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The ATREIDES program in search of lost exo-Neptunes

A team of astronomers led by UNIGE is launching a major research program on Neptunes to better understand the mechanisms of formation and evolution of planetary systems.

An international team led by the University of Geneva (UNIGE), including scientists from the National Centre of Competence in Research PlanetS, the University of Warwick, and the Canary Islands Institute of Astrophysics, has launched an ambitious program to map exoplanets located around the Neptunian Desert. The goal: to better understand the formation and evolution of planetary systems. This collaboration, known as ATREIDES, has delivered its first results with the observation of the TOI-421 planetary system. Analysis of this system reveals a surprisingly inclined orbital architecture, offering new insights into the chaotic history of these distant worlds. This inaugural study has been published in the journal *Astronomy & Astrophysics*.

What are the physical mechanisms that govern the formation and evolution of planetary systems? To address this broad question, a group of scientists led by the UNIGE Department of Astronomy decided to focus on a specific class of exoplanets: exo-Neptunes, planets outside our solar system that are about 20 times more massive than Earth.

Over the past decade, scientists have made major discoveries about the distribution of exoplanets. Exo-Neptunes are absent in regions very close to stars. However, recent studies, in which UNIGE has participated, show that in areas slightly farther away from stars—a more temperate region in the distribution of exoplanets known as the “savanna” — this type of planet is more prevalent. Finally, between this savanna and the desert lies a region called the “Neptunian ridge,” where exo-Neptunes are even more numerous than in the other two regions.

“The complexity of the exo-Neptunian landscape provides offers a unique window onto the processes involved in the formation and evolution of planetary systems. This is what inspired the ambitious ATREIDES scientific cooperation, which is based in particular on a large-scale observation program that we are conducting on the largest European telescopes — the ESO’s VLTs — using the world’s most accurate spectrograph, ESPRESSO,” explains Vincent Bourrier, senior lecturer and researcher in the Department of Astronomy at the UNIGE Faculty of Science, principal investigator of the ATREIDES program, and lead author of the consortium’s first study.

High resolution pictures

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Conquering the “desert”

The ATREIDES program focuses on exo-Neptunes to identify the processes responsible for Neptunian ridge, savanna, and desert, and to derive more general information about the formation and evolution of planets. Scientists plan to use ESPRESSO to observe a large number of Neptunes and to analyse and model data from all planets in a consistent and coherent framework. This systematic approach should enable a real comparison between different planetary systems and a better understanding of the mechanisms that shape this complex Neptunian landscape.

Designed as an open, international community initiative, the ATREIDES collaboration invites all interested astronomers to join this scientific effort, following the example of the University of Warwick. «We are using the NGTS telescopes, an exoplanet observation program based on the transit method, to observe the transits of these Neptunes and thus optimise our use of ESPRESSO/VLT. This allows us to obtain much more accurate measurements and identify processes, such as stellar flares, that could affect the ESPRESSO data,» says Daniel Bayliss, associate professor in the Department of Physics at the University of Warwick.

TOI-421: a “misaligned” orbital architecture

The first system observed and analysed as part of ATREIDES is called TOI-421. It has two planets: a hot Neptune, TOI-421 c, located in the savanna, and a smaller planet closer to the star, TOI-421 b. Astronomers have been able to trace the chaotic history of this system.

One of the hypotheses of the ATREIDES program states that the Neptunian landscape was sculpted by the way these planets migrated from their birthplace to their current orbits. Some planets would migrate slowly and early through the gas disk in which they formed, a process that should produce aligned orbits. Others would be violently propelled into their orbits much later, through a chaotic process called “high-eccentricity migration,” which results in highly misaligned orbits.

One of the key variables in this hypothesis is therefore the alignment between the star’s equatorial plane and the orbital plane of each planet. By measuring this alignment for TOI-421, scientists were able to show that the two planets in the system are highly misaligned, which is very different from our solar system where the planets are aligned and therefore rotate almost in the equatorial plane of our Sun. This points to a turbulent history in the evolution of the TOI-421 system after its formation.

The analysis of TOI-421 is just a taste of what is to come. It provides valuable information to scientists but also, and above all, helps to refine the analysis and modeling tools developed in the ATREIDES collaboration. However, a large number of planetary systems with exo-Neptunes will need to be observed and analyzed with the same rigor before we can outline the evolution and formation of planetary systems.

“A thorough understanding of the mechanisms that shape the Neptunian desert, savanna, and ridge will provide a better understanding of planetary formation as a whole...but it’s a safe bet that the Universe has other surprises in store for us, which will force us to develop new theories,” concludes Vincent Bourrier.