SOFIA Science

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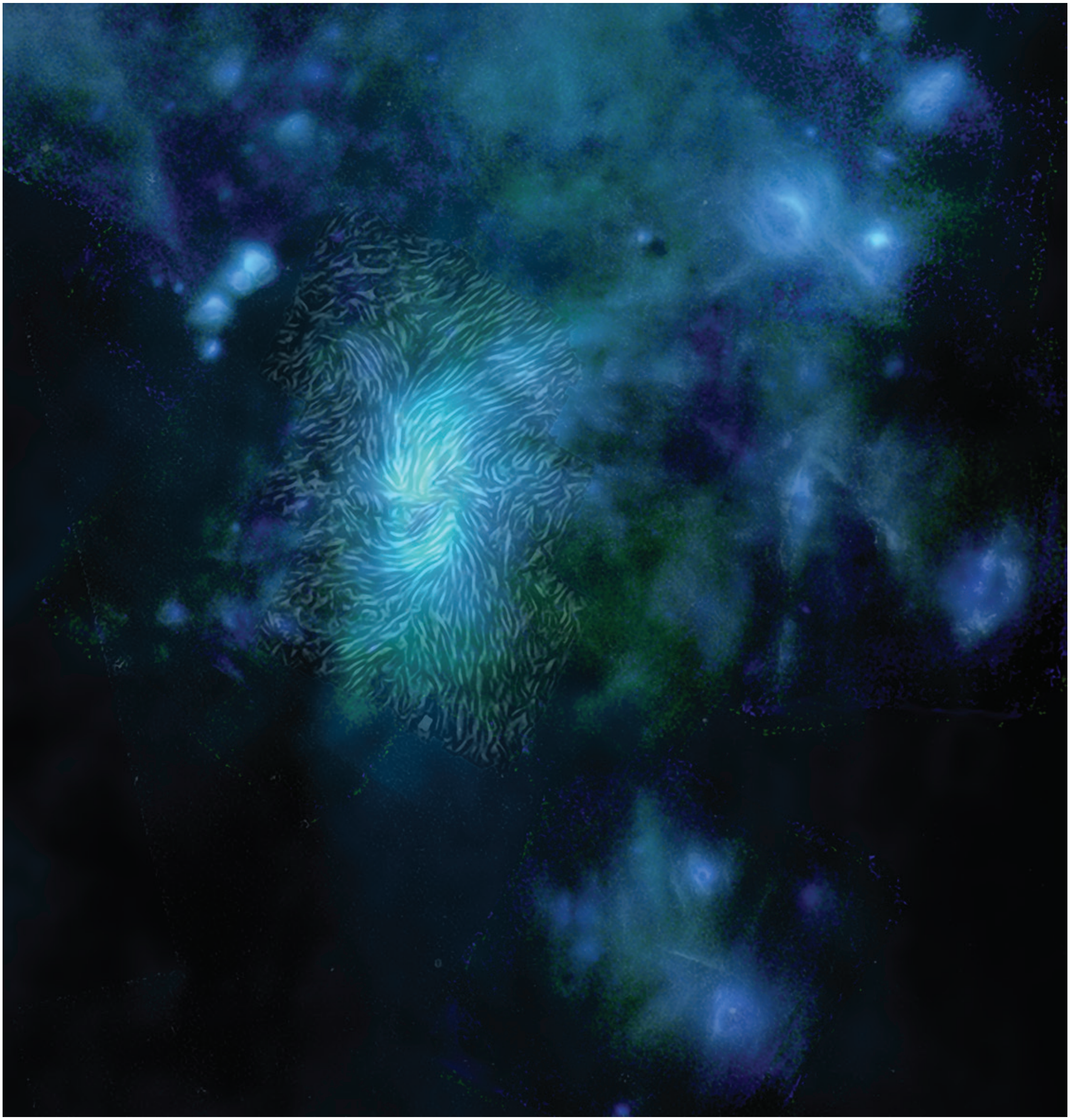

A composite image of the central region of our Milky Way galaxy, known as Sagittarius A. See Science Spotlight, page 4. *(NASA/SOFIA/L. Proudfit; ESA/Herschel; Hubble Space Telescope)*

SOFIA Observers Resources

SOFIA offers the following tools and documentation to facilitate the proposal process. These resources are available at: https://www.sofia.usra.edu/science/proposing-observing

Core Documentation

The Call for Proposals (CfP) solicits observing proposals from the U.S. and international astronomy communities. The document describes how to prepare and submit proposals, including details on how proposals will be evaluated, and formally establishes the policies and rules governing SOFIA operations for the relevant cycle.

The Observer's Handbook is the primary technical reference for astronomers who wish to submit a proposal in response to the CfP, providing detailed information about the instruments and observing modes that will be available for observations during the relevant cycle.

Proposal Submission Tools

All SOFIA proposals are prepared and submitted using the Unified SOFIA Proposal and Observation Tool (USPOT). USPOT contains many built-in features to help with planning observations, such as the Target Visibility tool that can be used to determine which time of year the target is most visible from the take-off location of SOFIA. The USPOT Manual guides users through the procedures for submitting proposals for SOFIA, with specific instructions for each instrument.

Estimations of exposure times for each instrument can be made using the SOFIA Instrument Time Estimator (SITE), a web-based tool that provides total integration time or S/N for a given instrument, filter(s), source type (point, extended, emission line), and water vapor overburden.

The atmospheric transmission as a function of wavelength may be obtained using the online tool ATRAN. The use of ATRAN is necessary for planning SOFIA high-resolution spectroscopic observations.

Public Archival Data

The SOFIA Science Center provides raw and calibrated data for the entire instrument suite. The level of data processing ranges from corrections for instrument artifacts, to flux calibrated and telluric corrected data, to maps and mosaics. These data are publicly available for further exploration after their exclusive use periods expire.

The observatory has transitioned from storing data in the SOFIA Data Cycle System (DCS) to the IPAC Infrared Science Archive (IRSA), which has become the primary data archive. Access the SOFIA webpage on IPAC at https://irsa.ipac.caltech.edu/Missions/sofia.html ■

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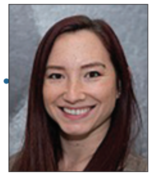
Science Spotlight



Casey Honniball, *NASA Goddard Space Flight Center*
Paul Lucey, *University of Hawai‘i at Mānoa*
Joan Schmelz, *Universities Space Research Association*

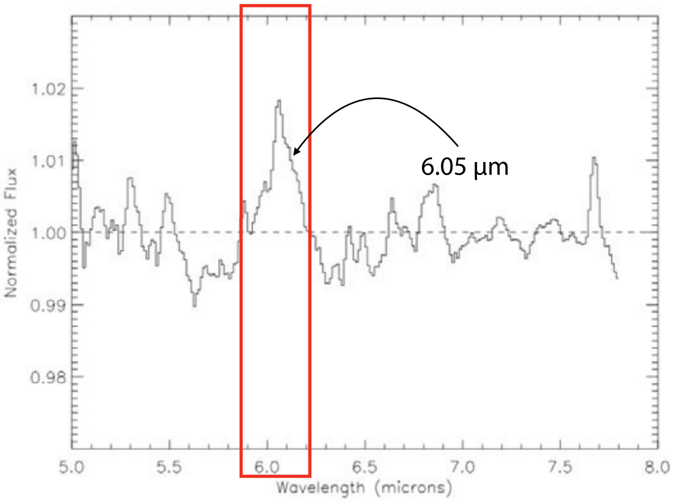
SOFIA Detects Water on the Moon

Researchers using SOFIA have made the first-ever detection of the water molecule (H_2O) on the sunlit surface of the Moon. This discovery refines our understanding of the behavior of water and how volatile elements and compounds interact with airless bodies throughout the Solar System and beyond.

Water and other volatiles can influence the internal processes and surface expression of planets. Water suppresses the melting point of rock, promoting volcanism, and reduces the viscosity of planetary interiors, enabling more efficient internal circulation and heat transfer. Water and other volatiles tend to concentrate on planetary surfaces, creating atmospheres, hydrospheres, and cryospheres, and can even dominate the surface geology.

The Moon likely formed in a giant impact, stripping it of its initial volatile inventory and allowing it to begin as a "blank slate" for volatiles. This made the Moon a natural laboratory for the study of volatile elements and compounds added later in Solar System history. The hydrogen-rich solar wind and water-bearing meteorites are thought to be the principle conveyors of water to planetary surfaces, but their relative contributions as well as the space-surface chemistry interactions are poorly known.

Water has been detected previously in trace amounts in the lunar exosphere and in sparse occurrences as ice in permanent shadow at the lunar poles, but the possible pathways of water through the lunar environment are poorly understood. For decades, laboratory studies have shown that water's cousin, hydroxyl (OH-), can form from the hydrogen in the solar wind and oxygen in lunar minerals. Lunar hydroxyl has been detected remotely in reflectance spectra at 3 µm by spacecraft.



SOFIA spectrum from the lunar Clavius Crater showing the first detection of the water emission bands at 6 µm. *(Honniball et al., 2020.)*

About this Spotlight

Paper: Molecular water detected on the sunlit Moon by SOFIA
Authors: C. I. Honniball, P. G. Lucey, S. Li, S. Shenoy, T. M. Orlando, C. A. Hibbitts, D. M. Hurley, W. M. Farrell
Reference: Nature Astronomy 2020.

Recent laboratory experiments have shown that it is possible to form H_2O vapor from hydrogen irradiation by adding the energy simulating a meteorite impact. Studies have also shown that water from meteorites can be trapped in the glass formed during the impact. But H_2O has never been detected directly on the sunlit lunar surface. In fact, the H_2O and OH signals are blended at 3 µm, so these spacecraft observations cannot separate water from drain cleaner. Direct detection of water on the Moon had, therefore, eluded scientists, and new methods were needed to continue the search.

The unambiguous water detection was made possible by SOFIA's unique capabilities and the sensitivity of the Faint Object InfraRed CAmera for the SOFIA Telescope (FORCAST) spectrometer. The fundamental bending vibration of the H-O-H molecular bond occurs at 6.1 µm in the infrared. This region of the spectrum is completely obscured from the ground by water in the Earth's atmosphere, but is highly transparent from SOFIA's operational altitude in the stratosphere. In addition, the spectral

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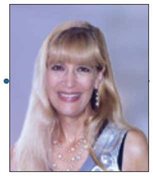
Science Spotlight

Joan Schmelz, *Universities Space Research Association*



The Role of the Magnetic Field in the Galactic Center

Even in a region where gravity dominates, there could be areas where magnetic fields govern the physics. The Earth's magnetosphere and the solar corona are two well-known examples. Although the gas in the central five parsecs of the Milky Way is largely neutral, the high fluxes of X-rays and cosmic rays ensure that there is sufficient residual ionization to collisionally couple the ions and neutrals. Consequently, the gas can react to the magnetic field, making the plasma beta (β) a useful indicator of the importance of the magnetic field in the environment. β is the ratio of the thermal pressure to the magnetic pressure. If the thermal pressure is greater than the magnetic pressure, then $\beta > 1$ (referred to as a high-β plasma), and the gas dynamics will control the structure of the environment. The magnetic field may be present, but it does not dominate, as is the case in the solar photosphere. If the thermal pressure is less than the magnetic pressure, then $\beta < 1$ (referred to as a low-β plasma), and the magnetic field can control the dynamics of the environment as it does in the magnetosphere and the corona.

The High-resolution Airborne Wideband Camera Plus (HAWC+) instrument on SOFIA is providing high-quality polarization measurements for astrophysically interesting environments including the galactic center. We used these data and the Davis-Chandrasekhar-Fermi method to determine the component of the magnetic field strength in the plane of the sky. This method relates the line-of-sight velocity dispersion and the plane-of-sky polarization angle dispersion. It assumes an isotopically turbulent medium whose turbulent kinetic and turbulent magnetic energy components are in equipartition. Results indicate that B ~ 5 milliGauss, similar to the values determined for the line-of-site component of the magnetic field measured using the Zeeman Effect. Using this estimate for the magnetic field as well as values for density and temperature from the literature, we found $\beta \sim .0001$ for the overall region and $\beta \sim .001$ for sub-regions like the Western Arc and the Northern Arm.

This is clearly in the low-beta regime, but observations

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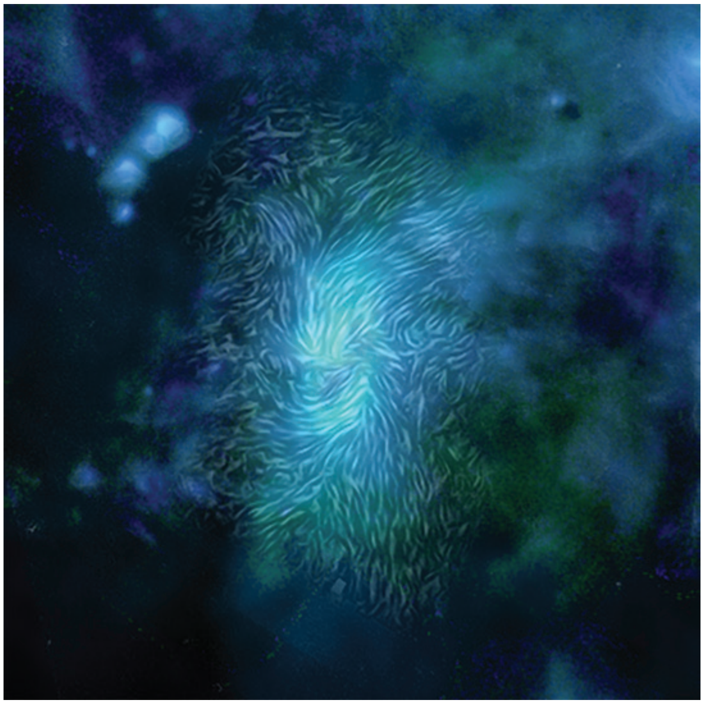


A composite image of the central region of our Milky Way galaxy, known as Sagittarius A. SOFIA found that magnetic fields, shown as streamlines, are strong enough to control the material moving around the black hole, even in the presence of enormous gravitational forces. SOFIA's results can help answer long-standing, fundamental questions about the galactic center region: why the star formation rate is significantly lower than expected and why our galaxy's black hole is quieter than those in other galaxies. SOFIA data is shown in green (37 μm) and dark blue (25 and 53 μm). The light blue is from Herschel Space Observatory (70 microns) and the gray is from the Hubble Space Telescope. *(NASA/SOFIA/L. Proudfit; ESA/Herschel; Hubble Space Telescope)*

About this Spotlight

Paper: The Strength and Structure of the Magnetic Field in the Inner 5 Parsecs of the Galaxy
Authors: C. D. Dowell et al.
Reference: 2020, Astrophysical Journal, in prep.

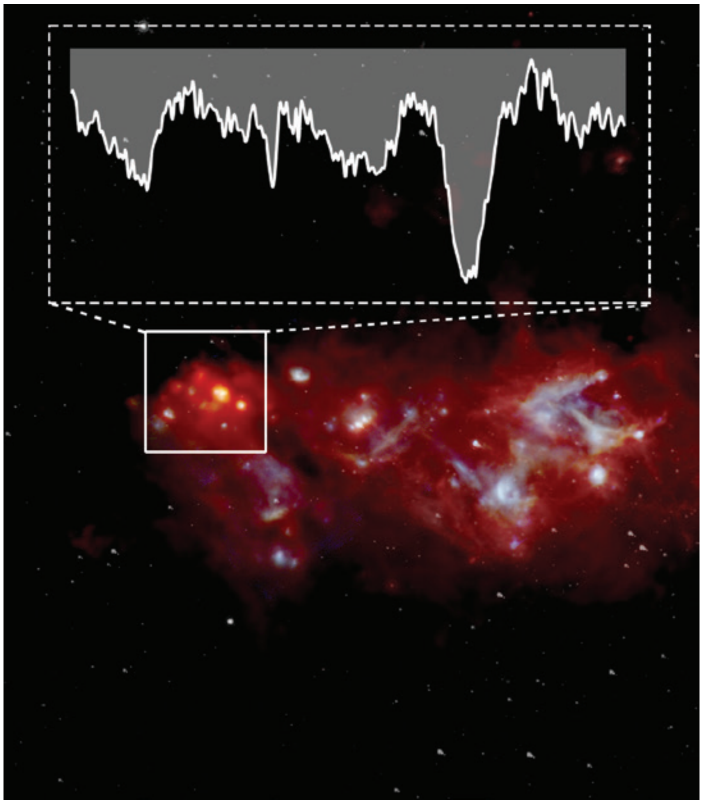
Science Spotlight

Arshia Jacob, *Max-Planck-Institut für Radioastronomie*
Joan Schmelz, *Universities Space Research Association*

First Detection of ^{13}CH in the Interstellar Medium

The $^{12}C/^{13}C$ isotopic ratio has been investigated extensively because it is an important diagnostic tool for probing the nuclear history of the galaxy. Chemical evolution models predict that the ratio will increase with distance from the galactic center and decrease with time. This is because ^{12}C is a *primary* product, meaning that it results from a stellar nucleosynthesis process that can occur even in a star composed initially of pure hydrogen and helium. ^{13}C is a *secondary* product in that it forms during the carbon-nitrogen-oxygen cycle, which can occur only in stars with preexisting ^{12}C. Since primary nucleosynthesis can begin at an earlier epoch, an isotopic abundance ratio like $^{12}C/^{13}C$ that involves a product of both primary and secondary processes can probe the star formation history of the galaxy.

These model predictions have been confirmed by observational measurements of rotational transitions of several simple species like CO, CN, and H_2CO and with more complex species like CH_3CH_2CN and CH_3CCH. However, the trends found using different molecules show systemic variations. These are often related to isotope-selective chemical processes, which are more likely to affect the formation of the less abundant isotope. This results in $^{12}C/^{13}C$ ratios that are either higher or lower than the underlying value. In addition to these chemical effects, which do not affect every molecule in the same way, both saturation and self-absorption may skew estimates of the ratio. In an attempt to provide additional constraints, a new tracer — the methylidene radical, CH — is investigated.



The first detection of ^{13}CH in the interstellar medium. SOFIA absorption spectrum of ^{13}CH corresponding rotational transition near 2 THz in the direction of SgrB2(M) superposed over a composite infrared image of the Sgr B complex. Data from SOFIA taken at 25 and 37 µm, shown in blue and green, is combined with data from the Herschel Space Observatory, shown in red (70 µm), and the Spitzer Space Telescope, shown in white (8 µm). *(Jacob et al., 2020; NASA/SOFIA/JPL-Caltech/ESA/Herschel)*

Since its discovery in 1937, CH has been studied extensively because it initiates the formation of a large fraction of the C-bearing molecules in the interstellar medium. The fundamental rotational lines of CH are in the sub-mm regime and are, therefore, best observed with air- and space-borne telescopes in order to avoid atmospheric absorption.

About this Spotlight

Paper: First detection of ^{13}CH in the interstellar medium
Authors: A. M. Jacob, K. M. Menten, H.Wiesemeyer, R. Güsten, F. Wyrowski, B. Klein
Reference: 2020/08, A&A, 640A, A125.

The observed absorption spectra arise from the diffuse clouds present in spiral-arm and inter-arm regions along sightlines toward far-infrared bright, high-mass star-forming regions. Some early results with Herschel at 532/536 GHz

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Science Spotlight

Kevin Cooke, *University of Kansas*
Allison Kirkpatrick, *University of Kansas*
Joan Schmelz, *Universities Space Research Association*

Cold Quasars and the Evolution of Galaxies

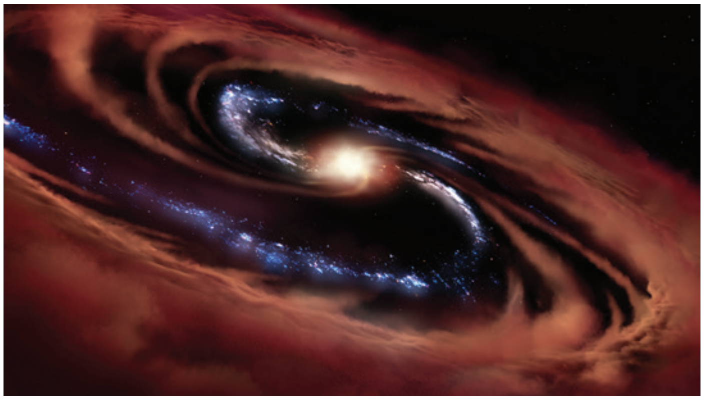

Illustration of the galaxy called CQ4479. The extremely active black hole at the galaxy's center is consuming material so fast that the material is glowing as it spins into the black hole's center, forming a luminous quasar. Quasars create intense energy that was thought to halt all star birth and drive a lethal blow to a galaxy's growth. But SOFIA found that the galaxy CQ4479 is surviving these monstrous forces, holding on to enough cold gas, shown around the edges in brown, to birth about 100 Sun-sized stars a year, shown in blue. The discovery is causing scientists to re-think their theories of galactic evolution. (*NASA/ Daniel Rutter*)

Galaxies evolve over cosmic time from brilliant blue star producers to dull red stellar graveyards — from the proverbial *Blue-and-New* to *Red-and-Dead*. Astronomers observe that the early universe is filled with galaxies with an average star formation rate hundreds of times that of today, but the population over time has become more dominated by galaxies where stars are no longer born. To understand how galaxies came to be, we must investigate how their star formation histories are affected by both stellar and non-stellar processes.

Star formation can be shut down through many routes, one of which relies on the supermassive black hole in the heart of massive galaxies. When a supermassive black hole actively accretes interstellar gas, the surrounding material becomes luminous across the electromagnetic spectrum. The energetic output from the resulting quasar has a tremendous effect on the host galaxy, heating and expelling the gas, and shutting down star formation. This feedback model is commonly cited as the method that causes a star-forming, gas-rich galaxy to transition to a non-star-forming, gas-poor galaxy. This crucial transition process is difficult to investigate, as the hot material surrounding the black hole outshines the host galaxy at nearly all wavelengths of interest. The one exception is the far infrared.

The HAWC+ instrument on SOFIA observes in this vital wavelength band. It is able to detect light from the star formation process without being overwhelmed by emission from the accreting black hole. The gas surrounding young stars is heated and reradiates its thermal energy in the far infrared. These observations are used to estimate the amount of star formation that has taken place over the past 100 million years.

About this Spotlight

Paper: Dying of the Light: An X-Ray Fading Cold Quasar at z ~ 0.405
Authors: K. C. Cooke, A. Kirkpatrick, M. Estrada, H. Messias, A. Peca, N. Cappelluti, T. T. Ananna, J. Brewster, E. Glikman, S. LaMassa, T. K. D. Leung, J. R. Trump, T. J. Turner, C. M. Urry
Reference: 2020 ApJ 903 106.

SOFIA targeted a special *cold quasar*, a galaxy caught in that astronomically brief transition phase when the supermassive black hole is actively accreting but a significant amount of the infrared-luminous gas remains. Cold quasars continue to host star formation rates of ~100s of solar masses per year, hundreds of times more active than our own Milky Way galaxy.

HAWC+ observations at 89 µm of the cold quasar, CQ4479, were combined with optical observations from the Sloan Digital Sky Survey, infrared data from the Spitzer and Herschel space telescopes, and X-ray data from XMM-Newton to model the stellar component of the galaxy and the accretion behavior of the black hole.

The optical to far-infrared data were fit with a collection of stellar population, dust, and black hole models to

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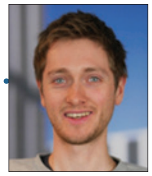
Science Spotlight

Andrew Barr, *Leiden University*
Alexander Tielens, *Leiden University*
Joan Schmelz, *Universities Space Research Association*



Molecular Processing in the Disks of Massive Stars

Over the last two decades, astronomers have discovered that almost all stars have an associated planetary system. This gives rise to a number of key questions including, "What is the chemical inventory accessible to forming planets?" and, "What chemical and physical processes are important in the evolution of the organics delivered to newly forming planets?" To address these questions, we have initiated a survey of the mid-infrared spectra of the disks around massive stars.

While observations of disks around low-mass stars have become routine, even the *detection* of their high-mass counterparts is rare. So despite the importance of disks to star and planet formation, little is known about the physical and chemical processes that govern the early phases of high-mass stellar evolution.

High resolution mid-infrared spectroscopy with the Echelon-Cross-Echelle Spectrograph (EXES) instrument on SOFIA provides a unique view of these regions. With EXES, molecules can be studied that have no pure rotational transitions in the sub-millimeter, and hence, instruments such as the Atacama Large Millimeter/submillimeter Array (ALMA) cannot detect their presence and derive their abundances. This includes such simple organic species as acetylene and methane, the building blocks of complex organic molecules in warm gas.

EXES observations are capable of probing these disks on the scales of planet formation. The spectra show that large amounts of water and simple organics are produced within 50 AU of the protostar, which means this material could eventually be incorporated into planetary systems around these massive stars.

About this Spotlight

Paper: High-resolution Infrared Spectroscopy of Hot Molecular Gas in AFGL 2591 and AFGL 2136: Accretion in the Inner Regions of Disks around Massive Young Stellar Objects
Authors: A. G. Barr, A. Boogert, C. N. DeWitt, E. Montiel, M. J. Richter, J. H. Lacy, D. A. Neufeld, N. Indriolo, Y. Pendleton, J. Chiar, A. G. G. M. Tielens
Reference: 2020/09, ApJ, 900, 104.

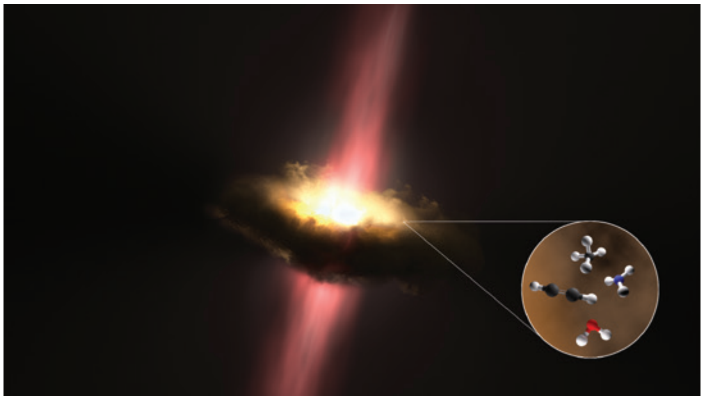


Illustration of a dusty disc rotating around a massive newborn star that's about 40 times the size of the Sun. SOFIA found the inner regions of two of these kinds of discs are filled with organic molecules that are important for life as we know it. These include water, ammonia, methane, and acetylene — which is a chemical building block to larger and more complex organic molecules — illustrated in the callout. *(NASA/SOFIA)*

EXES has conducted the first ever full spectral survey at high spectral resolution of the 4.5–13 μm regime towards two massive protostars, AFGL 2591 and AFGL 2136. Across the wavelength range of the spectral survey, absorption lines of CO, H_2O, HCN, C_2H_2, NH_3, and CS are detected. All of these molecules are predicted to form in large quantities in the inner regions of circumstellar disks. Temperatures of 600 K are derived towards both sources, consistent with models.

Previous modelling and imaging of sub-millimeter emission lines towards these sources places the absorbing gas close to the central protostar, at a distance of around 50 AU. This is the planet-forming zone so this material may eventually be incorporated into planets orbiting these stars. The composition of the gas in these disks is different from that of cold molecular clouds in which these stars are formed, attesting to the importance of chemical processing in the warm, dense

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Science Spotlight

Thushara Pillai, *Boston University*
Joan Schmelz, *Universities Space Research Association*

Magnetized Filamentary Gas Flows in Serpens South

The vast space between stars is home to filamentary gas and dust features that appear to play a major role in channeling mass into young clusters where stars can form. These formation processes are driven by a complex interplay of several fundamental forces including turbulence, gravity, and the magnetic field. In order to get an accurate description for how dense clusters of stars form, astronomers need to pin down their relative roles. Turbulent gas motions as well as the mass content of filaments (and therefore gravitation force) can be gauged with relative ease. However, the signature of the interstellar magnetic field is so weak — about 10,000 times weaker than Earth's magnetic field — that measuring the field strengths in filaments is a formidable task.

Fortunately, a small fraction of the interstellar mass is composed of dust grains that tend to align perpendicular to the direction of the magnetic field. As a result, the light emitted by these grains is polarized, and this polarization can be used to chart the magnetic field directions. Recently, the Planck satellite produced a highly sensitive all-sky map of the polarized dust emission at wavelengths smaller than 1 mm. This provided the first large-scale view of the magnetization in interstellar filamentary features and their environments.

Studies done with Planck data found that filaments are not only highly magnetized, but they are coupled to the magnetic field in a predictable way. The orientation of the magnetic fields is parallel to the filaments in low-density environments and perpendicular in high-density environments. This result implied that magnetic fields are playing an important role in shaping filaments.

But this observation also points toward a problem. In order for stars to form in gaseous filaments, these filaments have to lose these magnetic fields. When and where does this happen? With an order of magnitude higher angular resolution than Planck, the HAWC+

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Composite image of the Serpens South Cluster. Magnetic fields observed by SOFIA are shown as streamlines over an image from the Spitzer Space Telescope. SOFIA results indicate that gravity can overcome some of the strong magnetic fields to deliver material needed for new stars. The magnetic fields have been dragged into alignment with the most powerful flows, as seen in the lower left where the streamlines are following the direction of the narrow, dark filament. This is accelerating the flow of material from interstellar space into the cloud, and fueling the collapse needed to spark star formation. *(NASA/SOFIA/T. Pillai; NASA/JPL-Caltech/L. Allen)*

About this Spotlight

Paper: Magnetized filamentary gas flows feeding the young embedded cluster in Serpens South
Authors: T. G.S. Pillai, D. P. Clemens, S. Reissl, P. C. Myers, J. Kauffmann, E. Lopez-Rodriguez, F. O. Alves, G. A. P. Franco, J. Henshaw, K. M. Menten, F. Nakamura, D. Seifried, K. Sugitani, H. Wiesemeyer
Reference: Nature Astronomy 2020.

SOFIA Detects Water on the Moon

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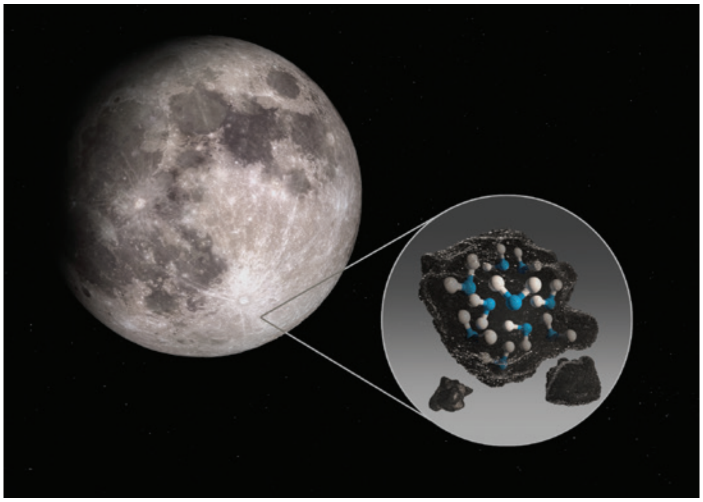
feature at 6.1 µm is unique to H_2O and does not suffer from blending from other OH-related compounds.

SOFIA targeted high lunar latitudes near the South Pole, where the low temperatures could allow migrating water to transiently remain on the surface, and the high hydroxyl abundances could promote creation and trapping of water by impacts of small meteorites. Comparing the 6.1 µm emission band intensity to those of carefully calibrated water-bearing glasses, the team found water abundances of a few hundred parts per million. It is the extreme sensitivity of SOFIA that allowed scientists to detect this miniscule amount of water, which is 100 times less than that in the Sahara Desert.

But even this amount of water is high by lunar standards, more in fact than can be adsorbed on lunar grains at the surface temperatures recorded by SOFIA. This result indicates that much of the water must be trapped in impact glasses or within/between grains sheltered from sunlight. Therefore, the water could have a meteoritic origin or be produced on the lunar surface itself from pre-existing hydroxyl. The team also found that the abundance of water varies with latitude, suggesting that meteorites may not be the only source of water.

Further observations with SOFIA will create water maps of the nearside lunar surface and gather evidence supporting theories of the origin of lunar water. Observations covering large areas obtained at various times of the lunar day will enable scientists to learn about the storage, retention, and migration of water on the surface of the Moon. Studying lunar water remotely with SOFIA is critical for future NASA missions, including the VIPER lunar rover, a mobile robot that will explore the landscape near the moon's South Pole in 2022, and the Artemis program that will return humans to the moon by 2024. ■



This illustration highlights the Moon's Clavius Crater in the southern hemisphere, where traces of water were detected by SOFIA. This is the first time water has been found on the sunlit surface of the Moon. The callout depicts water molecules trapped inside tiny, glass bead-like structures within the lunar soil. These structures may prevent water from being lost to space, allowing it to remain on the harsh, nearly airless lunar surface. *(NASA/Ames Research Center/Daniel Rutter)*

Magnetized Filamentary Gas Flows in Serpens South

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instrument, a polarization-sensitive detector onboard SOFIA, is now able to resolve the regions where the filamentary magnetic field becomes less important.

HAWC+ observations were obtained to study the role of magnetic fields in Serpens South Cluster, a young, nearby star forming region that sits at the center of a network of dense filaments. HAWC+ confirmed the trend seen in the lower resolution — that the magnetic field is parallel to low-density gaseous filaments and perpendicular at higher densities.

The finer resolution of HAWC+, however, also revealed a twist to the Planck story. In the most opaque parts of certain filaments, the observations show that the magnetic field is once again aligned. This transition appears to result as the magnetic field succumbs to the strength of the gas flow, allowing gravitational collapse and cluster formation to occur even in the presence of relatively strong magnetic fields. Additional observations and modeling will be needed to understand the magneto-hydrodynamic forces that govern the complex processes involved in star formation. ■

The Role of the Magnetic Field in the Galactic Center

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tell us that turbulence is important in this region, and the traditional plasma beta does not account for this. Defining β′ as the ratio of the turbulent-to-magnetic pressure and using a velocity dispersion from the literature, we find β′ ~ 0.03. This too is in the low-beta regime, indicating that the magnetic field is capable of channeling the matter. So even though gravity dominates in the galactic center, there appear to be regions near the central black hole where the physics may be governed by the magnetic field.

These results have implications for two long-standing mysteries about the galactic center region. The first is about star formation. Even though there is an abundance of raw material, the amount of star formation is significantly less than expected. The second is about activity. Black holes at the centers of many galaxies are active, but ours is relatively quiet. A strong magnetic field could solve both these mysteries. It could suppress star formation, and it could keep the black hole from swallowing the matter it needs to form jets.

Future work will include updating the Davis-Chandrasekhar-Fermi method to work in the high-shear regions near the massive black hole. Detailed magneto-hydrodynamic modelling will also be required to explore the interplay between the magnetic field, the tidal stresses, and the turbulent motions of the gas in this extreme environment. ■

First Detection of ^{13}CH in the Interstellar Medium

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established CH as a tracer for H_2 in diffuse clouds, but analysis of these spectra is complicated by emission features from the surrounding gas. SOFIA observes the CH transitions at 2 THz, where all the spectral features are seen in deep absorption. The analysis of these profiles is straightforward and yields reliable measurements of column density and abundance.

Observations indicate that CH and H_2 show a strong linear correlation, which make CH a promising tracer for the "CO-dark" component of the interstellar medium.

Unlike HF and OH, which are precursors to the formation of CO, CH has a distinct advantage in that its spectra are almost always optically thin and show no saturation, particularly at the velocities corresponding to the molecular clouds themselves.

While various transitions of ^{12}CH have been studied using a wide array of observational techniques and instruments, ^{13}CH had not been observed in the interstellar medium. SOFIA was able to detect, for the first time, the corresponding rotational transition of ^{13}CH near 2 THz towards four high-mass star-forming regions, SgrB2(M), G34.26+0.15, W51e, and W49(N).

Furthermore, because it is optically thin and relatively unaffected by isotope-selective chemical effects, CH should produce a reliable ^{12}C/^{13}C ratio. Therefore, the detections of ^{13}CH along with observations of ^{12}CH towards the same sources provides a new and independent diagnostic for determining the ^{12}C/^{13}C abundance ratio across the galaxy.

By combining the ^{12}C/^{13}C values derived using CH with previous measurements from different chemical species, a revised galactic gradient can be determined. The steeper slope provides new constraints on the degree of nuclear processing and galactic chemical evolution models. In addition, studies of CH will improve our understanding of interstellar chemistry. Although direct substitution of ^{13}C in more complex species is currently poorly understood, it could originate in simple precursors like CH. ■

Cold Quasars and the Evolution of Galaxies

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determine the relative contribution of each to the total amount of light emitted by the galaxy. This process accounts for energy balance between the stars and dust, ensuring that the re-processed light observed in the far-infrared is consistent with the amount of energy absorbed by the gas. CQ4479 is best fit with a star-formation rate of 95 solar masses per year, nearly 50 times the rate in the Milky Way. Results indicated that the inclusion of just one extra data point from SOFIA, which traces the peak of far-infrared emission, can better constrain the star formation estimate by nearly a factor of two.

The black hole growth rate is constrained using archival X-ray and [O III] optical emission data from the XMM-Newton and the Sloan Digital Sky Survey, respectively. The X-ray emission indicates a slower growth rate than the [O III] estimate. One possible explanation for this discrepancy is that the X-rays trace the accretion rate on more instantaneous time scales than the [O III], so the black hole could have slowed down its accretion, at least at the epoch of observation.

Overall, the results indicate that the stellar population and black hole mass in CQ4479 are growing at the same rate, which is surprising since theory predicts that black hole growth succeeds stellar growth. CQ4479 is at the lower mass end of both stellar mass and black hole mass. The active black hole and stellar population could continue to grow for another 500 million years, tripling the mass of each before the black hole halts star birth.

Cold quasars represent an early stage of active galactic nucleus feedback and are a valuable laboratory for understanding how star formation and active supermassive black holes can co-exist. This brief window, where the galaxy has not yet succumbed to the devastating effects of the quasar, can help explain how massive galaxies formed in the early universe. As the only telescope capable of observing the majority of the host galaxy's emission, observations from SOFIA are crucial for understanding how these galaxies evolved over cosmic time into the universe we see today. ■

Molecular Processing in the Disks of Massive Stars

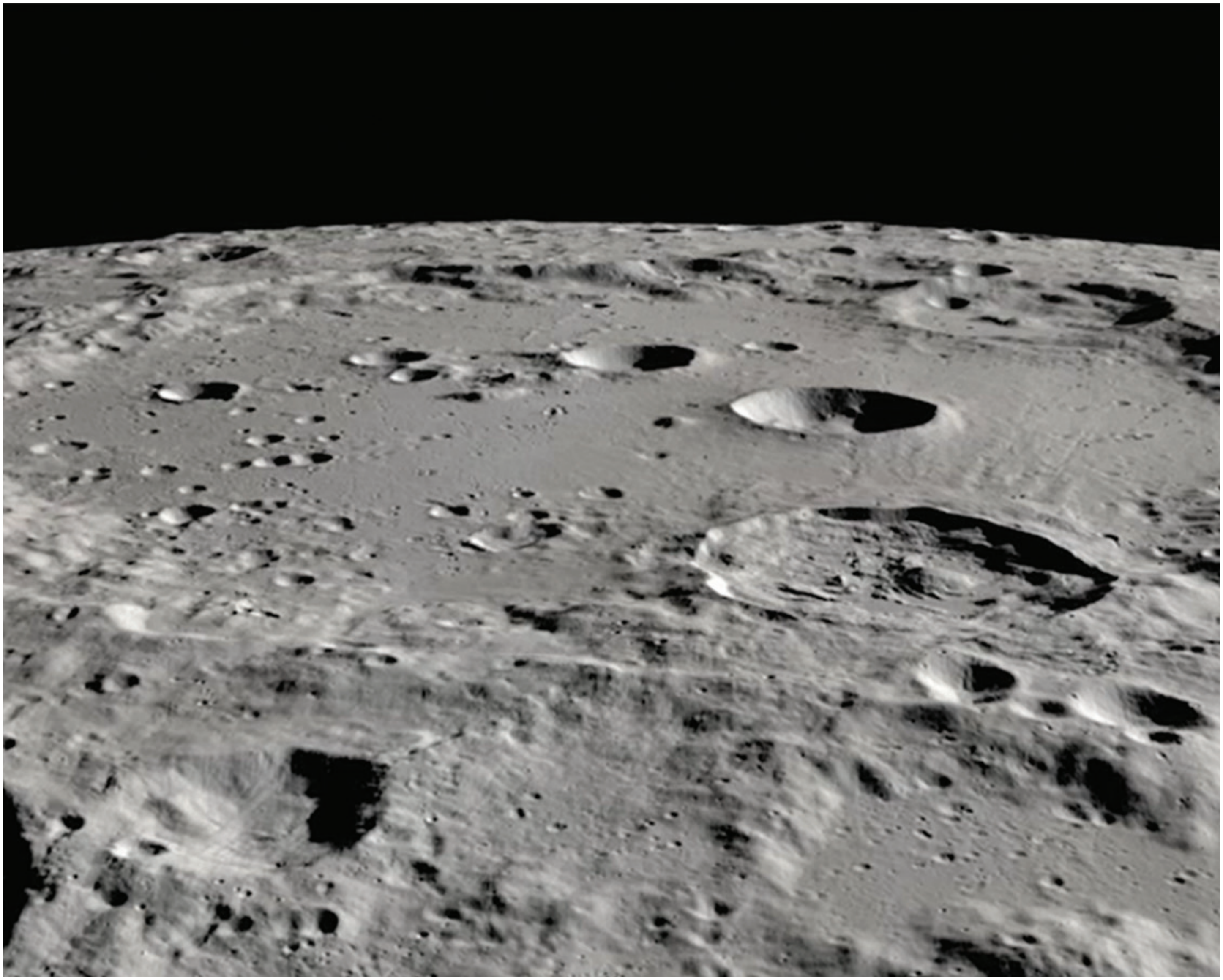
(continued from page 7)

environment of these disks. Astronomers think that similar processes played a role in the early solar nebula in which the terrestrial planets were formed.

The fact that the molecules are seen in absorption implies that the disk photosphere behaves like a stellar atmosphere, with a temperature that decreases outwards. Using this approach, we were able to calculate the chemical abundances of each molecule. This study provides a a benchmark to guide future observations using the Mid-Infrared Instrument on the James Webb Space Telescope, which will be able to carry out this kind of research towards low mass protostars in a similar stage of their evolution as AFGL 2591 and AFGL 2136.

Absorption lines have also been observed towards other massive protostars. Physical conditions are consistent with an accreting disk with a high abundance of material in the planet-forming zone. We are continuing the study of these objects with follow-up spectral surveys to each of these known sources.

SOFIA provides a unique view and opportunity to carry out these kinds of studies, piercing through the dusty environs to the hearts of these disks. As we begin to get more data from these rarely observed objects, we will begin to unravel some of the questions surrounding the disks of massive protostars and the formation of planets in them. ■



View of the Clavius Crater and its terrain generated using data from the Lunar Reconnaissance Orbiter (LRO). *(NASA/Moon Trek/U.S. Geological Survey/Lunar Reconnaissance Orbiter)*

SOFIA is a Boeing 747SP jetliner modified to carry a 106-inch diameter telescope. It is a joint project of NASA and the German Aerospace Center, DLR. NASA's Ames Research Center in California's Silicon Valley manages the SOFIA program, science and mission operations in cooperation with the Universities Space Research Association headquartered in Columbia, Maryland, and the German SOFIA Institute (DSI) at the University of Stuttgart. The aircraft is maintained and operated from NASA's Armstrong Flight Research Center, Building 703, in Palmdale, California.

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