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Four classes of planetary systems

Astronomers have long been aware that planetary systems are not necessarily structured like our solar system. Researchers from the Universities of Bern and Geneva, as well as from the National Centre of Competence in Research PlanetS, have now shown for the first time that there are in fact four types of planetary systems.

In our solar system, everything seems to be in order: The smaller rocky planets, such as Venus, Earth or Mars, orbit relatively close to our star. The large gas and ice giants, such as Jupiter, Saturn or Neptune, on the other hand, move in wide orbits around the sun. In two studies published in the scientific journal Astronomy & Astrophysics, researchers from the Universities of Bern and Geneva and the National Centre of Competence in Research (NCCR) PlanetS show that our planetary system is quite unique in this respect.

Like peas in a pod

"More than a decade ago, astronomers noticed, based on observations with the then groundbreaking Kepler telescope, that planets in other systems usually resemble their respective neighbours in size and mass – like peas in a pod," says study lead author Lokesh Mishra, researcher at the University of Bern and Geneva, as well as the NCCR PlanetS. But for a long time it was unclear whether this finding was due to limitations of observational methods. "It was not possible to determine whether the planets in any individual system were similar enough to fall into the class of the ‘peas in a pod’ systems, or whether they were rather different – just like in our solar system," says Mishra.

Therefore, the researcher developed a framework to determine the differences and similarities between planets of the same systems. And in doing so, he discovered that there are not two, but four such system architectures.

Four classes of planetary systems

"We call these four classes 'similar', 'ordered', 'anti-ordered' and 'mixed'," says Mishra. Planetary systems in which the masses of neighbouring planets are similar to each other, have similar architecture. Ordered planetary systems are those, in which the mass of the planets tends to increase with distance from the star – just as in our solar system. If, on the other hand, the mass of the planets roughly decreases with distance from the star, researchers speak of an anti-ordered architecture of the system. And mixed architectures occur, when the planetary masses in a system vary greatly from planet to planet.

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"This framework can also be applied to any other measurements, such as radius, density or water fractions," says study co-author Yann Alibert, Professor of Planetary Science at the University of Bern and the NCCR PlanetS. "Now, for the first time, we have a tool to study planetary systems as a whole and compare them with other systems."

The findings also raise questions: Which architecture is the most common? Which factors control the emergence of an architecture type? Which factors do not play a role? Some of these, the researchers can answer.

A bridge spanning billions of years
"Our results show that 'similar' planetary systems are the most common type of architecture. About eight out of ten planetary systems around stars visible in the night sky have a 'similar' architecture," says Mishra. "This also explains why evidence of this architecture was found in the first few months of the Kepler mission." What surprised the team was that the "ordered" architecture – the one that also includes the solar system – seems to be the rarest class.

According to Mishra, there are indications that both the mass of the gas and dust disk from which the planets emerge, as well as the abundance of heavy elements in the respective star play a role. "From rather small, low-mass disks and stars with few heavy elements, 'similar' planetary systems emerge. Large, massive disks with many heavy elements in the star give rise to more ordered and anti-ordered systems. Mixed systems emerge from medium-sized disks. Dynamic interactions between planets – such as collisions or ejections – influence the final architecture," Mishra explains.

"A remarkable aspect of these results is that it links the initial conditions of planetary and stellar formation to a measurable property: the system architecture. Billions of years of evolution lie in between them. For the first time, we have succeeded in bridging this huge temporal gap and making testable predictions. It will be exciting to see if they will hold up," Alibert concludes.

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Bernese space exploration: With the world's elite since the first moon landing

When the second man, "Buzz" Aldrin, stepped out of the lunar module on July 21, 1969, the first task he did was to set up the Bernese Solar Wind Composition experiment (SWC) also known as the "solar wind sail" by planting it in the ground of the moon, even before the American flag. This experiment, which was planned, built and the results analyzed by Prof. Dr. Johannes Geiss and his team from the Physics Institute of the University of Bern, was the first great highlight in the history of Bernese space exploration.

Ever since Bernese space exploration has been among the world's elite, and the University of Bern has been participating in space missions of the major space organizations, such as ESA, NASA, and JAXA. With CHEOPS the University of Bern shares responsibility with ESA for a whole mission. In addition, Bernese researchers are among the world leaders when it comes to models and simulations of the formation and development of planets.

The successful work of the Department of Space Research and Planetary Sciences (WP) from the Physics Institute of the University of Bern was consolidated by the foundation of a university competence center, the Center for Space and Habitability (CSH). The Swiss National Fund also awarded the University of Bern the National Center of Competence in Research (NCCR) PlanetS, which it manages together with the University of Geneva.

Exoplanets in Geneva: 25 years of expertise crowned by a Nobel Prize

The first exoplanet was discovered in 1995 by two researchers from the University of Geneva, Michel Mayor and Didier Queloz, laureates of the 2019 Nobel Prize in Physics. This discovery allowed the Department of Astronomy of the University of Geneva to be at the forefront of research in the field, with the construction and installation of HARPS on the ESO 3.6m telescope in La Silla in 2003. For two decades, this spectrograph was the most efficient in the world for determining the mass of exoplanets. However, HARPS was surpassed in 2018 by ESPRESSO, another spectrograph built in Geneva and installed on the Very Large Telescope (VLT) in Paranal, Chile. Switzerland has also been involved in space-based observations of exoplanets with the CHEOPS mission, the result of two national expertises: the space know-how of the University of Bern in collaboration with its Geneva counterpart, and the ground-based experience of the University of Geneva assisted by its colleague in the Swiss capital. These two scientific and technical skills have also made it possible to create the National Center of Competence in Research (NCCR) PlanetS.