IOP PUBLISHING EUROPEAN JOURNAL OF PHYSICS

Eur. J. Phys. **34** (2013) S161–S177 doi:10.1088/0143-0807/34/6/S161

SOFIA, an airborne observatory for infrared astronomy

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Received 3 May 2013, in final form 5 July 2013

Published 22 October 2013

Online at stacks.iop.org/EJP/34/S161

Abstract

The Stratospheric Observatory for Infrared Astronomy (SOFIA) is a joint US/German project operating a 2.7 m infrared airborne telescope onboard a modified Boeing 747-SP in the stratosphere at altitudes up to 13.7 km. SOFIA covers a spectral range from 0.3 μm to 1.6 mm, with an average atmospheric transmission greater than 80%. After successfully completing its commissioning, SOFIA commenced regular astronomical observation in spring 2013, and will ramp up to more than one hundred 8 to 10 h flights per year by 2015. The observatory is expected to operate until the mid 2030s. SOFIA's initial complement of seven focal plane instruments includes broadband imagers, moderate-resolution spectrographs and high-resolution spectrometers. SOFIA also includes an elaborate program for Education and Public Outreach. We describe the SOFIA facility together with its first light instrumentation and include some of its first scientific results. In addition, the education and public outreach program is presented.

(Some figures may appear in colour only in the online journal)

Program overview

The Stratospheric Observatory for Infrared Astronomy (SOFIA) is a joint project of NASA, USA and the German Aerospace Center (DLR). The NASA and DLR development and operations costs, as well as the scientific observation time, are divided into 80:20 proportions respectively. The observatory is stationed at the NASA Dryden Aircraft Operations Facility (DAOF) in Palmdale, CA, USA. The SOFIA Science Mission Operations (SMO) is located nearby at the NASA Ames Research Center, in Moffett Field, CA. The German 20% of the program is managed by the Deutsches SOFIA Institut (DSI) located at the University of Stuttgart. DSI also coordinates the German observing-time allocation procedure and supports astronomers in preparing for their granted observation time with SOFIA.

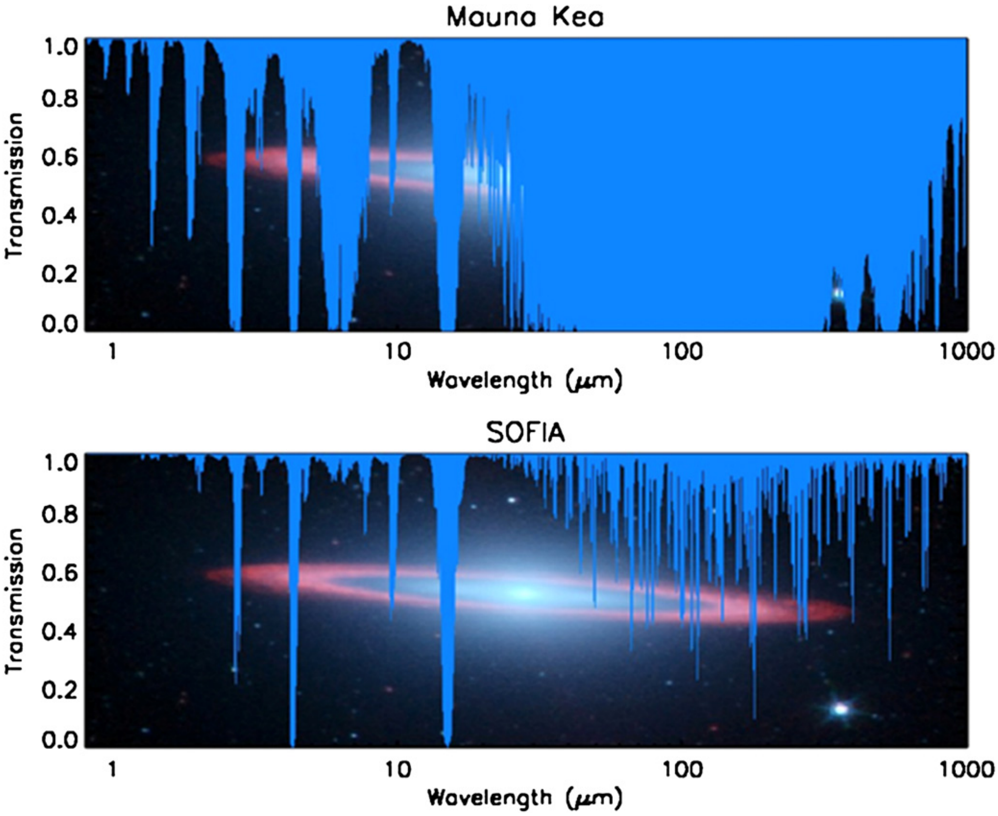

Figure 1. Typical atmospheric transmission at the SOFIA observing altitude of 13.7 km as compared with the transmission on a good night at Mauna Kea (4.2 km). Between 1 and 1000 μm, the average transmission is $\geqslant$80% except in the center of absorption lines, and is mostly due to telluric H_2O. The remaining steep absorption features at 4.3 μm and at 15 μm are due to CO_2. The background image is a Spitzer false color image of the Sombrero Galaxy (NASA/JPL-Caltech©).

SOFIA consists of a 2.7 m Cassegrain-type telescope developed by the German companies *MT-Mechatronics* and *Kayser-Threde* by order of DLR, residing in a modified Boeing 747-SP aircraft. Operated at the Nasmyth focus (using a flat tertiary mirror, see figure 4), the telescope has been optimized for infrared radiation, enabling observations of a wide variety of astronomical objects at wavelengths from 0.3 μm to 1.6 mm (Krabbe and Röser 1999, Krabbe *et al* 1999, Stutzki 2006, Gehrz *et al* 2009). SOFIA builds upon the legacy of NASA's Kuiper Airborne Observatory, a 0.9 m infrared telescope that flew between 1974 and 1995 (Gillespie 1981). SOFIA cruises at altitudes of up to 13.7 km, which is above 99.8% of atmospheric water (H_2O) vapor. The typical precipitable H_2O column depth at cruising altitude is about 10 μm, roughly a hundred times lower than at very good ground-based sites. Such a low water content enables observations in large parts of the infrared spectrum that are otherwise inaccessible from the ground. Figure 1 compares the atmospheric transmission from the operating altitude of SOFIA with that from a very good terrestrial site at Mauna Kea, Hawaii.

Education and Public Outreach (EPO) are important elements of the SOFIA mission both in the US and in Germany. Consequently, the DSI also developed an elaborate well-balanced program to present SOFIA to the public, to network with different kinds of

Figure 2. With the sliding door open showing its 17-ton infrared telescope, SOFIA soars over California's snow-covered Southern Sierras on a test flight on 14 April 2010 (NASA©).

media and to cooperate with various educational institutions. One highlight of the EPO program is the idea of flying educators on SOFIA to enable them to inspire their students even more.

The telescope resides in an open cavity in the aft section of the aircraft and views the sky through a port-side doorway (figure 2). The door has a rigid upper segment and a flexible lower segment that can be tracked together to allow the telescope to operate, unvignetted, over an elevation range of 23°–58°. The telescope is moved by magnetic torquers around a 1.2 m diameter spherical hydrostatic bearing that floats under an oil pressure of 20 atmospheres within two closely fitting spherical rings.

The travel of the bearing for azimuth tracking is only $\pm 3°$, so the aircraft heading must be periodically adjusted to keep the source within the telescope's field of view (FOV). The control deck (figure 3) in the forward part of the airplane is pressurized and air-conditioned comparable to a commercial airliner. This deck also provides access to the scientific instruments during the flight.

The first scientific observations with SOFIA happened in December 2010, followed in 2011 by 32 Early Science Flights using the mid-infrared camera FORCAST, the high-speed imaging photometer HIPO, and the German heterodyne spectrometer GREAT. Table 1 shows SOFIA's first generation scientific instruments. Currently, SOFIA is in its first regular observing cycle (Cycle 1).

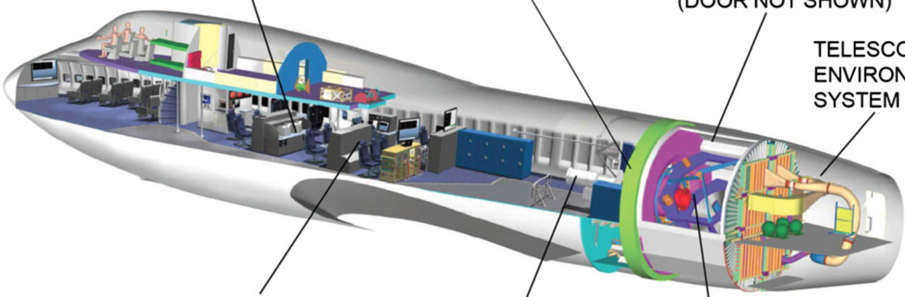

Figure 3. A cutaway schematic of the SOFIA observatory. The pressurized cabin is in front of the pressure bulkhead. The telescope looks out of the left side of the airplane. The light for the scientific instrument is fed through the Nasmyth tube, which goes through the bearing. An environmental control system prevents condensation during descent when the door is closed after a night of observations.

Table 1. The first light instruments for SOFIA.

Name	Description	Principal investigator	Institution	Wavelengths (μm)	FWHM spectral resolution
FORCAST	Mid Infrared Camera and Grism Spectrometer	T Herter	Cornell University, USA	5–40	200
GREAT	Heterodyne Spectrometer	R Güsten	MPIfR, Bonn	60–240	10^6–10^8
FLITECAM	Near Infrared Camera and Grism Spectrometer	I McLean	UCLA, Los Angeles	1–5	2000
HIPO	CCD Occultation Photometer	T Dunham	Lowell Obs. Flagstaff, USA	0.3–1.1	few
EXES	Mid-Infrared Spectrometer	M Richter	University of California, Davis, USA	5–28	3000, 10^4, 10^5
HAWC	Far-Infrared Camera	D A Harper	Univ. Chicago	50–240	
FIFI-LS	Integral Field Far Infrared Spectrometer	A Krabbe	Univ. Stuttgart	42–210	1000–3800

The telescope

The SOFIA telescope is a bent classical Cassegrain with a 2.69 m diameter parabolic primary mirror and a 0.35 m hyperbolic secondary mirror. Different from optical telescopes, where

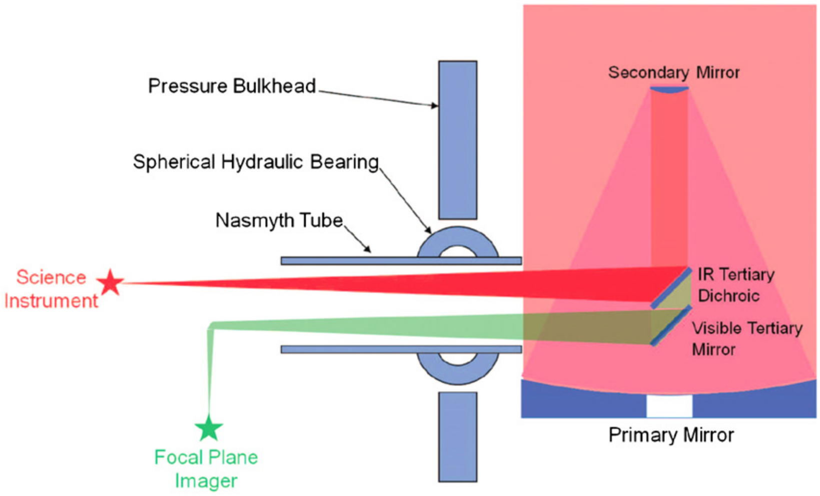

Figure 4. A schematic of the optical system of the SOFIA telescope. Everything left of the bulkhead is contained in the forward pressurized crew cabin, while everything to the right is contained in the open telescope cavity.

the secondary mirror is usually oversized, the secondary mirror of SOFIA (as well as those of most infrared telescopes) is deliberately undersized and only illuminates a 2.5 m diameter effective aperture on the primary mirror. In infrared telescopes the secondary mirror (instead of the primary) acts as the pupil stop, not only to reduce thermal background but also to allow for differential measurements on the sky (chopping) while restraining the beam to the area of the primary mirror. The secondary mirror is attached to a chopping mechanism providing amplitudes of ± 4 arcmin at chop frequencies up to 20 Hz. The unvignetted FOV is 8 arcmin. The $f/19.6$ Nasmyth infrared focus is fed by a 45° gold-coated dichroic mirror (figure 4). This dichroic mirror separates the light into a reflected infrared beam that is sent to the scientific instrument and a visible light beam that is sent to a CCD guide camera, the Focal Plane Imager. Two other imaging/guiding cameras, the Wide Field Imager and the Fine Field Imager, are used as part of the acquisition system. They are attached to the front ring of the telescope. A more detailed description of the telescope has been provided by Krabbe (2000).

The pointing of the telescope is performed more like a space telescope than a ground-based telescope. The primary reference frame for SOFIA is a set of fiber-optic gyroscopes that maintain an inertial reference frame. Once a target is acquired in the sky, its position is stabilized by these gyroscopes with occasional updates by the guide cameras. In contrast to earth-bound observations, the image sizes of point-like objects will not only be due to diffraction from the telescope optics, but also due to telescope movements in the flying plane, which leads to additional smear-out.

The telescope optics are designed to provide 1.1″ FWHM (full width at half maximum) images on-axis at 0.6 μm with diffraction-limited performance at wavelengths longer than 15 μm. However, the telescope is subject to various vibrations as well as variable wind loads in flight, which affect the telescope pointing stability and hence the delivered image quality. SOFIA has active and passive damping systems designed to mitigate some of these effects.

In the future, after the optimization of the damping systems, the rms pointing stability is expected to improve to 0.5″, which will deliver an image quality of 2.1″ FWHM at 19.7 μm.

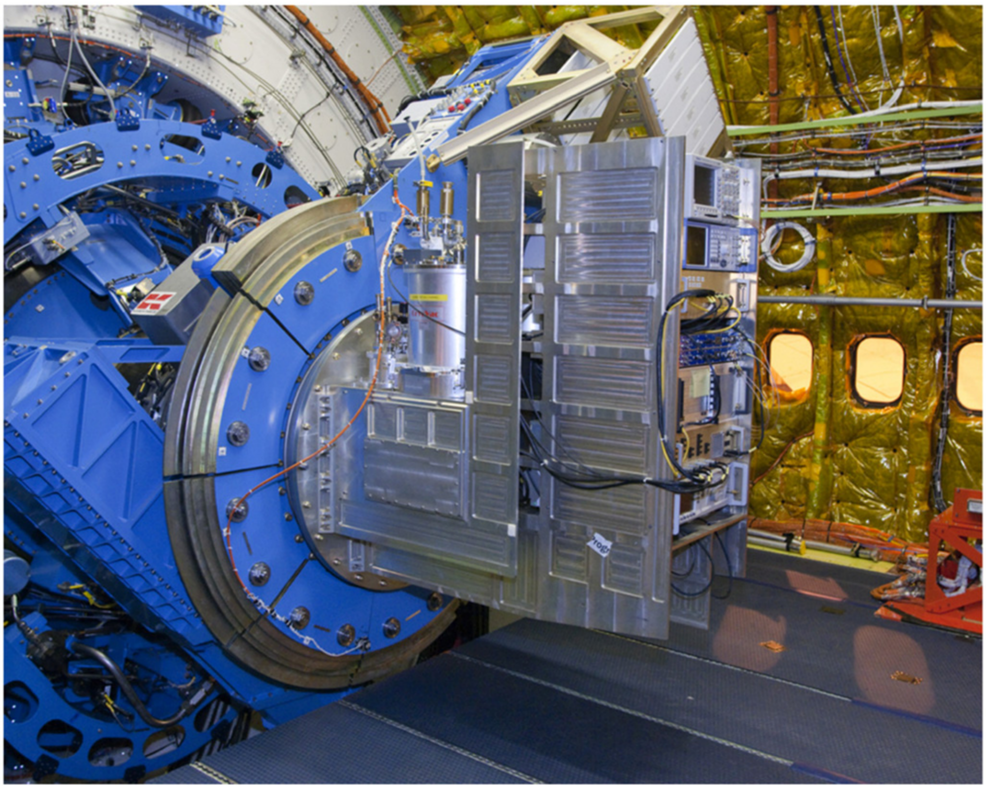

Figure 5. The German GREAT instrument mounted at the instrument port of the SOFIA telescope. GREAT can simultaneously operate two receivers, each of them housed in a separate cryostat. One of the cryostats is visible in the figure, the other one is hidden by the instrument support structure. The instrument port is surrounded by counterweight plates (GREAT Team©).

Instrumentation

One of the strengths of the SOFIA observatory over infrared satellites is the ability to change, refill and easily maintain instruments. For SOFIA, seven first-generation instruments have been developed. Three of them are near completion. Some of them are facility class instruments, which are general-purpose instruments maintained and operated by the observatory. Principal Investigator class instruments are provided and maintained by instrument teams from the astronomical community. Special-purpose instruments with specialized capabilities are also supported by such instrument teams. Table 1 provides some details of the various instruments. Two of those instruments, GREAT as well as Field Imaging Far-Infrared Line Spectrometer (FIFI-LS), have both been developed by German research institutions and are being furnished as PI class instruments.

FORCAST is described in Herter *et al* (2012), while GREAT is presented in Heyminck *et al* (2012). Both instruments were used during Early Science in 2011 for guaranteed time observations by the instrument teams and also for open programs from the astronomical community.

GREAT is a heterodyne receiver (figure 5) designed to observe spectral lines in the THz region with high spectral resolution and sensitivity. Heterodyne receivers work (like most radio receivers) by mixing the signal from a source at a given frequency ν_s with that from a local oscillator (LO) at a specified (and precisely controlled) frequency ν_{LO}, and amplifying the result. The mixing results in two frequency bands, called the signal and the image bands, located symmetrically on either side of ν_{LO} and separated from ν_{LO} by the intermediate frequency $\nu_{IF} = |\nu_s - \nu_{LO}|$. GREAT operates in double sideband mode, i.e. both the image and signal bands are equally sensitive to incoming radiation. By definition the spectral line of interest is always centered in the signal band, which can be chosen to be either above (upper side band) or below the LO frequency (lower side band). For sources rich in spectral lines, care has to be taken so that a spectral line in the image band does not overlap or blend with the line in the signal band.

GREAT is a dual-channel heterodyne instrument. The front-end unit consists of two independent cryostats, each containing one of a set of four mixers, sensitive to different specific frequencies (low, medium and high). Two mixers (one in each cryostat) can be operated simultaneously. GREAT has used the low frequency configuration for basic science, covering the frequency ranges from 1.25 to 1.5 THz and from 1.8 to 1.92 THz. The configuration includes a set of back ends consisting of two acousto-optical array spectrometers with 4×1 GHz bandwidth and 1 MHz spectral resolution, and four ultra-high-resolution chirp transform spectrometers (CTSs) with 200 MHz bandwidth and 50 kHz resolution. Each CTS can be centered on a particular line in the bandpass and is used to achieve very high velocity resolution, for example when resolving a narrow absorption line. The double sideband receiver temperatures for the low configurations are 1600 and 2000 K respectively. Recently the receiver temperatures have been successfully lowered by almost a factor of 2 in both channels, thus improving the overall sensitivity of the instrument by about a factor of 1.7 (Güsten private communication).

Two other instruments, HIPO (Dunham *et al* 2004) and FLITECAM (McLean *et al* 2006), were used on development flights on board SOFIA. The remaining three instruments, EXES (Richter *et al* 2003), FIFI-LS (Klein *et al* 2010) and HAWC (Harper *et al* 2004, Dowell *et al* 2013) are expected to be offered in a second or third annual Call for Proposals (Cycle 2 or 3). The SOFIA program also plans to introduce new instruments in future years.

FIFI-LS is the second German instrument. It is an imaging spectrograph, comprised of two medium resolution ($R \sim 2200$) grating spectrometers that feed two 16×25 pixel detector arrays, enabling simultaneous line observations within two wavelength ranges (42–110 μm and 110–210 μm). An image slicer provides spatial information, redistributing the FOV along a 25 pixel entrance slit. FIFI-LS will offer instantaneous coverage at 50–240 km s^{-1} in velocity resolution ($\Delta v/c$) over a velocity range of 1500–3000 km s^{-1} around selected lines for each of the 25 spatial pixels. See figure 6 for details.

FIFI-LS covers a wavelength range similar to that covered by two other SOFIA first-generation instruments, the heterodyne spectrometer GREAT and the FIR camera HAWC (table 1). Its spectral resolution, however, is matched to spectral lines prevailing in nearby external galaxies. FIFI-LS's imaging capabilities cover a FOV comparable to that of HAWC, however not Nyquist sampled at all wavelengths.

Operations

SOFIA is based at the NASA Dryden Aircraft Operations Facility (DAOF) in Palmdale, CA. The SOFIA Operations Center is also located at the DAOF and performs the mission operations and laboratory support for the observatory. The SOFIA Science Center is located at the NASA Ames Research Center in Moffett Field, CA. Collectively, the SOFIA Science Center and the SOFIA Operations Center combine to make up SOFIA Science Mission Operations, which is responsible for carrying out the science on SOFIA. The Science Mission Operations is jointly managed by the Universities Space Research Association (USRA) for NASA and the DSI at

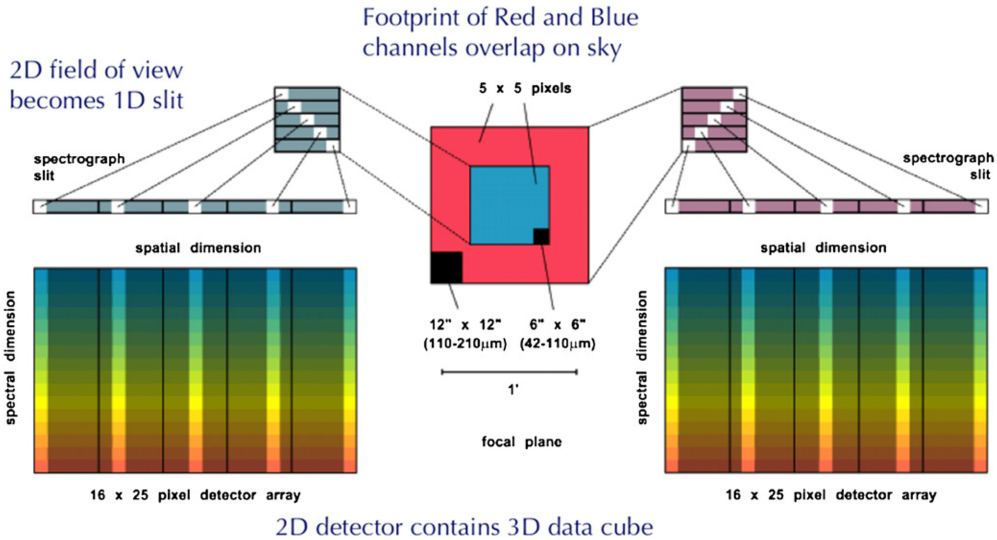

Figure 6. Imaging spectroscopy of FIFI-LS. The 5 × 5 spatial pixels in both the red and the blue channel are each optically rearranged to form a long slit before entering the red and blue grating spectrometer. The correct arrangement of the pixels will be reestablished during data reduction to form a data cube. (FIFI-LS Team©).

the University of Stuttgart, Germany, for DLR. SOFIA will mainly operate from its home base at DAOF, but will also be deployed to operate from other bases in various parts of the world, in particular, the Southern Hemisphere.

After take-off, the initial aircraft cruising altitude is 11.6–11.9 km. As fuel is burned off, the aircraft can fly higher. The performance of the aircraft allows for 6 h observing time above 12.5 km (41 000 ft), four of which can be above 13.1 km (43 000 ft). The maximum flight time under routine operations is 10 h.

During the 11 months of Early Science in 2011, SOFIA conducted 32 observational flights with more than 200 h of research time. SOFIA is expected to ultimately fly approximately 120 flights per year with 960 research hours or more.

First scientific results

The Early Science campaign resulted in more than 30 publications in US and European astrophysics journals. Two results shall briefly be presented here.

The galactic center

The center region of our galaxy is about 8 kpc away and is hidden behind a curtain of dust along the line of sight. Observations in the near and mid infrared between 1 and 30 μm have uncovered the existence of both a four million solar mass black hole (Ghez *et al* 2008, Gillessen *et al* 2009) and a stellar cluster indicating recent star-forming activities (Krabbe *et al* 1995, Eisenhauer *et al* 2005). The young stellar cluster as well as the feeding of the black hole both require a mass inflow or infall from the outside into the volume dominated by the stellar cluster and the black hole. By 1982, a molecular torus had been discovered with the Kuiper Airborne Observatory[3] (Becklin *et al* 1982 and figure 7). This pc-size torus is co-aligned with

[3] The predecessor of SOFIA.

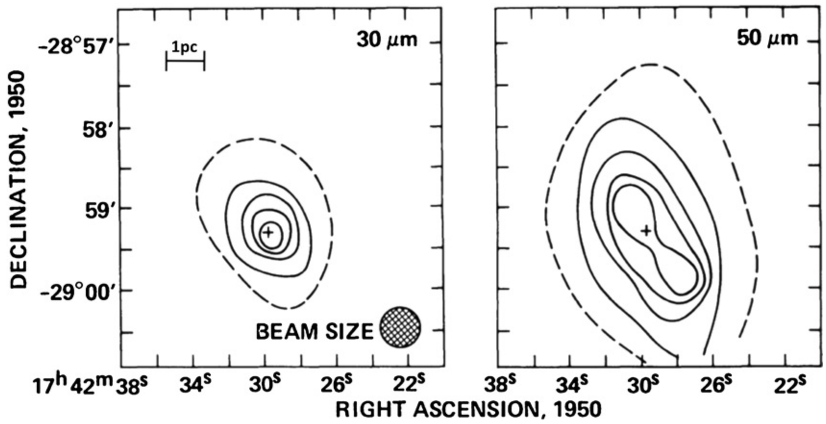

Figure 7. Discovery image of the molecular torus around the Galactic Center in 1982. Note the large effective beam size as well as the relatively poor angular resolution. The torus shape has been derived from the observation obtained at 50 μm. Reproduction from Becklin *et al* (1982).

the Galactic Center, however, it is still unclear if such a torus can provide enough material to feed the observed star formation and the black hole.

This torus was observed again with SOFIA and the FORCAST instrument in June 2011 at 19.7, 31.5 and 37.1 μm (Lau *et al* 2013). Chopping and nodding (fast and slow flips of the telescope's FOV) were used to remove variations in the sky and telescope thermal background, respectively. The quality of the images was consistent with near-diffraction performance at all wavelengths. A false color image of the observations is shown in figure 8 and demonstrates—if compared with figure 7—the advancement of data quality and angular resolution within the last 30 years of infrared observations. The ring is overlaid by streamers of gas, connecting the molecular ring with the central region at a diameter of about 1/10 pc. The molecular ring turns out to be an almost perfect circle at a radius of 1.5 pc and an inclination at 72° with respect to the plane of the sky. The thickness of the ring is only about 1/10 of its diameter, giving it the geometry of a disc rather than a torus. The emission of the disc is significantly bluer (i.e. hotter) on the inside than on the outside, which is an indication that the disc is heated from the center rather than self-heated. This is also reflected by a temperature gradient of 85–65 K apparent between the inside and the outside of the ring. The total gas mass of the ring has been estimated based on the new observations to 460 solar masses (Lau *et al* 2013). Figure 8 represents the clearest and best view ever of this structure. Follow-up observations with SOFIA will now clarify whether there is a mass flow through the ring.

Discovery of interstellar mercapto radicals (SH)

Only a handful of diatomic hydrides have been discovered in the interstellar gas so far: OH (Weinreb 1963), H_2 (Carruthers 1970), HCl (Blake *et al* 1985), NH (Meyer and Roth 1991), HF (Neufeld *et al* 1997) and (tentatively) SiH (Schilke *et al* 2001). Since diatomic hydrides represent the simplest of interstellar molecules, they may provide key information about the interstellar environment. For example, the rate of cosmic ray ionization is reflected in the OH^+ abundance while the CH^+, OH and SH^+ abundances probe the influence of shocks and turbulent dissipation, which, for example, heat the interstellar gas (Neufeld *et al* 2012).

The mercapto radical SH is expected to show a strong abundance enhancement in warm regions that are heated by shocks or turbulent dissipation, but so far has escaped detection. From its ground state, SH can be excited via the $^2\Pi_{3/2}\ J = 5/2 \leftarrow 3/2$ lambda doublet near

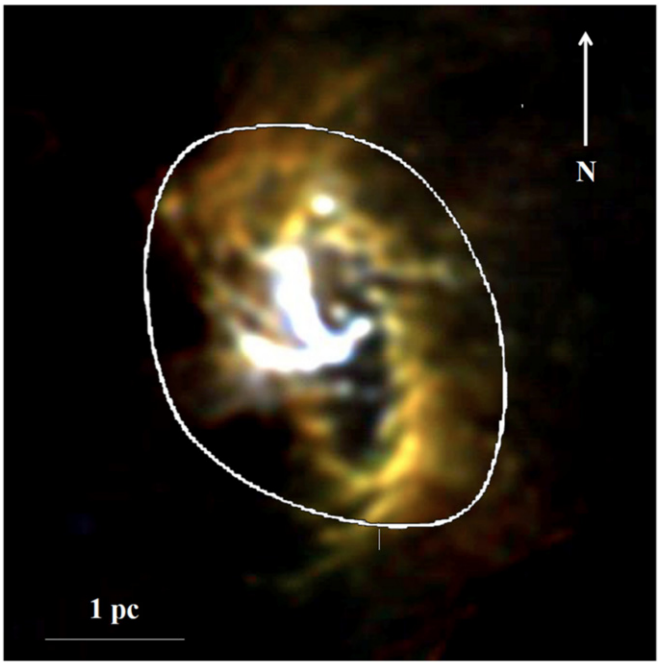

Figure 8. SOFIA/FORCAST false-colour mosaic image of the inner 6 pc of the Galactic Center at 19.7 (blue), 31.5 (green), and 37.1 μm (red). The Circum Nuclear Ring is the cool, reddish ring enclosing the hotter Northern Arm and East–West Bar, both reproduced in white. The outermost non-dashed contour line from figure 7(a) is overplotted for reference. Reproduced from Lau *et al* (2013).

1383 GHz. This frequency is not only totally inaccessible from the ground, it also falls between the bands of the heterodyne spectrometer HIFI onboard the Herschel satellite. Consequently, this spectral region was observed with SOFIA using the upper sideband of the German GREAT instrument Channel L1 receiver. The observations of the $^2\Pi_{3/2}$ $J = 5/2 \leftarrow 3/2$ were carried out on 28 September 2011 toward the submillimeter continuum source W49 N.

The W49 N region is one of the most luminous regions of active star formation in the Galaxy. At a distance of 11.4 kpc it generates a total bolometric luminosity of 6.8×10^6 solar luminosities. Because of extremely high extinction at visible wavelengths, this region can only be studied at radio and infrared wavelengths. Maps of W49 N in the infrared at 53 μm (Harvey *et al* 1977) showed a number of separate condensations, each of which is coincident with a radio continuum source (Wynn-Williams 1971, Webster *et al* 1971). Due to the intense star-forming activities, W49 N was one of the most ideal candidates for such observation.

Figure 9 shows the result with the frequency scale corrected to the Local Standard of Rest (LSR, corrected for the movement of the Earth relative to the Sun). Absorption by SH is clearly detected in the range $v_{\rm LSR}$ 5–20 km s^{-1}, near the systemic velocity of the source. In addition, a narrow absorption feature is detected near $v_{\rm LSR}$ $\sim$39 km s^{-1}, which arises in a foreground cloud unassociated with W49 N (Neufeld *et al* 2012). Comparing their results for the foreground cloud with ancillary observations of the 1_{10}–1_{01} 168.763 GHz transition of H_2S for the same cloud, using the IRAM 30 m telescope located on Pico Veleta near Granada (Spain) in December 2006, the authors find a SH/H_2S ratio of 0.13. This value is significantly smaller than what was to be expected from the OH/H_2O ratio $\sim$1.0 observed by SOFIA for this absorbing cloud (Wiesemeyer *et al* 2012).

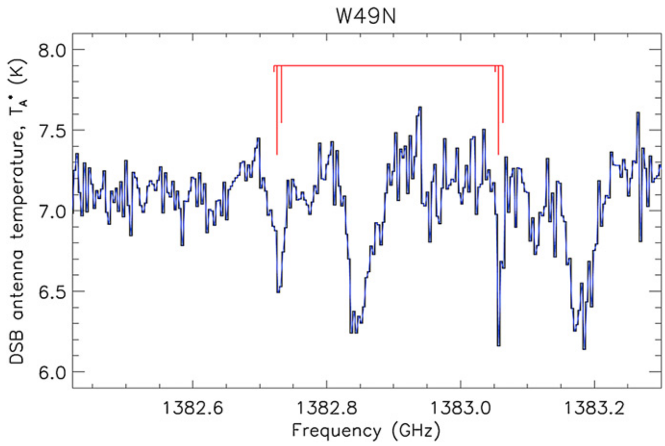

Figure 9. Spectrum of SH $^2\Pi_{3/2}\ J = 5/2 \leftarrow 3/2$ obtained by GREAT toward W49N. The lambda doubling and hyperfine splittings are indicated by the red bars for a component at an LSR velocity of 40 km s^{-1}. Reproduced from Neufeld *et al* (2012).

Although the discrepancy between the observed abundance ratio between SH and H_2S and the models was unexpected, it marks the path towards a deeper understanding of sulfur chemistry in photon-dominated regions and doubtlessly requires further investigations with SOFIA.

Education and public outreach

A special feature of the SOFIA project is its elaborate program for EPO both in the US and in Germany. SOFIA is an interdisciplinary project involving natural and engineering sciences of various disciplines, namely physics, astronomy, aerospace engineering, construction engineering, chemistry and biology. Thus, it is capable of inspiring a wide range of public interest. DSI has developed the German EPO program in close collaboration with partners within SOFIA, such as DLR, NASA, and USRA, as well as with several external partners from industry plus research and educational institutions. The main milestones that have already been reached, as well as upcoming projects and vision, will be outlined here.

Public outreach

The vision for the public outreach activities is to provide a wide range of tools to present SOFIA at various events—not only by DSI itself but also by partners and appropriate external organizations. Therefore DSI developed several kinds of display modules, for example models of the SOFIA telescope and aircraft at different scales, plus a mobile exhibit booth. An original-size air spring was even provided by one industrial partner to accompany the booth. Twenty-four of these air springs are implemented in the bulkhead to decouple the telescope from the vibrations of the aircraft and thus provide the foundation for the required pointing stability of the flying observatory.

In cooperation with Expo-Star GmbH, SOFIA was also included in the ESA exhibition 'Augen im All' (Eyes in the Universe; see figure 10) and is operated on demand in Germany, Austria and Switzerland.

The major DSI public outreach highlight to date was SOFIA's visit to Stuttgart in September 2011 (see figure 11). More than 2000 partners and public visitors enjoyed a tour to

Figure 10. SOFIA module in the ESA exhibition 'Augen im All' (Expo-Star GmbH©).

Figure 11. SOFIA at the Airport Stuttgart from 19–21 September 2011 (DSI©).

and through the SOFIA aircraft conducted by DSI engineers, technicians and scientists, sharing their own experience with the public: telescope engineers explained and demonstrated how to move the telescope and control its pointing stability. Technicians elucidated how they helped improve the telescope's capabilities. Scientists considered how they could take advantage of this flying observatory to promote their knowledge of star formation, planetary science or the

Figure 12. DSI staff explaining the SOFIA project to fascinated siblings visiting the BIAS 2012 with their parents (DSI©).

Galactic center. Flight engineers shared their experiences regarding how to fly an aircraft with a 4×4 m^2 hole in its fuselage. Instrument scientists pointed out how they want to raise the efficiency of their respective detectors.

SOFIA is expected to return to Germany and Stuttgart occasionally. Whenever this happens, DSI plans to offer similar SOFIA tours and events. Following a decade-long tradition, DLR and DSI will also continue to present the SOFIA project at the Berlin International Air Show (BIAS) every other year (see figure 12). If compatible with the project schedule, the SOFIA aircraft itself might also show up at the BIAS.

Educational outreach

One central goal of the DSI EOP is to connect the SOFIA project with schools and educational institutions all over Germany. The vision that is driving this idea is to reach out to potential future academics, engineers or technicians while they are still young. Hence, within the last couple of years, DSI established a nationwide network of 35 partner schools, representing all federal states. These partner schools usually sponsor an astronomical working group and often own a small ground-based optical observatory or telescope. Through all their activities the partner schools are advised and supported by the DSI team. Reciprocally, the partner schools deliver valuable contributions to the project's public and educational outreach work during public 'open house' days, offering workshops for colleagues or pupils and helping with other types of relevant events. Meanwhile the partner schools are cooperating closely together, mainly independently of DSI, on a number of SOFIA-connected topics such as infrared spectroscopy, astrobiology, multi-spectral imaging or aerodynamics.

Figure 13. Infrared kit for schools (DSI©).

Infrared astronomy in the classroom. In cooperation with *Wissenschaft in die Schulen*[4] DSI developed an infrared kit (see figure 13) consisting of 14 experiments, starting with a remake of the historical Herschel experiment to envision how infrared 'light' has been detected. After visualizing the electromagnetic spectrum from the optical to the infrared range by means of the so called 'Spektrino', the other experiments cover the near, the mid and the far infrared part of the electromagnetic spectrum and their applications for astronomy. The explorer will detect that a common remote control emits near infrared signals that can be observed by an ordinary cell phone camera. Different properties of infrared radiation (reflection, absorption and transmission) can also be investigated. These experiments demonstrate how such knowledge can help students to understand the dusty process of star formation or how the atmospheres of exoplanets may be explored.

The DSI partner schools tested the experiments with respect to their feasibility in classrooms before they were released. Also, all partner schools were equipped with their own IR kit, and some additional kits are available for all schools and educational institutions to be borrowed from DSI.

Flying educators. The most exciting feature of the DSI educational outreach program is the SOFIA German Ambassador program, which is mainly a concept for flying educators! Educators all over the nation can apply to participate in one of SOFIA's observing flights. The vision behind the SOFIA German Ambassador program is to connect teachers closely with

[4] I.e. Science into Classrooms.

Figure 14. From left to right: Wolfgang Vieser (German teacher), Cecilia Scorza (DSI), Jochen Eislöffel (German scientist) and Jörg Trebs (German teacher) (DSI©).

Figure 15. From left to right: US educator Constance Gardner, Vincent Washington, Chelen Johnson, Ira Harden flying on SOFIA on 12 February 2013, watching SOFIA data displayed at the EPO console (USRA©).

scientists, engineers and technicians in order to enable the educators to inspire their students and pupils even more. The personal experience of flying on SOFIA and witnessing how the different components of this extraordinary platform combine forces to reveal the secrets of the universe is expected to be a key experience enabling the educators to inspire future generations.

The first two German educators flew on SOFIA in July 2011 (see figure 14). From their experience DSI is developing a general concept to select the best candidates for flying educators, to prepare them optimally for their flights, and finally for them to fly. DSI is aiming at lasting positive effects not only for the teachers, but also for their students. The US partners began routinely flying educators in February 2013 (figure 15), while DSI will catch up, flying educators routinely in the fall of 2013 with plans to ramp up to eight German educators per year by 2015.

Online information about SOFIA can be found on the pages of several organizations contributing to SOFIA.

www.nasa.gov/mission_pages/SOFIA/index.html
www.dlr.de/rd/desktopdefault.aspx/tabid-2448/3635_read-21374/
www.sofia.usra.edu/
www.dsi.uni-stuttgart.de/

Acknowledgments

The authors wish to thank the FORCAST and the GREAT teams for their enthusiastic support of the flying educator program. DM wishes to thank D Backman for helpful discussions and AK wishes to thank R Güsten for useful comments. SOFIA, the Stratospheric Observatory for Infrared Astronomy is a joint project of Deutsches Zentrum für Luft- und Raumfahrt eV (DLR; German Aerospace Centre, grant: 50OK0901) and National Aeronautics and Space Administration (NASA). It is funded on behalf of DLR by the Federal Ministry of Economics and Technology based on legislation by the German Parliament, the State of Baden-Württemberg and the University of Stuttgart. Scientific operation for Germany is coordinated by the Deutsches SOFIA-Institut (DSI) of the University of Stuttgart, in the USA by the Universities Space Research Association (USRA).

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