ASTR 1120 Section 1 (3 credit hours): Spring 2006

SUMMARY OF KEY CONCEPTS: WEEK #6

Lecture #11 – Reading Chapter 18 (either edition)

We first reviewed the Newtonian concept of a `dark star' or black hole. For any star or planet, we can calculate the *escape velocity* – the minimum speed an object must have to completely escape the gravitational influence of the star. This is derived by equating the kinetic energy with the gravitational potential energy. The escape velocity is large for massive, compact (small radius) stars. A sufficiently massive, compact star would have an escape velocity larger than the velocity of light – so in Newtonian theory it would be completely dark.

Unfortunately this concept is flawed, since Special Relativity is based on the idea that the speed of light is a constant for all observers – we can't view photons in the same way as tennis balls!

The relativistic theory of black holes dates to Karl Schwarzschild in 1916. He showed that a spherically symmetric (non-rotating) body of mass M has a critical radius – now called the Schwarzschild radius, given by,

$$R_s = \frac{2GM}{c^2}$$

where c is the speed of light and G the gravitational constant. The Schwarzschild radius is very small – for an object of a Solar mass it is 3 km and it scales linearly with mass (so a 10 Solar mass object has a Schwarzschild radius of 30 km etc).

For a non-rotating black hole the Schwarzschild radius is the radius of the *event horizon*. An event horizon is the defining property of a black hole. It is a one way boundary through which matter can fall but nothing – matter, light or information – can escape. Near the horizon (but still outside) radiation that escapes is strongly red shifted (the photons lose energy escaping from the strong gravity of the black hole), and clocks run slow as seen by a distant observer at a safe distance. This gravitational time dilation is completely distinct from the Special Relativistic kind. Due to the time dilation, an unfortunate astronaut plunging into the black hole appears to freeze at the horizon rather than cross it as seen from outside – though the light rapidly becomes dim and red so the astronaut fades away rather than remaining poised at the horizon for eternity. From the astronaut's point of view though, the horizon has no special significance – he or she falls through the point of no return and is shortly afterward obliterated at or near the singularity at the center of the black hole.

Observational signatures of a black hole rely on observing radiation that passes near – but still outside – the horizon.

Lecture #12 – Chapter 18

There is strong observational evidence that Nature forms black holes in (at least) two mass ranges. Stellar mass black holes have masses between perhaps 5 and 100 times the mass of the Sun – these can be formed from the collapse of massive stars or via the merger of neutron stars.

Supermassive black holes have masses between one million and one billion (or even more) Solar masses – these are found at the center of galaxies such as the Milky Way.

The strongest evidence for a supermassive black hole is found at the center of the Milky Way. The Galactic Center is hard to observe, because obscuration by dust means it cannot be imaged in visible light – only in infrared light, radio, or X-ray radiation which penetrate dusty gas better. In the infrared, we see that the Galactic Center harbors clusters of young massive stars, whose velocity increases as we move closer toward the center. At the exact center lies an enigmatic radio source called Sagittarius A^*.

The best images of the Galactic Center are obtained using a technique called adaptive optics, which compensates (in part) for the blurring of images caused by the Earth's atmosphere. Using adaptive optics, we see that the stars closest to Sagittarius A^* are all orbiting a single point at very high speeds – as high as 10,000 km/s.