Second Solar System detected

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A team of astrophysicists at the German Aerospace Center (Deutsches Zentrum für Luft und-Raumfahrt; DLR), together with German and other European colleagues, has discovered the most extensive planetary system to date. Seven planets circle the star KOI-351 – more than in other known planetary systems. They are arranged in a similar fashion to the eight planets in the Solar System, with small rocky planets close to the parent star and gas giant planets at greater distances. Although the planetary system around KOI-351 is packed together more tightly, it provides an interesting comparison to our cosmic home.

Important step in the search for a 'twin Solar System'

Astrophysicists around the world have been searching for a star system similar to our own for a long time. Now, the team led by Juan Cabrera, an astrophysicist at the DLR Institute of Planetary Research in Berlin-Adlershof has taken a major step in this direction. Three of the seven planets in orbit around the star KOI-351 were discovered in recent years, and have periods of 331, 211 and 60 days, similar to those of Earth, Venus and Mercury.

The planets discovered by Cabrera and his team are even closer to the star and have orbital periods of 7, 9, 92 and 125 days. The outermost planet orbits the star at a distance of about 150 million kilometres, or roughly one Astronomical Unit (AU), so the entire planetary system is compressed into a space corresponding to the distance between Earth and the Sun.

In the article published in the Astrophysical Journal, Juan Cabrera and his colleagues emphasise the similarities between KOI-351 and the Solar System: "No other planetary system shows such a similar 'architecture' to that of our cosmic home as does the planetary system around KOI-351," says Cabrera. "Just as in the Solar System, rocky planets with roughly the size of Earth are found close to the star, while, 'gas giants' similar to Jupiter and Saturn are found as you move away from the star."

"We cannot stress just how important this discovery is. It is a big step in the search for a 'twin' to the Solar System, and thus also in finding a second Earth," said Cabrera. Heike Rauer, head of the Extrasolar Planets and Atmospheres working group at the DLR Institute of Planetary Research and professor at the Centre for Astronomy and Astrophysics at the University of Berlin, adds: "The discovery of this complex planetary system helps us to better understand the processes that give rise to such planetary systems." Tilman Spohn, Head of the DLR Institute of Planetary Research states that: "DLR is proud to have made a significant contribution to the discovery of new planetary systems."

Specially developed computer program enabled discovery

The development of a special computer algorithm enabled Juan Cabrera and his team to detect the four new planets around KOI-351. The DLR astrophysicist was able to filter out the light curves that reveal the 'transit' of a planet across its parent star from the Kepler measurements. A transit is inferred from the small, periodic dimming of the star's light as the planet crosses the star's disc. This technological development is likely to be crucial in the search for similar multiple systems using large data sets from future space telescopes. The discovery was confirmed shortly afterwards by a US group led by Joseph R. Schmitt of Yale University, by visual inspection of the light curves recorded by Kepler.

KOI is the abbreviation for 'Kepler Object of Interest', which means the star was observed by NASA's Kepler space telescope, between 2008 and 2013, and classified as a candidate for the

existence of exoplanets. At present, KOI-351 is the star with the most extrasolar planets, or exoplanets for short. The star is 2500 light years away from Earth.

Unusual resonances between the planets

"The resonances of the planetary orbits are another interesting feature of this system," explains Szilárd Csizmadia, a member of the team led by Cabrera. Orbital resonance occurs when two or more orbiting bodies exert a regular, periodic gravitational influence on one another. "Resonances also play an important role in the Solar System; for example, the moons of Jupiter. So KOI-351 is a gold mine for all researchers investigating planetary formation and the stability of multi-body systems."

The resonances in the planetary system of KOI-351, however, greatly complicated the search for the planets. Due to the strong interaction between the planets, the signals sought by Juan Cabrera in the Kepler data were not strictly periodic, but showed strong variations in the orbital periods. Rudolf Dvorak of the University of Vienna highlights the planet KOI-351g as being particularly interesting: "The orbital period of planet g varies by about a day between consecutive transits during the observations. Disturbances of this kind have been noted previously, but so far only with maximum deviations of a few minutes."

Groundbreaking discovery for the future of exoplanet research

The discovery also demonstrates the future in the search for extrasolar planets. After the two successful space telescopes CoRoT and **Kepler** were decommissioned this year, planet hunters are now hopeful with regard to the pending decision on the PLATO mission. PLATO (Planetary Transits and Oscillations of Stars) will build on the experience of CoRoT and Kepler in the search for planetary systems around nearby bright stars, and thus allow for extensive follow-up observations. This could allow the determination of the radius (as in the system KOI-351) and the mass of the planets, as well as a first look at the composition of the planet. Furthermore, it would even be possible to examine the atmosphere of the planets in such systems, which may give rise to indications of the activity of living organisms. This would be a major breakthrough in search for a 'second Earth'. The European Space Agency will make a decision on the PLATO mission in early 2014.

Just recently, and about 25 years after their initial discovery, the 1000th exoplanet has been confirmed. Until now, 771 stars with planets have been identified. However, most of the exoplanets discovered so far are 'solitary'. Only 170 stars are known to be orbited by more than one planet. Large planetary systems are the exception – not because they do not exist, but because they are particularly difficult to detect and characterise. At present, only a handful of systems with at least five planets have been confirmed.

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Details of individual planets around KOI-351:

The planets **KOI-351b** and **351c** were confirmed. They are only 31 percent and 19 percent larger than the Earth. To detect such small planets, a special algorithm was developed by Juan Cabrera. Besides the size of these planets, what is remarkable is the 5:4 orbital resonance. In the time it takes planet b to complete five orbits, planet c has completes exactly four orbits. Similar resonances are found among the inner moons of Jupiter.

Planet **KOI- 351d** was already known. It has an orbital period of 60 days. Its diameter is 2.9 times that of Earth's. It is therefore likely a 'super-Earth' or a 'mini-Neptune'. Since the mass is not known, it is not yet possible to classify this planet.

The planet **KOI-351e** is also a new discovery and is roughly the same size as **KOI- 351d** (2.9 times the diameter of Earth). We know that neighbouring planets in planetary systems have similar sizes, as we see in the Solar System (Neptune and Uranus, or Venus and Earth). This has now been observed for the first time in exoplanets, and underlines the similarity of this system to our own.

The large gas giants **KOI-351g** and **351h** (about 8 and 11 times the diameter of Earth) are outer planets and have long orbital periods (211 and 331 days). This is very reminiscent of the Solar System, where there also four rocky planets (Mercury, Venus, Earth, Mars) and two gas giants (Jupiter and Saturn) with diameters 10 and 8 times that of Earth.

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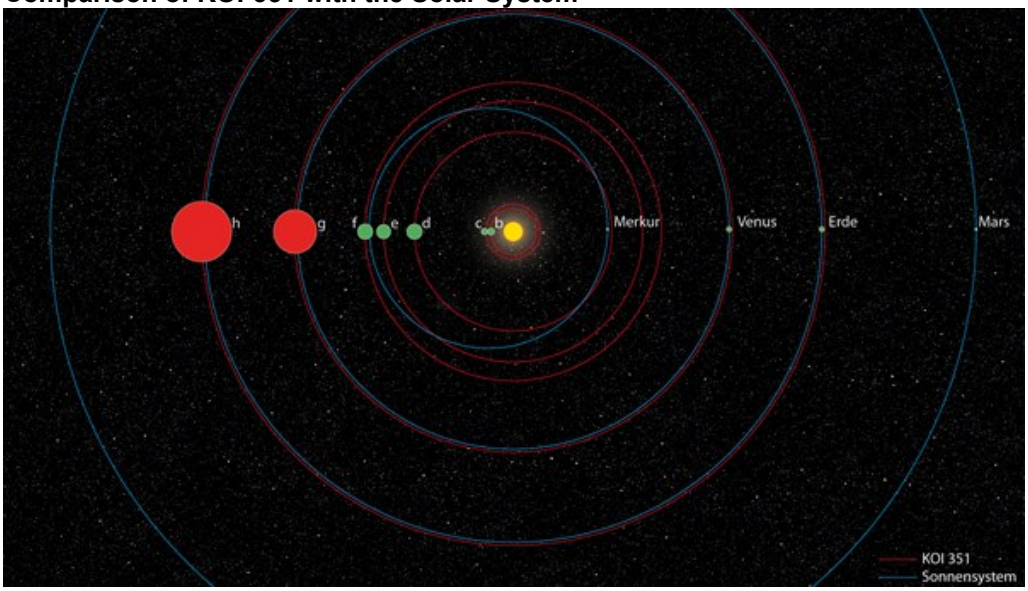
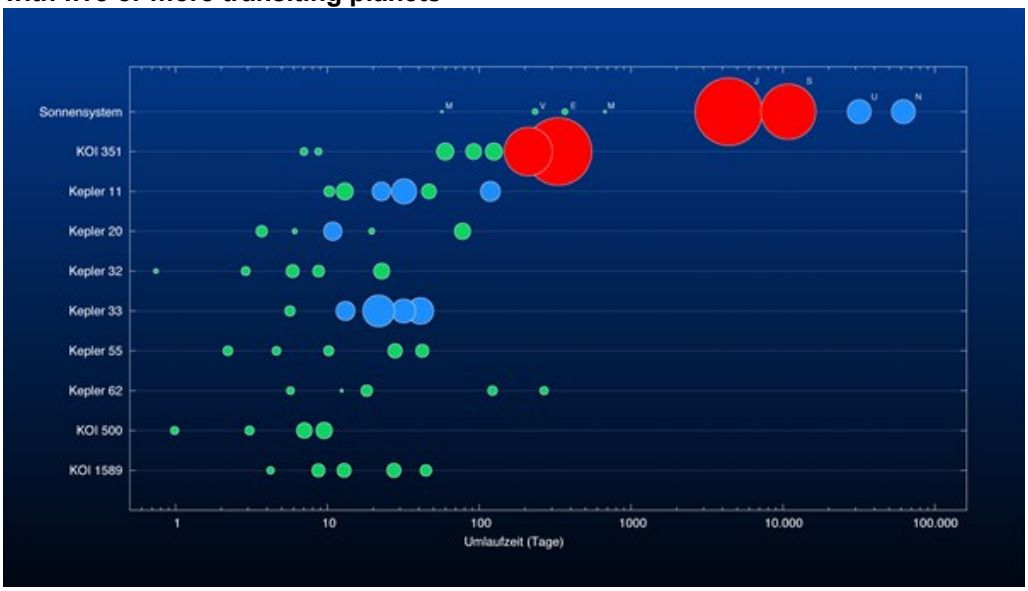
Comparison of KOI-351 with the Solar System



This image compares the system KOI-351 to our own. The orbits of the planets in the Solar System are shown in red, and those of KOI-351 in blue. It can clearly be seen that the path of the outer gas giants in KOI-351 (red) corresponds approximately to the distance between Earth and the Sun; the entire system lies within one Earth orbit.

Credit: DLR (CC-BY 3.0).

Comparison of the planetary system KOI-351 with all known planetary systems with five or more transiting planets



Comparison of the planetary system KOI-351 with all known planetary systems with five or more transiting planets, showing the Solar System for comparison (top line). The colours of different size classes of planets are: blue –'super-Earths' – planets that are smaller than Neptune and planets with a solid surface like Earth, or less dense, gas-rich planets such as in the system Kepler 11; green – Neptune-sized planets – larger than super-Earths, but smaller than 'gas giants' such as Jupiter or Saturn, which typically have at least eight times the diameter of the Earth and are shown in red.

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