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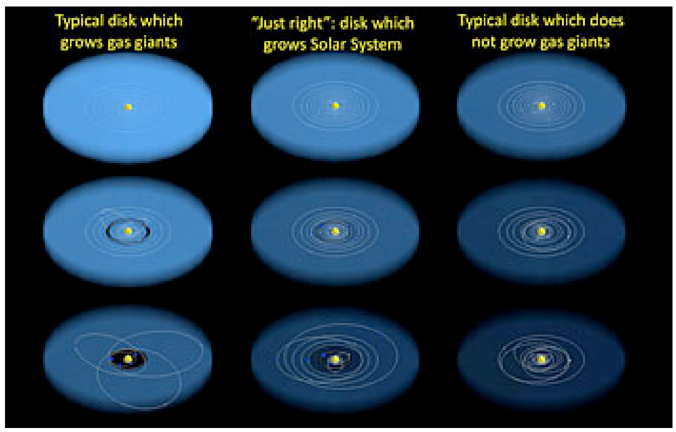
Astronomers Put Solar System In Perspective: Special Indeed

Video: Ed Thommes, a former postdoctoral fellow at Northwestern, discusses surprising solar system findings

Audio: Frederic A. Rasio, professor of physics and astronomy, discusses the solar system and why it is special



Three different key cases of planets forming in a gas disk: the violent version (left); the "barren" version (right); and in between these two, where conditions are just right (center).

EVANSTON, Ill. --- Prevailing theoretical models attempting to explain the formation of the solar system have assumed it to be average in every way. Now a new study by Northwestern University astronomers, using recent data from the 300 exoplanets discovered orbiting other stars, turns that view on its head.

The solar system, it turns out, is pretty special indeed. The study illustrates that if early conditions had been just slightly different, very unpleasant things could have happened -- like planets being thrown into the sun or jettisoned into deep space.

Using large-scale computer simulations, the Northwestern researchers are the first to model the formation of planetary systems from beginning to end, starting with the generic disk of gas and dust that is left behind after the formation of the central star and ending with a full planetary system. Because of computing limitations, earlier models provided only brief glimpses of the process.

The researchers ran more than a hundred simulations, and the results show that the average planetary system's origin was full of violence and drama but that the formation of something like our solar system required conditions to be "just right."

The study, titled "Gas Disks to Gas Giants: Simulating the Birth of Planetary Systems," will be published in the Aug. 8 issue of the journal Science.

Before the discovery in the early 1990s of the first planets outside the solar system, our system's nine (now eight) planets were the only ones known to us. This limited the planetary formation models, and astronomers had no reason to think the solar system unusual.

"But we now know that these other planetary systems don't look like the solar system at all," said Frederic A. Rasio, a theoretical astrophysicist and professor of physics and astronomy in Northwestern's Weinberg College of Arts and Sciences. He is senior author of the Science paper.

"The shapes of the exoplanets' orbits are elongated, not nice and circular. Planets are not where we expect them to be. Many giant planets similar to Jupiter, known as 'hot Jupiters,' are so close to the star they have orbits of mere days. Clearly we needed to start fresh in explaining planetary formation and this greater variety of planets we now see."

Using the wealth of exoplanet data collected during the last 15 years, Rasio and his colleagues have been working to understand planet formation in a much broader sense than was possible previously. Modeling an entire planetary system -- the varied physical phenomena associated with gas, gravity and grains of material, on such a variety of scales -- was a daunting challenge.

The work required very powerful computers. The researchers also had to judiciously decide what information was important and what was not, so as to speed up the calculations. They decided to follow the growth of planets, the gravitational interaction between planets, and the whole planetary system in its entire spatial extent. They chose not to follow the gas disk's fluid dynamics in fine detail, but rather more generally. As a result, they were able to run simulations spanning a planetary system's entire formation.

The simulations suggest that an average planetary system's origin is extremely dramatic. The gas disk that gives birth to the planets also pushes them mercilessly toward the central star, where they crowd together or are engulfed. Among the growing planets, there is cut-throat competition for gas, a chaotic process that produces a rich variety of planet masses.

Also, as the planets approach each other, they frequently lock into dynamical resonances that drive the orbits of all participants to be increasingly elongated. Such a gravitational embrace often results in a slingshot encounter that flings the planets elsewhere in the system; occasionally, one is ejected into deep space. Despite its best efforts to kill its offspring, the gas disk eventually is consumed and dissipates, and a young planetary system emerges.

"Such a turbulent history would seem to leave little room for the sedate solar system, and our simulations show exactly that," said Rasio. "Conditions must be just right for the solar system to emerge."

Too massive a gas disk, for example, and planet formation is an anarchic mess, producing "hot Jupiters" and noncircular orbits galore. Too low-mass a disk, and nothing bigger than Neptune -- an "ice giant" with only a small amount of gas -- will grow.

"We now better understand the process of planet formation and can explain the properties of the strange exoplanets we've observed," said Rasio. "We also know that the solar system is special and understand at some level what makes it special."

"The solar system had to be born under just the right conditions to become this quiet place we see. The vast majority of other planetary systems didn't have these special properties at birth and became something very different."

In addition to Rasio, other authors of the Science paper are Edward W. Thommes, an adjunct professor at the University of Guelph in Ontario, former postdoctoral fellow at Northwestern and lead author, and Soko Matsumura, a postdoctoral fellow at Northwestern.

The computer simulations were performed on a supercomputing cluster operated by Northwestern's Theoretical Astrophysics Group and partially funded by a Major Research Instrumentation grant from the National Science Foundation (NSF). Rasio's research group on exoplanets also is funded by a grant from the NSF Division of Astronomy.