Turbulence responsible for black holes' balancing act

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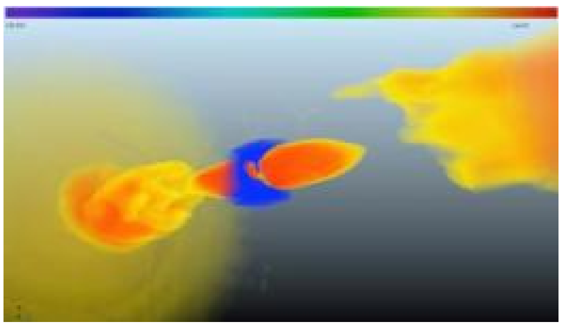

This is a snapshot of gas temperatures in a three-dimensional computer simulation of a cool-core cluster. The blue ring shows the cool gas accreting onto the central black hole disk; the red and yellow jets show the hot gas ejected by this disk. Older bubbles from an earlier outburst are visible on the far left and right sides of the image. Turbulence generated by the jets mixes the hot and cool material together, which stabilizes further accretion and allows the cluster to perform its remarkable balancing act. Credit: E. Scannapieco/ M. Brueggen / ASU Fulton High Performance Computing Initiative

We live in a hierarchical Universe where small structures join into larger ones. Earth is a planet in our Solar System, the Solar System resides in the Milky Way Galaxy, and galaxies combine into groups and clusters. Clusters are the largest structures in the Universe, but sadly our knowledge of them is not proportional to their size. Researchers have long known that the gas in the centers of some galaxy clusters is rapidly cooling and condensing, but were puzzled why this condensed gas did not form into stars. Until recently, no model existed that successfully explained how this was possible.

Evan Scannapieco, a theoretical astrophysicist, has spent much of his career studying the evolution of galaxies and clusters. "There are two types of clusters: cool-core clusters and non-cool core clusters," he explains. "Non-cool core clusters haven't been around long enough to cool, whereas cool-core clusters are rapidly cooling, although by our standards they are still very hot."

Scannapieco is an assistant professor in Arizona State University's School of Earth and Space Exploration in the College of Liberal Arts and Sciences.

X-ray telescopes have revolutionized our understanding of the activity occurring within cool-core clusters. Although these clusters can contain hundreds or even thousands of galaxies, they are mostly made up of a diffuse, but very hot gas known as the intracluster medium. This intergalactic gas is only visible to X-ray telescopes, which are able to map out its temperature and structure. These observations show that the diffuse gas is rapidly cooling into the centers of cool-core clusters.

At the core of each of these clusters is a black hole, billions of times more massive than the Sun. Some of the cooling medium makes its way down to a dense disk surrounding this black hole, some of it goes into the black hole itself, and some of it is shot outward. X-ray images clearly show jet-like bursts of ejected material, which occur in regular cycles.

But why were these outbursts so regular, and why did the cooling gas never drop to colder temperatures that lead to the formation of stars? Some unknown mechanism was creating an impressive balancing act.

"It looked like the jets coming from black holes were somehow responsible for stopping the cooling," says Scannapieco, "but until now no one was able to determine exactly how."

Scannapieco and Marcus Brüggen, a professor at Jacobs University in Bremen, Germany, used the powerful supercomputers at ASU to develop their own three-dimensional simulation of the galaxy cluster surrounding one of the Universe's biggest black holes. By adapting an approach developed by Guy Dimonte at Los Alamos National Laboratory and Robert Tipton at Lawrence Livermore National Laboratory, Scannapieco and Brüggen added the component of turbulence to the simulations, which was never accounted for in the past.

That was the key ingredient.

Turbulence works in partnership with the black hole to maintain the balance. Without the turbulence, the jets coming from around black hole would grow stronger and stronger, and the gas would cool catastrophically into a swarm of new stars. When turbulence is accounted for, the black hole not only balances the cooling, but goes through regular cycles of activity.

"When you have turbulent flow, you have random motions on all scales," explains Brüggen. "Each jet of material ejected from the disk creates turbulence that mixes everything together."

Scannapieco and Brüggen's results, to be published in the journal *Monthly Notices of the Royal Astronomical Society*, reveal that turbulence acts to effectively mix the heated region with its surroundings so that the cool gas can't make it down to the black hole, thus preventing star formation.

Every time some cool gas reaches the black hole, it is shot out in a jet. This generates turbulence that mixes the hot gas with the cold gas. This mixture becomes so hot that it doesn't accrete onto the black hole. The jet stops and there is nothing to drive the turbulence so it fades away. At that point, the hot gas no longer mixes with the cold gas, so the center of the cluster cools, and more gas makes its way down to the black hole.

Before long, another jet forms and the gas is once again mixed together.

"We improved our simulations so that they could capture those tiny turbulent motions," explains Scannapieco. "Even though we can't see them, we can estimate what they would do. The time it takes for the turbulence to decay away is exactly the same amount of time observed between the outbursts."

Source: Arizona State University (news : web)