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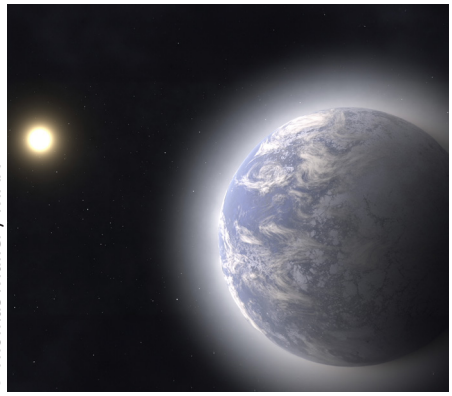
Water-worlds, the key to an exoplanet enigma

Exoplanets with a radius twice that of the Earth are rare. A team from MPIA, UNIGE and UNIBE has come up with new explanations.

Why are so few exoplanets about twice the size of Earth detected? On the basis of computer simulations, a team from the Max Planck Institute for Astronomy (MPIA) and the Universities of Geneva (UNIGE) and Bern (UNIBE) has confirmed that the migration of sub-Neptunes planets – water-worlds - could explain this absence. As these planets move closer to their central star, the water ice that evaporates forms an atmosphere that makes them appear larger than in their frozen state, well beyond twice Earth's radius. At the same time, smaller rocky planets, are gradually losing part of their original gaseous envelope, leading to a significant reduction in their radius. These results open up new perspectives for the study of exoplanets. Find out more in *Nature Astronomy*.

In 2017, the Kepler space telescope revealed the absence of planets with a size of around two Earth radii. This "gap" in the distribution of planetary radii is known as the "radius valley". "Its existence is one of the most important observational constraints for understanding the origin and composition of exoplanets whose radius is between that of the Earth and that of Neptune," explains Julia Venturini, SNSF Ambizione grantee, scientific collaborator in the Department of Astronomy at the UNIGE, member of the NCCR PlanetS and co-author of the study. "Like two other research groups, we had predicted on the basis of our calculations, even before the 2017 observations, that such a valley should exist," adds Christoph Mordasini, professor in the Division of Space Research and Planetary Sciences (WP) at UNIBE, member of the NCCR PlanetS and co-author of the study.



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When icy, water-rich oceanic planets migrate towards their star, the ice melts and eventually forms a thick atmosphere of water vapour, increasing their radius.

High resolution pictures

Where does the radius valley come from?

Two types of exoplanet populate the radius range between one and four Earth radii. On the one hand, there are rocky planets - "super-Earths" - that are likely larger versions of the Earth. On the other hand, there are gaseous planets known as sub-Neptunes (or mini-Neptunes), some of which, known as water-worlds, could harbour such a large quantity of water that their surface would be covered by a water layer several thousands of kilometres deep. Of these two types of planet, super-Earths and sub-Neptunes, astronomers are discovering very few with a radius twice that of the Earth.

To explain the appearance of this valley, the mechanism most often suggested is that some planets lose part of their original atmosphere under the effect of the star's irradiation. "This explanation assumes that the planets form and remain very close to their star, where they would be dry, with no water," explains Julia Venturini. "However, this explanation contradicts planet formation models, which show that

planets with a size of between two and four Earth radii, the sub-Neptunes, generally come from the more distant icy regions of the stellar system".

Numerous clues suggest that certain planets could move away from their birthplace during their evolution, migrating towards the interior or exterior of their system. This migration would allow planets born in cold, icy regions, such as ocean planets, to complete their formation in orbits very close to their star.

Wandering ice planets

As icy, water-rich ocean planets migrate towards their star, the ice melts and eventually forms a thick atmosphere of water vapour. This process causes their radius to increase to larger values, beyond twice Earth's radius. Conversely, water-poor super-Earths "shrink" by losing the volatile gases in their original atmosphere, such as hydrogen and helium, under the influence of the star.

The combined computer models of formation and evolution indicate that the migration of water-worlds contributes significantly to the large number of planets detected with a radius greater than two Earth radii, while the atmospheric evaporation of super-Earths contributes to the excess number of planets smaller than two Earth radii. At the centre of these two populations is the radius valley. "We already found this result in 2020. The new study confirms it with a different formation model. This reinforces the conclusion that sub-Neptunes are predominantly water-worlds." Clarifies Julia Venturini, who led the 2020 study.

Further work ahead

As well as explaining a hitherto mysterious phenomenon, this work opens up new perspectives for the study of exoplanets. "If we were to expand our results to temperate regions, where water is liquid, this might suggest the existence of water worlds with deep oceans," Mordasini says. "Such planets could potentially host life and would be easier targets for searching for biomarkers due to their size."

Observations with telescopes such as the James Webb Space Telescope or the Extremely Large Telescope, currently under construction, could also be useful. They would be able to determine the atmospheric composition of planets as a function of their size, which would make it possible to test the simulations described.

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