Dawn of the Giants

TeraGrid simulations study theories about the origin of planets like Jupiter and Saturn

Visualizations of gas density in a gravitationally unstable disk. Researchers are using simulations like these, facilitated by the TeraGrid to study the effects of an already existing planet’s gravity on the surrounding nebula, and its influence on planet formation. Courtesy: Indiana University
To astronomers, they’re known as the “gas giants”—massive planets like Jupiter and Saturn composed largely of non-solid matter such as hydrogen and helium. Though sophisticated telescopes are discovering even larger gaseous behemoths in solar systems beyond ours, their origins are still shrouded in mystery.

Now, however, a team of astronomy researchers from Indiana University and from other institutions—with the help of TeraGrid resources—is starting to uncover clues that may help settle some questions about gas giant formation. The results may have implications not only for our own solar system, but for other critical astronomical questions.

“Gas giants dominate the structure of planetary systems,” says Richard Durisen, an astronomy professor at Indiana University. “Understanding how gas giants form can help astronomers answer even larger questions such as where in the Universe other Earth-like planets are likely to exist. This, in turn, can guide the search for extraterrestrial life.”

In recent years, more than 450 planets—mostly gas giants—have been discovered around other stars in our galaxy. So, astronomers therefore believe gas giants are relatively common throughout the universe. Astronomers also recognize that the intricate process of planet formation begins in a swirling mass of gas and dust surrounding a nascent star, called a protoplanetary disk. Smaller, rockier planets such as our own planet Earth are created when solids in the disk collide with each other, stick together, and progressively grow into a planet-sized body. The same basic process—known as “core accretion”—is thought to occur with so-called ice giants like Neptune, which are built in the colder regions of the disk.

For a while, astronomers thought gas giants had a similar genesis: start with a rocky core, add gas from the disk, and the result is something like Jupiter. But here, the mystery begins—time gets in the way of this theory. In the standard core accretion picture, it would take many millions of years to form a solid core massive enough to attract a gaseous atmosphere from the disk to grow to the final size of a Jupiter or Saturn. But typically, by then, most of the gas in a protoplanetary disk would have disappeared. Gas giants around other stars can be much more massive than Jupiter, and thus making the premise for core accretion even more problematic. So, Durisen and others have been looking into another possibility.

“Nature clearly found a cosmological short-cut to build at least some of the gas giants,” says Durisen. “We, and others, have been studying such a process where the gas in the protoplanetary disk undergoes a self-gravitating instability and clumps together in a short time, providing the seed around which a Jovian planet can develop quickly.”

Recent simulations and animations by former Indiana Ph.D. student Aaron C. Boley, now a Sagan Fellow at the University of Florida, in collaboration with the Indiana University team led by Durisen and Thomas Steiman-Cameron suggest that this process—known as gravitational instabilities (GIs)—may indeed resolve the mystery surrounding the formation of the gas giants in at least some planetary systems. The simulations show that for sufficiently extended and massive disks, gas giant planets can form via direct collapse caused by gravitational instabilities on a time scale of thousands rather than millions of years.

The team, which also includes co-investigators Scott Michael, Aaron C. Boley and Kai Cai, has used Pople, the Pittsburgh Supercomputer Center’s (PSC) SGI Altix 4700 shared-memory system as well as NCSA’s Cobalt to produce more than 50 terabytes of simulation data over the past two years. Indiana University’s Data Capacitor wide area file system facilitates data transfer between IU and Pittsburgh allowing the team to access their results quickly, as if they were generated locally on a computer in their home lab. The simulations are then analyzed at IU using the Big Red supercomputer.

Not only are the simulations helping astronomers understand the origins of gas giants, they’re also offering insights into why some massive planetary embryos may migrate toward the center of the protoplanetary disk, while others remain on the periphery.

“Preliminary results from my dissertation studies show that GIs can accelerate the inward migration of newly formed gas giants, but that, in regions where the disk is not susceptible to GIs, the inward migration is slowed or halted altogether,” adds Scott Michael, one of Durisen’s current doctoral students.

“This may explain why planets are not always drawn into the central star. In an inactive laminar disk without GIs, migration is expected to cause gas giants forming by core accretion to drift inward rapidly.”

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