SOFIA Newsletter

SOFIA
Stratospheric Observatory for Infrared Astronomy

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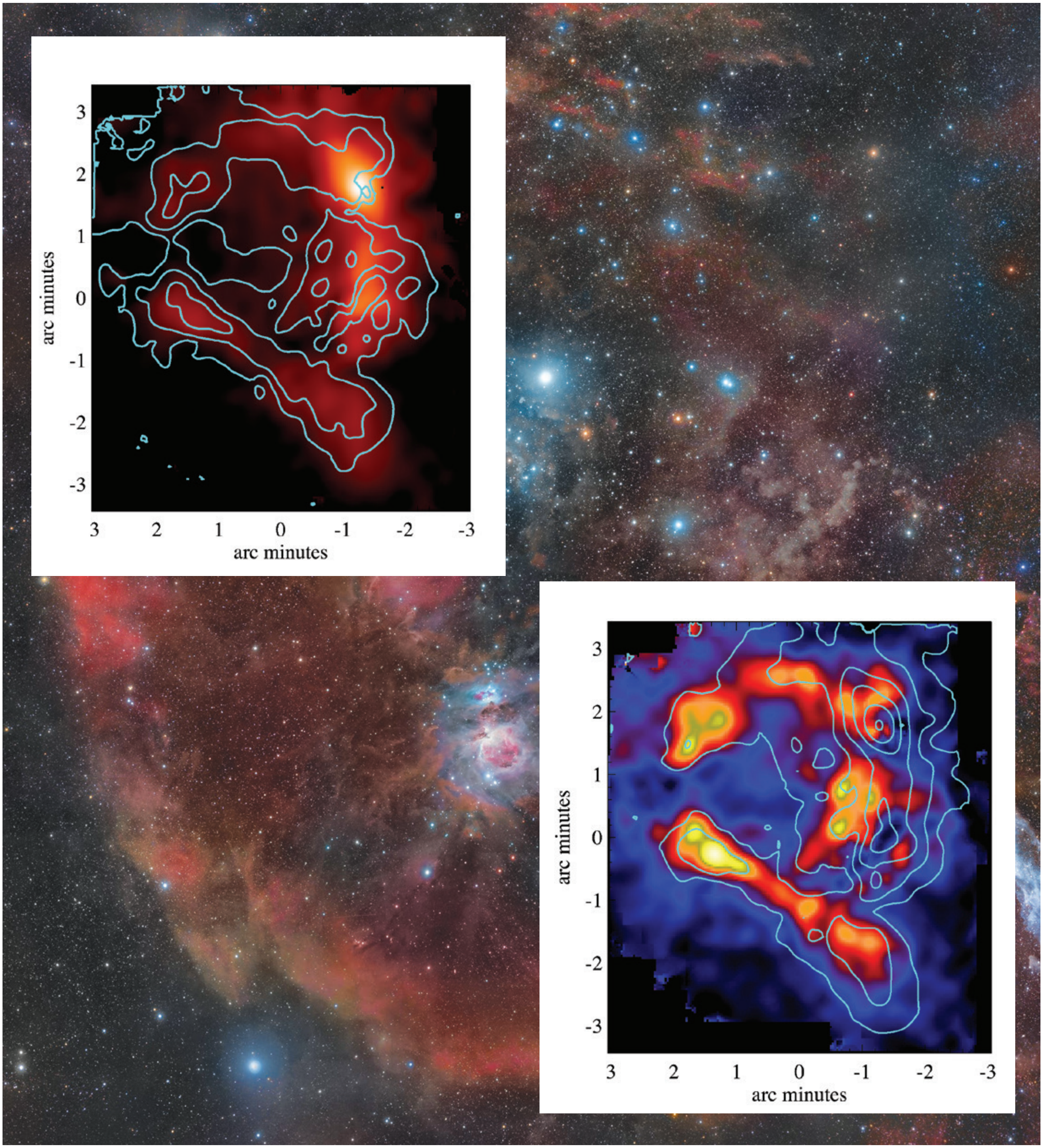

The Orion Nebula (M42) observed by SOFIA/FIFI-LS at 146μm. The bottom right figure shows the [OI] line emission as false-color map and the continuum emission as contours. The top left figure shows the same data with map and contours reversed. *Background image credit: Rogelio Bernal Andreo.*

Director's Message

Harold Yorke, *Science Mission Operations Director*

Since the publication of the inaugural issue of the newsletter in June 2016, SOFIA has experienced several changes, one of which directly involves the Science Mission Operation (SMO) leadership. Erick Young passed the baton to me in October. In order to make this transition as smooth as possible, I left JPL in August and joined the SOFIA staff to shadow Erick as director-in-training. Erick will remain on the SOFIA staff for a while to help me navigate through this initial transition period.

The fact that the project now produces a regular newsletter is a consequence of what I would call SOFIA's entry into a dynamic steady state of *normal* operations. The reader may ask him- or herself, "What does Hal mean with the concept of 'dynamic steady state of normal operations'?" To me this means that SOFIA is simultaneously executing several phases of a multi-year cycle of (1) providing the astronomical community regular and reliable access to its observing capabilities, (2) helping investigators reduce data and publish their results, thus contributing to our understanding of the universe, while (3) constantly renewing itself by adding new modern instrumentation and instrument upgrades to the existing cadre of well-tested and well-characterized workhorses of the observatory.

Science Mission Operations is currently dealing with multiple phases of science support. While completing Cycle 4 observations, SMO is providing mature archival data from earlier cycles. Based on the Time Allocation Committees' evaluation of submitted Cycle 5 proposals, SMO made its formal selection of proposals, and is planning the approved observations. Finally, SMO has already started the process of preparing for the Cycle 6 solicitation. This process includes determining the details of the observing modes that will become available with new instrumentation and with upgrades to some existing instrumentation.

We recently celebrated first light of the second-generation instrument, the High-resolution Airborne Wideband Camera-plus (HAWC+). This instrument is currently going through a formal process of commissioning and acceptance by NASA, and at the same time the instrument team for the newly selected third-generation instrument, the HIgh Resolution Mid-InfrarEd Spectrometer (HIRMES), has just begun its work with a goal of commissioning in 2019. Moreover, NASA is planning to put out a call for the next generation SOFIA instrument by summer 2017. These developments, together with the frequency augmentation of the German PI Instrument upGREAT, show that the concept of "dynamic steady state" describes a modern astronomical facility with continually improving unique state-of-the-art observing capabilities.

Finally, I want to point out that now, more than ever, the concept of "dynamic, steady state" means that SOFIA has been able to transition into an observatory that supports a wide scientific community, from planetary scientists to extragalactic researchers, with a wide breadth of interesting and compelling areas of exploration in-between. I encourage all scientists to visit our website **https://www.sofia.usra.edu/science** to learn about the improved capabilities and opportunities offered by SOFIA, only some of which are mentioned above. ■

SOFIA SENIOR SCIENCE LEADERSHIP

Harold Yorke, *Science Mission Operations Director*

(Vacant), *Deputy Science Mission Operations Director*

Kimberly Ennico Smith, *NASA Project Scientist*

William T. Reach, *Deputy Director, Science*

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German Perspective

Hans Zinnecker, *Science Mission Operations Deputy Director*

The last few months kept us all busy generating the results of the Cycle 5 Time Allocation Committee. In Germany, we had 27 proposals, with an oversubscription factor of approximately 3 times, with most of the proposals asking for observing time for the upGREAT heterodyne spectrometer (75 percent) and a number for FIFI-LS and HAWC+. There was a total of approximately 75 hours open time available and awarded for the German queue, including a limited award to a U.S./German joint impact proposal to map the so-called Galactic Center circum-molecular zone (CMZ) in the ionized carbon (C+) fine structure gas cooling line at 158 microns during the 2017 southern deployment in New Zealand. This large, joint proposal will require several cycles to be fully completed.

This is to be my last message as Science Mission Operations deputy director. After six-and-a-half years here at NASA Ames I will retire at the end of the year. I plan to move to Chile, and hope to be involved in astronomy and with SOFIA. Maybe SOFIA will need to deploy to Chile to observe a Galactic supernova! I will be available to DSI and DLR as an advisor until my successor is appointed.

It is mandatory in the German system to retire now, and so it is a coincidence that it is just at the time when my close colleague and mentor Hal Yorke takes over as SMO Director. Hal and I have known each other for more than a quarter of a century, and we have trained many young students in star formation theory and observations. Ten years ago, we published a review article on massive star formation in the *Annual Review of Astronomy and Astrophysics*, perhaps one of the most cited papers for both of us (Zinnecker and Yorke 2007). SOFIA will be in good hands with him as the new SMO director. Moreover, Germany is lucky, because Hal knows astronomy and astronomers in Germany extremely well.

Now is the moment to publicly thank Erick Young, the former SMO director, who always appreciated the importance of a strong partnership with Germany. I would also like to express my personal thanks to Erick; it was a pleasure to work with him at the SMO. I learned a lot from him about science management and how to keep calm and collected, even when times got rough.

This is an opportunity to thank Helen Hall, former program manager (now retired) for her unfailing support, both to me and to the DSI team. This is also the time to recall the contributions of Hans-Peter Röser (1949–2015), a great friend of SOFIA, who was largely responsible for the founding of the German SOFIA Institute at the University of Stuttgart and was also the chairman of the search committee that selected me as SOFIA's first SMO deputy director.

Finally, let me say that with all the new instrumentation in development and planned (THz arrays, a far-infrared polarimetric camera, a spectrometer filling the last far-infrared spectroscopic gap), SOFIA is in good shape to overcome the challenges of the future, and to inspire all parties involved to participate with passion, pride, and determination. We are on a mission to study the interstellar medium, the stuff between the stars, the stuff we are made of. ■

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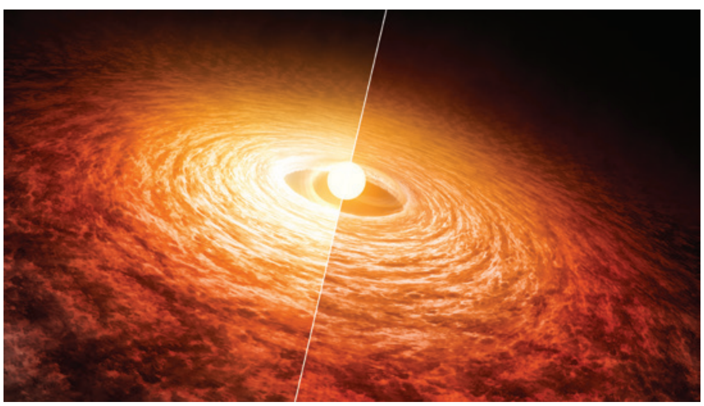
W. T. Reach, *Deputy Director, Science*

In this and future editions of the printed SOFIA Newsletter, this column will highlight some of the observatory's recent scientific successes. Would you like to use this space to highlight your work? Please let us know and send an image and short writeup comparable to those included below, which are gleaned from recent papers and preprints.

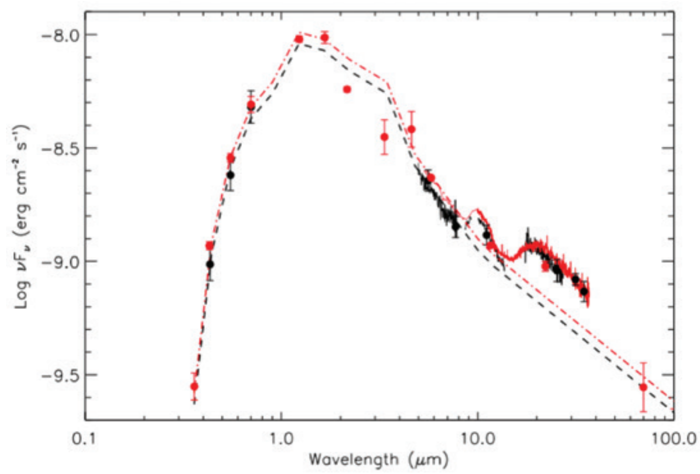
"Sound and fury": FU Ori Outbursts

Joel Green and collaborators observed the outbursting star FU Ori in February 2016 with FORCAST, using the instrument in both its imaging and grism modes. The results were compared to earlier observations with Spitzer in 2004 to search for changes in the disk over the 12-year interval between the two observations.



Artist conception of the star FU Ori and the material around it. The left-hand side shows what the disk may have looked like in 2004, and the right-hand side shows what such a disk would look like in 2016 based on the conclusions of the SOFIA observers. The inner portion of the disk (within a few solar radii) is gone, having drained onto the surface of the star, while the outer portion remains relatively unchanged.

The remarkable consistency in shape of the 10-micron silicate emission feature observed with Spitzer/IRS in 2004 and SOFIA/FORCAST in 2016 demonstrates the high quality of data produced by SOFIA as well as the unchanging nature of the dust in the presence of a declining outburst. Lower-amplitude absorption features near the 6-micron wavelength are also consistent between the SOFIA and Spitzer spectra, confirming the presence of water vapor at a level that remains approximately unchanged.



Spectral energy distribution of FU Ori comparing observations in 2004 (red) to those in 2016 (black). The decrease (14 percent) in brightness at 5-9 microns is evident, while the longer wavelengths appear to have changed much less (<7 percent).

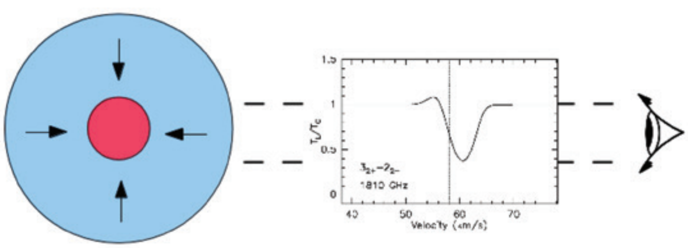
The primary result is measurement of a decrease in brightness by about 10 percent at the shorter mid-infrared wavelengths (5–10 microns) while the longer mid-infrared wavelengths remained approximately constant. Because the shorter wavelengths sample the higher temperature portions of the disk, and the disk is heated by the star, this means that the inner portion of the disk is decreasing in brightness. Green et al. conclude that the dimming in FU Ori is due to the inner portion of the disk (within a few solar radii from the surface of the star) having "drained" onto the star. The more extended disk out to several astronomical units remains relatively unchanged.

"Falling and I can't get up": Infalling gas on protostars

F. Wyrowski and coinvestigators at the Max Planck Institute for Radio Astronomy at Bonn have been utilizing the GREAT heterodyne spectrograph to observe an ammonia (NH_3) transition at 1810 GHz. This line can only be observed with SOFIA, where the atmospheric transmission is about

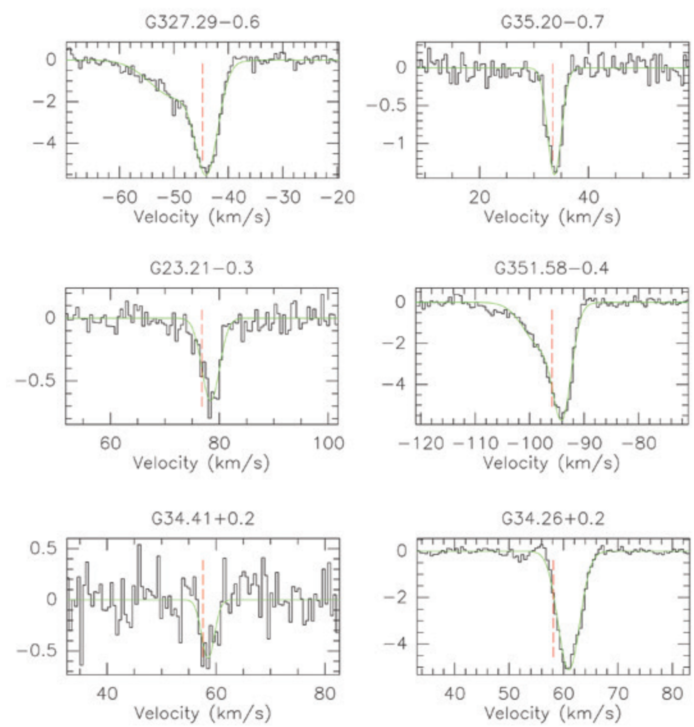
75 percent from 43,000 feet altitude. (From the highest mountaintop, transmission is less than one percent, and at this time humanity has no space-based far-infrared capabilities.) The technique is to observe the ammonia line, at very high velocity resolution, absorbed against the thermal emission from protostellar envelopes.

The technique is illustrated by Wyrowski in the following schematic. The effective photosphere of the protostar, shown in red, emits bright, continuum thermal radiation across the far-infrared. The material surrounding the star, shown in blue, would be moving radially inward if the core is currently increasing in mass. If we look from the direction of the eyeball toward the protostar, the gas in front of the protostar, which absorbs the continuum radiation of the central hot core, is moving away from us if it is falling into the hot core. The signature of infall is thus a red-shifted (that is, Doppler-shifted to more positive velocity) absorption.



Ammonia infall was previously seen for three sources with GREAT (Wyrowski et al. 2012, A&A 542, L15), and the new observations add five more. The high detection rate (8 out of 11 observed) indicates that infalling gas is common for molecular clumps with a wide range of evolutionary stages. Infalling gas has been sought extensively through millimeter and radio observations of dense cores, which have long been suspected of being actively growing toward becoming young stars. Those prior searches were largely hampered by the presence of molecular outflows from the very same sources onto which the gas is infalling. Theoretically, gas is expected to accrete through equatorial regions while conservation of angular momentum is satisfied by a smaller amount of gas expanding rapidly through polar regions. The infalling material is the gas being channeled to the accretion disk from the envelopes. The NH_3 spectral line observed with SOFIA is sensitive to the denser infalling gas because of the high critical density required to excite the molecules to the lower level of the observed absorption line.

Based on the observations, infall rates were calculated to range from 0.0003 to 0.0016 solar masses per year. The authors compared their results to characteristic infall rates for a 1,000 solar mass clump, and they note that the extremely high accretion rates determined from the SOFIA data could only be maintained for about 10,000 years, depending on the rate of outflow simultaneous with the infall. That means the dense clumps are in the brief, most intense phase of mass growth for the large stars that will form within them.

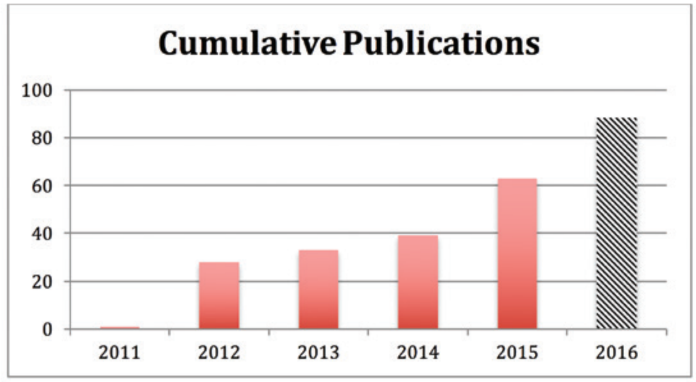


Ammonia absorption observations toward six dense clumps using SOFIA/GREAT. The red dashed line indicates the central velocity of other spectral lines. The sources with absorption shifted blueward (toward more positive velocity) of the systemic velocity are those with large mass infall rates onto their cores.

SOFIA Publications

The SOFIA Science Center monitors the progress of observing programs and the resulting publications. Reports are presented to the SOFIA Users Group, for which all presentations are public at **http://go.nasa.gov/2eGHGak**.

The number of refereed publications based on SOFIA data is steadily growing. An interesting metric is the average amount of observing time on SOFIA per refereed publication — the total science hours accomplished on SOFIA through the end of 2015 divided by the number of publications through September 2016 yields 13 hours per paper, which may be compared to the average of 8 science hours per flight. Many observations obtained in recent cycles are being actively prepared for publication. There remain other observations not yet published that are nonetheless publishable, and are available in the SOFIA Science Archive. ■



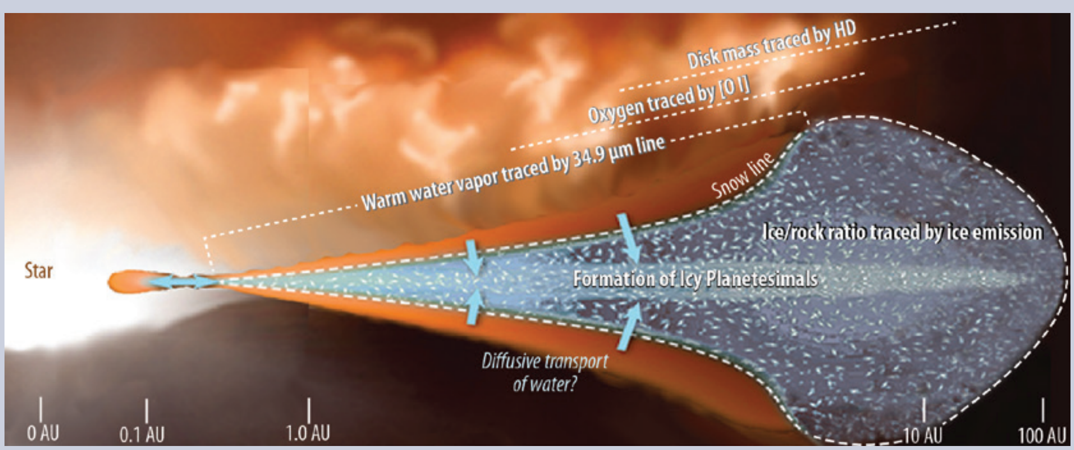
The bar for 2016 is an estimate based on publications through September, extrapolated to the complete year.

New 3rd-Generation Science Instrument

A team from NASA's Goddard Space Flight Center in Greenbelt, Maryland, led by principal investigator, Samuel Harvey Moseley, is now developing a new, third-generation facility science instrument for SOFIA.

The HIgh Resolution Mid-InfrarEd Spectrometer (HIRMES) is optimized to detect neutral atomic oxygen, water, as well as normal and deuterated (or "heavy") hydrogen molecules at infrared wavelengths between 28 and 112 microns. These wavelengths are key to determining how water vapor, ice, and oxygen combine at different times during planet formation, and will enable new observations of how these elements combine with dust to form the mass that may one day become a planet.

Moseley and his team will construct HIRMES over the next two and a half years with flights on board SOFIA slated for spring 2019. At that time, this unique research asset will also be made available for use by the larger astronomical community. ■



(HIRMES Science Team)

Science Operations and Outreach

B-G Andersson, *Associate Director for Science Operations*

The SOFIA summer and early fall have been both very busy and successful. The Cycle 4 Southern Deployment to Christchurch, New Zealand (NZ), produced exciting FIFI-LS and FORCAST data. These data have since been pipeline-processed and sent to the program principal investigators for analysis. A number of proposals were received in response to the SOFIA Cycle 5 call, which had an early July deadline. During this period, several members of the SMO were actively engaged in preparing for the 2016 SOFIA Conference that was held in mid-October.

Cycle 5 Results

After the deadline, the submitted proposals were considered by peer review panels in the United States and Germany at the end of August and beginning of September, respectively. The panels found the proposals to be of high quality, and submitted their recommendations independently to the SMO. The SMO Director (Erick Young) and Deputy Director (Hans Zinnecker) then merged these lists, producing a final observing program consisting of 95 approved proposals for a total of 535 hours of Cycle 5 observing time. Cycle 5 observing will span February 2017 to January 2018.

The distribution of accepted time among the instruments is shown in Table 1. Awarded programs cover a wide range of astronomical science areas from solar system studies, interstellar, circumstellar to extra-galactic, including several large observation time proposals.

Table 1. Cycle 5 Results

Instrument	Accepted time [%]
EXES	17
FIFI-LS	12
FLITECAM	1
FORCAST	17
GREAT	26
HAWC+	23

The Cycle 5 instrument schedule, laid out based on these selections and programmatic requirements is shown in Table 2. As the table shows, we are planning to take the three instruments, GREAT, FIFI-LS and FORCAST, on the Cycle 5 Southern Deployment, in June–August 2017. In addition to the planned regular science flight series, the program manager is adding two, high-priority activities in the cycle, namely:

- An occultation observation of Triton, over the Atlantic, in early October 2017.
- A visit to the AAS 2018 Winter meeting in Washington, D.C., in January 2018.

Table 2. Cycle 5 Flight Series[1]

Flight Series	Instrument	Dates
OC5A	GREAT	February 2017
OC5B	FIFI-LS	Feb/March
OC5C	EXES	March
OC5D	FORCAST	April
OC5E	HAWC+	May
OC5F	EXES	May
OC5G	GREAT	June
OC5H	GREAT (NZ)	June/July
OC5I	FIFI-LS (NZ)	July
OC5J	FORCAST (NZ)	August
OC5K	HAWC+	September
OC5L	FLIPO	October[2]
OC5M	FORCAST	October
OC5N	HAWC+	Oct/Nov
OC5O	EXES	January[3] 2018

1) Aircraft maintenance and other engineering activities are not shown

2) Triton occultation observation, based at a U.S. east coast airfield.

3) Preceded by the SOFIA visit to Washington, D.C. for the 2018 Winter AAS meeting.

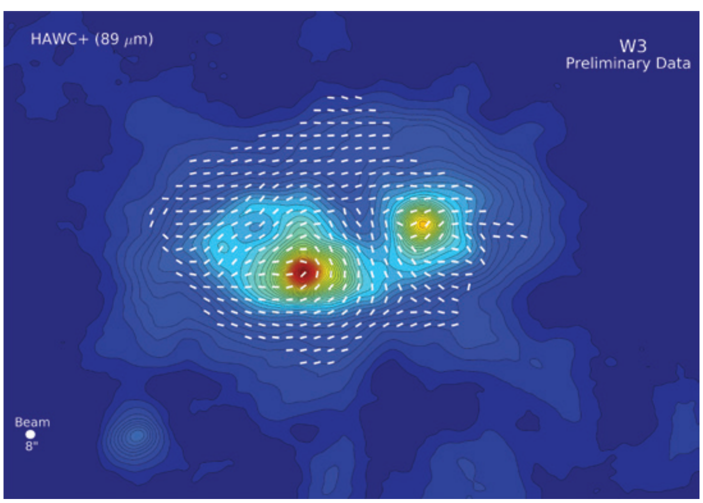
After establishing the availability of HAWC+ for Cycle 5 operations, based on characterization flights in early October, the proposal selection letters were sent out on

October 24. Follow-up instructions for the Phase II inputs were distributed shortly thereafter, and that work is now in progress with a deadline of December 5. Titles and abstracts for approved Cycle 5 proposals can be viewed on the SOFIA web site at **http://go.nasa.gov/2eOqEdR**

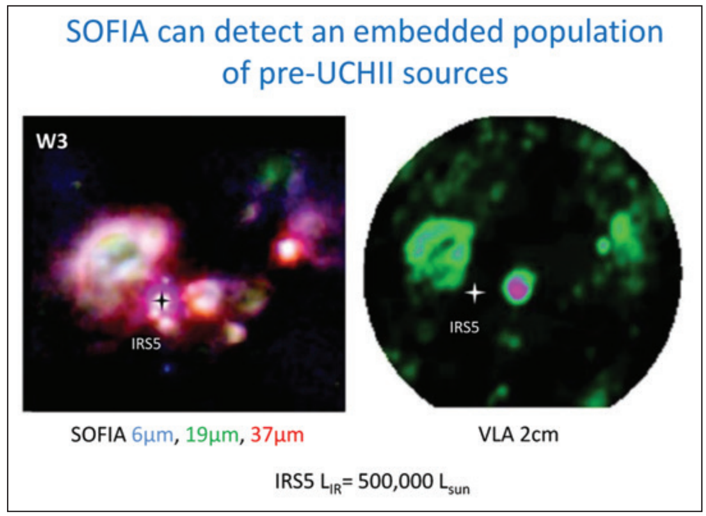
SOFIA Science Conferences

The SOFIA project's long-term plan of organizing conferences in alternate years in Germany and in the United States is proceeding well. The first of these meetings took place at Schloss Ringberg in Bavaria in May 2015, and the second this past October at the Asilomar Conference Grounds in Northern California. The next meeting in the series is currently being organized for Schloss Ringberg, in March 2017, and we expect to start planning a U.S.-based meeting for 2018 in the near future.

"The Local Truth: Star Formation and Feedback in the SOFIA Era" conference was held October 17–20. The meeting was well attended and received, and enjoyed the beautiful vistas and weather of the Monterey peninsula in the fall. A large amount of new, exciting SOFIA data was presented and discussed, touching on most aspects of star formation research. Edwin Erickson and Eric Becklin also provided engaging reviews of the first 50 years of airborne astronomy that were appreciated by all. The presentation slides have been posted on the conference web pages on the SOFIA site (**http://go.nasa.gov/2eOqoLM**).



Darren Dowell (Caltech), the PI of HAWC+ showed preliminary polarization data of the W3 star forming region. In this image, the E vector directions are shown overlaid on a total intensity image. For clarity only one-quarter of the polarization measurements are shown and the line segments are set to a fixed length.



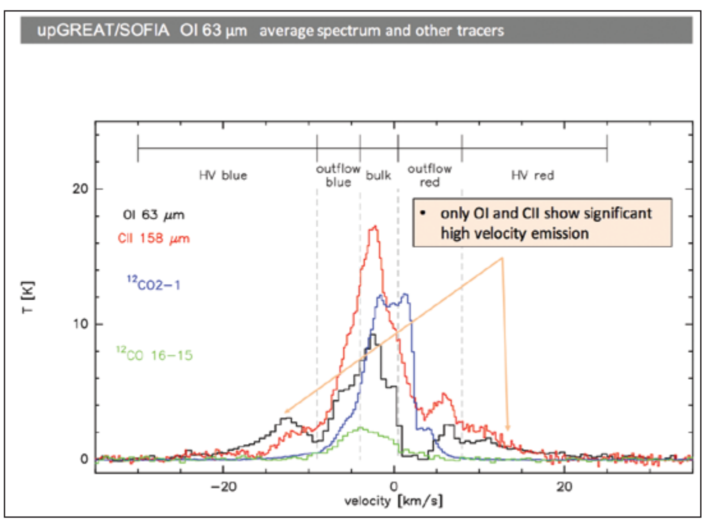
Jim De Buizer (USRA/SOFIA) presented his work on FORCAST studies of high-mass star formation and showed how SOFIA can detect embedded cores. These massive stars will soon create ultra-compact HII regions.

Happy New SOFIA Year

The SOFIA Operations team is busy supporting the Cycle 5 phase II ingest and detailed planning for the cycle, as well as executing the remaining Cycle 4 program. We have three job postings out on the AAS Job register for instrument scientists and an instrument operator, which we bring to your attention. We're looking forward to seeing many of you at the Grapevine, Texas, AAS winter meeting (January 2017), to discuss SOFIA science, plans and jobs.

We wish you a happy and productive new SOFIA year! ■

Conference participants gathered outside the Fred Farr Forum.



Nicola Schneider (Univ. of Cologne) presented FIR-line spectroscopy of the bipolar nebula and star-forming region S106 obtained with SOFIA. These observations obtained with the upGREAT instrument reveal the high velocity atomic gas in the system.

Charles Townes with graduate students Sarah Beck and Don Brandshaft, and computer operator Tom Matheson on board the KAO (1978) from Ed Erickson's presentation on the Evolution of SOFIA.

Public Outreach

Coral Clark, *Co-Manager, NASA Airborne Astronomy Ambassadors*

Astronomers awarded telescope time on SOFIA have a unique opportunity to support science, technology, engineering, and math (STEM) learning and science literacy through NASA Airborne Astronomy Ambassadors (AAA) and SOFIA Outreach efforts.

From 2011–15, SOFIA supported an immersive professional STEM experience in astronomical research for more than 100 teachers and science museum educators. The U.S. AAA teams during this time period, selected by a peer panel through a highly competitive process, represented 31 states, and more than 50 cities and towns. The energetic and dedicated group remains part of the extended SOFIA Outreach team for public engagement efforts.

Beginning in 2016, the AAA became part of a coordinated NASA Science Mission Directorate education program using SOFIA facilities to provide flight opportunities to teachers in specific partner school districts, and will be in an educational research phase through 2018. The SETI Institute is responsible to NASA for executing a professional development plan and conducting education research that exploits the unique and inspirational attributes of SOFIA, improves science teaching, and impacts student standards-based classroom outcomes. The institute will work in partnership with teachers, high schools, and school districts during this two-year research phase to gather data on student impact and learning. AAAs will continue to take what they learn during their SOFIA training and flights back to their classrooms to improve curricula, increase science literacy, and generate interest in STEM-related courses and careers.

At the EPO console are Airborne Astronomy Ambassadors Jeff Peterson, Jacqueline Fernandez-Romero, Melissa Aguirre, and Troy Cockrum. *Credit: NASA/SOFIA*

During their SOFIA flight week, educator participants will be highly engaged in a STEM Immersion Experience. Flight weeks will include overnight flights aboard the airborne observatory, on-ground facility tours, and select meetings with subject matter experts (scientists and engineers), as available. They will observe multiple aspects of mission operations and science research processes, including instrument preparations and flight mission briefings. Teachers may also have the opportunity to connect with their students via social media from the airfield before or after a flight. On board the aircraft, educator participants will view observatory operations from a dedicated console, while the AAA flight facilitator and instrument team provides background on SOFIA instruments. As most SOFIA flights collect data in connection with several proposals, AAAs will observe the SOFIA science team conducting research on several astronomical targets, witnessing data collection in real time as acquired by the observatory. Flight participants are also able to interact with select SOFIA science staff and other key crewmembers, to learn their backgrounds, their roles on SOFIA, and other topics relevant to astronomy and the observatory.

Flight Week makes an impression on AAAs

- Jennifer Catelli (Massachusetts high school teacher; 100 students/year) observed the commitment, teamwork, and professionalism of the entire SOFIA crew and their ability to work together to solve problems and to achieve the science objectives. Their openness and welcome to the educators on board gave her a priceless glimpse into how their research is done, which will help her to excite and inspire her students.
- Brian Gonyar (Maine high school teacher; 100 students/year) recognized the intense need for teamwork to support successful program operations, and will increase opportunities for his students to practice team problem-solving skills in his classroom immediately upon his return from flight week.
- Larry Grimes (California high school teacher; 110 students/year): "This SOFIA experience has been one of the richest experiences of my life. The high profile exposure leading up to this flight week has created great interest in our district and among the students at my site. One direct off-shoot of my involvement with the SOFIA program is the establishment of an astronomy course at our school, and the creation of three star parties a year at our district headquarters for more than 600 students and their parents. It is no exaggeration to say that SOFIA has totally changed the focus on astronomy and space sciences in our district."
- Eric O'Dea (Science Communicator at the Museum of Science, Boston; 40+ public science lectures/month) has been able to get first-hand experience of the magnitude of planning and precision required for a mission of this caliber. Seeing the SOFIA team solve problems in person will lend a whole new level of excitement and a personal touch to all related presentations at the museum in the future.

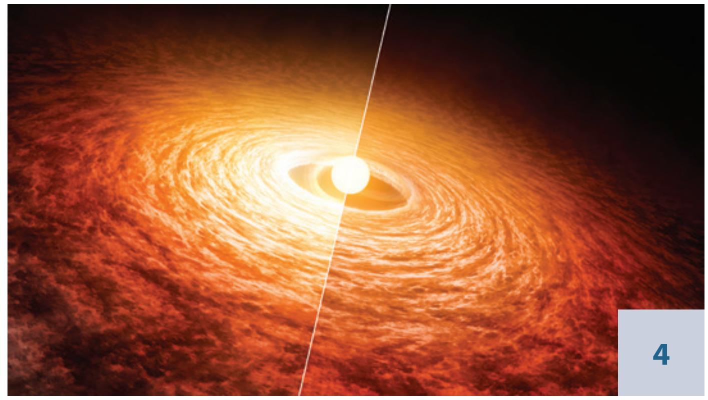
UCLA graduate student and FLITECAM team member Sarah Logsdon invites participants to the learn about infrared astronomy and SOFIA at UCLA's Exploring Your Universe community event, held November 6, 2016. *Credit: Eric Wang*

AAA connection to and involvement with SOFIA guest observers and subject matter experts in astronomy and astrophysics continues to be in high demand. We hope you will actively participate in one or more of the following ways:

- In-person discussions with AAA teachers either during SOFIA flights or while visiting NASA Armstrong Flight Research Center.
- Audio or video recorded vignettes introducing key team-members, overviewing your research, and highlighting research results (when available).
- Formal partnerships with a specific AAA teacher, high school, or school district. This type of participation provides the greatest level of direct involvement to the K–12 STEM learners, and usually includes on-going updates of research progress through webcasts or in-person presentations to students at school sites.

Members of the Airborne Astronomy Ambassadors management team and Outreach office will be in contact with guest observers after the SOFIA science office has awarded telescope time. We look forward to discussing the many ways you and your team can be a part of SOFIA science communication efforts and contribute to NASA SMD Education goals and educational research through the Airborne Astronomy Ambassadors. ■

Stratospheric Observatory for Infrared Astronomy



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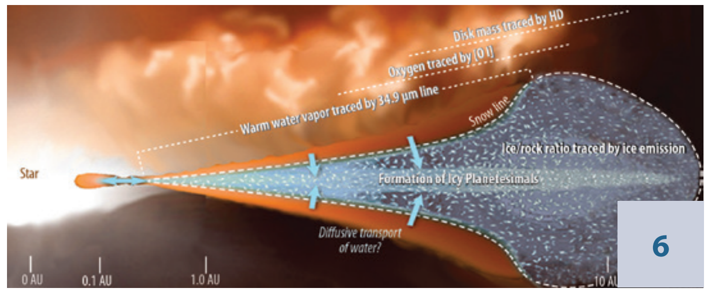

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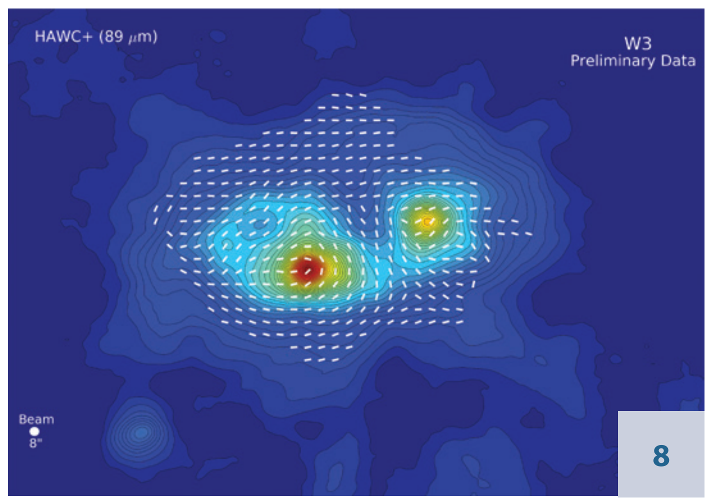

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