A supermassive black hole (SMBH) is the largest type of black hole, on the order of hundreds of thousands to billions of solar masses ($M_\odot$), and is found in the center of almost all currently known massive galaxies.[1][2] In the case of the Milky Way, the SMBH corresponds with the location of Sagittarius A*.[3][4]

Supermassive black holes have properties that distinguish them from lower-mass classifications. First, the average density of a supermassive black hole (defined as the mass of the black hole divided by the volume within its Schwarzschild radius) can be less than the density of water in the case of some supermassive black holes.[5] This is because the Schwarzschild radius is directly proportional to mass, while density is inversely proportional to the volume. Since the volume of a spherical object (such as the event horizon of a non-rotating black hole) is directly proportional to the cube of the radius, the minimum density of a black hole is inversely proportional to the square of the mass, and thus higher mass black holes have lower average density. In addition, the tidal forces in the vicinity of the event horizon are significantly weaker for massive black holes. As with density, the tidal force on a body at the event horizon is inversely proportional to the square of the mass: a person on the surface of the Earth and one at the event horizon of a 10 million $M_\odot$ black hole experience about the same tidal force between their head and feet. Unlike with stellar mass black holes, one would not experience significant tidal force until very deep into the black hole.

### History of research

Donald Lynden-Bell and Martin Rees hypothesized in 1971 that the center of the Milky Way galaxy would contain a supermassive black hole. Sagittarius A* was discovered and named on February 13 and 15, 1974, by astronomers Bruce Balick and Robert Brown using the baseline interferometer of the National Radio Astronomy Observatory.[6] They discovered a radio source that emits synchrotron radiation; it was found to be dense and immobile because of its gravitation. This was, therefore, the first indication that a supermassive black hole exists in the center of the Milky Way.

### Formation

The origin of supermassive black holes remains an open field of research. Astrophysicists agree that once a black hole is in place in the center of a galaxy, it can grow by accretion of matter and by merging with other black holes. There are, however, several hypotheses for the formation mechanisms and initial masses of the progenitors, or "seeds", of supermassive black holes. The most obvious hypothesis is that the seeds are black holes of tens or perhaps hundreds of stellar masses that are left behind by the explosions of massive stars and grow by accretion of matter. Another model involves a large gas cloud in the period before the first stars formed collapsing into a "quasi-star" and then a black hole of initially only around ~20 $M_\odot$, and then rapidly accreting to become relatively quickly an intermediate-mass black hole, and possibly a SMBH if the accretion-rate is not quenched at higher masses.[7] The initial "quasi-star" would become unstable to radial perturbations because of electron-positron pair production in its core, and may collapse directly into a black hole without a supernova explosion, which would eject most of its mass and prevent it from leaving a black hole as a remnant.

Yet another model[10] involves a dense stellar cluster undergoing core-collapse as the negative heat capacity of the system drives the velocity dispersion in the core to relativistic speeds. Finally, primordial black holes may have been produced directly from external pressure in the first moments after the Big Bang. Formation of black holes from the deaths of the first stars has been extensively studied and corroborated by observations. The other models for black hole formation listed above are theoretical.

The difficulty in forming a supermassive black hole resides in the need for enough matter to be in a small enough volume. This matter needs to have very little angular momentum in order for this to happen. Normally, the process of accretion involves transporting a large initial endowment of angular momentum outwards, and this appears to be the limiting factor in black hole growth. This is a major component of the theory of accretion disks. Gas accretion is the most efficient and also the most conspicuous way in which black holes grow. The majority of the mass growth of supermassive black holes is thought to occur through episodes of rapid gas accretion, which are observable as active galactic nuclei or quasars. Observations reveal that quasars were much more frequent when the Universe was younger, indicating that supermassive black holes formed and grew early. A major constraining factor for theories of supermassive black hole formation is the observation of distant luminous quasars, which indicate that supermassive black holes of billions of solar masses had already...
formed when the Universe was less than one billion years old. This suggests that supermassive black holes arose very early in the Universe, inside the first massive galaxies.

Currently, there appears to be a gap in the observed mass distribution of black holes. There are stellar-mass black holes, generated from collapsing stars, which range up to perhaps 53 $M_\odot$. The minimal supermassive black hole is in the range of a hundred thousand solar masses. Between these regimes there appears to be a dearth of intermediate-mass black holes. Such a gap would suggest qualitatively different formation processes. However, some models suggest that ultraluminous X-ray sources (ULXs) may be black holes from this missing group.

**Doppler measurements**

Some of the best evidence for the presence of black holes is provided by the Doppler effect whereby light from nearby orbiting matter is redshifted when receding and blue shifted when advancing. For matter very close to a black hole the orbital speed must be comparable with the speed of light, so receding matter will appear very faint compared with advancing matter, which means that systems with intrinsically symmetric discs and rings will acquire a highly asymmetric visual appearance. This effect has been allowed for in modern computer generated images such as the example presented here, based on a plausible model for the supermassive black hole in Sgr A* at the centre of our own galaxy. However the resolution provided by presently available telescope technology is still insufficient to confirm such predictions directly.

What already has been observed directly in many systems are the lower non-relativistic velocities of matter orbiting further out from what are presumed to be black holes. Direct Doppler measures of water masers surrounding the nuclei of nearby galaxies have revealed a very fast Keplerian motion, only possible with a high concentration of matter in the center. Currently, the only known objects that can pack enough matter in such a small space are black holes, or things that will evolve into black holes within astrophysically short timescales. For active galaxies farther away, the width of broad spectral lines can be used to probe the gas orbiting near the event horizon. The technique of reverberation mapping uses variability of these lines to measure the mass and perhaps the spin of the black hole that powers active galaxies.

Gravitation from supermassive black holes in the center of many galaxies is thought to power active objects such as Seyfert galaxies and quasars.

An empirical correlation between the size of supermassive black holes and the stellar velocity dispersion $\sigma$ of a galaxy bulge[^13] is called the M-sigma relation.

**In the Milky Way**

Astronomers are very confident that our own Milky Way galaxy has a supermassive black hole at its center, 26,000 light-years from the Solar System, in a region called Sagittarius A*[^15] because:

- The star S2 follows an elliptical orbit with a period of 15.2 years and a pericenter (closest distance) of 17 light-hours ($1.8 \times 10^{13}$ m or 120 AU) from the center of the central object.[^16]
- From the motion of star S2, the object's mass can be estimated as 4.1 million $M_\odot$, or about $8.2 \times 10^{36}$ kg.
- The radius of the central object must be less than 17 light-hours, because otherwise S2 would collide with it. In fact, recent observations from the star S14[^19] indicate that the radius is no more than 6.25 light-hours, about the diameter of Uranus' orbit. However, applying the formula for the Schwarzschild radius yields just about 41 light-seconds, making it consistent with the escape velocity being the speed of light.
- No known astronomical object other than a black hole can contain 4.1 million $M_\odot$ in this volume of space.

The Max Planck Institute for Extraterrestrial Physics and UCLA Galactic Center Group[^20] have provided the strongest evidence to date that Sagittarius A* is the site of a supermassive black hole[^15] based on data from ESO's Very Large Telescope[^21] and the Keck telescope.[^22]

On 5 January 2015, NASA reported observing an X-ray flare 400 times brighter than usual, a record-breaker, from Sagittarius A*. The unusual event may have been caused by the breaking apart of an asteroid falling into the black hole or by the entanglement of magnetic field lines within gas flowing into Sagittarius A*, according to astronomers,.[^23]
Unambiguous dynamical evidence for supermassive black holes exists only in a handful of galaxies.[25] These include the Milky Way, the Local Group galaxies M31 and M32, and a few galaxies beyond the Local Group, e.g. NGC 4395. In these galaxies, the mean square (or rms) velocities of the stars or gas rises as ~1/r near the center, indicating a central point mass. In all other galaxies observed to date, the rms velocities are flat, or even falling, toward the center, making it impossible to state with certainty that a supermassive black hole is present.[25] Nevertheless, it is commonly accepted that the center of nearly every galaxy contains a supermassive black hole.[26] The reason for this assumption is the M-sigma relation, a tight (low scatter) relation between the mass of the hole in the ~10 galaxies with secure detections, and the velocity dispersion of the stars in the bulges of those galaxies.[27] This correlation, although based on just a handful of galaxies, suggests to many astronomers a strong connection between the formation of the black hole and the galaxy itself.[26]

On March 28, 2011, a supermassive black hole was seen tearing a mid-size star apart.[35] That is the only likely explanation of the observations that day of sudden X-ray radiation and the follow-up broad-band observations.[37][38] The source was previously an inactive galactic nucleus, and from study of the outburst the galactic nucleus is estimated to be a SMBH with mass of the order of a million solar masses. This rare event is assumed to be a relativistic outflow (material being ejected in a jet at a significant fraction of the speed of light) from a star tidally disrupted by the SMBH. A significant fraction of a solar mass of material is expected to have accreted onto the SMBH. Subsequent long-term observation will allow this assumption to be confirmed if the emission from the jet decays at the expected rate for mass accretion onto a SMBH.

In 2012, astronomers reported an unusually large mass of approximately 17 billion $M_\odot$ for the black hole in the compact, lenticular galaxy NGC 1277, which...
lies 220 million light-years away in the constellation Perseus. The putative black hole has approximately 59 percent of the mass of the bulge of this lenticular galaxy (14 percent of the total stellar mass of the galaxy). Another study reached a very different conclusion: this black hole is not particularly overmassive, estimated at between 2 and 5 billion $M_\odot$ with 5 billion $M_\odot$ being the most likely value.[40] On 28 February 2013 astronomers reported on the use of the NuSTAR satellite to accurately measure the spin of a supermassive black hole for the first time, in NGC 1365, reporting that the event horizon was spinning at almost the speed of light.[41][42]

In September 2014, data from different X-ray telescopes has shown that the extremely small, dense, ultracompact dwarf galaxy M60-UCD1 hosts a 20 million solar mass black hole at its center, accounting for more than 10% of the total mass of the galaxy. The discovery is quite surprising, since the black hole is five times more massive than the Milky Way's black hole despite the galaxy being less than five-thousandth the mass of the Milky Way.

Some galaxies, however, lack any supermassive black holes in their centers. Although most galaxies with no supermassive black holes are very small, dwarf galaxies, one discovery remains mysterious: The supergiant elliptical cD galaxy A2261-BCG has not been found to contain an active supermassive black hole, despite the galaxy being one of the largest galaxies known; ten times the size and one thousand times the mass of the Milky Way. Since a supermassive black hole will only be visible while it is accreting, a supermassive black hole can be nearly invisible, except in its effects on stellar orbits.

### References


### In fiction

**See also**

- Active galactic nucleus
- Central massive object
- Galactic center
- General relativity
- Hypercompact stellar system
- List of most massive black holes
- M-sigma relation
- Spin-flip

Further reading


External links

- Images of supermassive black holes (http://chandra.harvard.edu/photo/2002/0157/0157_composite.jpg)
- NASA images of supermassive black holes (http://antwrp.gsfc.nasa.gov/apod/image/0210/mwcentre_eso_big.jpg)
- The black hole at the heart of the Milky Way (http://www.einstein-online.info/en/spotlights/milkyway_bh/index.html)
- ESO video clip of stars orbiting a galactic black hole (http://www.eso.org/public/videos/eso0846a/)
- Star Orbiting Massive Milky Way Centre Approaches to within 17 Light-Hours (http://www.eso.org/outreach/press-rel/pr-2002/pr-17-02-02.html) ESO, October 21, 2002
- Images, Animations, and New Results from the UCLA Galactic Center Group (http://www.astro.ucla.edu/research/galcenter/)
- Washington Post article on Supermassive black holes (http://www.washingtonpost.com/wp-dyn/content/article/2007/10/30/AR2007103002073.html?nav=most_emailed)
- A simulation of the stars orbiting the Milky Way's central massive black hole (http://www.youtube.com/watch?v=uVlcIb-rCII)


Categories: Black holes | Galaxies | Supermassive black holes

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