Review

Final exam (Monday, May 20, 10:30 AM to 12:30 PM) will be on material extending over entire class, but will have more emphasis on material after the midterm. That includes star formation and evolution (single and binary) and assorted stuff on black holes, rotation, and neutrinos. Closed book and notes. Please bring a calculator but don't program it, and bring pen and paper.

We've had a number of different segments in the course, so let's come up with some of the most important concepts for each. **Ask class:** for list in each case.

Overall stellar structure

1. Symmetry and things that can be ignored. We've assumed spherical symmetry (we showed that deviations are usually small). We have ignored all kinds of things, from magnetic fields to the strong and weak force, because these were shown to be insignificant. Selective neglect is a major tool in astrophysics!

2. Equilibrium. This includes hydrostatic and thermal equilibrium. It is justified because for almost the whole life of stars they are in near-equilibrium for most or all of their mass.

3. Virial theorem. Relation between potential energy and internal energy. Internal energy can be thermal, kinetic (e.g., rotation), degenerate, or other. Applications.

Energy generation

1. Fusion vs. other. Why fusion? For the majority of a star's life, fusion is a stable reservoir of plenty of energy, and other sources don't work. Note, however, that other energy sources (gravitational contraction, rotation, magnetic fields, thermal, etc.) find their applications in other parts of astrophysics. As a first cut, finding out where the energy comes from is a good step towards understanding a phenomenon.

2. Basics of fusion. Coulomb barrier. Tunneling. Binding energy curve. Strong temperature dependence. Higher temperature required for heavier elements, leading to increasing losses by neutrinos and photodissociation. Proton-proton chain vs. CNO cycle as ways of burning hydrogen.

Equation of state

1. General states of matter: solid, liquid, gas, plasma, degenerate. Comparison of energies: thermal, Coulomb, Fermi, crystal, etc. to estimate state of matter.

2. Fermi-Dirac vs. Bose-Einstein statistics. Degeneracy. Principles of ionization, photo- vs. collisional/density-induced. When can one assume ionization equilibrium?

Opacities

1. General types of opacities (radiative, conductive, convective). How do these add? When linearly, when harmonically?

2. For radiative, opacity vs. cross section. Opacity is the effective area per gram; cross section is effective area of a given particle. Cross section can be high and opacity low if there are few of the particular particles in a volume.

3. When are radiative, conductive, convective opacities most important? Conductive is mainly at low temperature, for degenerate matter. When does convection occur? If temperature gradient is steeper than adiabatic, convection takes over.

Star formation

1. Origin in molecular clouds. How do we know this? We can see it directly.

2. Collapse of molecular clouds. Jeans mass. Angular momentum problem (too much of it; how can it be removed?). Angular momentum transport in accretion disks. What about magnetic fields?

3. Pre main sequence evolution. Jets and disks.

Star evolution

1. Primary driver is mass. At what mass does the CNO cycle take over from the pp chain? When is the helium core degenerate vs. non-degenerate? When does the star evolve into a white dwarf as opposed to exploding in a supernova?

2. Path from main sequence to red giant to white dwarf. Path for higher-mass stars, sequence of burning. Trigger for supernova. Stellar winds and mass loss as an important new feature for higher-mass stars.

3. Binary stars. Crucial differences from single stars. Mass transfer.

Miscellaneous

1. Black holes and neutron stars. The "pit in the potential" and effectively stronger gravity in general relativity. Evidence for black holes. Pulsars, neutron degeneracy.

2. Rotation of normal stars. Typically weak. Causes oblateness. All structural deviations must be even-powered in rotation frequency, by symmetry.

3. Neutrinos. Produced in nuclear reactions. Deficit seen in electron neutrinos; now thought to be because of flavor mixing.