CHAPTER 6B

TNF Time Scales for the core of a $20M_\odot$ star:

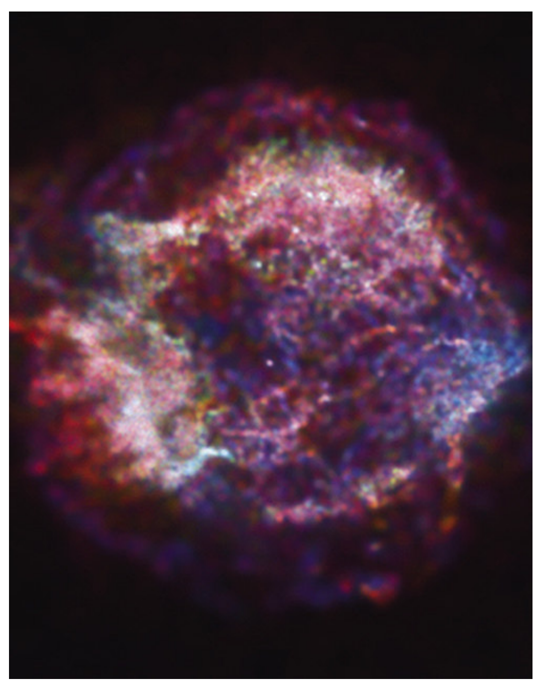
Fuel	Exhaustion Time (years)
H	7×10^6
He	0.5×10^6
C	600
Ne	1
O	0.5
Si	1 day

L. Supernova

Exactly which stars become supernovae is not yet clear, but more than likely they are massive stars that become highly evolved. A star that develops an iron core will contract and get hotter but the iron will not undergo fusion. Finally, a temperature is achieved where very energetic gamma rays dominate the EM radiation in the core. These gamma rays collide with the iron nuclei and cause them to undergo photodisintegration.

$$Fe + \gamma \rightarrow 13He + \nu^o + 4n^o$$

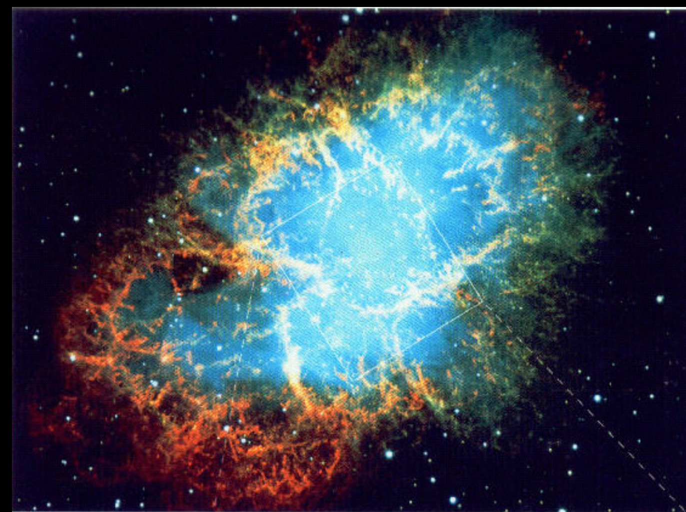
The neutrinos escape from the star and carry off thermal energy very rapidly. This causes the pressure in the core to drop precipitously and the core then collapses under the enormous weight of the upper layers. The collapsing upper layers of the star produce a shock wave while the electrons and protons in the core are forced to combine and form neutrons. The production of neutrons produces an outward flow of more neutrinos, but the density of the core is now so great that it is opaque to the neutrinos. This produces another shock consisting of an expanding shell of neutrinos. This interacts with the other shock of the in-falling outer layers so that it bounces off the core and propagates upwards through the star resulting in an explosive repulsion of the upward layers. Many nuclear fuels in the upper layers of the star may ignite explosively also. In addition to the direct fusion o heavy nuclei, many other elements are produced as a result of neutron capture or proton and alpha particle absorptions. This all happens within a few seconds.



This produces a Type II supernova, whose spectrum displays Balmer lines revealing the presence of a hydrogen envelope.

Observationally, a supernova event causes the star to brighten by a factor of 1 million or more and can outshine all the stars in the galaxy containing the event. To observers on the Earth, this event appears as a new star in the galaxy, because previously it was too faint to be detected. This is the origin of the term "Nova". There are different kinds of novae, but ordinary novae outbursts are not as luminous as supernovae events.

The outer layers of the star blow off at very high speed, leaving behind the core of the star that is referred to as a supernova remnant. That remnant may be a neutron star, white dwarf, or black hole, depending on its mass after the explosion.



A Supernova Remnant, M1 in Taurus (The Crab Nebula)

The blown off layers continue to expand and eventually enrich the interstellar medium with the heavy elements the star produced. The Crab Nebula in Taurus is a good example of the expanding envelope from a Type II supernova explosion. Historical records indicate that the explosion happened in the year 1054 AD. A pulsar has been discovered at the center of this rapidly expanding envelope. Pulsars are the observational manifestation of rapidly rotating neutrons stars.

So stars are slowly causing a change in the chemical composition of a galaxy. Successive generations of stars will then have a higher abundance of heavy elements. In this way, the age of a star may be determined by the relative abundance of metals. Some of the heavy elements will form microscopic particles that are called “dust”. Only in this way does it become possible to make planets and people. So we are made of “stardust.”

A supernova event happens only for very massive stars. The Sun will not become a supernova. It and other low mass stars will shed their outer layers as they evolve to their final stage. The shedding of the outer layer non-explosively is called the planetary nebula stage. This name arose from the fact that these expanding shells appeared like fuzzy planets to early telescopic observers.

Other Types of Supernovae:

Type Ia supernovae are believed to be white dwarfs that have collapsed after accreting too much mass from a companion star. As mentioned above, the spectrum reveals the presence of a hydrogen envelope. It also might be the result of the merger of 2 white dwarfs.

Type Ib and Ic supernovae originate much like Type II, that is a massive star that undergoes core collapse after exhausting all nuclear fuel in the core. However, they have spectra with no indication of hydrogen. The precursor stars are believed to have lost their hydrogen envelopes to a companion star or by wind action.

M. Final Stages

When a star is prevented from collapsing so that it cannot ignite another TNF reaction it enters into a final stage where it slowly cools off and dies as a star. The possible final stages, depending on what stops further contraction are:

(1). White dwarf
(2). Neutron star
(3). Black Hole.

Which final stage a star eventually reaches depends critically on its mass. Very massive stars may undergo a supernova explosion and then become either a white dwarf, neutron star, or black hole, depending on how much mass the star has after the explosion.

Stars like the Sun and those less massive than the Sun evolve to become white dwarfs. In a while dwarf, the repulsive forces between electrons is strong enough to balance gravity if the star's mass is less than 1.4 times the Sun's mass. The theory for this was first worked out by S. Chandrasekhar, for which he was awarded the Nobel Prize. This limiting mass for a white dwarf is known as the Chandrasekhar Limit. White dwarfs eventually cool to become black dwarfs, but the universe is insufficiently old for this to have occurred for any star yet.

Stars slightly more massive than 1.4 solar masses contract to the point where all electrons are forced into the nuclei to combine with the protons and form neutrons. The repulsive force of neutrons then balances gravity. This is a neutron star. Neutron stars are very small, have intense magnetic fields, and spin very rapidly. The radiation emitted along the magnetic axis is very strong. If the magnetic axis is tilted with respect to rotational axis, we would observe the radiation coming from the star to be in pulses, much like a rapidly rotating lighthouse. Such objects have been detected and are called "pulsars". Hence, pulsars are evidence that neutron stars exist.

Stars that enter the final stage of evolution with more than 3 solar masses become black holes. Here the gravity of the star is so strong that light cannot escape from the star, so it is said to be black. There is no known force that can stop the star from contracting and this is a problem. Ordinary classical physics cannot explain what happens in a black hole and we must turn to the general theory of relativity. In general relativity, very massive objects distort space and time and gravity is viewed as the curvature of space-time.