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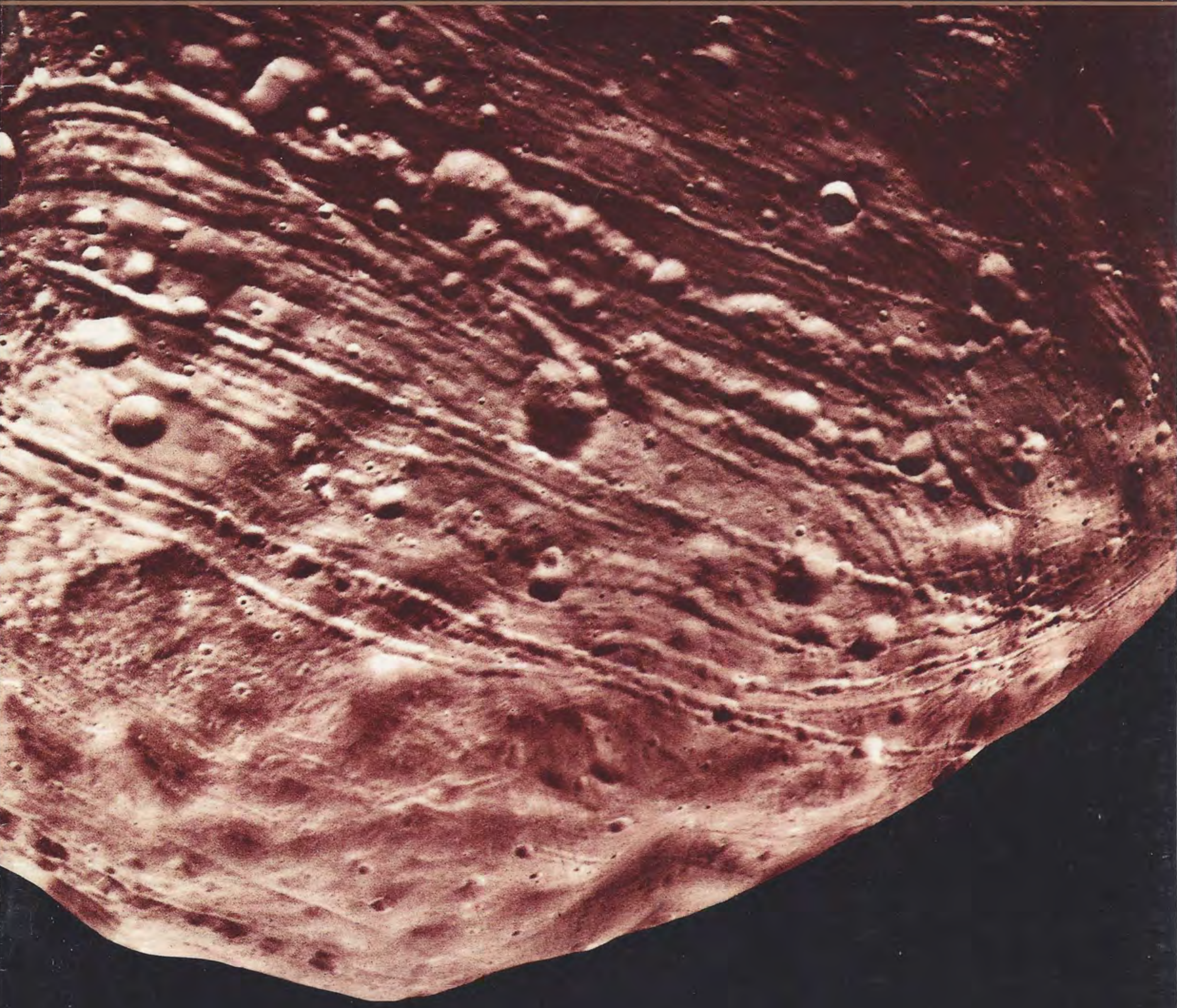

Asteroids

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COVER: Phobos, the larger of the two Martian moons, may be an asteroid captured by the planet's gravity. It is only about 20 kilometers in diameter and is very dark, suggesting that it may be related to the C-type (carbonaceous) asteroids. The grooves that score the surface may have been generated in an ancient impact with a smaller asteroid that punched in the end of Phobos, excavating the crater Stickney. ***Image: Spacecraft Planetary Imaging Facility, Cornell University***

REPORT TO OUR MEMBERS:

Asteroid Project Discovers Best Mission Candidates

by Eleanor Helin

Last year The Planetary Society awarded a grant to the World Space Foundation for their Asteroid Project, which supports astronomical research to detect, identify and characterize near-Earth asteroids. As the Asteroid Project's principal investigator, Eleanor Helin of the Jet Propulsion Laboratory directs the grant. Here, she reports on what has been accomplished with Planetary Society support:

With the approval and review of the World Space Foundation and The Planetary Society, we have employed an undergraduate at the California Institute of Technology, Steven Swanson, on a part-time basis. As an astronomy major, he is ideally suited for our observing and data reduction work. We were able to hire Steve for 10 hours per week. He typically travels from the campus to JPL two to three afternoons each week, as his class schedule permits. Steve has also made several trips to the Palomar Observatory as a team member.

As part of our continuing program to search for near-Earth asteroids, we have discovered two of the best mission candidates, Apollo asteroid 1982DB (see *The Planetary Report,* July/August 1982) and Amor asteroid 1982XB (see our January/February 1983 issue). Swanson and Amara Graps, a World Space Foundation volunteer, assisted in the December observing run when we discovered 1982XB. It is the best observed and investigated near-Earth asteroid to date. 1982XB appears to be an S-type object, composed of silicaceous rock, with a rotation period of 9 hours. From photometric and radiometric observations, researchers have deduced a diameter of 350 meters, making 1982XB one of the smallest near-Earth asteroids known.

Apollo asteroid 1982TA is one of the other interesting asteroids that we have discovered in recent months, although it is not a candidate for a mission. This object travels in a comet-like orbit similar to that of Comet Encke; this orbit suggests that it might be the remains of a burnt-out comet. Steve Swanson assisted me on the position measurements and data reduction for 1982TA. On October 14, we informally announced the details of its discovery at a "Friends of the Asteroids" party, held for World Space Foundation and Planetary Society staff and volunteers.

In addition to hiring a student assistant, we have also used the Planetary Society grant to purchase photographic film for asteroid search observations with the 46-centimeter Schmidt telescope at Mount Palomar. The grant has also covered travel and lodging costs at the Palomar Observatory for Steve Swanson and Amara Graps.

I would like to express my heartiest appreciation for the financial support provided by The Planetary Society. The grant has made it possible for me to get some much needed assistance, as well as covering the costs of photographic supplies, both necessary for the continuation of our near-Earth asteroid search program. ☐

NEWS BULLETIN—Scientists at the Jet Propulsion Laboratory in Pasadena have just announced the discovery of three new asteroids, designated 1983LB, 1983LC and 1983LD. Their discovery of these small solar system bodies broke a six-month "drought" during which no new near-Earth asteroids had been observed anywhere in the world. Steven Swanson, a student at the California Institute of Technology, discovered the first asteroid, 1983LB, on a photographic plate taken by Eleanor Helin and R. Scott Dunbar at the Mount Palomar Observatory in California. Swanson's work is funded by a grant from The Planetary Society to the World Space Foundation. This new object is an Amor asteroid, which follows a path crossing the orbit of Mars and closely approaching the Earth. The orbits of 1983LC and 1983LD have not yet been determined.

EXPEDITIONS TO THE ASTEROIDS

by Louis Friedman and Carl Sagan

Hurtling and tumbling through space, mainly in the zone between the orbits of Mars and Jupiter, are thousands of rocky and metallic and organic little worlds called asteroids. The first asteroid was discovered at the very beginning of the 19th century and the rate of discovery of new ones has increased steadily since then. But no one has ever studied an asteroid close up. There are, as yet, no images of their surfaces. The best we have done so far is to photograph Phobos (*see cover photo*) and Deimos around Mars; the outer small satellites of Jupiter; and Phoebe, the outermost Saturnian moon. These are small worlds between a few kilometers and a few tens of kilometers across, which, largely because of their peculiar orbits, are thought to be asteroids captured when they wandered too close to larger nearby planets. Some asteroids on occasion come close to the Earth, but, so far as we know, there are no asteroids in orbit about the Earth.

Although we have never scrutinized a bona fide asteroid from short range, we may nevertheless know a great deal about some of them—because most meteorites that fall on the Earth probably originate from asteroids. They are pieces chipped off by collisions with space debris—generally a comet or another asteroid—which, over immense periods of cosmic time, are eventually swept up by the Earth. (The other planets must do their sweeping too, and such impacts, particularly by large asteroids, are a major source of the cratering visible on the moons and planets of the inner solar system.) The trouble is that we do not know which meteorites come from which asteroids. There are many varieties of each. Some rare meteorites have apparently been ejected from the Moon or Mars. Many are still of unknown origin. The spectral properties of iron meteorites are similar to those of M-type (metallic) asteroids; perhaps iron meteorites come preferentially from M-type asteroids. C-type (carbonaceous) asteroids are very dark; they reflect only a few percent of the light that falls on them. The same is true of the organic-rich meteorites called carbonaceous chondrites. Could the C-type asteroids (and the moons of Mars, which resemble them) be worlds composed significantly of ancient organic matter from the early history of the solar system?

The largest asteroid known, 1 Ceres, 1,000 kilometers (about 600 miles) in diameter, is of this very dark, slightly red variety. Such asteroids, all presumably containing abundant organic (carbon-rich) matter, are very common; about 60 percent of the main-belt asteroids between the orbits of Mars and Jupiter are carbonaceous.

Originally, asteroids were named for gods and goddesses of Greek mythology, but the rate of astronomical discovery soon outstripped the number of available names, and astronomers were reduced to naming them after friends, spouses, favorite educational institutions, and real or hoped-for sources of research funding. Upon discovery, an asteroid is now given a temporary designation consisting of the year of discovery and two letters. The first letter indicates the half month of discovery and the second the order of discovery. For example, 1982DB was the second asteroid discovered (B) in the second half of February (D) 1982.

A typical asteroid might be a few kilometers across, about the size of a flying mountain (or a cometary nucleus). It could be cratered by past impacts, may exhibit low hills and deep valleys, and need not be spherical. Small, dark asteroids are comparatively hard to find, and there may be enormous numbers of them. However, most of the mass and most of the surface area of asteroids are in the larger varieties, which thereby are reasonable early targets for space vehicle exploration. Some asteroids will look dark and red; others may be rocky; and still others will here and there show a metallic glint. Some may be shaped like dumbbells. The variety of the asteroids is striking. A family portrait of a typical group of small asteroids might resemble the collage of small moons of Saturn discovered by *Voyagers 1* and *2* (*see photograph below*). Some asteroids may have smaller asteroids orbiting them.

Because of their small sizes, asteroids have very low escape velocities: an asteroid 10 kilometers (km) across will have a force of gravity about 0.1 percent that on the Earth, and a tiny escape velocity, about four meters per second (9 miles per hour). The corresponding escape velocity from the Earth is 11.2 km per second (7 miles per second). This means it takes a very little push to leave an asteroid and very little rocket thrust to land gently on one. In fact, an astronaut on a 10 km asteroid could high jump 1 km into space before gently floating back, and could throw a baseball off the asteroid entirely. Perhaps some day we will witness unparalleled athletic feats televised back to Earth as a minor sidelight of an expedition with a human crew to some asteroid of great scientific interest.

Not only are there many different kinds of asteroids, they also exhibit many different orbital characteristics. We have sent four spacecraft on journeys that will take them out of the solar system altogether; so, in principle, almost all the asteroids can be examined by spacecraft. Which ones should be visited first? The near-Earth asteroids (of which there are now about 70 known) are easier to get to, but we are not sure of their origin. The main-belt asteroids are of

Asteroids may resemble these smaller moons of Saturn posing for their family portrait, which are probably fragments of larger bodies broken up by asteroid bombardment during the early history of the Saturnian system.

VOYAGER COMPOSITE IMAGE: JPL/NASA

A geologist explores a multiple asteroid system. Asteroids may be broken apart by collisions, eventually to be reformed by gravity into a single body. However, a large chunk might remain in orbit, becoming, at least temporarily, an asteroidal satellite.

PAINTING: M. E. VICARY-DIDDAMS

enormous interest, and are probably related to material that formed as the solar system condensed from its parent nebula of cloud and dust, but they are more difficult to reach. More exotic dynamical families—for example, the Trojan asteroids which share the orbit of Jupiter in two clusters, one preceding Jupiter around the Sun 60 degrees ahead of it, the other following Jupiter 60 degrees behind it—will probably be left to 21st century missions. What can be done today?

This is a subject called mission analysis: calculating, with Newton's law of gravitation, optimum trajectories threaded through a cloud of thousands of asteroids. In an ideal mission a spacecraft would rendezvous with an asteroid, or at least fly by at low relative speed. "Rendezvous" here means matching not only the position of the target world, but also its velocity—so that the spacecraft and its objective are stationary with respect to each other, even though hurtling together around the Sun. Gravity assist—accelerating the spacecraft by first flying by some larger world(s)—or a midcourse or later trajectory correction by igniting rocket motors in short bursts are admissible strategies. In addition, proposals have been made to use an emerging technology which provides a low but continuous source of thrust.

Until recently, we believed that to rendezvous with main-belt asteroids we needed such low-thrust propulsion on the spacecraft, supplied by solar-electric or nuclear-electric power to ion engines, or by a solar sail. Last year, however, Dr. Chen-wan Yen at the Jet Propulsion Laboratory (JPL) has found that an ordinary robotic ballistic spacecraft launched by the Space Shuttle, with either the Inertial Upper Stage or a *Centaur* Upper Stage, can rendezvous with one or more main-belt asteroids. And if we can also use low-thrust propulsion, our opportunities open dramatically.

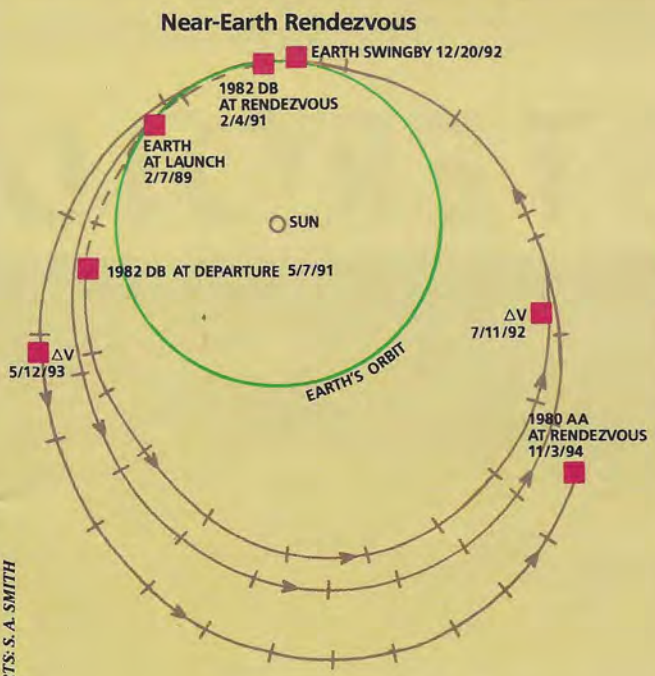
Many possible multiple-asteroid rendezvous missions have been studied. A typical one, employing both low thrust and gravity assist, is shown in a diagram on page 5. On September 24, 1992, the five-ton spacecraft is launched from the Shuttle by the Inertial Upper Stage. A few days later a solar-electric system is activated and the craft steered for a gravity-assisted swingby of Mars on August 5, 1993. Its first asteroid rendezvous then occurs with 8 Flora on February 1, 1995. After examining Flora for about two months, the mission continues in a spiral trajectory around the Sun, encountering 149 Medusa on November 22, 1996; 407 Arachne on December 22, 1998; 10 Hygeia on July 4, 2000(!); 338 Budrosa on November 26, 2001; 241 Germania on March 30, 2004; and 271 Penthesilea on June 25, 2006. In 14 years, we could rendezvous with seven main-belt asteroids—four carbonaceous, one rocky, one metallic and one other, still incompletely classified.

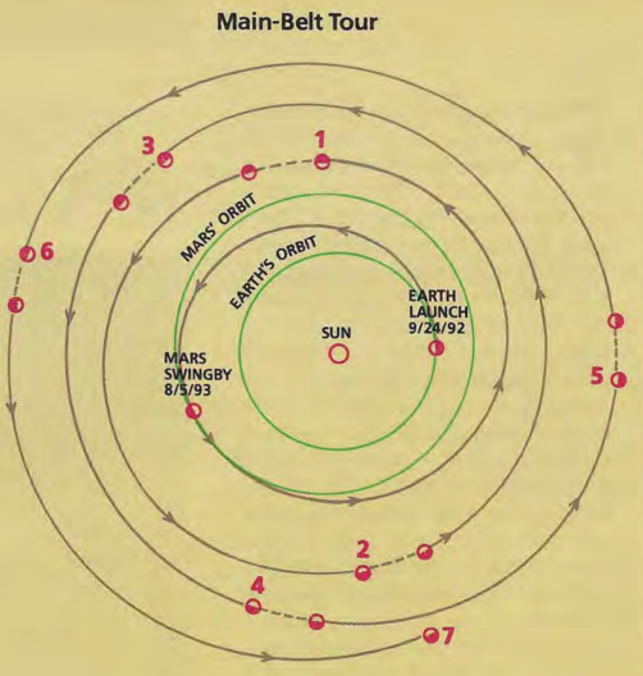
The judicious use of Earth, Mars and Jupiter gravity assists would make pure ballistic rendezvous missions possible, obviating the need for low-thrust propulsion. Dr. Yen has discovered both single and multiple rendezvous and rendezvous/flyby trajectories for several asteroids. One particularly interesting one requires a launch on October 6, 1992; the spacecraft would swing by Mars in 1993, rendezvous with the asteroid 149 Medusa in 1997, and fly by four other asteroids by the end of July, 2002.

Lately, the near-Earth asteroids have been receiving considerable attention, thanks to new discoveries by Eugene Shoemaker of the U. S. Geological Survey, and Eleanor Helin of JPL. Although pieces of such asteroids have been bombarding Earth as meteorites for eons, the two scientists point out that "until these asteroids are actually explored and sampled directly," understanding which meteorites come from which parent bodies "will remain speculative." And the speculation grows: Are some of these objects burned-out nuclei of comets? Have they provided water and other volatiles to the terrestrial planets? Are they debris from collisions elsewhere in the solar system? Did one of them hit the Earth with such force 65 million years ago that it led to the extinction of the dinosaurs? Are any near-Earth asteroids undisturbed remnants of solar system formation? Might some of them be mined for their mineral resources?

Beyond these mainly scientific questions, the near-Earth asteroids are important because some of them are the easiest solar system objects, after the Moon, to reach with spacecraft. Landing on an asteroid, sampling the surface, and safely returning to Earth constitutes a natural and worthwhile objective for the first post-*Apollo* voyage of humans beyond Earth orbit.

The asteroids that never stray too far from the Earth and whose orbits are only moderately inclined to the Earth's are likely to be visited first. We know a few candidates for missions, and many more are probably out there (which is why The Planetary Society is supporting the search for such asteroids—see the report by Eleanor Helin, page 2). The





FAR LEFT: Scientists have designed several trajectories for rendezvous with near-Earth asteroids; the paths to two objects are shown here. The time ticks mark off 50-day intervals; ΔV indicates midcourse maneuvers.

NEAR-LEFT: Following this trajectory, a spacecraft could rendezvous with seven main-belt asteroids. The dashed lines indicate the times when the craft is in rendezvous with an asteroid.

ARRIVE

1: 8 Flora—2/1/95
2: 149 Medusa—11/22/96
3: 407 Arachne—12/22/98
4: 10 Hygeia—7/4/00
5: 338 Budrosa—11/26/01
6: 241 Germania—3/30/04
7: 271 Penthesilia—6/25/06

CHARTS: S. A. SMITH

five most accessible asteroids discovered to date are (in order): 1982DB, 1943 Anteros, 1982HR, 1982XB and 1980AA. Ms. Helin discovered the first and fourth of these during work supported in part by The Planetary Society, and is also co-discoverer of 1980AA. (From the designations of these asteroids, it is clear how recently they were discovered.)

A round-trip mission requires not only that a spacecraft match position and velocity with the asteroid, but also that it wait at the asteroid until the orbital geometry permits a return to Earth. Because of the elliptical shape of orbits, and their relative inclinations, this is not always easy. In most cases there is a natural tradeoff between flight time and propulsion requirements. On a robotic mission we usually take a little longer to save energy; but on a human mission we would want to minimize the long flight time.

Neal Hulkower at JPL has extensively analyzed trajectories to 1982DB. He has found that *round-trip* missions (for example, returning samples of 1982DB to Earth) are possible in 11 out of the 14 years between 1988 and 2002. One of the least demanding in terms of energy, and therefore propulsion, requires launch in January, 1991, and would arrive at the asteroid in August, 1992. The spacecraft would stay there three months and return to Earth in February, 1995, for a total trip time of 578 days.

Alan Friedlander of Science Applications Inc., Chicago, has found a different class of trajectories to that same asteroid, requiring much more energy for spacecraft propulsion but having total flight times of less than one year. One in particular can be accomplished in 124 days: launch on September 7, 2001, and return to Earth on January 9, 2002. For humans to make a round-trip voyage to one of the near-Earth asteroids discovered to date, at least 25–30 Space Shuttle launches would be required to assemble the asteroid-bound spacecraft in Earth orbit. John Niehoff of Science Applications Inc. made this estimate, assuming that *Apollo*-type hardware would be used, with life support requirements of 10 kilograms (kg) per day per person for a three-person crew. A very preliminary cost analysis of such a mission suggests it could be accomplished for about one-sixth the cost of a single *Apollo* lunar mission. Naturally, the mass requirements for a robotic mission are much less, and, indeed, most of the easier round-trip robotic missions could be accomplished with one or two Shuttle launches.

One other exciting possibility was recently discovered by Neal Hulkower—a rare opportunity to rendezvous with two near-Earth asteroids. The trajectory, which utilizes an Earth gravity assist, is shown above. In a six-year mission, a 600 kg (1,300 lb) spacecraft could be sent to rendezvous with both 1982DB and 1980AA with a single Shuttle launch.

Of course, we do not know that 1982DB will remain the easiest known asteroid to reach; we might discover a new one next week. Three of the currently known near-Earth asteroids appear to be carbonaceous—2100 Ra-Shalom (named by its discoverer, Ms. Helin, to commemorate Egyptian-Israeli amity); 1979VA and 1580 Betulia. This last, however, is on a highly inclined orbit, and is extremely difficult to get to. More suitable nearby carbonaceous asteroids are likely to be found in the coming years; the search for them is being actively supported by The Planetary Society. Because we suspect, from meteorite evidence, that carbonaceous asteroids have been little changed since the earliest history of the solar system, and because the organic molecules on such worldlets are clearly related to the problem of the origin of life on Earth, they represent a spectacularly interesting mission objective.

A manned mission to a near-Earth carbonaceous asteroid represents an important convergence of the objectives of many different communities interested in the exploration of space: scientists ranging from cosmologists to organic chemists; advocates of a vigorous space program utilizing human crews; and those who foresee a time when large space engineering structures will be assembled in Earth orbit using resources mined from nearby asteroids. Public interest in the exploration of these exotic, low-gravity worlds should be substantial. They represent a ready, and comparatively easy, arena for space activities by many nations, combining fundamental science, preparation for conceivably vital economic activities in Earth orbit, and human high adventure. We suspect that the late 20th and early 21st century will witness many expeditions to the small and ancient worlds which by chance live near the Earth.

Carl Sagan has played a leading role in the Mariner, Viking *and* Voyager *expeditions to the planets. Louis Friedman was formerly in charge of mission analysis and advanced project design at JPL. The authors would like to thank Neal Hulkower and John Niehoff for supplying data for this article.*

ASTEROID

RIGHT: On the Earth, watchers of the night sky are familiar with meteors, dust-sized projectiles that leave intense glowing trails as they fall through our atmosphere. Most of these visitors from space burn up high in the sky. Those that make it to the ground are called meteorites. By studying meteorites, we may learn much about the composition and evolution of asteroids.

PHOTO: DENNIS MILON

The formation of our local planetary system some 4.5 billion years ago was not particularly efficient. The Sun and its planets condensed from a glowing nebula of gas and dust, a fragment of an immense interstellar cloud. Most of the nebular gases were lost from the solar system; a small portion remained gravitationally bound to the largest planets. Much of the solid material was also lost, slung into interstellar space after swinging by the nearly-grown planets. Most of the remaining solid stuff was swept up and accreted by the planets. By chance, some icy and rocky debris escaped this fate, and today many small bodies, generally much less than a few kilometers across, sweep through our solar system.

The icy remnants, called comets, have survived in the cold, outer reaches of the solar system. Such samples of the original nebula, kept in the freezer over the eons, should give invaluable clues as to how the solar system formed. But comets are generally small and too far away to see. Only a few stragglers, scattered into the inner solar system, are ever seen from the Earth. By the time they pass close enough to study they are coming apart in the warmth of the Sun, already in a pathological state, choked in their own exhaust.

Asteroids, the rocky remnants of planet formation, seem more willing to reveal their long-held secrets. Compared with the comets, they are nearby neighbors of ours. Most asteroids lie in a belt between the orbits of Mars and Jupiter. The wide space between those planets allows the asteroids' orbits to remain stable for billions of years. Other asteroids, the "Trojans," occupy the zones of stability, called Lagrange points L4 and L5, 60 degrees ahead of and behind Jupiter in its orbit around the Sun. We have observed and studied thousands of asteroids in the main belt, and know dozens of Trojans. Countless smaller bodies may also populate these zones. We have named, numbered and precisely calculated the orbits of over 2,400 asteroids, and their total numbers may be as high as 100,000.

After intensive study over the last dozen years, we now know a great deal about asteroids. Most represent the very primitive material that served as building blocks of the planets. Others are far from primitive; they have been heated and have evolved much as did the full-size terrestrial planets. That such small objects should have lava surfaces surrounding iron cores seems incredible, but some almost certainly do.

All of these objects are so small that, when viewed in a telescope, they appear as mere points of light blurred by the Earth's atmosphere, hence the name "asteroid" or "star-like." (Scientists also use the name "asteroid" for starfish, but I restrict use of the word to the extraterrestrial kind.) Nevertheless, astronomers have been able to determine a great deal about them by measuring the light they reflect from the Sun. Their colors, or more precisely, their reflectivities of different wavelengths of light, indicate what minerals are present. Their heat, or infrared brightness, when compared with visible brightness, tells us how big the asteroids are and how dark their surfaces are. Polarization of the light reveals surface roughness and can also be used to infer size and darkness. New techniques such as speckle interferometry—which is yielding crude images of the larger asteroids—promise to tell us a great deal more.

The most astounding way that asteroids bring us the story of the early solar system is by delivering samples of themselves to Earth. These "shooting stars" were called "meteors"—from the Greek word "meteoron" for astronomical phenomenon, a thing in the

S

by Richard Greenberg

heavens above—and scientists once believed they were formed within the Earth's blanket of air. But for a couple of hundred years now an atmospheric origin has seemed implausible. When a meteor falls to Earth, it becomes a "meteorite," and these rocks are sufficiently different from Earth rocks that we can identify them whether or not they were seen to fall. In Antarctica, ice sheets have served as natural collecting surfaces where the alien rocks are relatively easy to spot. In places, movement of the ice has, conveniently for collectors, concentrated the samples.

Most meteorites are probably broken from their parent bodies by collisions. From the number of asteroids and the speeds at which they cross each other's orbits in the main belt, we know that collisions, of at least 10,000 miles per hour, occur fairly frequently compared with the amount of time it takes most meteorites to get to Earth—a few tens of millions of years. So, there is a fairly steady supply arriving here, punctuated at much greater intervals by debris from major collisions in the main belt. We know the meteorites' travel times from measurements of cosmic ray tracks in the samples; the tracks show how long the samples were exposed in space after being excavated from their parent asteroids.

Just how the meteorites get to Earth is still a mystery. If they were ejected from their parents at the expected asteroidal collision velocities, their orbits would be roughly asteroidal, and stable against accretion by a planet for billions of years. To be put in orbits that cross the Earth's, they would need to be launched several times faster. Such high ejection speeds seem inconsistent with laboratory collisional experiments and also with the unshocked character of minerals in most meteorites.

The key to delivering pieces of asteroids to the Earth may lie in a set of narrow bands of unstable orbits running through the main belt. These orbits are unstable because they "resonate" with Jupiter; for example, their orbital periods may be near small-number fractions of Jupiter's. While the giant planet takes 12 years to revolve around the Sun, an asteroid in a resonant zone would go around in one-half or one-third the time. In such cases, the geometry of closest encounters is very regular and repetitious, so that the gravitational influence of Jupiter, although small compared to the pull of the Sun, acts repeatedly to perturb the asteroids' orbits. Resonant orbits can become highly eccentric, crossing the paths of Jupiter or other planets. Asteroids on such orbits can either be scattered out of the solar system or be accreted by a planet. In fact, these resonant zones within the main belt are relatively free of asteroids, indicating removal by resonance.

If debris from a collision between asteroids is launched onto a nearby resonant orbit, it may become "Earth-crossing" and eventually hit our planet. Other fates are also possible, of course. Like most of the solid material in the early solar system, asteroids may be ejected into interstellar space or accreted by some other planet. Or they may be shattered by impacts with other small bodies into pieces too tiny to survive the fall through Earth's atmosphere or to be recognized as meteorites. We are still grappling with the statistics of the resonance delivery process. Questions remain about whether or not enough of the right sorts of asteroids are close enough to resonant zones to have sent the meteorites to Earth in this way, and there are fundamental uncertainties about

TYPES OF ASTEROIDS

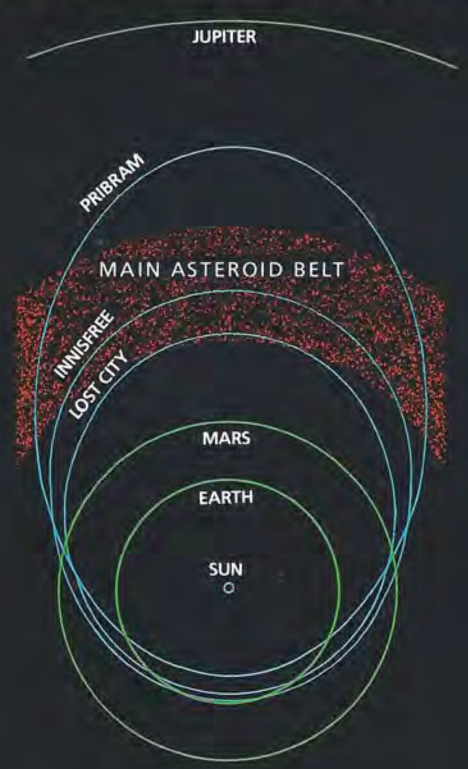
The asteroids are now classified, based on how much light of various colors they reflect, into six main types: C, S, E, R, M and U. U means "unknown," C stands for "carbonaceous," S, E and R refer to different "stony" compositions, and M means "metallic." For historical reasons the taxonomy of meteorites is much more complicated, but many of them can be placed in these general asteroid categories.

C-type asteroids appear to be covered with dark, carbon-based material, as are carbonaceous chondrite meteorites. Some scientists find these asteroids particularly interesting for they may contain ancient organic matter left over from the formation of the solar system.

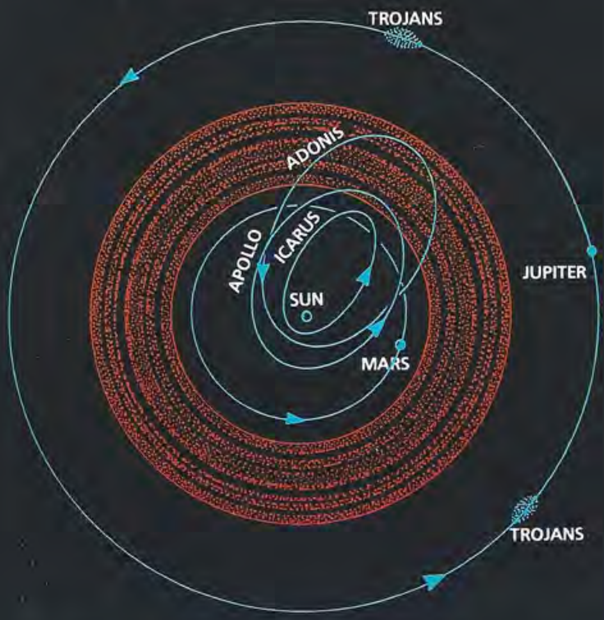
S-type asteroids, and many of the stony meteorites believed to come from them, are more like the terrestrial planets, in that at least some of them have been differentiated by internal (presumably radioactive) heating into bodies with dense cores and lighter crusts. Certain meteorites are basaltic lava rocks which must at some time have been molten in or on an evolving parent body.

M-type asteroids may possibly be the surviving metallic cores of small, differentiated planets whose rocky crusts have been stripped off by collisions. Iron meteorites have spectral properties similar to those of M-type asteroids, so there may be a genetic connection between them. Also iron meteorites contain large metallic crystals indicative of very slow cooling, as might have happened in the interior of a small planet.

Despite these clues, there is as yet no general scientific consensus on the nature and origin of the asteroid classes or their relations to the various meteorite types. To resolve these questions, it will be necessary to visit and sample these small and richly variegated worlds.



ABOVE: From photographs of their trails through our atmosphere, scientists have reconstructed the orbits of three meteorites. They turn out to have come from near the main asteroid belt. Something perturbed their orbits and sent them on to Earth. The exact relationship between main belt asteroids and meteorites is not yet clearly understood.



ABOVE: Most asteroids orbit the Sun in a belt between Mars and Jupiter. This main belt is separated into smaller bands by the Kirkwood Gaps, which are caused by orbital gravitational resonances with Jupiter. Two groups of asteroids, called the Trojans, travel along Jupiter's orbit, 60 degrees behind and 60 degrees ahead of the planet. A few asteroids, including Apollo, Icarus and Adonis, travel in orbits that bring them near the Earth.

CHARTS: S. A. SMITH

whether resonances really can deliver the samples within the required times of a few ten millions of years.

The problem is less puzzling for iron meteorites, which are strong enough to have survived much longer delivery routes. From their cosmic ray exposure ages, we know that many have been traveling for over a billion years. Delivery of this debris did not require launching onto resonant orbits. Any slightly unstable orbit would do.

From comparing meteorites and asteroids, the following picture emerges. Most asteroids are probably made of the same material as the kind of meteorites known as ordinary chondrites. Chondrites are very primitive rocks, the kind of stuff from which the terrestrial planets formed. On the Earth, where all rocks have been well-cooked, native chondrites are unknown. But the chemical composition is such that, when used as input for models of planetary evolution, it yields rocks and planetary structures close to what actually exists. Also, chondrites look primitive. They are often conglomerations of small (1/16 inch or so), round structures called "chondrules" that may be droplets condensed from the early solar nebula. Some dark asteroids have been identified with carbonaceous chondrites, another class of primitive meteorites rich in organic compounds and water.

All asteroids have endured long histories of collisions with other asteroids and possibly with other small bodies in the early solar system. The very existence of a belt of asteroids, rather than a full-sized planet at its position, indicates that collisions there have been more violent. Apparently the relative velocities among growing asteroids were pumped up so high that further accretion was impossible. Jupiter may have been responsible, by stirring things up with its gravity and by scattering other bodies into the asteroid zone. The asteroidal population has evolved into a continuous size distribution, with a few large ones and ever-increasing numbers at smaller sizes. Many asteroids are probably rubble piles weakly held together by their own gravity. A few may even have satellites.

Some asteroids, however, have remained intact, according to the following evidence. Meteorites called achondrites are highly evolved rocks. They are the sort of material that rises to the surface of a hot planet, like the lava that flows from terrestrial planets. Thus, some asteroids have apparently been heated, differentiated, and cooled early on, and then have remained intact so that samples can be chipped from their surfaces. Asteroid 4 Vesta appears to be an achondrite, based on the spectral reflectivity of its surface. But most differentiated bodies have not remained intact. We believe iron and stony-iron meteorites come from asteroids that have been blasted apart by impacts, leaving only the surfaces of their iron cores to later be sampled as meteorites.

Besides specimen-sized meteorites, the asteroid belt also sends very large and dangerous pieces of debris onto Earth-crossing orbits. These bodies are in a class called "Apollo asteroids." The observed ones—about 30, so far—are typically a mile or more across. We do not know whether these objects are simply another part of a continuous size distribution of debris that includes meteorites, or if they are produced in some special way. A substantial fraction may be extinct comets, dusty remains whose volatile parts have evaporated. But some Apollos have the spectral appearance of main-belt asteroids and almost certainly come from there.

The Earth-crossing material represents the tail-end of the accretionary bombardment that produced our own and other planets some 4.5 billion years ago. Fortunately for civilization, Apollos are rare compared with meteorite-sized Earth-crossers. While meteorites can do some damage—several have punctured roofs and at least one killed a dog—an Apollo would be devastating. Numerous scientists believe that such impacts have had major effects on the evolution of life on Earth, possibly causing the extinction of the dinosaurs.

Asteroids are thus interesting for practical as well as scientific reasons. They do represent a threat to life and civilization on the Earth (especially now, when the impact of one might be misinterpreted and lead to a nuclear missile exchange), but they also present a grand opportunity for exploration and development of their mineral and metal resources for human futures in space. And so, we have several strong reasons to investigate them. Fortunately, asteroid science is now advancing rapidly. The laboratories and techniques developed for studying lunar samples returned by *Apollo* astronauts have been readily applied to analyzing meteorites. Also, a broad range of new ground-based astronomical instrumentation has made possible critical measurements of the asteroids themselves. And most important, there has been a change in scientific perception: a recognition that, while asteroids may well be characterized as the garbage of the solar system, there is nothing undignified or trivial about delving into their secrets.

Rick Greenberg is an astronomer at the Planetary Science Institute, a division of Science Applications, Inc. He specializes in planetary dynamics and the origin and evolution of the solar system.

EUROPEAN MISSIONS TO ASTEROIDS

BY ANDRE BRAHIC

The last two decades of planetary missions, considered the golden age of solar system exploration, produced a wealth of basic discoveries at a rate unparalleled in history, deeply transformed our view of the solar system and contributed to a better understanding of our planet Earth. The United States and the Soviet Union led this era of discovery, but, happily, other countries including France, Germany, Great Britain, Holland, India, Italy and Japan are now entering the race. This exploration should be continued by many countries, and, with increasing costs and static science budgets, international collaboration has become highly desirable.

At the end of the 1980s, the Sun, Pluto and the asteroids will be the only bodies in the solar system not to have been visited by a spacecraft. Due to their scientific value as clues to the origin of the solar system, and possible economic value as sources of minerals and metals, an exploratory mission to the asteroids is now one of the highest priorities of both the European and American planetary science communities. But with their great numbers, diversity and locations spread across much of the solar system, the choice of a first mission is not easy. The French and German space agencies have done a number of studies in the past four years and they are considering several proposed missions.

Why Visit Asteroids?

Asteroids will remain star-like points of light even to the largest ground-based telescopes. We need *in situ* measurements to answer many of the questions raised by asteroid science. How did they form? Is primitive material from which the solar system formed still intact on some asteroids? Have some asteroids evolved as planets did, forming differentiated cores and crusts? Do they contain easily exploitable resources?

We have studied some ancient solar system materials, meteorites and lunar samples. and this has helped our understanding of our parent solar nebula. The lunar material, although less primitive, has the advantage of a known geological context. Meteorites need to be placed in a similar context, and the only way to do that is to understand their primary sources—the asteroids.

It is impossible to answer all the scientific questions with a single mission to the asteroids and without a sample return to Earth. But we must start somewhere, and even a flyby mission can divest us of some of our preconceptions so that we can begin to work with the physical reality of asteroids.

The type of propulsion system constrains the type of mission: a rendezvous where the spacecraft would travel alongside the asteroid for an extended time, or a flyby where it would zoom by. We have studied three possibilities:

☐ With a classical chemical propellant, changes in trajectories are easy and instantaneous, but the number of possible changes is limited by the maximum mass of fuel that can be launched from the Earth. We could rendezvous with only one Earth-crossing asteroid, but could do several flybys of main-belt asteroids.

☐ Using a Mars gravity assist, as *Voyager* used Jupiter and Saturn to help it en route to Uranus, we could decrease the amount of needed fuel and launch a more massive spacecraft. The craft could rendezvous with two main-belt asteroids and fly by several others. But the proper launch positions of the Earth and Mars repeat only every 25 months, and the Mars-to-asteroid positions repeat every 3 to 4 years. This significantly decreases the launch opportunities and increases the duration of the missions.

☐ The ion drive propulsion system, long studied in the U.S. and now being developed in France and Germany, is powered by a solar array or solar concentrator. This system could deliver a 1,000 kilogram payload to a main-belt asteroid within one year, and could later fly by several others. But it could not be used too far from the Sun, and the main belt seems the limit for this ion drive system.

We can achieve most of the scientific objectives of the first asteroid mission with a multiple flyby. However, there are several advantages to a rendezvous mission.

☐ The spacecraft would fly by the asteroid rather quickly, so that only the sunlit side could be observed with the highest resolution. The whole surface of the asteroid could be observed during a rendezvous, with good resolution from both the cameras in visible light and the infrared spectrometer in the infrared.

☐ The mass, volume and density of the asteroid could be determined with more precision during a rendezvous than during a flyby. Detailed information on the gravity field could be gathered during a rendezvous, allowing a first approximation of the internal structure of an asteroid.

☐ Gamma ray and x-ray spectroscopy, which would be used to remotely sense the surface chemistry, require long exposure times and would be possible only during a rendezvous.

Which Target?

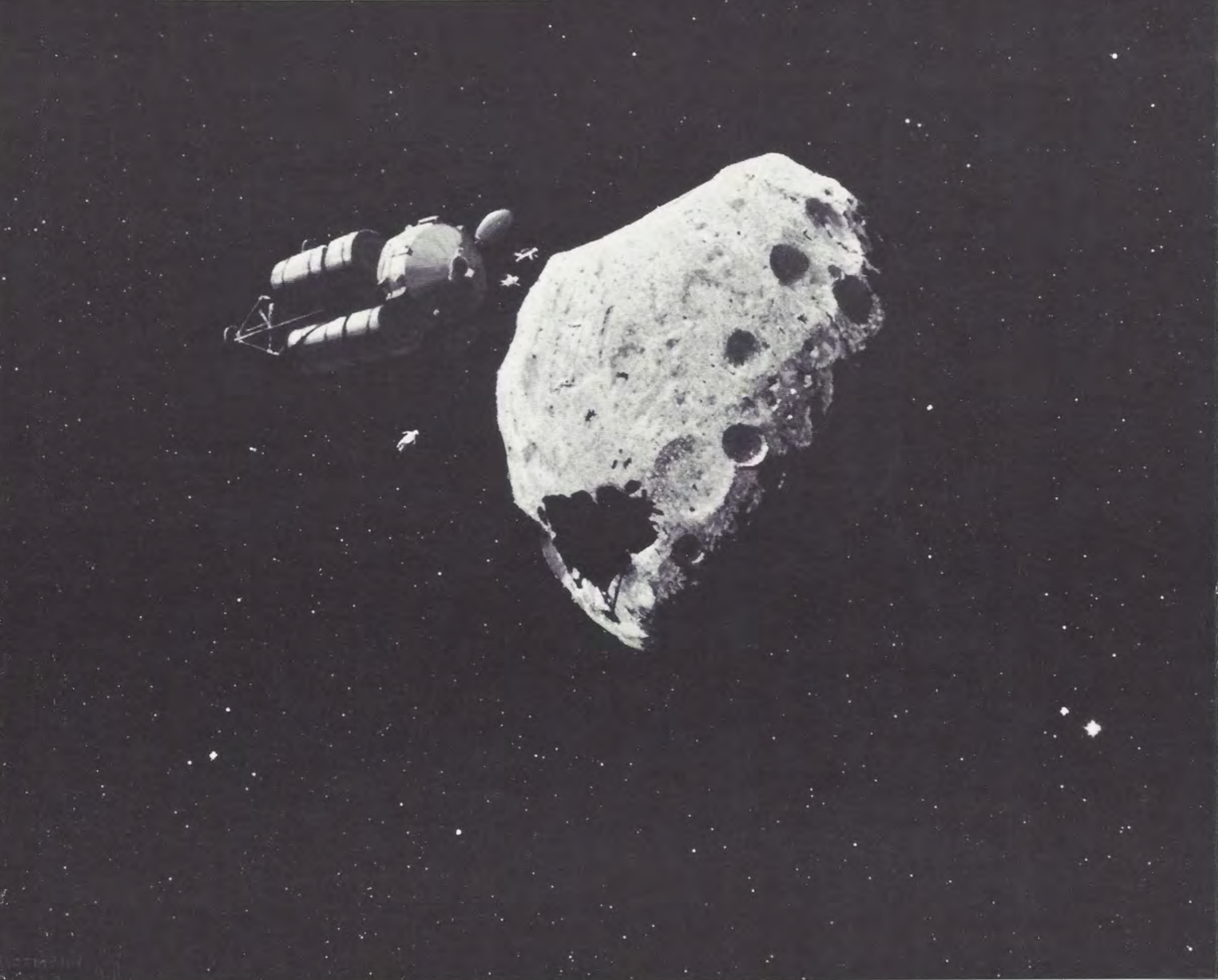
It would be hard to choose an asteroid that would not give exciting and unexpected results, but an essential characteristic of the asteroid population is its variety. The first mission would ideally sample the three main types of asteroids: type C, the carbonaceous chondrites whose surfaces appear to be covered with organic molecules; type S, the stony asteroids made primarily of silicates; and type M, asteroids made of iron, or combinations of stone and iron. Some possible targets are:

☐ 4 Vesta, a large asteroid that seems to be differentiated into a metallic core and a stony surface. Somehow this small (compared to planets) body has been heated and

LEFT:* *The hero of The Little Prince, a fantasy by Antoine de Saint Exupéry, lived on an asteroid. Each day he cleaned out the volcanos, which he used for cooking, to prevent violent eruptions. While there is as yet no evidence for volcanos on asteroids, some of the larger asteroids may have been melted and differentiated into metal cores with silicate crusts.

Drawing from Le Petit Prince, by Antoine de Saint Exupéry, © 1943 by Harcourt Brace Jovanovich, Inc.: Renewed 1971 by Consuelo de Saint Exupéry. Reproduced by permission of the publisher.

BELOW:* *Earth-approaching asteroids may someday be visited by explorers from our planet. The asteroids may hold clues to understanding the origin of our solar system and might also contain economically promising deposits of minerals and metals. In this painting, a spacecraft approaches an asteroid about 100 meters long. The Earth and Moon appear as the bright objects at lower right. *Painting: William K. Hartmann*



partly melted to differentiate minerals from metals. It may have been fragmented and might be typical of the original parent bodies of differentiated meteorites.

☐ 1 Ceres or 2 Pallas, large C-type objects that are probably unfragmented and relatively primitive. They may not have undergone thermal evolution like 4 Vesta, and may resemble the original planetesimals from which the planets formed.

☐ An M-type object, which probably has a metallic surface. It might be a fragment or a primitive core or a parent body of the iron meteorites.

☐ A small, dark C-type object which may enable us to understand its accretion history and allow us to examine primitive organic material.

☐ The nucleus of a dead comet.

☐ A fragment of a larger body, which may allow us to study the internal structure of larger asteroids.

☐ A main-belt asteroid with a small orbital eccentricity that is far from regions of resonance that might have delivered meteorites to the Earth.

☐ An Apollo-Amor asteroid that could provide a link between the main-belt asteroids and the meteorites.

Finding a Trajectory

In planning missions to the planets, whose orbits are well-known, it is relatively easy to calculate a trajectory. But with the less-studied asteroids, it is not a trivial task to select the best mission for the maximum scientific return with the minimum energy at launch. There are so many variables —launch date, targets, spacecraft mass, mission length, etc.—that a complete study of all possible trajectories is extremely difficult. The University of Arizona has published the orbital elements of over 2,000 asteroids. The French and European Space Agencies have calculated tens of thousands of trajectories, and several hundreds appear extremely attractive. For example, a 700-kilogram spacecraft, launched by *Ariane* and using a chemical propellant, could successively visit three to six asteroids. There would be many launch opportunities, and for a launch around 1990, we have found more than 200 trajectories with flybys of three or more asteroids.

Which Instruments?

We have given the highest priority to three instruments: imaging cameras, an infrared spectrometer and a radar altimeter. The imaging camera system could determine the size, shape, volume and rotation period of an asteroid, and study the surface structure, morphology, albedo, and other properties to permit comparison with other bombarded planetary surfaces.

An infrared spectrometer would provide information on the mineralogy, and thus the chemistry, of an asteroid. A number of minerals, such as pyroxenes, olivines, plagioclase feldspars, etc., have characteristic spectral signatures and could be identified by this instrument.

A radar altimeter could measure the distance between the spacecraft and the asteroid, the rotation period of the asteroid, and the velocity of the spacecraft relative to the asteroid. It could help determine the asteroid's mass and the depth of its craters and depressions. A more advanced radar, such as a microwave radiometer or a radio sounder, could provide information on the thermal and electrical properties of the surface, on the thickness of the regolith (the crushed and smashed-up rocky surface) and on the physics of the crust.

If weight and energy requirements allow, we might be able to include experiments on the interplanetary medium and dust, radio science and cosmic rays. If a rendezvous is possible, gamma ray and x-ray spectrometers might be added. We have also considered surface penetrators, small landers and even sample return capsules, but these devices would best be included on a later mission.

Missions Under Study

We have studied several possible missions to asteroids and have a few proposals:

☐ Asterex (Asteroid Exploration). After a suggestion from a group of French scientists in 1979, the French Space Agency studied the feasibility of an asteroid mission using the *Ariane* rocket and available European technology. The European Space Agency twice selected the Asterex project from among several other candidate missions. ESA concluded that a mission to the asteroids is feasible, interesting and necessary and could be done for about $200 million, a moderate price for a space mission.

☐ AGORA (Asteroid Gravity, Optical and Radar Analysis). In 1982, a large group of scientists reconsidered and improved the original Asterex proposal and submitted it to ESA. This new plan would allow a rendezvous with an asteroid. The spacecraft could be launched between 1990 and 1992.

☐ AMSAT. ESA is offering a free launch on the 1986 or 1987 test of *Ariane IV*, and has sent out a call for proposals for passenger satellites. The AMSAT organization (an amateur radio union) has already built low-cost satellites for amateur radio communications, and they have proposed to test ion drive engines mounted on one of their satellites, and fly it to the asteroid belt. This would be a technological test to gather critical flight data, and any asteroid science would be a bonus, not the main goal. If this proposal is successful, it could demonstrate that low-cost technologies and management techniques can be extended to scientific payloads.

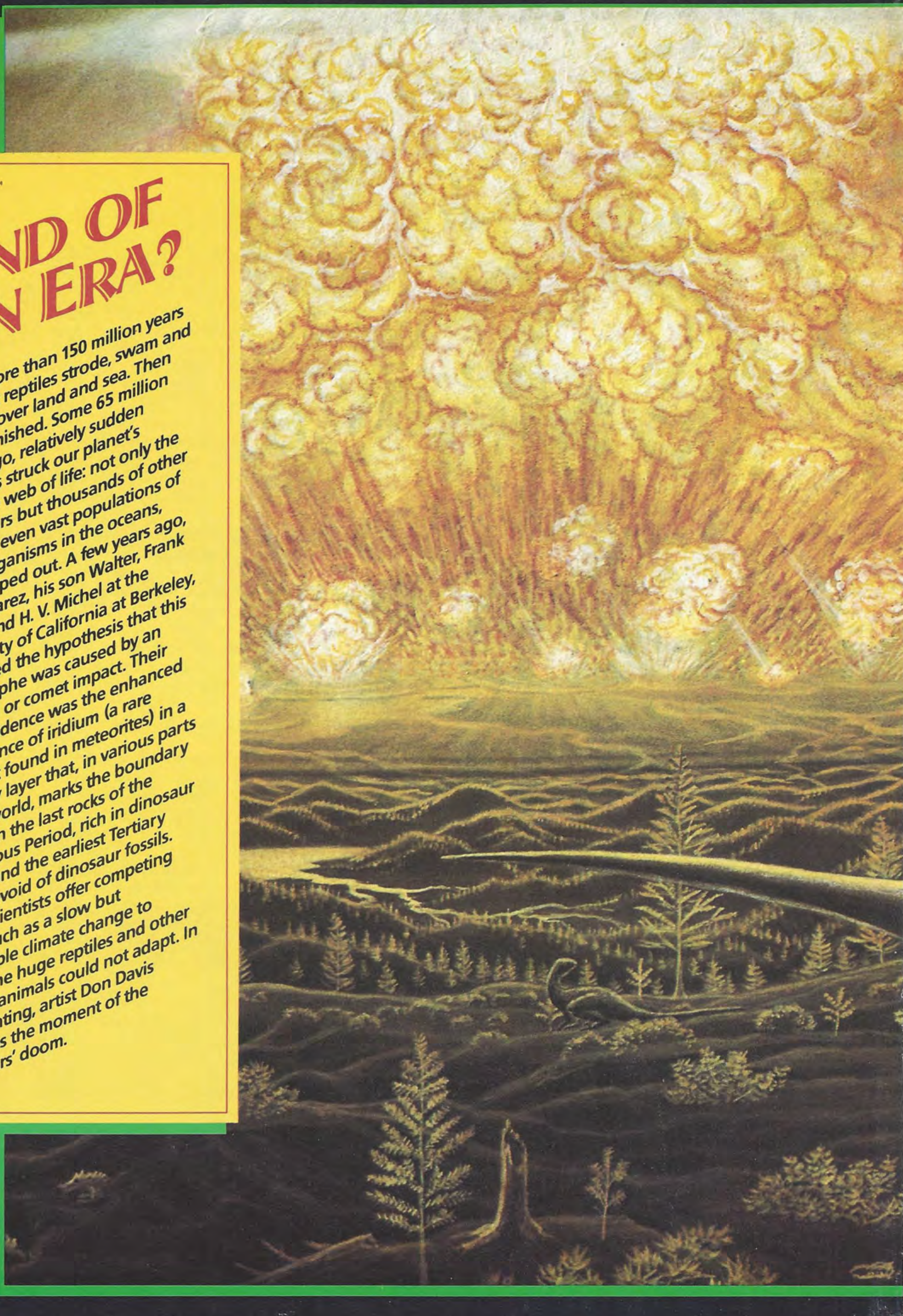
During the 1970s and '80s, missions to the asteroids were the least defined of potential space missions. There are special problems in the exploration of these bodies, each one smaller than anything yet explored by spacecraft, and they are distributed throughout an immense volume of space. Now, the development of ion drive enables a wide range of missions, including several rendezvous and flybys. Asteroid exploration in the 1990s is possible, using chemical rockets and ionic propulsion. With the combined technical and financial capabilities of Europe and the United States, we could conduct a very ambitious mission, possibly a "Grand Tour" with rendezvous with an Earth-crosser like Eros, a main belt asteroid like 4 Vesta, a periodic comet like Tempel 2, with a number of asteroid flybys.

There is now a real hope of launching a spacecraft to these still unexplored bodies before the end of the century, and we can repeat after Fraser Fanale: "We have just now reached the threshold of knowledge where a valid investigation of this enormous population of objects from space may be intelligently planned."

Andre Brahic, a Professor at the University of Paris with a laboratory at the Paris Observatory, has an interest in the rings of Uranus and Saturn and the physics of small bodies. He is actively participating in the planning of European space missions and serves on several international planetary science advisory groups.

END OF AN ERA?

For more than 150 million years great reptiles strode, swam and soared over land and sea. Then they vanished. Some 65 million years ago, relatively sudden changes struck our planet's intricate web of life: not only the dinosaurs but thousands of other species, even vast populations of microorganisms in the oceans, were wiped out. A few years ago, Luis Alvarez, his son Walter, Frank Asaro and H. V. Michel at the University of California at Berkeley, advanced the hypothesis that this catastrophe was caused by an asteroid or comet impact. Their chief evidence was the enhanced abundance of iridium (a rare element found in meteorites) in a thin clay layer that, in various parts of the world, marks the boundary between the last rocks of the Cretaceous Period, rich in dinosaur fossils, and the earliest Tertiary rocks devoid of dinosaur fossils. Other scientists offer competing ideas, such as a slow but inexorable climate change to which the huge reptiles and other ancient animals could not adapt. In this painting, artist Don Davis imagines the moment of the dinosaurs' doom.



The Origin and Composition of Near-Earth Asteroids

by Lucy McFadden

Those asteroids that pass through our region of the solar system, crossing the orbits of the Earth and Mars, have recently sparked the interest of researchers who are now trying to determine if these wandering bodies contain useful minerals and metals. Asteroidal resources might add to our stores of scarce earthly materials, or could be the raw stuff used to make rocket propellants, sustain life and build structures in space. Using telescopes, scientists are identifying minerals on the surfaces of near-Earth asteroids, and their findings are helping to answer questions about how asteroids form and where they come from.

Near-Earth asteroids fall into three categories: the Apollos, whose orbits cross those of the Earth and Mars; the Atens, whose orbits cross only that of the Earth; and the Amors, which cross the orbit of Mars but only approach the Earth. From these asteroids may come many of the meteorites that strike the Earth, sometimes harmlessly, sometimes catastrophically.

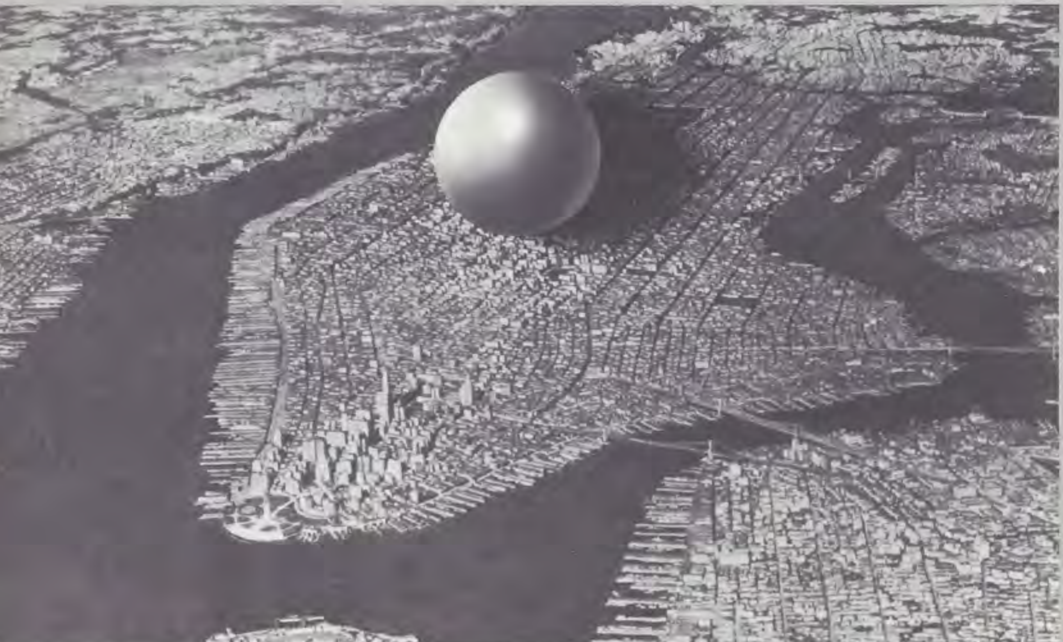
Ernst Öpik of the Armagh Observatory calculated the population of Apollo asteroids, assuming the present Apollos have occupied their present orbits since the beginning of the solar system, 4.5 billion years ago. He reasoned that the rate of collisions of asteroids with a planet changes with time (as evidenced by the greater number of old craters than young ones on the Moon, Mars and Mercury) and that the rate was proportional to the number of Apollo asteroids present at any given time. Starting with 7 Apollos known in 1963 (when he made the calculation), and a collision rate with the Earth of one every 100 million years, he extrapolated back to the beginning of the solar system and found there should have been many trillions of asteroids with Earth-crossing orbits. He tried to test the possibility of such a large population by calculating the total mass of these hypothetical original Apollos, and found a figure 1,000 times the mass of the Sun. This is so unlikely that the Apollo asteroids must not have been in their present, near-Earth orbits since they formed. They have come from some other part of the solar system.

James R. Arnold of the University of California at San Diego has designed computer simulations of the orbital evolution of near-Earth asteroids, assuming that one will either collide with a planet or be ejected from the solar system, on the average, every 10 to 100 million years. Main-belt asteroids, however, travel in orbits that have never crossed the Earth's orbit during the lifetime of the solar system. Thus, Arnold's simulations suggest, as do Öpik's calculations, that the near-Earth asteroids are dynamically different from their main-belt brethren. This information motivates us to find out where these objects orbited before moving into Earth-crossing or approaching paths. Are they fragments from other planets? Were they comets that once glowed with sunlight scattered from dust and ice particles? Are they sent to us from unstable regions in or near the main belt of asteroids?

Because their orbits carry them so close to the Earth, we expect that near-Earth asteroids are similar to the meteorites that fall on the Earth. By studying asteroids' physical properties and comparing them to meteorites and other solar system material, we can search for their source regions. The most desirable method of study would be to retrieve samples from all relevant solar system objects and compare them in the laboratory. But until this is possible, we must indirectly measure their characteristics using ground-based telescopes and one-way spacecraft voyages.

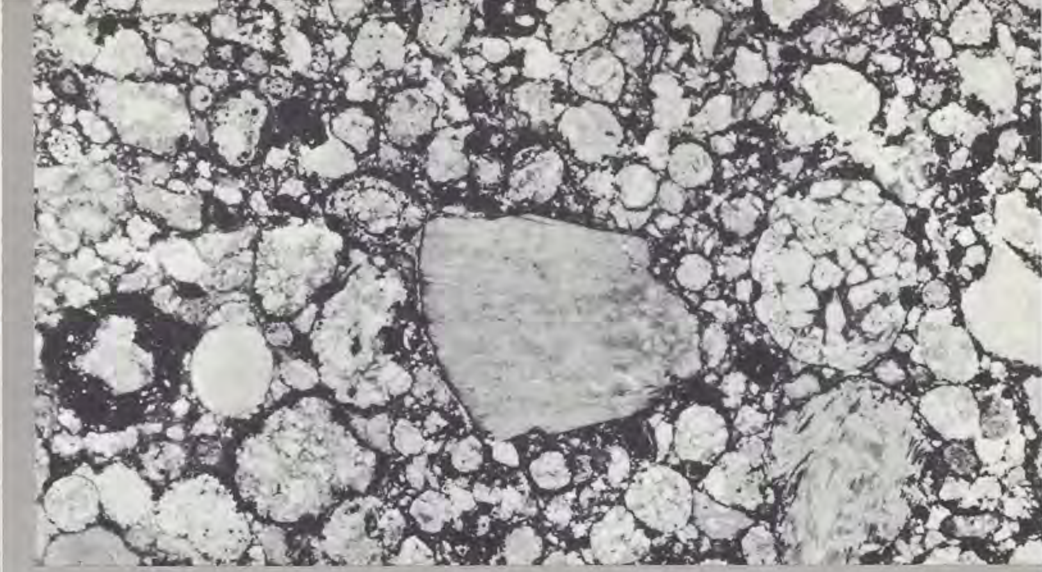
In 1937, the asteroid Hermes passed within 800,000 kilometers of Earth, inspiring this illustration of the asteroid over Manhattan Island. To give an idea of the object's size, Central Park is the clear area behind Hermes. Although the asteroid in this model is spherical, Hermes is probably really irregular in shape, as are most of the observed small bodies in our solar system.

Illustration courtesy of the American Museum of Natural History



As we discover more and more asteroids, and as scientific priorities shift toward the study of these objects, more large telescopes and sensitive instruments have been allocated to asteroid researchers. We can currently determine the diameter and brightness of an asteroid, measure variations in brightness to determine its shape and rate of rotation, measure how its brightness changes with the solar phase angle (the angle between the Sun and the Earth as it would be measured on the asteroid) to provide information on surface texture, use radar to infer size and surface roughness, and identify surface minerals using reflected visible and infrared light.

I have recently measured the visible reflectance spectrum of nine near-Earth asteroids using the University of Hawaii's



This cross section of the chondrite Chainpur reveals millimeter-sized round chondrules embedded in a black matrix. Chondrules are glassy, solidified droplets of silicates and scientists are debating how they formed. Some suggest that they condensed out of the original solar nebula, others suggest that they are drops of materials melted by collisions between solid bodies.

Photo: Laurel Wilkening, Lunar and Planetary Laboratory, University of Arizona

2.2 meter telescope on Mauna Kea. Reflection spectroscopy is a very powerful tool for diagnosing the presence of certain minerals. As sunlight falls on these minerals, certain crystalline structures absorb the light at discrete wavelengths as the Sun's energy moves electrons to higher energy levels. This is a fleeting phenomenon; the excess energy dissipates and the electron returns to its stable ground state. The crystals' ingestion of light shows up as absorption bands in spectra of reflected sunlight, which can then be used to identify specific crystalline structures. By studying known crystals in the laboratory using artificial sunlight, we can learn to diagnose the crystalline structure and chemistry of a mineral, based on the position, depth and width of its absorption bands.

Some of the most abundant solar-system minerals, such as olivine and pyroxene, have absorption bands in the near-infrared region of the spectrum. Detecting these minerals on an asteroid tells us something about the temperatures and pressures to which the body has been subjected. Other cosmically abundant materials, such as metallic iron and clay-like minerals, can also be studied in reflected light. However, not all materials allow us to identify them by the light they reflect. In continuing laboratory studies of solar system material, we are attempting to determine diagnostic features that can be measured indirectly with telescopes or spacecraft instruments. By identifying the stuff of which asteroids are made, we hope to better understand how they formed, whether they condensed from the solar nebula and have been little altered since then, or if they have been totally remelted and then solidified into differentiated layers of metal and rock.

There are about 70 known bodies that pass close to the Earth, and observers are rapidly discovering more. We have visible reflection data on 17 near-Earth asteroids, with additional ultraviolet and infra-red spectral information on 9 of them. The available spectra show that these bodies differ in composition from most of the asteroids observed in the main belt. They absorb more light in the ultraviolet and near-infrared regions of the spectrum. My colleagues, Michael Gaffey and Thomas McCord, and I are not sure what causes this difference; it could be that there are more silicate minerals with strong absorption bands in these regions and fewer minerals that absorb light at all wavelengths. Before we can be sure of this interpretation, we must eliminate other possible explanations, such as differences in surface texture, which might also cause strong absorption bands.

The observed spectra of all but one near-Earth asteroid can be interpreted in terms of cosmically abundant minerals and other known materials. 2201 Oljato has a spectrum with features seen in the laboratory only in very unusual materials. If we look at the features as emission bands instead of absorption bands, we can interpret the spectrum as showing the light-scattering effects of particles being ejected from the surface, as on comets. However, the activity apparently is too slight to make the asteroid glow like a comet when seen through a telescope. 2201 Oljato may provide observational evidence to link comets to asteroids; many asteroids may be dead comets, no longer having glowing comas or dust tails.

We have found compositional analogs of near-Earth asteroids in three large main-belt asteroids, but their compositions are infrequent among main-belt bodies. The Earth-crosser 1915 Quetzalcoatl and portions of the main-belt object 4 Vesta, the only previously-known basaltic asteroid (one with lava on its surface), have the same spectral features, and hence similar surface compositions. Based on the same reasoning, the main-belt asteroid 349 Dembowska (which may also have a basaltic surface) and near-Earth object 1685 Toro have the same composition. The asteroids 2 Pallas (main belt) and 1580 Betulia (near Earth) both travel in orbits highly inclined to the ecliptic (the plane through which the orbits of the planets pass), and both have similar compositions.

We have searched for spectral analogs to these asteroids among the Kirkwood Gaps (regions in the main belt that have been partly cleared of asteroids by orbital resonances; see article on pages 6–8). Some researchers have proposed these regions as sources for near-Earth asteroids, based on studies of orbital dynamics. However, there is as yet no experimental evidence to favor these over other regions that have been proposed, on dynamical grounds, as sources for near-Earth asteroids.

In the laboratory, we have measured spectra of meteorites to compare them with their possible parents among the asteroids. The near-Earth asteroids are compositionally more diverse than the known meteorites, but we have found some analogs: a certain basaltic meteorite compares with 1915 Quetzalcoatl; two ordinary chondrites compare with 1862 Apollo and 1980AA, respectively; two carbonaceous chondrites compare with 887 Alinda and 1981QA; and one carbonaceous chondrite compares with 2100 Ra-Shalom. However, the orbits of the ordinary chondrite compositional analogs are not similar to the few known orbits from which ordinary chondrite meteorites come. Thus, the known asteroid analogs are not likely to be the parent bodies of the most common meteorites. These results indicate either that most meteorite parent bodies have been fragmented into objects smaller than those now detectable from ground-based experiments, or that their sources are few in number and located in regions where objects have not yet been discovered.

Our work is one of several pioneering studies that are beginning to reveal the nature of near-Earth asteroids. Much more work is needed, and new techniques must be developed, before we will understand these unusual members of the solar system.

Lucy McFadden is now working in the Earth Resources Division of the NASA/Goddard Space Flight Center. Her specialty is the composition, origin and evolution of near-Earth asteroids. Last year she received a Space Industrialization Fellowship from the Space Foundation in Houston, Texas.

The Planets That Bloom in the Spring

THE LUNAR AND PLANETARY SCIENCE CONFERENCE

by Bevan M. French

Each year, as spring returns to Houston, Texas, hundreds of space scientists celebrate their own long-standing Rite of Spring—the Lunar and Planetary Science Conference. This year's gathering, the fourteenth, brought more than 500 participants together for a busy and exciting meeting that stretched from March 14 to March 18, included 475 papers in 28 separate sessions, and covered subjects ranging in size from tiny cosmic dust particles to the solar system itself.

During its 14 years the conference has changed radically with our changing exploration of the solar system. Beginning in 1970 as the *Apollo 11* Lunar Science Conference, the meeting concentrated on the new loads of samples that continued to come back from the Moon, and the conference was informally known for many years as the "Rockfest." Gradually the conference began to reflect our wider exploration of the solar system, and the screens of its lecture rooms came alive with results from Mars, from Venus, and finally from the outer planets reached by the *Voyager* spacecraft.

This year the meeting again spread out to include the whole solar system. The rocky ancestry of the conference was still apparent in about half the sessions, in which the continuing research on lunar samples has been joined by exciting studies on meteorites and cosmic dust particles. Larger planetary objects were covered in other sessions: Mars, Venus, the Moon, outer planet satellites, planetary rings, and the evolution of the solar system.

The star of the conference (if a lunar and planetary conference can have a star) was a one-ounce meteorite called ALHA 81005, which was picked up from the Antarctic ice cap in December, 1981. At first glance, 81005 was unusual, with white rock fragments in a greenish matrix. "It looks like a lunar rock," observed Dr. Brian Mason of the Smithsonian Institution, who did the initial examination of the specimen last fall. In a special session on the morning of a lively St. Patrick's Day, scientist after scientist presented detailed results to prove that 81005 was in fact a piece of the Moon, blasted to the Earth by a meteorite impact perhaps a million years ago. Everything about the little rock—chemistry, mineral composition, gas content and exposure to cosmic rays—was virtually identical to the white calcium- and aluminum-rich samples returned from the lunar highlands by the *Apollo 15* and *16* missions. However, 81005 is not just another *Apollo* sample. Slight differences in composition indicate that it does not come from the areas that the *Apollo* missions sampled, and it may actually come from the far side of the Moon.

The afternoon of St. Patrick's Day was equally lively. Now that 81005 had established that meteorites could be blasted to Earth from large planetary bodies, the scientists turned to the evidence that other meteorites may have come from a larger and more distant object: the planet Mars. The possibility of a Martian origin for a small group of unusual meteorites—collectively called "SNC meteorites" from the initials of their rather exotic names (shergottites, nakhlites and chassignites)—had been casually discussed for the last few years, but the special afternoon session presented enough new evidence to force even skeptics to think seriously about Mars. Larry Nyquist reviewed the evidence that the SNC meteorites are young—only about 1,300 million years old—too young to be pieces of asteroids, but about the same age estimated for Martian volcanos. Benton Clark described the chemical similarities between the SNC's and the fine Martian surface material analyzed by the *Viking* landers.

Trapped gases in the SNC meteorites provide the strongest evidence for a Martian origin. Donald Bogard discussed the similarities between the Martian atmosphere (as measured by the *Viking* landers) and the noble gases (argon, neon, xenon, etc.) trapped in one Antarctic SNC meteorite, and Robert Pepin presented data to show that the trapped gases also have the same enrichment in heavy nitrogen (nitrogen 15) seen in the Martian atmosphere.

Against this impressive circumstantial evidence were set the arguments of the theorists whose models suggested that meteorite impacts could not throw large chunks of rock into space from the surface of Mars. The gap between data and current theories may be closed in the future by a combination of more theoretical studies and more work on other SNC meteorites, many of which have been little-studied curiosities until now.

No possible Venus samples have turned up (yet), but the planet itself was the subject of active discussion. The Reagan administration's decision to support NASA's Venus Radar Mapper as a new start project in fiscal year 1984 provided a new immediacy and excitement to the results being obtained from Earth-based radars and from U.S.S.R. surface landers. Radar studies from Arecibo, Puerto Rico continue to provide, even at low resolution, new details about the shape of Venus' surface. Jim Head described how Maxwell Montes, the 11-kilometer-high region on Ishtar Terra, has been subdivided into a number of different terranes—banded, mottled and patchy—all of which probably represent different landforms, surface roughnesses and possibly rock types. Maxwell also shows a large circular ringed feature about 100–200 kilometers across, which may be a depression.

In other regions of Venus, radar backscatter images from Akna Montes and Freyja Montes have revealed a curious banded structure of huge parallel ridges 10 to 30 kilometers apart, which resembles many terrestrial mountain systems. Head and his colleagues believe that the ridges are caused by tectonic forces in the crust of Venus. However, they are still uncertain about whether the parallel ridges have been produced by compression (like the Appalachians on Earth) or by tension (like the Basin and Range region of the western United States). The higher resolution to be obtained from the Venus Radar Mapper may help settle the problem.

The Soviet Union's soft-landing spacecraft, *Veneras 13* and *14*, provided a close look at Venus, and the results were reviewed by a group of visiting Soviet scientists: V. L. Barsukov, I. L. Khodakhovsky, Yu. A. Surkov and their colleagues. The spacecraft, much more sophisticated than earlier *Venera* landers, obtained TV panoramas, carried out soil mechanics studies, and actually scooped up samples of the Venus surface material and analyzed them.

The *Venera* pictures suggest that the surface is a kind of crust—lithified and breakable rather than dusty or sandy. However, the surface material is not hard bedrock; the mechanical tests suggest that it is similar in strength to volcanic ash, packed beach sand or foamed concrete. The *Venera 14* pictures show loose material and sedimentary layering. The chemical analyses are most like the alkaline basalt lavas found in the Earth's ocean basins, and there was considerable discussion about whether the surface of Venus is covered by volcanic sediments produced by explosive volcanic eruptions. However, the high surface temperatures and deep chemical alteration on Venus could easily produce surface material very different from the original bedrock.

The "Lunar" part of the conference was also well represented. Nearly 15 years after the *Apollo 11* landing, the lunar sample collection is still yielding new insights into the Moon. Larry Taylor and his co-workers presented evidence for an unusually old episode of volcanic activity about 4.2 billion years ago. Their work suggests that the formation of the dark lunar regions—the maria—extends much further back in time than we thought, perhaps even back into the period of giant impacts on the Moon's surface.

There were also extensive studies of "new" rocks from the *Apollo 11* collection by J. C. Laul and his associates, who have developed such precise techniques that they can analyze "rocks" which are only 0.2 to 1.0 millimeters in size. In studying this formerly inaccessible material, they found something unexpected: many of the rocks from the *Apollo 11* site are similar to those returned from the *Apollo 16* site in the distant lunar highlands.

Even from the Earth, the Moon continues to provide surprises. Earth-based near-infrared observations of the lunar highlands are being used by Carle Pieters to determine the chemical composition of the lunar crust. Much of the top kilometer of the crust seems to be rich in the minerals feldspar and orthopyroxene, but material from 5 to 10 kilometers deep, which has been lifted up in the central peaks of large impact craters, appears different. One area, the central peak of Copernicus, is magnesium-rich and contains large amounts of the mineral olivine. In the region around Aristarchus, similar studies by B. R. Hawke indicate an unusual highlands composition, rich in feldspar and clinopyroxene and overlain by darker deposits that may be ash layers from relatively young volcanic eruptions.

The Moon also appeared in the role of a world to go back to. A crowded special session on "Return to the Moon" heard several speakers discuss the nature and implications of future lunar exploration: permanent bases, resources, unsolved scientific questions, and political and economic considerations. Dr. Hans Mark, NASA's Deputy Administrator, gave the keynote speech and drew strong parallels between the future exploration of the Moon and our past exploration of the once-inaccessible Antarctic continent. Dr. Mark stressed the need for an "enabling vehicle" that would do for lunar exploration what the airplane has made possible in the Antarctic and added that, if his "somewhat conservative" analogy held, "then we should have a permanent population of the order of a thousand people on the Moon by the year 2040 and we should be in the position of beginning to exploit lunar resources."

Around these highlights, the conference continued, active, exciting and exceedingly well-run. Scientists spilled out of sessions to talk in the halls and around the coffee bars. Research projects were updated on the spot and new cooperative work was planned. The youth and enthusiasm of many of the attendees was especially striking. "I don't recognize half the faces here," said one long-time NASA program manager as he surveyed a crowd of scientists who must have been about 12 years old when *Apollo 11* landed. "That's a good sign," he added. "It means that there's a new generation coming in, ready to do their own great things."

This "free" lunar sample was provided by an impact on the Moon perhaps a million years ago. Scientists collected this meteorite, ALHA 81005, from the Antarctic ice cap in 1981. At the 1983 Lunar and Planetary Conference, researchers agreed that it is a lunar rock, although it does not come from the areas sampled by the Apollo missions. It may even be a piece from the unsampled far side of the Moon.

Photo: NASA/Johnson Space Flight Center

Bevan French is the Discipline Scientist for Planetary Materials in the Planetary Division at NASA Headquarters. His research focuses on samples of extraterrestrial materials and terrestrial impact craters.

WORLD WATCH

by Louis D. Friedman

WASHINGTON, D.C.: Dr. Geoffrey Briggs has been named to head the Solar System Exploration Division at NASA. Formerly with Bellcomm, Inc. and the Jet Propulsion Laboratory, Dr. Briggs was Deputy Director of the Earth and Planetary Division for several years, serving as the chief planetary scientist at NASA. He is a founding member of The Planetary Society and has volunteered his services to us in the past, once serving as our chief technical judge in the national high school essay contest that we sponsored for Planetfest '81.

Al Diaz, formerly the NASA Headquarters manager for the *Galileo* project and for planetary advanced studies, was named as Deputy Director of the Solar System Exploration Division.

Congressional action on the NASA budget has been generally favorable so far. The Venus Radar Mapper is strongly supported by the committee responsible for the space budget. Both the Senate and House authorizing committees added money for research support of planetary science to the budget proposed by the Reagan administration. The amounts were significant ($10 million in the Senate, $15 million in the House), although this is less than is necessary to restore the program to 1980 levels and to insure the continuation of research and data analysis programs. Action by the conference committees and the Appropriation Committee is still necessary, and will require support from those interested in a vital United States planetary program.

MOSCOW: American scientists are listening with great interest to their Soviet counterparts' reports on the continued exploration of Venus. The Soviet Union began attempting to reach Venus in 1961 and has successfully launched spacecraft to the Earth's nearest neighbor at eight out of the ten opportunities since 1965.

Launch opportunities for Venus missions occur every 19 months—the synodic period of Venus—when the relative positions of the Earth and Venus are favorable from an energy standpoint. The most recent launch opportunity fell in May–June 1983, and, following a minimum energy trajectory, a spacecraft could arrive at Venus in October, 1983. The next launch opportunity is December, 1984, with a June, 1985 arrival. That opportunity will be used for the Soviets' extraordinary VEGA (VEnus-HAlley) mission. (The "h" in English is transliterated as a "g" in Russian.) But what (if anything) is planned for 1983 has not been publicized.

Rumors about a Soviet radar mapping mission of Venus have been circulating in the scientific community. In early June, the Soviet news agency, TASS, announced launches of spacecraft to Venus, but gave no details of objectives or payload. Scientists involved in the U.S. Venus Radar Mapper (VRM) mission believe that a Soviet mission will not render U.S. plans moot, but rather that it would present an opportunity for complementary science.

I recently discussed some aspects of the Soviet space program with Planetary Society advisor Roald Sagdeev and with Yu. A. Surkov, a principal scientist of the *Venera 13* and *14* missions. I talked with Dr. Surkov, of the Vernadsky Institute of Geochemistry and Analytical Chemistry, at the Lunar and Planetary Science Conference (LPSC) where he and his co-investigators reported on the latest *Venera* findings. We will present a summary of my discussion with Dr. Surkov in the next issue of *The Planetary Report*.

The interview with Academician Sagdeev is our first opportunity to establish a liaison with officials in the Soviet space program, and to help in the planning of future cooperative or complementary ventures for the peaceful exploration of the solar system. Academician Sagdeev is the Director of the Institute for Cosmic Research of the Academy of Sciences of the U.S.S.R. This and the Vernadsky Institute are two of several organizations in the Academy which conduct experiments in the Soviet space program.

The interview with Academician Roald Z. Sagdeev follows:

A Talk with Roald Sagdeev

Louis Friedman: Dr. Sagdeev, we are delighted by your joining the Board of Advisors of The Planetary Society. Can you tell our members about your interest and involvement in planetary science and exploration?

Roald Sagdeev: Well, my involvement is straightforward. Ten years ago I was nominated as the Director of the Institute for Cosmic Research. As such, my administrative duty is to promote and support planetary science. There are four major departments in the Institute, of which planetary physics is one of the most important.

My personal interests used to be far from planetary science. I was in plasma physics and fusion. Naturally, this leads into magnetospheric physics, which relates to planetary science. For the last few years I've been trying to involve myself creatively as well as administratively. For example, I feel like a real member of the *Veneras 11* through *14* mission teams, and I am very involved with the VEGA mission. In fact, approximately 50 percent of my time is spent on VEGA (some people at my institute complain that this is too much involvement in planetary missions). I have a number of ideas now which I wish to pursue that bridge my old field, plasma physics, with solar system exploration.

LF: What is the importance of space exploration in the Soviet Union?

RS: It is considered one of the most important areas for science and exploration in general. That is why it was supported as far back as the early 1950s, which, of course, resulted in our accomplishment with *Sputnik*. We have a very good infrastructure now which supports the systematic exploration and conduct of space programs. Naturally, there are various opinions about manned versus unmanned space activities, science programs, application programs, etc. However, I believe the diversity of interest is good, and we are able to conduct programs in many of these areas.

LF: In light of the recent *Venera* results, what are the major objectives and significance for continued Venus exploration?

RS: Some people in the Soviet space establishment are questioning why we are concentrating on Venus versus the broader approach being done by the Americans. My answer is that it is a reasonable, complementary approach. While you are doing widespread reconnaissance, somebody must do deep exploration. What we are doing on Venus is a paradigm of such exploration. Of course, with the Halley's Comet mission we are spreading out a little more. It's interesting that this is the opposite of our two countries' approach to agriculture. There, you are doing intensive work, while we are doing extensive. The American farming program is concentrating on getting more yield per acre, while the Soviet program is looking at farming more acreage. In both agriculture and planetary science the two approaches are complementary. We need to find better ways of taking advantage of the benefits that each can offer.

LF: Might you do a mission similar to the Venus Radar Mapper?

RS: We are very interested and may do something. However, it will not duplicate your radar mapping mission. We might do something like spot coverage of the poles. (The U.S. mission will not map the polar regions of Venus with great resolution.) This would be an intermediate step but, again, it would be of a complementary nature.

LF: What is next for the U.S.S.R. at Venus—long-lived landers, more and different landing sites, balloons, hoppers, helicopters, rovers?

RS: Presently the situation is quite obscure. Everyone feels something technologically new should be brought forward, and lots of options are being discussed. With the French we are considering high-temperature technology to provide long-lived landers or low-altitude balloons. Another completely unexplored area is the seismology of Venus.

LF: What are the near-term science objectives for the U.S.S.R. in space?

RS: We are pursuing two lines in parallel: first, basic and fundamental science as part of the basic research program in the Soviet Union; second, applied science and technology for possible benefits, such as the remote sensing of Earth resources, manufacturing and materials processing in space. It is important to proceed in both these areas, even where there are no concrete applications. If science were done otherwise, we would never have discovered Newton's Laws.

LF: What are the Soviet goals in planetary exploration?

RS: We have quite a broad space program and, naturally, some percentage of this is devoted to deep space exploration. There are many arguments for it: increasing national prestige, stimulating technology development, and doing the science that is exceptionally important for humankind. Throughout the millennia, it has been important to compare ourselves with others. These are the major questions that motivate our exploration of the solar system.

LF: We have a theme in The Planetary Society, "Searching for Our Analogs," that is very similar to that idea.

RS: That's very good, and can be broadened beyond planetary exploration to all of space science. It provides a connection between what we learn from space exploration and all branches of science.

LF: Besides Venus and the VEGA mission, what missions are being seriously studied in the Soviet Union? What about geochemical orbiters of the Moon or Mars?

RS: The lunar mission is one possibility. It has been rejected by your country and by Europe, and some of our scientists are also saying that it is a dead-end and not interesting to the general public. But I think it could be very appealing. It raises the idea that the Moon could be a place where we apply advanced remote sensing technology to study solar system cosmochemistry. This mission would feed back to Earth program technology. On this mission would be gamma ray and other spectral detectors as are used to observe the Earth. This is in line with the idea of pursuing complementary ways of exploring the solar system.

LF: Anything else?

RS: Yes. After the Halley's Comet mission it would be interesting to do small body missions. Asteroids are particularly interesting. One idea I have is to take a laser to an asteroid and hit a part of the asteroid with the laser beam, causing a plasma cloud. We could then analyze the plasma cloud to learn about the chemical composition of the asteroids. This, of course, combines my own two fields of interest.

LF: The Planetary Society is supporting a program to look at near-Earth asteroids. Is anything like that going on in the Soviet Union?

RS: We have lots of people interested in studying the orbits of asteroids and of new objects, but no serious money is going into this for missions.

LF: What are the goals for Mars exploration?

RS: Everybody is trying to recover from the shock of not finding any life on Mars. I think it will take some time, but we should recover, and surely there is a future for exploration of Mars.

LF: You're totally negative on the life question?

RS: Well, maybe not totally negative, but it doesn't look good. There is the business, however, to explain the interesting chemistry of the surface.

LF: I have just come from the Lunar and Planetary Science Conference where a great deal of interest was expressed in a lunar base or facility. Is there similar interest in the U.S.S.R.?

RS: We're very interested in the lunar geochemical orbiter, as I mentioned earlier. With regard to a lunar base, several years ago the astronomical community was interested in having some sort of observatory or facility on the Moon. About that time, however, there was a great deal of discussion about a dust envelope on the Moon, and that idea seems to have gone away. I don't think we'll have a lunar science base in this century.

LF: NASA is considering a space station, which, as someone suggested, would be used for scientific, and sometimes for other, purposes. Is the Soviet Union likely to build a space station, and will it be used for science?

RS: This is quite a hot topic for discussion; actually, a topic for hot discussion. My opinion is that most science can and should be done by simpler means, without having to involve men, at least in the beginning. Manned technology is important for the development of technology and it is not always easy to find a balance between these two programs.

(continued on next page)

LF: Might the space station be built anyway, and be used for science later?

RS: That kind of argument would never justify the space station. It has to be justified by manufacturing in space, remote sensing or promoting new fields of science and technology.

LF: Is it likely?

RS: Salyut, of course, is a prototype, but you're asking about a new vehicle, and I think such a thing does have a future.

LF: Concern is growing that increased military activities in space will work against science and exploration in the future. Do you think so? Will space be a largely military arena?

In this painting of Venera 9 on Venus, the horizon appears curved due to refraction by the planet's dense atmosphere.
Painting: A. Sokolov

RS: In my opinion, any increase in military activity anywhere works against science, and space is only one of those places. Personally, I hope that some kind of agreement is found to minimize space military activity—maybe to exclude weapons, at least in space. If there is no agreement or treaty with such limits, then, yes, we are very likely to be faced with this situation in the future.

LF: The Soviet program has been growing internationally, with the French at Venus, with the VEGA mission, etc. Is this a trend? What are the benefits?

RS: I believe it is an essential element of our approach to space research. I can cite a personal example of the benefits directly from my own career in fusion. Fusion is one of those areas that has been established as an internationally cooperative program, and we see the United States and the Soviet Union cooperating on such programs. I try to bring this into space because it is the same, natural, broad area which admits to great benefits and sharing of knowledge from international cooperation.

LF: What are the opportunities for cooperation between the U.S. and the U.S.S.R.?

RS: This is not a simple question. There are regular exchanges now on a small scale, and certainly we are sharing data—at Venus, for example—and cooperating on the VEGA mission. But to cooperate on a major mission, we need a more favorable political situation. This is not yet the case. I can only hope that it will become possible. It could be of great benefit to both countries.

LF: Is there popular interest in the Soviet Union in space exploration?

RS: Yes, I would say that there is popular interest. A lot of people ask why we are spending so much when there are no concurrent economic benefits. We must strike a balance, of course. However, there is sufficient popular support and it needs to be carefully nurtured with constant explanation and involvement of the public.

LF: Do you do any popularization on TV and in magazines?

RS: Yes, I do these things. The Academy of Sciences is encouraging involvement in educational and popularization programs. We publish articles in most of the major newspapers and science magazines, and there are some programs on television. One special program is the biweekly "Man-Earth-Universe," which covers space activity. It is hosted by Cosmonaut Sevastyanov. In fact, sometimes the requests are so frequent that it gets to be too much and we have to refuse.

LF: How do you develop enthusiasm and interest in young people?

RS: There are education programs. And from time to time we organize contests about space exploration or conduct creative activities for students, allowing them to make proposals, build models, do experiments, etc. These are very popular.

LF: Do you have a problem getting good students into the space science field?

RS: The problem is in all fields of science, because science is developing so quickly. I don't think it is particularly worse in space science. We are closely affiliated with the Moscow Physical Technical Institute, and they do a program where their students come to work at our institute and our staff does some part-time teaching. We get some of the best students to come to work for us after they finish school.

LF: What do you suggest The Planetary Society could do to establish a liaison in the Soviet Union at the popular level and to promote new missions?

RS: There are several possibilities. It would be a good idea to have a Russian translation of *The Planetary Report. Scientific American* is just starting to translate their magazine, and I believe yours would be very popular. It is a very good magazine. There is a great deal of popular interest in science and astronomy in the Soviet Union, and several organizations deal with this. We could establish contacts, material exchanges, and so forth. Thirdly, we might do a feature about The Planetary Society on Soviet television. When either you or Dr. Sagan are in the Soviet Union, we should explore these three ideas and perhaps the publication of additional material that could be disseminated in the Soviet Union, and make contacts so that you can receive additional material about the Soviet space program. □

News & Reviews

by Clark R. Chapman

By late spring of 1983, three of the four relevant committees in the United States Congress had voted to add between $10 and $15 million to President Reagan's proposed budget for planetary research and analysis. The President's budget request contained a new start for a planetary spacecraft mission, and all three congressional committees had agreed. If these signs of spring mature into budgetary reality by autumn, the American planetary exploration program will be back on its feet again.

Why have the fortunes of the planetary program been turned around? An essential role in the resurrection of the American planetary program has been played by NASA's Solar System Exploration Committee (SSEC). Committees come and go and usually rival each other only in their ineffectiveness. But the SSEC was in place when it was needed, and it appears to have accomplished the hard but necessary task of gaining acceptance (some of it grudging, some enthusiastic) of its proposed "Core Program" of planetary missions. Much credit goes to Dr. Geoffrey Briggs, who served for the last two years as Executive Director of the SSEC and was recently rewarded for his resourcefulness and hard work by being promoted to lead NASA's Solar System Exploration Division.

Much credit is also due Dr. Noel Hinners and Prof. David Morrison, who are the two most recent chairmen of the committee. They combined their talents in preparing the cover story for the May 6, 1983 issue of *Science*, the magazine of the American Association for the Advancement of Science. (See the May/June 1983 issue of *The Planetary Report* for a summary by Prof. Morrison.) The *Science* article gives the philosophical background for the somewhat more complete description of the Core Program found in a thin, colorfully illustrated booklet that is the executive summary of the SSEC's findings and recommendations: "Planetary Exploration Through Year 2000: A Core Program." (Available for $5.50 from The Planetary Society, P.O. Box 91327, Pasadena, CA 91109.)

Despite the political compromises that were made and the essentially political context in which the SSEC report is being received, the actual documents (both the executive summary and the full report soon to be published) present an exceptionally convincing and logical argument for the recommended Core Program, whose planetary missions will be "constrained" so as to meet stringent dollar limitations. They will take advantage of "inheritance," which means using existing hardware and techniques when possible. At least temporarily, the planetary program will forego technological advances and will concentrate on getting the job done with available tools. This means using industrial, production-line spacecraft for a series of "Planetary Observers" for exploring the inner solar system and developing a new, but nonetheless modest, modular spacecraft —the *Mariner Mark II*— for somewhat more advanced missions. To support the entire program, strength will be returned to the basic university programs of research and instrument development.

In press reports, there has been some ambiguity about just what the Core Program is. For understandable reasons, the SSEC report concentrates on the first four missions: the Venus Radar Mapper, a Mars Observer, a comet rendezvous mission, and a Titan mission to follow-up on *Voyager*'s remarkable findings. Despite what *The New York Times* News Service reported, however, these are not the only missions intended for the next two decades. Ten additional small-to-moderate missions are also part of the Core Program. They are to explore the Earth-approaching asteroids, the asteroid belt, comets, the Moon, Saturn and Uranus, as well as revisit Mars and Venus to make measurements complementary to those undertaken by early Core Program missions.

After reading the succinct descriptions of the SSEC's conclusions, two kinds of questions remain in one's mind: First, what is the role of international cooperation? A group of American and European scientists, working under the sponsorship of the National Academy of Sciences and the European Science Foundation, is currently addressing the potential for cooperation in planetary missions. The SSEC report and the Morrison/Hinners *Science* article are muddy on the question of whether it is intended to seek European help in Core Programs missions, or instead to combine the joint resources of Europe and America to forge some larger, more challenging missions as augmentations to core programs of the European Space Agency and NASA. Also unresolved is the question, of interest to many Planetary Society members, whether or not the United States is prepared to explore space in a more ambitious manner than the constrained SSEC approach. The SSEC itself is studying larger missions this year, but political receptivity for anything beyond the Core Program is not yet apparent.

Interview with a Planetary Geologist

One of the most captivating personalities in planetary science is Eugene Shoemaker, a geologist who divides his time between the United States Geological Survey in Flagstaff, Arizona, and the California Institute of Technology in Pasadena. An interview with this man, who has led hundreds of tours into the bowels of Arizona's Meteor Crater, is published in the March issue of *PSA Magazine*, the in-flight reading material provided by Pacific Southwest Airlines. Shoemaker describes how his late-1940s decision that he would go to the Moon led him to begin a career of geological research that resulted, within a decade, in his definitive proof that the Arizona crater was indeed produced by impact. The interview traces some of Shoemaker's later thoughts about the role of asteroidal and cometary impact on the Earth and other planets, including his latest musings about catastrophic interruptions in the evolution of species of life on the Earth's surface.

Unfortunately, the *PSA* interview bears the same resemblance to the jovial Shoemaker as an "edited for television" movie does to one's favorite full-length, wide-screen feature film. Some glimpses of the real man do penetrate the editorial screen. Apparently, space limitations kept this resourceful geologist from elaborating on his new part-time occupation as an astronomer. Although his research tools have changed from rockhammer to telescopic-camera, he is still pursuing the same basic goals as he hunts for Earth-approaching asteroids, part of the population of bodies that have produced catastrophies in the past and are sure to do so again. Despite its imperfections, the *PSA* article reminds me how rare are the books and articles about planetary exploration that delve in any depth into the people involved. With the exception of rare profiles in *The New Yorker*, one must rely on infrequent and fairly shallow journalistic treatments of the personalities of planetary exploration.

Clark R. Chapman advised the Solar System Exploration Committee about asteroid and comet missions and also is involved in American/European discussions about cooperative missions to the small bodies.

Society Notes

by Louis D. Friedman

The Price-Waterhouse audit of our complete 1982 financial statements resulted in an unqualified opinion that those statements were in conformity with commonly accepted accounting procedures. The Planetary Society's cash reserves increased by $200,000 in fiscal year 1982 (ending September 30, 1982), out of a total budget of about $1,700,000. Approximately one-third of our income is from dues, 60 percent from donations (for general use and for specific programs), and the rest comes from events, sales and interest. About half of our expenses are for keeping the public informed, promoting space exploration and mailing out printed material. Support of research projects accounted for 10 percent of our expenditures, as did the production of special events and administration. 1982 was the first year that we began to seriously fund research projects, with the initiation of Suitcase SETI.

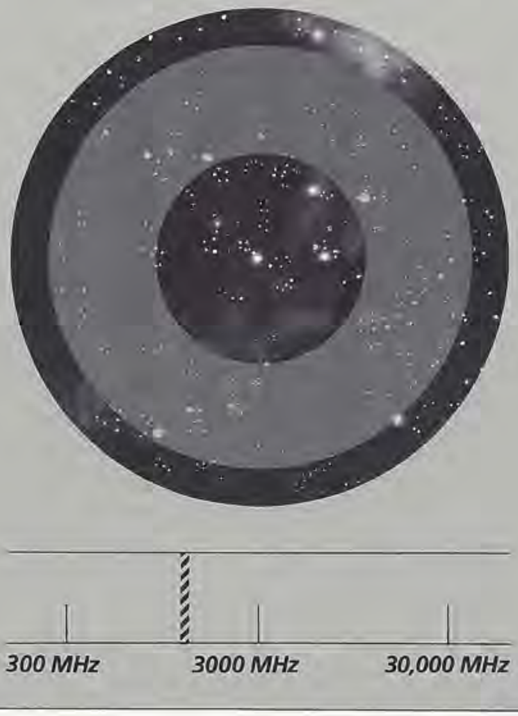
Membership renewals dominate our finances. They continue to go well; the rate is now above 60 percent—better than most new organizations. The rate of renewal is even higher among our second-year members. The offsetting bad news is that the costs of getting new members are rising, especially as we reach out to new communities to promote interest in space exploration. For the first time it costs more than $15.00 to bring a new member into the Society.

PROJECT SENTINEL

The Search for Extraterrestrial Intelligence Continues

Professor Paul Horowitz reports that, as of July 18, 1983, The Planetary Society/Harvard University Project Sentinel has reached 27.5 degrees north of the celestial equator in its search for radio signals from extraterrestrial civilizations. Using the radio telescope at Oak Ridge Observatory, Project Sentinel scans the sky, monitoring a band of 128,000 contiguous frequencies centered on the 1420 megahertz (MHz) emission line of hydrogen. No extraterrestrial signals have been detected, nor, of course, were any expected so soon. The project is designed to continue for years. In this illustration, the band across the sky represents the area of sky already covered. The chart at the bottom indicates the frequency being monitored.

We will print similar charts periodically in The Planetary Report to keep our members up-to-date on the progress of Project Sentinel, a search for extraterrestrial intelligence being funded by donations to The Planetary Society. CHART BY JON LOMBERG



The recession began to affect us at the end of 1982. A recent telephone poll of former members showed that, by a factor of 3 to 1, the dominant reason for not renewing was a temporary lack of money.

The dues of The Planetary Society will remain, at least for the present, $15.00 per year for members within the United States, and approximately $20.00 per year (usually rounded off in foreign currency) in Canada, Mexico and overseas. We prefer to rely on donations for additional income to offset increased expenses, rather than to raise our popularly-priced membership fee.

Donations from our members to the Society have been significant. More than one-third of you send in additional donations when renewing, and many of you also support our special appeals for project funds. This has provided the sound financial base of our organization.

The Board of Directors has identified several new areas for Society support, and we are starting some new activities. An increased commitment to the Search for Extraterrestrial Intelligence (SETI) is our first priority; we reported on Project Sentinel at Harvard University's Oak Ridge Radio Observatory and an experiment at the radio telescope at Tidbinbilla in Australia in the last issue of this magazine. Recently, we provided start-up funds for the International Astronomical Union's new SETI commission. In this special asteroid issue of *The Planetary Report* we report on progress in Eleanor Helin's program to discover asteroids that pass close to the Earth. The Mars Institute has gotten off to a slow start, although we have completed the analysis of the questionnaire sent to planetary scientists and have identified an initial set of courses and projects for the Institute. A Mars Institute brochure is now circulating among participants and we have also announced a student research contest on a Mars colonization topic.

Recognizing that space exploration has been a great motivator for students, the Board of Directors has decided to capitalize on that interest by undertaking an education program structured around the scientific exploration of the solar system and the search for extraterrestrial life. We have formulated a five-point plan that will reach students and educators in junior and senior high schools and provide incentives for the best college students. Our staff has begun work on this program and will report to members within a few months.

We recently completed another project: a multi-media show called "Exploring Other Worlds." Produced by Jon Lomberg and narrated by Carl Sagan, the show tells the story of The Planetary Society and outlines the exploration that we promote. Many of the best images of our neighboring worlds are presented. In May, more than 3,000 people saw the show's premiere at the FutureWorld Expo in Los Angeles. "Exploring Other Worlds" will soon be shown at several places around the country.

The third area of Society "investment" is international growth. We now have more than 5,000 members in Canada, membership offices in the Netherlands and Japan, and have begun liaison activities in France, Australia and Great Britain. We are also pleased to announce an official liaison between The Planetary Society and the Hungarian Astronomical Society, the first such east-west official tie we know of in the space movement. □

The Solar System in Pictures and Books

● BOOKS	PRICE	QUAN.	TOTAL
Voyages to Saturn by David Morrison – Description of both *Voyager* Saturn encounters, with color photographs.	**$14.00**		
Voyage to Jupiter by David Morrison and Jane Samz – Description of both *Voyager* Jupiter encounters, with color photographs. 199 pages.	**$10.00**		
Pioneer: First to Jupiter/Saturn and Beyond by Richard O. Fimmel, James Van Allen and Eric Burgess – Illustrated accounts of two *Pioneer* missions. 285 pages.	**$14.50**		
Beyond the Atmosphere by Homer E. Newell – History of the United States space program. 500 pages.	**$14.00**		
Voyager 1 Encounters Jupiter – An illustrated booklet with the best pictures of Jupiter from *Voyager 1*. 40 pages.	**$ 5.00**		
Voyager 1 Encounters Saturn – An illustrated booklet with the best pictures of Saturn from *Voyager 1*. 40 pages.	**$ 5.00**		
The Planets: A Cosmic Pastoral by Diane Ackerman – A collection of poems about the planets. 159 pages.	**$2.00** **On sale!**		
The Grand Tour: A Traveler's Guide to the Solar System by Ron Miller and William K. Hartmann – A beautifully illustrated guide to 25 worlds in our solar system. 192 pages.	**$ 9.00**		
The Surface of Mars by Michael H. Carr – A definitive summary of *Viking* mission results. Large format. 232 pages.	**$20.00**		
Planets of Rock and Ice by Clark R. Chapman – Guide to the small planets from Mercury to the moons of Saturn.	**$10.00**		
Universe by Don Dixon – A large format look at the universe, illustrated with paintings by the author. 240 pages.	**$30.00**		
The New Solar System edited by J. Kelly Beatty, Brian O'Leary and Andrew Chaikin – Up-to-date information on our planetary neighborhood. 224 pages. **Soft cover** **Hard cover**	**$ 8.50** **$16.00**		
The Moon by Patrick Moore – An atlas and guide to our satellite. 96 pages.	**$11.00**		
Jupiter by Garry Hunt and Patrick Moore – A well-illustrated look at the largest planet in our solar system. 96 pages.	**$11.00**		
The *Voyager* Flights to Jupiter and Saturn—The official summary of the *Voyager* encounters. 64 pages.	**$ 6.50**		
Murmurs of Earth by Carl Sagan, Frank Drake, Ann Druyan, Timothy Ferris, Jon Lomberg and Linda Salzman Sagan – Account of the development of the *Voyager* record, a message from humanity to possible extraterrestrial life forms. 273 pages.	**$ 7.00**		
The Planets edited by Bruce Murray — Collected articles from *Scientific American*, presenting the state-of-the-art in planetary science. **Soft cover** **Hard cover**	**$ 8.50** **$14.50**		
A Meeting with the Universe edited by Bevan M. French and Stephen P. Maran – Everything from the origin of the Sun to the edge of the universe is covered in this well-illustrated volume, 221 pages.	**$14.00**		
Distant Encounters by Mark Washburn – The excitement of the *Voyager* encounters is captured for those who could not be part of the events. 272 pages.	**$10.00**		
Out of the Darkness by Clyde W. Tombaugh and Patrick Moore – The discovery of Pluto is chronicled by its discoverer and a noted science writer. 221 pages.	**$13.00**		
Mission to Mars by James E. Oberg – Plans and concepts for the first human mission to Mars are detailed in this up-to-date book. 221 pages.	**$13.00**		
Planetary Exploration Through Year 2000—This colorfully illustrated executive summary of the Solar System Exploration Committee details the proposed future of planetary exploration. 30 pages.	**$5.50**		

Back issues of THE PLANETARY REPORT are now available to Society members. Volume I and Volume II each contain six issues, Numbers 1–6. (Volume II, Numbers 1 and 5 have been sold out.) Specify the issues you would like by volume and number. A donation of $1.50 per issue to cover printing and postage costs is appreciated.

Total quantity of back issues ______________ Total price ______________

● COLOR PHOTO REPRODUCTIONS (8½" x 11")	PRICE	QUAN.	TOTAL
Jupiter – A montage of the planet and its Galilean Moons, the Great Red Spot and dynamic Io. (set of 3 prints)	**$ 2.00**		
Mars – Approaching the red planet, Martian sunrise and sunset, the rocky surface at both *Viking* landing sites (set of 4 prints)	**$ 3.75**		
The Best of *Voyagers 1 & 2* at Saturn – The planet, its rings and satellites (set of 15 prints)	**$10.00**		
***Voyager 2's* Future Missions** – Don Davis paintings of the encounters with Uranus and Neptune (set of 2 prints)	**$ 2.00**		

● LASER COLOR PRINT (16" x 20")	PRICE	QUAN.	TOTAL
Apollo Photograph of Earth (full disk)	**$ 8.00**		

● VOYAGER COLOR POSTERS	PRICE	QUAN.	TOTAL
***Voyager* at Jupiter** (Six 23" x 35" posters)	**$16.00**		
***Voyager 1* at Saturn** (Two 11" x 17" mini-posters) **On sale!**	**$ 5.00**		
***Voyager 1* at Saturn** (Five 23" x 35" posters)	**$16.00**		
Planetfest '81 Posters (Two 23" x 35") of Saturn and the F-ring **On sale!**	**$ 6.00**		

● 35MM SLIDE SETS	PRICE	QUAN.	TOTAL
***Voyager 1* Saturn Encounter** (40 slides with sound cassette)	**$15.00**		
***Voyager 2* Saturn Encounter** (40 slides with sound cassette)	**$15.00**		
***Viking 1 & 2* at Mars** (40 slides with sound cassette)	**$15.00**		
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The Solar System Close-Up (50 slides with booklet)	**$36.00**		

The Sounds of Saturn — The *Voyager* spacecraft soundsheet is now available through The Planetary Society. We request a donation of $1.00 for each soundsheet to cover postage and handling.

Total quantity of soundsheets ______________ Total price ______________

Mars in 3-D—This 16mm film, produced by Elliott Levinthal, depicts the Martian landscape as seen by *Viking*. It may be purchased for $125.00 or rented for $25.00, with a deposit of $100.00. 3-D glasses are available for $.25 each. Write to the address below for a rental agreement or purchase information.

Mail order and payment to:

THE PLANETARY SOCIETY
P.O. Box 91327
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All prices include postage and handling. Foreign orders add $3.00 for additional postage. California residents add 6% sales tax. Los Angeles County residents add an additional ½% transit tax.

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The metals and minerals of asteroids may, as human activity expands in space, prove worth their weight in gold. They are already in space and do not need to be lifted, at vast expense, out of Earth's deep gravitational well. Great structures, long dreamed of in science fiction, can someday be built in space—but only if humans learn to use the energy and raw materials available beyond our planet's gravitational grasp. In this painting, a geologist floats above the surface of a promising asteroid.

Pamela Lee, who lives in Modesto, California, is an advertising illustrator whose work has been published in Art Direction Creativity and the Society of Illustrators Annual.

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