# Searching for Life in Other Solar Systems

Life remains a phenomenon we know only on Earth. But an innovative telescope in space could change that by detecting signs of life on planets orbiting other stars

by Roger Angel and Neville J. Woolf

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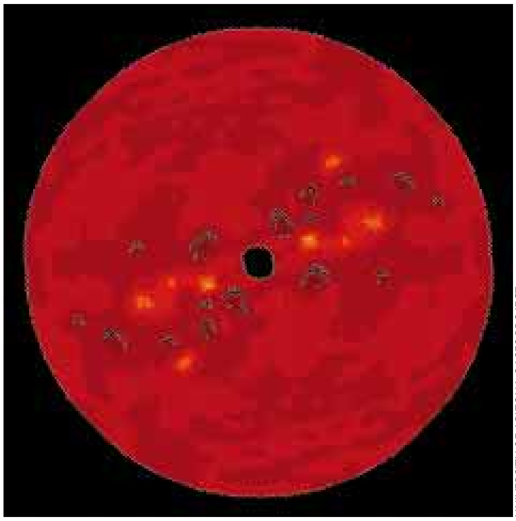


UNIVERSITY OF ARIZONA OASES PROJECT

IMAGE OF DISTANT PLANETS, created from simulated interferometer signals, indicates what astronomers might reasonably expect to see with a space-based telescope. This study displays a system about 30 light-years away, with four planets roughly equivalent in luminosity to Earth. (Each planet appears twice, mirrored across the star.) With this sensitivity, the authors speculate that the instrument could easily examine the planet found in 1996 orbiting 47 Ursae Majoris.

The search for extraterrestrial life can now be extended to planets outside our solar system. After years of looking, astronomers have turned up evidence of giant planets orbiting several distant stars similar to our sun. Smaller planets around these and other stars may have evolved living organisms. Finding extraterrestrial life may seem a Herculean task, but a space telescope mission called the Terrestrial Planet Finder, which the National Aeronautics and Space Administration plans to start in 2005, aims to locate such planets and search for evidence of life-forms, such as the primitive ones on Earth.

The largest and most powerful telescope now in space, the Hubble Space Telescope, can just make out mountains on Mars at 30 kilometers (19 miles). Pictures sharp enough to display geologic features of planets around other stars would require an array of space telescopes the size of the U.S. But pictures of Earth do not reveal the presence of life unless they are taken at very high resolution. Such images could be obtained with unmanned spacecraft sent to other solar systems, but the huge distance between Earth and any other planet makes this approach impractical.

Taking photographs, however, is not the best way to study distant planets. Spectroscopy, the technique astronomers use to obtain information about stars, can also reveal much about planets. In spectroscopy, light originating from an object in space is analyzed for unique markers that help researchers piece together characteristics such as the celestial body's temperature, atmospheric pressure and chemical composition. Simple life-forms on our planet have profoundly altered conditions on Earth in ways that a distant observer could perceive by spectroscopy of the planet atmosphere.

Fossil records indicate that within a billion years of Earth's formation, as soon as heavy bombardment by asteroids ceased, primitive organisms such as bacteria and algae evolved and spread around the globe. These organisms represented the totality of life here for the next two billion years; consequently, if life exists on other planets, it might well be in this highly uncommunicative form.

Earth's humble blue-green algae do not operate radio transmitters. Yet they are chemical engineers, honed by evolution, operating on a huge scale. As algae became more widespread, they began adding large quantities of oxygen to the atmosphere. The production of oxygen, fueled by energy derived from sunlight, is fundamental to carbon-based life: the simplest organisms take in water, nitrogen and carbon dioxide as nutrients and then release oxygen into the atmosphere as waste. Oxygen is a chemically reactive gas; without continued replenishment by algae and, later in Earth's evolution, by plants, its concentration would fall. Thus, the presence of large amounts of oxygen in a planet's atmosphere is a good indicator that some form of carbon-based life may exist there.

In 1993 the Galileo space probe detected oxygen's distinctive spectrum in the red region of visible light from Earth. Indeed, this observation tells us that for a billion years—since plant and animal life has flourished on Earth—a signal of life's presence has radiated into space. The clincher that reveals life processes are occurring on Earth is the simultaneous presence in the planet's spectrum of methane, which is unstable around oxygen but which life continuously replenishes.

What constitutes detection of distant life? Some scientists hold that because life elsewhere is improbable, proof of its detection requires strong evidence. It seems likely, though, that life on other planets would have a carbon-based chemistry similar to our own. Carbon is particularly suitable as a building block of life: it is abundant in the universe, and no other known element can form the myriad of complex but stable molecules necessary for life as we know it. We believe that if a planet looks like Earth and has liquid water and oxygen (evident as ozone), then this would present strong evidence for its having life. If such a planet were found, subsequent investigations could strengthen the case by searching for the more elusive spectral observation of methane.

Of course, there could be some nonbiological oxygen source on a lifeless planet, a possibility that must be considered. Conversely, life could arise from some other type of chemistry that does not generate oxygen. Yet we still should be able to detect any stirrings from chemical residues.

### Searching for Another Earth

Planets similar to Earth in size and distance from their sun—ones likely to have oceans of water—represent the most plausible homes for carbon-based life in other solar systems. Water provides a solvent for life's biochemical reactions and serves as a source of needed hydrogen. If each star has planets spanning a range of orbital distances, as occurs in our solar system, then one of those planets is likely to orbit at the right distance to sustain liquid water—even if the star shines more or less brightly than the sun.

Temperature, though, means little if a planet's gravitational pull cannot hold on to oceans and an atmosphere. If distance from a star were the only factor to consider, Earth's moon would have liquid water. But gravity depends on the size and density of the body. Because the moon is smaller and less

SPACE-BASED TELESCOPE SYSTEM that can search for life-bearing planets has been proposed by the authors. The instrument, a type of interferometer, could be assembled at the proposed international space station (*lower left*). Subsequently, electric propulsion would send the 50- to 75-meter-long device into an orbit around the sun roughly the same as Jupiter's. Such a mission is at the focus of the National Aeronautics and Space Administration's plans to study neighboring planetary systems.

dense than Earth, its gravitational pull is much weaker. Any water or layers of atmosphere that might develop on or around such a body would quickly be lost to space.

Clearly, we need a technique to reveal characteristics as specific as what chemicals can be found on a planet. Previously we mentioned that the visible radiation coming from a planet can confirm the presence of certain molecules, in particular oxygen, that are known to support life. But distinguishing faint oxygen signals in light reflected by a small planet orbiting even a nearby star is extraordinarily difficult.

A larger version of the Hubble Space Telescope, specially equipped for extremely accurate optical correction, possibly could spot Earth-like planets if they are orbiting the three nearest sunlike stars and search them spectroscopically for oxygen. A more robust method for sampling dozens of stars is needed.

Faced with this quandary, in 1986 we proposed, along with Andrew Y. S. Cheng, now at the University of Hong Kong, that midinfrared wavelengths would serve as the best spectral region in which to find planets and to search for extraterrestrial life. This type of radiation—really the planet's radiated heat—has a wavelength 10 to 20 times longer than that of visible light. At these wavelengths, a planet emits about 40 times as many photons—particles of light—as it does at shorter wavelengths. The nearby star would outshine the planet "only" 10 million times, a ratio 1,000 times more favorable than that which red light offers.

Moreover, three key compounds that we would expect to find on inhabited planets—ozone (a form of oxygen usually located high in the atmosphere), carbon dioxide and water—leave strong imprints in a planet's infrared spectrum. Once again, our solar system provides promising support for this technique: a survey of the infrared emissions of local planets reveals that only Earth displays the infrared signature of life. Although Earth, Mars and Venus all have atmospheres with carbon dioxide, only Earth shows the signature of plentiful water and ozone. Sensitively indicating oxygen, ozone would have appeared on Earth a billion years before oxygen's infrared spectral feature grew detectable.

What kind of telescope do we need to locate Earth-like planets and pick up their infrared emissions? Some of today's ground-based telescopes can detect strong infrared radiation emanating from stars. But the telescope's own heat plus atmospheric absorptions would swamp any sign of a planet. Obviously, we reasoned, we must move the telescope into space.

Even then, to distinguish a planet's radiation from that of its star, a traditional telescope must be much larger than any ground-based or orbiting telescope built to date. Because light cannot be focused to a spot smaller than its wavelength, even a perfect telescope cannot form ideal images. At best, light will focus to a fuzzy core surrounded by a faint halo. If the halo surrounding the star extends beyond the planet's orbit, then we cannot discern the much dimmer body of the planet inside it. By making a telescope mirror and the resulting image very large, we can, in principle, make the image of a star as sharp as desired.

Because we can predict a telescope's performance, we know in advance what kind of image quality to expect. For example, to monitor the infrared spectrum of an Earth-like planet circling, say, a star 30 light-years away, we need a supergiant space telescope, close to 60 meters in diameter. We have made recent steps toward the technology for such telescopes, but 60 meters remains far beyond reach.

### Rethinking the Telescope

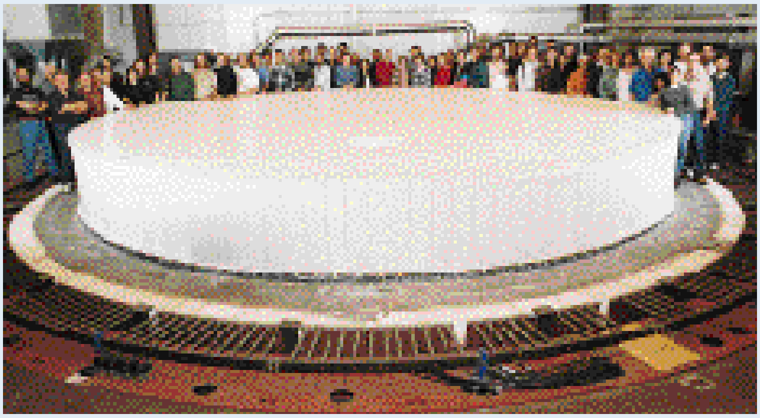
We knew that to develop a more compact telescope to locate small, perhaps habitable, planets would require some tricks. Twenty-three years ago Ronald N. Bracewell of Stanford University suggested a good strategy when he showed how two small telescopes could together search for large, cool planets similar to Jupiter. Bracewell's proposed instrument consisted of two one-meter telescopes separated by 20 meters. Each telescope alone yields blurred pictures, yet together the two could discern distant worlds.

With both telescopes focused on the same star, Bracewell saw that he could invert light waves from one telescope (flipping peaks into troughs), then merge that inverted light with light from the second telescope. With precisely overlapping im-

## Building an Earth-Based Interferometer

A consortium of American, Italian and German astronomers is now building a ground-based interferometer on Mount Graham in Arizona. At the Mirror Lab on the University of Arizona campus, where one of us (Angel) works, technicians have cast the first of two 8.4-meter-diameter mirrors (*right*), the largest ever made. Mounted side by side in the Large Binocular Telescope, two such mirrors will serve as a Bracewell interferometer, measuring heat emitted around nearby stars potentially hosting Earth-like planets.

Deformable secondary mirrors will correct for atmospheric blurring. This system is sensitive enough to detect giant planets and dust clouds around stars but not enough to spot another Earth-like planet. Designing a superior space-based interferometer depends on critical dust measurements. If dust clouds around other stars prove much denser than the cloud around the sun, then placing a Terrestrial Planet Finder instrument far from the sun (to avoid local heat from interplanetary dust) will offer no advantage. Instead an interferometer with larger mirrors that is closer to Earth will be needed. *—R.A. and N.J.W.*



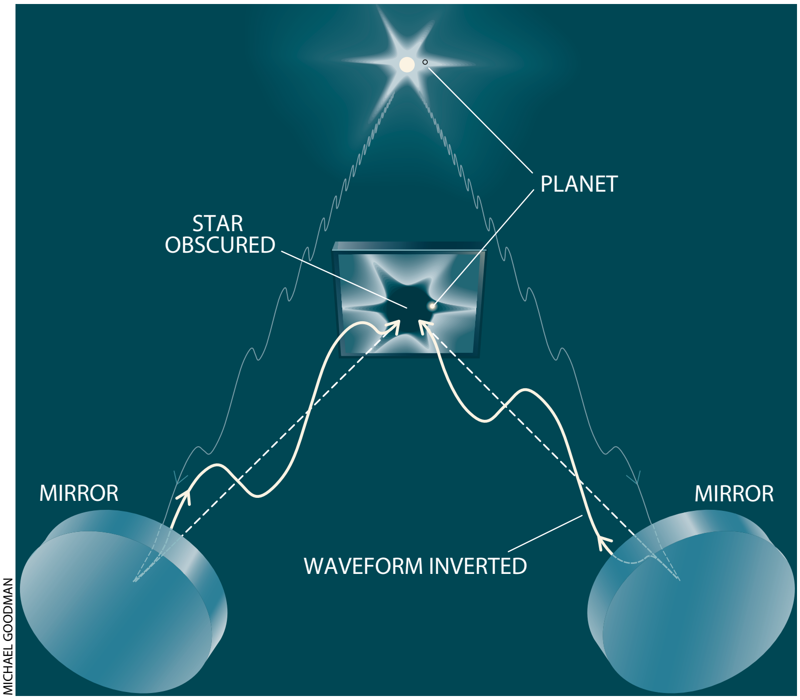
JOHN FLORENCE

*GIANT MIRROR at the University of Arizona is to be mounted in the Large Binocular Telescope.*

ages, the star's light—from its core and surrounding halo—would cancel out. Yet the planet's signal, which emanates from a slightly different direction, would remain intact. Scientists refer to this type of instrument as an interferometer because it reveals details about a light source by employing interference of light waves.

Bracewell's envisioned telescope would have enough sensitivity to spot Jupiter-size planets, although Earth-size planets would still be too faint to detect. To see Earth-size planets, an interferometer must cancel starlight more completely. In 1990, however, one of us (Angel) showed that such precision becomes possible if more than two telescopes are involved.

Another problem—even after canceling starlight completely—stems from background heat radiated from our solar system's cloud of dust particles, referred to as the zodiacal glow. As Bracewell realized, this glow would nearly overwhelm the signal of a giant planet, let alone that of an Earth-size one. Alain Léger and his collaborators at the University of Paris proposed the practical solution of placing the device in orbit around the sun, at roughly Jupiter's distance, where the dust is so cold that its background thermal radiation is negligible. He showed that an orbiting interferometer at that distance with telescopes as small as one meter in diameter would be sensitive enough to detect an Earth-size planet. Only if the star under study has its own thick dust cloud would detection be obscured, a difficulty that can be assessed with ground-based observations [*see box on opposite page*].




CANCELING STARLIGHT enables astronomers to see dim planets typically obscured by stellar radiance. Two telescopes focused on the same star (*top*) can cancel out much of its light: one telescope inverts the light—making peaks into troughs and vice versa (*right*). When the inverted light is combined with the noninverted starlight from the second telescope (*left*), the light waves interfere with one another, and the image of the star then vanishes (*center*).

### Space-Based Interferometer

In 1995 NASA selected three teams to investigate various methods for discovering planets around other stars. We assembled an international team that included Bracewell, Léger and his colleague Jean-Marie Mariotti of the Paris Observatory, as well as some 20 other scientists and engineers. The two of us at the University of Arizona studied the potential of a new approach, an interferometer with two pairs of mirrors all arranged in a straight line.

Because this interferometer cancels starlight very effectively, it could span about 75 meters, a size offering important advantages. It permits astronomers to reconstruct actual images of planets orbiting a star, as well as to observe stars over a wide range of distances without expanding or contracting the device. As we envision the orbiting interferometer, it could point to a different star every day while returning to interesting systems for more observations.

If pointed at our own solar system from a nearby star, the interferometer could pick out Venus, Earth, Mars, Jupiter and Saturn. Its data could be analyzed to find the chemical composition of each planet's atmosphere. The device could easily study the newly discovered planet around 47 Ursae Majoris. More important, this interferometer could identify Earth-like planets that otherwise elude us, checking such planets for the presence of carbon dioxide, water and ozone—perhaps even methane.

Thanks to new ultralightweight mirrors developed for NASA's Next Generation Space Telescope, a space-based interferometer combining telescopes as large as six meters in diameter looks feasible. Such an interferometer would suffer less from background heat and would function effectively in a near-Earth orbit. Also, it could better handle emissions from dust clouds around nearby candidate stars, if these clouds prove denser than those around the sun.

Building the interferometer would be a substantial undertaking, perhaps an international project, and many of the details have yet to be worked out. NASA has challenged designers of the Terrestrial Planet Finder to keep construction and launch costs below $500 million. A first industrial analysis indicates the price tag is not unrealistic.

The discovery of life on another planet may arguably be the crowning achievement of the exploration of space. Finding life elsewhere, NASA administrator Daniel S. Goldin has said, "would change everything—no human endeavor or thought would be unchanged by that discovery." SA

*The Authors*

ROGER ANGEL and NEVILLE J. WOOLF have collaborated for 15 years on methods for making better telescopes. They are based at Steward Observatory at the University of Arizona. A fellow of the Royal Society, Angel directs the Steward Observatory Mirror Laboratory. Woolf has pioneered techniques to minimize the distortion of images caused by the atmosphere. Angel and Woolf consider the quest for distant planets to be the ultimate test for telescope builders; they are meeting this challenge by pushing the limits of outer-space observation technology, such as adaptive optics and space telescopes. This article updates a version that appeared in *Scientific American* in April 1996.