Cosmic Catastrophes Wheeler
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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.

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.

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 “breadstick” shaped or “bagel” 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, is ejected in the equatorial torus. This may provide an observational test of the model.

Failed explosion - if there is no core collapse explosion, outer layers fall in, crush neutron star (maximum mass ~2$M_\odot$) to form a black hole.

Type Ia - must generate explosion in old (1 to 10 billion years) stellar system. Most plausible mechanism mass transfer onto white dwarf.

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

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.

Kepler's Third Law — The total mass of two stars in orbit can be determined by measuring the period of the orbit and the distance between the stars. Subtracting the mass of the known star then gives the mass of the unknown star: a white dwarf, neutron star, or black hole.

Roche Lobes — Region of gravitational dominance of each star in a double system. More massive star reaches out further, has the largest lobe.

Inner Lagrangian Point — Connection point between Roche Lobes through which mass can be transferred between stars.

Algol Paradox — The evolved star is the less massive. Resolution - mass has been transferred between the stars.

Mass Transfer — Most massive star of close pair evolves first, fills its Roche lobe and some of its mass begins to leak through inner Lagrangian point to the companion star.

First stage of mass transfer - Mass transfer begins when the originally more massive star becomes a red giant with a tiny core. Transfer stops only when whole envelope has been stripped from the core and passed to the companion or lost from the system.

Second Stage of Mass transfer — the star which initially had the smaller mass of the pair now burns out its hydrogen, tries to form a red giant and begins passing mass through the inner Lagrangian point of the Roche lobes to a white dwarf.

Accretion disk — matter streaming through inner Lagrangian point does not directly strike the tiny, orbiting, white dwarf, but circles around and forms a flat spiraling disk. The disk has its own life in the system.

Friction — matter at smaller distance from the center of the disk moves more quickly, rubbing against matter just beyond it moving more slowly and against matter interior to it moving more quickly. The result is friction and heat and light generated everywhere in the disk. The friction also drags material inward giving rise to the *accretion* onto the central compact star.

Disk radiation — the outer parts of disks typically have temperatures comparable to the Sun and shine with optical light. Middle parts are hotter and glow in ultraviolet light. This is appropriate for white dwarfs. The innermost parts can be hot enough to emit X-rays. This is appropriate to neutron stars and black holes.

Cataclysmic variable — system consisting of a white dwarf receiving mass via an accretion disk from a companion, frequently a small mass main sequence star.

U Sco — An example of a recurrent nova in the constellation of Scorpius. The white dwarf has been measured to have a mass greater than 1.3 $M_\odot$ and is thought to be headed to a thermonuclear supernova explosion.

Identifying the binary evolution that makes Type Ia has been difficult. Nova explosions will reduce the mass of the white dwarf, not grow it. There may be too few white dwarf pairs, too few recurrent novae.

Final evolution of cataclysmic variables — one possibility is that a massive white dwarf may reach mass limit of 1.4 $M_\odot$ and explode.

White dwarfs nearing 1.4 $M_\odot$ made of C/O will explode completely after igniting carbon under conditions of quantum pressure support.