The Stratospheric Observatory for Infrared Astronomy (SOFIA)

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Abstract*— The Stratospheric Observatory for Infrared Astronomy (SOFIA) is a joint U.S./German Project to develop and operate a 2.5-meter infrared airborne telescope in a Boeing 747-SP that flies in the stratosphere at altitudes as high as 45,000 and is capable of observations from 0.3 µm to 1.6 mm with an average transmission greater than 80 percent. SOFIA will be staged out of the NASA Dryden Flight Research Center aircraft operations facility at Palmdale, CA and the SOFIA Science Mission Operations Center (SSMOC) will be located at NASA Ames Research Center, Moffet Field, CA. First science flights will begin in 2010 and a full operations schedule of more than 100 8 to 10 hour flights per year will be reached by 2014. The observatory is expected to operate until the mid 2030's. SOFIA will initially fly with eight focal plane instruments that include broadband imagers, moderate resolution spectrographs that will resolve broad features due to dust and large molecules, and high resolution spectrometers capable of studying the kinematics of molecular and atomic gas lines at km/s resolution. We describe the SOFIA facility and outline the opportunities for observations by the general scientific community, future instrumentation developments, and operations collaborations. The operational characteristics of the SOFIA first-generation instruments are summarized and we give several specific examples of the types of scientific studies to which these instruments are expected to make fundamental scientific contributions. Additional information about SOFIA is available at http://www.sofia.usra.edu .

I. INTRODUCTION: PROJECT OVERVIEW AND STATUS

NASA's Stratospheric Observatory for Infrared (IR) Astronomy (SOFIA) will soon join the Spitzer Space Telescope [1,2], Herschel Space Observatory [3], and James Webb Space Telescope (JWST) [4] as one of the premier observatories for IR/Submillimeter astronomy during the next 25 years. SOFIA, a joint project of NASA and the German Space Agency (DLR), is a 2.5-meter telescope in a Boeing 747SP aircraft (Figure 1) designed to make sensitive IR measurements of a wide range of astronomical objects. SOFIA will fly at altitudes up to 45,000 feet (13.72 km), above 99.8% of the obscuring atmospheric H_2O vapor. It will enable observations at wavelengths from 0.3 µm to 1.6 mm with ≥ 80% transmission, concentrating especially on the obscured region between 30 and 300 µm (Figure 2). At this altitude, the precipitable water column depth is typically less than 10 µm.

Science support for the SOFIA user community will be provided by the SOFIA Science Mission Operations Center (SSMOC) at NASA Ames Research Center, Moffett Field,

1. (Left) The NASA/DLR SOFIA observatory flying with its observatory door opened to full aperture for the first time on Dec. 18, 2009. (NASA Photo / Carla Thomas).

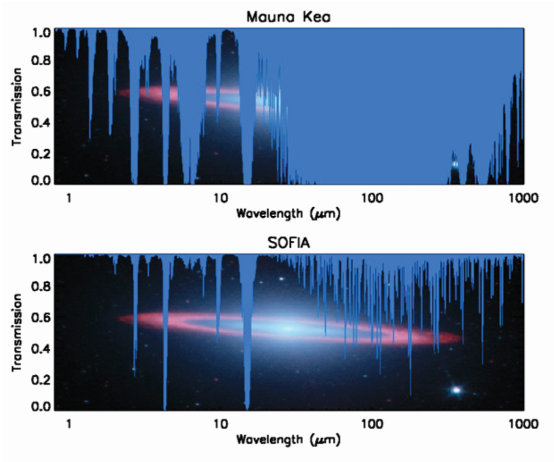


Fig. 2. The typical atmospheric transmission at an altitude of 45,000 feet as compared to the transmission on a good night at Mauna Kea (13,800 ft. MSL). From 1 to 1000 μm, the average transmission is ≥80% except in the center of absorption lines due to mostly H_2O, CO_2, and O_2. Background image: IRAC false color image of the Sombrero Galaxy, courtesy of NASA/JPL-Caltech.

California and the Deutsches SOFIA Institut (DSI) at the University of Stuttgart, Stuttgart, Germany. The home base for flight operations of the SOFIA aircraft, Clipper Lindbergh, will be NASA's Dryden Aircraft Operations Facility (DAOF) in Palmdale, California. SOFIA will also operate from other bases world wide, including some in southern hemisphere, to enable observations at any declination in the sky and to facilitate timely observations of transient events such as variable stars, comet apparitions, occultations, extoplanet transits, novae, and supernovae.

SOFIA will provide community-wide opportunities for forefront science, invaluable hands-on experience for young researchers, and an extensive and unique education and public outreach program. With observing flexibility and the ability to deploy new and updated instruments, the observatory will make important contributions towards understanding a variety of astrophysical problems well into the 21st century.

First test flights of the observatory began in April 2007 at L-3 Communications in Waco, Texas after which it was ferried to DAOF where further flight testing and development has been conducted. Closed door testing was completed in January, 2008. The first flight of the DAOF open door test series occurred on December 9, 2009, and the door was opened to expose the full aperture of the telescope a week later on December 18, 2009. SOFIA will see first light in April of 2010, and by 2014, is expected to begin making more than 100 8-10 hour scientific flights per year until the mid 2030s.

II. THE SOFIA TELESCOPE

The SOFIA telescope (Table 1 and Figures 3 and 4), supplied by DLR under an agreement with NASA in exchange for observing time on SOFIA, is a bent Cassegrain with a 2.7m (2.5m effective aperture) parabolic primary mirror and a 0.35m diameter hyperbolic secondary mirror with a f/19.6 Nasmyth infrared focus fed by a 45° gold coated dichroic mirror.

The infrared Nasmyth focus is 300mm behind the instrument flange. The dichroic mirror allows transmitted optical light to be reflected by a second tertiary behind the dichroic to a visible Nasmyth focus where it is fed into an optical focal plane guiding camera system, the Focal Plane Imager (FPI). Two other imaging and guiding cameras, independent of the FPI, are available: the Wide Field Imager (WFI) and the Fine Field Imager (FFI). The WFI and the FFI are attached to the front ring of the telescope. The dichroic tertiary mirror can be replaced by a fully reflecting tertiary for applications requiring maximum throughput at the shorter wavelengths.

Table 1. Characteristics of the SOFIA Observatory and Telescope

Nominal Operational Wavelength	0.3 to 1600 μm	**Diffraction Limited Wavelengths**	≥ 15 μm
Primary Mirror Diameter	2.7 meters	**Optical Configuration**	Bent Cassegrain with chopping secondary mirror and flat folding tertiary
System Clear Aperture Diameter	2.5 meters	**Chopper Frequencies**	1 to 20 Hz for 2-point square wave chop
Nominal System f-ratio	19.6	**Maximum Chop Throw on Sky**	+/- 4 arcmin (unvignetted)
Primary Mirror f-ratio	1.28	**Pointing Stability**	= 1.0" rms at first light = 0.2" rms in operations
Telescope's Unvignetted Elevation Range	20 to 60 degrees	**Pointing Accuracy**	= 0.5" with on-axis focal plane tracking
Unvignetted Field-of-View Diameter	8 arcmin	**Total Emissivity of Telescope (Goal)**	15% at 10 μm with dichroic tertiary 10% at 10 μm with aluminized tertiary
Image Quality of Telescope Optics at 0.6 μm	1.5 arcsec on-axis (80% encircled energy)	**Recovery Air Temperature in Cavity (and Optics Temperature)**	= 240 K
Diffraction Limited Image Size	0.1" • λ μm FWHM		

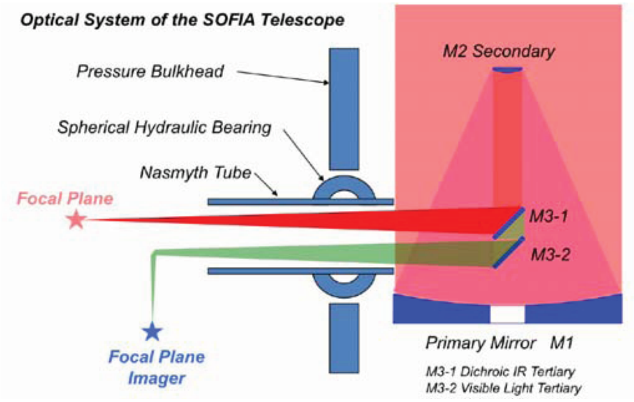


Fig. 3. (**left**) The bent Cassegrain-Nasmyth optical configuration of the SOFIA 2.5-meter infrared telescope. (**right**) Main cabin looking aft toward the pressure bulkhead and telescope assembly (courtesy of the NASA Dryden Flight Research Center Photo Collection.).

The secondary mirror is attached to a chopping mechanism providing chop amplitudes of up to ± 4 arcmin at chop frequencies between 0 and 20 Hz, programmable by either a user supplied wave-form or by the telescope control electronics.

III. SOFIA'S FIRST GENERATION INSTRUMENTS

SOFIA's eight first generation Science Instruments (SIs, Table 2) cover a much wider range of wavelengths and spectral resolutions than those of any other observatory (Figure 5). These include three Facility Class Science Instruments (FSIs) that will be maintained and operated by the SOFIA Science Mission Operations (SMO) staff: the High-resolution Airborne Wideband Camera (HAWC), the Faint Object InfraRed Camera for the SOFIA Telescope (FORCAST), and the First Light Infrared Test Experiment CAMera (FLITECAM). FSI pipeline-reduced and flux calibrated data will be archived for general access by the astronomical community after a one year exclusive access (proprietary) period.

The remaining five SIs are Principal Investigator (PI) class instruments are maintained and operated by the PI teams at their home institutions. These instruments are designed to be less general in their potential applications than FSIs. They are more likely to undergo upgrades between flight series so that they can be maintained at the state-of-the-art, albeit at the expense of not having fixed capabilities. General investigators will be able to propose for PI instruments in collaboration with the PI team. Present development plans are for pipeline reduced data from the US PI instruments to be added to the science archive after a one year exclusive access period Two PI-class instruments are being developed in Germany. It is planned that the German PI instrument

Fig. 4. (**Below**) Cutaway view of the SOFIA Observatory showing the locations of the critical components

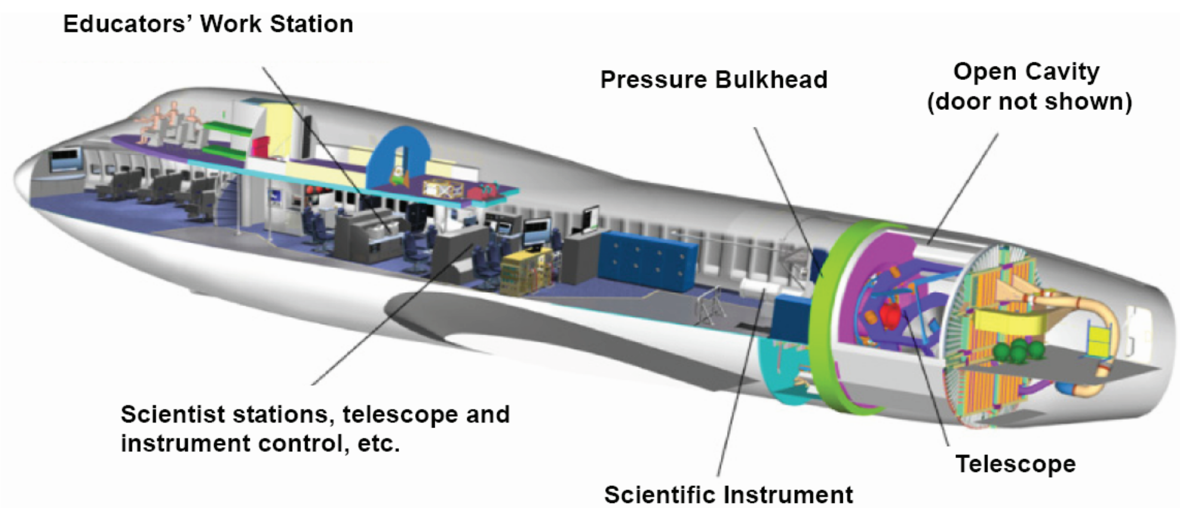


Table 2. SOFIA First Generation Instrument Summary

SOFIA Instrument	Description	Built by / PI	λ range (μm) spec res ($\lambda_o/\Delta\lambda$)	Field of View Array Size	Available
FORCAST	Faint Object InfraRed CAmera for the SOFIA Telescope Facility Instrument - Mid IR Camera and Grism Spectrometer	Cornell T. Herter	5 - 40 R ~ 200	3.2' x 3.2' 256 x 256 Si:As, Si:Sb	2010
GREAT	German Receiver for Astronomy at Terahertz Frequencies PI Instrument - Heterodyne Spectrometer	MPIfR, KOSMA DLR-WS R. Güsten	60 - 200 R = 10^6 - 10^8	Diffraction Limited Single pixel heterodyne	2010
FIFI LS	Field Imaging Far-Infrared Line Spectrometer PI Instrument w/ facility-like capabilities - Imaging Grating Spectrometer	MPE, Garching A. Poglitsch	42 - 210 R = 1000 - 3750	30"x30" (Blue) 60"x60" (Red) 2 - 16x5x5 Ge:Ga	2010
HIPO	High-speed Imaging Photometer for Occultation Special PI Instrument	Lowell Obs. E. Dunham	.3 - 1.1	5.6' x 5.6' 1024x1024 CCD	2012
FLITECAM	First Light Infrared Test Experiment CAMera Facility Instrument - Near IR Test Camera and Grism Spectrometer	UCLA I. McLean	1 - 5 R~2000	8.2' x 8.2' 1024x1024 InSb	2012
CASIMIR	CAltech Submillimeter Interstellar Medium Investigations Receiver PI Instrument - Heterodyne Spectrometer	Caltech J. Zmuidzinas	200 - 600 R = $3x10^4$ - $6x10^6$	Diffraction Limited Single pixel heterodyne	2012
HAWC	High-resolution Airborne Wideband Camera Facility Instrument - Far Infrared Bolometer Camera	Univ of Chicago D. Harper	50 - 240	Diffraction Limited 12x32 Bolometer	2013
EXES	Echelon-Cross-Echelle Spectrograph PI Instrument - Echelon Spectrometer	UT/UC Davis NASA Ames M. Richter	5 - 28 R = 10^5, 10^4, or 3000	5" to 90" slit 1024x1024 Si:As	2013

The Field Imaging Far-Infrared Line Spectrometer (FIFI LS) will be available to the US science community as a Facility-like instrument under special arrangement with the FIFI LS team. The FIFI LS data will be pipeline-reduced and flux-calibrated before it is placed in the data archive.

Information about all the first-generation instruments is at:

http://www.sofia.usra.edu/Science/instruments/index.html .

IV. EARLY SCIENCE WITH FORCAST AND GREAT

Early science programs during 2010-2011 will be conducted with the Cornell FORCAST imager and the German spectrometer GREAT (see Figure 5).

FORCAST is a facility class, mid-infrared diffraction-limited camera with selectable filters for continuum imaging

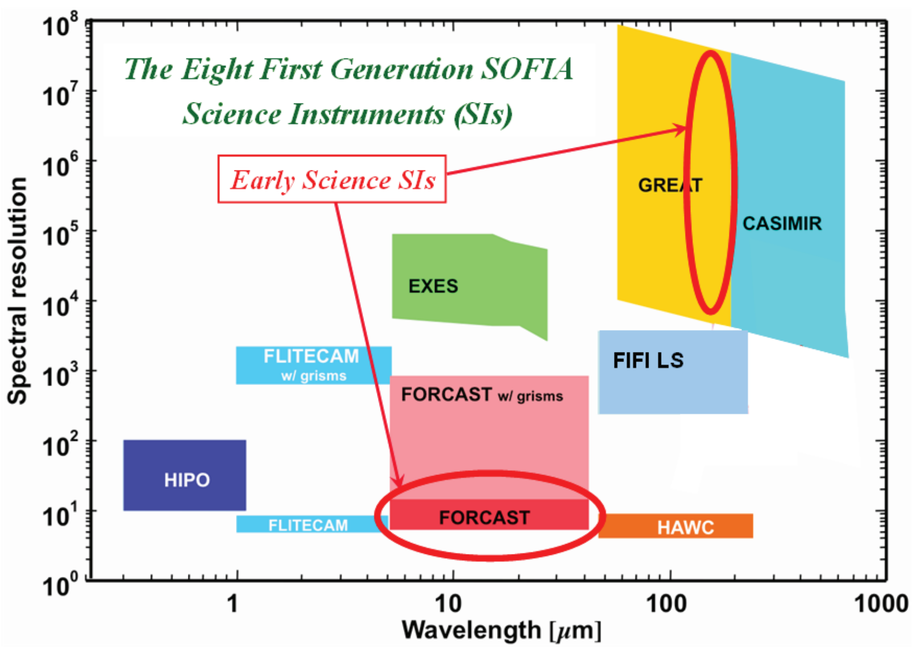


Figure 5. (Right) SOFIA's first generation instruments shown in a plot of log spectral resolution vs. log wavelength. FORCAST and GREAT will operate in the regimes indicated by the large red ovals at first light and during early science operations

in two 4-25 µm and 25-40 µm bands, and also incorporates low resolution (R = 200-800) grism spectroscopy in the 4-8, 16-25 µm and/or 25-40 µm regions. It will provide the highest spatial resolutions possible with SOFIA, enabling detailed imaging of protostellar environments, young star clusters, molecular clouds, and galaxies. Simultaneous high-sensitivity wide-field imaging can be performed in the two-channels using 256x256 Si:As and Si:Sb detector arrays which sample at 0.75 arcsec/pixel giving a 3.2 arcmin x 3.2 arcmin field-of view. For small objects, chopping can be performed on the array to increase sensitivity.

GREAT, a PI-class instrument, will investigate a wide range of astronomical questions requiring the highest spectral resolution. These include observations of the158µm fine-structure transition of ionized carbon (CII), which is the most important cooling line of the cold interstellar medium and is a sensitive tracer of the star forming activity of a galaxy. Observations of the 112µm rotational ground-state transition of HD will allow the derivation of the abundance profile of deuterium across the galactic disk and nearby galaxies, thereby providing unique information on the chemical evolution and star formation history of these systems. GREAT is a 2-channel heterodyne instrument that offers observations in three frequency bands with frequency resolution down to 45 kHz (3.74×10^{-6} µm). The lower band, 1.4-1.9 THz (157.89 -214.29 µm), covers fine-structure lines of ionized nitrogen and carbon. The middle band is centered on the cosmologically relevant 1-0 transition of deuterated molecular hydrogen (HD) at 2.6 THz (112 µm) and the rotational ground-state transition of OH. A high-frequency band includes the 63µm transition of OI. The receivers employ sensitive superconducting mixer elements, SIS tunnel junctions and hot electron bolometers. A polarizing beam splitter allows simultaneous measurements of two lines at the same time.

V. Performance Specifications of SOFIA with its First Generation Instruments

SOFIA's first generation SIs will initially provide for high-resolution spectroscopy ($R \geq 10^4$) at wavelengths between 5 and 600 µm, and the 8 arcminute diameter field of view (FOV) allows use of very large format detector arrays. Despite the relatively large thermal IR background at SOFIA's operational altitude, the 2.5-meter aperture of the SOFIA telescope will be capable of measurements with an order of magnitude better photometric sensitivity than IRAS (Figure 6) and a factor of > 3 better linear spatial resolution than that of the *Spitzer* Space Telescope (Figure 7). It will be comparable in sensitivity to the European Space Agency (ESA) Infrared Space Observatory (ISO). SOFIA's capability for diffraction-limited imaging beyond 15 µm will produce the sharpest images of any current or planned IR telescope operating in the 30 to 60 µm region (Figure 5). SOFIA's performance for line flux measurements with various first generation instruments is shown in Figure 8. Each instrument will have an exposure time calculator on the SOFIA website to enable prospective observers to evaluate the feasibility of the programs they propose to conduct. See http://www.sofia.usra.edu for details.

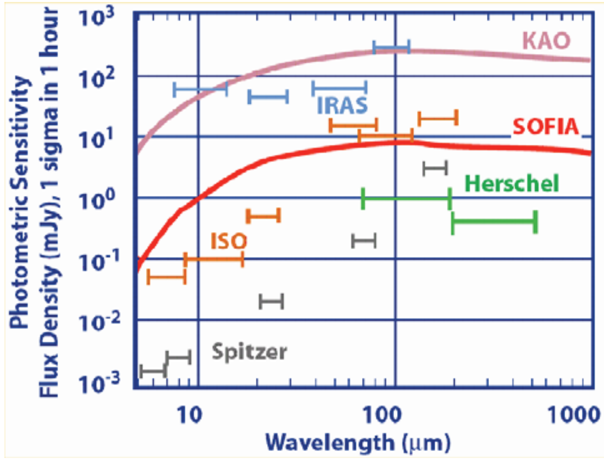


Fig.6. SOFIA's photometric sensitivity will be comparable to that of ISO.

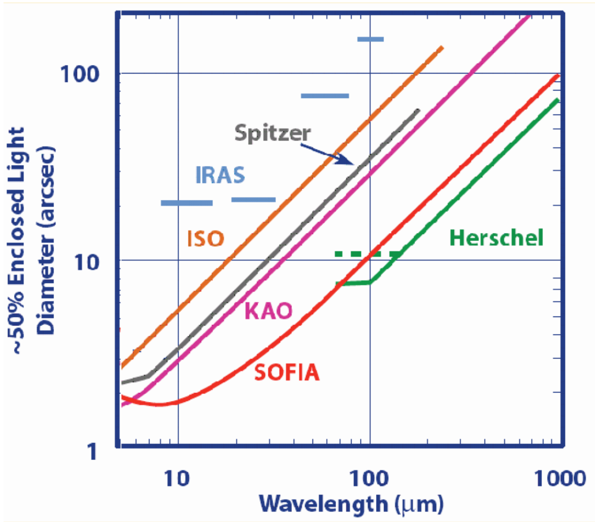


Fig.7. SOFIA's high angular resolution will make it a premier IR imaging facility.

VI. Unique Advantages of SOFIA

Key advantages of the SOFIA Observatory concept promise to make it a unique asset for astronomy in the coming decades. First, SOFIA is an observatory operating in a near-space environment that comes home after every flight. Thus, its SIs can be exchanged regularly to respond to changing science requirements and new technologies that need not be space qualified. Second SOFIA can accommodate large, massive, complex instruments requiring substantial power and heat dissipation. Third, simple repairs and adjustments to SIs can be performed in flight to optimize

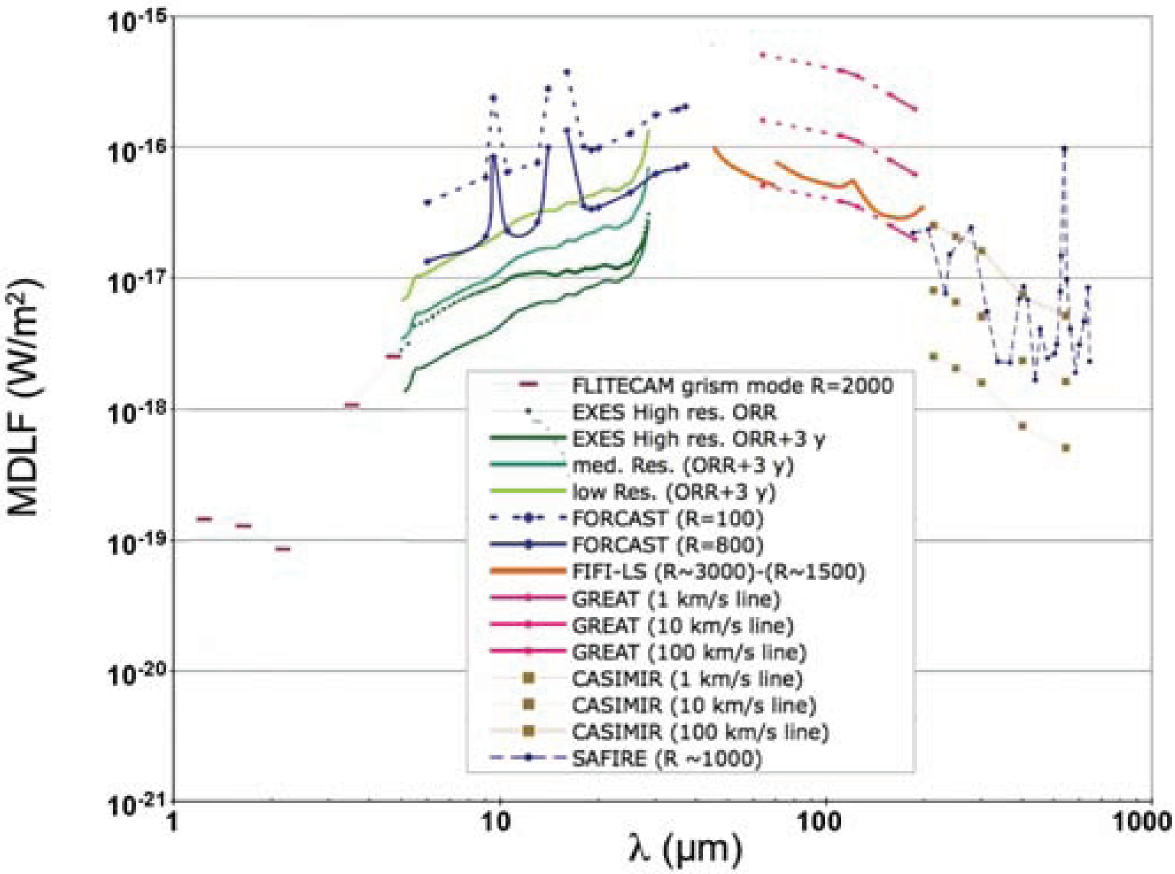


Fig. 8 (**Above**) The expected line sensitivity of SOFIA spectrometers at the time of full operational capability. Shown is the 10 σ minimum detectable line flux (MDLF) in watts per meter squared for 900 seconds of integration on source. Observing and chopper efficiency have not been included.

SOFIA's science productivity. Fourth, SOFIA is a unique platform for studying transient events because it can operate from airbases worldwide on short notice to respond to new discoveries at all declinations. SOFIA can respond to such diverse events as supernova/nova explosions, cometary impacts, comet apparitions, eclipses, occultations, near-Earth objects, activity in Active Galactic Nuclei, and activity in luminous variable stars. Fifth, SOFIA's versatile complement of SIs will facilitate a coordinated panchromatic science program on specific targets. No other observatory operating in SOFIA's wavelength range has such a large variety of SIs for such a long period of time. Sixth, SOFIA will be able to access events that many space observatories cannot view because of the constraints imposed by their orbits. For example, SOFIA can observe objects close to the sun, enabling temporal monitoring of supernovae, novae, and variable stars, throughout the year. It will be the only infrared mission that can view the inner planets and bright, active comets during perihelion passage when they are brightest and most active.

Finally, SOFIA's 20-year operational lifetime will enable long-term temporal studies and follow-up of work initiated by SOFIA itself and by other observatories.

VII. Training Students and Developing Technology with SOFIA

The US and German science communities have identified the continuous training of instrumentalists as a high priority. SOFIA will contribute to this objective by enabling the training of students and faculty in instrument hardware and software development. It provides an optimal environment for students to participate in the hands-on, development of forefront technologies, an opportunity generally not available to students working on satellite projects. SOFIA will inspire the next generation of young experimental astrophysicists to develop their talents in many different areas of science and engineering. Just as was the case with the Kuiper Airborne Observatory (KAO)[5], SOFIA graduate and post - doctoral students will form a rich reservoir of talent that will become the next generation of Principal Investigators and Instrument Scientists.

SOFIA will facilitate the early deployment of new detector and instrumentation technology applicable to space-flight. Unlike space borne observatories, which must use technologies qualified for space-flight years in advance of launch, SOFIA will always be able to utilize the latest state-of-the-art technology in terms of sensitivity, detector response time, observation technique, spectral resolution and more, by conducting an ongoing instrument development program. As noted above, SOFIA instruments can be more complex, larger in volume and weight, and require higher power consumption than instruments typically flown on space-based observatories.

VIII. SCIENCE OPERATIONS AND SCHEDULE

The SOFIA Science and Mission Operations Center (SSMOC) is located at NASA Ames Research Center in Moffett Field, CA. The Universities Space Research Association (USRA) and the Deutsches SOFIA Institut (DSI) in Stuttgart, Germany manage science and mission operations for NASA and DLR. The SOFIA Program will support approximately 50 investigation teams per year, selected by a peer reviewed proposal process. An on-going instrumentation development program will ensure that the facility is operating at the state-of-the-art during its flight lifetime.

IX. GENERAL OBSERVER OPPORTUNITIES WITH SOFIA

Three Early Short Science (ESS) flights with FORCAST and GREAT will occur in 2010. ESS flights, limited in scope, will call for collaboration with the Principle Investigators (PIs) of FORCAST and GREAT. Routine observations will begin in 2011. A first call to the astronomical community for proposals for a fifteen flight Early Basic Science (EBS) Program will occur on April 19, 2010, with proposals due on July 2, 2010. The ~ 15 flight EBS program will be executed during 2011. The first call for General Investigator (GI) science proposals will occur in 2011. There will be future GI science calls at least every 12 months. The first GI flights will occur in 2012. GI science flights conducted annually on a shared risk with the SI PI's. There will be additional GO flight opportunities with Facility Instruments. The annual flight rate will ramp up to at least 100 8-10 hour flight by 2014. SOFIA's

X. INSTRUMENTATION DEVELOPMENT PROGRAM

With observing flexibility and the ability to deploy new and updated instruments, the observatory will make important contributions towards understanding a variety of astrophysical problems well into the 21st century. The SOFIA instrumentation development program will include the development of new science instruments (both FSIs and PSIs), upgrades existing SIs, and studies of instruments and technology. The second call for SOFIA science instruments is expected to be in 2011, and there will be additional calls for new instrumentation development every 3 years and the Project anticipates that there will be one new instrument or upgrade per year. The approximate funding level for the new science instrument development program will be ~$10 M/yr.

XI. SELECTED EXAMPLE SCIENCE OPPORTUNITIES WITH SOFIA

SOFIA science emphasizes four major themes: 1) The formation of stars and planets, 2) The Interstellar Medium (ISM) of the Milky Way, 3) galaxies and the Galactic Center, and 4) planetary science. Many of these studies involve objects that are hidden from view by dense layers of obscuring dust and gas. Others are at very low temperatures. SOFIA, with its diverse complement of instruments, is uniquely suited to study cool and deeply embedded objects and to determine their role in the evolution of the universe. Below, we describe detail a selected sample of the science problems from these themes that we expect will be studied to advantage with SOFIA during the early years of its mission.

A. Studies of Protoplanetary Disks

Much of our understanding about the origin of the Solar System will be gained by studying circumstellar disks in which planets may be forming around young stars. Such studies involve obtaining the spectral energy distributions (SEDs) and direct imagies at IR and submillimeter wavelengths.. SOFIA's spectrometers will provide data on circumstellar disks that will reveal their kinematics, composition, and evolution. It is generally believed that water (H_2O) plays a major role in the formation and early evolution of planetary systems. Water is the dominant reservoir of oxygen under nebular conditions so that water ice condensation will dominate the mass budget of newly-formed planetesimals. It is thought that the cores of giant planets are formed beyond the "snow line": the boundary in a disk where the temperature falls below the 170K sublimation temperature of water ice[5]. Thus, the origin and distribution of water in the inner proto-planetary disks is crucial to our understanding of the abundance of water on terrestrial planets in the habitable zones around stars. While the spatial resolution of SOFIA will be limited, the resolved line profile provides, in combination with Kepler's law, will yield the distribution of the water and other biogenic molecules in the emitting layers of the disk (see Figure 9). Observations of water lines in the 2.0 to 2.4μm window have revealed the power of such molecular line studies, but these are of course limited to very hot gas close to the protostar. The 6μm region, on the other hand, is sensitive to the warm gas in the terrestrial planet zone and near the snow line. We note that studies of the pure rotational lines (at submillimeter wavelengths) are hampered by either severe beam dilution or by telluric absorption. The strength of the lines will provide direct measurements of the temperature and column density of water in these disks.

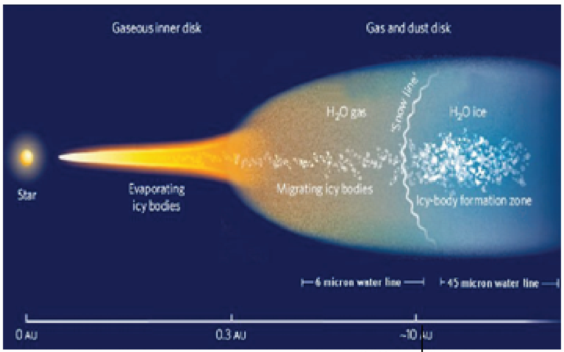
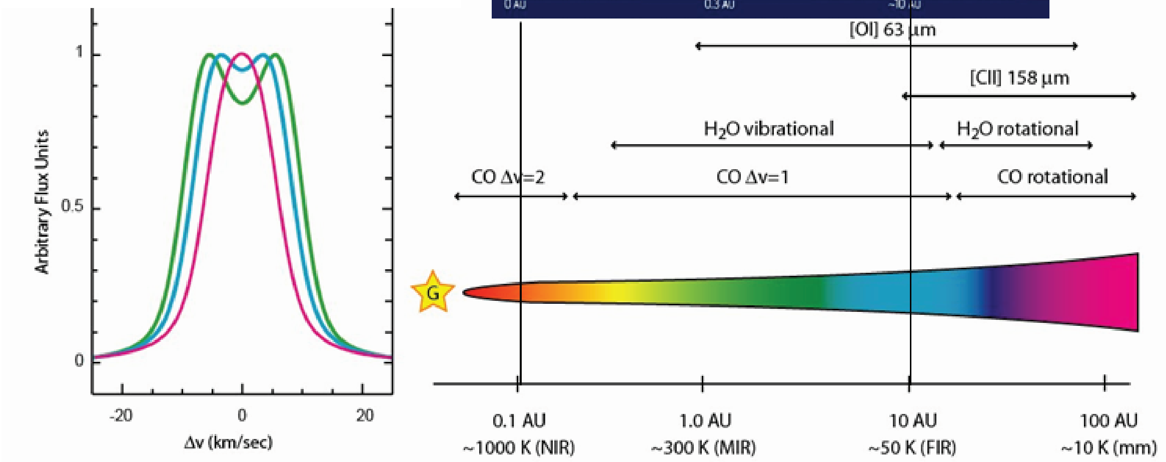


Fig.9. (**left**) A schematic diagram showing the location of the three phases of water as modified from van Boekel 2007 [6]. (**lower left**) models of velocity-resolved lines in a disk. The Doppler separation of the peaks gives the location within the disk of the chemical causing the line emission and are color coded to match the color in the schematic diagram of the disk (**lower right**) showing how lines can be used to determine the chemical structure of the disk (based on models by Kamp & Dullemond 2004)[7].



B. Star Formation and the Interstellar Medium of Galaxies

The interstellar medium (ISM) plays a central role in the evolution of galaxies as both the birth site of new stars and the repository for old stellar ejecta as shown schematically in Figure 10. The formation of new stars slowly consumes the ISM, locking it up for millions to billions of years. As these stars age, the winds from low-mass, asymptotic giant branch stars (AGB) and high-mass, red supergiants (RSG), novae, and supernovae inject products of stellar and explosive nucleosynthesis into the ISM, slowly increasing its metallicity. This constant recycling and the associated enrichment drives the evolution of a galaxy's visible matter and changes its emission characteristics. To understand this recycling, we must study the physical processes of the ISM, star formation, mass-loss from evolved stars, and the relationships of these processes on a Galactic scale. Dust and gas play a major role in these processes. SOFIA with its wide wavelength coverage and high spectral resolution capabilities is destined to play a dominant role in this field.

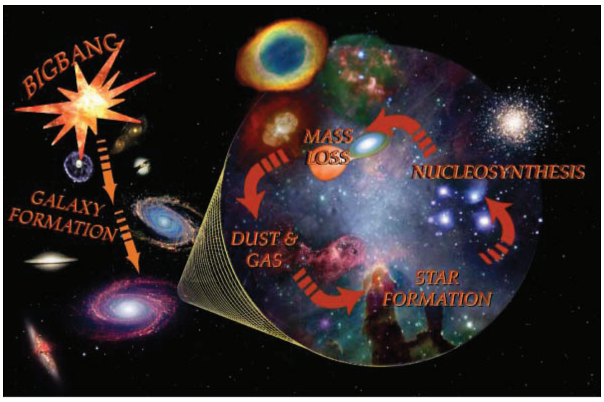


Fig. 10 Chemical Evolution of the universe (after Gehrz 2008 [8]

The 5-1000 μm spectral region accessible to SOFIA contains atomic forbidden lines, molecular ro-vibrational lines, and dust emission features that are critical for understanding the physical processes at work in regions of star formation. A typical sample of these is sown in Figure 11. At the spectral resolutions available to SOFIA, these lines can be used to study the mineralogy of the dust, abundances of elements in the gas and dust, and the kinematics of the gas phase elements.

C. The Interstellar Deuterium Abundance

Deuterium in the universe was created in the Big Bang and the primordial deuterium abundance provides the best constraint on the mass density of baryons in the universe. Its abundance provides strong constraints on the physical

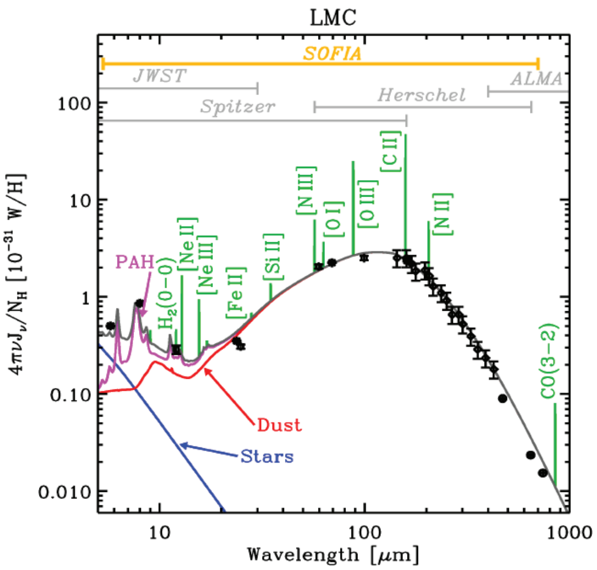


Fig.11. The spectral energy distribution of the entire LMC, based on data from Spitzer, IRAS and FIRAS [9]. SEDS are fitted with the dusty PDR model of Galliano et al. [10]. Spitzer has and Herschel will provide good photometric coverage of a galaxy's spectral energy distribution (SED) over a portion of the wavelengths. SOFIA will provide excellent wavelength coverage and spectroscopic capability across the entire SED. In the future, JWST and ALMA will provide complementary wavelength coverage and work on nearby galaxies and the most distant Universe. Figure courtesy of Galliano.

conditions during the first few minutes of the universe's expansion. However, this record of the Big Bang has subsequently been modified by stellar nuclear burning as material has been cycled from stars to the interstellar medium and back to stars during the chemical evolution of the universe by the cycle of stellar evolution (see Figure 12). Deuterium is thus potentially a key element for probing the origin and evolution of the universe as well as the star

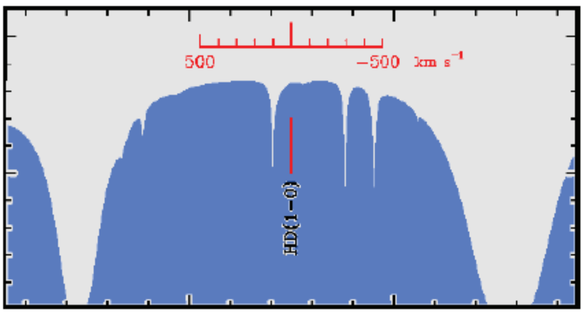


Fig. 12. Schematic representation of the atmospheric transmission around the 2.6 THz (112 µm) HD line at 40,000 feet

formation history of the universe. As pointed out by Neufeld et al. [11], HD is a proxy for the cold molecular hydrogen component of the ISM in the Galaxy, and the distribution of

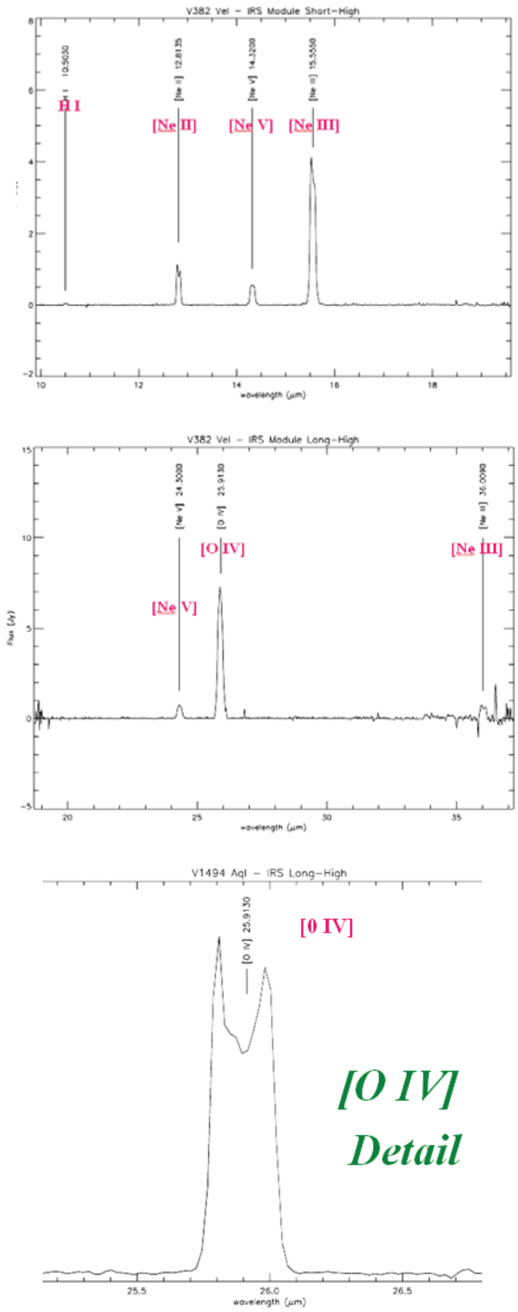


Fig. 13. (Right) Nova explosions caused by thermonuclear runaways on the surfaces of white dwarfs accreting matter in close binary systems lead to the production of Ne and O as shown the top and middle panels above in Spitzer Space Telescope IRS Short and Long-High Resolution Spectra. Abundances and kinematics (see lower panel) can be determined from the high spectra. Data from NASA/JPL/Caltech/R. D. Gehrz

deuterium in the Galaxy thus probes both stellar processing and the efficiency with which the debris of stellar evolution is mixed into the interstellar medium. HD has a much lower excitation temperature than molecular hydrogen and a dipole moment that essentially compensates for the higher abundance of molecular hydrogen. Measuring the amount of cold HD (T<50K) and therefore the deuterium abundance throughout our Galaxy can best be done by observing the 2.6 THz (112 µm)µm ground state (1-0) rotational transition line of deuterated molecular hydrogen (HD) at with SOFIA (Figure 9).

The 112 micron line can also be observed at high spectral resolution ($R>10^5$ or <3km/s) with SOFIA's GREAT spectrometer to determine the velocity structure across the Galaxy.

D. Nucleosynthesis in Classical Nova Explosions

The astrophysical thermonuclear runaways that produce classical nova explosions may play an important part in producing some of the isotopic anomalies that are present in the meteoritic and cometary debris that represent the remains of the primitive solar system [8]. Metal abundances in nova ejecta can be deduced from IR dust emission features and IR forbidden emission lines from highly ionized metals. Recent IR observations with ground-based telescopes and the Spitzer Space Telescope (Figure 13) have shown that some recent novae ejected shells that were extremely overabundant in CNO, Ne, Mg, Al, and Si. These novae also produced every known type of astrophysical dust. SOFIA will be a superb platform for observing nova explosions on several counts. First, its mobility will enable the timely monitoring of the temporal development of nova events. This requires observational capabilities that cover all possible declinations and the capability of following events that develop on time-scales of days, weeks, and months.

SOFIA's ability to observe objects close to the sun by flying a path that places the sun below the horizon will enable a continuous record of the temporal development of such events to be recorded. Second, the spectroscopic capabilities of SOFIA will enable the recording of many forbidden lines obscured by the atmosphere from ground-base observatories and unavailable to the spectrometers of other space missions.

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