# ASTRONUM 2015

# BOOK OF ABSTRACTS

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**ASTRONUM 2015 - PRELIMINARY TALK SCHEDULE (SUBJECT TO CHANGE WITHOUT NOTICE)**

| Mon | Tue | Wed | Thu | Fri |
|---|---|---|---|---|
| | | | | |
| *CHAIR:* | *CHAIR:* | *CHAIR:* | *CHAIR:* | *CHAIR:* |
| 8:15-8:25 AM: Welcome E. Audit | 8:00-8:25 AM: D. Balsara | 8:00-8:25 AM: M. Mac Low | 8:00-8:25 AM: J. Büchner | |
| 8:25-8:50 AM: J. Cho | 8:25-8:50 AM: W. Müller | 8:25-8:50 AM: R. Walder | 8:25-8:50 AM: M. A. Aloy | 8:25-8:50 AM: V. Izmodenov |
| 8:50-9:15 AM: E. Hansen | 8:50-9:15 AM: R. Klein | 8:50-9:15 AM: S. Li | 8:50-9:15 AM: C. Graziani | 8:50-9:15 AM: D. Rodgers-Lee |
| 9:15-9:40 AM: I. Kulikov | 9:15-9:40 AM:N. Bucciantini | 9:15-9:400 AM: S. Markidis | 9:15-9:40 AM: P. Mimica | 9:15-9:40 AM: J. Pratt |
| **9:40-10:05 AM: BREAK** | **9:40-10:05 AM: BREAK** | **9:40-10:05 AM: BREAK** | **9:40-10:05 AM: BREAK** | **10:10-10:30 AM: BREAK** |
| *CHAIR:* | *CHAIR:* | *CHAIR:* | *CHAIR:* | *CHAIR:* |
| 10:05-10:30 AM : F Miniati | 10:05-10:30 AM: A. ud-Doula | 10:05-10:30 AM: H Kucharek | 10:05-10:30 AM: D. Bisikalo | 10:05-10:30 AM: R. Pinto |
| 10:30 -10:55 AM: A. Marcowith | 10:30-10:55 AM: T. Goffrey | 10:40-11:05 AM: J. Linker | 10:30-10:55 AM: E. Audit | 10:30-10:55 AM: Y. Kudoh |
| 10:55 -11:20 AM: T. Gardiner | 10:55-11:20 AM: T. Hanawa | 11:05-11:30 AM: R. Keppens | 10:55-11:20 AM: M. Obergaulinger | 10:55-11:20 AM: B. Vaidya |
| 11:20-11:45 AM: L. Del Zanna | 11:20-11:45 AM C. Federrath | 11:30-11:55 PM: T. Amano | 11:20-11:45 AM: R. Pakmor | 11:20- 11:45 AM : G. Vogman |
| 11:45 - 12:10 PM O. Zanotti | 11:45 -12:10 PM S. Van Loo | 11:55-12:20 PM: J. Raeder | 11:45-12:10 AM: F. Spanier | |
| **12:00-1:30 PM: LUNCH** | **12:00-1:30 PM: LUNCH** | **12:25-1:30 PM LUNCH** | **12:10-1:30 PM: LUNCH** | |
| *CHAIR:* | *CHAIR:* | | *CHAIR:* | |
| 1:30-1:55 PM: V. Kolobov | 1:30-1:55 PM: G. Colin de Verdiere | | 1:30-1:55 PM: S. Falle | |
| 1:55-2:20 PM: M. Viallet | 1:55-2:20 PM: M. Wiltberger | | 1:55-2:20 PM: B. Van Straalen | |
| 2:20-2:45 PM: C. McNally | 2:20-2:45 PM: A. Mignone | | 2:20-2:45 PM: A. Khokhlov | |
| 2:45-3:10 PM: C. Cardall | 2:45-3:10 PM: G. Toth | | 2:45-3:10 PM: M. Innocenti | |
| **3:10-3:30 PM: BREAK** | **3:10-3:30 PM: BREAK** | | **3:10-3:30 PM: BREAK** | |
| *CHAIR:* | *CHAIR:* | | *CHAIR:* | |
| 3:30-3:55 PM: G. Zank | 3:30-3:55 PM: S. von Alfthan | ***AFTERNOON FREE*** | 3:30-3:55 PM: R. Oran | |
| 3:55-4:20 PM: K. Fujimoto | 3:55-4:20 PM: B. van der Holst | | 3:55-4:20 PM: D. Folini | |
| 4:20-5:00 PM: G. Lapenta | 4:20-4:45 PM: B Lembege | | 4:20-4:45 PM: U. shumlak | |
| 5:00-5:25 PM: N. Lugaz | 4:45-5:10 PM: N. Pogorelov | | 4:45-5:10 PM: T. Tricco | |

Author: Miguel Ángel Aloy Torás

## Title : Minimally implicit Runge-Kutta methods for hyperbolic equations with stiff source terms

Abstract :

The Relativistic Resistive Magnetohydrodynamic equations are a hyperbolic system of partial differential equations used to describe fluid dynamics in presence of strong magnetic fields with a finite (but potentially large) conductivity when the velocities involved are close to speed of light. In the case of a finite high-conductivity regime, the term proportional to the conductivity is a potentially stiff source term, and cannot be handled with standard explicit time integration methods. Some possibilities considered in the literature add iterative loops computationally expensive and with no guarantee of convergence. We propose an alternative class of methods which we name Minimally Implicit Runge-Kutta methods. These methods avoid the development of numerical instabilities without increasing the computational costs in comparison with explicit methods, need no iterative extra loop, the analytical inversion of the implicit operator is trivial and the several stages can actually be viewed as stages form explicit Runge-Kutta methods with an effective time-step. We test these methods with two different one-dimensional test beds in different conductivity regimes, and show that our second-order schemes satisfy the theoretical expectations.

Takanobu AMANO

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**Title : Quasi-neutral Two-fluid Plasma Simulation Model**

Abstract :

**We propose the quasi-neutral two-fluid (QNTF) plasma simulation model. The basic equations consist of ion and electron fluid equations and Maxwell equations without displacement current, consistent with the charge neutrality assumption. The QNTF model fully takes into account finite electron inertia effect, whereas high frequency waves (such as Langmuir or electromagnetic waves) are absent.**

**We show that the QNTF equations may be written in the conservative form, allowing us to employ schemes designed for the conservation laws. We develop a three-dimensional simulation code solving the proposed equations with the HLL (Harten-Lax-van Leer) approximate Riemann solver. The scheme is combined with the Upwind Constrained Transport (UCT) method [c.f., Londrillo & Del Zanna, 2004], which guarantees the divergence-free property of the magnetic field up to machine accuracy. The code resolves sharp discontinuities as well as dispersive waves associated with shocks in multidimensions. Thanks to the finite electron inertia effect, there is no sign of numerical instability associated with short-wavelength whistler waves. We thus think the QNTF model offers a better alternative to the Hall-MHD of fully electromagnetic two-fluid models.**

**Edouard AUDIT**
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## Numerical simulations of super-luminous supernovae of type IIn

E. Audit, L. Dessart and J Hillier

We present numerical simulations that include 1-D Eulerian multi-group radiation-hydrodynamics, 1-D non-Local-Thermodynamic-Equilibrium (non-LTE) radiative transfer, and 2-D polarised radiative transfer for super-luminous interacting supernovae (SNe). Our reference model is a ~10 Msun inner shell ramming into a ~3 Msun cold outer shell (the circumstellar-medium, or CSM) that extends from $10^{15}$ to 2 $10^{16}$ cm and moves at 100 km/s. We discuss the light curve evolution, which cannot be captured adequately with a grey approach. In these interactions, the shock-crossing time through the optically-thick CSM is much longer than the photon diffusion time. Radiation is thus continuously leaking from the shock through the CSM, in disagreement with the shell-shocked model that is often invoked. Our spectra redden with time, with a peak distribution in the near-UV during the first month gradually shifting to the optical range over the following year. Initially Balmer lines exhibit a narrow line core and the broad line wings that are characteristic of electron scattering in the SNe IIn atmospheres (CSM). At later times they also exhibit a broad blue shifted component which arises from the cold dense shell. Our model results are broadly consistent with the bolometric light curve and spectral evolution observed for SN 2010jl. Invoking a prolate pole-to-equator density ratio in the CSM, we can also reproduce the ~2\% continuum polarisation, and line depolarisation, observed in SN 2010jl. By varying the inner shell kinetic energy and the mass and extent of the outer shell, a large range of peak luminosities and durations, broadly compatible with super-luminous SNe IIn like 2010jl or 2006gy, can be produced.

Presenter's first and LAST Name : Dinshaw S. Balsara

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**Title : Subluminal Relativistic MHD**

Abstract : The fundamental problem with all relativistic hydro and MHD codes is their brittleness. For non-relativistic hydro and MHD we now understand how to ensure that the pressure and density remain positive. For Rhydro and RMHD, one has to additionally guarantee that the velocity of the flow also remains sub-luminal. Thus far, this has remained an unsolved problem in the literature. The present talk shows how the update strategy for RMHD codes can be modified to ensure that the flow is subluminal throughout the course of a timestep.

Dmitry BISIKALO

Co-author: Alexander Cherenkov

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**Gas dynamic simulations of the interaction between coronal mass ejections and hot Jupiter exoplanets**

Abstract : Hot Jupiters, have a number of outstanding features, caused mostly by their proximity to the host star, e.g.: gas outflowing from the planet's atmosphere to the star, as it happens in close binary stars. In addition, the short distance between the planet and the star results in a large planet's orbital velocity. If this velocity exceeds the local sound speed a bow-shock forms ahead of the planet. Gas-dynamical modeling shows that, if the dynamical pressure of the stellar-wind is high enough to stop the outflow from the vicinity of the inner Lagrangian point, a quasi-closed non-spherical envelope, bounded by the bow-shock of a complex shape, forms in the system. In this paper we study the variations of flow patterns in the gaseous envelopes of hot Jupiters, occurring under the action of coronal mass ejections, by using 3D gas dynamic simulations.

Niccolo’ BUCCIANTINI

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Coauthors: A.G. Pili, L. Del Zanna

**Modeling the structure of magnetic fields in Neutron Stars: from the interior to the magnetosphere.**

The phenomenology of the emission of pulsars and magnetars depends dramatically on the structure and properties of their magnetic field. In particular it is believed that the outbursting and flaring activity observed in AXPs and SRGs is strongly related to their internal magnetic field. Recent observations have moreover shown that charges are present in their magnetospheres supporting the idea that their magnetosphere are tightly twisted in the vicinity of the star. In principle these objects offer a unique opportunity to investigate physics in a regime beyond what can be obtained in the laboratory. We will discuss the properties of equilibrium models of magnetized neutron stars, and we will show how internal and external current can be related. This will be discussed both from the point of view of their stability, relevant for their origin and possibly connected events like SNe and GRBs, and also in the case of a twisted magnetosphere and their general topology. A general formalism based on the simultaneous numerical solution of the general relativistic Grad–Shafranov equation and Einstein equations will be presented. Possible observables will be discussed.

Presenter's first and LAST Name : Christian Y. Cardall

**Title : GenASiS Basics: Object-oriented utilitarian functionality for large-scale physics simulations**

Abstract :

Aside from numerical algorithms and problem setup, large-scale physics simulations on distributed-memory supercomputers require more basic utilitarian functionality, such as physical units and constants; display to the screen or standard output device; message passing; I/O to disk; and runtime parameter management and usage statistics. I describe Fortran 2003 classes furnishing extensible object-oriented implementations of this sort of rudimentary functionality, along with individual `unit test' programs and larger example problems demonstrating their use. These classes compose the Basics division of our developing astrophysics simulation code GenASiS (General Astrophysical Simulation System), but their fundamental nature makes them useful for physics simulations in many fields.

Jungyeon Cho

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## Title : Inverse Cascade in Electron MHD Turbulence

Abstract : Electron magnetohydrodynamics (EMHD) provides a simple description of small-scale magnetized plasmas. In this talk I will discuss inverse helicity/energy cascade in EMHD turbulence. First, I'll discuss the dynamics of EMHD wave packets moving in one direction. In the presence of a strong magnetic field, disturbances travel along magnetic field lines. Unlike MHD waves, EMHD waves moving in one direction can interact with each other and exhibit inverse cascade, which is due to magnetic helicity conservation. Second, I'll discuss inverse cascade in imbalanced EMHD turbulence, in which waves moving in one direction (dominant waves) have higher amplitudes than waves moving in the other direction (sub-dominant waves). Inverse cascade in such turbulence is also driven by magnetic helicity conservation. It is interesting that a usual Kolmogorov-type scaling argument does not work for the inverse cascade.

Presenter's first and LAST Name : Guillaume JL Colin de Verdière

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**Title : Exascale computing roadmap, Impact on legacy code**

Abstract :
**Architectures of supercomputers are at a tipping point. The race to the Exascale has already started and has put pressure on silicon vendors to offer solutions to this goal. In this talk, we will describe the forces at play, the hardware solutions that are taking place, in an HPC oriented approach. From this low level view, we will emphasize the impacts on (legacy) codes that can be foreseen to warn code developers about what they'll need to change in their codes to take the most out of the forthcoming supercomputers.**

Luca DEL ZANNA

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## The *ideal* tearing mode: theory and resistive MHD simulations

Classical MHD reconnection theories, both the stationary Sweet-Parker model and the tearing instability, are known to provide rates which are too slow to explain the observations. However, a recent analysis (Pucci and Velli, ApJ, 2014) has shown that there exists a critical threshold on the current sheet's thickness, namely a/L~S^(-1/3), beyond which the tearing modes evolve on fast macroscopic Alfvenic timescales, provided the Lunquist number S is high enough, as invariably found in solar and astrophysical plasmas. Therefore, the classical Sweet-Parker scenario, for which the diffusive region scales as a/L~S^(-1/2) and thus can be up to ~100 times thinner than the critical value, is likely to be never realized in nature, as the current sheet itself disrupts in the elongation process. We present here two-dimensional, compressible, resistive MHD simulations, with S ranging from 10^5 to 10^7, that fully confirm the linear analysis. Moreover, we show that the plasmoid secondary instability always occurs when the same critical scaling is reached on the local, smaller and smaller current sheets, leading to a cascading, explosive process, reminiscent of the flaring activity.

Presenter's first and LAST Name:
Christoph Federrath

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**Title:**
**The role of turbulence, magnetic fields and feedback for star formation**

Abstract:
Star formation is inefficient. Only a few percent of the available gas in molecular clouds forms stars, leading to the observed low star formation rate (SFR). The same holds when averaged over many molecular clouds, such that the SFR of whole galaxies is again surprisingly low. Indeed, considering the low temperatures, molecular clouds should be highly gravitationally unstable and collapse on their global mean freefall timescale. And yet, they are observed to live about 10-100 times longer, i.e., the SFR per freefall time (SFR_ff) is only a few percent. Thus, other physical mechanisms must provide support against quick global collapse. Magnetic fields, turbulence and stellar feedback have been proposed as stabilising agents, but it is still unclear which of these processes is the most important and what their relative contributions are. Here I will present numerical simulations of star cluster formation that include turbulence, magnetic fields, and protostellar jet/outflow feedback. These simulations produce nearly realistic star formation rates consistent with observations.

Doris Folini

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**Title : Relativistic reconnection in an ion-electron plasma: 2D PIC simulations :**

Abstract :Relativistic reconnection is a prime candidate for the production of high-energy non-thermal particles in various astrophysical objects. The underlying physical mechanisms are, however, still not fully understood.

We present 2D PIC simulations of relativistic reconnection for an ion electron plasma, starting from a relativistic Harries sheet. To our knowledge, these are the first simulations of their kind. We highlight aspects of the reconnection zone particular to the relativistic reconnection studied and discuss the physics involved. In particular, we show that 45 to 75 percent of the initial magnetic energy is converted into kinetic energy, a larger fraction than in the non-relativistic case. Of this kinetic energy, ions get 30 to 60 percent, depending on the guide field. Particles from the background plasma get efficiently accelerated by the reconnection electric field. The latter is maintained primarily by bulk inertia, in contrast to the non-relativistic case where thermal inertia takes this role. Particles accelerated in this way form a power law of index p = -d log n(gamma) / d log gamma, with p depending mostly on the inflow Alfven speed and magnetizations. We find values up to p ~ 1.2 for electrons and high enough magnetization, much harder than for Fermi-acceleration.

We conclude by putting our idealized findings in a larger astrophysical context. The hardness of the particle distribution could be of interest, for example, in connection with microquasars, where a coronal population of non-thermal high-energy electrons is required by the observation of MeV photons. A comprehensive explanation of the latter will, however, ultimately have to take into account the large scale properties of the object: the global flow sets the conditions for reconnection (initial field strength and global topology, forcing).

Presenter's first and LAST Name : Keizo FUJIMOTO

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## Title : 3D dynamics of collisionless magnetic reconnection in anti-parallel configuration

Abstract :

**The 3D dynamics of collisionless reconnection is one of the key issues in space and astrophysical plasmas. It is related with the mechanisms of the magnetic dissipation and the momentum and energy transport of plasmas. The observations in the Earth's magnetosphere, solar flares, and laboratory experiments have suggested that the reconnection processes are fully three-dimensional, accompanied by intense wave activities at the x-line and localized flow burst downstream the x-line. We have challenged the 3D reconnection problems by means of the particle-in-cell simulations with adaptive mesh refinement. Large-scale 3D simulations have revealed that the thin current layer formed around the x-line is unstable to two types of the electromagnetic waves in the anti-parallel configuration. One is a current sheet shear mode which has an intermediate scale between the ions and the electrons, and gives rise to the electron momentum transport leading to the anomalous resistivity. The other is a larger-scale kink mode which has the ion scale. It is found that both the waves are significantly enhanced due to plasmoid (flux rope) ejections. The turbulent current layer results in 3D outflow jet, indicating that the reconnection outflow structure is coupled with the wave activities in the current layer.**

# Simulations of Shear Mixing for Stellar Hydrodynamics

T. Goffrey*[1], I. Baraffe[1], and M. Viallet[2]

[1]College of Engineering, Mathematics and Physical Sciences, University of Exeter, Exeter, EX4 4QL, UK
[2]Max−Planck−Institut für Astrophysik, Karl Schwarzschild Strasse 1, Garching, D-85741, Germany

The modelling of stellar interiors is a complex and challenging computational problem. The time-scales involved dictate the use of one-dimensional models to explain the processes occurring over a stellar life time. However, such an approach results in multi-dimensional phenomena being parametrised into one-dimensional effects. One particularly important such process is rotationally, or shear, driven mixing. The mixing of chemical species can dramatically alter the evolution of stellar objects, and extend their lifetime by transporting fuel to the core. Furthermore observed surface chemical abundances provide clear signatures of chemical mixing, linking these observations to computational results is paramount to the success of the one-dimensional approach. We seek to validate and adapt such models by performing multi-dimensional simulations of stellar interiors. To this end a time implicit, fully compressible, hydrodynamics code, MUSIC, has been developed. We explore and demonstrate the codes ability to resolve Mach numbers differing by up to six orders of magnitude. We also investigate shear driven mixing, and the effect of driving and thermal diffusion, as a precursor to quantifying mixing in a full stellar environment.

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Presenter's first and LAST Name
Carlo Graziani

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**Title : The Biermann Catastrophe in Numerical MHD**

Abstract :
**The Biermann Battery effect is frequently invoked in cosmic magnetogenesis and studied in High-Energy Density laboratory physics experiments. Direct implementation of the Biermann effect in MHD codes does not capture this physical process, and worse, produces unphysical magnetic fields at shocks whose value does not converge with resolution. We show that this convergence breakdown is due to naive discretization, which fails to account for the fact that discretized irrotational vector fields have spurious solenoidal components that grow without bound near a discontinuity. We show that careful consideration of the kinetics of ion viscous shocks leads to a formulation of the Biermann effect that gives rise to a convergent algorithm. We note two novel physical effects: a resistive magnetic precursor in which Biermann-generated field in the shock ``leaks'' resistively upstream; and a thermal magnetic precursor, in which field is generated by the Biermann effect ahead of the shock front due to gradients created by the shock's electron thermal conduction precursor. Both effects appear to be potentially observable in experiments at laser facilities.**

Presenter's first and LAST Name
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**Title : Multi-color Model for the Protoplanetary Disk HL Tau**

Abstract :

HL Tau, a young star located in the Taurus star-forming region, shows quite different appearances depending on the wavelength. In the optical and near infrared, the central star is obscured and surrounded by a highly flared disk. However, a recent ALMA observation has revealed that the disk consists of concentric rings when seen in the sub-mm. The vertical height of the rings should be small since the gaps between them are clearly seen in the ALMA image. In order to explain the complex vertical structure of the disk, we have constructed a passive disk model for HL Tau on the basis of multi-color radiation transfer calculation. Our model takes account of radiation ranging from 100 nm to 3.16 mm. We used the M1 model to solve the radiative equilibrium. If the dust has grown up to 1mm in size and the central star is less massive, the model is qualitatively consistent with the existing observations. The model provides us the temperature distribution in the disk. We also argue the structure of the infalling envelope surrounding the disk.

Edward Hansen

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**Title: Multi-physics with AstroBEAR 3.0**

Abstract: AstroBEAR is a highly parallelized magnetohydrodynamics (MHD) code which is under active developement and application at the University of Rocehster. It uses grid-based adaptive mesh refinement (AMR) to achieve high effective resolution within large domains. In addition to solving the MHD equations, AstroBEAR 3.0 can incorporate a variety of multi-physics modules including self-gravity with sink particles, accurate non-equilibrium cooling, anisotropic heat conduction, and magnetic resistivity. The updated non-equilibrium cooling routines make possible the production of synthetic emission maps which are crucial for comparisons with observations. In this talk we present an overview of AstroBEAR 3.0 with a focus on applications to star formation, binary star interactions and heterogeneous stellar outflows.

# The Multi Level Multi Domain (MLMD) method: a semi-implicit adaptive algorithm for Particle In Cell plasma simulations

presenter: Maria Elena Innocenti
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Particle In Cell (PIC) descriptions of plasmas are a typical example of high-yielding, computationally expensive models for heliospheric and astrophysical plasma simulations. The invaluable amount of information they provide on space plasma processes is paid for in terms of their extremely high computing cost, which restricts in space and time the domain that PIC simulations can cover. These limitations can be partially circumvented in many ways, among which using reduced mass ratios between the particle species, using semi-implicit or fully implicit schemes (although, if ion rather than electron scales are resolved, electron scale processes are averaged out) or adaptive methods.
The Multi-Level Multi-Domain (MLMD) method recently introduced in Innocenti *et al.* [1], Beck *et al.* [2], Innocenti *et al.* [3] combines these last two approaches. Different grid levels are simulated with different spatial and temporal resolutions. Specific inter-grid operations are performed to maintain coherence between the levels. Since high resolutions are used only in a very limited part of the domain (typically, in the areas where electron rather than ion scale processes take place), realistic mass ratio plasmas can be simulated in large domains at low computing costs and without loss of physical information. It has been measured that a MLMD simulation with an high jump in resolution between the grid levels is 70 times cheaper than the same simulation performed with a "standard" PIC code.
Here, we review the basics of the MLMD method and we show realistic mass ratio MLMD simulations of magnetic reconnection in the terrestrial magnetotail and of plasma turbulence. In magnetic reconnection simulations, higher resolution is used in correspondence of the Electron Diffusion Region, where both species are unmagnetized and electron processes (e.g., formation of electron jets) need to be resolved. In turbulence simulations, the grid simulated with higher resolution is used to capture the higher wave number part of the power spectra: turbulent cascade is initiated at low wave numbers by the grid simulated with lower resolution and proceeds seamlessly at the wave numbers simulated only by the higher resolution grid. Dissipative processes then break the cascade there.

[1] M. Innocenti, G. Lapenta, S. Markidis, A. Beck, and A. Vapirev, Journal of Computational Physics **238**, 115 (2013).
[2] A. Beck, M. Innocenti, G. Lapenta, and S. Markidis, Journal of Computational Physics **271**, 430 (2014), frontiers in Computational Physics Modeling the Earth System.
[3] M. Innocenti, A. Beck, T. Ponweiser, S. Markidis, and G. Lapenta, Computer Physics Communications **189**, 47 (2015).

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**Title :**
**Parallel, block-adaptive MHD simulations for solar coronal dynamics.**

Abstract :
I present the open source MPI-AMRVAC simulation toolkit [Keppens et al., 2012, JCP 231, 718; Porth et al., 2014, ApJS **214**, 4], with a focus on solar physical applications modeled by its magnetohydrodynamic module. Spatial discretizations available cover standard shock-capturing finite volume algorithms, but also extensions to conservative high-order finite difference schemes, both employing many flavors of limited reconstruction strategies. Multi-step explicit time stepping includes strong stability preserving high order Runge-Kutta steppers to obtain stable evolutions in multi-dimensional applications realizing up to fourth order accuracy in space and time. The parallel scaling of the code is discussed and we obtain excellent weak scaling up to 30000 processors allowing to exploit modern peta-scale infrastructure.

Solar physics applications target the formation of flux rope topologies through boundary-driven shearing of magnetic arcades, following the in situ condensation of prominences in radiatively controlled evolutions of arcades and fluxropes, and the enigmatic phenomenon of coronal rain, where small-scale condensations repeatedly form and rain down in thermodynamically structured magnetic arcades.

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Title: “Numerical Simulations of Star Formation in Filamentary Dark Molecular Clouds: From Large Scale Magnetized Clouds to Stellar Clusters”

Abstract:

Infrared Dark Clouds (IRDCs) are believed to be the precursors to star clusters and massive stars. The complex intertwined braid-like structure of IRDCs poses a challenge to theorists to explain their dynamics and formation. We have performed large-scale adaptive mesh refinement, driven turbulence, MHD simulations to study the structure and formation of IRDCs. Filamentary structure emerges naturally from our simulations. Magnetic field lines pierce the dark cloud filament primarily in the direction normal to the filament axis. The column density profiles of the main features are well fit by the power law $N \propto r^{-n}$ with n from 0.6 to 0.8 as observations have found. The dark cloud filaments in the simulation resemble the dark cloud SDC13 and our 3D simulations are used to explain the observed structure and dynamics of SDC13. We have carried out the most detailed analysis to date of the magnetic field properties of the cloud clumps in our simulations (Li, McKee and Klein, 2015), finding excellent agreement with the Zeeman observations of Crutcher et al. (2010). We then perform deep zoom-in simulations into the main IRDC filament that include the fully coupled effects of magnetic fields, protostellar outflows, and radiation transport, and continue one of the simulations to study the formation of a stellar cluster inside IRDCs. By including radiation feedback and proto-stellar outflows, we obtain a proto-stellar mass function (PMF) for comparison with theoretical PMFs) and the Chabrier IMF. In this talk, I will discuss key aspects of our simulations that address the formation of filamentary IRDCs, their complex braided filamentary structure, the magnetic properties of cloud clumps inside the IRDC filaments, and star cluster formation in the first half of a free fall time of the system.

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# Development of Plasma Simulation Tool with Adaptive Mesh and Hybrid Kinetic-Fluid Models

## Abstract

We develop a next-generation plasma simulation tool using adaptive kinetic and fluid models for modern heterogeneous computing architectures. The new tool will have a) ability to dynamically switch between fluid and kinetic approaches, b) robust auto-mesh generation and adaptive mesh refinement algorithms, c) implicit solvers adapted for massively parallel CPU-GPU systems, d) modular structure for easy incorporation of physics sub-models and databases for atomic and materials physics. The project leverages the previously developed Unified Flow Solver (UFS) using adaptive mesh and algorithm refinement (AMAR) methodology. The AMAR methodology is being adapted for heterogeneous computing systems, and the previously developed plasma and electromagnetic modules in UFS are being advanced for kinetic-fluid simulations of partially ionized non-equilibrium plasmas. We will describe key innovations of the project including: a) parallel generation of adaptive Cartesian meshes on distributed multicore systems by regularization of dynamic data structures using patches, b) implicit algorithms for parallel CPU-GPU systems, and c) physics-based criteria for switching kinetic and fluid solvers for different plasma components. We will discuss our current research towards demonstrating feasibility of this approach, and our plans for developing, testing and applications of this methodology.

Supported by the DARPA SBIR Phase I Project W31P4Q-15-C-0047.

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**Title : Hybrid Simulations for Investigating Turbulence in the Heliosphere**

Abstract:
Hybrid simulations have been successfully used to investigate particle acceleration at shocks and to study the growth and the properties of instabilities. Nowadays, these simulations are self-consistent and can accommodate several ion species including neutrals. Depending on the system size and computer resources fully 3D simulations are possible which bridge the gap between kinetic particle simulations and magneto-hydrodynamic simulations. The data from Voyager spacecraft leaving the solar system and the IBEX mission providing all sky maps in the light of energetic neutral atoms changed completely the global picture of our heliosphere. Many features such as the IBEX ribbon and the acceleration of anomalous cosmic rays may depend on the level of turbulence in certain heliospheric regions. In this talk we will present the results of fully 3D hybrid simulations for the wave turbulence and the acceleration of ions in heliospheric boundaries underlining the importance of particle kinetics in large-scale magnetic structures.

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**Title :**
A New Scheme to Solve the Two-Fluid Cosmic-ray Magnetohydrodynamic Equations

Abstract :
The two-fluid cosmic-ray magnetohydrodynamic (MHD) equations take account of the dynamical effects of cosmic rays in the simplest form. Hence they are often applied for MHD simulations in which cosmic rays have important roles in the dynamics. Inclusion of cosmic rays produces the pressure balance mode in addition to the ordinary MHD waves as pointed out by Rice and Zank (1999). When the pressure balance mode arises, the cosmic-ray pressure has a jump across the contact discontinuity, while the sum of cosmic ray and thermal gas pressures is constant. We have found that the numerical diffusion of the balance mode causes spurious oscillation if they are solved in the HLLE scheme. The oscillation is most serious when the jump in the cosmic-ray pressure is large compared to the thermal energy density of the gas. Similar spurious oscillations are seen also in the literature, although they are often alleviated by additional diffusion based on physics. Here we discuss the origin of the spurious oscillation and propose a new scheme to fix it without additional diffusion. We use the fully conservative form of the two-fluid cosmic-ray MHD equations in our numerical scheme. The change in the cosmic-ray pressure is rewritten in conservation of cosmic-ray particle numbers. Our scheme guarantees conservation of the total energy as well as conservation of mass and momentum of gas. It evaluates the increase of the cosmic-ray pressure by compression at the shock fronts accurately. It is based on the approximate Riemann solution of Roe-type. Our scheme is validated by the 1D shock tube problems.

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## A New Hydrodynamic Model for Numerical Simulation of Interacting Galaxies on Intel Xeon Phi Supercomputers

The movement of galaxies in dense clusters turns the collisions of galaxies into an important evolutionary factor. The numerical simulation by means supercomputers is the main approach for research of these processes. We present a new mathematical model of interacting galaxies, in which the first moments of the collisionless Boltzmann equation for describing of stars and dark matter components was used. Using this model, allows us to use the uniform numerical method for numerical solution of the hydrodynamic equations, the magnetohydrodynamic equations, and the first moments of collisionless Boltzmann equation. The numerical method is based on combination of operator splitting approach and piecewise-parabolic method on local stencil. The hybrid strategy allows to obtain very simple, high-order accurate and low dissipation on shock waves, non-decrease entropy, Galilean invariant and scalability solver. Numerical results of free-passage scenario of interacting galaxies in new model are presented and analyzed. Using of uniform approach for construction of numerical method allowed obtaining speed-up factors of 134 for Intel Xeon Phi accelerator and maximum efficiency of 92% is demonstrated using 64 Intel Xeon Phi in native mode on the cluster PetaStream of the Joint Supercomputer Center of the Russian Academy of Sciences.

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## Title :Using HPC Kinetic Simulations to help the MMS mission find its target : reconnection diffusion regions.

Where will the soon to be launched Magnetospheric MultiScale (MMS) mission find its primary target, the electron scale diffusion layer around reconnection sites? MMS is a four spacecraft mission desigend to find in situ evidence for regions of reconnection where the ion and electron physics become dominant. But where is this most likely to happen? We study here where these regions are found in full 3D simulations. The result is very different from 2D. In 2D the sites of electron diffusion, defined as the regions where magnetic topology changes and electrons move with respect to the magnetic field lines, are located near the reconnection site. But in 3D we find that also the reconnection exhaust far from the primary reconnection site becomes host to secondary reconnection sites generated by interchange instabilities in the exhaust. We consider two scenarios: one where the exhaust form multiple x-lines form a plasmoid (a flux rope in 3D) and one where the exhaust encounters pristine unreconnected plasma and forms a pile-up front. Four diagnostics are used to demonstrate the presence of secondary reconnection: i) the direct observation of new topology of the field lines not possi- ble without secondary reconnection, ii) the direct measure of topological field line breakage associated with a region of magnetic field reversal around a null point, iii) the measure of electron jets emerging from secondary reconnection regions, iv) the violation of the frozen in condition. We conclude that secondary reconnection is happening in a large part of the exhaust, providing a lot more chances for MMS to find itself in the right region to hit on its target.

*Work in collaboration with the Colorado MMS-IDS Team: M. Goldman, D. Newman, L. Andersson, S. Eriksson.*

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# Title : 2-D hybrid simulations of downstream high speed jets generated by a non-stationary and rippled quasi-parallel shock front

Abstract : Experimental observations from space missions (including Cluster data more recently) have clearly revealed the existence of high speed jets (HSJs) in the downstream region of the quasi-parallel terrestrial bow shock. Presently, two-dimensional (2-D) hybrid simulations are performed to reproduce and investigate the formation of such HSJs through a rippled quasi-parallel shock front. The simulation results retrieve (i) that such shock fronts are strongly nonstationary (self reformation) along the shock normal, and (ii) that ripples are evidenced along the shock front as the upstream ULF waves (excited by interaction between incoming and reflected ions) are convected back to the front by the solar wind and contribute to the rippling formation. Then, these ripples are inherent structures of a quasi-parallel shock and the self reformation of the shock is not synchronous along the surface of the shock front. As a consequence, new incoming solar wind ions interact differently at different locations along the shock surface. Present results show that some ion flows can be only deflected (instead of being decelerated) at locations where ripples are large enough to play the role of local « secondary » shock. Therefore, the ion bulk velocity is different locally after ions are transmitted dowstream, and local high-speed jets patterns can be formed somewhere downstream. Our presentation will focuss (i) on our preliminary simulation results obtained on HSJ, (ii) on their relationship with local bursty patterns of (turbulent) magnetic field evidenced at the rippled front, and (iii) on the spatial and time scales of HSJ to be compared with experimental observations. Such downstream HSJs are generated by the nonstationary shock front itself and do not require any upstream disturbance incident from the far solar wind to be convected back and to interact with the shock front before penetrating downstream.

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**Title :** Modeling and Simulation of HL TAU Proto-Planetary Disk

Abstract :

We have proposed a model and method to simulate the gap formation of HL TAU Disk. Recent observation from ALMA reveals several concentric dust gaps. We focus on our effort on three clear gaps which may be formed by massive planets. We have performed extensive simulations with different disk parameters (density and temperature profile, viscosity etc) and planet masses. We find the disk self-gravity is important in the gap formation during the young life of HL TAU. We also find that the HL TAU can easily become eccentric if correct physics is included in the simulations. All of our simulations are performed using our code LA-COMPASS, which can simulate the dusty disk-planet interaction problems efficiently. We also combine our code with RADMC-3D to generate image to match the observation of ALMA.

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**Title: An Empirically Driven Time-Dependent Model of the Solar Wind**

Abstract:
As the solar corona expands outward to become the solar wind, its structure and dynamics are defined by the solar magnetic field, including the locations of fast and slow solar wind, the position of the heliospheric current sheet, and the evolution of coronal mass ejections. The magnetized solar wind also plays an important role in the transport and propagation of energetic particles. Maps of the solar magnetic field (usually built up from the line-of-sight field measured in the photosphere) are the key observational input to models of the corona and solar wind. A good example is the WSA-Enlil model, which uses a potential field source surface (PFSS) model and an empirical prescription to drive a heliospheric MHD model. At the present time, such models typically use a single magnetic map to represent a particular day or time period, and integrate the MHD equations to steady state. Flux transport models, like the Air Force Data Assimilative Photospheric flux Transport (ADAPT) model, represent the evolution of the photospheric magnetic field on the entire sphere while incorporating magnetograms on the Earth side of the Sun. Here we describe the use of sequences of ADAPT maps to drive a time-dependent model (MAS) of the solar wind, using PFSS solutions and an empirical prescription for the coronal part of the solution. We compare results from the time-dependent model with in situ observations and models for individual Carrington rotations.
Results supported by NASA, AFOSR, and NSF.

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**Title : Propagation and Interaction of CMEs: MHD Modeling and Comparison with Observations**

Abstract: Numerical simulations have been the favored way to learn about the properties of coronal mass ejections (CMEs) during their propagation between the Sun and the Earth, due in part to the historical scarcity of data in the heliosphere. Remote-sensing heliospheric observations since the mid-2000s and multi-spacecraft measurements have been providing new information about CME properties, which can be used to validate and test numerical modeling, and to learn about CME heliospheric evolution. One of the most complex phenomena in the inner heliosphere is the interaction of successive CMEs. By combining global MHD simulations and the analysis of remote observations, I will discuss the expansion of isolated and interacting CMEs, the propagation of a shock through a CME, the interaction of two CMEs and the formation of complex ejecta. I will also examine how numerical simulations can be used to test analysis techniques and prepare for new *in situ* measurements of CMEs, closer to the Sun with Solar Probe+ and Solar Orbiter.

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**Title : Ionization and Outflows in Massive Star Forming Regions**

Abstract : Most stars form in massive star forming regions, so understanding the processes that limit the star formation efficiency in such regions is central to understanding the star formation rate in galaxies. Stellar outflows, magnetic fields, and ionization have all been suggested as important limiting processes on star formation in such regions. We review our own and others' simulations of this situation. We highlight the inability of these mechanisms to completely cut off star formation, and the observational correlates that support the validity of the simulations, such as flickering H II regions and broad, chaotic, bipolar outflows.

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**Title : Cosmic Ray transport in magnetized turbulence**

Abstract : In their journey through the Galaxy, Cosmic Rays (CRs) are scattered by magnetic perturbations the can be well described by the magneto-hydrodynamic theory. The very nature of the interaction however still remains largely unknown. In this work we investigate by the mean of direct numerical calculations the CR propagation in large scale driven turbulence. The MHD fluctuations are generated using the code RAMSES over a periodic 3dimensionnal box. We discuss the CR mean free path obtained with respect to the CR energy, the turbulence level and the geometry of the forcing.

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**Title:**
**Global Particle-in-Cell Simulations of Magnetospheres on Petascale Supercomputers**

Abstract :
Particle-in-Cell simulations of the interaction between solar wind and planetary magnetospheres are still one of the frontiers of computational phsyics. Global magnetosphere simulations require the smallest space and temporal scales, typically Debye length and plasma period, to be resolved by simulation grid spacing and time step to retain the numerical stability. When realistic plasma parameters are in use, these plasma scales are extremely small and simulations of large-scale magnetospheres are unfeasible.
We present the first step towards realistic global simulations of magnetosphere formation with a massively parallel Particle-in-Cell code, called iPIC3D. We use an implicit formulation of the Particle-in-Cell method to relax the numerical stability conditions on time step and grid spacing allowing us to use large time steps and coarser grids. In addition, we re-designed the parallel communication of the code to achieve high parallel efficiency on current petascale supercomputers. In this talk, we present both algorithmic and software improvements to model magnetosphere formation on massively parallel system discussing challenges and obstacles to carry-out the first planetary magnetosphere simulations with realistic plasma parameters.

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**Title :**

Nonideal MHD and Current Sheets in Protoplanetary Disks

Abstract :

Stresses arising from magnetic fields in sufficiently ionized regions of protoplanetary disks lead to mass accretion. This can take the form of either a turbulent stress, or a large-scale wind torque. In recent models, it has been found that including ambipolar diffusion and non-thermal ionization sources in global simulations with a net vertical field leads to a laminar flow with a wind driven accretion. At smaller radii, where thermal ionization and Ohmic dissipation dominate, the dissipation of the potential energy associated with this accretion is a component of the balance which determines the thermal structure of the disk. To model the resulting thermal structure of the disk, it is critical to recognize that magnetized turbulence dissipates its energy intermittently in current sheet structures. Our models predict that these turbulent current sheets drive order unity temperature variations even where the MRI is damped strongly by Ohmic resistivity. I will discuss work on characterizing this intermittent energy dissipation, temperature fluctuations, and the current sheets which drive them from both Eulerian and Lagrangian perspectives, and discuss consequences for particle heating and motion.

Petar MIMICA

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**Title : Numerical simulations of hydrodynamics and emission from a tidal disruption event powered jet of Swift J1644+57**

Abstract : The non-thermal transient Swift J1644+57 is modeled as emission from a relativistic jet powered by the accretion of a tidally-disrupted star onto a super-massive black hole. The early time emission is similar to a gamma-ray burst afterglow. An open mystery is the origin of the late-time radio re-brightening. I discuss the technical details, difficulties and results from high-resolution multi-dimensional hydrodynamic simulations (using MRGENESIS) coupled to a self- consistent radiative transfer calculation (using SPEV). We computed multi-wavelength synchrotron radio-maps and light curves of a number of models for the Swift J1644+57 jet. Once the best-fit model for the Swift J1644+57 events is presented, I show the results of the synthetic off-axis observations of that model. The aim is to discuss the implications for the presence of relativistic jets from tidal disruption events (TDEs) detected via their thermal disk emission, as well as the prospects for detecting orphan TDE afterglows with upcoming wide-field radio surveys and resolving the jet structure with long baseline interferometry.

Author: Francesco Miniati

**Title :** ***Intracluster Turbulence and the Origin of Magnetic Field and Diffuse Radio Emission in Giant Galaxy Clusters***

Abstract :

We have recently produced high resolution fully cosmological simulations of ICM turbulence in a massive galaxy cluster (M~10^15 M_sun) that allows us to resolve the hydrodynamic turbulent cascade and measure the time dependent evolution of the turbulent velocity statistical properties, for both the solenoidal and compressible components. Solenoidal turbulence amplifies magnetic energy by way of dynamo action and compressional turbulence is thought to accelerate to relavistic energy the particles responsible for the observed diffuse radio emission in massive galaxy clusters.
In this talk I will discuss a number of new and far reaching results implied by numerical model for both the origin and structure of magnetic field as well as relativistic particles in the intracluster medium.

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**Title :**
**A higher-order constrained-transport central-scheme for astrophyiscal MHD**

Abstract :
**By revisiting the dimensionally split reconstruction described by Kurganov et al.[1] a simple fourth-order central scheme is introduced to solve 3D hyperbolic conservation laws. The applied 1D CWENO reconstruction allows to obtain fourth order accuracy when combined with the semi-discrete method of Kurganov et al.[1] and appropriate time integration. The talk also elaborates on the involved constrained-transport algorithm since the combination of face-averaged magnetic fields and the other volume-averaged dependent variables represents an additional complication.**
**Benchmarks indicate that higher-order central-schemes of the present type are able to compete with standard Godunov-solvers.**

**[1] A. Kurganov, D. Levy, SIAM J. Sci. Comput. 22 (2000) 14611488**

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**Title:**
**Termination of the MRI via parasitic instabilities in core-collapse supernovae**

Abstract:
The ability of the MRI to amplify a weak seed field in rotating supernova cores to a dynamically relevant strength depends on the amplitude at the termination of its growth. Secondary, parasitic instabilities of Kelvin-Helmholtz or tearing-mode type play a key role in this process. We studied the importance of these two types of parasites in two- and three-dimensional shearing-disc simulations. Our findings indicate that the theoretical analysis of Pessah (2010) presents a good description of the result. In particular, Kelvin-Helmholtz modes are dominant under the conditions of supernova cores, while tearing modes play a role only in a restricted range of parameters.

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**Title :**
**Type Ia Supernovae from merging White Dwarfs**

Abstract :
The progenitor system and explosion mechanism of Type Ia Supernovae is still unknown. The double degenerate scenario, in which the explosion is cause by the interaction or the merger of two white dwarfs in a binary system has been disfavoured for a long time. However, with the help of a new generation of merger simulations we were able to show that the binary system can already ignite in the merger leading to a thermonuclear explosion. I will present our latest results that employ the moving-mesh code Arepo and allow us to reach unprecedented precision and spatial resolution for this type of problem. This allows us to identify a new robust mechanism to explode a binary system of two Carbon-Oxygen white dwarfs based on the small surface layer of helium of those WDs.

Author: Rui Pinto

## Title : Emergence and eruption of twisted flux-ropes in the Sun

Abstract :

Twisted magnetic flux-ropes play an important role on the dynamics of the surface of the Sun and of the corona. These flux-ropes are generated deep inside the Sun's convection zone. Under the right circumstances, they will rise buoyantly across the turbulent convective layers and emerge. The emergence of magnetic flux ropes has both local and global consequences, leading to the triggering of flares in active regions and influencing the large-scale structure of the coronal magnetic field.
The major difficulty on modelling the flux-rope rise - emergence - flaring sequence lies in that it connects very different physical regimes, and spatial and temporal scales.
I will address some key aspects of this problems by means of numerical 3D MHD simulations which use state-of-the-art numerical codes.
These describe the emergence of buoyant flux-ropes in interaction with the dynamo field of the Sun at a global scale, and on the flaring of smaller kink-unstable flux-ropes in the solar corona.

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## Title : Magnetic Field at the Edge of the Heliosphere

Abstract :

Ion energization and transport throughout the heliosphere are strongly dependent on the magnetic field distributions. We present the results of our numerical simulation of the heliospheric magnetic field and its coupling with the interstellar magnetic field (ISMF) at the heliopause. The effects of the ISMF draping are discussed together with the heliopause instability and magnetic reconnection. It is shown that the heliopause has complicated structure that resembles the transition region observed by Voyager 1 when it was on the way from the heliosphere into the local interstellar medium (LISM). Special attention is paid to the magnetic field distribution in the heliotail, its displacement under the action of the ISMF, and modifications to the unperturbed LISM magnetic field due to the presence of the heliosphere. Possibilities are discussed of constraining the interstellar medium properties using IBEX, SOHO, and TeV cosmic ray anisotropy data. Numerical results are obtained with a Multi-Scale Fluid-Kinetic Simulation Suite (MS-FLUKSS) – a suite of numerical codes that solve self-consistently MHD, gas dynamics Euler, and kinetic Boltzmann equations.

Jane Pratt

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**Title :** Time-implicit compressible simulations of turbulent convection in the interior of a young sun

Abstract :

Current physical understanding of the evolution of stellar interiors is drawn from one-dimensional calculations, which efficiently allow astrophysicists to explore a wide range of stellar environments. In one-dimensional calculations, turbulent convection in stellar interiors is modelled using mixing length theory. Concrete understanding of the differences between mixing length theory, and 2 and 3-dimensional fluid convection under realistic stellar conditions could improve the quality and fit of models for one-dimensional stellar evolution codes, and could determine to what extent 2 dimensional simulations can be used predictively. With this motivation, we describe how the multi-dimensional, time implicit, fully compressible, hydrodynamical, implicit large eddy simulation code MUSIC has been designed to expand the results of a one dimensional stellar evolution calculation into a 2 or 3-dimensional fluid simulation. We use MUSIC to study an early stage in the evolution of a star that is convective from the central regions to the surface. We perform two- and three-dimensional simulations that include different physical sections of the star in the numerical domain. The effect of small-scale convection in the near surface layers on the fundamental characteristics of deep convection in the star is explored. Similarly, we examine how the dynamics of waves in the radiative zone can affect the fundamental characteristics of deep convection. These studies are preliminary to characterizing convective overshooting at the boundary between the radiative and convective zones.

Joachim Raeder, Shiva Kavosi, and Kai Germaschewski

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## Title : Kelvin-Helmholtz waves rattling the magnetosphere

Abstract :

Kelvin-Helmholtz (KH) waves, driven by velocity shear, are ubiquitous in nature. In Earth's magnetosphere they occur primarily at the magnetopause. Recent studies have shown that KH waves occur quite frequently, ~10% of the time regardless of SW conditions, and up to 40% during northward IMF. While the observations fit some theoretical expectations, others remain unsolved. Here, we use OpenGGCM simulations to address the KH occurrence and their dependence on parameters, and their consequences, in particular ULF wave generation and plasma entry into the magnetosphere.

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**Title :**
Global Multifluid Simulations of the Magnetorotational Instability in Protoplanetary Disks

**Abstract :**
The physical mechanism which allows material to accrete from a protoplanetary disk onto the central protostar is still poorly understood, although the magnetorotational instability (MRI) still appears to be the most likely mechanism. While ideal magnetohydrodynamic (MHD) simulations have shown that the MRI can lead to the observed accretion rates, much debate now centres around the influence of non-ideal terms. Protoplanetary disks are believed to be very weakly ionised for large parts of the disk and therefore the assumptions of ideal MHD are invalid here. This makes it imperative to include the contribution of non-ideal MHD effects in any sensible treatment of the problem. The non-ideal MHD effects to be included are Ohmic dissipation, ambipolar diffusion and the Hall effect. Both ambipolar diffusion and the Hall effect can introduce severe restrictions on the allowable stable timestep. The fully multifluid MHD code HYDRA ameliorates the restriction on the allowable stable timestep using super-timestepping and the Hall diffusion scheme. I will present the results of our global multifluid simulations and illustrate, specifically, the significant influence of the Hall effect on the nature, and strength, of the turbulence generated by the MRI.

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**Title : High Fidelity Physics using the Multi-Fluid Plasma Model**

Abstract :
The multi-fluid plasma model is derived from moments of the Boltzmann equation for each species. The two-fluid plasma model has electron and ion species. Additional fluids can include neutrals, impurities, or excited ions. Moment equations are truncated, e.g. after five, ten, thirteen, or twenty equations, and are closed with expressions that relate higher moment variables to lower moment variables. Higher moment models extend the region of validity to plasmas with lower collisionality. Reduction of the two-fluid plasma model to single-fluid MHD is accomplished by applying asymptotic approximations, which reduces the physical fidelity of the plasma model. In addition, these approximations alter the dispersion relations and can require artificial dissipation for numerical stability. Large mass differences between electrons and ions in the multi-fluid plasma model introduce disparate temporal and spatial scales and require numerical algorithms with sufficient accuracy to capture the multiple scales. Source terms couple the fluids to themselves (interspecies interactions) and to the electromagnetic fields. Interspecies interactions also occur through collisional source terms that account for the direct transfer of momentum and energy. In addition to plasma and electrodynamic physics, the multi-fluid plasma model can capture atomic physics in the form of reaction rate equations for ionization and recombination, which introduce new temporal scales to the plasma dynamics. The numerical algorithm must treat the inherent stiffness introduced by the multiple physical effects of the model and tightly couple the source terms of the governing equations. The governing equations are expressed in a balance law form. A discontinuous Galerkin method with an approximate Riemann solver is developed for the spatial discretization and Runge-Kutta methods perform the temporal advance. Particular attention is paid to satisfying the divergence constraint relations of Maxwell's equations. Because of the large span of plasma spatial scales, development and implementation of non-reflecting, open boundaries are required for simulations on finite domains. A lacuna-based, non-local boundary treatment has been developed. The algorithms are benchmarked against analytical solutions for wave dispersion and published solutions for the electromagnetic plasma shock problem, lower hybrid drift instabilities, and the GEM magnetic reconnection problem.

Felix SPANIER

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**Title : Simulation of relativistic pair beams**

Abstract :
Recently the propagation relativistic electron-positron beams has attracted a lof of interest: Since beams created from TeV photons through pair production on the extragalactic-background light may be a source of GeV photons, their presence or absence can help determine the nature of the intergalactic magnetic field.

To understand the nature of the instability caused by relativistic beams and especially the distribution function of ultra-high energy pairs, simulations are needed due to the nonlinear interaction of beam and background. Simulation methods available are either particle-in-cell codes or Vlasov codes.

We will discuss the problems associated with ultra-relativistic beams in particle-in-cell codes, especially the distinction between physical effects and numerical artifacts. Results from electromagnetic and electrostatic simulations will be presented giving an overview of the general importance of plasma instabilities in the field of GeV photon detection.

Gabor TOTH and Yuxi CHEN

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**A fifth-order accurate finite difference scheme for curvilinear AMR grids**

We present a new fifth-order accurate finite difference method implemented into the general purpose BATS-R-US hydrodynamic and magnetohydrodynamic code. The scheme employs the 5th order accurate monotonicity preserving limiter MP5 to construct high order accurate face fluxes. The fifth-order accuracy of the spatial derivatives is ensured by a flux correction step. The method is generalized to curvilinear grids with a free-stream preserving discretization. The method is also extended to block-adaptive grids using carefully designed ghost cell interpolation algorithms. Only three layers of ghost cells are required, and the grid blocks can be as small as 6 x 6 x6 cells. Dynamic grid refinement and coarsening are also fifth-order accurate. All interpolation algorithms employ a general limiter based on the principles of the MP5 limiter. The finite difference scheme is fully conservative on static uniform grids. Conservation is only maintained at the truncation error level at grid resolution changes and during grid adaptation, but our numerical tests indicate that the results are still very accurate. We demonstrate the capabilities of the new method on a number of numerical tests, including smooth but non-linear problems as well as simulations involving discontinuities. While the fifth-order scheme is about 2-3 times more expensive than the classical second order TVD method, the improved accuracy makes the 5th order method much more computationally efficient.

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**Title : Simulating the small-scale dynamo amplification of magnetic fields in supersonic turbulence using smoothed particle magnetohydrodynamics**

Abstract :
Supersonic turbulence is believed to be at the heart of star formation. We have performed smoothed particle magnetohydrodynamics (SPMHD) simulations of the small-scale dynamo amplification of magnetic fields in supersonic turbulence. The calculations use isothermal gas driven at rms velocity of Mach 10 so that conditions are representative of star-forming molecular clouds in the Milky Way, and we follow the growth of magnetic energy for 10 orders in magnitude until it reaches saturation. The simulations utilise the latest algorithmic developments we have developed to simulate magnetic fields with SPMHD. In particular, they use a new divergence cleaning approach to maintain the solenoidal constraint on the magnetic field and a method to reduce the numerical dissipation of the magnetic shock capturing scheme. We compare the results of our turbulence calculations with results from grid-based methods, finding excellent agreement on their statistics and their qualitative behaviour. I will discuss the SPMHD methods developed, and present the results of the turbulent dynamo comparison. I will focus on the power spectra of magnetic energy and the probability distribution functions of magnetic field strength and density, both during the amplification phase and once the magnetic field has reached saturation. Finally, I will discuss some general issues of including an Ohmic resistivity and a Navier-Stokes viscosity in supersonic turbulence.

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**Title : 3D Simulations of Magnetic Massive Star Winds**

Abstract : Due to computational requirements and numerical difficulties associated with coordinate singularity in spherical geometry, fully dynamic 3D magnetohydrodynamic (MHD) simulations of massive star winds are not readily available. Here we report results of the first such a 3D simulation using specific parameters representing the prototypical slowly rotating magnetic O star $\theta^1$ Ori C, for which centrifugal and other dynamical effects of rotation are negligible. The computed global structure in latitude and radius resembles that found in previous 2D simulations, with unimpeded outflow along open field lines near the magnetic poles, and a complex equatorial belt of inner wind trapping by closed loops near the stellar surface, giving way to outflow above the Alfven radius. In contrast to this previous 2D work, the 3D simulation described here now also shows how this complex structure fragments in azimuth, forming distinct clumps of closed loop infall within the Alfven radius. Applying these results in a 3D code for line radiative transfer, we show that emission from the associated 3D ‘dynamical magnetosphere’ matches well the observed H$\alpha$ emission seen from $\theta^1$ Ori C, fitting both its dynamic spectrum over rotational phase and the observed level of cycle-to-cycle stochastic variation.

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## Title : Incorporating Lagrangian Particles in PLUTO Code : An hybrid approach to study particle non-thermal spectral signatures from AGN environments.

Abstract :

Powerful AGN jets propagating at relativistic speeds are considered to be factories of high energy particles observed in the universe. Theoretical models involving the mutual interaction between particles and fluid require a computational approach where particles and fluid are solved simultaneously.

In this talk I present a recent implementation of a fully parallel, hybrid framework that allows the evolution of Lagrangian particles coupled to fluid dynamics in the PLUTO code. Among the possible applications, I focus mainly on the spectral evolution of macro particles (ensembles of electrons with multiple energy bins) required to model non-thermal spectral signatures from AGN environments. Effects due to several physical processes like diffusive shock acceleration, synchrotron emission and adiabatic expansion are taken into account as the particles interact with MHD shocks. Such a spectral evolution study in conjunction with propagation of particles through regions of varying magnetic field provides a consistent picture of particle energetics.

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**Including Subgrid Physics in a Global MHD Solar Wind Model**

We present a global single-fluid magnetohydrodynamic model of the solar corona and inner heliosphere that uses Alfven wave turbulence to provide heating and acceleration of the plasma. The outward propagating low-frequency waves are partially reflected by Alfven speed gradients along the field lines. The resulting oppositely directed waves are responsible for the nonlinear energy cascade to smaller perpendicular scales. The cascading process, wave dissipation at and below the proton gyro-radius, and the apportioning of the dissipated wave energy to the coronal heating of the species are treated analytically. To validate the coronal heating by Alfven wave turbulence in the low corona, we compare the synthesized EUV images with the observations from STEREO and SDO. At 1AU we compare the model results with ACE data. We further present a generalization of this model to multi-fluid magnetohydrodynamics by including alpha-particle dynamics. We discuss the feasibility for Alfven wave turbulence to address both the coronal heating and proton-alpha differential streaming.

Sven VAN LOO

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**Title :** MAGNETIC FIELDS AND GALACTIC STAR FORMATION RATES

Abstract :

The regulation of galactic-scale star formation rates (SFRs) is a basic problem for theories of galaxy formation and evolution: which processes are responsible for making observed star formation rates so inefficient compared to maximal rates of gas content divided by dynamical timescale? In this talk I will discuss the effect of magnetic fields of different strengths on the evolution of giant molecular clouds (GMCs) within a kiloparsec patch of a disk galaxy and resolving scales down to □ 0.5pc. Including an empirically motivated prescription for star formation from dense gas ($n_H > 10^5$ $cm^{-3}$) at an efficiency of 2% per local free-fall time, we derive the amount of suppression of star formation by magnetic fields compared to the nonmagnetized case. We find GMC fragmentation, dense clump formation and SFR can be significantly affected by the inclusion of magnetic fields, especially in our strongest investigated B-field case of 80μG. However, our chosen kpc-scale region, extracted from a global galaxy simulation, happens to contain a starbursting cloud complex that is only modestly affected by these magnetic fields and likely requires internal star formation feedback to regulate its SFR.

Genia Vogman

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**Title : Modeling kinetic instabilities in magnetized plasmas using high-order continuum methods**

Abstract :
In kinetic theory collisionless plasmas are modeled by the Vlasov equation, which governs the evolution of probability distribution functions in 6D phase space. Recent advances in numerical techniques and supercomputing capabilities have made continuum methods for solving kinetic theory governing equations a viable alternative to particle-in-cell methods. Continuum methods are advantageous in that they can be cast in conservation-law form, are not susceptible to noise, and can be implemented using high-order numerical methods, which provide enhanced solution accuracy. A fourth-order accurate finite volume method has been developed to solve the continuum kinetic Vlasov-Poisson equation system using the Chombo library. This work describes 3D (x,v_x,v_y) continuum numerical simulations of the electrostatic Dory-Guest-Harris instability in magnetized plasmas, and its relevance to auroral precipitation and magnetic mirror confinement. Rigorous comparisons to linear theory predictions are presented. Extensions of the solver to include multiple particle species and dynamic fields are described.

Sebastian von Alfthan

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**Title : Vlasiator: Hybrid-Vlasov Simulation Code based on a Conservative Semi-Lagrangian method**

Sebastian von Alfthan, Yann Kempf, Sanni Hoilijoki, Otto Hannuksela, Urs Ganse, Rami Vainio, Minna Palmroth

Abstract :

We present the latest version of Vlasiator, the first global magnetospheric simulation code based on a hybrid-Vlasov description of plasma. Ions are represented by a sparse six-dimensional distribution function, while electrons are modeled as a charge neutralizing fluid. To propagate the distribution function we use a conservative Semi-Lagrangian approach that replaces the previous finite volume method in Vlasiator. This solver enables longer time-steps to be taken, and is fifth-order accurate in space. We have parallelized the code with a two-level MPI and OpenMP scheme, and it scales well to tens of thousands of cores. The new solvers are vectorized, and we are able to efficiently utilize the lowest level of concurrency on modern supercomputers. We also present results from new kinetic-resolution Vlasiator simulations where we have simulated the magnetosphere using various interplanetary magnetic field and solar wind parameters in steady conditions.

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Co-authors :
Doris Folini, Mickaël Melzani, Christophe Winisdoerffer, Jean M. Favre

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**Title : Wind accretion in High Mass X-ray binaries**

Abstract :

**I present results of full-scale, binary orbit to accretor, hydro-dynamical simulations of wind-accretion in black hole binaries, using a simple polytropic equation of state.**

**On the orbital scale, the spherical symmetry of the donor wind is broken by different processes. The flow is dominated by the spirally shaped wake behind the accreting black hole. This wake is bound by strong shocks, redirecting the gas towards the accretor, towards the court yard of the black hole.**

**I will discuss the flow features in this court yard and in particular discuss whether and under what conditions an accretion disk is formed. If present, such a disk will be geometrically thick and non-Keplerian. Angular momentum is advected either by shocks or by vertical exchange of matter from the environment with the disk. Such a disk will be hot as it consists of double-shocked matter. It will be surrounded by the somewhat less hot material of the accretion wake.**

**I will show how wind speeds of the donor star and the polytropic index influence typical distances of the main bowshock to the black hole, temperatures, densities, and the volume and the mass of the hot gas and the mass and angular momentum accretion rate.**

**Finally, I will address some physical inconsistencies of the simple hydrodynamical model: are the shocks collisional or collisionless, to what degree do photons and non-thermal particles play a dynamically important role, how will the inclusion of magnetic fields change the picture? This analysis will guide us on how to improve such full-scale simulation towards fully consistent numerical models.**

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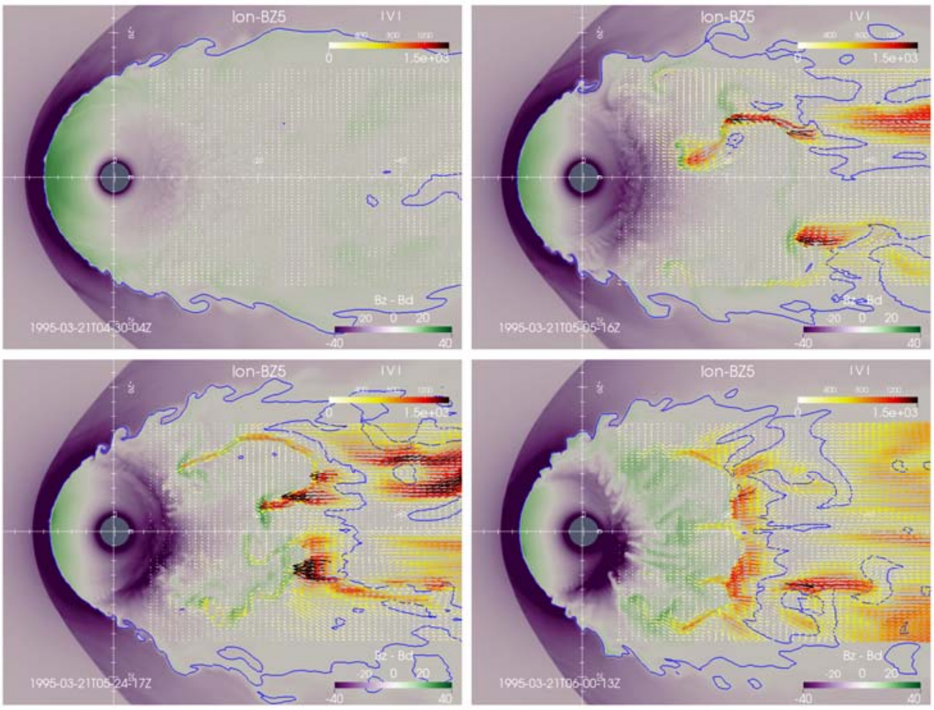
**Title : High Resolution Global Magnetohydrodynamic Simulation of Bursty Bulk Flows**

Abstract :

A high-resolution global magnetohydrodynamic simulation is conducted with the Lyon-Fedder-Mobarry (LFM) model for idealized solar wind conditions. Within the simulation results high-speed flows are seen throughout the magnetotail when the interplanetary magnetic field (IMF) is southward. Case study analysis of these flows shows that they have an enhancement in $B_Z$ and a decrease in density preceding a peak in the flow velocity. A careful examination of the structure within the magnetotail shows that these features are driven by bursts of magnetic reconnection. In addition to the case study, a superposed epoch analysis of flows occurring during a 90 minute interval of southward IMF yields statistical properties that are in qualitative agreement with observational analysis of bursty bulk flows (BBFs). The most significant differences with the observational results are a broader velocity profile in time and a larger density drop after flow passage. The peak $B_Z$ amplitude is larger than in observations and precedes the peak in the flow velocity. We conclude that the LFM simulations are reproducing the statistical features of BBFs and they are driven by spatially and temporally localized reconnection events within the simulation domain.



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Title : **Pickup ion mediated plasmas. 1) Basic model for the local interstellar medium**

Abstract : Pickup ions (PUIs) in the outer heliosphere and the local interstellar medium (LISM) are created by charge exchange between protons and hydrogen (H) atoms, forming a thermodynamically dominant component. In the supersonic solar wind beyond > 10 AU, in the inner heliosheath (IHS), and in the very local interstellar medium (VLISM), PUIs do not equilibrate collisionally with the background plasma. Using a collisionless form of Chapman-Enskog expansion, we derive a closed system of multi-fluid equations for a plasma comprised of thermal protons and electrons, and suprathermal PUIs. The PUIs contribute an isotropic scalar pressure to leading order, a collisionless heat flux at the next order, and a collisionless stress tensor at the second-order. The collisionless heat conduction and viscosity in the multi-fluid description results from a non-isotropic PUI distribution. A simpler 1-fluid MHD-like system of equations with distinct equations of state for both the background plasma and the PUIs is derived. The application of this model to the large-scale structure of the heliosphere and its interaction with the local interstellar medium is discussed.

# Numerical Relativistic Magnetohydrodynamics with ADER Discontinuous Galerkin methods on adaptively refined meshes.

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We describe a new method for the solution of the ideal MHD equations in special relativity which adopts the following strategy: (i) the main scheme is based on a Discontinuous Galerkin (DG) approach, allowing for an arbitrary accuracy of order N+1, where N is the degree of the basis polynomials; (ii) in order to cope with oscillations at discontinuities, an "a-posteriori" sub-cell limiter is activated, which scatters the DG polynomials of the previous time-step onto a set of 2N+1 sub-cells, over which the solution is recomputed by means of a robust finite volume scheme; (iii) a local spacetime Discontinuous-Galerkin predictor is applied both on the main grid of the DG scheme and on the sub-grid of the finite volume scheme; (iv) adaptive mesh refinement (AMR) with local time-stepping is used. The divergence-free character of the magnetic field is taken into account through the so-called "divergence-cleaning" approach. The convergence of the new ADER scheme, with a single step for the time update, is verified up to the 5-th order and the results for a sample of significant numerical tests are shown. We apply the new tool to the relativistic Kelvin–Helmholtz instability with a magnetic field, as well as to the propagation of relativistic jets.

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