Outline

- Go over homework (8.2)
- Einstein equations with cosmological constant
- Friedmann equations with cosmological constant
- Observable effects of cosmological constant/dark energy
Einstein Equations

- The Einstein tensor is only a function of the metric.

\[ G_{\mu\nu} = R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = \frac{8\pi G}{c^4} T_{\mu\nu} \]

- It is possible to add another term to the Einstein tensor without destroying its transformation properties. The term must be a constant multiplied by the metric.

\[ R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R + \Lambda g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu} \]

- This changes the Friedmann equations...
Friedmann Equations

- First Friedmann equation: 
  \[ \left( \frac{\dot{R}}{R} \right)^2 = \frac{8\pi}{3} G \rho - \frac{k c^2}{R^2} + \frac{\Lambda}{3} \]

- Acceleration equation: 
  \[ \frac{\ddot{R}}{R} = -\frac{4\pi G}{3 c^2} \left( \rho c^2 + 3 P \right) + \frac{\Lambda}{3} \]

- Energy conservation: 
  \[ \dot{\rho} c^2 = -3 \frac{\dot{R}}{R} \left( \rho c^2 + P \right) \]

- Key feature is that \( \Lambda \) can lead to a positive acceleration.
- Interpret \( \Lambda \) as energy density, show that it eventually dominates expansion of the universe.
Homework

- For next class, problem 8.3.
- Have a nice spring break!