The galaxy M87

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Chapter 1

The Galaxy M87[1]

1.1 Messier 87

Messier 87 (also known as Virgo A or NGC 4486, generally abbreviated to M87) is a supergiant elliptical galaxy in the constellation Virgo. One of the most massive galaxies in the local Universe, it has a large population of globular clusters—about 12,000 compared with the 150-200 orbiting the Milky Way—and a jet of energetic plasma that originates at the core and extends at least 1,500 parsecs (4,900 light-years), traveling at relativistic speed. It is one of the brightest radio sources in the sky and a popular target for both amateur and professional astronomers.

The French astronomer *Charles Messier* discovered M87 in 1781, and cataloged it as a nebulous feature while searching for objects that would otherwise confuse comet hunters. M87 is about 16.4 million parsecs (53 million light-years) from Earth and is the second-brightest galaxy within the northern Virgo Cluster, having many satellite galaxies. Unlike a disk-shaped spiral galaxy, M87 has no distinctive dust lanes. Instead, it has an almost featureless, ellipsoidal shape typical of most giant elliptical galaxies, diminishing in luminosity with distance from the center. Forming around one-sixth of its mass, M87's stars have a nearly spherically symmetric distribution. Their population density decreases with increasing distance from the core. It has an active supermassive black hole at its core, which forms the primary component of an active galactic nucleus. The black hole was imaged using data collected in 2017 by the EVENT HORIZON TELESCOPE[2], with a final,

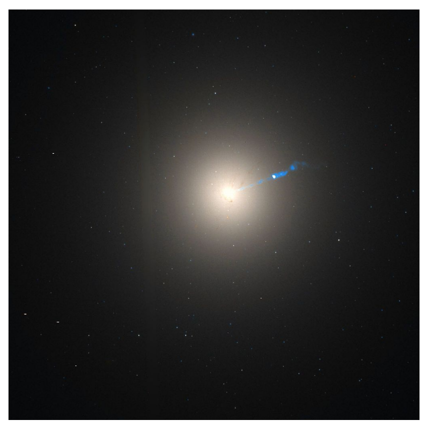

Figure 1.1: Messier object 87 by Hubble space telescope. This is the galactic core show as a composite image of visible and infrared observations in order to resolve the blue jet. The field of view is about 1.5 arc minutes across, the jet extends to about a third of an arc minute (or 20 arc seconds) with a width of about 2 arc seconds (absolute length 5 kly at a distance of 53 Mly By en:NASA, en:STScI, en:WikiSky https://commons.wikimedia.org/w/index.php?curid=7598267

[1]Source: https://en.wikipedia.org/wiki/Messier_87
[2]https://en.wikipedia.org/wiki/Event_Horizon_Telescope

processed image released on 10 April 2019.

1.1.1 Radio emission and the central black hole

The galaxy is a strong source of `multiwavelength radiation`, particularly radio waves. Its galactic envelope extends to a radius of about 150 kiloparsecs (490 thousand light-years), where it is truncated – possibly by an encounter with another galaxy. Its interstellar medium consists of diffuse gas enriched by elements emitted from evolved stars.

The core contains a SUPERMASSIVE BLACK HOLE, designated **M87***, whose mass is billions of times that of the Sun; estimates have ranged from $(3.5 \pm 0.8) \times 10^9$ $M_\odot$ to $(6.6 \pm 0.4) \times 10^9$ $M_\odot$ with a measurement of $7.22^{+0.34}_{-0.40} \times 10^9$ $M_\odot$ in 2016. In April 2019, the EVENT HORIZON TELESCOPE released measurements of the black hole's mass as $(6.5 \pm 0.2_{\text{stat}} \pm 0.7_{\text{sys}}) \times 10^9$ $M_\odot$ (Event Horizon Telescope Collaboration et al., 2019b). This is one of the highest known masses for such an object. *A rotating disk of ionized gas surrounds the black hole*, and is roughly perpendicular to the relativistic jet. The disk rotates at velocities of up to roughly 1,000 km/s, and spans a maximum diameter of 0.12 parsecs (25,000 AU; 0.39 ly; $3{,}700 \times 10^9$ km). By comparison, Pluto averages 39 astronomical units (0.00019 pc; 5.8×10^9 km) from the sun. Gas accretes onto the black hole at an estimated rate of one solar mass every ten years (about 90 Earth masses per day). The Schwarzschild radius of the black hole is 5.9×10^{-4} parsecs (1.9×10^{-3} light-years), which is around 120 times the Earth-Sun distance.

A 2010 paper suggested that the black hole may be displaced from the galactic center by about seven parsecs (23 light-years). The displacement was claimed to be in the opposite direction of the jet, indicating acceleration of the black hole by the jet. Another suggestion was that the change in location occurred during the merger of two supermassive black holes. However, a 2011 study did not find any statistically significant displacement, and a 2018 study of high-resolution images of M87 concluded that the apparent spatial offset was caused by temporal variations in the jet's brightness rather than a physical displacement of the black hole from the galaxy's center.

This black hole is the first and, to date, the only to be imaged. An image taken by the EVENT HORIZON TELESCOPE in 2017 was published on 10 April 2019. The image shows the shadow of the black hole, surrounded by an asymmetric emission ring with a diameter of 3.36×10^{-3} parsecs (0.0110 light-years). The shadow radius is 2.6 times that of the black hole's Schwarzschild radius (Event Horizon Telescope Collaboration et al., 2019a).

1.1.2 Relativistic jet

The relativistic jet of matter emerging from the core extends at least 1.5 kiloparsecs (5,000 light-years) from the nucleus and consists of matter ejected from a supermassive black hole. The jet is highly collimated, appearing constrained to an angle of 60 within 0.8 parsecs (2.6 light-years) of the core, to about 16 at two parsecs (6.5 light-years), and to 6–7 at twelve parsecs (39 light-years). Its base has the diameter of 5.5±0.4 `Schwarzschild radii`, and is probably powered by a prograde accretion disk around a spinning supermassive black hole. The German-American astronomer *Walter Baade* found that light from the jet was plane polarized, which suggests that the energy is generated by **the acceleration of electrons moving at relativistic velocities in a magnetic field**, see in Baade (1956).

The total energy of these electrons is estimated at $\mathbf{5.1 \times 10^{56}}$ ergs (5.1×10^{49} joules or 3.2×10^{68} eV). This is roughly 10^{13} times the energy produced by the Milky Way in one second, which is estimated at 5×10^{36} joules. **The jet is surrounded by a lower-velocity non-relativistic component**. There is evidence of a counter jet, but it remains unseen from the Earth due to relativistic beaming. The jet is precessing, causing the outflow to form a helical pattern out to 1.6 parsecs (5.2 light-years).Lobes of expelled matter extend out to 80 kiloparsecs (260 thousand light-years).

In pictures taken by the HUBBLE SPACE TELESCOPE in 1999 (see Figure 1.1), the motion of M87's jet was measured at four to six times the speed of light. This phenomenon, called **superluminal motion**, is an illusion caused by the relativistic velocity of the jet. The time interval between any two light pulses emitted by the jet is, as registered by the observer, less than the actual interval due to the relativistic speed of the jet moving in the direction of the observer. This results in perceived faster-than-light speeds. Detection of such motion is used to support the theory that quasars, BL Lacertae objects and radio galaxies may all be the same phenomenon, known as active galaxies, viewed from different perspectives. It is proposed that M87 is a BL Lacertae object (with a low-luminosity nucleus compared with the brightness of its host galaxy) seen from a relatively large angle. Flux variations, characteristic of the BL Lacertae objects, have been observed in M87. M87 black hole is a strong source of radio waves Radio wavelength image of M87 showing strong radio emission from the core.

Variability 1 *Observations indicate that the rate at which material is ejected from the supermassive black hole is variable. These variations produce pressure waves in the hot gas surrounding M87. The Chandra X-ray Observatory has detected loops and rings in the gas. Their distribution suggests that minor eruptions occur every few million years. One of the rings, caused by a major eruption, is a shock wave 26 kiloparsecs (85 thousand light-years) in diameter around the black hole.*

Variability 2 *Other features observed include narrow X-ray-emitting filaments up to 31 kiloparsecs (100 thousand light-years) long, and a large cavity in the hot gas caused by a major eruption 70 million years ago. The regular eruptions prevent a huge reservoir of gas from cooling and forming stars, implying that M87's evolution may have been seriously affected, preventing it from becoming a large spiral galaxy. These observations also indicate that the variable eruptions produce sound waves of about 56 to 59 octaves below middle C in the medium.*

Gamma ray emission

M87 is a very strong source of gamma rays, the most energetic rays of the electromagnetic spectrum. Gamma rays emitted by M87 have been observed since the late 1990s. In 2006, using the High Energy Stereoscopic System Cherenkov telescopes, scientists measured the variations of the gamma ray flux coming from M87, and found that the flux changes over a matter of days. This short period indicates that the most likely source of the gamma rays is a supermassive black hole. In general, the smaller the diameter of the emission source, the faster the variation in flux, and vice versa.

X-ray emission

A knot of matter in the jet (designated HST-1), about 65 parsecs (210 light-years) from the core, has been tracked by the Hubble Space Telescope and the Chandra X-ray Observatory. By 2006, the X-ray intensity of this knot had increased by a factor of 50 over a four-year period, while the X-ray emission has since been decaying in a variable manner.

Radio lobes

The **interaction of relativistic jets of plasma** emanating from the core with the surrounding medium gives rise to radio lobes in active galaxies. The lobes occur in pairs and are often symmetrical.The two radio lobes of M87 together span about 80 kiloparsecs; the inner parts, extending up to two kiloparsecs, emit strongly at radio wavelengths. Two flows of material emerge from this region, one aligned with the jet itself and the other in the opposite direction. The flows are asymmetrical and deformed, implying that they encounter a dense intracluster medium. At greater distances, both flows diffuse into two lobes. The lobes are surrounded by a fainter halo of radio-emitting gas.

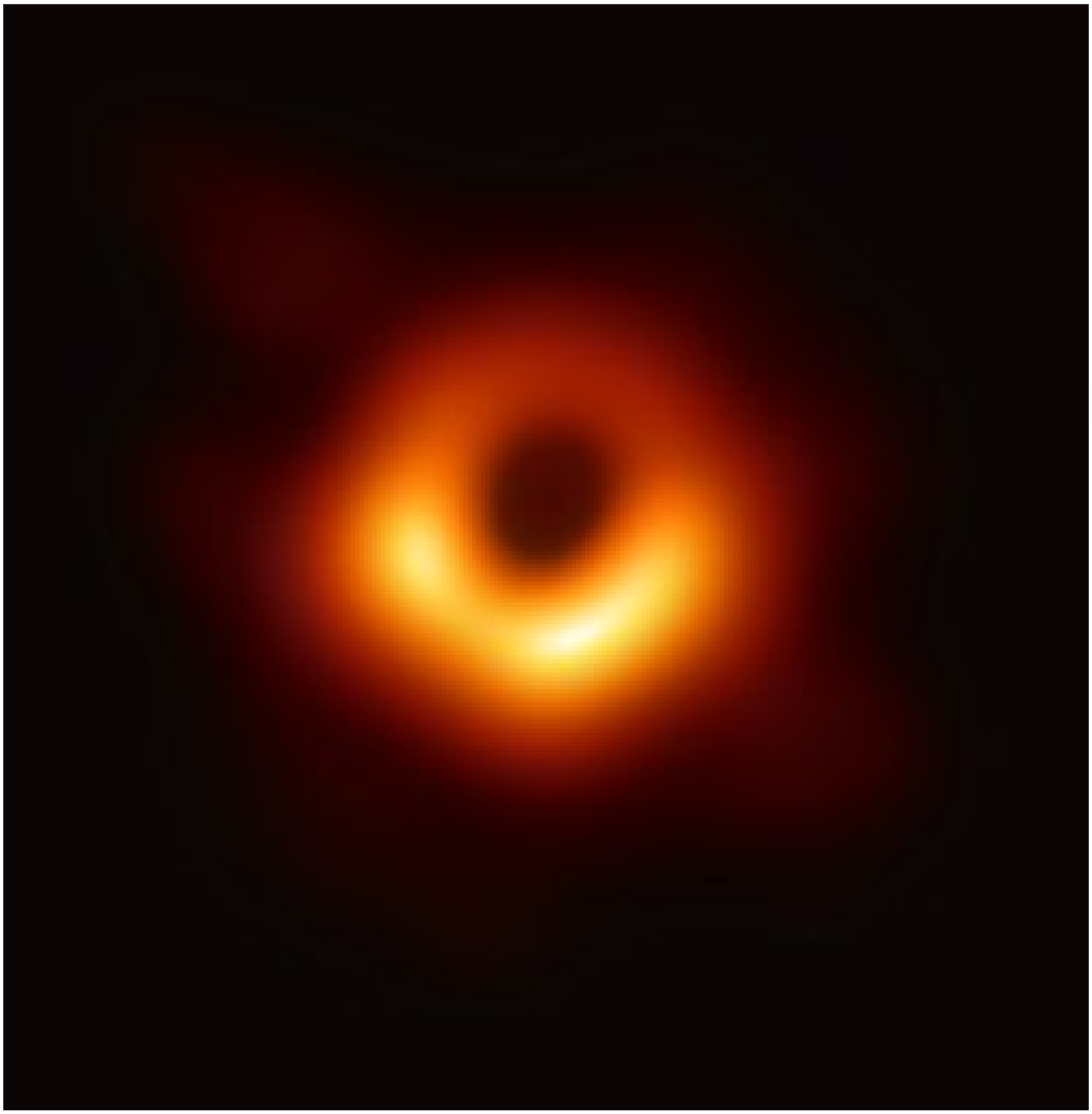

Figure 1.2: The Event Horizon Telescope image of the core of M87 using 1.3 mm radio waves. The central dark spot is the shadow of the black hole and is larger than the black hole's event horizon.

Bibliography

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