54.9: Black Holes

A star like our Sun exists in a state of equilibrium: its own gravity tries to pull the Sun's mass inward toward the center, but the outward radiation force due to nuclear fusion (which burns hydrogen fuel to create helium, causing the Sun to shine) is pushing outward. The inward and outward forces are in balance, and the Sun assumes the shape of a sphere of its current size.

Eventually (about 5 billion years from now), the Sun will run out of hydrogen fuel to burn, and the Sun will begin to collapse. The collapse will cause the Sun's material to heat again; the Sun will then enter a phase where it becomes a red giant star and burns helium as fuel to create carbon and other heavy elements. Once the helium fuel is used up, what's left behind will be a dense stellar core called a white dwarf star. Eventually, over 10 billion years or so, a white dwarf star will cool into a black dwarf star. [2] A similar fate awaits any star with a mass less than about 4 to 8 solar masses.

For a bigger star (4-8 up to about 10-15 solar masses), the star's gravity is strong enough to actually collapse the atoms in what would have been a white dwarf at the end of the star's life. The electrons are pushed into the atomic nuclei, forming essentially a giant ball of neutrons called a neutron star. As described in Chapter 4, neutron star material is extremely dense.

Stars with an initial mass of greater than about 10-15 solar masses face an even more exotic destiny. The gravitational force will be so strong that even the neutrons are collapsed. Once the star runs out of fuel, the entire star collapses into a mathematical point called a singularity: it is essentially a hole punched in space itself. Surrounding the black hole is a spherical region of space called the event horizon, where the force of gravity is so strong that not even light can escape. Any matter—even light—that crosses inside the event horizon can never escape from the black hole's gravity, and effectively becomes cut off from the rest of our Universe. The radius of the event horizon (called the Schwarzschild radius) is found by setting the escape velocity (Eq. 54.6.2) to the speed of light c, which gives

$$R=\frac{2GM}{c^2} \tag{54.9.1}$$

The existence of black holes is predicted by general relativity, and their reality has been confirmed to the satisfaction of most astronomers. A well-known example is called Cygnus X - 1 , an X-ray source in the constellation Cygnus.

In addition to the stellar-mass black holes described here, astronomers have recently discovered that most, if not all, galaxies contain a supermassive black hole at their center, with a mass on the order of millions or billions of solar masses. Our own Milky Way galaxy has such a supermassive black hole at its center called Sagittarius A^*, with a mass of 4 million solar masses.

We don't know what goes on inside a black hole's event horizon. Some astrophysicists believe a wormhole may be formed-essentially a tunnel leading to a distant part of our Universe, or even to another Universe. Black hole research is still in its infancy, and is at the frontier of astrophysics research.

[2] No black dwarf stars have yet been detected.