Expanding the Habitable Zone

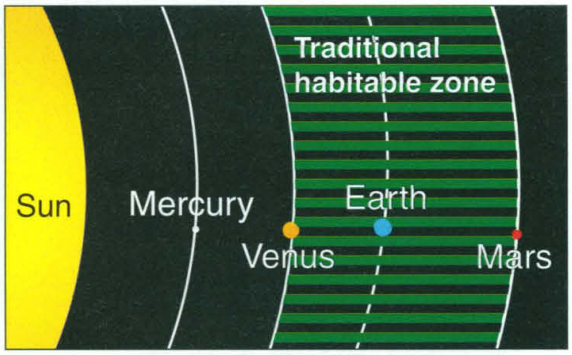
Once restricted to a relatively narrow slice of the solar system, the possible environments for life in space are multiplying, reaching Pluto and even into interstellar space

On *Star Trek*, the best place for Captain Kirk and his crew to "seek out new life and new civilizations" was on what the show's writers called a class M planet: a world with a thick atmosphere of oxygen and nitrogen, often close to a stable star and having fertile soil and a pleasant climate—a place just like Earth. But Kirk and company suffered from a failure of imagination. Whereas scientists, like the *Star Trek* crew, once defined the "habitable zone" around a sunlike star as a halo no larger than about 1.5 Earth orbits, they are now expanding the list of places in the universe that might nurture living things.

New finds on Earth, such as colonies of bacteria deep underground, have suggested that organisms can thrive even if sealed off from the sun, by living on chemical rather than solar energy. And discoveries in space, such as a possible subsurface ocean on Jupiter's moon Europa, have opened up any number of odd corners of the universe as possible wellsprings of life. Pluto's moon Charon and even rogue planets in interstellar space are now all contenders. "Life might have a far wider canvas to work on than people had thought," says planetary scientist David Black of the Lunar and Planetary Institute in Houston.

Assuming that life elsewhere follows the rules we know on Earth, there are only a few requirements—in particular, water, which provides a solvent for life's essential chemical reactions. "The search for life has been the search for liquid water," says cosmochemist Christopher Chyba of the SETI Institute in Mountain View, California. "That's the sine qua non." Also high on the list, he notes, are an energy source and protection from radiation damage—and these too are turning out to be more common than previously thought.

In spite of its focus on Earth-like planets, the crew of the Starship Enterprise managed to discover unusual organisms nearly every week. Microbiologists seeking new life-forms on Earth have been almost as successful, finding life just about everywhere they look. Take for example the diverse chemosynthetic organisms at hydrothermal vents, which thrive on Earth's internal heat and chemicals. The existence of these organisms, discovered in the 1970s, proved that life can thrive without sunlight, although such organisms still rely on carbon and oxygen produced by photosynthesis near the surface. Other startling discoveries include microbes buried deep under northeastern Virginia; these may have been living independently of the surface by existing on ancient organic matter in nearby rocks for millions of years, says Princeton University geomicrobiologist Tullis Onstott (*Science*, 2 May 1997, p. 703).



The inner zone. Researchers once thought life could survive only on the inner planets.

Onstott and his colleagues have also found life more than 3.5 kilometers down in a South African gold mine, in rocks that may have been sealed off from the surface 2 billion years ago. The scientists have cultured bacteria that thrive on iron oxides and hydrogen in the lab. And in the Columbia River Basin, researchers found evidence for bacteria that seem to eke out an existence on hydrogen gas and carbon dioxide from dissolved rock thousands of meters belowground (*Science*, 20 October 1995, p. 377).

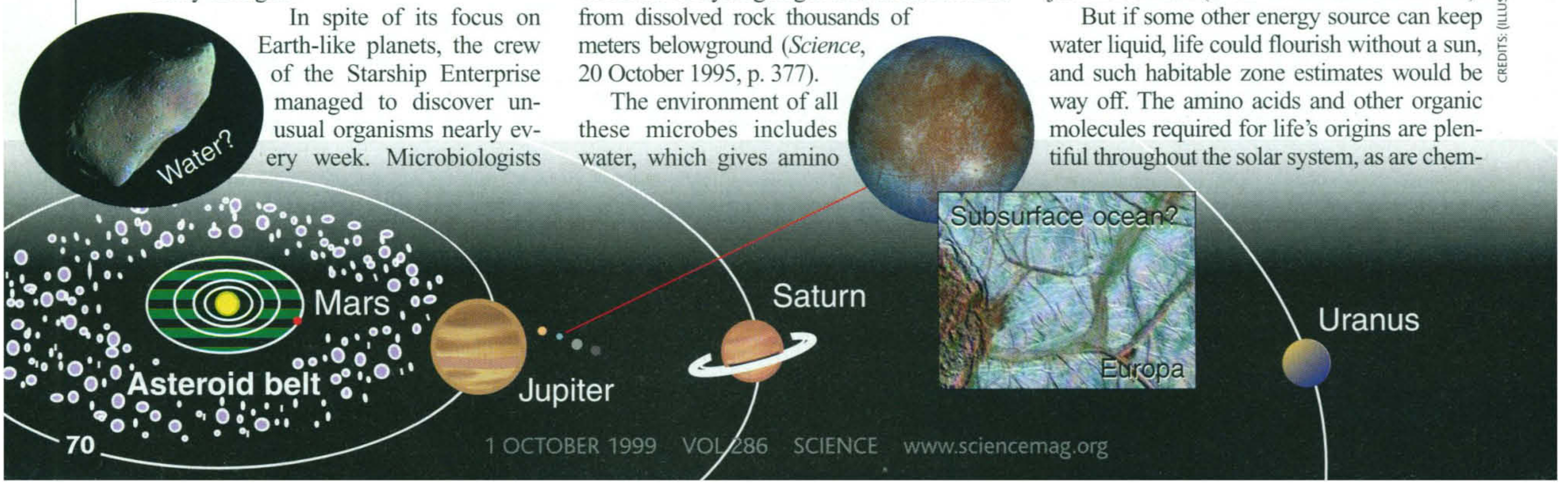
The environment of all these microbes includes water, which gives amino acids and other organic molecules a liquid medium in which to mingle and react. Substances that stay liquid at chillier temperatures, such as ammonia or hydrocarbons, might be possible solvents. But reactions at low temperatures would likely be so slow as to rule out Earth-like life.

Here on Earth, the need for liquid water is not much of a limit. For example, cosmochemist Christopher McKay of NASA Ames Research Center in Mountain View, California, and his colleagues cultured microbes from 3.5-million-year-old permafrost in remote Siberia (see p. 36), where microscopic films of liquid water surround grains of soil even at –20°C. As they reported at a recent meeting, these organisms incorporate radioactively labeled carbon, a sign that they are indeed alive, if barely. Whereas many bacteria double their populations in a matter of hours, these cells divided only once a day at about 5°C, and only about twice a year at –20°C, the team found. Also encouraging is the preliminary evidence that life can survive on scarce water deep underground, says Onstott.

This is good news to those who suspect underground microbial life exists on Mars, which lost its surface water—and therefore presumably any surface life—some 3.5 billion years ago. If life can flourish in isolated regions deep within Earth, then "the prospect of going to Mars, drilling a couple of kilometers down, and … coming back with organisms becomes exceedingly better," Onstott says.

In space, new discoveries keep widening the region researchers believe might harbor water—the so-called habitable zone around a star. Many variables, including the star's mass and age and the presence of a heat-trapping atmosphere on the planet, influence the size of that zone. But for a star like the sun, traditional estimates extend from an orbit as close as Venus's (about 0.7 times Earth's orbit) to one just inside Mars (about 1.4 times Earth's orbit).

But if some other energy source can keep water liquid, life could flourish without a sun, and such habitable zone estimates would be way off. The amino acids and other organic molecules required for life's origins are plentiful throughout the solar system, as are chem-



CREDITS: (ILLUSTRATIONS) CARIN CAIN; (ASTEROID) NASA/USGS; (EUROPA) UNIVERSITY OF ARIZONA/NASA; (EUROPA INSET) PIRL/UNIVERSITY OF ARIZONA ical energy sources such as hydrogen and iron oxides. And as researchers probe the solar system, they are finding a variety of heat sources, from gravitational tugging to internal radioactivity. "The bottom line is that if life could emerge in a liquid water environment, then the main energy source need not be solar radiation," says planetary scientist Douglas Lin of the University of California, Santa Cruz. "The physical range which would allow habitable environments to evolve can extend over the entire solar system."

For example, the pictures of Jupiter's moon Europa, sent back by the Galileo spacecraft, suggest a liquid ocean sloshing under an icy crust (*Science*, 8 August 1997, p. 764), more than tripling the textbook width of the habitable zone. That's physically possible, scientists say, because the gravitational strain from Jupiter and Europa's sister moons might knead Europa's insides enough to generate heat that would melt a subsurface ocean.

Even farther afield, Lin and his colleagues suggest that Pluto's moon Charon may be hot enough to have liquid water—in an orbit 40 times more distant from the sun than Earth's is. Like an amusement park Tilt-A-Whirl, Charon's orbit is tipped 110 degrees with respect to Pluto's own path around the sun, and the team's preliminary calculations suggest that the conflicting pulls from Pluto and the sun may be enough to melt Charon's interior. "All of a sudden the so-called habitable zone has extended by an order of magnitude," says Lin.

Earth-sized rocky bodies that formed far from their parent sun might not need gravitational interactions to maintain a deep ocean, says Fred Adams of the University of Michigan, Ann Arbor. According to computer models that he and space scientist Greg Laughlin of NASA Ames presented at the American Astronomical Society meeting in June, rocky planets could readily form between Mars and Jupiter, at two to four times Earth's orbit (see diagram). Planets formed so far from the sun would likely have deeper oceans than Earth's, as the sun's heat would evaporate less water during their formation. And internal heating alone could melt any ice deeper than 14 kilometers below the surface on an Earth-sized planet. Says SETI's Chyba, "If you make the ocean deep enough, you're not going to freeze it all."

CREDITS: (TOP) H. DONG; (PLUTO AND CHARON) JPL/NASA

Because deep-ocean planets are common in model solar systems, they "might be the most likely place for life to exist in the galaxy," Adams says. The recent discovery of liquid water in a meteorite (*Science*, 27 August, p. 1377) implies that life could conceivably hop from one such water world to another. Water must have been present on the meteorite's parent body—perhaps a large, rocky protoplanet, smaller than a full-grown specimen but warmed enough by internal heat to melt ice. If life got started on such a body, it might survive even after impacts broke up the earlier planet, in fragments that could seed larger, more hospitable worlds.

Hot stuff. Heat-loving bacteria from a deep South African mine eat iron oxides.

At least one prominent theorist thinks extraterrestrial life on small bodies is a good bet. At a meeting this summer, theoretical physicist Freeman Dyson of the Institute for Advanced Study in Princeton, New Jersey, offered to bet $100 that the first extraterrestrial life would be found on an asteroid or even in a cloud of space dust, rather than on a planet. Smaller objects account for much of the solar system's mass, and so have "simply so much more real estate" for life to colonize, both at and below the surface.

But other researchers think Dyson is likely to lose his wager. Even if life could survive on an asteroid, it would probably find only a temporary home, most astrobiologists say. Asteroids are too small to support an atmosphere or produce much heat, so any Earth-like life-form would be frozen and dormant, with activities such as DNA repair systems shut down. With radiation streaming in from a distant sun or internal radioactivity, organisms there would accumulate lethal doses of radiation after millions of years, says NASA's McKay.

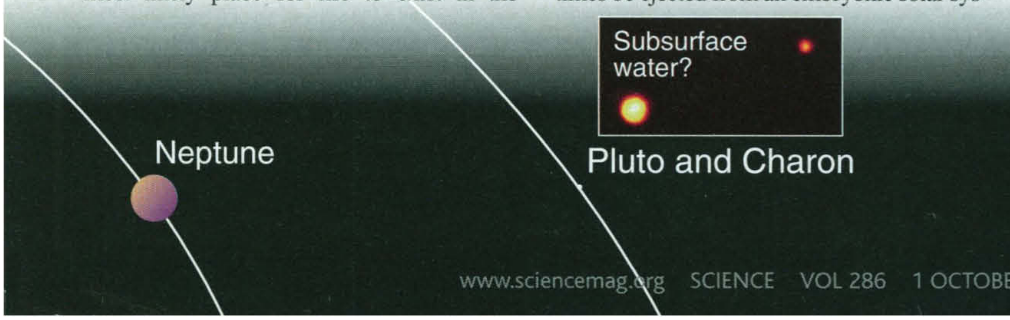
An even more far-out possibility is that life might not need a star at all, says planetary scientist David Stevenson of the California Institute of Technology. In July in *Nature*, he proposed that an Earth-sized planet might sometimes be ejected from an embryonic solar system before the star's increasing heat had a chance to drive off the planet's tenuous hydrogen atmosphere. As the wayward planet cooled, he calculates, the atmosphere would condense enough to cause a sort of greenhouse effect, trapping the heat produced by radioactive decay in the planet's interior. This could melt water at the surface and provide a promising place for simple life to develop while the planet drifted in interstellar space.

The theory makes sense, says Michigan's Adams, who notes that a planet being ejected from a solar system is more probable than a person winning a lottery on Earth. Indeed, a lone planet might provide a safe long-term refuge for life. In 3.5 billion years, the expanding sun is expected to burn most of Earth's life away, but a rogue planet's internal heat could keep some life alive for at least 30 billion years. The catch, Stevenson acknowledges, is that it would be nearly impossible to detect such dark planets. "It's in the category of things you bring up to stimulate the thinking," he says. "It's not in the same category as real discoveries."

And even if simple life-forms could thrive in such a desolate place, researchers say it would not be a promising habitat for advanced life—the "new civilizations" so often encountered on *Star Trek*. "Complex life like animals and plants needs a lot of energy," McKay says, and the energy on such a starless planet would be one-thousandth of that available to us from the sun.

All this, of course, is completely in the realm of theory. The next real discoveries—less sensational but more concrete—may come when the Mars Polar Lander touches down on 3 December. If all goes well, the lander will deploy two probes to search for water ice under the Red Planet's surface, allowing scientists to add some data to their speculations about liquid water there. And scientists envision the planned Terrestrial Planet Finder as a suite of telescopes working together to see much deeper into the sky—able to spot Earth-like planets around other stars and even collect evidence of their chemistry, including any oxygen or liquid water, based on the wavelengths of light they reflect (*Science*, 17 September, p. 1864). Finally, depending on the outcome of this fall's budget negotiations, NASA hopes to design a probe to visit Europa. "The million-dollar question is to go to Europa and see what's there" in its deep ocean, says Chyba. For Dyson, at least, it's a $100 question.

–GRETCHEN VOGEL



Water worlds. The regions of space that might harbor water—and therefore life—keep expanding.