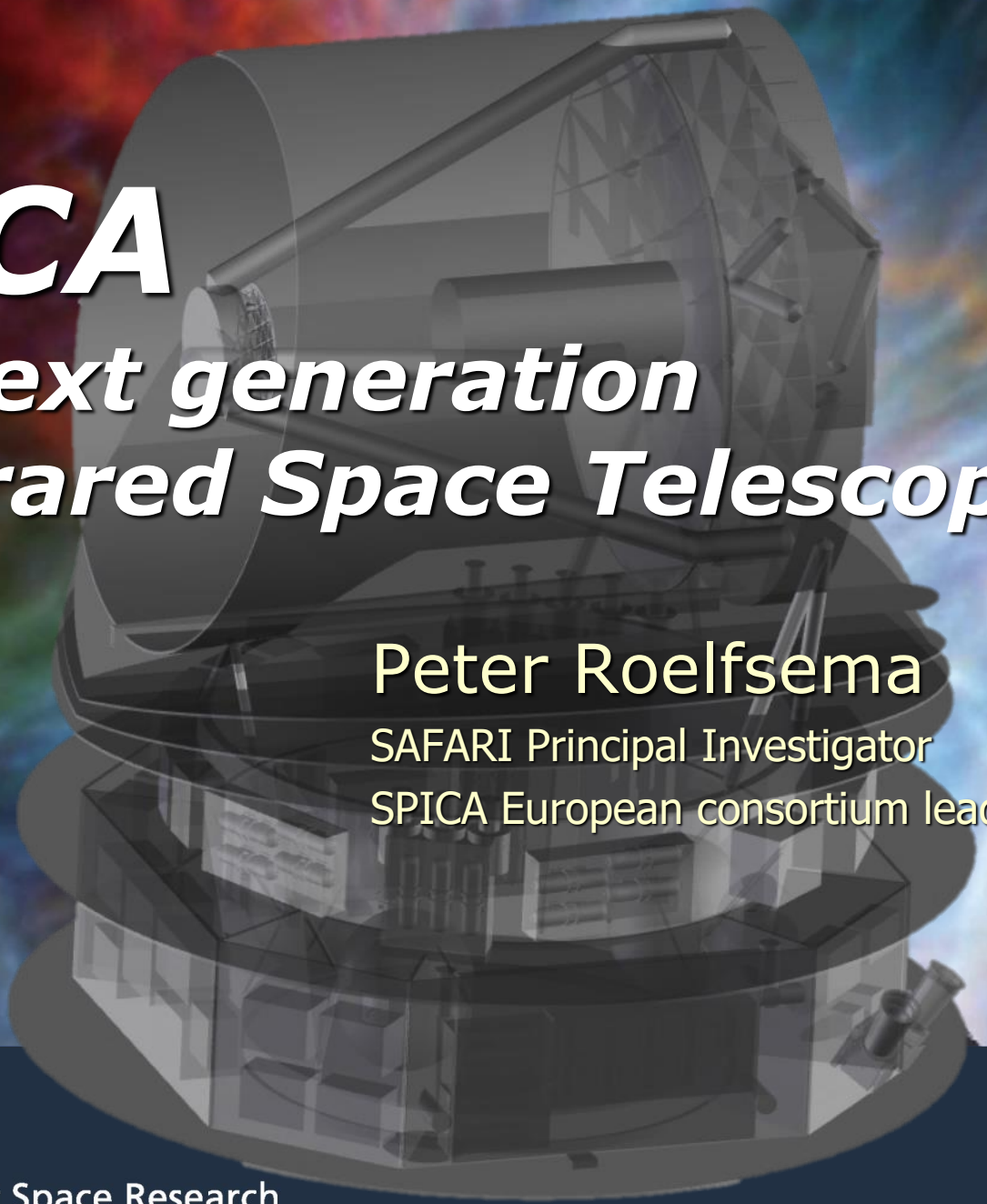
SPICA

the next generation Infrared Space Telescope



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SPICA European consortium lead

SRON

Netherlands Institute for Space Research

Netherlands Organisation for Scientific Research

SAFARI

Contents

- The goal – a big cold IR facility; SPICA
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  - The science case for the (far) IR
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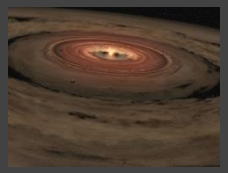
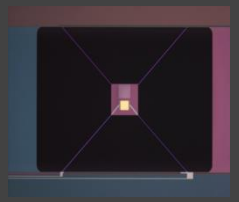
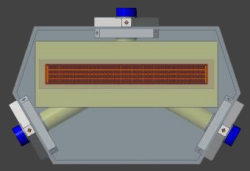
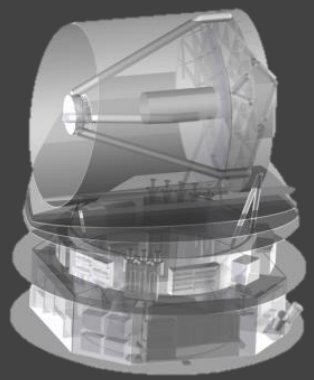
- SPICA – mission overview
  - Concept and instrumentation
- The European instrument – SAFARI
- Towards M5









Infrared Space Observatories – a common drive


IRAS 1985


ISO 1995


Herschel 2009-2013


IRTS 1995


Akari 2006


Spitzer 2003


SPICA!

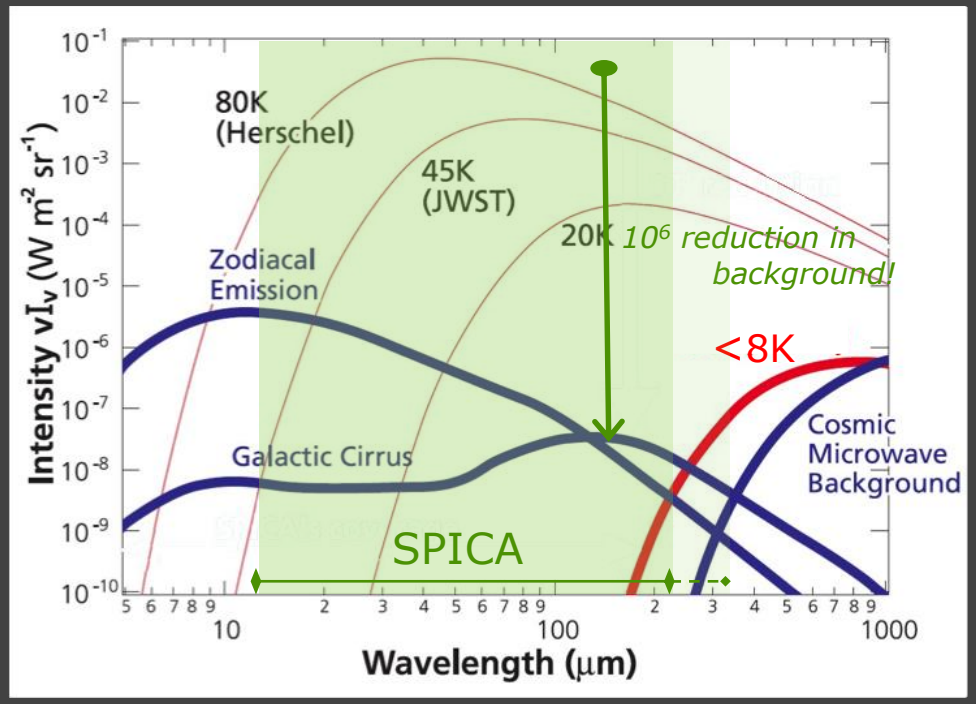

JWST 2018?

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
  → go-ahead for M5

The SPICA 'sweet spot' – the dusty universe

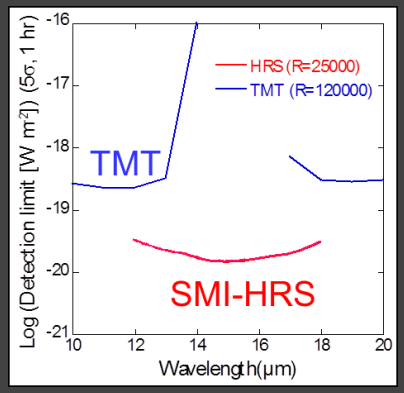
A unique observatory
looking through the veils, enabling
transformational science

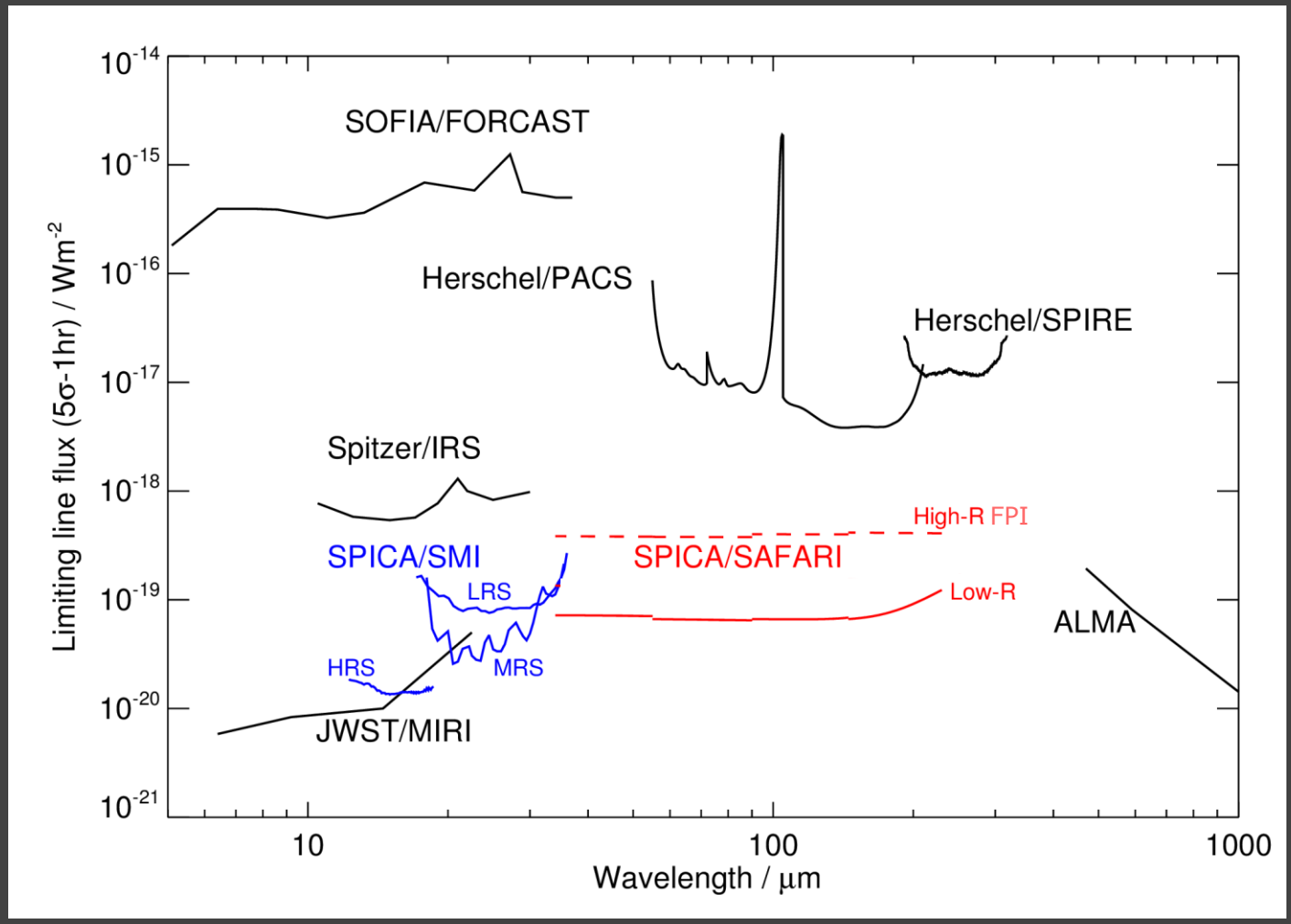


What is so unique?

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

SPICA's sensitivity; making a huge leap forward!

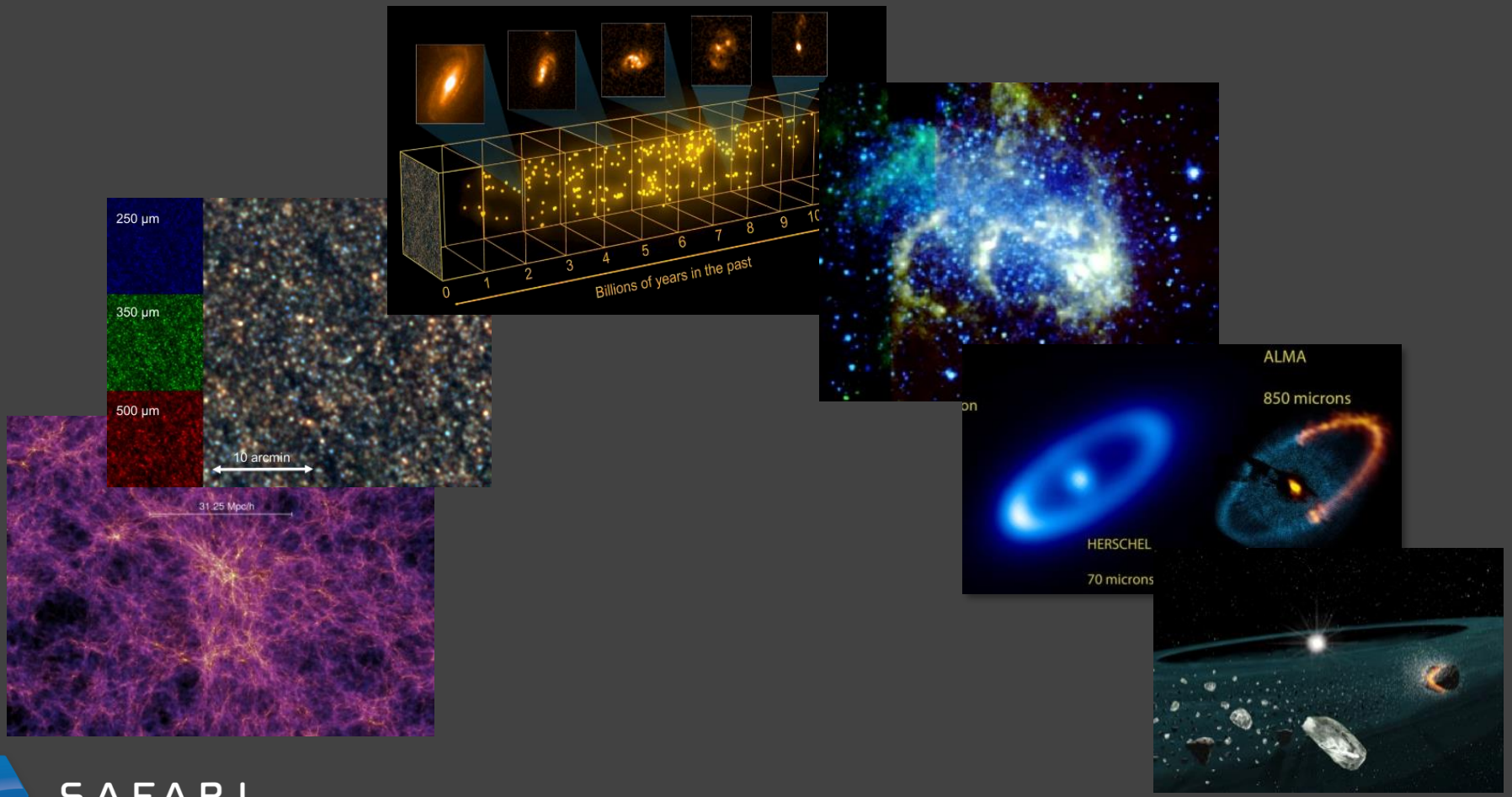




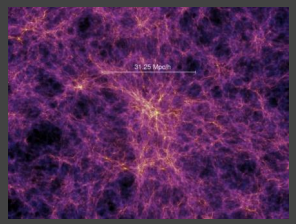
Raw sensitivity improvement **>2 orders** of magnitude
Instantaneous full spectra → huge step in efficiency

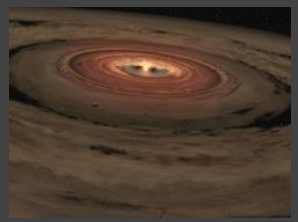
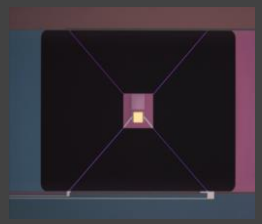
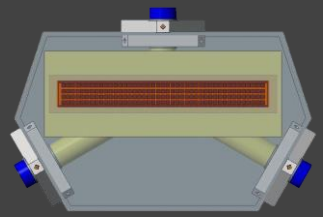
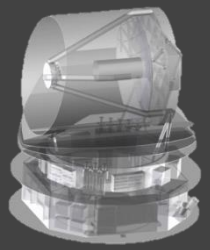
SPICA will unveil the dusty matter in the universe

Seeing through the veils on cosmic timescales
from galaxy evolution to the formation of (proto) planetary disks



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**?

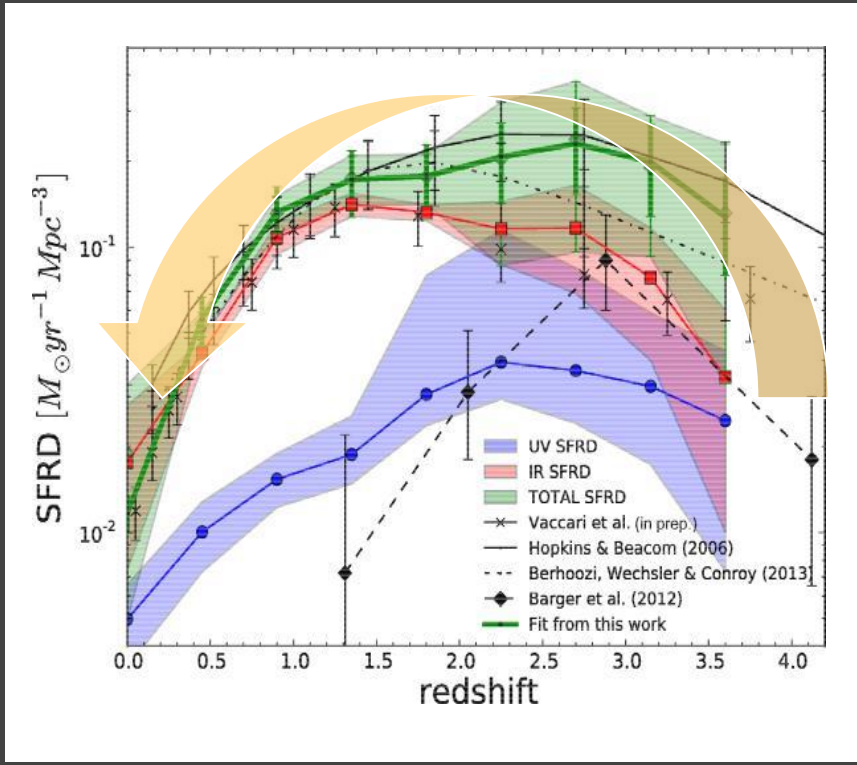
Established over the last few years by the joint Japanese-European-US science team, including community inputs through various workshops

More details later by others

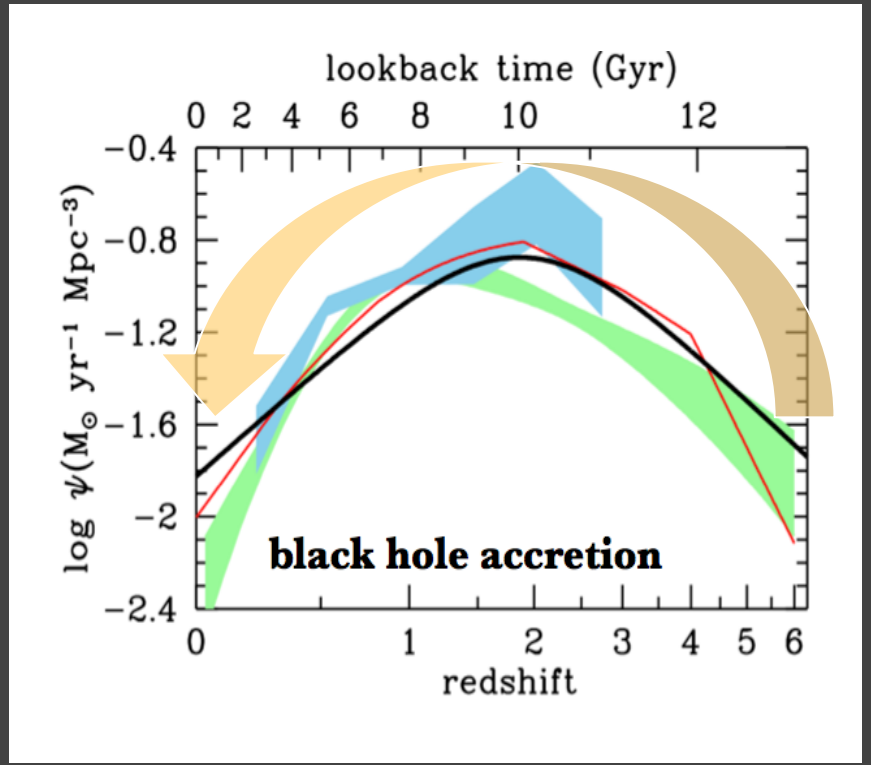
** i.e. high sensitivity spectroscopy in the mid/far IR*

Star formation and black hole accretion

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

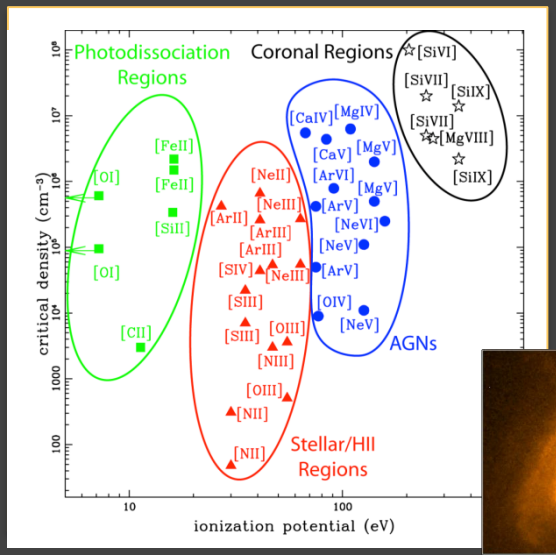


SFR densities in the UV, uncorrected for dust extinction (blue) in the far-IR (red), and in total (i.e., UV+far-IR, green). (Burgarella et al. 2013).

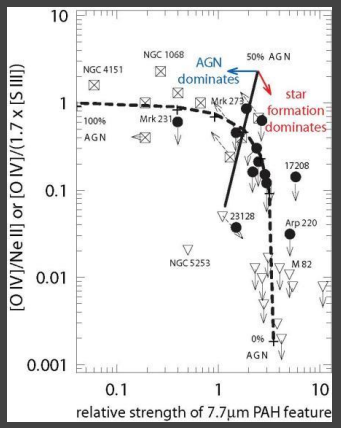


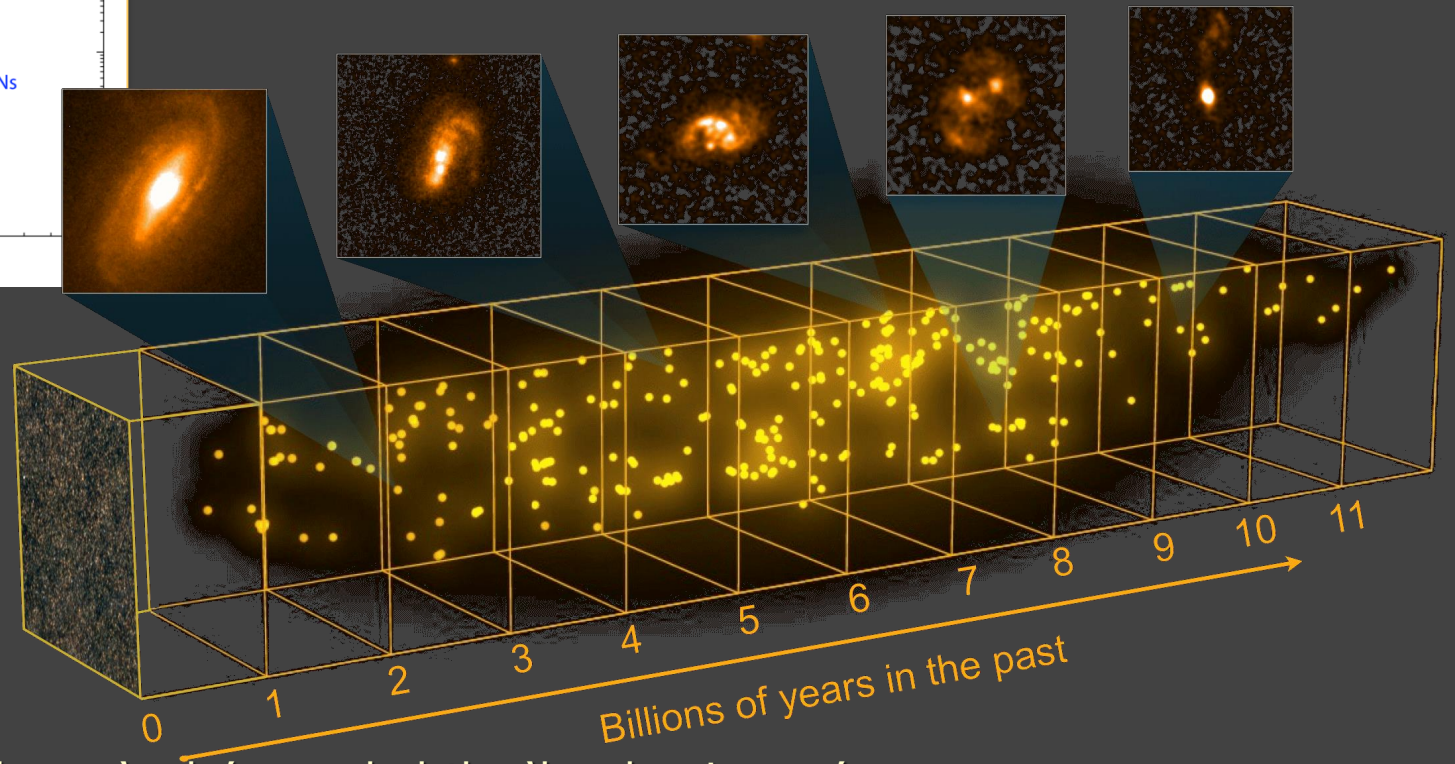
Black hole accretion history from X-ray (red line and green shading) and IR data (blue shading). (Madau & Dickinson, 2014).

Evolution of IR-luminous galaxies



- FAR-IR diagnostic tools
  - Line-ratios → physical state of dust and ionised gas
  - Line profiles → outflow/infall
  - Discriminate between AGN and star-formation

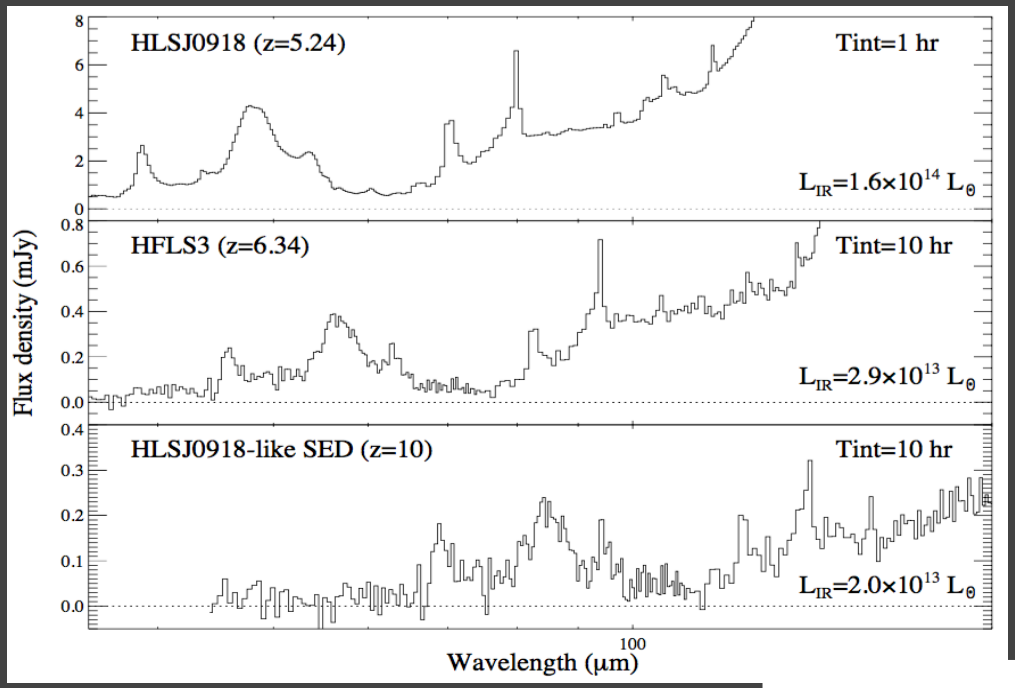




So far only we 'only' sampled the 'local universe'…

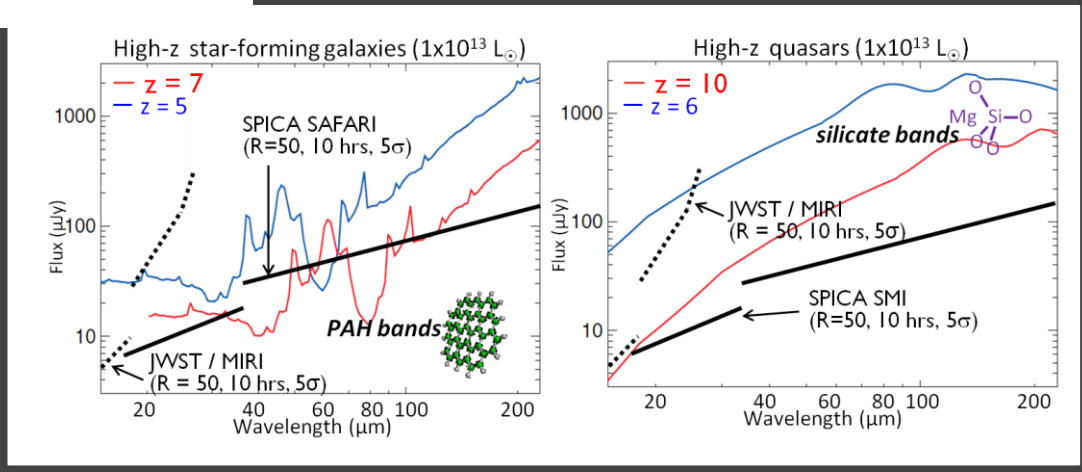
*…SPICA will **measure physical conditions** out to **z~3***

Nature of the first dust

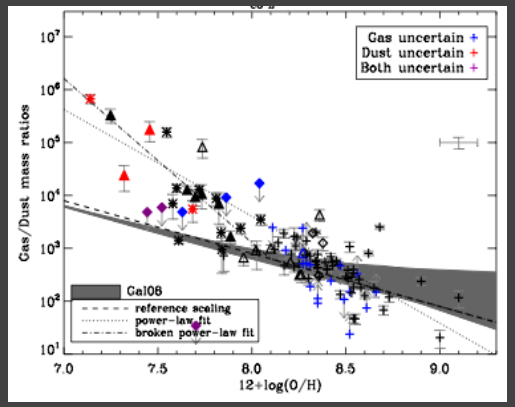


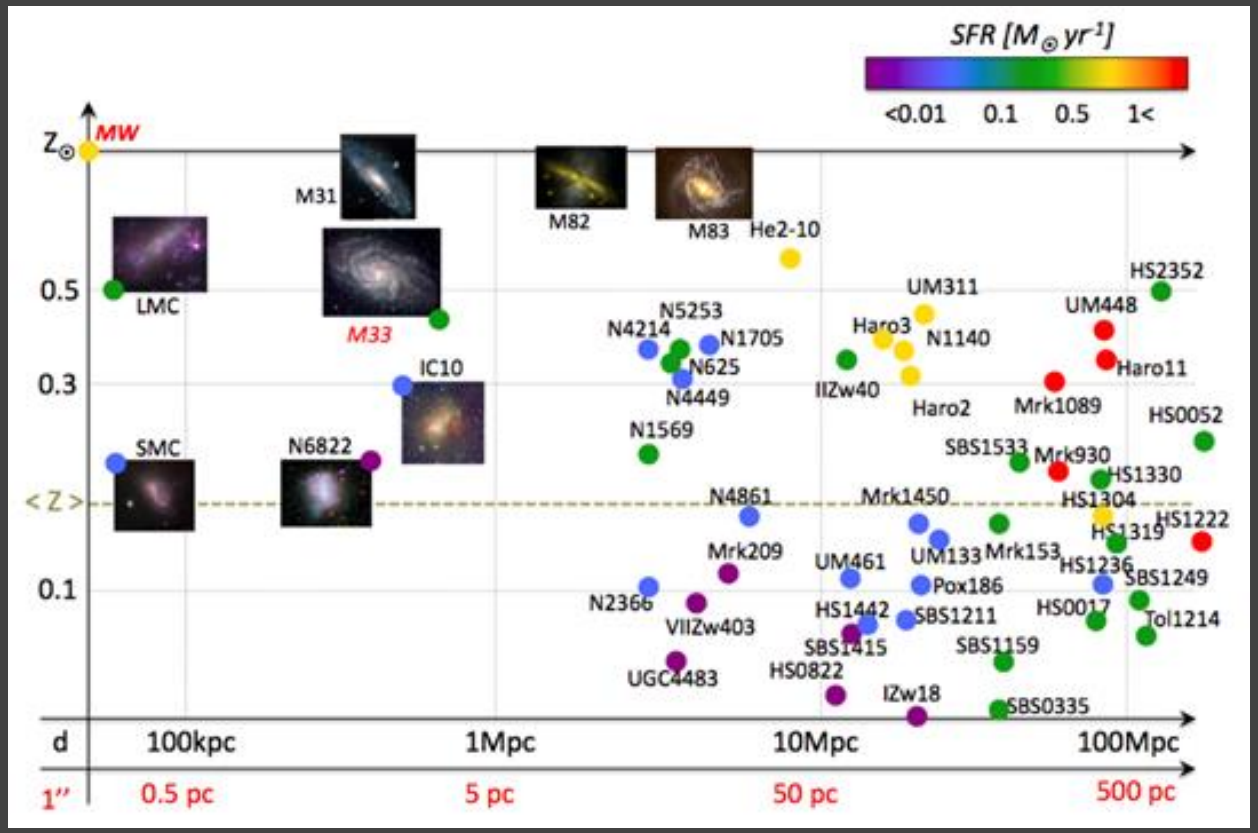
Simulated SPICA observations of high-redshift (lensed) galaxies (10 hr integration time) – PAH features easily detected.

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



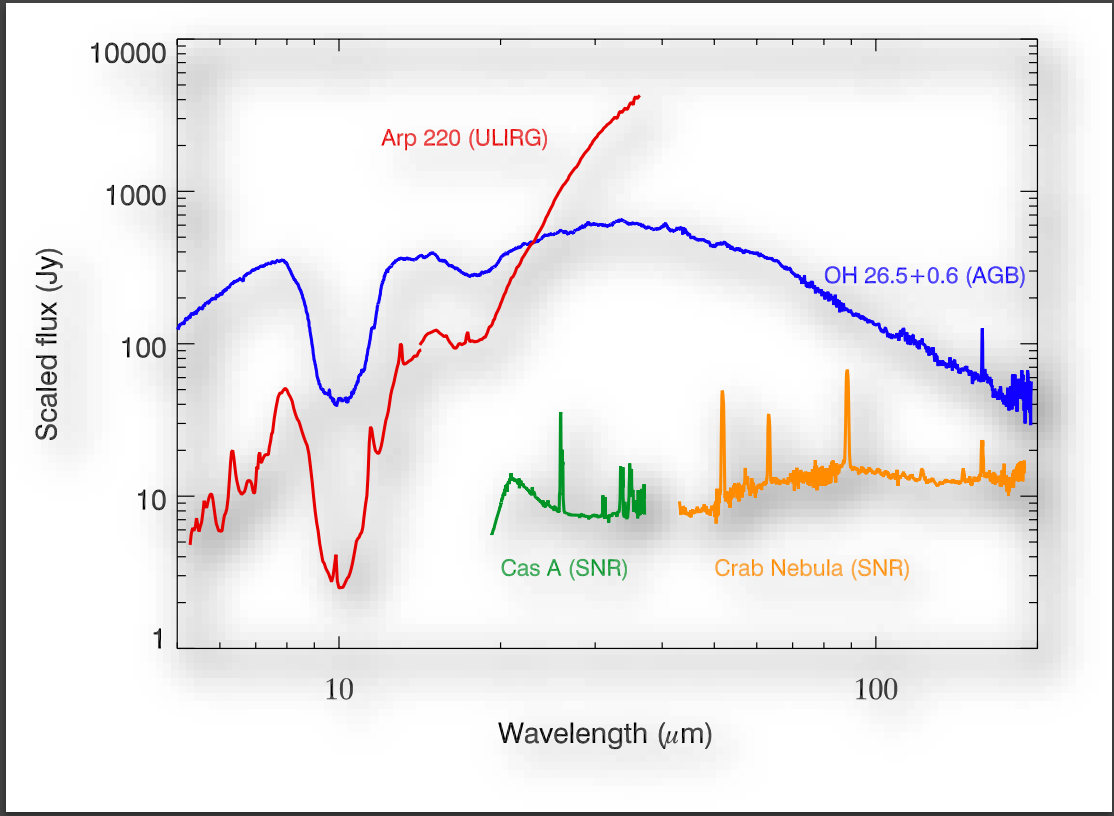
The 'nearer by' universe: local Galaxies





- 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*
  - *Unbiased survey out to ~100 Mpc to cover the largest possible range of star formation rates, metallicities, and morphological types.*

Dust in local galaxies



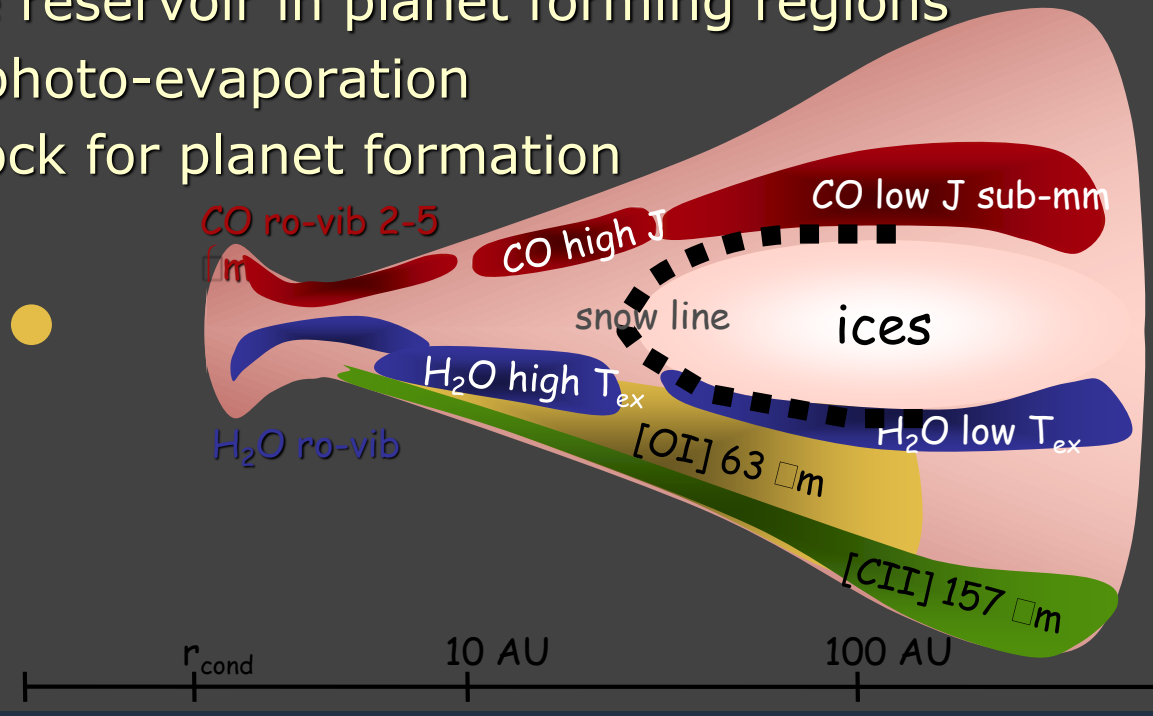
Dust life-cycle

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

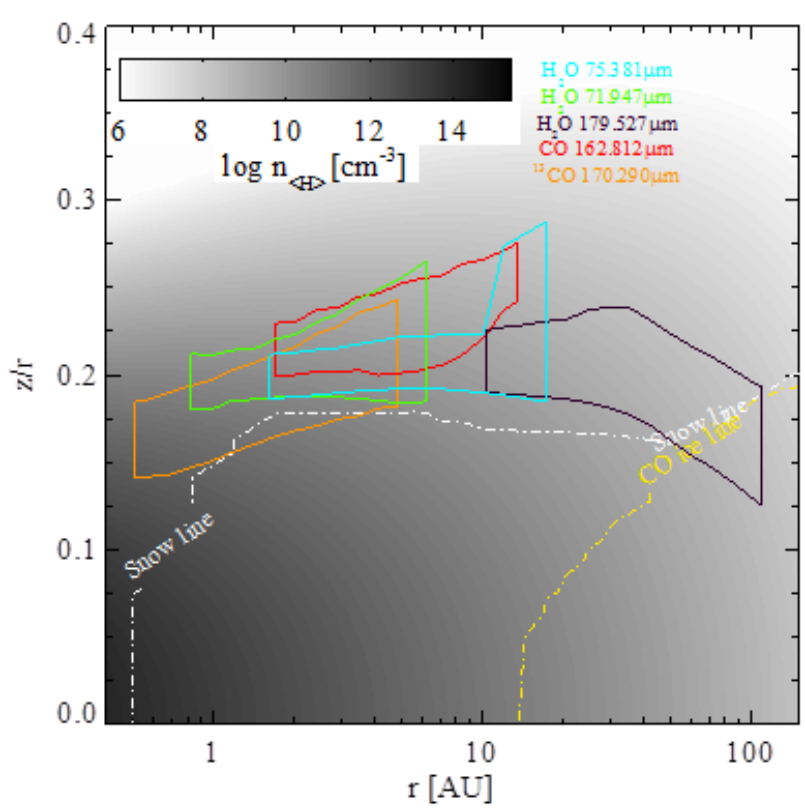
Star and Planet Formation and Evolution

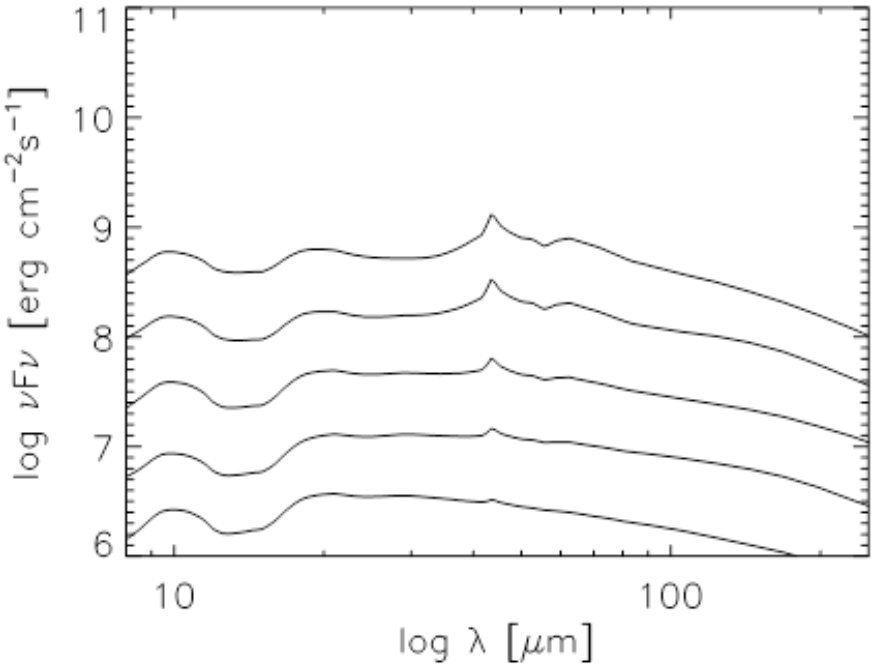
Unique areas of planet formation to be studied with SPICA:

- 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

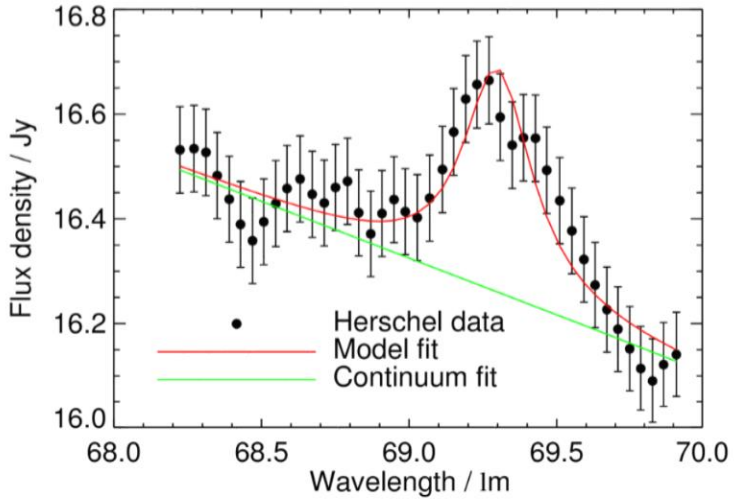
Simulated SEDs for T Tauri discs with varying fraction of icy grains (from bottom to top: 5, 10, 20, 50, 100%).

Mineralogy of debris discs

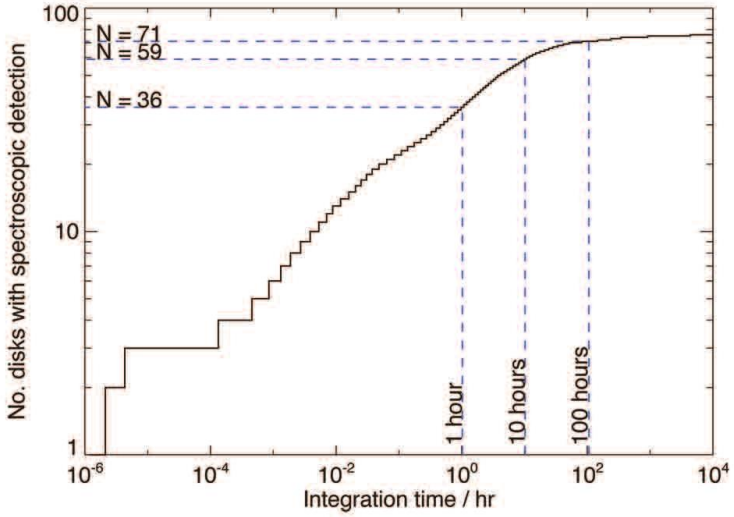
The mineralogy of micron-sized dust particles in discs directly probes the composition of their parent bodies

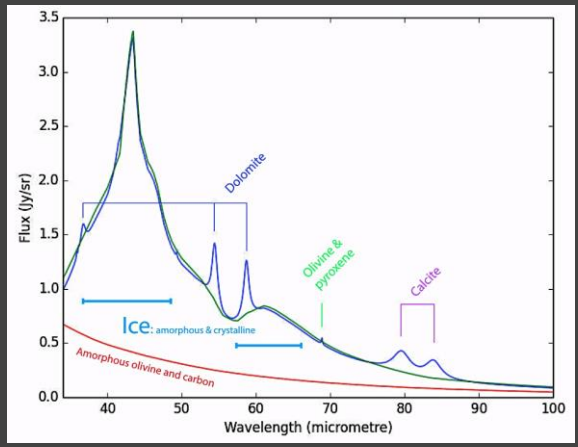
- SPICA provides access to the far-IR resonances of several minerals, allowing a precise determination of their composition and structures
- The the composition of refractory dust in its exo-comets and make a direct comparison with our Solar System

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





A wealth of other SPICA science…

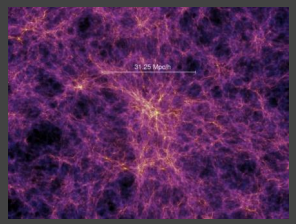
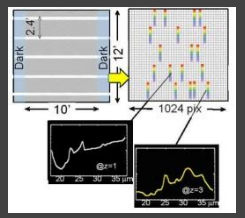
- These were the cases used to specify the mission requirements
  …but much more can/will be done

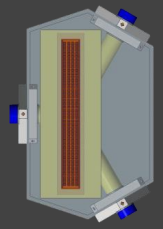
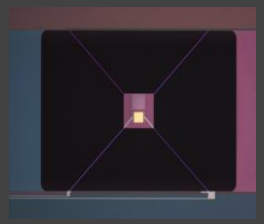
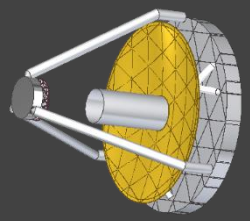
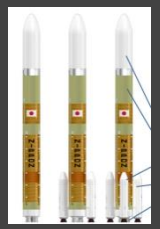
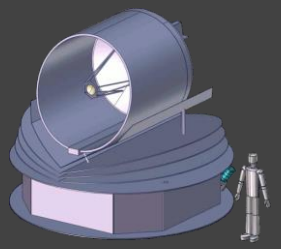
- Characterisation of dust in our galaxy
- Dust/gas in SNR's
- H_2 - out to high z… (?)
- TNO's
- Planets
- …
- Etc. etc.

…this will be up to the community, but can (due to page limitations) only be hinted at in the M5 proposal

→ suggestions are very welcome!

The SPICA mission
the M5 configuration

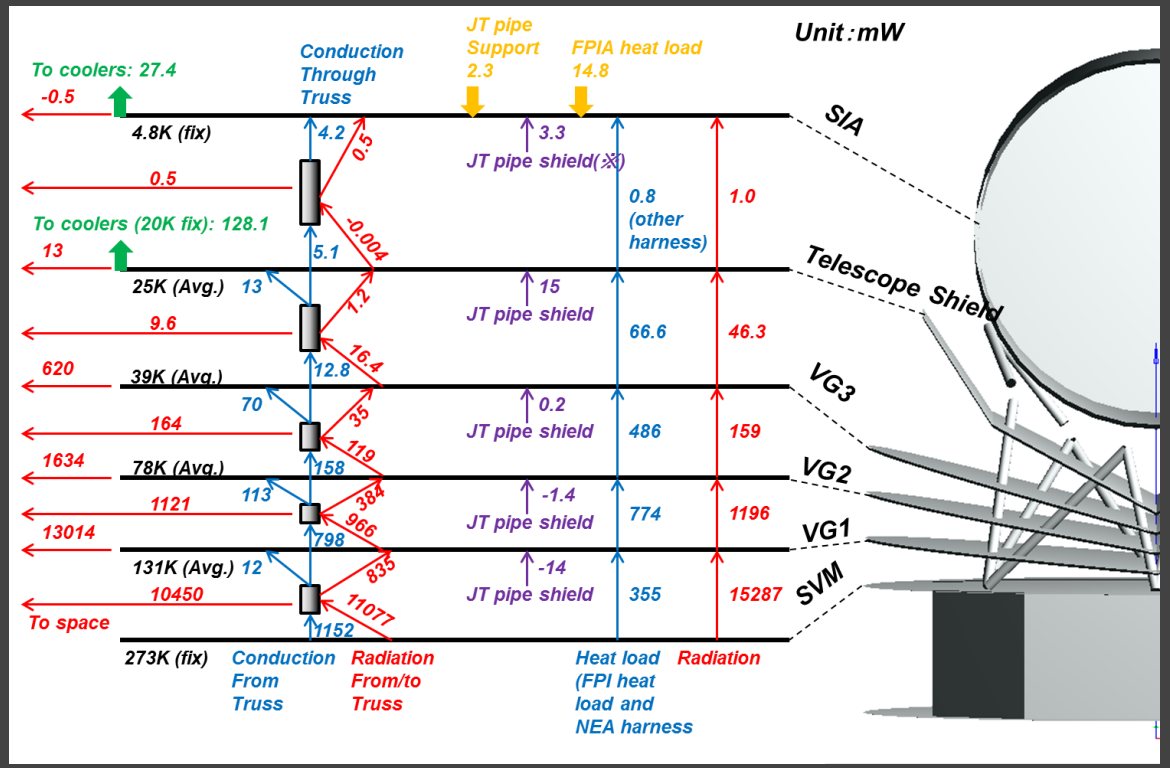






The mission concept

- Joint ESA-JAXA mission
- '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
- 'standard' Herschel/Planck SVM
- Japanese H3 launcher, L2 halo orbit
- 5 year goal lifetime

Main challenge – thermal design

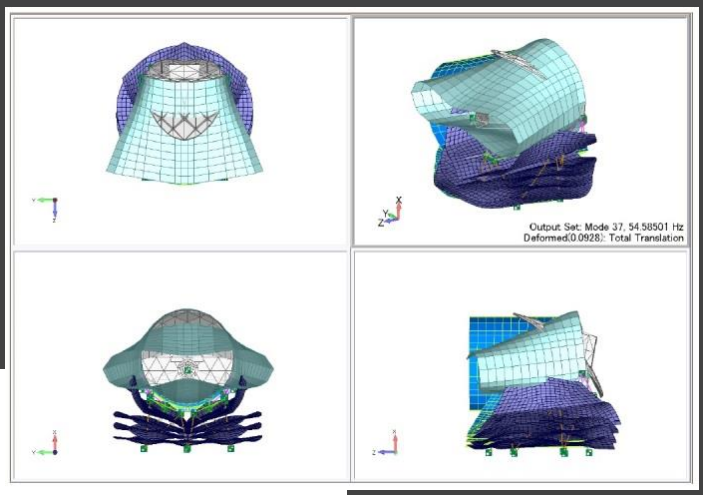
- V-grooves – passive cooling to 40K
- Active cooling to 4K and 1.7K
  - Detector modules at 50mK with dedicated mK coolers (SAFARI)
- Detachable support struts

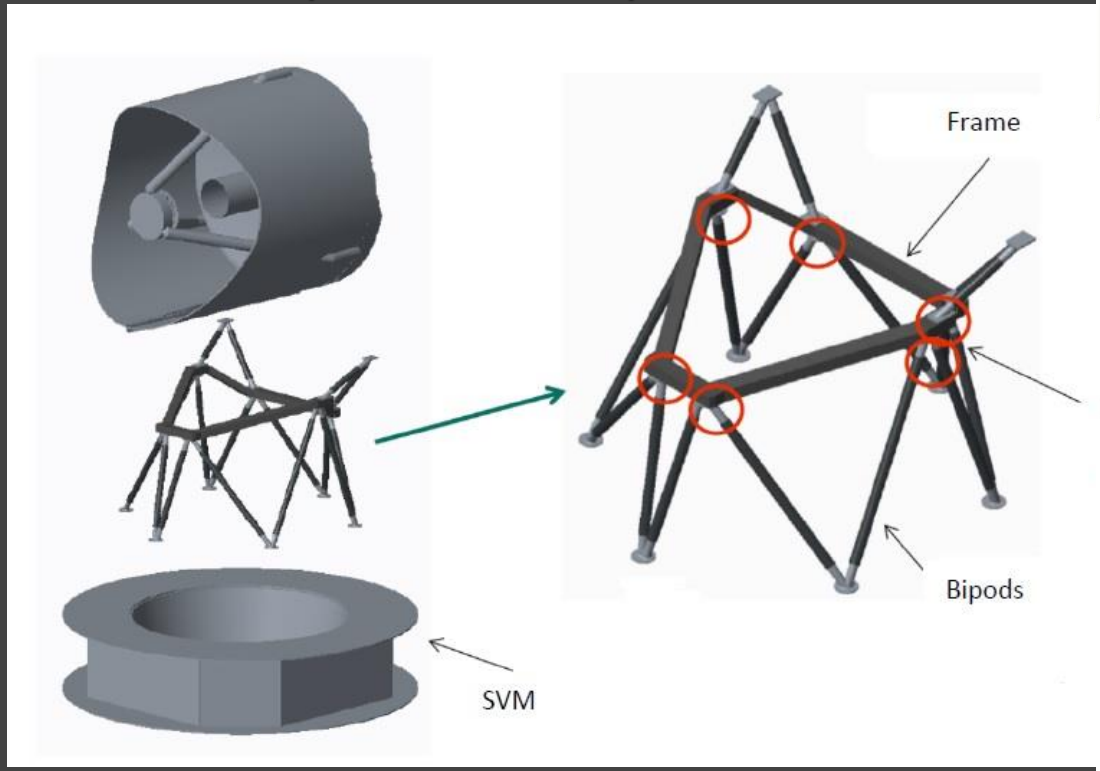


Telescope support structure

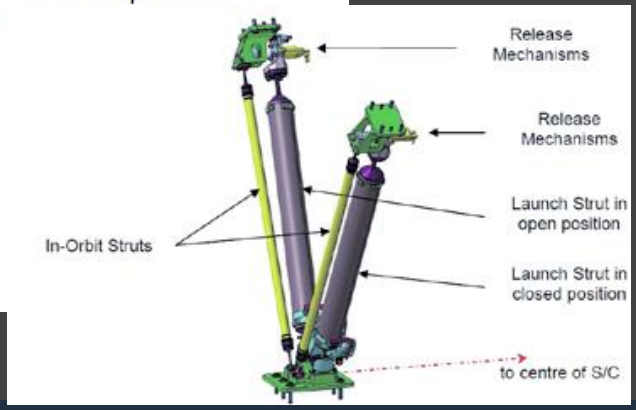
Structure analysis on-going

- Further optimization: stiffness, thermal…
- Launch and in-flight requirements differ
  → in space truss separation

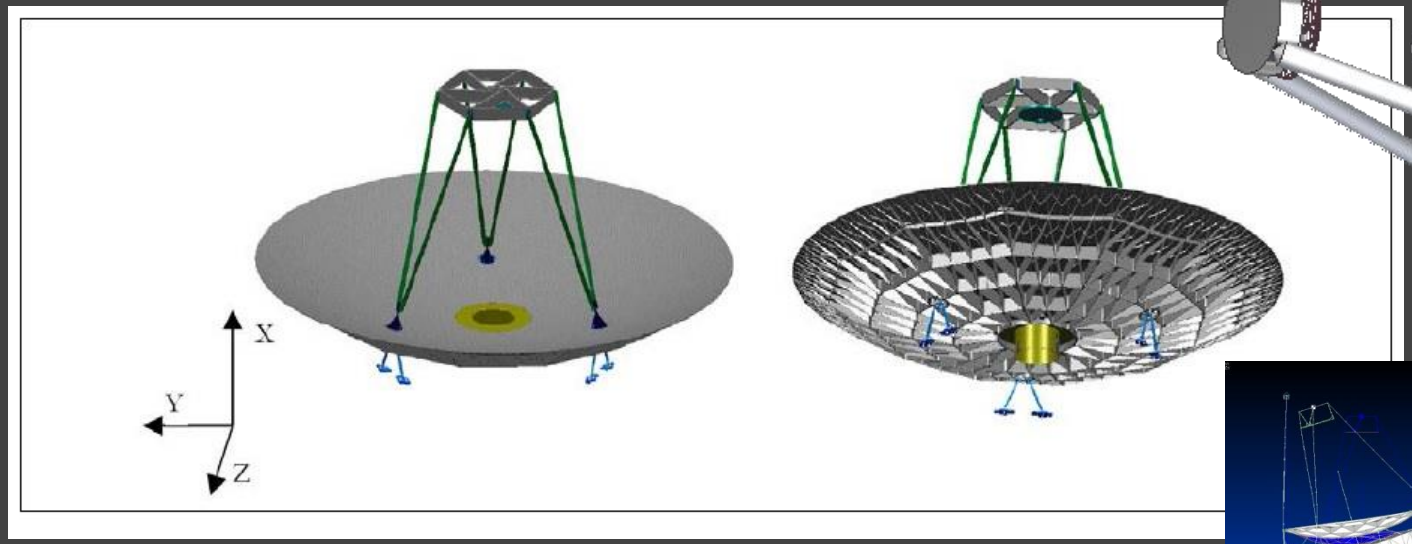


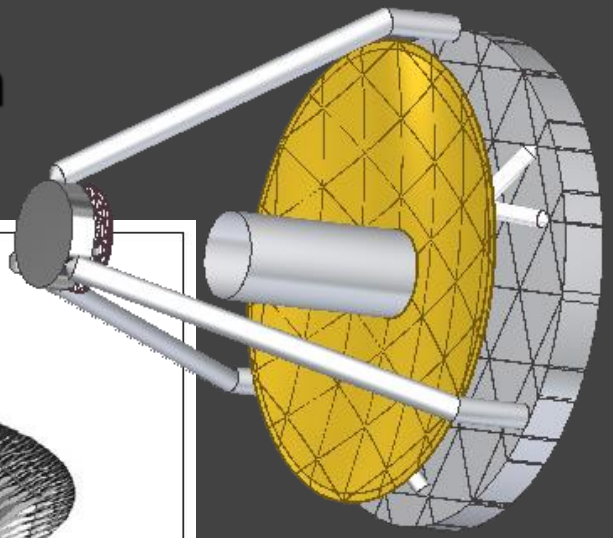


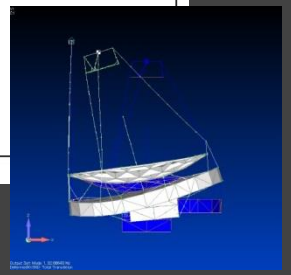
- Points of on orbit Truss separation

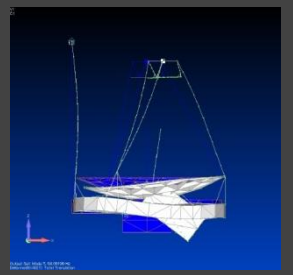


Telescope – 2.5m Ritchy-Chrétien



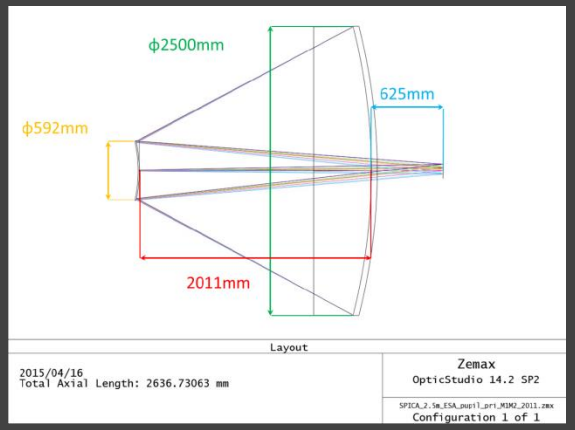


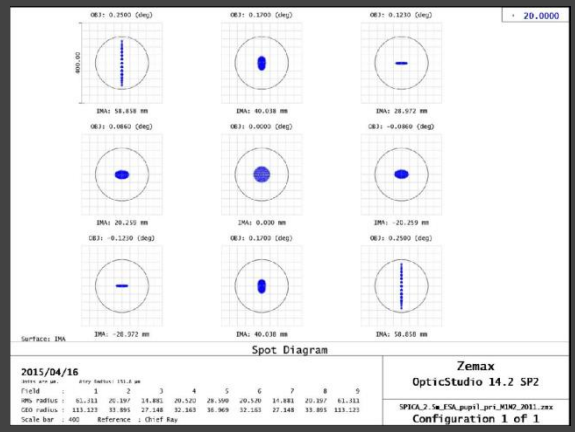




Herschel heritage

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





Who provides what

Telescope (ESA)

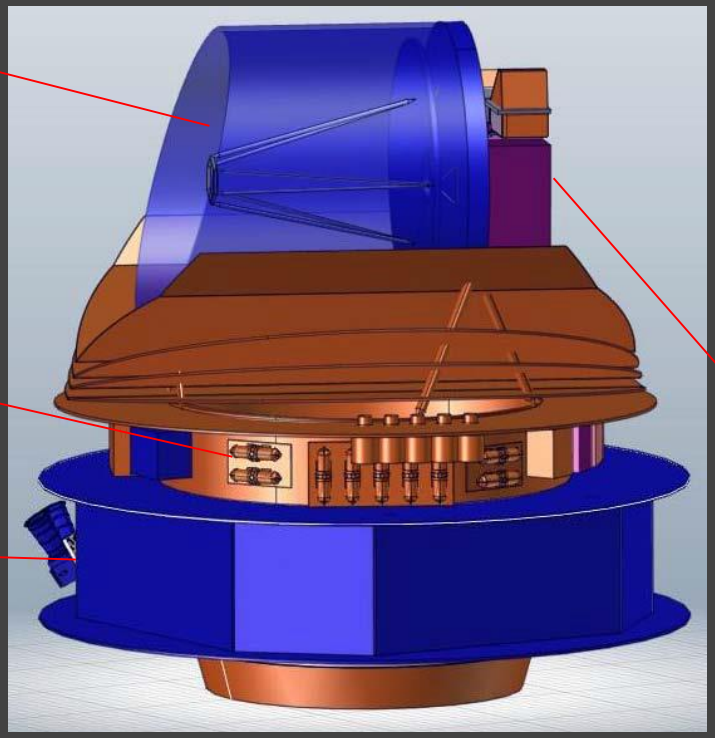
Payload Module

Cryocooler

Bus Module

Launcher

SPICA Data Center



Focal Plane Attitude Sensor

Focal Plane Instrument Assembly

FIR Spectrometer (SAFARI)

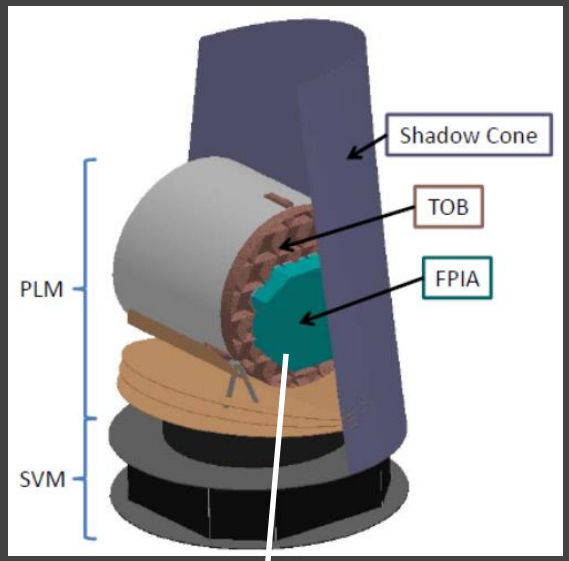
NL + European countries + Canada & US

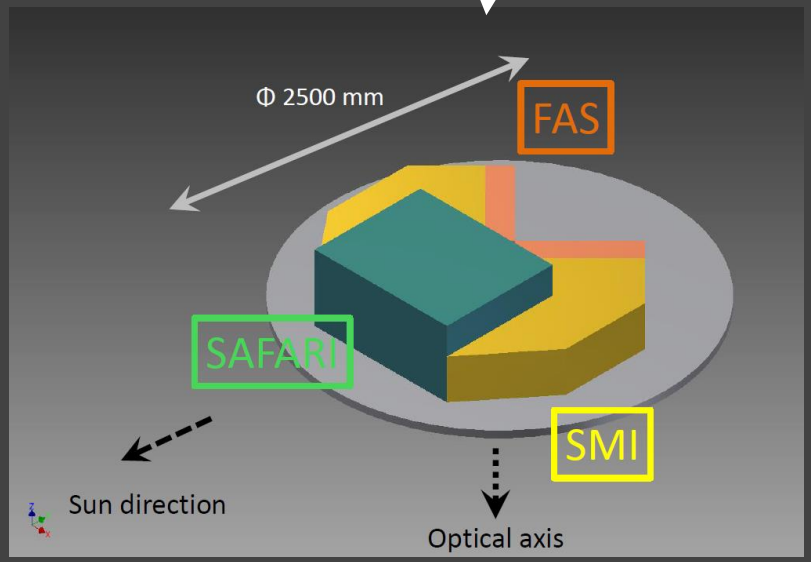
MIR Instrument (SMI)

Complexity in responsibilities and interfaces
→ challenging AIV program

The SPICA focal plane assembly

- Focus on spectroscopic capability
  - SAFARI 35–230 μm – R~300/3000
  - SMI 17–35 μm – R~100/1500
  - SMI 12–18 μm – R ~ 28000
- Imaging capability
  - SMI 17–35 μm camera
- Final FPIA iterations ongoing

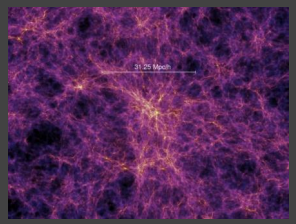


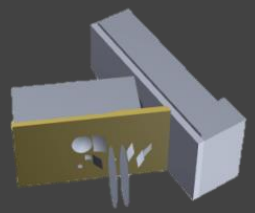


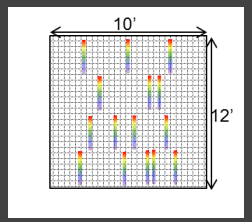
- Options (still) under consideration
  - Extending SAFARI to 300/350 μm
  - Additional 60/120/200 μm imager/polarimeter

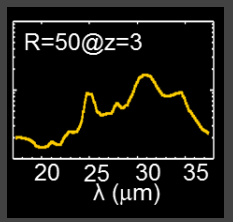
… but feasibility ***very*** dependent on ***(thermal) budget***

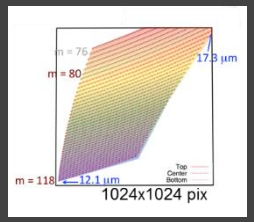
The SPICA Mid-infrared Instrument
...fully covered later by Hidehiro Kaneda

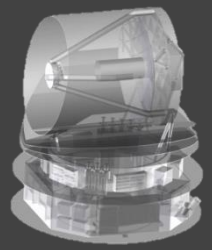




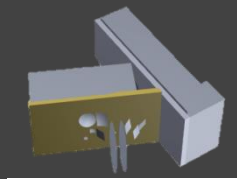




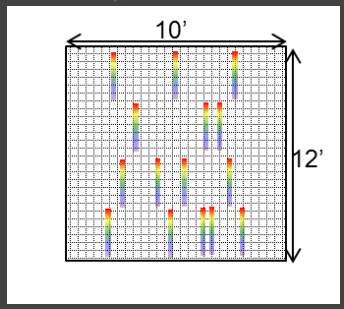


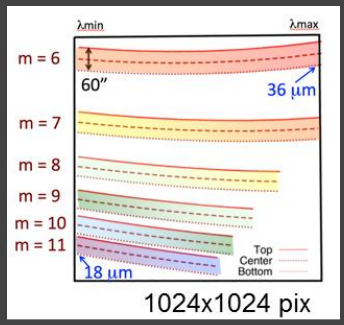


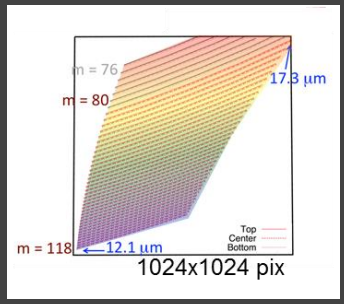
SMI - SPICA Mid-infrared Instrument



- **LRS** – large area low resolution surveyer
  - 17 – 36 μm, R = 50 – 120
  - 4 slits (10’ long) with prism
  - Detector: Si:Sb
  - Camera mode with slit viewer
- **MRS** – medium resolution mapper
  - 18 – 36 μm, R = 1200 – 2300,
  - 1 slit (1’ long) with grating
  - Detector: Si:Sb w/ beam-steering mirror
- **HRS** – molecular physics/kinematics
  - 12 – 18 μm, R = 28,000
  - 1 slit (4” long) with immersion grating
  - Detector: Si:As





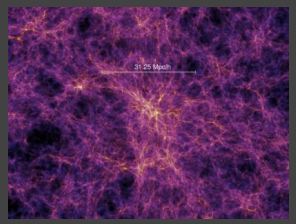
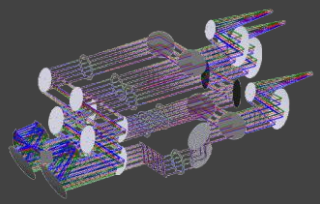
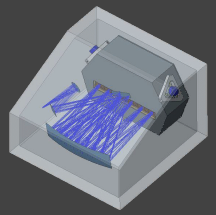
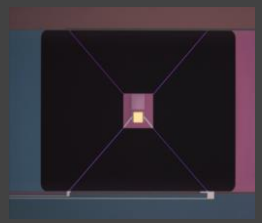
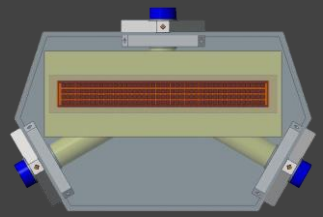
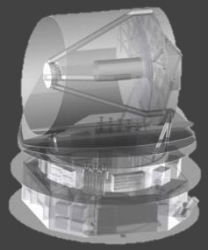


- SMI Consortium
  - Nagoya Univ., Univ. of Tokyo, Osaka Univ.
    Tohoku Univ., Kyoto Univ., & ISAS/JAXA

SAFARI

SRON

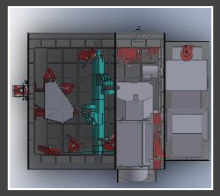
The SAFARI grating spectrometer

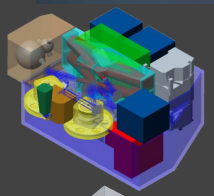
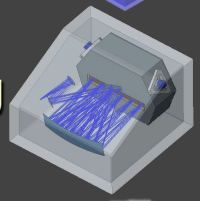
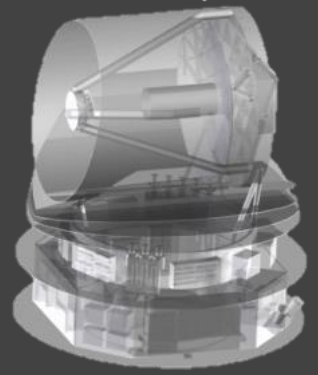







Some history – Europe, SPICA and SAFARI

- 2004 – UK leads SAFARI and European SPICA effort
- 2009 – Phase-A study → consolidated FTS design
- 2010 – detector review → Transition Edge Sensors (TES)
  - SAFARI reference design
- 2014 – re-evaluation of science (late 20'ies!) → SAFARI/Grating
  - following joint JAXA/ESA CDF mission study
- 2015 – SAFARI consortium says yes to leading M5

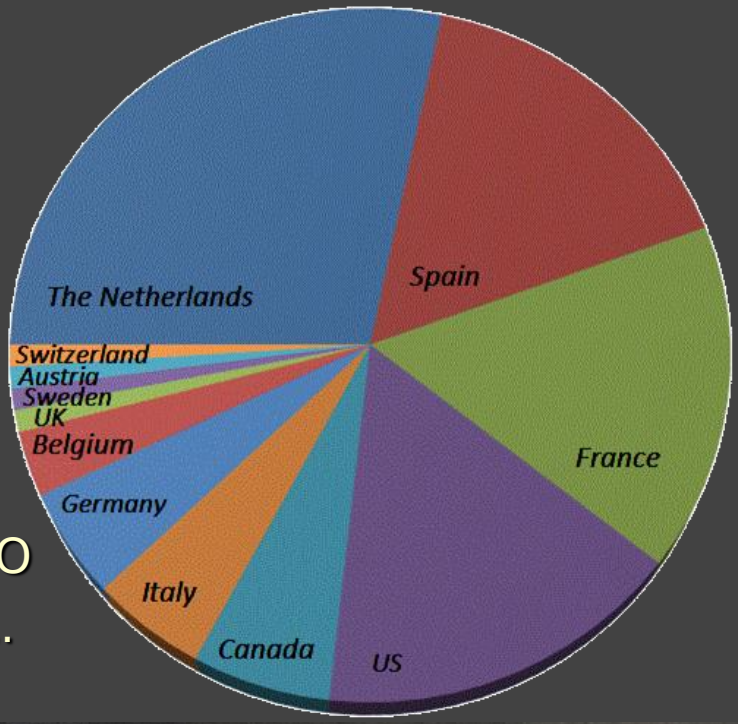
  → go-ahead for M5



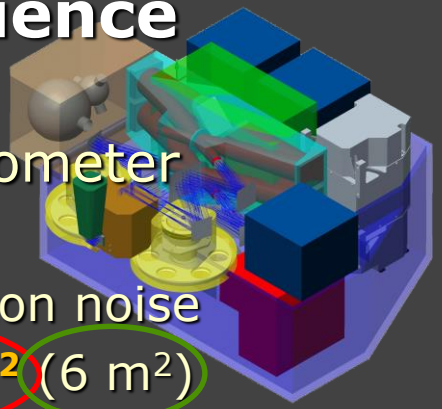




The European drive – the SAFARI consortium

- Started already in 2004
  - Gradually growing since then
  - Apply experience on 'who does what'
  - First only SAFARI, now also SPICA
- Drive and experience!
  - Pushing design ***and*** science
  - Heritage from Herschel (e.g. FTS), ISO
  - Working with/for future astronomers…



SAFARI – evolution dictated by the science



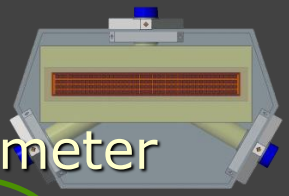
Original design: Imaging Fourier Transform Spectrometer

- 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!

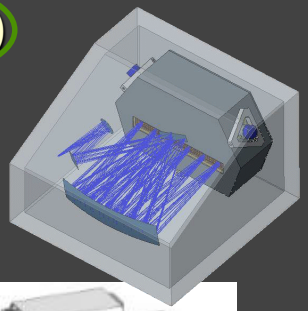


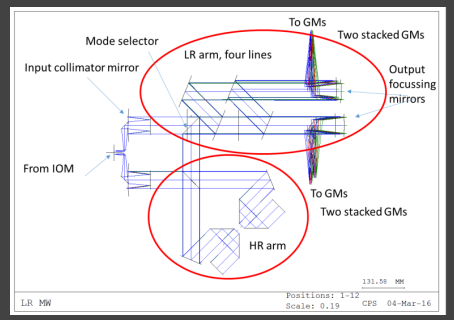
New approach for better sensitivity: grating spectrometer

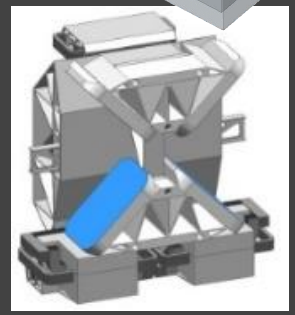
- Basic R~300 mode → 1hr/5σ **~6-8×10^{-20} W/m^2** (4.6 m^2)
  - Improves with better TES performance!
- Martin Puplett Interferometer to provide R~3000 mode
  - Backup: Fabry-Pérot Interferometer
- 4 bands covering 35-230 micron

  …but limited imaging capability:

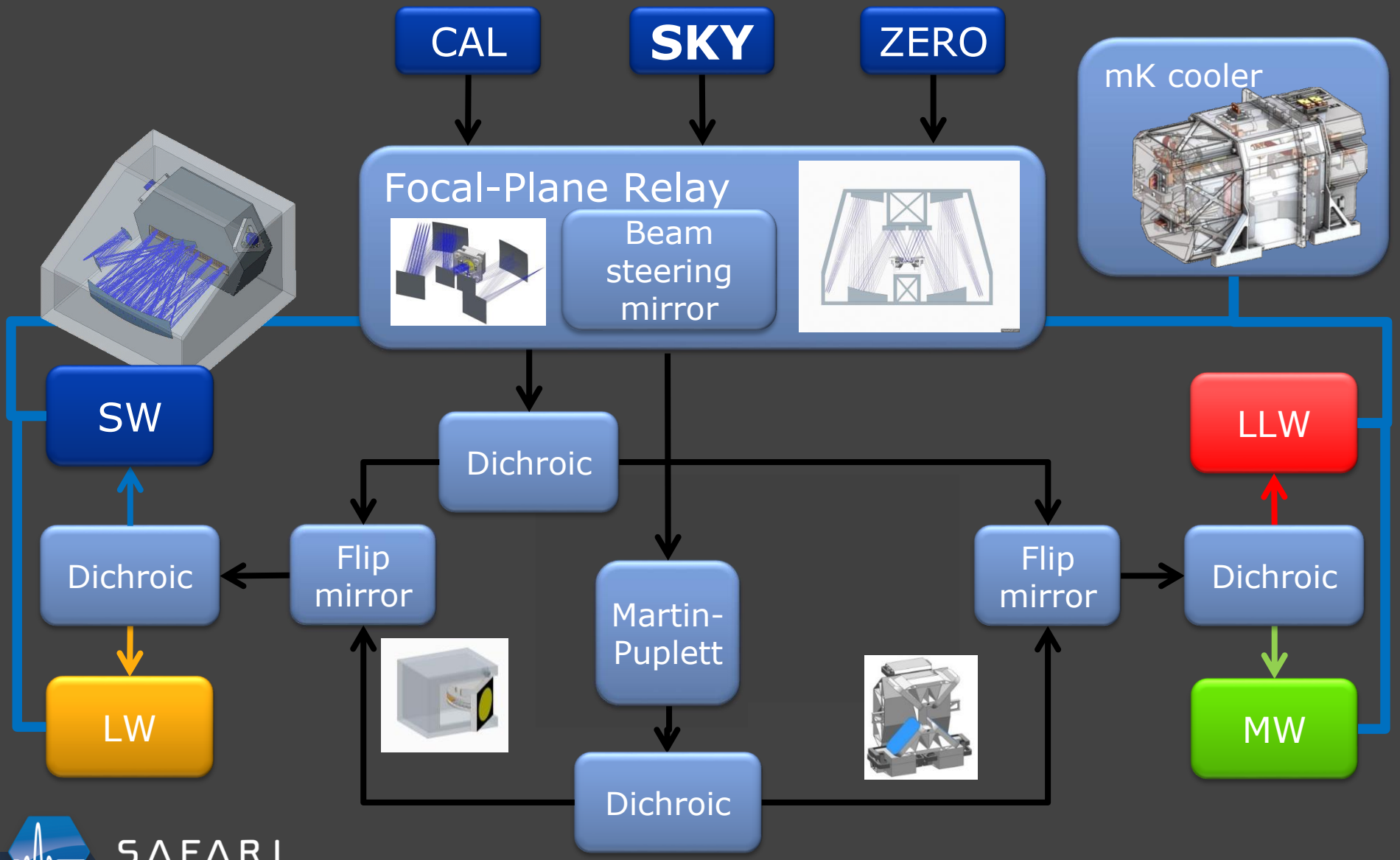
  only 3 pixels on-sky





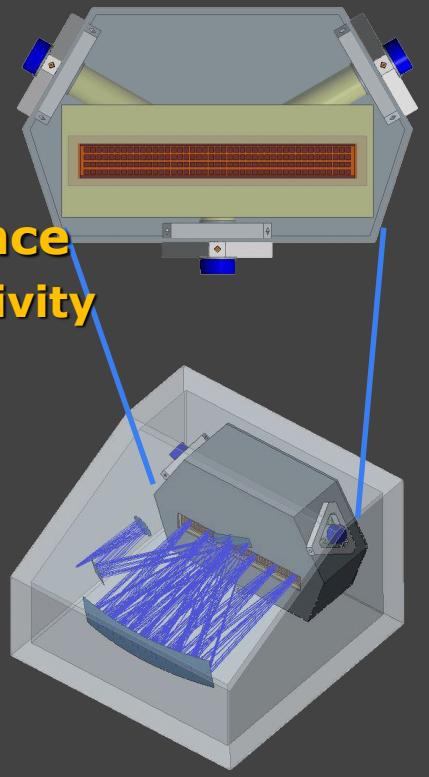


SAFARI system design – with existing technology



Detectors: integrated TES/grating modules

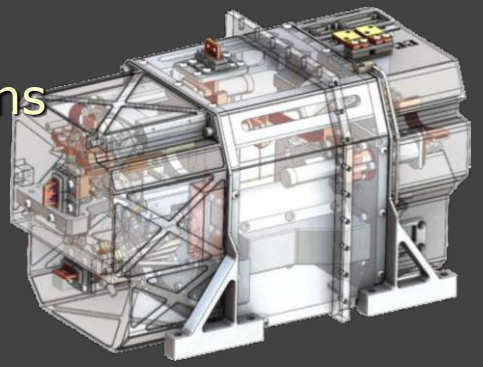
- Linear TES arrays with FDM readout
  - Detector at 1.5 Fλ separation in spectral domain
  - Profit from **already achieved** TES/FDM **performance**
    - Further TES improvement will give **still better sensitivity**



- 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

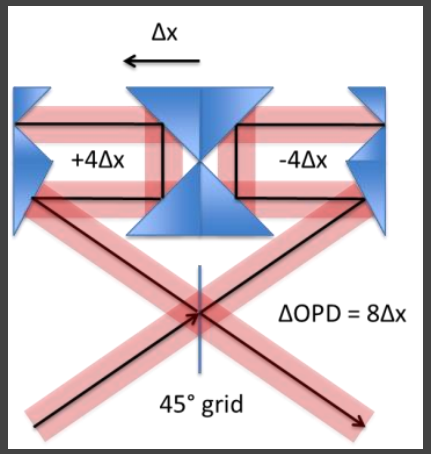
- Cooler
  - **Original SAFARI cooler** with (small) modifications
  - EM already manufactured

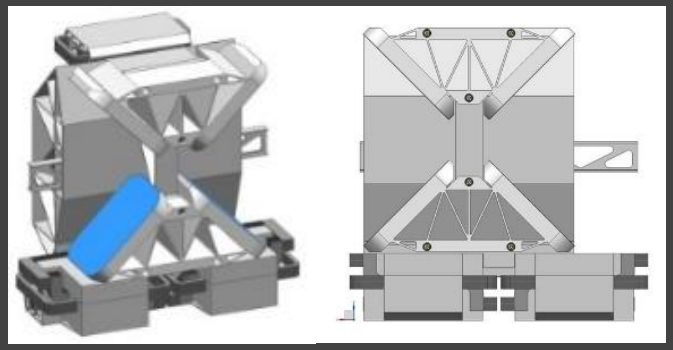
  → high TRL level (still) applies

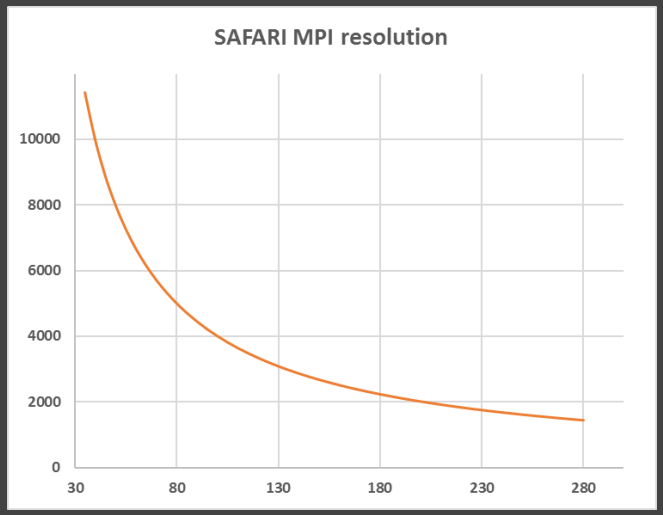


High resolution mode baseline: Martin-Puplett

- Mechanism as in original SAFARI concept
- Sensitivity factor of ~2 below R 300 mode
- Compact layout achieves R~11000-2000

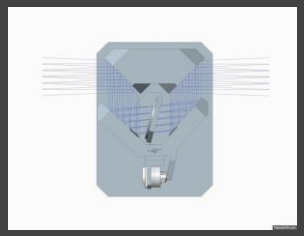


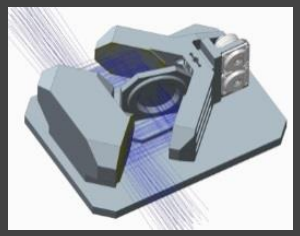




- Backup: Fabry-Pérot Interferometer
  - ISO heritage
  - 4 FPI's i.s.o. single MPI

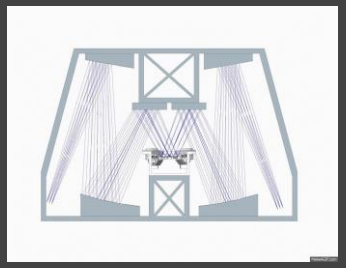
  → Ongoing parallel study (led by Canada)

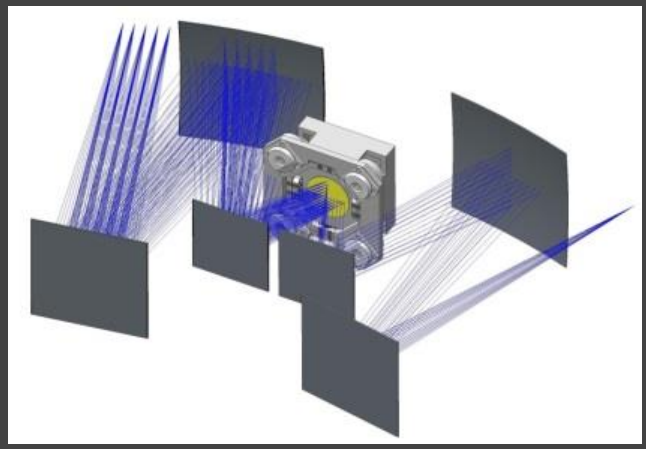




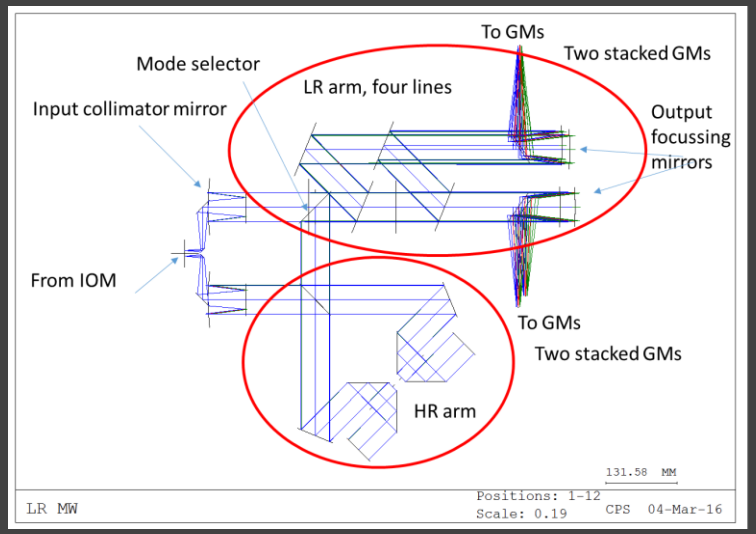
Optical layout

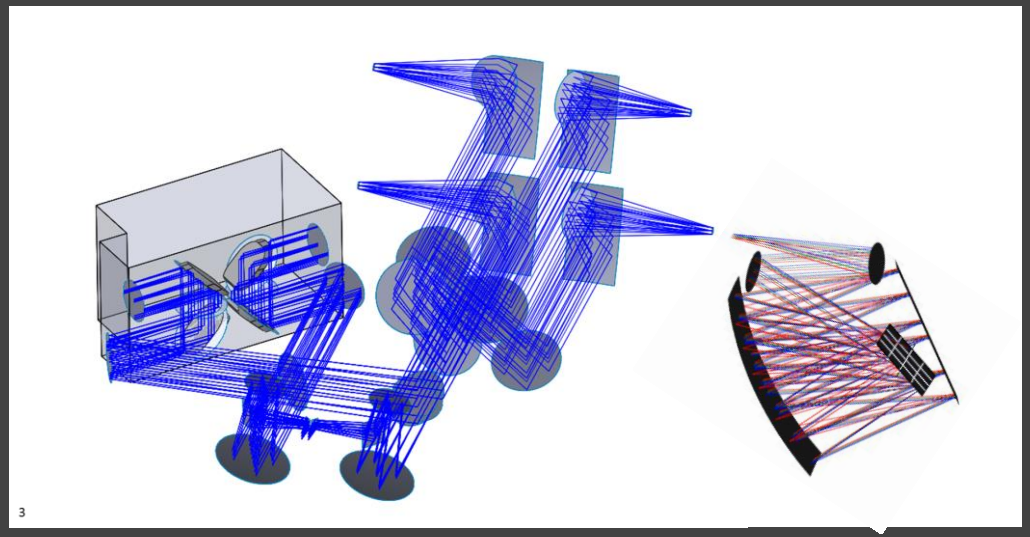
- Beam Steering Mirror as input selector
  - Offner relay
  - Mechanism: SPIRE heritage



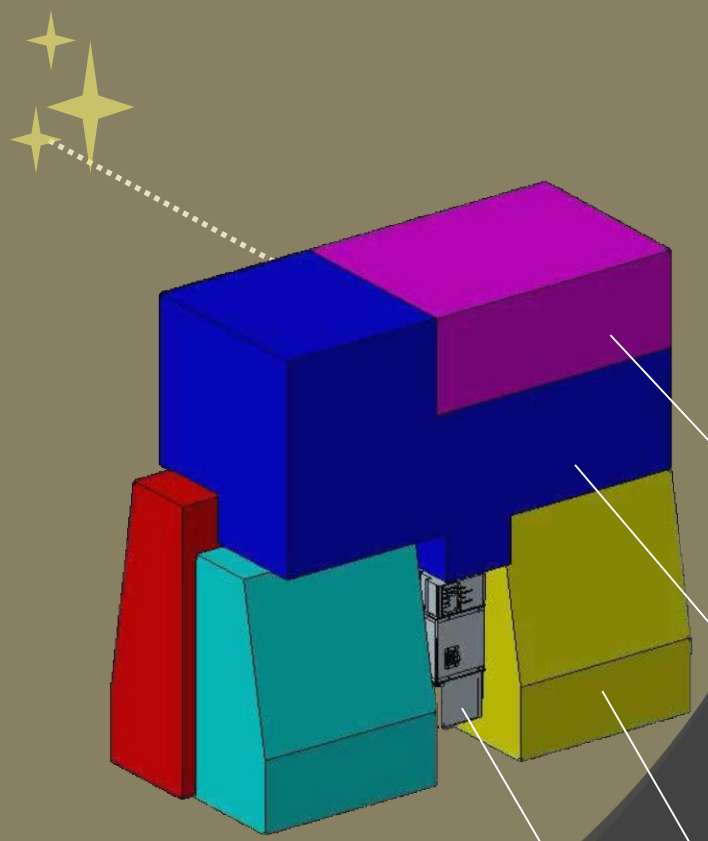


- Final optimization iterations for overall layout





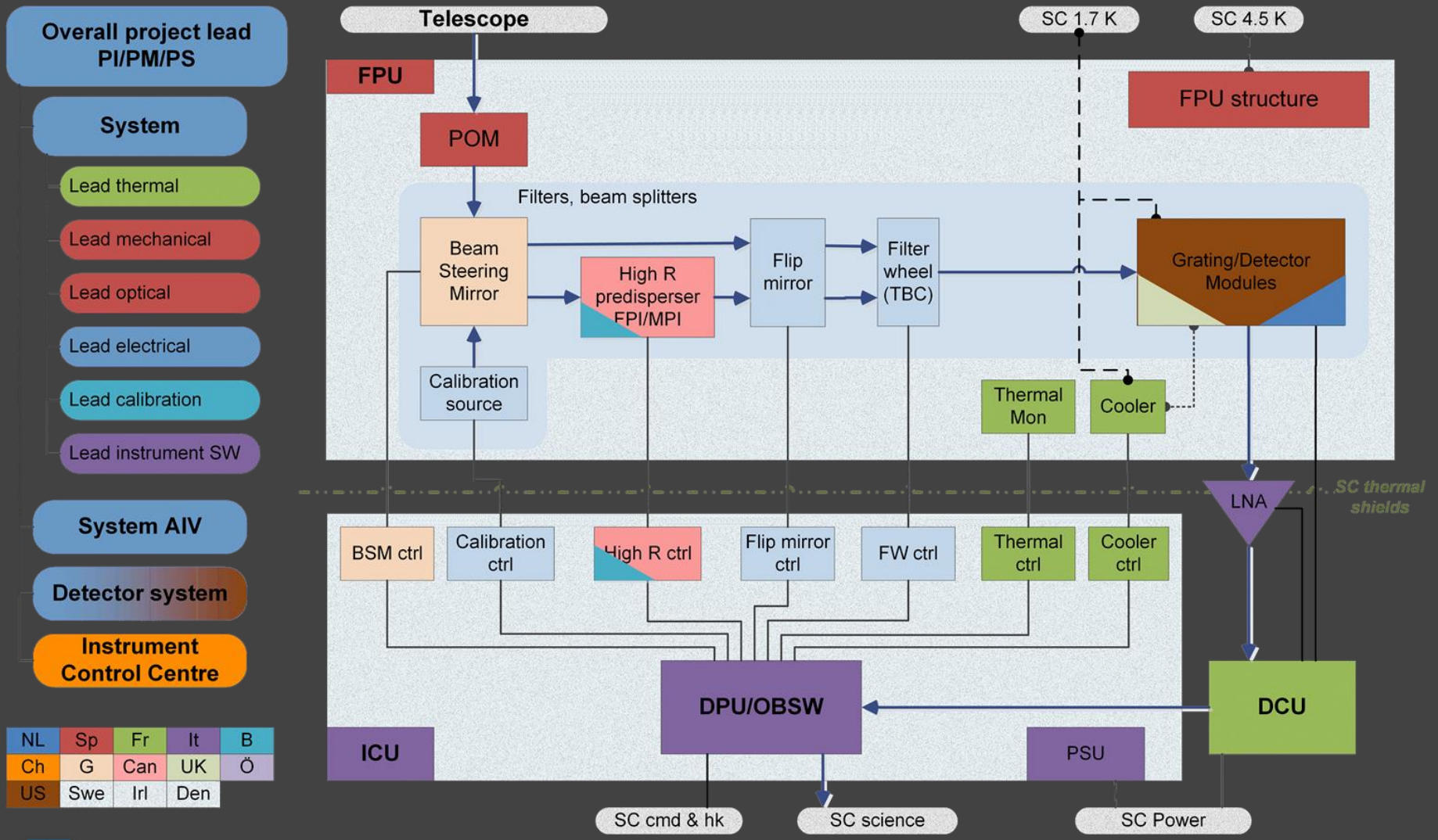
Impression of instrument on the FPIA



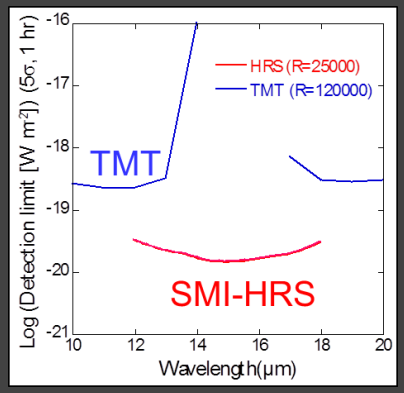
Volume is still challenging
→ further iterations needed
(…ongoing right now)

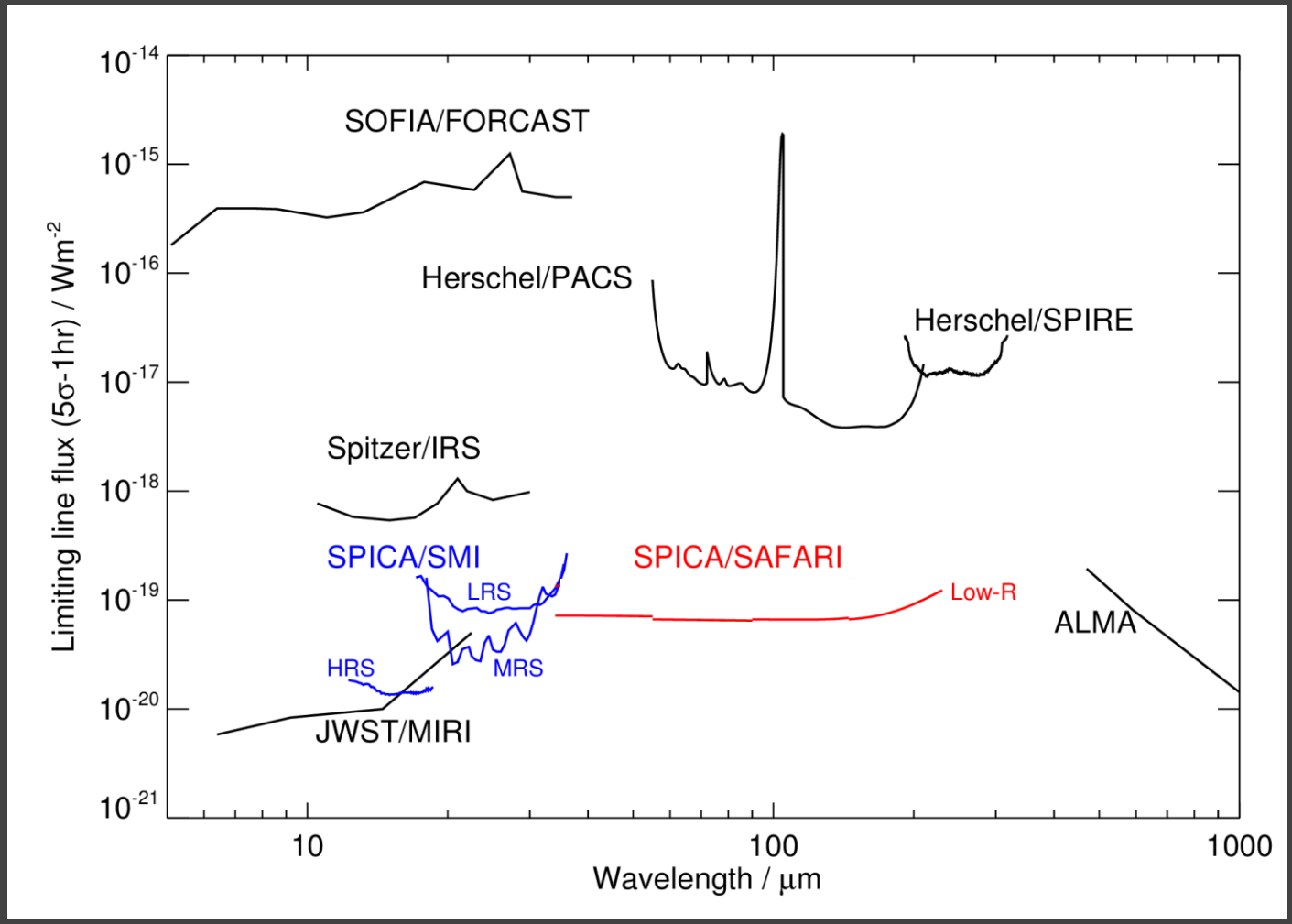
M5 baseline configuration to be presented at upcoming SAFARI consortium meeting

Work distribution in the SAFARI consortium



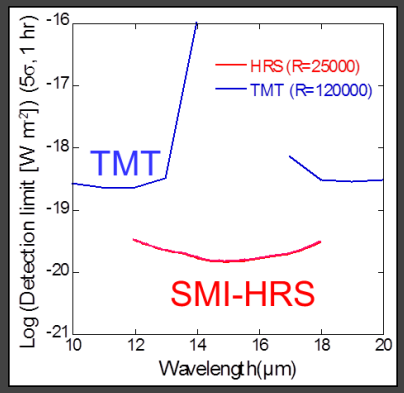
SPICA sensitivity – a huge step forward

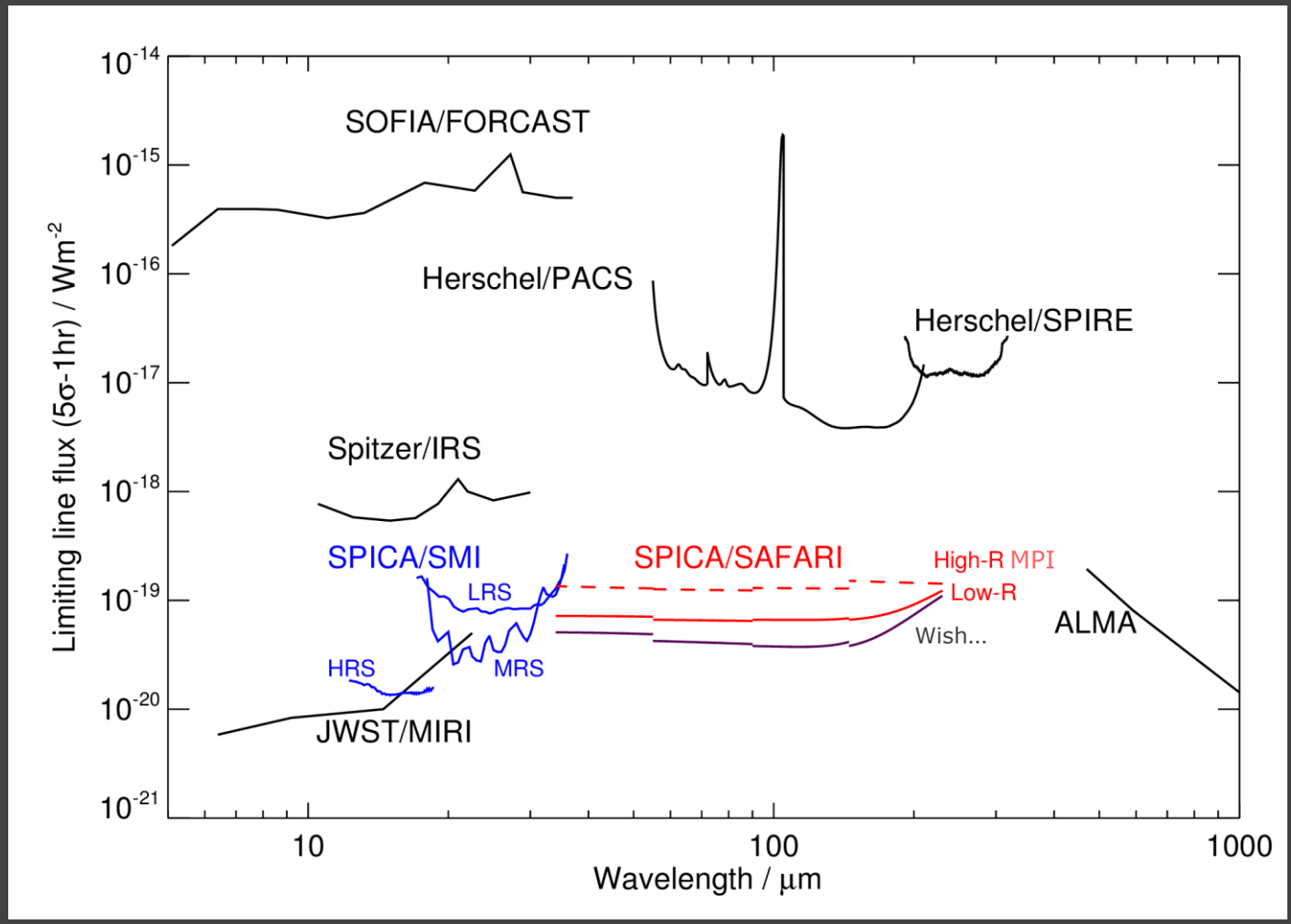




Raw sensitivity improvement **>2 orders** of magnitude
Instantaneous full spectra → huge step in efficiency

SPICA sensitivity – there is a chance for more

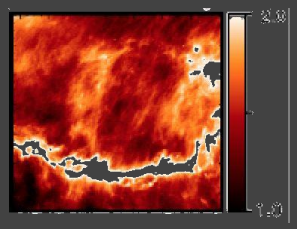
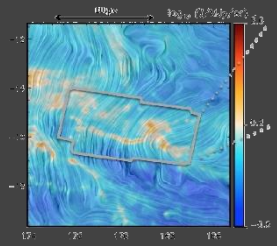
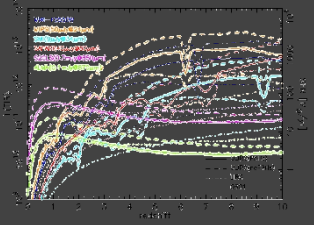
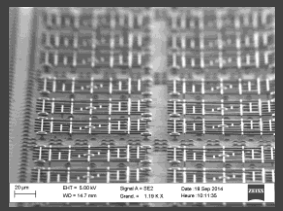
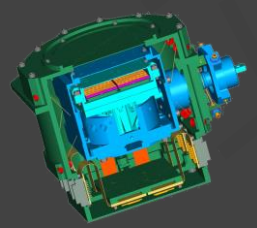
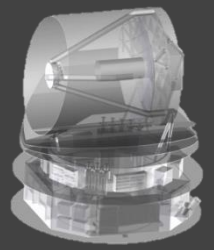




Raw sensitivity improvement **>2 orders** of magnitude
Instantaneous full spectra → huge step in efficiency
…and further TES performance would give further improvement

Potential for a third instrument...?

photometry/polarimetry 50-110-220-350 μm

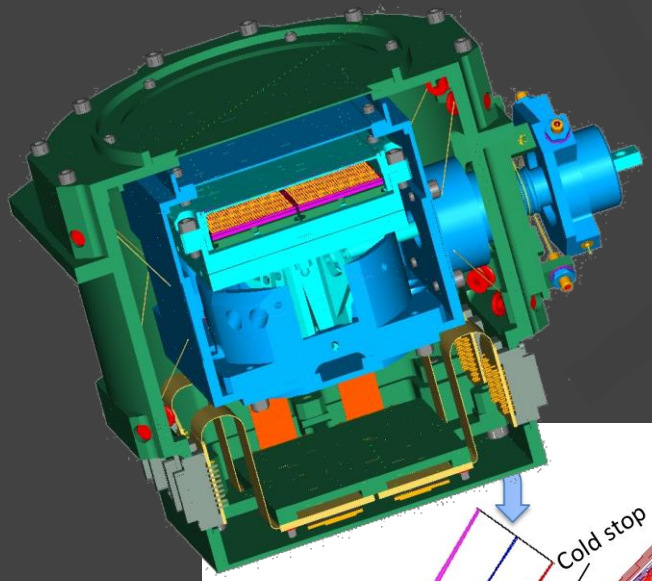







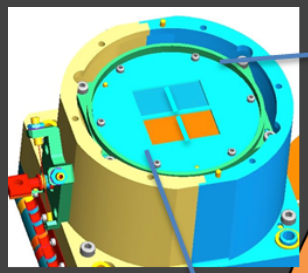
Considerations for an imager/polarimeter

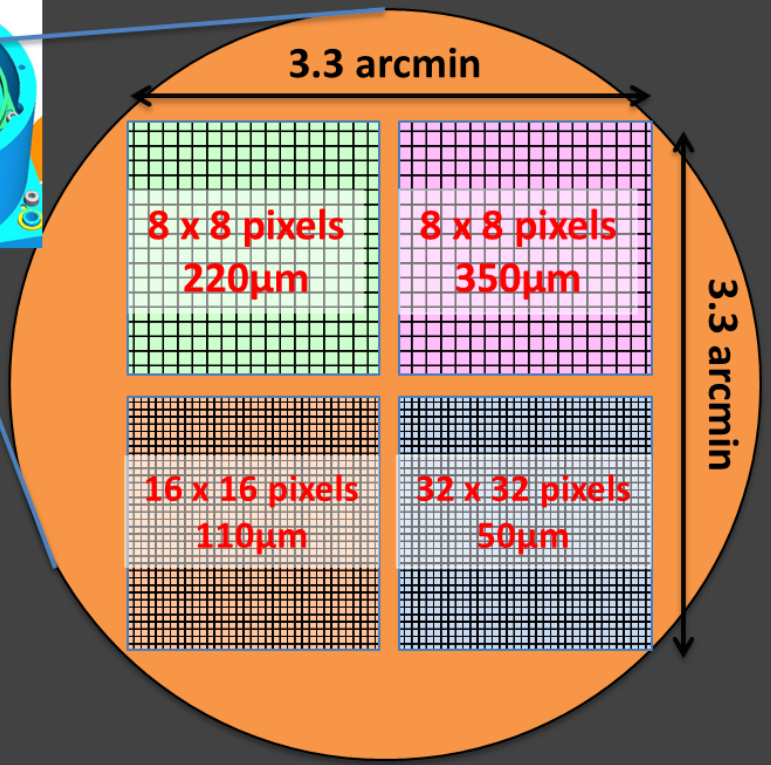
- SAFARI evolution to grating – loss of FIR imaging capability
  → small team volunteered to look into options to recover

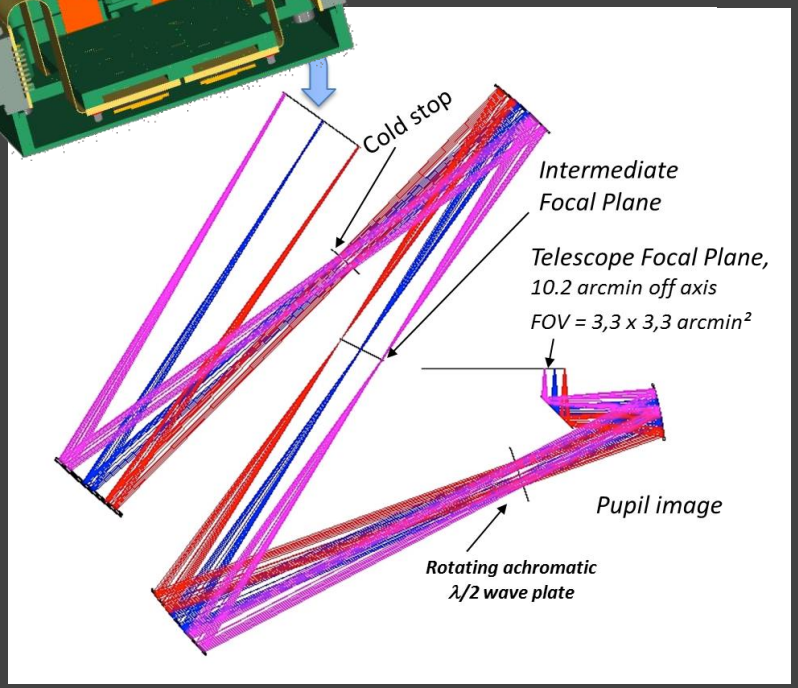
- CEA/Saclay – interest in leading instrument implementation
  - Building on development for candidate SAFARI detectors (2010)
  - Science interest; magnetic fields in dust filaments → polarization
- CAB/INTA Madrid – instrument support
  - Science interest; characterization of high-z sources

BiBoP imager polarimeter





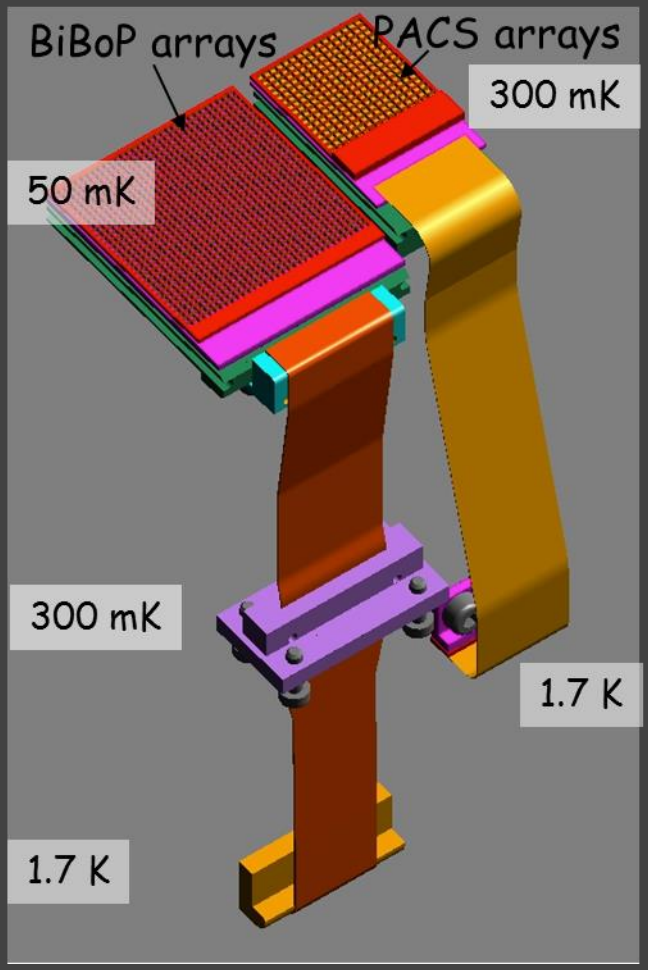


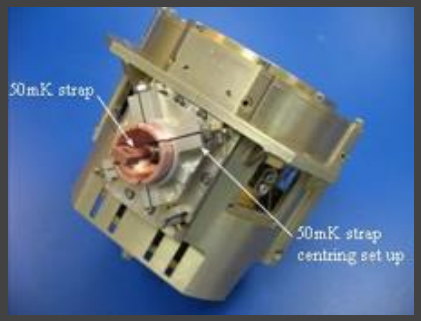


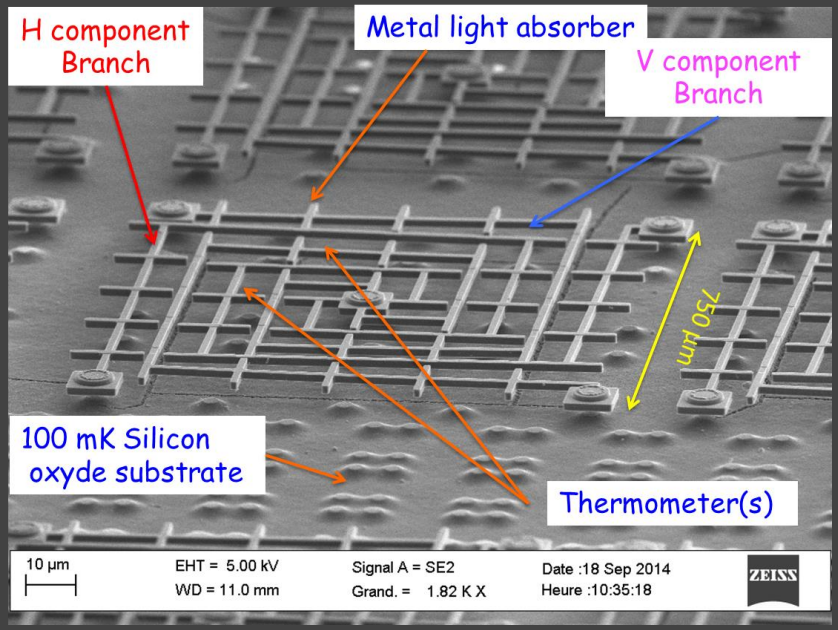
Ideal Nyquist sampling:

50µm	→ 2,06"
110µm	→ 4,54"
220µm	→ 9.08"
350µm	→ 14.4"

Underlying technology well understood

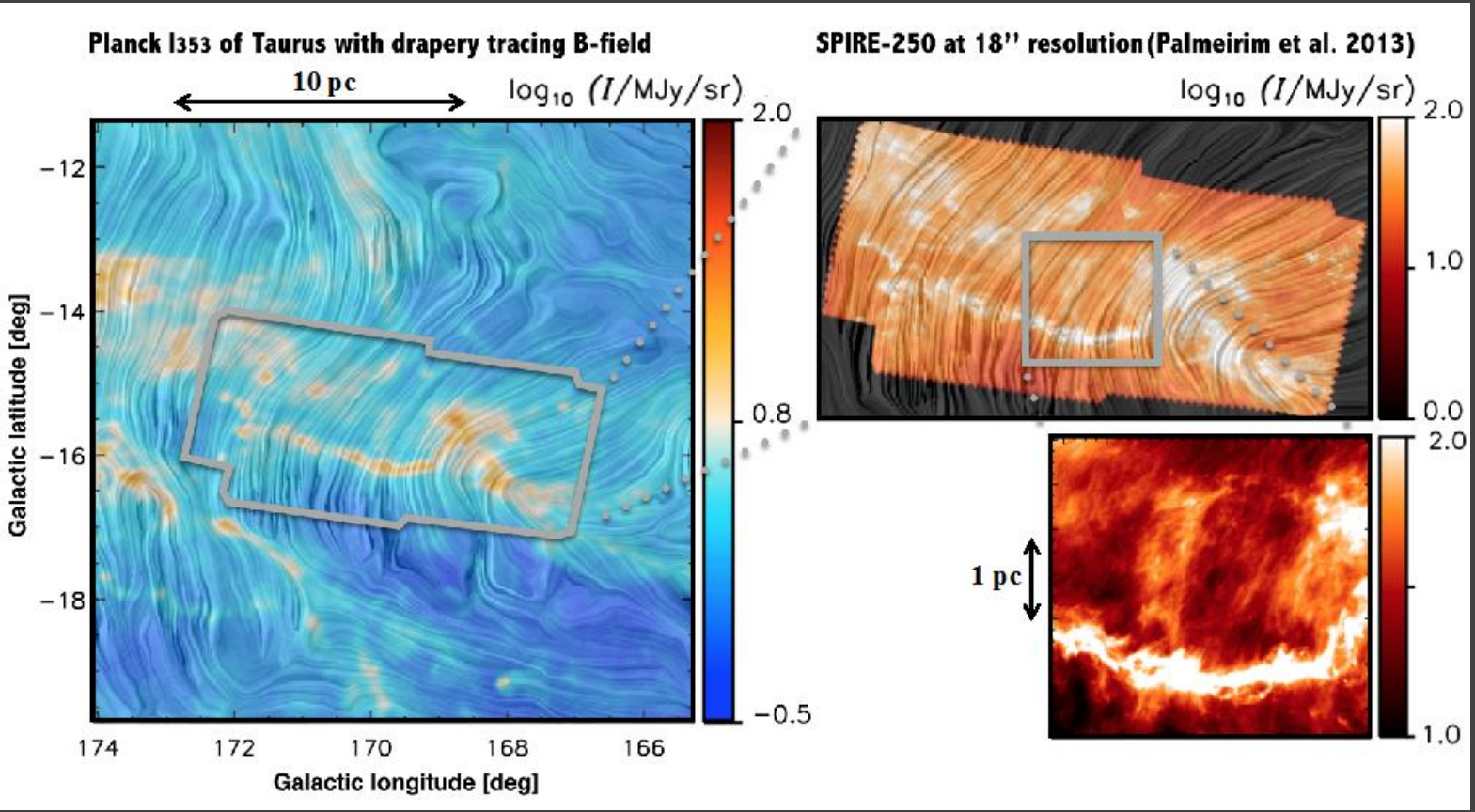






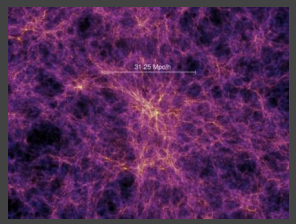
- Based on PACS: expected @50mK NEP ~ 3×10^{-18} W/√Hz

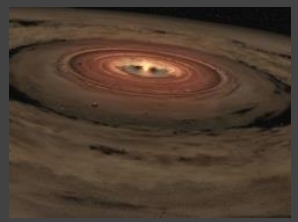
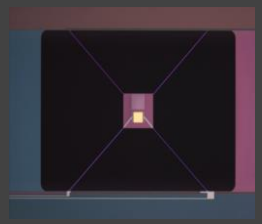
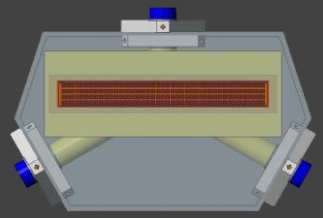
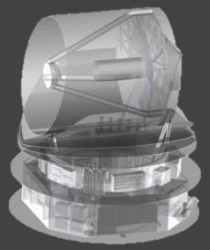
Science case – magnetic field in dust filaments



- Hershel @5"-10" – galactic dust in thin filaments
- PLANCK @5' – ***large scale*** magnetic field ***seems*** perpendicular to filaments…
  → SPICA @5"-15" can ***measure*** magnetic field ***within*** filaments

The programmatic context and the outlook

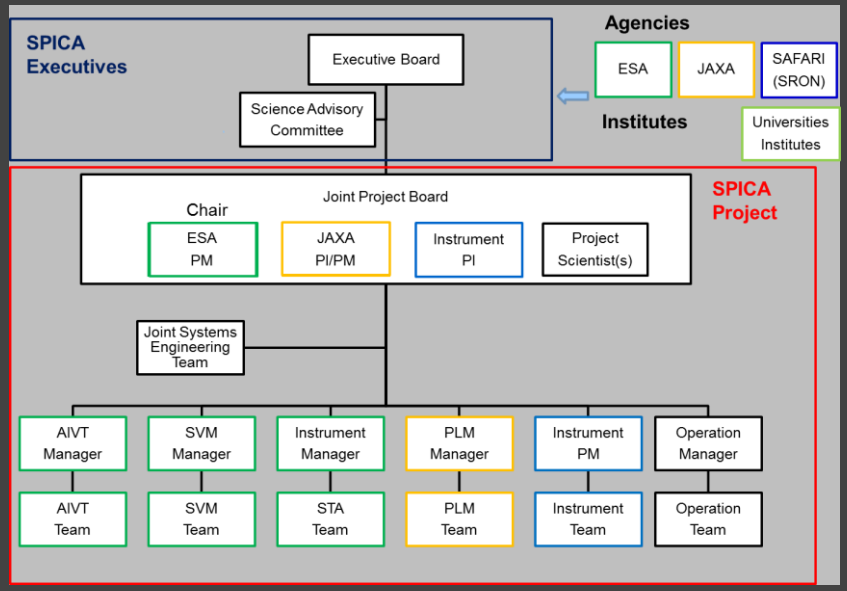


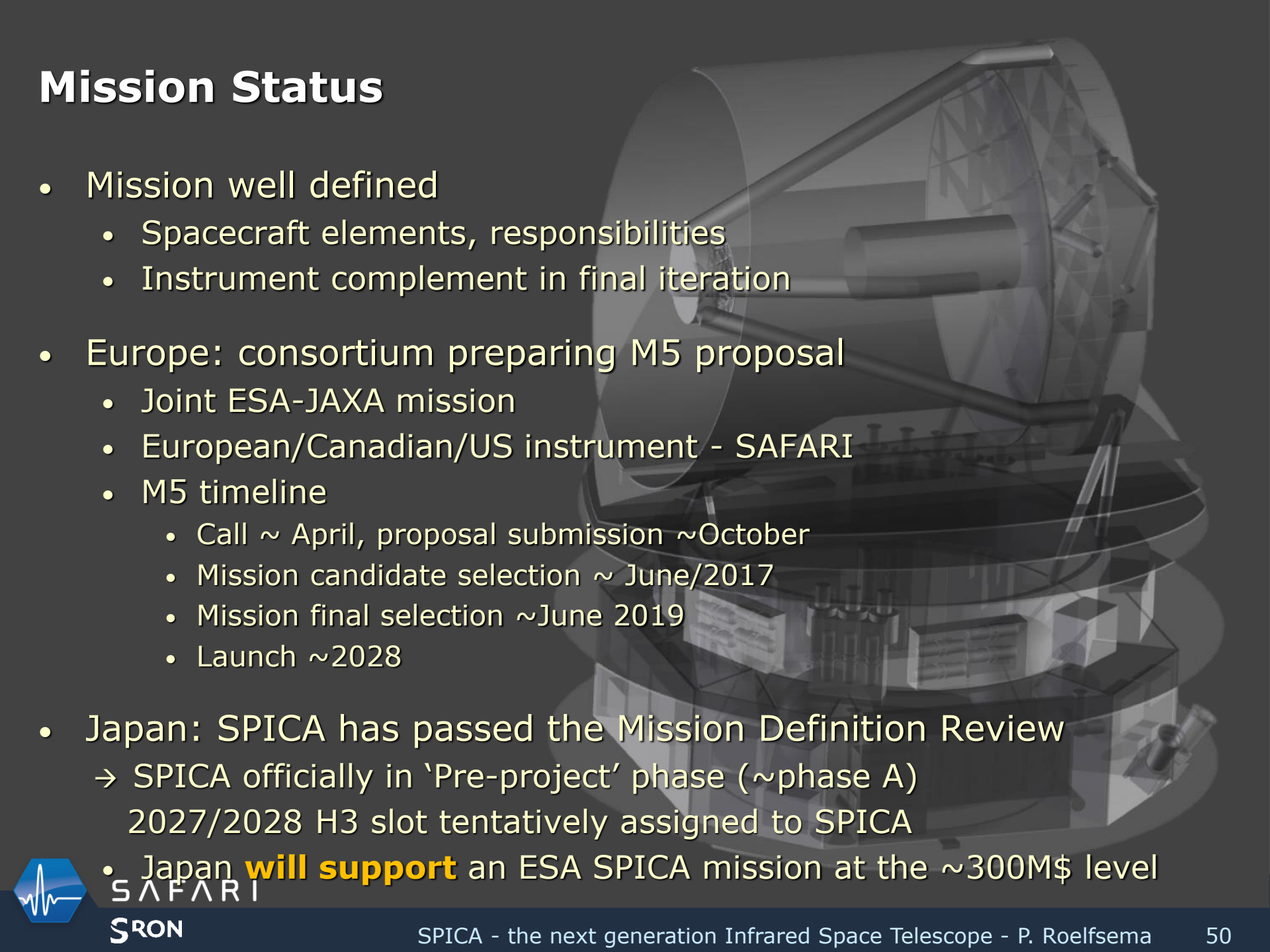
Governance and harvesting

- 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
  - Use/implementation of e.g. 'Key projects' (still) open
  - Time Allocation Committee
- **Consortium well positioned**
  - Leading science definition
  - Leading mission definition

  …will lead in the harvesting



Mission Status



- Mission well defined
  - Spacecraft elements, responsibilities
  - Instrument complement in final iteration
- Europe: consortium preparing M5 proposal
  - Joint ESA-JAXA mission
  - European/Canadian/US instrument - SAFARI
  - M5 timeline
    - Call ~ April, proposal submission ~October
    - Mission candidate selection ~ June/2017
    - Mission final selection ~June 2019
    - Launch ~2028
- Japan: SPICA has passed the 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 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 to come out next month
  - SAFARI 'founding fathers'… are in front row *and* driver seats

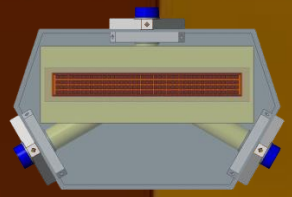
SPICA supporters/joiners? - register by email at **spica@sron.nl**

- Contact Luigi

..or contact me – P.R.Roelfsema@sron.nl

for the next generation:

SPICA



SAFARI

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