

Review for Test #1
WHITE DWARFS

When hydrogen is burned out in the center, the outside becomes larger, cooler, and redder. The star becomes a red giant.

Most stars less than $8 M_{\odot}$ eject their envelopes as planetary nebulae, core of C and O cools to become white dwarf, ~ 10 - 100 billion in the galaxy.

White dwarfs—most are single stars, mass about $0.6 M_{\odot}$. Radius comparable to Earth about 1% of the sun cooling time longer than the age of the Universe.

Newton showed gravity acts as if all mass is in the center, more compact stars have higher gravity at their surface.

Thermal pressure. For most of the lifetime of the star this is the dominant source of outward pressure.

With thermal pressure a star can regulate its temperature. 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 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 quantum pressure a star cannot regulate its temperature. 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, \rightarrow explosion!

Maximum mass of white dwarf, Chandrasekhar Mass $\sim 1.4 M_{\odot}$, 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 stars in a double system. More massive star reaches out further, has the largest lobe.

Inner Lagrangian Point – Connection point between Roche Lobes, point 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.

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 the remains of the first star—a white dwarf, neutron star, or black hole.

Accretion disk—matter streaming through inner Lagrangian point does not directly strike the tiny, orbiting, companion star, 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.

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 a process in the disk causing mass transferred from the companion star to be stored until a critical density is reached. A wave of heating causes a sudden rise in brightness. The matter then flows rapidly inward toward the white dwarf. A wave of cooling subsequently occurs, the disk returns to a storage mode, and the cycle begins again.

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.

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, thermonuclear explosion or collapse.