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SPICA搭載遠赤外線分光撮像装置SAFARI

We present an outline of a study that is being undertaken by a consortium of European, Canadian and Japanese institutes, along with JPL, for a FIR instrument for the proposed JAXA-led Japanese-ESA mission, SPICA. SPICA is a JAXA proposed mission to be launched in early 2020s to conduct innovative infrared observations. SPICA is also proposed to ESA as one of a small number of missions that are being under selection to go to the next stage of the recent ESA's Cosmic Vision process. SAFARI – SpicA FARinfrared Instrument – is an imaging spectrometer with both spectral and photometric capabilities covering the \sim 34-210 μ m waveband. We highlight the core science justification for the instrument, a possible conceptual design; its predicted performance and the technical challenges that need to be met in order to realise the full potential of the instrument.

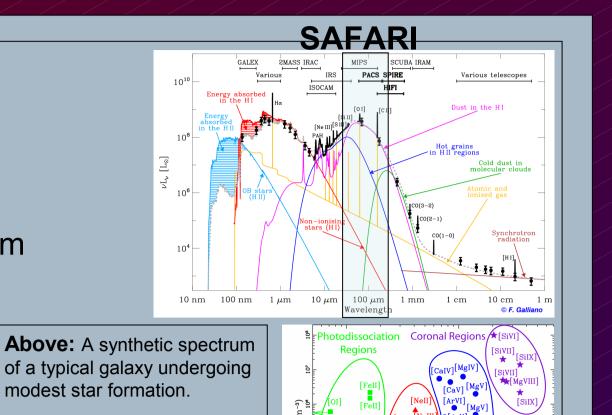
Why another FIR mission

Key waveband

- Unique and extensive spectroscopic toolkit of key diagnostic lines (FIR&redshifted MIR) + thermal continuum
- Long lineage of very successful FIR missions
- IRAS, KAO, ISO, IRTS, Spitzer, AKARI, Herschel...
- Herschel?
- •Confusion-limited at λ >100um, detector-limited below due to passively cooled, warm (~80 K) mirror

• ALMA?

- •"complementary" science
- FIR: undetectable λ 's from ground



Galaxy evolution, near and far

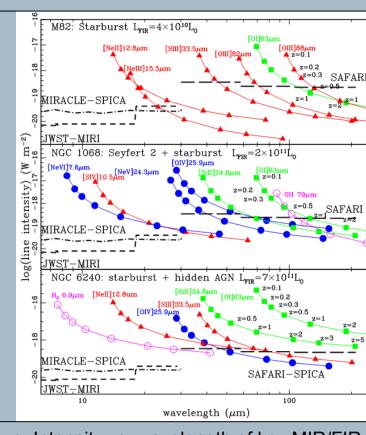
•The AGN-starburst connection at high-z

• Through deep spectroscopy, characterise the distant MIR/FIR galaxy population out to $z\sim4$ and beyond, and start to disentangle the interplay between AGN and starburst

Deep cosmological surveys:

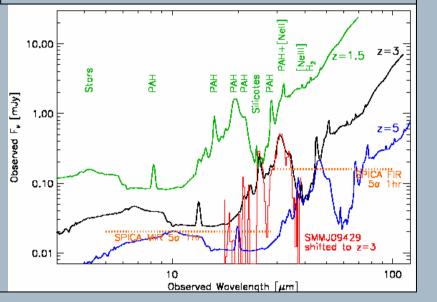
• Through deep, confusion limited surveys at 70µm complete a census on (i) star formation down to MW/4 @z~1, 90% of the CIRB over 80% of Hubble time (ii) massive black-hole growth by unveiling the missing dust-obscured, Compton-thick AGN population responsible for the 30keV peak in the x-ray background

•Punching through the traditional confusion limit:



Above: Intensity vs. wavelength of key MIR/FIR lines in three archetypical objects -dashed line represents 5- σ 1hr sensitivity of SPICA

Below: Detectability of redshifted PAH features with SAFARI in low-res., mode (R~50)



• SPICA (< 6 K) \rightarrow Cooled Herschel:

• Much lower background \rightarrow deep spectroscopy • Imaging vs. point-source \rightarrow determines science capabilities/sensitivities/instrument design •Long lived mission \rightarrow no cryogenics

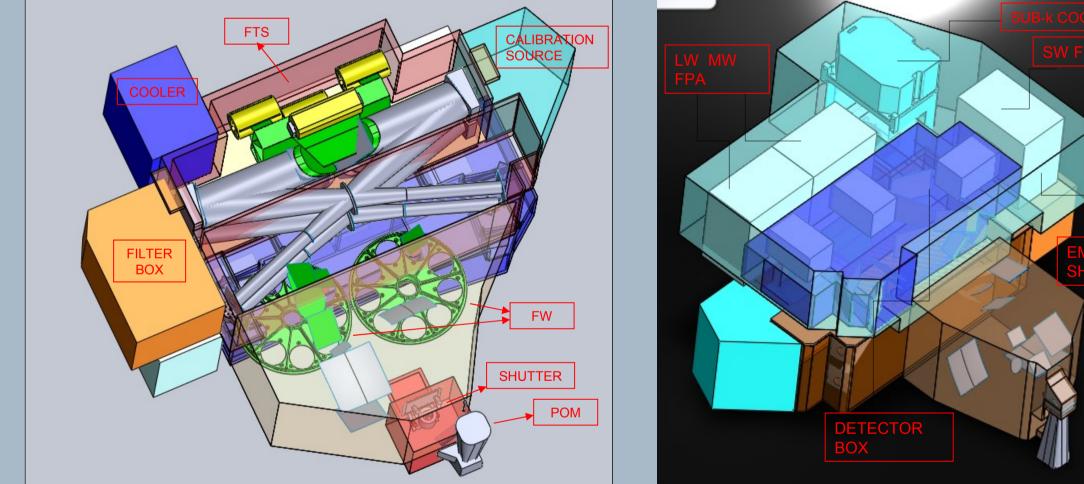
Instrument concept:

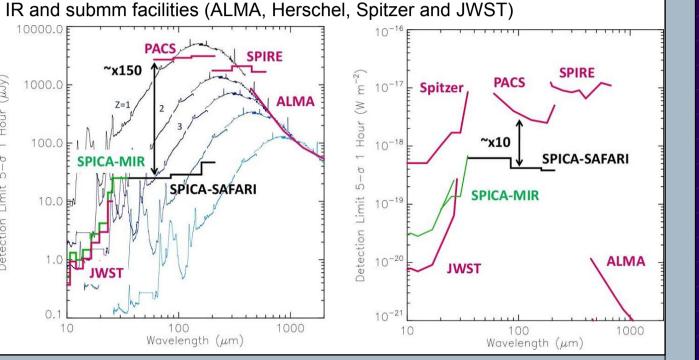
- Imaging Fourier Transform Spectrometer (FTS) **Wavelength coverage** of ~34-210µm (using 3-detector arrays, $F\lambda/2$ sampling)
- Range not covered by JWST or ALMA!
- Field of view of 2' x 2'
- Spectroscopy R up to ~2,000 + photometry (R~3)

Sensitivity required: Unresolved lines 5σ -1hr: few x 10⁻¹⁹ W/m² Photometry 5σ -1hr : <50µJy

Technical challenges and solutions:

- **Detector sensitivity, dynamic range and complexity**
- Cooler technology: a full multi-stage ADR and a hybrid sorption cooler/ADR are under consideration
- **Broadband beamsplitters and filters: ~3 octave** bandwidth required
- FTS cryo-mechanisms: space-qualified mechanisms exit
- EMC susceptibility: careful shielding / filtering / operation concept required





Photometric (left) and spectral (right) sensitivity of SAFARI relative to other

Right: A selection of

redshifted MIR/FIR emission

lines accessible with SPICA

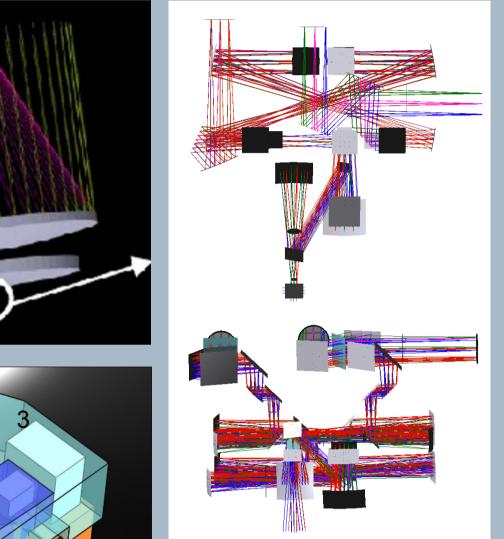
density ionization potential

Between them, they cover a

wide range of physical and

excitation conditions

plotted as a function of critical



INPUT OPTICS UNIT 2. MAIN BODY FRAME UNIT DETECTOR SYSTEM 3. UNIT

- Break confusion through deep, spectral imaging of "blank" sky
- Cosmology at low spectral resolution:
- Deep surveys using redshifted PAH features
- Local galaxies: proxies for the distant Universe

From gas and dust to planets **Protoplanetary disks: from ices to oceans**

- Tracing the presence of stellar FIR photometric excesses (due to circumstellar disks) out to the edge of the galaxy • Providing a comprehensive inventory of stars with circumstellar disks for future planet imaging facilities
- Resolving the "snow line" (water ice) in nearby "Vega" disks
- Access to the main gas coolants & key chemical species (e.g. water, oxygen, organics) in proto-planetary disks
- Searching for FIR signatures of transiting exoplanets (water?)⁻

Building blocks of the Solar System:

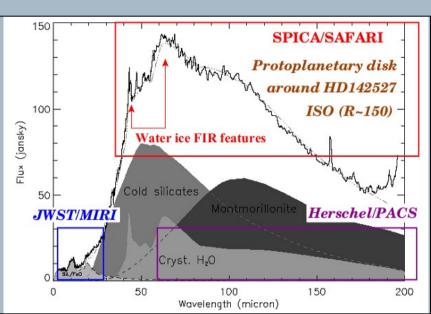
• Determining the chemical history of the Solar nebula by detection & characterisation of 100s of asteroids, TNOs and KBOs

• The dust life-cycle:

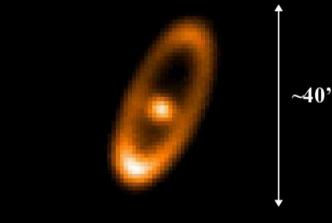
Tracing the evolutionary cycle of dust through spectral& photometric imaging of the faint,,extended medium where dust grains are formed (e.g. evolved stars) and reprocessed (SNe remnants & the diffuse ISM), before incorporation into star-forming clouds

Image of Formalhaut debris disc a 70um with Herschel/PACS (PSF~6"; Acke et al., in prep). SAFARI's large

FOV and smaller PSF at shorter wavelengths (~4" at the~44m water-ice feature) will provide very detailed spectroscopic images of nearby discs.

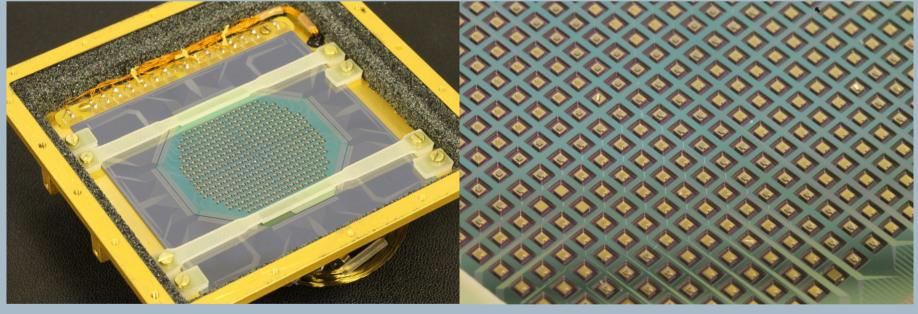


The ISO spectrum towards the young star HD142527 (Malfait et al.) showing the model components of the MIR/FIR disk emission. Water ices can be directly detected through the $43/62\mu m$ emission features.



Fomalhaut (Herschel/PACS 70um)

TES detector arrays



Prototype 388 TES array (1.6mm pitch) with flat Si backshorts

	Band	λ_{c}	Pixel Size on sky	Number of pixels	Field size
	μm	μ m	arcsec	-	Arcmin
SW	34-60	48	2.68	43X43	1.92
MW	60-110	85	3.05	38x38	1.93
LW	110-210	160	5.75	20x20	1.917

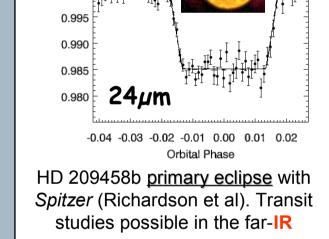


Exoplanet research in the far-IR

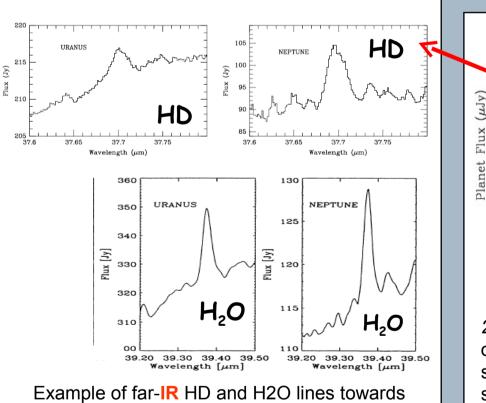
• 2 orders of magnitude higher sensitivity than Herschel/PACS to detect and characterize zodiacal backgrounds in a statistical sample of stars (~10⁵ Sun-like stars at d<180 pc).

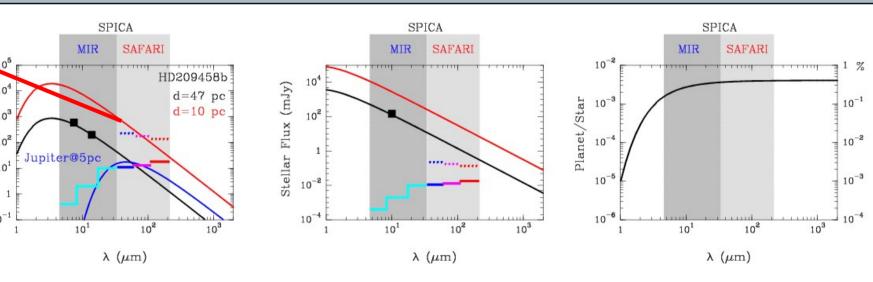
• Key to prioritising Earth-like candidates for future TPF-type missions.

• Complement to SPICA's mid-IR coronagraph and spectrometer. • Very stable detectors and efficient, high cadence and high S/N



observations to perform transit photometry and low-R spectroscopy in the far-IR. • Cool EPs around cool stars ? Spectral signatures (water?, HD?, ice?)





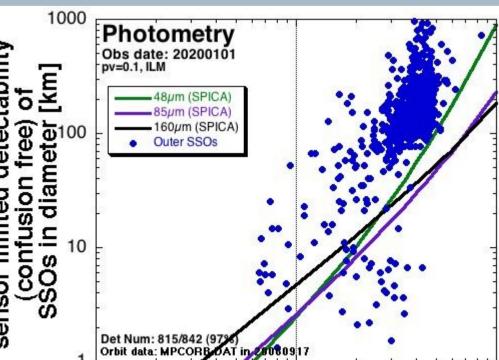
Left: Fit to HD 209458b "hot Jupiter" MIR fluxes inferred from a secondary transit with Spitzer (Swain et al. 2008a) around a G0 star ($d \sim 47 \, pc$, in black) and interpolation to $d = 10 \, pc$ (red). The expected emission of a Jupiter-like planet at 5 pc is shown in blue (reflected emission neglected). 5σ-1hr photometric sensitivities of SPICA/MIR instruments (cyan) and SAFARI (blue, magenta and red) are shown. Dashed lines show sensitivities in spectrophotometric mode ($R \sim 25$).SAFARI can potentially extract their FIR spectrum for the first time. Middle: Flux from the host star at different distances. Right: Planet-to-star contrast.

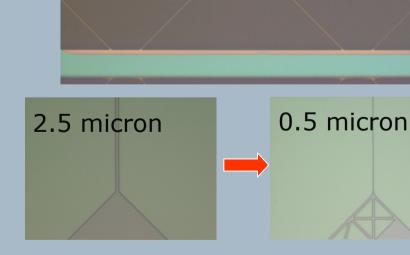
TNOs roundup

Uranus & Neptune (Fouchet; Feuchtgruber et al.)

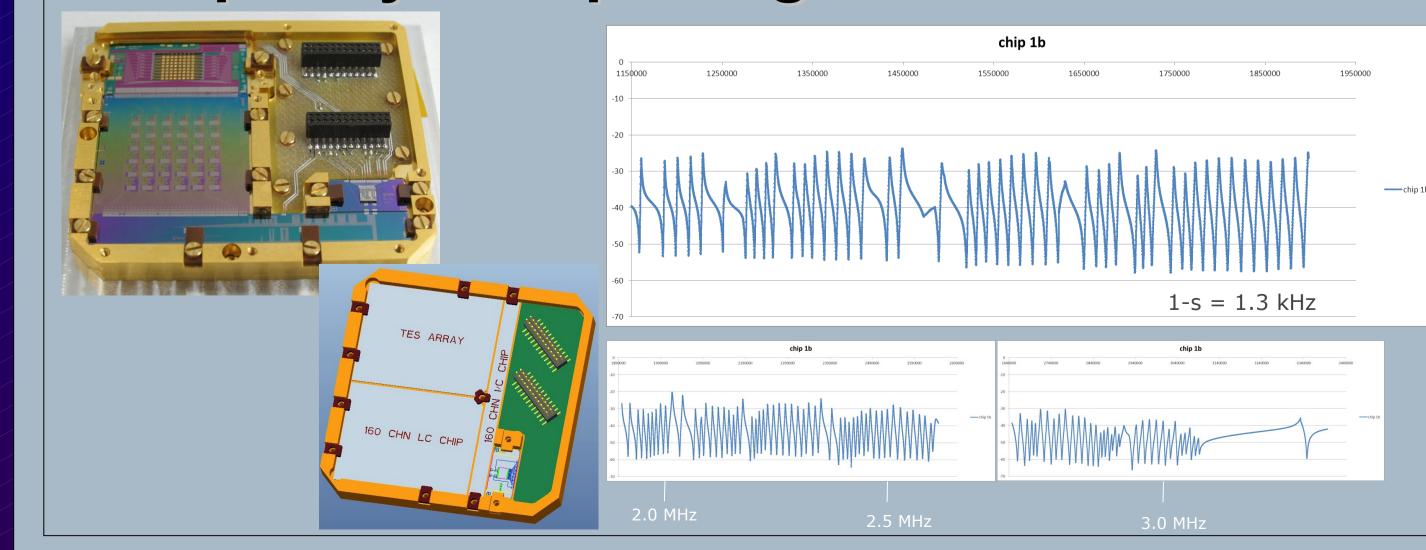
• The outer Solar System provides the closest "template" to study the composition, processing and transport of minerals, ices and organic matter by studying debris disc bodies "one by one".

• SAFARI photometry (~48, 85 and 160um) and low spectral resolution (a few hundred) spectroscopy of bodies in the Solar System Kuiper Belt (KBOs or TNOs). For the first time SAFARI provides the required sensitivity to carry out FIR spectroscopy of TNOs and study their grain and ice composition at their emission peak.





Thinner SiN suspension for higher sensitivity



• SAFARI will detect photometrically almost all known KBOs (those with diameters > 100 km) in only \sim 75 hr at a rate of \sim 1 object per minute.

• The expected sensitivity in the SED mode will be a factor ~x2.5 better than Herschel photometric cameras (i.e. all TNOs detected photometrically with Herschel could be observed spectroscopically with SPICA-SAFARI.

