The PLANETARY REPORT

Volume XXII Number 4 July/August 2002

Radar "Eyes"

A PUBLICATION OF THE PLANETARY SOCIETY

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From The Editor

The news services have given considerable time lately to space science discoveries: an asteroid passes close by Earth; vast quantities of water lie just beneath the Martian surface; a planetary system similar to ours orbits a nearby star. In this issue, you'll read about how such discoveries advance our understanding of the worlds around us.

The press realizes that space exploration can still excite the public. The public still marvels at amazing discoveries. But other concerns on the rapidly changing radar of this planet can drive such enthusiasms to the bottom of priority lists, as we've seen reflected in opinion polls. The world has changed from the supercharged days of the early space age, when we were ready to undertake any challenge any time, especially, to paraphrase President John F. Kennedy, if it was hard. All space exploration is hard.

For us in The Planetary Society, this change in society as a whole presents a formidable challenge. It's up to us to make sure that the exploration of the solar system and search for extraterrestrial life receives the priority it deserves.

In the coming months, we will call upon you to join again in supporting planetary exploration, through political action and other means. As always, together we can make it happen.

—Charlene M. Anderson

On the Cover:

As the Sun dramatically drops from sight in California's Mojave Desert, Goldstone's 70-meter antenna stands poised and ready for work. Part of NASA's Deep Space Network—used to communicate with planetary spacecraft—Goldstone is one of the world's two primary facilities set up for planetary radar astronomy. Scientists are using radar to peer into the dark regions of our solar system, discovering and tracking potentially hazardous near-Earth asteroids.

Image: JPL/NASA

Features

Departments

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Members' Dialogue

A Long-Term Plan

In my mind, "Whither, O Splendid Ship?" by James D. Burke and John Young (see the January/February 2002 issue of *The Planetary Report*), addresses a larger problem: that to survive as a species, we must come to terms with our most serious evolutionary weaknesses. There are innumerable steps on the path to attaining greatness as a spacefaring civilization. Accepting responsibility as custodians of Earth counts as a first step.

Second, imagine if our race drew as much satisfaction from scientific research as from the entertainment industry. I find it frustrating that technology progresses most rapidly when there is a short-term materialistic goal to be achieved. How is it that an intelligent species cannot recognize that its very survival hinges on its ability to plan for the "long run"?

I concur with the authors that education is vital. People must recognize the common sense of a long-term strategy while obtaining a passion for the future.
—JANE GOODHUE GILHOOY,
Norfolk, Virginia

What to Tell Them?

It seems to me that the following question may be important to many of your members, even though they may have not thought to articulate it: how does someone tell anyone else just why it is so important to understand not only the planet on which we live but also the solar system in which this planet lives, the galaxy in which this solar system lives, and the universe in which this galaxy lives?

If someone were interested, I could give them an earful in, maybe, an hour or more, but I'm honestly tongue-tied when it comes to summing up this issue in 25 well-chosen words or less.
—JAMES WALKER,
Brasilia, Brazil

We invite our members to respond to Mr. Walker's query. How would you get this important point across—in 25 words or less?
—Charlene M. Anderson, Associate Director

I want to thank The Planetary Society for the issues of *The Planetary Report* discussing the strange acceleration of *Pioneers 10* and *11* (beginning with the November/December 2001 issue). We at the NASA Ames Research Center Pioneer Mission office have worked with the authors of the article by providing data to aid their investigation of this vexing anomaly.

Since their launch, the *Pioneer 10* and *11* missions—being in the vanguard of space travel and science investigation—have captured the imagination of the space community. The plaque on *Pioneer* (the first emissary into outer space) tells the story of humanity's presence on Earth around the last quarter of the 20th century.

If, ironically, the anomalous acceleration effect allows *Pioneer* to be captured in the Oort cloud and returned to Earth's vicinity millions of years in the future—as postulated by John Anderson—what a fantastic science fiction scenario it would make for some sentient, intelligent being to discover the plaque (recalling the anachronistic Statue of Liberty in the first *Planet of the Apes* story).
—LARRY LASHER,
Moffett Field, California

A Tribute to Stephen Jay Gould

Leading paleontologist and evolutionary theorist Stephen Jay Gould passed away on May 20, 2002. Neil de Grasse Tyson, vice president of The Planetary Society and director of the Hayden Planetarium at the American Museum of Natural History in New York City, came to know Gould (a member of the Society's Advisory Council) through his close association with the museum. Their popular essays shared space within the covers of Natural History *magazine. Tyson wrote the following in memory of his colleague:*

"I feel lonely without Stephen Jay Gould. Who would have thought, before he landed on the pages of *Natural History* magazine, that essays on science could be raised to a form of art? The success of his efforts gave me confidence to step onto this landscape with him. From 1995 through 2001, each of our essays bookended the central articles of the magazine. We wrote, of course, on completely different subjects. But I continually felt a deep kinship of mission—a mission that forces me every month to ask of the universe, 'What stories have I yet to tell? What turns of phrase will I use to tell them? How best can I share with readers this glorious journey of the soul we call science?' "

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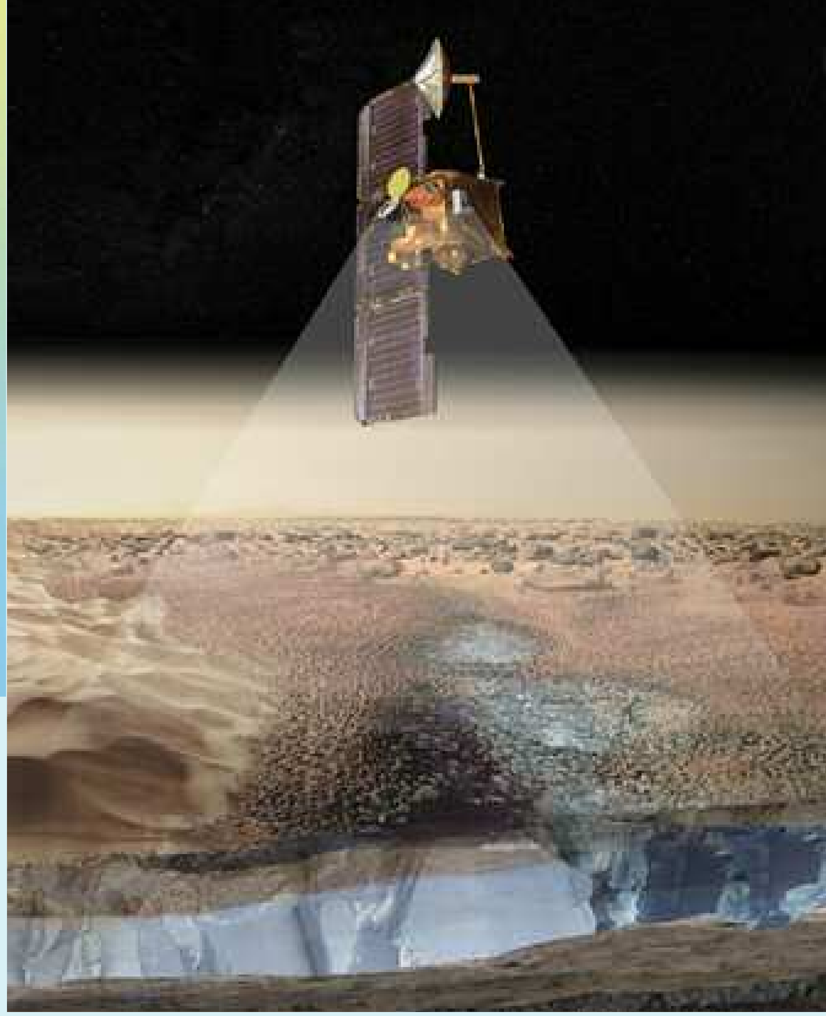
THE *MARS ODYSSEY* CONTINUES

by Bruce Betts



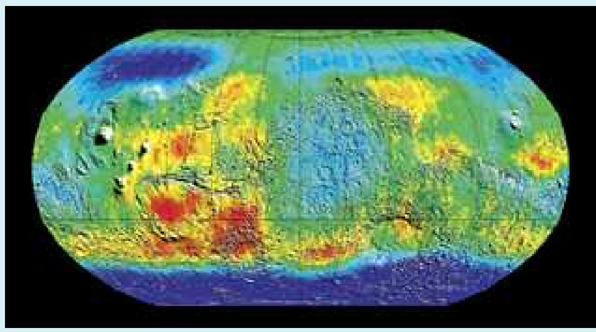
Above: In this artist's rendering, Mars Odyssey*'s Gamma Ray Spectrometer suite of instruments detects ice-rich layers in the soils of the Red Planet. The view of the spacecraft in this image is not to scale, as the observations are obtained from an orbital altitude of 400 kilometers (250 miles).* *Image: NASA/JPL/University of Arizona/Los Alamos National Laboratories*

Mars Odyssey's instruments have been returning a wealth of exciting new data—evidence for large percentages of water-ice in the upper surface of the Martian polar regions, stunning visible and thermal images of many areas on Mars, and data about the Martian radiation environment. Since beginning the mapping phase of its mission in February (see the March/April 2002 issue of *The Planetary Report*), the *Odyssey* spacecraft continues to work flawlessly. *Odyssey* has also passed its last major engineering hurdle: deployment of the gamma ray boom.

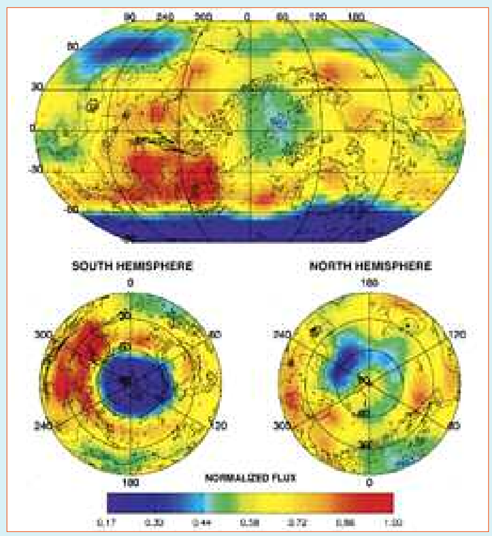
Ice in Them Thar Poles

Within 10 days of starting its mapping mission, the Gamma Ray Spectrometer (GRS) team reported they were already detecting hydrogen—inferred as water-ice—within 30 degrees of the Martian south pole (as reported in the March/April 2002 issue of *The Planetary Report*). By the end of May, the team had published scientific papers on the subject and put out press releases that attracted a lot of attention. These documents offered estimates of the amounts of ice detected and also provided more detail regarding location and layering.

By way of background, the GRS



This global view of Mars represented in intermediate-energy, or epithermal, neutrons is based on the first three months of data from the Neutron Spectrometer (part of the Gamma Ray Spectrometer suite). Soil enriched by hydrogen is indicated by the deep blue colors on the map, showing a low intensity of epithermal neutrons. Progressively smaller amounts of hydrogen are shown in the colors light blue, green, yellow, and red. The deep blue areas in the polar regions may contain up to 50 percent water-ice, in a lower layer within the upper meter of soil. The light blue regions near the equator contain slightly enhanced near-surface hydrogen, which is thought to be chemically or physically bound in the soil—water-ice not being stable in the near surface at this distance from the equator. *Image: NASA/JPL/University of Arizona/Los Alamos National Laboratories*



Another view of Mars' epithermal neutrons collected, in this case, by the High Energy Neutron Detector part of the Gamma Ray Spectrometer suite. Soil enriched by hydrogen is indicated by the purple and deep blue colors on the maps, which show a low intensity of epithermal neutrons. Hydrogen in the far north is hidden at this time beneath a layer of carbon dioxide frost (dry ice). Contours of topography are superimposed on these maps for geographic reference. *Image: NASA/JPL/University of Arizona/Russian Aviation and Space Agency* suite of instruments detects hydrogen, not water-ice. In fact, the instruments don't directly detect hydrogen but rather gamma rays emitted by hydrogen as well as neutrons that are affected (reduced in number) by hydrogen. Scientists then try to use other information to infer, if they can, with what the hydrogen is associated. Hydrogen doesn't exist in the surface in any significant quantities by itself but can be present, for example, as water-ice or as part of hydrated minerals.

The GRS, under the overall direction of William V. Boynton at the University of Arizona, is a suite of three instruments: the Gamma Subsystem, which detects gamma rays and was built at the University of Arizona; the Neutron Spectrometer, built at Los Alamos National Laboratory; and the High Energy Neutron Detector, provided by the Russian Aviation and Space Agency. These instruments are sensitive down to about one meter beneath the surface, hence the reason that all reports refer to ice in the upper meter.

Many reports in the popular press about the GRS team's discovery made it seem as if the detection of water-ice on Mars was a big surprise. To the contrary, where large amounts of hydrogen were detected (within about 30 degrees of the Martian poles) is where scientists predicted near-surface water-ice using models based on Martian conditions and geologic evidence. Certainly, the confirmation of these predictions is significant and important but not unexpected. What was unexpected was in the details: the amounts of water-ice found were higher than many anticipated. In addition, the GRS suite constituted the first orbital instruments flown at Mars to sample below the topmost layer.

Combining the data from the three instruments, the GRS team has concluded that the hydrogen is not uniformly distributed within the upper one meter they sampled. This result is also not totally unexpected, since the deeper ice will be more stable. But again, the confirmation and the details are new and important. The measurements are consistent with two layers: the lower layer being ice-rich and varying in depth from about 60 centimeters (24 inches) at 60 degrees south latitude to 30 centimeters (12 inches) at 75 degrees south latitude. The GRS team reports that the percentages of ice by mass in the lower layer within 30 degrees of the Martian south pole range

Color differences in this daytime infrared Thermal Emission Imaging System (THEMIS) image represent differences in the mineral composition of the rocks, sediments, and dust on the surface. The image shows a portion of a canyon, within the Valles Marineris system, named Candor Chasma. The area shown is approximately 30 by 175 kilometers (19 by 110 miles). This image combines three THEMIS images centered at three different wavelengths of infrared light.

Image: NASA/JPL/Arizona State University

from 20 to 50 percent, causing Principal Investigator Boynton to say, "It may be better to characterize this layer as dirty ice rather than as dirt containing ice."

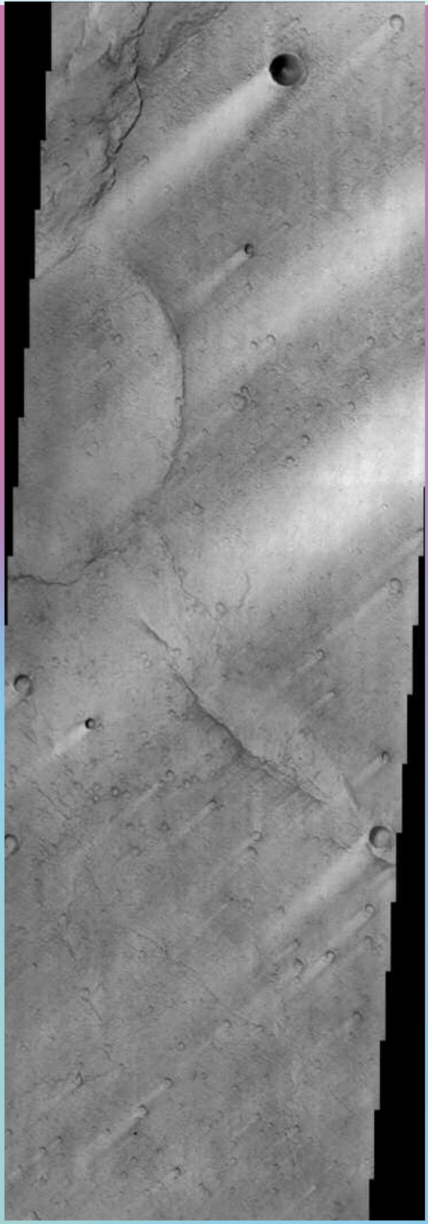
The signature of buried hydrogen seen in the south polar region is also seen in the north, though not in areas close to the pole. A seasonal carbon dioxide ice (dry ice) cap currently covering areas near the north pole blocks any signal/sampling of hydrogen by the GRS. With northern spring approaching, the carbon dioxide frost is starting to recede, already noticed by the Neutron Spectrometer, so eventually, the GRS will be able to sample hydrogen in all the north polar regions.

The reported neutron data also show that large areas at low to middle latitudes on Mars—that is, closer to the equator—contain slightly enhanced amounts of hydrogen, equivalent to several percent water by mass. The GRS team's preliminary hypothesis is that this signal is likely to be due to hydrogen chemically bound to minerals in the soil rather than in the form of water-ice. Scientists do not expect water-ice to be stable in the upper meter of the surface at low latitudes on Mars because of greater surface heating than in the polar regions.

Taking Mars' Temperature

Odyssey's Thermal Emission Imaging System (THEMIS) continues to churn out images at both visible and infrared wavelengths. THEMIS infrared images are basically temperature maps of the surface, whereas the visible wavelength images produce black-and-white images similar to what our eyes would see. These latter images will eventually give us a complete map of Mars at 18 meters per pixel.

Surface temperature can be used to infer physical properties of the surface,



***Above:** This Thermal Emission Imaging system (THEMIS) visible image illustrates the terrains within Terra Meridiani—one of the more complex regions on Mars, with a rich array of sedimentary, volcanic, and impact surfaces. Terra Meridiani lies at the eastern edge of a unique geologic area that was discovered to have high concentrations of gray (crystalline) hematite—a mineral typically formed by processes associated with water. As a result, the region is a leading candidate for further exploration by one of NASA's upcoming* **Mars Exploration Rovers**. *The brightness and texture of the surface vary remarkably throughout this image. Several distinct layers can be seen within the crater toward the bottom of the image, indicating that this feature—which measures 20 kilometers, or 12 miles, in diameter—once contained layers of sedimentary material that have since been removed.*

***Right:** This image captures an area near the southern edge of a low, broad volcanic feature called Syrtis Major. A close look at the image reveals a wrinkly texture, indicating the very rough surface associated with the lava flows covering the area. Visible on a larger scale are numerous bright streaks that trail topographic features such as craters. These bright streaks are in the wind shadows of the craters, where dust that settles onto the surface is not easily scoured away. The streaks are bright only in a relative sense to the surrounding image. Syrtis Major is one of the darkest regions on Mars—as dark as fresh basalt flows or dunes here on Earth. Image size is about 60 by 24 kilometers (37 by 15 miles).* Images: NASA/JPL/Arizona State University

that is, how much dust, sand, and rock there is, which tells us about the geologic processes that have acted on that surface. Very few of the infrared images have been made public yet, as the science team is working to validate and understand them, but those images that have been released are being interpreted as showing physical properties differing from one geologic layer to another. This finding may imply the environment was changing as those layers were laid down.

THEMIS also has several spectral channels, essentially "colors" in the infrared. These will allow some mineralogy of the surface to be determined at the 100-meter-per-pixel resolution of the images. This resolution, at 30 times better than that achieved by any previous instrument with spectral capability in the infrared, could lead to very important discoveries.

The visible images, meanwhile, reveal stunning geologic landscapes. Many can be viewed online at *themis.asu.edu/latest*. For much of Mars, these are the highest-resolution images we have. *Mars Global Surveyor*'s Mars Orbiter Camera yields 1.4 meters per pixel but images only small portions of the surface.

How Rad Is That?

Since life was breathed back into MARIE (Martian Radiation Environment Experiment) in March after several months of no communication, it continues to measure a radiation environment that would be hard on humans. MARIE data show an environment two to three times harsher than at the International Space Station.

A Boom with a View

Odyssey accomplished its last major engineering task on June 4, 2002, when it successfully deployed the 6.2-meter boom that holds the gamma ray sensor head. This was a potentially risky action since some failure modes would have endangered the entire spacecraft. Mission managers breathed a sigh of relief as all went perfectly, signaling that the last of many risky actions was behind them. From here on, *Odyssey* operates in its normal mapping mode.

The gamma ray sensor head is on a boom to lessen the effects of gamma rays emerging from the spacecraft itself. Before boom deployment, the sensor head was able to detect strong signals that overcame the spacecraft contribution—such as the hydrogen in the south polar region. But for elements common in the spacecraft, such as aluminum, the boom deployment is critical to obtaining a detectable signal from Mars. Boom deployment will also improve the accuracy of hydrogen measurements.

The *Odyssey* Continues

Mars Odyssey has obtained only a fraction of the data expected over its 2.5 Earth years' primary science mapping mission. And scientists have had little time to analyze what data have been taken. Already, results are exciting and tantalizing, but we are seeing only the tip of the iceberg. Stay tuned for more updates as the odyssey continues.

Bruce Betts is director of projects at The Planetary Society.

World Watch

by Louis D. Friedman

Japan—*Nozomi* (Hope) is on its way to Mars. Launched in 1998, the orbiter mission was expected to arrive at its destination in 1999. But a deep-space propulsion misfiring in December 1998 meant it would not reach its target on time. A quick change of trajectory was carried out to permit the spacecraft to be retargeted for an arrival in late 2003.

In April of this year, a solar flare apparently knocked out *Nozomi*'s communications system. The rest of the spacecraft is operating normally, and engineers at the Institute for Space and Astronomical Science in Japan expect to repair the damaged system. They estimate this will take six months.

Paris—The European Space Agency (ESA) unveiled its new plan for future space science missions in a program called Cosmic Vision. Because of a no-cost growth strategy for space science at ESA, the agency's mission list has been cut back from that discussed more than a year ago. David Southwood, ESA's director of science, presented the plan to ESA's Science Program Committee in May.

Planetary missions currently in the plan include those scheduled for launch next year: *Rosetta*, a comet rendezvous and lander, and the *Mars Express* orbiter carrying the *Beagle 2* lander. Also planned for launch in 2003 is *SMART 1*, a mission testing solar electric propulsion technology, set to go to the Moon. Approved for 2010–2012 is *BepiColombo*—consisting of two Mercury orbiters and a lander.

A proposed Venus orbiter mission, *Venus Express*, which was to start development next year, was not included in the plan.

Because mission approval in the European Space Agency involves all the member states, ESA plans are generally firmer than NASA's—and harder to change. Notably, ESA's current plan for planetary exploration makes no provision for Mars missions after *Mars Express*. Once results from *Mars Express* and from the *Huygens* probe at Titan are received in 2004, ESA will see no planetary results for eight years—until *Rosetta* reaches its target.

Is this a cosmic vision? ESA may be planning astronomy and space science missions that extend beyond our solar system, but for this observer, the agency's vision for planetary exploration seems a bit myopic. A "corrective lens," however, is possible. ESA has earmarked $15 million to study a program called AURORA, which sets integrated robotic and human Mars exploration as a goal. The Society has long advocated such an integrated approach, and a program greenlighted by the ESA study could fill the gap in post-2004 Mars exploration.

Washington, DC—Silence is all we hear (at the time we go to press) from the US Congress concerning the NASA budget and thus the fate of the outer planets missions: *New Horizons* (to Pluto and the Kuiper belt) and a Europa orbiter.

The first step in the budget process is the congressional Budget Committees' allocations to the Appropriations Committees in the House of Representatives and the Senate. That finally happened at the end of May.

Next, the Appropriations Subcommittees must meet and distribute their allocations among the various agencies and programs under their jurisdiction. Budget allocation is made by function (for example, science), while the Appropriations Committees are organized by bureaucracy (for example, NASA is governed by the Subcommittee on Veterans Affairs, Housing and Independent Agencies). Some iteration is required to get the numbers of the "functions" to agree with the numbers of the Appropriations Subcommittees.

Then the subcommittees make specific allocations to particular programs. At press time, congressional staff were predicting that no action would come on the NASA budget until after the July 4 recess. Some speculated that action might wait until the fall, just barely in time for the beginning of the new fiscal year (October 1).

In addition to the outer planets missions, we are monitoring the fate of the nuclear power and propulsion initiative, the evolution of the Mars program, and the politics surrounding the space station. We'll keep watching—and keep you informed on our website and through e-mail.

Great Britain—On a recent trip to London, I had a chance to visit Open University. This institution, primarily devoted to distance learning, has developed a very strong planetary science department. Most noteworthy, the university is in charge of payloads that will land on two different worlds in 2004: on Mars with the *Beagle 2* lander and on Titan with the *Huygens* probe. New facilities and flight hardware, in addition to test areas, are being built on the university campus. A fully qualified clean room and sterile facility for the *Beagle 2* are almost ready for the spacecraft.

Louis D. Friedman is executive director of The Planetary Society.

Extra! Extra! Read All About It:

BY STEVE B. HOWELL

Have you ever looked up at the night sky and wondered if we were alone? Well, if you've imagined the presence of human or other life-forms, the answer to if we're alone remains unknown. But if you've considered the existence of other planets, the answer is definitely no, we are not alone. Today, more than 60 extrasolar planets (ESPs) comparable to Jupiter are known to us; yet, so far, none appears to be in a solar system similar to our own. Still, it is estimated that 2 to 4 percent of all solarlike stars harbor massive planets—indicating that of the nearly 50 billion solarlike stars in the Milky Way, at least 1.5 billion or so host planets, some fraction of which may be Earth-like.

DETECTION OF EXTRASOLAR PLANETS

The detection of the first ESP is not a story from the distant past—it is, in fact, less than a decade old. On October 6, 1995, the Swiss team of Michael Mayor and Didier Queloz discovered a Jupiter-size planet orbiting the star 51 Pegasi (51 Peg). The so-called hot Jupiter found orbiting 51 Peg has an estimated mass of about half that of Jupiter and orbits its sun every 4.23 days.

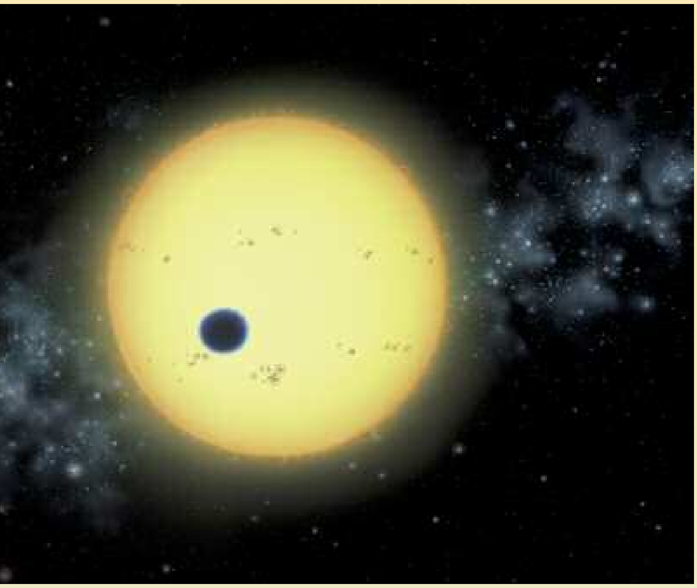
Various techniques have been proposed to detect planets in orbit around other suns, among them, gravitational lensing, laser beacon detection, detection of produced radio emissions, direct imaging of the planet, and observations of comets plummeting into their suns. This article will focus on three other methods: (1) Doppler radial velocity searches using spectroscopy, (2) astrometric detection, and (3) high-precision photometry observations of the actual passage of a planet in front of its parent star (a transit).

Radial velocity techniques were applied to planet hunting nearly a decade ago, as spectrography was then sufficiently advanced to allow the measurement of small velocity changes (tens of meters per second). Full realization of this technique requires observation of the very brightest stars and use of the very largest telescopes. Photometric observations have also been attempted, and many programs utilizing this technique are either planned or already under way.

DOPPLER AND ASTROMETRIC

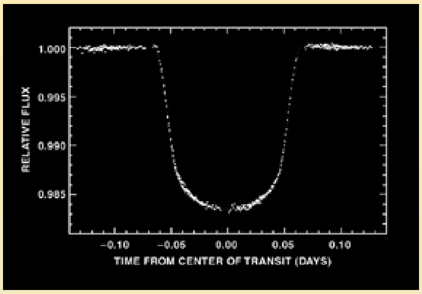
The Doppler effect is probably best known by its applica-

EXTRASOLAR PLANETS ON THE RISE!



Above: For the first time, scientists have witnessed a distant planet passing in front of its star, providing direct and independent confirmation of the existence of extrasolar planets. This painting depicts the transit of the gas giant across the face of its star, HD209458. Until now, all alien worlds have been inferred only from the telltale wobbles they produce in their parent stars. *Painting: Lynette Cook*

Left: The first extrasolar planet ever discovered was found in 1995 around the star 51 Pegasi. Nearly half the size of Jupiter, it is known as 51 Pegasi b. The planet's orbit is nearly 20 times closer to its star than Earth is to the Sun. In this painting, 51 Pegasi b is seen from a small moon as it eclipses its host star, which is emitting superheated flares similar to those produced by our own Sun. *Painting: Ron Miller*



This figure shows photometric data of the transit of HD209458 b as observed by the Hubble Space Telescope. The transit lasts a little more than two hours, during which the light from the star dims by 1.4 percent.

Illustration: Space Telescope Science Institute

tion to sound waves. For example, when a police car with its siren blaring passes us, we hear the characteristic shift in the pitch of the siren as the police car moves from approaching us (blue shift) to receding from us (red shift). Light emitted by a star encircled by a planet demonstrates the same effect. Objects moving toward an observer emit light, which looks bluer than if the object were not moving at all. Similarly, receding objects emit slightly redder light.

As a massive planet orbits its star, the star periodically shifts back and forth due to the gravitational tug of the planet. Scientists detect this motion by looking for periodic red shifting and blue shifting of known spectral lines in the parent star. The time it takes these lines to shift back and forth is the planet's orbital period, while the relative amount the lines shift provides an estimate of the planet's mass. If the planet's orbit about its star is edge-on as viewed from Earth, the measured Doppler shifts provide the planet's mass directly. However, in all known cases except one, the inclination (tilt) of the planet's orbit as viewed from Earth is unknown. In these cases, the planet's mass can only be estimated as a lower limit, its real mass possibly being larger.

Astrometric detection of planets relies on the same type of reflex motion but instead attempts to directly measure the position of the parent star in space and determine its actual side-to-side motion as the planet orbits it. Doppler radial velocity techniques work best for massive planets in orbits that are more or less in our line of sight. Astrometric detection, however, is most effective for massive planets in orbits perpendicular to our line of sight, that is, close to face-on.

Both techniques, as well as the photometric method described below, will preferentially find planets with short orbital periods. Because it is the periodic nature of the observed signal that enables a planet's detection, only those planets with orbital periods less than about one-half the observational time can be detected. Given that radial velocity studies have been ongoing for about nine years, it is no surprise that the longest-known ESP orbital periods are nearly five years, or 1,800 days.

PHOTOMETRIC DETECTION

Probably the easiest search method to understand, as far as ESPs are concerned—though the task itself is daunting—is photometric detection. The observer must study any given star long enough and precisely enough to detect the ESP transit, that is, to observe the ESP crossing in front of or eclipsing its star. Only ESP systems with an orbital plane in the line of sight of the observer will show transits because otherwise, the planet will not pass in front of the star as viewed from Earth.

On average, only a few percent (about 10 percent for 51 Peg-type planets, down to near 1 percent for most ESP systems) of all stars are so aligned—thus, photometric searches must use a shotgun approach. That is, they must observe many thousands of stars in order to find the few that have planets at all, then the paltry percent that show transits and, furthermore, that show them during the time they are under observation.

Observation of planetary transits is not a new idea. As far back as 1858, Dionysius Lardner's three-volume set, *Handbooks of Natural Philosophy and Astronomy*, contained the idea. In his discussion of stellar variability, Lardner wrote: "Periodical obscuration or total disappearance of the star may arise from transits of the star by its attendant planets."

However, by 1900, most astronomy textbook authors understood that in order for a planet to cause the then-observable large variability of its host star, the planet would have to be very large in size, comparable even to its host. Thus, the idea of observing planetary transits, based on planets of the size known from our own solar system, fell from grace due to the extraordinary photometric precision needed. Planets the size of Jupiter transiting a star like our Sun cause a 1 percent drop in the light output during the eclipse; a planet the size of Neptune would produce a 0.1 percent drop in light; and a planet as small as Earth transiting the Sun would cause a drop of only 0.01 percent. Currently, the best photometric precisions achievable from the ground approach 0.1 percent—space-based observations most likely will be needed to obtain the more exact observations required to reach the level of detection for Earth-size ESP transits.

To date, the only confirmed transiting ESP orbits the star HD209458. The planetary transit in this case has allowed astronomers to make fairly precise determinations of the planet's properties and even to detect a weak signal from sodium atoms within the planetary atmosphere itself. The giant planet in HD209458 is 1.4 times the diameter of Jupiter, leading to a transit depth (the drop in light during the planet's passage in front of the sun) of 1.7 percent of the uneclipsed light. This is a small signal change, but with modern astronomical detectors and special photometric analysis techniques, I have been able to observe this transit with only an 8-inch telescope and an inexpensive charge-coupled device (CCD).

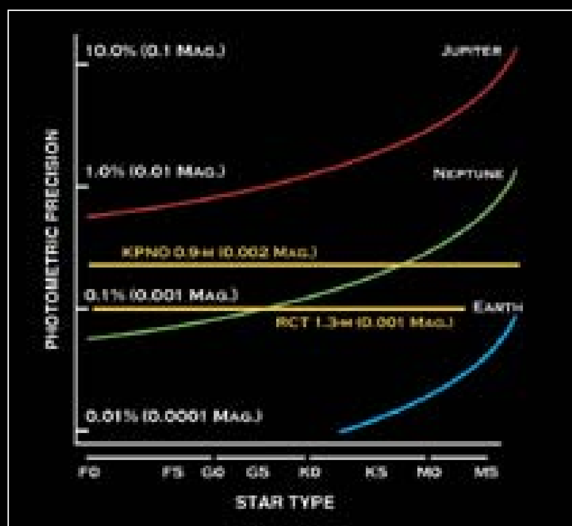
Of course, this type of observation is possible because we know which star to look at and when the transit will occur. The greatest challenge to ESP hunting via photometric transit searches is that one must find a star with a planet in an orbit that is along one's line of sight, then be able to make observations more precise than the amount of dimming that will occur when the planet eclipses its sun and, finally, observe long enough to actually identify transits.

DEMOGRAPHY OF EXTRASOLAR PLANETS

With 60 or more confirmed ESPs, let's take a look at their properties and see what manner of beast we are dealing with. The planetary systems discovered to date have a number of common themes. First, they are all more massive than Earth, and most are more massive than Jupiter (that is, super-Jovian). In fact, they are assumed to be gas giants of some sort. Second, most extrasolar planets have close-in orbits, that is, with orbital periods of less than 100 days. Third, all known ESPs have been discovered using Doppler radial velocity techniques.

Given these three common properties of the known extrasolar planetary systems, it might appear that our

The 1.3-meter telescope on Kitt Peak has a rich history, including its role as a prototype for remotely controlled telescopes. After nearly 30 years of service, budget constraints forced the closing of this telescope as part of the Kitt Peak National Observatory (KPNO) in 1995. The Robotically Controlled Telescope (RCT) consortium is now the operator of the telescope, and the participation of the Planetary Science Institute in this consortium—and in our search for extrasolar planets—is supported by The Planetary Society. This bird's-eye view of KPNO, showing the location of the 1.3-meter RCT, was taken just before refurbishment on the telescope began.



When we think about photometric searches for extrasolar planets, it's useful to plot the precision required to detect the planet's transit against the type of star being observed. The star type matters because the transit's depth is related to the star's size as well as to the planet's size. Large planets orbiting small stars will have transits of the greatest depth. Stars become smaller in size as they go from the hotter, solarlike stars (type F), to the cooler, lower-mass stars (type M). Our Sun is a G2-type star.

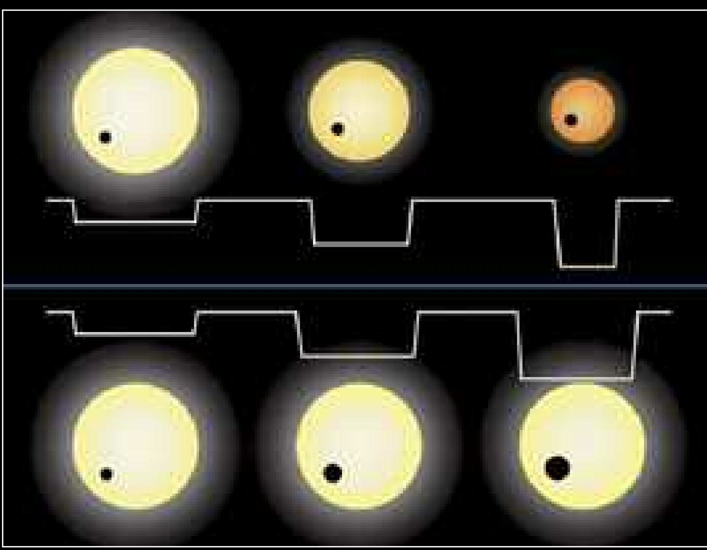
Shown on the diagram are the transit depths for extrasolar planets of a size equal to Jupiter, Neptune, and Earth if they were to transit stars of type F to type M. The numbers indicate the photometric precision (as a percentage of the signal received) needed to detect the transit. The extrasolar planetary transit in HD209458 had a depth of 1.4 percent, greater than that of Jupiter transiting our Sun. Even though the planet in HD209458 is only 0.7 times Jupiter's mass, the planet is close to its parent star and thus is hotter and expanded in size.

The two yellow horizontal lines represent the photometric levels already obtained by our group with the Kitt Peak National Observatory's 0.9-meter telescope, and the precision we expect from the 1.3-meter Robotically Controlled Telescope project, which will start this fall.

The Kepler *mission is expected to achieve a photometric precision near 0.001 percent—sufficient to detect Earth-size extrasolar planets.*

Here's the partially reassembled, newly painted RCT telescope. Over the past year and a half, the telescope has been completely refurbished; it now has a newly recoated mirror, dome control, and completely new wiring. Computers are being installed that will run the telescope, instruments, and dome by remote control, including data acquisition and reduction. The heart of the extrasolar planet search—the CCD camera—is being tested and will soon be taken to the mountaintop and attached to the telescope.

*Thanks to the support of organizations like The Planetary Society, we look forward to a great scientific expedition and (we hope) the discovery of a number of extrasolar planets. More details about the RCT, the search for extrasolar planets project, a history of the 1.3-meter telescope, and other information can be found by following the "Extrasolar Planets" link from the The Planetary Society's home page (*planetary.org*).*



While transits are simple to understand, they can present confusing information. The top half of this illustration shows three planets of equal size transiting progressively smaller stars. Note how the depth and width of the transit (represented by the white line) change. The bottom row shows three planets of increasing size transiting the same star. Again, the shapes of the transit changes for each scenario. As the planet passes in front of its parent star, the intensity of its light drops off by a small amount. The shape of the transits provide valuable information about the planet's size, its orbital period, and its host star.

All images: Steve Howell and Gil Esquerdo

particular solar system is different from most. However, these three properties probably say more about how astronomers have searched for ESPs than about shared characteristics of extrasolar planetary systems. All ESP searches have two things in common: they can be conducted for only a finite period (so far, about eight years), and massive planets with close-in orbits are the easiest (and in some cases, the only) planets that can be detected. Both Doppler methods and photometric transit searches are significantly more sensitive to more-massive (larger) planets, as such planets produce the most easily detectable signals. Present-day Doppler techniques are limited to planets of roughly Saturn's mass or greater, while current photometric methods are limited to planets approximately the size of Neptune.

While the extrasolar planets found to date are different from our own, they can still provide us with valuable information about the types of stars that harbor them and the galactic environments where they live. Indeed, astronomers have determined that ESP host stars share certain characteristics.

For example, the parent stars appear to contain an amount of metals equal to or higher than those in the Sun, whereas the number of metal-poor stars with ESPs is much lower, approximately only 1 percent. (*Metal* in astronomy means any element other than hydrogen or helium.) Essentially, all the metals in these stars were formed during the life cycles of previous generations of stars. In fact, the metals comprising the extrasolar planets, our own planets, and all life itself were produced by now-dead stars. The ESP host stars also seem to be about the same age as the Sun: 5.6 plus or minus 3.5 billion years (the Sun is about 4.5 billion years old). So, it appears that middle-age stars containing fair amounts of metals are likely breeding grounds for planets.

CURRENT AND FUTURE ESP SEARCHES

The detection of extrasolar planets is a milestone in astronomy. The fact that it is a discovery less than a decade old makes it all the more interesting. Searches for ESPs have grown like weeds and, currently, a number of dedicated search telescopes are scanning the skies. Theoretical work on the formation of super-Jovian planets orbiting close to their parent stars is also well under way.

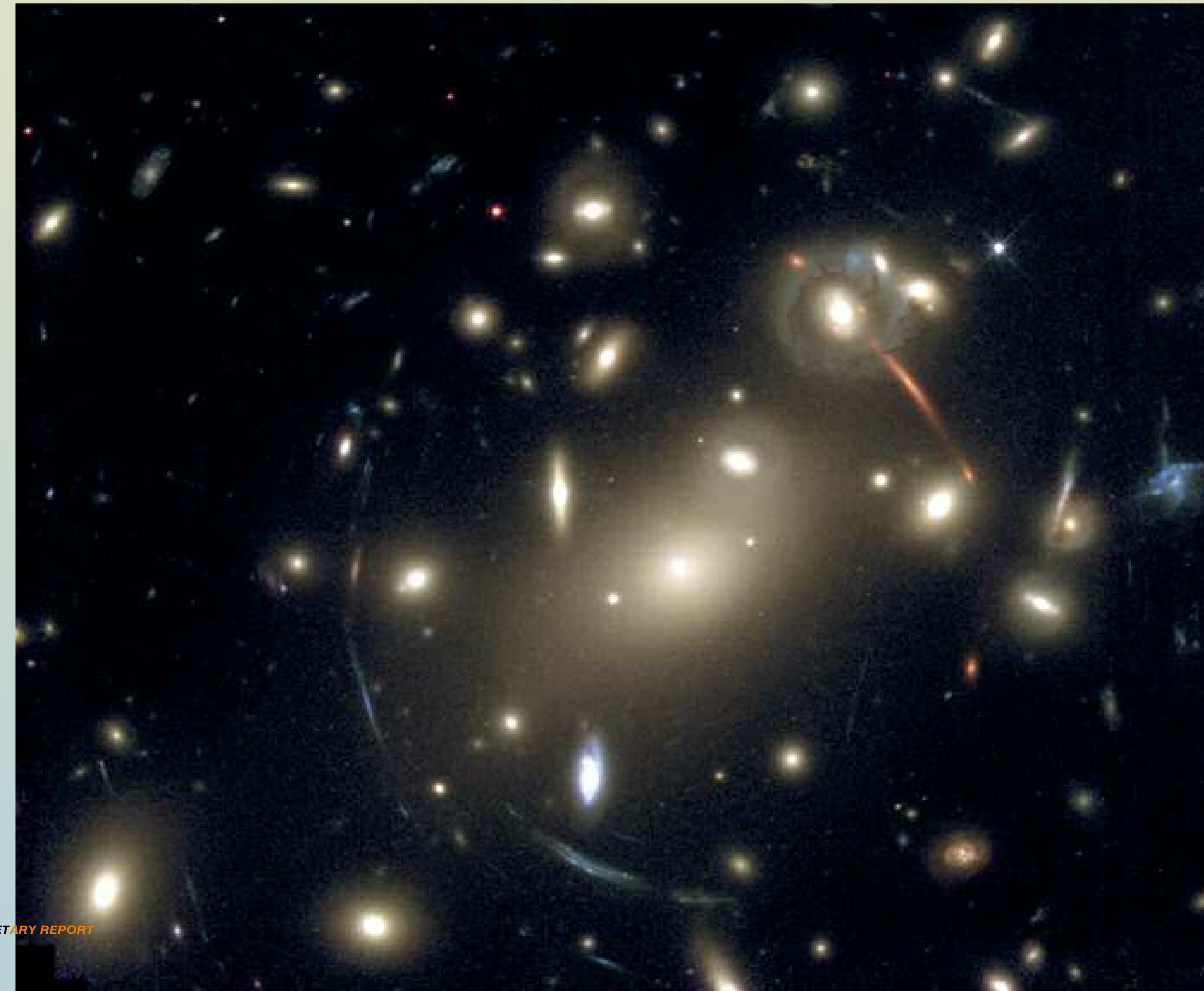
Ground-based telescopic searches for extrasolar planets continue to rely heavily on Doppler methods employing spectrographs at large telescopes such as those at Lick, McDonald, and Keck Observatories. Photometric searches are ongoing at sites worldwide as well, with most depending on wide-field camera-type optics imaging many square degrees of the sky onto a CCD detector. These search projects (such as STARE; *www.hao.ucar.edu/public/research/stare/stare.html*) observe 6,000 to 10,000 stars per year and are capable of detecting Jupiter-size extrasolar planets orbiting bright, solarlike stars. The Extrasolar Planets Encyclopedia website (*cfa-www.harvard.edu/planets*) offers an up-to-date list of ESP search programs as well as details on known ESPs.

On the horizon are two space-based missions whose primary science objectives are photometric surveys that will search for transiting extrasolar planets. *COROT*, a French space mission (*cfa-www.harvard.edu/planets/corot.html*) planned for launch in late 2004, and *Kepler*, a NASA Discovery mission expected to launch in 2006 (*www.kepler.arc.nasa.gov*), will provide exceptionally precise photometric observations with the goal of detecting Earth-size extrasolar planets. Future NASA missions, such as the Space Interferometry Mission (*sim.jpl.nasa.gov*) and Terrestrial Planet Finder (*planetquest.jpl.nasa.gov/TPF/tpf_index.html*), plan to make precise measurements of planets orbiting nearby stars and even, it is hoped, obtain direct images of these planets.

One especially interesting ESP ground-based search project starting this summer—which is partially supported by The Planetary Society and in which I will be participating—will use the newly refurbished 1.3-meter Robotically Controlled Telescope (RCT; *www.psi.edu/rct/index.html*) located on Kitt Peak in southern Arizona. A consortium of five institutions including the Planetary Science Institute operates the RCT. The telescope will perform a number of observational programs, with the ESP search program receiving the lion's share of telescope time. I will lead an effort to observe many thousands of stars each year that are fainter, farther away, and of a different type from those observed by other ESP search programs. Additionally, our search program will provide photometric observations

A MATTER OF DEFINITION

A planet is an object whose mass is equal to or less than 20 times the mass of Jupiter (0.02 the mass of the Sun), while objects measuring 40 times the mass of Jupiter (0.04 the mass of the Sun) or more are considered brown dwarf and very low mass stars. Planets form in a protoplanetary disk surrounding their parent star, while stars form as independent condensations in their parent molecular cloud. To date, few objects are known to exist in between the mass limits identified above.



IN THE NEIGHBORHOOD

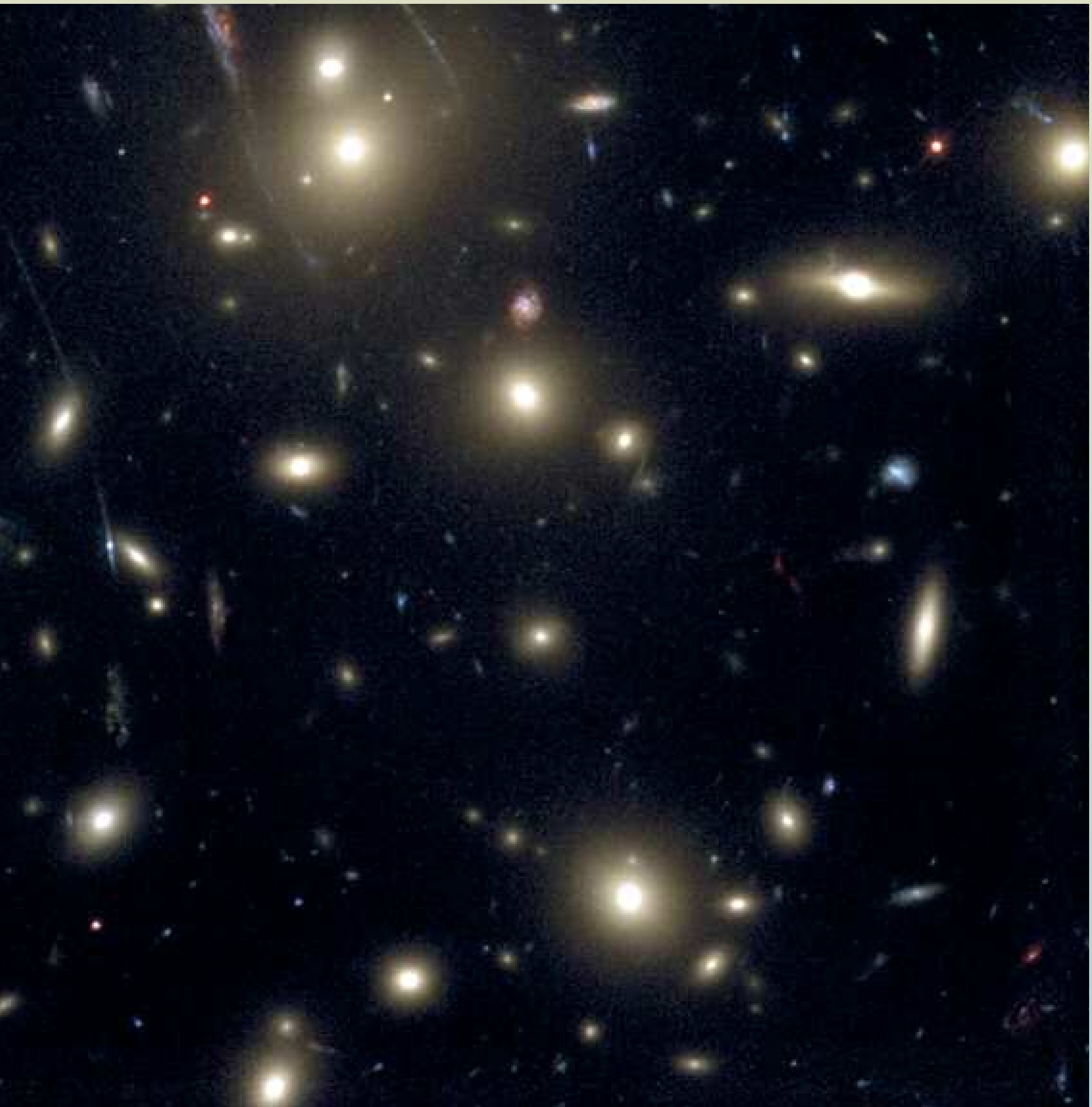
Our present sample of extrasolar planets is limited to planets that orbit stars in the solar neighborhood because of the challenges of observing distant stars. In fact, most known hot Jupiters lie within 100 light-years of the Sun. Even so, of the 480 or so local neighborhood solar-type stars, less than 4 percent are known to have planets. Whether this percentage holds at greater distances from the Sun and throughout the galaxy is not yet known. —*SBH*

with extreme precision, allowing us to detect transits by planets smaller than those observed so far.

As is the case with all large astronomical projects, our ESP search program is a collaborative effort. Collaborators include RCT consortium scientists and scientists at the Jet Propulsion Laboratory utilizing the Palomar and Keck telescopes. Once a candidate extrasolar planetary system is discovered, follow-up work will be needed to obtain spectroscopy that will determine the precise type of its host star; in some cases, more-detailed observations of the transit event itself may be required. Detection is complicated by the fact that one-half or more of the stars in the galaxy are binary (two stars orbiting each other)—observational distinctions between an eclipse of one star by another and a transit by a planet can be fuzzy. Thus, identification of transit candidates will call for additional detective work.

The RCT ESP search program is just beginning. With support from organizations such as The Planetary Society, government agencies such as NASA, and interested individuals, we plan to operate the search for a period of three to five years. In that time, we hope to fully utilize the telescope and to collect enough observations to obtain scientifically meaningful data, discover many ESPs, and offer conclusions about the true nature of extrasolar planets. For more information on how you can get involved, visit *www.psi.edu/esp*.

Steve B. Howell is head of the astrophysics group at the Planetary Science Institute in Tucson, Arizona. He splits his time between searching for ESPs and investigating close binary stars that have ongoing mass exchange.



A moment's thought about the worlds that surely circle stars all over the Milky Way—and in galaxies beyond our own—provides a staggering reminder that, in our search for extrasolar planets, we are just getting our feet wet.

***In January 2000, the Hubble Space Telescope captured this image of a cluster of galaxies, called Abell 2218, in the constellation Draco, about 2 billion light-years from Earth. The cluster is so massive, its huge gravitational field creates a powerful "zoom lens" for viewing distant galaxies that could not normally be observed with the largest telescopes. To read more about this image, visit* http://oposite.stsci.edu/pubinfo/pr/2000/08/pr-photos.html.**

Image: Space Telescope Science Institute

Taking the MEASURE of MICROWORLDS

BY ROBERT BURNHAM

Planetary radar has found ice on Mercury, mapped lava flows on Venus, and tracked frozen debris swirling around comet nuclei. Yet radar's greatest benefit for Earthlings lies among the almost infinitely varied asteroids.

In March 2001, an asteroid designated 1950 DA sailed past Earth at 21 times the Moon's distance. In solar system terms, the miss was fairly generous—some 7.8 million kilometers (4.8 million miles). Asteroids routinely pass Earth, some closer, some farther; some bigger, some smaller. Although humans largely ignore the fact, Earth travels amid a cloud of close-approaching asteroids. One of them could hit us at any time.

As 1950 DA sailed past, planetary radar scientists bounced echoes off it using antennae at the Arecibo Observatory in Puerto Rico and NASA's Deep Space Network at Goldstone, California. Like a roadside cop targeting a speeder, the radar nailed 1950 DA's orbit to high precision.

"Once an asteroid is discovered, radar is the most powerful way to find its exact orbit," says planetary scientist Steven Ostro of the Jet Propulsion Laboratory (JPL) in Pasadena, California. Radar, he says, surpasses optical methods: "It can locate a near-Earth asteroid to about 10 meters and measure its velocity to within a millimeter per second."

The future of 1950 DA's orbit held a disquieting surprise. Calculations showed that after 15 more passes near Earth and Mars, on March 16, 2880, the asteroid might strike Earth, hitting the North Atlantic off the US coast. The estimated chance of this happening is at most 1 in 300—small, but enough to make 1950 DA, at 1.3 kilometers (0.8 mile) in diameter, the most threatening space rock yet found. The uncertainties lie in not knowing how 1950 DA's orbit will evolve in response to almost 900 years of sunlight pressure, diurnal heating and cooling, and other effects.

"Optical searches coupled with radar follow-up can give us centuries of advance warning," says Jon Giorgini, a JPL radar engineer and head of the team of 14 scientists who studied the observations. Don Yeomans, the manager of NASA's Near Earth Object Program at JPL, concurs: "Radar helps us push predictions at least five to ten times further into the future."

Someday, scientists will discover an asteroid with Earth's name on it. When that happens, we will need a warning time measured in decades or even centuries to prepare. Says JPL's Ostro, "The radar results on 1950 DA urge us to begin thinking on millennium timescales; 1950 DA won't affect us or our immediate descendants, but knowing the threat gives us time to learn how to deal with it."

Zapping the Heavens

Planetary radar grew out of World War II military radar, blending electronic engineering, radio astronomy, and solar system science. (See "In the Band," page 18.) It's the only kind of Earth-based astronomy that can actually experiment with a target. While planetary radar resembles radar used to spot aircraft and speeding drivers, the greater distances involved demand vastly more signal strength. Solar system radars use powers ranging from 500,000 to 1 million watts, some

LDS

Asteroids wander dangerously close to home in this painting entitled Juggernaut. *While most asteroids orbit in the space between Mars and Jupiter—a safe distance from Earth—some lurk in the neighborhood. Impact craters scar the surfaces of Mars, the Moon, and our own home planet—proof that these space rocks don't always stay in space.*
Painting: Joe Tucciarone

First discovered in 1950, asteroid 1950 DA disappeared from view after just 17 days of observation. A half-century later, an object discovered on December 31, 2000 turned out to be the long-lost asteroid. In March 2001, during the asteroid's 7.8 million-kilometer (4.8 million-mile) approach to Earth, radar observations like this one from Arecibo took a closer look at 1950 DA. The slightly asymmetrical spheroid with a diameter of 1.3 kilometers (0.8 mile) is projected to swing by Earth in 2880 at a distance that could be too close for comfort.
Image: S. Ostro/JPL/NASA

Left: Three giant antennae—each measuring 34 meters in diameter—look far beyond the brilliant blue desert sky out to the depths of space. These antennae, part of the Goldstone Deep Space Communications Complex located in California's Mojave Desert, are the latest addition to NASA's Deep Space Network (DSN). In addition to providing radio communications for all of NASA's interplanetary spacecraft, the DSN is used for planetary radar astronomy and radio observations of the solar system and beyond. *Photo: JPL/NASA*

10 to 20 times stronger than the wattage used by commercial radio stations. Radar's reach extends from the Moon to the Saturnian system.

When radar scientists beam radio waves, they can vary the polarization, signal strength, and modulation. Changes in the echo tell of the target's rotation and shape, as well as surface rock sizes, composition and structure, large- and small-scale topography, and bulk density. It's hands-on astronomy, minus the astronaut.

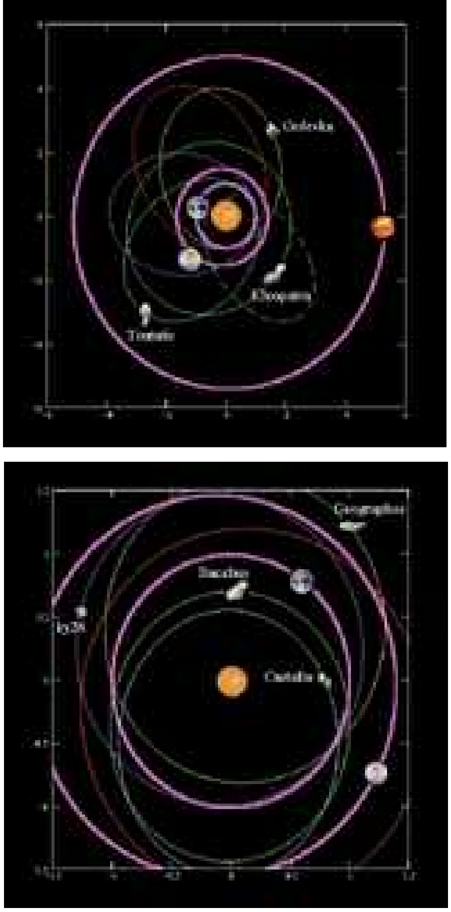
Planetary radar piggybacks on antennae used for radio astronomy and mission tracking, principally Arecibo Observatory's 305-meter dish and NASA's 70-meter Goldstone DSS-14 antenna. Each can send and receive, or one may send while the other receives. The latter bistatic arrangements are common and not just between these two. Other antennae increasingly paired with Arecibo and Goldstone include the 100-meter Green Bank Telescope in West Virginia and a 34-meter dish also at Goldstone. In addition, the 27-antenna Very Large Array radio telescope in New Mexico has seen duty as a high-resolution receiver.

"Arecibo's size means it can reach almost twice as far as Goldstone," says Ostro. "On the other hand, Goldstone's steerability lets it see twice as much sky and track objects at least three times longer."

Scouting Rocks in Our Path

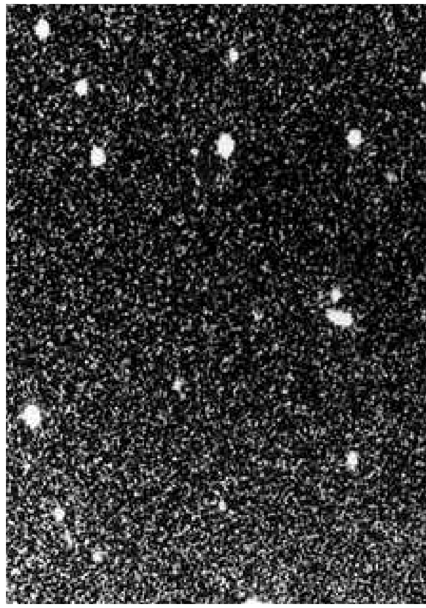
While some radar scientists study planets and moons, radar contributes most to a major NASA research program dubbed Spaceguard. In 1998, the US Congress directed NASA to identify, within 10 years, 90 percent of all asteroids (and comets) greater than 1 kilometer (0.6 mile) in diameter with orbits approaching Earth. The chosen size limit marks where an impact would have worldwide consequences.

The job of discovery falls on optical surveys, which can image lots of sky all at once, catching everything brighter than a given magnitude. As of early April



These diagrams show the orbits of a few known asteroids in relation to the Sun and planets. Note that the asteroids and planets are not shown to scale in these figures.

Diagrams: Scott Hudson, Washington State University



Near right: The slightly elongated smudge near the center of this image is asteroid Castalia, first discovered on August 9, 1989 by Eleanor Helin using Palomar Observatory's 18-inch Schmidt telescope. Days after discovery, the asteroid passed within the Arecibo Observatory's field of view, providing echoes much stronger than in previous asteroid radar observations. The radar data were used to derive three-dimensional model predictions (far right) of the asteroid for further study. *Image: Elinor Helin, JPL/NASA; Model: Scott Hudson, Washington State University*

Stepping STONES

Planetary radar has identified a number of near-Earth asteroids that are prime candidates for exploration. Some are easier to reach than even the Moon. These would make ideal sites to try out technologies for a manned flight to Mars.

One NEA candidate is a baseball diamond–size microworld named 1998 KY26. It shuttles from slightly inside Earth's orbit out to about Mars' orbit every 1.36 years.

KY26 is a carbonaceous chondrite whose mass includes 5 to 20 percent chemically bound water. That means it has lots of hydrogen and oxygen for fuel and human use that easily could be extracted from its surface materials. Moreover, getting there from low Earth orbit takes a change in velocity of only 3.3 kilometers (2.1 miles) per second.

A robotic spacecraft, Japan's *MUSES-C*, is set to visit a different NEA, 1998 SF36. The spacecraft is due for launch late this year. Its flight plan is to rendezvous with SF36 in mid-2005, collect surface samples, and return these to Earth in June 2007. —*RB*

2002, surveys had found roughly 1,800 near-Earth asteroids (NEAs), of which almost 600 are big enough to do widespread harm if they were to strike. In all, scientists estimate they'll find about 1,000 NEAs bigger than a kilometer.

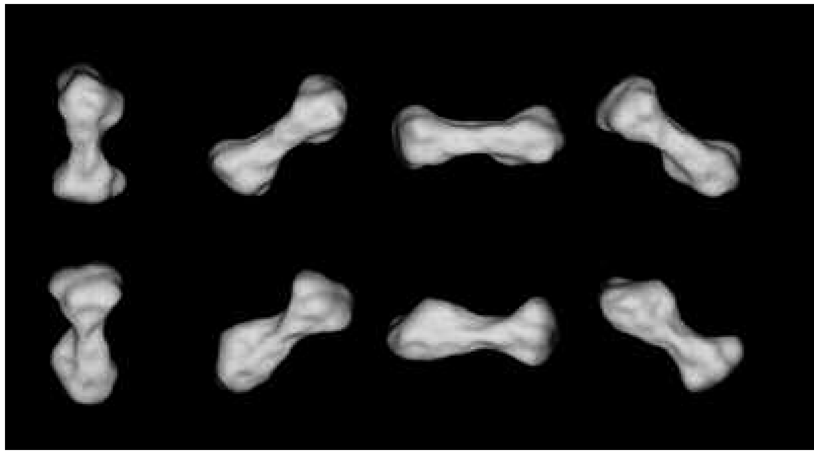
Radar enters the picture when a newly discovered NEA gets a preliminary orbit and scientists check whether Arecibo or Goldstone can spot it. Once radar detects an asteroid, its orbit is secure. Says Ostro, "Even a single radar detection is enough to guarantee an asteroid will not be lost for decades or centuries." Because a typical NEA comes within range only once every few dozen years, it's important for radar to observe NEAs whenever opportunities occur.

Getting in Touch

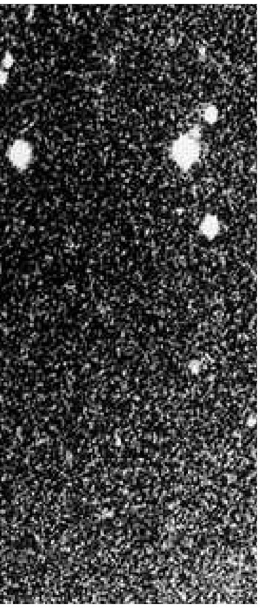
Radar confers another benefit besides accurate orbit — it's the only way to see what these microworlds look like without sending a spacecraft. In autumn 1989, a team led by JPL's Ostro checked out a new NEA, 1989 PB (now named 4769 Castalia). What they saw astounded

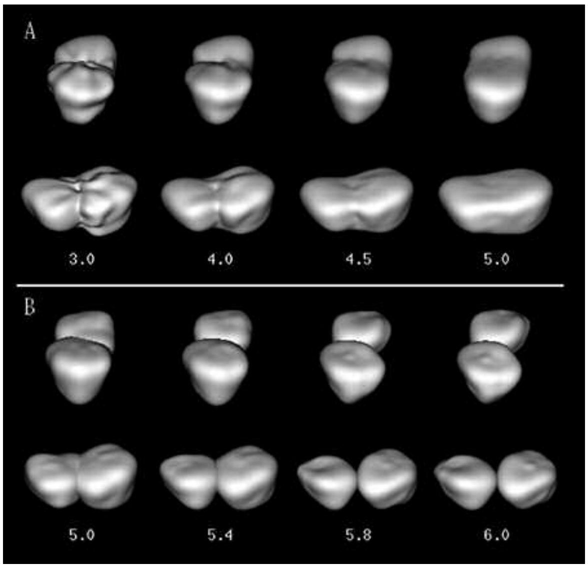
Twilight settles on the Very Large Array—27 radio antennae, each one measuring 25 meters in diameter, that form a giant Y-shape complex in the New Mexico plains. The data from the antennae are combined electronically to give the resolution of an antenna 36 kilometers (22 miles) across with the sensitivity of a dish 130 meters in diameter.

Photo: Dave Finley, courtesy National Radio Astronomy Observatory and Associated Universities Inc.



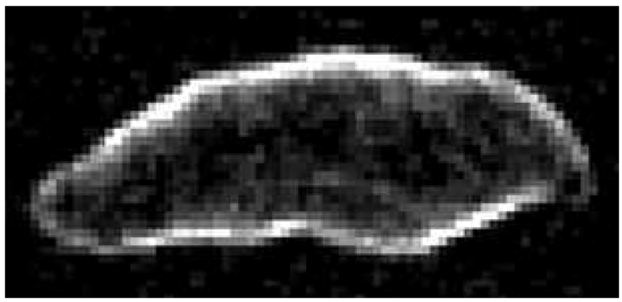
These images show several views from a radar-based computer model of asteroid 216 Kleopatra. First discovered April 10, 1880, 216 Kleopatra is located in the main asteroid belt between Mars and Jupiter. The giant asteroid is about 217 kilometers (135 miles) long and about 94 kilometers (58 miles) wide—approximately the size of New Jersey. A team of astronomers observing Kleopatra used Arecibo's 305-meter telescope to bounce encoded radio signals off the asteroid. Applying sophisticated computer analysis techniques, they decoded the echoes, transformed them into images, and assembled a computer model of the asteroid's shape. *Models: S. Ostro, JPL/NASA*





Below: Discovered at Mt. Palomar in September 1951 and observed again in 1994, 1620 Geographos was the eighth near-Earth asteroid (NEA) to be observed using radar. Radar imaging of NEAs can provide dramatic images with resolutions down to 8 meters, comparable to the images obtained by the* Galileo *and* NEAR-Shoemaker *spacecraft.

Image: S. Ostro, JPL/NASA



them. As Castalia slowly spun in the radar beam, it displayed two kilometer-size lumps in contact.

Other asteroids show different features: craters mark the dusty surface of 1620 Geographos, and rubble heaps up at its ends. Its 5.1-kilometer (3.2-mile) length stretches almost three times its width. Another oddball is 216 Kleopatra, a dogbone-shaped asteroid the size of New Jersey, its high radar reflectivity suggesting a metallic composition.

And then there's 4179 Toutatis. Scott Hudson of Washington State University "inverted" the radar data, turning 18 radar snapshots into a three-dimensional computer model. Toutatis is misshapen: 1.9 by 2.4 by 4.6 kilometers (1.2 by 1.5 by 2.9 miles). Radar shows craters and linear features, and rocks the size of a fist or bigger cover a third of its surface. Radar also determined that Toutatis has a complex rotation, with periods of 5.4 and 7.3 days. This wobble may be due to off-center collisions that merged its pieces.

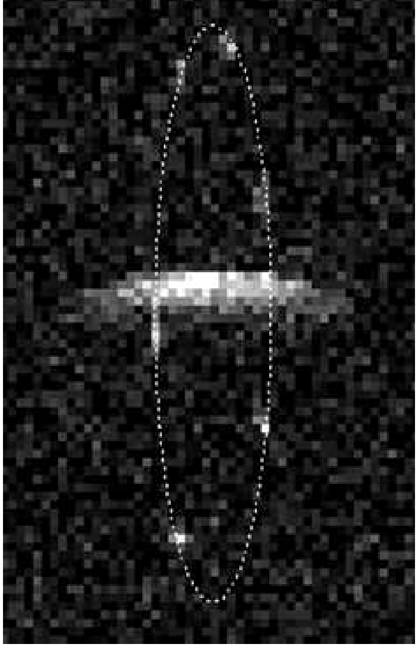
Toutatis hinted that NEAs are unusual, but a recently published radar discovery underscores how little we know of these objects, despite living amid a swarm of them: some NEAs have moons.

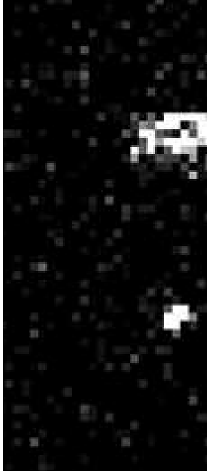
Seeing Double

Planetary scientists have long noticed that Earth is dotted with a number of doublet craters, where two meteorites struck side by side. Thus, the recent announcement that radar has found five near-Earth asteroids, each with a moon, raises intriguing questions, both scientific and from the hazard point of view. The five binary NEAs—2000 DP107, 2000 UG11, 1994 KW4, 1998 ST27, and 2002 BM26—demonstrate why it's necessary to explore all asteroids reachable with radar; no other technique short of a space mission can see them so clearly.

Planetary scientist Jean-Luc Margot of the California Institute of Technology heads the team that recently published an account of the five binary NEAs. Asked what produces them, Margot suggests tidal effects: "Radar shows that many near-Earth asteroids are porous rubble piles with little cohesion. Thus, a close flyby of Earth—

The Arecibo Observatory in Puerto Rico operates the world's largest, most sensitive radio telescope. This gigantic instrument consists of a large collecting surface, the suspended receiving elements, and an array of signal-processing equipment. Unlike most telescopes, which point by shifting the main mirror or reflector, the Arecibo telescope tracks celestial objects by moving the receiving elements suspended above the stationary reflector.
Photo: David Parker/Science Photo Library





In the BAND

Planetary radars operate at several radio frequencies. For historical reasons, frequency ranges are called *bands* and carry letter designations. The frequencies are listed in kilohertz (kHz), megahertz (MHz), or gigahertz (GHz), with 1 megahertz equaling 1 million wave-cycles per second. A gigahertz is 1,000 times higher than that in frequency, while a kilohertz is 1,000 times lower.

Ordinary broadcast bands (AM and FM radio, plus television) are shown for comparison. (For the curious, police radar uses X, K, or Ka band; garage door openers use X band; and microwave ovens can operate from 900 MHz to 2,560 MHz, or UHF to S band.)

Band	Frequencies	Length of Waves
AM	530–1,700 kHz	566–176 m (1,860'–578')
FM	88–108 MHz	341–278 cm (134"–109")
TV	55–800 MHz	545–34 cm (215"–15")
UHF	**420–450 MHz** (used at Arecibo)	**71–67 cm (28"–26")**
	890–942 MHz	34–32 cm (13"–12")
L	1,215–1,400 MHz	25–21 cm (10"–8.4")
S	**2,300–2,500 MHz** (Arecibo and Goldstone)	**13.0–12.0 cm (5.1"–4.7")**
	2,700–3,700 MHz	11.1–8.1 cm (4.4"–3.2")
C	5,250–5,925 MHz	5.7–5.1 cm (2.3"–2.0")
X	**8.5–10.68 GHz** (Goldstone)	**3.5–2.8 cm (1.4"–1.1")**
K	24.05–24.25 GHz	1.25–1.24 cm (0.5")
Ka	33.4–36.0 GHz	0.90–0.83 cm (0.35"–0.33")

S band is often called *decimeter* because waves are about 0.1 meter long. Band frequencies shown are those used in radar, not the band's full width. **Bold type** indicates the ranges most commonly used in planetary astronomy and planetary communications. —*RB*

Below: 1999 KW4 was the third binary near-Earth asteroid revealed by radar. Astronomers using the Goldstone radar telescope collected these images in May 2001. The three frames show several-hour time exposures of radar echoes from the binary asteroid. The secondary object moves around the primary clockwise. (Gaps in the trail are due to breaks in the data.) The primary is roughly 1.5 kilometers (0.9 mile) in diameter, while the secondary is roughly one-third as large. *Image: JPL/NASA*

within a few radii, say—could generate tidal forces to tear the objects apart."

"We will surely find more of these systems," Margot continues. "Based on our survey, about one NEA in every six bigger than 200 meters across could be a binary system. Calculations show that binary NEAs are produced frequently compared to their lifetimes in Earth-crossing orbits, which is about 10 million years. To see the number we do means that on a rough average, a new binary is made about every 20,000 years."

When the time comes that we have to divert an NEA from a collision course, we will need radar to learn its shape, density, rigidity, reflectivity, composition—and, most definitely, whether it is binary.

Scoping the Future

Asteroid radar has unique capabilities that have yielded striking results impossible to achieve except at much higher cost. In recognition of these capabilities, NASA recently spent $11 million to upgrade the Arecibo facility specifically for planetary radar studies, and it currently budgets almost $2.5 million for all kinds of asteroid studies, including radar. Yet radar faces significant challenges too.

All told, planetary radar commands a mere 8 percent

Far left: This composite of delay-Doppler images of 2000 DP107, obtained from Arecibo observations in September and October 2000, reveal the first near-Earth binary asteroid ever observed using radar. The primary (larger object), visible in the center of the image, is roughly spherical. The smaller component, or secondary, is shown at different phases of its orbital cycle. Although the orbit appears elliptical in this representation, it is actually circular in space.

Near left: Asteroid 2000 UG11 is the second near-Earth binary asteroid known. The primary (upper part of the image), which measures about 230 meters in diameter, is separated from the smaller secondary (bright dot below) by at least 300 meters. This image of 2000 UG11 was obtained on November 7, 2000. *Images: J. L. Margot, California Institute of Technology*

Asteroid 4179 Toutatis was discovered in 1989. Its eccentric, four-year orbit extends from just inside the Earth's orbit to the main asteroid belt between Mars and Jupiter. In September 2004, Toutatis will make the closest predicted approach to Earth of any asteroid or comet during the next 30 years. This highest-resolution image (below) shows craters with diameters ranging from about 100 to 600 meters. A computer-generated model (right) highlights the asteroid's asymmetrical shape. *Image below: JPL/NASA; Right: Scott Hudson, Washington State University*

of Arecibo's time, with roughly half of that devoted to asteroids; at Goldstone, the figure is 6 percent, and less than half that time is budgeted for asteroids. (Indeed, Goldstone's efforts will drop further as mission-tracking demands grow in the years ahead.) While some international radar experiments have been performed, US efforts will dominate as long as giant antennae set the pace. Planetary radar is a small field with a big reach, yet its visibility suffers from being buried within much larger operations.

So what future does radar have? There's clearly a need for it, given asteroid discovery rates, associated scientific questions, and concerns over tracking NEAs to determine hazards. Moreover, planetary radar can do such marvelous things as map the ice (or whatever it is) near Mercury's poles, probe the surface of Titan to preview what *Cassini* will find, and explore the near-nucleus region of comets—and all from Earth.

Planetary radar remains one of the most promising exploration technologies since spaceflight itself. It can give us vital information about the microworlds surrounding Earth—especially those that might harm us. It's important for the future of all of us to keep open this highly cost-effective window onto the solar system.

Robert Burnham is the author of the forthcoming constellation guide, Exploring the Starry Sky*, soon to be published by Cambridge University Press.*

Getting the RANGE on Asteroid RADAR

Online

The story of 1950 DA
neo.jpl.nasa.gov/1950da/

Asteroid radar research
echo.jpl.nasa.gov/

List of radar-detected asteroids
echo.jpl.nasa.gov/asteroids/index.html

Small-body astrometric radar observations
ssd.jpl.nasa.gov/radar_data.html

Asteroid shapes from radar
www.eecs.wsu.edu/~hudson/Research/Asteroids/index.htm

JPL's Sentry asteroid threat monitor
neo.jpl.nasa.gov/risk/

Asteroid and comet impact hazards
impact.arc.nasa.gov/

Asteroid collisions and impacts
www.es.ucsc.edu/~asphaug

Arecibo radio telescope
www.naic.edu/

Goldstone solar system radar
www331.jpl.nasa.gov/radar/

Basics of radio astronomy (orientation for beginners)
www.jpl.nasa.gov/radioastronomy

Basics of spaceflight (more orientation for beginners)
www.jpl.nasa.gov/basics

In Print

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Questions and Answers

How is it that a dust storm like the one recently detected on Mars can gather enough force to cover the entire planet? Considering Mars' thin atmosphere and distance from the Sun, that doesn't seem possible.
—Juan Ysit,
Mexico City, Mexico

One of the big challenges in understanding Mars is figuring out how such an event happens. We know the planet's dust is so fine that, even in Mars' thin atmosphere, it can stay suspended for months. But first, it must get off the ground, and that poses a mystery. Mars' winds are generally not strong enough to lift the dust—fine particles are sticky, and they tend to stay attached to whatever surface they're on.

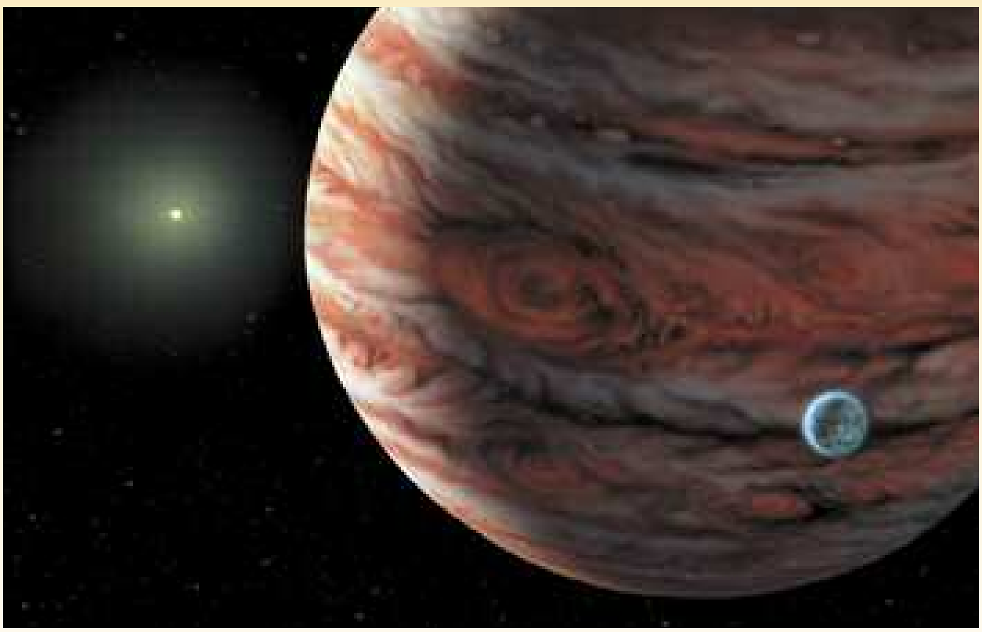
High wind speeds, however, are generated on Mars. The Sun heats the planet's surface much more than it does the atmosphere, causing that dark surface to become quite warm. Convection carries this surface heat upward through the atmosphere. Surface features or uneven heating may trigger the formation of a vortex—a spinning cylinder of air. If this vortex spins fast enough and then hits a dusty area, a dust devil is formed. We've seen dust devils on Mars from the ground as well as from orbit. They can be hundreds of meters across and kilometers high. We don't know if dust devils are involved in starting dust storms, but they do keep the atmosphere moder-

Factinos

Scientists have finally found a planetary system that reminds them of our own. On June 13, 2002, Geoffrey Marcy of the University of California, Berkeley, and Paul Butler of the Carnegie Institution of Washington announced the discovery of a Jupiter-like planet orbiting a Sun-like star at nearly the same distance that the Jovian system orbits our Sun (see painting below).

The newfound planet orbits at 5.5 astronomical units (AU), comparable to Jupiter's 5.2 AU distance from our Sun. (One AU equals the Earth-Sun distance of 150 million kilometers or 93 million miles.) The new planet's slightly elongated orbit takes it around its host star in about 13 years, comparable to Jupiter's orbital period of 11.86 years. The planet is between 3.5 and 5 times as massive as Jupiter.

"We haven't yet found an exact solar system analog, which would have a circular orbit and a mass closer to that of Jupiter. But this shows we are getting close, that we are at the point of finding planets at distances greater than 4 AU from the host star," said Butler. "I think we will be finding more of them among the 1,200 stars we are now monitoring."
—from NASA Headquarters



The newly discovered planet orbiting 55 Cancri is the closest thing scientists have found to a member of our own planetary system. The gas giant is shown here with a hypothetical icy moon. This system has two other confirmed planets, shown as small dots of light to the left and right of the parent star. The innermost planet (discovered by Geoffrey Marcy and Paul Butler in 1996) whips around 55 Cancri in only 14.6 days, while the middle world takes a bit more than 44 days to orbit the star. *Painting: Lynette Cook*

This past June, an asteroid made one of the closest approaches to Earth ever recorded. This is only the sixth time an asteroid has been seen to penetrate the Moon's orbit, and June's intruder is by far the biggest rock to do so. What has worried some scientists is that the object wasn't detected until June 17, three days after its initial flyby on June 14.

The space rock was found by researchers assigned to the Lincoln Labately dusty between storms.

Despite the planet's thin atmosphere, there is enough solar energy on Mars to trigger dust devils and dust storms. The trick will be to figure out why Mars experiences dust devils and small storms during some years, and why, during other years, it has global storms. So, I would ask not only how a global dust storm on Mars happens, but also why there isn't one every year.

—MARK T. LEMMON,
Texas A&M University

What is the hottest planet in the solar system?
—Shannon Hunt,
Victoria, British Columbia, Canada

You would think that because Mercury is closer to the Sun, it would be hotter than Venus. It's not. Indeed, during the daytime the surface of Mercury can get very hot—up to 430 degrees Celsius (800 degrees Fahrenheit). However, because it has no atmosphere, at night the surface can be very cold—as low as –180 degrees Celsius (–290 degrees Fahrenheit).

In contrast, Venus has a very dense atmosphere of carbon dioxide (CO_2) that acts as an insulating blanket for the planet, preventing heat from escaping and thus making it hotter than Mercury. Venus' surface temperature is a constant 470 degrees Celsius (880 degrees Fahrenheit), night and day.

Before the space age, scientists hoped that Venus' similarities to Earth—in both its size and its distance from the Sun—would make it a habitable destination for future astronauts. But radio observations of Venus made during the 1950s began to raise warning flags about the temperature of the planet's surface. In the early 1960s, Carl Sagan predicted that enough CO_2 in a planet's atmosphere could cause a runaway greenhouse effect in which trapped solar radiation would evaporate any oceans, cause carbon dioxide to accumulate, and result in unrestrained heating of the surface. Measurements by *Mariner 2* and the Soviet *Venera* spacecraft later confirmed the hellish conditions of high temperature and crushing atmospheric pressure on our sister planet.

—EMILY STEWART LAKDAWALLA,
Science and Technology Coordinator

oratory Near Earth Asteroid Research (LINEAR) program in Socorro, New Mexico. Cataloged as 2002MN, the asteroid was traveling at more than 10 kilometers a second (23,000 miles per hour) when it passed Earth at a distance of about 120,000 kilometers (75,000 miles). The last time such an object is recorded to have come that close was in December 1994.

With a diameter between 50 and 120 meters, the object is actually quite small when compared with many other asteroids and incapable of causing damage on a global scale. Nonetheless, if 2002MN had hit Earth, it would have caused local devastation similar to that which occurred in Tunguska, Siberia in 1908, when the air blast from an incoming object flattened 2,000 square kilometers (1,240 square miles) of forest.

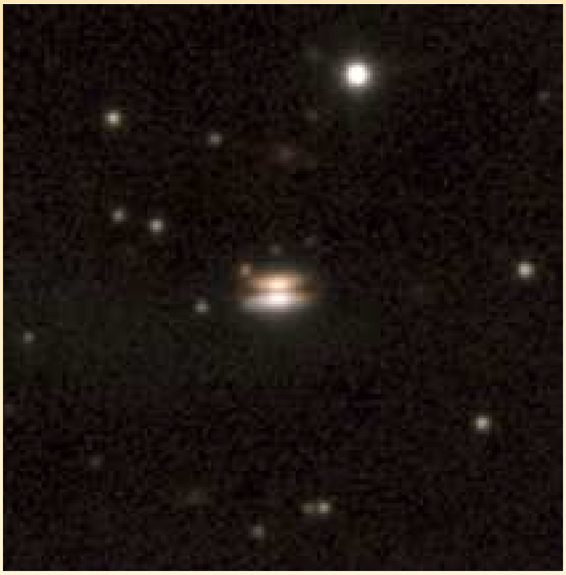
John Davies, of the Royal Observatory, Edinburgh, calculated the asteroid's orbit using the LINEAR data. He concluded that the object came from the direction of the Sun and was impossible for LINEAR to see until one hour after its closest flyby of Earth.

—from BBC News Online

A team of scientists has discovered a dusty and opaque disk surrounding a young solar-type star in the outskirts of a dark cloud in the Milky Way (see image at right). The new object appears to be a perfect example of a very young star encompassed by a disk in which planets are forming or will soon form. It provides a striking portrait of what our solar system must have looked like in its infancy. The team, led by Nicolas Grosso of Germany's Max Planck Institute for Extraterrestrial Physics, used the European Southern Observatory's 3.6-meter New Technology Telescope in La Silla and the Very Large Telescope at Paranal—both in Chile—to make the observations.

The disk of gas and dust is at least twice as massive as the planet Jupiter, and its radius measures about 45 billion kilometers (28 billion miles)—five times the size of Neptune's orbit. Because of the disk's appearance, researchers have nicknamed it the "Flying Saucer."

The object was discovered far from an active star-forming environment. Most young stars, especially those born in dense regions, run a serious risk that their natal dusty disks will be destroyed by the radiation of their more massive and hotter siblings. The star at



This close-up view of the dusty disk surrounding a young star was compiled from images taken on August 15, 2001, during follow-up observations from the European Southern Observatory's Very Large Telescope at Paranal, Chile. The two reflection nebulae are clearly visible and the dark dust lane well resolved, although the reddish aspect of the upper nebula is not yet fully understood.
Image: European Southern Observatory

the center of the "Flying Saucer" seems destined to live a long and quiet life in a planetary system very much like our own.

—from the European Southern Observatory

Society News

Society Members Save at Discovery Channel Stores

Planetary Society members can still receive a 10 percent discount on all telescopes and telescope accessories purchased at Discovery Channel Stores or online at *discoverystore.com*. Just show your Planetary Society membership card, or use the coupon code "PLANET" at the website, and receive this substantial members-only discount.

For nonmembers, the Discovery Channel Store is offering a free one-year Planetary Society membership to anyone who purchases a telescope at a Discovery Channel Store or online at the website before December 31, 2002. (Proof of purchase in the form of a receipt, along with name and return address, should be mailed directly to The Planetary Society at 65 Catalina Avenue, Pasadena, CA 91106.) So, tell your friends, members and nonmembers alike, about these great offers from the Discovery Channel Store.

—Linda Kelly, Program Development Manager

Expedition to Argentina

Interested in accompanying us on our next expedition? We are considering traveling to Argentina in January-February 2003 to study some intriguing outcrops in Patagonia. The expedition is still in the initial planning stages, so details are not yet available. If you're curious and want to be added to a list for updates, call Lu Coffing at (626) 793-5100, extension 234, or e-mail her at *lu.coffing@planetary.org*.

—Lu Coffing, Financial Manager

Society Joins AAA Michigan's Show Your Card & Save Program

The Planetary Society is offering a 25 percent discount on regular, student, and senior memberships to members of AAA Michigan as part of AAA Michigan's Show Your Card & Save Program. Information on the benefits of Society membership can be found in AAA Michigan's *Michigan Living Magazine* and on AAA Michigan's website, *www.autoclubgroup.com/michigan*.

All new Society members in Michigan will receive information about the AAA discount, as well as a one-time opportunity to renew their Planetary Society membership at the AAA rate.

—LK

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If you've visited The Planetary Society store online at *planetary.org*, you may have noticed that the prices shown are higher than those listed in *The Planetary Report*. Because *The Planetary Report* is a members-only publication, we can advertise discounted members-only prices. The online prices are intended for the general public (and are therefore higher). Society members can obtain the same prices online as they are listed in the magazine by entering the coupon code "TPSDIS" at checkout.

The members-only discount code also applies while shopping at our online store partner, *spacemedia.com*, which offers unique space-related products including space art, models, DVDs, patches, and other collectibles.

Whether you're shopping via *The Planetary Report* or The Planetary Society store online, we strive to keep our prices as low as possible for our members.

—Jennifer Vaughn, Managing Editor

Planetary Society Honors Bruce Murray

On June 8, hundreds of friends of The Planetary Society gathered at the Millennium Biltmore Hotel in Los Angeles to honor cofounder Bruce Murray upon his retirement as president. Dr. Murray now ascends to chairman of the Board.

The evening included a VIP reception, silent auction, four-course dinner, and tribute to Bruce led by Society Board member Bill Nye the Science Guy, Society Executive Director Louis D. Friedman, renowned author and Society adviser Ray Bradbury, and Society Vice President Neil de Grasse Tyson.

For a more in-depth story and pictures of the event, visit our website, *planetary.org*.

—JV

Planetary Society Member Names to Land on an Asteroid

The Planetary Society has teamed with The Planetary Society of Japan (TPS/J) to fly the names of all our members—past and present—to an asteroid on the Japanese mission *MUSES-C*. The 560,000 member names will be combined with more than 200,000 individual submissions from around the world.

Our affiliated organization, TPS/J, coordinated with Japan's Institute of Space and Astronautical Science (ISAS) to fly the names on *MUSES-C*, the first sample return mission to an asteroid.

The names will be etched on an aluminum foil sheet, which will be enclosed inside a target marker—a softball-size container. The target marker will be released onto the asteroid surface as a guide to enable the spacecraft to touch down safely to collect samples. ISAS will launch *MUSES-C* in November or December 2002.

—Susan Lendroth, Manager of Events and Communications

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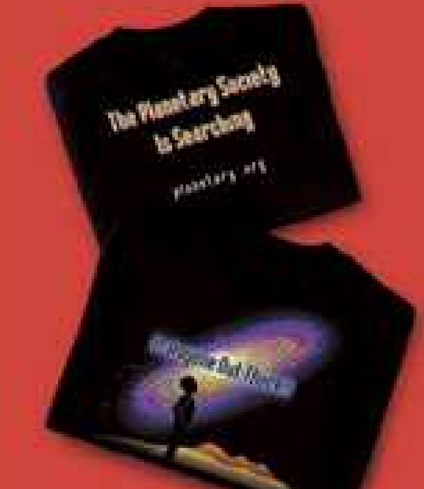

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Most of the extrasolar planets known to us today have been compared to Jupiter. When will we learn of another world like our own? Scientists all over the globe are working diligently to find one. In *Alien Sea*, a Moon-like satellite looms large in the dreamy skies above an Earth-like planet's calm blue ocean.

David Palermo is an artist who thinks of himself mainly as a photographer. He describes his work as "part analog, part digital"—which means that he usually starts with a photograph of a landscape and then embellishes it with computer-generated art. He lives and works in Santa Barbara, California.

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