The PLANETARY REPORT

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Sampling the Moon

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COVER: Harrison Schmitt, now a U.S. Senator from New Mexico, investigated this giant boulder during the Apollo 17 mission to the Moon. The Apollo astronauts returned over 360 kilograms of lunar geological samples to Earth. The "Moon rocks" are now housed in the Lunar Curatorial Facility in Houston, Texas. PHOTO: JOHNSON SPACE CENTER/NASA

LETTERS TO THE EDITOR

I am not an American citizen (I am French), but your publication is the first one that makes me "feel at home" in a cosmic sense: *The Planetary Report* dwells in the grand and noble, not the petty and the senseless. I feel happier to know that there is a team like yours, devoted and striving to open the frontierless expanse of the universe to the public at large. You are humanists before being scientists; this is sound, good, comforting. Such a sound spiritual and intellectual balance means hope. I very much appreciate the place you give to the artist, writer, poet, alongside the scientist; in this way all creative facets of the human mind are associated with the marvelous adventure. Thanks to your undertaking, the chances of our planet becoming a better world to live in are increased. I am most grateful to all of you for the time, work and dedication that you give and the hope that you make possible.

PIERRE FRASSIE, *Hollins College, Virginia*

The interview with Dr. Hans Mark was very revealing and somewhat disappointing. While one cannot deny the military applications of the space program under the guise of "national defense," one would think that a man in Dr. Mark's position would have a wider, more humanistic approach to our space efforts. He vastly underestimates the true nature of public support for the space program, as displayed by the success of Delta Vee's fund raising activities and of The Planetary Society itself. Again, it is an example of our political leaders being out of touch with the real sentiments of the public.

BOB SAFIR, *Los Angeles, California*

As with Hans Mark, I am an early member of The Planetary Society. I also agree with Dr. Mark that a permanent Earth-orbital facility and lunar base are our next logical priorities. I would also suggest that the geological study of the Moon and Apollo asteroids, along with industrial and biological experiments in space, are of more immediate importance than long-range probes to the outer planets (although we should by no means abandon *Voyager*). It is missions such as these which will have the greatest near-term economic and psychological impact and build the momentum needed to carry this country, and humanity, forward.

It seems clear that once the public and its leaders perceive the solar system—and not merely Earth—as the environment in which they live, there will be sufficient impetus and funds for further large-scale exploration. I believe that mankind will be better served by Dr. Mark's superior grasp of socio-political reality than by the wishful thinking expressed by some members of our Society. In this regard, I suggest that Dr. Mark deserves our support.

JASON G. ALBERT, *East Windsor, New Jersey*

Louis Friedman's interview with Dr. Hans Mark was indeed provoking. And while I will concede the truth of some of [Mark's] statements, I take issue with his implication that planetary exploration is not "socially imperative."

I believe it is a social imperative of the highest order to encourage scientific endeavor such as planetary exploration which seeks to answer who we are and where we came from. Answers to these questions force us to more seriously regard our uniqueness, our unity and our interdependence. The broader perspective offered from space must surely illuminate the vanity with which we presume justification of our unconscionable treatment of one another.

Imperative? The scientific exploration of space and dissemination of the resulting knowledge may well be our last hope of release from the bonds of provincialism which threaten us with extinction.

DONNA ROBINO, *Sacramento, California*

Our "Talk with Hans Mark" in the March/April 1982 issue drew more mail than we have received on any other topic.—ED.

Value of the Planetary Program

by David Morrison

The program of planetary science and exploration that the United States has pursued for the past twenty years has contributed greatly to our knowledge of the planetary system and thereby to our understanding of our planet Earth. At the same time, this program has significantly enhanced our technological capability, supporting our economy and contributing to our national defense. Finally, the program has been a source of national pride and international prestige.

Planetary science is basic science of the sort that is appropriate for support by the federal government. It is not directed to specific short-term goals; rather, it is the exploration of new ideas as well as other worlds, carried out in the expectation that knowledge, in the long run, will have lasting benefits for humanity. We have so far only begun to reap the harvest of our investment in planetary exploration, but there are a number of items that illustrate the potential. I am particularly impressed by the comparative studies of atmospheric circulation that are leading to improved understanding of weather and climate on the Earth. The problems of long-term climate change on our planet are of profound practical significance, and it is the planetary program that has provided the sobering examples of Venus, with its run-away carbon-dioxide greenhouse effect, and Mars with its evidence of climate deterioration from a warmer and wetter past to a current desiccated ice age. The link between other planets and our own is, of course, provided by the people who are able to see and utilize the connections—people such as Jim Pollack and Brian Toon of NASA Ames Research Center. They have utilized their understanding of Venus and Mars to contribute greatly to current models for the effects, on the delicate climate balance of the Earth, of carbon dioxide released by fossil fuels and of the dust produced by volcanic eruptions.

In a time when the workable ore deposits of Earth are rapidly being depleted, we must also look to space for possible new resources. On our planet, most of the metals and other materials of economic value are deep in the core, forever inaccessible, and the ones that we do have on the surface are the result of peculiar and often poorly understood chemical and geological processes. In contrast, we now believe that many asteroids contain an abundance of iron, nickel and other valuable materials in easily accessible form. We have barely begun to look at these potential resources, and certainly I cannot tell you today how practical their development might be. But I can say that some of these asteroids are among the most easily reached objects in the solar system, and if we do not investigate them, we will never have the chance to assess their potential value to us.

The asteroids and comets are also of interest to us for their potential to damage the Earth, perhaps catastrophically. We know that impacts by large objects do take place; Meteor Crater in Arizona was formed only a few thousand years ago, and even in our century a collision with what was probably a cometary fragment created a 1908 blast in Siberia equivalent to a hydrogen bomb in energy. One of the exciting discoveries of the past few years has been the link between such extraterrestrial events and the evolution of life. It is now well established that a catastrophic collision with a 10 kilometer asteroid probably was responsible for the mass extinction of life 65 million years ago at the end of the Cretaceous Period, and other discontinuities in the development of life may also be related to impact events. Today, there is yet another danger from even a relatively small impact, since it is feared that the resulting explosion could trigger an accidental nuclear exchange. The entire subject of impacts of asteroids and comets with the planets is in its infancy. One of the many casualties of budgetary restrictions in the planetary program has been our ability to pursue this area with the vigor it merits.

While the knowledge gained from planetary exploration may require decades before its usefulness is apparent, the technological benefits of the program are immediate. Deep space exploration challenges many technologies, including electronic miniaturization and reliability assurance, compact power generation, robotics, computer hardware and software development, and production of advanced detector arrays for remote sensing. The economic payoffs from such developments are obvious.

I would also like to argue for the less tangible benefits of the high technology of planetary exploration. Missions such as *Viking* and *Voyager* are highly visible, and the fact that it is American technology, and only American, that is capable of these remarkable feats can have profound importance in a highly competitive world market. In effect, it is free advertising of the best kind for all of America's industry. In the same way, the success of our space missions contributes to American security by increasing the confidence of the world in our economy and the capabilities of our advanced weapons systems. In a world where the ultimate weapons must remain forever untried, much advantage is to be gained by a demonstration of capability in a public area such as planetary exploration. Although I am neither an economist nor a military strategist, I strongly suspect that a strong program of planetary exploration could be fully justified on both economic and military grounds, even without the benefits of the scientific results obtained.

Finally, I wish to mention again the intangible but very important values of national pride and international prestige that derive from all of our civil space programs. In a time when the nation is beset by problems, both internal and external, it is particularly important that we undertake visible, challenging tasks and carry them out successfully. All Americans were thrilled by the success of the shuttle. But the planetary program also contributes substantially in this area, and it does so in a highly cost-effective way. It is imperative that we continue, through a renewed commitment to space exploration, to provide world leadership in this important area.

David Morrison is a professor of astronomy at the University of Hawaii. He has served as chairman of the Division for Planetary Sciences of the American Astronomical Society and is a past acting Deputy Associate Administrator for Space Science at NASA.

This article is excerpted from Dr. Morrison's testimony before the Subcommittee on Space Science and Applications in the House of Representatives.

Discovering an Asteroid

by Eleanor F. Helin

Eleanor F. ("Glo") Helin is a planetary scientist and member of the technical staff at the Jet Propulsion Laboratory in Pasadena. In 1960, she began her work in planetary science at the California Institute of Technology, analyzing meteorites and terrestrial rock samples in preparation for the return of samples from the Moon. For the past ten years, she and Dr. Eugene Shoemaker of Caltech have carried out a systematic search for near-Earth asteroids using the 48-inch Schmidt telescope at Mount Palomar Observatory in California. Among Dr. Helin's discoveries are the Apollo asteroid 1976AA, the first asteroid found to have an orbit smaller than the Earth's; Ra-Shalom (named in honor of the Camp David peace talks), which has the smallest orbit of any known asteroid; and Comet Helin, which she found in the spring of 1977.

Early this year, Dr. Helin made another important discovery—the Apollo asteroid 1982DB, which orbits so close to Earth that it would be easier to reach than the Moon. In this article, Dr. Helin describes how she discovered this best known candidate for an asteroid rendezvous mission.

My drive to the Caltech campus that Saturday morning was made pleasant by the prospect of having my friend and colleague, Gene Shoemaker, join me at Palomar Observatory for the first time in several years. We were leaving early so that we could arrive at Palomar by midafternoon; Gene would then have time to become familiar again with the 48-inch Schmidt telescope and our general observing procedure. After we arrived at the observatory, I reviewed details with Gene and he practiced plate loading and darkroom procedure. We discussed the observing plan that I had prepared for our new program of photographing periodic comets (those which return to the inner solar system at regular intervals). Our objective was to observe faint comets at large distances from the Sun, where perhaps the bare nucleus could be resolved and measured.

We discussed size and type of emulsion plates that we thought best for the night's comet observations. Our plan for the night was to photograph accessible periodic comets, guiding the exposure at the comet's rate of motion. These variable rates were calculated and the telescope was set to track the comet throughout the exposure. We started our observations for the night of February 27–28, around 7:30 p.m., and moved along as planned until after 5:00 a.m. Ten plates were obtained, including one standard asteroid field. Through the night as comet fields were photographed, we developed the plates and set them to dry so that we could examine them as soon as possible.

Sunday's weather turned bad; dark clouds rolled in and rain began to fall. Gene and I grabbed a few hours sleep. In the afternoon, we returned to the 48-inch dome and started to carefully inspect the plates we'd taken the night before.

We checked the comet images and then scanned the plates for other objects of interest. A number of moderately interesting asteroid tracks were marked on each plate. In the early evening of the 28th, I found a highly inclined trail showing rapid motion relative to other asteroids on the plate. After determining approximate positions, we found it was the Apollo asteroid Antinous. Apollo asteroids orbit the Sun on trajectories that take them across the orbit of the Earth. This was an independent rediscovery of Antinous, since the asteroid appeared on a routinely observed standard field for our systematic search for planet-crossing asteroids.

With dinner our spirits were lifted and our tastebuds treated to steak *au poivre* prepared by the excellent Palomar "monastery" chef, Michael Thornberry. This was a special dinner because it was Mike's "last supper," as he called it, before he transferred to the Mount Wilson Observatory.

Later Gene and I spent a tedious Sunday night at the dome watching for a break in the weather. Finally, around 2:00 a.m. we gave up the vigil and retired to the monastery to catch up on our sleep.

The next morning Shoemaker returned to Caltech to meet his Monday class. I spent the afternoon reviewing the ten plates, carefully scanning those we had examined Sunday. Late in the afternoon, I put the Comet Du-Toit plate on the lightbox and focused in on the unusual split comet. I mused that, unlike the other plates that showed at least some asteroid trails, this plate of Du-Toit appeared to be void of such telltale streaks. The plate was tracked at the rate of the comet, 1.03 degrees per day, and showed the comet as two tadpole-shaped images about a degree apart, each slightly fuzzy, but showing a generally "solid" nucleus with a thin tail. The rest of the plate was covered with trailed images of stars that moved at a different rate relative to the "tracked" comet. In this instance, I was looking for a special trail which would appear different from the star trails, lying at a different angle and of a different length.

After looking closely at the main component of Comet Du-Toit, I went to the upper-left-hand corner of the plate and began systematically scanning back and forth across it with a magnifying lens. Finally, a little more than a centimeter away from the main component of the comet, my eyes caught a long trail inclined to the shorter star trails. The finely etched trail showed the same guiding zigzags as the stars. It was surely a real object but it moved at a different rate than the stars—an asteroid! Shortly after I found the trail, Roger Higson, the night assistant, came in and I showed him the asteroid. He expressed approval in his typical manner: "Good value, Glo."

As it neared 5:00 p.m., I rushed back to the monastery for dinner, a bit excited with my find. Shortly, Gene arrived and I told him about the new asteroid. After dinner and a soulful look at the weather report on TV, we returned to the dome and examined the new discovery once more. We both made position measurements and concurred on its approximate position. But we only had one plate of 50 minutes exposure and so we didn't know the direction of apparent motion. Usually, when photographing asteroid fields with the 48-inch Schmidt, we "gate," or interrupt, the exposure to determine the direction of motion with one plate. In this new program of pho-

PHOTO: JPL/NASA

The inclined trail of asteroid 1982DB (B) lies in the upper right quarter of this photograph. One component of the split Comet Du-Toit (A) appears in the lower left of the picture. Helin and Shoemaker were observing this comet when the asteroid was discovered.

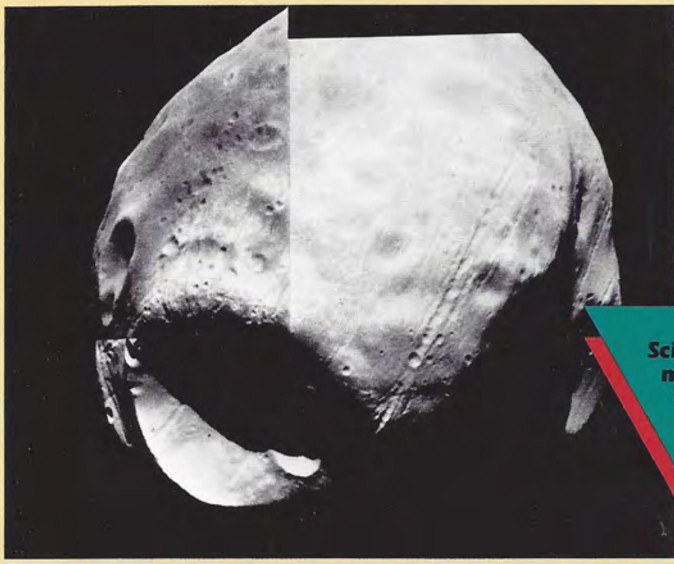


PHOTO: JPL/NASA

Scientists have speculated that the Martian moon Phobos (left) and its smaller companion, Deimos, may be asteroids that have been captured by the planet's gravity. 1982DB might be similar in appearance.

Some asteroid researchers have suggested that it might be feasible to "capture" an asteroid and bring it into orbit around the Earth, where it could be mined for minerals and metals. In this painting, an Apollo asteroid is being moved past the Moon and into geosynchronous orbit.

PAINTING: DON DIXON

tographing comets, it seemed unnecessary. However, because we didn't have this plate gated, we had a bit of detective work to do. The apparent movement of the new object could be either prograde (in the direction that planets orbit the Sun) or retrograde (in the opposite direction). We carefully measured the length of the trail and Gene extrapolated positions for either direction. I telephoned B. G. Marsden of the Minor Planet Center at the Harvard-Smithsonian Center for Astrophysics, reported the discovery, and gave him its approximate position in right ascension and declination, the time of observation and an estimated magnitude of 16. He gave me the preliminary designation "1982DB" for the newly discovered asteroid.

Soon after, I decided to phone Ted Bowell of the Lowell Observatory, tell him of the discovery and explain our plight—the bad weather at Palomar would make recovery difficult. I gave him Gene's predicted positions. He told me the weather was also uncertain in Flagstaff, but assured us that he would do what he could.

The night of March 1, we stayed late at the monastery as heavy fog, clouds and rain enshrouded the observatory. Along about midnight, it started to clear intermittently. We opted to go to the dome and be ready if the opportunity arose to reobserve 1982DB. Although the humidity was high, about 2:00 a.m. we opened for a short exposure, assuming prograde motion. But soon the humidity rose above 90 percent and the dome was closed for the rest of the night. I developed the plate, hurriedly examined it, and found no image of an asteroid. We spent more time examining it after the plate was dry, but still found no trace of 1982DB. Although we found no asteroid, its absence essentially eliminated the prograde direction and pointed to retrograde apparent motion for 1982DB.

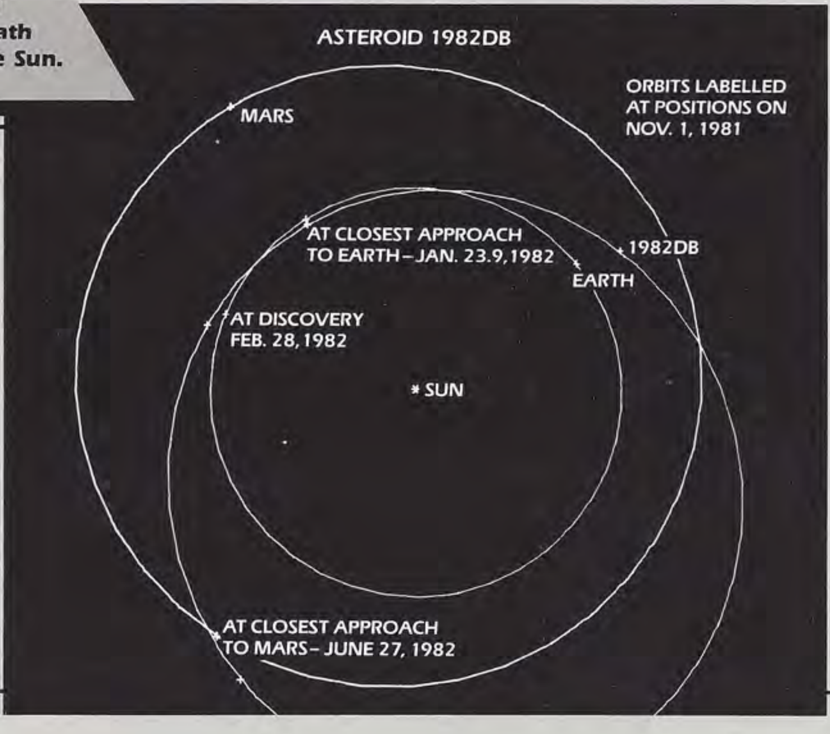
On Tuesday, March 2, our scheduled observing time was over. Jim Gibson of JPL followed us on the 48-inch Schmidt. We asked him to make an observation of 1982DB which he did—successfully recording it in the predicted position calculated for a retrograde motion.

Ted Bowell telephoned shortly thereafter and confirmed that he had also observed 1982DB, so now we could calculate an orbit. Since precise position measurements are extremely important, when I returned to JPL Scott Dunbar and I immediately measured the trails of 1982DB and the split comet on an X-Y measuring machine. When the numbers were reduced, we promptly reported the asteroid's position to Brian Marsden at the Minor Planet Center. He mentioned that, in extrapolating DB's position backward in time, he found that it had come within 4.3 million kilometers of the Earth on January 23, making it the closest cosmic visitor in some years. Brian also offered preliminary orbital elements which showed "DB" to be an Apollo asteroid with a very low inclination of 1.4° to the plane of the ecliptic, a moderate eccentricity of 0.375 and a perihelion (the closest point in its orbit to the Sun) of 0.951 Astronomical Unit (the distance from the Sun to the Earth, about 150 million kilometers). I had already surmised that the inclination was very low from the discovery plate, since the image had moved nearly parallel with the split comets, which were close to the plane of the ecliptic.

With such a low inclination, moderate eccentricity and perihelion distance less than one AU, it occurred to me that "DB" was likely to be a good mission candidate. I called Neal Hulkower of JPL and gave him the preliminary orbital elements to determine just how good it might be. Neal enthusiastically agreed to do a mission analysis for the new asteroid. The results came out most positively. 1982DB is the best known mission candidate, requiring less energy for rendezvous than Anteros, the asteroid previously considered the best candidate.

Still later, 1982DB observations were made at Palomar's 18- and 48-inch Schmidt telescopes, and at Harvard's Oak Ridge station, which improved the precision of the orbit. Although no physical observations have yet been obtained for the new Apollo asteroid, it could range in size from 0.5 to 1 kilometer in diameter, depending on whether it is a light or dark object. This new discovery offers us renewed confidence that still more favorable mission asteroids will be found in the future. □

This computer-generated orbit plot shows the path of 1982DB around the Sun.



The Care and Feeding of Lunar Samples: The Lunar Curatorial Facility

by Michael Duke

The Lunar Curatorial Facility, located at the Johnson Space Center in Houston, Texas, could become a casualty of proposed cuts in NASA's planetary program. The facility houses the samples collected on the* Apollo *missions to the Moon, and serves as a focus for the continuing analysis of the "Moon rocks." In recent years, the responsibilities of the facility have expanded and it now also houses meteorites and samples of "cosmic dust" collected by high-altitude aircraft— dust which probably comes from comets and may reveal information about the formation of the solar system.

Funds to keep the Lunar Curatorial Facility open run to about $1 million per year, or about .017 percent of the total NASA budget. In its proposed budget for fiscal year 1983, the Reagan administration included a $40 million cut to planetary research. Congress is now considering the restoration of these funds. The decision to close or not to close the facility will be made by the NASA Administrator, James Beggs.

The air crackled with excitement as the *Apollo 11* Preliminary Examination Team prepared to open the first box of rocks returned from the Moon. To this privileged group of scientists, the chance to participate in this endeavor was a miracle. The culmination of an intense national effort to reach the Moon was the delivery of these first pieces of Earth's sister planet to the Lunar Receiving Laboratory in Houston, and the team had the awesome responsibility for describing the samples and trying to make preliminary interpretations of their scientific significance.

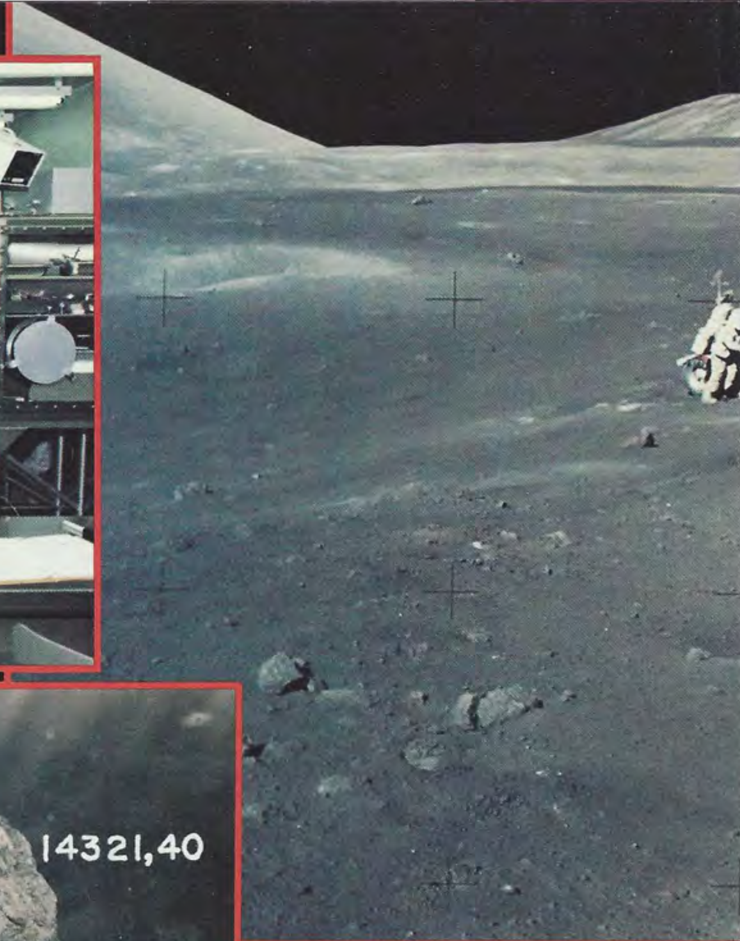
At first, their observations were tentative. "Is that glass?" "Is that basalt?" "I don't know, it looks like basalt, but it's from the Moon!" Confidence grew quickly after preliminary tests and it soon became evident that the samples, while complex, were understandable: careful work could unlock lunar secrets frozen in stone for billions of years. Some secrets were quickly discovered, others have required painstaking detective work still underway, and some will not be unlocked until other key areas on the Moon can be explored.

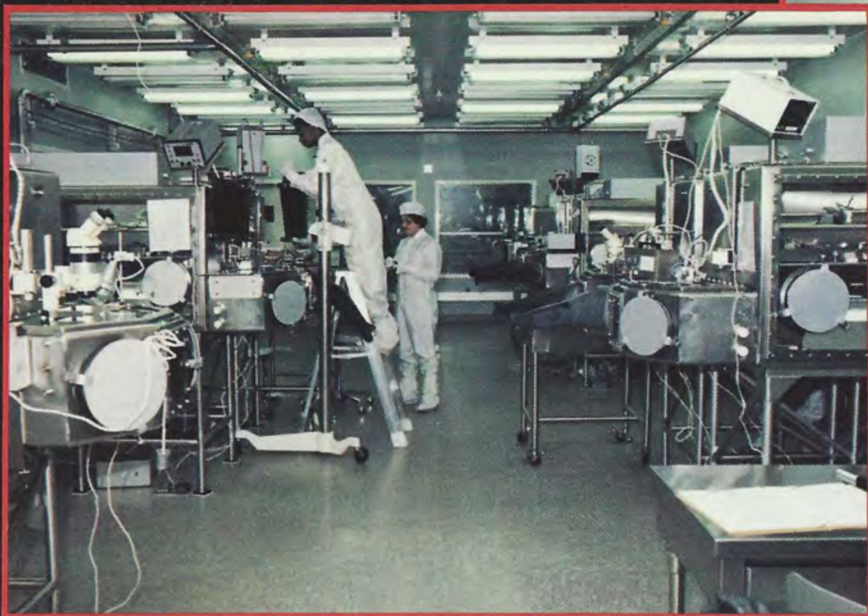
Some scientists were amazed by the amount of material collected by the *Apollo 11* astronauts. Many had been prepared to compete for the opportunity to study small bits, but here was more than twenty kilograms. Moreover, the collection was made of diverse materials. Some larger rocks appeared to be homogeneous basalts, but most samples were aggregates containing small fragments of different rocks, and in the soil there were millimeter-sized fragments differing from the larger rocks. Even smaller glass droplets in the soil apparently represented a still more diverse set of rocks melted by impacts at distant locations on the Moon.

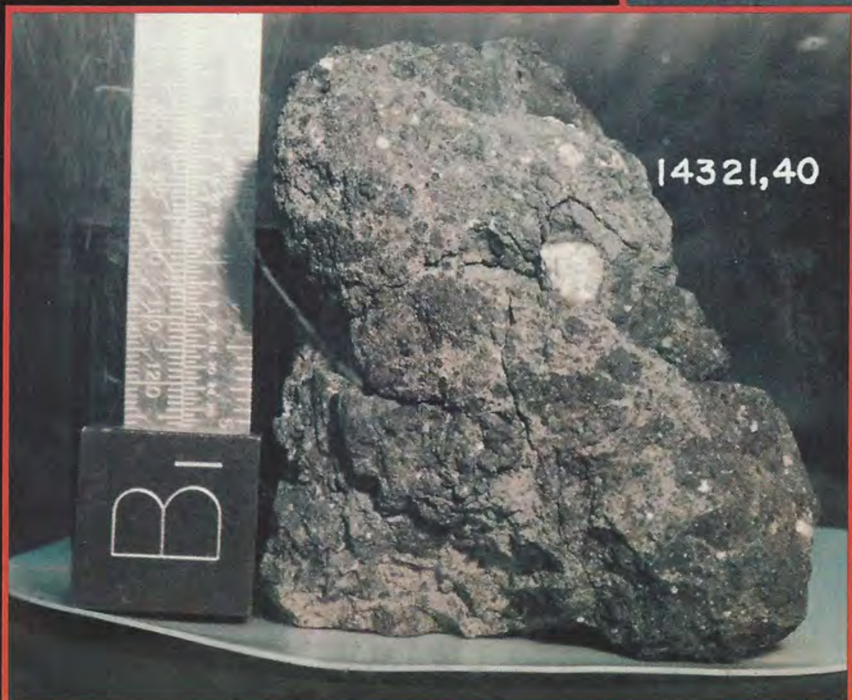
With subsequent missions, the sample collection became larger and more diverse. *Apollo 12* sampled a second mare region, while *Apollos 14, 15, 16,* and *17* sampled more complex sites near or in the lunar highlands. The total collection grew to include over 360 kilograms of rocks, soil, core tubes and other special samples. Some of those samples had been collected with great difficulty, such as the *Apollo 15* drill sample which took astronauts Dave Scott and Jim Irwin a frustrating hour of intense physical exertion to pull out of its hole. While they worried about retrieving the sample, mission control worried about their falling behind the timeline. This precious collection of samples was acquired at great personal risk by the astronaut-geologists, and as a result of a major national effort.

The jigsaw puzzle of lunar history began to fit together with the first samples, but most of the studies between the flight missions were purely descriptive since there was not sufficient time to do thorough work. Here were materials different from those found on Earth. The rocks were completely free of water or alteration products associated with water. Iron existed partly in the metallic state, which very rarely occurs naturally on Earth. The mineral ilmenite (an iron-titanium oxide) was so abundant in some basalts that they would be considered an ore on Earth. Several new minerals were discovered (e.g. tranquillityite, named for the *Apollo 11* landing site, and armalcolite, named after the *Apollo 11* crew, Armstrong, Aldrin and Collins). Lunar basalts had much less sodium and volatile heavy trace metals (mercury and lead) than similar terrestrial basalts. As determined by the decay of their radioactive isotopes, many rocks were very old. Aluminum-rich materials dominated the lunar highlands rocks, as distinct from the iron-rich mare basalts. The lunar maria—singular "mare"—are the dark basaltic lowlands of the Moon. All of the rocks and soils had been irradiated by cosmic rays, were slightly radioactive, and thus yielded the amount of time they had been sitting on the lunar surface after being excavated by impacts. The glasses in the soils were analyzed and shown to represent diverse rock types.

As the worldwide scientists' network evolved into a definite lunar sample study program, both intense competition and new forms of cooperation were stimulated. Competition fostered the development and application of new, more precise analytical techniques. The lunar mare basalts were found to range from 3.8 to 3.2 billion years old, and it was important to distinguish ages within that narrow range. To detect age differences of 0.1 billion years within the lunar basalts by the rubidium/strontium isotopic technique required the determination of relative abundances of strontium isotopes to one part in 10,000 or better. Such precision was unattainable before *Apollo*, but several laboratories developed this capability specifically for measuring the ages of lunar rocks. These ages are the basis for an outline of lunar history.







ABOVE: Apollo 17 astronaut Harrison
New Mexico, gathered samples from t
A trained geologist, Senator Schmitt u
on the Moon and investigate the lunar

TOP LEFT: Technicians photograph a s
The cabinets are slightly pressurized (
nitrogen gas to maintain an oxygen- a

LEFT: A pristine granite fragment was
breccia last year. The fragment provid
comparison with granites of Earth.

TOP RIGHT: A lunar breccia is examine
curatorial facility. A cut surface displa

RIGHT: This pristine sample of the anc
Apollo 17 astronauts. It was formed 4

Competition for material developed for particularly small but unusual samples. Different studies were coordinated so that many investigations could be done on the same piece of material. This not only replaced competition with cooperation, it also ensured that the maximum scientific information was obtained from each sample. This required careful preparation of especially precious samples and the further development of techniques. Eventually even samples as tiny as a few millimeters could be studied chemically, mineralogically and isotopically. This consortium approach has been modified and amplified to the point that now teams of investigators with diverse interests do a substantial number of new lunar sample studies. Similar team techniques have now been more widely applied in studies of meteorites and many terrestrial rocks. They have also been extended to interplanetary dust grains.

Scientists are now attempting to piece together the early history of the Moon. A similar history can only be guessed for the Earth, because here no rocks from that period remain. On the Moon before 3.9 billion years ago, before the mare basalts were formed, the lunar crust formed and the lunar highlands took shape. Deciphering this period has been difficult because it was dominated by collisions with asteroids, meteoroids and comets that thoroughly fragmented, mixed and, in some cases, transformed the lunar crust and changed rocks into new chemical and mineralogical forms.

Although clues were found during the early years of the program, most identification and analysis of these early crustal rock fragments has been accomplished in the past six years, when "fingerprints" for crustal rocks have been found. A critical step was to develop analytical techniques for trace amounts of metals such as gold and iridium, which are tracers for meteorite contamination but occur in exceedingly small amounts in the "pristine" uncontaminated rocks. The work is painstaking, beginning with

PHOTOS: JOHNSON SPACE CENTER, NASA

…chmitt, now a U.S. Senator from …e Taurus Littrow valley on the Moon. …as the first (and only) scientist to walk …geology.

…pecimen in the Lunar Curatorial Facility. …notice the protruding gloves) with …nd water-free environment.

…ound on a cut surface of this lunar …ed the first good sample for direct

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…ent lunar crust was collected by the …5 billion years ago, deep within the Moon.

detailed description of highland breccias in the curatorial facility and then chipping off of fragments to provide small amounts for preliminary analysis. Only a few of the fragments selected in this way are from pristine crustal rocks, so the work goes slowly.

The lunar crust appears to have formed between 4.4 and 4.5 billion years ago, immediately after the Moon and the rest of the solar system formed from a nebular cloud of gas and dust. The pristine rocks are igneous, indicating that major sections of the crust were molten during formation. It has been proposed that the outer 200 kilometers of the Moon were entirely molten in a "magma ocean" which segregated lighter crystals toward the surface, forming a distinctive crust while dense crystals sank. Enough evidence has been gathered to indicate that such an explanation is too simple and alternative models should be studied. Because only a small portion of the lunar material has really been studied in detail, and because of its complexity, rarer but potentially important lunar rock types remain to be found in the samples. For example, the first large (more than one gram) fragment of a pristine lunar granite was discovered this year.

As *Apollo*'s treasures were first examined, thoughtful scientists realized that analyzing and understanding the samples would take a long time, that many of the samples were rare or one of a kind, and that it might be many years before new collections could be made. They recognized that, in addition to making them available for study, it was necessary to provide a long-term means of conserving and protecting the samples. The permanent curatorial laboratory at Houston emerged, not without growing pains, from this commitment to the lunar sample collection as a scientific treasure and as a symbol of *Apollo*, a great national achievement. The present facility, dedicated on the tenth anniversary of *Apollo 11*, provides permanent secure stor-

(continued on page 14)

Harold Clayton Urey: 1893–1981

by Carl Sagan

Harold Urey was one of the founders of modern planetary science, a major force in early American lunar exploration, an Associate Editor of *Icarus* from its inception in 1962 through 1979, and a member of the founding Advisory Board of The Planetary Society. His involvement with planetary science began in the late 1940s, and it is easy to forget that by then Urey had already completed several major scientific and public careers.

He was born in Walkerton, Indiana, on April 29, 1893, before the discovery of the electron or the invention of the airplane. In 1914, Urey entered Montana State University majoring in zoology, his first research project being on Missoula River protozoa. His interest in biology remained with him all his life: its expression ranged from raising orchids to his trailblazing experiments with Stanley Miller on the first steps in the origin of life; his seminal 1960 reports for the Space Science Board of the National Academy of Sciences (of which he had been a founding member) urged that the understanding of the origin of the solar system and the search for life on other planets should be the principal scientific objectives of planetary exploration. "I don't like rocks," he once confessed, "I like life."

Urey received his baccalaureate degree in 1917, just as the United States entered World War I, and soon thereafter found himself in Philadelphia as a research chemist in a munitions factory. He attributed his interest in an academic career to this experience. After the Armistice he returned as an instructor in chemistry at Montana State and in 1923 received his doctorate in physical chemistry at the University of California at Berkeley. In 1930, having moved to Columbia University, he announced that he, together with G. M. Murphy and F. G. Brickwedde, had discovered a heavy isotope of hydrogen, called deuterium. For this work, Urey received the 1934 Nobel Prize in chemistry.

By 1940 another war had intervened to change the course of Urey's life. From 1940 to 1945 he led Columbia University's major contribution to the Manhattan Project. Urey's responsibility was the development of the most effective means for large-scale production of heavy water and for the separation of uranium isotopes. This was work which naturally followed his research of the previous decade. While recognizing the apparent military necessity for the development of the first atomic bombs, Urey, like most of the principals in the early development of these weapons, was appalled by the consequences of their use on Japan. "Atomic bombs are evil," he wrote in 1946. "They cannot be used to maintain peace." He said, "There is no constructive solution to the world's problems except eventually a world government capable of establishing law over the entire surface of the Earth." But not many people listened.

In his late fifties, with a distinguished record of professional accomplishment and public concern, Urey might well have faded slowly into retirement: had he done so, no one would have accused him of an unproductive career. But instead he embarked on what may well be considered, if we manage to avoid nuclear self-annihilation, the most important of his contributions. In the summer of 1950, Urey and Harrison Brown agreed to give a summer course on "Chemistry in Nature" at the University of Chicago. In preparing his lecture notes for this course, Urey found that on such questions as the heat balance of the Earth and the fractionation of the chemical elements during the early history of our planet he had something to say. At about the same time he was fascinated by Ralph Baldwin's 1949 book, *The Face of the Moon*. Baldwin discussed basaltic lava flows, cratering statistics, and a general attempt to describe the evolution of the lunar surface. Indeed, the story of lunar cratering mechanics was not entirely unlike the physics of the excavation of craters made by Urey's nuclear weapons. The twin themes of the origin of the Earth and the origin of the Moon converged into a full-scale rethinking of the nature and origin of the solar system, which found a systematic exposition in Urey's Silliman lectures at Yale University, published in 1952 as *The Planets: Their Origin and Development*.

This was also the time when, at the University of Chicago, Gerard P. Kuiper was making great progress both in physical studies of the solar system and in his developing ideas on its origins. Although there was a considerable degree of mutual acrimony, there is no question that their ideas cross-fertilized. Urey wrote: "Perhaps it will surprise readers of this volume that a physical chemist would undertake to prepare a book on the planets...indeed it astonished me.... However, as astronomers have had undisputed possession of the field since ancient times, except for some interference from religious leaders and ancient religious writings, some discussion from other sciences may prove useful." The mere fact that a scientist of Urey's eminence considered a full-scale treatment of planetary cosmogony possible was a major contribution to the field, quite apart from his specific conclusions. The book is filled with candid and illuminating comments on the scientific method such as: "I early expressed certain tentative views with more confidence than was justified, was attacked for them, and found myself trying to justify them when perhaps they should have been abandoned."

The book's principal conclusions—then thought quite radical—were that the terrestrial planets were formed at low temperatures, and that the core of the Earth differentiated from the mantle "at least partly" during geological time. *The Planets* is still enormously provocative. For example, in a one-paragraph discussion of Titan we read: "The mean temperature of Titan should be about 90 degrees Kelvin, and the vapor pressure of methane at this temperature is 0.1 atmosphere.... The atmosphere is apparently not saturated at the surface. However, the presence of noncondensible gases, which might be nitrogen and argon, would provide an inert atmosphere, and hence just as in the case of water on Earth less than a saturated amount of methane should be present...it may be that methane forms glaciers on Titan, since the melting point is 90.7 degrees Kelvin." Or, "The calculation on the heat balance of the Moon...shows that the interiors of objects of similar mass regardless of their original temperatures must have risen above the melting point of ice in their interiors, and hence the water of the Jovian moons must all be at or near their surfaces. In fact, water flows instead of terrestrial lava flows may occur from time to time." He would not have excluded Enceladus. Or, in a discussion of the evolution of the terrestrial planets: "As time progressed, hydrogen would be lost from all these planets and photochemical dissociation would

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This obituary is excerpted from one published in Icarus, *Volume 48, Number 3, December 1981, pages 348–352.*

produce hydrogen from water in the high atmosphere which would escape while the oxygen remained. Gradually, ammonia would be oxidized to nitrogen and methane to carbon dioxide. However, intermediate oxidation states would include many organic compounds such as aldehydes, acids, amines, amino acids, and so forth, and the oceans should have been more or less diluted or concentrated solutions of organic compounds...it can be postulated that photochemical processes arising from ultraviolet light from the Sun or atmospheric electrical processes caused the formation of such thermodynamically unstable compounds. They are soluble in water and in the absence of organic life would remain for long periods of time in the primitive oceans...this would provide a very favorable situation for the origin of life."

It was on this question of the origin of life that I first went to see Urey in 1952, before *The Planets* had been published. He was accessible and generous to an enthusiastic but very unsophisticated undergraduate and, among other things, he urged me to look up a graduate student of his who was carrying out an experimental program to check his suggestion about amino acids and other organic molecules. The student was named Stanley Miller, and the results were first hinted at later that year. Urey's starting point had been the realization that cosmic abundances require the early composition of the Earth's atmosphere to be reducing. When asked more specifically what organic compounds he expected to be made, he replied "Beilstein," referring to the massive German language compendium on all organic compounds known to humans. He was not far wrong. When Miller presented their results in a colloquium at the chemistry department at Chicago, there were many in the audience who voiced their concern that some terrible mistake had been made—that, for example, Miller had exercised insufficient care in sterilizing his reaction vessel and that the ninhydrin-positive compounds he was detecting were not prebiological but biological. Urey rose vigorously to Miller's defense, arguing both that the control experiments had been performed and that Miller's amino and alpha-hydroxy acids were precisely the sorts of compounds that *should* be produced in such experiments. He was, of course, right. The Miller-Urey experiment is now recognized as the single most significant step in convincing many scientists that life is likely to be abundant in the cosmos—a triumphant contribution to Urey's old love, biology.

When I remember Urey the man, I see a melange of images: He once called his secretary from Pittsburgh and asked, a little petulantly, "I'm in Pittsburgh. Why am I here?" (He had a certain tendency toward absentmindedness.) I recall one geologist cautioning, in the acknowledgments to an important paper, that not all those he had thanked were in agreement with his conclusions, "as one of them has been at some pains to point out." That was Urey. I see him lecturing gently before the fledgling "University of Chicago Astronomical Society" that Toby Owen and I founded, and I see him in furious debate at scientific meetings—where he would often rise to correct the pronunciation of the word kilometer. When it's a *unit* of measurement, he would say, you accent the first syllable: cen'timeter, not centi'meter. When it's an *instrument* of measurement, you accent the second syllable: thermom'eter, not ther'mometer. Thus, kil'ometer, not kilo'meter. I remember his willingness to change his mind in a case where he had blocked the advancement to tenure of a young scientist at another institution and then later asked to be forgiven. He would tell his graduate students that he would be happy to have his name on their papers or not, according to what they thought would best aid the advancement of their careers. I recall a luncheon I had with him at a COSPAR (Committee on Space Research) meeting in Warsaw in the early 1960s, after he had moved to the University of California at San Diego, in which he complained about being treated as "the fastest gun in the West." To make their reputations, some younger scientists had come gunning for him, he said. Then he brightened, and concluded that the youngsters had their merits: they forced him to reconsider his ideas. He was 70 years old.

I look at my ancient copy of *The Planets* and at the signature he wrote for me on the title page and think about his role in guiding NASA into serious scientific exploration of the Moon, and of his delight at the results from the early *Ranger* and *Surveyor* missions, how he helped make experimental solar system cosmogony and the search for extraterrestrial life respectable, about how much the planetary community owes to him. My last letter from him, dated May 20, 1980, accepts our invitation to serve on the Advisory Board of The Planetary Society. He died seven months later, in his 88th year, a scientist who transcended disciplinary boundaries, who confounded the traditional wisdom about significant research being the province of the young, and who helped carry us to the Moon and the planets.

Carl Sagan is the David Duncan Professor of Astronomy and Space Sciences, and Director of the Laboratory for Planetary Studies at Cornell University.

News & Reviews

by Clark R. Chapman

In early March, the Soviet Union landed two complex spacecraft on the broiling hot surface of Venus. *Veneras 13* and *14* not only took sharp pictures of the rocky surface, including the first ever in color, but made direct x ray measurements of the chemical composition of Venus's rocks. Two weeks later, Soviet scientists Valeriy Barsukov and Yuri Surkov, armed with preliminary results, arrived in Houston to attend the annual Lunar and Planetary Science Conference at Johnson Space Center.

Venus Diary

When planetary news is happening, there is always at least one experienced reporter on the scene: Jonathan Eberhart of *Science News*. Hardly a weekly issue appears without a pithy, readable article by Eberhart on a solar system topic. Widely regarded as the dean of planetary science writers, Eberhart is also an accomplished songwriter and folk singer. His latest album on Folk-Legacy Records, "Life's Trolley Ride," features his poignant song about the changing climate of Mars.

Three timely articles kept *Science News* readers up-to-date this spring about the Soviet *Venera* probes. The March 20 issue features early versions of three of the Venus pictures (see *The Planetary Report*, May/June 1982, pages 7 and 8) and a portrait of the *Venera 14* lander itself. Eberhart's March 27th report from Houston tabulates the x ray results, which indicate that the *Venera 13* site may be atop a high-potassium, alkaline, basaltic lava flow. The *Venera 14* site instead has a composition more like lavas on the Moon and on the Earth's ocean floors.

Science News gave Venus full-blown coverage in its April 10 issue with a centerspread of the *Venera 13* color picture. Jonathan Eberhart's accompanying article traces the history of Venus research back to 1975 when the first *Venera* picture was successfully transmitted to Earth. (He references earlier Venus articles in *Science News*). The April 10 front cover shows part of a global topography map of Venus, made from *Pioneer* Venus Orbiter altimeter data, with seven *Venera* landing sites plotted. With the acreage of all *Venera* photos together equal to that of a modest Earthly park, Eberhart reminds us that there is yet no approval for the American Venus radar mapper mission that could reveal the planet's geology and place the local *Venera* landscapes in context with the global-scale topography already mapped.

Venus was only one of many topics discussed at the thirteenth annual "rock conference" in Houston. The first such meeting on planetary geoscience was held back in 1970 and provided a forum for scientists to announce the results of their initial analyses of the *Apollo 11* Moon rocks. Now the June, 1982 issue of *Geotimes*, with Martian volcano Olympus Mons on its front cover, is devoted to eleven articles summarizing the scientific sessions of the latest conference. *Geotimes* is written for professional geologists, not the lay public. Still, the summaries are concise and readable. There are discussions of whether a 200-kilometer ocean of magma ever existed on the Moon, where igneous meteorites come from, and how the planets formed.

Antarctic Treasure Trove

In the desolate polar wastes of Antarctica, snow piles up relentlessly. It compresses itself into ice, then slowly spreads outward, over millennia, to the continental margin. The ice breaks from the edge. Later the resulting oceanic icebergs melt and the moisture ultimately cycles back to the ice pack via snowstorms. When the meandering Antarctic ice encounters a mountain barrier, it bulges and becomes susceptible to erosive ablation by the bitterly cold "katabatic" winds. These circumstances provide an unlikely setting for an extraterrestrial bonanza, first discovered by Japanese explorers in 1969.

In the March/April 1982 issue of *American Scientist*, William Cassidy and Louis Rancitelli describe why Antarctic meteorites, which have been picked up by the thousands from special concentration zones, rival in numbers the total historical collection of meteorites from the entire world. Cassidy has been on several Antarctic expeditions himself, and Rancitelli has studied the cosmic ray record in many of the new meteorites.

The environment that concentrates meteorites in Antarctica also protects them from the chemical attack and disintegration called weathering. Thus, Antarctica has preserved these space fragments for over a million years, instead of the mere two centuries represented by most other meteorites. (Eighteenth century scientists regarded reports of meteorite falls as modern scientists treat flying saucers. Most meteorites found before 1800 were dismissed as worthless rocks and thrown away.)

Extraterrestrial Life?

Cassidy and Rancitelli say that the polar deep freeze protects meteorites from contamination, permitting measurements of amino acids that reflect chemical processes in the primordial solar system that may have been precursors to life itself. In the intervening four-and-one-half billion years, life has evolved to where we can wonder whether or not other similar beings exist in other planetary systems. In the April, 1982 issue of *Sky and Telescope*, Woodruff T. Sullivan reports on the recent conference on the Search for Extraterrestrial Intelligence (SETI) held in the Soviet Union. (See the May/June *Planetary Report*, pages 12 and 13.)

Another article in the April *Sky and Telescope* describes the Lunar Curatorial Facility at Johnson Space Center, which cares for the *Apollo* Moon rocks as well as the Antarctic meteorites. NASA's lunar sample and meteorite research, as well as the Facility itself, are threatened by budget cuts. The *Sky and Telescope* article shows why there is vitality in these basic research endeavors and underscores the need for changing our nation's budgetary priorities.

Clark R. Chapman, author of the new book, Planets of Rock and Ice, *is a research scientist at the Planetary Science Institute in Tucson, Arizona.*

Society Notes

by Louis Friedman

Professor Paul Horowitz's "Suitcase SETI" multi-channel signal analyzer, which he has been building with Planetary Society funds, is now complete and he has taken it to the Arecibo radio telescope to try it out. We congratulate Dr. Horowitz on rapidly reaching the first milestone in his project, and we look forward to seeing the instrument in use at observatories around the world. The "Suitcase SETI" (which is now more steamer-trunk-sized) is a special purpose analyzer which listens for signals from space at special radio frequencies in the hopes of detecting extraterrestrial civilizations. In itself, it is one small part of the total Search for Extraterrestrial Intelligence (SETI) program, but "Suitcase SETI" is a very innovative project.

Meanwhile, the Society has been encouraging reinstatement of the NASA SETI program, dropped from the federal budget last year, which is a combination of a broad multi-frequency all-sky survey and a set of targeted searches for radio signals. Congress should take action on this budget item soon.

Through a combination of member support and coordination with scientific colleagues, the Society's special projects program has rapidly moved forward. The search for planets around other stars has long been recognized as important, not only to the SETI program, but to the study of the origin and evolution of planetary systems. The existence of these "extrasolar planets" about many stars is theoretically predicted, but none have yet been found. To help look for these planets is of obvious interest to The Planetary Society.

The astrometric method, where astronomers look for "wobbles" in the motion of stars caused by the perturbing effects of the hypothesized planets, is one way to search for extrasolar planets. A group at the Allegheny Observatory of the University of Pittsburgh is building a new astrometric telescope, primarily with private funds, and The Planetary Society was able to provide them with a key grant. But astrometric observation is only one technique for detecting extrasolar planets, and some space methods have been proposed that may enable direct observation of such planets. Dr. David Black of the NASA Ames Research Center recently chaired a session on this subject at the American Astronomical Society meeting and has agreed to present a survey and assessment of the various observation methods to Planetary Society members.

The Planetary Society has also decided to become involved with the investigation of Earth-crossing asteroids. Elsewhere in this issue, Dr. Eleanor Helin reports on the latest discovery of such an asteroid. The significance of Earth-crossing asteroids in the evolution of the Earth and its life forms, their role as possible future exploratory targets, as well as their potential importance in understanding the basic properties of the solar system, make discovering and investigating these objects extremely important. For this reason, the Society will provide public information and education, and will sponsor research and space missions study of the Earth-crossers. A preliminary program study is now being done.

We recently announced that we may sponsor a series of graduate level courses, projects and seminars devoted to the future exploration of Mars. Frustrated by the lack of any current study on Mars exploration within NASA, we have decided to keep the subject alive by working with faculty and students to provide source material, coordination, communications and documentation for a set of Mars studies dealing with the science and engineering for future exploration. The general thrust is to take us from our present knowledge toward a determination of the steps for human colonization of Mars. Response to a questionnaire sent to our scientific and engineering colleagues was excellent, and a number of good courses were proposed. We will shortly select specific courses and projects for immediate implementation. We thank the students and their associates at the Boulder Center for Science and Policy who organized the "Case for Mars" conference at the University of Colorado, with our co-sponsorship, and initiated and stimulated the development of these further Mars studies.

Member support for these projects will help them succeed and will enable The Planetary Society to play an innovative role in seeding new missions of exploration of the solar system and new activities in the search for extraterrestrial life. We have been gratified by the frequency and amount of donations for these projects and are pleased that we have been able to move forward far more quickly than we anticipated. This has both helped the projects and proved public interest in a vital space exploration program.

Events and Lectures

We have been pleased by the turnout at a number of Society-sponsored events in the last few months. Griffith Observatory in Los Angeles was sold out and a second show had to be quickly arranged for members to hear Dr. Richard Terrile of the *Voyager* Imaging Team discuss the latest discoveries about Jupiter and Saturn. Many members in the Sacramento area, as part of a "Community Day" at the American River College, heard me talk on possibilities for solar system exploration. Professor Reta Beebe of New Mexico University spoke to more than 500 persons at a Texas star party about planetary science and solar system exploration. And, at the Field Museum in Chicago, more than 750 people attended a Planetary Society lecture on the state of solar system exploration. Other events included our co-sponsoring SpaceFest at the Copernican Observatory in New Britain, Connecticut, co-sponsoring a lecture by Dr. David Morrison at the meeting of the Astronomical Society of the Pacific at the University of California at San Diego, and an exhibit at the Baltimore meeting of the American Institute of Aeronautics and Astronautics.

Several other events are planned for the remainder of this year in different locations around the country. Members will be notified of these events and lectures by special mailings, and can also keep informed of upcoming happenings by using our telephone information lines: east of the Mississippi, call (213) 793-4328; west of the Mississippi, call (213) 793-4294.

Thank Yous

We wish to thank David Brown, president of Time Energy Corporation, for his very generous donation of an Apple computer for The Planetary Society. Not only will we use the computer for our office management, word processing and accounting, but we plan to work it in as a research tool as part of the Society's special projects in SETI, future Mars exploration and the search for Earth-crossing asteroids. We are also indebted to Sheila Bell, of Mr. Brown's company, who has helped us with both the hardware and software of the Apple system.

We would also like to thank Dr. Terry Martin of the Jet Propulsion Laboratory and his colleagues for their help in answering scientific inquiries sent to the Society. □

WASHINGTON WATCH

by Louis Friedman

Watching Washington these days is a bit like peering through the clouds of Titan from a flyby spacecraft. Nothing is visible through the murky atmosphere and, while there may be tantalizing hints, if not of life itself, then of the basic elements necessary for life, there is little that can be predicted on the basis of the few facts gathered thus far. For a long time this spring the President and the Congress were unable to agree on a budget. Therefore, the entire budget process was delayed and this, in turn, introduced uncertainty for the work of the authorization and appropriation committees. Passage of the budget resolution is a necessary first step so that the committees have approximate guidelines for their work in dealing with specific NASA programs.

In our last issue we reported on the critical situation in the research and technology of the planetary program. For want of approximately $40 million in the total $6 billion NASA budget, spacecraft may be turned off, facilities closed, and one-third of the scientists involved in planetary research could have their work stopped. We have been pleased to note that the congressional committees have not been insensitive to this problem; we have had several detailed discussions on these issues with congressional staff members, and their offices have heard from a great many Planetary Society members. This has had an effect.

The House Committee on Science and Technology specifically added $23 million of the NASA authorization for planetary research in the fiscal year 1983 budget. This was subsequently passed by the full House. The Senate Committee on Commerce and Science went even further in redistributing funds so that the entire $40 million would be made available. This redistribution of funds resulted from a proposal by Senator Harrison Schmitt (Republican-New Mexico), which would have the Department of Defense pay a greater share of space shuttle operations costs, commensurate with its use of the shuttle. This provision is controversial and it is unknown at this time whether it will become law and lead to increased money for science projects in NASA. Congressional leadership for additional authorization of planetary research and technology funds came from Senators Schmitt and Howard Cannon (Democrat-Nevada) and Representative Ronnie Flippo (Democrat-Alabama). Following passage of the committee bills by the Senate and House, a conference will be held to resolve differences for a final bill.

Congressional action on the appropriations (as distinct from authorization) for NASA is expected to take at least two months longer. However, Congress did take significant appropriations action when it passed a supplement to the 1982 budget. They redirected NASA to develop the *Centaur* as a shuttle upper stage for use on the *Galileo* mission. This would delay the launch to 1986—but not the spacecraft's arrival at Jupiter. On the high performance *Centaur, Galileo* can fly directly to Jupiter without following the ΔVEGA trajectory (explained in the March/April 1982 *Planetary Report*). This would save about two years in flight time. Whether *Galileo* will fly on the *Centaur* or on the Interim Upper Stage (IUS) with a ΔVEGA trajectory will probably not be determined for a few months. The decision will depend on resolution of the differences between the administration and Congress.

In another part of Washington, the Solar System Exploration Committee (SSEC), a NASA advisory group, met to consider its recommended program for future exploration. The committee expressed continued support for a Venus Radar mapper, a scaled-down version of the Venus Orbiting Imaging Radar (VOIR), as the next new start. It is being backed strongly for inclusion in the 1984 budget. The proposed spacecraft would return a more modest amount of data and travel on a more eccentric orbit about Venus than VOIR. But the mission would still provide a 500-meter resolution map of the entire surface of the planet, unveiling Venus and providing important comparative planetology data about Earth's sister planet. The SSEC is also closely examining small orbiters of Mars (for geochemical and climatology data) and of the Moon (for geochemical and water detection data); a Titan probe (perhaps as part of a U.S.-French mission); and comet and asteroid rendezvous missions. The committee's final recommendations will be made in September, 1982.

Dr. Noel Hinners, the current head of the Solar System Exploration Committee, announced that he is leaving his position as Director of the Smithsonian National Air and Space Museum to become Director of NASA's Goddard Spaceflight Center. Dr. Hinners was formerly NASA Associate Administrator for Space Science. He was also a scientist for Bellcomm Corporation during the *Apollo* program, evaluating landing sites and helping to plan the astronauts' scientific activities on the Moon. □

Lunar Curatorial Facility
(continued from page 9)
age of the collection under exacting oxygen- and water-free environmental conditions and supports the continued study of the lunar sample collection by scientists worldwide. This facility's skilled staff carries out the "care and feeding" of this remarkable zoo of extraterrestrial material and makes them available for scientific study and public display.

The Lunar Curatorial Facility is one of the keys to further progress in lunar science. Improved analytical techniques allow better determination of strontium isotopes as clues to ages and chemistry of crustal rock fragments. However, a microscopic bit of the gypsum wallboard that surrounds us in most homes and offices could ruin a strontium isotope analysis if it should get into a sample. Many other elements and compounds are potential contaminants that might invalidate an analysis, such as gold in jewelry or lead in solder, and even the most minute amounts must be avoided. Through advanced preservation, storage and analysis techniques, scientists may be confident that the samples they study are valid measures of the Moon.

Contamination control, however, is only one function of the curatorial facility. Perhaps even more important is the focus that it gives for cooperative, interdisciplinary studies. There the work of many scientists can be brought together toward an understanding of the nature of the Moon and its history. Many problems remain in lunar sciences, and progress depends not only on development of new analytical techniques and new lunar theories, but on the proper preservation and the continued availability of lunar materials for study.

Michael Duke is the chief of Planetary and Earth Sciences at NASA—Johnson Space Center in Houston, Texas.

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A COMET OVER WASHINGTON, D.C.—In this painting, artist Ron Miller imagines the appearance of a comet in the dawn sky over the Capitol. Comets may be remnants from the formation of the solar system some 4.5 billion years ago, holding the answers to questions on how our world came to be.

Ron Miller lives and works near Fredericksburg, Virginia. He is the author of Space Art and co-author of The Grand Tour and the forthcoming Worlds of Chesley Bonestell.

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