PROCEEDINGS OF SCIENCE

SOFIA: Peering into the Dusty Universe

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The Stratospheric Observatory for Infrared Astronomy (SOFIA) is a 2.7-m telescope mounted on board a Boeing 747-SP aircraft. Optimized for observations from infrared through sub-mm wavelengths, SOFIA observes from an altitude of 37,000 – 45,000 feet, above 99% of the atmospheric water vapor. The Observatory's complement of instruments exhibits a broad range of capabilities that are well suited for the observation of dusty astronomical sources. During its first year of preliminary operations, SOFIA made a number of exciting observations, including the discovery of a new high-mass protostar in the Orion Nebula (IRc4), the first detection of OD outside our Solar System, the detection of interstellar mercapto radicals (SH), and some of the highest resolution mid-IR observations of the transient Galactic circumnuclear ring to date. Here we present a selection of the available instruments available on board SOFIA and discuss their potential for future studies of dust in the Universe.

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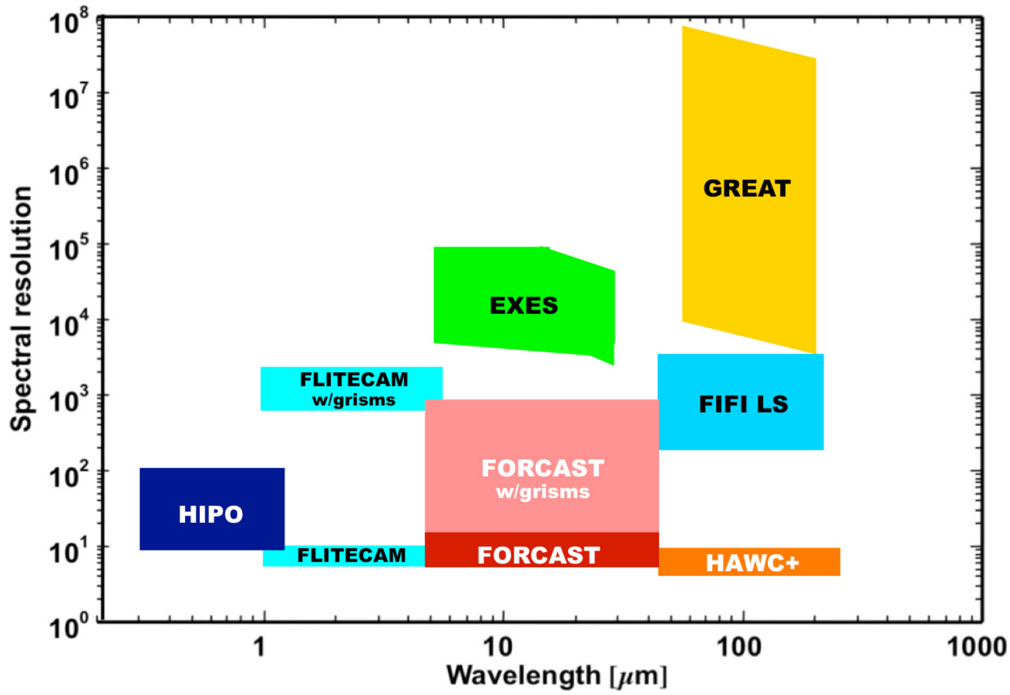

Figure 1: This plot presents the spectral resolution (R=$\lambda/\Delta\lambda$) as a function of wavelength for the current suite of instruments available on board SOFIA.

1. SOFIA Overview

The Stratospheric Observatory for Infrared Astronomy (SOFIA) is a 2.7 meter telescope carried aboard a Boeing 747-SP aircraft with imaging and spectroscopic capabilities across the 0.3 – 1600 μm wavelength range. The telescope is inertially stabilized with a pointing accuracy at Full Operational Capability of $0\farcs5$. Imaging is nearly diffraction limited at all wavelengths longer than $\sim$15 μm. Since SOFIA observes at altitudes between 37,000 and 45,000 feet, above 99% of the water vapor in the Earth's atmosphere, it is able to obtain IR and sub-mm observations unavailable to ground-based observatories. Descriptions of the instruments available on SOFIA are given below and summarized in Figure 1 and Table 1.

Many of SOFIA's capabilities are especially well suited for studies of dusty environments in our Solar System, the Galaxy, and beyond. During its first year of preliminary operations, SOFIA made a number of exciting observations, including the discovery of a new high-mass protostar in the Orion Nebula (IRc4) [1], the first detection of OD outside our Solar System [2], the detection of interstellar mercapto radicals (SH) [3], and some of the highest resolution mid-IR observations of the transient Galactic circumnuclear ring to date [4]. Here we present a selection of the instruments available on board SOFIA that will prove to be very useful for future dust studies.

2. Instruments

2.1 FORCAST

The FORCAST two channel, mid-infrared camera for SOFIA is composed of a short wavelength camera (SWC) that operates from 5 – 25 μm and a long wavelength camera (LWC) that operates from 25 – 40 μm. The cameras can be used individually or together using a dichroic for simultaneous imaging of the same field of view. FORCAST utilizes 256×256 Si:As and Si:Sb blocked-impurity-band arrays to provide high-sensitivity imaging that is nearly diffraction limited at $\lambda > 15$ μm. The instrument also offers low resolution (R $\simeq$ 200 – 1200) grism spectroscopy over the majority of the 5 – 40 μm range.

2.2 FLITECAM

The FLITECAM near-IR camera operates in the 1.0 – 5.5 μm waveband. It consists of a 1024×1024 InSb detector with $0\farcs00475$ square pixels and uses refractive optics to provide an $8\farcm0$ diameter field of view. The instrument has a set of both narrow and broadband filters for imaging, as well as grisms for low to moderate resolution spectroscopy (R $\simeq$ 800 – 1800). Additionally, FLITECAM was designed to be co-mounted on the telescope with the High-speed Imaging Photometer for Occultations (HIPO; see below), providing simultaneous optical through NIR imaging capabilities.

2.3 EXES

To take advantage of SOFIA's unique potential for high-resolution spectroscopy in the mid-infrared, the Echelon-Cross-Echelle Spectrograph (EXES) will operate in three spectroscopic modes (R $\simeq$ 10^5, 10^4, and 1500) from 4.5 – 28.3 μm. EXES uses a 1024^2 Si:As IBC detector. High dispersion is provided by an echelon, a coarsely-ruled, steeply-blazed aluminum reflection grating. Using the echelon requires an echelle grating to cross-disperse the spectrum, resulting in continuous wavelength coverage of $\sim$10 cm^{-1} for a slit length of $\sim$10$''$, yielding R=10^5. Optionally, the echelon can be bypassed so that the echelle or a low order grating acts as the sole dispersive element. This results in a single order spectrum with slit lengths of roughly 100$''$ and 50$''$ for the medium and low resolution modes respectively. The low resolution grating also serves as a slit positioning camera when it is rotated face on.

2.4 FIFI-LS

A dual channel, far-IR integral field spectrometer, FIFI-LS will provide the ability to simultaneously observe an object in two spectral lines in the wavelength ranges 42 – 110 μm, and 110 – 210 μm, respectively. FIFI-LS will have two separate medium resolution (R $\sim$ 1700) liquid helium cooled grating spectrometers with common fore-optics feeding two large Ge:Ga detector arrays (16×25 pixels each). An image slicer redistributes 5×5 pixel spatial fields-of-view (nearly diffraction-limited in each wave band) along the 1×25 pixel entrance slits of the spectrometers. The spectrally dispersed images of the slits are anamorphically projected onto the detector arrays, to independently match spectral and spatial resolution to detector size, thus enabling instantaneous coverage over a velocity range of $\sim$1300 – 3000 km s^{-1} around selected FIR spectral lines, for each of the 25 spatial pixels.

2.5 Other Instruments

- **GREAT:** A far-IR dual channel heterodyne spectrometer with four frequency windows at 63, 110 – 125, 156 – 165, & 200 – 240 μm

- **HIPO:** An optical high-speed dual-band imaging photometer, which uses standard Johnson UBVRI and Sloan Digital Sky Survey u′ g′ r′ i′ z′ filters, able to be co-mounted with the FLITECAM near-IR imager
- **HAWC+:** A far-IR bolometer camera and polarimeter with four passbands centered at 53, 89, 155, & 216 μm

3. Proposing for time on SOFIA

Observing time on SOFIA is open to all qualified astronomers in the U.S. and outside the U.S., except for those currently affiliated with German institutions. Astronomers with a German professional affiliation must participate through the DLR/DSI led program. All proposals that are considered to be scientifically well justified through peer review will be considered for selection with preference given to investigations that demonstrate significant scientific impact from SOFIA observations. Further information on SOFIA, the available suite of science instruments, and the current Call for Proposals are available on the SOFIA **Information for Researchers**[1] web pages.

References

[1] De Buizer, J. M., Morris, M. R., Becklin, E. E., et al. 2012, ApJL, **749**, L23

[2] Parise, B., Du, F., Liu, F.-C., et al. 2012, A&A, **542**, L5

[3] Neufeld, D. A., Falgarone, E., Gerin, M., et al. 2012, A&A, **542**, L6

[4] Lau, R. M., Herter, T. L., Morris, M. R., Becklin, E. E., & Adams, J. D. 2013, ApJ, **775**, 37

[1] http://www.sofia.usra.edu/Science/index.html

Table 1: SOFIA Science Instrument Suite

Instrument	Description	Coverage; Resolution (R = $\lambda/\Delta\lambda$)	Field of View; Array Characteristics
EXES	Mid-IR Echelle Spectrometer	5 – 28 μm 1000 – 10^5	5″to 90″slits 1024 × 1024 Si:As
FIFI-LS	Far-IR Field Imaging Grating Spectrometer	40 – 210 μm 1000 – 4000	30″×30″(Blue) 60″×60″(Red) 2 – 16 × 5 × 5 Ge:Ga
FLITECAM	Near-IR Camera & Grism Spectrometer	1 – 5 μm 5 – 2000	8.′2×8.′2 1024×1024 InSb
FORCAST	Mid-IR Camera & Grism Spectrometer	5 – 40 μm 6 – 1200	3.″2×3.″2 2 – 256×256 Si:As, Si:Sb
GREAT	Far-IR Heterodyne Spectrometer	60 – 240 μm 10^6 – 10^8	Single Beam Heterodyne Receiver
HAWC+	Far-IR Bolometer Camera & Polarimeter	50 – 240 μm 5 – 10	27″×72″(53μm) 96″×256″(215μm) 12×32 Bolometer
HIPO	High-Speed Imaging Photometer	0.3 – 1.1 μm 1 – 300	5.′6×5.′6 1024×1024 CCD