TOTAL 2003 SKY EVENTS COVERAGE • PULL-OUT MAPS

Astronomy's Explore the Universe

9TH EDITION 2003

DISPLAY UNTIL DECEMBER 31, 2002

Best Images from Hubble's New Camera

50 Great Telescopes Described

How to Find Cool Astro Gear

Extrasolar Planets: Closing in on Earth

HOTTEST COSMIC STORIES OF THE YEAR

astronomy.com

$5.95 • $7.95 Canada

35>

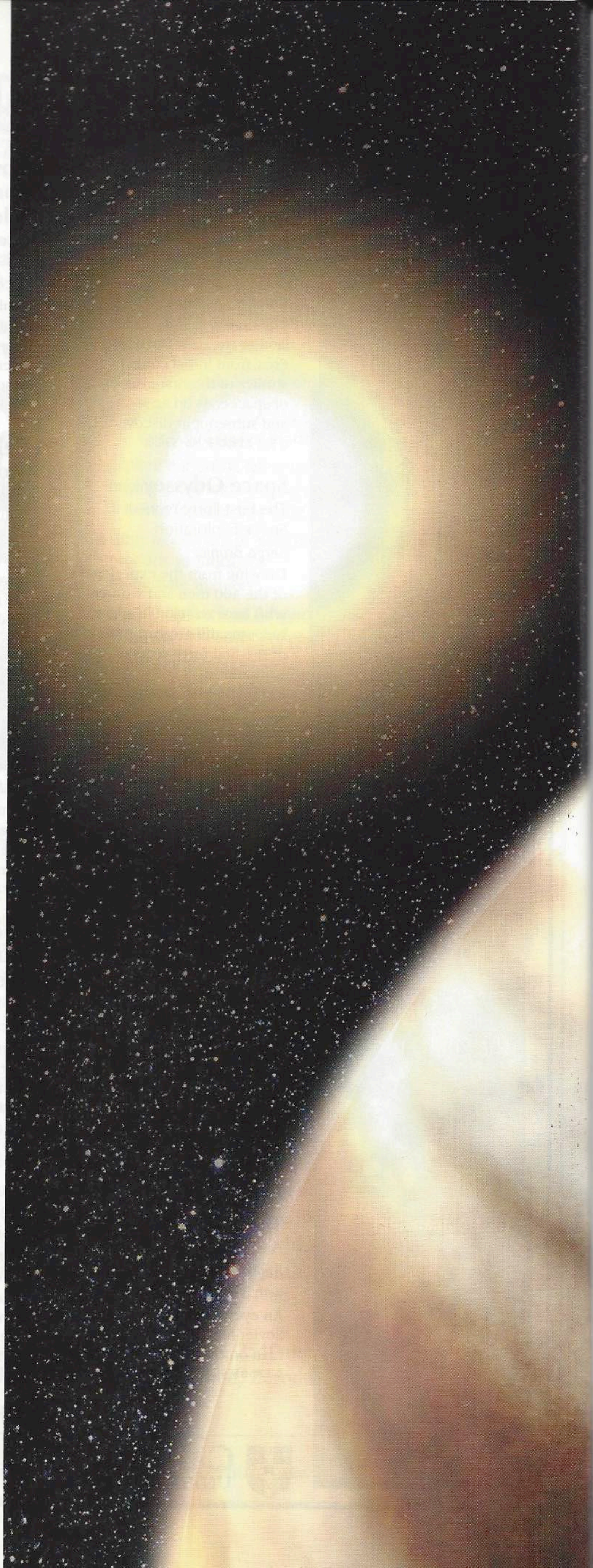
0 73361 98377 0

Narrowing the Field

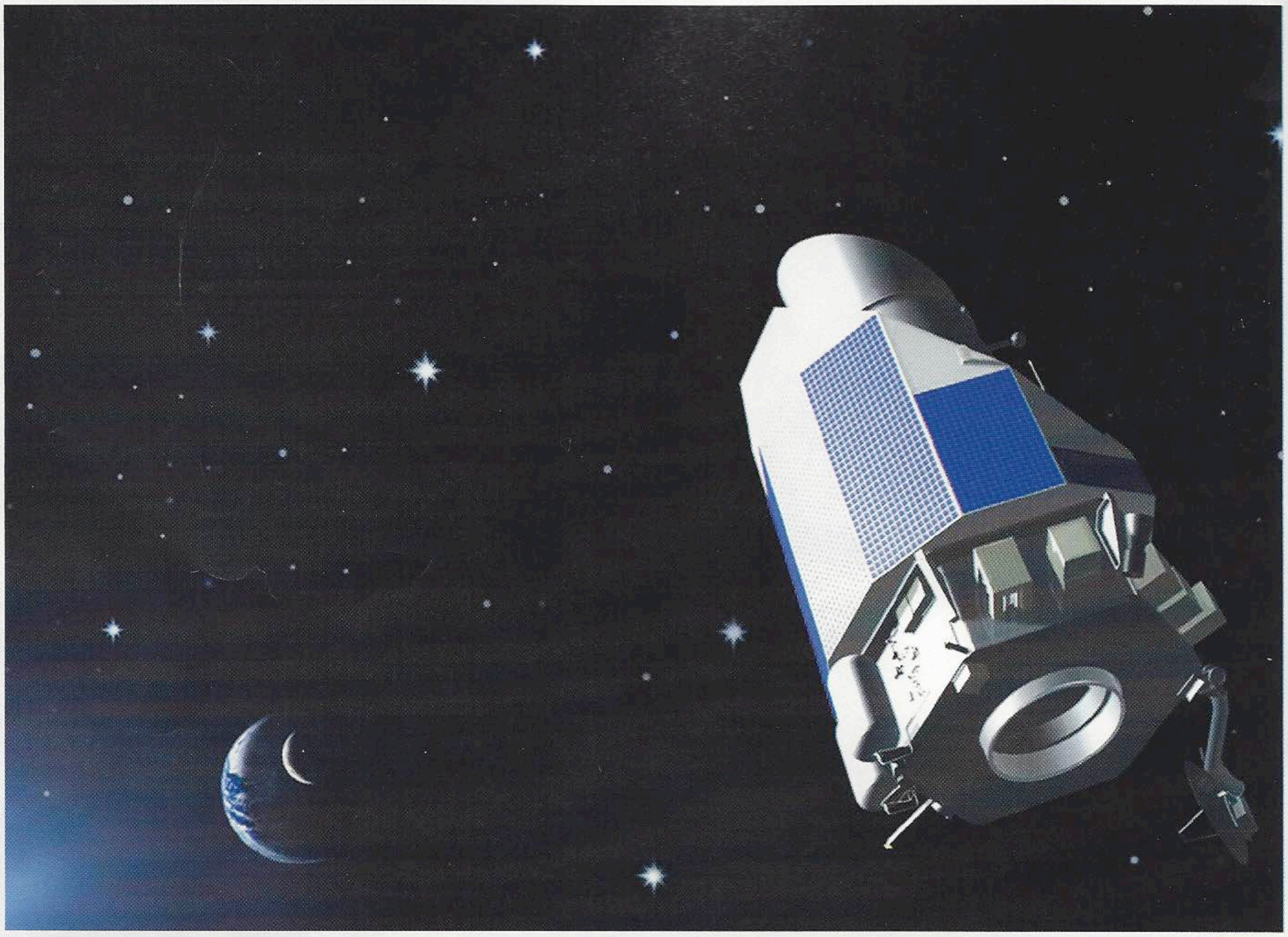
Are astronomers close to finding other Earths in distant solar systems?

by John Armstrong

Life may be difficult to define, but we tend to recognize it when we see it. In the late 17th century, when Antony van Leeuwenhoek first observed his tiny animalcules in rainwater, their motions within the fluid revealed their true nature — miniscule protozoa, thriving with life. Since then, as scientists explore the Earth, they find all sorts of microscopic organisms. Life thrives in the extreme cold of Antarctica, the boiling water of Yellowstone's hot springs, and even miles below Earth's surface. The search for life also extends to the



The first extrasolar planet with a measured atmosphere, discovered by astronomer David Charbonneau in November 2001, reflects light from its parent star in this illustration. The sunlike star, HD 209458, lies 150 light-years away in the direction of the constellation Pegasus. The planet's atmosphere betrays a strong presence of sodium. G. Bacon, STScI



NASA's Kepler spacecraft, slated for launch in 2006, will carry a photometric telescope to search for earthlike planets in the galaxy. NASA

other planets in the solar system. Mars and Jupiter's moon Europa are the most likely candidates, but beyond the solar system, planets orbiting other stars may hold life.

Recognizing the absence of extraterrestrial life seems to be a bigger problem. Despite many probes and experiments designed to detect life, scientists still debate the possible existence of it on Mars. In 1996, the discovery of controversial biological tracers in the martian meteorite ALH84001 marked a renewed interest in looking for life on the Red Planet. But the closer we look, the more we argue whether or not there is life on Mars.

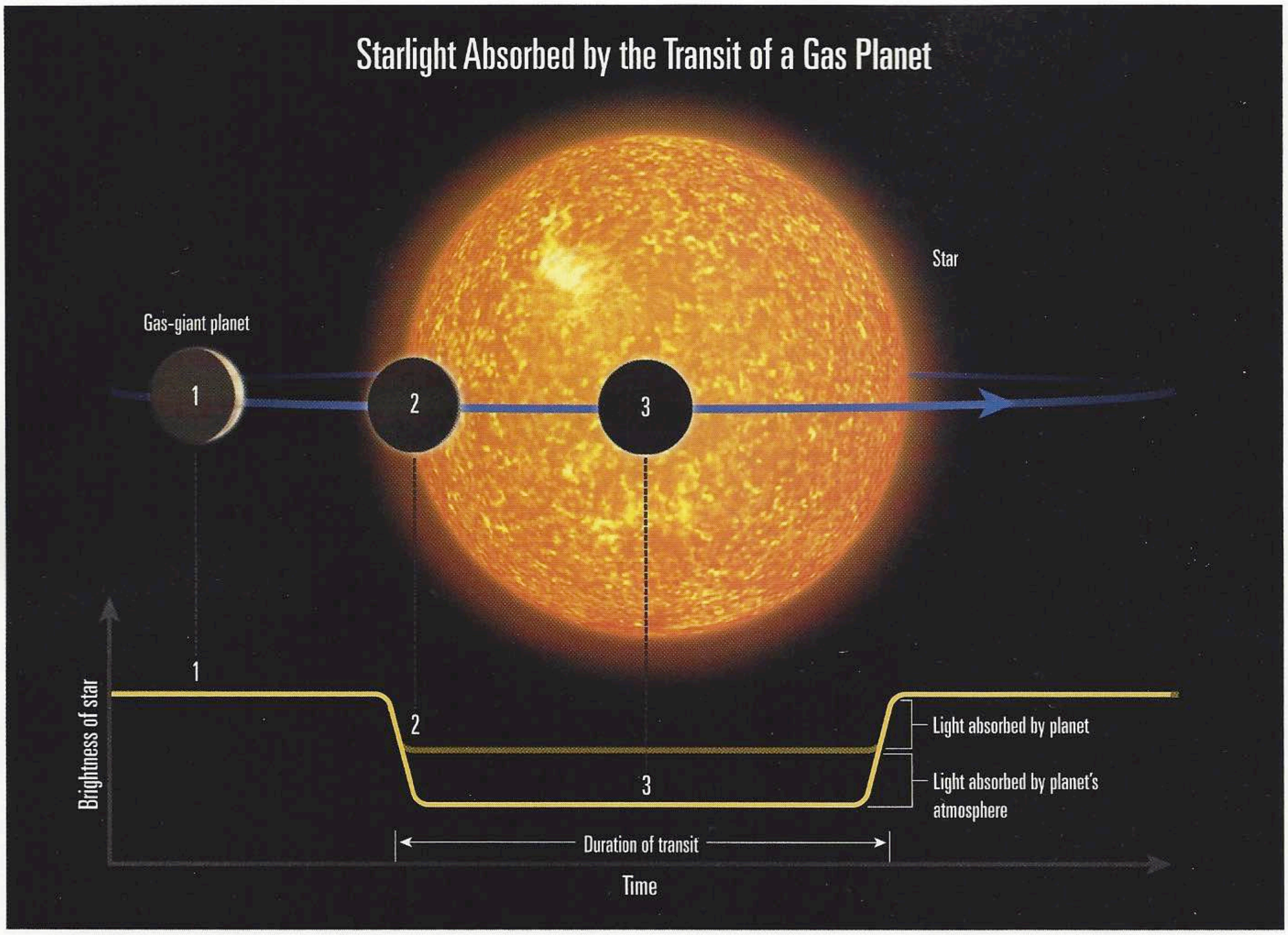
And what about beyond our solar system? During a 50-year search, SETI, the Search for Extraterrestrial Intelligence, has uncovered no artificial signals from another planet, and despite more than 100 newly discovered planets around other stars, there is no evidence for life beyond our solar system. The best astronomers can do is stare at pinpricks of light in an attempt to milk every last drop of information about the planets' properties. So far, astronomers have only discovered massive, and presumably sterile, Jupiter-like planets, most orbiting closer to their parent star than Mercury orbits the sun. That doesn't mean earthlike planets aren't out there, but unless someone starts broadcasting an alien version of "I Love Lucy" across the void, the chances of seeing them with today's instruments are slim.

But if "they" are out there, and if their technology is only a few decades more advanced than our own, they may already know about us. Even ignoring the recent technological riot of electromagnetic noise, our planet reveals subtle hints in the radiation we reflect and emit: hints to our atmosphere's constituents, clues to the chemistry that dominates the cycles of our environment, and even evidence for the existence of life itself.

These clues are imprinted on our star's light every time Earth crosses in front of the sun. Some of the light from the sun passes through our atmosphere, and the constituents therein absorb some of the energy, writing their signature on the sun's spectrum as it speeds out of the solar system. Our planet also reflects the light of the sun, and the conditions in our atmosphere — the dust and clouds, ice and snow — change the amount of light we reflect. Finally, Earth emits its own infrared energy, carrying information about the temperature of the planet. The atmosphere absorbs some of this light as well, encoding more data about the state of Earth. All of this information is packaged in sunlight and sent to the far reaches of the galaxy. Anybody with sufficient interest, and advanced enough technology, could receive this and unlock the secret of Earth.

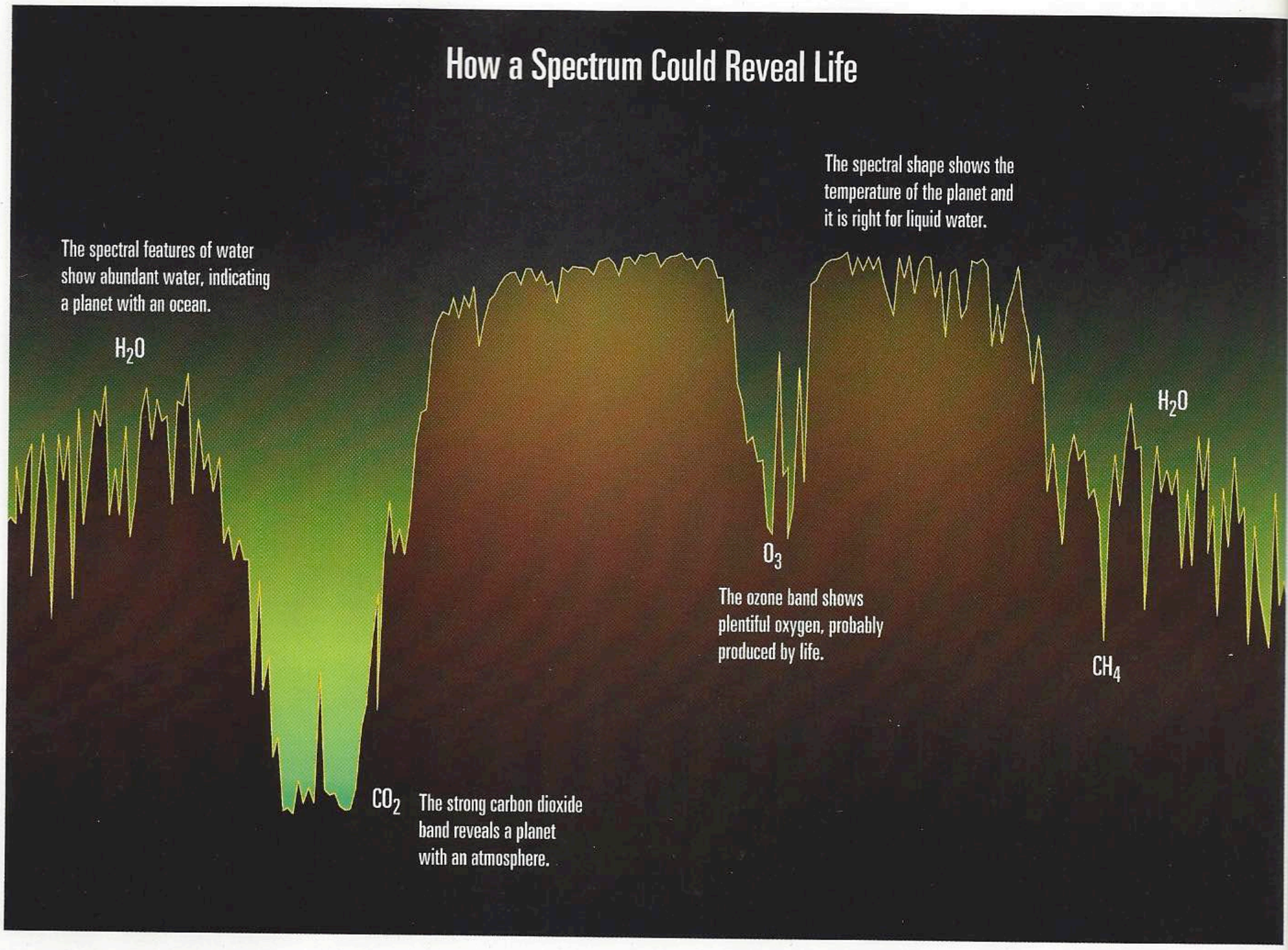
Hayseed in a Haystack

Finding the hint of Earth in this sea of starlight presents a seemingly gargantuan task. The dimming of the light due to Earth passing in front of the sun is one part in 10,000. The tiny effects due to the presence of Earth's atmosphere are less than a millionth the total light of the sun. Forget about a needle in a haystack; it's more like looking for a hayseed in a haystack. But the information about our Earth is there, tangled in the starlight, for anyone to find.



How to Recognize Properties of Planets

Property	Implication for life	Technique
Orbit characteristics (radius, eccentricity, etc.)	Existence of planet in habitable zone	Astrometry, radial velocity, nulling interferometry
Mass	Ability to retain atmosphere	Astrometry, radial velocity
Radius	Density and surface gravity	Transit photometry, direct detection
Combination temperature, radius, albedo	Ability to support liquid water, presence of greenhouse effect	Direct detection in infrared
Atmospheric composition (major gases)	Existence of atmosphere (CO_2), presence of water (H_2O), suggestions of life (O_3, CH_4)	Direct detection with low resolution infrared spectroscopy
Combination of radius, albedo	Density, surface/cloud properties	Direct detection in visible light
Atmospheric gases (minor gases)	Confirmation of life (CH_4, N_2O, O_2 via A-band), atmospheric structure via line profiles	Direct detection with high resolution imaging spectroscopy in visible light/infrared
Presence of moons	Presence of tides	Direct detection with high resolution imaging
Surface features and composition	Existence of oceans and continents	Direct detection with high resolution imaging



And back on Earth, our own scientists have made the first tentative steps toward detecting such signatures of life from other planets around nearby stars. Recently, David Charbonneau, Millikan Postdoctoral Scholar at Caltech, and his colleagues announced the detection of sodium in the atmosphere of an extrasolar giant planet orbiting the star HD 209458. The group used the Hubble Space Telescope to measure the minuscule influence of the planet's atmosphere on the starlight as it crossed the disk of its parent star. While most of the star's light is unaffected by this distant eclipse, some of the light passes through the planet's atmosphere. Imprinted upon this light is information about the atmosphere's constituents. By carefully observing the star before, during, and after transit, the researchers teased out the tiny effect.

"We went to look for sodium and we found it," says Charbonneau, "but now we can use it to probe the atmosphere." For example, he says, they detected less sodium than expected. This could be due to a lack of sodium, or perhaps something obscures the deeper reaches of the atmosphere, reducing the observed influence of the sodium. "This would be due to clouds. On Earth, they're made of water, but on these planets there might be more exotic species," says Charbonneau, like clouds made of magnesium silicates. "We start to see all the exciting molecular chemistry we see in our own solar system."

This, coupled with a measurement of the radius of the planet during the transit, represents a fundamental shift in extrasolar planet research. "For the first time," says Charbonneau, "we have the mass and the radius of the planet."

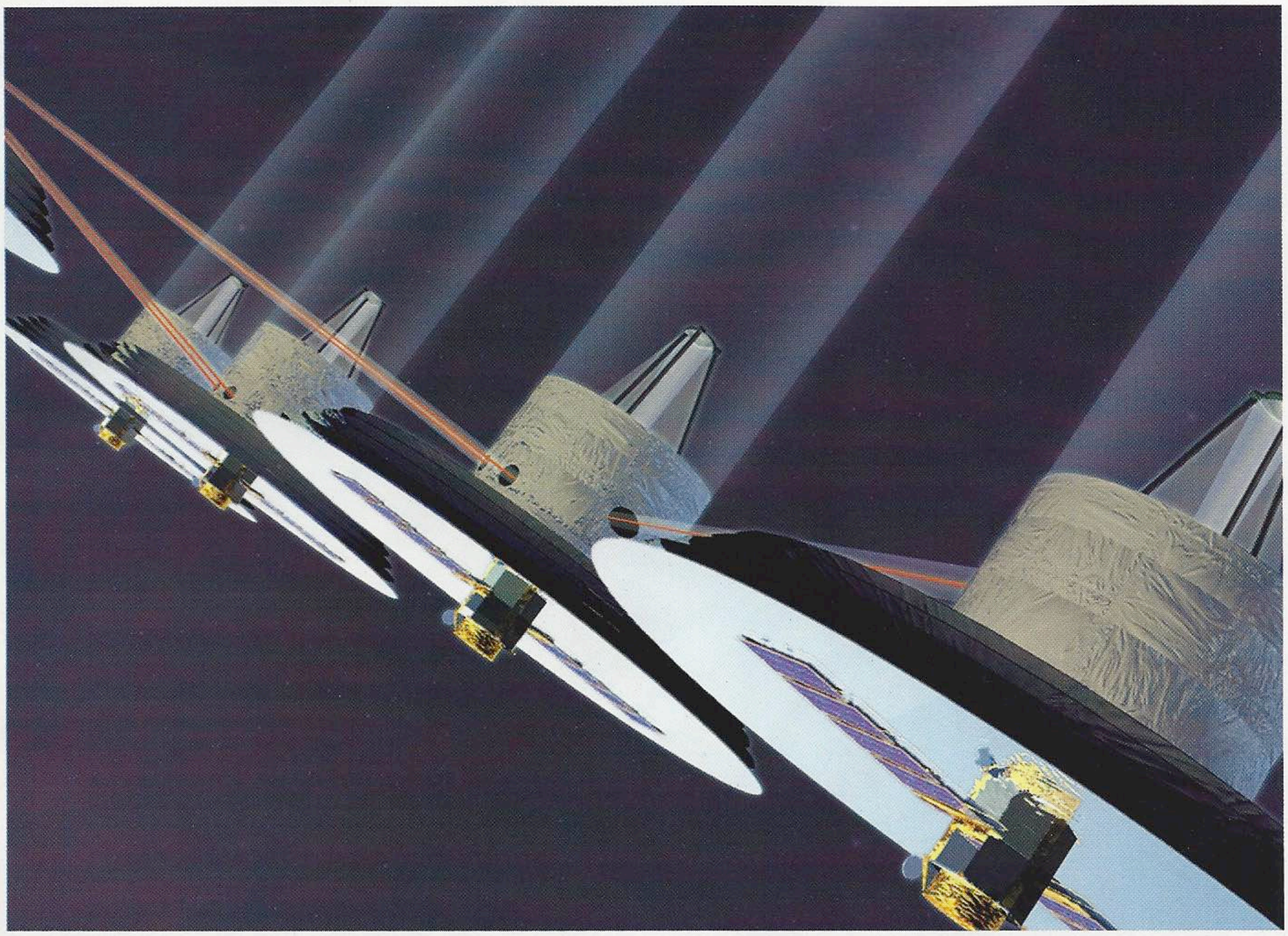
Until recently, all researchers could say definitively about extrasolar planets was that they exist. The dominant detection method gave a lower limit on the planet's mass, as well as orbital parameters like the planet's period and eccentricity. While this provided a wealth of data for scientists studying dynamical properties of such systems, planetary scientists used to the abundance of detail provided by spacecraft missions were slow to be impressed.

Into a Totally New Era

Enter the planet orbiting HD 209458, with known mass and radius, and therefore a known density. Adding to that are measurements of a dominant chemical component, sodium, and information about the reflectance of the atmosphere itself.

Researchers found themselves looking at not just an extrasolar planet, but a planet 0.7 times the mass and 1.3 times the size of Jupiter, giving it a density of about 40 percent that of water. And it contained sodium. In short, the planet around this star began to develop a list of known properties comparable to the massive planets of our own system, like Jupiter and Saturn. They could only wonder what they would find next.

With that type of information, scientists begin to explore more details about how these planets were formed. For that, the density is particularly helpful. "If the planet moves in slowly, after it collapses, it won't puff back up," says Charbonneau. "But if it moves in quickly, it will contract more slowly since it is in a hotter environment." The result is a massive, Jupiter-like planet forming a great distance from the star and migrating in quickly, thus maintaining a lower density, a confirmation of some formation models.



Terrestrial Planet Finder, a NASA craft to be launched in 2011, will be an interferometric telescope designed for planet searching. NASA

However, as Sara Seager of the scientific staff in the Department of Terrestrial Magnetism at the Carnegie Institution of Washington is quick to point out, it is only one planet. "At the moment, this is a 'one planet, one method' problem," says Seager, stressing that she doesn't want to downplay the importance of the discovery. "So far, they've only looked at one line out of the entire spectrum." She goes on to suggest that unless more planet transits like this are found, and more components of the atmosphere are measured, the data will remain somewhat anecdotal.

"One interesting point is that we don't really know much about them," says Seager. We know the minimum mass, and the orbital characteristics, but, "in terms of their physical characteristics, we don't know much."

Charbonneau and others are attempting to remedy this with further observations of HD 209458. "We can now get the precision we need to gather data across the visible spectrum," says Charbonneau, to look for features from other molecules like water. However, this is still only applied to one star, and researchers anxiously await another transit detection.

While waiting for more data, Seager and others use our own solar system to work out the models used to examine the data from systems like HD 209458. "The exact way that light varies tells us about the atmosphere," she says. For example, clear atmospheres reflect starlight differently than cloudy atmospheres. For her Ph.D. dissertation, Seager studied the effects of starlight on extrasolar giant planets using Jupiter's atmosphere as a model. But, since Jupiter is in the outer solar system, Seager explains, scientists have never seen it from the same perspective as they see the extrasolar planets. In that sense, Venus is a better model.

"Nature was kind," says Seager, "giving us a planet like Venus in the inner solar system." Venus has a thick atmosphere and orbits the sun interior to the Earth's orbit. Therefore, it goes through a full sequence of phases, from fully illuminated, to half lit, to invisible, just like the phases of the moon. Similarly, extrasolar giant planets orbiting other stars go through a complete set of phases. The trick for theorists is trying to understand what an atmosphere like Jupiter's would look like going through phases like Venus, with the signal swamped by the starlight of the parent star.

And with that in mind, Seager, Charbonneau, and others await the launch of other instruments to help further their goals. Several ground-based telescopes, such as STARE (Stellar Astrophysics and Research on Exoplanets) and Charbonneau's own Palomar Planet Search Telescope, patiently search for more transits of extrasolar giant planets. Once identified, more sensitive instruments like Hubble can be used to measure the atmospheric component.

Other space-based telescopes are being readied for deployment. Two missions, the Canadian MOST (Microvariability and Oscillations of STars) and the Danish MONS (Measuring Oscillations of Nearby Stars) are designed primarily to study astroseismology, the tiny fluctuations in starlight due to oscillations of the stellar surface. However, these devices will have the

precision to look for extrasolar planet transits as well. Another mission, the French COROT (COnvection, ROtation and planetary Transits), will also search for extrasolar planets. These small satellites, however, are designed to explore only the brightest stars, hampering their ability to survey a large number of potential candidates.

With the exception of COROT, none of these missions are specifically designed to search for planets. The next step is finding and characterizing planets with masses much less than Jupiter and Saturn. In December 2001, NASA announced support for the Kepler mission, a larger orbiting telescope scheduled for launch in 2007. This mission plans to push the size limit of detection into the realm of planets like Venus and Earth. In fact, according to the Kepler group, if earthlike planets are common, as many as 50 will be detected by mission's end.

Researchers across the field of extrasolar planets agree that Kepler-style missions are the next logical step. "The extrasolar planets are currently known on an anecdotal basis," says Greg Laughlin, extrasolar planet researcher and assistant professor at the University of California, Santa Cruz. "I think of them as sort of individual stories. By getting a huge census you start to look at an entire population." And while Laughlin thinks the current techniques for finding extrasolar planets such as Doppler radial velocity measurements won't be supplanted "any time soon," he stresses, "You are just not going to find earthlike planets with the radial velocity technique."

All of these instruments rely on measurements of the starlight as the planet passes over the face of the parent star, giving a measurement of the size of the planet, and, in the case of larger planets with thick atmospheres, some indication of the atmospheric conditions. These types of measurements will give the frequency of earthlike planets, but a telescope of this type designed to detect the effect due to such a small planet's atmosphere seems completely unrealistic.

"We could know about the incidence of earthlike planets by 2010," says Charbonneau, but Kepler will not help study the effects of the atmosphere during a transit of earthlike planets. And even a larger telescope similar to Kepler probably won't be able to get at that kind of information, according to Charbonneau. "Such a telescope does not seem realistic," he says, "but Kepler will determine the frequency of earthlike planets and set the scale for such detections."

Enter Space Interferometry

What's required is a different type of space-based instrument designed to cancel out the light of the parent star and allow researchers to directly detect the light from the planet itself, and from that light extract a spectrum. And such an instrument is

not science fiction. The NASA plan for the Terrestrial Planet Finder (TPF) envisions a fleet of free-flying space-based telescopes circling the sun near the orbit of Jupiter. These separate satellites would fly in formation and use the technique of nulling interferometry to remove the light from the central star by interfering the light from the separate telescopes, allowing detection of the relatively feeble reflected and infrared light from the planets to shine through. Given a sensitive enough instrument, the full spectrum of a planet's atmosphere could be recorded, which would be astonishing.

What are we looking for? The key, according to many researchers, is disequilibrium chemistry. Earth's atmosphere, for example, contains a large fraction of oxygen. Left on its own, oxygen reacts quickly with just about everything. Without photosynthesizing plants to constantly replenish it, the atmosphere would be scrubbed clean of oxygen in a short period of time. Sunlight reacts with oxygen to produce ozone, a prominent feature in Earth's atmospheric spectrum. Therefore, the signature of ozone could indicate the presence of life. However, oxygen in Earth's atmosphere, and the organisms that rely on it, has only been around for the last two billion years, leading some researchers to suggest that other tracers like methane would also be good proxies for life.

While the technological hurdles to getting such a spectrum are not insurmountable, they may be a long way off. "The technology required to get an earthlike spectrum with enough signal to noise to detect oxygen is not going to be ready for today's undergraduate to work on as a graduate student," says Charbonneau, "but it is certainly something such a person could expect to see in his lifetime."

Sunlike stars like HD 222582b may harbor planets with plentiful water and atmospheres that resemble Earth's. Lynette Cook

Seager agrees, noting that the will of the people, rather than the technology, will determine whether such an instrument flies. "TPF is interesting, but it is a science per dollar issue," she says. "Finding an earthlike planet is priceless, but what if we spend $2 billion of the tax payers' money and it doesn't reach its goal? It's just a question of money. The technological challenges can be overcome."

And it is missions like Kepler that will fuel the public debate. By 2010, we should know if earthlike planets are common or rare, and whether or not the chances are good that anyone is out there, looking down on us. ◼

John Armstrong is an astronomy graduate student at the University of Washington in Seattle.