Mystery solved: How the orbits of extrasolar planets became so eccentric

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Except for the fact that we call it home, for centuries astronomers didn't have any particular reason to believe that our solar system was anything special in the universe. But, beginning with the discovery 10 years ago of the first planet outside our solar system, evidence suggests that, as far as planetary systems go, the solar system might be special indeed.

Image: Artist's rendering of the Upsilon Andromedae planetary system, where new research suggests the circular orbit of planets was disrupted by an unseen planet caroming through the solar system. (Image by Sylwia Walerys / Northwestern University)

Instead of the nice circular orbits our nine planets enjoy, most of the

more than 160 extrasolar planets detected in the last decade have eccentric orbits: so elongated that many come in very close to the central star and then go out much further away. In a paper to be published April 14 by the journal Nature, astrophysicists at Northwestern University are the first to report direct observational evidence explaining the violent origins of this surprising planetary behavior.

"Our results show that a simple mechanism, often called 'planet-planet scattering,' a sort of slingshot effect due to the sudden gravitational pull between two planets when they come very near each other, must be responsible for the highly eccentric orbits observed in the Upsilon Andromedae system," said Frederic A. Rasio, associate professor of physics and astronomy. "We believe planet-planet scattering occurred frequently in extrasolar planetary systems, not just this one, resulting from strong instabilities. So while planetary systems around other stars may be common, the kinds of systems that could support life, which, like our solar system, presumably must remain stable over very long time scales, may not be so common."

Verene Lystad, an undergraduate student majoring in physics at Northwestern, and Eric B. Ford, a post-doctoral fellow at the University of California Berkeley and a former student of Rasio's at the Massachusetts Institute of Technology, are members of Rasio's research team and authors on the Nature paper.

The system they focused on, three huge Jupiter-like planets orbiting the central star Upsilon Andromedae, was the first extrasolar multi-planet system ever discovered by Doppler spectroscopy. (In this technique, planets are detected and studied indirectly by measuring the reflex motion they impose on their parent stars.) The inner planet, a "hot Jupiter" so close to the star that its orbit is only a few days, was discovered in 1996, and the two outer planets, with elongated orbits that perturb each other strongly, were discovered in 1999. As a result, the

system now has been well studied for many years and offered the best and most accurate data for the research team's calculations.

"In this system the two outer planets are in a very peculiar orbital configuration, which kept puzzling us for a long time," said Rasio.

To understand this better, Rasio and his collaborators developed a precise computer model of the orbits of the planets as they are today and then evolved them back tens of thousands of years. Their analysis showed that the system evolved over time exactly as would be expected if the initially stable system was suddenly perturbed, with the sudden disturbance affecting the outermost planet only.

They showed that a fourth giant planet, which is no longer in the system, must have come in too close and scuffled with the outer planet in a gravitational feud, eventually kicking the outer planet into the middle one. The fourth planet -- the troublemaker -- was ejected into space. The abrupt kick sent the outer planet into an elliptical orbit, while the middle planet initially remained on a circular orbit. Over time, the outer planet eventually perturbed the middle planet's orbit enough to deform it slowly into an eccentric orbit as well, which is what is seen today, although every 7,000 years or so the middle planet returns gradually to a circular orbit.

"This is what makes the system so peculiar," said Rasio. "Ordinarily, the gravitational coupling between two elliptic orbits would never make one go back to a nearly perfect circle. A circle is very special."

"Originally the main objective of our research was to simulate the Upsilon Andromedae planetary system, essentially in order to determine whether the outer two planets lie in the same plane like the planets in the solar system do," said Lystad, who started working with Rasio when she was a sophomore and did many of the computer integrations as part of

her senior thesis. "We were surprised to find that for many of our simulations it was difficult to tell whether the planets were in the same plane due to the fact that the middle planet's orbit periodically became so very nearly circular. Once we noticed this strange behavior was present in all of our simulations, we recognized it as an earmark of a system that had undergone planet-planet scattering. We realized there was something much more interesting going on than anyone had found before."

Understanding what happened during the formation and evolution of Upsilon Andromedae and other extrasolar planetary systems has major implications for our own.

"In these newly discovered systems things have not remained stable for billions of years," said Rasio. "While they may have formed like the solar system, after a while things went catastrophic. Our solar system, it appears, is rather peculiar in its long-term stability."

Source: Northwestern University