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Extra-Solar Planets

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COVER: The Great Nebula in Orion is a cloud of gas and dust illuminated from within by young stars. Infrared radiation and radio waves have revealed bizarre goings-on in this stellar nursery where stars and perhaps planetary systems are forming, hidden within the vast, turbulent cloud.
Photo: David F. Malin, Anglo-Australian Telescope Board © 1981

Letters to the Editor

We encourage our members to write us on topics related to the goals of The Planetary Society: continuing planetary exploration and the search for extraterrestrial life. Letters for publication should be short and to the point. Address them to: Letters to the Editor, P.O. Box 91687, Pasadena, CA 91109.

EDITOR: Ben Bova's properly upbeat recital (*The Planetary Report,* May/June 1984) of all the scientific joys that *could* flow from a space station is positively inspiring. Unfortunately, he reveals his naiveté with one word when he objects to Dr. Chapman's "grumble" over the cost.

Some of us have understood for decades that the Space Shuttle, sold as ultimate economy, has really been the rich relative mousetrapping the poor one. In the long run, the Shuttle will be recognized as the first in a sequence of military vehicles, with the space station as the probable second. Meanwhile, every nickel spent on space science is viewed by the *ignorati* as money that would otherwise have eliminated the common cold and raised this planet's carrying capacity to infinity.

With the current intellectual and imaginative climate likely to continue, it behooves those of us who believe in exploring the solar system to emulate the early mammals. We should step lively and warily among the dinosaurs.

ALVIN L. SCHREIBER, *Somerville, Massachusetts*

EDITOR: As a long-time member of The Planetary Society, I was most distressed by the Society's cool response to NASA's space station initiative. Unfortunately, it serves as a classic example of the factional bickering that has undone so much of the progress that has been made by grassroots space activism.

A permanently manned space station would contribute much to the exploration of the solar system. It could serve as a valuable biomedical test-bed to explore the physiological impact of long-duration space flight, such as a voyage to Mars. Furthermore, the value of such a facility as a staging area for manned or unmanned planetary exploration cannot be ignored.

The exploration of the solar system is one of the most important space priorities, but it is not the only one. The solar system is a magnificent treasure trove of scientific knowledge, but it is also a wonderful manufacturing site and, possibly, a source of energy.

As enlightened members of The Planetary Society, we all hope that the ominous space battle-stations now planned are never built. But it would be the height of naiveté to even suggest that all military activity will be banned from space. It is no secret that communications, command and control functions have been deeply entrenched in Earth orbit for decades.

Members of organizations such as The Planetary Society would do well to remember that the average American tends to lump all space activities into one pigeonhole. The benefits of space exploration will never be fully exploited if space organizations continue to promote the myopic view that sees only one aspect of the greatest of all human adventures.

If space organizations are indeed serious about promoting a wide-ranging, adequately-funded space effort, they should spend more time cooperating and less time arguing about how much of the pie should go where. Unless these splintered factions start working together on common ground, there may be far less of the pie to go around. For everyone.

PAUL CONTURSI, *Brooklyn, New York*

In Search of Other Worlds

by David C. Black

Is Earth the only life-bearing planet in the universe? Do planets circle other stars? These questions have occurred many times to people who have pondered the solar system, and in recent years scientists have made serious attempts to answer them. In this special issue of *The Planetary Report* we examine the possibility of other planetary systems, and hear from the scientists who are now searching for them. These searches are particularly important because we now have *no* observational evidence for the existence of any planets around other stars, nor any observational evidence refuting the idea that they are abundant.

With confidence, I can say that our search for other planetary systems is *essential* to understanding our own solar system. Put another way, we will never fully understand how the solar system was formed if we do not undertake a search for other planetary systems. This is a strong, but I think irrefutable, statement.

Why is a search so fundamental to planetary research? The answer is that, although we can and do develop theoretical models to explain the origin of the solar system using experimental and observational studies, the *only* way we can put these models to a valid scientific test is to see if they correctly predict the character of other planetary systems. If they do not, then they are in error or are incomplete in some essential way. Only by studying other planetary systems can we learn how our models are wrong and then repair or replace them.

Our efforts to find other planetary systems touch upon another search effort: the Search for Extraterrestrial Intelligence (SETI). We only dimly understand the origin of life on Earth and the evolution of that life into human form. However, there is general agreement that in order for nature's experiment to produce intelligent life it must have a reasonably stable environment. Planets could provide the required environments (as we know from at least one example), so any evidence of planets about other stars supports SETI research. Known planetary systems could be targets for radio searches. (See *The Planetary Report*, March/April 1983)

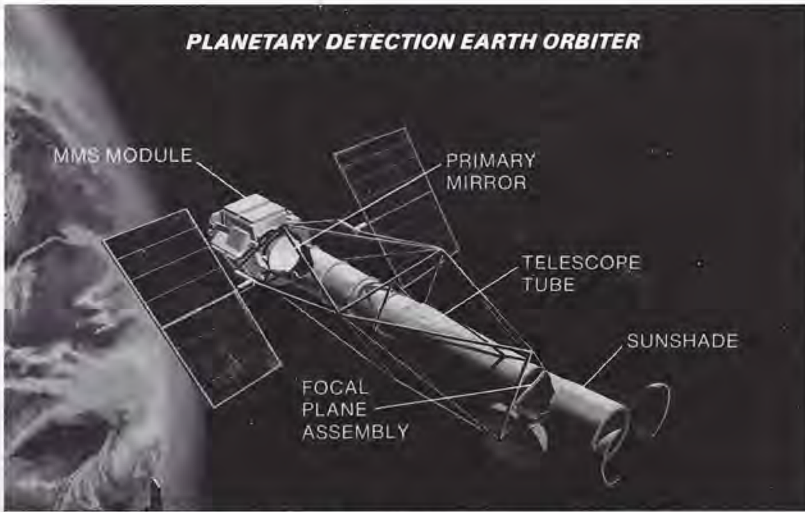
Finding and studying other planetary systems would also improve our understanding of star formation. In the first two articles, Gene Levy and Martin Cohen detail our present picture of how stars and planets might form from whirling clouds of gas and dust. If this picture is correct, then we can deduce a great deal about those protostellar clouds and the early phases of stellar evolution by studying the final product: planetary systems.

Since the time of the Greeks, people have speculated that where there are stars there might be planets. Today astronomers have, or will soon have, tools capable of finding other planetary systems. In this issue, Don McCarthy, Bob McMillan, John Stein and Jane Russell describe these new instruments and the methods to use them.

A large proportion of stars do not travel alone through space, but go as pairs or in groups. Could stars in these binary or multiple systems have planetary companions? Bob Harrington deals with the questions of planets in orbit around these types of stars.

All this speculation and searching is important to planetary science and astronomy, but I believe there is another, perhaps more significant, reason for seeking out other planetary systems. As Bob McMillan mentions in his article, the instrument he is using at the University of Arizona was the vision of Dr. Krzysztof Serkowski, who died before he realized his dream of finding another planetary system. I once asked Kris, "Why should we search for other planetary systems?" This was his response:

How did the Earth form? This is one of those fundamental questions asked by children and philosophers since time immemorial. Our present-day science has no answer to this question—only numerous contradictory hypotheses. One cannot choose among them because we know only one example of a planetary system: our own. Therefore, we cannot exclude hypotheses that explain the origin of our planetary system as a unique or extremely unlikely event. Finding which types of stars have planetary systems and what are typical masses and orbital periods of the largest planets would be a great step toward explaining the origin of planetary systems and the origin of the Earth. Since at least one planet, Earth, is an abode of life and of civilization, the planets are, from a philosophical point of view, incomparably more important astronomical objects than lifeless stars or nebulae.

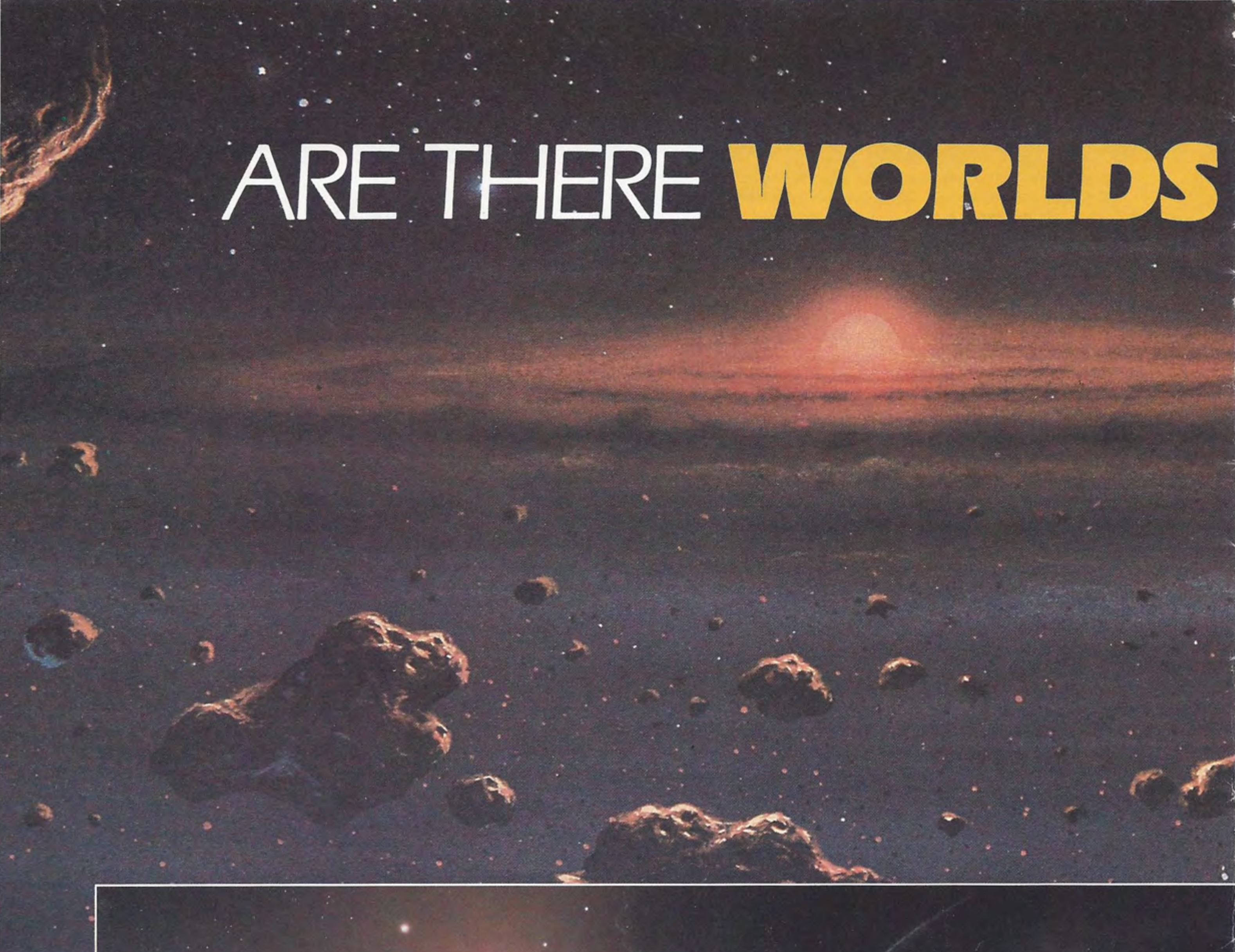


Someday, above Earth's distorting and obscuring atmosphere, orbiting telescopes may be dedicated to the search for other planetary systems. Painting: Dick Allison, Ames Research Center/NASA

I would like to dedicate this issue to the spirit of Krzysztof Serkowski, and I thank the authors for their contributions. I hope that you, our readers, will sense and share our excitement as we begin a search that heralds the beginning of a new scientific discipline: planetary systems science. The results of our search, be they positive or negative, will profoundly and irreversibly affect our perceptions of the universe and our role in it.

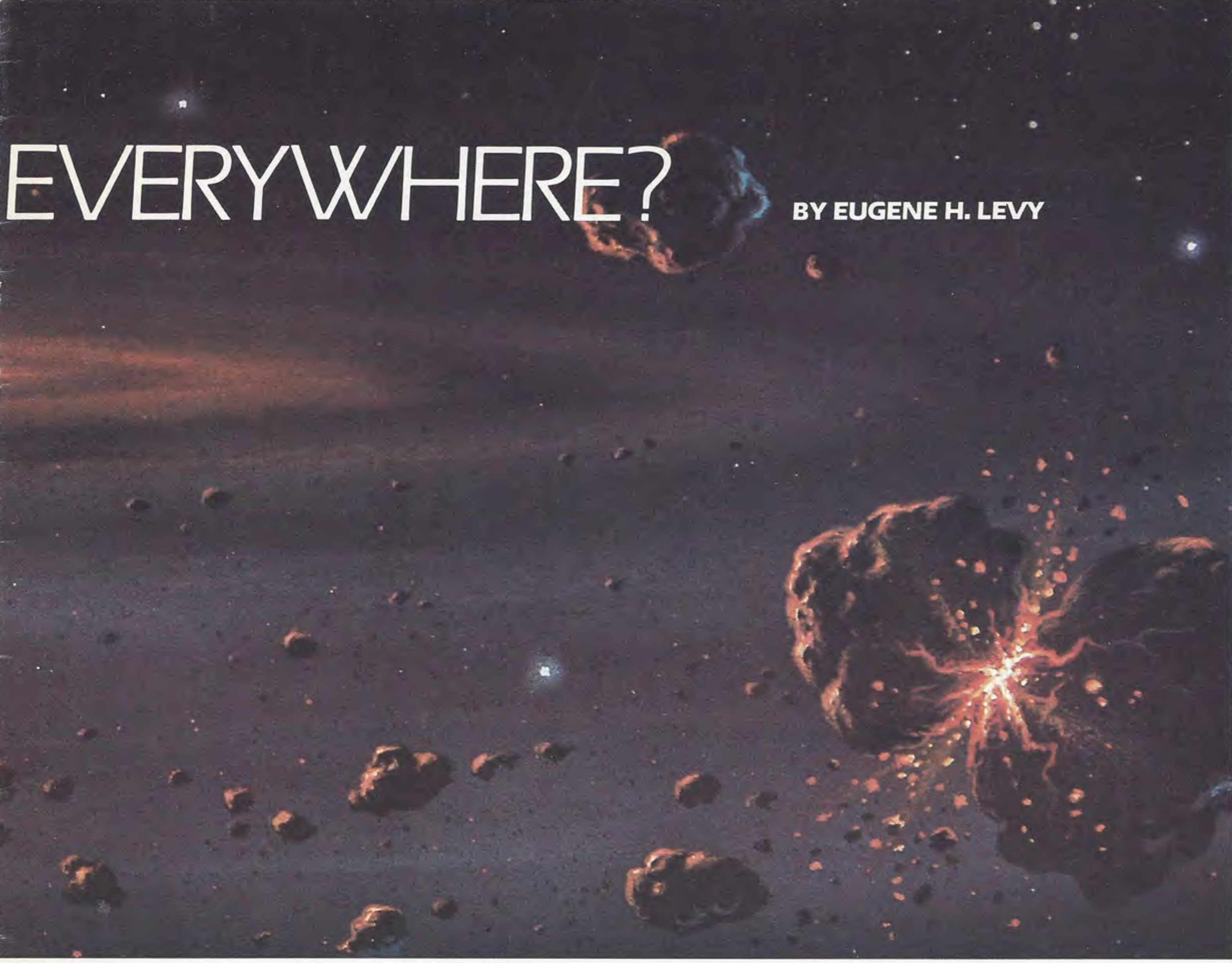
David Black, theoretical astrophysicist at NASA's Ames Research Center, is the guest technical editor for this special issue of The Planetary Report. *He is the author of the forthcoming* Searching for Other Planetary Systems *(CRC Press, 1985) and has edited a NASA Special Publication,* Project Orion, *on the search for other planetary systems.*

ARE THERE WORLDS



EVERYWHERE?

BY EUGENE H. LEVY



Questions about the origin of the world have intrigued people since the dawn of recorded history. Humans have a long intellectual tradition of attempting to extrapolate everyday experience into a general picture of the way nature works, and using that picture to explain mysterious events. Present-day scientific attempts to understand the world around us continue this long human tradition, which in earlier days was embodied in religion, folklore and myth.

Science provides a foundation of fact and understanding on which we build our ideas about the origin of our world. This foundation has been painstakingly built by astronomers who spend years studying the night sky, meteoriticists who cleverly and carefully pry secrets from meteorites that collide with Earth, and physicists who investigate the basic behavior of matter. We now have a broad picture of how the universe evolved and how the Sun, Earth and readers of *The Planetary Report* are part of that evolution. Although this picture is still little more than a blurred sketch, we can at least see certain features with clarity.

Coming Into Being

The present universe came into being some 10 to 20 billion years ago in a spectacular and poorly understood event that we call the Big Bang. Shortly thereafter the rapidly expanding universe consisted almost entirely of hydrogen and helium; the heavier stuff to make planets and people did not yet exist. As it expanded, the universe cooled, just as high pressure gas cools when it is released from a container.

Patches of matter collapsed under the pull of their own gravity to become small, bound objects. Within these gravitationally bound objects, the collapse proceeded in a hierarchical fashion, producing smaller and ever more tightly bound clusters of matter. Thus, from the expanding universe were born clusters of galaxies, individual galaxies, clusters of stars and individual stars. As yet the details of this process remain beyond our grasp.

In the interiors of ordinary stars, energy is generated by nuclear fusion. (Fusion is the joining together of things to make bigger things, fission is the breakup of something into smaller pieces. Stars shine by fusing four hydrogen nuclei together to make one helium nucleus plus a little energy which is released by the star.) In later stages of stellar evolution, red-giant

ABOVE: In this imagined scene during the collapse and heating-up of a new star, planetesimals have condensed out of the cooling gases and are orbiting and colliding—a violent prelude to the formation of planets. As the planets grow, they will sweep up most of these small objects. *Painting: David Hardy*

LEFT: In this imaginary portrait of a giant molecular cloud, stars are collapsing and forming. Radiation from the new stars sends heated gas and dust out as turbulent shock waves into the cold, dark outer regions of the cloud.
Painting: Mark Paternostro

stars generate energy by combining successively heavier atomic nuclei to form atomic elements as heavy as iron. Atomic elements with nuclei more massive than iron cannot be produced through these processes in stellar interiors; more exotic events are needed to make elements such as carbon,,calcium, gold, silver and uranium.

Exhausted Supplies

Having exhausted their nuclear energy supplies, the interiors of many stars collapse and release enormous energy as supernovas. These stellar explosions blow away the outer layers of stars, dispersing into interstellar space the heavy elements that were produced in the stars' interiors. Moreover, the energy produced by supernovas is so large, the temperatures so great, that many of these nuclei combine further, ultimately to make all the heavy elements in the periodic table. Heavy nuclei ejected from generations of very massive, rapidly evolving stars have been mixed with interstellar matter to produce the cosmic abundance we see today—a few percent of heavy elements mixed into a preponderance of hydrogen and helium. It is partly from the heavy ashes of exploding stars that planets are formed.

Evidence gleaned from the present structure and material of the solar system suggests that the Sun and its planetary system formed at about the same time, some four and one-half billion years ago. To see how the solar system formed, imagine that we can follow the collapse of a cloud of gas from its diffuse interstellar origin to its birth as a star. Because of its initial random motion, acquired as it is buffeted about in interstellar space, and because it partakes of the rotation of the galaxy, our protostellar cloud has a small initial rotation about some axis. As the cloud collapses to smaller size and higher density, the conservation of angular momentum causes the cloud to spin faster, just as a spinning skater speeds up when she brings her arms closer to her body. Eventually the spin increases to the point where centrifugal force inhibits further collapse toward the spin axis. However, centrifugal force does not stop collapse in directions parallel to the axis of spin. And so, our protostar collapses into a flattened, spinning disk.

Feeling Friction

The matter near the center of our disk orbits more rapidly than matter farther out. This causes the disk to feel frictional forces that transfer energy and angular momentum from its center to its outer reaches. Inner material accumulates at the center, while outer material moves farther out. At the same time, friction converts some of the kinetic and gravitational energy of the orbiting matter into heat; this raises the temperature of the gas in our protostellar nebula. The temperature is highest at the center, where the star is accumulating, and decreases toward the edge.

At the very high temperatures near the center of the nebula—near the protostar—all matter remains in a gaseous state. But moving outward we come to regions where the temperature is not high enough to keep all chemical elements vaporized. The farther we go from the center, the lower the temperature, and the fewer chemical species remain in vapor. In the outer reaches of the nebula, most species will exist as solids. (At the low pressures of such nebulae, liquids are usually not stable and material passes directly from vapor to solid.)

Calculations suggest that near the center of our nebula, temperatures will be around 1200 degrees Celsius. At such temperatures refractory oxides (as used in our ceramics) are solids while the remaining matter is still vaporized. Farther from the center, at distances approaching an Astronomical Unit (one AU is the distance from Earth to the Sun, 150 million kilometers), metals and silicate rocks will also be solids. Moving farther from the center, to four or five AU, the temperature will be low enough that water ice—a dominating constituent in the cosmic abundance—can form.

The Farthest Reaches

In the farthest reaches of the nebula, at tens of AU, even very low-temperature condensates, such as methane and carbon dioxide, can freeze into solids. At those distances only the lightest elements—hydrogen and helium—exist as gases.

Although the details are still only poorly understood, we believe that aggregations of these condensed materials formed the planets. Starting as small particles of dust, the pieces stuck together through slow collisions and grew larger and larger. Several other physical processes probably contributed to the formation of the planets, including gravitational collapse of material and collisions between larger protoplanetary bodies.

The planets vary in size and composition, but they are not randomly distributed through the solar system. Planets near the Sun are almost entirely rock and metal, materials that could condense at the high temperatures near the center of the protoplanetary nebula. As we move out through the solar system, planets are increasingly composed of materials that can condense to solids only at the low temperatures near the edge of the nebula. The outer planets are also more massive, partly because the low-temperature condensates are more abundant.

Natural Structure

And so, the structure of our solar system is not an accident, but a natural and straightforward consequence of the physical processes that carried a clump of interstellar gas to life as a compact star.

The implications of our present understanding are provocative:

☐ Our own Sun formed in a chain of unremarkable events, common to star formation throughout the universe;
☐ Our own planetary system formed, not by accident, but through expected processes in the nebula from which our Sun formed;
☐ The general properties of the planets and their arrangement in the solar system are also not accidental, but arose from the specific chemical and physical structure of the nebula.

Stars similar to the Sun—and even nearly identical to it—are ubiquitous in our galaxy and throughout the universe. We believe the events and processes that produced our own solar system are no different from those that produce common stars throughout the universe. It is conceivable that, around single stars, planetary systems are the norm and not curiosities.

A Pressing Question

There is much that we do not yet know about the formation of stars and planets. But science has carried our ideas to a point where the existence of other planetary systems is a sharp and pressing question. If, as many scientists believe today, the formation of our own system was unremarkable, then there should be planetary systems everywhere. Earth with its benign environment may not be a rare cosmic accident; similarly habitable planets may be common.

On the other hand, our current ideas could be wide of the mark; the formation of our planetary system might have been rare and remarkable. Perhaps only an interstellar cloud with very specific values of mass, temperature and angular momentum could produce a system of planets. Perhaps some other accident, beyond our ken, contributed along the way. Perhaps habitable environments are nearly nonexistent in the universe.

Few questions cut so deeply into our perceptions about the universe and our own place in it. It is time to establish the presence or absence of planetary systems about other stars and, upon finding them, to try to understand them.

Eugene Levy is a Professor at the University of Arizona, where he is also Director of the Lunar and Planetary Laboratory and Head of the Department of Planetary Sciences. His research includes magnetic fields in cosmical bodies and the formation of the solar system.

DUST DISKS Around Young Stars

by Martin Cohen

The study of forming stars is an international effort. Japanese astronomers are now using a new forty-five-meter radio telescope at the Nobeyama Radio Observatory to search for disks around many young stars. One of their most spectacular successes has been the discovery of a large and extended gas disk associated with a cloud observed in the infrared source region known as IRS-5 L1551. The disk is nearly 10,000 Astronomical Units in radius and has a mass about twice that of the Sun. Using data from other researchers, the astronomers at Nobeyama have constructed a detailed model of this exciting object. Martin Cohen discusses IRS-5 in the accompanying article.

Stars can live for billions of years, but with the lifetimes of astronomers being so much shorter, we must study objects now at different stages in their evolution to get an idea of how stars are born, live and die. The life histories of planets are intimately connected with stars for, so far as we know, there are no planets without stars. In our search for other planetary systems, we must first look to the stars. One particularly promising field is the study of young stars and the dust that surrounds them. We believe it is from this dust that planets are formed.

The birth of a star is an inherently messy process. It happens within dense clouds of dust that veil the emerging starlight. Astronomers use infrared (heat) radiation to penetrate the obscuring curtain and probe the inner workings of stellar nurseries. For over 20 years we have known that large, sometimes prodigious, quantities of infrared radiation are emitted by some young stars, perhaps given off by dusty, disk-shaped cocoons surrounding the stars. Our ability to detect such disks depends on several factors: how much material makes up the cloud, how much matter remains in the disk and is not sucked into the growing stellar core, and how long it takes planets to form and deplete the supply of circumstellar dust particles.

This latter issue is a vital one, with suggested answers ranging from a brief hundred thousand years to a tedious few billion. If planets form rapidly, then our chances of observing a young star's dust disk are 1000 times poorer than if the more sluggish process operates.

Where Can We Look?

Where can we look to test these time-scale estimates? We might look to stable hydrogen-burning stars like our Sun, middle-aged objects (our Sun is 4.6 billion years old) with seething atmospheric surfaces, yet whose apparent vigor is a ghostly echo of the activity in their formative years. Or we could investigate the visible young stars, only 100,000 to a few million years old, that will grow into Sun-type stars. These are the T Tauri stars, named after their prototype, the variable star "T" in the constellation of Taurus the Bull. This star began to intrigue astronomers almost 130 years ago. The T Tauri stars emit copious amounts of infrared radiation; in some extreme cases they shine hundreds of times more brightly in infrared radiation than in visible light.

What can we learn from mature stars? If we viewed our solar system from far outside its boundaries, we would discover that the Sun emits more radiation than we might naively expect from such a star. But this excess radiation is a mere one percent of the total solar output and it arises from the small amount of dust that litters the solar system. This dust was never incorporated into larger chunks, such as planets, moons or comets, and now it circles the Sun in a very tenuous ring between and beyond the planets. This solar system debris would be extremely hard to detect from far away, even if we looked in the infrared.

Ring Around Vega

Nonetheless, several mature stars recently became newsworthy because of IRAS, the Infrared Astronomical Satellite. IRAS made very long wavelength measurements (sensitive to cold dust) of a number of nearby mature and optically bright stars. Most remarkable is Vega, a star much hotter than our Sun and surrounded by a very cool, dusty zone. We think we've seen a cloud of cool (–150 degrees Celsius) particles, each larger than one millimeter in diameter, orbiting Vega in a ring about twice as large as the orbit of Pluto. This dust is apparently left over from Vega's birth and may be a distant region of debris akin to our solar system's comet-forming zone. Another mature star, Epsilon Eridani, has such a substantial cool debris cloud that comets may frequently fly through its inner planetary system — *if* it has one.

The IRAS data also revealed that 10 to 20 percent of nearby main-sequence dwarf stars give off excess infrared radiation. If we assume that this excess arises from dust rings similar to Vega's, then this evidence may imply

NASA's C-141 Kuiper Airborne Observatory, carrying a one-meter infrared telescope, enables astronomers to observe above most of the water vapor in Earth's atmosphere.

Photo: Ames Research Center/NASA

that a large fraction of these nearby stars have rings.

None of these observations confirm the existence of other planetary systems, but they do suggest a kinship with our outer solar system. Furthermore, these stars show no evidence of hotter dust that could exist close to their surfaces at planetary distances. Either the once hot dust has now accumulated into inner planets, or there was never an appreciable mass of hot materials to form rocky planets.

Attending to Young Stars

T Tauri stars are much younger and have received a lot of attention, particularly the optically faint star, HL Tau. HL Tau is the only T Tauri star that reveals the presence of circumstellar water ice grains, and it seems to be surrounded by more silicate dust than other stars in its class. Its light is more strongly polarized than that of similar stars at visible and near-infrared wavelengths, indicating reflection off oriented dust grains. These extreme properties suggest that we might be viewing this T Tauri star directly through the plane of a forming planetary system. Even so, the amount of dust and ice seen in the infrared is only a tiny fraction of the mass estimated to have been present in its original nebula.

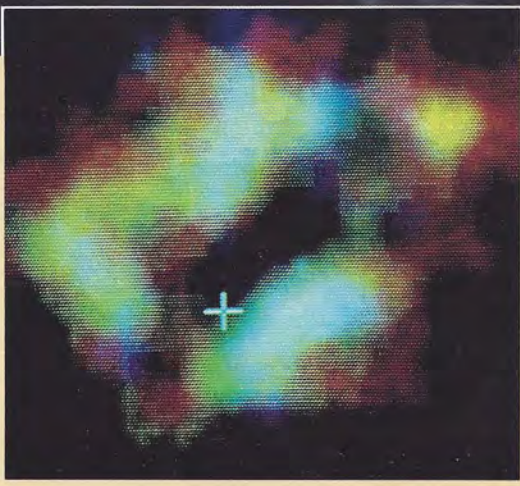
Is this evidence that planets have already formed around this remarkable star, only 100,000 years old? There is a tantalizing clue from airborne infrared measurements: The coolest dust around HL Tau seems organized into a region perhaps a hundred times the size of Pluto's orbit, but still too small for IRAS to see as more than a point of light at the distance of 500 light years. The high optical polarization of HL Tau suggests that starlight is scattered into our direction from a symmetrical cloud, indicating a high degree of organization of the circumstellar dust. Very fine-scale infrared images of HL Tau also suggest that the dust cloud is elongated. We could not see individual planets unless they were super-Jupiters in size, but there is plainly an extended, flattened, dusty nebula around HL Tau.

Jets from Young Stars

Most remarkable are the unprecedentedly vigorous and well-collimated (aligned) phenomena characterizing stars even younger than HL Tau. Very young stars often eject tiny gas clouds at great speed into their dark, cloudy environs. These events are repeated and occur in one direction or two opposite ones.

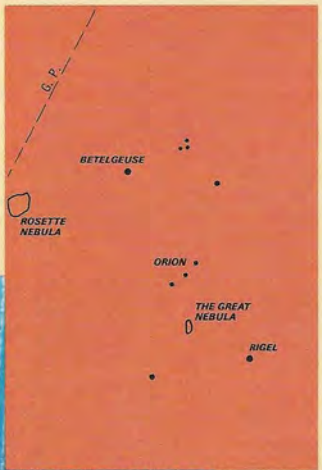
A region of space known as L1551 IRS5 is one such system, discovered by infrared techniques. Radio studies reveal a long and extremely thin double-sided jet of gas streaming away from IRS5. Associated with these streams are small blobs of dense gas, ejected from the central star within the past few thousand years. A cloud of radio-emitting molecular gas surrounds this heavily obscured star. The phenomenon is displayed by several other extremely young systems whose cool dust structures appear unresolved in the

ABOVE: In this painting, jets are emitted from the polar regions of a forming star. As the nebular disk spins and material moves inward, a combination of gas-dynamic and electromagnetic forces forms a "nozzle" over each pole, through which blasts of glowing material are emitted in an almost-polar direction.
Painting: Michael Carroll



RIGHT: Viewed in the infrared, a shell-like structure appears around a newborn star (at position marked by +) in a molecular cloud. Radiation and the stellar wind dissipate the cocoon of gas and dust that once surrounded the star. The dark area in the center has been swept clean by the stellar wind.
Photo: R. D. Gehrz, G. L. Grasdalen and J. A. Hackwell, Wyoming Infrared Observatory.

ABOVE:* *The Infrared Astronomical Satellite (IRAS) discovered a ring of cold debris about Vega, one of the brightest stars in our sky. This debris ring may be similar to the Oort Cloud of comets circling our own Sun out beyond Pluto's orbit. *Painting: JPL/NASA*



RIGHT:* *This chart shows the familiar "landmarks" of Orion, including the mature stars, Betelgeuse and Rigel, that are nearly invisible in the infrared. *Chart: JPL/NASA*

BELOW:* *Orion in the infrared looks very different from the familiar winter constellation seen in visual light. Areas with young, forming stars glow brightly, while older stars are nearly invisible. *Image: JPL/NASA*

direction of flow from the central stars but are extended perpendicular to the sense of flow.

A striking example of this is an infrared object associated with a visible family of five distinct blobs of gas that the star has repeatedly thrown off to one side. Data taken using NASA's Kuiper Airborne Observatory reveal a well-resolved structure resembling a disk almost 130 times the size of Pluto's orbit. It is viewed nearly edge-on and is oriented perpendicular to the chain of gaseous missiles.

Tantalizing Evolution

These findings suggest a tantalizing sequence of stellar evolution. When they are very young, stars are surrounded by large, dusty disks — the spinning debris left over from starbirth. In time the disk thins and shrinks in radius as material spirals into the growing central protostar, or it is carried away by powerful, narrowly-collimated jets from the star's poles. Or it clumps into protoplanets.

If we are very fortunate, we may be looking into the disk plane of a forming planetary system. These disks are so thin that the alignment required for us to be able to see them is critical; hence the rarity of HL Tau among its peers.

HL Tau gives us a clue that perhaps planets begin to grow only 100,000 years after a dust nebula begins to collapse. Once particles grow to the sizes of golf balls or Volkswagens, it is practically impossible to observe them. T Tauri stars over a million years old show only vestiges of these early disks. IRAS's contribution may be the realization that cool ghosts of these disks persist hundreds of millions of years into stellar evolution, their particles waiting to be locked up into comets.

Dismemberment and Disappearance

We have witnessed the dismemberment and disappearance of dusty disks around young stars that will one day be very like our present-day Sun. Unless stellar jets can scour clean almost all the disk material, planets are a very plausible repository for the vanished matter. We cannot yet point a finger at entities that could become planets around distant stars, but we do believe we know those sites in which they may be assembling. We recognize that if planet-building is happening around these stars, it is a process that starts very early in a star's lifetime.

These infrared studies, made possible by instruments above Earth's atmosphere, provide strong evidence that part of our theoretical picture of star formation, the presence of disk-like structures around young stars, is basically correct. Whether planets can and do form from these disks is a question that cannot be answered by measuring the properties of dust. We must use other techniques, such as those discussed in the following articles.

Martin Cohen is an astronomer at both the University of California at Berkeley and NASA's Ames Research Center. His research interests include star formation, using radio, infrared and ultraviolet techniques.

EVIDENCE FOR SUB-STELLAR COMPANIONS

by D. W. McCarthy, Jr.

The search for other planetary systems is intensifying, fueled by indirect evidence indicating that a lot of dark matter is spread throughout our galaxy and in its distant relations as well. This dark matter might be subatomic particles, comets, rocky planets or large gas balls such as Jupiter; all too small to become the thermonuclear furnaces that power normal stars. These objects may be planetary companions to ordinary stars or solitary wanderers silently drifting through interstellar space.

Astronomers have recently used a new technique known as infrared speckle interferometry to detect small stellar companions and stars still growing in their dusty nurseries. Stars usually form in pairs—binary stars. Our Sun may be an exception to the rule. A few people have suggested that even our Sun may have a distant, faint, stellar companion, but their evidence is highly conjectural. Whether or not it has a companion star, the Sun does not travel through space alone. Orbiting around it is a family of planets, comets, asteroids and assorted debris, dark matter that would be nearly invisible from the vicinity of another star.

Detecting Hidden Planets

The glare of a massive, brightly glowing star would make it extremely difficult to see a small, faint object orbiting near it. And viewed from Earth, the problem is compounded by the air currents in our atmosphere that can make two close objects appear as a single, fuzzy, twinkling blob, even when seen through the largest telescopes. For these reasons, most astronomers use indirect techniques to search for planets, instead of techniques that directly "image" the planet and star. These techniques have included astrometric and spectroscopic measurements (see pages 15 through 17).

But a recently developed method of direct imaging—infrared speckle interferometry—has proved promising in the search for companions to nearby stars. The purpose is to overcome atmospheric blurring and "resolve," or separate, the image of a companion from that of the star. The image is taken at infrared wavelengths where the cooler, redder companion may be brighter than the hotter, bluer star. Based on work done at optical wavelengths in the early 1970s by Antoine Labeyrie, the technique was first applied in the infrared in 1979 by Pierre Lena of the Meudon Observatory and Francois Sibille of the Lyons Observatory.

The term "speckle" refers to the small, bright patches of light making up the telescopic images of a star taken in a quick exposure (about 1/100th of a second). Just as ocean waves combine to form high crests in a violent storm, wavelengths of starlight, slowed by turbulent air pockets in our atmosphere, interfere with each other to produce bright speckles in a telescopic image. Each speckle is a perfect image of the star as it might be seen from a telescope orbiting above our atmosphere. But with ground-based telescopes, the starlight is spread out over hundreds of speckles, making each one faint and difficult to detect.

Unfortunately, atmospheric winds and turbulence make the speckles move many times a second; thus, long exposures yield fuzzy blobs of starlight. Because astronomers prefer long exposures to accumulate the light from faint objects, they need special techniques to combine the information from each speckle during long exposures and thereby preserve fine detail in the final image.

To do this, they take thousands of exposures, each short enough to freeze the air currents (as a high-speed camera freezes the motion of a hummingbird's wings) and reveal speckle structure in the star image. Each image is decomposed into its component frequencies, just as a musical chord can be broken up into its component notes. This process, called Fourier analysis, forms the bases of modern music and voice synthesizers. The strengths of the component frequencies can be added to give us the equivalent of a long-exposure photograph. We can then transform this product into an actual image of the object as it would appear without atmospheric blurring.

Finding Companions to Nearby Stars

During the last two years, while working with Drs. Frank Low and Susan Kleinmann, I have been using the infrared speckle technique to detect small companions suggested by astrometric measurements of about 30 nearby stars. In the previous 40 years, only two companions had been detected at optical wavelengths; the smaller companions are usually over 100 times fainter than the accompanying star, and lie very close to their larger hosts. The space between them would be about as easy to see as a penny four kilometers away.

At infrared wavelengths, the brightness difference between the two objects decreases at least 30 times. Hot objects, like stars, radiate energy primarily at wavelengths visible to our eyes, while cool objects radiate primarily at infrared wavelengths beyond the sensitivity of human eyes. Thus, in the infrared, a cool object can appear brighter than a hot object. So infrared astronomers often point their telescopes at objects they cannot see.

Using our infrared techniques, we have detected fifteen companions. We have measured the separation between the paired objects and have determined their apparent brightnesses. By combining these data with astrometric measurements, we can directly determine the masses and absolute brightnesses of the component objects. To date, most of the companions are small red stars (red dwarfs) with masses ranging from 0.08 to 0.3 solar masses. In some cases, we may have detected small companions that are not quite stars, although their brightnesses and masses are quite close to those expected for the smallest possible stars.

In this picture of a bright star, the individual bright spots, or speckles, are near-perfect images produced by the telescope. Atmospheric air currents blur the image of the star into the numerous speckles.
Photo: E. K. Hege

The star CC 20,986, located 24 light years away, is a star whose companion has been studied in detail both astrometrically and by infrared speckle interferometry. This star was discovered in 1930 at the Cincinnati Observatory in a survey to detect nearby objects. Astrometric measurements taken between 1938 and 1977, and analyzed by Lippincott and Borgman of the Sproul Observatory, revealed a small wobble in the star's motion. In 1982, infrared speckle measurements detected the companion. It is a small object and fainter than we would expect a star to be.

Using astrometric methods, astronomers have measured small wobbling motions of several stars, leading to the prediction that they have companions too small to be stars. (See pages 15 through 17.) In theory, the suspected companions should not emit enough radiation to be detected with existing equipment. In fact, infrared speckle measurements do not reveal any companions. This means that these stars do not have stellar companions. But they may have companions that are smaller and darker than stars, such as planets. Or they may have no companions at all, for the wobbling motions are almost too small to be accurately measured.

Continuing the Search

Planets, as we know them, range from rocky lightweights, such as Mercury and Earth, to gaseous giants, such as Jupiter and Saturn. There may be planetary companions as massive as 85 Jupiters. Objects ranging from a few Jupiter masses up to this limit are called brown dwarfs. They are not massive enough to ignite nuclear reactions and turn into stars. Brown dwarfs are probably cold objects (120 to 2000 degrees Kelvin), slowly losing their heat of formation as it radiates back into space over millions of years. Believing this, we expect them to shine brightly at infrared wavelengths.

I am now examining about 50 stars within 20 light years of the Sun, trying to detect brown dwarfs orbiting the nearby stars. These companions could have been missed in previous astrometric measurements. Our theoretical considerations suggest that several such objects might exist within this volume of space.

Infrared speckle interferometry has also been used to study young objects in regions of star formation. The most exciting result has been the detection of a cool (800 degrees Kelvin), red companion to the young star T Tauri (see pages 7 through 9). Mel Dyck and Ted Simon of the University of Hawaii, working with Ben Zuckerman of the University of Maryland, discovered this companion in 1982.

T Tauri is only about one million years old, so the red companion might be a small object still contracting into a star. This explanation seems the most plausible. However, it is also possible that this companion is a brown dwarf that has not yet cooled off. Our future speckle measurements of young stars may reveal many brown dwarf companions.

Future Infrared Searches

The Infrared Astronomical Satellite (IRAS) surveyed the sky from above Earth's distorting and absorbing atmosphere, and within the data it collected there could be evidence of brown dwarfs drifting alone through space. They would be revealed by their cool temperatures and infrared emissions, and also by their rapid motion against the background of more distant stars. Scientists are now waiting to analyze the data.

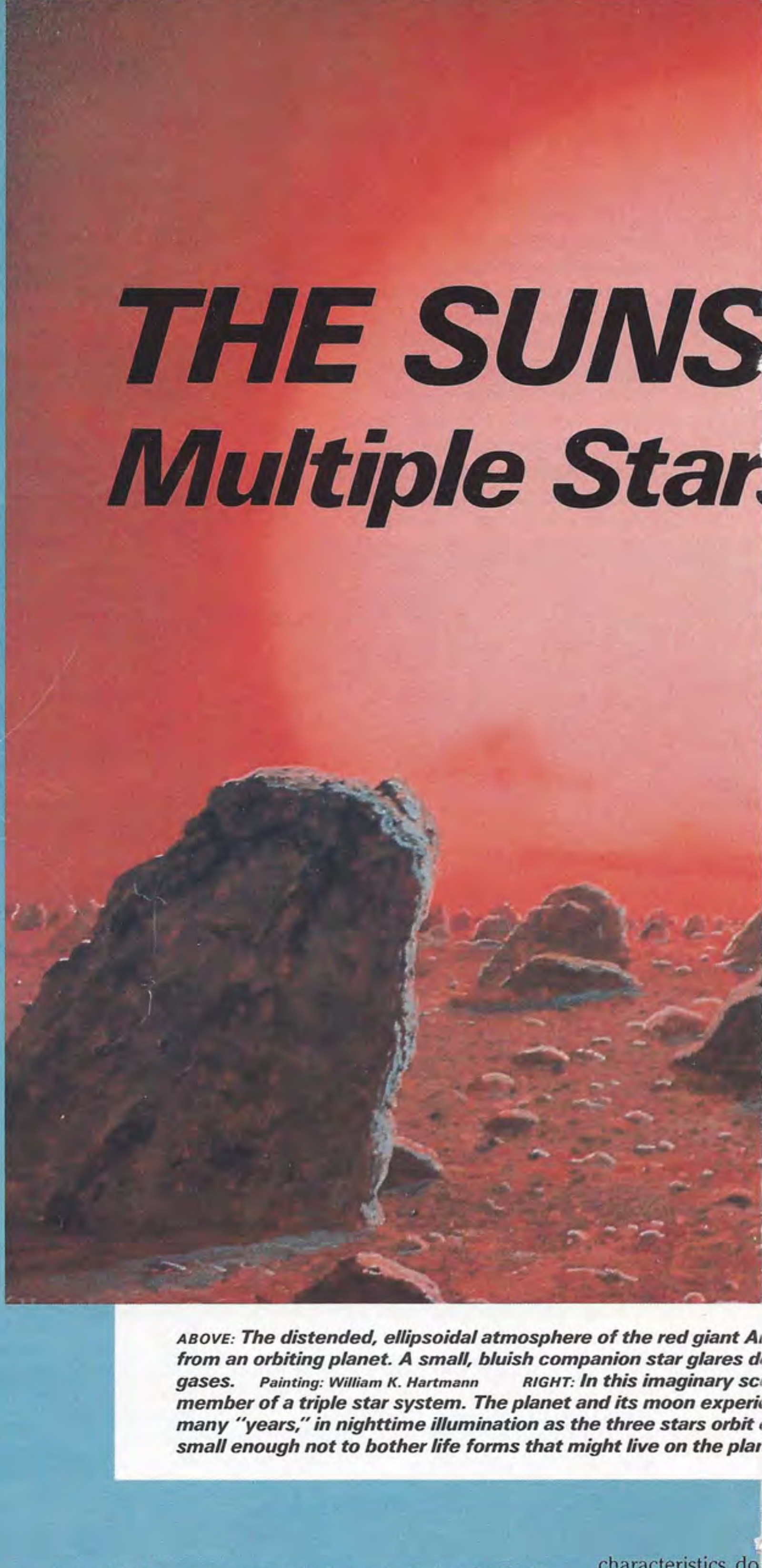
Future infrared searches, conducted from space, will be able to see more stars more clearly. The Space Infrared Telescope Facility (SIRTF), now being planned by NASA, will be a one-meter telescope with detector arrays 1000 times as sensitive as IRAS. This instrument would be able to see Jupiter-sized companions around several of the nearest stars.

Infrared studies are opening up new horizons in astronomy. Nature seems to prefer to make stars with companions, and most of the companions we have seen so far are themselves stars—parts of classic binary star systems. But some of the objects seem too small to qualify as stars; they may be members of other planetary systems. Or they may just be unusual binaries where only one member is a star. If so, they will give us valuable data about binary systems, but we will have to look elsewhere for planets.

By the end of this century, we should learn of other planetary systems, or realize that the formation of such systems is a rare event. In either case, we will be closer to knowing if we are alone in the universe.

D. W. McCarthy is Associate Astronomer at the Steward Observatory of the University of Arizona. He specializes in infrared astronomy and plays fast-pitch softball in his spare time.

THE SUNS
Multiple Star



ABOVE: ***The distended, ellipsoidal atmosphere of the red giant A*** ***from an orbiting planet. A small, bluish companion star glares d*** ***gases.*** Painting: William K. Hartmann *RIGHT:* ***In this imaginary sc*** ***member of a triple star system. The planet and its moon experi*** ***many "years," in nighttime illumination as the three stars orbit*** ***small enough not to bother life forms that might live on the pla***

by R. S. Harrington

Companionship is in, solitude is out. At least, that's the way things seem to be among the stars. Stars like to get together in binary and multiple systems, in associations and in clusters. We can say quite confidently that *at least* half of all the stars we see are members of multiple systems.

There is good reason to believe that stellar multiplicity is even more common, because we know that there are serious observational limitations to finding such systems. Some would even suggest that multiplicity is essentially universal, with the Sun and its large gas-giant planets being no exception.

Characteristically, the components of all these mature multiple systems are arranged in a hierarchical pattern such that the system can be broken down into combinations of binary systems. Thus, a triple star will have a close binary with a distant third star, while a quadruple will have either two close binaries that are well-separated from each other, or it will have a close binary, a distant third, and a very distant fourth star.

Stable Systems

Systems of this nature are dynamically stable. Their motions can always be described as those of a series of two-body systems with only small perturbations. Indeed, the young unstable systems such as clusters and associations will eventually break up, with some members escaping from the system, leaving the remainder behind, bound up in these hierarchical patterns. Whether this entirely accounts for the origin of multiple systems remains to be seen, but the statistical results are encouraging.

We are now concerned with questions such as: Is it possible to have planets in such systems? Could such planets maintain the conditions necessary for the evolution of life? We have to ask not only whether planets could form in the first place, but also whether such planets would be in dynamically stable orbits.

The formation question is a tough one, because we do not understand either planetary or multiple star formation well enough to give a good answer. If multiple star systems condense out of their primordial nebulae in essentially their present geometry, the perturbations caused by two massive bodies would probably keep things stirred up so that condensation of planets would be impossible. On the other hand, if the stars in the systems originally formed in loosely packed larger groups, they could have gathered planets before the disruption of the unstable groups. If, in addition, some of the closest binaries formed by fission—if a parent star split into two binaries—planets could have formed in the outer fringes of the primordial nebulae before the centers split.

The question of dynamical stability is much easier to deal with, and the situation with planets is no different from that with only stars. So long as a hierarchical structure is preserved, everything is stable and the perturbations are small and periodic. Thus, it would be quite possible to have planets tucked in close to one or more components of a wide star system, or well outside a close one, with complete stability. Replace the Sun by two stars separated by, say, 0.2 AU (an Astronomical Unit is the average distance from the Sun to Earth, 150 million kilometers), and you lose Mercury but Earth is hardly affected. Inflate Jupiter to one solar mass, and you lose Mars, but again Earth is hardly affected.

Maintaining Stability

It is, however, not easy to say precisely what the limits are for a system of this type to maintain the required stability. By stability, we mean very little change in the size and shape of the planetary orbit, ensuring that heat and light on the planet do not vary significantly with time. Theory is of little use here because mathematical models tend to break down near the onset of instability. Extensive computer simulations, with theory setting some guidelines, can be used but often cannot sample all parameters or run for the required amounts of time.

However, from many computer experiments run by me as well as by David Black and his coworkers, some general characteristics do play a role, but th Assuming the pla it is close to one than about five tir etary orbit is aro greater than abou

Consider Alph

Consider the tripl stellar neighbors. nent called Proxin

IN THE SKY
s and Planetary Systems

tares is here imagined as if seen own through the red giant's glowing ene, an Earth-like planet orbits a nce a variation, with a period of ach other, but the effect could be et. Painting: Mark Paternostro

emerge. The relative masses of the stars important thing is their relative distances. et is in an approximately circular orbit, if star, the other star should not get closer es the planetary orbit's radius. If the plan- nd the entire binary, its radius should be five times the separation of the stars.

a Centauri

star Alpha Centauri system, our nearest Excluding the probably unbound compo- a, this is a binary system with a solar-type

(continued on next page)

star plus a somewhat cooler orange star. These stars revolve around each other in around 80 years with a separation that varies between about 11 and 35 AU.

An Earth orbiting around the brighter star would experience virtually the same dynamics as our own, and the temperature variations over the course of a human lifetime, due to the presence of the other body, would be less than a quarter of a degree Celsius. The secondary body would be about 250 times as bright as our full Moon but less than one one-thousandth as bright as the Sun, and it would vary in brightness by a factor of 6 over the course of one planetary revolution. This would produce a slightly more complex pattern of variation of darkness and daylight than on Earth, but probably not significantly so in an ecological sense. Likewise, an Earth orbiting about the secondary star would be in a very stable orbit, providing the real possibility of a science fiction writer's dream: a double, habitable planetary system.

A close binary, with its two stars exchanging and shedding material, is here seen from an imagined planet orbiting the two stars.
Painting: David Hardy

An Interesting Neighborhood

What other interesting systems are there in our immediate neighborhood? Moving outwards beyond Alpha Centauri, we next encounter Barnard's Star, a small red dwarf once thought to have two Jovian-type planets. New evidence, while by no means conclusive, tends not to support this older idea. Next comes Wolf 359, then Lalande 21185, both single, relatively old dwarfs. Then there is the binary system L726-8, both components of which are very cool, very low mass red dwarfs. One of these is the well-known flare star UV Ceti. While these stars are probably too unstable in energy output to support a life-bearing planet, there is plenty of room in the system for stable planetary orbits. Next comes the very bright Sirius, a known binary containing a white dwarf, but almost certainly no other stellar component, despite periodic suggestions to the contrary. Because the primary star is so luminous, and the secondary has gone through the explosive phase of its evolution, this is one of the few nearby systems in which it might not be possible to have good, stable planetary orbits.

And so it goes. Within 25 light years of the Sun there are 110 known stellar systems containing 148 known stars. Sixty-nine of these stars are bound up in 27 binaries, 3 triples and a sextuple system. Also in this volume of space are 8 known or reasonably suspected unseen companions (see pages 15 and 16). All but one of these unseen companions are substellar in mass, and five of them (including the clearly stellar case) are associated with components of multiple systems. Four of these eight unseen companions have masses probably less than one percent that of the Sun. It remains to be seen whether we should call these very small brown dwarfs or very large Jovian planets.

A Sextuple System

Perhaps the most interesting system in this region of space is the sextuple system Wolf 629/Wolf 630/VB 8. Wolf 629 is a known spectroscopic binary: Its two sets of spectral lines shift, due to the Doppler effect, as the stars move around each other, so we know it is double, even though we cannot see the stars as two separate images. Wolf 630, about 470 AU from 629, is a visual binary, one component of which is itself a spectroscopic binary.

At a distance of about 1500 AU from this system is the very faint red dwarf which is number 8 of van Biesbroeck's list (VB 8) of faint, fast-moving companions to known nearby stars. This star, in mass less than eight percent that of the Sun, may have an even fainter unseen companion, and, while the analysis of this system is far from complete, this companion could have a mass only two or three times that of Jupiter.

Binary and multiple star systems are common throughout the galaxy, and they may be even more common than we realize. They are also perfectly capable of holding onto planetary systems with very stable orbits. And in most cases the region in which these stable orbits could exist includes the region in which planets would be quite habitable. We should definitely include such star systems in any search for planets and whatever we may find on them.

R. S. Harrington is an astronomer at the United States Naval Observatory in Washington, DC.

ASTROMETRY: The Search for Other Planetary Systems

by John W. Stein

Living on Earth, we are passengers on a vehicle traveling down a massive and somewhat crowded galactic highway. Looking about us we see other vehicles—the stars—all moving in about the same direction as we are, circling the distant center of our home galaxy.

Not all stars are moving at the same speed, however. Some are moving faster and, in a few hundred thousand years, they will overtake us and be lost in the distance as they pull ahead. Others we will overtake, and lose to view as they fall behind.

Astrometrists measure the positions of celestial objects against the background sky and so are used to seeing this effect as they continue their observations year after year. For all practical purposes, this *proper motion* appears as the motion of a given star in a straight line relative to the stars around it. When a star is accompanied in its travels through space by an object in orbit around it—be it a planet, brown dwarf, or another star—it will show another motion superimposed onto its proper motion.

Picture the Sun

We usually picture the Sun sitting fixed and immobile as the Earth circles it once a year, but this picture is not accurate. An observer suspended in space watching the Earth and Sun would notice that there is a point between their centers around which both objects orbit, each requiring one year to complete a circuit. Astronomers call this point the *barycenter.*

The Thaw Telescope at the Allegheny Observatory of the University of Pittsburgh is being used in astrometric searches for planets about other stars.
Photo: Tom Reiland

The barycenter has a lot in common with the pivot point of a playground seesaw. When the seesaw is balanced by two people of equal weight, the pivot is halfway between them. If one person is heavier than the other, the pivot must be shifted toward the heavier person.

So it is with the Earth and Sun. Because the Sun is so much more massive than the Earth, the barycenter lies very close to the center of the Sun (about 480 kilometers from the Sun's center and 150 million kilometers from the Earth). As seen by our observer suspended in space, the Sun circles the barycenter once per year in a near-circular orbit with a 480-kilometer radius. Were the Earth more massive or farther from the Sun, the barycenter would lie farther from the center of the Sun.

The Galactic Highway

If we were to observe the Sun from a nearby star, the Sun's path down the galactic highway would not be perfectly straight. It would have a slight wobble due to the Sun's annual motion around the Earth-Sun barycenter.

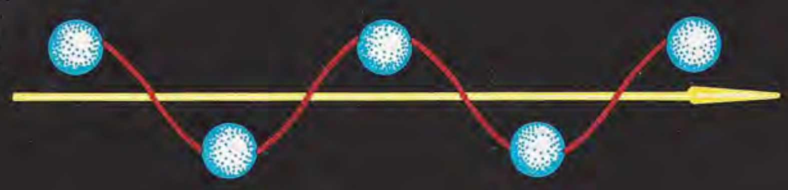
Notice one important fact: It is not necessary to see the Earth to know of its presence. We only have to detect the wobble, or *perturbation,* in the Sun's proper motion!

Of course, the farther this hypothetical observer is from the Sun, the smaller that 480-kilometer-radius orbit of the Sun will look. So, being realistic, we must recognize that even if we use the best modern measuring equipment, there will be some maximum distance beyond which we won't be able to detect a planetary perturbation in the proper motion of a given star. Just what that limit is depends upon how accurately we can measure the position of the star.

How large an effect, caused by planets revolving about other stars, can we expect to see? If we looked at a star like the Sun, but sitting 33 light years from the Earth, then the amplitude of the wobble would be about 0.0005 arc seconds for a Jupiter-sized planet, and roughly 0.000003 arc

Suspected Planetary Companions as of June, 1984

YEAR REPORTED	STAR	PRESENT STATUS	SIZE AND ORBIT
1943	61 Cygni	Doubtful	Object 8 times Jupiter's mass in a 4.8-year orbit.
1960	Lalande 21185	False alarm	Object 10 times Jupiter's mass in an 8-year orbit.
1963	Barnard's Star	False alarm	Two objects, first of 1 Jupiter mass in 11.5-year orbit, second of one-half Jupiter mass in 22-year orbit.
1974	Epsilon Eridani	False alarm	Object with mass no less than 6 times that of Jupiter in a 25-year orbit.
1979	Barnard's Star	Unconfirmed	Two objects, first of 0.8 Jupiter masses in a 20-year orbit, second, of 0.4 Jupiter masses in a 12-year orbit.
1983	Van Beisbroeck 8	Unconfirmed	Object with mass no less than 3 times that of Jupiter in a 4.9-year orbit.



If a star has an unseen companion, it may appear to wobble as, over many years, it moves across the sky.

seconds for an Earth-sized planet. (An arc second, one thirty-six-hundredth of a degree, is the angular size of a golf ball seen at a distance of a couple of miles.) The size of the wobble varies in proportion to the mass of the planet: the larger the planet, the larger the wobble. It also varies with the mass of the star: Stars smaller than the Sun would show us larger wobbles. But no matter what the sizes of the orbiting objects, the wobbles will appear extremely small when seen from the Earth.

Stars and Hot Roads

Ultimately, the Earth's atmosphere sets limits on the accuracy for determining, from the Earth's surface, a star's position. Distant objects seen down a hot road on a summer day seem to shimmer and dance as hot air currents, rising from the road's surface, bend the path of the light as it travels from the objects to our eyes. For the same reason, stars seen through telescopes dance about their true positions. Because of these "seeing" effects, ground-based astronomers cannot—even in principle—measure the star's true position instantly and with infinite precision. Instead, repeated measurements are taken while the star dances about, and later the measurements are averaged to get an idea of the star's true position (see pages 10 and 11).

"Seeing" effects are not the only sources of error that astrometrists search-

Spectroscopic Searches for Other Planetary Systems

by Robert S. McMillan

Why is a search for planets orbiting other stars now being promoted with such urgency? After all, people have been wondering and speculating about other worlds for thousands of years. Even scientific questions about the properties of other possible solar systems have been discussed and debated for more than 200 years. But now, because of advances in technology, the observations necessary to find other planetary systems are possible, and so the search becomes compelling.

Our present technology gives us several methods for finding planets. One method, astrometry, detects small wobbles in a star's apparent motion as it moves across the sky. These wobbles could be caused by unseen planets orbiting the star. (See pages 15 through 17.) Here I will describe spectroscopy, another indirect method of detecting the presence of planets.

Light from stars can be made to show a spectrum, just as sunlight passing through a prism is spread into all the colors of the rainbow. But if we look very closely at the spectrum of the Sun or another star, we see hundreds of dark, narrow gaps. These gaps, or "spectral lines," are due to the characteristic absorptions of light by the atoms of various chemical elements in the atmosphere of the Sun or a star.

Speeding Light

One of the properties of light is that its apparent color is affected by the speed at which the source of light approaches or recedes from the observer. A star in a binary system, or one with a planetary companion, will appear to change speed as it orbits around the system's barycenter, or center of mass. As the star moves toward us in its orbit, its light becomes bluer; as it moves away, it becomes redder, changing the positions of the spectral lines. The back and forth shift will have the same period as the planet's orbit about the star, which means we may have to watch the star for years before seeing a shift in color!

We call the dependence of color on speed the *Doppler shift.* Detection of a star's orbital motion requires us to accurately measure the change of Doppler shift of a star over many years. The instrument astronomers use to observe the spectrum of light from a star is called a *spectrometer;* a spectrometer designed to measure Doppler shift is called a Doppler spectrometer.

Changing Shifts

Astronomers have been using Doppler spectrometers for about 100 years. At first they could only detect the very large changes in Doppler shift due to pairs of stars (spectroscopic binaries) rapidly orbiting each other. As methods and equipment improved, the instruments were able to measure smaller and smaller changes in Doppler shift. We will soon have several spectrometers able to detect the very small effect that a planet the size of Jupiter would have on a star like the Sun.

The Doppler technique works best on

A periodic Doppler shift in the spectrum of light from a star can indicate the presence of a companion. Each dark or bright line in the spectrum is part of the signature of an atom or molecule absorbing or emitting light of a particular color. The upper spectrum is that of a star approaching us, with lines shifted toward the shorter blue wavelengths by the Doppler effect. The center spectrum is that of a star at rest, and the lower spectrum is that of a star receding from us, with the lines shifted to longer red wavelengths. A star with a dark companion whose orbit is inclined in our direction will alternately show blue and red Doppler shifts.

ing for other planetary systems must deal with. Present telescopes, even specially designed astrometric telescopes, were not designed to deliver the kind of accuracies demanded by planet search programs. In most of these telescopes, changing optical distortions are large enough to hide the tiny planetary perturbations. Still, with modern optics and state-of-the-art detectors, the detection of Jovian-class planets orbiting neighboring stars is quite feasible.

However, the obvious place to observe with maximum astrometric accuracy is from space. There, above the Earth's turbulent atmosphere, the star images no longer dance but sit firm and still, awaiting measurement. There, gravity cannot deform the telescope's optics. Of course, no one knows the exact accuracy that might be achieved under these circumstances, but it could be as much as one thousand times better than our best efforts to date from the Earth's surface. With such accuracies we could detect even the Earth's effect on the motion of the Sun from a distance of over 30 light years. In principle, the orbits of six of the nine planets in our solar system could be traced. With such a telescope at our disposal a whole new field of planetary science would be opened up—the comparative study of planetary systems.

John Stein is a Senior Observer at the Allegheny Observatory of the University of Pittsburgh.

stars with planets in small orbits, while astrometric instruments (see page 15) work best on stars with planets in large orbits. Doppler spectrometry can be done with almost any conventional ground-based telescope and is not seriously degraded by having to observe through the turbulent atmosphere of Earth. Astrometry, on the other hand, requires telescope optics with special properties and stable sky ("seeing") conditions. Also, with the Doppler method, we can see more distant stars. Combining data from both techniques, we can confirm discoveries and obtain more information about the orbits of planets.

Special Problems

However, there are special problems with the Doppler technique. We can't tell how much a planet's orbit is tilted with respect to our line of sight. A large planet or companion star, in a nearly face-on orbit, might show the same oscillation of Doppler shift as a small planet in an orbit viewed edge-on. The stars themselves might do things that would fool us. For example, the spectral lines that allow us to detect changes of Doppler shift can also be affected by spots on stars similar to sunspots. Observations made by any technique have to be cross-checked and interpreted carefully.

Doppler spectroscopy is a growing field and at least six research groups have or are building instruments to detect planets orbiting other stars. Bruce Campbell and his collaborators with the 3.6-meter telescope of the Canada-France-Hawaii (CFHT) Corporation have done most of the observing up until now. M. J. Mumma and Drake Deming of the NASA Goddard Space Flight Center have proposed a Doppler spectrometer calibrated by an infrared laser. Bill Cochran at the University of Texas at Austin and A. K. Forrest in the United Kingdom have their own unique approaches to this challenging goal. And Graham Flint of Albuquerque, an amateur astronomer, is building his own Doppler spectrometer.

A Dedicated Life

Our instrument at the University of Arizona was conceived and built by the late Krzysztof M. Serkowski, who, upon learning that he had a fatal illness, decided to dedicate the remainder of his life to searching for other planetary systems. He believed that contact with an advanced alien civilization would help provide solutions to some of humanity's basic, long-standing problems. We have redesigned and rebuilt his spectrometer, and last November we began test observations of bright stars. At first look our data appear very promising.

For the next few years astronomers will be trying out new instruments on problems with known solutions to check their accuracy and data reduction software. We'll be observing sunlight and making observations of the same star simultaneously with more than one instrument. More accurate orbits of known binary stars, discovery of small stars orbiting other stars, and measurement of the effects of starspot cycles are short-term projects the new Doppler spectrometers make possible.

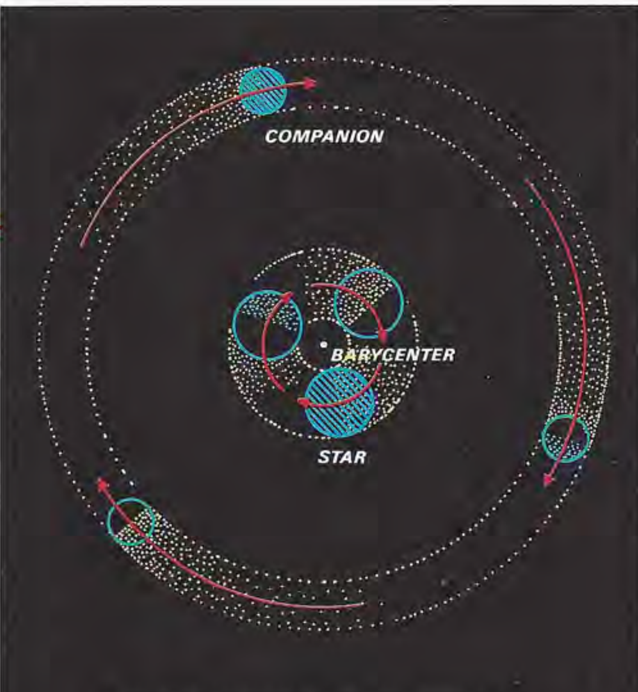
Five years of intense, accurate observations of some solar-type stars will let us detect planets the size of Jupiter orbiting very close to their parent stars. No one knows for sure whether gas giant planets like Jupiter might orbit as close to other stars as Mars orbits the Sun.

An Ultimate Goal

The ultimate goal of all the ground-based searches for planets is to make a list of stars with large planets. Then, a space-borne telescope can search for much smaller planets and give theoreticians the detailed data necessary to gain an understanding of how planetary systems are formed.

In the 21st century, we can expect to see a catalog of planets in other solar systems. The lucky members of a 21st century committee may have the pleasant duty of deciding to which one of those systems an interstellar space probe should be sent!

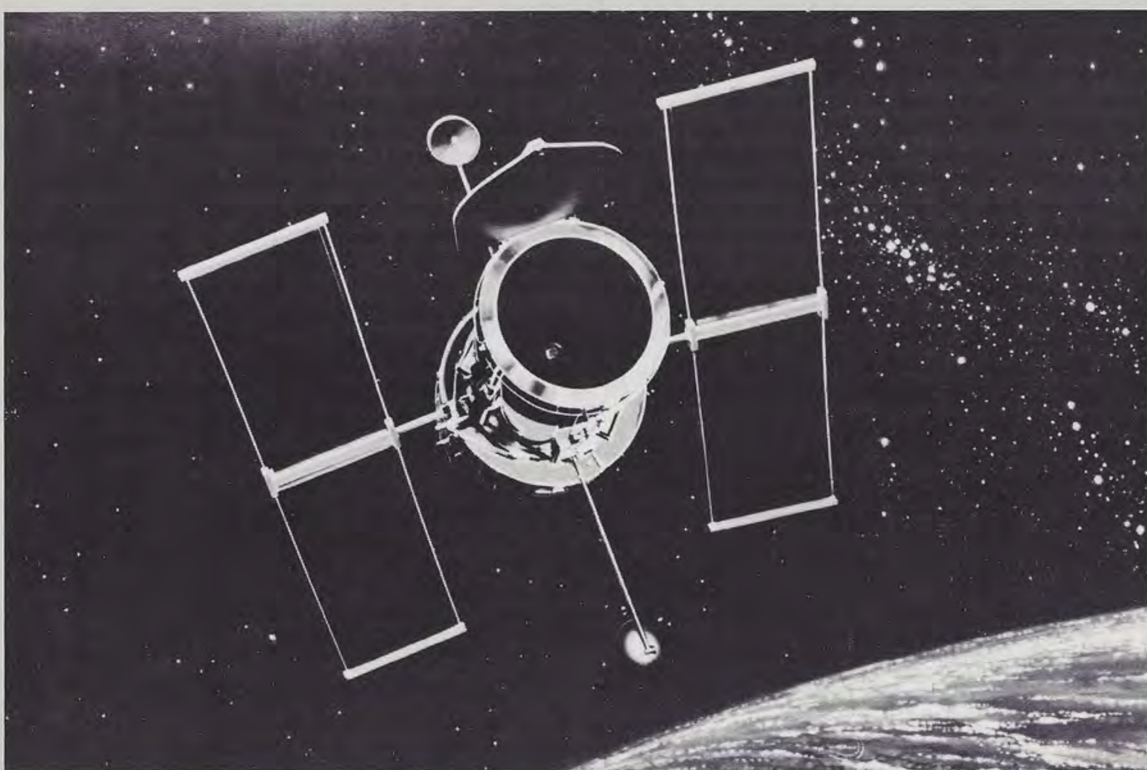
Robert McMillan is Senior Research Associate at the Lunar and Planetary Laboratory of the University of Arizona. For the past five years he has been working on Doppler spectrometers and electronic detectors for astronomical applications.



A double star, or star and planet, system is here portrayed in three positions as the members orbit their common center of gravity, called the barycenter. If the small companion cannot be seen, its presence can still be detected by observing either the motion of the brighter visible star about the barycenter or shifts in the star's spectrum.

Illustrations: S. A. Smith

The Space Telescope's Search for Planets Around Other Stars



The Space Telescope is scheduled for launch from the Space Shuttle in mid-1986. It will be able to see seven times farther into space than we can now, increasing by 350 times the volume of observable space.
Painting: NASA

by Jane Russell

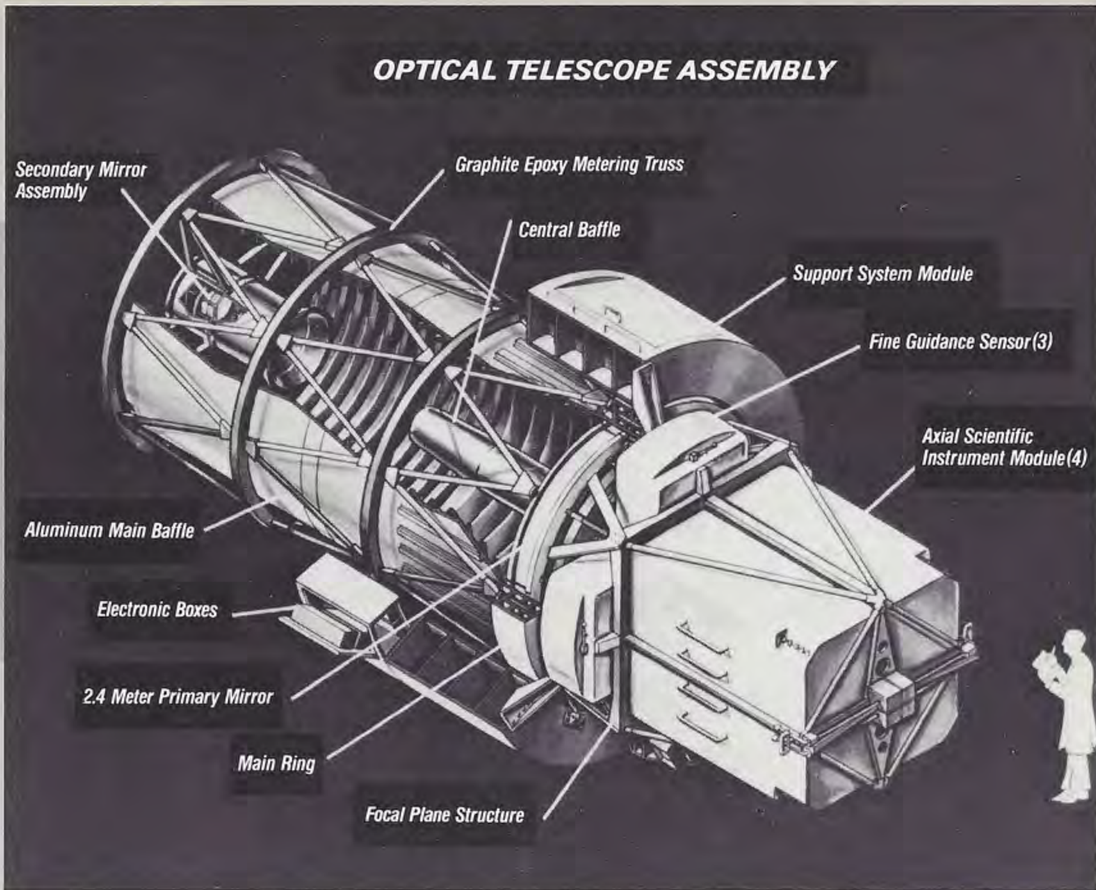
Scientists will soon have a powerful new tool in their search for planets around other stars: the Edwin P. Hubble Space Telescope. The Space Telescope is a multipurpose orbiting observatory that will carry many instruments, including three that can be used to detect Jupiter-sized planets around distant stars. Using one of these instruments, we may be able to *see* planets in another solar system for the first time—but we could not see little green men waving back at us. We simply hope for the first direct evidence that our Sun's planetary system is not alone in the universe.

Scheduled for launch from the Space Shuttle in 1986, the Space Telescope will be able to see objects fifty times fainter than we have seen before. Stars or galaxies that we can barely see now with the largest Earth-based telescopes will be visible to the Space Telescope even if they were seven times farther away. Thus, the edge of the discernible universe will be moved out seven times farther than before.

This increase in power is equivalent to that which Galileo experienced when he first used his telescope. With his new instrument, he discovered the moons of Jupiter, the phases of Venus, and the fact that the Pleiades were not just seven stars but over one hundred, gathered into a small area of space. We don't know what we will discover with the Space Telescope, but some of its findings might include planets around other stars.

Seeing From Above

The Space Telescope will see faint objects because it will be placed above Earth's atmosphere. Its primary mirror is only 2.4 meters (94 inches) wide, compared to the 5-meter (200 inch) telescope on Mount Palomar, which has 4 times the light collecting power. But light from stars and galaxies must travel through Earth's atmosphere on its way to Palomar, so the light that was initially aimed directly at the giant telescope gets slightly redirected or scattered away entirely on



This cutaway view of the Optical Telescope Assembly of the Space Telescope shows the optical elements and the stray light baffling system. Light enters the open end (left) of the telescope, is projected by the primary mirror onto a smaller secondary mirror, and from there it is directed to the scientific instruments.
Illustration: NASA

its passage. Even the light that does strike the mirror has been so diverted that the images of stars, which should appear as points of light, are spread out into fuzzy blobs.

The atmospheric effect that spreads a point of light also affects images of objects where we can distinguish some detail, such as planets and galaxies. Taken through the atmosphere, photographs of these objects appear washed out or blurred, and we could be missing some important details. We did not know that Mars was marked with craters until *Mariner 4* sent back images of its surface. The Space Telescope will have the same above-atmosphere advantage; its pictures of planets in our solar system should be as detailed as those taken by flyby spacecraft. Astronomers expect their first detailed look at galaxies, nebulae and other astronomical phenomena. And, perhaps, this capability will give us our first look at a planet around a nearby star.

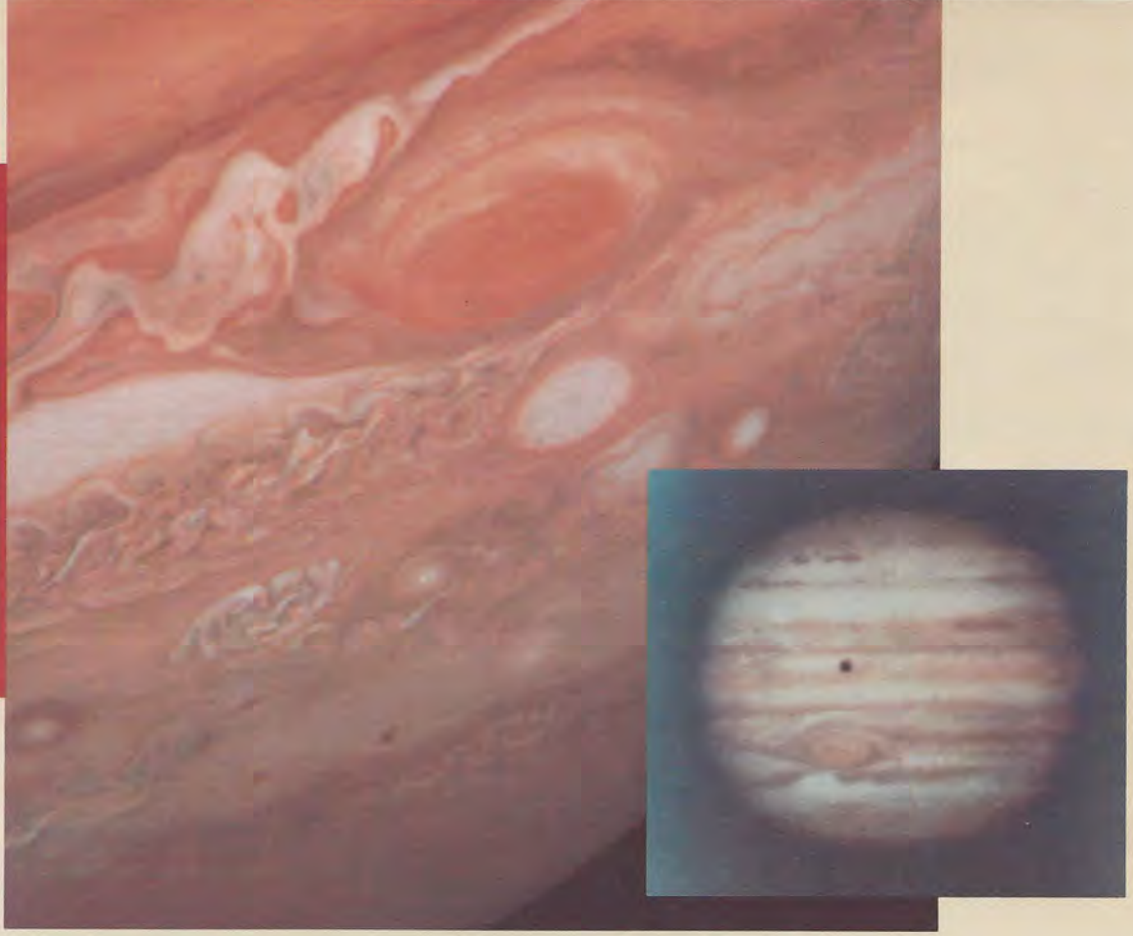
Seeing the Light

The Space Telescope will contain several instruments, but only three will be used to search for planets. One of these, the Faint Object Camera, will be used for direct detection. Direct detection is simply seeing the light from a star reflected off a planet revolving about it. The problem is twofold: Planets are so close to their central stars and the central stars are so bright that the planets are lost in the glare, with little hope of ever being seen. Trying to see a planet is something like trying to see a lighted match held three inches from a searchlight when you are standing five miles away. To see the match, you need three advantages: high angular resolution (eyes good enough to see the match and the searchlight at such small separation); wide dynamic range (ability to see both a very bright and a very dim object); and no scattered light (no haze or other medium to blur the images).

The Faint Object Camera should meet all these requirements and be able to see planets directly. It can place a star behind an occulting finger, an obstruction in the optics that blocks most of the light from the star and, in effect, increases the dynamic range of the camera. Because the camera will be operating above Earth's atmosphere, scattered light from the air will not be a problem. However, the instrument is so sensitive that it might pick up light accidentally scattered from within the telescope itself, and read that light as a planet. We have designed both the instrument and our experiment to reduce this problem.

Seeing Again

To assure that any discoveries are truly planets and not faint background stars, we will have to reobserve the star and planet for several weeks to verify that they are moving together through space. The first measurements we make of possible planets around other stars will be very exciting because, unlike such indirect detection techniques as astrometry, they will not simply measure the effect of the planet upon the star. We won't have to wait for the planet to make a



The picture in the lower right was taken with an Earth-based telescope, the image above by the Voyager 1 spacecraft. For Jupiter and Saturn, the Space Telescope will have about the same resolution as this moderate-resolution flyby image (Voyager also obtained images with much greater resolution). For Uranus and Neptune, the Space Telescope will have about the same resolution as the ground-based photograph of Jupiter.

Voyager image: JPL/NASA
Telescope photo: Space Telescope Science Institute

complete revolution of the star to prove that it is really there.

We will also be able to search for planets astrometrically with two other instruments on the Space Telescope: the Wide Field/Planetary Camera and the Fine Guidance Sensors. Both instruments will be accurate enough to detect a planet as small as Saturn around Barnard's Star (six light years away). The Wide Field/Planetary Camera can image the sky in two different ways, hence its double name. The Planetary Camera will obtain high-resolution images of objects such as Jupiter and Saturn. Although somewhat more accurate astrometrically than the Wide Field mode, the Planetary mode has a narrow field of view; we cannot include enough background stars against which to measure stellar motion, and so see the wobble indicating a companion.

The Wide Field Camera has the widest field of any instrument on the Space Telescope, but the term "wide field" applies only in comparison to the other instruments. The camera still sees an area of sky only about one percent of the area of the full Moon. But this is enough to include reference stars for detecting a wobble.

The Wide Field Camera will see objects fainter than any now being watched for planets, and it will simultaneously see the star under study and its background stars. Its only disadvantage is its small field of view, compared to most other telescopes, but the Fine Guidance Sensor should make up for that. Although this sensor sees a very small field of view at any one time—less than one percent of the view from the Wide Field Camera—it can move about and sample an area 10 times larger. There is some danger that the spacecraft might move or be jolted while shifting between stars. But each observation takes 5 to 10 minutes, while moving between stars would last only a few seconds. And two of the sensors keep the spacecraft stabilized while the third is making the measurements, so the chance of error is minimal.

Seeing It Through

The Space Telescope's ability to detect large planets about other stars is both good news and bad news: good news because we may soon find other nearby planetary systems, bad news because the characteristics that make it so useful for planet searches also make it useful for other types of experiments. A recent survey of astronomers around the world showed that, if all the projects they now planned for the Space Telescope were to be executed, we would have to launch 15 orbiting observatories.

But the planet search program will go on in the same spirit in which all Space Telescope plans are being made: in anticipation of finding something new and different. We know what unexpected things Galileo found with his new instrument; we can only imagine what discoveries we will make with the Space Telescope. Perhaps one of these will be the first sign of neighbors in our galaxy.

Jane Russell is the Project Astrometrist for the Guidance Star Selection System for the Space Telescope Science Institute, and she has worked on astrometric planet searches for a long time.

World Watch

by Louis D. Friedman

WASHINGTON—Before the summer recess, Congress passed NASA's 1985 budget, authorizing the space agency to begin development of a space station. NASA estimates it will take ten years and $8 billion to put a station in Earth orbit, and Congress has now given them $150 million to start the task.

The Congressional Office of Technology Assessment (OTA) recently released its report on the space station proposal for a "permanent manned presence in Earth orbit." The OTA recommended that NASA consider other options, such as automated orbital facilities, before committing to the permanently manned option. Congress also directed NASA to study a broad range of options. But although NASA will study other options, the three concepts funded for definition studies were all for a permanently manned facility.

Congress also approved a new start for the Mars Geoscience/Climatology Observer (MGCO), which NASA hopes will be the first of the Planetary Observers, a line of spacecraft missions recommended by the National Academy of Sciences' Solar System Exploration Committee. (See the May/June 1984 *Planetary Report*.) The MGCO mission was given $20 million toward its expected total cost of $180 million. This action on MGCO follows last year's approval of the Venus Radar Mapper, and seems to signal a revitalization of the US planetary program.

Congress increased funding for the planetary research and data analysis programs, as they have done for the past three years. NASA itself has been asking less than Congress has been willing to appropriate for these programs.

WASHINGTON—NASA is studying several missions for the 1990s which would use the *Mariner Mark II* spacecraft now being developed at the Jet Propulsion Laboratory in Pasadena. These include an asteroid flyby and rendezvous with Comet Kopff, to launch in 1992, and a Saturn Orbiter/Titan Probe, a cooperative mission with the European Space Agency (ESA) to launch in 1993.

The space agency is also looking at two exploration opportunities that would make use of existing spacecraft: *Galileo* and the test model of *Giotto*. On its way to Jupiter, the *Galileo* spacecraft will fly through the asteroid belt and has a chance to take a close look at a large asteroid (see page 22). ESA's *Giotto* will fly by Halley's Comet in 1986, but a spare spacecraft will remain on Earth. It would be possible to send the spare to another comet, carrying an American-built sample collection and return device, and bring back a piece of a comet. NASA has time to think about the comet mission, but they must quickly make a decision on the *Galileo* option if it is to be done.

MOSCOW—The Soviet Union has several new missions under study, and may visit Mars, the Moon, Venus and a near-Earth asteroid within the next eight years.

A proposed 1988 mission to Mars and its moon, Phobos, would include orbital observations of Mars, a close rendezvous with Phobos and study of solar-terrestrial processes both before and after the Phobos mission is completed. The spacecraft would pass within 50 meters of Phobos' surface, returning detailed images and remotely determining some of the surface constituents by directing the output from a small laser, ion or electron beam at the nearby surface of the moon and analyzing the resulting plasma cloud. (See the July/August 1983 *Planetary Report*.) If approved, this will be a cooperative international mission, led by the Soviets.

Soviet scientists and engineers are also studying a lunar polar orbiter mission for 1989 or 1990 and a Venus lander and balloon mission for 1992. The Venus mission could also send a spacecraft to rendezvous with a near-Earth asteroid, according to an advanced mission study.

Members who are interested in NASA's fiscal year 1985 budget can obtain more information from the U.S. Congress Document Offices. The addresses are: Document Office, House of Representatives, Washington, D.C. 20515; and Document Office, Senate, Washington, D.C. 20510. The budget Authorization is contained in House of Representatives bill 5154 and Conference Report 98-873; the Appropriation is in House of Representatives bill 5713 and Conference Report 98-867.

The Office of Technology Assessment Report on the Space Station is available from the OTA, Washington, D.C. 20510.

GRAZ, AUSTRIA—At the meeting of COSPAR (Committee on Space Research of the International Council of Scientific Unions) here, Soviet scientists displayed new radar images of Venus, taken by their orbiting *Venera 15* and *16* spacecraft. By joining single images into a mosaic, they were able to create a videotape simulating flight over the planet.

The Soviets have released detailed information about their *Venera* radar system and the images it has taken and, as a result, American scientists are modifying their Venus Radar Mapper plans to provide higher-resolution pictures.

In conjunction with the Graz meeting, The Planetary Society organized a discussion of cooperative Soviet-American planetary programs. Society members will soon be given details of the meeting in a special letter.

PRAGUE—Halley's Comet is still a year-and-a-half away, but already excitement is building. The latest pictures of the comet, still out near Jupiter, show a reddish color around its nucleus.

Meanwhile, both amateur and professional scientists are preparing for its arrival, and they discussed their work at a meeting of the steering committee of the International Halley Watch.

The International Halley Watch, a coordinated team of professional and amateur comet watchers, recently completed a trial run of their observing network by using Comet Crommelin. This small comet revealed little new information, but the observers were able to test the communication procedures they will use as they study Halley's Comet.

Committee members discussed progress on Project Pathfinder, a cooperative effort of the Soviet and Japanese space agencies, NASA and ESA to improve spacecraft observations of Halley's Comet. (See the April/May 1981 and January/February 1984 *Planetary Reports*.) The Soviets and Japanese are both sending spacecraft to fly by the comet, and their reports on Halley's position will be provided to NASA's Deep Space Network and ESA's tracking network to improve predictions of the comet's path around the Sun. These predictions will be used for last-minute targeting of ESA's *Giotto* spacecraft to help it get as close as possible to the comet's nucleus.

The Asteroid and the Spacecraft

by Clark R. Chapman

This is a story about the United States' premier planetary mission of the 1980s: the *Galileo* mission to Jupiter. And it's the story of a not-so-small asteroid, numbered 29 and named for Neptune's legendary wife, Amphitrite.

Our tale begins four-and-one-half billion years ago, as the cloud of dust and gas swirling about the newly-formed Sun gradually coagulated into a myriad of small rocky and icy bodies called planetesimals. They bumped into each other and began to accumulate into five rocky planets. Four of them we now call Mercury, Venus, Mars and Earth. But, mysteriously, the fifth never formed. In the huge, torus-shaped space between the orbits of Mars and Jupiter, countless asteroids revolve today, a tableau of an Earth-like planet somehow arrested in its development.

Another chapter in our story was written only about a year ago by some engineers at the Jet Propulsion Laboratory in Pasadena, California, working on Project *Galileo*—a spacecraft mission to Jupiter and its satellites. They fed the list of 3000 numbered asteroids into a computer, along with the latest planned trajectory for *Galileo*. The computer showed them an amazing piece of good luck: *Galileo* would pass near several asteroids while en route to Jupiter, but its very best encounter target was no ordinary asteroid!

With a diameter of 200 kilometers, 29 Amphitrite is one of the thirty-five largest asteroids. It's an S-type asteroid, a type with relatively bright, slightly pinkish surfaces. Spectra of sunlight reflected from S-type asteroids reveal the telltale absorption bands of two important rock-forming minerals, pyroxene and olivine. The spectra of S-types also show the signature of shiny nickel-iron metal.

One might think that astronomers have the compositions of S-types well-pegged, but Nature has played a trick on us. Two radically different classes of meteorites are composed of pyroxene, olivine and metal. The most common meteorites in our museums are ordinary chondrites, pyroxene-olivine rocks containing millimeter-sized flecks of metal. These rocks are primitive, never-altered condensates from the original solar nebula—the stuff from which our Earth is thought to have been made.

But the stony-iron meteorites are also made of olivine, pyroxene and metal; they are solid chunks of metal with imbedded rocky minerals. We think stony-irons are chips from the iron cores of small planets originally made of ordinary chondritic material, but which were heated to melting. The flecks of dense iron sank through the molten magma, accumulating into large molten cores that, with time, cooled and solidified. Later catastrophic collisions among asteroids split some of them apart and stripped their cores of much of their rocky crusts and mantles.

Perhaps Amphitrite is such an exposed core. If so, it would shed light on some perplexing questions: What source of heat could have been intense enough to melt small asteroids? Why did the S-types melt, while the other asteroids stayed cool? Are the S-types really stony-irons? Some astronomers are convinced, from detailed spectral interpretation, that they are, while others aren't so sure. Radar echoes bounced off one well-studied S-type, 8 Flora, by the huge Arecibo radar dish indicate less metal than the stony-iron hypothesis would require.

We have pushed our Earth-based interpretations as far as they can go. It is time to send a spacecraft to the asteroid belt. European scientists have shown increasing interest in asteroid exploration, and this past July, at the COSPAR (Committee on Space Research) meeting in Graz, Austria, the Soviet Union announced its preliminary plans to send an elaborate spacecraft to rendezvous with an asteroid by the early 1990s. But the American plans for a Multiple Asteroid Rendezvous Mission won't come to fruition until the late 1990s.

Which brings us back to *Galileo*. Its scan-platform instruments, designed to study the surfaces of Jupiter's moons, could hardly have been better designed for an asteroid flyby. Its modern camera can photograph Amphitrite as beautifully as *Voyager* did Saturn's enigmatic moon, Enceladus. *Galileo*'s Near-Infrared Mapping Spectrometer can map the surface of Amphitrite, perhaps highlighting the putative core/mantle boundaries. Ultraviolet, thermal and polarimetric measurements can be made as well. *Galileo*'s trajectory need only be tweaked a little bit, and its instruments turned on as it hurtles past Amphitrite on December 6, 1986. It would be an historic encounter: the first measurements of an asteroid by a spacecraft from Earth.

But if things go on as they are now, the story will conclude with *Galileo* flying a few million kilometers from Amphitrite *without even turning on its cameras!* How can that be? Well, one never gets anything for free, and within the tightly constrained NASA Planetary Program budget, there seems to be no small change to pay for the alterations in mission strategy.

Project Manager John Casani estimates that it might cost $7 million over the next two years to pay for some speedups and reworkings of engineering studies. For example, the Amphitrite flyby will delay arrival at Jupiter by three months, so engineers must recalculate the Jupiter satellite tour for that later arrival date. (You might worry that the Jupiter science will be compromised, but *Galileo* Science Manager Clayne Yeates feels that Amphitrite can be studied at the expense of only three percent of the Jupiter science goals, chiefly the goals of the same scientists interested in asteroids.)

The $7 million additional cost might seem cheap for a mission whose total cost is pushing $1 billion. But Geoff Briggs, Director of NASA's Solar System Exploration Division, just doesn't have the money in his budget. Faced with rising costs of a Space Station, NASA Administrator James Beggs and Associate Administrator Burt Edelson have given Briggs a target budget that doesn't even pay for thorough analysis of *Voyager* data. Far from thinking about the world's cheapest asteroid mission, Briggs is simply trying to avoid turning off still-flying *Pioneer* spacecraft.

It seems absurd. It's like paying for an automobile trip across the country but not being able to afford the parking fees to stop and see the St. Louis Arch! Project Manager Casani believes an Amphitrite flyby is technically straightforward, but he would be hesitant—even if given the extra money—to guarantee success. His team of engineers is already stretched thin, and he worries about "defocusing" their attention during the post-launch months. The *Galileo* scientists interested in Amphitrite feel they can relieve Casani's concerns by asking for just a "best-effort" attempt to look at the asteroid, rather than *requiring* success, as is normally done for a mission's prime goals.

Meanwhile, Amphitrite, a jagged world as big as West Virginia, mutely awaits the decision on its place in human history. Casani has told Briggs that, to make an orderly transition to the Amphitrite mission, he needs a "go/no go" decision by October 1, 1984. It is in the hands of NASA's top management to decide our next step toward understanding the solar system of which we are all part.

Clark Chapman will return to his regular "News & Reviews" column in the next issue.

SPACE WEAPONS SYMPOSIUM

The implications for civil space activities of introducing weapons into space, whether for use against objects in orbit or as defense against ground-based threats, will be discussed by a panel of distinguished scientists in Washington, DC on the afternoon of January 12, 1985. The discussion will be part of a symposium cosponsored by The Planetary Society and the American Academy of Arts and Sciences. Chaired by Dr. Bruce Murray, Society Vice President, the panel will include Dr. Philip Morrison of the Massachusetts Institute of Technology, an Advisor to the Society, and Dr. Carl Sagan, President of The Planetary Society. Several other leading aerospace figures will complete the panel, representing a broad range of views on the subject.

On the morning of January 12th, before the symposium, a panel organized by the American Academy of Arts and Sciences will present their report on the military and strategic consequences of weapons in space.

Attendance at this symposium, to be held at the National Academy of Sciences Auditorium in Washington, DC, is open to Planetary Society members, but seating will be limited, so you are advised to register early. The registration fee of $25.00 includes both sessions, lunch and a 5:30 pm reception. Please send your $25.00 per person to: The Planetary Society, Symposium, 110 S. Euclid Ave., Pasadena, CA 91101.

UPCOMING EVENTS

Several organizations are holding meetings and conferences over the next few months that may be of interest to Society members. These include:

☐ A meeting of the Solar System Exploration Management Council Advisory Group, in Kona, Hawaii, October 7–8, 1984;

☐ The annual meeting of the Division for Planetary Sciences (DPS) of the American Astronomical Society, in Kona, Hawaii, October 9–12, 1984;

☐ A symposium on Lunar Bases and Space Activities in the 21st Century, in Washington, DC, October 29–31, 1984;

☐ The Sixteenth Lunar and Planetary Science Conference, Houston, Texas, March 12–15, 1985;

☐ The annual meeting of the American Association for the Advancement of Science, Los Angeles, California, May 26–31, 1985 (The Planetary Society is sponsoring a session on comparative planetology and will have an exhibit at the meeting);

☐ A Comparative Planetology Conference and public lecture, cosponsored by The Planetary Society, Pasadena, California, June 8, 1985.

You can obtain additional details of these events by calling the Society information lines, 818/793-4328 from east of the Mississippi, 818/793-4294 from west of the Mississippi.

SPACE SCIENCE CENTER de SANTA FE

With seemingly boundless energy and initiative, Felipe Cabeza de Vaca, a community organizer and activist, has opened a space science center in the barrio of Santa Fe, New Mexico. Mr. Cabeza de Vaca wrote to the Society last February with his plans to turn an adobe apartment building behind his home into a museum and auditorium. He hoped to make a place where neighborhood children and other people fascinated by the excitement of space exploration could come and learn more about the universe around them.

On June 15, the Space Science Center de Santa Fe opened. The Planetary Society was pleased to supply the Center with posters, slide sets and taped lectures. Mr. Cabeza de Vaca tells us that the film, "Mars in 3-D," has been a particular "smash."

MATCHING GIFTS

Members often tell us that they want to give financial support to the Society but have limited financial resources of their own. A relatively simple and effective method to double or even triple the size of a small donation is to take advantage of corporate matching gifts. Well over fifty companies in the United States now match any donation to a nonprofit organization. Some, such as the Atlantic Richfield Company and the Sohio Matching Gift Plan, give matching gifts on a two-for-one basis. Do you work for Avon Products, Digital Equipment Corporation, John Hancock Mutual Life Insurance Company or Transamerica Corporation? If so, your company is one whose matching gift can be assured.

Society members should check with their companies to see if they participate in matching-gift programs. If so, you should be able to obtain a form from your matching gift coordinator (usually in the personnel or community relations department) and send it along with your gift to The Planetary Society. The Society's staff will handle the rest of the work.

FOREIGN CHECKS

Bank fees can take large bites from the dues we receive from our members outside the United States. Our bank charges us a fee to cash a foreign check, while banks in some members' countries add an additional fee for issuing a check in US dollars. So that more of your membership dues can go to Society projects, please use US money orders or a bank with a US correspondent. (Many international banks have a branch in the US.) If this is not possible, please convert the amount of your dues to the equivalent value and send the check in your currency.

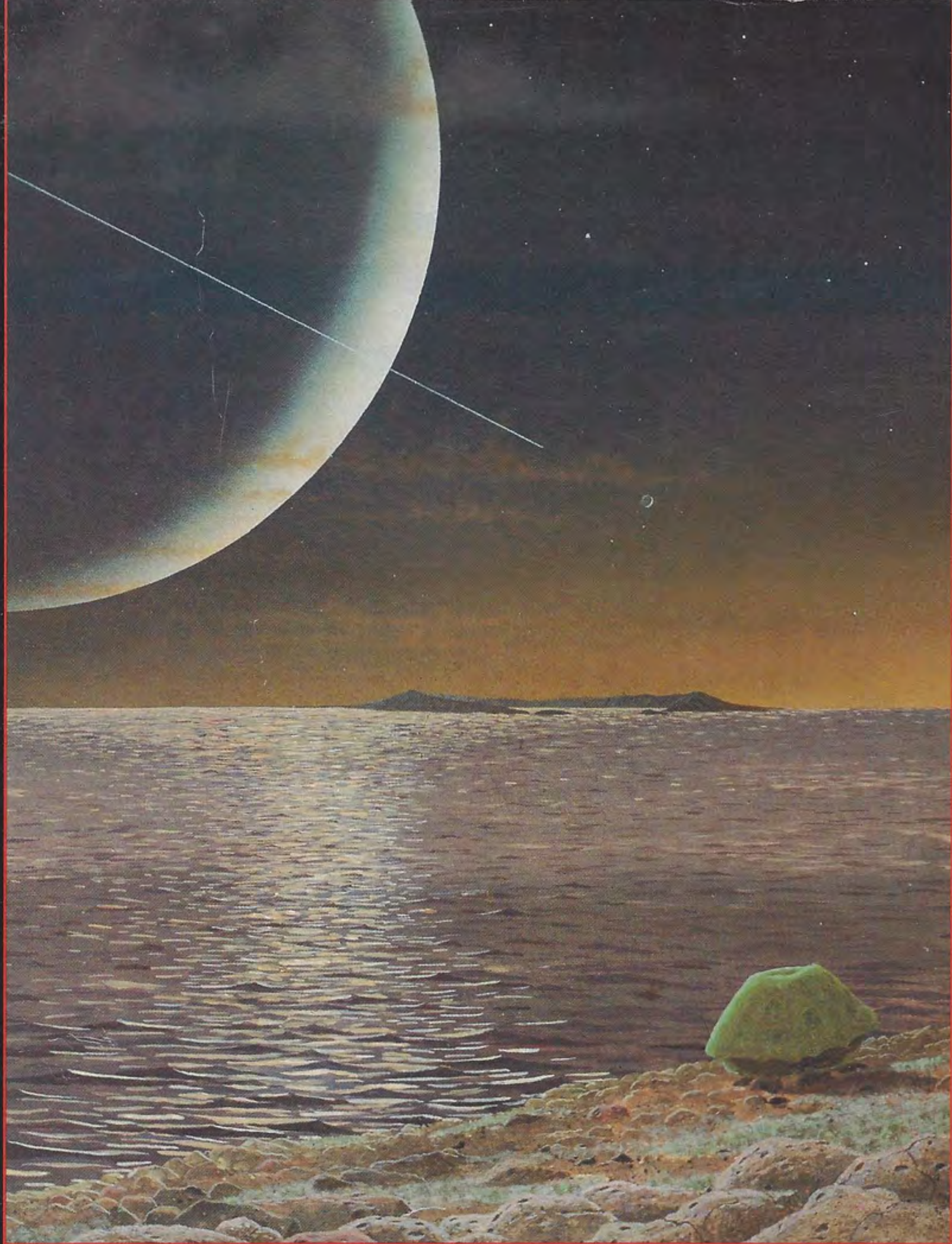
Canadian and Dutch members can send their membership dues in their local currencies directly to our offices in their countries. However, sales orders are processed more quickly when they are sent directly to our Pasadena office.

THE CASE FOR MARS II

In its September cover story, *Discover* magazine reported on the Case for Mars II, a conference sponsored by the Mars Institute of The Planetary Society. The *Discover* issue also included an article by Dr. Carl Sagan, Society President, on the possibility of a human mission to Mars. Held at the University of Colorado in Boulder during July 10–14, 1984, the conference was attended by over 100 people representing university, government and industry. They discussed the problems and potential of human exploration of Mars, including the establishment of a human base on the planet's surface and the use of resources from the Martian environment to support researchers living and working on Mars.

In a highlight of the conference, Christopher McKay, Mars Institute Coordinator, announced the winners of the Institute's student contest to design a water supply system for a Mars base. The winning design was the work of Douglas Jones, C. Flint Webb, Michael LaPointe, Amy Larson and Helen Hart, all students at the University of Colorado. Mitchell Clapp of the Massachusetts Institute of Technology was awarded second prize.

Society members made this conference possible, and should be pleased with its success.



SUNSET ON THRAXISP—
A tunnek, a (hypothetical) intelligent life form inhabiting the (hypothetical) planet Thraxisp, catches the last rays of a setting sun, while the (hypothetical) gas giant planet Wixitap presides over the sky. In this imaginary planetary system, created by a group of artists, writers and scientists, Earth-like Thraxisp orbits the Jupiter-like Wixitap, and both revolve around a small, reddish star one-third the mass of our Sun. In this painting, artist William Hartmann gives us the view from the edge of an ocean on this strange but plausible world.

William K. Hartmann is a scientist, artist and writer living in Tucson, Arizona. Leaving the Cradle, a new book of his paintings, and those of astronomical artists Pamela Lee and Ron Miller, will soon be available from Workman Publishing, New York.

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