National Aeronautics and Space Administration

Cosmic Origins Newsletter

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Spring 2017 Cosmic Origins Program Update

Mansoor Ahmed, COR *Program Manager*
Susan Neff, COR *Program Chief Scientist*

Welcome to the March 2017 Cosmic Origins (COR) newsletter. In this issue, we provide updates on several activities relevant to COR Program objectives. Although some of these activities are not under the direct purview of the program, they are relevant to COR goals; therefore we try to keep you informed about their progress.

The **article by Paul Hertz** (Director, NASA Astrophysics) provides an overview of the state of the NASA Astrophysics Division, and an introduction to new leadership of the NASA Science Mission Directorate. Dr. Hertz kicked off four large mission concept studies in the spring of 2016, in preparation for the 2020 Decadal Survey of Astronomy and Astrophysics. Two of these studies, one for a Large UV-Optical-near IR mission (LUVOIR) and one for a far-Infrared mission (Origins Space Telescope, OST), are primarily focused on the COR science objectives. The Science and Technology Definition Teams (STDTs) for these studies have made great progress in the past year, with initial versions of key science drivers, architecture concepts, technology gaps, and instrument requirements. Articles by the Community Chairs of the **LUVOIR** and **OST** teams summarize team accomplishments, status, and plans. More information on the studies may be found at the **LUVOIR** and the **OST** study websites.

Also in spring 2016, the three Astrophysics Program Analysis Groups (PAGs) recommended that the Astrophysics Division sponsor several studies of possible Astrophysics Probe mission concepts, in advance of the Decadal Survey, to determine if such missions would be scientifically and technically feasible. A call for such studies was issued by the Astrophysics Division, with proposals due in November 2016. Twenty-seven proposals were submitted. Selections are expected in March and will be shared on the **COR News email** when released.

The *James Webb Space Telescope* (*JWST*) is not formally part of the COR program, but much of the science that *JWST* will address COR science. The observatory continues towards its planned launch in 2018 on time and on budget. The first community call

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for science observations was announced in January for Directors Discretionary Early Release Observations. Proposals are due in August 2017, and are expected to provide public data that will allow the scientific community to start learning how to work with *JWST* data. More proposal deadlines are expected to follow in 2018. We provide a quick **status of *JWST***.

WFIRST is managed by the Exoplanet Exploration office, but its science and capabilities are of great interest for COR science. WFIRST is currently in Phase A, and the project is working towards Systems Requirements Review and Mission Definition Review in July 2017. We provide a quick look at **WFIRST progress.**

Spitzer recently was fundamental in the discovery of seven (!) exoplanets around a nearbly ultra-cool dwarf star, and continues to obtain data that will help optimize the science programs for *JWST* and WFIRST. **SOFIA** continues to operate well; it has started its fifth cycle of observations, commissioned a new instrument, and selected a third-generation instrument for development. *Hubble Space Telescope* continues to obtain breathtaking images and fundamental spectroscopic measurements of our Universe. A few (of many) science results from these missions are scattered through the newsletter.

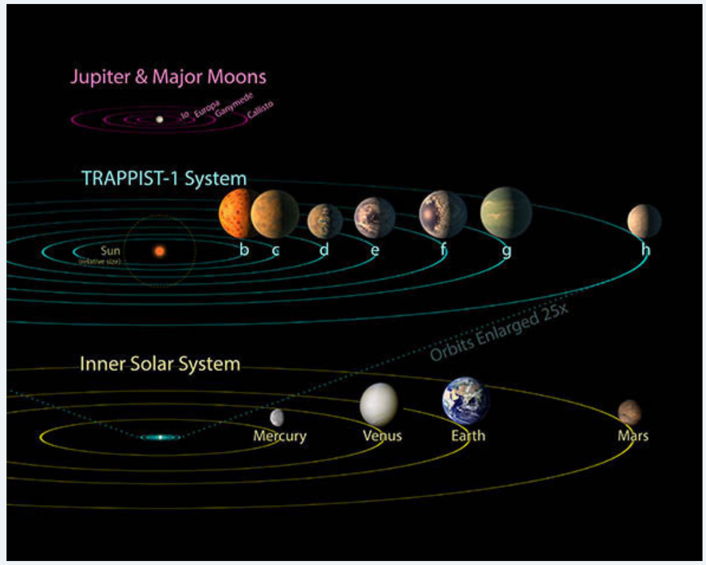
Technology development is a crucial part of planning for future missions, large or small, and a key part of the COR Program is managing technology development needed for future COR discoveries. We provide an article about the **Technology Needs** for future COR strategic missions, such as those being studied by the LUVOIR and OST teams, and a short article about the **Nancy Roman Technology program**, designed to support early-career technology developers. We also introduce **Hubble fellow Sarah Sadavoy**, who studies the earliest stages of star formation in molecular clouds; she is one of the young researchers who is likely to use missions enabled by this new technology.

The COR program, like all of NASA's science, relies on community participation in all areas of the program. For the COR program, the primary conduit for community involvement is the Cosmic Origins Program Analysis Group (COPAG), and its Science Analysis Groups and Science or Technology Interest Groups. The **article by Paul Scowen**, COPAG chair, summarizes recent and planned activities of the COPAG. Note that all interested parties are welcome to join the COPAG or its various working groups—please become involved if you are not already.

Spitzer Reveals Largest Batch of Earth-Size, Habitable-Zone Planets Around Single Star

NASA's *Spitzer Space Telescope* has revealed the first known system of seven Earth-size planets around a single star. Three of these planets are firmly located in the habitable zone, the area around the parent star where a rocky planet is most likely to have liquid water. All seven planets could have liquid water—key to life as we know it—under the right atmospheric conditions, but the chances are highest with the three in the habitable zone.

This exoplanet system, TRAPPIST-1 (named for The Transiting Planets and Planetesimals Small Telescope, in Chile) was found in 2016 to have three planets. *Spitzer* observations, assisted by several ground-based telescopes, confirmed the existence of two of these planets and discovered five more planets. *Spitzer* data indicates that all of the TRAPPIST-1 planets are likely to be rocky. Further observations will help determine whether they are rich in water, and may reveal whether any could have liquid water on their surfaces. *Spitzer* is uniquely positioned in its orbit to observe enough crossings—transits—of the planets in front of the host star to reveal the complex architecture of the system.



All seven planets in orbit about TRAPPIST-1 could easily fit inside the orbit of Mercury, the innermost planet of our solar system, with room to spare. TRAPPIST-1 is an ultra-cool dwarf star and its planets orbit very close to it. Since the star TRAPPIST-1 is only a fraction of the size of our Sun, the TRAPPIST-1 system's proportions look more like Jupiter's moons than like our solar system. The planets are all Earth-sized and terrestrial (rocky). Image Credit: NASA / Jet Propulsion Laboratory.

"The seven wonders of TRAPPIST-1 are the first Earth-size planets that have been found orbiting this kind of star," said Michael Gillon, lead investigator of the TRAPPIST exoplanet survey at the University of Liege, Belgium. In contrast to our sun, the TRAPPIST-1 star—classified as an ultra-cool dwarf—is so cool that liquid water could survive on planets orbiting very close to it, closer than is possible on planets in our solar system. Ultra-cool dwarf stars make up about 15% of stellar objects in the Solar neighborhood, and are predicted (in some planetary system formation models) to have significant populations of Earth-mass planets. Discoveries of similar planetary systems around more of these small stars are likely to revise our understanding of star and planetary system formation.

All seven of the TRAPPIST-1 planetary orbits are closer to their host star than Mercury is to our sun. The planets also are very close to each other, so a person standing on one of the planets could potentially see geological features or clouds of neighboring worlds, which would sometimes appear larger than the moon in Earth's sky. The planets are likely to have weather patterns totally unlike those on Earth, such as strong winds blowing from the day side to the night side, and extreme temperature changes.

"*Spitzer* will follow up in the fall to further refine our understanding of these planets so that the *James Webb Space Telescope* can follow up," said Sean Carey, manager of NASA's *Spitzer* Science Center. *Hubble* observations of the two innermost planets found no evidence for puffy atmospheres, strengthening the case that the planets closest to the star are rocky in nature. NASA's planet-hunting *Kepler* space telescope also is studying the TRAPPIST-1 system, to refine our knowledge of the properties of the known planets and to search for additional planets in the system.

Spitzer, *Hubble*, and *Kepler* data will help astronomers plan for follow-up studies using NASA's upcoming *James Webb Space Telescope*, launching in 2018. With much greater sensitivity, *JWST* will be able to detect the chemical fingerprints of water, methane, oxygen, ozone, and other components of a planet's atmosphere, if they are present. *JWST* will also be able to analyze planets' temperatures and surface pressures—key factors in assessing their habitability.

For more information see: **https://www.nasa.gov/press-release/nasa-telescope-reveals-largest-batch-of-earth-size-habitable-zone-planets-around**

Deborah Padgett, COR Deputy Chief Scientist, has left the Program Office. We congratulate her on her new position and wish her the best in her future endeavors at JPL. Eric Tollestrup has replaced Kartik Sheth as Deputy Program Scientist; we welcome him to the COR program.

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Message from the Astrophysics Division Director

Paul Hertz, *Director, Astrophysics Division, Science Mission Directorate,* NASA *Headquarters*

The NASA Science Mission Directorate started the New Year under new leadership. In October 2016, Dr. Thomas Zurbuchen joined NASA as the Associate Administrator for the Science Mission Directorate. Dr. Zurbuchen comes from the University of Michigan, where he was professor of space science and aerospace engineering, and founding director of the Center for Entrepreneurship. In December 2016, Mr. Dennis Andrucyk was appointed the Deputy Associate Administrator for the Science Mission Directorate. Mr. Andrucyk has served in a number of senior NASA leadership roles, including Deputy Associate Administrator for the Space Technology Mission Directorate and Director of Engineering at Goddard Space Flight Center. I look forward to continuing to execute NASA's broad and balanced portfolio of astrophysics activities under their leadership. See **https://science.nasa.gov/about-us/leadership/bios** for more information.

As I described during the NASA Town Hall at the 229th meeting of the American Astronomical Society (AAS) in Grapevine, TX, the Astrophysics Division is continuing to execute a broad portfolio of research activities and missions for the community, many of which were the subject of sessions at the AAS meeting. In order to maximize the science return from the NASA astrophysics program, we rely on community participation at every level of the program. This includes The Astrophysics Advisory Committee (formally the Astrophysics Subcommittee), the Program Analysis Groups (PAGs), Science and Technology Definition Teams for future missions, mission and archive User Groups, and peer review panels. I invite you to self-nominate yourself to participate in any of these community groups.

NASA has issued a new update to the Astrophysics Implementation Plan. This document explains NASA's plans and progress for implementing the priorities and recommendations of the 2010 Decadal Survey, as well as the strategy in the 2014 NASA Strategic Plan and the 2014 NASA Science Plan. The 2016 Astrophysics Implementation Plan Update is at **https://science.nasa.gov/astrophysics/documents/**.

The next two years will see the launches of four NASA astrophysics missions into orbit. The Neutron star Interior Composition Explorer (NICER), an Explorer Mission of Opportunity, will be launching to the International Space Station (ISS) in early 2017 (**https://heasarc.gsfc.nasa.gov/docs/nicer**). After that, the Cosmic Ray Energy and Mass (CREAM) experiment, a successful balloon-born experiment repackaged for space, will join NICER on the ISS (**http://cosmicray.umd.edu/iss-cream**). In early 2018, the Transiting Exoplanet Survey Satellite (TESS), a Medium-class Explorer (MIDEX) mission, will be launched (**http://tess.gsfc.nasa.gov/**). The launch dates for all three of these missions depends on the return-to-flight schedule for the Falcon 9 rocket. Then in October 2018, the *James Webb Space Telescope* will be launched on an Ariane 5 rocket to its orbit at Sun-Earth L2 (see below for details).

NASA is operating at the Fiscal Year (FY) 2016 levels through April 2017 under a continuing resolution; this budget level is generally continued in the proposed FY2017 budget. Under these budgets, NASA astrophysics is provided with ~$1.35B for its programs and missions, including the *James Webb Space Telescope*. This funding level is sufficient for NASA astrophysics to continue its planned programs, missions, projects, research, and technology; the operating missions will continue to generate important and compelling science results, new missions will continue being developed; and progress will be made toward implementing the recommendations of the 2010 Decadal Survey.

A new Small Explorer (SMEX) mission, the Imaging X-ray Polarimetry Explorer (IXPE) led by Martin Weisskopf (Marshall Space Flight Center), has been selected for development. IXPE will provide a new capability for the study of high-energy phenomena, imaging X-ray polarimetry. The proposed launch date for IXPE is November 2020. NASA's announcement is at **https://www.nasa.gov/press-release/nasa-selects-mission-to-study-black-holes-cosmic-x-ray-mysteries**.

NASA supports the astrophysics community through a number of competed programs, including Guest Observer/Guest Investigator (GO) programs, Research and Analysis (R&A) programs, and Postdoctoral Fellowship (*Hubble*, *Einstein*, and *Sagan*) programs. Funding for R&A has been increased by 20% since the 2010 Decadal Survey. However proposal numbers have grown faster than funding over this period, so selection rates have fallen. The selection rate in 2016 was 22% for R&A proposals and 27% and for GO proposals. 100% of selections were announced within 154 days of the proposal due date during 2016.

The funding balance between the R&A programs and the postdoctoral fellowship programs has become suboptimal; the fellowship programs have grown from 1/10 of the R&A budget to 1/6 of the R&A budget. NASA is rebalancing the funding balance between the two programs. Starting with the 2017–2018 fellowship year (fellows selected in early 2017), the number of Fellows selected will be reduced. The funding freed up will be invested in the R&A programs. At the same time, the application and review process for all three Fellowships will be combined into a single application and review. The changes will not alter the current balance or the mix of science topics within the overall Fellowship program.

The 2017 Research Opportunities for Space and Earth Science (ROSES) solicitation was released in mid-February 2017 and posted at **http://nspires.nasaprs.com/**. Beginning with ROSES-2017, Astrophysics Theory Program (ATP) proposals will be solicited every other year. NASA expects to issue its second call for Theoretical and Computational Astrophysics Networks (TCAN) proposals in late 2017 with proposals due in early 2018.

There is a new process for selecting early-career Nancy Grace Roman Technology Fellows; prospective applicants should read the ROSES-2017 program element carefully.

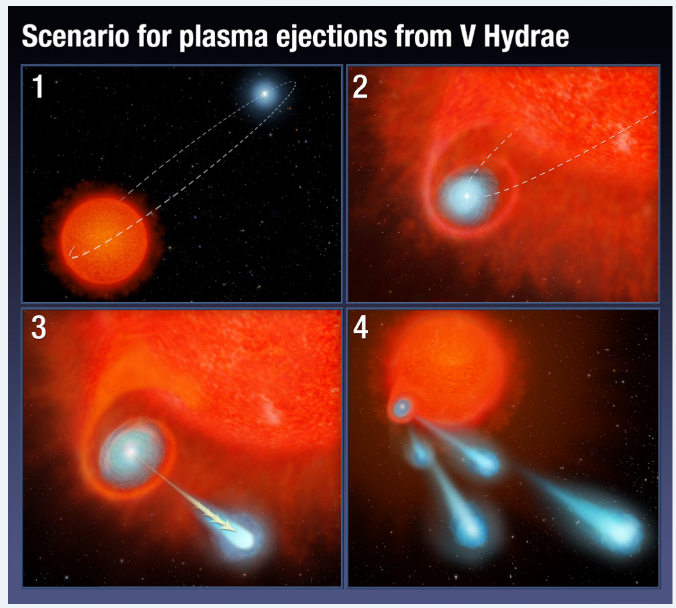
Based on the findings of the 2016 Senior Review of Astrophysics operating missions, NASA is continuing all of the missions that were reviewed for extended missions in 2017 and 2018. End-of-mission plans have been approved for the completion of the *Spitzer* and *Kepler*/K2 missions in 2019. The full reports of the 2016 Astrophysics Senior Review panels and NASA's response can be found at **http://science.nasa.gov/astrophysics/2016-senior-review-operating-missions/**.

NASA continues to make progress developing the *James Webb Space Telescope* according to plan during the integration and test phase. The telescope and instruments have been integrated into a science payload, and ambient testing of the science payload has started at Goddard Space Flight Center in Greenbelt, MD; the spacecraft assembly is nearly complete at Northrup Grumman Space Park in Redondo Beach, CA; and the third and final test of the pathfinder telescope and ground support equipment has been completed in the large Chamber A thermal-vacuum environmental test chamber at Johnson Space Center in Houston, TX. In 2017, the ambient testing of the science payload will be completed and it will be shipped to Johnson Space Center where end-to-end performance testing of the telescope and instruments will be conducted in space-like conditions within Chamber A. In addition, the spacecraft and sunshields will be completed and integrated. 2017 is also the year that the science community begins developing the *JWST* science program. The call for Early Release science was

Hubble Detects Giant 'Cannonballs' Shooting from Star

The *Hubble Space Telescope* (HST) has detected superhot blobs of gas, each twice as massive as the planet Mars, being ejected near a dying star. This stellar "cannon fire" has continued once every 8.5 years for at least the past 400 years, astronomers estimate. The fireballs puzzled astronomers because the ejected material could not have been shot out by the host star, called V Hydrae, which is a bloated red giant star.

The current best explanation is that the plasma balls were launched by an unseen companion star in an elliptical orbit around the red giant. Every 8.5 years, the elongated orbit carries the companion into the puffed-up atmosphere of V Hydrae, where it gobbles up material from the bloated star. This material settles into a disk around the companion, and serves as the launching pad for blobs of plasma, which travel at roughly a half-million miles per hour (they would travel from Earth to the moon in 30 minutes). This star system could explain the dazzling variety of glowing shapes uncovered by *Hubble* that are seen around dying stars.



Artist's conception of how V Hydrae launches ball of plasma into space: 1) Two stars orbit each other. One of the stars is nearing the end of its life and has swelled in size, becoming a red giant. 2) The smaller star passes through the red giant's expanded atmosphere. As the star moves through the atmosphere, it gobbles up material from the red giant, which settles into a disk around the star. 3) The buildup of material reaches a tipping point and is ejected as blobs of hot plasma along the smaller star's spin axis. 4) The ejection process repeats every eight and a half years, the time it takes the orbiting star to make another pass through the bloated red giant's envelope. Image Credit: NASA, ESA, and A. Field (STScI)

"We suggest that these gaseous blobs produced during this late phase of a star's life help make the structures seen in planetary nebulae." said Raghvendra Sahai of NASA's Jet Propulsion Laboratory in Pasadena, California, lead author of the study. "We want to identify the process that causes these amazing transformations from a puffed-up red giant to a beautiful, glowing planetary nebula. These dramatic changes occur over roughly 200 to 1,000 years, which is the blink of an eye in cosmic time."

Sahai's team used *Hubble*'s Space Telescope Imaging Spectrograph (STIS) to observe V Hydrae and its surrounding region over an 11-year period, from 2002 to 2004, and then from 2011 to 2013. The data show a string of monstrous, superhot blobs, each with a temperature of more than 17,000 degrees Fahrenheit—almost twice as hot as the surface of the sun. "The observations show the blobs moving over time," Sahai said. STIS detected gas blobs as far as 37 billion miles away from V Hydrae, more than eight times farther away than the Kuiper Belt of icy debris at the edge of our solar system is from the sun.

Surprisingly, the disk does not fire monster clumps in exactly the same direction every 8.5 years. The direction flip-flops slightly from side-to-side to back-and-forth due to a possible wobble in the accretion disk. Furthermore, V Hydrae is obscured every 17 years, as if something is blocking its light. Sahai and his colleagues suggest that due to the back-and-forth wobble of the jet direction, the blobs alternate between passing behind and in front of V Hydrae. When a blob passes in front of V Hydrae, it shields the red giant from view.

"This accretion disk engine must be very stable because it has been able to launch these structures for hundreds of years without falling apart," Sahai said. The team hopes to use *Hubble* to conduct further observations of the V Hydrae system, including the most recent blob ejected in 2011.

For more information: **https://www.nasa.gov/feature/goddard/2016/hubble-detects-giant-cannonballs-shooting-from-star** issued in January 2017, and the call for Cycle 1 General Observer proposals will be issued in November 2017. *JWST* remains on cost and on schedule for an October 2018 launch. Information on the *Webb Telescope* is at **https://jwst.nasa.gov/**, and information on the proposal opportunities is at **https://jwst.stsci.edu/**.

NASA is working toward a System Requirements Review in June 2017, and the start of Phase B in October 2017, for the *Wide-Field Infrared Survey Telescope* (WFIRST). The WFIRST Formulation Science Working Group is developing the science requirements for WFIRST, and these science requirements will guide the mission design and mission capabilities. The technology development of the next-generation detectors and the coronagraph instrument is on schedule. WFIRST does not have a starshade; however, independent of the WFIRST project, NASA is developing the starshade technology that would be required for a starshade mission that could work with WFIRST. Such a starshade mission could be considered by the 2020 Decadal Survey. Information on WFIRST is at **https://wfirst.gsfc.nasa.gov/**.

The National Academies conducted a review of NASA's progress during the first half of the decade, and NASA's plans during the second half of the decade, for implementing the 2010 Decadal Survey. This Midterm Assessment, available at **http://www.nap.edu/download/23560**, made recommendations to NASA regarding its implementation of WFIRST, the Explorers Program, and U.S. contributions to the European Space Agency's Euclid, Athena, and gravitational wave missions. NASA will be implementing all of the Midterm Assessment's recommendations; the full details can be found in the 2016 Astrophysics Implementation Plan Update at **https://science.nasa.gov/astrophysics/documents/**.

NASA is sponsoring community-based studies in preparation for the 2020 Decadal Survey. Four mission concept studies for large missions are underway. Each study is being led by a Science and Technology Definition Team supported by the engineering capabilities of a NASA Center. The entire community is invited to get involved with one or more of these studies; links to each of the studies is at **http://science.nasa.gov/astrophysics/2020-decadal-survey-planning/**. NASA has also solicited proposals to conduct mission concept studies for medium-size "probe class" missions, and expects to select five to eight proposals by March 2017.

My entire Town Hall presentation from the January AAS meeting, which includes information on additional topics across the breadth of NASA astrophysics, is available at **http://science.nasa.gov/astrophysics/documents/** .

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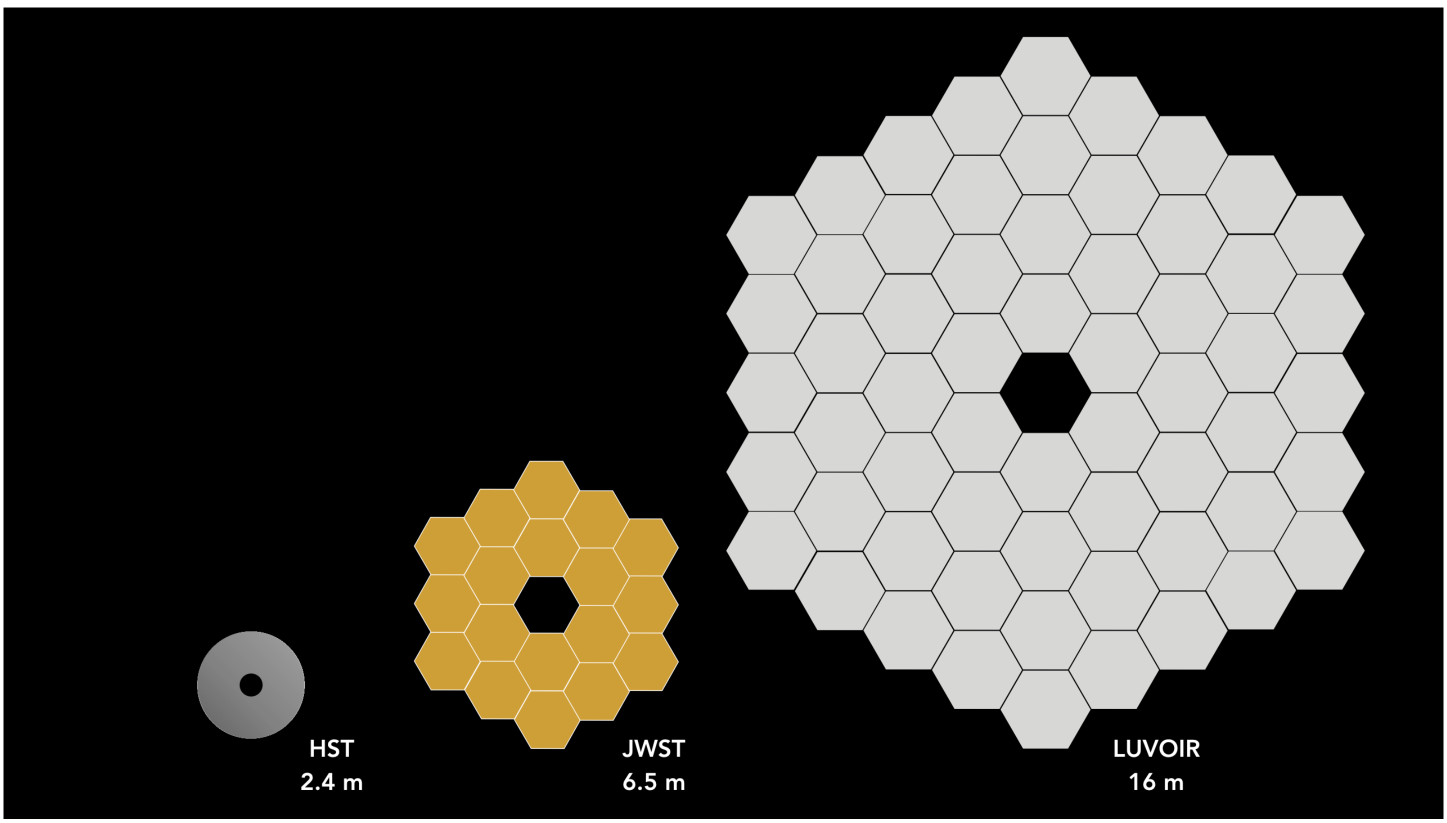
The Large Ultraviolet/Optical/Infrared (LUVOIR) Study Status

Brad Peterson, Ohio State U. and STScI, *Co-Chair*, LUVOIR STDT

The Large UV/Optical/IR Surveyor (LUVOIR) is a concept for a highly capable, multi-wavelength observatory that will be general purpose, serviceable, and upgradable in the tradition of *Hubble Space Telescope*. LUVOIR will enable great leaps forward over a broad range of science, from the epoch of reionization, through galaxy formation and evolution, star and planet formation, to solar system remote sensing, and to characterizing large numbers



The 16-m version of the LUVOIR primary mirror, with HST and JWST mirrors shown for size comparison. Figure credit: J. Tumlinson of exoplanets, including those that might be habitable. A Decadal Mission Concept Study for LUVOIR began in Jan 2016; further information on all aspects of the study is available at **https://asd.gsfc.nasa.gov/luvoir/**.

Under the direction of the 24-member Science and Technology Definition Team (STDT), the LUVOIR study has made excellent progress since its inception. Three public meetings of the STDT—one jointly with the HabEx STDT—have taken place, and the next one is scheduled for April at JPL. The LUVOIR team has also participated in a number of other conferences, including a special session on future missions at the 229th AAS meeting in January. Information on future STDT meetings (and remote participation info) may be found in the "Events" tab on the **LUVOIR website**.

Over several months, a large number of science cases have been assembled based on extensive input from the broad astrophysics and solar system communities. On the basis of the science requirements, a suite of four instruments was chosen for study: an optical/NIR coronagraph, a UV spectrograph and imager, an optical/NIR wide-field imager, and an optical/NIR spectrograph. A fifth LUVOIR instrument will be studied independently by a consortium of European institutions, under the leadership of the French National Space Agency (CNES).

The LUVOIR team has chosen to study two architectures for LUVOIR, one with a primary telescope diameter of around 16-m (Architecture A), illustrated in the Figure, and a second with a diameter of around 9-m (Architecture B). Detailed engineering design work on Architecture A in the NASA GSFC Integrated Design Center began in December 2016, and will culminate in a complete mission design in the summer of 2017.

Meanwhile, additional work on science goals, detailed instrument design, and science return assessment continues. To these ends, the LUVOIR team has developed several tools for simulating various observations with LUVOIR-like observatories. These tools were presented in a hands-on splinter session at the Jan 2017 AAS meeting and are available online in the "Simulation Tools" tab on the **LUVOIR website**. We encourage the community to make use of these tools and to send any and all feedback to the LUVOIR team (**contact info on LUVOIR website**).

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The Origins Space Telescope (OST) Mission Study

Margaret Meixner, STScI, *Co-Chair* OST *Study*
Asantha Cooray, UC Irvine, *Co-Chair* OST *Study*
and the Origins Space Telescope Science and Technology Definition Team[1]

The Origins Space Telescope (OST) is an evolving concept for the Far-Infrared Surveyor mission, and the subject of one of the four science and technology definition studies supported by NASA to prepare for the 2020 Astronomy and Astrophysics Decadal survey. The mission has four science themes: (i) Characterizing small bodies in the outer Solar system; (ii) Tracing the signatures of life and the ingredients of habitable worlds; (iii) Unveiling the growth of black holes and galaxies over cosmic time; and (iv) Charting the rise of metals, dust and the first galaxies.

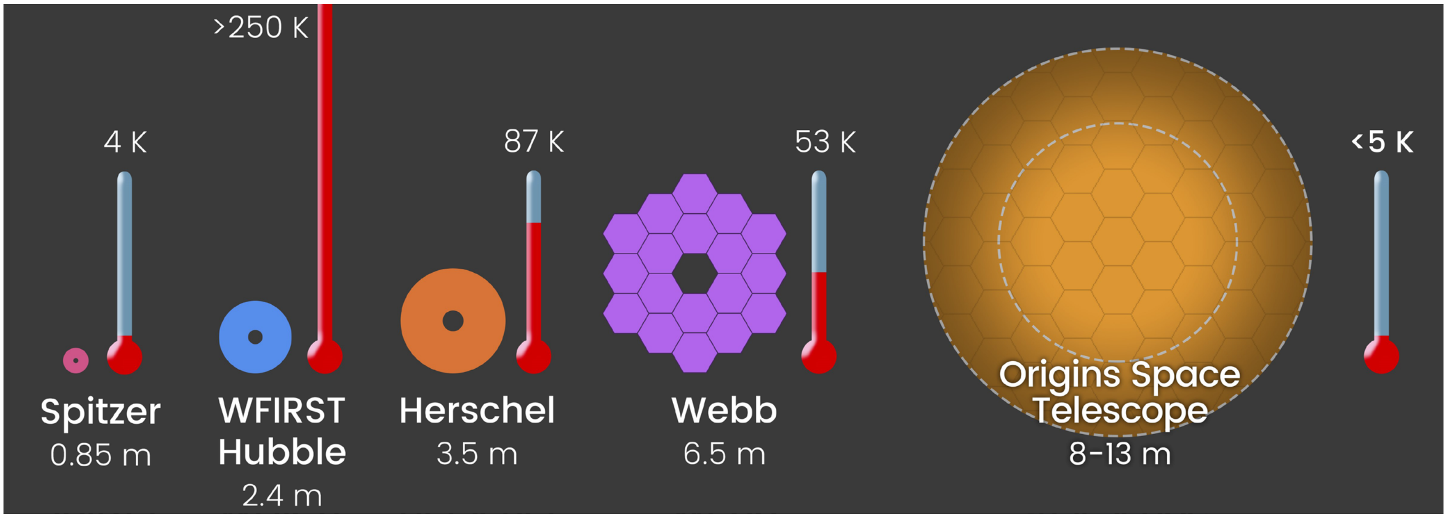
The OST will open a vast discovery space in the study of cool exoplanets in habitable zones and in following the trail of ingredients needed to foster life in exoplanetary systems. Targeting the 6–40 micron wavelength range, it will measure the temperatures and search for basic chemical ingredients for life in the atmospheres of small, warm planets. This may be accomplished by a combination of transit spectroscopy and direct coronagraphic imaging. Leveraging orders of magnitude of improvements in sensitivity over past missions in the mid- to far-infrared range, the OST will also trace the path of water as both ice and gas from the interstellar medium to the inner regions of planet-forming disks, and definitively measure the total masses of disks around stars across the stellar mass range out to distances of 500 pc.

By exploiting sensitive spectral diagnostics of both ongoing star formation and galactic nuclear activity, the OST will be able to trace the co-evolution of stars and supermassive black holes in galaxies over more than 95% of the age of the Universe. With access to a rich set of infrared diagnostic lines, and the ability to map large areas of the sky, the OST will measure the physical conditions that regulate star formation as a function of redshift, age, nuclear activity, and galactic environment. The OST will also be able to study the properties of the first stars via the fingerprints they leave in the interstellar medium, and detect some of the earliest forming structures as they collapse and cool via H_2 emission out of the cosmic web.

OST studies of the Interstellar Medium (ISM) in the Milky Way and nearby galaxies will provide fresh insights into our

Origins Space Telescope science themes range from the cosmic origin of dust and metals to the formation of habitable planets. Image credit: R. Hurt/IPAC

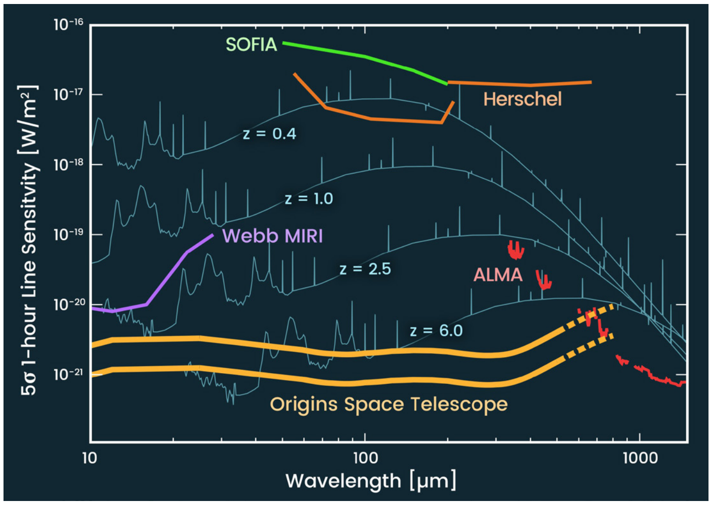
1 See **http://asd.gsfc.nasa.gov/firs/team/** for a list of study team members



With a large, actively cooled telescope, the Origins Space Telescope will attain sensitivities 100-1000X greater than any previous far-infrared telescope. Image credit: R. Hurt/IPAC

understanding of how stars and planetary systems form. The OST will enable a comprehensive view of magnetic fields, turbulence, and the multi-phase ISM; connecting physics at all scales, from galaxies to protostellar cores. With unprecedented sensitivity, the OST will measure and characterize the mechanisms of feedback from star formation and active galactic nuclei over cosmic time and trace the trail of water from interstellar clouds, to protoplanetary disks, to Earth itself in order to understand the abundance and availability of water for habitable planets.

Studies of our own solar system with the OST will contribute to our understanding of the connection between star formation processes and the development habitable environments. A survey to measure the deuterium-to-hydrogren ratio in comets will provide a statistical sample to constrain the cometary contribution of water and other organics to Earth and other terrestrial bodies. Additionally, the OST will survey thousands of ancient Trans-Neptunian Objects in the outer solar system (>100 AU), allowing



Unprecedented Sensitivity: Fast mapping speed with hundreds or thousands of independent beams will enable 3D surveys of large areas of sky, pushing to unprecedented depths to discover and characterize the most distant galaxies (spectra shown above for redshift values up to z = 6), and measure low surface brightness circumstellar disks and faint objects in the outer Solar System. The two orange lines indicate 9m and 14m diameter primary meters for OST. Image credit: M. Bradford/JPL

for a thorough investigation of the size distribution of these small bodies down to sizes of less than 10 km.

Over the summer of 2016, the OST Science and Technology Definition Team (STDT), engaged the community to develop breakthrough science proposals for our mission study. More than 32 community-driven science proposals were developed by five science working groups. These science proposals were used to select a baseline architecture to best address the key scientific questions of the next decade. The selected architecture is an actively-cooled, filled-aperture telescope with effective diameter around 9 meters.

During the November 2016 face-to-face meeting, the OST STDT defined the requirements for the telescope instrument suite. Imaging spectrometers, wide-field, broad-band imagers, and coronagraphs are now under consideration in the 6 to 600 micron range. The five instruments under study are: three imaging spectrometers for low (R=300–10000), medium ($R=10^5$), and high ($R=10^7$) spectral resolving power, a wide-field, broad-band imager with polarization capability, and a mid-infrared (6–40 μm) imager/Imaging Field Unit (IFU) with a coronagraph for direct imaging of exoplanets and transit/secondary eclipse/phase curve studies.

Key enabling technologies for the OST are under development or approaching maturity. The greatest technology need is for large arrays of detectors with sufficient sensitivity to attain astrophysical-light photon background performance. Everything needs to be cold with detectors at ~50 mK and the telescope optics at ~4 K. These temperatures can be obtained with existing or incrementally improved cryocooler systems, sub-Kelvin coolers, and careful observatory thermal design. Instrument technologies such as compact direct-detection spectrometers are also needed to enable fast, multiplexed spectroscopy.

We will continue to develop the scientific requirements for the OST and detailed design of instruments. All members of the scientific community are encouraged to participate in future discussions. Our next face-to-face meeting will be 21–22 March 2017 in Pasadena, California, hosted by the Infrared Processing and Analysis Center (IPAC) at Caltech. We invite community members to attend our meetings and to become familiar with the mission and study process. Remote participation is encouraged and will be available.

Members of the community interested in contributing to the science case for the OST should contact any member of the STDT (**http://origins.ipac.caltech.edu**) or email us at **ost_info@lists.ipac.caltech.edu** .

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The Restructured Nancy Grace Roman Technology Fellowship (RTF) Program

William Lightsey, Marshall SFC, RTF *Program Officer*

The Astrophysics Division initiated the Nancy Grace Roman Technology Fellowships (RTF) Program in 2011 in response to a recommendation from the Astrophysics Subcommittee (APS, now the Astrophysics Advisory Committee, or APAC). RTF proposals are solicited through Element D.9 of the annual Research Opportunities in Space and Earth Sciences (ROSES) solicitation. The purpose of the RTF program is to foster the career development of astrophysics instrumentation technologists who are within seven years of obtaining a PhD. The program provides the leverage of a named fellowship title and laboratory startup funds to help advance the Fellow's career.

The original RTF solicitation involved a two-step process, where, during the first phase (Concept Phase), selected applicants developed an in-depth plan and proposal for a four-year Development Phase effort. This Development Phase proposal was peer reviewed approximately nine months after the start of the Concept Phase, and the successful proposers continued their technology development efforts as Fellows for an additional four years.

The number of proposals submitted to the RTF solicitation has steadily declined since inception of the program, with only five proposals submitted in response to the 2015 solicitation. In an attempt to address this problem, the program has been restructured to simplify the application and review processes. The new RTF program is modeled after the Planetary Science Division's (PSD) Early Career Fellowship (ECF) program.

Under the new RTF program, early career candidates (as defined in the RTF solicitation, but generally those within seven years of their Ph.D.) will submit technical proposals in response to the Astrophysics Research and Analysis (APRA) Program Element (D.3) of the annual ROSES solicitation, and indicate on the proposal cover page the desire to be considered for RTF. Early career candidates will also submit a one-page bio/application along with their proposal to establish eligibility for the RTF award. The same peer review panel that reviews the technical proposal will assess this one-page bio/application as well. Applicants that are selected for an APRA award and fulfill the RTF early-career criteria become eligible to receive an RTF fellowship, but the fellowship is not automatically conveyed upon receiving an APRA award. Additional criteria are considered prior to naming a Fellow.

The program is designed to provide incentives to help the Fellow establish a long-term position at their institution. Candidates in a permanent-track position at the time of receiving the fellowship are eligible to submit a (simple) proposal requesting fellowship funds to establish a lab or research group. Candidates not in a permanent-track position at the time of receiving the fellowship become eligible to submit a fellowship funds proposal once they obtain a permanent-track position. Fellowship funding proposals can request up to $300k (total), and should demonstrate the employing institution's long-term commitment to the early career researcher's career development.

The fellowship funds awards are independent of the APRA award that initially enabled the fellowship, and the funds do not have to be used in direct support of the APRA effort. The fellowship remains in place for 10 years from the date of receiving the PhD, and fellowship funds proposals can be submitted at any time during this period. Thus, it is possible to submit the fellowship funds proposal even after the enabling APRA effort has ended.

The ROSES 2016 solicitation was amended in early January 2017 to include the restructured RTF solicitation. Interested candidates should consult Element D.9 of the ROSES solicitation. Proposals are due March 17, 2017. It is anticipated that RTF will again be solicited in ROSES 2017.

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Technology Gaps for the Large Ultraviolet/Optical/IR (LUVOIR) and Origins Space Telescope (OST) Mission Concept Studies

Thai Pham, Harley Thronson, and Opher Ganel, GSFC, COR *Program Technologists*

As in prior years, the COR Program Office (PO) solicited technology gaps from the community, with a 1 June 2016 cutoff for inclusion in the annual prioritization to inform the Astrophysics Division on technology planning, solicitation, and selection. As before, the PO forwarded to the COR Program Analysis Group (COPAG) Executive Committee (EC) all the gaps from the 2015 prioritization list plus 15 new community-submitted entries to help integrate. Integrating the gaps involves combining similar or overlapping gaps, refining them as needed to make them unique, complete, accurate, and compelling, and adding any gaps the EC feels is missing.

On June 30, the EC returned to the PO a list of 27 gaps for prioritization by the Program Technology Management Board (TMB). In parallel, the Large UV/Optical/IR (LUVOIR) Science and Technology Definition Team (STDT) submitted to the PO seven gaps, identifying three as "highest priority" and the remaining four as "important." The Origins Space Telescope (OST, previously Far-IR Surveyor) STDT submitted eight gaps. Of the seven LUVOIR gaps, two were deemed to be driven by exoplanet science considerations, and thus left for prioritization by the Exoplanet Exploration Program (ExEP).

To streamline the prioritization process, a subset of the full TMB consolidated the resulting 40 gaps into a more concise set of 26 unique gaps, of which six were new relative to the 2015 list.

Priority	COR 2016 Prioritization Showing only Study Teams Technology Gaps	Submitted by
1	Large-format, low-noise and ultralow noise Far-IR direct detectors	OST STDT
	Heterodyne Far-IR detector arrays and related technologies	OST STDT
	Large cryogenic optics for the Far-IR	OST STDT
	High-performance, sub-Kelvin coolers	OST STDT
	Compact, Integrated Spectrometers for 100 to 1000 μm	OST STDT
	Large-format, high-sensitivity, high-dynamic-range UV/FUV detectors	LUVOIR STDT
2	Advanced Cryocoolers	OST STDT
	Mid-IR spectral coronagraph	OST STDT
	High-reflectivity mirror coatings for UV/Vis/NIR	LUVOIR STDT
	High-contrast segmented aperture coronagraphy	LUVOIR STDT
	Ultra-stable opto-mechanical systems	LUVOIR STDT
	Very-large-format, high-QE, low-noise, radiation-tolerant detectors for UV/Vis/NIR	LUVOIR STDT
3	FIR interferometry	OST STDT

At the start of its meeting, the full TMB decided to further merge gaps, resulting in a final list of 18 gaps to be prioritized.

The TMB used the same criteria in 2016 as in prior years to arrive at priority recommendations: Strategic Alignment, Benefits and Impacts, Scope of Applicability, and Urgency. The 2016 gaps submitted by the study teams and considered by the TMB are listed below in priority tiers. Gaps within a given tier have equal priority. For a complete listing of the prioritization please see our 2016 **Program Annual Technology Report** (PATR).

The PO considers gaps submitted or adopted by a study team as "owned" by that team. In practical terms, this means the PO will forward to the team any community-proposed edits to such a gap. The study team may then consider the edits for possible inclusion into their next submission. The teams' unmatched expertise in the technology needs of their respective mission concepts gives great credibility to their opinions, increasing the likelihood of higher-priority ranking for team-owned gaps. We encourage all members of the community to support our efforts to identify the highest-priority technology gaps by submitting new gaps and proposing edits to existing ones before the 1 June 2017 cutoff date by sending a downloadable form to the COR Technology Development Manager. We also encourage community members to submit proposals in response to Strategic Astrophysics Technology (SAT) solicitations by the 17 March deadline.

Please refer to the **COR Program website** and the 2016 COR PATR for more details on COR science, technology development program and process, recent gap submissions, priority recommendations for this year's SAT solicitation, and status and plans of all current COR SAT projects. We welcome your questions or comments on our process or any other aspect of the Program, which should be directed to the COR Technology Development Manager.

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JWST Progress and Plans

Susan Neff, COR *Program Chief Scientist*

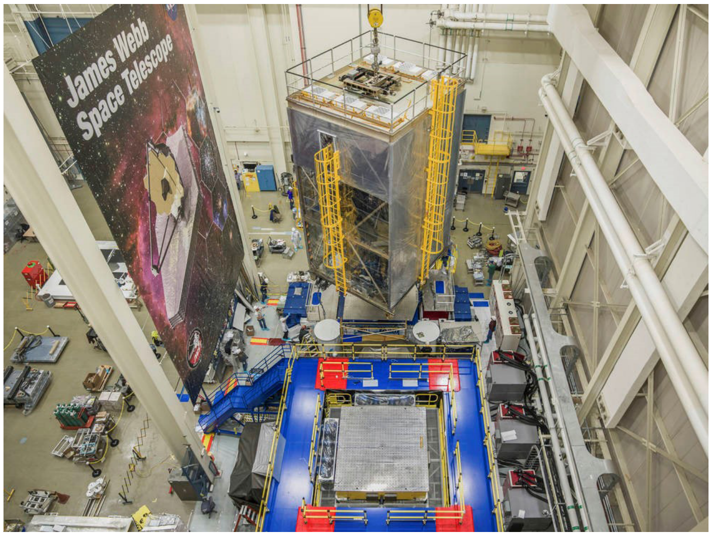
The *James Webb Space Telescope* (*JWST*) continues on schedule for launch in 2018. Observations made by *JWST* are expected to advance all aspects of astrophysics, particularly COR science.

The first community call, for **Director's Discretionary Early Release Science Observations**, was announced at the January 2017 meeting of the American Astronomical Society. Notices of Intent were due 3 March 2017, and proposals are due 18 August 2017. Observations will be selected for their potential to help researchers learn to use *Webb* science capabilities early in the mission. The data will have no proprietary period, are expected to have lasting archival value, and to be useful for reasons beyond the proposed science goals. More information may be found at: **https://jwst-docs.stsci.edu/display/JSP/JWST+Director%27s+Discretionary+Early+Release+Science+Call+for+Proposals**. The DD-ERS call offers 500 hours of observing time; the call for the remainder of Cycle 1 will come out in November 2017 with a due date of 2 March 2018.

A scientific meeting-in-a-meeting, "**JWST Proposal Planning**," will be held at the AAS Meeting, 4–8 June 2017, Austin, TX.

In October 2016, the "before" center-of-curvature test was performed on the *JWST* deployed mirror with a custom-built interferometer. After acoustic and vibration testing is complete for the Optical Telescope element and Integrated Science instrument module (OTIS), the mirror segments will be remeasured to check for any changes.

A clean tent is carefully lowered into place around the folded JWST telescope structure, December 2016, in preparation for acoustic and vibration testing. Image credit: NASA/Goddard/Chris Gunn



JWST, folded up and enclosed in in a clean tent, is carefully positioned onto one of the shaker tables before vibration testing at NASA's Goddard Space Flight Center, December 2016. Image credit: NASA/Goddard/Chris Gunn

In December 2016, during routine vibration testing, an unexpected response occurred from several (out of more than 100) accelerometers, devices designed to detect small changes in the motion of the telescope structure. Testing was put on hold until the responses were understood. A team of engineers and scientists analyzed the response, and determined that the cause of the unexpected result was (small) motions of several launch-restraint-mechanisms for one of the telescope's wings, and that it was safe to continue the testing. Vibration testing was successfully completed in February 2017 and acoustic testing in early March. The OTIS assembly is expected to be shipped to Johnson Space Center (JSC) in April 2017.

At JSC, the third and final Pathfinder test was conducted in the fall of 2016; it successfully validated the thermal ground support equipment/procedures needed for the thermal-vacuum testing of OTIS. The Johnson Test Chamber A (originally used for Apollo mission training) is now preparing for the real thing: an end-to-end optical test, in a cryogenic thermal-vacuum environment. The flight OTIS test is expected to last nearly 100 days. Following that test, the OTIS will go to Northrop Grumman in California, for integration with the spacecraft and sunshield.

More information about *JWST* progress and status, may be found at the *JWST* web site: **http://jwst.nasa.gov/index.html**

The *JWST* team, as well as many others, will miss Phil Sabelhaus, who was the project manager 2002 to 2010. Without Phil's leadership and wisdom over the years he was the *JWST* Project Manager, the project would not be where it is today.

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WFIRST Status and Plans

Susan Neff, COR *Chief Scientist*
Dominic Benford, NASA HQ, WFIRST *Program Scientist*

The *Widefield Infrared Survey Telescope* (WFIRST) was the top recommendation in the 2010 Decadal Survey for large space missions. Although it is not formally part of the COR portfolio, the science to be done by WFIRST is of great interest to the COR community. WFIRST is a NASA observatory designed to perform wide-field imaging and surveys of the near-infrared sky. The primary science goals are 1) to track how dark energy and dark matter have affected the evolution of our universe, 2) to conduct a large-scale search for exoplanets, and 3) to settle essential questions in infrared astrophysics. The project is also planning for a robust Guest Observer (new observations) and Guest Investigator (archival research) program.

WFIRST moved into Phase A when it passed Key Decision Point (KDP) A, in February 2016. The WFIRST team is now working to define the science and instrument performance requirements for successful exoplanet imaging (with the Coronograph Instrument (CGI)) and for scoping the design and operations of the Wide Field Imager (WFI). The Systems Requirements Review (SSR) and the Mission Definition Review (MDR) are planned for July 2017. KDP-B is planned for October 2017, and will mark the transition from mission formulation (Phase A) to detailed system design (Phase B). Launch is currently baselined for 2025.

The WFIRST Project has successfully completed its early technology development phase, retiring much of the risk in the advancement of new capabilities for the next major astrophysics mission to follow *JWST*. In February 2014, NASA initiated a focused technology development effort for WFIRST, co-funded by the Astrophysics Division and the Space Technology Mission Directorate. This work consisted of two thrusts: the maturation of the large-format infrared detector arrays to a technology readiness level meeting NASA's requirements for being prepared for space flight, and the development of coronagraph technologies to enable a complete system-level test in a simulated environment. A set of five quantitative, verifiable milestones were developed to track progress on the infrared detectors and a set of nine milestones to track the progress on the coronagraph technologies. An independent technology assessment committee was empaneled to review these milestones and provide useful insight and suggestions for continuing and improving the work. The milestones were slated to be completed in December 2016. Now, three years after inception, and with the last milestone met in January 2017, we can declare success on the WFIRST technology development effort. The Near-IR detectors have reached TRL 6, and the coronagraph has reached TRL 5.

Technology development milestone reports are available online at **https://wfirst.gsfc.nasa.gov/library.html**. The infrared detectors have completed all necessary testing for the spaceflight environment, including radiation testing. These detectors, Teledyne H4RG arrays, have demonstrated state-of-the-art performance with typical quantum efficiencies in excess of 90%, typical dark currents at around 10e-/hr, and a typical read noise level of 15e- (CDS) and have completed environmental testing. The coronagraph technology development, consisting of two parallel architectures (a hybrid Lyot + shaped pupil version and a phase-induced amplitude apodization version as a backup), has demonstrated adequate full-system-level performance. In a simulated WFIRST dynamic environment, a raw contrast of better than 10^{-8} was achieved by the hybrid Lyot and shaped pupil architecture using low-order wavefront sensing and control to correct for the simulated disturbances. With this success, the backup architecture is no longer necessary, and the hybrid Lyot + shaped pupil architecture will be advanced toward flight.

The WFIRST team has also started working on community science support. Current plans are for the Space Telescope Science Institute (STScI, Baltimore) to provide science support for the Wide-Field Imager: instrument calibration and observation support, pipeline processing, and proposals tools. The Infrared Processing and Analysis Center (IPAC, Pasadena) will provide science support for the coronograph and for microlensing observations from the WFI. A scientific meeting, "**Astronomy in the 2020s: Synergies with WFIRST**" is planned for 26-28 June in Baltimore, MD. Abstracts are due 1 April and registration opens around 1 May 2017.

Thirteen **Science Investigation Teams** (SITs) were selected in December 2015 to help design a science reference mission plan, and the teams have been busy since. In August 2016, the SIT chaired by Margaret Turnbull issued a challenge to the astronomical community. The challenge involves retrieval of simulated exoplanet spectra from simulated WFIRST coronagraph observations. The winning team will successfully retrieve the required measurements for four hypothetical planets from the simulated data, thereby winning one team member a free trip to an exoplanets scientific meeting. This exercise will help to define several key properties of the planned coronographic instrument, and to understand the impacts of signal-to-noise ratios and spectral resolution on the ability to address important scientific questions. The challenge winner will be announced in March 2017. (More information at: **https://wfirst.ipac.caltech.edu/sims/CGI_Data_Challenges.html**). Other, similar science or data challenges are expected in the future.

The WFIRST team, as well as the larger science community, is mourning the loss of Project Scientist Neil Gehrels. He was a champion of WFIRST from the very beginning, recognizing the importance of understanding the fundamental nature of our Universe. Through his intelligence, integrity, humanity and tireless effort, he provided leadership and scientific direction for WFIRST since its early days.

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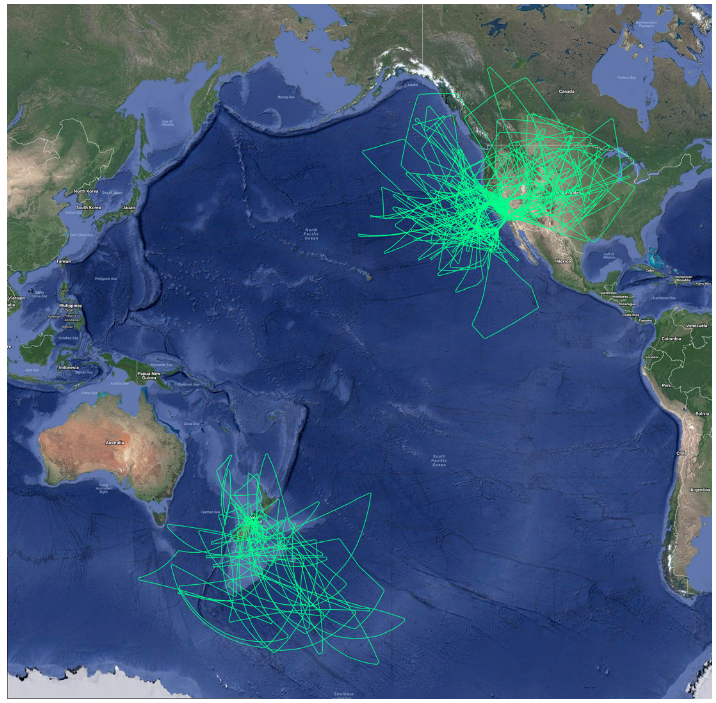
SOFIA Today – Cycle 5 Underway

Harold Yorke, Ames Research Center/USRA, *Director of* SOFIA *Science Mission Operations*

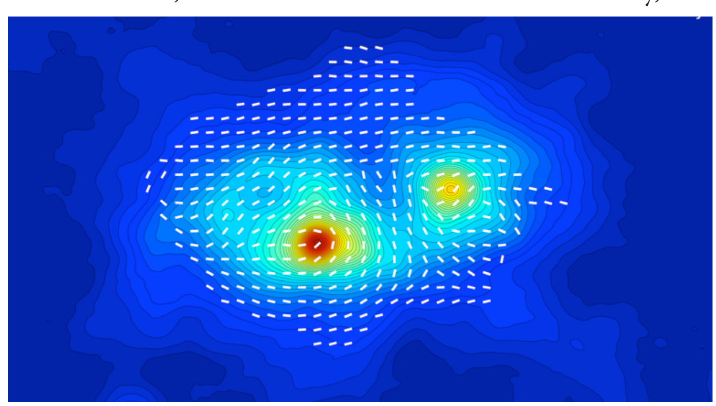
The *Stratospheric Observatory for Infrared Astronomy* (SOFIA) is as joint venture by NASA and the German Aerospace Center (DLR). The heavily modified 747SP aircraft carries and eight-foot telescope and one of six instruments to altitudes high enough not to be obscured water vapor in Earth's atmosphere, which blocks most infrared radiation from celestial sources. SOFIA completed Cycle 4 observations on 3 February 2017, and began Cycle 5 on 5



All SOFIA Flight Paths for 2016, with flights operating out of Palmdale, California, USA and Christchurch, New Zealand. "Suitcase" deployments are also possible, and one or two are being evaluated for Cycle 5 (2017).

February 2017. Cycle 4 was SOFIA's first complete cycle with 80+ science flights. Cycle 5 is expected to include 102 science flights, using 7 instruments, with increased schedule robustness due to planned contingency flights. Calls for Cycle 6 proposals will come out around 1 May 2017, with US proposals due 30 June 2017.

SOFIA plans to deploy to New Zealand (NZ) from 22 June–13 August 2017, and will conduct 24 observing flights with GREAT (German Receiver for Astronomy at Terahertz Frequencies), FIFI-LS (Field Imager Far-Infrared Line Spectrometer), and FORCAST (Faint Object InfraRed Camera for the SOFIA Telescope) while in the southern hemisphere. Focus of the NZ deployment will be the Galactic Center, the Central Molecular Zone of our Galaxy, and



This image shows how dust grains are aligned in the W3 star forming region, approximately 6200 light years from Earth. Polarization vectors are overlaid on an image at the same wavelength: 89 μm. Here, polarization is caused by emission from dust grains, partially oriented by magnetic fields. When analyzed in conjunction with other data and models of the local environment, the structure and strength of the polarization can be used to derive the characteristics of the embedded magnetic field. This is the first polarization image from SOFIA's new HAWC+ instrument. Image credit: NASA/SOFIA/Caltech/D. Dowell

SOFIA Sees Super-Heated Gas Streams Churning up Possible Storm of New Stars

Scientists on board SOFIA observed roiling material streaming from a newly formed star, which could spark the birth of a new generation of stars in the surrounding gas clouds.

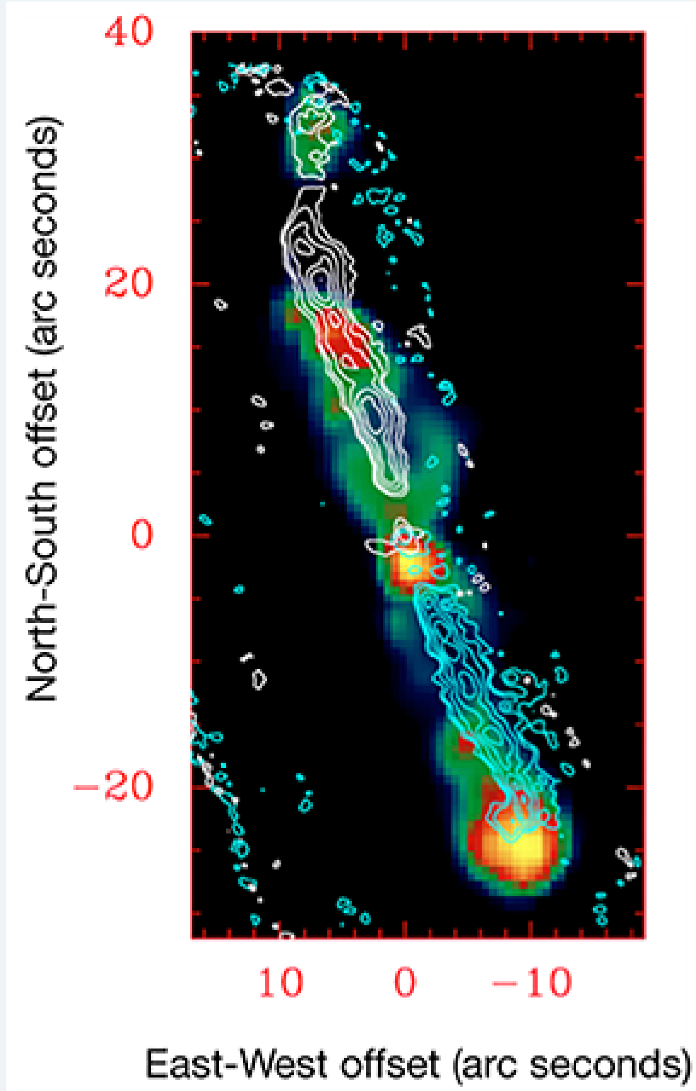
Stars in the early stages of formation often super-heated material in two streams, known as bipolar outflows or jets, which flow out in opposite directions. A team of scientists led by Bertrand Lefloch from the University of Grenoble Alpes, France, used SOFIA to observe the jets coming from Cepheus E, a massive protostar at the earliest stage of star formation. Lefloch's team is studying how such outflows originate and the effects those jets have on star formation in the surrounding clouds.

"SOFIA observations have unveiled new clues to how these jets powered by protostars actually form, and clarified the physical conditions reigning in these objects," Lefloch said. Lefloch's team determined that the jets are less than 1,000 years old, making this process astronomically very young. The jets are shown to extend out to a distance of 118 billion miles and the jet material is moving at speeds between 200,000 and 300,000 mph.

The team's observations were made using SOFIA's German Receiver at Terhertz Frequencies, (GREAT), to map the hottest and densest portions of the matter ejected from Cepheus E. The researchers identified three main parts of the outflow: the jet itself, regions of the surrounding gas and dust cloud through which the jets have plowed, and shock waves at the farthest ends of the jet.

The formation of new stars is thought to be triggered by these shocks. "The physical conditions in the outflowing gas are still poorly known. We are just beginning to be able to study this processs, using new instruments," said Universities Space Research Association's SOFIA Science Mission Director Harold Yorke. "SOFIA is a powerful tool for mapping areas around star-forming regions. The SOFIA data are helping us develop a more comprehensive picture of star formation. Further investigations of this target, and similar systems, will be necessary to definitively determine how this violent activity impacts star formation.

Full article: **https://www.nasa.gov/feature/sofia-sees-super-heated-gas-streams-churning-up-possible-storm-of-new-stars**



Map of the newly formed star Cepheus E, showing the jets of material flowing to the upper left and lower right from the protostar in the center of the image. The central yellow-red peak indicates the newly-formed star, and the other red and yellow shows the location of hydrogen emission (4.5 microns). Contours indicate emission from cool carbon monoxide gas, measured by the Plateau de Bure radio telescope. SOFIA's GREAT instrument measured the amount and velocity of hot carbon monoxide gas at multiple positions along both "arms" of the outflowing jets. Image credit: Lefloch/Univ. Grenoble Alpes

several extragalactic targets, including the Magellanic Clouds. The project is also studying the feasibility of observing an occultation of Kuiper Belt object MU69 (size 25–50km) with the Focal Plane Imager (FPI+). A "suitcase" deployment from the US east coast is planned in October 2017, to observe a stellar occultation by Neptune's moon Triton using the High Speed Imaging Photometer for Occultations (HIPO) + First Light Infrared Experiment Camera (FLIGHTCAM) instruments.

SOFIA resumed normal science operations on 19 January 2017, after its scheduled maintenance over the holiday period, with a 5-flight observing series with the Echelon-Cross-Echelle Spectrograph (EXES), SOFIA's high-resolution mid-IR spectrograph. Non-planetary science observing included [ArII] mapping of M82 (starburst galaxy), measurement of water vapor in a massive protostar in the Orion nebula, and observations of SO_2 in massive Young Stellar Objects.

The EXES series had a strong planetary science component, with observations of Venus, Mars, and Jupiter. The Venus observation was particularly challenging, because the initial planning for the most sensitive measurements was geared toward flying SOFIA well before sunset, pointing the telescope 47 degrees from the Sun. The observatory ended up with a more conservative approach by performing telescope set-up during daylight in a direction away from the Sun, then opening the door to start Venus observation at sunset.

SOFIA also executed a campaign with the upgraded German REceiver for Astronomy at Terahertz frequencies (upGREAT) instrument. [CII]158 μm mapping of Orion and M51, two large impact programs, were both completed. Technological advances in high frequency heterodyne technology have increased SOFIA-upGREAT's [CII] mapping speed by a factor of about 50 (in comparison to *Herschel*-HIFI's band 7), and further improvements are planned for later this year that will allow simultaneous mapping of [CII] and [OI] at 63 µm. The January–February upGREAT observations also included the first heterodyne observations of the [OI] 145 µm line, which, together with the [OI] 63 µm line, give important diagnostic information on structure and temperature.

In December 2016, SOFIA commissioned its latest instrument, the High-resolution Airborne Wideband Camera-plus (HAWC+), a multi-wavelength far infrared camera operating at 40–300 µm, and demonstrated a new capability: polarimetry. HAWC+ is the only currently operating astronomical camera that observes far-Infrared (40–300 µ) light, allowing studies of the low-temperature, early states of star and planet formation.

In September 2016, NASA selected a new (third-generation) facility instrument for SOFIA. The High Resolution Mid-InfrarEd Spectrometer (HIRMES) team will be led by Harvey Moseley, at GSFC. HIRMES in optimized to detect neutral atomic oxygen, water, and hydrogen molecules at infrared wavelengths between 28 and 112 microns. These wavelengths are key to determining how water vapor, ice, and oxygen combine at different times during planet formation. HIRMES is slated to begin flying on SOFIA in spring 2019. More information at: **https://www.nasa.gov/feature/nasa-selects-next-generation-spectrometer-for-sofia-flying-observatory**

A call for SOFIA fourth-generation instrumentation is expected to be released in late summer / early fall. See : **SOFIA NEXT GENERATION INSTRUMENTATION**

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Moth's Eye Inspires Critical Component on SOFIA's Newest Operational Instrument

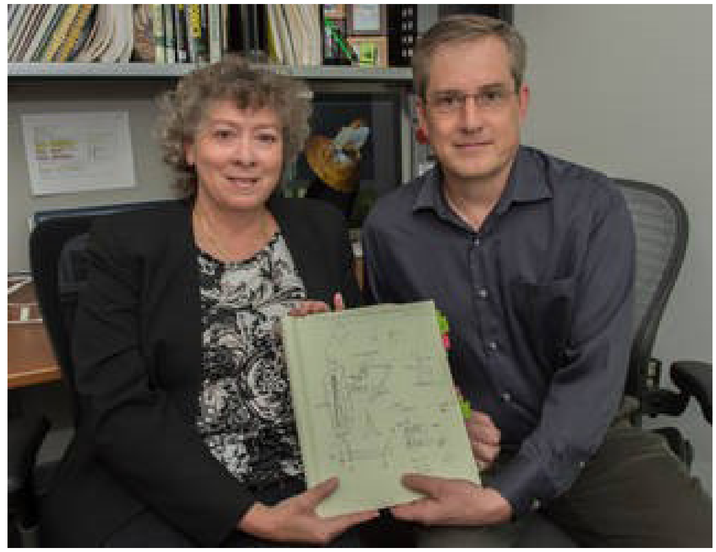
Lori Keesey, Goddard Space Flight Center

Nature, and more particularly a moth's eye, inspired the technology that allows a new NASA-developed camera to create images of astronomical objects with far greater sensitivity than was previously possible.

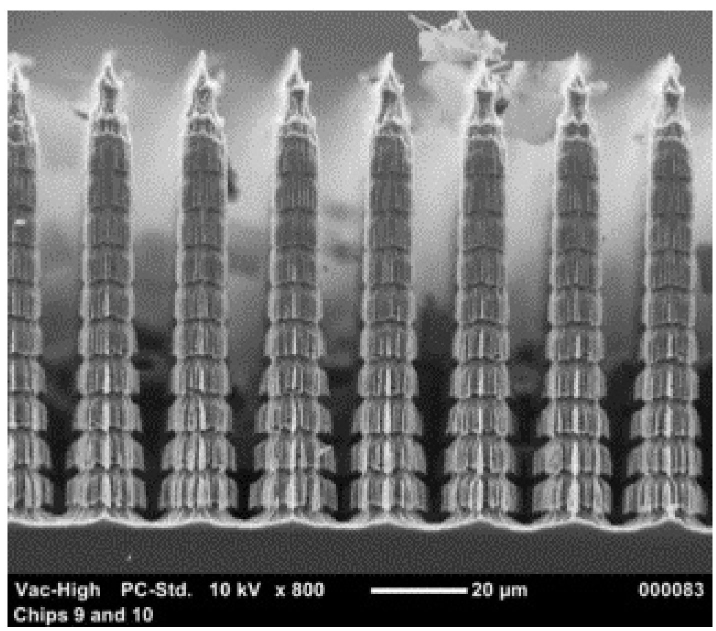
The idea is simple. When examined close up, a moth's eye contains a very fine array of small tapered cylindrical protuberances. Their job is to reduce reflection, allowing these nocturnal creatures to absorb as much light as possible so that they can navigate even in the dark.

The same absorber technology concept, when applied to a far-infrared absorber, results in a silicon structure containing thousands of tightly packed, micro-machined spikes or cylindrical protuberances no taller than a grain of sand. It is a critical component of the four 1,280-pixel bolometer detector arrays that a team of scientists and technologists at NASA's Goddard Space Flight Center in Greenbelt, Maryland, created for the High-Resolution Airborne Wideband Camera-plus (HAWC+).

NASA just completed the commissioning of HAWC+ onboard SOFIA. The upgraded camera not only makes images, but also measures the polarized light from the emission of dust in our galaxy. With this instrument, scientists will be able to study the early stages of star and planet formation, and, with HAWC+'s polarimeter, map the magnetic fields in the environment around the supermassive black hole at the center of the Milky Way.



Christine Jhabvala and Ed Wollack hold the sketch of the absorber technology they created. Containing thousands of tightly packed, micro-machined spikes or cylindrical protuberances no taller than a grain of sand, the absorber is a critical component of the four 1,280-pixel detector arrays used in HAWC+. Credits: NASA/W. Hrybyk



These images taken with a scanning electron microscope show details of a new absorber that is enabling observations by the High-Resolution Airborne Wideband Camera-plus, or HAWC+, a new SOFIA instrument. The "spikes" were inspired by the structure of a moth's eye. (Credit: NASA)

With such a system—never before used in astronomy—even minute variations in the light's frequency and direction can be measured. "This enables the detector to be used over a wider bandwidth. It makes the detector far more sensitive — especially in the far infrared," said Goddard scientist Ed Wollack, who worked with Goddard detector expert Christine Jhabvala to devise and build the micro-machined absorbers critical to the Goddard-developed bolometer detectors.

Bolometers are commonly used to measure infrared or heat radiation, and are, in essence, very sensitive thermometers. When radiation is focused and strikes an absorptive element, typically a material with a resistive coating, the element is heated. A superconducting sensor then measures the resulting change in temperature, revealing the intensity of the incident infrared light.

This particular bolometer is a variation of a detector technology called the backshort under-grid sensor, or BUGS, used now on a number of other infrared-sensitive instruments. In this particular application, the reflective optical structures—the so-called backshorts—are replaced with the micro-machined absorbers that stop and absorb the light.

The team had experimented with carbon nanotubes as a potential absorber. However, the cylindrically shaped tubes now used for a variety of spaceflight applications proved ineffective at absorbing far-infrared wavelengths. In the end, Wollack looked to the moth as a possible solution.

"You can be inspired by something in nature, but you need to use the tools at hand to create it," Wollack said. "It really was the coming together of people, machines, and materials. Now we have a new capability that we didn't have before. This is what innovation is all about."

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COPAG Status

Paul Scowen, ASU, *COPAG Chair*

The COPAG community has been very active in helping define and shape the visions for the four large mission concepts currently under study: Lynx (formerly the X-ray Surveyor), the Origins Space Telescope (formerly the FIR Surveyor), LUVOIR, and HabEx. The STDTs for the four mission concepts have entered the serious work of design and requirement definition with active studies underway for their instrument suites as well as architecture trades for the overall size and scope of each mission. The Science Traceability for each mission, and each instrument, are still actively being defined, but these are likely to settle within the next 6 months to allow the study to converge on design solutions. We encourage members of the COPAG community to engage these groups at various meetings and conferences.

During the AAS meeting in Texas, all three PAGs (COPAG, PhysPAG, and ExoPAG) hosted a joint session to hear first from Paul Hertz about programmatic accomplishments and plans looking forward for SMD Astrophysics, and then received overview presentations from all four large mission concept study teams to update the community on progress made during 2016. A lively Q&A session was part of this session.

The COPAG is planning to create a new Technology Interest Group, or TIG. The TIG is intended to foster a stronger connection between the members of the Cosmic Origins community who are primarily science-focused and those who are primarily technology-focused. The goal is to help the scientists learn more about what is currently possible with new technologies and what science that may enable, while the technologists learn about what capabilities the scientists need. This group will also be tasked with helping the COPAG execute the annual assessment of technology gaps that feed into the shaping of both the APRA and SAT opportunities each year. If interested, please contact the co-chairs for the Group: Sarah Tuttle (**tuttlese@uw.edu**) and Paul Lightsey (**plightse@ball.com**).

The COPAG Executive Committee welcomed new members at the end of the calendar year 2016: Paul Lightsey (Ball Aerospace), Tom Megeath (U. Toledo), John O'Meara (St. Michael College), Claudia Scarlata (U. Minnesota) and Sarah Tuttle (U. Washington). We also bade farewell to members who completed their term on the committee, and thanked them for their service: Daniela Calzetti (U. Massachusetts - Amhert), Dennis Ebbets (Ball Aerospace), James Green (U. Colorado), Sally Heap (NASA GSFC) and Chris Howk (U. Notre Dame).

The work of the three Science Interest Groups (SIGs) continues, with meetings held at the Winter AAS meeting in Grapevine, TX in January 2017. All three groups reported that members were more active in helping the STDTs mentioned above with their work rather than pursuing independent study of issues germane to their group's focus.

SIG 1 - FIR Astronomy

J.D. Smith, U. Toledo, *Co-Chair*

The Far-Infared Science Interest Group (SIG #1) hosted a splinter session at the Winter AAS in Texas jointly with the Origins Space Telescope (OST) study team. In addition to learning about OST, we heard important updates on SOFIA, SPICA, and a variety of smaller missions under study. The highlight of the session was a chaired panel discussion with several plenary speakers including Nobel Prize recipient John Mather and Henry Norris Russell Lecturer Professor Chris McKee. All panel members gave tremendous feedback on the scientific and policy directions of the FIR-Space community from an outside perspective. A newly formed SIG steering committee will build on this success to grow and engage the community at future meetings.

On 23 March 2017 at Caltech, we are helping organize a "**Far Infrared Next Generation Instrumentation Community Workshop**" focusing on the next generation of SOFIA instruments and other Far-IR platforms. Remote participation is encouraged. More information: **http://www.cfa.harvard.edu/~mmacgreg/FIR_SIG/events.html**

Meet *Hubble* Fellow Sarah Sadavoy

Hubble Fellow Sarah Sadavoy investigates the earliest stages of star formation in nearby giant molecular clouds. One of her fields of interest is studying how molecular clouds fragment, first into dense molecular cores and then further into binary star systems. She is also interested in how dust grains grow in size between the very small (micron-sized) grains in molecular clouds to pebble sizes expected in planet-forming disks.

As a *Hubble* Fellow at the Harvard-Smithsonian Astrophysical Observatory (SAO), Sarah is concentrating on the role(s) of magnetic fields in star formation. She uses data from SOFIA, as well as data from several ground-based telescopes, to map magnetic fields in nearby star forming regions by observing dust polarization at far-infrared, sub-mm, and mm- wavelengths. Previous surveys of large regions have had low spatial resolution, and higher resolution studies have tended to cover very small areas. Sarah is studying magnetic fields on both large and small scales: molecular clouds and individual protostars within the clouds. She is also investigating how the magnetic fields shape the protostars, and vice versa.

Sarah was an undergraduate at York University in Physics and Astronomy where she explored chemical abundances in nearby galaxies and outflows from quasars. She earned her MSc at the University of Victoria using *Spitzer* + SCUBA observations to identify and classify dense cores in several nearby molecular clouds. In her PhD work (also U. Victoria), she used *Herschel* + *Spitzer* observations to compare star formation activity and core properties in different subregions (environments) of the same cloud, *Herschel* + SCUBA-2 data to probe for evidence of changing dust grain properties between the larger cloud and its denser core(s). During a postdoctoral position at the Max-Planck-Institut für Astronomie, she also explored the relationship between cloud fragmentation and the local motions and gas densities using *Herschel* observations with molecular line emission from ground-based telescopes, and she used *Herschel* + *Spitzer* data to connect the youngest protostars with the quantity of dense material in subregions of molecular clouds.

Sarah credits three people for introducing her to astronomy: "1) My dad for taking me to see meteor showers when I was a child, 2) a student teacher in my Grade 3 class who did an astronomy unit with us for two weeks, and 3) my sister who took me to our the York University Observatory to see a comet when I was about 14 years old. While at the observatory, I learned that one could pursue astronomy as a career (my sister likes to say my eyes lit up when I heard that) - and I never really looked back." At age 15, she volunteered at the York Observatory to learn more, and then worked there while an undergraduate student (eventually becoming the student coordinator of the entire group of volunteers and staff). Paul Delaney, the director of the observatory, was a fantastic mentor. "I still find it amazing that he would not only allow but encourage a 15 year old high school student to operate the telescope, take observations, and greet visitors. He deserves a lot of credit!"

When she isn't thinking about star formation, Sarah enjoys swing dancing, board games, and hiking.

In addition to meetings, the FIRSIG hosts **monthly webinars** drawing a variety of speakers from around the community. Follow our SIG activities at **tinyurl.com/firsig**

SIG 2 - UV-Visible Astronomy from Space

Paul Scowen, ASU, *Chair*

The UV-Visible Science Interest Group (SIG #2) met at the AAS meeting in Grapevine, Texas to learn more about the UV-visible instrumentation being designed into both the LUVOIR and HabEx large mission concepts. Both missions have strong General Astrophysics portfolios and the instrumentation, in both case, consist of wide field cameras and FUV spectrographs, although the specific capabilities differ depending on the science cases that drive their requirements. The much awaited workshop paper from the Summer 2015 workshop held by SIG2 at NASA GSFC has been accepted for publication in the PASP and is available online here: **https://arxiv.org/abs/1611.09736**.

SIG 3 - Cosmic Dawn Science

Joe Lazio, JPL, *Chair*

The Cosmic Dawn Science Interest Group (SIG #3) held a **face-to-face meeting** just prior to the 229th AAS meeting focused on technology development relevant to future missions addressing Cosmic Dawn science.

Speakers covered a range of topics including technology development for the Origins Space Telescope, future far-IR and sub-millimeter missions, 21 cm missions, and new concepts for Probe-class missions. A science overview highlighted the strong synergy between studies of the neutral intergalactic medium (via highly redshifted HI) with potential X-ray observations (such as might be undertaken with the Lynx/X-ray Surveyor).

The meeting concluded with a presentation and discussion of the Cosmic Origins Program's Technology Program and its annual technology roadmap by H. Thronson.

Presentations are posted at **https://cd-sig.jpl.nasa.gov/events.html#sig_meeting2**

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Cosmic Origins Organization

Program Office

Program Manager: Mansoor Ahmed
mansoor.ahmed-1@nasa.gov

Deputy Program Manager: Azita Valinia
azita.valinia-1@nasa.gov

Chief Scientist: Susan Neff
susan.g.neff@nasa.gov

Chief Technologist: Harley Thronson
harley.a.thronson@nasa.gov

Technology Development Manager:
Thai Pham
thai.pham@nasa.gov

Chief Engineer
Gabe Karpati
gabriel.karpati@nasa.gov

Headquarters

Program Executive: Shahid Habib
Shahid.Habib-1@nasa.gov

Program Scientist: Mario Perez
mario.perez@nasa.gov

Deputy Program Scientist:
Eric Tollestrup
eric.v.tollestrup@nasa.gov

Upcoming Events

20–24 March 2017	Science with HST and *JWST*, Venice, Italy
March 21–22, 2017	OST STDT meeting, Pasadena, CA
23 March 2017	Community Workshop: Far IR Next Generation Instrumentation, Pasadena, CA
3 April 2017	NASA IRTF proposals due
7 April 2017	*Hubble* Cycle 25 Proposals due
17–18 April 2017	LUVOIR STDT meeting, Pasadena, CA
24–27 April 2017	STScI Symposium "Lifecycle of Metals Throughout the Universe: 50 years of UV Astronomy" Baltimore, MD
16 May 2017	Astrophysics Data Analysis proposals due
Summer 2017	SOFIA 5th Generation Instruments proposals due
Summer 2017	SOFIA Cycle 6 Proposals due
4–8 June 2017	*JWST* Proposal Planning – AAS Meeting-in-a-Meeting, Austin, TX
14–15 June 2017	OST STDT meeting, Washington, D.C. area
25–29 June 2017	Workshop: Science Enabled by Novel IR Instrumentation, Ithaca, NY
26–28 June 2017	STScI Conference "Astronomy in the 2020s: Synergies with WFIRST", Baltimore, MD
30 June 2017	SOFIA Cycle 6 proposals due for US proposers
10–14 July 2017	Symposium on UV Sky Survey, Tel Aviv
27 July 2017	Astrophysics Theory proposals due
31 July– 02 August 2017	STScI Workshop: Spectral Diagnostics to Explore the Cosmic Dawn with *JWST*, Baltimore, MD
18 August 2017	*JWST* Director's Discretionary Early Release Science proposals due (NOI required, due March 3)
September 2017	SOFIA Generation 4 instrument proposals due
18–22 September 2017	STScI Symposium, "Taking Stellar Ages to the Next Power", Elba, Italy
November 2017	NASA Postdoc Program Proposals Due
November 2017	*Hubble* Fellowship Proposals Due

Visit our **Cosmic Origins** Web site at **http://cor.gsfc.nasa.gov**