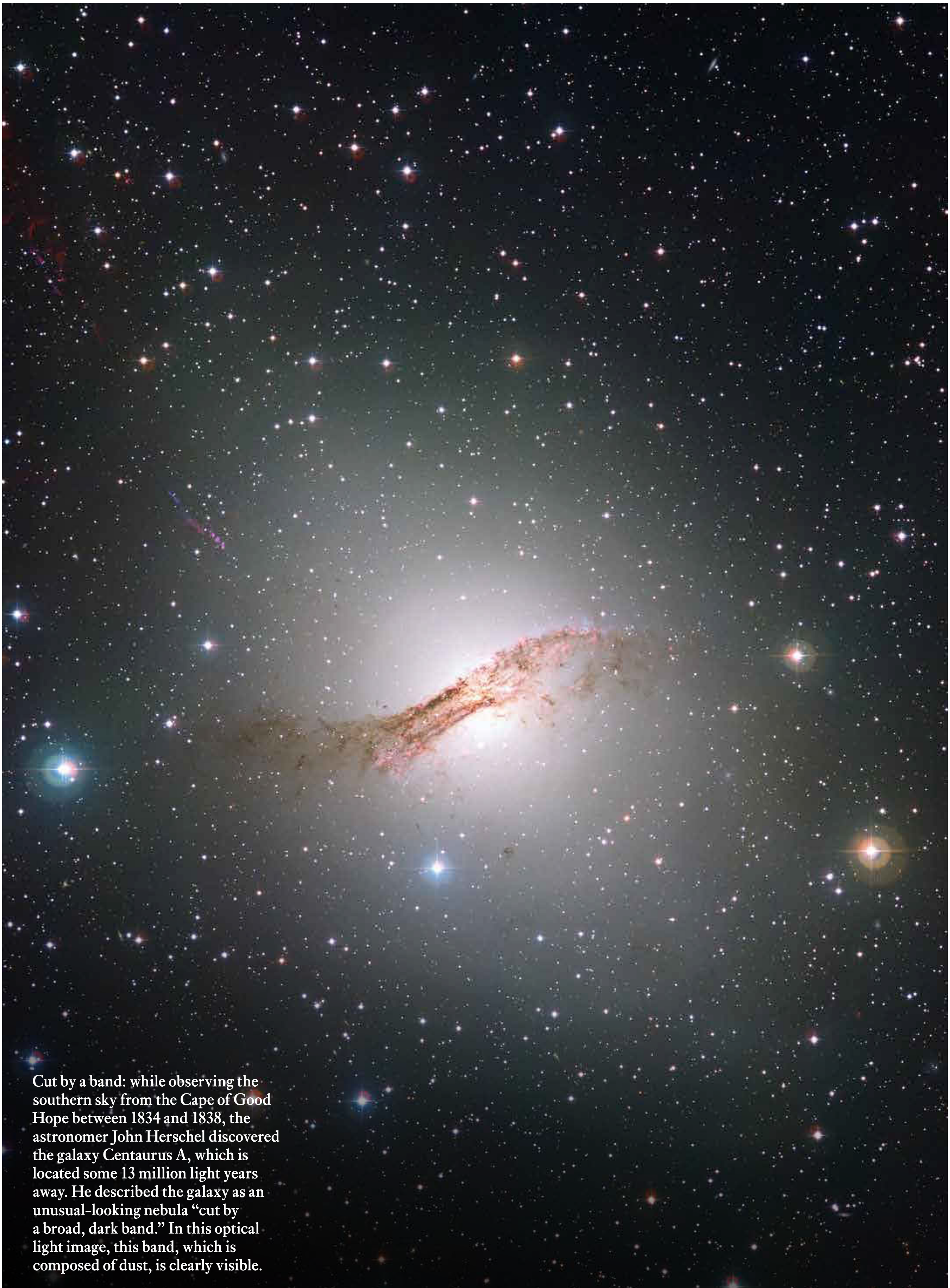

Cut by a band: while observing the southern sky from the Cape of Good Hope between 1834 and 1838, the astronomer John Herschel discovered the galaxy Centaurus A, which is located some 13 million light years away. He described the galaxy as an unusual-looking nebula "cut by a broad, dark band." In this optical light image, this band, which is composed of dust, is clearly visible.

PHOTO: ESO

ZOOMING INTO THE HEART OF CENTAURUS A

TEXT: HELMUT HORNUNG

Centaurus is one of the most famous constellations in the southern sky. Take a closer look at the constellation through binoculars and you'll see a pale nebula known as Centaurus A – it is in fact a distant galaxy in which a supermassive black hole resides. Michael Janssen from the Max Planck Institute for Radio Astronomy in Bonn and Radboud University Nijmegen led an Event Horizon Telescope team that has now come closer than ever before to understanding the nature of this gravity trap.

The chronicle of Centaurus A begins in the nineteenth century at the Cape of Good Hope. There, at the southern tip of Africa, astronomer John Herschel constructed an observatory. He observed the night sky there from 1834 to 1838 and a few years later published a catalog of astronomical objects. In this, he describes, among other things, an unusual-looking nebula "cut by a broad, dark band."

Designated NGC 5128, Herschel's discovery was listed in *A New General Catalogue of Nebulae and Clusters of Stars*. However, it was not until the 1950s that, thanks to increasingly precise observations, astronomers discovered that NGC 5128 was a galaxy entirely separate from our own. It is approximately 13 million light-years from Earth.

Research into Centaurus A began gaining momentum with a paper published by John Bolton and two co-authors in the scientific journal Nature in 1949. Shortly after World War II, the British-Australian astronomer and his team had begun matching cosmic radio sources with objects that had long been observed in visible light. The scientists were utilizing a completely new observational window on space: radio astronomy. At that time, this technology had only been around for less than two decades.

In the early 1930s, Karl Jansky was tasked by Bell Telephone Laboratories in New Jersey with investigating the source of radio transmission disturbances. In the summer of 1931, he constructed a 30-meter-long massive contraption made of wood and wire to eavesdrop on the radio spectrum and apprehended the culprit – thunderstorms!

Jansky could have been content to leave it right there, had he not also noticed a strange, steady hiss. It seemed to originate from a particular source that moved across the sky daily every 23 hours, 56 minutes and 4 seconds, precisely the period of the Earth's rotation relative to the stars. In the spring of 1933, it became clear that this hiss could only be coming from the depths of the universe.

Two years later Karl Jansky wrote that "these radiations are received any time

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the antenna system is directed towards some part of the Milky Way system." He was referring to the glowing band that, at our latitudes, can be seen stretching across the sky on summer nights. This is a section of the Milky Way, our galaxy, which is shaped like a slightly bent frisbee and is home to hundreds of billions of stars – one of which is our Sun with its eight planets.

Focusing in on the Milky Way

Jansky's discovery was ignored by the scientific community, however. Only one person appreciated the potential of the new method: Grote Reber. Reber, an amateur radio operator, invested $ 2,000 in materials to construct a fully movable dish nearly ten meters tall. He positioned it in the backyard of his home in Wheaton, Illinois, and directed it at the Milky Way every spare minute he had. In 1943, Reber published the data of his sky survey.

Gradually, this observational technique began to establish itself. A few years later, a group led by John Bolton employed a specialized radio telescope located on the coast of Australia. Constructed as a "sea cliff interferometer", it simultaneously recorded two signals – one emitted directly from the source in the sky and the other reflected from the surface of the Pacific Ocean. Superimposing the two signals – a technique known as interferometry – made it possible to mimic a radio telescope several hundred meters in diameter.

This allowed the group to successfully identify previously detected radio sources, such as Centaurus A, Virgo A, and Taurus A, with their optical counterparts: respectively, the galaxies NGC 5128 and M87 in the constellation Virgo, and the Crab Nebula, which is a supernova remnant in Taurus. Bolton's group reported these findings in the paper in *Nature* mentioned above.

The results represent a technical triumph, since the resolution of a telescope is dependent on the wavelength of radiation it detects. The longer the wavelength, the fewer details the telescope can record. Radio waves are nothing more than light waves with a very long wavelength. The Earth's atmosphere is transparent to submillimeter and millimeter radiation (just beyond the infrared), all the way through to radio waves with a wavelength of centimeters to several meters.

SUMMARY

Radio astronomers have observed Centaurus A for many decades.

The Event Horizon Telescope has now succeeded in giving us an unprecedented view into the center of this active galaxy, almost to the base of its enormous jet.

The observations help elucidate the mechanism that causes such jets to emerge close to black holes.

Due to the low resolution of radio antennas, they always need to be large; the dish of the Effelsberg Radio Telescope, for instance, is 100 meters in diameter. One clever way to trick nature is through interferometry. John Bolton was one of the first to exploit this trick. The Event Horizon Telescope (EHT) is also based on this principle. It consists of eight interconnected telescopes distributed around the globe at greater or lesser distances from each other. They all simultaneously observe the same object in the sky. Once the recorded signals are superimposed, the telescopes effectively function as a single telescope with a diameter equal to the greatest distance between the participating observatories.

In the case of the Event Horizon Telescope, this adds up to a virtual telescope with a diameter the size of the Earth itself. The EHT array detects radio waves with a wavelength of 1.3 millimeters and can resolve objects 20 millionths of an arc second apart. With it, you could theoretically read a newspaper from Munich (ignoring the curvature of the Earth) that someone was reading on a bench in New York's Central Park.

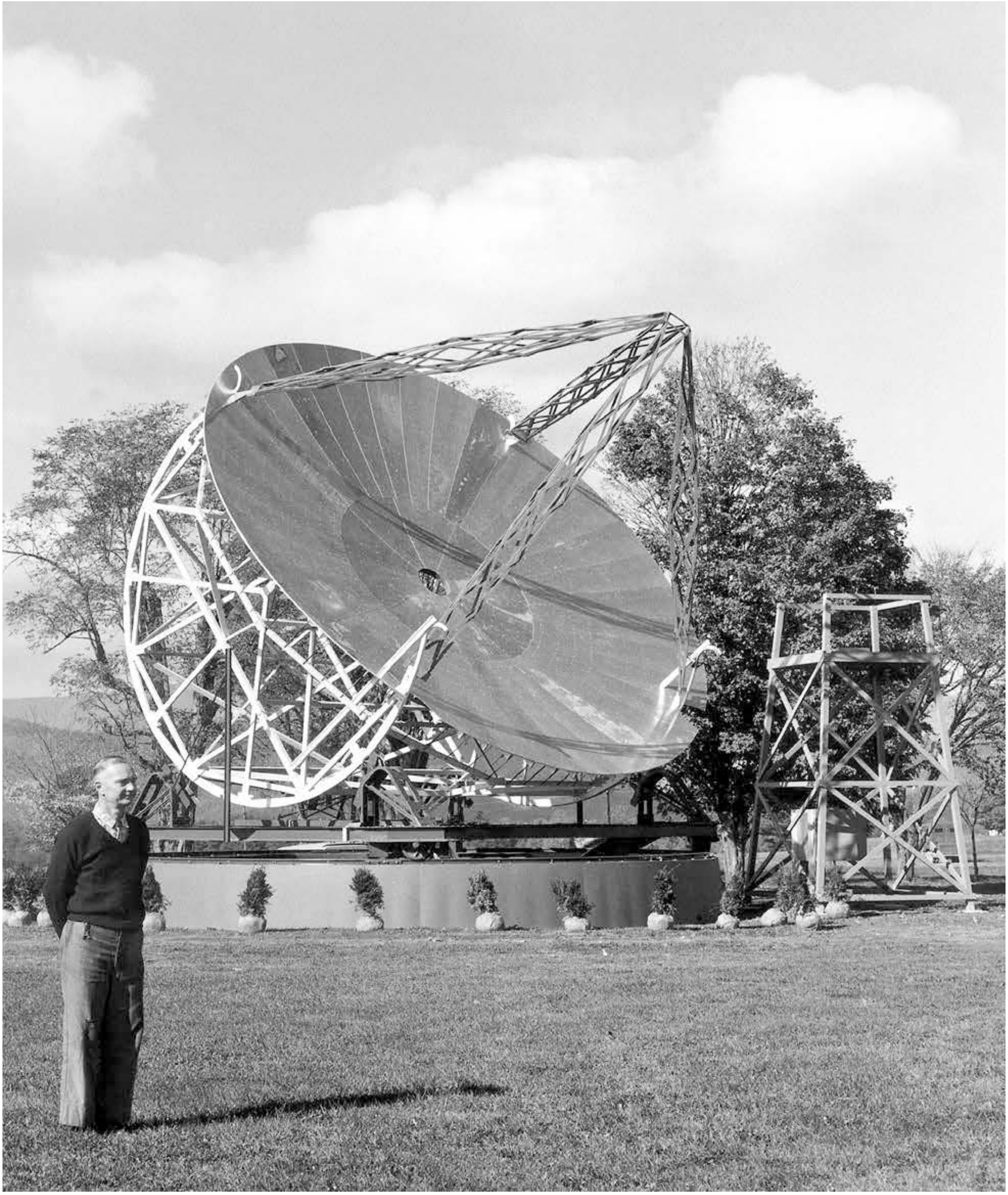
On April 10th 2019, the Event Horizon Telescope Collaboration released the now iconic first image of the shadow of a black hole. The data for this image were collected in 2017 from the center of the giant elliptical galaxy M87. At that time, the EHT Collaboration also recorded data from Centaurus A. After lengthy analysis, they released an image in July 2021 showing the heart of this galaxy, where a black hole is lurking that is 55 million times the mass of the Sun. From it – as is typical of most active galaxies – a jet of matter issues that symmetrically extends several hundred thousand light-years into space.

Rendering details smaller than a light-day

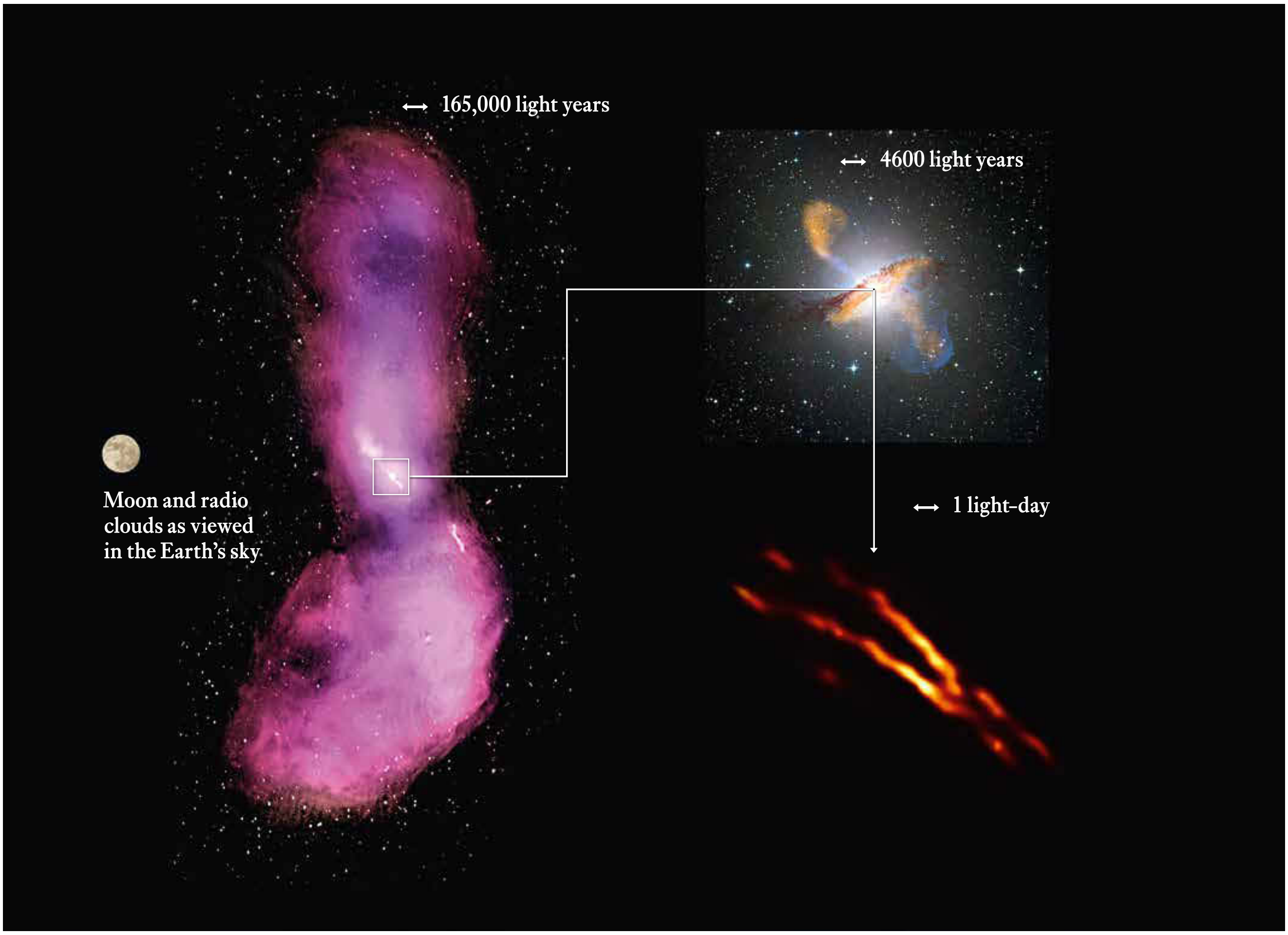
The black hole itself remains hidden. "But now, for the first time, we can study an extragalactic radio jet on scales smaller than the distance light travels in a day," says team leader Michael Janssen, who conducts research at the Max Planck Institute for Radio Astronomy in Bonn and Radboud University in Nijmegen. "We see first-hand how such a massive jet is born."

Supermassive black holes located at the centers of active galaxies like Centau-

PHOTO: SCIENCE HISTORY IMAGES / ALAMY



Pioneer: in the 1930s, Grote Reber built a dish in the garden of his home in Wheaton, Illinois that was similar in form to contemporary radio telescopes. In 1943, Reber published the data from his full sky survey – opening a new observational window on space.



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Zooming in: in the radio-wave spectrum, the extended symmetric gas clouds of the Centaurus A jet extend over an arc in the sky as wide as 16 full-moon diameters (left). The composite image depicting submillimeter, X-ray, and visible light images reveals only the galaxy itself (top right). The view into the heart of Centaurus A using the Event Horizon Telescope is many orders of magnitude more accurate, while the image of the jet has the highest detail resolution (bottom right).

rus A exert an almost irresistible pull on their surroundings. These black holes consume gas and dust causing them to release huge amounts of energy. Most of the matter near the edge of a black hole falls into this cosmic abyss. However, some of the surrounding particles escape just before they can be captured. This creates the jets we see, but the underlying mechanism behind these remains a mystery.

Researchers are attempting to explain exactly how matter behaves near a black hole using a variety of models. But what process is responsible for launching the jets from their galactic centers? And how do they come to extend many thousands of light years out into space, far surpassing their host galaxies in size? It is hoped the EHT will help answer these questions.

For example, the new image shows that the Centaurus A jet is brighter at the edges than in the center. Scientists are familiar with this phenomenon from other jets, but it has never been observed so clearly. “Thanks to this striking feature, we can now rule out all those theoretical models of jets that do not result in such edge brightening,” explains Matthias Kadler, an astrophysicist at the University of Wuerzburg. In addition, the EHT measurements have identified to a high degree of accuracy the position of the black hole from which the jet originates.

In the future, observations at even shorter wavelengths and higher detail resolution will make it possible to depict the black hole at the heart of Centaurus A – in the same way the black hole in the giant galaxy M87 was imaged. The researchers are now turning their attention to studying the magnetic fields. “I feel sure that we'll soon master the improved methods needed to analyze the data,” declares Anton Zensus, Director at the Max Planck Institute for Radio Astronomy.

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