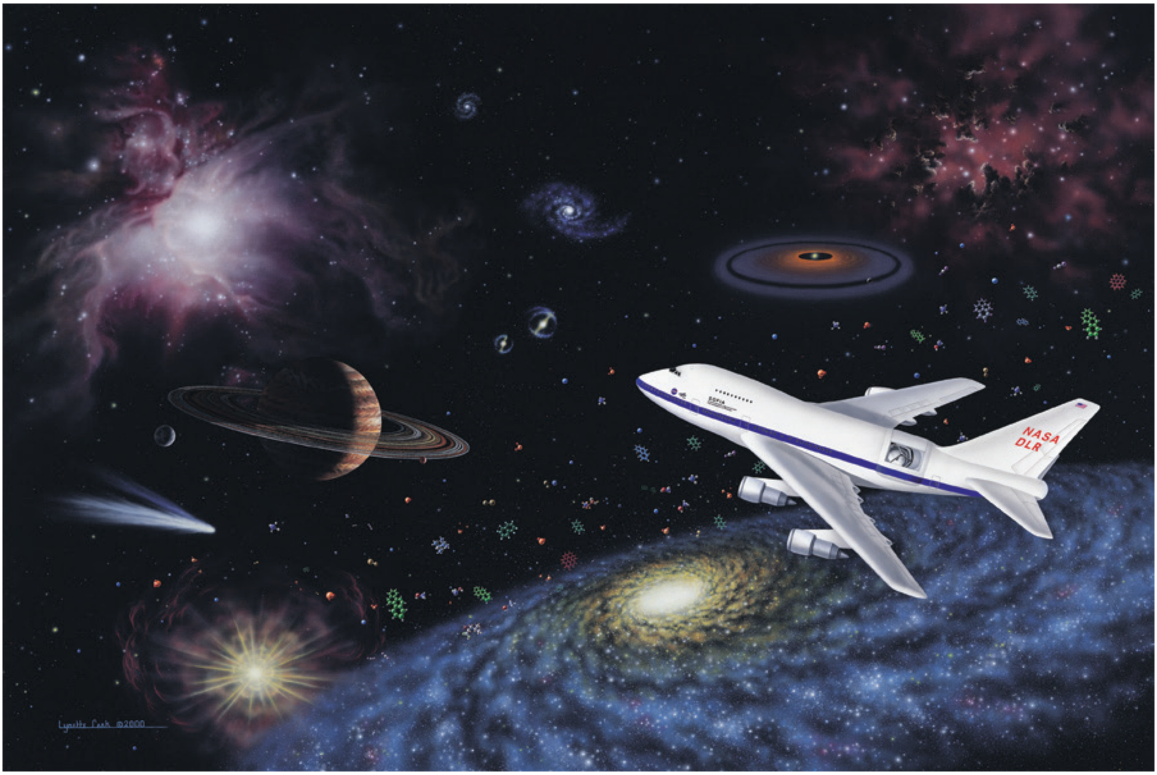
SOFIA and the Infrared Universe

Visually striking and scientifically impactful images of SOFIA science

Gallery Exhibition Catalog

NASA Ames Research Center • Building 232



Stratospheric Observatory for Infrared Astronomy (SOFIA) Artist Concept ①

Artist's impression

California artist Lynette Cook created an impressionistic montage that includes the SOFIA aircraft set against the types of cosmic phenomena that SOFIA observes, including a star-forming region, the Orion Nebula, comets, a supernova, a variety of biogenic molecules, a protoplanetary disk, Jupiter-like extrasolar planets likely to have moons, and various galaxies, including the Milky Way.

SOFIA's instruments — cameras, spectrometers and polarimeters — operate at near-, mid- and far-infrared wavelengths, each suited to studying a particular phenomenon. Flying into the stratosphere at 38,000–45,000 feet puts SOFIA above 99 percent of Earth's infrared-blocking atmosphere, letting astronomers study the solar system and beyond in ways that are not possible from the ground. SOFIA is an 80/20 partnership of NASA and the German Aerospace Center (DLR).

SOFIA observes the solar system and beyond, gathering data to investigate fundamental astrophysical phenomena such as star birth and death, formation of new solar systems, organic compounds in space, nebulae and the ecosystems of galaxies, celestial magnetic fields, black holes at the center of galaxies, and planets, comets and asteroids in our solar system.

SOFIA investigates the physical, chemical, and dynamical processes at work in the formation of stars and planets. These data help us understand how massive stars form in various environments. It also investigates astrochemistry, including the chemical composition of the gaseous and solid-state material out of which new planets form. SOFIA also studies the formation of complex hydrocarbons and the far-reaching implications for understanding our place in the universe.

SOFIA surveys the interstellar medium, which contains an elemental record of the generations of stars that have lived and died since the galaxy's birth. SOFIA's instruments are well suited for spectral imaging of bright sources and extended regions of the Milky Way and nearby galaxies. These data are used to probe the physics and chemistry of a variety of environments and conditions. SOFIA explores how stars interact with their environments, the origin of dust, and the role of complex molecules.

SOFIA, the Stratospheric Observatory for Infrared Astronomy, is a Boeing 747SP aircraft modified to carry a 2.7-meter reflecting telescope.

SOFIA studies the center of our galaxy and is particularly valuable for investigating the many questions that arise in this complex environment. The central molecular zone represents the most massive concentration of dense gas in our galaxy and provides important lessons about phenomenology of galactic nuclei in general. At a distance of only 8 kiloparsecs, the galactic center offers us critical, spatially resolved information about how the activity there is produced by the interactions of stars, powerful gas flows and stellar winds, strong magnetic fields, and the supermassive black hole. Because of the extreme visual extinction to the galactic center, its abundant energy emerges almost entirely in the infrared and is well suited for study by SOFIA.

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 maps polarized light that results from the effect magnetic fields have on dust in and around celestial objects, allowing astronomers to learn how magnetic fields affect the birth of stars, the dynamics of the galactic center, and even the extreme environment of active galactic nuclei.

FORCAST and HAWC+ Instruments

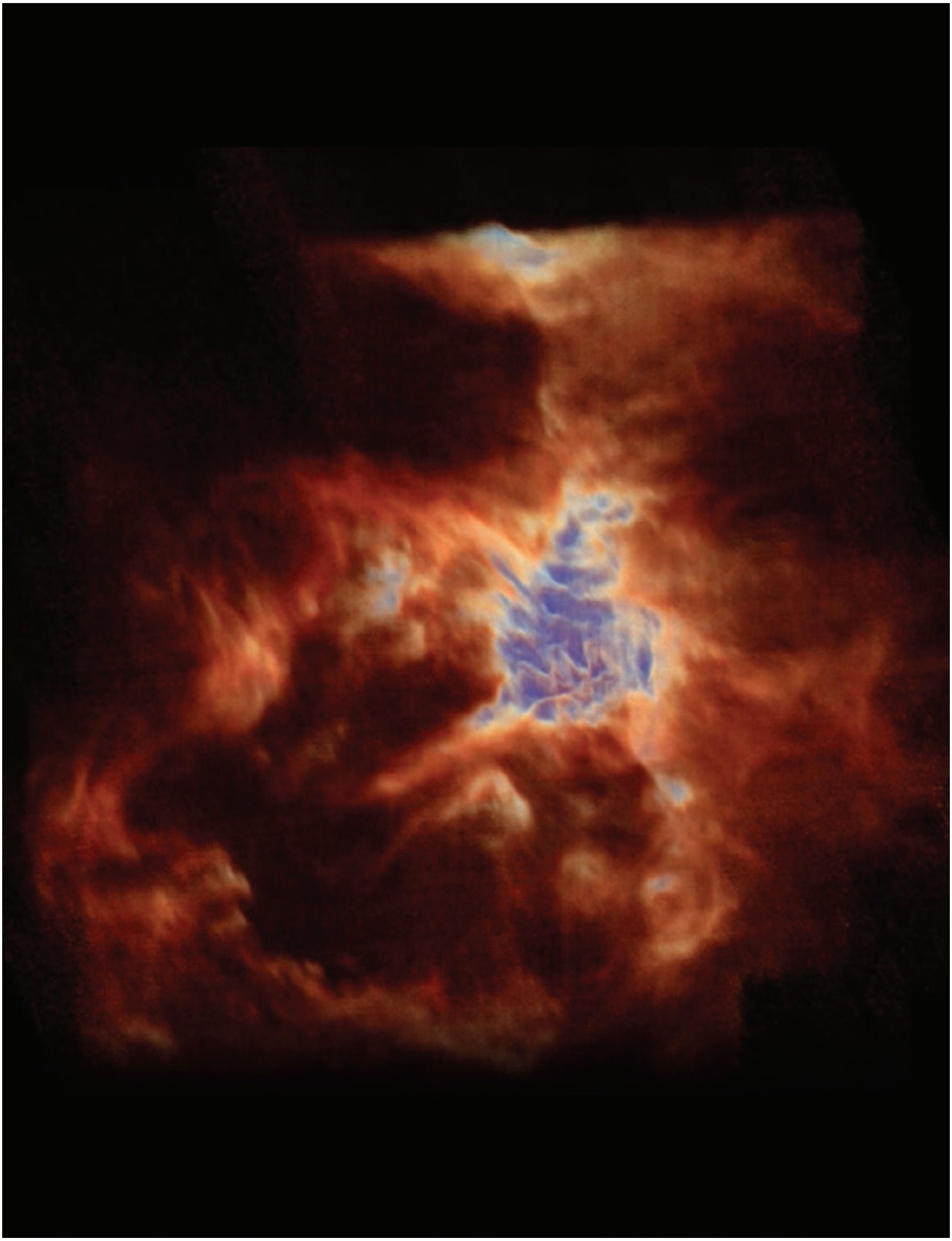
Color shows the SOFIA FORCAST and HAWC+ image of the dusty arcs that surround and possibly feed the massive black hole at the center of our Milky Way galaxy. Streamlines show the magnetic field morphology from SOFIA HAWC+ polarization maps. This combination allows us to compare the direction of the magnetic field and the orientation of the dusty material. The star field is from Hubble Space Telescope Near Infrared Camera and Multi-Object Spectrometer.

NASA/SOFIA/D. Dowell/W. Reach/L Proudfit

SOFIA image of the inner 2.80 arcminutes (6.5 parsecs) of the Milky Way, where the massive black hole at the galactic center is surrounded by a ring of gas and dust. Streamlines show the magnetic field morphology from the High-resolution Airborne Wideband Camera-plus (HAWC+) 53 micron polarization maps. The superposition allows us to compare the direction of the magnetic field with the orientation of the dusty material. The magnetic field closely follows the shape of the ring and streamer structures, as would happen if the material is flowing along magnetic field lines or if the field is being sheared by differential motions of material along the directions indicated by the streamlines. The two streams that seem to plunge toward the black hole (which are blue in the image because they contain much warmer dust) have magnetic fields that are distinct from the ring. They follow their respective directions, even reaching a point where the two streams intersect and the polarization makes an abrupt right-angle turn as it switches from tracing one streamer to another.

> ***SOFIA results inspire new scientific questions, like: Is the magnetic field strong enough to channel the plasma onto the massive black hole?***

These results help determine how material in the extreme environment of the central black hole interacts with it, including addressing a longstanding question of why our central black hole is relatively quiet while those of other galaxies are active and bright due to accretion of material onto the event horizon. These observations inspire new scientific questions, including: Is the field channeling the plasma or is the plasma dragging the field? How strong would the magnetic field have to be to affect the galactic center dynamics? Does the magnetic field control or even quench the plasma flow to the massive black hole?



upGREAT Instrument

Far-infrared imaging spectroscopy of the Orion nebula from SOFIA upGREAT. Over 2 million [C II] 158 microns (μm) spectra create a 3-D data cube of right ascension, declination, and line-of-sight velocity. As the cube turns around the vertical axis, the dragon figure is revealed as the rotation approaches 180 degrees. A stellar wind from the star, Theta^1 Orionis C, has created a bubble by sweeping up over 2,000 solar masses.

NASA/SOFIA/A. Tielens/C. Pabst/R. Taylor

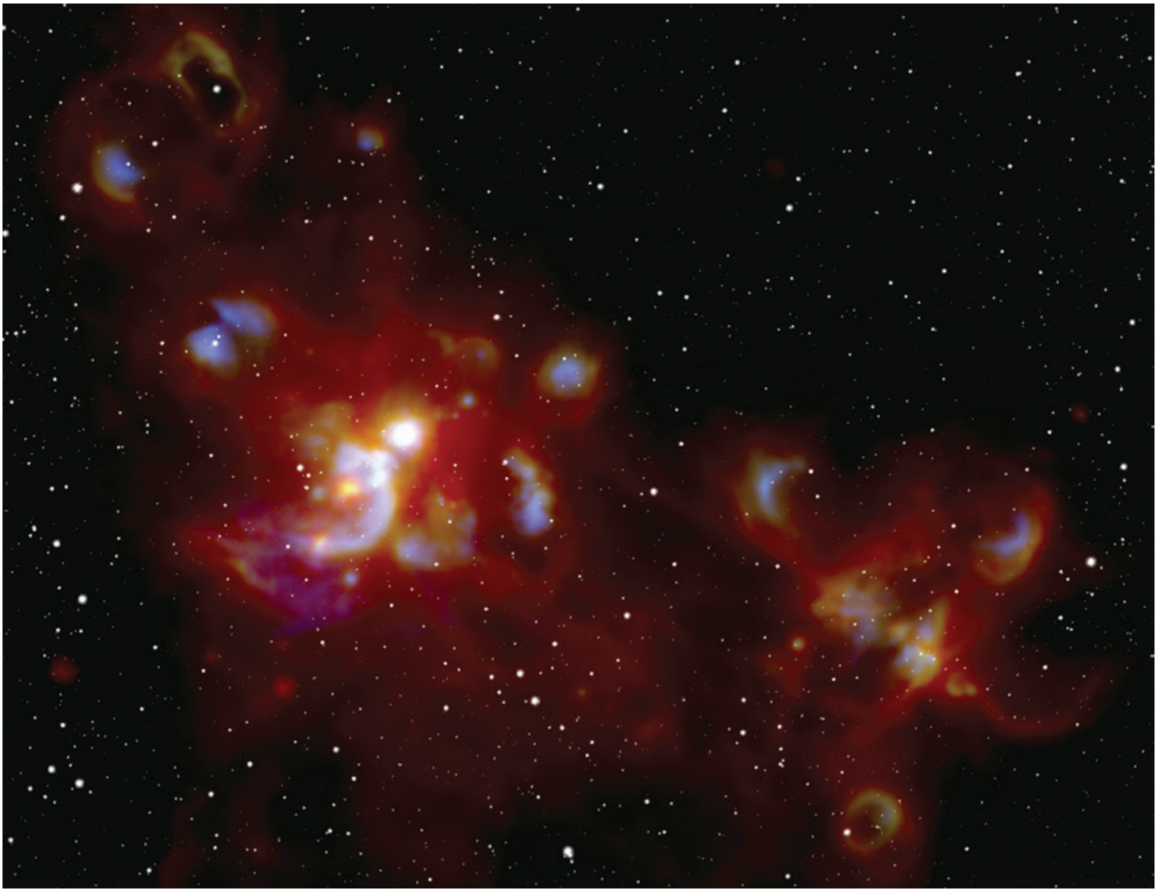
The stellar wind from a newborn star in the Trapezium of the Orion Nebula forms a bubble and disrupts star birth in its neighborhood. At the same time, it pushes molecular gas to the edges of the bubble, creating new regions of dense material where future stars might form. These feedback effects regulate the physical conditions of the nebula, influence the star formation activity, and ultimately drive the evolution of the interstellar medium.

The German Receiver for Astronomy at Terahertz Frequencies (GREAT) on SOFIA recorded over 2 million [CII] spectra in only 40 hours. Researchers then created a data cube that they can rotate, zoom in, and even dive through to better understand how stars are forming. Rotating the cube by 180 degrees along the vertical axis gives us our first glimpse of the structure that we've nicknamed "Orion's Dragon."

The observations provide new insights into the kinematics and dynamics of the shell surrounding the bubble of material blown out by the strong stellar wind. This 3-D view also reveals a rich structure of the nebula, including filaments, colliding flows, and a completely distinct view of the molecular gas distribution.

SOFIA maps of the Orion Nebula in 3-D reveal a powerful stellar wind, strong enough to affect the next generation of star formation.

The interaction of massive stars with their surrounding environments regulates the evolution of star formation. Energy from these massive stars stirs up the medium, heats the gas, and disrupts the birth sites of new stars. Until now, it was generally thought that supernova explosions were the dominating factor controlling the environment of star-forming clouds, but these results from SOFIA show that the stellar wind interactions dominate feedback at a much earlier phase in the cloud's star-producing lifetime.



SOFIA Observations of W51A

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FORCAST Instrument

W51A is one of the largest and brightest star-forming regions in the Milky Way. It lies 18,000 light-years away in the constellation of Aquila. This image is composed of mid-infrared data from the FORCAST instrument for the SOFIA Telescope (FORCAST; 20 µm=blue; 37 µm=green), and Herschel far-infrared data (70 µm=red). Colors trace the warm emission from dust that is being heated by the ongoing star formation activity. The star field is from Sloan (0.9 µm).

These data reveal, among other things, a young stellar object of up to ~100 solar masses, a candidate for the most massive young star in the Milky Way. These results demonstrate that FORCAST is a powerful tool to trace deeply embedded massive young stellar objects.

NASA/SOFIA/J. De Buizer/W. Lim

Massive stars, more than ten times more massive than our sun and a million times more luminous, are playing a critical role in the history and evolution of our galaxy as a heating source for the interstellar medium and in enriching it with heavy elements. Despite their importance, we are literally in the dark about the details of how massive stars form. They are rare (<1% of all stars), typically far away (a few kiloparsecs), and deeply embedded in dense interstellar medium at their early evolutionary stages. SOFIA's infrared vision peered into the massive star forming region W51A revealing the cosmic fireworks sparked by massive stars.

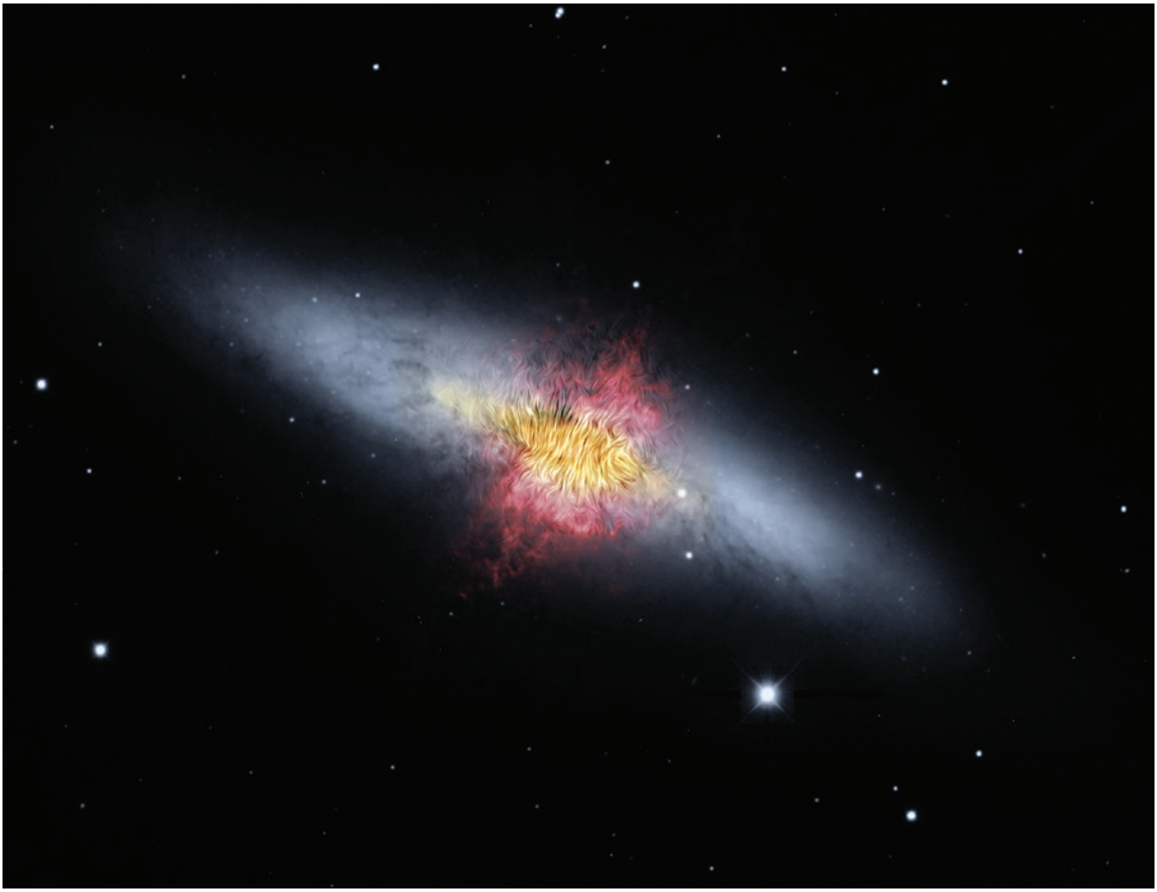
The vast majority of stars form within massive star clusters. Most theories of star formation assume a star forms in isolation and ignore the fact that the cluster environment and, especially, the presence of extremely energetic and high mass young stellar objects nearby, may have a profound impact on the formation process of a typical cluster member.

SOFIA reveals the role massive stars play in the shaping of our galaxy.

Giant HII regions like W51A are rich laboratories to study massive star formation and evolution as they contain many different evolutionary stages. W51A hosts a population of objects that can reveal a wealth of information on the environment of the earliest stages of clustered star formation and how it is affected by feedback from the most massive cluster members. The Faint Object infraRed CAmera for the SOFIA Telescope (FORCAST) imaged W51A for the first time ever at the mid-infrared wavelengths with high angular resolution (~3 arcseconds) and a large area (~10×20 arcminutes) mosaics.

Spectral energy distributions for dozens of sources were compared with massive star formation models. These results reveal the nature and detailed physical characteristics of individual sources as well as the global properties of the region itself. Of the many new findings from this study, particularly interesting was the use of the SOFIA data to quantify the relative ages of the sub-regions within W51A, which showed that W51A is comprised of multiple generations of star formation. However, it does not appear that feedback from older stars drove the formation of later generations.

The SOFIA data also led to the discovery of a population of radio-quiet, embedded sources that have not yet ionized the gas in their immediate surroundings. They represent the youngest generation of presently forming massive stars, which are only detectable at the longer infrared wavelengths provided by SOFIA.



SOFIA Observations of M82

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HAWC+ Instrument

Messier 82 is a starburst galaxy about 12 million light-years away in the constellation Ursa Major. Streamlines show the magnetic field morphology determined from 53 μm polarization maps obtained with SOFIA's HAWC+ instrument. The image combines visible starlight (gray) and H-alpha emission (red) from the Kitt Peak 2.1 m (Spitzer Infrared Nearby Galaxy Survey Legacy project), and near-infrared and mid-infrared starlight plus dust from Spitzer and SOFIA (3.6 and 53 μm; yellow).

The magnetic field is clearly perpendicular to the plane of the galaxy and appears to follow the bipolar outflows generated by the intense nuclear starburst. This geometry extends over a region at least 700 parsecs (pc) along the disk and up to 200 pc above and below the plane.

NASA/SOFIA/E. Lopez-Rodriguez/W. Reach/L. Proudfit

Starburst galaxies like M82 are characterized by enhanced star formation and strong outflows, which feed gas and dust into the intergalactic medium. It displays a bipolar, super galactic wind emanating from its central regions. Astronomers have long theorized that these winds would also drag the galaxy's magnetic field in the same direction, but despite numerous studies, there has been no observational proof of the concept.

Although M82 has been observed extensively from X-Ray to radio wavelengths, very little is known about the generation and morphology of its magnetic field. Observations of polarized synchrotron emission from relativistic electrons can reveal the field geometry. But synchrotron observations at radio wavelengths suffer from Faraday rotation and only sample the population of relativistic electrons, which may not be representative of the denser interstellar gas. Interstellar polarization of starlight extinguished by dust grains aligned by the ambient magnetic field has long been used to study the magnetic field geometry in the Milky Way. However, for diffuse emission from galaxies, optical and near infrared polarimetry is strongly contaminated by highly polarized scattered light, which greatly complicates the measurement of interstellar polarization.

HAWC+ maps polarization of the far-infrared emission from dust grains, which is directly indicative of the magnetic field orientation and probes the majority of the interstellar medium, making it a superior method for tracing magnetic fields in galaxies.

SOFIA discovered that the galactic wind is dragging its magnetic field and blowing huge amounts of material into intergalactic space.

To build a complete view of dust emission, HAWC+ observed at two wavelengths: 53 μm, which samples the warmer dust in the interior of M82, and 154 μm, which favors the cooler dust surrounding the central regions.

The data reveal a magnetic field geometry perpendicular to the plane of the galaxy, extending at least 700 pc along the disk, with a transition to a more planar field further away from the galaxy center. The galactic wind also transports a huge amount of gas and dust — the equivalent of 50 to 60 million suns.

The ability to image in polarized light at far infrared wavelengths provides a powerful technique to map the magnetic fields in the Milky Way and other galaxies. These observations indicate that the powerful winds associated with the starburst phenomenon could be responsible for seeding material and injecting magnetic fields into the intergalactic medium. If similar processes took place in the early universe, they would have affected the fundamental evolution of the first galaxies.

SOFIA Observations of the “New Starry Nights” ❻

HAWC+ Instrument

The Orion Nebula is among the best observed and most photographed objects in the night sky. It is the closest star-formation laboratory to Earth. Streamlines show the magnetic field morphology determined from 53 µm polarization maps obtained with SOFIA’s HAWC+ instrument. These are superposed on an infrared image taken by the Very Large Telescope in Chile, which shows the Trapezium stars in white and the Becklin-Neugebauer object in pink.

SOFIA’s HAWC+ instrument is sensitive to the alignment of dust grains, which line up along magnetic fields, letting researchers infer the direction and strength. The polarimetry observations have produced some of the most detailed magnetic field line maps to date, with spatial scales of ~0.01 pc (53 µm band).

NASA/SOFIA/D. Chuss/ L. Proudfit

Researchers used HAWC+ observations to investigate the role of magnetic fields in the Orion Nebula, which is often used as an archetype or "Rosetta Stone" for understanding high-mass clustered star formation throughout the galaxy. The high-resolution results enable the mapping of the field within the cores of the clouds where the later stages of the star formation process occurs. These observations confirm previous results showing that magnetic fields do in fact help regulate the star formation process in dense interstellar clouds.

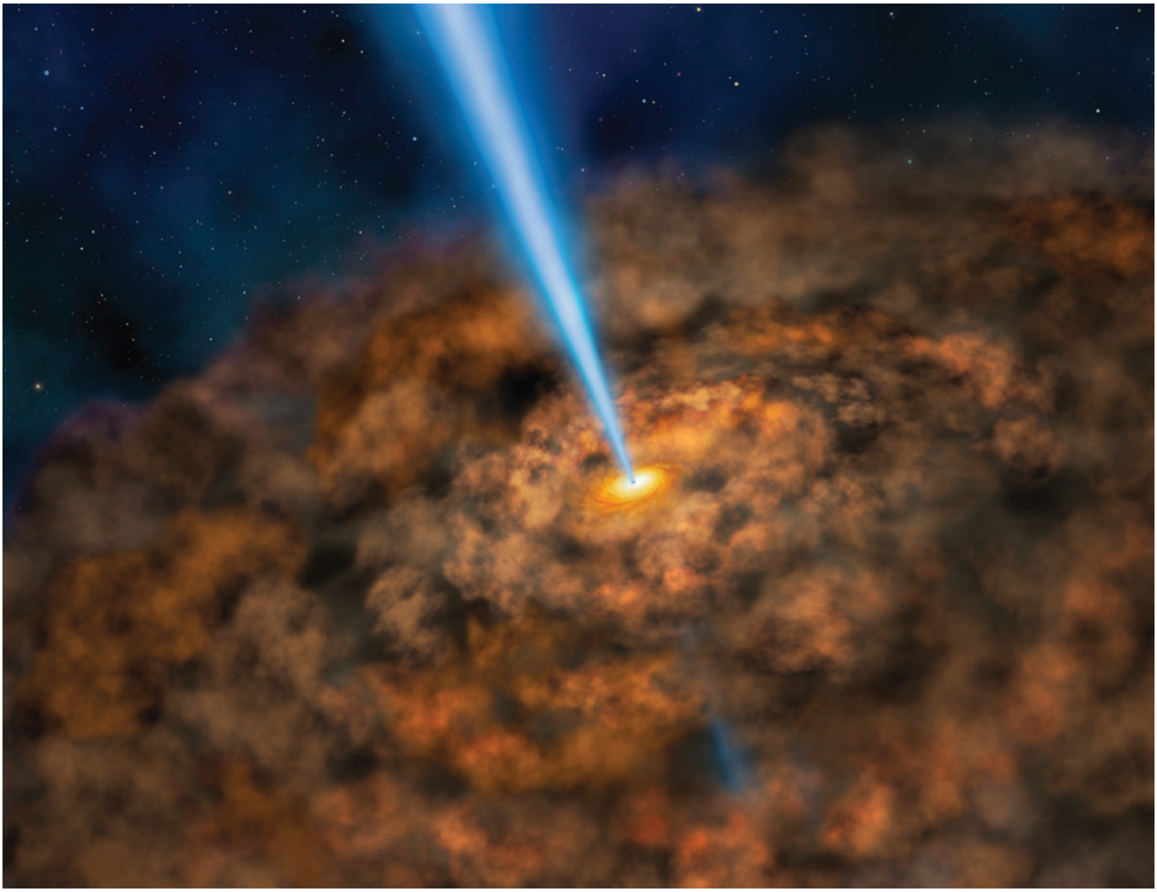
These polarimetry maps have produced two additional interesting results. The first result pertains to the process by which the dust grains become aligned. The grain-alignment mechanism is the subject of great interest both because it provides the basis for the measurements of magnetic fields and because it provides key, testable insights into the physics of the dust and its environs.

The current leading theory suggests that anisotropic radiation fields are an important ingredient for the alignment of the grains with the magnetic field. In other clouds, it has been observed that grain alignment efficiency degrades in the cores of clouds, presumably where the grains are shielded from the interstellar radiation field. However, the Orion results show no evidence that the efficiency of this alignment process falls off in dense regions. This is likely due to the nature of the strong radiation field present within the observed clouds, presumably due to the young stars themselves.

> ***SOFIA observations in the Orion Nebula show how magnetic fields may be affecting star formation.***

A second result is that the magnetic field traces the "explosive outflow" emanating from the heart of region. This explosion of material was likely caused 500–1,000 years ago by collision of two stars after the orbital decay of a protostellar triple star system. Near the center of the explosion, the magnetic fields are overwhelmed by the energetics of the explosion; however farther out, the kinetic energy is weaker and it appears as though the magnetic fields are guiding the ejecta. The magnetic field measurements provide valuable constraints on the energetics of this unique outflow, one of only a handful thought to result from a stellar merger.

These results for Orion are a powerful example of the utility of SOFIA/HAWC+ in understanding magnetic fields in star forming clouds. Future results will continue to advance our understanding of the role of magnetic fields in the interstellar medium in general, and in the star formation process in particular.



SOFIA Observations of Dusty Tori

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Artist's impression

This image shows the thick ring, or torus, of dust that can obscure the energetic processes that occur near the supermassive black holes that power active galactic nuclei. The FORCAST instrument was used to observe the infrared emission around 11 supermassive black holes with active galactic nuclei located at distances of 100 million light-years and more.

The resulting observations were used to determine the size, opacity, and distribution of dust in each torus. SOFIA observations suggest that the dust distribution is about 30 percent smaller than previously thought.

NASA/SOFIA/Lynette Cook

Most, if not all, large galaxies contain a supermassive black hole at their centers. Many of these black holes are relatively quiet and inactive, like the one at the center of our Milky Way galaxy. However, some are currently consuming significant amounts of material, resulting in the emission of huge amounts of energy. These black holes power active galactic nuclei.

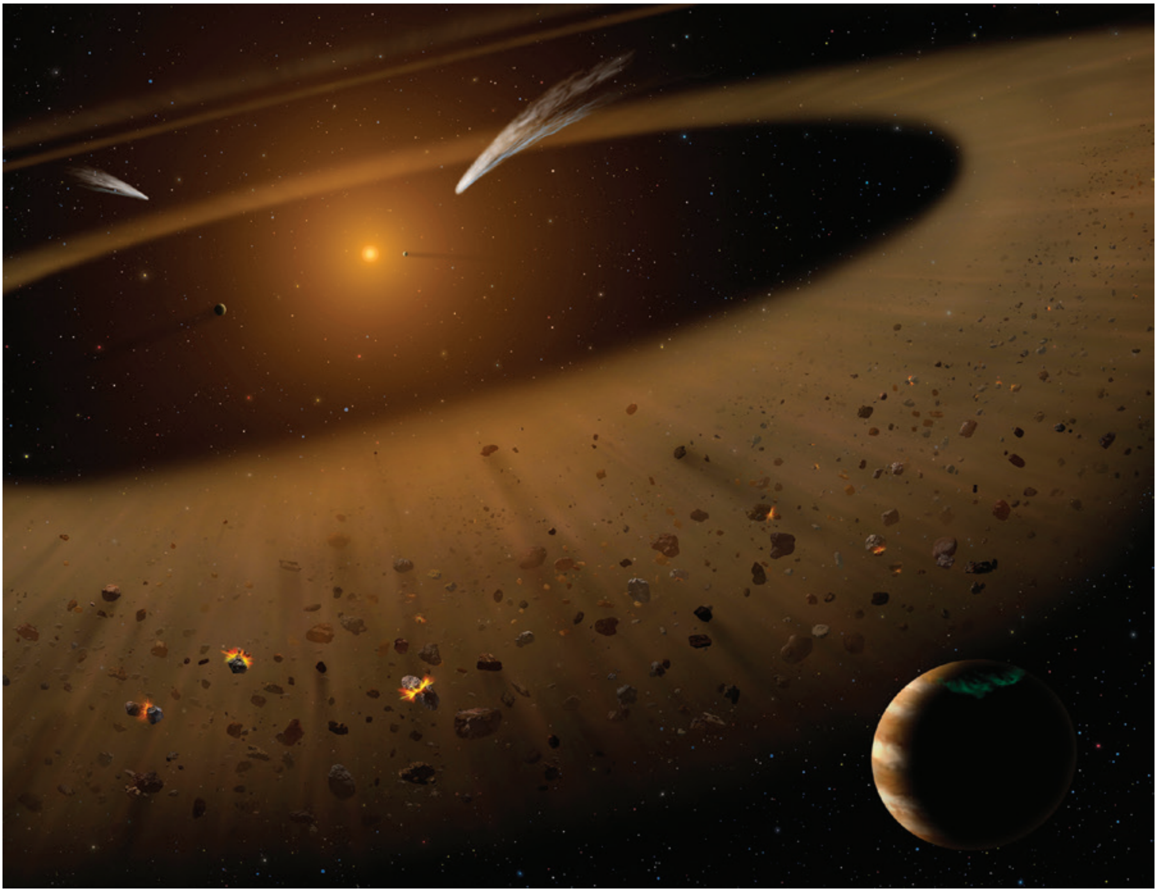
Previous studies have suggested that all active galactic nuclei have essentially the same central structure, but are viewed from different lines of sight. This orientation-based model depends on a circumnuclear toroidal region of optically and geometrically thick dust that can obscure a central region containing the super massive black hole and accretion disc, which are responsible for producing high-energy photons. Models indicate that this donut-shaped dust structure, known as a torus, surrounds the supermassive black hole.

FORCAST observed 31.5 μm imaging photometry of 11 nearby Seyfert galaxies. Subarcsecond resolution 1–18 μm imaging and 7.5–13 μm spectroscopic observations were used to compute the nuclear spectral energy distribution of each galaxy. The data revealed that the turnover of the torus emission occurs at wavelengths greater than 31.5 μm. A CLUMPY torus model was used to fit the nuclear infrared spectral energy distribution and infer trends in the physical parameters of the torus for each galaxy. The implication is that the dust obscuring the central black hole is more compact that previously thought and that the peak infrared emission may be at longer infrared wavelengths. Further observations in the 32–40 μm regime would add additional constraints to the CLUMPY model, pinning down the peak infrared emission and providing further insight into the torus outer limit.

SOFIA found that the dust clouds surrounding active, ravenous black holes are much more compact than previously thought.

SOFIA was able to obtain the most spatially detailed observations possible at these wavelengths, allowing the observers to make new discoveries on the characterization of active galactic nuclei dust tori.

Future observations are necessary to determine whether or not all of the observed emission originates in the torus, or if there is some other component adding to the total emission of the active galactic nuclei. The next goal will be to use SOFIA to observe a larger sample of active galactic nuclei, and at longer wavelengths. That will result in tighter constraints on the physical structure of the dusty environment surrounding the active galactic nuclei.



SOFIA Observations of the Epsilon Eridani System

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Artist's impression

This image depicts the Epsilon Eridani system, where a Jupiter-mass planet orbits its parent star at the outside edge of an asteroid belt. Another narrow asteroid or comet belt plus the outermost belt (similar in size to our solar system's Kuiper Belt) appear in the background. Observations from the FORCAST instrument confirmed the existence of the asteroid belt adjacent to the orbit of the Jovian planet.

The strongest infrared emission from the warm material surrounding the star, at wavelengths between 25–40 μm, is undetectable by ground-based telescopes because of strong absorption by the Earth's atmosphere. The similarity of the structure of the Epsilon Eridani system to our solar system is remarkable, even though Epsilon Eridani is much younger than our sun.

NASA/SOFIA/Lynette Cook

Investigations using data obtained by the SOFIA observatory confirmed that a nearby planetary system, located 10.5 light-years away in the constellation Eridanus, has an architecture remarkably similar to that of our own solar system. This is also the storied location of the *Babylon 5* space station in the science fictional television series of the same name.

The planetary system orbiting the star Epsilon Eridani, eps Eri for short, is similar to what researchers believe the solar system might have been like when our sun was young. It is a prime location to study how planets form around solar type stars.

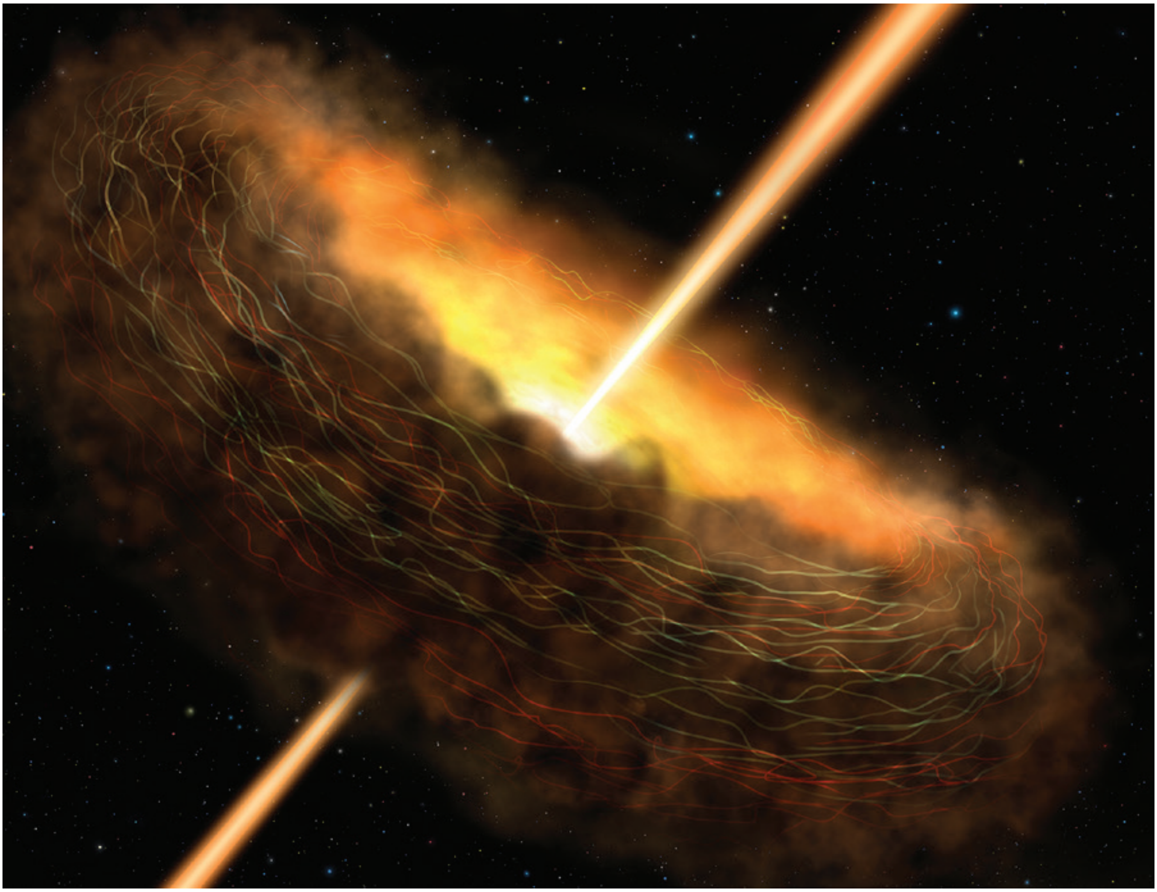
Previous studies indicate that eps Eri has a debris disk composed of the leftover material still orbiting the star, long after planet formation ended in the system. The debris can take the form of gas and dust as well as small rocky and icy bodies. Careful measurements of the motion of eps Eri indicate that a planet with nearly the same mass as Jupiter circles the star at a distance comparable to Jupiter's distance from the sun.

> ***SOFIA confirmed that a nearby planetary system has an architecture remarkably similar to that of our solar system.***

SOFIA observations were able to distinguish between two theoretical models for the location of warm debris in the eps Eri system. One model indicates that the material is in two narrow rings, which would correspond respectively to the positions of the asteroid belt and the orbit of Uranus in our solar system. Using this model, theorists predict that the largest planet in a system might normally be associated with an adjacent debris belt. The other model attributes the warm material to dust originating in the outer Kuiper belt-like zone and filling in a disk of debris toward the central star. In this model, the warm material is in a broad disk. It is not concentrated into asteroid belt-like rings nor is it associated with the any planets in the inner region.

SOFIA results confirm that the warm material around eps Eri is in fact arranged like the first model suggests; it is located in at least one narrow belt rather than in a broad continuous disk.

The high spatial resolution of SOFIA combined with the unique wavelength coverage and impressive dynamic range of the FORCAST camera allowed researchers to resolve the warm emission around eps Eri, confirming the model that located the warm material near the Jovian planet's orbit.



SOFIA Observations of Cygnus A ⑨

Artist's impression

Cygnus A, surrounded by a torus of dust and debris with jets launching from its center. Magnetic fields are illustrated as thin ribbons trapping the dust. Cygnus A is the closest and most powerful active galaxy, the perfect candidate to study 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.

SOFIA observed the central 20 pc of Cygnus A with the HAWC+ instrument at 53 and 89 µm and an angular resolution of 5 and 9 arcseconds. These observations are sensitive to temperatures of 30–50 K and show highly polarized infrared emission dominated by a well-aligned dusty structure.

NASA/SOFIA/Lynette Cook

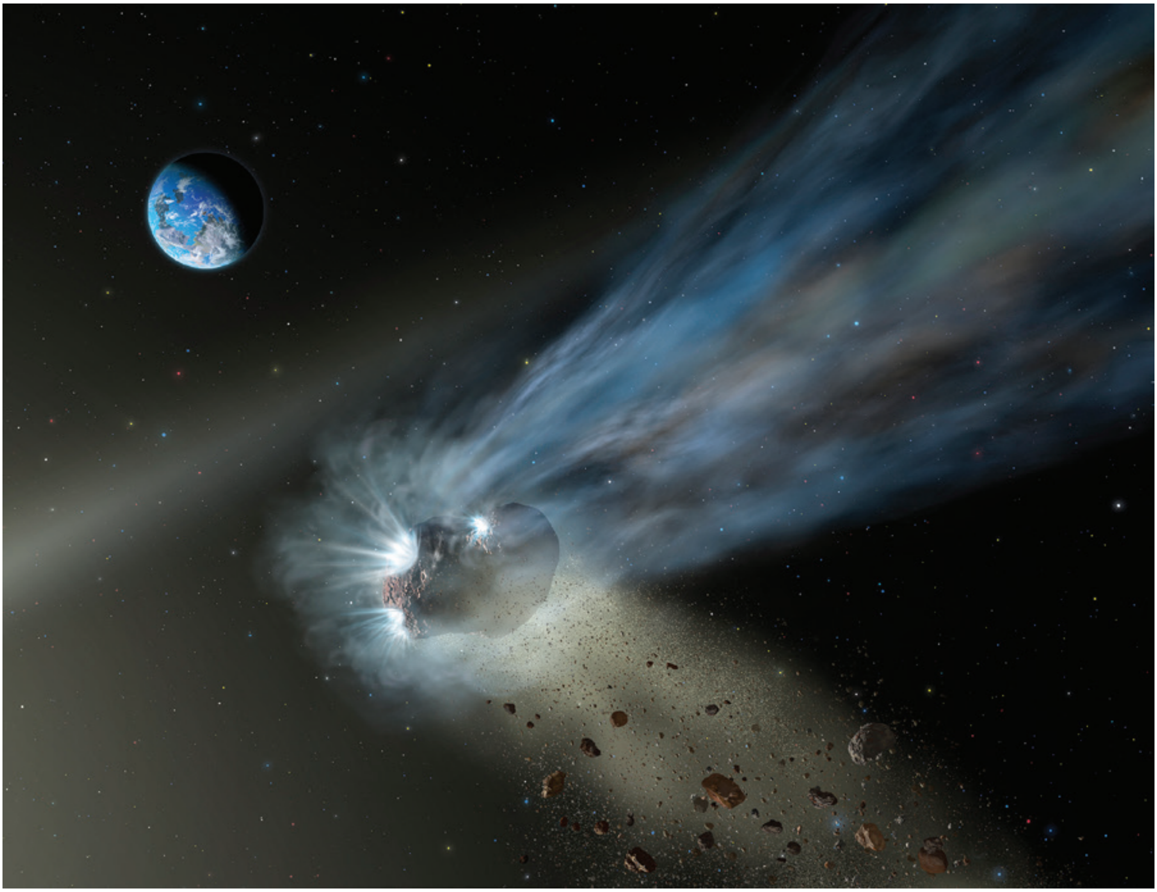
Observations from SOFIA reveal that magnetic fields are trapping and confining the obscuring dust near the center of the active galaxy, Cygnus A, and feeding material onto the supermassive black hole. The unified model of active galaxies maintains that the core is surrounded by a dusty torus that absorbs 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.

SOFIA found that magnetic fields are trapping the material that feeds the supermassive black hole in the galaxy Cygnus A.

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. Optical emission from scattered starlight and radio light from relativistic electrons are sometimes used to study magnetic fields, but optical wavelengths are too short and the radio wavelengths are too long to observe the torus directly. The infrared wavelengths observed by SOFIA are just right, allowing scientists, for the first time, to target and isolate the dusty torus. 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.

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 both the accretion process and jet formation.



SOFIA Observations of Comet Pan-STARRS

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Artist's impression

The short and long wavelength cameras on the FORCAST instrument were used to study light emitting from Comet C/2012 K1 (also called Pan-STARRS). The observations focused on the coma, the gas and dust that form around a comet's nucleus as it is heated by the sun. The data were used to deduce the size and composition of the dust grains and to identify and categorize their thermal properties.

These observations revealed weak silicate emission features from the comet, rather than the anticipated strong silicate features found in some prior Oort Cloud comet observations, including those of Comet Hale-Bopp and studies conducted with the Spitzer Space Telescope.

NASA/SOFIA/Lynette Cook

Comets are our most direct link to the earliest stages of the formation and evolution of the solar system. A new comet making its first trip to the inner solar system from the Oort Cloud is only discovered every few years. Such rare opportunities offer astronomers a chance to study a special class of comets.

SOFIA observed Comet C/2012 K1 (also called Pan-STARRS after the observatory that discovered it in 2012), searching for new insights into the evolution of the early solar system.

Comets originating from the Oort Cloud, like Comet C/2012 K1, remain unaffected by the thermal heating and radiation processing of the sun. The pristine nature of these comets can preserve surface materials making them ideal targets for determining the gas and dust particle composition.

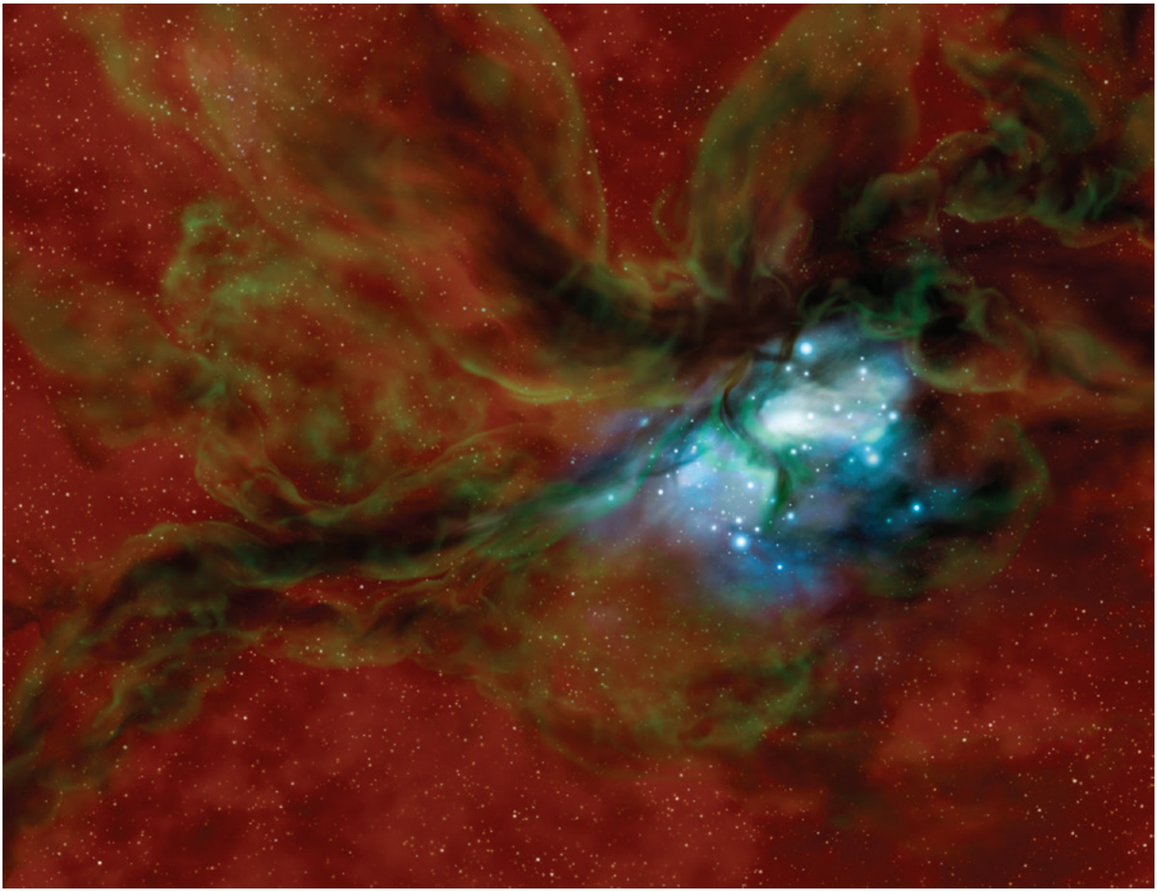
Comet C/2012 K1 is a time capsule of the early solar system's composition. Every opportunity to study these bodies contributes to our understanding of the general characteristics of comets and the formation of small bodies in in our solar system.

SOFIA observations challenge existing models of the formation of Oort cloud comets.

The FORCAST observations were used to deduce the size and composition of the dust grains and to identify and categorize their thermal properties. Unexpectedly, these observations revealed weak silicate emission features from the comet, rather than the anticipated strong silicate features found in some prior Oort Cloud comet observations. By analyzing these silicate emissions and comparing them to thermal models, the researchers determined that the coma's dust grains are large and comprised predominately of amorphous carbon rather than crystalline silicate. This composition challenges existing theoretical models of how Oort cloud comets form.

Comets are made of materials similar to those of planets, so studying the dust in them can help us understand the content, origin, and evolution of the early solar system, including the process of forming rocky planets.

While missions like the European Space Agency's Rosetta or NASA's Stardust provided direct sampling of comet materials, remote observations such as those conducted aboard SOFIA provide researchers with an opportunity to understand similarities and differences between various types of comets. The strength of Comet C/2012 K1's silicate features observed in mid-infrared with SOFIA have set the stage for the James Webb Space Telescope — to study even fainter more distant comets, providing a nice synergy between those two missions.



SOFIA Observations of Cloud Collisions ⑪

Artist's impression

This image shows a star cluster forming from the collision of turbulent molecular clouds, which appear as dark shadows in front of the background galactic star field. Star clusters are conceived in the hearts of optically dark clouds where the early phases of formation have historically been hidden from view. But these cold, dusty clouds shine brightly in the infrared, so telescopes like SOFIA can begin to reveal these long-held secrets.

The molecular clouds are surrounded by atomic envelopes, here illustrated in green, which have been detected via emission from ionized carbon by the GREAT instrument on board SOFIA. The spatial offset and motions of these envelopes confirm predictions of simulations of cloud collisions.

NASA/SOFIA/Lynette Cook

The sun, like all stars, was born in a giant cold cloud of molecular gas and dust. It may have had dozens or even hundreds of stellar siblings — a star cluster — but these early companions are now scattered throughout the Milky Way. Although the remnants of this particular creation event have long since dispersed, the process of star birth continues today within our galaxy and beyond.

Traditional models claim that gravity may be solely responsible for the formation of stars and star clusters. More recent observations suggest that magnetic fields, turbulence, or both are also involved and may even dominate the creation process. But just what triggers the events that lead to the formation of star clusters?

Astronomers used SOFIA's GREAT instrument to map the [C II] ground-state fine-structure line at 157.7 μm for an entire filamentary infrared dark cloud known as IRDC H. Such observations are possible because of the scan-mapping agility of the SOFIA telescope and the multi-beam upgrade to the Terahertz receiver. Those data reveal motions within the cloud that offer new evidence that star clusters form through collisions between giant molecular clouds.

[CII] images trace the material surrounding the filament. The authors showed that the [C II] emission is spatially offset from the dark molecular filament and that the envelope is dynamically offset, with a velocity shift of 3 km/s between [C II] (envelope) and 13CO (molecular cloud).

These offsets are signatures of the filament formation process. Synthetic observations from the 3D MHD code produced simulations of colliding and non-colliding molecular clouds along the line-of-sight. In the colliding case, there is an offset of a few parsecs between [CII] emission and the column density peaks, but there is no such offset in the non-colliding case. Researchers therefore conclude that molecular filaments are likely to form from cloud-cloud collisions rather than direct collapse.

SOFIA provides new evidence that star clusters form through collisions between giant molecular clouds.

While there is not yet scientific consensus on the mechanism responsible for driving the creation of star clusters, these observations have helped scientists take an important step toward unravelling the mystery. This field of research remains an active one, and these data provide crucial evidence in favor of the collision model. Future observations will test this scenario to determine if the process of cloud collisions is unique to this region, more widespread, or even a universal mechanism for the formation of star clusters.

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