Main Concepts (Midterm #1)

- FUNDAMENTAL OBSERVATIONS
  - Cosmological Principle (*Olber’s Paradox, mean free path*)
  - CMB (*blackbody radiation*)
  - Hubble Expansion
  - Abundance of Light Elements
- THEORETICAL TOOLS (*General Relativity, Robertson-Walker Metric*)
  - Cosmic Time
  - Comoving Distance
  - Proper Distance
  - Cosmological Redshift
- SOLUTIONS TO THE FRIEDMANN EQN. (*Fluid Eqn., Eqn. of State*)
  - Evolution of the energy density (*e.os., critical density, density parameter*)
  - Dominant energy density (*Critical density, Density parameter, Evolution of the energy density*)
  - Redshift-time relation (*Lookback time*)
  - Redshift-distance relation (*Horizon distance*)
  - Acceleration Equation (*Dark Energy*)
  - Measuring the curvature of space
Main Concepts Continued (Midterm #1)

- **MEASUREMENTS OF COSMOLOGICAL PARAMETERS**
  - Measuring kinematics of the universe determines cosmological parameters.
  - Proper distance depends on redshift via the Hubble constant, to first order.
  - Higher order terms are needed to obtain other cosmological parameters.
  - Proper distance is not appropriate. We need stuff we can measure.
    - Luminosity Distance
    - Angular-Diameter Distance
    - Standard Candles and Rulers
    - Fitting $H_0$ and $q_0$
    - Surface-Brightness Dimming & Tests of the Expansion

- **ASTROPHYSICS TO KEEP IN MIND**
  - Measuring the Hubble constant using nearby galaxies requires corrections for peculiar motions (i.e. attraction between galaxies).
  - Distances to nearby galaxies are determined by bootstrapping empirical distance indicators to direct distance measurements. This is known as the distance ladder.

- **IMPLICATIONS**
  - Type Ia Supernovae can be seen at large distances (i.e. $z \sim 1$). Measurements of the brightness and redshift indicate a negative deceleration parameter.
  - We live in an accelerating universe! And Einstein’s cosmological constant is back in fashion.
  - SNe and CMB give marginally inconsistent $H_0$. Stay tuned for multi-messenger astronomy.
Summary of Distances

1. Co-moving Distance
2. Proper Distance
3. Luminosity Distance
4. Angular-Diameter Distance

- As $z \rightarrow 0$, we have
  \[d_A \sim d_L \sim d_p(t_0) \sim c H_0^{-1} z\]
- As $z \rightarrow \infty$, we have
  \[d_p(t_0) \text{ goes to } d_{\text{hor}}(t_0)\]
  \[d_L \text{ goes to } z d_{\text{hor}}(t_0)\]
  \[d_A \text{ goes to } d_{\text{hor}}(t_0) / z\]
- Benchmark model has maximum $d_A = 1800$ Mpc at $z=1.6$; and object subtends the smallest angle
Measuring Cosmological Parameters

- Measuring the Hubble constant using nearby galaxies requires corrections for peculiar motions (i.e. attraction between galaxies)
- Distances to nearby galaxies are determined by bootstrapping empirical distance indicators to direct distance measurements. This is known as the distance ladder.
- Type Ia Supernovae are the best standard candle that can be seen at large distances (i.e. $z \sim 1$). Measurements of the brightness and redshift indicate a negative deceleration parameter.
- We live in an accelerating universe! And Einstein’s cosmological constant is back in fashion.