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In Search of Planet X

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Cover: After it encounters Neptune in August 1989 (see page 21),* Voyager 2 *will join its sister spacecraft*—Pioneers 10 *and* 11 *and* Voyager 1—*now racing through the outer reaches of our solar system. By carefully analyzing the radio signals from these spacecraft, scientists can determine what, if any, objects might be affecting the space craft gravitationally. If there is a Planet X orbiting the Sun outside of Pluto's orbit, these plucky robotic explorers may help us find it. The search begins on page 6.

Image: Voyager Mission Planning Office and the JPL Computer Graphics Laboratory

FROM THE EDITOR

This summer Mars is brightening in the nighttime sky, soon to shine its brightest in 17 years. Around the world astronomers and others interested in the planets will be watching the Red Planet with renewed interest. Mars is also a prime focus of The Planetary Society—its officers and its members—as you will see in this July/August issue of *The Planetary Report*. But we also reach to the edges of the solar system, go back in time to the heyday of American planetary exploration and contemplate the workings of science.

Page 3—Members' Dialogue—Some members have written to tell us that they feel a lunar base should be NASA's next major goal. Others support our Directors' position that to drive the space program NASA needs a grander, more adventurous goal, and that Mars is the only objective that fits the bill. Tens of thousands have now signed the Mars Declaration; General Secretary Mikhail Gorbachev has proposed a joint US-USSR mission; in editorials both *The New York Times* and the *Los Angeles Times* have endorsed cooperative human Mars missions. Everywhere we see demonstrations of the idea's power. We are still attentive to our members' opinions and encourage you to continue to write.

Page 4—The Saying of Science—Science is not a monolithic institution. It is not an inexorable grinding toward "the Truth." It is something people do, and like many other human endeavors, science can stand or fall on the turn of a phrase. In this essay the respected science writer Jonathan Eberhart contemplates some recent controversies in planetary science and how a lack of care in communications can lead to thorny problems.

Page 6—Planet X: Fact or Fiction?—Is there a tenth planet in our solar system? Does Planet X orbit somewhere outside of Pluto, exerting subtle influences on the other planets? You might think that with advanced telescopes, roaming spacecraft and computer-aided calculations, by now scientists would have found any errant planets. But these questions are not so easily answered. John Anderson of the Jet Propulsion Laboratory is grappling with the mysteries of Planet X and here shares his work with our members.

Page 10—Humans to Mars: The Mission That NASA Did Not Fly—Long before *Apollo* set humans on the Moon, before *Sputnik* launched us into the space age, and after Percival Lowell popularized his canals, Mars was a destination for dreamers. Until the 1970s it was also the destination of NASA planners who, with the inspiration of space pioneer Wernher von Braun, saw the Moon as a stepping-stone to Mars. What changed that vision? To understand the current state of the American space program, we must be aware of the events that shaped it. In this issue historian Edward Ezell takes a look at what happened to NASA's once-obvious goal of a human mission to Mars.

Page 15—Mars Watch '88: A Close Encounter of the Red Kind—This September the view of Mars from Earth will be the best it has been since 1971. To take advantage of this opportunity, The Planetary Society, working with the Association of Lunar and Planetary Observers, is launching Mars Watch '88. We'll tell you how to get ready to watch the Red Planet.

Pages 16, 17 and 18—World Watch, News & Reviews and Society Notes—Our regular features continue to keep you up-to-date on the latest happenings in space exploration and in The Planetary Society.

Page 20—Q & A—This column for July/August covers asteroids, comets, the solar wind and *Voyager 2*'s exploration of Neptune. If you have any questions about our solar system or the search for extraterrestrial life, please share them with us and other members of The Planetary Society, who might be wondering about the same thing.

So welcome to our second issue in a new format, and if you haven't yet, please let us know what you think of it.
—*Charlene M. Anderson*

ERRATUM: The meteorite pictured on page 13 of the May/June 1988 *Planetary Report* was erroneously identified as possibly having come from Mars. While several other meteorites are believed to have reached Earth from Mars, this particular rock is believed to have come from the Moon.

Members' Dialogue

As leaders of a membership organization, The Planetary Society's Directors and staff care about and are influenced by our members' opinions, suggestions and ideas about the future of the space program and of The Planetary Society. We encourage members to write us and create a dialogue with us on topics relating to the planetary program, such as the space station, the lunar base and the exploration of Mars.

Send your letters to: Members' Dialogue, The Planetary Society, 65 N. Catalina Avenue, Pasadena, CA 91106.

In the November/December 1987 issue of *The Planetary Report* Bernard M. Oliver warns of the imminent loss of one of the most valuable of the SETI windows. It's an interesting article on a subject that he obviously feels deeply about. But he spoiled it by including a diatribe against space travel. He states that no voyage will be worth thousands of years of a planet's energy consumption.

Come now, Dr. Oliver. Have you forgotten what the Bishop of Rome said to Columbus? "No trireme has been built large enough to carry all the food needed to feed all the oarsmen necessary for a trip of that duration. And besides, the waves will come in all those itty-bitty oar holes and swamp your ships." Need you be reminded that Horace Greeley's urgings for westward migration almost came to naught when the scientific establishment pointed out that since the great plains were short on timber, the east coast would have to be clear cut to supply fuel for all those itty-bitty wood-burning locomotives pulling young men west?
CHARLES W. JARVIS, *White Bear Lake, Minnesota*

My 18-year-old son, Lane, to whom your survey letter [a recent membership acquisition mailing] was mailed, died suddenly and unexpectedly in August 1987. Lane was an avid advocate of your ideals and goals for an active space program. He was an exceptional young man, graduating sixth in his class at Slidell High School in May. He was a participant in Texas University's Gifted Students' Summer Program, where he was involved with computer science as well as space exploration. During that program he met and had as an instructor June Scobie, wife of Commander Scobie of the ill-fated *Challenger.*

Lane had been offered no fewer than five academic scholarships, and he chose to attend the University of Texas in the fall of 1987. His death was caused by a cardiac arrythmia in an otherwise perfectly healthy body—the result of an unexplained neurological malfunction. Lane's brother, Glen, now a graphic design artist in Minneapolis, was one of your national essay contest winners for Planetfest 1981. Our family accompanied Glen on his free trip to Pasadena and the Jet Propulsion Lab, where Lane developed his interest in your accomplishments.

It is in Lane's memory and on his behalf that I submit the survey form for your use. Please remove his name from your mailing list and replace it with mine.
DAVID R. SMITH, *Slidell, Louisiana*

Although putting humans on Mars as soon as possible may be a personal favorite of the Society's leaders, I believe human progress to the Red Planet should follow the outlines proposed by both the Paine and Ride Commissions—by way of the Moon. Much can be said about the benefits a joint American/Soviet mission would bring to world peace, but politics should not play a part in our choice of missions.

I propose that we, The Planetary Society, in these difficult times for space interests, decide to promote the more natural and most accepted path of humans into space rather than the leapfrog approach we now appear to be promoting. Moving out from the space station to the Moon and then to Mars will not be as quick as going directly to Mars but may turn out to be the more useful of the two schemes.
RANDALL BRIGGS, *Worcester, Massachusetts*

A permanent, expandable space station, heavy-lift launch vehicles, space tugs and a permanent Moon base are all parts of the infrastructure that will be necessary to continue humankind's expansion of our environment past the confines of Earth. The utilization of lunar resources in this long-term effort has been given only perfunctory and dubious reference in

(continued on page 19)

NEWS BRIEFS

President Reagan's latest space policy calls for US leadership in many areas of space science, but it does not strongly endorse international cooperation.

Herman Pollack, a former State Department official, observes that leadership in space doesn't come "because you've built a bigger launcher than the other fellow has. It's because you put it to use in a way that serves not only your purposes but their purposes and therefore they turn to you for direction and guidance."
—from Peter N. Spotts in the *Christian Science Monitor*

NASA is looking into achieving a "quicker first" in space with an astronaut mission to Phobos. According to space agency officials, this could take as little as five to seven years. The mission might need only about half as much fuel and equipment as a Mars landing because it would avoid passing in and out of the planet's gravitational pull.

The Phobos mission would carry six astronauts who could do a "sprint" mission to the martian surface and/or send robotic probes to explore and collect samples.
—from the *Washington Post*

On June 1, during President Reagan's visit with General Secretary Mikhail Gorbachev, the two leaders agreed on a new initiative to expand civil space cooperation by exchanging opportunities for scientific instruments to fly on each other's spacecraft and by swapping results of independent national studies of future robotic solar system exploration missions as ways to assess prospects for further US/Soviet cooperation in space.

They also agreed to expand exchanges of scientists and of space science data and noted Moon and Mars missions as areas of possible bilateral and international cooperation.
—US State Department communique

The Saying of Science

by Jonathan Eberhart

The conduct of science often leads not so much from answer to specific answer as it does along converging successions of questions—a matter of the often subtle but sometimes critical distinction between fact and hypothesis. Yet despite all the constraints of the scientific method, that fragile awareness sometimes has a way of evolving into what has been called "canonical wisdom"—assumptions, in other words, that are occasionally found masquerading as established fact.

Around the turn of the century, when Percival Lowell was asserting that features he "observed" on the surface of Mars represented artificially constructed canals, some astronomy students expressed confidence that they, too, would be able to see the canals when they became sufficiently competent observers. In the case of another planet, with essentially nothing to go on but the telescopic appearance of impenetrable clouds, chemistry Nobel laureate Svante Arrhenius asserted flatly in 1918 that "everything on Venus is dripping wet."

It is not that such conclusions were necessarily wrong; more to the point is that one could not know them to be correct. The problem arises when taking a different line of inquiry that might have led in a more meaningful direction. If you are determined enough to "confirm" the existence of a "fact" such as the presence of Martian canals, who can say what interpretations you might overlook—or reject out of hand—when phenomena seemingly inconsistent with that "reality" present themselves to view? The situation here is somewhat analogous to that raised by physicians who are concerned not that a person may be trying an unproven "cure" for some illness, but rather that the sufferer may therefore be ignoring more established therapies that offer at least some medical benefit.

One of the more dramatic findings in the quarter-century of spacecraft studies of Venus was the 1981 determination (from a 1978 probe that had been part of the *Pioneer* Venus mission) of the ratio between the deuterium and hydrogen (D:H) in the water of Venus's atmosphere. It was dramatic because it seemed promptly to resolve one of the leading questions about the history of that cloud-shrouded world: Did such a dry place once have an earth-like ocean of water?

> ***"Who can say what interpretations you might overlook . . . when phenomena seemingly inconsistent with . . . 'reality' present themselves . . . ?"***

Deuterium is an isotope of hydrogen that is twice as heavy as the more familiar kind (each molecule has an extra neutron), and which makes up a minor portion of the universe's total hydrogen abundance. The idea is that if Venus formed with a given quantity of water, some of the hydrogen in that water would have been deuterium. As ultraviolet sunlight and/or other factors then dissociated the water into atoms of oxygen and hydrogen, most of the hydrogen would have escaped into space, but most or all of the part that was deuterium would have stayed behind, "enriching" the deuterium fraction, or D:H ratio, in the bit of water remaining. The amount of the enrichment, it is reasoned, would indicate the amount of water that was there at the planet's beginnings.

So was there an ocean? The measured ratio, about 0.016, has seemed, in the view of many, to indicate that the answer is "yes." And that may indeed be the case. David Grinspoon of the University of Arizona in Tucson does not say that it is "no" (though he does have a point of view)—he merely reports, in the Dec. 18 *Science*, that the provocative data do not prove the point.

Countless other scientific questions remain similarly unresolved, but among the many in planetary research, this is a particularly significant one. Of all the planets in the solar system, Venus is most like the earth in terms of its size, mass and distance from the sun. Yet the temperature at the surface would melt zinc. The atmosphere there presses in like the water more than half a mile below the waves of a terrestrial ocean, and the clouds of earth's so-called "twin" are rich in sulfuric acid as concentrated as the stuff in the battery of a car. In fact, it was a droplet of "Venus acid"—ignored by researchers for nearly three years because it was known primarily for having clogged one of the atmosphere probe's instruments—that was eventually recognized as a possible source of enough "Venus water" to yield a D:H ratio.

Did worlds now so different formerly resemble each other in such a fundamental way as the existence of watery seas, thus far identified on no planet but our own? The University of Michigan's Thomas M. Donahue, one of the scientists who first noted the exciting measurement (*Science News*: Dec. 12, 1981, p. 372), described the issue at the time as a "major question, and perhaps *the* major question, regarding the formation of Venus."

Six years have passed, during which several other spacecraft have been that way (all of them Soviet), and numerous other studies of the planet have been published. By now, notes Grinspoon, the Venus D:H ratio "has been accepted as proof" of a "wetter, more earth-like past on that planet."

For example, in the second edition of *Theory of Planetary Atmospheres: An Introduction to Their Physics and Chemistry* by Joseph W. Chamberlain and Donald M. Hunten, Academic Press, 1987 (the first edition predated the D:H measurement), the respected scientists who are its authors write that the finding "means that Venus has outgassed (and subsequently lost through escape) a large amount of H_2O—perhaps as much as the earth outgassed." Not that it "suggests," or "apparently means," or "indicates," or even that it "means, if the measurement is correct" (though no one seems yet to have disagreed with that part).

Hunten notes that the book does not categorically state how much water "a large amount" is, though there are estimates that various researchers feel to be consistent with the available evidence. Some planetary scientists occasionally find fault with one of their most well-known colleagues for saying that a given scientific finding is "not inconsistent with" some provocative interpretation. Fair enough, if one is finding fault with what is perceived as sheer sensationalism; but it can be another matter if the consequence is the rejection of a potentially fruitful inquiry.

There have certainly been other shadings. In a book called *The Planets* (Byron Preiss, Ed.; Bantam Press, 1985), the *Pioneer* Venus mission's project scientist, Lawrence Colin of NASA, wrote only that "overwhelming evidence suggests" the early Venus to have had much more water than it does today. On the other hand, when Donahue and colleagues first published their D:H measurement in a scientific journal (the May 7, 1982 *Science*), they unambiguously titled the piece "Venus was wet."

> ***"Without some . . . caveat, the words of even the most careful . . . of scientists can sometimes have a misleading effect . . ."***

But unraveling the real story may be more complicated than that. Venus is closer than the earth to the heat of the sun, and some researchers maintain that it would thus have had far less water available during its formation—in other words, that Venus was essentially "born dry." On the other hand, there is another and probably larger body of opinion to the effect that the tiny "planetesimals" of raw material thought to have coalesced into Venus, earth and Mars would have become sufficiently mixed in the process that all three planets began with significant quantities of water.

Furthermore, if Venus was in fact born dry, how can there be a D:H ratio that indicates it to be at least somewhat "wet" now? According to Grinspoon, for example, the calculated amount of water in the present Venus atmosphere could be gone in 100 million years—a mere fraction of the solar system's generally agreed upon age of nearly 5 billion. If that is true, he concludes, some source must be supplying Venus with enough water, or at least its hydrogen, to compensate for the rate of the hydrogen's escape. Together with the University of Arizona's John Lewis (who has favored the idea of a "dry" early Venus for at least a decade and a half), Grinspoon proposes that a likely source could be the icy nuclei of comets. In fact, the two researchers note, in a paper soon to be published in *Icarus*, "the water now observed on Venus is quite possibly more than 99 percent of cometary origin."

That little phrase, "quite possibly," is important. Without some such caveat, the words of even the most careful and qualified of scientists can sometimes have a misleading effect, particularly when they are the vital tools of communication with students, or even professional colleagues.

I recall a discussion I had several years ago with Baerbel Lucchitta of the US Geological Survey in Flagstaff, Ariz., on the subject of permafrost on Mars. Permafrost, despite its name, does not necessarily imply the presence of ice; technically it refers only to permanently frozen ground. But the term, Lucchitta noted, is not always used with such precision. Even among scientists, the "-frost" part sometimes evokes the impression of water-ice—an impression that can be misleading if one is being swept along by a sense of the general opinion of some part of the scientific community.

Mars, for example, is a parched and arid planet that somehow preserves sinuous channels, possible braided silt patterns and other such apparently fluid-formed features. Indeed, although journalists, too, are sometimes condemned for trampling on the lines separating proof, likelihood and mere speculation, Lucchitta's point at the time was that even qualified scientists reading their journals and going to meetings could be—and occasionally were—swayed by what they took to be numerous evocations of water-ice on Mars, when some of the cited authors meant nothing more than ever-frozen terrain. (More recently, she says, scientists seem to have become much more careful about one another's uses of the term "permafrost," although in the case of Mars, she admits, "I, too, subscribe to the idea that there is ice in the permafrost zone."

> ***The scientist's role "should be similar to that of the lawyer . . . whose profession often stands or falls on the preservation of subtle distinctions in communication."***

Martian canals are not the point here, any more than are oceans or volcanoes on Venus, the possibility of asteroids with their own moons, the existence of planets orbiting other stars or any of the other intriguing topics that enrich planetary science. The role of the scientist sometimes is, and should be, similar to that of the lawyer, the conduct of whose profession often stands or falls on the preservation of subtle distinctions in communication. In the awesomely exciting matter of whether there may turn out to be intelligent extraterrestrial lifeforms, for example, the issue is simply too important for its reality to rest on matters of hunch, "belief" or other such toothless methodologies. There is just too much at stake.

Jonathan Eberhart is Space Sciences Editor of Science News.

PLANET X:

by John Anderson

For those interested in planetary exploration, there could hardly be a more fundamental question than whether or not there are undiscovered planets in our solar system. Only 58 years ago, in 1930, Clyde Tombaugh, working at Lowell Observatory, discovered the planet Pluto, and in 1977 a search of the sky by Charles T. Kowal of the California Institute of Technology revealed the giant asteroid Chiron, initially hailed as a tenth planet by the press. In 1978 James L. Christy and Robert Harrington of the US Naval Observatory discovered Pluto's satellite Charon.

Yet Chiron is much too small to qualify as a planet, and even Pluto and Charon, with diameters of 2,200 kilometers and 1,200 kilometers respectively, are more like satellites than planets, at least from the standpoint of size. Even the mean density of the Pluto-Charon system, only about two times as dense as water, is more typical of large satellites such as Ganymede, Callisto and Titan that are combinations of rock and ice.

Although the Pluto-Charon system and Chiron would be fascinating to study and explore, the possibility of a tenth planet offers us something far different, a planet on the scale of the Earth or perhaps larger. The term "Planet X," coined by Percival Lowell before the discovery of Pluto, is used for any undiscovered planet outside Neptune's orbit. Some of us believe that such a planet exists, but we do not have a single shred of hard evidence for any planets outside of the nine known ones.

What appears to me as compelling indirect evidence that a Planet X may exist may in fact be telling us something quite different, perhaps something even more tantalizing. In fairness, I should point out that some of my colleagues do not consider the indirect evidence in the least bit compelling and instead look to faulty data for explanations.

I choose to ignore evidence, taken seriously by some, that borders on mysticism, such as ancient Babylonian texts, numerology and mythology. Although possibly valuable for other scholarship or for inspiration, such material is inappropriate within the context of the scientific method. But let me explain what evidence we have.

First of all, we have no convincing theoretical argument that the planet system ends at Neptune. Before William Herschel's discovery of Uranus in 1781, the outermost known planet was Saturn. In 1846, Urbain Jean Joseph Leverrier realized that perturbations in Uranus' orbit could be explained if another massive planet orbited the Sun outside of Uranus. He sent his calculations to Johann Gottfried Galle, who discovered Neptune the same night he received Leverrier's prediction. With Galle's discovery, the radius of the known solar system increased to 30 times the average distance between Earth and the Sun (30 AU). One Astronomical Unit is equal to approximately 150,000,000 kilometers.

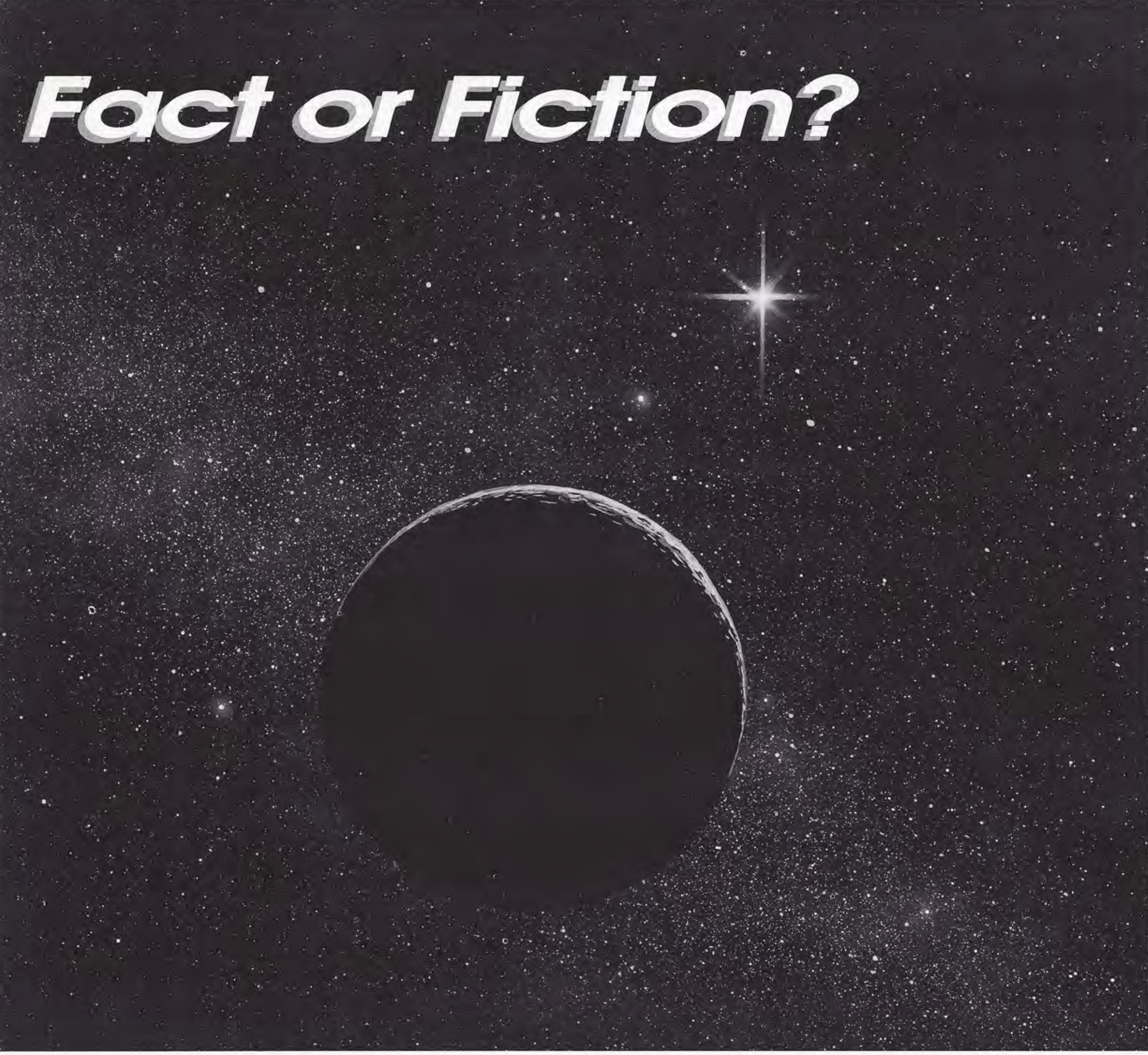
Yet the distance of the hypothetical Oort cloud of comets is more than 1,000 times farther from the Sun than Neptune, while the nearest star, Alpha Centauri, is over 9,000 times farther than Neptune. To get an idea of the scale of that distance, let a US dime represent the solar system within Neptune's orbit. Then the distance to Alpha Centauri is about 82 meters (89 yards). There is still plenty of room for more planetary orbits about the Sun.

Searching with Telescopes

Since Herschel and Galle's searches of the sky with telescopes resulted in the discovery of two planets about 15 to 17 times more massive than Earth, it is hardly surprising that at least a few people were eager to carry on the search with the improved instruments of the 20th century. The most extensive search, spanning the years 1929 to 1943, was conducted by Clyde Tombaugh at the Lowell Observatory near Flagstaff, Arizona. After 14 years of persistent work and the discovery of Pluto, he was convinced that no other planet visible with his 13-inch telescope existed within a large portion of the sky north and south of the ecliptic, the plane cut by Earth's orbit about the Sun. (All the known planets except Pluto orbit in about the same plane.) In a wider region, no brighter planets existed.

Yet Tombaugh left one-third of the sky out of his survey. Some of the neglected region was near the celestial south pole and hence inaccessible from Flagstaff. Other neglected regions, though in the northern hemisphere, were far from the ecliptic, where planets are less likely. Later, between 1977 and

Based on perturbations in Neptune's orbit, the famous astronomer Percival Lowell mathematically predicted that a ninth planet would be found in our solar system. Observers at the Lowell Observatory began a systematic telescopic search for this Planet X that continued after Lowell's death in 1916. Fourteen years later a young astronomer named Clyde Tombaugh photographed the sky in the area predicted on January 23 (left) and 29 (right), 1930. While examining these plates on February 18, he discovered that one of the small dots on the plates had moved—and so discovered the planet that he named Pluto. The "Pl" honors Percival Lowell, as does the planet's symbol, ♇. *Photographs: Lowell Observatory*



1984, Charles T. Kowal used the 48-inch Schmidt Telescope at Palomar Observatory to survey a region 15 degrees north and south of the ecliptic. Because of the Schmidt telescope's larger aperture, Kowal was able to include dimmer stars not available to Tombaugh. He found no planets.

It is unlikely that anyone in the future will repeat these efforts of Tombaugh and Kowal, who examined literally tens of millions of stars. The next extensive search for planets will probably be done with automated instruments, freeing the observer from the thousands of hours required to compare hundreds of photographic plates taken at the telescope.

It is sometimes difficult to understand why no one has seen a planet larger than Earth. But if we consider the number of candidate objects in the sky, practically all of them invisible to the naked eye, we can get an idea of the difficulty of selecting one out of about 100 million possibilities.

Influencing Orbits

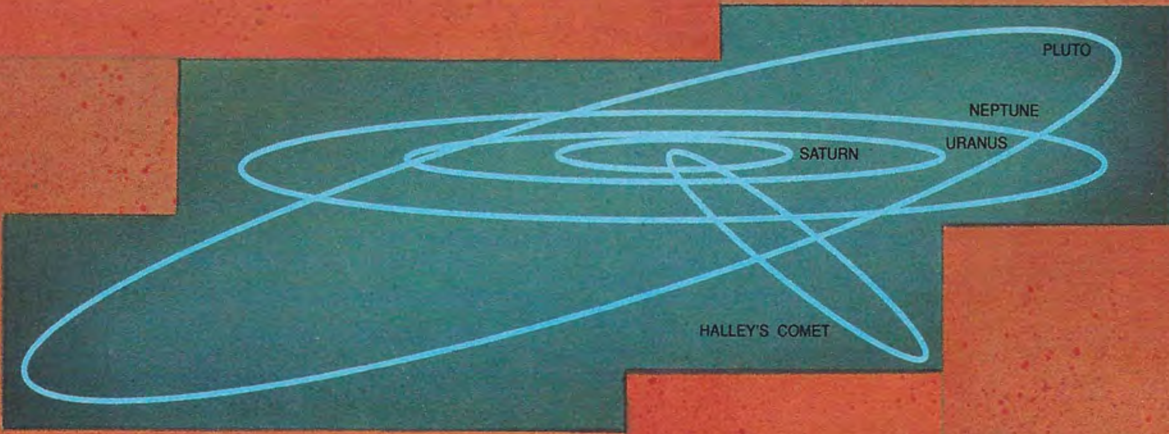
For that reason, scientists have shifted their emphasis from surveying a large region of the sky toward identifying likely regions for Planet X and then concentrating the search there. With this new approach, some of us have been trying to cast the search for Planet X in terms of gravitational influences on the orbits of known objects in the solar system.

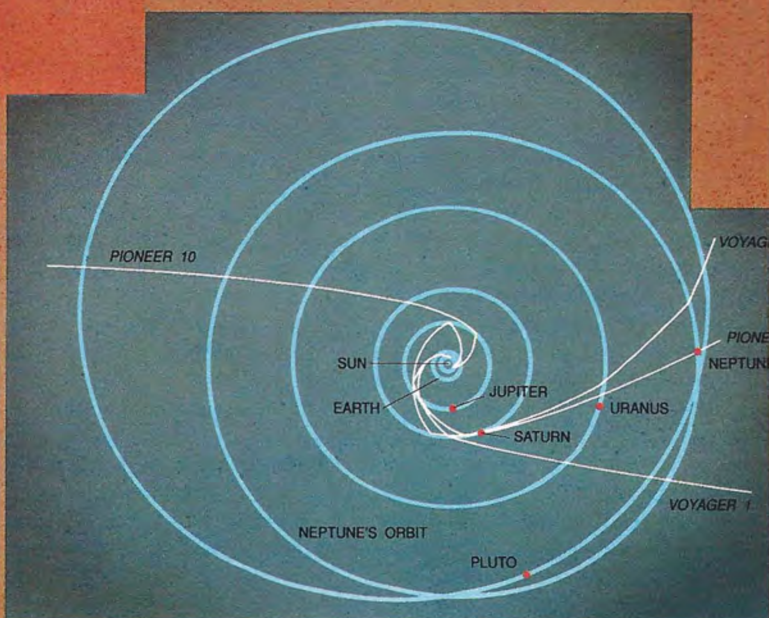
Actually, attempts to locate Planet X through its effects on other bodies have a long ancestry. The discoveries of both Neptune and Pluto were preceded by mathematical calculations showing systematic errors in Uranus' orbit, and Pluto was, in fact, found near the location predicted by Percival Lowell from his calculations.

However, in light of Pluto's small mass, we know now that it could not have caused the disturbances in Uranus'

Nobody knows where Planet X might be, what it might look like, or even if it exists. In this imaginary view, artist Ron Miller portrays a cold, dark planet out beyond Pluto.

Painting: Ron Miller





***Top:* Not all planets, comets and other objects orbit the Sun within the ecliptic (the plane defined by Earth's orbit), as you can see from this almost-edge-on view of the outer solar system. Pluto and Halley's Comet travel paths that are particularly inclined to the ecliptic. If there is a Planet X, its orbit may be even more steeply inclined, perhaps almost perpendicular, to the paths of most planets.**

***Left:* Four spacecraft are now exploring the outer reaches of our solar system: Pioneers 10 and 11, and Voyagers 1 and 2. By carefully tracking their orbits, scientists are trying to detect any perturbation that may betray the presence of a tenth planet.**

Illustrations: S.A. Smith

and Neptune's orbits that Lowell noted. Nevertheless, after its discovery and well into the 1950s, some astronomers were convinced that unless Pluto had a mass at least as big as Earth's, the observed orbital disturbances of Uranus and Neptune could not be explained.

By the 1960s it was becoming clear that Pluto's influence was insufficient to explain Uranus' and Neptune's irregular orbits, and at the same time the data that were so important to Lowell began arousing suspicion. At the US Naval Observatory and at JPL we decided to disregard the older data and to concentrate solely on information obtained with instruments whose hardware and data-reduction procedures we understood.

Particularly at JPL, where the emphasis is on computing planetary orbits for the space program, we severely limited the data on Uranus and Neptune to first include only observations made at the US Naval Observatory with either the 6- or 9-inch transit-circle instruments (telescopes that can measure planetary positions very precisely), and then to include only data taken after 1911, when a further improvement in instruments, the impersonal micrometer, was introduced. Using those data, as well as data extending back to 1846, astronomers at the US Naval Observatory concluded in 1971 that our current model of the outer solar system is incomplete. This could imply undiscovered planets, though we should remember that when unexplained motions were detected in Mercury's orbit about 100 years ago, it took Einstein's 1916 Theory of General Relativity to reconcile the discrepancies.

More recently, R.S. Gomes and S. Ferraz-Mello in Brazil have analyzed essentially the same data, but extending to 1982. They've determined, with a reliability of greater than 99 percent, that there is an unaccounted influence on the motion of Neptune. They've also concluded that we cannot rule out a source of gravitational attraction, including the possibility of a tenth planet with a mass about that of Earth.

The discrepancies in Uranus' and Neptune's orbits are most noticeable over the years since 1846. The unexplained motions account for at least 4,400 kilometers (2,700 miles) in the location of Neptune and at least 2,800 kilometers (1,700 miles) in the location of Uranus.

New Insights from Pioneer

Puzzled by these discrepancies, I undertook a program a few years ago to examine the orbits of *Pioneers 10* and *11* for unexplained motions. *Pioneer 10* had an encounter with Jupiter in December 1973. *Pioneer 11* visited Jupiter in December 1974 and then proceeded to Saturn. Both spacecraft are leaving the solar system on orbits that take them far beyond Uranus and Neptune. *Pioneer 10* is now 43.5 AU out, almost one and one-half times farther from the Sun than Neptune, and *Pioneer 11* is at a distance of 25.6 AU, well beyond the orbit of Uranus.

The two spacecraft are being tracked by the NASA/JPL Deep Space Network (DSN) with radio equipment that allows the spacecraft's motions to be determined accurately at interplanetary distances. However, we've found no unexplained motions that could be attributed to Planet X. Although negative, such information nevertheless tells us something about the characteristics of the hypothetical tenth planet's orbit. We know, for example, that there can be no planets of Earth size within 40 AU or so of either *Pioneer* spacecraft.

We will continue to monitor the motions of the two *Pioneer* spacecraft for perhaps another five years, when their power sources will become too feeble for radio tracking. For now the search for Planet X must be guided by the unexplained motions of Uranus and Neptune and by the negative results from the DSN data. But at least one other piece of indirect evidence is significant.

It is unfortunate that tight budgets caused the Grand Tour missions to the outer solar system to be scaled down and eventually reduced to the *Voyager* mission to only Jupiter and Saturn. Even with the unexpected bonus of *Voyager 2*'s Uranus and Neptune flybys, we have not taken full advantage of the infrequent alignment of the outer planets that has occurred during the past decade. For example, Grand Tour mission designs at JPL in the early 1970s included one or more Pluto flybys.

With the advantage of hindsight and the recent discoveries made with ground-based astronomy, we can conclude that a close reconnaissance of the Pluto-Charon system would have yielded fascinating results. But for now and for a long time to come, our exploration of planets beyond Saturn will be limited to *Voyager 2* and to whatever can be learned from Earth-based observations, including astronomical instruments in orbit or on the Moon. —*J. A.*

Simulating Orbits

Thomas C. Van Flandern and Robert Harrington of the US Naval Observatory have shown with computer simulations that a planet with peculiar orbital characteristics and a few times bigger than Earth could explain both Pluto's orbit and the fact that Triton, Neptune's large satellite, revolves in a clockwise direction while other major satellites and planets move counterclockwise. In the scenario analyzed by Van Flandern and Harrington, Planet X passed sufficiently close to Neptune in the distant past that it expelled one of its satellites (Pluto) and reversed the motion of Triton.

If this happened, Planet X is now in a peculiar orbit of its own with a period of about 800 years and a present distance of about three times Neptune's distance from the Sun. Robert Harrington has been searching the sky for this planet but has found nothing yet. It is interesting that the planet he seeks is consistent with the Uranus and Neptune data as well as the negative results from the two *Pioneer* spacecraft.

So does Planet X exist? Nobody knows. It is an interesting possibility, and in my opinion well worth the search, but admittedly not all share my view. Nonetheless, whatever the form of the direct or indirect evidence, I suspect there will always be a few people sufficiently motivated by the possibility of success to carry on the tradition of planet hunting.

John Anderson, a Senior Research Scientist at the Jet Propulsion Laboratory, is a member of the Radio Science Team for Voyager 2 *at Uranus and Neptune and won NASA's Medal for Exceptional Scientific Achievement for his work as Principal Investigator on the* Pioneer 10 *and* 11 *missions.*

Humans to Mars

The Mission That NASA Did Not Fly

by Edward Ezell

Sending humans to Mars has been a recurring theme of the American space program. Proposals for such missions have repeatedly demonstrated their technological feasibility, yet neither the American public nor its political leaders (with the exception of a few like Spiro T. Agnew) have embraced this ambitious goal. Since Mars was the primary goal of early planners including Wernher von Braun—lunar exploration being viewed as something of a detour—it is useful to examine why we have not gone there.

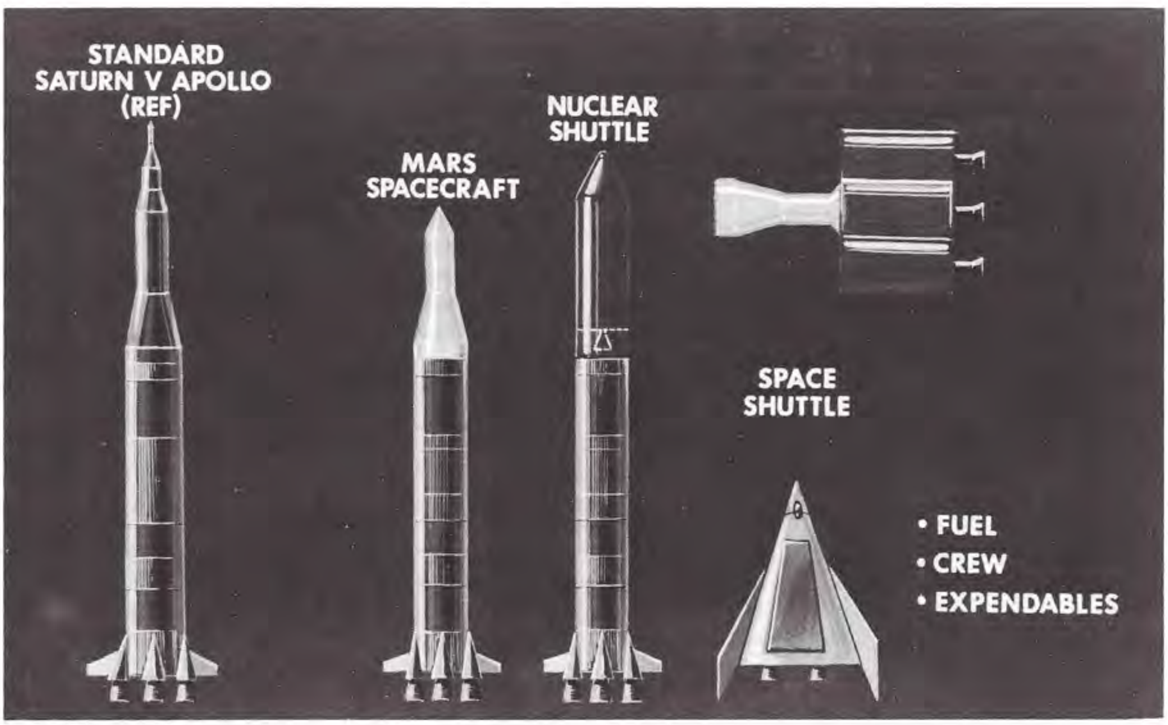
Three sources inspire my inquiry. First, a 1976 book by Alison Sky and Michelle Stone entitled *Unbuilt America: Forgotten Architecture in the United States from Thomas Jefferson to the Space Age* illustrates conceptually significant but unrealized projects in architecture and environmental arts. *Unbuilt America* led me to consider the proposals for piloted Mars spaceflight sponsored by the National Aeronautics and Space Administration in the 1960s. Future designers can learn much by examining such proposed Mars missions.

A second source of inspiration was research done as co-author of *On Mars: Exploration of the Red Planet 1958-1978*, a NASA history of robotic Mars missions. Early in those investigations, we learned that many NASA planners saw Mars as the primary goal. The political decision for a lunar landing was a detour that was accepted because it offered the only opportunity to develop hardware required for deep space flights. Below the surface there was an unwritten agenda: after the Moon, Mars.

A final inspiration was John Logsdon's 1974 paper "The Space Program during the 1970's: An Analysis of Policymaking," which examined the personalities and political forces that gave us the space shuttle program and held in check enthusiasm for a human mission in the 1980s.

Why Mars?

Since the 16th century, learned people have recognized Mars as a planet not unlike our own. Before the technological



During his time at NASA, visionary rocket pioneer Wernher von Braun tried to point the agency beyond the Moon to Mars, with humans landing on the Red Planet in the early 1980s. These illustrations are briefing prints prepared for a 1969 Space Task Group Manned Mars Study. The various launch vehicles, based on modifications to the Saturn V *rocket, are shown to the right, along with an early conception of the space shuttle. The proposed Mars lander (far right) was to accommodate its crew on the surface for one month. The ship would have also supported a rover and a laboratory. Human adventurers would have explored the surface, taken core samples, performed experiments and returned pieces of Mars to Earth.*

Illustrations produced by Marshall Space Flight Center for NASA, provided to The Planetary Report *by Lee Saegesser* capability provided by liquid-fueled rockets, they only dreamed of traveling to the stars. Best known among these dreamers was Percival Lowell, who speculated in his 1895 book *Mars* that markings seen on the planet's surface were canals built by an intelligent Martian race.

As planetary travel became a realizable goal, Wernher von Braun prepared *Das Marsprojekt*, published in 1952 (published in English as *The Mars Project* in 1953). He argued that it was feasible to reach Mars using conventional chemical propellants. Since he didn't intend to wait until more advanced propulsion systems were ready, "a flotilla of ten space vessels manned by not less than 70 men" would be necessary. These ships would be assembled in Earth orbit over eight months with materials shuttled to orbit by 950 space ferry flights. In this scheme, we see the germ of the space shuttle and space station. Once the flotilla reached Mars, wings would be attached to three craft to enable glider-like entry into the martian atmosphere.

The launch of *Sputnik* in October 1957 brought new urgency to US space activities. When the newly created National Aeronautics and Space Administration sought advice from scientists about goals, probes to Venus and Mars were high on the list. Several Mars studies were underway. The Instrumentation Laboratory of the Massachusetts Institute of Technology was planning for the return flight from Mars of a miniature photographic laboratory. Concurrently, von Braun's team at the Army Ballistic Missile Agency at Redstone Arsenal (renamed the George C. Marshall Space Flight Center after the ABMA became part of NASA in 1960) was working on planetary propulsion systems.

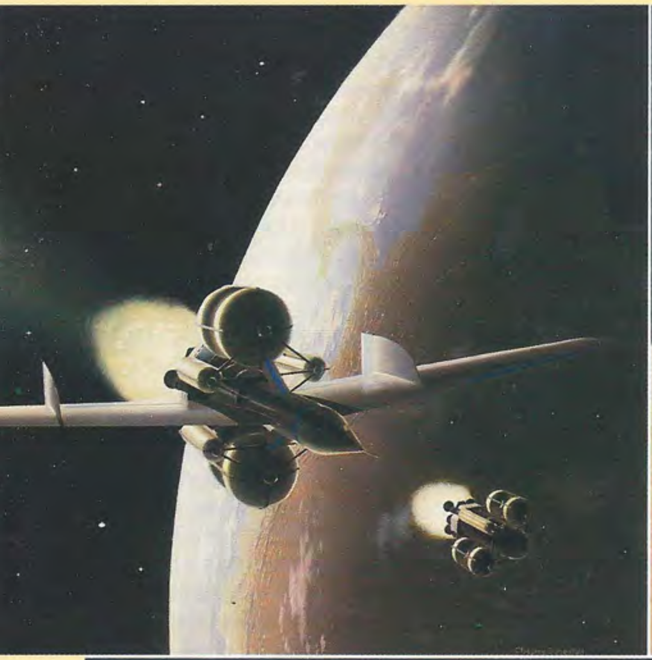
Apollo *Intervenes*

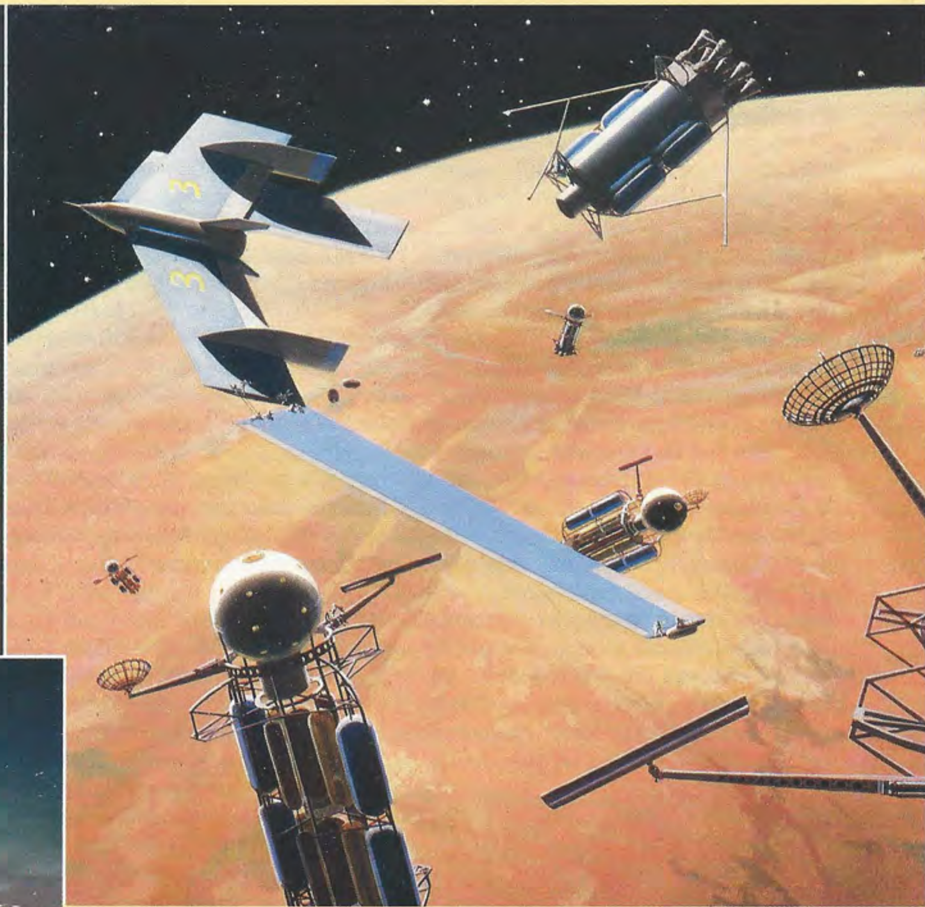
On May 25, 1961, President John F. Kennedy announced that the United States would land an astronaut on the Moon and return him or her safely by the end of the decade. Several motives influenced this decision. Yuri Gagarin had orbited Earth on April 12, 1961—another technological and propaganda coup for the Soviets. Kennedy called Lyndon Johnson to his office on April 19th and asked him to find a "space program which promises dramatic results." A landing on the Moon was sufficiently dramatic and had less potential for failure than a more ambitious trip to Mars. While most NASA engineers at the Marshall Space Flight Center and the Langley, Virginia Space Task Group focused on Kennedy's lunar goal, small planning groups at both centers studied planetary missions. By 1963, between 30 and 40 people were assigned to work on Mars missions at Houston; about the same number were involved at Marshall. Support for such missions was at its greatest in Houston before 1964; then the budget began to shrink. At Marshall, the funding crunch came in 1966.

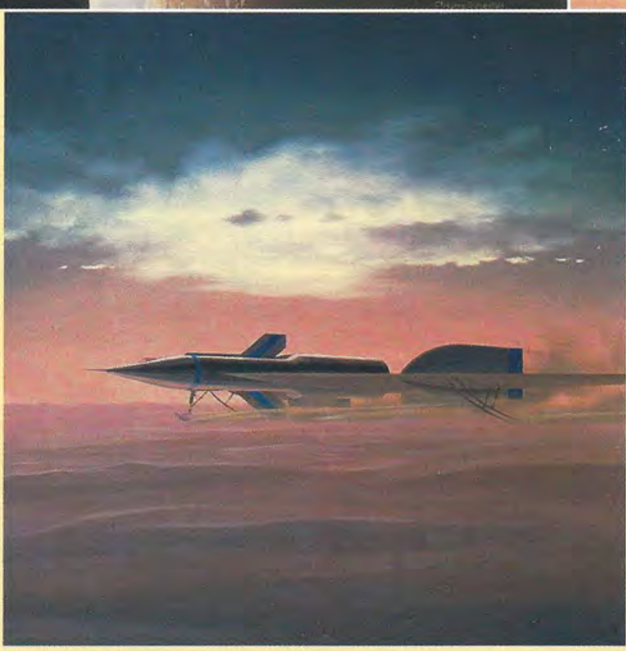
In 1962 and 1963 it was reasonable to believe that humans might go to Mars or Venus after *Apollo*. Those who saw *Apollo* as an interruption could console themselves with the fact that important hardware and software systems were being developed that would support planetary spacecraft projects. A patchwork of interplanetary mission studies was considered between 1962 and 1967. Langley Research Center in Virginia and Lewis Research Center in Ohio joined Marshall and the Manned Spacecraft Center (MSC) in Houston in these investigations. The general feeling was that each center should get into the act and thus be prepared for any big planetary project.

Between 1961 and 1966 over 60 study contracts totalling $7.5 million were awarded. The first went to Lockheed Missiles and Space Company in the fall of 1961, when engineers calculated all possible trajectories for missions travelling from Earth to Mars and Venus through the end of the century. In June 1962, examination of specific hardware systems was begun under the name EMPIRE: Early Manned Planetary-Interplanetary Roundtrip Expeditions. Three contractors—Ford Aeronutronics, General Dynamics Astronautics Division and Lockheed—worked to define a piloted Mars-Venus flyby mission between 1970 and 1972.

While Marshall's studies were oriented toward propulsion topics, those sponsored by the MSC focused on the spacecraft that voyagers would occupy during the journey. Early investigation of the Mars Excursion Module (MEM), used for "transporting personnel and scientific equipment from . . . Mars orbit to the Mars surface" and back to Mars orbit, specified a craft not to exceed 25,000







In the 1950s, Wernher von Braun and artist Chesley Bonestell collaborated on a series of magazine articles vividly portraying their vision of our future in space.* **Collier's** *magazine printed text and illustrations in 1954 depicting an expedition to Mars that might have been accomplished in the then-not-too-distant future. Massive spacecraft would be assembled in Earth orbit and then launched on a trajectory to Mars (above). Upon reaching Mars orbit, the landing craft would be readied for its historic descent (top left). A sleek winged spacecraft would carry the first martian explorers to a landing on one of the poles.

Paintings: Chesley Bonestell, courtesy of Space Art International

kilograms with a scientific payload of about 1,000 kilos.

North American Aviation (now Rockwell International) also studied the MEM, drawing on their *Apollo* Command Module work. Lockheed investigated the return craft, the Earth Module, for the MSC. And NASA personnel conducted related in-house investigations.

Ford Aeronutronics engineers presented results of their MEM study at the third Manned Space Flight Conference in Houston in November 1964. They concluded that a piloted Mars landing could occur nine years after a hardware contract was awarded. Much of the necessary technology for such a flight was being generated by the *Apollo* program. While it would differ in shape, the MEM's functions closely paralleled those of the Lunar Excursion Module. It would be taken to orbit around Mars by a command module. After landing on Mars, it would support its crew for 40 days. At mission's end, the MEM would ascend and rendezvous with the mother ship. Franklin P. Dixon, Ford's MEM manager, noted that it did not require any technological breakthroughs since such missions were increasingly keyed to exploiting emerging *Apollo* technology. Mars seemed more and more the logical extension of the lunar program. Unfortunately, non-technical problems on the horizon would pose greater threats to the piloted Mars idea.

By mid-1964 NASA's budget had grown to \$5.1 billion, with over \$2.64 billion allotted for *Gemini* and *Apollo*. Significantly, NASA planners were beginning to think about short-term followups to *Apollo*. Use of *Apollo* hardware to expand lunar exploration and activities in Earth orbit spawned the *Apollo* Applications Program, which led in turn to the *Skylab* missions. This very ambitious enterprise siphoned monies from planetary work. Before November 1964, \$3.5 million had been allocated in nine contracts for piloted planetary studies during a 17-month period. Between November 1964 and May 1966, only four piloted planetary projects were

fidence in NASA's accuracy in forecasting its programs' price tags. As indicated by a Louis Harris poll, public support for the space program also flagged. Detroit Mayor Jerome P. Cavanagh voiced the concern in many people's minds: "What will it profit this country if we . . . put our man on the Moon by 1970 and at the same time you can't walk down Woodward Avenue in this city without fear of some violence?"

The space program suffered from too much visibility at the wrong time. Attacks on President Johnson's Vietnam policy still ran the risk of being labeled unpatriotic. One certainly could not fault welfare programs without incurring the wrath of restive inner-city residents. But the space program was fair game. Given the political climate, *Voyager* would have survived if NASA had taken care in promoting its programs. Unfortunately, MSC chose early August 1967 to solicit prospective contractors regarding a "Planetary Surface Sample Return Probe Study for Manned Mars/Venus Reconnaissance/Retrieval Missions" for the 1975-1982 "unfavorable time period." This was a grave error.

MSC's request infuriated Representative Karth, who was fighting an uphill battle to preserve *Voyager*. He was "absolutely astounded," given congressional warnings about new starts, and remarked, "Very bluntly, a manned mission to Mars or Venus by 1975 or 1977 is now and always has been out of the question . . . ." Although Houston's request was just one more in a series of modestly funded mission investigations, the timing could not have been worse. Making things even blacker, MSC's proposed mission was billed as an extension of *Voyager*, which was cast as a "foot in the door" for piloted planetary flights that could cost billions.

MSC's solicitation was the last straw. In August 1967, the House Appropriations Committee voted down all monies for *Voyager* and the Houston study. Later, the House approved a $4.59 billion budget for NASA, half a billion less than requested. Despite attempts to save *Voyager*, it died in the conference committee. Reduction of the FY 1968 budget confirmed a downward slide begun two years earlier. From a high of $5.25 billion in FY 1965, the budget fell until it reached its lowest point, $3.03 billion in FY 1974.

funded, for a total of $465,000. New contracts in late 1966 supported 12 studies with a budget of $2.32 million.

This shift in emphasis was natural. *Apollo* hardware (launch vehicles as well as spacecraft) demanded a limited number of short engineering flights to the Moon. Since adapting equipment for lunar and Earth-orbital operations was easier than altering it for planetary missions, existing hardware dictated what missions could be flown.

Voyager *Under Siege*

Robotic exploration of Mars had its impact on plans for piloted missions. And as it turned out, proposals for crewed flights had a devastating effect on the robotic program. As early as 1960, NASA scientists had been seeking an advanced post-*Mariner* planetary craft. Designated *Voyager* (and not to be confused with the later *Voyagers 1* and *2* to Jupiter and beyond), this ambitious project was geared toward landing an automated scientific station on the martian surface. As is so often the case in the American space program, projected costs grew dramatically as the nature of the enterprise was more clearly defined. Problems facing *Voyager* planners were numerous and complex, reflecting technological, scientific, political and economic concerns. *Voyager*'s demise in the summer of 1967 underscored NASA's complicated political environment.

1967 was an unhappy year for the United States at home and abroad. Foremost among the traumas was the war in Southeast Asia. More than half a million Americans were on duty in Vietnam. Nearly 25,000 had lost their lives in a conflict that was costing the American taxpayer $2 billion monthly. Faced with an ever-growing deficit, the Johnson administration reduced non-defense expenditures and raised taxes. More trouble lay ahead. Between June and August 1967, as NASA's appropriation was finalized, civil rights riots or violent demonstrations occurred in 67 American cities. The summer of disorder (the third since 1965) forced Congress to focus on concerns more pressing than sending humans to Mars.

Meanwhile, *Apollo* and *Voyager* costs mounted. Congressmen such as Joseph E. Karth, Chairman of the House Subcommittee on Space Science and Applications, expressed decreasing con-

Another Try for Mars

There was another official attempt to secure a piloted Mars expedition. As space scientists worked to create more economically and politically realistic automated Mars lander projects (the genesis of *Viking*) they pondered, "After *Apollo*, what shall we do?" Von Braun, NASA Administrator Thomas O. Paine and Vice President Spiro Agnew all supported a proposal to send humans to Mars. Each had different motives for endorsing this goal, but all agreed that having set sail on the ocean of space, we should not terminate the voyage at the first port of call.

In retrospect, 1969 was clearly a peculiar year for the space agency. At Christmastime 1968 three Americans aboard *Apollo 8* had circled the Moon; on July 20, 1969 the *Eagle* landed on the Moon, and Neil Armstrong became the first person to set foot on the surface of another body in our solar system. As most of the world focused on *Apollo*'s triumph, people in the space program fretted about what NASA and the nation could do for an encore. Lyndon Johnson chose not to define NASA's policy for the post-*Apollo* era, leaving that task to Richard Nixon.

To aid his deliberations, Nixon created a task force under Charles Townes, Nobel laureate in physics and member of the President's Science Advisory Committee. The Townes committee recommended against "a commitment now to a large space station, extensive development of 'low-cost boosters,' or a manned planetary expedition." Townes and his associates supported a constant NASA funding level of about $4 billion per year.

Nixon's science advisors had no enthusiasm for ambitious space activities. To consider NASA's post-*Apollo* programs, Nixon created a Space Task Group (STG) in February 1969. Chaired by Vice President Agnew, it consisted of Air Force Secretary Robert C. Seamans, Jr.; NASA Administrator Paine; Presidential Science Advisor Lee A. Dubridge; and observers such as Robert P. Mayo, Director of the Bureau of the Budget. While Agnew and Paine advocated continuing NASA's activities at current or slightly increased levels, Dubridge, Seamans and Mayo favored retrenchment. Paine's request for an increased FY 1970 budget was justified as necessary for the survival of piloted and robotic spaceflight. Budget Director Mayo opposed such an increase and would not recommend it to the President.

As Paine and Mayo squared off, the STG rejected Paine's call for a permanent piloted space station, a defeat quickly followed by cuts to the FY 1970 budget. In 1969, there was no Gagarin to galvanize national attention and no crisis to shape the space policy debate. Direct competition with the Soviet Union in space was no longer politically potent. The space program had lost much popular support. Legislators felt that problems here on Earth needed solving before the United States undertook additional space spectaculars. While further deliberations of the STG led to approving the space shuttle and "the long-range option or goal of manned planetary exploration with a manned Mars mission before the end of the century," the concrete suggestions of Mars flights in 1981, 1983 or 1986 were rejected.

As members of The Planetary Society know, the desire to send humans to Mars did not come to an end just because legislators were unwilling to allocate the necessary resources. In fact, the past two decades have only served to heighten interest and enthusiasm for planetary exploration. *Viking*'s successful Mars landings in 1976 provided additional nourishment for the dream. Society members have worked hard through symposia such as "Human Exploration of Mars" (1985) and "The Case for Mars III" (1987) as well as direct contact with government officials to keep the concept before the scientific and political communities. The goal of humans to Mars was reasserted by the National Commission on Space chaired by former NASA Administrator Paine in 1986.

To Mars Someday

At this point, the historian's standard question must be asked: So what? Will NASA send humans to Mars in the near future? Although the answer probably will be no, that should not be cause for undue pessimism or discouragement. We can draw several significant lessons from the United States' past failures to support piloted Mars missions.

It is important for those of us in the US to realize that just because something is interesting and challenging, just because it is technologically feasible, just because it should be done, does not mean that it will be done. We live in a world of finite economic and natural resources, and competition for budget dollars has become keen. In 1969 sending humans to Mars appeared to be too difficult and too costly, in spite of the fact that we had just sent men to the Moon. In part, the success of *Apollo* argued against going to Mars. Many people felt that we did not need to visit another heavenly body, that "if you've seen one, you've seen 'em all."

We as a nation made a big mistake by allowing the piloted Mars option to lie fallow. So I have a second response to the question "So what?" I believe that we need the goal of piloted Mars missions or a comparable goal for the sake of the human spirit. We should not forsake the dream of planetary travel. Most of the people who wanted to travel with the first crew to Mars, if only vicariously, saw it as a great adventure. I am certain that the legislators of the nation who oppose space projects would not have supported the Spanish government's investment in the impractical-sounding voyages of Columbus. But an absence of political enthusiasm for planetary or other exploratory adventures in 1989 does not mean that in 1999 or in 2009 or in some other decade individuals will not want to visit the planets.

We must realize also that opposition to high technology has grown in the past 20 years. Once again the space program is an easy target. People who would like to decentralize our energy and industrial activities and direct us away from the highly complex economy that we know today certainly do not favor piloted Mars missions. But we must caution proponents of government austerity to take care lest they carelessly close out future economic and technological options by simplistic choices. We should encourage those who view visiting Mars as unrealistic not to rule out the possibility of ever making the trip.

In addition to lobbying for more resources for planetary research and becoming more politically adept, we need to preserve the unbuilt spaceships for Mars. These craft should be recorded so future generations can examine past ideas for space travel just as we examine the unconsummated ideas of Leonardo da Vinci by studying his notebooks. Each generation should decide for itself whether it wants to go to Mars or stay Earthbound. But let us not destroy the dream.

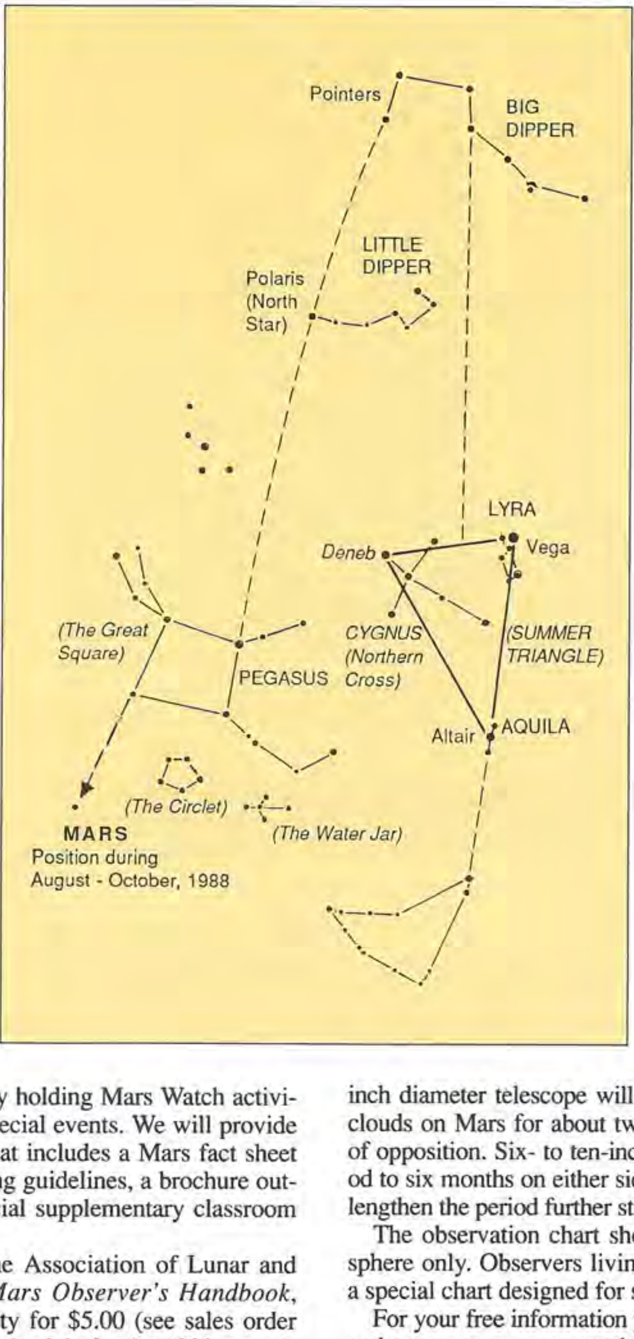
Gerald A. Soffen, former *Viking* Project Scientist, remarked during the *Viking* landings that he would like to visit Mars—to stand on the spot where the first lander touched down, view that horizon and then explore the surrounding terrain. Though he did not expect to make that journey himself, he was convinced that one day men and women from Earth would venture forth to the Red Planet. Since he had glimpsed that world through the eyes of a mechanical surrogate, making the journey just seemed a natural thing to do.

Edward Ezell is Supervisory Curator of the Armed Forces History Division at the Smithsonian Institution in Washington, DC.

MARS WATCH '88

A CLOSE ENCOUNTER OF THE RED KIND

by Stephen Edberg and Susan Lendroth



On September 22, 1988 Mars will be both in opposition and near perihelion, closer to Earth than it has been in 17 years or will be again until 2003. (A planet is in opposition when it is on the opposite side of Earth from the Sun; it's at perihelion when it makes its closest approach to the Sun.) To take advantage of one of the most favorable oppositions of the 20th century, The Planetary Society has launched Mars Watch '88, a program designed to encourage everyone to take a better look at this fascinating world next door.

Oppositions of Mars actually occur every 2.14 years, but since Mars' orbit is more elliptical than Earth's, the distances between the two planets at different oppositions vary. Favorable (perihelic) oppositions, when Mars and Earth are closest, occur every 15 to 17 years. Although Mars will be closest to Earth on September 22, actual opposition occurs on September 28.

The Planetary Society urges astronomy groups, planetaria, schools and individuals to join us by holding Mars Watch activities such as telescope parties and special events. We will provide on request an information packet that includes a Mars fact sheet and observation chart, event-planning guidelines, a brochure outlining available resources, and special supplementary classroom materials for educators.

Observers may want to order the Association of Lunar and Planetary Observers' (ALPO's) *Mars Observer's Handbook*, available from The Planetary Society for $5.00 (see sales order #131). A special supplement designed solely for the 1988 opposition will accompany each order. The handbook not only provides a comprehensive guide to making scientifically accurate observations of Mars but also explains how amateur astronomers may join the Mars Recorders, a worldwide network of observers.

Observing Mars

The best viewing period for the opposition will be during the weeks directly preceding and following September 22. Rising at sunset, Mars will be easily visible all night long, a brilliant crimson spark in the evening sky.

To locate Mars, use the Big Dipper and the North Star (Polaris) as reference points. The Big Dipper will be low in the northern sky in September. In the Big Dipper locate the two stars that make up the side of the bowl opposite the handle (the Pointers). Imagine a straight line five times as long as the distance between these two stars leading down out of the bowl of the Big Dipper. You will hit a fairly dim, isolated star. This star is Polaris, the North Star.

Extend the line farther, about twice as far as the separation between the Pointers and Polaris. This brings you to the Great Square of the constellation Pegasus. Find the opposite side of the Great Square and follow that side the distance of one and one half of its lengths as your eye moves farther away from Polaris. There you will find a lonely, bright reddish-orange pinpoint of light: the planet Mars.

For careful observers, a four-inch diameter telescope will show surface detail and atmospheric clouds on Mars for about two and one-half months on either side of opposition. Six- to ten-inch telescopes extend the viewing period to six months on either side of opposition, and larger telescopes lengthen the period further still.

The observation chart shown above is for the northern hemisphere only. Observers living south of the equator may write for a special chart designed for southern skies.

For your free information packet, contact The Planetary Society, and open your eyes to another world with Mars Watch '88.

Stephen Edberg is Coordinator for Amateur Observations for the Jet Propulsion Laboratory's International Halley Watch. He also serves as Coordinator for The Planetary Society's Mars Watch '88 program. Mr. Edberg has been president of the Western Amateur Astronomers since 1983. Susan Lendroth is The Planetary Society's Manager of Events and Communications.

World Watch

by Louis D. Friedman

WASHINGTON—The US capital is a city of contradictions. The swirling Presidential campaign has focused attention on the President to follow Ronald Reagan, while the US Congress and the federal agencies are absorbed in the fiscal year '89 budget battles. Since President Reagan's FY '89 budget had very few new initiatives, the proposal for a 30 percent increase in the NASA authorization stood in dramatic contrast. The total request for NASA was $11.5 billion.

The NASA appropriation is part of a general budget category including science, technology and medical research and is handled by the housing subcommittee. Thus, Congress was forced this year to choose among funding for the homeless, the Superconducting Super Collider, AIDS research or NASA. The final compromises are still being made, but it is clear that NASA will not receive the total proposed increase, most of which had been earmarked for the space station.

In mid-May the House Appropriations Committee acted on the proposed new budget. They appropriated $10.7 billion, $757 million less than the administration request. Their action, which still gave NASA a significant increase over its 1988 budget, funded the space station almost fully at the expense of other programs, limiting the new start for the advanced X-ray telescope and cutting the Pathfinder technology development program by more than 50 percent.

As we go to press, the full House and Senate Committees had not yet taken action on this appropriations bill. Most congressional staff members were predicting lower allocations.

The budget and funding appropriation will immediately affect NASA programs. At the same time several interesting policy initiatives of longer-term significance should interest Planetary Society members. One proposal initiated by Representative George Brown (D-CA) and already adopted by the House authorizing committee states, "The Congress declares that the extension of human life beyond Earth's atmosphere, leading ultimately to establishment of space settlements, will fulfill the purposes of advancing science, exploration, and development and will enhance the general welfare."

The House legislation also asserts, "The Congress hereby declares that the United States shall prepare for and carry out an International Manned Mission to Mars as a major goal of the United States space program, and shall seek the participation of the Soviet Union and any other interested nations in the conduct of an International Manned Mission to Mars."

In addition, legislation introduced by Representative Robert Torricelli (D-NJ) and Senator Tom Harkin (D-IA) establishing a blue-ribbon "National Mars Commission" to encourage Mars missions as a US priority and as a focus of international cooperation was incorporated in the House's NASA authorization bill. The Senate has yet to act, but these developments obviously demonstrate that our Mars Declaration is making an impact and we are building a nationwide US constituency for the goal of human expeditions to Mars.

PASADENA—The NASA budget proposed to Congress for Fiscal Year 1989 does not include a new start for the Comet Rendezvous Asteroid Flyby (CRAF) project, as planetary scientists had hoped. The Planetary Society submitted a statement to the Senate Committee on Commerce, Science and Transportation in support of the CRAF mission. Project leaders have now decided that it will be impossible to prepare the spacecraft and scientific instruments in time for the planned 1993 launch to comet Tempel 2 and asteroid Hestia.

Project leaders are now studying several options. Comets Wild 2 and Kopff are two candidates for a launch in the fall of 1994 with arrival in the year 2000. Although NASA will most likely keep options open, Wild 2 is currently preferred based on the comet's orbital history and the mission's larger payload capacity.

The CRAF mission will include an asteroid flyby enroute to the comet, but the specific target has not yet been identified. We will publish that information when it becomes available.

Both candidate comets will pass through their perihelions (their closest approaches to the Sun) in 1990—Kopff on January 20 and Wild 2 on December 17. Project leaders are seeking astronomers' cooperation in observing these comets over the next few years to help in modeling the comets' nuclei and in planning the mission.

Also on the table is a proposal to combine the CRAF mission in a single project with *Cassini*—the Saturn Orbiter/Titan Probe mission under study by NASA and the European Space Agency for a 1996 launch.

WASHINGTON—This summer as the two Soviet *Phobos* spacecraft head for the strange martian moonlet for which they are named, one will carry a last-minute contribution from the United States: a plaque duplicating the page from Asaph Hall's telescope log book on the night he discovered Phobos. Hall, a US astronomer, first spotted Phobos and Deimos, Mars' other known moon, from the Old US Naval Observatory above Foggy Bottom. His telescope, a 26-inch refractor and the most powerful of the time, is still in use at the Naval Observatory's Washington, DC, headquarters.

On April 30 Captain Richard Anawalt, superintendent of the observatory, presented the plaque to 25 Soviet scientists in a formal ceremony there. About 150 descendants of Asaph Hall turned out for the presentation.

The lightweight, anodized aluminum plaque is virtually indestructible, and it is expected to remain on Phobos forever. Inscribed below the photographic etching of Hall's notes is the line: "USSR *Phobos* Mission, 1988."

Louis Friedman is the Executive Director of The Planetary Society.

News & Reviews

by Clark R. Chapman

If ever there was a subject in the history of science that proved that scientists knew what they were doing, it was solar system mechanics. Physicists' explications of the regular, orderly movements of the planets helped to establish physics as a believable, predictive science. Even today we rely on Newtonian physics in our daily lives. Einstein's relativistic corrections pertain only to velocities germane to Star Trek's *Enterprise*, and the disturbing uncertainties of modern quantum mechanics affect only the submicroscopic realm, which we can readily ignore.

Conventional physics was eventually rebuffed by phenomena apparently too complex for solution, such as turbulence. But physicists remained confident that their own creative brilliance combined with the raw power of modern computers would eventually unravel such complexities. In the 1960s, as recounted by James Gleick in his new book, *Chaos: Making a New Science* (Viking, 1987, $19.95), Massachusetts Institute of Technology meteorologist Edward Lorenz reached the demoralizing conclusion that even weather forecasts would be forever beyond our grasp; the tiniest eddy created by a butterfly in Peking could, within a month, grow exponentially and unpredictably into an Atlantic hurricane. While Lorenz doomed TV weathercasters to roles as the perpetual buffoons of science, he simultaneously ushered in the "science of chaos."

Gleick's book—itself a bit chaotic in its organization—is filled with anecdotes about the somewhat wayward creators of the new science. He presents the highly mathematical subject qualitatively, metaphorically and even philosophically, applying it to medicine, biology, climatology and economics. But Gleick's occasional references to Jupiter's Red Spot and the asteroids fail to emphasize that even those paragons of orderly Newtonian physics, the motions of the planets, have been assaulted by unanticipated chaos.

Heavenly Chaos

Jack Wisdom, now also at MIT, has found abundant chaos in the solar system, past and present. Saturn's Hyperion tumbles ominously and weirdly, and this motion helps to reconcile confusing data from the two *Voyager* spacecraft that flew by Saturn in 1980 and 1981. Dr. Wisdom now thinks most planetary satellites went through epochs of chaotic rotation. Some asteroids may spontaneously leave their ordinary paths in the main belt and rush headlong toward Mars, or even Earth. Such chaotic behavior explains why asteroidal fragments can strike our planet and fall as meteorites.

Most recently (see *Science* for May 20th) Dr. Wisdom has used a small, specially-built computer to calculate the orbits of the outer planets back for a billion years. At least one, Pluto, is in an unstable orbit, according to Dr. Wisdom, who is adept at recognizing the telltale signs of chaos. It is possible that Pluto "could without warning head off into a new orbit," according to *Science* reporter Richard Kerr. Jack Wisdom has so far only hinted at the surprises awaiting us in what had seemed the most secure domain of science, the motions of the heavenly bodies.

Struggling US Space Science

We face a different sort of chaos on the ground. As Sally Ride wrote a year ago, "A space program that can't get to orbit has all the effectiveness of a navy that can't get to sea." NASA's management conundrums are being compounded by the budget deficits of the 1980s. The explosion that destroyed the Pacific Engineering and Production Company plant in Henderson, Nevada also destroyed much of the nation's capability for producing space propellant—another hurdle to surmount in our renewed quest to reach orbit. But a special issue of *Physics Today* (May 1988) reminds us that the launch hiatus is only the latest problem in what Tom Donahue, Chairman of the Space Science Board of the National Academy of Sciences, terms a "decade long crisis" in space science.

Articles in the May *Physics Today* about the Soviet space program (by Roald Sagdeev, Gorbachev's advisor on S.D.I. as well as an Advisor to The Planetary Society) and about the ambitious plans of the European Space Agency (by Ian Axford, who directs one of the Max Planck Institutes in Germany) serve as counterpoints to the American space science effort. Donahue notes the stunning potential for space science of NASA's grounded spacecraft and other projects already approved. The projects are all described in an article by NASA officials Joseph Alexander and Frank McDonald. But the reality remains painful; we have become aware of the threats of single-point failures, of NASA's inability to control skyrocketing costs and of the country's failure to support space scientists. That infrastructure is essential for maintaining the intellectual fervor and commitment required for big-ticket missions.

Policy makers are grappling with issues cogently summarized by Louis Lanzerotti and Jeffrey Rosendhal in the final article of the issue. Officials responsible for NASA's budget must realize, they write, "that the more focused projects and the ongoing operation of existing satellites—along with basic research, data interpretation and associated theory—are as indispensable to the conduct of a successful science program as are those major projects that more readily catch the public's attention." Whether their formulas for productive space science truly address the larger dilemma of NASA and the US space program, which many believe has been the inability to commit to a national goal in space, will remain a contentious issue.

Clark R. Chapman has recently retired as chairman of the advisory committee overseeing NASA's research and analysis program in Planetary Astronomy.

SOCIETY *Notes*

AVOID MEMBERSHIP PROBLEMS

Avoid membership snafus by remembering these tips:

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❍ Remember that it takes time to process and mail new memberships. It may be six to eight weeks before you receive your first magazine.

Thank you!—*Sue Pratt, Membership Correspondent*

TEACHING THE TEACHERS

On June 25 and 26 at a summer astronomical conference held in Vancouver, British Columbia, The Planetary Society held a special Mars Watch '88 educators' workshop in conjunction with a teachers' workshop sponsored by the Astronomical Society of the Pacific, the Royal Astronomical Society of Canada and the British Columbia Science Teachers' Association. Blythe Stokes-Whittall, who along with Stephen Edberg prepared the educator materials for Mars Watch '88, conducted our workshop.—*Susan Lendroth, Manager of Events and Communications*

INTERNATIONAL ART EXHIBIT

The USSR's Union of Artists and The Planetary Society have signed an agreement for a series of workshops and exchanges using space art to express international cooperation in space exploration. The agreement will include a workshop in Iceland for space artists this summer and exhibitions at both the *Voyager* encounter with Neptune and the *Phobos* encounter with Phobos/Mars in 1989.

The New Millennium Committee is soliciting donations for the exhibit and workshop. An overall goal of $75,000 has been established, although the immediate need is for $2,500 and $4,000 sponsorships of artists for the upcoming workshop. Interested members may write to me for additional information.—*Louis D. Friedman, Executive Director*

DOLPHIN COMMUNICATION

At The Planetary Society's offices on May 16, an audience of scientists, students and staff listened to Diana Reiss of the Marine World Foundation describe her research in understanding dolphin communication. If a signal from an extraterrestrial civilization is ever detected, attempts to understand how another earthly species transfers information might serve as models for deciphering the signal's code. To explore such possible connections, The Planetary Society awarded Dr. Reiss a $6,000 grant for her fascinating work.—*LDF*

CALTECH BALLOON SYMPOSIUM

On May 3 American, Soviet and French scientists gathered at the California Institute of Technology for a day-long meeting on Mars ballooning. The Society is spurring development of the novel concept, which will be implemented for a 1994 Soviet Mars mission, by providing support for an ad hoc team to test and analyze different payload concepts. Balloon researchers described the status of their work and presented options for four different types of balloons: the dual-gas thermal balloon (see the May/June 1987 *Planetary Report*); a super-pressurized balloon; a simple, classic balloon; and a "buoyant kite." I led a discussion of future planning, noting the Society's willingness to support an international science advisory group.—*LDF*

UPCOMING EVENTS

July 14-24, 1988: ICELAND—US/USSR Space Art Exchange Workshop sponsored by The Planetary Society and the Union of Artists of the USSR.

July 18-29, 1988: ESPOO, FINLAND—COSPAR (Committee on Space Research of the International Council of Scientific Unions) Conference. A public lecture by Michael Carr, "Robotic Mars Exploration: Bringing Back a Sample," July 21 and a scientific symposium, "The European Role in Mars Sample Return," July 23.

October 7-8, 1988: TORONTO, CANADA—International SETI (Search for Extraterrestrial Intelligence) conference sponsored by The Planetary Society and the Ontario Science Center. Public session with Carl Sagan on October 8.

October 30, 1988: AUSTIN, TEXAS—Public lecture prior to meeting of the Division for Planetary Sciences of the American Astronomical Society.

December 8-9, 1988: WASHINGTON, DC—International Cooperation Conference sponsored by The Planetary Society and the George Washington University Space Policy Institute.

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Members' Dialogue /continued from page 3

The Planetary Report. It is unfortunate that The Planetary Society's leadership is either unaware of or has chosen to ignore the extensive and promising work of the Space Studies Institute on mass drivers, lunar resource assessment and lunar materials processing.

We must have the courage to take the long-term view and build bit by bit for the future, even if it means that many of us may not have the gratification of seeing Mars visited in our lifetimes.
JAY ALBERT, *East Windsor, New Jersey*

In Australia we don't hear much about the efforts made by the United States space program and have no claim to fame in that area, with the exception of AUSSAT. However, we do feel at one with the Americans and are proud to be in alliance with them. My personal view regarding the Moon as a stepping-stone to Mars is that it would only be useful as a fuel-saving launch pad and nothing more. The cost of setting up and maintaining a base there would be unjustified, not to mention the even longer delay it would create in our endeavors to reach Mars.

I can still remember how the first landing on the Moon brought the people of the world together in hope and rejoicing and filled us with respect for the American initiative. Many of us over here feel that an effort should be made to generate a two-step Earth-orbit-to-Mars expedition, and I pray that it will happen in my lifetime. As an astronomer, however, I still find Venus an exciting challenge for more robotic research.
STEVE MASSEY, *New South Wales, Australia*

I am shocked to hear that NASA is planning to build a lunar base before attempting any human exploration of Mars. This sounds as though NASA is stalling for time. We have the technology and the know-how to send a mission to Mars right now, but I am afraid we no longer have the courage needed to explore the unknown. John Aaron claims (in the March/April 1988 *Planetary Report*) a lunar outpost is needed to send astronauts to Mars. Is it really? Planners hope to have a working lunar base by 2020, so figure on 2025 or 2030. And then how long do we play around on the Moon before we finally set our sights on Mars?

Time is wasting. There is so much we could learn from human exploration (or I'll settle for robotic) of Mars. Forget the lunar outpost. I love Mars. That's why I joined The Planetary Society!
DAVE SCOTT, *Cincinnati, Ohio*

The space program in this country is dead because people are tired of having their tax dollars mismanaged by an organization (NASA) that is too politically oriented and overcome with bureaucratic red tape. I think an article in the February issue of *Physics Today* by Richard Feynman on his experiences as a member of the commission on the *Challenger* accident tells it all. This country cannot have a space program operated by the federal government. Hardly any agency of our government knows how to manage money.

Space programs need to be operated by universities and funded by grants in a manner similar to places like the California Institute of Technology and the Jet Propulsion Lab. How about letting the National Academy of Sciences guide our space program? Let's get NASA out of the space business and reduce its contribution to one of basic research and development such as NASA Ames Research Center. If there was a more credible organization behind the American space program, I would gladly support a move to provide tax credits via the 1040. Maybe through organizations like the Planetary Society we could also fund these programs.
RICHARD A. COX, *Saratoga, California*

It seems as though the USSR is almost ready for the mission to Mars that it has been building up to for so many years (just look at all those man-hours in orbit). If the USSR will let the mission be a joint one with the US, I believe we should jump at the opportunity to work with our "enemies" and devote ourselves to the project.

I would also like to see NASA leave things, like putting regular satellites in orbit, for the commercial ventures and so devote more of its time and energy to the exploration and related scientific discoveries of the solar system. Finally, although I support the search for extraterrestrial life, I do not believe that it should be given as much priority at present as the "active" exploration of the solar system, which, sad to say, may be humanity's only hope for survival and eventual meeting with other life forms.
MARK HNATIUK, *Lemoyne, Quebec*

NEWS BRIEFS

Nearly eight years ago, Pope John Paul II ordered a review of the case of Galileo Galilei, whom the Inquisition convicted of heresy in 1633 for teaching that the Sun, not Earth, is in the center of the solar system and that all the planets, including Earth, revolve around it.

Since then, however, there has been no recommendation that Galileo be exonerated. In fact, a spokesman from the Vatican recently said, "The case is closed."
—from Lee Dembart in the *Los Angeles Times*

NASA has developed a master plan setting priorities for scientific research. The outline, published in April, gives priority to completing existing projects and orbiting four "Great Observatories."

First in line would be the Hubble Space Telescope, which is ready to go once shuttle flights resume. Next would be the recently started Gamma-Ray Observatory and the Advanced X-Ray Astrophysics Facility. Last in line is the Space Infrared Telescope Facility, which is still being planned.
—from Warren F. Leary in *The New York Times*

In April over 500 people attended a symposium in Houston on human inhabitation of the Moon. In some 200 papers, lunar scientists, engineers, biologists, architects, mining and manufacturing leaders, social scientists, lawyers, historians and artists presented their concepts of what may lie ahead as humans resume exploration and settlement of the Moon. The meeting was the second in a series intended to set up a framework of lunar knowledge within which research, development and political activities can proceed toward the day when humans go to the Moon to stay.
—from James D. Burke of Jet Propulsion Laboratory

Questions & Answers

Do any known asteroids have their own satellites?
—Frank J. Melillo, Valley Stream, NY

Nearly 4,000 asteroids have been numbered to date, but we cannot be sure that any of them has a natural satellite. That does not mean that none does, however. As long ago as 1929, Lick Observatory astronomer N.T. Bobrovnikoff wrote that "if an occasional asteroid were not a single body but consisted of several pieces. . .we could never tell the difference." The reason is that a double asteroid would look like a single "star" even in a large telescope unless the satellite were especially large and quite far from the main body.

There have been reports of suspected satellites. Visual observations and occasional photoelectric records of asteroids passing near stars have occasionally shown the star to "blink out" momentarily, as though an unseen asteroidal satellite had briefly eclipsed the star. (532 Herculina is a well-documented case). But none of these observations has been confirmed by any other observer watching at the same time. Also, there are a number of asteroids whose brightness variations as they spin (their "lightcurves") resemble eclipsing binaries. But in most cases, a single body with an oblong shape can fit the data equally well or better. According to Stuart Weidenschilling of the Planetary Science Institute, the asteroids with lightcurves most likely indicating double bodies are numbers 43, 63 and 192. Also, 216 Kleopatra and the large Trojan 624 Hektor could be "contact binaries" that appear to Earth-based observers using radar to be split in two.

A couple of asteroids with extremely long-period lightcurves, 288 Glauke and 1220 Crocus, may be revealing spin-axis precession, forced by as-yet-unseen satellites. (Precession is the slow wobbling of the spin axis due to external forces, most readily observed in a wobbling top; the Earth's spin axis precesses in a circle every 26,000 years and is only temporarily pointed at the North Star.) We will probably have to await observations by the Hubble Space Telescope before we have direct evidence for asteroidal satellites. But scientists who study the collisions among asteroids won't be surprised if a number of asteroids turn out to have satellites.
—CLARK R. CHAPMAN, *Planetary Science Institute*

How does an icy body (or comet nucleus) from the Oort cloud "fall into" our solar system and become a periodic comet? How often does this happen?
—Moshe J. Kremer, Los Angeles, CA

As remnants of the solar system's formation, many of the icy comets were originally thrown to its outer reaches by gravitational shoves from close-passing planets. Many were given enough push to escape our solar system, while others remained loosely bound in the Oort cloud by our Sun's gravity.

The Oort cloud is named after Jan Oort, the Dutch astronomer who first suggested it in 1950. It is thought to contain some two trillion comets located 60 to 80 thousand times farther from the Sun than Earth. Once in the Oort cloud, the perturbing effects of close-passing stars and the more important tidal pull of the Milky Way galaxy can nudge some comets into the inner solar system. About 16 fair-sized comets, fresh from the Oort cloud, arrive in the solar neighborhood each year. These comets are termed "new" or long-period comets to distinguish them from their more evolved brethren, the short-period comets.

Some Oort cloud comets repeatedly voyage through the solar system and have many close encounters with the outer planets over 100 million years or more. As a result, a few will repeatedly lose some of their orbital energy to the planets they encounter—thus reducing their orbital periods. If a comet's period falls below 200 years, it's called a short-period comet. Roughly one new short-period comet must be introduced into the inner solar system every 100 years to maintain the population against losses by disintegration and ejection into interstellar space by planetary encounters. During each of these close approaches a comet can either gain or lose orbital energy to the planet, depending upon the circumstances of their encounter; at any of these encounters the comets can be ejected from the solar system. Hence it is rare when an icy body from the Oort cloud survives this celestial pinball to become a short-period comet. It is a very inefficient process because tens of thousands of comets must drop from the distant Oort cloud to produce a single short-period comet.

It's not clear whether short-period comets come from the distant Oort

We don't yet know whether or not any asteroids have satellites.

Painting: William H. Hartmann

cloud or from a belt of comets located much closer to our Sun. Recent computer simulations of long-term comet-planet interactions suggest that the orbital characteristics of short-period comets are far easier to explain if we assume that these comets evolve from an inner belt of comets. Only 100,000 would be required to resupply the reservoir of short-period comets. According to this hypothesis, the distant Oort cloud delivers the long-period comets to the inner solar system, while the comet belt, just outside of Neptune's orbit, supplies the short-period comets.
—DONALD K. YEOMANS, *Jet Propulsion Laboratory*

What was* Voyager 2*'s distance from Neptune in August 1987, two years before its encounter? How much distance remained to be covered before the encounter? Has* Voyager 2 *imaged Neptune yet? How close to Neptune, Triton and Nereid will the spacecraft fly?
—Trevor R. Eagles, Halifax, Nova Scotia

The straight-line distance to Neptune two years before encounter was about 7.2 Astronomical Units (AU); one AU equals about 150,000,000 kilometers (93,000,000 miles), the average distance between the Sun and Earth. The travel distance remaining before closest approach to Neptune was about 8.4 AU.

Since before the Uranus encounter in January 1986 both *Voyagers 1* and *2* have been imaging Neptune infrequently, and Triton became visible in those photos in early 1987. Of course, the images are still very small. The amount of detail visible from *Voyager 2* images of Neptune won't exceed that available from Earth-based telescopes until about the beginning of 1989. At the poor resolving powers now available, Neptune still appears bland, but a substantial amount of internal heat escaping from the planet gives us reason to think that the planet will have more visible storms than Uranus. We also expect that during the 80 days of continuous approach observations, many new satellites and ring arcs will be discovered, and we may be able to image some of these from relatively short ranges later in the sequence.

During the final days of approach *Voyager 2*'s range will decrease by nearly one and a half million kilometers per day (just under one million miles), reaching a minimum range of 29,000 kilometers from the center of Neptune at 4:00 am Greenwich Mean Time on August 25, 1989. We won't see the data until four hours and six minutes later, so the "Earth-Received Time" of closest approach will be 8:06 am Greenwich Mean Time.

Voyager 2 will fly within about 5,000 kilometers of the cloudtops over Neptune's north pole. About 12 hours before closest approach to Neptune, the spacecraft will pass a distant 4.6 million kilometers from tiny Nereid. Five hours after Neptune it will fly within 40,000 kilometers of the center of Triton.
—ELLIS D. MINER, *Jet Propulsion Laboratory*

What is the solar wind, and what is its effect on human space flights? What type of shielding is or will be used to protect the crew and equipment from it and other elements of space?
—Bruce A. Johnson, Ft. Bragg, NC

The solar wind is created by the continuous expansion of the Sun's atmosphere through interplanetary space. It is a very hot (usually over 100,000 degrees), very tenuous (only about 10 ions and electrons per cubic centimeter at Earth's orbit), gas of charged particles, or plasma, which flows outward from the Sun at speeds ranging from 200 to 1,000 kilometers per second.

Belts of charged particles, traveling along magnetic field lines, surround most planets, and the solar wind blows them back into the magnetotails that stream out behind the planets. While the solar wind is powerful enough to affect these particles, it is far too weak to threaten piloted spaceflight. The energies of the electrons, protons and other charged particles that make up the solar wind are much too low to penetrate even the thinnest spacecraft walls or space suits.

The potential danger to piloted space flight comes not from the always-present solar wind, but from the (fortunately) rare, huge bursts of energetic particles released in unusually large solar flares. In an article in the May 28, 1982 issue of *Science* magazine, David Rust concludes that "in some orbits there is no reasonable level of shielding material that will protect shuttle occupants from potentially lethal doses of radiation." Current research is aimed at improving our capability to forecast such events far enough in advance to be able to get a crew out of the dangerous location.
—MARCIA NEUGEBAUER, *Jet Propulsion Laboratory*

FACTINOS

A recent study from the California Institute of Technology suggests that the dinosaurs gradually died out because the "greenhouse effect" made Earth too warm after an asteroid hit the planet 65 million years ago.

"We think the asteroid landed on a limestone layer and produced an enormous increase in the amount of carbon dioxide in the atmosphere" by liberating the gas from the crushed rocks, said geophysicist Thomas Ahrens. Higher atmospheric carbon dioxide levels would have greatly increased global temperatures, slowly killing the dinosaurs and other species by dehydration and killing the plants and other organisms they ate.
—from the Pasadena *Star News*

○

After a long study of the huge sodium cloud enveloping Io, University of Arizona lunar and planetary scientist Nicholas M. Schneider concludes that the jovian moon has a "thick" atmosphere as high as 700 kilometers (about 400 miles).

These new findings will help scientists unravel the mystery of Io's interaction with the plasma torus of Jupiter, a doughnut-shaped cloud of electrically charged particles of Io's own making and the cause of its own impressive rate of erosion.
—from Lori Stiles, the University of Arizona *"A" News*

○

Comets may be less similar to the materials present at the birth of the solar system than most astronomers think, University of Colorado at Boulder researchers speculate. Instead, they say, heating from unusually bright stars and supernovae have altered comets' characteristics over the last 4.5 billion years.

J. Michael Shull and S. Alan Stern say that while still in their distant orbits the comets are heated to differing extents, producing boiling that obliterates the original structure and chemical compositions of their surfaces.
—from the *Los Angeles Times*

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A CREVASSE ON THE SLOPE OF OLYMPUS MONS—Mars' Olympus Mons, the largest known volcano in our solar system, would cover an area the size of France if it were placed on Earth. Olympus Mons appears to be a shield volcano similar to those that formed the Hawaiian Islands.

Ludek Peŝek is an internationally renowned artist whose work appears frequently in National Geographic. This painting is part of a series inspired by the Viking mission. Mr. Peŝek, a native of Czechoslovakia, now lives in Switzerland. Painting courtesy of Space Art International

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