Jupiter's formation linked to that of primitive meteorites

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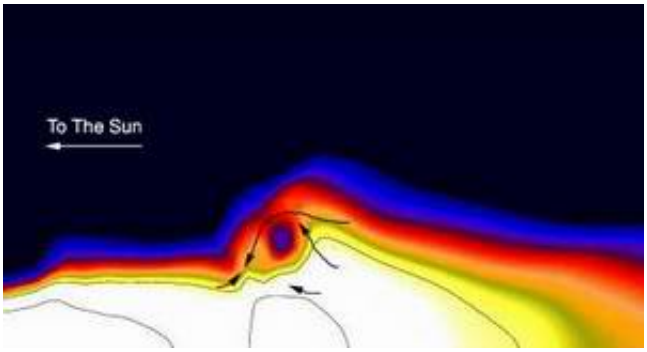

The process that formed the giant planet Jupiter may also have spawned some of the tiniest and oldest members of our solar system -- millimeter-sized spheres called chondrules, the major part of the most primitive meteorites. As witnesses to the early history of the solar system, chondrules may provide important clues to how the planets formed.
A report of this research result, by theorists Alan P. Boss of the Carnegie Institution of Washington and Richard H. Durisen of Indiana University in Bloomington, will be published in the March 10 issue of *Astrophysical Journal Letters*.

Image: Shooting the tube in the solar nebula? This is a side view of a crashing wave of gas using color to represent density. The height of the wave is about half of the Earth-sun distance at its highest point. The gas is

thrown upward as it runs into a spiral arm in the nebula, then curls over and crashes back. The black arrows show the direction of gas flow. Just as with ocean waves, as the wave breaks it forms a tube. In this case, the "tube" is nearly 1,000 Earth diameters wide. (Courtesy of Indiana University)

Chondrules are glassy particles that experienced flash-melting and rapid cooling. They are found in meteorites but not in terrestrial rocks, and they are among the first solids that formed in the cloud of gas and dust called the solar nebula that swirled around the young sun and eventually gave rise to the solar system.

"One of the great puzzles of solar system origin has been that the bulk of primitive meteorites, which come from the asteroid belt, consists of chondrules," Durisen said. "The texture of chondrules shows that they were flash-melted and rapidly cooled. Most of the solid material in the inner solar nebula apparently experienced these mysterious energetic melting events."

"Understanding what formed the chondrules has been one of the biggest problems in the field for over a century," Boss said. "Scientists realized several years ago that a shock wave was probably responsible for generating the heat that cooked these meteoritic components. But no one could explain convincingly how the shock front was generated in the solar nebula some 4.6 billion years ago. These latest calculations show how a shock front could have formed as a result of spiral arms roiling the solar nebula at Jupiter's orbit. The shock front extended into the inner solar nebula, where the compressed gas and radiation heated dust particles as they struck the shock front at 20,000 miles per hour, thereby creating chondrules."

Independent simulations by Boss and by Durisen's research group show that spiral waves in a gravitationally unstable disk of gas and dust at or

beyond Jupiter's distance from the sun (five times the Earth-sun distance) could have produced shock waves at half that distance in the inner solar system -- especially in the asteroid belt -- that were capable of melting dust clumps to form chondrules.

"A striking consequence of these waves is revealed in our simulations at Indiana University," Durisen said. "A considerable amount of gas and dust is kicked upward by the shock-heating. We see gigantic curling and breaking waves arc over the surface of the solar nebula, like waves crashing on a beach. These waves are huge, comparable in size to a substantial fraction of the distance from Earth to the sun."

IU graduate student Aaron C. Boley, who works with Durisen on chondrule-producing spiral waves, said, "The crashing waves produce strong shocks, mix chondrules and their precursors around the nebula like shells in the surf, and produce turbulence that may have assisted in compacting newly formed chondrules into larger solid bodies."

An animation of a crashing wave of gas in the solar nebula is available at westworld.astro.indiana.edu/movies.html ("Shock waves").

"This calculation has probably removed the last obstacle to acceptance of how chondrules were melted," said theorist Steven J. Desch of Arizona State University, who showed several years ago that shock waves could do the job. "Meteoriticists have recognized that the ways chondrules are melted by shocks are consistent with everything we know about chondrules. But without a proven source of shocks, they have remained mostly unconvinced about how chondrules were melted. The work of Boss and Durisen demonstrates that our early solar nebula experienced the right types of shocks, at the right times, and at the right places in the nebula to melt chondrules. I think for many meteoriticists, this closes the deal. With nebular shocks identified as the culprit, we can finally begin to understand what the chondrules are telling us about the earliest stages

of our solar system's evolution."

Although Durisen's group and Boss have some disagreements about exactly how gas giant planets form, they agree that, in order to make Jupiter, the solar nebula had to have been at least marginally gravitationally unstable, so that it would have developed spiral arms at an early stage and resembled a spiral galaxy. Chondrules would have formed at the very earliest times and would have continued to form for a few million years, until the solar nebula disappeared. Late-forming chondrules in meteorites are thus the last souvenirs of the process that formed our planetary system.

Boss's research is supported in part by the NASA Planetary Geology and Geophysics Program and the NASA Origins of Solar Systems Program. The calculations were performed on the Carnegie Alpha Cluster, the purchase of which was supported in part by the National Science Foundation's Major Research Instrumentation Program, and on Indiana University's IBM SP supercomputer cluster. Durisen's research also was supported in part by the NASA Origins of Solar Systems Program.

Source: Indiana University