Space and airborne missions for submm astronomy

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SRON
Netherlands Institute for Space Research

Netherlands Organisation for Scientific Research

Overview

- The need to go to space
- The space programme
- SOFIA – airplane, instruments and science
- Herschel – instruments and science
- JWST – instruments and science
- Darwin, H2EX, Millimetron, SPICA
- High spatial resolution in the Far IR – FIRI

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The need to go to space

- Atmosphere is generally not transparent between 28 and 300 micron except for a few windows
- There are important diagnostics in this region where astrophysics could benefit from:
  - The FIR toolkit includes [OI], [CII], High-J CO and H2O
  - The FIR gives access to HD lines and the H2 J=2-0 line
  - The SED of star-forming cores and galaxy nuclei peaks in the FIR
  - The mid-IR has many very important dust and ice features
  - The FIR has a few unique dust features
- But: Space is very expensive!!

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The Space Programme

- Spitzer
- Akari
- Herschel Space Observatory
- JWST

- SPICA
- Millimetron
- Darwin
- H2EX
- FIRI

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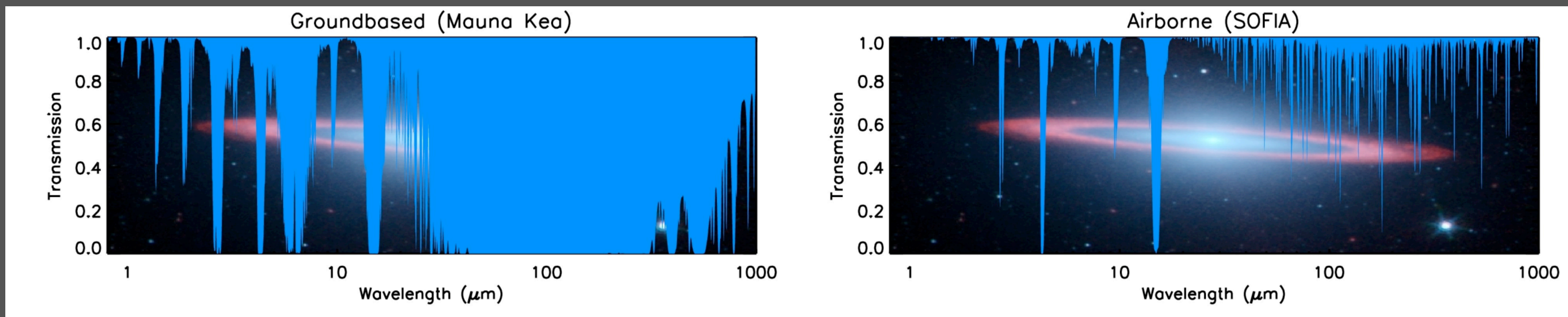
SOFIA – Lindbergh

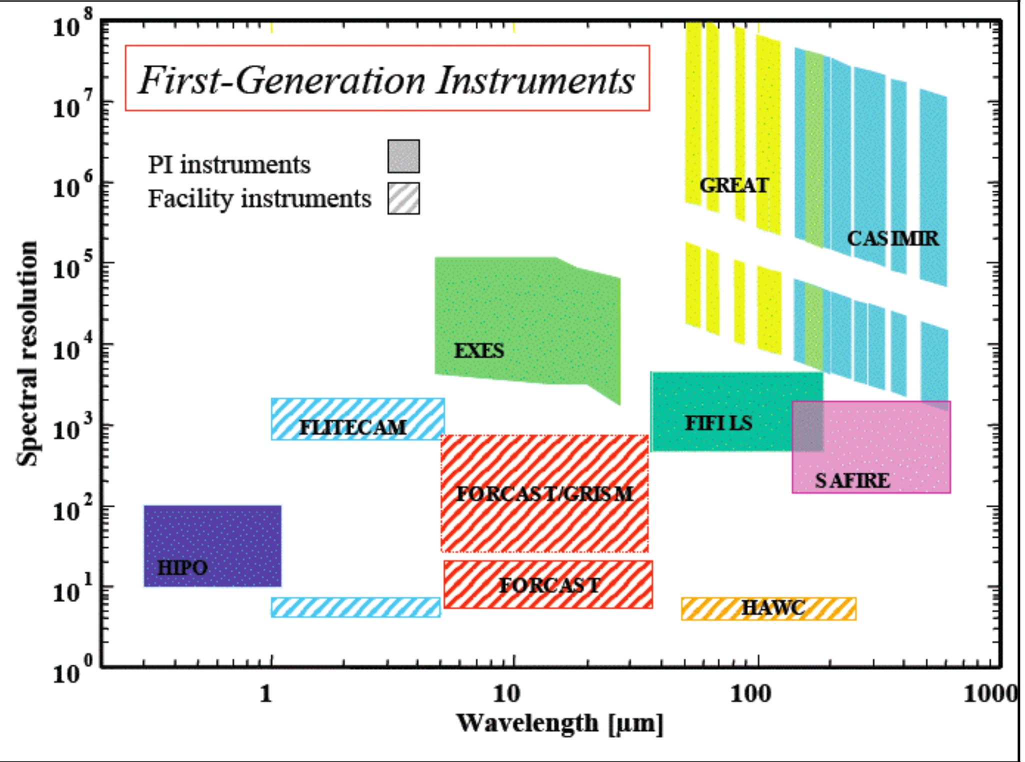
SOFIA

- SOFIA flies above the tropopause - above 99.9% of the water vapor in the atmosphere - thereby opening up the IR universe
- SOFIA is a near-space observatory that comes home after every flight and coupled with a long life time this enables:
  - Wide instrument complement and fast change out
  - Larger and more complex instrumentation than space-based platforms
  - Rapid instrument upgrades
  - Rapid incorporation of new, cutting-edge technology
  - Test bed for future space instrumentation
  - Training ground for young experimentalists



SOFIA – Instrument complement

- **As an airborne mission, SOFIA has a unique, wide instrument complement**
- SOFIA covers the full IR range with imagers and low, moderate, and high resolution spectrographs
- 4-5 instruments at Initial Operational Capability (IOC); 8-9 instruments at Full Operational Capability (FOC)
- SOFIA can take full advantage of improvements in instrument technology
- Both Facility and PI Instruments



SOFIA – Science Vision

SOFIA will uniquely address:

- How does matter accumulate to form stars (like the Sun) and their planets (like the Earth) ?
- Were some of the organic molecules needed for life on Earth created in space, and are they present in other planetary systems that are now forming?
- What are the properties of the dwarf-planets on the outskirts of our solar system (their sizes? presence of moons? atmospheres?), and what does that tell us about how our solar system formed?
- What is happening near the enormous black hole in the center of our Milky Way Galaxy?
- How are other nearby galaxies different from our Milky Way?

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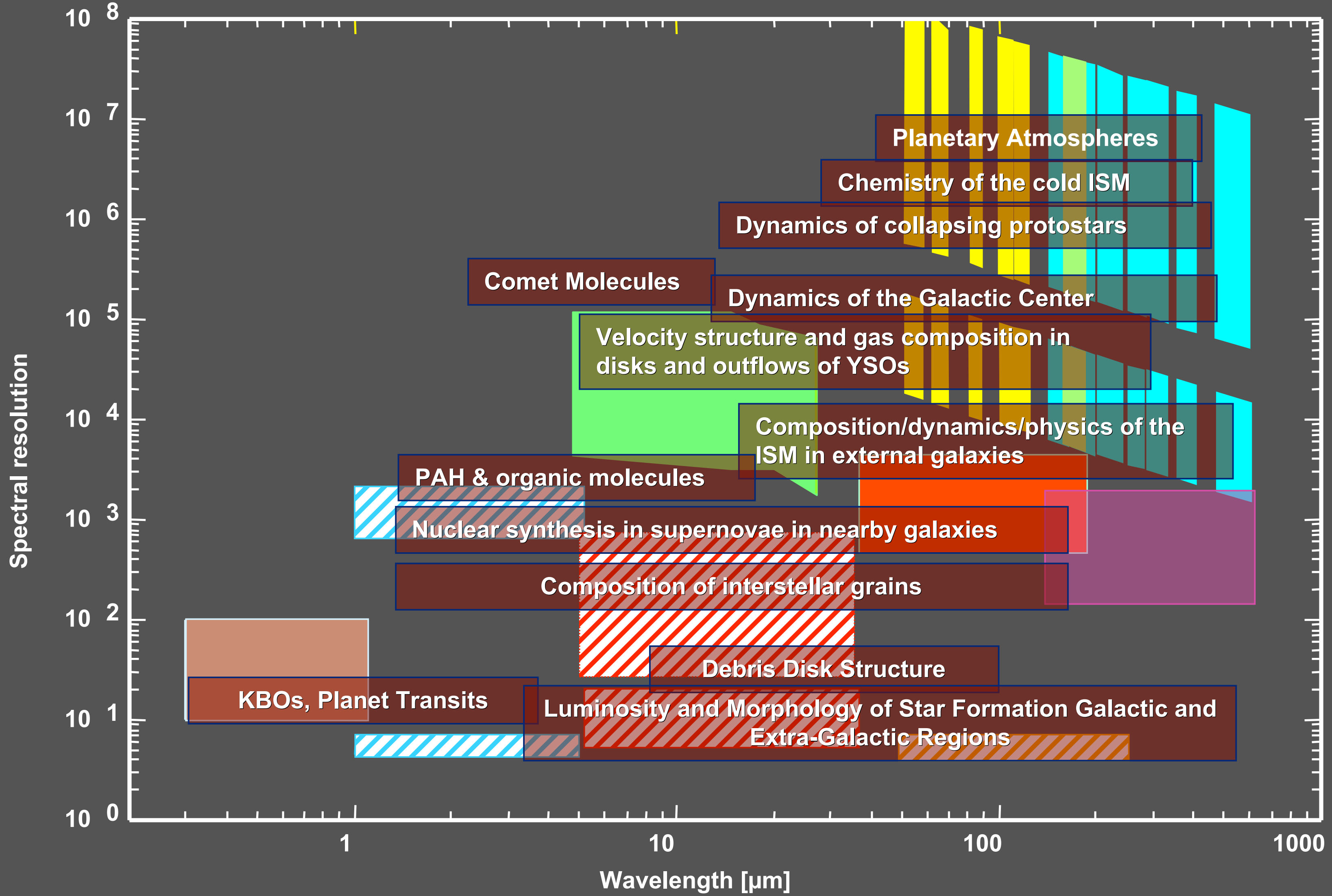
SOFIA – Science



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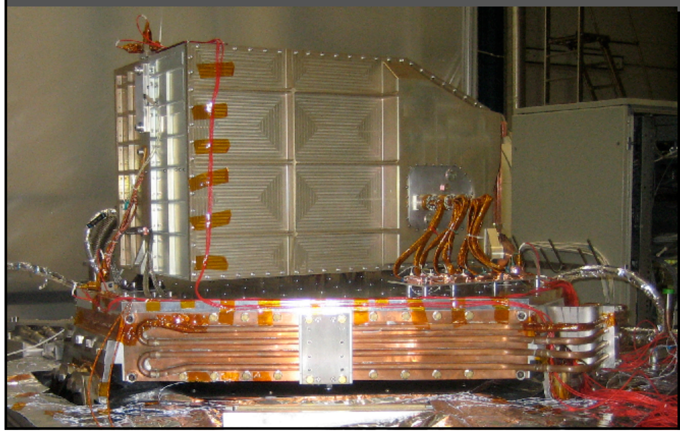
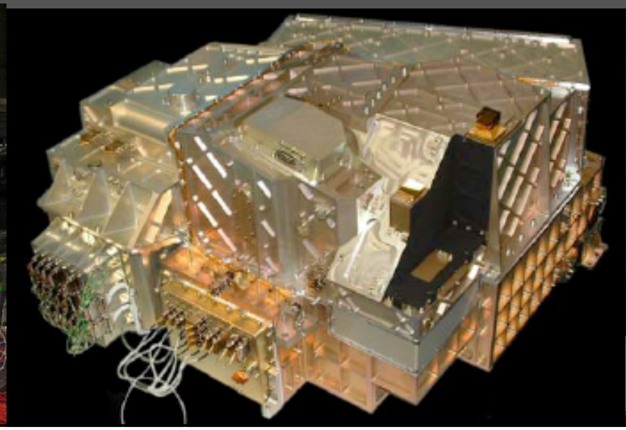
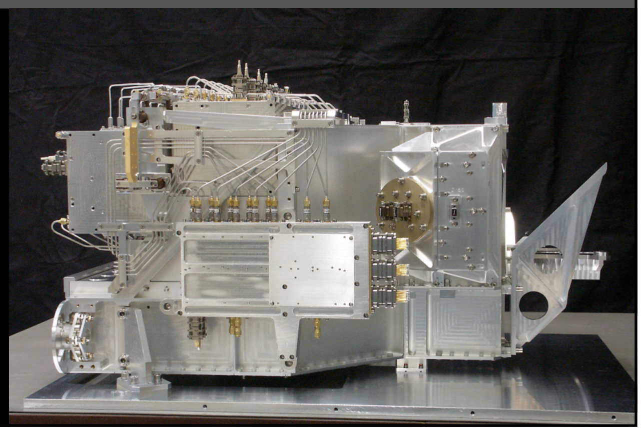
Herschel – the mission

- **Herschel** is the fourth of the European Space Agency's Cornerstone missions and will be open to the international community for proposals for submillimeter astronomical observations.
- 3.5 m dish in L2 at ambient temperature (80 K), lifetime > 3.5 year, launched together with Planck
- Instruments (SPIRE, PACS & HIFI) are cooled below 15 K, detectors at much lower temperature

Herschel – instrument complement

- SPIRE: 3 band imaging photometer (250, 350, 500 micrometer simultaneous) and imaging FT spectrometer (194-672 micrometer)
- PACS: Imaging photometry (60-85/85-130 & 130-210 micrometer) and integral field line spectroscopy (57-210 micrometer, R~1500)
- HIFI: Single pixel heterodyne spectrometer 480-1250 GHz & 1410-1910 GHz
- http://herschel.esac.esa.int/OT_KP_wkshop.shtml for all information about science, sensitivity and operating modes

Herschel – science

- Study the formation of galaxies in the early universe and their subsequent evolution
- Investigate the creation of stars and their interaction with the interstellar medium
- Observe the chemical composition of the atmospheres and surfaces of comets, planets and satellites
- Examine the molecular chemistry of the universe

- Herschel is very versatile: from deep fields to large areas to deep single line observations to spectral surveys

JWST – the mission

- Mission objective: The birth and evolution of galaxies
- 6.5 m deployable dish optimized for 0.5-28 micrometer
- Operating from L2
- 3 science instruments: NIRcam, NIRspec and MIRI
- Sensitivity figures and other characteristics:
- http://jwst.gsfc.nasa.gov/resources/isim_fast_facts_feb071.pdf

JWST – instrument complement

Near Infra-Red Camera (NIRCam)

- Detects first light
- 0.6 to 5 microns
- Includes Coronagraph Imaging Capability
- Supports Wavefront Sensing and Control
- FPAs passively cooled to 37K
- Univ. of AZ - LMATC instrument

Near Infra-Red Spectrometer (NIRSpec)

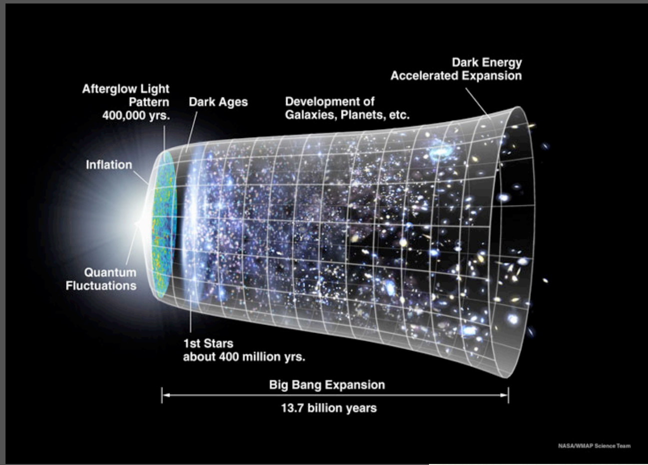
- Studies galaxy formation, clusters, chemical abundances, star formation, and kinematics
- 0.6 to 5 microns
- Simultaneous spectra of >100 objects
- Resolving powers of ~100 and ~1000
- FPA passively cooled to 37K
- ESA provided with NASA Detectors & Microshutter

Mid-Infra-Red Instrument (MIRI)

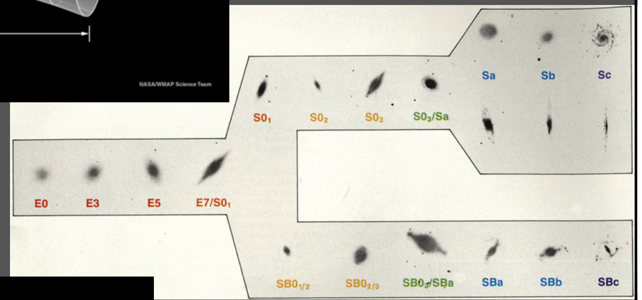
- 100x sensitivity over previous systems
- Imaging and spectroscopy capability
- 5 to 28 microns
- Cooled to 7K by cryocoolers
- Combined ESA/NASA-JPL contributions

JWST - Science

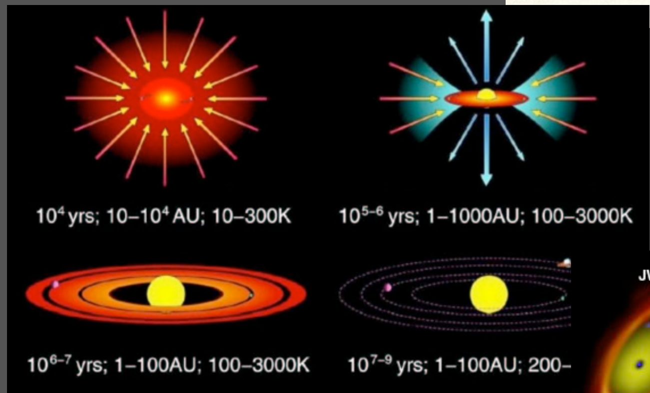
- First light and reionization



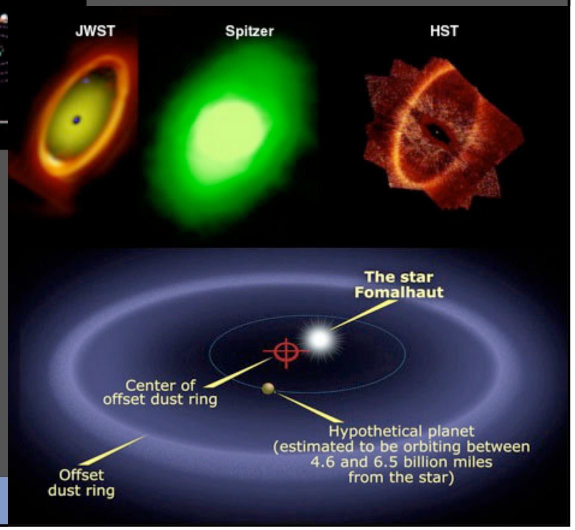
- The assembly of galaxies



- Birth of stars and proto-planetary systems



- Planetary systems and the origins of life



- http://jwst.gsfc.nasa.gov

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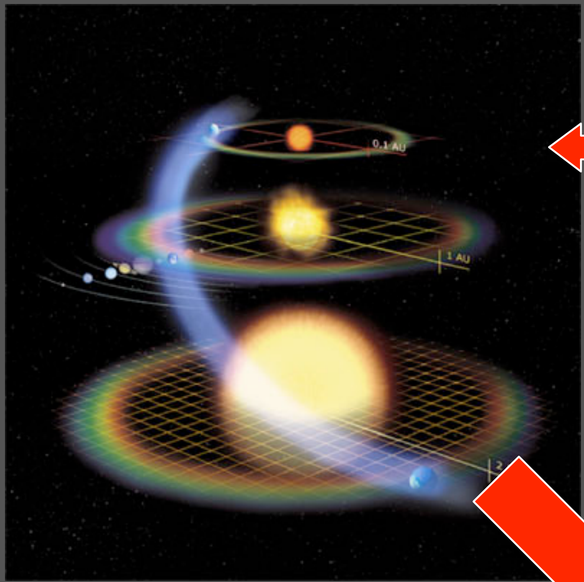
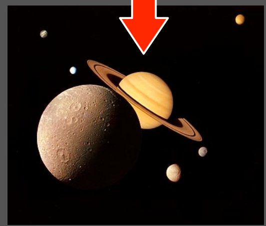
JWST: Search for the origins/assembly of galaxies

- When and How Did the Hubble Sequence Form?
    - Where were stars in the Hubble Sequence galaxies formed?
    - When did luminous quiescent galaxies appear?
    - How does this process depend on the environment?
- How did the Heavy Elements Form?
    - Where and when are the heavy elements produced?
    - To what extent do galaxies exchange material with the intergalactic medium?
- What Physical Processes Determine Galaxy Properties?
    - When and how are the global scaling relations for galaxies established?
    - Do luminous galaxies form through the hierarchical assembly of dark matter halos?
- What are the Roles of Starbursts and Black Holes in Galaxy Evolution?
    - What are the redshifts and power sources of the high-redshift ultra-luminous infrared galaxies (ULIRGs)?
    - What is the relation between the evolution of galaxies and the growth and development of black holes in their nuclei?

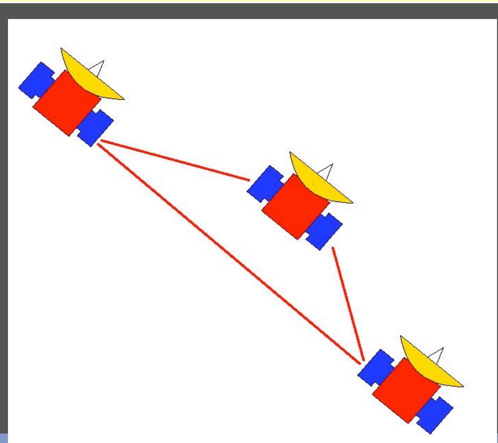
Cosmic Vision context





1) What are the conditions for planetary formation and the emergence of life?

Far infrared observatory



4) How did the Universe originate and what is it made of?

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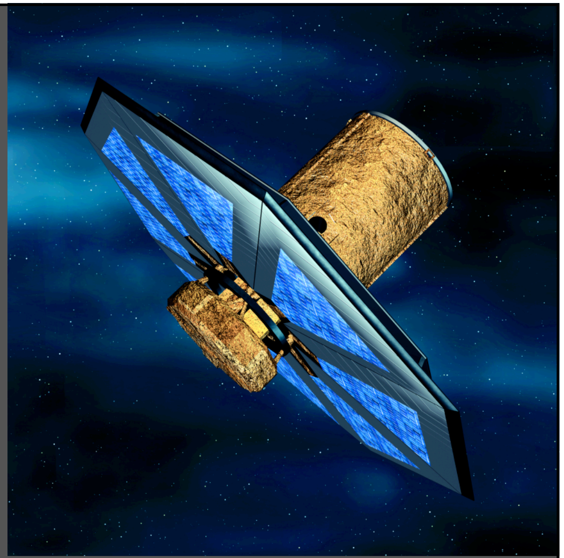
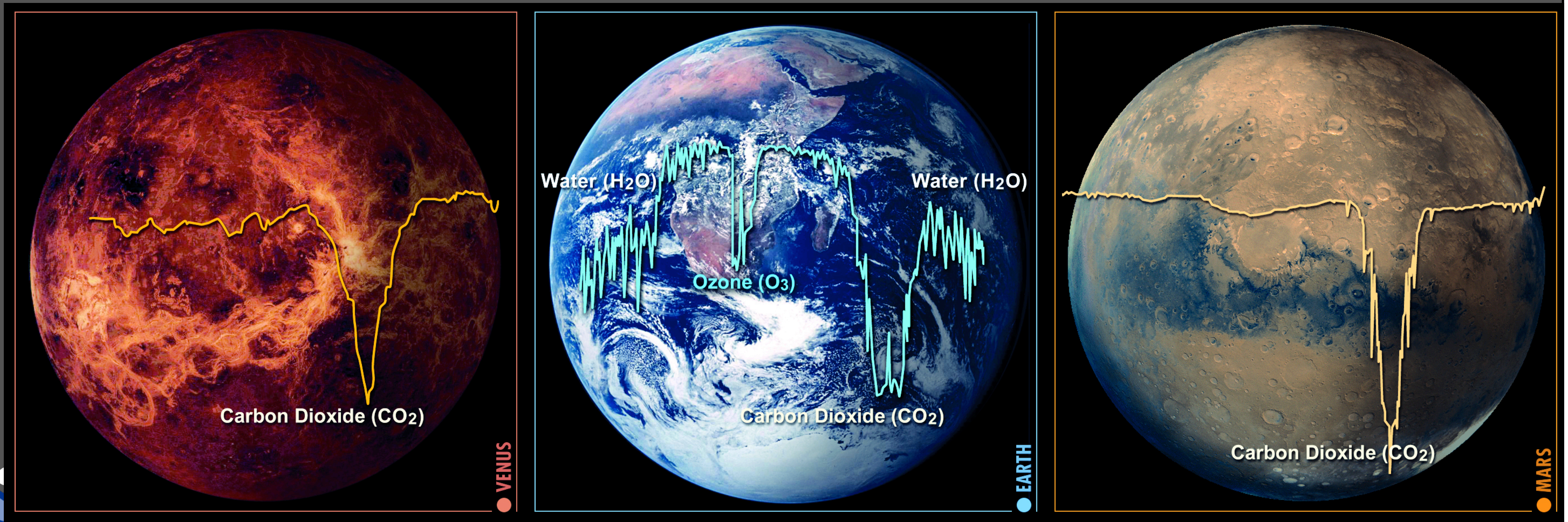
Info from Page & Griffin

Darwin

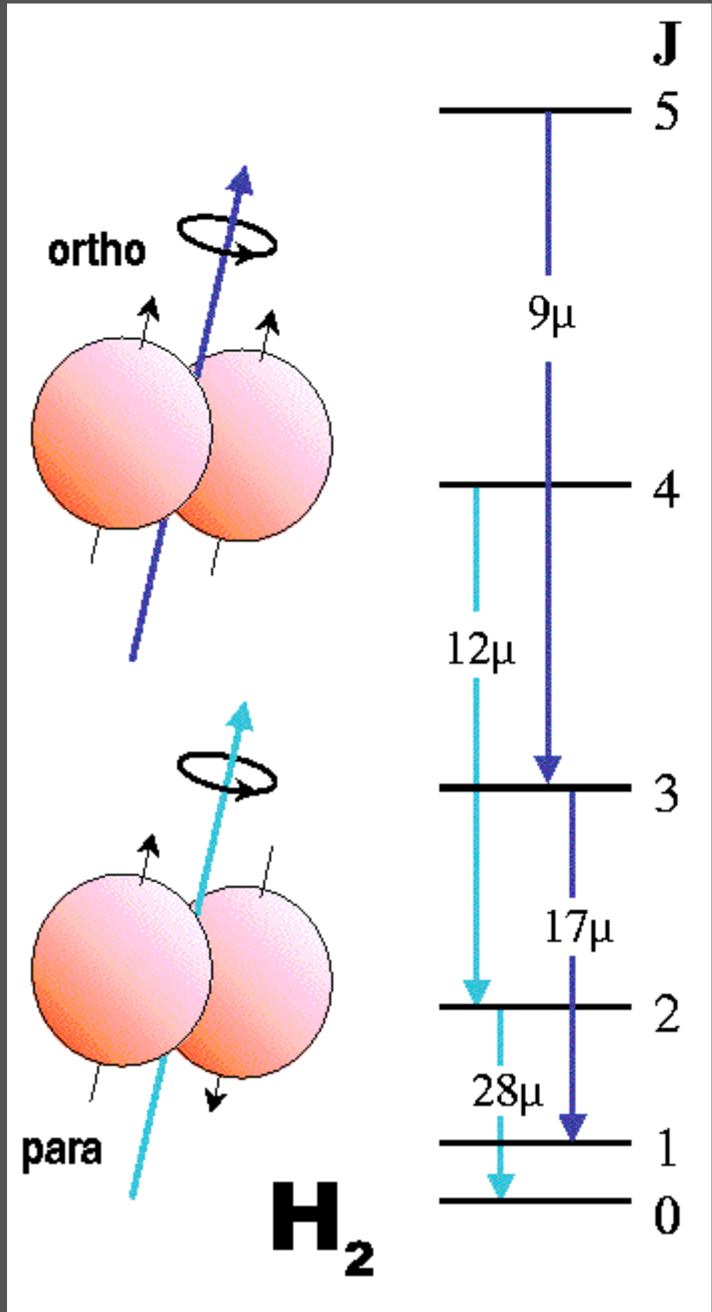


- Mission for finding terrestrial planets orbiting nearby stars, using nulling interferometry
- Possible capacity for imaging: General Astrophyics



H2EX

- H2 is the most abundant molecule in the Universe
- It is directly linked to star-formation and galaxy evolution
- It is difficult to observe!
- Instrument is a wide field 40’x40’ imaging (2.3” pixels) FTS with high (R=20,000) resolution for measuring the H2 lines
- It also has a low resolution mode (R=500) between 5-28 micrometer
- http://www.ias.u-psud.fr/website/modules/content_mic/index.php?id=55



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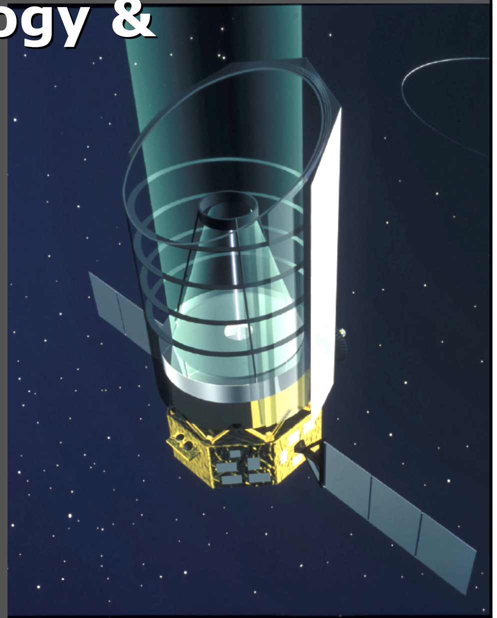
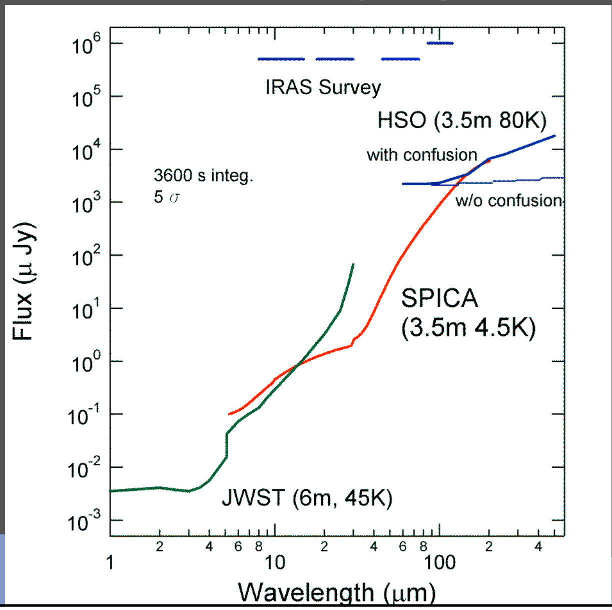
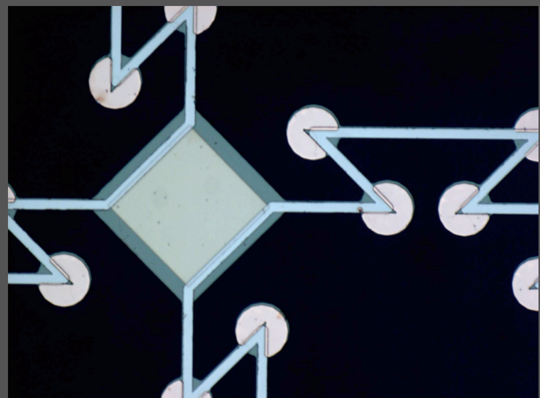
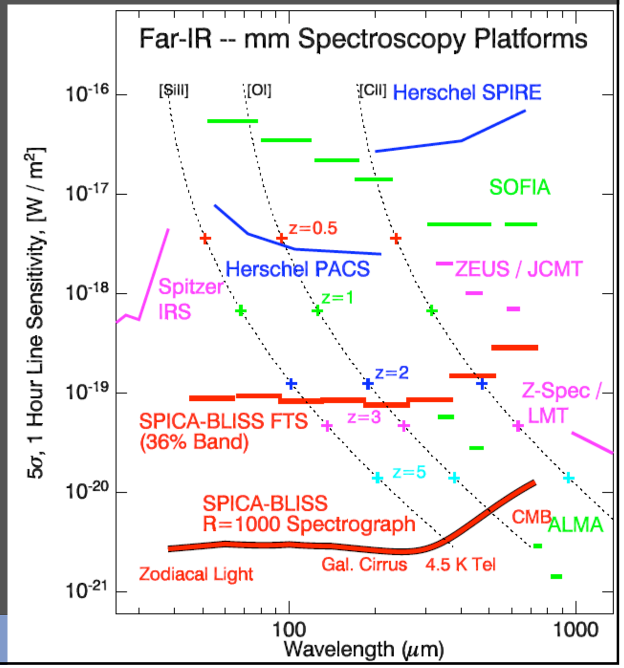
SPICA – SPace Infrared telescope for Cosmology & Astrophysics



- Scientific Objectives
  - Birth and Evolution of galaxies
  - Chemical Evolution of Universe
  - Birth & Evolution of Stars & Planets
- Infrared spectroscopy and imaging
- 3.5m telescope at 4.5 K with cryocoolers
- 3(?) instruments: MIR coronograph; MIR imaging spectrometer & FIR imaging spectrometer

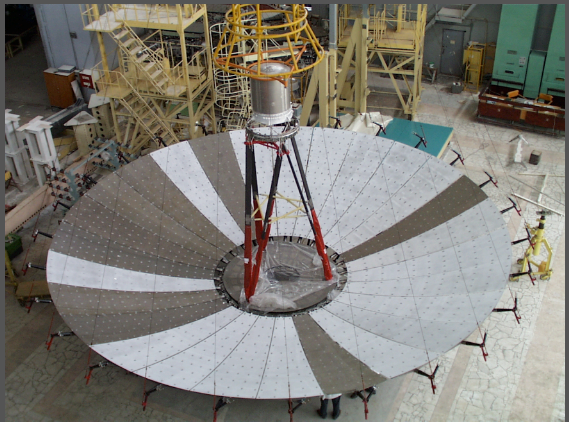


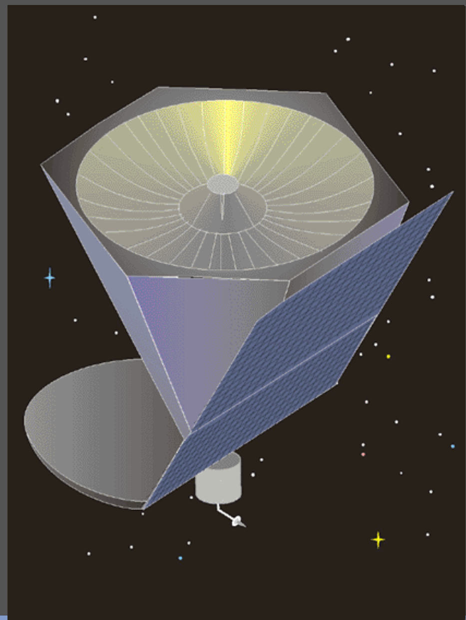




Millimetron

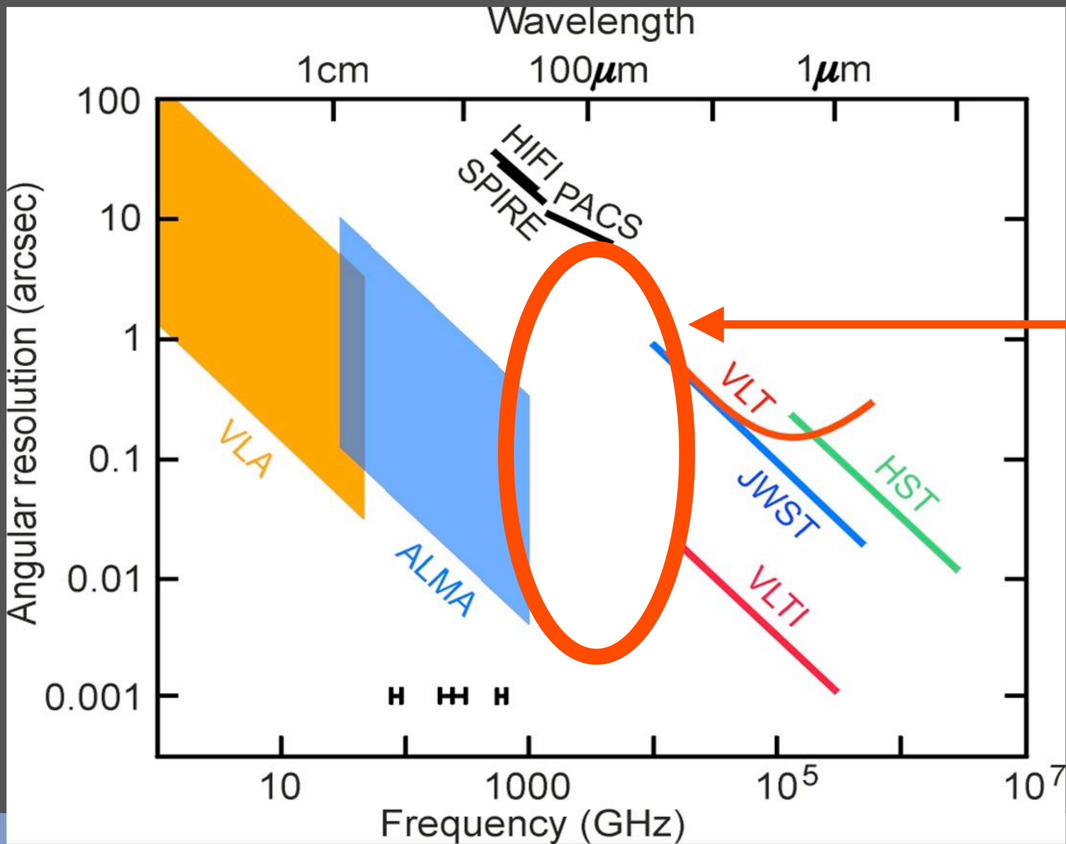
- Russian MILLIMETRON space mission, launch 2017
- 12m deployable submm/THz antenna
- Mission approved and funded by the Russian Space Agency (except instruments)
- Follow-up to Russian RADIOASTRON mission (launch 2008)
- Millimeter VLBI and submm/THz astronomy (imaging and spectroscopy)
- http://www.sron.nl/millimetron





The promise of the future – interferometry in space

- There is a need for very high special resolution, also in the FIR
- 1 AU at 100 pc = 0.01 arcsec equals ~100pc at z~10
- At 100 micrometer only an interferometer provides this capability: FIRI – the Far InfraRed Interferometer



The "Far-IR gap"

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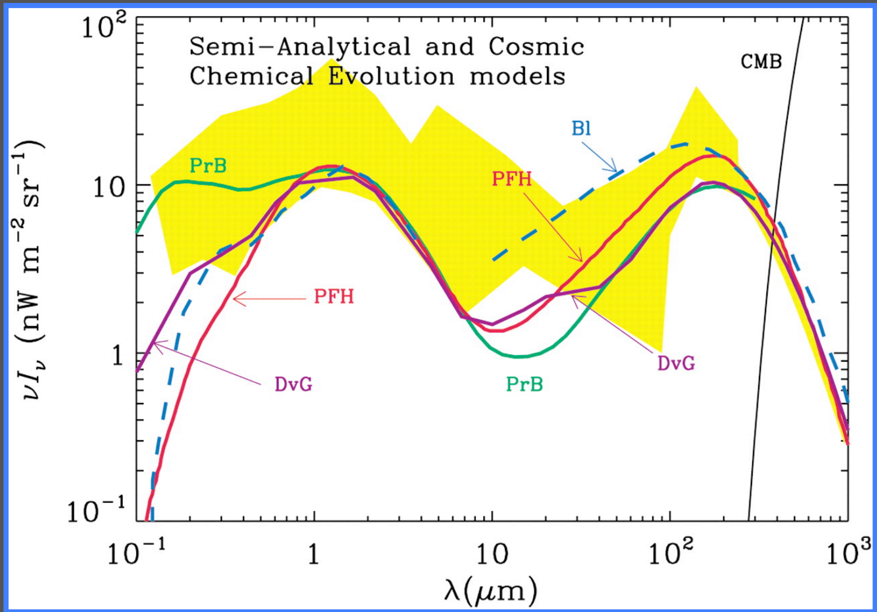
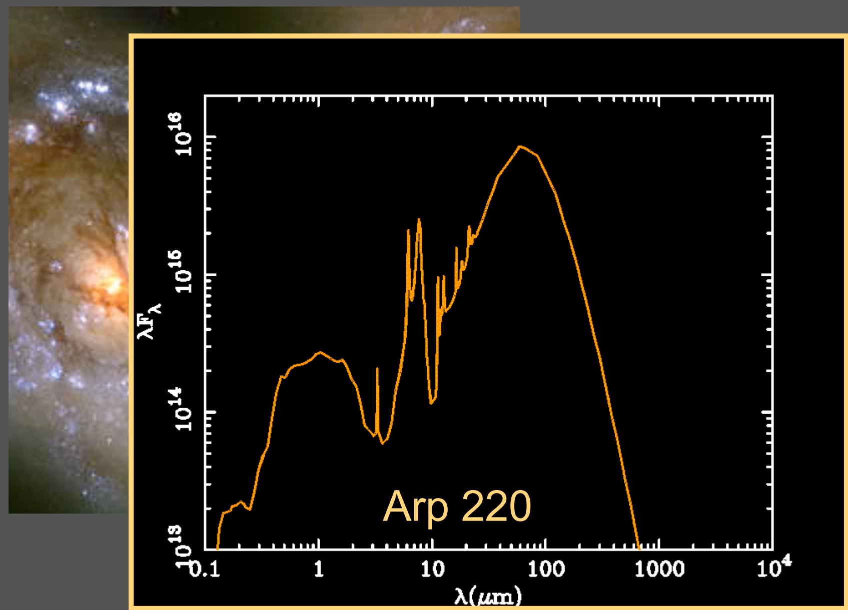
How did the Universe take shape?

Half of the energy emitted by stars and black holes has been absorbed and reradiated by dust in the far-IR

Rapidly star-forming galaxies are often highly obscured. Most of their radiation emerges in the far-IR



Hauser & Dwek 2001

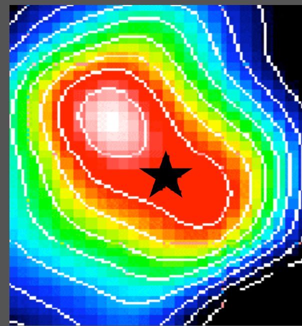


The far-IR is fundamental to understanding the Universe as it took shape.

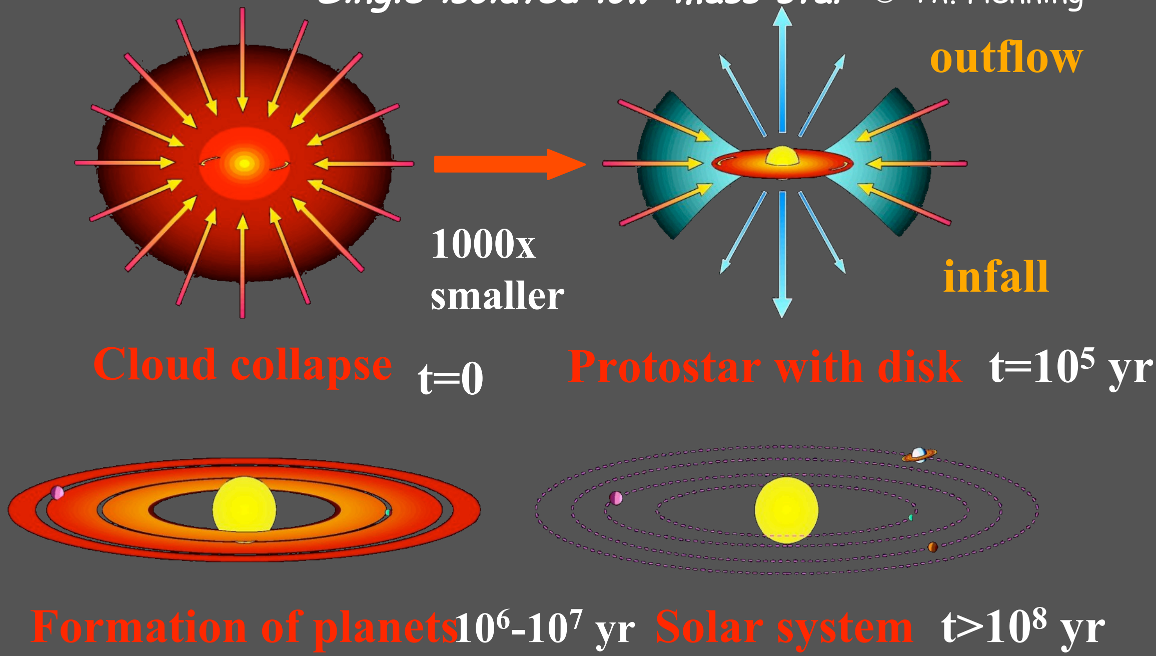
How do planetary systems form?

- Core accretion?
- Gravitational instability?
- What are the architectures of planet systems?
- Evidence for life?
- Origin of water?
- When do the large organic molecules form?

Vega
(SCUBA @ 850μm)



Single isolated low-mass star © Th. Henning



To understand the formation of planetary systems, we need far infrared spectroscopy with good spatial resolution.

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Most important science cases

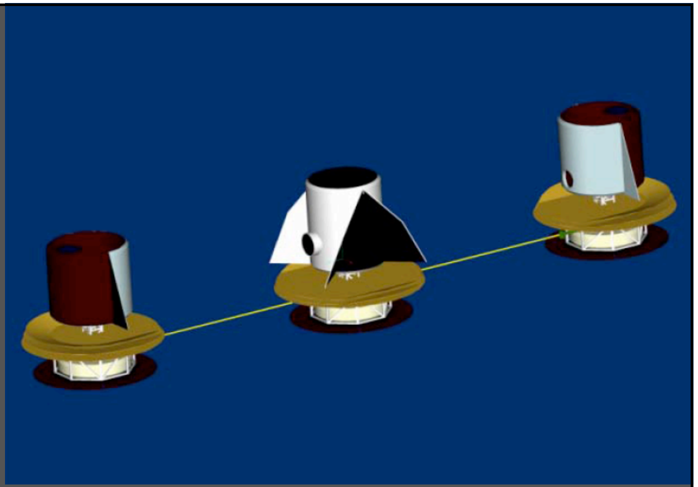
- Water (and other oxygen bearing species) in proto-planetary disks
- Dust in proto-planetary disks and debris disks
- Determining the luminosity function in clusters throughout the Galaxy and the universalness of the IMF
- Probing the origins of outflows and infall in cores

- Probing Compton-thick AGN
- Disentangling the cosmic history of star-formation and accretion onto SMBHs
- The evolution of dust through cosmic ages
- Assembling Milky Way-type galaxies

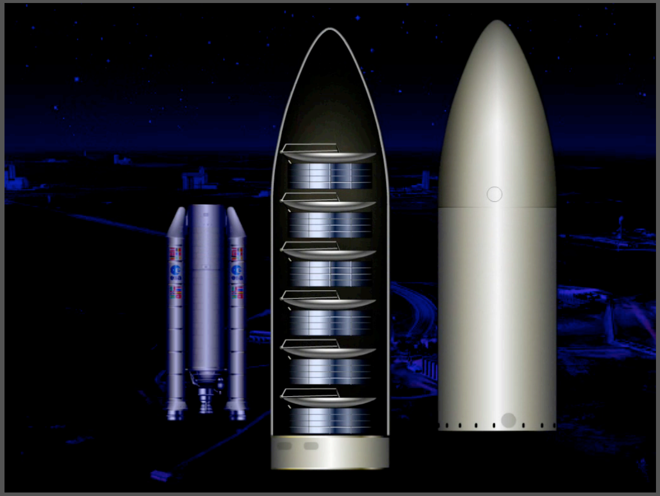
What is needed?

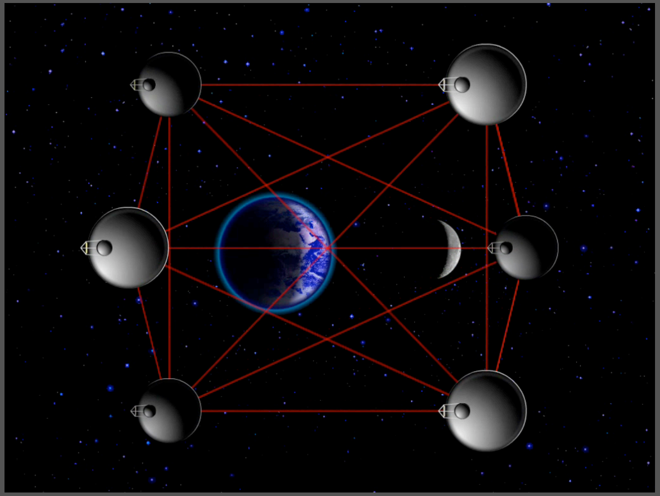
- 0.02" at 100 micrometer implies 1 km base-lines with wide range of spectral resolution
- Instruments could be heterodyne interferometer like ALMA and a direct detection interferometer like VLTI
- In the FIRI proposal we combined the two in a three element interferometer with central beam combiner as a straw-man design
- They could evolve in a SPECS or ESPRIT-like interferometer
- Studies needed in many areas!
  - Detector and LO development, cryogenic beam-combiners and delay lines, correlators, free-flying, *(u,v)* plane filling, lightweigthing of telescope, structures, electronics, better and lighter solar panels, focal plane cooling, telescope coolers, propulsion system, metrology, optical design, stray-light suppresion, calibration, AIV, etc., etc.

Cosmic Vision proposal



- Nearly ready!
- Science case very solid
- Technical case less well developed
- Money and manpower is needed to get FIRI on the right Technological Readiness Level
- FIRI is not isolated, but can build on developments in other areas. Only detection system is unique to FIRI





Sensitivity

- ESPRIT: http://www.damir.iem.csic.es/jcg/ ; Wild et al. 2006, Proc SPIE 6265, 62651
  - 18 K line sensitivity, 1km/s, 0.02" in one day (7.5mK at 1")
  - 2.5 mJy in one day at 0.02" (380 microJy at 1")
- SPECS: Leisawitz et al. 2004, Proc. SPIE 5487, 1527 & Proc. SPIE 5491, 212; Harwit et al.2006, New AR 50, 228
  - Comparable with SPICA but at much higher resolution
- SPIRIT Leisawitz et al. 2007, Adv. Sp. Res, accepted, same sensitivity as Spitzer-IRS and Herschel-PACS
  - Point source line sensitivity (R=3000, 1 hour, 5 sigma, 0.3") 3×10^{-18} Wm^{-2}
  - Continuum (1 hour, 5 sigma, 0.3") ~1 microJy

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Links

- SPIRIT: http://www.nasa.gov/centers/goddard/news/topstory/2004/0915spirit.html
- SPECS: http://space.gsfc.nasa.gov/astro/specs/
- ESPRIT: http://www.sron.nl/esprit
- Millimetron (Russian): http://radioastron.ru/index.php?dep=20
- Millimetron: http://www.asc.rssi.ru/millimetron/default.htm
- Darwin: http://sci.esa.int/science-e/www/area/index.cfm?fareaid=28
- Darwin: http://www.esa.int/esaSC/120382_index_0_m.html
- Herschel: http://www.esa.int/science/herschel
- Herschel: http://herschel.esac.esa.int/
- Herschel: http://sci.esa.int/science-e/www/area/index.cfm?fareaid=16