Cosmic Catastrophes Wheeler
309N SPRING 2006 February 7, 2006
(48165)

Review for Test #1

WHITE DWARFS

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.

Quantum pressure. Electrons cannot occupy the same region of space if they have the same energy. As matter is squeezed down, electrons develop more 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.

Stellar furnace — Nuclear fusion. On the Main Sequence, stars fuse hydrogen into helium and thus supply energy.

The nuclear burning is regulated 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.

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, and redder. The star becomes a red giant.

Loss of energy, 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!

Most stars less than 8 $M_\odot$ eject their envelopes as planetary nebulae, core of C and O cools to become white dwarf, size of Earth, mass of Sun.

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

Kepler's Third Law — The total mass of the two stars can be determined by measuring the period of the orbit and the distance between the stars.

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.

Mass transfer begins when 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 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. The innermost parts, found only for neutron stars and black holes, are hot enough to emit X-rays.

Disk heating instability — when mass transfer rate is low, material is stored in the disk in a cool state. Eventually heat is trapped, leading to a runaway heating instability which turns the whole disk hot and bright. The disk then thins out and cools and returns to the storage state.

White dwarfs — Supported by the quantum pressure. Most are single stars, mass about 0.6 $M_\odot$, cooling time longer than the age of the Universe.

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

Dwarf nova — flares about 10 times brighter every month or so. Probably due to the disk heating instability.

Recurrent Novae — flare 1000 times brighter every 10-100 years. The mechanism is thought to be similar to that of Classical Novae, a thermonuclear explosion of an accreted layer of hydrogen, but on an especially massive white dwarf, where the strong gravity leads to frequent but weaker flashes. Recurrent Novae may grow the white dwarf to the Chandrasekhar mass limit of 1.4 $M_\odot$, at which point the white dwarf would explode.

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.

Classical Novae — flares 10^4 to 10^5 times brighter, suspected to recur, but no direct evidence. Mechanism is layer of accreted hydrogen supported by the quantum pressure that builds up on the surface of the white dwarf and then ignites, burns unstably and explodes. About 10^{-4} $M_\odot$ is ejected.

Classical Nova explosions show an enrichment in heavy elements suggesting that some matter has been ripped from the white dwarf itself, thus reducing its mass.

Common envelope evolution — when the first star evolves its envelope may surround both its core and the companion star. Core and companion may spiral together. Possible explanation of why cataclysmic variables have main sequence companions.

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

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

Gravitational Radiation — A systematic "wiggling" of the curvature of space sends out gravitational waves of space curvature. Carry energy, angular momentum from a binary star system.

Double white dwarfs — If the first white dwarf does not grow and explode, the second star can evolve to produce a white dwarf, resulting in two orbiting white dwarfs. These will spiral together by gravitational radiation, until smaller mass, larger radius white dwarf fills its Roche lobe. Mass transfer causes small white dwarf to be transferred essentially entirely to the larger one. May get larger white dwarf or, thermonuclear explosion