Cosmology Final Review

1. Compact Objects
    a. Stars, Supernovae, white dwarfs, brown dwarfs, black holes, neutron stars
    b. HR Diagram and classifications,
    c. Dark matter, rotation curves, detection
    d. Gravitational Lensing, halos, Einstein rings, $\alpha = \frac{4GM}{c^2 b}$
    e. MACHOs, WIMPs, axions, neutrinos (and flavors)
    f. Radio astronomy, pulsars, quasars, First radio sources, …
    g. Black holes – Wheeler, Bekenstein, Hawking, no hair theorem, Hawking radiation
2. Cosmic Background Radiation, CMB 2.7255 ± 0.006 K
    a. History – Timeline, People
    b. Kelvin, Poincare, Slipher, Leavitt, Einstein, Schwarzschild, Friedmann, Lemaitre, Hubble, Robertson, Walker, Lundmark, van Oort, Zwicky, Rubin, Ford, ….
    c. Gamov, Alpher, Dicke, Peebles, Roll, Wilkinson, Hoyle, Bondi, Gold, Fowler, Burbidge
    d. Bell Labs, Jansky,Ryle, Baade, Penzias, Wilson,
    e. Steady state theory
    f. Experiments – High Altitude balloons, Boomerang, COBE, WMAP, Planck
    g. Results
        i. Blackbody spectrum
        ii. Dipole distortion (motion of COBE, Earth, Sun, Galaxy, Local group motions)
        iii. Temperature fluctuations
        iv. Multipoles and spherical harmonics
        v. Mollweide projection
    h. Baryon to photon ratio $\eta = 6 \times 10^{-5}$
    i. (Radiative) Recombination epoch ($z = 1380, T = 3760K, t = 250,000 yr$)

       $p + e^- \leftrightarrow H + \gamma$
    j. Photon decoupling ($z = 1090, T = 2970K, t = 371,000 yr$)

       Thomson scattering $\lambda + e^- \leftrightarrow \gamma + e^-$
    k. Last scattering surface
    l. Fractional ionization, *X*
    m. *Saha Equation* $\frac{1-X}{X^2} = S = 3.84\eta \left(\frac{kT}{m_e c^2} \right)^{3/2} e^{Q/kT}$ for recombination $S = 0.5$
3. Big Bang Nucleosynthesis
    a. Know timeline.
    b. Binding energy per nucleon
    c. Binding energies $p + e^- \leftrightarrow H + 13.6\text{eV}$ $p + n \leftrightarrow D + 2.22\text{MeV}$
    d. $T_{nuc} = 7.6 \times 10^8 K, t_{nuc} = 200s$
    e. He fraction, $Y_{\max} = \frac{2f}{1+f}, f = \frac{n_n}{n_p}$, Y – primordial 24%, max 1/3
    f. Beta decay $n \to p + e^- + \bar{\nu}_e$ ($\tau_n = 880s$)

g. Binding energy – compute from difference in rest energies
h. Beyond Deuterium – what about other elements?
i. Baryon-antibaryon asymmetry

4. Inflation
   a. What is inflation? Know key problems at the time – Flatness, Horizon, Monopole
   b. Standard Model of Particle Physics – Glashow, Weinberg, Salam, Gell-Mann, Higgs Quarks, Baryons, Mesons, Bosons (photons, gluons, W, Z), Leptons
   c. Symmetry breaking, Higgs mechanism (gives mass) Mexican Hat
   d. Phase transitions (loss of symmetry) and unification of forces. See Figure 11 and blackboard rendition online – including energy, temperature and time scales, electroweak, GUT and TOE, QED, QCD
   e. Topological defects
   f. General model of inflation – simple case $a(t) = \begin{cases} a_i \left(t/t_i\right)^{1/2} & t < t_i \\ a_i e^{H_i(t-t_i)} & t_i < t < t_f \\ a_i \left(t/t_f\right)^{1/2} e^{H_i(t_f - t_i)} & t > t_f \end{cases}$
   g. Number of e-foldings, $N = H_i(t_f - t_i)$.
   h. Alan Guth, 1979, Inflaton field, false vacuum
5. Miscellaneous
   a. Planck scales, $\ell_P, M_P, t_P, E_P, T_P$.
   b. Hubble Law $v = H_0 r,\ z \approx \frac{v}{c}$, Hubble parameter $H(t) = \frac{\dot{a}(t)}{a(t)}$
   c. Hubble constant $H_0 = 68 \pm 2 \text{ km s}^{-1} \text{ Mpc}^{-1}$,
   d. Hubble time $H_0^{-1} = 14.38 \pm 0.42 \text{ Gyr},$, Hubble length $\frac{c}{H_0} = 4380 \pm 130 \text{ Mpc}$
   e. Horizon distance $d_p(t) = c\int_0^{t_0} \frac{dt}{a(t)}$
   f. Red shift $1 + z = \frac{1}{a(t_e)},\ a(t_0) = 1.$
      i. Friedmann Equation: $\left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G}{3c^2}\varepsilon - \frac{\kappa c^2}{R_0^2 a^2}$ and $H_0^2 = \frac{8\pi G}{3c^2}\varepsilon_0 - \frac{\kappa c^2}{R_0^2}$,
   g. Density parameters
      i. $\Omega_{CMB} = 5.35 \times 10^{-5}$, $\Omega_\nu = 0.681\Omega_{CMB}$, $\Omega_r = 9.0 \times 10^{-5}$
      ii. $\Omega_m = 0.31, \Omega_\Lambda = 0.69$ (Benchmark)
   h. Units – AU, pc, Mpc, Planck units, light year, flux, luminosity, Size of Milky Way
   i. Blackbody radiation - $\varepsilon_\gamma = \alpha T^4$, $n_\gamma = \beta T^3$, Stefan-Boltzmann Law
   j. Doppler Effect, $\frac{\Delta\lambda}{\lambda} = \frac{v_r}{c}$