Cosmic Catastrophes
309N Spring 2014
(48690)

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February 25, 2014

Review for Test #2

SUPERNOVAE (continued)

Type Ib Supernovae - no hydrogen, but observe helium early on, O, Mg, Ca later. Occur in spiral arms, never in elliptical galaxies. Massive star core collapse.

Type Ic Supernovae - no hydrogen, little or no helium early on, O, Mg, Ca later. Occur in spiral arms, never in elliptical galaxies. Massive star core collapse.

Light curves of Type Ib and Ic are similar to Type Ia, but dimmer at maximum brightness.

To burn a thermonuclear fuel, the star must get hotter to overcome the charge repulsion. This happens automatically in massive stars supported by the thermal pressure that regulates their burning. These stars produce shells of ever-heavier elements and finally a core of iron.

Iron (with 26p and 30n) is endothermic, absorbing energy. This will reduce the pressure in the core and cause the collapse of the iron core to form a neutron star.

The collapse of the core, a gravitational collapse, causes essentially all the protons to be converted to neutrons, releasing a flood of neutrinos and forming a neutron star.

Repulsive nuclear force between highly compressed neutrons and neutron quantum pressure halt the collapse and allow the neutron star to form.

Neutron star – mass of Sun, but size of a small city. Huge density, surface gravity. Maximum mass of about 2 solar masses.

Forming a neutron star by core collapse produces about 100 times more energy than needed to create an explosion, but most of that energy is carried off by neutrinos.

The core collapse explosion of the outer layers of the star may occur in one of three ways:

1. Prompt mechanism: The neutron star rebounds, driving a shock wave into the outer parts of the star. The bounce shock occurs, but is insufficient to cause an explosion.
2. Delayed mechanism: Neutrinos stirred out by the boiling neutron star deposit heat behind the standing shock and reinvigorate it. Not clear this is sufficient.
3. Jet mechanism: the collapsing rotating neutron star squeezes the magnetic field and sends a jet up the rotation axis. Naturally makes asymmetric explosion, but not yet clear sufficiently strong jets are produced.

Standing shock – a strong pressure wave that forms due to neutron-star bounce, but which stalls a certain distance from the neutron star as outer material rains down on it.

All core-collapse supernovae measured to date, Type Ib, Ic, and II, are not spherical. They may be "football" shaped or "pancake" shaped or some combination of elongation and flattening.

Jet mechanism - rotation will produce a dynamo amplifying magnetic fields. Computer calculations show that rotation wraps up magnetic field "lines of force" causing the magnetic field and trapped matter to be expelled up (and down) the rotation axis. The generic phrase for this jet mechanism is the "tube of toothpaste effect." It is an open question whether or not sufficiently strong jets to explode a star can be produced in this way when a neutron star forms, but the Crab pulsar, other young pulsars, Cas A and SN 1987A show evidence of jet-like features.

Jet-induced explosions - Supercomputer computations show that sufficiently powerful jets can blow up a star. The jets plow up and down along one axis creating a “breadstick” shape and driving bow shocks. The bow shocks propagate away from the jets toward the equator where they collide. The result of this collision is to blow much of the star out along the equator in a torus or “bagel” shape. The final configuration is far from spherical, but has jets in one direction and a torus expanding at right angles to the jet.

Jet-induced asymmetry – in addition to producing the jet/torus shape, the jet model predicts that iron is blown along the jet and other elements in the outer layers, He, are ejected in the equatorial torus. This may provide an observational test of the model.

Massive star binaries - Explosions of massive stars in close binary systems are expected to occur in a bare thermal pressure-supported core from which the outer layers of hydrogen have been transferred to the companion star. The core, supported by the thermal pressure, will continue to evolve to iron, even in the absence of the hydrogen envelope. This is probably the origin of Types Ib and Ic.

Failed explosion - if there is no core collapse explosion, outer layers fall in, crush neutron star (maximum mass about 2 solar masses) to form a black hole.

Type Ia - must generate explosion in old (1 to 10 billion years) stellar system. Most plausible mechanism, explosion of a white dwarf.

White dwarfs nearing 1.4 solar masses made of C/O will explode completely after igniting carbon under conditions of quantum pressure support.

Spectra of Type Ia reveal intermediate elements (O, Mg, Si, S, Ca) on the outside and iron-like material on the inside. Consistent with models of Chandrasekhar mass carbon-oxygen white dwarfs that begin with a subsonic *deflagration* (“flame”) and then ignite a supersonic *detonation* (“bomb”).

Deflagration – a flame, propagates slower than the speed of sound

Detonation – burning drive a self-propagating supersonic shock wave.

Shockwave – a supersonic wave that involves a sudden, steep increase in pressure at the wave front. The force, related to the rate of charge of pressure, is especially destructive.

A deflagration flame will make a transition to a detonation if there is sufficiently strong turbulence to fold and pack the flame.

Pressure waves and exploding stars expand at about the speed of sound, faster than a deflagration, slower than a detonation.

Thermonuclear burning of carbon and oxygen at white dwarf densities will produce iron. Burning at lower densities in an expanding, exploding white dwarf will produce intermediate mass elements.

Deflagration burning can never catch up with the outer expanding matter. Detonation burning will overtake the outer expanding matter.

Detonation alone would turn whole white dwarf to iron. Deflagration alone leaves too much unburned carbon. A combination of deflagration converting to detonation accounts for the observations.