SOFIA
Stratospheric Observatory for Infrared Astronomy

Summary

In the past astronomers have used the 91 cm telescope of NASA's Kuiper Airborne Observatory (KAO) to obtain astronomical data in the infrared regime, which is inaccessible to ground based observatories. One of the outstanding results of KAO measurements was the discovery of the rings of Uranus. With the KAO reaching the end of its design lifetime and the infrared regime still largely unexplored, scientists of the United States of America and Germany demonstrated the need to develop a future even more capable airborne platform for infrared astronomy: with 3-times better angular resolution, a 10-fold increased sensitivity and high spectral resolution this airborne observatory will address fundamental questions in galactic and extragalactic astronomy and the origin and evolution of the solar system.

Thus NASA and the German Aerospace Center (DLR) agreed to jointly develop a new observatory called SOFIA (Stratospheric Observatory for Infrared Astronomy). The cooperation and responsibilities between NASA and DLR have been mutually agreed in a Memorandum of Understanding stating the distribution of tasks and responsibilities during the development and the operations phase. Germany provides the telescope assembly and contributes 20% to the operations, thereby receiving 20% of the observation time for German science institutes. NASA provides, refurbishes and modifies the airplane and operates the observatory from its home base in southern California.

The characteristic feature of the modified 747SP is the large opening at the port side of the aft fuselage covered by a protecting door. At observing altitudes between 39.000 and 45.000 ft. the door slides open and allows the telescope a nearly unobstructed view of the celestial sky. The absorption by telluric water vapour is significantly reduced at those altitudes, which otherwise prohibits infrared radiation from celestial objects to reach ground based telescopes.

After being pre-assembled and tested in Germany the telescope was air-shipped to the integration site in Waco, Texas. After integration into the modified 747SP and thorough tests on the ground SOFIA had its maiden flight on April 26, 2007. Following its ferry flight to the NASA Armstrong Aircraft Operations Facility in Palmdale, California, SOFIA entered an extensive flight test program.

With the first science flight in December 2010 SOFIA started its observation phase. Since then the German instruments GREAT and FIFI-LS and the U.S. instruments FORCAST, HIPO, FLITECAM, EXES and HAWC+ have been successively put into operation. In 2013 a first deployment to New Zealand to observe the southern hemisphere was successfully conducted. This is now a yearly event for SOFIA. The observatory will operate for a 20 year lifetime, conducting approx. 120 astronomy missions per year – with 8 science hours each. About 50 science teams, selected by annual peer review, will use the 6-8 available instruments per year.

SOFIA offers frequent flight opportunities, easy to change state-of-the-art instruments and hands-on training of young scientists. Thus a broad participation by the science-community is ensured. The flexibility of SOFIA also provides worldwide access to short-term observing targets of opportunity. Due to the relatively short times for instrument development SOFIA will offer an excellent test bed for future space missions.

SOFIA test flight with open door and exposed telescope high above the Mojave Desert in southern California. Picture: NASA-AFRC.

The SOFIA-telescope-assembly was designed, built and delivered to the U.S. under a DLR contract with the German companies MAN-Technologie (MT-Mechatronics, now OHB-Systems) and Kayser-Threde (KT, now OHB-Systems). Dozens of European companies contributed to the development of the telescope-assembly under subcontracts with MAN/KT
In 2014 SOFIA was due for a major maintenance milestone. Under a DLR contract with Lufthansa Technik AG (LHT), SOFIA was completely overhauled during a five month layover at the LHT maintenance facility in Hamburg/Germany.

For the provision of the German contributions to the SOFIA Operations Center in the U.S., DLR signed a contract with the University of Stuttgart in November 2004 for the creation of the Deutsches SOFIA Institut (DSI). Besides the provision of personnel, spare engines, telescope spares and fuel for the flights dedicated to German scientists, the DSI is responsible for the science coordination and representation in Germany and for education and public outreach. The state of Baden-Württemberg contributes substantially to the funding of the DSI.

Scientific Objectives

As already demonstrated by the KAO and by the satellites ISO (Infrared Space Observatory), Spitzer and Herschel infrared radiation characterizes a multitude of rich and varied physical processes, and reveals astronomical phenomena occurring in regions of the cosmos normally hidden behind dense dust clouds. SOFIA will exploit and extend this scientific legacy by means of high spectral and spatial resolution observations spanning the infrared domain. Topics to be addressed by SOFIA scientists include:

* Physics and chemistry of interstellar molecular cloud and embedded star formation in our galaxy
* Proto-planetary disks and planet formation in nearby stellar systems
* Origin and evolution of biogenic atoms, molecules, and minerals
* Composition and structure of planetary atmospheres and rings, and comets
* Star formation, dynamics, and chemical content of other galaxies
* The dynamic activity in the center of the Milky Way.

In addition to science, SOFIA is a major factor in the development of observing techniques, of instrumentation and of education of young scientists and teachers in the discipline of infrared astronomy and in the area of public outreach.

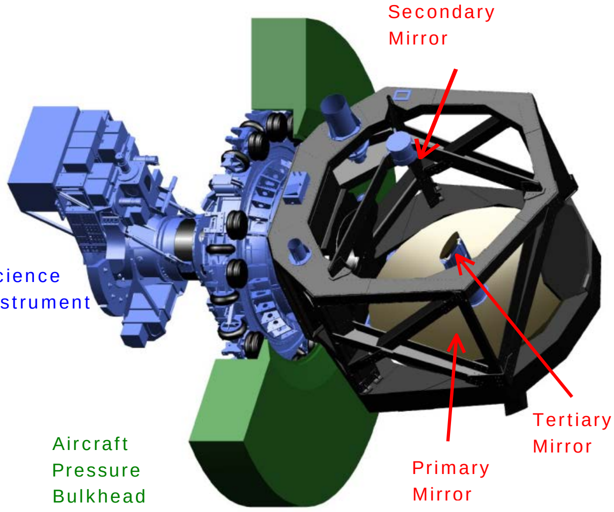
Key Characteristics of SOFIA

Start of Development phase:	January 1997
Start of flight testing:	2007
Begin of science operations:	December 2010
Design lifetime:	20 years
Number of observing flights per year:	approx. 120
Telescope platform:	Boeing 747SP open cavity on port side of aft fuselage
Cruising altitude:	37,000 to 45,000 ft.

Observing time at 41,000 ft. or higher:	ca. 8 hours
Total Research Flight Hours per year:	ca. 1000 hours
Ambient temperature in the cavity:	210 to 330 K
Operation crew:	3 on flight deck 15-30 operators/technicians/scientists
Home base:	Armstrong Aircraft Operations Facility Palmdale, California, regular deployments to southern hemisphere

Key Telescope Characteristics

Weight of telescope: ca. 45.000 lb.
Configuration: Cassegrain-telescope with Nasmyth focus, permanent access to science instrument from cabin
Structural layout: Carbon fiber-structure in dumbbell configuration with trusswork metering tube
Rotation isolation system: spherical hydrostatic bearing with 2 rings, 1,200 mm diameter, 10-30 bars hydraulic pressure
Rotation drive system: gear drive for coarse elevation, and brushless DC spherical segment motor drives for fine elevation, cross-elevation and line-of-sight (L.O.S.)
Vibration isolation system: 12 air spring elements radial and 12 tangential/axial elements and 3 damper elements
Primary mirror (PM) : diameter 2.70 m, effective aperture 2.50 m, lightweighted ZERODUR structure on 18-point whiffle-tree support, PM ratio f/1.28, aluminum coated
Secondary mirror (SM) : from Silicon-Carbide (SiC) material, 352 mm diameter, aluminum coated
SM functions: focus, alignment, chopping (2-axis in arbitrary directions, offset, three point, stationary)
Tertiary mirror(TM) : 2 flat mirrors, dichroic (gold coated) and non-dichroic (aluminum coated)
System focal ratio: f/19.6
Wavelength range: 0.3 to 1,600 microns
Unvignetted field of view: 8 arcminutes
ranges of motion: elevation 15-70^0 (20-60^0 unvignetted), cross-elevation and L.O.S. ± 3.0^0
Image quality: 80% energy in 1.5 arcseconds circle
Image stability: 0.8 arcseconds at begin of operation, with the goal of 0.2 arcseconds



German Science Instruments under development

Instrument-Name	Frequency-/Spectral Ranges	Institutes
GREAT (German Receiver for Astronomy at Terahertz Frequencies)	Channel 1: 1.25 - 1.50 THz (240 - 200 µm) Channel 2: 1.82 - 1.92 THz (165 - 156 µm) Channel 3: 2.40 - 2.70 THz (125 - 111 µm) Channel 4: 4.70 THz (63 µm)	MPIfR, Bonn University of Cologne DLR-PF, Berlin / TU-Berlin
FIFI LS (Far-Infrared Field-Imaging Line Spectrometer)	Channel 1: 1.43 – 2.72 THz (210 - 110 µm) Channel 2: 2.72 – 7.15 THz (110 - 42 µm)	IRS, Stuttgart

Points of Contact

DLR
RD-RX
Heinz-Theo Hammes
Postfach300364
53183 Bonn
Germany

Deutsches SOFIA Institut
Universität Stuttgart
Prof. Alfred Krabbe
Pfaffenwaldring 29
70569 Stuttgart
Germany

http://www.dlr.de/sofia
http://sofia.arc.nasa.gov
http://www.sofia.usra.edu
http://www.irs.uni-stuttgart.de

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