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

SUMMARY OF KEY CONCEPTS: WEEK #7

Lecture #13 – textbook 4.4 (4th edition) or 5.3 (3rd edition)

How can we measure the mass of the black hole at the Galactic Center? We start by noting that if we know the mass – call it M – then we can work out the velocity v needed to stay in a circular orbit at distance r. This is worked out in the textbook (check that) and leads to the formula:

$$v^2 = \frac{GM}{r}$$

The orbital velocity is large for large masses and / or small radii. For the stars orbiting the Galactic Center, we measure the velocity and the radius – we can then rearrange the formula to find the mass. This gives a result of about 4 million Solar masses, which must be packed into a volume no larger than the Solar System! No ordinary star or cluster or stars can attain such a high density, so a black hole is the only plausible explanation that satisfies known physical laws.

Hawking radiation is a prediction that derives from combining General Relativity with quantum mechanics. Hawking predicted that the event horizon itself, rather than being completely black, ought to radiate *extremely weak* radiation. Although unobservable for any black hole whose existence we know about, this prediction is important in principle because it means that black holes are not eternal – given enough time (far far longer than the age of the Universe so far) any black hole should lose energy (and thus mass) and finally evaporate into pure radiation. Very small black holes, which might have been formed early in the history of the Universe, would be evaporating about now and are predicted to finally explode in a brief fireball of high energy particles. No evidence that this is happening has been found. It is important not to confuse Hawking radiation with the radiation that *is* observed from black hole systems – the observed radiation comes from gas *outside the event horizon*.

Lecture #14

We discussed the fate of stars of different masses. Stars with masses similar to our Sun live for billions of years, before swelling up to become a red giant, blowing off their outer layers to form a planetary nebula, and leaving behind an Earth-sized stellar remnant known as a white dwarf. Because of their large radii, red giants are extremely luminous.

More massive stars – those with masses above about 8 Solar masses – have much shorter main sequence lifetimes. Their cores become much hotter than the core of the Sun, which allows additional stages of nuclear fusion that convert the core into iron. Iron is the most stable atomic nucleus, so once an iron core has formed no additional nuclear reaction (neither fusion nor fission) can liberate more energy. Deprived of its energy source, the star cannot maintain the pressure gradient that previously supported the core against the inward force of gravity. The core collapses in a fraction of second, the outer layers are blown off in a supernova explosion, and the collapsed core remains as a neutron star or a stellar mass black hole.

A supernova explosion, which lasts a few months, is one of the most violent astronomical events known. A single supernova can outshine a whole galaxy containing billions of ordinary stars!

Neutron stars were discovered following the discovery of pulsars by Jocelyn Bell in 1967. Pulsars are rotating neutron stars that emit extremely regular pulses of radio emission in a manner similar to a lighthouse. All pulsars are neutron stars, but not all neutron stars (in fact only a very small subset) are pulsars.

A neutron star is extremely small and dense – the mass is similar to that of the Sun but the radius is only about 10 km. The density of the matter – predominantly neutrons – is comparable to the density of the atomic nucleus.

One pulsar is surrounded by a planetary system – how this formed is unknown.