Lecture 6. Observational evidence of Supermassive black holes

A supermassive black hole is a black hole with a mass of an order of magnitude between 10^5 and 10^{10} of solar masses.

It is currently thought that most, if not all galaxies, including the Milky Way, contain supermassive black holes at their galactic centers.

There is also evidence that two supermassive black holes can form binaries (see Lecture 5). Supermassive black hole interact with surrounding stars.They can destroy, capture or just swallow a star, see Fig.6.1 [Top: artist's conception of a supermassive black hole tearing apart a star. Bottom: images believed to show a supermassive black hole devouring a star in galaxy RXJ].

The average density of a supermassive black hole (measured as the mass of the black hole divided by its Schwarzschild volume) can be very low.

It may actually be lower than the density of air. 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, and mass merely increases linearly, the volume increases at a greater rate than mass. Thus, density decreases for increasingly larger radii of black holes.

The tidal forces in the vicinity of the event horizon are significantly weaker than in the case of stellar solar masses. For this reason matter supply for supermassive black holes can not be produced by tidal disruption of stars if the mass of black hole exceeds some critical mass determined from the condition that the tidal radius of is equal to the Schwarzschild radius (see Relativistic Astrophysics). In other words, a hypothetical astronaut travelling towards the black hole center would not experience significant tidal force until very deep into the black hole.

Formation of supermassive black holes

There are several models for the formation of black holes of this size, for example:

1. Slow accretion of matter starting from a black hole of stellar size.

2. A large gas cloud collapsing into a relativistic star of hundred thousand solar masses or larger. The star would then become unstable to radial perturbations due to 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 preventing it from leaving a supermassive black hole as a remnant.

3. Primordial black holes may have been produced directly from external pressure in the first instants after the Big Bang and then the can grow accreting surrounding matter.

Black holes of intermidiate masses (IMBHs)

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, and explains the formation of accretion disks. 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 33 solar masses. 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 objects. 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. See Fig.6.2 [A Chandra image of NGC 4485 and NGC 4490: two potential ULXs].

In 2004 a team of astronomers reported the discovery of the first intermediate-mass black hole in our galaxy, orbiting three light-years from Sagittarius A. This medium black hole of 1,300 solar masses is within a cluster of seven stars, possibly the remnant of a massive star cluster that has been stripped down by the Galactic Centre. This observation may add support to the idea that supermassive black holes grow by absorbing nearby smaller black holes and stars. However, recently, a German research group claimed that the presence of an IMBH near the galactic center is doubtful. This conclusion is based on a dynamical study of a small star cluster in which should reside the suspected intermediate mass black hole. The debate on the real existence of intermediate mass black holes is still open. Fig.6.3 [Sgr A* (centre) and two light reflections from a recent explosion (circled)].

Example of observational evidence of existence of supermassive black holes

Fig.6.4 [The orbits of stars within the central 1.0 X 1.0 arcseconds of our Galaxy. In the background, the central portion of a diffraction-limited image taken in 2004 is displayed. While every star in this image has been seen to move over the past 9 years, estimates of orbital parameters are only possible for the seven stars that have had significant curvature detected. The annual average positions for these seven stars are plotted as colored dots, which have increasing color saturation with time. Also plotted are the best fitting simultaneous orbital solutions. These orbits provide the best evidence yet for a supermassive black hole, which has a mass of 3.7 million times the mass of the Sun.]

The UCLA Galactic Center Group is part of the UCLA Physics and Astronomy department and is dedicated to researching the innermost regions of the Milky Way. High angular resolution infrared observations taken with the Keck telescopes are used to study this extreme environment including the proposed super massive black hole believed to lie at the exact center of our Galaxy. Fig.6.5