Can Earth-sized planets survive their star's expansion?

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This shows two planets that survived the red-giant expansion of their host star. Credit: Illustration by Stéphane Charpinet/Institut de Recherche en Astrophysique et Planétologie in Toulouse, France.

Two Earth-sized planets have been discovered circling a dying star that has passed the red giant stage. Because of their close orbits, the planets must have been engulfed by their star while it swelled up to many times its original size.

This discovery, published in the science journal *Nature*, may shed new light on the destiny of stellar and planetary systems, including our solar system.

When our sun nears the end of its life in about 5 billion years, it will swell up to what astronomers call a red giant, an inflated star that has used up most of its fuel. So large will the dying star grow that its fiery outer reaches will swallow the innermost planets of our solar system – Mercury, Venus, Earth and Mars.

Researchers believed that this unimaginable inferno would make short work of any planet caught in it – until now.

This report describes the first discovery of two planets – or remnants thereof – that evidently not only survived being engulfed by their parent star, but also may have helped to strip the star of most of its fiery envelope in the process. The team was led by Stephane Charpinet, an astronomer at the Institut de Recherche en Astrophysique et Planétologie, Université de Toulouse-CNRS, in France.

"When our sun swells up to become a red giant, it will engulf the Earth," said Elizabeth 'Betsy' Green, an associate astronomer at the University of Arizona's Steward Observatory, who participated in the research. "If a tiny planet like the Earth spends 1 billion years in an environment like that, it will just evaporate. Only planets with masses very much larger than the Earth, like Jupiter or Saturn, could possibly survive."

The two planets, named KOI 55.01 and KOI 55.02, circle their host star in extremely tight orbits. Having migrated so close, they probably plunged deep into the star's envelope during the red giant phase, but survived. In the most plausible configuration, the two bodies would respectively have radii of 0.76 and 0.87 times the Earth radius, making them the smallest planets so far detected around an active star other than our sun.

The host star, KOI 55, is what astronomers call a subdwarf B star: It consists of the exposed core of a red giant that has lost nearly its entire envelope. In fact, the authors write, the planets may have contributed to the increased mass loss necessary for the formation of this type of star.

The authors concluded that planetary systems may therefore influence the evolution of their parent stars. They pointed out that the planetary system they observed offers a glimpse into the possible future of our own.

The discovery of the two planets came as a surprise because the research team had not set out to find new planets far away from our solar system, but to study pulsating stars. Caused by rhythmic expansions and contractions brought about by pressure and gravitational forces that go along with the thermonuclear fusion process inside the star, such pulsations are a defining feature of many stars.

By studying the pulsations of a star, astronomers can deduce the object's mass, temperature, size and sometimes even its interior structure. This is called asteroseismology.

"Those pulsation frequency patterns are almost like a finger print of a star," Green said. "It's very much like seismology, where one uses earthquake data to learn about the inner composition of the Earth."

To detect the frequencies with which a star pulsates, researchers have to observe it for very long periods of time, sometimes years, in order to measure tiny variations in brightness.

"The brightness variations of a star tell us about its pulsational modes if we can observe enough of them very precisely," Green said. "Let's say there is one pulsational mode every 5859.8 seconds, and there is another one every 9126.39 seconds. There could be lots of stars with rather different properties that could all manage to pulsate at those two frequencies. However, if we can measure 10, or better yet, 50 pulsational modes in one star, then it's possible to use theoretical models to say exactly what the star must be like in order to produce those particular pulsations."

"The only way to do that is to have a telescope sitting in space," she added. "On Earth, we can only observe a star at night. But unless we follow it 24/7, the mathematics give us artifacts. Observing through the atmosphere means that even in the very best of cases we can only detect brightness variations to a ten-thousandth of a percent. But if you've got 50 or a 100 modes going in a star, you need to measure better than that."

For that reason, the team used data obtained from NASA's Kepler Space Telescope for this study.

Unobstructed by the Earth's atmosphere and staring at the same patch of sky throughout its five-year mission, the Kepler Space Telescope sits in a prime spot to detect tiny variations in brightness of stars.

Green had been pursuing a survey to look for hot subdwarf stars in the galactic plane of the Milky Way.

"I had already obtained excellent high-signal to noise spectra of the hot subdwarf B star KOI 55 with our telescopes on Kitt Peak, before Kepler was even launched," she said. "Once Kepler was in orbit and began finding all these pulsational modes, my co-authors at the University of Toulouse and the University of Montreal were able to analyze this star immediately using their state-of-the art computer models."

This was the first time that researchers were able to use gravity pulsation modes, which penetrate into the core of the star, to match subdwarf B star models to learn about their interior structure.

While analyzing KOI 55's pulsations, the team noticed the intriguing presence of two tiny periodic modulations occurring every 5.76 and 8.23 hours that caused the star to flicker ever so slightly, at one five thousandth percent of its overall brightness. They showed that these two frequencies could not have been produced by the star's own internal pulsations.

The only explanation came from the existence two small planets passing in front of the star every 5.76 and 8.23 hours. To complete their orbits so rapidly, KOI 55.01 and KOI 55.02 have to be extremely close to the star, much closer than Mercury is to our sun. On top of that, the sun is a cool star compared to KOI 55, which burns at about 28,000 Kelvin, or 50,000 degrees Fahrenheit.

"Planets this close to their star are tidally locked," Green said, "meaning the same side always faces the star, just like the same face of the moon always faces the Earth. The day side of Mercury is hot enough to melt lead, so you can imagine the harsh conditions on those two small planets racing around a host star that is five times hotter than our sun at such a close distance."

The extremely tight orbits are important because they tell the researchers that the planets must have been engulfed when their host stars swelled up into a red giant.

"Having migrated so close, they probably plunged deep into the star's envelope during the red giant phase, but survived," lead author Charpinet said.

"As the star puffs up and engulfs the planet, the planet has to plow through the star's hot atmosphere and that causes friction, sending it spiraling toward the star," Green added. "As it's doing that, it helps strip atmosphere off the star. At the same time, the friction with the star's envelope also strips the gaseous and liquid layers off the planet, leaving behind only some part of the solid core, scorched but still there."

"We think this is the first documented case of planets influencing a star's evolution," Charpinet said. "We know of a brown dwarf that possibly did that, but that's not a planet, and of giants planets around subdwarf B stars, but those are too far away to have had any impact on the evolution of the star itself."

"I find it incredibly fascinating that after hundreds of years of being able to only look at the outsides of stars, now we can finally investigate the interiors of a few stars – even if only in these special types of pulsators – and compare that with how we thought stars evolved," Green said. "We thought we had a pretty good understanding of what solar systems were like as long as we only knew one – ours. Now we are discovering a huge variety of solar systems that are nothing like ours, including, for the first time, remnant planets around a stellar core like this one."

More information: "A compact system of small planets around a former red-giant star," by S. Charpinet et al., *Nature*, Dec. 22, 2011

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