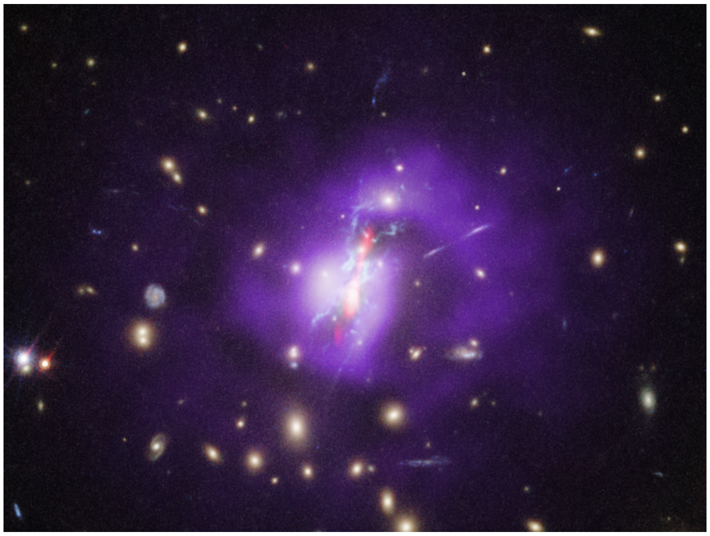
How Black Holes Help Stars Form

In the Phoenix galaxy cluster, the presence of a black hole allows gas to cool, collapse, and form stars at an extremely high rate, in contrast with other clusters where the black hole heats the gas and slows star formation.

By **Elizabeth Fernandez**

A black hole that resides within the central region of a massive cluster of galaxies can both enhance and diminish the rate of the star formation in those galaxies. How these competing forces play out, however, is a bit of a mystery. Now a team of astronomers has gained insight into this balance by observing the Phoenix galaxy cluster [**1**]. This cluster, which is 5.7 billion light years away and in the constellation Phoenix, is forming stars much faster than any other galaxy cluster. This star growth is caused by the presence of a massive amount of cooling gas, imaged in detail for the first time by the team. The researchers found that the process by which massive black holes can heat gas in their surroundings does not appear to dominate in the Phoenix cluster. Instead, gas is allowed to cool, collapse, and form stars at an extremely high rate. Their observations will help in understanding how hot gas behaves in the extreme environments in the center of large galaxy clusters.



Composite image of the core region of the Phoenix galaxy cluster.
Credit: NASA; CXC; NRAO; ESA; M. McDonald/MIT

Regions of dense gas are normally expected to cool over time. As that happens the gas can lose enough energy to condense into stars. Yet gas cooling is limited at the centers of some massive galaxy clusters, with only about 1 to 10 times the mass of our Sun being converted into stars per year. This low cooling rate in galaxy clusters is dubbed the cooling-flow problem.

Researchers understand the cooling-flow problem, says Roland Timmerman, a radio astronomer at Durham University, UK, who was not involved in the Phoenix cluster study. The gas gets heated by extremely violent accretion by the black hole, offsetting any cooling the gas experiences. This energy typically manifests as jets, which pump mechanical energy into gas and limit star formation within the center regions of galaxy clusters.

But for every rule there are exceptions, of which the Phoenix cluster appears to be one. This cluster is the most rapidly cooling galaxy cluster known, has the highest star-formation rate within its central galaxy, and has the highest x-ray luminosity. The team, led by Michael Reefe of the MIT Kavli Institute for Astrophysics and Space Research, used the JWST to observe the central part of this galaxy using an emission line called [NEVI], which traces gas as it cools past 300,000 K. This emission line is in a wavelength region where astronomers can obtain high-resolution spectra without obfuscation from dust, a problem that can hinder x-ray observations or observations of other emission lines. The researchers analyzed images taken of the central part of the cluster and of two cooling clouds near its nucleus. The observations indicate that around 5000 to 23,000 solar masses of gas are cooling per year, compared to the 1 to 10 solar masses of regular clusters.

This study is the first to map the positions of gas at a temperature of $\sim$300,000 K on large scales and with high resolution, Reefe says. We have “opened the pathway for future studies to begin to understand the morphology of this gas and how it relates to the bigger picture of cooling in galaxy clusters,” he says. For example, the team observed that this massive cooling flow led to a starburst—a massive amount of stars forming in a localized area. “In that sense, the Phoenix cluster is one of the best experiments the Universe has given us because it’s a showcase of what happens when you turn up one parameter (the cooling rate) to the maximum,” Reefe says. It is truly a unique observation, he adds.

The Phoenix cluster is very unusual, Timmerman says. “The central supermassive black hole apparently does not emit enough energy to begin offsetting the cooling [unlike what we see in other galaxy clusters].” Understanding why could help researchers understand the balance between heating and cooling of gas in extreme environments. For example, it may be that the central black hole in the Phoenix cluster is undermassive for the cluster’s size. As it tries to “catch up” in growth, it undergoes a rapid accretion rate. This higher accretion rate can lead to more energy going into radiation, or radiative feedback. “The fact that a significant fraction of the black hole’s energy output is going into its radiative feedback means there is less energy going into the particle jets,” Reefe explains. Radiation is less effective at heating gas than jets, thus the gas cools more rapidly to form stars.

Reefe says that this period of cooling, however, will most likely be short-lived. The researchers predict the cooling phase will last only until the region reaches a pressure equilibrium with its surroundings, which they expect to take about 10 million years. However, even a brief cooling phase cannot explain why seeing a cooling flow is so rare, Reefe says. If every cluster experienced such a phase, astronomers would see evidence of rapid periods of intense star formation in other galaxy clusters as well. “That is something that we don’t see, so it’s a hint that this rapid cooling phase may be more of a unique feature of the Phoenix cluster rather than a ubiquitous phase,” Reefe says.

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REFERENCES

1. M. Reefe *et al.*, “Directly imaging the cooling flow in the Phoenix cluster,” **Nature 638, 360 (2025).**