Latest Science and Status of Your Flying Observatory – SOFIA

Stratospheric Observatory for Infrared Astronomy

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Overview

Flying high above the atmosphere's obscuring water, SOFIA, the Stratospheric Observatory for Infrared Astronomy, unveils the mid-infrared (MIR) and far-infrared (FIR) sky at wavelengths impossible to observe from the ground or any current space-based mission. As half of the radiant energy in the Universe emerges at these wavelengths, observers using SOFIA investigate a diverse range of targets in the Solar System, in the Milky Way, and in distant galaxies. As a mobile observatory SOFIA can be and has been deployed to both hemispheres and alternate sites across the globe for important targets of opportunity and occultations of Solar System bodies. Annual calls for Guest Observer and larger Legacy programs plus year-round Director's Discretionary Time is available to astronomers.

By design, SOFIA remains responsive to emerging science needs with upgradable instrumentation. A FIR photometer/polarimeter recently achieved first light and is delivering new insights about the role of magnetic fields in star forming regions and in other galaxies. A third generation MIR/FIR spectrometer is under development to enable studies of the mass and composition of protoplanetary disks.

In this next decade, deeper studies of the infrared and submillimeter universe are enabled by the James Webb Space Telescope (JWST, launch 2021), and the Atacama Large Millimeter/submillimeter Array (ALMA, operational since 2013). As exceptional as these facilities are, the wavelength coverage where JWST ends and where ALMA begins, the part of the spectrum most important to understanding the physics of the interstellar medium, is provided by SOFIA. In addition, SOFIA has and continues to enable long-term studies and follow-up work initiated by *Spitzer, Herschel, Hubble, Chandra,* and ground-based submillimeter observatories.

Recent science using the Observatory plus exciting updates of the SOFIA instrumentation suite are summarized here. For the latest news from SOFIA, please visit **www.sofia.usra.edu**.

Local Truth

SOFIA's Role: Deliver star formation studies of the nearest black hole (our Galactic Center) and local galaxies, challenging interpretation of "single-pixel" information from the most distant galaxies.

Birth of Stars & Planets

SOFIA's Role: Make fundamental measurements of magnetic fields, turbulence, and the physical conditions (temperature, density, etc.) of star-forming regions.

Path to Life

SOFIA's Role: Use spectroscopy to trace the chemical pathways from simple to more complex compounds necessary for life: water, organic molecules, and ices.

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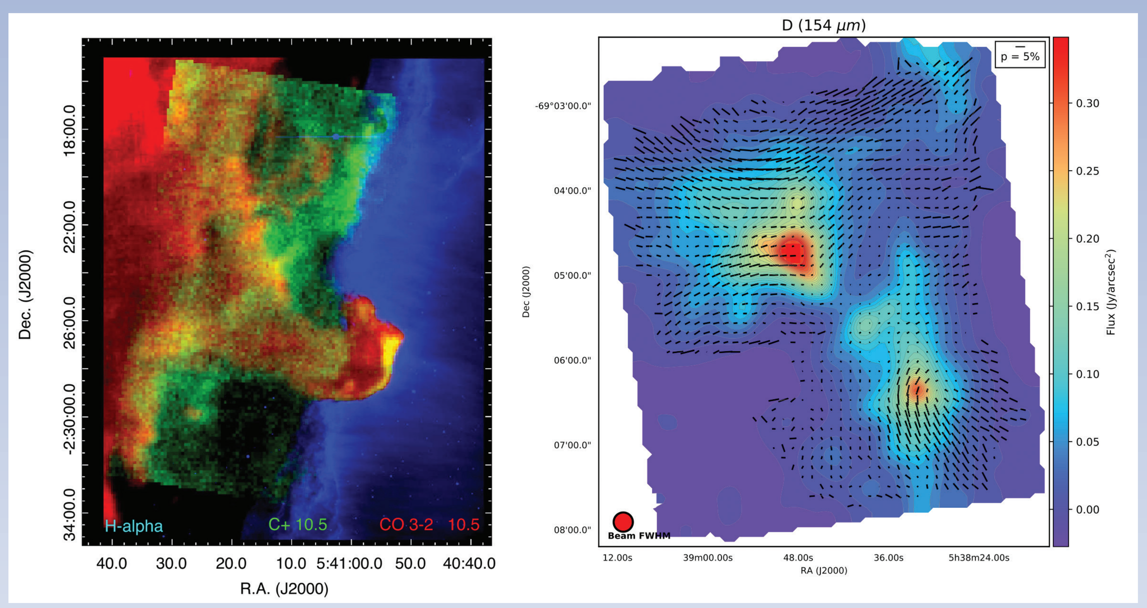
Current status and recent updates of SOFIA's technical performance and flight planning plus in-depth descriptions of the science instruments.
www.worldscientific.com/worldscinet/jai

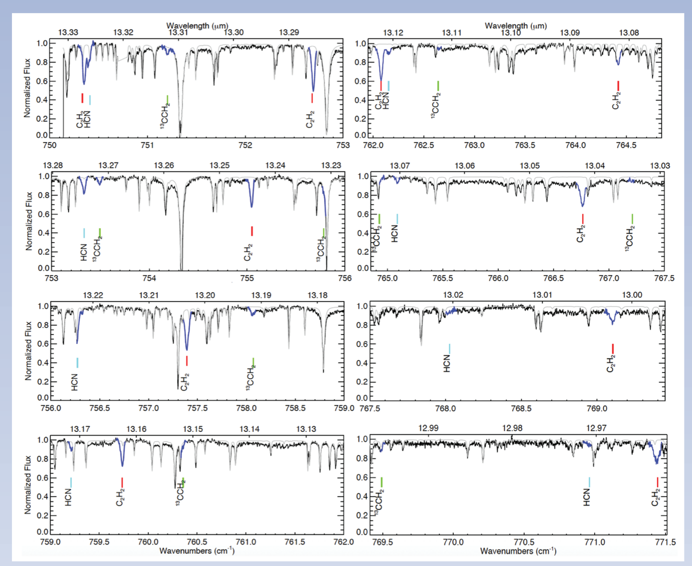
Birth of Stars



(Left) **Velocity-Resolved Fine Structure Line Mapping:** The Horsehead Nebula in Orion marks the boundary between a surrounding cold molecular cloud and a rich area where massive stars have already formed. Modeling using observed ionized carbon (green) measured by SOFIA/GREAT, combined with H-alpha (blue) and CO 3-2 (red), indicate the Nebula itself has very little star formation (Pabst et al. 2017, Bally et al. 2018).

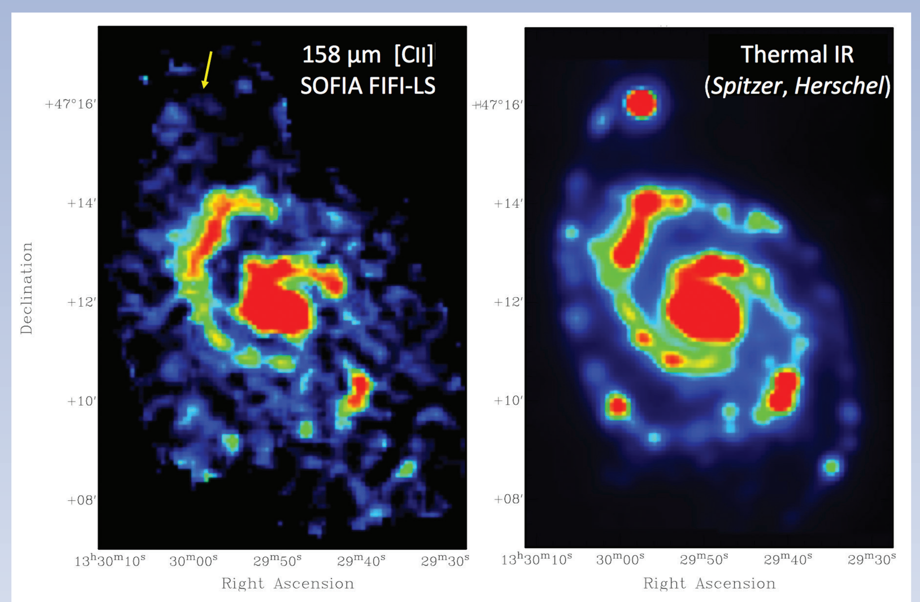
(Right) **Cloud Scale Polarimetric Mapping:** 30 Doradus in the Large Magellanic Cloud is an excellent laboratory to study a starburst region. What roles magnetic fields play in inhibiting or enhancing star formation here are being addressed with numerous FIR polarimetry measurements by SOFIA/HAWC+ across the entire region. One wavelength (154 μm) of four observed are shown here. Data taken July 2018. See Gordon et al., arXiv:1811.03100 describing this publicly-available dataset available for analysis.

Path to Life

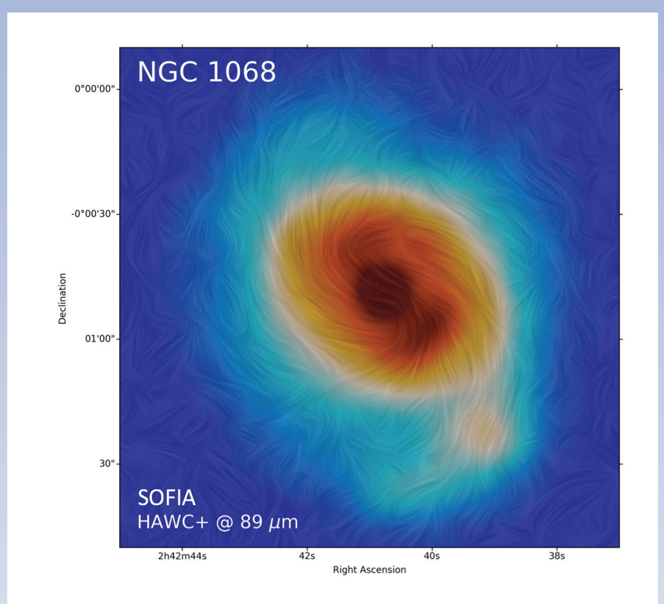


Blind Line Surveys: SOFIA has now undertaken blind line surveys with its high-resolution MIR spectrometer SOFIA/EXES to quantify the chemical inventory in hot cores, the phase in star formation when complex organics form. A sample of the Orion Hot Core reveals several ro-vibrational lines of C_2H_2, $^{13}CCH_2$, and HCN with resolved velocity profiles (Rangwala et al. 2018). The completion of these line surveys will identify new molecules, greatly improve astrochemical models of star-forming regions, and provide a benchmark for interpreting much lower spectral resolution studies of hot cores and disks by JWST/MIRI.

Local Truth as an Anchor for Galaxy Evolution

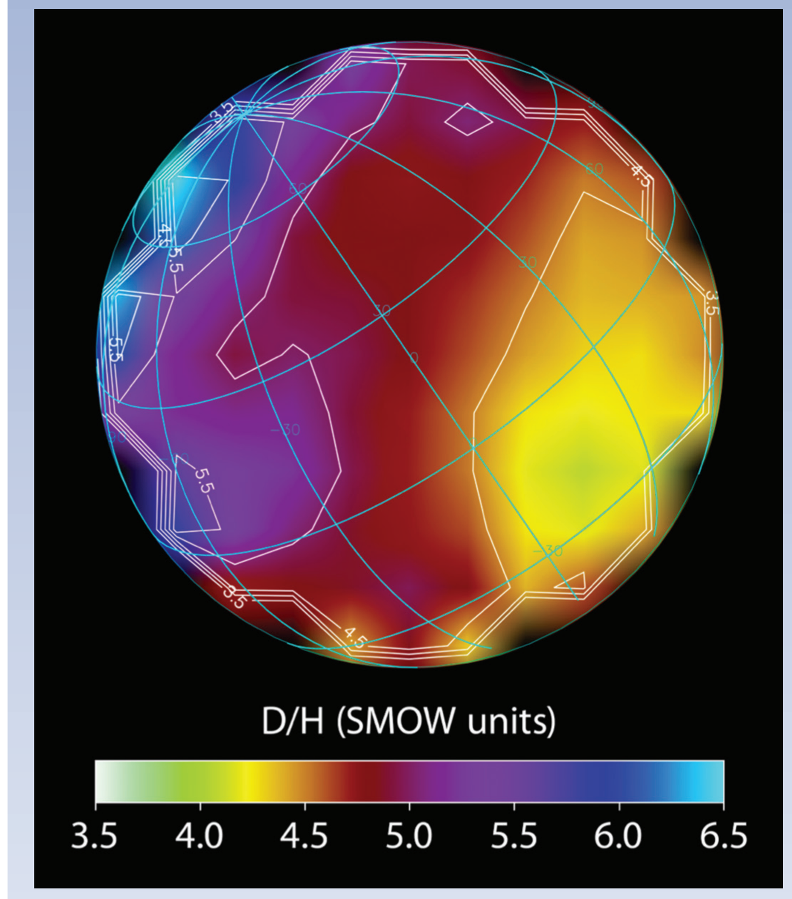


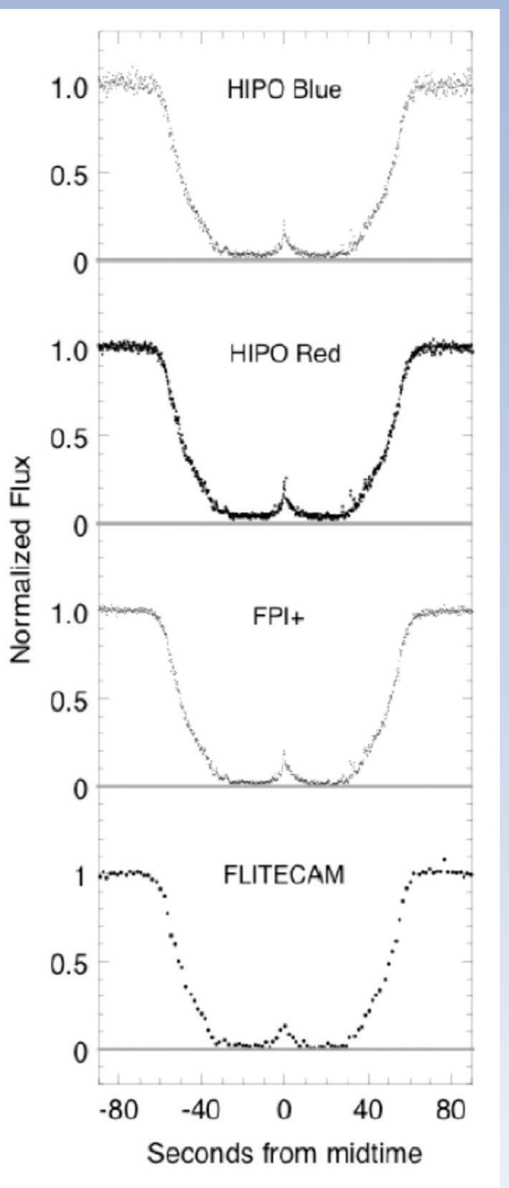
Full-Disk C+ Mapping: (Left) Ionized carbon emission toward the Whirlpool Galaxy NGC 5194 (M51) and its small, red companion galaxy NGC 5195 by SOFIA/FIFI-LS. Ionized carbon is nearly absent in the dwarf companion (yellow arrow), despite its large infrared continuum luminosity (right). Because the infrared continuum is usually thought to indicate star formation deeply embedded in dusty, opaque clouds, the lack of ionized carbon emission is surprising (Pineda et al. 2018).



Galactic Magnetic Fields: Polarimetry observations in the visible did not reveal the central effects of the spiral arms dominating the magnetic field by disk rotation in the spiral galaxy NGC 1068 (Scarrott et al. 1991). Observing at the peak wavelength of 89 μm of the galaxy's SED, new data from SOFIA/HAWC+ unveils the central S-shape of the magnetic field that had been obscured by scattering at visible wavelengths. NGC 1068 has spiral magnetic arms strong enough even to affect the magnetic field towards its center (Jones et al. in prep).

Solar System



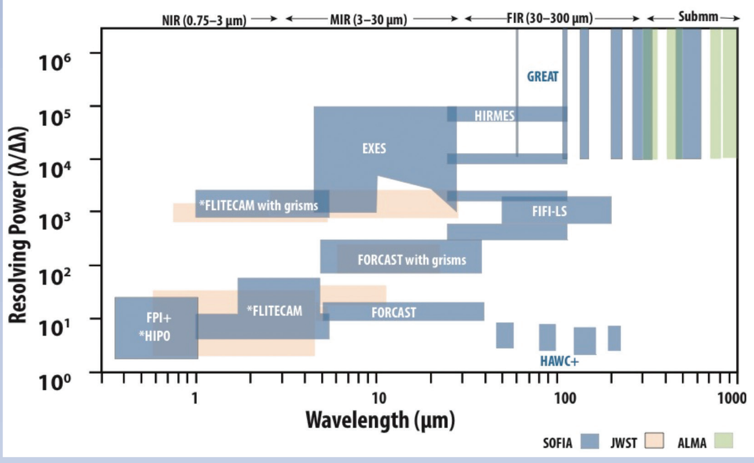


(Above left) **Mars D/H:** Deuterium enrichment, due to differential escape rates of the heavier HDO and lighter H_2O molecules, constrains the duration and stability of planetary water cycles. SOFIA/EXES reveals high D/H ratios toward polar regions (cyan) and low D/H ratios in the high-altitude Tharsis plateau (yellow) of Mars (Encrenaz et al. 2016). Future SOFIA observations will study seasonal variations and refine our understanding of Mars's water history and cycles.

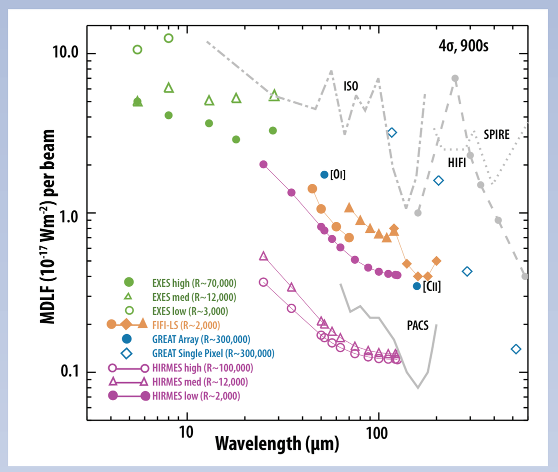
(Above right) **Pluto:** SOFIA captured Pluto occulting a distant star on June 29, 2015 with simultaneous visible (top three curves, SOFIA/HIPO, SOFIA/FPI+) and infrared (bottom curve, SOFIA/FLITECAM) detections. This dataset provides critical cross-calibration of this Earth-based occultation technique with the atmospheric studies during the New Horizons spacecraft's July 14, 2015 flyby. Analysis confirms high-level haze (Bosh et al. in prep.).

Instrumentation Suite Updates

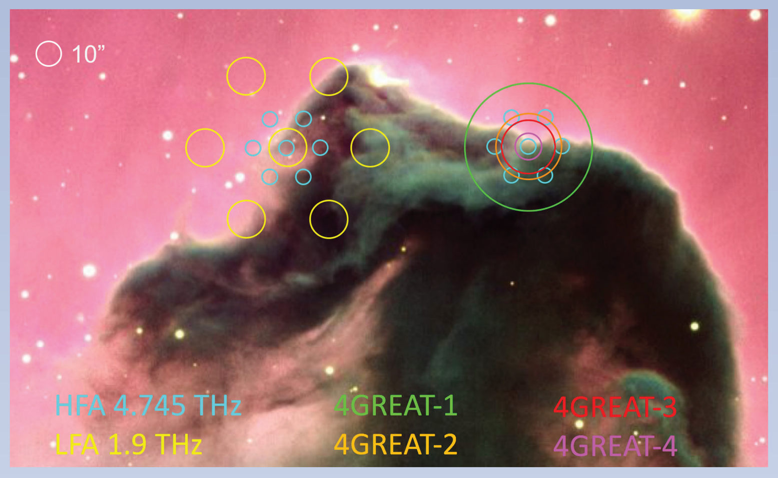
SOFIA overcomes several constraints (power, mass, cooling, and computing capacity) of FIR space-based missions. It is a platform to develop new instruments and train the next generation of instrument-builders. The new FIR polarimeter HAWC+ enables studies of the role of magnetic fields in star formation regions. New channels on GREAT offer access to the light hydrides to challenge fundamental astrochemical pathways. The HIRMES spectrometer (coming in 2020) will address key questions in planet formation that could not be done with earlier instrumentation.



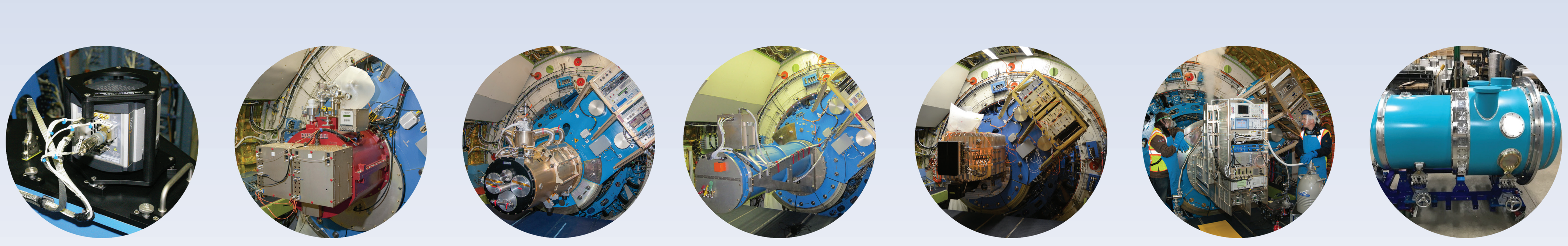
SOFIA instrumentation suite vs. resolution and wavelength coverage. SOFIA (blue boxes) complements ALMA and JWST. SOFIA's instruments fill the spectral gap between JWST's (orange) longest wavelength (28 μm) and ALMA's (green) shortest wavelength (320 μm). HIPO and FLITECAM were retired in Feb 2018. HIRMES becomes available in 2020.



Building on recent advancements in technology, SOFIA's latest MIR and FIR high-resolution spectrometers are more sensitive than those from Herschel and ISO (shown in grey).



Transitioning from single pixels to pixel arrays and adding simultaneous multiple frequencies has transformed SOFIA/GREAT into an efficient mapping spectrometer. GREAT's beam-sizes (colors) and spatial configuration are superimposed on the Horsehead Nebula. For the 158 μm (1.9 THz) ionized carbon line, GREAT's mapping speed is ~50x faster than Herschel/HIFI to reach the same mapping sensitivity for an extended object (≥ few arcminutes).



FPI+ FORCAST HAWC+ EXES FIFI-LS GREAT HIRMES

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