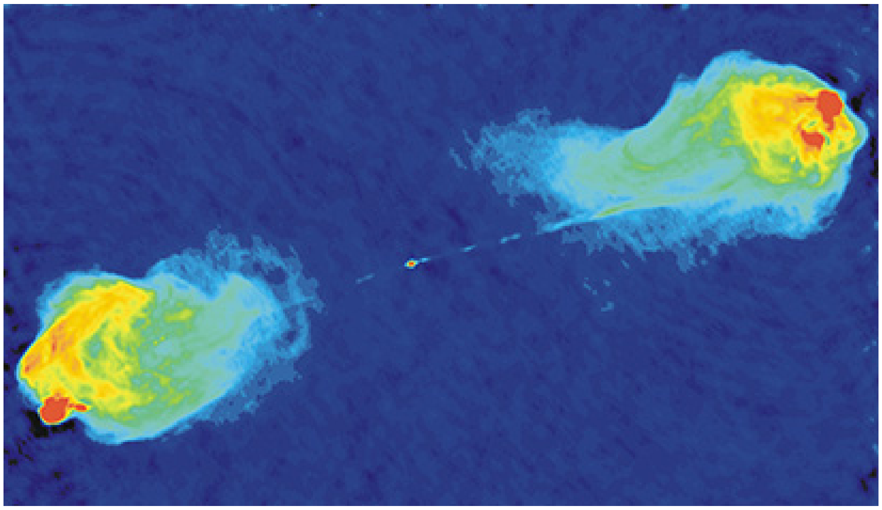
How black hole jets punch out of their galaxies

June 17 2016, by Robert Sanders



This false-color image of the radio jet and lobes in the very bright radio galaxy Cygnus A is an example of the powerful jets that can be produced by supermassive black holes at the cores of large galaxies. Credit: R. Perley, C. Carilli & J. Dreher

A simulation of the powerful jets generated by supermassive black holes at the centers of the largest galaxies explains why some burst forth as bright beacons visible across the universe, while others fall apart and never pierce the halo of the galaxy.

About 10 percent of all galaxies with active nuclei – all presumed to have supermassive black holes within the central bulge – are observed to have jets of gas spurting in opposite directions from the core. The hot ionized gas is propelled by the twisting magnetic fields of the rotating black hole, which can be as large as several billion suns.

A 40-year-old puzzle was why some jets are hefty and punch out of the galaxy into intergalactic space, while others are narrow and often fizzle out before reaching the edge of the galaxy. The answer could shed light on how galaxies and their central black holes evolve, since aborted jets are thought to roil the galaxy and slow star formation, while also slowing the infall of gas that has been feeding the voracious black hole. The model could also help astronomers understand other types of jets, such as those produced by individual stars, which we see as gamma-ray bursts or pulsars.

"Whereas it was rather easy to reproduce the stable jets in simulations, it turned out to be an extreme challenge to explain what causes the jets to fall apart," said University of California, Berkeley theoretical astrophysicist Alexander Tchekhovskoy, a NASA Einstein postdoctoral fellow, who led the project. "To explain why some jets are unstable, researchers had to resort to explanations such as red giant stars in the jets' path loading the jets with too much gas and making them heavy and unstable so that the jets fall apart."

By taking into account the magnetic fields that generate these jets, Tchekhovskoy and colleague Omer Bromberg, a former Lyman Spitzer Jr. postdoctoral fellow at Princeton University, discovered that magnetic instabilities in the jet determine their fate. If the jet is not powerful enough to penetrate the surrounding gas, the jet becomes narrow or collimated, a shape prone to kinking and breaking. When this happens, the hot ionized gas funneled through the magnetic field spews into the galaxy, inflating a hot bubble of gas that generally heats up the galaxy.

Powerful jets, however, are broader and able to punch through the surrounding gas into the intergalactic medium. The determining factors are the power of the jet and how quickly the gas density drops off with distance, typically dependent on the mass and radius of the galaxy core.

The simulation, which agrees well with observations, explains what has become known as the Fanaroff-Riley morphological dichotomy of jets, first pointed out by Bernie Fanaroff of South Africa and Julia Riley of the U.K. in 1974.

"We have shown that a jet can fall apart without any external perturbation, just because of the physics of the jet," Tchekhovskoy said. He and Bromberg, who is currently at the Hebrew University of Jerusalem in Israel, will publish their simulations on June 17 in the journal *Monthly Notices of the Royal Astronomical Society*, a publication of Oxford University Press.

Bendable drills

The supermassive black hole in the bulging center of these massive galaxies is like a pitted olive spinning around an axle through the hole, Tchekhovskoy said. If you thread a strand of spaghetti through the hole, representing a magnetic field, then the spinning olive will coil the spaghetti like a spring. The spinning, coiled magnetic fields act like a flexible drill trying to penetrate the surrounding gas.

The simulation, based solely on magnetic field interactions with ionized gas particles, shows that if the jet is not powerful enough to punch a hole through the surrounding gas, the magnetic drill bends and, due to the magnetic kink instability, breaks. An example of this type of jet can be seen in the galaxy M87, one of the closest such jets to Earth at a distance of about 50 million light-years, and has a central black hole equal to about 6 billion suns.

"If I were to jump on top of a jet and fly with it, I would see the jet start to wiggle around because of a kink instability in the magnetic field," Tchekhovskoy said."If this wiggling grows faster than it takes the gas to reach the tip, then the jet will fall apart. If the instability grows slower than it takes for gas to go from the base to the tip of the jet, then the jet will stay stable."

The jet in the galaxy Cygnus A, located about 600 million light-years from Earth, is an example of powerful jets punching through into intergalactic space.

Tchekhovskoy argues that the unstable jets contribute to what is called black hole feedback, that is, a reaction from the material around the black hole that tends to slow its intake of gas and thus its growth. Unstable jets deposit a lot of energy within the galaxy that heats up the gas and prevents it from falling into the black hole. Jets and other processes effectively keep the sizes of supermassive black holes below about 10 billion solar masses, though UC Berkeley astronomers recently found black holes with masses near 21 billion solar masses.

Presumably these jets start and stop, lasting perhaps 10-100 million years, as suggested by images of some galaxies showing more than one jet, one of them old and tattered. Evidently, black holes go through binging cycles, interrupted in part by the occasional unstable jet that essentialy takes away their food.

The simulations were run on the Savio computer at UC Berkeley, Darter at the National Institute for Computational Sciences at the University of Tennesee, Knoxville, and Stampede, Maverick and Ranch computers at the Texas Advanced Computing Center at the University of Texas at Austin. The entire simulation took about 500 hours on 2,000 computer cores, the equivalent of 1 million hours on a standard laptop.

The researchers are improving their simulation to incorporate the smaller effects of gravity, buoyancy and the thermal pressure of the interstellar and intergalactic media.

More information: C. J. Clarke et al. A self-similar solution for thermal disc winds, *Monthly Notices of the Royal Astronomical Society* (2016). DOI: 10.1093/mnras/stw1178

Provided by University of California - Berkeley

Citation: How black hole jets punch out of their galaxies (2016, June 17) retrieved 19 April 2024 from https://phys.org/news/2016-06-black-hole-jets-galaxies.html