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SPICA

Space Infrared Telescope for Cosmology and Astrophysics

REVEALING THE ORIGINS OF PLANETS AND GALAXIES

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On behalf of the SPICA Consortium

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ESA

SRON
Netherlands Institute for Space Research

The Cosmic Vision needs an FIR Observatory

What are the Conditions for Planet Formation and the Emergence of Life?

1.1 From gas and dust to stars and planets

Map the birth of stars and planets by peering into the highly obscured cocoons where they form

Investigate star-formation areas, proto-stars and proto-planetary discs and find out what kinds of host stars, in which locations in the Galaxy, are the most favourable to the formation of planets

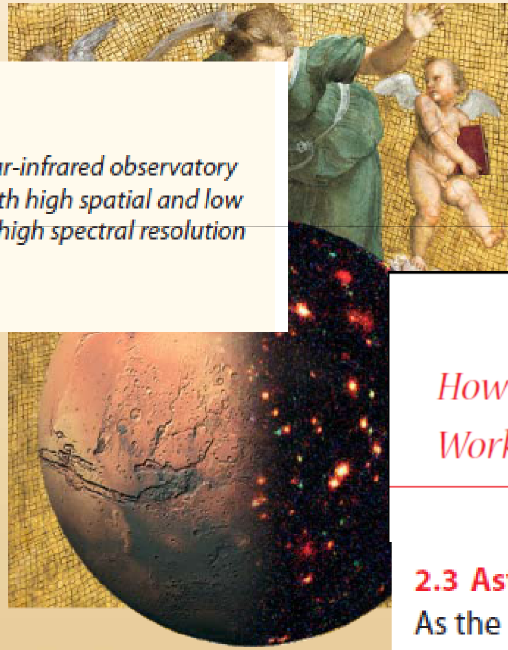
Far-infrared observatory with high spatial and low to high spectral resolution

Investigate the conditions for star formation and evolution

esa

BR-247

Cosmic Vision



Space Science fo

European Space Agency
Agence spatiale européenne

How Did the Universe Originate and What is it Made of?

Although JWST will register the redshifted visible light from very distant objects (redshifts up to $z{\sim}10$) it will miss the star-forming regions hidden by dust. They will be observable, in the longer term, only by a new-generation **far-infrared observatory.**

Resolve the far-infrared background into discrete sources, and the star-formation activity hidden by dust absorption

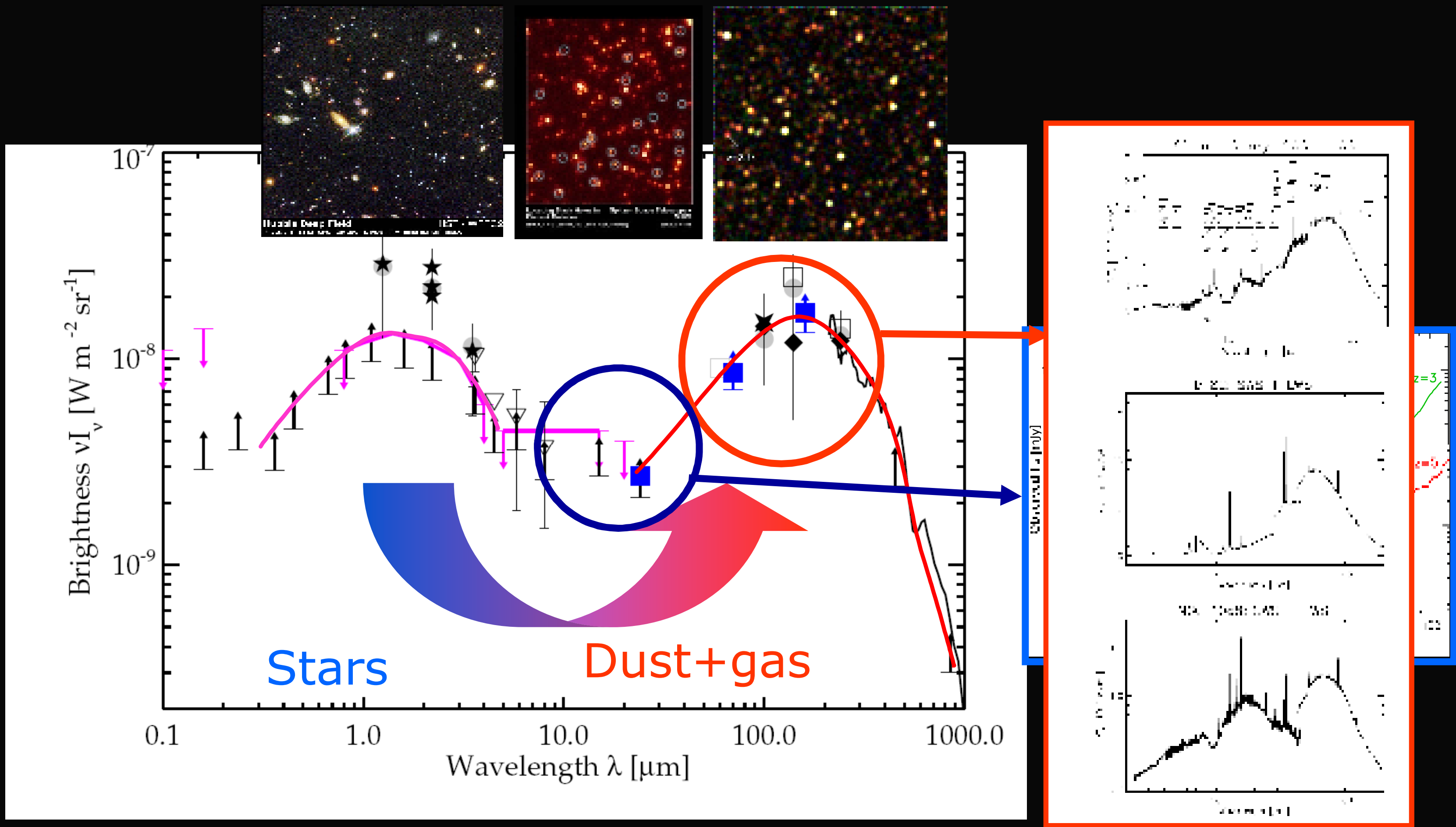
Far-infrared observatory

How Does the Solar System Work?

2.3 Asteroids and other small bodies

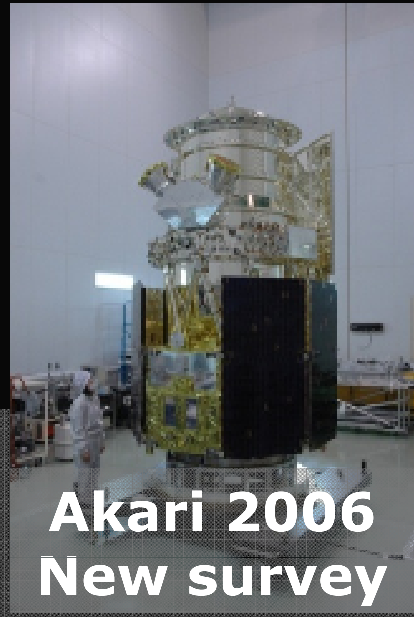
As the primitive, leftover building blocks of planet formation, small bodies of the Solar System offer clues to the chemical mixture from which the planets formed.

Why observe in the FIR?



Starlight "recycled" by dust and gas
Complete picture only seen by observing MIR/FIR

Space IR observatories



Observing >30 microns is hard

Cold telescopes – cold instruments

Progress has been incremental

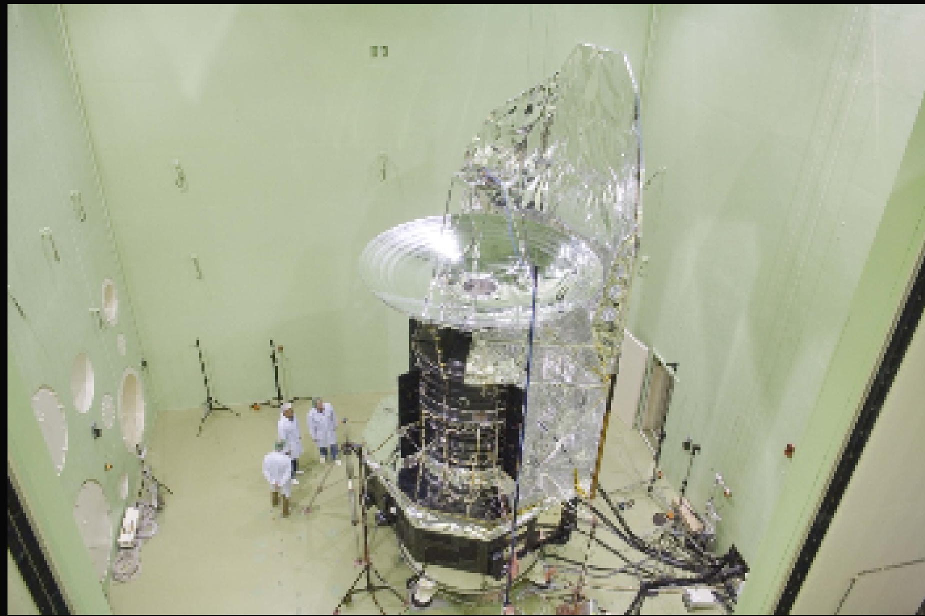
Telescope T < 5 K but Φ<1 m

Poor spatial resolution

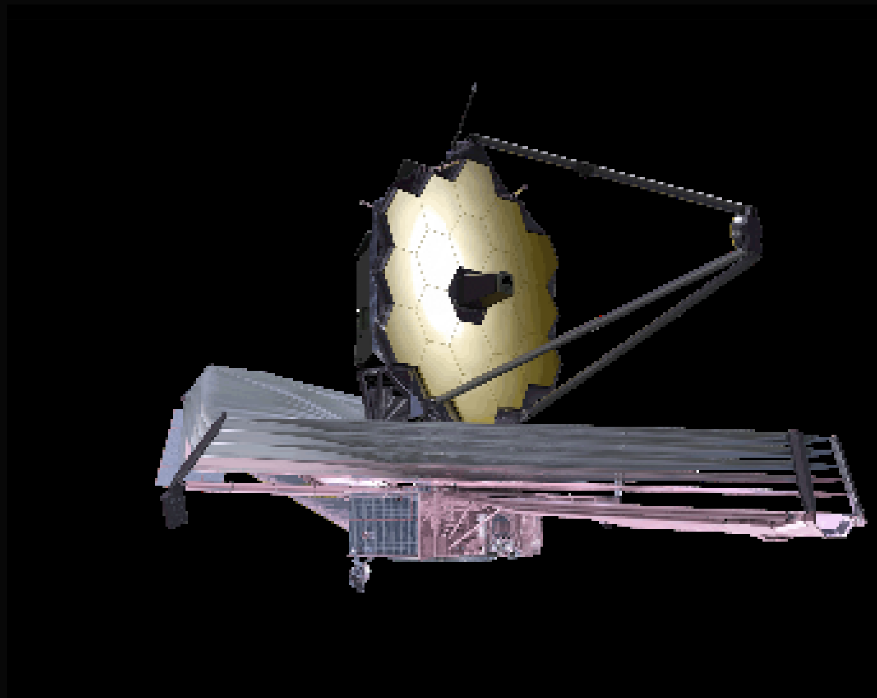
→ Need bigger aperture

→ Ideally it should be cold

Big Apertures

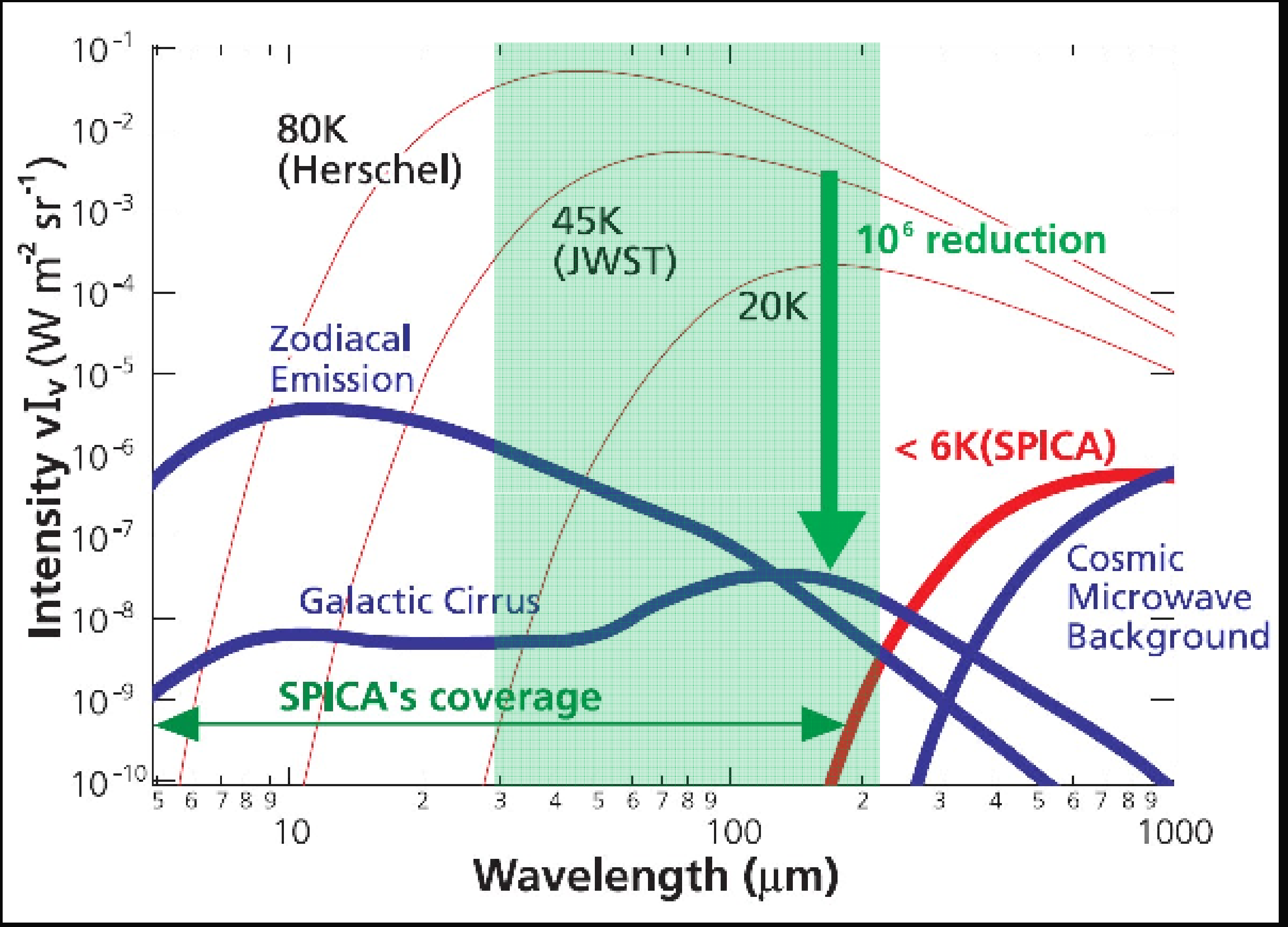


- **Herschel**
  - **3.5 m**
  - **T_{tel}~80 K**
  - **λ > 57 micron**



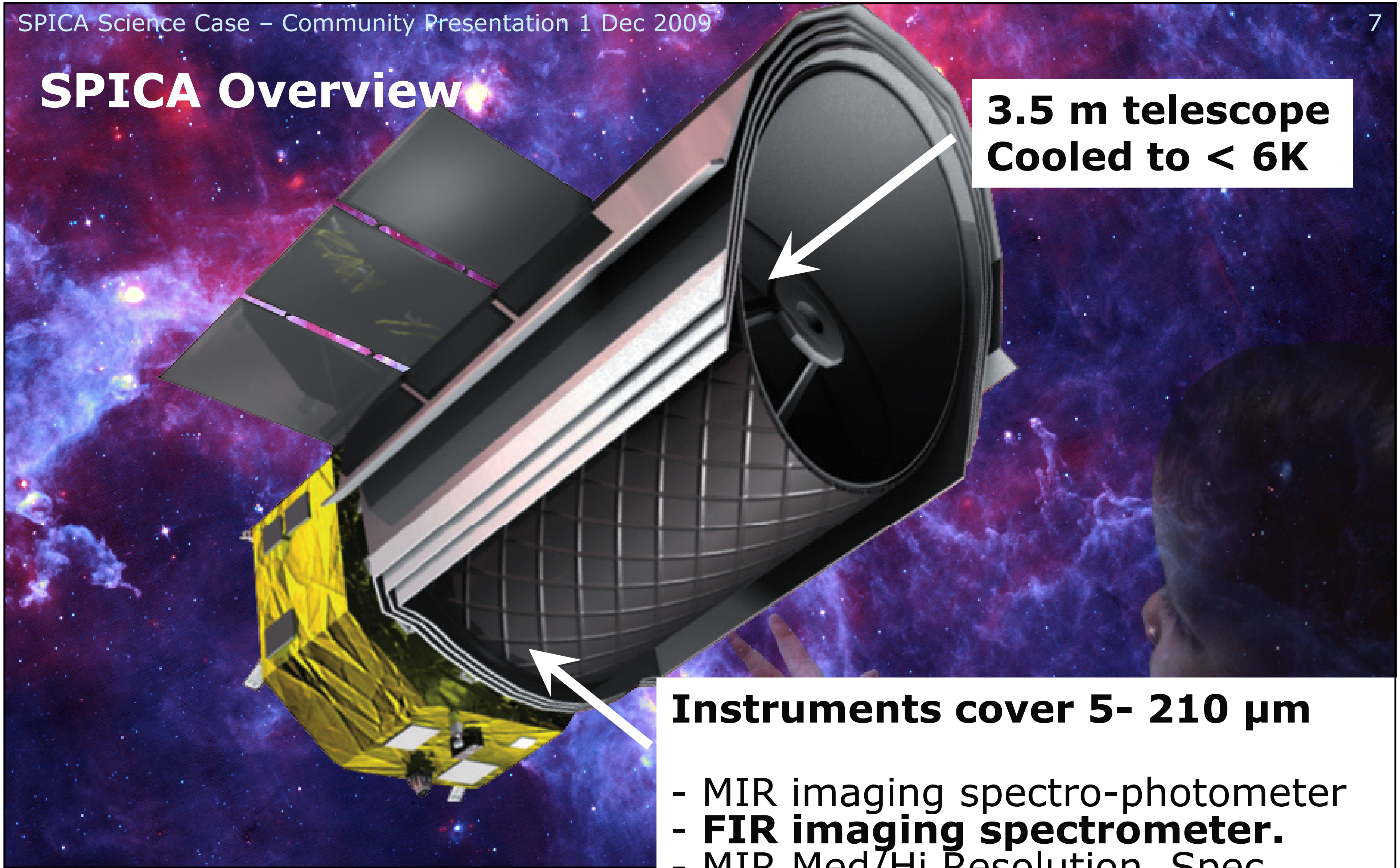
- **JWST**
  - **~6.5 m**
  - **T_{tel}~45 K**
  - **λ < 28 micron**

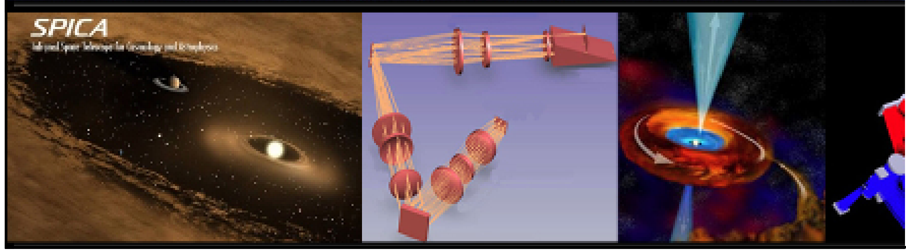
Zodiacal light limited sensitivity



Background limited <200 μm if T_{tel}<~6 K

SPICA Overview



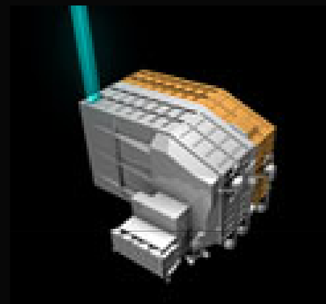


Instruments cover 5- 210 µm

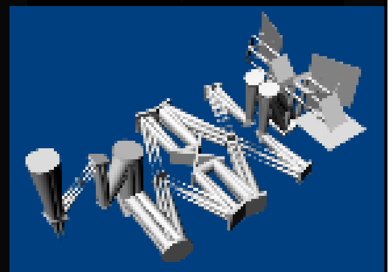
- MIR imaging spectro-photometer
- **FIR imaging spectrometer.**
- MIR Med/Hi Resolution Spec.
- MIR coronagraph
- Focal Plane Camera (guiding)
- LW spectrometer (optional)

European contribution to SPICA

1. **SPICA Telescope Assembly:**
   ESA provided based on Herschel heritage (industrial assessment study).



2. **SAFARI instrument:**
   SPICA FIR Imaging Spectrometer (assessment study carried out by the instrument consortium). ESA acting as official interface to JAXA. Based on Herschel heritage.

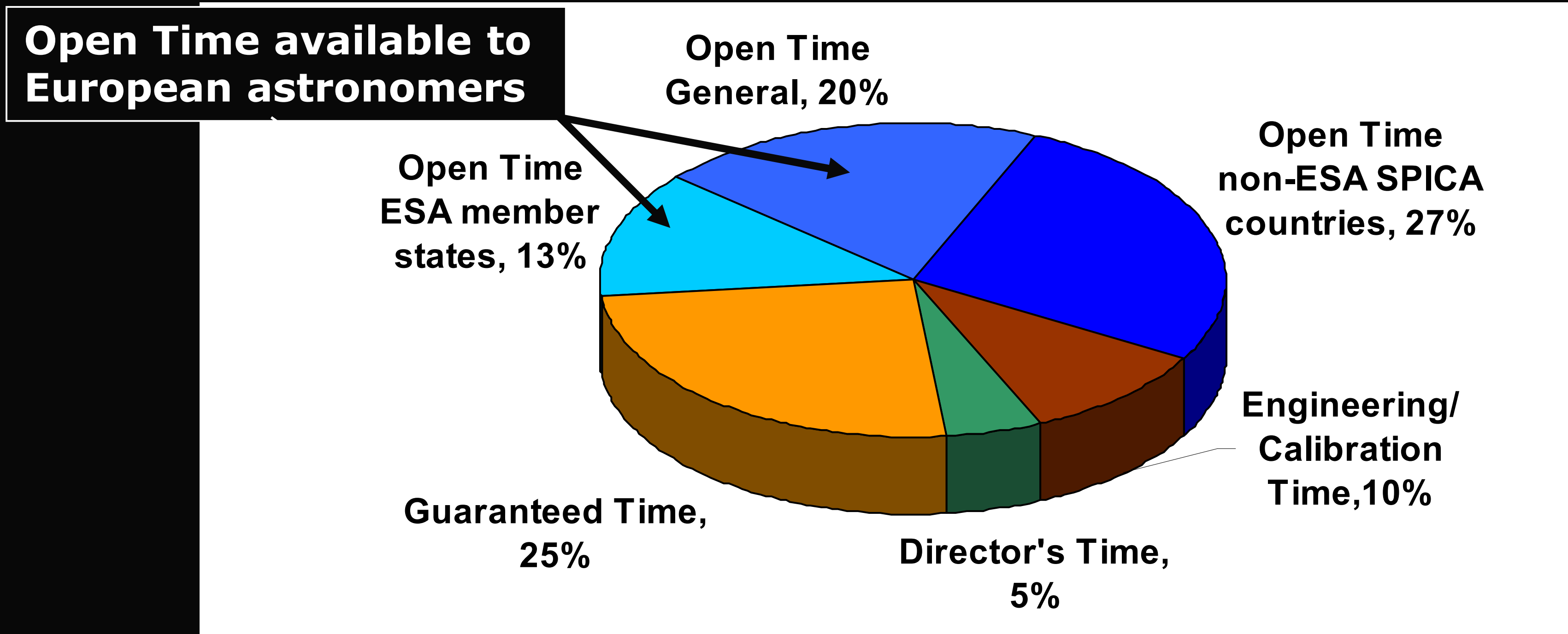


3. **GND segment contribution:**
   Provision of a ground station for 4hr/day

4. **European Science Centre:**
   Supporting the European scientists in accessing the SPICA observatory

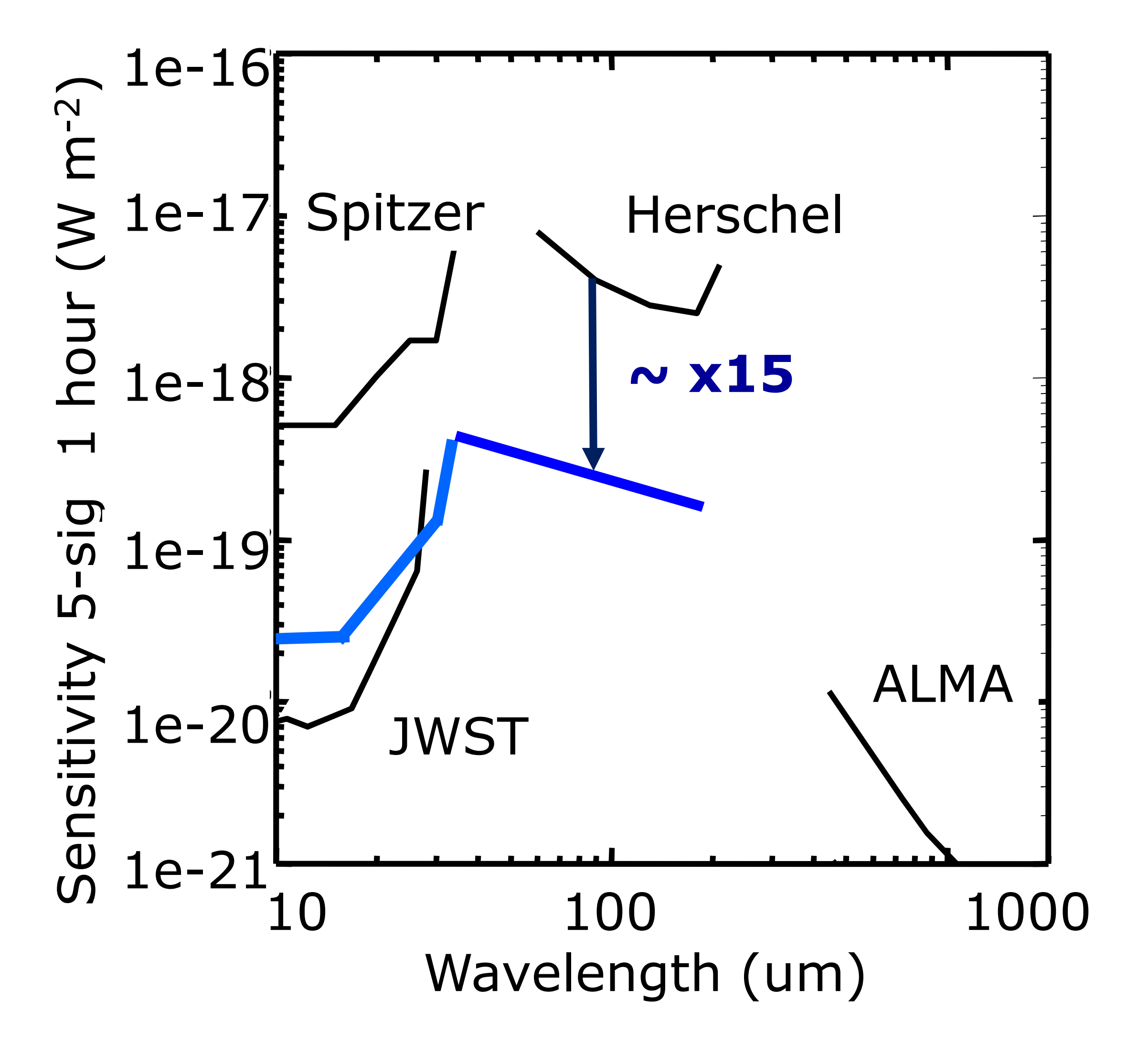
SPICA: A World Observatory

- SPICA is an *observatory* open to the astronomical community
- A single international Time Allocation Committee
- Legacy and normal programmes



Provisional observing time distribution

SPICA Sensitivity - spectroscopy

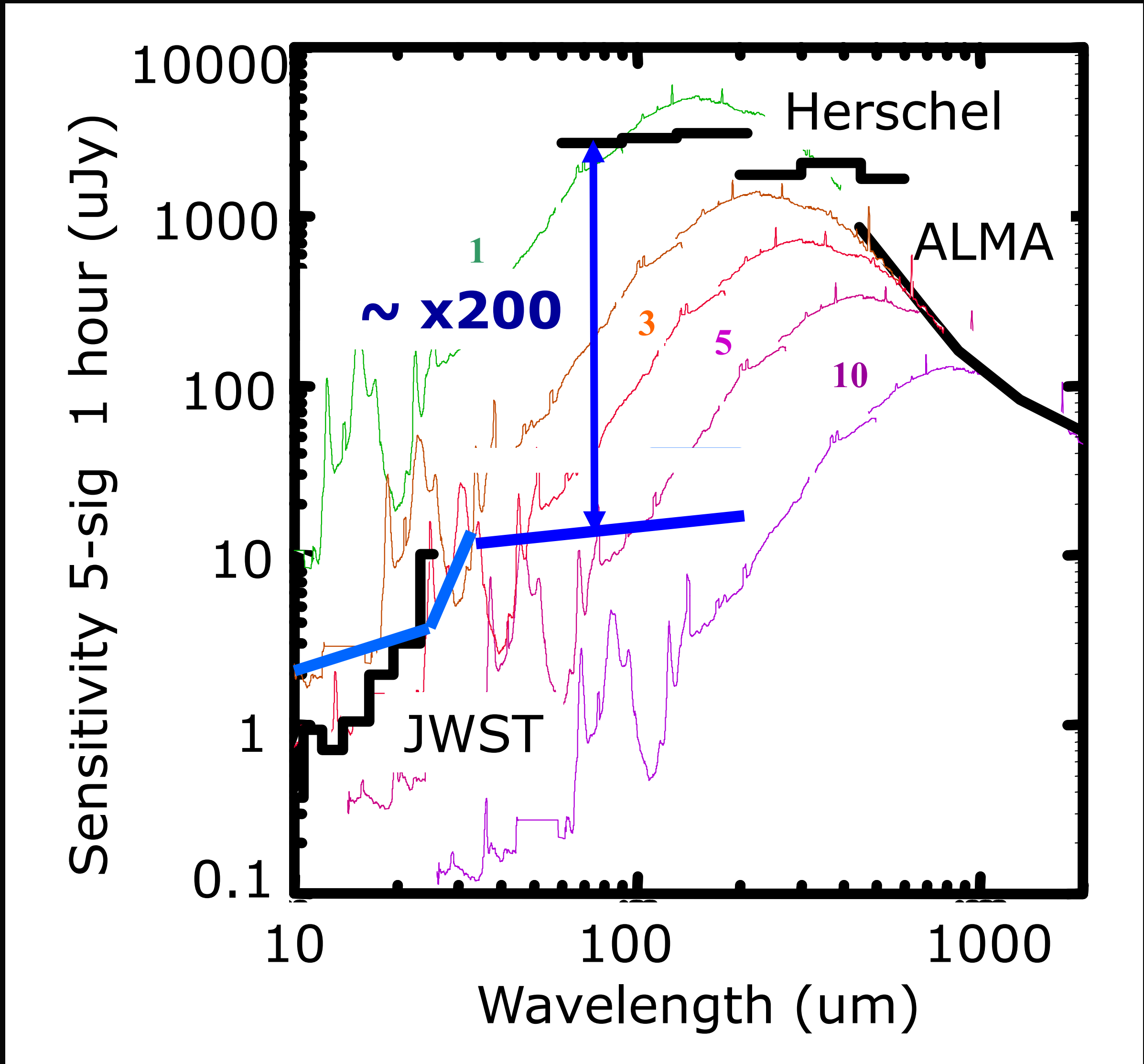


Single unresolved line in single object

Covers Missing Octave – 30-60 µm

FTS 100’s times faster to cover multiple lines over large field of view

SPICA Sensitivity - photometry



>10000x faster than Herschel

Can detect M82 like starburst galaxy at z~>5

Can detect Solar type Zodiacal cloud at 30 pc

Science case overview

1. Planetary system formation

- Oxygen and water chemistry in planetary formation
- Disk mineralogy at all stages of planetary formation
- High resolution spectroscopy of H_2 in gas disks
- Exo-Zodiacal dust in 100's of stars
- Direct MIR spectroscopy of exo-planets
- Composition of outer Solar system objects (KBO/TNOs, dust)

Science case overview

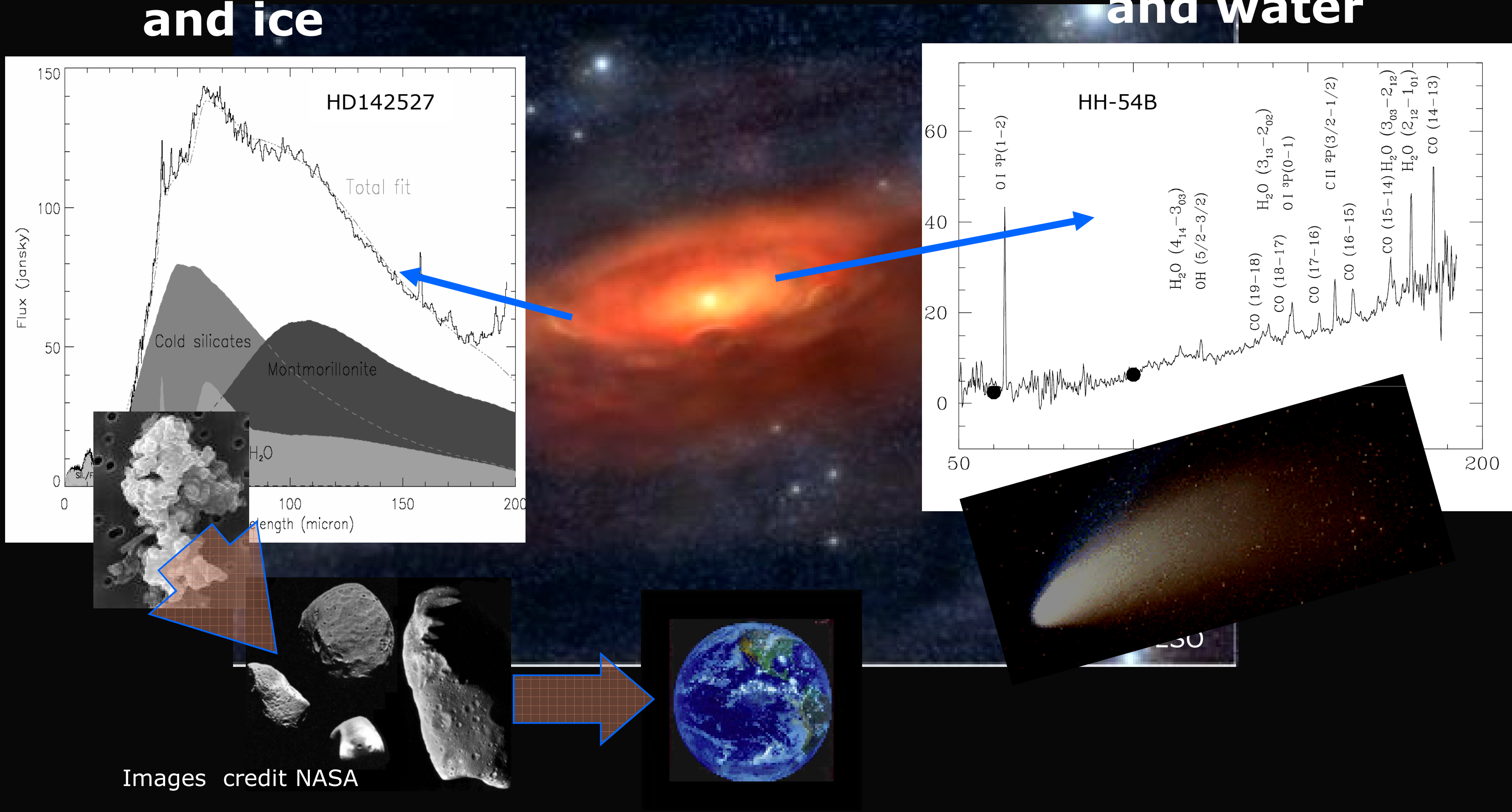
2. Galaxies: co-evolution of stars and black holes

- **First FIR spectroscopic cosmological surveys:**
- Redshift and nature of the sources in single shot
  - Evolution of the massive, dusty distant galaxy population
  - What is shaping the mass and luminosity functions of galaxies?
  - How do star formation rate and AGN activity vary with environment and cosmological epoch?
  - How and when do normal galaxies such as our own form?

Planetary formation

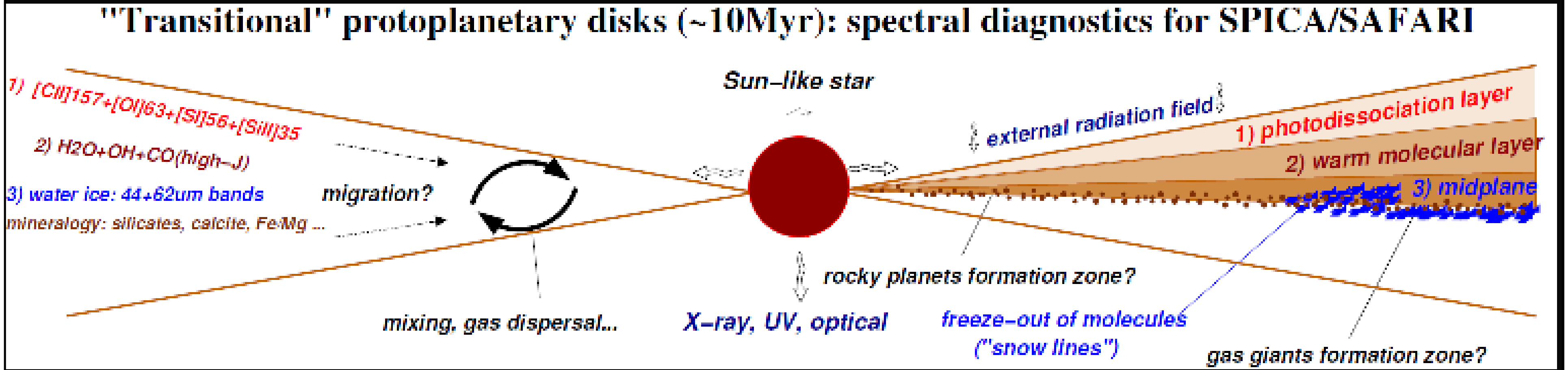
Dust mineralogy and ice

Oxygen chemistry and water



Rocky planets and oceans

Planetary Formation – protoplanetary disks



- **SPICA: traces all layers**
  - Warm molecular layer
    - → CO, HCN, CN... ALMA
    - → H_2O, OH.. SAFARI
  - Midplane
    - →ice
    - →dust mineralogy

- **Gas, dust and ices:**
  - Major lines detectable to ~100 pc
  - Test planet formation and evolution theories

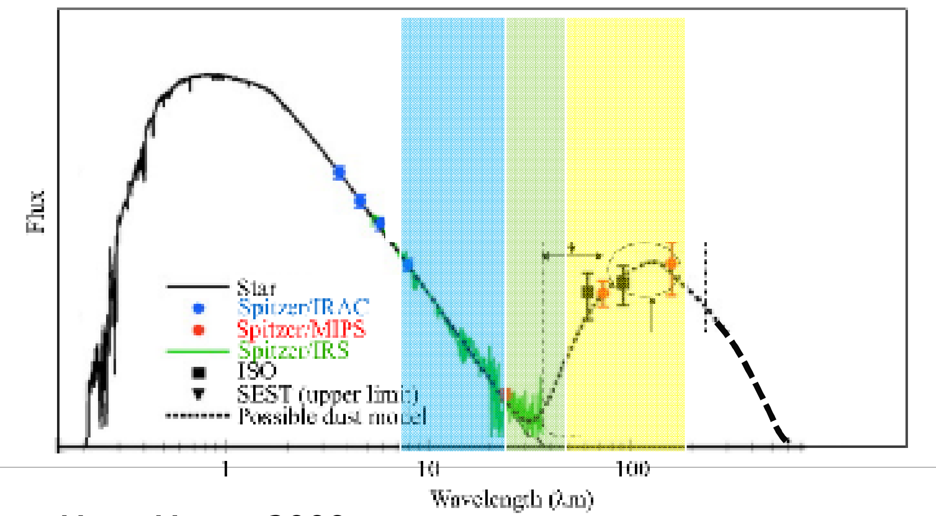
Detecting Kuiper and Asteroid Belt analogs in distant extrasolar systems

- Little MIR emission implies clearing of inner disk
- MIR→FIR SED necessary to constrain the disk inner radius
- FIR will constrain shape and peak of SED → cold dust

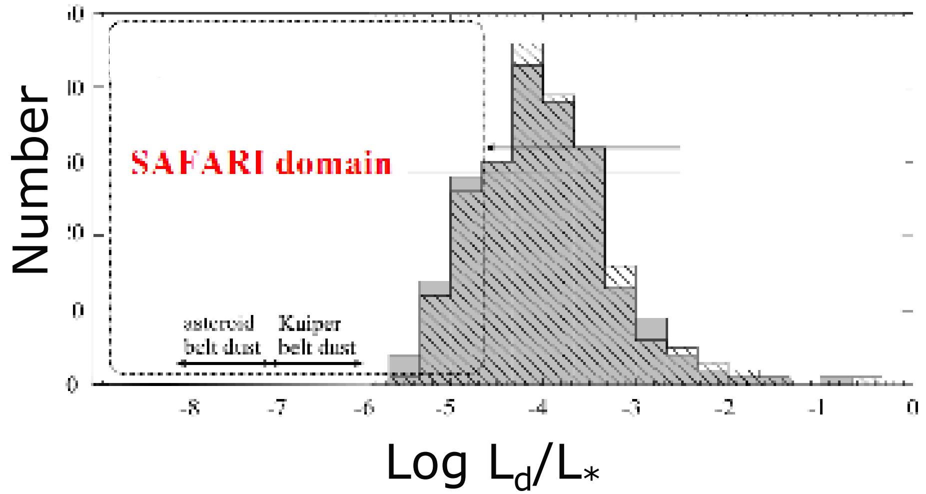
- Dust implies continuing collision and accretion

- First systematic survey for Solar type KB and AB type dust mass

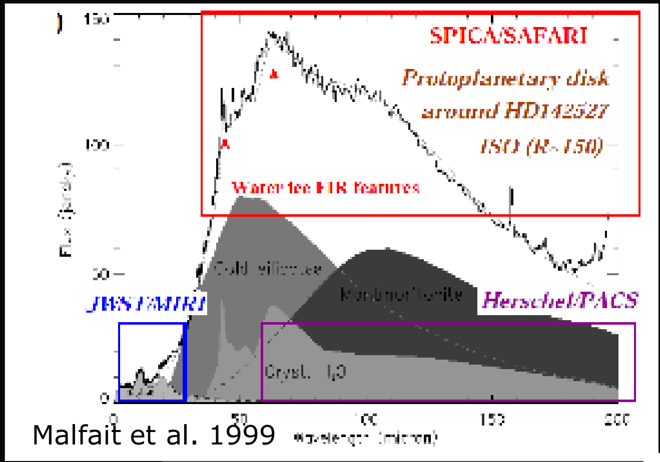
Adapted from Meyer et al. 2008



Moro-Martin 2009



Resolving the "snow line" in nearby disks



Water ices important in grain coagulation → planet formation

Water first hydrogenated molecule to freeze out (T<150 K) → marks “snowline”

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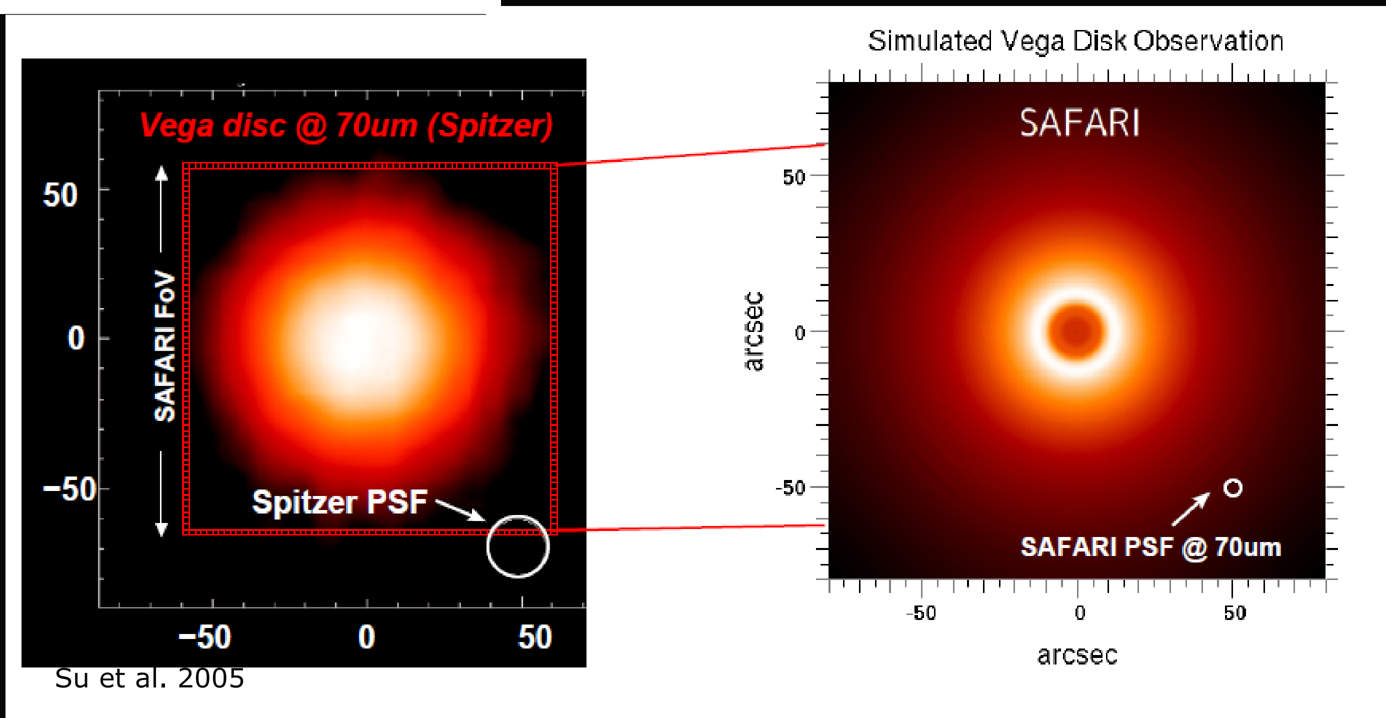
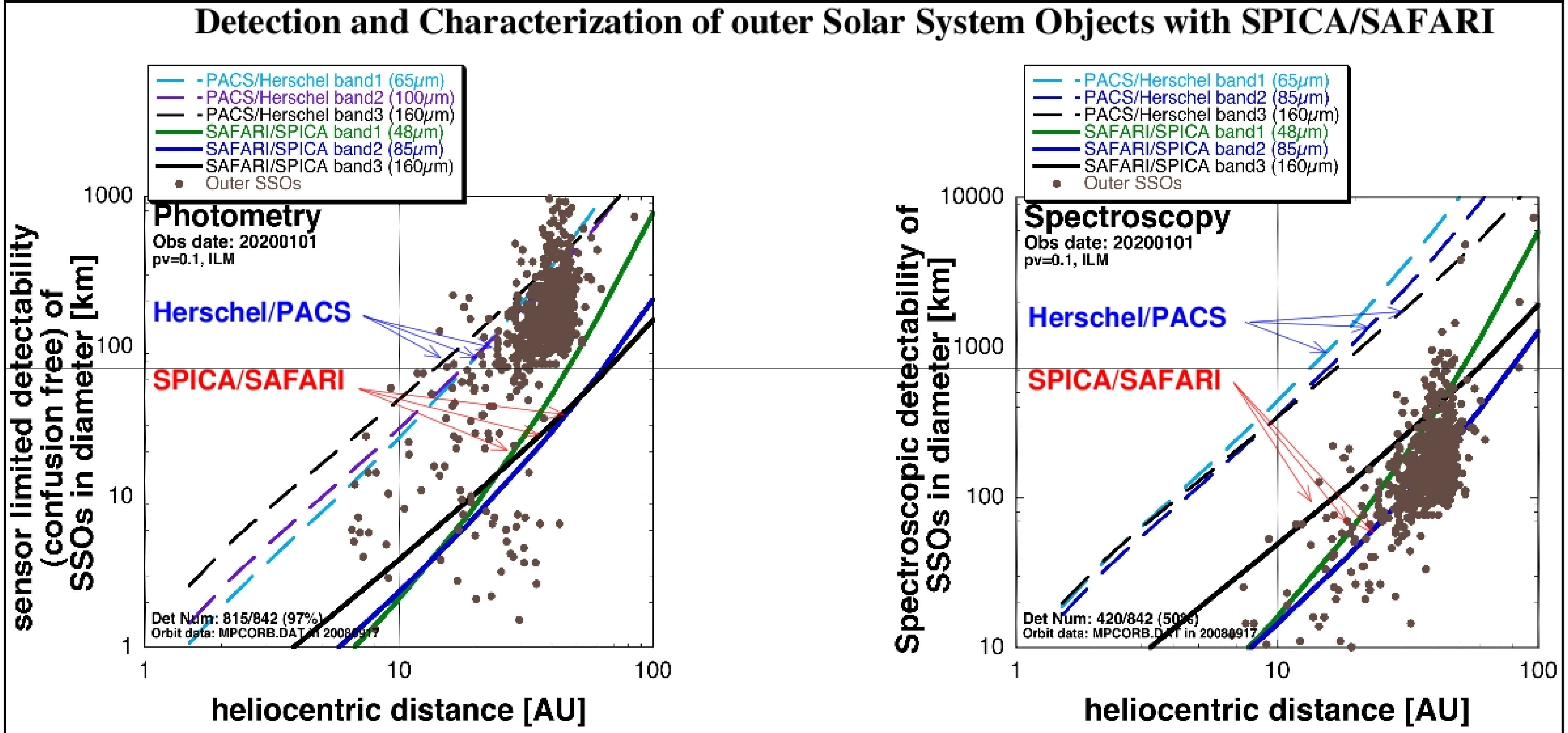


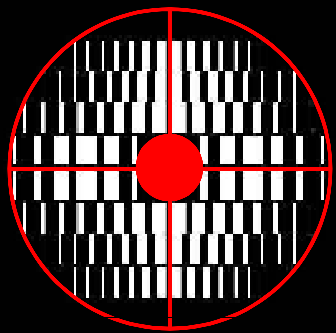
Detecting and characterising our own Debris disk



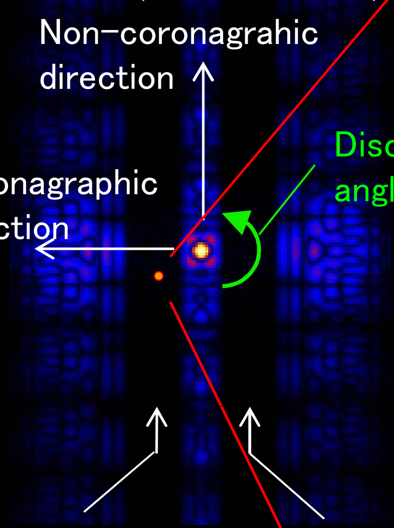
Updated from Hasegawa (2000)

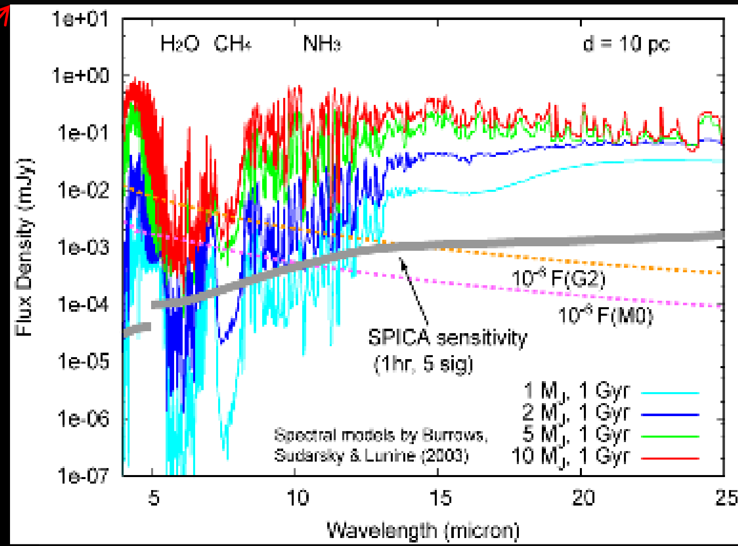
Coronagraph for exo-planet characterisation

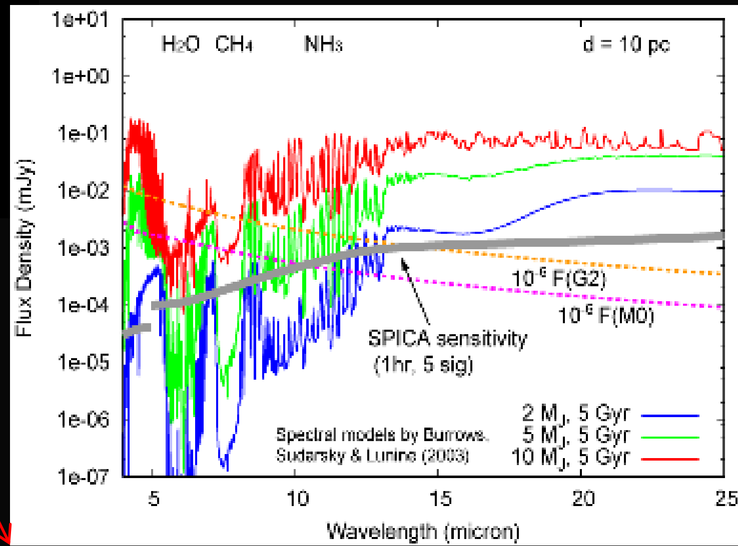
Pupil mask (design)



PSF (simulation)







Adapted from Burrows et al ()

Binary mask gives 10^{-6} suppression to 1 arcsec @ 5 μm

Allows **direct** MIR spectroscopy of gas giant exo-planets

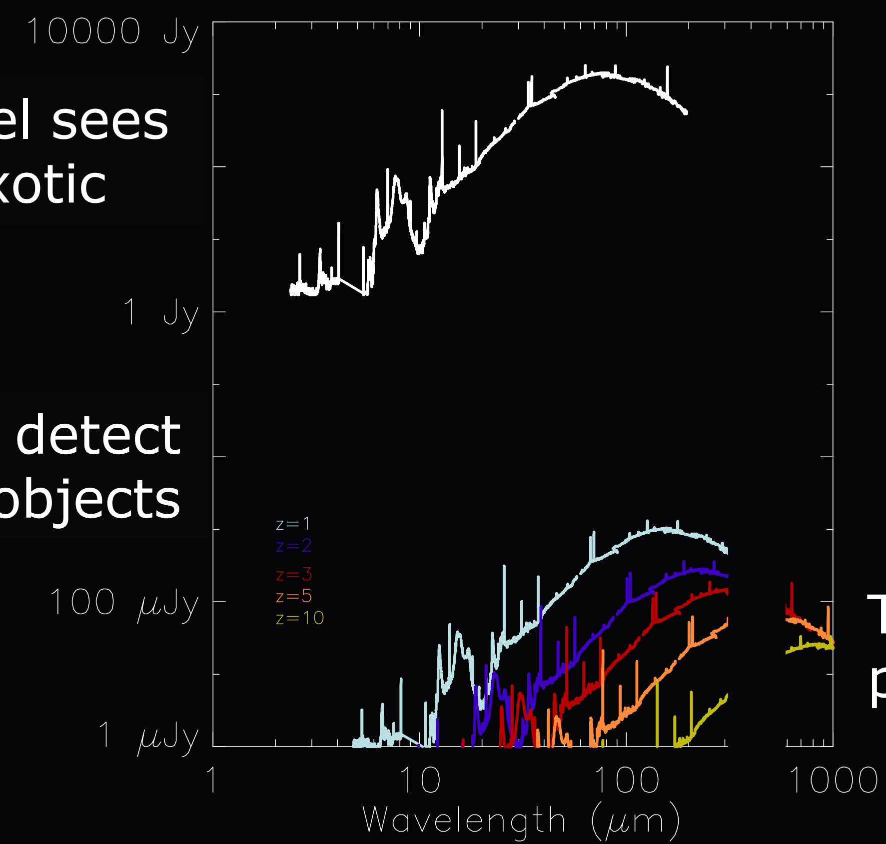
Spectroscopy of high redshift FIR galaxies

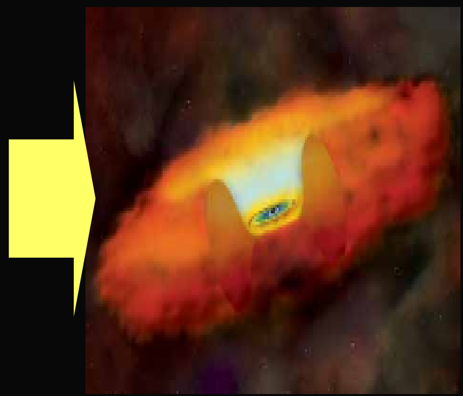
Herschel and SCUBA-2 → thousands of objects in photometric surveys

Only spectroscopy can reveal nature and role of AGN and star formation in galaxy evolution

Herschel sees local/exotic

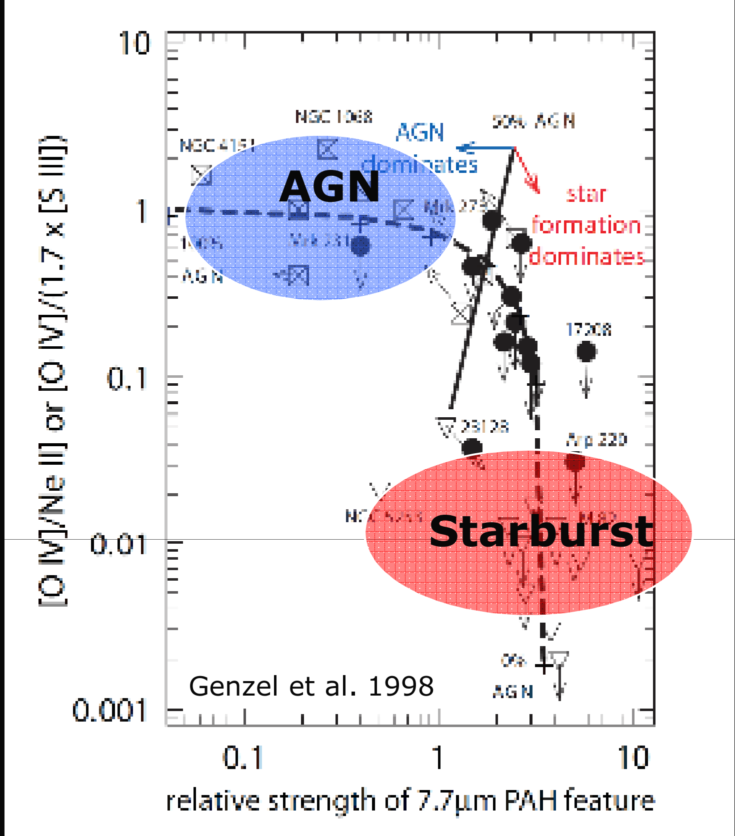
Need to detect distant objects



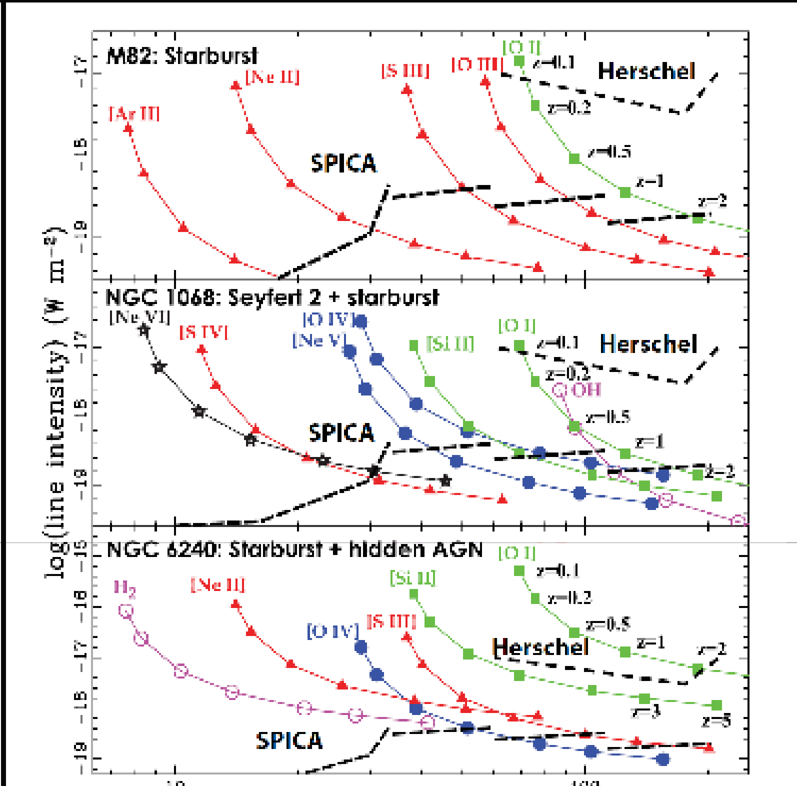


To reveal their nature and physics and chemistry

MIR/FIR Line ratios as diagnostics



Genzel et al. 1998

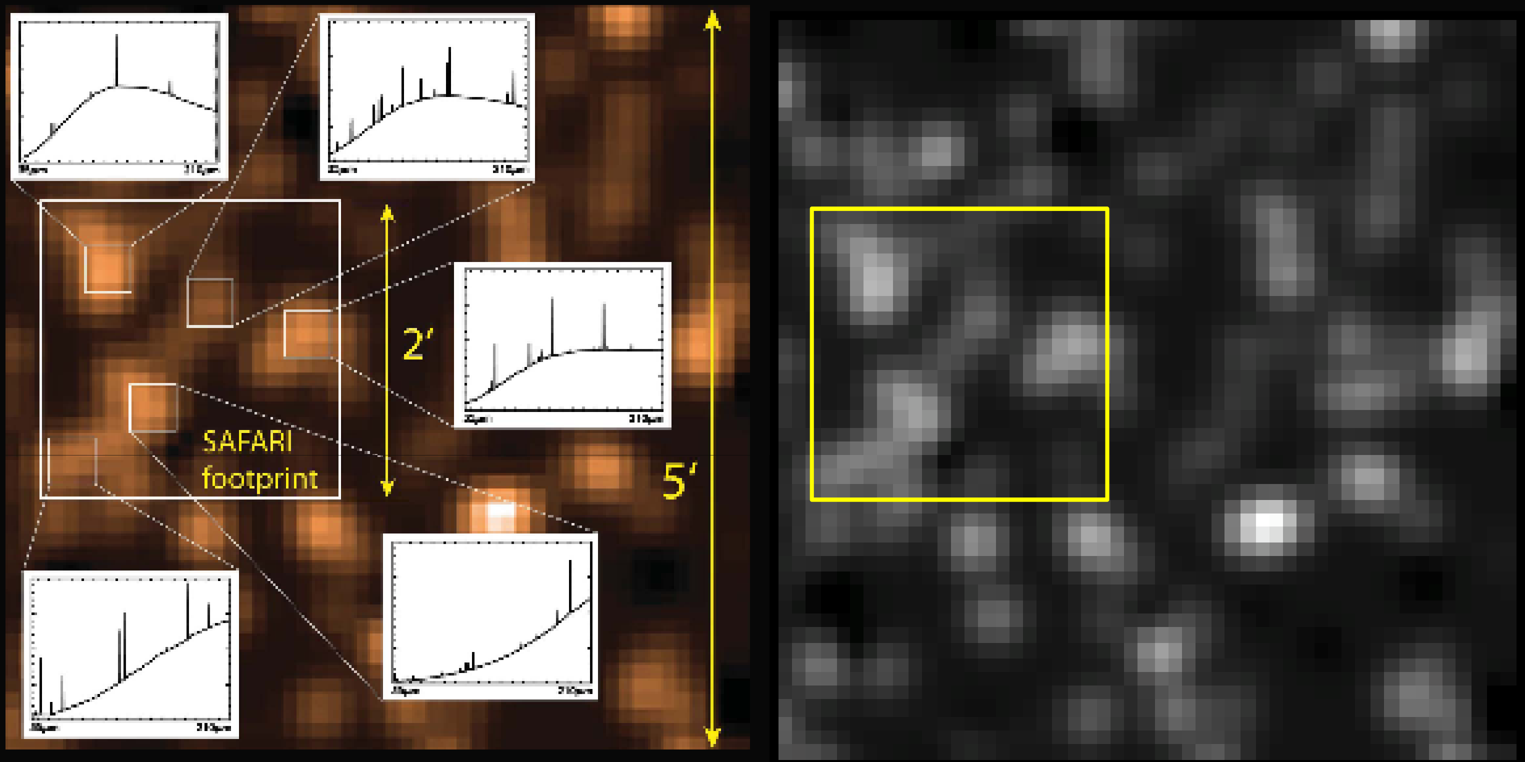


Spinoglio et al 2009

- Key diagnostic lines out to z~3 and beyond
- 35-210 μm bandwidth → multiple lines in single observation
- 2′ x 2′ → multiple sources in single observation

The Multiplex Advantage

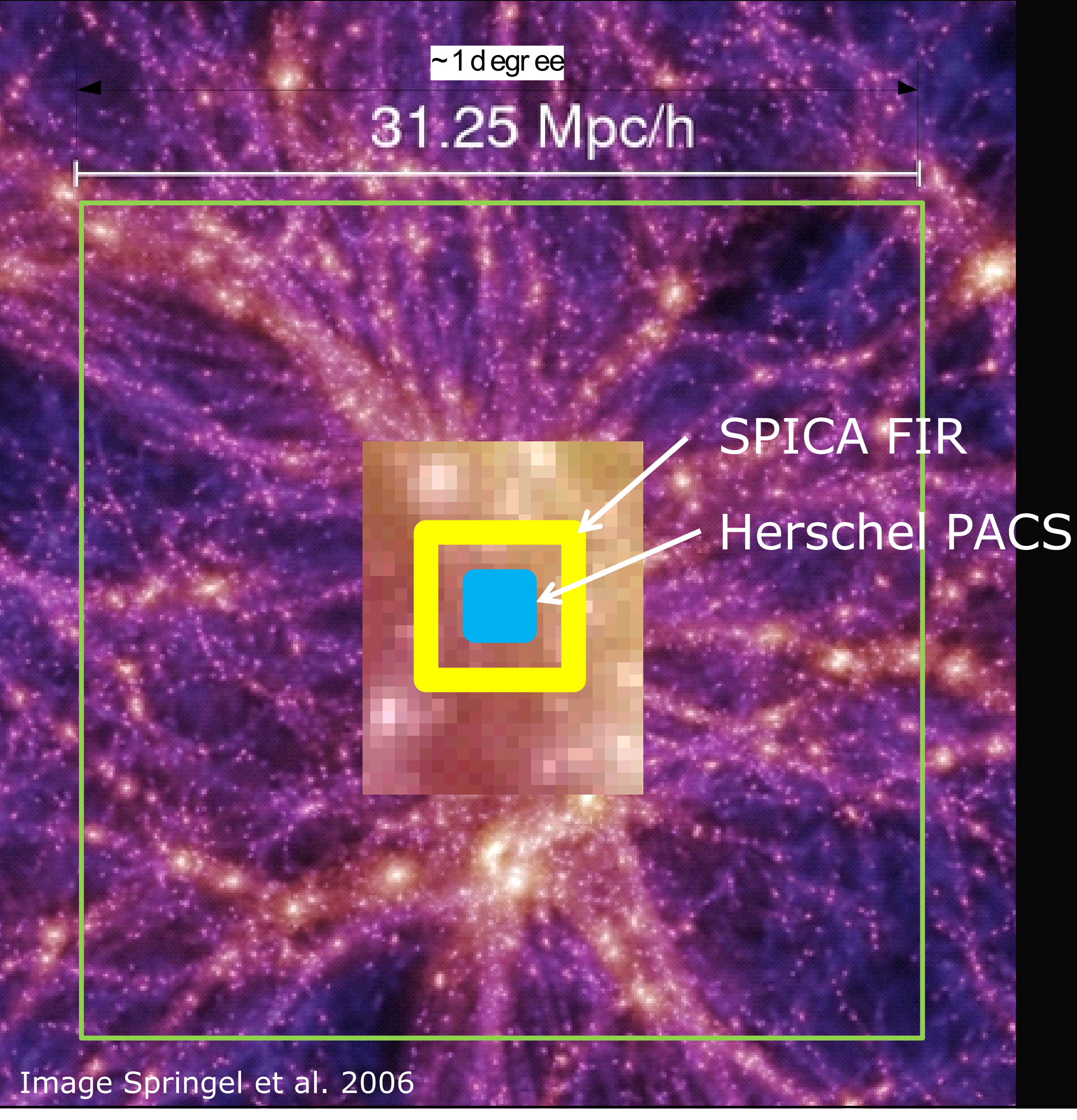
Looking closer at the SPIRE background sources



SPICA FIR FTS will take spectra of 7-10 sources/field

Images Rosenbloom, Oliver, Smith, Raab private communication

SPICA FIR 900 hour spectral survey

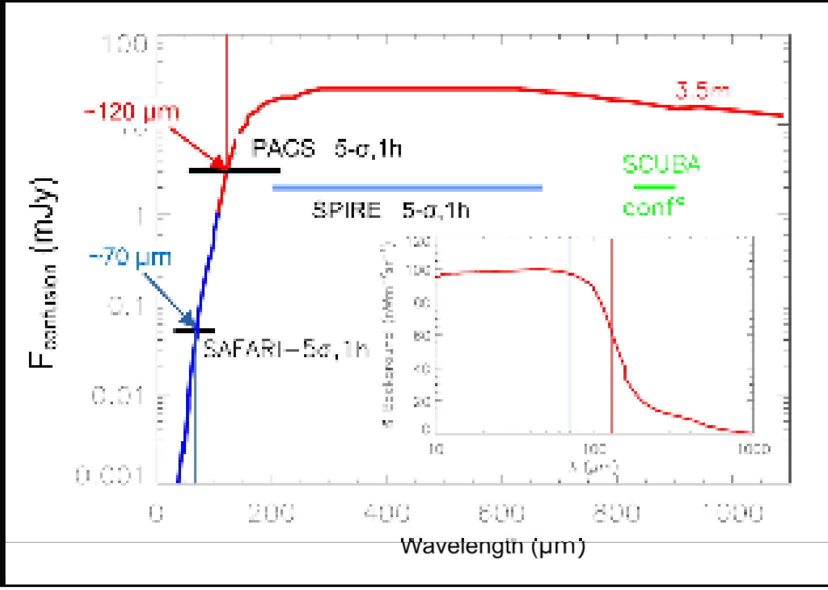


Resolving the Cosmic Infrared Background

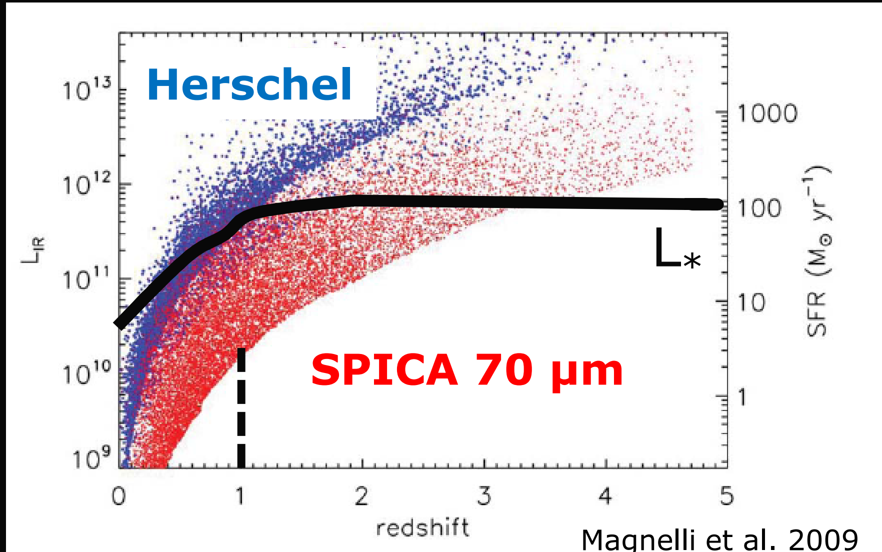
- Confusion limit for 3.5 m telescope varies rapidly <200 μm
- Warm Herschel telescope means confusion is reached at 120 μm in 1 hour

  → ~60% of CIRB
- SPICA-SAFARI is not confusion limited until 70 μm

  → 100% of CIRB

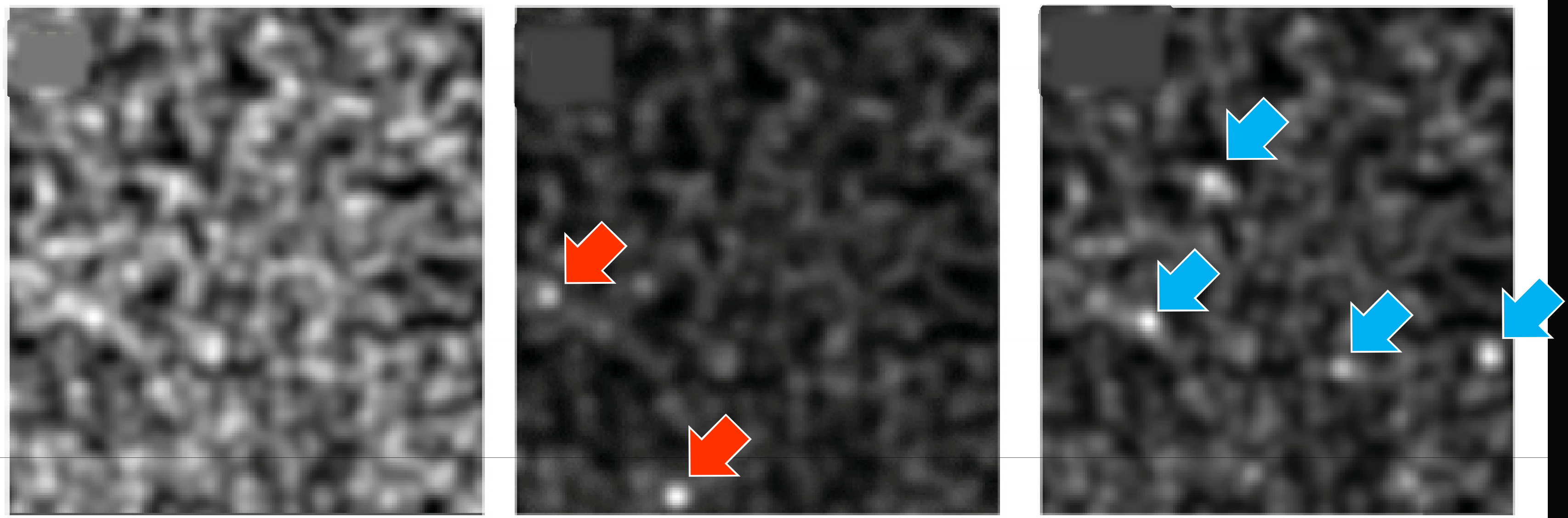


- Wider deeper surveys trace L_* to z~3
- Can trace evolution of more modest – Milky Way – type galaxies



Magnelli et al. 2009

Breaking confusion with spectroscopy



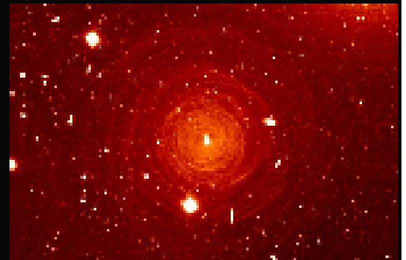
Photometry @ 120μm Slice @ 63.2μm Slice @ 58.3 μm

"Spectral Slicing" beats spatial confusion

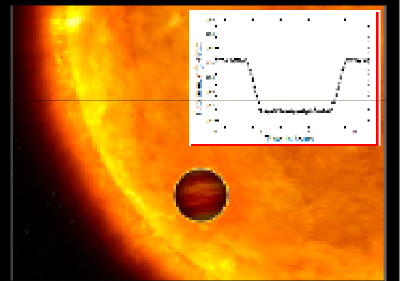
Sources with lines at different redshift appear in different wavelength "slices"

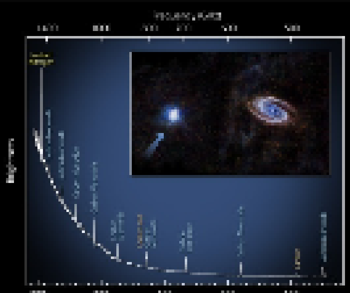
"Discovery" Science

- ***The death of planetary systems:*** Detection of water and ice features in evolved stars indicating sublimation of entire Kuiper belt
- ***First identification of PAHs molecules in Space:*** SPICA-FIR will be especially adapted for deep searches of the "Grand-PAH" FIR band
- ***A new window in exoplanet research***: FIR spectroscopy during eclipses of Jupiter-size EPs may be possible
- ***Mass accretion from the IGM:*** How is primordial gas is accreted from the IGM to fuel on-going star formation in galaxies?
- ***Galaxy formation and evolution at z~5-10:*** Rest frame MIR spectroscopy of very luminous objects may reveal the very earliest stages of galaxy formation

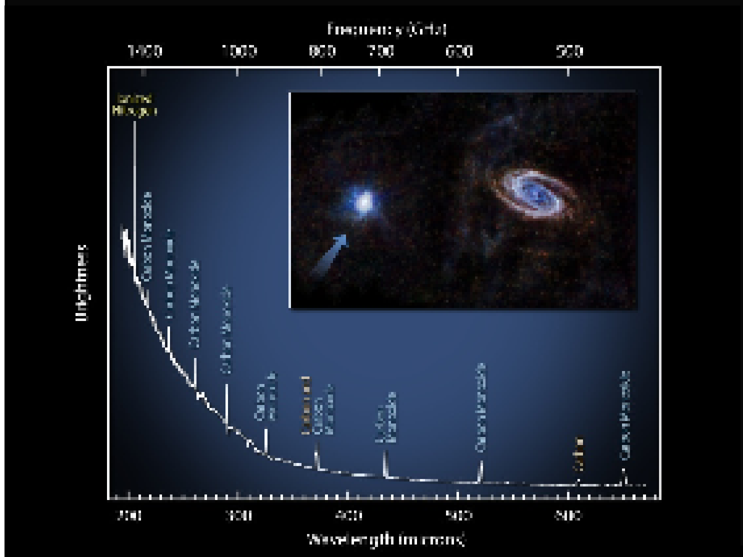

I. Leao (UFRGN, Brazil)

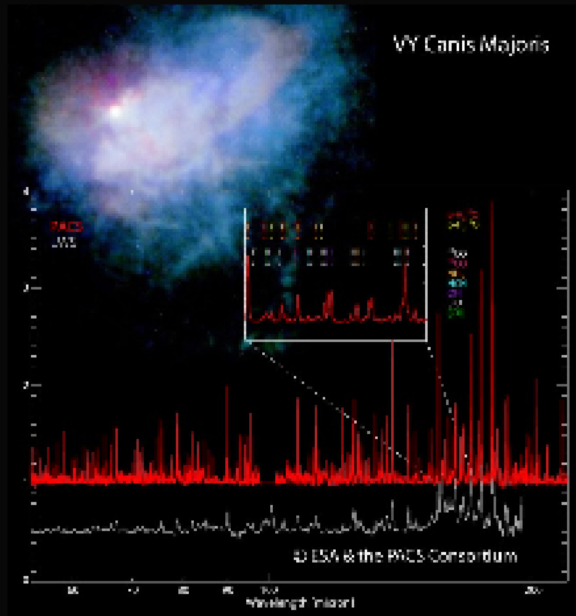

NASA

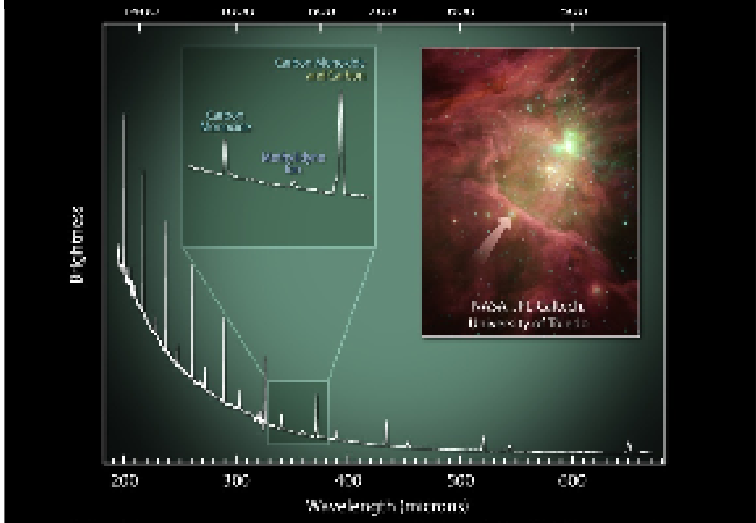

NASA/ESA/G. Bacon (StSci)

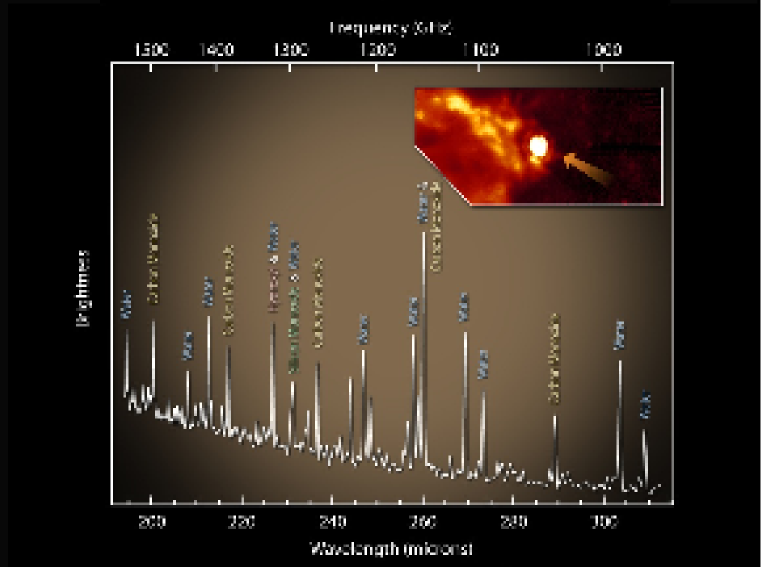

ESA/SPIRE consortium

European scientists and engineers are at the forefront of space infrared astronomy and technology



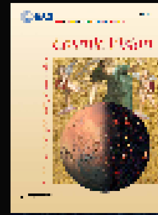


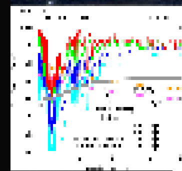


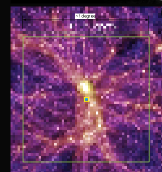
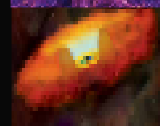
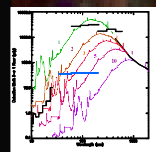
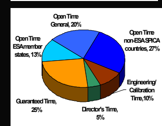


Summary

- SPICA is essential to Europe's Cosmic Vision
  - Crucial observations of water ice → the role of the "snow line" in planetary formation
  - First systematic direct characterisation of gas giant exo-planets
  - Characterise hundreds of objects in our own "debris disk"
  - Characterise thousands of obscured galaxies through spectroscopy
  - Disentangle the interplay between star-formation and black holes in galaxy evolution
  - SPICA provides the leap in sensitivity required to go beyond Herschel and bridge the gap from JWST to ALMA
- SPICA is an *observatory open to all*
  - it will do much, much more than highlighted in this talk

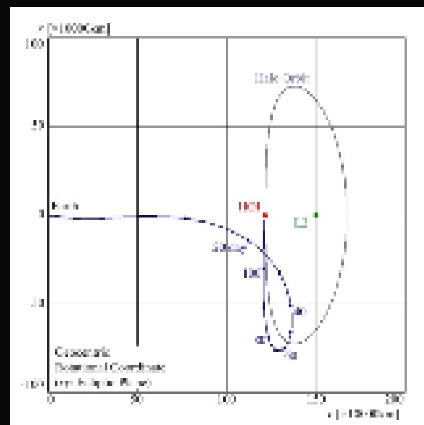




Overview of SPICA mission

- SPICA is a <u>JAXA led mission</u> (Phase A) scheduled for launch by 2018.
- Mid- and far- IR observatory operating between 5 and 210 um.
- Very high sensitivity via cold telescope (3.5 m diameter, T < 6K).
- Launcher vehicle is JAXA’s HII-B. Large halo orbit at SE-L2.



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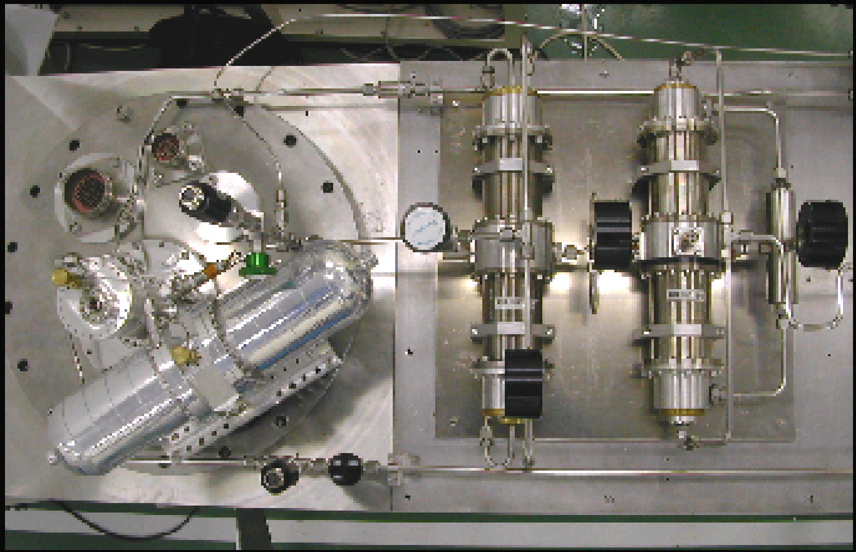
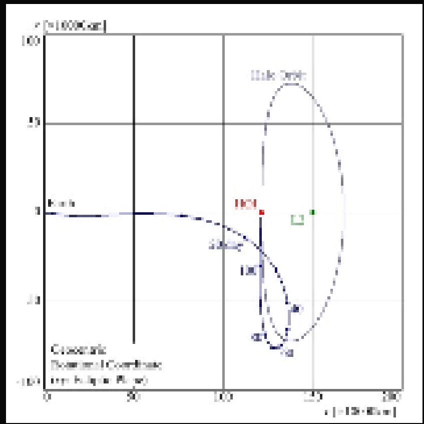
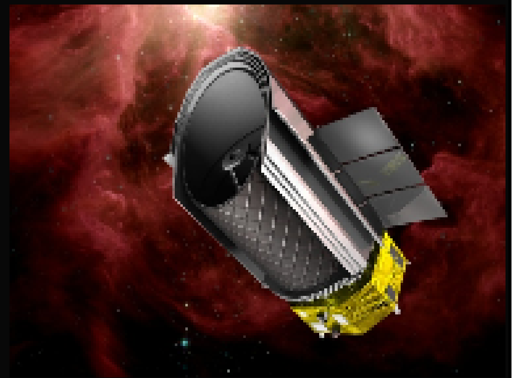
- Launcher vehicle is JAXA's HII-B. Large halo orbit at SE-L2.
- Nominal mission lifetime: 3 yr (5 yr goal).
- Cryogen free mission
- ^3He JT cooler with 2-stage Stirling developed for Astro-H and SMILES

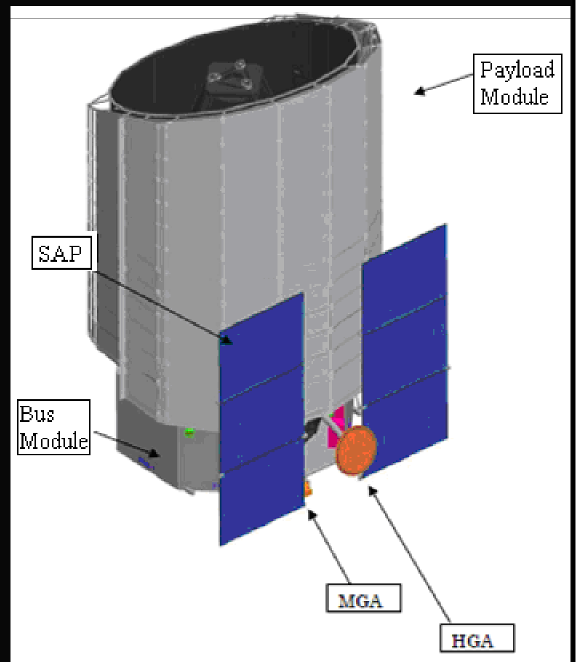




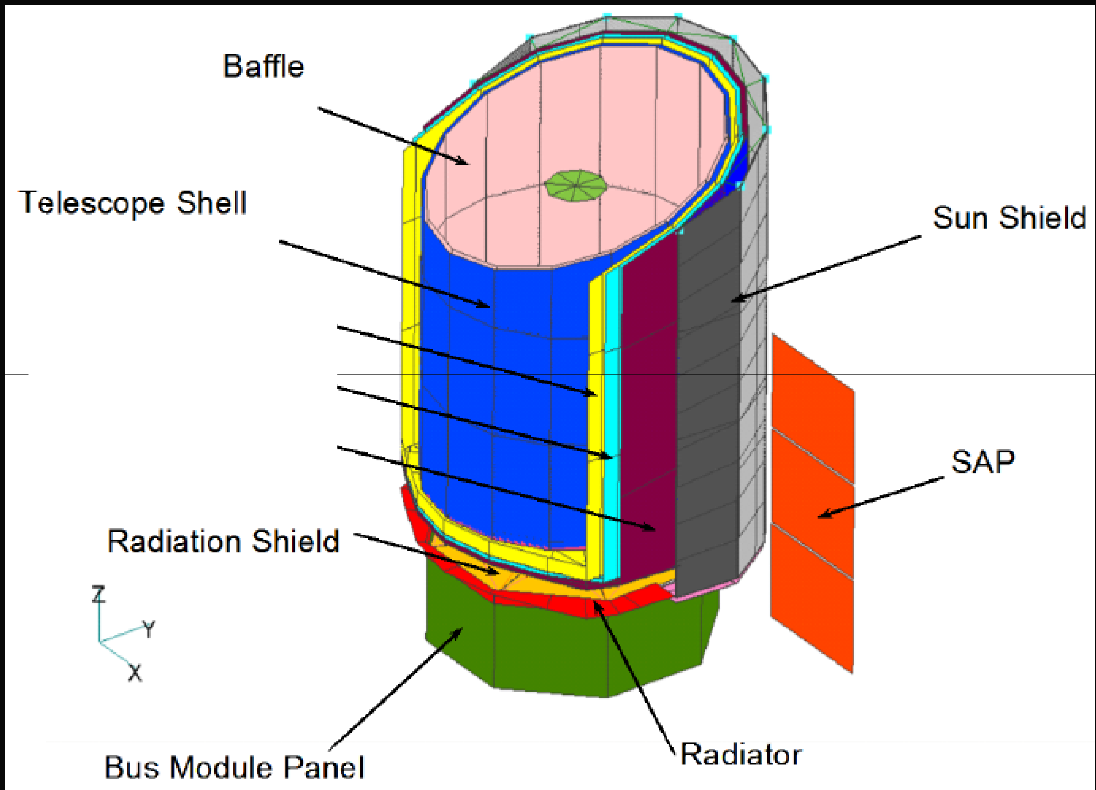
The SPICA spacecraft

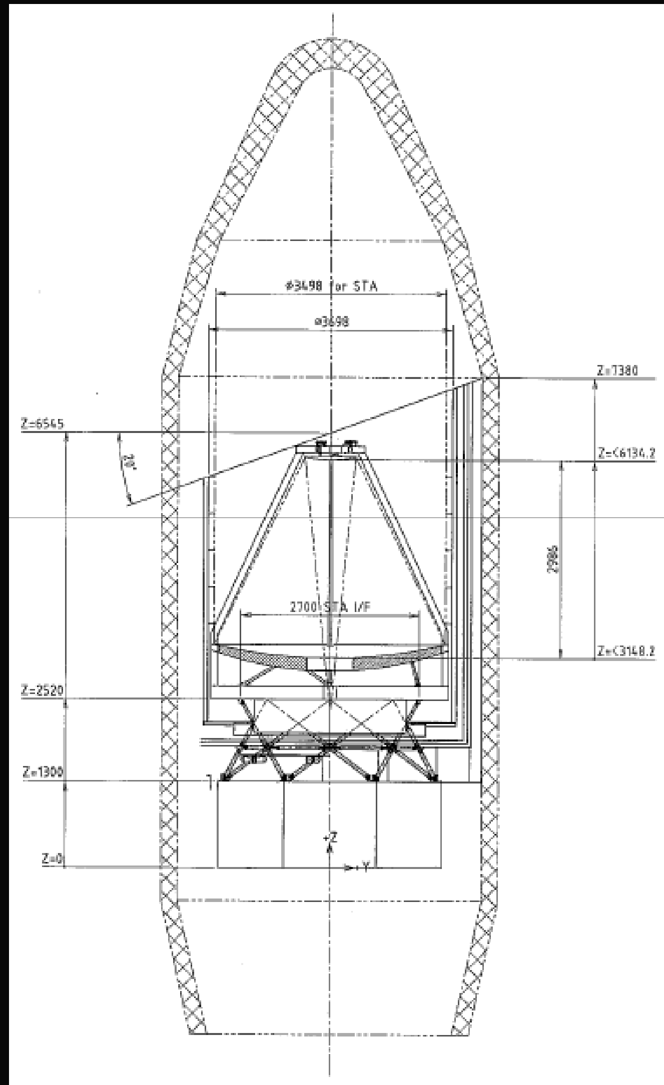
Configuration:	Cryogenic PLM. ~ 4.4 m diameter, 7.5 m high.
Mass & power:	Total mass ~ 4 ton; total peak power ~ 2.4kW.
Attitude & Orbit Control:	3-axis stabilised. Focal Plane Camera (FPC) in AOCS loop.
Thermal Control: System:	Passive cooling via coaxial Sun and thermal shields, (reaching ~11K). Active cooling via 2-stage Stirling and JT units (4.5 & 1.7 K stage).
Data Handling:	Science data: 24h * 4 Mb/s = 350 Gbit/day.
TT&C - Ground	Data science down-link in X-Stations: Band, Usuda (JAXA), Cebreros or DS3 (4 hr/day).





The SPICA spacecraft





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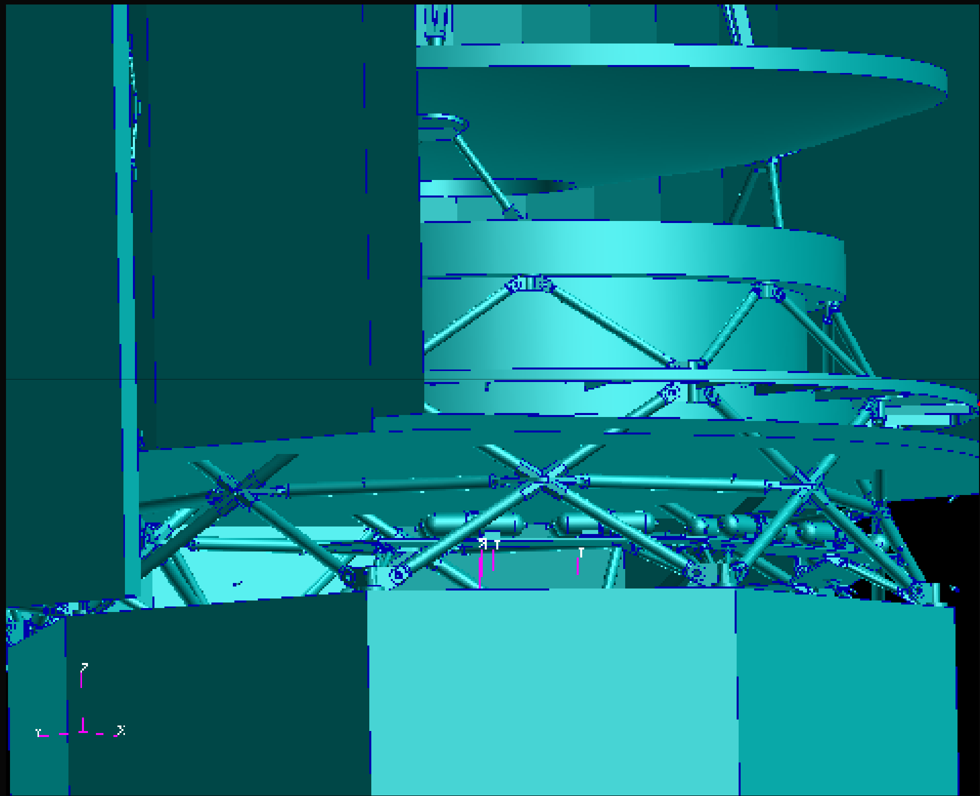
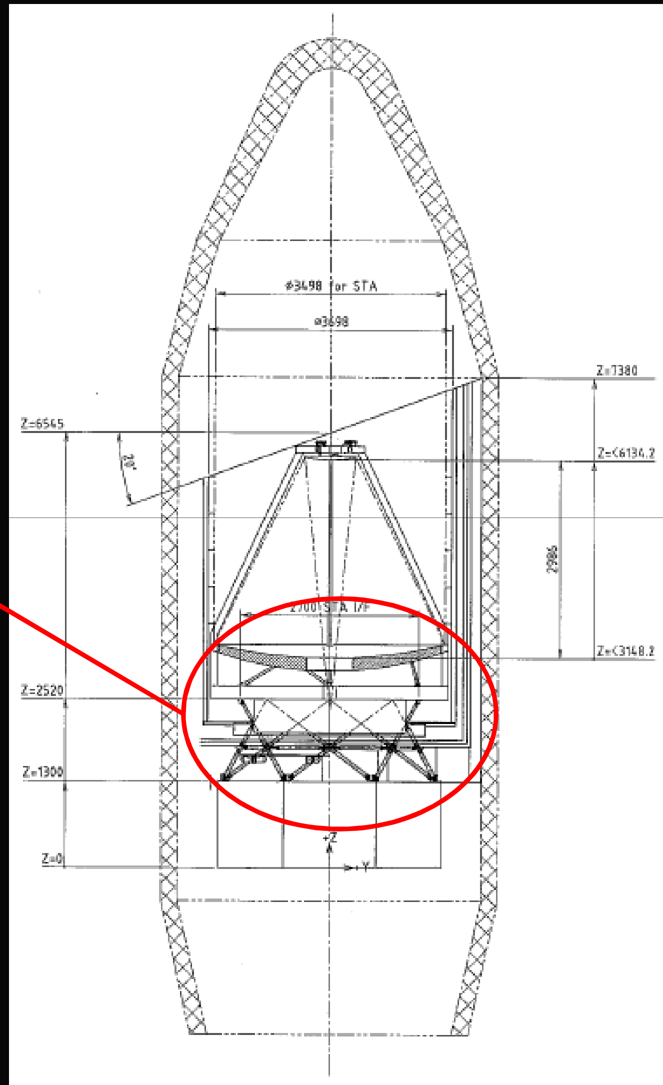
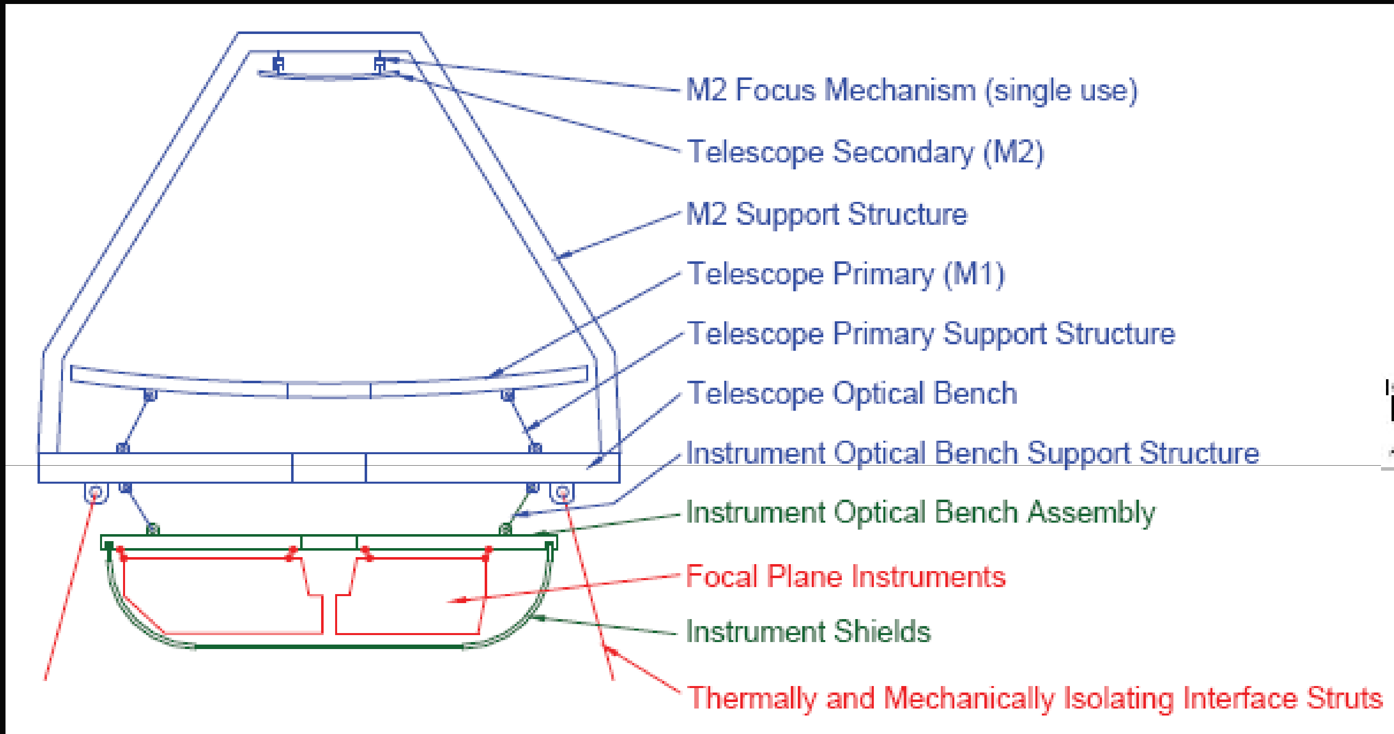
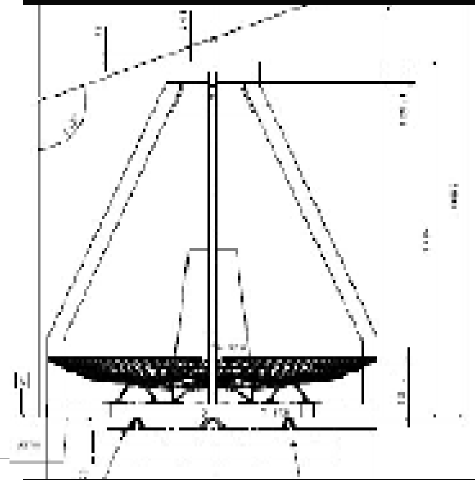
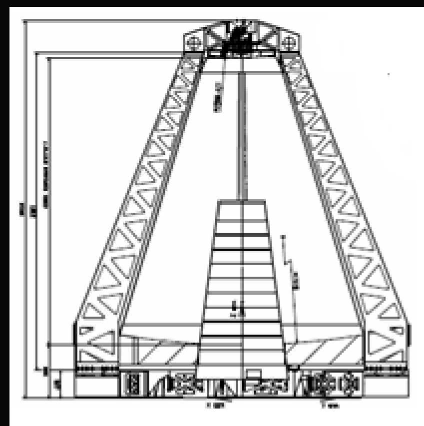




SPICA Telescope Assembly (STA)







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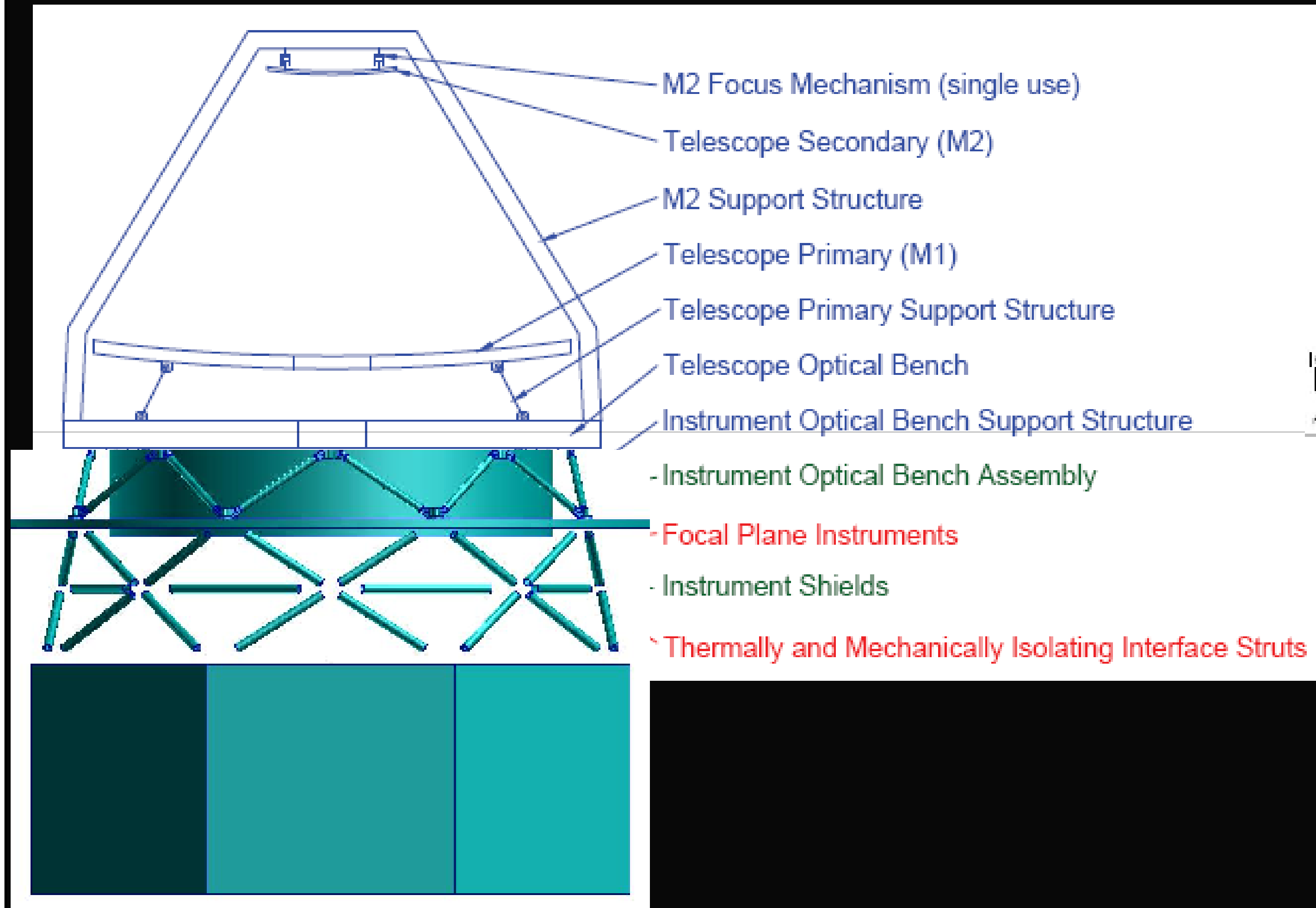

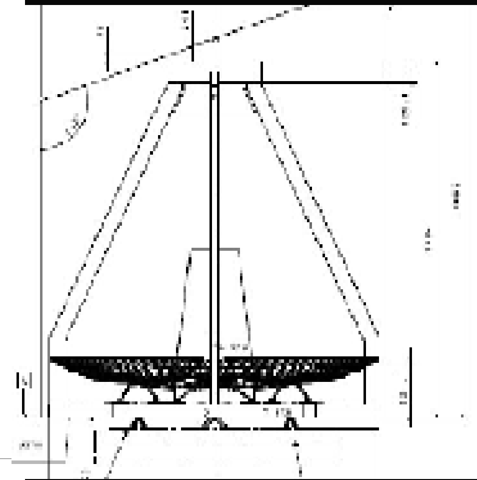

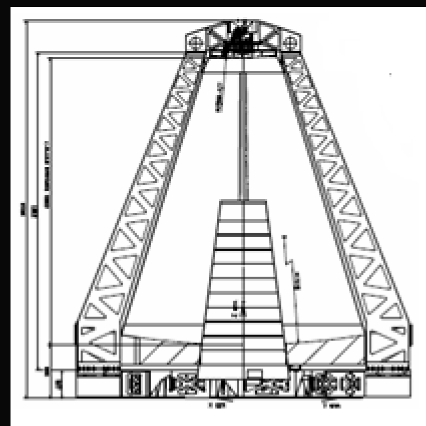

Telescope assessment study

AS

TA

Main requirements:

- Primary mirror diameter = 3.5 m.
- Diffraction limited performance at λ = 5 um.
- Optical surfaces at T< 6K.
- Total mass (including design margins) < 700 kg.
- M2 structure based on 4-leg design (Coronagraph).
- Interface to SVM via Telescope Optical Bench.

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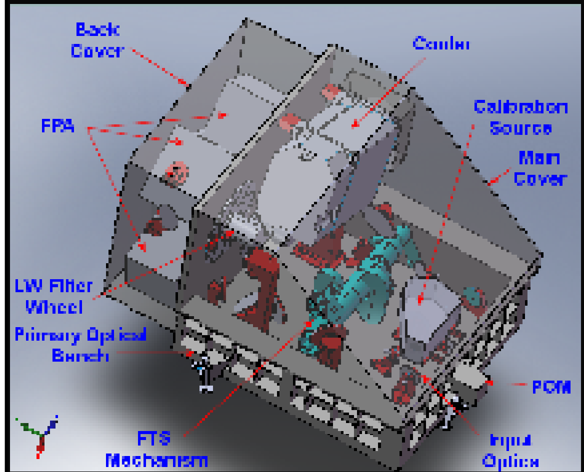
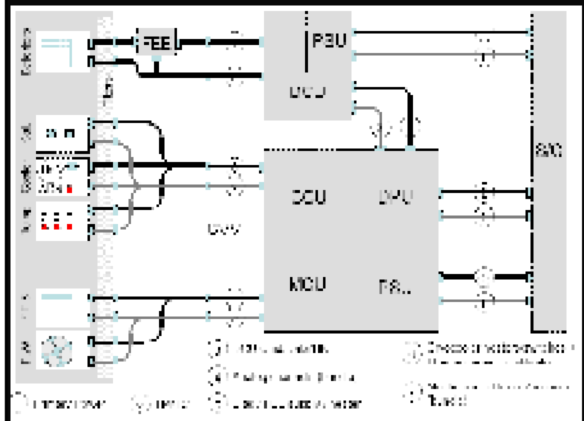
Baseline design:

- Ritchey-Chretien.
- All ceramic design (mirrors and support structure).
- Dedicated Instrument Optical Bench required.
- Focus and tip/tilt mechanism (at M2).
- Detailed thermal and mechanical analysis performed.
- Optical surfaces at T < 6K; heat load ~ 20 mW at 4.5K.
- Thermo-elastic analysis shows compliance with WFE.
- Overall feasibility confirmed by assessment study.
- PFM delivery to JAXA by Q1/17 (in line with JAXA).

European contribution: SAFARI





Main requirements:

- **Imaging and spectroscopy (range 34 – 210 um).**
- **Photometric camera mode with R ~ 2 to 5.**
- **Spectroscopic mode with R = 2000 at 100 um.**
- **FOV = 2x2 arcmin^2.**
- **Line sensitivity ~3E-19 W/m^2 (at 48 um).**
- **Mass of cold assembly < 50 kg. Warm electronics < 30 kg.**
- **Flight Model delivery to JAXA by Q2 / 2016 (latest).**

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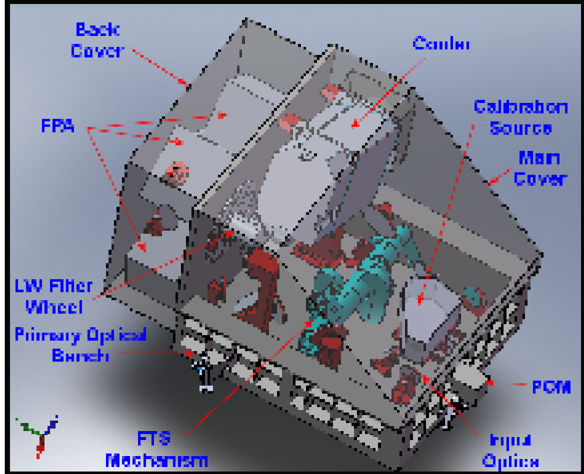

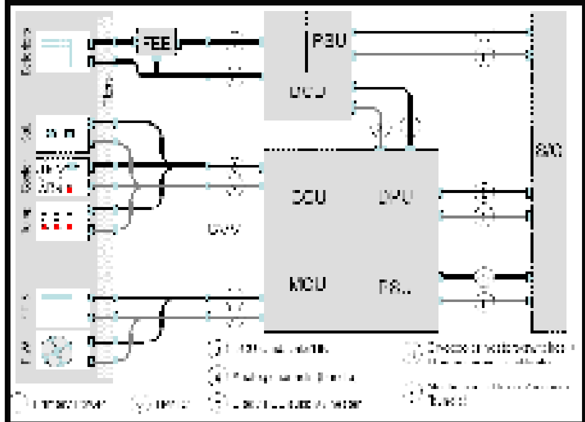

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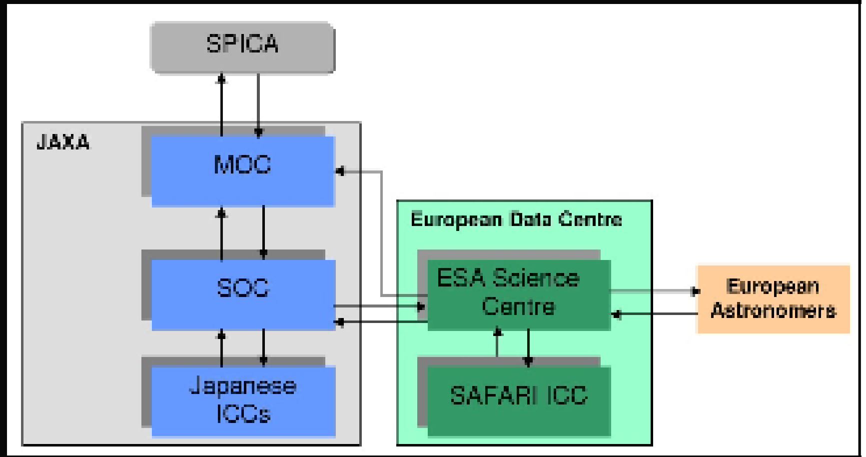
Baseline design:

- Imaging Fourier Transform Spectrometer.
- Modified Mach-Zehnder interferometer.
- 3x Focal Plane Arrays (total ~ 6000 px).
- Selection of detector technology (TES, KID, Si bolo, Photo-cond.) impacts design, planned by mid 2010.
- Phase A study assumed TES (*design stressing case*).
- Additional internal cooler required by TES, KID and Si-Bolometer (Sorption Cooler + ADR → ~ 100 mK).

- Key role within SPICA payload complement (FIR band).
- Herschel class instrument (c.f. SPIRE, PACS).

SPICA ground segment



Mission Operations Centre:

- Located in Japan linked to JAXA's SOC.
- Primary station Usuda (64m), additional ESOC station (Cebreros / DS3).
- JAXA SOC interfaced to ESA's SOC.

European SPICA Science Centre:

- ESA SPICA Science Centre (ESSC) located at ESAC.
- SAFARI Instrument Control Centre, distributed in several European countries, contact via Principal Investigator (SRON).
- ESSC to act as interface for the European community to the SPICA observatory and interface between SAFARI ICC and JAXA's SOC/MOC,

ESA review: risk items

STA:

- Further consolidation of interface requirements.
- Focusing mechanism development (dedicated TDA planned).
- Schedule driven by M1 polishing (dedicated TDA planned).

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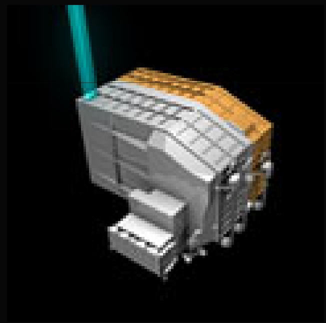
SAFARI:

- Further consolidation of interface requirements and instrument design.
- Early selection of focal plane detector technology required.
- FTS scanning mechanism, internal cooler and FEE developments (TDAs).
- Revision of development plan, in view of meeting PFM delivery date and of required developments.

Conclusions of assessment activities



The European industry and scientific community are very well placed to contribute effectively to the SPICA mission:

- Large heritage from Herschel programme allows to exploit expertise and to minimise the development risk.
- The Telescope Assembly is feasible and can be developed by the European industry with an acceptable level of risk.
- The SAFARI instrument can rely on significant heritage and expertise with the consortium (e.g. SPIRE, PACS).
- The provision of MOC and SOC services by ESA does not present any critical issues.


The European contribution to SPICA is a real
'mission of opportunity',
with the potential of a large scientific return
at a fraction of an M class mission cost.
SPICA
Space Infrared Telescope for Cosmology and Astrophysics
A Japanese and European
Space Odyssey for 2018