

What can SOFIA do for studies of Outflows, Winds and Jets?

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ABSTRACT

SOFIA, the Stratospheric Observatory for Infrared Astronomy, is a Boeing 747-SP airplane with a 2.5 m telescope, designed to operate at altitudes from 12 to 14 km and wavelengths from 0.3 μm to 1.6 mm over a 20 year lifetime. The telescope is diffraction limited at wavelengths beyond $\sim 15 \mu\text{m}$. At 100 μm the angular resolution is ~ 10 arcsec, which is comparable to the angular resolution of large ground-based telescopes such as IRAM, JCMT, APEX, and CSO. SOFIA has now started science operations and already completed its first limited observing cycle. SOFIA's first suite of instruments offer unique opportunities to study the physics and chemistry of outflows and jets. GREAT, the German heterodyne receiver, has two low frequency bands covering 1.25 - 1.52 THz and 1.82 - 1.92 THz, a mid frequency channel from 2.4 - 2.7 THz, and a high frequency channel at 4.75 THz (63 μm) is being developed. These frequency bands allow studies of several OH transitions, high J CO lines, as well as studies of the forbidden [CII] and [OI] lines, which can be very strong in outflows. FIFI-LS, an imaging spectrometer similar to PACS on Herschel, and EXES, a high resolution mid-IR spectrometer, will also be available. In this presentation we will show some results on outflows from early science with GREAT on SOFIA and discuss how SOFIA can complement facilities like ALMA and EVLA in studies of outflows and jets.

Introduction

SOFIA is now airborne and has completed its early science cycle. Results from FORCAST will be presented in a special ApJ Letters issue while results from GREAT will be published in a special A&A issue. The cycle I proposal call, which offered four instruments, FLITECAM, FORCAST, GREAT, and HIPO, closed in January for the US community and was heavily oversubscribed, but results will not be made available until the German proposal call closes. The properties of the first generation instruments are listed below. The results from the second generation instrument call are expected to be announced in March.

SOFIA FIRST GENERATION INSTRUMENTS

Instrument name	Type	Array & pixel size	Wavelength coverage & resolution
Facility Instruments			
HAWC	Far Infrared Bolometer Camera	12 x 32, 2.3" - 8"/pixel	40 - 300 μm
FORCAST	Mid IR Camera	256x256, 0.75"/pixel	5 - 40 μm + GRISMS
FLITECAM	Near IR Test Camera	1024x1024, 0.48"/pixel	1 - 5 μm + GRISMS
PI Instruments			
EXES	Echelon Grating Spectrometer	1024x1024, 1" - 4" slit	5 - 28 μm , R=3 $10^3 - 10^5$
FIFI-LS	Image Sliced Grating Spectrometer	5x5 (x2), 7" & 14"/pixel	42-110, 110-210 μm R= 2000
GREAT	Heterodyne Spectrometer	Single, diff. limited	63, 110-125, 156-240 μm R=10 ⁶ -10 ⁸
HIPO	High speed optical imager	1024x1024, 0.055"/pixel	0.3 - 1.1 μm

Most first generation instruments offer opportunities for studying various aspects of jets and outflows. Here we just highlight a few. You can probably think of many more.

FLITECAM, our 1 - 5 μm imager, has a large field of view and offers several narrow band filters, like P α and a 3.3 μm PAH filter. Imaging in P α may be a good way to trace shocks in highly obscured regions. FLITECAM also offers GRISMS with a resolution of 1700 or 900, better than that of the IRAS or ISO. Spectroscopy of vibrationally excited H₂ will enable us to study hot gas in outflow shocks, while [Fe II] 1.644 μm can trace jets.

FORCAST grism spectroscopy offers many opportunities to study jets and outflows. The cross dispersed modes with an instantaneous coverage from 4.9 - 7.8 μm at R = 1200 and 8.4 - 13.7 μm at R = 800 will be especially useful. The 4.9 - 7.8 μm window has several H₂ transitions (S(5) - S(8)) and there are two more H₂ lines in the 8.4 - 13.7 μm window (S(2) and S(3)), which will enable characterization of the physical conditions in outflows.

GREAT is a German heterodyne receiver, which offers ample opportunities to study the physical conditions of outflows. See results from early science. The GREAT high-frequency channel, not yet available, targets the [OI] 63 μm line, which we know is strong in jets, based on Herschel PACS observations. With GREAT we will for the first time be able to resolve the line in velocity and separate the emission from the disk from that of the outflow.



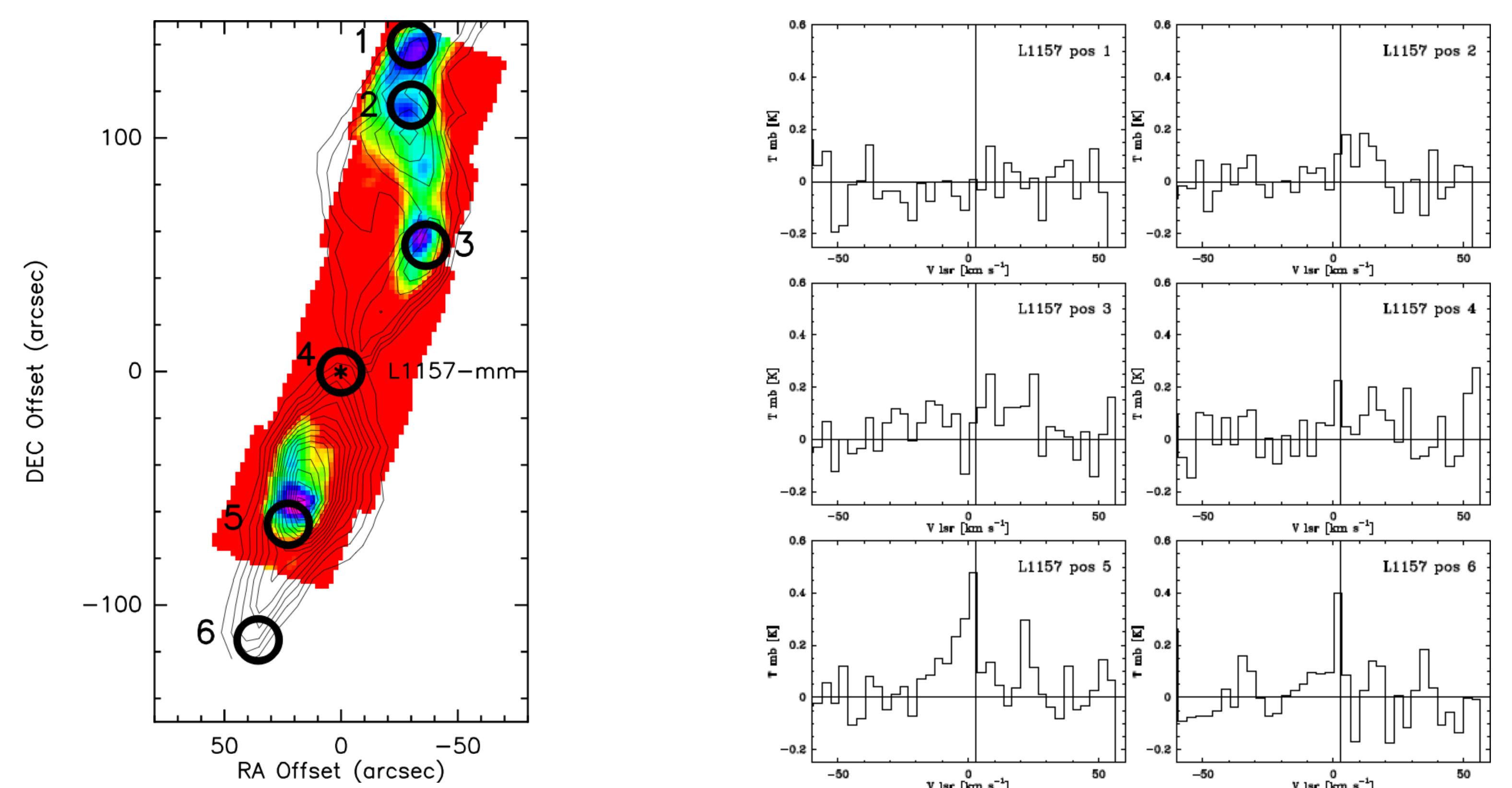
SOFIA flying over the snow capped Sierras during a test flight before early science.

FIFI-LS is an integral field spectrometer similar to PACS. With FIFI-LS we can map [CII] and [OI] in outflows and also probe their physical conditions using high J CO transitions.

EXES, with its high spectral resolution, is ideal for studying the chemistry and kinematics of jets and outflows. EXES can reach all the pure rotational lines of H₂ from S(0) to S(9) as well as many transitions of H₂O, providing a unique probe of the hot gas in outflows.

Two GREAT results from early science

There were several successful GI programs, who used GREAT to study various aspects of outflows, and expected to appear in a special A&A issue. Eislöffel et al. observed the L1157 outflow in CO J = 13 - 12 and found that the emission comes from slow moving gas with densities of 10⁵ - 10⁶ cm⁻³ and temperatures of 60 - 100 K. This gas is hotter than the cold entrained gas, but colder than the hot shocked gas in the interior of the outflow.



The L1157 outflow in the H₂ S(1) line (color) overlaid on a CO 2-1 contour plot. The circles show the observed GREAT positions. The corresponding spectra are shown on the right.

