Infrared Science Interest Group

Newsletter | Number 2 | May 2019

CONTENTS

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Letter from the SIG Leadership Council

We are delighted to share with you the second newsletter from the Infrared Science Interest Group (IR SIG).

As you might have noticed from the title, we have recently expanded our wavelength coverage from the Far-Infrared to the Infrared. This change considerably expands the scope of our SIG activities to incorporate observations and technology including the WFIRST and JWST communities. As we move forward, we are eager to solicit input on how to most effectively engage these communities in light of this expansion.

In addition to this expansion, our IR SIG has already had a number of achievements this year. In January, we held a successful splinter session at the winter AAS meeting in Seattle, WA, despite the continuing government shutdown. This splinter session served to jumpstart our efforts to coordinate white papers amongst the infrared community in preparation for the Astro2020 Decadal Survey. And, most recently, our review article on far-infrared instrumentation and technology development (led by Duncan Farrah) was published in JATIS and is available at http://bit.ly/ir_jatis.

Our key objective continues to be to collect community input and help shape the long-term goals of IR astrophysics. This newsletter series is part of this effort; it will present recent news, science highlights, and mission and technology updates and developments from the community at-large. We will continue to publish a new newsletter each semester. Going forward, please send us updates on your recent scientific and technological advances! These can be sent to irsiglc@gmail.com or submitted via http://bit.ly/irsig_newsletter.

Lastly, we are continuing our previous activities to enhance the presence and voice of IR astronomy in the broader astronomical community. These activities include organizing a monthly webinar series (see our website for the schedule and recordings of past webinars: https://fir-sig.ipac.caltech.edu). In all of these efforts, we are keen to increase the participation of early-career scientists of diverse backgrounds. Reach out to the IR SIG leadership council to get involved! We are also actively recruiting up to three new SIG members this summer (see last page of this newsletter for additional details).

Sincerely,
Meredith MacGregor (newsletter editor)
and the entire IR SIG Leadership Council

A First Astrophysical Detection of a Very Special Molecule

Written by: Kimberly Ennico Smith (NASA)

Paper: Astrophysical detection of the helium hydride ion HeH+
Güsten et al. Nature, 17 April 2019, doi: 10.1038/s41586-019-1090-x

Researchers using SOFIA have made the first-ever detection of the helium hydride molecular ion (HeH^+) in interstellar space. This discovery refines our understanding of the underlying chemical networks that control the formation and destruction of this special molecular ion, a first step toward the huge diversity of molecules in the Universe today.

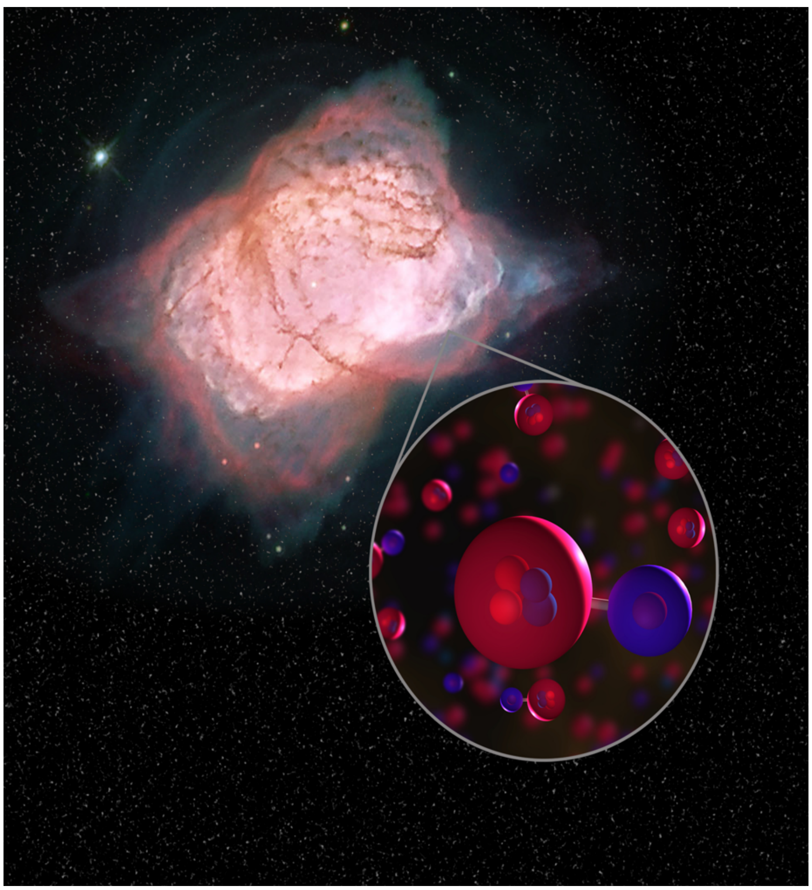

Figure 1: Image of planetary nebula NGC 7027 with illustration of helium hydride molecules. In this planetary nebula, SOFIA detected helium hydride, a combination of helium (red) and hydrogen (blue), which was the first type of molecule to ever form in the early universe. This is the first time that helium hydride has been found in the modern universe.
Credit: NASA/ESA/Hubble Processing: Judy Schmidt

Understanding how that early gas (mostly hydrogen and helium) evolves into the Universe filled with galaxies, stars, and planets we see today, some 13.8 billion years later, remains one of the most important goals of modern astrophysics. When temperatures in the early Universe had fallen below ~4,000 K, the light elements produced in the Big Bang began to combine. Ionized hydrogen interacting with neutral helium created the “Universe’s first molecular bond” in the helium hydride ion (HeH^+). Destruction of HeH^+ created one of the earliest paths to forming molecular hydrogen (H_2), the most abundant and significant molecule in the Universe. The growing abundance of such molecules influenced the structure of the early Universe by providing a dominant mechanism for gas to cool and form stars.

Having been predicted by chemical models and created in the laboratory, decades-long searches for this elusive molecule in an astrophysical environment turned up short – until now.

HeH^+ was detected toward the planetary nebula NGC 7027 with the German REceiver for Astronomy at Terahertz Frequencies (GREAT) spectrometer aboard SOFIA. The hard radiation field produced by the central white dwarf star (T > 100,000 K) combined with a high density of hydrogen and helium, proved to be an excellent place where HeH^+ could form today. Comparing the observed *J=1-0* emission at 149 μm to detailed models of the nebula's helium and hydrogen ionization fronts, the team found the observed flux was a factor four times brighter than predictions. The results constrain the radiative association creation ($He^+ + H \rightarrow HeH^+ + h\nu$) and the dissociative recombination rates ($HeH^+ + e^- \rightarrow He + H$) in the NGC 7027 environment. This in turn may stimulate future advance studies of these important reactions and of the corresponding radiative association under conditions of the early universe ($He + H^+ \rightarrow HeH^+ + h\nu$). Future studies of HeH^+ (*J=1-0* and *J=2-1* at 149 and 75 μm, respectively) can help us further study overlap ionization regions in planetary nebulae.

SOFIA made this discovery possible by accessing the electromagnetic spectrum in the region where the HeH^+ can be detected and having the sensitivity and technology to measure the rotational ground-state *J=1-0* transition at 149.137 μm with high-enough spectral resolution to separate it from the nearby Λ-doublet of CH at 149.09 and 149.39 μm. CH is among many molecules abundant in photodissociation regions, and had been previously detected in NGC 7027 with the Infrared Space Observatory's Long Wavelength Spectrometer (LWS). However, LWS's spectral resolution was too low to distinguish the adjacent HeH^+ transition from the CH, and the authors from that study provided an HeH^+ upper limit (see Liu, X.W. et al. MNRAS, 290, L71-L75 [1997]). The latest advances in terahertz technology enabled this first unambiguous HeH^+ detection in interstellar space, by GREAT on SOFIA.

Additional Updates from SOFIA:

The results of the Cycle 7 Call for Proposals were released in February and can be found here:
https://www.sofia.usra.edu/science/proposing-and-observing/proposal-calls/cycle-7/selected-proposals

From May to August 2019, members of the SOFIA science team will be deployed across the U.S. to present recent SOFIA science and provide help to current users and proposers through seminars and workshops, depending on the needs of the local community. At no cost to participants or the host institution, SOFIA Science on Tour enables research institutes and university departments to offer staff and students free resources to learn about new research discoveries and opportunities through a diverse range of presentations, tutorials, and targeted technical support. A schedule can be found here: https://www.sofia.usra.edu/science/meetings-and-events/science-on-tour.

For more news and updates, you can follow SOFIA on Twitter @SOFIAtelescope!

An Overview of the ALMA Telescope

Written by: Lisa Locke (Jansky Fellow, NRAO)

The **Atacama Large Millimeter/submillimeter Array** [1] **(ALMA),** located at 5000m on the Chajnantor plateau of the Atacama Desert in northern Chile, is an interferometer capable of observing over a broad range within the millimeter and submillimeter region of the electromagnetic spectrum. The site was chosen for its high atmospheric transparency at millimeter and submillimeter wavelengths, and the low perceptible water vapor which is partly due to the high elevation. The 66-element array is composed of 12 m antennas with baselines from 150 m to 16 km and a compact mostly-stationary array of 7 m and 12 m antennas for imaging large-scale sources.

The **ALMA Front End system** is the first element in a complex chain of signal reception, conversion, processing, and recording. Within the cryostat are 10 individual cold receiver cartridges that can be installed or replaced with relative ease. The wavelength coverage is currently from Band 3 (2.6 – 3.6 mm) to Band 10 (0.3 – 0.4 mm)[2], allowing for observations of molecular clouds, dust-obscured galaxies and cold star-forming regions at very sensitive levels and with high angular resolution.

With the highly sensitive antennas and very long baselines, high resolution imaging requires very accurate calibration and correction of atmospheric phase errors. The **water vapor radiometer** at 183 GHz is a calibrated radio receiver that measures the actual water vapor column along the line of sight to each telescope, estimates the incurred path delay and applies it as a phase correction to the observed data.

A schematic of the ALMA Band 6 (211—275 GHz) receiver cartridge follows on the next page.

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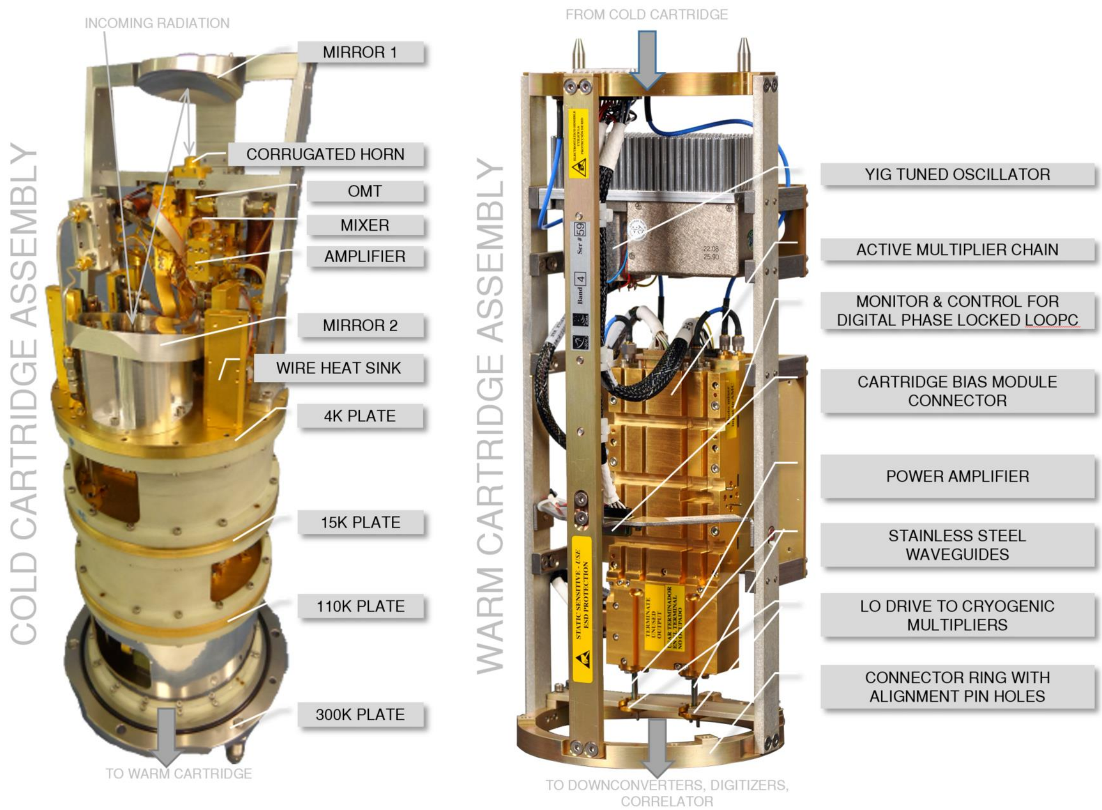
[1] The Atacama Large Millimeter/submillimeter Array (ALMA) is an international partnership of the European Southern Observatory (ESO), the U.S. National Science Foundation (NSF) and the National Institutes of Natural Sciences (NINS) of Japan, together with NRC (Canada), NSC and ASIAA (Taiwan), and KASI (Republic of Korea), in cooperation with the Republic of Chile.

[2] Bands 1 (6 – 8.5 mm) is under construction and Band 2 (3.3 – 4.5 mm) will be added in the future. [Ref: https://www.eso.org/public/usa/teles-instr/alma/receiver-bands/, accessed April 15, 2019]



ALMA BAND 6 RECEIVER CARTRIDGE (211 - 275 GHz)

Cold Cartridge

Horn: after the mirror optics, a highly efficient and low sidelobe corrugated horn brings in the signal.

Polarizing element: To extract dual polarizations, either a wire polarizing grid or an orthomode transducer is used.

SIS Mixer: a three port superconducting device that downconverts the signal using a high frequency local oscillator input and outputs a lower frequency version of the signal, usually 4-12 GHz.

LNA: a low noise amplifier provides a large amount of gain while keeping the thermal noise contribution at a minimum.

Warm Cartridge Assembly Further amplification and filtering are performed here.

IF Processor (not shown): Frequency conversion, filtering and amplification.

Correlator (not shown): One of the fastest supercomputers in the world is housed at the Array Operations Site (AOS) Technical Building, where the main and compact array correlators create images from comparing each antenna pair – up to 1225 possible pairs in the main array alone.

SPHEREx Selected as Next NASA MIDEX Mission

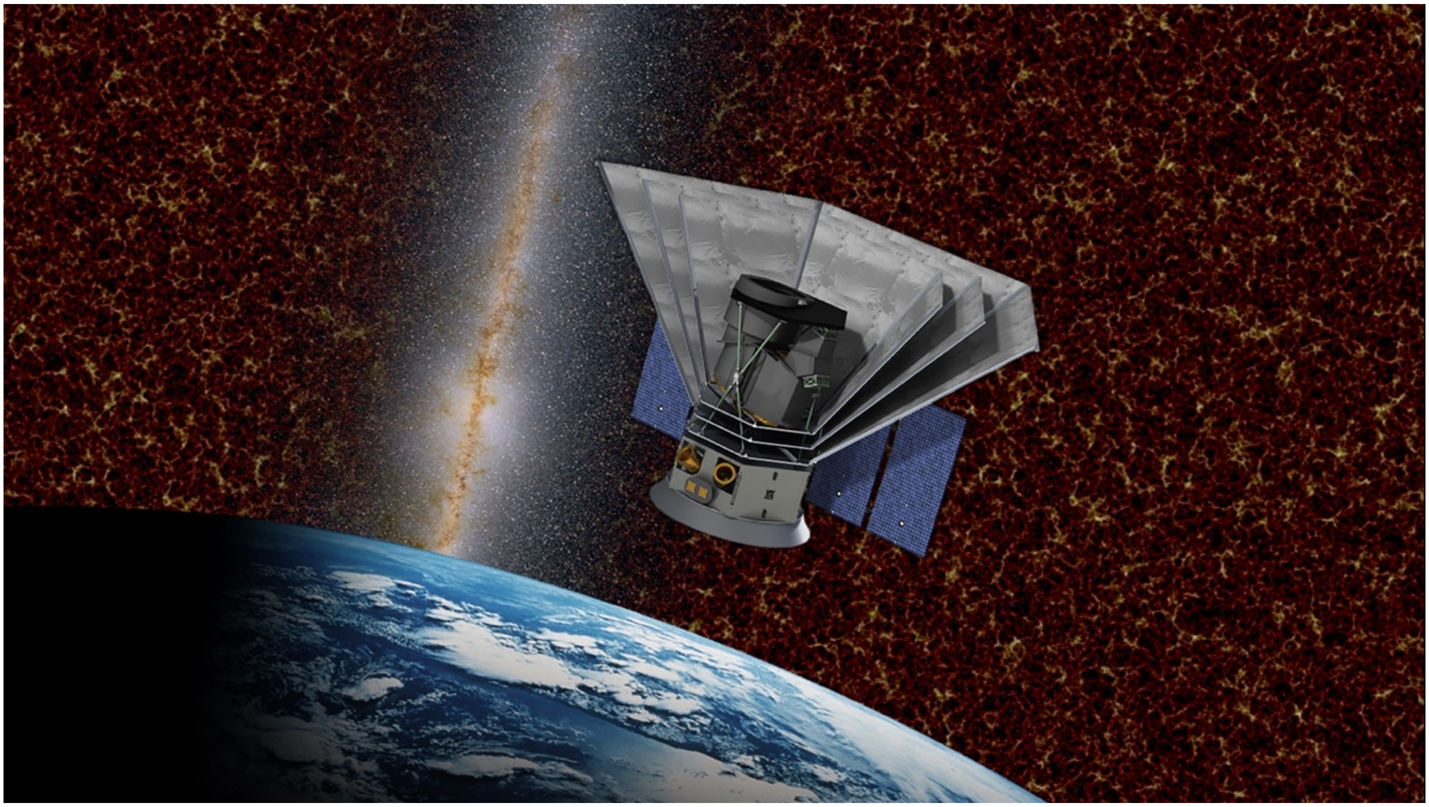
Written by: Michael Zemcov (RIT) and James Bock (Caltech/JPL)

SPHEREx, the Spectro-Photometer for the History of the Universe, Epoch of Reionization, and Ices Explorer, was selected as the next NASA MIDEX mission, as announced on 13 February[3]. Launching in 2023, SPHEREx will perform the first all-sky spectral survey at wavelengths between 0.75 and 2.42 µm (at spectral resolution $\lambda/\Delta\lambda=R=41$), 2.42 and 3.82 µm (at $R=35$), 3.82 and 4.42 µm (at $R=110$), and 4.42 and 5.00 µm (at $R=130$). At the end of its two-year mission, SPHEREx will have obtained near-IR spectra of every 6.2×6.2 arcsec^2 pixel on the sky, with a 5σ sensitivity AB~19 per spectral channel. In the context of existing data sets, SPHEREx will obtain spectra of every source in the 2MASS PSC (bands at 1.2µm, 1.6µm, 2.2µm) catalog to at least (40σ, 60σ, 150σ) per spectral channel, and per spectral element $S/N \geq 3$ of the faintest sources detected by WISE.

The SPHEREx team has three specific science investigations they plan to perform with this unique data set: cosmic inflation, interstellar and circumstellar ices, and the extra-galactic background light, each which addresses one of the three major themes of NASAs astrophysics program. SPHEREx will probe the origin of the universe by constraining the physics of inflation by measuring galaxy redshifts over a large cosmological volume. A sufficiently precise measurement of the three-dimensional positions of galaxy clusters allows significant constraints on different parameters of inflationary models. SPHEREx will investigate the origin of water and biogenic molecules in the early phases of planetary system formation in environments ranging from molecular clouds to young stellar systems with planet-forming disks by measuring absorption spectra to determine the abundance and composition of ices. Chief among these are water ices, which may offer insights to the emplacement and distribution of H_2O in the early stages of planetary system formation. Finally, SPHEREx will chart the origin and history of galaxy formation through a deep mapping survey. Statistical methods will be used to disentangle the history of emission from galaxies over cosmic time, including light from the first stars and galaxies emitted during the epoch of reionization.

While these three scientific issues are compelling, they are just a fraction of the potential scientific output of SPHEREx. All-sky surveys (e.g. IRAS, WMAP, Planck, GALEX, WISE) have played a major role in advancing modern astrophysics, enabling ground-breaking science and producing versatile legacy archives that have proven valuable for decades. SPHEREx will continue this tradition by creating a unique all-sky spectral database that includes spectra of huge numbers of astronomical and solar system targets, including both extended and diffuse sources, reviewed at a high level in Table 1. The SPHEREx data enable a wide variety of scientific investigations, and the team is dedicated to making data public on an aggressive schedule that will allow the community to use them either alone

[3] https://www.nasa.gov/press-release/nasa-selects-new-mission-to-explore-origins-of-universe



or in concert with the surveys and instruments of the mid-2020s. SPHEREx is well-timed to have follow-up synergy with large missions such as JWST, TESS, and eROSITA; to identify targets for more detailed study by JWST, SOFIA, or ALMA; and to set the stage for later missions such as WFIRST and PLATO. The synergy between SPHEREx and JWST is particularly strong, since SPHEREx will map the whole sky while JWST will hone in on the most compelling sources. This gives SPHEREx a particular timeliness to the missions of the 2020s, and the team's hope is that SPHEREx will play an important role in making the profound, un anticipated discoveries that will change our view of the astronomical Universe in the next decade and beyond.

Table 1

Object Type	# Sources	Legacy Science Enabled
Detected Galaxies	1.4 billion	Properties of distant and heavily obscured galaxies.
Galaxies $\sigma_z/(1+z) < 0.03$	120 million	Study (H, CO, O, S, H2O) line and PAH emission by galaxy type. Explore galaxy and AGN life cycle.
Galaxies $\sigma_z/(1+z) < 0.003$	10 million	Cross check Euclid photo-z redshifts. Measure dynamics of groups and map filamentary structure.
QSOs	>1.5 million	Understand QSO lifecycle, environment, and taxonomy.
QSOs at $z > 7$	2 - 300	Determine if early QSOs exist. Follow-up spectroscopy probes EOR through Lyα forest.
Clusters with > 5 members	100,000	Redshifts for all eRosita clusters $z < 1$, merger dynamics.
Main sequence stars	>100 million	Test uniformity of stellar mass function within our Galaxy as input to extragalactic studies.

More details on SPHEREx's design, implementation, specifications, and science reach are available at http://spherex.caltech.edu.

Two technical papers highlighting the range of science enabled by the SPHEREx data set are available on arXiv: https://arxiv.org/abs/1606.07039; https://arxiv.org/abs/1805.05489

The Origins Space Telescope

Written by: Margaret Meixner (OST Study Co-Chair, STScI), Asantha Cooray (OST Study Co-Chair, UC Irvine), and the OST Science and Technology Definition Team

Study website:
https://asd.gsfc.nasa.gov/firs/team/
https://origins.ipac.caltech.edu/page/team

Introduction:
Half of the light emitted by stars, planets, and galaxies over the lifetime of the Universe emerges in the infrared. The Origins Space Telescope (*Origins*) accesses this information-rich spectral region to uncover the crucial missing pieces of our cosmic history. *Origins* is a community-led, NASA-supported mission concept study in preparation for the 2020 Astronomy and Astrophysics Decadal Survey.

***Origins* Baseline Mission Concept:**
The *Origins Space Telescope* [1, 2, 3] and its suite of instruments utilize next-generation detectors and operate with spectral resolving power in steps from ~3 to 3×10^5 over wavelengths from 2.8 to 590 μm, the telescope and instruments are cryocooled to 4.5 K, and the light collecting area, 25 m^2, matches that of JWST. The Baseline Concept is a low-risk design concept that has minimal dependence on deployments and leaves appropriate margin between science-driven measurement requirements and estimated performance. The telescope's 5.9 m diameter primary mirror is segmented, like JWST, but round and it launches in its operational configuration. This departure from the JWST approach is enabled by new launch vehicle capabilities now in development. The telescope is a three-mirror anastigmat with an on-axis secondary. The telescope is diffraction limited at 30 μm and is used as a light bucket at shorter wavelengths.

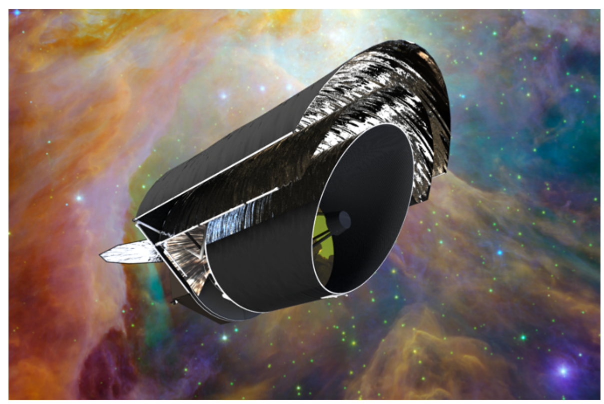


Figure 1: The Origins Space Telescope enables high-impact science in all three of NASA's key astrophysics areas, and our concept for the mission is low-risk and executable in the decade ahead.

Three science instruments provide powerful, new spectroscopic and imaging capabilities: Origins Survey Spectrometer (OSS, 25-590 *μ*m) [4], Far-infrared Imager and Polarimeter (FIP, 50 and 250 *μ*m) [5], Mid-Infrared Spectrometer and Camera (MISC) – Transit spectrometer (TRA, 2.8-20 *μ*m) [6].

***Origins* Science:**
Origins enables revolutionary scientific discoveries in many areas including:

How does the Universe work?

Origins probes our earliest cosmic origins by charting the rise of dust and metals in galaxies over cosmic time, and determine how the coevolution of star formation and supermassive black holes leads to the diversity in galaxies today.

How did we get here?

Origins follows the trail of water from the birth of the planet-forming disk to the assembly of pre-planetary materials, and in comets to understand the origin of Earth's oceans.

Are we alone?

Origins measures biosignatures in transiting exoplanet atmospheres at mid-infrared wavelengths to assess the habitability of nearby exoplanets and search for signs of life.

Equally important to these compelling questions, *Origins* is a flagship general observatory which provides the astronomical community access to unprecedented discovery space in the infrared. *Origins* is up to a factor of 1000 more sensitive than previous far-infrared space telescopes. Its versatile instrument suite enables deep and wide 3D surveys of the sky from the most distant galaxies to the outer reaches of our Solar system. The ultra-stable mid-infrared spectrometer builds upon JWST's expected work on exoplanets and push it to detection of biosignatures.

Status:

On April 26, the *Origins* Study Team submitted its report to NASA HQ for review. The team will continue to improve the report with the final submission in late August to NASA HQ which will submit the report to the NAS Astro2020 Decadal Survey. **At the summer AAS in St. Louis, there will be an *Origins* splinter session on Tuesday, June 11 come and discuss your ideas for Origins science!**

References:

[1] Battersby, C., Armus, L., Bergin, E. et al. (2018), Nature Astronomy. Volume 2, p. 596-599
[2] Meixner, M., Armus, L., Battersby et al. (2018), *SPIE, 10698*, 0NM
[3] Leisawitz, D., Amatucci, E., et al. (2018), *SPIE, 10698*, 15
[4] Bradford, C.M., Cameron, B. et al. (2018), *SPIE, 10698*, 18
[5] Staguhn, J., Amatucci, E., et al. (2018), *SPIE, 10698,* 1
[6] Sakon, I., Roellig, T., et al. (2018), *SPIE, 10698,* 17

Additional Information:

https://origins.ipac.caltech.edu
https://asd.gsfc.nasa.gov/firs/

IR SIG Astro2020 White Paper Coordination

Written by: Eric Murphy (NRAO)

In the last six months leading up to the submission deadline for Astro2020 Science White Papers, the IR-SIG Leadership Council helped create several resources to facilitate the coordination of white papers among the astronomical community.   These resources included the creation of a Google-Document to help identify white papers in thematic areas that would highlight key science advances achievable by observations in the infrared. The IR-SIG also worked with NRAO to make use of their community-supported website aimed at coordaining white papers amongst groups of astronomers working on the same science topic across wavelengths.

In addition to both of these online resources, the IR-SIG Leadership Council led a community discussion on white paper coordination at their splinter session at the 2019 AAS in Seattle Washington. This splinter session was extremely well attended, with roughly 50 participants, and helped increase the awareness of these online community forums.   In the end, there were ~60+ white papers listed on both of these websites, accounting for more than 10% of all Astro2020 Science White Papers submitted and clearly indicating that these efforts provided significant value to the astronomical community.

UPCOMING EVENTS

13-14 May 2019 – Herschel Ten Years After Launch: Science and Celebration
ESAC, Villafranca del Castillo, Madrid, Spain
https://www.cosmos.esa.int/web/herschel/herschel_ten_years_after_launch

13-17 May 2019 – New Horizons in Planetary Systems
Victoria Conference Center, Victoria, British Columbia, Canada
http://go.nrao.edu/NewHorizons

20-23 May 2019 – Exploring the Infrared Universe: The Promise of SPICA
Aldemar Knossos Royal, Crete, Greece
http://www.spica2019.org

3-7 Jun 2019 – IAU 352: Uncovering Early Galaxy Evolution in the ALMA and JWST Era
Viana do Castelo, Portugal
https://www.iaugalaxies2019.com

9-13 Jun 2019 – 234th American Astronomical Society (AAS) Meeting
*** OST Splinter June 11 3:30-4:30pm (Jefferson/Knickerbocker Room)**
St. Louis Union Station Hotel, St. Louis, MO
https://aas.org/meetings/aas234

18-20 Jun 2019 – Exploring the Galaxy and the Local Group with WFIRST
Caltech, Pasadena, CA
https://conference.ipac.caltech.edu/wfirstlocalgroup/

20-21 Jun 2019 – Origins Space Telescope: Community Science Meeting
Flatirons Institute, New York, NY
https://www.simonsfoundation.org/event/origins-space-telescope-community-science-meeting/meeting/

25-27 Jun 2019 – Radio/Millimeter Astrophysical Frontiers in the Next Decade
NRAO, Charlottesville, VA
http://go.nrao.edu/ngVLA19

22-26 Jul 2019 – 18th International Workshop on Low-Temperature Detectors
Palazzo Lombardia, Milan, Italy
https://www.ltd18.unimib.it/

5 Aug 2019 – ESA Voyage 2050 White Paper Workshop
Observatory of Paris, paris, France
https://cosmos.esa.int/web/voyage-2050

UPCOMING EVENTS

6-8 Aug 2019 – **Great Lakes Cosmology Conference**
Rochester Institute of Technology, Rochester, NY
https://www.rit.edu/glcw12/

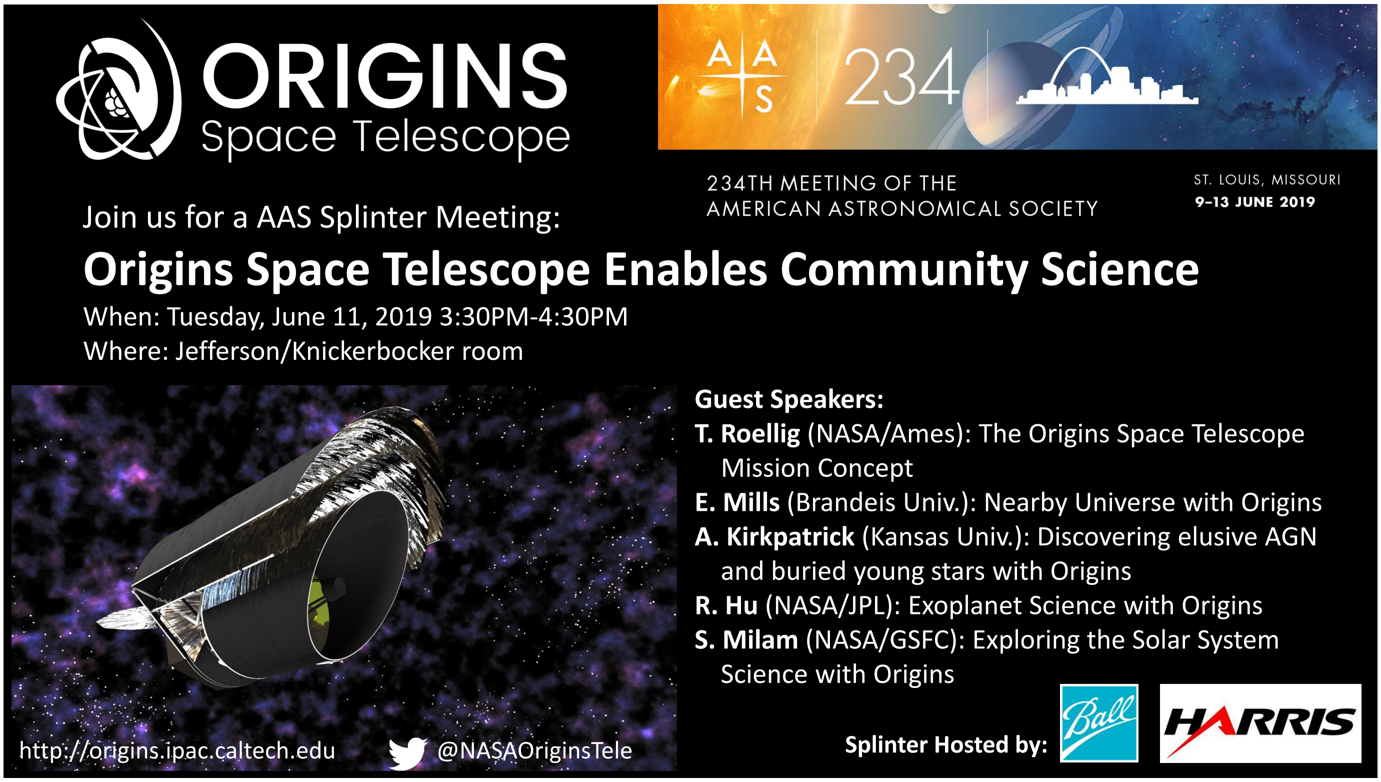
11-15 Aug 2019 – **SPIE Optics+Photonics Conference**
San Diego Convention Center, San Diego, CA
http://spie.org/conferences-and-exhibitions/optics-and-photonics?SSO=1

26-30 Aug 2019 – **Understanding the Nearby Star-Forming Universe with JWST**
Skyway Mont Blanc, Courmayeur, Italy
http://www.stsci.edu/institute/conference/unsfjwst2019

2-6 Sep 2019 – **The Physics and Chemistry of the Interstellar Medium**
Palais des Papes, Avignon, France
https://tielens2019.sciencesconf.org/

14-18 Oct 2019 – **ALMA2019: Science Results and Cross-Facility Synergies**
Cagliari, Sardinia, Italy
http://www.eso.org/sci/meetings/2019/ALMA2019Cagliari.html

UPCOMING EVENTS



ESA Voyage 2050 White Paper Call and Far-IR Workshop

ESA has issued a call for white papers for **Voyage 2050 Long-term Planning of the ESA Science Programme.** Details can be found at: https://cosmos.esa.int/web/voyage-2050

Deadline: 5th August 2019

Eligibility: any scientist (without restriction of nationality or residence)

We would like to invite you to a workshop to discuss possible far-IR White Papers for the ESA Voyage 2050 call at the Observatory of Paris on Friday 14th June 2019. If interested in the workshop please register at: https://evento.renater.fr/survey/far-ir-voyage-2050-meeting-participation-nm9lpr84. For those not available, but interested in staying on the e-mail list, just enter your name and email and click “no” for availability.

Please e-mail talk titles and any questions to martina.wiedner@obspm.fr (LOC).

Hoping to see you in Paris,

Susanne Aalto, Dimitra Rigopoulou, Frank Helmich, Maryvonne Gerin, Marc Sauvage, Lingyu Wang, Chris Pearson and Martina Wiedner

IR SIG Leadership Council

The current members of the IR Science Interest Group (SIG) Leadership Council are:

Duncan Farrah	**University of Hawaii**
Jeyhan Kartaltepe	**Rochester Institute of Technology**
Tiffany Kataria	**Jet Propulsion Laboratory**
Jens Kauffmann	**Massachusetts Institute of Technology**
Lisa Locke	**Jansky Fellow, National Radio Astronomy Observatory**
Enrique Lopez Rodriguez	**SOFIA Science Center**
Meredith MacGregor	**NSF Fellow, Carnegie Department of Terrestrial Magnetism**
Elisabeth Mills	**Brandeis University**
Eric Murphy (Co-Chair)	**National Radio Astronomy Observatory**
Omid Noroozian	**National Radio Astronomy Observatory**
Naseem Rangwala (Co-Chair)	**SOFIA Science Center**
Dave Sanders	**University of Hawaii**
JD Smith	**University of Toledo**
Johannes Staguhn	**Johns Hopkins University, NASA GSFC**
Mike Zemcov	**Rochester Institute of Technology**

Additional information about the IR SIG can be found at our website: **https://fir-sig.ipac.caltech.edu/**

To contact the IR SIG LC directly, email: **irsiglc@gmail.com**.

We are recruiting new members!

The Infrared Science Interest Group Leadership Council (IR SIG LC) invites applications to fill up to three council vacancies, to commence before September 1st 2019. Membership terms are flexible: 1, 2, or 3 years depending on availability. Applications are due by **July 15th 2019, 5pm Pacific time**.

The IR SIG LC is interested in applications from individuals working in areas relevant to the infrared astronomy community, including any area of science, and any instrument development domain. We are especially interested in applications from people who are dedicated to growing and developing community activities, and representing the needs of the community to NASA.

Applications, consisting of a cover letter plus two-page CV, should be sent by email to the IR SIG LC co-chairs: Naseem Rangwala (naseem.rangwala@nasa.gov) and Eric Murphy (emurphy@nrao.edu).