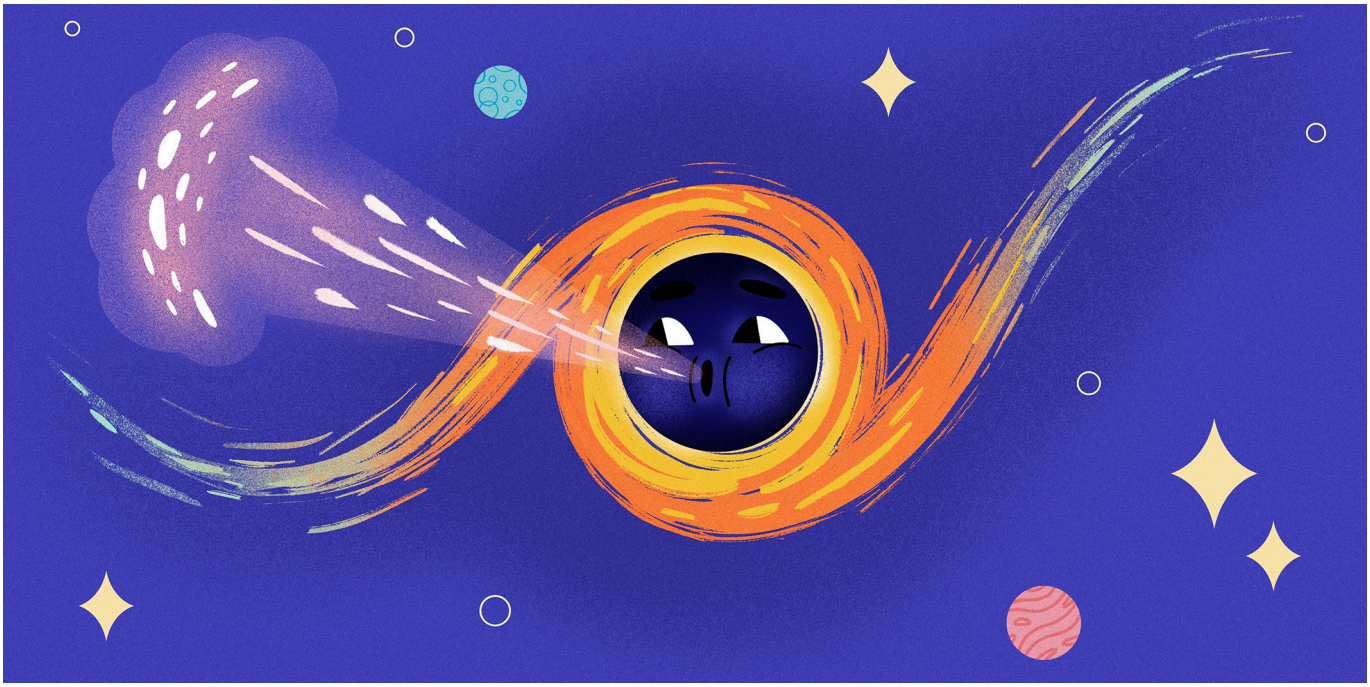
frontiers | Frontiers for Young Minds

ASTRONOMY AND PHYSICS
Published: 27 June 2023
doi: 10.3389/frym.2023.1032977



HOW SUPERMASSIVE BLACK HOLES SHAPE GALAXIES

Ying-He Celeste Lü * ***and Letizia Diamante*** *

University of Cambridge, Cambridge, United Kingdom

YOUNG REVIEWERS:

CLARA

AGE: 10

CONRAD

AGE: 12

We often think of black holes as mysterious objects that swallow everything that passes by them—from dust to entire stars. In reality, black holes "eat" in a messy way, while spinning around super quickly. They do not swallow their whole "meal" (such as interstellar gas and dust) in a mouthful. Part of it rotates around the spinning black hole, like a merry-go-round, and is eventually thrown outward as very bright, energetic streams of particles called jets. Supermassive black holes the centers of galaxies can create jets that travel very far and affect the birth of baby stars! In this article, we will describe some of the things we know about black holes, including how astronomers found out about black hole jets using powerful telescopes. We will also mention some of the things we still do not understand about black holes and their jets.

BLACK HOLE

A place in space where gravity is so strong that even light cannot get out. A supermassive black hole has a mass over 100, 000 times the mass of the Sun.

THE SECRET LIFE OF SUPERMASSIVE BLACK HOLES

If you like astronomy, you have probably heard of **black holes**—the beasts of the universe. Better stay very far away from them because

they devour everything near them in one bite, do they not? Black holes have the reputation of being very hungry objects. In reality, rather than evil beasts, astronomers consider black holes to be the unsung heroes of the **galaxies**—heroes that eat in a messy way. Black holes are very mysterious, but one thing is sure: without them, our universe would not look the same!

GALAXY

A huge collection of gas, dust, stars, planets, and space objects held together by gravity. Our Earth and Sun belong to the Milky Way galaxy.

Take the supermassive black holes in the centers of galaxies (Figure 1). As you can tell from the name, they are very, very massive—they can grow to be billions of times the mass of the Sun! There are many interesting and puzzling questions about these odd heroes of the galaxies. For example, how can such powerful objects exist in the first place?

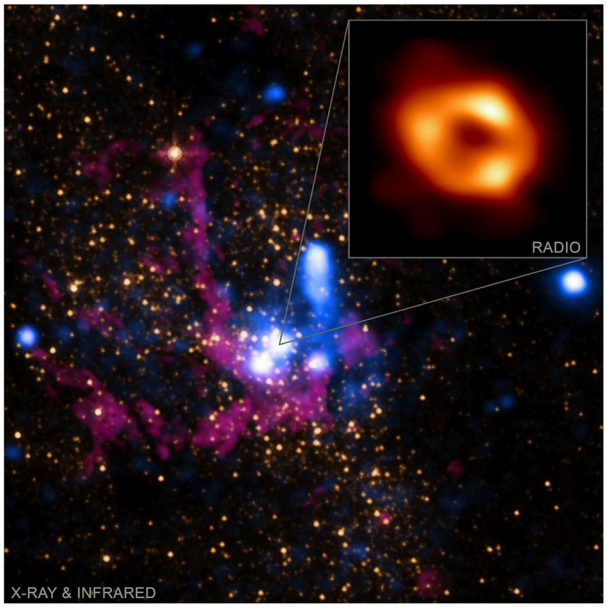


Figure 1

Photo of Sagittarius A*, the supermassive black hole in the middle of our galaxy, the Milky Way. All the red, blue, and yellow dots or clouds are stars or gas clouds. The photo was unveiled in May 2022 [Credit: X-ray by NASA/CXC/SAO; Infrared by NASA/HST/STScI. Inset: Radio (EHT Collaboration) https://www.flickr.com/photos/nasamarshall/52070907639/].

Nowadays, scientists think that supermassive black holes formed in the early days of the Universe, when many smaller black holes merged. The bigger the black holes became, the bigger their appetites. However, it is not yet fully clear the exact roles that supermassive black holes play in the formation and structure of galaxies—but it does not seem a mere coincidence that they usually lie in a galaxy's center (rather than on the edge), and that the more massive the black hole is, the faster the stars move around it. Over the last few decades, astronomers have accumulated a fair amount of knowledge that can shed light on some of the mysteries of black holes' messy eating behavior [1].

WHEN BLACK HOLES THROW UP

Photos of supermassive black holes often show a red "doughnut"—a ring of light (Figure 2) [2]. What is this doughnut made of? To explain

this, we must look at a black hole's diet. Massive things have a huge **gravitational force**, which means they attract other, less massive objects—just as the Earth pulls you back down when you jump. For this reason, supermassive black holes attract and eat up gases, stars, and smaller black holes.

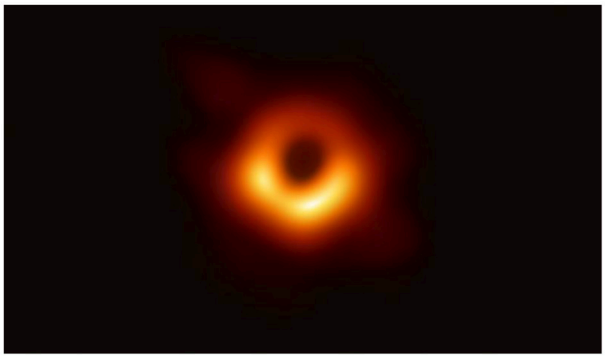


Figure 2

GRAVITATIONAL FORCE

A force that causes objects to attract each other. Gravity keeps planets orbiting the sun, and the moon orbiting the Earth. It also makes objects fall inside black holes.

Figure 2

This is the first photo of a black hole ever taken. The doughnut-shaped accretion disk surrounds M87*, the black hole located in the center of galaxy M87. This photo was published in 2019 (Credit: Event Horizon Telescope collaboration et al.; https://www.nasa.gov/mission_pages/chandra/news/black-hole-image-makes-history).

However, they do not swallow everything around them. Gas particles and clouds that do not get close enough to the black hole are not captured, but they rotate around the supermassive black hole because of the black hole's gravity—like the Earth rotates around the Sun because the Sun is more massive than the Earth. As a result, instead of falling inside the black hole directly, these gas particles run around the black hole, like they are on a merry-go-round, and they serve as the black hole's food supply. It is actually a bit messier than a standard merry-go-round, because the gas particles hit each other while rotating around the black hole [3]. Imagine a merry-go-round combined with a bumper car ride!

ACCRETION DISK

A disk of gas and space dust surrounding a black hole, due to gravity. Accretion means growing by accumulation. In photos, it looks like a doughnut-shaped ring of bright red light.

The closer the gas particles get to the black hole, the more energy they lose in the forms of heat and light. The result is a super bright disk structure that surrounds the black hole and looks like a doughnut. Astronomers call this an **accretion disk**—*accretion* means growing by accumulation. Supermassive black holes are the largest objects in the galaxies, and their accretion disks can be trillions of times brighter than the Sun. In fact, astronomers saw the radiation from these "doughnuts" as far back as 100 years ago, long before we could take pictures of supermassive black holes themselves!

MAGNETIC FIELD

A region around a magnetic material or a moving electric charge where other magnetic objects feel the attraction or repulsion.

INTERSTELLAR

Between the stars in a galaxy.

At this point, you might be thinking, "That is so cool!" However, supermassive black holes, gas particles, and gravity are only some of the players in this messy drama. There is one additional character that we have not yet mentioned: **magnetic fields**. **Interstellar** gas particles with positive or negative charges carry weak magnetic fields. However, when gas particles get really hot in accretion disks, they can form strong magnetic fields that influence the movement of new gas particles that approach the disk or the black hole. These

approaching gas particles experience a tug-of-war between the black hole's gravity and the disk's magnetic field, pulling them in opposite directions—while gravity pulls the gas particles toward the black hole, the magnetic field forces them outwards in a spiral path. If the magnetic force is stronger than the gravitational force, the gas particles fly *away* from the black hole, in a direction perpendicular to the disk, and start to form their own structure. Imagine a candle sticking out of the "doughnut". Through a powerful telescope, it looks like the black hole has thrown up its food. We call these outward flows **jets** because they can travel very quickly, often reaching close to the speed of the light. Jets can be powerful and shine very brightly. If the black hole is really big, its jets can travel the distance of several thousand to millions of **light years** away from the black hole, so these jets have a big impact on the rest of the galaxy [4]. But do not worry, we are safe here on Earth: the closest big black hole to us, Sagittarius A*, does not have very energetic jets.

JET

Bright, energetic streams of particles that are launched out of a black hole almost at the speed of light.

LIGHT YEAR

The distance covered by light in 1 year, which corresponds to 9.46 trillion kilometers.

Jets never fail to surprise us: they are usually launched out of a black hole in pairs, but some black holes have only one jet. Some have jets that are bent in the middle, and some have several jets that are thrown out at different times—as if these black holes take breaks from time to time [5]! Sometimes jets are very dim; other times they are very powerful. There are still so many things to discover, but astronomers have been working quite hard on jets—by doing fancy calculations on supercomputers, and by building big radio telescopes that can help us look even further and deeper into the sky.

As jets travel in space and pass through gas clouds, they inevitably slow down and interact with the surroundings. Similar to how planes leave white trails behind them in the sky, jets leave interesting structures like filaments and bubbles. The difference is that the trails of jets are not easily detectable with our own eyes, so we need radio and X-ray telescopes to see them (Figure 3). Using these telescopes, astronomers can now take pictures of black holes and their jets: these pictures are not only beautiful, but also help astronomers to figure out the fate and history of the galaxies! Remember—in astronomy, cool pictures can help us understand how the universe works!

THE MYSTERY OF THE MISSING STARS

Like our Milky Way galaxy, many galaxies contain billions of stars and are still actively forming new stars. For example, the Milky Way forms around seven stars per year [6]. Astronomers know that certain types of gases naturally become cradles of star formation when they reach a certain cold temperature. However, according to this theory, we should count a greater number of stars in many galaxies than we actually see. What's going on? Supermassive black holes are claiming their territory—their super-hot, energetic jets are effectively blowing away and heating up the cold gas clouds in their paths. Therefore, not

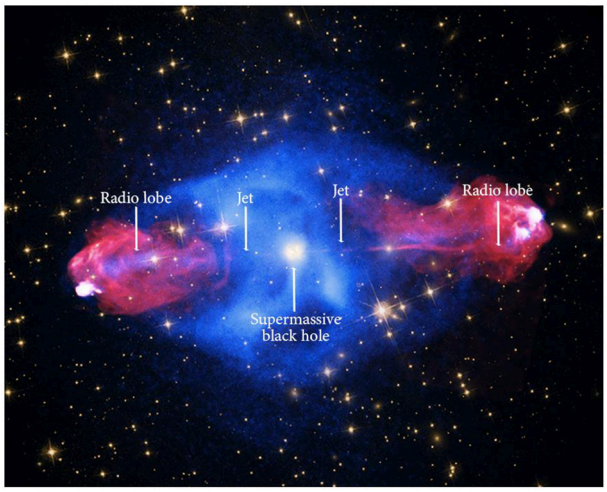


Figure 3

Figure 3

A spectacular image of galaxy Cygnus A with X-ray emissions (in blue) and radio wave emissions (in pink/red). The jets extend to either side of the supermassive black hole for nearly 300,000 light years (which is around 3 billion kilometers), and end with two radio lobes (teardrop-shaped pink areas) that emit strong radio signals. X-rays are detected by satellites orbiting the Earth and radio waves are detected using radio telescopes on Earth (Modified from https://apod.nasa.gov/apod/ap150124.html).

enough gas is left to form baby stars. Maybe black holes do not like baby stars much!

These actions have consequences, though. As the cold gas is swept away by a black hole's jets, less gas falls closer to the black hole, which effectively puts the black hole on a diet. The less a black hole eats, the less powerful its jets are. Eventually, the jets would not be powerful enough to fully block the formation of new stars. This often continues like a cycle: as soon as there are enough gas particles around, the black hole quits its diet and starts to attract the gas again. The gas that does not fall into the black hole is blasted by the jets, disturbing the formation of new stars. When too much gas is swept away, the cycle starts again [7].

By counting the star formation rate in galaxies and measuring the temperatures of the gases in the galaxies' centers, we can figure out how powerful jets are and how efficient they are at sweeping gases away. However, we do not fully understand many details of this process because we are still not completely sure how black holes work. For example, in very rare cases, astronomers have also seen the complete opposite of what we have described here: that is, black holes that spark (rather than hinder) the formation of baby stars [8].

SUMMARY

To sum up, supermassive black holes have very exciting lives and they play a very important role in the formation and evolution of galaxies. The formation of accretion disks and jets, the interaction of jets with gas clouds, and the birth of stars are all pieces of a big puzzle that has captivated astronomers for many decades. We are only starting to piece everything together, and astronomers are still building new

telescopes to take more photos of black holes and galaxies, and understand them in more detail.

REFERENCES

1. Ferrarese, L., and Merritt, D. 2000. A fundamental relation between supermassive black holes and their host galaxies. *ApJ*. 539:L9–L12. doi: 10.1086/312838
2. The Event Horizon Telescope Collaboration, Akiyama, K., Alberdi, A., Alef, W., Asadaet, K., et al. 2019. First M87 event horizon telescope results. I. The shadow of the supermassive black hole. *Astrophys. J. Lett.* 875:L1. doi: 10.3847/2041-8213/ab0ec7
3. Shakura, N. I., and Sunyaev, R. A. 1973. Black holes in binary systems. Observational appearance. *Astron. Astrophys.* 24:337–55. doi: 10.1007/978-94-010-2585-0_13
4. Fabian, A. C. 2012. Observational Evidence of Active Galactic Nuclei Feedback 2012. *ARAA*. 50:455–89. doi: 10.1146/annurev-astro-081811-125521
5. Lister, M. L., and Homan, D. C. 2005. MOJAVE: monitoring of jets in active galactic nuclei with VLBA experiments. I. First-epoch 15 GHz linear polarisation images. *Astron. J.* 130:1389–417. doi: 10.1086/432969
6. Diehl, R., Halloin, H., Kretschmer, K., Lichti, G. G., Schönfelder, V., Strong A. W., et al. 2006. Radioactive 26Al from massive stars in the Galaxy. *Nature*. 439:45–7. doi: 10.1038/nature04364
7. Di Matteo, T., Colberg, J., Springel, V., Hernquist, L., and Sijacki, D. 2008. Direct cosmological simulations of the growth of black holes and galaxies. *APJ*. 676:33–53. doi: 10.1086/524921
8. Dasyra, K. M., Paraschos, G. F., Bisbas, T.G., Combes, F., and Fernández-Ontiveros J. A. 2022. Insights into the collapse and expansion of molecular clouds in outflows from observable pressure gradients. *Nat. Astron.* 6:1077–84. doi: 10.1038/s41550-022-01725-9

SUBMITTED: 31 August 2022; **ACCEPTED:** 08 June 2023;
PUBLISHED ONLINE: 27 June 2023.

EDITOR: Edward Gomez, Las Cumbres Observatory Global Telescope Network, United States

SCIENCE MENTORS: Kalee Tock and Chris North

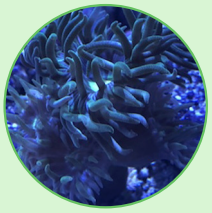
CITATION: Lü Y-HC and Diamante L (2023) How Supermassive Black Holes Shape Galaxies. Front. Young Minds 11:1032977. doi: 10.3389/frym.2023.1032977

CONFLICT OF INTEREST: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

YOUNG REVIEWERS

CLARA, AGE: 10

Hello! My name is Clara and I live in Wales. I enjoy playing Minecraft and Roblox. I also like reading. My favorite books are the Dragon Realm series and Percy Jackson. I love playing the violin, piano and two different recorders.



CONRAD, AGE: 12

I like coral reefs. I play the cello. Neuroscience is cool, but I enjoy all the sciences, and also competitive math and learning new languages.

AUTHORS

YING-HE CELESTE LÜ

Ying-He Celeste Lü is a postdoctoral research associate in the Cavendish Astrophysics Group at the University of Cambridge. She studies supermassive black hole jets and their feedback effect on galaxies and groups of galaxies, as well as using radio telescopes to look at them. She currently works with a team of scientists and engineers trying to build the world's largest group of radio telescopes to date—the Square Kilometre Array—to see more black holes! In her spare time, she enjoys reading and talking to others about science and the life of scientists. *yl790@cam.ac.uk

LETIZIA DIAMANTE

Letizia Diamante works as a science communicator for the Engineering Department of the University of Cambridge. She is also a writer of science books for children and a big fan of science festivals and science museums. *letizia.diamante@gmail.com