SOFIA CYCLE 2 SCIENCE STATUS AND TARGETS OF OPPORTUNITY

Helen J. Hall[1], Erick T. Young[1], Hans Zinnecker[2],[3]

[1]*SOFIA Science Center, Universities Space Research Association, NASA Ames Research Center MS 232-12, Moffett Field, CA 94035, USA*

[2]*SOFIA Science Center, NASA Ames Research Center, MS 232-12, Moffett Field, CA 94035, USA*

[3]*Deutsches SOFIA Institut, Universität Stuttgart, Pfaffenwaldring 29, D-70569 Stuttgart, Germany*

ABSTRACT

SOFIA, the Stratospheric Observatory for Infrared Astronomy, is a joint project between NASA and the Deutsches Zentrum für Luft-und Raumfahrt (DLR) to provide a 2.5-m telescope that flies at stratospheric altitudes. Access to large parts of the otherwise obscured infrared spectrum is enabled. SOFIA covers a unique niche of wavelengths from 30 – 300 microns not observable from the ground. SOFIA just achieved its Full Operational Capability (FOC) level 1 milestone and is successfully conducting science. This year two more Science Instruments were commissioned, the FIFI-LS line spectrometer, and the EXES high resolution spectrometer. In this paper we present the current highlights from Cycle 2 depicting targets of opportunity enabled by a moveable platform.

Key words: infrared: Cycle 2, Targets of Opportunity (ToO)

1. INTRODUCTION

The Stratospheric Observatory For Infrared Astronomy (SOFIA) is a joint project of the National Aeronautics and Space Administration, USA (NASA) and the German Aerospace Center (DLR). SOFIA consists of a German-built 2.5-meter telescope mounted in a modified Boeing 747-SP aircraft supplied by NASA. Operations costs and observing time are shared by the United States (80%) and Germany (20%). Flying at altitudes up to 45,000-feet, SOFIA observes from above more than 99 percent of Earth's atmosphere water vapor, thereby opening windows to the universe not available from ground-based telescopes. SOFIA can observe at wavelengths from 0.3 μm to 1.6 mm. Depending on funding, approximately 1000 high-altitude observing hours could be offered to the science community per year and the observatory will operate for 20 years. [1] The Universities Space Research Association (USRA) and the Deutsches SOFIA Institute (DSI) from the University of Stuttgart are the science mission contractors. Science flights originate from the NASA Armstrong Flight Research Center (AFRC) in southern California and the science center is located at the NASA Ames Research Center (ARC) near San Francisco.

Five of the current suite of seven SOFIA instruments were developed in the US and two were developed in Germany providing multiple imaging and spectroscopic capabilities. The instruments are primarily divided into two classes. The Facility Science Instruments (FSI)s are supported by the SOFIA Science Mission Operations (SMO) organization which is made up of USRA and the DSI. The FSIs are maintained at Building 703 in Palmdale for General Investigator (GI) use. Principal Investigator (PI) class science instruments are also available for GI use, but will be supported by the respective instrument PIs, better facilitating future instrument upgrades. [2]

Table 1

SOFIA First Generation Instruments

Name	Description	PI	Institution	Wavelengths (μm)	Spectral Resolution
FORCAST	Mid-infrared Camera and Grism Spectrometer	T. Herter	Cornell	5-40	200
GREAT	Heterodyne Spectrometer	R. Güsten	MPIfR	60-240	10^6-10^8
FLITECAM	Near-infrared Camera and Grism Spectrometer	I. McLean	UCLA	1-5	2000
HIPO	CCD Occultation Photometer	T. Dunham	Lowell Obs	0.3-1.1	
EXES	High Resolution Mid-infrared Spectrometer	M. Richter	UC Davis	5-28	3000, 10^4, 10^5
HAWC+	Far-infrared Camera and Polarimeter	C.D. Dowell	JPL	50-240	
FIFI-LS	Integral Field Far-infrared Spectrometer	A. Krabbe	U Stuttgart	50-200	1000-3750

Note: Details available at http://www.sofia.usra.edu/Science/instruments [3]

2. TARGET OF OPPORTUNITY AND DIRECTOR'S DISCRETIONARY TIME

SOFIA has three types of programs that are offered in the Cycle 3 Call for Proposals (CfP): Regular Programs, Survey Programs, and Target of Opportunity (ToO) Programs. Regular Programs are observations of specific targets with known positions and timing constraints. Survey programs are intended to allow studies of a target class, as well as provide the SOFIA project flexibility in flight planning. These programs should identify a sample of targets and observations with a common scientific justification. ToO programs can be for known targets, but unknown timing of the observations. Examples are known novae, and periodic variables. Also, ToO programs are for unknown targets and/or unknown timing, such as new comets, new (super) novae, etc. For ToO observations, the proposer should discuss the triggering criteria, the required turn-around time between the triggering and observation, and any other timing constraints. Since SOFIA can only observe with a single instrument at a time (with the exception of the co-mounting of HIPO and FLITECAM), rapid turn-around ToO requests with a specific instrument may be difficult to implement. So the ToO proposals should address the viability of observing the event/target with any of the SOFIA instruments. Data proprietary period is one year for ToO. [4]

Out of the science research hours, 7% are set aside as Director's Discretionary Time (DDT). These are observations outside the normal call for proposal period. These observations are typically for extraordinary and unique events. The proposer should provide a brief science case and send it to the SMO Director. These data will have no proprietary period.

The Cycle 3 Call for Proposals (CfP) solicited proposals for approximately 450 US hours and up to 50 German hours of observing from March 2015 through February 2016. The call was issued in May 2014 by USRA. Funding to support the selected applicants are issued through USRA. The total GI funding through Cycle 3 is approximately \$1.6 M. [5]

All the Science Instruments (SI)s listed above are available for Cycle 3 except HAWC+.

3. CURRENT SCIENCE HIGHLIGHTS

Recently a series of observations were taken on the Supernova SN2014J in M82 in DDT. Per SOFIA's news release astronomers estimate that the first light from the SN2014J explosion reached Earth during the night of January 14, 2014, but was first noticed on January 21st by a group of students at the University of London Observatory. SOFIA's supernova studies were accomplished using DDT described above. [6]

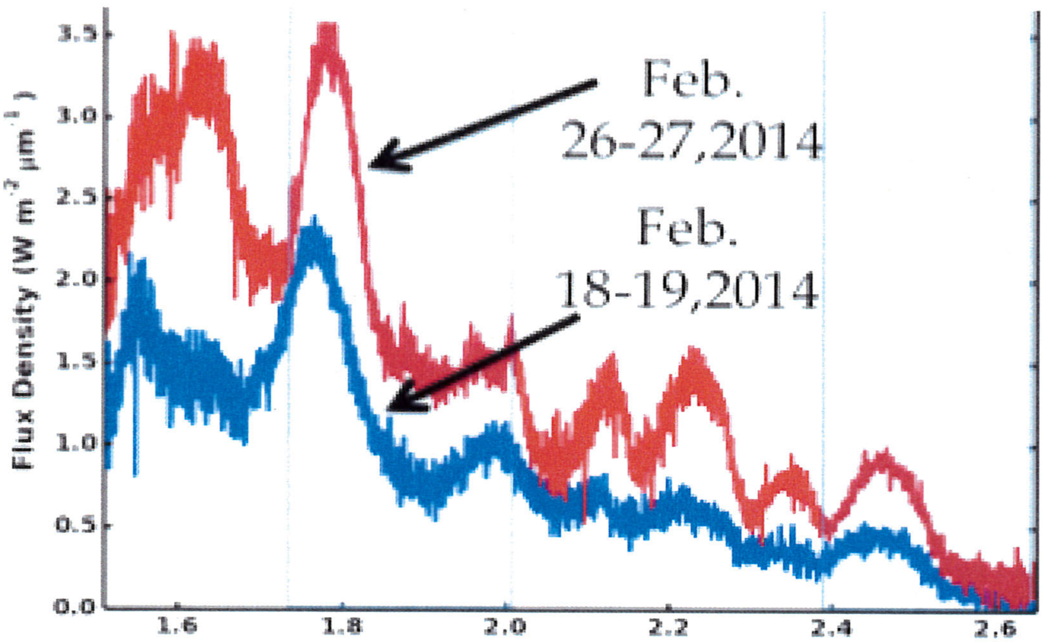
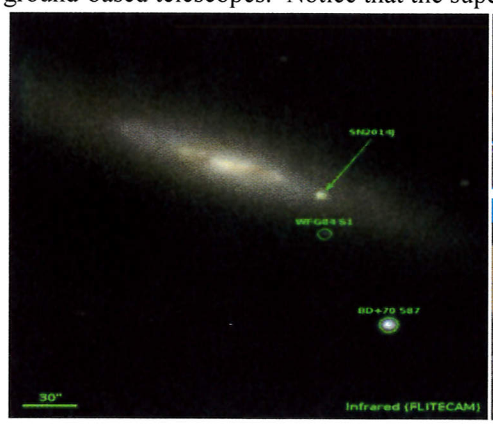


Fig. 3 – Spectrum by SOFIA/FLITECAM taken two weeks apart of SN2014J with FLITECAM and HIPO mounted together. The observations were made using grisms. The blue bands represent wavelengths that are not visible from ground-based telescopes. Notice that the supernova brightened over the course of one week. [7]



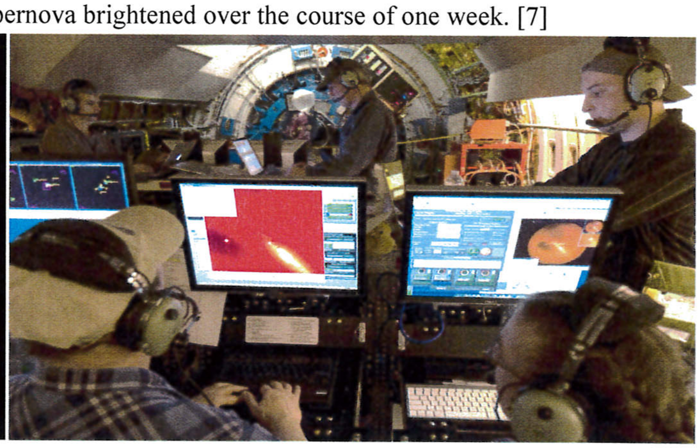


Fig. 4 FLITECAM image of SN2014J, photo Credit: S. Shenoy

Another interesting image taken during the series of flights in February was NGC 2024 in Paschen-α at 1.875 μm. This was taken to demonstrate FLITECAM's ability to observe wavelengths typically obscured by water vapor at lower altitudes, as well as its ability to perform imaging of extended objects. FLITECAM also takes advantage of the entire SOFIA field of view (diameter ~ 8'). [8]

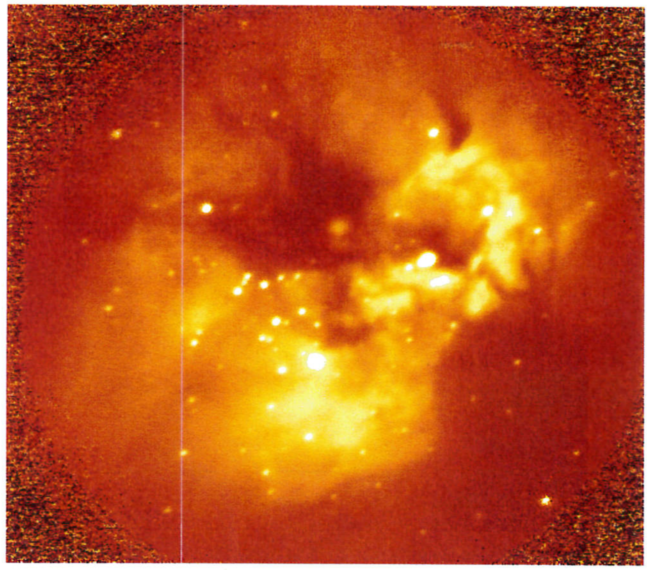


Fig. 5 – FLITECAM Image of NGC 2024, the Flame Nebula

=

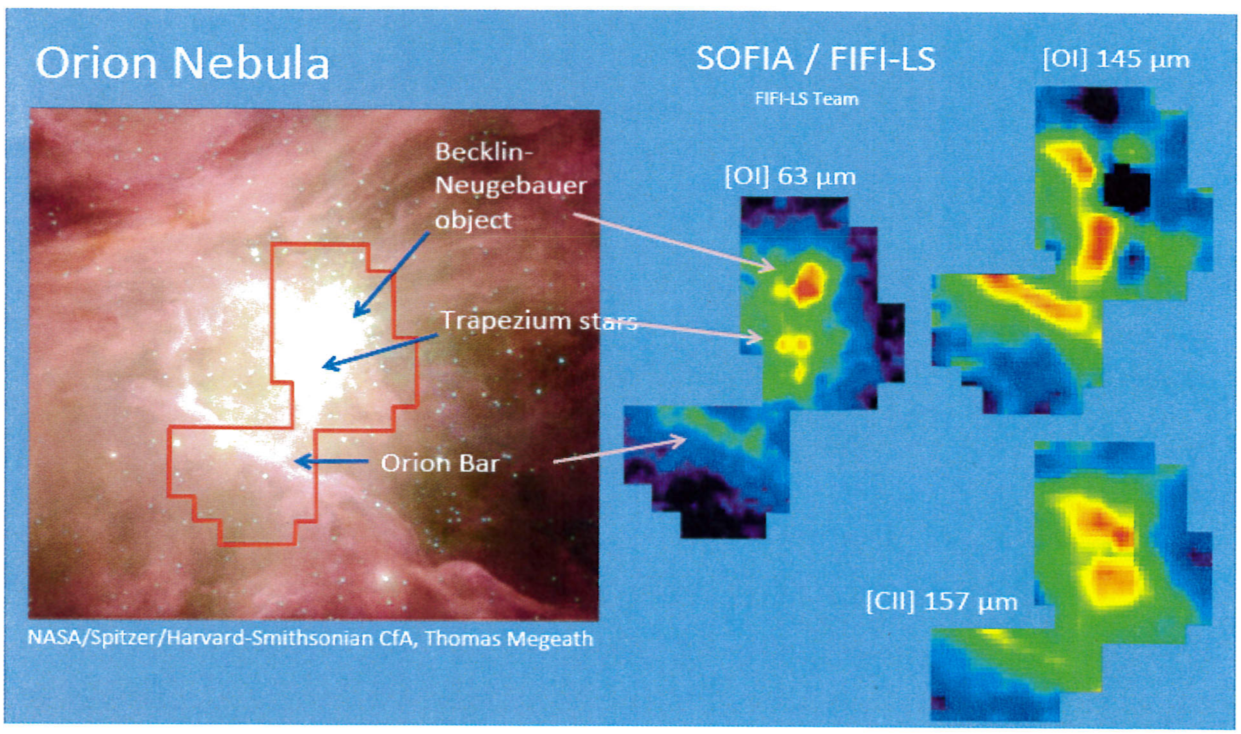


Fig. 6 – Right: The Becklin-Neugebauer object, the Trapezium stars, and the Orion Bar observed using FIFI-LS at wavelengths 63, 145, and 157 microns, corresponding to prominent lines of neutral oxygen [OI] and singly ionized carbon [CII]. Left: Spitzer red image with the footprint of the FIFI-LS observation mosaics. [9]

With the commissioning of FIFI-LS, a new far infrared line mapping capability exists on SOFIA. FIFI-LS has two gratings which allow the instrument to map two independent wavelengths at once. The agile telescope of SOFIA allows scientists to map a large area of the sky, see figure 6.

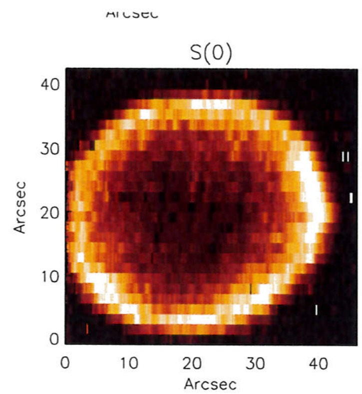


Fig. 7 – EXES Commissioning Science example: Jupiter imaged in the S(0) H_2 line at 28.3 μm (J=2-0 rotational transition) that is unobservable from the ground

On its first commissioning flight, EXES observed emission from Jupiter's atmosphere in two molecular hydrogen lines at 28 μm and 17 μm, see figure 7. This observation is to measure the ortho/para ratio of the H_2 molecule, which allows scientist to study how gas rises from deep in Jupiter's interior and mixes into the planet's upper atmosphere.

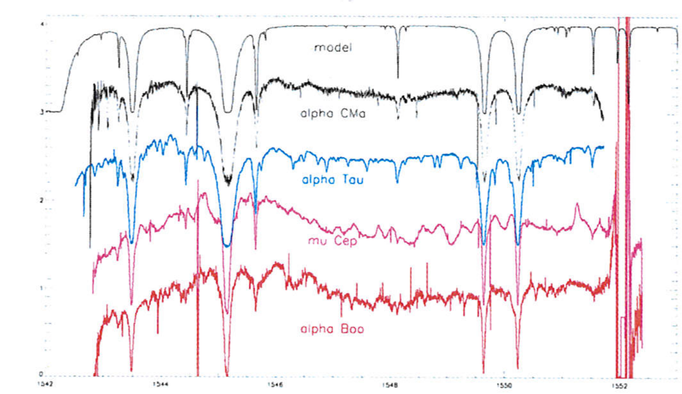
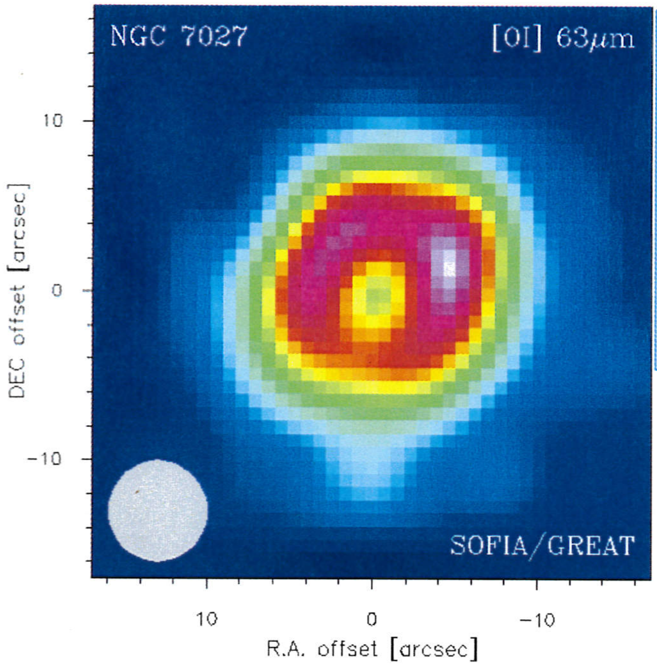


Fig – 8 EXES Spectra of the Calibrators

Now that EXES has phase 1 commissioning completed, the observatory has a very high spectral resolution spectrometer at wavelengths 5 to 28 μm. In all modes, EXES achieves calibration through observation of atmospheric lines, see figure 8. [8] The instrument weight capacity of SOFIA gives the observatory a unique ability to carry instruments like EXES.

A highlight of the GREAT Team was to commission their 4.7 THz channel on their heterodyne spectrometer. The purpose of this channel is to gather velocity resolved observations of the [OI] 63 μm line in the interstellar medium, see figure 9. [5]



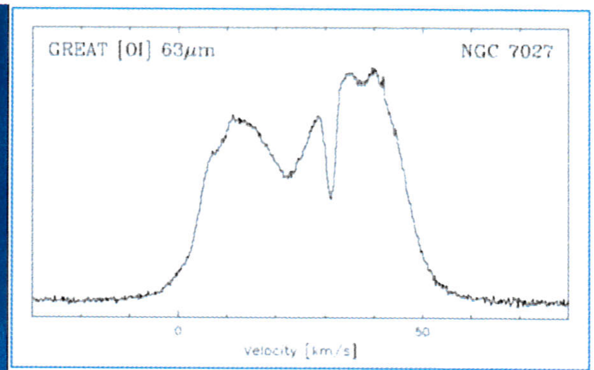


Fig – 9 GREAT observations of the planetary nebula NGC 7027 in the 63 μm [OI] fine structure line, (Rolf Güsten & the GREAT Consortium). A velocity profile at the central position of the [OI] map is also shown.

Since the beginning of Cycle 2 in February, 2014, SOFIA had over 240 hours of observations.

SOFIA Science Mission Operations are conducted jointly by the Universities Space Research Association (USRA), Inc. under NASA contract NAS2-97001, and the Deutsches SOFIA Institut (DSI) under DLR contract 50 OK 0901 to the University of Stuttgart.

1. *The Science Vision for the Stratospheric Observatory For Infrared Astronomy,* NASA Ames Research Center, Moffett Field, CA, June 2009
2. Hall H., Young E., Zinnecker H., *Science Mission Operations and Early Science Instruments for SOFIA,* proceedings Advance Maui Optical and Space Surveillance Technologies Conference (AMOS Tech), 2012
3. Young E. et al, *Early Science with SOFIA, The Stratospheric Observatory for Infrared Astronomy,* ApJ Letters, 749:L17 (5pp), 2012 April 20
4. http://www.sofia.usra.edu/Science/proposals/cycle3/SOFIA_Cycle3_CfP.pdf
5. Young, E., Andersson, B-G., Becklin, E.E., Reach, W.T., Sankrit, R., Zinnecker, H., and Krabbe, A., *SOFIA General Investigator Science Program,* SPIE, Ground-based and Airborne Telescopes V, Paper 9145-25, 2014
6. http://www.sofia.usra.edu/News/news_2014/03_03_14/index.htm
7. Logsdon et al, *FLITECAM: Early commissioning results*, 2014, Proceedings of the SPIE, 9147
8. Smith, E.C., et al, *SOFIA Science Instruments: Commissioning, Upgrades, and Future Opportunities,* 2014, Proceedings of the SPIE, 9147
9. http://www.sofia.usra.edu/News/news_2014/05_12_14/index.htm