

Lucifer's planets

Three newly discovered, low-mass worlds could be rocky super-Earths — and among the strangest planets yet.

/// BY RAY VILLARD ///

The search for extrasolar planets has crossed a key threshold. In August, three teams of

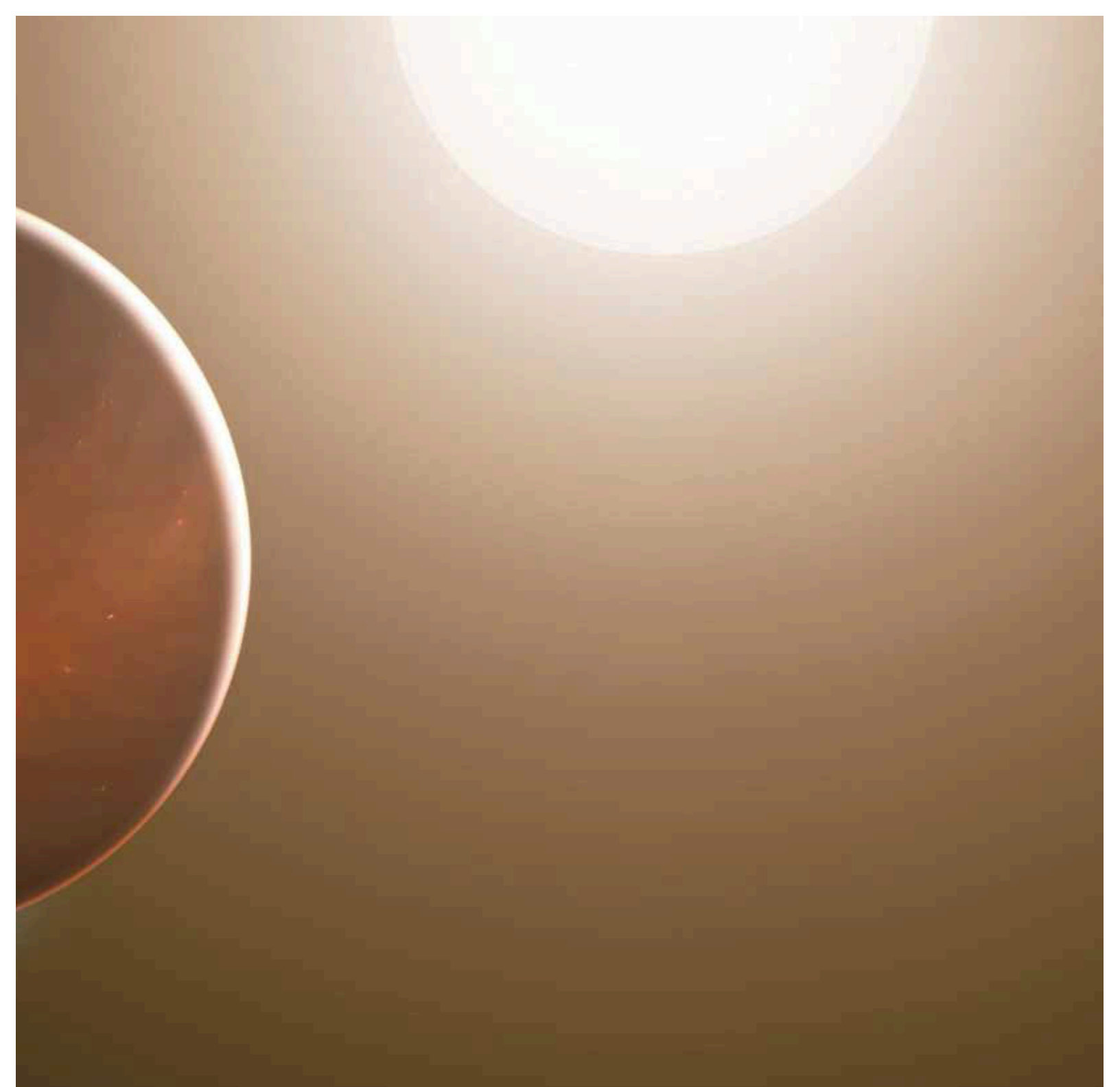
astronomers announced the discovery of three extrasolar planets small enough that they could be made primarily of rock and metal. All previous planets found circling normal stars are probably gaseous. The new planets' masses fall roughly between 15 and 20 Earth masses, putting them in the same ballpark as Neptune. They all whirl around

their stars within a few days at a fraction of Mercury's distance from our Sun.

Although the discovery of these planets made big news, one aspect garnered little publicity: If these worlds are rocky, they are among the most bizarre and surprising planets found so far. Even among exoplanet experts, who have learned to expect the

unexpected in the diversity of alien worlds, these places are baffling. They make craggy, Sun-baked Mercury look comparatively temperate. At least one of the new planets is hot enough to have a surface of bubbling lava.

Michel Mayor of the Geneva Observatory and his colleagues targeted Mu Arae, a solar-type star located 50 light-years away in the southern constellation Ara. By measuring a slight wobble in the radial velocity of the star — which reflects the gravitational pull of an



orbiting planet — they deduced the presence of a planet with at least 14 times Earth's mass that takes 9.5 days to complete one revolution. This is the second planet discovered around Mu Arae.

Paul Butler of the Carnegie Institution of Washington and Geoffrey Marcy of the University of California at Berkeley used the same technique to discover a planet circling Gliese 436, a small star located 33 light-years away in the constellation Leo. The planet orbits the

star every 2.64 days at a distance of 2.6 million miles and has a minimum mass of 21 Earths. Gliese 436 possesses just four-tenths the mass of our Sun, and this planet is only the third known to orbit an M-class dwarf star.

The third new planet also revealed its presence through a tiny wobble in the radial velocity of its parent, the solar-type star 55 Cancri. Barbara McArthur of the University of Texas at Austin and her coinvestigators found a planet that whips around 55 Cancri every

2.81 days at a distance of 3.5 million miles — merely one-tenth Mercury's distance from the Sun. Three gas-giant planets also revolve around this star, located 41 light-years from Earth in the constellation Cancer, with periods

A POSSIBLE SUPER-EARTH lurks close to the Sun-like star 55 Cancri. This world is one of the smallest extrasolar planets discovered to date — and quite possibly one of the most bizarre. ADOLF SCHALLER

of 15, 44, and 4,520 days. McArthur's team also observed the system with the Hubble Space Telescope to determine the star's wobble on the sky. Combining this with the radial-velocity measurements gives the orbital inclination of the planets and a fairly precise mass estimate for the new planet: 18 Earths.

On the trail of Earths

Since the first extrasolar planets were discovered nearly a decade ago, improvements in planet-detection techniques have brought astronomers ever closer to finding Earth-mass worlds in Earth-like orbits — the most exciting worlds because they would be most likely to harbor life. Predictably, the more massive planets popped up first because they exert a greater pull on their parent stars and so produce larger wobbles in the stars' motions. The recent discoveries bring the mass range for extrasolar planets down to the size of Neptune, or perhaps Uranus.

No observational evidence shows whether these new planets are super-Earths or more akin to Uranus and Neptune. If any of the planets was seen transiting its star, astronomers would know — a puffy gas giant would block more starlight than a ball of rock.

It's reasonable to expect "star-hugger" super-Earths to lurk among the Milky Way's stars. A star-hugger is a planet that migrates close to its star and then, somehow, its orbit stops shrinking just before it falls into the

OCEANS OF MOLTEN LAVA lap against a distant shore on the starlit side of the possible super-Earth orbiting 55 Cancri. Such a planet's dark side likely would feature continents of solid crust floating on a magma sea. ADOLF SCHALLER

star. Many of the known exoplanets have been dubbed "hot Jupiters" because they are gas giants that lie close to their parent stars. Whether or not these new planets are solid or gaseous, it's likely that "hot rocks" exist somewhere in our galaxy.

A super-Earth orbiting close to its star presents a stark and baffling picture that leaves planetary scientists in awe. "It would not be hard to just scale-up an earthlike rock to that size and predict its thermal history," says Mark Richards of the University of California at Berkeley. "But my good sense tells me that would probably be an empty exercise without putting a lot of thought into how such a planet might evolve in a fashion that is qualitatively different from Earth." Greg Laughlin of the University of California at Santa Cruz adds, "We're currently trying to understand more about how these types of objects would behave. If I were to speculate right now, I would envision a nasty, high-mass version of Venus."

A fully baked world

The most intriguing of the newly discovered worlds has to be the one orbiting 55 Cancri. It certainly ranks as the most extreme. Located just 3.5 million miles above the star's seething photosphere, a rocky planet would have an ocean of liquid magma on its sunlit side. Call it the Lucifer planet. (Coincidentally, the Romans called Venus "Lucifer" when it appeared in the morning sky. It makes an apt name for this new planet, whose sunlit surface would be

as hot as a lightbulb filament.) Depending on how cool the crust is on the planet's shadowed farside, sluggish waves of lava, creeping under a pull twice that of Earth's gravity, would slosh up to frozen basaltic shores near the boundary between day and night.

As if the stellar radiation isn't bad enough, a rocky world of 18 Earth masses also would be seething from the inside. Such a world would have a core of radioactive elements perhaps 30 times bigger than Earth's because its parent star has about twice the fraction of heavy elements as the Sun. But the planet's radius would be only three times that of Earth's, yielding a surface area for radiating heat only about 10 times that of our planet. Aside from being baked from the outside, the



planet would have a lot of trapped heat to vent. Radar mapping of cloudy Venus by the Magellan spacecraft gives us a preview of what the dark side of our Lucifer planet might look like [although Magellan did not record active volcanism]. Just imagine molten rock pouring from immense but shallow volcanic calderas, creeping across the nighttime surface like a luminous monster stretching its tentacles. There also could be oozing pancake domes, lava channels, sinuous rilles, and rolling volcanic plains.

The interior of the planet might be so hot that the dark-side crust would float on molten rock — a fiery analogue to the ice rafts floating on Europa's subsurface ocean. These possibly continent-size rafts might drift onto the planet's sunlit side, where they would melt like pats of butter left on a sunny picnic table. New volcanic material upwelling on the planet's farside would cool and make new crust, keeping the conveyor belt going.

Gravity might tidally lock Lucifer to its star, forcing the planet to keep one hemisphere pointed permanently toward the star just as our Moon keeps one face toward Earth. However, the only planet we know where tides have drastically slowed its spin is Mercury. And it is *not* in synchronous rotation but instead spins three times every two orbits. The situation would get even more complicated if the steamy, starlit side of the Lucifer planet loses mass into space. This would shift the planet's center of gravity and keep it from being tidally locked. So it could have a bizarre

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wobble or rotation that exposes the entire surface to 55 Cancri over time.

Regardless of tidal lock, the whole planet simply may be a ball of plastic mush. "The best guess would be to look at the speculations regarding geology on the Archean Earth," says Jonathan Lunine of the University of Arizona, "when heat flowed through the surface at a much higher rate than today. And I don't think the geologic style cares much about whether it is night-side or day-side."

Laughlin points out that two relatively nearby gas-giant planets also pull on the overheated planet. This would make it an aggressive, distant cousin of Jupiter's moon Io. The gravitational tug of Jupiter's large satellites pumps energy into Io, driving continuous volcanism. Likewise, because the 55 Cancri system contains a Jupiter-mass planet 11 million miles from the star and a second one 22 million miles out, the gravitational tug-of-war with these giants would heat the planet's already molten interior even further.

Under twice the pull of gravity, you might expect the planet to hold onto a dense atmosphere that could help warm the dark side. Withering, superheated gales would blow from the molten side to the cold trap on the farside. "A planet that massive ought to keep its carbon dioxide atmosphere, with the proviso that proximity to the star will yield high photolysis [breakdown of molecules by light] and hence escape rates of the atoms," says Lunine.


The view from up close

Even more enticing than the nature of 55 Cancri's potential super-Earth is the possibility this star might be one of the nearest with one or more inhabited planets. There's room for terrestrial planets to be distributed between

the set of three inner planets and the outer-most giant, which orbits nearly 500 million miles from the star — about Jupiter's distance from the Sun. Because 55 Cancri is as old as the Sun, planets would have had enough time for intelligent life to evolve [assuming Earth is a rule rather than an exception].

Alien astronomers living on an earthlike world embedded in this bizarre system would have a field day. The brilliant giant planets would have been known about since antiquity. The concepts of a heliocentric system would have developed quickly as early skywatchers followed the motions and phases of the two inner giants. But the innermost Lucifer planet lies too close to the star to be seen visually from an earthlike distance. Perturbations in the orbits of the other two giant inferior planets, however, surely would lead Cancrean astronomers to predict the presence of the third, innermost body. Their solar astronomers likely would stumble upon the planet directly by catching a fleeting transit across the face of their star.

Whether anyone lives there or not, the 55 Cancri system would have to be a top contender for a visit from an unmanned interstellar probe dispatched from Earth in the far future. Streaking across the system at a significant fraction of the speed of light, the probe's last duty — after examining the three known gas giants — might be to fall near the star to image the Lucifer planet. This is one extremely strange place that scientists would love to see up close and personal. It almost certainly will remain beyond the reach of the most powerful Earth-based telescopes imagined. ■

 Find out the basics about the known extra-solar planets at www.astronomy.com/toc

