How supermassive black holes came into existence shortly after the Big Bang

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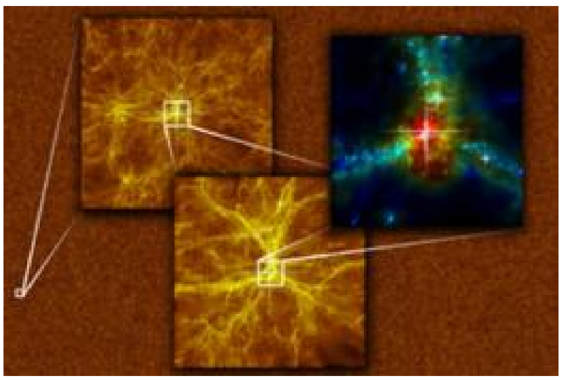

Pictured is the large scale cosmological mass distribution in the the MassiveBlack simulation. The projected gas density over the whole volume ("unwrapped" into 2-D) is shown in the background image. The two images on top show two close-ups of the regions where the most massive black hole is formed. The black hole is at the center of the image and is being fed by cold gas streams. Credit: Yu Feng

(PhysOrg.com) -- Researchers at Carnegie Mellon University's Bruce and Astrid McWilliams Center for Cosmology have discovered what caused the rapid growth of early supermassive black holes — a steady diet of cold, fast food.

Computer simulations, completed using supercomputers at the National Institute for Computational Sciences and the Pittsburgh Supercomputing Center, and viewed using CMU's GigaPan technology, show that thin streams of cold gas flow uncontrolled into the center of the first black holes, causing them to grow faster than anything else in the universe. The findings will be published in the *Astrophysical Journal Letters*.

In the early days of the universe, a mere 700 to 800 million years after the Big Bang, most things were small. The first stars and galaxies were just beginning to form and grow in isolated parts of the universe. According to astrophysical theory, black holes found during this era also should be small in proportion with the galaxies in which they reside. However, recent observations from the Sloan Digital Sky Survey (SDSS) have shown that this isn't the case — enormous supermassive black holes existed as early as 700 million years after the Big Bang.

"The Sloan Digital Sky Survey found supermassive black holes at less than 1 billion years. They were the same size as today's most massive black holes, which are 13.6 billion years old," said Tiziana Di Matteo, associate professor of physics at Carnegie Mellon. "It was a puzzle. Why do some black holes form so early when it takes the whole age of the universe for others to reach the same mass?"

Supermassive black holes are the largest black holes, with masses billions of times larger than that of the sun. Typical black holes have masses only up to 30 times larger than the sun's. Astrophysicists have determined that supermassive black holes can form when two galaxies collide and their two black holes merge into one. These galaxy collisions happened in the later years of the universe, but not in the early days. In the first few millions of years after the Big Bang, galaxies were too few and too far apart to merge.

"If you write the equations for how galaxies and black holes form, it doesn't seem possible that these huge masses could form that early," said Rupert Croft, an associate professor of physics at Carnegie Mellon. "But we look to the sky and there they are."

To find out exactly how these supermassive black holes came to be, Di Matteo, Croft and Carnegie Mellon post-doctoral researcher Nishikanta Khandai created the largest cosmological simulation to date. Called MassiveBlack, the simulation focused on recreating the first billion years after the Big Bang.

"This simulation is truly gigantic. It's the largest in terms of the level of physics and the actual volume. We did that because we were interested in looking at rare things in the universe, like the first black holes. Because they are so rare, you need to search over a large volume of space," Di Matteo said.

They began by running the simulation under conditions set under the standard model of cosmology — the accepted theories and laws of modern day physics governing the formation and growth of the universe.

"We didn't put anything crazy in. There's no magic physics, no extra stuff. It's the same physics that forms galaxies in simulations of the later universe," Croft said. "But magically, these early quasars, just as had been observed, appear. We didn't know they were going to show up. It was amazing to measure their masses and go 'Wow! These are the exact right size and show up exactly at the right point in time.' It's a success story for the modern theory of cosmology."

Their simulation data was incorporated into a new technology developed by Carnegie Mellon computer scientists called GigaPan Time Machine. The technology allowed the researchers to view their simulation as if it was a video with extremely high resolution. This enabled them to easily pan across the simulated universe as it formed and move back and forth through time as necessary. They could then zoom in on events that looked interesting, viewing them in greater detail than could be seen using a telescope.

As they zoomed in to the creation of the first supermassive black holes, they saw something unexpected. Normally, when cold gas flows toward a black hole it collides with other gas in the surrounding galaxy. This causes the cold gas to heat up and then cool back down before it enters the black hole. This process, called shock heating, would stop black holes in the early universe from growing fast enough to reach the masses we see. Instead, Di Matteo and Croft saw in their simulation thin streams of cold dense gas flowing along the filaments that give structure to the universe and straight into the center of the black holes at breakneck speed, making for cold, fast food for the black holes. This uncontrolled consumption caused the black holes to grow exponentially faster than the galaxies in which they reside.

And since a galaxy forms when a black hole forms, the results could also shed light on how the first galaxies formed, giving more clues to how the universe came to be. Di Matteo and Croft hope to push the limits of their simulation a bit more, creating even bigger simulations that cover more space and time.

Provided by Carnegie Mellon University