Radar “Eyes”
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

Features

4 The Mars Odyssey Continues

In May, the Mars Odyssey mission team announced that the spacecraft’s Gamma Ray Spectrometer (GRS) had detected large amounts of hydrogen—inferrred as water-ice—around Mars’ south pole. The Society’s director of projects, Bruce Betts, has been following Mars Odyssey since it entered Mars orbit last fall. Here, Bruce continues his coverage, examining the GRS results and updating us on the mission’s progress.

8 Extra! Extra! Read All About It: Extrasolar Planets on the Rise!

Back in 1982, The Planetary Society began supporting searches for extrasolar planets—we were among the first to grasp the potential significance of finding worlds like ours circling other stars. Projects we initiated—one led by George Gatewood at the Allegheny Observatory in Pittsburgh and another by Bruce Campbell at the University of Victoria in British Columbia—advanced the field but made no confirmed discoveries. Since then, more than 60 Jupiter-size extrasolar worlds have been discovered. Now, we are sponsoring a new program at the Kitt Peak National Observatory. Project leader Steve Howell reports on its progress.

14 Taking the Measure of Microworlds

Asteroids are small, dark, distant, and, in general, hard to see. Even using the most powerful optical telescopes, we observe them only as points of light or streaks against a star field. Scientists have, however, developed the means to render exact orbits and give shape to points of light: radar astronomy. Science writer Robert Burnham reports on the discoveries of this little-known but highly productive technology.

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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 space-faring 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
GILHOOLY,
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 to 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 well can I share with readers this glorious journey of the soul we call science?’”

Please send your letters to Members’ Dialogue
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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—inferring 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...
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 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,
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.

**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 environ-
ment two to three times harsher than at the
International Space Station.

**A Boom with a View**

*Odyssey* accomplished its last major engi-
neering task on June 4, 2002, when it suc-
sessfully 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 be-
hind 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. Be-
fore boom deployment, the sensor head
was able to detect strong signals that over-
came the spacecraft contribution—such as
the hydrogen in the south polar region.
But for elements common in the space-
craft, such as aluminum, the boom de-
ployment is critical to obtaining a de-
tectable 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.

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Bruce Betts is director of projects at The Planetary Society.
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.
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-
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

![Image of a telescope and stars]

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 Roboticly 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.

![Graph of photometric precision vs. star type]

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 Roboticly 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.
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.
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.
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 astronony, 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
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
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
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—
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

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**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 2,550 MHz, or UHF to S band.)

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

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
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.
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-

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

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 Lab-
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 the center of the “Flying Saucer” seems destined to live a long and quiet life in a planetary system very much like our own.
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
Is Anybody Out There?" Poster
Can we be alone in the universe? This astounding image, obtained by the Two Micron All Sky Survey, reveals only a fraction of the 400 billion stars in our own Milky Way galaxy. Surveying such abundance, one can’t help but wonder how many of these suns support planets and how many of those planets nurture life.
16" x 39" 1 lb. #795 $16.00

Is Anybody Out There?" T-Shirt
As we gaze upon the heavens at a vibrant spiral galaxy, the question arises, “Is anybody out there?” This dramatic T-shirt captures the feeling of wonder when pondering our place in the universe.
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Future Martian T-Shirt
Child sizes: S, M, L
1 lb. #565 $13.50

Pale Blue Dot Poster
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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.