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Upgrading FIFI-LS for SOFIA with KIDs:

Enabling large sample (extragalactic) surveys

INTRODUCTION

We present the initial design, performance improvements and science opportunities for an upgrade to the Field-Imaging Far-Infrared Line Spectrometer: FIFI-LS on the Stratospheric Observatory for Infrared Astronomy SOFIA.

FIFI-LS provides simultaneous observations of two spectral lines in the far-infrared, having two spectrally independent channels working between 51-125 µm and 115-203 µm respectively.

The potential Field-of-View (FOV) and sensitivity of FIFI-LS are limited by its 90s-era photoconductor arrays. These limits can be overcome by upgrading FIFI-LS to **FIFI+LS** using Kinetic Inductance Detector (KID) arrays.

Field Imaging Concept

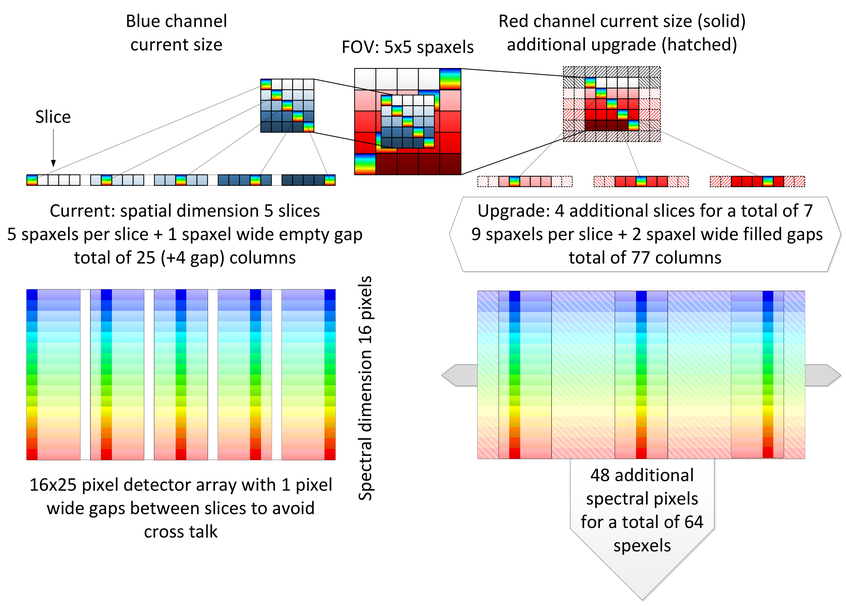

Figure 1: Schematic of field imaging principle of FIFI-LS. Left: Current setup - showing blue channel 5x5 spaxel FOV reorganized to 1x25 spaxel slit spectrally dispersed on 16x25 pixel detector array. Right: Upgrade setup - partially showing red channel 7x9 spaxel FOV reorganized on 1x63 (+14 gaps) spaxel slit spectrally dispersed on 64x77 pixel detector array with filled gap columns.

Each channel of FIFI-LS uses an integral field unit based on three sets of mirrors to reorganize the 2-Dimensional FOV along a 1-Dimensional long slit that is fed into the reflective grating spectrometer of the respective channel. The spectrally dispersed light is then imaged onto the detectors (Figure 1).

The new detectors of FIFI+LS will allow increasing the FOV from 5x5 spatial pixels to 7x9 and the spectral width from 16 to 64 pixels.

Performance Improvements

Table 1: Upgraded FIFI+LS instrument parameters compared to FIFI-LS

	FIFI+LS Blue Chan.	FIFI+LS Red Chan.	FIFI-LS Blue Chan.	FIFI-LS Red Chan.
Wavelength Range [µm]	**51-125**	**115-206**	51-125	115-203
Spect. Res. [km/s]	**130-435**	**160-425**	155-550	160-425
Instant Spect. Range [km/s]	**2500-9000**	**3200-10000**	800-3000	800-2550
Field-Of-View	**45" x 35"**	**90" x 70"**	30" x 30"	60" x 60"
Spatial Pixels	**9 x 7**	**9 x 7**	5 x 5	5 x 5
Spatial Pixel Pitch	**5"**	**10"**	6"	12"
Spect. Pixels per Spaxel	**64**	**64**	16	16
Image Slices	**7**	**7**	5	5
Detector Width [Pixel]*	**(9+2)x7=77**	**(9+2)x7=77**	5x5=25	5x5=25
Detector Size [Pixel²]	**77x64=4928**	**77x64=4928**	25x16=400	25x16=400

* 2 additional pixels per slice to allow for gaps and avoid crosstalk between slices

New KID-arrays for FIFI+LS would improve the point source sensitivity of the instrument by a factor >√2 due to their negligible generation-recombination noise in comparison to photo-conductors. Additional gains are likely by exceeding the quantum efficiency of 30% of the current detectors.

The larger attainable pixel counts of KIDs allow increasing the FOV by a factor of 1.75 and the instantaneous spectral coverage by a factor of 4. Combined, these improvements allow **faster observing by a factor of at least 2 and up to 12**. Table 1 compares the parameters of FIFI-LS with the current baseline for the upgrade

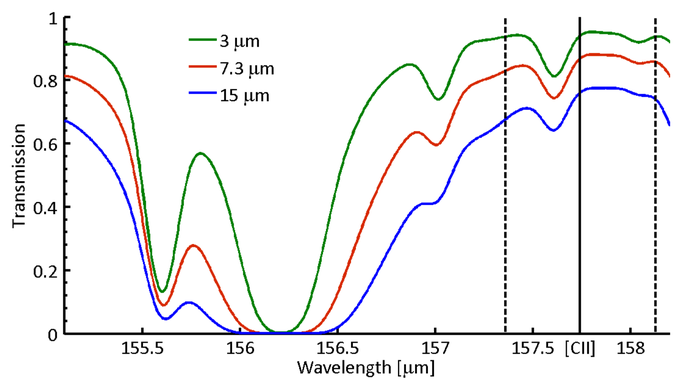

Figure 2: Atmospheric transmission for three different values of precipitable zenith water vapor close to the [CII] fine structure line; current spectral coverage within dashed lines; upgrade covers full spectral width shown; telluric water features at 155.6 and 156.2 are used for atmospheric calibration

The increased instantaneous spectral coverage will not only allow coverage of more baseline for even wide astronomical lines from galaxies, but also measurement of water vapor in the atmosphere for simultaneous accurate atmospheric calibration of the data (Figure 2).

Upgrade Changes

The instrument upgrade is designed to minimize the effort for changes to the overall instrument and instrument concept. The main changes are in three areas:

1. Detector System and Readout

   The current 400 pixel photo-conductor arrays would be upgraded to ~5000 pixel KID-arrays.

2. Instrument Optics

   The common entrance optics may remain unchanged. The reflective gratings of FIFI-LS may be reused. The integral field unit is expanded from 5 to 7 slices.

3. Cooling system

   The current FIFI-LS detectors work at temperatures of 1.8K. New KID-arrays will need operating temperatures <250mK. The cooling system would be upgraded using either multi-stage adiabatic demagnetization fridges (ADR) or a combination of ADR and Helium sorption fridges (Figure 3).

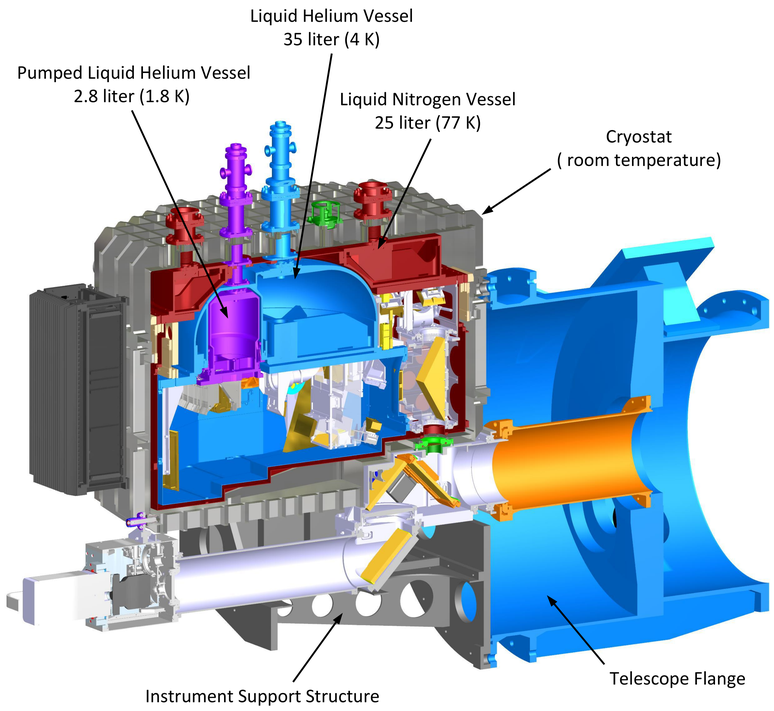

Figure 3: Schematic of FIFI-LS incl. cooling system. For the upgrade the space of the pumped liquid helium vessel may be used for the new detector cooling. A more invasive solution would also replace the 35-liter liquid helium vessel with a pulse-tube-refrigerator.