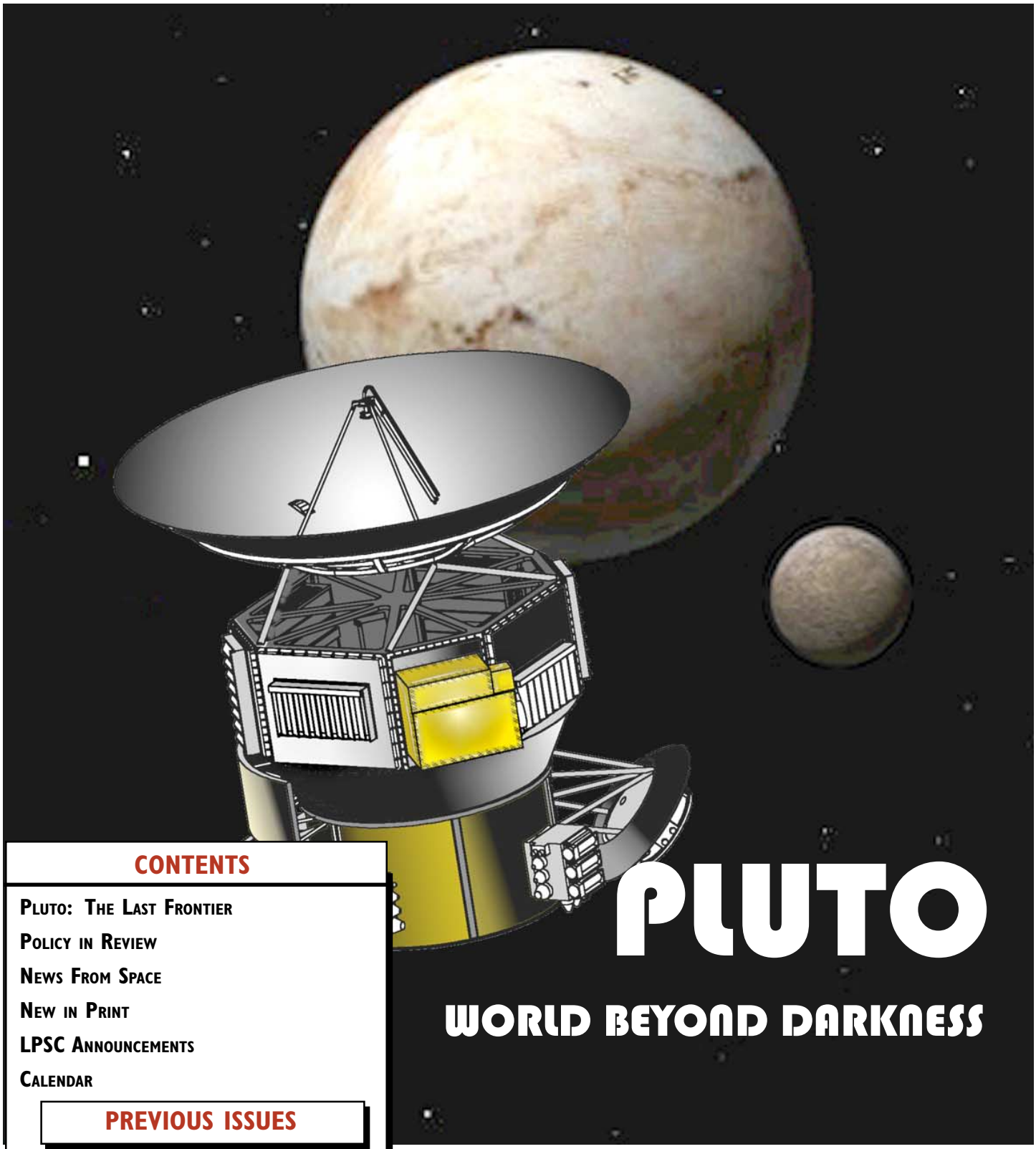
Lunar and Planetary Information
BULLETIN

Fall 2001/NUMBER 91 • LUNAR AND PLANETARY INSTITUTE • UNIVERSITIES SPACE RESEARCH ASSOCIATION



PLUTO

WORLD BEYOND DARKNESS

CONTENTS

PREVIOUS ISSUES

Pluto: The Last Frontier

In November, NASA announced that it had selected a proposal to proceed with the second phase of the Pluto-Kuiper Belt (PKB) mission, intended to explore the most distant planet in the solar system. Phase B will involve preliminary design studies for the mission and has been dubbed New Horizons: Shedding Light on New Worlds and will be led by principal investigator Dr. S. Alan Stern of the Southwest Research Institute in Boulder, Colorado.

"Both proposals were outstanding, but New Horizons represented the best science at Pluto and the Kuiper Belt as well as the best plan to bring the spacecraft to the launch pad on time and within budget," said Dr. Ed Weiler, associate administrator for space science at NASA Headquarters.

Clyde W. Tombaugh, at age 22, stands next to his home-built 9-inch reflector telescope.

The current plan calls for a 2006 launch date and a flyby of the Pluto system before 2020. Completion of the mission after Phase B will depend on the subsequent approval of technical and risk-assessment feasibility factors by a NASA committee and on the availability of future funding.

Although Congress has approved $30 million in fiscal 2002 to initiate PKB spacecraft and instrumentation and vehicle development, the budget plan does not provide for guaranteed future funding.

Nonetheless, the second greenlight for the mission represents a major milestone for those who wish to see the Pluto robotic flyby mission succeed. For scientists, the ninth planet represents the dark corner of the solar system, the least-understood and least-known planet in our solar system. The mission provides an opportunity for a wealth of new data and new scientific study. For the public, the tiny planet has always been a source of mystery and inspiration. For almost everyone, a robotic mission to the Pluto system remains a tantalizing idea.

The Pluto system as imaged by the Hubble Space Telescope in 1994.

In the following pages, the *Bulletin* presents a select compilation on the facts and lore surrounding Pluto, one of the most recently discovered and best-loved members of the solar system.

—Brian Anderson

About the cover: The illustration is an artist's rendition of the Pluto-Kuiper Express mission as it was envisioned by the Jet Propulsion Laboratory before a stop-work order was issued in September 2000. The illustration does not serve to illustrate the new proposed robotic mission.

Discovery and Origins of Pluto

By Bill Arnett

Pluto was discovered in 1930 by a fortunate accident. Calculations that later turned out to be in error had predicted a planet beyond Neptune, based on the motions of Uranus and Neptune. Not knowing of the error, Clyde W. Tombaugh at Lowell Observatory in Arizona did a very careful sky survey that turned up the tiny planet.

In Roman mythology, Pluto (Greek: Hades) is the god of the underworld. The planet Pluto, discovered in 1930, received this name from a suggestion by 11-year-old Venetia Burney, because its distance from the Sun rendered it in perpetual darkness and coldness. Others considered the name fortuitous because it began with the initials of Percival Lowell.

After the discovery of Pluto, it was quickly determined that Pluto was too small to account for

Pluto: The Bare Facts

Mass (kg).....1.29 × 10^{22}
Diameter (km).....2300
Mean density (kgm^3).....2030
Escape velocity (m/s).....1100
Avg. distance from Sun (AU).....39.53

Rotation period (length of day in Earth days).....6.39

Revolution period (length of year in Earth years).....247.7

Obliquity (tilt of axis in degrees).....122.5

Orbit inclination (degrees).....17.15

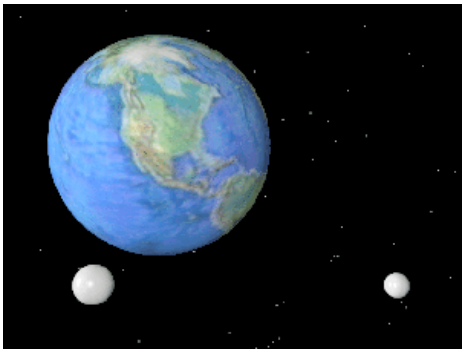
Orbit eccentricity (deviation from circular).....0.248

Mean temp. (K).....37

Visual geometric albedo (reflectivity).....~0.5

Atmosphere .....methane + nitrogen?

Surface materials.....methane ice?



Jeff Alu/Jet Propulsion Laboratory

Size comparison of the Earth (top) with Pluto and its moon Charon.

the discrepancies in the orbits of the other planets. The search for Planet X continued but nothing was found. Nor is it likely that it ever will be: The discrepancies vanish if the mass of Neptune determined from the *Voyager 2* encounter with Neptune is used.

Pluto's satellite Charon was discovered in 1978, just before its orbital plane moved edge-on toward the inner solar system. It was therefore possible to observe many transits of Pluto over Charon and vice versa. By carefully calculating which portions of which body would be covered at what times, and watching brightness curves, astronomers were able to construct a rough map of light and dark areas on both bodies.

The Properties of Pluto

Though the sum of the masses of Pluto and Charon is known pretty well (it can be determined from careful measurements of the period and radius of Charon's orbit and basic physics), the individual masses of Pluto and Charon are difficult to determine because this requires determining their mutual motions around the center of mass of the system, which requires much finer measurements. The ratio of their masses is probably somewhere between 0.084 and 0.157; more observations are underway but a flyby mission is most likely needed for definitive data.

There are some who think Pluto would be better classified as a large asteroid or comet rather than as a planet. Some consider it to be the largest of the Kuiper Belt objects (also known as transneptunian objects). There is some merit to the latter position (the argument depends mainly on how a "planet" is defined"), but historically Pluto has been classified as a planet and it is likely to remain so.

Pluto's orbit is highly eccentric. At times it is closer to the Sun than Neptune (as it was from January 1979 through February 1999). Pluto rotates in the opposite direction from most of the other planets. In addition, Pluto is the second most "contrasty" body in the solar system (after Iapetus). Exploring the origin of that contrast is one of the priority goals for the proposed flyby mission.

Pluto is locked in a 3:2 resonance with Neptune; i.e., Pluto's orbital period is exactly 1.5 times longer than Neptune's. Its orbital inclination is also much higher than the other planets'. Thus though it appears that Pluto's orbit crosses Neptune's, it really does not and the two bodies will never collide.

Like Uranus, the plane of Pluto's equator is at almost right angles to the plane of its orbit.

The surface temperature on Pluto varies between about –235° and –210°C (38 to 63 K). The "warmer" regions roughly correspond to the regions that appear darker in optical wavelengths.

Composition and Atmosphere

Pluto's composition is unknown, but its density (about 2 g/cm^3) indicates that it is probably a mixture of 70% rock and 30% water ice, much like Triton. The bright areas of the surface seem to be covered with ices of nitrogen with smaller amounts of (solid) methane, ethane, and carbon monoxide. The composition of the darker areas of Pluto's surface is unknown but may be due to primordial organic material or photochemical reactions driven by cosmic rays.

Little is known about Pluto's atmosphere, but it probably consists primarily of nitrogen with some carbon monoxide and methane. It is extremely tenuous, the surface pressure being only a few microbars. Pluto's atmosphere may exist as a gas only when Pluto is near its perihelion; for the majority of Pluto's long year, the atmospheric gases are frozen into ice. Near perihelion, it is likely that some of the atmosphere escapes to space, perhaps even interacting with Charon. The Pluto mission planners want to arrive at Pluto while the atmosphere is unfrozen.

The unusual nature of the orbits of Pluto and of Triton and the similarity of bulk properties between Pluto and Triton suggest some historical connection between them. It was once thought that Pluto may have once been a satellite of Neptune's, but this now seems unlikely. A more popular idea is that Triton, like Pluto, once moved in an independent orbit around the Sun and was later captured by Neptune. Perhaps Triton, Pluto, and Charon are the only remaining members of a large class of similar objects the rest of which were ejected into the Oort Cloud. Like the

(continued on page 7)

POLICY IN REVIEW

The following letter, directed to Dr. Carl Pilcher of NASA Headquarters, presents the most recent findings of the Solar System Exploration Subcommittee of the Space Science Advisory Committee, which met July 18–20 , 2001, to discuss the future of solar system space exploration. Dr. Michael J. Drake, chair of that committee, has submitted this letter to this forum for public review. The layout and some emphases (italics and bold) were changed for publication purposes.

August 13, 2001

Dear Carl:

The Solar System Exploration Subcommittee (SSES) of the Space Science Advisory Committee (SScAC) met from July 18–20 in Washington, D.C. The purpose of this letter is to summarize the findings and recommendations of that meeting. The SSES would appreciate responses to specific recommendations (in **bold italic**) at the December SSES meeting in Cocoa Beach.

Dr. Bergstralh gave a general briefing on the state of the Planetary Program. Dr. Weiler briefed the SSES on the state of the Space Science Program.

Discovery

The SSES reiterates that the cost cap on the Discovery Program has not been adjusted in recent years for inflation, increase in launch vehicle cost due to retirement of Delta II-class vehicles, and increased costs associated with the re-evaluation of the acceptable degree of risk. The SSES notes that the loss of small Delta II-class launch vehicles has implications for Mars Scout and Explorer Program mission. ***The SSES recommends raising the Discovery Program cost cap to an appropriate level.***

Space Operations Management Organization (SOMO)

Paul Hertz briefed the SSES on major challenges facing the Space Operations Management Organization (SOMO). The Deep Space Network (DSN) has no amortization budget and consumes its maintenance budget to preserve operations. The SSES agrees that it is essential that the SOMO problem be resolved expeditiously as there are major DSN activities critical to the Solar System Exploration Division concentrated initially in the December 2003/January 2004 time frame, but recurring at later times. An inability to communicate with planetary spacecraft during critical maneuvers is unacceptable.

These problems translate into a budget shortfall for SOMO of about $400 million over about five years. The Office of Space Science uses about 98% of the DSN usage. The SSES endorses Associate Administrator Weiler's solution of paying those costs from the Office of Space Science budget in return for control of the DSN. The SSES strongly endorses protecting Research and Analysis and Data Analysis from budget cuts arising from this unbudgeted expense, and accepts as inevitable some delay in the Discovery Program and the Mars Program. ***The SSES expects to be fully involved in discussions of program slippage and the impact of such slippage.***

Extended Missions

The Solar System Exploration Program does not budget for extended missions. At its February 2001 meeting, the SSES specifically recommended planning for extended missions be incorporated into the Solar System Exploration Program budget. The SSES did not receive a response to this recommendation, hence it is reiterated here.

Terminating an expensive, viable spacecraft that still has high quality peer-evaluated science to conduct is an unconscionable squandering of the nation's resources. Every successful planetary mission in recent memory has conducted one or more extended missions, stretching the Solar System Exploration Program severely as the Director reprograms funds. Recent examples of the investment of small amounts of money compared to the overall cost of the missions in which new high-quality data of great scientific importance have been or will be returned are *Galileo*, *Mars Global Surveyor*, and *NEAR-Shoemaker*.

The SSES recommends that NASA:

1. Develop a plan to fund extended mission(s) for the Cassini spacecraft. It would be irresponsible to turn off a functioning $3 billion plus spacecraft if high-priority peer-reviewed science remains to be done.

2. For all future missions, plan in advance for MO&DA funds for extended missions.

Mars

Orlando Figueroa and James Garvin briefed the SSES on the state of the Mars Program.

The SSES commends NASA on the introduction of its Mars Fundamental Research Program. The SSES urges NASA not to restrict content. This program will engage young scholars, facilitate interdisciplinary studies, etc. Program direction is best driven by unrestricted peer-reviewed proposals.

The Mars Program is at present healthy, but significant challenges lie ahead. In the short term, it is noted that the Mars Exploration Rovers are on a very tight schedule. On both short and long terms, the DSN presents challenges. The "traffic jam" in December 2003/January 2004 has been noted above. In addition, communicating with missions in the 2007 time frame, including the Scout mission, challenge existing DSN capabilities.

Finally, budget problems related to SOMO (see above) and possible Congressional action have serious negative implications for the Mars Program from FY 2002 onwards. In particular, Scout missions, designed to fill in gaps in the Mars Program and respond to new discoveries, appear to be in jeopardy.

For these reasons, the SSES looks forward to a briefing concerning the status of these critical Mars missions at its December meeting in Cocoa Beach, and expects to play an active role in any discussions of Mars Program modification.

Outer Planets

Colleen Hartman briefed the SSES on Outer Planets exploration. Several issues point to the fragility of the Outer Planets exploration.

First, the only approved mission is the *Europa Orbiter* mission. Its run-out costs have now risen to $1.2B. This mission is complex, operating deep in Jupiter's gravity well in an extremely high radiation environment, and there is no evidence that these costs can be reduced.

The SSES requests an interim report from the Europa Study Team, commissioned by you to investigate alternative and cheaper ways of achieving Europa science objectives, at its December meeting in Cocoa Beach.

Second, Congress may approve a Pluto-Kuiper Belt mission. The SSES reaffirms that a Pluto-Kuiper Belt mission is its highest priority for an outer planets mission because of the unique orbital characteristics of Pluto with attendant scientific and mission operations implications. However, NASA has only two available RTGs. If one is used for Pluto, inadequate power is available for *Europa Orbiter*. NASA must urgently address the problem of power sources for outer planets missions.

NASA does not have a viable Outer Planets Program. The exploration of the outer solar system after *Cassini* depends critically on the success of one approved mission. It will be clearer by the next meeting whether this situation has changed.

Technology

Exploration of the outer solar system, interstellar space, and human missions will be greatly enabled with the development of two advanced technology lines. These technology lines should not be tied to specific missions, but should take the long view of enabling robust outer planets, interstellar, and human exploration.

The first technology line is in-space propulsion. Current travel times to the outer planets are one to two decades. A robust Outer Planets Program requires the development of in-space propulsion technologies. Such technologies would also reduce the exposure of humans on missions to Mars, and possibly make feasible robotic missions to nearby star systems.

The second technology line is nuclear power. It is not practical to use solar cells for long-term power on the surfaces of planets with dusty atmospheres like Mars, or in the outer solar system, and certainly not in interstellar space.

The SSES requests a briefing on the technology needs of the Solar System Exploration Division at its December meeting.

NASA HQ Reorganization

Colleen Hartman briefed the SSES on the reorganization of the Office of Space Science. The SSES was pleased to see clear lines of authority reestablished in the Office of Space Science and the Solar System Exploration Division.

Research and Analysis

Gunter Riegler briefed the SSES by telephone on the state of the Research and Analysis Program. The SSES commends Dr. Riegler on his responsiveness to SSES concerns outlined in its February 2001 letter. The SSES is particularly pleased to see the severe personnel shortage in Research and Analysis management addressed, and the introduction of procedures that should reduce the processing time of grants.

Dr. Riegler also briefed the SSES on the outcome of the Senior Review. It is gratifying, if not surprising, to see that the peer-review process has ensured high quality, relevant research in almost all of NASA's Research Space Science Research and Analysis Programs. The Senior Review suggests that, with only about 1 in 3 proposals receiving funding, an across the board augmentation to Research and Analysis is warranted.

Astrobiology

Michael Meyer briefed the SSES on the state of the Astrobiology initiative, broadly defined. Both in basic research and education and public outreach

POLICY IN REVIEW

Astrobiology appears to be functioning very effectively.

Roadmapping

The SSES devoted a full day to the next Solar System Roadmap. An overarching theme of Solar System Evolution and Habitability emerged to guide our planning. Reports from the Inner Planets and the Outer Planets subcommittees, tasked at the February meeting, were received.

Ellen Stofan, chair of the Inner Planets subcommittee, reported on *Evolution of a Habitable Planet.* It was agreed that discussions of missions to Mercury were premature given that both MESSENGER and BEPI-COLUMBO are in development. Discussion centered on integrating Mars into this theme, even though it is a separate program. It was suggested that Venus missions might not be possible under the Discovery Program, with the probable exception of orbiters. The logical conclusion that the divergent paths of Venus, Earth, and Mars should be the focus of this program, with mission to Venus and the Moon being an integral component. Sending technology demonstration packages to Venus' surface on any future Venus mission was also suggested. The Inner Planets subcommittee will recommend a specific strategy and mission set at the December meeting. A preliminary written document will be circulated by mid-September.

William McKinnon, chair of the Outer Planets subcommittee, reported on *Exploring Organic Rich Environments.* It was agreed that the objectives could best be met with an initial set of four missions. These missions, in priority order, are the Pluto-Kuiper Belt mission, the Europa Orbiter, the Comet Nucleus Sample Return (CNSR), and a Titan mission. The Pluto-Kuiper Belt mission will provide information on the building blocks available at the outer reaches of the solar system. The Europa Orbiter will provide information on the processing of outer solar system building blocks including possible biological evolution. CNSR will provide information on the building blocks available in the region of the giant planets, from which Oort Cloud comets are thought to be derived. A Titan mission, as a follow-on to the Cassini/Huygens mission, would provide information about prebiotic processing of material similar to that returned by the CNSR mission.

It was generally agreed that the objectives of the Titan mission must await the results of the Cassini-Huygens mission, arriving in 2005. Stardust should also return nonvolatile cometary coma material in 2006, further guiding CNSR. The Outer Planets subcommittee will recommend a specific strategy and mission set at the December meeting. A preliminary written document will be circulated by mid-September.

Planetary Data System

Jay Bergstralh briefed the SSES on the results of a study commissioned by him and chaired by Rita Beebe. The SSES endorses the conclusions of the Beebe Report.

Curation of Extraterrestrial Materials

Carlton Allen briefed the SSES on the current state and future plans of the Johnson Space Center for the curation of lunar samples, cosmic dust, Antarctic meteorites, spacecraft parts, future Genesis solar wind samples, Stardust comet particles, and returned Mars samples. It is noted that many years lead-time is required for the scientific curation of returned samples. An appropriate facility is in place for Genesis, and workable plans are being developed for Stardust and Muses-C. Curation of the valuable samples from the latter missions may require new funding, since curation support was not considered when these missions were approved. ***The SSES urges NASA to develop concrete plans for curation of Mars samples and other returned samples, detail funding requirements, and plan for developing the necessary facilities.***

Access to Space

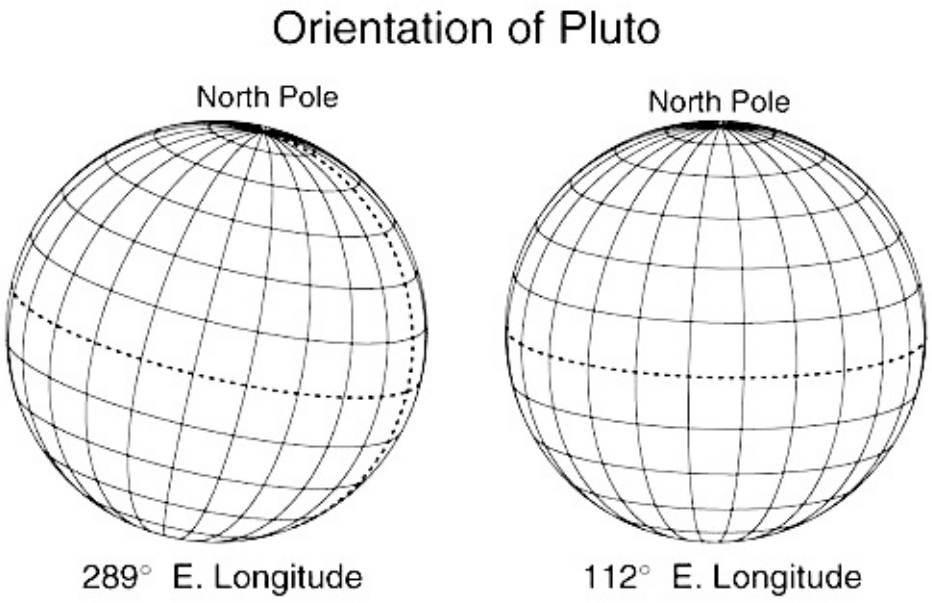
A recurrent theme of the meeting was the loss of relatively inexpensive access to space with the retirement of the Delta II line and the difficulty of finding alternative access such as Arianne small-attached payloads (ASAP). Discovery missions are already being driven to the Program cost cap by lack of cheap access to space. This problem will likely affect Mars Scout missions as well. It is an Office of Space Science-wide problem that will also affect Explorer missions. It might be appropriate to examine the possible capabilities of planetary missions in the class of SMEX and MIDEX, with a view to initiating parallel Discovery missions.

With kindest regards.

Sincerely,

Michael J. Drake, Chair
Solar System Exploration Subcommittee

c. Dr. Ed Weiler, Associate Administra-



Orientation grid created in 1996 by A. Stern and M. Buie.

PLUTO (continued from page 3)

Earth's Moon, Charon may be the result of a collision between Pluto and another body.

Pluto can be seen with an amateur telescope but it is not easy. There are several Web sites that show the current position of Pluto (and the other planets) in the sky, but much more detailed charts and careful observations over several months will be required to actually find it.

Charon

Charon (pronounced "KAIR en") is Pluto's only known satellite. Its orbit is 19,640 km from Pluto and its diameter is 1172 km.

Charon is named for the mythological figure who ferried the dead across the River Acheron into Hades (the underworld). (Though officially named for the mythological figure, Charon's discoverer James Christy also named it in honor of his wife, Charlene. Thus, those "in the know" pronounce it with the first syllable sounding like 'shard').

Prior to the discovery of Charon in 1978, it was thought that Pluto was much larger. Charon is unusual in that it is the largest moon with respect to its primary planet in the solar system (a distinction once held by Earth's Moon). Some prefer to think of Pluto/Charon as a double planetary system.

Charon's radius is not well known. JPL's value of 586 has a margin of error of ±13, more than 2%. Its mass and density are also poorly known.

Pluto and Charon are also unique in that not only does Charon rotate synchronously but Pluto does, too: They both keep the same face toward one another. (This makes the phases of Charon as seen from Pluto very interesting.)

Charon's composition is unknown, but its low density (about 2 g/cm^3) indicates that it may be similar to Saturn's icy moons (i.e., Rhea). Its surface seems to be covered with water ice. Interestingly, this is quite different from Pluto.

Unlike Pluto, Charon does not have large albedo features, though it may have smaller ones that have not been resolved.

It has been proposed that Charon was formed by a giant impact similar to the one that formed Earth's Moon.

It is doubtful that Charon has a significant atmosphere.

Bill Arnett's Web site (www.nineplanets.org) presents information on the solar system in the form of a multimedia tour. This article has been used with persmission and has been edited for content and style.

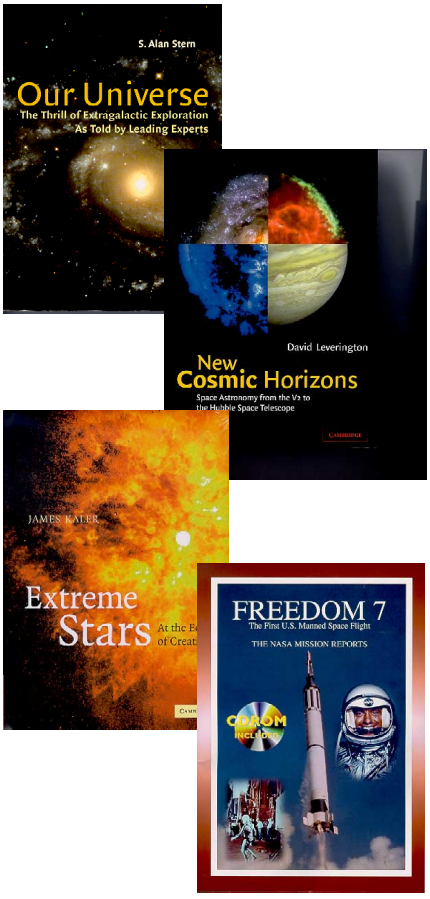
Venetia Burney, age 11, the "girl who named a planet"

How does Pluto compare?

Pluto is the farthest planet from the Sun (usually) and by far the smallest. Pluto is smaller than seven of the solar system's moons (the Moon, Io, Europa, Ganymede, Callisto, Titan, and Triton).

NEW IN PRINT

These publications are available from booksellers or the publisher listed. Please note that the LPI does not offer these books through its order department.



RECENTLY PUBLISHED

Our Universe: The Thrill of Extragalactic Exploration as Told by Leading Experts. By S. Alan Stern. Cambridge Univ. Press, 2001. Hardcover, $54.95, Softcover, $19.95. Collection of essays on extragalactic astronomy and cosmology. Authors include John Huchra, Esther Hu, John Mather, Megan Donahue, and Gregory Bothun.

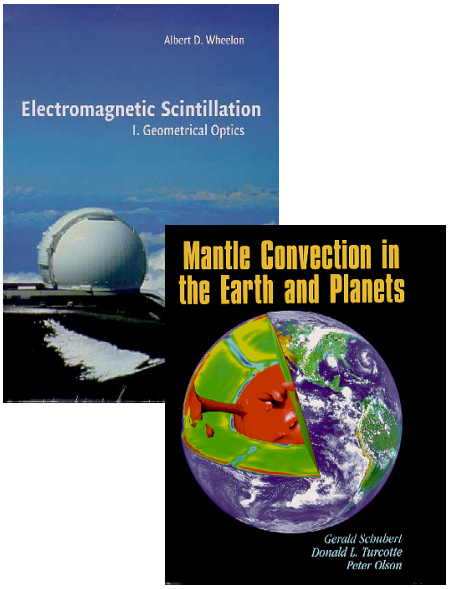
New Cosmic Horizons: Space Astronomy from the V2 to the Hubble Space Telescope. By David Leverington. Cambridge Univ. Press, 2000. Hardcover, $85. History of space-based astronomy since World War II, beginning with the launch of the V2 rocket in 1946.

Extreme Stars: At the Edge of Creation. By James Kaler. Cambridge Univ. Press, 2001. Hardcover, $34.95. Explanation and description of the stages of stellar evolution designed for the nonexpert.

Freedom 7: The First U.S. Manned Space Flight. NASA Mission Reports. Apogee Books, 2001. Softcover, $16.95. Review of material related to Alan Shepard's 1961 suborbital spaceflight, including technical reports and other relevant documents. An accompanying CD-ROM features video from the *Freedom 7* Earth-sky camera and postflight press activities.

Dictionary of Astronomy and Cosmology. Horsham, Pa.: Editorial Castilla La Vieja, 2001. Hardcover, $225. Spanish-English/English-Spanish reference work includes 1,041 pages and more than 24,000 entries.

Exploring the Unknown: Selected Documents in the History of the U.S. Civil Space Program, Volume V: Exploring the Cosmos. Edited by John M. Logsdon. Washington, DC.: NASA Special Publications. Fifth volume in an ongoing series of reference books for those interested in space history and space policy.



Also Received

Rock Magnetism: Fundamentals and Frontiers. By David J. Dunlop and Özden Özdemir. Cambridge Univ. Press, 2001. Softcover, $49.95.

Electromagnetic Scintillation. By Albert D. Wheelon. Cambridge Univ. Press, 2001. Hardcover, $110.

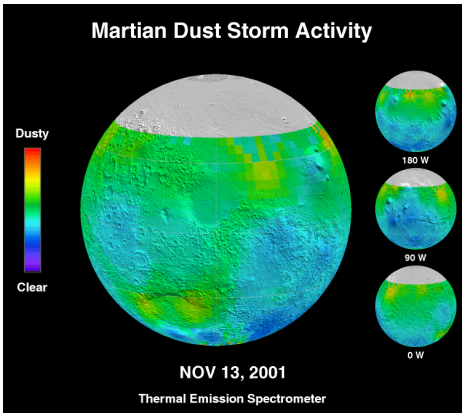
Mantle Convection in the Earth and Planets. By Gerald Schubert et al. Cambridge Univ. Press, 2001. Hardcover, $200. Softcover, $74.95.

The Grip of Gravity: The Quest to Understand the Laws of Motion and Gravitation. By Prabhakar Gondhalekar. Cambridge Univ. Press, 2001. Hardcover, $27.95.

Cosmic Butterflies: The Colorful Mysteries of Planetary Nebulae. By Sun Kwok. Cambridge Univ. Press, 2001. Hardcover, $29.95.

Celestial Treasury: From the Music of the Spheres to the Conquest of Space. By Marc Lachièze-Ray and Jean-Pierre Luminet. Cambridge Univ. Press, 2001. Hardcover, $59.95.

NEWS FROM SPACE



JPL/NASA

A thermal emission spectrometer-derived image of global atmospheric dust opacity on Mars.

Dust Storm Swallows Half of Mars

The largest dust storm to be seen on Mars since NASA's *Mars Global Surveyor* spacecraft arrived in 1997 was spotted raging across about half the planet in July.

"This is by far the largest storm we've seen during the *Mars Global Surveyor* mission," said Dr. Philip Christensen of Arizona State University in Tempe, principal investigator for the *Global Surveyor*'s thermal emission spectrometer. The instrument has been monitoring the martian atmosphere since March 1999.

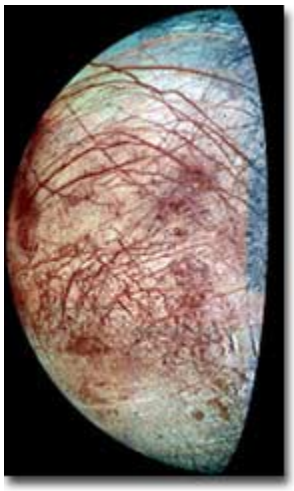
"We expect that the storm will continue to grow — perhaps becoming a global storm of the type that was seen during the *Mariner 9* and *Viking* missions in the 1970s," Christensen said.

Daily observations by the instrument are made into maps that allow scientists to determine both the temperature and the amount of dust in the atmosphere. Mars dust storm maps are posted at http://tes.la.asu.edu.

Scientists first noticed the onset of the storm on June 15, 2001, when a region of dust began to appear in the Hellas Basin in the southern hemisphere. A week and a half later, on June 26, the storm began to intensify and expand. The storm dramatically grew in size and severity, expanding well into the northern hemisphere and wrapping more than halfway around the planet, Christensen said.

This storm also began earlier than normal for martian dust storms. In the past when a large storm has occurred early in the season, several large storms have usually followed during the year. NASA scientists will be monitoring Mars over the next few months to see how this major storm develops and to test their predictions of more storms to come.

For more information on the Mars Exploration Program, see http://mars.jpl.nasa.gov.



NASA/JPL

Europa's frozen surface.

Temperature Map of Volcanic Moon Io Presents a Puzzle

Earth's tropics are hotter than the polar regions for a good reason, so scientists are puzzled that the same pattern doesn't show on Jupiter's moon Io.

A new map of Io's nighttime surface temperatures comes from NASA's *Galileo* spacecraft. Aside from hot spots at volcanic sites, night temperatures on Io appear to be about the same near the equator as near the poles, even though, as on Earth, the equator gets more direct sunshine to heat the surface.

According to Dr. John Spencer, of the Lowell Observatory, Flagstaff, Arizona, some possible explanations for Io's odd heat balance include that the poles may have more volcanic heating than the lower latitudes, or they may be surfaced with materials that cool off slower at night.

The Io temperature map is available online at http://www.jpl.nasa.gov/images/io and a new, enhanced-color *Galileo* image of Europa's icy surface is available at http://www.jpl.nasa.gov/images/europa.

Some 250 scientists met June 24–30 in Boulder, Colorado, to discuss Io, Europa, and other members of the Jupiter system. For more information about the Jupiter conference, visit the Web site at http://lasp.colorado.edu/jupiter.

NASA/JPL

Bright scars on a darker surface testify to a long history of impacts on Jupiter's moon Callisto.

Galileo Flyby Reveals Callisto's Bizarre Landscape

A spiky landscape of bright ice and dark dust shows signs of slow but active erosion on the surface of Jupiter's moon Callisto in new images from NASA's *Galileo* spacecraft.

The pictures taken by *Galileo*'s camera on May 25 from a distance of less than 138 kilometers, or about 86 miles, above Callisto's surface give the highest-resolution view ever seen of any of Jupiter's moons.

"We haven't seen terrain like this before. It looks like erosion is still going on, which is pretty surprising," said James Klemaszewski of Academic Research Lab, Phoenix, Arizona. Klemaszewski is processing and analyzing the *Galileo* Callisto imagery with Dr. David A. Williams and Dr. Ronald Greeley of Arizona State University, Tempe.

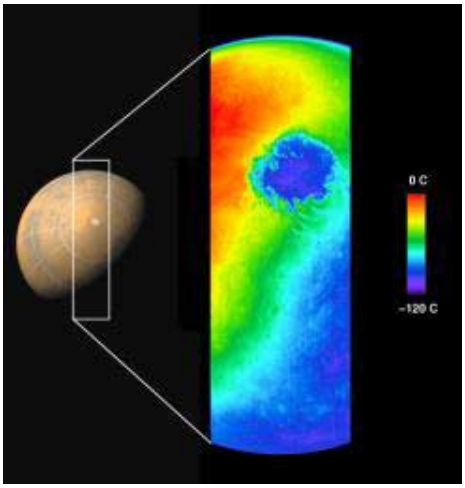
Callisto, about the same size as the planet Mercury, is the most distant of Jupiter's four large moons. Callisto's surface of ice and rock is the most heavily cratered of any moon in the solar system, signifying that it is geologically "dead." There is no clear evidence that Callisto has experienced the volcanic activity or tectonic shifting that have erased some or all of the impact craters on Jupiter's other three large moons.

The jagged hills in the new images may be icy material thrown outward from a large impact billions of years ago, or the highly eroded remains of a large impact structure, Williams said. Each bright peak of dust is surrounded by darker dust that appears to be slumping off the peak.

"They are continuing to erode and will eventually disappear," Klemaszewski said.

One theory for an erosion process is that, as some of the ice turns into vapor, it leaves behind dust that was bound in the ice. The accumulating dark material may also absorb enough heat from the Sun to warm the ice adjacent to it and keep the process going. The new images show areas where the sharp knobs have apparently eroded away, leaving a plain blanketed with dark material.

The close-up images show craters as small as about 3 meters across, though not as many as some predictions anticipated. One scientific goal from the high-resolution images is to see how many small craters are crowded onto the surface. Crater counts are one way to estimate the age of a moon's surface, and since Callisto has been so undisturbed by other geological processes, its cratering density is useful in calibrating the estimates for Jupiter's other moons.



NASA/JPL

Thermal infrared image of Mars.

Mars Odyssey's First Look at Mars

In October, NASA's 2001 *Mars Odyssey* gave mission managers its first look at the Red Planet: a thermal infrared image of the martian southern hemisphere that captures the polar carbon dioxide ice cap at a temperature of about –120°C (–184°F).

The spacecraft first entered orbit around Mars in late October after a six-month, 285-million-mile journey.

The image, taken as part of the calibration process for the instrument, shows the nighttime temperatures of Mars, demonstrating the "night-vision" capability of the camera system to observe Mars, even when the surface is in darkness.

"This spectacular first image of Mars from the 2001 *Mars Odyssey* spacecraft is just a hint of what's to come," said Dr. Ed Weiler, Associate Administrator for Space Science at NASA Headquarters in Washington. "After we get *Odyssey* into its final orbit it will be much closer to Mars than when it took this image, and we'll be able to tell whether or not there are any hot springs on Mars, places where liquid water may be close to the

(continued page 13)

PUBLICATIONS FROM LPI

QUANTITY	CODE	TITLE	PRICE	TOTAL
		EDUCATIONAL PRODUCTS **You can preview all our educational products by visiting http://www.lpi.usra.edu/education/products/products.html**		
	S-IMPACT	TERRESTRIAL IMPACT CRATERS, SECOND EDITION **(40 SLIDES)**	$25.00	
	S-SOLAR	THE SOLAR SYSTEM IN 3-D **(40 SLIDES)**	$25.00	
	S-VENUS	IT'S A DRY HEAT: THE GEOLOGY OF VENUS FROM MAGELLAN **(40 SLIDES)**	$25.00	
	S-LIFE	ANCIENT LIFE ON MARS??? **(40 SLIDES)**	$25.00	
	S-RED	THE RED PLANET: A SURVEY OF MARS, SECOND EDITION **(40 SLIDES)**	$25.00	
	S-VOLC	VOLCANOES ON MARS **(20 SLIDES)**	$22.00	
	S-HUMAN	SHUTTLE VIEWS THE EARTH: HUMAN IMPRINTS FROM SPACE **(40 SLIDES)**	$25.00	
	S-OCEANS	SHUTTLE VIEWS THE EARTH: THE OCEANS FROM SPACE **(40 SLIDES)**	$25.00	
	S-CLOUDS	SHUTTLE VIEWS THE EARTH: CLOUDS FROM SPACE **(40 SLIDES)**	$25.00	
	S-GEOL	SHUTTLE VIEWS THE EARTH: GEOLOGY FROM SPACE **(40 SLIDES)**	$25.00	
	S-CLEM	CLEMENTINE EXPLORES THE MOON, SECOND EDITION **(35 SLIDES)**	$25.00	
	S-TOUR	A SPACECRAFT TOUR OF THE SOLAR SYSTEM, SECOND EDITION **(40 SLIDES)**	$25.00	
	S-HAWAII	VOLCANIC FEATURES OF HAWAII AND OTHER WORLDS **(40 SLIDES)**	$25.00	
	TG-3DTOUR	TEACHER'S GUIDE TO THE 3-D TOUR OF THE SOLAR SYSTEM **(HARD COPY)**	$50.00	
	TG-3DTCD	TEACHER'S GUIDE TO THE 3-D TOUR OF THE SOLAR SYSTEM **(CD-ROM)**	$20.00	
	C-ATLAS	3-D TOUR OF THE SOLAR SYSTEM **(CD-ROM) (NEW VERSION 2.0)**	$15.00	
	C-SSRG	SPACE SCIENCE REFERENCE GUIDE **(CD-ROM) (NEW)**	$20.00	
	P-3DSTORM	THUNDERSTORMS IN 3-D **(3-D POSTER)** ***NEW PRICE***	$7.00	
	P-3DVOLC	VOLCANO IN 3-D **(3-D POSTER)** ***NEW PRICE***	$7.00	
	R-SPEC-2	ALTA REFLECTANCE SPECTROMETER **(VERSION 2 , 11 COLORS) (NEW)** A simple classroom instrument designed to help students learn about light, color, and spectroscopy. The ALTA handheld spectrometer weighs only 9 ounces. **(SCIENTIFIC INSTRUMENT)**	$160.00	
	B-RSPECTG	ALTA REFLECTANCE SPECTROMETER CLASSROOM LESSONS **(BOOK)**	$25.00	
	C-RSPECTG	ALTA REFLECTANCE SPECTROMETER CLASSROOM LESSONS **(CD-ROM)**	$10.00	
	R-SPEC	ALTA REFLECTANCE SPECTROMETER **(VERSION 1)**	$130.00	
		OTHER PUBLICATIONS **AVAILABLE FOR THE COST OF SHIPPING AND HANDLING**		
	CB-954	TRACES OF CATASTROPHE: HANDBOOK OF SHOCK-METAMORPHIC EFFECTS IN TERRESTRIAL METEORITE IMPACT STRUCTURES **(BOOK)**	$0.00	
	CB-969	WORKSHOP ON THERMAL EMISSION SPECTROSCOPY AND ANALYSIS OF DUST, DISKS, AND REGOLITHS **(BOOK)**	$0.00	
	CB-971	NINTH ANNUAL V. M. GOLDSCHMIDT CONFERENCE **(BOOK)**	$0.00	
	CB-979	SECOND ANNUAL HEDS-UP FORUM **(BOOK)**	$0.00	
	CB-1057	SECOND INTERNATIONAL CONFERENCE ON MARS POLAR SCIENCE AND EXPLORATION **(BOOK)**	$0.00	
	CB-1062	CONCEPTS AND APPROACHES FOR MARS EXPLORATION **(BOOK)**	$0.00	
	CB-1063	THIRD ANNUAL HEDS-UP FORUM **(BOOK)**	$0.00	
	CB-1084	FORUM ON INNOVATIVE APPROACHES TO OUTER PLANETARY EXPLORATION 2001-2002 **(BOOK)**	$0.00	
	CB-1095	CONFERENCE ON THE GEOPHYSICAL DETECTION OF SUBSURFACE WATER ON MARS **(BOOK)**	$0.00	
	CB-1097	MERCURY: SPACE ENVIRONMENT, SURFACE, AND INTERIOR **(BOOK)**	$0.00	

PUBLICATIONS FROM LPI

BALANCE FROM PREVIOUS PAGE $ _____

	CB-1101	FIELD TRIP AND WORKSHOP ON THE MARTIAN HIGHLANDS AND MOJAVE DESERT ANALOGS **(BOOK)**	$0.00	
	C-32	LPSC XXXII ABSTRACTS **(CD-ROM)**	$0.00	
	C-1088	ELEVENTH ANNUAL V. M. GOLDSCHMIDT CONFERENCE **(CD-ROM)**	$0.00	

(PRICES EFFECTIVE THROUGH APRIL 2002)

Shipping and Handling Charges

	U.S.	Canada Foreign Surface	Foreign Air Europe/S. Am.	Foreign Air Pacific Ocean
One Slide Set or CD-ROM	$6.00	N/A*	$9.00	$9.00
Ea. Additional, add:	$1.00	N/A*	$5.00	$5.00
One Book or Poster	$6.00	N/A*	$12.00	$15.00
Ea. Additional, add:	$1.00	N/A*	$5.00	$6.00
Each Spectrometer	$8.00	N/A*	$40.00	$40.00
Each Teacher's Guide (hard copy)	$8.00	N/A*	$40.00	$40.00

*Foreign air is the only shipping service available for slide sets and CD-ROMs.

SUBTOTAL $ _____

SHIPPING AND HANDLING $ _____
(SEE CHART AT LEFT)

ADD 8.25% SALES TAX $ _____
FOR TEXAS DELIVERY

(APPLY TAX TO SUBTOTAL AND SHIPPING)

TOTAL AMOUNT ENCLOSED $ _____

PRICES EFFECTIVE THROUGH 4/2002

Method of Payment

☐ Check (in U.S. dollars drawn on U.S. bank) **MAKE CHECKS PAYABLE TO: UNIVERSITIES SPACE RESEARCH ASSOCIATION (USRA).**

☐ Money Order

☐ Credit Card
VISA, American Express, MasterCard, Discover

Account Number

Expiration Date

Print exact name appearing on credit card

Signature _____

Phone (____) _____ FAX (____) _____

PLEASE INDICATE BUSINESS HOURS PHONE.

PLACE ALL ORDERS WITH:

Order Department
Lunar and Planetary Institute
3600 Bay Area Boulevard
Houston TX 77058-1113
Phone: 281-486-2172
Fax: 281-486-2186
E-mail: order@lpi.usra.edu

MAKE CHECKS PAYABLE TO:
UNIVERSITIES SPACE RESEARCH ASSOCIATION (USRA)

FOREIGN ORDERS MUST BE PREPAID

Ordered By

Organization _____

Name _____

Address _____

_____

City _____

State _____ Zip _____ Country _____

E-mail _____

Phone (____) _____ (required to process order)

PLEASE INDICATE BUSINESS HOURS PHONE.

Ship To All domestic orders must ship to a street address only.

Organization _____

Name _____

Address _____

_____

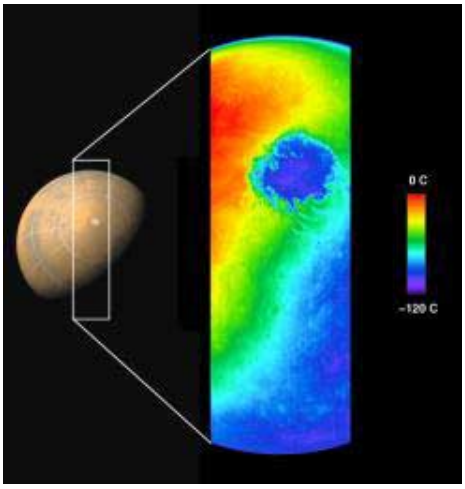
City _____

State _____ Zip _____ Country _____

E-mail _____

Phone (____) _____ (required to process order)

PLEASE INDICATE BUSINESS HOURS PHONE.



NASA/JPL

Thermal infrared image acquired by Mars Odyssey on October 30.

surface. If there are any such locations they would be places we might like to explore on future missions."

The image covers a length of more than 6500 kilometers (3900 miles), spanning the planet from limb to limb, with a resolution of approximately 5.5 kilometers (3.4 miles) per pixel, at the point directly beneath the spacecraft.

The spacecraft was about 22,000 kilometers (about 13,600 miles) above the planet looking down toward the south pole of Mars when the image was taken.

The image was taken in what would be late spring in the martian southern hemisphere. The extremely cold, circular feature (shown in blue in color images) is the martian south polar carbon dioxide ice cap, which is more than 900 kilometers (540 miles) in diameter at this time and will continue to shrink as summer progresses.

Sky Survey Lowers Risk of Asteroid Impact

The odds of Earth suffering a catastrophic collision with an asteroid over the next century are about one in 5000, which is less likely than previously believed, according to research published this month.

Astronomers using data from the Sloan Digital Sky Survey found that the solar system contains about 700,000 asteroids big enough to destroy civilization. That figure is about one-third the size of earlier estimates, which had put the number at around two million and the odds of collision at roughly one in 1500 over a 100-year period.

"Our estimate for the chance of a big impact contains some of the same uncertainties as previous estimates, but it is clear that we should feel somewhat safer than we did before we had the Sloan survey data," said lead researcher Zeljko Ivezic of Princeton University.

The results were published in the November issue of the *Astronomical Journal*. The new estimate draws on observations of many more asteroids, particularly small faint ones, than were available in previous impact risk estimates, said Ivezic. The ability to detect faint objects in large numbers is a hallmark of the Sloan survey, a multi-institutional collaboration that is mapping one-quarter of the sky.

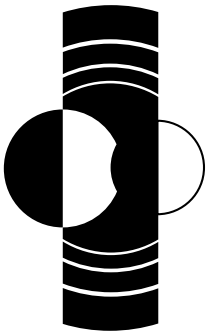
While its main purpose is to look at objects outside our galaxy, the survey also records images of closer objects that cross the view of its telescope, which is located at the Apache Point Observatory in New Mexico.

The survey data also allowed the astronomers to gauge the size of asteroids with improved accuracy, which required categorizing the objects by their composition. Asteroids with a surface of carbon — looking like giant lumps of coal — are darker than those made of rock. A small rocky asteroid therefore looks just as bright as a much larger one made of carbon.

"You don't know precisely the size of an object you are looking at unless you know what type it is," Ivezic said, noting that the Sloan survey provides information about the color of objects, which allows astronomers to distinguish between carbon and rock.

Based on observations of 10,000 asteroids, the researchers estimated that the asteroid belt contains about 700,000 that are bigger than one kilometer in diameter, which is the minimum size thought to pose a catastrophic risk to humans and other species. The asteroid belt is the source for a smaller group of asteroids called "near-Earth objects," which have broken from the belt and have the potential to collide with Earth. Although they did not specifically observe near-Earth objects, the researchers believe that their census of main-belt asteroids reveals the likelihood of collisions with similarly sized near-Earth asteroids.

33rd LPSC Dates and Venue Changed



The events of September 11, 2001, have affected all of us in one way or another. Some of the effects will be short-term, transitory phenomena. Others effects may have longer-term implications. Those of us who share the fruits of our labor and exciting new ideas with our colleagues at scientific meetings will find that our past experience with travel may not be what we have in the future. We may also find that LARGE, INTERNATIONAL meetings at government laboratories become difficult, perhaps even impossible, at least in the short term.

Unfortunately, this is the case for the 33rd Lunar and Planetary Science Conference. Because of security procedures that are now in place at the Johnson Space Center, and the uncertainty as to when those would be relaxed to a point that we could run the LPSC as we have in the past, we must change the venue of the Conference. This year the LPSC, both oral and poster sessions, will be held at the **South Shore Harbour Resort and Conference Center,** which is located almost directly across Clear Lake from JSC. Another consequence of this change is that we will have to move the time of the LPSC back one week. *****THE NEW DATES FOR THE LPSC ARE MARCH 11–15, 2002.*****

The second announcement and additional logistical information are available on the meeting Web site (http://www.lpi.usra.edu/meetings/lpsc2002/). It is our hope and expectation that steps will be taken at JSC to permit easier public access to the Gilruth Center by the time of the 34th LPSC.

We regret any inconvenience that these changes may cause, but hope that you will bear with us, and more importantly, with the LPI staff as they adjust on the fly to what is a major logistical change.

Sincerely,

Carl Agee and David C. Black
Co-Chairs, Lunar and Planetary Science Conference

The *Lunar and Planetary Information Bulletin* is published quarterly by the Lunar and Planetary Institute, 3600 Bay Area Boulevard, Houston TX 77058-1113.

Brian Anderson, Editor

Editorial and production support are provided by the LPI Publications and Program Services Department.

The Bulletin welcomes articles and essays dealing with issues related to planetary science and exploration. Please send articles or announcements to B. Anderson, 3600 Bay Area Boulevard, Houston TX 77058-1113. Copy deadline for the next issue is Feb. 1, 2002.

ISSN 0891-4664 (Print) 1534-6587 (Online)

Phone: 281-486-2164, fax: 281-486-2125
E-mail: lpibed@lpi.usra.edu

LPI *Space Science Reference Guide* now available

The Lunar and Planetary Institute has published a CD-ROM set containing space science material designed for use by educators and publishers.

The *Space Science Reference Guide* was originally conceived as a way to distribute information in a compact and efficient format to textbook and other educational publishers. Overseen and edited by scientists and staff at the LPI, the two-disk package was designed with quality and accuracy in mind.

The guide can be viewed using standard Internet browser software. The first CD is divided into three sections: space science missions, science articles, and images. The second CD provides high-resolution versions of most of the images contained in section 3 of the first CD.

For information on ordering the *Space Science Reference Guide*, see the form on page 11.

CALENDAR 2002

FEBRUARY 2002

3–7

Space Technology and Applications International Forum, Albuquerque, New Mexico.
Contact: Regents' Professor Mohamed S. El-Genk, University of New Mexico, Room 239, Albuquerque NM 87131-1341.
Phone: 505-277-4950; fax: 505-277-2813
E-mail: isnps@unm.edu
http://www-chne.unm.edu/isnps

MARCH

11–15

33rd Lunar and Planetary Science Conference, Houston.
Contact: Program Services Department, Lunar and Planetary Institute, 3600 Bay Area Boulevard, Houston TX 77058-1113.
Phone: 281-486-2123; fax: 281-486-2160
E-mail: perry@lpi.usra.edu
http://www.lpi.usra.edu/meetings/lpsc2002.html

JULY

22–26

65th Annual Meteoritical Society Meeting, University of California, Los Angeles, California.
Contact: Paul H. Warren, Institute of Geophysics & Planetary Physics, UCLA, Los Angeles, CA 90095-1567.
Phone: 310-825-3202; fax: 310-206-3051
http://www.lpi.usra.edu/meetings/metsoc2002/

AUGUST

18–23

12th Annual V. M. Goldschmidt Conference, Davos, Switzerland.
Contact: P.O. Box 27, Cambridge, CB1 8TR, UK
E-mail: conference@the-conference.com
http://www.goldschmidt-conference.com/2002/gold2002/

OCTOBER

6–11

34th Annual Meeting of the Division for Planetary Sciences of the American Astronomical Society, Ann Arbor, Michigan.
Contact: DPS Chair Mark Sykes
E-mail: Sykes@as.arizona.edu

27–30

Geological Society of America Fall Meeting, Denver, Colorado.
Contact: Geological Society of America
Phone: 303-447-2020 or 1-800-472-1988
E-mai: meetings@geosociety.org

DECEMBER

6–10

American Geophysical Union Fall Meeting, San Francisco, California.
Contact: AGU, 2000 Florida Avenue N.W., Washington, DC 20009.
Phone: 202-462-6900

Letters ...

The Bulletin received this letter from W. David Carrier providing further illumination on the origin of the expression "blue moon." The letter was edited for style and length.

"...For many years, I thought the latter part of this explanation [that a blue moon was a term for a second full Moon in a month] was correct. But a couple of years ago, I was reading a book, which attributed the saying to

'…the comparatively rare appearance of the moon on unusually clear nights when the entire surface of the moon is visible [tinged blue] although no more than a thin edge is illuminated.'

Surprised and curious, I called [astronaut Harrison H.] Jack Schmitt and asked him about it. He confirmed that while on the way to the Moon on *Apollo 17*, he could see that the dark side, that is, the portion illuminated by earthshine, was indeed bluish.

But wait. It gets better! A few weeks after calling Jack, my wife and I went to a conference in Lisbon, Portugal. ... When we arrived, we noticed an exhibit on a recently discovered Leonard da Vinci codex, so we decided to have a look. Many of the pages from Leonardo's manuscript were on display, along with translations. The first page I looked at was an explanation by Leonardo that the Moon appears blue because of light reflected from Earth's oceans. I was floored! ...

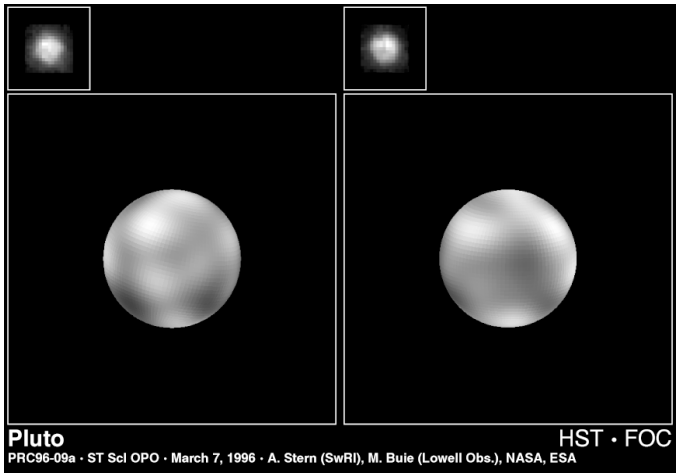
So, apparently, a new moon would always be bluish if viewed from space. Presumably the phase of the Earth, as seen from the Moon, also has something to do with it. And the atmosphere has to be right for us terrestrial dwellers to see it, making the right combination of factors even rarer. And, more importantly, making the occurrence of a blue moon random, as opposed to completely predictable if it is just the second full moon in a month.

Sincerely,

W. David Carrier III
Director, Lunar Geotechnical Institute

Please send letters and calendar items to LPIBED@lpi.usra.edu.

INSIDE



Pluto
See Page 2

Universities Space Research Association USRA

LUNAR AND PLANETARY INSTITUTE
3600 Bay Area Boulevard
Houston TX 77058-1113

ADDRESS SERVICE REQUESTED

NON-PROFIT
U.S. POSTAGE PAID
PERMIT NO. 600
HOUSTON TX