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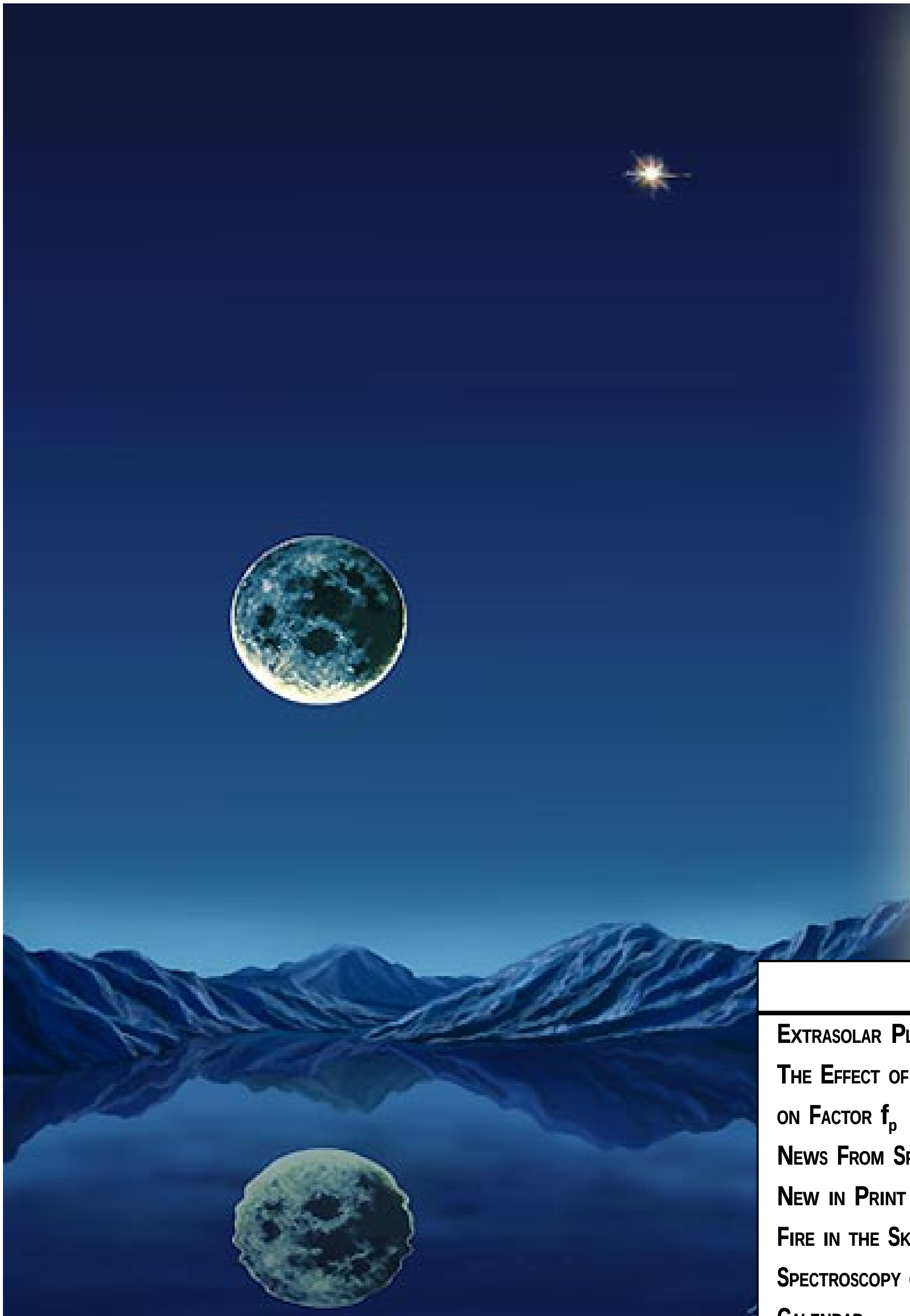

EXTRASOLAR PLANETS

THE SEARCH FOR NEW WORLDS

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EXTRASOLAR PLANETS:

THE SEARCH FOR NEW WORLDS

By

D. B. Anderson

In recent years, headlines have trumpeted the beginning of a new era in humanity's exploration of the universe: "A Parade of New Planets" (*Scientific American*), "Universal truth: Ours Isn't Only Solar System" (*Houston Chronicle*), "Three Planets Found Around Sunlike Star" (*Astronomy*).

With more than 20 extrasolar planet or planet candidate discoveries having been announced in the press since 1995 (many discovered by the planet-searching team of Geoff Marcy and Paul Butler of San Francisco State University), it would seem that the detection of planets outside our own solar system has become a commonplace, even routine affair. Such discoveries capture the imagination of the public and the scientific community, in no small part because the thought of planets circling distant stars appeals to our basic human existential yearning for meaning.

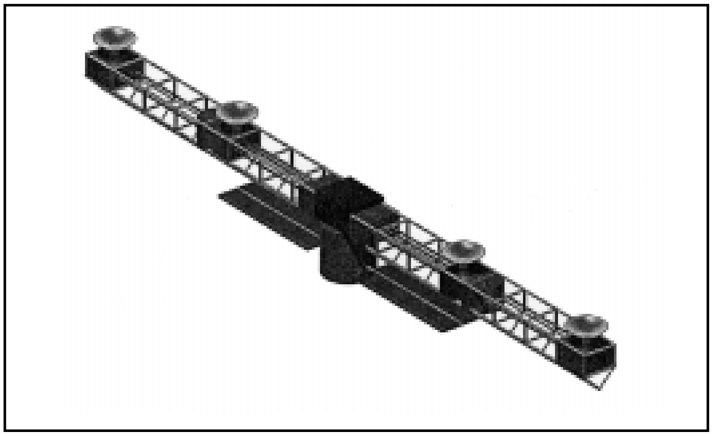
In short, the philosophical implication for the discovery of true extrasolar planets (and the ostensible reason why the discovery of extrasolar planets seems to draw such publicity) is akin to when the fictional mariner Robinson Crusoe first spotted a footprint in the sand after 20 years of living alone on a desert island. It's not exactly a signal from above, but the news of possible extrasolar planets, coupled with the recent debate regarding fossilized life forms in martian meteorites, heralds the beginning of a new way of thinking about our place in the universe.

While philosophers such as Giordano Bruno, who in 1584 declared the existence of "countless earths," have pointed to the intuitive, metaphysical improbability that we are indeed alone, astronomers have sought harder evidence. The recent discovery of low-mass companions around other stars would seem to be the concrete evidence they have been waiting for.

But do the observational data as collected so far truly point to extrasolar planets as the most probable culprit? Or are these "unseen" objects in fact low-mass brown dwarfs or some other, as-yet-unnamed type of object. It would in fact be a remarkable thing if our Sun were the only star in the universe to have a retinue of planets revolving around it. But such intuitive reasoning cannot be used as the basis for scientific conclusions. While the discussion regarding these objects is in fact evolving, and even planet hunters such as Marcy are cautious about using the term "planet," it is important to provide a balance to the way the term is used with such unabashed enthusiasm in the press, and to explore the possible alternative explanations for these objects.

HOW ARE PLANETS DETECTED?

Astronomers generally use two different kinds of methods in the search for other planetary systems: direct detection and indirect detection. Using direct detection methods, astronomers observe either reflected (e.g., visible light) or intrinsic (e.g., thermal) radiation from the planet. Direct detection methods must minimize or eliminate light from the star around which the planet revolves. In contrast, astronomers using indirect methods observe the star for measurable effects (e.g., gravitational perturbation, or a "wobble" in the star's movement) that unseen companions would have on a star. Each of the two techniques reveals different properties and data about the objects observed. For instance, both the direct and indirect method can be used to discern the orbital period of a planet. But only the direct method can be used



Artist's conception of the Planet Finder, a space-based interferometer that could be used to detect Earth-like planets.

to determine the planet temperature and atmospheric composition, and only the indirect method can be used to determine the orbital structure (e.g., the inclination of the orbit) and planet mass.

Because of the problem of the distances involved and the relative brightness of stars to their companions, it appears unlikely that we will be able to detect planetary systems through direct methods using current telescopes anytime in the near future. One exception would be young, Jupiter-like planets that would be hotter and brighter than a mature planet, thus making them easier to detect.

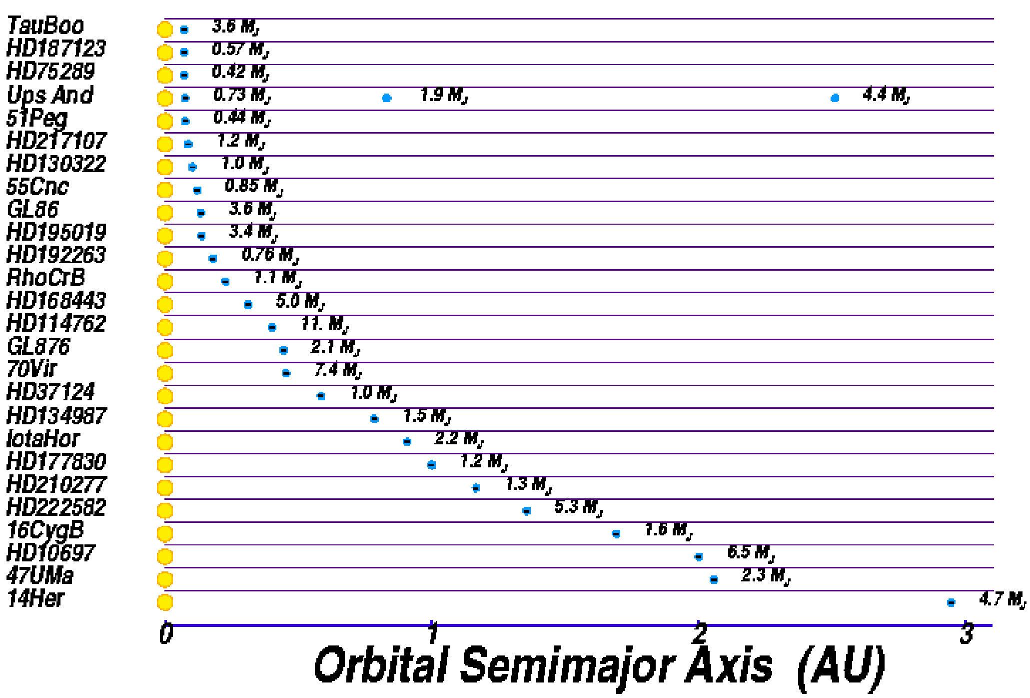
Two indirect methods have surfaced as the most reliable techniques for detecting extrasolar companions: astrometric and radial velocity observations**.** Both of these methods are based on the fact that if a star has companions orbiting it, the star itself revolves around the center of mass (also called the barycenter) of the entire system.

Using astrometric detection, observers look for a slight "zig-zag" motion in a star as it makes its way across the sky. This method requires precise, laborious observation of a star's position over time, and no companions have been detected thus far through the astrometric method alone. However, a NASA Explorer program mission planned for 2004, the Full-sky Astrometric Mapping Explorer, will perform precise brightness and position measurements of approximately 40 million stars and will be able to detect large planets within 1,000 light years of the Sun using the astrometric method.

By contrast, radial velocity observations rely on measuring changes in the star's spectrum over time. This method, which has been the technique of choice thus far, looks for periodic Doppler shifts in the light of the star, thus signaling the presence of a companion.

(Another method, photometric detection, would involve detecting a "dimming" in a star due to a companion blocking some of the light of the star as seen by the observer, a sort of "interstellar eclipse." Although this method seems to rely on an unlikely, chance alignment of orbits and observer, it could hold promise if observations were systematically done on thousands of stars at a time. In fact, in November, a team based at the Harvard Center for Astrophysics announced such a discovery around star HD 209458. Using a related method, gravitational lensing, astronomers look for a magnification of light from a distant star as a result of a planet or star passing in front of the path of its light.)

To date, radial velocity observational programs in Switzerland, California, and Texas have detected an array of some 20-odd low-mass companions, most with "minimum masses" at or below 10-



Graph courtesy of Geoffrey W. Marcy, San Francisco State University.

Jupiter masses, that merit further examination and observation. With time, and with further direct observation as the technology becomes available, these "companions" may yet reveal themselves to be low-mass brown dwarfs (as other objects discovered in these programs have been confirmed to be), bona fide planets, or members of an entirely new class of objects that has yet to be named or defined.

WHAT'S IN A NAME?

Some believe the decisions whether to call these objects planets or something else entirely centers around an essentially "unknowable" factor, i.e., how these extrasolar objects formed. A "brown dwarf" is basically a star that never becomes hot enough to begin hydrogen fusion, whereas a planet is believed to form through accretion. Others believe the debate concerns the mass of these objects; the generally accepted definition of a planet allows for a mass no larger than 10 Jupiters, at which point it would become a brown dwarf (i.e., a substellar object). So why not just call them planets, as most of the objects are in fact less than 10 Jupiter masses? After all, as seen from the recent "Pluto debate," the definition of a planet may have more to do with tradition than anything else.

Much of the current discussion surrounding the discovery of extrasolar companions hinges on the mass of the objects. Yet no lower limit for the mass of brown dwarfs has been determined, so the primary definition of a brown dwarf still rests on how it formed. Current theory holds that if a companion with at least 10 Jupiter masses formed from a collapsing cloud of interstellar gas, it would be termed a brown dwarf. Objects in the range of 10 to 80 Jupiter masses cannot fuse hydrogen, but have enough mass to ignite deuterium fusion in their cores.

A planet, on the other hand, is traditionally defined as an object that forms through accretion, or the accumulation of matter (whether gas or solids) from the original stellar disk. While the debate surrounding Pluto's status as a planet, minor planet, or asteroid is surely one of semantics, as all these bodies are thought to form through the same process of accretion, the difference between brown dwarfs and planets is a more fundamental difference. While no upper limit for planets or lower limit for

Masses and Orbital Characteristics of Extrasolar Planets

	Star Name	Msini (Mjup)	Period (d)	Semimajor Axis (AU)	Eccentricity	K (m/s)
1	HD 187123	0.52	3.097	0.042	0.00	72
2	Tau Bootis	3.64	3.3126	0.042	0.00	469
3	HD 75289	0.42	3.508	0.047	0.00	54
4	51 Pegasi	0.44	4.2308	0.051	0.01	56.
5	Upsilon Andromedae (b)	0.69	4.617	0.059	0.04	73.
6	Upsilon Andromedae (c)	2.0	241.3	0.82	0.23	54.
7	Upsilon Andromedae (d)	4.1	1280.6	2.4	0.31	67.
8	HD 217107	1.28	7.11	0.07	0.14	140
9	Rho1 55 Cancri	0.85	14.656	0.12	0.03	75.8
10	Gliese 86	3.6	15.8	0.11	0.04	379
11	HD 195019	3.43	18.3	0.14	0.05	268
12	Rho Corona Borealis	1.1	39.6	0.23	0.1	67.
13	HD 168443	5.04	58	0.28	0.54	330
14	Gliese 876	2.1	60.9	0.21	0.27	239.
15	HD114762	11.0	84	0.41	0.33	619
16	70 Virginis	7.4	116.7	0.47	0.40	316.8
17	HD 210277	1.36	437	1.15	0.45	41
18	16 Cygni B	1.74	802.8	1.70	0.68	52.2
19	47 Ursae Majoris	2.42	1093	2.08	0.10	47.2
20	14 Herculis	4	~2000	~3	~0.35	80
21	Iota Hor	2.26	320	0.91	0.16	80
22	HD130322	1.08	10.7	0.103	0.03	115
23	HD192263	0.76	24.1	0.18	0.12	68
24	HD10697	6.59	1083	2.0	0.12	123
25	HD37124	1.04	155	0.585	0.19	43
26	HD134987	1.58	260	0.78	0.24	50
27	HD177830	1.28	391	1.00	0.43	36
28	HD222582	5.4	576	1.35	0.71	187

Table courtesy of Geoffrey W. Marcy, San Francisco State University.

brown dwarfs has been established, a small brown dwarf cannot be called a planet, and a large planet cannot arbitrarily be termed a brown dwarf.

Similarly, just as the lack of a lower mass limit for planets sparked much of the "Pluto controversy," the lack of a clear limit for brown dwarfs presents a problem when attempting to classify extrasolar low-mass companions. As Dr. David Black of the Lunar and Planetary Institute has pointed out, few objects in nature are so clearly delineated, and there is no reason to expect that brown dwarfs should fall on any more clear of a continuum than do planets and asteroids.

Moreover, the "unknowable" factor of how a companion formed may not be so unknowable. A companion formed through accretion, such as a planet, would tend to reveal the presence of more heavy elements, whereas a strong compositional similarity between a companion and its star might indicate a brown dwarf or object formed in a manner similar to a star. Spectral observations (through "direct detection" methods) may one day reveal these characteristics; the same methods may one day reveal, through the detection of significant quantities of life-related gases such as oxygen and methane, whether a planet is habitable or possibly inhabited.

A BREED APART

At present, the more nagging issue may be the fact that the masses, orbital periods, and eccentric orbits of the companions detected so far are not consistent with what we know about planets in our own solar system. The smallest object thus detected has a *lower-limit* mass of approximately one-half that of Jupiter, but most of the objects have masses greater than that of Jupiter, up to 10 times more. This fact, coupled with the fact that the objects appear to orbit the stars at relatively close distances (most orbit at less than half the distance of the Earth to the Sun) seems to point to the anomalous nature of these companions. Stated simply, they do not fall into our traditional schematics of how solar systems form – e.g., that gas giants form at relatively great distances from the Sun, where cold temperatures allow for ice and frozen gases to accumulate.

(While the typical explanation for these large, presumably gaseous objects being so close to the star is that they migrated toward the star after forming, no compelling mechanism has yet been proposed on how this migration would occur for such a large fraction of the systems. It is yet another problem that must be overcome in order to definitively tag these objects as planets.)

It makes sense that most of the companions discovered so far have been short-period, giant objects, since these are the easiest to detect in short periods of time using the Doppler technique. The detection of Earth-like bodies – set as a priority by NASA administrator Daniel S. Goldin – will likely have to await the launching of a space-based interferometer (an array of telescopes). Discussion and research into building such a interferometer is already under way.

Moreover, most of the companions detected appear to be single companions, which would fall outside of what we believe to be true about planetary systems – that is, that the process of planet formation is more likely to lead to multiple companions, as seen in the solar system and in the micro-systems of Jupiter, Uranus, and Saturn. (On this question, the Upsilon Andromedae system is often held up as proof of a system at least superficially like our own in that it may have three planets or more circling a single star. Yet the three-planet model for the U.A. system remains somewhat controversial.)

The notion of planets circling solar-like stars tugs at our collective desire for to succeed in the search for other worlds like our own, an extension of the philosophical paradigm shift set in motion by Copernicus, and these early discoveries have only piqued our curiosity. Indeed, it seems promising and even likely that such objects will be confirmed in years to come. Until then, we should proceed with caution, with suspicious minds attuned to the possibility that the footsteps in the sand may be an indication of something other than a companion living on the other side of the island. ⌀

SOLAR CANNIBALS DEVOUR NEAREST NEIGHBORS

According to scientists at the Space Telescope Science Institute, perhaps as many as 100 million of the Sun-like stars in our galaxy once harbored close-orbiting gas giant planets like Jupiter or brown dwarfs that were doomed to be gobbled up by their parent stars.

STScI astronomer Mario Livio and postdoctoral fellow Lionel Siess say they did not directly observe the planets, because they had already been swallowed by their parent stars.

But Livio says he did find significant telltale evidence that some giant stars once possessed giant planets that were then swallowed. The devouring stars release excessive amounts of infrared light, spin rapidly, and are polluted with the element lithium. About 4 to 8 percent of the stars in the galaxy display these characteristics, according to Livio and Siess.

An aging solar-type star will expand to a red giant and in the process engulf any close-orbiting planets. If the planets are the mass of Jupiter or larger, this process will have a significant effect on the red giant's evolution.

First, according to Livio's calculations, such a star becomes bigger and brighter because it absorbs gravitational energy from the orbiting companion. This heats the star so that it puffs off expanding shells of dust, which radiate excessive amounts of infrared light.

The orbiting planet also transfers angular momentum to the star, causing it to spin at a much faster rate than it would normally have. Finally, a chemical tracer is the element lithium, which is normally destroyed inside stars. A devoured Jupiter-like planet would provide a fresh supply of lithium to the star, and this shows up as an anomalous excess in the star's spectrum.

In our solar system Jupiter is too far from the Sun to be swallowed up when the Sun expands to a red giant in about 5 billion years. However, detections of large-mass companions with unexpectedly close orbits may reveal worlds that are doomed to be eventually swallowed and incinerated. ⌀

THE EFFECT OF PLANET DISCOVERIES ON FACTOR f_p

What exactly are the stakes involved when debating the reality of extrasolar planets?

Implicit in any discussion of extrasolar planets is that the discovery of these objects means something significant — that planets exist outside our own solar system. Whether or not these particular objects are capable of harboring life (and if they are gas giants, it would seem unlikely based on our current knowledge), the very existence of these companions seems to open up new realms of possibilities for life elsewhere.

While the confirmed existence of extrasolar planets would not come close to proving the existence of life elsewhere, it would certainly open a floodgate in the way we think about our place in the universe, yet another in the series of ego-shattering discoveries since Copernicus first postulated that Earth was not the center of the universe. The discovery of brown dwarfs, adding to the incomprehensible roster of extinct and would-be stars, while significant from a scientific standpoint, admittedly does not have this kind of dramatic appeal.

Those familiar with the Drake Equation, an esoteric mathematical formula used to estimate the number of advanced technical civilizations in the Milky Way galaxy, might conjecture that the discovery of extrasolar planets would affect estimates of factor f_p, which represents the fraction of stars in the galaxy that form planets.

Dr. Frank Drake, director of the SETI Institute (which is no longer funded by NASA) and creator of the Drake Equation, does not believe the recent discovery of low-mass companions, even if they were confirmed to be planets, would affect factor f_p or that it would affect the overall mathematical likelihood of intelligent life existing elsewhere in the universe.

"It essentially confirms what we already believed to be true – that planets are relatively abundant in the universe," Drake said.

Of course, theorists such as Drake and others who speculate on the likelihood of the existence of life elsewhere in the universe traditionally hold out optimistic values for the factors in the Drake Equation. In the past, Drake and his colleagues have estimated the fraction of stars forming planets to be anywhere from one-fifth to one-half. Other scientists believe the confirmed existence of extrasolar planets would affect — if not mathematically, then intuitively — the likelihood for life elsewhere.

Drake

"For me, it quite dramatically changes my view of the possibility of life in the universe in a real, empirical, hard-evidence sort of way," San Francisco State astronomer Debra Fischer told the *Florida Day* recently.

The other factors in the Drake Equation (as originally conceived) include the rate of star formation, the number of planets hospitable to life, the fraction of those planets where life actually forms, the fraction of planets where life evolves into intelligent beings, the fraction of planets with intelligent creatures capable of interstellar communication, and the length of time that such a civilization remains detectable.

Drake and his colleagues first pondering the question in 1961 concluded that the number of intelligent, communicative civilizations in the universe would boil down to the value of L (the length of time that an intelligent civilization remains detectable). Even with our own civilization only having been detectable for some 50 years, and the threat of nuclear war and other hazards looming strong in the early 1960s, Drake and other scientists attending that early meeting (including J. Peter Pearman and Carl Sagan) still pegged the low-end estimate of the number of technological civilizations in the Milky Way galaxy at a staggering 10,000. But as far as hard, scientific evidence goes, the question remains decidedly open. ∅

—D. B. Anderson

FURTHER READING ON EXTRASOLAR PLANETS

Websites:

Extrasolar Planet Search Project, San Francisco State University http://www.physics.sfsu.edu/~gmarcy/planetsearch/planetsearch.html

The Extrasolar Planets Encyclopaedia http://cfa-www.harvard.edu/planets/

Extrasolar Visions (a collection of speculative artwork) http://www.jtwinc.com/Extrasolar/

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Marcy G. W. et al. (1999) "Extrasolar Planets Around Main Sequence Stars." *Protostars and Planets IV,* in press.

Marcy G. W. and Butler R. P. "Giant Planets Orbiting Faraway Stars." Scientific American. Available at http://astron.berkeley.edu/~gmarcy/sciam.html.

Stepinski T.F. and Black D.C. (1999) "Statistics of Low-Mass Companions to Stars: Implications for Their Origin." *ApJ,* submitted.

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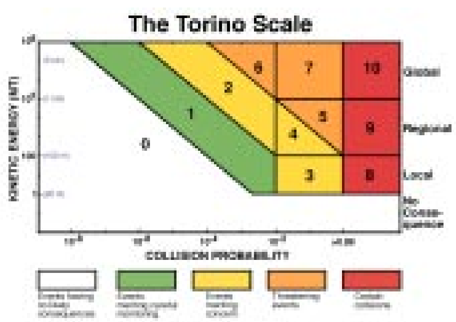
Goldsmith, Donald. *Worlds Unnumbered: The Search for Extrasolar Planets.* Sausalito, Calif.: University Science Books, 1997. (Reviewed in *LPIB 83*.)

Lemonick, Michael D. *Other Worlds: The Search for Life in the Universe.* Touchstone Books, 1999.

NEWS FROM SPACE



NEW SCALE ASSESSES IMPACT HAZARD

Planetary scientists have developed a new risk-assessment scale, similar to the Richter scale used for earthquakes, to assign values to asteroids and comets moving near Earth.

The Torino Impact Hazard Scale, developed by Dr. Richard P. Binzel at the Massachusetts Institute of Technology, will run from zero to 10. An object with a value of zero or 1 will have virtually no chance of causing damage on Earth; a 10 means a certain global climatic catastrophe.

“These events have a small probability of occurring, but if they happen they can have severe consequences,” said Binzel. “It is difficult to figure out what level of anxiety we should have about an approaching asteroid or comet. I hope the Torino scale will put in perspective whether a Near-Earth Object merits public concern, just as the Richter Scale does with earthquakes.”

The scale was adopted by the International Astronomical Union in June 1999. “What I find especially important about the Torino impact scale is that it comes in time to meet future needs as the rate of discoveries of Near-Earth Objects continues to increase,” said Dr. Hans Rickman, IAU Assistant General Secretary.

The scale takes into account the object’s size and speed, as well as the probability that it will collide with Earth. The scale can be used at different levels of complexity by scientists, journalists, and the public.

Close encounters, assigned Torino-scale values from 2 to 7, could be categorized as ranging from “events meriting concern” to “threatening events.” Certain collisions would merit values of 8, 9, or 10, depending on whether the impact energy is large enough to cause local, regional, or global devastation.

Binzel, who has been working on the scale for five years, noted that no asteroid identified to date has ever had a value greater than 1. Several asteroids that had initial hazard scale values of 1 have been reclassified to zero after additional orbit measurements showed that the chances of impact with the Earth were essentially zero.

“Nobody should lose sleep over an asteroid in the zero or 1 category,” Binzel said. “Scientists haven’t done a very good job of communicating to the public the relative danger of collision with an asteroid. The Torino Scale should help us clearly inform but not confuse the public.”

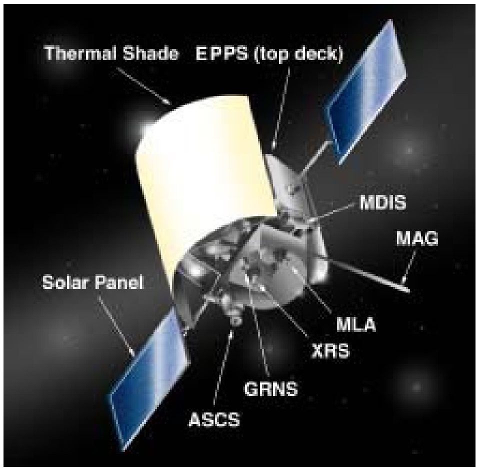
A more detailed explanation of the points on the Torino scale and related graphics are available on the Internet at http://impact.arc.nasa.gov.

NASA GREENLIGHTS MERCURY MISSION

The first comprehensive mission to map pockmarked Mercury and a mission to excavate the interior of a comet have been selected as the next flights in NASA’s Discovery Program.

The MErcury Surface, Space ENvironment, GEochemistry and Ranging mission, or MESSENGER, will carry seven instruments into orbit around the closest planet to the Sun. It will send back the first global images of Mercury and study its shape, interior, and magnetic field. Dr. Sean Solomon of the Carnegie Institution, Washington, DC, will lead MESSENGER.

The Deep Impact mission will send a 500-kilogram copper projectile into Comet P/Tempel 1, creating a crater as big as a football field and as deep as a seven-story building. A camera and infrared spectrometer on the spacecraft, along with groundbased



MESSENGER's propulsion system is integrated into the spacecraft structure, making economical use of mass. The miniaturized instruments are located on a science deck facing Mercury, while the spacecraft is shielded from the blistering sunlight by a lightweight thermal shade. Most of the instruments are fixed-mounted, so that coverage of Mercury is obtained by spacecraft motion over the planet. The imaging system uses a miniature scan mirror so that it can quickly build up image mosaics of the planet.

observatories, will study the resulting icy debris and pristine interior material. Dr. Michael A'Hearn will lead Deep Impact from the University of Maryland in College Park.

"MESSENGER is a flagship-quality effort that, in tandem with a separate Pluto mission, enables us to seize the opportunity to complete our historic initial reconnaissance of the solar system," said Dr. Edward Weiler, associate administrator for space science at NASA Headquarters in Washington.

MESSENGER, to be launched in spring 2004, will be NASA's first mission to Mercury since the Mariner 10 flybys in 1974 and 1975, which provided information on only half the planet. Its challenging flight plan begins with two Venus flybys, then two Mercury flybys in January and October 2008 and a subsequent orbital tour of Mercury beginning in September 2009.

Among MESSENGER's goals will be to discover whether Mercury has water ice in its polar craters. The cost of MESSENGER to NASA is $286 million. It will be built and managed by the Johns Hopkins University's Applied Physics Laboratory, Laurel, Maryland. Further information about the mission is available on the Internet at http://sd-www.jhuapl.edu/MESSENGER.

Deep Impact will be launched in January 2004 toward an explosive July 4, 2005, encounter with P/Tempel 1. It will use a copper projectile because that material can be identified easily within the spectral observations of the material blasted off the comet by the impact, which will occur at an approximate speed of 22,300 miles per hour (10 kilometers per second). The total cost of Deep Impact to NASA is $240 million. Deep Impact will be managed by NASA's Jet Propulsion Laboratory in Pasadena, Calififornia, and built by Ball Aerospace in Boulder, Colorado.

FAST-SPINNING ASTEROID STUDIED

Spinning faster than any object ever observed in the solar system, a lumpy, water-rich sphere known as 1998 KY26, measuring about the diameter of a baseball diamond, is rotating so swiftly that its day ends almost as soon as it begins, NASA scientists report.

Asteroid 1998 KY26, where the Sun rises or sets every five minutes, was observed June 2–8, 1998, shortly after it was discovered and as it passed 800,000 kilometers (half a million miles) from Earth, or about twice the distance between Earth and the Moon. Publishing their findings in a recent issue of *Science* magazine, Dr. Steven J. Ostro of NASA's Jet Propulsion Laboratory, Pasadena, California, and an international team of astronomers used a radar telescope in California and optical telescopes in the Czech Republic, Hawai'i, Arizona, and California to image the 30-meter, water-rich ball as it twirled through space. It is the smallest solar system object ever studied in detail.

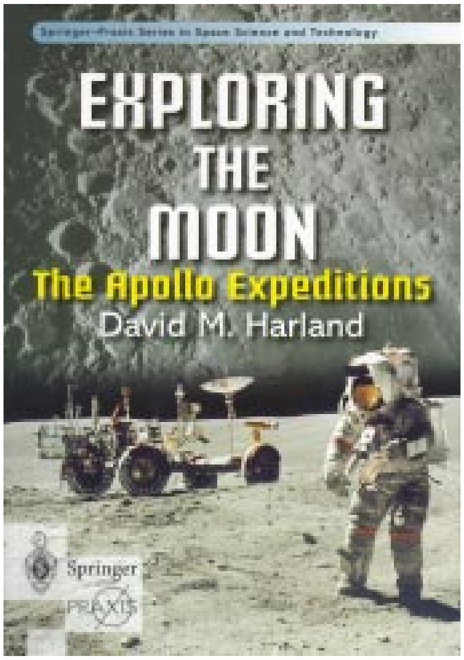
"Enormous numbers of objects this small are thought to exist very close to Earth, but this is the first time we've been able to study one in detail. Ironically, this asteroid is smaller than the radar instruments we used to observe it," Ostro said.

The asteroid's rotation period was calculated at just 10.7 minutes, compared to 24 hours for Earth and at least several hours for the approximately 1000 asteroids measured to date. In addition, the minerals in 1998 KY26 probably contain about a million gallons of water, enough to fill two or three olympic-sized swimming pools, Ostro said.

Continued on page 15

NEW IN PRINT

These publications are available from the publisher listed or may be ordered through local bookstores.



REVIEW

EXPLORING THE MOON: The Apollo Expeditions
by David M. Harland
397 pages
Springer-Verlag and Praxis Publishing, 1999

Over the years, many books of varying quality have been written about the Apollo program. A number of such books have been published recently to coincide with the 30-year anniversary of Apollo 11. Of these recent books, David Harland's *Exploring the Moon* deserves particular attention.

Harland does not attempt a comprehensive discussion of the Apollo program. The robotic precursors to Apollo are covered in just 20 pages, Apollo 11 in just eight pages, and the Apollo 13 near-disaster in a mere two paragraphs. Instead, the focus is on the scientific exploration, and in particular the field geology, performed by the Apollo crews. Given this focus, it is inevitable that the bulk of the book is devoted to the final three Apollo missions, which included the vast majority of geologic research performed during the Apollo program. Each of these three missions is discussed in detail: Apollo 15 receives a full 100 pages and Apollo 16 and 17 more than 60 pages each. Less detailed treatments are also included of the Apollo 12 and 14 geologic traverses.

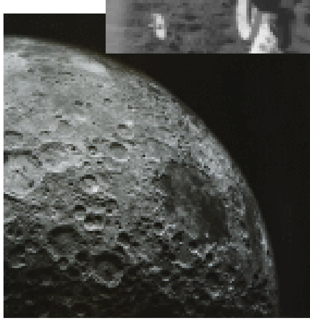
As the book progresses through each EVA, a clear sense emerges of what it was like to work on the Moon, including both the challenges and the pleasures. The reasons for choosing particular field stations and the selection of particular samples are explained: We learn not just what was done, but also why it was done. We also see the interaction between the crew's observations and the recommendations of the geologists in Mission Control's "Back Room" as the schedule was adapted to fit the contingencies that occurred on each mission. The ever-present sense of time pressure, of trying to extract the most science possible into a limited period of time, and the frustrations of occasionally having to abandon important objectives, are portrayed well. End-of-chapter summaries place the results of each mission into context, describing how each mission influenced our understanding of that particular landing site and contributed to our understanding of the Moon as a whole. Many of the technical terms that are used are explained in the text when first introduced, but nongeologists will also appreciate the 13-page glossary at the back of the book.

Some mistakes are inevitable in any book of this depth. For example, Harland describes several Apollo 16 impact melts as igneous rocks. Apollo 16 was in fact targeted to search for highland volcanism, but actually found a terrain that was thoroughly controlled by large basin impact ejecta. The impact melts that Harland cites as igneous are actually extreme examples of impact processing. Perhaps because of my own research background, I found more to quibble with in the discussions of geophysics experiments and the internal structure of the Moon. I was surprised, for instance, to read that the Moon's mantle might be too thick to be convecting at present. In fact, thicker layers make it easier for convection to occur, and the vigor of convection in a planet is controlled mostly by its internal temperature. Deep in its interior, weak convective motions may still be occurring on the Moon. Overall, however, these are minor issues in what is generally a very solid book.

Exploring the Moon is very well illustrated. Most books about Apollo include a limited number of photos, usually restricted to one or two photo-insert sections. Harland has included more than 200 photos in his book. These are integrated into the text and serve to enhance the written discussion. Overall, the reproduction quality of the photographs is quite high. Many of the photos are actually mosaics, but one cannot tell where the frame boundaries of the original images occur. Except for the cover photo, all the photographs are in black and white. This is not a problem for the chapters about Apollo. However, the final chapter discusses recent results from the Galileo, Clementine, and Lunar Prospector missions. The multispectral images and maps from these missions were all originally in color, and the black and white versions reproduced here are not particularly useful.

So how does *Exploring the Moon* stack up against its competition? Two of the very best previous books about Apollo are Andrew Chaikin's *A Man on the Moon* and Don Wilhelms' *To a Rocky Moon.* Each of these three books fills a different niche. Chaikin's book is likely the single best book ever published about the Apollo program as a whole, although it is not particularly strong on the scientific aspects of the program. Wilhelms' book emphasizes the scientific aspects of lunar exploration. He includes the Ranger, Surveyor, and Lunar Orbiter precursor missions and the geology training of the Apollo crews, along with the Apollo missions themselves, written with the authority of someone who participated in many of the events that he describes. Harland's book shines in its detailed focus on the last three Apollo missions, told in two to three times the length of either Chaikin or Wilhelms. Harland's book is also by far the best illustrated of these three books. All aficionados of the Apollo program will find much to appreciate in *Exploring the Moon.*

—Walter S. Kiefer



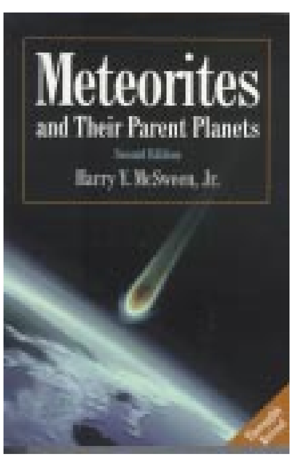
FULL MOON

by Michael Light
Published by Alfred A. Knopf, 1999

Full Moon tells the story of the Apollo journeys to the Moon in a unique manner, using photographs rather than words. This is a beautiful book. There are 129 photographs, more than half in color, and all reproduced in a large 12-by-12-inch format that allows the full image detail to be appreciated. Five fold-out sections show panoramas that are 45 inches across. The book is organized in three sections: the outward voyage, the lunar surface, and the return home. Photographs from each of the Apollo missions are interspersed, so the resulting story is of a single, synthetic mission rather than of any particular flight. Photo captions are collected at the end of the book to avoid interrupting the visual flow. Essays by the author and by Andrew Chaikin provide additional context.

—Walter S. Kiefer

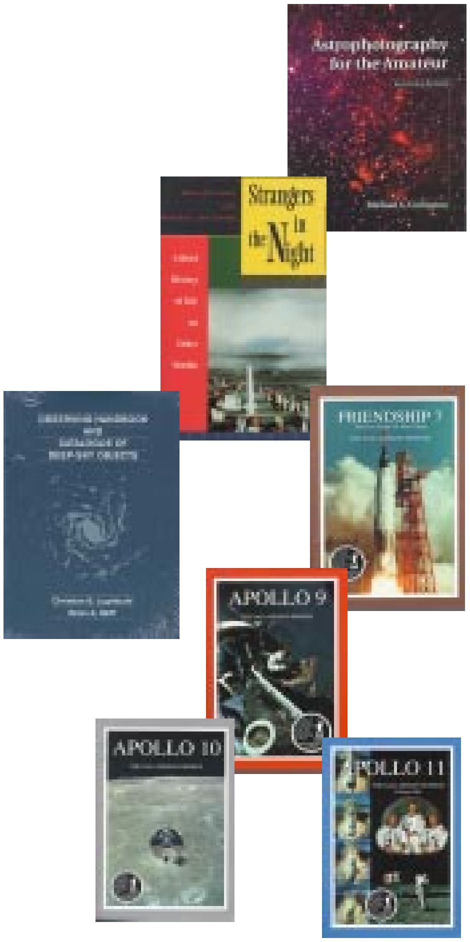
(Dr. Kiefer is a staff scientist at the Lunar and Planetary Institute.)



RECENTLY PUBLISHED

Meteorites and Their Parent Planets, Second Edition, by Harry Y. McSween Jr., Cambridge University Press, 1999, Hardback $74.95, Paperback, $29.95. Revised version of McSween's 1987 book on meteoritics provides an interdisciplinary overview of meteorites, their origin, and their journey to Earth. The book is written for a broad-based audience and should appeal to scientists as well as meteorite collectors and students.

Cambridge Starfinder: The Complete Astronomy Map and Guide Pack, Cambridge University Press, 1999, $24.95. This "getting-started" pack for amateur astronomers includes a detailed map of the nearside of the Moon, a wall star chart that can be used at any latitude, and a rotating planisphere for locating stars and constellations at any hour of



the year. The pack is available in two different versions for observers in southern and northern U.S. latitudes.

Astrophotography for the Amateur, by Michael A. Covington, Cambridge University Press, 1998, Hardback $80.00, Paperback $34.95. Expanded and updated guide to taking pictures of the stars, galaxies, the Moon, the Sun, comets, meteors, and eclipses.

Strangers in the Night: A Brief History of Life on Other Worlds, by David E. Fisher and Marshall Jon Fisher, Counterpoint, 1998, Hardback, $25.00. In this book intended for a popular audience, the father-son writing team trace the story of humankind's attempts to discover extraterrestrial life, from the hoaxes and mythology of past centuries to the possible evidence of fossilized martian organisms and extrasolar planets of today.

Observing Handbook and Catalogue of Deep-Sky Objects, by Christian B. Luginbuhl and Brian A. Skiff, Cambridge University Press, 1998. Detailed guide for observing galaxies, clusters, and nebulae. The objects addressed in the guide range from those visible with binoculars to faint galaxies requiring a 30-centimeter telescope.

NASA Mission Reports. Compiled and edited by Robert Godwin, this series from Apogee Books (http://www.cgpublishing.com/apogee.htm) repackages original NASA mission reports. Each book includes such material as the original press kit, the premission report and objects, technical reports, and postflight reports and summaries. In addition, each book includes a CD-ROM with documentary footage to supplement the text. New books in the series include:

- *Apollo 9*, 240 pp., $14.95.
- *Apollo 10*, 176 pp., $14.95.
- *Apollo 11: Volume One*, 248 pp., $16.95.
- *Friendship 7: The First Flight of John Glenn*, 208 pp., $14.95.

BOOK GIVEAWAY

The Bulletin is giving away a new softcover edition of *Managing Martians*, by Donna Shirley, which was reviewed in the fall 1998 issue of the *Bulletin*. To qualify for the book drawing, readers should send an e-mail to the address shown below with answers to the following five space-science-related trivia questions:

1. What seven moons of the solar system are larger than Pluto?
2. Who discovered the Periodic Table of Elements?
3. Red dwarfs make up what percentage of all stars in the galaxy?
4. What star, discovered in 1784, pulsates every 7.176779 days?
5. Planetary nebulae eject what two heavy elements into the galaxy?

Entries should be sent to LPIBED@lpi.usra.edu. The final winner will be randomly selected from all correct entries received.

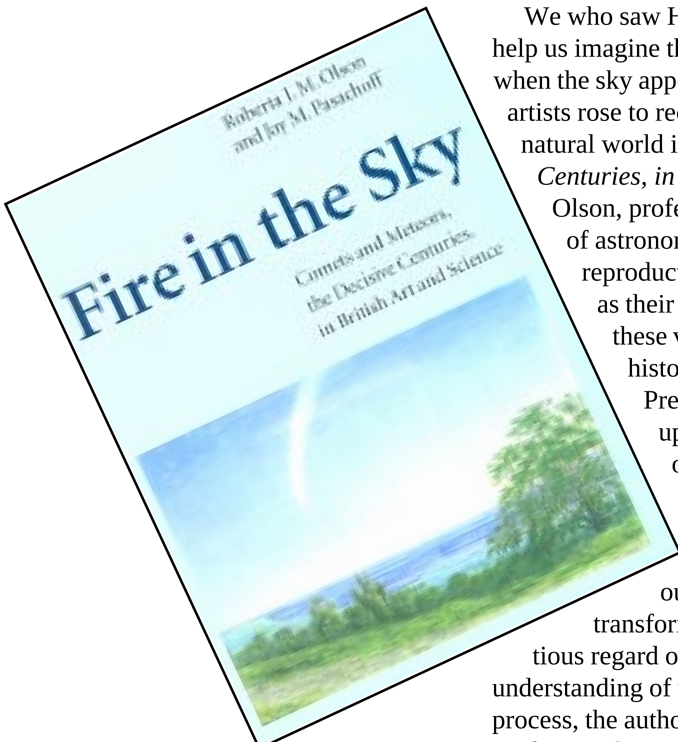
EARTH SCIENCES HISTORY PUBLISHED

A new issue of *Earth Sciences History*, the journal of the History of Earth Sciences Society, is now available. The most recent issue of the journal includes such papers as "Earth and Heaven, 1750–1800: Enlightenment Ideas about the Relevance of Geology of Extraterrestrial Operations and Events" by Kenneth L. Taylor and "Shooting the Moon: Understanding the History of Lunar Impact Theories" by Peter H. Schultz, as well as a number of book reviews. For more information contact Dorothy Sacks, Department of Geography, Ohio University, Athens OH 45701.

Comets Spark Artistic Imagination of Humanity

REVIEW
by Craig White

FIRE IN THE SKY: COMETS AND METEORS, THE DECISIVE CENTURIES, IN BRITISH ART AND SCIENCE.
By Roberta J. M. Olson and Jay M. Pasachoff
Cambridge University Press, 1998
369 pages, illustrated, $74.95 (Softcover edition available October 1999)



After decades in which highly publicized comets like Kahoutek and Halley turned out to be no-shows, the appearance in 1997 of Comet Hale-Bopp rewarded an aging generation of stargazers and etched the memories of a new one. "I see it," declared my teenage daughter, pointing up through the windshield as we rode home one spring night that year, and for a month thereafter Hale-Bopp dusted the night sky with its tail of sparkling dust. We knew what it was, but against the familiar stars the comet's strange appearance — built for speed yet not perceptibly moving — provoked wonder and invited interpretation.

We who saw Hale-Bopp may not see its like again, but the remembered vision may help us imagine the experience of Europe and America more than a hundred years ago, when the sky appeared unusually bright with celestial phenomena that astronomers and artists rose to record and interpret. This opportunity to reach across history through the natural world is inspired by *Fire in the Sky: Comets and Meteors, the Decisive Centuries, in British Art and Science*, a new book co-authored by Roberta J. M. Olson, professor of art history at Wheaton College, and Jay M. Pasachoff, professor of astronomy and director of Hopkins Observatory at Williams. More than 160 reproductions of paintings, photographs, and art-objects with comets and meteors as their subjects stud this book's pages. An accompanying text comments on these visual highlights while tracing accompanying developments in the history of science. Color plates and a toney layout by Cambridge University Press commend *Fire in the Sky* as either a specialized art book or an upscale "coffee-table book" that a scientific institution, departmental office, or academic household might leave lying about for quick reference or for the occasional pleasure of leafing through its pages.

Fire in the Sky's illustrations chronicle the development of British visual art concerning comets and meteors from the late Renaissance to our own century. Across the same period, Olson and Pasachoff trace the transformation of human understanding of meteors and comets, from a superstitious regard of them as volatile omens of disaster or propitious births to the modern understanding of them as predictable mechanisms in the clockwork universe. In the process, the authors recount a traditional history of science: the increasing professionalization of the astronomical discipline; technical advances in lenses and photography; development of supportive institutions such as the Royal Astronomical Society; and the emergence of titans like Isaac Newton and Edmond Halley who stand on the shoulders of their predecessors to observe farther and more surely with each generation.

This narrative of empirical progress is incontrovertible on its own terms. By limiting their interpretation to the triumphal rise of science with accompanying illustrations, however, Olson and Pasachoff fail to account for a corresponding historical decline in the value or interest of the works of art their book reproduces. That is, the volume's earlier, more "stylized" representations of comets and meteors, despite their comparative scientific benightedness, evoke the sublime wonder of celestial phenomena far more than the scientifically precise or "naturalistic" sketches and photographs that emerge along with the rise of astronomical science.

For instance, the book's first color plate reproduces a 1590 oil portrait of Arabella Stuart, cousin to King James I of England and Scotland, over whose shoulder appears the spidery blazon of a comet, which was a device of her family's heraldry. The book's final plate, a telescopic photograph taken four centuries later, is of Hale-Bopp, its tail a striking sapphire blue. A comparison of these two plates raises questions about science and art that the authors of *Fire in the Sky* generally disregard. My mind and eye returned repeatedly to Lady Arabella's spider-comet as they had to Hale-Bopp itself in 1997. However, the page featuring the photo of Hale-Bopp — regardless of its dead-on accuracy and its potential scientific use as a record of what actually happened — was quickly turned and nearly forgotten. Even discounting for the charms of antiquity, the sixteenth-century painting seems more deeply invested with human talent and labor, which forge a link between celestial subject and human observer. Turning again to the photography, the viewer's sense of wonder seems to have diminished with the advance of scientific accuracy. Even the striking blue of Hale-Bopp's tail against a magnified field of stars seems no more profound than a "special effect" created by color filters or digital processing — as the recent, computer-designed *Star Wars* installment dazzled without leaving a residue.

Olson and Pasachoff acknowledge this gain and loss only briefly, noting of a "post-Halley" print depicting the comet of 1744: "The artist's sense of wonder has been transformed into a fascination with the scientific aspects of the comet's appearance and observance." The authors' reluctance to wade further into these aesthetic depths may be partly accounted for by *Fire in the Sky*'s need to serve diverse audiences. Yet their text sporadically expresses nostalgia for historical moments and characters where the arcs of cometary art and science momentarily crossed and mutually benefited each other. *Fire in the Sky*'s weaknesses and strengths thus derive from its indeterminate status between genres: scholarly "art book" or mass-market "coffee-table book"? Casual purchasers may buy a handsome, class-indexed consumer item for display as well as for occasional reading forays. For her part, an art historian like Olson finds an opportunity to publish scholarly writings in a tome that simultaneously displays the works of art being described. Similarly, Pasachoff, in addition to writing or vetting the book's scientific passages, includes his own fine photograph of Hale-Bopp over the Williamstown horizon. These diverse elements may appeal to historians of art, science, literature, and culture, as well as to scientists currently pursuing cometary research. The power of *Fire in the Sky* to forge a dynamic reading community of these disparate elements is undermined, however, by the tacit rule governing all coffee-table books: Each page must be capable of being read without reference to any previous or subsequent page, so that a casual reader leafing through its reproductions might enter the text at any point without discouragement.

Thomas Rowlandson, *The Observation of a Comet,* ca. 1821.

In this context, the first positive verdict to be delivered of the book's text is that it invites and rewards skimming. The prose is always clearly written, and the facts appear to check out, though appropriately the range of style and thought is rarely adventurous. For readers who graduate from reading the odd page, individual chapter openings efficiently brief casual readers on the necessary scientific information for comprehending the discoveries that are afoot.

The centrifugal forces of art and science sometimes get the better of Olson and Pasachoff, however. After long stretches in the certain realm of generalization, other sections are more exacting, making the text appear built of spare parts from old conference papers, as when consecutive chapters offer extended surveys of comets and meteors in the esoteric visual art of the poet William Blake. Transitions between such parts are sometimes improvisational, as when a discussion of Blake's tangential portrayal of a flea segues to that insect's contemporary

Thomas Rowlandson, *John Bull Making Observations on the Comet,* 1807.

observation through a microscope, whose lenses bring us back to a discussion of telescopes. The points at which readers grow indifferent to the book's medley of subjects may naturally depend on their areas of specialization. For the consolations of philosophy, I compared the text's oscillating pace — accelerating as it neared my favored subjects, slackening as it retreated — to the elliptical path of a comet, which speeds up as it nears a focus but slows as it departs.

Indeed, once hope of an overarching line of thought is abandoned, the fancy is freed to find pleasure rising instead from the sheer variety of historical premises and media used for depicting comets or meteors. In addition to the heraldry, oils, and photographs previously mentioned, the book reproduces broadsides, satirical prints, technical and topical engravings, astronomers' pen-and-inks, and watercolors. Olson's analyses of such artifacts frequently lead one to look and look again, so that the illustrations' pleasures are doubled. Happily, too, the text sometimes connects the properties of the heavens with those of earthly art: Given the exceedingly transitory nature of meteors, which appear and vanish in a few seconds, watercolor became the preferred nineteenth-century medium on account of its speed and accuracy in composition.

The transient qualities of comets and meteors lend a particular poignancy to the "Ephemera" of the book's catalog. Business cards, clocks, and tankards featuring comet and meteor icons are represented, while comet valentines, board and card games, and a "Comet Rag" ditty that became popular following appearances by Comet Halley are mentioned. In keeping with the book's status as a consumer item, the most compelling ephemera are antique letter openers, weathervanes, and ornamental pins in the shape of comets. One instinctively wishes to grasp these artifacts or to purchase facsimiles in a museum gift shop, a desire partly compensated by the pleasure of owning and holding such a handsome book.

In its scholarly aspect, *Fire in the Sky* transcends such material excitements by alluding repeatedly (though again unself-consciously) to earlier models of interdisciplinary research in science and the arts. Describing the social enterprise and optimism that gave rise to early modern science in the seventeenth and eighteenth centuries, Olson and Pasachoff observe that today's "various disciplines" were regarded as "an interconnected whole," an attitude benefiting the "exchange of ideas among individuals involved in the arts and sciences." The members of England's Royal Society, which combined private sponsorship and political leadership, included such polymaths as Christopher Wren, now better known as the architect of London after the Great Fire of 1666 (preceded by comets!), who was a Professor of Astronomy at Gresham College, London. The authors of *Fire in the Sky* consistently evince appreciation for poets like Blake and Thomas Hardy who represent heavenly phenomena in both verse and illustrations as well as for various "gentlemanly amateurs" who practiced astronomy in context with theology and politics.

The greatest endorsement for the book's wide-cast net is the figure of Charles Piazzi Smyth, the most distinguished exemplar of its interests in both astronomy and art. Smyth's career combined success as an artist with real contributions as an astronomer, and his life (1801–1900) spanned what Olson and Pasachoff call the "Comet-Crazed Century," when either "accelerated interest" in science or "a statistical fluke" led to an unusually large number of comet apparitions. The very model of the cosmopolitan, eccentric "Victorian gentleman" at his most interdisciplinary, Smyth's exotic middle name was received from his godfather, the court astronomer at Palermo and the first discoverer of an asteroid. His birth father was a naval officer, amateur astronomer, and member of the Royal Society who built a home observatory and later secured his son's appointment as Astronomer Royal for Scotland. Smyth observed all the nineteenth century's great comets, beginning with Halley in 1835, and his drawings, lithographs, watercolors, and oils evince both a refreshingly “naïve” quality that evokes the wonder caused by these apparitions and a “faithful imitation” of the phenomena themselves. He also authored treatises on astronomy in relation to art and photography, and his zoological and geological journeys to the Canary Islands in 1856 led to recommendations that future observatories be raised on mountain peaks, as many are today. Olson’s and Pasachoff’s survey of Smyth closes endearingly by noting that we might have heard more of this artist-scientist had he had not tarnished his late career by traveling to Egypt in order to correlate modern astronomy with occult pyramidology. *Fire in the Sky*’s own conclusion is more scientifically reputable but nonetheless distracts from the book’s earlier purposes.

Olson’s and Pasachoff’s text ends with the reappearance of Comet Halley in 1910 followed by a brief summary of the decline of British astronomy and the “reduction in the cross-currents between the two fields” of astronomy and art in subsequent decades. Surprisingly, there then appears a sparsely illustrated epilogue by Colin T. Pillinger that enthusiastically previews comet probes planned for the early twenty-first century and half-heartedly relates their names — *Giotto*, *Rosetta* — to the history of art. Contemporary scientists indifferent to history might go directly to this epilogue, but readers who have enjoyed the previous 300-plus pages may feel perplexed by its quantum leap across the twentieth century into a new visual format and a new level of technical complexity.

Charles Williams, *The Comet!!!,* 1811.

— Craig White

(Craig White is an associate professor of literature at the University of Houston—Clear Lake.)

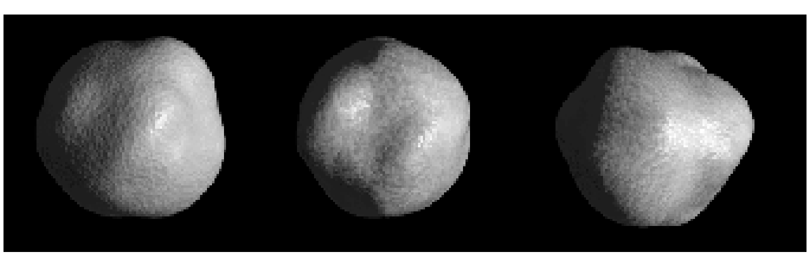
NEWS FROM SPACE *continued from page 8*

“This asteroid is quite literally an oasis for future space explorers,” he said. “Its optical and radar properties suggest a composition like carbonaceous chondrite meteorites, which contain complex organic compounds that have been shown to have nutrient value. These could be used as soil to grow food for future human outposts. And among the 25,000 or so asteroids with very reliably known orbits, 1998 KY26 is in an orbit that makes it the most accessible to a spacecraft.”

The solar system is thought to contain about 10 million asteroids this small in orbits that cross Earth’s, and about 1 billion in the main asteroid belt between Mars and Jupiter. However, only a few dozen of these tiny asteroids have ever been found and, until now, hardly anything was known about the nature of these objects.

Ostro and his colleagues used the 70-meter-diameter Goldstone, California, antenna of NASA’s Deep Space Network to transmit radar signals continuously to the asteroid and turned a 34-meter-diameter antenna on it to collect echoes bouncing back from the object.

1998 KY26’s color and radar reflectivity showed similarities to carbonaceous chondrites, primordial meteorites that formed during the origin of the solar system and are unlike any rocks formed on Earth. They contain complex organic compounds as well as 10–20% water. Some carbonaceous chondrites contain amino acids and nucleic acids, which are the building blocks of proteins and DNA, and hence are of interest to scientists trying to unravel the origins of life.



A second team of astronomers used optical telescopes to track 1998 KY26, which was discovered by the University of Arizona’s Spacewatch telescope, the

Continued on page 16

world's first instrument dedicated to searching for near-Earth asteroids. Dr. Petr Pravec of the Czech Republic's Academy of Sciences said collisions likely gave 1998 KY26 its rapid spin.

But one way or another, Pravec said, this object's 10.7-minute "day" is the shortest of any known object in the solar system.

"The motion of the sky would be 135 times faster than it is on Earth," he said. "Sunrises and sunsets take about two minutes on Earth, but on 1998 KY26, they would take less than one second. You'd see a sunrise or sunset every five minutes."

Dr. Scott Hudson of Washington State University in Pullman found the asteroid's shape particularly surprising. Asteroids thousands of times larger have spherical shapes as a result of their large masses and strong gravitational fields, he said. 1998 KY26 is very unusual, however, because gravity and mass play no significant role in its shape. Instead, the spheroid shape is the result of collisions with other asteroids.

(Portions of these news briefs were adapted from NASA press releases.)

PLANETARY ALIGNMENT

Predictions about Y2K rollover meltdown may have proved to be a dud, but those eager to find possible end-of-the world scenarios in year 2000 have turned to the phenomenon known as 5/5/2000, a planetary alignment that will occur in May of this year. Although the physical effects on the Earth will be nil (no giant tidal waves), and the observational advantages minimal, the topic is still likely to generate some interest. Information about the alignment can be found at the Griffith Observatory website at http://www.griffithobs.org/SkyAlignments.html.

ABOUT THE COVER ART

Blue Moon over Fjord is a recent painting by Belgian artist Erik Viktor. Viktor has been specializing in painting visionary art about space since October 1984, when he gave up his career as a commercial pilot. His work has appeared in such magazines as *Figaro, Bunte,* and *Washington Post,* and his work has also been commissioned by NASA and various aerospace companies. In recent months, he has spearheaded the European SpaceWorld touring exhibition, which features work of his own and other artists plus various space-related displays. Viktor also designed the Astrobike, a futuristic, lightweight bicycle whose prototype was sold to a European bicycle manufacturer. His prints and other merchandise are available for purchase at http://www.ctv.es/USERS/spaceworld/.

GENESIS ANALYTICAL FACILITIES

Procurement for Analytical Facilities for the study of returned solar wind samples will take place during 2000. Bids for the facilities will be solicited. The March issue of the LPI Bulletin will contain more detailed information on the selection process. Alternatively, contact D.S. Burnett (burnett@gps.caltech.edu). Technical information on the Genesis mission is available at http://www.gps.caltech.edu/genesis/genesis3.html.

MORE ON LPSC HISTORY

In the "LPSC Through the Years" list in the last issue of the Bulletin, it was stated that only a *Proceedings* volume, and no abstract volume, was published for the first Apollo 11 conference. John Wood of the Harvard-Smithsonian Center for Astrophysics has since sent along a copy of the cover for the abstract volume of the first conference. Dr. Wood also pointed out that the M.I.T. Press was one of the several publishers who handled the *Proceedings* volume through the years. Thanks to Dr. Wood for clearing up these early bits of LPSC history.

The *Lunar and Planetary Information Bulletin* is published quarterly by the Lunar and Planetary Institute, 3600 Bay Area Boulevard, Houston TX 77058-1113.

Brian Anderson, Editor

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The Bulletin welcomes the submission of articles and essays dealing with issues related to planetary science and exploration. Please send articles or announcements to: B. Anderson, 3600 Bay Area Boulevard, Houston TX 77058-1113.

Phone: 281-486-2164, fax: 281-486-2125
E-mail: lpibed@lpi.usra.edu

SPECTROSCOPY OF THE MARTIAN SURFACE: WHAT NEXT?

Mineralogy is an essential tool for assessing environments on Mars that may have been conducive to the support and preservation of life and biomarkers. Reflectance and emission spectroscopy remain the most capable methods for remote mineral identification. On June 10–11, leaders of the planetary community with expertise in spectroscopy and remote mineral identification met to discuss the state of understanding Mars' surface composition and to assess what critical gaps may exist in planned spectral measurements of Mars and supporting research programs. Here we present a summary of the conclusions, and an interesting historical note about the meeting.

Participants concluded that after the successful return of planned global datasets, there is a need for targeted measurements to aid in the selection of the most desirable landing sites. They determined that these measurements from an orbited instrument should (1) be targeted to regions of interest, as identified by global mapping missions; (2) have very high information content (high signal to noise ratio, high spectral resolution, and cover both the reflectance and emission spectral regions); and (3) have high spatial resolution. Targeted rather than global measurements will allow the return of greater information content per spectrum, which will allow the return of the greatest amount of spectral information for proposed landing sites. This information will provide the best opportunity to select the most desirable site among proposed landing sites.

Selecting among potential landing and sample return sites will be aided by a clear, unambiguous interpretation of spectra measured from orbit. Participants also discussed the ability of the community to interpret current and planned spectral datasets. Some participants stated a need for (1) laboratory measurements that are publicly archived; that measure the entire wavelength range covered by current and planned datasets; and that include measurements of a range of materials, weathering products, and particle sizes (including poorly crystalline) that may be present on Mars; (2) upgrading the community laboratory facility (RELAB) to measure the full wavelength range of current and planned data sets (0.4–50 µm); and (3) testing known and unknown samples for evaluation of currently available methods for quantitative analysis, and evaluating similar methods developed by Department of Defense and Intelligence Agencies. Other participants stated that there is not a need to publicly archive spectra measured under NASA programs, that private spectral libraries are sufficient for current and planned interpretations, and that there is not a need to test and compare the currently available quantitative methods. The workshop did not have the goal of addressing these issues, but they were felt to be of fundamental importance, and were found to warrant further discussion in a future workshop.

In summary, to provide adequate support for the landing site selection process, participants recommended the measurement from orbit of high information content spectra of targeted regions, and further discussion of what is needed for supporting research programs. This integrated approach will provide essential tools in the phased approach to Mars exploration that NASA has developed.

The workshop had an unusual breadth of researchers present, and included expertise in spectroscopy of Mars, Earth, and the Moon; from the NASA and the DOD/Intelligence community; and in laboratory spectral research and computational spectral analysis.

However, an interesting historical note was the presence of all three builders of the only U.S. thermal infrared spectrometers ever sent to Mars. It is the first, and will perhaps be the only time, that all three have been together.

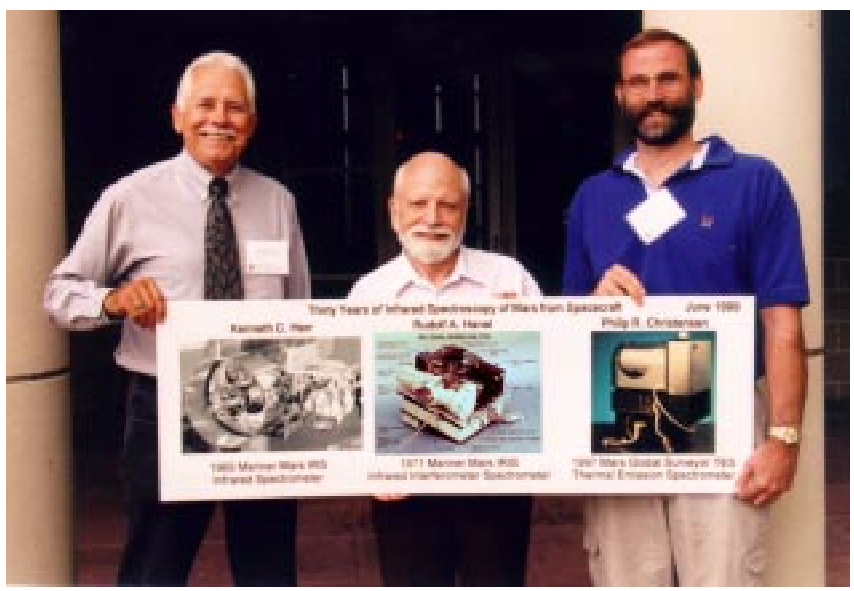

Photo Credit: Debra Rueb, LPI Staff Photographer.
Taken during the workshop, at the entry to the LPI.

*The three builders of the only thermal infrared spectrometers sent to Mars, (*left to right*),* ***Kenneth C. Herr*** *(1969 Mariner Mars 6/7 Infrared Spectrometer,* IRS*);* ***Rudolf A. Hanel*** *(1971 Mariner Mars 9 Infrared Interferometer Spectrometer,* IRIS*);* ***Philip R. Christensen*** *(1997 Global Surveyor Thermal Emission Spectrometer,* TES*)*

CALENDAR 2000

FEBRUARY

28–Mar. 2

Space 2000 and Robotics 2000, Albuquerque, New Mexico.
http://www.spaceandrobotics.org

MARCH

13–17

31st Lunar and Planetary Science Conference, Houston, Texas
Contact: Lunar and Planetary Institute, 3600 Bay Area Boulevard, Houston TX 77058-1113.
Phone: 281-486-2158; fax: 281-486-2125
E-mail: simmons@lpi.usra.edu
http://www.lpi.usra.edu/meetings/lpsc2000/

27–29

Workshop on Photolysis and Radiolysis of Outer Solar System Ices, Laurel, Maryland. Contact: Diana Whitman, Applied Physics Laboratory.
E-mail: first.last@jhuapl.edu

APRIL

25–29

European Geophysical Society XXV General Assembly: Millennium Conference on Earth, Planetary & Solar Systems Sciences, Nice, France. Contact: EGS Office, Max-Planck-Str. 13, 37191. Katlenburg-Lindau, Germany.
Phone: 49-5556-1440; fax: 49-5556-4709
E-mail: egs@copernicus.org

MAY

2–5

Fourth IAA International Conference on Low-Cost Planetary Missions, Laurel, Maryland. Abstract Deadline: October 22, 1999.
Contact: Diana Whitman, Johns Hopkins University, Applied Physics Laboratory, 11100 Johns Hopkins Road / MS 4-278, Laurel MD 20723-6099.
Phone: 240-228-7150; fax: 240-228-5969
E-mail: diana.whitman@jhuapl.edu
http://sd-www.jhuapl.edu/IAA

16–20

AMICO 2000: Asteroids, Meteorites, Impacts, and their Consequences, Nördlingen, Germany. Contact: AMICO 2000, Rieskrater-Museum Nördlingen, Eugene-Shoemaker-Platz 1, D-86720, Nördlingen, Germany.
Phone: +49-9081-273-8220; fax: +49-9081-273 82220
E-mail: rieskratermuseum.noerdlingen@donau-ries.de
http://www.stecf.org/~ralbrech/amico

JULY

9–12

Catastrophic Events and Mass Extinctions: Impacts and Beyond, Institute of Geochemistry, University of Vienna, Vienna, Austria.
Contact: Christian Koeberl, Institute of Geochemistry, University of Vienna, Althanstrasse 14, A-1090 Vienna, Austria.
Phone: +43-1-31336-1714; fax: +43-1-31336-781
E-mail: christian.koeberl@univie.ac.at
http://www.lpi.usra.edu/meetings/impact2000

17–19

Cosmos in the Classroom: National Symposium on Teaching Astronomy to College Non-science Majors, Pasadena, California.
Contact: 2000 Cosmos in the Classroom, Astronomical Society of the Pacific, 390 Ashton Avenue, San Francisco CA 94112.
Fax: 415-337-5205
Email: meeting@aspsky.org

AUGUST

6–17

31st International Geological Congress, Rio de Janeiro, Brazil.
Contact: Av. Pasteur, 404, Casa Brazil 2000, Urca, Rio de Janeiro, RJ, Brazil.
Phone: 55-21-295-5847; fax: 55-21-295-8094
E-mail: 31igc@31igc.org
http://www.31igc.org

21–25

The Second International Conference on Mars Polar Science and Exploration, University of Iceland, Reykjavik, Iceland. Contact: Stephen Clifford, Lunar and Planetary Institute, 3600 Bay Area Boulevard, Houston TX 77058-1113.
Phone: 281-486-2146
E-mail: clifford@lpi.usra.edu
http://www.lpi.usra.edu/meetings/polar2000/

27–Sept. 1

25th European Congress on Molecular Spectroscopy, School for Sciences and Technology, University of Coimbra, Coimbra, Portugal.
Contact: Rui Fausto, Department of Chemistry, University of Coimbra, P-3049 Coimbra, Portugal.
Phone: +351-39-852080 / +351-39-857037; fax: +351-39-827703
E-mail: rfausto@gemini.ci.uc.pt
http://qui.uc.pt/~rfausto/eucmos_xxv/principal.html

28–Sept. 1

63rd Annual Meeting of the Meteoritical Society, Chicago Illinois.
Contact: Andrew M. Davis, Department of the Geophysical Sciences, The University of Chicago, 5734 South Ellis Avenue, Chicago IL, 60637.
Phone: 773-702-8164; fax: 773-702-9505
E-mail: a-davis@uchicago.edu
http://www.lpi.usra.edu/meetings/metsoc2000/