Summary of Lecture 22

Key points include:

1. As we're heard, white dwarfs have a maximum possible mass of about $M_{\rm max} = 1.4\ M_\odot$, where as usual $M_\odot$ is the mass of the Sun. Neutron stars also have a maximum mass, but it isn't known as well because of complexities of how neutrons interact. That maximum isn't more than $3\ M_\odot$, and could be more like $2.2\ M_\odot$.
2. But now for the last possible stellar remnants: black holes. Unlike other objects, black holes don't have surfaces. Instead they have a point of no return called an *event horizon*. This is a radius inside of which the gravity is so strong that nothing can escape, not even light. If a black hole has a mass M, then the radius of the event horizon is $R_{\rm EH} = 2GM/c^2$, where G is Newton's gravitational constant and c is the speed of light.
3. By astronomical standards, the event horizon radius is really small. In fact, $R_{\rm EH} \approx 3\ {\rm km}\ (M/M_\odot)$, so a few-solar-mass black hole would fit inside a city(!!!).
4. If you fall into a black hole you can't come back out again, and you keep falling until you reach the center, which is the location of the *singularity*. In our current theory of gravity (Einstein's theory of *general relativity*), the singularity is an infinitesimal point of infinite density. Probably that prediction tells us that the theory fails at the singularity and that some more broadly applicable theory is needed to explain the center of a black hole. But we don't have such a theory yet.
5. It is important to remember that far from a black hole, its gravity operates just as would the gravity of anything else of the same mass. If, for example, the Sun were magically turned into a black hole of one solar mass, the Earth would continue to orbit the (now) black hole without any change.
6. But *near* a black hole, things are weird. For example, if you were far from a black hole and talking (say, using radio waves) with a friend who was just outside the event horizon, then your friend would seem to you to be talking and moving very slowly. To your friend, you would seem to be talking and moving very rapidly.
7. Some people and movies hope that black holes can somehow be bonded together to form *wormholes*, through which we could move rapidly from point to point in space. But probably they don't exist.
8. If you fall feet-first toward anything that is gravitating, your feet are closer to the thin than is your head, which means that your feet experience a greater gravitational acceleration than your head. In turn, this means that you are stretched. Close to a low-mass black hole, this would stretch you out like a strand of spaghetti, and would

tear you apart. This is known as *spaghettification*. Black holes can actually tear stars apart in this way.

9. Gravity affects everything, including light. Thus the gravity of a black hole (or even an ordinary star, but not by as much) can bend light. This is called *gravitational lensing*.

10. Something that falls into a black hole doesn't come back out. Thus black holes by themselves would be invisible. However, they can reveal their existence via their effect on other things. For example, gas spiraling into a black hole experiences friction with itself, which heats up the gas and allows it to radiate. Indeed, this is how some of the brightest things in the universe (quasars) are powered: by gas spiraling into supermassive black holes. Another way that you can detect the presence of a black hole is to see one or more stars orbiting around an empty patch. This is, for example, seen in our Milky Way galactic center.