SAFARI fact sheet

1 Introduction

The purpose of this note is to explain and provide guidance on how-to-use the SAFARI fact sheet version 1.0. The term “fact sheet” is itself misleading, there are no “facts”’ in the sheet just current best guesses. The sensitivities noted in the sheet are based on a very simplistic model of SAFARI with no spectral or spatial variation across a sub-band. The fact-sheet can be used to estimate the time to execute observation programs but with uncertainty. It should not be used to “optimize” a science program.

Bear in mind that any estimate will be without calibrations and other overheads.

2 SAFARI bands and band – properties

SAFARI will use 4 spectral bands covering the spectral range from 34 to 230 μm. Three significant band parameters are listed in the table 1. The FWHM parameter identifies the SAFARI beam at the band center.

Table 1: Parameters of SAFARI wavebands

Parameter	Waveband			
	SW	MW	LW	LLW
Band centre / μm	45	72	115	185
Wavelength range / μm	34-56	54-89	87-143	140-230
Band centre beam FWHM	4.5″	7.2″	12″	19″

3 Instrument and Noise Model

The current SAFARI sensitivity model is built up from best guesses for what the actual telescope and instrument will be.

- SAFARI sensitivity model ingredients
  - Telescope: M1 2.5 m, M2 60 cm → A_{eff} 4.6 m^2
  - Component efficiencies, aperture, horn, etc. : total η = 0.22
  - All optics elements – at 4K, 1.7K, 0.3K and 0.05K
    - Transmission *T* of grating, mirrors, and filters: → T_{optics} ~ 0.24
    - Emission ε = 1 – *T*
  - Power from Zodiacal light – JWST/MIRI model
    - Two blackbody model: 5500K/ε=3.5×10^{-14} and 270K /ε=3.6×10^{-8}
    - f(pole)~0.9, f(ecliptic)~8 → model uses f=2.5
  - Power from zodiacal light, source and optics/telescope/baffle transmitted to detector → photon NEP_{phot}
  - Power from astronomical source (see Figure 1)

- Astronomical source is assumed spatially unresolved.
- Detector noise as per requirement $NEP_{det} = 2\times10^{-19}$ W/√Hz

$$\Delta F = \frac{\sigma_{lim} \bullet \sqrt{(NEP_{det}^2 + NEP_{phot}^2)}}{A_{eff} \bullet \eta \bullet T_{optics} \bullet \sqrt{(2 \bullet t_{obs})}} \ W/m^2$$

5 σ detection → $\sigma_{lim} = 5$: Signal /Noise ratio of 5
σ → noise in W/m^2
1 hr observations → $t_{obs} = 3600$ sec

4 Time Estimation for point source spectroscopy

The sensitivity table results from the instrument noise model in the section above which provides the estimated noise per detector. In the noise model, the sensitivity within a sub-band is only slightly wavelength dependent and therefore considered constant throughout a sub-band.

For the sensitivities listed in Table 2, a detection sequence is assumed where an off position has been subtracted which increases the limiting flux per detector by about 20%.

Table 2: Limiting flux and flux density for point sources

Point source spectroscopy (5σ-1hr)					
LR	**Limiting flux** / $\times10^{-20}$ Wm^{-2}	7.2	6.6	6.6	8.2
	Limiting flux density / mJy	0.31	0.45	0.72	1.44
HR	**Limiting flux** / $\times10^{-20}$ Wm^{-2}	13	13	13	15
	Limiting flux density / mJy	18	17	17	19

Time estimation for SAFARI is simple:

- 1 hour integration can observe: ~ 6-8 x 10^{-20} W/m^2 at 5σ
- Signal (5 x noise level) after time T hours: ~ 7 x 10^{-20} / √T W/m^2
- For FTS operation use ~ 1.4 x 10^{-19} W/m^2 (single pol. → factor 2 loss) with 3 scans as minimum time → 9 minutes
- For mapping – use same algorithm per pixel i.e., raster mapping.
- Not yet addressed – scan maps, optimized strategy for FTS maps

The “LR” mode in the factsheet refers to the sky signal passing thing through the grating. Whereas the “HR” refers to observing the sky with the Martin-Puplet interferometer inserted before the grating.

4.1 Grating observation of point source

The calculations assume a spatial unresolved point source with spectrally unresolved lines. The fact sheet numbers give the 5 sigma flux that a detector can measure in one hour. That is to say, the signal-to-noise of the resulting measurement is 5. The noise is assumed to be white.

The grating should produce a spectral resolution of about 300 at the band center ($\nu_c/\delta\nu_c$). In the current configuration, this spectrum will be sampled twice within each resolution element.

The flux density in Table 2 for the LR mode depends on the wavelength since the resolution is assumed constant over the waveband (as opposed to the HR mode, see below)

4.2 FTS observation of point source

The high frequency mode of SAFARI is achieved with a Martin-Puplet Interferometer. The FTS can only make use of one polarization. This means that the limiting source flux is ~ 2 higher than the low-resolution mode.

The spectral resolution in high resolution mode is determined entirely by the maximum optical path displacement (OPD) of the interferometer. For SAFARI, the result is a constant frequency resolution of 0.749 GHz. This is reflected in Table 2 as a relatively constant flux density limit across all wavebands. The resolution as a function of wavelength is shown in Figure 1.

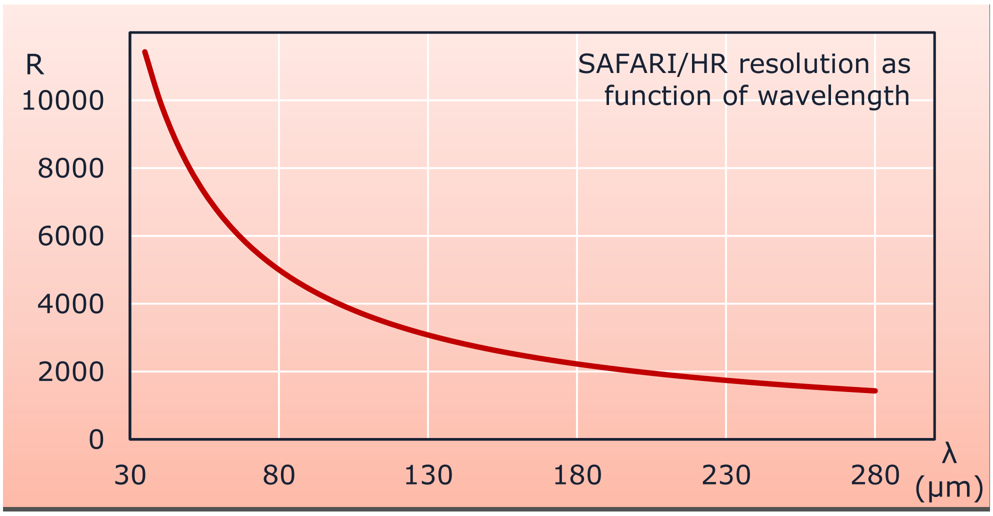

Figure 1: Spectral resolution of the FTS.

5 Band centers

All sensitivities and band parameters are appropriate for the band centers. There will be some changes near the edges of the bands i.e. sensitivity, resolution of grating and beam FWHM. For the purpose of rough ideas about length of projects, the band center values are the most appropriate.

6 Source brightness and saturation

SAFARI grating is detector noise limited but close to background limited. There are lines-of-sight where the background photons are contributing the greatest fraction of the noise. That will be true in the Ecliptic and Galactic Plane. The noise values below assume a mid-latitude ecliptic elevation (~30% of maximum zodiacal contamination) and away from the Galactic Plane. The zodiacal model is that used by MIRI for JWST.

The observed source will add to the photon noise to achieved noise level. Figure 2 shows the fractional added noise level given the strength of the astronomical source up to the saturation limit where each curve stops. Data given up to the instrument flux density saturation limits for each band (31, 51, 87 and 131 Jy for the SW, MW, LW and VLW bands respectively, shown in the figure as colored circles). This correction must be taken into account when observing a week line on top of a bright continuum.

For example, the expected noise in the SW band observing a source of 200 mJy is about 2 times the most sensitive case i.e., observing to the same signal-to-noise level will take 4 times as long. A 5σ detection of 0.31 mJy on a continuum-free source takes 1 hr. With a 200 mJy continuum, detecting 0.31 mJy above the continuum (total 200.31 mJy) takes 4 hrs.

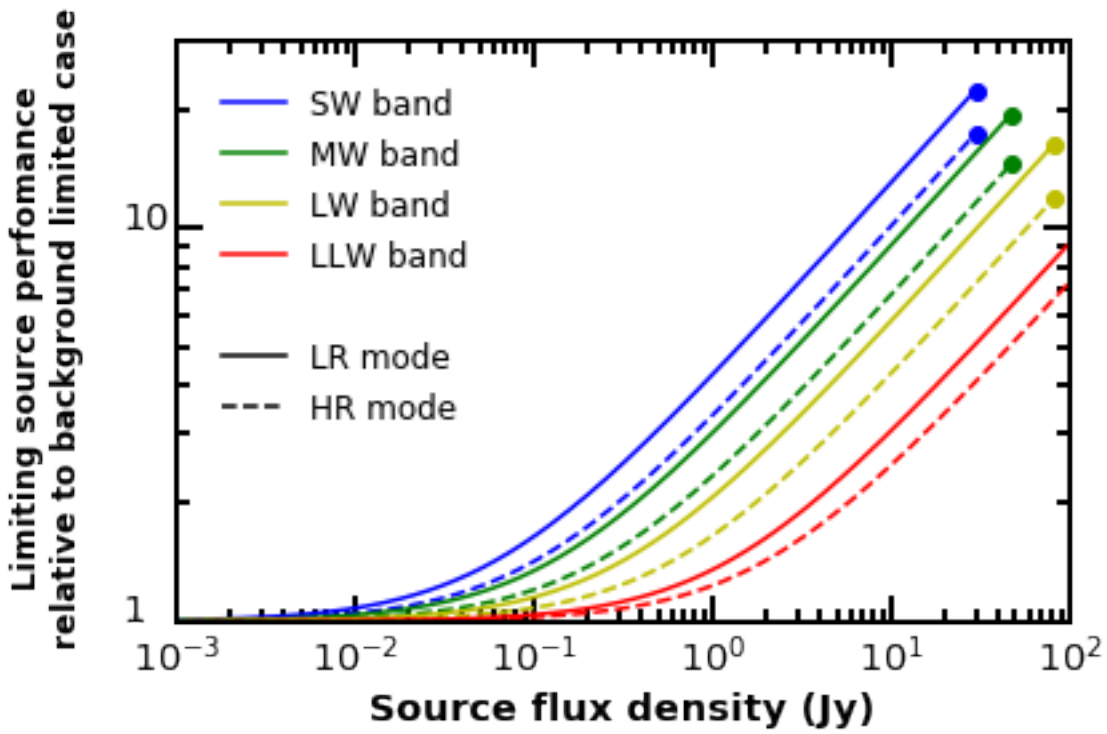

Figure 2: Sensitivity degradation factor based on source flux density. Solid lines and dashed lines are for the low resolution grating and high resolution FTS respectively. Colors indicate which wavelength band the curve applies. The solid circles indicate saturation limits.

7 Mapping modes:

The fact sheet also estimates the time to map using SAFARI either in low resolution mode (LR) or high resolution (HR) (Table 3). In this calculation, only raster mapping is considered. For each SAFARI band (SW, MW, LW and VLW) the table lists the limiting flux (at 5σ) per map position that would be achieve for a Nyquist sampled map of 1 $arcmin^2$. Note that the Nyquist sampled map is achieved for the central wavelength of each band.

Unlike the point source calculation, the map noise estimate does not account for subtracting a "zero" level.

As with the point source mode, the observed noise towards a position will increase with the brightness of the background source (see Figure 2).

Table 3: Limiting flux and flux density for mapping

Mapping spectroscopy* (5σ-1hr)					
LR	**Limiting flux** / $\times10^{-20}$ Wm^{-2}	84	49	30	23
	Limiting flux density / mJy	3.6	3.3	3.3	4.1
HR	**Limiting flux** / $\times10^{-20}$ Wm^{-2}	189	113	73	51
	Limiting flux density / mJy	253	151	97	67

8 Photometric Mapping

The fact sheet also list limits for a photometric mapping mode where all detectors within a waveband are averaged. As can be seen in table 4, such a mode will quickly run into the source confusion limit in the longest waveband.

All mapping mode limits are 1 hour integration of a 1 $armin^2$ area.

Table 4: Sensitivity and confusion limits

Photometric mapping* (5σ-1hr)				
Limiting flux density / μJy	209	192	194	239
Confusion limit (5σ)	15 μJy	200 μJy	2 mJy	10 mJy