Simulation Tracks Planetary Evolution

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Two British astronomers have constructed a computer simulation that tracks how giant protoplanets tend to form and migrate inward toward their central star.

In an article to be published in the journal Astronomy and Astrophysics, Paul Cresswell and Richard Nelson of Queen Mary University said their model demonstrates the complete planetary formation process, which begins as dust grains coagulate to form planetesimals up to 1 kilometer (0.64 mile) in diameter.

Planetesimals grow into planetary embryos from 100 kilometers (64 miles) to 1,000 kilometers (640 miles) wide, after which they tend to agglomerate in "oligarchic" manner, where a few large bodies dominate the formation process, and accrete the surrounding and much smaller planetesimals.

Eventually, the scientists said, the oligarchs form terrestrial planets near the central star and planetary cores of about 10 Earth masses in the giant-planet region beyond 3 astronomical units – or nearly 300 million miles away from the star.

Cresswell and Nelson acknowledged that their model does not explain the formation of gas giant planets – something previous simulations likewise have not been able to demonstrate – because predicted gravitational interaction between the gaseous disc and the massive planetary cores seems to cause them to move rapidly inward over about 100,000 years, in a process called migration.

They said rapid inward migration of giant protoplanets constitutes a major problem, "because this timescale is much shorter than the time needed for gas to accrete onto the forming giant planets." They said theories still predict giant protoplanets merging into the central star before planets have time to form – which "makes it very difficult to understand how they can form at all."

One possibility: in a small number - about 2 percent - of cases, interaction with stellar gravity can eject inward-migrating giant protoplanets, thereby lengthening their lifetimes. In most cases, however – 98 percent - the protoplanets are trapped in a series of orbital resonances and migrate inward in lockstep, often merging with the central star.

The scientists said in most cases gravitational interactions within a swarm of protoplanets embedded in a disc cannot stop their inward migration, so the theoretical problem requires more investigation.

Other potential solutions include the possibility that several generations of planets form and only the ones that form as the disc dissipates survive the formation process.

This outcome may make it harder to form gas giants, however, because the disc can become depleted of the material from which gas giant planets form. If enough gas lies outside of the planets' orbits, it could allow still-forming planets to accrete new material.

Another solution might be related to the physical properties of the disc. In their simulations, Cresswell and Nelson assumed the disc is smooth and non-turbulent, which might not be the case. Large parts of the disc could be chaotic as a consequence of instabilities caused by magnetic fields – something that could prevent inward migration over long time periods.