ESI: A European SPICA Instrument

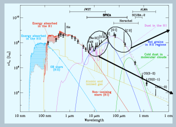
Kate Isaak, Cardiff University

On behalf of the ESI consortium:
UK: RAL, Cardiff, Imperial College, Sussex, MSSL, Open University, UCL, ATC, Oxford, UCLAN; Belgium: IMEC/RMA, KUL; **France:** CEA-Saclay, CEA-Grenoble,LERMA, IAS, OAMP, CESR, GEPI; **Germany:** MPE, MPIA, MPIK; **Netherlands:** SRON, Leiden; **Italy:** IFSI, La Sapienza; **Spain:** IAC, CSIC; **Canada:** Lethbridge, HIA/NRC, UBC, UWO,Calgary; **Japan:** ISAS, JAXA

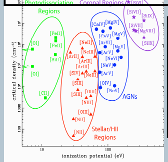
In this poster we present a brief summary of a concept study that has been undertaken by a consortium of European institutes for a European instrument for the Japanese-led MIR/FIR mission, SPICA. ESI – the European SPICA Instrument – is an imaging spectrometer that will operate over the ~30-210μm waveband. We describe the core science justification for an instrument working in this wavelength range; a possible conceptual design; its predicted performance and the technical challenges that need to be met in order to realise the potential of the instrument

The Far-Infrared Waveband

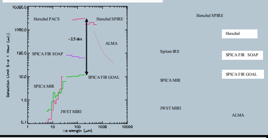
The Mid- and Far-Infrared (MIR/FIR) waveband plays host to a unique spectroscopic and photometric toolkit with which to not only advance our understanding of the formation/evolution of many structures in the local and distant Universe, but also the physical processes that drive them. The proposed SPICA mission represents the next step in MIR/FIR astronomy, building on the IRAS/ KAO/ISO heritage, more recent successes of AKARI and Spitzer, and (to-be-launched) Herschel. With its 3.5m aperture cooled to ~5K, SPICA will be at least 20 times more sensitive than Herschel in the 30-210μm waveband. Such sensitivity will open up, for the first time, the detailed study of the evolution of galaxies from the epoch of the peak of star formation to present; will allow us to determine the chemical composition of mineral constituents of dust in the ISM and planetary systems, and will provide the unique possibility of unbiased, spectral line surveys with which to probe the galaxy population responsible for the bulk of the Cosmic Infrared Background.



A synthetic spectrum of a galaxy undergoing modest rates of star formation, illustrating the wealth of both spectral and broadband features to be found in the FIR



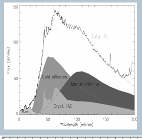
A selection of the MIR/FIR fine-structure and ionic lines that can be observed with SPICA – probing a wide range of physical/excitation conditions



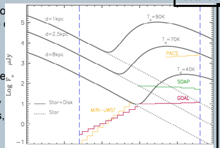
Predicted photometric (left) and spectroscopic performance (right) of SPICA in the MIR/FIR. Note the huge increase in sensitivity of SPICA in the FIR over current facilities

Planetary System Formation: From Gas/Dust to Planets, Ices to Oceans

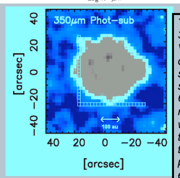
- **Dust in circumstellar disks:** FIR spectroscopy provides a unique means by which to determine the mineralogy of the dusty disks that surround many young stars. The photometric capabilities of ESI will trace the variation in grain size distribution and temperature in the dusty disks, both of which are expected to evolve with disk age, and which manifest themselves most markedly in the FIR
- **Water Ices - the "snow-line":** ESI's access to the FIR water ice features will enable mapping of the "snowline" for the first time, giving insight into the role of water ice in the formation and evolution of planetary systems
- **Evolved stars - dust factories:** Evolved stars are the principal source of dust in the ambient ISM. FIR vibrational spectroscopy provides a unique means by which to probe the inner warm, dense circumstellar shells, tracing non-polar organic molecules which are otherwise invisible, yet play a key role in the interplay between gas and dust chemistry
- **Simple → complex molecules:** The ISM plays host to many complex molecules, yet our understanding of how these form is poor. ESI will provide the first opportunity to make extensive observations of the more complex carbon chains, many of which have no dipole moment and so can only be detected in the FIR through their vibrational transitions



The ISO spectrum of the young star HD 142527, (Malfait et al.) showing the model components of the MIR/FIR emission. Water ices can only be directly detected through the 44/ 63μm emission features



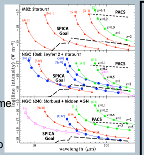
The predicted photospheric emission for an AO (Vega-like) star as a function of wavelength and distance from the Sun. The sensitivities of SPICA, JWST-MIRI and Herschel PACS are shown along with the typical disk excess



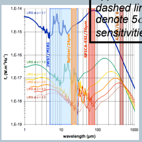
The CSO SHARCII 350μm image of Vega (Marsh et al.), onto which is superposed the pixel scale of SPICA at 44-63μm. The spatial resolution attainable with ESI is equivalent to~23 AU, sufficient to detect the presence of the expected snow-line region at 42 AU.

Galaxy Evolution: near and far

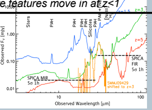
- **The AGN-starburst connection at high-z:** By the time of launch of SPICA, deep cosmological surveys will have detected many thousands of faint, distant MIR/FIR galaxies. Herschel will measure the FIR continuum in these sources, constraining dust temperatures and masses out to z~2. Through deep spectroscopy ESI will go well beyond this: establishing key physical properties/conditions of the gas, providing the means by which to characterise the local radiation fields and to start to disentangle the interplay between AGN and starburst activity
- **Deep cosmological surveys:** ESI's exquisite photometric sensitivity will enable large-area surveys to the confusion limit at 70μm to be made. Such surveys will provide the cleanest measure of the star formation rate in distant galaxies (without PAH contamination) and will complete the consensus on the growth of massive black holes by probing the missing population of dust-obscured, Compton-thick AGN responsible for the 30 keV peak in the x-ray background
- **Punching through confusion:** ESI's spectral capability provides a novel way to break the traditional confusion limit through the detection of the characteristic cooling lines produced by star formation and AGN activity
- **Cosmology at low spectral resolution:** ESI's low/medium resolution sensitivity is high enough to undertake deep, wide-field surveys of the redshifted PAH/silicate emission features in distant galaxies. These features can be used to not only estimate directly star formation rates of the dusty galaxy population, but also to measure redshifts and so to start to constrain the bolometric luminosity of luminous infrared galaxies
- **Local galaxies-proxies for the distant Universe**



Plots of intensity as a function of redshift of key MIR/FIR emission lines visible with SPICA in three archetypical objects: M82, NGC 1068 and NGC 6240.The upper/lower dashed lines denote 5σ-1hr sensitivities



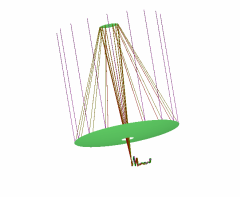
A plot of the spectral coverage of a selection of photometric surveys overlaid onto a redshifted SED of the LIRG model of Lagache et al. The 70μm waveband remains free of contamination from redshifted PAH/silicate features out to z~3, in contrast to the JWST/MIRI band, where features move in at z<1



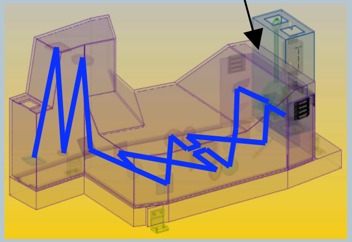
ESI will have the sensitivity in low-resolution mode (R~50) to detect PAH/silicate features in dusty galaxies out to z~3 in 1hr

Current Instrument Concept

- Imaging Fourier Transform Spectrometer
- Wavelength coverage of ~30-210μm (set by beam splitter performance), achieved using 3-4 detector arrays
- Spatial sampling of Fλ/2 at centre of array bands
- Field of view of 2' x 2', set by no: pixels/detector array sizes
- Spectral resolution R~100 –10 000 (photometric mode R<10)
- Photometric sensitivity of <50μJy (5σ-1hr); line sensitivity of <few x 10^{-19} W/m^2 (5σ-1hr) at R~2000
- Detector options include photoconductors (cf. Herschel-PACS/ Spitzer) operating at 1.7-4.5K, Transition Edge Superconducting bolometers (TES) operating at <100 mK, Silicon bolometers and Kinetic Inductance Detectors (KIDs)



Optical layout of FTS concept, to scale with the 3.5m SPICA telescope



Solid model of the imaging FTS, tracing optical beam

Technical/Technological Challenges

European institutes and industry are world-leaders in many of the technology areas relevant to ESI and SPICA. There are, however, several technical challenges that need to be met to realise the full potential of ESI:

- Detector Technology:
  - TES detectors offer the best prospects for high-sensitivity arrays .Several European groups are working on TES technology, along with the multiplexing/support electronics, for x-ray/ submillimetre-wave applications. Frequency coverage is excellent, dynamic range may be an issue
  - Photoconductor technology to cover much of the ESI waveband has already been developed for existing space missions, with additional scaling/development of reliable cold electronics only required. Detector time constants may be an issue for an FTS-type instrument. Detector development over the 35-50μm waveband is needed, and is planned by the Japanese
- Cooler Technology:
  - Cooling to <100mK is required if TES detectors are to be used. An ultra-compact, light-weight hybrid ^{3}He sorption cooler/adiabatic demagnetisation refrigerator concept which provides continuous cooling below 100mK is under development at CEA-SBT: regulated temperatures of 50mK are currently being achieved
- Cryogenic materials for the telescope/optical structures:
  - Silicon Carbide has many excellent material properties that make it particularly suitable for cryogenic application. European industry leads the world in this area