REVIEW FOR THE FINAL EXAM

   This review sheet is intended to be a broad guide to help you prepare for the examination. Some of the exam questions will test basic knowledge of the material (i.e., knowing just the facts), but others test understanding of the implications of these facts. So, you will be tested on knowledge and application. This is NOT an exhaustive listing! Material for the final exam will not be limited to what appears here, but if it appears here, I consider it to be important. Calculators will be needed. Expect 60 multiple choice questions with a few being quantitative problems.

   Focus your study on my lecture notes and past quizzes. Treat the book as supplemental. And of course, if you have any questions, feel free to ask.

1. *Miscellany:* Be aware of basic information, such as names and order of the planets, name of our galaxy, name of North Star, etc. Be able to interpret graphical data.

2. *Historical:*

   - Ptolemy and the geocentric model; Aristarchus, Aristotle, Pythagoras, Eratosthenes
   - Copernicus and the heliocentric model - understand how retrograde loops motivated the heliocentric approach
   - Kepler and his three laws of planetary motion (know about ellipses, and jargon such as "semi-major axis" and "eccentricity")
   - Galileo's contributions to modern astronomy, especially the heliocentric model
   - Hooke - central forces
   - Newton and his three laws of motion; terminology: forces, inertia, speed, velocity, acceleration, momentum, angular momentum ("spinnedness")
   - Kirchoff's three laws - different cases
   - blackbodies - know what these are plus Wien's law and Stefan-Boltzmann law
   - Bohr atom - know about electrons, protons, neutrons, nucleus, energy levels, absorption, emission, ionization, recombination and relation to Kirchoff's laws

3. *Science:*

   - scientific notation, order of magnitude, metric prefixes
   - Gravity (know the formula), circular motion under gravity, meaning of escape speed, gravity explains orbital motions of Kepler's laws
   - Planck's Law - photons and photon energy
   - Blackbodies - Wien's law and Stefan-Boltzmann's Law
   - Flux (i.e., the inverse square law of light), luminosity,
   - Doppler shift - connection to motion, use of redshift and blueshift
   - Electromagnetic spectrum – different kinds of light, wavelengths, frequencies, relation between wavelength and frequency and speed of light, also photons and energy of light

- Observing with telescopes - atmospheric "seeing", atmospheric transparency, why put telescopes in space, concept of "resolution" for image detail (angular resolution) and spectral detail (spectral resolution), telescopes as "light buckets" (aperture size)
- Gases, Pressure, Temperature, Density and the Ideal Gas Law; concept of gas as particles in motion, thermal speed of particles

4. *The Sky:*

- Order of the planets from the Sun (remember there are 8 now!)
- celestial sphere, terminology
- know what constellations are (no, do not memorize all of the constellations, but understand how stars in space relate to the celestial sphere)
- perspective issues: rotation of Earth and diurnal motion, star trails, revolution of the Earth around the Sun and relation to seasonal constellations, circumpolar stars
- the ecliptic, the tilt of the Earth, reason for seasons

5. *Sun:*

- be familiar with general properties of the Sun – composition, different sections (core and convective zone), etc
- interior – fusion, p-p chain (hydrogen to helium), neutrinos, the neutrino problem and resolution, how long the Sun can live
- atmosphere – the three components (photosphere, chromosphere, corona) and general properties, activity (sunspots, solar flares), solar wind
- the solar cycle for sunspots, that it is associated with magnetic fields, and that the cycle is 11 years

6. *Topics on General Star Properties:*

- Stellar brightnesses, apparent and absolute magnitudes
- H-R Diagram (HRD) - know what the HRD is a plot of (luminosity and temperature), Main Sequence, spectral types and meaning and their sequence (OBAFGKM), luminosity classes, know why some stars have strong hydrogen absorption lines and others do not, know the 'anatomy' of the HRD (main seq, giant, supergiants, WD stars)
- Stellar properties - how are mass, luminosity, radius, and temperature measured or deduced?
- General trends - mass-luminosity relation; stellar census, what kinds of stars are common/rare: hot O stars rare, and cool M stars common
- Distances - stellar parallax, spectroscopic parallax and related issues (such as extinction and reddening), proper motion
- Binaries - types (eclipsing, visual, spectroscopic), deriving masses, know about eclipsing binary lightcurves (getting relative luminosities, radii, temperatures)
- Nature of stars - what is hydrostatic equilibrium (gas pressure balances gravity)? what is the Eddington Limit (cap for star luminosity)? what are brown dwarfs? what does it mean to be a star?

7. *Stellar Evolution:*

- Star Formation - sequence of formation, cloud collapse, phases, and the timescales (see next)
- Important timescales - the Kelvin-Helmholtz timescale, cloud collapse timescale (or "free-fall" timescale); you show know characteristic numbers for these; Main Sequence timescale (fuel over consumption rate); you show know characteristic numbers for these (such as, the sun can live for 10 billion years, massive stars are more like tens and hundreds of millions of years, and lower mass stars are 100 billion years and longer)

- know that the mass of a star is all-important for determining the type of star and its evolution
- low mass stars have nuclear fusion of H in their cores ala the proton-proton chain, but high mass stars fuse H via the carbon cycle
- know how convection can influence the lifetime of a star
- know about the idea of evolutionary tracks in the HRD
- know that mass loss (stellar winds) affects the lifetime of stars because it alters their mass
- know about the period-luminosity relation for Cepheids
- know about star clusters and the main sequence turn-off point, and how star clusters are relevant to understanding stellar evolution; know cluster types (globular vs galactic or open)

8. *Stellar Remnants:*

- Termination of stars - why this happens and what stars become as a function of initial star mass: supernovae, planetary nebulae, white dwarfs, neutron stars, black holes
- Pauli exclusion principle and degeneracy pressure (pressure that depends on density but not temperature)
- White Dwarfs - electron degeneracy pressure, know typical size, know Chandrasekhar mass limit, connection with novae and cataclysmic variables
- supernova events, why they happen, extremely bright, Type Ia versus Type II and their progenitors
- Neutron Stars - neutron degeneracy pressure, typical size, mass limit, discovery, pulsars, rotation and magnetic field
- Black Holes - properties, common misconceptions, Schwarzschild radius, event horizon, how they are found, example of Cygnus X-1

9. *The Milky Way Galaxy:*

- Interstellar Medium – components, properties, nebulae (reflection nebulae, planetary nebulae, HII regions, supernova remnants)
- the characteristic size and shape of the MW
- measuring distances in the MW
- Attempts by Herschel and Kapteyn to find where we are in the MW, and why they were wrong
- How Shapley used globular clusters to get the right answer!
- Differential rotation of the MW and the rotation curve of the galaxy
- How we map the spiral structure of the MW (what do we use as "tracers"?), and what is going on in the spiral arms? The spiral arms as a pattern, and relation of arms to star formation
- evidence for dark matter in the halo of the MW, rotation curve of the galaxy, terminology such as "flat rotation curve", knowing how to recognize the edge of a galaxy in terms of the rotation curve
- conditions at the Galactic center, evidence for a supermassive black hole
- stellar populations (Pop I vs Pop II) and properties; know that different populations have different metallicities

10. *Galaxies:*

- Clusters and the Local Group – know basics about the Large Magellanic Cloud (LMC), Small Magellanic Cloud (SMC), and M31
- Types and general properties – spirals, ellipticals, irregulars (which are most common, which have young stars, which are metal-poor vs metal-rich, and so on)

- know about galaxy formation and evolution (such as colliding galaxies and mergers)
- Distance Ladder – the expanding Universe, Hubble's law, redshift, finding the Hubble constant, concept of standard candles: Cepheids, Type Ia SNe, Tully-Fisher relation

11. *Active Galaxies:*

- know the types (Seyferts, Blazars, Radio galaxies, Quasars, etc)
- know the properties (jets, radio emission, broad/narrow lines, IR or X-ray)
- know about the **Unified model** and our understanding of Active Galactic Nuclei in terms of mass infall onto black holes (and the relevance of the Eddington limit for this)
- what are the arguments for SBH's (high luminosities from compact volumes!); recall properties of black Holes, such as Schwarzschild radius

12. *Cosmology*

- Large Scale Structure – mapping of galaxies and clusters of galaxies in space; know basic description in terms of voids, filaments, and sheets
- Special Relativity and postulates, the idea that speed of light is absolute and so events are not generally simultaneous as perceived by different observers; General Relativity, the Equivalence Principle, curvature of space, gravitational lensing
- Olber's paradox - what is the question and what are the potential resolutions
- the expanding universe, and getting the age of the Universe from the Hubble constant, H
- the Cosmological Principle – concepts of isotropy and homogeneity, what is the "steady-state model"
- Some 'highlights' – early Universe filled with light, formation of Helium, 'decoupling', formation of galaxies
- Cosmic Background Radiation (CBR) – Gamow's fireball model, discoverers Penzias and Wilson, relevance to the Big Bang model
- Critical Density and relation to curvature of space (positive, negative, zero/flat) and the 'fate' of the Universe
- the Inflationary universe - what is it, and what does it solve?
- Dark Energy - evidence for it from Type Ia SNe, the cosmological constant, quintessence; dark energy represents 70% of the 'content' of the universe, and dark matter represents 30%; the dark energy accelerates the expansion of the universe
- Cosmologists define the parameter Ω as as a number that represents the total matter and energy content of the universe with spacetime curvature implications: $\Omega = 1$ is a "flat" universe, $\Omega < 1$ is closed (positive curvature), and $\Omega > 1$ is open (negative curvature)
- The idea that Ω consists of matter and energy contributions, such as Ω_B is for the baryon (normal) matter, Ω_{DM} is for dark matter, and Ω_{DE} is for dark energy; then

$$\Omega_{total} = \Omega_B + \Omega_{DM} + \Omega_{DE}$$

- It is currently accepted that $\Omega_{total} = 1$, with DM 30% of it and DE 70% of it.

13. *Extra-solar Planets:*

- Know about the different search techniques: eclipse, Doppler shift, astrometric, photometric or imaging, microlensing
- Know that the transit method (NASA's Kepler) has yielded the most discoveries to date

- know basic characteristics of detected planets: tend to be Jupiter mass; some are very odd, being in small short-period orbits (so-called hot Jupiters); some are multi-planet systems

14. *Life in the Universe:*

- Essentials for life – "reproduction" capability, water, carbon, radiation (or energy)
- Habitable zones - know what this means and what sets its boundaries
- Searching for life – know about SETI and radio listening efforts, know about searches for life in the Solar System other than Earth, be familiar with Fermi's question and implications
- Galactic colonization – relevant issues, typical time required; know about the Fermi question
- know about the Drake equation

EXPRESSIONS WE HAVE SEEN - Be familiar with what the equations <u>represent</u>!

Wave properties of light, $\lambda \nu = c$

Energy property of photons, $E = h\nu$

Doppler shift, $\frac{\Delta \lambda}{\lambda} = \frac{v}{c}$

Kepler's 3rd law for the Solar System, orbital period $P^2 \propto a^3$

Force of gravity, $F_G = GMm/d^2$

Escape speed, $v_{\text{esc}} = \sqrt{2GM/R}$

Circular orbital speed, $v_{\text{c}} = \sqrt{GM/R}$

Newton's version of Kepler's 3rd Law, $a^3 = \frac{G(m_1 + m_2)}{4\pi^2} P^2$

Newton's 2nd law, force $F = ma$

Ideal gas law, pressure $P \propto \rho T$

Thermal speed of gas particles $v_{\text{th}} \propto \sqrt{T/m}$

Flux of light, flux $F \propto L/d^2$

Wien's law, $\lambda_{\text{max}} \propto 1/T$

Stefan-Boltzmann law, surface brightness $F_{\text{BB}} \propto T^4$

Geometric Stellar Parallax $d(\text{pcs}) = 1/\theta(\text{arcsec})$

Newton's version of Kepler's 3rd Law $(M_1 + M_2) \propto a^3/P^2$

flux $F \propto L/d^2$

$L_{\text{MS}} \propto M^3$

$L \propto R^2 T^4$

$t_{\text{ff}} = 50 \text{ Myr} \sqrt{\frac{1}{n_{\text{cloud}}}}$

$t_{\text{KH}} = 30 \text{ Myr } \frac{M^2}{RL}$

$t_{\text{MS}} \propto \frac{M}{L}$

$t_{\text{MS}} = 10^{10} \text{ Gyr } \frac{1}{M^2}$

Period $-$ Luminosity Relation, $P \propto L$

Schwarzschild Radius, $R_S = \frac{2GM}{c^2}$

Mean density, $\rho = 3M/4\pi R^3$

The Hubble law $v = Hd$

Relation of the Hubble constant to the age of the universe age $\approx 1/H$

Rotation curves: $v_{\text{rot}} = \sqrt{GM/r}$, where M is the interior mass of the orbit