Publications Watch

by Andrew J. LePage

Notes on recent articles and papers pertaining to SETI and bioastronomy

Analog Science Fiction and Fact

Volume 117, Number 12, December 1997

"Biology at the Extremes for Terraforming and Beyond," by Mark S. Lesney, pp. 41-58

This fully referenced popular-level article reviews the latest investigations of terrestrial organisms that live in extreme environments. These studies strongly hint that the progenitors of all life on Earth today, including a wide variety of organisms that thrive in environments that are highly saline, acidic, or alkaline, were hyperthermophyllic microorganisms.

While a study of these organisms can lead to an understanding of the origins of life and the discovery of commercially useful production methods, the author's primary interest here is in adapting and using such organisms to terraform planets. Unlike many pieces on the subject, the author also examines the possibility of using the knowledge gained from the study of such organisms to adapt human beings to what would otherwise be deadly environments.

Astronomy & Astrophysics

Volume 328, December (I) 1997

"β Pictoris Light Variations. I. The Planetary Hypothesis," by A. Lecavelier des Etangs, A. Vidal-Madjar, G. Burki, H.J.G.L.M. Lamers, R. Ferlet, C. Nitschelm, and F. Sevre, p. 311

"β Pictoris Light Variations. II. Scattering by a Dust Cloud," by H.J.G.L.M. Lamers, A. Lecavelier des Etangs, and A. Vidal-Madjar, p. 321

The disk discovered surrounding the young star β Pictoris is generally believed to be the debris left over from the formation of its own family of planets. The conditions around this star are thought to be similar to those in our Solar System some four billion years ago. On November 10, 1981, an exceptional photometric event was recorded in this system when it appeared to brighten for ten days. During this event a central day-long dip in brightness was also observed.

A variety of explanations have been proposed for this event which involves some sort of localized change in the structure of the disk surrounding β Pictoris. In this pair of papers two of these explanations have been modeled in detail to determine the origin of this event: The passage of a planet or a dust cloud between us and β Pictoris.

The planetary hypothesis is examined in the first paper. Here the brightening is explained by the passage of a dust-free region surrounding a planet with the central dip caused by the transit of the planet itself. Their model, which takes into account the partial occultation phase and limb darkening in the star, easily explains the details observed in this event. Their model implies the existence of a Jupiter-sized planet orbiting about 5 AU from β Pictoris. The presence of a planet with these properties has also been proposed to explain the presence of a warp found in the disk surrounding β Pictoris.

The second paper examines the possibility that the passage of a dust cloud is responsible for the event. This hypothesis calls for a strongly forward-scattering dust cloud 0.45 to 4.0 AU from the star with an effective scattering surface of a few times 10^{24} square centimeters. A model consisting of a flat cloud with a mass of 2×10^{21} grams ($3 \times 10^{-7} M_{\oplus}$) that is elongated in the orbital plane and possessing a pointed shape with the largest optical depth closest to the star could explain the observed results. Such a cloud could be produced by a comet or series of comet fragments with a periastron of about 0.4 AU.

While more observations are required to determine which model is correct, either explanation is consistent with the formation of a Sun-like solar system around β Pictoris.

Astronomy & Astrophysics

Volume 329, January (II) 1998

"Search for Planetary Mass Objects in the Galactic Halo Through Microlensing," by C. Renault, E. Aubourg, P. Bareyre, S. Brehin, M. Gros, M. Lachieze-Rey, B. Laurent, E. Lesquoy, C. Magneville, A. Milsztajn, L. Moscoso, N. Palanque-Delabrouille, F. Queinnec, J. Rich, M. Spiro, L. Vigroux, S. Zylberajch, R. Ansari, F. Cavalier, M. Moniez, J.-P. Beaulieu, R. Ferlet, P. Grison, A. Vadal-Madjar, J. Guibert, O. Moreau, E. Maurice, L. Prevot, C. Gry, S. Char, and J. Fernandez, p. 522

Many astrophysical observations hint at the need for large quantities of nonluminous or dark matter in spiral galaxies. One of the many proposed forms of dark matter are MACHOs (MAssive Compact Halo Objects). These objects could be anything from isolated black holes to rogue planets orbiting in our galaxy's halo. Presented here are the final results of a European Southern Observatory program called EROS (Experience de Recherche d'Objets Sombres) that searched for these objects by the means of gravitational microlensing.

This project monitored the brightness of hundreds of thousands of stars in the Large Magellanic Cloud using a 0.4-meter telescope with a 16-CCD camera in the hope of observing the brightening of a background star caused by a microlensing event. After weeding out data for variable stars and other suspect objects or events, the EROS team had 350,000 usable light curves. None of these light curves displayed the photometric signature expected for a microlensing event.

Taking into account the program's overall detection efficiency and various galactic halo models, the team concluded that objects of planetary mass do not contribute significantly to the mass of the Milky Way's halo. These results essentially confirm EROS's preliminary findings published in *Astronomy & Astrophysics* more than a year earlier (see review of "Observational Limits on the Contribution of Sub-Stellar and Stellar Objects to the Galactic Halo" in *SETIQuest* Vol. 3, No. 1, p. 17).

Astronomy & Astrophysics

Volume 329, January (III) 1998

"A Vega-like Disk Associated with the Planetary System of ρ^1 Cnc," by C. Dominik, R.J. Laureijs, M. Jourdain de Muizon, H.J. Habing, p. 53

Excess infrared emissions from young main sequence stars, such as those detected from Vega and other nearby stars, have been generally considered to come from disks of dust left over from the formation of a planetary system. Described here is the discovery of such an infrared excess from the Sun-like star ρ^1 Cancri which is thought to be orbited by one or possibly two extrasolar giant planets. One of these planets is a close-orbiting epistellar planet similar to the one thought to orbit 51 Pegasi while the other, which has only been tentatively identified by radial velocity observations, orbits several astronomical units away. If the presence of the disk and the planets are confirmed, this will go a long way toward confirming the connection between the dust disks and planetary systems.

The infrared observations were made in May 1996 using the ISOPHOT camera onboard the Infrared Space Observatory (ISO) which was launched into Earth orbit by the European Space Agency (ESA). Measurements of ρ^1 Cancri's infrared flux at a wavelength of 25 micrometers are consistent with a photospheric origin. But at a longer wavelength of 60 micrometers an excess flux of 170 millijanskys was detected. The authors interpret this excess as being due to the presence of a disk of dust with a mass of 4×10^{-5} $M_\oplus$ and a temperature of 40 to 100 degrees K 60 AU from ρ^1 Cancri.

Although the exact origin of the dust, which should have a very short lifetime, is still a subject of debate, it could come from a swarm of comet-like bodies in a region similar to the Kuiper belt in our Solar System.

Astronomy & Astrophysics

Volume 330, February (I) 1998

"Making a Comet Nucleus," by J. Mayo Greenberg, p. 375

Comets are of great interest to astronomers—and those interested in the origin of life—for a variety of reasons. For example, the impact of a comet 65 million years ago could have been responsible for the demise of the dinosaurs. But even further back in Earth's history comets might have been responsible for supplying this planet with a sizable fraction of its supply of water and other volatiles and they may have also delivered important organic compounds that helped life originate.

In this paper Mayo Greenberg combines data from a variety of sources to determine the bulk chemical composition of a typical comet. According to the author's analysis, about 30 percent of the mass of a comet is water ice. Combined with the water is a mixture of other simple molecules (carbon monoxide, carbon dioxide, and methanol) at a level of two to three percent each. Another 26 percent of a comet's mass is in the form of refractory compounds of silicon, magnesium, and iron minerals. Another 23 percent of a comet's bulk mass is in the form of carbon and other organic refractory materials. Most important of all for the origin of life, nine percent of the mass is in the form of attogram (10^{-18} gram) particles of carbonaceous compounds and large organic molecules such as PAHs (Polycyclic Aromatic Hydrocarbons). The maximum mean density of this mixture of materials is about 1.65 grams per cubic centimeter. The actual density of a comet nucleus, which would not likely be compacted very much, would be much less.

The Astrophysical Journal

Volume 490, Number 1
November 20, 1997

"Non-Radial Oscillations in the Solar-Temperature Star 51 Pegasi," by David F. Gray and Artie P. Hatzes, pp. 412-424

The discovery of epistellar planets such as the one detected orbiting 51 Pegasi has challenged all previous theories of planet formation. These theories predicted that large Jupiter-like planets would only form several astronomical units away from their suns. The fact that epistellar planets orbit closer to their stars than Mercury orbits the Sun was totally unexpected. One way to explain this situation is that these extrasolar giant planets formed several astronomical units from their suns and then migrated by some means to their current tiny orbits. While several methods have been proposed to make giant planets migrate, they all result in the destruction of any terrestrial planets that have formed in or near a system's habitable zone. If this phenomenon is common, habitable terrestrial planets could be very rare.

All the epistellar planets found to date have been discovered by means of precise radial velocity determinations. These are made by carefully measuring the positions of dozens or even hundreds of lines in the target star's spectrum relative to the lines in a precisely controlled reference spectrum. It has been demonstrated many times that this method yields accurate results for quiescent stars like the Sun whose line shapes stay constant. But it has also been observed that these measurements can be skewed by chromospheric activity or various forms of pulsation that alter spectral line shapes with time. A variety of indirect arguments have been made that epistellar planets like 51 Pegasi B exist and are not the products of stellar activity. The simple fact of the matter is that none of the epistellar planets discovered to date has been independently confirmed using a different technique. As a result, these discoveries are still on somewhat shaky footing.

In this paper Gray and Hatzes build on Gray's earlier work presented in *Nature* (see review of "Absence of a Planetary Signature in the Spectra of the Star 51 Pegasi" in *SETIQuest* Vol. 3, No. 2, p. 19) to show that the apparent radial velocity changes in 51 Pegasi B are the result of changes in spectral line shape and not an orbiting planet. The authors used 39 spectra obtained between 1989 and 1995 using the 1.2-meter telescope and coude spectrograph at the University of Western Ontario. This instrument was used to study the Fe I line at 6252.57 Angstrom with a spectral resolving power of 100,000 and a mean signal-to-noise ratio of 405. Hatzes's earlier simulations had shown that these sorts of measurements would be needed to distinguish nonradial pulsations from true radial velocity variations (see review of "Simulations of Stellar Radial Velocity and Spectral Line Bisector Variations: I. Nonradial Pulsations" from *Publications of the Astronomical Society of the Pacific* in *SETIQuest* Vol. 3, No. 1, p. 21).

The authors noted in their analysis that this line's shape varied with time. Because the observations are scattered over many years it is difficult to determine the period of this variation but the authors' analysis indicates that it is identical to the 4.23-day orbital period of the supposed planet. Gray and Hatzes conservatively estimate that there is less than one chance in 300 that the two periods would appear to match by chance. The authors go on to show that the observed variations in line shape are consistent to stellar oscillations having $l = -m = 4$ degree (where l and m indicate traveling waves modes across the bulk of the star).

This paper is hardly the last word on the subject. Many astronomers disagree with the authors' analysis and a host of papers on the subject, both pro and con, are currently on their way to publication. But if this analysis proves to be true, epistellar planets might not exist after all and theories of planet migration (and their consequences for habitable terrestrial planets) will not be needed.

The Astrophysical Journal

Volume 491, Number 1
December 10, 1997

"Possible Metallicity Enhancements from the Accretion of Planets," by Gregory Laughlin and Fred C. Adams, p. L51

One of the consequences of the planet migration theories involving tidal interactions with protoplanetary disks is that the system's newborn sun will accrete disk material and possibly whole planets for a time. For stars like the Sun with deep convective zones, the increase in the "metal" (i.e., elements heavier than helium) content at the surface of the star would be short-lived as the accreted material is mixed with a large amount of stellar material. On the other hand, late F- and early A-type stars with masses in the 1.5 to 2.0 $M_{\odot}$ range have very shallow convective zones during the first 10 million years of their life. As a result, the enhancement in metals from accreting even modest amounts of disk material would be easily observed. The authors compared the photometrically estimated metallicity of several hundred unevolved F-type stars that lie within 40 parsecs of the Sun to an accretion model they derived. Their results indicate that the metallicities of these stars are consistent with the accretion of about 2 $M_{♃}$ worth of material from a protoplanetary disk with a 10-million-year lifetime. While there is still more work needed to verify this result, it hints that accretion of disk material is common. What is still to be determined is how this process affects the formation of solar systems like our own.

Icarus

Volume 129, Number 1, September 1997

"Biological Potential of Extraterrestrial Materials," by Michael N. Mautner, Anthony J. Conner, Kenneth Killham, and David W. Deamer, pp. 245-253

In this paper the authors investigate whether materials derived from meteorites can be used directly as nutrients by terrestrial life forms. Such raw materials would have been readily available on the young Earth and they may have sustained its earliest forms of life. During the course of their investigations the authors fed aqueous extracts from the Murchison meteorite (which is classified as a primitive C2 carbonaceous meteorite) to a genetically modified microorganism called Pseudomans flourescence, as well as soil microorganisms such as Nocardia asteroides and Arthrobacter pascens, and they all thrived. Tissue cultures of higher plants such as asparagus and potatoes displayed lower growth rates when the meteoritic extracts were the sole source of nutrients, but they did display some enhanced growth when used in conjunction with a normal nutrient media. In addition to providing evidence that carbonaceous asteroids could have supplied early life forms with nutrients, this study also suggests that these bodies may supply essential macronutrients to future space-based artificial ecosystems.

Icarus

Volume 129, Number 2, October 1997

"Simulations of the Atmospheres of Synchronously Rotating Terrestrial Planets Orbiting M Dwarfs: Conditions for Atmospheric Collapse and the Implication for Habitability," by M.M Joshi, R.M. Haberle, and R.T. Reynolds, pp. 450-465

For some time the conventional wisdom held that M-type dwarf stars, which comprise about three quarters of all stars in the galaxy, are incapable of possessing habitable planets. With a habitable zone only 0.03 to 0.4 AU from these dim stars, any planet present would quickly become tidally locked with one hemisphere permanently facing its sun. Under such conditions a planet would experience atmospheric collapse when its allotment of water vapor and carbon dioxide eventually freeze out on the planet's cold, perpetually dark side. As a result of this belief, the vast numbers of M-type dwarf stars have generally been excluded from the list of the most promising SETI targets (see "A List of SETI Targets," *SETIQuest* Vol. 1, No. 2, pp. 3-8).

In this paper the authors use new three-dimensional computer models of atmospheric circulation to determine if this belief is true. In these models the surface temperatures of an Earth-sized planet possessing a carbon dioxide atmosphere with a variety of optical depths and surface pressures was examined. It was found that at Earth-like values of insolation, collapse of a carbon dioxide-dominated atmosphere would not occur until surface pressures fell below about 30 millibars. This value would be much lower still for a nitrogen-dominated atmosphere like our own. These models also indicate that a 1 to 1.5 bar carbon dioxide atmosphere would allow the existence of liquid water over the entire surface. The authors also briefly investigated the effects of planet size and gravity on atmospheric collapse and found that a planet more massive than the Earth would be more prone to atmospheric collapse. This is because heat must be transported over longer distances and the stronger Coriolis effect perturbs atmospheric circulation required to transfer heat. Despite these problems, habitable conditions are still possible on larger worlds.

While this work is just the first step in fully exploring parameter space for planetary habitability, it does seem to destroy the conventional wisdom and shows that M-type dwarf stars could be capable of possessing habitable planets over a large range of conditions.

Icarus

Volume 130, Number 1, November 1997

"Episodic Ocean-Induced CO_2 Greenhouse on Mars: Implications for Fluvial Valley Formation," by V.C. Gulick, D. Tyler, C.P. McKay, and R.M. Haberle, pp. 68-86

The discovery a quarter of a century ago of ancient valleys carved by flowing water on Mars has been one of the most important clues of Mars's climatic history. While the Martian surface is cold and bone dry today, it must have experienced (at least briefly) much higher temperatures and atmospheric pressures in its past so that large quantities of liquid water could carve these valleys. In this paper the authors examine in detail what sort of atmospheric changes would be needed to support fluvial erosion and valley formation.

The results of the authors' calculations indicate that pulses of carbon dioxide released into the atmosphere could create a warmer greenhouse condition on Mars. A 1 or 2 bar pulse of carbon dioxide would be enough to raise the mean surface temperature to 240 to 250 degrees K for a period of tens if not hundreds of millions of years. Eventually the atmosphere would collapse as the atmospheric carbon dioxide is locked up into carbonates. Before this happened, however, large amounts of water picked up from the surface of frozen lakes or seas could be carried to higher elevations and precipitate in the form of snow. If there were any localized heat sources (e.g., from volcanoes or magmatic intrusions), some of the snow would melt and form the fluvial features seen today as the water flowed back toward the Martian lakes and seas. This snowfall would also allow the formation of glaciers and the geologic features associated with them. According to planetary geologists, there is some evidence for the presence of such glaciers in the imagery captured by the Viking scans of the Martian surface.

In any case, the existence of large bodies of water from outflow channel discharges combined with the release of sufficient quantities of carbon dioxide would allow for a limited hydrological cycle to become established. Similar environments in Antarctica have been discovered to harbor communities of microorganisms and any Martian life forms might have done the same during an ancient, more Earth-like epoch. This is yet another argument for the existence of past life on Mars as well as targeting ancient sedimentary deposits for the search for fossils.

Icarus

Volume 130, Number 1, November 1997

"CO_2 Greenhouse in the Early Martian Atmosphere: SO_2 Inhibits Condensation," by Y.L. Yung, H. Nair, M.F. Gerstell, pp. 222-224

One of the problems with relying on a carbon dioxide-dominated greenhouse effect to keep Mars warm in its early history (as well as defining the outer limits of a star's habitable zone) is the formation of carbon dioxide clouds. Early studies of the effects of these clouds hinted that they would reflect too much light away from the planet and lead to a drop in atmospheric temperatures. Based on these studies it would appear that carbon dioxide alone will not keep Mars's surface warm.

In this paper the authors examine the possibility that volcanically derived sulfur dioxide in Mars's middle atmosphere helped inhibit the formation of carbon dioxide clouds early in Mars's history. Sulfur dioxide is a strong absorber of solar ultraviolet light. In small quantities sulfur dioxide would not directly affect surface temperatures but higher up it could slightly increase atmospheric temperatures just as ultraviolet-absorbing ozone does in Earth's stratosphere.

The authors' calculations, based on a one-dimensional radiative model, indicate that 0.1 part per million by volume of sulfur dioxide in a 2 bar carbon dioxide atmosphere is enough to raise the middle atmosphere's temperature by 10 degrees C. Such a temperature increase could be enough to stop the formation of cooling carbon dioxide clouds. Another benefit derived from the addition of small amounts of sulfur dioxide to the Martian atmosphere is that it would help shield a hypothetical Martian biosphere from deadly solar ultraviolet light just as the ozone layer does on Earth.

Journal of Geophysical Research—Planets

Volume 102, Number E10
October 25, 1997

"High Temperature Life Without Photosynthesis as a Model for Mars," by Everett L. Shock, pp. 23,687–23,694

One of the more exotic families of organisms discovered over the past couple of decades are hyperthermophiles. These heat-loving bacteria and archaea not only thrive under high-temperature conditions but require them for survival. Recent genetic analysis of these and other organisms indicate that the last common ancestors for bacteria, archaea, and eucarya (which includes plants and animals) were hyperthermophiles. This hints that life on Earth may have originated in hydrothermal vents or similarly hot environments.

In this paper the author delves into the details of the chemistry of such environments. Shock finds that these ecosystems, with their exotic mix of simple compounds, are far from thermodynamic equilibrium. Microorganisms on Earth have taken advantage of these "resources" of geochemical energy and thrive without the need for photosynthesis. Given the evidence that Mars may have possessed similar environments in its past, life may have had a chance to get started and thrive on Mars during the same period of history that life arose on the Earth. Today, while conditions on the Martian surface are very hostile (and probably fatal) to life, conditions beneath its surface may allow life to still exist there without any noticeable surface expression. Despite years of work, it appears that the question of life on Mars is still far from settled.

Nature

Volume 390, Number 6659
December 4, 1997

"No 'Nanofossils' in Martian Meterorite," by J.P. Bradley, R.P. Harvey, and H.Y. McSween Jr. with reply by David S. McKay, Everett Gibson Jr., Kathie Thomas-Keprta, and H. Vali, pp. 454-455

Since the announcement in August of 1996 of the discovery of evidence of relic life in the Martian meteorite ALH84001, scientists have presented a range of non-biological explanations for what was seen. In this piece of scientific correspondence, Bradley et al. fire the latest volley against the alleged nanofossils present in the carbonates in ALH84001. The authors of this letter present the case that these structures are not nanofossils but are instead the edges of mineral crystal growth faces and vapor-deposited magnetite whiskers. As for the rounded, segmented appearance of the alleged nanofossils, Bradley et al. claim that these are artifacts of the conductive coatings that had to be applied to the samples so that they could be examined with an electron microscope. Further, they believe that these structures lose their biological appearance if viewed from different directions.

In their reply, McKay et al. state that while some of the textures and structures observed on the carbonates are certainly abiotic, other features appear to be biological in origin. For example, not all the nanofossils lie parallel to each other as would be expected from crystal growth faces. The nanofossils are also larger than these sites as well as the magnetite whiskers. As for the appearance of the nanofossils, while the application of a conductive coating can alter the appearance of features, the spatial scale of these changes is much smaller than the details seen in the alleged nanofossils. In addition, the authors of the rebuttal have performed further tests with uncoated samples and metallic replicas of original surfaces and they still see the same elongated, rounded, segmented structures.

While both teams seem to have reasonable explanations for what they have seen, the primary problem seems to be that each team is looking at different structures on different samples using different techniques. This makes direct comparisons of these and other teams' results very difficult. With this sort of approach there will probably never be any consensus in the scientific community about the origins of the carbonates and other features in ALH84001.

Nature

Volume 390, Number 6661
December 18/25, 1997

"A Resonance in the Earth's Obliquity and Precession Over the Past 20 Myr Driven by Mantle Convection," by Alessandro M. Forte and Jerry X. Mitrovica, pp. 676-680

The obliquity of a planet and how it changes with time can have a profound influence on its habitability. Obviously understanding the processes that affect obliquity is of great importance in determining it and predicting how it can affect a planet's ecosystems. At this time the terrestrial planets of our Solar System, and the Earth in particular, give us our only opportunity to identify and understand the importance of various planetary properties that affect obliquity.

In this paper Forte and Mitrovica present their analysis of the evolution of the Earth's obliquity to show the effects of convection in its mantle. The authors used viscous flow theory to determine the changes in the Earth's dynamic ellipticity (i.e., its degree of flattening) to compute perturbations to a nominal multibody model of the evolution of Earth's obliquity. It was found that the results of the model with and without mantle convection diverge significantly after only five million years. This is much shorter than the 20-million-year time scale where the Earth's obliquity becomes chaotic (in the sense that it cannot be precisely predicted). This indicates that mantle convection does play a significant role in the evolution of planetary obliquity and that it must be included when developing models in the future.

Science

Volume 278, Number 5336
October 10, 1997

"Organics and Other Molecules in the Surfaces of Callisto and Ganymede," by T.B. McCord, R.W. Carlson, W.D. Smythe, G.B. Hansen, R.N. Clark, C.A. Hibbitts, F.P. Fanale, J.C. Granahan, M. Segura, D.L. Matson, T.V. Johnson, and P.D. Martin, pp. 271-275

Since entering orbit around Jupiter in December of 1995, the Galileo spacecraft has made periodic close flybys of the Jovian moons Europa, Ganymede, and Callisto. Among the many instruments used to observe these planet-sized bodies is the Near-Infrared Mapping Spectrometer (NIMS) which is capable of making images simultaneously in 408 spectral channels in the wavelength range of 0.7 to 5.2 micrometers with a spatial resolution of five kilometers at a range of 10,000 kilometers. Such an instrument is ideal for determining the makeup of the targets it examines.

Not surprisingly, a close examination of the spectra obtained of Ganymede and Callisto indicate that their surfaces are primarily composed of water ice and hydrated minerals. In this paper the authors present the results of their interpretation of five other absorption features they observed in the spectra of these two moons. These features are located at the wavelengths of 3.4, 3.88, 4.05, 4.25, and 4.57 micrometers. These bands are thought to be caused by the presence of carbon dioxide ice, organic compounds such as tholins containing triply bound groups of carbon and nitrogen and singly bound groups of carbon and hydrogen, sulfur dioxide, and compounds containing an SH-functional group (a paired sulfur/hydrogen atom). Cyanogen may also be present in the surface materials as collections of a few molecules each. It is likely that the sulfur-bearing compounds are derived from materials escaping Io's powerful volcanoes. While some of the organic compounds may form as a result of exposure to solar ultraviolet light and Jupiter's radiation belts, the raw materials are probably derived from meteorites that strike these moons. If the same processes are taking place elsewhere in the Jovian system, Europa's surface may also be accumulating these same organic compounds. Combined with the possible presence of liquid water beneath its icy surface and tidally derived heat, on paper Europa would seem to have all the ingredients necessary for life. Future close-up observations of Europa during the recently started Galileo Europa Mission could help to locate these compounds on Europa's surface as well as search for them in materials that have upwelled from below the surface.

Science

Volume 278, Number 5340
November 7, 1997

"Age and Origin of the Moon," by Der-Chen Lee, Alex N. Halliday, Gregory A. Snyder, and Lawrence A. Taylor, pp. 1098-1103

The importance of the Moon to Earth's habitability and the evolution of its life forms has been recognized repeatedly in recent years. But the Moon's origin remains largely a mystery to this day. Despite this, theories for lunar origin abound but fall into four general categories: co-accretion, fission, giant impact, and capture. One key piece of information needed to choose between the options is the date of the Moon's origin.

In this paper the authors used the hafnium-tungsten chronometer, previously used by Lee and Halliday to estimate the time needed to form planetary cores (see the review of the *Nature* article titled "Core Formation on Mars and Differentiated Asteroids" in *SETIQuest* Vol. 3, No. 4, p. 22) to estimate the time of the Moon's origin.

Their measurements of the concentration of tungsten-182 (the decay product of radioactive hafnium-182) and tungsten-184 in 21 lunar samples indicates that the Moon formed between 4.52 and 4.50 billion years ago. That's 50 to 70 million years after the generally accepted beginning of the formation of the planets 4.57 billion years ago.

By this point in history, Earth, Vesta, and Mars had already finished forming cores. If the Moon formed along with the Earth (as in the co-accretion theory) or formed elsewhere in the Solar System to be captured later, it should be a few tens of million years older. But such a late date for the origin of the Moon is consistent with either the fission or giant impact theories for the origin of the Moon.

Given the many difficulties known to exist with the old fission theory, this latest finding lends support for the giant impact origin of the Moon.

Science

Volume 278, Number 5341
November 14, 1997

"Warming Early Mars with Carbon Dioxide Clouds That Scatter Infrared Radiation," by François Forget and Raymond T. Pierrehumbert, pp. 1273-1276

A limitation for maintaining planetary surface temperatures using a carbon dioxide-dominated greenhouse effect is the formation of carbon dioxide ice (dry ice) clouds. Earlier work indicated that such clouds would scatter visible light efficiently and would be even more transparent in the thermal infrared than water ice clouds. These effects combine to lower surface temperatures by allowing less light to reach the surface and heat generated at the surface to escape into space.

The authors examine the probable sizes of the carbon dioxide ice particles in these clouds and their optical properties. Earlier work with these clouds assumed that the particles' sizes would be very small but in reality there is little knowledge on how large these ice crystals will grow. The authors surmise that these particles would easily grow to 10 to 100 micrometers across (similar to the size of water ice crystals in terrestrial cirrus clouds) if not larger. Crystals of this size readily scatter thermal infrared radiation. Using a one-dimensional atmospheric model incorporating the effects of multiple scattering, Forget and Pierrehumbert discovered that their carbon dioxide ice clouds were very efficient reflectors of thermal infrared light and more than made up for any energy lost from scattering incoming solar radiation. In other words, the presence of carbon dioxide clouds actually *increases*, not decreases, planetary surface temperatures.

This finding has a number of major implications. In the case of Mars (and possibly the early Earth), clouds of this type can easily explain the faint Sun paradox. Calculations indicate that Martian surface temperatures could be kept above freezing with as little as a few hundred millibars of carbon dioxide in the presence of carbon dioxide ice clouds. Even as little as 300 millibars of carbon dioxide would keep the temperatures high enough to allow for ice-covered bodies of water. This result has even broader implications for the location of the outer limit of a star's habitable zone. A water-saturated 10-bar carbon dioxide atmosphere (to provide a maximum greenhouse effect) with thick carbon dioxide ice clouds (providing an efficient means of reflecting heat back toward the surface) could maintain above-freezing surface temperatures to distances greater than 2.4 AU from a Sun-like star. This is much greater than the previous assumed outer limit of about 1.37 AU and potentially increases the chances of finding habitable planets and moons.

Science

Volume 278, Number 5344
December 5, 1997

"Overview of the Mars Pathfinder Mission and Assessment of Landing Site Predictions," by M.P. Golombek, R.A. Cook, T. Economou, W.M. Folkner, A.F.C. Haldemann, P.H. Kallemeyn, J.M. Knudsen, R.M. Manning, H.J. Moore, T.J. Parker, R. Rieder, J.T. Schofield, P.H. Smith, and R.M. Vaughan, pp. 1743-1748

"Interior Structure and Seasonal Mass Redistribution of Mars from Radio Tracking of Mars Pathfinder," by W.M. Folkner, C.F. Yoder, D.N. Yuan, E.M. Standish, and R.A. Preston, pp. 1749-1752

"The Mars Pathfinder Atmospheric Structure Investigation/Meteorology (ASI/MET) Experiment," by J.T. Schofield, J.R. Barnes, D. Crisp, R.M. Haberle, S. Larsen, J.A. Magalhaes, J.R. Murphy, A. Seiff, and G. Wilson, pp. 1752-1758

"Results from the Mars Pathfinder Camera," by P.H. Smith, J.F. Bell III, N.T. Bridges, D.T. Britt, L. Gaddis, R. Greeley, H.U. Keller, K.E. Herkenhoff, R. Jaumann, J.R. Johnson, R.L. Kirk, M. Lemmon, J.N. Maki, M.C. Malin, S.L. Murchie, J. Oberst, T.J. Parker, R.J. Reid, R. Sablotny, L.A. Soderblom, C. Stoker, R. Sullivan, N. Thomas, M.G. Tomasko, W. Ward, and E. Wegryn, pp. 1758-1765

"Characterization of the Martian Surface Deposits by the Mars Pathfinder Rover, Sojourner," by Rover Team, pp. 1765-1768

"Magnetic Properties Experiments on the Mars Pathfinder Lander: Preliminary Results," by S.F. Hviid, M.B. Madsen, H.P. Gunnlaugsson, W. Goetz, J.M. Knudsen, R.B. Hargraves, P. Smith, D. Britt, A.R. Dinesen, C.T. Mogensen, M. Olsen, C.T. Pedersen, and L. Vistisen, pp. 1768-1770

"The Chemical Composition of the Martian Soil and Rocks Returned by the Mobil Alpha Proton X-ray Spectrometer: Preliminary Results from the X-ray Mode," by R. Rieder, T. Economou, H. Wanke, A. Turkevich, J. Crisp, J. Bruckner, G. Dreibus, and H.Y. McSween Jr., pp. 1771-1776

On July 4, 1997, Mars Pathfinder successfully landed on the surface of Mars, making it the first spacecraft from the Earth to do so since the Viking mission more than two decades ago. In addition to its own suite of instruments, Mars Pathfinder also carried a semiautonomous rover that was able to inspect and analyze the soil and rocks in the landing area using a pair of cameras and an alpha-proton X-ray spectrometer. The papers presented here give the preliminary science results from the Mars Pathfinder's 30-Sol (i.e., 30-Martian-day) primary mission.

Among the more important findings of this mission is ample evidence for there having been a warmer and wetter climate on Mars in the distant past. Mars Pathfinder's landing site near the mouth of Ares Vallis displayed all the signs of multiple inundations: water-based erosion features, the presence of sand and pebbles, the systematic alignment of rocks, water-based weathering products, and so on. An inspection of the rocks also shows indications of the presence of various types of sedimentary deposits and the formation of conglomerates where smaller stones of various types are cemented together.

The alpha-proton X-ray spectrometer carried by the Sojourner rover was also able to carry out the first-ever chemical analysis of Martian rocks (the Viking landers were only able to analyze soils samples at their landing sites). Preliminary analysis shows that some of the rocks in the area have a much higher silica content than that found in any other extraterrestrial samples or SNC (Shergotty-Nakhla-Chassigny) meteorites (which are generally thought to come from Mars). This type of rock on Earth is generally associated with the recycling of basaltic crust in the presence of water. This was a totally unexpected finding and hints that Mars experienced more Earth-like geologic processes in the past.

Radio tracking of Mars Pathfinder, when combined with similar results from the previous Viking mission, has been able to better define the precession of Mars's rotational axis and its other axial motions. These results have allowed investigators to estimate the radius of the Martian core to be between 1300 and 2000 kilometers. Compared to the Earth, Mars's core comprises a much smaller fraction of the planet's total mass. Quite interestingly the tracking results seem to indicate that the cartographic network in the landing area is offset by about 20 kilometers. If this is typical across the Martian surface, pinpoint landings at targets of interest will require much more accurate maps in the future. While there is still much analysis of these data to be performed (not to mention analysis of the data from Mars Pathfinder's extended mission), this relatively inexpensive planetary mission adds weight to the possibility that Mars was once a much more hospitable abode for life than it is today.

Science

Volume 278, Number 5345
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"A Pulsar, the Heliosphere, and Pioneer 10: Probable Mimicking of a Planet of PSR B1257+12 by Solar Rotation," by Klaus Scherer, Horst Fichtner, John D. Anderson, and Eunice L. Lau, pp. 1919-1921

The existence of planets orbiting a handful of pulsars has been inferred by the presence of periodic timing residuals on the order of microseconds in the regular, clock-like radio pulses received on the Earth. These planets, many of which are of terrestrial proportions, likely formed from the debris left over from the supernova that created the pulsars they orbit. While it is incredibly unlikely that any of these worlds are habitable due to the extreme environment near a pulsar, the existence of pulsar planets does demonstrate how robust the planetary formation process is. One pulsar in particular, PSR B1257+12, displays timing residuals consistent with the presence of three terrestrial-sized planets. These planets have orbital periods of 25.34, 66.54, and 98.22 days and masses of 0.015, 3.4, and 2.8 $M_\oplus$, respectively. This system of planets offers our only glimpse (outside of our Solar System) of the dynamics of a multi-planet system with orbits comparable in size to those expected for habitable planets orbiting Sun-like stars.

In this paper the authors show that the inner Moon-sized planet may not actually exist but instead is due to some sort of periodic change in the properties of the Sun's heliosphere. Scherer et al. analyzed a decade's worth of ranging data returned from the NASA Pioneer 10 probe. After taking into account all possible sources of perturbation, the authors found that the ranging data residuals clearly displayed a periodicity of 13.3 days, 25.3 days, and about a year. Further analysis shows that the period of 25.3 days is almost identical to the inferred 25.34-day period of the inner planet of PSR B1257+12. Since this pulsar and Pioneer 10 lie close to the ecliptic as viewed from the Earth, it is likely that the delays in their radio signals are being affected by the same mechanism. Analysis of other satellite data hints that these variations could be related to periodic changes in the plasma density caused by the rotation of the Sun. While doubt has been cast on the existence of the inner planet of PSR B1257+12, these results do not seem to rule out the presence of the other two planets.

Science News

Volume 152, Number 18
November 1, 1997

"C'est la Vie, Searching for Life in the Solar System," by Ron Cowen, pp. 284-285

During the past couple of years there has been an incredible resurgence of interest in searching for life (both extinct and extant) elsewhere in this Solar System. This article reviews some of the latest research and space missions to some of the more promising sites. What scientists hope to learn about Titan—using the recently launched Cassini mission—tops the list. This spacecraft is carrying the Huygens probe which will land on Saturn's largest moon in 2004. While life is not likely to be found on this body, Titan is a marvelous natural laboratory for exploring prebiotic conditions on planetary bodies. Discussion includes Europa, and what has been learned from the now-extended Galileo mission. Finally the latest studies pertaining to the possibility of subsurface microorganisms on Mars and the search for Martian fossils are also summarized.

Scientific American

Volume 277, Number 6, December 1997

"The Case for Relic Life on Mars," by Everett K. Gibson, Jr., David S. McKay, Kathie Thomas-Keprta, and Christopher S. Romanek, pp. 58-65

This popular-level article tells the story behind ALH84001 and the possible discovery of microfossils within it. Written by four of the scientists that were responsible for the discovery announced in August 1996, this piece explores the story behind this meteorite and the investigations of it. All the evidence of their discovery and its significance to the larger picture are discussed. In addition to the original discovery evidence, the authors also present new evidence to back their claims. Criticisms of their claims that have appeared in the literature and their counter arguments receive only brief attention. Despite this largely one-sided presentation of the story, it is excellently written and should help the lay public understand the nature of this discovery. A hyperlinked version of this article is available at www.sciam.com.

Sky & Telescope

Volume 94, Number 6, December 1997

"Europa: Distant Ocean, Hidden Life?," by Michael Carroll, pp. 50-55

This excellent article concisely summarizes our present understanding of Europa largely based on the discoveries made by NASA's Galileo mission. Making generous use of spacecraft images and clear diagrams, Carroll explains the origin of the geologic features observed on Europa's icy surface. All of this evidence strongly suggests the presence of a tidally heated ocean of water beneath a thin veneer of ice—if not in the present epoch, then in the geologically recent past. This combination of a vigorous heat source and liquid water opens the possibility of the existence of life on this bizarre Jovian moon. The author examines this possibility, drawing heavily on studies of terrestrial ecosystems centered on hot springs to show that Europan microorganisms could in theory exist. The article ends with a review of the Galileo Europa Mission and proposed next-generation missions to Europa and what they hope to find. Despite its alien nature and great distance, Europa promises to be one of the hottest targets in our Solar System for exobiological exploration as we enter the next century.

Sky & Telescope

Volume 95, Number 2, February 1998

"Gamma-Ray Bursts of Doom," by Peter J. Leonard and Jerry T. Bonnell, pp. 28-34

In the past couple of decades a number of classes of natural disasters, some of astronomical origins, have been identified as the cause of the mass extinctions that appear throughout Earth's history. In this article yet another potential source of disaster has been identified: nearby gamma-ray bursters.

The origin of cosmic gamma-ray bursts, which occur at the rate of about once per day, has been a mystery since they were first observed three decades ago. Recent observations and the fortuitous identification of the optical counterparts of some of these events has finally allowed astronomers to determine that they are typically quite distant and occur throughout the universe. Because of their great distance and apparent brightness, gamma-ray bursts are probably the most energetic events in the Universe. While many details remain to be worked out by astrophysicists, the only event that could create these enormous, relatively common flashes of energy is the merging of closely orbiting neutron stars.

In this article the authors examine the consequences of a nearby gamma-ray burst. If gamma-ray bursts are caused by the merging of neutron stars, they can be expected to occur once every two or three million years in our galaxy. At that rate, a gamma-ray burst would occur within an uncomfortably close 3,000 light years every 100 million years (comparable to the time between Earth's mass extinctions). The immediate effects of such a close gamma-ray burst would be the destruction of the Earth's ozone layer caused by the production of nitric oxides in the upper atmosphere. These compounds could also produce a dense smog-like layer that would engulf the Earth and require years to disperse. While the increase in solar ultraviolet light and the decrease in solar illumination would certainly be devastating, some models of neutron-star mergings hint that a lethal dose of cosmic rays could hit the Earth a few days after the gamma-ray burst is observed. The total amount of muon radiation produced from the month-long hail of cosmic rays would be 100 times the dose lethal to humans. These same cosmic rays would also split the nuclei of many air molecules producing lethally radioactive isotopes that would require years to decay. Only organisms shielded by more than hundreds of meters of rock or water would be expected to survive this assault.

While there is still much theoretical work to be done to determine the properties of gamma-ray bursts, it does seem possible that they can have a profound effect on any nearby habitable planets.