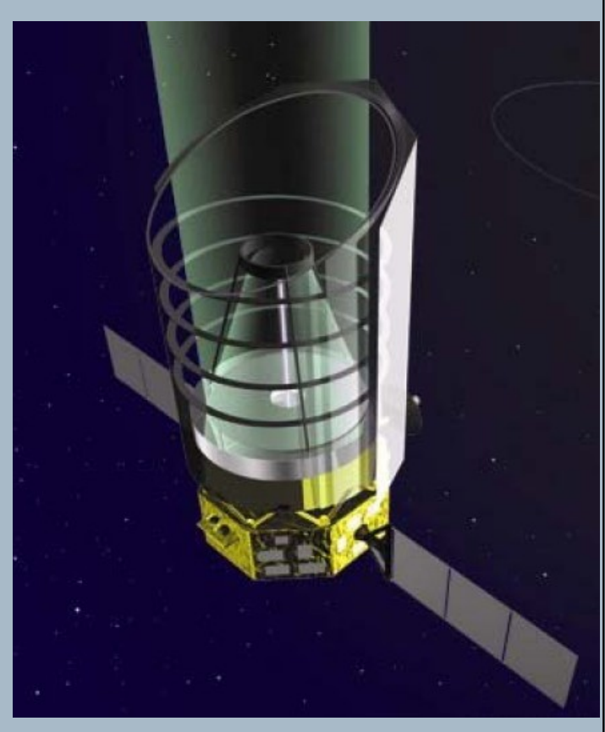


Yasuo Doi, U.Tokyo
Bruce Swinyard, RAL
Kate Isaak, Cardiff
Javier Goicoechea, CAB-CSIC
Mitsunobu Kawada, Nagoya U.

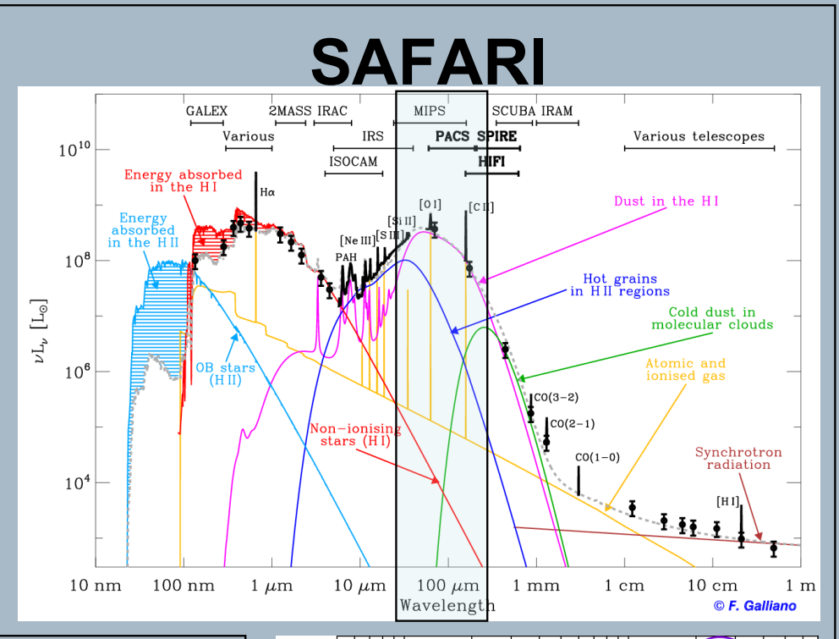
On behalf of the SAFARI consortium: **UK:** RAL, Cardiff, Imperial College, Sussex, UCL, MSSL, OU, ATC /Edinburgh, Oxford, UCLAN, Strathclyde, Durham, Hertfordshire; **Belgium**: MEC/RMA, KUL; **France:** CEA-Saclay, IAS, CEA-Grenoble, Bordeaux,LERMA, OAMP, CESR, GEPI; **Germany:** MPE, MPIA, MPIK, PTB-Berlin; **Netherlands:** SRON, Utrecht, TNO-Delft, Leiden; **Italy:** IFSI, INAF, La Sapienza, ISAF-Rome, TAS; **Spain:** IAC, CSIC; **Austria:** UVienna; **Canada:**Lethbridge, HIA/NRC, UBC, UWO, Calgary; **Japan:** ISAS, JAXA, UTokyo, NagoyaU, NAOJ; **USA:** Cornell, JPL

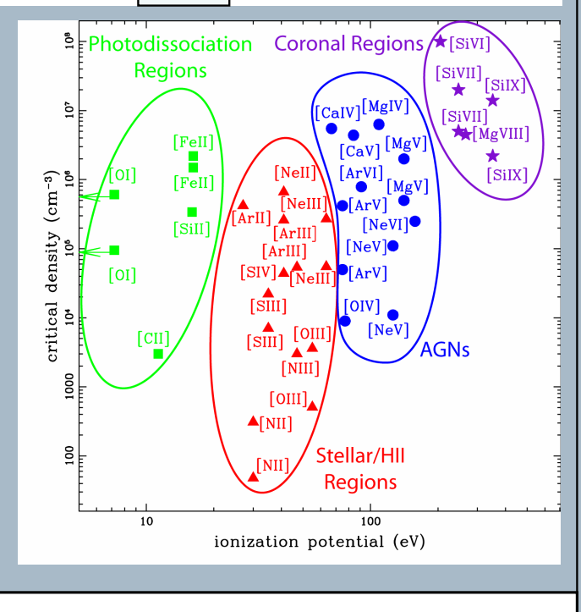
SAFARI – a FIR Imager/Spectrometer for SPICA

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 ~2018 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** – **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 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
- **SPICA (< 6 K) → Cooled Herschel:**
  - Much lower background → deep spectroscopy
  - Imaging vs. point-source → determines science capabilities/sensitivities/instrument design
  - Long lived mission → no cryogenics

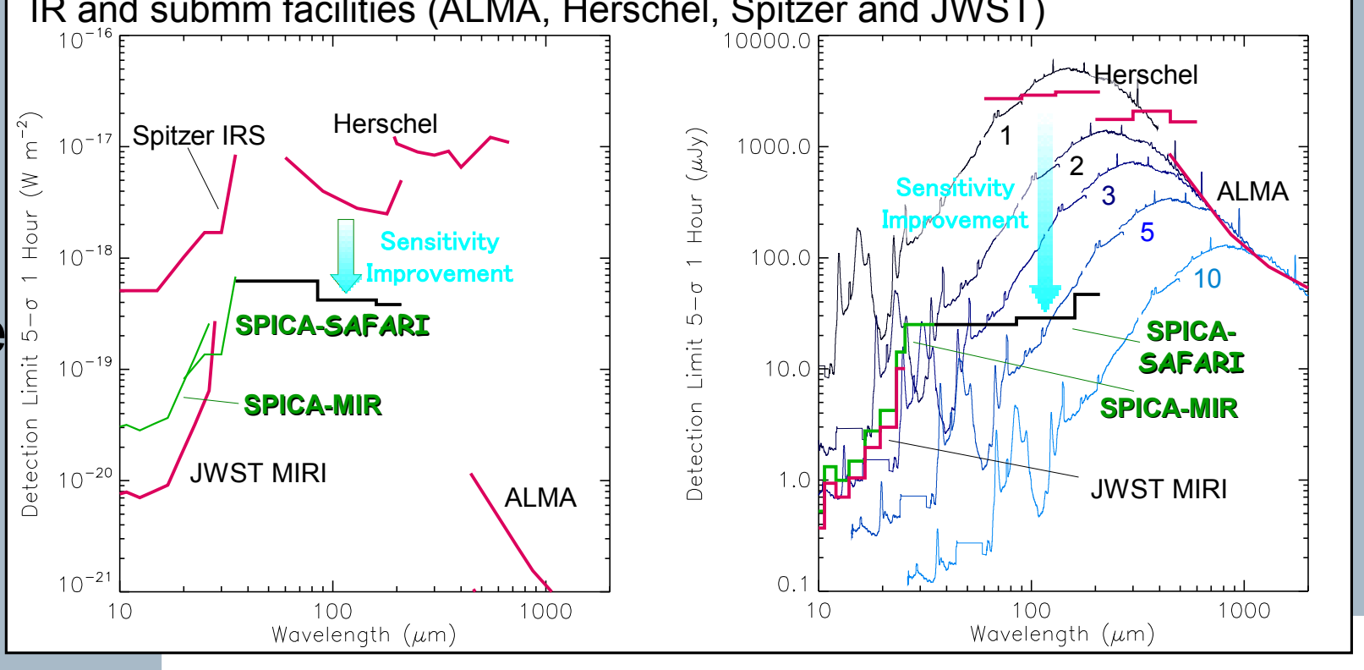




Above: A synthetic spectrum of a typical galaxy undergoing modest star formation.

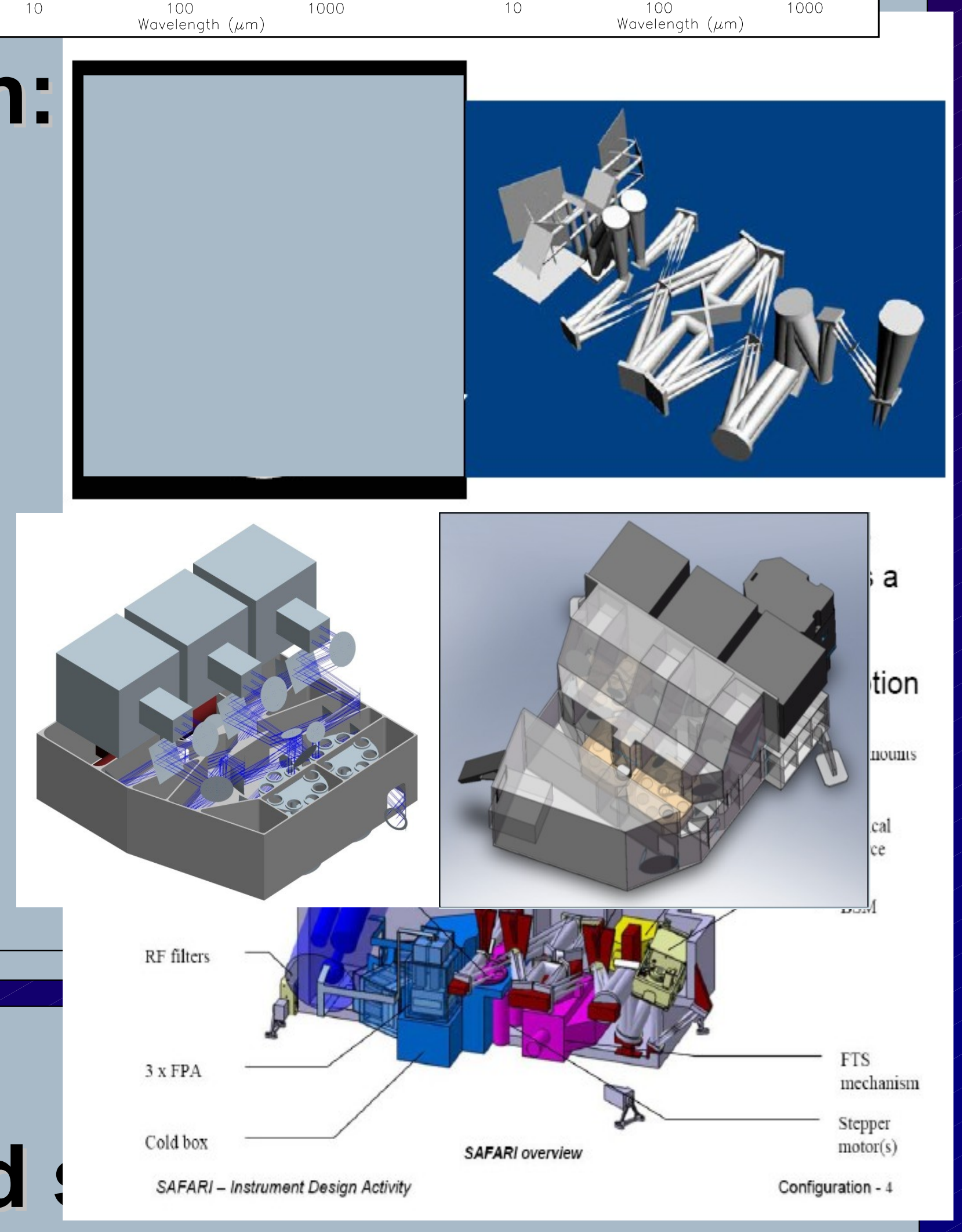
Right: A selection of redshifted MIR/FIR emission lines accessible with SPICA, plotted as a function of critical density ionization potential. Between them, they cover a wide range of physical and excitation conditions

Spectral (**left**) and photometric (**right**) sensitivity of SAFARI relative to other IR and submm facilities (ALMA, Herschel, Spitzer and JWST)



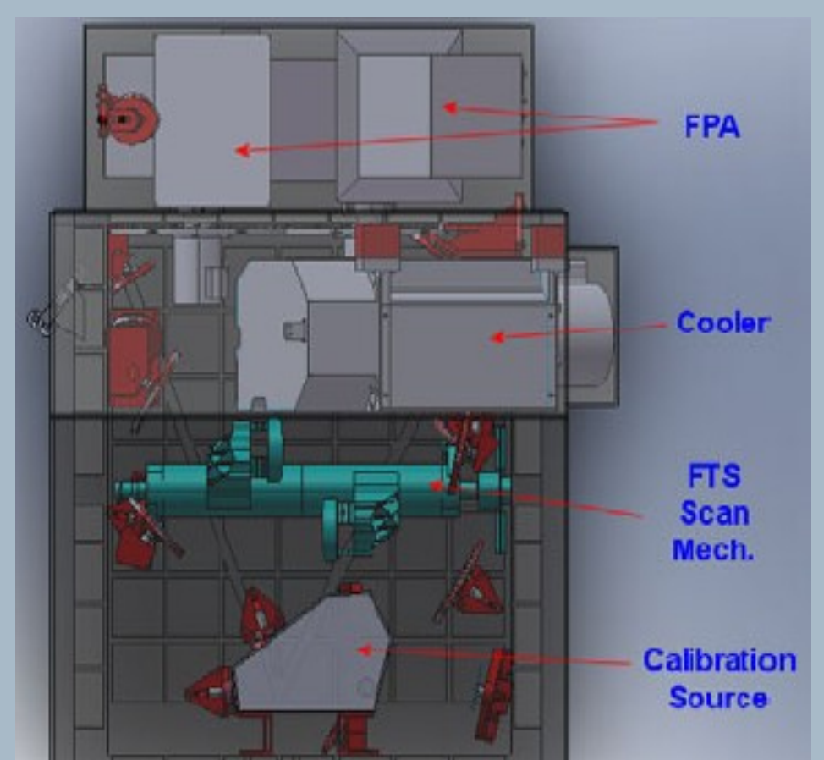
Instrument specification:

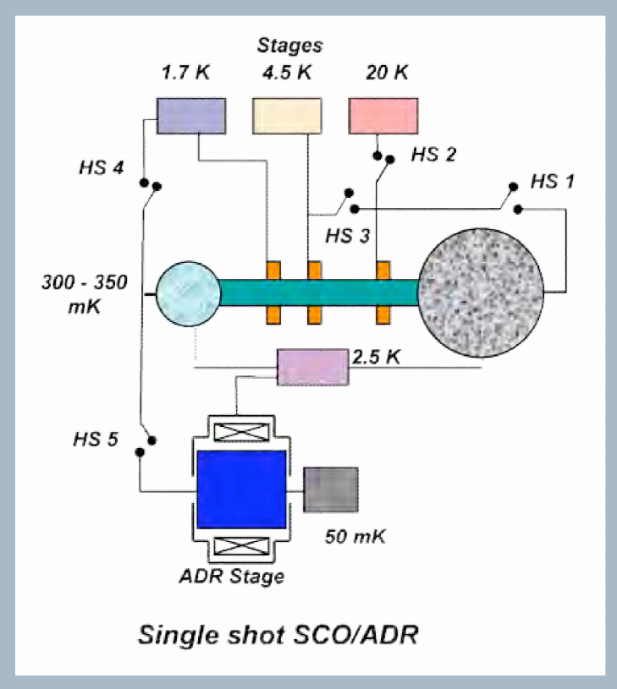
- **Imaging Fourier Transform Spectrometer (FTS)**
- **Wavelength coverage** of ~34-210µm
  (using 3-detector arrays, Fλ/2 sampling)
- Range **not covered** by **JWST** or **ALMA!**
- **Field of view** of 2' x 2'
- **Spectroscopy** R up to ~2,000 + photometry (R~3)
- **Sensitivity** required:
  - *Unresolved lines 5σ-1hr*: few x 10^{-19} W/m^2
  - *Photometry 5σ-1hr* : <50µJy
- *TES* bolometers at < 100mK
- Filter options for photometry under study



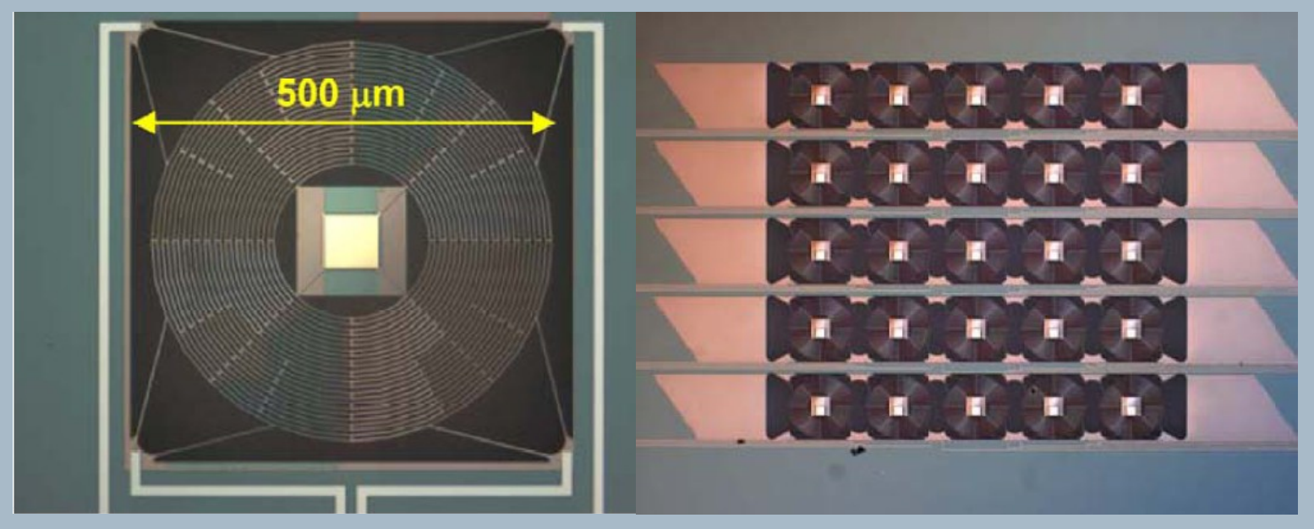
Technical challenges and s

- 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 exist





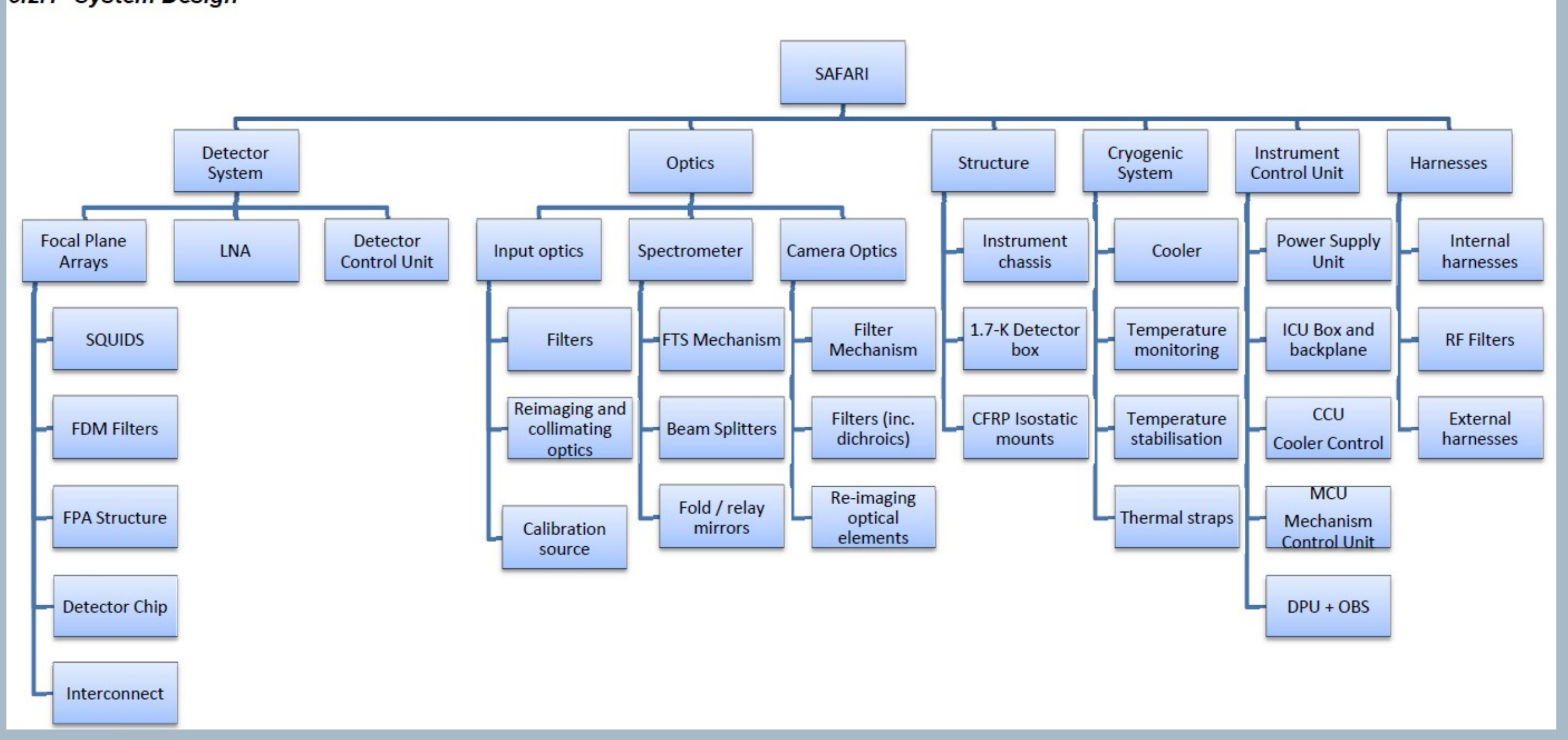
Schematic of one of the CEA-Grenoble (SBT) cooler designs under consideration for SAFARI



Prototype TES detectors under test and development at Cardiff/SRON/Cambridge

International Consortium

5.2.1 System Design

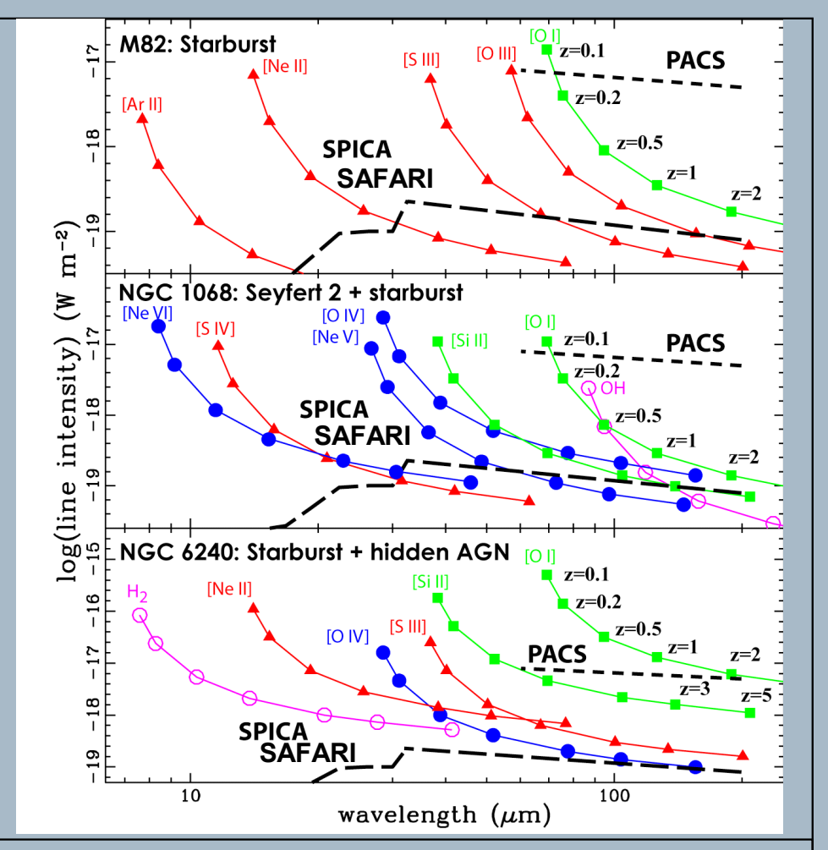


- SAFARI
  - Detector System
    - Focal Plane Arrays
      - SQUIDS
      - FDM Filters
      - FPA Structure
      - Detector Chip
      - Interconnect
    - LNA
    - Detector Control Unit
  - Optics
    - Input optics
      - Filters
      - Reimaging and collimating optics
      - Calibration source
    - Spectrometer
      - FTS Mechanism
      - Beam Splitters
      - Fold / relay mirrors
    - Camera Optics
      - Filter Mechanism
      - Filters (inc. dichroics)
      - Re-imaging optical elements
  - Structure
    - Instrument chassis
    - 1.7-K Detector box
    - CFRP Isostatic mounts
  - Cryogenic System
    - Cooler
    - Temperature monitoring
    - Temperature stabilisation
    - Thermal straps
  - Instrument Control Unit
    - Power Supply Unit
    - ICU Box and backplane
    - CCU Cooler Control
    - MCU Mechanism Control Unit
    - DPU + OBS
  - Harnesses
    - Internal harnesses
    - RF Filters
    - External harnesses

- **Science organisation under discussion**

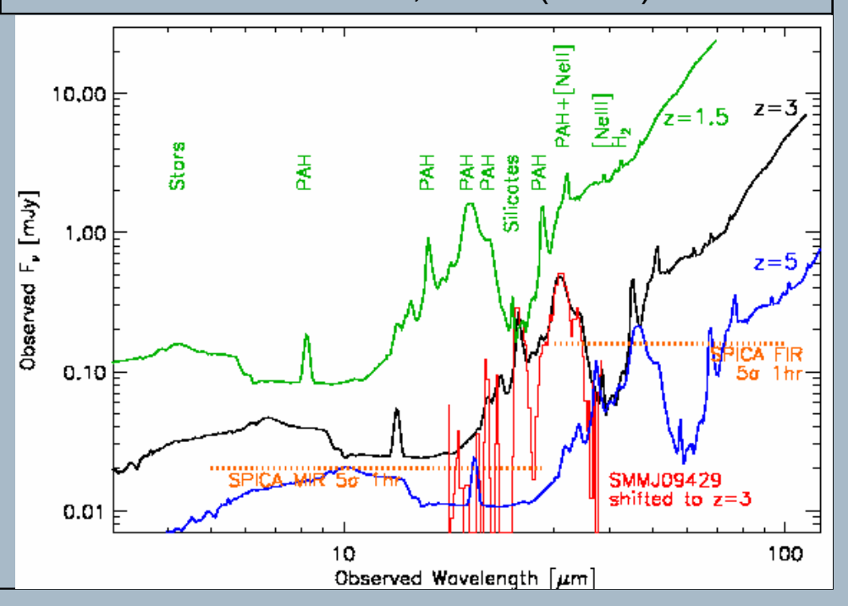
Galaxy evolution, near and far

- **The AGN-starburst connection at high-z**
  - Through deep spectroscopy, characterise the distant MIR/FIR galaxy population out to z~4 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:**
  - 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**



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

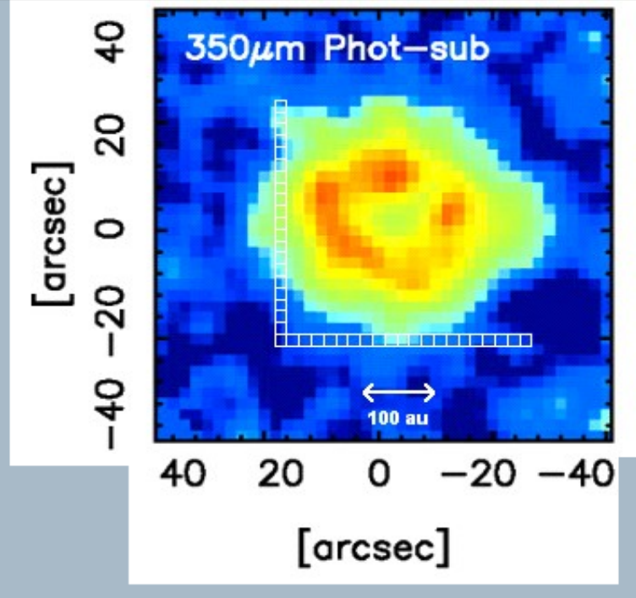
Below: Detectability of redshifted PAH features with SAFARI in low-res., mode (R~50)



From gas and dust to planets

- **Protoplanetary disks: from ices to oceans**
  - 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

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.), onto 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.

Exoplanet research in the far-IR

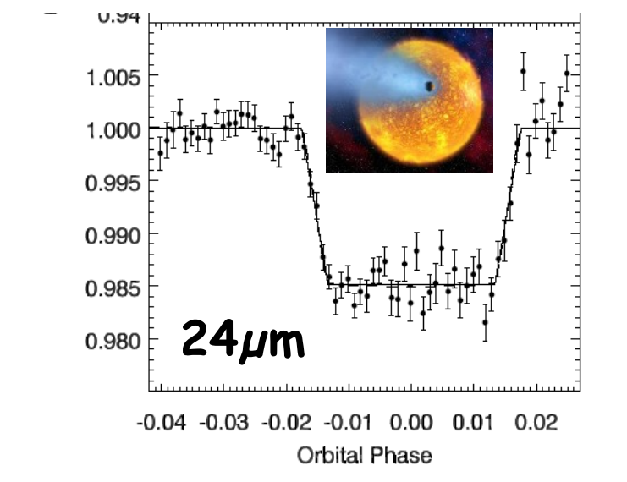
- 2 orders of magnitude higher sensitivity than Herschel/PACS to detect and characterize zodiacal backgrounds in a statistical sample of stars (~10^5 Sun-like stars at d<180 pc).
- Key to prioritising Earth-like candidates for future TPF-type missions.

mid-IR coronagraph and spectrometer.

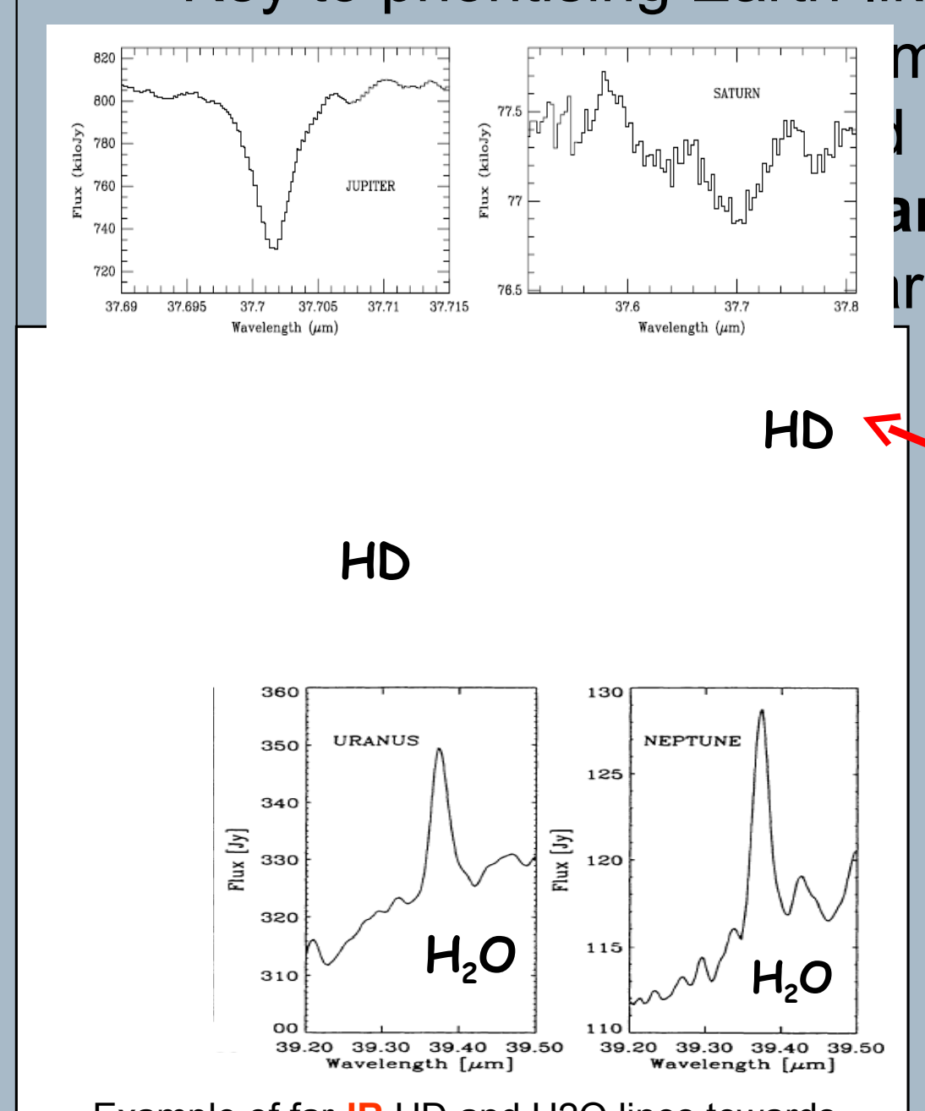
l efficient, high cadence and high S/N

ansit photometry and low-R spectroscopy in the far-IR.

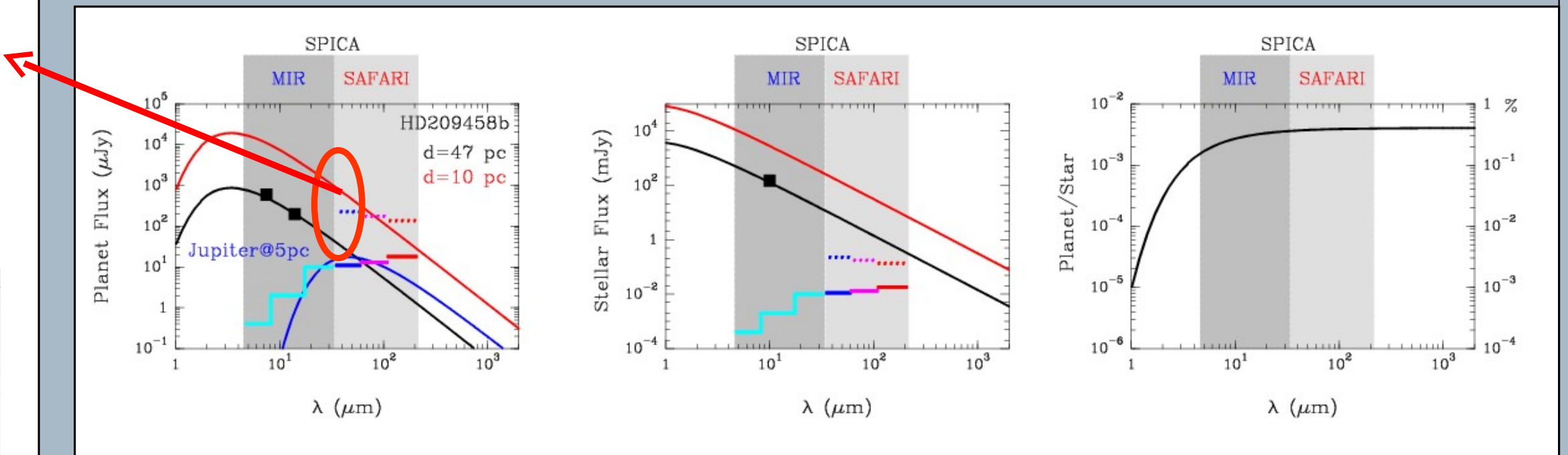
rs ? Spectral signatures (water?, HD?, ice?)



HD 209458b primary eclipse with *Spitzer* (Richardson et al). Transit studies possible in the far-IR



Example of far-IR HD and H2O lines towards Uranus & Neptune (Fouchet; Feuchtgruber et al.)



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 ∼ 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 ~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.

TNO roundup

- 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.
- SAFARI will detect photometrically almost all known KBOs (those with diameters > 100 km) in only ~ 75 hr at a rate of ~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.