SOFIA Newsletter

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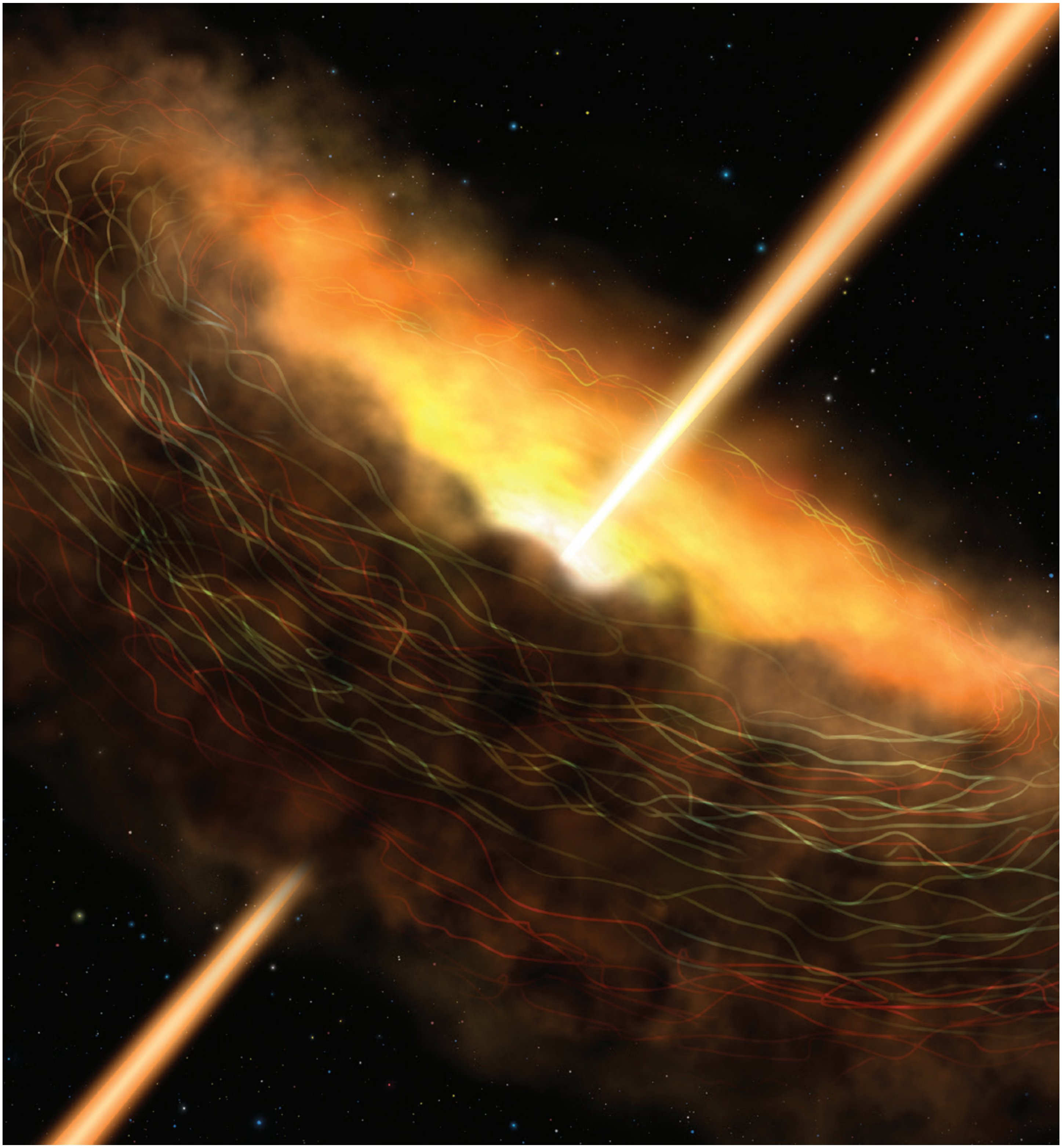

Artist's conception of Cygnus A. See Science Spotlight, page 3. *(NASA/SOFIA/Lynette Cook)*

Director's Message

Harold Yorke, *Science Mission Operations Director*

The past six months since our last newsletter have been a remarkably productive and eventful period for SOFIA, highlighted by a very successful New Zealand deployment and some important news about NASA's review of the observatory.

After consulting with Congress and receiving further clarification, NASA has informed SOFIA that the SOFIA Senior Review, initially planned for Spring 2019, will instead be a joint U.S-German five-year "Flagship Mission Review" to assess the observatory's scientific productivity. This science-oriented review will be coupled with a SOFIA operations and maintenance facility review to assess the observatory's operations procedures and processes. The SOFIA team is proud of its past achievements and welcomes the reviews that will evaluate our plans to further improve delivery of great science. We are particularly happy that our German partners are now able to participate in all aspects of this science review, scheduled for February 2019, with the final report submission planned for April 2019. One of the goals of the review is to investigate operations and maintenance models to execute at least 150 flights per year.

SOFIA is now engaged in its Cycle 6 flights and is preparing for Cycle 7. After a longer than expected maintenance and repair period, Cycle 6 was extended through April 2019. For Cycle 6, SOFIA has introduced the concept of "orange" flights, which are primarily used as contingency flights, if a previous flight is missed. If an "orange" flight is not needed as a contingency, then it will be flown with either lower priority science or used for "strategic Director's Discretionary Time" (s-DDT) projects, such as the High-resolution Airborne Wideband Camera-plus (HAWC+) polarization measurements of the 30 Doradus region (see page 13). Strategic Director's Discretionary Time level 3 data are immediately available to the international community, i.e. there is no proprietary period before it is released.

SOFIA had a remarkably successful New Zealand deployment with the upGREAT (the seven beam array configuration of the German REceiver for Astronomy at Terahertz Frequency) and HAWC+ instruments. This required an intensive effort from the staff to execute 24 of 25 scheduled flights over the course of six weeks. During

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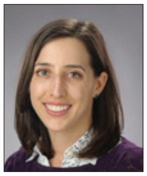
Science Spotlight

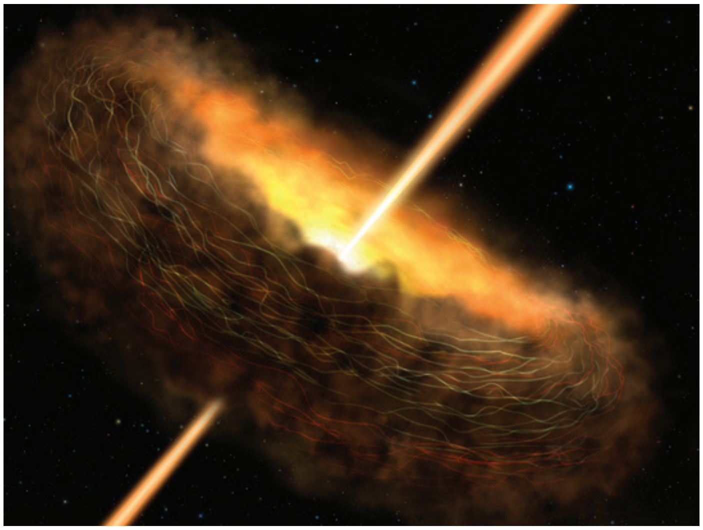

Enrique Lopez-Rodriguez, *Instrument Scientist*
Kassandra Bell, *Communications Specialist*
Joan Schmelz, *Associate Director for Science and Public Outreach*

Magnetic Fields Confine the Torus at Cygnus A's Core

Observations from SOFIA reveal that magnetic fields are trapping and confining the obscuring dust near the center of the active galaxy Cygnus A, and feeding material onto the supermassive black hole. The unified model of active galaxies maintains that the core is surrounded by a dusty torus that absorbs radiation at all wavelengths and re-emits it in the infrared. How this obscuring structure is created and sustained has never been clear, but these new results from SOFIA confirm that the magnetic field plays a crucial role.

The presence of collimated jets that emanate from the core of active galaxies like Cygnus A implies strong accretion onto the supermassive black hole. The jets may be launched by extracting rotational energy from the black hole itself. This process requires strong magnetic fields in the nucleus of the galaxy that can help convert the rotational energy to a launching energy sufficient to overcome the enormous force of gravity near the black hole's event horizon. In fact, the fundamental difference between radio-loud galaxies like Cygnus A and their radio-quiet siblings may indeed be due to the presence or absence of a strong, coherent magnetic field surrounding the black hole.

Although magnetic fields are notoriously difficult to observe, polarimetric observations of the infrared emission from aligned dust grains has proven to be a powerful technique. SOFIA recently observed the central 20 parsecs (65.2 light-years) of Cygnus A with the High-resolution Airborne Wideband Camera (HAWC+) at 53 and 89 microns with an angular resolution of five arcseconds and nine arcseconds. These observations are sensitive to temperatures of 30–50 K and show highly polarized infrared emission dominated by a well-aligned dusty structure. The polarization vectors indicate that the most powerful radio-loud active galaxy in the sky, with its iconic large-scale jets, is able to confine the obscuring torus that feeds the supermassive black hole using a strong magnetic field.



Artist's conception of Cygnus A, surrounded by the torus of dust and debris with jets launching from its center. Magnetic fields are illustrated trapping dust near the supermassive black hole at the galaxy's core. *(NASA/SOFIA/Lynette Cook)*

Cygnus A is in the perfect location for observations of the role magnetic fields play in confining the tori of the unified model, channeling material into supermassive black holes, and launching jets at relativistic speeds because it is the closest and most powerful active galaxy. More observations of different types of active galaxies are necessary to get the full picture of how magnetic fields affect the evolution of the environment surrounding supermassive black holes. If, for example, a HAWC+ survey reveals highly polarized infrared emission from the centers of radio-loud active galaxies but not from radio-quiet galaxies, it would imply that magnetic fields play a crucial role in the accretion process and jet formation. ■

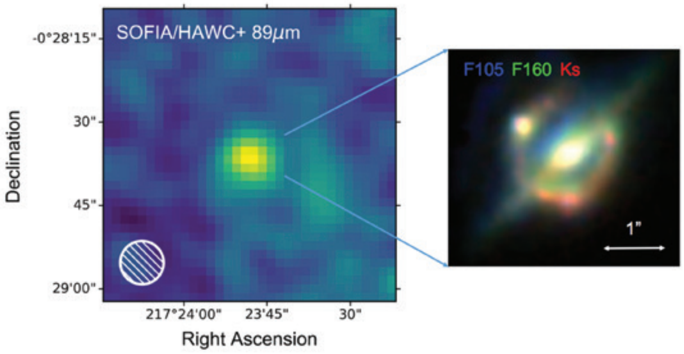
About this Spotlight

Paper: The Highly Polarized Dusty Emission Core of Cygnus A
Authors: E. Lopez-Rodriguez, R. Antonucci, R. Chary, M. Kishimoto
Reference: 2018, ApJL, 861, L23

Science Spotlight

Jingzhe Ma, *Postdoctoral Researcher, University of California, Irvine*

A Gravitationally Lensed Starburst Galaxy at High Redshift



Left: SOFIA/HAWC+ 89 micron detection of J1429-0028. The hatched circle shows the beam full-width at half-maximum of 7.8 arcsec. *Right:* The 3-color image of the gravitationally lensed system using HST F105W (blue), F160W (green), and Keck Ks (red) imaging data.

Dusty star-forming galaxies at high redshift make up the bulk of the cosmic infrared background and provide stringent constraints on galaxy formation theories. They are characterized by very high-intrinsic, infrared luminosities (~1 to 10 trillion times solar luminosity) and dust-enshrouded intense star formation (with star formation rates exceeding ~100–1000 solar masses per year). Dusty star-forming galaxies are in a unique phase of galaxy formation and evolution, and provide a laboratory for studying the co-evolution of galaxies and their super massive black holes. Whether the very high infrared luminosities are powered by pure star formation, or also by actively accreting super massive black holes, is an important question and affects measured star formation rates.

Galaxy emission in the mid-infrared contains rich information about the underlying power sources within the galaxy, including polycyclic aromatic hydrocarbon features, which trace star formation, and additional hot dust emission from around any accreting black hole. Combined with photometric data covering ultraviolet, optical, near-infrared, far-infrared and radio, multi-wavelength spectral energy distribution modeling techniques are powerful tools to decompose star formation and black hole activity, and to quantitatively constrain the fraction that is contributed by black hole activity, in addition to providing self-consistent constraints on stellar masses, star formation rates, and dust properties.

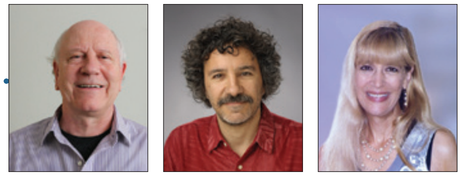
However, these galaxies often do not have mid-infrared observations due to their faintness and lack of facilities operating at these wavelengths. Mother Nature provides us with natural magnifying lenses that can boost the brightness and spatial resolution of the background sources, namely the gravitational lensing effect, which makes detection much easier. The figure (above left) shows the detection at 89 microns of a gravitationally lensed, dusty star-forming galaxy, HATLASJ1429-0028, at a redshift of 1.03 using the High-resolution Airborne Wideband Camera-plus (HAWC+) onboard SOFIA for only 15 minutes. The spectacular lensing system (above right: three-color image) consists of an edge-on foreground disk galaxy at redshift of 0.22 and a nearly complete Einstein ring of an intrinsic, ultra-luminous, infrared galaxy at redshift of 1.03. The multi-wavelength spectral energy distribution for the background dusty star-forming galaxy, including the new SOFIA/HAWC+, constrains the contribution from an accreting black hole to the total infrared luminosity to be negligible.

This is the first detection of a high-redshift extragalactic source with SOFIA. This result demonstrates the potential of utilizing HAWC+ for studying bright, distant galaxies, including the decomposition of star formation and accreting black hole components, which cannot be accomplished with other current facilities. ■

About this Spotlight

Paper: SOFIA/HAWC Detection of a Gravitationally Lensed Starburst Galaxy at Z=1.03
Authors: J. Ma, A. Brown, A. Cooray, H. Nayyeri, H. Messias, N. Timmons, J. Staguhn, P. Temi, C. D. Dowell, J. Wardlow, D. Fadda, A. Kovacs, D. Riechers, I. Oteo, D. Wilson, I. Perez-Fournon
Reference: 2018, ApJL, 894, 60

Science Spotlight



Phil Appleton, *Senior Research Scientist, Caltech/IPAC*
Dario Fadda, *Pipeline Scientist*
Joan Schmelz, *Associate Director for Science and Public Outreach*

Probing Shocked Gas in an Active Galaxy

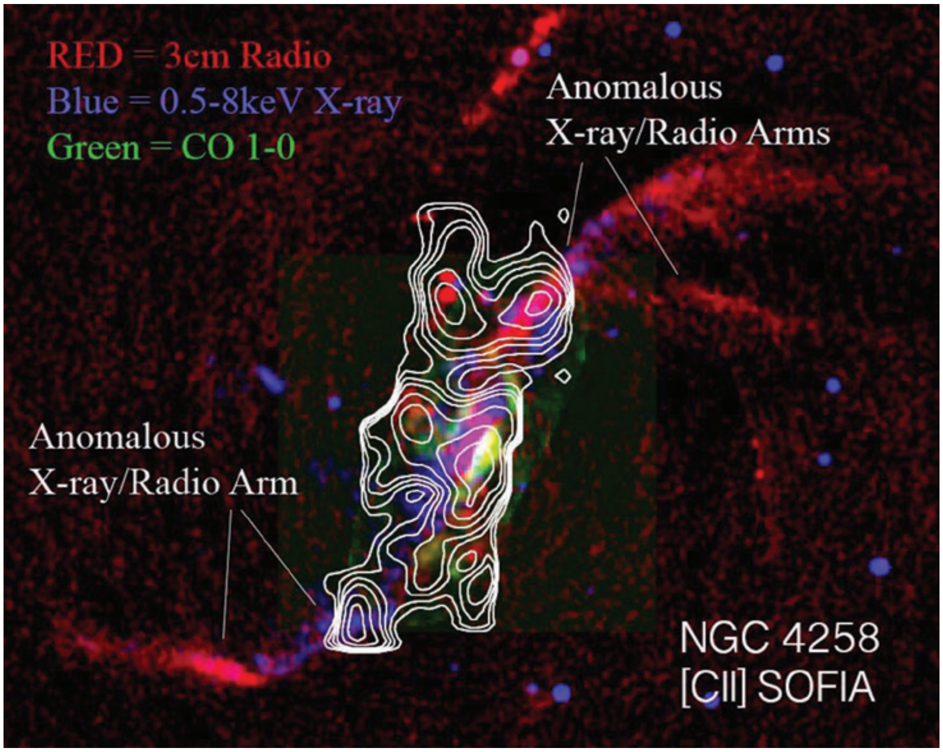


Figure 1: The distribution of [CII] emission (contours) from SOFIA FIFI-LS plotted over the radio/X-ray/CO emission (color) from the galaxy NGC 4258.

SOFIA observations were instrumental in separating shock-enhanced ionized carbon [CII] emission from that associated with star formation in NGC 4258, a nearby spiral galaxy with a radio jet that is feeding energy into the surrounding interstellar medium. As matter falls onto the supermassive black hole at the center of the galaxy, a small fraction of energy of the infalling material is accelerated and ejected as a jet of particles along the spin-axis of the black hole. The jet seems to be injecting energy into molecular gas, which triggers enhanced [CII] emission. On a much larger scale, the galaxy also shows evidence of peculiar radio/X-ray emitting "anomalous" spiral arms, which are believed to be somehow linked to current or previous nuclear activity. Some of the [CII] emission is also seen associated with the inner parts of these arms. This is the first time that shock-enhanced [CII] emission has been definitively associated with spatially resolved regions of molecular gas heated by a radio jet. The authors estimate that approximately 40 percent of the [CII] emission arises in regions not associated with star formation — most likely shock-heated molecular hydrogen.

The Far Infrared Field-Imaging Line Spectrometer (FIFI-LS) observed the inner five kiloparsecs (kpc) of NGC 4258 at 157.7 microns. The resulting [CII] map shows widespread emission with an irregular distribution (see Figure 1) and peculiar gas motions. Some of these features are clearly associated with star formation, like the one that extends approximately one kiloparsec along the minor axis and is closely associated with a loop of HII regions (middle contours). Although several other regions appear consistent with [CII]-associated star formation, other features show unexpected properties. South of the nucleus, there is a close correspondence between the [CII] emission and the warm molecular hydrogen distributed along the southern jet previously discovered with the Spitzer Space Telescope. An analysis of the line-widths of the [CII] emission shows that many of the

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About this Spotlight

Paper: Jet-Related Excitation of the [CII] Emission in the Active Galaxy NGC 4258 with SOFIA
Authors: P. N. Appleton, T. Diaz-Santos, D. Fadda, P. Ogle, A. Togi, L. Lanz, K. Alatalo, C. Fischer, J. Rich, P. Guillard
Reference: in press.

Science Operations and Outreach

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

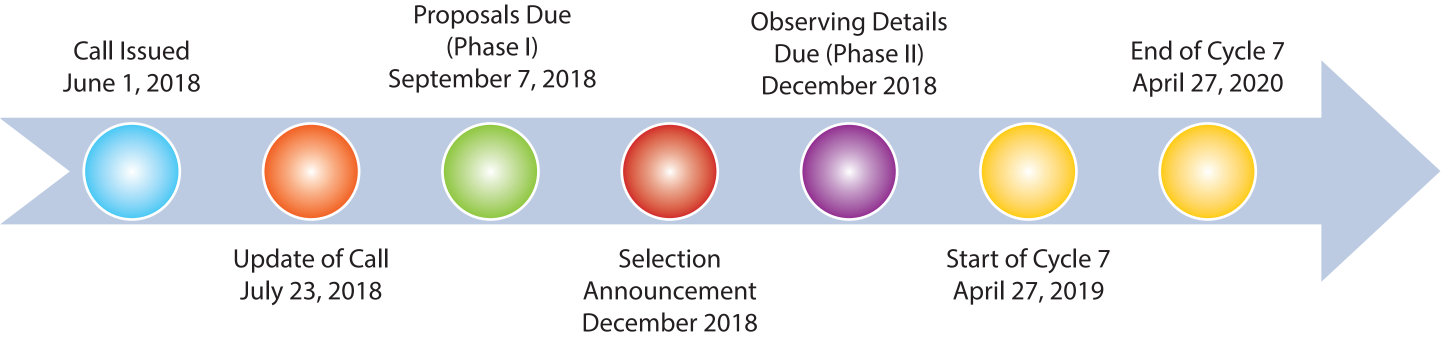
The Cycle 7 solicitation process culminated on September 7 with the proposal deadline. More than 230 Legacy and Guest Observer proposals were submitted requesting observing time at an over-subscription rate of 4.5. The proposal call attracted very high-quality proposals for the full SOFIA instrument complement.

The Legacy proposal call, which asked for significant projects providing value-added efforts (analysis tools, theory effort, high-level processing products, etc.), was new for Cycle 7. Ten of the proposals were submitted in this category, spanning the full range of SOFIA science.

The proposal review was held in mid October, with five (U.S.) subject panels, in addition to a separate Legacy panel. For the first time, the German review was co-located with the U.S. meeting, allowing a more immediate comparison of the proposals.

To assist the Science Mission Operations Director in matching the very best proposals with SOFIA scheduling constraints and instrument team availability, the science center uses two software packages developed in-house. The first is referred to the "Cycle Scheduler" and is used to lay out and evaluate the best sequence of instruments on the observatory during the year. This allows us to optimize not only when each instrument should be active — including which instruments should be considered for the Southern Hemisphere deployment for the cycle — but also helps SOFIA to schedule the required maintenance periods in an optimal way. With a cycle schedule laid out, we progress to using the "Short Term Scheduler" which generates individual flight plans for each flight over the full year. At this time these flight plans are only preliminary, because we do not yet have the specific observing details for the proposals. SOFIA schedule simulations are of the so-called "NP-complete" problems (same class as the famous "Traveling Salesman Problem") and cannot be solved in closed form (and you can't even prove that you have achieved the best possible solution), so both the Cycle Scheduler and the Short Term Scheduler work by generating a very large number of candidate plans and selecting among them by figures of merit. These simulations support the proposal selections for Cycle 7. The selection of Cycle 7 proposals was announced in December 2018, followed by invitations to the approved proposal teams to submit their phase II inputs, providing the details of their observations.

With the detailed phase II inputs, inputs from those instrument teams that have Guaranteed Time Observations remaining and with updated information of the HIRMES commissioning, we will produce nominal schedules in early 2019 for a cycle start at the end of April. As in previous cycles, the final flight plans are generated on a rolling schedule starting about 10 weeks before the first flight in each flight series. At this time we will be inviting Guest Observers whose observations are scheduled to participate in "their" flights. We hope to see you then! ■



SOFIA Science Instrument Development Update

Alan C. Rhodes, *SOFIA Science Instrument Development Manager*

One of the key strengths of the SOFIA platform is the ability to take advantage of new technology and new methods of observing. SOFIA can do this by updating its instrument suite by developing new instrumentation that utilizes cutting edge technology to reach further into the infrared universe. These instrument development efforts also give NASA, as an agency, a method to train the next generation of scientific instrumentalists on how to plan and build new instruments that may one day be used for infrared space missions. With the High-Resolution Mid-infrared Spectrometer (HIRMES) and next generation science instrument development efforts underway, the observatory is positioned to open new windows to the universe with new technology and techniques of observing.

The HIRMES instrument is entering the portion of development known as integration and test. This is where the development team is working on the final product and putting together all of the subsystems into what will become the overall instrument. The team at the Goddard Space Flight Center, with assistance from

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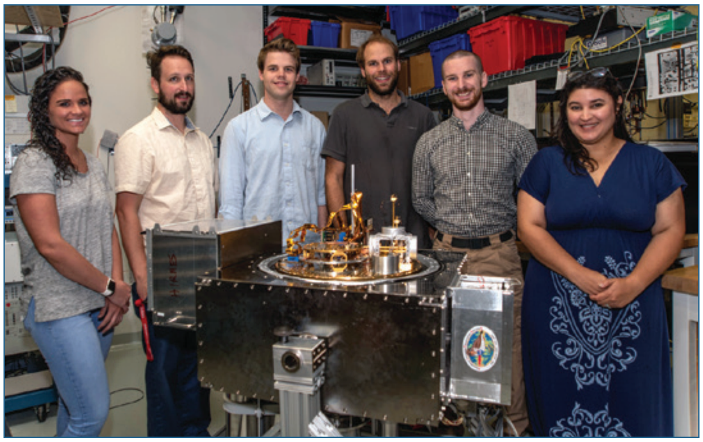


The HIRMES team, in front of the HIRMES detector test stand. *Left to right:* Shannon Wilks, Mechanical Engineer; James Hays-Wehle, Detector Scientist; Iver Jenstrom, Mechanical Engineer; Peter Nagler, Engineering Physicist; Samuel Richards, HIRMES Instrument Scientist; Samelys Rodriguez, Electrical Technician.

Table 1. HIRMES Observing Modes and Instrument Capabilities

Parameters	High-Res	Mid-Res	Low-Res	Spectral Imaging
Sensitivity (5σ, 1hr)	≤ 1 × 10–17 W/m^2	~1 × 10–16 W/m^2		
Resolving Power (R = λ/δλ)	50,000–100,000	12,000	600	2,000
Angular Resolution	Diffraction Limited			
Slit Size / FOV (arcsec)	Length: 139.5"; Width: 8.7", 6.1", 4.2" & 3.0"			113.0" × 106.8"
Spectral Range	25–122 microns			Selected lines[a]
Simultaneous Spectral Coverage (δλ/λ)	λ/R	0.1λ		0.001λ
Detector Format	8 × 16pix[b]	16 × 64 array[c]		
Detector Type	Transition Edge Sensor (TES)			

a) Single Wavelength Setting for Selected Filters (51.8 microns, 88.3 microns [OIII], 57.3 microns [NIII], 121.9 microns [NII]).

b) High resolution detector consists of eight 16 pixel linear arrays, whose pixel size increases per array. Shorter wavelength light is positioned onto the smaller pixel arrays, longer wavelength light onto the larger pixel arrays.

c) Spectral Imaging uses only a 16 × 16 pixel section of the 2D array.

Top Three Heterodyne Results: Big Performance from a GREAT Instrument

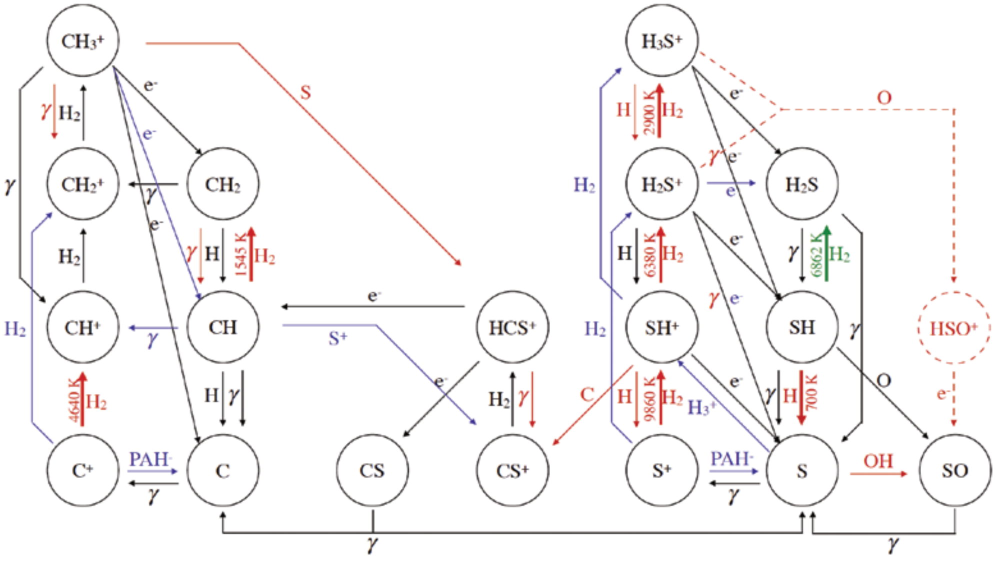
SOFIA's Project Scientist, Kimberly Ennico Smith, selected her three favorite results from the German Receiver for Astronomy at Terahertz frequencies, or GREAT, a dual channel heterodyne spectrometer with a resolution of R = 10^8 for frequencies between 0.490 and 4.747 THz (63–612 microns).

Rewriting Chemistry with the First Detection of the Mercapto Radical

Sulphur-bearing Molecules in Diffuse Molecular Clouds: New Results from SOFIA/GREAT and the IRAM 30 m Telescope; Neufeld et al., 2015

In 2012, GREAT made the first astronomical detection of the mercapto radical, SH [Neufeld et al., 2012]. No other observatory had been able to observe SH because the Herschel HIFI spectrometer was not equipped to view its 1.383 THz absorption line and the Earth's atmosphere completely blocks observations from the ground. This subsequent study combined the original observation of SH with further observations onboard SOFIA and H_2S, CS, and SO data from the Institut de Radioastronomie Millimétrique (IRAM) 30-meter telescope to yield column density ratios for five diffuse molecular clouds. The resulting analysis completely changed the way we view the physics of these clouds and the carbon-sulphur chemical network.

Efficient production of SH requires endothermic reactions at very warm temperatures, not conditions we associate with cold diffuse molecular clouds. Observations by GREAT revealed a surprising abundance of SH in all five clouds — a factor of ~100 greater than what is predicted by standard models of photodissociation regions — with relatively constant column density ratios.



Chemical network for sulfur *(right)* and carbon *(left)*. Shown are reactions only important in photodissociation regions *(solid blue arrows)*, reactions only important in turbulent dissipation regions or shocks *(solid red arrows)*, suggested pathway enabling velocity memory effect *(green arrows)*, and suggested pathway of SO *(dashed red arrows)*. *(Neufeld, et al., 2015)*

These results indicate that warm chemistry is occurring on a much larger scale than what had previously been realized in diffuse clouds. The physical implications of the data suggest these areas must be incredibly dynamic to produce a warm chemistry environment, peppered with C-type shocks or turbulent dissipation regions. "It's starting to paint a picture that you can use these simple molecules to tell you a lot about the environment," says NASA SOFIA Project Scientist Kimberly Ennico Smith. "That was just incredibly transformational for the observatory and for astronomy in general."

Yet even when taking shocks and turbulent dissipation regions into account, there is still a discrepancy between theoretical and observational quantities by a factor of ~10 for H_2S and SO. Further analysis to explain why the models weren't matching up with observational data led to the formation of a new addition to the chemical model for sulphur- and carbon-bearing molecules called the "velocity memory effect."

The standard chemical network for sulphur- and carbon-bearing molecules shows that H_2S^+ or H_3S^+ can undergo dissociative recombination to produce SH. If the SH molecule could retain some of the velocity of its

Raquel Destefano, *Science & Technical Communications Specialist*

ionized parent molecules, it would cause a translational excitation that would enable SH to combine with H_2 to produce H_2S and H. When incorporating this "velocity memory effect" into theoretical calculations, the discrepancy between theoretical and observational quantities of H_2S reduces to a factor of ~3. Furthermore, the prediction for SO is increased by a factor of 10 if it turns out that H_2S can undergo a rapid reaction with O to produce HSO^+ and H, a process that would be followed by the dissociative recombination of HSO^+ to produce SO.

Verifying these findings requires more observations with SOFIA and detailed line profile calculations for turbulent disassociation regions and shock models. "The next logical step is to map the abundance of sulfur in multiple regions, such as high- and low-mass star formation regions, CO dark clouds, and so forth," Ennico says. "I'd love to see these isolated measurements start putting together a bigger theory of what's going in in clouds, like a unified theory of basic chemical reactions supported by observational evidence." Given further research, this study could prove to significantly advance our understanding of the carbon- and sulfur-chemical network and have further implications on the way we perceive diffuse clouds.

Dating Protostellar Systems from the First Detection of Ortho-D_2H^+

Detection of Interstellar Ortho-D_2H^+ with SOFIA;
Harju et al., 2017

Within the last decade, the realization of the significance of nuclear spin on deuteration — the substitution of normal hydrogen, H, by heavy hydrogen, D — has prompted laboratory tests and theoretical studies to generate models to try to figure out how deuterated molecules form. This study provided the first astronomical observation of the deuterated molecule ortho-D_2H^+. "We're truly testing the way we understand deuterium in the most isolated cases using the universe as a laboratory," Ennico says. Deuteration can be used to determine the chemical makeup of gas conditions and provide a lower limit for the age of the protostellar environment, effectively making the deuterated variants of H_3^+ a chemical clock for monitoring the timescales of early star-formation processes.

Deuteration must occur at temperatures below 20K to allow CO to freeze into dust grains, which would otherwise react with H_3^+ and impede deuteration. This makes star-forming regions the ideal laboratory for testing theoretical deuteration chemistry, as cold temperatures are required to achieve densities great enough for star formation to occur. So if we observe significant deuteration occurring, we can model the physical processes of the protostellar region more effectively.

The deuteration of H_3^+ involves a series of chemical reactions with HD that produces H_2 and one of the deuterated variants: H_2^+, followed by D_2H^+, then finally resulting in D_3^+. Depending on how nuclear spins are combined, H_2 and the variants of H_3^+ are labeled as either ortho or para. The energy contained in the ground state of ortho-H_2 causes a reverse reaction that inherently reduces the amount of deuterium. More ortho-H_2, less deuterium, and vice versa. In cold star-forming clouds, the ortho and para

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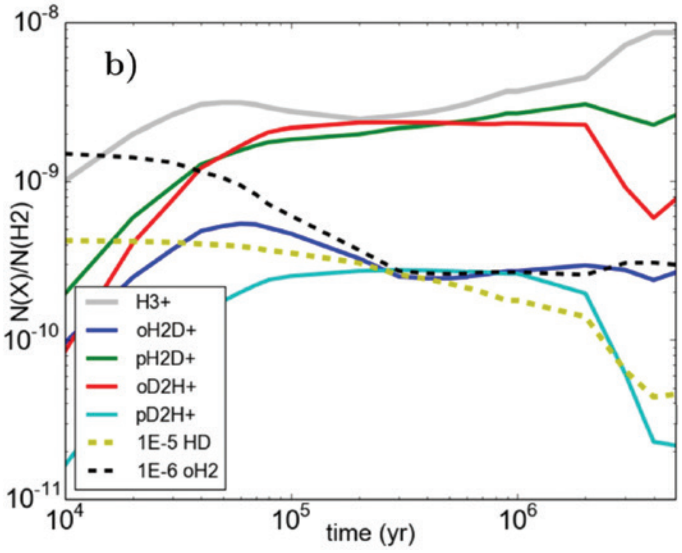

Time evolution of the average fractional abundances of ortho- and para-D_2H^+ and ortho- and para-H_2D^+ in the outer layers (radius = 2500–6900 AU) of the protostellar envelope of IRAS 16293-2422 per a chemical model that uses (re-processed) abundances from a dark cloud stage after 5 × 10^5 years. The team uses different chemical models to interpret the measured ortho- and para-D_2H^+ and ortho- and para-H_2D^+.observations. *(Harju et al., 2017)*

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modifications of H_2 stay in their lowest energy levels, and thus cannot be directly observed. Luckily the ortho-to-para ratio of H_2 is closely linked to those of the observed deuterated variants of H_3^+.

Models tell us that the ortho-to-para ratio of H_2 should decrease with time, so determining this ratio using deuterated species allows us to approximate the age of the cloud by how long it's been chemically processing. In other words, this allows us to estimate how long it has taken for the cloud to collapse to form stars.

Observations have already existed for ortho-H_2D^+ and para-D_2H^+ for some time. In 2014 GREAT was used to make the first (and as of yet, the only) detection of para-H_2D^+ at 1.3701 THz (219 microns) [Brünken, 2014]. To continue these efforts, in 2017 GREAT made the first observation of ortho-D_2H^+ at 1.4766 THz (203 micron) from the protostellar binary IRAS 16293-2422. This most recent observation, in addition to confirming our understanding of deuterium chemistry, allowed for the fractional abundances and ortho/para ratios to be calculated and established a lower limit for the chemical age of the core of IRAS 16293-2422 at about 500,000 years. "The combination of the Brünken and the Harju papers is this area of chemistry that no one else is doing," Ennico says. "You're really probing these basic chemical ladders."

Rovibrational transitions in the infrared allow H_3^+ and D_3^+ to be detectable by spectroscopy, however only H_3^+ has been detected thus far. The next natural progression for studying this chemistry would be to search for D_3^+ utilizing the Echelon-Cross-Echelle Spectrograph (EXES) on SOFIA.

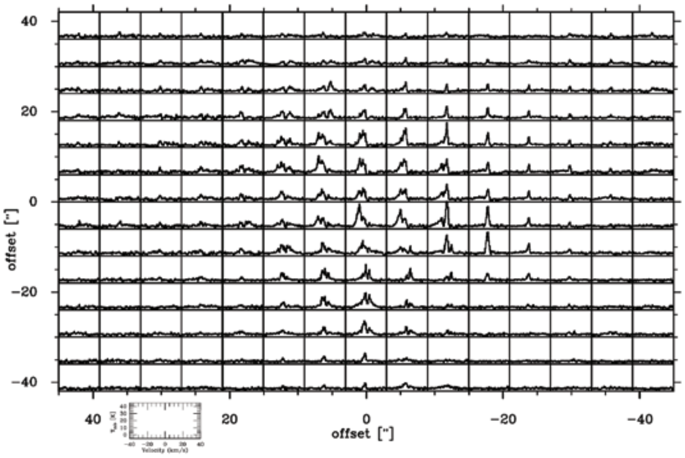
The Case of the Massive Stellar Nursery

Anatomy of the Massive Star-forming Region S106; Schneider, et al., 2018

The dynamic physical processes of massive star formation have long eluded astronomers because their intricacies are obscured by the complex conditions in which these giants must form. Intent on figuring out just what in the name of Newton is going on in one of these massive stars, Schneider and her team will use data from GREAT and other observatories over a series of studies to combine spatial, velocity, and intensity information from atomic and molecular line observations and continuum from the millimeter to the far-infrared. "This paper is a herald of things to come," Ennico says. "We're really going to start seeing that third dimension by reconstructing and providing an in-depth look of the structure of something that's been completely enigmatic to astronomers until now."

In the pre-stellar phase, the energy levels of rotational transitions are generally too high for molecular line emission to be visible in the far-infrared. Light hydrides may be sometimes observed in diffuse clouds where most stars form, but high mass stars form in incredibly dense clumps that are a few thousand times more massive than the sun in an area of ~1 parsec.

Before hydrogen begins to burn in the stellar core, the protostellar phase is marked by accretion of the cloud into a disk. This releases an atomic jet of ionized gas orthogonal to the disk that drives a molecular outflow. For the average star this process is quite civilized, lasting for about a million years with distinctive, orderly jets and outflows. Contrastingly, massive stars collapse within about a thousand years, and are actually burning hydrogen while still accreting. To keep things interesting, massive stars typically form as binary or multiple



GREAT spectral map of 63 micron [OI] emission of the bi-polar star formation complex S106 with a velocity resolution of 1 km/s on a 6 arcsec beam-sampled grid in the velocity range from -40 to 40 km/s and main beam brightness temperature range from -4 to 40 K. This data, combined with information from other atomic and molecular species provides a rare detailed study of the late stages of the formation of massive close binary systems and their circumstellar environments, both immediate and extended. *(Schneider, et al., 2018)* star systems, and these surrounding protostars within the dense cloud result in a complicated overlapping of molecular outflows with random alignments that are difficult to discern.

The high energy of these outflows causes them to become ionized and creates a confined HII region, such as the bipolar nebula S106 that contains a binary star system. Bipolar nebulae often exhibit a belt of cold dense gas along their equatorial plane, the nature of which and impact on shaping the nebula and HII region has yet to be ascertained. Outflows and accretions can lead to shocks that exhibit the same tracer lines as photodissociation regions: [CII] for diffuse gas, [OI] for dense gas, and high-J CO lines. This makes it extremely challenging to determine what is causing the observed emission contributions.

Previous studies of the S106 binary system only looked at line integrated fluxes, whereas the velocity resolution provided by GREAT can be used to model the line ratios within different velocity ranges to map the overall anatomy of S106 and ascertain if shocks are being produced. "This puts us, basically, at the crime scene," Ennico explains. "You go to a stellar nursery and you're just left with a snapshot of time, but you don't know what's happened in the past. You only know what's going on now and you have to piece together what created such crazy beautiful objects and where they will go next."

Deciphering the step-by-step mechanics of massive star formation in compact HII regions requires combining detailed, velocity-resolved observations of the [OI] 63-micron line and high-J CO lines as tracers, with existing [CII] observations from GREAT. This study was able to resolve in great detail the direction and speed of [OI] emission at various ranges to create the first spectrally resolved map of the [OI] 63 micron far-infrared cooling line for S106. "It will be really interesting to see how this approach of using velocity resolved spectral mapping will continue to advance our interpretation of these exotic places," Ennico says. Future studies will investigate a possible shock origin of the [OI] emission by applying irradiated shock models and the large-scale structure of the bipolar nebula using [C II] 158-micron data collected by previously by the team with SOFIA. ■

SOFIA Science Instrument Development Update

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the SOFIA team, have begun outfitting the instrument with the scientific equipment that will allow the HIRMES instrument to open new windows of exploration. As the integration and testing efforts continue, the team will complete outfitting the instrument at then begin the process of cooling the instrument to its operating temperature of 0.07 degrees Kelvin or −273.08 degrees Celsius. This ultra-low temperature is necessary for the HIRMES detectors to function and one of many technical challenges that a development team faces when planning a new instrument. There will be a number of cooling cycles and tests performed in the lab prior to the instrument shifting to the aircraft to begin commissioning. In anticipation of the coming commissioning flights, the HIRMES science team is already working to determine what astronomical targets they will use to test the instrument and to set the first scientific exploration campaigns once commissioning is complete.

Along with the HIRMES development, a team led by NASA Headquarters has just completed a competitive solicitation for the Next Generation instrument for SOFIA. Specific details of the competition are still in review, but more information about the selected instrument development efforts and the new capabilities those instruments will provide for SOFIA are expected in the near term. This nationwide solicitation has helped the NASA team to learn about new technologies and techniques and will result in new capabilities for the Agency and open new windows of exploration for the astronomical community. ■

German Perspective

Bernard Schulz, *Science Mission Operations Deputy Director*

Our observatory flies, and time does too. My first half year on the project has passed quickly and a multitude of things happened. The impact of the long downtime at the beginning of the year due to important, but unplanned repairs at Lufthansa Technik in Hamburg, could be minimized through creative re-scheduling. Even though the repairs took much longer, the end date of Cycle 6 needed to be delayed by only two months to April 2019. This allowed for recovery of all of the previously lost targets, except for the time dependent ones.

The SOFIA Workshop that took place in May at the German SOFIA Institute in Stuttgart was well received. The gathering of 55 participants was certainly useful for those who wanted to learn about SOFIA, the latest call for proposals, and how to write a successful SOFIA proposal for Cycle 7. The 33 proposals we received after the deadline in September from German proposers, asking for a total of 184 observing hours, with about 70 hours actually available, show the continued rising interest in the German community. At the same time, the workshop turned out to be a great opportunity for various face-to-face meetings of project members from both sides of the Atlantic Ocean. Yet again, we experienced the tremendous communicative benefits of meeting in-person compared to telecons or even videocons.

Cycle 6 started with a GREAT flight from Palmdale, followed by a very successful New Zealand campaign, where 24 out of 25 flights were executed. I accompanied the first two weeks of that campaign and experienced first-hand the day-to-day operation of SOFIA from the U.S. Antarctic Program's facility in Christchurch.

After 15 flights out of Christchurch, the last mission of one of the most productive German REceiver for Astronomy at Terahertz Frequencies (GREAT) flight series also marked the last science flight of Rolf Güsten as principal investigator (PI) of this instrument before his retirement. Güsten was instrumental in one of the big success stories of the SOFIA project. He assembled and managed a team that pushed the boundaries of heterodyne technology substantially beyond the high bar already set by the Heterodyne Instrument for the Far-Infrared (HIFI) that flew very successfully on the Herschel mission. The GREAT team's use of a successively upgradeable modular design in order to fast-track the latest technology to the telescope, is exemplary. I wish Rolf all the best on his next endeavors, that, as I hear, will allow more time for even more fascinating science after Prof. Jürgen Stutzki takes over his responsibilities as GREAT PI.

SOFIA's telescope assembly keeps performing marvelously, yet there is always room for improvement. With substantial support from the DSI, NASA re-activated the Active Mass Damper (AMD) for the first time since 2013. The stand-alone system reduces the prime mirror deformations during flight that negatively affect image quality. The basic functionality of actuators and sensors could be restored and verified, and their respective positions in the system identified. The full functionality in closed-loop operation, however, could not yet be shown due to residual noise issues. The team is pressing forward to achieve this important milestone soon.

I am particularly happy about the recent conversion of the planned Senior Review into a five-year Flagship Mission Review, because it allows German participation in the process again, which would not have been possible under the previous scheme. This enables having a truly constructive process with the goal to improve the system further and achieve more excellent science results and publications. If the Flagship Mission Review could be made a regular event, it would also boost the German instrument funding process, which matches much better with a five-year cycle than the triennial U.S. Senior Review process.

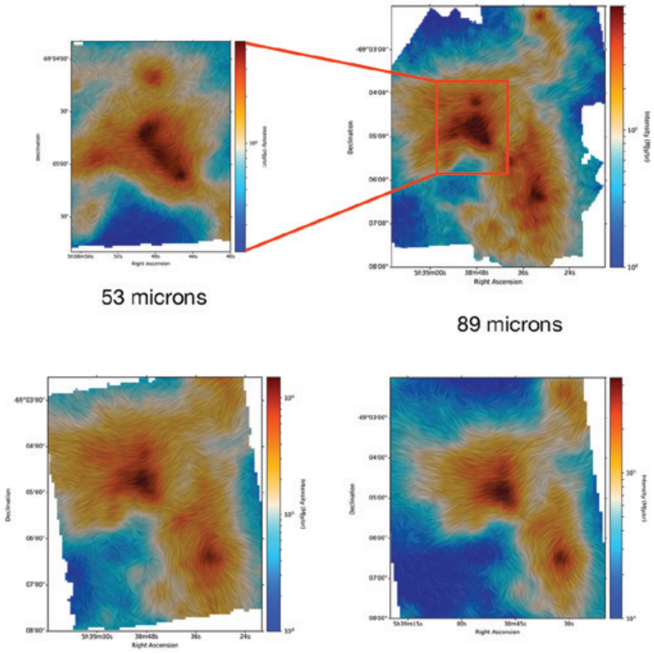
Talking about publications, I want to take this last bit of space to remind the astronomical community of the next SOFIA workshop at Ringberg Castle in Germany, that is scheduled for January 20–23, 2019. ■

SOFIA Reveals Never-Before-Seen Magnetic Field Details

Kassandra Bell, *Communications Specialist*

SOFIA released new data from its recent Southern Hemisphere observations revealing the structure of celestial magnetic fields in the region known as 30 Doradus, or 30 Dor, at a scale that has never been seen before. The data set is now available to the scientific community to facilitate studies of how magnetic fields affect stars forming in nearby galaxies.

These images show the infrared radiation emitted by the dust and the magnetic fields in 30 Dor, which is a star-forming region within the Tarantula Nebula located in the satellite galaxy called the Large Magellanic Cloud. Observations have shown that 30 Dor is one of the best and closest laboratories to study the starburst phenomenon — in which large numbers of massive stars and stellar clusters are formed rapidly in a small volume. But the effect magnetic fields have on these processes is not well understood.



53 microns

89 microns

154 microns

214 microns

Images taken at multiple wavelengths showing the dust and the magnetic fields in 30 Doradus. The color scale shows the intensity of the infrared radiation from the dust, or dust emission, and the lines show the morphology, or the structure, of the magnetic fields. The images taken at the shorter wavelengths (53–89 microns), reveal warmer dust, while the images taken at the longer wavelengths (114–213 microns) show cooler dust. *(NASA/SOFIA)*

Using the observatory's newest instrument, HAWC+, which has a device called a polarimeter that maps celestial magnetic fields, the SOFIA team observed 30 Dor in a range of wavelengths sensitive to dust temperatures between 10–100 Kelvin (–441 to –280 F). The images taken at the shorter wavelengths reveal warmer dust, while the images taken at the longer wavelengths show cooler dust. These can be used to study potential disturbances on the magnetic fields in the dense and compact regions of 30 Dor, as well as the large-scale magnetic fields governing the whole structure of the nebula — both of which may impact star formation.

"SOFIA's pioneering observing techniques let us gather this exciting data," said Kimberly Ennico Smith, SOFIA project scientist. "We're thrilled to offer it to the scientific community so soon after the observations were completed."

Instructions to download HAWC+ 30Dor data.

- If you don't have a DCS account, yet, register for one here: https://dcs.arc.nasa.gov/userSupport/registration.jsp
- Log into DCS: https://dcs.arc.nasa.gov
- Go to "Search Science Archive"
- Fill in:
  - Instrument: HAWC_PLUS from drop-down menu
  - Processing State: LEVEL_4 from drop-down menu
  - Target: 30Dor (No need to resolve the name via Simbad or NED. If resolved use a large search radius, e.g. 600")
  - Click the "search" button
- Consult the HAWC+ Data Handbook accessible on this page: www.sofia.usra.edu/science/proposing-and-observing/data-products/data-resources

For further assistance, please contact the SOFIA Help Desk: sofia_help@sofia.usra.edu ■

Director's Message

(continued from page 2)

the deployment, the s-DDT project, "HAWC+ polarization measurements of the 30 Dor region," was implemented to comply with SOFIA users' request for sample, non-proprietary HAWC+ polarization data and, at the same time, provide the astronomical community with a rich archival data set of this mini-starburst region.

Proposals for Cycle 7 were reviewed and selected in mid-October 2018, and will be executed between April 2019 and April 2020. The response to the Cycle 7 call for proposals was excellent; the oversubscription rate in terms of hours requested versus hours offered was 4.5. In Cycle 7, SOFIA introduced a new "Legacy Proposal" category, designed to support large, two-year projects and additional tools which are in high demand by the community. Ten such projects were proposed for Cycles 7 and 8. Data from the Legacy Projects will have no proprietary period.

SOFIA continues to improve its instrument suite to accommodate even more exciting science. Next year the High-Resolution Mid-Infrared Spectrometer (HIRMES) instrument will be deployed and tested, and a new instrument will be selected from NASA's recent Call for the Next Generation SOFIA Instrument. The selected instrument should begin operations in 2022 and will have its own non-proprietary Legacy Program. As the observatory evolves and improves, we eagerly await SOFIA's next scientific discoveries. ■

Probing Shocked Gas in an Active Galaxy

(continued from page 5)

profiles are quite broad, with the highest intrinsic width, Full width at half maximum equaling 455 kilometers per second (FWHM = 455 km/s), at the position of the southern bow-shock. However, the peculiar [CII] gas properties extend even further into the galaxy, beyond the optical bow-shock, which has previously been assumed to be the termination of the jet. Not only do the line-widths remain broad beyond the southern bow-shock, the [CII] emission diverges more and more from those properties found in normal (star forming) galaxies. For example, the ratio of [CII] emission to that of the polycyclic aromatic hydrocarbon ([CII]/PAH) feature at 7.7 microns rise to values that seem incompatible with star formation processes. Interestingly, the regions along the northern jet do not show these peculiar properties, suggesting that the northern component of the jet is much less strongly interacting with its surroundings.

These results are only possible because of the high spatial resolution afforded by FIFI-LS for a nearby galaxy like NGC 4258. They provide a cautionary note for the simple interpretation of [CII] emission as a star formation indicator, since cases like NGC 4258, the radio jet can deposit a significant fraction (up to one percent) of the black-hole accretion energy into the [CII] line emission through its turbulent interaction with surrounding gas in the host galaxy. ■

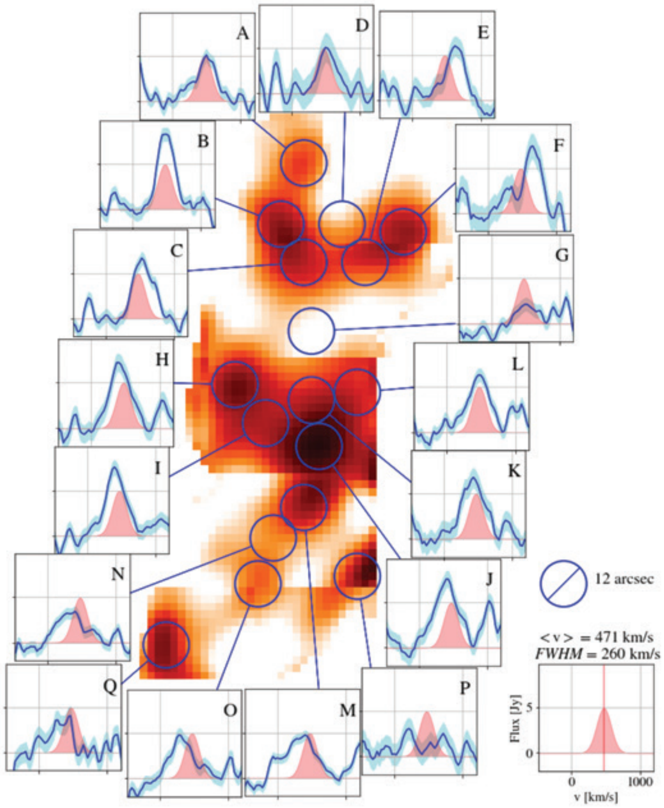


Figure 2. SOFIA/FIFI-LS [CII] emission spectra of different regions in NGC 4258. An unresolved line pink shown in the lower right is plotted at the redshift of the galaxy for comparison. Many spectra appear broader than the FIFI-LS spectral resolution, especially those associated with the jet blow-shock (region M) and the X-ray hot-spots (regions F and Q).

Airborne Astronomy Ambassadors

Dana Backman, *Manager, NASA Airborne Astronomy Ambassadors Program*

The SETI Institute's Airborne Astronomy Ambassador (AAA) program continued with flights of 15 Cycle 6 Ambassadors during September and October 2018 (Figure 1).

The AAA program consists of pre-flight teacher professional development involving webinars, on-line content learning, and hands-on workshops. The teachers receive a 'capstone' professional development experience at the Armstrong Flight Research Center's science aircraft facility in Palmdale, California (Figure 2), that includes participation in SOFIA science flights.

Following their SOFIA flights, AAA teachers implement a two-week *Electromagnetic Spectrum & Multi-wavelength Astronomy* curriculum module that includes illustrative examples from SOFIA science observations. The curriculum was produced by AAA SETI Institute staff and is carefully aligned with national Next Generation Science Standards (NGSS).

The ultimate AAA program goal is to measure changes in student content knowledge and STEM (Science, Technology, Engineering, and Math) engagement fostered by the new curriculum and by their teachers' SOFIA flight experiences.

During the 2017–18 school year, WestEd education consultants conducted a Randomized Control Trial (RCT) experiment with Cycle 5 teachers acting as the "treatment" group. Cycle 6 teachers, who had not yet flown on SOFIA and taught the electromagnetic spectrum in conventional fashion, served as the control group. The results of the RCT were that students who received the new electromagnetic spectrum curriculum module from teachers who had flown on SOFIA had significantly higher content knowledge and interest in science than their comparison cohort.

Figure 1: Cycle 6 AAAs and flight facilitators onboard SOFIA.

Figure 2: Cycle 6 AAAs, along with NASA Astrophysics education lead Hashima Hasan. receiving a tour of the SOFIA Science Instruments lab from USRA SOFIA Science Lab Supervisor Zaheer Ali.

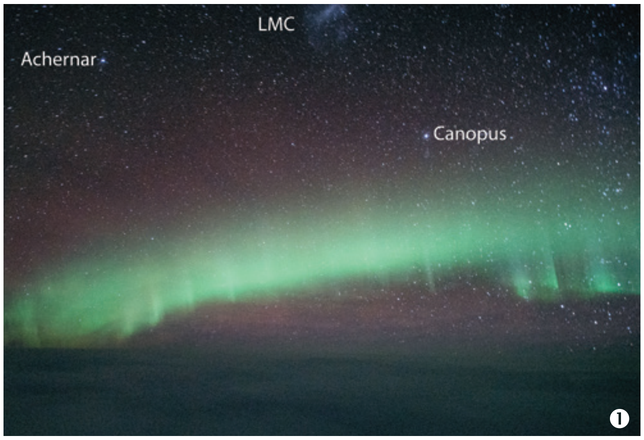
Looking ahead, the AAA program has received funding to extend operations through the end of FY19. AAA staff worked during summer 2018 to establish memorandums of understanding with 15 school districts for program participation in Cycle 7. AAA Cycle 7 represents a return to national scope after the two-year research phase that was limited to California school districts. New partner districts extend from Nevada to Massachusetts.

Note to SOFIA staff scientists and guest observers: If you are in Palmdale during a week when an AAA group is scheduled to fly, the AAA program staff and participants will be grateful if you can spare some time, pre-flight or during your flight, to talk with the teachers about your research project.

The SETI Institute is one of 26 organizations conducting science education efforts via cooperative agreements with NASA's Science Mission Directorate. The Airborne Astronomy Ambassadors program is now a NASA Headquarters-funded program given access to SOFIA facilities by the SOFIA Program Office. SETI Institute AAA program staff include Dana Backman, Coral Clark, and Pamela Harman. ■

SOFIA Southern Deployment

SOFIA deployed to Christchurch, New Zealand, in June and July 2018, to take advantage of the excellent observing conditions in the Southern Hemisphere. ❶ Although we don't study aurorae, they are a beautiful natural phenomena. A bright aurora australis is seen with Achernar, the brightest star in the constellation Eridanus, the Large Magellanic Cloud — a satellite galaxy of our Milky Way galaxy, and Canopus (Alpha Carinae) the brightest star in the constellation Carina *[Ian Griffin]*; ❷ Wide field imager (visible light) view of the Tarantula Nebula (30 Doradus) *[N. Veronico]*; ❸ Infrared radiation emitted by the dust and the magnetic fields of 30 Doradus *[NASA/SOFIA]*; ❹,❺ SOFIA's Southern Deployment team on the U.S. Antarctic Program ramp *[Dennis Radermacher and Waynne Williams]*.



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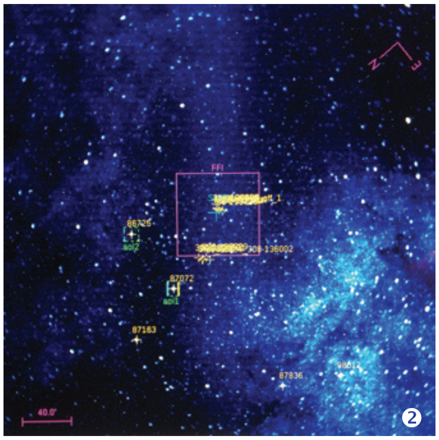

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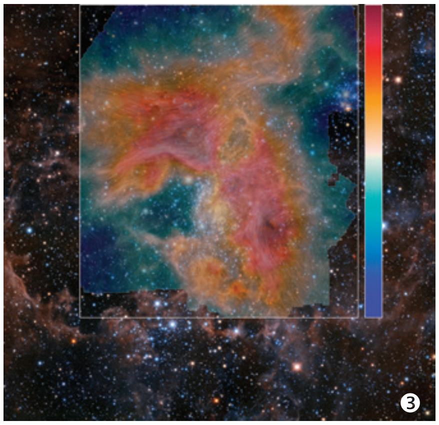

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