2011A&A...536A..25P	50.000	déc-11
	Planck Collaboration; Abergel, A.; Ade, P. A. R.; Aghanim, N.; Arnaud, M.; Ashdown, M.; Aumont, J.; Baccigalupi, C.; Balbi, A.; Banday, A. J.; and 190 coauthors	Planck early results. XXV. Thermal dust in nearby molecular clouds	
262	2010ApJ...720..912A	50.000	sept-10
	Abdo, A. A.; Ackermann, M.; Ajello, M.; Baldini, L.; Ballet, J.; Barbiellini, G.; Bastieri, D.; Bechtol, K.; Bellazzini, R.; Berenji, B.; and 165 coauthors	Fermi Large Area Telescope Observations of Misaligned Active Galactic Nuclei	
263	2009ApJ...707L.142A	50.000	déc-09
	Abdo, A. A.; Ackermann, M.; Ajello, M.; Baldini, L.; Ballet, J.; Barbiellini, G.; Bastieri, D.; Bechtol, K.; Bellazzini, R.; Berenji, B.; and 140 coauthors	Radio-Loud Narrow-Line Seyfert 1 as a New Class of Gamma-Ray Active Galactic Nuclei	

264	2009MNRAS.394.2266P	50.000	avr-09
	Pastorello, A.; Valenti, S.; Zampieri, L.; Navasardyan, H.; Taubenberger, S.; Smartt, S. J.; Arkharov, A. A.; Bärnbantner, O.; Barwig, H.; Benetti, S.; and 24 coauthors	SN 2005cs in M51 - II. Complete evolution in the optical and the near-infrared	

List of various lectures given by AIM staff

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		J.-P. Chièze	Hydrodynamique	3
Ecole d'Eté	Cargèse	P.A. Duc	Effets de marée	2
Ecole d'Eté	CNRS/IN2P3	A. Meuris	Formation CNRS/IN2P3 « Du détecteur à la mesure »	3
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		R. Lehoucq	Cours Athens: « Physique stellaire »	32
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Licence	Paris-Diderot	Enseignants-Chercheurs	UEs astronomie toutes disciplines en option L1-L2-L3	1350
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		A. Meuris	Les détecteurs semiconducteurs	6
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		S. Ronayette	TP Zemax	30
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		C. Pigot	Détection X et Gamma	12
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		J.-P. Chièze	Option « Plasmas astrophysiques » FCI 9 (Paris)	25
		S. Brun	Module « Equilibre & stabilité MHD» FCM 3 (Aix-Marseille)	12
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Books

« **Un autre cosmos ?** » ouvrage collectif, éditions Vuibert 2012 (J.-M. Bonnet-Bidaud),
« **Le Soleil dans la peau** », éditions Robert Lafont 2012 (J.-M. Bonnet-Bidaud co-écrit avec A. Froment, P. Moureaux, A. Petit)
« **La Science, une ambition pour la France** », édition O. Laffont 2012 (A. Brahic).
« **Le Big Bang** », édition Hatier 2012 (Marc Lachièze-Rey co-écrit avec de P. Gerbaud)
« **Les extraterrestres expliqués à mes enfants** », éditions Le Seuil, janvier 2012 (R. Lehoucq).
« **De feu et de glace** », édition O. Laffont 2012 (A. Brahic).
« **Astrophysique** », éditions J.-P. Bayol 2011 (M. Cassé)
« **Le Beau Livre de l'Univers** », éditions Dunod 2011 (J. Paul co-écrit avec J.-L. Robert-Esil)
« **... et Alice Tao se souvint du futur** », édition O. Laffont 2010 (D. Elbaz)
« **Une fenêtre sur le ciel : Dialogues d'un astrophysicien et d'un théologien** », Bayard Jeunesse 2010 (M. Lachièze-Rey co-écrit avec J. Arnould et L. Ligot)
« **Mission Caladan** », roman, éditions Le Pommier, octobre 2010 R. Lehoucq, co-écrit avec Claude Ecken).
« **Science et Science-fiction** », ouvrage collectif, éditions La Martinière, octobre 2010 (R. Lehoucq).
« **Passeport pour les deux infinis** » directeur d'ouvrages collectif, éditions Dunod 2010 (J. Paul).
« **Le big bang n'est pas une théorie comme les autres** » ouvrage collectif, édition La Ville Brûle 2009 (J.-M. Bonnet-Bidaud),
« **Etoiles dans la nuit des temps** » ouvrage collectif Eurasie, vol. 18, édition l'Harmattan, 2009 (J.-M. Bonnet-Bidaud),
« **Les Trous noirs en pleine lumière** », Odile Jacob 2009 (M. Cassé)
« **De l'infini... : Mystères et limites de l'univers** » Points Sciences, édition du Seuil 2009 (M. Lachièze-Rey co-écrit avec J.-P. Luminet)
« **La physique, à quoi ça sert ?** », éditions Belin, novembre 2009 (R. Lehoucq, avec Bénédicte Leclercq).
« **La physique pour les nuls** », ouvrage collectif sous la direction de Dominique Meier, Editions Générales First, novembre 2009 (R. Lehoucq).
« **29 notions clés pour savourer et faire savourer la science** », chapitre « Les couleurs du ciel », ouvrage collectif publié sous la direction de P. Léna, Y. Quéré et B. Salviat, éditions Le Pommier, collection La Main à la Pâte, septembre 2009 (R. Lehoucq).
« **Calendriers, miroirs du ciel et des cultures** », ouvrage collectif publié sous le label La Main à la Pâte, éditions le Pommier, avril 2009 (R. Lehoucq).
« **Le roman des rayons cosmiques** » éditions Ellipses 2009 (J. Paul co-écrit avec J.-L. Robert-Esil)
« **Oh, l'Univers** », éditions Dunod 2009 (J. Paul co-écrit avec J.-L. Robert-Esil)
« **Lumières d'étoiles. Les couleurs de l'invisible** », édition O. Laffont 2008 (A. Brahic, I. Grenier)
« **Histoire de l'astrophysique nucléaire : La naissance des atom**es », édition Vuibert 2008 (M. Cassé co-écrit avec L. Celnikier)
« **Au-delà de l'espace et du temps : La nouvelle physique** », éditions le Pommier 2008 (M. Lachièze-Rey)
« **Petite histoire de la matière et de l'univers, chapitre « L'univers a-t-il une forme ?** », ouvrage collectif dirigé par H. Reeves, éditions le Pommier, octobre 2008 (R. Lehoucq).
« **Graines de Sciences 9, chapitre « Science et fiction** », ouvrage collectif publié par les éditions Le Pommier, collection La Main à la Pâte, septembre 2008 (R. Lehoucq).
« **Cosmologie dite à Rimbaud** », éditions J.-P. Bayol 2007 (M. Cassé)
« **Même pas fausse ! : La physique renvoyée... dans ses cordes** », Quai des sciences, édition Dunod 2007 (M. Cassé co-écrit avec P. Woit)
« **Le Vase de Pépi : Ou les Mémoires d'un noyau d'atome** », édition O. Laffont 2007 (D. Elbaz, M. Cassé)
« **Le grand récit de l'Univers** », ouvrage collectif publié par les éditions Le Pommier, octobre 2007 (R. Lehoucq ; M. Lachieze-Rey).
« **Graines de Sciences 8, chapitre « Les couleurs du ciel** », ouvrage collectif publié par les éditions Le Pommier, collection La Main à la Pâte, août 2007 (R. Lehoucq).
« **SF : la science mène l'enquête** », éditions Le Pommier, avril 2007 (R. Lehoucq).
« **Explosions cosmiques** », éditions Ellipses 2007 (J. Paul)

Press releases – Scientific News ("Faits marquants")

Le ballet des lunes de Saturne révèle l'intérieur de la planète
Forte dissipation d'énergie à l'intérieur de Saturne - 02 septembre 2012
Les premiers pas d'une micro-étoile
Une naine brune en formation - 06 juillet 2012
Trou noir Taille M
Découverte d'un jet radio transitoire autour d'un trou noir de masse intermédiaire - 05 juillet 2012
Feu vert pour la mission spatiale Euclid
Décoder matière et énergie noires - 20 juin 2012
Un berceau d'étoiles aux débuts de l'Univers

Le mystère de la galaxie HDF850.1 enfin résolu - 13 juin 2012
MIRI en route vers la NASA
Livraison du premier des quatre instruments scientifiques qui équiperont le JWST - 09 mai 2012
Conflit de générations stellaires
Les galaxies elliptiques forment trois fois plus d'étoiles que prévu - 25 avril 2012
Des étoiles au grand coeur
Certaines étoiles massives en rotation rapide ont un coeur très important - 22 février 2012
Supernova dans un verre d'eau
Première analogue hydraulique de l'explosion asymétrique d'une étoile - 03 février 2012
Avis de temps froid et sec
La transparence atmosphérique du ciel antarctique propice aux observations astronomiques - 21 décembre 2011
L'origine des lunes glacées de Saturne enfin dévoilée
Des lunes de glace autour d'une planète au coeur de roches et de glaces - 13 décembre 2011
Voir tourner le coeur des géantes
La sismologie révèle la rotation interne des étoiles géantes rouges - 07 décembre 2011
L'Europe spatiale dans le rouge
Des détecteurs CEA/Sofradir pour l'astrophysique dans l'infrarouge proche - 29 novembre 2011
Ballet de particules dans le Cygne
Un cocon de rayons cosmiques dévoilé par le télescope Fermi - 25 novembre 2011
Comment nourrir les trous noirs géants ?
Une nouvelle hypothèse pour l'origine des trous noirs massifs - 11 novembre 2011
Le modèle du Soleil en trois dimensions récompensé
Le prix "La Recherche" 2011 est attribué à Allan Sacha Brun pour ses travaux sur le Soleil - 18 octobre 2011
"Solar Orbiter" et "Euclid" sélectionnées pour l'espace
Deux nouvelles missions spatiales pour la fin des années 2010 - 04 octobre 2011
Formation d'étoiles en douceur
Le télescope spatial Herschel minore le rôle des collisions de galaxies - 13 septembre 2011
Galaxies elliptiques bien plus complexes
Etonnantes structures filamentaires révélées par la caméra Megacam - 20 juillet 2011
IDeF-X, une technologie française de pointe exportée aux U.S.A.
Des microcircuits de très haute technologie sélectionnés pour l'espace - 16 juin 2011
Regain d'activité des débris de SN1987A
Les derniers clichés du HST révèlent une nouvelle source d'énergie - 09 juin 2011
Le grand prix scientifique 2011 de la Fondation del Duca attribué à Romain Teyssier
11 mai 2011
Bouleversement dans la compréhension des étoiles
Réunion de Presse CEA (29 avril 2011) - 29 avril 2011
L'univers en XXL
Une carte géante de l'Univers chaud - 26 avril 2011
Herschel dénoue les filaments interstellaires
Le fil d'ariane de la formation des étoiles - 13 avril 2011
Palpitations de stars
Mesure de la masse des étoiles par leurs oscillations - 08 avril 2011
Le coeur des étoiles géantes révèle leur source d'énergie
La preuve de la combustion en couche par la sismologie - 30 mars 2011
Jet gamma de Cygnus X-1
Première mesure d'une polarisation gamma autour d'un trou noir galactique - 24 mars 2011
Des astronomes prennent le pouls d'une étoile géante
Première détection des ondes de gravité dans une géante rouge - 17 mars 2011
Planck découvre d'étonnants amas de galaxies
Amas et super-amas à plusieurs milliards d'années-lumière - 29 janvier 2011
Le satellite PLANCK livre ses premiers résultats
14 janvier 2011
L'opacité des étoiles en laboratoire
Le gaz chaud des étoiles recréé par des tirs laser - 15 décembre 2010
Le magnétisme fossile des étoiles
Des aimants cosmiques permanents - 30 novembre 2010
Nano, astro, cerveau : la force des images
Journée "Images de sciences" à la Cité des sciences et de l'industrie (20 novembre 2010) - 20 novembre 2010
Cinq galaxies lointaines détectées grâce à Herschel
05 novembre 2010
Cousins proches
Découverte dans un magnétar d'un champ magnétique similaire à celui des pulsars - 14 octobre 2010
Le Message des Antennes
La plus célèbre collision de galaxies décodée par des simulations 'haute résolution' - 04 octobre 2010
Planck : première découverte d'un superamas de galaxies grâce au rayonnement fossile
Communiqué de presse national: 15 septembre 2010 - 16 septembre 2010
Ping-pong dans l'environnement proche de SN1987A
Nouvelles observations de la supernova avec le télescope spatial Hubble rénové - 02 septembre 2010

Astérosismologie et activité magnétique
Le satellite CoRoT révèle le cycle magnétique d'une étoile - 26 août 2010
Anneau de gaz et collision de galaxies
L'anneau de gaz géant du Lion formé lors de la collision de deux galaxies - 30 juin 2010
Le secret des anneaux de Saturne
Des simulations montrent comment de petites lunes naissent à partir des anneaux - 08 juin 2010
Reflet du passé
Les nuages moléculaires révèlent une éruption géante du trou noir central de la Galaxie - 27 mai 2010
De très jeunes galaxies géantes
Premières images des plus grosses galaxies lointaines - 20 mai 2010
Premier anniversaire pour le satellite Herschel
Résultats scientifiques prometteurs pour le plus grand télescope spatial - 06 mai 2010
La caméra infrarouge du prochain télescope spatial est déjà prête
Livraison du modèle de vol pour un lancement prévu en 2014 - 22 avril 2010
Le satellite européen Planck achève son premier tour de ciel
Vers la carte haute résolution de la première lumière de l'Univers - 24 mars 2010
Tremblements stellaires
Premiers résultats astérosismologiques du satellite KEPLER - 01 mars 2010
L'évolution des débris d'une explosion d'étoile en 3D
L'influence de l'accélération des particules - 26 février 2010
Images d'étoiles avant leur naissance
Le satellite Herschel découvre plusieurs centaines de coeurs pré-stellaires dans le nuage sombre de l'Aigle - 17 décembre 2009
Fil d'ariane pour satellites
SpacewireCEA : un nouveau micro-logiciel pour transférer les images de l'espace - 14 décembre 2009
Un quasar 'nu' pris en flagrant délit
Les quasars engendrent-ils les galaxies ? - 26 novembre 2009
La puissance révélée d'un accélérateur cosmique
Première découverte d'une émission gamma d'un microquasar - 24 novembre 2009
Le nouveau cycle solaire est arrivé
Le cycle 24 du Soleil révélé par la sismologie - 08 novembre 2009
Pulsations d'étoiles
Derniers résultats astérosismiques du satellite CoRoT - 20 octobre 2009
Cascade de naissances dans les nuages sombres
La naissance des étoiles massives est provoquée par des forces extérieures - 30 septembre 2009
Herschel se prépare à une moisson de galaxies infrarouges
Premières lumières avec l'instrument SPIRE - 10 juillet 2009
Le télescope spatial Herschel découvre l'Univers
Succès total pour la caméra PACS conçue et réalisée au CEA - 19 juin 2009
La plus ancienne carte d'étoiles connue
La redécouverte d'un précieux document chinois de la Route de la Soie - 18 juin 2009
Fin d'été très nuageuse sur Titan
Première carte des nuages du satellite de Saturne - 01 juin 2009
L'Europe lance le plus grand télescope spatial
L'observatoire spatial Herschel en route sur la piste des étoiles - 14 mai 2009
Autopsie d'un sursaut
Surprenantes variations de polarisation gamma découvertes par INTEGRAL - 03 avril 2009
Boule de feu aux confins de l'Univers
L'observatoire FERMI découvre le sursaut gamma le plus énergétique jamais détecté - 19 février 2009
Une nouvelle théorie pour la formation des galaxies
Les galaxies naissent de courants froids - 22 janvier 2009
Compte à rebours vers Herschel
Découvrez le site Web du CEA dédié au plus grand télescope spatial qui sera lancé en avril 2009 - 18 janvier 2009
Voyage au centre de la Galaxie
Exposition du CEA au Palais de la Découverte: ouverture le 3 Février 2009 - 17 janvier 2009
Lunettes gamma polarisantes
Vents de particules et polarisation gamma au sein de la nébuleuse du Crabe - 20 novembre 2008
Gigantesques aimants dans la Galaxie
Nuages denses d'électrons autour d'étoiles à neutrons - 17 novembre 2008
Vibrations de sphères célestes
Découverte d'oscillations à la surface d'étoiles similaires au Soleil - 23 octobre 2008
Image infrarouge profonde autour de l'étoile la plus brillante du ciel.
Pas de planètes autour de Sirius ? - 29 septembre 2008
Cataclysme vers le centre de la Galaxie
Zoom à haute résolution sur un reste d'explosion d'étoiles - 22 septembre 2008
Images gamma de l'Univers
Premières images du satellite GLAST/Fermi - 26 août 2008
Débris de marée et amas d'étoiles
Des simulations numériques de collisions de galaxies expliquent la formation des amas globulaires - 01 juillet 2008

A la découverte de l'Univers extrême
Le satellite de rayons gamma GLAST placé sur orbite avec succès - 11 juin 2008
Radiographie à travers la poussière
Le satellite INTEGRAL révèle la complexité des sources X enfouies - 05 juin 2008
Bon pour l'espace
L'instrument MIRIM-OB du JWST réussit son examen de passage - 16 avril 2008
Naissance d'une micro-caméra X
Des matrices de détecteurs ultracompactes pour l'Astrophysique des hautes énergies - 08 février 2008
Première détection de gaz moléculaire dans des jeunes galaxies massives
Une nouvelle vision de la formation des étoiles (23 Janvier 2008) - 23 janvier 2008
Source d'antimatière identifiée dans la Galaxie
INTEGRAL révèle une fabrique d'anti-électrons dans la Voie lactée (10 Janvier 2008) - 10 janvier 2008
Signal d'alerte avant l'éjection de matière d'un trou noir
Deux ans de surveillance d'un trou noir galactique (21 décembre 2007) - 21 décembre 2007
Soucoupes volantes autour de Saturne
La forme inattendue des satellites dans les anneaux (7 décembre 2007) - 07 décembre 2007
Existe-t-il des galaxies sans étoiles ?
Certaines galaxies sombres ne seraient que des débris de collisions (15 novembre 2007) - 15 novembre 2007
La revanche des trous noirs masqués
Des millions de galaxies de l'Univers jeune cachent un trou noir - 22 octobre 2007
Débat sur la formation des étoiles
Comment se détermine la masse d'une étoile ? - 19 octobre 2007
Cinq ans de découvertes pour le satellite INTEGRAL
Une nouvelle vision du ciel gamma - 17 octobre 2007
70 milliards de particules pour décrire l'Univers
Record absolu dans la simulation cosmique (17 septembre 2007) - 17 septembre 2007
Panorama avant la naissance des planètes
VISIR révèle le gaz dans un disque protoplanétaire autour d'une étoile très jeune - 09 septembre 2007
Le plus grand catalogue de sources de rayons X de l'Univers
Le satellite XMM-Newton recense 200 000 objets (7 septembre 2007) - 07 septembre 2007
Cosmic vision 2015-2025
Les futures explorations spatiales au SAp - 18 juillet 2007
Artémis à 5100m d'altitude
Première image obtenue au Chili par une nouvelle caméra submillimétrique (6 juillet 2007) - 06 juillet 2007
Une étape franchie pour le satellite Herschel
L'instrument PACS est livré à l'ESA (6 juillet 2007) - 06 juillet 2007
Le JWST, digne successeur du télescope spatial Hubble
Signature de l'accord sur la participation officielle de l'ESA (18 juin 2007) - 18 juin 2007
Coup de semonce pour un cataclysme
Une exceptionnelle explosion d'étoile annoncée par un flash lumineux (14 juin 2007) - 14 juin 2007
Formation d'étoiles dans l'Univers lointain
Davantage d'étoiles pour les groupes denses de galaxies (7 Juin 2007) - 07 juin 2007
Matière fantôme dans galaxies naines
Contradiction avec les modéles théoriques de formation des galaxies (10 mai 2007) - 10 mai 2007
Battements de coeur solaires
Découverte des modes d'oscillations internes du Soleil (4 Mai 2007) - 04 mai 2007
Amas et protoétoiles
Comment se condensent les embryons d'étoiles - 12 mars 2007
H.E.S.S. : prix pour un nouvel Univers
La collaboration H.E.S.S. récompensée par le prix Descartes 2006 (7 mars 2007) - 07 mars 2007
L'astronomie à l'assaut des pôles
Première expérience et projets en Antarctique (1 Mars 2007) - 01 mars 2007
INTEGRAL révèle la Galaxie gamma
400 sources de hautes énergies dans le ciel gamma - 13 février 2007
Fresque cosmique
Première image détaillée d'un réseau de matière noire et de galaxies - 07 janvier 2007
L'Univers dans un super-calculateur
processeurs pour calculer l'évolution de l'Univers en 4 mois - 07 janvier 2007

Participation of AIM Staff to commitees

NOM et prénom	Organisme/laboratoire	Fonction/titre	Début - fin
ANDRE Philippe	ESO Observing Programmes Committee (OPC)	Membre	2008-2010
ANDRE Philippe	IRAM Scientific Advisory Committee	Membre	2008-2013
ANDRE Philippe	ANR, Comité de Sélection	Membre	2012
ARNAUD Monique	Chandra, Time Allocation Committee	Président	2009
ARNAUD Monique	Suzaku, Time Allocation Committee	Membre	2007
ARNAUD Monique	ES,O Observing Programmes Committee (OPC)	Membre	2010-2011
ARNAUD Monique	ESA/XEUS, Science Advisory Group	Membre	2002-2007
ARNAUD Monique	ESA/XEUS, Science Study	Membre	2007-2009
ARNAUD Monique	IRAP, Conseil Scientifique et Technique	Membre	2011-
ARNAUD Monique	CNRS/INSU, Conseil Scientifique	Membre	2010-
ARNAUD Monique	Observatoire de Paris, Haut Comité Scientifique	Membre	2010-
ARNAUD Monique	CNRS/INSU, Programme National Galaxies et Cosmologie, Conseil Scientifique	Président	2009-
ARNAUD Monique	XMM Newton, Users Group	Président	2006-2010
ARNAUD Monique	CNRS, Comité National de la Rechcherche Scientifique, Section 17	Membre	2012-
ARNAUD Monique	CDS, Conseil Scientifique	Membre	2004-2007
AUDIT Edouard	CNRS/INSU, Programme National de Physique Stellaire, Comité Scientifique	Membre	-
AUDIT Edouard	PRACE, Groupe d'experts	Membre	-
AUDIT Edouard	GENCI,Comité de Programme "astrophysique"	Président	-
AUSSEL Hervé	CFHT, Legacy Survey, Steering Group	Président	2008-2009
AUSSEL Hervé	CNRS/INSU, Programme National Galaxies et Cosmologie, Conseil scientifique	Membre	2009-
AUSSEL Hervé	OPTICON, Time Allocation Committee	Membre	2010-2012
BALLET Jean	CNRS, Comité National de la Recherche Scientifique, Section 17	Membre	2004-2008
BALLET Jean	CNRS, Comité National de la Recherche Scientifique, Commission Interdisciplinaire 47	Membre	2004-2008
BALLET Jean	XMM Newton, Time Allocation Committee	Membre	2011-2012
BALLET Jean	AERES, Comité Visiteur	Membre (évaluation ARTEMIS)	2007
BALLET Jean	AERES, Comité Visiteur	Membre (évaluation Obs de Strasbourg)	2008
BALLET Jean	Observatoire de Strasbourg, Conseil d'Administration	Président	2008-2011
BALLET Jean	Observatoire de Paris, Haut Comité Scientifique	Membre	2006-2009
BALLET Jean	AERES	Délégué Scientifique Adjoint	2009-2010
BALLET Jean	LAPP (Annecy), Conseil Scientifique	Membre	2008-2010
BOURNAUD Frédéric	ESO, Observing Programmes Committee (OPC)	Membre	2010-2011
BOURNAUD Frédéric	GENCI,Comité d'allocation du temps de calcul	Membre	2008-
BOURNAUD Frédéric	CCRT, TGCC, User's Committee	Membre	2010-
BRUN Sacha	CNRS/INSU, Programme National Soleil Terre,	Membre	2012

	Conseil scientifique		
CHARNOZ Sébastien	GENCI, Comité de Programme "astrophysique"	Membre	2008-2010
CHARNOZ Sébastien	Université Paris Diderot, Conseil Scientifique du Campus Spatial	Membre	2010-2011
CHARNOZ Sébastien	Université Paris Diderot, UFR de physique	Membre	2007-2011
CHARNOZ Sébastien	Université Paris Diderot, GET astronomie	Membre	2009-2012
CHARNOZ Sébastien	Université Paris Diderot, CSE-Section 34	Membre	2004-2008
CHARNOZ Sébastien	Université Paris Diderot, conseil de l'école d'ingénieur	Membre	2012-
CHATY Sylvain	ESO, Observing Programmes Committee (OPC)	Membre	2012-2013
CHATY Sylvain	Université Paris Diderot, Conseil Département de Physique	Membre	2007-2012
CHATY Sylvain	Université Paris Diderot, Conseil Scientifique	Membre	2012-
CHATY Sylvain	Université Paris Diderot, Vice-Présidence "vie culturelle"	Conseiller scientifique	2009-
CHATY Sylvain	INTEGRAL, Time Allocation Committee	Membre	2012-2014
CHATY Sylvain	CNU section 34	Membre	2009-2011
CHIEZE Jean-Pierre	Institut Lasers et Plamas	Directeur-Adjoint	2003-2008
CHIEZE Jean-Pierre	Fédération de Recherche FR2707 « ILP-Recherche »	Directeur	2003-2008
CHIEZE Jean-Pierre	Université Paris Diderot CSE-Section 34	Membre	2007-2008
CHIEZE Jean-Pierre	AERES Comité Visiteurs (évaluation du LUTH)	Membre	2009
CHIEZE Jean-Pierre	Programme National de Physique Stellaire, Comité Scientifique	Membre	2010-
CHIEZE Jean-Pierre	Institut Lasers et Plamas, comité de direction	Membre	2012
CORBEL Stéphane	Chandra Time Allocation Commitee	Membre	2006
CORBEL Stéphane	AERES, comité visiteur	Membre (évaluation station de Nançay)	2009
CORBEL Stéphane	INTEGRAL, User's group	Membre	2005-2007
CORBEL Stéphane	CNU, Section 34	Membre	2007-
CORBEL Stéphane	PES, jury	Membre	2007-2012
CORBEL Stéphane	Université Paris Diderot, UFR de physique, Conseil Scientifique	Membre	2008-2012
CORBEL Stéphane	Action spécifique SKA/LOFAR	Membre	2010-2013
CORBEL Stéphane	Astronet, ETRC	Membre	2011-2013
CORBEL Stéphane	Section 34, Commission de spécialiste	Membre	2003-2008
DADDI Emmanuel	HST, Time Allocation Committee	Membre	2010-2011
DECOURCHELLE Anne	XMM-Newton, User's group	Membre	2012-2016
DECOURCHELLE Anne	XMM Newton, Time Allocation Committee	Présidente thématique Supernovae	2007-2008
DECOURCHELLE Anne	ESA, Astronomy Working Group	Membre	2008-2010
DECOURCHELLE Anne	CNES, Groupe Astronomie	Membre	2011-
DECOURCHELLE Anne	CNES, CERES	Membre	2008-
DECOURCHELLE Anne	GDR Phénomène Cosmique de Hautes Energies, Conseil scientifique	Membre	2007-2008
DECOURCHELLE Anne	CNFA	Trésorière	2005-2007
DECOURCHELLE	MESR, Direction Générale de la Recherche et de	Chargé de	2011-

Anne	l'Innovation	mission	
DUC Pierre-Alain	CFHT, Telescope Allocation Committee	Président du TAC français	2004-2008
DUC Pierre-Alain	Programme National Galaxies, bureau du conseil scientifique	Secrétaire	2005-2008
DUC Pierre-Alain	IRAM, Time Allocation Committee	Membre	2009-2011
DUC Pierre-Alain	Action Spécifique ALMA, Conseil Scientifique	Membre	2008-2012
DUC Pierre-Alain	OAMP, Conseil Scientifique de l'OSU	Membre	2004-2008
DUC Pierre-Alain	MESR, Direction Générale de la Recherche et de l'Innovation	Expert pour la MEI	2009-
DUC Pierre-Alain	CFHT, Conseil Scientifique (SAC)	Président	2006-2009
ELBAZ David	Spitzer, Fellowship Program Committee	Membre	2007
FERRARI Cécile	Université Paris Diderot, CSE-Section 34	Président	2007-2009
FERRARI Cécile	Université Paris Diderot, GET-Section 29-34	Membre	2012-
FERRARI Cécile	CNU, Section 34	Vice-président	2008-2011
FERRARI Cécile	AERES, Comité Visiteur	Membre (évaluation IMCEE, LAOG, LAM)	2009-2011
FOGLIZZO Thierry	INSU/CNRS, Programme National Hautes Energies, Conseil Scientifique	Membre	2012-
FROMANG Sébastien	GENCI, Comité de Programme "astrophysique"	Membre	2008-2012
FROMANG Sébastien	CNRS/INSU, GDR Calcul, Conseil Scientifique	Membre	2008-2011
GONZALEZ Matthias	Université Paris Diderot, Conseil Scientifique du Campus Spatial	Membre	2010-
GONZALEZ Matthias	Université Paris Diderot, UFR de physique, Conseil des Enseignements	Membre	2012-
GRENIER Isabelle	ERC, evaluation panel for starting grants	Membre	2012-
GRENIER Isabelle	CNU, Section 34	Membre	2012-
GRENIER Isabelle	Université Paris Diderot, Conseil d'Administration	Membre	2009-2012
GRENIER Isabelle	Université Paris Diderot, Commission des Moyens	Membre	2009-2012
GRENIER Isabelle	Royal University of Technology of Sweden, Comité d'Evaluation	Membre (évaluation département de physique)	2008
HENNEBELLE Patrick	Ecole Normale Supérieure, concours entrée	Responsable physique	2011-2012
HENNEBELLE Patrick	CNRS/INSU, Programme National Milieu Interstellaire, Conseil Scientifique	Membre	2012
KOSACK Karl	Hess, Time Allocation Committee	Président	-
LAGAGE Pierre-Olivier	CNES, CERES	Membre	2007-2012
LAGAGE Pierre-Olivier	AERES, Comité Visiteur	Président (Comité visite CRAL, LAM)t	2010-2011
LAGAGE Pierre-Olivier	CNRS/INSU, CSA	Membre	2011-2014
LAGAGE Pierre-Olivier	Ecole doctorale A&A, Conseil	Membre	2010-2013
LAGAGE Pierre-Olivier	DIM ACAV, Comité de Direction	Membre	2012-2015
LAGAGE Pierre-Olivier	GIS MOTESPACE, Comité de Direction	Membre	2009--2012
LAGAGE Pierre-Olivier	CFHT, Conseil d'Administration (board)	Vice-président	2012-2013
LAGAGE Pierre-Olivier	Observatoire de Paris, Conseil d'Administration	Membre	2007-2010

LE FLOC'H Emeric	Spitzer, Time Allocation Committee	Membre	2008
LEHOUCQ Roland	Festival Les Utopiales (Nantes)	Président	2012-
LEHOUCQ Roland	Moulin des Arts, comité scientifique	Membre	2011-
LEHOUCQ Roland	Association "Les petits débrouillards", Conseil scientifique	membre	2010-
LEHOUCQ Roland	Sociéte Française de Physique –Prix Jean Perrrin	Président du Jury	2005-2012
LEHOUCQ Roland	Centre Nationale du Livre, Commission "livre scientifique"	Membre	2008-2011
LEHOUCQ Roland	Palais de la Découverte, Comité Scientifique	Membre	2007-2010
MINIER Vincent	ARENA (réseau FP6), Conseil d'Administration	Membre	2008-2010
MINIER Vincent	ATNF Time Allocation Committee (Australie)	Reader	2009-2012
MIRABEL Félix	Cherenkov Telescope Array	Chargé de la coordination de l'infrastructure	2012
MOTTE Frédérique	CNRS, Comité National de la Recherche Scientifique, Section 17	Membre	2008-2012
RODRIGUEZ Jérôme	XMM Newton, Time Allocation Committee	Membre	2007-2008
RODRIGUEZ Jérôme	INTEGRAL, Time Allocation Committee	Membre	2007-2008
RODRIGUEZ Jérôme	Suzaku, Time Allocation Committee	Membre	2009-2010
RODRIGUEZ Sébastien	Université Paris Diderot, GET-Section 29-34	Membre	2012-
RODRIGUEZ Sébastien	Université Paris Diderot, CSE-Section 34	Membre	2010-
RODRIGUEZ Sébastien	CNU, Section 34	Membre	2011-
SAUVAGE Marc	ANR, Comité de Sélection	Membre	2010-2012
STARCK Jean-Luc	Springer, Editorial Board	Membre	2012-
STARCK Jean-Luc	Image Processing On line Journal, Editorial Board	Membre	2012-
TURCK-CHIEZE Sylvaine	Institut Lasers et Plamas, Conseil Scientifique	Membre	2009-
TURCK-CHIEZE Sylvaine	GANIL, Conseil Scientifique	Membre	2007-2011
TURCK-CHIEZE Sylvaine	Association Femmes et Science, Conseil Scientifique	Membre	2012
TURCK-CHIEZE Sylvaine	Prospective Astrophysique Nucléaire IN2P3-IRFU	Présidente	2011

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Un directeur heureux !