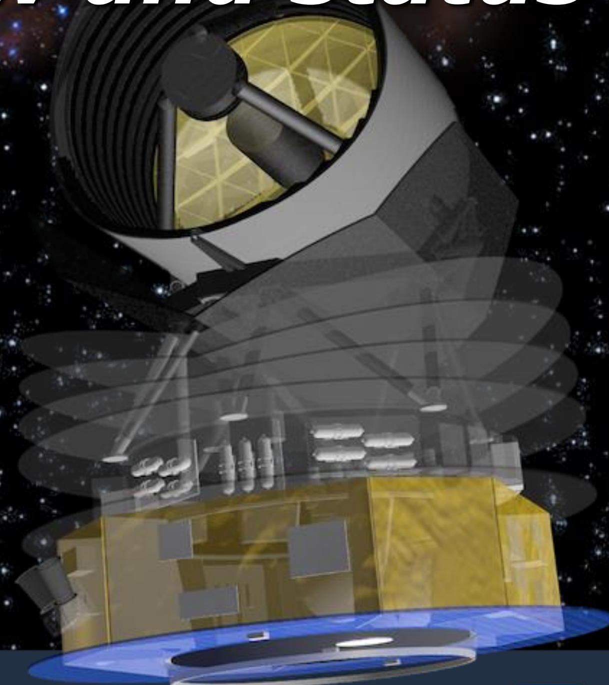
SPICA – a joint infrared space observatory

Mission overview and status



Peter Roelfsema

SAFARI Principal Investigator

SPICA Collaboration lead

SPICA Science Study Team lead

JAXA ISAS

SRON

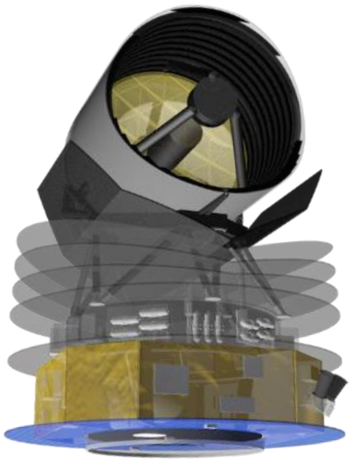
Netherlands Institute for Space Research

Netherlands Organisation for Scientific Research

SPICA SAFARI

Overview

- The goal – a big cold IR facility; SPICA
  - …a long and winding gestation process
  - Now under development as a joint ESA(M5)-JAXA mission
- SPICA – mission overview
  - M5 mission concept
  - The M5 context – 'we are not alone'
  - Updates already in the pipeline...
  - Instruments, capabilities
  - Next steps towards selection in 2021
- SPICA science
  - The 'core' and mission driving science
  - …examples of what we can, and *will* do



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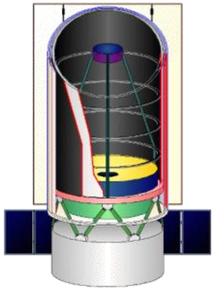
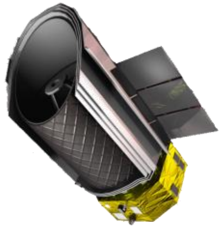
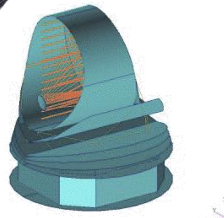
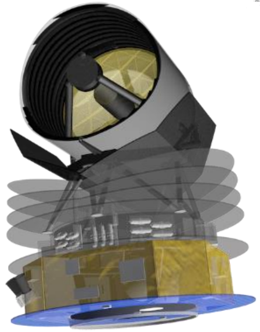
…SPICA's long history

- 1995-2000 Japanese HII/L2 project
- 2007 – M-class JAXA mission with ESA telescope
- 2010 – HIIB to HIIA launcher → smaller telescope
- 2011/2012 – 'Risk Mitigation Phase'
  - Too big for Japan alone → ESA partnership needs to increase → M4 mission?
- 2014 – ESA/JAXA consider SPICA not viable under M4
  - Late 2014 – joint JAXA/ESA CDF study → M5 concept, but a (too) 'small' mirror
  - Mission lead moves from Japan to Europe
- 2015 – viable concept with **2.5m** telescope/**SAFARI-grating**
- 2016 – M5 mission proposal submitted
- 2017 – delays in M5 decision process… project in a 'holding pattern'
- 2018 - ESA/M5 candidate mission

  2019 – Phase-A study underway

  2021 – mission selection

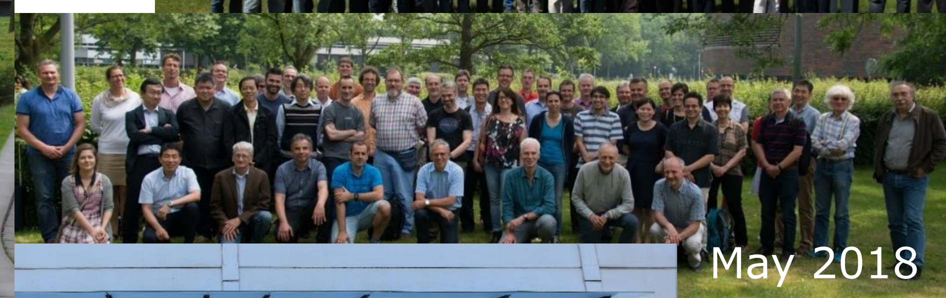



…SPICA's long history of ups and downs

A collaboration with long history

- Most day-1 partners are still on-board
- Very motivated and enthusiastic partners
- Most have ‘space experience’
- Continuous remote interaction
- Bi-annual collaboration meetings



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The SPICA 'sweet spot' – the dusty universe

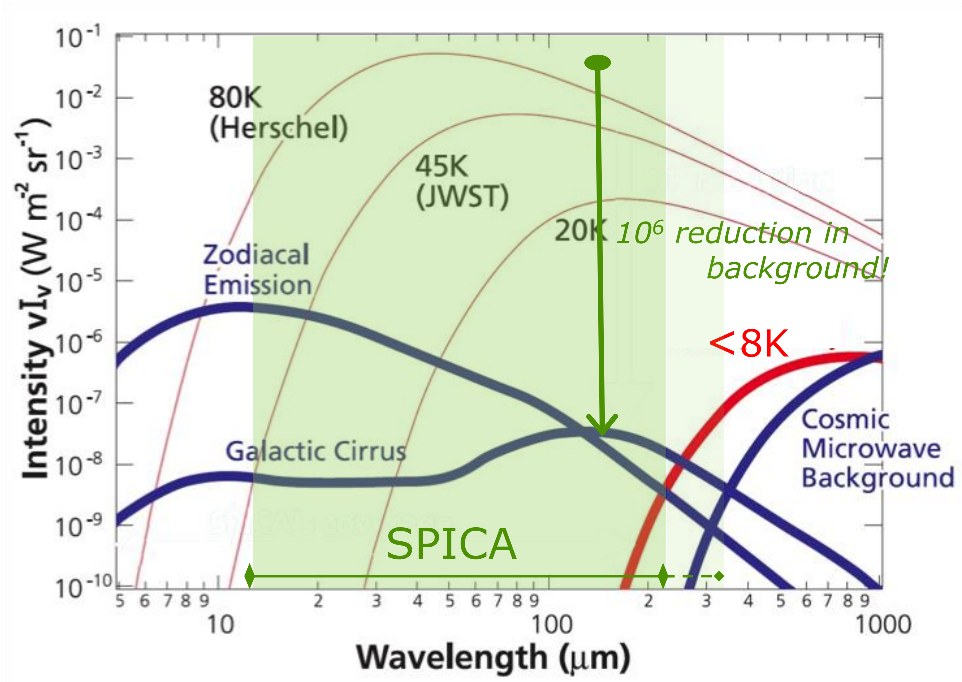
A unique observatory

looking through the veils, enabling transformational science

…imagine going

a factor 100+ deeper

than Hershel!



What is so unique?

- A ***COLD***, ***big*** mirror
  → true ***background limited*** Mid/Far-IR observing
- ~20 to ~350 μm ***inaccessible*** for any other observatory
  → the wavelength domain where obscured matter shines

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

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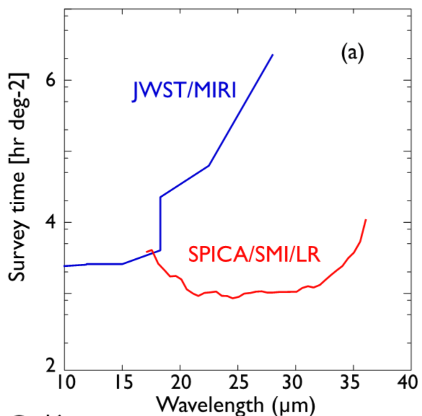
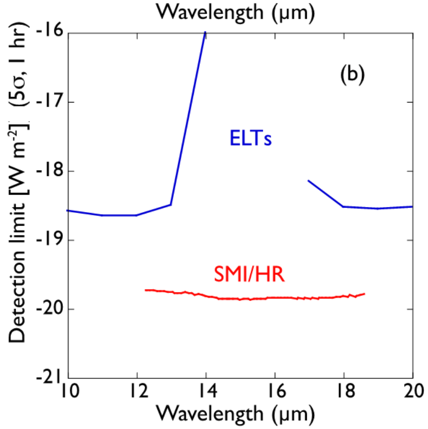
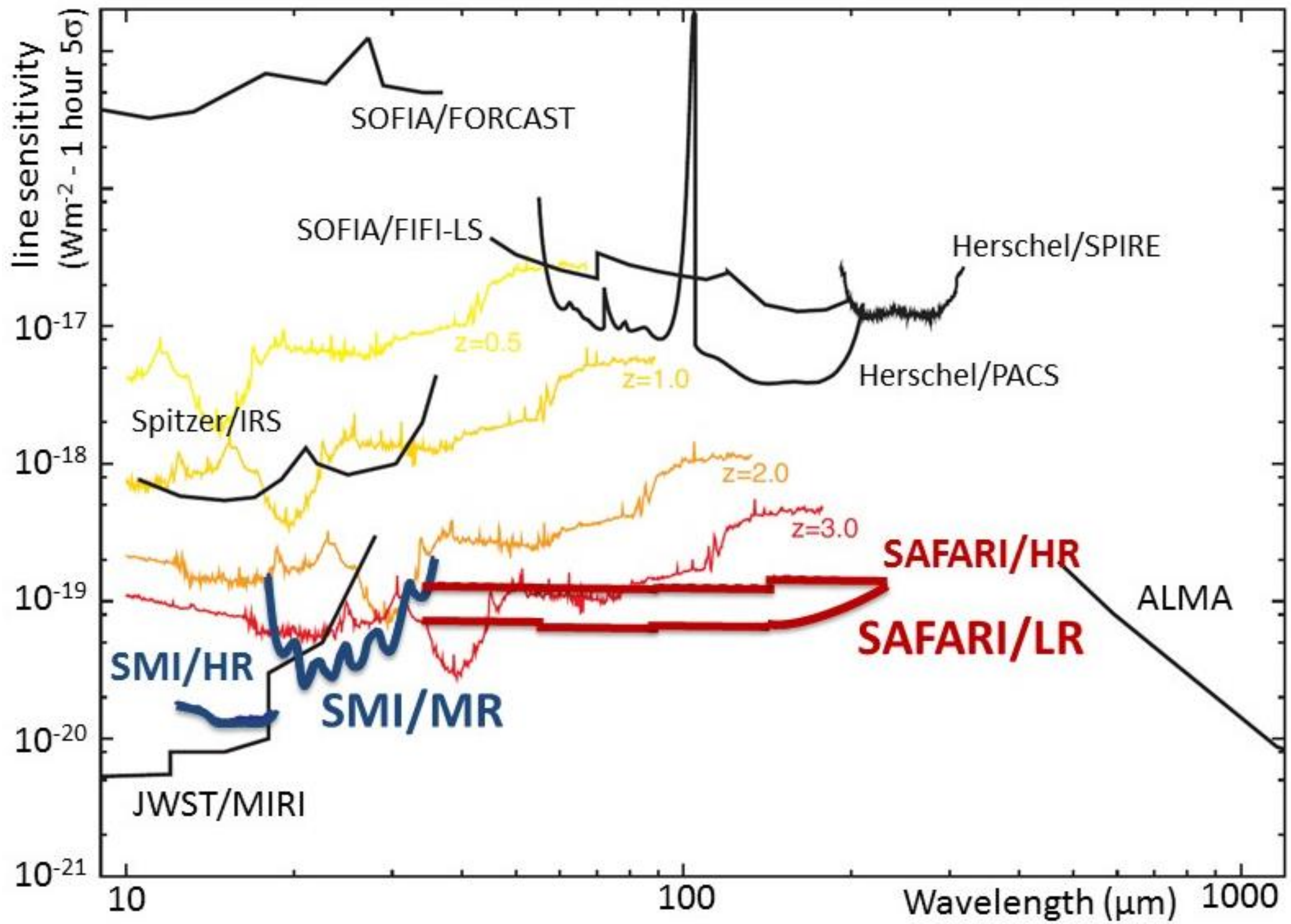
SPICA sensitivity/speed – a ***huge*** leap forward

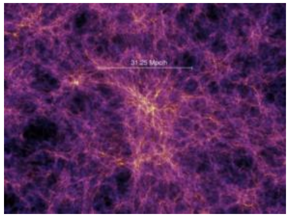
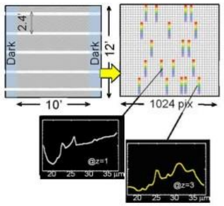


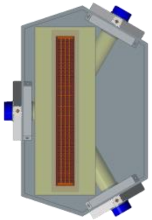
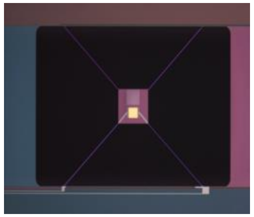
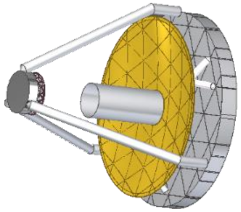


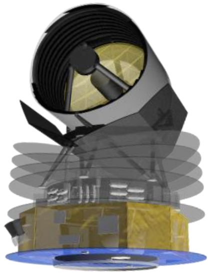


Raw sensitivity improvement ***>2 orders*** of magnitude
Instantaneous full spectra → huge step in efficiency

The SPICA mission configuration

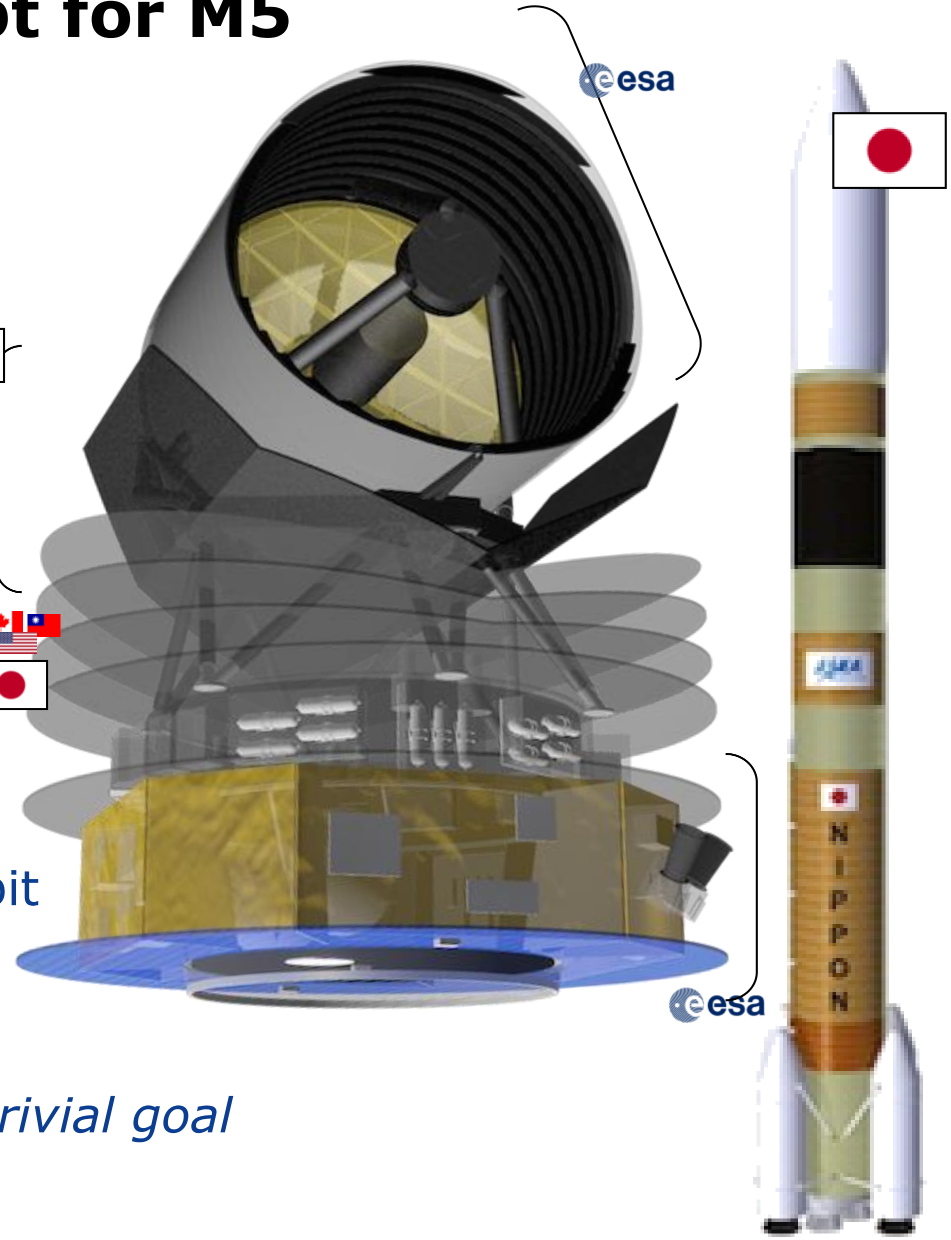





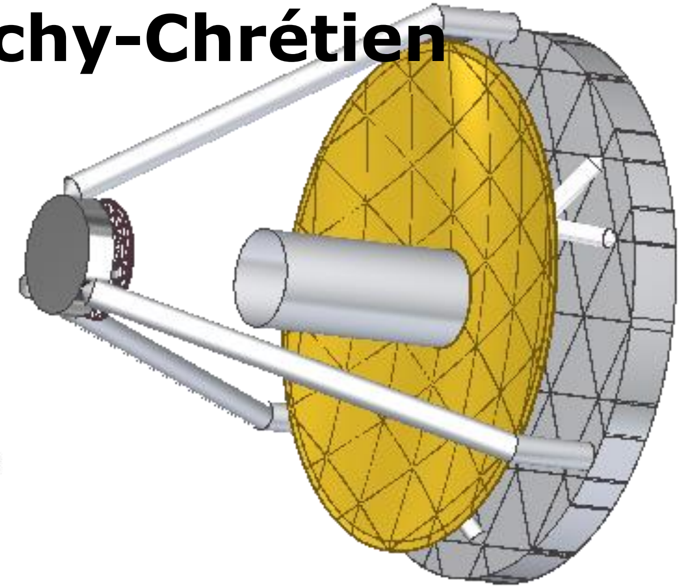
SPICA – the basic concept for M5

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



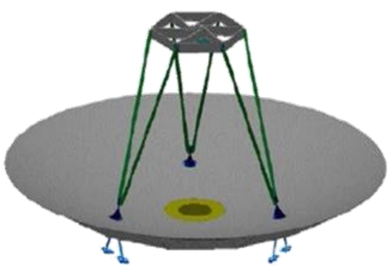
…phase 0 showed this is not a trivial goal

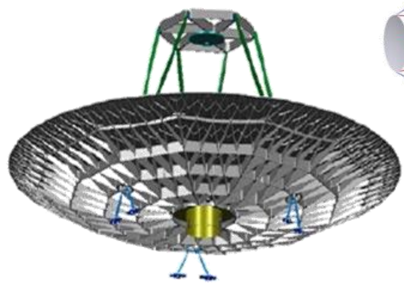
Telescope – monolithic 2.5m Ritchy-Chrétien

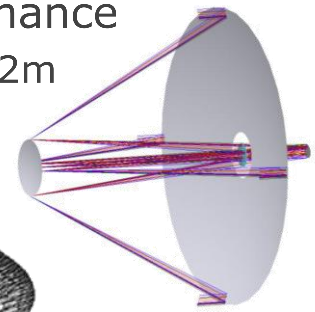


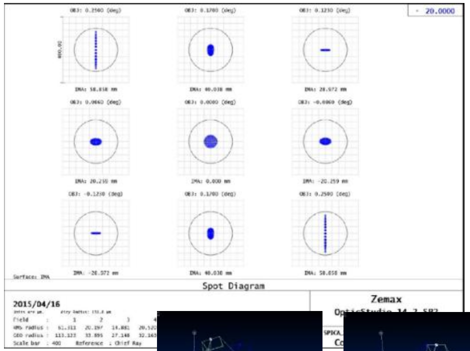
Herschel heritage

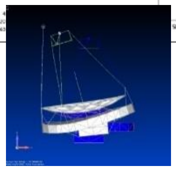
- Preliminary design from ESA/industry studies
  - 20 μm diffraction limited performance
  - M1: 2.5m F/1, M2: ~0.6m, M1-M2 ~2m

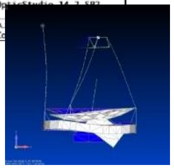






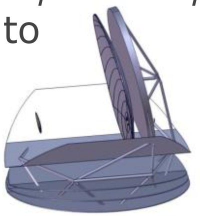


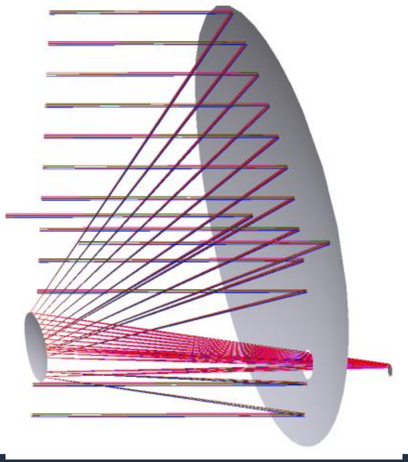




Conceivable (?) alternate configuration: off-axis

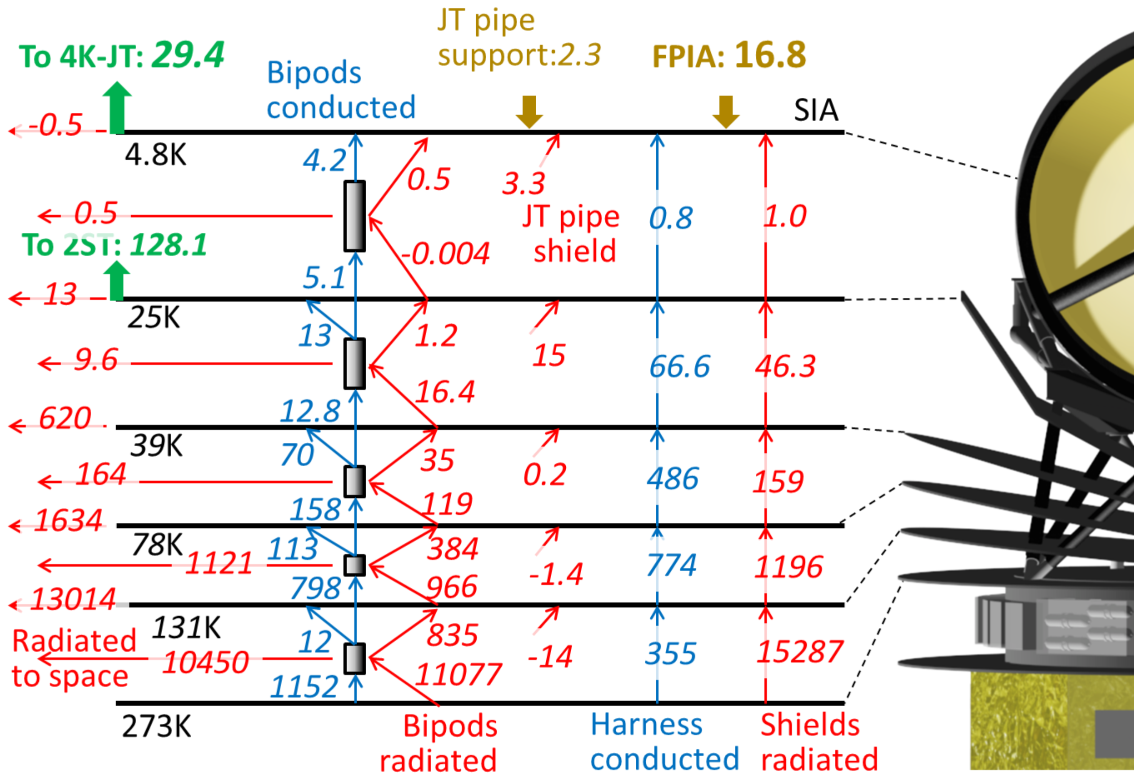
- Potential for larger area/margin
- Optics more challenging
  …but SPICA is primarily spectroscopy
- …might be looked into





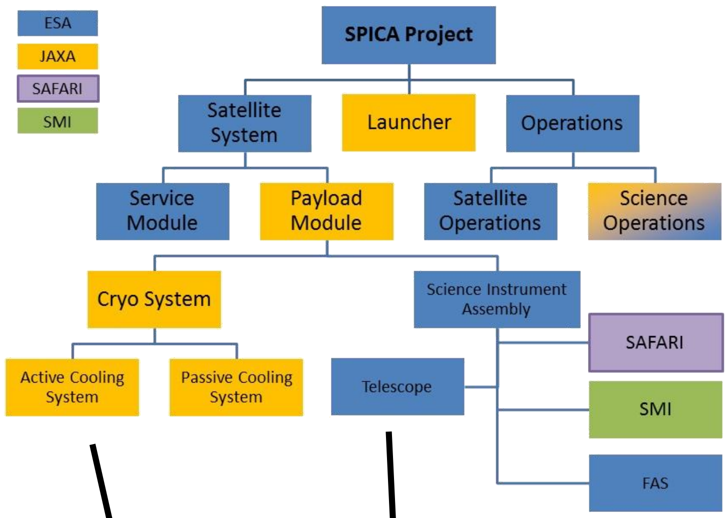
Cryogenics to cool telescope *and* instruments

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

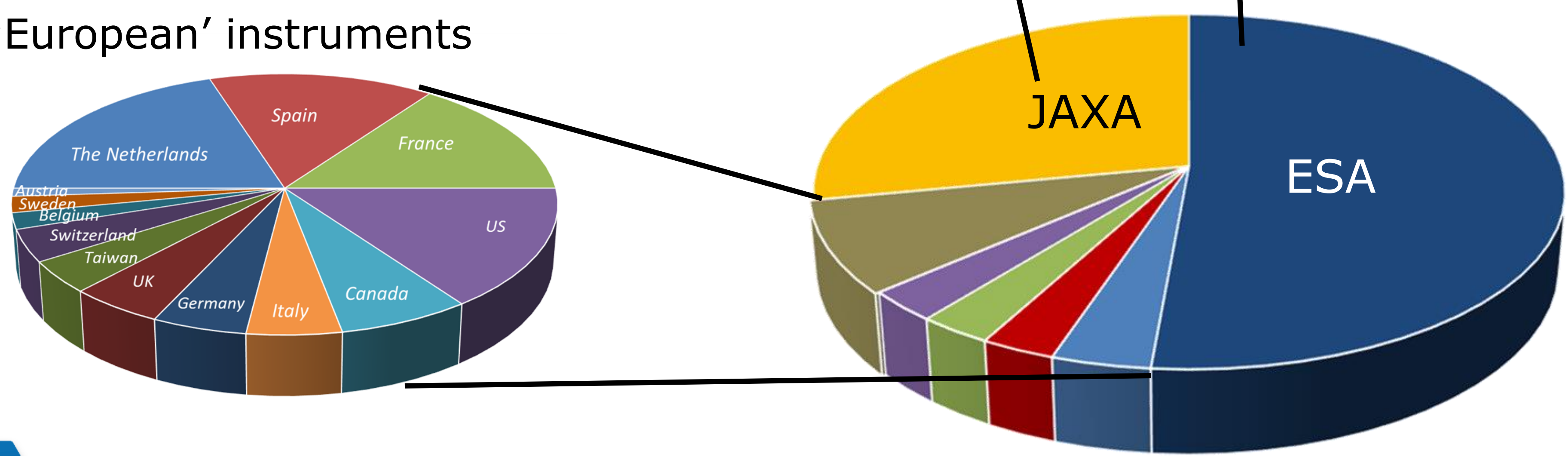


The SPICA project

- Joint ESA-JAXA project
  - ESA overall responsibility
  - JAXA major partner
    …instruments also significant partner
  - Challenging organization
  - Total mission cost ~ 1Bn€

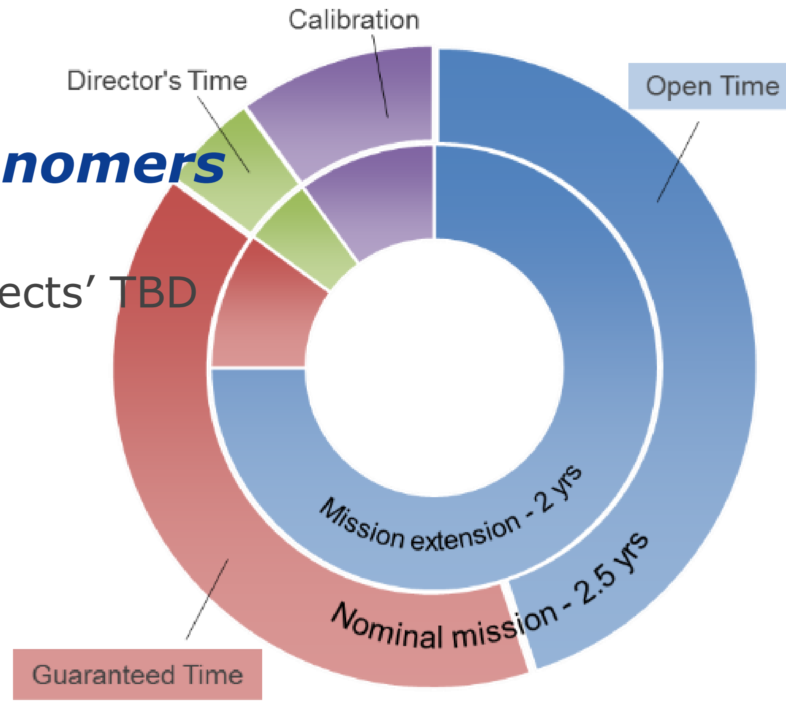


‘European’ instruments



Observatory harvesting and governance

- 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



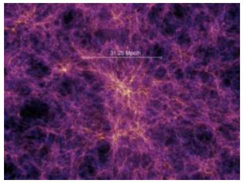
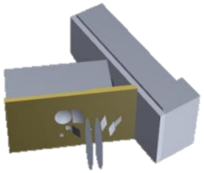
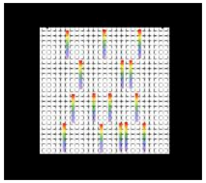
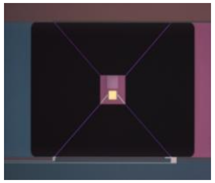
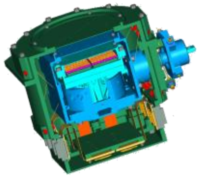
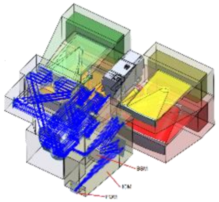
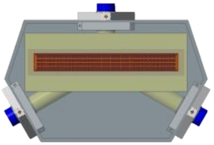
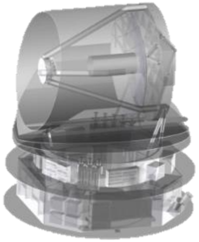
- International mission → international oversight/cooperation
  - SPICA Science Study Team (ESA installed) – represent science community
  - SPICA collaboration ≡ 3 instrument consortia + overall SPICA (science) consortium
  - Later; Science advisory committee, SPICA executive board

Heritage – Herschel and Planck taught us well

Examples of heritage being put to good use:

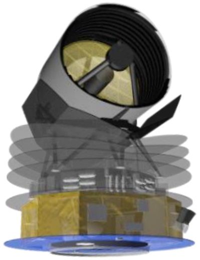
- H/W
  - Telescope
  - Cryo configuration with V-grooves
  - SVM elements
  - INAF as common instrument control unit supplier
  - Instrument cooler concepts
- Operations
  - Autonomous operations
  - Distributed ground segment
  - Likely; science operations concepts and possibly even tools
- Experience
  - …the same faces all over the place

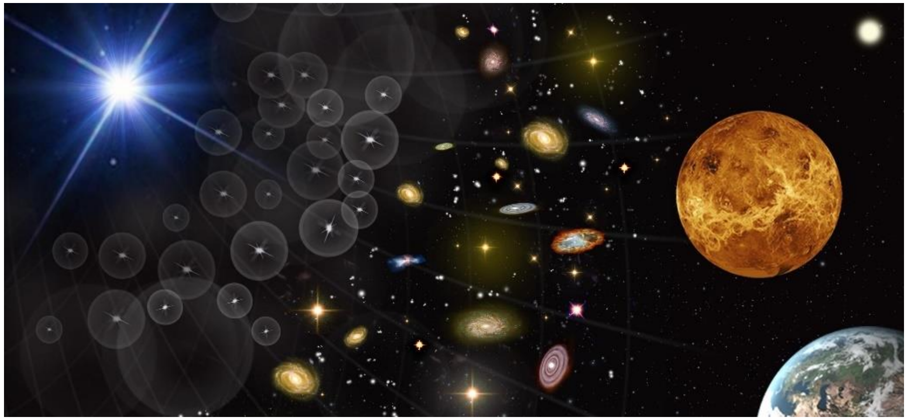
M5 – plans and progress

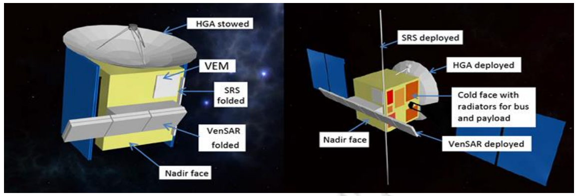
The M5 competition

- SPICA





- Envision (UK)
  - *Why did Earth and Venus evolve so differently?*



- THESEUS (Italy)
  - *How did the Universe begin and what is it made of?*
    - Complete census of the Gamma-Ray Burst (GRB) population in the Early Universe

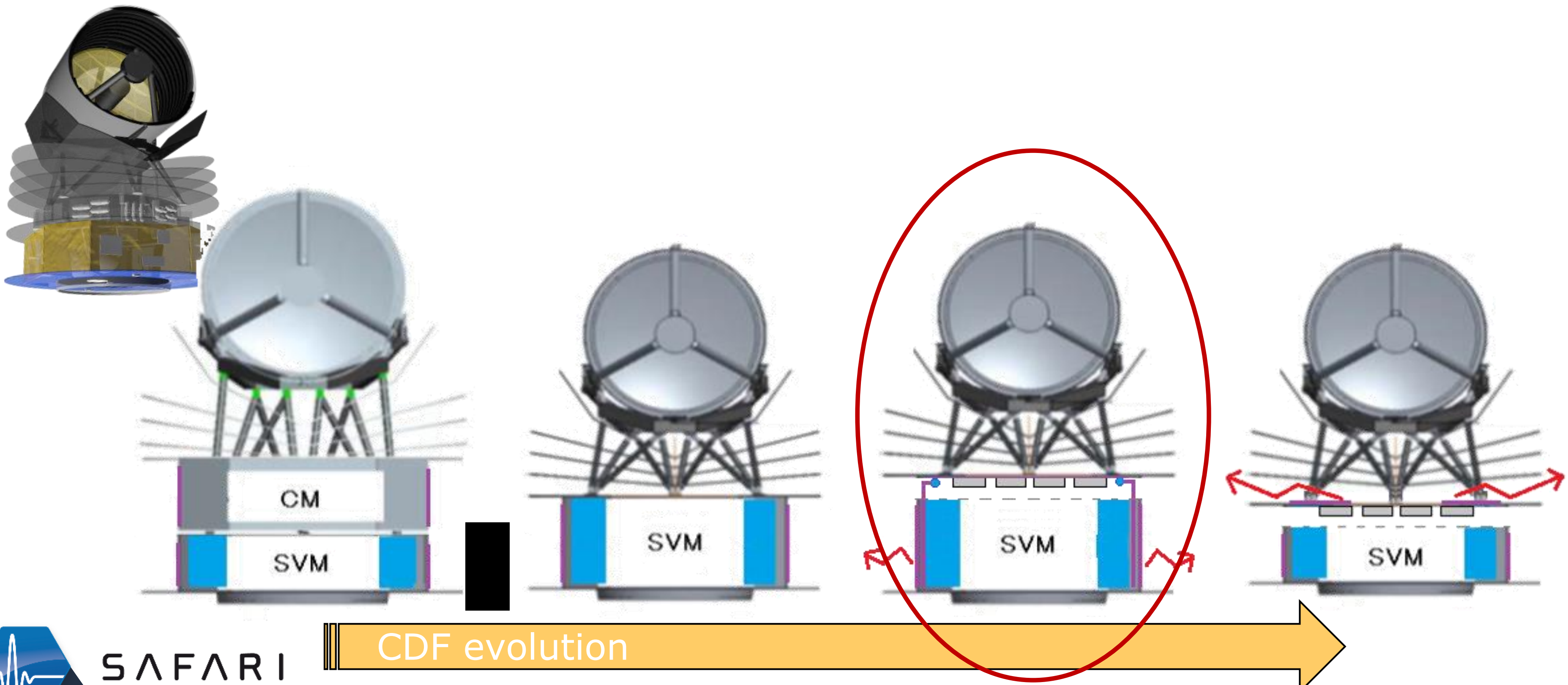
…in principle all are equally strong candidates

- …and in the US there is OST
  - *Regular, good contact between SPICA and OST*

Evaluation/evolution of SPICA in Phase 0/A

Main conclusion – overall a valid proposition

- It fits… however, Mass is a worry → track that carefully in Phase A
- It fits… however, downlink requires (planned) upgrades (QPSK or 8PSK /SCCC)
- Cannot do small Lissajous L2 orbit → large halo – more "earth-constraint"
- Cryogenics Module/SVM configuration being optimized – weight/thermal



SPICA Science Study Team

Establish/maintain SPICA science drivers and requirements

- Represents full science community
    - Europe: Elbaz, Griffin, Kamp, Martin-Pintado, Spinoglio
    - Japan: Honda, Kotaro, Nagao, Nomura
    - PI's: Kaneda, Roelfsema (chair), Sauvage
    - ESA/JAXA study scientists: Tauber, Onaka
- Outputs
    - Now: SPICA science requirements document (for ITT)
    - For mission selection: SPICA Yellow Book
- Five topical science work groups → open for participation
    - PPD's, galaxy evolution, nearby galaxies, ISM, solar system
    - Science (cases) to be documented in set of 'white' papers

- Meetings; October, January, next one in June

Next steps – the schedule

Next real review: MCR
~ MSR dress rehearsal
(...or turkey shoot?!?)

MSR documents deadline:
~February 2021!!

Event	Date	Objective
Mission Definition Review (MDR) ✓	21/11/2018	Check readiness for Phase A
Phase A ind. ITT ✓	Jan. 2019	
Phase A ind. KO	June 2019	
Phase A Mission Consolidation Review (MCR)	*June 2020 (TBC)*	*Close Mission and System-level trade-offs*
Release Yellow book	*Apr. 2021*	*Provide to Selection advisory board*
Mission Selection Review (MSR)	*Apr. 2021*	*Technical/programmatic part. Confirm mission is within M5 boundaries*

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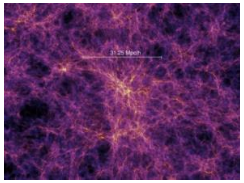
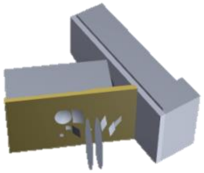
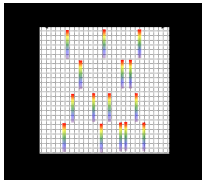
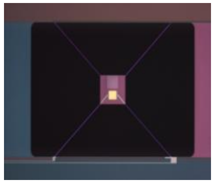
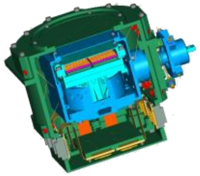
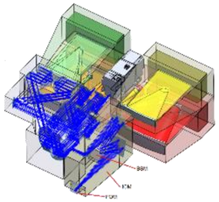
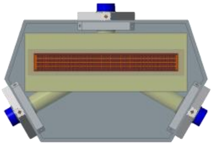
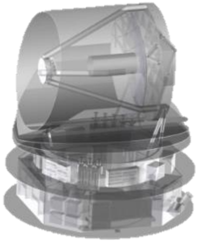
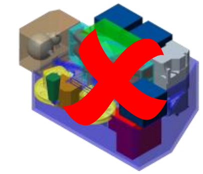
The SPICA Instruments

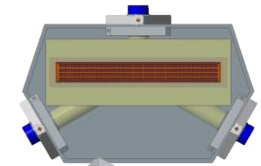
SAFARI – evolution dictated by science

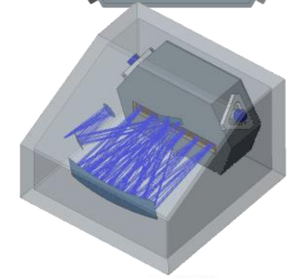


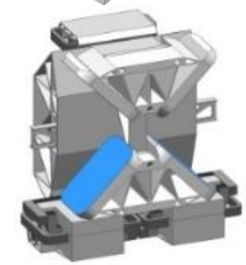
Original design: Imaging Fourier Transform Spectrometer

- Fast/efficient large area spectroscopic mapping

  …but fundamentally limited in maximum sensitivity due to photon noise







SAFARI V2.0: highly sensitive grating spectrometer

- Basic R~300 mode → 1hr/5σ **-5-7×10^{-20} W/m²** (4.6 m²)

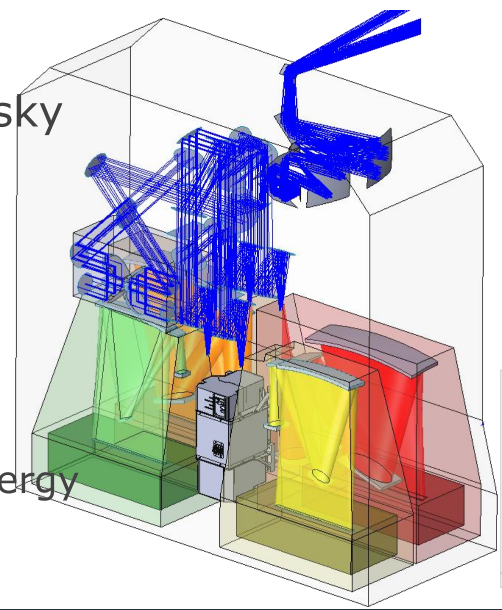
  Will improve with (likely) better TES performance

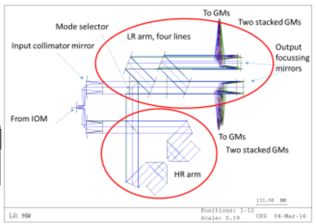
- Martin Puplett Interferometer to provide R~3000 mode
- 4 bands covering 35-230 micron

  limited imaging capability: 3 pixels on-sky

- Critical technologies in very good shape
  - Detectors: goal sensitivity achieved
    - FDM 176pix/channel achieved
  - FTS mechanism close to TRL4
  - Cooler EM built and tested

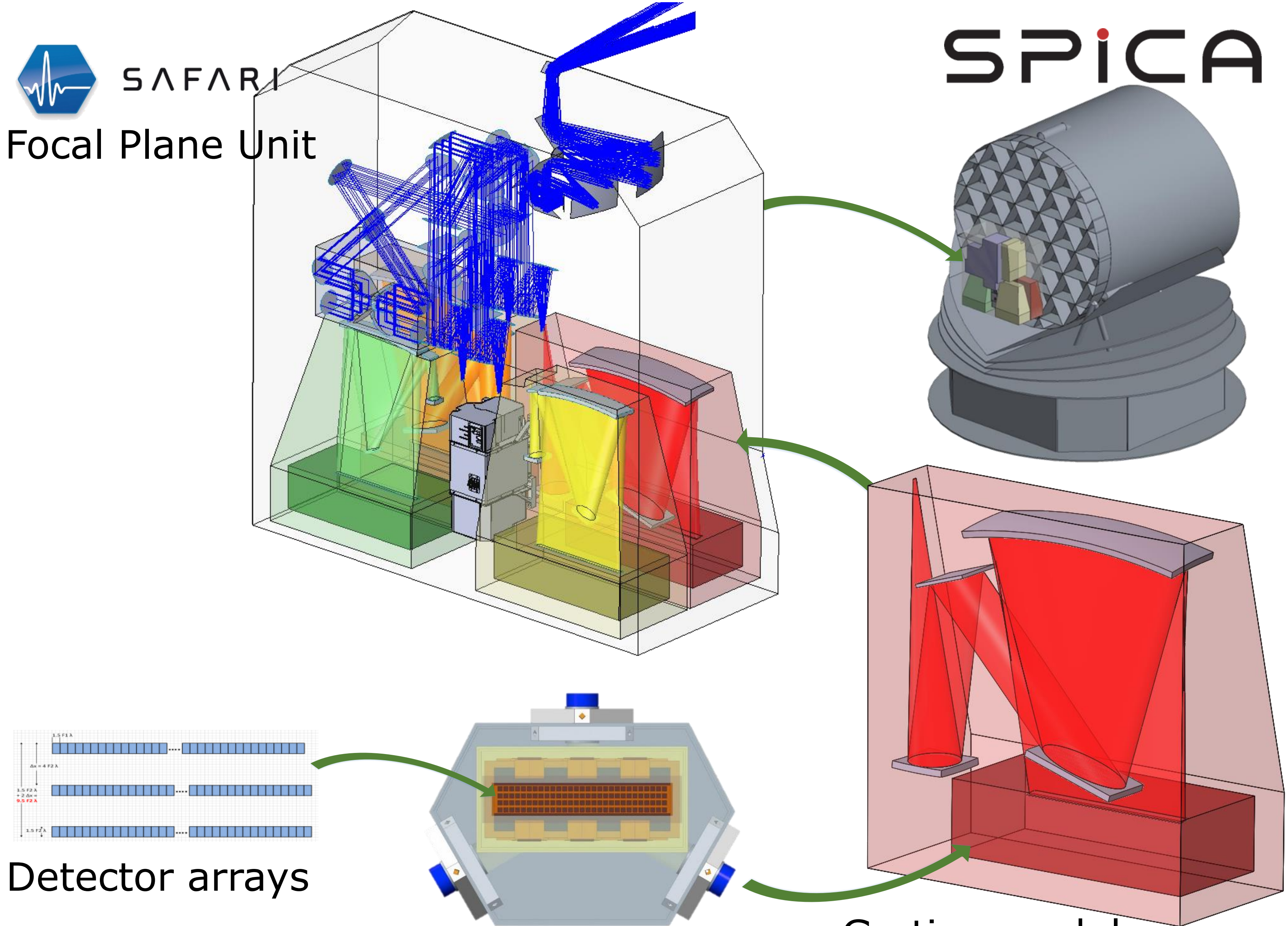
    With Japanese coolers: ~SPICA-ATHENA synergy





SAFARI

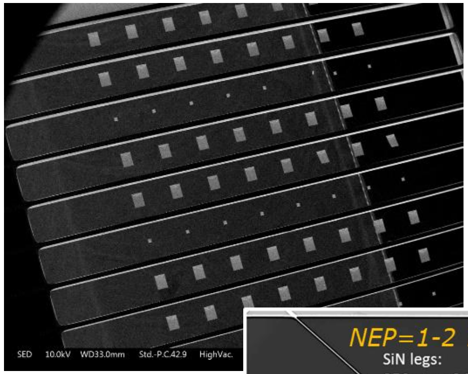
SRON

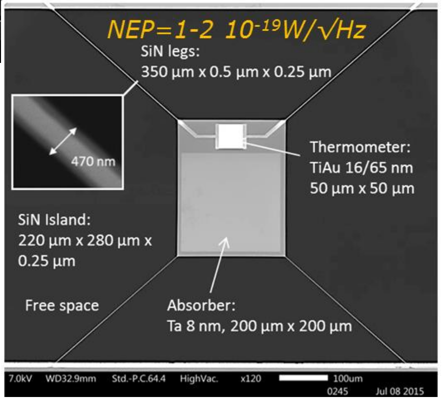


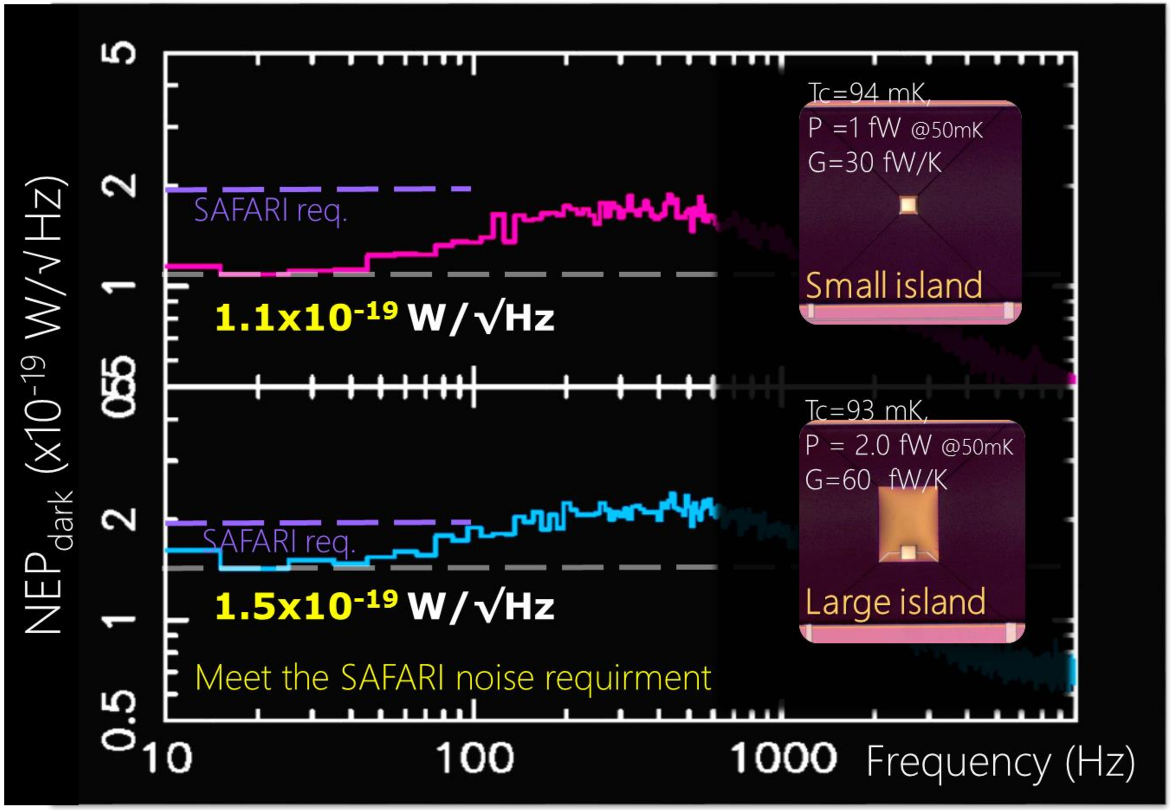
Focal Plane Unit
Detector arrays
Detector assembly
Grating module

TES NEP - SAFARI requirement within reach

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

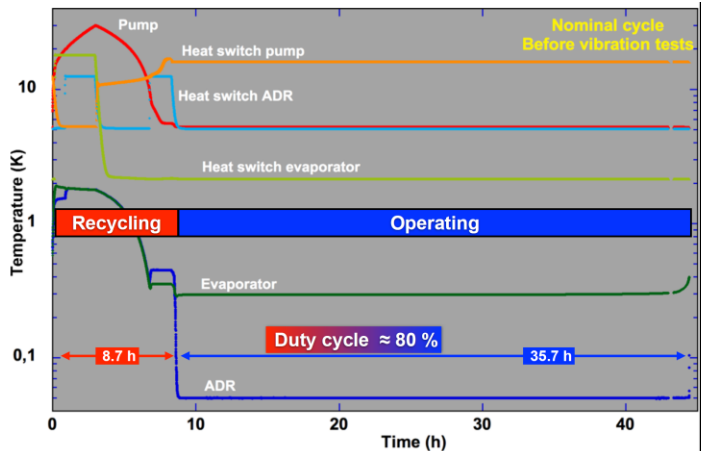


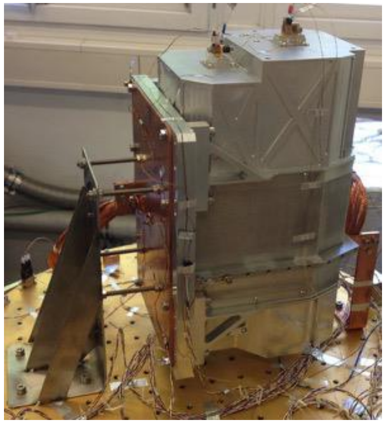




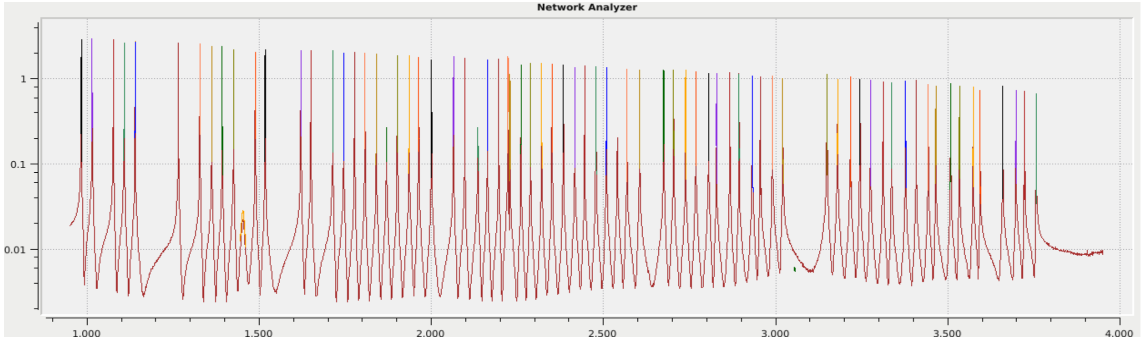
Cooler – Frequency Domain Multiplexing

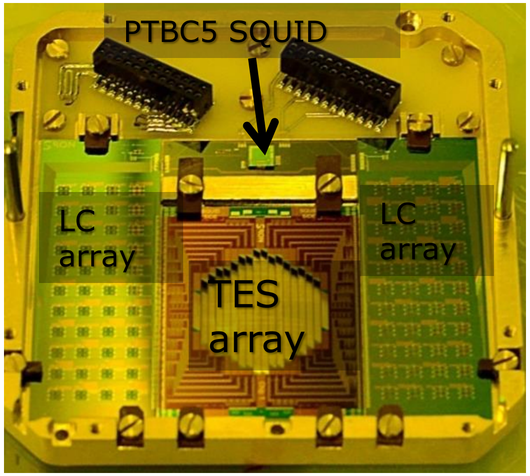
- Cooler EM built and tested, also with JAXA coolers



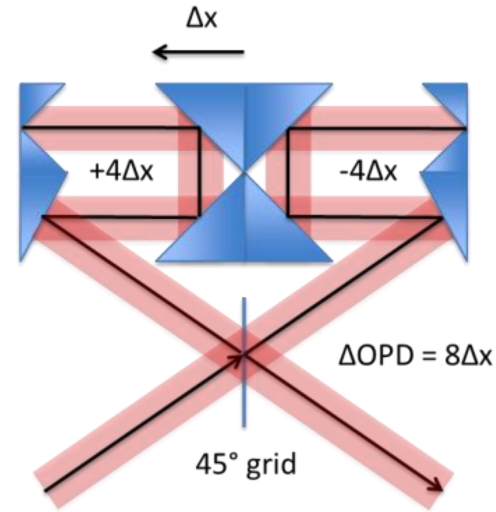


- FDM 176 pix/channel demonstrated
  - Requirement: 160 pix/channel

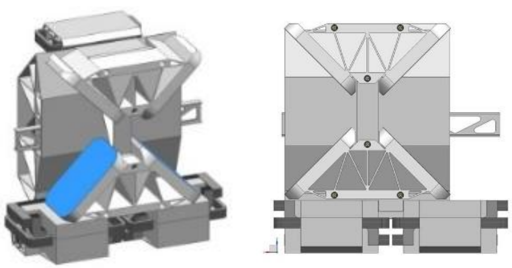




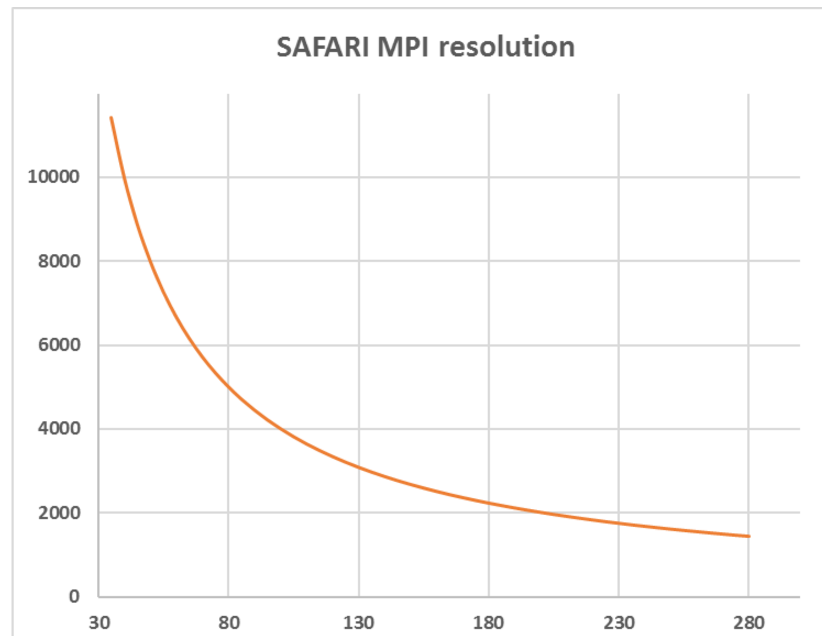
High Resolution - Martin-Puplett interferometer



- Mechanism as in original SAFARI concept
- Sensitivity factor of ~2 below R=300 mode
- Compact layout achieves R~11000-2000
- Development by ABB (Canada)
  - ‘EM’ unit already fabricated
    → cryogenic tests; e.g. metrology achieves ~15nm

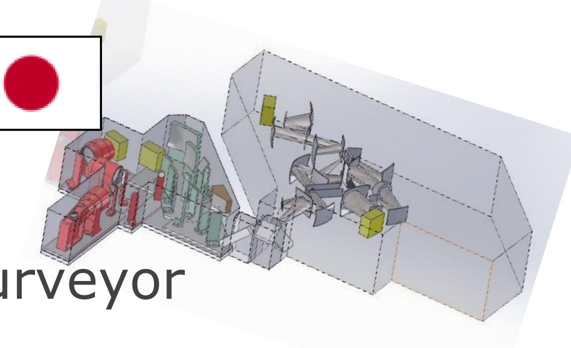


SAFARI V1.0 concept

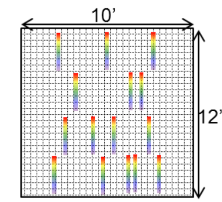


Current concept
ABB proprietary

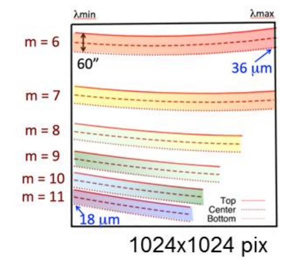
The Mid-infrared Instrument SMI



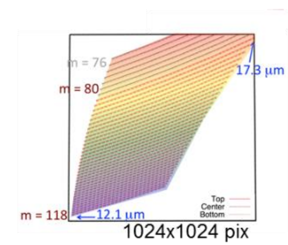
- **SMI/LR-CAM** – large area low resolution surveyor
  - 17 – 36 μm, R = 50 – 120
  - 4 slits (10′ long) with prism
  - Detector: Si:Sb
  - Camera mode 10′x12′ FoV



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



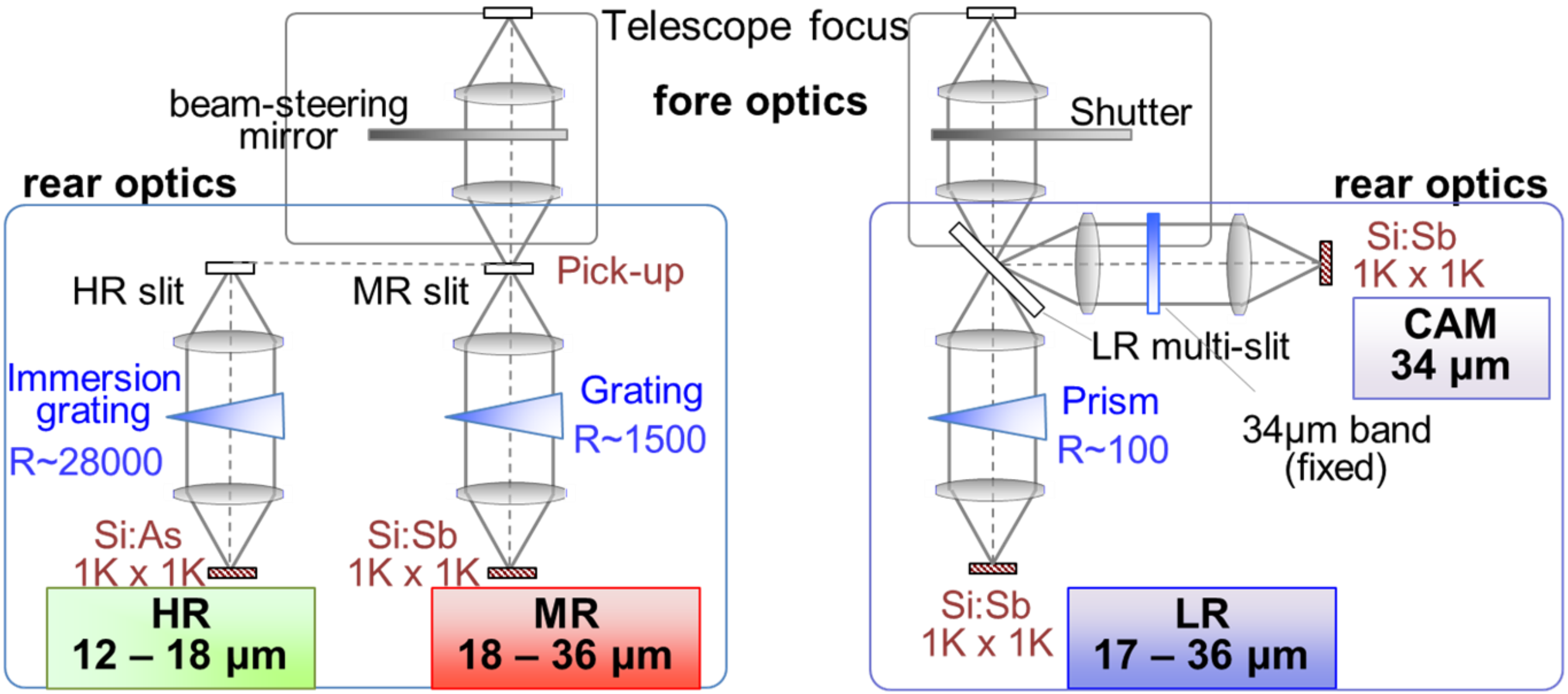
- **SMI/HR** – molecular physics/kinematics
  - 12 – 18 μm, R = 28,000
  - 1 slit (4″ long) with immersion grating
  - Detector: Si:As



- Japanese consortium
  - PI: H. Kaneda/Nagoya U., ISAS

SAFARI
SRON

SMI functional block diagram

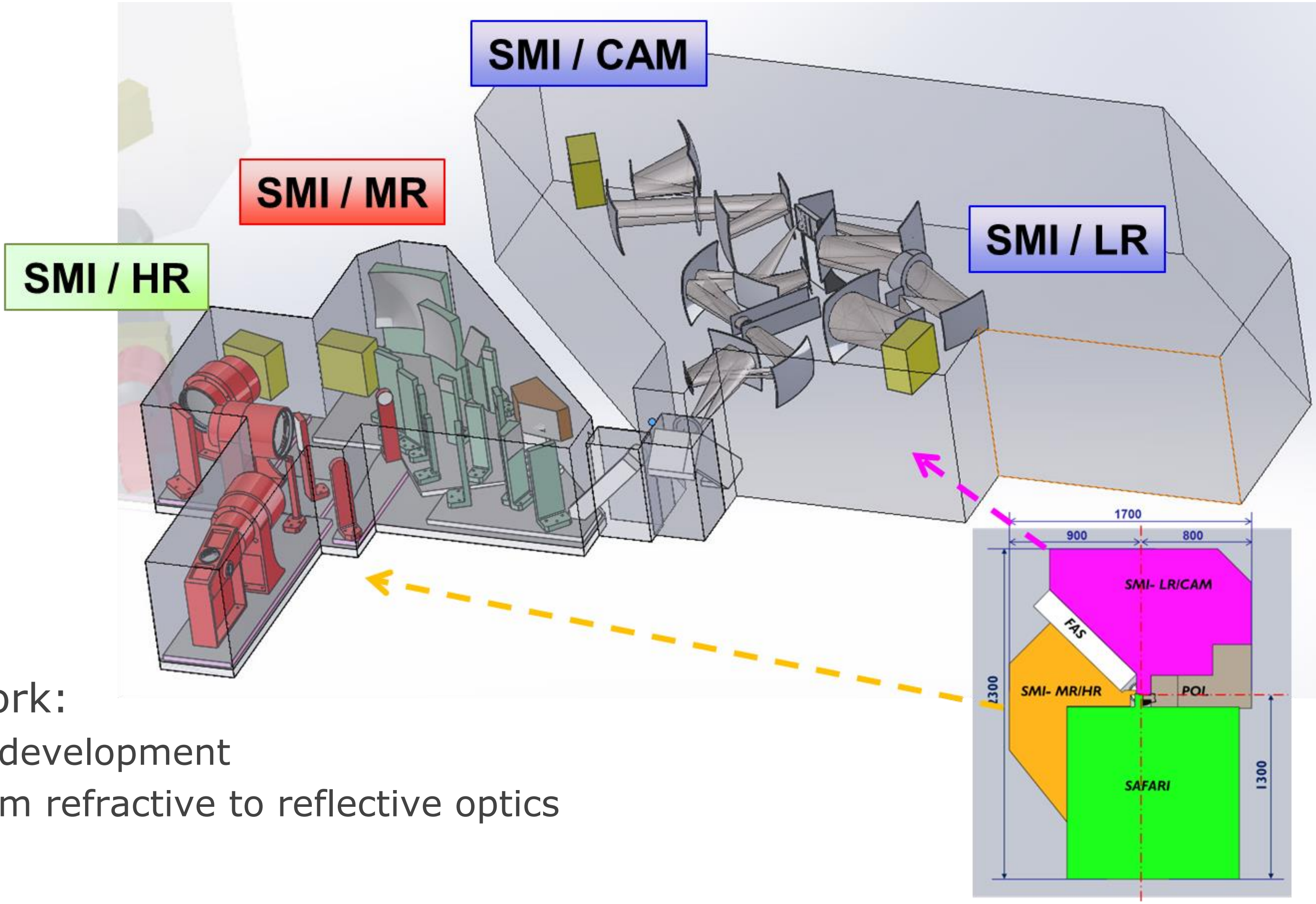


SMI / LR-CAM: Multi-slit prism + Si:Sb w/ 10'x12' slit viewer
17 – 36 μm, R = 50 – 120, slit:10' long, 4 slits

SMI / MR: Grating + Si:Sb w/ beam-steering mirror
18 – 36 μm, R = 1200 – 2300, slit: 1' long

SMI / HR: Immersion grating + Si:As w/ beam-steering mirror
12 – 18 μm, R = 28,000, slit: 4" long

SMI optical layout



Ongoing work:

- Detector development
- Going from refractive to reflective optics

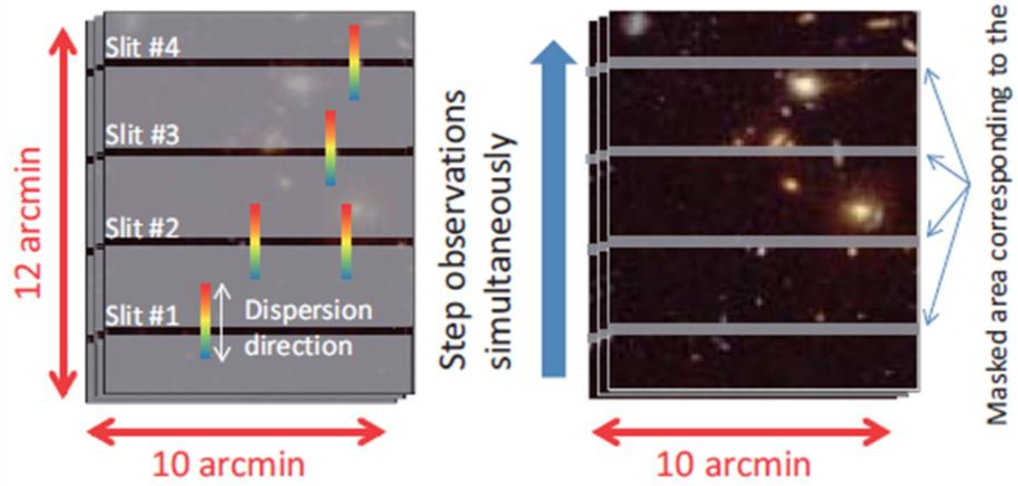
Observing with SMI

Slit viewer

LR

CAM

For large area surveys. Telescope scan with 90 steps (1 step length = 2" ~ 0.5 x slit width) produces a spectral map and a 34 μm broad-band image of 10' x 12' area, ***simultaneously***.



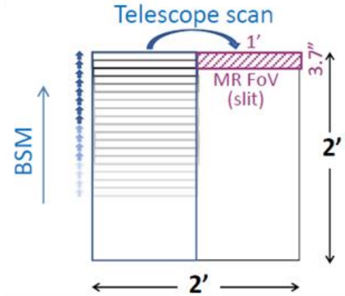
1-D Beam-steering mirror

MR

HR

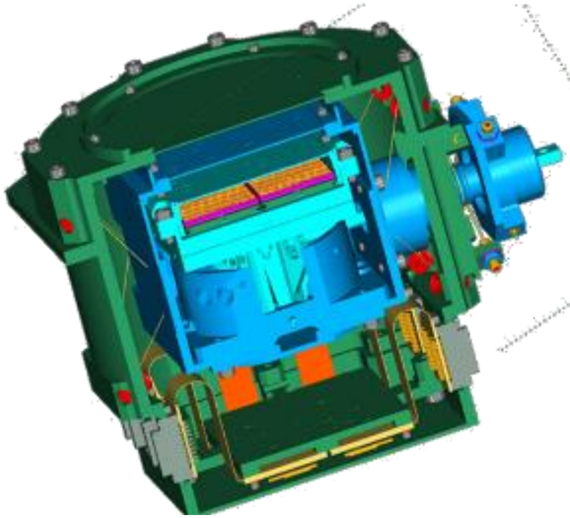
For spectral mapping of small areas. e.g., covering 2' x 2' by 60 step scan with 1-D BSM and 1 telescope scan

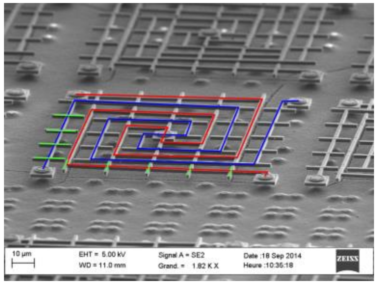
For fine adjustment of target peak positions

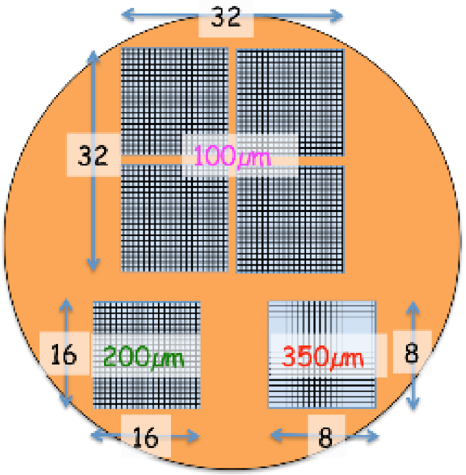


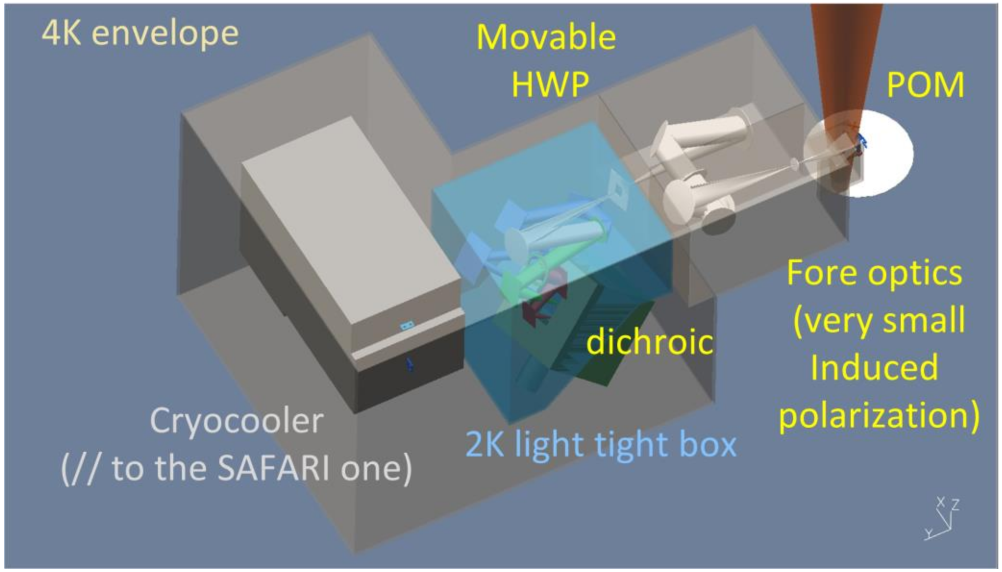
B-BOP – the far IR imager/polarimeter

- **B-BOP -** imager polarimeter
  - 3 bands with polarization sensitive bolometers
    - 3 bands: 70, 220,350 µm
    - observe same field simultaneously
  - FPA architecture designed and tested
  - Readout analogous to PACS system
  - European consortium (in statu nascendi)
    - PI M. Sauvage/CEA Saclay

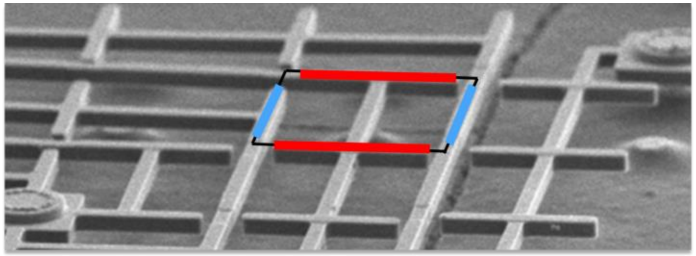


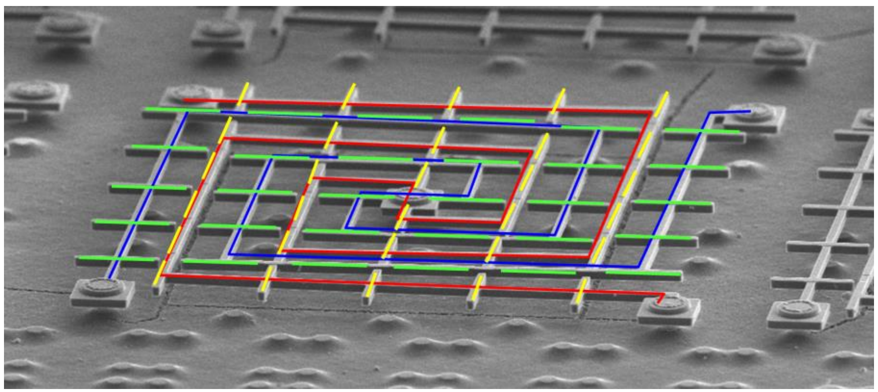


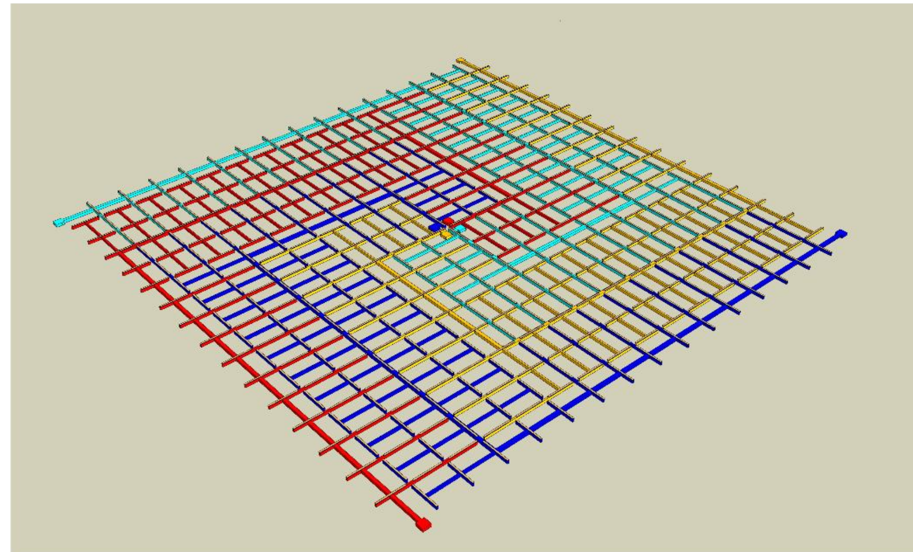


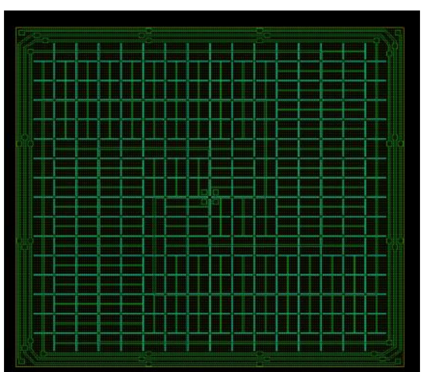


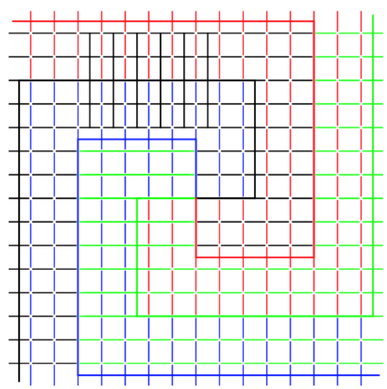
Spiral thermistors with absorbing dipoles

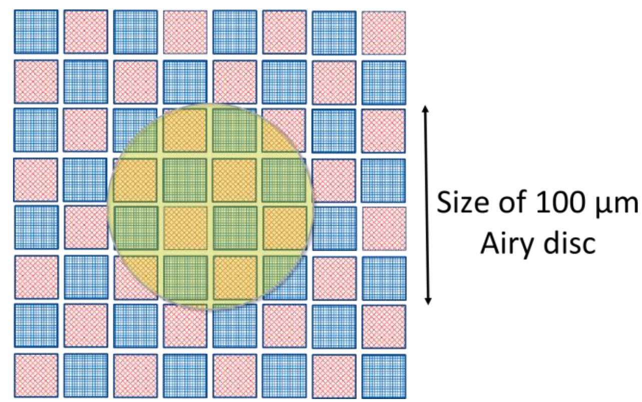






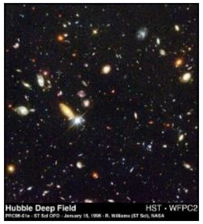


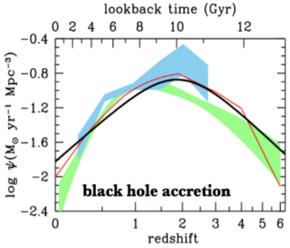


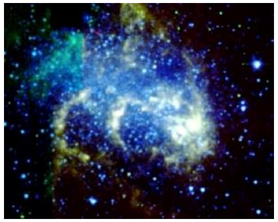


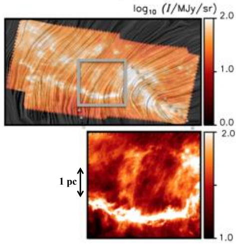
SPICA’s science

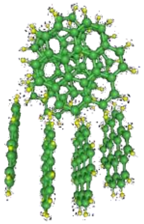
Unveiling dusty matter in the universe

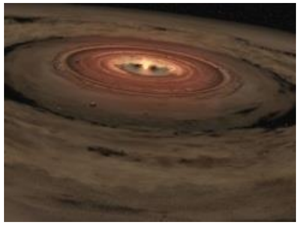


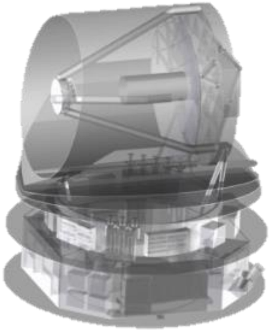






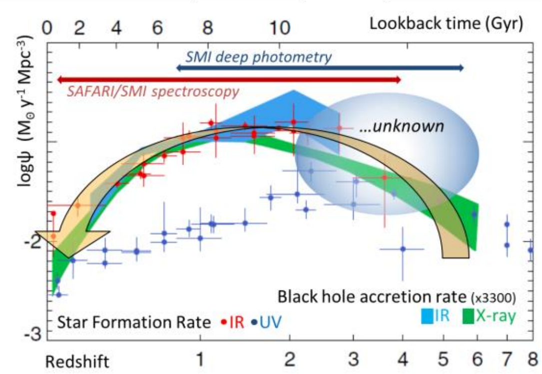


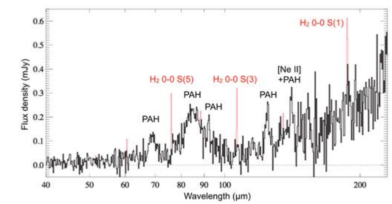




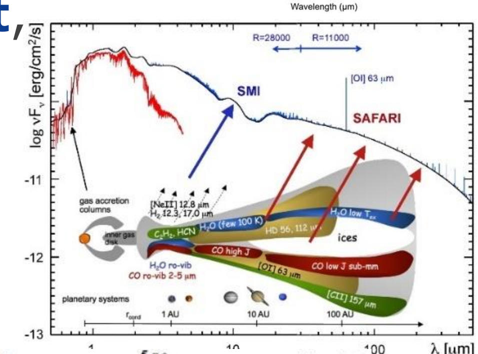
Science Objectives – mission design drivers

- 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

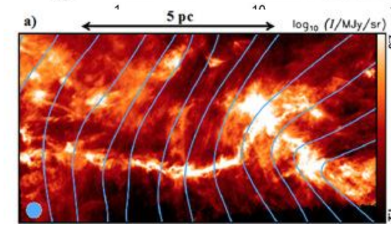




- What is the **origin** and composition of **the first dust**, how does this relate to present day dust processing?
- What is the thermal and chemical **history** of the **building blocks of planets** – connecting planet forming systems with **our own solar system**

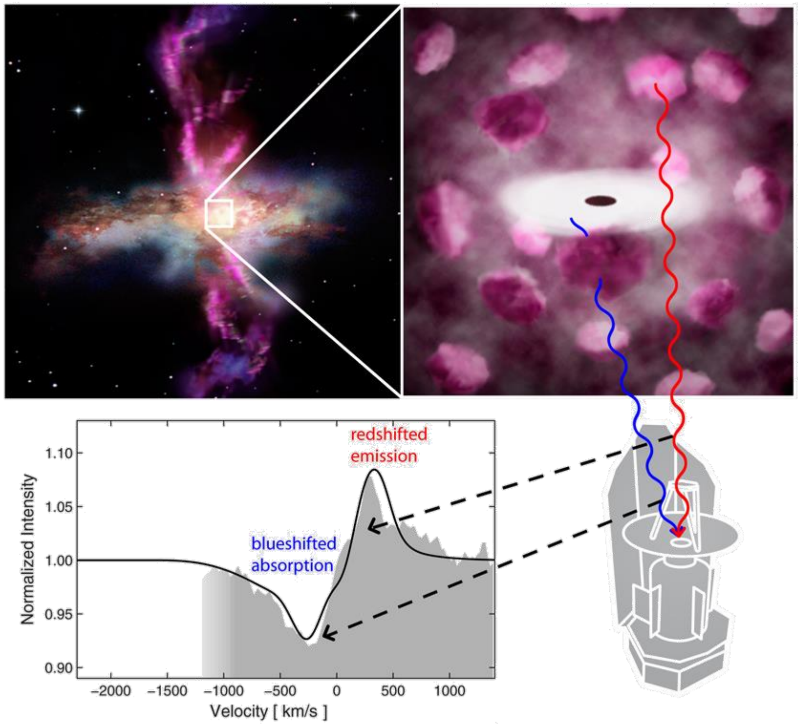


- What is the role of magnetic fields in dust filaments?



…all described extensively in the SPICA white papers

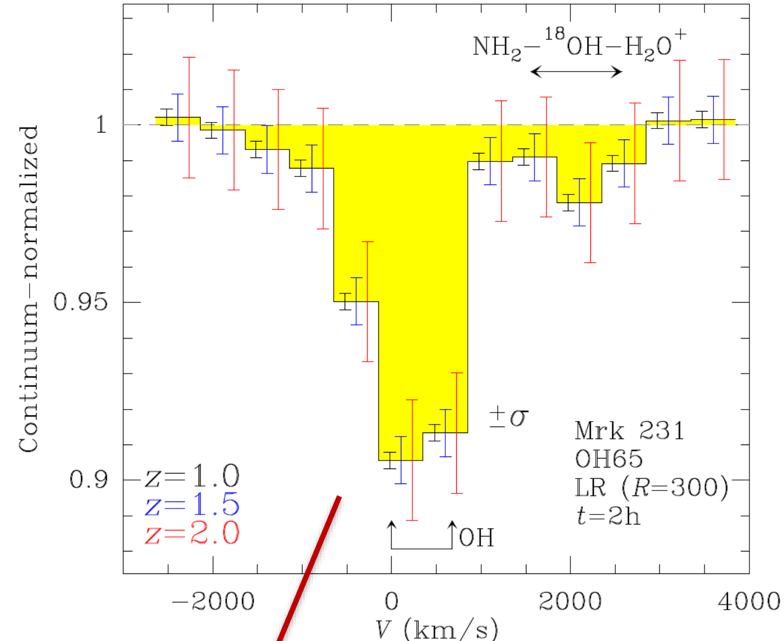
High-velocity AGN-driven outflows - Mrk 231

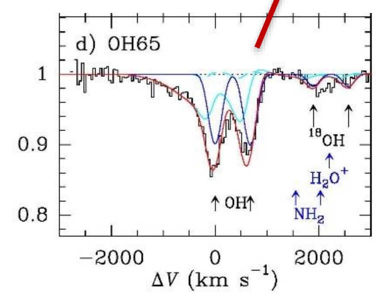


Local z=0.04 ULIRG OH spectra (Herschel/PACS)

Dark blue: quiescent gas, light blue: high velocity outflow (1700 km s^{-1}, ~100 M_{sun} yr^{-1} sr^{-1}), dashed light blue: low velocity outflow, green: low excitation

Gonzalez-Alfonso 2014, A&A 561





SPICA simulation:
Mrk 231 at z 1,1.5,2
OH 85μm
R~300

10-30 Jy… Mrk 231 is too bright for SPICA/SAFARI

→ SPICA will do this for many objects out to z~1.5-2!

SAFARI

SRON

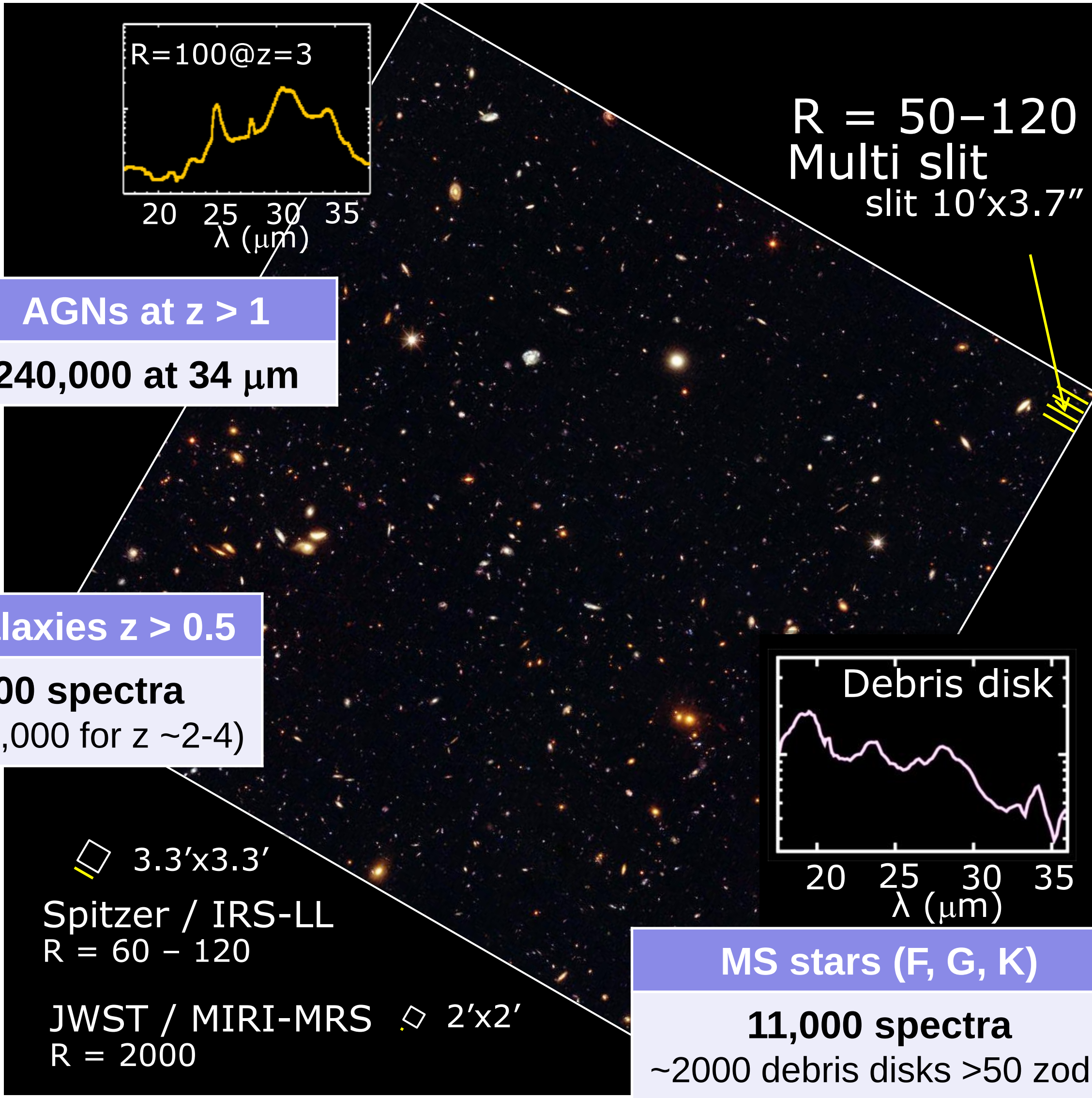
Charting the unknown – SMI LR/CAM surveys

Large area blind survey

- 10 deg^2 ~ 600 hr
- 300 x 2 hr/field (10′x12′)

- Galaxy population
- Dust in galaxies
- Stars with debris disks
- …

→ *follow up with **SAFARI** and **SMI/MRS***



AGNs at z > 1
240,000 at 34 μm

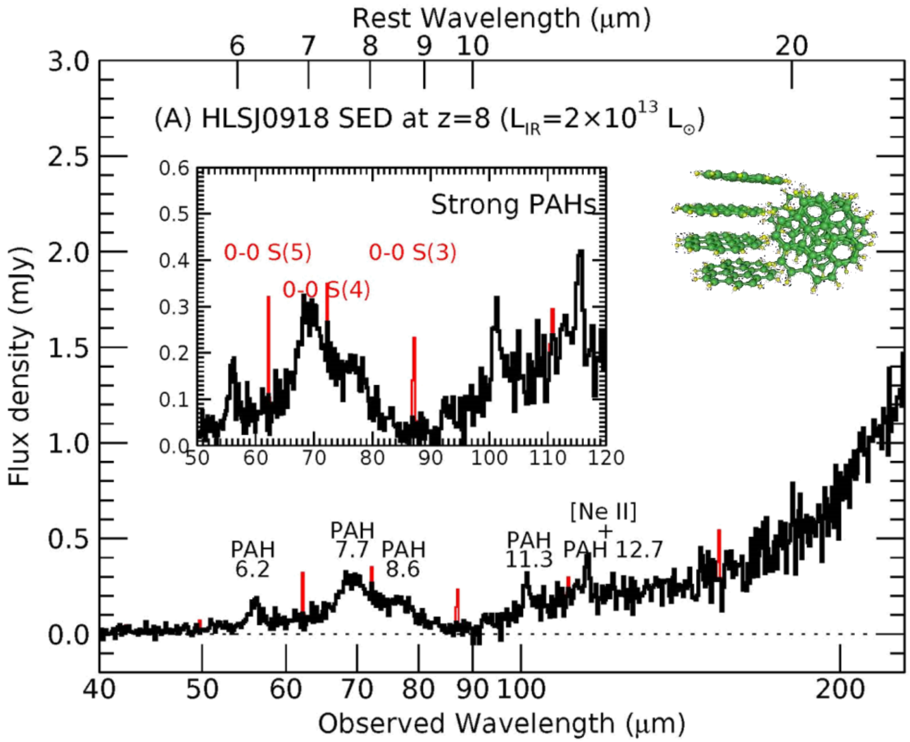
PAH galaxies z > 0.5
82,000 spectra
(14,000 for z ~2-4)

MS stars (F, G, K)
11,000 spectra
~2000 debris disks >50 zodi.

For comparison:
Area for ~600 hr surveys at similar depth with Spitzer or JWST

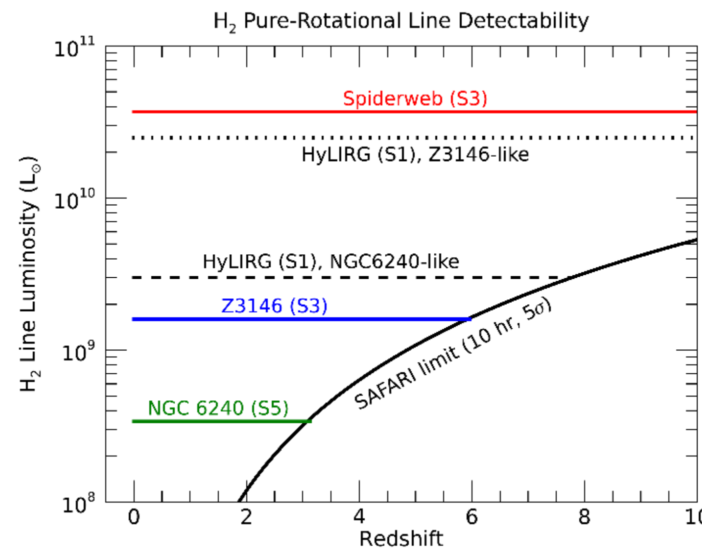
The first galaxies – H_2 and dust at ~1 Bn yr

Simulated SPICA observations of lensed galaxies at high redshift (z~8/10 hr)



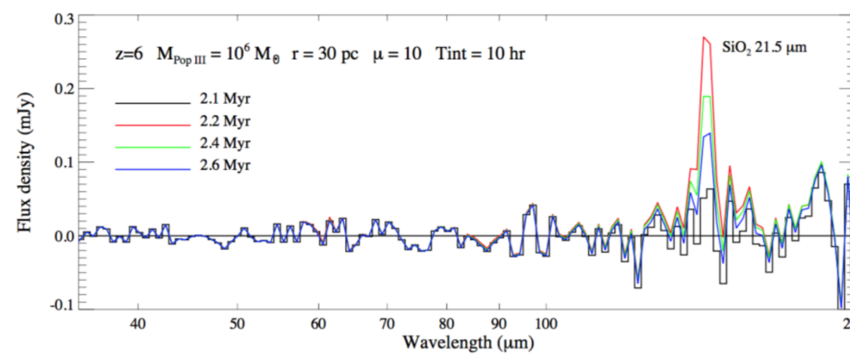
- PAH features readily detected

- Shocked H_2 lines out to high z



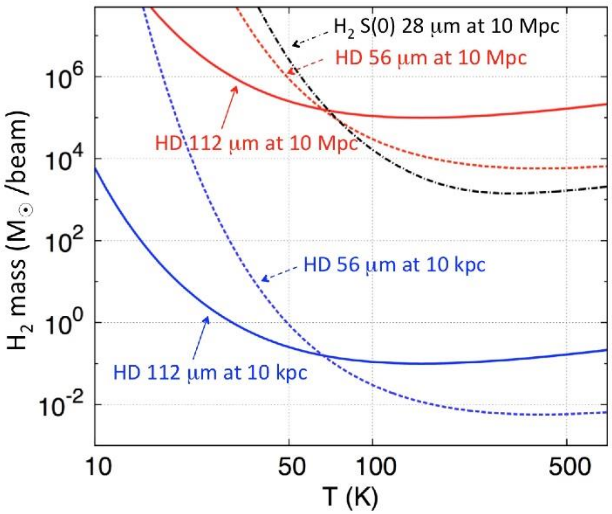
The long shot: rapidly evolving SiO_2 feature produced by Pop III pair-instability supernovae in a $10^6\ M_\odot$ Pop III Star Cluster

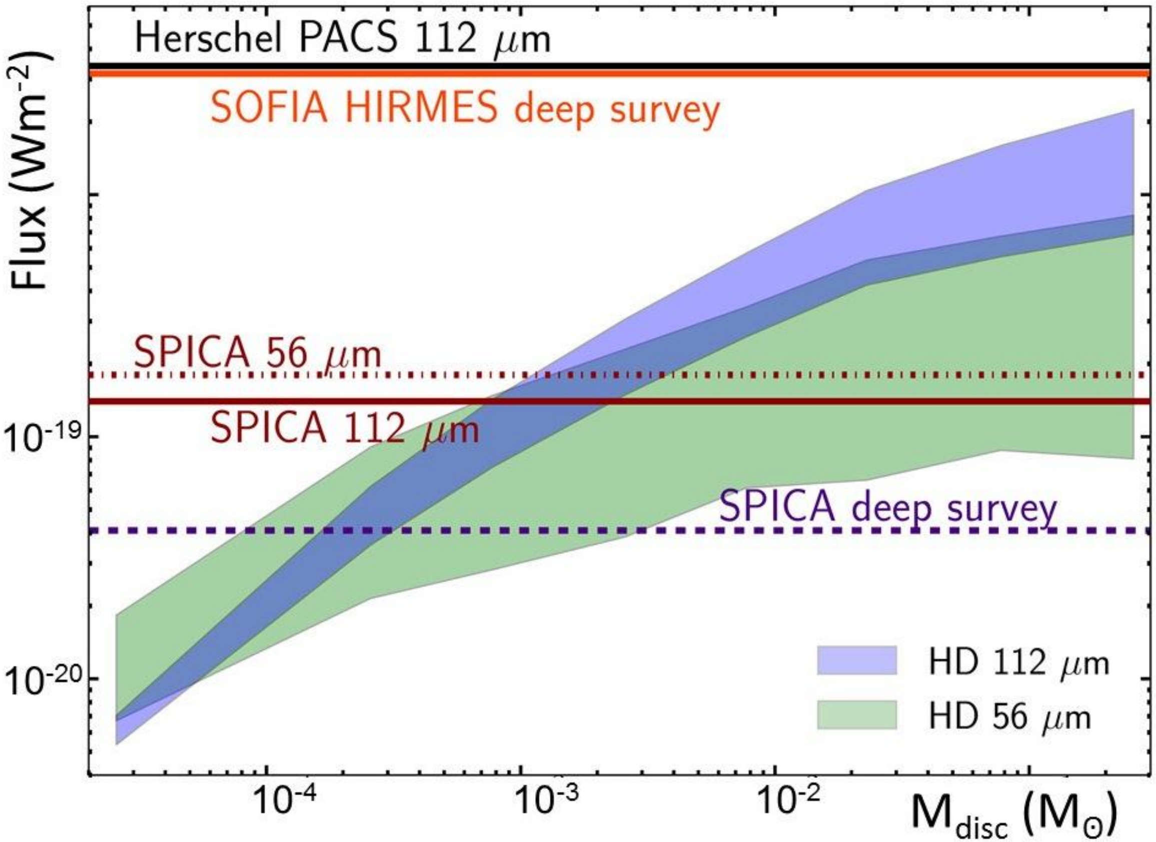
(10x magnification/10-hr integration)



HD – probing the mass of planetary disks

- HD 56/112 μm lines in the SAFARI bands
  - Direct tracer of gas mass in PPD's
  - Opens new domain of disk masses



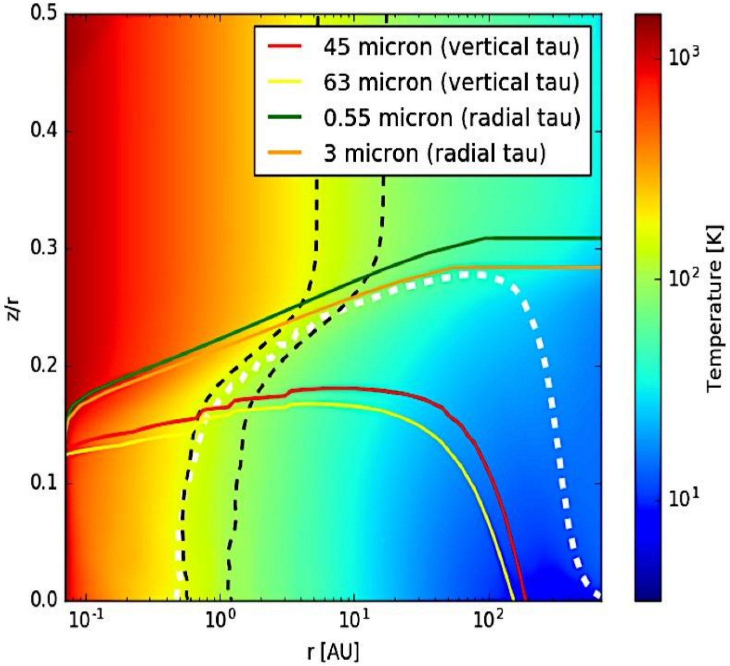


Trapman et al 2017

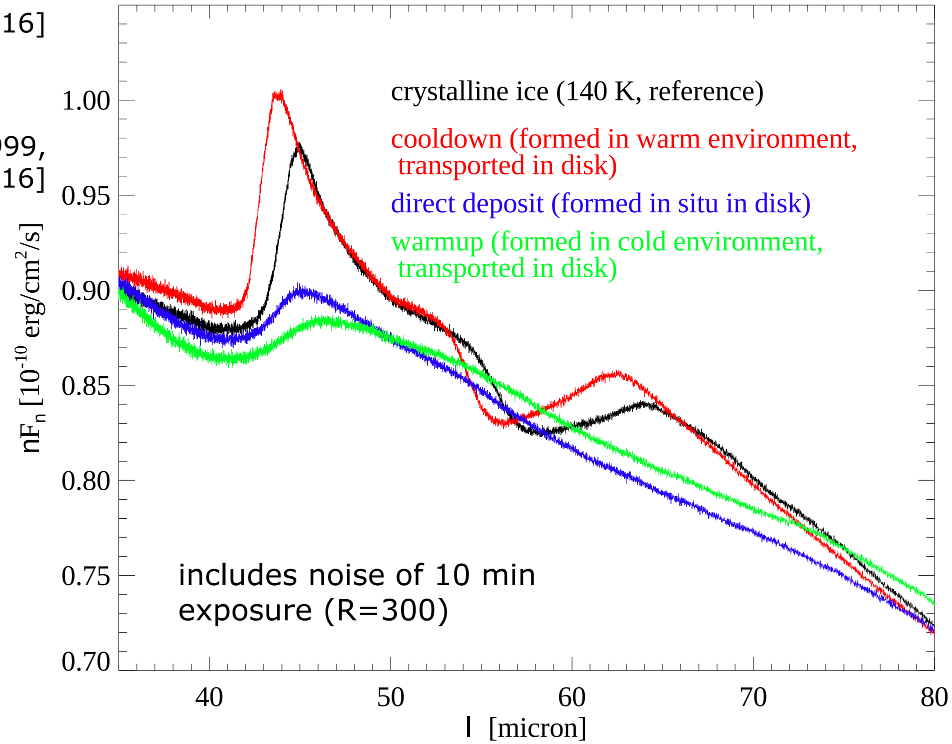
Ice histories: Pristine versus disk origin

Ices detected in scattered light @ 3μm
[TT: Terada et al. 2007; HAe: Honda et al. 2009, 2016]

Ices in emission @ 40 and/or 60 μm
[TT: McClure et al. 2013, 2015; HAe: Malfait et al. 1999, Meeus et al. 2001, Min et al. 2016]



standard T Tauri disk model from Woitke et al. (2016) with MCMax (Min et al. 2009, 2016) – consistent ice opacities [Kamp, Scheepstra, Min, Klarmann in prep



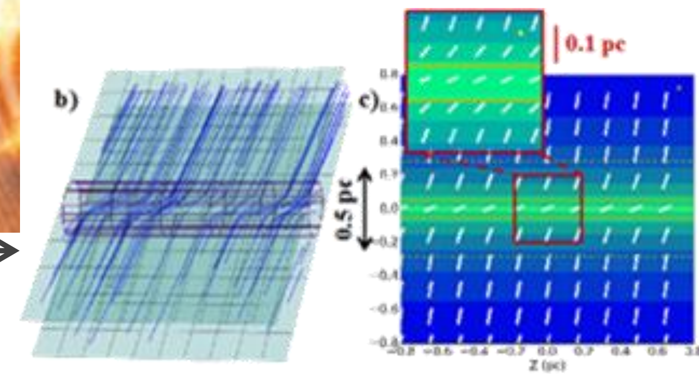
→ SPICA will probe the history of water ice in hundreds of T Tauri disks

Magnetic fields – driver in star formation in ISM filaments?

2.7 deg ~ 3 pc

Example:
Taurus B211 filaments

Herschel 250 µm and PLANCK magnetic field



B-BOP will probe the link between magnetic field, low-density filaments (striations) and dense star-forming filaments

characteristic filament width of 0.1 pc observable out to d ~ 350 pc

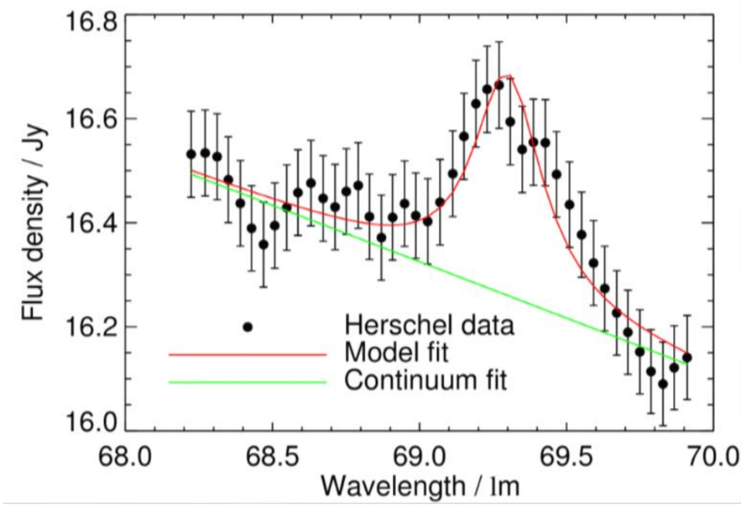
not accessible to ALMA, neither to ground-based SCUBA2-Pol, NIKA2-Pol, neither to SOFIA, nor to balloon-borne Super BLAST-Pol

SAFARI

SRON

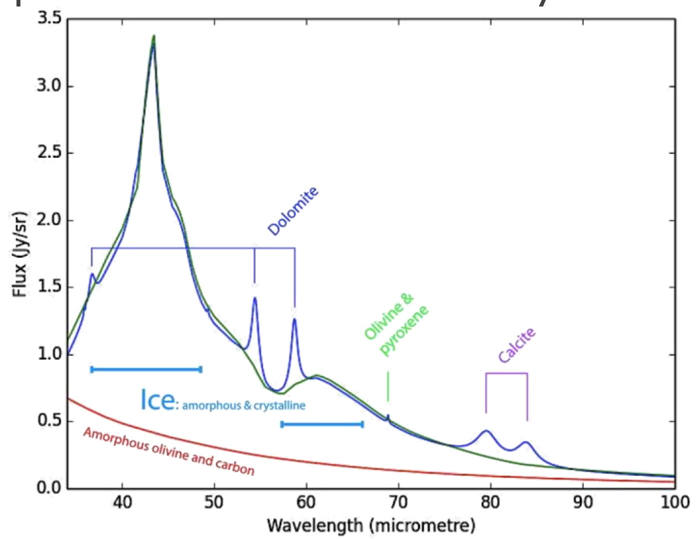
Mineralogy – e.g. debris discs

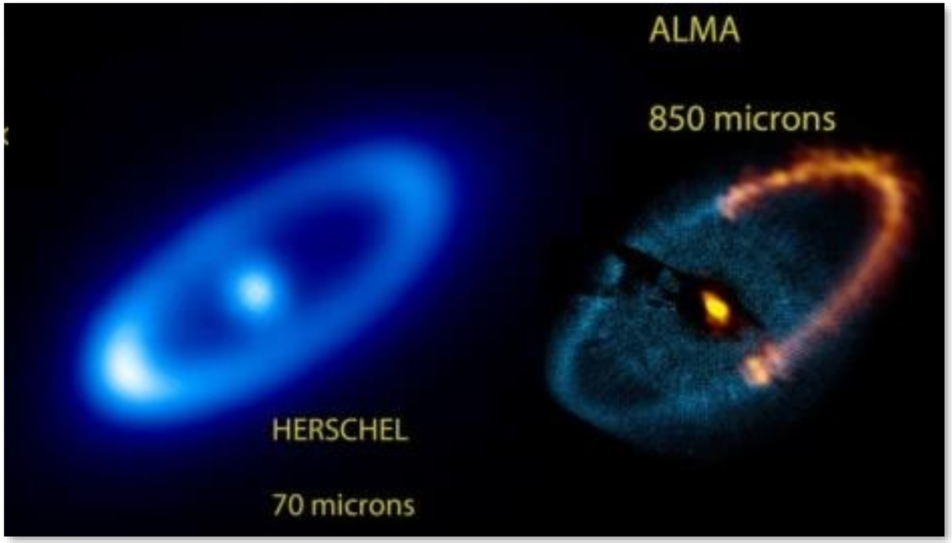
69 μm feature for β-Pic (de Vries et al. 2012)



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



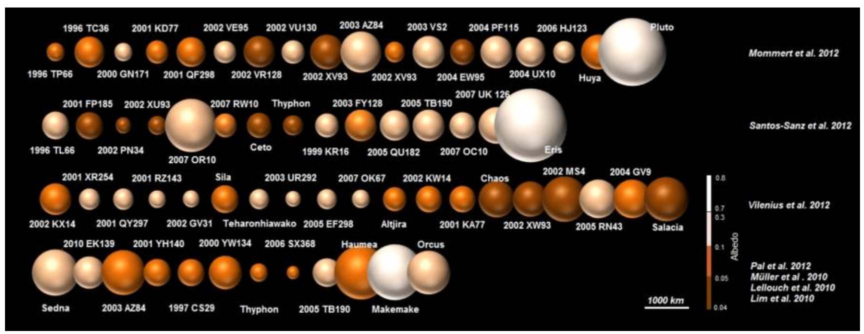


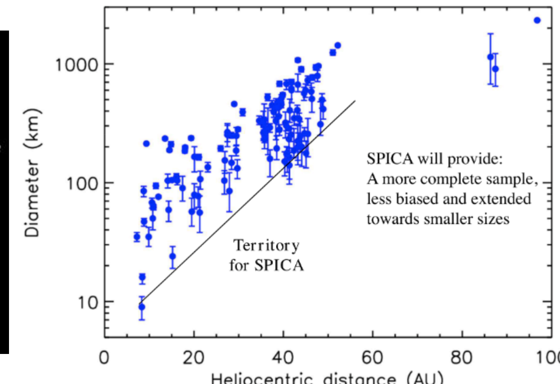
Solar-System Science with SPICA

Uniquely suited to study the *cold outer Solar System*, Saturn and out

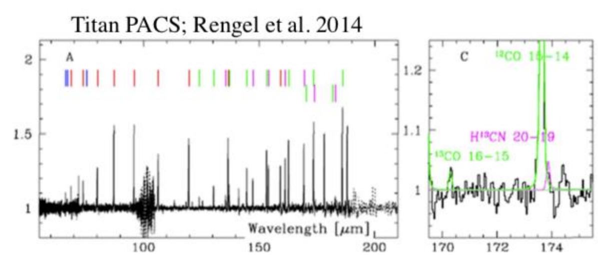
(thermal emission peaks at SAFARI wavelengths)

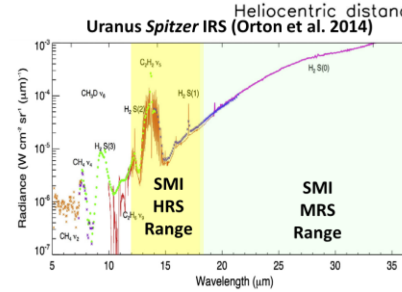
- Many spectral features unique to SPICA:
  - HD: direct handle on D/H
  - Mg/Fe in silicates (comet atmospheres, asteroids, …)
  - Water ice: comets, asteroids, …
- Trans-Neptunian Objects, our "debris disk" (follow-up to Spitzer/Herschel)





- Atmospheres
  (e.g., Titan, Uranus)





- Mineralogy of, e.g., Saturn Phoebe ring (discovered with Spitzer/MIPS!)

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Summary

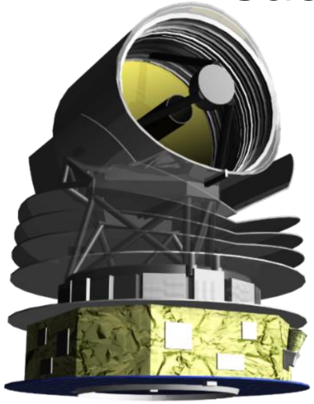
- SPICA: a mid-far infrared space observatory
  - 2.5 m diameter mirror, actively cooled to 8 K

  → ***unprecedented sensitivity*** in ***mid/far IR***
- SPICA focus: spectroscopy of the obscured universe, straddling the gap between JWST and ALMA

- SPICA - joint ESA-JAXA project
  - ***Mission*** final ***selection*** – 2021 ~TRL5 milestone
  - ***Phase 0/A -*** started re-iteration of capabilities and design
  - Science goals/capabilities to be revisited/upgraded

    → SPICA science conference in Crete next week

    www.spica2019.org



SPICA information: ***www.spica-mission.org***

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