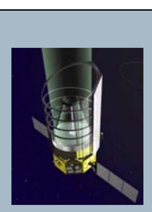

SAFARI: A FIR imaging spectrometer for SPICA

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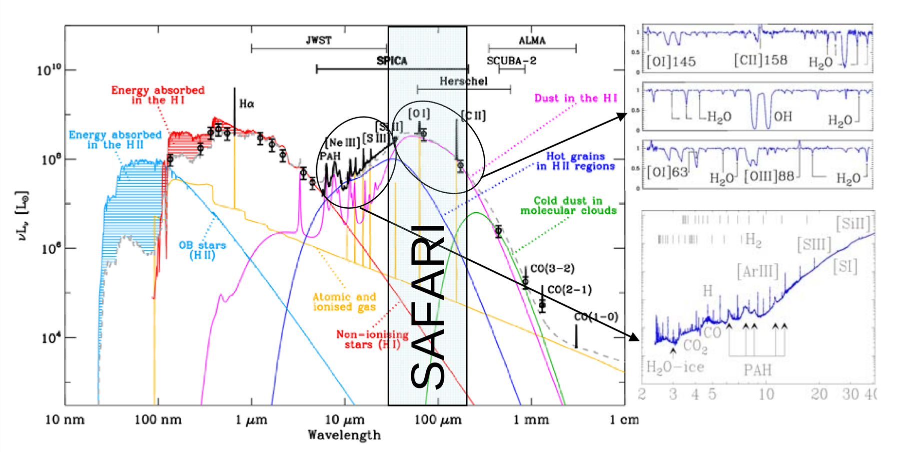
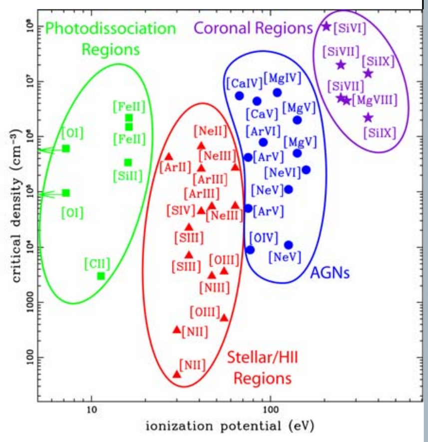
We present an outline of a study that is being undertaken by a consortium of European, Canadian and Japanese institutes, supported by JPL, for a FIR instrument for the proposed JAXA-led Japanese-ESA mission, SPICA. SPICA is one of a small number of missions that have been selected to go to the next stage of ESA's Cosmic Vision 2015-2025 process. SAFARI – **S**pic**A** **FAR**-infrared **I**nstrument -- is an imaging spectrometer with both spectral and photometric capabilities covering the ~33-210μm 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 the Far Infrared?

- **Key waveband**
  - Unique and extensive spectroscopic toolkit of key diagnostic lines (FIR&redshifted MIR) + thermal continuum
- **A successor to Herschel**
  - Herschel confusion-limited at λ>100 μm, detector limited below. Massive increase in sensitivity at ~70 μm needed to complete picture of CIRB
  - 1000s of distant,FIR sources will be found by Herschel, but what are they?
  - Deep spectroscopy needed to characterise: e.g.. AGN vs. starburst
- **Complementary to ALMA**
  - MIR lines/continuum redshifted into FIR
  - ALMA cannot detect rest frame water or oxygen
- **SPICA → Cooled Herschel:**
  - Much lower background → deep spectroscopy
  - Imaging vs. point-source → determines science capabilities/sensitivities/instrument design
  - Long lived mission – no cryogens



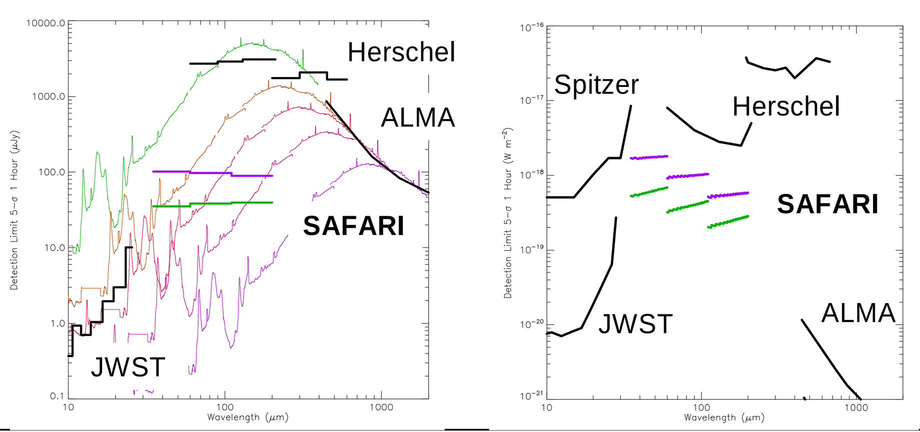
Above: A synthetic spectrum of a typical galaxy undergoing modest star formation and insets showing the richness of the spectrum in the FIR and MIR wavebands



Right: A selection of redshifted MIR/FIR emission lines accessible with SPICA, plotted as a function of critical density ionization potential. Between them, they cover a wide range of physical and excitation conditions

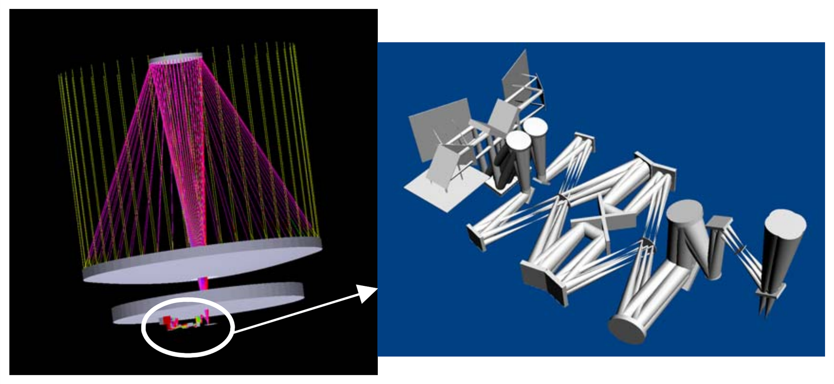
Left panel: A plot of the photometric sensitivity of SAFARI overlaid on redshifted (z=1-5) M82 SED

Right panel: Plot of spectroscopic sensitivity of SAFARI



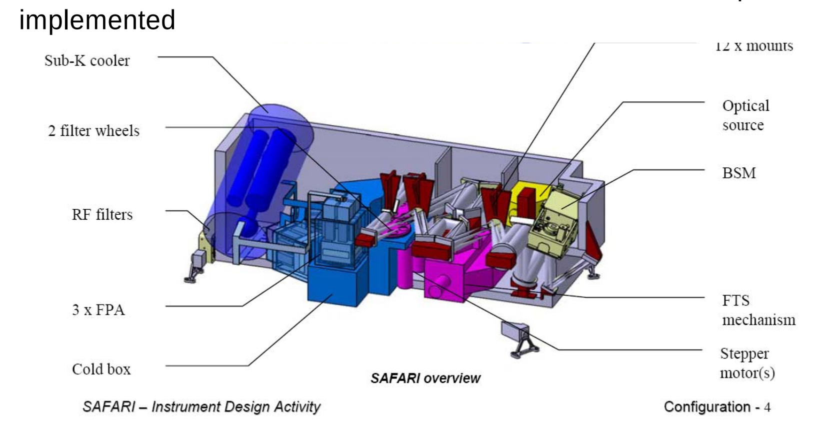
Instrument concept

- Imaging Fourier Transform Spectrometer
- Wavelength coverage of ~33-210μm: 3 detector arrays, Fλ/2 sampling)
- Field of view of 1' x 1', with goal of 2' x 2'
- Spectroscopy (10<R<10 000) & photometry (R~3)
- Sensitivity required:
  Unresolved lines 5σ-1hr: few x10^{-19} W/m^2
  Photometry 5σ-1hr: <50μJy
- Detector sensitivity required of fewx10^{-19} W/ Hz
- Four detector technologies under consideration
  - Ge:Ga Photoconductors at 1.7 - 4.5K
  - TES bolometers operating at < 100mK
  - Silicon bolometers, also operating at sub-K temperatures
  - Kinetic Induction Detectors (KIDS) at <100 mK



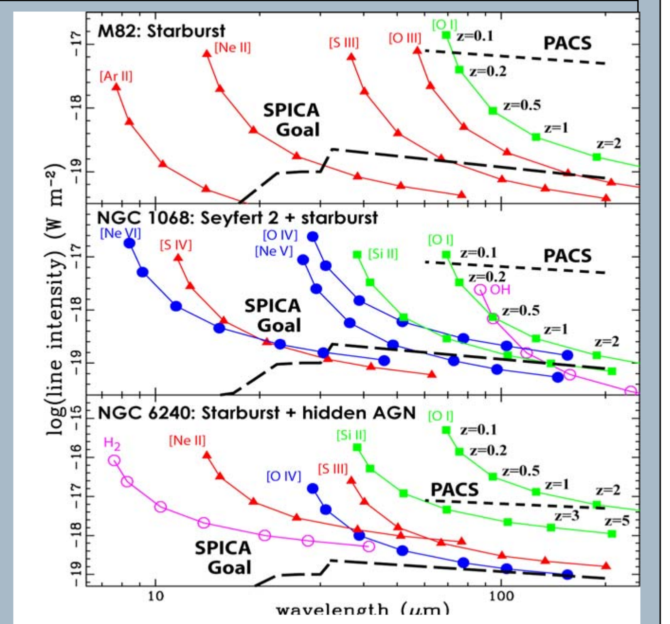
Above: Optical layout of the FTS concept, to scale with the 3.5m telescope (left) and with the optical beams rendered as a solid model (right)

Below: CAD Model of the instrument with the bolometer option implemented



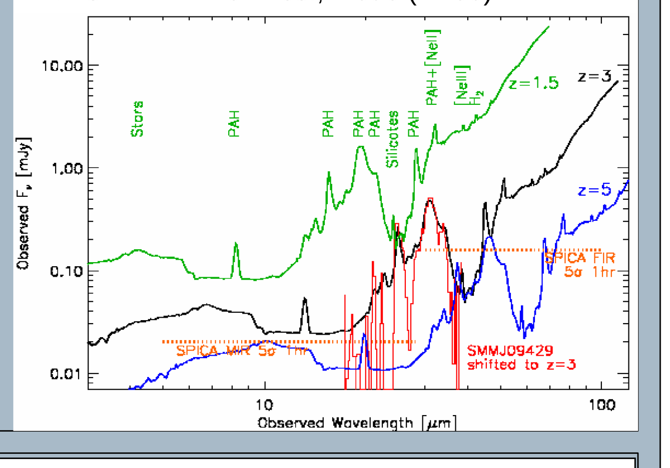
Galaxy evolution, near and far

- **The AGN-starburst connection at high-z**
  Through deep spectroscopy SAFARI can characterise the distant MIR/FIR galaxy population out to z~4 and beyond, and start to disentangle the interplay between AGN and starburst
- **Deep cosmological survey**
  Through deep, confusion limited surveys at 70μm, SAFARI gives a complete census of 90% of the CIRB over 80% of Hubble time. Also traces massive black-hole growth by unveiling the missing dust-obscured AGN population responsible for the 30keV peak in the x-ray background
- **Punching through the traditional confusion limit**
  SAFARI can break confusion through deep spectral imaging of "blank" sky
- **Cosmology at low spectral resolution**
  Deep surveys using red shifted PAH features
- **Local galaxies: proxies for the distant Universe**
  SAFARI will complete the spectral atlas of all types of galaxy in the local Universe



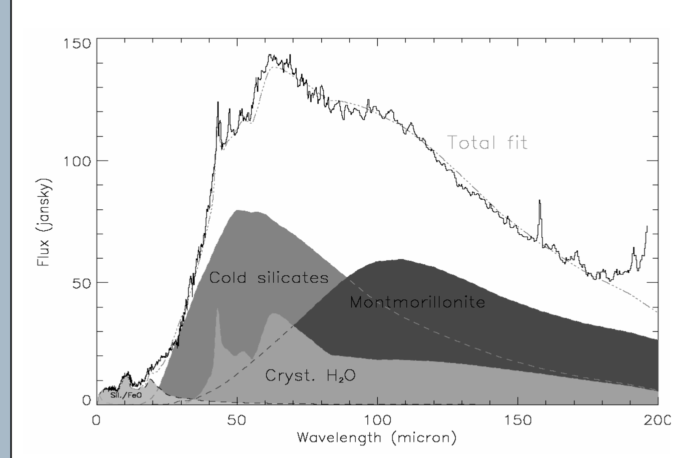
Above: Intensity vs. wavelength of key MIR/FIR lines in three archetypical objects -dashed line represents 5-σ 1hr sensitivity of SPICA

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

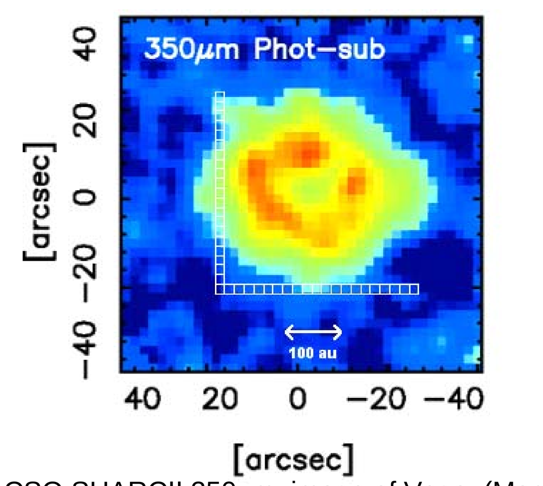


From gas and dust to planets

- **Protoplanetary disks: from ices to oceans**
  High sensitivity FIR photometry can trace the presence of FIR excesses due to circumstellar disks in stars out to the edge of the galaxy
  Provides a comprehensive inventory of stars with circumstellar disks for future planet imaging facilities
  Access to the solid state water ice features allows imaging of the "snow line" in nearby Vega-like disks
  Access to the main gas coolants & key chemical species (e.g. water, oxygen, organics) in proto-planetary disks allows chemistry of planet formation regions to be understood
  SAFARI can search for FIR signatures of transiting exoplanets
- **Building blocks of the Solar System:**
  Determining the chemical history of the Solar nebula by characterisation of 100s of asteroids, comets and TNOs
- **The dust life-cycle:**
  Spectral imaging can trace the evolutionary cycle of dust grains from the faint extended envelopes where they are formed through their reprocessing in the ISM to their incorporation into star-forming clouds



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 43/62μm emission features.



The CSO SHARCII 350μm image of Vega (Marsh et al.) with SAFARI pixel scale at 43-62μm overlaid. Spatial resolution equivalent to ~23 AU will be possible, enough to detect the expected snow-line region at 42 AU.

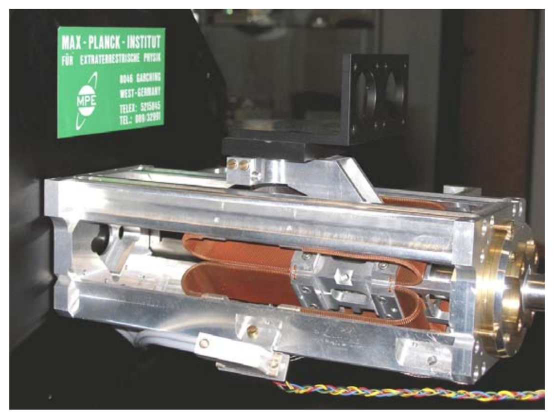
Technical challenges and solutions:

Detectors: The required sensitivity, dynamic range and array formats are all challenging for currently available technology. We give an illustration here of one type under development for SAFARI

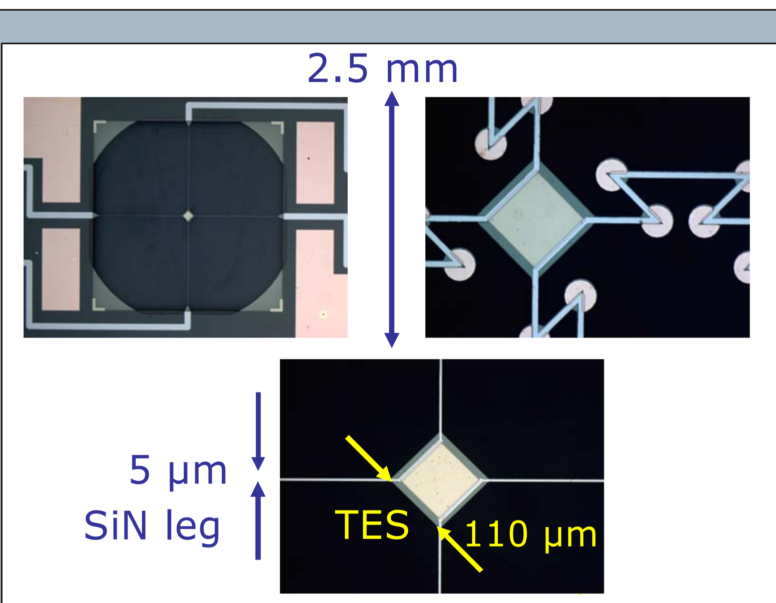
Cooler technology: a hybrid sorption cooler/ADR is under consideration for the low temperature detector options.

Broadband beam splitters and filters: ~3 octave bandwidth required

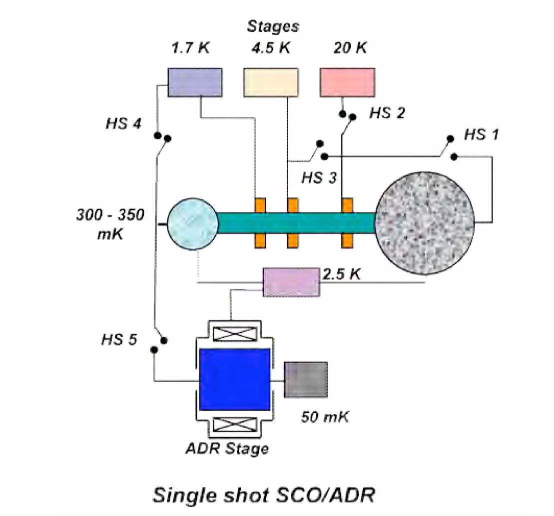
Cryo-mechanisms: space-qualified mechanisms exists but require development to fit with spacecraft resources (mass, power etc)



The FTS scanner mechanism developed for the GIRL (German Infrared Laboratory) spectrometer. This friction-free mechanism has a scan length of 100mm and is fully space-qualified.



Prototype TES detectors under test and development at Cardiff/SRON/Cambridge with a parallel development programme at JPL



Schematic of one of the CEA-Grenoble (SBT) cooler designs under consideration for SAFARI