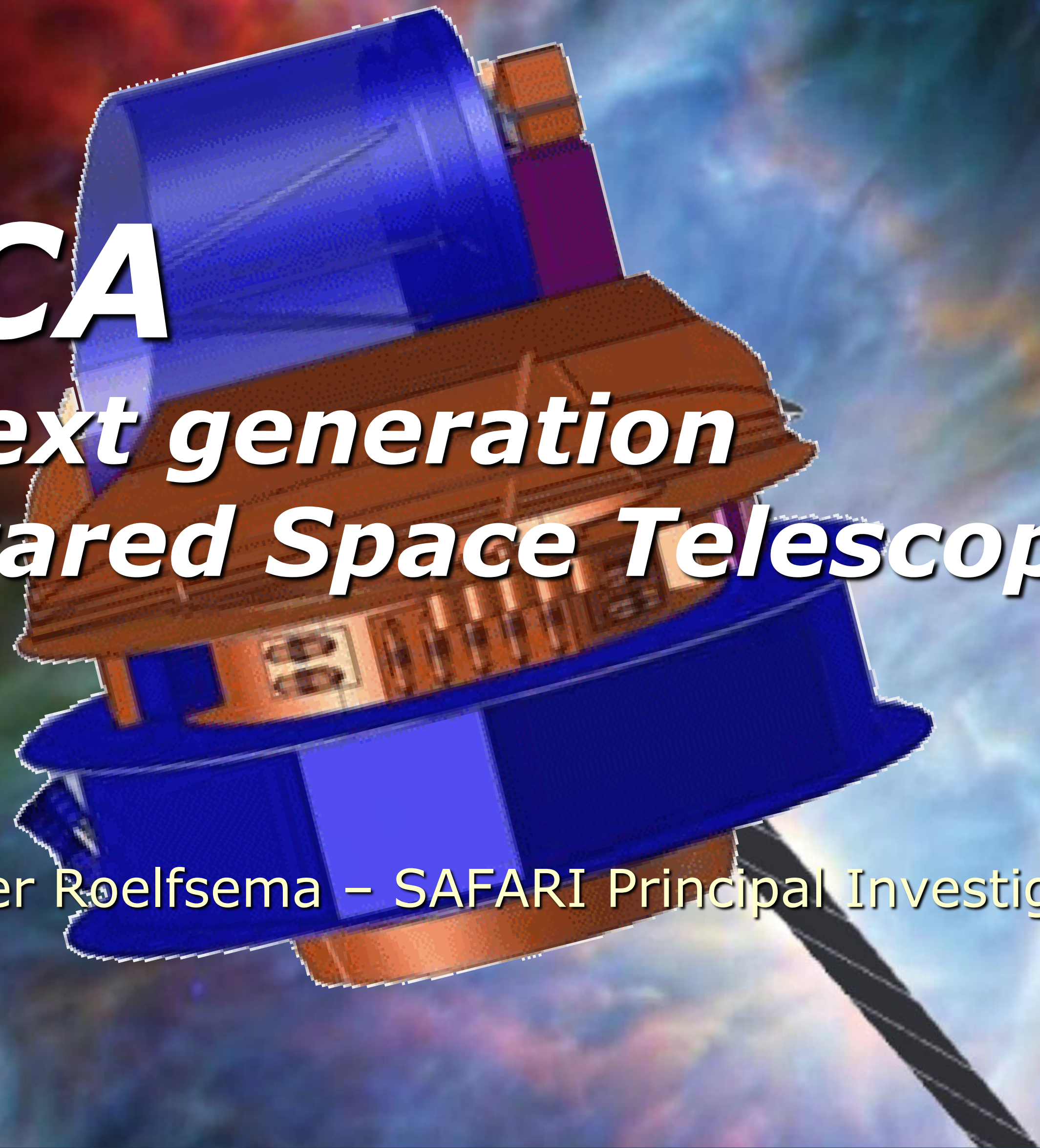
SPICA

the next generation Infrared Space Telescope



Peter Roelfsema – SAFARI Principal Investigator

SRON

Netherlands Institute for Space Research

Netherlands Organisation for Scientific Research

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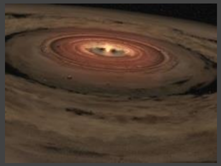
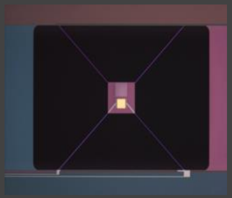
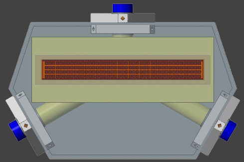
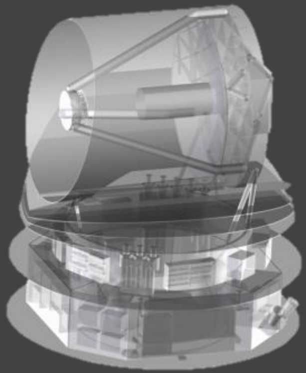




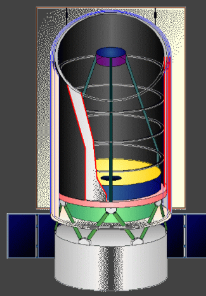
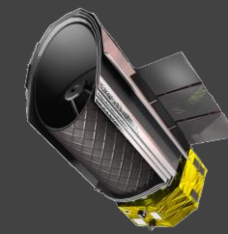


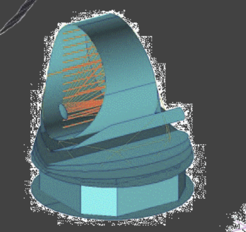
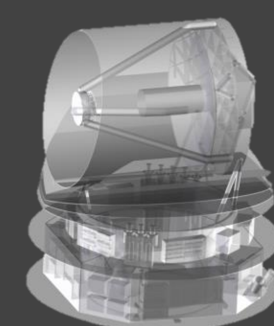


- The goal; a big cold IR facility – SPICA
- The heart of the matter – SPICA science
  - The science case for the (far) IR
  - Requirements for the mission and instruments
- SPICA – mission overview
  - Concept
  - instrumentation
- The European instrument – SAFARI
- Towards M5
  - Context – agencies, the consortia
  - Timeline
  - Supporting, participating

SPICA – some history

- Japan (Matsumoto, Onaka) initiated HII/L2 project late 90'ties
  - Cryogenic telescope as follow up for after (then) FIRST
- 2004 – UK leads SAFARI and European SPICA effort
- 2007 – SSAC: M-class JAXA mission with ESA telescope (Moo)
  → Yellow book, ESA telescope studies, SAFARI/FTS
- 2010 – rescope HIIB to HIIA launcher → smaller telescope
- 2011/2012 – 'Risk Mitigation Phase'
  - Good plan, but too big for Japan alone
    → ESA partnership needs to increase: from 'Moo' to 'M'
- 2014 – joint JAXA/ESA CDF mission study → M5 concept
  - Re-evaluation of science (in late 20'ies!) → SAFARI/Grating#
  - Mission lead moves from Japan to Europe
- 2015 – Japan passes Mission Definition Review
  – SAFARI consortium says yes to leading M5
  → ***go-ahead for M5***

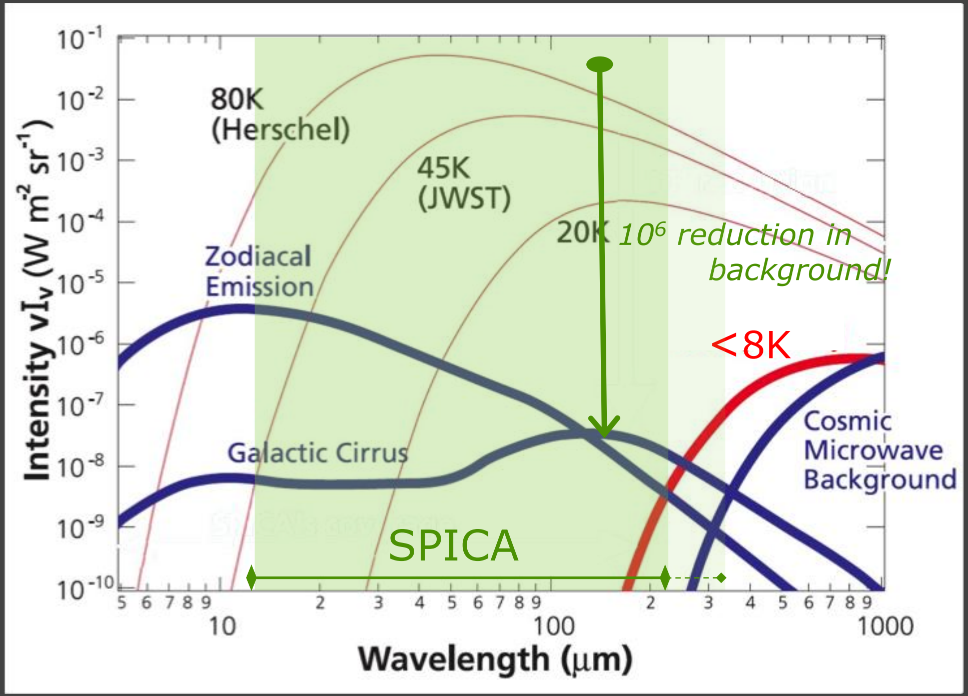



The SPICA 'sweet spot' – the dusty universe

A unique observatory

looking through the veils, enabling

transformational science



What is so unique?

- A ***COLD***, ***big*** mirror

  → ***true background limited*** Mid/Far-IR observing

  >2 orders of magnitude better raw sensitivity than Herschel

- ~20 to ~350 μm ***inaccessible for any observatory***

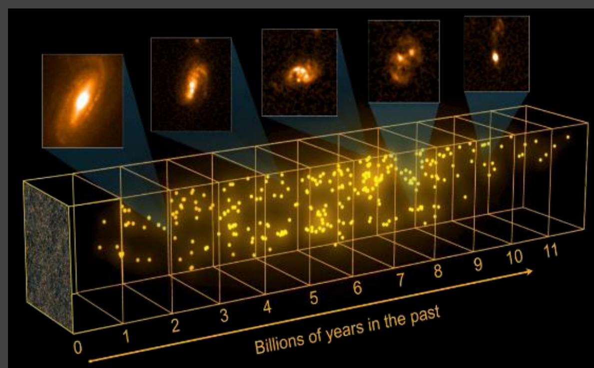
  → the wavelength domain where ***obscured matter*** shines

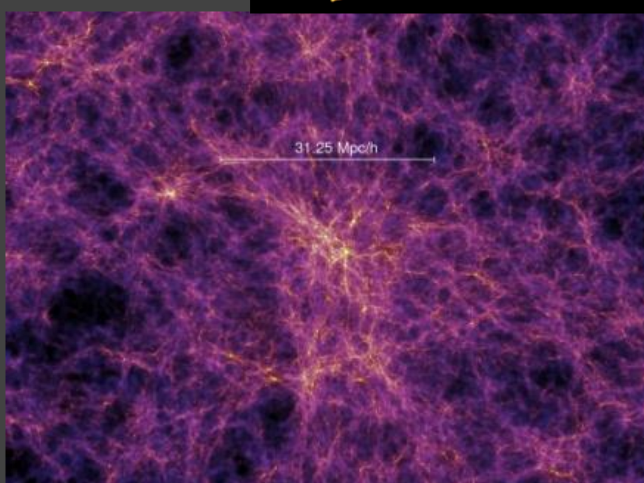
  Filling the void between JWST and ALMA @ R~ few 1000

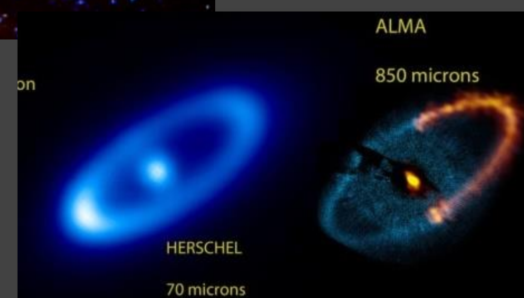
Enabling us to follow dusty matter in the universe

Seeing through the veils on cosmic timescales

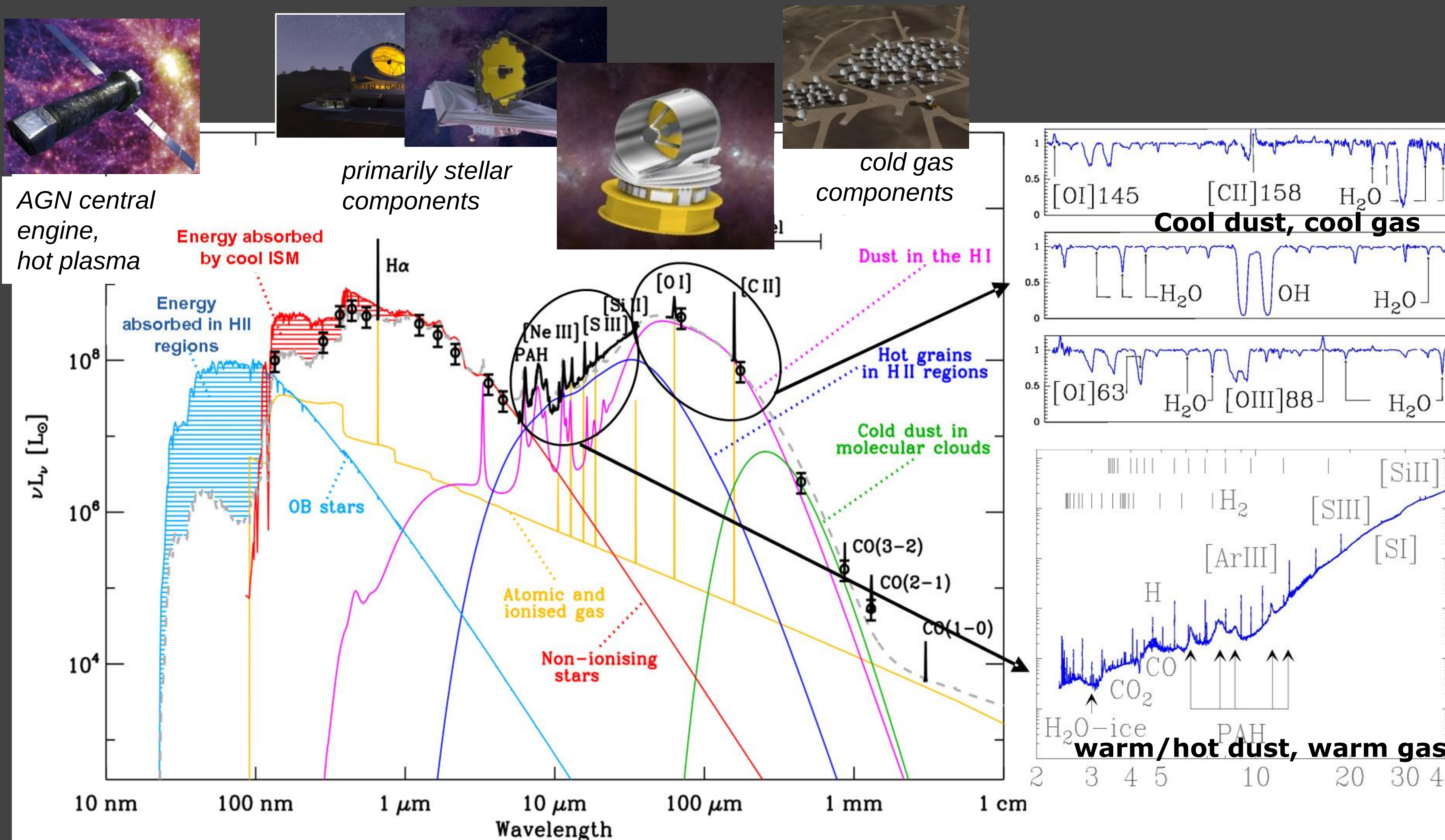
from galaxy evolution to the formation of proto planetary disks







Understanding the multiphase ISM



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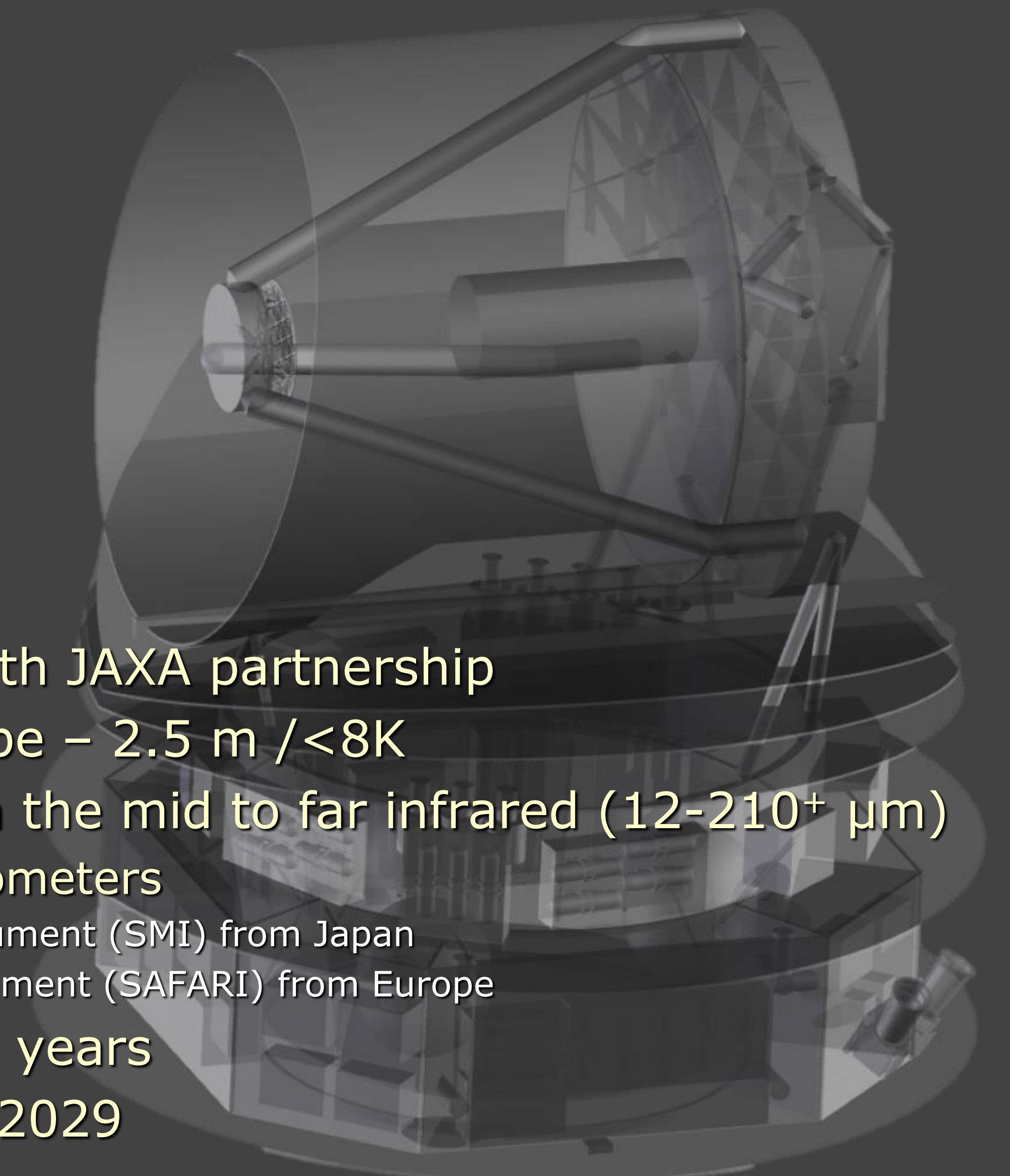
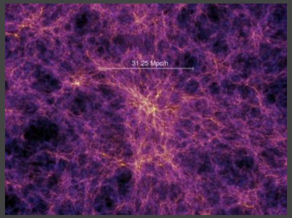
Mission Overview

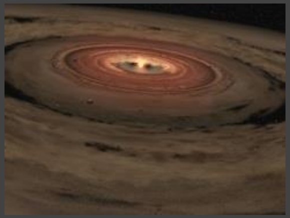


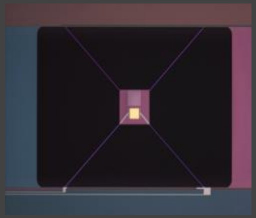
To be proposed for M5:

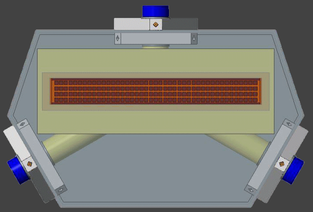
- European led mission with JAXA partnership
- Large/cryogenic telescope – 2.5 m /<8K
- Spectroscopic mission in the mid to far infrared (12-210^{+} μm)
    - Highly sensitive spectrometers
        - SPICA Mid-Infrared Instrument (SMI) from Japan
        - SPICA Far-Infrared Instrument (SAFARI) from Europe
- Mission goal lifetime – 5 years
- Proposed launch date – 2029

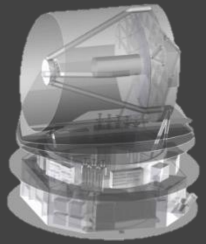
The SPICA science case











Science Objectives – mission design drivers

Major science questions that require SPICA*

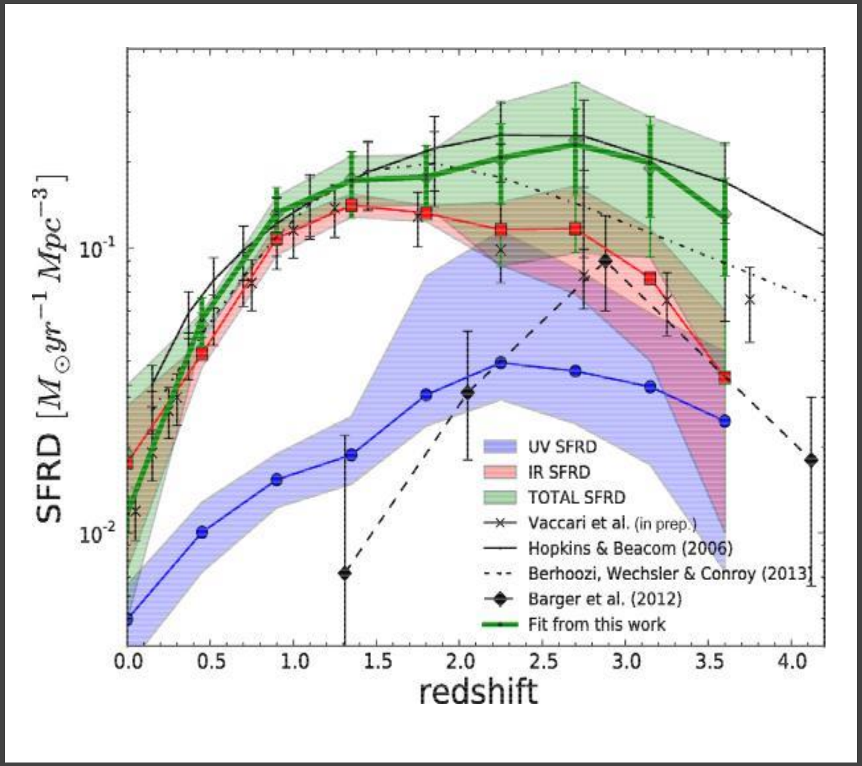
- What processes govern **star formation across cosmic time** - what starts it, controls it, and stops it?
  - What are the major physical processes in the most obscured regions of the universe?
- What is the **origin** and composition of **the first dust**, and how does this relate to present day dust processing?
- What is the thermal and chemical **history** of the **building blocks of planets**?

Established over the last few years by the joint Japanese-European-US science team, including community inputs through various workshops

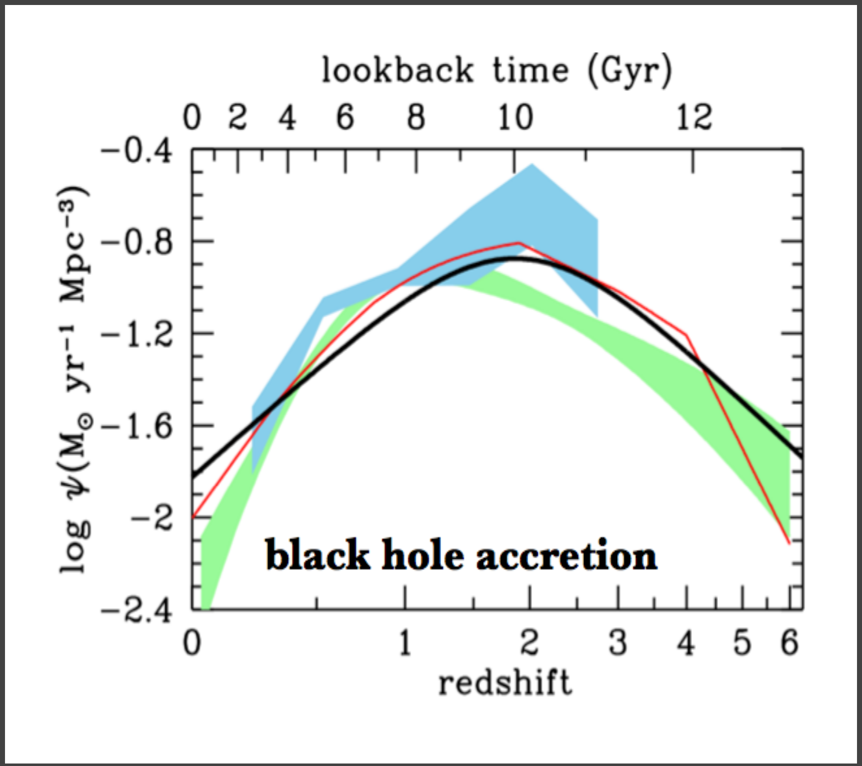
** i.e. high sensitivity spectroscopy in the mid/far IR*

Star formation and black hole accretion

Why is the rate of galaxy evolution changing so dramatically over time?



SFR densities in the UV, uncorrected for dust extinction (blue) in the far-IR (red), and in total (i.e., UV+far-IR, green). (Burgarella et al. 2013).



Black hole accretion history from X-ray (red line and green shading) and IR data (blue shading). (Madau & Dickinson, 2014).

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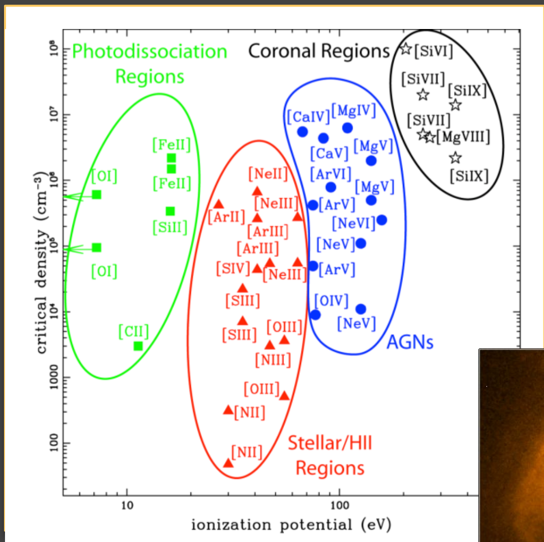
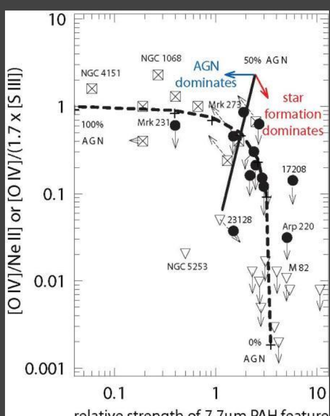
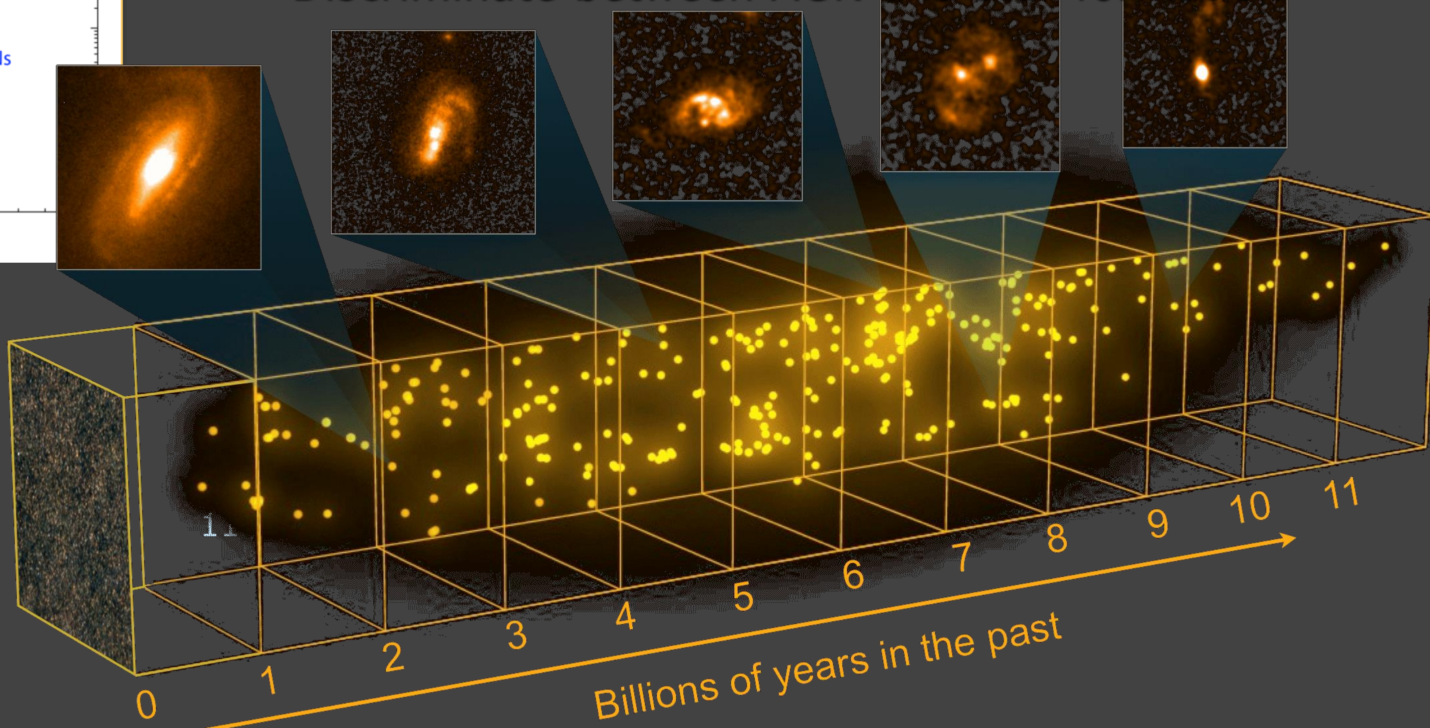
Evolution of IR-luminous galaxies



- ISO/Herschel showed large range of FAR-IR characteristics of IR-bright galaxies
- FAR-IR diagnostic tools
  - Line-ratios → physical state of dust and ionised gas
  - Discriminate between AGN and star-formation





So far only we 'only' sampled the 'local universe'…

…SPICA Far-IR allows ***looking further back*** *in time*

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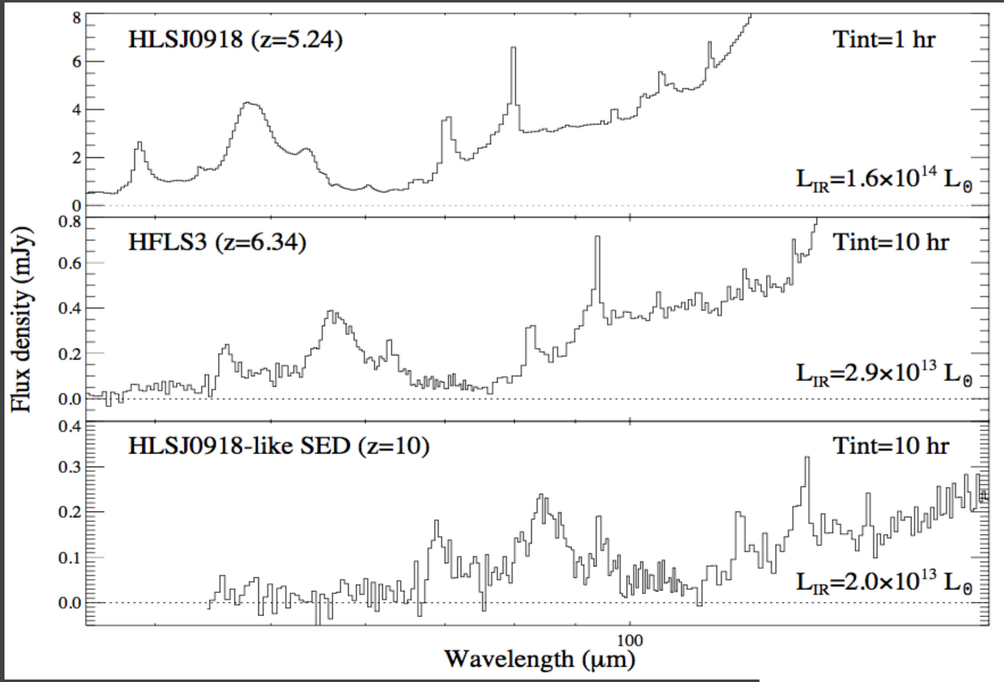
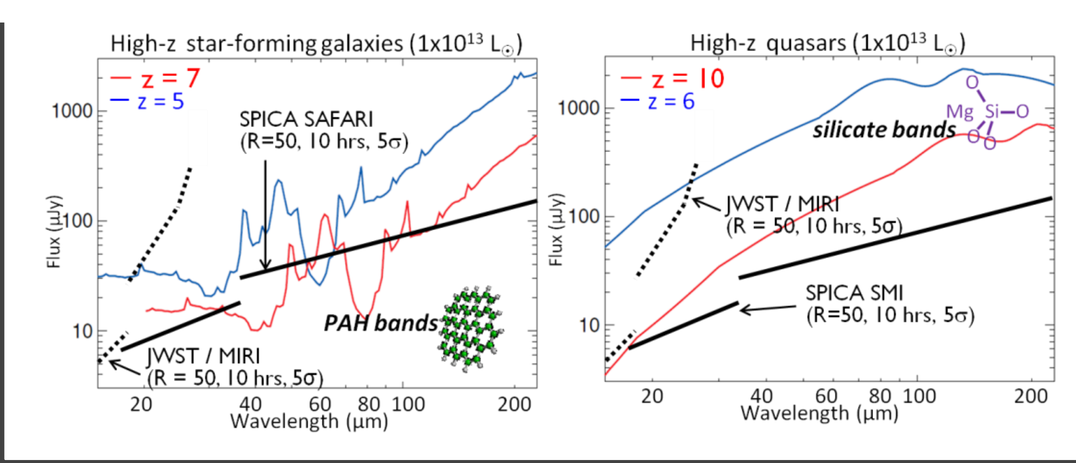
Nature of the first dust



Simulated SPICA observations of high-redshift (lensed) galaxies (10 hr integration time) – PAH features easily detected.

SPICA can access PAH and Silicate features at redshifts beyond JWST: grain chemistry of the first dust



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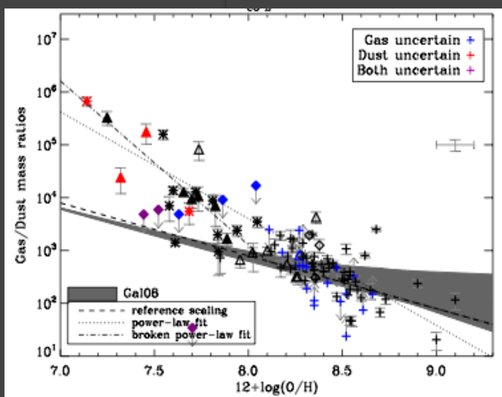
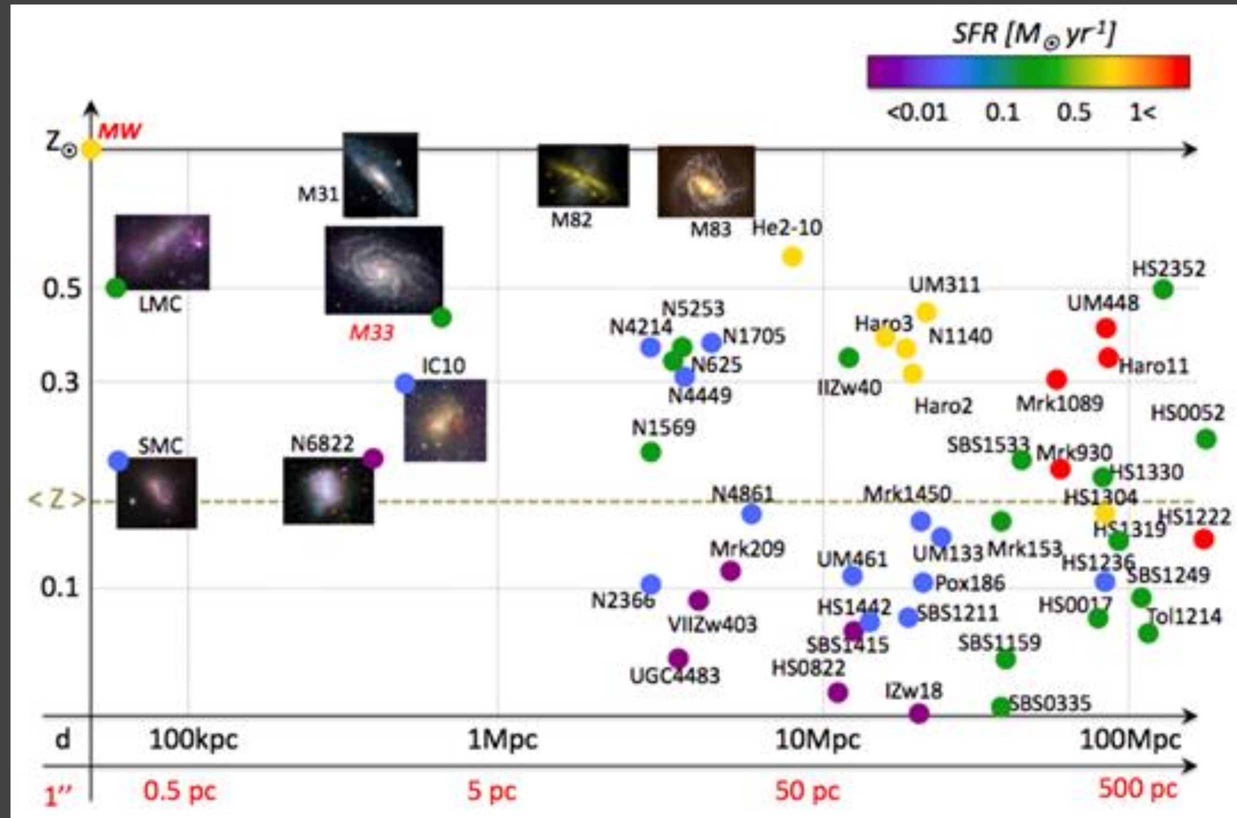
The 'nearer by' universe: local Galaxies

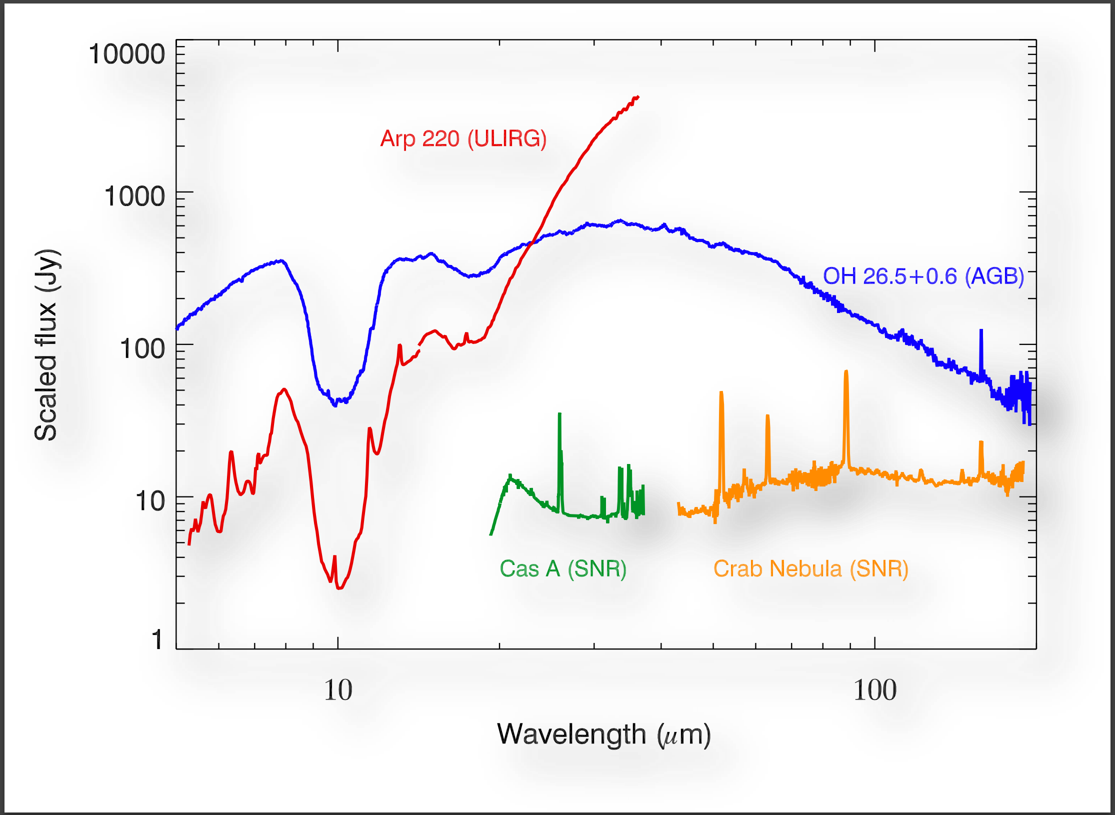




- Spatially resolved and point source spectroscopy
  - Sample large range of physical conditions, SFR, metallicity etc.
  - *Connect correlations for z=0-3: e.g. gas/dust-metallicity, [CII]-CO luminosity*

Understanding how galaxies work requires an unbiased survey out to ~100 Mpc, to cover the largest possible range of star formation rates, metallicities, and morphological types.

Dust in local Galaxies



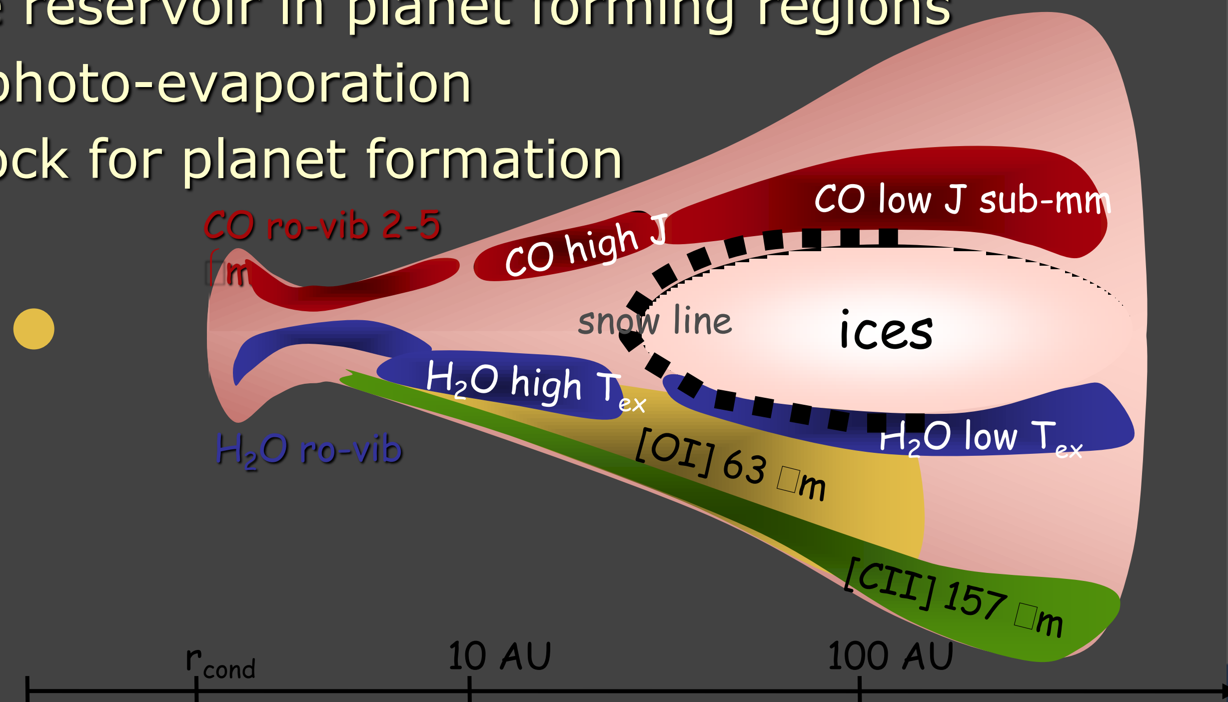
Dust life-cycle

- Where are dust grains formed?
- How are they processed?
- How do dust grains end their lives?
- How do galaxy properties impact on dust evolution?

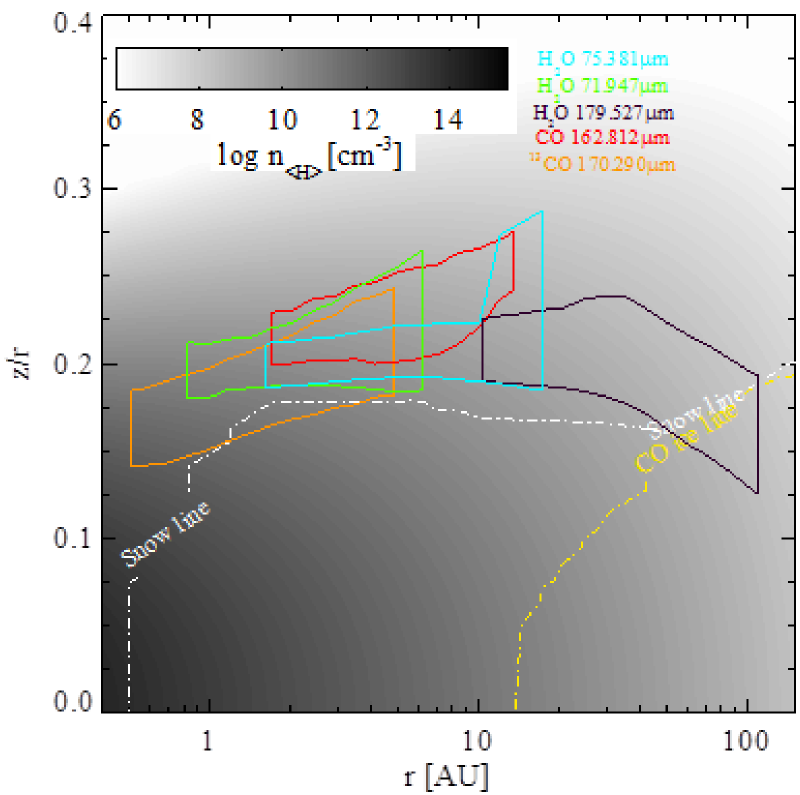
Star and Planet Formation and Evolution

Unique areas of planet formation to be studied with SPICA:

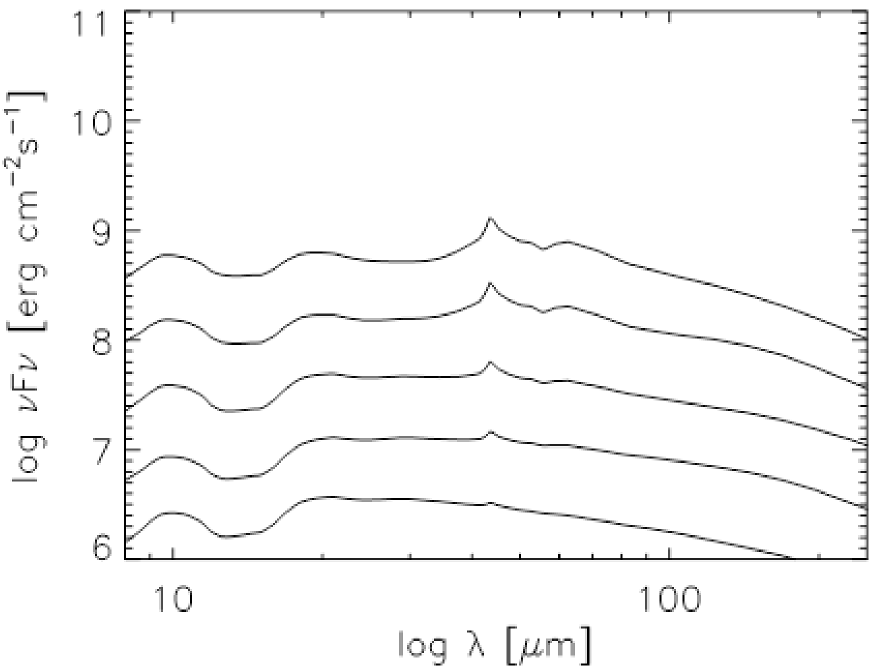
- The water trail → tracing the snow line
- From pristine dust to differentiated bodies
  → making the link to the Solar System
- The gas revolution:
  → measuring the reservoir in planet forming regions
- Gas dissipation and photo-evaporation
  → setting the clock for planet formation



The water trail – tracing the snow line



T Tauri disk model: Water gas lines scan the disc surface above the snow line (white dashed); colored boxes outline the region from which 50% of the line flux originate

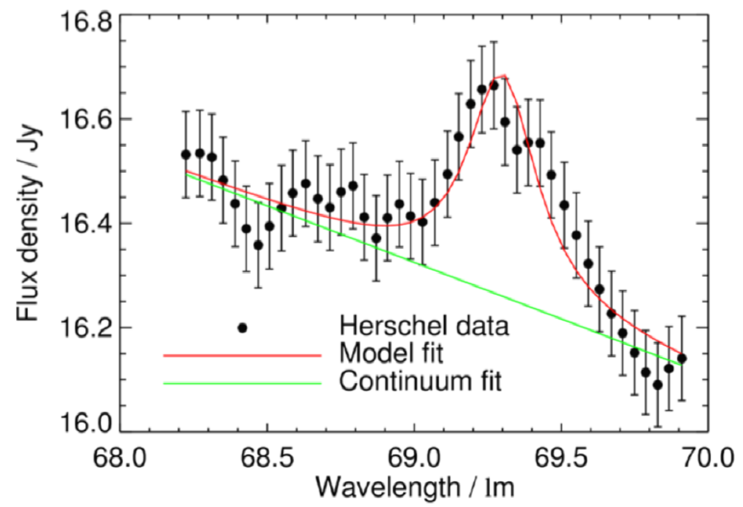


Simulated SEDs for T Tauri discs with varying fraction of icy grains (from bottom to top: 5, 10, 20, 50, 100%).

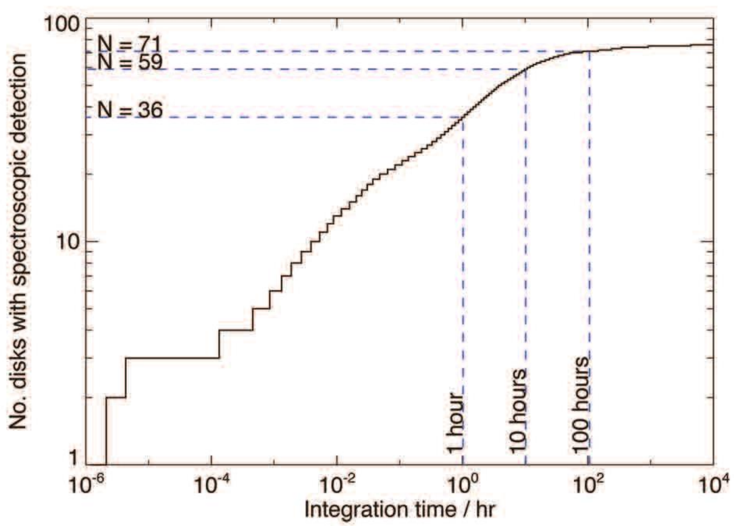
Mineralogy of debris discs

- The mineralogy of micron-sized dust particles in discs directly probes the composition of their parent bodies
- SPICA provides access to the far-IR resonances of several minerals, allowing a precise determination of their composition and structures
  - e.g. the 69 µm band of crystalline olivine
- The the composition of refractory dust in its exo-comets and make a direct comparison with our Solar System

69 µm feature for β-Pic (de Vries et al. 2012)

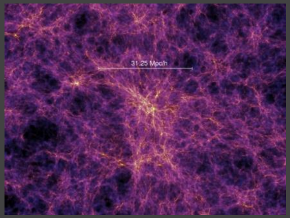


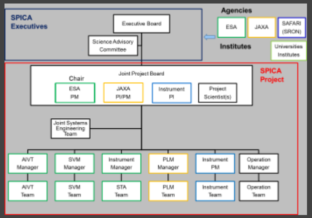
Predicted number debris discs with Forsterite detections with SAFARI as a function of survey time

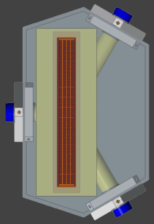


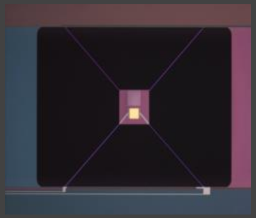
The mission as we see it now

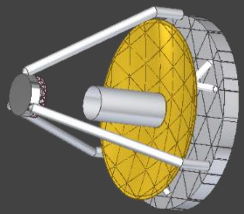
concepts and capabilities

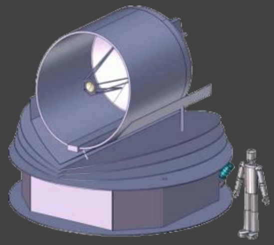












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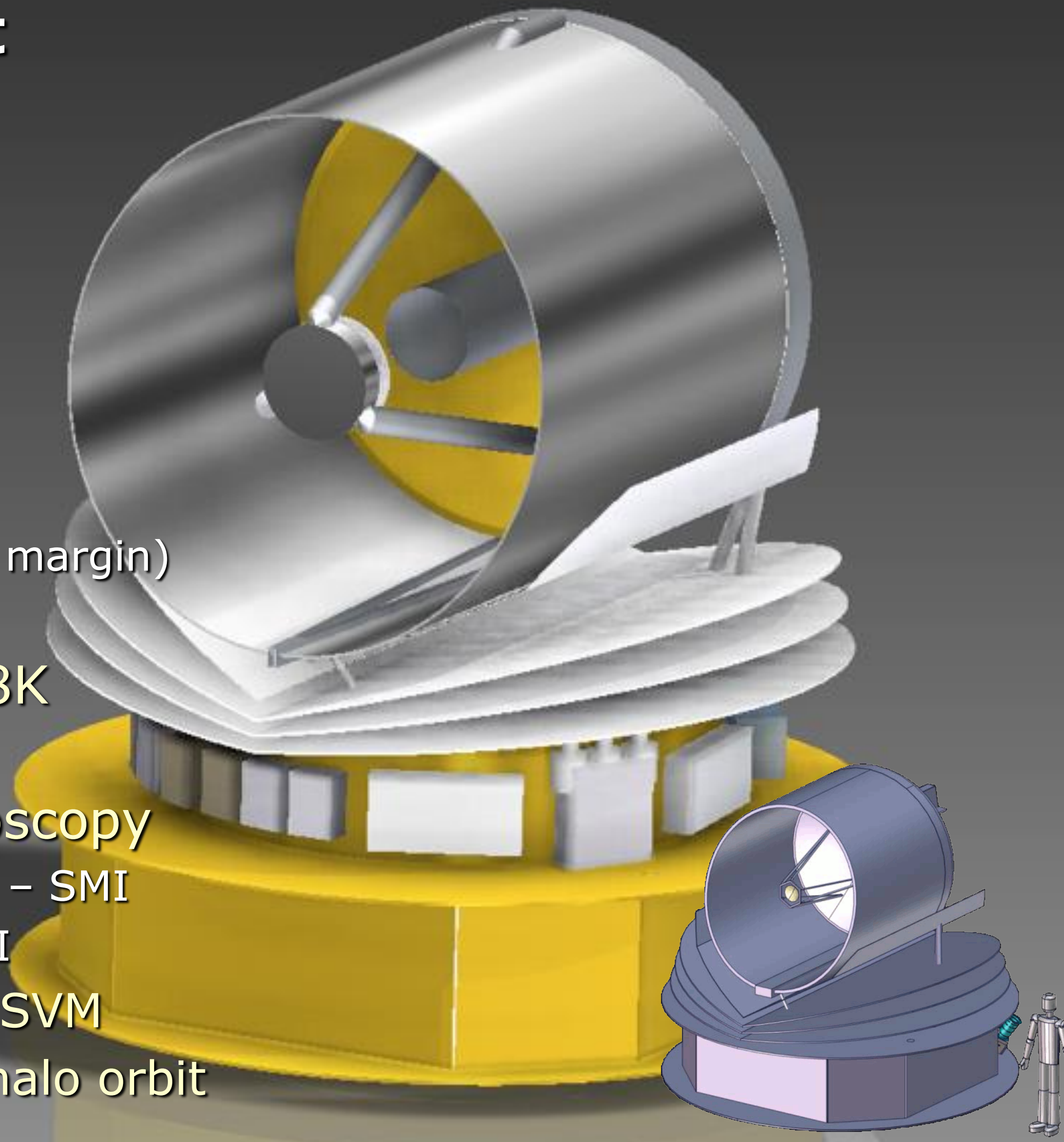
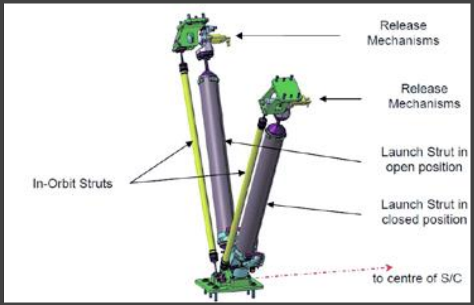
The mission concept

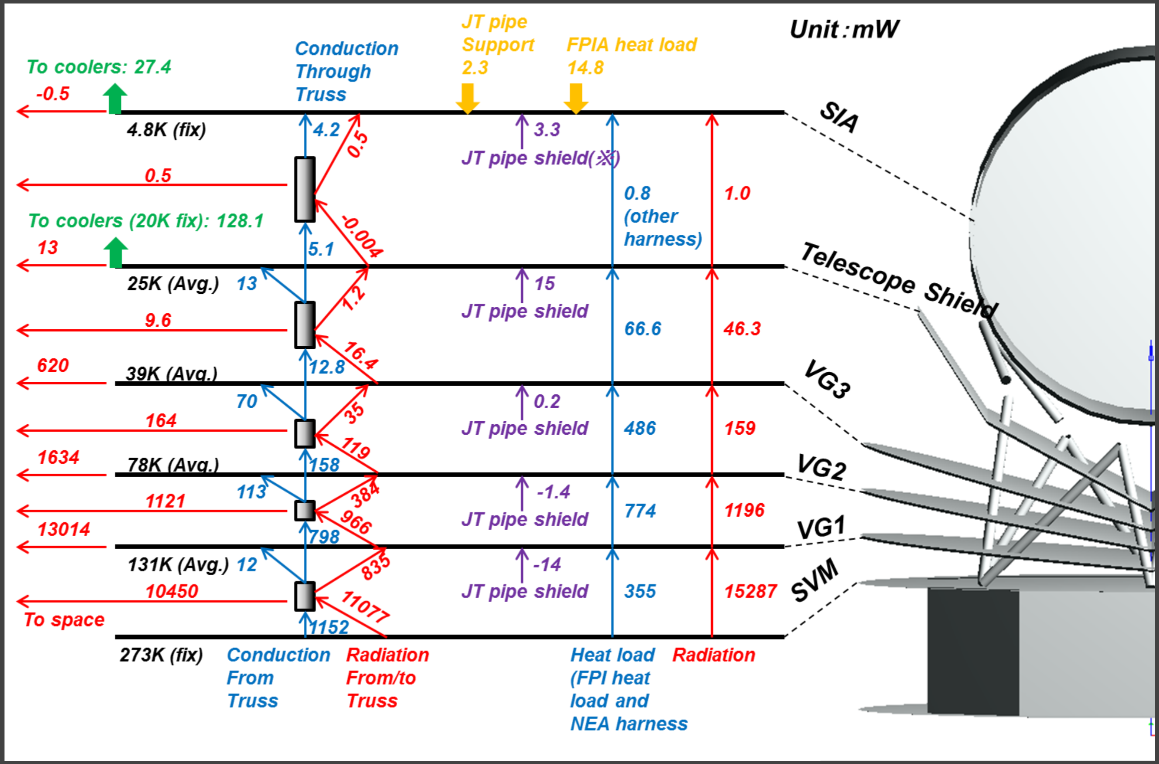


- ‘PLANCK configuration’
  - Size - Φ4.5 m x 5.3 m
  - Mass - 3450 kg (wet, with margin)
  - V-grooves
- 2.5 meter telescope, < 8K
  - Warm launch
- 12- 210/230 μm spectroscopy
  - MIR imaging spectroscopy – SMI
  - FIR spectroscopy – SAFARI
- ‘standard’ Herschel/Planck SVM
- Japanese H3 launcher, L2 halo orbit
- 5 year goal lifetime

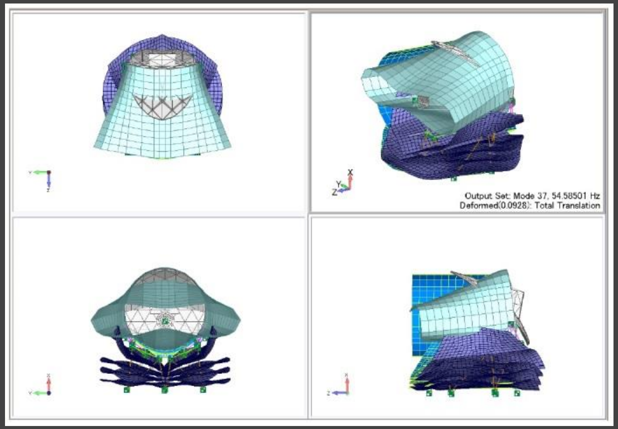
Thermal design – main elements



- V-grooves – passive cooling to 40K
- Active cooling to 4K and 1.7K
  - Detector modules at 50mK with dedicated mK coolers (SAFARI)
- Detachable support struts

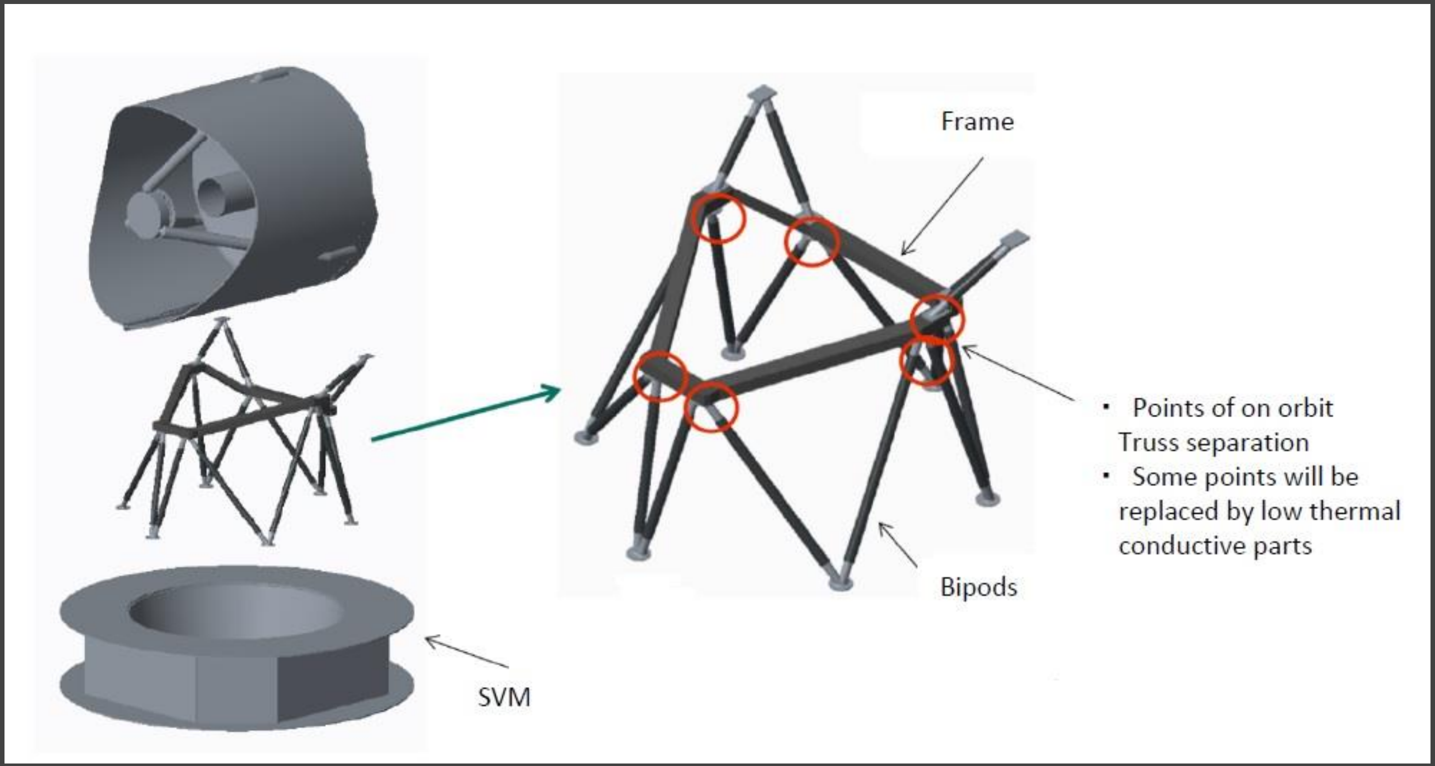


Telescope support structure

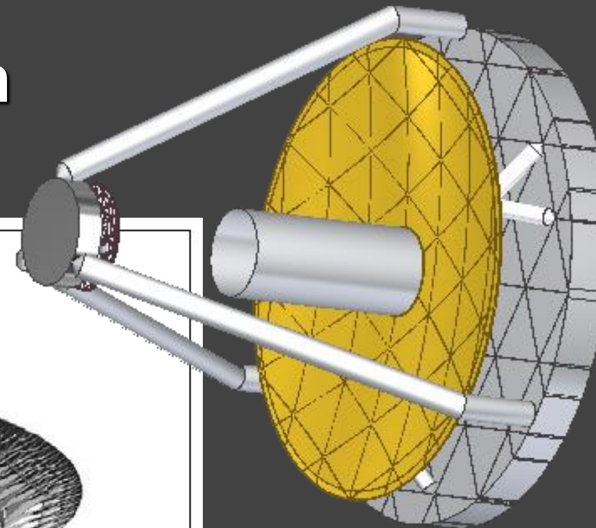


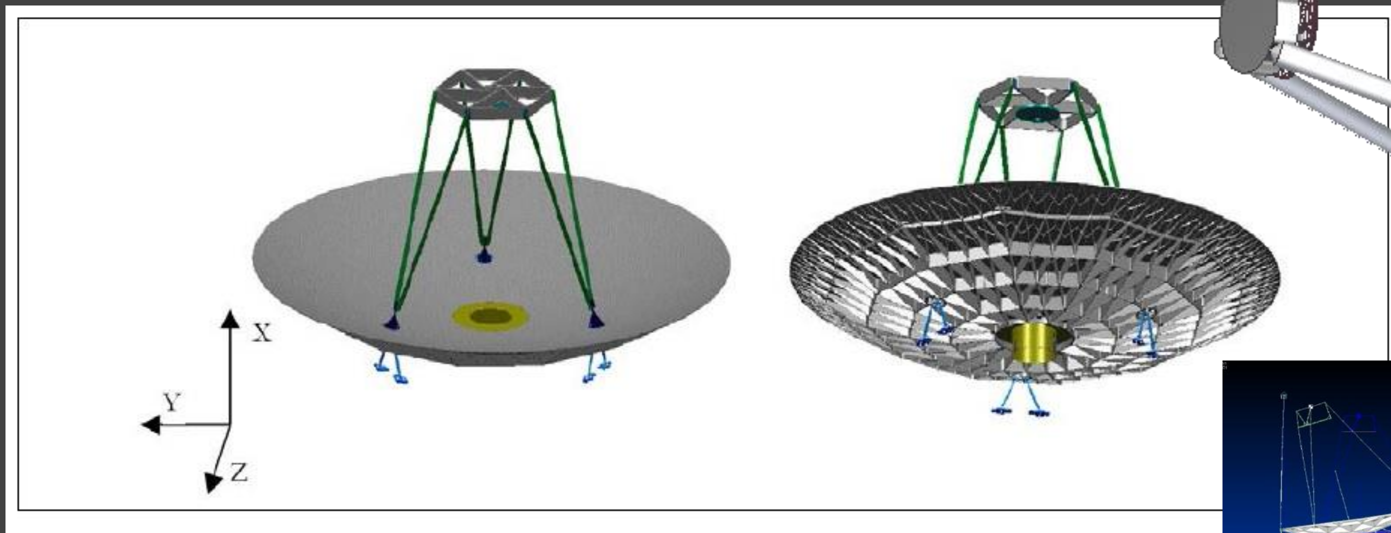
Structure analysis on-going

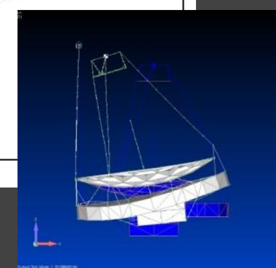
- Requirements different for launch as for in-flight → in space truss separation
- Further optimization: overall stiffness, thermal…

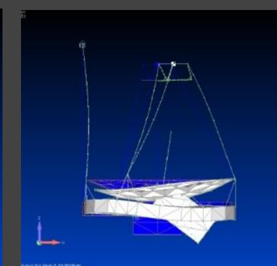


Telescope – 2.5m Ritchy-Chrétien



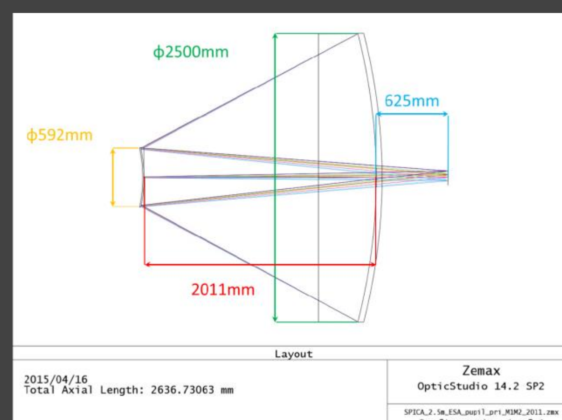


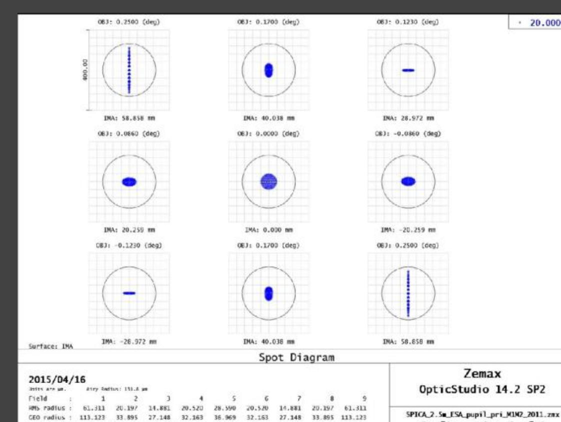




Herschel heritage

- ESA/industry studies
- Preliminary design:
  - M1: 2.5m F/1
  - M2: ~0.6m
  - M1-M2 distance ~2m





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Who provides what

Telescope (ESA)

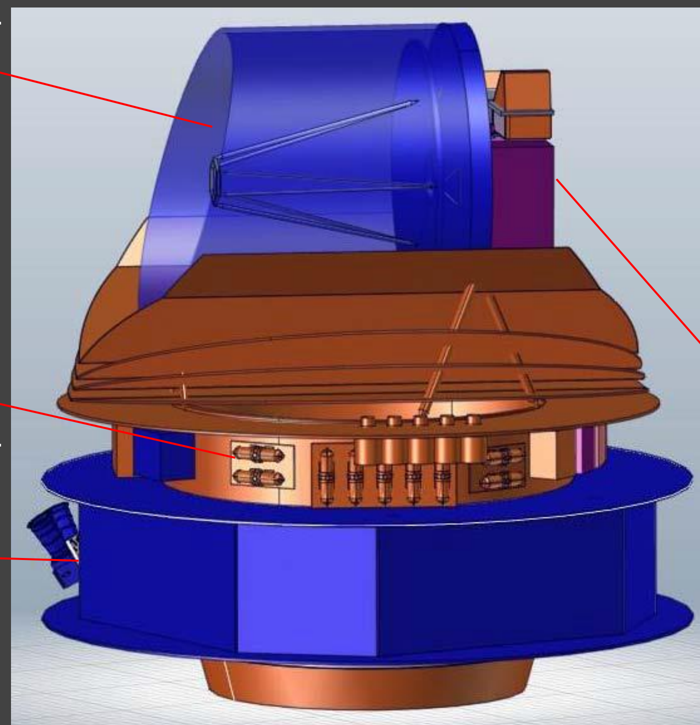
Payload Module

Cryocooler

Bus Module

Launcher

SPICA Data Center



Focal Plane Attitude Sensor

Focal Plane Instrument Assembly

FIR Spectrometer （SAFARI）

NL + European countries + Canada & US

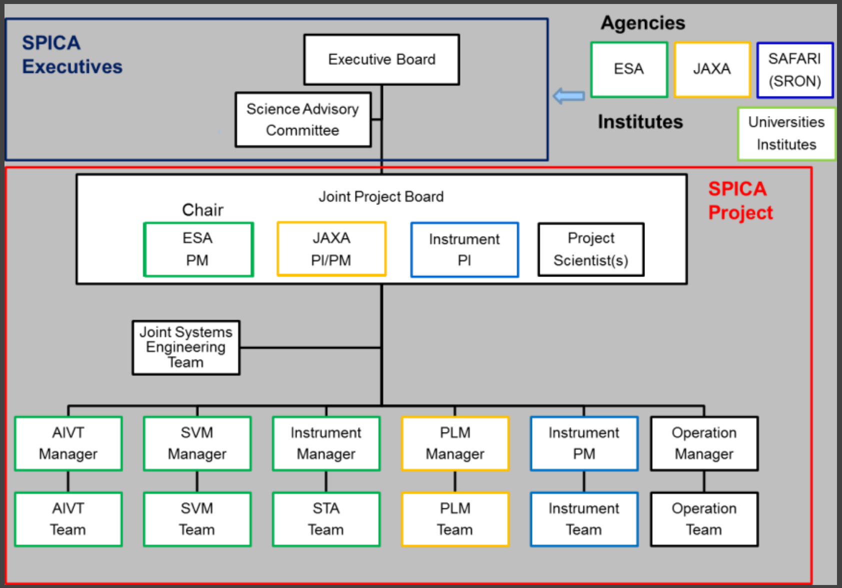
MIR Instrument（SMI）

Complexity in responsibilities and interfaces
→ challenging AIV program

Governance

- International mission → international oversight
  - Influence on project through SPICA executive board
  - Science advisory committee

- **Observing time** – mission will be open for **all astronomers**
  - Guaranteed v.s. open time details TBD
  - Use of e.g. 'Key projects' under discussion
  - Time Allocation Committee



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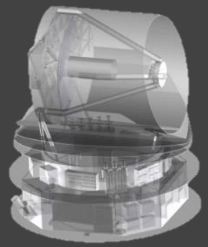
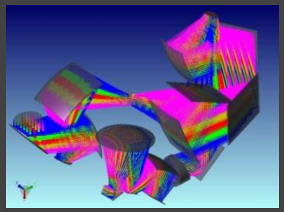
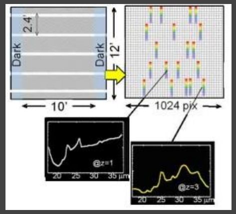
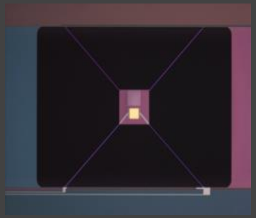
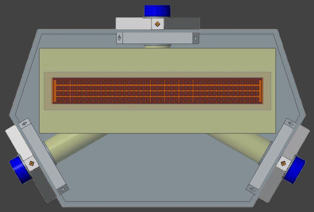
The SPICA instruments

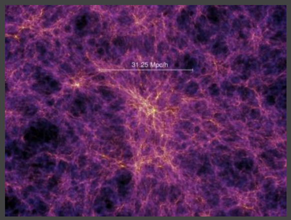




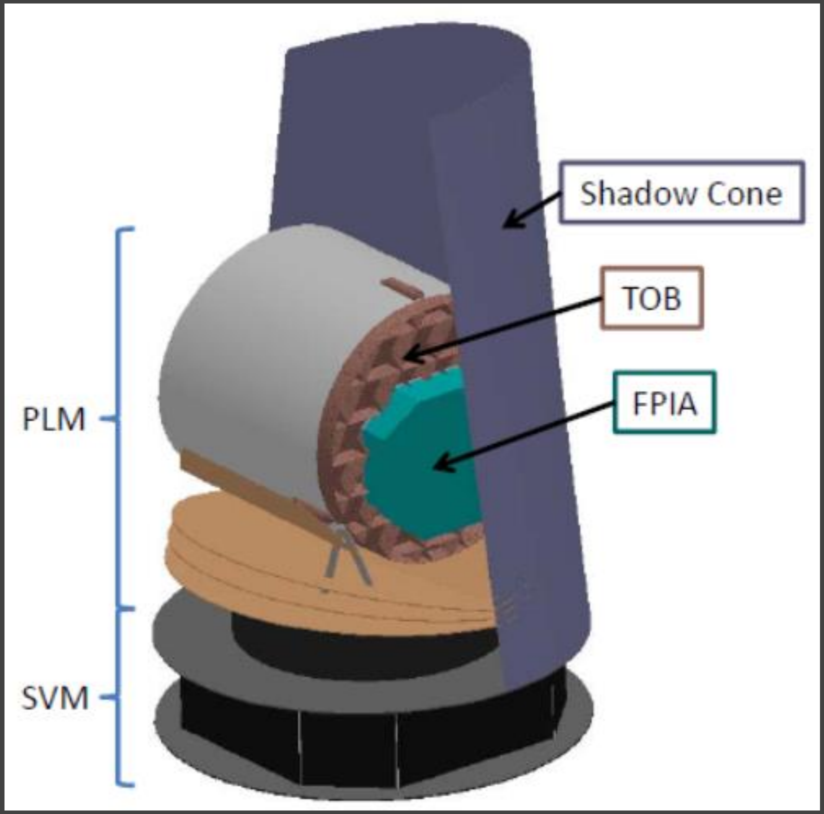


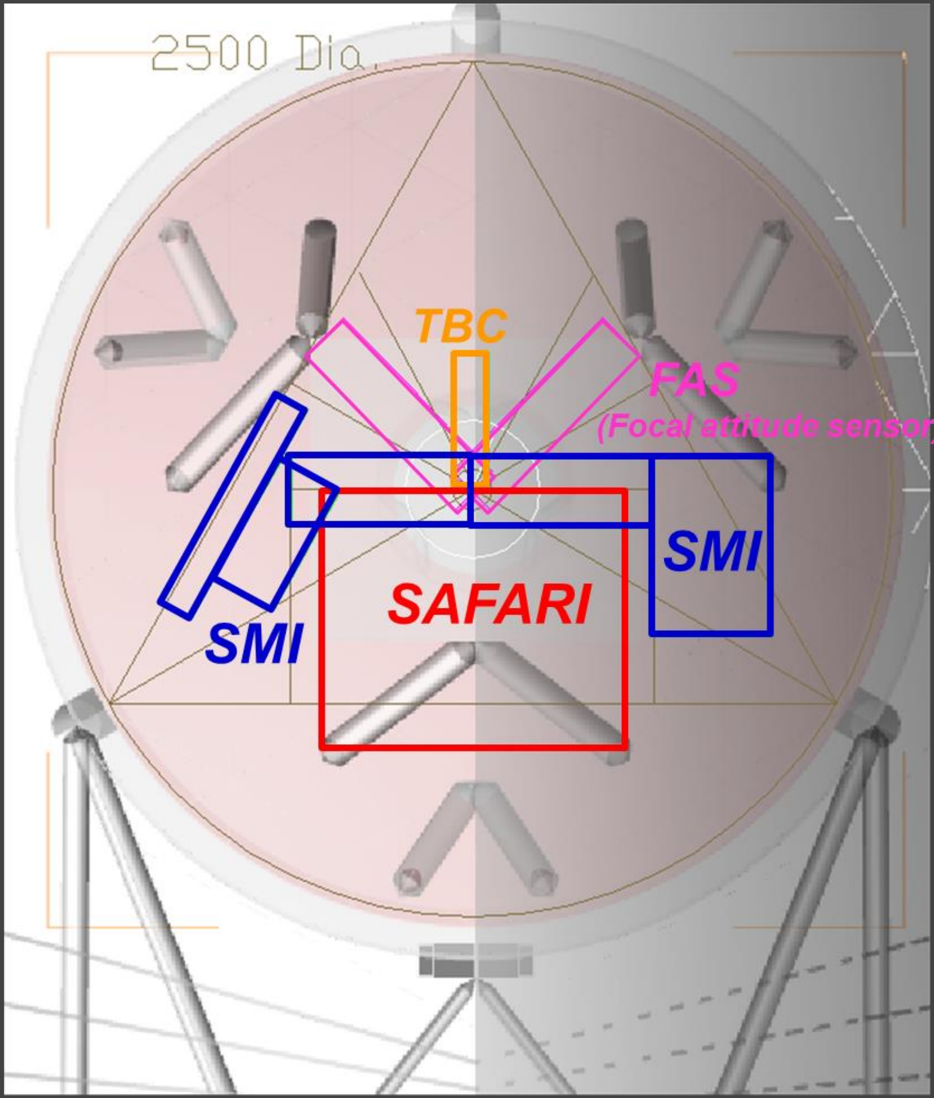






The instrument focal plane assembly





SPICA Mid-Infrared Instrument (SMI)

Japanese instrument

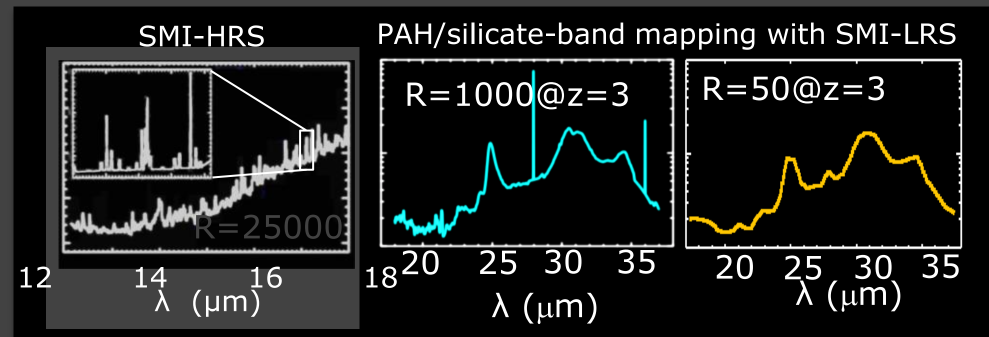
- Three spectrometers
  - λ~17 – 37 μm
  - R~50-26000
- 34 μm large area camera
  - FoV~10'x10'
- High performance spectroscopic mapping capability

Parameter		Function: Low Resolution Spectrometer (LRS)	Medium Resolution Spectrometer (MRS)	High Resolution Spectrometer (HRS)	Camera
Wavelength range		17 – 36 μm	18 – 36 μm	12 – 17 μm	30 – 37 μm
Spectral Resolution (point source)		50 – 120	1300 – 2300	25000 – 26000	N/A
Field of View		600"x 3."7 x 4 slits	60" x 3."7 (slit)	4"x1."7 (slit)	10' x 10' (slit viewer)
FWHM		2" – 3.7"	2" – 3.7"	2"	3.4"
Pixel scale		0.7"x 0.7"	0.7"	0.5"	0.7"x 0.7"
Point source	**Limiting flux density (1 hr, 5σ)**	20 – 140 μJy	200 – 4000 μJy	2 – 4.2 mJy	25 μJy
Point source	**Limiting flux (1 hr, 5σ)**	(6 – 23) x 10^{-20} W/m^2	(3 – 40) x 10^{-20} W/m^2	(1.5 – 3) x 10^{-20} W/m^2	
Diffuse	**Sensitivity (1 hr, 5σ)**	**Continuum**	**Line**		**Continuum**
Diffuse		0.1 – 0.5 MJy/sr	(0.5 – 2) x 10^{-9} W/m^2/sr	(4 – 8) x 10^{-10} W/m^2/sr	
Saturation limit		~ 2 Jy	~ 140 Jy	~ 1200 Jy	~2

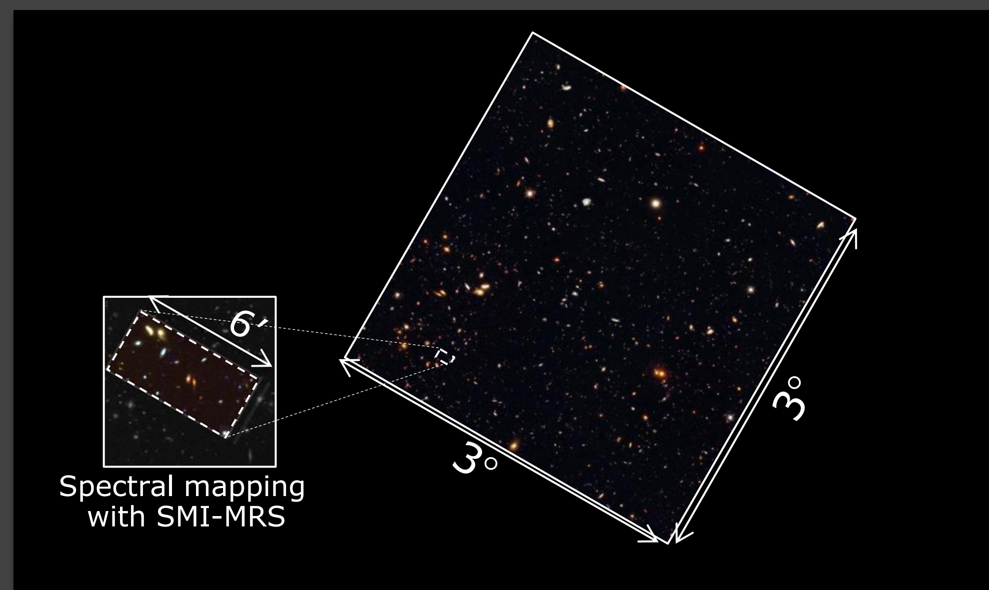
SPICA Mid-Infrared Instrument (SMI)

Spectroscopic mapping performance

- LRS – 27 arcmin^2/hr
- MRS – 1.5 arcmin^2/hr
- $\Delta S_{5\sigma 1hr}$~100 μJy
- $\Delta F_{5\sigma 1hr}$~$3x10^{-19}$ Wm^{-2}



Simultaneous photometric mapping with LRS and MRS



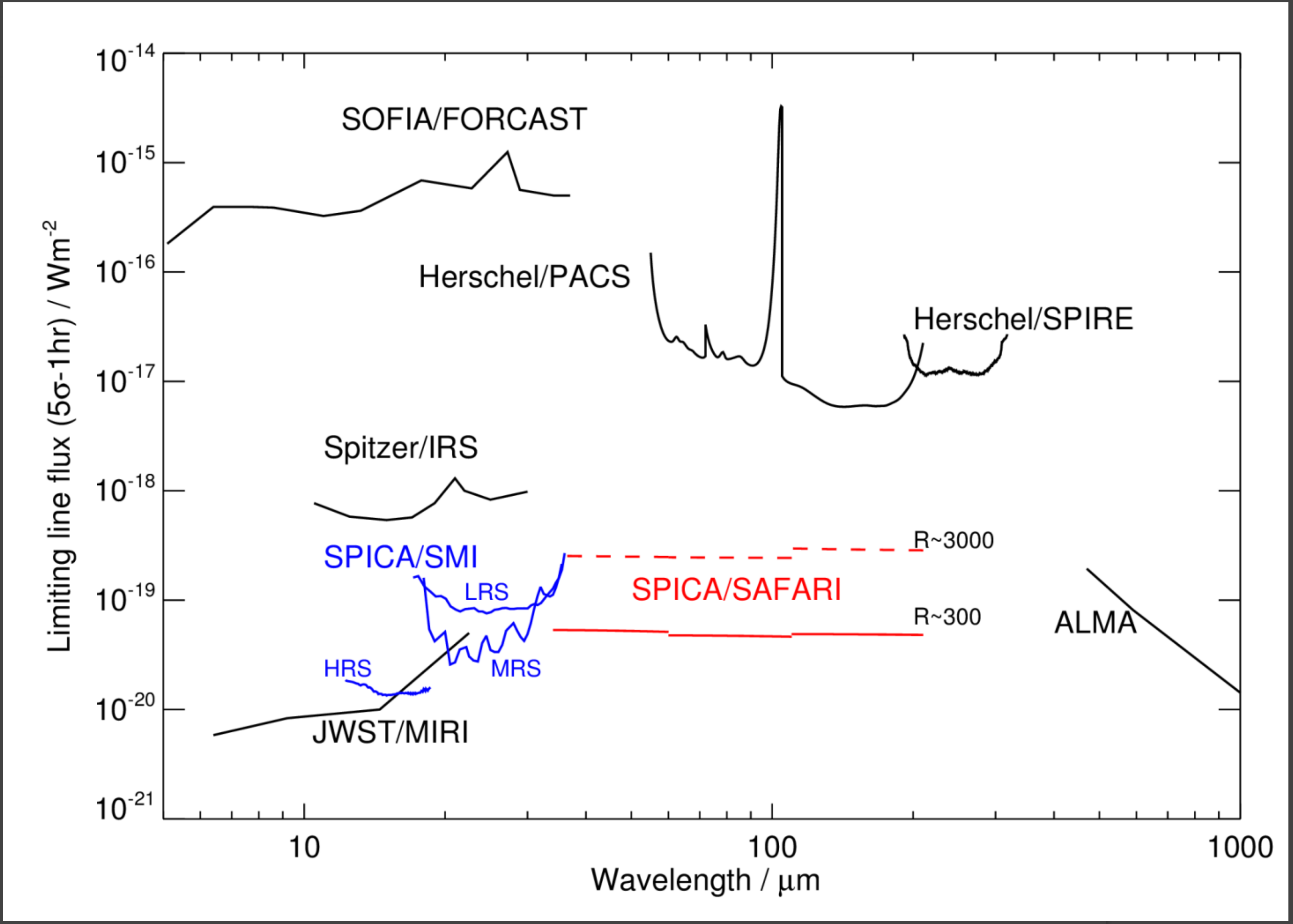
SPICA Far-Infrared Instrument (SAFARI)

European instrument

- Three/four (TBD) band grating spectrometer
- Continuous spectral coverage from 35-230 µm
- Two spectral resolution modes
  - Nominal – R~300
  - High resolution – R~3000
- Spectral mapping capability within 2'x2' FoV per pointing

	Parameter	Waveband		
		SW	MW	LW
	Band centre / µm	47	85	160
	Wavelength range / µm	34-60	60-110	110-210
	Band centre beam FWHM	4.7″	8.6″	16″
Point source spectroscopy (5σ-1hr)				
R~300*	Limiting flux / x10^{-20} Wm^{-2}	5.3	4.5	6.5
R~300*	Limiting flux density / mJy	0.25	0.36	0.92
3000*	Limiting flux / x10^{-20} Wm^{-2}	25	24	29
Mapping spectroscopy ** **(5σ-1hr)**				
R~300*	Limiting flux / x10^{-20} Wm^{-2}	59	28	22
R~300*	Limiting flux density / mJy	2.8	2.3	3.0
3000*	Limiting flux / x10^{-20} Wm^{-2}	340	190	120
Photometric mapping ** **(5σ-1hr)**				
	Limiting flux density / mJy	0.15	0.12	0.16

SPICA sensitivity – a huge step forward



Raw sensitivity improvement >2 orders of magnitude

Instantaneous full spectra → huge step in efficiency

SAFARI

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Dreams - what we also think about

- Hold your horses!!

…we are very much **resource limited**:

Thermal **– mass – power**

…but we might want to

- Extend the (SAFARI) wavelength coverage
  - how important is the 210-350/400 μm domain?

- Do imaging/polarimetry in the Far Infrared?
  - What are the best wavelengths?
  - France/CEA group looking into this

→ *what are the* ***overwhelming science questions*** *here?*

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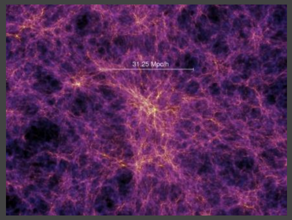
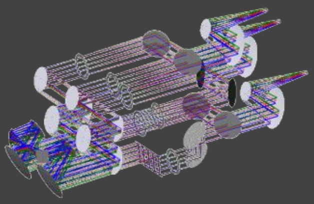
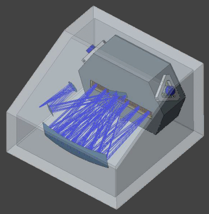
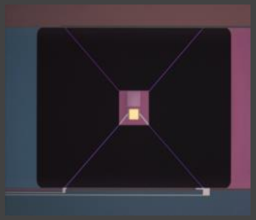
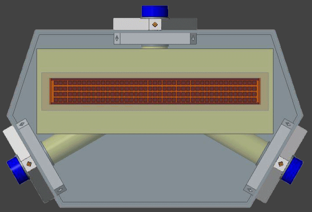
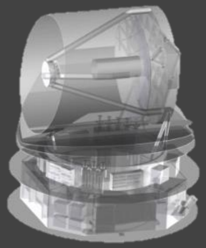
The SAFARI grating spectrometer

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The new concept

Original plan:

- Imaging Fourier Transform Spectrometer
  - Fast/efficient large area spectroscopic mapping

    …but: limited in maximum sensitivity due to photon noise

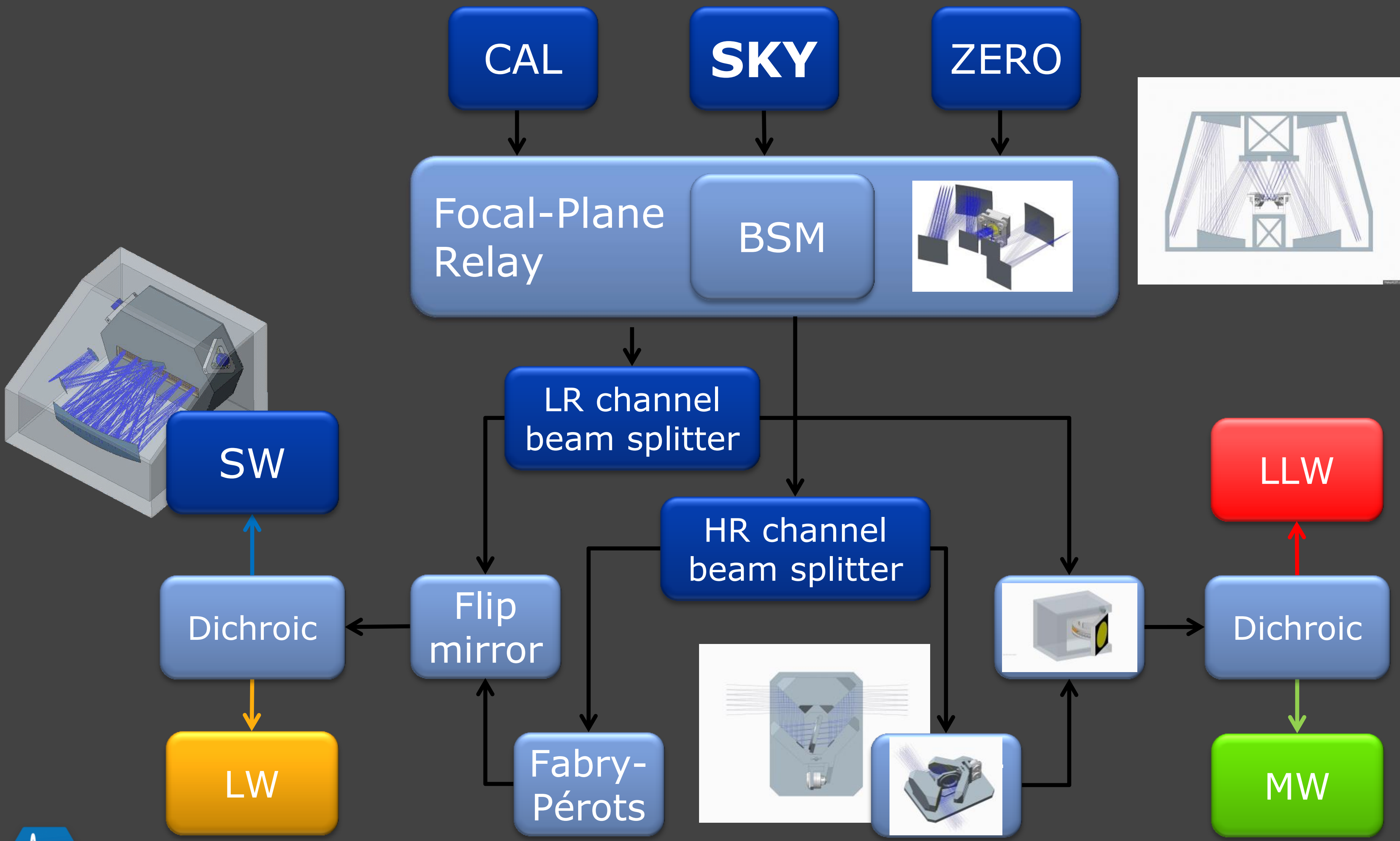
    Best achievable 1hr/5σ ~2-3×10^{-19} W/m2 ($6m^2$)
    - Independent of TES performance!

New approach to **achieve better sensitivity**:

- Grating based spectrometer
  - Basic R~300 mode → 1hr/5σ ~**4-6×10^{-20} W/m^2** ($6m^2$)
    - Improves with better TES performance!!
  - FP enhanced R~3000 mode
  - 3/4 bands covering 35-210/(230) micron

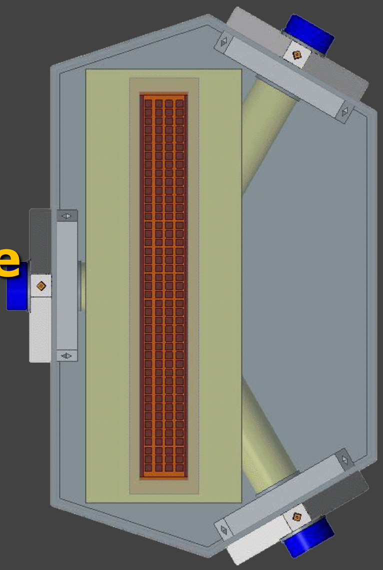
    …but: limited imaging capability: only 3 pixels on-sky

General concept – work in progress

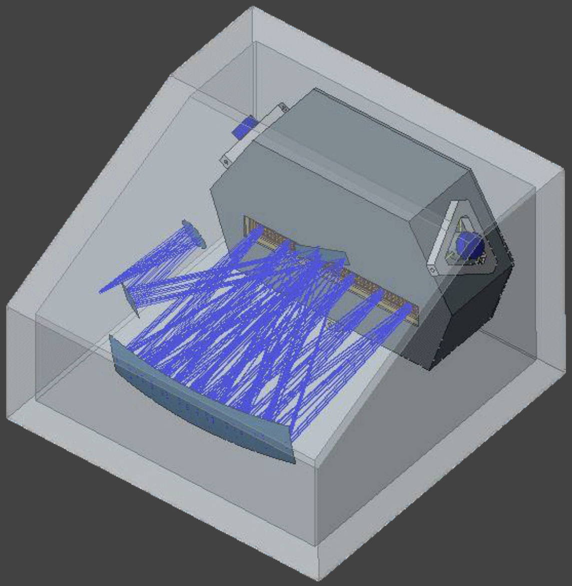


Basic components

- Detectors – linear TES arrays with FDM readout
  - Builds on **already achieved** TES/FDM **performance**
  - Profits from continued TES **improvement**
  - Shielding etc. → same issues as before
  - Cooler – same number of detectors
    → original SAFARI cooler approach applies
  - Detector footprint/layout being optimized

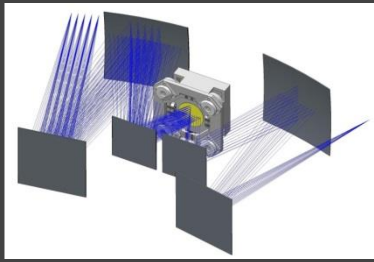


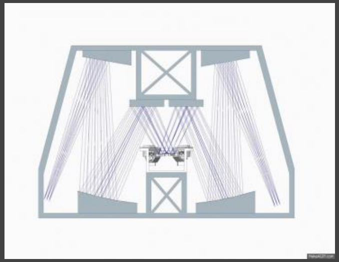
- Redesigned integrated FPA/Grating unit
  - Grating optics at 1.7K
  - **Shielding integrated** in structure
  - Detector modules suspended inside at 50mk
  - Volume… is becoming large (that is a worry)



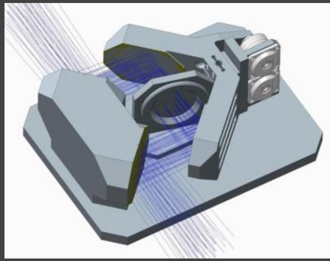
A glimpse of the hard work…

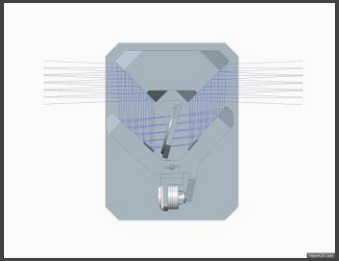
- Beam steering mirror
  - SPIRE heritage



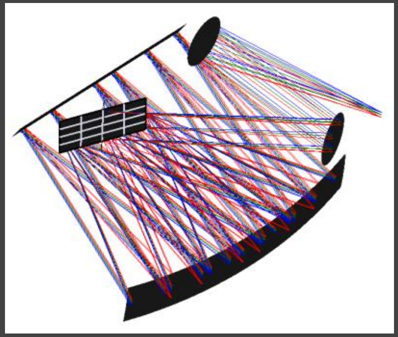


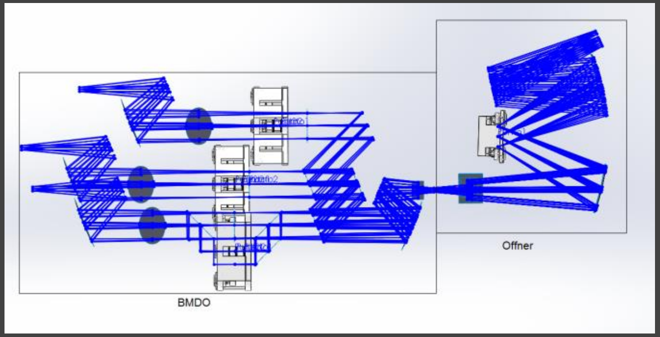
- High resolution channels
  - FP and selector switches -ISO heritage
  - Option is to use Martin-Puplett interferometer is under investigation
    - Single unit i.s.o. 4 FP's
    - Improved sensitivity





- Optics design ongoing





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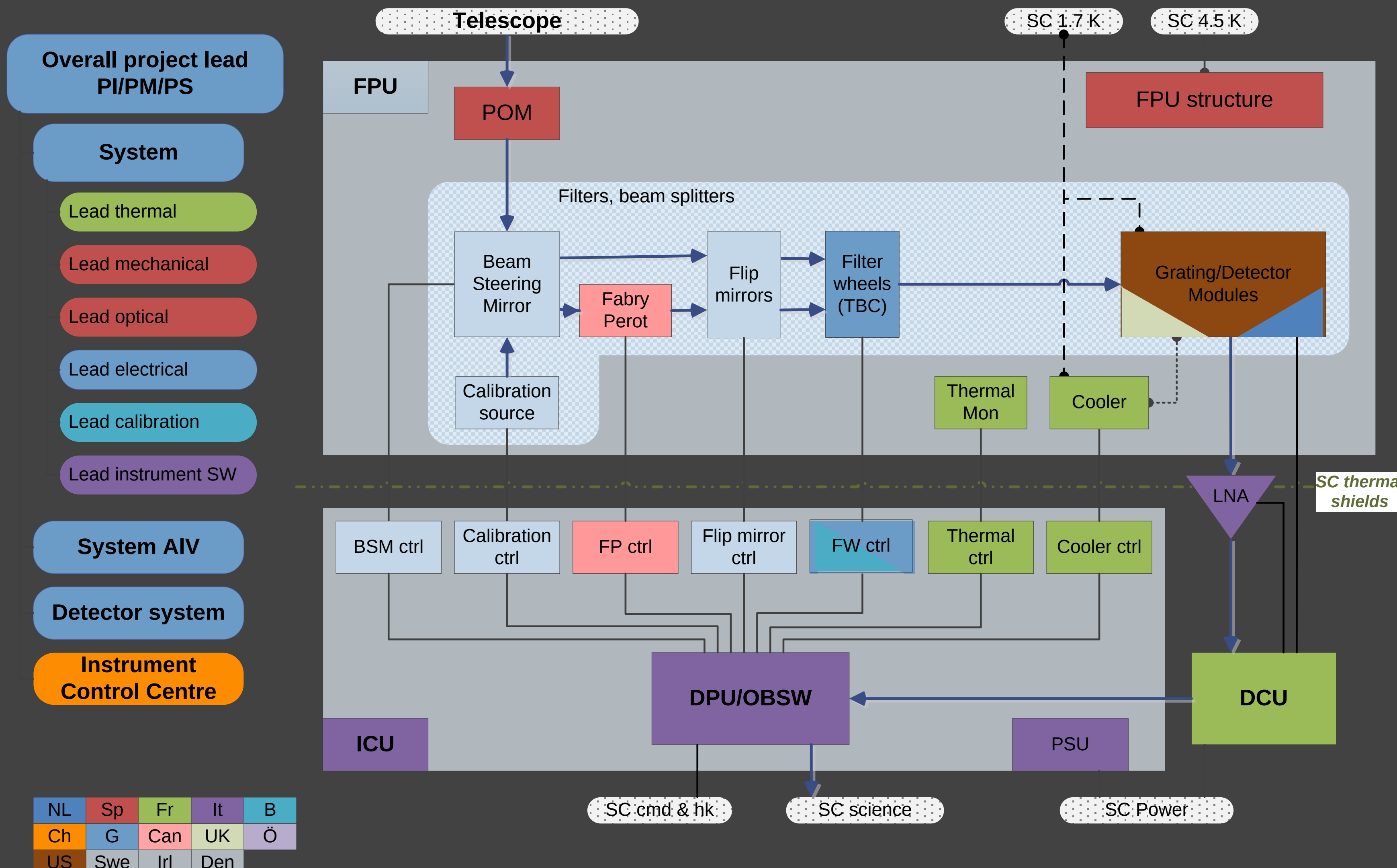
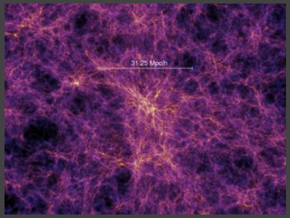
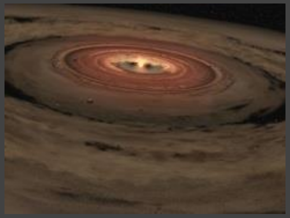
Who could do what....

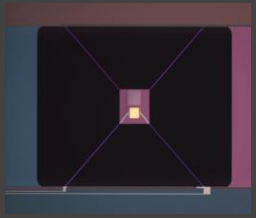


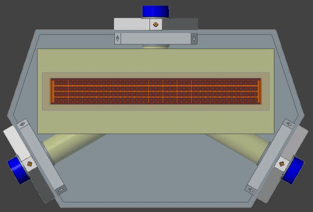
The SAFARI consortium – keeps on going…!

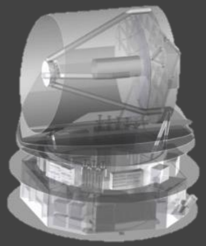
The programmatic context and the outlook











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Mission Status

- Mission well defined
  - Spacecraft elements, responsibilities
  - Instrument complement in final iteration
- Europe: consortium preparing M5 proposal
  - Joint ESA-JAXA mission
  - European instrument - SAFARI
  - M5 timeline (TBC)
    - Call ~ April, proposal submission ~August
    - Mission candidate selection ~ February/2017
    - Mission final selection late 2018/early 2019
    - Launch ~2029
- Japan: SPICA has passed the Mission Definition Review
  → SPICA officially in 'Pre-project' phase (~phase A)
  - Japan **will support** an ESA SPICA mission at the ~300M$ level

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M5 SPICA mission proposal

- Mission will be proposed as an ESA M5 mission candidate
  - Lead by the SAFARI consortium
  - The proposal is **now** being put together
  - The SPICA team is **very open** to new membership from interested members of the community
- Proposal team **spica@sron.nl**
  - Lead – Peter Roelfsema *p.r.roelfsema@sron.nl*
  - Lead/Japan – Hiroshi Shibai
    - Lead technical – Willem Jellema/Takao Nakagawa
    - Lead SMI – Hidehiro Kaneda
  - Science teams
    - Star and planet formation/evolution – Inga Kamp, Marc Audard
    - Nearby galaxies – Sue Madden, Floris vd Tak
    - Galaxy evolution – Luigi Spinoglio, Lee Armus

Summary

- SPICA: a mid-far infrared space observatory
  - 2.5 m diameter mirror, actively cooled to 8 K

    → ***unprecedented sensitivity*** in ***mid/far IR***

- SPICA will focus on spectroscopic observations of the obscured universe, spanning the gap between JWST and ALMA

- SPICA will be submitted as a candidate for ESA's 5th M-Class mission slot – call expected early 2016

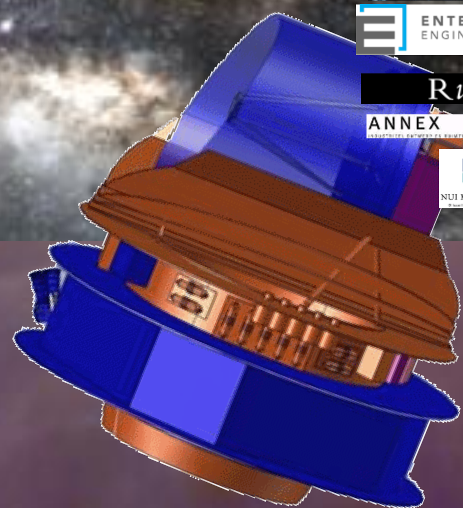
- SPICA supporters/joiners? - register by email at **spica@sron.nl**

..or contact me – p.r.roelfsema@sron.nl

UK lead: Matt.Griffin@astro.cf.ac.uk

the next generation
SPICA

The next generation SPICA



www.sron.nl/SAFARI - **SPICA@SRON.nl**