A joint infrared space observatory: SPICA revised and upgraded

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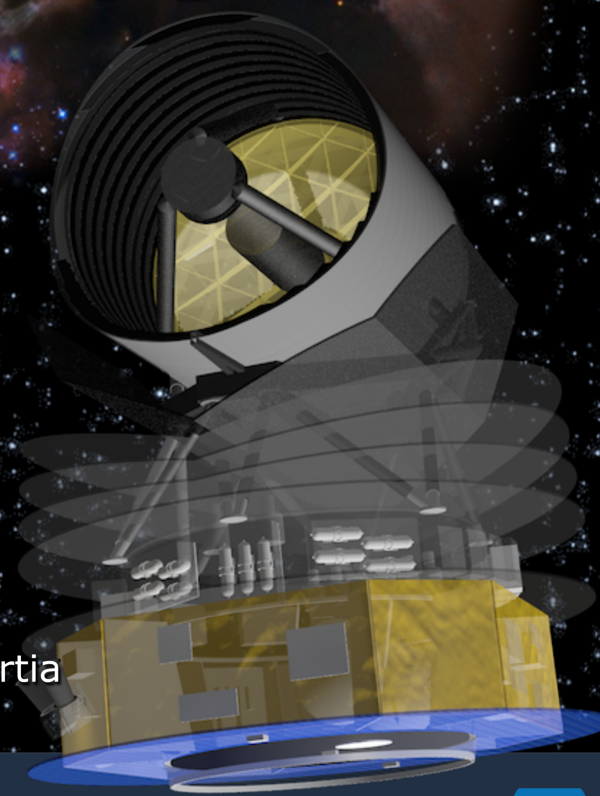


Netherlands Institute for Space Research
Netherlands Organisation for Scientific Research

SPICA SAFARI

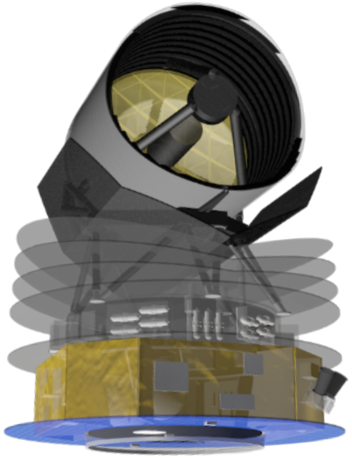
Contents

- 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
  - Satellite concepts
  - Instruments, capabilities

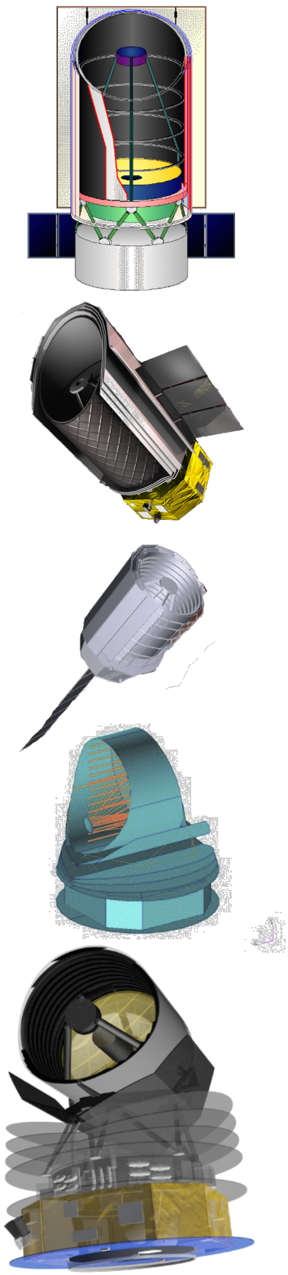
- Project status
  - M5 proposal is submitted !!



Some history – SPICA

- 1995-2000 Japanese HII/L2 project
  - Cryogenic telescope as follow up for after (then) FIRST
- 2007 – M-class JAXA mission with ESA telescope
  → Yellow book, ESA telescope studies
- 2010 – HIIB to HIIA launcher → smaller telescope
- 2011/2012 – ‘Risk Mitigation Phase’
  - Good plan, but too big for Japan alone
    → ESA partnership needs to increase
- 2014 – joint JAXA/ESA CDF mission study → M5 concept
  - Mission lead moves from Japan to Europe
- 2015 – Japan passes Mission Definition Review

next: European/Japanese proposal for ESA/M5

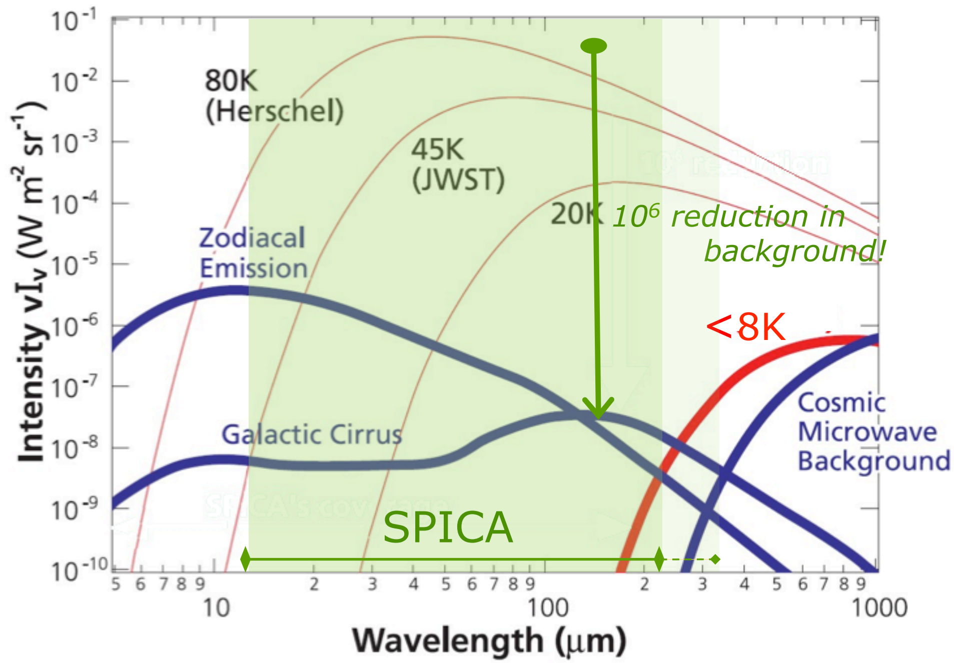


The SPICA ‘sweet spot’ – the dusty universe

A unique observatory

looking through the veils, enabling

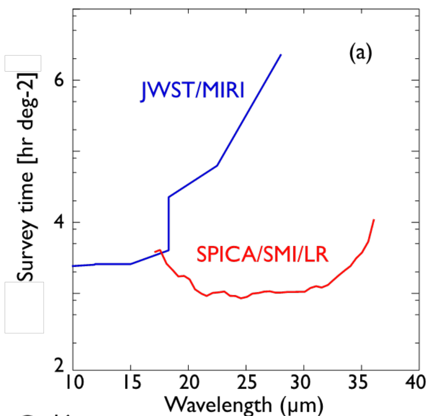
transformational science

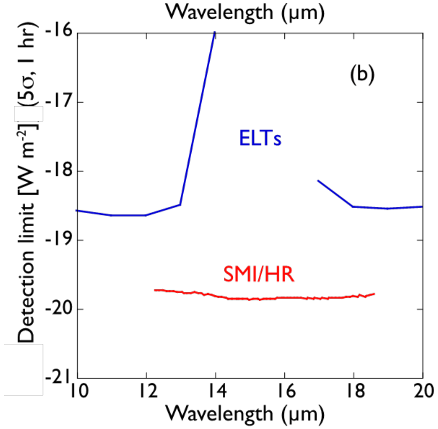


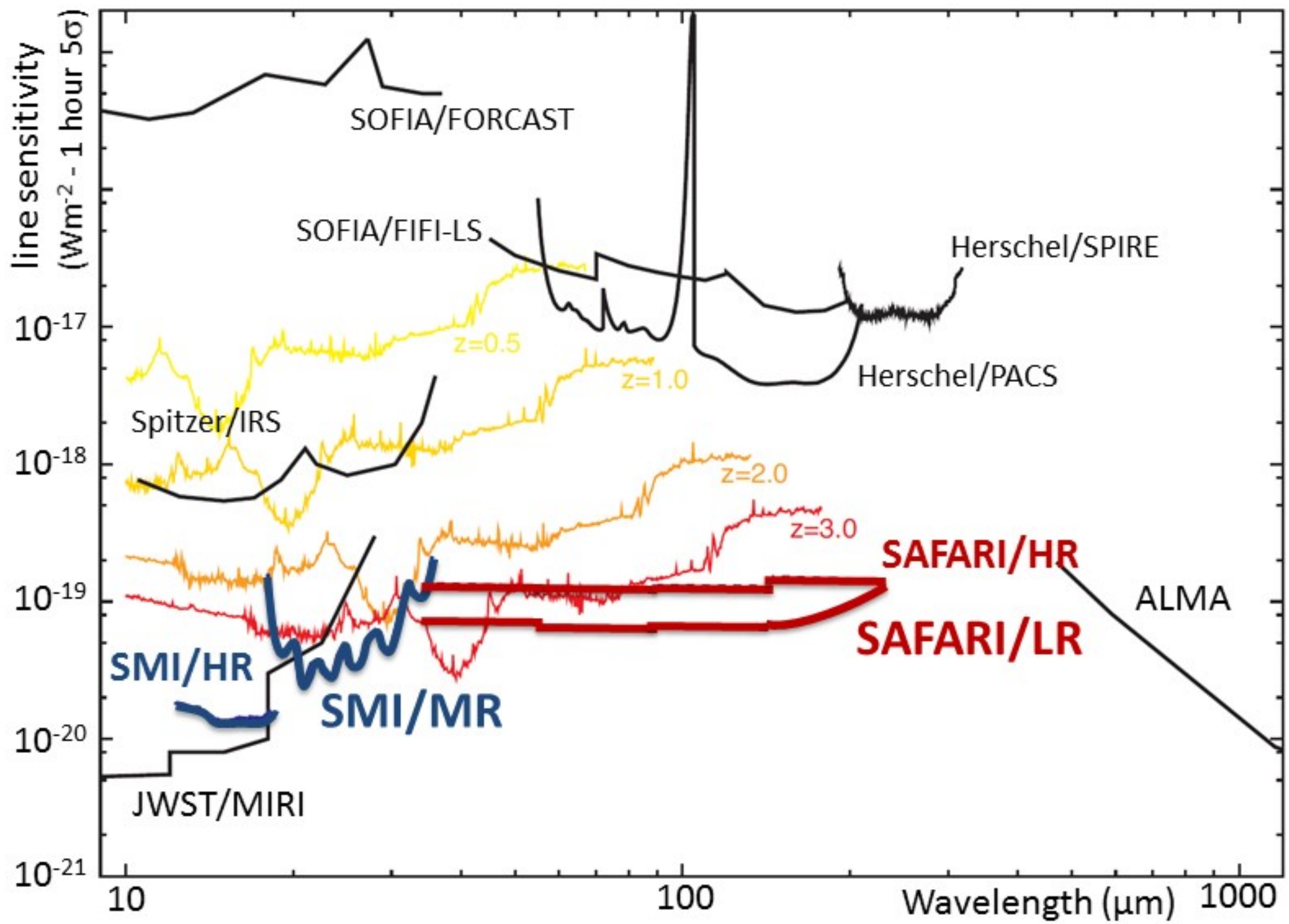
What is so unique?

- 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
  fill the blind spot between JWST and ALMA @ R~ few 1000

SPICA sensitivity/speed – a *huge* leap forward



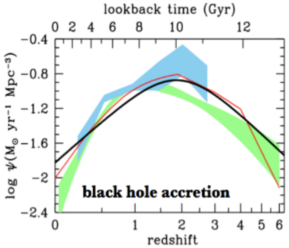


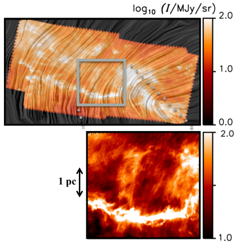


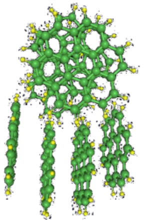
Raw sensitivity improvement ***>2 orders*** of magnitude
Instantaneous full spectra → huge step in efficiency

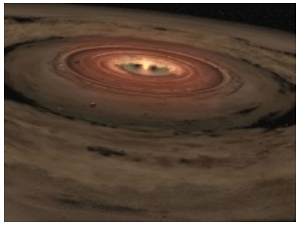
SPICA’s science

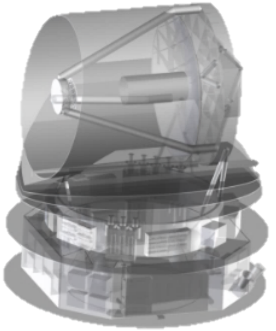
M5; unveiling dusty matter in the universe











Science Objectives – mission design drivers

Major science questions that require SPICA*

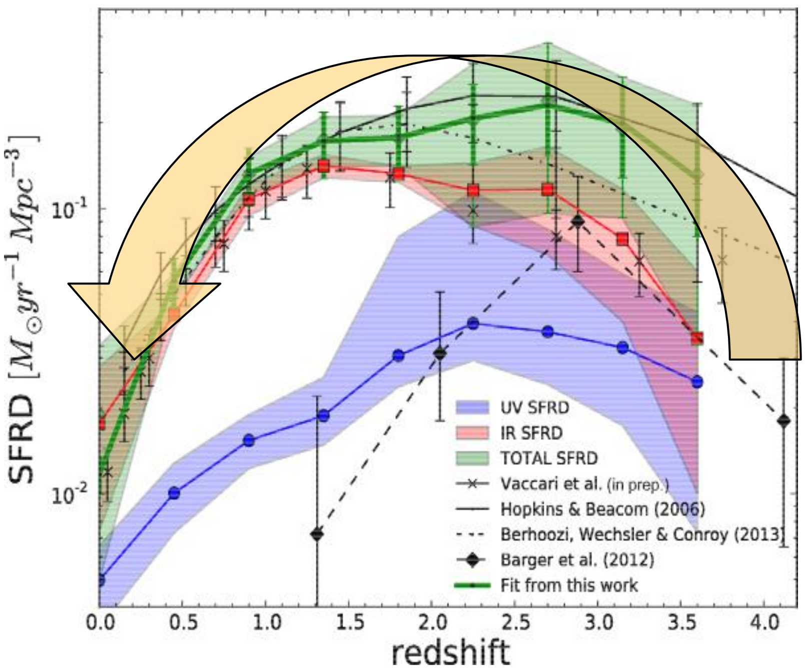
- What processes govern **star formation across cosmic time** - what starts it, controls it, and stops it?
  - What are the major physical processes in the most obscured regions of the universe?
  - How is this related to the enrichment of the universe with metals?
- What is the **origin** and composition 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**?

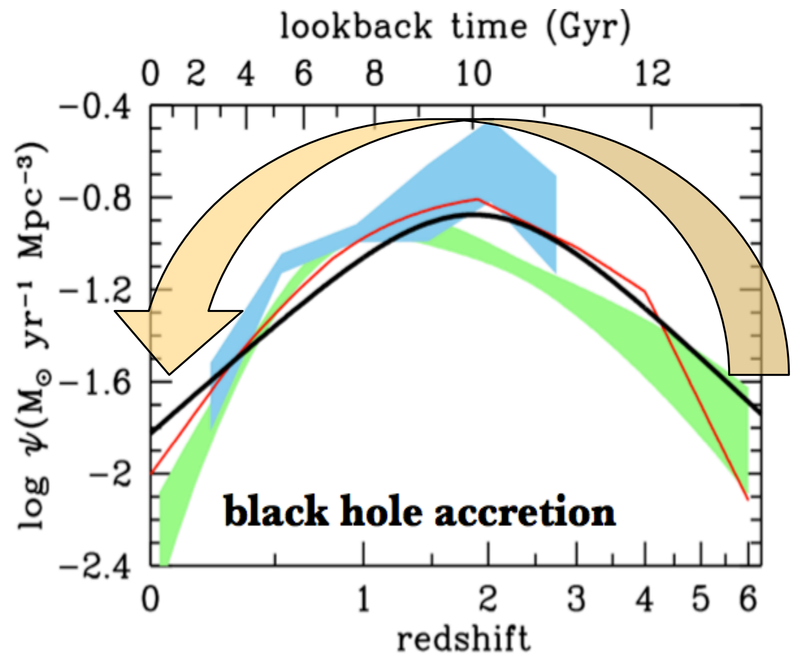
Established over the last few years by the joint Japanese-Canadian-European-US science team, including community inputs through various workshops

* *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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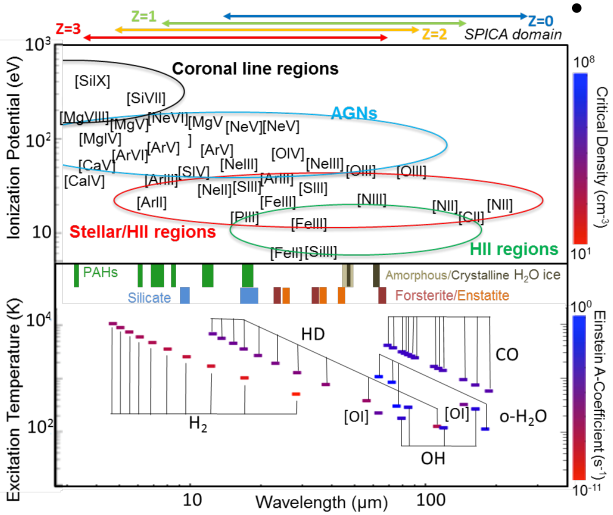
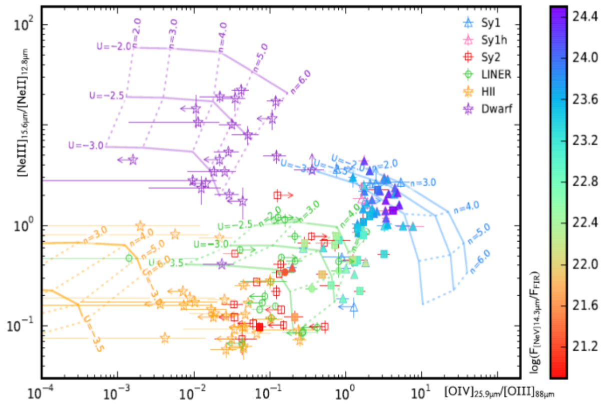
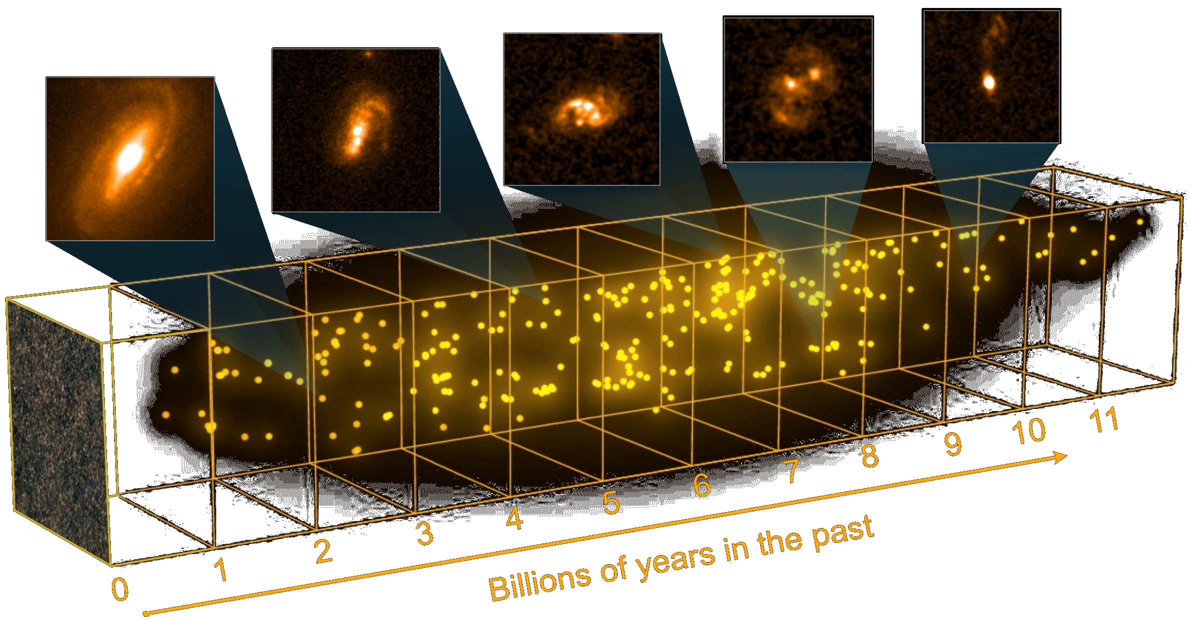
Evolution of IR-luminous galaxies



- FAR-IR diagnostic tools
  - Line-ratios → physical state of dust and ionised gas
  - Line profiles → outflow/infall, cycling of matter
  - Line strengths → metal enrichment
  - Discriminate between Active Galactic Nucleus and star-formation





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

…SPICA ***measures physical conditions*** *10Bn years ago*

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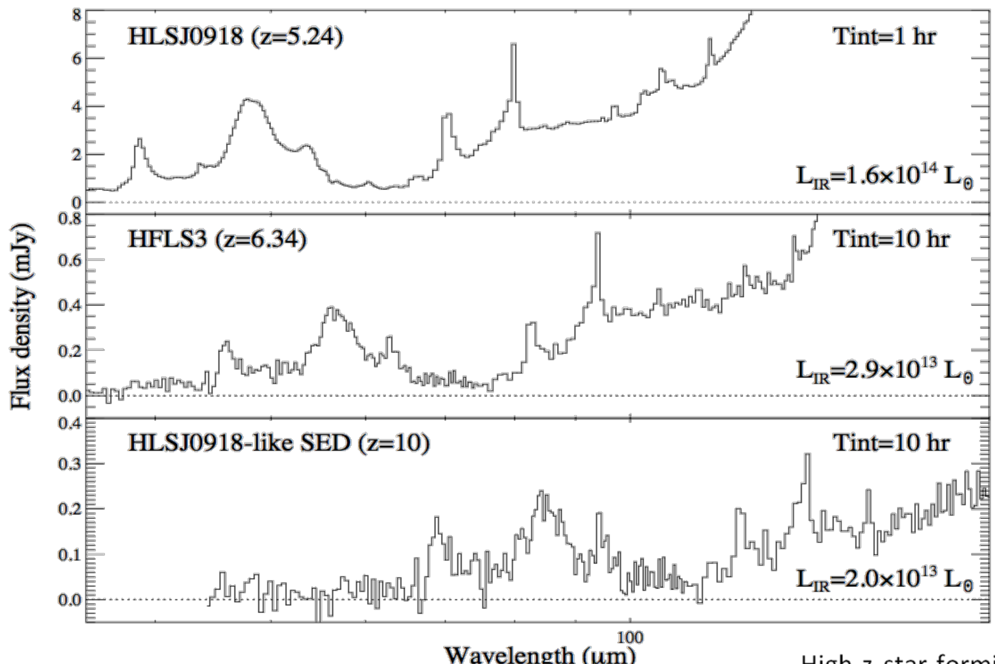
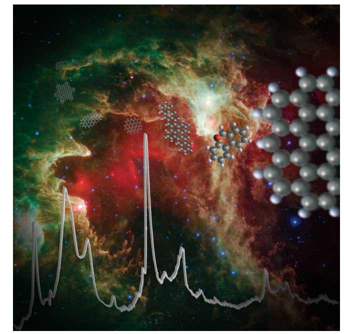
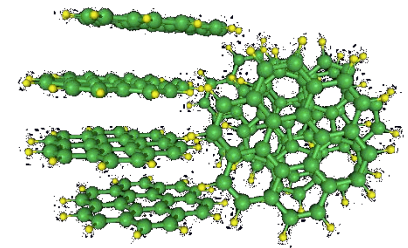
Nature of the first dust – PAH's at ~1 Bn year





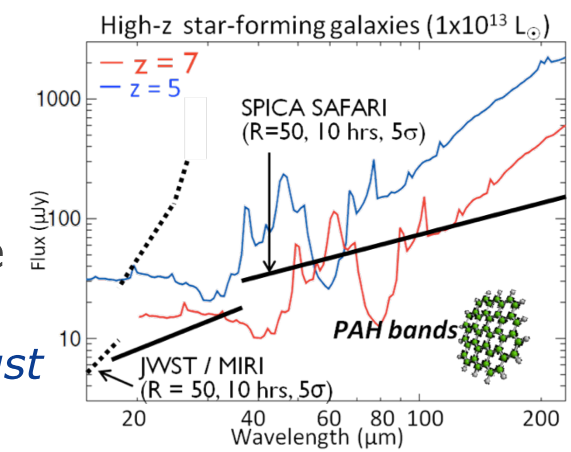
$(C_{24}H_{12})_8$

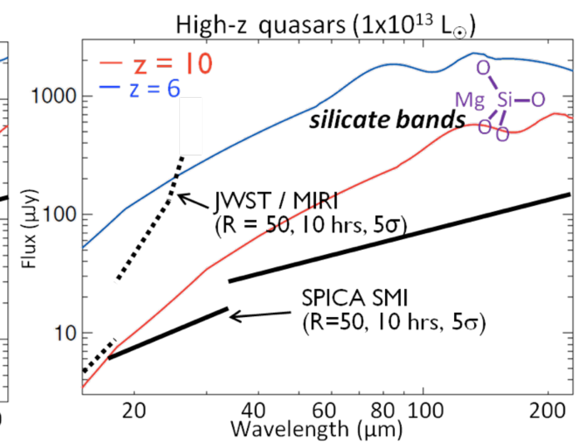


Simulated SPICA observations of high-redshift (lensed) galaxies

(10 hr integration time)

→ *PAH features easily detected*





SPICA accesses PAH and Silicate features at z~5-7 beyond JWST

→ *grain chemistry of the first dust*

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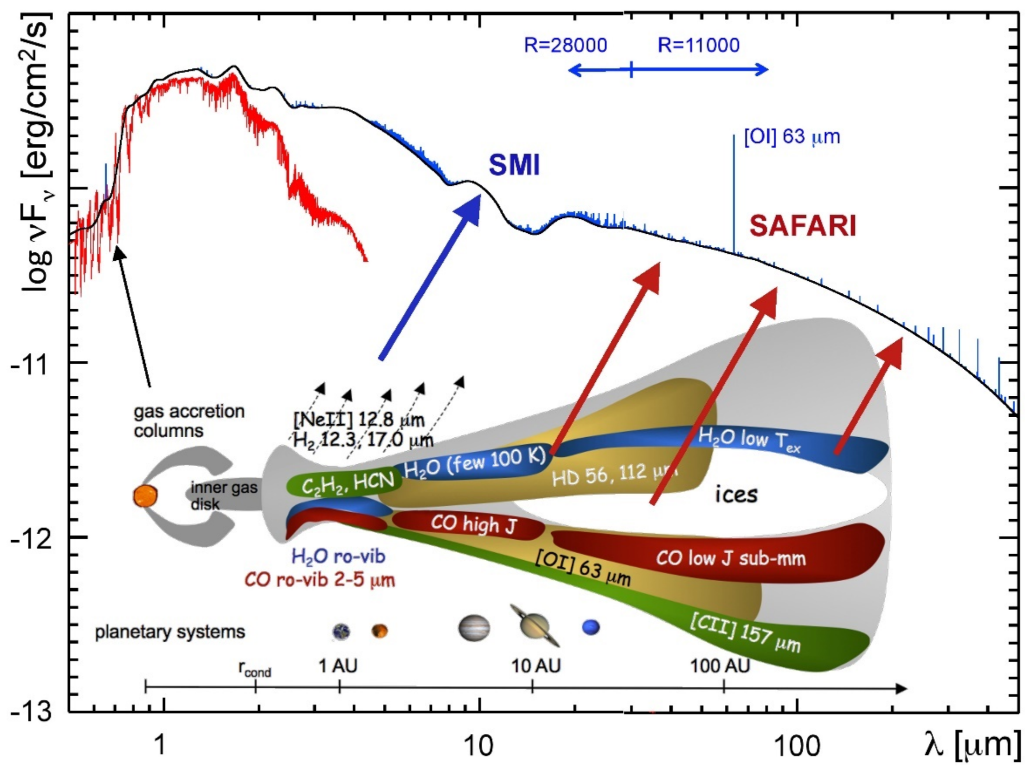
Star and Planet Formation and Evolution

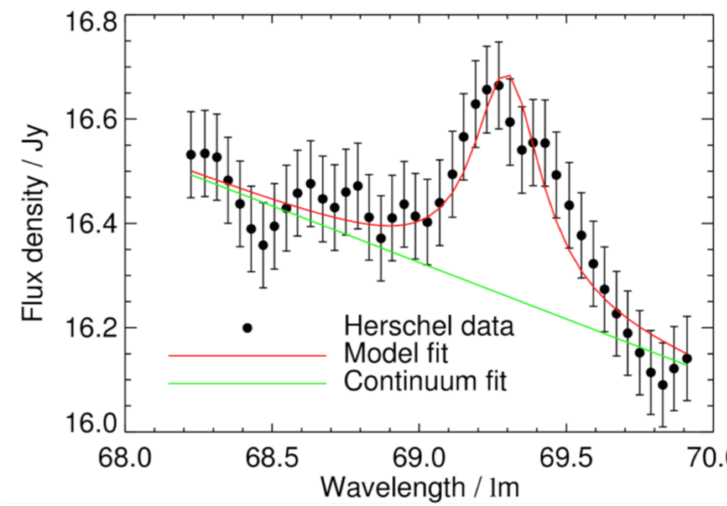
Unique areas of planet formation to be studied with SPICA:

- 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



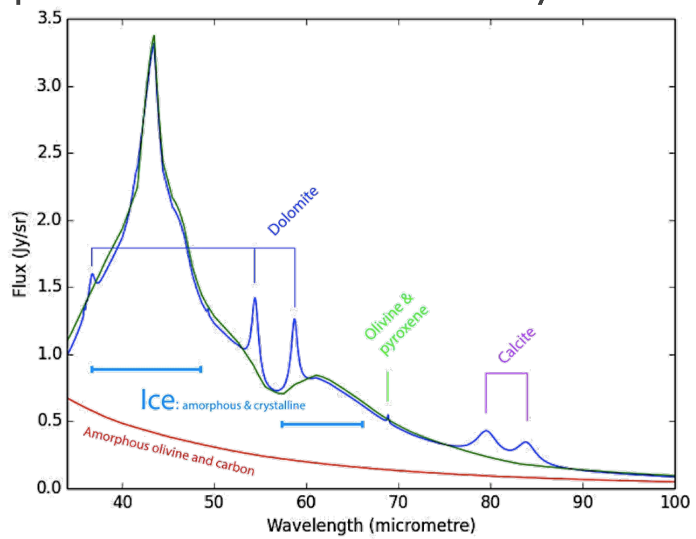
Mineralogy – e.g. debris discs

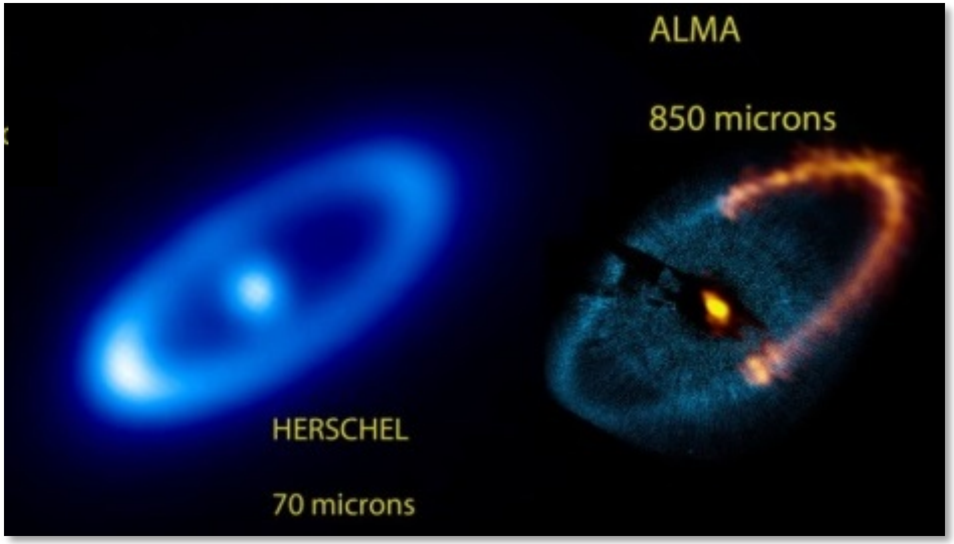
69 μm feature for β-Pic (de Vries et al. 2012)



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
- The the composition of refractory dust in its exo-comets and make a direct comparison with our Solar System





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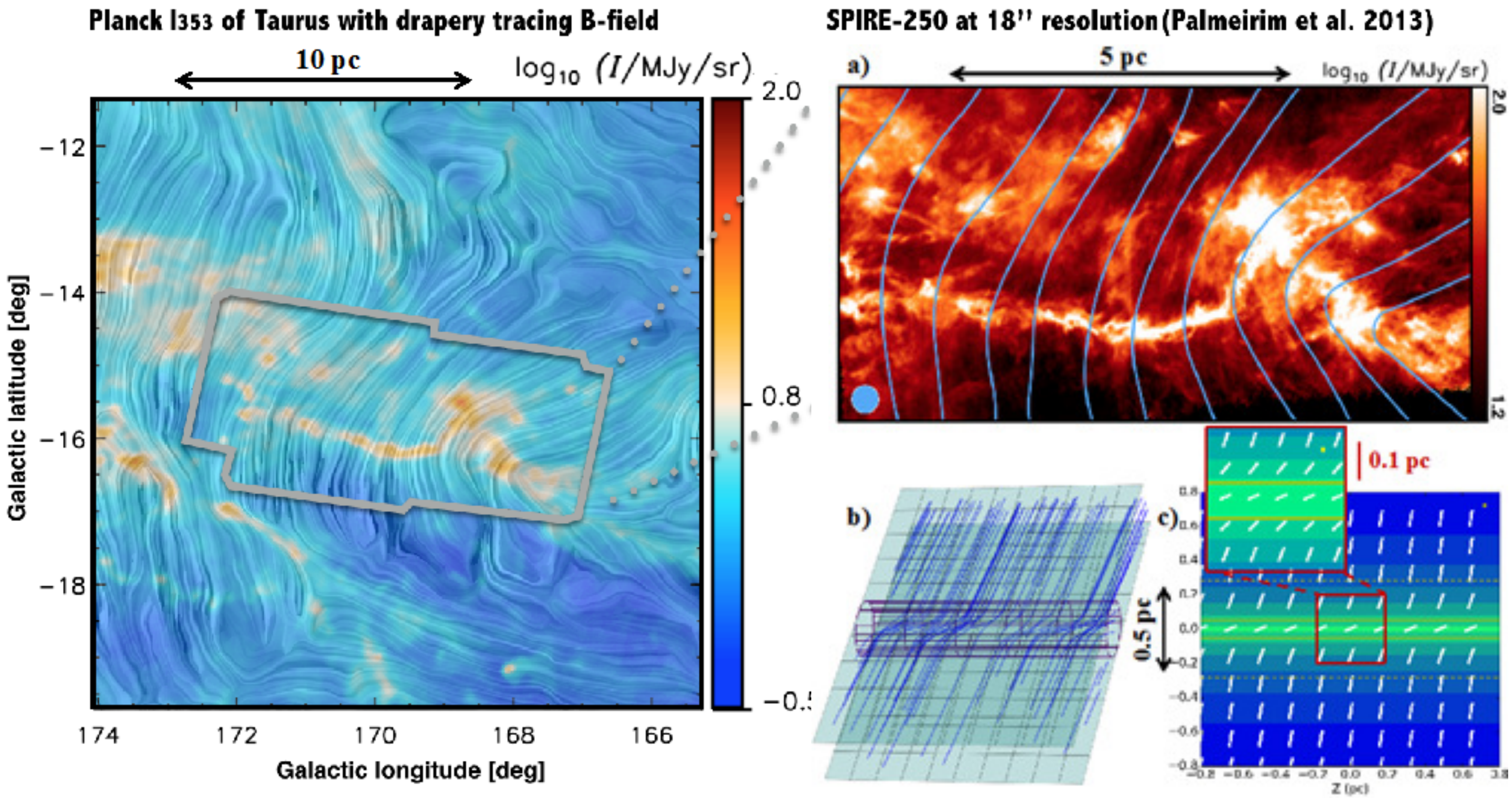
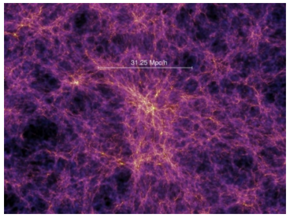
Magnetic field in dust filaments

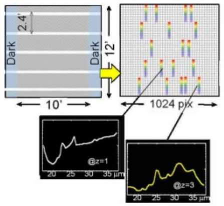


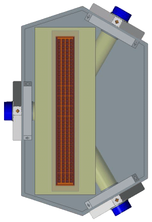
- Hershel @5"-10" – galactic dust in thin filaments
- PLANCK @5' – ***large scale*** magnetic field ***seems*** perpendicular to filaments…

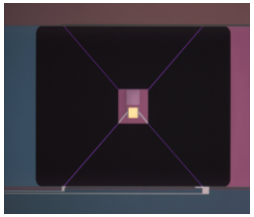
→ need to ***measure*** magnetic field ***within*** filaments @5"-15"

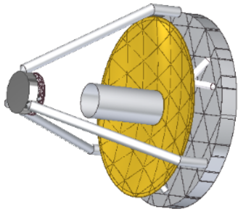
The SPICA mission
the M5 configuration

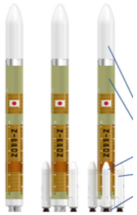


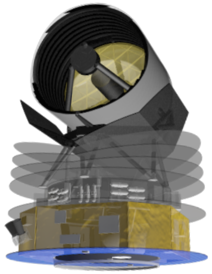






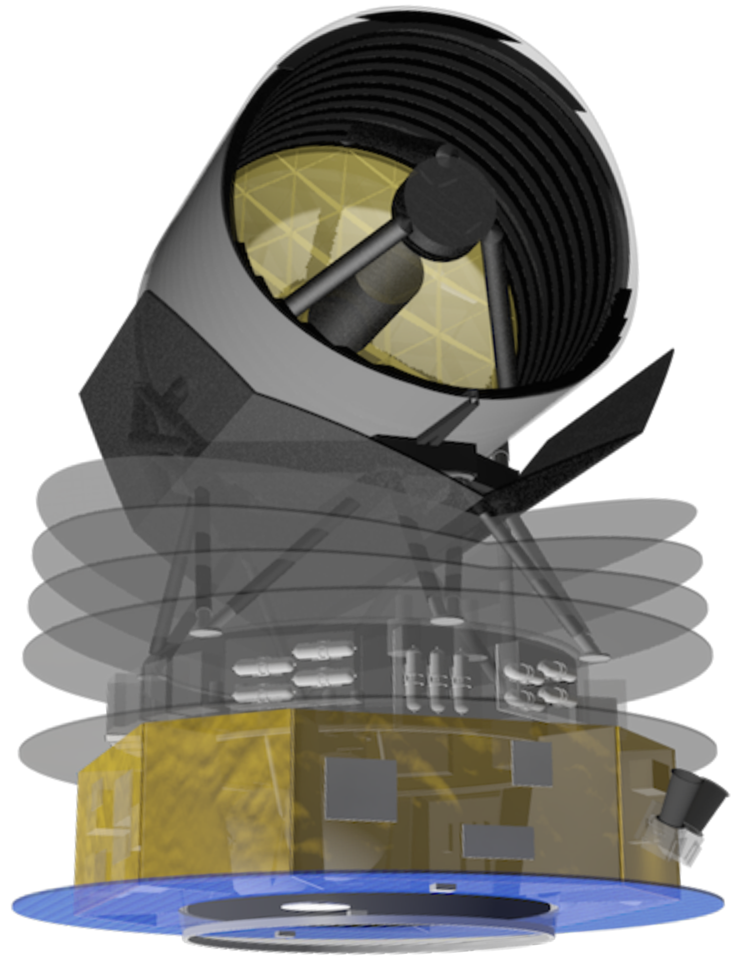






SPICA – to be proposed for ESA/M5

- ESA-led mission
  with large JAXA contribution
- ‘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 - 230 μm spectroscopy
  - MIR imaging spectroscopy – SMI
  - FIR spectroscopy – SAFARI/SPEC
  - FIR polarimetry – SAFARI/POL
- ‘standard’ Herschel/Planck SVM
- Japanese H3 launcher, L2 halo orbit
- 5 year goal lifetime



Who provides what

Telescope (ESA)

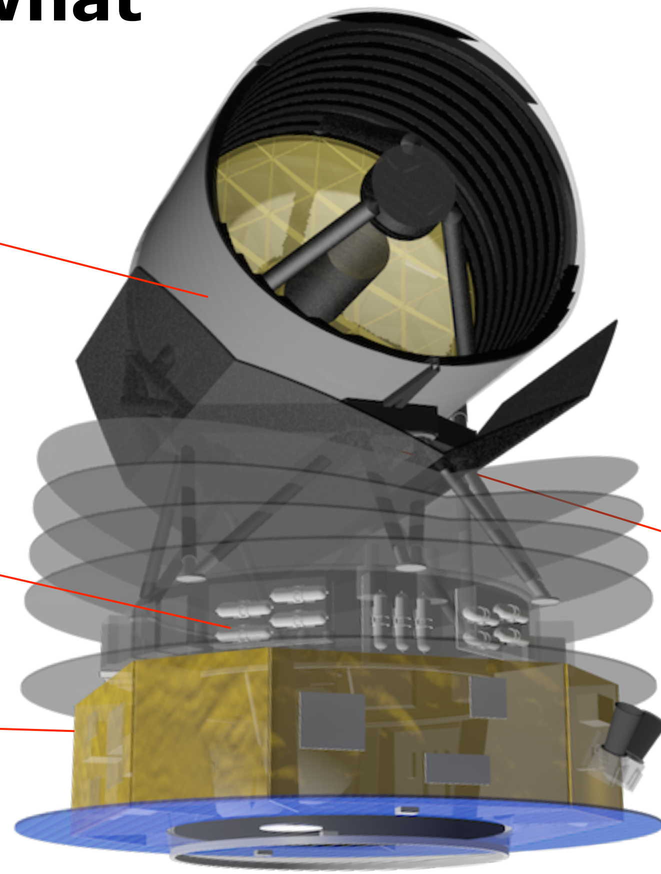
Payload Module

Cryocooler

Bus Module

Launcher

SPICA Data Center



Focal Plane Attitude Sensor

Focal Plane Instrument Assembly

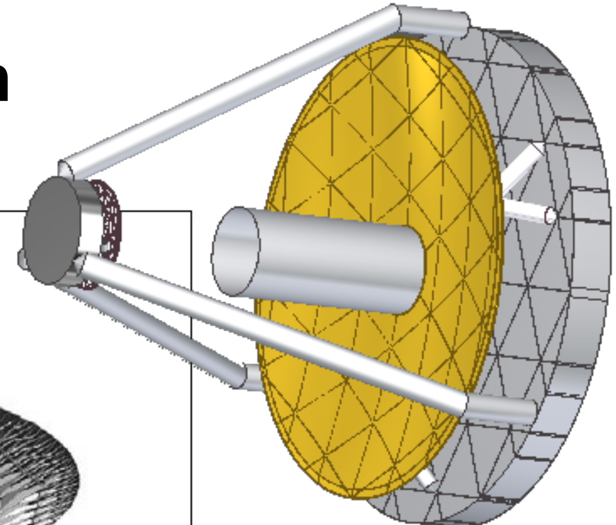
FIR Spectrometer (SAFARI)

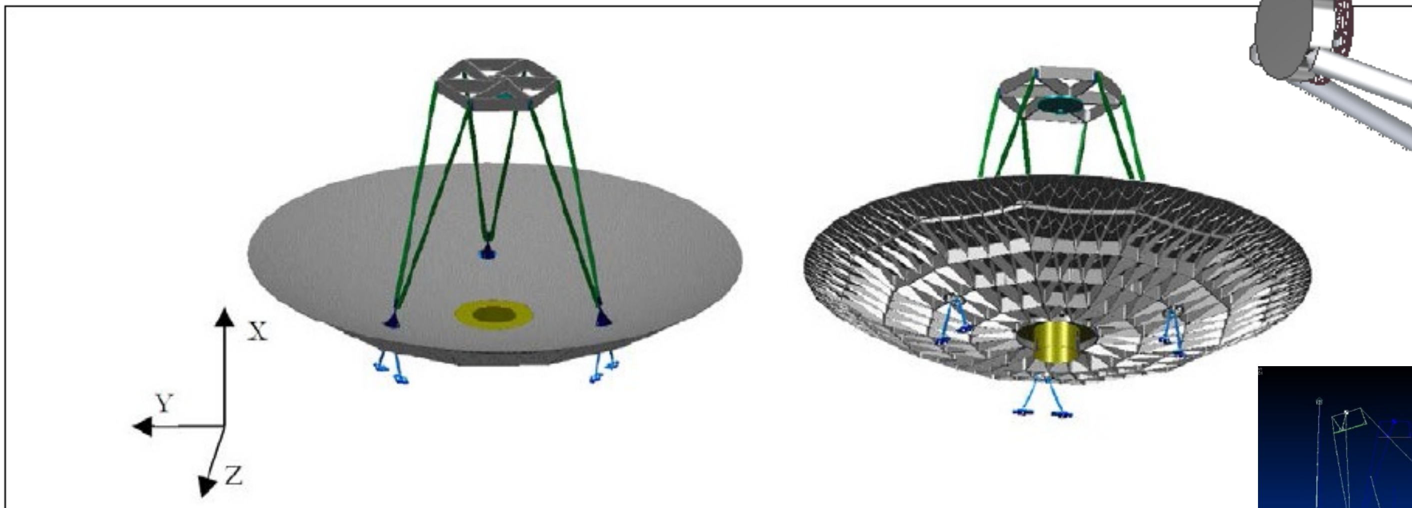
NL + European countries + Canada & US

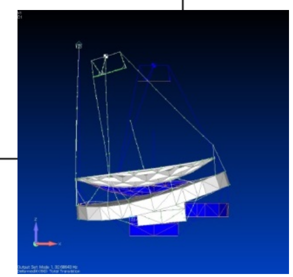
MIR Instrument (SMI)

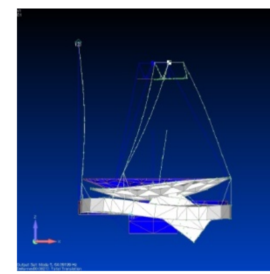
Complexity in responsibilities and interfaces
→ challenging AIV program

Telescope – 2.5m Ritchy-Chrétien



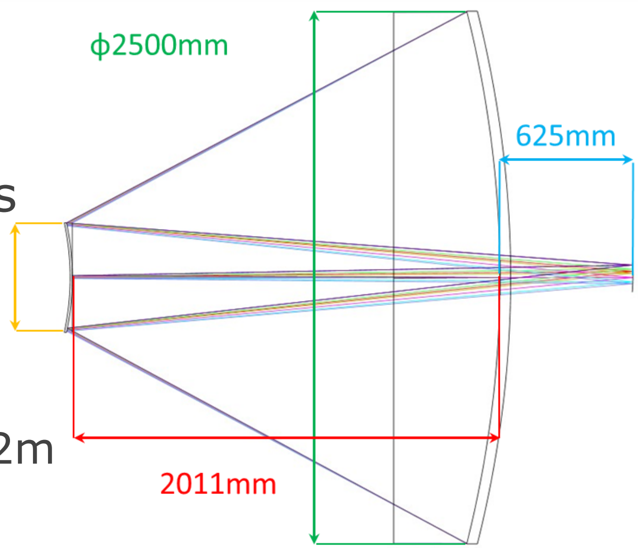


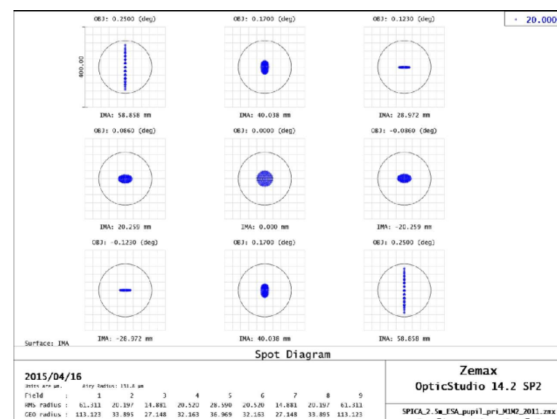




Herschel heritage

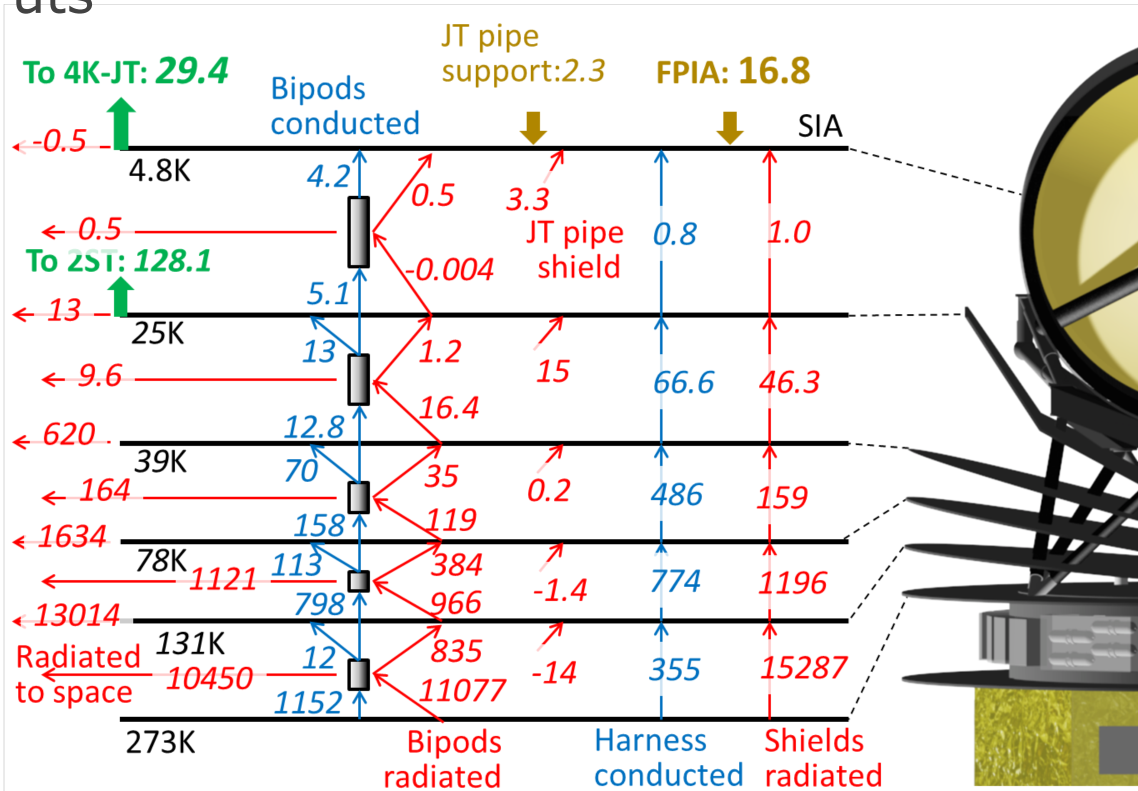
- ESA/industry studies
- Preliminary design:
  - M1: 2.5m F/1
  - M2: ~0.6m
  - M1-M2 distance ~2m





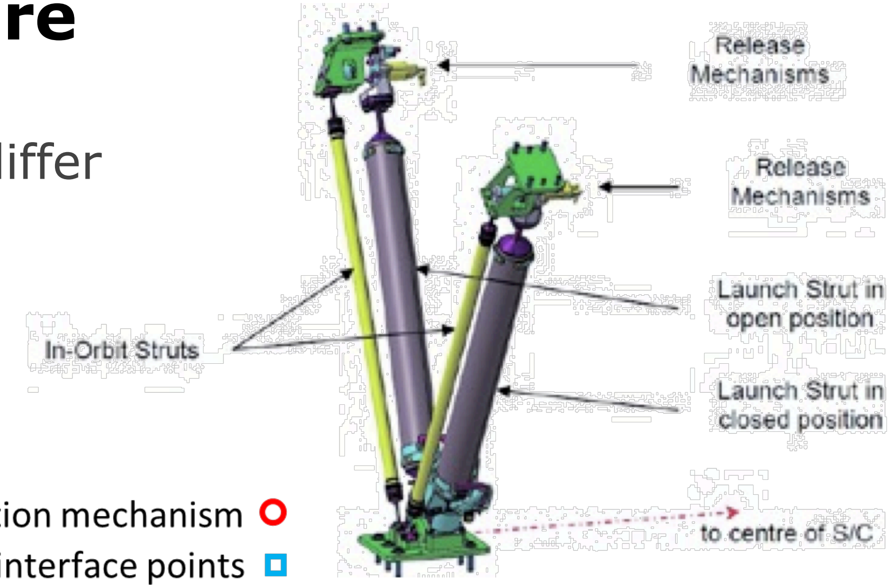
Main challenge –<8K telescope thermal design

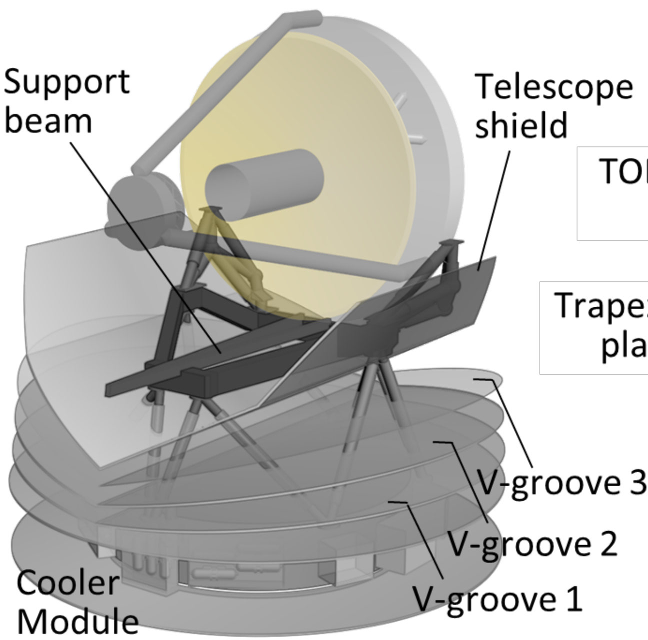
- Active cooling to 4K and 1.7K
  - Detector modules at 50mK with dedicated mK coolers (SAFARI)
- V-grooves – passive cooling to 40K
- Detachable support struts

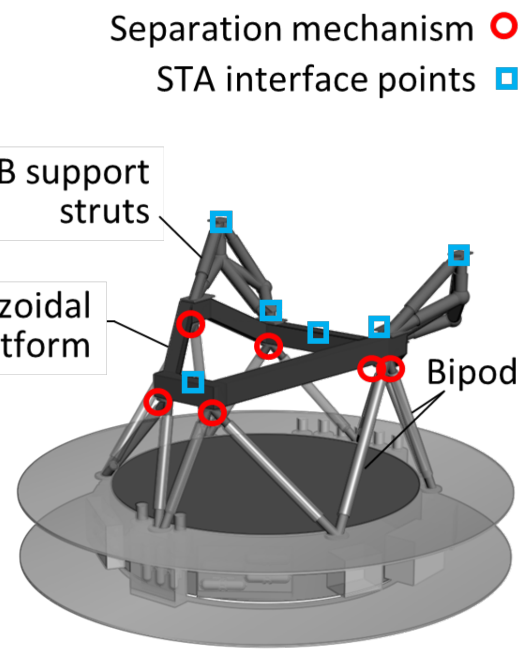


Telescope support structure

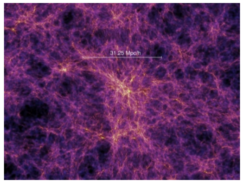
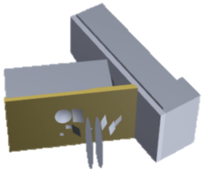
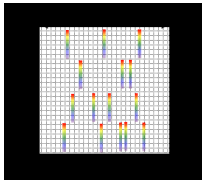
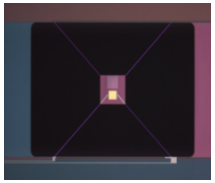
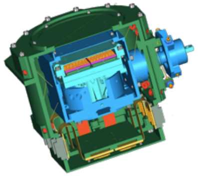
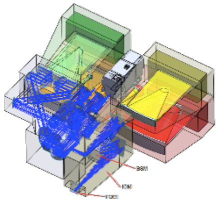
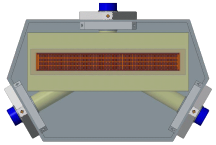
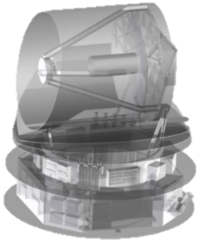
- Launch and in-flight requirements differ
  → in space truss separation



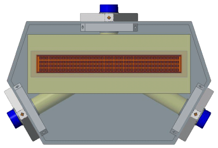
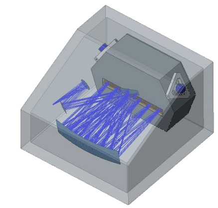
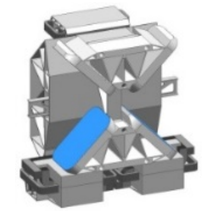




The SPICA Instruments

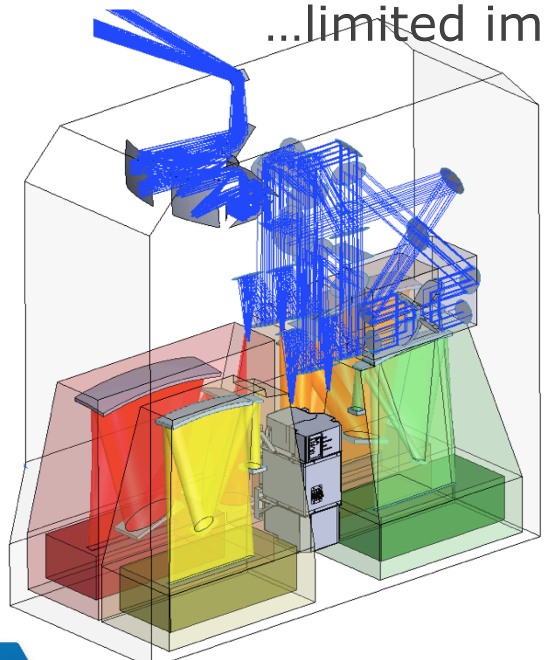
SAFARI – evolution dictated by science

SAFARI/SPEC - high sensitivity grating spectrometer

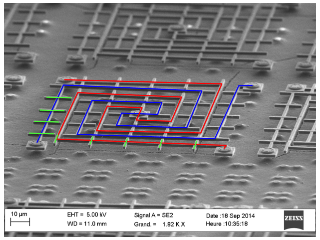
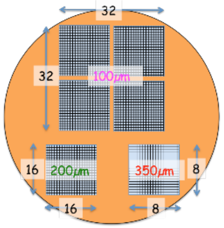
- Basic R~300 mode → 1hr/5σ **-5-7×10^{-20} W/m^2** (4.6 m^2)
  - Improves with better TES performance!
- Martin Puplett Interferometer to provide High-R mode
  - Backup: Fabry-Pérot Interferometer
- 4 bands *instantaneously* covering 35-230 micron

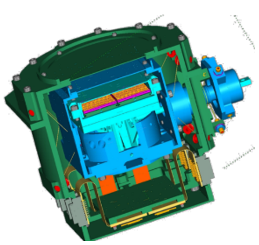
…limited imaging capability: 3 pixels on-sky



SAFARI/POL - imager polarimeter

- Polarization sensitive bolometers
  - 3 bands: 110, 220,350 µm
- FPA architecture designed and tested
- Readout analogous to PACS system

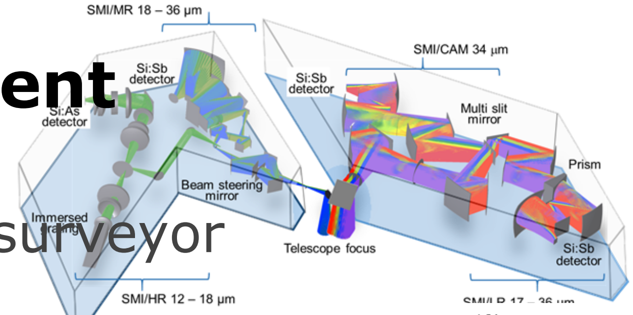





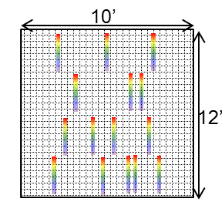
SAFARI

SRON

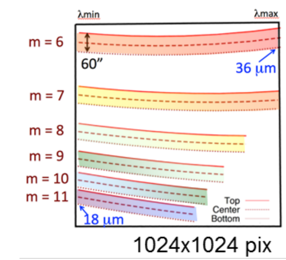
SMI - SPICA Mid-infrared Instrument



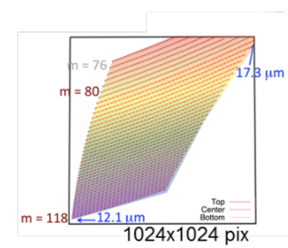
- **SMI/LR-CAM** – large area low resolution surveyor
  - 17 – 36 μm, R = 50 – 120
  - 4 slits (10′ long) with prism
  - Detector: Si:Sb
  - Camera mode 10′x12′ FoV



- **SMI/MR** – medium resolution mapper
  - 18 – 36 μm, R = 1200 – 2300,
  - 1 slit (1′ long) with grating
  - Detector: Si:Sb

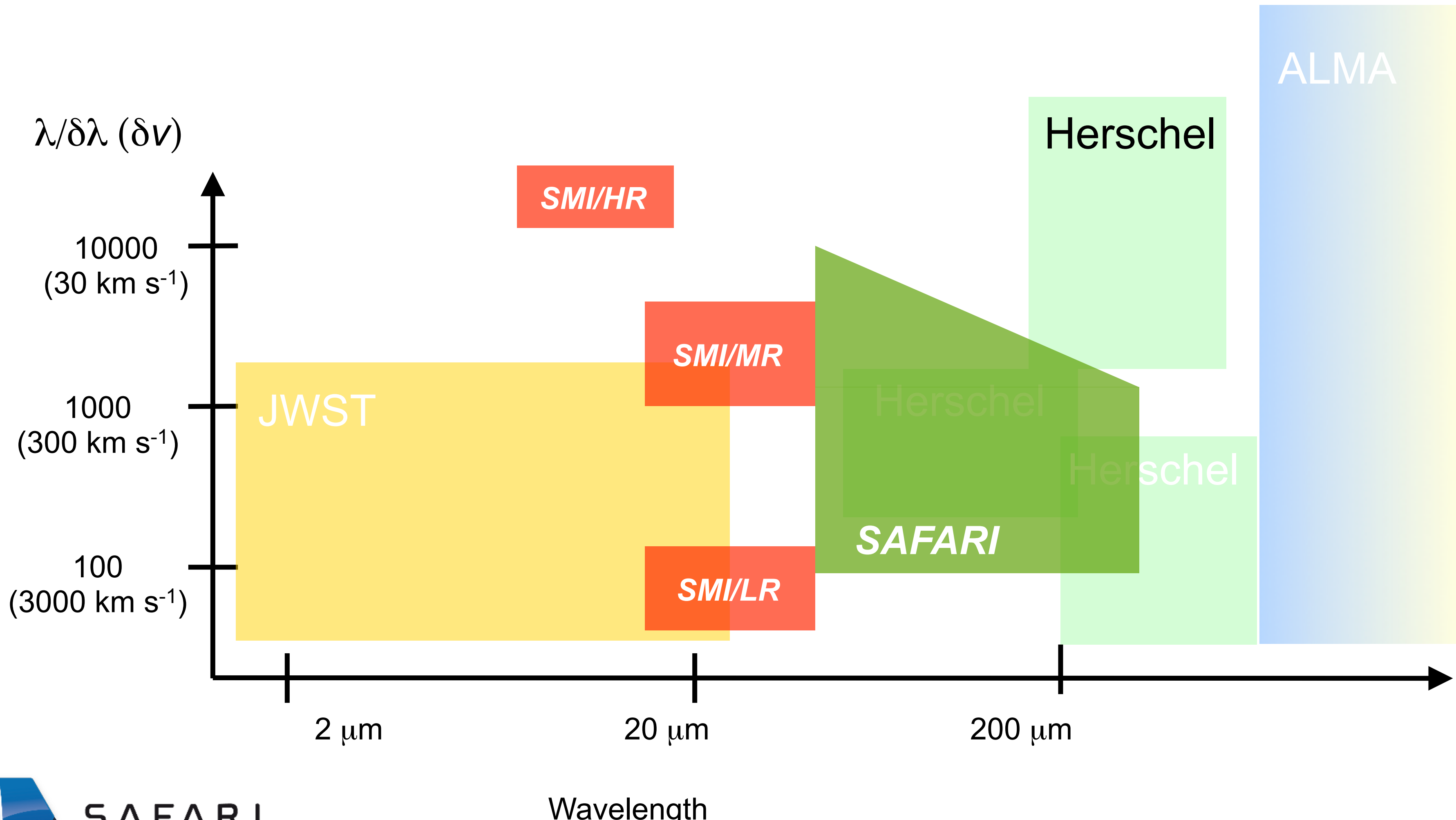


- **SMI/HR** – molecular physics/kinematics
  - 12 – 18 μm, R = 28,000
  - 1 slit (4″ long) with immersion grating
  - Detector: Si:As

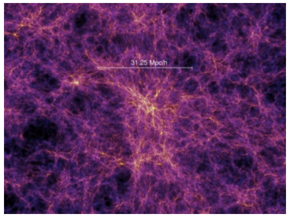


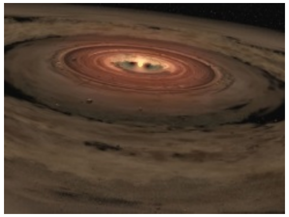
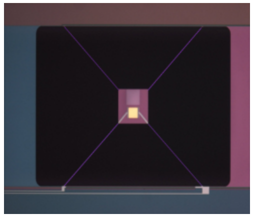
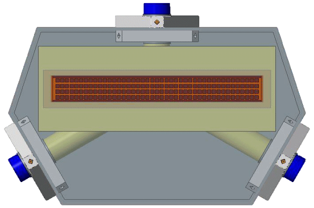
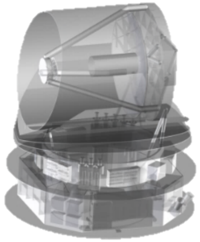
9904-83 - Kaneda et.al., 9904-142 - Sakon et.al

SPICA capabilities - spectral resolution



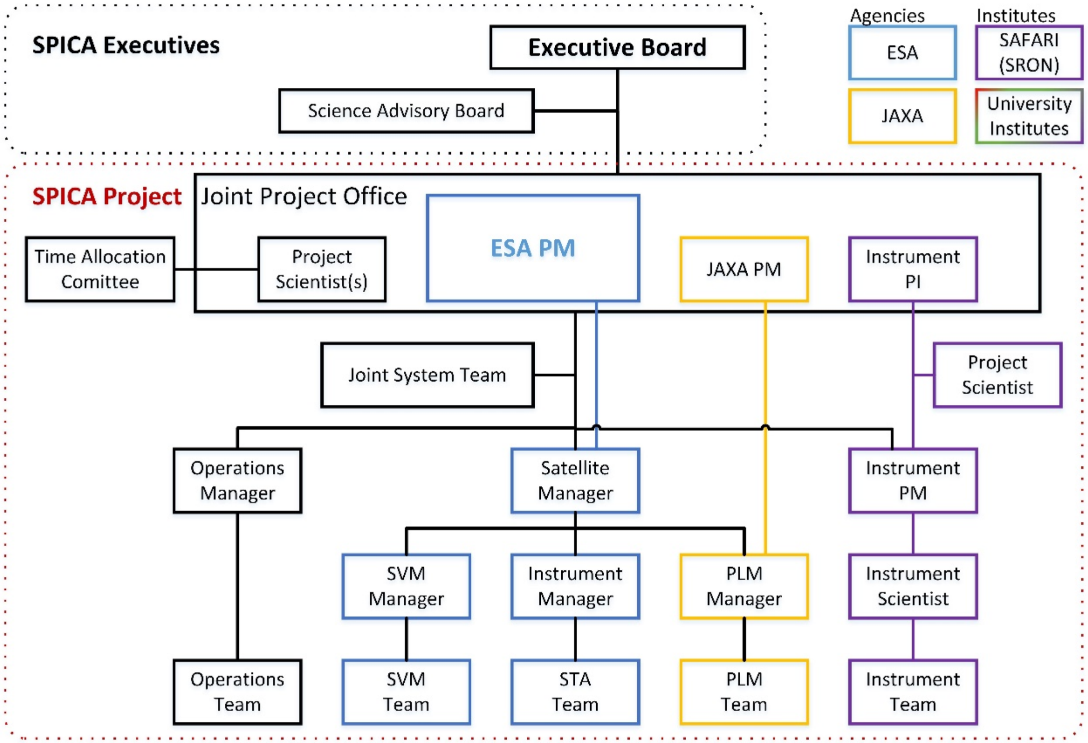
The programmatic context and the outlook



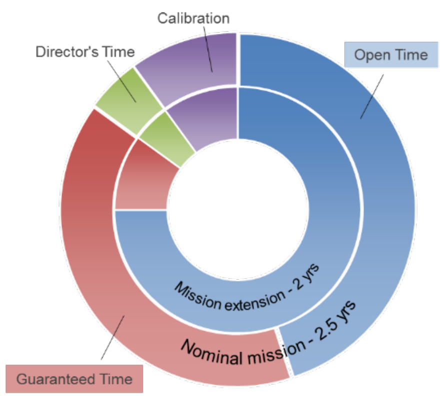





Governance and harvesting

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



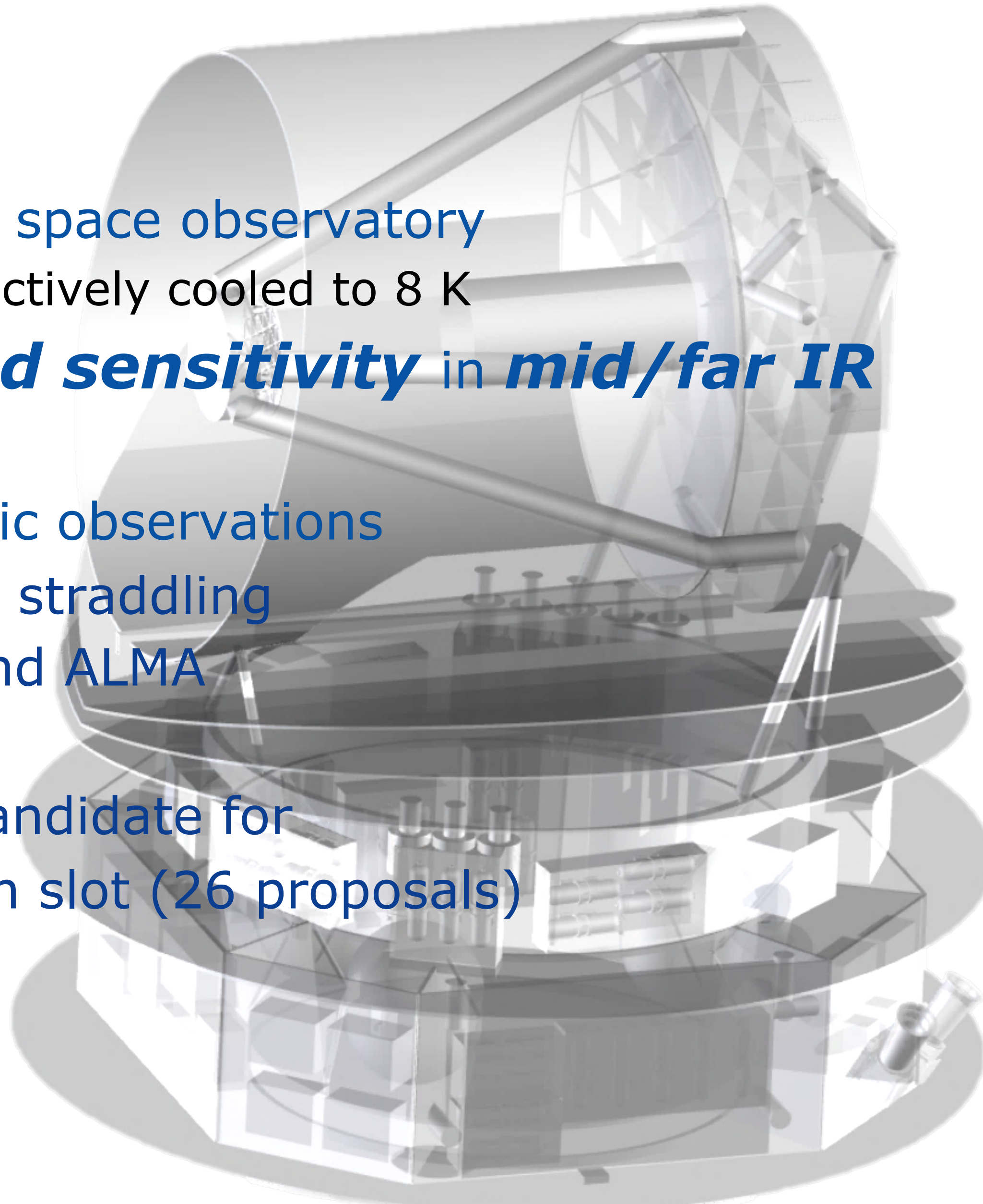
- Observing time:
  mission will be open for ***all astronomers***
  - Guaranteed v.s. open time details TBD
  - Detailed implementation of e.g. 'Key projects' TBD
  - Time Allocation Committee



Mission Status

- Mission well defined
  - Spacecraft elements, responsibilities
  - Instrument complement in final iteration
- Europe: consortium finalized a M5 proposal
  - ESA-led mission with JAXA participation
  - European/Canadian/US instrument - SAFARI
  - M5 timeline
    - Proposal submission: October 5 2016
    - Mission candidate selection: June/2017
    - Mission final selection: 2019
    - Launch: 2028/2029
- Japan: SPICA passed ‘Mission Definition Review’
  - SPICA officially in ‘Pre-project’ phase (~phase A)
    - 2027/2028 H3 slot tentatively assigned to SPICA
  - Japan ***will support*** an ESA SPICA mission at the ~300M$ level

Summary



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

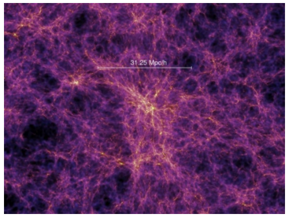
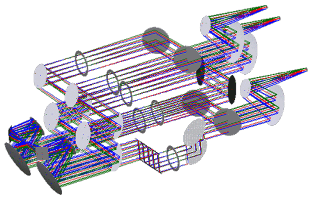
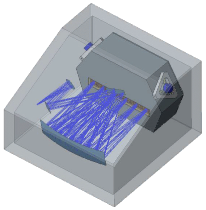
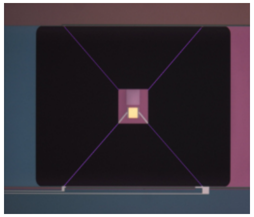
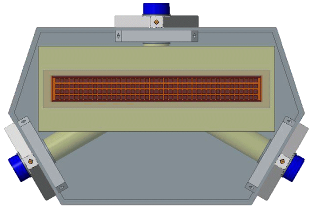
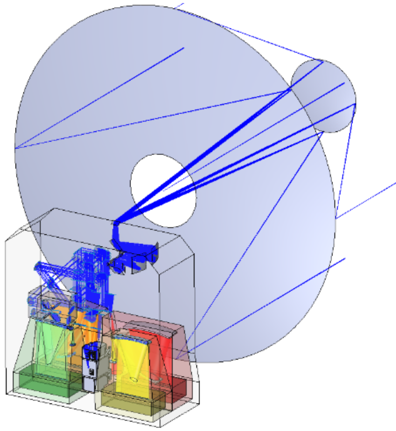
    → ***unprecedented sensitivity*** in ***mid/far IR***

- SPICA focus: spectroscopic observations of the obscured universe, straddling the gap between JWST and ALMA

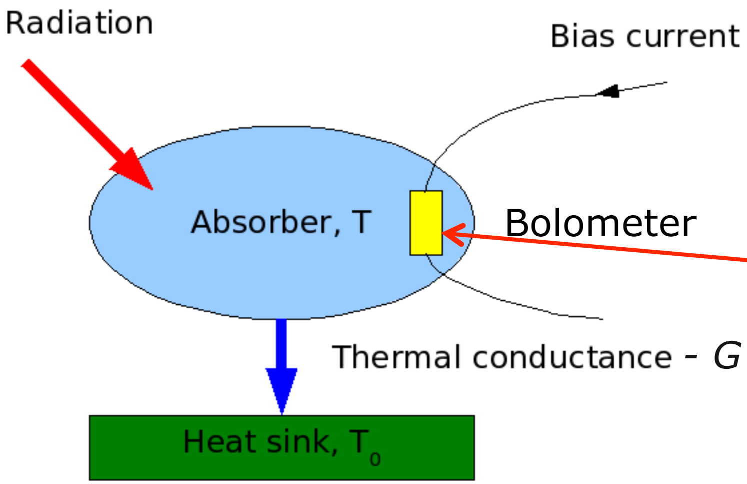
- SPICA is proposed as a candidate for ESA's 5th M-Class mission slot (26 proposals)

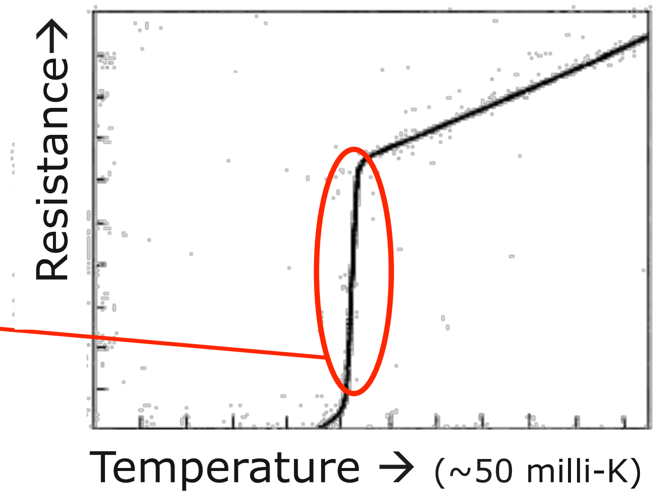
The SAFARI grating spectrometer

the ‘European’ instrument

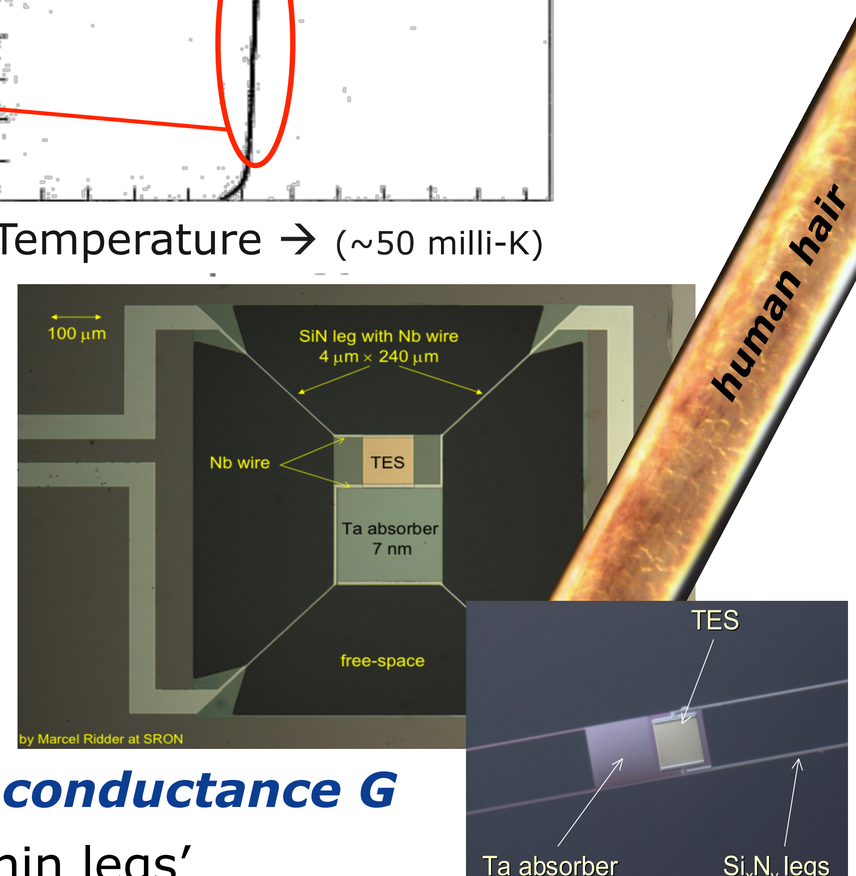







For ultimate sensitivity; Transition Edge Sensors





- Limit in NEP: phonon-noise ~T√*G*

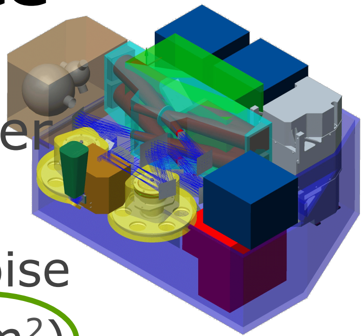


Challenges:

- ***~milli-K*** environment
- ***Very sensitive to E/B fields***
- ***Small*** pixels (480 µm), ***low thermal conductance G***

→ trying layout with 'long thin legs'

SAFARI – evolution dictated by the science



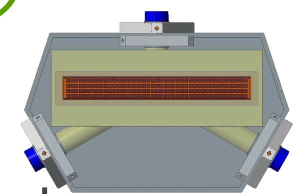
Original design: Imaging Fourier Transform Spectrometer

- Fast/efficient large area spectroscopic mapping

  …but limited in maximum sensitivity due to photon noise

  Best achievable 1hr/5σ 'only' **~2-3×10^{-19} W/m^2** (6 m^2)

  - Independent of TES performance!

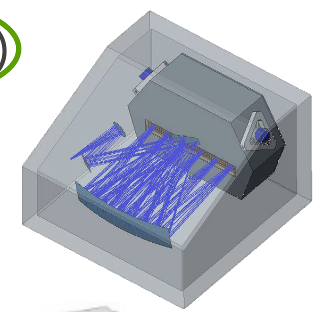


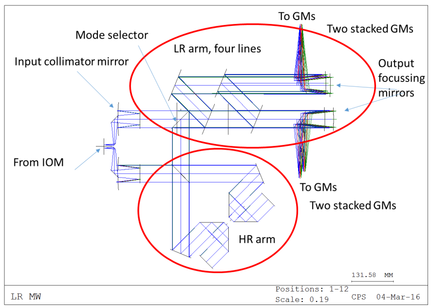
New approach for better sensitivity: grating spectrometer

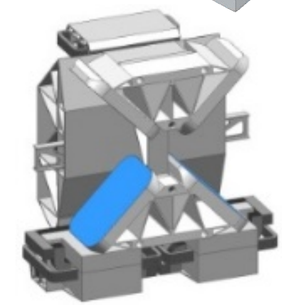
- Basic R~300 mode → 1hr/5σ **~6-8×10^{-20} W/m^2** (4.6 m^2)
  - Improves with better TES performance!
- Martin Puplett Interferometer to provide R~3000 mode
  - Backup: Fabry-Pérot Interferometer
- 4 bands covering 35-230 micron

  …but limited imaging capability:

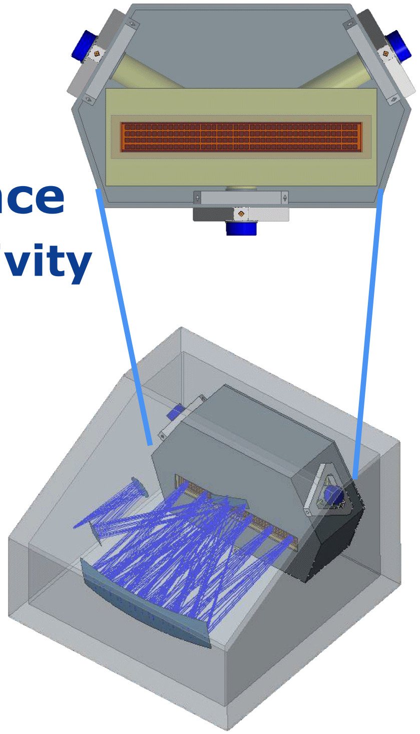
  only 3 pixels on-sky







Detectors: integrated TES/grating modules

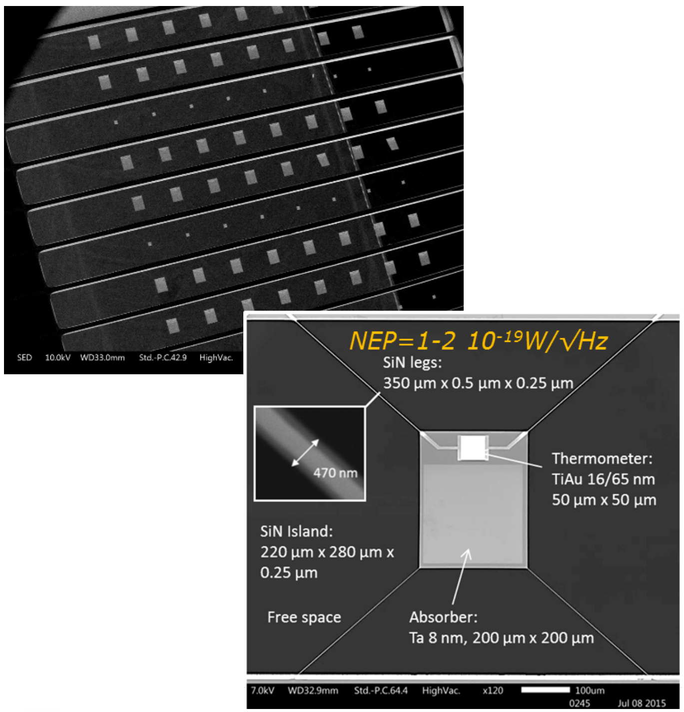


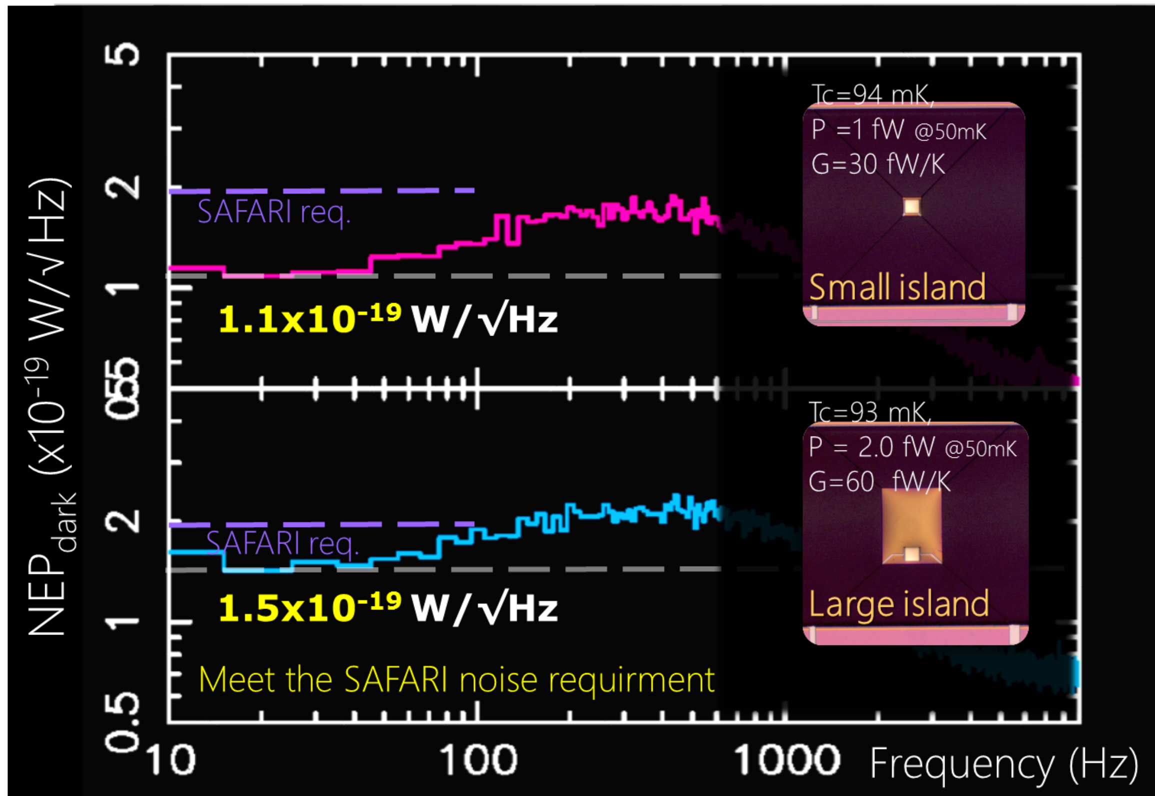
- Linear TES arrays with FDM readout
  - Detector at 1.5 Fλ separation in spectral domain
  - Profit from **already achieved** TES/FDM **performance**
    - Further TES improvement will give **still better sensitivity**

- Redesigned integrated FPA/Grating unit
  - Grating optics at 1.7K
  - **Shielding integrated** in structure
    - Builds on SAFARI/FTS development
  - Detector modules suspended inside at 50mk

TES NEP - SAFARI requirement within reach

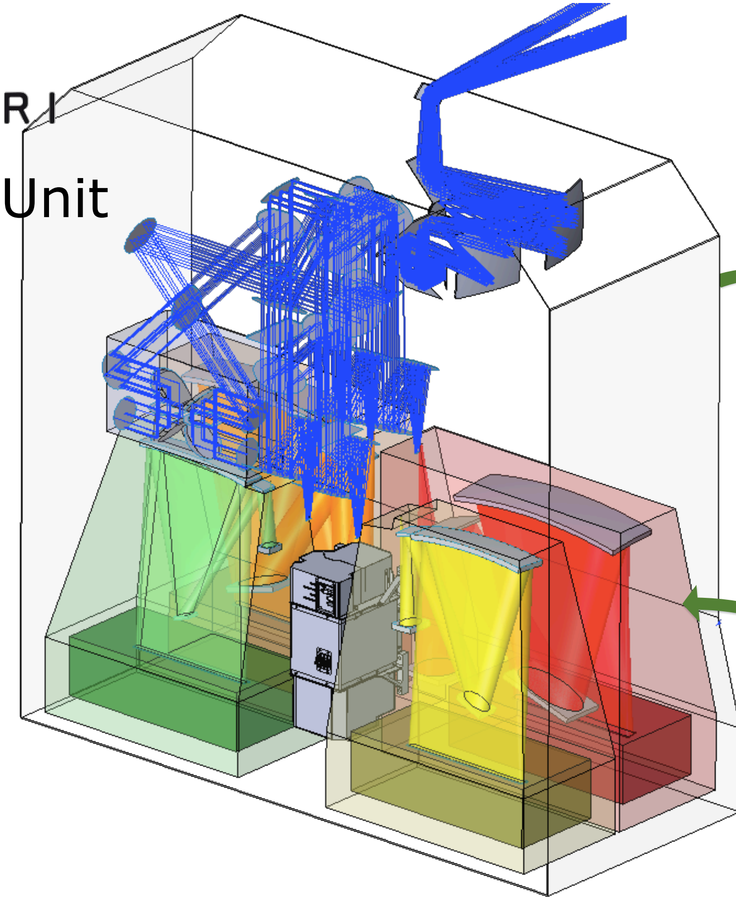
- SAFARI requirement: ~$2x10^{-19}$ W/√Hz
- Ongoing TES research: achieve best possible device layout
  - Working towards larger array sizes
  - Production process
  - Optical characterization



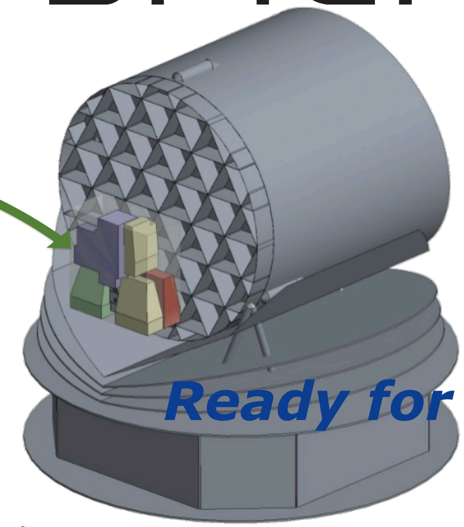


SAFARI

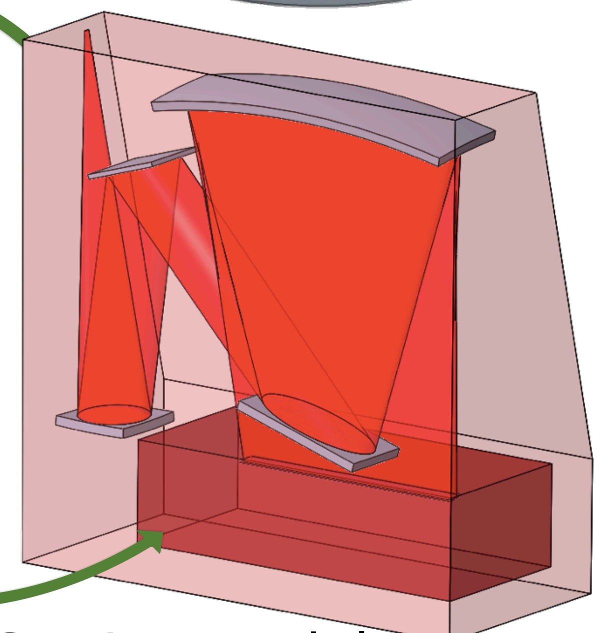
Focal Plane Unit

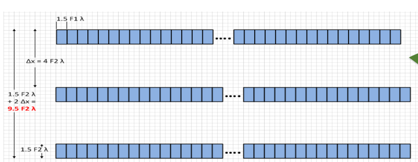


SPICA

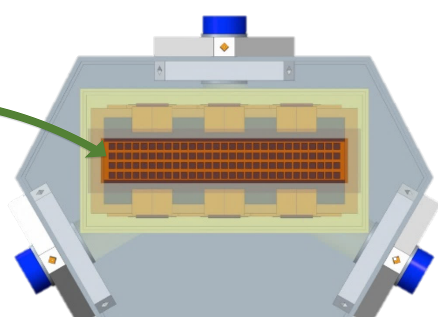


Ready for M5!





Detector arrays



Detector assembly

Grating module

Infrared Space Observatories – pushing deeper