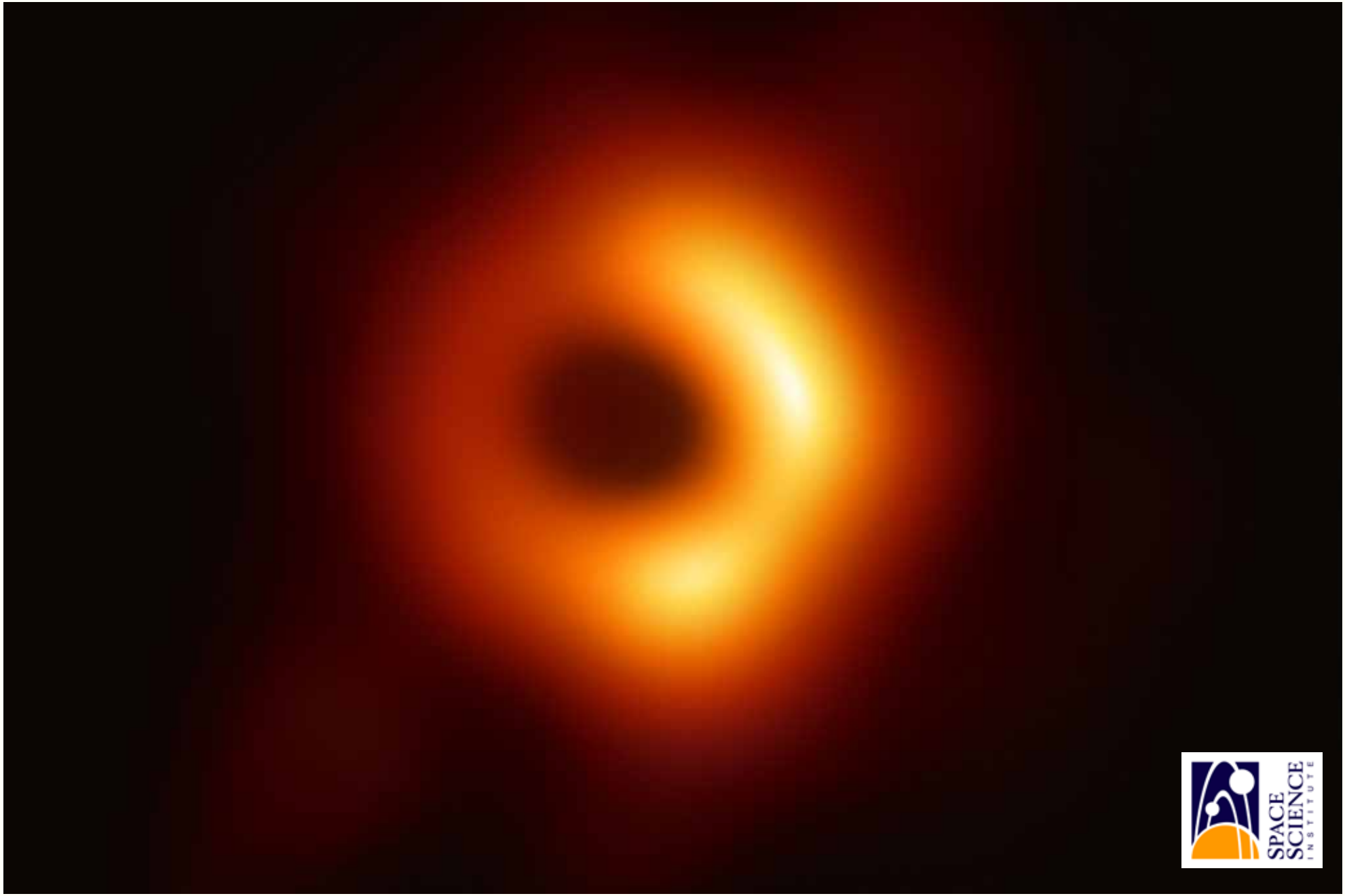
Space Science Institute . 4765 Walnut Street . Suite B . Boulder, Colorado 80301 . 720.974.5888 . www.spacescience.org . www.facebook.com/spacescienceinstitute

ANNUAL REPORT 2019



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.

Cover Image: Using the Event Horizon Telescope, scientists obtained an image of the black hole at the center of galaxy M87, outlined by emission from hot gas swirling around it under the influence of strong gravity near its event horizon.
Credits: Event Horizon Telescope collaboration et al.

Table of Contents

Image Credit: X-ray: NASA, CXC, U. Michigan, J-T Li et al.; Optical: NASA, STScI

Message from the Chairs of the Board of Directors

2019 was a year of highs and lows for SSI but the team rose to the challenges and came out well on the other side. Because SSI is dominantly dependent on government funding, the 2018-2019 government shutdown heavily impacted SSI by temporarily sidelining some of the brightest minds in our country. SSI quickly rebounded and continued its projects full steam while also relocating to its new headquarters. Notable projects included NCIL's "Summer of Space" campaign, which partnered STAR Net resources with the Collaborative Summer Library Program's "Universe of Stories" summer reading program to celebrate the 50th anniversary of the Apollo moon landing. We are pleased to report that SSI's financials over the previous 5 years received a clean bill of health from the NASA's Office of Inspector General.

One of the Board's long-serving members, Ann Goldman, cycled off in 2019. As co-founder of the fundraising service Front Range Source, Ann contributed valuable strategic direction and many hours to helping SSI with its nonprofit development plan. We thank Ann for her many terms of service and personal dedication to the institute's well being. This year, we welcomed two new members to our Board, Nancy Geyer and treasurer Gary Zarlengo. Nancy was the executive director and CEO of the Museum of Boulder from 2001-2019 and brings to the Board experiences from the museum, formal education, and nonprofit communities. Gary has forty years of financial experience across federal government and private sector STEM organizations (e.g., NASA; Orbital Sciences/Northrup Grumman, Ball Aerospace) as well as startup and nonprofit expertise. We are excited to work with Nancy and Gary and to continue to build the strongest Board to help serve SSI's mission.

As we approach 2020, we are hopeful for the future but certainly do not take our strengths and good fortune for granted. We intend to continue to work with SSI's executive team to innovate and strengthen risk management so we can build on our strengths and protect against external influences. We hope you will join our efforts in helping this active nonprofit become even better positioned to create long-term value for our communities in the future.

William R. Purcell, Ph.D.
(Chair)
Jan. - Aug. 2019

Steven Jolly, Ph.D.
(Chair)
Aug. 2019 - present

Karly Pitman, Ph.D.
(Executive Director)

Image Credit: SpaceX

Overview

In this section:

Image Credit: JPL-Caltech

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 (to be launched in 2020), and James Webb Space Telescope (to be launched in 2021).

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).

Image Credit: NASA/JPL/Space Science Institute

Present

Today, SSI manages 75 scientists and 11 educators 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. SSI's science research and education programs support its overall mission: to shape our future by enabling scientists to advance our understanding of Earth and the Universe; to increase science and technology literacy for people of all ages and backgrounds; and to inspire youth to pursue science-technology education and career opportunities. 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; the NASA Jet Propulsion Laboratory; the Space Telescope Science Institute; and the U. S. Department of Energy, among other funders.

Global Reach: On-site & Off-site (2018)

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.

Scientists now have enough data to map 15 percent of the ocean floor, according to the Nippon Foundation-GEBCO Seabed 2030 Project.
Image Credit: GEBCO

2019 Board Members

- Dr. Jack Burns, Professor & Vice President Emeritus for Academic Affairs & Research, University of Colorado
- Dr. Douglas Duncan, Astronomer, University of Colorado
- Ms. Nancy Geyer, Retired Executive Director and CEO, Museum of Boulder
- Ms. Ann Goldman, Co-Founder, Front Range Source
- Dr. Dick Green (ex officio), Former President and Chief Executive Officer, CableLabs, Inc.
- Ms. Jennifer Griest (Executive Secretary, ex officio), General Counsel, Legal and Policy Specialist, Space Science Institute
- Dr. Marilyn Johnson, Former Science Director, Oregon Museum of Science and Industry
- Dr. Steve Jolly (Vice-Chair/Chair), Systems Engineering Director, Lockheed Martin Corporation
- Dr. Karly Pitman (ex officio), Executive Director / Senior Research Scientist, Space Science Institute
- Dr. Bill Purcell (Chair/Vice-Chair), Senior Manager Advanced Systems, Ball Aerospace and Technologies Corporation
- Mr. Gary Zarlengo (Treasurer), Small Business Consultant

2019 Executive Advisory Committee

- Dr. Paul Dusenbery (Education/National Center for Interactive Learning)
- Dr. James Harold (Information Systems and Technology)
- Dr. Ralph Shuping (Associate Director/Research)
- Mr. Carl Wuth (Business Operations)

2019 Grants & Contracts

SSI gratefully acknowledges support from research and education grants and contracts from the following organizations in 2019:

- NASA
- Arizona State University
- Boston University
- Carnegie Institute of Washington
- JPL (Jet Propulsion Laboratory)
- Johns Hopkins University Applied Physics Laboratory
- Malin Space Science Systems
- Smithsonian Astrophysical Observatory
- Space Telescope Science Institute
- Universities Space Research Association
- University Corporation for Atmospheric Research
- University of Alabama
- University of Arizona
- University of California, Los Angeles
- University of Colorado, Boulder
- University of Houston
- University of Maryland, College Park
- National Science Foundation
- University of Michigan
- University of New Hampshire
- Institute of Museum and Library Services
- City of Mesa
- Urban Libraries Council
- DOE (Department of Energy)
- Los Alamos National Laboratory
- Science Museum of Minnesota
- University of Colorado, Laboratory for Atmospheric and Space Physics
- Colorado Gives Foundation

Donors

SSI wishes to thank the generous individuals who contributed to the Space Science Institute in 2019, including donations made in memory of Josh Bandfield, Billy Don Mitchell, and Orlan Youngren:

- Jack O. Burns
- the Coe family
- Paul & Michelle Dusenbery
- Nancy Geyer
- Good Today
- Jennifer Griest
- Nicholas G. Heavens
- the Holland family
- Philip James
- Steve Jolly
- Kerry Lightenburger
- the McCallum family
- Brooks Mitchell
- the Moberg-Wolff family
- Julianne Moses
- Greg Mosshammer
- Alexey Pankine
- Dawn Peterson
- Karly Pitman & Damian Crevello
- William & Bernadette Purcell
- Mike Sitko
- Evaldas Vidugiris
- Peeranut Visetsuth
- Greg Wimpey
- Carl & Traci Wuth
- Eric Youngren
- Anonymous (7)

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.

Image Credit: NASA/JPL-Caltech

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, the Afterschool Alliance, Pacific Science Center, Cornerstones of Science, American Society of Civil Engineers, Lunar and Planetary Institute, University of Colorado, University of Virginia, Arizona State University, Engineers Without Borders-USA, the National Renewable Energy Lab, American Geophysical Union, Association of Rural and Small Libraries, and many more.

Project BUILD workshop participants.
Credit: SSI/NCIL

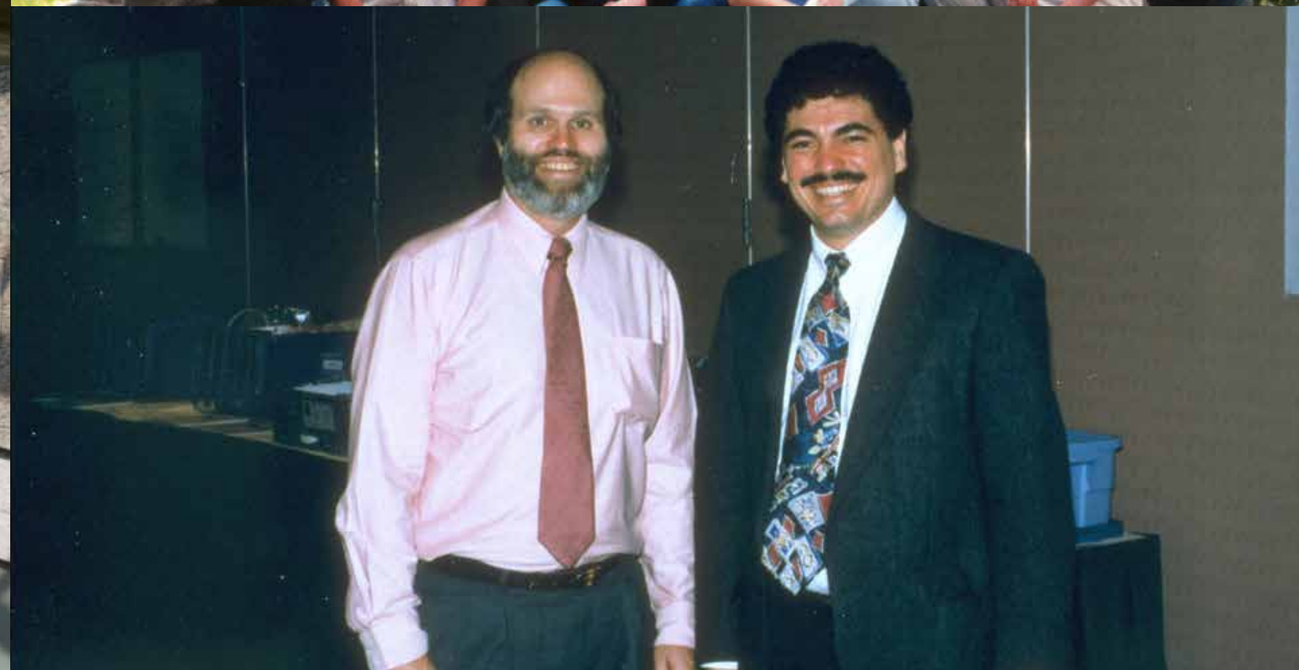
Library patrons getting ready for the 2017 Solar Eclipse
Credit: SSI/NCIL

New Headquarters in Boulder

In Aug. 2019, SSI relocated to its new building at 4765 Walnut St., Suite B in Boulder, CO. Amenities of the newly renovated two-story space include large conference rooms and workspaces, as well as a central atrium for hosting guests and in-house workshops.

SSI Celebrates Its 25th Anniversary of Operations

Top photo: First Space Jam event in 1999
Bottom: Executive Director Paul Dusenbery and Board Member Ramon Lopez at the 1994 Board Meeting



Discovery & Exploration

In this section:

This closeup shows some wind-blown deposits inside eroded craters on Mars.
Credit: NASA/JPL-Caltech/Univ. of Arizona

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 2019, the Research Branch welcomed 9 new scientists, for a total of 75 scientists (funded and unfunded). Ten of the 75 are located on-site at SSI's Boulder headquarters with the rest distributed across the U.S. and internationally. A number of scientists left SSI this year to pursue other opportunities including Senior Scientist Phil James who retired after a long a productive career in Mars science (see retrospective below). And finally, SSI and the planetary geology community in general suffered a huge loss in the summer of 2019 when Senior Scientist Josh Bandfield passed away unexpectedly (see "In Memoriam" below).

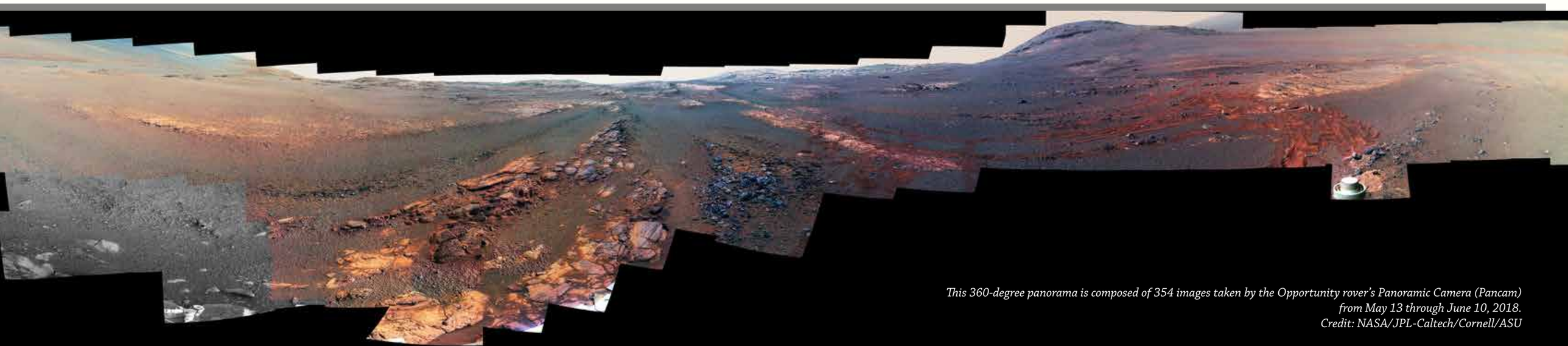
While any individual scientist may pursue the subject area of his or her choice, SSI's Research Branch also runs four "Research Centers" to facilitate and promote collaborative research in topical areas of interest: the Center for Mars Science (CMS), the Center for Space Plasma Physics (CSPP), the Center for Extrasolar Planetary Studies (CEPS), and the Center for Polarimetric Remote Sensing (CPRS). In December 2019, SSI created a Center for Data Science in order to foster discussion and collaboration around the growing field of machine learning, artificial intelligence, and their applications to space science, planetary science, and astrophysics. See center reports below for more detail on center activities.

SSI scientists were awarded 23 new grants and contracts in 2019, primarily from NASA and NASA-funded primes, including significant awards to study the Martian atmosphere (PIs: Alexey Pankine and Nick Heavens), instabilities and magnetic reconnection in Earth's magnetosphere (PI: Giovanni Lapenta), photochemistry in the atmosphere of Neptune (PI: Julie Moses), and a large early career grant to PI Mike Hartinger to study the connection of ultra-low frequency waves in the magnetosphere to geoelectric and geomagnetics fields at the Earth's surface that can affect technological infrastructure (e.g. power grids, submarine cables, etc...).

2019 Impacts

Total scientists:	75 (51 funded/24 unfunded)
Papers published:	>110 (refereed and non-refereed)
Invited/Public talks:	>20
Proposals Submitted (PI+co-I):	79
Grants/contracts awarded:	23

Missions Supported:
Stratospheric Observatory for Infrared Astronomy (SOFIA), Rosetta (ROSINA), Hubble Space Telescope, Mars Exploration Rovers, THEMIS, OSIRIS-REx, Mars Reconnaissance Orbiter, Mars Global Surveyor (Thermal Emission Spectrometer), Lunar Reconnaissance Orbiter, Mars 2020 Rover, Juno, Mars Science Laboratory, Emirates Mars Mission (UAE)



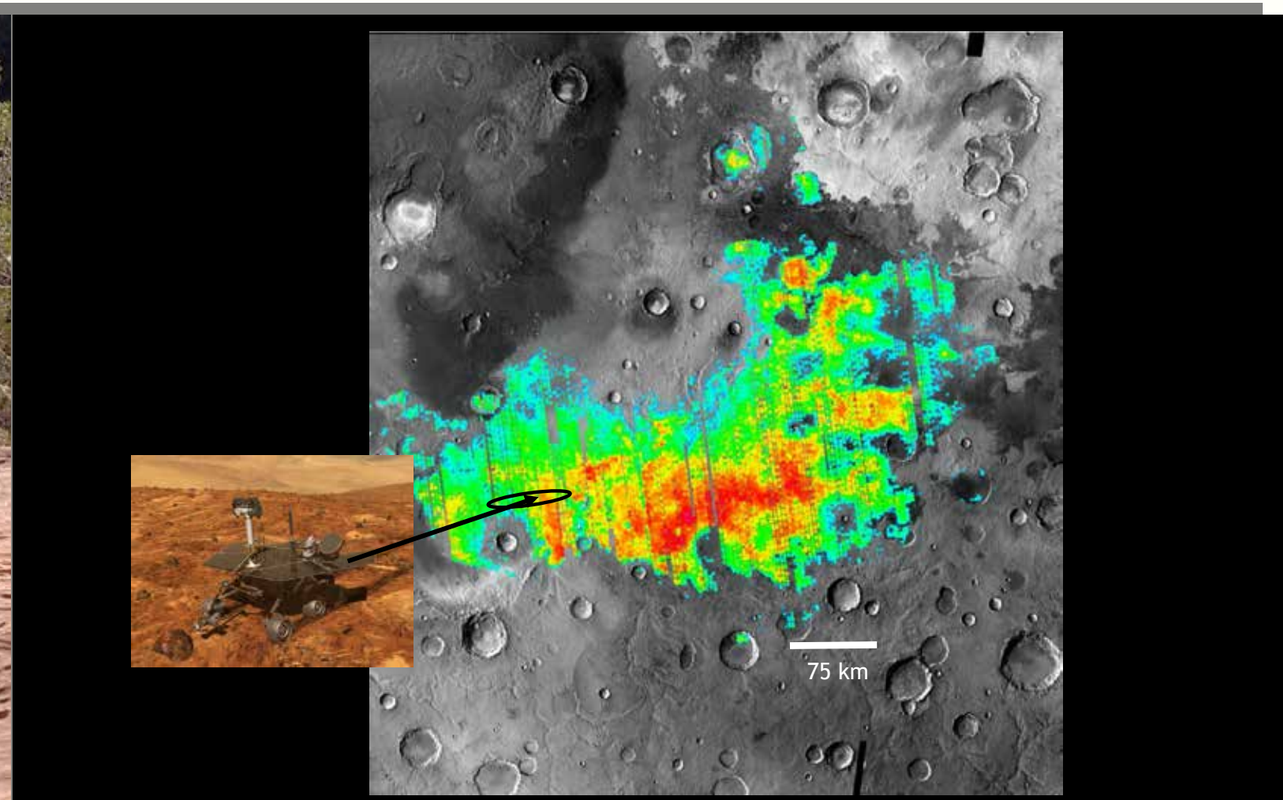
This 360-degree panorama is composed of 354 images taken by the Opportunity rover's Panoramic Camera (Pancam) from May 13 through June 10, 2018.
Credit: NASA/JPL-Caltech/Cornell/ASU

In Memoriam: Josh Bandfield

SSI Senior Research Scientist Josh Bandfield was an expert in using thermal infrared and visible spectral imaging data to determine the mineralogical, thermophysical, and morphological properties of planetary surfaces. He authored/co-authored over 90 peer-reviewed and 240 non-refereed articles on planetary geology, spectroscopic remote sensing, radiative transfer, and thermal modeling. He developed observation and data analysis strategies for the collection and derivation of surface properties from thermal infrared observations. His spacecraft operational experience includes OSIRIS-REx, 2001 Mars Odyssey, Mars Reconnaissance Orbiter, Lunar Reconnaissance Orbiter, Mars Global Surveyor, and Mars Exploration Rovers.

He designed, implemented, and validated calibration and data processing strategies for the Thermal Emission Spectrometer (TES), Thermal Emission Imaging System (TES), Miniature Thermal Emission Spectrometer (mini-TES), MCS, Diviner Lunar Radiometer Experiment (DLRE), and Planetary Fourier Spectrometer (PFS) investigations. Josh served as a co-investigator on the Lunar Reconnaissance Orbiter's Diviner Lunar Radiometer Experiment and the 2001 Mars Odyssey THEMIS instruments. He also served as a participating scientist on several missions, including NASA's OSIRIS-REx and the Mars Reconnaissance Orbiter.

Josh was also active in public outreach, and helped many students and early career scientists. Josh's unexpected and untimely passing in 2019 has been a tragic blow to his family, friends, colleagues and the wider scientific community to which he contributed so much. His enthusiasm, professionalism, and kindness will be sorely missed.



Mapping of coarse-grained hematite on the surface of Mars using data from the Thermal Emission Spectrometer (TES) on the Mars Global Surveyor, one of Josh's many important contributions to the field of Martian geology. The discovery of this form of hematite was interpreted as evidence of the precipitation of the mineral from liquid water. The Mars Exploration Rover Opportunity was targeted to the Meridiani Planum region indicated by the ellipse. Upon landing, Opportunity discovered hematite spherules (colloquially known as "blueberries") as the bearer of the gray hematite.

In Recognition

Dr. Phil James, Senior Research Scientist (Emeritus)

Phil completed his Ph.D. in particle physics at the University of Wisconsin in 1966. In 1968, Phil accepted a physics professorship at the University of Missouri, St Louis. During a sabbatical in 1977-78, Phil took a senior NRC fellowship at JPL to work on the seminal Viking mission, where he conducted imaging analyses of the Mars south polar cap. In this manner, he worked with and became one of the pioneers of Mars atmospheric science. He also met his friend and colleague Leonard Martin at JPL and developed a key interest in ground-based observations of Mars.

Phil assumed a position as Chair of the Physics department at the University of Toledo in 1990, where he taught physics and directed PhD graduate students in Mars research. Phil also began a uniquely visible and productive Hubble Space Telescope (HST) Guest Observer program of Mars observations in December 1990 (the first GO observations with HST), which continued through 2003. These observations were consequential in advancing our understanding of the Mars atmosphere, and fostered the careers of many grateful Mars researchers/friends, especially at SSI. He has participated in Mars mission investigations continuously from Viking to the Mars Reconnaissance Orbiter (1976-2019), and through these investigations shaped our understanding of the seasonal ice caps of Mars. He has contributed to over 100 publications, many more conference talks, review panels, and mentoring of young scientists.

Phil and Sharon, the proud parents/grandparents of two sons, a daughter, 3 granddaughters and a grandson, moved to Prescott, AZ in 2006. At this time, Phil retired from the University of Toledo and joined SSI as a Senior Research Scientist, rejoining his former HST team and fostering a remarkable rise in Mars atmospheric research at SSI over the past two decades.

Dr. Barbara Whitney, Senior Research Scientist (Emeritus)

Barb Whitney began her most excellent journey in astronomy when she accidentally took physics during her senior year in high school. She obtained a bachelor's degree at Rice University in 1983, and received her Ph.D. at the University of Wisconsin (UW) in 1989. In collaboration with her thesis advisor, Art Code, Barb developed a set of codes that allowed her to solve complicated problems using random numbers. This foray into Monte Carlo techniques connected her with radiative transfer past and future. Her thesis "grandfather" was none other than S. Chandrasekhar, while her thesis work represented a new direction in computational astrophysics.

Barb continued her work in radiative transfer at the Harvard-Smithsonian Center for Astrophysics in Cambridge MA, expanding into studies of star formation and cool stars (as in, temperature). During this period, she retained her Wisconsin connections through participation in the Wisconsin Ultraviolet Photo Polarimetry Experiment, a spectropolarimeter that flew on two space shuttle flights during the 1990s. She also observed with many telescopes from the ground (in Arizona, Hawaii, and Chile) and space (International Ultraviolet Explorer and Hubble Space Telescope), testing out her models of star formation and other ideas about cool carbon stars. That was a blast!

Barb returned to Wisconsin in the late 1990s and became familiar with the Space Science Institute (SSI), then in its early days. She eventually joined the august ranks of Wisconsin SSI members in 1998, continuing her radiative transfer adventures by expanding her interests into planetary atmospheres and adding a thermal and magnetic component to her codes, in collaboration with some smart people. She made the radiative transfer codes publicly available, which led to many more citations and collaborations, proving the old adage that the more you give, the more you receive. The tools have been used by many researchers throughout the world, and provided the basis for several addition Ph.D. theses. In addition, she renewed her ties to the UW and became involved in the naissance of the Spitzer Space Telescope Legacy project GLIMPSE, which led to a series of follow up projects (e.g., GLIMPSE II, GLIMPSE3D, GLIMPSE360, and Deep GLIMPSE). As with all of her previous projects, Barb embraced the new challenges and techniques, which involved much more data processing and cataloging than she ever imagined possible. These catalogs are probably now dwarfed by several "big data" projects that are currently in progress. But the GLIMPSE team did pioneering work and produced fantastic panoramic images and catalogs of our Milky Way Galaxy.

As one of the initial members of the SSI remote research group, Barb experienced the growth and heady years where a new researcher represented a 5-10% growth in the research staff. In addition, Barb mentored and fostered the careers of several students and post-docs. Through her contributions to the astronomy, radiative transfer, and the SSI communities, Barb has touched the lives of many. And while she continues to do so, her interests have shifted to other pursuits. She does remain available to her colleagues and is involved in the activities of the Wisconsin branch of SSI (which typically occur in coffee shops throughout the Madison-Milwaukee corridor). Nevertheless, the SSI community extends their thanks, congratulations, and best wishes to Barb in the next chapter of her life.

Research Center Updates

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, and the analysis of the signatures of planetary formation as reflected in debris disks.

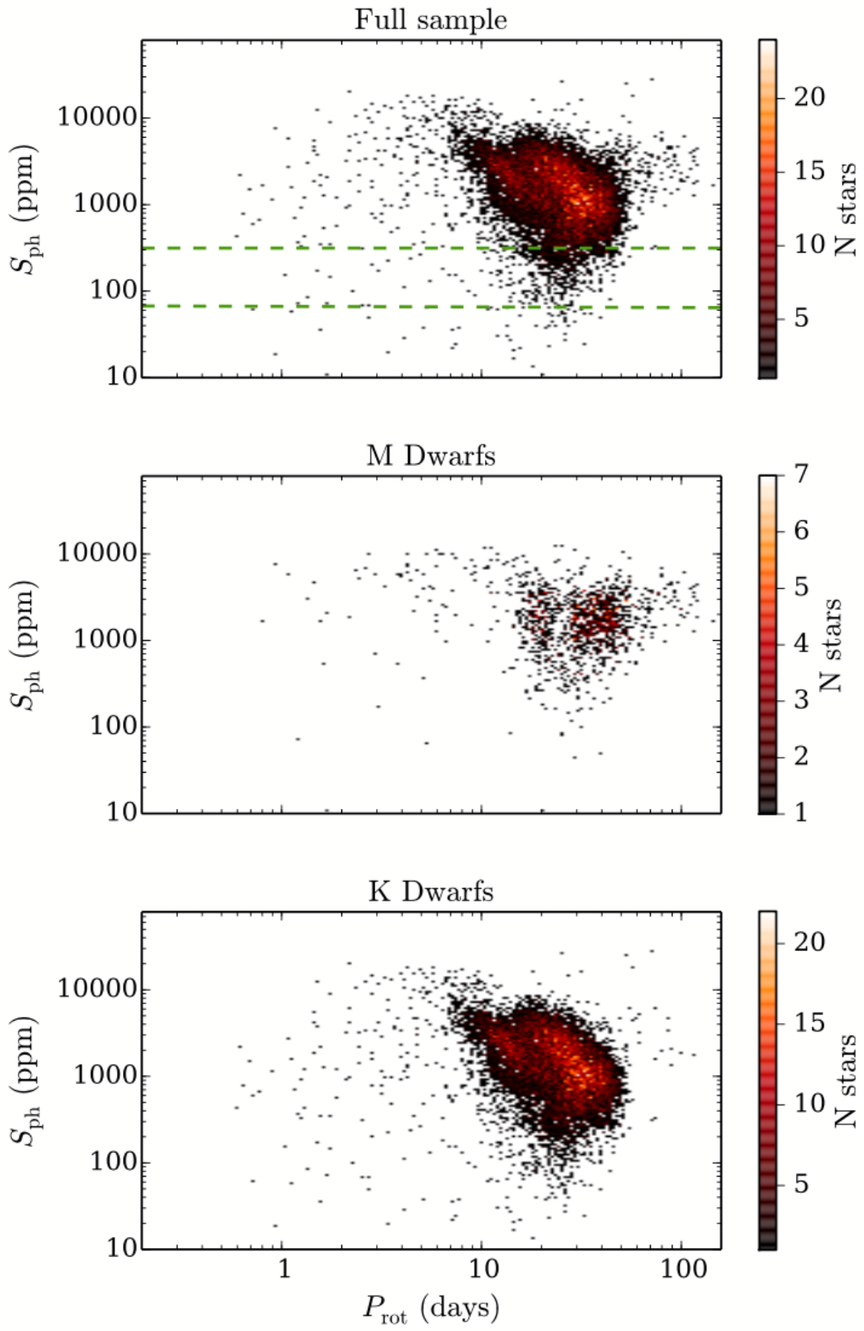
The Center for Extrasolar Planetary Systems welcomed two new members this year (Dr. Nicholas Heavens and Dr. Angela Santos) and now includes 13 scientists who in 2019 participated in over 50 peer-reviewed publications in scientific journals, along with numerous conference and workshop presentations, ongoing education and outreach activities, observing collaborations (including Hubble, Spitzer, IRTF, ALMA, and VLT), and several grant proposals.

Research highlights include the publication of a rotation and photometric activity catalog of main-sequence and subgiant solar-type stars observed by Kepler (Santos et al 2019), improved characterization of agglomerated particles in debris disks (Videen), modeling of atmospheric chemistry as a function of altitude and longitude in advance of the ESA ARIEL mission (Moses), and continued work exploring atmospheric evolution by The Living, Breathing Planet team as part of NASA's Nexus for Exoplanet Systems Science (Heavens, with collaborators from Hampton University).

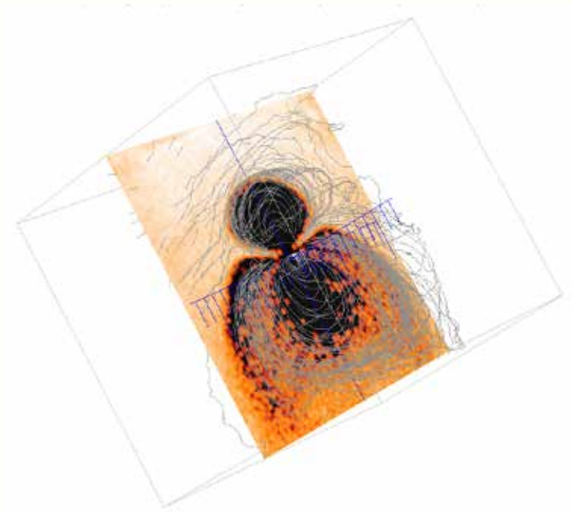
CEPS maintains a website (http://ceps.spacescience.org/home-page.html), accessible through SSI's main page, to highlight research being done by center members and to provide an interface with the public and other researchers in the exoplanet community.

Artist's impression of K2-18b.
Image Credit: ESA/Hubble, M. Kornmesser

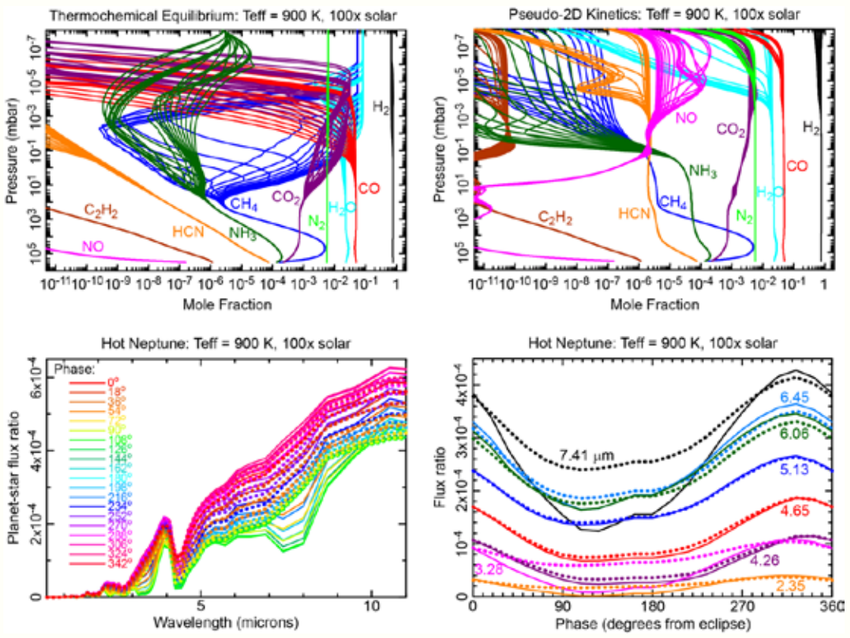
Photometric activity proxy as a function of the rotation period color coded by number of stars in a given parameter range for: all *Kepler* M and K dwarfs (from Santos et al 2019).



Prototype simulation of a planetary magnetosphere (showing plasma density and field lines) for models exploring atmospheric escape processes from Earth-like (telluric) exoplanets. From Gronoff, et al (incl CEPS researcher Heavens), *JGR: Space Physics*, 2020).



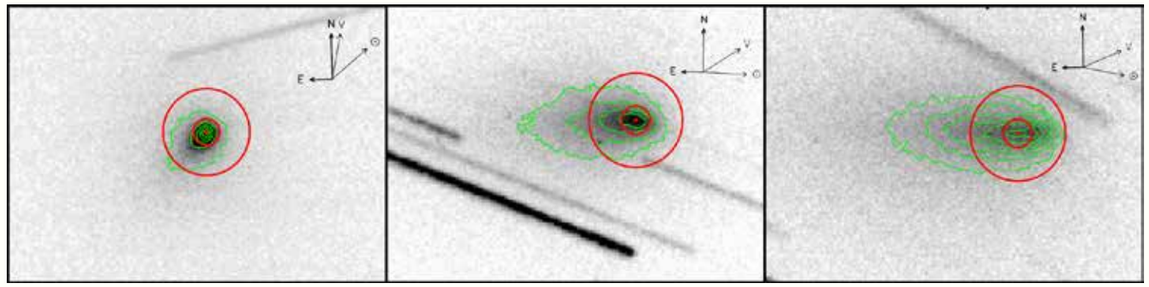
Recent modeling results by Dr. Moses, showing the relative roles of chemical equilibrium and kinetics at multiple longitudes in a hot Neptune atmosphere. Strong diurnal temperature swings in can yield large variations the abundances of key gases and, in turn, changes in the infrared emission as a function of orbital phase.



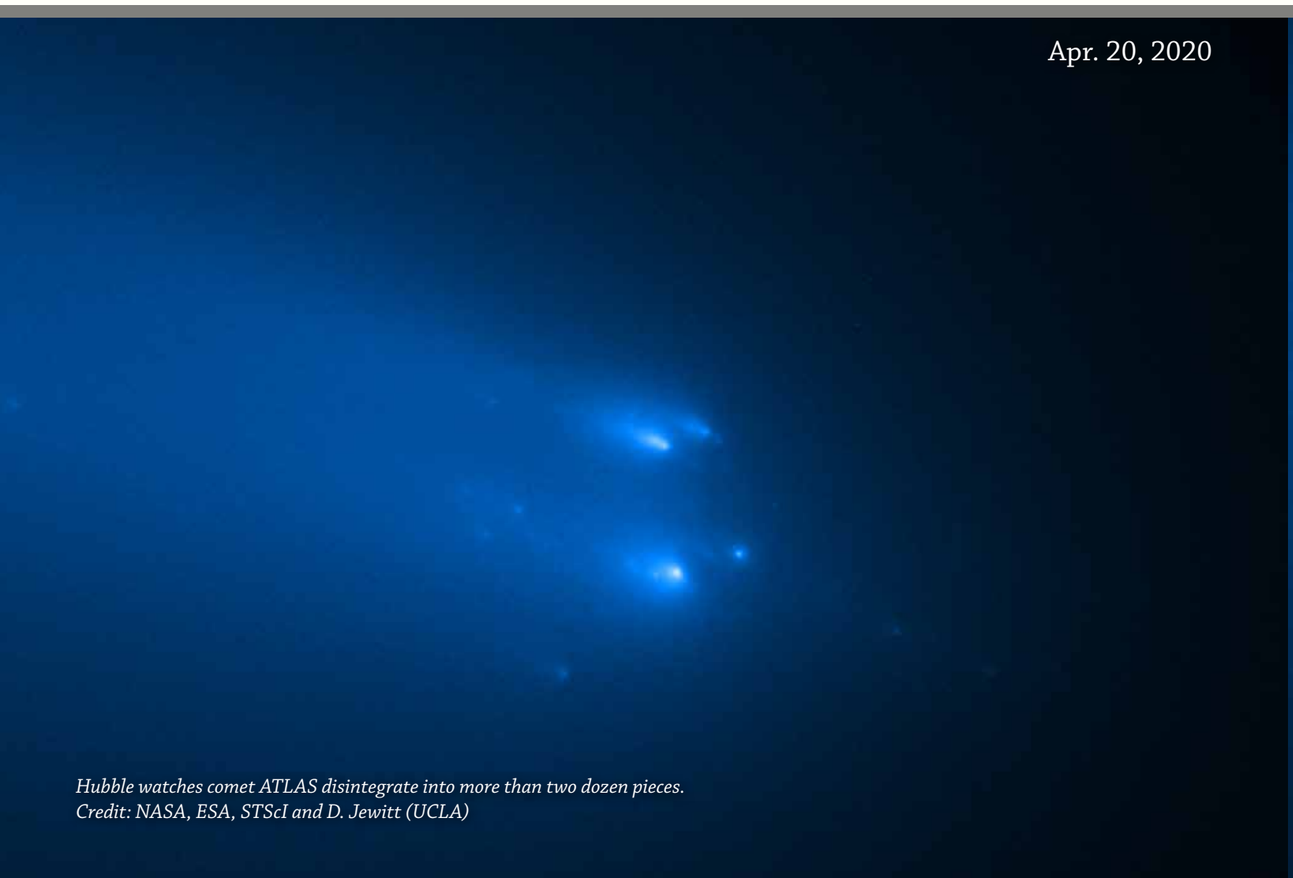
Center for Polarimetric Remote Sensing

The Center for Polarimetric Remote Sensing (CPRS) is pushing the boundaries of remote sensing in developing and using polarimetric techniques. Polarimetry is providing information that complements traditional, spectroscopic remote sensing, and in some cases challenges interpretations. The researchers of SSI have been driving the field and extending applications. SSI researchers are working with the Korea Astronomy and Space Science Institute (KASI) to incorporate a polarimetric camera on the Korean Pathfinder Lunar Orbiter (KPLO) whose mission is to map lunar regolith properties polarized light. The PolCam is a versatile piece of equipment and versions are being developed to map atmospheric aerosols and super-thin clouds that affect Earth's weather to fly on CubeSats.

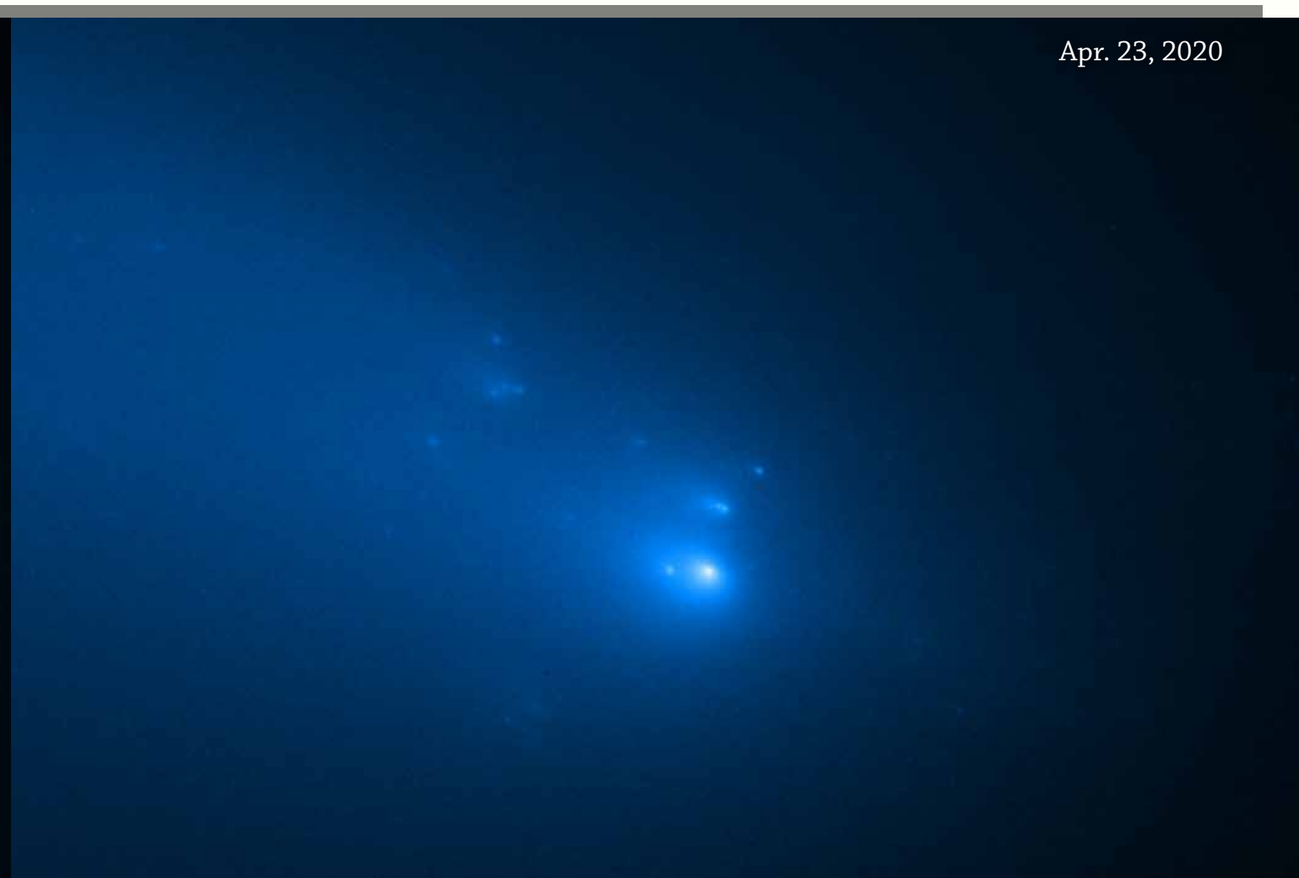
Research continues on dust characterization with Center researchers interpreting rapid fluctuations in the response from comets, signifying change in the dust populations. Polarimetry provides a means of constraining the sizes and chemical properties of this dust that is independent of spectral techniques. Such methods are especially valuable in low-light situations that challenge the traditional methods. These techniques also can characterize debris disks, providing insight into the evolution processes of star systems.



Polarimetry is used to quantify the changes in comet ATLAS as it disintegrates on its approach to the Sun in April 2020. From Zubko et al. MNRAS 497 1536 (2020).



Hubble watches comet ATLAS disintegrate into more than two dozen pieces.
Credit: NASA, ESA, STScI and D. Jewitt (UCLA)

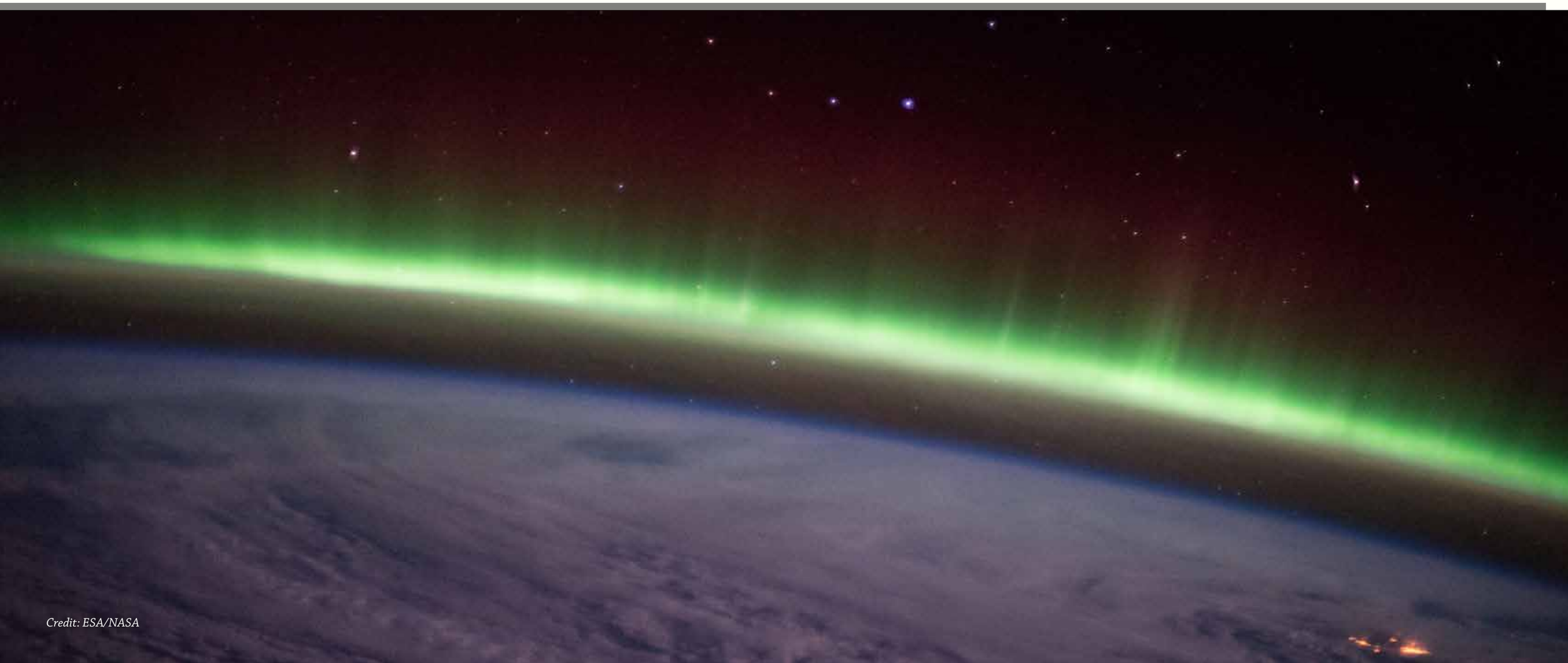


Center for Space Plasma Physics

The Center for Space Plasma Physics (CSPP) provides an umbrella for very broad NASA-sponsored, NSF-sponsored, and DoE-sponsored research efforts on plasma physics and the plasmas of the heliosphere. In calendar year 2019 the members of CSPP published 63 papers in refereed journals: 15 papers as primary authors and 48 papers as contributing authors.

Research highlights in 2019 dealt with Alfven-wave turbulence, cold-particle populations, magnetosonic modes in the magnetosphere, reconnection, the substorm current wedge, auroral arcs, system science, information theory, and solar-wind electrons.

One member of the CSPP was the lead organizer for a workshop on ion composition in the solar wind and magnetosphere held July 28 - August 3 in Durango, Colorado and two members of the CSSP were co-organizers of a conference on cold plasma in the magnetosphere held June 2-7 in Bra-Pollenzo, Italy.



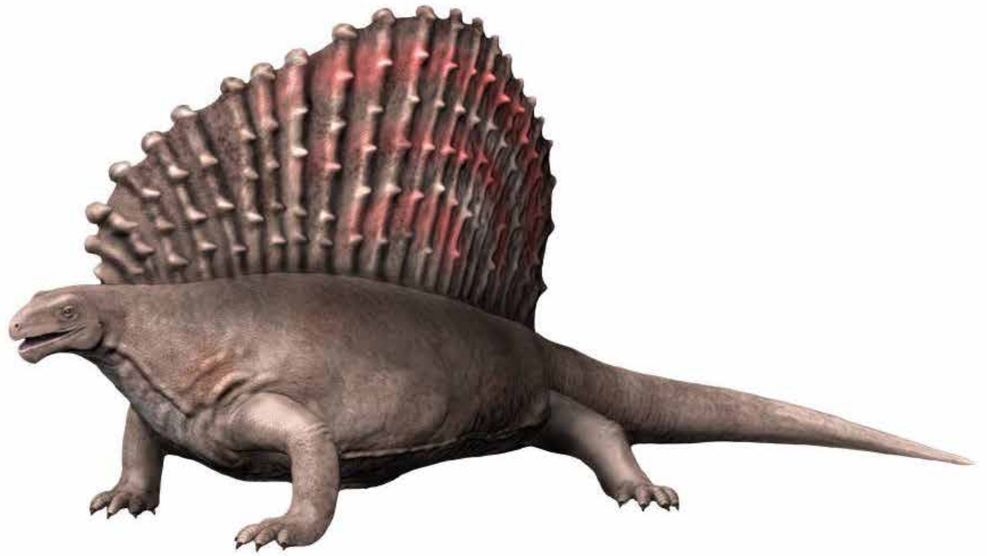
Credit: ESA/NASA

Exploring The Tropical Glacial Valleys of Late Paleozoic Colorado

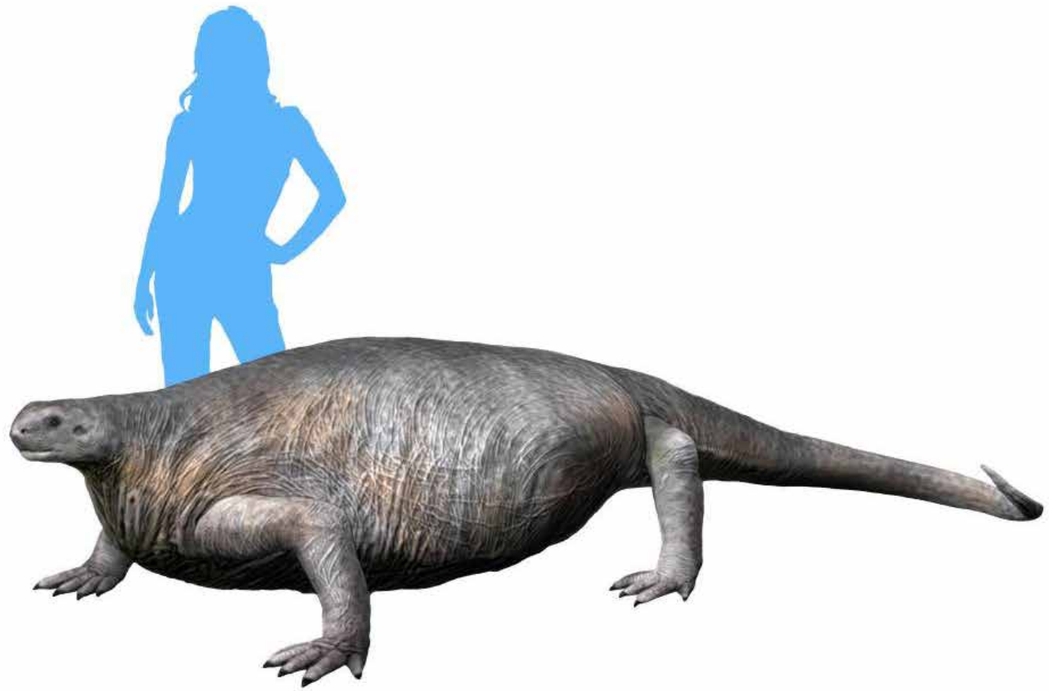
Dr. Nicholas G. Heavens;
London, UK

Rocks are really useful things. They make nice houses, walls, and industrial abrasives. But they are also little time machines, telling us much about the Earth's past. SSI researcher Nicholas Heavens has set his time machine for 330-270 million years ago ("the late Paleozoic Era"), when Antarctica, Australia, Africa, and South America were one great southern hemispheric continent called Gondwanaland; and Gondwanaland was colliding with North America and Europe to form an even bigger continent called Pangaea.

Pangaea would have been both a strange and familiar place to visit. Ice sheets were growing and shrinking on Gondwanaland, just like ice sheets have advanced and retreated across North America more recently. The coal deposits that powered the Industrial Revolution and started us on the pathway of present-day anthropogenic climate change were forming in tropical and temperate swamps. And on the savanna-like plains of equatorial North America, familiar predator-prey relations were developing. Except the gazelles and lions were giant lizards, like sail-backed *Edaphosaurus* and *Dimetrodon*, or beer-bellied *Cotylorhynchus*.

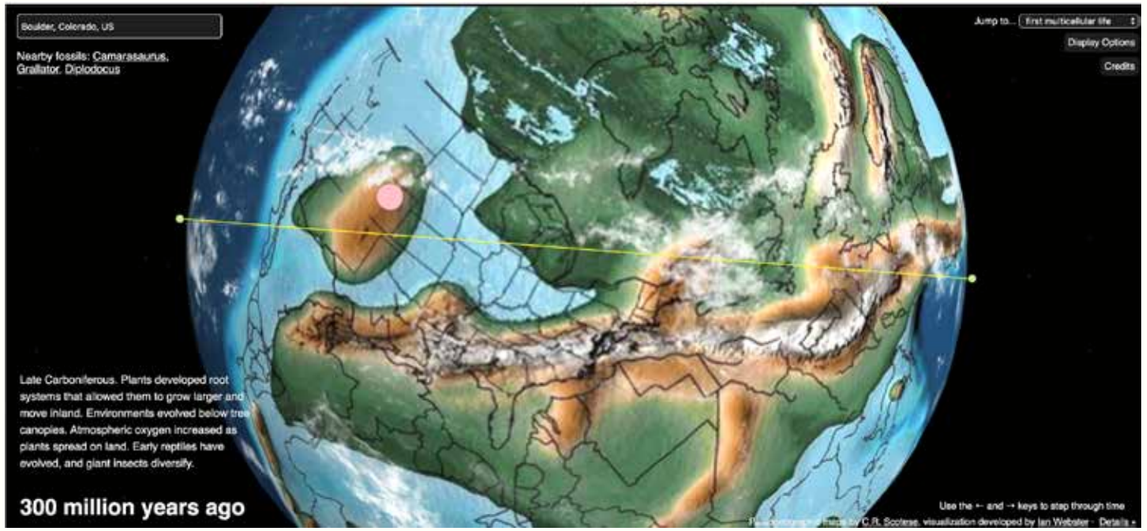


Edaphosaurus pogonias (illustration by Nobu Tamura)



Cotylorhynchus romeri (illustration by Nobu Tamura)

In fact, the “Flatirons” in Boulder---visible from SSI headquarters---are ancient petrified sand dunes from the late Paleozoic. And Colorado in general contains many important and puzzling rock formations from this time in places like the Aspen Valley and especially Unaweep Canyon, south of Grand Junction.



Boulder in the pink dot on this reconstruction of late Paleozoic geography, located in a mountain range known as the Ancestral Rocky Mountains. The Equator is marked with a yellow line. The Appalachians are one remnant of the continent-spanning mountain range south of the Equator. (Modified from a web application available at: dinosaurpictures.org).

Unaweep Canyon looks like a glacial valley, but no one is quite sure when the glaciers carved it out. Was it during the last glaciation, 20,000 years ago? Was it 650 million years ago, when the Earth was covered almost entirely with ice? Or was it 300 million years ago, when Unaweep was located about 10 degrees from the Equator? If the latter, it would suggest tropical glaciers might have reached 1000-1500 m elevation, more than 1000 m lower than they have during the most recent glaciations. Low enough to imply an extraordinarily cold climate, where tropical glaciers ground rocks into the dust making up the Maroon Bells or the famous red dust of Oklahoma.

This past year, NSF funded Dr. Heavens and collaborators from the Universities of Oklahoma and Minnesota to drill into Unaweep Canyon and figure out what the rocks are saying. Dr. Heavens’ role is to use climate modeling to help interpret what a glacial valley near the Equator means for global climate. The modelling effort uses the gold standard Community Earth System Model (CESM), 100 km resolution simulations of climate around 1850 or when ice sheet extent peaked 21,000 years ago. At this resolution, the mountains south of Quito, Peru (one area of focus) stand 1100-1600 m high, too low to sustain glaciers. It is possible, however, to look at glaciation here by using CESM to generate hourly to daily atmospheric data and then using this data as input to one component of CESM, the Community Land Model (CLM).

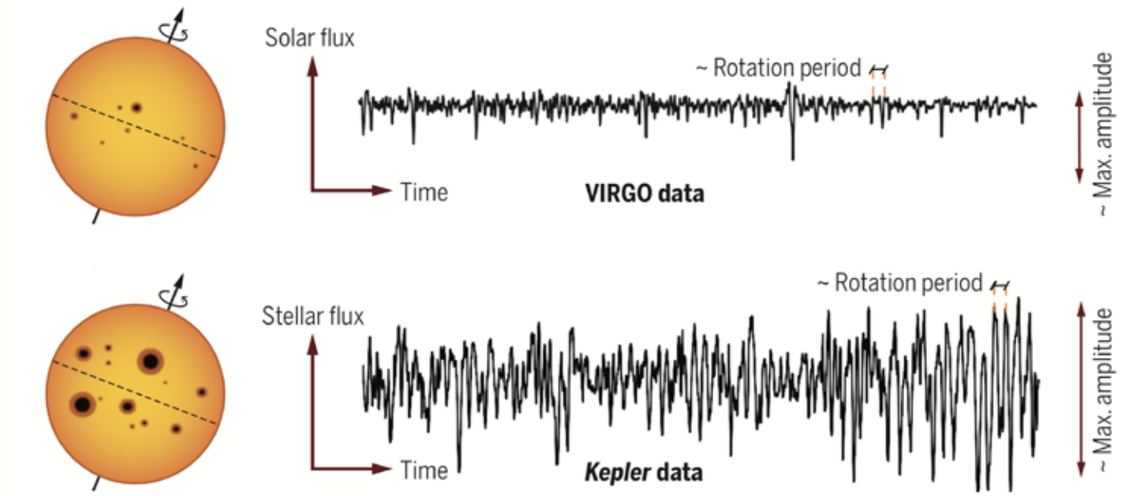
To do so, most of the boundary conditions at CESM’s lower resolution are kept; but high resolution (~1 km) topography is added to the boundary conditions for simulating glaciers. At this resolution, major glaciated mountains are resolved for purposes of estimating snowfall and snowmelt in considerable detail. The main parameter that can be adjusted is the lapse rate: how much temperature decreases with elevation. The lapse rate is typically higher for drier atmospheres, but its variability at high altitude is not easily observed and only partly understood. By finding the lapse rates that result in CLM matching where glaciers were stable 100-200 years ago and 21,000 years ago, Heavens and his team can understand how lapse rate might have changed in tropical areas between warmer and cooler global climates. The final step is to push a global climate simulation to be so cold that glaciers in the high-resolution domain are stable at 1000-1500 m elevation for a realistic lapse rate. This step will help determine how and why late Paleozoic Colorado could have gotten cold enough to drive glacial cycles near the equator; and perhaps solve the mystery of when Unaweep Canyon was carved.

Characterizing Solar and Stellar Magnetic Activity and Rotation

Dr. Ângela Santos;
Boulder, CO office

Low-mass stars, including our Sun, have convective outer layers. The convective motions together with differential rotation, i.e. different rotation rates at different latitudes, are considered key ingredients for the generation of magnetic fields and magnetic activity cycles. As stars evolve, they are observed to spin down and become less magnetically active. Therefore, both properties can be used as proxies for stellar age and can help us to better understand solar and stellar evolution. Stellar rotation and magnetic activity are also important properties for exoplanet research. Their signatures in the data can hide the planetary signals, hampering the detection and characterization of planets. Moreover, magnetic activity can also affect the habitability of planets.

The most noticeable manifestation of solar magnetic activity is the emergence of dark sunspots on the surface. Spots are regions of strong magnetic field which reduces the efficiency of the convection. Therefore, spots are cooler than the surroundings and appear dark. As sunspots follow the solar surface, one can track them and infer the rotation for the Sun. However, one cannot resolve the surface of distant stars and directly observe the starspots. Instead, we detect the effects of starspots, for example, on the stellar brightness. As the dark starspots come and go out of view, they modulate the stellar brightness (as illustrated in the figure), producing the so-called rotational modulation. The period of the signal is related to the stellar rotation period, while its amplitude is related to the spot coverage of the stellar surface. The larger the spot coverage, the higher the magnetic activity level. The advent of planet-hunting space missions, particularly the NASA Kepler satellite, yield high-precision continuous and long-term brightness observations for hundreds of thousands of solar-type stars. For those stars exhibiting rotational modulation, one can constrain surface rotation and magnetic activity.

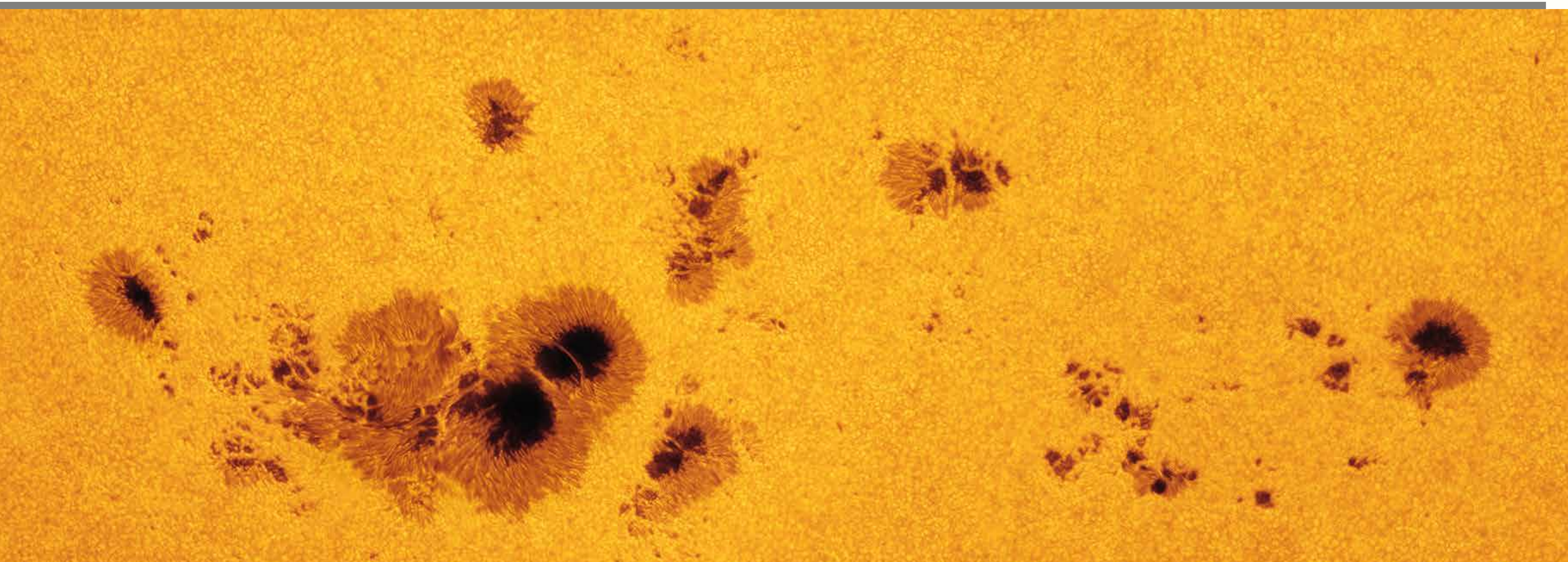


Left: Illustration of the surface of solar-type stars with dark magnetic spots. *Right*: Examples of solar/stellar light curves exhibiting brightness variations due to the presence of dark spots. *Credit*: Santos & Mathur, 2020, Science 368, 466.

SSI Research Scientist Ângela Santos and collaborators are conducting the analysis of the long-term Kepler data for more than 150,000 main-sequence and subgiant solar-type stars. One of the objectives is to retrieve their rotation periods and average activity levels, providing the largest catalog of its kind to date. From a more detailed analysis, they found that stars spinning faster are magnetically more active and also more variable in time than slower rotators. Interestingly, solar-type stars tend to group into two parallel branches in the activity-rotation relation. However, the origin of the two distinct behaviours is still a matter of debate and investigation. Furthermore, hotter stars are found to be typically faster rotators with stronger differential rotation (cont'd)

than cooler stars. Simultaneously, the brightness variations due to dark starspots become more complex and less stable in time. In fact, the starspots in hot stars are found to be short-lived in comparison with those of cool stars. The short spot lifetimes can explain the less coherent rotational signals. The different behaviour between hot and cool solar-type stars is interpreted as the result of shallower convection zones with increasing temperature.

Although Kepler's main mission was concluded in 2014, at present Kepler still provides an unique opportunity for studying stellar rotation and magnetic activity thanks to its high-quality long-term observations. The new NASA planet-hunting mission, TESS, is now collecting data for millions of solar-type stars. While TESS observations are less suitable for stellar rotation and activity studies due to their short observational time, TESS is observing brighter and closer stars than those observed by Kepler. This allows for ground-based follow-up observations, which will provide a variety of independent and complementary constraints and potentially improve our knowledge on rotation and activity, the relation between the two properties, their evolution, and their impact on stellar evolution itself.



A group of sunspots, labeled as Active Region 1520 rotated into view over the left side of the sun on July 7, 2012. The large spot on the bottom left stretches more than 11 Earths, or 87,000 miles across. The full chain of spots is closer to 200,000 miles across.

Credit: Alan Friedman

Shedding light on the dynamics of the Sun-Earth system using laboratory plasma physics experiments

Dr. Seth Dorfman;
Los Angeles, CA

Ninety-three million miles from here, on the outermost portion of the sun, hot matter called plasma is ejected outwards into space. This streaming solar wind plasma is usually deflected by the Earth's magnetic field, leaving us on Earth mostly unaffected. However, intense space weather events can damage satellites and power grids, disrupting cell phone, GPS, TV, and other crucial communications. Predicting space weather and limiting damage from these events requires a intimate understanding of the plasma physics of our sun-Earth system. Key questions abound: Why is the outer surface of the sun much hotter than the layer just below? What is the nature of the turbulence in the solar wind and in near-Earth space? How can we map the Earth's magnetic field during a geo-magentic storm?

Dr. Seth Dorfman, a research scientist at SSI, works to explore key plasma physics process in our sun-Earth system that may shed light on these and other questions. He uses both laboratory experiments and satellite observations and is currently working on several projects:

Coupling between an energetic electron beam and plasma waves in the laboratory:

We are currently working to put together the hardware necessary to deploy a relativistic electron beam on the Large Plasma Device (LAPD) at UCLA to study... (cont'd)

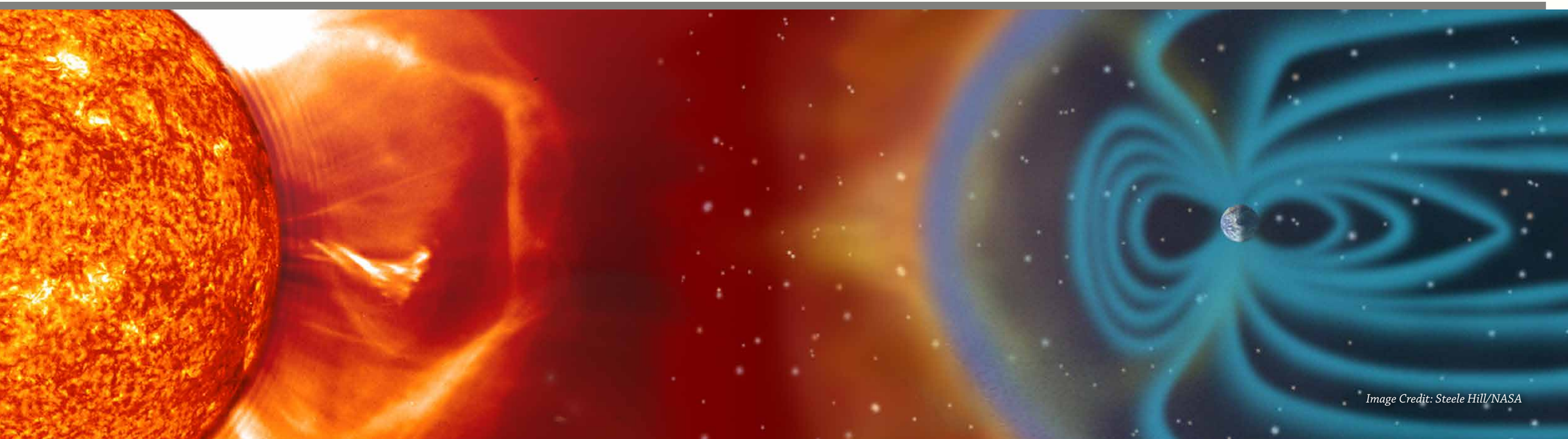


Image Credit: Steele Hill/NASA

...the waves generated and how the beam propagates through the plasma. The physics we learn will aid future missions to put electron beams on spacecraft where they can trace magnetic field lines, allowing us to see how space weather disturbs the field. Results will also improve our understanding of radio bursts thought to be generated by energetic electron beams on the sun. Preliminary experiments with a lower energy beam show robust wave generation via a Landau resonance process. This work includes collaborators at Los Alamos and the University of Minnesota.

Non-linear interactions between Alfvén waves:

Alfvén waves, the fundamental magnetic mode of plasmas, are thought to play a key role in the heating of the solar corona, the nature of the turbulent solar wind, and energetic particle loss in tokamaks. In all three contexts, parametric instabilities of large amplitude Alfvén waves may be an important mechanism. In a 2016 paper in Physical Review Letters, we documented the first observation of a sheer Alfvén wave parametric instability in the laboratory. Unlike traditional parametric instabilities predicted by the simplest theories, the finite perpendicular extent of the pump wave was found to play a key role. Following up on this work, new scaling studies show that this perpendicular parametric instability is most active at a transition point between inertial (electron inertia dominated) and kinetic (electron pressure dominated) Alfvén wave regimes. This parameter regime is highly relevant to the lower solar corona, suggesting a possible role for this instability in space.

Ultra low frequency (ULF) waves upstream of the Earth's bow shock

When the fast-moving plasma of the solar wind hits the Earth's magnetic shield, a bow shock is formed. Just like the curve of water that bends to the side in front of a moving ship, the bow shock is where hot plasma is deflected to the side, leaving us on Earth mostly unaffected. A very small portion of the plasma, however, bounces straight back towards the sun. This reflected ion beam may interact with the solar wind plasma to generate large-amplitude, Ultra Low Frequency (ULF) waves at a small fraction of the ion cyclotron frequency. Under a recently awarded NASA Early Career Investigator Program grant, Dr. Dorfman and SSI postdoctoral researcher Kun Zhang will use observations and global simulations to understand the structure and properties of the observed waves and their relationship to the observed ion beams. Possible signatures of non-linear interactions will also be investigated. This work has the potential to improve our understanding of waves generated by energetic particles throughout our heliosphere in ways applicable to present and future space missions.

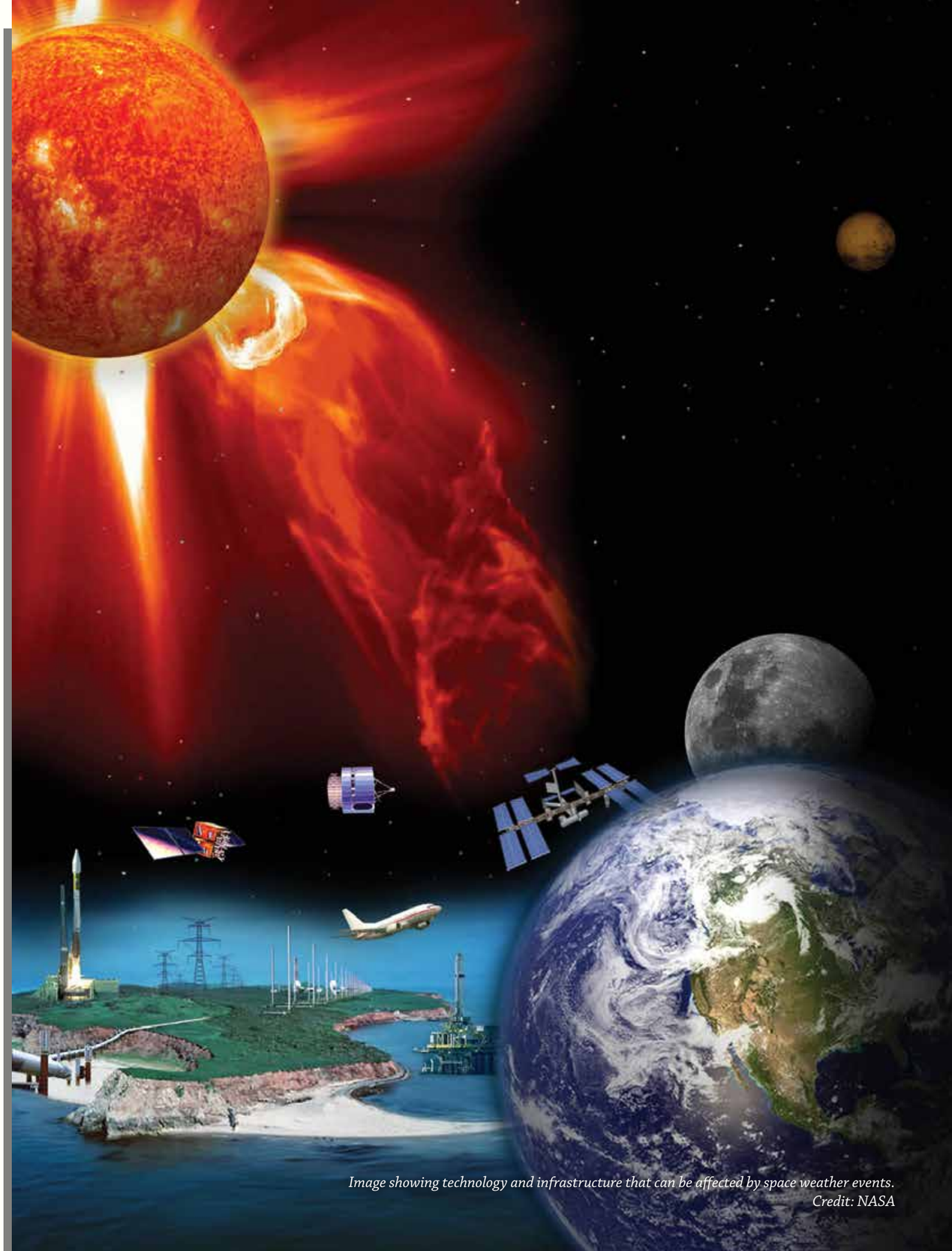


Image showing technology and infrastructure that can be affected by space weather events. Credit: NASA

Education & Inspiration

In this section:

Telescope viewing during the 2019 Summer of Space campaign.
Credit: Deaf Smith County Library, TX

National Center for Interactive Learning

SSI's ***National Center for Interactive Learning*** (NCIL) is led by Dr. Paul Dusenbery (Boulder Office). NCIL is a leader in developing STEM-themed exhibitions, active learning programs, and educational games and apps that can be deployed on websites, mobile devices (e.g. smartphones and tablets), and multi-touch tables. In 2019, there were 11 staff members working on 7 active grants and contracts.

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 STEM and STEM facilitation. NCIL's social media and *STEM Activity Clearinghouse* have a national reach that numbers in the millions. NCIL (ncil.spacescience.org) is organized around four interdependent groups: 1) Exhibition Development, 2) Community Engagement, 3) Professional Development, and 4) Digital Learning.

The STAR Library Network (*STAR Net*) is NCIL's flagship STEM program serving the public library community. It is a hands-on learning network for libraries and their communities across the country. STAR Net focuses on helping library professionals facilitate STEM learning for their patrons by providing "science-technology activities and resources" (STAR) and training to use those resources. It began in 2009 and now numbers over 8,000 members. The community can access webinars, monthly newsletters, blogs, partnership opportunities, facilitation guides, book recommendations, and much more, including *STAR Net's STEM Activity Clearinghouse*. It also has an active social media presence including Facebook, Twitter, YouTube, and Flickr. *STAR Net*'s website also includes an area called STEM in Libraries that has resources for emerging and established library leaders on topics such as family/adult programming, expanding diversity, and collaboration ideas. STAR Net is built upon a strong network of collaborators and partners, led by NCIL. They include the American Library Association's Public Programs Office, American Society of Civil Engineers, Chief Officers of State Library Agencies, Cornerstones of Science, Education Development Center, Lunar and Planetary Institute, Institute for Learning Innovation, Twin Cities PBS, University of Colorado, University of Virginia, and many others.

The Clearinghouse is a one-stop shop for free STEM activities designed specifically for the library setting, based on librarian demand and feedback. Thanks in large part to *STAR Net*'s recent Summer of Space event in 2019 (see Highlight below), hundreds of STEM activities from NASA and other vetted sources were uploaded to the Clearinghouse, bringing the total number of activities to over 400. *STAR Net*'s professional development team used analytical data and user feedback to add new features in order to increase the Clearinghouse's overall usability. From 10/14/18-10/15/19, the *STEM Activity Clearinghouse* saw a 372% increase in the number of users (37,839 vs. 8,022) and a 358% increase in the number of pageviews (164,116 vs. 35,811), when compared to the previous calendar year.

Young patrons prepare for a rocket launch.
Credit: Siouxland Public Library, SD

Full body coding in the Exploring Space Exhibition at Westminster Public Library
Credit: NCIL/SSI

NCIL had four major programs that were active in 2019: *Partners for Middle School STEM*, *Exploring Space*, *NASA@ My Library*, and *Project BUILD*.

The IMLS-funded project called *Partners for Middle School STEM* is a partnership between the lead organization, Urban Libraries Council, and NCIL. This program is described in the Highlight Section below.

NCIL also developed a traveling exhibition program, called *Exploring Space*, that was funded by an NSF supplement to its successful *STAR Net Phase 2* program. The supplement allowed the NCIL team the opportunity to explore computing and programming within libraries as informal learning environments. Library patrons experienced computing and programming through the engaging context of space exploration. See the Highlight Section below for more details.

Through the *NASA@ My Library* project, NASA, public libraries, and state library agencies work together to increase and enhance STEM learning opportunities for millions of library patrons throughout the nation, including geographic areas and populations that are currently underserved in STEM education. The *NASA@ My Library* team engages key stakeholders (e.g., NASA subject matter experts (SMEs), public library partners, and state library partners) centered around high-profile NASA, Earth, celestial, and library events (e.g., 2017 solar eclipse, Earth Day, and summer learning events at libraries like the Summer of Space campaign in 2019).

Project BUILD partners include NCIL/SSI, University of Virginia, American Society for Civil Engineers (ASCE), and Education Development Center. The program engages children in grades 2-5 and their families in age-appropriate, technology-rich STEM learning experiences that are based on the Engineering Design Process. The ultimate goal of the program is to increase youths' awareness of and motivation to pursue STEM-related educational and career pathways, especially for youth from rural and/or geographically isolated areas and populations traditionally underrepresented in STEM. The project utilized several mechanisms to reach this goal including Community Dialogues, circulating kits, and library programs.

STEM program at the Fairfield Public Library. Credit: Fairfield Public Library, CT

Community Engagement

The goal of NCIL's Community Engagement Group (led by Anne Holland, Boulder Office) is engage public and professional communities in the work we do, and to encourage public libraries to work with (not for) their communities to address local needs. Activities range from community outreach at science festivals and schools locally in Colorado, to providing personal attention and assistance to members of our professional learning community across the country through the *STAR Net* Community of Practice. *Community Dialogues* have recently become an important focus of STAR Net, with more than 150 Dialogues being conducted by public libraries across multiple NCIL programs. These *Dialogues* aim to help libraries identify potential partners, work more closely with underserved and underrepresented groups in their communities, and get a clearer pulse on the needs of the community they serve.

A Community Dialogue at the Broward County African American Research Library.
Credit: SSI/NCIL

Professional Development

The Professional Development Group (led by Keliann LaConte, Boulder Office) oversees training and activity development. *STAR Net* engaged library, education, and STEM professionals nationwide through 24 webinars and presentations at 8 conferences in 2019. In 2019, monthly webinars were offered to public library staff to provide insights from leaders in the field, foster discussion between informal educators, and promote free educational resources. Virtual training has become a pivotal tool for NCIL in reaching their goal of strengthening the infrastructure of STEM education in libraries.

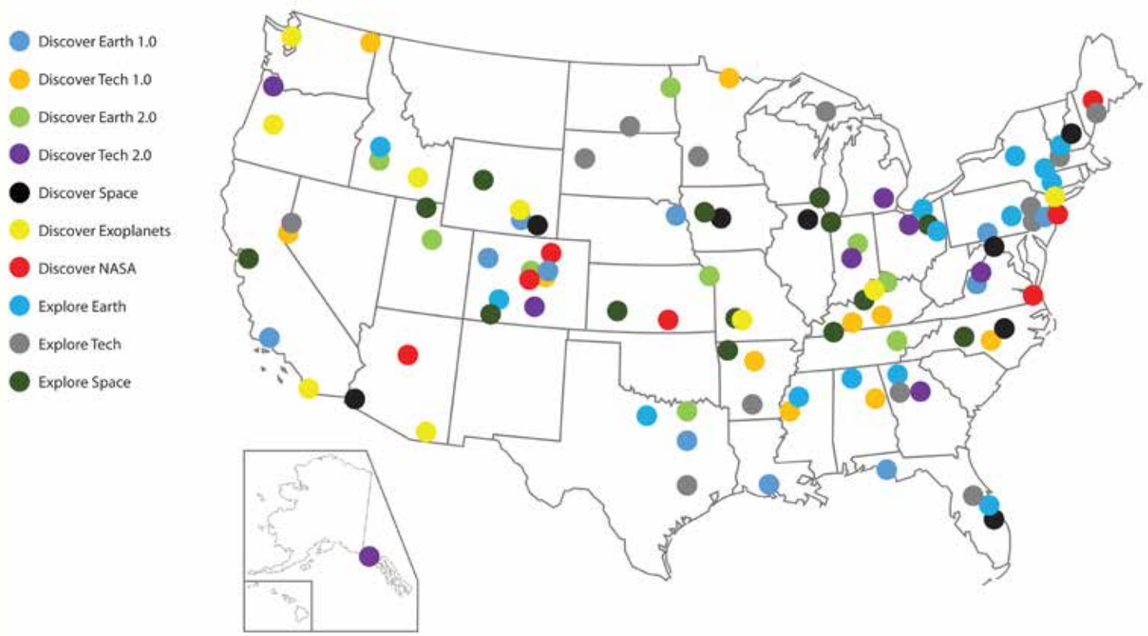
STEM workshop session at the 2019 annual ALA conference.
Credit: ALA

Digital Learning

NCIL has been exploring the potential of digital media for two decades, ranging from interactive experiences for museums and libraries to online games. The Digital Learning Group is led by Dr. James Harold (Boulder Office). Digital media doesn't simply create more engaging experiences, it can allow learners to interact with data, explore simulations, and connect to each other through social media. The potential only increases as portable, connected devices become more commonplace, allowing us to reach people in a variety of different environments and contexts. In the past year we have continued our work developing interactive kiosks and games for library exhibitions, and mobile apps to support librarians in exploring NASA STEM topics with their patrons. In particular, we placed an increased emphasis on activities that support "Computational Thinking" topics, including the Exploring Space exhibition that's described below in the Highlight Section.

Interactive kiosk display in the Discover NASA exhibit at the Louisville Public Library, CO.
Credit: SSI/NCIL

NCIL Impacts for 2019



STAR Net exhibition host library sites. Credit: SSI/NCIL

Traveling Exhibit Visitors

STAR Net's *Discover Tech* Library Exhibit (2 host sites):	16,200
STAR Net's *Discover Space / Exploring Space* Exhibit (4 host sites):	37,043
STAR Net's *Discover NASA* Exhibit (3 host sites):	227,957
STAR Net's *Explore Earth* Exhibit (2 host sites):	30,000
STAR Net's *Explore Tech* Exhibit (2 host sites):	21,200
STAR Net's *Explore Space* Exhibit (3 host sites):	45,000
STAR Net's *Discover Exoplanets* Exhibit (8 host sites):	132,087
Total:	**509,487**

STAR Net Library Program Participants: 64,180

In-person Professional Development Participants: 751

Webinar Participants

Unique Live Views:	1,400
YouTube Live Views:	1,993

STAR Net Online Community Members: 8,200

NCIL Outreach Event Participants: 1,395

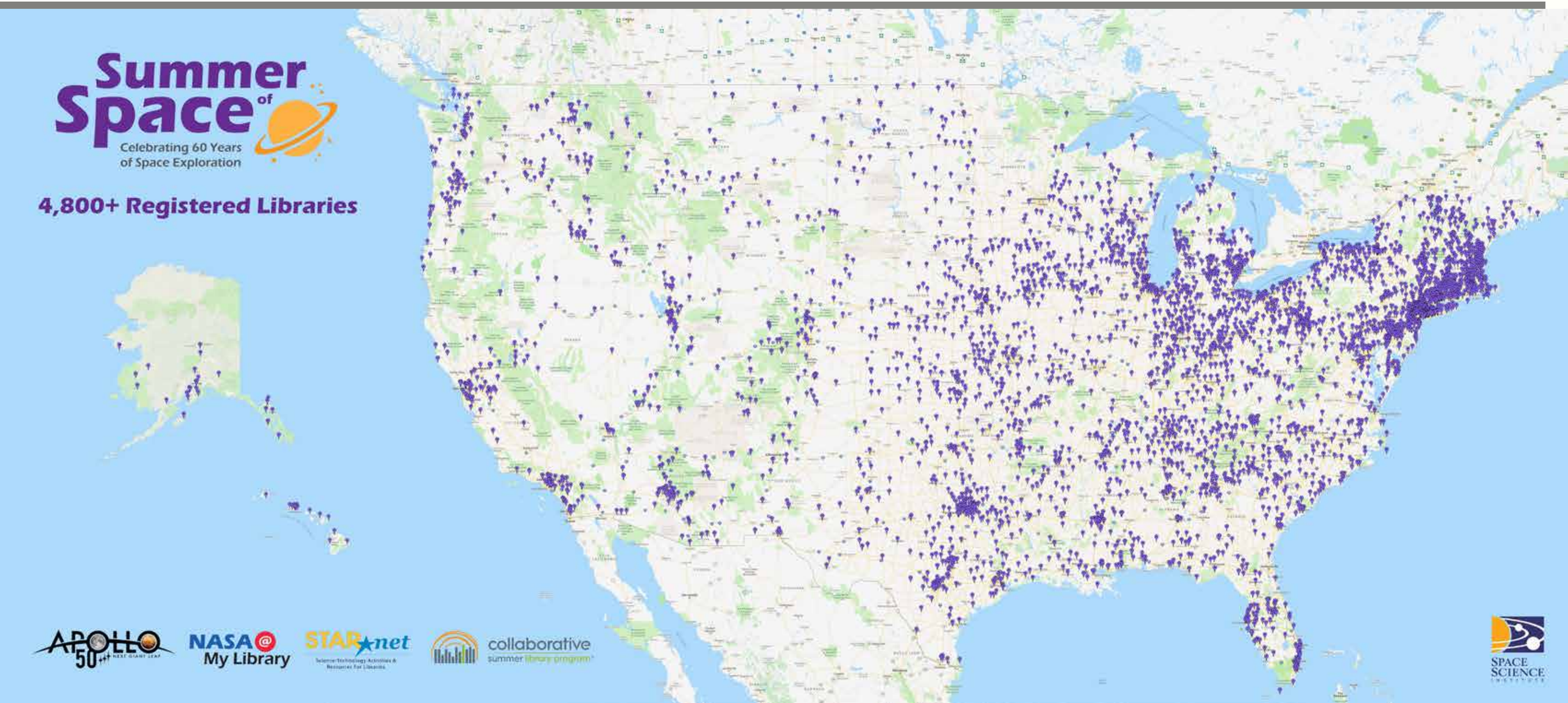
Exhibition Website Visitors

	Page Views:
Alien Earths:	292,719
Giant Worlds:	53,358
MarsQuest Online:	91,418
SciGames:	56,977
Space Weather Center:	264,598
Killer Asteroids:	67,836
Starchitect:	230,409
STAR Net:	205,939
STEM Activity Clearinghouse:	159,636
National Center for Interactive Learning:	3,108
Total:	**1,425,998**

2019 Highlights

Libraries Participate in the Summer of Space Campaign

The Space Science Institute's (SSI) National Center for Interactive Learning (NCIL) manages the STAR Library Network (*STAR Net*) and its *NASA@ My Library* program. The STAR Net team in partnership with the Collaborative Summer Library Program (CSLP) worked together to share science- and technology-related activities and resources with libraries across the nation as part of CSLP's 2019 summer learning theme. The slogan "A Universe of Stories" was chosen by library professionals to help inspire children of all ages to dream big, believe in themselves, and create their own story. It coincided with NASA's celebration of the 50th anniversary of the Apollo 11 Moon landing. (cont'd)



STAR Net's Summer of Space (SoS) campaign was chosen to serve both NASA and CSLP interests and can be used as a template for future summer events. The SoS webpage included numerous STEM resources that libraries utilized in their celebration of space exploration such as a collection of vetted STEM activities, giveaways, partnership opportunities, media templates, printables, and a collection of spectacular images and videos.

Scholastic Publishing and Haptically Speaking were also key partners in expanding the reach of Summer of Space. The partnership with Scholastic provided *STAR Net* with a donation of over 800 space related children's books that were distributed to libraries who registered as incentives and prizes. Included in those prizes were *Getting a Feel for Lunar Craters*, a braille book for visually impaired readers that was produced by Haptically Speaking and funded by NASA. These relationships were important for the success of Summer of Space, increasing the impact on diverse learners that STEM engagement can have across the country.

The *STAR Net* team led numerous in-person trainings through the *NASA@ My Library* project that gave library professionals an in-depth look at STEM facilitation techniques and NASA resources. Facilitators (from both SSI/NCIL and the Lunar and Planetary Institute) led NASA STEM Workshops in 12 different states that reached 363 library professionals (from November 2018 – May 2019).

Reach. More than 4,800 public libraries were supported and participated in Summer of Space activities (see map above). The resources, activities, and giveaways provided

to libraries empowered staff to showcase space related content in a fun, educational, yet easy to understand way that kept patrons interested and engaged throughout the summer.

"We had a wonderful summer using the NASA resources. The children and adults learned much from our summer in space. One child said, "I really think I will be an astro-engineer someday and work on the space station because of being at the library." - Kim King, Priestly Forsyth Memorial Library, Pennsylvania

Several key events during the summer helped to enrich what libraries were already planning to do for their space-themed summer programs. The three largest events that libraries participated in were 1) the Apollo 11 Re-enactment with the American Museum of Natural History (AMNH) in partnership with *STAR Net*, 2) NASA's 50th Anniversary Live Event, and 3) the NASA In-Flight Education Downlink with the International Space Station at the Slover Library in Norfolk, Virginia. A summary video of the Slover event was produced by the City of Norfolk.

By connecting CSLP's theme of "A Universe of Stories" to the Apollo 50th Anniversary and *STAR Net*'s International Space Station Education Downlink at the Slover Library in Virginia, participating libraries were able to create a summer learning program dedicated to space science and other STEM topics. Some libraries implemented a STEM program for the first time; others were able to expand their STEM programming beyond their normal activities. With all 50 states represented, the *Summer of Space* campaign made a national impact on participating libraries and their communities.

NASA STEM Workshop in Arizona. Credit: SSI/NCIL

2019 Summer of Space event. Credit: Fort Meade Public Library, FL

Integrating Computational Thinking in the Exploring Space Exhibition

2019 presented an exciting opportunity for this project. Building on a long tradition of library-led summer educational events, and reflecting the increased infusion of STEM, *STAR Net* worked closely with four libraries to help them prepare for their summer CSLP events and to host a traveling exhibition entitled *Exploring Space: Smart Spacecraft, Big Data, and Modeling Reality*. This exhibit expanded upon the nationwide interest in space science to include computation and computational thinking (CT), based on promising practices from this project and broad interest by the American Library Association (ALA) and the National Science Foundation (NSF) in CT as a scientific practice.

Two representatives from each of the four host libraries met with the NCIL team for a workshop about the exhibit and the hands-on activities that accompany it at the College Hill Branch of Westminster Public Library in July of 2019. During the workshop participants became familiar with the *Exploring Space* exhibit's multimedia components, which included a 42'' touch table where visitors can build their own artificial solar system, a Discovery Table where people can play with programmable robots, interactive displays about exoplanets, and several kiosks. One kiosk showcased "Rover Coder", a game that introduces basic programming concepts in the context of driving a rover on Mars. Players start with very basic commands and simple goals. As they progress, the goals become more difficult and can only be achieved using more complex commands (e.g., loops). The game is also available on the Android and iOS app stores.

Workshop participants reflected on the way computing concepts are being used to explore space and how they are used in our daily lives, from detecting bank fraud to coding video games. When asked why libraries should focus on computational thinking, one participant responded, "We are shaping the minds of our youth and making learning fun. [These] hands-on experiences can build on school experiences." The workshop was followed by two webinars showcasing additional hands-on CT activities both on and off computers. The evaluation findings from this small-scale implementation in four libraries will help lay the groundwork for a future research study regarding CT knowledge and interest development in the library setting.

Entrance area for the Exploring Space exhibit at the College Hill Branch of Westminster Public Library, CO. Credit: SSI/NCIL

Host library staff learn about the Exploring Space exhibit at the College Hill Branch of Westminster Public Library, CO. Credit: SSI/NCIL

Engaging Middle School Youth in STEM Learning

The Professional Development Group is serving as a partner and lead STEM education experts on the *Partners for Middle School STEM* project funded by the Institute for Museum and Library Services and led by the Urban Libraries Council. Eleven participating public library systems built multi-sector community partnerships to increase STEM learning opportunities for underserved youth, ages 10-13. NCIL staff supported the project kickoff in Chicago on March 13-14, 2019 and shared STAR Net resources as part of the ALA Annual Conference session, "Partnerships to Advance STEM Programming." NCIL staff also facilitated one-on-one support calls and presented at frequent webinars to engage participating libraries and support STEM programming and partnership development. For example, How Public Libraries can Bridge the Middle School STEM Gap webcast was offered on December 12, 2019.

Middle school patrons engage in a STEM activity. Credit: Mount Vernon Public Library, WA.

Financial Summary

Space Science Institute • Summary Statement of Financial Position
as of December 31, 2019 and 2018

ASSETS	2019	2018
Assets		
Cash and cash equivalents	453,797	249,117
Accounts receivable	1,311,013	1,811,820
Prepaid expenses and deposits	120,144	131,434
Net furniture, equipment, and property	237,839	21,865
Total assets	**$ 2,122,793**	**$ 2,214,236**

LIABILITIES AND NET ASSETS		
Liabilities		
Accounts payable and accrued liabilities	743,760	1,170,293
Deferred revenues	317,758	231,850
Line of credit	475,000	500,000
Note Payable	115,842	-
Total liabilities	$ 1,643,360	$ 1,902,143
Net assets		
Unrestricted	473,688	233,336
Temporarily restricted	5,745	5,745
Total net assets	$ 479,433	$ 239,081
Total liabilities and net assets	**$ 2,122,793**	**$ 2,141,224**

Summary Statement of Activities
for the years ended December 31, 2019 and 2018

SUPPORT AND REVENUE	2019	2018
Grants, contracts, and cooperative agreements	8,339,015	8,606,532
Contributions	30,611	11,331
Exhibit and workshop income	6,643	229
Interest income	335	208
Total support and revenue	**$ 8,376,604**	**$ 8,618,300**

EXPENSES		
Science research programs	4,276,955	4,668,084
Science education programs	1,991,029	2,092,793
Fundraising	6,526	5,194
General and administrative	1,861,742	1,780,475
Total expenses	$ 8,136,252	$ 8,546,546
Change in net assets	240,352	71,754
Net assets, beginning of year	239,081	167,327
Net assets, end of year	**$ 479,433**	**$ 239,081**

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, 2019 and 2018, from which the summarized information was derived. A copy is available upon request.

WWW.SPACESCIENCE.ORG

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

Your contribution will help:

- Ensure 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