pick a signal out of random noise if the shape of the signal is known — that is, when you know what you're looking for. This is the case with the double wink.

In this algorithm, a computer generates all possible configurations of stars and planets, from the closest stable orbits out to orbits that take years. The predicted brightness variations can then be matched with the observed variations. If the effect of a planet is buried in the data, it will surface when many observations are added up. The technique is like getting ants to stand on top of each other to be seen above tall grass. The odd but predictable little transit signals will add together to be recognized above the noisy photometry.

With this technique, our 1-meter-class telescopes can detect Earth-sized planets within the habitable zone of CM Draconis — the region around the stars which gets the same amount of energy that Earth receives from the Sun. Several months of observing is enough. A 4-meter telescope would halve this time; a 10-meter telescope would allow the detection of planets around stars 10 times the size of those in CM Draconis.

The algorithm is, however, computationally demanding. To date, TEP has collected 40,000 CCD images of CM Draconis spanning 650 hours of observations. When we have finished a third observing season, we will have over 50 gigabytes of data, and the number-crunching will commence. For orbital periods from 7 to 270 days, there are 1 million possible configurations to match the data against.

TEP is not the only way that amateurs can participate in planet-hunting. They can look for Jupiter-mass planets in eclipsing binaries without having to wait for transits. If the stars are lightweight, planets cause the eclipse timing to drift noticeably. With precise timekeeping, amateurs can check for this drifting. This is basically the same technique Wolszczan used to find the pulsar planets, except that the times of the eclipses, rather than the radio pulses, are the clock. If a binary system has a giant planet, the system will wobble, causing a periodic delay in the times of the eclipses.

I have worked with Deeg, Jenkins, Ted Dunham of NASA Ames, and J. Ellen Blue of SRI International to develop this idea. The Global Positioning System [see "Relativity in the Palm of Your Hand," May/June, p. 23] provides timing accuracy of about 10 milliseconds for each measurement, allowing observers to determine the time of an eclipse to within 2 seconds in Universal Time. In 250 known eclipsing binaries, the delay due to a Jupiter-like planet would be more than 2 seconds.

What's in the Air?

To look for planets by this method, you need a GPS timing system (now around $2,000), a CCD camera or photometer, and a telescope 24-inch or larger, which can do fairly good photometry on 12th-magnitude stars. I will soon be publishing a list of the candidate stars, but you may contact me directly for more information.

The transit method has another important advantage over other techniques: the potential for follow-up observations. Like a microscope slide held in front of a search lamp, the transparent atmosphere of the planet will absorb a tiny amount of light each time the planet crosses between us and the star. By taking a spectrum of the star during transits, and subtracting it from spectra of the star at other times, astronomers can pick out the absorption features of the planet's atmosphere. It is easier to detect what is on a small slide held in front of a search light than what is on a slide held to the side reflecting the searchlight. In the same way, it would be easier to detect the constituents of a planet's atmosphere in transmission (during transit) than in reflection.

Of course, knowing the constituents of a planet's atmosphere would be very exciting indeed. They might turn out to be indications of life: water-vapor absorption lines or free oxygen or ozone, the latter two so chemically reactive that they must be routinely produced to remain a major constituent of the atmosphere. Such an atmospheric signature has existed on Earth for almost 500 million years. Will an amateur astronomer be the first person to discover a forested planet around another star? *m*

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I Hope That I Could Come

For today's budding scientists, research is not just looking taking data or through telescopes. It is also giving talks to inspire younger students.

Elizabeth Waterhouse
Shaker High School

In January 1995, NASA asked scientists to recommend a long-term national strategy for searching for and characterizing other planetary systems. But scientists were not the only ones to respond to the challenge.

A team of 28 teen-agers also have presented their recommendations to NASA administrator Daniel Goldin. During the weeklong Advanced Astronomy Camp at the University of Arizona last summer, we wrestled with problems and conducted observing runs at the 40- and 60-inch telescopes on Mount Lemmon and the 10-meter Sub-Millimeter Telescope on Mount Graham. We developed our own road maps not only for extrasolar planet hunts, but also for participatory science education.

The 28 campers included nine women and 19 men, aged 13 to 18, from 10 states, France, and Mexico. The camp is an annual event started by Don McCarthy in 1988 [see "Astronomy

Camp: Adventures in Scientific Research," November/December 1993, p. 24]. McCarthy is also a science team member in NASA's road-map process. Despite the campers' strong interest in astronomy, upon arrival 50 percent could not correctly explain the phases of the Moon and 80 percent were confused about the causes of the seasons. Many of these initial misconceptions were addressed in hands-on activities.

Astronomy Campers at the Sub-Millimeter Telescope on Mount Graham, Ariz. Later, they used the 10-meter dish to observe Mars. Photo courtesy of Donald W. McCarthy Jr.

The author with Project WHEEL students Jake Bowland and Lauren Marozzi. Photo courtesy of Donald W. McCarthy Jr.

Each day we learned another technique for seeking extrasolar planets, and each night we applied that technique at the telescopes. We considered direct detection of planets and then attempted to image the martian satellites. We studied astrometric, Doppler, and eclipse techniques and then went out to measure the orbital motion of Pluto, the redshift of a distant galaxy, and the brightness changes of variable stars. We learned about spectroscopic methods for detecting oxygen in planetary atmospheres and then mapped carbon dioxide in the atmosphere of Mars with the Sub-Millimeter Telescope.

Raised as an only child in Suburbia, N.Y., I had been ignorant to the beauty of my home, the fragile beauty of this planet Earth. Yet, on June 24, 1995, I saw the night sky of Arizona, the elusive darkness festooned with diamond chiffon. Hope and truth were abundant; I was a part of an esoteric, powerful, and magnificent world.

My week at Astronomy Camp was a turning point in my life. The learning process culminated in an opportunity to devise and present papers that delineated visions of NASA's future. It was this experience that both intensified my love of astronomy and heightened my reverence for the cosmos.

My road-map team (Timothy Bowers, Jason Lee, Rick St. Clair, Mike Rouse) enjoyed heated debates on such issues as how to define life, what types of planets to look for, and how to determine the most efficient process for locating life. The camp created an environment where curiosity was catered to and questions were always significant. Such opportunities instill a love for learning. This effect of astronomy, this impregnation of divine wonder, should be NASA's ultimate goal.

On the last afternoon of camp, three student teams presented road maps for three extrasolar planet searches. Although some voiced concerns about money being potentially wasted in a fruitless search, most students endorsed this research program. We recommended that NASA do the following:

- Make the research program an international effort in order to spread the financial burdens and spark public interest. This effort must not be limited by political boundaries, but by the Earth's atmosphere.
- Lead an effort to improve scientific education and inform children about its search for life.
- Make all data accessible to the public via the news media and the Internet.
- Invest in improved technology for both ground- and space-based methods.
- Launch a high-resolution interferometer to the cool region around Jupiter to search for Earth-like spectra in extraterrestrial planets.

After leaving Astronomy Camp, I shared my knowledge in a teaching program in Newtonville, N.Y. entitled Project WHEEL. This program was provided for intellectually advanced students in fourth- through sixth-grades in the North Colonie Central school system.

Beginning with the question, Is there life in outer space and if so how would you prove it? I guided the children through the scientific method in completing their own group road map. I spoke on spectroscopy, astrometry, gravitational lensing, interferometry, and NASA's preliminary road map. Finally, I asked each student to write a letter explaining either what he or she had learned or what he or she recommended that NASA pursue.

Only two of the 40 students did not support the road map; seven students expressed interest in pursuing a career or camp experience involved with space. Their recommendations included:

- I would like to see Nasa cancel the shuttle program, as much as we have benefited from it, it costs money and it would be cheaper and safer to use satellites for research. — *Tim McDonald*
- I would like to see Nasa build a new kind of spacecraft. — *Matt Lockwood*
- I think that N.A.S.A. should work hard to try to discover life and other planets. They should send something or someone into a black hole. — *Jake Boland*
- Dear NASA, I think that you should keep exploring. It is very important. I hope that I could come. Sincerely, John Cowan

NASA's success depends on public support. To ensure the long-term success of the road map for extrasolar planet searches, we believe NASA should develop a road map for science education — emphasizing real participation for all ages. In my experience, K–8 students have great enthusiasm for science and technology and can understand many concepts generally taught only in high school or college. We should consider innovative ways of involving people of all ages in the extrasolar adventure. ***m***

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