Astronomers analyze masses, orbital properties and atmospheric features of six exoplanets

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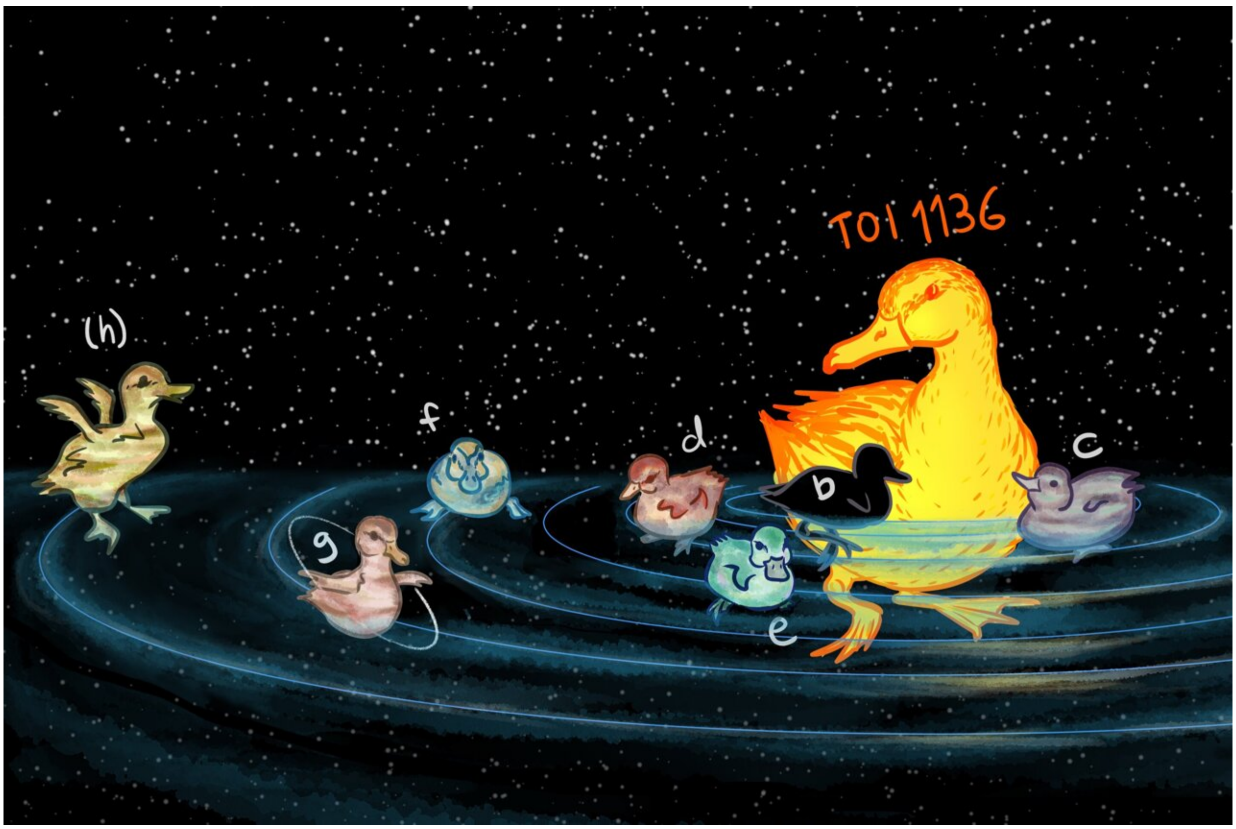

A team of researchers led by astronomers at UCI has obtained highly precise information about six confirmed exoplanets orbiting TOI-1136, a dwarf star about 270 light years from Earth. Credit: Rae Holcomb / UCI

A recently discovered solar system with six confirmed exoplanets and a possible seventh is boosting astronomers' knowledge of planet formation and evolution. Relying on a globe-spanning arsenal of observatories and instruments, a team led by researchers at the University of California, Irvine has compiled the most precise measurements yet of the exoplanets' masses, orbital properties and atmospheric characteristics.

In a paper published today in *The Astronomical Journal*, the researchers share the results of the TESS-Keck Survey, providing a thorough description of the exoplanets orbiting TOI-1136, a dwarf star in the Milky Way galaxy more than 270 light years from Earth. The study is a follow-up to the team's initial observation of the star and exoplanets in 2019 using data from the Transiting Exoplanet Survey Satellite. That project provided the first estimate of the exoplanets' masses by clocking transit timing variations, a measure of the gravitational pull that orbiting planets exert on one another.

For the most recent study, the researchers joined TTV data with a radial velocity analysis of the star. Using the Automated Planet Finder telescope at the Lick Observatory on California's Mount Hamilton and the High-Resolution Echelle Spectrometer at the W.M. Keck Observatory on Hawaii's Mauna Kea, they could detect slight variations in stellar motion via the redshift and blueshift of the Doppler effect—which helped them determine planetary mass readings of unprecedented precision.

To obtain such exact information on the planets in this solar system, the team built computer models using hundreds of radial velocity measurements layered over TTV data. Lead author Corey Beard, a UCI Ph.D. candidate in physics, said that combining these two types of readings yielded more knowledge about the system than ever before.

"It took a lot of trial and error, but we were really happy with our results after developing one of the most complicated planetary system models in exoplanet literature to date," Beard said.

The large number of planets is one factor that inspired the astronomy team to conduct further research, according to co-author Paul Robertson, UCI associate professor of physics & astronomy.

"We viewed TOI-1136 as being highly advantageous from a research standpoint, because when a system has multiple exoplanets, we can control for the effects of planet evolution that depend on the host star, and that helps us focus on individual physical mechanisms that led to these planets having the properties that they do," he said.

Robertson added that when astronomers try to compare planets in separate solar systems, there are many variables that can differ based on the distinct properties of the stars and their locations in disparate parts of the galaxy. He said that looking at exoplanets in the same system enables the study of planets that have experienced a similar history.

By stellar standards, TOI-1136 is young, a mere 700 million years old, another feature that has attracted exoplanet hunters. Robertson said that juvenile stars are both "difficult and special" to work with because they're so active. Magnetism, sunspots and solar flares are more prevalent and intense during this stage of a star's development, and the resulting radiation blasts and sculpts planets, affecting their atmospheres.

TOI-1136's confirmed exoplanets, TOI-1136 b through TOI-1136 g, are categorized as "sub-Neptunes" by the experts. Robertson said the smallest one is more than twice the radius of Earth, and others are up to four times Earth's radius, comparable to the sizes of Uranus and Neptune.

All these planets orbit TOI-1136 in less than the 88 days it takes

Mercury to go around Earth's sun, according to the study. "We're packing an entire solar system into a region around the star so small that our entire planetary system here would be outside of it," Robertson said.

"They're weird planets to us because we don't have anything exactly like them in our solar system," said co-author Rae Holcomb, a UCI Ph.D. candidate in physics. "But the more we study other planet systems, it seems like they may be the most common type of planet in the galaxy."

Another odd component to this solar system is the possible yet unconfirmed presence of a seventh planet. The researchers have detected some evidence of another resonant force in the system. Robertson explained that when planets are orbiting close to one another, they can pull on each other gravitationally.

"When you hear a chord played on a piano and it sounds good to you, it's because there is resonance, or even spacing, between the notes that you're hearing," he said. "The orbital periods of these planets are spaced similarly. When the exoplanets are in resonance, the tugs are in the same direction every time. This can have a destabilizing effect, or in special cases, it can serve to make the orbits *more* stable."

Robertson noted that far from answering all his team's questions about the exoplanets in this system, the survey has made the researchers want to pursue additional knowledge, particularly about the composition of planetary atmospheres. That line of inquiry would be best approached through the advanced spectroscopy capabilities of NASA's James Webb Space Telescope, he said.

"I am proud that both UCO's Lick Observatory and the Keck Observatories were involved in the characterization of a really important system," said Matthew Shetrone, deputy director of UC Observatories. "Having so many moderate-sized planets in the same system really lets us test formation scenarios. I really want to know more about these planets! Might we find a molten rock world, a water world and an ice world all in the same solar system? It almost feels like science fiction."

More information: Corey Beard et al, The TESS-Keck Survey XVII: Precise Mass Measurements in a Young, High Multiplicity Transiting Planet System using Radial Velocities and Transit Timing Variations, DOI 10.3847/1538-3881/ad1330 , iopscience.iop.org/article/10. … 847/1538-3881/ad1330

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