



次世代赤外線天文衛星



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

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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

Investigate the conditions for star formation and evolution



Cosmic Vision



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



European Space Agency
Agence spatiale européenne

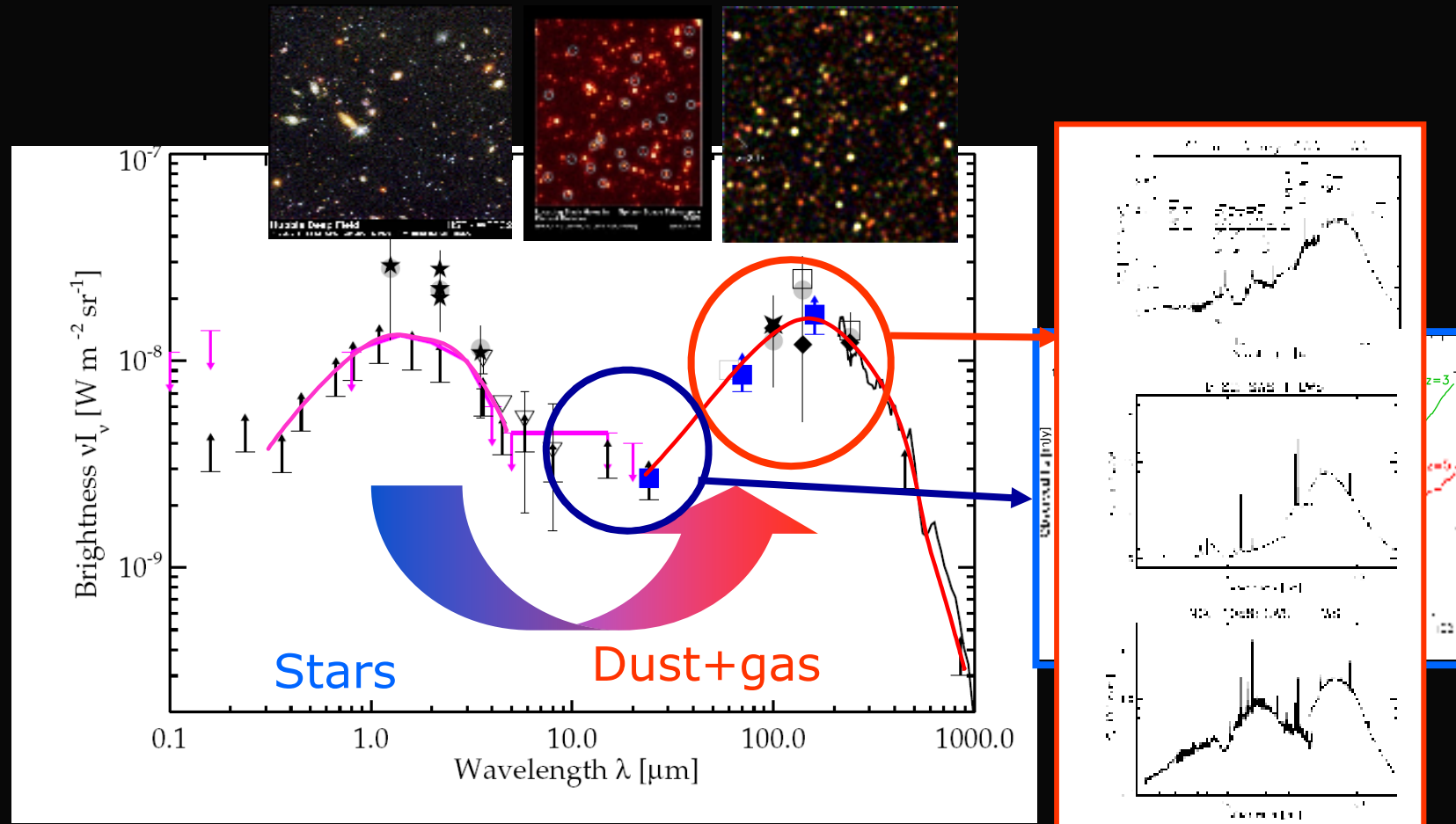
Far-infrared observatory

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

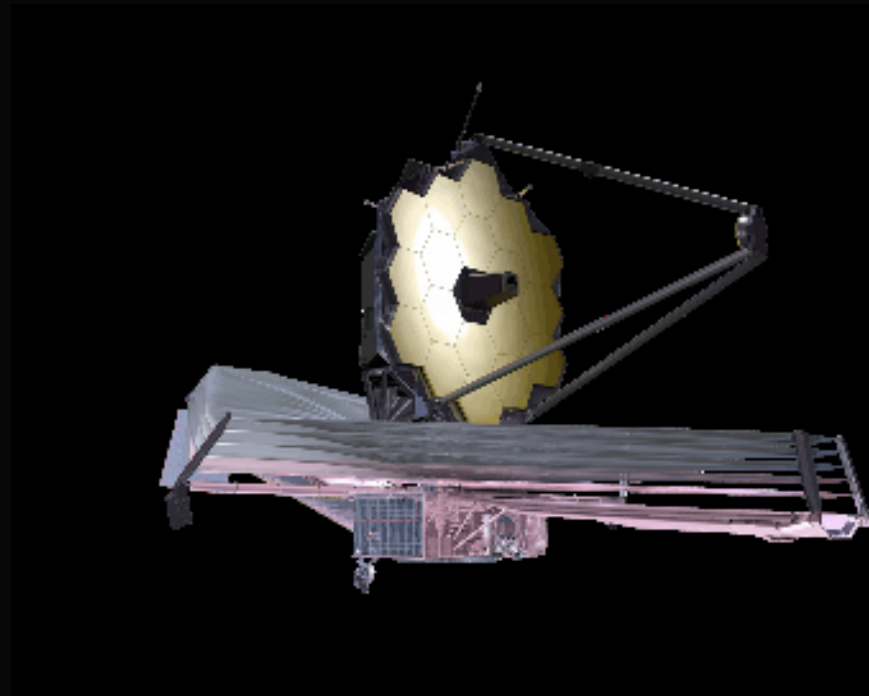
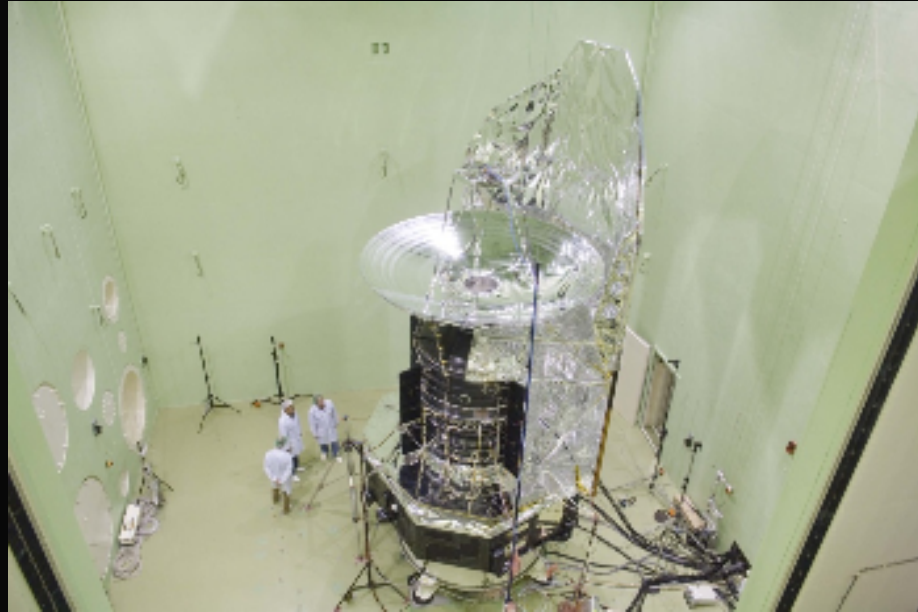
Space IR observatories



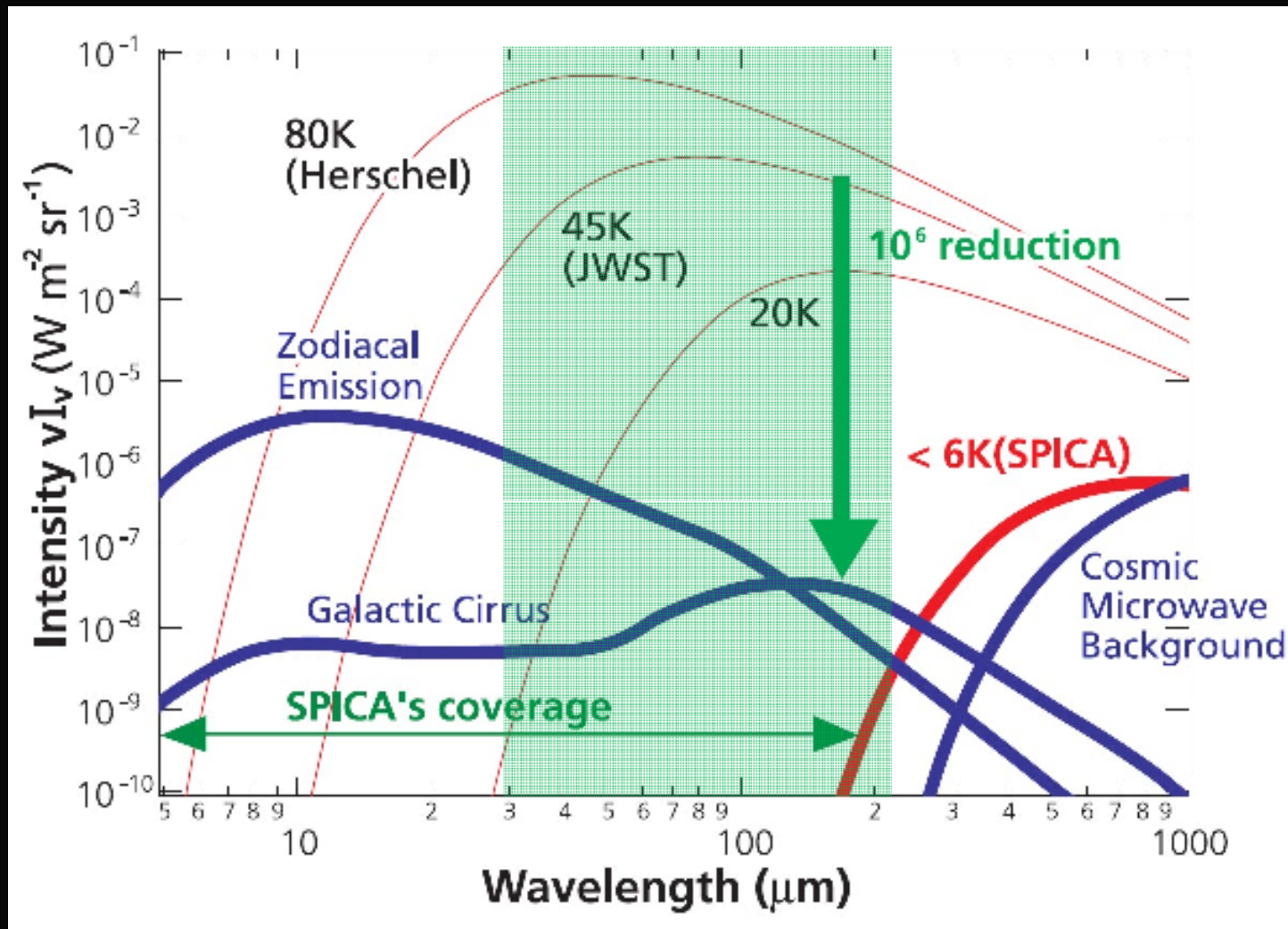
Observing >30 microns is hard
Cold telescopes – cold instruments
Progress has been incremental
Telescope $T < 5$ K but $\Phi < 1$ m
Poor spatial resolution
→ Need bigger aperture
→ Ideally it should be cold

Big Apertures

- **Herschel**
 - 3.5 m
 - $T_{\text{tel}} \sim 80$ K
 - $\lambda > 57$ micron
- **JWST**
 - ~ 6.5 m
 - $T_{\text{tel}} \sim 45$ K
 - $\lambda < 28$ micron



Zodiacal light limited sensitivity



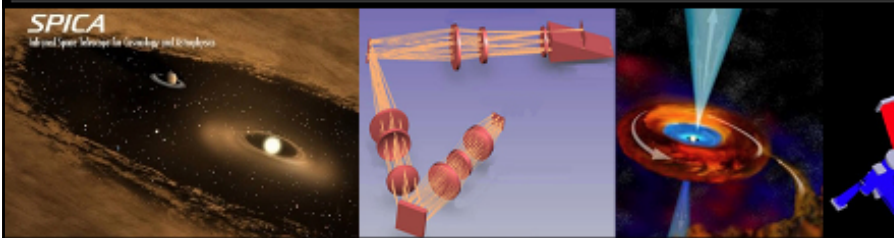
Background limited $< 200 \mu\text{m}$ if $T_{\text{tel}} < \sim 6 \text{ K}$

SPICA Overview

**3.5 m telescope
Cooled to $< 6\text{K}$**

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

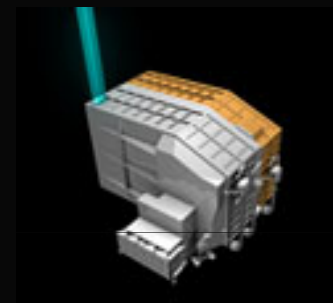
1. SPICA Telescope Assembly:

ESA provided based on Herschel heritage (industrial assessment study).



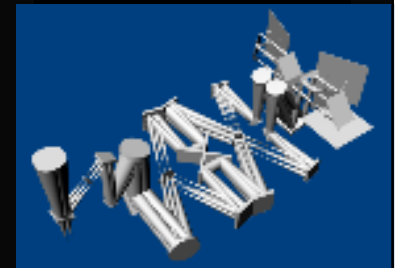
2. SAFARI instrument:

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:

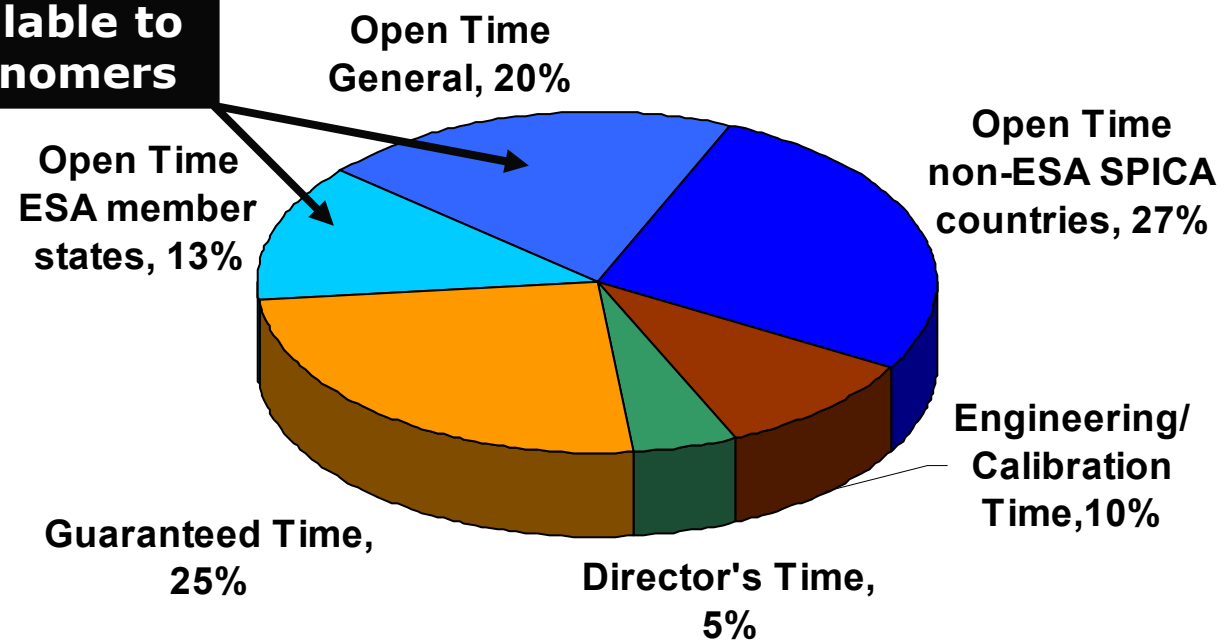
Supporting the European scientists in accessing the SPICA observatory



SPICA: A World Observatory

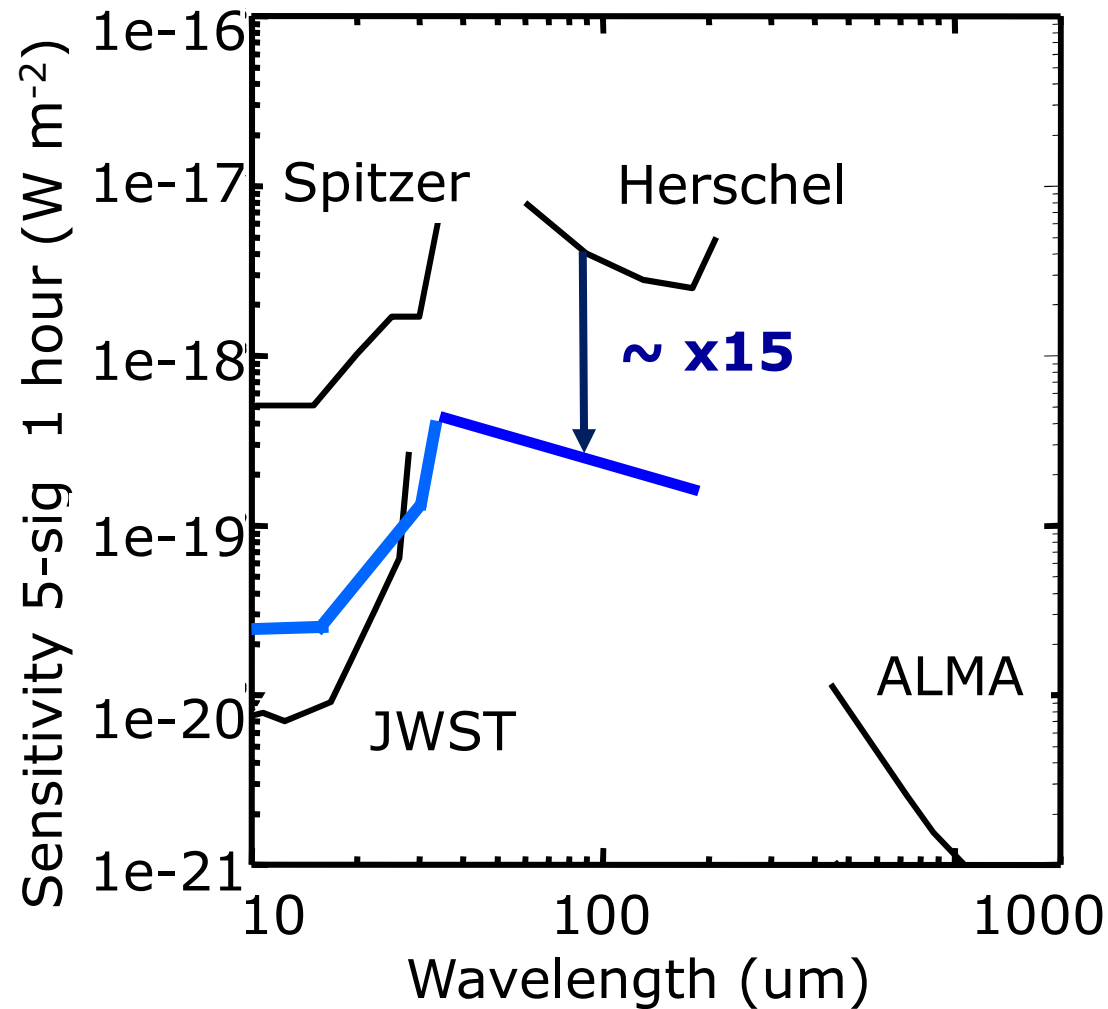
- SPICA is an *observatory* open to the astronomical community
- A single international Time Allocation Committee
- Legacy and normal programmes

Open Time available to European astronomers



Provisional observing time distribution

SPICA Sensitivity - spectroscopy

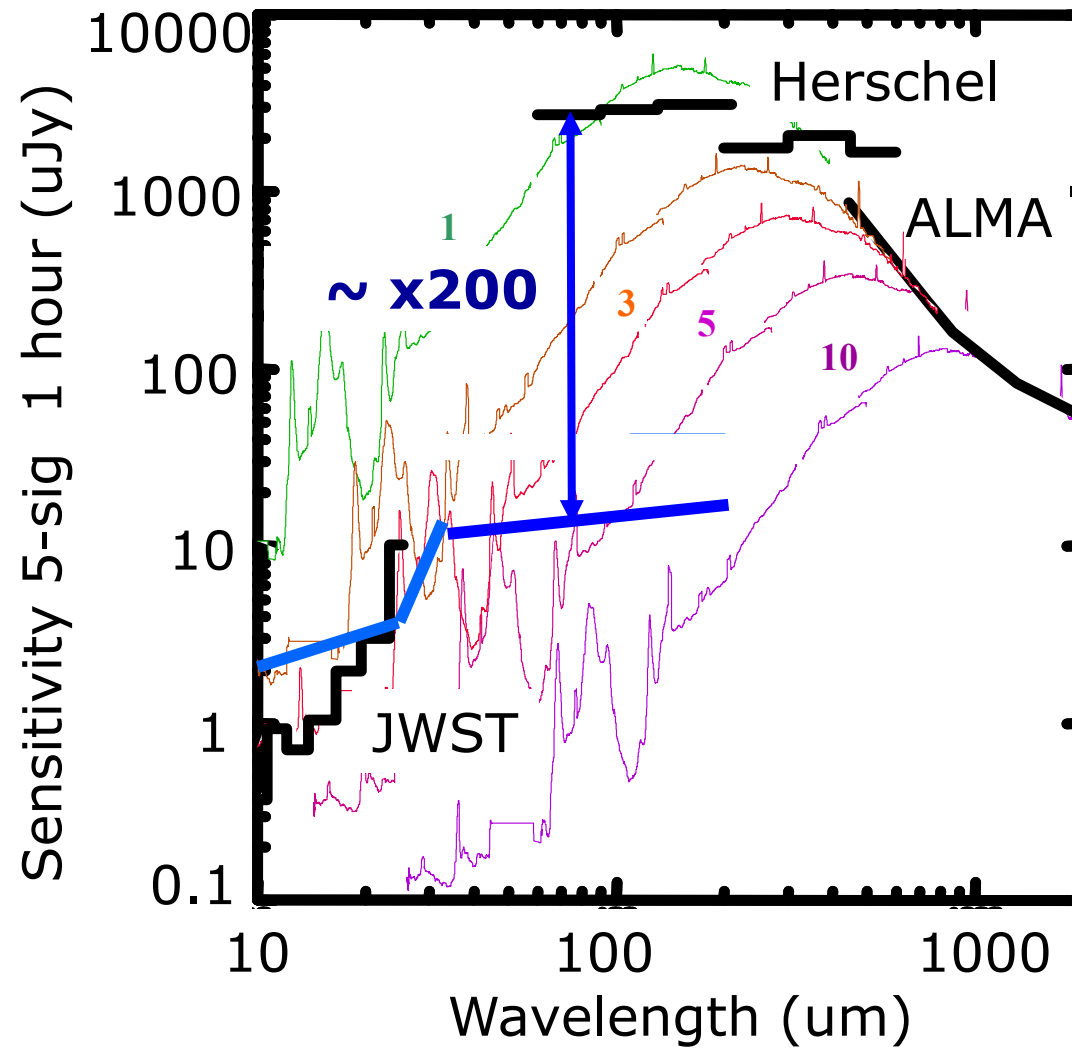


**Single unresolved
line in single object**

**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
 $z \sim > 5$**

**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 H₂ 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)

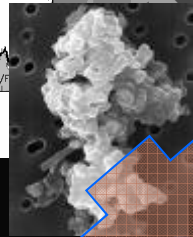
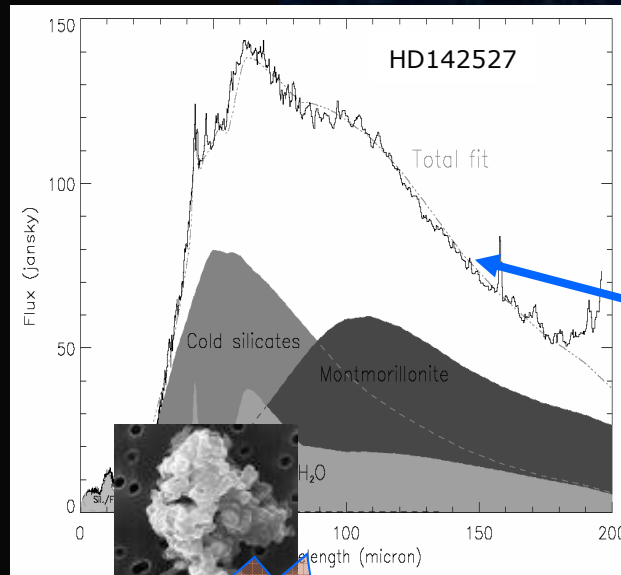
Science case overview

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

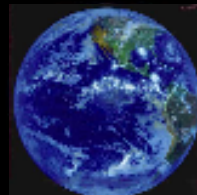
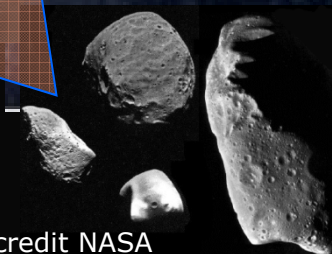
- **First FIR spectroscopic cosmological surveys:**
- Redshift and nature of the sources in single shot
 - Evolution of the massive, dusty distant galaxy population
 - What is shaping the mass and luminosity functions of galaxies?
 - How do star formation rate and AGN activity vary with environment and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

Planetary formation

Dust mineralogy and ice

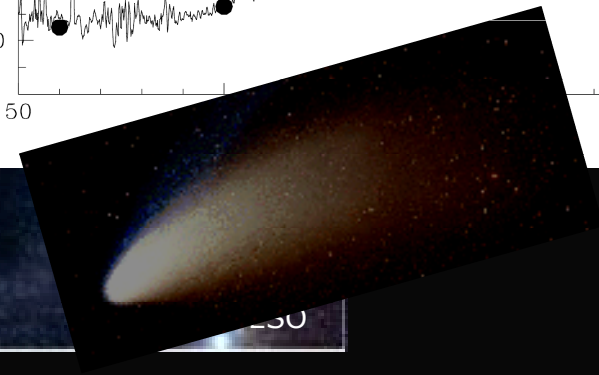
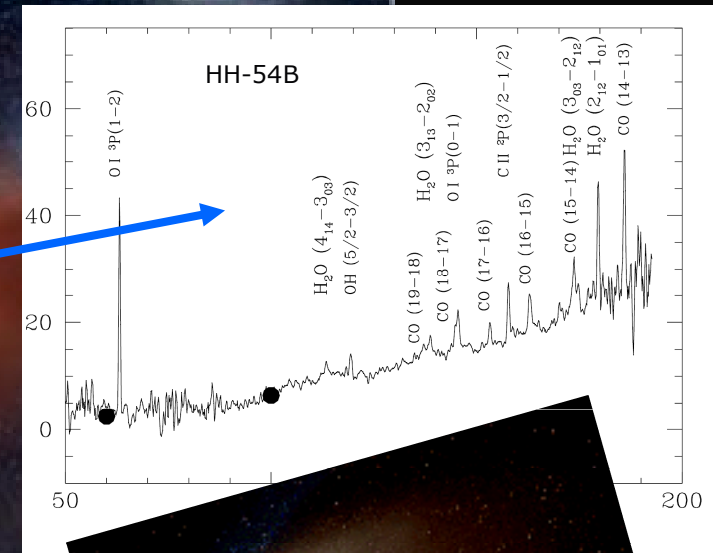


Images credit NASA



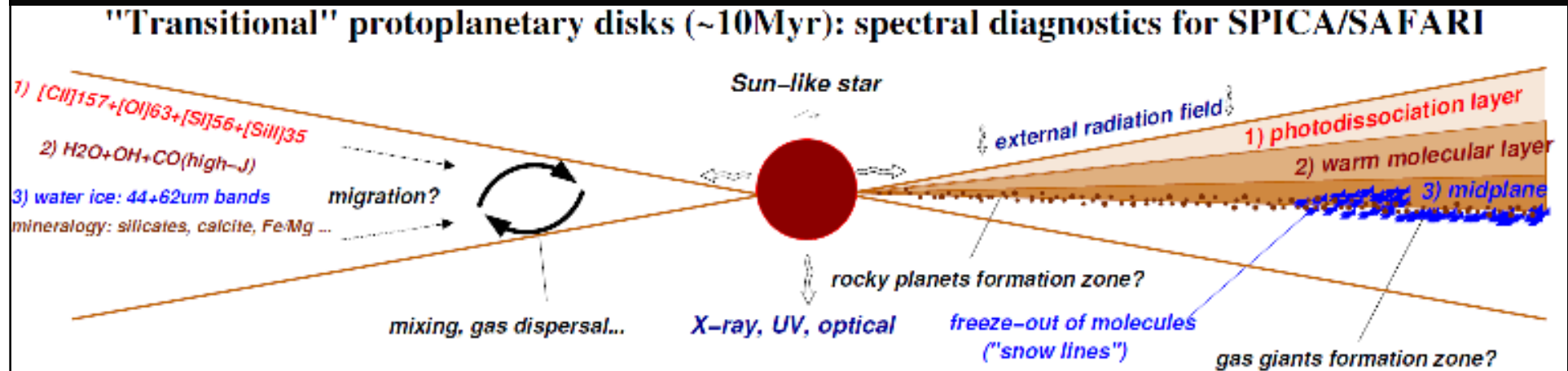
Rocky planets and oceans

Oxygen chemistry and water



SAFARI

Planetary Formation – protoplanetary disks

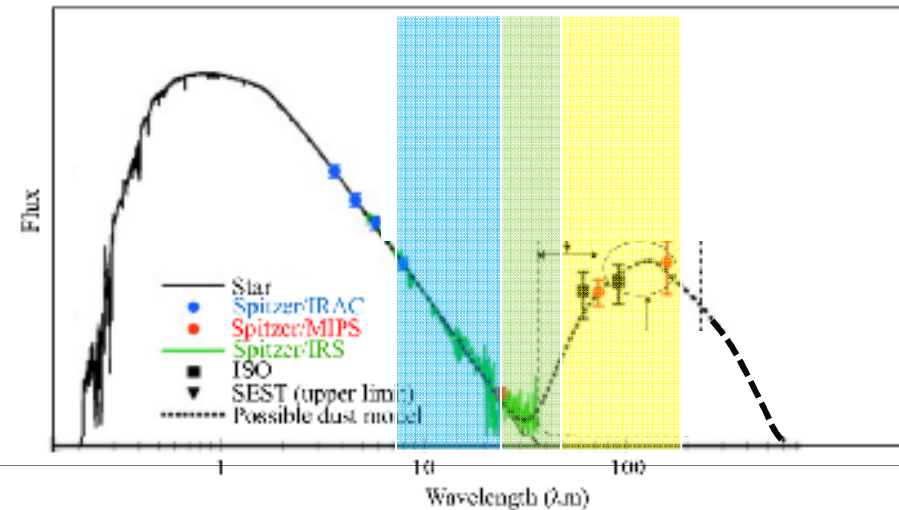


- **SPICA: traces all layers**
 - Warm molecular layer
 - CO, HCN, CN... ALMA
 - H₂O, OH.. SAFARI
 - Midplane
 - ice
 - dust mineralogy
- **Gas, dust and ices:**
 - Major lines detectable to ~100 pc
 - Test planet formation and evolution theories

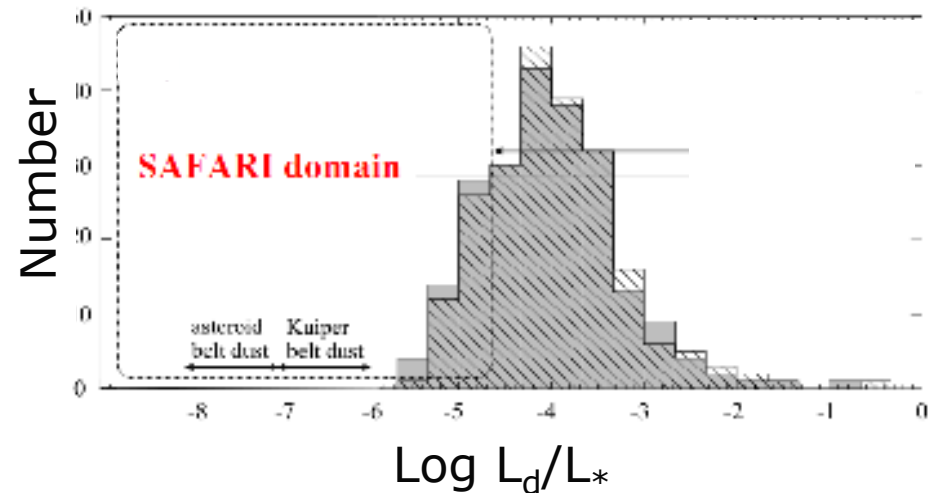
Detecting Kuiper and Asteroid Belt analogs in distant extrasolar systems

- 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

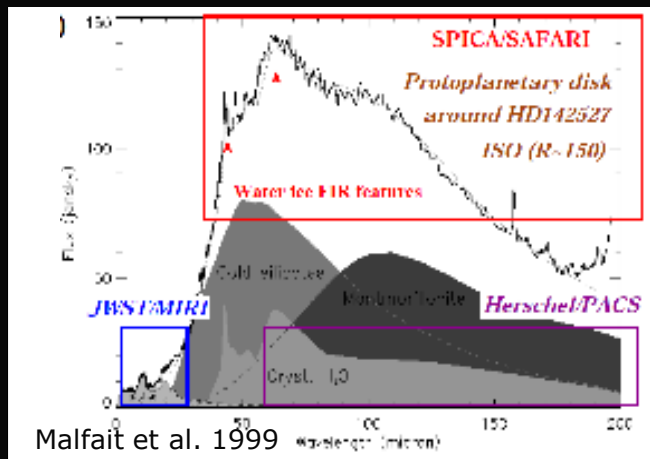
Adapted from Meyer et al. 2008



Moro-Martin 2009

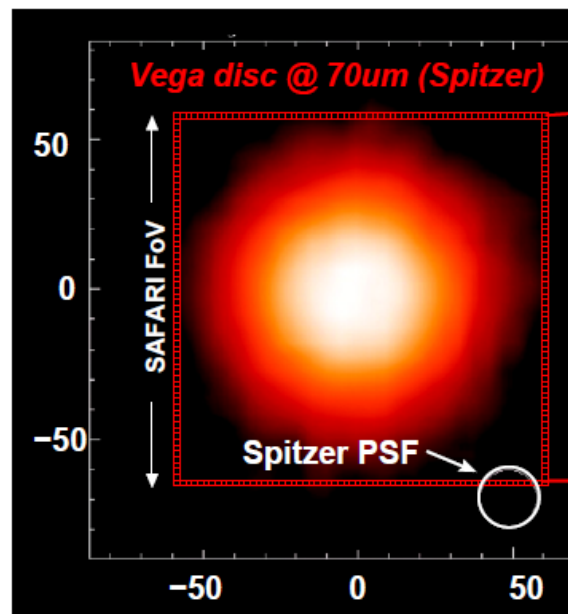


Resolving the "snow line" in nearby disks



Water ices important in grain coagulation → planet formation

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



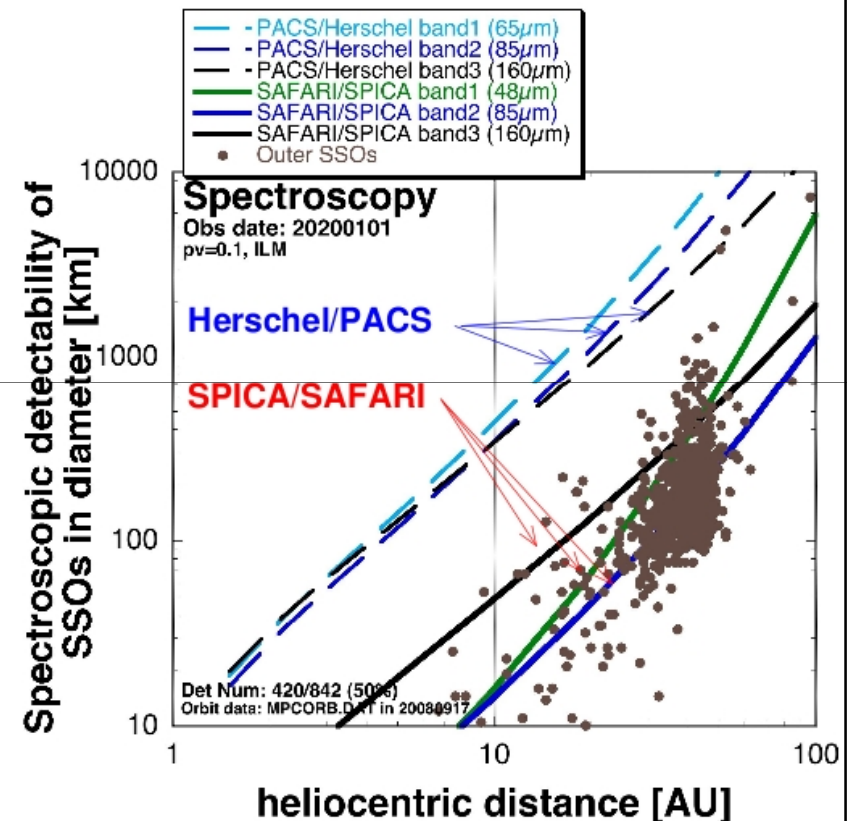
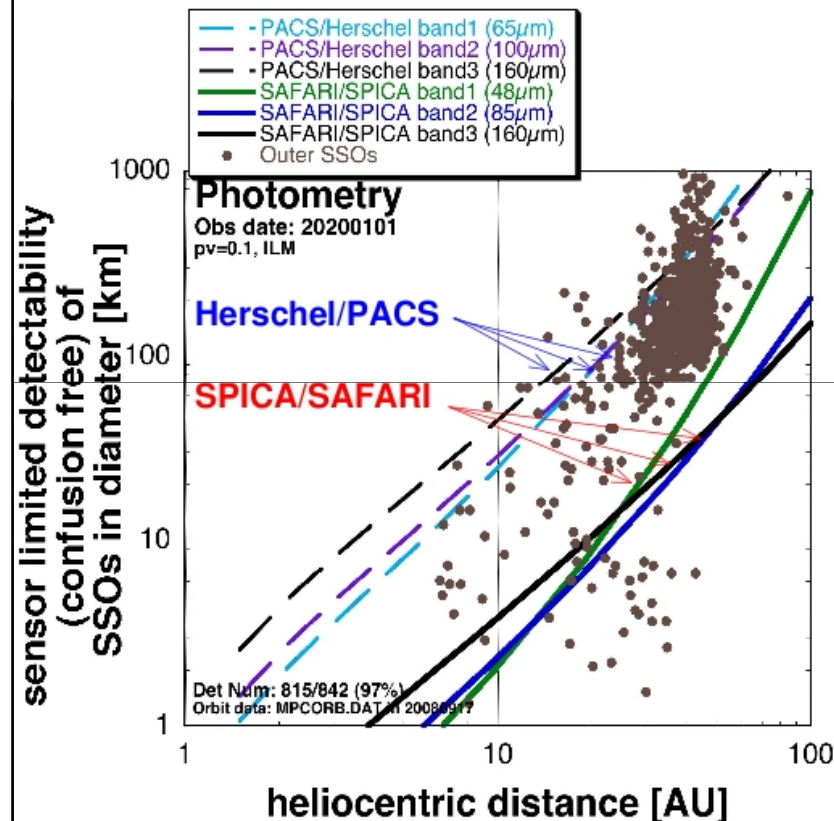
Su et al. 2005

Simulated Vega Disk Observation

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Detecting and characterising our own Debris disk

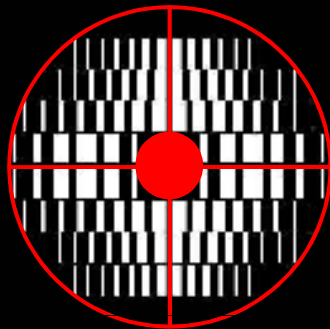
Detection and Characterization of outer Solar System Objects with SPICA/SAFARI



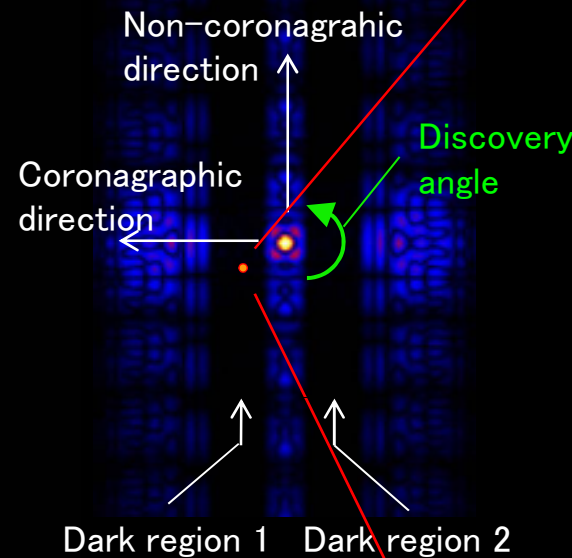
Updated from Hasegawa (2000)

Coronagraph for exo-planet characterisation

Pupil mask
(design)

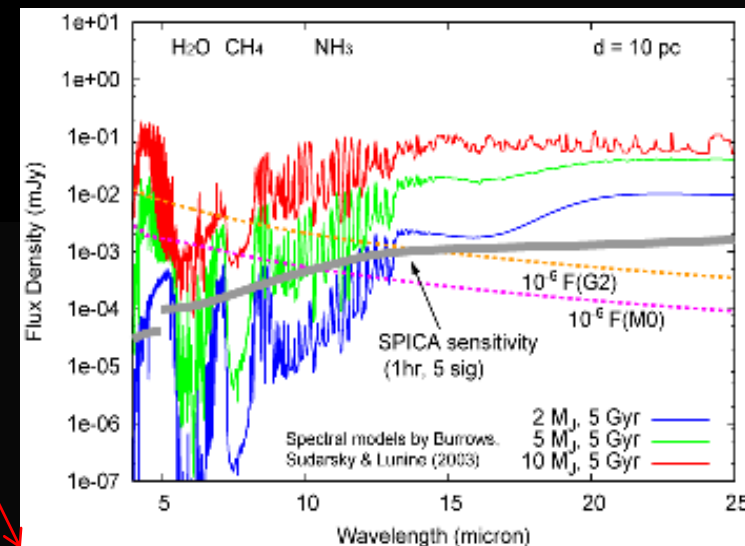
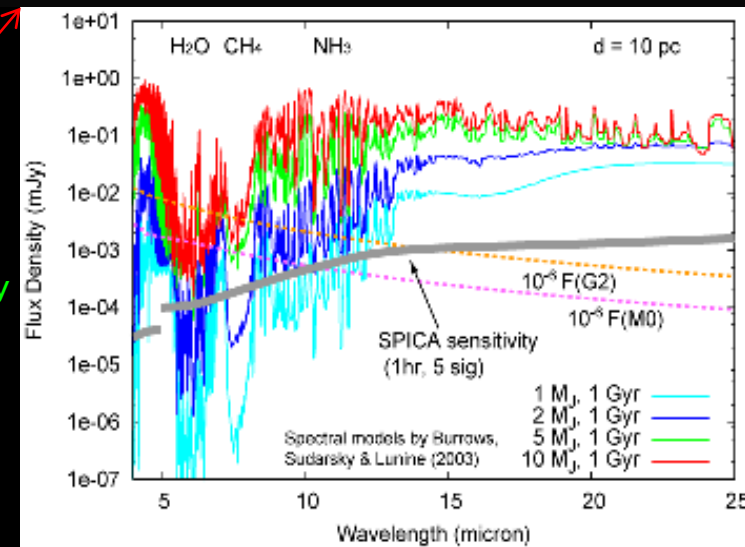


PSF (simulation)



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

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

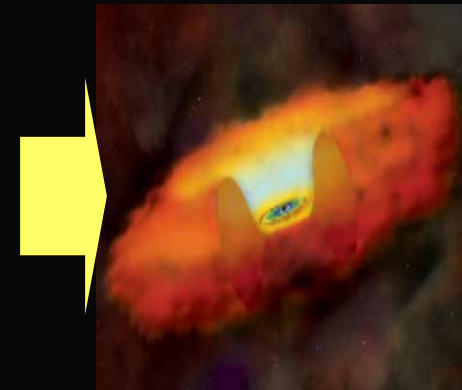
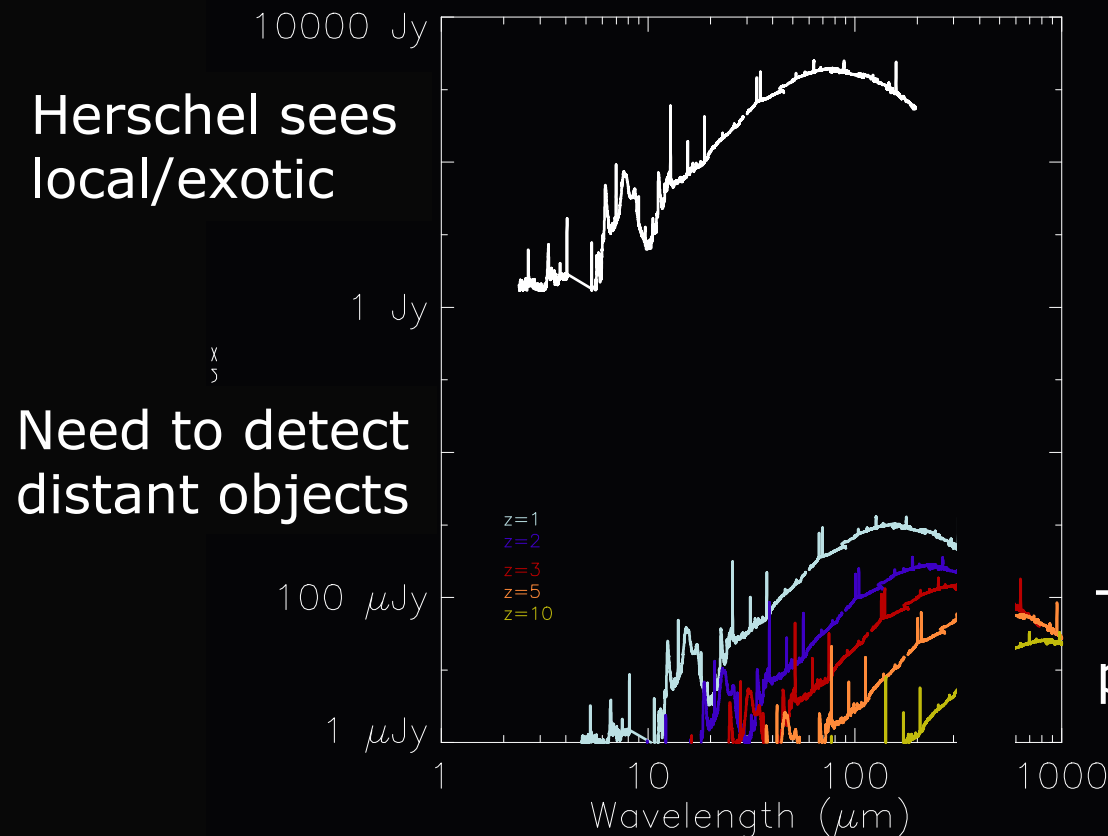


Adapted from Burrows et al ()

Spectroscopy of high redshift FIR galaxies

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

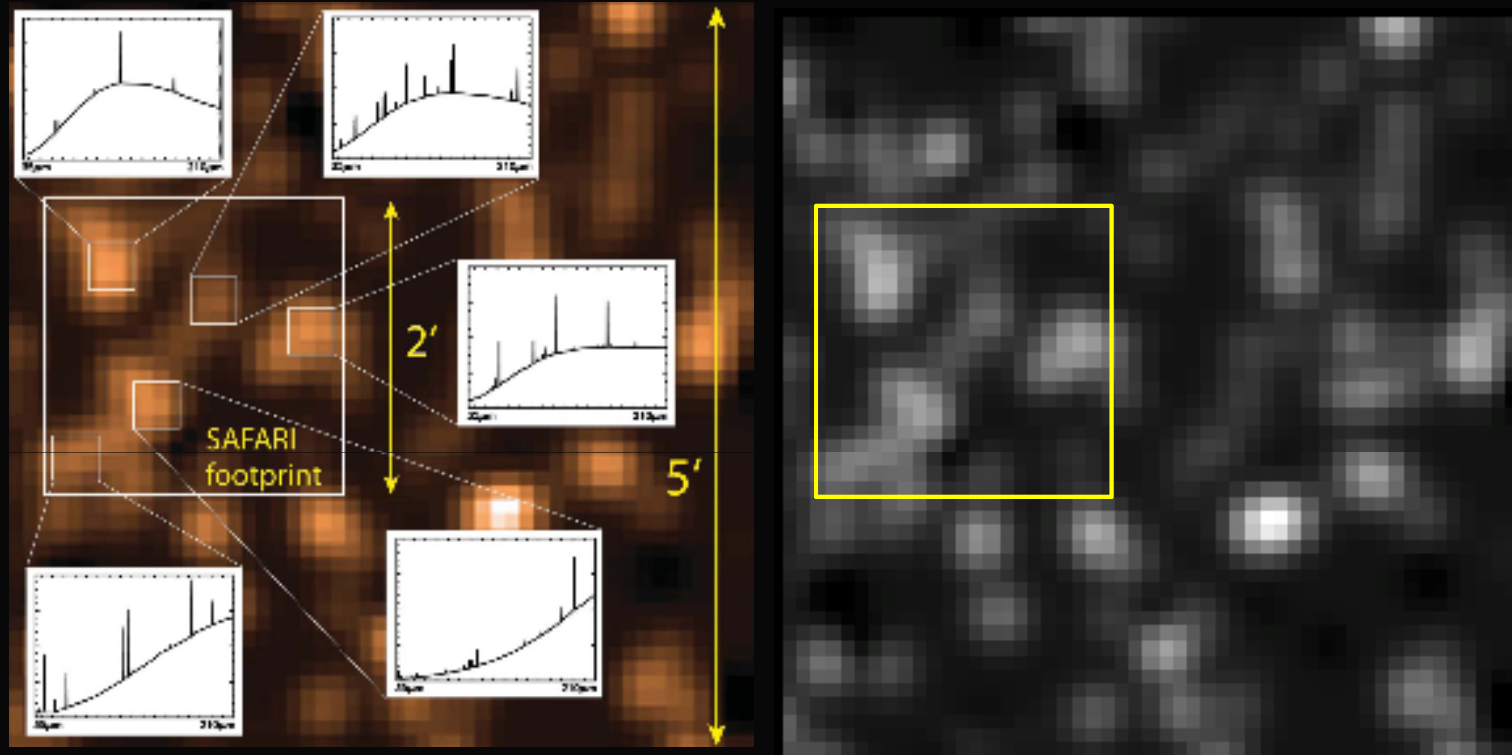
Only spectroscopy can reveal nature and role of AGN and star formation in galaxy evolution



To reveal their nature and physics and chemistry

The Multiplex Advantage

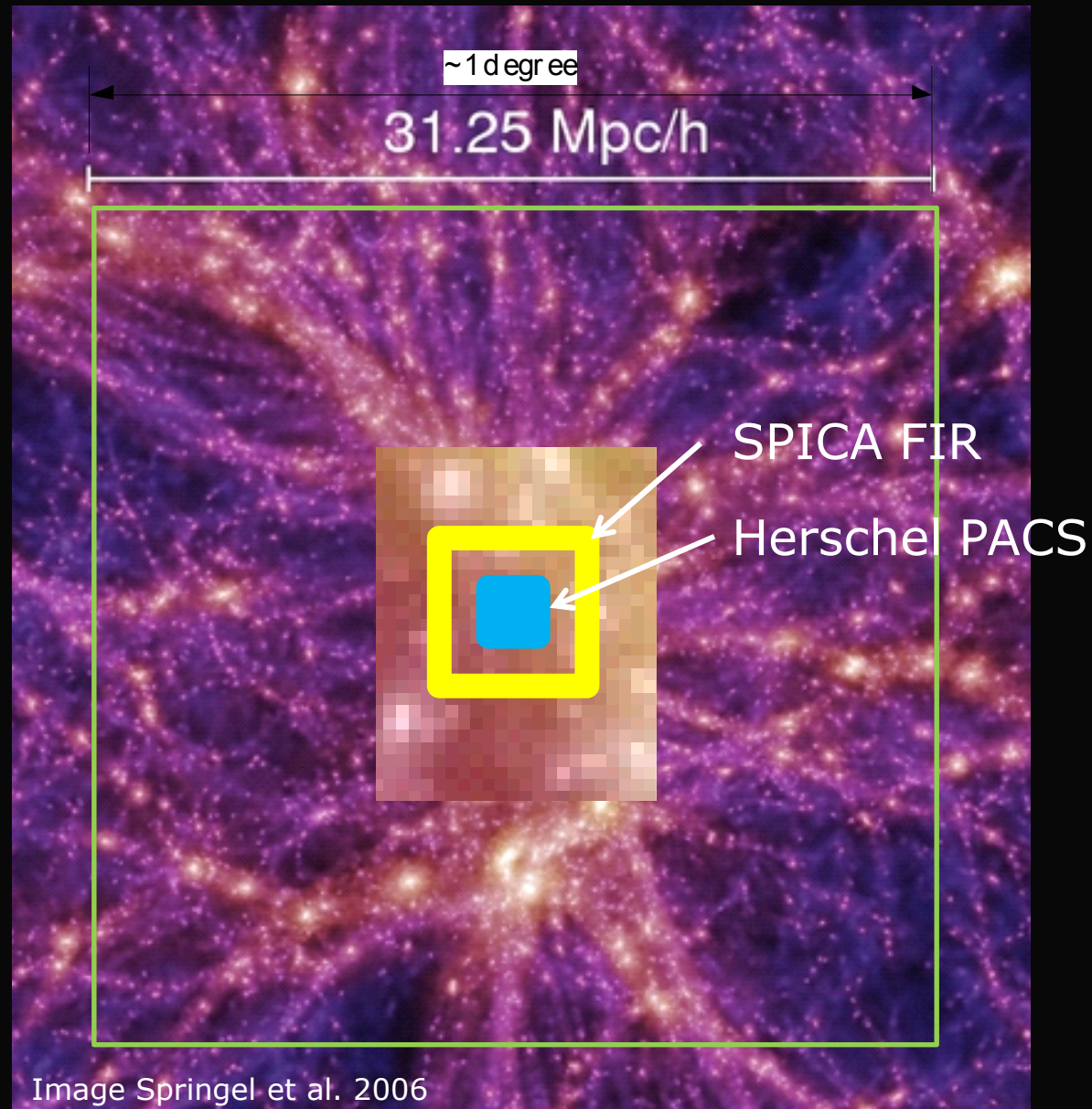
Looking closer at the SPIRE background sources



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

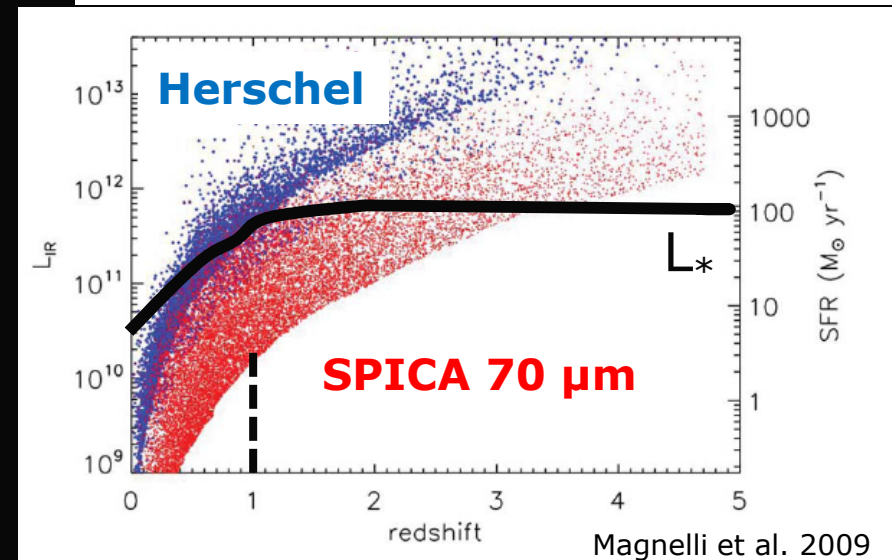
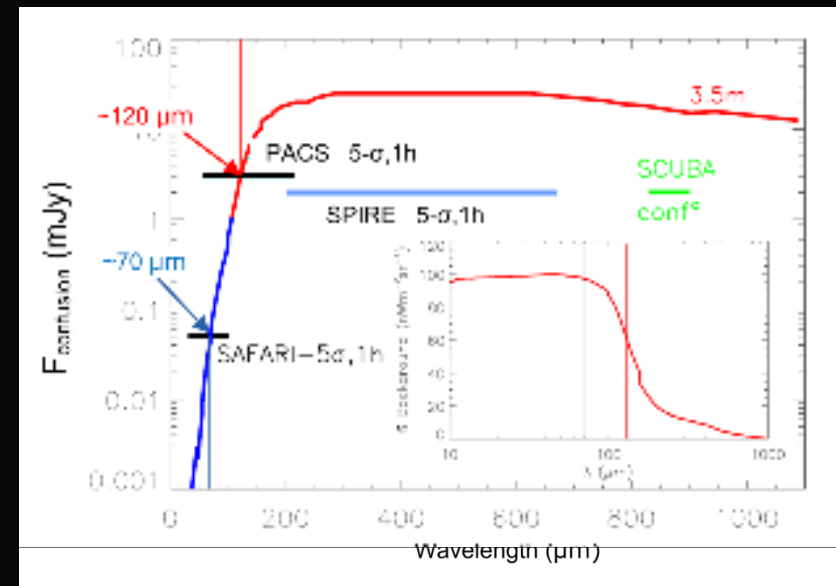
Images Rosenbloom, Oliver, Smith, Raab private communication

SPICA FIR 900 hour spectral survey

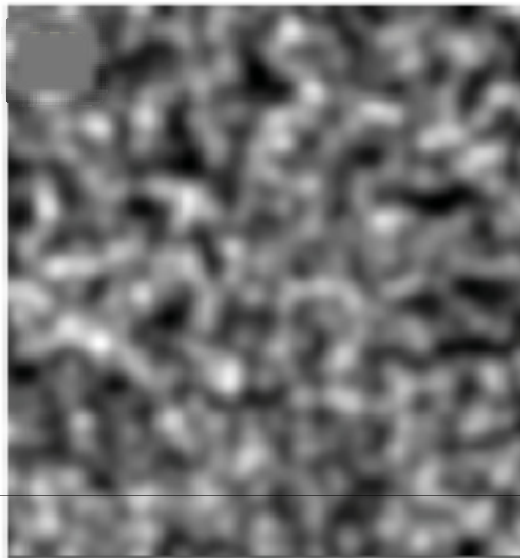


Resolving the Cosmic Infrared Background

- Confusion limit for 3.5 m telescope varies rapidly $<200 \mu\text{m}$
- Warm Herschel telescope means confusion is reached at $120 \mu\text{m}$ in 1 hour
→ $\sim 60\%$ of CIRB
- SPICA-SAFARI is not confusion limited until $70 \mu\text{m}$
→ 100% of CIRB
- Wider deeper surveys trace L_* to $z \sim 3$
- Can trace evolution of more modest – Milky Way – type galaxies



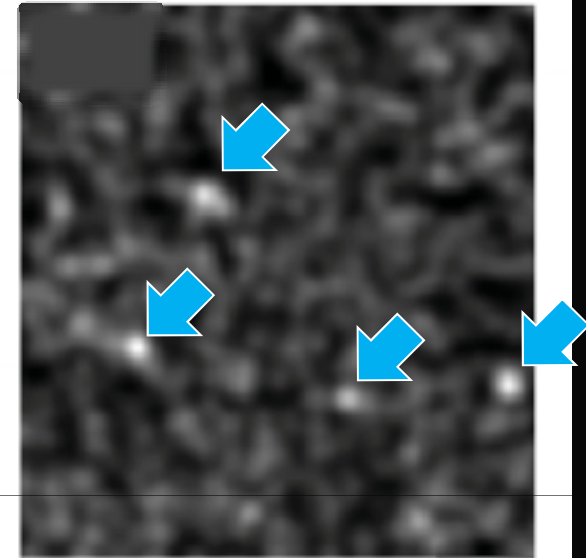
Breaking confusion with spectroscopy



Photometry @ 120 μ m



Slice @ 63.2 μ m



Slice @ 58.3 μ m

“Spectral Slicing” beats spatial confusion

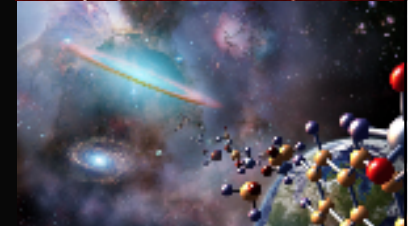
Sources with lines at different redshift appear in different wavelength “slices”

“Discovery” Science

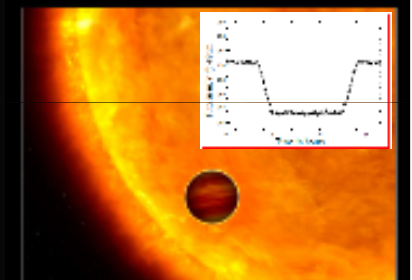
- ***The death of planetary systems:*** Detection of water and ice features in evolved stars indicating sublimation of entire Kuiper belt
- ***First identification of PAHs molecules in Space:*** SPICA-FIR will be especially adapted for deep searches of the “Grand-PAH” FIR band
- ***A new window in exoplanet 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 $z \sim 5-10$:*** Rest frame MIR spectroscopy of very luminous objects may reveal the very earliest stages of galaxy formation



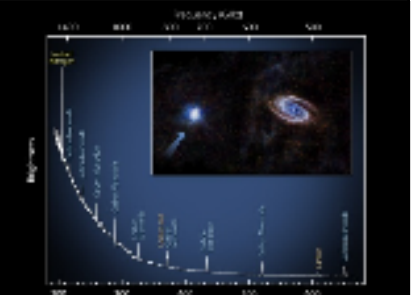
I. Leao (UFRGN, Brazil)



NASA

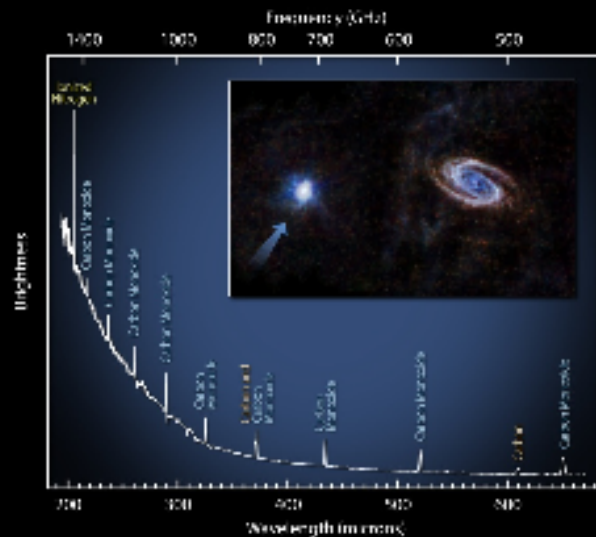


NASA/ESA/G. Bacon (StSci)

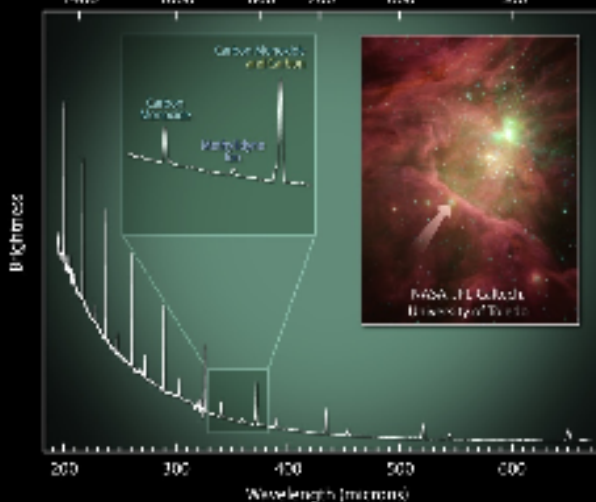


ESA/SPIRE consortium

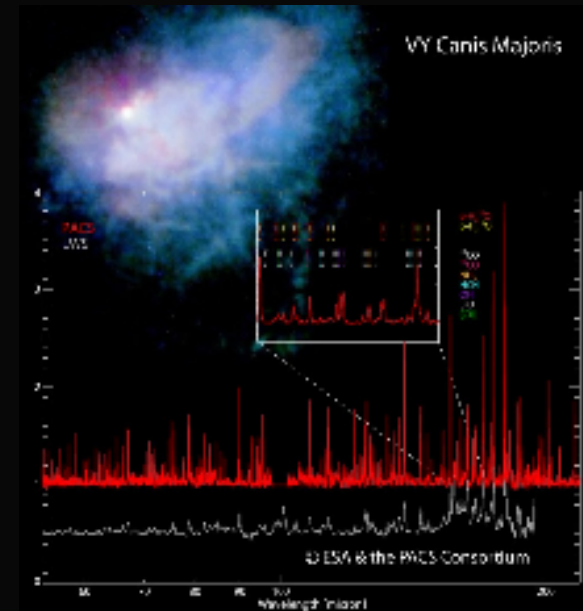
European scientists and engineers are at the forefront of space infrared astronomy and technology



Mission #2 & ESA and the SPIRE consortium

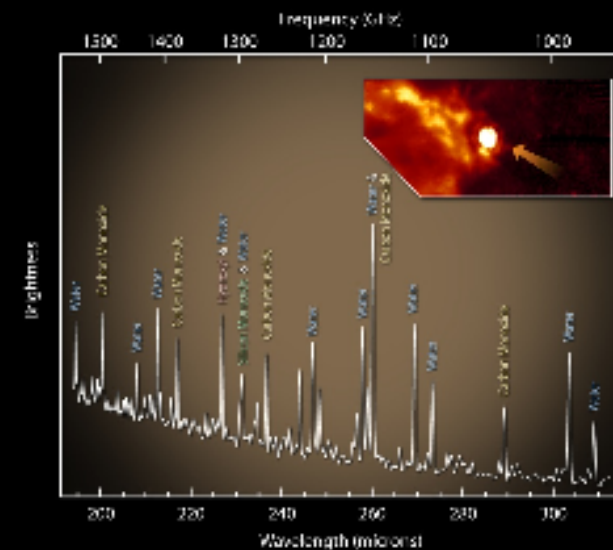


Orion Bar & ESA and the SPIRE consortium



VY Canis Majoris

© ESA & the PACS Consortium

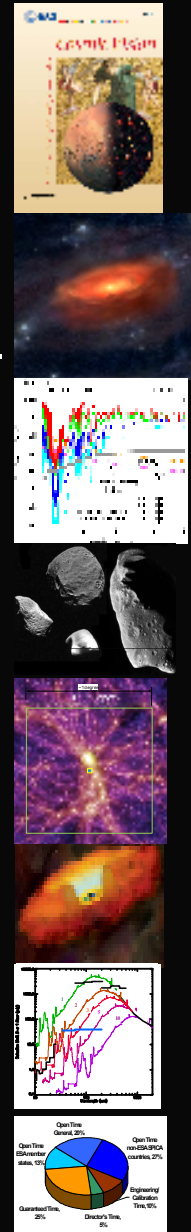


VY Canis Majoris

© ESA and the SPIRE consortium

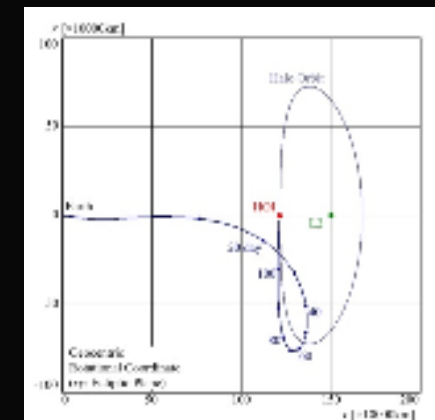
Summary

- 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 exoplanets
 - 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



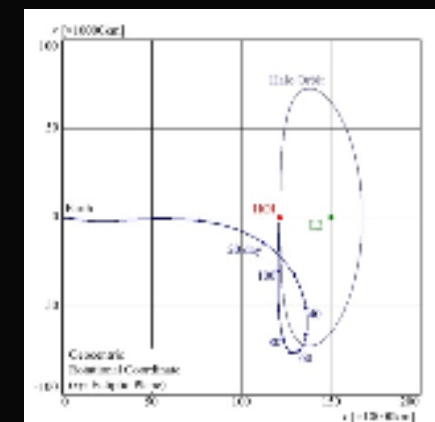
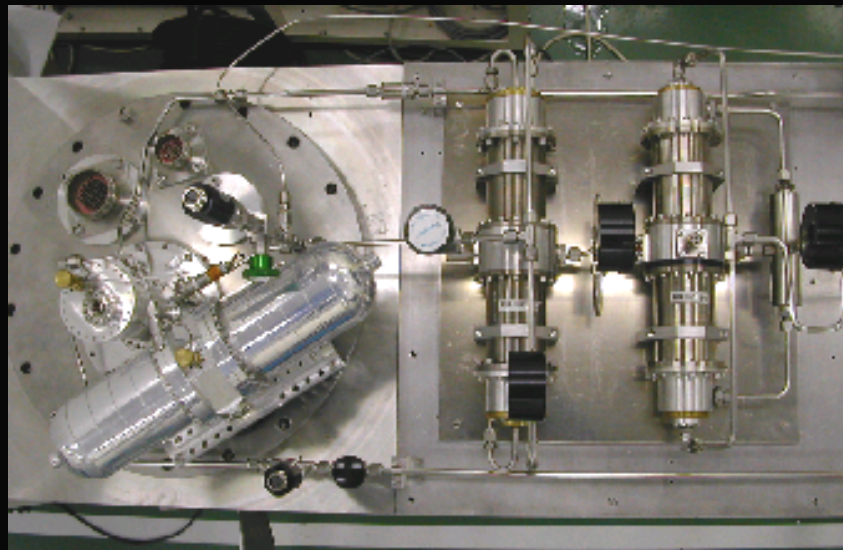
Overview of SPICA mission

- **SPICA is a JAXA led mission (Phase A) scheduled for launch by 2018.**
- **Mid- and far- IR observatory operating between 5 and 210 μm .**
- **Very high sensitivity via cold telescope (3.5 m diameter, $T < 6\text{K}$).**
- **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.

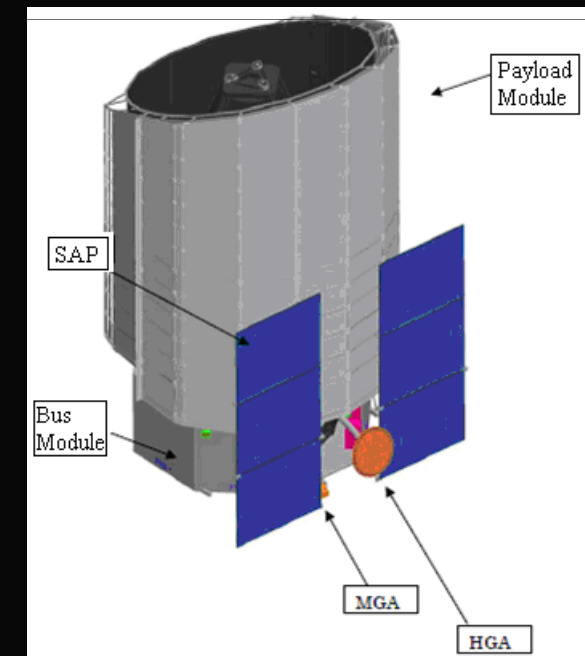
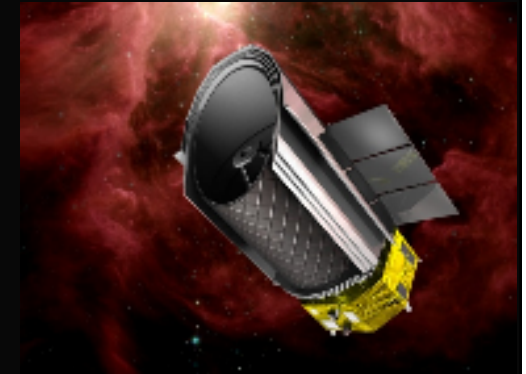
Mass & power: Total mass ~ 4 ton; total peak power ~ 2.4 kW.

Attitude & Orbit Control: 3-axis stabilised. Focal Plane Camera (FPC) in AOCS loop.

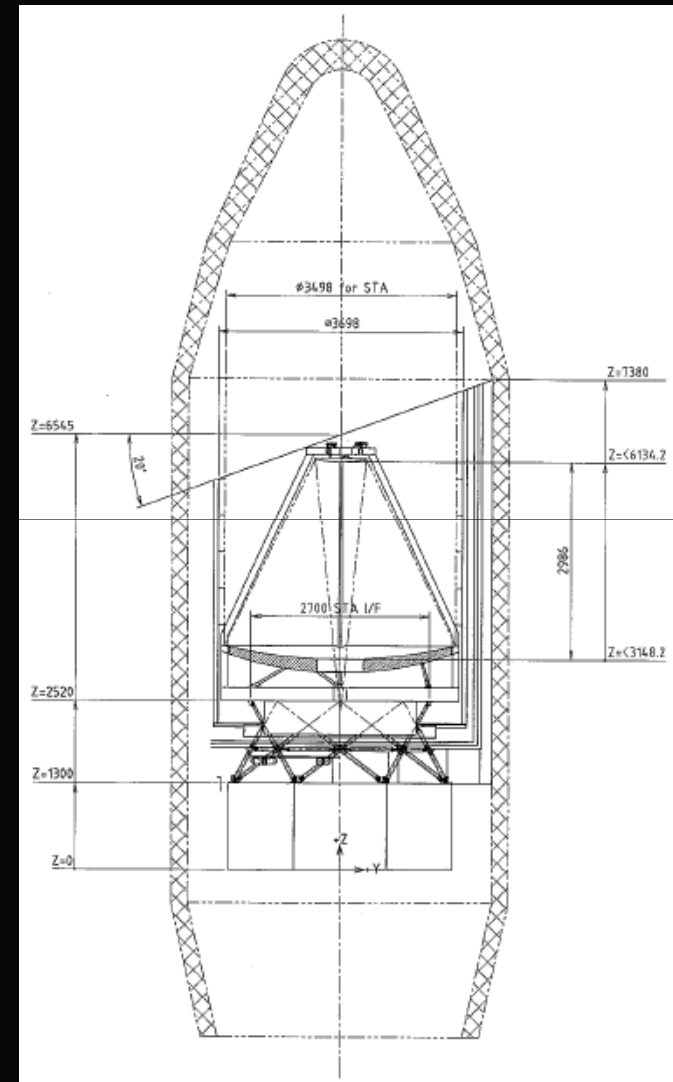
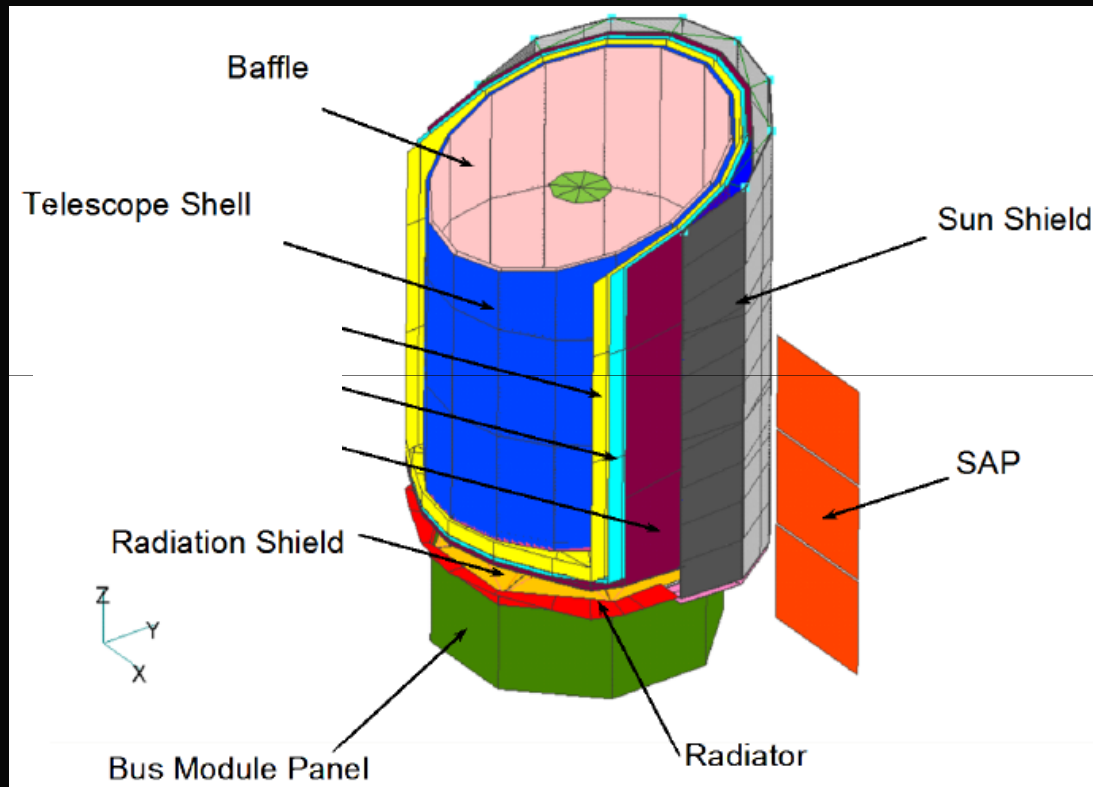
Thermal Control: Passive cooling via coaxial Sun and thermal shields, (reaching ~ 11 K). Active cooling via 2-stage Stirling and JT units (4.5 & 1.7 K stage).

Data Handling: Science data: $24\text{h} * 4 \text{ Mb/s} = 350 \text{ Gbit/day}$.

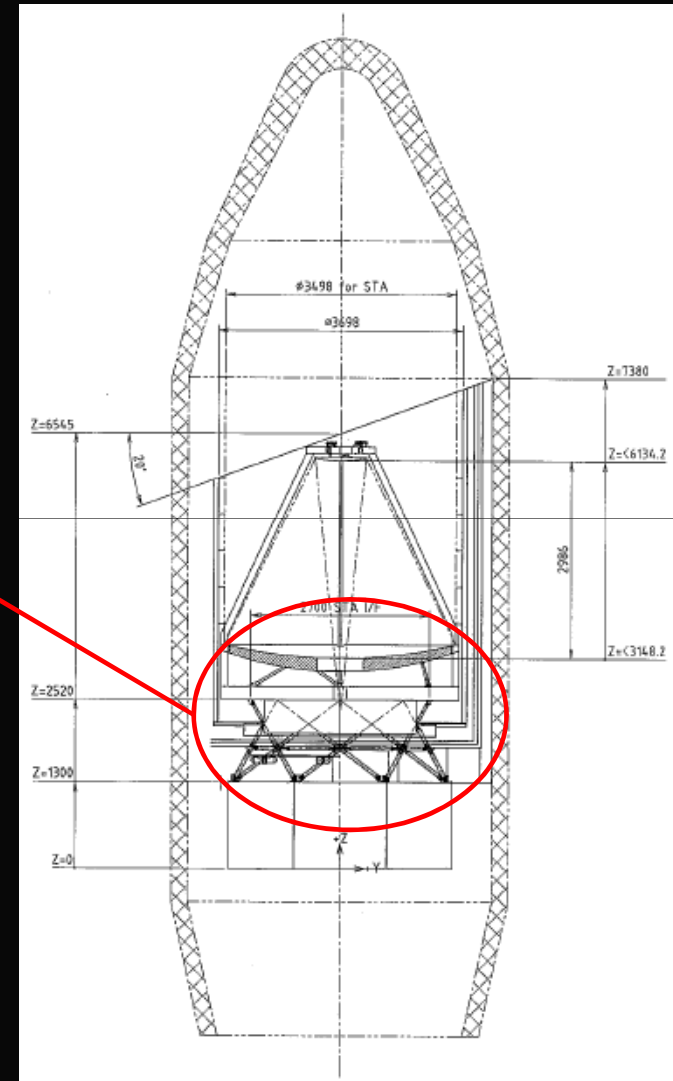
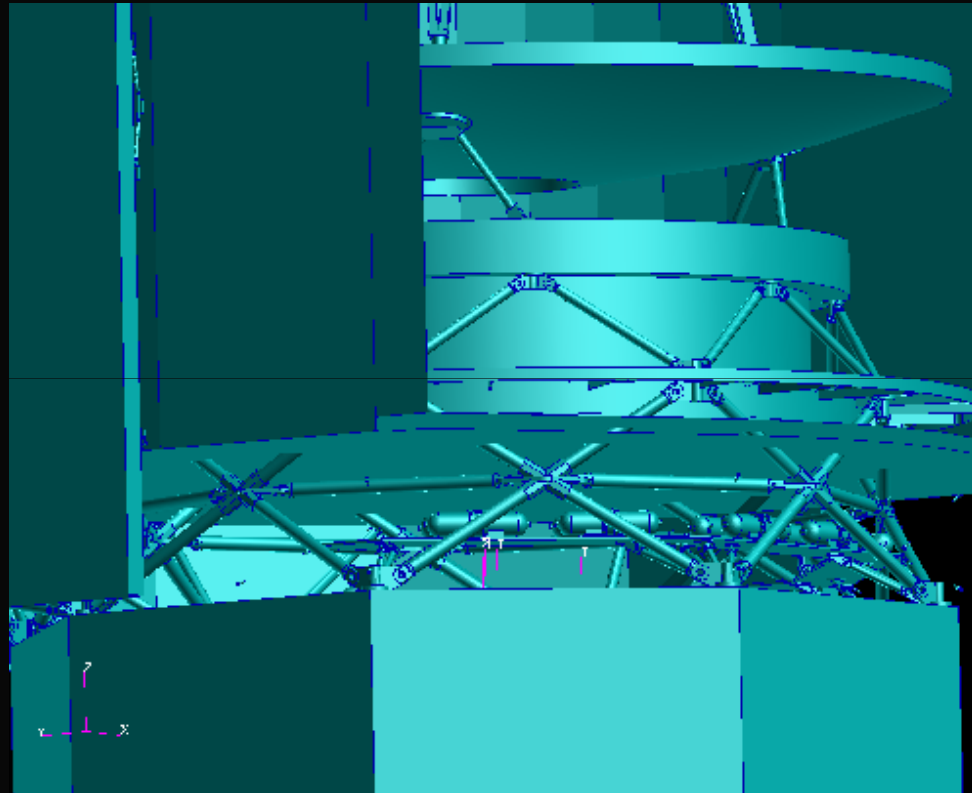
TT&C - Ground Data science down-link in X-Stations: Band, Usuda (JAXA), Cebreros or DS3 (4 hr/day).



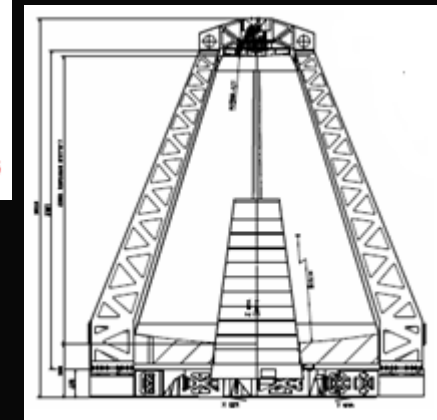
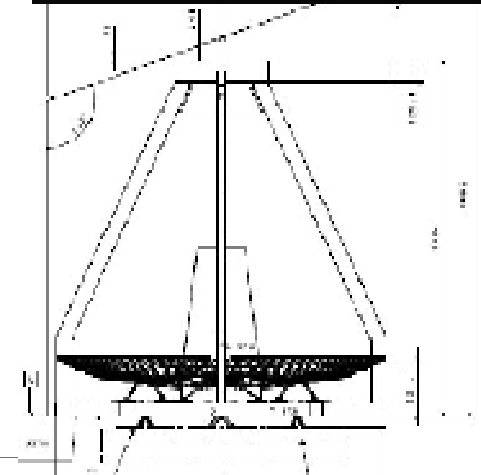
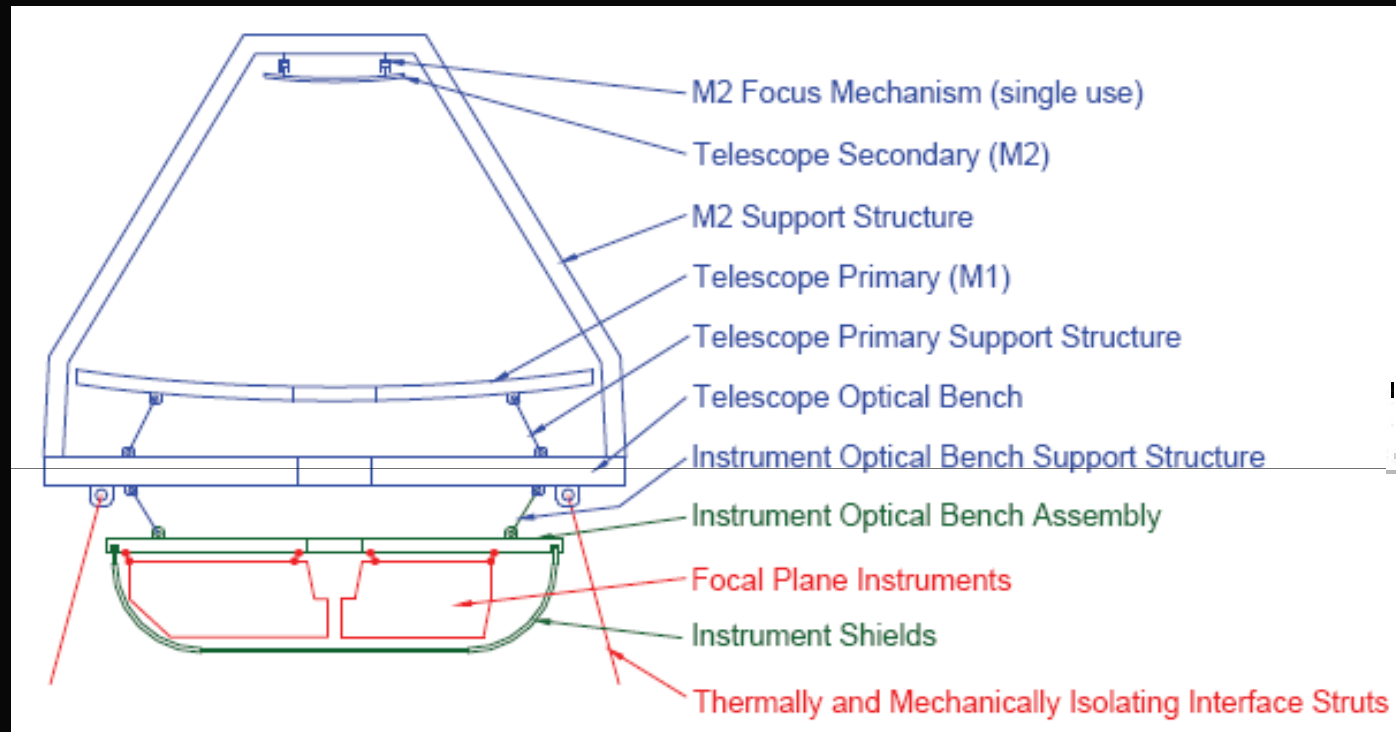
The SPICA spacecraft



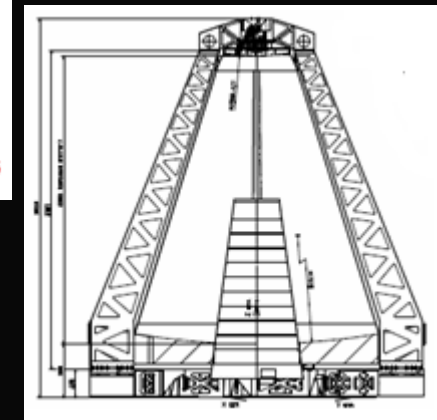
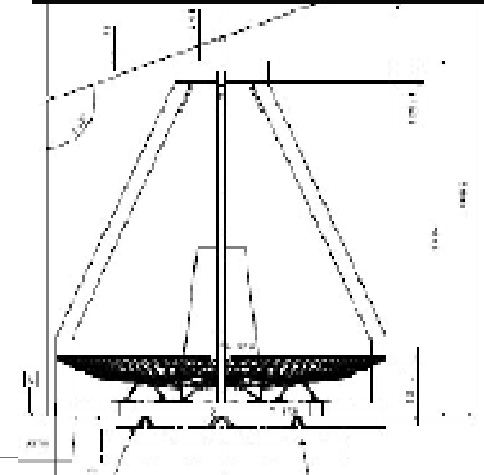
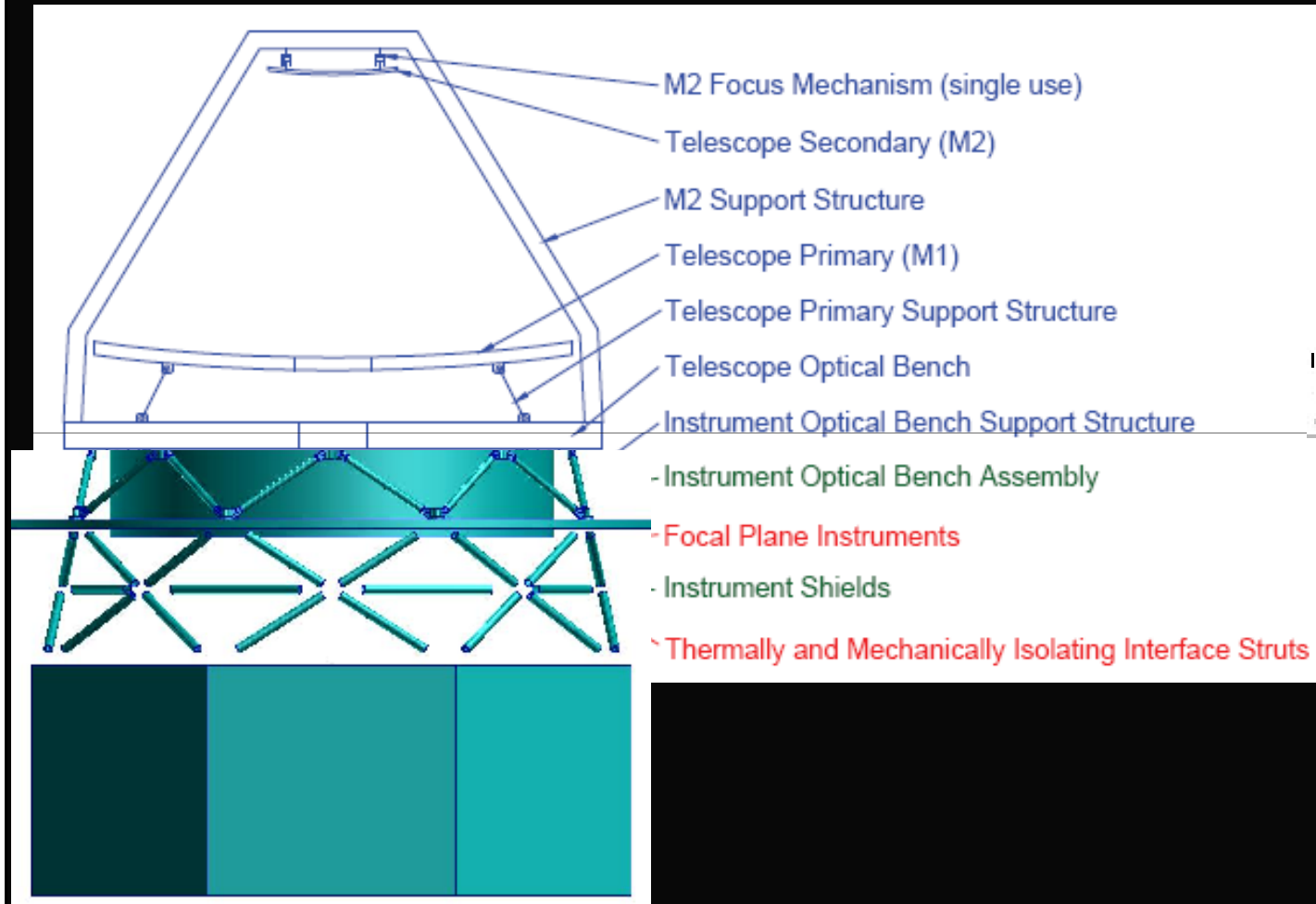
The SPICA spacecraft



SPICA Telescope Assembly (STA)



SPICA Telescope Assembly (STA)



Telescope assessment study



Main requirements:

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



Telescope assessment study



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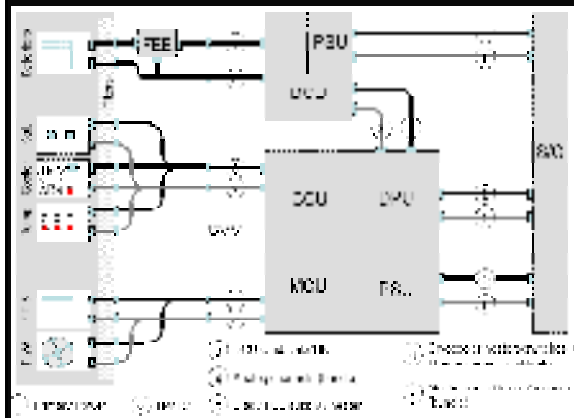
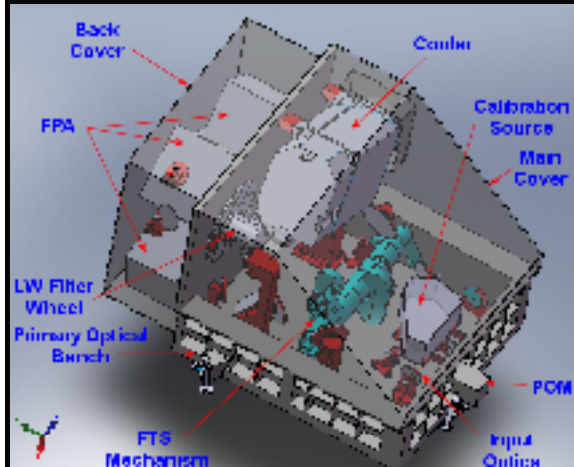
Baseline design:

- 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 $T < 6\text{K}$; heat load $\sim 20 \text{ mW}$ 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).

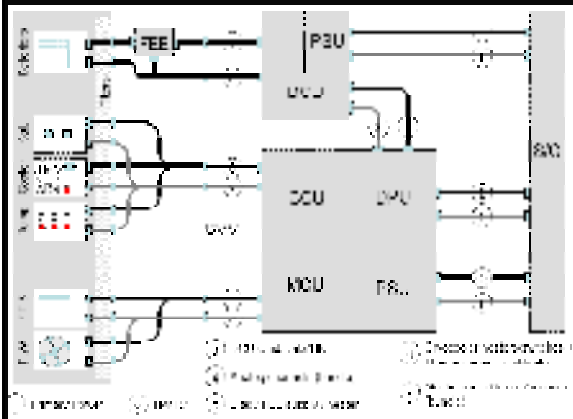
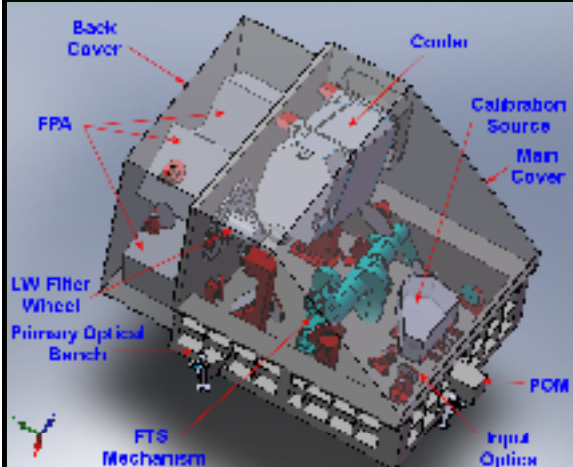
European contribution: SAFARI

Main requirements:

- Imaging and spectroscopy (range 34 – 210 μm).
- Photometric camera mode with $R \sim 2$ to 5.
- Spectroscopic mode with $R = 2000$ at 100 μm .
- $\text{FOV} = 2 \times 2 \text{ arcmin}^2$.
- Line sensitivity $\sim 3 \times 10^{-19} \text{ W/m}^2$ (at 48 μm).
- Mass of cold assembly $< 50 \text{ kg}$. Warm electronics $< 30 \text{ kg}$.
- Flight Model delivery to JAXA by Q2 / 2016 (latest).



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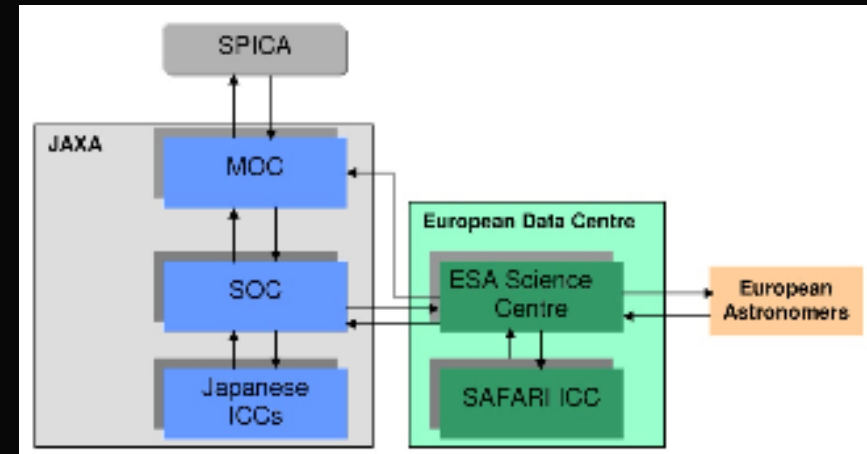
Baseline design:

- **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.
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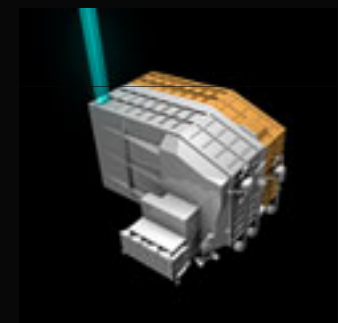
SAFARI:

- 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