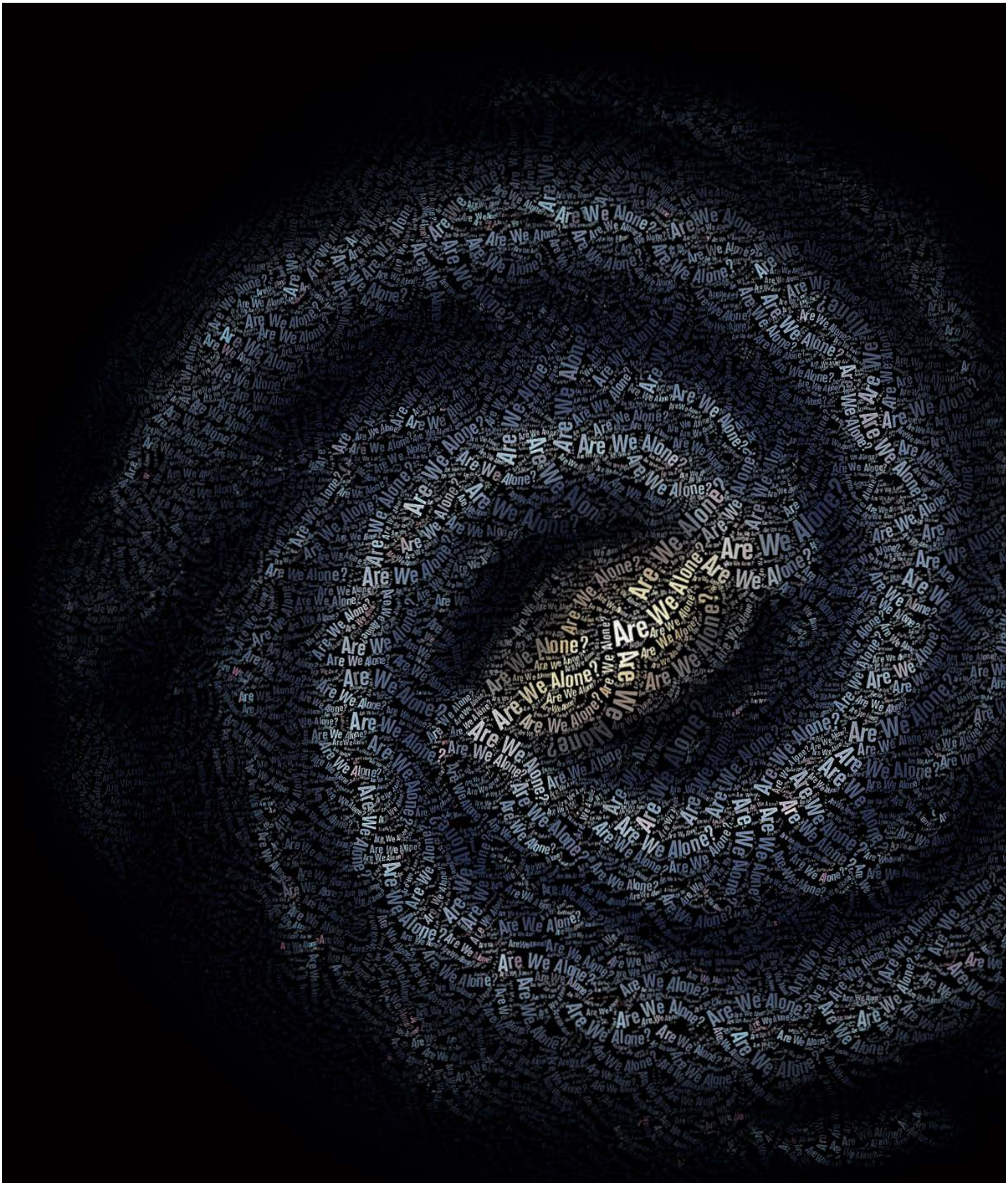

Are We Alone?

Are We Alone?

By Kimm Fesenmaier

Thirty years ago—not even the blink of a cosmic eye—we had no real proof that planets existed beyond our solar system. Certainly, there was the hope that such extrasolar planets, more commonly known as exoplanets, were out there, and there was scientific support for the belief that we would find them. Still, until 1991, when astronomers first detected exoplanets orbiting a pulsar—the dense remains of a dead star—we and our seven solar system counterparts were essentially alone. Four years later another team found an exoplanet, dubbed 51 Pegasi b, orbiting a more sunlike star.

Fast-forward to today—an era in which it's actually difficult to keep up with the discoveries of and about exoplanets. At this point, the number of exoplanets that have not only been seen but confirmed as planets by follow-up observations and analyses has skyrocketed to more than 800, with an additional 2,000-plus unconfirmed candidates waiting for their chance to be officially recognized.

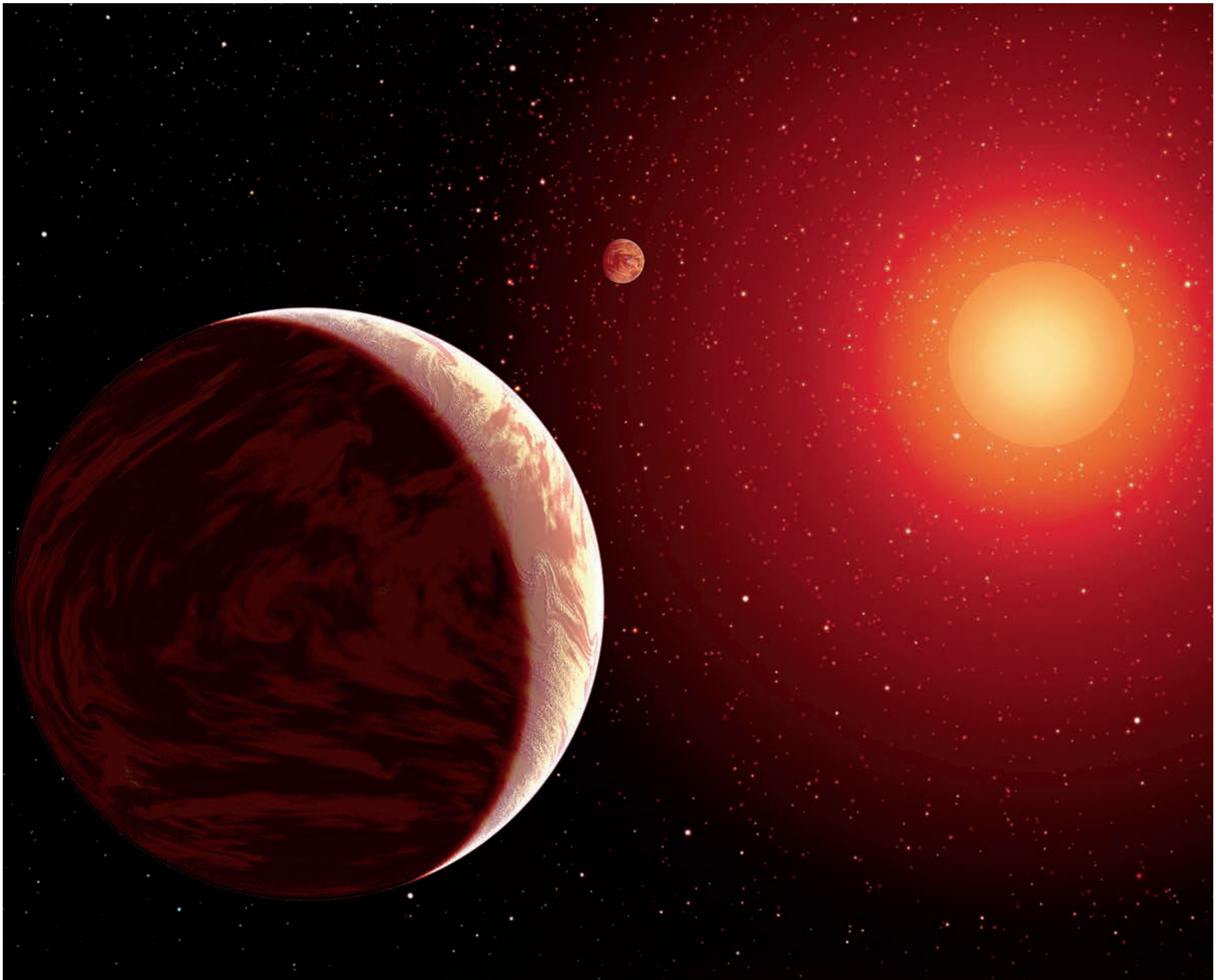
And they are only the beginning, according to astronomers John Johnson and Jonathan Swift, who recently published a paper suggesting that there is about one planet per star throughout the Milky Way: a total of about 100 billion planets. In other words, there are still *plenty* of planets out there for the finding.

The astronomers who do the searching—who are sometimes called exoplanet hunters—are driven by such lofty goals as enhancing human understanding of our place in the cosmos; determining whether we, as a planet or a solar system, are a galactic oddball; learning just how planetary systems form and evolve; and deciding where our sun fits into the spectrum of stars in the galaxy. And yet, at the heart of the field lies the more basic, age-old question, "Are we alone?"

The short answer: no one knows. Still, with every research-packed year it gets increasingly difficult to believe that we are as alone in the cosmos as we once thought we were. As astronomers identify more exoplanets, the sheer numbers—let alone the scale of the universe—point to the possibility that there are other planets out there capable of hosting life.

In the early days of exoplanet studies, all of the newly discovered worlds were gas giants—enormous planets that, like Jupiter, are not primarily solid—that orbit far too close to their host stars to harbor life. As technology and techniques have improved—and with the launch of NASA's planet-hunting, space-based telescope, Kepler—the average size of detected exoplanets has shrunk, with the majority of candidates now two to six times the size of Earth or smaller.

But what astronomers are *really* looking for are rocky planets that are 0.8 to 1.25 times the size of Earth and whose orbits keep them within the region around their host stars, called the habitable zone, where conditions would be right for liquid water to exist.



Such planets, after all, are the ones most likely to be home to some kind of living creature. And, in the interest of follow-up studies, it would be ideal if they were located relatively nearby.

In April, the astronomy world was abuzz with the news that the Kepler mission had detected two planets—one 40 percent, the other about 60 percent larger than Earth—in the habitable zone of a star in the constellation Lyra. Unfortunately, that planetary system is some 1,200 light-years away.

And so, even as the systematic investigation of Mars continues with NASA's Curiosity and Opportunity rovers—not to mention the fleet of satellites circling the planet—and even as we learn more about the potential habitability of moons like Europa and Titan, the reality is that Earth's astronomers and astrobiologists are still working with a statistical sample of one when it comes to worlds known to host life.

Still, there is hope that change is just around the corner and can be reached with a lot of hard work—work that Caltech researchers are right in the thick of. Some of those researchers, like Johnson and Swift, are busy hunting planets. Others, like planetary astronomer Heather Knutson, are characterizing their atmospheres. And then there's the NASA Exoplanet Science Institute (NExScI), an entire center on the Caltech campus dedicated to supporting NASA's Exoplanet Exploration Program missions by—among other tasks—maintaining the Exoplanet Archive, an interactive table of exoplanets both confirmed and not, which is used by researchers around the world.

SHIFTING TARGETS

One of the most exciting discoveries of 2012 came when Johnson's group pinpointed three planets orbiting a red dwarf, a small, rather dim type of star. These planets, named after

their host star, KOI-961, were not only the first rocky planets ever found around a red dwarf, but were also the three smallest confirmed planets ever detected outside our solar system.

"When we found those three tiny planets it was exhilarating and a huge boost of energy for my group," Johnson says.

Why was it so exciting? Because the team realized that rather than focusing on sunlike stars, as the Kepler mission does, they could look for small, rocky planets around small red dwarfs.

To understand why that's good news, you need to understand that one of the ways astronomers search for exoplanets is called the transit method. It involves watching for tiny dips in the amount of light coming from a star—dips caused by the movement, or transit, of a planet in front of that star. The strength of that signal's dip depends on the size of the transiting planet relative to the size of its host star: the more starlight the planet blocks, the larger the signal.

All of which is to say that if you're looking for stronger, easier-to-detect signals you need either a larger planet or—as is the case with the three tiny planets and their red dwarf—a smaller star.

Red dwarfs make up only about 3 percent of the 150,000 or so stars Kepler has been studying—distant stars in a slice of the Milky Way extending from hundreds to thousands of light-years away. But red dwarfs are thought to account for about 70 percent of all the stars in the galaxy. Which is why Johnson believes our galaxy must be swarming with little potentially habitable planets around faint red dwarfs.

WHERE THE SUN SETS TWICE

Of course, red dwarfs aren't the only stars that are capable of hosting planets teeming with life. Longtime exoplanetary scientist Stephen Kane and postdoctoral scholar Natalie Hinkel have been interested in another type of star system—a so-called circumbinary system, in which an exoplanet orbits more than one star. (Yes, some planets can indeed orbit more than one star, à la the planet Tatooine in *Star Wars*.) They recently showed that many studies trying to calculate the extent of such systems' habitable zones have oversimplified the story by using the parameters of only one star to determine where life might be possible.

"We heard people give talks about circumbinary systems, and we found that they had taken all of the fun out of the problem," Hinkel says. "By knocking the system down to just one star, they took something that's interesting—that has motion and will move and change—and simplified it to the point where it was sort of boring."

Hinkel and Kane brought back the fun, recalculating habitable zones for a number of planet candidates identified by Kepler in circumbinary systems. In making their reckonings, they took into consideration not only the masses of both stars but things like the brightness of the stars relative to each other and the distance between them. What they found was that looking at both stars often made a significant difference; in one case, for instance, where the two stars were very similar in size, the habitable zone turned out to be peanut-shaped.

Such discoveries will now need to be incorporated into Kane's Habitable Zone Gallery (hzgallery.org), an online database of already-calculated habitable zones, which Kane created and maintains.

But Kane is known for much more than his database. He's become expert in three different exoplanet-detecting techniques over the years: microlensing (which identifies exoplanets through the gravitational light-bending effect they and their host stars can have, magnifying images of perfectly aligned, more distant stars), the transit method, and something called the radial velocity, or Doppler, method, which essentially measures the wobble in a star that is caused by its planets as they orbit. (An orbiting planet actually tugs its star back and forth ever so slightly—a small but measurable effect that can signal a planet's presence.)

"As far as I know, I'm still the only person who has discovered a planet using all three of these techniques," Kane says. "That's my claim to fame."

Kane's range of experiences has shown him not only how to use these individual methods to find planets,

Above: An artist's concept depicting three planets orbiting a red dwarf. Caltech astronomers and their colleagues recently discovered such a planetary system orbiting red dwarf KOI-961.

but also how the methods can complement one another. To that end, he's combined his work on radial velocities and transits to predict when planets detected with the radial velocity method will transit their host stars—information that can help other scientists, like Heather Knutson, who aim to characterize those planets.

GETTING DOWN TO DETAILS

Knutson gets information on the size of a planet relative to its star via the transit technique; the radial velocity measurements tell her all she needs to know about the planet's mass. By combining those pieces of information, she can compute a particular planet's average density, which in turn says something about the basic composition of the planet—whether it's mostly gas, mostly rock, or something in between.

To learn even more about a particular planet, Knutson collects another set of measurements when it swings behind its star—an event called a secondary eclipse. By imaging this event at different wavelengths, she can create a spectrum indicating the amount of light emitted by the planet and its atmosphere at particular wavelengths. "Once we have a spectrum, we can start to fit it with different models and try to figure out the details of the composition of the planet," Knutson explains. "It also tells us the temperature of the planet."

Knutson also measures the amount of light coming from the planets during transit events themselves, learning about the molecules present in a planet's atmosphere based on which wavelengths of the star's light are absorbed. "Just the fact that you see absorption at all tells you that the planet must have an atmosphere, and then you can start to ask what kind of atmosphere it is," Knutson says.

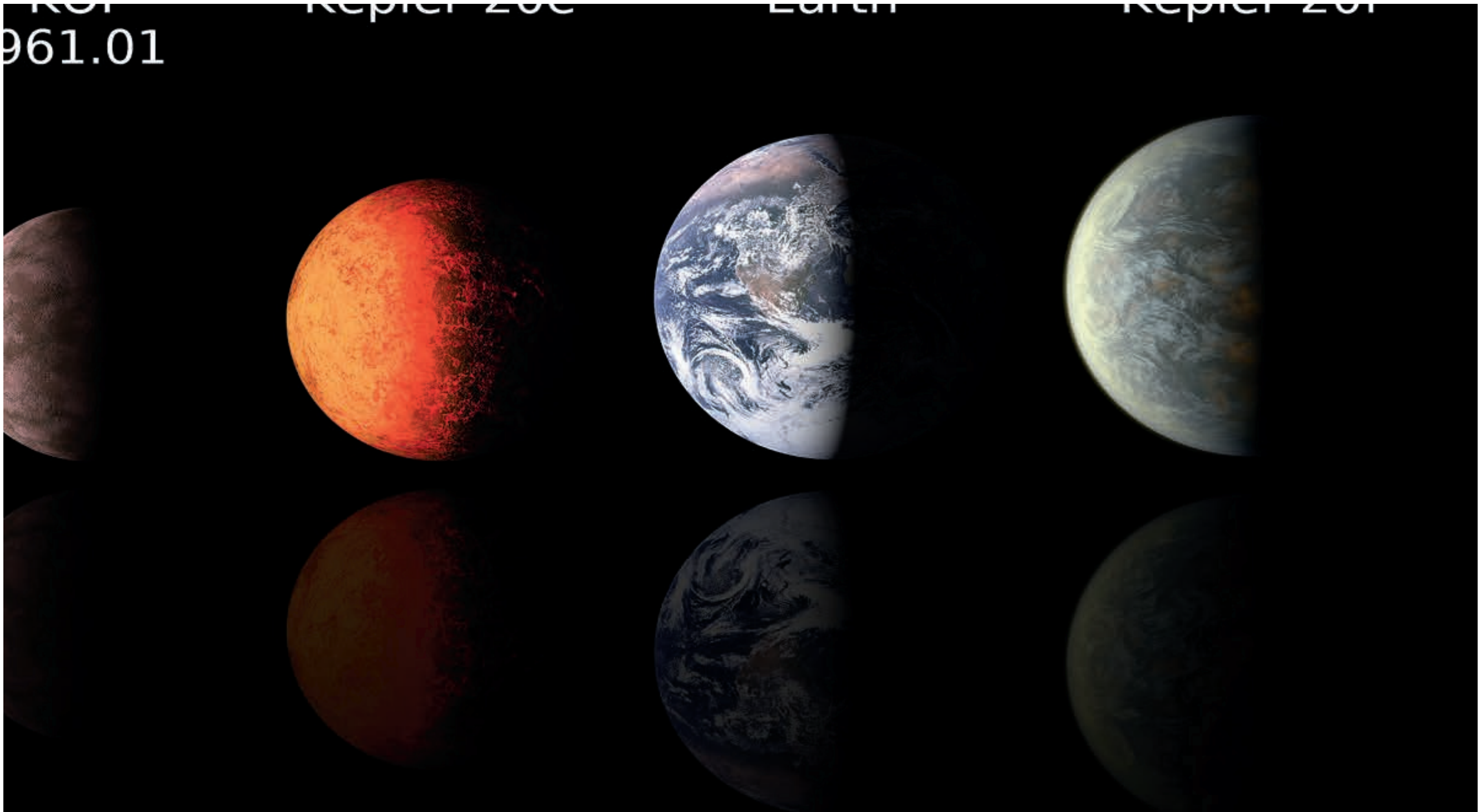
To capture such tiny signals—which require a high level of precision to measure—Knutson has mostly relied on NASA's Spitzer and Hubble Space Telescopes. She and her colleagues are currently using the telescopes to survey large samples of planets—enough to be able to say whether a given type of planet, such as a gas giant, can have a wide variety of properties. "If I tell you that I have a Jupiter-sized planet with a temperature of 1,000 kelvins, do all planets with those properties look exactly the same?" she asks. "Do they have the same amounts of molecules such as methane or water in their atmospheres? Do they all have clouds? Our goal is to learn more about the detailed properties of these planets, beyond the simple classifications of 'rocky' or 'gas giant.'"

THE DIRECT ROUTE

Lynne Hillenbrand and her colleagues are seeking answers to the same types of questions, but are approaching the problem in a different way, using an advanced imaging system dubbed Project 1640 (in honor of a representative wavelength, in nanometers, at which the instrument collects measurements). Project 1640 was designed especially for the Hale Telescope at Palomar Observatory and allows astronomers to directly collect broad spectra of nearby exoplanets even if they are not transiting their host stars.

After nearly a decade of development, Project 1640 started its survey—slated to run for three years—in June 2012 and quickly proved itself by collecting the spectra of four previously known planets orbiting the star HR 8799, which is some 128 light-years away. Those worlds are five to 10 times the mass of Jupiter, and compared to the planets that have been detected via the radial velocity or transit methods, they orbit farther from their host star, which makes them more like the gas giants in our solar system.

Above: This chart compares several small exoplanets to Earth and Mars. When three worlds orbiting red dwarf KOI-961 were reported on in early 2012, they were the smallest known exoplanets. Kepler-20e and Kepler-20f were the first Earth-size exoplanets ever found. None of the pictured exoplanets lie in the habitable zone of its central star.



"Imaging techniques like ours are most sensitive to objects that are farthest away from the star because of the necessary contrast," Hillenbrand explains. "We need to block out the light from the bright, glaring star, which can be more than a million times brighter than the planets we are looking for around the youngest stars."

The overall design concept is based on an idea that Ben Oppenheimer (PhD '99) of the American Museum of Natural History first developed for the U.S. Air Force AEOS telescope in Maui. The setup at Palomar, which was translated from this original idea, relies on the larger Hale Telescope and its sophisticated new adaptive optics system, which minimizes the blurring effects of Earth's atmosphere on its observations. Engineers at JPL have even built an additional back-end piece of hardware to further refine those antiblurring corrections and control diffracted and scattered light. At the heart of the instrument, however, is a coronagraph—a sophisticated device that blocks the light from the star—as well as a spectrograph that splits the remaining light into 40,000 individual spectra from the postcoronagraph image. Finally, two software packages process the spectra and pull out any signals of planet-like objects.

Over the next few years, Project 1640 will survey 200 or so nearby stars hotter than the sun to see if it can detect and characterize undiscovered exoplanets. Eventually, astronomers would like to get to the point where a similar system could obtain spectra for planetary objects that are the mass and size of Earth. "So there's a long way to go," Hillenbrand says.

However far that may be, all exoplanet researchers are working toward a common goal: a greater understanding of what lies beyond our own solar system. How many planets are there? How and when did they form? What do their spectra look like? Which of them might be habitable? And what, then, does all that information say about the formation and evolution of home sweet home? The vast number of remaining questions might seem daunting, but as Knutson explains, that's part of the allure when you're an astronomer.

And that, she and her colleagues agree, is what makes being a planet hunter so stimulating. "We think we know something about planets," Knutson says, "but we're constantly being surprised by the results of our observations. That's good, because it means that there are always new questions to tackle." E&S

Lynne Hillenbrand is a professor of astronomy.

John Johnson is an assistant professor of planetary astronomy. His work is funded by the David and Lucile Packard Foundation and the Alfred P. Sloan Foundation.

Stephen Kane is a research scientist with NExScI.

Heather Knutson is an assistant professor of planetary science. She is currently funded by JPL-Caltech and by NASA via the Space Telescope Science Institute.