National Aeronautics and Space Administration

Cosmic Origins Newsletter

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Winter 2015 Cosmic Origins Program Update

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

Welcome to the March 2015 Cosmic Origins (COR) newsletter. In this issue, we provide updates on several activities relevant to the COR Program objectives. Some of these activities are not under direct purview of the program, but are relevant to COR goals, therefore we try to keep you informed about their progress.

In January 2015, Paul Hertz (Director, NASA Astrophysics) asked the Program Analysis Groups (PAGs) for help as he begins planning for the 2020 Decadal Study of Astronomy and Astrophysics and deciding which large missions should be studied in depth by NASA prior to the next Decadal Study. The **article by Ken Sembach**, Cosmic Origins PAG (COPAG) chair, explains what Paul has asked the PAGs to do and how the COPAG plans to involve the full COR community in responding to Paul. We strongly encourage all astronomers to participate in this process, which will help shape the future of space astrophysics research.

The COPAG has been busy during the past six months, as you will see in the **status report** by COPAG chair Ken Sembach. A new Science Interest Group (SIG) for UV/Visible Wavelength Science and Technology was started, and another new SIG for Cosmic Dawn Science is under consideration. The Far-IR SIG is planning a follow-on workshop on the **Future of Far-IR Astrophysics** in June. All interested parties are welcome and encouraged to participate in COPAG activities, including the SIGs and Science Analysis Groups (SAGs).

We particularly welcome the participation of young researchers, as they will be the ones using future space observatories to answer fundamental questions. We introduce two of the recently selected ***Hubble* fellows, Drs. Cooke and Deason**, who are currently exploring intergalactic gas clouds and the stellar halo of our Milky Way Galaxy, respectively.

Science breakthroughs continue to be made by *Hubble* and *Spitzer*, as well as from archival data of "emeritus" missions no longer taking in operation (*Herschel*, GALEX, WISE). We include highlights of a few recent science results in boxes throughout the newsletter. In December, *Spitzer* announced selection of new investigations for its 11th cycle of Guest Observers, and *Hubble* is accepting proposals for its 23rd observing cycle.

Hubble will mark the 25th anniversary of launch this April. *Hubble* huggers, as well as artists, philosophers, teachers, and students will participate in a yearlong celebration for this milestone, throughout the US and around the world. We present a sampling of some of these activities, and **information on where to find out about more**.

Good progress is also being made in missions and projects not formally part of the COR program. The *James Webb Space Telescope* (*JWST*) continues development on time and on budget. We provide a **quick status** as well as an article about the **development of metrology techniques** that are vital for testing *JWST* and for building possible future multi-segmented telescopes. The Stratospheric Observatory for Infrared Astronomy (SOFIA) has returned from its "heavy maintenance" sojourn in Germany and will begin its spring observing campaign in March. SOFIA Cycle 4 Guest Observer proposals will be due in April. The Wide-Field Infrared

Inside this Issue

Survey Telescope (*WFIRST*) presented its pre-formulation study results to HQ in February.

A key part of the COR program is managing technology development that will be required for future COR discoveries. The Strategic Astrophysics Technology (SAT) program is intended to help bring key technologies to a development level suitable for infusion into a flight mission. Thus, technologies supported by the SAT program are vital to the future of COR science. During spring 2015, the COR Program asks for your help in identifying "technology gaps," i.e., technologies needed for future COR missions that are not currently available. The updated list of technology gaps will influence the next SAT call for proposals and may also affect proposal calls from the Space Technology Mission Directorate (STMD) at NASA HQ. Please see the **article about the STMD** by Program Scientist Mario Perez and the discussion of updating the **Technology Gaps list** by Technologist Thai Pham. We also profile one of the sounding rocket investigations relevant to COR. The suborbital program is a fundamental part of NASA's technology maturation process, providing an opportunity to flight-test new technologies as well as to train future technologists.

In late January, the COR Program welcomed Jeanne Davis as the new COR Program Executive; she replaces Lia Lapiana. We look forward to working with Jeanne.

Message from the Astrophysics Division Director

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

The enduring science questions for astrophysics—how does the universe work, how did the familiar sky of galaxies and stars come to be, are we alone—form the foundation of the strategic science drivers behind the past five decadal survey documents provided by the National Academy of Science, including the 2010 Decadal Survey, New Worlds, New Horizons in Astronomy and Astrophysics.

As I described during the NASA Town Hall at the 225th meeting of the American Astronomical Society in Seattle, WA, NASA is looking forward to making progress toward these goals in 2015.

- In 2014, NASA Astrophysics flight missions continued to be highly productive, announcing groundbreaking discoveries every month.
- The FY15 Appropriations Act provides funding for NASA astrophysics sufficient to continue its programs, missions, and projects as planned. The total funding appropriated for NASA astrophysics, including *JWST*, is $1.33B, the same as appropriated in FY14. This appropriation fully funds *JWST* to remain on plan for an October 2018 launch; funds continued pre-formulation and

Hubble Sees 'Ghost Light' from Dead Galaxies

The *Hubble Space Telescope* has detected the faint glow of stars ejected from ancient galaxies that were gravitationally ripped apart billions of years ago. The mayhem happened 4 billion light-years away, in a collection of nearly 500 galaxies known as Abell 2744. The scattered stars are no longer bound to any one galaxy, but drift freely between galaxies in the cluster.

Hubble data suggests that up to six galaxies were torn apart, inside the cluster, over a stretch of 6 billion years. Computer modeling of gravitational dynamics suggest that galaxies as big as our Milky Way are likely to have been torn apart as they plunged through the center of the galaxy cluster, where gravitational tidal forces are strongest. Astronomers have long hypothesized that the light from scattered stars should be detectable after the parent galaxies are destroyed. However, the predicted "intracluster" glow of stars is very faint and was therefore a challenge to identify.

"The *Hubble* data revealing the ghost light are important … in understanding the evolution of galaxy clusters," said Ignacio Trujillo of the Instituto de Astrofísica de Canarias (IAC), La Laguna, Tenerife, Spain, one of the researchers. "It is … amazingly beautiful that we found the telltale glow by utilizing *Hubble*'s unique capabilities." "The results are in good agreement with what has been predicted to happen inside massive galaxy clusters," added lead author Mireia Montes of the IAC.

Hubble measurements determined that the phantom stars are rich in heavier elements like oxygen, carbon, and nitrogen. This means the scattered stars must be second- or third-generation stars that were enriched with the elements forged in the hearts of the universe's first-generation stars. Spiral galaxies—like the ones believed to have been torn apart—can sustain ongoing star formation that creates chemically enriched stars.

The combined light of about 200 billion outcast stars contributes approximately 10 percent of the cluster's brightness. Because these extremely faint stars are brightest at near-infrared wavelengths, the team emphasized that this type of observation could only be accomplished with *Hubble*'s infrared sensitivity to extraordinarily dim light.

Full story at: **http://hubblesite.org/newscenter/archive/releases/2014/43/full/**

The massive galaxy cluster Abell 2744. Blue indicates stellar light while galaxies appear as blue-white blobs. Starlight can be seen between the galaxies. The diffuse starlight comes from orphaned stars, scattered into space when gravitational forces ripped apart their parent galaxies. Credit: NASA/ESA and HFF team

technology work leading toward *WFIRST*; restores SOFIA to the budget albeit with a 17% reduction from FY14; provides funding for SMD's education programs; and funds NASA's core astrophysics research, technology, Explorers, and operating mission programs.

• The astrophysics operating missions continue to generate important and compelling science results, and new missions are under development for the future. *Chandra*, *Fermi*, *Hubble*, *Kepler*/K2, *NuSTAR*, *Spitzer*, *Suzaku*, *Swift*, and *XMM-Newton* have been awarded mission extensions following the 2014 Senior Review. *SOFIA* is in prime operations as of May 2014. Missions under development (and their currently planned launch dates) include *ISS-CREAM* (2015), *LISA Pathfinder* (2015), *ASTRO-H* (2015), *NICER* (2016), *TESS* (2017), *JWST* (2018), and *Euclid* (2020). New Explorers will be selected (SMEX in 2015, MIDEX in 2017), and NASA is joining the European Space Agency's (ESA's) *ATHENA* mission and ESA's *L3* gravitational wave observatory.

• *JWST* continues to make progress, having completed a highly successful cryovacuum test of the Integrated Science Instrument Module in 2014. The start of the primary mirror assembly is scheduled for 2015, among other major milestones. *JWST* remains on cost and on schedule for an October 2018 launch.

• The *Hubble* Space Telescope 25th Anniversary on April 24, 2015, will be celebrated through a series of events including social and traditional media outreach programs; exhibits around the world at museums, airports and other venues; education programs in all 50 states; re-release of the IMAX "*Hubble* 3D" movie; and many more activities to engage the public, students, and educators worldwide.

• The pre-formulation study of *WFIRST* continues in 2015 with the $50M appropriated for the purpose. In early 2015, the Science Definition Team submitted its report to NASA; it will be available at **http://wfirst.gsfc.nasa.gov/**. The rest of the year will include technology development for the instruments and continued risk mitigation activities for the telescope and the mission.

• NASA and the National Science Foundation (NSF) have initiated a partnership for exoplanet research in response to the 2010 Decadal Survey recommendation to "…support an aggressive program of ground-based high-precision radial velocity surveys of nearby stars to identify potential candidates … for a future space imaging and spectroscopy mission." Initially, the National Optical Astronomy Observatory (NOAO) share of the WIYN telescope will be made available to the U.S. astronomical community using the existing instrumentation for an exoplanet-targeted Guest Observer program. A NASA-funded facility-class Extreme Precision Doppler Spectrometer for the WIYN telescope will be made available when it is completed around 2018; NASA is currently soliciting proposals for instrument development through ROSES.

• An Announcement of Opportunity for the Astrophysics Explorers Program was released in September 2014, and approximately 25 proposals were received before the December 18, 2014, due date. The target for Step 1 selections is summer 2015 (for additional information, see **http://explorers.larc.nasa.gov/APSMEX/**).

• The Astrophysics Research Program had a proposal selection rate of between 11% and 56% for ROSES R&A competitions in 2014, with an overall average proposal selection rate of ~20% across all of astrophysics; the details are available in my Town Hall presentation. There will be no solicitation for proposals for the Astrophysics Theory Program (ATP) in 2015; there is no loss in ATP funding, just resynching the solicitation schedule with the availability of funding to reduce the long waiting period for the distribution of funds.

• Progress continues to be made towards achieving 2010 Decadal Survey priorities through strategic technology development and partnerships, as described in earlier newsletters. A "scoreboard" of progress against Decadal Survey prioritized recommendations is available in my Town Hall presentation.

• The Astrophysics Mid-Decade Review will be conducted during 2015–2016. The study will be co-sponsored by NASA, NSF, and the Department of Energy (DOE), which are in the process of charging the National Research Council. The formation of the Study Committee will begin soon.

• A major activity for the Astrophysics Division this year is beginning preparation for the 2020 Decadal Survey. To enable prioritization of large space mission concepts to follow *JWST* and *WFIRST* by the 2020 Decadal Survey Committee, NASA needs to conduct mission concept studies and initiate technology development for candidate large space missions. NASA's plans are described in Planning for the 2020 Decadal Survey: An Astrophysics Division White Paper, available at **http://science.nasa.gov/astrophysics/documents/**.

Finally, we are seeking one or more experienced scientists to take leave from their U.S. home institution for a 2-year visiting position (can extend up to 6 years) to work in the Astrophysics Division at NASA Headquarters. Your talent can make a difference in the management of the Astrophysics grants programs; planning, development, and management of NASA missions; and strategic planning for the future of NASA astrophysics. Please contact Stefan Immler at stefan.immler@nasa.gov.

My entire Town Hall presentation from the January AAS meeting, as well as the 2014 Update to the Astrophysics Implementation Plan, is available at **http://science.nasa.gov/astrophysics/documents/**

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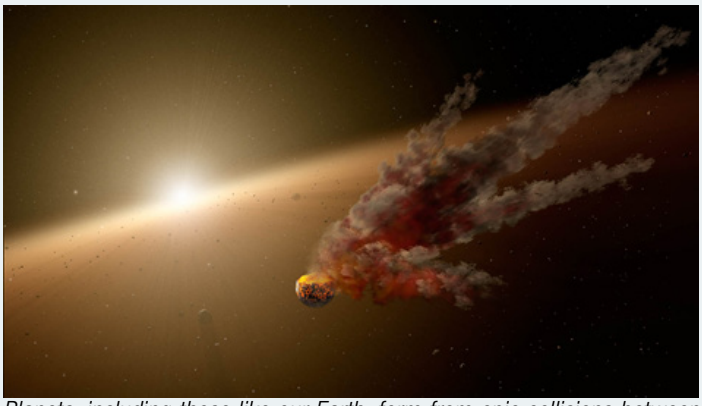
Future Large NASA Astrophysics Missions – COPAG Solicits Community Input

Ken Sembach, *COPAG Chair*

Dr. Paul Hertz, Director of NASA Astrophysics, addressed a joint session of all three Astrophysics Program Analysis Groups (PAGs) at the January AAS meeting in Seattle. After reviewing NASA's progress against the priorities of the 2010 Decadal Survey of Astronomy and Astrophysics and commenting on the current and expected future state of his budget, he asked the PAGs for help as the Astrophysics Division begins planning for the next Decadal Survey.

Spitzer Spots Likely Asteroid Smashup near Young Star



Planets, including those like our Earth, form from epic collisions between asteroids or larger bodies. Sometimes the colliding objects are ground to dust, and sometimes they stick together to ultimately form larger, mature planets. This artist's conception shows one such collision, which was detected by NASA's Spitzer Space Telescope. Image credit: JPL

NASA's *Spitzer* Space Telescope has spotted an eruption of dust around a young star. Scientists had been tracking the dusty star NGC 2547-ID8, when it produced a surge of fresh dust. "We think two big asteroids crashed into each other, creating a huge cloud of grains the size of very fine sand, which are now smashing themselves into smithereens and slowly leaking away from the star," said lead author Huan Meng, graduate student at the University of Arizona, Tucson. Dusty aftermaths of suspected asteroid collisions have been observed by *Spitzer* before, but this is the first time scientists have collected data before and after a planetary system smashup. The event offers a glimpse of the violent process of making rocky planets like ours.

Rocky planets begin life as dusty material circling around young stars; dust clumps form asteroids that collide. Although most asteroids are destroyed, some grow into proto-planets. NGC 2547-ID8 is about 35 million years old and lies 1,200 light-years away. Previous observations had detected variations hinting at possible ongoing asteroid collisions. In the hope of witnessing an even larger impact, astronomers used *Spitzer* to observe the star regularly. The dramatic change occurred when *Spitzer* had to point away from NGC 2547-ID8 to avoid our sun. When *Spitzer* started observing the star again five months later, the team was shocked by the data they received. "We not only witnessed … the wreckage of a huge smashup, but have been able to track how it is changing … as the cloud destroys itself by grinding the grains down …and they escape from the star," said co-author Kate Su of the University of Arizona. "*Spitzer* is the best telescope for monitoring stars regularly and precisely for small changes in infrared light."

A very thick cloud of dusty debris now orbits the star in the zone where rocky planets form. As scientists observe the star system, the infrared signal from this cloud varies based on what can be seen from Earth. For example, when the elongated cloud is facing us, more surface area is exposed and the signal is greater. When the head or the tail of the cloud is in view, less infrared light is observed. By studying the infrared variations, the team is gathering first-of-its-kind detailed data on the outcome of asteroid collisions

"We are watching rocky planet formation happen right in front of us," said George Rieke, a University of Arizona co-author of the new study. "This is a unique chance to study this process in near real-time."

The team is continuing to keep an eye on the star with *Spitzer*, to determine how long the dust cloud persists, and possibly to catch another smashup while *Spitzer* looks on.

Full article at: **http://www.spitzer.caltech.edu/news/1696-ssc2014-06-NASA-s-Spitzer-Telescope-Witnesses-Asteroid-Smashup**

Dr. Hertz noted that the 2020 Decadal Survey will prioritize large space missions to follow *JWST* and *WFIRST*, likely to be started as *WFIRST* approaches launch in the mid 2020s. For the 2020 Survey committee to make an informed recommendation, they will need (for each mission): a science case, a strawman mission design with a technological readiness assessment, and a realistic cost estimate. Further, if the missions are to be plausible candidates for prioritization, NASA will need to invest in significant technology development between now and 2020. NASA has a limited budget for mission studies and technology development, and would like to use those resources efficiently.

In a public white paper, (**http://cor.gsfc.nasa.gov/docs/**), Dr. Hertz identified four large missions he believes have the community support and technical potential to win an endorsement by the next decadal survey. They were each prioritized in the **2010 Decadal Survey** or described in the **Astrophysics Roadmap, "Enduring Quests, Enduring Visions,"** or both. He proposes to study only these four large missions, in detail, in preparation for the next Decadal Review. Each PAG has been charged with soliciting community input on these four missions and any other as yet to be identified flagship mission candidates that enjoy broad community support. Smaller, "probe" class missions may be addressed in the future.

The four large missions proposed are: 1) A Far-Infrared Surveyor, 2) a Habitable Exoplanet Imaging Mission, 3) a UV/Optical Surveyor, and 4) an X-ray Surveyor. (Note: "Surveyor" is the terminology adopted in the Astrophysics Roadmap, and does not necessarily imply that the mission performs wide field surveys.) Dr. Hertz's presentation to the PAGs, a white paper with more information on his background thinking and the formal charge to the PAGS, reports of the 2010 Decadal Survey, and the Roadmap can all be found at: **http://cor.gsfc.nasa.gov/docs/**. Brief descriptions of the missions can be found in the white paper, with more detailed information in the Roadmap.

Dr. Hertz has asked each PAG for a report on community responses concerning all four large missions by the October 2015 meeting of the NASA Advisory Council's Astrophysics Subcommittee. Because there is no AAS meeting this summer, where we might plan a dedicated COPAG face-to-face meeting, the COPAG Executive Committee (EC) is planning several alternate paths for community discussion of this question. The first event will be an electronic COPAG community "Town Hall" web meeting on March 10, 2015. Future electronic Town Halls are planned for April, May, and possibly June. The COPAG EC is also soliciting 1–2 page white papers from interested parties. Information on all of these, and likely other opportunities for input, will be announced on the COR

announcement list (sign up at **http://cor.gsfc.nasa.gov/cornews-mailing-list.php**) and at **http://cor.gsfc.nasa.gov/copag/**

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"Beyond JWST" Study - AURA

Susan Neff, *COR Program Chief Scientist*

(Editor's note: We believe this study is highly relevant to future COR science, and therefore of interest to the COR community. However, it is not part of NASA's COR program, nor is it endorsed by the COR program.)

The "Beyond *JWST*" committee, convened by Association of Universities for Research in Astronomy (AURA), presented its work in January at the Seattle AAS meeting. The committee's detailed written report and official recommendations will be published later this spring.

The committee has worked to develop recommendations for a future mission with a compelling science theme that resonates universally (e.g., with the public and with stakeholders), engages the astrophysics community, and has a feasible, fundable technology path. Mindful that transformative science results from gains of orders of magnitude in sensitivity and in resolution, they are recommending a High Definition Space Telescope (HDST) that will image and search for biosignatures of dozens of potentially habitable (Earth-like) exoplanets, and will tell the full story of how the Universe gets from galaxy- and star-formation to living planets.

Of interest to the COR community, the HDST described by the committee will be able to resolve 100 pc (326 light years) anywhere in the Universe (with a clear line of sight from Earth), with resolution 5–6 times better than *Hubble*'s. This would allow us to answer questions such as "How do galaxies grow, evolve, and die?", "How does star formation create the diversity of shapes and sizes of galaxies seen?", "How do galaxies acquire, process, and recycle their gas?", "How do stars end their lives and disperse the metals they have formed?", and "How do planets form in disks?"

The committee recommends a highly efficient 10–12 m UV, Optical, and Infrared (UVOIR) Observatory, simultaneously executing a dual mission of focused discovery, and of wide-field and transient surveys. They suggest that the HDST should operate at all wavelengths between 0.092–2 microns, and should be diffraction-limited with angular resolution better than 0.01 arcsec. Recommended instruments include a coronagraph for starlight suppression (to search for faint exoplanets), a high spectral resolution UV spectrograph, a panoramic UVOIR imager and a UVOIR multi-object spectrograph.

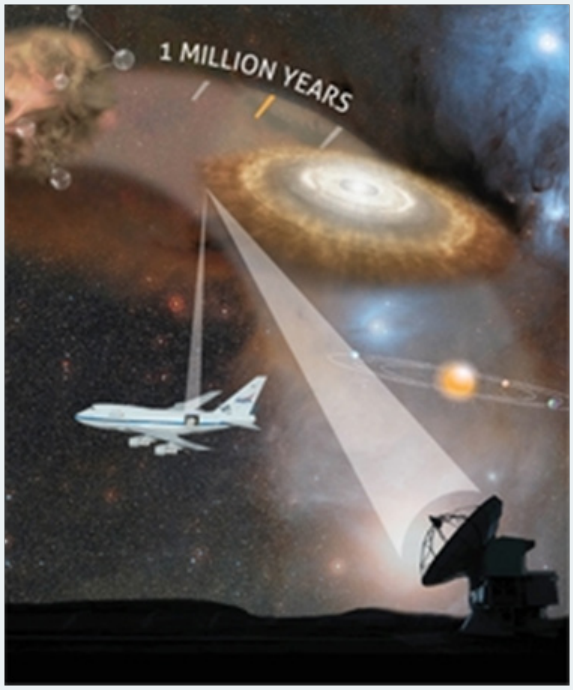
As envisaged, the HDST requires development of UV and Vis/NIR photon counting detectors in gigapixel arrays, a 10–12 m segmented deployable mirror, the ability to do high-contrast coronagraphy with a segmented aperture, and high efficiency coatings down to 92 nm. Probably the most daunting technology challenges is the requirement for ~10 picometer stability of the combined telescope + coronagraph wavefront.

SOFIA Determines Age of a Stellar Nursery

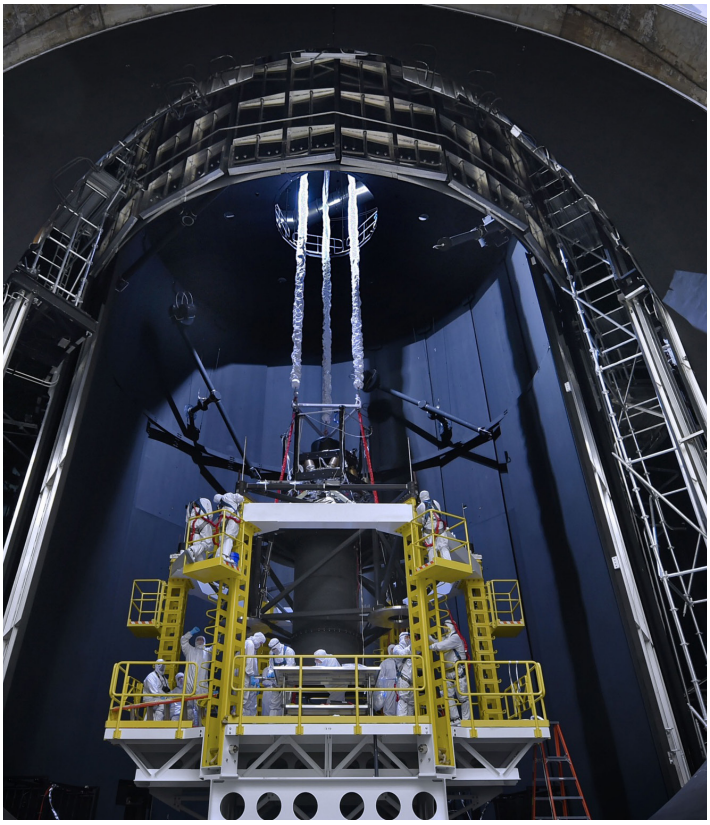
An international science team led by scientists at the University of Cologne, Germany, made a surprising discovery using SOFIA: A star-forming cloud located at a distance of about 400 light years in the direction of the constellation Ophiuchus, is at least 1 million years old yet is still making sun-like stars. This result is surprising, as current models predict star formation should proceed much more rapidly in these environments.

Stars like our sun and their planetary systems form from cold and dense interstellar gas and dust clouds that collapse under their own weight. In the first step, the material condenses into stellar "embryos" called protostars. Details of how such condensations occur, and on what timescales, are not well understood. For example, do the clouds collapse toward their respective centers solely under the influence of gravity, or is the collapse significantly slowed by other factors?

SOFIA used spectroscopic observations of the molecule H_2D^+ (two atoms of ordinary hydrogen plus one atom of 'heavy' hydrogen, deuterium) to study a stellar nursery called IRAS 16293-2422, about 400 light years away from us. The molecule is enriched in dense and cold star forming regions, and it radiates strongly at a characteristic far-infrared wavelength of 219 microns. Although the Earth's atmosphere absorbs all far-infrared radiation from celestial sources, the GREAT spectrometer on SOFIA, operating at an altitude of about 14 km (above most of the atmosphere), is able to measure this important stellar age indicator. The team was able to combine the SOFIA measurement with other observations at radio wavelengths, and to estimate the age of this nursery for Sun-like stars. Full story at:
http://www.nasa.gov/mission_pages/SOFIA/ames/sofia-observations-help-determine-the-age-of-a-star-nursery/#.VPRjP0jvbby



By flying above the majority of the Earth's atmosphere, SOFIA is able to observe a crucial stellar age indicator, which showed that a nursery for Sun-like stars is significantly older than predicted. Credits: NASA/Carla Thomas, C. Durán/ESO/APEX (MPIfR/ESO/OSO), ESO/Digitized Sky Survey 2/Davide De Martin, ESO/ L. Calçada, Bill Saxton, NRAO/AUI/NSF



The giant thermal-vacuum Chamber A at Johnson Space Center, being prepared for testing of the JWST "Pathfinder" in spring 2015, and for eventual testing of the completely assembled JWST. Chamber A was originally used to prepare for human spaceflight missions. Image Credit: NASA/Chris Gunn

More information on the study and its conclusions, and video of the presentations may be found at: **http://www.aura-astronomy.org/news/hdst.asp**.

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JWST Status and Progress

Susan Neff, *COR Chief Scientist*

The *James Webb Space Telescope* (*JWST*) is not currently part of the Cosmic Origins (COR) portfolio. However, once launched, *JWST* is expected to be transformational for COR science, and fundamental to the continued advance of many other astrophysics fields of study.

JWST development is going well, on time and on budget. Recently the *JWST* project carried out a complete cryo-vacuum (CV) test of the fully integrated Integrated Science Instrument Model (ISIM), completed commissioning of the large Test Chamber A at JSC, and successfully completed deployment testing of the full-scale five-layer sunshield engineering model. In early February, a model telescope structure (called "Pathfinder") was delivered to JSC. It will begin cryogenic testing in Chamber A to prepare the facility and team for eventual testing of the flight hardware. The ISIM is on-track for Integration and Testing in January 2016.

Below, we describe a recent advance in metrology that will help track the optical alignment of *JWST* mirrors—key for the success of the mission.

More information about *JWST* progress and status, including a live camera feed, may be found at the *JWST* web site: **http://jwst.nasa.gov/index.html**, and in the "Webb Update" (newsletter): **http://jwst.nasa.gov/newsletters.html**.

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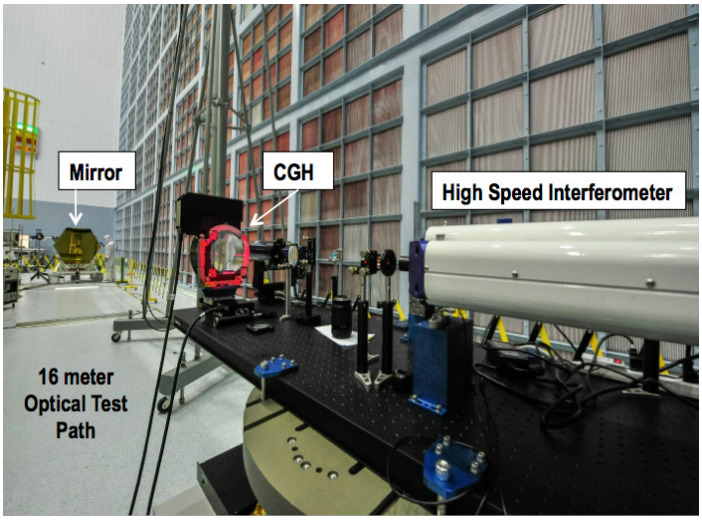
JWST – Early Wavefront Testing Results

Babak Saif, NASA/GSFC
Scott Smith, NASA/MSFC
David Chaney, Ball Aerospace

JWST will be the most complex telescope ever to fly in space. Although multi-mirror telescopes have been used for ground-based astronomy, they have not previously operated in space. Verifying the segments' shape, keeping the individual segments aligned, and tracking any changes in figure or alignment during testing, all require major advances in optical metrology. New techniques developed for *JWST* will also be required for testing and pre-launch verification of future large-aperture space telescopes, if they are to be constructed of multiple segments or to have tight optical tolerances for e.g., coronagraphy.

The *JWST* primary mirror segments will be tested both statically and dynamically by repeatedly measuring the surface of each segment. The testing uses a computer-generated hologram at the center of curvature of each primary mirror segment.

Static surface measurements will track changes to the segment surfaces before and after environmental vibration and acoustics tests. Astigmatism is the dominant aberration expected from adverse changes, and is also the dominant aberration expected from optical test misalignment—therefore great care must be taken to repeat the test setup alignment. The predicted change to static astigmatism of the segment is less than 10 nm rms. The noise level for the static measurements is set by the environmental repeatability of the clean room, including temperature, air turbulence, and vibration. Recent testing on *JWST* flight spares has found that in the tight temperature and airflow control of the clean room, the



Test setup for measuring JWST mirror segments. Credit :B. Saif

surface figure noise floor is around 10 nm (rms), and the astigmatism RMS noise level is about 20 nm (rms) .

Dynamic testing will measure mirror surface figure of the mirror using the same interferometer and computer generated hologram test setup. However, rather than a single snapshot of the surface, a series of figure measurements are taken with a sampling speed of at least 1 KHz—in a single 10 second measurement, 10,000+ individual surface figure measurements are taken. Mirror movement will be compared to input vibration levels by stimulating the telescope assembly at several places and measuring the dynamic behavior of the primary mirror segments.

High speed interferometer dynamic surface measurements were successfully obtained in the last 6 months with the two *JWST* test mirror segments, demonstrating the capability to observe and detect structural changes in either the mirrors or the structure holding them. Similar dynamic testing will be used for diagnosing the structural conditions of the Optical Telescope/Instrument Module (OTIS) and for tracking the mirror behavior throughout *JWST* testing.

More information will be published in the *Journal of Applied Optics*; until then, copies of the paper can be requested by contacting the authors.

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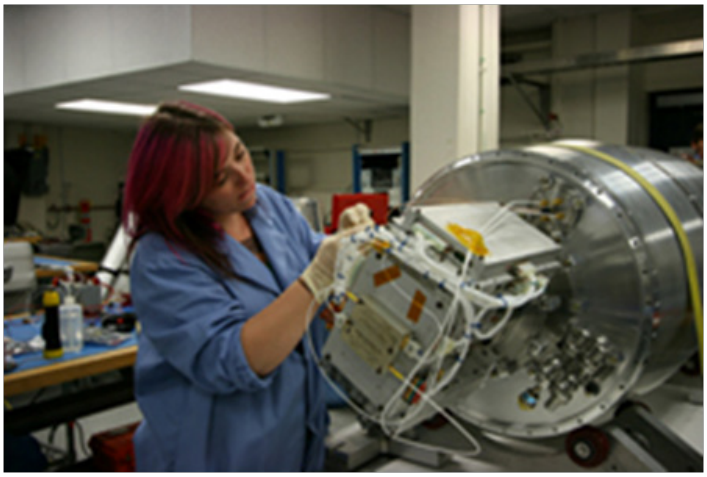
Cosmic Origins Suborbital Program: Sounding Rockets

Susan Neff, *COR Program Chief Scientist*

NASA's exciting scientific discoveries are made through a combination of access to space (freedom from atmospheric attenuation) and new observational capabilities. Instruments developed as sounding rocket and balloon payloads have been precursors to most of NASA's astrophysics missions. The suborbital program provides great flexibility, with short development times, and fast access to space. Suborbital missions provide an opportunity to demonstrate new technologies, and are a rigorous training ground for students and postdocs who will become future Principal Investigators. Astrophysics sounding rockets are funded through NASA's Astrophysics Research and Analysis (APRA) program, managed by the HQ Heliospheric Division, and are part of NASA's Sounding Rocket Program, operated at Wallops Flight Facility in Virginia. Currently there are four funded rocket programs relevant to Cosmic Origins.

Dr. Brian Hicks, then-UMass Lowell postdoc (now at Goddard Space Flight Center), works on installing shutter door cables during integration at the Wallops Flight Facility.



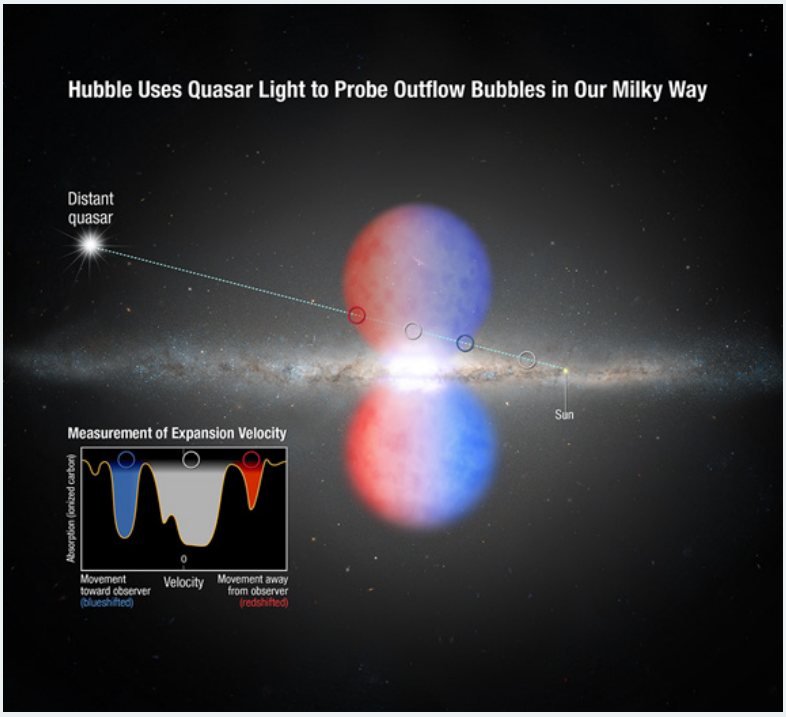
Boston University graduate student Meredith Danowski installs cables and connectors on the IMAGER payload assembly. The IMAGER results will be a major part of her PhD thesis.

The Interstellar Medium Absorption Gradient Experiment Rocket (IMAGER) experiment (PI Timothy Cook, University of Massachusetts Lowell) was designed to obtain ultraviolet images of large astronomical fields (~30 arcmin) in four different 400Å-wide bandpasses simultaneously, at 1450, 1750, 2150 and 2550 Å. The camera, designed by then-UMass Lowell postdoctoral fellow Brian Hicks, was combined with a 0.5m Cassegrain telescope to image a ~30 arcmin diameter field. The detector is a microchannel plate with CsTe photocathode and four wedge & strip anodes, used with refurbished sounding rocket readout electronics. During pre-flight integration, the electronics for one channel developed an irreparable malfunction, and the choice was made to drop the shortest wavelength band for the initial flight. Boston University graduate student Meredith Danowski led the field operations, and is using the data in her PhD thesis research.

IMAGER made its first flight on November 21, 2012, reaching an altitude of 293km and collecting astronomical data for 380 seconds. During the flight the detector system experienced significant noise, not seen in any of the ground testing. This resulted in fewer on-image counts than expected, and reduced signal strength in two of the photometric bands. Data reduction and analysis is ongoing, although the reduced signal to noise in the data makes data interpretation challenging. The IMAGER team hopes to fly an improved payload in the future, with new detector anodes, improved readout electronics, and fewer optical elements.

Despite these setbacks, the IMAGER team successfully observed the nearby galaxy M101 (the "Pinwheel Galaxy") simultaneously in three ultraviolet bands, demonstrating the instrument's

Hubble Detects Massive Outflow from Milky Way Core



This graphic shows how Hubble probed the light from a distant quasar to analyze the so-called Fermi Bubbles, two lobes of material being blown out of the core of our Milky Way galaxy. Image credit: NASA, ESA, and A. Feild (STScI)

Two million years ago, when our human ancestors had mastered walking upright, the heart of our Milky Way galaxy underwent a titanic eruption, driving material outward at 2 million miles per hour. Now, astronomers are witnessing the aftermath: billowing clouds of gas towering about 30,000 light-years above and below the Galaxy plane. The enormous structures were discovered five years ago by NASA's *Fermi* gamma-ray telescope, and have since been detected in X-ray and radio emission. However, astronomers needed *Hubble* to measure the velocity, composition, and mass of the material being blown out of the Galaxy.

The lobes, dubbed "*Fermi* Bubbles", resemble flows of gas and charged particles ejected from the active cores of other galaxies, and may be energized by winds from a burst of star formation or by a central super-massive black hole. "When you look at the centers of other galaxies, the outflows appear much smaller because the galaxies are farther away," said Andrew Fox of the Space Telescope Science Institute in Baltimore, Maryland, lead researcher of the study. "But the outflowing clouds we're seeing are only 25,000 light-years away in our galaxy. We have a front-row seat."

Fox used *Hubble*'s Cosmic Origins Spectrograph (COS) to probe the ultraviolet light from a distant quasar that that lies behind the base of the northern bubble. Imprinted on that light as it passes through the bubble is information about the velocity, composition, and temperature of the expanding gas inside the bubble. Fox's team determined that gas on the near side of the bubble is moving toward Earth, and gas on the far side is moving away, all while it is rushing from the galactic center at 3 million kilometers per hour. They also found that gas in the bubble contains silicon, carbon, and aluminum, indicating that the gas has been enriched in heavy elements—which are produced inside stars. HST detected gas at about 17,500 degrees Fahrenheit, much cooler than the gas emitting X-rays and gamma rays. "We are seeing cooler gas, perhaps interstellar gas in our galaxy's disk, being swept up into that hot outflow," Fox explained.

The bubbles are short-lived compared to the age of our Galaxy, which suggests that these bubbles may be a repeating phenomenon in the Milky Way's history, triggered episodically. Similar observations of other background quasars may reveal gas ejected in previous eruptions.

Full story at: **http://hubblesite.org/newscenter/archive/releases/2015/03/full/**.

feasibility. The observational goal was to measure the dust extinction curve at many locations in the M101 disk, from the center to the outer edges of the disk. Understanding how dust properties vary across the galaxy will allow the investigators to determine the evolutionary and star-formation history of the galaxy.

Further information on IMAGER is at:

http://people.bu.edu/danowski/IMAGER/

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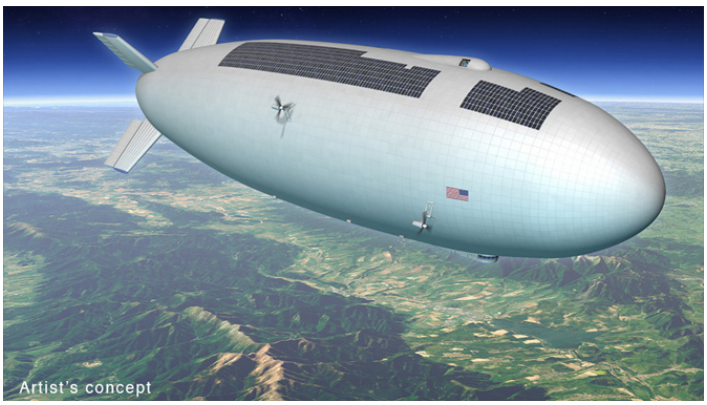
Astrophysics Technologies and Space Technology Mission Directorate (STMD)

Mario R. Perez, *COR Program Scientist*
William D. Lightsey, *Astrophysics Technology Lead*
Astrophysics Division, NASA Headquarters

Historically the Astrophysics Division (APD) has collaborated with the NASA Office of the Chief Technologist (OCT). Since the February 21, 2013 inception of the Space Technology Mission Directorate (STMD), APD has provided content, expertise, and assistance in executing STMD's portfolio of solicitations and technology initiatives.

STMD focuses on advancing multipurpose technology across its entire lifecycle, including innovation, development, maturation and flight programs. Their activities have a natural overlap with Astrophysics technology solicitations, namely: the Astrophysics Research and Analysis (APRA) and the Strategic Astrophysics Technology (SAT) programs. These synergies have been exploited to co-fund and co-sponsor joint investigations that are responsive to multiple solicitations.

APD has participated in several solicitations in the STMD portfolio, including the Early Stage Innovation (ESI), NASA Innovative Advanced Concepts (NIAC), Game Changing, and Small Business Innovation Research (SBIR) competed programs. For example, APD supplied research topics for active wavefront control and X-ray optics in the 2012 ESI solicitation. In 2013, APD proposed ESI topics seeking proposals for cryogenic technologies



Artist's concept for a high-altitude, long-duration airship that could be used as a research platform or for commercial purposes. Image credit: Mike Hughes (Eagre Interactive)/Keck Institute for Space Studies

and optical coatings for instrumentations. Subsequently, APD conducted the peer review process for these ESI research topics and a total of four grants were awarded for a two-year duration.

APD also provides assessments of proposed NIAC selections. NIAC projects with direct astrophysics applications (e.g., meta materials for mirrors) have been reviewed by APD and they have become part of potential technology innovations and solutions. Additionally, APD provides annual assessments of the SBIR selections that result from the Center-led SBIR review process. All SMD Divisions, as APD, provide prioritizations relative to the strategic alignment of the SBIR selections with SMD priorities.

In the past, Astrophysics has provided solicitation topics to the Game Changing Division's Flight Opportunities Payloads solicitations. APD also collaborates with the Game Changing Division on annual proposed "new starts" for technology initiatives. The most notable success in this area is the on-going partnership to co-develop coronagraph architectures for *WFIRST*.

STMD has issued several Centennial Challenges Programs (e.g., 2014 Cube Quest Challenge). One of particular interest to the astronomical community was the request for information (RFI) for the Airship 20-20-20 Challenge. (Responses were due on December 1, 2014.) This RFI solicited community interest in applications for a high-altitude, long-duration suborbital platform, which could be used for a variety of astronomical observations as described in the study leading to the RFI (see **http://cor.gsfc.nasa.gov/news/Airships_rhodes_HQ_Sept_2014-v2.pdf**). If STMD decides to proceed with this challenge, with a prize purse ranging from 2 to 3 million dollars, the astronomical community should participate by proposing innovative applications for thesuborbital platform.

STMD has prioritized technology investments that are strategically important to SMD. A fruitful collaborative environment exists between STMD and APD, and we expect to make it even more meaningful to the astronomical community in the near future.

Another area of interest for early career technologists is the NASA Space Technology Research Fellowship (NSTRF) offered to graduate students that can contribute to new space technologies by enhancing their training while remaining at their university campuses (see at: **http://www.nasa.gov/directorates/spacetech/strg/archives_nstrf.html**).

We strongly encourage the community to apply to the different solicitations and challenges announced by STMD. Further information is at:

http://www.nasa.gov/directorates/spacetech/home/index.html#.VNEKEFpPpV

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Addressing COR Technology Gaps – a Joint NASA/Community Effort

Thai Pham, NASA/GSFC
Opher Ganel, Cascia & Associates

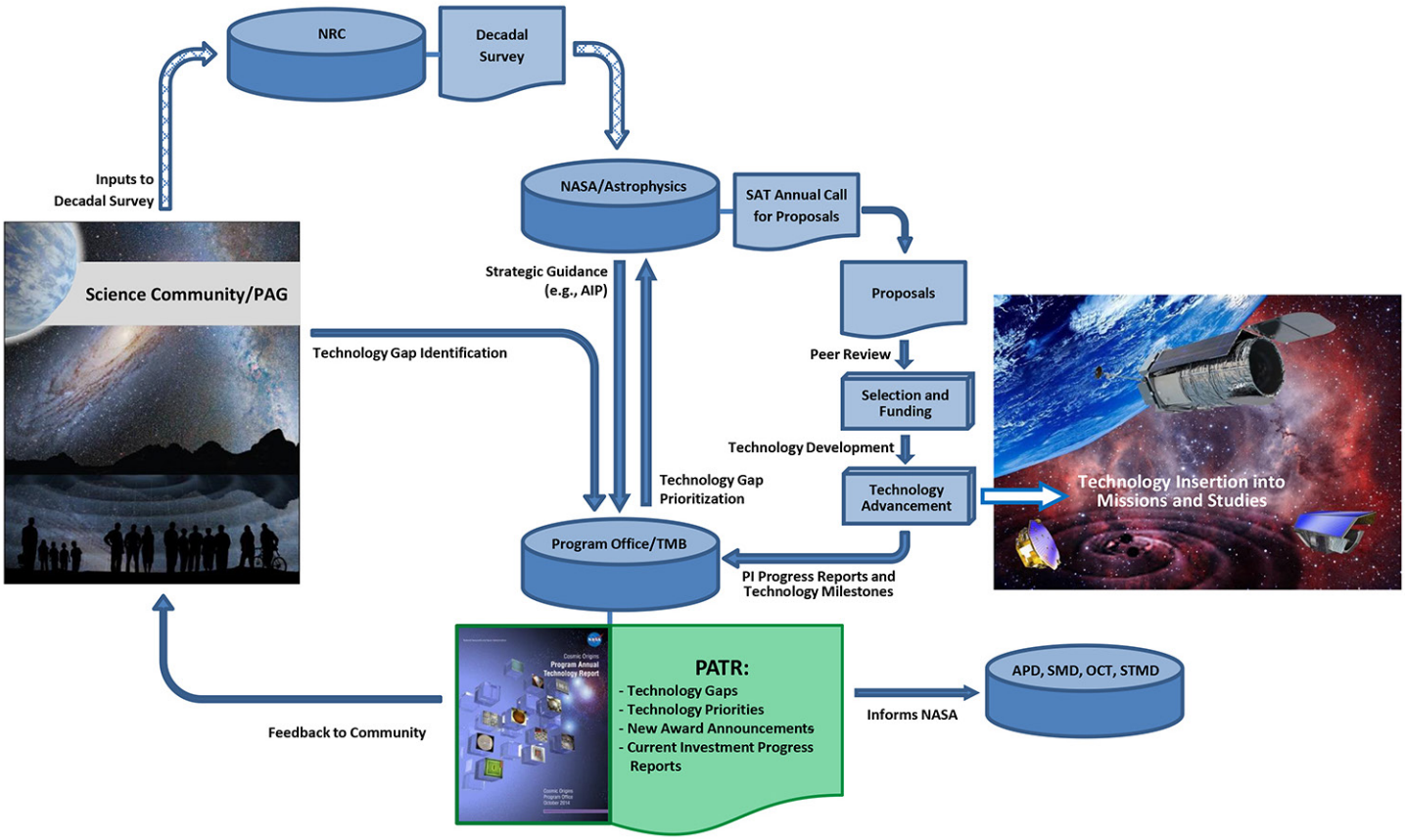
As described by other articles in this newsletter, the potential future of COR science in the coming decades is an exciting one. To enable COR's long-term scientific program, we must develop technologies that close gaps between current capabilities and those needed for future missions. As Paul Hertz stated at the Seattle AAS meeting, "NASA needs to initiate technology development for candidate large missions so that technology will be available when needed."

Identifying and addressing these "technology gaps" is a main charge of the COR Program Office (PO), and one we cannot accomplish without close collaboration with the COR community. It takes a joint NASA/community effort to identify and prioritize technology gaps, and then solicit, fund, and manage the technology maturation projects that will close them. The flowchart below, from our 2014 COR Program Annual Technology Report (**PATR**), illustrates our process, clearly showing the community's central role. This role includes input to the decadal survey, submission of technology gaps for prioritization, responding to COR Strategic Astrophysics Technology (SAT) calls, and doing the work to develop key technologies.

While we accept technology gap submissions continuously through a downloadable form, each year we establish a cutoff date for gaps to be considered and prioritized by our Technology Management Board (TMB). This year's June 1 cutoff accommodates a new consolidation process.

The TMB evaluates gaps according to their strategic alignment, benefits and impacts, scope of applicability, and time to anticipated need. We will publish this year's priority ranking in our 2015 COR PATR, to be released in October. To increase the likelihood your submission ranks in the highest priority category, we offer the following guidelines:

- Focus on gaps associated with missions prioritized by the 2010 Decadal Survey, Astrophysics Implementation Plan, Astrophysics Roadmap, and other relevant planning documents.
- Submit unique, well-defined gaps, within the COR charter, with a current Technology Readiness Level (TRL) of 3 to 5.
- Submit technology capability gaps separating the current state-of-the-art from what is needed to achieve strategic science objectives, not specific implementations or approaches.



• Present gaps succinctly, with enough detail to make your case, avoiding proprietary details, ITAR-sensitive information, and endorsement or bias for any person, group, or organization.

Please refer to the **COR PATR** or **COR Program website** for more details on COR science, technology development program and process, recent gap submissions, 2014 priority recommendations for the 2015 SAT solicitation, and status and plans of all current COR SAT projects. All these can inform your consideration of what gaps we should be addressing as we work now to help realize the COR missions of the coming decades. We will reevaluate all gaps from the 2014 PATR. Please resubmit these only if you believe they should be modified. If you have identified a new or different gap, please submit it by June 1 to thai.pham@nasa.gov. Questions or comments are also welcome.

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Cosmic Origins Program Analysis Group (COPAG) Update

Kenneth Sembach, *COPAG Chair*

The COPAG solicits community input for topics relevant to NASA's Cosmic Origins (COR) program, and provides their analyses to the Astrophysics Subcommittee (APS) of the NASA Advisory Council (NAC). The COPAG Executive Committee (EC) coordinates the activities of the COPAG, which can include articulating or prioritizing key science drivers for COR research, evaluating potential mission capabilities, and assessing technology needs for COR science.

The COPAG uses Science Analysis Groups (SAGs) and Science Interest Groups (SIGs) to foster and focus topical discussions and analysis of science and technology interests. Membership in the COPAG and in the various SAGs and SIGs is open to all interested individuals, and we encourage broad community involvement in all of these activities.

The COPAG currently has two active SAGs. These are "COR Science Enabled by the *WFIRST* Archive" (SAG#8, led by Sally Heap), and "Science Enabled by Dedicated *Spitzer* Observations Prior to the Launch of *JWST*" (SAG#9, led by Daniella Calzetti and David Leisawitz). These SAGs are expected to complete their work during 2015 with reports to the Astrophysics Subcommittee. Input from the community to both SAGs is still strongly desirable, so please contact the SAG chairs if you are interested. Two other SAGS, "COR Science Enabled by a *WFIRST* Coronagraph" (SAG#6, led by Dennis Ebbets), and "Science Enabled by Operations Overlap of HST and *JWST*" (SAG#7, led by Jim Green) have completed their work. Reports may be found at **http://cor.gsfc.nasa.gov/copag/**

The COPAG also has two active SiGs and a third one is being discussed. SIGs are viewed as active forums, where information is shared and longer-term strategies are considered. The SIG for Far-Infrared Science and Technology (chaired by Paul Goldsmith and David Leisawitz) has sponsored one community workshop on the future of Far-Infrared Science from Space (May 2014, **http://asd.gsfc.nasa.gov/conferences/FIR/**) and is planning another for

COPAG EC members interacting with the astronomy community during the Seattle AAS meeting (January 2015).

early June (see article below). The SIG for UV-Visible band Science and Technology (chaired by Paul Scowen) had its kickoff meeting at the Seattle AAS (**http://cor.gsfc.nasa.gov/copag/aas_jan2015/**), is currently structuring itself into several subgroups, and is considering a community workshop later this year. A possible SIG for Cosmic Dawn Science is in active discussion right now—for more information contact Joe Lazio.

The full COPAG met together with the ExoPAG in Seattle (agenda and talks at **http://cor.gsfc.nasa.gov/copag/aas_jan2015/**) where they had an update on the **"Beyond JWST" study being conducted by AURA**, heard about the status of the two Exoplanet Probe studies (coronagraph and starshade), and learned about the work of COPAG SAGs 6 and 8. Finally, all of the Astrophysics PAGs were asked by Paul Hertz to collect and provide community feedback to the APS and to him, on what flagship missions NASA should study in-depth as preparation for the 2020 Decadal Survey.

All interested members of the community are members of the COPAG. Please join us, as a SIG or SAG member, or by commenting on future NASA missions. More information about the COPAG can be found at: **http://cor.gsfc.nasa.gov/copag/**

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Hubble at 25 – Join the Celebration

Tom Griffin, NASA/GSFC
Ken Sembach, STScI

On April 23, 2015, the *Hubble* Space Telescope will reach a major milestone—25 years in space. In those 25 years, *Hubble* has produced stunning views of the Universe, opened new cosmic frontiers, and become a cultural icon. In celebration of this anniversary, NASA, the European Space Agency (ESA), the *Hubble* team, educators, artists, planetariums, and museums around the world are planning a variety of educational and celebratory events. *Hubble* is truly the people's telescope, and NASA is inviting all to participate in this extended birthday party.

Events, news, videos, and images related to the anniversary can be found at **http://hubble25th.org/**. Among the many activities and products planned are:

- Creation of a 25th anniversary e-book highlighting some of *Hubble*'s discoveries and most famous science images.
- The three Baltimore-Washington, D.C airports will showcase *Hubble* science, images, artifacts, and educational materials for the public. Keep an eye out for these throughout the year if you happen to pass through the area.
- An ongoing exhibition, "*Hubble*@25" at the Intrepid Air, Sea, & Space Museum (**http://www.intrepidmuseum.org/**) in New York City highlights artifacts from the *Hubble* servicing missions and *Hubble* science discoveries.
- A series of videos featuring the people who built *Hubble*, operate the observatory, and perform research with its data is being produced, with a new video each month this year.
- The 2010 IMAX movie, "*Hubble* 3D" chronicling the events of Servicing Mission 4 in May 2009 will be re-released in theaters this spring. If you didn't see it the first time around, you'll have another chance!
- The European Space Agency contest "Ode to *Hubble*" lets anyone inspired by *Hubble* express their feelings or share their ideas in a creative and innovative way. This is your chance to cel-

ebrate *Hubble*'s anniversary by submitting a short video showing how *Hubble* has inspired you. See **http://www.spacetelescope.org/Hubble25/odetohubble/** for details. (#OdeTo*Hubble*)

Some key dates of upcoming events include:

- March 13–17, 2015 - *Hubble* science, imagery, and outreach goes hi-tech at the South by Southwest conference in Austin, Texas.
- April 20-23, 2015 – The Space Telescope Science Institute symposium "*Hubble* 2020: Building on 25 years of Discovery" will highlight *Hubble* science past and present, and look toward the future when *Hubble* operations overlap with those of the *James Webb Space Telescope*. See **http://www.stsci.edu/institute/conference/hubble25/** for details.
- April 24, 2015 - The unveiling of the 25th anniversary image will occur at the Newseum (**http://www.newseum.org/**) in Washington, D.C. There will also be a daylong webcast of events at the Smithsonian National Air & Space Museum (NASM) in Washington DC, as well as coordinated events worldwide.
- April 25, 2015 - The NASM Udvar-Hazy Facility (near Washington's Dulles Airport) will host a family day, where the public will be able to interact with astronauts who participated in the *Hubble* deployment and servicing missions.
- April 25-26, 2015 - A multi-day event at the Griffith Observatory in Los Angeles will feature public lectures on the history of *Hubble* and special activities for kids of all ages throughout the weekend.
- April 30, 2015– A panel discussion "*Hubble* and our Altered Universe" at New York's Intrepid Air Sea, & Space Museum.will highlight *Hubble*'s most important scientific discoveries, including the confirmation of dark energy, which led to the 2011 Nobel Prize in Physics.

You are encouraged to join these celebrations and others across the country. Let us know what you'll be doing to celebrate *Hubble*'s silver anniversary and express your creativity at #*Hubble*25.

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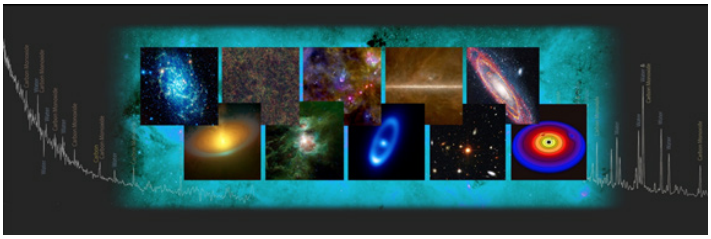
Far-IR SIG Plans June Workshop

David Leisawitz, NASA/GSFC
Paul Goldsmith, JPL
Matt Bradford, Caltech

The Far-IR Science Interest Group (Far-IR SIG) will hold their next workshop June 2–5, 2015 on the Caltech campus in Pasadena with the purpose of preparing a community response to the NASA white paper. The SIG believes coherent community support for the "Far-Infrared Surveyor" mission is the best way to ensure that the mission will be selected for study and technology investment in the years leading up to the Decadal Survey. Workshop participants will develop the science rationale for the "Far-IR Surveyor" and decide which mission architecture best provides the essential measurement capabilities at an affordable cost. Examples of architectures under consideration are a direct detection cryo-cooled interferometer, a cryo-cooled single aperture telescope, and a passively cooled single aperture telescope. In preliminary discussions, a consensus has emerged that by "affordable" we mean approximately $1–2B. A mission in this cost range could enter development in the latter half of the next decade if it is prioritized in the Decadal Survey.

All interested members of the community are encouraged to participate in defining the "Far-IR Surveyor" mission. More information on the upcoming workshop may be found at: **http://www.submm.caltech.edu/~bradford/FarIRSurveyor/workshop.html**

Information about the previous Far-IR SIG community workshop may be found at: **http://asd.gsfc.nasa.gov/conferences/FIR/**



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Meet *Hubble* Fellows Ryan Cooke and Alis Deason

The origin of the chemical elements in the early universe and the assembly of galaxies are subjects under examination by a pair of 2012 and 2014 *Hubble* Fellows currently doing research at the University of California, Santa Cruz, Ryan Cooke and Alis Deason.

Ryan's work probes neutral gas clouds in the intergalactic medium that preserve primordial chemical abundances and provide insight into the elements produced in the first and second generation of stars. His *Hubble* Fellow research seeks to refine the ratio of deuterium to hydrogen, as well as helium and lithium abundances, in these clouds to constrain the impact of effects not captured by standard particle physics and cosmological models. Ryan has just obtained data from his *Hubble* proposal to determine the primordial lithium abundance.

Alis's current research focuses on studying the stellar halo of our own Milky Way Galaxy. This diffuse envelope of stars contains the stripped stellar remnants of less massive dwarf galaxies that have been "cannibalized" by the Milky Way. Despite comprising only ~1% of the total luminosity of the Galaxy, the stellar halo presents a unique "archaeological" record of the Milky Way's past accretion history. By studying the structure and kinematics of these halo stars she hopes to uncover the building blocks of the Galactic halo.

Alis obtained her undergraduate degree at Cambridge, U.K. in Natural Sciences/Astrophysics, during which course she found her astrophysics classes to be far more interesting than the ones in regular physics. Her PhD research on the stellar and dark matter halos of local group galaxies was performed under the tutelage of Dr. Vasily Belokurov and Prof. Wyn Evans. While working on her graduate degree, Alis met Ryan, who hailed from the Gold Coast of Australia with an undergraduate degree in Physics/Astrophysics jointly from Queensland University of Technology and University of Sydney.

Ryan first became interested in astronomy while doing undergraduate research on emission nebulae around a black hole binary in the Large Magellanic Cloud. Ryan's graduate research started with a study of uniformity in the expansion rate of the universe with Prof. Donald Lynden-Bell, then switched to his thesis research under Prof. Max Pettini to find pristine clouds of gas that were formed about 2 billion years after the Big Bang. After moving to UCSC, Ryan was awarded the Morrison Fellowship prior to becoming a *Hubble* Fellow.

Cosmic Origins Organization

Program Office

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

Deputy Program Manager: Thomas Griffin
thomas.j.griffin@nasa.gov

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

Deputy Chief Scientist: Deborah Padgett
deborah.l.padgett@nasa.gov

Chief Technologist: Bernard Seery
bernard.d.seery@nasa.gov

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

Headquarters

Program Executive: Jeanne Davis
jeanne.davis@nasa.gov

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

Deputy Program Scientist: Michael Garcia
michael.r.garcia@nasa.gov

Upcoming Events

March 9–11, 2015	*Hubble* Fellows Symposium, STScI, Baltimore
March 10, 2015	COPAG Virtual Town Hall
March 20, 2015	NASA's Astronomy and Physics Research and Analysis (APRA) and Strategic Astrophysics Technology (SAT) proposals due
April 10, 2015	*Hubble* Cycle 23proposals due
April 20–23, 2015	"*Hubble* 2020: Building on 25 Years of Discovery," STScI, Baltimore, MD
late April 2015	SOFIA Cycle 4 proposals due
May 20-21, 2015	SOFIA Observers Workshop, Mountain View, CA
June 2-5 2015	"Future of Far-Infrared Astronomy", Caltech, Pasadena, CA
July 1, 2015	NASA Postdoctoral Program (NPP) proposals due
August 3-14, 2015	IAU General Assembly, Honolulu, HI
September 11, 2015	*Spitzer* Cycle 12 Proposals Due
Early October 2015	PAG responses concerning Future Large Missions due
November 1, 2015	NASA Postdoctoral Program (NPP) proposals due
November 2015	Nancy Grace Roman Technology Fellowship proposals due
November 2015	*Hubble* Fellow Proposals due
January 2016	COPAG meetings at AAS, Kissimmee, Florida

Visit our

Cosmic Origins

Web site at

http://cor.gsfc.nasa.gov