

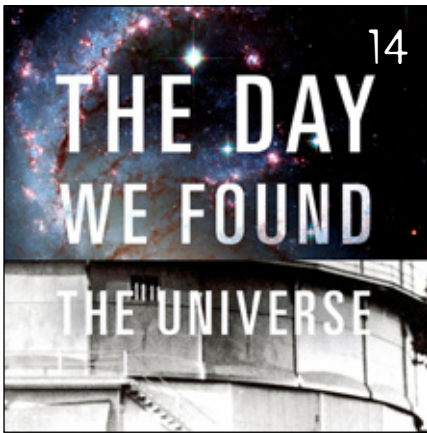
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The Day We Found the Universe

MARCIA BARTUSIAK

The discovery of the modern universe is a story filled with trials, errors, serendipitous breaks, battles of wills, and brilliant insights — a book excerpt by the winner of the ASP's 2010 *Klumpke-Roberts Award*.

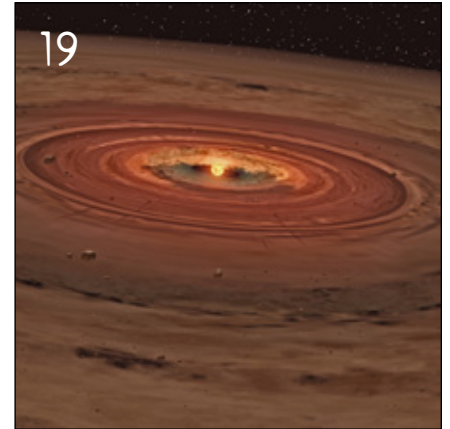
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Learning How to Build a Solar System

JOEL D. GREEN

I'm in the planet-construction business, though only as an observer. It's a hard job, because new stars are shrouded in dust and gas. But we're finally beginning to uncover a few of their long-held secrets.



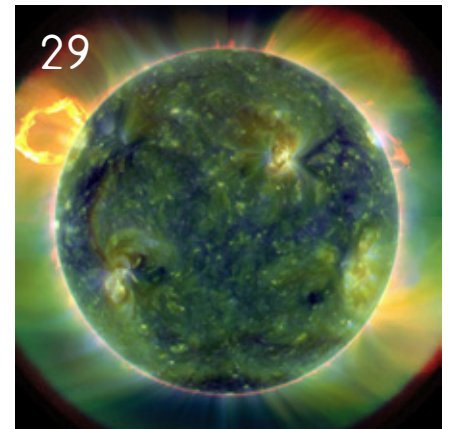
NASA's New Airborne Observatory Sees "First Light"

NICHOLAS A. VERONICO

After more than a decade of hard work (and numerous funding challenges), a unique telescope finally takes to the air to seek out the secrets of the infrared universe.

Astronomy in the News

Spectacular first-light images of the Sun, a planetary system out of tilt, and a vast reservoir of intergalactic gas 400 million light-years away — these are some of the discoveries that recently made news in the astronomical community.



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NASA'S NEW AIRBORNE OBSERVATORY SEES "FIRST LIGHT"

A unique telescope takes
to the sky to help reveal
the infrared cosmos.

by **Nicholas A. Veronico**



Illustration: Lynette Cook

NASA's Stratospheric Observatory For Infrared Astronomy, or [SOFIA](#), reached its "First Light" flight milestone during the early morning hours of May 26, when the aircraft's telescope and attached infrared camera collected light from celestial targets for the first time at altitude.

"With this flight, SOFIA begins a 20-year journey that will enable a wide variety of astronomical science observations not possible from other Earth- and space-borne observatories," said Jon Morse, NASA's Astrophysics Division director. "It clearly demonstrates that SOFIA will provide us with 'Great Observatory'-class astronomical science."

The flight was conducted from NASA's Dryden Aircraft Operations Facility at the Palmdale Airport in Southern California. SOFIA is a highly modified Boeing 747SP fitted with a 100-inch (2.5-meter) diameter infrared telescope in the aft section of the plane, and is a joint program between NASA and the German Aerospace Center, Deutsches Zentrum für Luft- und Raumfahrt (DLR), Bonn, Germany.

The First Light flight lasted nearly eight hours as the team of 10 scientists, engineers, and technicians from Universities Space Research Association (USRA), the German SOFIA Institute (DSI), and Cornell University tested the the telescope assembly and other systems at 35,000 feet over the Pacific Ocean southwest of San Diego. Energy collected by SOFIA's telescope was channeled into the Faint Object infraRed Camera for the SOFIA Telescope (FORCAST). FORCAST, built by a team from Cornell University, headed by Principal Investigator Dr. Terry Herter, is a mid-infrared camera that records images through filters in the wavelength range of 5 to 40 microns. (For comparison, the human eye sees light with wavelengths between 0.4 and 0.7 microns.)



NASA Photo: Jim Ross

With its sliding door open wide to reveal its 17-ton infrared telescope, NASA's Stratospheric Observatory for Infrared Astronomy soars over California's snow-covered Southern Sierras during a test flight on April 14, 2010.

Project Management

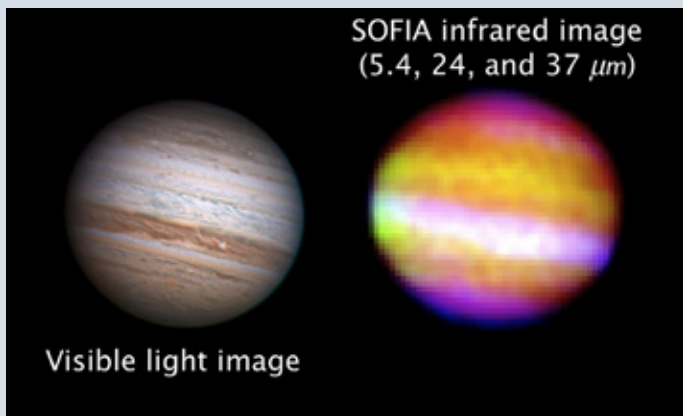
SOFIA is a joint program between NASA and the German Space Aerospace Center, [Deutsches Zentrum für Luft- und Raumfahrt](#) (DLR), Bonn, Germany. The SOFIA program is managed at NASA's [Dryden Flight Research Center](#), Edwards, California, and the aircraft is based at the Dryden Aircraft Operations Facility, Palmdale, Calif. NASA's [Ames Research Center](#), Moffett Field, Calif., manages the SOFIA science and mission operations in cooperation with the [Universities Space Research Association](#) (USRA), Columbia, Md., and the [Deutsches SOFIA Institute](#) (DSI) Stuttgart, Germany.

— N. V.



NASA Photo by Tom Tschida

SOFIA program officials representing NASA, the Universities Space Research Association (USRA) and Deutsches SOFIA Institut (DSI) line up on the access stairs to the open telescope cavity in the SOFIA 747SP. From top to bottom are: DSI telescope assembly/science instrument manager Thomas Keilig, NASA's SOFIA program manager Bob Meyer, deputy program manager Eddie Zavala, aircraft project manager John Carter, USRA's SOFIA science mission operations director Erick Young, and chief SOFIA science advisor Eric Becklin.



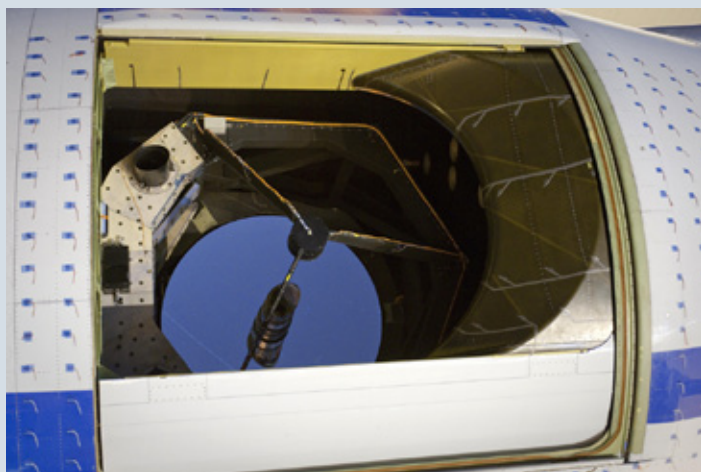
Infrared: NASA/SOFIA/USRA/Cornell University
Visible light: Anthony Wesley

This composite infrared image showing Jupiter at wavelengths of 5.4 (blue), 24 (green), and 37 microns (red), was acquired by Cornell University's FORCAST camera during SOFIA's First Light flight. A recent visual-wavelength picture of approximately the same side of Jupiter is shown for comparison. The white stripe in the infrared image is a region of relatively transparent clouds through which the warm interior of Jupiter can be seen.

Using FORCAST, scientists recorded images of Jupiter and the galaxy M82 (located approximately 12 million light-years away in the constellation Ursa Major) at wavelengths unobservable by either ground-based observatories or current space-based telescopes. The composite Jupiter image shows heat pouring out of the planet's interior through transparent portions of its clouds. The composite M82 image peers through that galaxy's interstellar dust clouds to show three "starburst" knots in which stars are forming by the thousands.

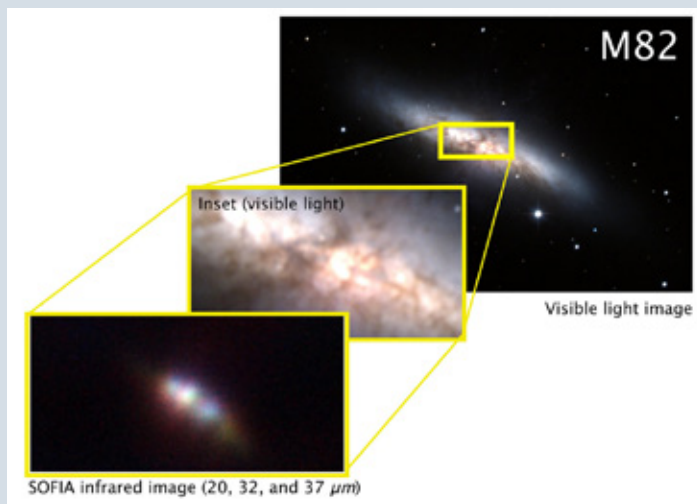
"It's tremendous for me personally to see these images; this feels like the culmination of my career," said USRA SOFIA senior science advisor Eric Becklin. Becklin was the leader of the team that answered the original call for proposals from NASA and won the competition to develop and operate SOFIA. Becklin made some of the first infrared observations of planets and galaxies when infrared astronomy began in the 1960s.

The results, according to NASA SOFIA project scientist Pam Marcum, were gratifying. "Wind tunnel tests and supercomputer calculations made at the start of the SOFIA program predicted we would have sharp enough images for front-line astronomical research; a preliminary look at the first light data indicates we indeed accomplished that." The stability and precise pointing of the



NASA Photo: Tom Tschida

Faint specks of starlight are reflected by SOFIA's 100-inch (2.5-meter) primary mirror during ground testing of the Faint Object infraRed Camera for the SOFIA Telescope (FORCAST).



N.A. Sharp / NOAO / AURA / NSF

This composite infrared image of the central portion of galaxy M82, from SOFIA's First Light flight, was taken at wavelengths of 20 (blue), 32 (green) and 37 microns (red). The middle inset image shows the visible-light center of the galaxy. The infrared image sees past the stars and dust clouds and peers deep into the star-forming heart of the M82. The long dimension of the inset boxes is about 5,400 light years.

German-built telescope met or exceeded the expectations of the engineers and astronomers who put it through its paces during the flight.

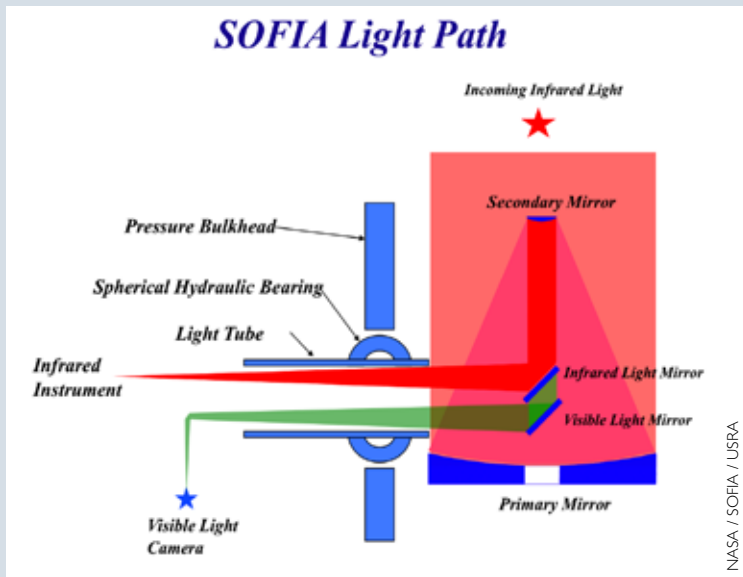
Science Operations

When flying science missions, SOFIA will operate between 39,000- and 45,000-feet, which is above more than 99% of the water vapor in Earth's atmosphere. Research flights are planned to ramp up to an average rate of two to three times per week by 2015, equaling more than 900 science-flight hours per year. Using a suite of eight purpose-built instruments, one per mission, SOFIA will observe the universe in the infrared spectrum between wavelengths of 0.3 and 1,600 microns, a broader range than any other observatory on the ground or in space.

The flying observatory's suite of instruments will enable astronomers to look at (among other sights) galaxies and the Milky Way's galactic center, focusing on starburst history and the motions of stars around supermassive black holes; the Milky Way's interstellar medium including the environs of star-forming regions, organic molecules in space, and how interstellar material is recycled; details of the formation of stars and planets, especially massive stars, and the chemistry and dynamics of planet-forming disks; and planetary science observations of comets, near-Earth asteroids, the planet Venus, and Saturn's moon Titan.

The observatory's first science program will begin in October 2010, with researchers Mark Morris (University of California at Los Angeles) and Paul Harvey (Colorado University, Boulder) collaborating with the FORCAST team to study several star-forming regions. The FORCAST instrument will be used to develop high-resolution, mid-infrared views of the star-formation process. Additionally, Harvey will work with the FORCAST team to interpret those data to carefully characterize SOFIA's imaging capabilities for future users.

David Neufeld (Johns Hopkins University, Baltimore, Md.) was selected to study the chemistry of the interstellar medium using data obtained by SOFIA's second instrument, the German Receiver for Astronomy at Terahertz Frequencies (GREAT). The instrument is a spectrometer developed for SOFIA by a consortium of German research institutes, led by Rolf Güsten at the Max Planck Institute



NASA / SOFIA / USRA

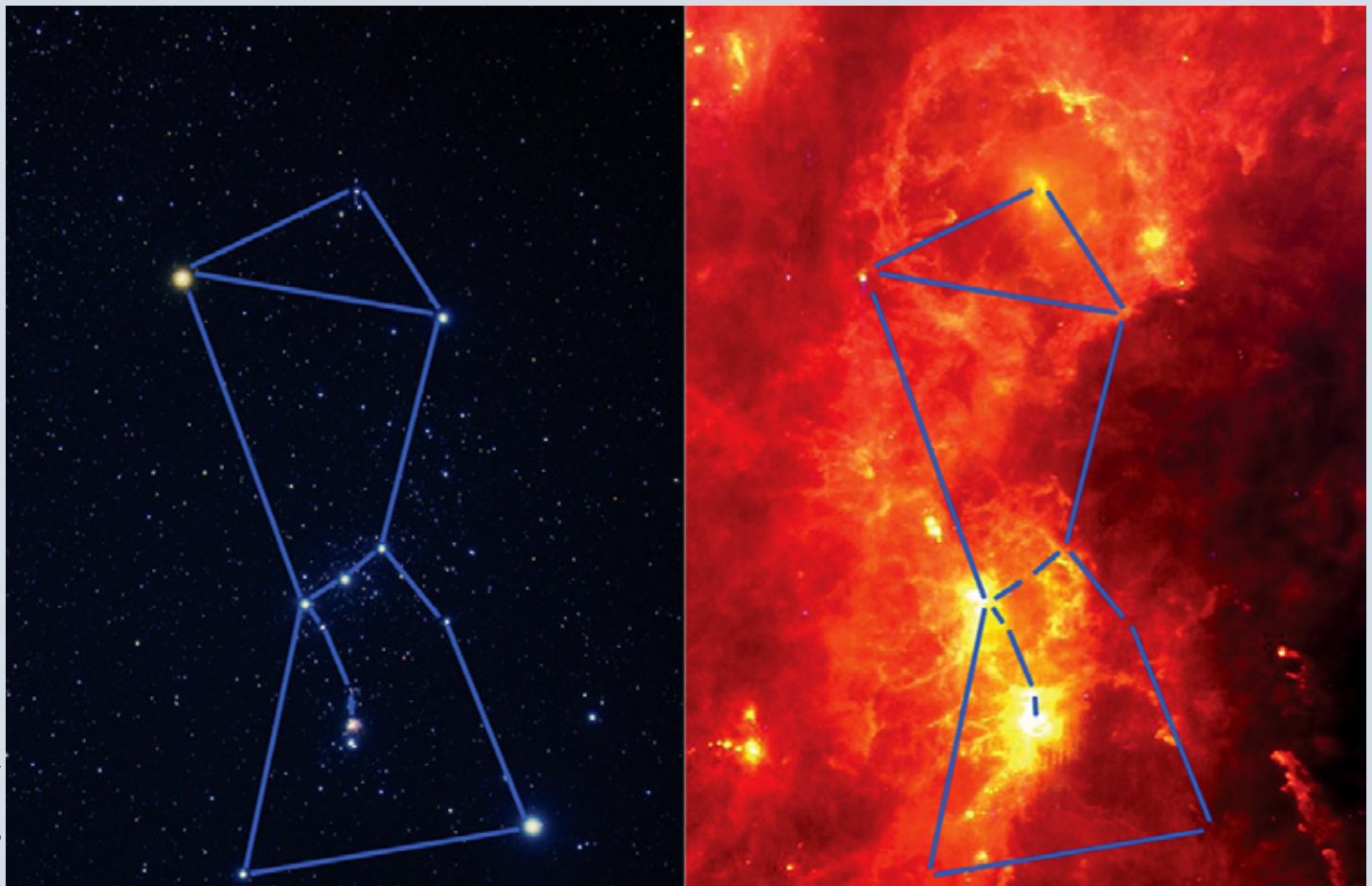
Infrared radiation from celestial objects enters the telescope cavity and is reflected from the primary mirror up to the secondary mirror. From the secondary, the infrared rays are bounced to a mirror that sends the radiation down the light tube into the pressurized compartment of the aircraft, and then to an instrument (for example an infrared camera or spectrometer). Visible light reflected by the secondary passes the infrared mirror, is reflected by the visible-light mirror into the light tube, and then is captured by a visible-light instrument — typically a camera. This allows SOFIA to take Hubble-like photos as well as make infrared measurements.

for Radioastronomy in Bonn, Germany. Neufeld will use GREAT to focus on warm interstellar gas by observing spectral emission lines from molecules such as carbon monoxide (CO). That study will help researchers understand the nature of chemical reactions taking place in the warm gas found around forming stars and in other regions of the interstellar medium.

Future opportunities for the astronomical community to use SOFIA were announced in April of this year. The Call for Proposals for SOFIA Basic Science solicits observing programs using FORCAST and GREAT. The deadline for submitting proposals is July 30, 2010, and more information can be found [here](#). At this website, potential proposers will find the call for proposals, a downloadable copy of the *SOFIA Observer's Handbook for Basic Science*, and other helpful tools.

Developing A Flying Observatory

Airborne astronomy got its start in the 1920s with telescopes being taken aloft to view comets and solar eclipses. Infrared airborne observations, initiated in 1957, studied the solar spectrum at wavelengths between 1.0 and 6.5 microns. Beginning in 1965, NASA's Ames Research Center in Mountain View, California, initiated a series of flying telescope platforms that eventually culminated in the design and development of SOFIA. From 1965 until 1973, a Convair 990 jet called *Galileo* was used as an airborne laboratory for research in aeronautics, earth science, and astronomy. Between 1966 and 1976, most airborne astronomical observations were made by the LearJet Observatory, which had a



Visible light: Akira Fujii; Infrared: Infrared Astronomical Satellite

The visible light (left) and infrared (right) images of the constellation Orion, the Hunter, are of the exact same area. These images dramatically illustrate how features that cannot be seen in visible light show up very brightly in the infrared.



NASA

For more than 20 years, the Kuiper Airborne Observatory (KAO) and its 36-inch telescope made a remarkable series of discoveries in the infrared portion of the spectrum.

10-inch telescope and instruments observing at wavelengths between 0.3 and 250 microns.

From 1974 to 1995, NASA flew a civilian version of the Lockheed C-141 Starlifter, known as the [Kuiper Airborne Observatory \(KAO\)](#). The KAO was named for astronomer [Gerard P. Kuiper](#), who first suggested that an airborne observatory could be a best-of-both-worlds facility, combining the virtues of ground- and space-based observatories. The KAO was fitted with a 36-inch (0.9-meter) diameter infrared telescope, mounted forward of the wing, which was capable of studying objects at wavelengths from 0.3 to 1,600 microns (the same as SOFIA). Using its 36-inch scope, scientists on board the KAO learned a great deal about the universe, discovering such phenomena as the rings around the planet Uranus, water in Jupiter's atmosphere and in the interstellar medium, and early evidence for the black hole at our galactic center.

Based on the KAO's exciting results, researchers envisioned a larger telescope and could only imagine what revelations it might bring. To that end, in 1995 the KAO was sidelined to channel its funds into the development and construction of a more capable instrument that would become known as SOFIA.

SOFIA is Born

The Boeing 747SP (Special Performance) that would become SOFIA made its first flight on April 25, 1977, from Boeing's factory at Everett, Washington, and was subsequently delivered to Pan American World Airways on May 6 of that year. Fourteen days later, on the 50th anniversary of Charles Lindbergh's solo crossing of the Atlantic, Charles' widow, Anne Morrow Lindbergh, christened the jetliner *Clipper Lindbergh* in his honor. After nine years of service, Pan Am sold the jetliner to United Air Lines, which flew the plane until 1994, when it was put into storage.

The Boeing 747SP was 55 feet shorter than a standard 747 (fuselage length: 177 feet/53.9 meters), yet maintained the aircraft's wing span (196 feet/59.7 meters) and fuel load (300,000 pounds/44,776 US gallons) giving the SP a range of 6,625 nautical miles. The SPs operated on long-haul routes such as New York to Tokyo, or New York to Johannesburg. Boeing built 45 of the 747SP models, and approximately 14 are still flying today.

NASA acquired the *Clipper Lindbergh* on October 27, 1997, and began the modification process that was optimistically planned to

take only three years. After years of conceptual tests (wind tunnel tests and fluid dynamics predictions using supercomputers), metal began to be cut. The physical modifications to the aircraft included major reconstruction of the fuselage pressure bulkheads, rerouting the aircraft's control cables, and upgrading the aircraft's engines — just a few of the items from a tremendously long list of modifications.


Once ready to soar again, SOFIA made her first post-modification flight on April 26, 2007, from Waco, Texas. The aircraft program then moved to NASA's Dryden Flight Research Center in California, and later to its Palmdale aircraft operating facility. Further modifications and envelope expansion flights (the "envelope" is the combination of speeds and altitudes at which SOFIA was tested and OK'd) were conducted during the balance of 2007 and for the two years following. On December 19, 2009, the airborne observatory made its first flight with the telescope cavity door fully open. Operational rehearsals and another series of flight tests were made in the opening months of 2010, culminating with the Telescope Assembly Characterization and First Light flight on May 25/26.

At the conclusion of the First Light flight, SOFIA Program Manager Bob Meyer said, "We're seeing the result of many years of hard work by hundreds of inspired and dedicated people to develop this fantastic facility for the world scientific community."

Inspiring the Next Generation

SOFIA is a tremendous platform for expanding the horizons of students from all age groups. To accomplish this goal, the SOFIA team has expanded upon the successful Flight Opportunities for Science Teacher EnRichment (FOSTER) — the "educators in the stratosphere" program initiated with the Kuiper Airborne Observatory. During the last five years of the KAO's operation, more than 70 teachers were matched with astronomer teams to assist with actual science observations in the stratosphere. In addition, the teacher teams were paired with a reporter from one of their local news media outlets, which enabled the educators and journalists to take their experiences back to the classroom and to share their inspiration with the local community through print and electronic media outlets, at science museums, and with the general public.

SOFIA is now gearing up for its Airborne Astronomy Ambassadors (AAA) program, which is expected to roll out in 2013. Each year (when fully operational), the AAA program will have as many as 80 educators working side-by-side with astronomers on board SOFIA. Following their flight experience, SOFIA's Ambassadors will make multiple visits to classrooms, youth groups, and other public events as master teachers to share their inspiring astronomy experiences. The AAA program and SOFIA's other education and public outreach activities are managed by a partnership between the SETI Institute and the Astronomical Society of the Pacific.

Looking toward the future, USRA SOFIA Mission Operations Director Erick Young said, "SOFIA's First Light flight ushers in a new era of airborne astronomical discoveries. We're at the dawn of 20 years of new infrared observations that will expand our knowledge of the universe." 

NICHOLAS A. VERONICO, SOFIA Science Center Public Affairs Officer, holds a journalism and a business management degree, and is the author or co-author of more than 25 books on subjects including aviation, military, and local history.