THE PLANETARY DATA SYSTEM

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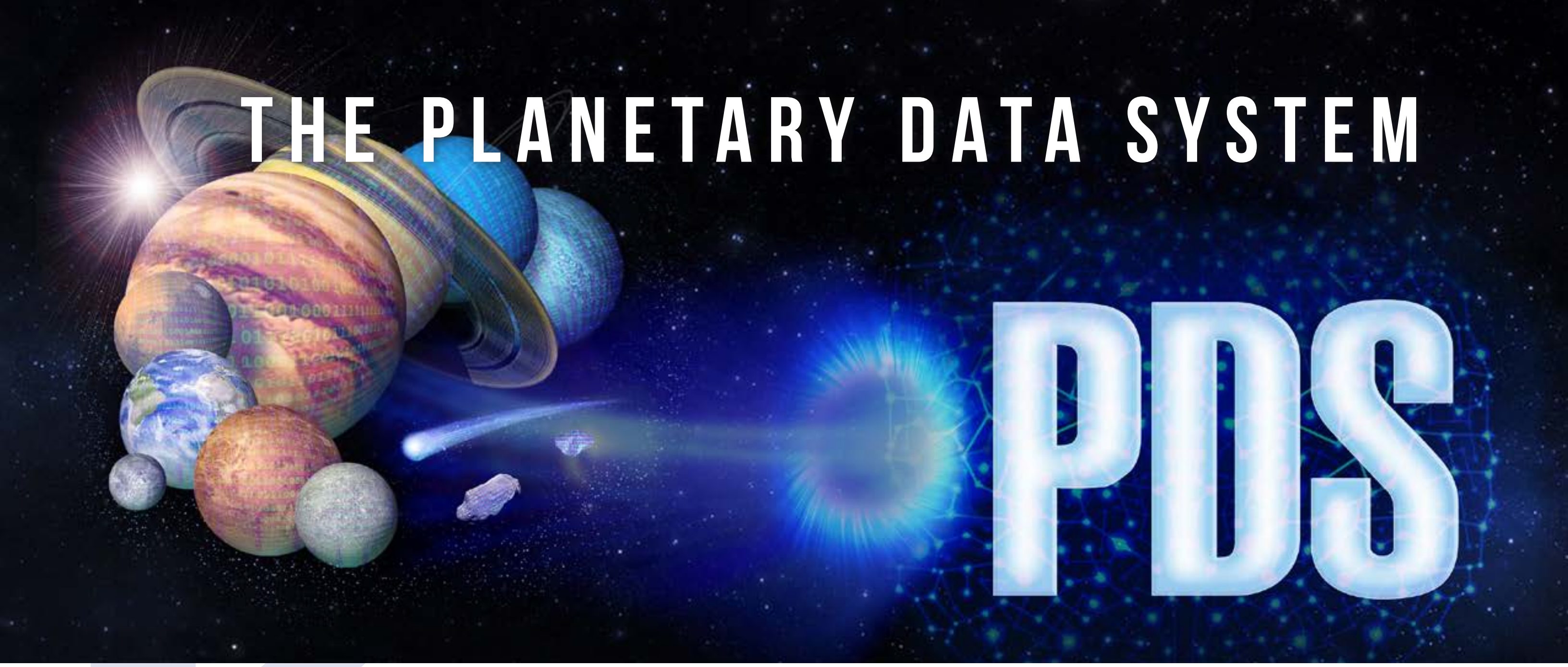


By Charles Acton (California Institute of Technology/Jet Propulsion Laboratory), Susan Slavney (Washington University), Raymond Arvidson (Washington University), Lisa Gaddis (U.S. Geological Survey), Mitchell Gordon (SETI Institute), and Susan Lavoie (California Institute of Technology/Jet Propulsion Laboratory)

In the early 1980s, the Space Science Board (SSB) of the National Research Council was concerned about the poor and inconsistent treatment of scientific information returned from NASA's space science missions. The SSB formed a panel [The Committee on Data Management and Computation (CODMAC)] to assess the situation and make recommendations to NASA for improvements. The CODMAC panel issued a report [1,2] that led to a number of actions, one of which was the convening of a Planetary Data Workshop in November 1983 [3]. The key findings of that workshop were that (1) important datasets were being irretrievably lost, and (2) the use of planetary data by the wider community is constrained by inaccessibility and a lack of commonality in format and documentation. The report further stated, "Most participants felt the present system (of data archiving and access) is inadequate and immediate changes are necessary to insure retention of and access to these and future datasets."

Note from the Editors: This issue's lead article is the eighth in a series of reports describing the history and current activities of the planetary research facilities funded by NASA and located nationwide. This issue features the Planetary Data System (PDS), which archives and distributes scientific data from NASA planetary missions, astronomical observations, and laboratory measurements.

— Paul Schenk and Renée Dotson

A consequence of the workshop was the formation of a Pilot Planetary Data System (PPDS), intended to adopt and apply modern technology and methods to the archiving and dissemination of planetary data. In 1989, after several years of operation, the activities of the PPDS were deemed sufficiently responsive to the CODMAC and workshop reports that NASA established the Planetary Data System (PDS) that is in operation today.

Objectives

From its 2006 Strategic Roadmap, the PDS articulated its mission:

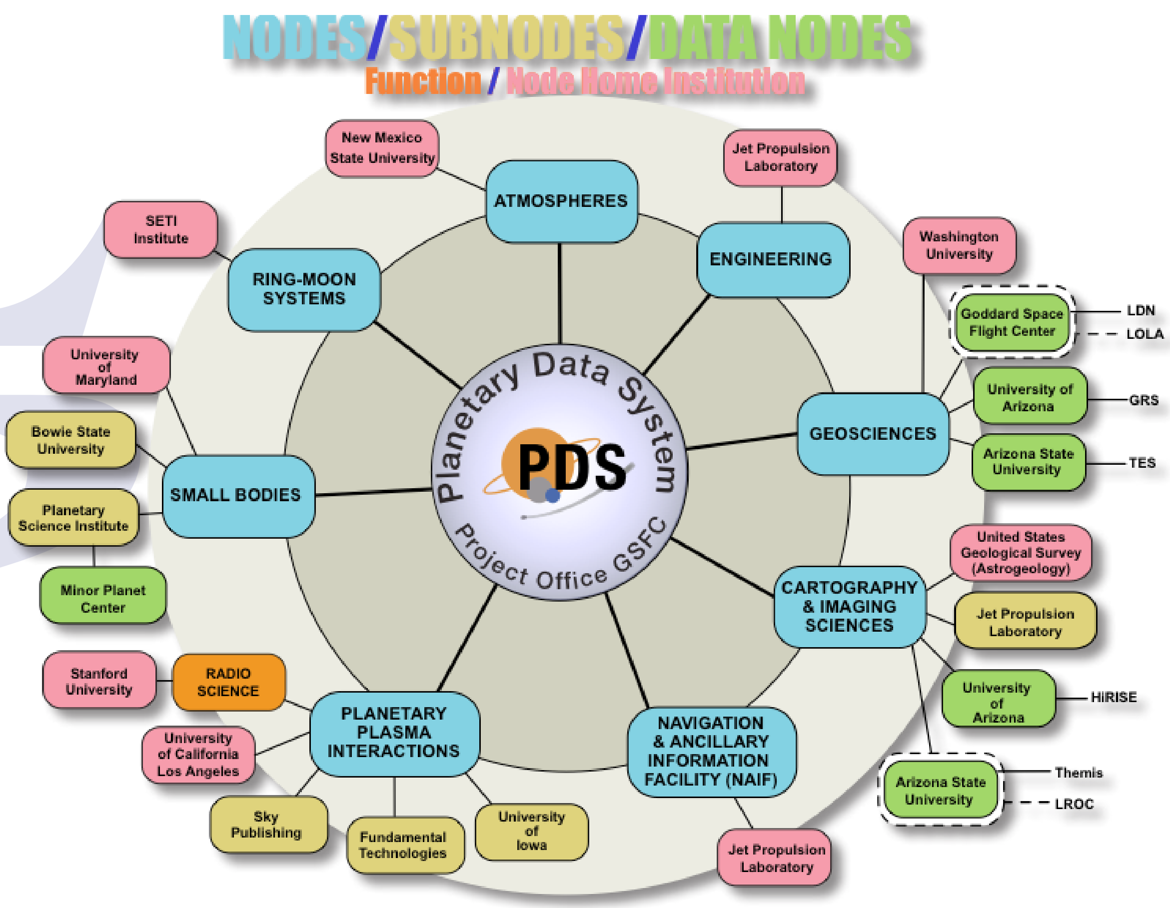
- To gather and preserve the data obtained from exploration of the solar system by the U.S. and other nations
- To facilitate new and exciting discoveries by providing access to and ensuring usability of those data to the worldwide community
- To inspire the public through availability and distribution of the body of knowledge reflected in the PDS data collection
- To support the NASA vision for human and robotic exploration of the solar system by providing an online scientific data archive of the data resources captured from NASA missions

The PDS deals only with digital data — not hardcopy images, maps, or physical samples. The PDS does not currently archive software associated with an instrument or dataset. Additionally, the growth of other national archives — acting in concert with the PDS — means the PDS has a diminishing role in archiving digital data from foreign missions.

Organization

A key finding of CODMAC was that NASA's science archives should be held at discipline centers where active scientists can oversee the archiving and provide expertise on data applicability to various research problems, aid scientists in the interpretation and use of those data, and provide a suite of facilities appropriate to perform research in that discipline. This led to the distributed PDS organizational structure that is in use today.

All PDS nodes operate cooperatively as a federation, with guidance decisions worked out during three yearly meetings and intervening teleconferences. Members of each node participate in the various data design and technical operations activities led by the Engineering Node. For each NASA planetary flight project, one science node is designated to provide the primary or lead interface to the project, with other nodes also participating according to the types of instruments being flown and the scientific measurements to be made by them.



The current organization of PDS is in response to a key finding of the CODMAC report, which recommended that NASA's science archives should be held at discipline centers where active scientists can oversee the archiving and provide expertise on data applicability.

Science Discipline Node Activities

The science discipline nodes interface with missions to ensure the science results are properly archived for future use. They also provide expert consultation to users of those archives, as detailed below.

Before Launch —

NASA requires its planetary missions to archive the science data they generate in the PDS to ensure that high-quality, peer-reviewed archives from the missions are available to the science community now and in decades to come. To make sure this happens, a mission begins archive planning long before its launch date. The mission and PDS co-lead a joint working group of science instrument teams and PDS personnel from the nodes that will receive the mission's archives; one node is selected as lead node to coordinate the PDS work. The working group's job is to make sure each instrument team determines the types of data products they will generate, from raw to highly processed data, and defines the products down to bit-level detail. The products must meet the PDS's rigorous standards for archive quality.

The teams then create realistic prototypes of each archive, including not only science data but metadata in PDS format, calibration files, documentation, and any other material needed to make the archive complete. These archives are submitted to peer review conducted by the PDS. The reviewers are drawn from the community of interested scientists both inside and outside the mission who are experts in the types of data under review.

The peer review process is a critical step in the development of a PDS archive. As a mission is expected to make many deliveries to the PDS over a period of some years, it would not be practical to review every delivery of every dataset from every instrument. Instead, the peer reviews take place well before the start of operations using realistic examples of data products. In this way if the reviews lead to recommendations for changes, there is still time for the teams to modify their data processing pipelines.

Finally, the archive working group determines the schedule and procedures for delivering the data to the PDS. A typical delivery schedule might require all instrument teams to deliver their accumulated science data every three months, starting six months after science operations have begun. The working group delivers an archive plan to the mission, documenting the products to be generated and the schedule for deliveries to PDS.

During Flight Operations —

As soon as a mission begins science operations, typically based on post-launch instrument checkout and calibration, the archive clock starts ticking. Instrument teams are required to deliver their first batch of data to PDS two or three weeks before the first release date, according to the schedule in the archive plan. The PDS nodes that receive the data then validate the deliveries to make sure the structure and metadata match that of the peer-reviewed archives, and that the deliveries meet PDS standards in general. When the archives pass these tests, they are put online on public PDS websites and their release is announced. This process is repeated every three months or so, depending on the schedule, until the end of the mission.

Often during the course of a mission, an instrument team will revise data products that have already been released due to improvements in calibration data or processing software, or to correct errors. PDS keeps the archives up to date and ensures that the user community understands these updates and their implications for data uses and interpretations. Instrument teams may also generate entirely new types of data products inspired by their discoveries; these new products are peer reviewed before they are incorporated into the PDS archives.

At End of Mission and Afterward —

Some planetary missions have a predetermined end date, but some, like the Mars Reconnaissance Orbiter, can be extended every few years as long as the instruments are healthy and there is valuable new science to be gained.

When a mission finally ends, instrument teams may decide to deliver a final and best update to their archives, sometimes with specially derived products that can only be generated at the end of the mission. PDS works with the teams to make sure the final archives are complete and well documented before the team members move on to the next opportunity. Once in the PDS, archives are maintained indefinitely. Almost all PDS archives are available online. The design of PDS archives is such that the data, metadata, and documentation will be accessible and readable decades after the end of the mission. PDS policy is to maintain multiple copies of all archives, distributed in various locations for safety, including one copy at the National Space Science Data Coordinated Archive (NSSDCA).

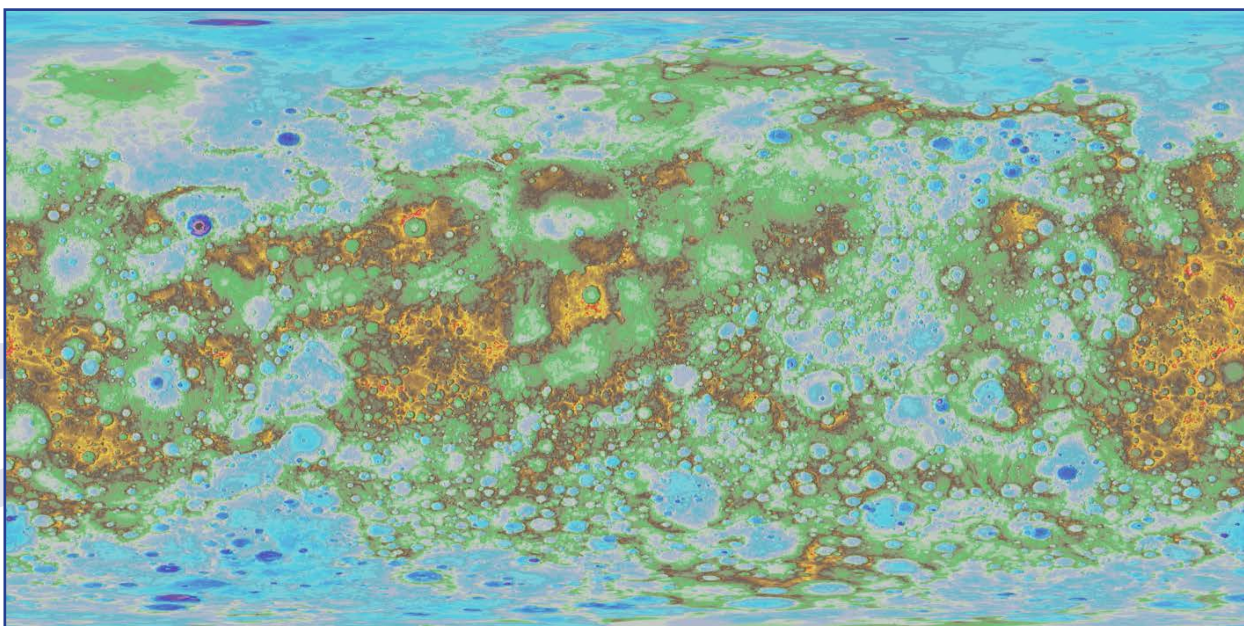
Expert Consultation and Services: Finding the Data —
With the exponential increase in PDS data holdings over the past two decades, searching the archives has become a major service provided by PDS, enabling users to find data products specific to their needs. Such product level searches currently are available at the Cartography and Imaging Node, the Geosciences Node, the Ring-Moon Systems Node, and the Small Bodies Node. Each search is tailored to support the data at that node.

Among the most popular and useful products served by PDS are images of planetary surfaces, moons, rings, stars, etc. While most of the nodes serve images unique to their science disciplines, the primary host of some of the larger image archives within PDS is the Cartography and Imaging Sciences Node (Imaging, or IMG).

Image access tools provided by the Imaging Node help users more easily retrieve the data needed for their research.

The Planetary Photojournal (*https://photojournal.jpl.nasa.gov/*) serves many of the most beautiful renditions of data from planetary missions, often used in press releases. For the scientist, the primary tool for locating images is the Planetary Image Atlas (*https://pds-imaging.jpl.nasa.gov/search/*). Users can start by selecting the desired mission, then they can select from a variety of instruments, science targets, types of products, etc. More and more sophisticated searches are possible using the Atlas, including searches by details of lighting geometry, color filters, surface location, time constraints, and so on. Images can be viewed, selected, and downloaded individually or in bulk.

An additional sophisticated search capability is offered by the Planetary Image Locator Tool (PILOT) (*https://pilot.wr.usgs.gov/*), where users can not only select by surface location and detailed spacecraft operation and instrument information, but they can view, select and route information to be processed using the U.S. Geological Survey's Imaging Software for Imagers and Spectrometers (ISIS), the premier package for scientific and cartographic processing of planetary image data. Thus, image data can be processed and delivered as a calibrated digital mosaic. To select portions of data from digital mosaics that are already in the PDS archive, Map-A-Planet (*https://astrogeology.usgs.gov/tools/map-a-planet-2*) allows users to use ISIS to identify desired regions and extract them for delivery in a wide variety of common image formats. The PDS thus serves a large number of users worldwide with tools ranging from simple to sophisticated.

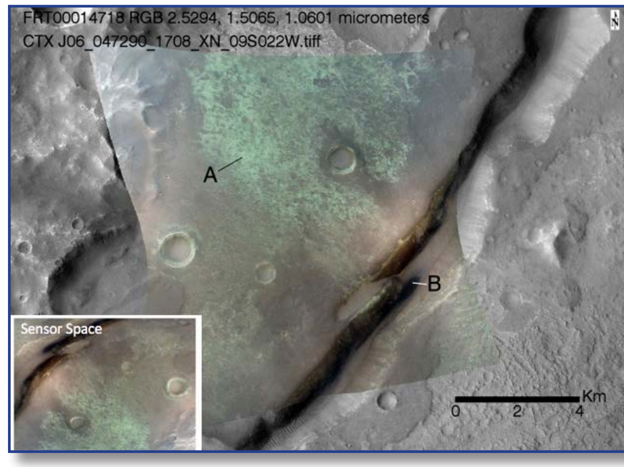


Using the Integrated Software for Imagers and Spectrometers and observations from Mercury Dual Imaging System (MDIS) narrow-angle camera and multispectral wide-angle camera, this global digital elevation model (DEM) of Mercury was created from data returned by the MESSENGER spacecraft.

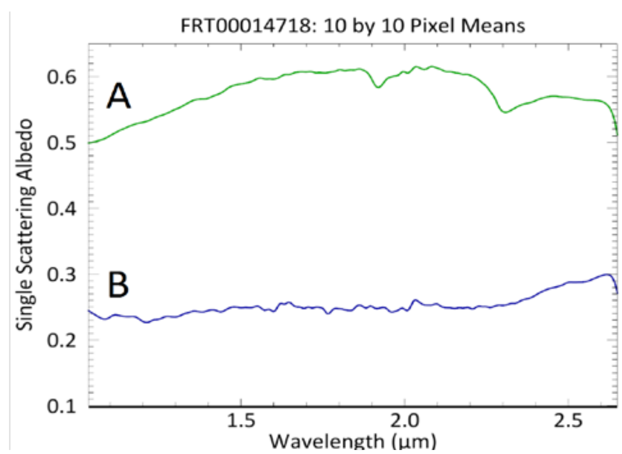
Expert Consultation and Services: Understanding the Data —

Many archives consist of complex and interrelated data products that demand a thorough understanding before any science analysis can be undertaken. All PDS nodes provide tools and expertise to novice and experienced users alike.

An example of a mission archive is the data acquired by the Mars Reconnaissance Orbiter (MRO) Compact Reconnaissance Imaging Spectrometer for Mars (CRISM). This instrument operates in a variety of modes, including targeted full-resolution 18 m/pixel coverage from 362–3920 nm at 6.55 nm/channel. The PDS Geosciences Node hosts the CRISM archive and provides related services. CRISM data products include raw and radiometrically calibrated sensor space data along with pointing information that allows users to map-project the data (*http://pds-geosciences.wustl.edu/missions/mro/crism.htm*). Given the complex nature of the data products, the Geosciences Node provides CRISM Analysis Tool (CAT) software to further process and analyze results for mineralogy. As CRISM data are typically acquired at the same time as Context Imager data and HiRISE images — both of which are archived at the Imaging Node — the Geosciences Node offers the Mars Orbital Data Explorer tool (ODE) to allow users to identify and download the coordinated data products (*http://ode.rsl.wustl.edu/mars/indextools.aspx?displaypage=coordinatedobs*).



PDS-archived CRISM image of a region within Margaritifer Terra on Mars, inset in a map-projected image derived from the PDS product and overlain onto Context Imager data. The green regions are exposed hydrated smectite clay minerals. Regions A and B show areas for which spectra were retrieved from the hyperspectral image cube (see additional figure below).



Single-scattering albedo spectra are shown for a portion of the CRISM spectral range sensitive to the presence of hydrated smectite clay minerals (Spectrum A, corresponding to Region A shown in the figure above). The absorptions at ~1.9 and 2.3 µm are diagnostic of the presence of these minerals. Spectrum B (corresponding to Region B in the preceding figure) is located in an area with anhydrous basaltic sands. Image cube data have been highly processed to remove atmospheric contributions and the effects of light and viewing.

Data Restoration Efforts —

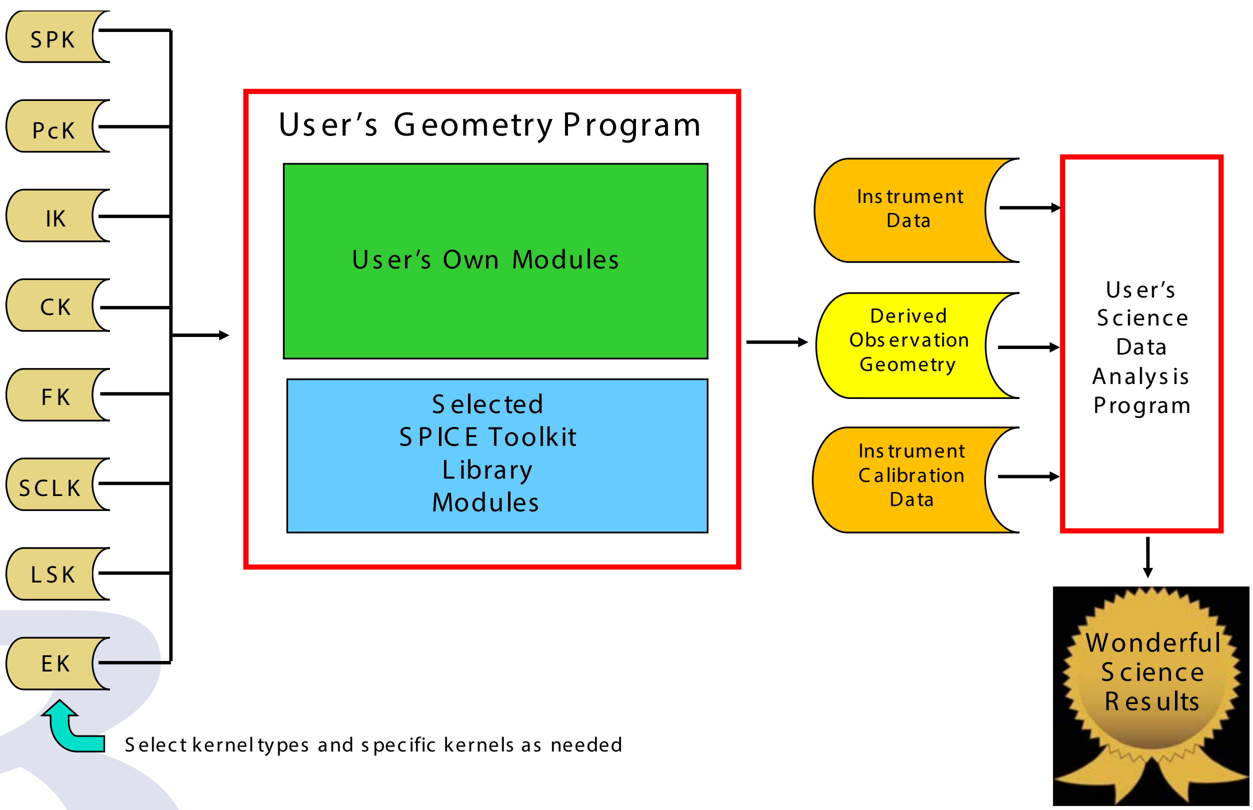
Most of the nodes have been involved to some degree in restoring pre-PDS science data archives, such as those for the Viking and Halley missions, into PDS-compliant archives. Some data restorations are complete, while others are ongoing and being completed as time permits.

Archiving Research Results —

Most nodes are also tasked with helping researchers archive datasets produced by work performed under various types of research grants funded by NASA. Data from individual researchers must meet the same strict archiving requirements as mission-generated data, including peer review.

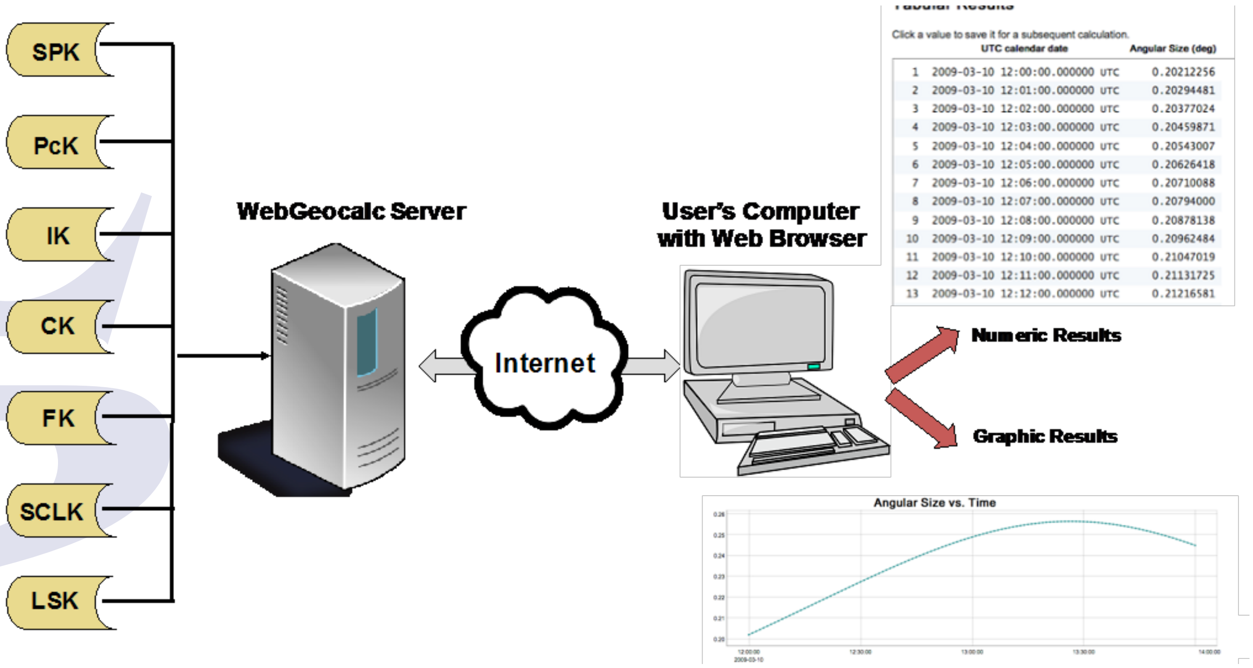
Navigation and Ancillary Information Facility (NAIF) Node Activities —

Similar to the science discipline nodes, the Navigation and Ancillary Information Facility (NAIF) Node is responsible for peer review and archiving of the Spacecraft, Planet, Instrument, Camera-matrix, Events (SPICE) observation geometry data produced by missions, as well as some generic solar system geometry data that is independent of any particular mission (for a description of SPICE, visit *https://naif.jpl.nasa.gov/naif/aboutspice.html*). NAIF staff provide expert consultation as needed to users of these archived "navigational" data.



Workflow diagram showing how SPICE data and software can be used by scientists in their research.

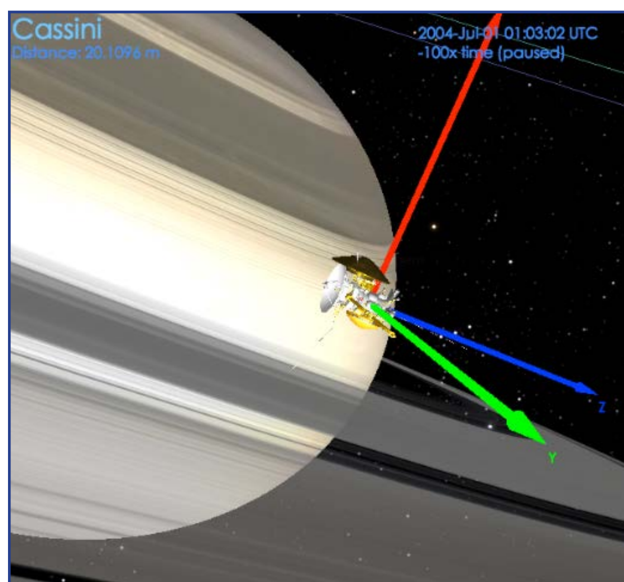
NAIF has the additional responsibility of developing the SPICE system capabilities, as well as deploying and operating the SPICE system for missions managed by the Jet Propulsion Laboratory. SPICE experts at other NASA centers operate SPICE in support of their own missions, as well as planetary missions operated by the European Space Agency, the Japanese Space Exploration Agency, the Indian Space Research Organization, and the Russian Space Agency.



The WebGeocalc Geometry Engine is offered by NAIF as a web-based interface to SPICE data.

The primary user interface with SPICE data, usually called "kernels," is via self-made programs that incorporate a few SPICE Toolkit subroutines. However, NAIF also offers the WebGeocalc tool, a web-based interface to SPICE data, and SPICE-Enhanced Cosmographia, a three-dimensional mission visualization tool.

NAIF offers a free SPICE training class approximately every 18 months. Information about training, releases of SPICE Toolkit software and data, and other important items pertaining to SPICE are provided via the "spice_announce" Mailman system, described on the NAIF home page (*https://naif.jpl.nasa.gov*).



NAIF offers for public use a SPICE-enhanced version of the open source visualization tool named Cosmographia. This is an interactive tool used to produce three-dimensional visualizations of planet ephemerides, sizes, and shapes; spacecraft trajectories and orientations; and instrument field-of-views and footprints. Cosmographia has many user controls, allowing users to manage what is displayed, what vantage point is used, and how fast the animation progresses.

Engineering Node (Mission-Independent) Activities

The Engineering Node is responsible for overall system engineering, data standards, common software tools and services, implementation and operations of the PDS central web and data services, and data engineering support to the nodes and missions. The Engineering Node led the recent development of PDS Version 4 (PDS4), the largest upgrade in the history of the PDS, to an online, distributed, model-driven, service-oriented architecture. The International Planetary Data Alliance, formed in 2006, has supported the development of PDS4 and endorsed its use for all member-agency planetary missions. PDS4 has been operationally deployed to successfully support the NASA Lunar Atmosphere and Dust Environment Explorer (LADEE), NASA Mars Atmosphere and Volatile Evolution (MAVEN), and ESA Exo-Mars missions. Approximately 10 more missions internationally are now adopting the PDS4 architecture and standard.

Here to Serve You

The PDS exists to serve the planetary science community; if you're not already using PDS resources, give them a try! Each node will happily answer any questions you might have about use of the data it has archived; points of contact are listed at *https://pds.jpl.nasa.gov/contact/contact.shtml*.

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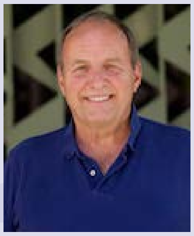
[1] Bernstein R. et al. (1982) *Data Management and Computation, Volume 1, Issues and Recommendations*, National Academy Press, 167 pp., *http://www.nap.edu/openbook.php?record_id=12366&page=R1*.

[2] Arvidson R. et al. (1986) *Issues and Recommendations Associated with Distributed Computation and Data Management Systems for the Space Sciences*, National Academy Press, 111 pp., *http://books.nap.edu/openbook.php?record_id=12343&page=R1*.

[3] Kieffer H., ed. (1983) *Proceedings of the Planetary Data Workshop*, Greenbelt, Maryland, November 29–December 1, 1983, USGS Astrogeology Branch, NASA Conference Publication 2343 (Parts 1 and 2).

The research was carried out in part at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration, as well as at Washington University, the Astrogeology Branch of the U.S. Geological Survey, and the SETI Institute.

About the Authors:



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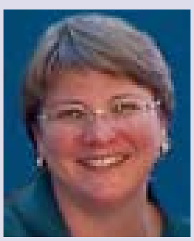

Lisa Gaddis is the Principal Investigator and Lead Scientist for the PDS Imaging Node. Gaddis is a planetary scientist with expertise in geologic analysis of remote sensing data for the Earth, Moon, Mars, and Venus.

Planetary scientist **Mitch Gordon** serves as the Deputy Manager for the PDS Ring-Moon Systems Node. Gordon joined the SETI Institute as a principal investigator in 2005. While his research interests focus on planetary ring systems and the resonant interactions between rings and the attendant natural satellites, the bulk of his time is spent preserving the vast treasures of planetary data returned by NASA's spacecraft.

Susan K. LaVoie is the Co-Investigator and Institutional Principal Investigator for the PDS Imaging Node. LaVoie provides oversight of Imaging Node tasks carried out at JPL, sets the technical direction for the Imaging Node and provide management of those activities, assists the PI in negotiation of project requirements and funding; participates in the PDS Management Council, and works with the PI and with Imaging Node staff to define project objectives, schedules, and budgets for Imaging Node activities.

The *Lunar and Planetary Information Bulletin* collects, synthesizes, and disseminates current research and findings in the planetary sciences to the research community, science libraries, educators, students, and the public. The *Bulletin* is dedicated to engaging, exciting, and educating those with a passion for the space sciences while developing future generations of explorers.

The *Bulletin* welcomes articles dealing with issues related to planetary science and exploration. Of special interest are articles describing web-based research and educational tools, meeting highlights and summaries, and descriptions of space missions. Peer-reviewed research articles, however, are not appropriate for publication in the *Bulletin*. Suggested topics can be e-mailed to the editors, who will provide guidelines for formatting and content.

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FROM THE DESK OF

Jim Green

A Personal View of the Archiving of Planetary Data: The Foundational Years

In 1964, Dr. Homer Newell, the Associate Administrator for Space Science and Applications, told Congress that NASA had an obligation to make information gained from space exploration available to the public and that he was establishing a National Space Science Data Center (NSSDC) at the Goddard Space Flight Center. The NSSDC was created to assure continuing accessibility and utility of data produced by all NASA science missions. The NSSDC began soon after, well-funded and in a new building built specifically as the location of NASA's archive. However, over time the funding level became variable, as it became one of those activities funded with end of the year money and no clear Headquarters advocate. NASA science missions were becoming more and more successful, and so by the early 1980s the NSSDC was not able to really step up to its assigned responsibility. In 1982, the National Academy of Sciences chartered the Committee on Data Management and Computation (CODMAC), which monitored the data archiving situation, holding a number of meetings over a several-year period. In the end, CODMAC come out with a number of critical concerns and recommendations.

In 1985, I became the head of the NSSDC and led a number of modernizing activities to make the best use of the funding it was getting. For more than 20 years the NSSDC acquired data that were then held offline in the form of magnetic tapes, microforms, photographic films, and hardcopies. In the offline environment, NSSDC typically acquired reduced and analyzed data from individual scientists, archived these data, retrieved data in response to requests with the aid of an automated information system, duplicated tapes or film, and mailed data along with a documentation package to the requestors.

Since I had established NASA's first national computer network (SPAN) in 1980, it was a natural step to have the NSSDC begin the process of becoming an accessible archive open 24 hours per day by putting as much data as possible online. As computer networks and mass storage devices became more ubiquitous, archival data became easily reachable for scientists connected to computer networks. For the offline data, NSSDC began to move to higher-density storage media, optical disks for digital data, and videodisks for analog images. With respect to online data and electronic data communications, NSSDC brought some of its archive online to allow access from remote computers. At that time, users began computer-to-computer access to online data. NSSDC became the provider of a Central Directory/Catalog Service, which included the data characteristics and offered users a first look at the data location and access procedures.

All this sounds great, but a number of fundamental things were still missing. It was difficult for the NSSDC to be able to acquire all the necessary higher-level data products sufficiently calibrated and documented that these data could stand on their own. CODMAC also pointed out that scientists with significant knowledge of the data quality and its usage were needed to be more directly involved over a period of time that the data were actively used. Even though the NSSDC had a number of really outstanding data scientists, there was no hope for the organization to be able to cover all disciplines and types of data. The mid-1980s was an exciting time to openly discuss the CODMAC findings with each of NASA's science disciplines, and a new concept of "distributed active archives" began to emerge. New active archives were being defined, such as the Earth Science Data and Information System, the Astrophysics Data System, the Planetary Data System, and the Space Physics Data Facility.

It was within this backdrop of activity that in December 1986 a Memorandum of Understanding (MOU) was signed by the principles: myself (NSSDC); Thomas Renfrow from the JPL management node of the Planetary Data System (PDS); and Geoffrey Briggs, Director of Solar System Exploration, NASA Headquarters. This MOU, being the NSSDC's first working agreement with the active archives, was a major milestone in distributed science discipline data centers and NSSDC relationships. It was designed to have PDS provide highly specialized services to the planetary community that the NSSDC simply did not have the resources to provide in the past. The NASA data management responsibilities changed overnight from a completely centralized system to acquiring, archiving, and disseminating planetary data through a distributed series of planetary nodes, but it would take several years before it would come into operation.

At first, the PDS would provide the management of planetary data, a catalog of such data, and selected data. Over a few years the PDS management would define and fund discipline nodes to take on specific data types and responsibilities. I was delighted this was happening. It was the right approach to keep the data close to the data experts who cared about it the most, and the PDS concept brought new funding and resources into the business of data management and archiving that otherwise would never have happened.

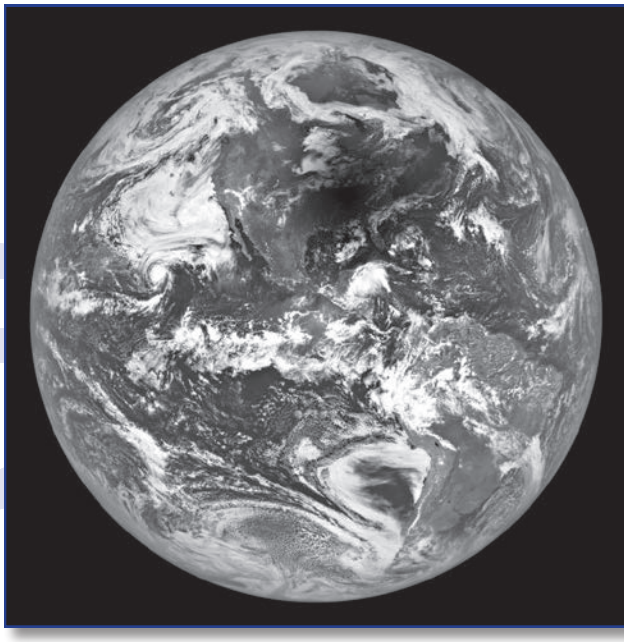
Overall, the new distributed science discipline archive approach transformed the NSSDC into the nucleus for the high-level management of NASA data; a sort of a top-level directory of all NASA data, providing a new level of coordination, in addition to being the long-term archive backing up all the data in the PDS. At that time, with a simple menu-driven system, the NSSDC offered information about the location, access procedures, and other characteristics of data sets in broad ranges of the Space and Earth Sciences. Queries were possible by dataset source or by disciplines. For that era, this was the first step into the twenty-first century of data mining. But even that would evolve as the PSD grew and took on more responsibilities.

Over time the PDS became responsible for planetary data collections, content definition, validation, and catalog management, and NSSDC's role for the long-term back-up archiving of planetary data remained. The distribution and access responsibilities were divided between both groups. NSSDC handled requests involving replications of whole digital media and all film products, while PDS handled requests requiring specific scientific expertise or data manipulation. At that time PDS was in its early formative years. The MOU was particularly significant as the first of a number of MOUs NSSDC signed with other discipline data centers as well.

Also in the mid-1980s, a key concept was beginning to emerge, and that was the use of a common data format in which multiple datasets could be manipulated and analyzed with the same set of tools. One such format was the NSSDC's Common Data Format (CDF). The CDF was specially designed to support scientific applications in a discipline independent fashion. This also resulted in the creation of a powerful tool for the development of systems that could archive, manage, manipulate display, or analyze data. CDF and its evolved format, called netCDF, are used extensively in Earth Science and also in Space Physics. Another format was the Flexible Image Transport System (FITS). Although the evolution of the FITS format was driven by the astronomical community, it is a format sometimes used for planetary data. The NSSDC established the NASA Science Data Systems Standards Office in order to promote and help users use standard data formats. For example, this office assisted in evaluating FITS products for conformance to FITS standards and to apply the experience gained in working with the science community to help guide the evolution of the FITS standard. I believe this office was instrumental in firmly establishing the FITS and CDF family of science formats as standard formats for the community.

In closing, as we approach the 40th anniversary of the Voyager missions, I am reminded by the power that comes from our vast archival data appropriately documented and accessible. This truly came out brilliantly again in the recent "New Findings from Old Data" (Baganal et al., 2017) article in *EOS*. These scientists are looking into archived datasets from the Voyager flybys that occurred 40 years ago, applying knowledge and updated software, and finding new information. As we acquire new planetary datasets, such as those from the Cassini mission, I cannot help but wonder about the groundbreaking findings these data will help us discover in another 40 years, but we must remain vigilant and keep up our legacy of archiving while evolving methods and capabilities with the times.

— James L. Green, Director, NASA's Planetary Science Division, September 2017



NASA's Lunar Reconnaissance Orbiter shows the shadow of the Moon cast on the U.S. during the August 21, 2017, total solar eclipse. Credit: NASA/GSFC/Arizona State University.

NASA's Lunar Mission Captures Solar Eclipse as Seen from the Moon

During the total solar eclipse on August 21, 2017, NASA's Lunar Reconnaissance Orbiter (LRO) captured an image of the Moon's shadow over a large region of the U.S., centered just north of Nashville, Tennessee. As LRO crossed the lunar south pole heading north at 5760 kilometers per hour (3579 miles per hour), the shadow of the Moon was racing across the U.S. at 2414 kilometers per hour (1500 miles per hour).

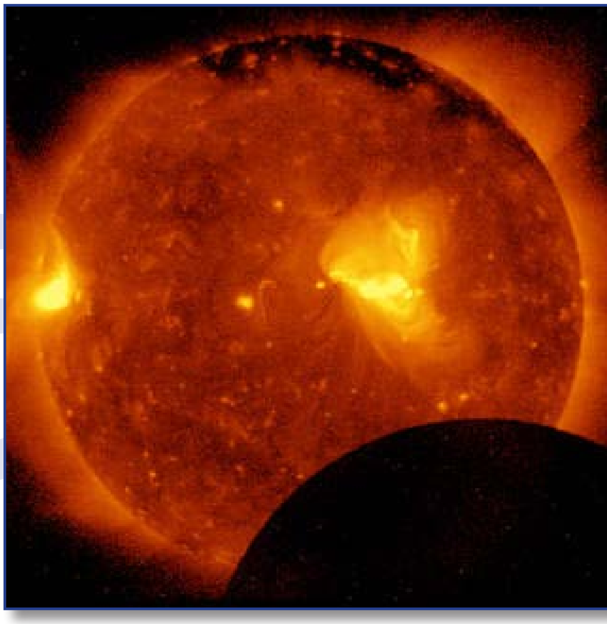
A few minutes later, LRO began a slow 180° turn to look back at Earth, capturing an image of the eclipse very near the location where totality lasted the longest. The spacecraft's Narrow Angle Camera began scanning Earth at 2:25:30 p.m. EDT (18:25:30 UTC) and completed the image 18 seconds later. The Narrow Angle Camera is part of the Lunar Reconnaissance Orbiter Camera (LROC) system. Two Narrow Angle Cameras capture high-resolution black and white images, and a third, the Wide Angle Camera, captures moderate-resolution images using filters to provide information about the properties and color of the lunar surface.

The Narrow Angle Camera builds up an image line by line rather than the more typical "instantaneous" framing that occurs with digital or cell-phone cameras. Each line of the image is exposed for less than one-thousandth of a second; the exposure time was set as low as possible to prevent bright clouds from saturating the sensor. It takes about 18 seconds to acquire all 52,224 lines for the image.

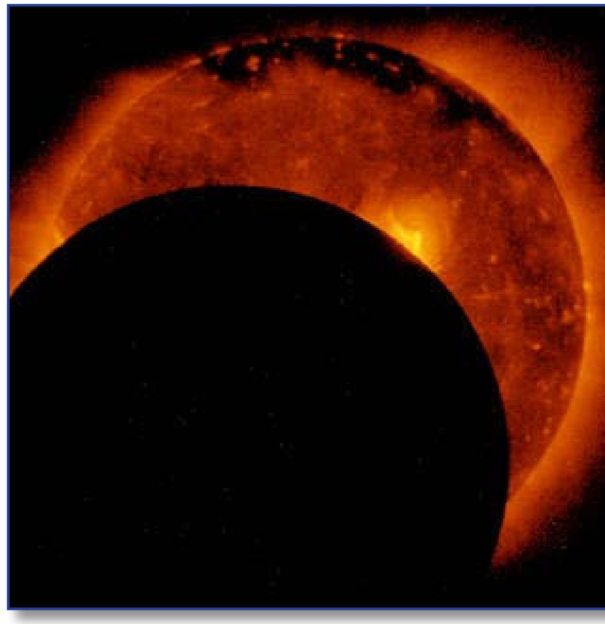
While the thrill of the total eclipse was in experiencing the shadow of the Moon sweep across us on Earth, on the Moon this was just another day. The lunar nearside was one week into its two-week night, while the Sun shone on the farside in the middle of its two-week day. Because solar eclipses do not affect the health or power supply of the spacecraft, LRO operated normally during the total solar eclipse.

Launched on June 18, 2009, LRO has collected a treasure trove of data with its seven powerful instruments, making an invaluable contribution to our knowledge about the Moon and reminding us, through these eclipse images, of the beauty of our Earth. For more information, visit *https://www.nasa.gov/feature/goddard/2017/LRO-captures-eclipse-from-the-moon*.

Hinode Satellite Captures Powerful August 21 Eclipse Images



Hinode captures a shot of the August 21 total solar eclipse two minutes into the Moon's transit across the face of the Sun. Credits: JAXA/NASA.



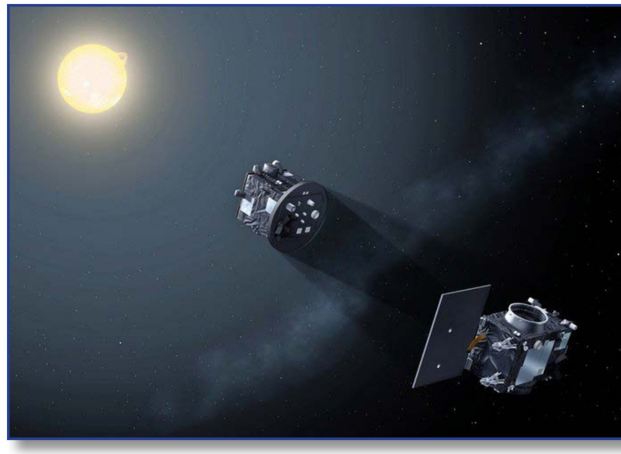
A second image from Hinode of the August 21 total solar eclipse, taken approximately five minutes farther into lunar transit. Credit: JAXA/NASA.

As millions of Americans watched the total solar eclipse that crossed the continental U.S. on August 21, the international Hinode solar observation satellite captured its own images of the awe-inspiring natural phenomenon as it orbited the planet. Scientists from the Japan Aerospace Exploration Agency, the National Astronomical Observatory of Japan, and NASA adapted the still images into a time-lapse video presentation.

Among its many solar research tasks, the satellite's observation of the eclipse was intended to add new data to ongoing scientific study of the coronal structure in the Sun's polar region and the mechanism of jets of superheated plasma frequently created there. These powerful jets can sometimes erupt 10 million to 12 million miles into space. The images were taken with Hinode's X-ray telescope (XRT) as it flew above the Pacific Ocean, off the west coast of the United States, at an altitude of approximately 680 kilometers (422 miles).

Hinode is a joint endeavor by the Japan Aerospace Exploration Agency, the National Astronomical Observatory of Japan, the European Space Agency, the United Kingdom Space Agency, and NASA. Learn more about the August 21 eclipse at *https://eclipse2017.nasa.gov.*

ESA's Proba-3 Will Create Artificial Solar Eclipses



Proba-3 satellites form an artificial eclipse. Credit: ESA.

Astrophysicists joined sightseers in watching the August 21 total solar eclipse across North America, but in the decade to come, they will be viewing eclipses that last for hours instead of a few minutes, thanks to a pioneering European Space Agency (ESA) space mission. Aiming for launch in late 2020, Proba-3 is two small meter-scale satellites, lining up to cast a precise shadow across space to block out the solar disk for six hours at a time and give researchers a sustained view of the Sun's immediate vicinity.

Total eclipses occur thanks to a remarkable cosmic coincidence. Earth's Moon is about 400 times smaller than our parent star, which is about 400 times further away. During the rare periods when the two overlap, the Moon can sometimes blank out the Sun entirely. This brief period of totality — the one during the August 21 eclipse was just 160 seconds long at most — reveals features of the Sun normally hidden by its intense glare, most notably the faint atmosphere, known as its corona.

The corona is a focus of interest because it is the source of the solar wind and space weather that can affect satellites and Earth itself, especially through the irregular eruptions of energy called coronal mass ejections. With temperatures reaching more than 1,000,000°C (1,800,000°F), the corona is also much hotter than the relatively cool 5500°C (9932°F) surface of the Sun, a fact that seems to contradict common sense.

Researchers seek ways to increase the corona's visibility, chiefly through coronagraphs — telescopes bearing disks to block out the direct light of the Sun. These are used both on the ground and in space, as onboard the veteran Sun-watching Solar and Heliospheric Observatory (SOHO) satellite.

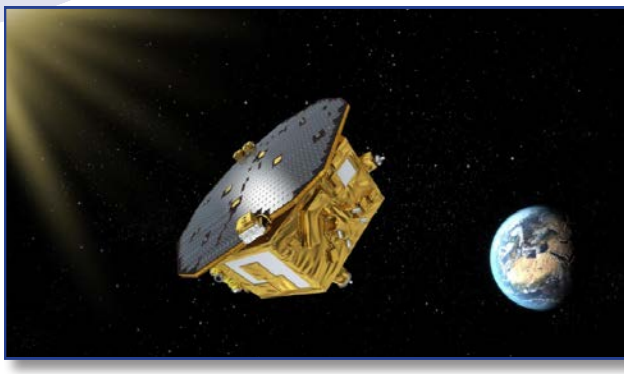
"The inner extent of the view afforded by standard coronagraphs is limited by stray light," explains Andrei Zhukov of the Royal Observatory of Belgium, serving as Principal Investigator for Proba-3's coronagraph. Stray light is a sort of light pollution inside an instrument. In coronagraphs, it is a kind of bending of the sunlight around the blocking disk. This problem can be minimized by extending the coronagraph length, the distance between the camera and the disk, as far as possible, but there are practical limits to coronagraph size. Instead, Proba-3's coronagraph uses two craft: a camera satellite and a disk satellite. They fly together so precisely that they operate like a single coronagraph, 150 meters (492 feet) long.

Each six-hour artificial eclipse per 19.6-hour Proba-3 orbit of Earth should provide a view close to the Sun's visible surface. This will span the current observing gap between standard coronagraphs and the extreme-ultraviolet imagers used to monitor the face of the Sun on missions such as NASA's Solar Dynamics Observatory and ESA's Proba-2.

The challenge is in keeping the satellites safely controlled and correctly positioned, using new technologies and sensors, plus intelligent software, but this time in space. Proba-3 development is progressing well, with a structural and thermal model version of the coronagraph built ahead of its critical design review this autumn, followed by that of the entire mission.

For more information, visit *http://www.esa.int/Our_Activities/Space_Engineering_Technology/Proba_Missions*.

A Final Farewell to LISA Pathfinder



An artist's concept of the European Space Agency's LISA Pathfinder spacecraft, designed to pave the way for a mission detecting gravitational waves. Credit: NASA/JPL.

With the push of a button, final commands for the European Space Agency's LISA Pathfinder mission were beamed to space on July 18, 2017, a final goodbye before the spacecraft was powered down. The LISA Pathfinder had been directed into a parking orbit in April, keeping it out of Earth's way. The final action this week switches it off completely after a successful 16 months of science measurements. While some spacecraft are flashy, never sitting still as they zip across the solar system, LISA Pathfinder was as steady as they come.

It housed a space-age motion detector so sensitive that it had to be protected against the force of photons from the Sun. That was made possible thanks to a system of thrusters that applied tiny reactive forces to the spacecraft, cancelling out the force of the Sun and allowing the spacecraft to stay within 10 nanometers of an ideal gravitational orbit. These requirements for Pathfinder were so challenging and unique that LISA Pathfinder flew two independent systems based on different designs — one provided by NASA and one by ESA — and ran tests with both during its 16-month mission.

"We were trying to hold it as stable as the width of a DNA helix," said John Ziemer, systems lead for the U.S. thruster system at NASA's Jet Propulsion Laboratory (JPL) in Pasadena, California. "And we went down from there to the width of part of a DNA helix."

JPL finished primary mission experiments in the fall of 2016. In March and April of this year, they continued validating the algorithms used in stabilizing the spacecraft. They improved them through a number of tests. "The main goal for us was to show we can fly the spacecraft drag-free," Ziemer said. "The main force on the spacecraft comes from the Sun, from photons with extremely tiny force that can subtly move the spacecraft."

So why build something this sensitive to begin with? LISA Pathfinder was just a starting point. The mission was led by ESA as a stepping-stone of sorts, proving the technology needed for an even more ambitious plan, the Laser Interferometer Space Antenna (LISA): a trio of spacecraft proposed to launch in 2034. With each spacecraft holding as still as possible, they would be able to detect the ripples sent out across space by the merging of black holes. These ripples, known as gravitational waves, have been a source of intense scientific interest in recent years. The groundbased Laser Interferometry Gravitational Wave Observatory detected gravitational waves for the first time in 2015.

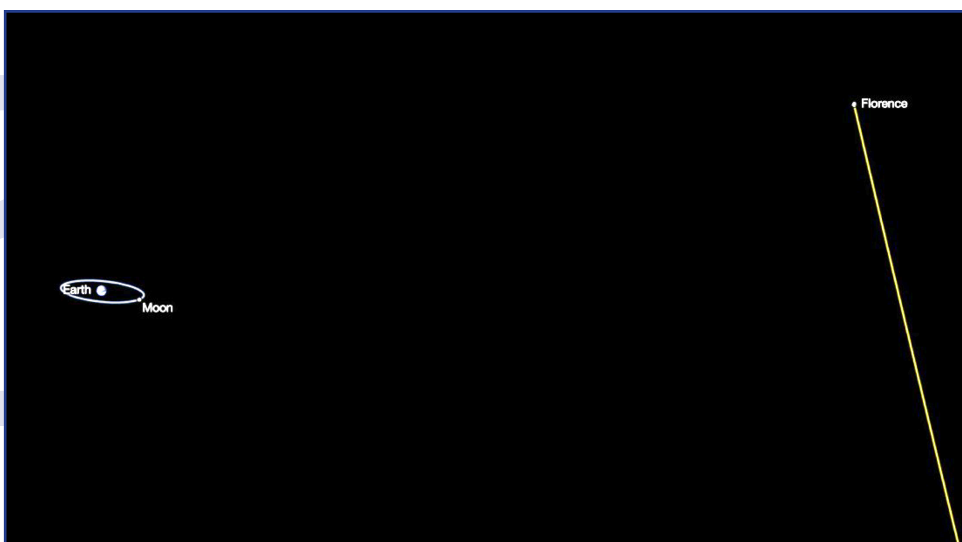
But there's a bigger role for thrusters like the ones on LISA Pathfinder. Ziemer said the operation of super-steady thrusters could serve as an alternative to reaction wheels, the current standard for rotating and pointing spacecraft. "This kind of technology could be essential for space telescopes," Ziemer said. "They could potentially hold them still enough to image exoplanets, or allow for formation flying of a series of spacecraft."

The thrusters are an enabling technology, opening up a magnitude of precision that simply wasn't available before. For more information, visit *http://sci.esa.int/lisa-pathfinder/*.

Large Asteroid Safely Passed Earth

Asteroid Florence, a large near-Earth asteroid, passed safely by Earth on September 1, 2017, at a distance of about 7 million kilometers (4.4 million miles, or about 18 Earth-Moon distances). Florence is among the largest near-Earth asteroids that are several miles in size; measurements from NASA's Spitzer Space Telescope and NEOWISE mission indicate it is about 4.4 kilometers (2.7 miles) in size.

"While many known asteroids have passed by closer to Earth than Florence [did] on September 1, all of those were estimated to be smaller," said Paul Chodas, manager of NASA's Center for Near-Earth Object



Asteroid Florence, a large near-Earth asteroid, passed safely by Earth on September 1, 2017, at a distance of about 7 million kilometers (4.4 million miles). Credit: NASA/JPL-Caltech.

Studies (CNEOS) at the agency's Jet Propulsion Laboratory in Pasadena, California. "Florence is the largest asteroid to pass by our planet this close since the NASA program to detect and track near-Earth asteroids began."

This relatively close encounter provides an opportunity for scientists to study this asteroid up close. Florence is expected to be an excellent target for groundbased radar observations. Radar imaging is planned at NASA's Goldstone Solar System Radar in California and at the National Science Foundation's Arecibo Observatory in Puerto Rico. The resulting radar images will show the real size of Florence and could reveal surface details as small as about 10 meters (30 feet).

Asteroid Florence was discovered by Schelte "Bobby" Bus at Siding Spring Observatory in Australia in March 1981. It is named in honor of Florence Nightingale (1820–1910), the founder of modern nursing. The 2017 encounter is the closest by this asteroid since 1890 and the closest it will ever be until after 2500. Florence brightened to ninth magnitude in late August and early September, making it visible in small telescopes for several nights as it moved through the constellations Piscis Austrinus, Capricornus, Aquarius, and Delphinus.

For more information, visit *https://cneos.jpl.nasa.gov/*.

A Clockwork Rover for Venus

AREE is a clockwork rover inspired by mechanical computers. A JPL team is studying how this kind of rover could explore extreme environments, like the surface of Venus. Credit: NASA/JPL-Caltech.

A good watch can take a beating and keep on ticking. With the right parts, can a rover do the same on a planet like Venus? A concept inspired by clockwork computers and World War I tanks could one day help us find out. The design is being explored at NASA's Jet Propulsion Laboratory (JPL) in Pasadena, California.

The Automaton Rover for Extreme Environments (AREE) is funded for study by the NASA Innovative Advanced Concepts (NIAC) program. The program offers small grants to develop early stage technology, allowing engineers to work out their ideas. AREE was first proposed in 2015 by Jonathan Sauder, a mechatronics engineer at JPL. He was inspired by mechanical computers, which use levers and gears to make calculations rather than electronics. By avoiding electronics, a rover might be able to better explore Venus. The planet's hellish atmosphere creates pressures that would crush most submarines. Its average surface temperature is 462°C (864°F), high enough to melt lead.

Mechanical computers have been used throughout history, most often as mathematical tools like adding machines. The most famous might be Charles Babbage's Difference Engine, a nineteenth century invention for calculating algebraic equations. The oldest known is the Antikythera mechanism, a device used by ancient Greeks to predict astronomical phenomena like eclipses.

Mechanical computers were also developed as works of art. For hundreds of years, clockwork mechanisms were used to create automatons for wealthy patrons. In the 1770s, a Swiss watchmaker named Pierre Jaquet-Droz created "The Writer," an automaton that could be programmed to write any combination of letters. Sauder said these analog technologies could help where electronics typically fail. In extreme environments like the surface of Venus, most electronics will melt in high temperatures or be corroded by sulfuric acid in the atmosphere. "Venus is too inhospitable for kind of complex control systems you have on a Mars rover," Sauder said. "But with a fully mechanical rover, you might be able to survive as long as a year."

Wind turbines in the center of the rover would power these computers, allowing it to flip upside down and keep running. But the planet's environment would offer plenty of challenges. No spacecraft has survived the venusian surface for more than a couple of hours. Venus' last visitors were the Soviet Venera and Vega landers. In the 1970s and 1980s, they sent back a handful of images that revealed a craggy, gas-choked world. "When you think of something as extreme as Venus, you want to think really out there," said Evan Hilgemann, a JPL engineer working on high-temperature designs for AREE. "It's an environment we don't know much about beyond what we've seen in Soviet-era images."

Sauder and Hilgemann are preparing to bake mechanical prototypes, allowing them to study how thermal expansion could affect their moving parts. Some components of the Soviet landers had actually been designed with this heat expansion in mind — their parts would not work properly until they were heated to venusian temperatures.

AREE includes a number of other innovative design choices. Mobility is one challenge, considering there are so many unknowns about the venusian surface. Sauder's original idea was inspired by the "Strandbeests" created by Dutch artist Theo Jansen. These spider-like structures have spindly legs that can carry their bulk across beaches, powered solely by wind. Ultimately, they seemed too unstable for rocky terrain. Sauder started looking at World War I tank treads as an alternative. These were built to roll over trenches and craters.

Another problem will be communications. Without electronics, how would you transmit science data? Current plans are inspired by another age-old technology: Morse code. An orbiting spacecraft could ping the rover using radar. The rover would have a radar target, which if shaped correctly, would act like "stealth technology in reverse," Sauder said. Stealth planes have special shapes that disperse radar signals; Sauder is exploring how to shape these targets to brightly reflect signals instead. Adding a rotating shutter in front of the radar target would allow the rover to turn the bright, reflected spot on and off, communicating much like signal lamps on Navy ships.

Now in its second phase of NIAC development, the JPL team is selecting parts of the AREE concept to be refined and prototyped. Team members hope to flesh out a rover concept that will eventually be able to study the geology of Venus and perhaps drill a few samples.

For more information, visit *https://www.nasa.gov/directorates/spacetech/niac/2017_Phase_I_Phase_II/Automaton_Rover_Extreme_Environments.*

NASA's Next Mars Mission to Investigate Interior of Red Planet

Preparation of NASA's next spacecraft to Mars, InSight, has ramped up this summer, on course for launch next May from Vandenberg Air Force Base in central California, the first interplanetary launch in history from America's West Coast. Lockheed Martin Space Systems is assembling and testing the InSight spacecraft in a clean room facility near Denver. "Our team resumed system-level integration and test activities last month," said Stu Spath, spacecraft program manager at Lockheed Martin. "The lander is completed and instruments have been integrated onto it so that we can complete the final spacecraft testing including acoustics, instrument deployments, and thermal balance tests."

The Mars lander portion of NASA's InSight spacecraft is lifted from the base of a storage container in preparation for testing, in this photo taken June 20, 2017, in a Lockheed Martin clean room facility in Littleton, Colorado. Credit: NASA/JPL-Caltech/Lockheed Martin.

InSight is the first mission to focus on examining the deep interior of Mars. Information gathered will boost understanding of how all rocky planets formed, including Earth. "Because the interior of Mars has churned much less than Earth's in the past three billion years, Mars likely preserves evidence about rocky planets' infancy better than our home planet does," said InSight Principal Investigator Bruce Banerdt of NASA's Jet Propulsion Laboratory, Pasadena, California. He leads the international team that proposed the mission and won NASA selection in a competition with 27 other proposals for missions throughout the solar system. ("InSight" is an abbreviation for Interior Exploration using Seismic Investigations, Geodesy, and Heat Transport.)

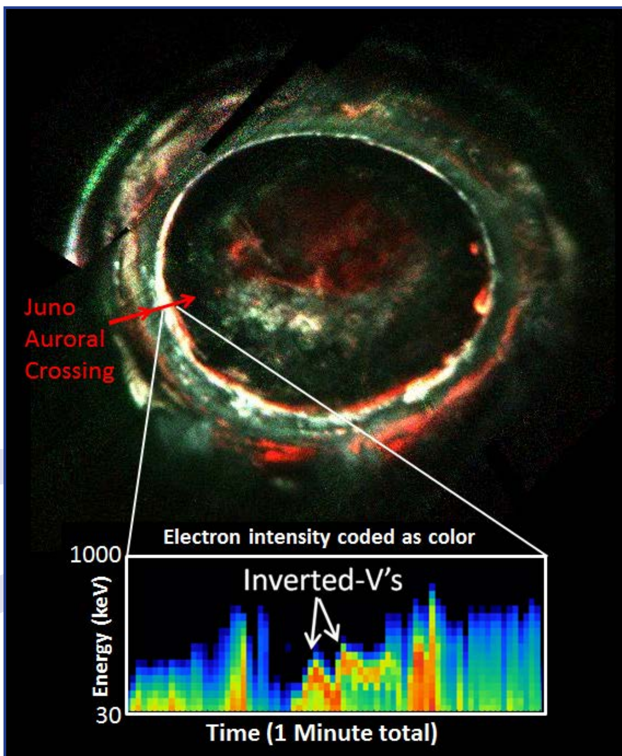
Whichever day the mission launches during a five-week period beginning May 5, 2018, navigators have charted the flight to reach Mars the Monday after Thanksgiving in 2018. The mission will place a stationary lander near Mars' equator. With two solar panels that unfold like paper fans, the lander spans about 6 meters (20 feet). Within weeks after the landing — always a dramatic challenge on Mars — InSight will use a robotic arm to place its two main instruments directly and permanently onto the martian ground, an unprecedented set of activities on Mars. These two instruments are (1) a seismometer, supplied by France's space agency, CNES, with collaboration from the U.S., the United Kingdom, Switzerland, and Germany; shielded from wind and with sensitivity fine enough to detect ground movements half the diameter of a hydrogen atom, it will record seismic waves from "marsquakes" or meteor impacts that reveal information about the planet's interior layers; and (2) a heat probe, designed to hammer itself to a depth of 3 meters (10 feet) or more and measure the amount of energy coming from the planet's deep interior. The heat probe is supplied by the German Aerospace Center, DLR, with the self-hammering mechanism from Poland.

A third experiment will use radio transmissions between Mars and Earth to assess perturbations in how Mars rotates on its axis, which are clues about the size of the planet's core.

The spacecraft's science payload also is on track for next year's launch. The mission's launch was originally planned for March 2016, but was called off due to a leak into a metal container designed to maintain near-vacuum conditions around the seismometer's main sensors. A redesigned vacuum vessel for the instrument has been built and tested, then combined with the instrument's other components and tested again. The full seismometer instrument was delivered to the Lockheed Martin spacecraft assembly facility in Colorado in July and has been installed on the lander. "We have fixed the problem we had two years ago, and we are eagerly preparing for launch," said InSight Project Manager Tom Hoffman, of JPL.

The best planetary geometry for launches to Mars occurs during opportunities about 26 months apart and lasting only a few weeks. Together with two active NASA Mars rovers, three NASA Mars orbiters, and a Mars rover being built for launch in 2020, InSight is part of a legacy of robotic exploration that is helping to lay the groundwork for sending humans to Mars in the 2030s. For more information, visit *https://www.nasa.gov/insight.*

Jupiter's Auroras Present a Powerful Mystery



This image marks the path of Juno's readings of Jupiter's auroras, highlighting the electron measurements that show the discovery of the so-called discrete auroral acceleration processes indicated by the "inverted Vs" in the lower panel. Credit: NASA/JPL-Caltech/SwRI/Randy Gladstone.

Scientists on NASA's Juno mission have observed massive amounts of energy swirling over Jupiter's polar regions that contribute to the giant planet's powerful auroras, only not in ways the researchers expected. Examining data collected by the ultraviolet spectrograph and energetic-particle detector instruments onboard the Jupiter-orbiting Juno spacecraft, a team led by Barry Mauk of the Johns Hopkins University Applied Physics Laboratory (APL) observed signatures of powerful electric potentials, aligned with Jupiter's magnetic field, that accelerate electrons toward the jovian atmosphere at energies up to 400,000 electron volts. This is 10 to 30 times higher than the largest auroral potentials observed at Earth, where only several thousands of volts are typically needed to generate the most intense auroras (known as discrete auroras), the dazzling, twisting, snake-like northern and southern lights seen in places like Alaska and Canada, northern Europe, and many other northern and southern polar regions.

Jupiter has the most powerful auroras in the solar system, so the team was not surprised that electric potentials play a role in their generation. What's puzzling the researchers, Mauk said, is that despite the magnitudes of these potentials at Jupiter, they are observed only sometimes and are not the source of the most intense auroras, as they are at Earth. "At Jupiter, the brightest auroras are caused by some kind of turbulent acceleration process that we do not understand very well," said Mauk, who leads the investigation team for the APL-built Jupiter Energetic Particle Detector Instrument (JEDI). "There are hints in our latest data indicating that as the power density of the auroral generation becomes stronger and stronger, the process becomes unstable and a new acceleration process takes over. But we'll have to keep looking at the data."

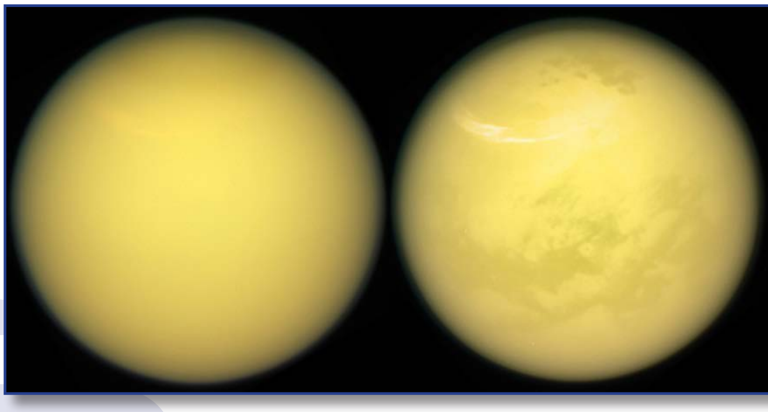
Scientists consider Jupiter to be a physics lab of sorts for worlds beyond our solar system, saying the ability of Jupiter to accelerate charged particles to immense energies has implications for how more distant astrophysical systems accelerate particles. What they learn about the forces driving Jupiter's auroras and shaping its space weather environment has practical implications in our own planetary backyard.

"The highest energies that we are observing within Jupiter's auroral regions are formidable. These energetic particles that create the auroras are part of the story in understanding Jupiter's radiation belts, which pose such a challenge to Juno and to upcoming spacecraft missions to Jupiter under development," said Mauk. "Engineering around the debilitating effects of radiation has always been a challenge to spacecraft engineers for missions at Earth and elsewhere in the solar system. What we learn here, and from spacecraft like NASA's Van Allen Probes and Magnetospheric Multiscale mission (MMS) that are exploring Earth's magnetosphere, will teach us a lot about space weather and protecting spacecraft and astronauts in harsh space environments. Comparing the processes at Jupiter and Earth is incredibly valuable in testing our ideas of how planetary physics works." Mauk and colleagues presented their findings in the September 7 issue of the journal *Nature.*

Cassini Says Goodbye to a True Titan

Mere weeks away from its dramatic, mission-ending plunge into Saturn, NASA's Cassini spacecraft had a hectic schedule, orbiting the planet every week in its Grand Finale. On a few orbits, Saturn's largest moon, Titan, was near enough to tweak Cassini's orbit, causing the spacecraft to approach Saturn a bit closer or a bit farther away. A couple of those distant passes even pushed Cassini into the inner fringes of Saturn's rings. A last, distant encounter with the moon occurred on September 11, with the spacecraft sending back precious science data. This gravitational pushing and shoving isn't a new behavior for Titan. It's been doing that all along, by design.

Repeated flybys of Titan were envisioned, from the mission's beginning, as a way to explore the mysterious planet-sized moon and to fling Cassini toward its adventures in the Saturn system. Scientists had been eager for a return to Titan since NASA's Voyager 1 spacecraft flew past in 1980 and was unable to see through the dense, golden haze that shrouds its surface. Titan is just a bit larger than the planet Mercury. Given its size, the moon has significant gravity, which was used for bending Cassini's course as it orbited Saturn. A single close flyby of Titan could provide more of a change in velocity than the



These two views of Saturn's moon Titan exemplify how NASA's Cassini spacecraft has revealed the surface of this fascinating world. Credit: NASA/JPL-Caltech/Space Science Institute.

entire 90-minute engine burn the spacecraft needed to slow down and be captured by Saturn's gravity upon its arrival in 2004.

The mission's tour designers — engineers tasked with plotting the spacecraft's course, years in advance — used Titan as their linchpin. Frequent passes by the moon provided the equivalent of huge amounts of rocket propellant. Using Titan, Cassini's orbit could be stretched out farther from Saturn — for example, to send the spacecraft toward the distant moon Iapetus. With this technique, engineers used Titan flybys to change the orientation of Cassini's orbit many times during the mission, for example, lifting the spacecraft out of the plane of the rings to view them from high above, along with high northern and southern latitudes on Saturn and its moons.

Over the course of its 13-year mission at Saturn, Cassini made 127 close flybys of Titan, with many more-distant observations. Cassini also dropped off the European Space Agency's Huygens probe, which descended through Titan's atmosphere to land on the surface in January 2005. Successes for Cassini during its mission included the revelation that, as researchers had theorized, there were indeed bodies of open liquid hydrocarbons on Titan's surface. Surprisingly, it turned out Titan's lakes and seas are confined to the poles, with almost all the liquid being at northern latitudes in the present epoch. Cassini found that most of Titan has no lakes, with vast stretches of linear dunes closer to the equator similar to those in places like Namibia on Earth. The spacecraft observed giant hydrocarbon clouds hovering over Titan's poles and bright, feathery ones that drifted across the landscape, dropping methane rain that darkened the surface. There were also indications of an ocean of water beneath the moon's icy surface.

Early on, Cassini's picture of Titan was spotty, but every encounter built upon the previous one. Over the course of the entire mission, Cassini's radar investigation imaged approximately 67% of Titan's surface, using the spacecraft's large, saucer-shaped antenna to bounce signals off the moon's surface. Views from Cassini's imaging cameras, infrared spectrometer, and radar slowly and methodically added details, building up a more complete, high-resolution picture of Titan.

Scientists now have enough data to understand the distribution of Titan's surface features (like mountains, dunes, and seas) and the behavior of its atmosphere over time, and they have been able to begin piecing together how surface liquids might migrate from pole to pole. Among the things that remain uncertain is exactly how the methane in Titan's atmosphere is being replenished, since it's broken down over time by sunlight. Scientists see some evidence of volcanism, with methane-laden water as the "lava," but a definitive detection remains elusive.

Cassini's long-term observations could still provide clues. Researchers have been watching for summer rain clouds to appear at the north pole, as their models predicted. Cassini observed rain clouds at the south pole in southern summer in 2004. So far, clouds at high northern latitudes have been sparse. "The atmosphere seems to have more inertia than most models have assumed. Basically, it takes longer than we thought for the weather to change with the seasons," said Elizabeth Turtle, a Cassini imaging team associate at Johns Hopkins Applied Physics Laboratory, Laurel, Maryland.

The sluggish arrival of northern summer clouds may match better with models that predict a global reservoir of methane, Turtle said. "There isn't a global reservoir at the surface, so if one exists in the subsurface that would be a major revelation about Titan." This points to the value of Cassini's long-term monitoring of Titan's atmosphere, she said, as the monitoring provided data that can be used to test models and ideas.

Cassini made its last close flyby of Titan on April 22. That flyby gave the spacecraft the push it needed to leap over Saturn's rings and begin its final series of orbits, which passed between the rings and the planet. During that flyby, Cassini's radar was in the driver's seat — its observation requirements determining how the spacecraft would be oriented as it passed low over the surface one last time at an altitude of 979 kilometers (608 miles). One of the priorities was to have one last look for the mysterious features the team dubbed "magic islands," which had appeared and then vanished in separate observations taken years apart. On the final pass there were no magic islands to be seen. The radar team is still working to understand what the features might have been, with leading candidates being bubbles or waves.

Most interesting to the radar team was a set of observations that was both the first and last of its kind, in which the instrument was used to sound the depths of several of the small lakes that dot Titan's north polar region. Going forward, the researchers will be working to tease out information from these data about the lakes' composition, in terms of methane vs. ethane.

As Cassini zoomed past on its last close brush with Titan, headed toward its Grand Finale, the radar imaged a long swath of the surface that included terrain seen on the very first Titan flyby in 2004. "It's pretty remarkable that we ended up close to where we started," said Wall. "The difference is how richly our understanding has grown, and how the questions we're asking about Titan have evolved."

For more information, visit *https://saturn.jpl.nasa.gov/*.

NASA's Voyager Spacecraft Still Reaching for the Stars After 40 Years

Humanity's farthest and longest-lived spacecraft, Voyagers 1 and 2, achieved 40 years of operation and exploration this August and September. Despite their vast distance, they continue to communicate with NASA daily, still probing the final frontier. Their story has not only impacted generations of current and future scientists and engineers, but also Earth's culture, including film, art, and music. Each spacecraft carries a Golden Record of Earth sounds, pictures, and messages. Since the spacecraft could last billions of years, these circular time capsules could be the only traces of human civilization.

This artist's concept depicts one of the twin Voyager spacecraft. Humanity's farthest and longest-lived spacecraft are celebrating 40 years in August and September 2017. Credit: NASA.

"I believe that few missions can ever match the achievements of the Voyager spacecraft during their four decades of exploration," said Thomas Zurbuchen, associate administrator for NASA's Science Mission Directorate (SMD) at NASA Headquarters. "They have educated us to the unknown wonders of the universe and truly inspired humanity to continue to explore our solar system and beyond."

The Voyagers have set numerous records in their unparalleled journeys. In 2012, Voyager 1, which launched on September 5, 1977, became the only spacecraft to have entered interstellar space. Voyager 2, launched on August 20, 1977, is the only spacecraft to have flown by all four outer planets — Jupiter, Saturn, Uranus, and Neptune. Their numerous planetary encounters include discovering the first active volcanos beyond Earth, on Jupiter's moon, Io; hints of a subsurface ocean on Jupiter's moon, Europa; the most Earth-like atmosphere in the solar system, on Saturn's moon Titan; the jumbled-up, icy moon Miranda at Uranus; and icy-cold geysers on Neptune's moon, Triton.

Although the spacecraft have left the planets far behind — and neither will come remotely close to another star for 40,000 years — the two probes still send back observations about conditions where our Sun's influence diminishes and interstellar space begins.

Voyager 1, now almost 13 billion miles from Earth, travels through interstellar space northward out of the plane of the planets. The probe has informed researchers that cosmic rays — atomic nuclei accelerated to nearly the speed of light — are as much as four times more abundant in interstellar space than in the vicinity of Earth. This means the heliosphere, the bubble-like volume containing our solar system's planets and solar wind, effectively acts as a radiation shield for the planets. Voyager 1 also hinted that the magnetic field of the local interstellar medium is wrapped around the heliosphere.

Voyager 2, now almost 11 billion miles from Earth, travels south and is expected to enter interstellar space in the next few years. The different locations of the two Voyagers allow scientists to compare right now two regions of space where the heliosphere interacts with the surrounding interstellar medium using instruments that measure charged particles, magnetic fields, low-frequency radio waves, and solar wind plasma. Once Voyager 2 crosses into the interstellar medium, they will also be able to sample the medium from two different locations simultaneously.

"None of us knew when we launched 40 years ago that anything would still be working, and continuing on this pioneering journey," said Ed Stone, Voyager project scientist based at Caltech in Pasadena, California. "The most exciting thing they find in the next five years is likely to be something that we didn't know was out there to be discovered."

The twin Voyagers have been cosmic overachievers, thanks to the foresight of mission designers. By preparing for the radiation environment at Jupiter, the harshest of all planets in our solar system, the spacecraft were well equipped for their subsequent journeys. Both Voyagers are equipped with long-lasting power supplies, as well as redundant systems that allow the spacecraft to switch to backup systems autonomously when necessary. Each Voyager carries three radioisotope thermoelectric generators, devices that use the heat energy generated from the decay of plutonium-238 — only half of it will be gone after 88 years.

Space is almost empty, so the Voyagers are not at a significant level of risk of bombardment by large objects. However, Voyager 1's interstellar space environment is not a complete void. It's filled with clouds of dilute material remaining from stars that exploded as supernovae millions of years ago. This material doesn't pose a danger to the spacecraft, but it is a key part of the environment that the Voyager mission is helping scientists to study and characterize.

Because the Voyagers' power decreases by four watts per year, engineers are learning how to operate the spacecraft under ever-tighter power constraints. To maximize the Voyagers' lifespans, they also have to consult documents written decades earlier describing commands and software, in addition to the expertise of former Voyager engineers.

"The technology is many generations old, and it takes someone with 1970s design experience to understand how the spacecraft operate and what updates can be made to permit them to continue operating today and into the future," said Suzanne Dodd, Voyager project manager based at NASA's Jet Propulsion Laboratory in Pasadena, California.

Team members estimate they will have to turn off the last science instrument by 2030. However, even after the spacecraft go silent, they'll continue on their trajectories at their present speed of more than 48,280 kilometers per hour (30,000 miles per hour), completing an orbit within the Milky Way every 225 million years. For more information, visit *https://www.nasa.gov/voyager.*

Hubble Detects Exoplanet with Glowing Water Atmosphere

This artist's concept shows hot Jupiter WASP-121b, which presents the best evidence yet of a stratosphere on an exoplanet. Credit: Engine House VFX, At-Bristol Science Centre, University of Exeter.

Scientists have discovered the strongest evidence to date for a stratosphere on a planet outside our solar system, or exoplanet. A stratosphere is a layer of atmosphere in which temperature increases with higher altitudes. "This result is exciting because it shows that a common trait of most of the atmospheres in our solar system — a warm stratosphere — also can be found in exoplanet atmospheres," said Mark Marley, study co-author based at NASA's Ames Research Center in California's Silicon Valley. "We can now compare processes in exoplanet atmospheres with the same processes that happen under different sets of conditions in our own solar system."

Reporting in the journal *Nature*, scientists used data from NASA's Hubble Space Telescope to study WASP-121b, a type of exoplanet called a "hot Jupiter." Its mass is 1.2 times that of Jupiter, and its radius is about 1.9 times Jupiter's — making it puffier. While Jupiter revolves around our Sun once every 12 years, WASP-121b has an orbital period of just 1.3 days. This exoplanet is so close to its star that if it got any closer, the star's gravity would start ripping it apart. It also means that the top of the planet's atmosphere is heated to a blazing 2500°C (4600°F), hot enough to boil some metals. The WASP-121 system is estimated to be about 900 light-years from Earth, a long way but close by galactic standards.

Previous research found possible signs of a stratosphere on the exoplanet WASP-33b as well as some other hot Jupiters. The new study presents the best evidence yet because of the signature of hot water molecules that researchers observed for the first time. "Theoretical models have suggested stratospheres may define a distinct class of ultra-hot planets, with important implications for their atmospheric physics and chemistry," said Tom Evans, lead author and research fellow at the University of Exeter, United Kingdom. "Our observations support this picture."

To study the stratosphere of WASP-121b, scientists analyzed how different molecules in the atmosphere react to particular wavelengths of light, using Hubble's capabilities for spectroscopy. Water vapor in the planet's atmosphere, for example, behaves in predictable ways in response to certain wavelengths of light, depending on the temperature of the water.

Starlight is able to penetrate deep into a planet's atmosphere, where it raises the temperature of the gas there. This gas then radiates its heat into space as infrared light. However, if there is cooler water vapor at the top of the atmosphere, the water molecules will prevent certain wavelengths of this light from escaping to space. If the water molecules at the top of the atmosphere have a higher temperature, they will glow at the same wavelengths.

The phenomenon is similar to what happens with fireworks, which get their colors from chemicals emitting light. When metallic substances are heated and vaporized, their electrons move into higher energy states. Depending on the material, these electrons will emit light at specific wavelengths as they lose energy: sodium produces orange-yellow and strontium produces red in this process, for example. The water molecules in the atmosphere of WASP-121b similarly give off radiation as they lose energy, but in the form of infrared light, which the human eye is unable to detect.

In Earth's stratosphere, ozone gas traps ultraviolet radiation from the Sun, which raises the temperature of this layer of atmosphere. Other solar system bodies have stratospheres as well; methane is responsible for heating in the stratospheres of Jupiter and Saturn's moon Titan, for example.

In solar system planets, the change in temperature within a stratosphere is typically about 56°C (100°F). On WASP-121b, the temperature in the stratosphere rises by 560°C (1000°F). Scientists do not yet know what chemicals are causing the temperature increase in WASP-121b's atmosphere. Vanadium oxide and titanium oxide are candidates, as they are commonly seen in brown dwarfs, "failed stars" that have some commonalities with exoplanets. Such compounds are expected to be present only on the hottest of hot Jupiters, as high temperatures are needed to keep them in a gaseous state.

"This super-hot exoplanet is going to be a benchmark for our atmospheric models, and it will be a great observational target moving into the Webb era," said Hannah Wakeford, study co-author who worked on this research while at NASA's Goddard Space Flight Center in Greenbelt, Maryland.

For more information, visit *https://nasa.gov/hubble.*

TRAPPIST-1 is Older than Our Solar System

If we want to know more about whether life could survive on a planet outside our solar system, it's important to know the age of its star. Young stars have frequent releases of high-energy radiation called flares that can zap their planets' surfaces. If the planets are newly formed, their orbits may also be unstable. On the other hand, planets orbiting older stars have survived the spate of youthful flares, but have also been exposed to the ravages of stellar radiation for a longer period of time.

Scientists now have a good estimate for the age of one of the most intriguing planetary systems discovered to date: TRAPPIST-1, a system of seven Earth-sized worlds orbiting an ultra-cool dwarf star about 40 light-years away. Researchers say in a new study that the TRAPPIST-1 star is quite old, between 5.4 and 9.8 billion years. This is up to twice as old as our own solar system, which formed some 4.5 billion years ago.

The seven wonders of TRAPPIST-1 were revealed earlier this year in a NASA news conference, using a combination of results from the Transiting Planets and Planetesimals Small Telescope (TRAPPIST) in Chile, NASA's Spitzer Space Telescope, and other groundbased telescopes. Three of the TRAPPIST-1 planets reside in the star's "habitable zone," the orbital distance where a rocky planet with an atmosphere could have liquid water on its surface. All seven planets are likely tidally locked to their star, each with a perpetual dayside and nightside.

This illustration shows what the TRAPPIST-1 system might look like from a vantage point near planet TRAPPIST-1f (at right). Credit: NASA/JPL-Caltech.

At the time of its discovery, scientists believed the TRAPPIST-1 system had to be at least 500 million years old, since it takes stars of TRAPPIST-1's low mass (roughly 8% that of the Sun) roughly that long to contract to its minimum size, just a bit larger than the planet Jupiter. However, even this lower age limit was uncertain; in theory, the star could be almost as old as the universe itself. Are the orbits of this compact system of planets stable? Might life have enough time to evolve on any of these worlds?

"Our results really help constrain the evolution of the TRAPPIST-1 system, because the system has to have persisted for billions of years. This means the planets had to evolve together, otherwise the system would have fallen apart long ago," said Adam Burgasser, an astronomer at the University of California, San Diego, and the paper's first author. Burgasser teamed up with Eric Mamajek, deputy program scientist for NASA's Exoplanet Exploration Program based at NASA's Jet Propulsion Laboratory, Pasadena, California, to calculate TRAPPIST-1's age. Their results will be published in *The Astrophysical Journal*.

It is unclear what this older age means for the planets' habitability. On the one hand, older stars flare less than younger stars, and Burgasser and Mamajek confirmed that TRAPPIST-1 is relatively quiet compared to other ultra-cool dwarf stars. On the other hand, since the planets are so close to the star, they have soaked up billions of years of high-energy radiation, which could have boiled off atmospheres and large amounts of water. In fact, the equivalent of an Earth ocean may have evaporated from each TRAPPIST-1 planet except for the two most distant from the host star: planets g and h. In our own solar system, Mars is an example of a planet that likely had liquid water on its surface in the past, but lost most of its water and atmosphere to the Sun's high-energy radiation over billions of years.

However, old age does not necessarily mean that a planet's atmosphere has been eroded. Given that the TRAPPIST-1 planets have lower densities than Earth, it is possible that large reservoirs of volatile molecules such as water could produce thick atmospheres that would shield the planetary surfaces from harmful radiation. A thick atmosphere could also help redistribute heat to the dark sides of these tidally locked planets, increasing habitable real estate. But this could also backfire in a "runaway greenhouse" process, in which the atmosphere becomes so thick the planet surface overheats, as on Venus. "If there is life on these planets, I would speculate that it has to be hardy life, because it has to be able to survive some potentially dire scenarios for billions of years," Burgasser said.

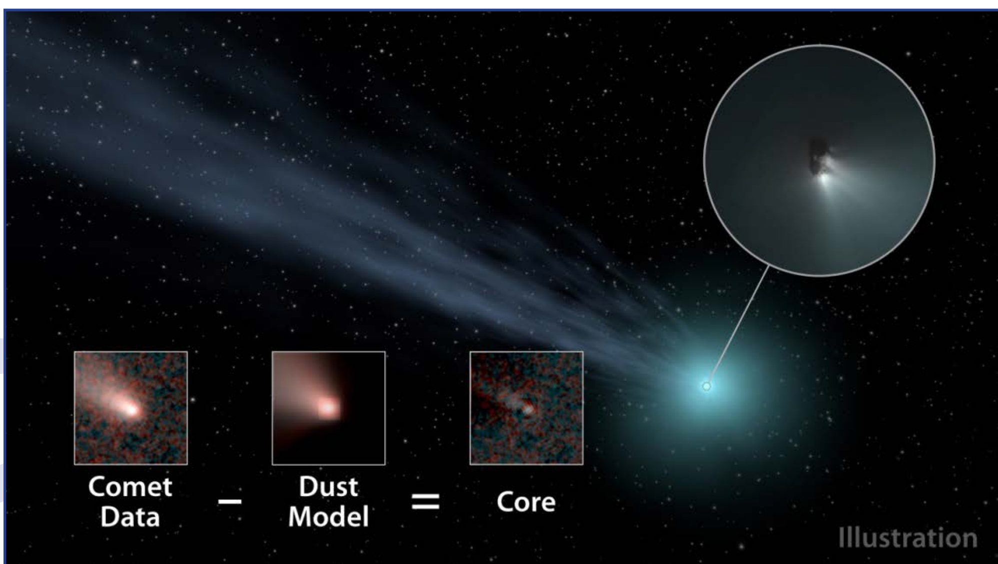
Fortunately, low-mass stars like TRAPPIST-1 have temperatures and brightnesses that remain relatively constant over trillions of years, punctuated by occasional magnetic flaring events. The lifetimes of tiny stars like TRAPPIST-1 are predicted to be much, much longer than the 13.7 billion-year age of the universe (the Sun, by comparison, has an expected lifetime of about 10 billion years).

"Stars much more massive than the Sun consume their fuel quickly, brightening over millions of years and exploding as supernovae," Mamajek said. "But TRAPPIST-1 is like a slow-burning candle that will shine for about 900 times longer than the current age of the universe."

Some of the clues Burgasser and Mamajek used to measure the age of TRAPPIST-1 included how fast the star is moving in its orbit around the Milky Way (speedier stars tend to be older), its atmosphere's chemical composition, and how many flares TRAPPIST-1 had during observational periods. These variables all pointed to a star that is substantially older than our Sun. Future observations with NASA's Hubble Space Telescope and upcoming James Webb Space Telescope may reveal whether these planets have atmospheres, and whether such atmospheres are like Earth's.

Future observations with Spitzer could help scientists sharpen their estimates of the TRAPPIST-1 planets' densities, which would inform their understanding of their compositions. For more information, visit *https://exoplanets.nasa.gov/trappist1*.

Large, Distant Comets More Common than Previously Thought



This illustration shows how scientists used data from NASA's WISE spacecraft to determine the nucleus sizes of comets. They subtracted a model of how dust and gas behave in comets in order to obtain the core size. Credit: NASA/JPL-Caltech.

Comets that take more than 200 years to make one revolution around the Sun are notoriously difficult to study. Because they spend most of their time far from our area of the solar system, many "long-period comets" will never approach the Sun in a person's lifetime. In fact, those that travel inward from the Oort cloud — a group of icy bodies beginning roughly 186 billion miles (300 billion kilometers) away from the Sun — can have periods of thousands or even millions of years.

NASA's Wide-field Infrared Survey Explorer (WISE) spacecraft, scanning the entire sky at infrared wavelengths, has delivered new insights about these distant wanderers. Scientists found that there are about seven times more long-period comets measuring at least 1 kilometer (0.6 miles) across than had been predicted previously. They also found that long-period comets are on average up to twice as large as "Jupiter-family" comets, whose orbits are shaped by Jupiter's gravity and have periods of less than 20 years.

Researchers also observed that in eight months, three to five times as many long-period comets passed by the Sun than had been predicted. "The number of comets speaks to the amount of material left over from the solar system's formation," said James Bauer, lead author of the study and now a research professor at the University of Maryland, College Park. "We now know that there are more relatively large chunks of ancient material coming from the Oort cloud than we thought."

The Oort cloud is too distant to be seen by current telescopes, but is thought to be a spherical distribution of small icy bodies at the outermost edge of the solar system. The density of comets within it is low, so the odds of comets colliding within it are rare. Long-period comets that WISE observed probably got kicked out of the Oort cloud millions of years ago. The observations were carried out during the spacecraft's primary mission before it was renamed NEOWISE and reactivated to target near-Earth objects (NEOs).

"Our study is a rare look at objects perturbed out of the Oort cloud," said Amy Mainzer, study co-author based at NASA's Jet Propulsion Laboratory, Pasadena, California, and principal investigator of the NEOWISE mission. "They are the most pristine examples of what the solar system was like when it formed."

Astronomers already had broader estimates of how many long-period and Jupiter-family comets are in our solar system, but had no good way of measuring the sizes of long-period comets. That is because a comet has a "coma," a cloud of gas and dust that appears hazy in images and obscures the cometary nucleus. But by using the WISE data showing the infrared glow of this coma, scientists were able to "subtract" the coma from the overall comet and estimate the nucleus sizes of these comets. The data came from 2010 WISE observations of 95 Jupiter-family comets and 56 long-period comets.

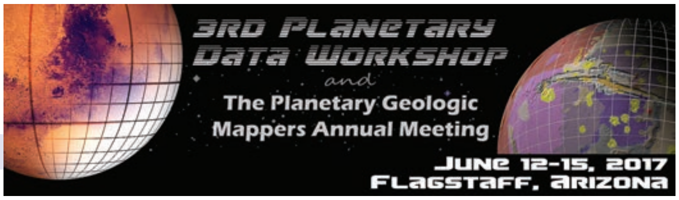
The results reinforce the idea that comets that pass by the Sun more often tend to be smaller than those spending much more time away from the Sun. That is because Jupiter-family comets get more heat exposure, which causes volatile substances like water to sublimate and drag away other material from the comet's surface as well.

"Our results mean there's an evolutionary difference between Jupiter-family and long-period comets," Bauer said. The existence of so many more long-period comets than predicted suggests that more of them have likely impacted planets, delivering icy materials from the outer reaches of the solar system. Researchers also found clustering in the orbits of the long-period comets they studied, suggesting there could have been larger bodies that broke apart to form these groups. The results will be important for assessing the likelihood of comets impacting our solar system's planets, including Earth. "Comets travel much faster than asteroids, and some of them are very big," Mainzer said. "Studies like this will help us define what kind of hazard long-period comets may pose."

For more information, visit *https://www.nasa.gov/wise*.

3rd Planetary Data Workshop

June 12–15, 2017
Flagstaff, Arizona



The volume of data available to planetary scientists is increasing rapidly and the NASA Planetary Data System (PDS) now serves over a petabyte of data from space missions (see related cover story in this issue). These data are widely used by scientists for research, mission planning, education, and outreach. Methods of identifying, acquiring, storing, and serving these data are advancing alongside improvements in analysis methods and data synthesis and visualization tools. There is a strong need for communication among data providers, scientists, engineers, tools developers, and users on how best to obtain just the right data and to work with them using the best possible tools.

Almost 200 participants from institutions worldwide discussed such topics recently at the 3rd Planetary Data Workshop (PDW3), held in June in Flagstaff, Arizona. The goal of these workshops is to bring together planetary scientists, data providers from current and recent planetary exploration missions, data archivists, and software experts to exchange ideas on current capabilities and needs for tools for planetary research and data analysis. The 2017 workshop included keynote presentations by Ross Beyer (NASA Ames Research Center), Sebastien Besse (European Space Astronomy Centre, Madrid, Spain), Dan Crichton (Jet Propulsion Laboratory), Kate Crombie (Indigo Information Services, LLC), and Justin Hagerty (USGS), as well as a wide variety of presentations by data users, mission data providers and archivists, and software developers. In addition to several informal discussions for tool developers, the workshop also featured a 1.5-day training session for PDS4 data archiving (see *https://pds.nasa.gov/pds4/training/2017-pdw/index.shtml*) and almost 30 hours of hands-on training and how-to presentations for acquiring, processing, and working with a variety of digital planetary data. Eighteen NASA and non-NASA data providers and missions were represented; one such training session featured the use of Mars Reconnaissance Orbiter's Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) instrument, presented by Kim Seelos (JHU/APL), Ray Arvidson (Washington University), and others. The workshop was facilitated by the Lunar and Planetary Institute.

This year we co-hosted the annual Planetary Geologic Mappers meeting (June 12 and 13), which involves NASA-funded principal investigators who are currently developing geological map products who gather to discuss the status of mapping tasks and to obtain guidance for the map publication process. About 40 scientists and students interested in planetary cartography, geological mapping, and map-related topical science attended this parallel meeting.

PDW3 featured updates on PDS4, the current planetary archive standard and information model, presented by PDS representatives and discussed in light of the new requirements for data archiving by research programs government-wide. Other themes at PDW3 included the challenges posed by "big data," informatics research and automated data analysis, the need for scalable storage and data access architectures, availability of planetary data, information on publicly available derived data products and services, and presentations by Trent Hare and Jason Laura (both at USGS/Astrogeology) on the latest methods for using tools such as Geographic Information Systems for cartographic processing and visualization of planetary data. Mission representatives summarized status and plans for their data archives and delivery services. Services such as the community's Integrated Software for Imagers and Spectrometers (ISIS3), the Regional Planetary Image Facilities, the Planetary Nomenclature function at USGS in support of NASA and the International Astronomical Union's Working Group on Cartographic Coordinates and Rotational Elements (WGCCRE), and tools and services from the NASA Solar System Exploration Research Virtual Institute (SSERVI) were also discussed.

Finally, the last half day of the meeting focused on town-hall-style presentations and a panel discussion hosted by the NASA-sponsored Mapping and Planetary Spatial Infrastructure Team (MAPSIT), chaired by Jani Radebaugh (Brigham Young University). Talks and discussions centered on the concept of an overarching but poorly understood "planetary spatial data infrastructure" (PSDI) program of research and product development. Aspects of PSDI are currently present in several active NASA operations, including the USGS Astrogeology's planetary cartography research program, the PDS, and MAPSIT. A panel discussion (involving Beyer, Radebaugh, Lisa Gaddis, Hagerty, and Hare) helped to clarify the relationships and overlaps between these elements and to identify future needs for moving forward with a more coherent view of how this concept can frame work and products from a wide variety of active researchers in planetary science.

The next Planetary Data Workshop is scheduled for June 2019, also in Flagstaff, Arizona. All those with questions or presentations about planetary data, tools, and services are welcome to join us!

For more information about the 3rd Planetary Data Workshop, including links to the program and abstracts, please visit *https://www.hou.usra.edu/meetings/planetdata2017/.* Presentations and tutorials from the workshop are available at *https://astrogeology.usgs.gov/groups/Planetary-Data-Workshop*.

XVIIIth International Conference on the Origin of Life

July 16–21, 2017
San Diego, California

The XVIIIth International Conference on the Origin of Life (the tri-annual meeting of the ISSOL society) took place on the campus of University of California, San Diego (UCSD), on July 16–21, 2017. A total of 257 people were registered. Sponsors included NASA, the Lunar and Planetary Institute, ELSI/EON, The Simons Foundation, and the division of Physical Sciences at UCSD. The scientific organizing committee consisted of Robert Pascal (Chair, University of Montpellier), Ram Krishnamurthy (The Scripps Research Institute), George Cooper (NASA Ames Research Center), Hiroshi Naraoka (Kyushu University), Antonio Lazcano (Universidad Nacional Autónoma de México), and Emmanuelle J. Javaux (University of Liege). The local organizing committee consisted of Ulrich Müller (Chair, UCSD), Yitzhak Tor (UCSD), Luke Leman (The Scripps Research Institute), Reza Ghadiri, (The Scripps Research Institute), Charlie Perrin (UCSD), Mark Thiemens (UCSD), and Jeff Bada (The Scripps Institute of Oceanography).

Sessions started on Sunday, July 16 (with a keynote lecture by Nobel Laureate Jack Szostak). During the week, lectures were held from 8:30 a.m. to 8:30 p.m. on Monday through Thursday, and ended in the late afternoon on Friday. On Wednesday afternoon participants could choose to either have a free afternoon, visit the Birch Aquarium, or attend one of two business meetings of the ISSOL society. On Thursday evening, during the usual dinner break from 5:30 p.m. to 7:00 p.m., a Gala dinner was held, with four awards being presented (three ISSOL fellowships and one Stanley Miller medal).

All lectures were plenary lectures. Topics covered by the scientific program extended from astronomy to geochemistry, inorganic/organic chemistry, biochemistry, and biology. A total of 80 oral presentations were given, many from established researchers such as Sarah Seager (MIT), David DesMarais (NASA/Ames), Bob Hazen (Carnegie), David Deamer (UC Santa Cruz), David Ross (SRI International), Matt Powner (University College London), Alan Schwartz (Radboud University), Gerald Joyce (Salk Institute), Niles Lehman (Portland State University), and Addy Pross (Ben Gurion University). The topic of lectures ranged from summaries over entire fields of research, updates on long-standing projects, and new developments that emerged during the three years since the last ISSOL conference in Nara, Japan (2014). Almost all lectures allowed enough time for questions from the audience. Additionally, the conference included four panel discussions with leaders in each field of research usually giving a short statement or splice presentation, and then addressing questions from the audience.

Poster sessions were ongoing from Monday noon to Thursday evening. About 150 posters were presented, covering the same areas of science as the oral presentations. A total of 17 poster awards were presented.

For more information about the conference, including links to the program and abstracts, please visit *https://www.hou.usra.edu/meetings/issol2017/.*

Astrobiology Science Conference (AbSciCon) 2017

April 24–28, 2017
Mesa, Arizona

On April 24–28, 2017, almost 800 scientists descended on the Mesa Marriott in Mesa, Arizona, to attend the 2017 Astrobiology Science Conference, or AbSciCon 2017. This NASA-sponsored conference was the latest in a series of AbSciCon conferences that meets roughly every other year, last meeting in Chicago (2015), Atlanta (2012), and Houston (2010). The purpose of these conferences is to bring together scientists across the umbrella field of astrobiology — astronomers, planetary scientists, biologists, geochemists — to advance knowledge of where life could exist in the universe, and how to search for it. Bringing together hundreds of different scientists across disciplines and from across the globe was a logistical challenge. Steve Desch was the chair of the organizing committees for this conference, and the Lunar and Planetary Institute (LPI) played a critical and expert role in organizing the conference at Arizona State University (ASU).

The main purpose of the conference was to announce new results from scientific research, and a tremendous amount of research was presented. There were 5 parallel sessions, morning and afternoon, Monday through Friday, during which almost 500 15-minute oral presentations were given. These were augmented by two poster sessions on Monday and Wednesday evenings, which saw hundreds more poster presentations. The topics spanned astrobiology and biosignatures on Mars, Europa, and other icy worlds; evolution of life on Earth, from prebiotic chemistry to genomics; fundamentals of the origin of life; the search for life on exoplanets; new technologies and techniques for searching for life; and innovations in teaching and communicating astrobiology. Plenary lectures covered planetary protection, origin of life, astrobiology education and social issues in astrobiology, anoxygenic photosynthesis, and astrobiology technology on planetary missions.

The conference also hosted dozens of breakout meetings, including town hall discussions, NASA briefings, workshops, and team meetings. Innumerable conversations were catalyzed in the hallways and coffee break areas as well, leading no doubt to science that will be presented at the next AbSciCon.

AbSciCon 2017 also provided opportunities for student training. A student mentoring program brought in students considering careers in astrobiology science from community colleges across Arizona, and a similar group visited from Mills College in California to experience what happens at scientific conferences. A student poster competition was held. Before the meeting a free "school" was offered at ASU to help early career scientists get up to speed on science within astrobiology but not in their immediate field of study.

Three events were made open to the public. On Monday was the "Meet the Scientists" event sponsored by the Foundation for Applied Molecular Evolution. On Tuesday, ASU's Beyond Center sponsored a panel discussion on "Where Will We Find a Second Example of Life?" PlanetWorks and the Origins Project at ASU sponsored a panel discussion on Thursday evening on "Managing Earth as a Planet." Spreading astrobiology to the public was aided by inviting social media reporters to the conference, including a tour of facilities at ASU. To get a glimpse of the conference from their perspective, visit *https://www.youtube.com/watch?v=KQAFfToChsk.*

Other social events allowed the attendees to connect with each other. The opening reception banquet at the Mesa Amphitheater on Sunday evening featured an outdoors buffet and live entertainment from Arizona dancers and singers. A highlight for some was the Open Mic night on Wednesday, during which scientists displayed their talents. Thursday morning featured a celebration of the career of Carl Pilcher, former director of the NASA Astrobiology Institute. At the end of the conference, excursions to Meteor Crater and the Grand Canyon were offered and guided by geologists from ASU. Some other highlights included the display of astrobiology-themed art at the conference venue.

It was a memorable conference overall, from the science, to the public events, to the student training, to the social aspects. Making it all happen was a team effort, and we thank NASA for their support, and our other sponsors, including the Earth-Life Science Institute, Blue Marble Space, Smart Sparrow, and Qwaltec. The organizing committees also worked very hard to sort abstracts and to plan the meeting, but it is safe to say that the meeting could not have happened without the logistical support from the LPI. Look for more information about AbSciCon 2019, which will be in Seattle, Washington.

For more information about AbSciCon 2017, including links to the program and abstracts, please visit *https://www.hou.usra.edu/meetings/abscicon2017/.*

Spotlight on Education

"Spotlight on Education" highlights events and programs that provide opportunities for planetary scientists to become involved in education and public engagement. If you know of space science educational programs or events that should be included, please contact the Lunar and Planetary Institute's Education Department at education@lpi.usra.edu.

Upcoming Public Event Opportunities

Upcoming opportunities exist for educator and public engagement around the broader topics of NASA planetary exploration. Contact local astronomical societies, planetariums and museums, local scientists, and NASA's Solar System Ambassadors (*http://solarsystem.nasa.gov/ssa/directory.cfm*) — ask them to join your events and share their experiences or resources with your audience.

Voyager 40th Anniversary, August/September 2017

Voyagers 1 and 2 have been out there for 40 years! Reach out to your community to celebrate the discoveries of this important program of solar system exploration.

International Observe the Moon Night, October 28, 2017

After celebrating the August solar eclipse, why not give the Moon its own night? Join lunar enthusiasts from around the globe to celebrate International Observe the Moon Night. Learn about the event, get activity ideas, and register your event at *http://observethemoonnight.org.*

Call for Mentors and Mentees — MentorNet

The Division of Planetary Science has a partnership with MentorNet (*http://mentornet.org*), a mentoring platform that connects STEM students with mentors working in STEM fields. MentorNet gives students an opportunity to grow their network outside of their current institution, and provides training sessions for mentors and mentees. For more information, please visit the DPS MentorNet Q&A page at *https://dps.aas.org/development/mentornet-qa*.

NASA Opportunities

NASA History Program Office Student Internships

http://history.nasa.gov/interncall.htm

The NASA History Program Office is seeking undergraduate and graduate students for spring 2018 internships. The History Division maintains archival materials to answer research questions. The division edits and publishes several books and monographs each year, and it maintains websites and social media featuring NASA history. Strong research, writing, and editing skills are essential to the internship. Students of all majors are welcome to apply. Application deadline is October 1, 2017.

NASA Internships, Fellowships, and Scholarships

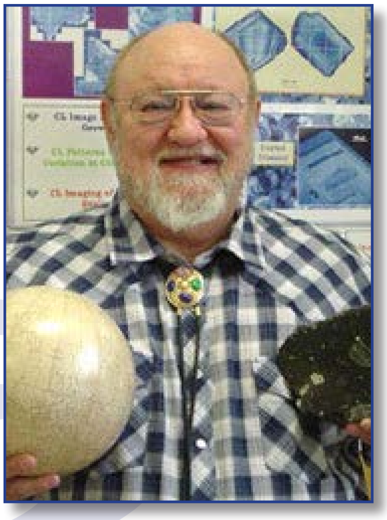
https://intern.nasa.gov

The NASA Internships, Fellowships, and Scholarships (NIFS) program is now accepting applications for spring 2018 opportunities. Applications are due October 17, 2017. The NIFS program provides students at all types of institutions access to a portfolio of opportunities offered agency-wide. The NIFS One Stop Shopping Initiative online application is an innovative system that enables students to easily access, register and complete the application, as well as search and apply for up to 15 opportunities. A completed NIFS OSSI application places the student in the applicant pool for consideration by all NASA mentors.

NASA Postdoctoral Program Fellowships

https://npp.usra.edu

The NASA Postdoctoral Program (NPP) supports NASA's goal to expand scientific understanding of Earth and the universe in which we live. Selected by a competitive peer-review process, NPP fellows complete one- to three-year fellowships that offer scientists and engineers unique opportunities to conduct research in fields of science relevant to NASA. These opportunities advance NASA's missions in Earth science, heliophysics, planetary science, astrophysics, space bioscience, aeronautics and engineering, human exploration and space operations, and astrobiology. Opportunities are available at NASA centers and other NASA-approved sites. Interested applicants may apply by one of three annual application deadlines: March 1, July 1, and November 1.



Lawrence A. ("Larry") Taylor, 1938–2017

Lawrence A. ("Larry") Taylor passed away on September 18 after a brief bout with brain cancer.

Taylor began his higher education in night school at Orange County Community College in Middletown, New York. He then went on to obtain a B.S. in chemistry and M.S. in geology from Indiana University, and a Ph.D. in geochemistry and materials science from Lehigh University. He also performed pre-doctoral experimental petrology research at the Geophysical Laboratory of the Carnegie Institution of Washington, which led to a postdoctoral fellowship at the Geophysical Lab, followed by a Fulbright Fellowship and Humboldt Stiftung at the Max-Planck-Institüt für Kernphysik in Heidelberg, Germany. After two years as an Assistant Professor at Purdue University, Taylor came to the University of Tennessee (UT) in 1973 just as UT was embarking upon its thrust into research.

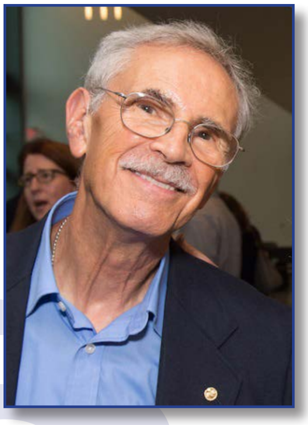
Although his career originally began as an economic geologist/experimental petrologist, the return of the first Apollo samples from the Moon played a major role in his research interests and funding. It was the mineralogy, petrology, and geochemistry of these unusual rocks from another world that excited Taylor and his fellow researchers. While being in the "back room" at Johnson Space Center in December 1972 during the Apollo 17 mission, Taylor had the opportunity to directly advise the astronauts on the Moon during their extravehicular activities, subsequently becoming good friends with Harrison ("Jack") Schmitt, the only geologist to go to the Moon and the last person to step onto the lunar surface.

Having continuously studied lunar rocks and soils since the early days of Apollo, Taylor considered himself a true "lunatic" (a term coined in the days of the Apollo program by those who passionately study lunar science and samples), but later in his career, his expanded his research efforts into the study of meteorites, as the many lunar and martian meteorites found in the Antarctic and equatorial hot deserts provided renewed interest for these heavenly bodies. In addition to planetary samples, Taylor also had an active research program on terrestrial mantle samples and diamonds. His research on diamonds, their mineral inclusions, and the host rocks for the diamonds focused on diamondiferous eclogites from Yakutia, Siberia, unique samples, that provide an opportunity to address the origin of diamonds as time capsules with pieces of information on the deepest portions of Earth.

As Director of the Planetary Geosciences Institute at UT, Taylor was particularly interested in space outreach efforts, working with the NASA-sponsored Tennessee Space Grant Consortium to provide student scholarships in space science and engineering as well as providing resources for K–12 teachers in the state. He also believed strongly in mentoring new talent in the field, and his dedication to generations of students will certainly stand the test of time.

One of the true giants in the field, Taylor made an incredible contribution to the lunar science community, and his work has had a profound impact that will live on through the work of his colleagues both young and old. His remarkable contributions to science, the mentoring of new talent, and dedication to generations of students are certain to stand the test of time.

— Portions of text courtesy of the University of Tennessee



John Freeman, 1935–2017

John Freeman, a Rice professor emeritus and research professor of physics and astronomy and first director of the Master of Liberal Studies program at the Glasscock School of Continuing Studies, died July 15 in Dallas. He was 82.

Freeman joined Rice's then-named Department of Space Science in 1964 after a year as a staff scientist at NASA headquarters in Washington, DC. Freeman's primary research focused on space weather. He followed in the footsteps of space science pioneer James Van Allen, his mentor at the University of Iowa, where Freeman earned his master's degree and a Ph.D. in 1963. He worked on early models of Earth's magnetosphere for space weather analysis and prediction and was instrumental in developing the Magnetospheric Specification and Forecast Model funded and deployed by the Air Force. He also worked on a program to evaluate the feasibility of satellite-based solar power.

In the late 1960s and early 1970s, Freeman was principal investigator of the Suprathermal Ion Detection Experiment (SIDE), part of the Apollo Lunar Surface Experiment Package (ALSEP). Set up on the Moon during the Apollo 12, 14 and 15 missions, the nuclear-powered ALSEP was an octopus-like set of experiments that measured characteristics of the thin atmosphere found near the Moon's surface. Pointed into the solar wind, it was the first to detect water vapor on the Moon and gathered groundbreaking data about the composition and nature of Earth's magnetosphere for nearly seven years.

During an interview in 2009, Freeman said that getting the experiments ready to fly was a monumental task, partly because the science was new but mostly because of Apollo's mandate to put humans on the Moon by the end of the 1960s. "The Apollo program had such incredible time pressures on it," he said. "We were building hardware and hiring subcontractors before we actually had the paper contracts. This was the story of NASA throughout." His work on Apollo earned Freeman the NASA Medal for Exceptional Scientific Achievement, the Apollo Achievement Award, and a Distinguished Service Citation from his undergraduate alma mater, Beloit College.

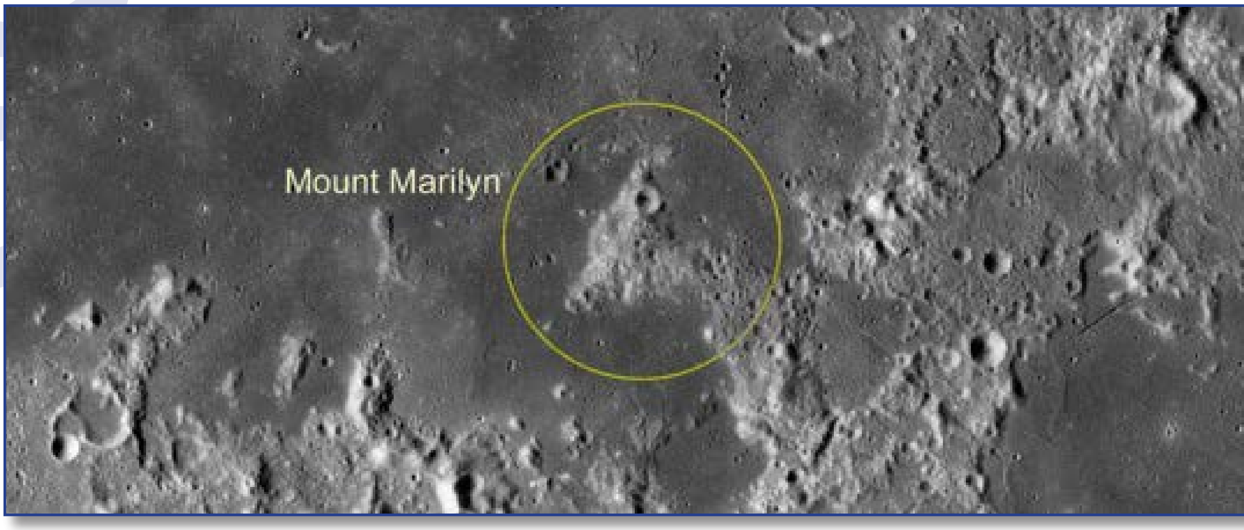
Over the years, Freeman taught both graduate and undergraduate space physics and physics courses, including a series of natural science courses for non-science majors as well as pre-med physics. Eighteen students earned their Ph.D.s in his group. Freeman retired from the department in 2000, although he continued to pursue his research interests. The author of numerous papers, articles, and presentations, he served as editor in chief of *Space Power*, a journal dedicated to space applications, and authored a book, *Storms in Space*, published in 2001.

He became the first director of the Master of Liberal Studies degree program at the Glasscock School in 2005, serving in that position until August 2016. According to the school, he helped select the first faculty, taught courses himself, and was instrumental in developing curriculums for humanities, social sciences, and natural sciences.

—Text courtesy of Rice University

IAU Adopts Names for Key Apollo Landmarks

The International Astronomical Union (IAU) has formally adopted names for three important lunar features associated with the Apollo missions. Originally unofficial nicknames given by the Apollo astronauts to notable lunar features used as landmarks for the Apollo 11 landing, the names of Mount Marilyn, Little West, and Double have now been added to the official database.



Mount Marilyn is located between the Sea of Tranquility (Mare Tranquillitatis), where the Apollo 11 lander touched down in 1969, and the Sea of Fecundity (Mare Fecunditatis). It was used as a key landmark on the approach to the landing site. Credit: NASA/GSFC/LROC School of Earth and Space Exploration, Arizona State University.

Mount Marilyn, lying near the eventual landing site on the Sea of Tranquility (Mare Tranquillitatis), was first identified by the Apollo 8 Astronaut James Lovell, who named it after his wife. It subsequently became a significant landmark for the momentous landing by Apollo 11 in 1969. The importance of this lunar feature to the success of the landing is now recognized by the IAU's official adoption of the name Mount Marilyn. Mount Marilyn did not have an official name for the last 44 years. The feature was formerly named Secchi Theta by IAU Commission 17 in 1932. However, in 1973, Greek letters for elevations on the Moon were phased out by the IAU, and the feature that had been known as Secchi Theta no longer had an official name.

Other landmarks used by the astronauts were nicknamed Little West and Double, and these names too have now been officially adopted. Additional lunar features were named for John E. Guest, formerly of University College London, and Michael J. Wargo, the former Chief Exploration Scientist at NASA Headquarters.

For more information, visit the database at *https://planetarynames.wr.usgs.gov/Page/MOON/target*.

NASA Selects Proposals to Study Sun, Space Environment


Illustration of the heliophysics system. Credit: NASA.

NASA has selected nine proposals under its Explorers Program that will return transformational science about the Sun and space environment and fill science gaps between the agency's larger missions; eight for focused scientific investigations and one for technological development of instrumentation. The broad scope of the investigations illustrates the many vital and specialized research areas that must be explored simultaneously in the area of heliophysics, which is the study of how the Sun affects space and the space environment of planets.

Under the selected proposals, five Heliophysics Small Explorer missions and two Explorer Missions of Opportunity Small Complete Missions (SCM) concept studies will be conducted that span a broad range of investigations focusing on terrestrial weather in the near-Earth space environment — magnetic energy, solar wind, and heating and energy released in the solar atmosphere.

The proposals were selected based on potential scientific value and feasibility of development plans. Small Explorer mission costs are capped at $165 million each, and Mission of Opportunity costs are capped at $55 million each.

Each Heliophysics Small Explorer mission will receive $1.25 million to conduct an 11-month mission concept study. The selected proposals are:

Mechanisms of Energetic Mass Ejection–eXplorer (MEME-X)
MEME-X will map the universal physical processes of the lower geospace system that control the mass flux through the upper atmosphere to space potentially transforming our understanding of how ions leave Earth's atmosphere.

Principal investigator: Thomas Moore at NASA's Goddard Space Flight Center

Focusing Optics X-ray Solar Imager (FOXSI)
FOXSI is a solar-dedicated, direct-imaging, Hard X-Ray telescope that would detect hot plasma and energetic electrons in and near energy release sites in the solar corona.

Principal investigator: Steven Christe at NASA's Goddard Space Flight Center

Multi-Slit Solar Explorer (MUSE)

MUSE will provide data to advance understanding of the difficult problems of mechanisms responsible for energy release in the corona and the dynamics of the solar atmosphere.

Principal investigator: Ted Tarbell at Lockheed Martin Inc.

Tandem Reconnection and Cusp Electrodynamics Reconnaissance Satellites (TRACERS)

TRACERS will fill a fundamental gap in our knowledge of the global variability in magnetopause reconnection by providing an abundant, well targeted set of new and unique *in situ* measurements.

Principal investigator: Craig Kletzing at the University of Iowa

Polarimeter to Unify the Corona and Heliosphere (PUNCH)

PUNCH will advance our understanding of how coronal structures fuel the ambient solar wind with mass and energy, and the dynamic evolution of transient structures in the young solar wind (near the source surface).

Principal investigator: Craig DeForest at Southwest Research Institute

Each Mission of Opportunity SCM will receive $400,000 to conduct an 11-month mission concept study. The selected proposals are:

Sun Radio Interferometer Space Experiment (SunRISE)

SunRISE will consist of a constellation of cubesats operating as a synthetic aperture radio telescope to address the critical heliophysics problems of how solar energetic particles are accelerated and released into interplanetary space.

Principal investigator: Justin Kasper at the University of Michigan

Atmospheric Waves Experiment (AWE)

AWE will investigate how atmospheric gravity waves, including those generated by terrestrial weather, impact the transport of energy and momentum from the lower atmosphere into near-Earth space, a fundamental question in heliophysics.

Principal investigator: Michael Taylor at Utah State University Research Foundation

A Partner Mission of Opportunity (PMO) proposal has been selected for components and scientific analysis for three *in situ* payload instruments onboard the Turbulence Heating ObserveR (THOR) mission — one of four proposed missions currently under consideration by the European Space Agency (ESA). After ESA's final selection, work will begin on implementation of the PMO if THOR is selected.

The chosen PMO is:

U.S. Contributions to the THOR mission (THOR-US)
THOR-US will provide components and scientific analysis for an investigation into how plasma is heated and accelerated by the dissipation of turbulent fluctuations through kinetic processes. The concept study for THOR-US was conducted prior to its selection for NASA's Explorer Program, so the team is positioned to move into the detailed design phase if its host mission is selected.

Principal investigator: Harald Kucharek at University of New Hampshire

One Mission of Opportunity SCM received highly favorable review for scientific and scientific implementation merit, but was deemed to require more technological development of the instrument's innovative optical design before further consideration of an implementation concept. This proposal is offered funding for a continued technology development study. The SCM chosen for a technology development investigation is:

COronal Spectrographic Imager in the Extreme ultraviolet (COSIE)
COSIE would provide a missing link between the physics of the low corona and that of the heliosphere with a unique and innovative instrument based on the International Space Station.

Principal investigator: Leon Golub at the Smithsonian Institution/Smithsonian Astrophysical Observatory

The Explorers Program is the oldest continuous NASA program designed to provide frequent, low-cost access to space using principal investigator-led space science investigations relevant to the agency's astrophysics and heliophysics programs. Since the Explorer 1 launch in 1958, which discovered Earth's radiation belts, the Explorers Program has launched more than 90 missions, including the Uhuru and Cosmic Background Explorer (COBE) missions that led to Nobel Prizes for their investigators.

The program is managed by Goddard for NASA's Science Mission Directorate in Washington, which conducts a wide variety of research and scientific exploration programs for Earth studies, space weather, the solar system, and the universe.

NASA Announces 2017 MUREP Awards to Tribal Colleges and Universities

NASA's Minority University Research and Education Project (MUREP) awarded approximately $1.8 million in new cooperative agreements to three Tribal Colleges and Universities (TCUs) across the United States. These agreements provide opportunities for TCU students, faculty, and staff to engage in NASA-related science, technology, engineering, and math (STEM) research and activities. The award is made jointly through the NASA MUREP for American Indian and Alaskan Native STEM Engagement (MAIANSE) and the Earth Systems, Technology, and Energy Education for MUREP (ESTEEM) activities.

TCU team develops science payloads for spaceflight during RockOn competition at NASA's Wallops Flight Facility, Virginia. Credit: NASA.

The selected institutions are Southwest Indian Polytechnic Institute, Albuquerque, New Mexico; Chief Dull Knife College, Lame Deer, Montana; and Northwest Indian College, Bellingham, Washington.

The awards range in value from approximately $422,200 to $844,400, which will support institutional capacity-building at tribal colleges and the continuation and creation of STEM engagement projects for students at the awarded institutions and their partner institutions.

The selected proposals offer innovative methods, approaches, and concepts to make appropriate use of NASA's current and unique engineering and scientific resources with a strong emphasis on engaging students and educators.

NASA Awards $400,000 to Top Teams at Second Phase of 3D-Printing Competition

NASA is making progress and awarding prizes in its competition to build a three-dimensional (3D) printed habitat for deep space exploration. The agency has awarded first place and a prize of $250,000 to Team Foster + Partners|Branch Technology of Chattanooga, Tennessee, for successfully completing Phase 2: Level 3 of NASA's 3D-Printed Habitat Challenge, a NASA's Centennial Challenges prize competition. Pennsylvania State University of University Park received second place and a reward of $150,000.

Challenge activities were held August 23–26, 2017, at Caterpillar's Edwards Demonstration and Learning Center in Edwards, Illinois. Teams were presented a check at the awards ceremony by Jim Reuter, deputy associate administrator for NASA's Space Technology Mission Directorate.

The Foster + Partners|Branch Technology team from Chattanooga, Tennessee, pose with their 3D-printed dome structure after it was strength tested at Caterpillar Inc.'s Edwards Demonstration and Learning Center in Peoria, Illinois. Credit: NASA/Joel Kowsky.

The multi-phase, $2.5 million 3D-Printed Habitat Challenge is designed to advance construction technology needed to create sustainable housing solutions for Earth and beyond. "The advancement and innovation in additive construction that we've seen from these teams is inspiring," said Reuter. "Meeting the technology goals of this challenge proves that competition can push boundaries, and their work puts us that much closer to preparing the way for deep space exploration."

Bradley University in Peoria, Illinois, is NASA's 3D-Printed Habitat Challenge partner. Bradley University also partnered with sponsors Caterpillar, Bechtel and Brick & Mortar Ventures to run the competition.

"Being a part of this competition has been an extraordinary opportunity for Bradley University," said Bradley University president Gary Roberts. "Our students, faculty, staff, and the Peoria community had a chance to see history in the making. We are a part of transforming technology and reshaping the way we think about construction. This was inspiring, and I am certain it changed the lives of many who experienced it."

Teams were required to develop the fundamental 3D printing technology necessary to produce a structurally sound habitat, including the printer itself and construction materials. Competitors then had to print beams, cylinders, and domes that were analyzed and compressed to failure to determine scores and prize awards. The competition activities were open to the public, and many industry leaders and local school groups attended the event. A gallery of photos from the challenge events can be found on the NASA Headquarters' Flickr site at *https://www.flickr.com/photos/nasahqphoto/sets/72157688059884085*.

Astrobotic and United Launch Alliance Announce Mission to the Moon

Astrobotic and United Launch Alliance (ULA) announced that Astrobotic's Peregrine Lunar Lander will be onboard a ULA launch vehicle in 2019, during the 50th anniversary of Apollo 11.

"Astrobotic is thrilled to select a ULA launch vehicle as the means to get Peregrine to the Moon," said John Thornton, CEO of Astrobotic. "By launching with ULA, Astrobotic can rest assured our payload customers will ride on a proven launch vehicle with a solid track record of success. Together, our two organizations will honor the past and trail blaze the lunar future."

An artist's conception shows the Peregrine lunar lander on the Moon's surface. Credit: Astrobotic.

This effort is a big step in realizing Astrobotic's goal of creating a Rust Belt-based international gateway to the Moon. The Peregrine Lunar Lander will fly 35 kilograms of customer payloads on its first mission, with the option to upgrade to 265 kilograms on future missions. Already 11 deals from 6 nations have been signed for this 2019 mission. The first mission in 2019 will serve as a key demonstration of service for NASA, international space agencies, and companies looking to carry out missions to the Moon. This announcement comes as Astrobotic continues to advance Peregrine toward flight, with the preliminary design review of the vehicle having already taken place in November 2016.

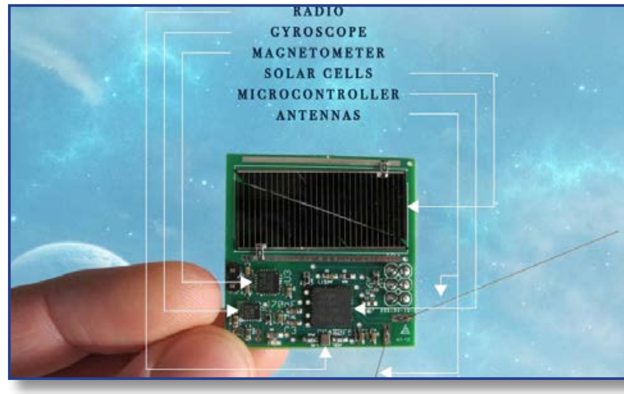
"We are thrilled that Astrobotic has selected ULA to launch the Peregrine Lander to the Moon," said ULA president and CEO, Tory Bruno. "The Moon is the next great frontier, but in a different way than when Neil Armstrong landed there. Enabling technologies like those from Astrobotic will allow people to live and work in the space between here and the Moon and take advantage of all those resources in a way that is sustainable."

ULA joins a world-class team of mission partners led by Astrobotic. These partners include NASA, who is providing Astrobotic access to some of the best spacecraft engineers and facilities in the world, as part of NASA's Lunar CATALYST Program; Airbus DS, who brings world-class spacecraft experience in human spaceflight and exploration and leverages previous lander development work with the European Space Agency; and Deutsche Post DHL Group, the world's leading mail and logistics company, who is the "Official Logistics Provider for Astrobotic's First Mission to the Moon."

On a Quest to Reach Alpha Centauri, Breakthrough Starshot Launches World's Smallest Spacecraft

Breakthrough Starshot, a multi-faceted program to develop and launch practical interstellar space missions, successfully flew its first spacecraft, the smallest ever launched.

On June 23, 2017, a number of prototype Sprites — the world's smallest fully functional space probes built on a single circuit board — achieved low-Earth orbit, piggybacking on OHB System AG's Max Valier and Venta satellites. The 3.5-by-3.5 centimeter chips weigh just 4 grams but contain solar panels, computers, sensors, and radios. These vehicles are the next step of a revolution in spacecraft miniaturization that can contribute to the development of centimeter- and gram-scale StarChips envisioned by the Breakthrough Starshot project.



The Sprites carry solar panels, computers, sensors, and radios. Credit: Breakthrough Starshot.

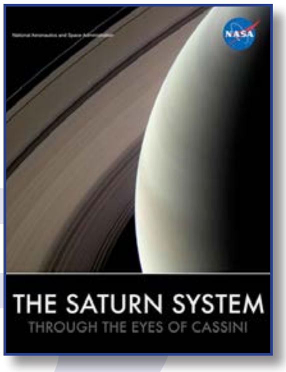
The Sprite is the brainchild of Breakthrough Starshot's Zac Manchester, whose 2011 Kickstarter campaign, KickSat, raised the first funds to develop the concept. The Sprites were constructed by researchers at Cornell University and transported into space as secondary payloads by the Max Valier and Venta satellites.

Before they ever reach the stars, Zac Manchester says that the Sprites are more likely to first form three-dimensional antennas in deep space to monitor space weather that could threaten earthly power grids and orbiting spacecraft. He believes larger interplanetary probes could deploy swarms of Sprites to pepper promising asteroids, moons, and planets with sensors seeking out mineral deposits or signs of extraterrestrial life.

According to Breakthrough Starshot Initiatives Executive Director, Pete Worden, this progression would be a powerful new paradigm for space science. "Eventually, every mission that NASA does may carry these sorts of nanocraft to perform various measurements," he says. "If you're looking for evidence of life on Mars or anywhere else, for instance, you can afford to use hundreds or thousands of these things — it doesn't matter that a lot of them might not work perfectly. It's a revolutionary capability that will open up all sorts of opportunities for exploration."

Note: Product descriptions are taken from the publisher's website. LPI is not responsible for factual content.

E-BOOK



The Saturn System Through the Eyes of Cassini.

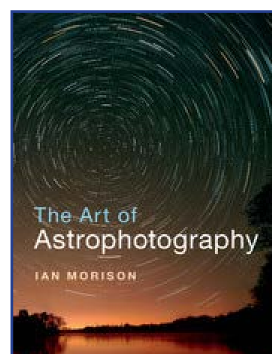
Produced by the Lunar and Planetary Institute, NASA's Planetary Science Division, and NASA's Jet Propulsion Laboratory. 2017, 110 pp., interactive e-book available in various formats. *www.nasa.gov/connect/ebooks/the-saturn-system.html*

The Lunar and Planetary Institute (LPI), NASA's Planetary Science Division (PSD), and NASA's Jet Propulsion Laboratory (JPL) have collaboratively developed *The Saturn System Through the Eyes of Cassini*, an interactive e-book, to commemorate the Cassini-Huygens mission, which came to its fateful end on September 15, 2017. The Cassini-Huygens mission has been nothing short of a discovery machine, captivating us with data and images never before obtained with such detail and clarity. While these images represent the tip of the iceberg — each telling a story about Saturn and its mysterious moons — our hope is that the mission will inspire future artists and explorers. The sheer beauty of these images is surpassed only by the science and discoveries they represent. This e-book features nearly 100 stunning images taken within the Saturn system by the Cassini spacecraft since its arrival in 2004. In addition to the stunning images, it includes six interactives that transport you to distant locales, such as the shore of one of Titan's methane seas or the icy plumes of Enceladus. The e-book is available in multiple formats to attract a variety of readers.

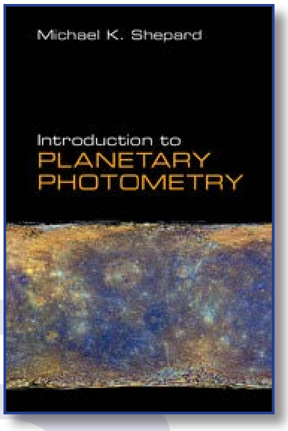
BOOKS

The Art of Astrophotography.

By Ian Morison. Cambridge University Press. 2017, 280 pp., Paperback, $44.99.
www.cambridge.org



In *The Art of Astrophotography*, astronomer and *Astronomy Now* columnist Ian Morison provides the essential foundations of how to produce beautiful astronomical images. Every type of astroimaging is covered, from images of the Moon and planets, to the constellations, star clusters, and nebulae within our Milky Way Galaxy and the faint light of distant galaxies. The book includes a series of worked examples and short project walk-throughs, detailing the equipment needed — starting with just a digital single lens reflex (DSLR) camera and tripod, and increasing in complexity as the book progresses — followed by the way to best capture the images and then how, step by step, these may be processed and enhanced to provide results that can rival those seen in astronomical magazines and books. Whether you are just getting into astrophotography or are already deeply involved, Morison's advice will help you capture and create enticing astronomical images.



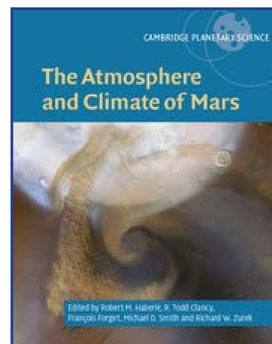
Introduction to Planetary Photometry.

By Michael K. Shepard. Cambridge University Press, 2017, 258 pp., Hardcover, $64.99.
www.cambridge.org

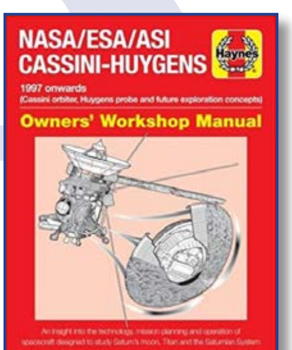
Introducing planetary photometry as a quantitative remote sensing tool, this handbook demonstrates how reflected light can be measured and used to investigate the physical properties of bodies in our solar system. The author explains how data gathered from telescopes and spacecraft are processed and used to infer properties such as the size, shape, albedo, and composition of celestial objects including planets, moons, asteroids, and comets. Beginning with an overview of the history and background theory of photometry, later chapters delve into the physical principles behind commonly used photometric models and the mechanics of observation, data reduction, and analysis. Real-world examples, problems, and case studies are included, all at an introductory level suitable for new graduate students, planetary scientists, amateur astronomers, and researchers looking for an overview of this field.

The Atmosphere and Climate of Mars.

Edited by Robert M. Haberle, R. Todd Clancy, François Forget, Michael D. Smith, and Richard W. Zurek. Cambridge University Press. 2017, 588 pp., Hardcover, $190.00.
www.cambridge.org



Humanity has long been fascinated by the planet Mars. Was its climate ever conducive to life? What is the atmosphere like today, and why did it change so dramatically over time? Eleven spacecraft have successfully flown to Mars since the Viking mission of the 1970s and early 1980s. These orbiters, landers, and rovers have generated vast amounts of data that now span a martian decade (roughly 18 Earth years). This new volume brings together the many new ideas about the atmosphere and climate system that have emerged, including the complex interplay of the volatile and dust cycles, the atmosphere-surface interactions that connect them over time, and the diversity of the planet's environment and its complex history. Including tutorials and explanations of complicated ideas, students, researchers and non-specialists alike are able to use this resource to gain a thorough and up-to-date understanding of this most Earth-like of planetary neighbors.



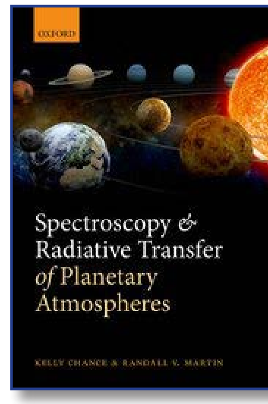
NASA/ESA/ASI Cassini-Huygens Owners' Workshop Manual.

By Ralph Lorenz. Haynes Publishing UK, 2017, 192 pp., Hardcover, $36.95.
www.haynes.com

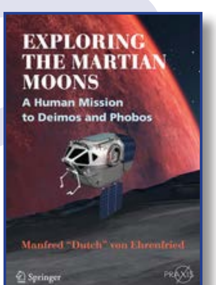
This manual provides an insight into the technology, mission planning, and operation of spacecraft designed to study Saturn's moon, Titan, and the saturnian system. The descent of the Huygens probe to the frozen surface of Saturn's moon, Titan, in 2005 is the most distant planetary landing ever made or presently foreseen. The Huygens probe's seven-year voyage through space (past Venus, Earth, and Jupiter) attached to the Cassini orbiter, its arrival at Saturn, and three-week dormant coast to Saturn's moon, Titan, culminated in Huygens' hypersonic entry into Titan's atmosphere, parachute descent, and continued operation for 72 minutes on the surface transmitting data back to Earth via the Cassini orbiter. Titan — one of Saturn's 62 confirmed moons — was chosen due to the presence of nitrogen and oxygen. If Titan received more sunlight, its atmosphere might well resemble that of a primitive Earth. This month the mission came to an end when the Cassini orbiter plunged into Saturn's atmosphere. Here is the detailed story of how the spacecraft were designed, the technology used, how the mission was planned, and what the project scientists have discovered.

Spectroscopy and Radiative Transfer of Planetary Atmospheres.

By Kelly Chance and Randall V. Martin. Oxford University Press. 2017, 160 pp., Hardcover, $55.00. *global.oup.com*



Spectroscopy and radiative transfer are rapidly growing fields within atmospheric and planetary science, with implications for weather, climate, biogeochemical cycles, and air quality on Earth, as well as the physics and evolution of planetary atmospheres in our solar system and beyond. Remote sensing and modeling atmospheric composition of Earth, of other planets in our solar system, or of planets orbiting other stars require detailed knowledge of how radiation and matter interact in planetary atmospheres. This includes knowledge of how stellar or thermal radiation propagates through atmospheres, how that propagation affects radiative forcing of climate, how atmospheric pollutants and greenhouse gases produce unique spectroscopic signatures, how the properties of atmospheres may be quantitatively measured, and how those measurements relate to physical properties. This book provides this fundamental knowledge to a depth that will leave a student with the background to become capable of performing quantitative research on atmospheres. Intended for graduate students or for advanced undergraduates, it spans across principles through applications, with sufficient background for students without prior experience in either spectroscopy or radiative transfer.



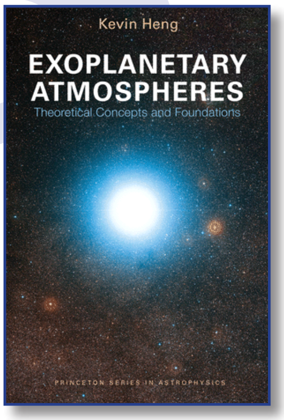
Exploring the Martian Moons: A Human Mission to Deimos and Phobos.

By Dutch von Ehrenfried. Springer, 2017, 255 pp., Paperback, $39.99. *www.springer.com*

This book explores the once popular idea of "Flexible Path" in terms of Mars, a strategy that would focus on a manned orbital mission to Mars's moons rather than the more risky, expensive, and time-consuming trip to land humans on Mars. This mission would take advantage of the operational, scientific, and engineering lessons to be learned from going to Mars' moons first. Unlike a trip to the planet's surface, an orbital mission avoids the dangers of the deep gravity well of Mars and a very long stay on the surface, and a Mars orbital mission could be achieved at least five years, possibly ten, before a landing mission. Furthermore, an orbital mission would not require all the extra vehicles, equipment, and supplies needed for a landing and a stay on the planet for over a year. The cost difference between the two types of missions is on the order of tens of billions of dollars. An orbital mission to Deimos and Phobos would provide an early opportunity to acquire scientific knowledge of the moons and Mars as well, since some of the regolith is presumed to be soil ejected from Mars. It may also offer the opportunity to deploy scientific instruments on the moons, which would aid subsequent missions and provide early operational experience in the Mars environment without the risk of a landing. The author argues that this experience would enhance the probability of a safe and successful Mars landing by NASA at a later date, and lays out the best way to approach an orbital mission in great detail.

Exoplanetary Atmospheres: Theoretical Concepts and Foundations.

By Kevin Heng. Princeton University Press, 2017, 296 pp., Hardcover, $95.00. *press.princeton.edu*



The study of exoplanetary atmospheres — the study of planets orbiting stars beyond our solar system — may be our best hope for discovering life elsewhere in the universe. This dynamic, interdisciplinary field requires practitioners to apply knowledge from atmospheric and climate science, astronomy and astrophysics, chemistry, geology and geophysics, planetary science, and even biology. *Exoplanetary Atmospheres* provides an essential introduction to the theoretical foundations of this cutting-edge new science. This book covers the physics of radiation, fluid dynamics, atmospheric chemistry, and atmospheric escape. It draws on simple analytical models to aid learning, and features a wealth of problem sets, some of which are open-ended. This authoritative and accessible graduate textbook uses a coherent and self-consistent set of notation and definitions throughout, and also includes appendixes containing useful formulae in thermodynamics and vector calculus as well as selected Python scripts. *Exoplanetary Atmospheres* prepares Ph.D. students for research careers in the field and is ideal for self-study as well as for use in a course setting.

POCKET GUIDES

The Moon: A Folding Pocket Guide to the Moon, Its Surface Features, Phases and Eclipses.

By James Kavanagh. Waterford Press, 2017. $7.95. *www.waterfordpress.com*

The Night Sky: A Folding Pocket Guide to the Moon, Stars, Planets and Celestial Events.

By James Kavanagh. Waterford Press, 2017. $7.95. *www.waterfordpress.com*

Laminated for durability, these pocket guides are great references. The simplified reference guide to the Moon includes maps highlighting prominent craters, mountain ranges, seas, highlands, and residuum from the Apollo Moon landing sites. The guide to the night sky includes seasonal glow-in-the-dark charts to the stars and constellations along with information about the solar system, the Moon, planets, meteor showers, and eclipses. These guides are ideal for astronomers of all ages.

DINNERWARE

Planet Plates.

Produced by The Unemployed Philosophers Guild. Set of eight 10” plates, $38.95. *www.philosophersguild.com*

This complete set of melamine dinnerware features eight 10” original watercolor portraits of our solar system. Planet Plates are dishwasher-safe and light enough to pack for a picnic, yet sturdy enough to orbit the rowdiest potluck supper. Your buffet table can be a geocentric homage to Ptolemy, or you can let the block party know exactly what you think of Copernicus deniers! This food-safe and FDA-approved set includes Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune.

FOR KIDS!!!

Planet Blocks.

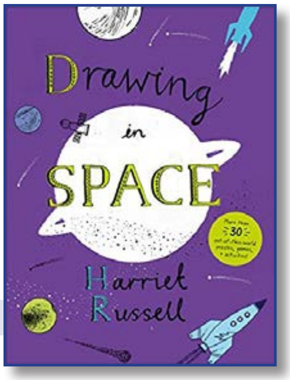
Produced by Uncle Goose. $20.00. *www.unclegoose.com*

This set of nine 1.75” basswood cubes represent the planets of our solar system plus dwarf planet Pluto. The four printed sides reveal a planet illustration, diameter, location, and distance from the Sun, and the two debossed sides feature a planet’s symbol, name, and number of moons. These blocks are made in the USA using child-safe, non-toxic inks. For ages 2 and up.

You Should Meet Katherine Johnson.

By Thea Feldman. Simon Spotlight, 2017, 48 pp., Hardcover, $16.99.
www.simonandschusterpublishing.com/simon-spotlight

Meet Katherine Johnson, a brilliant mathematician who worked at NASA in the early 1950s until retiring in 1986. Johnson’s unparalleled calculations (done by hand) helped plan the trajectories for NASA’s Mercury and Apollo missions, including the Apollo 11 Moon landing. She is said to be one of the greatest American minds of all time. A special section at the back of the book includes extras on subjects like history and math, plus inspiring careers for math lovers. For ages 6 to 8.



Drawing in Space.

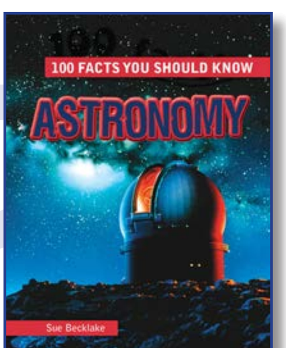
By Harriet Russell. Chronicle Books, 2017, 64 pp., Paperback. $18.95.
www.chroniclebooks.com

Did you know that the universe is expanding even as you read this? That stargazing is really looking back in time millions of years, and that sound cannot travel in space, so you can be as noisy as you like? With witty pen-and-ink illustrations, mazes, puzzles, and games, this activity book engages readers of all ages on every page with fun facts about the amazing realm beyond Earth's atmosphere. Readers learn to calculate their age in Jupiter years, draw their own solar systems, and navigate out of a black-hole maze, while discovering more about planets, stars, comets, asteroids, and other celestial objects. For ages 10 and up.

Celestial Buddies.

Produced by Celestial Buddies, LLC. $21.99–$29.99. *www.celestialbuddies.com*

Celestial Buddies is an original line of plush characters each personifying a celestial body occupying our heavens. The Celestial Buddies' "Big Bang" moment occurred after the creator of this miniature stuffed universe saw a documentary series on the solar system. Have you ever noticed that there is so much variation among the planets and that each planet has its own unique characteristics, identity, and personality? There are 13 Celestial Buddies to choose from, or get them all. For ages 3 and up.



Astronomy: 100 Facts You Should Know.

By Sue Becklake. Gareth Stevens Publishing, 2017, 48 pp., Hardcover. $31.95.
www.garethstevens.com

Astronomy is both a study and a skill, and both aspects of astronomy are thoughtfully presented in this volume that encourages readers to look to the sky. Even though our universe is vast, readers can travel to points around the solar system and galaxy through the stunning photographs and illustrations on each page. Key points about space science are presented through 100 interesting and accessible facts, and quizzes and activities will hone understanding. Included are instructions for making a sundial and an eclipse demonstration. For ages 9 to 11.

Calendar 2017

For the latest version of the meeting calendar, visit https://www.hou.usra.edu/meetings/calendar.

October

2–6 **Fourth International Conference on Early Mars: Geologic, Hydrologic, and Climatic Evolution and the Implications for Life,** Flagstaff, Arizona. *https://www.hou.usra.edu/meetings/earlymars2017/*

5–7 **Venera-D Venus Modelling Workshop,** Modvoe, Russia. *http://www.lpi.usra.edu/planetary_news/2017/07/07/venera-d-modelling-workshop-and-8th-moscow-solar-system-symposium/*

9–13 **The Eighth Moscow Solar System Symposium,** Moscow, Russia. *http://ms2017.cosmos.ru*

10–12 **Annual Meeting of the Lunar Exploration Analysis Group,** Columbia, Maryland. *https://www.hou.usra.edu/meetings/leag2017/*

12–13 **Back to the Moon Workshop,** Houston, Texas. *https://www.hou.usra.edu/meetings/moon2017/*

15–20 **49th Annual DPS Meeting,** Provo, Utah. *https://dps.aas.org/*

16–20 **Fifth Workshop on Robotic Autonomous Observatories,** Mazagon, Spain. *http://astrorob.iaa.es*

17–20 **The Cosmic Wheel and the Legacy of the AKARI Archive: From Galaxies and Stars to Planets and Life,** Tokyo, Japan. *http://www.ir.isas.jaxa.jp/AKARI/akari2017/*

22–25 **2017 GSA Annual Meeting,** Seattle, Washington. *https://www.geosociety.org/GSA/Events/Annual_Meeting/GSA/Events/gsa2017.aspx*

November

1–2 **Europa Deep Dive I: Ice-Shell Exchange Processes,** Houston, Texas. *https://www.hou.usra.edu/meetings/europadeepdive2017/*

6–11 **9th International Conference on Geomorphology,** New Delhi, India. *http://www.icg2017.com/*

7–9 **SPICE Training Class,** Pasadena, California. *https://naif.jpl.nasa.gov/*

11–12 **Workshop on Modern Analytical Methods Applied to Earth, Planetary, and Material Sciences II,** Budapest, Hungary. *https://www.hou.usra.edu/meetings/methods2017/*

12–13 **Joint ISAS-LPL Workshop on Planetary Science Enabled by Epsilon Class Missions,** Tucson, Arizona. *https://www.lpl.arizona.edu/jaxaworkshop/*

13–15 **Planning Solar System Observations with JWST,** Baltimore, Maryland. *https://jwst.stsci.edu/news-events/events/events-area/stsci-events-listing-container/planning-solar-system-observations-with-jwst---stsci-venue?mwc=4*

13–15 **1st IAA Conference on Space Situational Awareness,** Orlando, Florida. *http://www.icssa2017.com*

13–17 **Astronomical Heritage of the Middle East,** Yerevan, Armenia. *http://heritage.aras.am/*

13–17 **Habitable Worlds 2017: A System Science Workshop,** Laramie, Wyoming. *https://nexss.info/community/workshops/habitable-worlds-2017*

14–16 **15th Annual Meeting of the Venus Exploration Analysis Group,** Laurel, Maryland. *http://www.lpi.usra.edu/vexag/meetings/vexag-15/*

26–Dec 1 **IAU Astrobiology 2017 Conference,** Coyhaique, Chile. *http://astrobiology2017.org/*

30–Dec 1 **A Fractured Universe? Fundamental Physics, Symmetry and Life,** Sydney, Australia. *http://www.physics.usyd.edu.au/~luke/2017FTConf/*

December

4–8 **51st Eslab Symposium "Extreme Habitable Worlds,"** Noordwijk, The Netherlands. *http://esaconferencebureau.com/2017-events/eslab2017*

5–6 **Research Opportunities on the Deep Space Gateway,** Noordwijk, The Netherlands. *http://exploration.esa.int/moon/59377-workshop/*

5–8 **Beyond the Eclipse (ASP 2017),** St. Louis, Missouri. *http://www.astrosociety.org/education/asp-annual-meeting/*

11–15 **Exoplanets and Planet Formation,** Shanghai, China. *https://indico.leeinst.sjtu.edu.cn/event/25/*

11–15 **2017 AGU Fall Meeting,** New Orleans, Louisiana. *http://fallmeeting.agu.org*

11–15 **JWST Proposal and Planning Workshop,** Pasadena, California. *https://jwst.stsci.edu/news-events/events/events-area/stsci-events-listing-container/jwst-proposal-and-planning-workshop-1?mwc=4*

12–15 **Space Science and Technology,** Ho Chi Minh City, Vietnam. *http://sst.phy.hcmiu.edu.vn/*

13–15 **JWST Solar System Workshop,** Noordwijk, The Netherlands. *https://www.cosmos.esa.int/web/jwst-ssws-2017/home*

18–20 **Next-Generation Suborbital Researchers Conference,** Broomfield, Colorado. *http://nsrc.swri.org*

January 2018

22–Feb 2 **2018 EON/ELSI Winter School on Earth-Life Science,** Tokyo, Japan. *https://elsischool.com/*

25–28 **22nd International Microlensing Conference,** Auckland, New Zealand. *https://www.physics.auckland.ac.nz/en/about/international-microlensing-conference.html*

February

6–9 **Magnetic Fields or Turbulence: Which is the Critical Factor for the Formation of Stars and Planetary Disks?,** Hsinchu, Taiwan. *http://events.asiaa.sinica.edu.tw/workshop/20180206/index.php*

12–16 **Water During Planet Formation and Evolution,** Zurich, Switzerland. *https://waterzurich.github.io/*

25–Mar 2 **The 2nd Rencontres du Vietnam on Exoplanetary Science,** Quy Nhon, Vietnam. *http://rencontresduvietnam.org/conferences/2018/exoplanetary_science/*

26–Mar 2 **IX Taller de Ciencias Planetaries (IX Planetary Science Workshop),** La Plata, Argentina. **http://tcp2018.fcaglp.unlp.edu.ar/**

27–28 **From Mars Express to Exomars,** Madrid, Spain. *http://upwards.iaa.es/content/mars-express-exomars*

March

5–9 **Diversi Mundi (OPS-III): The Solar System in an Exoplanetary Context,** Santiago, Chile. *http://www.eso.org/sci/meetings/2018/ops2018.html*

9 **Merging Giant-Star Asteroseismology with the Fate of Extrasolar Planetary Systems,** London, United Kingdom. *https://sites.google.com/view/ras-evolsystems/home*

19–23 **49th Lunar and Planetary Science Conference,** The Woodlands, Texas. *https://www.hou.usra.edu/meetings/lpsc2018/*

24–28 **Communicating Astronomy with the Public (CAP 2018),** Fukuoka, Japan. *https://www.communicatingastronomy.org/cap2018/*

April

18–19 **International Conference on Nanoscience and Nanoengineering,** Las Vegas, Nevada. *https://nanotech.conferenceseries.com/*

24–26 **Planetary Science Informatics and Data Analytics Conference,** St. Louis, Missouri. *https://psida.rsl.wustl.edu/*

May

1–3 **Mercury: Current and Future Science of the Innermost Planet,** Columbia, Maryland. *https://www.hou.usra.edu/meetings/mercury2018/*

7–11 **Differentiation: Building the Internal Architecture of Planets,** San Gabriel Valley, California. *https://www.hou.usra.edu/meetings/differentiation2018/*

14–15 **2018 European Lunar Symposium,** Tolouse, France. *https://els2018.arc.nasa.gov/*

14–17 **9th Workshop on Catastrophic Disruption in the Solar System (CD9),** Kobe, Japan. *http://www.impact-res.org/CD2018/Catastrophic_Disruption_2018/Welcome.html*

14–Jun 8 **MIAPP 2018 Workshop — Near Earth Objects: Properties, Detection, Resources, Impacts and Defending Earth,** Munich, Germany. *http://www.munich-iapp.de/programmes-topical-workshops/2018/near-earth-objects-properties-detection-resources-impacts-and-defending-earth/*

June

5–7 **Cryovolcanism in the Solar System Workshop,** Houston, Texas. *https://www.hou.usra.edu/meetings/cryovolcanism2018/*

18–22 **Amazonian Climate Workshop,** Lakewood, Colorado. *https://webdev.hou.usra.edu/meetings/amazonian2018/*

26–29 **Astrophysical Frontiers in the Next Decade and Beyond: Planets, Galaxies, Black Holes, and the Transient Universe,** Boulder, Colorado. *http://go.nrao.edu/ngVLA18*