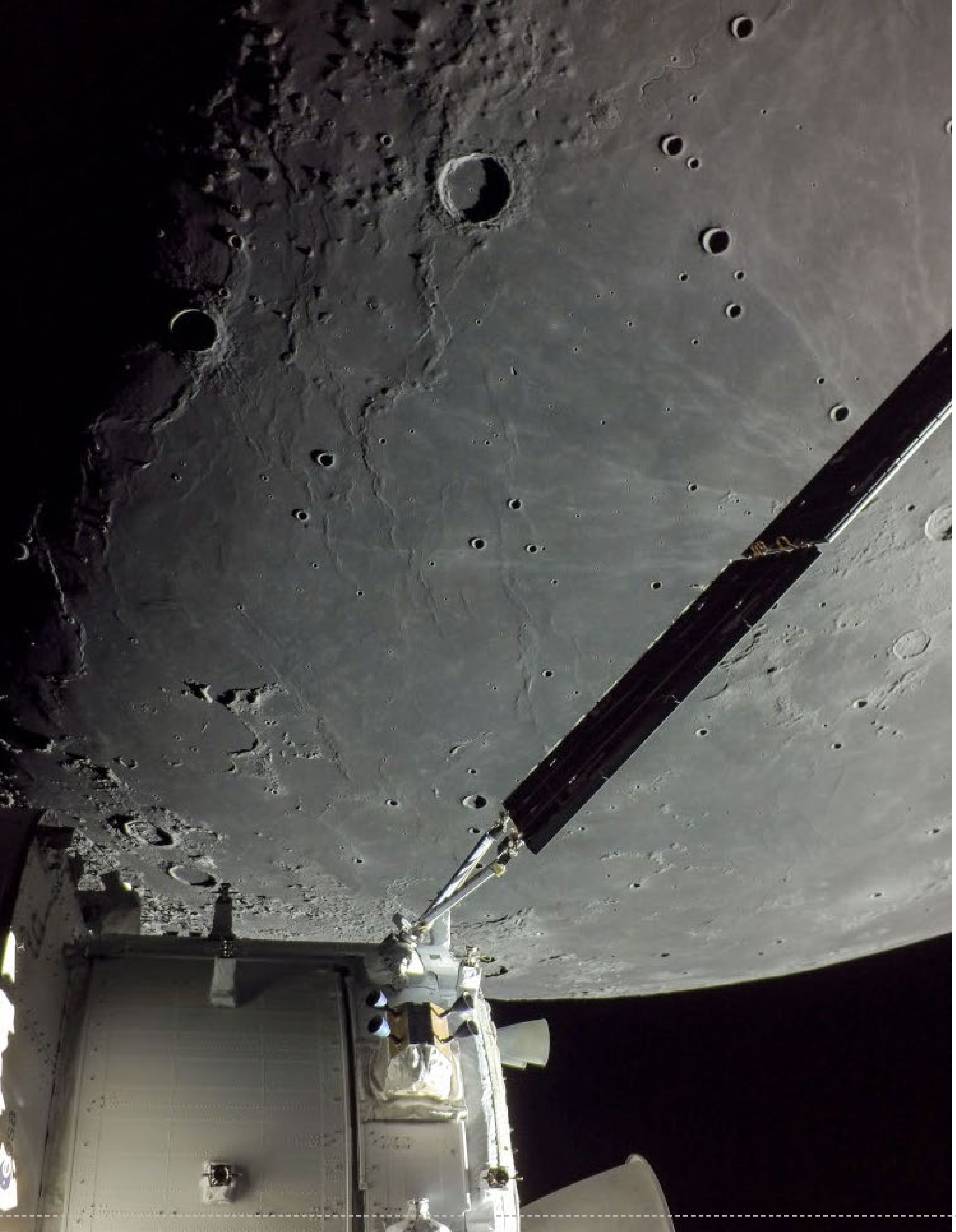
SPACE SCIENCE INSTITUTE

ANNUAL REPORT 2022

Space Science Institute . 4765 Walnut Street . Suite B . Boulder, Colorado 80301 . 720.974.5888 . www.spacescience.org . www.facebook.com/spacescienceinstitute



Our Mission

The Space Science Institute is shaping our future by enabling scientists to advance our understanding of Earth and the Universe; increasing science and technology literacy for people of all ages and backgrounds; and inspiring youth to pursue science-technology education and career opportunities.

Table of Contents

On the cover: NASA's Space Launch System rocket carrying the Orion spacecraft launches on the Artemis I flight test, Wednesday, Nov. 16, 2022, from Launch Complex 39B at NASA's Kennedy Space Center in Florida. Credit: NASA/Joel Kowsky

Left: A camera on board the uncrewed Orion spacecraft captured this view on December 5 as Orion approached its return powered flyby of the Moon. Credit: NASA, Artemis 1

Message from the Executive Director and Board of Directors

We are happy to present to you the best of Space Science Institute 2022 edition!

Thanks to health and safety protocols, SSI weathered the COVID-19 pandemic successfully. The Omicron variant spike hit SSI in January 2022, with key employees out sick. SSI minimized the number of people working onsite and invoked business continuity backups as mitigation strategies, and all deadlines for proposals, required reporting and filing, and taxes were met. We are thankful to our staff for coming together to support each other and ensure that our projects could continue. While Boulder, CO remained at "Medium" or "High" CDC community levels for COVID-19 for much of 2022, we were relieved when in February, mask mandates expired for SSI headquarters and when in May, Dr. Anthony Fauci declared that the U.S. was "out of the pandemic phase" and in a transitional phase where people could begin resuming more normal activities. This enabled SSI to return to more in-person group meetings and events, including our corporate retreat, Space Jam, which was held in person for the first time since the beginning of COVID-19.

SSI supported over 130 active federal awards in 2022 (up from 2021), and had impressive proposal successes, with first time proposal wins as well as new awards on compelling science and education topics. For example, the Gordon & Betty Moore Foundation approved a large grant for SSI's education team to support public engagement in libraries for the 2023 annular and 2024 total solar eclipses, which will provide 5 million solar viewing glasses, in-person training workshops, education kits, and print resources to 10,000 public libraries and 55 state library agencies across the U.S. and U.S. territories in the Pacific. SSI scientists also continued to be highly productive during the pandemic, clocking over 200 scholarly journal articles in 2022. Though some major conferences changed format to hybrid (part in-person, part virtual) or entirely virtual, by the middle of 2022, SSI principal investigators and programmatic staff were back on the road, with travel exceeding 2019 pre-pandemic levels, including international destinations (France, UK, Finland, Denmark, Canada, Spain, UAE).

This year's annual report features both a diversity of projects and projects on diversity. Our Research spotlight articles cover the gamut from infrared astronomy (Barnes), to a new SSI-led heliophysics mission concept study, MIO (Borovsky), and atmospheric studies of Saturn and Venus (Moses; Navarro). Our education team, SSI's National Center for Interactive Learning, led and supported approximately 10 large-scale projects in 2022, a few of which are featured in this report. Two new programs that we introduce here are NIFTY and STEM Tales, in which SSI educators have partnered with Twin Cities PBS and collaborators to reach underrepresented youth. The NIFTY (NASA Inspires Futures for Tomorrow's Youth) program connects NASA role models with youth-serving science, technology, engineering, and mathematics (STEM) programs for girls and historically excluded genders ages 9-14. The NSF-supported STEM Tales program aims to foster interest and self-confidence in STEM subjects and careers among children of color ages 4-8 from low-income urban communities with culturally responsive content.

SSI also welcomed two new members to our Board of Directors in 2022, Lisa May and Mike Gazarik. Lisa is the NexGen Strategy Lead for Lockheed Martin's Commercial Civil Space Advanced Programs and formerly served at NASA Headquarters, where she managed NASA's diverse portfolio of Mars missions. Mike is Vice-President of Engineering at Ball Aerospace and served as the Associate Administrator for the Space Technology Mission Directorate at NASA. We are very happy to have their strategic perspective and volunteer spirit on our Board and look forward to working with them in the years to come.

With the support of dedicated staff, volunteers, grantees, partners, and donors, we feel very fortunate to be able to continue delivering transformative work in STEM and communities. All of us at SSI and our Board of Directors wish for your continued health and happiness in 2023.

Karly Pitman, Ph.D.
Executive Director

Steven Jolly, Ph.D.
Chair (Jan - Aug)

William R. Purcell, Ph.D.
Vice-chair (Jan - Aug)
Chair (Aug - Dec)

Jack Burns, Ph.D.
Vice-chair (Aug - Dec)

Overview

History & Background

In the early 1990s, when Dr. Paul Dusenbery was conducting space physics research at the University of Colorado Boulder (CU), he recognized that, with regard to space science, a glaring divide stood between the academic world and the general public - and that there was a need for a better link between the two. In response, Dr. Dusenbery engaged other scientists in the field and founded a 501(c)(3) nonprofit, the Space Science Institute (SSI), in 1992. In its initial startup, SSI had a staff of three scientists who focused on advancing research and promoting space science education. By 2000, SSI was garnering national recognition for its advancements in space science. In 2003, SSI moved from the CU campus to Boulder, creating more space for business operations and for onsite research scientists and STEM educators.

Through collaborations with NASA, the European Space Agency, and other institutes, SSI scientists have secured participation in prestigious space missions and observatories, including the Mars Exploration Rovers, Rosetta, Cassini, Mars Reconnaissance Orbiter, Mars Global Surveyor, Hubble Space Telescope, THEMIS, Lunar Reconnaissance Orbiter, Mars Science Laboratory, Juno, Stratospheric Observatory for Infrared Astronomy, ExoMars Trace Gas Orbiter, OSIRIS-REx, Emirates Mars Mission and Mars 2020 Rover, James Webb Space Telescope, and Korea Pathfinder Lunar Orbiter (Danuri).

SSI has since expanded its impact in science and education through the creation of SSI's National Center for Interactive Learning (2010), Center for Extrasolar Planetary Systems (2013), Center for Space Plasma Physics (2013), Center for Mars Science (2014), Center for Polarimetric Remote Sensing (2017), and Center for Data Science (2019).

Left: A stellar flash like this had never been seen before - supernovas and novas expel matter out into space. Although the V838 Mon flash appears to expel material into space, what is seen in the featured image from the Hubble Space Telescope is actually an outwardly expanding light echo of the original flash. Credit: NASA, ESA, H.E. Bond (STScI)

Present

Today, SSI manages 75 employees and 21 affiliates, working in Colorado, nationally, and internationally. SSI is a leader in developing innovative science, technology, engineering, and math (STEM) programs that make engaging with science accessible, meaningful and fun for people of all ages and backgrounds. We conduct world-class scientific research and use the wonder of that discovery to inspire a broad population. SSI's role in advancing science understanding and pushing the frontiers of STEM learning has been recognized through competitive awards from NASA; the National Science Foundation; NASA Jet Propulsion Laboratory; the Space Telescope Science Institute; and the U.S. Department of Energy, among other prestigious funders.

Global Reach: On-site & Off-site

Map Diagram : SSI employees and affiliates work either on-site at SSI headquarters in Boulder or off-site at locations across the United States and internationally. SSI's education programs operate in all 50 states and 2 US territories.

Left: Danseiji IV projection of Earth
Credit: Justin Kunimune, Félix Pharand-Deschênes, Kirk Bergstrom and Michael Saup

2022 Board Members

- Dr. Jack Burns (Vice-Chair), Professor & Vice President Emeritus for Academic Affairs & Research, University of Colorado
- Dr. Douglas Duncan, Astronomer, Emeritus Faculty, Department of Astrophysical and Planetary Sciences, Former Director of Fiske Planetarium, University of Colorado
- Ms. Amanda Fisher, Manager, Association of Science and Technology Centers
- Dr. Mike Gazarik, Vice President of Engineering, Ball Aerospace
- Dr. Richard R. Green (ex officio), Former President and Chief Executive Officer, CableLabs, Inc.
- Ms. Jennifer Griest (Corporate Secretary, ex officio), General Counsel / Legal and Policy Specialist, Space Science Institute
- Dr. Steve Jolly (Chair), Systems Engineering Director, Lockheed Martin Corporation
- Ms. Lisa May, NextGen Strategy Lead, Lockheed Martin Corporation
- Dr. Windsor Morgan, Professor of Physics and Astronomy, and Charles M. Kanev Planetarium Director, Dickinson College
- Dr. Karly Pitman (ex officio), Executive Director / Senior Research Scientist, Space Science Institute
- Dr. Bill Purcell (Vice-Chair), Senior Manager Advanced Systems, Ball Aerospace and Technologies Corporation
- Mr. Gary Zarlengo (Treasurer), Small Business Consultant

2022 Executive Advisory Committee

- Dr. James Harold (Director, Education/National Center for Interactive Learning and Information Systems and Technology)
- Dr. Ralph Shuping (Deputy Director/Acting Director of Research)
- Mr. Carl Wuth (Director, Business Operations)

2022 Grants & Contracts

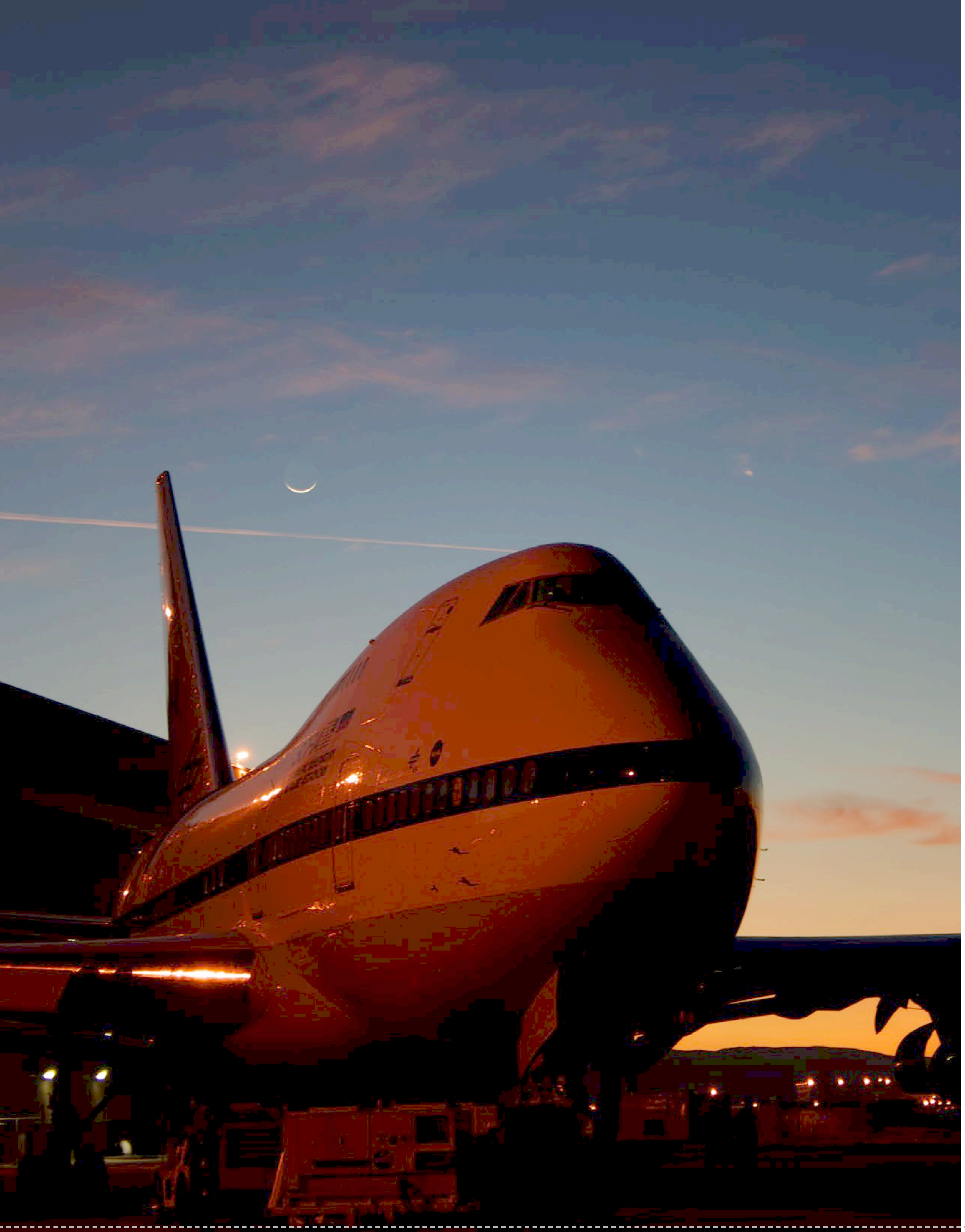
SSI gratefully acknowledges support from research and education grants and contracts from the following organizations in 2022:

- Aerospace Corporation
- Arizona State University
- Boston University
- U.S. Department of Energy
- NASA Jet Propulsion Laboratory, California Institute of Technology
- Laboratory for Atmospheric and Space Physics, University of Colorado Boulder
- Los Alamos National Laboratory
- Malin Space Science Systems
- Gordon and Betty Moore Foundation
- NASA
- National Science Foundation
- New Mexico Consortium
- Northern Arizona University
- Planetary Science Institute
- Purdue University
- Southwest Research Institute
- Space Telescope Science Institute (STScI)
- Twin Cities Public Television
- Universities Space Research Association
- University Corporation for Atmospheric Research
- University of Alabama, Huntsville
- University of Arizona
- University of California, Los Angeles
- University of Colorado, Boulder
- University of Iowa
- University of Maryland
- University of New Hampshire
- Virginia Polytechnic Institute and State University

2022 Colorado Gives Donor List

SSI wishes to thank the generous individuals who contributed to the Space Science Institute in 2022:

- Beth Buck
- Jack Burns
- Maria Dainotti
- Gregg Denning
- Douglas Duncan
- Paul Dusenbery
- Christine Eyler
- Amanda Fisher
- Michael Gazarik
- Jay Goguen
- Jennifer Griest
- Michael Hartinger
- Anne Holland
- Steve Jolly
- Steven Lee
- Mark Lemmon
- Kerry Lightenburger
- Thomas Lippert
- Lisa May
- Karin & Myron McCallum
- Neal Miller
- Brooks Mitchell
- Julianne Moses
- Thomas Navarro
- Alexey Pankine
- Karly Pitman
- William Purcell
- Claire Ratcliffe
- Ralph Shuping
- Michael Sitko
- Gorden Videen
- Evaldas Vidugiris
- Michael Wolff
- Carl Wuth



We Discover & Explore

SSI researchers work on the cutting edge of astrophysical, planetary, and space plasma sciences. The Research Branch is home to world experts in multiwavelength astronomy, Mars atmospheric and surface studies, cometary and outer Solar System research, and heliospheric physics. Our researchers come to work here from across the U.S. and abroad, leaving prestigious jobs at universities and national labs (e.g., NASA's Jet Propulsion Laboratory, Caltech and Los Alamos National Laboratory) to pursue the kind of creative freedom and work-life balance that SSI offers. SSI scientists are key team members on high-profile robotic and spacecraft missions for NASA and the European Space Agency, as well as for the exoplanet finding space observatory Kepler, the Stratospheric Observatory for Infrared Astronomy (SOFIA), and the Hubble Space Telescope. SSI is a pioneer in remote employment; nearly 75% of our employees do their scientific observations and calculations while telecommuting, offering freedom of movement to present at conferences around the world and flextime to work throughout the day and night to better collaborate and observe.

We Educate & Inspire

SSI is home to the National Center for Interactive Learning, which leverages SSI's successful experience in developing and implementing interactive STEM programs for museums, science centers and public libraries. NCIL also has a robust public outreach program and has developed a variety of digital and online programs that reach millions of people annually. Through engagement with communities in Colorado and across the U.S., we seek to enhance general STEM literacy and access to STEM careers especially for underserved and underrepresented groups.

A small sample of our strategic project partners in these efforts include: American Library Association (ALA), Chief Officers of State Library Agencies (COSLA), Association of Science-Technology Centers (ASTC), American Society of Civil Engineers, Lunar and Planetary Institute, University of Colorado, University of Virginia, Arizona State University, Engineers Without Borders, American Geophysical Union, Association of Rural and Small Libraries, Twin Cities Public Television, Education Development Center, GLOBE, Solar System Ambassadors, Night Sky Network, Space Telescope Science Institute (STScI), Informal Learning Institute, and many more.

Left: NASA's Stratospheric Observatory for Infrared Astronomy (SOFIA). Credit: R. Shuping

Discovery & Exploration

SSI Research Branch

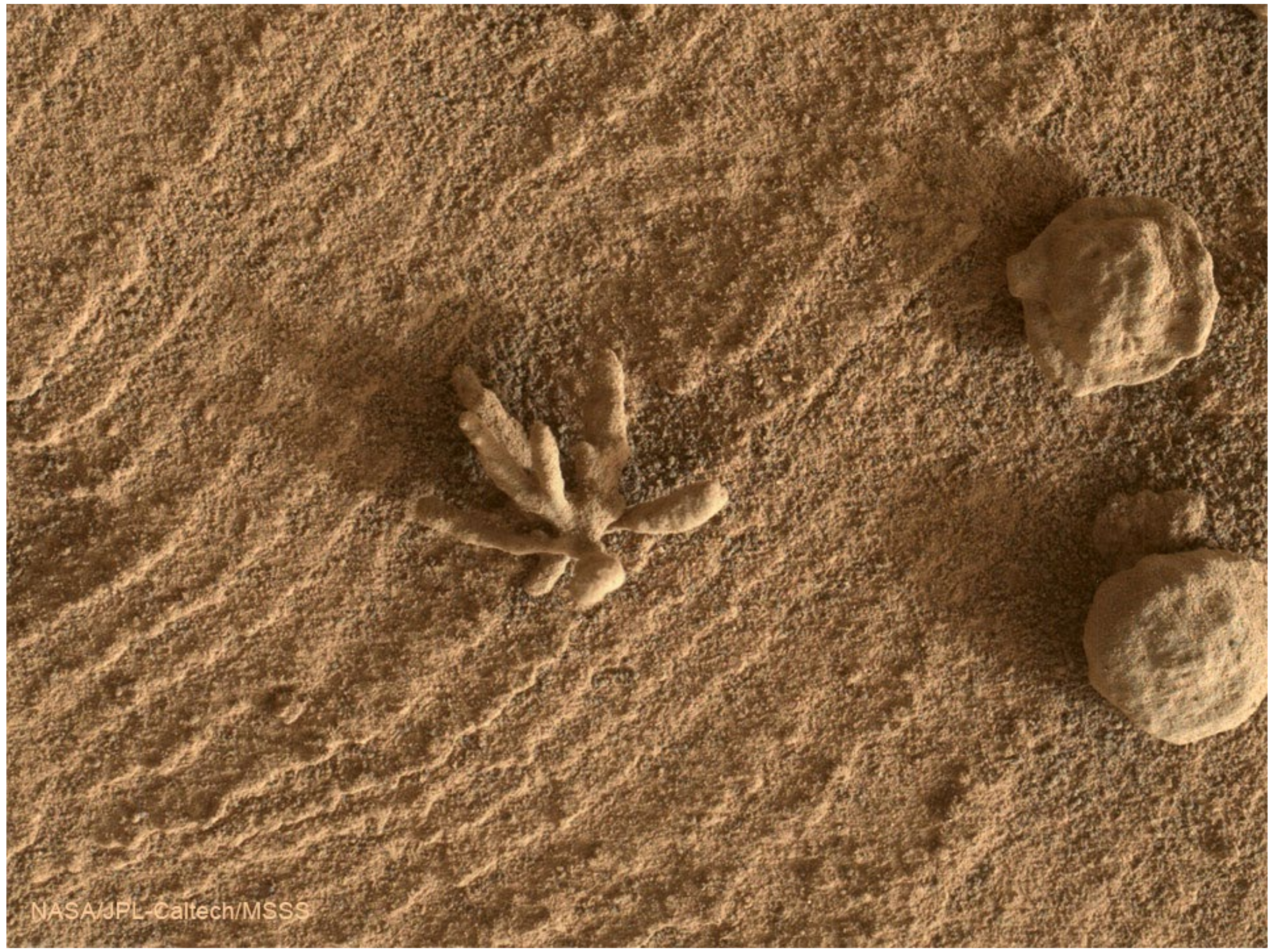
SSI's Research Branch scientists participate in a broad array of space science activities, including Earth science, space physics, planetary science, and astrophysics. Specific areas of expertise include Martian atmosphere and geology, extrasolar planets, helio- and asteroseismology, Earth's magnetosphere, and multiwavelength astronomy.

In 2022, the Research Branch welcomed 5 new principal investigators (PIs), 1 new postdoctoral research associate, and 1 new student research assistant, bringing our total number of branch team members to 80. In addition, we promoted one of our post-docs---Dr. Mel Abler---to full PI status after they secured funding for their own project. Ten of the 80 team members are located on-site at SSI's Boulder headquarters with the rest distributed across the U.S. and internationally.

While any individual scientist may pursue the subject area of their choice, SSI's Research Branch also runs five "Research Centers" to facilitate and promote collaborative research in topical areas of interest: the Center for Mars Science (CMS), the Center for Space Plasma Physics (CSPP), the Center for Extrasolar Planetary Studies (CEPS), the Center for Polarimetric Remote Sensing (CPRS), and the newly created Center for Data Science (CDS). See center reports below for more detail on center activities.

SSI scientists were awarded 27 new grants and contracts in 2022, primarily from NASA and NASA-funded primes, including notable awards in:

» space plasma physics (PIs: Mel Abler, Kristina Collins, Joe Borovsky, Jack Scudder)
» planetary and exoplanetary atmospheres (PIs: Julie Moses, Thomas Navarro)
» theoretical astrophysics (PI: Regner Trampedach)
» multiwavelength astronomy (PIs: Nicole Karnath, Derck Massa, Peter Barnes, Viviana Rosero)
» planetary geology (PIs: Shoshanna Cole, Bill Farrand)
» laboratory analogs (PI: Ahmed Mahjoub)



It is one of the more unusual rocks yet found on Mars. Smaller than a penny, the rock has several appendages that make it look, to some, like a flower. Credit: NASA, JPL-Caltech, MSSS

2022 Impacts

Total Research Branch Team Members:	80
Papers/abstracts/reports published:	>200
Invited/Public talks:	>40
New grant/contract proposals submitted (PI + co-PI):	75
New grants/contracts awarded:	27

Mission Support

Mars Curiosity and Perserverence Rovers (PIs: Michael Wolff, Mark Lemmon, Ben Clark)
Emirates Mars Mission (PI: Michael Wolff)
OSIRIS-REx (PI: Ben Clark)
Stratospheric Observatory for IR Astronomy (PI: Sachin Shenoy)

Research Center Updates

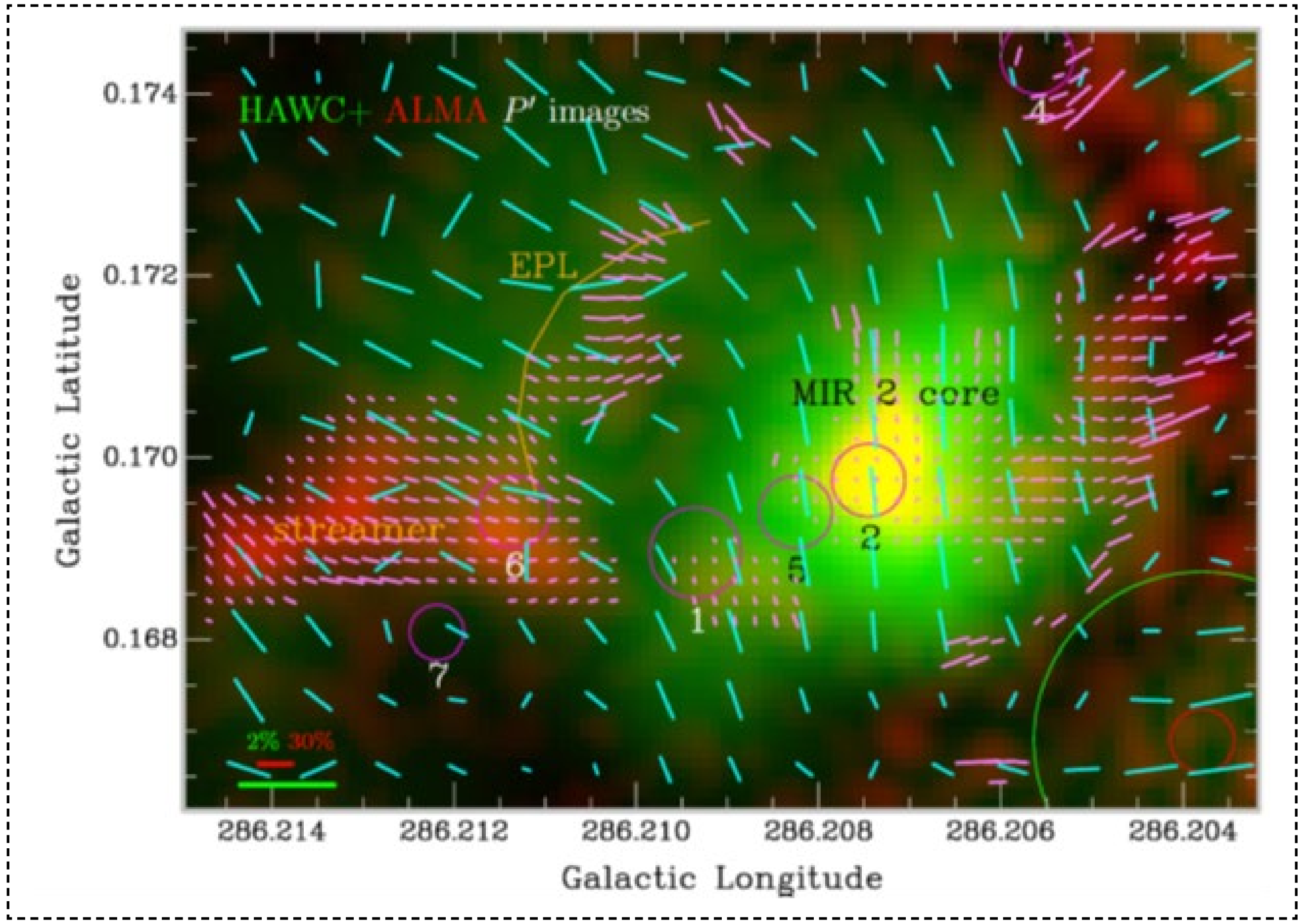
Center for Polarimetric Remote Sensing

The Center for Polarimetric Remote Sensing (CPRS) brings together SSI researchers interested in using polarization as a tool to further their research in characterizing extraterrestrial objects. In the last year at SSI, this research has taken many forms, a few of which we detail below.

Bill Farrand and Gorden Videen are members of the Korean Pathfinder Lunar Orbiter (KPLO) Participating Scientist Program and will use the polarization camera onboard the orbiter to characterize the lunar regolith. The KPLO, also known as Danuri, launched successfully in August 2022, and began transmitting lunar data at the beginning of 2023. The PolCam instrument design that is making lunar polarimetry measurements also will be incorporated into two CubeSats that will characterize superthin clouds and aerosols in Earth's atmosphere.

Peter Barnes is engaged in polarimetry studies of clouds. He recently completed a study of the magnetic fields in the star-forming cloud BYF 73. The polarization state of the observed electromagnetic fields reveals information about magnetic fields within these clouds, which can be used to characterize objects in these regions, including placing constraints on the masses of stars and protostars.

Gorden Videen recently published a book chapter with Evgenij Zubko summarizing how polarimetry can be used to characterize dust in cometary comae. This method that suggested material seen ejected by cometary jets was primarily organic was a radical notion for which the authors were lambasted, but their predictions were later verified by the Rosetta mission. The chapter, "Polarimetric Remote Sensing of Cometary Particles," was published in Light, Particles, and Plasmonics.



Polarization data from the central structures of the BYF 73 molecular core from HAWC+ and ALMA, taken from Barnes et al. (2023).

Center for Mars Science

The SSI Center for Mars Science (CMS) is composed of SSI researchers studying the surface and atmosphere of Mars. CMS researchers are involved in multiple NASA missions including the Mars Odyssey, Mars Reconnaissance Orbiter, and the Mars Science Laboratory Curiosity and Perseverance rovers. In the past year, CMS researcher and director, Bill Farrand, has been an active participant in Curiosity rover mission operations and in the analysis of data from its multispectral Mastcam instrument. Also involved with Curiosity rover operations and analysis of Mastcam data for Mars atmosphere studies is SSI researcher Mark Lemmon. SSI researcher Tim McConnochie is involved as a Participating Scientist with the Perseverance rover mission. CMS researchers Mike Wolff, Mikki Osterloo, Steve Lee, and Ralph Shuping have also been involved with the United Arab Emirates "Hope" Mars orbiter, working on that orbiter's EXI (Emirates Exploration Imager) instrument.

CMS researchers use the periodic CMS "Journal Club" teleconferences to present their results or to hear from guest speakers about their research. Journal Club speakers in the latter part of 2022 and into the first part of 2023 included CMS researcher Dr. Mike Wolff providing an update on "What's Going on with the Emirates Mars Mission?". Guest speaker Dr. Scott Van Bommel of Washington University in St. Louis spoke on his work studying Argon on the Martian atmosphere using data from the Curiosity rover's APXS instrument. Venturing beyond Mars, but on a topic with relevance for Martian geology, new SSI researcher Dr. David Trang, gave a CMS Journal Club presentation about his research into lunar pyroclastic deposits.

In terms of public outreach, CMS director Bill Farrand gave presentations on Curiosity and Perseverance rover activities to both a "Science and Spirits" night at the Spirit Hound Distillers in Lyons, CO in late summer of 2022 and a Nerd Nite Denver show in the spring of 2023.

Left: InSight's seismometer on May 4, 2022, the day it detected one of the largest Marsquakes ever.
Credit: NASA/JPL-Caltech

Center for Data Science

Center for Data Science (CDS) aims at bringing together domain experts in the space sciences and highly skilled computer scientists sharing a common interest in Data Science (DS) and Machine Learning (ML). Established in December 2020, CDS group consists of 27 scientists from various domains of space science and computer science.

One of the major highlights of the activities of CDS is an e-Book (available at https://www.frontiersin.org/research-topics/25408/) consisting of articles on applications of ML and statistics (or DS) in the domains of heliophysics, magnetospheric sciences, space weather, planetary sciences, exoplanets, astrophysics, and cosmology presented at the National Science Foundation-funded international (virtual) conference on "Applications of Statistical Methods and Machine Learning in the Space Sciences" during 17-21 May 2021 (http://spacescience.org/workshops/mlconference2021.php).

Another significant contribution of CDS to the scientific community is a peer-reviewed "Frontiers" article, on the need of "AI-ready data" for the purpose of applications of artificial intelligence (AI) in the various domains of space science (https://www.frontiersin.org/articles/10.3389/fspas.2023.1203598/full) and the standards and recommendations of getting the data "AI-ready). This multi-authored article, led by CDS, is a result of the various discussions on Zoom over several months (this is also available as a Heliophysics Decadal Survey White Paper at, https://baas.aas.org/vol-55-issue-3). Other CDS activities include exploring to various NASA and NSF funding opportunities that encourage proposals implementing DS/ML techniques, several peer-reviewed publications and numerous conference presentations.

As an organization of scientists, CDS plans to continue its activities in an attempt to inspire the scientific community to utilize key insights on emerging technologies such as AI that have profound impacts on the way scientific problems can be addressed and modeled.

Left: Adobe AI generated image using prompt "space science institute boulder colorado center for data science"

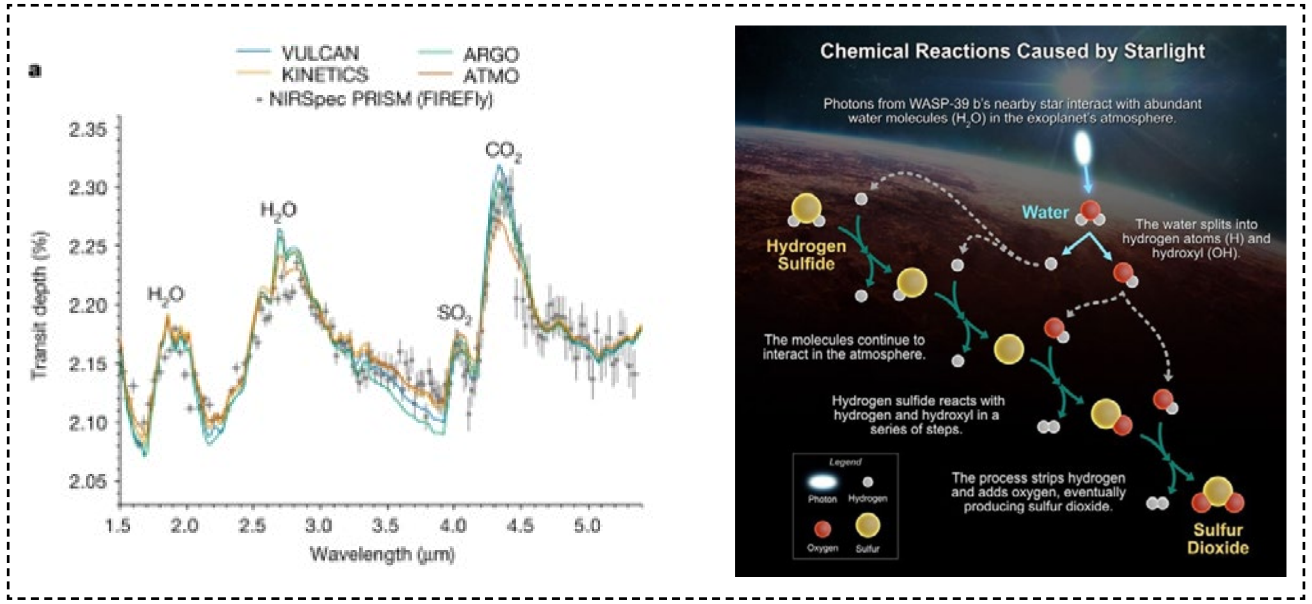
Center for Extrasolar Planetary Systems

The Center for Extrasolar Planetary Systems (CEPS) brings together SSI researchers who are interested in the exploration and characterization of diverse extra-solar planetary systems. CEPS provides a forum for its members to discuss recent scientific results and discoveries, collaborate on proposals and papers, and discuss and develop proposal strategies. Given the interdisciplinary nature of extrasolar planetary science, CEPS research covers a wide range of topics, including the study of exoplanet atmospheres and chemistry, young stellar objects, stellar formation, the formation of planetary systems, radiative transfer, the determination of planet-host star properties, the analysis of the signatures of planetary formation as reflected in debris disks, and lessons learned from observations of our own Solar System.

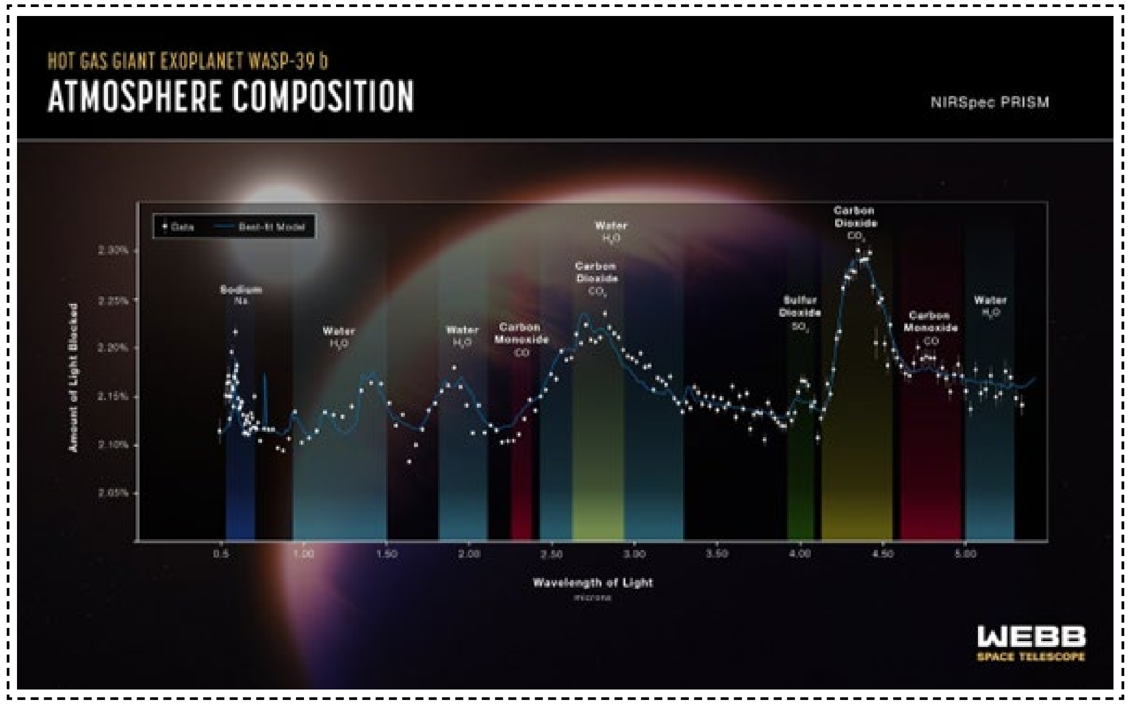
The Center for Extrasolar Planetary Systems includes 11 scientists who over the past 18 months contributed to over 70 peer-reviewed publications in scientific journals and numerous (over 100) conference and workshop presentations, along with ongoing education and outreach activities, observing collaborations (including *Hubble, Spitzer, IRTF, ALMA, VLT*, and *ARIEL*), and several grant proposals, and many new collaborative opportunities for new observations with the *James Webb Space Telescope*.

Recent research highlights include: new results obtained from initial observations with JWST, including the first robust detection of a photochemical product in the atmosphere of an exoplanet (SO2 on WASP-39b; Moses and Visscher, in Tsai et al. 2023), the near-infrared detection of CO2 (Moses, with JWST Transiting Exoplanet ERS Team 2023), and an exploration of day-night transport induced chemistry on WASP-39b (Moses, in Tsai et al. 2023); the possible detection of H2O in the atmosphere of the hot-Saturn HATS-5b (Fraine, in Allen et al. 2022); exploring disequilibrium chemical processes to probe atmospheric mixing in substellar atmospheres (Visscher, in Mukherjee et al. 2022); using atmospheric retrievals to study the observational effects of refractory cloud formation in brown dwarfs, including the behavior of patchy forsterite clouds in an exoplanet analog (Visscher, in Vos et al. 2023); developing new models to explore the atmospheric effects of energy balance and dynamics for Venus-type exoplanets (Parkinson et al. 2022); exploring the behavior of convective storms on Saturn (Dyudina in Gunnarson et al. 2023); long-term variability in Jupiter's tropospheric temperatures (Yanamandra-Fisher, in Orton et al. 2023); and new observations and analysis of dippers– a class of young stars that exhibit significant and aperiodic drops in brightness due to the presence of a protoplanetary disk. Dipper events in face-on disks may be caused by a misaligned inner disk, disk wind, the presence of exoplanets, or accretion onto the star (Sitko et al. 2023).

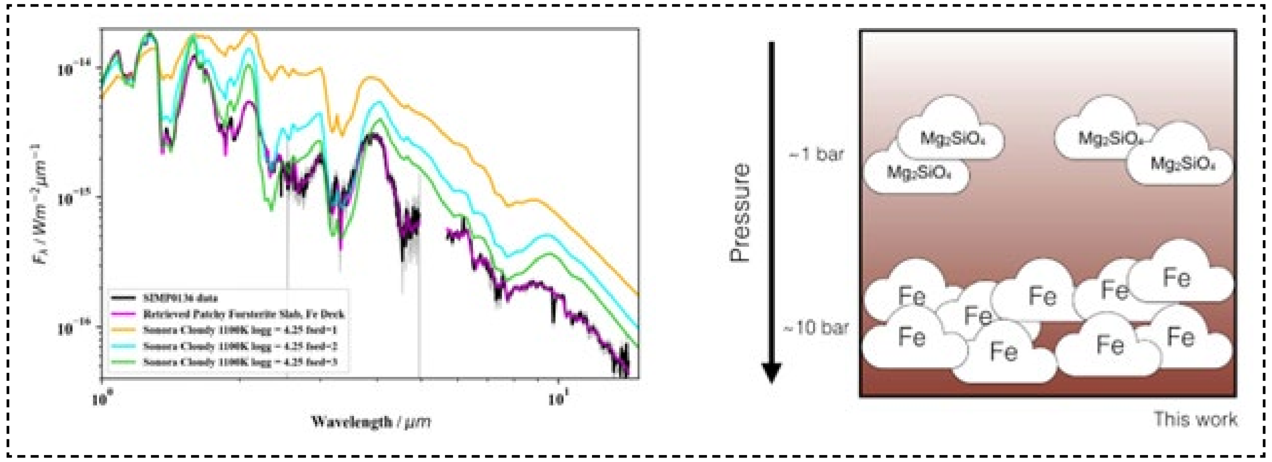
CEPS maintains a website (http://ceps.spacescience.org/home-page.html), accessible through SSI's main page, to highlight research being done by center members and to provide an interface with the public and other researchers in the exoplanet community.



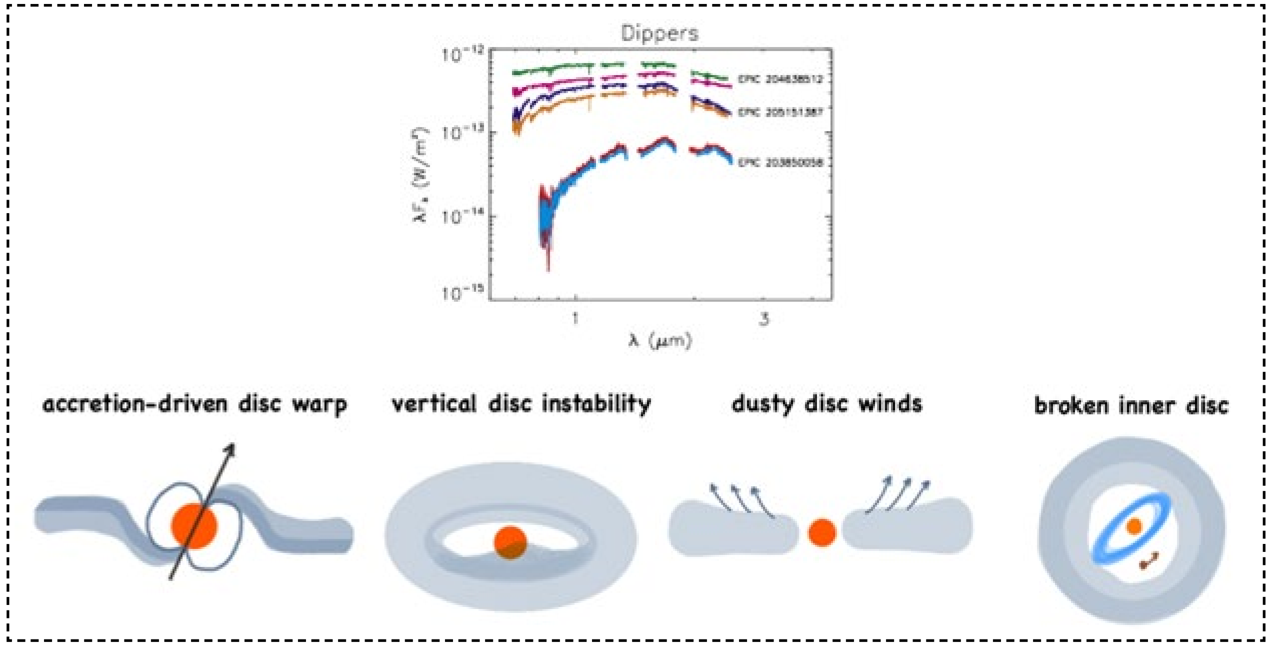
A comparison of transmission spectra generated by 1D photochemical models with JWST NIRSPec observations of WASP-39b. The detection of SO2 represents the first confirmed observation of active phtochemistry in an exoplanet atmosphere. Tsai, SM. et al. 2023, Photochemically produced SO2 in the atmosphere of WASP-39b, *Nature*, **617**, 483-487. Right image credit: NASA/JPL-Caltech/Robert Hurt; Center for Astrophysics-Harvard & Smithsonian/ Melissa Weiss



JWST NIRSpec PRISM spectrum of WASP-39b
Credit: NASA, ESA, CSA, J. Olmsted (STScI)



Model spectrum for the T dwarf exoplanet analog SIMP J0136+09 based upon retrievals of IRTF, Spitzer, and AKARI data. The retrieval results suggest the presence of patchy forsterite clouds above a deeper Fe cloud deck.Figure from Vos, J. et al. 2023, Patchy Forsterite Clouds in the Atmospheres of Two Highly Variable Exoplanet Analogs, *Astrophysical Journal*, **944**, 138.



Spectra of three dippers obtained with the IRTF SpEX spectrograph, Sitko, M.L. et al. 2023, Wavelength-dependent extinction and Grain Sizes in "Dippers", Astronomical Journal, 166(24). A number of mechanisms have been proposed to explain the observed behavior of dippers. Figure from Ansdell, M. et al. 2020, Are inner disc misalignments common? ALMA reveals an isotropic outer disc inclination distribution for young dipper stars, *Monthly Notices of the Astronomical Society*, **492**, 572-588.

ADS Links

Sitko et al https://ui.adsabs.harvard.edu/abs/2023AJ....166...24S/abstract
Ansdell et al. https://ui.adsabs.harvard.edu/abs/2020MNRAS.492..572A/abstract
Vos https://ui.adsabs.harvard.edu/abs/2023ApJ...944..138V/abstract
Tsai https://ui.adsabs.harvard.edu/abs/2023arXiv230519403T/abstract
Tsai https://ui.adsabs.harvard.edu/abs/2023Natur.617..483T/abstract
Mukherjee https://ui.adsabs.harvard.edu/abs/2022ApJ...938..107M/abstract
Allen https://ui.adsabs.harvard.edu/abs/2022AJ....164..153A/abstract
JWST Transit team https://ui.adsabs.harvard.edu/abs/2023Natur.614..649J/abstract
Orton https://ui.adsabs.harvard.edu/abs/2023NatAs...7..190O/abstract
Parkinson https://ui.adsabs.harvard.edu/abs/2022arXiv220510958P/abstract
Gunnarson https://ui.adsabs.harvard.edu/abs/2023Icar..38915228G/abstract

Center for Space Plasma Physics

The Center for Space Plasma Physics (CSPP) provides an umbrella for very broad NASA-sponsored and NSF-sponsored research efforts on plasma physics and the plasmas of the heliosphere. In calendar year 2022 the members of CSPP published 94 papers in refereed journals: 25 papers as primary authors and 69 papers as contributing authors.

Research highlights published in calendar year 2022 dealt with topics as diverse as magnetic reconnection, sonification of magnetospheric plasma waves, magnetospheric dipolarization events, turbulence, lunar gas plumes, and solar-wind/magnetosphere coupling.

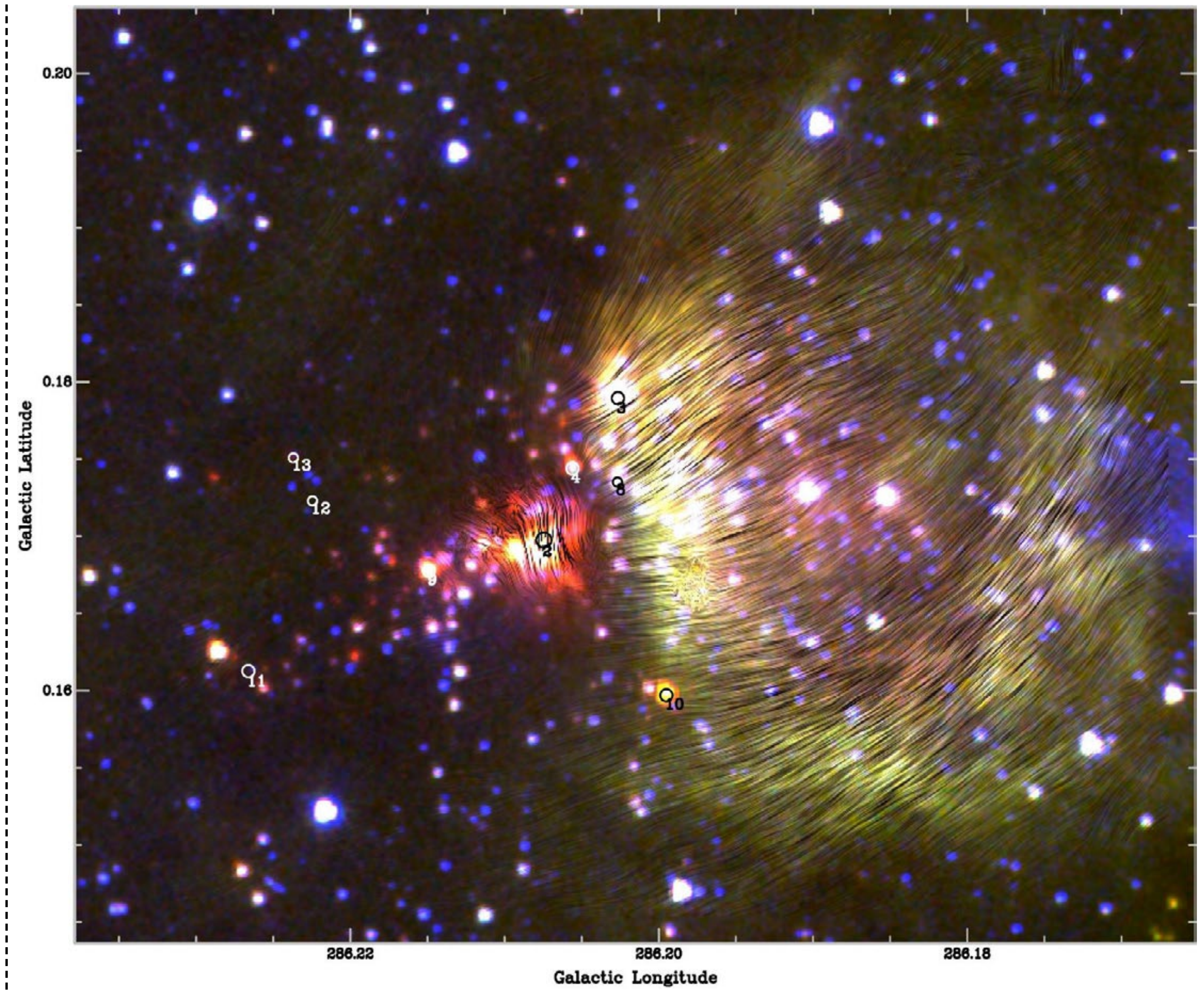
Dr. Peter Barnes; Gainesville, FL

I have been leading a team using polarimetry to study the role of magnetic fields in star formation in our Galaxy's molecular clouds. In 2023 we completed a project on the massive cloud BYF 73, using data from the SOFIA and ALMA observatories. This is outwardly an ordinary cold, dark molecular cloud a few parsecs (10 light years) in size and located about 2500 pc (8000 ly) away from us, in the Carina spiral arm of the Milky Way, with some indications of modest star formation. Despite this relatively small size, it is actually on the massive side (20,000 times the Sun's mass), and was originally noticed as having the strongest collapse rate of gas into the center of any molecular cloud known. Since massive star formation is still not well-understood, the ALMA+SOFIA project aimed to resolve the mass flow onto the central object (MIR 2), and how magnetic fields might be resisting the force of gravity which is causing the collapse.

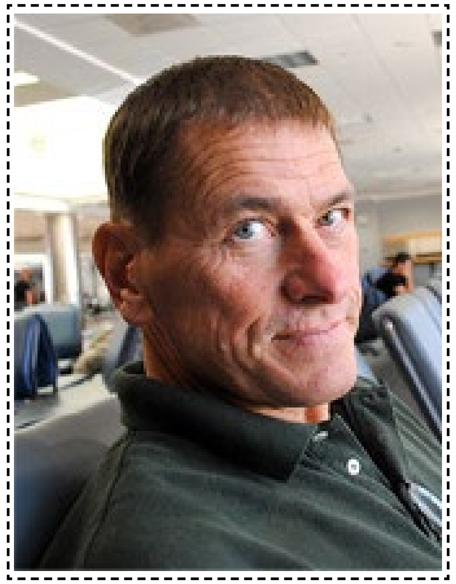
Like lower-mass protostars in the process of accumulating matter, MIR 2 was found to have a very strong bipolar jet which is carrying away the angular momentum of the infalling gas. The ALMA data allowed us to map the magnetic field in this outflow, suggesting that this feature is likely driven by magnetic energy release around MIR 2's accretion disk. All of these features show the hallmarks of youth: MIR 2 seems to have only started collapsing about 40,000 years ago, some time *after* humans first reached Australia.

On the more general question of what it takes to form massive stars in the first place, we discovered that MIR 2's gravity was even stronger than previously thought, and was likely from a protostellar core of mass 1300 Msun. At the same time, the magnetic fields in the cloud were also at the top end of the range for normal star-forming clouds, about half a milligauss. We believe that normal star formation in this cloud was hindered by the strong magnetic field, and because of this only a very massive protostar could generate enough gravity to overwhelm the magnetic field's outward pressure. This is in stark contrast to the more common low-mass (ie, Sun-like) star formation, where the magnetic fields are weaker and apparently allow smaller concentrations of gas to collapse to form the more ordinary, less massive stars.

The study was published in the Astrophysical Journal: Barnes, Ryder, Novak, Crutcher, Fissel, Pitts & Schap 2023 *ApJ* **945** 34.



The magnetic field orientations of BYF 73, as derived from SOFIA data, are overlain on a com-posite image of the region taken by the Spitzer Space Telescope and Anglo-Australian Telescope. The circled areas are locations of protostars in the region identified by ALMA and the Gemini Observatory. These studies help astronomers uncover the relationship between mag-netism and gravity in star formation. Credit: NASA/Spitzer/SOFIA/ALMA/Gemini/AAT/Barnes et al.



The MIO Mission-Concept Study

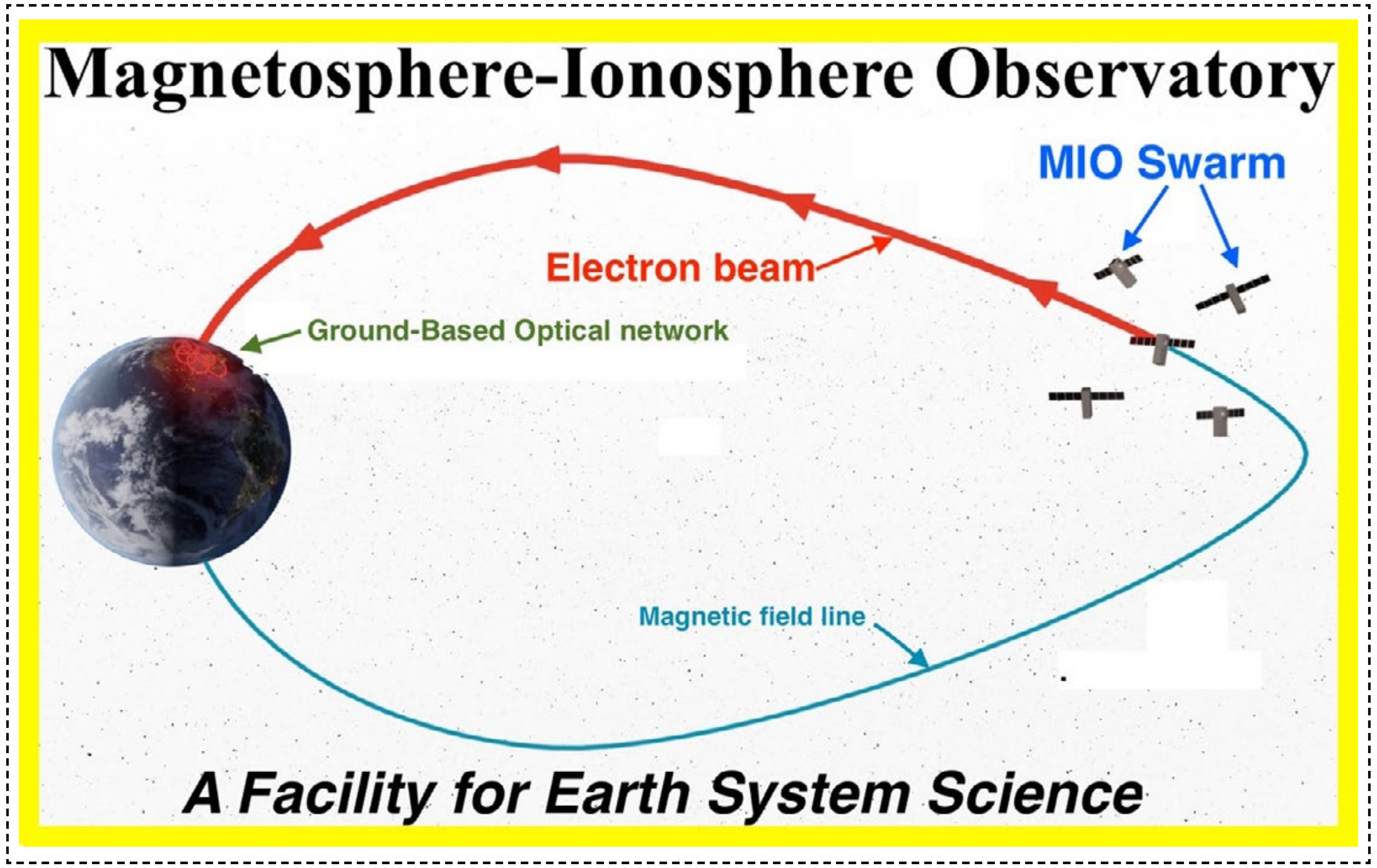
Dr. Joe Borovsky;
Los Alamos, NM

The Space Science Institute led a NASA-funded mission-concept study for the Magnetosphere-Ionosphere Observatory (MIO) concept via the NASA Heliospheric Mission Concept Study (HMCS) program.

The MIO mission is designed to fix a longstanding cause-and-effect problem in magnetosphere-ionosphere physics: In the nightside magnetosphere-ionosphere system we don't know what is magnetically connected to what. This lack of connection knowledge underlies our lack of understanding of what magnetospheric processes drive aurora and other ionospheric processes.

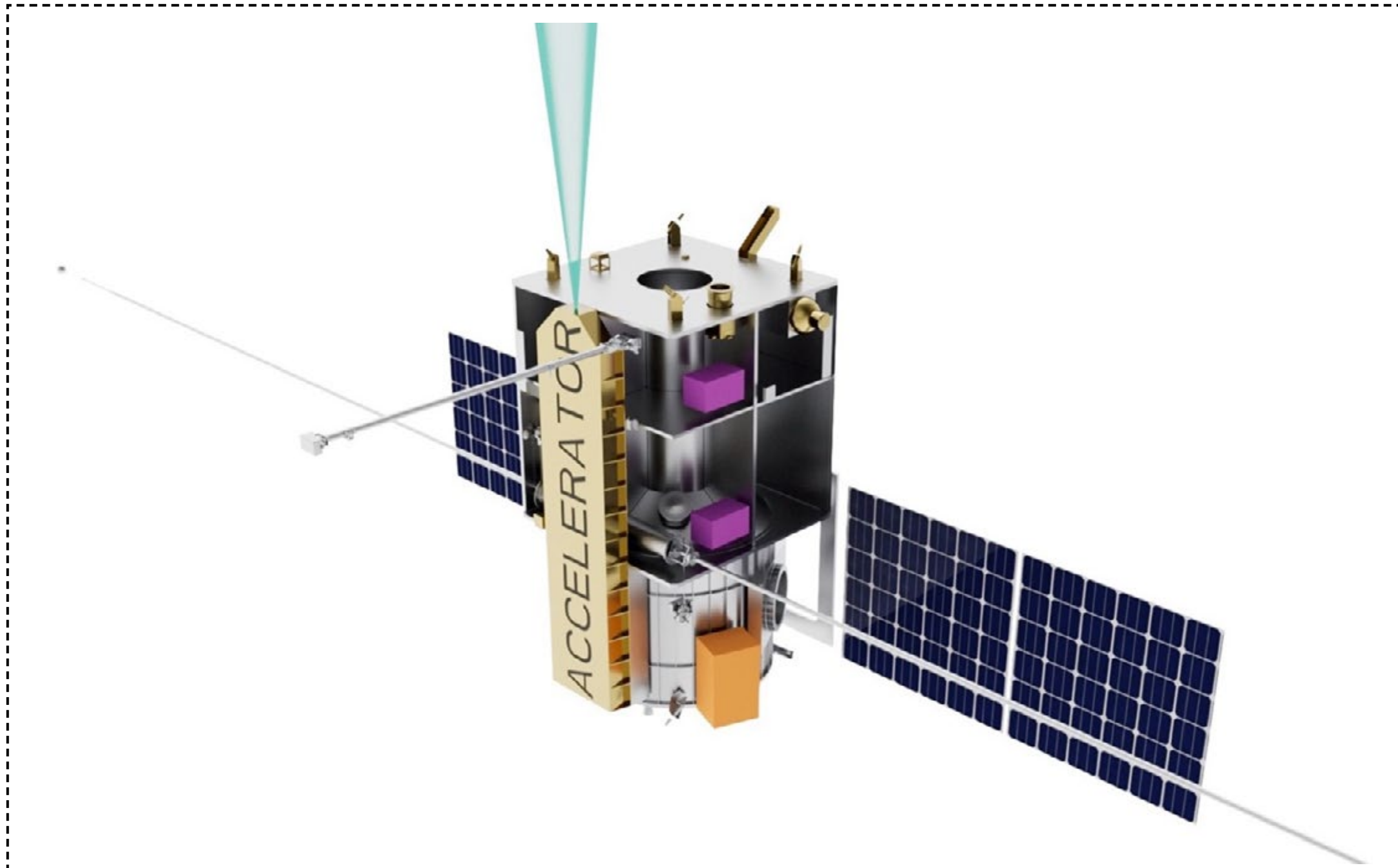
To overcome the magnetic-connection problem, the MIO mission concept is to operate a powerful 1-MeV electron accelerator on a main spacecraft in the equatorial nightside magnetosphere with the electron beam directed into the atmospheric loss cone to deposit ionizing electrons in the atmosphere sufficient to optically illuminate the magnetic footpoint of the spacecraft while 4 nearby daughter spacecraft make equatorial magnetospheric measurements. A network of ground-based imagers across Alaska and Canada would locate the optical beamspot thereby unambiguously establishing the magnetic connection between equatorial magnetospheric measurements and ionospheric phenomena. Critical gradient measurements would be made to discern magnetospheric field-aligned-current generator mechanisms. This enables the magnetospheric drivers of various aurora, ionospheric phenomena, and field-aligned currents to be determined.

The four specific science goals of MIO are to: (1) Determine to what regions in the magnetosphere the various auroral forms and the various ionospheric phenomena map. (2) Determine to where in the ionosphere magnetospheric regions, boundaries, and events map. (3) Determine what in the magnetosphere produces the various auroral forms and ionospheric phenomena. (4) Determine in what ways the magnetosphere drives field-aligned currents. The overarching objective of MIO is to unambiguously connect equatorial magnetospheric measurements to ionospheric phenomena. MIO would be a system-science facility that will support ground-based scientific campaigns and spacecraft-conjunction campaigns with the ionospheric, atmospheric, and magnetospheric communities.



An overview sketch of the MIO spacecraft swarm in the nightside magnetoshere.

The HMCS study resulted in a mission point design that represents a concept maturity level of 4 (CML-4), which demonstrates that MIO is technically feasible, fully addresses the science objectives and minimizes risk and cost of implementation. In summary, MIO consists of a small constellation of spacecraft in a 24-hour, low-inclination, eccentric orbit that maintains a magnetic footprint over Northern Canada and Alaska. The main spacecraft houses the electron accelerator, plasma contactor, plasma-wave instrument, electron-drift instrument, and magnetometer, while the four smaller spacecraft host electrostatic analyzers and magnetometers. The accelerator operations are focused around two years of winter and summer months. The accelerator will fire three, 0.5 second pulses (like a morse code S) at 5 minute intervals or when triggered by other sources. The 4 small spacecraft are in 200 x 400 km relative orbit about the main, allowing the constellation to measure radial and in-track gradients and to detect boundaries. Cross-links between the main spacecraft and the rest of the constellation allow for autonomous triggering of the accelerator. All other payloads will collect data at all times during nominal operations. At the end of life, all spacecraft will be disposed of by raising the orbit perigee above the GEO graveyard.



An engineering depiction of the MIO main spacecraft carrying the relativistic electron accelerator.

The SSI-led HMCS study involved 40 engineers at the JHU/APL ACELab. The full life cycle cost for the MIO mission (Phases A-F; with 50% unencumbered reserves, including the launch vehicle) was determined to be $1.33 B. The cost estimate is based on APL's extensive experience in deep space mission and includes a combination of actuals and historical data. This cost demonstrates that the MIO mission is feasible and compelling as a STP-class mission in the coming decade.

The study results were submitted to NASA and to the National Academies Solar and Space Physics Decadal Survey; additionally three research papers on MIO were published in the refereed literature.

Apparent conflict between Cassini mass spectrometer measurements and Saturn's deeper atmosphere: What does it all mean?

Dr. Julie Moses; Seabrook, TX

During the "Grand Finale" stage of the Cassini mission in 2017, the spacecraft spent five months in a series of north-south orbits passing between Saturn's innermost rings and the uppermost regions of the atmosphere, before the orbiter executed its final death plunge into Saturn's atmosphere. The spacecraft skimmed Saturn's equatorial upper atmosphere during the last few orbits, allowing the Ion Neutral Mass Spectrometer (INMS) instrument to directly sample the atmospheric composition for the first time. Scientists expected that only hydrogen and helium would be detected at these high altitudes, given that heavier molecules intrinsic to the planet should be confined to deeper atmospheric levels. The results were a surprise. Hydrogen and helium were certainly detected, but so were methane, water, ammonia, carbon dioxide, carbon monoxide and/or molecular nitrogen, and a slew of even heavier molecules, with a rich signal reminiscent of Titan's abundant organics. These molecules were not present in tiny quantities but constituted a non-trivial fraction of the local upper atmosphere. Given that these heavier molecules were sharply concentrated near the equatorial region, the INMS team concluded that the instrument was recording an inflow of molecules from the rings. (cont'd)

Figure 1

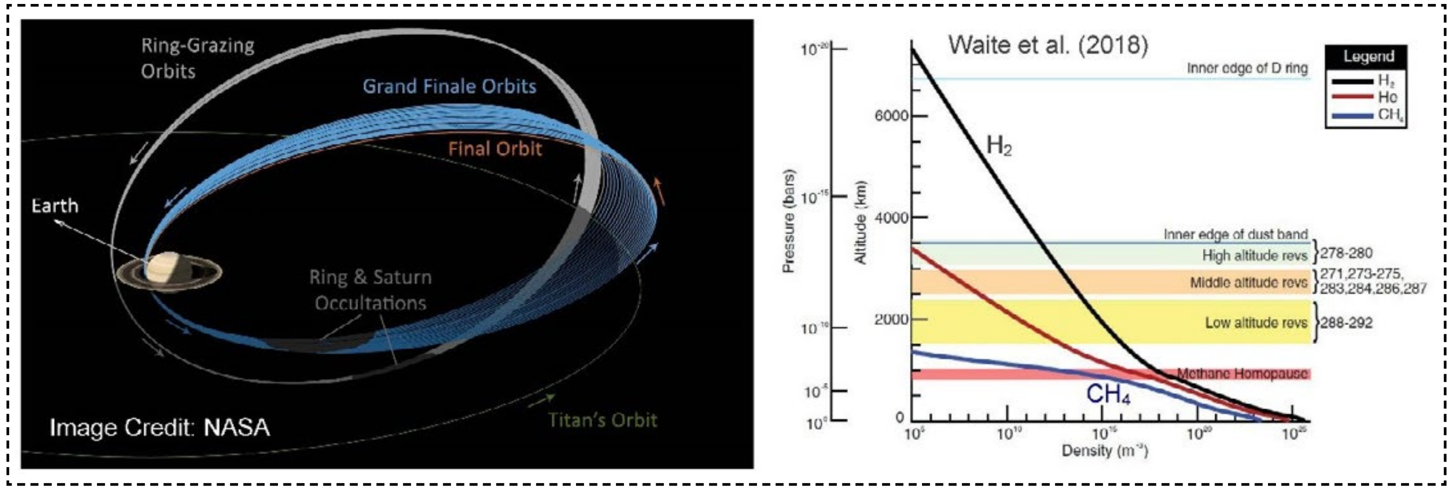
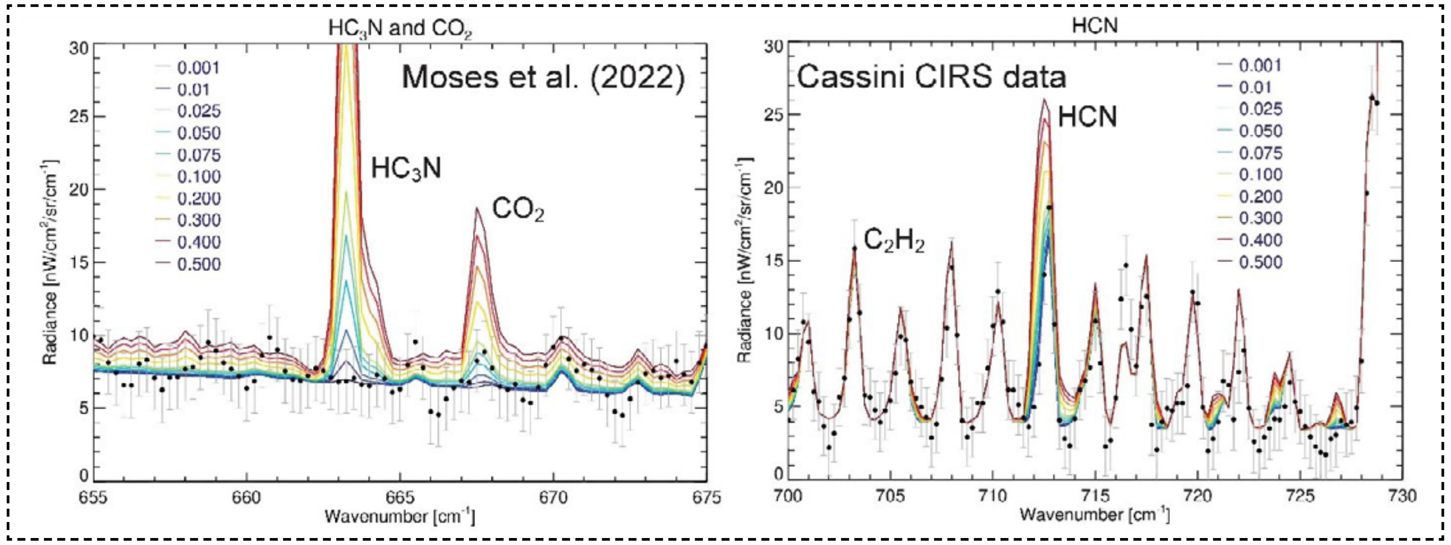


Figure 2



The resulting external inflow rates needed to maintain the measured abundances of these heavy molecules were found to be enormous by other planetary standards – a whopping 10,000 kg of material was inferred to be entering Saturn's equatorial atmosphere every second. The results clearly have implications for the lifetime of the rings, but this enormous ring influx rate would also have implications for atmospheric chemistry. A team led by SSI researcher Julianne Moses used atmospheric chemistry models to explore the consequences of this ring inflow for the composition of Saturn's thermosphere, ionosphere, and stratosphere. In a paper published in 2022, they found that the inflowing ring molecules would change the composition and structure of the equatorial ionosphere, with the main ionospheric peak being dominated by heavy ions such as HCNH+ and HCO+, rather than lighter H+ and H3+ – a result seemingly consistent with other measurements during the Cassini Grand Finale orbits. However, the consequences for the neutral stratosphere would be even more profound, with the ring molecules participating in local photochemistry, altering the abundances of previously observed hydrocarbons and producing a handful of very abundant oxygen- and nitrogen-bearing molecules. Here is where a conflict with other observations arises. Moses and colleagues found no evidence for these predicted abundant constituents or other changes to Saturn's atmospheric composition in contemporaneous remote-sensing observations from infrared and ultraviolet instruments aboard *Cassini*. Even under the most conservative assumption of complete global spreading before the ring material reaches the stratosphere, with much of the ring debris entering as dust and only the most volatile molecules entering the upper atmosphere as vapor, Moses and colleagues found that the chemical consequences of this ring inflow could not be hidden (see Fig. 2). How then can these different sets of observations be reconciled?

Moses et al. concluded that either (1) the inferred ring influx represents an anomalous, transient situation that was triggered by some recent dynamical event in the ring system that occurred a few months to a few years before the 2017 end of the Cassini mission, or (2) a large fraction of the incoming material must have been entering the atmosphere as small icy and organic-rich dust particles that impacted, fragmented, and vaporized within the INMS instrument during the flybys, rather than as vapor or as large particles that are likely to ablate and release vapor when entering the atmosphere. If the culprit is a recent perturbation within the rings that has continued to supply vapor to the atmosphere, some of the predicted consequences should begin to appear within Saturn's stratosphere within next few years; additional JWST or ground-based observations could shed light on the nature and timing of this putative ring-vapor inflow event. If small dust particles are responsible, no such changes will be observed, but then a discrepancy between the inferred flux of small dust particles from the INMS data must be reconciled with other dust-flux measurements from other instruments aboard Cassini. Regardless of the source of the puzzling INMS signals, it is clear that the Cassini Saturn observations will continue to intrigue us long after the mission's end.

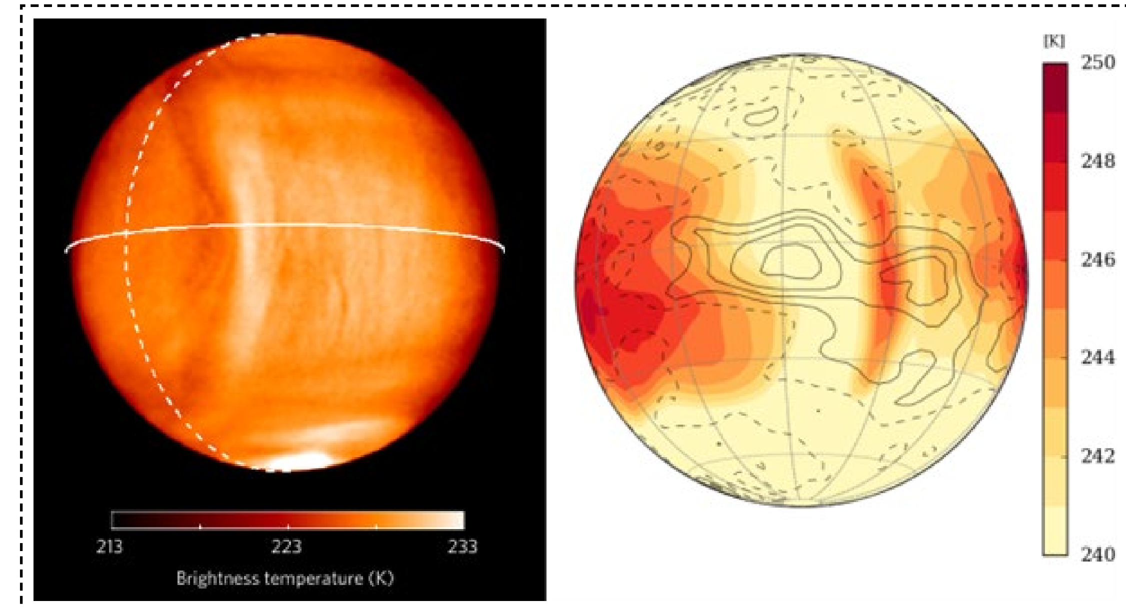
Exploring the Atmosphere of Venus through Computer Simulations

Dr. Thomas Navarro;
Montreal, QC, Canada

Venus, often referred to as Earth's twin sister due to its similar size and proximity, presents a stark contrast as a dry, inhospitable world shrouded in a global cover of sulfuric acid clouds. Among its fascinating features is the superrotation of its atmosphere, where clouds complete one rotation in just 4 Earth days, significantly faster than the planet's slow revolution, taking 243 Earth days. The mechanism behind this superrotation remains a mystery, although it is observed in other celestial bodies like Titan, Saturn's largest moon, and is believed to occur in all slow-rotating bodies, including exoplanets tidally locked to red dwarfs.

To delve into the atmospheric dynamics and superrotation of Venus, the Japanese Space Agency (JAXA) launched the spacecraft Akatsuki. It orbits Venus since 2015 and employs infrared and UV cameras to peer into its clouds. To aid in interpreting Akatsuki's images, I utilize numerical simulations with the IPSL PCM (Institut Pierre-Simon Laplace Planetary Climate Model), an advanced 3D atmospheric model capable of simulating various planetary atmospheres, including that of Venus. This state-of-the-art model, developed over decades, necessitates supercomputers to run effectively.

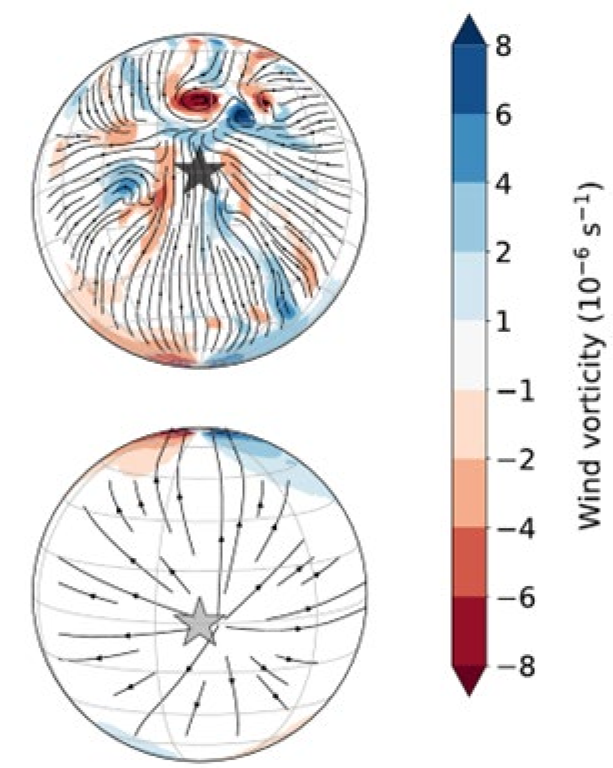
Upon its arrival, Akatsuki made a groundbreaking discovery at the cloud top (70 km) of Venus—a planetary-scale, bow-shaped structure, appearing fixed with the planet's surface rather than being influenced by the superrotating winds of the upper atmospheric layer. By refining the parameterization of the surface in the IPSL PCM, I successfully replicated this structure. Numerical models provide comprehensive spatio-temporal coverage, making them invaluable when they align with observational data. In this case, I identified the structure as a gravity wave triggered by air flowing along the flanks of Venus' highest mountains. Additionally, I explained how the diurnal cycle near the surface contributed to the periodic appearance of these waves, consistently observed during Venusian afternoons. Furthermore, I predicted that these mountain waves represent the primary means of angular momentum exchange between the planet's atmosphere and its solid body, a critical factor in explaining the surplus of angular momentum and potentially unraveling the origins of superrotation.



Venus' cloud top seen in the thermal infrared by Akatsuki (left) and simulated by the ISPL PCM (right). The mountain wave appears as a bow-shaped disturbance in the temperature field.

More recently, the IPSL PCM has been extended vertically into the thermosphere, allowing for simulations that capture the propagation of mountain waves from the surface to altitudes exceeding 130 km. These simulations not only elucidated the transport of momentum by mountain waves to the uppermost atmospheric layers of Venus, but also unveiled an unexpected result. Within the thermosphere, the model revealed that winds reach supersonic speeds, resulting in a planet-wide supersonic shock that induces decelerated and disorganized atmospheric motion downstream of the shock. This finding aligns with the observations made by ESA's Venus Express mission, which documented erratic motions of the oxygen airglow a decade ago—phenomena that we now fully replicate and comprehend using the IPSL PCM.

While the atmosphere of Venus still harbors numerous enigmas, numerical models serve as a powerful tool for bridging the gap between observations and their underlying physical causes, and the previous examples clearly illustrate the immense power of numerical simulations in unraveling the secrets concealed within Venus's atmosphere.



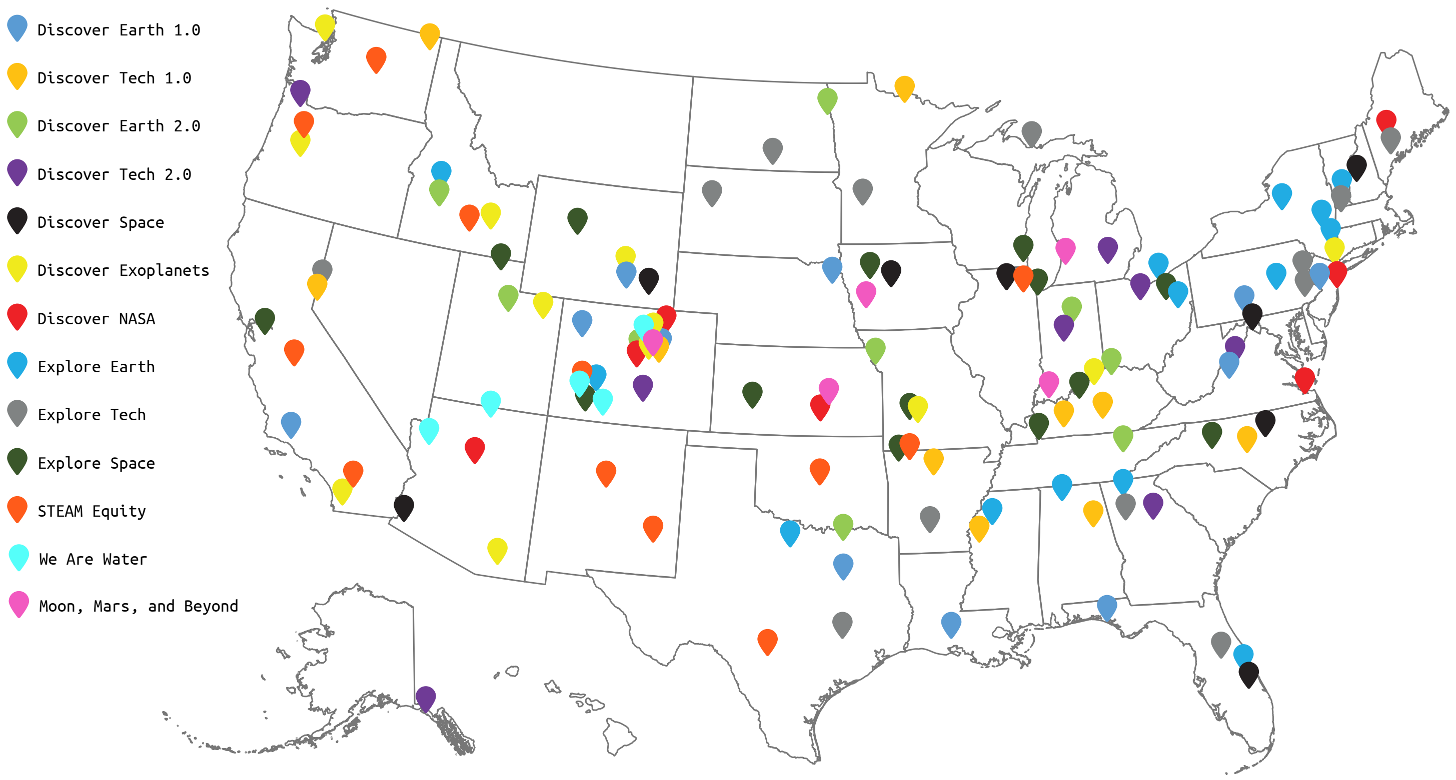
Simulated thermospheric winds showing the disorganized nightside downstream of a shock (bottom), in stark contrast to the organized, upstream dayside (top).

Education & Inspiration

Education / National Center for Interactive Learning

SSI's ***National Center for Interactive Learning*** (NCIL) is a leader in developing science, technology, engineering, and mathematics (STEM) educational resources, including exhibitions, active learning programs, and educational games. NCIL also employs a combination of in-person and online training methods to balance the need to reach a large audience, while laying the foundations for deep, ongoing learning in STEAM facilitation. For the last decade, NCIL has placed a particular focus on engaging and working with public libraries, which provide a pathway for reaching historically underrepresented and underserved audiences throughout the U.S. Current projects include a wide range of strategies, including traveling library exhibits, community dialogues, remote and in-person professional development trainings, check-out STEM education kits, online apps, and the STEM Activity Clearinghouse, which provides a one stop shop for vetted, library appropriate, hands on activities.

NCIL Impact Numbers for 2022



STAR Net exhibition host library sites

Traveling Exhibit Visitors

STEAM Equity Exhibit (12 host sites):	22,001
Discover Exoplanets (4 host sites):	33,136
Moon, Mars, and Beyond (5 host sites):	16,859
We Are Water (4 host sites):	71,996
Total Number of Visitors:	**143,992**

In-person Professional Development Participants: 159

Webinar Participants

Unique Live Views:	482
YouTube Recording Views:	838

STAR Net Online Community Members: 8,000

NCIL Outreach Event Participants: 500

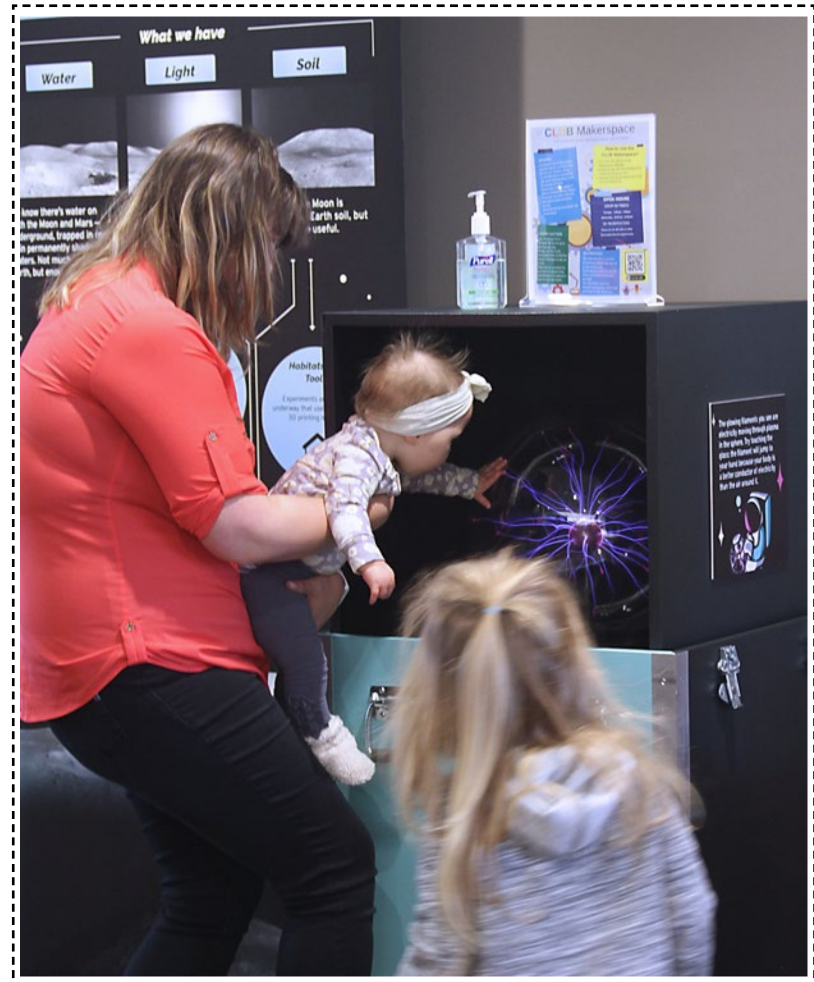
Exhibition Website Visitors

	Page Views:
Alien Earths:	25,315
Giant Worlds:	10,751
SciGames:	179,430
Space Weather Center:	34,188
Killer Asteroids:	46,382
Starchitect:	20,488
STAR Net:	85,580
STEM Activity Clearinghouse:	76,394
National Center for Interactive Learning:	3,078
Total Pageviews:	**481,606**

Featured Programs

From Our Town to the Moon, Mars, and Beyond

The Moon, Mars and Beyond exhibit, funded through the NASA Teams Engaging Affiliated Museums and Informal Institutions (TEAM II) program, kicked off its national tour in 2022, beginning with a workshop for host libraries. Held at the Erie Community Library in Colorado, 16 librarians, from 8 host sites, spent two days learning about the Artemis project, the exhibit, and activities they could do with their patrons. An optional extra day qualified attendees to check out lunar materials through the NASA Astromaterials program. The exhibit itself includes a mix of high tech kiosks (real time space weather, a quiz game, digital jigsaw puzzles, and more); low tech activities such as a coloring wall mural and "dot voting"; and displays that include hydroponic tomatoes grown from seeds flown to space. After its launch in Erie it moved on to Newburgh, Indiana; Coloma, Michigan; Florence, Arizona, and Avoca Iowa. In 2023 it will continue its tour to 3 more locations.



NIFTY

Funded by NASA as part of its Science Activation program, NASA Inspires Futures for Tomorrow's Youth (NIFTY) officially launched in July 2022. The NIFTY project goal is to connect NASA STEM role models with youth-serving STEM programs for underrepresented youth (ages 9-14), with a critical focus on girls and other historically excluded genders in STEM, which includes cis girls, trans youth, gender non-conforming, and/or non-binary youth, youth of color, and their families. The project is led by Twin Cities PBS (TPT). Partners include the National Girls Collaborative and NASA Langley Research Center, with Technology for Learning Consortium serving as the project's independent evaluator. A competitive RFP was designed to select 15 public library partners through the STAR Library Network and 35 educational outreach partners through the National Girls Collaborative to be matched with 50 NASA affiliated role models, and a literature review was conducted to update the SciGirls Role Model Strategies to be more gender-inclusive with evidence-based approaches for engaging youth.

A Mars Geochemist presenting to a group of youth

STEM Tales

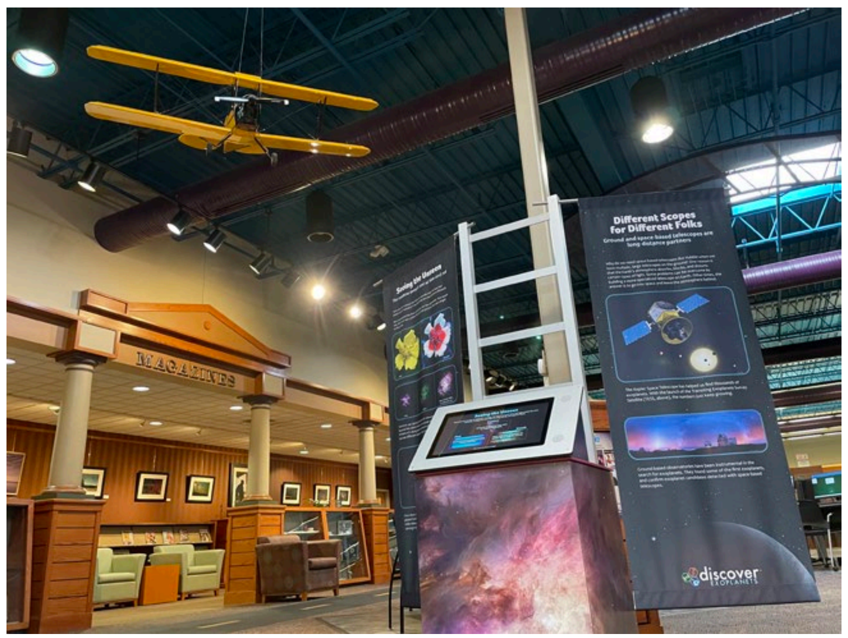
STEM Tales is a new project funded by NSF's Advancing Informal Science Learning (AISL) Initiative. The project began in September 2022 and is led by Twin Cities PBS (TPT) with partners from T2 Science & Math Education (creators of Storytime in Space) and American University's School of Education. The project is being evaluated by Rockman et al. STEM Tales aims to foster interest and self-confidence in STEM subjects and careers among children of color (ages 4-8) from low-income urban communities through culturally responsive digital media and aligned STEM library programs. Outreach programs will include storybooks read by scientists and engineers, age-appropriate STEM activities and family take-home kits. The media project will employ on-camera readers who identify as Black, Indigenous and people of color (BIPOC), stories written by diverse authors that feature characters of color, and the selection of libraries who serve BIPOC communities. Librarians will receive training in the use of digital media, activities, and culturally responsive teaching to engage 200+ children and 400+ parents and caregivers in outreach.

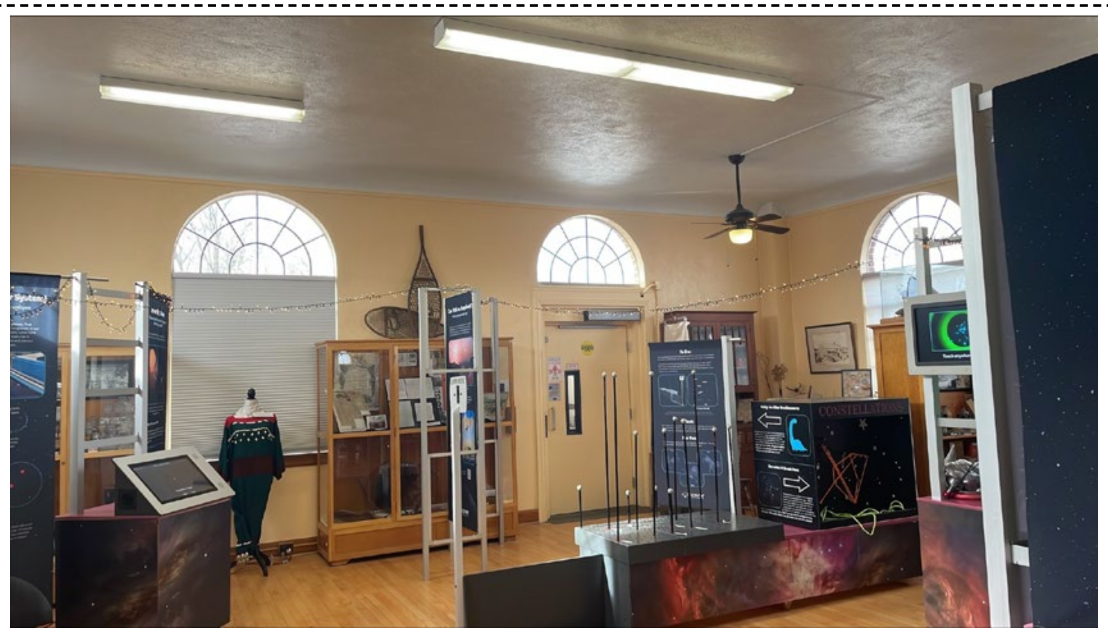
Animated characters from the STEM Tales pilot episode

Astronaut Kate Rubins reads Rosie Revere, Engineer from the International Space Station

Discover Exoplanets: 2022-2025

In 2022, Discover Exoplanets continued an extended tour after ending abruptly in 2020 due to the pandemic. The exhibit started in Colorado, then traveled to Springfield, MO, Vernal, UT, and East Meadow, NY, reaching upwards of 15,000 patrons. Because of that success, JPL funded SSI to refurbish the exhibit and continue on a new tour to ten new libraries in 2023.

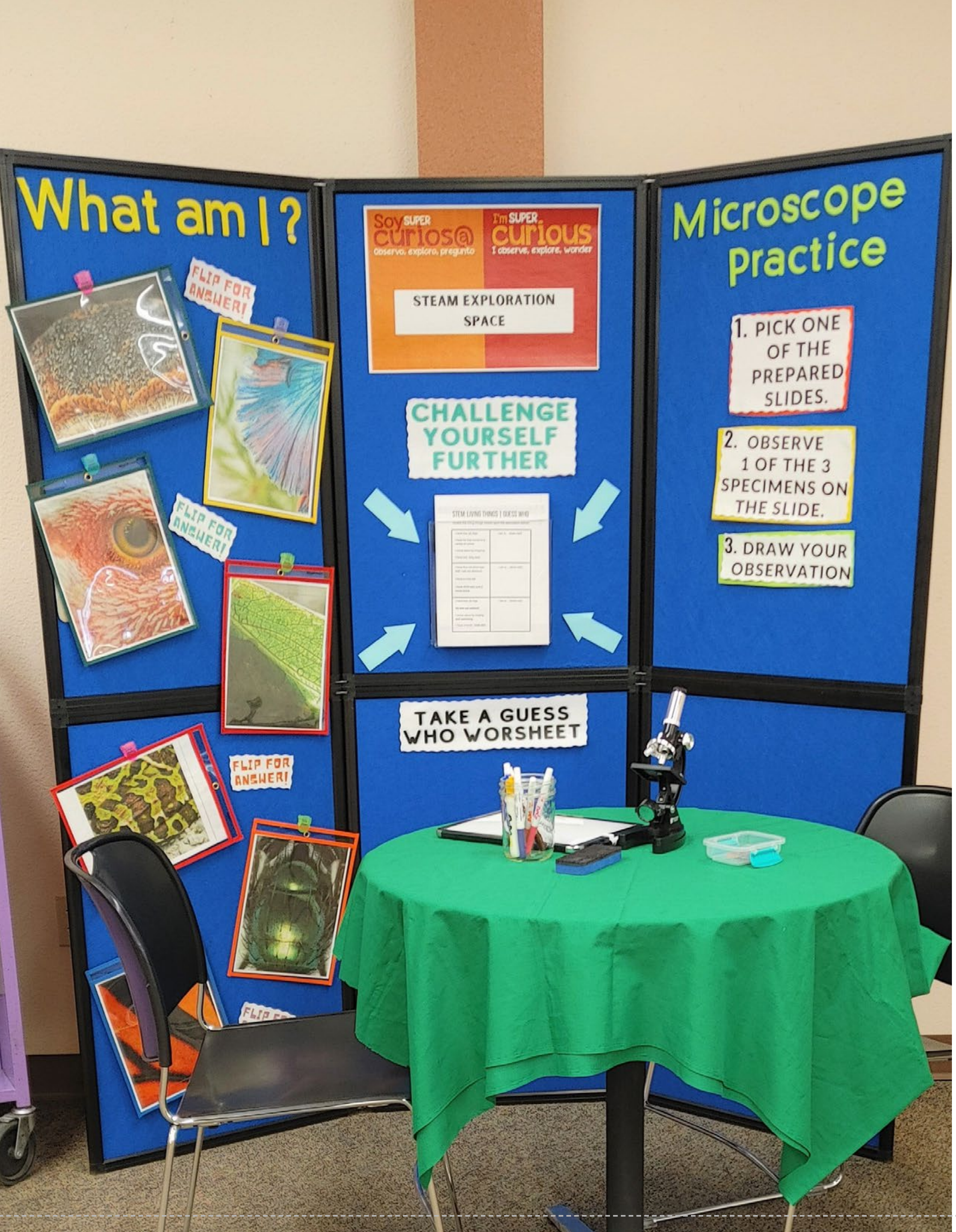




Continuing Programs

We are Water

The We are Water project, funded by NSF's AISL Initiative, engages with and serves communities across the Four Corners region in the Southwestern U.S. (CO, UT, NM, AZ), specifically Indigenous, Latinx, and underserved rural communities, through a traveling exhibit, community engagement activities and events, and capacity building for public and tribal library staff. 2022 was the third year of the project, during which the project team worked with Roto LLC to complete the final exhibition updates and fixes. The exhibition's four interactives—the Story Wall, the Augmented Reality Sandbox the Plinko Water Use game, and the Connect Four ecosystem game – was displayed at the final pilot site at Lafayette Public Library (Colorado) from March 1 – April 30, 2022 before going on tour at the first host site at Aztec Public Library (New Mexico) from May 1 – July 31. The exhibit was then hosted for three months each at Navajo Nation Library (Arizona) and Bayfield Public Library (Colorado). A competitive RFP was conducted to select the four 2023 host library sites.



STEAM Equity

The STEAM Equity Collaborative Project, funded through NSF AISL Initiative, focuses on twelve rural libraries to help engage tween, Latinx girls in STEM ideas and careers. In 2022, the project experienced rapid growth around the libraries' engagement and their kits. With the pandemic slowing down, and the libraries opening to more in-person programming, the development of their kits and exploration spaces exploded to meet with the new influx of patron engagement. 2022 saw a large increase in exhibit draw, programming interest, and kit check outs. The check in calls recorded positive growth within the libraries as their confidence in meeting project goals increased. The third year of the project saw the three exhibits each traveled to four of the twelve libraries, with each libraries hosting one exhibit. A full list of tour seen below.

Nov 23rd, 2021 – Feb 15th, 2022
Somos Super Creativ@s/We're Super Creative: Montrose Regional Library District
Soy Super/I'm Super: Pioneer Library System Foundation
Soy Super Curios@/ I'm Super Creative: Safford City- Graham Country Library

Feb 15th – May 10th, 2022
Somos Super Creativ@s/We're Super Creative: Mt. Angel Public Library
Soy Super/I'm Super: Burley Public Library
Soy Super Curios@/ I'm Super Creative: Hondo Public Library

May 10th – August 2nd, 2022
Somos Super Creativ@s/We're Super Creative: Los Lunas Public Library
Soy Super/I'm Super: Blue Island Public Library
Soy Super Curios@/ I'm Super Creative: Palm Springs Public Library

August 2nd – Oct 25th, 2022
Somos Super Creativ@s/We're Super Creative: Madera County Library
Soy Super/I'm Super: Berryville Public Library
Soy Super Curios@/ I'm Super Creative: North central Washington Library

Oct 25th, 2022 – Jan 17th, 2023
Somos Super Creativ@s/We're Super Creative: Pioneer Library System Foundation
Soy Super/I'm Super: Safford City- Graham Country Library
Soy Super Curios@/ I'm Super Creative: Montrose Regional Library District

Left: Exploration Space. Credit: Safford City-Graham Public Library

Preparing for the 2023 and 2024 solar eclipses

Eclipse Planning with the Gordon and Betty Moore Foundation

This $3.5 million award will allow SSI staff to provide eclipse support across the entire nation, including every state and U.S. territory. In-person workshops will be held in each state in partnership with the local state library, and sun-science kits will be distributed through the state libraries. The kits include a range of activities, from low tech to high, including Coronado solar telescopes. This program kicked off in the fall with a trip to Guam and the Northern Mariana islands, where an SSI team gave multiple workshops, including at the Pacific Islands Association of Libraries, Archives, and Museums (PIALA).

NASA@ My Library

The NAML program received an augmentation to support in part a co-development partnership with three Texas libraries (San Antonio, Comfort, and Hondo). These libraries will work with SSI to identify existing activities that can be translated and enhanced with culturally responsive language, create new activities relevant to a bilingual audience, and identify community groups that libraries across the country should work with to increase the engagement of Spanish speaking patrons. The project will also distribute bilingual, culturally responsive, library appropriate hands-on activities, videos, training materials and kits broadly across the US and US territories.

Financial Summary

Space Science Institute • Summary Statement of Financial Position

as of December 31, 2022 and 2021

ASSETS	2022	2021
Assets		
Cash and cash equivalents	$ 2,164,789	$ 464,262
Accounts receivable	1,331,344	914,382
Prepaid expenses and deposits	116,454	105,413
Net furniture, equipment, and property	163,493	170,362
Operating Right-of-Use-Asset	580,966	-
Total assets	**$ 4,357,046**	**$ 1,654,419**

LIABILITIES AND NET ASSETS	2022	2021
Liabilities		
Accounts payable and accrued liabilities	$ 747,429	$ 462,358
Deferred revenues	136,134	215,245
Line of credit	100,000	362,946
Note Payable	69,107	85,916
Lease Liability - Operating	588,323	-
Total liabilities	1,640,993	1,126,465
Net assets		
Without donor restrictions	559,562	525,449
With donor restrictions	2,156,491	2,505
Total net assets	2,716,053	527,954
Total liabilities and net assets	**$ 4,357,046**	**$ 1,654,419**

Summary Statement of Activities

for the years ended December 31, 2022 and 2021

SUPPORT AND REVENUE	2022	2021
Grants, contracts, and cooperative agreements	$ 8,316,216	$ 7,508,250
Contributions	3,533,910	51,039
Exhibit and workshop income	3,860	35,825
Interest income	935	66
Total support and revenue	**11,854,921**	**7,595,180**

EXPENSES	2022	2021
Science research programs	$ 4,882,076	$ 4,283,081
Science education programs	2,481,704	1,494,733
Fundraising	5,776	4,659
General and administrative	2,297,266	1,738,831
Total expenses	9,666,822	7,521,304
Change in net assets	2,188,099	73,876
Net assets, beginning of year	527,954	454,078
Net assets, end of year	**$ 2,716,053**	**$ 527,954**

The summary financial information does not include sufficient detail or disclosures to constitute presentation in conformity with accounting principles generally accepted in the United States of America. If the omitted detail or disclosures were included, they might influence the user's conclusions about the Organization's financial position, changes in net assets, and cash flows. Accordingly such information should be read in conjunction with the Organization's audited financial statements for the years ended December 31, 2022 and 2021, from which the summarized information was derived. A copy is available upon request.

SPACE SCIENCE INSTITUTE

WWW.SPACESCIENCE.ORG

You can support Earth and space science research and STEM Education!

Your contribution will help:

- Ensure historically underserved and underrepresented communities have access to STEM learning;
- Provide an environment where researchers with an entrepreneurial spirit can flourish and lead us to important new discoveries;
- Ignite a young person's curiosity and inspire them to pursue a career in STEM.

Make your personal contribution at
spacescience.org/support

facebook.com/spacescienceinstitute

Space Science Institute . 4765 Walnut Street . Suite B . Boulder, Colorado 80301 . 720.974.5888