Flying Telescopes

Following nearly four decades of bigger and better airborne observatories, NASA's **SOFIA** mission will carry infrared astronomy to new heights.

This Boeing 747SP, shown during a 1998 test flight, will house the SOFIA infrared telescope. The painted dark rectangular area on the rear of the fuselage marks the telescope's location. This aircraft is named the *Clipper Lindbergh*. It was christened in 1977 by Anne Morrow Lindbergh on the 50th anniversary of her late husband's solo transatlantic flight. Courtesy of L3 Communications, Integrated Systems.

by Sally Stephens

The airplane looks like any other 747, until you notice the large, gaping hole in its left side, just behind the wing. The hole is no accident. It will give astronomers an unobstructed view of the universe through a 2.5-meter telescope mounted inside the plane. When the airplane, nicknamed SOFIA, finally takes flight in 2004, it will become the latest in a small but distinguished series of flying observatories.

For nearly 40 years, astronomers have battled air turbulence, engine vibrations, and complicated aerodynamics of wind blowing past a hole in an airplane's side to gain a view of the universe impossible to achieve from the ground. Airborne astronomy has shown scientists the secrets of star formation, planetary rings, and the energetic cores of galaxies.

But why go to all the trouble? Ground-based telescopes work well for studying the sky in visible light. But Earth's atmosphere blocks most other forms of light from reaching the ground. This is good when it comes to ultraviolet light, X-rays, and gamma rays, which would otherwise damage skin and other cells in our bodies. But it's bad when it comes to infrared light, also known as thermal radiation or heat.

Astronomers are interested in infrared light because, unlike visible

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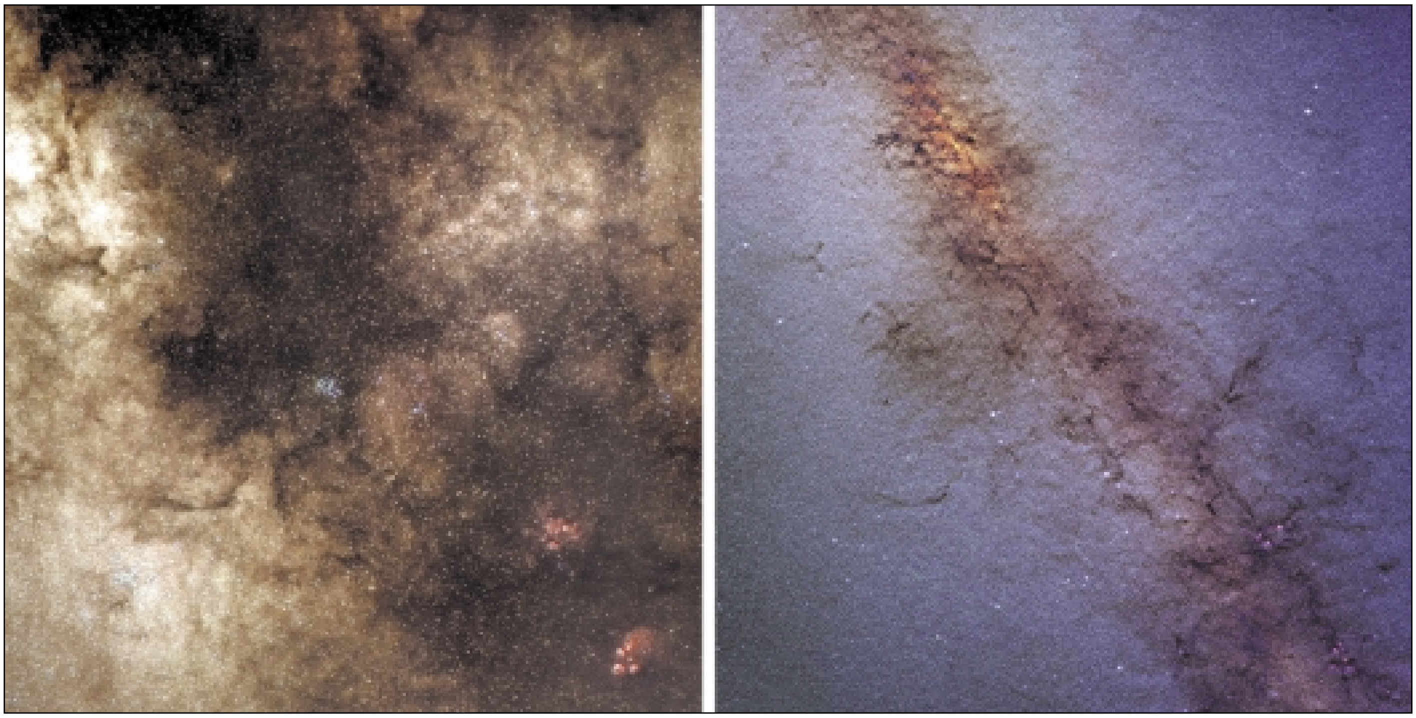

The center of the Milky Way Galaxy appears in visible (left) and infrared (right) light. Infrared light penetrates the thick interstellar dust seen in the visible light image, giving us a nearly unobstructed view of the galactic core. Courtesy of Howard McCallon, Gene Kopan, Robert Hurt, and 2MASS.

light, its wavelengths are too long to be scattered by tiny dust particles. That means an infrared telescope can see what is happening deep inside large dust clouds that appear opaque when viewed in visible light. Such clouds house the nurseries where stars are born and they hide the center of the Milky Way Galaxy from view.

Unfortunately, water vapor in Earth's atmosphere absorbs infrared light, keeping most of it from reaching even the tops of mountains. But water vapor is concentrated near the bottom of the atmosphere. That's where airplanes come in. At 41,000 to 45,000 feet (12,500 to 13,700 meters), the air contains only about 20% of the molecules present at sea level, but that's still enough air for the wings to generate lift, enabling an airplane to fly. But the amount of infrared-absorbing water vapor has gone down by a factor of a thousand. "It's kind of a happenstance of our atmosphere that you can fly an airplane and still see in the infrared," says UCLA astronomer Eric Becklin, chief scientist for SOFIA (Stratospheric Observatory For Infrared Astronomy).

Airborne Astronomy Takes Flight

The idea of using airplanes to carry telescopes above the water vapor crystallized in the mid-1960s. NASA had a Convair CV 990, named *Galileo*, that scientists were using to study Earth's atmosphere and ionosphere. It wasn't really designed for astronomy, however. Any onboard telescopes had to peer through window glass, severely reducing the amount of infrared light received. Despite the problems, a team led by University of Arizona astronomer Gerard Kuiper flew on *Galileo* to study planets in our solar system. From *Galileo* they made the first detection of water ice in Saturn's rings and proved that Venus's clouds were not made of water vapor, as had been thought. Tragically, in April 1973, while testing an instrument to track migratory sea mammals, *Galileo* collided with a Navy patrol plane in mid-air above a runway. Both aircraft crashed, killing all 11 onboard *Galileo*, and 5 of the 6 people on the Navy plane.

Kuiper's *Galileo* observations convinced astronomers that airplanes could provide a useful platform for the study of the infrared universe. In 1967, NASA scientists and engineers, led by Arizona's Frank Low, modified a twin-engine, six-passenger Lear Jet specifically for infrared astronomy. They removed the jet's back seats and replaced them with cramped racks for electronic equipment, tools, notebooks, and a vacuum pump. They designed a 12-inch telescope to fit in place of one of the aircraft's emergency exit windows. Sealed off from the rest of the cabin, the telescope was open to the atmosphere, with no glass to block infrared light.

Conditions aboard the Lear Jet Observatory (LJO) were primitive at best. Because the plane was not fully pressurized, astronomers and pilots had to wear bulky, uncomfortable oxygen masks. The cabin was often either too warm or too cold. "While observing, you sat on the floor," recalls Al Harper of the University of Chicago's Yerkes Observatory. "One person would sit by the front door of the plane operating the electronics. The telescope operator would sit with knees tucked up under the telescope. It was rather intimate."

Despite the hardships, astronomers using the LJO made significant discoveries. They confirmed that Jupiter and Saturn radiate more energy than they receive from the Sun, indicating both have substantial internal heat sources. They began to peer inside vast interstellar clouds whose dust had blocked observations in visible light. Indeed, LJO took the first far-infrared spectrum of the Orion Nebula, a large cloud of gas and dust where stars are being born.

Kuiper: A Giant Leap Forward

The LJO was limited by its small telescope and the fact that it could only stay aloft for 2.5 hours, half of which was spent

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Airborne astronomy took flight in the mid-1960s when astronomers installed a small infrared telescope inside a Convair CV 990 called *Galileo* (above). All images courtesy of NASA/Ames Research Center unless otherwise indicated.

Inset: University of Arizona astronomer Gerard Kuiper pioneered airborne astronomy when he mounted a telescope inside Galileo. Courtesy of Yerkes Observatory.

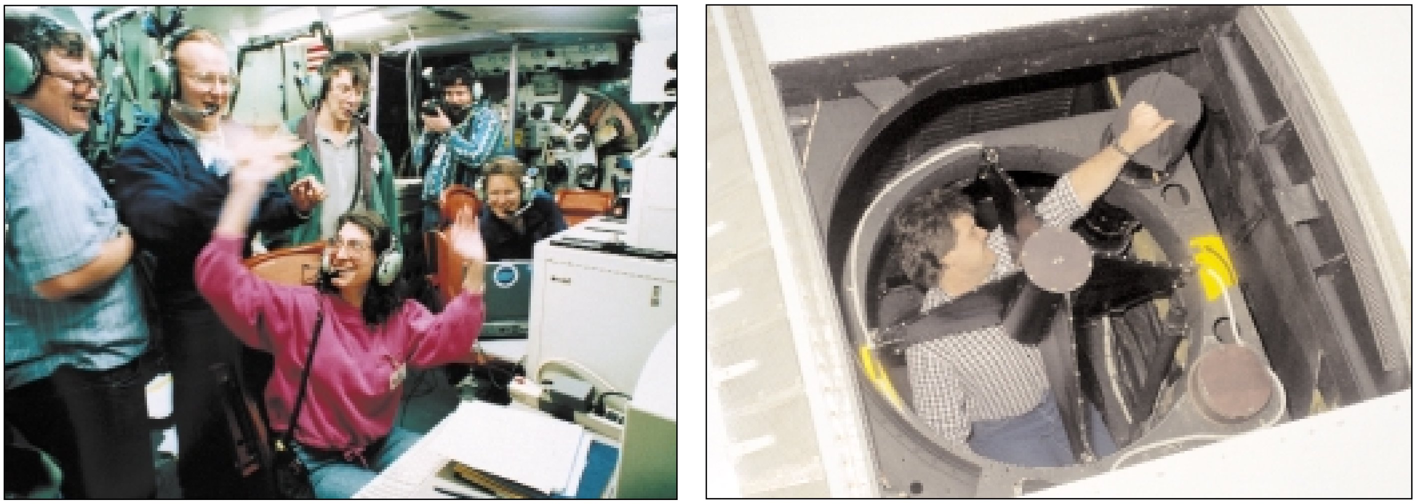
After *Galileo's* success, the next step in airborne astronomy was a 12-inch infrared telescope (inset) mounted inside a Lear Jet (above). Using this telescope, astronomers confirmed that Jupiter and Saturn radiate more energy than they receive from the Sun, meaning both planets have substantial internal energy sources.

climbing to and descending from altitude. Astronomers dreamed of an airplane with a larger telescope that could fly longer missions. In 1974 they got it, when NASA's Kuiper Airborne Observatory (KAO), named for the astronomer who first saw the potential of airborne astronomy, began its flights.

The KAO was a civilian version of a U.S. Air Force C-141 Starlifter transport. Scientists and engineers cut a hole (they call it a "port") just in front of the left wing, large enough to accommodate a 36-inch (91.5-cm) telescope. The open cavity enclosed the telescope but was sealed off from the cabin where the astronomers worked. During flight, the telescope was open to the stratosphere; during takeoff and landings, a sliding door protected the telescope cavity. Infrared light collected by the telescope bounced off mirrors and into detectors mounted on the cabin side of a pressurized bulkhead.

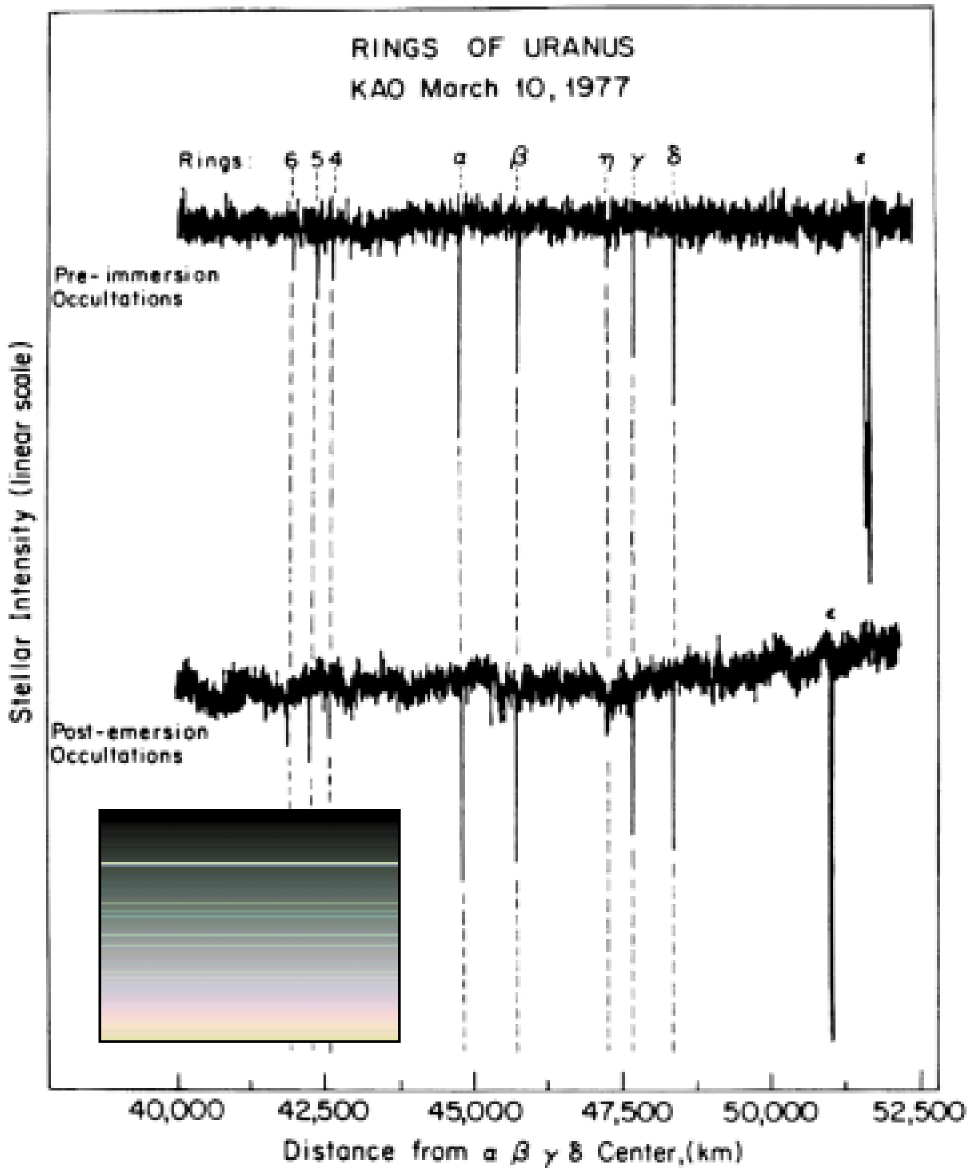
Inside the cabin, oxygen masks hung like stalactites from the ceiling, a constant reminder that in case of a sudden decompression, everyone would have just a few seconds to don a mask before passing out from lack of oxygen. Astronomers and technicians sat in front of several rows of monitors and computer consoles. Researchers could even begin to analyze the data while still in flight. "The LJO was about the size of a Volkswagen bus," Harper recalls. "The KAO was more like a Greyhound bus. It gave you more elbow room."

Although less cramped, the KAO could hardly be described as plush. It lacked the thermal insulation found on commercial airliners. As a result, over the course of a 7-



Left: Susan Stolovy, a Cornell University instrument specialist (she now is a Staff Scientist at the SIRTF Science Center, Caltech), gives her colleagues "high fives" during a July 18, 1994 KAO flight. She and her colleagues had just realized they had detected a whopping signal from the impact of Comet Shoemaker-Levy 9's G fragment on Jupiter. Right: Technician Terry Richardson performs maintenance work on the KAO's 36-inch telescope.

KAO discovered 9 rings around Uranus during a March 10, 1977 stellar occultation. The rings blocked some of the star's light, causing noticeable drops in its brightness. Courtesy of James Elliot (MIT) et al. Inset: In 1986 Voyager 2 took this false-color image of Uranus's 9 known rings. Courtesy of NASA/JPL.



hour flight, the cold of the stratosphere, where temperatures plummet to –50° C, seeped into the plane. Astronomers dressed in heavy sweaters and down jackets to ward off the chill. Those seated near the plane's outer skin often huddled under blankets as they worked. Soda froze solid inside cans left on the cabin's metal floor.

The roar of the KAO's engines made conversation difficult. Everyone wore headphones and spoke into microphones. With everyone tuned to the same channel, private conversations were practically nonexistent.

Harper recalls that when the KAO first began flying, the camera used to guide the telescope wasn't very good. Looking at the camera's monitor, he was lucky to see 4th-magnitude stars (the unaided eye can see stars six times fainter than that). To better guide the telescope, he would sit by it on a folding stool, looking through the eyepiece of a small guiding scope attached to the larger research telescope. A photographer's black hood covered his head to block out the cabin light. "I was always afraid of getting a black eye," he recalls, as turbulence bounced the plane — and the telescope's eyepiece — this way and that. The guidance system eventually improved, much to Harper's relief.

Innovation was a hallmark of KAO, and of airborne astronomy in general. During one KAO flight to observe a solar eclipse, astronomers used the hole in a snack cracker as a pinhole to project a solar image onto a piece of paper. It was an easy way to monitor the progress of the eclipse, while their instruments recorded the telescope's view.

"You have to be doubly prepared when you fly," says Becklin. "There's so much going on and things are happening. You not only have to worry about the telescope and the instruments, you also have to worry about flying the aircraft in the correct direction." Changing direction slightly to fly around a thundercloud, for example, while no big deal for a passenger flight, could be disastrous for astronomers observing a specific object. Any change in aircraft direction altered where in the sky the telescope pointed. Move too far, and the telescope could no longer see the object astronomers wanted to study.

During the KAO's 20 years of flights, it surpassed nearly everyone's expectations. Astronomers discovered a ring of gas orbiting the supermassive black hole at the center of our galaxy. They studied powerful infrared emissions from other galaxies and determined that spiral galaxies emit as much energy at far-infrared wavelengths as all other wavelength regions combined, making them more luminous than astronomers had thought. They revealed newborn stars inside Bok globules, thick interstellar dust clouds that appear completely black in visible light. They probed the distribution of water and organic molecules — materials thought to be necessary for life — in the spaces between stars and in star-forming clouds.

Inside the solar system, KAO astronomers detected water molecules in comets, the first proof that they really are "dirty snowballs." They discovered that Pluto has a thin methane atmosphere. And they made observations that revealed a system of narrow rings around Uranus.

SOFIA and Space Telescopes

For years, astronomers had dreamed of flying an even larger telescope to observe in the infrared. A bigger telescope collects more photons and can, therefore, view fainter objects. It also provides sharper images, especially at longer infrared wavelengths. In 1986, NASA began to study the technical challenges involved in modifying an even bigger airplane to accommodate a telescope significantly larger than the KAO's 36-incher. Work on SOFIA began in 1996. Unfortunately, it was necessary to retire the KAO in 1995 in order to provide adequate funding to develop SOFIA.

Today, an international consortium of scientists, engineers, and technicians is hard

The KAO telescope imaged Comet Halley crossing the Milky Way in April 1986. This photo was taken with equipment designed, mounted, and operated by a Charleston, South Carolina, County School District project. KAO astronomers detected water molecules, proving comets really are "dirty snowballs."

KAO represented a giant leap forward for airborne astronomy (note the telescope port in the top image). Right inset: KAO's Mission Director's console exemplifies the airplane's crowded interior.

at work on SOFIA, the next generation in airborne telescopes. They're modifying a Boeing 747SP to carry a 2.5-meter (8-foot) telescope — the largest telescope ever to leave the surface of Earth. The German Aerospace Center (DLR) is building the mirror and telescope. Both will then be flown to Waco, Texas, where L3 Communications, Integrated Systems is carrying out the airplane modifications. USRA (Universities Space Research Association), SOFIA's prime contractor, will operate the observatory for NASA, managing American telescope allocation time (DLR will control 20% of the time) and maintaining the observatory. USRA has teamed with United Airlines, whose personnel will fly SOFIA and perform aircraft maintenance work.

"SOFIA will have a sharper infrared view of the universe than any previous telescope," says Becklin. And that includes space-based telescopes, which tend to be smaller because of weight restrictions.

Size matters, but so does accessibility. If an instrument fails on any airborne observatory, technicians already onboard the plane can work on the instrument until it's fixed, most of the time before the flight ends. "We can install the latest and greatest detectors and instrumentation at any time," adds Becklin. That means SOFIA will carry state-of-the-art instruments throughout its 20-year scheduled lifetime. Space-based telescopes may begin with the latest technology, but, by the time their missions end, their equipment is usually obsolete.

SOFIA is also more flexible than space telescopes such as IRAS or SIRTF (see "SIRTF: NASA's Next Great Observatory," page 32). Think of SOFIA as the world's largest portable telescope. Airplanes can fly anywhere in the world to view an event in any part of the sky at any time. When KAO discovered Uranus's rings, for example, it flew out of Australia (where it needed to be) to record what happened when Uranus occulted a distant star, an event not visible everywhere on Earth. Such flexibility is impossible for telescopes anchored to the ground and is difficult for tightly scheduled space-based telescopes.

This is not to say that airborne telescopes are always better. Telescopes in the extreme cold of space experience fewer

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problems with background noise. “The infrared background,” explains Becklin, “is determined by photons from the surrounding thermal environment — the telescope, the sky. On SOFIA, we still have the residual temperature of the atmosphere. It’s typically –40° C in the stratosphere. But that still generates a lot of unwanted infrared photons. Space is much colder.” Eliminating background noise is critical when one views faint objects, the light of which can be lost amid noise, or when one looks for faint features in a bright spectrum.

Space-based and airborne telescopes each have their advantages and disadvantages. An airplane can observe for no more than 7 or 8 hours at a time, constrained by fuel consumption. Space telescopes have no such time restrictions. It’s not an either/or situation; the two complement each other. “The airborne program is an essential part of the support for the space program,” says Harper. “It provides ready access and a place to develop and test instruments and techniques that will fly on future space telescopes.”

Pointing the Telescope

Of course, any tests or astronomical observations made with an airborne observatory require that the telescope remain steady. The airplane itself plays a major role in keeping the telescope pointed at a desired object. An airborne telescope can only look out an open port on one side of the airplane (larger openings that would allow the telescope to look out both sides would leave the plane structurally unsound; traditionally, the holes have always been cut on the left). If astronomers want to look at an object visible in the west, for example, the plane has to fly north. The airplane’s flight path must be carefully plotted and flown to keep the telescope pointed in the right direction.

Anyone who’s ever flown knows that air turbulence and engine vibrations can shake an airplane severely and unpredictably. Recalling one particular incident of turbulence, Yvonne Pendleton of NASA’s Ames Research Center says, “It was amazing to me the first time I noticed the back of the

SOFIA Technical Details

Weight of Telescope, including Science Instrument	**about 20,000 kg**
Configuration	**Cassegrain telescope with Nasmyth focus**
Primary Mirror	**2.7 m diameter; 2.5 m effective aperture**
System Focal Ratio	**f/19.6**
Wavelength Range	**0.3 to 1,600 microns**
Field of View	**8 arcminutes**
Temperature of Telescope	**240 Kelvins**
Operating Altitude	**12,500 to 13,700 m**
Observation Time at Operating Altitude	**8 hours**
Number of Flights Per Year	**about 160**
Lifetime	**20 years**

Education and Outreach with SOFIA

For the past several years, NASA’s Office of Space Science has mandated that every mission devote a small percentage of its budget to education and public outreach. These initiatives provide immediate educational benefit to the American public that go beyond the long-range benefits of scientific research. SOFIA will devote its education effort to using the natural attraction of a “telescope in an airplane” to help educators teach basic concepts of science, astronomy, and critical thinking.

The Astronomical Society of the Pacific, in partnership with the SETI Institute, is responsible for the SOFIA Education and Public Outreach (E/PO) program. When fully operational, educators and the general public will be able to get involved in a variety of ways. The program will eventually touch millions of students of all ages.

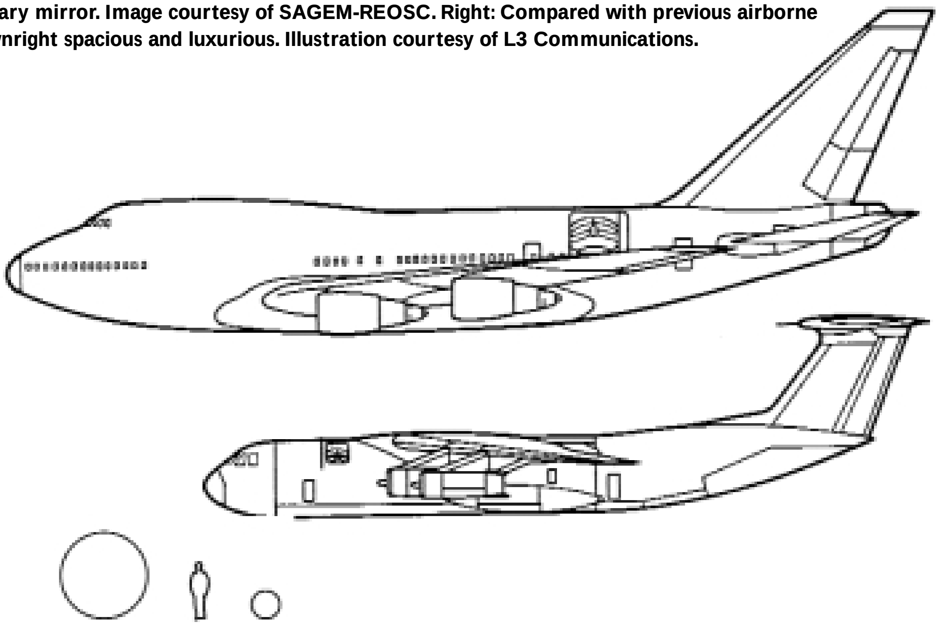
In the most visible aspect of the program, up to 200 educators per year will be trained as “Airborne Astronomy Ambassadors.” The educators will fly in groups of 2 or 3 aboard SOFIA missions, learning first-hand what scientists do and how they think. As important as helping the Airborne Ambassador teach more effectively, the prestige and enthusiasm these teachers will gain from such an experience will last for years and will have an impact on thousands of students.

The SOFIA E/PO staff will help teachers all over the country form educational partnerships with SOFIA-related scientists and will teach the scientists how to conduct effective classroom visits. Teachers will also have access to many specially developed classroom activities built around SOFIA science, available both on the Internet and in classroom-ready printed form.

Teachers flew aboard the Kuiper Airborne Observatory, and they’ll fly aboard SOFIA as well. This image shows teachers at work during a 1993 KAO flight. Courtesy of NASA/Ames Research Center.

For more information on SOFIA, or to learn more about the E/PO programs (including how to subscribe to the free Educators E-newsletter), visit www.sofia.usra.edu. — *Mike Bennett*

Left: A technician inspects SOFIA's 2.7-meter primary mirror. Image courtesy of SAGEM-REOSC. Right: Compared with previous airborne observatories, SOFIA's Mission Control area is downright spacious and luxurious. Illustration courtesy of L3 Communications.



Both SOFIA's airplane and mirror (bottom left) dwarf their KAO counterparts.

KAO's telescope turning this way and that. Then I looked at the monitor that depicted our stellar image and realized the image was quite stationary. It was suddenly obvious to me that the plane was moving around the telescope and not the other way around."

How does the telescope avoid all the bumps and shakes? The secret is pressurized air bladders that isolate the telescope from aircraft vibrations. SOFIA's telescope is shaped somewhat like a well-balanced dumbbell, with the telescope on one end and the instruments and counterweights on the other. After bouncing off the telescope's series of mirrors, infrared light passes through the "bar of the dumbbell," called a Nasmyth tube, on its way to the detectors. Twelve air bladders, also called air springs, are arranged symmetrically around the bar, and they absorb nearly all of the plane's vibrations, keeping the telescope's image relatively steady.

In addition, gyroscopes will help keep SOFIA's telescope pointed properly. They counter sudden gusts swirling from outside the 4-meter-wide opening into the telescope cavity (that's wide enough to drive an 18-wheel truck through). In flight, air flows along the airplane's side at more than 800 kilometers per hour. While observations in visible light will be somewhat blurred by this stream of air, infrared light, with its longer wavelengths, passes through essentially unscathed.

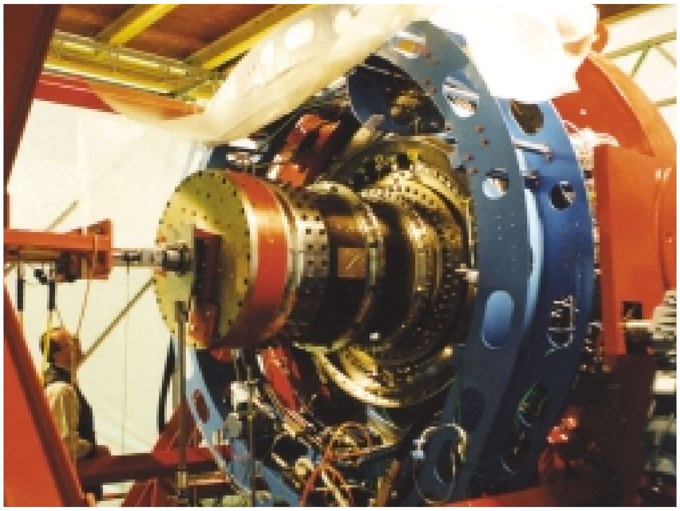
When the air stream reaches the telescope opening, it flows into the cavity, where it hits a small curved ramp near the top of the opening. The ramp deflects most of the air back outside. Indeed, wind tunnel tests show that turbulence in the airflow downstream from the opening is only slightly different from that of an unmodified airplane.

But some air does make it down to the telescope. It isn't a steady wind, however, but contains turbulence and gusts, which can continually nudge the telescope away from its intended target. If any or all of three gyroscopes attached to the telescope frame detect movement from one of these wind gusts, a computerized control system drives electromagnetic motors that nudge the telescope back in place. All of this happens automatically. According to Patrick Waddell, SOFIA Missions Operations Director, "Actions of the control system are essentially invisible to astronomers and the telescope operator."

The gyroscopes, along with the air bladders and the plane's heading, will provide SOFIA with unprecedented pointing accuracy. Imagine holding a laser pointer to illuminate a penny 16 kilometers away and not letting the beam waver from that penny. That's how steady SOFIA's pointing will be.

The Future of Airborne Astronomy

"I cannot wait for SOFIA to become operational," says Pendleton. "I never failed to get data from a KAO flight, and I am looking forward to an equally productive experience on SOFIA." When the modifications are completed, SOFIA will fly out of NASA's Ames Research Center in California's Silicon Valley. Three to four flights a week



Left: The SOFIA 747 (rear) rests in a Waco, Texas hangar along with a cut-up section of a "donor" 747 housing a full-scale dummy telescope. Courtesy of L3 Communications. Right: Technicians test the cabin side of the telescope's suspension assembly and Nasmyth tube. Courtesy of MAN-Technologies.

Among its many science targets, SOFIA will zoom into prolific star-forming regions such as the Orion Nebula, seen in this 2MASS infrared image. Courtesy of UMass/IPAC-Caltech/NASA/NSF.

are planned, each of which will spend 8 hours at altitudes of 12,500 to 13,700 meters, slightly higher than the cruising altitude of commercial jet airliners.

Astronomers plan to use SOFIA's telescope to further their understanding of how galaxies, stars, and planets form and evolve. SOFIA's high spatial resolution will enable astronomers to resolve and then study distinct features in star-forming regions that, until now, have appeared as indistinct blobs. Scientists will be able to map the gaseous outflows found around both young and old stars in greater detail, providing more clues about what happens as stars mature. Astronomers will be able to resolve features in the atmospheres of planets in our solar system. For example, they will be able to track seasonal movements of carbon dioxide and water vapor between polar ice caps and equatorial regions in Mars's atmosphere.

In addition, astronomers hope to use SOFIA to find distant galaxies, visible at long infrared wavelengths, which are thought to be in early stages of their evolution. SOFIA's high resolution will enable scientists to separate infrared emission in galactic nuclei from emission in the rest of a galaxy, giving them more information about the energetic processes occurring around supermassive black holes. Astronomers will be able to spatially resolve and investigate nearby merging galaxies and the bursts in star formation that typically ensue.

SOFIA's telescope and scientific instruments will also provide unprecedented spectral resolution, especially at longer infrared wavelengths. Astronomers hope to study the detailed chemistry of the interstellar medium, which emits most of its energy in the infrared. They will search for the presence of complex organic molecules and other atoms that are thought to be necessary for life and determine their distribution within giant molecular clouds and star-forming regions. Astronomers will look for clues about conditions in the early solar system and how life began on Earth by analyzing the composition of comets and asteroids that have remained unchanged since they formed billions of years ago.

Astronomers will fly on SOFIA, just as they did with the KAO. Conditions should be more comfortable, however, with more space and better noise and thermal insulation. Looking into the future, Becklin envisions an era when only a few technicians will actually fly on the plane. Astronomers will follow the flight and record data from the ground, either in a control room or in their offices. "This is not going to happen right away," says Becklin, "but it will in 10 years."

As SOFIA moves closer to its first science flight, one fact stands out: At roughly 20,000 kilograms, SOFIA's telescope alone weighs as much as the entire Lear Jet Observatory! How far airborne astronomy has come. ■

Former Mercury *editor SALLY STEPHENS is now a freelance science writer in San Francisco. Most recently, she has worked on a high-school science curriculum being developed by the SETI Institute and on material for the SOFIA website.*

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SIRTF: NASA's Next Great Observatory

by Michelle Thaller

Infrared astronomy is truly coming of age. Many of NASA's most important and ambitious upcoming missions, including SOFIA, the Next Generation Space Telescope, and Terrestrial Planet Finder, feature infrared telescopes, so the stage is being set for infrared science to play a leading role in the study of the universe for the coming decades.

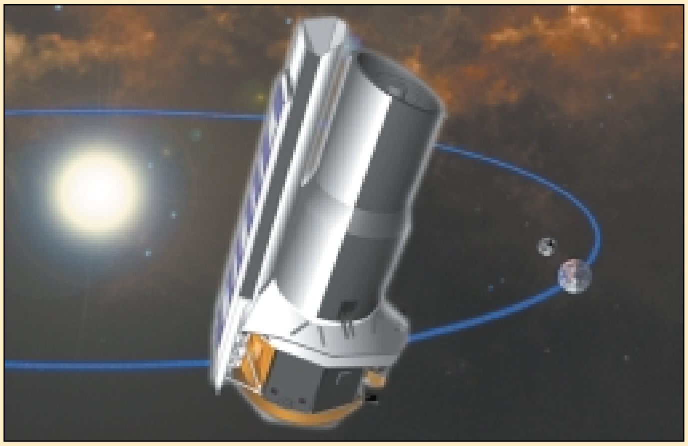
The next major infrared mission is the Space Infrared Telescope Facility (SIRTF), a cryogenic space telescope set to launch in early 2003. SIRTF was originally conceived to be the fourth and final installment of NASA's Great Observatories, a fleet of space telescopes designed to give astronomers a view of the universe across the entire electromagnetic spectrum. With the Compton Gamma-Ray Observatory having completed its mission, and with the other two Great Observatories (the Hubble Space Telescope and Chandra X-ray Observatory) still in place, SIRTF stands poised not just to round out the program, but also to connect that program solidly into NASA's new initiative, the search for humanity's cosmic origins.

In fact, the search for our origins best illustrates why infrared light has become such a popular wavelength region. While celestial bodies must have temperatures of around 10,000° C to radiate any significant amount of visible light, anything with a temperature above absolute zero emits infrared radiation. That includes a whole lot of stuff that has evaded thorough study, or even detection, up to this point.

In human terms, we tend to think of infrared light as heat radiation. With the example of infrared night-vision cameras in mind, it's easy to understand how astronomers hunt for extrasolar planets with infrared light. Just as infrared detectors can be used to find a warm person hiding in the dark, they can be used to image planets that emit no visible light of their own. Even around young stars where planets haven't fully formed, infrared light can be used to detect the warm disks of dust that will someday coalesce into planets. Other warm but dark objects include the still-mysterious brown dwarfs. Some brown dwarfs exist in extrasolar planetary systems, while still more seem to wander through space alone, kicked out of their star systems by gravitational interactions.

Infrared light is also a hot topic (or cool, depending on your temperature preference) when it comes to more exotic celestial specimens. Recent studies suggest that supermassive black holes lurk in the centers of most, if not all, large galaxies. Galactic cores, including our Milky Way, are obscured by vast clouds of dust and debris, making visible-light observations nearly impossible. Infrared light conveniently cuts through intervening material, allowing direct views of the warm, active regions close to the giant black holes. Infrared light's penetrating ability also allows astronomers to peer

SIRTF's orbit is similar to Earth's, but SIRTF will trail behind our planet. Courtesy of NASA/JPL/Caltech.



Lockheed Martin Space Systems (the main contractor) integrates the Cryogenic Telescope Assembly (built by Ball Aerospace and Technologies Corporation) with the rest of the spacecraft. Courtesy of Lockheed Martin.

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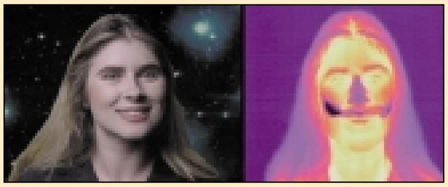
Technicians inspect SIRTF's infrared telescope, whose mirror is 0.8 meter in diameter. Courtesy of NASA/JPL/Caltech.

into the hearts of stellar nurseries, where they can bear witness to the early stages of star and planet formation. Turning to the outer reaches of the universe, infrared telescopes probe epochs when cosmic expansion has redshifted all of the light out of the visible range entirely. Astronomers will be able to probe the Dark Ages and find out how and when the very first stars turned on.

So, if the infrared universe has so many fascinating offerings, how come we haven't explored it in detail yet? The current age of infrared astronomy is being ushered in by an amazing leap in technology, largely fueled by the declassification of sensitive infrared detectors developed by the U.S. military. The last major infrared space telescope, the Infrared Astronomical Satellite (IRAS), gave astronomers a wonderful first glimpse of the infrared sky back in 1983 and serves as a great example of how technology has advanced in 20 years. IRAS was built before the era of large array cameras, and it had 60 separate infrared detectors covering the wavelength range of 8 to 120 microns. SIRTF, by comparison, will carry detector arrays with tens of thousands of pixels, enabling both imaging and spectroscopy over a 3 to 160 micron range.



Author Michelle Thaller appears in visible light (left) and in infrared light (right). Before the infrared image was taken, she rubbed an ice cube above her lips. The cold ice cube created the dark "mustache." Courtesy of Michelle Thaller.

The sensitivity of SIRTF's new infrared detectors is amazing. Have you ever turned your face up to the sky on a summer day and felt the warmth of the Sun on your skin? Now picture trying to feel the heat from distant stars and galaxies, and you have some idea what a telescope like SIRTF can do.

Another clever engineering trick was to discard the traditional thermos-bottle approach to infrared telescopes. Infrared telescopes must be cooled to within a few degrees above absolute zero, because astronomers are interested in heat from space, not from the telescope itself. In the past, space telescopes like IRAS and the more recent European Space Agency Infrared Space Observatory (ISO) solved the cooling problem by encasing the entire spacecraft in a liquid-helium refrigerator (called a cryostat). The liquid helium tanks added both mass and bulk, both of which make launch difficult and expensive. In SIRTF's case, the spacecraft has been designed to cool passively once it's exposed to the near-vacuum of space. Only the most sensitive instruments will be cooled with liquid helium, now reduced to a relatively tiny volume of 378 liters (which should last at least 2.5 years, possibly up to five). The reduced mass allows SIRTF to be launched on a relatively small Delta II booster, making the project even more economical.

With no liquid helium thermos, NASA must launch SIRTF beyond Earth orbit into a more distant, and therefore cooler, region of space. SIRTF will be launched with enough velocity to drift slowly but continually away from our warm planet. SIRTF will fall into a solar orbit similar to that of Earth, trailing behind at the rate of 0.1 astronomical unit (15 million kilometers) per year. This orbit will enable the telescope to operate more efficiently, with less of its view blocked by the bright Earth and Moon.

In the end, the most exciting things about SIRTF will be all the stuff we haven't even thought of yet. In an era of increasingly specific, scientifically focused space missions, SIRTF has a shot at serendipity. Astronomers have never seen the infrared sky in anything approaching the detail and sensitivity that SIRTF offers, and in some cases, we've never even had a chance to look at the universe in some of the wavelengths that SIRTF will cover. We will see things that we don't expect, and can't explain (at least not right away). And that's the best reason of all to welcome SIRTF's upcoming launch.

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Technicians at the Ball Aerospace and Technologies Corporation work on SIRTF's cryogenic tank. The tank is filled with liquid helium to keep critical components chilled to just a few degrees above absolute zero. Courtesy of Ball/NASA/JPL/Caltech.

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