SOFIA: Belle of the Infrared Sky

By Tom Vitron, former Media & Communications Coordinator at Lowell Observatory

Nearly half a century ago, Lowell scientists and facilities helped NASA send America's first intrepid astronauts to the Moon. Now, Lowell scientists are the intrepid NASA flyers, building and commissioning one of the first-light instruments for and flying aboard the Stratospheric Observatory For Infrared Astronomy (SOFIA), a modified Boeing 747SP which achieved "first light" in 2010. The torchbearer of airborne astronomy as the field enters its sixth decade, SOFIA is an 80/20 partnership between NASA and the German Aerospace Center (DLR). NASA Ames Research Center near San Jose, Calif. manages SOFIA's science and mission operations in cooperation with the Universities Space Research Association (USRA) and the German SOFIA Institute (DSI). Like Lowell, UCLA and Cornell University are also institutional partners who have built instruments for SOFIA's telescope.

On Monday, September 30, 2013, I had the chance to join three Lowell scientists – astronomer Ted Dunham, research scientist Georgi Mandushev, and software developer Peter Collins – on a SOFIA mission involving the Mars Hill-built High-speed Infrared Photometer for Occultation, or HIPO, to observe an exoplanet transit, the highlight among several scheduled research legs. For an aviation and astronomy geek like me, the opportunity to fly on a NASA mission, with Lowell scientists, to observe an exoplanet transit, was rare and surreal.

<u>Monday, 1 p.m. PDT, somewhere west of Victorville, CA</u>

For all its scenic beauty, seashore to mountaintop, California is blessed with some not-so-scenic deserts as well. The final showstopper on a long road trip through the Southwest, my journey to NASA's Dryden Aircraft Operations Facility at Palmdale Regional Airport (a.k.a. Plant 42) for a required 2:30 p.m. safety briefing prior to takeoff that night was right on schedule as I reached the sparse western edge of Victorville, less than an hour from my destination. Having missed a turn, I sought an alternative from my GPS, which quickly rerouted me with eerie precision. Though nothing like the Apple Maps debacle that sent lost Aussies to a remote countryside park, my nerves got a bit frayed and palms a bit sweaty when I uncovered that the GPS satellites (which depend on precise star locations) are far more precise than the maps we have of Earth, it would seem. Staring at miles of slightly duned sand but no actual road, I calmly recalculated my route.

That summoned calm was short lived as I realized that the flame-retardant, NOMEX-like cotton pants I intended to wear on SOFIA were still at home. With my desolate detour and a shopping stop now required, it left no time to idle. Not certain how much time I'd have between safety training and the mission briefing, I managed to breathe a sigh of relief and safely arrive with 10 minutes to spare, complete with way too much bottled caffeine and a new pair of robust cotton pajama pants that, when paired with a thermal top, would guarantee that I looked like I was readying to go to bed aboard the well-

traveled jet/research vehicle, not shadow elite astronomers as they do cutting-edge astrophysical work in the stratosphere. Then I remembered how a lot of astronomers I admire and respect dress and wondered if anyone would even notice the Yankee-like pinstripes on my new pants, the only suitable pair I could find. For now, still in casual daytime wear, I entered the facility, quickly releasing the tension and stress of the car trip, replacing it with a giddy, childlike attitude fueled by my indomitable passion for all things aviation.

Monday, 2:20 p.m. PDT, Main Hangar and Tarmac

After a brief stint in the security building to get my badge, I met my escort for the afternoon and overnight flight, SOFIA public information officer Beth Hagenauer. As we left the trailer-like office for the vast hangars behind, the looming political subtext of a likely government shutdown the next day was evident in what work was being done and the overall somber mood among the ever-professional NASA and U.S. Air Force (AF) folk. Having eased through security quickly, with the rush of arriving being replaced with the rush of being here, it left time for Beth to give this airplane nut a daylight tour of the place.

The main hangar is home to SOFIA (though it was outside being prepped on this day), an accompanying display about the aircraft and the history of airborne astronomy, a DC-8 Airborne Science Laboratory used to study the Earth's surface and atmosphere, a C-20A (a.k.a. Gulfstream III) used to test a new type of radar and for earthquake prediction work, and two ER-2s (or U2s), former spy planes turned into polyvalent high-altitude research platforms. The questions I could ask about other missions and craft were limited, while pictures of other craft were strictly prohibited. Throughout the hangar, the importance of and focus on safety becomes very evident. Aside from an impressive array of fire and biohazard suppression systems, basic worker safety is held to the highest federal standards, with well-marked safe pathways and danger zones, as well as ear-plug dispensers at every turn. Not knowing what might await when noisy craft were about, I grabbed a pair.

As we walked out and around another hangar, heading towards SOFIA as it fueled up on Jet A and liquid helium coolant, a doppelganger of sorts caused me a moment of confusion: on adjacent ramps sat a 747 for today's NASA and one from its recent storied past. Many who love astronomy also love aviation, and for obvious reasons: love of the sky, of modern aeronautical and aerospace technology, and a love for looking at our world (and others) from a different vantage point. However, aside from GPS and early pioneering pilots like St. Exupery who relied on stars for navigating night skies when need be, aviation and astronomy only seem to truly intersect occasionally. When the two engineering endeavors do pair up, however, the results are groundbreaking.

For the post-Apollo generation, the Space Shuttle program embodied the boldness of space exploration, of astronomy with its satellite deployment and repair role, and of aviation with the Shuttles' ability to re-enter the atmosphere, "glide" and be piloted to a

smooth landing by trained experts. But for observant aficionados like myself, we also loved the two Space Shuttle Carrier Aircraft (SCAs) – the modified 747-100s that transported the Shuttles from coast to coast as cargo atop its fuselage when factors conspired to force one to land at Edwards AFB, CA, or even at White Sands, NM; the still-airworthy SCA showed off and delivered the Shuttles to their final resting places during the past couple of years. I always embraced and read up on commercial aircraft since I knew I might get to fly on them. The SCA made the Shuttle more real to me and gave it scale since I've been lucky enough to occasionally fly 747s, the original double decker, pre-Airbus A380.

And now, rather than being locked up in a desert retirement home and being parted out, one of the SCAs lives at Plant 42… in the desert …being parted out to SOFIA! A sad and melancholic demise if you want, though I prefer seeing this as a happily retired organ donor assisting a fellow 747. It makes perfect sense but I hadn't expected to see the legendary porter here. I don't often truly "geek out" like a curious 5th grader anymore but expected I might on this trip. I didn't expect it would happen continuously from that point on, looking at a 747 that has seen better days, still hours from our flight to collect data from distant worlds in a 747 that is still in its prime.

Monday, 2:30 p.m. PDT, safety briefing

On the long inside edges of the main hangar are offices, conference rooms, workshops, and storage areas. After throttling back my excited geekdom a bit, Beth and I went to one of the offices where safety gear is stored and maintained for Plant 42 aircraft. A member of the dedicated flight safety team at the facility carefully walked me through a list of precautions, event scenarios, and also demonstrated and had me try myriad safety devices, including oxygen supplies and fire/smoke protection. While in flight, all passengers must carry a pouch around their necks that contains a basic mask in case the cabin fills with smoke. Critical personnel also have traditional oxygen masks and canisters, with other supplies positioned around the aircraft. With so much electronic circuitry producing heat all over the aircraft, fire risk is very apparent once aboard.

Among the safety procedures passengers are briefed about are escape options: two ramp slides, exiting through the landing gear hatch, and the daunting leap to safety that five people can make from the cockpit using handles attached to repelling wires; a safety video shows a brave soul making the leap of faith and after recoil, being lowered to the ground by the wire. The wires are not standard but were apparently added by Pan Am during the rash of hijackings in the 1980s and left in place by subsequent owners. Perhaps most extreme is the potential need to crack one of SOFIA's main doors open to evacuate smoke or even fire. The lead safety officer explains how the door can be tethered to the interior fuselage, creating an opening no bigger than 18 inches for air to rush out. Such a procedure would cause depressurization, another main focus of the safety protocol, as the risk is not insignificant; if the bulkhead's seal between the telescope nacelle and the cabin were to fail, pressure would drop quickly. As such, mission directors ask safety officers for many seal checks during flight.

My head now filled with every envisioned safety eventuality after being a quick study, Beth and I both headed out for rest prior to returning for the preflight mission briefing and the flight. Though I had a couple of hours to lay down in my hotel, thoughts of spooling engines, chasing distant objects at nearly Mach .9 (685 mph), and finally getting to fly with Ted sped around my head…

Monday, 7:00 p.m. PDT, preflight mission briefing

Now in the cover of dark, wearing my pinstripes and carrying a backpack full of supplies, I returned to Dryden with a feeling of unbridled excitement for the impending opportunity and pride for the amazing work Lowell does on this project. Once in the briefing room, I sensed the professionalism and boundary-pushing wonder that imbues SOFIA and all participants. That evening's mission was what is called a FLIPO flight, where UCLA's First Light Infrared Test Experiment Camera, or FLITECAM (FC), is coupled with HIPO. After meeting the UCLA team, led by Dr. Ian McLean, as well as involved USRA, NASA and AF personnel, I also met the German contingent: two technicians from DSI and a researcher from Rensselaer Polytechnic Institute who submitted the proposal to observe the exoplanet transit at the heart of the mission.

A nervous, excited tension permeated the erudite atmosphere, especially when I surprised Peter with my presence as he was not aware I would be flying that night. Though Lowell folk know Peter's legendary astronomical stamina, even he was a bit worse for the wear, having tossed and turned the previous night trying to figure out how to fix a HIPO bug that had just cropped up. The bug was fixed and takeoff approached so all was fine in Peter's world at that moment. The incident exemplifies how each flight is the end of a great deal of pre-flight choreography on the ground, with much constant communications and a variety of meetings between scientists, NASA staff, the mission directors (MDs), and the pilots. Plant 42 has a testing facility for the instruments, where the nine specially made instruments for SOFIA's 2.5-meter telescope are calibrated, debugged, and otherwise run through their paces so little valuable "airtime" is lost to a malfunction or worse, a non-functioning component or entire instrument.

With 31 passengers on the evening's manifest, this was one of the largest contingents ever aboard a SOFIA mission. Included were four from Lowell (including myself), Beth, four UCLA and five USRA scientists, two German technicians, the German researcher, a real-time flight data cruncher affectionately referred to as SOFIA's "data monkey", the MD, the assistant MD, two telescope operators (TOs), an assistant TO, three flight safety officers (FSOs), three pilots, a flight engineer, and a navigator. Shortened 90 minutes so FC could be assured of keeping cool despite an issue with its helium system's vacuum and seal, mission #134's flight plan called for several short and a few longer legs, entirely over North America in less than 9 hours. Because the key component was a transit, very precise timing would be required. Ahead of schedule, we headed for our ride, a "starship" unlike any other.

Monday, 8:00 p.m. PDT, preflight aboard SOFIA

During my daytime visit, SOFIA had looked mostly just like an especially short 747, save the telescope nacelle's bulge on the rear port side of the fuselage. At night, with the anticipation palpable, game plans reviewed, walking across the tarmac towards SOFIA – now lit from several sides and looking much more mighty – felt a tiny bit akin to what astronauts must feel as they step across the gantry for their rocket ride to space. On this late summer's eve, a gentle, dry breeze swept over the 31 "stratonauts" as they climbed up into the winged research platform for a night flight across much of the continent, from the Southwest to the central plains of Canada and the upper Midwest and back (see flight path).

Before settling into my seat in SOFIA's education/public outreach (EPO) section, next to the data monkey and in front of another flight data console (see figure), the MD and an FSO went through final safety checks with the group inside the aircraft. The "emergency procedure of the day" was the aforementioned fire/smoke suppression technique of strapping a cabin door ajar, a near-daredevil move by trained professionals that is a sobering reminder that SOFIA and its dangers are unique, as it is a highly modified version of an albeit well-understood type of aircraft.

As NASA ground technicians finished filling FC's liquid helium dewar immediately before the cabin doors closed for maximum retention, I noticed much that reminds of the Pan Am 747 "Clipper Lindbergh" it once was but also much that doesn't. With temperature and accessibility to equipment as critical in SOFIA as it is at ground-based observatories, not every inside section of the craft has full paneling and insulation. Much of the wiring and circuitry lives in lockers in the port side of the ground floor's first class section, for safety, accessibility and weight balance considerations. The restroom has no water, only a chemical flush and hand sanitizer, cutting the need for another system aboard. Lacking many of the comforts of a modern jumbo jet, a SOFIA research mission does deliver plenty of in-flight excitement and entertainment for geeks, and all are glad this business trip is full of important acronyms, but not TSA or even much FAA!

With the telescope's spotlit back end and FLIPO as a framing backdrop, the sheer mass of computers – no fewer than 20 built-in and laptops – in the mission control and science operations area of the craft's main cabin is a bright sight once everyone is set up. Two mascots live in the area today, the HIPO hippo and a knit data monkey, in honor of the human version. The FSOs occupy remaining seats next to circuit lockers in first class, always listening to comms on headsets even if resting. The flight crew was mostly alone upstairs, joined by an occasional napper looking for a quieter place to rest in business class, and a guest in the cockpit for takeoff (the German researcher) and one for landing (yours truly).

Seated with my back to SOFIA's nose, it was only the second time I've ever taken off facing backwards, a somewhat odd experience that is a slanted and speedier version of sitting as such in a fast train. With an over-the-shoulder harness buckle, it only adds to

the feeling of being strapped in for an important mission. The need for headsets (and ear plugs for bathroom visits) became clear once the engines spooled up for taxiing. After setting comms for optimal listening in and minimum interference by Beth and me, I gave the MD a "go" from our station. Just as we were to taxi for the final piece of SOFIA's pre-flight choreography – a calculated 20:57:41 p.m. PST takeoff on runway 25 (to the west/southwest) in light winds and 12 percent humidity, mere moments before the federal government did indeed shut down at midnight EST– the FC operator reported problems getting it back online after the helium fill. With plenty of time to spare and finish troubleshooting FC, the MD gave the pilot the OK for taxi. While at the taxi hold point, a possible fiber issue was thwarted by Ted as he had spares aboard. A few minutes early at 8:54 p.m. with FC back online, SOFIA lined up on one of the airfield's two massive 12,000-foot runways, followed by an 8:55 p.m. takeoff into smooth, clear skies, ideal for infrared observing.

Monday, 9:00 p.m. PDT, takeoff and first legs

Facing the rest of the main cabin as the craft climbed out gave me a quiet moment to reflect on what I saw. SOFIA is land based but certainly isn't like your average observing run on Earth. I imagined SOFIA as being like to taking a modern Perkins Telescope and cramming it into an airplane. Modern control rooms are complex enough as it is; now, imagine being tasked with designing and constructing a control room inside a former jetliner, where space, power, temperature, and fire danger play larger, more important roles than at terrestrial facilities, and that's notwithstanding the telescope's nacelle, an independently pressurized, stabilized portion of the cabin where the German-built reflector lives! Like a hybrid of the U2 variants and the DC-8 airborne laboratory at Plant 42, SOFIA is a type of spy plane and lab, only it exclusively looks up at the night sky, not the Earth below. It has none of the deep secrecy of a spy plane, but you never lose sense that you're in a one-of-a-kind research setting, wielding a set of singularly exceptional instruments designed to fill a need in astronomy that stratospheric aviation can fill.

The aeronautical and astronomical intermingling is so complex that it takes a set of genius devotees to build and operate such a wonder and to consider every parameter, variable, and situation that can affect SOFIA's ability to conduct observations at up to 45,000 feet in altitude, at up to Mach .9, while the telescope nacelle does its best to compensate for any turbulence, keeping the telescope as steady as possible; this can lead to the eerie sight of a steady nacelle managing mild turbulence on a couple occasions while the rest of the aircraft gets a little atmospheric jostle. Few bumps met us as we headed up to 35,000 feet, on our way to 39,000 feet, the bottom edge of the stratosphere on this evening, then later climbing to more than 43,000 feet.

After raising the cabin temperature a bit to deal with an oil temperature issue, the pilots switched off the seatbelt sign at 19,600 feet, turning the cabin into a beehive of action. After progressively gaining altitude, the telescope compartment's door opened seamlessly, not giving us any sense that a gaping but aerodynamic cavity was now open on the rear port fuselage. Standing nearest the telescope and in the glow of their monitors,

the Lowell team chatted with the UCLA team about water vapor, referencing a flight from the previous Thursday. Keen ears could occasionally hear Ted, HIPO's principal investigator (PI), muttering "ni ni ni" as he waited for a calculation from his laptop. The TOs and German technicians worked on calibrating the telescope using its Focal Plane Imager's (FPI) centroid tracking, getting ready for the target exoplanet to transit past the 8.3 magnitude star it orbits. As the data monkey began typing notes and keeping a detailed handwritten log (he usually completes his data reports "on the fly" by landing time), the telescope slewed for the first time during this mission, giving me my first look at the back end in motion; it can slew at least a little in all directions, but especially declination, obviously relying greatly on precise aircraft positioning for right ascension and overall pointing accuracy. With an egg timer set during each leg, Ted showed the UCLA team they had only eight minutes left to get their flats done, which they did mere moments prior to the start of the transit leg.

Monday, 10:00 p.m. PDT, chasing an exoplanet transit

The beehive's activity slowed but gained intensity as it became a situation room, everyone in their right place for show time, or so they hoped. As final equipment and software checks begin, Ted reminded all that shaving 90 minutes off the start of the mission, prior to the transit leg, would have instrument repercussions as the telescope did not have time to fully adjust to the -20C (-4F) air temperature at 39,000 feet. "It's a deal with the devil staring the transit leg so early," he said.

However, the first issue to arise was not related to the telescope's temperature or FC's helium retention. The FPI – one of SOFIA's three acquisition/guider/tracking cameras – required a circuit reset and reboot from the DSI instrument scientists. With an FSO or two close by at all times, they reset the FPI circuits then headed to the opposite end of the cabin, passing by a the tense gaggle of researchers before entering the restricted instrument area at the telescope's back end. Slipping past FLIPO, the taller DSI representative carefully reached to a lone computer rack attached to the back end, successfully rebooting the FPI.

With instrument issues, both old and new, a suggestion was made to use a HIPO imager, eliciting raised eyebrows and an immediate "no" from Ted. When asked about using HIPO guiding, an even bigger headshake. "HIPO guiding is not ready. We just started working on it," he told me later. When not staring at the live data streams on the console ahead of me, I would make myself a fly on the wall near the scientists, standing close by but out of the way by stretching my headset's cable along the ground 10 to 12 feet. The first time I punched my standing-room-only ticket, extreme troubleshooting began among the scientists. FC's functioning systems showed signs of struggling, leading to an investigative powwow and diagnosis. "It turns out that FC had additional electronic problems we weren't aware of during the flight that are now fixed," Ted told me after returning to Arizona.

Meanwhile, the DSI guys met with the assistant TO to figure out what could be done to keep the FPI working. But the circuit broke again and was left so since safety protocols do not allow a specific breaker to be reset more than once per flight because of the risk of an electrical fire. This, not my pinstriped PJs, would turn out to be the notable glitch on this NASA mission. (FPI is now working properly again.) Using another of the telescope's guider cameras, the Fine Field Imager (FFI), and a resilient FC, transit data collection began after turning to plan B. By mid-transit, the FC operator at that moment reported it was doing much better. After the nearly three-hour leg, it was time for in-flight midnight lunches and more forms of caffeine for those of us intending to stay awake for the rest of our nocturnal observing odyssey. Issues be damned, this was a mission after all.

Tuesday, October 1, 1 a.m. PDT, midnight lunch aboard a nighttime magic carpet ride

Keeping the blood sugar up is also critical as every second of a SOFIA journey is precious. Still learning what every telescope data readout in front of me meant (see diagram), I realized my meal resembled a hiker's snacks – granola, trail mix, and jerky – except for the obscene amount of Coca-Cola. In the slight daze before the energy boost kicked in, being clothed for bed and eating mostly like a long-distance trekker that barely needed to move a muscle on this journey was starting to make far too much sense. Other foods, from couscous salad to sub sandwiches to sweets and chocolates, were shared and enjoyed in the main cabin, which was notably more relaxed now.

Making his first foray up from his seat and five diligent hours of work, Peter crouched down to peer out a window near my seat. Like me, he enjoys the thought of SOFIA missions as nocturnal "magic carpet rides" over vast parts of Earth. Night flight is special in many ways anyhow. It is mostly reserved for a certain class of flights: short-haul commercial until about midnight, domestic and international red-eyes (of course), charters, cargo, military, and first responders. Over water, night flight remains somewhat foreboding, even in the 21st century. Over land, above the modern world, night flight in smooth air gives passengers a captivating look at the electrical grid (and just how many places are now bereft with wasted watts and polluting lumens).

On this night, rather than flying towards Polynesia or the Aleutian islands, flight #134 took us towards but not quite to Hudson Bay, Canada. Starting in the outskirts of America's second largest urban area and flying to Manitoba gave us a chance to spy on hamlets large and small, but mostly small. SOFIA has windows along one side of its "first class" seats in the front and in half the upper deck, as well as about 10 between the main door and mission control. Each of these windows is at seat level so scientists aboard grab onto the sturdy handrail that hangs from the side panels in the cabin and squat down to see what, if any, signs of life exist below at that moment. On this clear night, visibility is as sublimely clear and potentially fascinating below as above for me.

A few joked about fleeing American political gridlock and seeking asylum for the aircraft north of the border for a time. The occasional sign of life from below, as delivered by

Canadian air traffic control (ATC), could have not been better timed or more a propos. "Are you that flying observatory?," a controller asked the pilot, as relayed to us by the MD. Hopefully this asylum-seeking vessel had made a good impression, and that unlimited funding and a warm hangar awaited nearby (maybe in British Columbia?). Alas, all jokes by the American passengers were in good fun but were a way for scientists tense about the present and future of federal research funding to let off a bit of steam playfully. (Beth later informed me that the program lost some science flights during the shutdown. However, SOFIA was back in the air in November as part of the astronomical armada deployed or tasked to study the fascinating, sungrazing but, ultimately, not amazing and more than a bit teasing, Comet ISON.)

Tuesday, 2 a.m. PDT, an interview with Ted somewhere near Winnipeg

Up to this point in the flight, Ted et al. and HIPO had taken a back seat to the transit observations, but they never stopped gathering data and troubleshooting if need be as the aircraft and its instruments are still in their commissioning phase. The last science leg of this flight was all about HIPO. About an hour prior to this leg, observing and calibrating continued with occasional rewinds when the telescope was re-centered; the first light curves emerged from the exoplanet transit observing; frustration about FC's performance percolated among the UCLA/USRA folk; and Ted afforded me a few minutes for a brief interview. The chance to fly with Ted on SOFIA was something I had imagined for a long time, ever since I saw the first mockup once the 747 platform was chosen for the project. When he sat next to me, I was quite struck by the reality that this was finally happening.

Ted is one of the grizzled veterans of airborne astronomy at this stage in his illustrious career, having forged much of his early career in the belly of the Kuiper Airborne Observatory (KAO), the converted C-141A cargo plane fitted with a .95m telescope that was SOFIA's predecessor. (Ted worked aboard KAO as part of the team of ground-based and airborne observers that discovered the rings of Uranus in 1977.) Whenever a question came up, about the telescope and its myriad instruments, Ted's wise and cogent comments and suggestions were met with attentive ears and a solar mass of respect by all aboard; on this mission, he very proffered the solution that was subsequently implemented on several occasions. "It is really great to work with the Lowell/HIPO team," UCLA's Dr. McLean said by e-mail after the flight. "Ted is the de-facto PI for all the FLIPO flights and he is very knowledgeable about airborne astronomy and always very helpful with every aspect of the observing and testing that we plan. Ted frequently spots potential issues early so that we can avoid them in flight."

Few understand the SOFIA project like Ted and, yet, he is the first to remind that airborne observing is a continuous learning experience, especially on a collaborative research platform still in its relative scientific infancy (but by no means brand new.) "Everything we do on SOFIA is a team effort," said Ted after I noted his close involvement with the transit leg though HIPO was not being used at the time. "We've never tried this type of occultation with FC before so this is a milestone and will be good

for data correction." On the instrument and circuit reboots, Ted noted that a computer crash has caused a mission abort in the past. The 90-minutes trimmed off the beginning – this mission's compromise to help FC be at its best for the transit leg – meant that the telescope was too warm. "It experienced ambient thermal shock," he explained. "In the exoplanet transit leg, thermal instability was a big problem. That's the result of trying to save helium [in FC]." He noted that among the features and instruments that remain to be added to SOFIA is a pre-cooling cart to assist the telescope with temperature acclimation.

On the issue that had kept Peter awake, Ted explained that he had been able to fix a limit switch on HIPO's lenses manually after looking through old notes, exemplifying the importance of both taking meticulous notes and having them at the ready, just in case. "I'm an occultation man and you can't have problems at the wrong time [with very short-lived transient celestial events]," he said. "You need all your knowledge and to have fallbacks, like when we had to use the FFI instead of the FPI camera today." Now far down its path to full commissioning, SOFIA's capabilities are solidifying for planned 2014 flights, he added. "We have to keep in mind that SOFIA is already getting a bit old, in part due to a prolonged development period," he said. "At the same time, we also have to keep in mind that even in mature observatories, things break." My interview complete for now, the time for Ted to learn more about HIPO on this mission fast approached.

Tuesday, 3 a.m. PDT, on our last legs (figuratively, for most)

From the Black Hills to the Grand Canyon's North Rim, as other researchers aboard for the transit either reduced data or relaxed, Ted conducted a HIPO test of aperture photometry. "Scattered light is a big issue," he said. "We worked it on KAO as well." Measuring parts per thousand, the Lowell team looked for air density fluctuations by having SOFIA go through a series of minor but potentially consequential changes in altitude and velocity. Ted, by way of the MD, had the pilots climb and descend the aircraft from our current altitude of 43,000 feet by increments of 500 to 1500 feet. He also asked the pilots to speed up and slow down the jumbo jet from Mach .85 to Mach .87 and back, and then slow down to Mach .83 and back up to Mach .85. These are relatively subtle fluctuations in flight characteristics but they take skilled pilots a few minutes to execute while keeping the aircraft as stable as possible. For HIPO and its extreme level of sensitivity, fluctuations like these, occurring near or at the bottom edge of the stratosphere, can have a profound effect on the instrument's performance. "Little things can cause trouble," he said. "Ozone is a problem because it absorbs tons of yellow and red." Having been bucked by heavy turbulence strong enough to send the telescope into local mode when he first tried this test in January 2013, only a bit of excess comm chatter from researchers now done for the night got in the way and just for a moment. "The flight crew did an outstanding job of flying the test points and the atmosphere was also agreeably stable during the test," he said later.

This test might not have the sizzle of an exoplanet transit but the mundane must precede the captivating if every part of SOFIA is to deliver maximum scientific output. But without regular doses of sizzle for taxpayers and politicians, the government shutdown

reminded us all of just how precarious a position unique research projects like SOFIA currently find themselves in as austerity measures continue worldwide.

SOFIA's value has been questioned at times, since leaner economic times have put funding for such projects in greater jeopardy than at any time since the Cold War ended. No one, however, can question its capability. By flying above nearly if not all water vapor, and by being able to track or "chase" events like occultations, SOFIA and its instruments can get spectra of planets and other objects in a way only already oversubscribed, overburdened (and stationary) space telescopes can. Combine those two attributes – the ability to fly above the water-laden troposphere and chase the track of events as they can be seen from Earth – and you have a unique tool whose output cannot be mimicked by any one Earth-based or orbiting astronomical asset.

Tuesday, 5 a.m. PDT, coming back down to Earth

By now, the plane's partial insulation became clear, with the cabin temperature distinctly cooler even though it had been raised early in the flight, leading most to reach for another layer around this time. After an equally silent and seamless closing of the telescope compartment door, confirmed by the console display, I made my way to the upper deck and the jump seat in the very back of the cockpit. I had a poster of a 747 cockpit on my wall for a time as a kid so, yes, this opportunity made me giddy inside. With military clearance to do so, we flew over Fort Irwin National Training Center near Barstow, making our early morning approach to the lightly trafficked airport nearly a straight shot. The simple approach gave me a chance to focus on SOFIA's new cockpit instruments, finally installed after some delay. The number of flap settings is mind-boggling but nothing like engineer's panels. Even to my somewhat initiated eye, it looked much like the sort of fake panels you might see in a sci-fi B movie, full of dials and gauges. The only gauges I could identify with certainty were related to engine temperatures and engine cooling, which continues for at least a few minutes on the ground after a long flight. Lest we forget that the 747 itself is an engineering marvel!

On final approach, I shook my head when ATC handed the pilot off to Palmdale, which at that moment meant getting on the airport's universal radio frequency (Unicom), announcing our intention to land and asking if there was any other traffic in the area. Was it just a mere inconvenience stemming from a 6 a.m. landing or had federal furloughs kept controllers off the job? SOFIA had received permission to extend this mission past the shutdown at midnight Tuesday EST, should it occur. The lack of a controller also meant the pilots had to turn on the runway and taxiway lights themselves, also by radio. Like a light that turns green once you come to a full stop, we did not hear a controller until we were taxiing back to Plant 42, long after it would have been nice for the pilots to not have to be their own control tower on approach after a long night flight.

Tuesday, 6 a.m. PDT, dawn in the desert

Having missed the group pictures in front of the telescope's back end after landing, I took a few myself before parting ways with the Lowell guys. On our walk back to the security

office, Beth mulled what to do with all the free time she now had as we ran into others faced with the same uncertain dilemma. As dawn broke, my tired mind began pondering all that I had just experienced – flying a NASA mission with Lowell researchers – but first had to focus on the short drive to my hotel. Back in my room, I shed my work pajamas, washed the soda out of my pores, changed into my actual pajamas and began several hours of exhausted but ecstatic rest, my mind and body jetlagged not from arriving on the opposite side of the planet but from an overnight Palmdale-to-Palmdale business trip.

As I slowly eased into daytime sleep, I flashed back on a most singular scientific evening in my life, with the lingering echoes of the aircraft's white noise still ringing in my ears. My last conscious thought that morning involved revisiting and adding to the old aviation adage that if build a mile of road, you can go a mile but if you build a mile of runway, you can cross an ocean or a continent. Now, build two miles of runway and you can not only cross multiple continents, you can conquer the clouds and more closely and clearly commune with the cosmos for an evening, capturing photons from distant objects for further inspection and insights into the mysteries of space. Stratonauts might not travel as far as astronauts do for their NASA missions but their vision goes far beyond the Solar System, thanks to the bold and ingenious research platform that is SOFIA.

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