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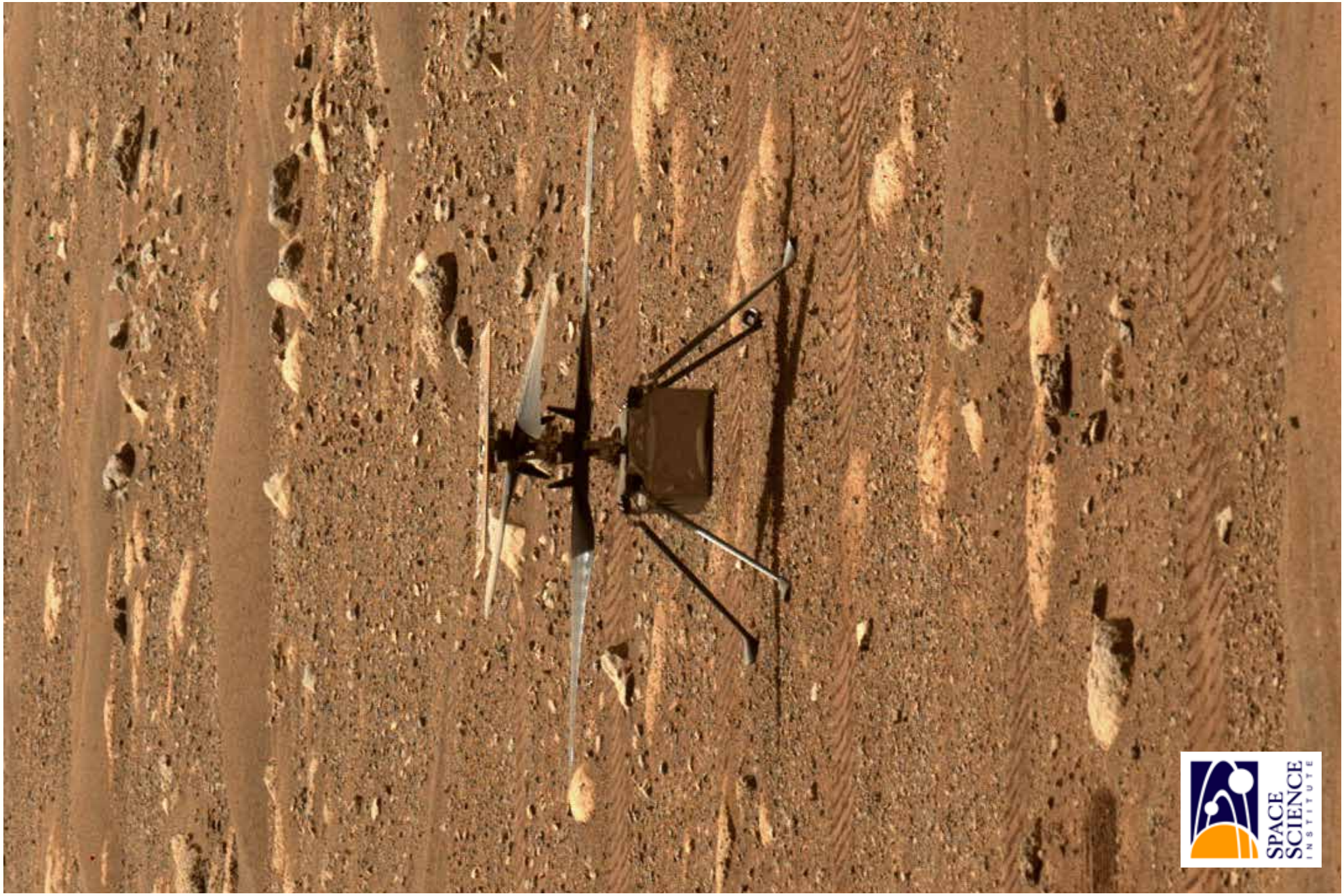
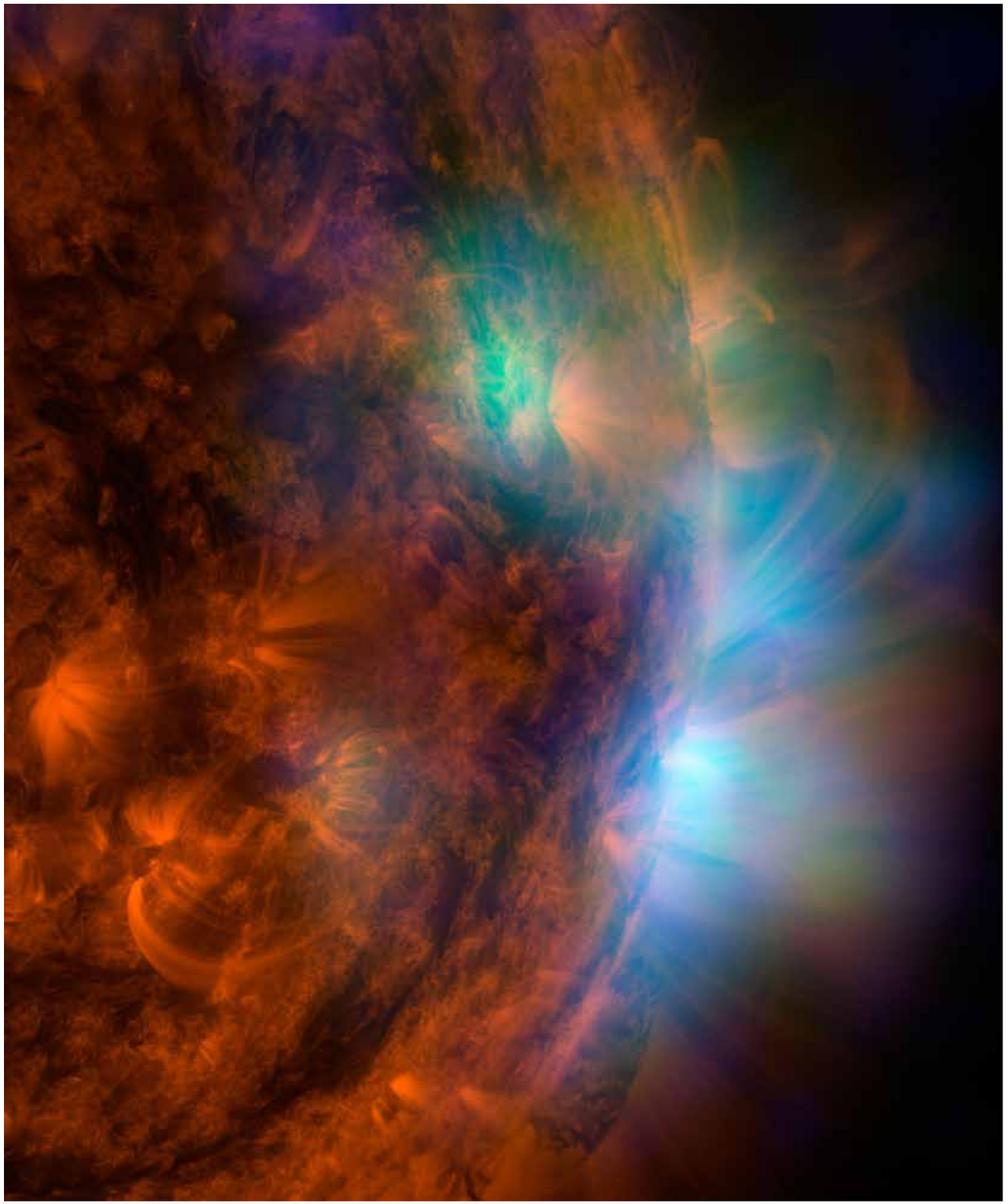
ANNUAL REPORT 2021





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.

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> On the cover: NASA's Ingenuity helicopter unlocked its rotor blades, allowing them to spin freely, on April 7, 2021, the 47th Martian day, or sol, of the mission.
> Credit: NASA/JPL-Caltech/ASU

> The Sun in X-rays from NuSTAR. Credit: NASA, NuSTAR, SDO

Message from the Executive Director and Board of Directors

2021 was an exceptionally eventful year for SSI, not only in terms of the pandemic but also milestones and new projects on the horizon.

Documenting the institute's progress during COVID-19, offices where SSI is headquartered were finally allowed to reopen to 100% capacity in mid-late 2021. Given the COVID-19 variants, SSI phased in its staff over time and was able to avoid outbreak and even successfully host several employee events, including a hybrid corporate retreat and retirement parties – see photos in this report of the celebration for SSI's founder and first emeritus educator, Dr. Paul Dusenbery. SSI also welcomed many new hires, including two new postdoctoral research associates, four student research assistants, and one specialist in our Research Branch, and now offers remote work for our STEM education branch.

This phase of the pandemic offered an opportunity for deep work. The number of scholarly journal articles submitted by SSI scientists in 2021 was over 295 total, a significant increase over the already impressive 170 articles in 2020. Kudos to our programmatic and operations staff for successfully executing record high proposal volume in 2021, over 30 submissions in May alone! Highlights for 2021 include several large ($1M+) proposals submitted or selected, including a NASA cooperative agreement to launch the "From Our Town to the Moon, Mars, and Beyond" exhibit featuring content related to NASA's Artemis I lunar mission, and a new SSI-led heliophysics mission concept proposal, MIO.

Given the volume and diversity of work done in 2021, this year's annual report spotlights a few of our many projects. In our expanded Center for Space Plasma Physics section, you'll read about cutting edge computer simulations and a NASA-funded citizen science effort, in which high school students analyze signals from plasma waves in space that have been turned into sounds. Our Center reports also describe two international virtual conferences that we hosted across 14 time zones, broadening participation for India and Africa, and experiments related to the Korean Pathfinder Lunar Orbiter (note: SSI scientists won 2 out of the 9 participating scientist slots on the mission).

Our education team, the National Center for Interactive Learning, led and supported approximately 10 large-scale projects in 2021, a few of which are featured here. The 2021 theme of Earth Science Week was "Water Today and For the Future." Read more about the "We Are Water" project, which works with libraries in the Four Corners region of the U.S. to share stories about the importance of water within the Indigenous and rural communities they serve. This report also includes a piece on "STEAM Equity," which involves three exhibits that are rotating together with content specifically aimed at Latinx tween girls.

SSI's Board of Directors welcomed a new member, Dr. Windsor Morgan, in 2021. He is an associate professor of physics and astronomy at Dickinson College in Carlisle, Pennsylvania. He is also the director of Dickinson's Charles M. Kanev Planetarium and has authored books on incorporating computer programming and techniques such as think-pair-share questions in introductory physics and astronomy courses. Windsor's work in astronomy education research is very complementary to SSI's mission and we are appreciative of his perspectives in our Board discussions.

2021 had a lot going on in many respects, both good and bad. There are positive memories to preserve and good things ahead, and we hope to brighten your spirits with that perspective. All of us at SSI and our Board of Directors send wishes for everyone's continued health and prosperity in the coming year.

> Karly Pitman, Ph.D.
> Executive Director

> Steven Jolly, Ph.D.
> Chair

> William R. Purcell, Ph.D.
> Vice-chair

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 (to be launched in 2022).

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).

> The Red Square Nebula. Credit: Peter Tuthill (Sydney U.) & James Lloyd (Cornell U.)

Present

Today, SSI manages 74 employees and 20 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.

2021 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. Amanda Fisher, Manager, Association of Science and Technology Centers
- 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. Steve Jolly (Chair), Systems Engineering Director, 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

2021 Executive Advisory Committee

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

2021 Grants + Contracts

SSI gratefully acknowledges support from research and education grants and contracts from the following organizations in 2021:

- Aerospace Corporation
- Arizona State University
- Boston University
- Carnegie Institution of Washington
- Department of Energy
- Jet Propulsion Laboratory (JPL)
- Laboratory for Atmospheric and Space Physics
- Los Alamos National Laboratory
- Malin Space Science Systems
- NASA
- National Science Foundation
- New Mexico Consortium
- Northern Arizona University
- Purdue University
- Smithsonian Astrophysical Observatory
- Southwest Research Institute
- Space Telescope Science Institute (STScI)
- Universities Space Research Association
- University Corporation for Atmospheric Research
- University of Alabama, Hunstville
- University of Arizona
- University of California, Los Angeles
- University of Colorado, Boulder
- University of Houston
- University of Iowa
- University of Maryland
- University of New Hampshire

2021 Colorado Gives Donor List

SSI wishes to thank the generous individuals who contributed to the Space Science Institute in 2021:

- Jack Burns
- Robert T. Clancy
- Jennifer Cruz / Scaled Agile Inc.
- The Doyle Family
- Douglas Duncan
- Paul Dusenbery
- Amanda Fisher
- Lieschen Gargano / in honor of Bill Gargano
- Nancy Geyer
- Jennifer Griest
- Anne Holland
- Steve Jolly
- Mark Lemmon
- Kerry Lightenburger
- Thomas Lippert
- Neal Miller
- Brooks Mitchell
- Windsor Morgan
- Julianne Moses
- Karly Pitman & Damian Crevello
- William Purcell
- Ralph Shuping
- Greg Wimpey
- Michael Wolff
- Carl Wuth

We Discover & Explore

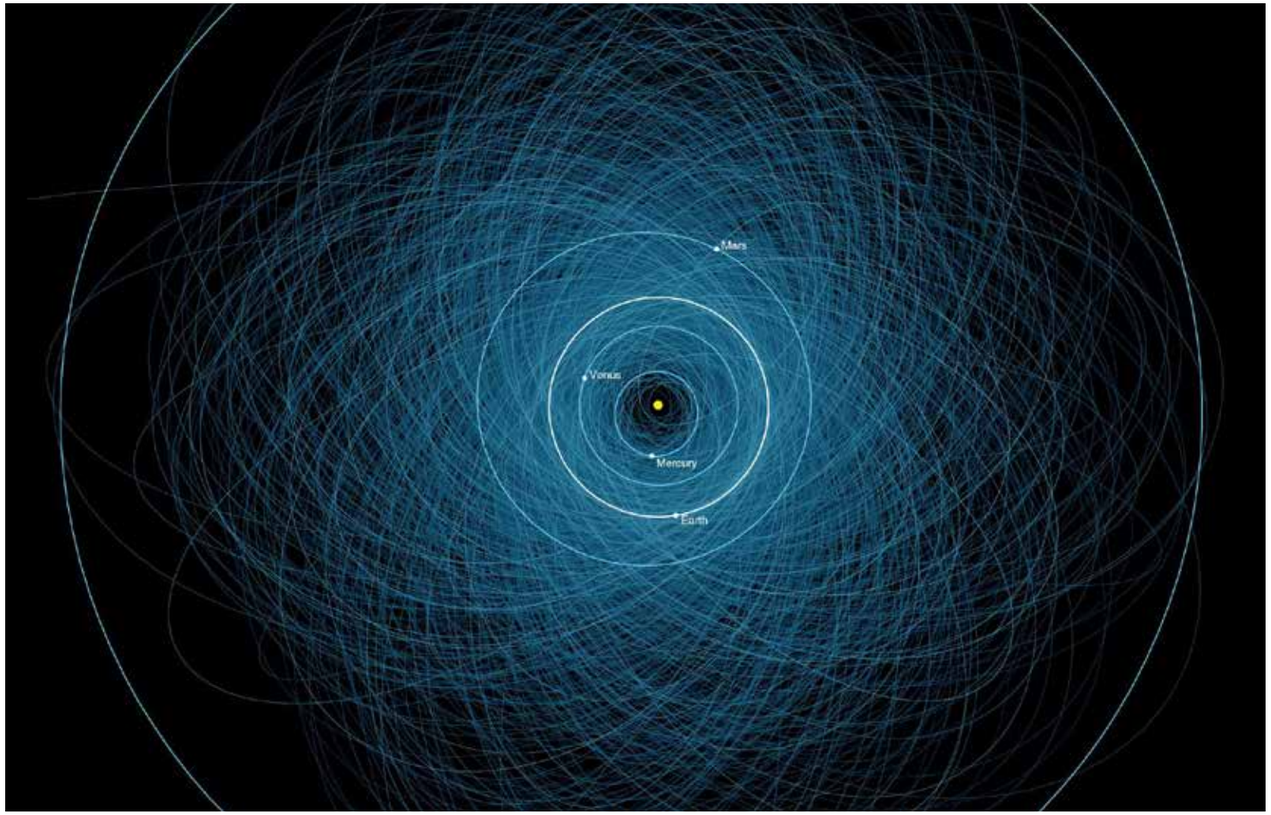
SSI researchers work on the cutting edge of astrophysical, planetary, and space plasma sciences. The Research Branch is home to world experts in multiwavelength astronomy, Mars atmospheric and surface studies, cometary and outer Solar System research, and heliospheric physics. Our researchers come to 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.

> Blue Straggler Stars in Globular Cluster M53. Credit: ESA/Hubble, NASA



> Orbits of Potentially Hazardous Asteroids. Credit: NASA, JPL-Caltech

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 2021, the Research Branch welcomed 4 new principal investigators, 2 new post-doctoral research associates, 4 new student research assistants, and 1 specialist, bringing our total number of branch team members to 77. Ten of the 77 team members are located on-site at SSI's Boulder headquarters with the rest distributed across the U.S. and internationally. Sadly SSI and the space plasma community suffered a tragic loss during 2021 when Sr. Research Scientist Peter Gary passed away (see "In Memoriam" below).

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 28 new grants and contracts in 2021, primarily from NASA and NASA-funded primes, including awards in:

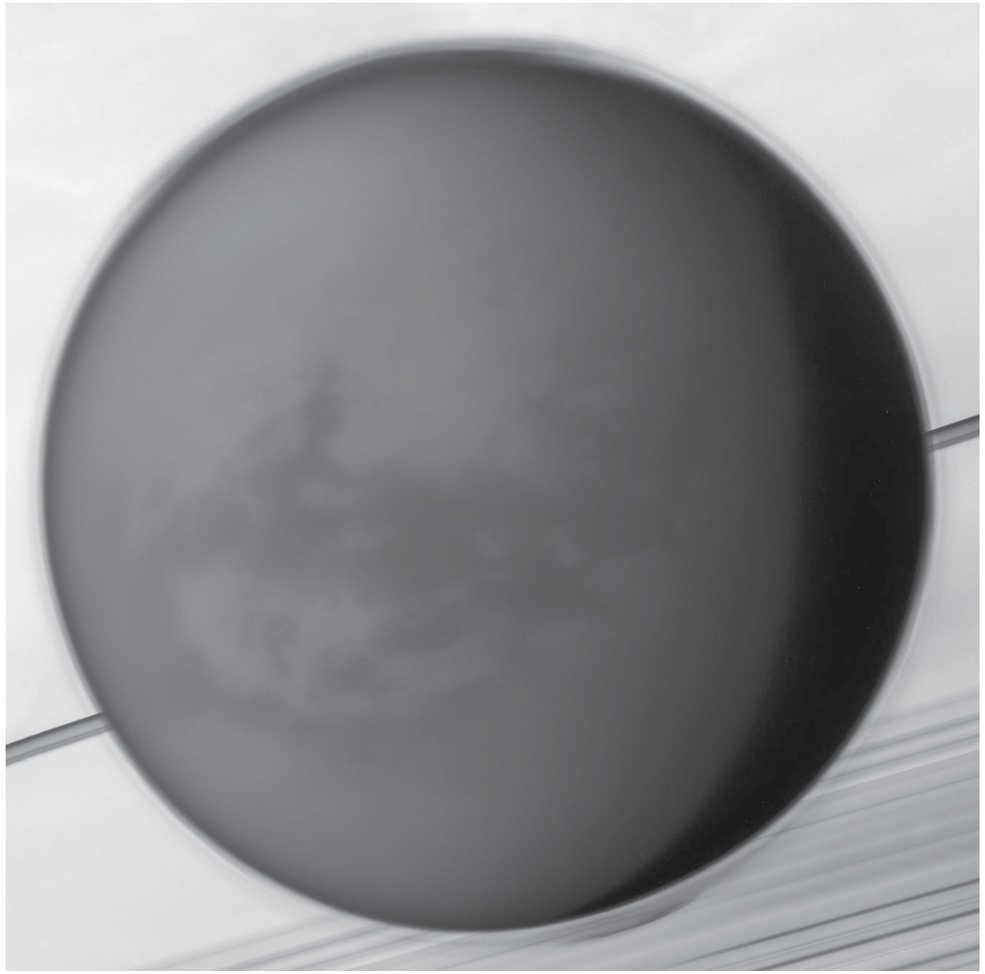
- space plasma physics (PIs: Joe Borovsky, Michael Hartinger, Mick Denton, Yuri Omelchenko, Vadim Roytershteyn, Thanasis Boudouridis, Giovanni Lapenta)
- planetary and exo-planetary atmospheres (PIs: Julie Moses, Frank Mills)
- Martian atmosphere (PIs: Tim McConnochie, Alexey Pankine)
- galactic astronomy (PI: Derck Massa)
- stellar atmospheric modeling (PI: Regner Trampedach)
- astronomy/astrophysics (other) (PIs: Peter Barnes, Eric Omelian, Heidi Hammel)
- planetary geology (PIs: Bill Farrand, Mikki Osterloo, Susan Sakimoto)
- laboratory analogs (PIs: Ahmed Mahjoub, Gorden Videen)
- and citizen science (PIs: Michael Hartinger, Padma Yanamandra-Fisher)

2021 Impacts

Total Research Branch Team Members:	77
Papers published:	>295 (refereed + non-refereed)
Invited/Public talks:	>50
New grant/contract proposals submitted (PI + co-PI):	81
New grants/contracts awarded:	26

Missions 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)



> Titan: Moon over Saturn. Credit: NASA, JPL-Caltech, Space Science Institute

Research Center Updates

Center for Data Science

SSI's Center for Data Science (CDS) is an initiative to bring together domain experts in space sciences and highly skilled computer scientists sharing a common interest in Data Science (DS), Artificial Intelligence (AI), and Machine Learning (ML). The group consists of nearly 30 scientists from all fields of space science and computer science.

CDS hosted an international (virtual) conference on "Applications of Statistical Methods and Machine Learning in the Space Sciences" on May 17-21, 2021 (http://spacescience.org/workshops/mlconference2021.php). The conference was made possible by the National Science Foundation whose support enabled 50 students and early career researchers to attend. There were over 220 registered participants and more than 100 contributed presentations. The participants included graduate and undergraduate students, early career and senior scientists in space sciences, and computer science and ML experts. The Conference had 14 keynote speakers and covered a wide variety of topics including machine learning, heliophysics, magnetospheric sciences, space weather, planetary sciences, exoplanets, astrophysics, cosmology and related fields.

CDS is preparing an e-Book on the various topics presented at the virtual conference published as a topical collection of the Frontiers journal (https://www.frontiersin.org/research-topics/25408/).

In the discussion sessions during the virtual conference, the availability and pre-processing of data were identified as the primary requirement for ML applications in all fields of space sciences. Based on these discussions and opinions of the attendees, CDS is leading a white paper on "AI-ready" data to be submitted to the upcoming Decadal Survey for Soloar and Space Physics (Heliophysics) 2024-2033. More than 10 co-authors met regularly on Zoom in 2021 to discuss the various aspects of AI-readiness and to formulate the recommendations to the federal agencies to achieve community goals by 2050.

There were 15 peer-reviewed publications and numerous conference presentations in 2021 by CDS members. CDS plans to continue its activities in an attempt to inspire the scientific community to utilize key insights on emerging technologies such as artificial intelligence (AI) that have profound impacts on the way scientific problems can be addressed and modeled.

> Big Data image credit: Camilia.boban

Center for Extrasolar Planetary Systems

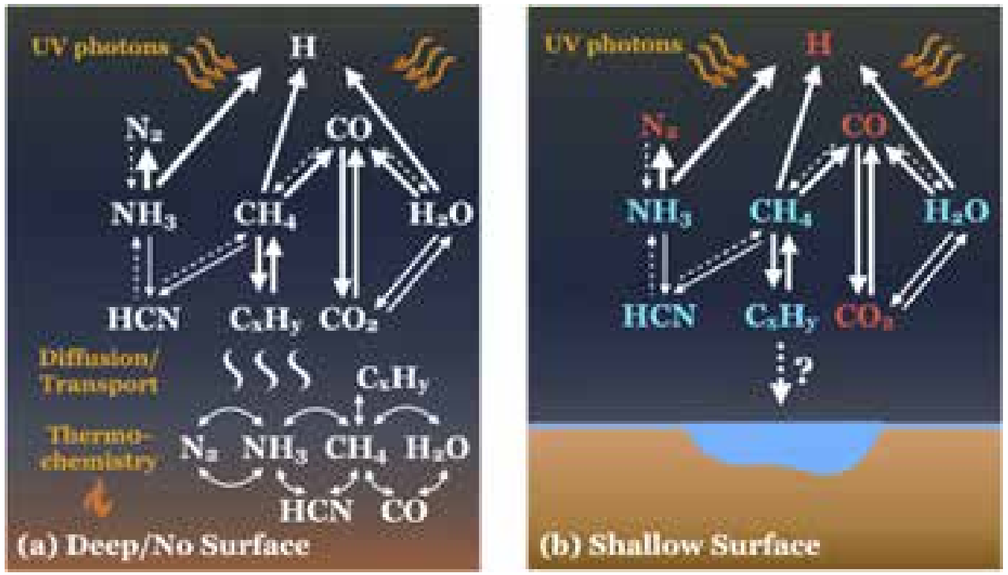
The Center for Extrasolar Planetary Systems (CEPS) brings together SSI researchers who are interested in the exploration and characterization of diverse extra-solar planetary systems. CEPS provides a forum for its members to discuss recent scientific results and discoveries, collaborate on proposals 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 includes 11 scientists who over the past year contributed to over 50 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 with the *James Webb Space Telescope*.

Recent research highlights include: characterizing and quantifying the variability in brightness of the HD 163295 circumstellar disk-jet system (Sitko, in Pikhartova et al. 2021); ongoing contributions to open-source community tools for the study of exoplanets and brown dwarfs, including the Exoplanet Characterization ToolKit (ExoCTK) for observation planning, forward modeling, data reduction, limb darkening, light curve fitting, and retrievals (Fraine, in Bourque et al 2021), and the SONORA substellar evolution models, for atmospheric modeling of L-, T-, and Y-type brown dwarfs and self-luminous extrasolar planets (Visscher, in Marley et al 2021 and Karlidi et al 2022); the development of psudeo-2d chemical models of chemistry in exo-Neptune atmospheres (Moses et al. 2022); photometric reflected light observations with the Hubble Space Telescope to characterize the dark dayside atmosphere of the exoplanet WASP-43b (Fraine et al. 2021); a detailed analysis of the role of clouds in model-data comparisons of substellar atmospheres (Visscher in Burningham et al. 2021); and characterizing surface-atmosphere chemical interactions on terrestrial exoplanets and what atmospheric observations might be able to tell us about their surfaces (Moses in Yu et al. 2021a, 2021b).

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.

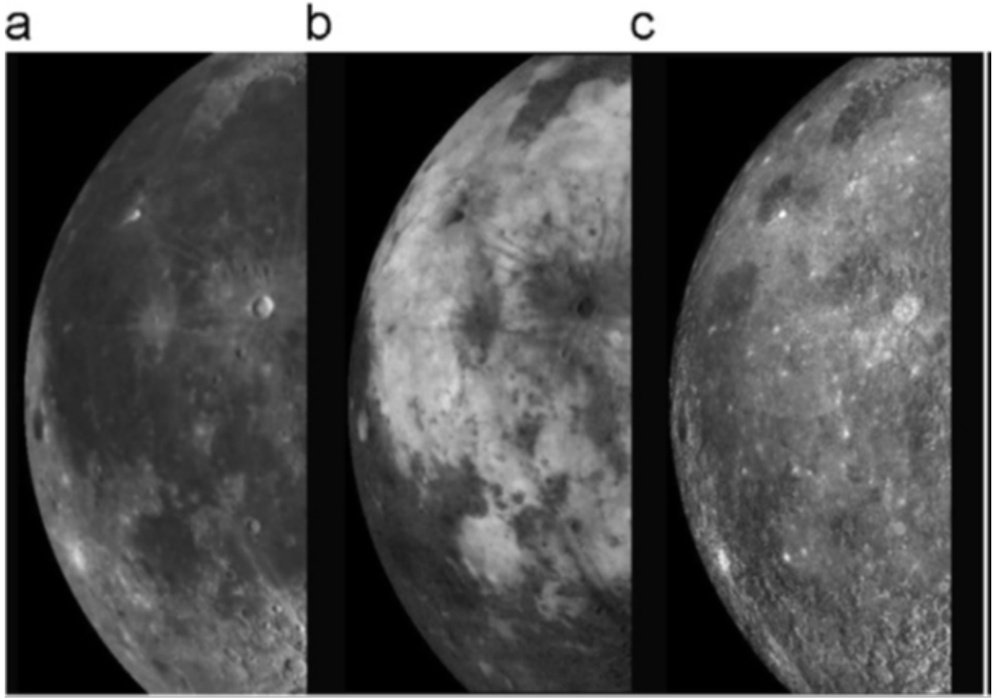
> Artist impression of the "super Earth" type exoplanet K2-18b.
> Credit: ESA/Hubble, M. Kornmesser - https://www.spacetelescope.org/news/heic1916



> Schematic diagram describing the main chemical pathways for the net production and loss of important observable species in the deep-surface or no-surface case vs. the shallow-surface case for K2-18b.
> Figure 2 from Yu et al. 2021 Astrophysical Journal, 914.

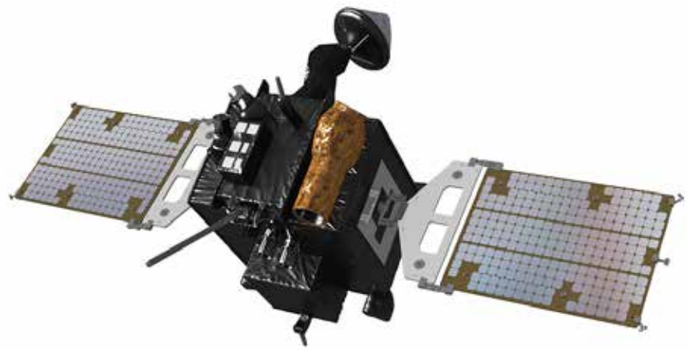
Center for Polarimetric Remote Sensing

SSI's Center for Polarimetric Remote Sensing (CPRS) actively promotes the use of polarimetry to gather information about heavenly bodies. The parameters affecting polarimetry are often different and complimentary to what can be obtained from conventional spectral measurements. For instance, polarimetry is sensitive to particle orientation, so it can be used to retrieve information on the forces affecting the particles, like magnetic fields. It also is sensitive to particle size and porosity, properties that are difficult to retrieve with other means.



> Maps of the lunar (a) albedo, (b) polarization degree and (c) deviation from Umov's law taken with a ground-based telescope.
> The KPLO PolCam mission will result in high-resolution maps of these lunar polarimetric properties that will be used to obtain information about the lunar regolith.
> The substrates produced by CPRS participants will help with the interpretation of this polarimetric data.

The Korean Pathfinder Lunar Orbiter (KPLO), an initiative of the Korea Astronomy and Space Science Institute (KASI), is scheduled to be launched in August 2022, and is the first lunar mission equipped with a polarimeter. CPRS will be lending expertise to this program through the NASA participating scientist program. Dr. Bill Farrand will be using polarimetric data to distinguish and characterize pyroclastic deposits using the PolCam instrument, while Dr. Gorden Videen will be performing experimental polarimetric measurements and modeling from lunar regolith simulants to help analyze the PolCam data.



> Some of the high-porosity lunar samples being produced using additive manufacturing. Lunar mare simulants are the darker samples and the lighter samples are constructed from materials representative of highland regions.

Because of the highly charged, low-gravity environment, lunar regolith has a fairy-castle structure with porosities on the order of 90%. Such structures are hard to replicate on Earth. As a result, it is difficult to obtain information from them because their optical properties have not been measured in a controlled fashion. This knowledge gap is being filled as members of CPRS are using additive-manufacturing processes to construct the first well-characterized lunar simulants having high porosity. Polarimetric measurements from these surfaces will provide the information necessary to interpret the KPLO data. These measurements also will be applicable to other atmosphereless bodies, like asteroids.

> KPLO image credit: Ministry of Science and ICT

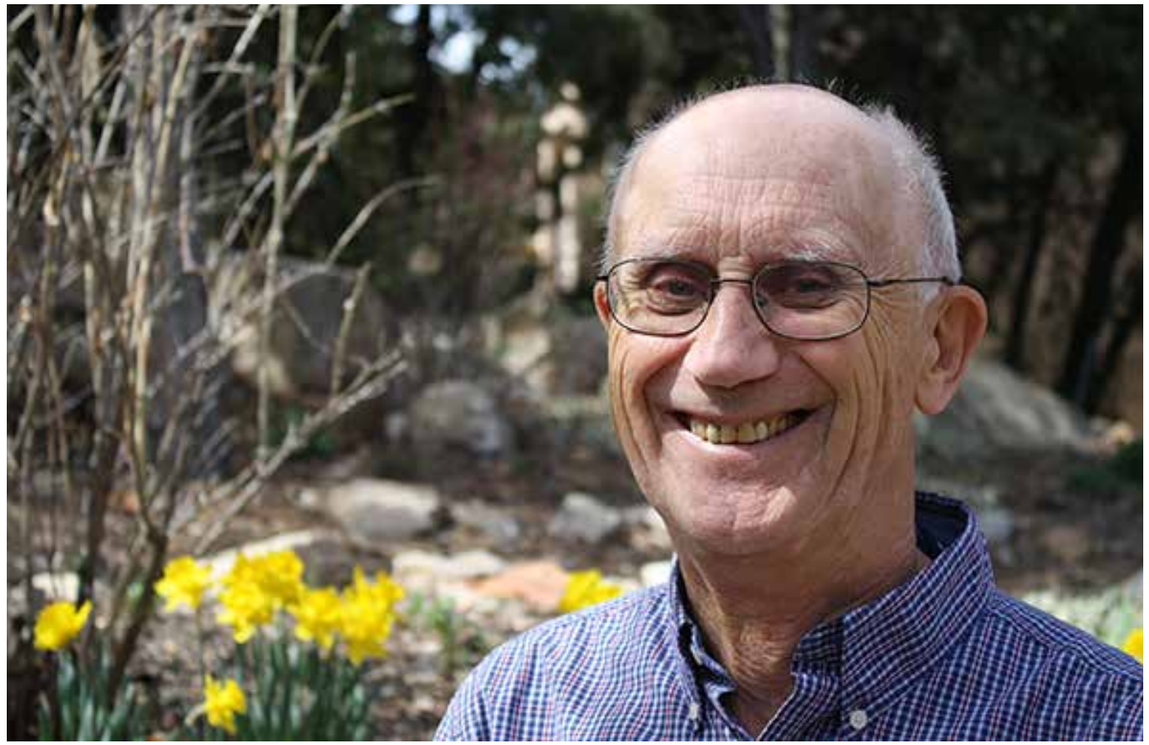
Center for Space Plasma Physics

SSI's 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 2021, the members of CSPP published 75 papers in refereed journals: 23 papers as primary authors and 52 papers as contributing authors.

Research highlights published in 2021 dealt with topics as diverse as magnetospheric depolarization events, low-beta plasma, solar-wind structure, solar-wind dynamic-pressure fronts, ultra low frequency (ULF) waves, solar-flare forecasting, reconnection, magnetosheath jets, whistler waves, plasma heat flux, and transfer entropy.

On August 30-September 2 and September 13-16, 2021 the CSPP co-organized an international online workshop on "Solar Wind - Magnetosphere Interaction" with 81 speakers from 19 different nations (on all continents but Antarctica) and this workshop was followed up with a special issue of Frontiers in Astronomy and Space Science.

In Memoriam: Dr. Peter Gary



S. Peter Gary, SSI Senior Research Scientist, Santa Fe, NM, was an international expert on the waves and instabilities of space plasmas. He received his B.S. in Physics from Case Institute of Technology in 1961, and his Ph.D. in Physics from Washington University in St. Louis in 1967. He served for six years on the faculty of the Physics Department at the College of William and Mary in Williamsburg, VA. Peter joined the staff of Los Alamos Scientific (now National) Laboratory in 1977 and subsequently served there as a respected manager, mentor, and intellectual leader. In 2012, Peter retired from LANL and joined SSI as a Senior Research Scientist. His distinguished research career concentrated on the theory and simulation of waves, instabilities, and turbulence in the collisionless plasmas of the Earth's magnetosphere and the solar wind. He authored 586 work, including well over 100 first author publications, and a scientific monograph, "Theory of Space Plasma Microinstabilities" (Cambridge Univ. Press, 1993). Peter is survived by his wife, Carol Ann Mullaney, his childrend, grandchildren, and extended family.

Heliophysics Audified: Resonances in Plasmas

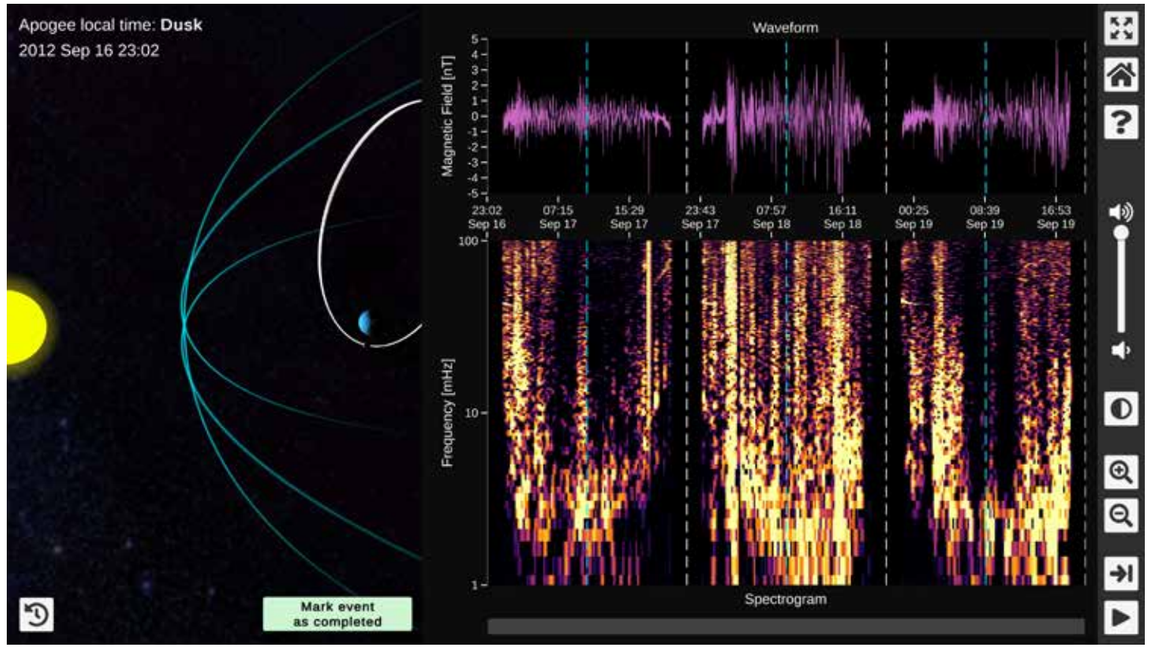
Dr. Michael Hartinger;
Los Angeles, CA

Plasma streams out from the Sun in all directions, spreading throughout our solar system. When these "solar wind" particles approach Earth, our planet's magnetic field mostly pushes them out of the way. But our magnetic shield isn't perfect or static, it's always changing in wave-like motions. Many of these waves are analogous to musical instruments. For example, we have a magnetic "harp," with each magnetic field line having a natural pitch that changes with the field line length and local plasma density. This harp is constantly retuned as the field lines are stretched and distorted during magnetic storms. These storms create the same conditions where waves can significantly impact the Earth's radiation environment, including fast-moving electrons that can damage satellites.

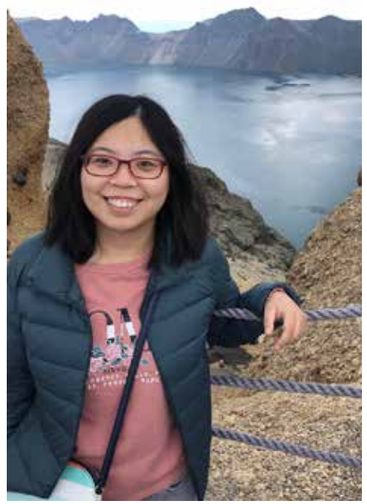
Heliophysics Audified: Resonances in Plasmas (HARP) is a NASA-funded pilot study at SSI to engage Citizen Scientists in space science research to better understand our magnetic harp. Our team at SSI/NCIL – with many collaborators at UCLA, Virginia Tech, NASA, and Imperial College – is using a process known as audification to convert satellite magnetic field measurements from NASA's THEMIS mission into audible sound by speeding up the playback so the wave pitch is in the human audible range. A day's worth of measurements can be listened to in about 12 seconds. By examining large quantities of THEMIS data and using a combination of visual inspection and audio playback, the citizen scientists can pick out multi-day trends in wave activity during storms that are poorly understood from standard visual inspection techniques and automated detection.

HARP is developing a web-based interface to facilitate analysis of spacecraft data converted into sound. It expands upon the MUSICS project (Magnetospheric Undulations Sonified Incorporating Citizen Scientists) led by Dr. Martin Archer, where similar work by high school students in the UK led to the discovery of a new type of plasma wave. Audio analysis has been widely used for scientific research in many biological fields (e.g., ornithology), but it is seldom used in space science research despite having many complementary features to visual inspection, including blind-source separation (why we can focus on a single conversation at a crowded cocktail party) and time-frequency acuity. The GUI we're developing can be applied to a wide range of other satellite and ground-based datasets to support future space science research projects.

Our first beta test involved working with high school student volunteers at a Boulder area library, and we plan a new beta test with university students and researchers soon. Audio analysis was used successfully in the MUSICS project to increase participation in space science research in London high schools, and the new HARP GUI is designed to broaden public participation in space science research even further.



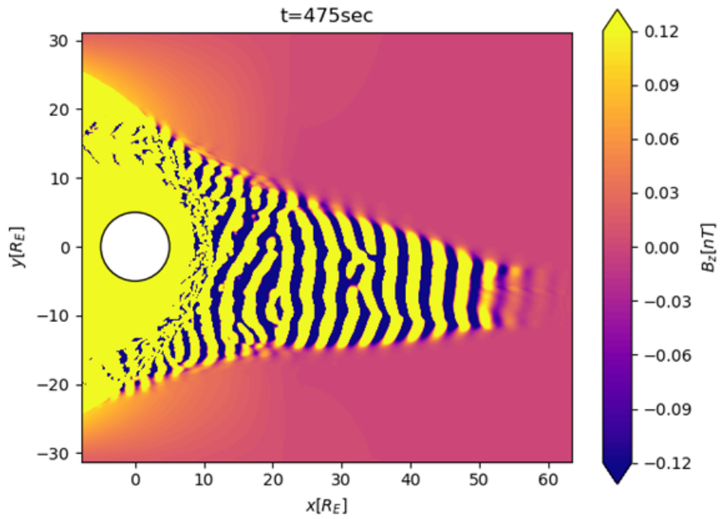
> v1.0 of the HARP GUI



Identifying Global Structure and Properties of ULF waves in the ion foreshock with Vlasiator, a Hybrid-Vlasov simulation

Dr. Kun Zhang;
Los Angeles, CA

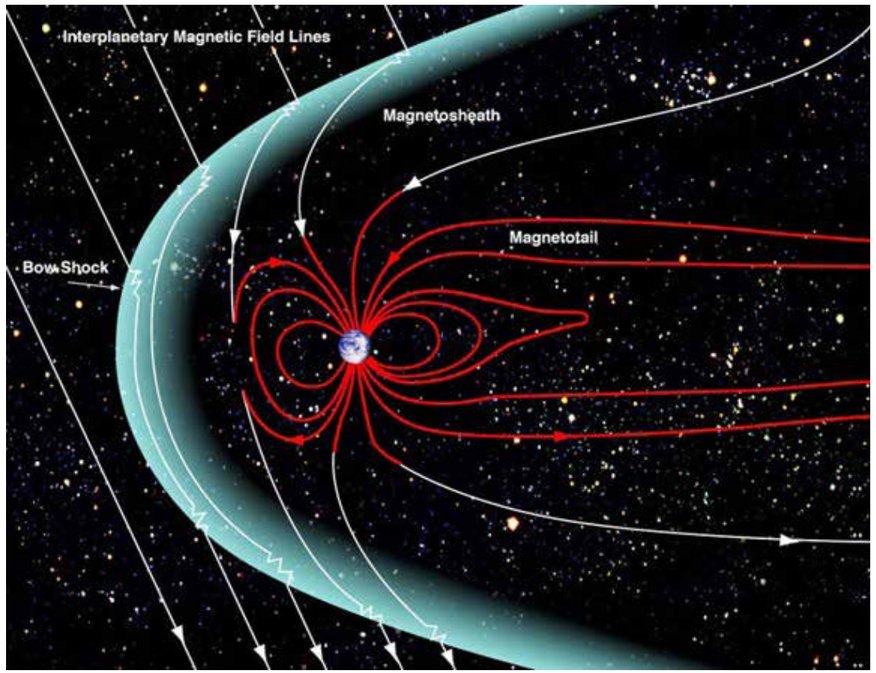
The Earth's ion foreshock is filled with backstreaming ions (charged particles) that are reflected at the Earth's bow shock and stream towards the Sun. Such backstreaming ions are capable of generating ultralow frequency (ULF) waves, which are commonly observed in the foreshock. The most well-known type of foreshock wave is the "30-second wave," named after its satellite-observed frequency. These waves almost always exist in the foreshock and have large amplitudes. They can be carried by the solar wind plasma and travel downstream to Earth, altering the topology and dynamics of the bow shock and injecting perturbations into the Earth's magnetosphere. Therefore, foreshock ULF waves are important to the interaction of the solar wind and Earth's magnetosphere. Knowing the detailed properties of foreshock ULF waves can help us understand how Earth's magnetosphere responds to the varying upstream conditions.



> Magnetic field intensity in the foreshock region in a Vlasiator simulation. Stripes show the wave fronts of the ULF waves in the ion forehsock.

The foreshock ULF waves evolve both spatially and temporally, making them difficult to be analyzed using single point measurements, such as by a single spacecraft. Instead, simultaneous observations at multiple points can help us study the properties of the waves and their global structures. We use global simulation results to study this problem. SSI scientist Dr. Seth Dorfman and I have worked closely with the Vlasiator team at University of Helsinki, the developer of the Vlasiator code, to investigate the global structure and properties of the foreshock ULF waves observed in a Vlasiator simulation. Vlasiator is a 3D hybrid-Vlasov simulation code that solves the ion kinetics in space plasmas and it can provide magnetic field measurements and full ion distributions across the simulation domain, which perfectly suits the purpose of our study.

We have analyzed the wave properties including the wave frequency, wave number, ellipticity, wave normal angle, etc., in the Vlasiator simulation by placing virtual spacecraft in the simulation domain. We found that accompanying the 30-second wave, there are also multiple harmonic waves that are left-hand polarized in the satellite frame, which is consistent with satellite observations. By placing multiple virtual spacecraft in the simulation domain, we examined the global structure of the ULF waves and found more oblique waves at the edge of the foreshock and more elliptically polarized waves deep in the center of the foreshock. We also utilized the multi-point observation to inspect the wave growth and study its relationship with the ion distributions. In all, Vlasiator simulations have been very helpful in improving our understanding of the foreshock dynamics and serve as a great supplement to satellite observations.



> Artists impression of Earth's magnetosphere and bowshock.
> Credit: NASA/Goddard/ Aaron Kaase

Education + Inspiration

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.

While the COVID pandemic had a significant effect on many of our programs, 2021 saw a gradual return to normalcy, with exhibits going back on tour, and a return to in-person trainings.

The Founder Retires

In 2021 Dr. Paul Dusenbery stepped down as NCIL Director and retired from SSI (though he prefers the phrase “moving on to the next new thing”). Paul founded SSI in the 1990s, when there were few research organizations doing education and outreach activities. Working with colleagues in Colorado (e.g., Dan Goter and Kevin Davis) and nationwide (e.g., Drs. Ramon Lopez and George Siscoe), he designed an organization to support both missions. In October 1992, SSI’s first Board of Directors appointed Dr. Dusenbery as the first Executive Director of the Institute.

The new organization’s first major education project was a traveling science exhibition for the space physics community. Based on a previous prototype, *Electric Space* was the first of a series of national traveling science center exhibits produced at SSI and funded through NSF and NASA. SSI was also the home of a long running series of annual workshops for scientists and educators. Eventually a new focus on working with libraries evolved, leading to the formation of STAR Net – the Science-Technology Activities and Resources Library Network. STAR Net has supported a number of projects in the last decade, and now includes an 8,000 member community of practice.

In his tenure as Director of NCIL Paul has contributed to the science, technology, engineering, arts, and mathematics (STEAM) movement in informal education, been a tireless advocate for STEAM programs in community centers including public libraries, worked with foundations to explore additional funding streams, and served as mentor to the next generation of SSI/NCIL education principal investigators.

> SSI’s first board of directors (second from left)

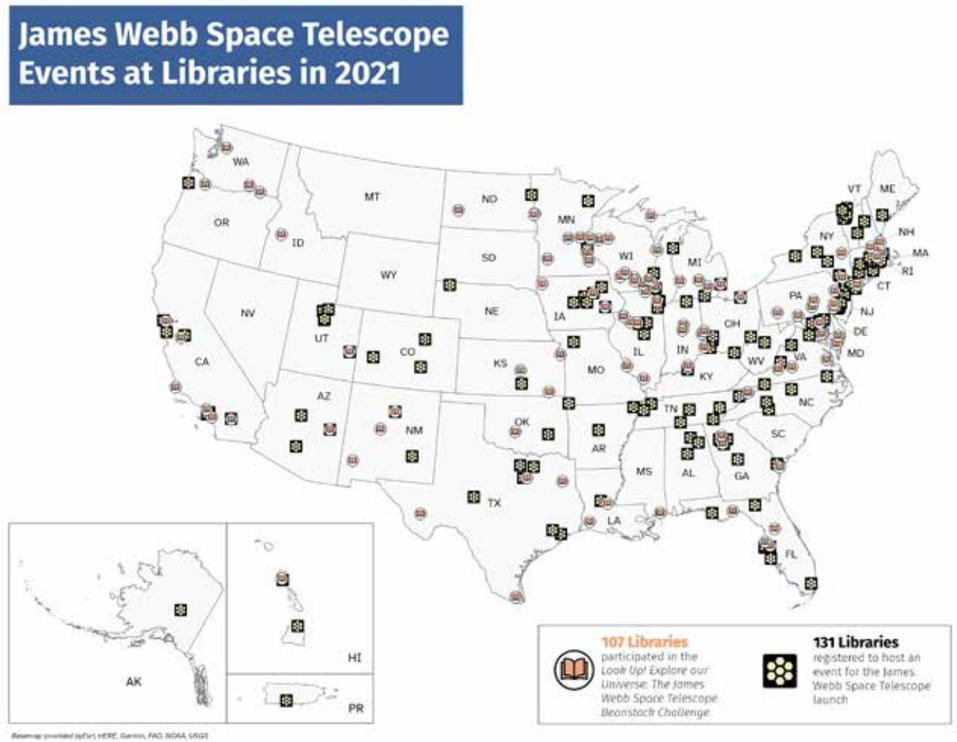
> Paul’s retirement party at SSI

Featured Programs

> Image credits: ESA-CNES-ARIANESPACE/Optique Video du CSG - OV; Desiree Stover/NASA; ESA - D. Ducros

JWST National Reading Challenge

In 2021, NCIL partnered with Zoobean to bring exciting NASA resources to public library patrons across the nation. Zoobean operates the popular Beanstack Reading Challenge platform, which is currently used in over 1,000 school and public library districts. NCIL developed a reading and activities challenge for Beanstack that enabled participants to access over 22 engaging NASA and NASA affiliate-developed resources (interactive websites, at-home activities, videos, and games) related to the James Webb Space Telescope. In total, 107 libraries participated in the "Look Up! Explore Our Universe with the James Webb Space Telescope" challenge, with their patrons logging over two million minutes of reading and completing nearly 3,000 activity badges (with each badge containing 4-6 individual activity challenges). Zoobean reported that the challenge participants were "very excited and engaged" and future collaborations were planned in 2022 to share more James Webb Space Telescope (JWST) and Artemis lunar mission resources with library patrons. NCIL efforts to promote the JWST mission were a part of larger NASA Science Activation (SciAct) program efforts to generate excitement about the telescope; a map highlighting these efforts can be seen in Figure 1.



> Figure 1: A map of libraries nationwide that either participated in the JWST Beanstack challenge or registered to host an event related to the JWST launch.

Water in the Four Corners Region: Libraries and Exhibits Connecting and Engaging Communities with Their Water Systems

The "We are Water" project (SSI PI: Claire Ratcliffe Adams) engages with and serves communities across the Four Corners Region of the Southwestern U.S. (CO, UT, NM, AZ), specifically Indigenous, Latinx, and historically underserved rural communities. The project, led by the Education & Outreach program at the University of Colorado's Cooperative Institute for Research in Environmental Sciences (CIRES) in partnership with the Space Science Institute's STAR Net education team, is working towards three broad project deliverables: a traveling exhibition about water, community engagement through STEAM activities and events, and capacity building for library staff. Exhibit development was delayed for 5 months in 2020 due to the pandemic, and restarted in January 2021 with construction and pilot testing in August to November 2021. During piloting, library patrons and library staff completed research and evaluation instruments. The exhibition includes four interactive exhibit pieces 1) a Story Wall, 2) an augmented reality table displaying the region, 3) a water use game, and 4) a water ecosystem game. Each of the exhibit panels have titles that are displayed in English, Navajo, and Spanish. QR codes that link to Navajo and Spanish audio and text are displayed at the bottom of each panel to ensure a completely trilingual exhibition experience. Virtual, take-home, and community activities were developed and tested for youth and families to support intergenerational STEM learning. Library staff from the Four Corners Region, including the first four We are Water exhibition host sites, were offered a variety of trainings and resources to increase their self-efficacy in STEAM, including virtual webinars, online material, and an in-person workshop for the pilot site.

> A young visitor uses the "Water in the Four Corners" themed "Connect 4" game in the We are Water exhibit at the Aztec Public Library in Aztec, NM.

> Patrons use an interactive, augmented reality terrain table at the We are Water exhibit at the Aztec Public Library in Aztec, NM.

Enhancing STEAM Equity Learning Opportunities in Libraries of Rural Communities

Funded through the National Science Foundation (NSF), the STEAM Equity project (SSI PI: Anne Holland) is a partnership between the Space Science Institute's National Center for Interactive Learning (SSI/NCIL), the American Library Association (ALA), Twin Cities PBS (TPT), Institute for Learning Innovation (ILI) and Education Development Center (EDC). The project's vision is to empower tweens and their families around equitable STEAM learning and career paths by leveraging their existing strengths, interests, and diverse cultures.

A key element of the STEAM Equity project is the travelling exhibit program, which began its tour in the Fall of 2021. The three exhibits – reached their first 6 library venues in California, Washington, Arkansas, Colorado, Oklahoma, and Arizona.

> Library patrons interact with exhibit components at the Berryville Public Library in Berryville, AR,...

> ...and the North Central Washington Library in Quincy, WA.

NCIL Impact Numbers for 2021

> STAR Net exhibition host library sites

Traveling Exhibit Visitors

STEAM Equity Exhibit (3 host sites):	1,762
Discover Exoplanets (2 host sites):	500
We Are Water (1 pilot site):	245
Total Number of Visitors:	**2,507**

In-person Professional Development Participants: 505

Webinar Participants

Unique Live Views:	512
YouTube Recording Views:	3,274

STAR Net Online Community Members: 8,000

NCIL Outreach Event Participants: 1,194

Exhibition Website Visitors

	Page Views:
Alien Earths:	31,592
Giant Worlds:	26,583
SciGames:	233,292
Space Weather Center:	52,820
Killer Asteroids:	50,577
Starchitect:	54,456
STAR Net:	64,853
STEM Activity Clearinghouse:	63,314
National Center for Interactive Learning:	3,017
Total Pageviews:	**580,504**

Financial Summary

Space Science Institute • Summary Statement of Financial Position
as of December 31, 2021 and 2020

ASSETS	2021	2020
Assets		
Cash and cash equivalents	$ 464,262	$ 700,842
Accounts receivable	914,382	818,805
Prepaid expenses and deposits	105,413	130,376
Net furniture, equipment, and property	170,362	205,638
Total assets	**$ 1,654,419**	**$ 1,855,661**

LIABILITIES AND NET ASSETS		
Liabilities		
Accounts payable and accrued liabilities	$ 462,358	$ 678,258
Deferred revenues	215,245	321,924
Line of credit	362,946	300,000
Note Payable	85,916	101,401
Total liabilities	1,126,465	1,401,583
Net assets		
Without donor restrictions	525,449	451,573
With donor restrictions	2,505	2,505
Total net assets	527,954	454,078
Total liabilities and net assets	**$ 1,654,419**	**$ 1,855,661**

Summary Statement of Activities
for the years ended December 31, 2021 and 2020

SUPPORT AND REVENUE	2021	2020
Grants, contracts, and cooperative agreements	$ 7,508,250	$ 7,853,354
Contributions	51,039	26,986
Exhibit and workshop income	35,825	150
Interest income	66	155
Total support and revenue	**7,595,180**	**7,880,645**
EXPENSES		
Science research programs	$ 4,283,081	$ 3,866,515
Science education programs	1,494,733	2,108,293
Fundraising	4,659	6,197
General and administrative	1,738,831	1,924,995
Total expenses	7,521,304	$ 7,906,000
Change in net assets	73,876	(25,355)
Net assets, beginning of year	454,078	479,433
Net assets, end of year	**$ 527,954**	**$ 454,078**

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, 2021 and 2020, from which the summarized information was derived. A copy is available upon request.

SPACE SCIENCE INSTITUTE

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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.

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