Cosmic Catastrophes — Wheeler
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(48535)

Review for Test #1
BACKGROUND AND INTRODUCTION TO SUPERNOVAE

The Universe is a strange place.

Gravity – acts as if all the mass beneath were concentrated in the center. Gravity at surface depends on the mass and the radius of the object. Gravity is stronger inside massive, compact stars. Gravity gets weaker further away from any object.

Stellar balancing act — dynamic equilibrium. A star spends most of its lifetime at a relatively constant size, temperature, luminosity, etc. while it fuses some fraction of its hydrogen into helium. During this time there is a balance between the forces inward and the forces outward.

Forces inward — due to gravity, without the forces acting outwards the star would collapse.
Forces outward — pressure

Thermal pressure — For most of the lifetime of the star this is the dominant source of outward pressure. With this pressure a star can regulate its temperature.

Regulated temperature – the nuclear burning is regulated when thermal pressure dominates, for instance, on the main sequence. If too much energy is temporarily lost, the star contracts and heats, increasing nuclear input. If too much energy is temporarily gained, the star expands and cools, and nuclear input declines.

Quantum Theory – Exclusion principle, uncertainty principle.

Quantum pressure — Electrons cannot occupy the same region of space if they have the same energy. As matter is squeezed down, electrons develop more "uncertainty" energy depending only on the density and independent of the temperature. The electrons' resistance to being squeezed any closer together provides pressure independent of temperature. With this pressure a star cannot regulate its temperature.

Unregulated temperature — the process of energy loss, contraction, and heating is stopped when the core becomes so compact and dense that electrons are squeezed together and the quantum pressure dominates. Broken thermostat. If such a star (or core) loses energy, it cools since pressure does not depend on the temperature, so there is no loss of pressure and the star does not contract and heat. If the star gains energy, it heats up, more nuclear reactions, more heat, explosion!

Main Sequence — stars fuse hydrogen into helium and thus supply energy.

Red Giant — when hydrogen burns out in the center, excess heat flowing from the contracting core causes the outer layers to *gain energy*. They then *expand and cool*. The outside becomes larger, cooler, redder, and more luminous.

Planetary nebulae —Most stars less than 8 $M_\odot$ eject their outer envelopes of unburned hydrogen as planetary nebulae. Core of C and O cools to become white dwarf.

White Dwarfs. Size of Earth, mass of Sun. Supported by the quantum pressure. Most are single stars, mass about 0.6 solar mass, cooling time longer than the age of the Universe.

Maximum mass of white dwarf, Chandrasekhar Mass ~ 1.4 $M_\odot$, supported by quantum pressure of electrons.

Two explosion mechanisms – collapse of core of massive star or exploding white dwarf.

Historical Supernovae in the Milky Way - several seen and recorded with naked eye in last 2000 years. SN 386 earliest on record, SN 1006 brightest, SN 1054, now the Crab Nebula, contains a rapidly rotating pulsar and suggestions of a jet. Tycho 1572, Kepler 1604. Cas A not clearly seen about 1680, shows evidence for jets, and a dim compact object in the center. The events that show compact objects also seem to show evidence of "elongated" explosions or "jets." SN 1006, and SN 1604 were probably Type Ia, exploding white dwarfs, SN1572 definitely was.

SN 1987A in a very nearby galaxy came from a massive star, about 20 solar masses, shows elongated ejecta, produced neutrinos so we know it was powered by core collapse.

Extragalactic Supernovae - many, but dimmer, more difficult to study. Galaxies like our Milky Way produce about 1 supernova per 100 years. Supernovae occur about 1 per second in the Universe and are discovered about once per day.

Supernovae are traditionally named alphabetically by discovery.

Common elements formed from "building blocks" of helium in stars: carbon, oxygen, neon, magnesium, silicon, calcium. Produced in massive stars before they explode, in white dwarfs during explosion.

Type I supernovae - no evidence for hydrogen in spectrum.

Type II supernovae - definite evidence for hydrogen in spectrum.

Type Ia Supernovae – relatively brighter, no hydrogen or helium, avoid spiral arms, occur in elliptical galaxies, origin in lower mass stars. Observe silicon early on, iron later. Unregulated burning, explosion in quantum pressure supported white dwarf of nearly Chandrasekhar mass. Star is completely disrupted, no neutron star or black hole. Light curve shows peak lasting about a week.

Type II Supernovae – relatively dimmer, explode in spiral arms, never occur in elliptical galaxies, normal hydrogen, massive stars, recently born, short lived. Observe H early on, O, Mg, Ca later. Probably result from core collapse in iron core of massive star. Light curve often shows month's-long "plateau." Characteristic of explosion in a red giant.

Betelgeuse – red giant 427 light years away, 15 to 20$M_\odot$, is expected to explode within 10,000 years, maybe tonight, as core collapse Type II supernova. Keep an eye on it.