Star Formation Studies in the SPICA/SAFARI Era

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Abstract

The Japanese JAXA SPICA space observatory, due for launch in 2022, will provide astronomers with a long awaited new window on the universe. Having a large cold telescope, cooled to only 6K above absolute zero, SPICA will provide a unique environment in which instruments are limited only by the cosmic background itself. A consortium of European and Canadian institutes has been established to design and implement the *SpicA FAR infrared Instrument* SAFARI, an imaging FTS spectrometer designed to fully exploit this extremely low far infrared background environment provided by the SPICA observatory. With SAFARI it will be possible to obtain continuous spectra spanning 34 – 210 µm within an instantaneous 2’x2’ field-of-view, at spectral resolutions of up to R = 2000 @ 100um (4000 @ 50um), within a single telescope pointing. This capability, coupled with the exquisite sensitivity provided by the cold SPICA telescope, makes SAFARI the ideal instrument to perform large area spectroscopic mapping surveys in the far-infrared.

SPICA/SFARI will provide new insights into a range of astronomical sources. By obtaining spectra for large, statistically significant samples, we can obtain a fundamental understanding of their chemistry and physical processes, and thereby characterise and understand the nature of these sources. Moreover, with the high sensitivity of SAFARI, it will be possible to extend current far-infrared studies of star formation processes to nearby galaxies, thereby putting our current understanding in a wider, universal, context. This poster provides a description of the SAFARI instrument and its capabilities. A brief representative sample of the contribution SAFARI can make in the field of star formation studies is also given, and compared to similar observations made using the *Herschel*-PACS instrument.

The SAFARI Instrument

The SAFARI instrument (Figure 1) is the long wavelength camera and spectrometer on-board the SPICA space observatory. It is a Fourier transform spectrometer and operates simultaneously in three spatially synchronous wavelength bands.

In spectroscopic mode SAFARI provides continuous spectra from 34-210µm over the full field-of-view. The instrument can also perform broadband photometric mapping, providing maps at 48, 85 and 160 µm.

- SPICA primary mirror diameter – 3.2 m
- Three band Fourier transform spectrometer
- Continuous spectroscopic coverage 34-210 µm
- Simultaneous broadband photometry in 3 bands
- Background limited performance
- Synchronous field of view of 2’x2’

Figure 1: Computer model of the SAFARI instrument

Parameter		Waveband			
		Short Wavelength	Medium Wavelength	Long Wavelength	
Band centre		47 µm	85 µm	160 µm	General
Wavelength range		34-60 µm	60-110 µm	110-210 µm	
Band centre beam FWHM		4”	7”	13”	
Number of detectors		43 x 43	34 x 34	18 x 18	
Confusion limit		0.015 mJy	0.5 mJy	5 mJy	Photometry
Minimum Zodiacal background		8.0 MJysr^{-1}	3.8 MJysr^{-1}	2.1 MJysr^{-1}	
Limiting source flux density (5σ-1hour)		14 µJy	21 µJy	32 µJy	
Time to reach confusion limit at 1σ		123 s	0.3 s	0.006 s	
Limiting line flux (5σ-1hour)		3.7x10^{-19} Wm^{-2}	3.4x10^{-19} Wm^{-2}	2.9x10^{-19} Wm^{-2}	Spectroscopy
Limiting line flux density 5σ-1hour*	High Res. (R~2000)	11 mJy	19 mJy	31 mJy	
	Medium Res. (R~500)	2.9 mJy	4.9 mJy	7.8 mJy	
	Low Res (R~50)	0.3 mJy	0.5 mJy	0.8 mJy	

Table 1: Summary of key SAFARI parameters and expected system performance

Star formation with SAFARI

The rich spectral information in young stellar objects (e.g. Figure 2) means that studies with SAFARI are expected to focus on large area spectroscopic mapping surveys of a range of star forming regions, both in our own galaxy, and in those nearby. The key questions to be answered by these surveys are:

- What fraction of typical giant molecular clouds is converted into stars during their lifetime and how does this depend on local conditions?
- What internal sources of energy (and cooling) drive the dynamics of molecular clouds after their formation?

Herschel observations show that nearby cold interstellar clouds are systematically structured in networks of filaments with a characteristic width of 0.1 pc (Arzoumanian et al. 2011), where this width is interpreted as the characteristic scale for turbulence dissipation. In most cases, these filaments are shown to be the only site of star formation in the clouds, with pre-stellar cores being detected as soon as the column density in the filament reaches a critical threshold that can be computed from linear gravitational instability along the filament (Schneider et al. 2012). For each region, the resulting IMF can be affected by the detailed physical processes at work (gas cooling, presence of UV radiation, shocks, etc.). Large- scale spectroscopic maps are clearly needed to characterize those processes.

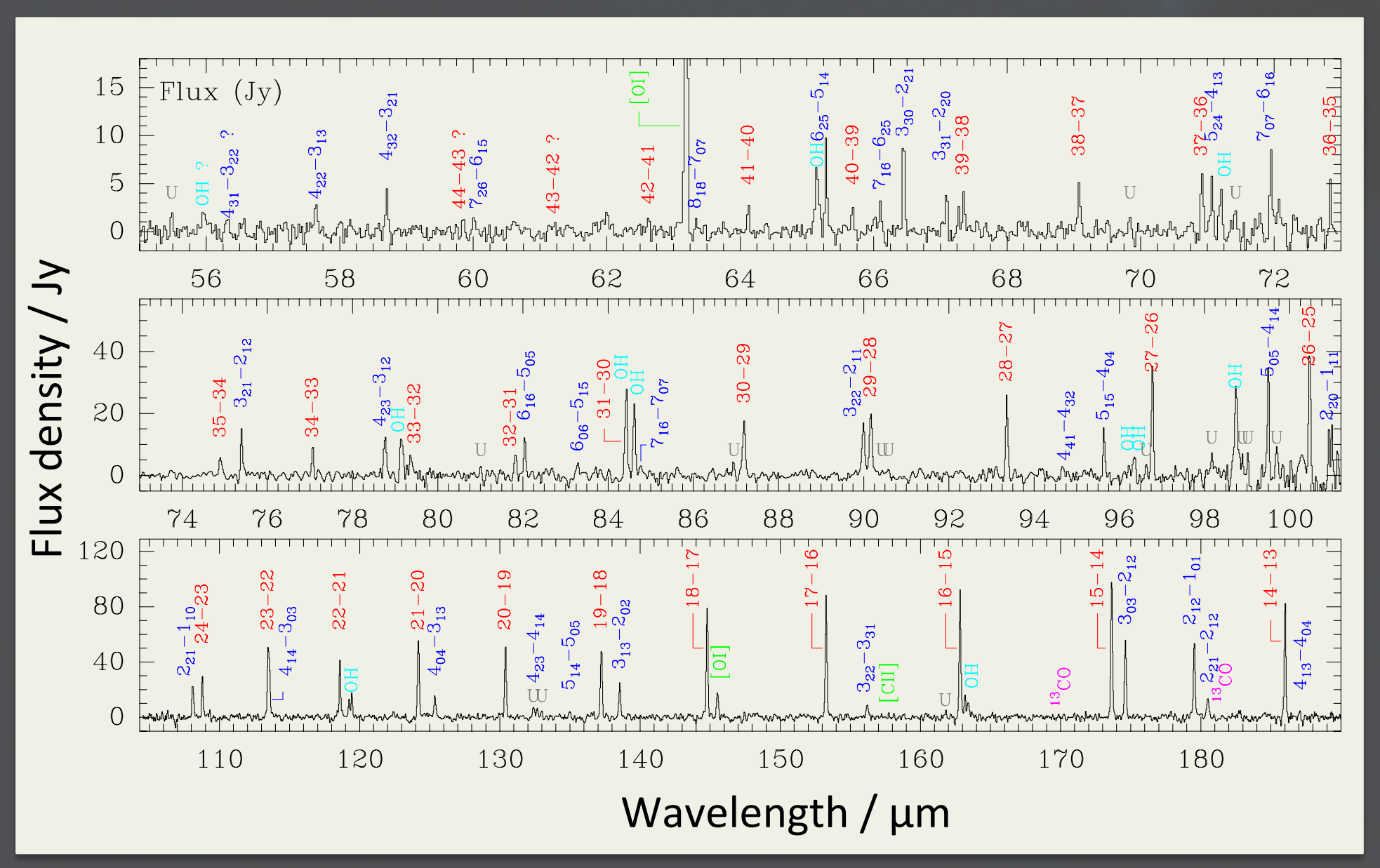

Figure 2: Far-IR continuum-subtracted spectra of the Serpens SMM1 Class 0 protostar with H2O (blue), CO (red), OH (cyan), 13 CO (magenta), [OI], [CII] and [CII] (green) lines labeled. The flux density scale is in Jy/PACS- spaxel (from Goicoechea et al. 2012). The line sensitivity is ~5E-18 W/m2 after ~3hours. This is one of the brightest low-mass (Sun-like) Class 0 protostars observed with Herschel. SAFARI will obtain complete (34-210um) spectra at similar resolution but improved sensitivity in only ~4 minutes.

Mapping GMCs across the broad instantaneous wavelength range of SAFARI at **multi-line mapping-speeds** orders of magnitude beyond the capabilities of the *Herschel*/PACS spectrometer, it is possible to completely sample multiple molecular cloud regions for: (a) pre-stellar cores below the hydrogen burning limit; (b) short-lived (and thus rare) first hydrostatic protostellar cores – the “holy grail” of star formation; and (c) deeply embedded protostars down to 0.01 $M_{\odot}$ throughout the Class 0-I-II stages from 0.1-1 Myrs. Dark clouds without clear signs of star formation and portions of triggered SFRs in the Milky Way (e.g., Elmegreen & Lada 1977) and in nearby galaxies such as the LMC (for which spectral mapping with *Herschel* require unrealistic amounts of time) will also be targeted. Not only will this provide a rich study of a potentially important mode of SF in interacting galaxies and the early Universe (*e.g.*, low metallicity regions), but it will also provide a range of diversity in “star forming environments”. SAFARI observations will thus help filling up the gap between SF galactic and extragalactic studies.

Large-scale mapping of SFRs with SAFARI will reveal their morphology while recording a complete census of prestellar and protostellar objects of different masses (impact of clustered SF). FIR spectroscopy and photometry will help us to classify hundreds of objects by their dust temperature and FIR emission lines ([CII], [OI], H2O, CO, OH, HD ...). We will also study the evolution of the observed structures with the gas energetics (heating and cooling) and with the evolving properties of dust.

Parameter	Serpens SMM1 @ 200pc Herschel/PACS	Protostars @ 2 kpc SPICA/ SAFARI
Spectrometer	Herschel/PACS grating	SAFARI FTS
Continuum @ 100 µm	250 Jy	2.5 Jy
[OI] @ 63 µm	8x10^{-15} Wm^{-2}	8x10^{-17} Wm^{-2}
CO J=30-29 @ 87.2 µm	7x10^{-16} Wm^{-2}	7x10^{-18} Wm^{-2}
Time for full FIR spectrum	~3 hours (rms ~ 5x10^{-18} Wm^{-2}) Field of view=47”x47”	~4 minutes (rms ~ 2x10^{-18} Wm^{-2}) Field of view = 120”x120”
Time to map 10’x10’ (R=2000 @ 100 µm fully sampled)	~100 hours ([OI] 63 µm line) rms ~ 1x10^{-17} Wm^{-2}	~3 hours (full 34-210 µm) rms ~ 2x10^{-18} Wm^{-2}

Table 2: SAFARI performance comparison with PACS for representative SF observations

Summary

The power of far-IR photometry and imaging-spectroscopy provided by SAFARI, with its unprecedented sensitivity, broadband coverage and large field-of-view, has the capability to address crucial questions that will drastically improve our understanding of the interstellar medium (from diffuse to dense), star formation, the environment of star forming cores and its link to galaxy evolution.

The SAFARI science team welcome all comments and feedback regarding desired SAFARI capabilities, and the associated science programme. If you would like to discuss SAFARI please contact Bruce Sibthorpe at b.sibthorpe@sron.nl or find me at this conference.

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