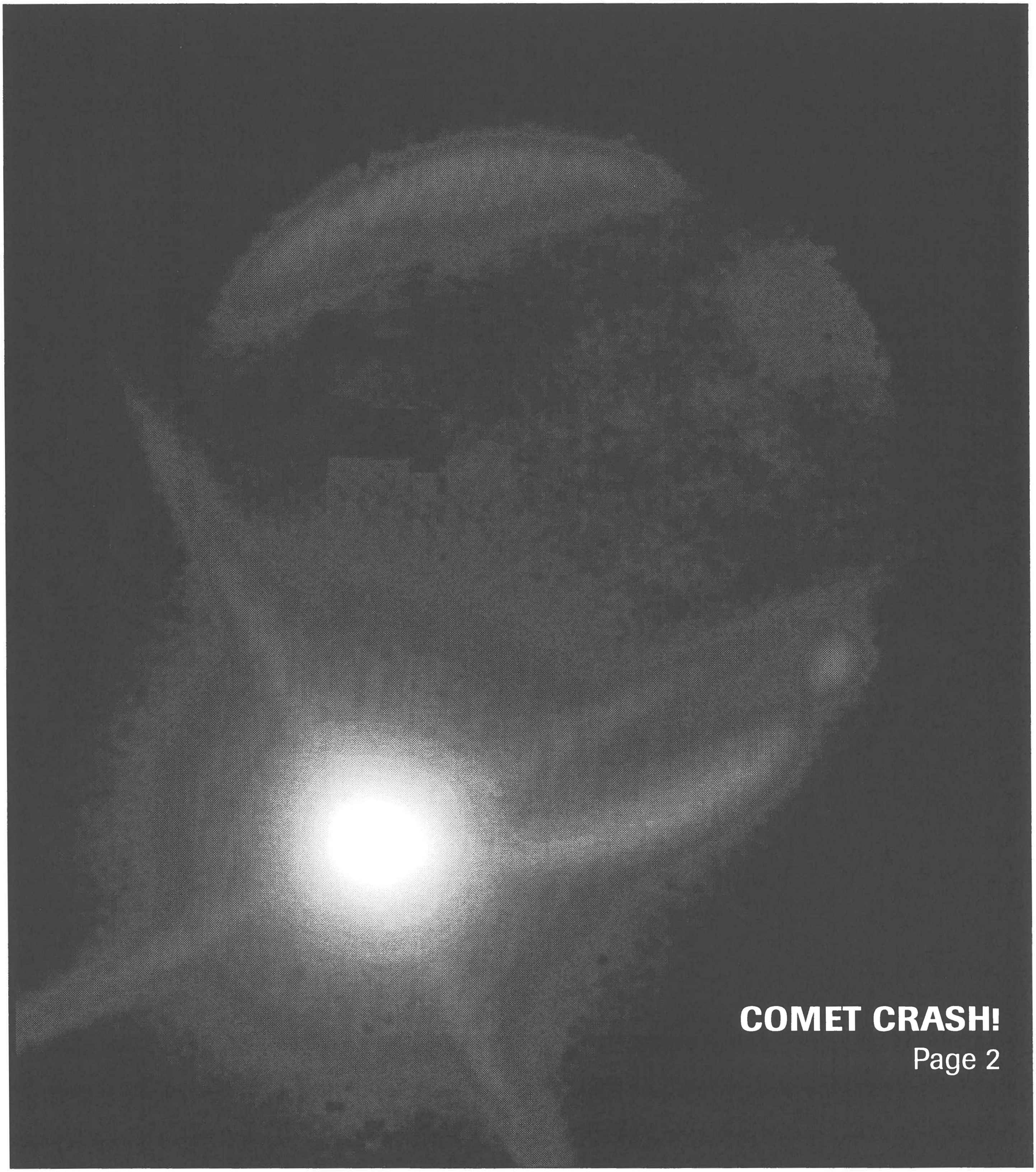
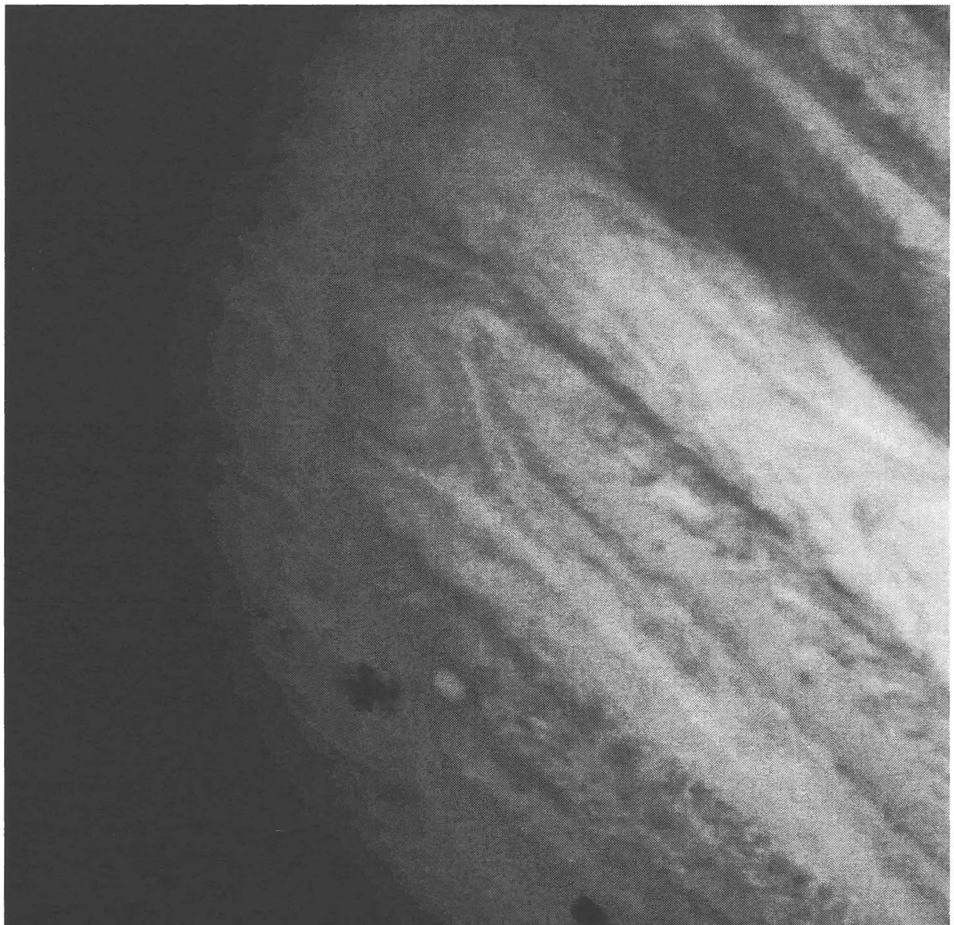
Lunar and Planetary Information
BULLETIN
AUGUST 1994/NUMBER 72 • LUNAR AND PLANETARY INSTITUTE • UNIVERSITIES SPACE RESEARCH ASSOCIATION



THE HORRENDOUS SPACE KABLOOEY AT JUPITER (the fate of comet Shoemaker-Levy 9)

by Paul Schenk and Julie Moses



4 PM CDT, July 16, 1994:

A single paragraph transmitted over the Internet is read by scientists across the world. We reread the message several times. Short on detail, the first reported observation, from Calar Alto, Spain, of the collision of the first fragment, A, of the comet P/Shoemaker-Levy 9 into Jupiter is nonetheless electrifying. Observers report that a "plume" is visible at 2.3 microns wavelength, brighter than Jupiter's moon Io. *It is the first indication, after over a year of speculation and teeth gnashing, that we are going to be treated to some major fireworks.*

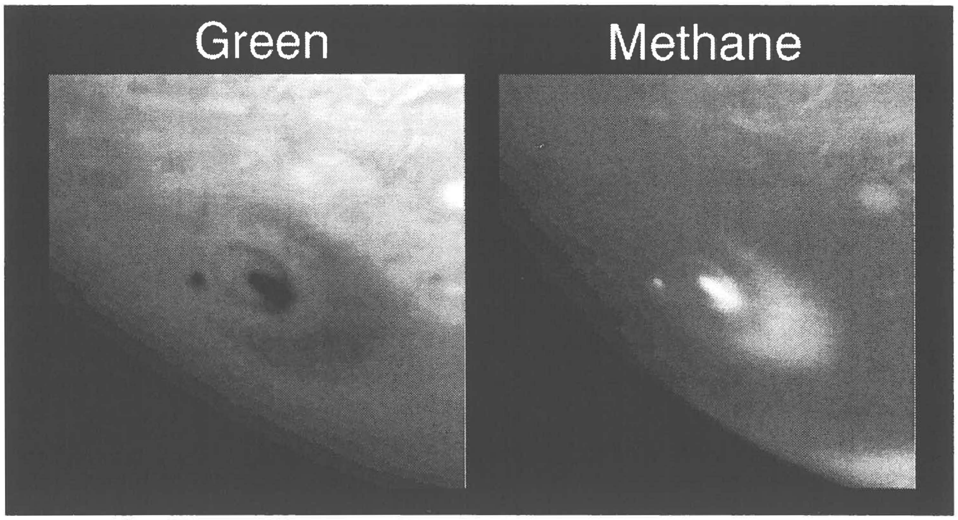
12:30 AM CDT, July 17, 1994:

Together with most of LPI's summer intern students, we return to LPI after a futile attempt to witness the impact of fragment B at the local observatory at Brazos Bend State Park. The impact of this second of 21 broken comet fragments to hit Jupiter was supposed to be visible from North America. Instead, we eagerly await the first images of the first impact earlier that afternoon from the Hubble Space Telescope (HST). They are quickly available on the Internet via the World Wide Web and are of stunning quality (proving in one evening the worth of HST to science, and the worth of the Web, for that matter). One image sequence shows a plume of hot gas rising hundreds of kilometers above Jupiter's horizon. Another image shows a prominent dark spot on Jupiter's cloudy surface, surrounded by a semicircular dark ring as large as the Earth. Clearly the first fragment, believed to be one of the smaller ones, had had a dramatic impact on Jupiter's appearance. We could only wonder what the other larger fragments might do to the giant planet.

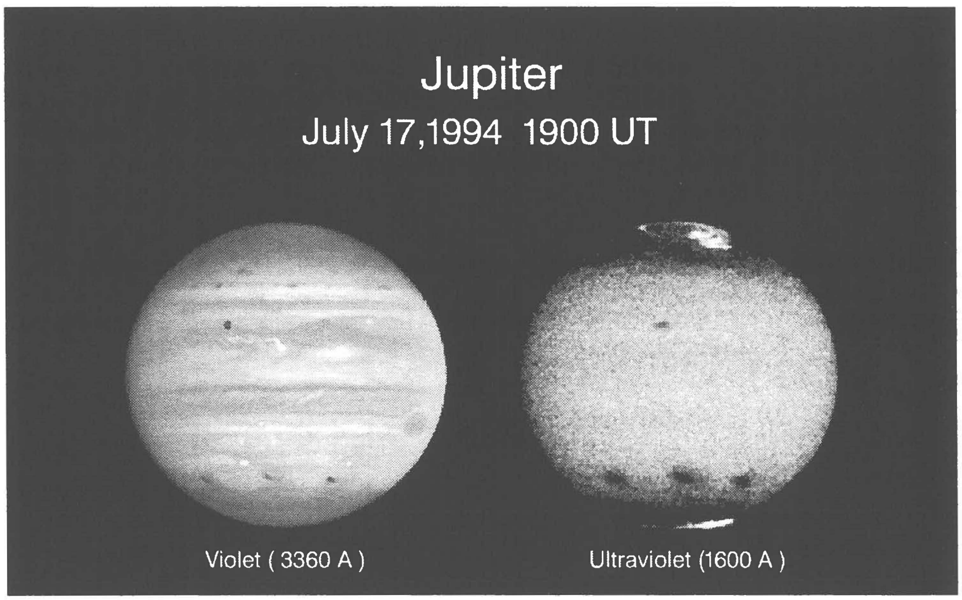
When astronomers on seven continents aimed every available telescope and instrument at Jupiter during the week of July 16, there were many predictions, ranging from "The Big Fizzle" to major impacts, to the disruptions of personal horoscopes and other catastrophes (Ice Ages) here on Earth. Although the magnitude of the damage done to Jupiter came as a pleasant surprise, equally surprising to scientists was that the event had actually produced visible results. After the failure of comet Kohoutek in 1974 and the great Perseid meteor storm of 1993 to materialize as predicted, most astronomers were extremely reluctant to predict anything (at least in public) concerning what might be seen.

The frantic effort of astronomers to observe the events in all portions of the spectrum was simple to understand: no one could predict with certainty what would happen. We have never witnessed a celestial collision before *(LPIB,* November, 1993). In general, many of the events did behave as expected (although a few fragments produced no visible effects and "fizzled"). Numerical simulations suggested that the fragments, striking at 60 km per second, would penetrate to near or below the visible ammonia cloud decks and explode. The resulting plume of hot gas would expand back up the column bored out by the fragment and expand upward, somewhat like a nuclear fireball. The plume would then collapse, splash back down, and spread out laterally in the upper atmosphere after reaching its maximum height. The unanswered questions were: How big were the fragments, how deep would they penetrate before breaking up, and what effect would the impacts have on the atmosphere?

Dramatic plume eruptions, seen rising above the planet's limb, were imaged by HST for several of the impacts. The plumes were also very prominent in thermal infrared wavelengths (e.g., 10 microns) and persisted for at least 30 minutes before gradually fading. The impact sites were also very bright in near-infrared wavelengths (e.g., at 2.3 microns



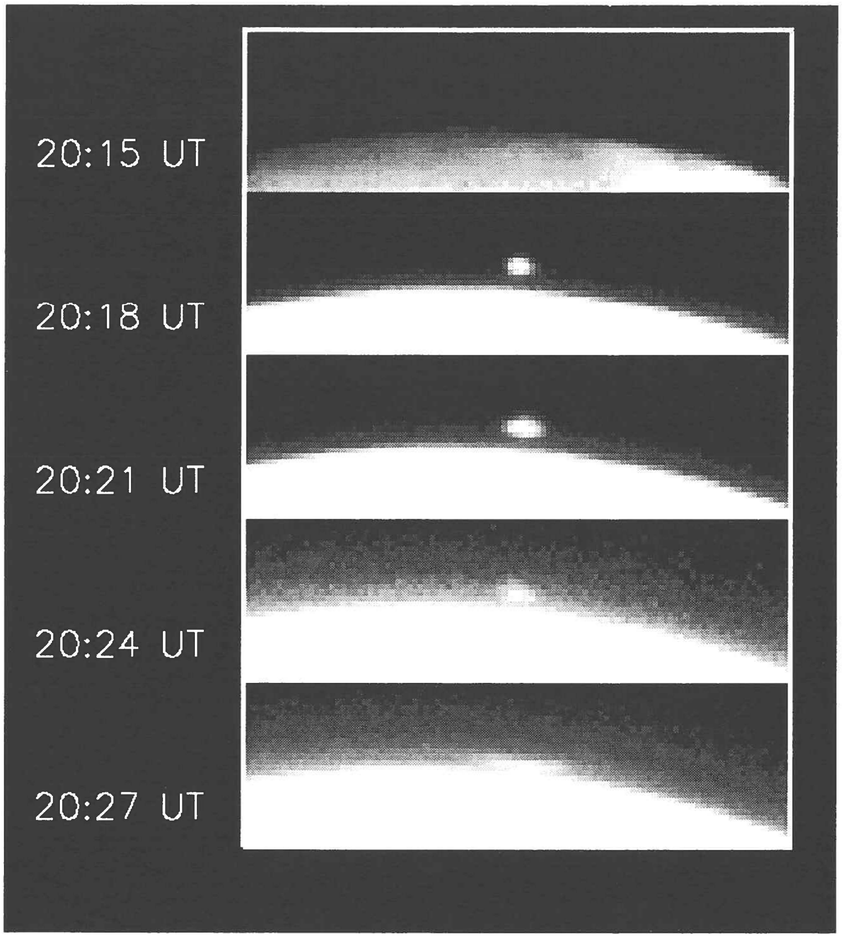
HST images obtained 1 1/2 hours after the impact of the largest fragment, G, of Shoemaker-Levy 9. The spot is larger than Earth even after this short time.



HST images of Jupiter obtained on July 17, 1994. Visible in the southern hemisphere are 3 spots, formed by the impacts of (from left to right) the C, A, and E fragments. Also visible in the ultraviolet image are Jupiter's polar aurorae.

and in other methane bands) and remained so for several weeks. Methane absorbs light at these wavelengths and the persistence of these spots demonstrates that the material in these plumes rose to high altitudes above the visible cloud decks and remained in the stratosphere for some time.

Most atmospheric scientists adventurous enough to hazard predictions expected bright clouds rather than dark spots. They expected bright water or ammonia ice to condense as the fireball cooled. Instead, the condensed material was dark at visible and ultraviolet wavelengths, and the spots were described as the most prominent features visible on Jupiter's surface since Galileo first examined the planet with a telescope in 1610. The dark spots began spreading and twisting in the winds within a week after formation. The evolution of these dark

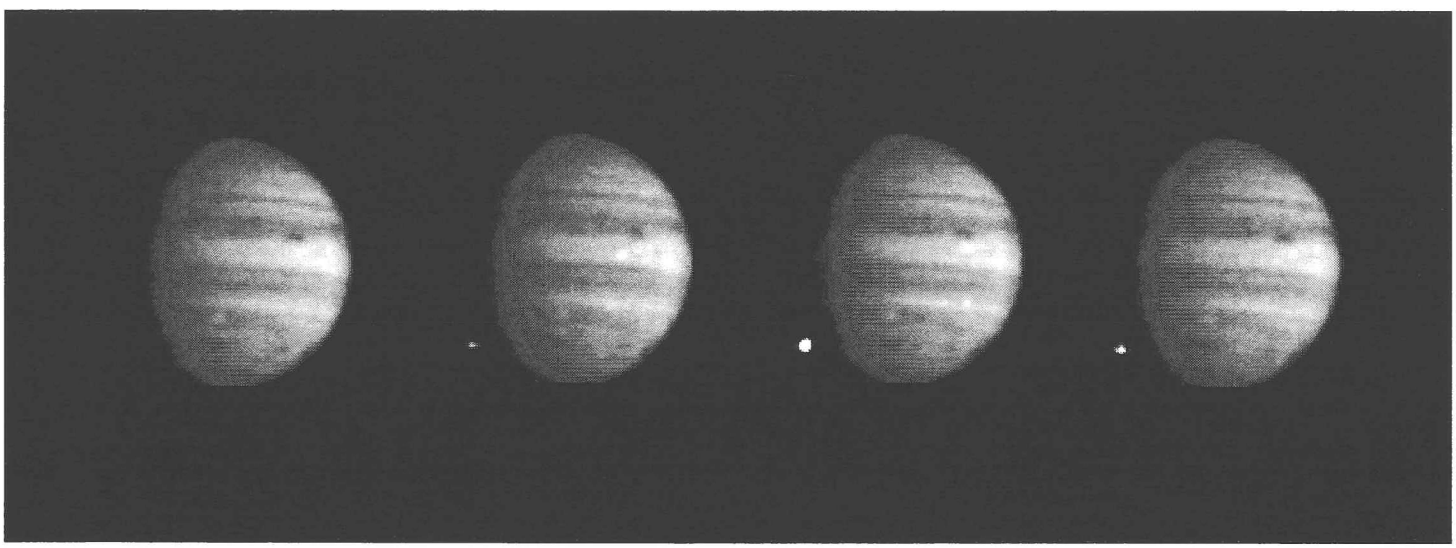


Hubble observed the plume of hot gas from the impact of the A fragment on July 16. During a span of 12 minutes, the plume is seen rising into sunlight and then collapsing. The dark zone between plume and planet is the shadow of Jupiter.

spots will help us map the winds and circulation in the Jovian stratosphere, a region about which we currently have little information. The dark spots, visible in telescopes as small as 6 inches for a week or so after the events, were observed by amateur astronomers who continue to monitor their evolution.

The composition of the dark material in the spots is still poorly understood but could help us to understand jovian atmospheric chemistry and the composition of the comet. Some molecules suspected or known to be present on Jupiter were observed after the impacts. These include ammonia, hydrogen cyanide, carbon monoxide, methane, ethane, acetylene, and hydrogen sulfide. Each impact site had its own spectral signature and time evolution, suggesting that the comet fragments were different sizes and/or were of variable composition. Surprising was the detection of diatomic sulfur (S_2), carbon disulfide (CS_2) and carbon monosulfide (CS), all of which have difficulty forming in the presence of large quantities of oxygen and hydrogen. Most surprising was the apparent *non*detection of water and other oxygen species for all but the largest of the impacts. If our current understanding of shock chemistry is correct, then the comet

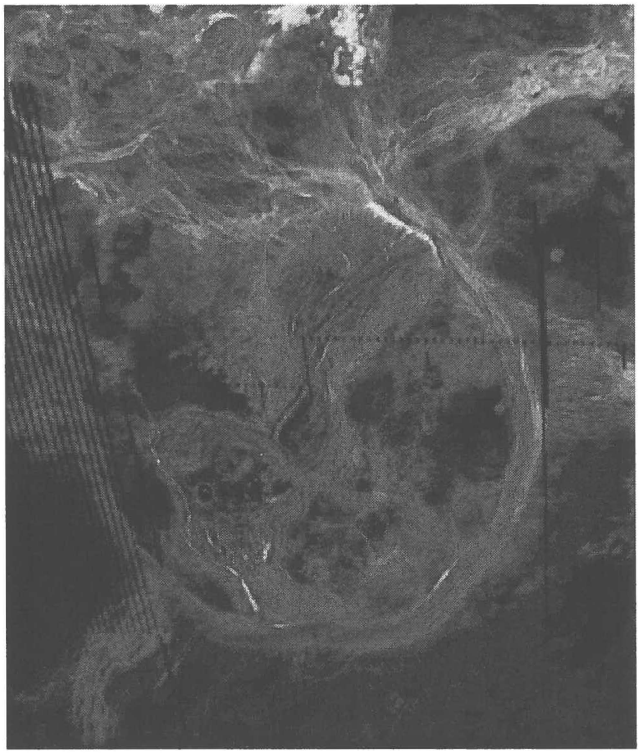
continued on page 13



0 **2.5** **5** **7.5**

The Galileo spacecraft obtained the only direct views of the impact. These 4 views taken over a space of 7.5 seconds shows the impact of the last major fragment, W, on July 22.

NEWS FROM SPACE



MAGELLAN ENTERS THE FINAL ACT

At meetings in late July, Magellan controllers made final plans for the completion of the craft's mission to Venus. Magellan will continue to collect gravity data from early August through early October to fill out the high-resolution Venus gravity map. On August 9, a third and final Radio Occultation Experiment will be performed in which the spacecraft will execute limb track maneuvers throughout each of five orbit occultations. A "Windmill" Experiment will be performed September 6–9, in which the high gain antenna will point to Earth so that the solar panel axis is at right angles to the velocity vector at periapsis. The solar panels will then be set to eight different sets of opposing angles to create torques on the spacecraft that will be sensed as increased speed in the onboard reaction wheels. This data will be used to determine lift and drag characteristics of the solar panels at different angles of attack. The results of this experiment will help engineers plan and design future aerobraking missions.

The Termination Experiment will be performed at three lower altitudes to gather data similar to the windmill experiment. In this final phase, the spacecraft's altitude will be lowered by successive orbital transfer maneuvers beginning October 10. In a configuration similar to the windmill experiment using the medium gain antenna rather than the high gain, Magellan should yield information about spacecraft aerodynamics as well as the structure of the venusian atmosphere.The spacecraft will enter the atmosphere permanently within a few hours after the periapsis altitude drops below 135 km. The actual demise of the spacecraft will probably not be detected on the ground because communications will be lost as Magellan is unable to point the antenna toward Earth. Certainly, some time in mid-October the spacecraft will be destroyed; what is not incinerated in the atmosphere will crash onto the surface of Venus, ending an extraordinarily successful planetary mission.

BATSE DETECTS UNUSUAL HIGH-ENERGY FLASHES IN THE ATMOSPHERE

Scientists at NASA's Marshall Space Flight Center have discovered unusual gamma-ray flashes in the upper atmosphere high above thunderstorms. These high-energy bursts have never been seen before in the Earth's atmosphere or surrounding space, according to Dr. Gerald Fishman of Marshall's Space Science Laboratory. They have now been detected by the Burst and Transient Source Experiment (BATSE), aboard NASA's orbiting Compton Gamma Ray Observatory.

"It is suspected that these flashes come from a rare type of powerful electrical discharge, similar to lightning, above large thunderstorm regions," Fishman said. "The flashes are very brief, lasting only a few thousandths of a second, although some of them consist of multiple pulses." They are seen very infrequently: only about twenty have been seen since the observatory was launched in April 1991.

"We saw our first flash of this type the first week that the detectors were turned on. We didn't know what to make of it," said Fishman. Gamma rays must be produced at altitudes above 100,000 feet to be detected with the spaceborne instrument. This is considerably higher than normal weather processes. The observations have been confirmed by other instruments on the observatory. The BATSE detectors were originally designed for sensitive observations of celestial objects in wavelength regions unobservable from the ground.

"The gamma-ray observations from the Earth's atmosphere come as a complete surprise to us. Atmospheric scientists are also surprised," said Fishman. "For many years, aircraft pilots have reported 'upward-going' lightning in clear air over thunderstorms. But these reports were either never taken seriously or were never studied in a scientific manner," he said.

In recent years, there have been video observations of electrical discharges above thunderstorms taken from the Space Shuttle and from research aircraft. The new gamma-ray flash observations may be related to these optical observations, Fishman said. "It is becoming apparent that the upper atmosphere is much more electrically active than we ever suspected," he concluded.

IDA'S MOON: NOT A CHIP OFF THE OLD ASTEROID?

New images and data from Galileo suggest that although the asteroid 243 Ida and its natural satellite—the first asteroid moon ever imaged—are similar in color and brightness, they appear to be composed of different types of material. Mission scientists also reported that new results show that Ida is more irregular in shape than Gaspra, another asteroid that Galileo encountered two years earlier.

Galileo took multiple images of Ida from different angles as the asteroid rotated during the spacecraft encounter, which scientists are using to estimate an orbit for the tiny moon. Its motion, in the same direction as Ida's rotation, appears to be in a plane viewed nearly edge-on by the spacecraft, making it difficult to determine the exact orbital shape and period.

"A circular orbit at 60 miles (90 kilometers), nearly in Ida's equatorial plane, with a period of about one Earth day, appears to fit the observations we have now," said Kenneth P. Klaasen of the imaging team. "However, a range of elliptical orbits cannot be ruled out yet," he added. "Other observations that are still on Galileo's onboard tape recorder to be played back next month should permit us to improve the calculation."

There are different theories about the origin of Ida's 1-mile-diameter (1.5-kilometer) moon. It might be a large block thrown off during an impact that formed one of the large craters on Ida's surface. "More likely," said imaging team member Dr. Clark Chapman, "the moon was formed during the cataclysmic fragmentation and disruption of a larger asteroid in which Ida itself was formed. In this scenario, the little moon was ejected from the explosion in practically the same orbit as Ida, and was captured in the larger object's gravitational field," Chapman explained, "while most other fragments went into independent orbits around the Sun."

Galileo's near-infrared mapping spectrometer, which initially confirmed discovery of Ida's moon, provided the data for thermal and mineralogical maps of the surface of Ida and mineralogical studies of its moon. "We have good data on what minerals make up these bodies," said Dr. Robert Carlson, principal investigator for the spectrometer. "The areas on Ida's surface where we have our best data appear to be predominantly olivine, with a bit of orthopyroxene, while its moon is quite different, with a roughly equal mixture of olivine, orthopyroxene, and clinopyroxene. This suggests the moon is not a chip off the asteroid."

Ida orbits the Sun at an average distance of 270 million miles (440 million kilometers) in about the middle of the asteroid belt between Mars and Jupiter. The asteroid is about 36 miles (58 kilometers) long and 14 miles (23 kilometers) wide, and rotates once every 4 hours, 40 minutes. One of only two asteroids ever observed close-up, it was encountered August 28, 1993, by the Galileo spacecraft on its way to Jupiter.

MARS GLOBAL SURVEYOR WILL BE BUILT BY MARTIN MARIETTA

Development of the Mars Global Surveyor—the first in a series of low-cost spacecraft to explore the martian environment—began in July in anticipation of a November 1996 launch to the red planet.

Jet Propulsion Laboratory Director Dr. Edward C. Stone announced the selection of Martin Marietta Technologies Inc. to build the lightweight orbiter after a rapid, industry-wide competition. "Martin Marietta Technologies Inc. has a successful record of developing unique planetary spacecraft, including the highly successful Magellan Venus radar mapping mission and the Viking Mars landers," Stone said.

"This is the beginning of a new era in the exploration of the martian environment and a new way of conducting business with our partners in industry," he said. "We are now on the way to building a viable, state-of-the-art spacecraft that will be ready for launch by November 1996 and assure us of many scientifically important results."

The Mars Global Surveyor will be readied for launch from Cape Canaveral in just 28 months, beginning NASA's decade-long plan to launch orbiters and landers to Mars every 26 months through the year 2005. The rigorous timeline, trimmed from an average five years or more in the past, reflects a new policy of streamlining the development and deployment of new planetary missions.

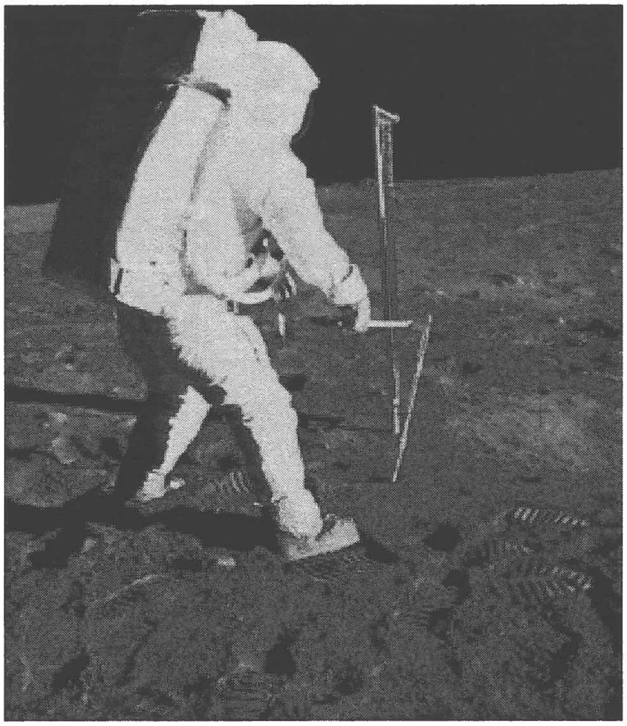
The new orbiter will be a low-mass, polar-orbiting spacecraft that can carry all but two of the eight science instruments that were on board the Mars Observer spacecraft when it was lost on August 21, 1993. Project costs through 30 days after launch have been capped at $155 million.

The Mars Global Surveyor will provide high-resolution, global maps of the martian surface, profile the planet's atmosphere, and study the nature of the magnetic field. The orbiter will be small enough to be launched on a Delta expendable launch vehicle and will spend 10 months in transit to Mars before entering a polar orbit in September 1997.

APOLLO LASER RANGING EXPERIMENTS YIELD RESULTS

Scientists who analyze data from the Lunar Laser Ranging Experiment have reported some watershed results from these long-term experiments, begun 25 years ago when the Apollo 11 astronauts deployed a reflector array in the Sea of Tranquillity. "Using the Lunar Laser Ranging Experiment, we have been able to improve, by orders of magnitude, measurements of the Moon's rotation," said Jet Propulsion Laboratory team investigator Dr. Jean Dickey. "We also have strong evidence that the Moon has a liquid core, and laser ranging has allowed us to determine with great accuracy the rate at which the Moon is gradually receding from the Earth."

The first laser ranging retroreflector was positioned on the Moon in 1969 by the Apollo 11 astronauts. By beaming laser pulses at the reflector from Earth, scientists



have been able to determine their roundtrip travel time that gives the distance between the two bodies at any time to an accuracy of about 3 centimeters. The laser reflector consists of 100 fused silica half-cubes, called corner cubes, mounted in a 46-centimeter square aluminum panel. Each corner cube is 3.8 centimeters in diameter. Corner cubes reflect a beam of light directly back toward the point of origin.

"Lunar ranging involves sending a laser beam through an optical telescope," Dickey said. "The beam enters the telescope where the eye piece would be, and the transmitted beam is expanded to become the diameter of the main mirror, then bounced off the surface toward the reflector on the Moon."

The reflectors are too small to be seen from Earth, so even when the beam is precisely aligned in the telescope, actually hitting a lunar retroreflector array is technically challenging. At the Moon's surface the beam is roughly four miles wide. Scientists liken the task of aiming the beam to using a rifle to hit a moving dime two miles away.

Once the laser beam hits a reflector, scientists at the ranging observatories use extremely sensitive filtering and amplification equipment to detect the return signal, which is far too weak to be seen with the human eye. Even under good atmospheric viewing conditions, only one photon is received every few seconds.

From the ranging experiments, scientists know that the average distance between the centers of the Earth and the Moon is 385,000 kilometers, with an accuracy of better than one part in 10 billion. Laser ranging has also made possible a wealth of new information about the dynamics and structure of the Moon. Among many new observations, scientists now believe that the Moon may harbor a liquid core. The theory has been proposed from data on the Moon's rate of rotation and very slight bobbing motions caused by gravitational forces from the Sun and Earth.

Ranging has also determined that the length of an Earth day has distinct small-scale variations of about one thousandth of a second over the course of a year, caused by the atmosphere, tides, and Earth's core. In addition, precise positions of the laser ranging observatories on Earth are slowly drifting as the crustal plates on Earth drift. The observatory on Maui is seen to be drifting away from the observatory in Texas.

Data also indicate that ocean tides on Earth have a direct influence on the Moon's orbit. Measurements show that the Moon is receding from Earth at a rate of about 3.8 centimeters per year. Ranging has also improved historic knowledge of the Moon's orbit, enough to permit accurate analyses of solar eclipses as far back as 1400 BC. Continued improvements in range determinations and the need for monitoring the details of the Earth's rotation will keep the lunar reflector experiments in service for years to come.

PUBLICATIONS FROM LPI

QUANTITY	CODE	TITLE	PRICE	TOTAL
		BOOKS		
	B-ACM	ASTEROIDS, COMETS, METEORS 1991	$80.00	
	PRO-20	PROCEEDINGS OF THE TWENTIETH LUNAR AND PLANETARY SCIENCE CONFERENCE	$25.00	
	PRO-22	PROCEEDINGS OF THE LUNAR AND PLANETARY SCIENCE CONFERENCE, VOLUME 22	$25.00	
	B-ORIGINS	ORIGIN OF THE MOON	$15.00	
	B-BASES	LUNAR BASES AND SPACE ACTIVITIES OF THE 21ST CENTURY	$15.00	
		SLIDE SETS		
	S-HAWAII	VOLCANIC FEATURES OF HAWAII AND OTHER WORLDS	$20.00	
	S-TOUR	A SPACECRAFT TOUR OF THE SOLAR SYSTEM	$20.00	
	S-IMPACT	TERRESTRIAL IMPACT CRATERS	$18.00	
	S-WINDS	THE WINDS OF MARS: AEOLIAN ACTIVITY AND LANDFORMS	$18.00	
	S-STONES	STONES, WIND, AND ICE: A GUIDE TO MARTIAN IMPACT CRATERS	$18.00	
	S-VOLC	VOLCANOES ON MARS	$15.00	
	S-APOLLO	APOLLO LANDING SITES	$20.00	
	S-OCEANS	SHUTTLE VIEWS THE EARTH: THE OCEANS FROM SPACE	$20.00	
	S-CLOUDS	SHUTTLE VIEWS THE EARTH: CLOUDS FROM SPACE	$20.00	
	S-GEOL	SHUTTLE VIEWS THE EARTH: GEOLOGY FROM SPACE	$20.00	
		TECHNICAL REPORTS AND CONTRIBUTIONS — AVAILABLE FOR THE COST OF SHIPPING AND HANDLING		
	92-01	TOWARDS OTHER PLANETARY SYSTEMS (TOPS): A TECHNOLOGY NEEDS ASSESSMENT WORKSHOP	$0.00	
	93-01	WORKSHOP ON THE SPACE ENVIRONMENT: THE EFFECTS ON THE OPTICAL PROPERTIES OF AIRLESS BODIES	$0.00	
	93-02	WORKSHOP ON ADVANCED TECHNOLOGIES FOR PLANETARY INSTRUMENTS, PARTS 1 & 2	$0.00	
	93-03	WORKSHOP ON EARLY MARS: HOW WARM AND HOW WET? PARTS 1 & 2	$0.00	
	93-04	WORKSHOP ON THE MARTIAN NORTHERN PLAINS: SEDIMENTOLOGICAL, PERIGLACIAL, AND PALEOCLIMATIC EVOLUTION	$0.00	
	93-05	WORKSHOP ON ATMOSPHERIC TRANSPORT ON MARS	$0.00	
	93-07	ANTARCTIC METEORITE LOCATION AND MAPPING PROJECT, 2ND EDITION	$0.00	
	94-01	VENUS DATA ANALYSIS PROGRAM: DIRECTORY OF RESEARCH PROJECTS (1993–1994)	$0.00	
	94-02	WORKSHOP ON THE ANALYSIS OF INTERPLANETARY DUST PARTICLES	$0.00	
	94-04	MARS PATHFINDER LANDING SITE WORKSHOP	$0.00	
	C-825	NEW DEVELOPMENTS REGARDING THE KT EVENT AND OTHER CATASTROPHES IN EARTH HISTORY	$0.00	
		LPSC ABSTRACT VOLUMES — AVAILABLE FOR THE COST OF SHIPPING AND HANDLING		
	ABS-25	LPSC XXV (1994)	$0.00	

(OVER PLEASE)

PAGE TOTAL $ ________

BALANCE FROM PREVIOUS PAGE $ ________

Shipping and Handling Charges				
	U.S.	Canada Foreign Surface	Foreign Air Europe/S. Am.	Foreign Air Pacific Ocean
Each Proceedings	$9.00	$9.00	$36.00	$36.00
Each Book	$5.00	$5.00	$28.00	$28.00
One Slide Set	$3.00	$3.00	$7.00	$7.00
Ea. Additional Set, add:	$1.00	$1.00	$2.00	$2.00
One Technical Report/Contrib.	$5.00	$5.00	$10.00	$10.00
Ea. Additional Report, add:	$1.00	$1.00	$2.00	$2.00
Each Abstract Set	$10.00	$15.00	$55.00	$75.00

SUBTOTAL $ ________

SHIPPING AND HANDLING $ ________
(SEE CHART AT LEFT)

ADD 7.25% SALES TAX $ ________
FOR TEXAS DELIVERY
(APPLY TAX TO SUBTOTAL AND SHIPPING)

TOTAL AMOUNT ENCLOSED $ ________

PRICES EFFECTIVE THROUGH 12/94

Method of Payment

☐ Check (in U.S. dollars drawn on U.S. bank) ☐ Money Order
☐ VISA
☐ MasterCard

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: (713) 486-2172
FAX: (713) 486-2186

FOREIGN ORDERS MUST BE PREPAID

PURCHASE ORDERS WILL NOT BE ACCEPTED UNLESS THE TOTAL IS $20.00 OR MORE.

Ordered By

Organization ________________

Name ________________

Address ________________

____

City ________________

State ________ Zip ________ Country ________

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 ________

Phone (____) ________________ (required to process order)

PLEASE INDICATE BUSINESS HOURS PHONE.

NEW IN PRINT

These publications are available from the publisher listed or may be ordered through local bookstores.

REVIEW

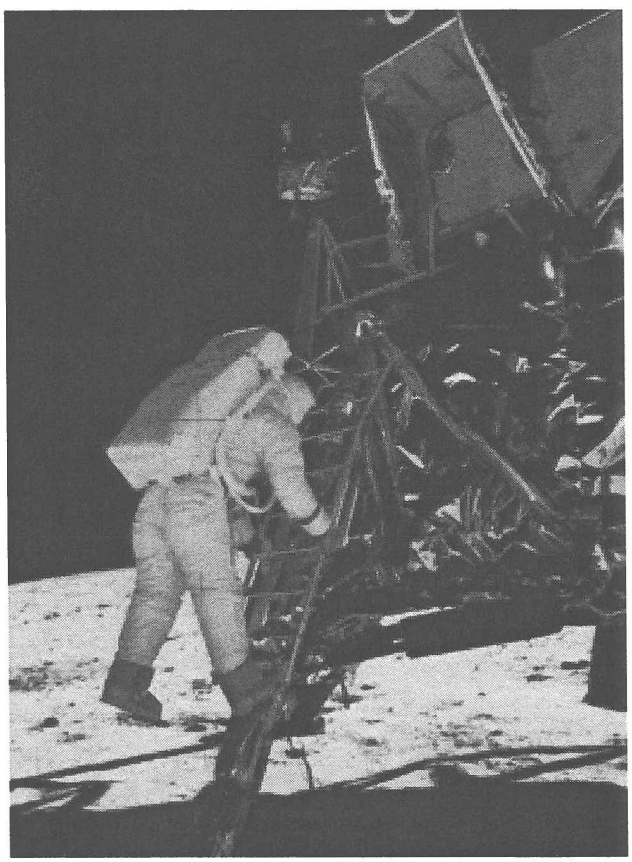
A MAN ON THE MOON: The Voyages of the Apollo Astronauts

by Andrew Chaikin
Viking Penguin, New York, 1994, 670 pp.
Black and white photographs. Hardcover. $27.95

This past July 20th marked the twenty-fifth anniversary of the Apollo 11 landing and became the occasion to introduce several new publications on the U.S. manned space program. *A Man on the Moon* is by far the most comprehensive and readable of all insofar as telling the story of the Apollo astronauts, and through them, the very human story of the Apollo program. In one of the jacket blurbs, Gene Cernan, the Apollo 17 Commander, says "I've been there. Chaikin took me back." Similar jacket endorsements by other Apollo astronauts are a testament to the respect for the author's ability to tell their story accurately and well.

The book is a product of hundreds of hours of in-depth interviews with the astronauts and others over a period of almost ten years. Twenty-four astronauts went to the Moon during Apollo, and, with the exception of Jack Swigert who died in 1982, Chaikin had access to them all.

The manned Apollo missions got off to a tragic start with the death of the three astronauts in the Spacecraft 012 fire on the launch pad in January of 1967, five years after Shepard's first 15-minute sub-orbital lob 300 miles downrange, and five years after John Kennedy's bold announcement that the U.S. was going to send men to the Moon and return them safely to Earth before the decade was out. There were only three more years to go in the decade and things weren't looking all that good.



Chaikin relates the events leading up to the fire and its aftermath along with flashbacks to the Gemini Program dealing with the individuals who would eventually be assigned to the Moon missions. This period only occupies a brief, but insightful, part of the book. By Chapter 3 (page 57) the author begins the story of the first manned Moon mission, Apollo 8, which flew in December of 1968, less than two years after the Spacecraft 012 fire (after the fire it had been designated Apollo 1). The decision for Apollo 8 to go into lunar orbit was a bold one in view of the fact that it was only the second manned Apollo mission and the first to fly atop the three stage Saturn V launch vehicle. Chaikin tells the story well—not just the technical side, which the average Apollo fan already knows, but, more importantly, we get a real feel for the human side—what is going on "off-line" not just with the astronauts, but their families as well: Jim Lovell breaking the news to his wife Marilyn that they weren't going to be spending Christmas in Acapulco after all, but that he would be spending it in lunar orbit; the fact that Frank Borman's worst fear wasn't that the Saturn would blow up or that they would get stranded in lunar orbit—it was that there might be some malfunction with the spacecraft in the initial Earth parking orbit that would prevent them from going on to the Moon, and he would be stuck with the alternate mission, ten long days in Earth orbit with essentially nothing to do.

Fortunately that didn't happen. Apollo 8 was a resounding success in more ways than one: In addition to racking up a lot of firsts and getting a real test of the end-to-end system at lunar distances, it clearly established the U.S. lead over the Soviet Union in the race to the Moon.

Subsequent missions were launched on two-month centers: Apollo 9 in March was a dress rehearsal in Earth orbit with the full-up spacecraft; Apollo 10 in May was much the same but in lunar orbit, where the Lunar Module separated from the Command and Service Modules and descended to within 50,000 feet of the lunar surface, and finally, in July, Apollo 11 ignited the descent engine at 50,000 feet and continued on to the first lunar landing. Chaikin's description of this period of intense activity along with several interesting and revealing flashbacks to the Gemini program, Apollo training, and crew selection make fascinating reading.

But this reviewer is lapsing into telling the story and not reviewing the book . . . . and is running out of space besides, although there are still another 250 pages to go in the book. The Apollo 11 landing concludes Book 1. Book 2 covers the so-called H-missions, Apollo 12, 13 and 14, with essentially the same spacecraft hardware as Apollo 11, but with an emphasis on science. Book 3 covers the J-missions, Apollo 15, 16, and 17, which were known as the Lunar Exploration Program—longer staytimes, longer EVAs, Lunar Rovers for greater mobility, and a rack of instruments in the Service Module for remote sensing from lunar orbit. With the help of the scientists involved in these missions, Chaikin continues to tell the story of the important science that these crews accomplished and what it means to our understanding of the Moon's origin and evolution.

When Apollo 17 splashed down a few days before Christmas in 1972 there were the usual celebrations and handshakes, but there was also a sense of having lost something that could never be regained. The author relates the wistful sense of accomplishment of one of the participants who likened it to how the architects of the pyramids must have felt when the last one was finished.

The book concludes with an Epilogue in which Chaikin relates the post-Apollo part of the astronauts story—what they did after returning from the Moon, what they are doing today, their reflections on their mission 20–25 years later. It's all very interesting reading.

The Apollo Program was supposed to have extended through Apollo 20, but the last three missions were cancelled along the way. NASA had to get on to other things. A pity, but, on the other hand, if there had been three more missions, we might have had to wait another two or three years for this excellent book.

A Man on the Moon is well documented with almost 600 notes, appendices containing mission facts and crew bios, a bibliography of further reading, and many interesting photographs. This reviewer would have preferred that the notes be cross referenced to the place they appear in the text, but it was probably judged that it would be distracting some readers.

—Jack Sevier

(The reviewer is currently with Universities Space Research Association. During Apollo he was at the Manned Spacecraft Center (now JSC) in the Apollo Spacecraft Program Office where he held various positions.)

REVIEW

FOR ALL MANKIND

Directed by Al Reinert
Videotape
National Geographic/Columbia TriStar Home Video, 80 minutes, $19.95

For All Mankind was originally released as a movie several years ago and was an Academy Award nominee for Best Documentary. It has recently been rereleased on VHS videotape. All phases of the Apollo missions are covered using in-flight movie footage, although the emphasis is, not surprisingly, on the Moon walks and on the more playful aspects of life in zero gravity. Narration is by the astronauts themselves, primarily with recollections of their experiences and feelings as told in interviews taped by director Al Reinert and supplemented by tapes of in-flight radio transmissions between the astronauts and Mission Control.

In this movie, the various Apollo missions are combined to produce a single "typical" mission rather than attempting to reproduce the details of any particular mission. Occasionally, this approach can be a bit jarring. For example, the movie gives the impression that spacewalks were routinely carried out during the 2 1/2 hour period between reaching Earth orbit and departing for the Moon. In fact, such spacewalks never occurred on any of the lunar missions—the events shown in the movie are from Gemini 4 and Apollo 9, both Earth orbital missions. Such problems are relatively rare, however, and overall the movie is quite successful in communicating a sense of what it was like to fly to the Moon. Of the many documentaries produced about America's manned space program, *For All Mankind* clearly ranks among the very best.

—Walter S. Kiefer

(Dr. Kiefer is a staff scientist at LPI.)

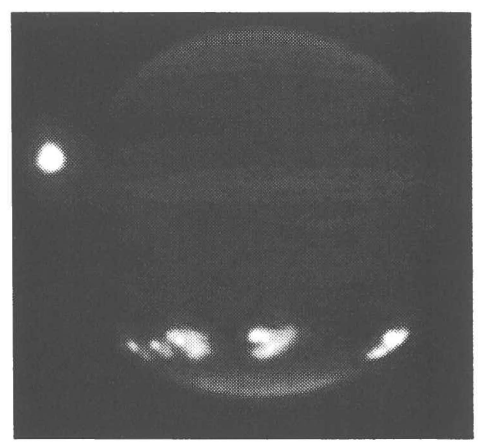
SHOEMAKER-LEVY 9
(continued from page 4)

was apparently water poor (or it may have been an asteroid), and it did not penetrate to the level of the water clouds near 3 bars pressure in the jovian atmosphere. Metals were also observed in the G cloud several days after it formed, indicating that the fragments contained a lot of rocky material. Only the Galileo spacecraft had a direct view of the impacts. It observed bright flashes lasting between 10 and 30 seconds during the K impact and the final impact, W.

3 AM CDT, July 22, 1994.

The last of the 21 fragments of Shoemaker-Levy 9 have been consumed by Jupiter. Earlier in the evening we had been observing Jupiter with a 15-inch telescope. Despite poor seeing conditions in Houston, the dark spots were clearly visible. Some observers are saddened that the comet's long death struggle is over, and many are exhausted from long nights observing and analyzing data. The first results seen over the past five days have already told us much about comets and Jupiter itself. Everyone involved is overwhelmed and overjoyed, however, by the flood of unprecedented data, which will take months, if not years, to fully understand.

(Drs. Schenk and Moses are Staff Scientists at LPI.)



Near infrared (2.2 microns) image of Jupiter on July 21. Numerous high altitude spots persist even several days after impact, forming a "necklace" of spots about Jupiter's South Pole.

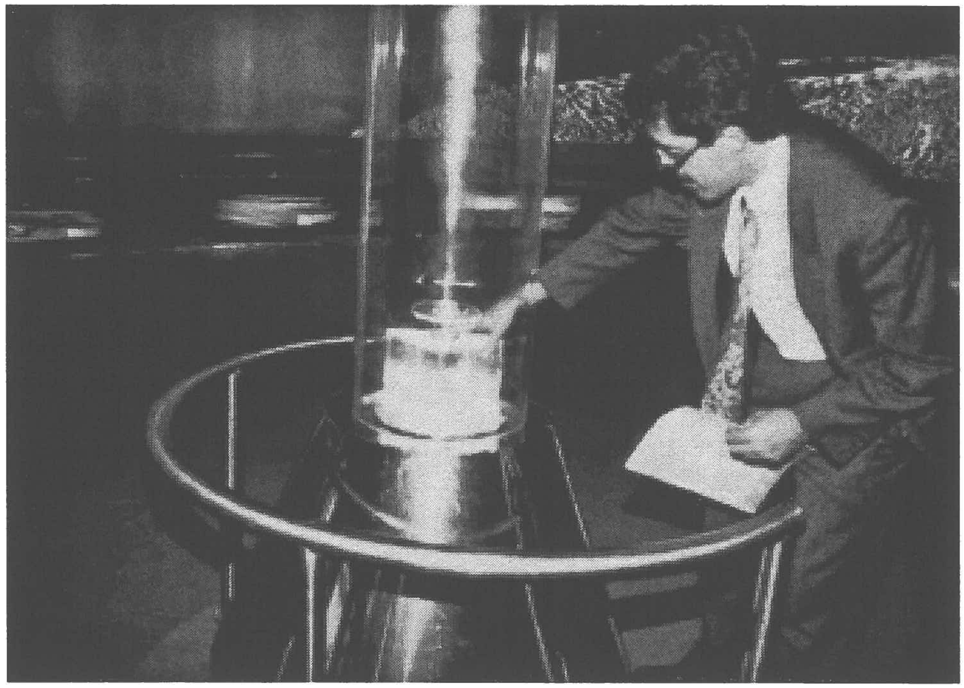
A LUNAR TOUCHSTONE FOR MEXICO

July of 1994 was a time of celebration and retrospective. It marked the silver anniversary of humanity's first halting steps on the surface of a body other than the Earth, the mission of Apollo 11. That mission, along with the other five Apollo missions that landed men on the Moon, signaled to many the beginning of a new era. It foretold new challenges and new adventures for this country and for people of all countries. However, that future was not chosen by the political leaders of the 1970s and 80s, and the promise represented by the Apollo program remains a dimly-perceived glow on the horizon.

There is one aspect of the Apollo legacy that remains vibrant today. The challenge issued by President Kennedy was to deliver a man to the Moon and return him safely by the end of 1969; it said nothing about what else that man might bring back. Indeed, the scientific aspects of Apollo, particularly the exploration of the Moon, developed as the program grew and became reality. The Apollo samples provided scientists with remarkable insight into key aspects of the formation and early evolution of the Moon, and while much of the early excitement and discoveries associated with the Apollo samples have passed, high-quality and important scientific information continues to be extracted from analysis of the "cargo" returned by the Apollo missions.

The Apollo program had a magical effect on people around the world who anxiously watched the launches of the majestic Saturn V rockets and then returned to their television sets a few days later to witness the exuberance of crew and ground support staff as two more humans experienced on behalf of their fellows the joy and awe of exploring the Moon. The return legs of the missions were no less riveting than the outbound trip; we all heaved a collective sigh of relief and felt just a little bit taller following the successful splashdown of yet another Apollo mission.

This magical effect carried over to a fascination in the samples returned by Apollo. The interest in seeing, and especially in touching, a piece of the Moon was high. Many pieces of the Apollo samples have been circulated to schools and museums for people to see, however, until recently, there have been only two so-called lunar "touchstones," lunar material that could be touched. These are housed at the Smithsonian Air and Space Museum in Washington, D.C. and at the Space Center Houston facility adjacent to the Johnson Space Center.



Touching the Moon—A visitor makes contact with a sample collected by the astronauts of the Apollo 17 mission. The touchstone exhibit opened in April of this year.

On April 30, 1994 the third lunar touchstone went on display in the new Museo de Las Ciencias at the Universidad Nacional Autónoma de Mexico (UNAM). The April ceremony was the last step in a nearly two year long odyssey that began with a request from UNAM to Dr. David C. Black, Director of the LPI. Because of a Memorandum of Understanding that exists between UNAM and the Institute to foster a variety of interactions, Dr. Black was asked to see if it would be possible to get a lunar touchstone for a major new exhibit that the museum wished to open. With the assistance of people in the Curator's Office and Public Affairs at the Johnson Space Center, and the guidance and encouragement of NASA's committee on allocation of lunar samples, the newest touchstone was prepared and delivered for the exhibit. NASA's Chief Scientist Dr. France Cordova, as well as Dr. Don Robbins, the Acting Director of Space and Life Sciences at JSC, participated in the exhibit opening. The touchstone, cut from the same Apollo 17 rock as the previous two touchstones, along with a whole rock from Apollo 11, were given to the museum on long-term loan.

It is estimated that more than a million people a year will see this outstanding exhibit.

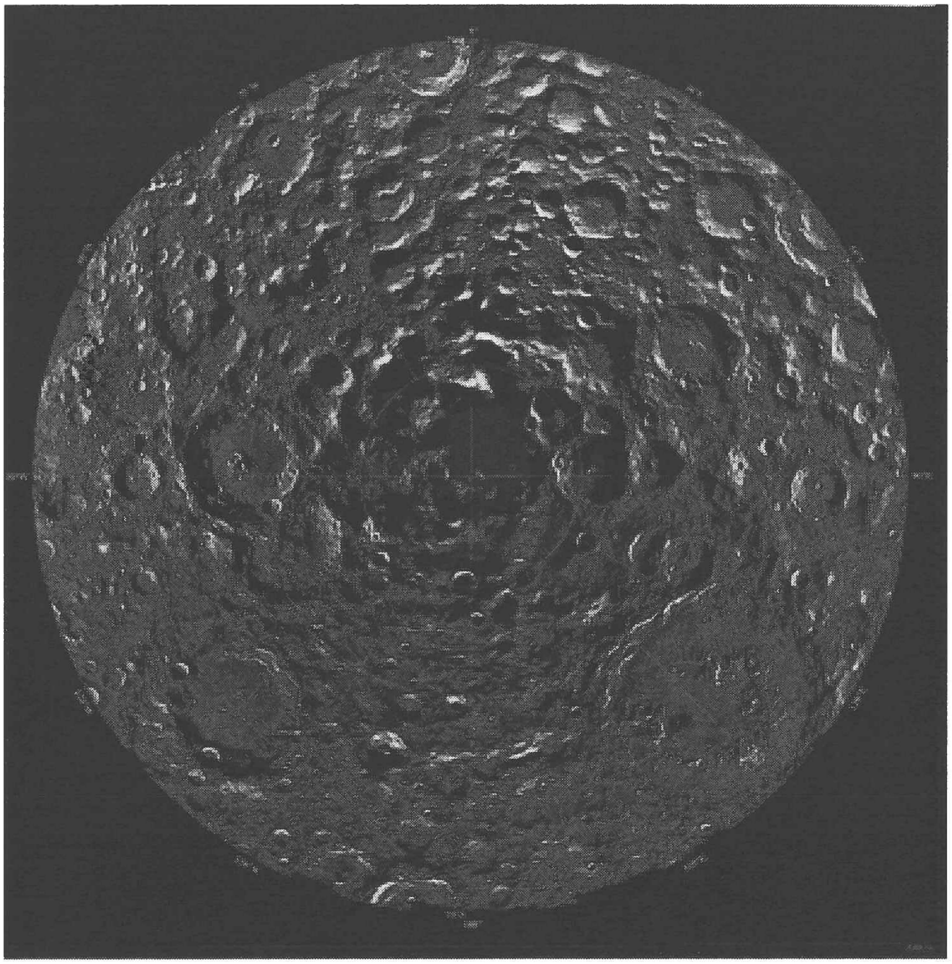
The *Lunar and Planetary Information Bulletin* is published quarterly by the Lunar and Planetary Institute, 3600 Bay Area Boulevard, Houston TX 77058-1113.

Pam Thompson, Editor

Editorial and production support are provided by the LPI Publications and Program Services Department. Copy deadline for the November issue of the LPIB is October 15, 1994.

Please send articles or announcements to:
P. Thompson, 3600 Bay Area Boulevard, Houston TX 77058-1113.

Phone: 713-486-2175, fax: 713-486-2162
E-mail: (NSI DECNET) LPI::THOMPSON
(Internet) thompson@lpi.jsc.nasa.gov



CLEMENTINE'S LUNAR MAPPING MISSION:

An Overview of Science Results

For 71 days in lunar orbit, Clementine systematically mapped the 38 million square kilometers of the Moon in eleven colors in the visible and near infrared parts of the spectrum. In addition, the tiny spacecraft took tens of thousands of high resolution and mid-infrared thermal images, mapped the topography of the Moon with a laser ranging experiment, improved knowledge of the surface gravity field of the Moon through radio tracking, and carried a charged particle telescope to observe the solar and magnetospheric energetic particle environment.

All the innovative lightweight sensors on the spacecraft, which were tested in deep space for the first time, met or exceeded expectations. They have provided the first view of the global color of the Moon, identifying major compositional provinces, and focussed on several complex regions, mapping their geology and composition in detail. In addition, they measured the topography of large, ancient impact features, including the largest (2500 km diameter), deepest (more than 9 km) impact basin known in the Solar System, and deciphered the gravity structure of a young basin on the limb of the Moon, where a huge plug of the lunar mantle may be uplifted below its surface.

The images from Clementine constitute the first-ever global digital data set for the Moon. The Science Team advised the project on the selection of color filters for the two principal mapping cameras: the UV-VIS camera (sensitive to light in the visible part of the spectrum, from about 0.3 to 1 micrometers) and the near-IR camera (which collects light in the near-infrared spectrum, from about 1 to 2.8 micrometers). The color of the Moon in the visible to near-infrared part of the spectrum is sensitive to variations in both the composition of surface material and the amount of time material has been exposed to space. The Clementine filters were selected to characterize the broad lunar continuum and to sample parts of the spectrum that are known to contain absorption bands diagnostic of iron-bearing minerals. By combining information obtained through several filters, multi-spectral image data are being used to map the distribution of rock and soil types on the Moon.

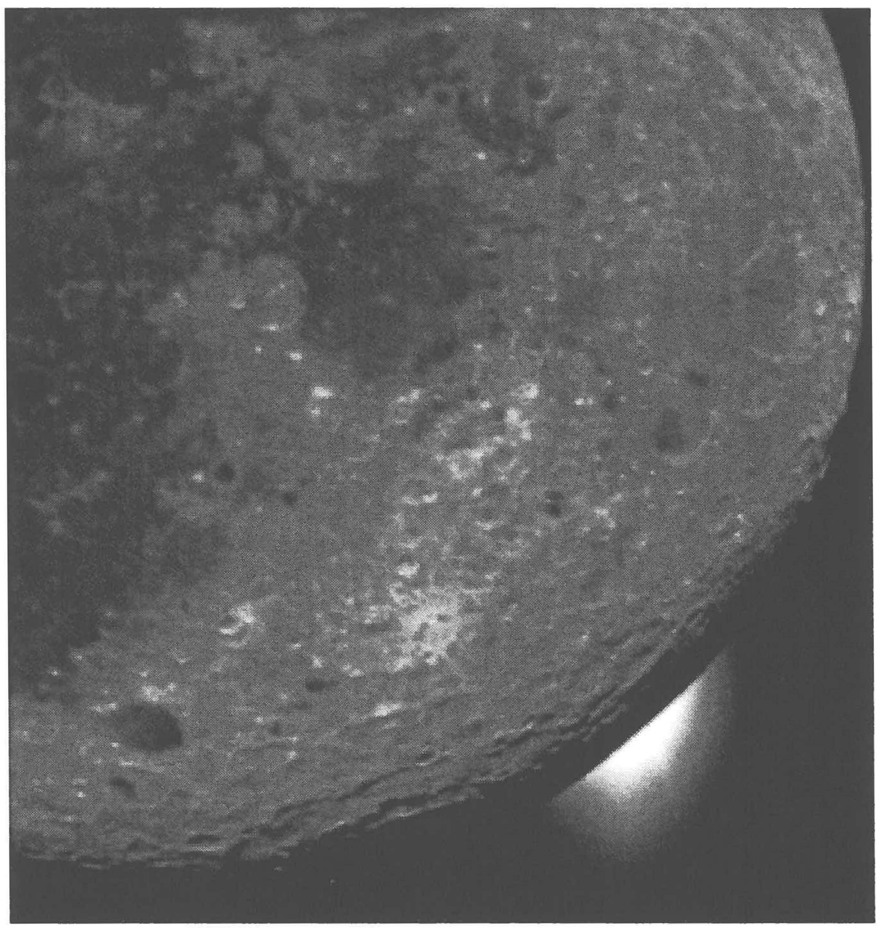
Clementine was successful in systematically mapping the Moon in these 11 colors at an average surface resolution of about 200 meters per picture element. The Mission Science Team has completed a preliminary look at the Clementine data on a global basis by reducing the resolution by a factor of several hundred, allowing the immense data volume to be easily manipulated. Several major compositional provinces are evident, including the volcanic lavas of the maria (the dark regions of the Moon), young and fresh craters, and the immense South Pole-Aitken basin, a compositional anomaly on the far side of the Moon. Preliminary studies of areas of already-known geological complexity, including the Aristarchus crater and plateau, the Copernicus crater (on the western near side), and the crater Giordano Bruno (on the eastern far side), have allowed the Team to identify and map the diversity within and between geological units, which have both impact and volcanic origins.

In addition to compositional data from the images, Clementine has allowed scientists to see either previously unknown regions of the Moon or known areas from a different and unique perspective, in both cases yielding new insights into lunar evolution. The Science Team has completed a mosaic of the South Polar region of the Moon, using over 1500 images obtained during the systematic mapping of the poles during the first month orbiting the Moon. This mosaic shows a previously unmapped portion of the Moon near the pole, south of the Orientale basin, in detail. A striking result from this mosaic, evidenced by an extensive region of shadow, is the discovery of a large depression centered very near the south pole, almost certainly an ancient impact basin about 300 km in diameter. Its significance lies in its geographic position: because the rotation axis of the Moon is nearly perpendicular to its plane of orbit around the Sun (axis inclination 1.5°), this dark region near the pole may never receive any sunlight. If so, it is very cold in these regions, possibly only about 40 Celsius degrees above absolute zero (–273° C). It has been suggested that water molecules, added to the Moon from impacting comets, may find their way into these cold traps and over billions of years, accumulate in significant amounts. To investigate further, Clementine beamed radio waves into the polar areas and the scattered radio signals were received on the large antennas of NASA's Deep Space Network. This "bistatic radar" experiment was designed to look for echoes that are diagnostic of water ice deposits. These data continue to be analyzed; no conclusive results have been reported yet.

The laser ranging data from Clementine have revealed the large scale topography of the lunar surface on a nearly global basis. A striking result from this experiment is the confirmation of the existence of a population of very ancient, nearly obliterated impact basins, randomly distributed across the Moon. These basins had been postulated on the basis of obscure circular patterns on poor quality photographs; Clementine laser ranging has provided dramatic confirmation of their existence, including their surprising depth, ranging from 5 to 7 kilometers, even for the most degraded features. Gravity data obtained from radio tracking of Clementine indicates that these great holes in the Moon's crust are compensated by plugs of dense rocks far below the surface; such dense rocks are probably caused by structural uplift of the mantle (the iron- and magnesium-rich layer below the low density, aluminum-rich crust) beneath these impact basins. Finally, Clementine laser ranging data have given the dimensions of the largest confirmed basin on the Moon, the 2500 km-diameter South Pole-Aitken basin: this feature averages over 9 kilometers deep, making it the largest, deepest impact crater known in the Solar System.

The Charged Particle Telescope on Clementine observed a large burst of particles from the Sun from February 20–24. It also monitored several additional low-energy particle bursts of magnetospheric origin over the course of the mission. These data will be combined with observations from many of the other spacecraft now operating in Earth-Moon space to observe and characterize the plasma environment from different vantage points.

The scientific significance of the lunar data set from Clementine is immense. For the first time, scientists have global, multi-spectral image data (of consistent viewing geometry, resolution, and lighting conditions) for an entire body of planetary dimensions. From the Apollo and Luna programs, they also have lunar rock and soil samples of known geological context. Such a data set does not exist for any other object in the Solar System, including the Earth. With Clementine data for the Moon, a new era begins in the exploration of the geology of the planets using global multi-variable data sets. Judging from an initial look at the Clementine data, such a powerful analytical technique will give scientists new insights into how the Moon has evolved over its protracted and complex history.



Above—Clementine star tracker image of the lunar surface lit by Earthshine. Opposite page: Mosiac of the south polar region of the Moon, mapped for the first time by Clementine.

CALENDAR 1994

AUGUST

12–14
Comets, Asteroids & Meteors Educators Conference, Pasadena, California. Contact: Public Services Office, Mail Stop 186-113, or Public Education Office, Mail Stop CS-530, Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena CA 91109-8099.
Internet: d.m.seidel@jpl.nasa.gov

21–26
Gordon Research Conference: Origin of Life, Newport, Rhode Island. Contact: David Des Marais, Mail Stop 239-4, NASA Ames Research Center, Moffett Field CA 94035-1000. Phone: 415-604-3220; fax: 415-604-1088.
Internet: david_desmarais@qmgate.arc.nasa.gov

26–29
Mapping and Remote Sensing Tools for the 21st Century, Washington, D.C. Contact: Registrar, Mapping and Remote Sensing Tools for the 21st Century, American Society for Photogrammetry and Remote Sensing, 5410 Grosvenor Lane, Suite 210, Bethesda MD 20814-2160. Fax: 301-493-0208.

29–Sep 1
Practical Robotic Interstellar Flight: Are We Ready? New York, New York. Contact: Edward Belbruno, The Geometry Center, University of Minnesota, 1300 South Second Street, Minneapolis MN 55101. Phone: 612-626-1845; fax: 612-626-7131.
Internet: belbruno@geom.umn.edu

28–30
Meteoroids, Bratislava, Slovakia. Contact: Anton Hajduk or Vladimir Porubcan, Astronomical Institute SAV, Dubravska 9, 84228 Bratislava, Slovakia. Phone: 42-7-375157; fax: 42-7-375157.
Internet: astropor@savba.savba.cs

SEPTEMBER

21–23
Space Debris course, University of Kent at Canterbury, UK. Contact: The Space Debris Course Organiser, Unit for Space Sciences, Physics Laboratory, The University, Canterbury, Kent CT2 7NR, UK.

21–23
Conference on Deep Earth and Planetary Volatiles, Pasadena, California. Contact: Publications and Program Services, LPI, 3600 Bay Area Boulevard, Houston TX 77058-1113. Phone: 713-486-2166; fax: 713-482-2160.
Internet: simmons@lpi.jsc.nasa.gov

SEPTEMBER (CONTINUED)

25–28
Fourth Astronomical Data Analysis Software and Systems Conference, Baltimore, Maryland. Contact: Betty Stobie. Phone: 410-516-8671; fax: 410-516-6864.
Internet: softconf@stsci.edu
WWW: http://ra.stsci.edu/ADASS.html

OCTOBER

1–2
SPACE 1994 Conference, Toronto, Canada. Contact: Peter White, SEDS-Canada, 4850 Keele St., North York, Ont., M3J 3L1. Phone: 416-650-9890.
Internet: space1994@eol.ists.ca
ftp: nereid.sal.ists.ca /pub/SEDS-York/
WWW: ftp://nereid.sal.ists.ca/pub/SEDS-York

13–15
Chondrules and the Protoplanetary Disk, Albuquerque, New Mexico. Contact: Publications and Program Services Department, LPI, 3600 Bay Area Boulevard, Houston TX 77058-1113. Phone: 713-486-2166; fax: 713-486-2160.
Internet: simmons@lpi.jsc.nasa.gov

16–19
1994 Hypervelocity Impact Seminar, Santa Fe, New Mexico. Contact: Jeanne Southward, Department 1433, Sandia National Laboratories, Albuquerque NM 87185-5800.

17–21
Third International Workshop on Positional Astronomy and Celestial Mechanics, Cuenca, Spain. Contact: Alvaro Garcia Lopez, Observatorio Astronomico, Avenida Blasco Ibanez, 13, 46010 Valencia, Spain. Phone, fax: 34-6-3864773.
Internet: obsast@vm.ci.uv.es

24–27
Annual Meeting of the Geological Society of America, Seattle, Washington. Contact: Jean Kinney, GSA Headquarters, Box 9140, 3300 Penrose Place, Boulder CO 80301. Phone: 303-447-2020.

30
Sixth International Conference on Laboratory Research for Planetary Atmospheres, Bethesda, Maryland. Contact: Kenneth Fox. Phone: 301-314-9124 or 301-262-5481.

OCTOBER (CONTINUED)

31–Nov 4

26th Annual Meeting of the Division for Planetary Sciences of the American Astronomical Society, Washington, DC. Contact: Publications and Program Services, LPI, 3600 Bay Area Boulevard, Houston TX 77058-1113. Phone: 713-486-2166; fax: 713-482-2160. Internet: simmons@lpi.jsc.nasa.gov

NOVEMBER

13–16

International Lunar Exploration Conference, San Diego, California. Contact: International Space Enterprises, 4909 Murphy Canyon Road, Suite 330, San Diego CA 92123. Phone: 619-637-5777; or National Space Society, phone: 202-543-1900.

DECEMBER

5–9

Flares and Flashes (IAU Colloquium 151), Sonneberg (Thuringia), Germany. Contacts: H. W. Dürbeck, Astronomisches Institut, Wilhelm-Klemm-Strasse 10, 48149 Münster, Germany. Phone: 49-251-83-3561; fax: 49-251-83-3669. J. Greiner, Max-Planck-Institut für Extraterrestrische Physik, 85740 Garching, Germany. Phone: 49-89-3299-3577; fax: 49-89-3299-3569. Internet: iauc151@cynus.uni-muenster.de

6–10

American Geophysical Union, Fall Meeting, San Francisco, California. Contact: AGU Meetings Department, 2000 Florida Avenue NW, Washington DC 20009. Phone: 202-939-3203; fax: 202-328-0566.

JANUARY 1995

4–7

Venus II—Geology, Geophysics, Atmosphere, and Solar Wind Environment, Tucson, Arizona. Contact: Amy Schumann, Lunar and Planetary Lab, Space Science Building, University of Arizona, Tucson AZ 85721. Phone: 602-621-2902. Internet: amys@lpl.arizona.edu

9–12

9th Annual Microgravity Science and Space Processing Symposium, Reno, Nevada. Contact: John Hockstein, Memphis State University. Phone: 901-678-2257.

FEBRUARY

7–10

1995 Yosemite Conference on Solar System Plasma Physics, Yosemite National Park, California. Contact: Jim Burch or Hunter Waite, Southwest Research Institute, P.O. Drawer 28510, San Antonio TX 78228. Phone: 210-522-2526; fax: 210-522-3493.

MARCH

13–17

26th Lunar and Planetary Science Conference, Houston, Texas. Contact: Publications and Program Services Department, LPI, 3600 Bay Area Boulevard, Houston TX 77058-1113. Phone: 713-486-2166; fax: 713-486-2160. Internet: simmons@lpi.jsc.nasa.gov

27–30

Solar System Ices, Toulouse, France. Contact: Michel Festou, Observatoire Midi-Pyrenees, 14, avenue Edouard-Belin, 31400-Toulouse, France. Fax: 33-61-53-67-22. Internet: festou@obs-mip.fr

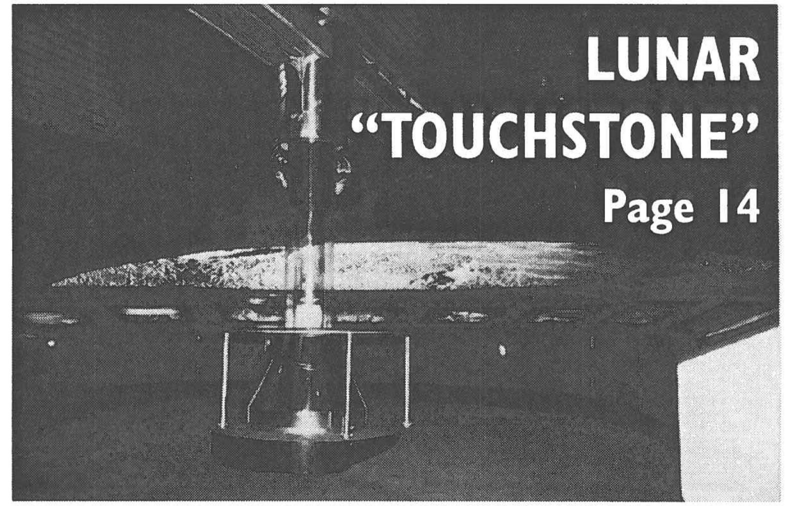
HAPPY HOLIDAYS!

Please make note of the **NEW deadline** for abstracts being submitted to the 26th Lunar and Planetary Science Conference:

January 6, 1995

This deadline is a change from the previously announced deadline of December 23, 1994.

INSIDE



Universities Space Research Association USRA

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

ADDRESS CORRECTION REQUESTED

NON-PROFIT
U.S. POSTAGE PAID
PERMIT NO. 29
LEAGUE CITY TX 77573