Outline

• Go over homework (8.3)
• Friedmann equations with cosmological constant
• Observable effects of cosmological constant/dark energy
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: \[ \frac{\ddot{R}}{R} = -\frac{4\pi G}{3 c^2} \left( \rho c^2 + 3P \right) + \frac{\Lambda}{3} \]

• Previously derived energy conservation equation from first two. Do that for the case with dark energy.

\[ \dot{\rho} c^2 = -3 \frac{\dot{R}}{R} \left( \rho c^2 + P \right) \]
Equation of State of the Universe

• Matter dominated: $\rho c^2 >> P$
  - Use energy conservation to show $\rho \sim R^{-3}$

• Radiation dominated: $P = (1/3)u = (1/3) \rho c^2$
  - Use energy conservation to show $\rho \sim R^{-4}$

• What is equation of state for $\Lambda$?
  - Use Friedmann equations substituting in $\varepsilon_\Lambda$ and $P_\Lambda$.
  - Find $P_\Lambda = -\varepsilon_\Lambda$
Homework

- For next class, problem 8.5.