Making stars: Studies show how cosmic dust and gas shape galaxy evolution

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This image from a supercomputer simulation shows galaxy formation occurring early in the history of the universe. The simulation was performed by Fermilab's Nickolay Gnedin and the University of Chicago’s Andrey Kravtsov at the National Center for Supercomputing Applications in Urbana-Champaign. Yellow dots are young stars. Blue fog shows the neutral gas. The red surface indicates molecular gas. The starry background has been added for aesthetic effect. Credit: Nick Gnedin

Astronomers find cosmic dust annoying when it blocks their view of the heavens, but without it the universe would be devoid of stars. Cosmic dust is the indispensable ingredient for making stars and for understanding how primordial diffuse gas clouds assemble themselves into full-blown galaxies.

"Formation of galaxies is one of the biggest remaining questions in astrophysics," said Andrey Kravtsov, associate professor in astronomy & astrophysics at the University of Chicago.

Astrophysicists are moving closer to answering that question, thanks to a combination of new observations and supercomputer simulations, including those conducted by Kravtsov and Nick Gnedin, a physicist at Fermi National Accelerator Laboratory.

Gnedin and Kravtsov published new results based on their simulations in the May 1, 2010 issue of The Astrophysical Journal, explaining why stars formed more slowly in the early history of the universe than they did much later. The paper quickly came to the attention of Robert C. Kennicutt Jr., director of the University of Cambridge's Institute of Astronomy and co-discoverer of one of the key observational findings about star formation in galaxies, known as the Kennicutt-Schmidt relation.

In the June 3, 2010 issue of Nature, Kennicutt noted that the recent spate of observations and theoretical simulations bodes well for the future of astrophysics. In their *Astrophysical Journal* paper, Kennicutt wrote, "Gnedin and Kravtsov take a significant step in unifying these observations and simulations, and provide a prime illustration of the recent progress in the subject as a whole."

Star-formation law

Kennicutt's star-formation law relates the amount of gas in galaxies in a given area to the rate at which it turns into stars over the same area. The relation has been quite useful when applied to galaxies observed late in the history of the universe, but recent observations by Arthur Wolfe of the University of Californa, San Diego, and Hsiao-Wen Chen, assistant professor in astronomy and astrophysics at UChicago, indicate that the relation fails for galaxies observed during the first two billion years following the big bang.

Gnedin and Kravtsov's work successfully explains why. "What it shows is that at early stages of evolution, galaxies were much less efficient in converting their gas into stars," Kravtsov said.

Stellar evolution leads to increasing abundance of dust, as stars produce elements heavier than helium, including carbon, oxygen, and iron, which are key elements in dust particles. "Early on, galaxies didn't have enough time to produce a lot of dust, and without dust it's very difficult to form these stellar nurseries," Kravtsov said. "They don't convert the gas as efficiently as galaxies today, which are already quite dusty."

The star-formation process begins when interstellar gas clouds become increasingly dense. At some point the hydrogen and helium atoms start combining to form molecules in certain cold regions of these clouds. A hydrogen molecule forms when two hydrogen atoms join. They do so inefficiently in empty space, but find each other more readily on the surface of a cosmic dust particle.

"The biggest particles of cosmic dust are like the smallest particles of sand on good beaches in Hawaii," Gnedin said.

These hydrogen molecules are fragile and easily destroyed by the intense ultraviolet light emitted from massive young stars. But in some galactic regions dark clouds, so-called because of the dust they contain, form a protective layer that protects the hydrogen molecules from the destructive light of other stars.

Stellar nurseries

"I like to think about stars as being very bad parents, because they provide a bad environment for the next generation," Gnedin joked. The dust therefore provides a protective environment for stellar nurseries, Kravtsov noted.

"There is a simple connection between the presence of dust in this diffuse gas and its ability to form stars, and that's something that we modeled for the first time in these galaxy-formation simulations," Kravtsov said. "It's very plausible, but we don't know for sure that that's exactly what's happening."

The Gnedin-Kravtsov model also provides a natural explanation for why spiral galaxies predominately fill the sky today, and why small galaxies form stars slowly and inefficiently.

"We usually see very thin disks, and those types of systems are very difficult to form in galaxy-formation simulations," Kravtsov said. That's because astrophysicists have assumed that galaxies formed gradually through a series of collisions. The problem: simulations show that when galaxies merge, they form spheroidal structures that look more elliptical than spiral.

But early in the history of the universe, cosmic gas clouds were inefficient at making stars, so they collided before star formation occurred. "Those types of mergers can create a thin disk," Kravtsov said.

As for small galaxies, their lack of dust production could account for their inefficient star formation. "All of these separate pieces of evidence that existed somehow all fell into one place," Gnedin observed. "That's what I like as a physicist because physics, in general, is an attempt to understand unifying principles behind different phenomena."

More work remains to be done, however, with input from newly arrived postdoctoral fellows at UChicago and more simulations to be performed on even more powerful supercomputers. "That's the next step," Gnedin said.

Provided by University of Chicago

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