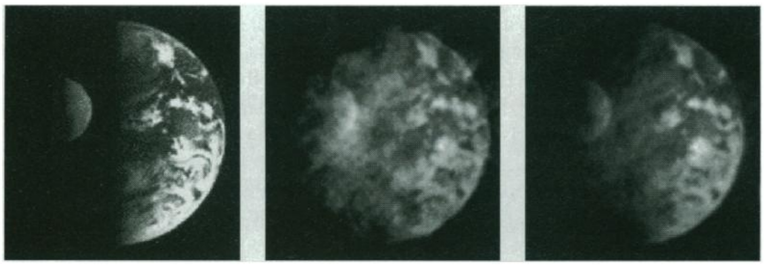
Now that we know extrasolar planets are out there, astronomers are gearing up to photograph one. But the job will require a sizable fleet of space observatories

Seeking a Snapshot of an Alien World

Ever since the subtle wobble of a nearby star gave astronomers their first indirect hint of a planet outside our solar system, they have longed for closeup views of distant worlds. Following that first planet detection, in 1995, such wobbles have revealed a total of about 10 candidate extrasolar planets tugging on their parent stars (*Science*, 30 May 1997, p. 1336). And although all are inhospitable "gas giants" similar to Jupiter, few astronomers doubt that small, rocky planets like our own—possible nurseries for life—are waiting to be discovered. Visiting them is out of the question. But by launching armadas of telescopes into space, astronomers hope to get a closeup look at other Earths and scan them for signs of life.

The undertaking has fired the imagination of astronomers and administrators alike, from Alain Leger of the Institute of Space Astrophysics in Orsay, near Paris, who calls it "a great adventure for humanity," to Dan Goldin, the NASA administrator, who has made planet searching a cornerstone of NASA's Origins program. And in a burst of studies and proposals over the past 3 years, astronomers in Europe and the United States have proposed a planet-spotting strategy and planned a series of missions that, within 25 years, may return portraits of an alien Earth and even reveal signs of life and large features such as an otherworldly Amazon jungle.



Imaging Earth. Views of home close up *(left)* and from 10 light-years away taken with a hypothetical interferometer with a 150-kilometer baseline and 48 telescopes *(center)* and 150 telescopes *(right)*.

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A useful single telescope able to spot tiny dim planets just a whisker away from a bright star would need a mirror roughly 100 meters across, 10 times as wide as the largest available today, and even such a monster telescope could not reveal any detail on an alien world. So astronomers are pinning their hopes on a relatively new technique called optical interferometry. Interferometry combines the light gathered by two or more standard-sized telescopes placed some distance apart in such a way that the resulting image has the resolution of a telescope as wide as the baseline of the interferometer (see sidebar). Interferometry "is just another way of building larger and larger telescopes," says Michael Shao of NASA's Jet Propulsion Laboratory (JPL) in Pasadena.

Which is not to say that building a planet-spotting interferometer will be easy. Optical interferometry stretches the limits of technology even on the ground, and planet imaging will have to be done from space. A space-based interferometer can be arbitrarily large, and the infrared wavelengths that carry information about substances such as oxygen and water—clues to possible life—are blocked by Earth's atmosphere and can only be detected in space. NASA is laying plans to fly, perhaps as early as 2002, a technology-demonstration mission to see whether space-based interferometry is even possible. The ultimate goal, penciled in for 2020, is an instrument with a baseline as wide as the United States, which would provide the first image of an alien world and probe its atmosphere for signs of life.

Precision flying

Interferometry is nothing new for radio astronomers, who build arrays of telescopes spanning thousands of kilometers on the ground and have even launched one antenna into space to create an interferometer larger than Earth itself (*Science*, 18 September, p. 1825). But the challenge of interferometry is in precisely combining the signals from the telescopes, which entails holding the path length from star to image through each scope steady to wavelength accuracy. That's a far easier task in radio astronomy, where wavelengths are measured in meters, than in optical astronomy, where wavelengths are less than a millionth of a meter.

Several experimental optical interfero-

Mission name	Deep Space 3	Space Interferometry Mission	Infrared Space Interferometer	Terrestial Planet Finder	Planet Imager
Agency	NASA	NASA	ESA	NASA	NASA
Baseline	1 km	10 m	50 m	100 m	6000 km
Resolution (mas)	0.1	0.001	50	25	0.0003
Waveband (micrometers)	optical	optical	7–17 Infrared	7–17 Infrared	7–17 Infrared
Function	Technology demo	Star wobble	Family portrait	Family portrait	Planet images
Launch Date	2002	2005	2009	2010	2020

meters are now in use around the world (*Science*, 6 March, p. 1449). But for planet searchers, says JPL's Charles Beichman, "the atmosphere is a major problem, so we need to go to space to fully realize the advantages of interferometry." Controlling the light paths is challenging enough on the ground; in space it is still more daunting. A space-based interferometer is likely to take the form of a flock of spacecraft, each carrying its own mirror, which would have to combine their light beams to the nearest tenth of a micrometer or better over long periods of time. But in just 4 years, if all goes well, planet searchers will test their ability to perform such precision flying.

The test will be a NASA mission called Deep Space 3. Despite the imminent launch, the final form that DS-3 will take has not yet been decided. In the latest version, two spacecraft would fly in tandem up to 1 kilometer apart, their relative positions controlled to centimeter precision. With the help of onboard correcting optics, the maximum resolution of its images should be 0.1 milli–arc seconds (mas), or 1/10,000 of a second of arc. Such a precision is stunning compared to the 10-mas theoretical best resolution of today's biggest telescopes, the 10-meter Keck telescopes in Hawaii, and should be at least enough to get a clear "family portrait" of a nearby planet system, showing planets as indistinct bright regions, like flashlights in a fog, around a central star.

In practice, however, this is not DS-3's primary goal. "Basically, DS-3 is a technology-demonstration project. … Its main goal is not to do science," says Shao, who heads JPL's interferometry center, which is masterminding the DS-3 project. Instead, the aim is to test interferometry combining light from separate spacecraft.

Formation flying "isn't quite as impossible as it sounds," says Shao. However, it does demand that the spacecraft fly well out of range of Earth's atmosphere, which would cause drag problems, and away from steep gravity gradients that might pull on one spacecraft more than another. This means that DS-3, like all formation-flying space interferometers, is destined to fly in deep space, circling the sun along with the planets.

To control drift, the craft would fire ion thrusters—devices already found on communication satellites. These thrusters require a far smaller mass of propellant than rockets, because they use solar electricity to ionize a substance such as cesium, then accelerate and eject the ions to provide thrust, explains Malcolm Fridlund of the European Space Agency's (ESA's) research center at Noordwijk, the Netherlands. A few kilograms of material can provide a year's thrusting. To make the final submicrometer-scale adjustments necessary to form interferometer images, the spacecraft will need to measure their separation with lasers and make finer scale corrections for drift with active optical elements such as moving mirrors. This kind of active optics control is already used in ground-based interferometers, according to Shao.

Although DS-3 will provide a test-bed for space interferometry, plans for the mission remain in flux, with Shao and his JPL team still working out the details. "The short story is that what we had originally wanted to do is a little bit more expensive than we can afford," says Shao. A recent decision to scale back from three to two spacecraft should allow the mission to meet its 2002 departure time.

Because the technology for formation flying is still in its infancy, the first space interferometer to do actual science will take a safer approach. This project, NASA's Space Interferometry Mission (SIM), will comprise seven or eight optical telescopes, each a modest 35 centimeters in diameter, placed on a fixed arm with a baseline of between 10 and 15 meters. SIM is not primarily designed for imaging; with its short baseline it would only be able to generate images with a resolution of 10 mas, enough for a fuzzy family snapshot of a planetary system. "SIM's major purpose is to do astrometry [measuring stellar positions], as opposed to imaging," says Shao, who is SIM's project scientist.

In this mode, which relies on comparing the position of the target star with a reference star, SIM would achieve a peak resolution of 0.001 mas, as much as 250 times better than anything currently available. It will look for planets using the same method now used from Earth: searching for the telltale wobbles in star positions. With its high resolution, SIM could look for Jupiter-sized planets around a billion or so close stars.

SIM's precision should also aid a wide range of other studies, including measuring the expansion rate of the universe, probing the spiral structure of our galaxy, and studying the spread of matter around supermassive black holes. By tracing the distortion

Interferometry: Getting More for Less

"Interferometry is really based on economics," says Michael Shao of the Jet Propulsion Lab in Pasadena, California, and planet searchers hope to get the best deal of all. By merging light from several small telescopes aboard spacecraft flying anywhere from a few tens of meters to thousands of kilometers apart, they hope to mimic single telescopes far too large and costly ever to be built. The payoff: a chance to see Earth-like planets around stars tens of light-years away and examine them for signs of life (see main text).

Bargain-hunting can be hard work, and optical interferometry, especially when it's done in space, comes with some punishing technological demands. One is controlling the optical paths—the distances from the target to the mirrors and on to the detector—to an accuracy of 1/100 of a micrometer, much less than the wavelength of light and roughly the size of a large protein molecule. That precise control has to be maintained while the array of free-flying mirrors rotates, expands, and contracts, forming new configurations in order to gather the data needed to form an image.

But interferometry is more than a cut-rate way to simulate a giant telescope; it also offers a major advantage over normal scopes. It can obliterate the image of a bright star so that faint, nearby planets can be seen more clearly. This trick, known as starlight nulling, is vital, as the glare of a star could be up to 10 billion times as bright as surrounding planets. It works because when light from an interferometer's mirrors is combined, the light waves reinforce each other—peak combines with peak and trough with trough. But if a half-wavelength shift is introduced into the light from just one of the mirrors, then when the waves combine, peaks will be superimposed on troughs and will cancel each other out, wiping out the brightness of the star. Any object off center in the image, such as a planet, is not completely canceled and still gives a relatively bright signal.

The first practical demonstration of starlight nulling was recently carried out by a team led by Roger Angel of the Steward Observatory in Tucson, Arizona, and was reported in the 17 September issue of *Nature*. Using a pair of mirrors of the Multiple Mirror Telescope on Mount Hopkins, Arizona, Angel and his team were able to cancel out the image of the star of their choice. One image, of the star α-Orionis, shows a dust nebula surrounding the star. The nebula—like a planet—would normally be lost in the glare. Starlight nulling "is the only way we can directly detect planets in the foreseeable future," says Malcolm Fridlund of the European Space Agency. **–A.W.**

of celestial objects due to the gravitational pull of Earth, the moon, other planets, and our sun, "SIM will be able to verify Einstein's general theory of relativity to a few parts per million, 300 to 500 times better than today," says Shao.

Although SIM will avoid the technical challenges of formation flying, it still has many hurdles to overcome. One of the toughest will be vibration. The kind of vibration that the Hubble Space Telescope has had to endure from the wheels of its tape recorders would spell disaster for a space interferometer. SIM will dispense with tape recorders, but it will have to rely on spinning wheels, known as reaction wheels, to control its spin and rotate it toward its targets. Even the best possible bearings transmit vibration to the optics. Vibration caused by thermal "snaps," when solar panels move between light and shade, also poses a threat to the interferometric signal. The JPL team hopes that a combination of vibration decoupling—"basically just a very soft spring," says Shao—and yet more active optics should overcome this problem.

World view

The effort to actually image extrasolar planetary systems will begin in earnest with ESA's Infrared Space Interferometer (IRSI) and NASA's Terrestrial Planet Finder (TPF). These two projects, still at a much earlier stage of planning than DS-3 and SIM, are both designed to snap more detailed family portraits of other systems and probe the atmospheres of the planets for elements and compounds that are hallmarks of life. Both will operate at infrared wavelengths, where the signatures of these substances are strongest. The infrared has other advantages, too: Planets are brighter in the infrared relative to their suns, and at these slightly longer wavelengths the demands for optical accuracy in the interferometer are loosened.

Top of the list of telltale substances is ozone, which can be formed when ultraviolet light strikes oxygen produced by plant life. "The presence of ozone would tell us that some form of life already exists on the planet, which would be fascinating indeed," says Fridlund. The other two key signatures of a life-bearing planet are water and carbon dioxide.

With a tentative launch date of 2009, IRSI is still very much on the drawing board. "Currently we are studying concepts, feasibility, eventual cost," says Fridlund. The current vision is for six 1.5-meter telescopes flying in a formation up to 50 meters across. The array will orbit the sun at L2, a point on the Earth-sun axis where the gravitational gradient is flat. There, says Fridlund, "the biggest force acting on the array is solar photon pressure."

Fridlund sees a mountain of technical challenges before IRSI takes its first pictures. "What is going to be extra challenging is the optical arrangement," he says. It would take the array about 10 hours to detect an Earth-like planet and perhaps 14 days to obtain a reasonable spectroscopic signal; holding the array steady over such long periods is a major issue, he notes.

Like IRSI, the TPF is still at a formative stage. Current plans envisage four to six mirrors, each up to 5 meters in diameter, spanning a total distance of between 75 and 100 meters, with a tentative launch date of 2010. The mirrors might be mounted on a single structure, but "formation flight is a very serious option," says JPL's Beichman, the TPF project manager. The big challenge facing TPF is the need for large, lightweight telescopes. "This relies on developments for the Next Generation Space Telescope project [the successor to Hubble]," says Beichman. "We also need interferometry techniques being developed for SIM. With these projects under our belt, TPF can be done with acceptable risk."

But of all the planned missions, the grandest, most speculative, and furthest over the horizon is NASA's Planet Imager (PI). The PI is a "dream mission," says Fridlund, and "a gleam in Mr. Dan Goldin's eye," according to Alan Penny of Britain's Rutherford Appleton Laboratory, a member of the IRSI project team. The PI, with a tentative launch date of 2020, is likely to comprise a squadron of TPF-type spacecraft, each one carrying four 8-meter telescopes. They would be dispersed over distances comparable to the width of the United States and would produce images of alien Earths which, although fuzzy, would have discernible details. In NASA's words, the PI will offer "humanity's first image of another world."

Whether or not it is NASA's PI that will give us our first glimpse of distant life, astronomers are convinced that some kind of space interferometer capable of seeing life-bearing planets is just a matter of time. The urge to learn about habitable new worlds is too basic to ignore for long, says Antoine Labeyrie, director of the Observatory of Haute-Provence near Marseilles, France. "It is perhaps the same curiosity which may have stimulated the prehistoric dwellers of the Greek coastline into observing and exploring the islands they could see in the distance," he says. Now that we have spotted clues to other worlds, he adds, "we are in a similar situation."

—**ANDREW WATSON**

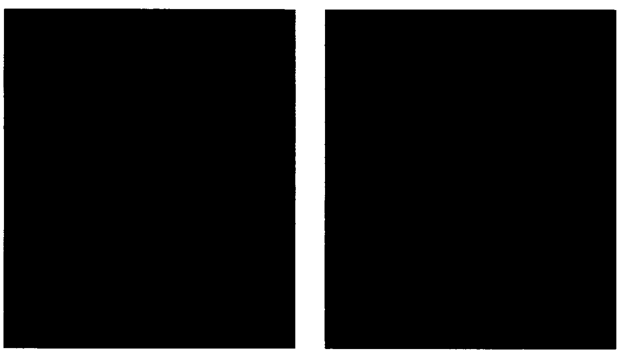
IMMUNOLOGY

Fly Development Genes Lead to Immune Find

Guided by fruit fly genetics, scientists are finding that the human innate immune system may be more specialized than they had thought

Like a lowly foot soldier toiling in the shadow of better equipped and better trained cavalry units, the innate immune system, the body's first line of defense against invading pathogens, has long been eclipsed by its partner, the adaptive immune system. In part, this relative lack of interest can be traced to immunologists' view of innate immunity as a sort of brute-force system that unleashes blunt, nonspecific weapons at any and every invader, keeping the foe at bay until the adaptive system with its highly specific weapons—antibodies and T cells—can take over. But now, aided by results from an unlikely source—the developmental control genes of the fruit fly—researchers are developing a new and more intriguing picture of the innate immune system.

Over the past few years, researchers have found that a family of proteins related to the Toll protein of fruit flies, which was first identified as a developmental protein, plays a key role in triggering innate defenses against bacterial and fungal invaders—not only in flies, but in organisms as divergent as tobacco plants and humans. Scientists are still sorting out the roles of the newly discovered proteins, but a few trends are emerging. There is strong evidence



First alert. The Dorsal protein (red) moves from the cytoplasm *(left)* to the nucleus *(right)* after infection in these larval fly cells.

K. ANDERSON