Outline

- Go over homework
  - What does it mean that the Universe is expanding?
- Equation of state of universe
- Solutions of the Friedmann equations

Friedmann Equations

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

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

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

- Want to find $R(t)$
  - First need to know dependence of ρ and P on R.
  - The equation of state of the universe.

Equation of State of the Universe

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

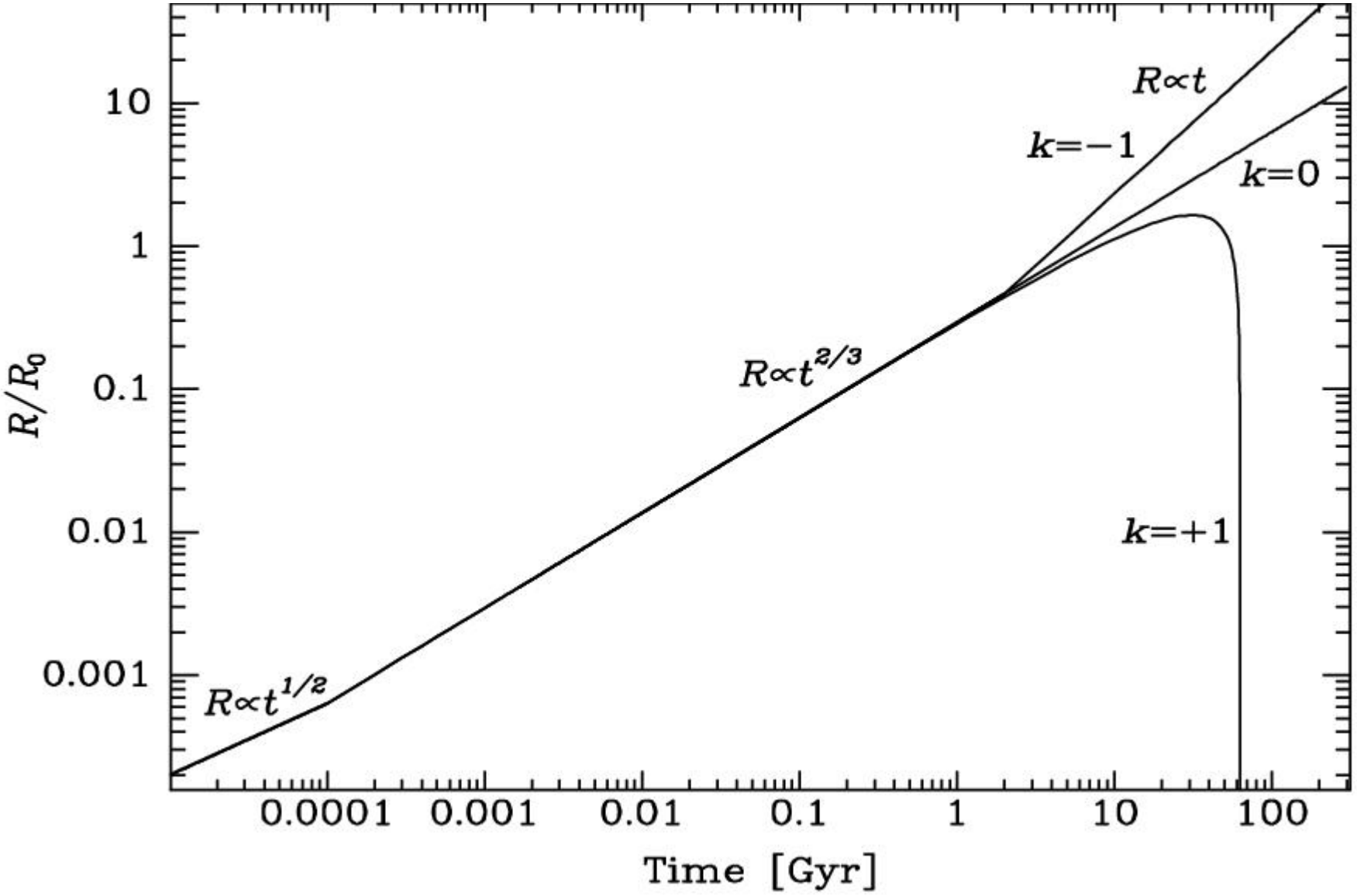
- Radiation dominated: $P = (1/3)u = (1/3)\,\rho c^2$
  - Use energy conservation to show $\rho \sim R^{-4}$

Time Evolution of the Universe

- Want to find $R(t)$, use first equation $\left(\frac{\dot{R}}{R}\right)^2 = \frac{8\pi}{3} G\rho - \frac{kc^2}{R^2}$
- R is smaller at earlier times
- Early enough, $\rho \sim R^{-3}$ or R^{-4} will dominate over R^{-2}
- Matter dominated: $R \sim t^{2/3}$ (work out on board)
- Radiation dominated: $R \sim t^{1/2}$ (work out on board)
- Radiation dominates at very early times, $R \to 0$, $\rho \to \infty$ = big bang

- Find evolution at later times, keeping k term, on board.
  - Recall $H = \dot{R}/R$

Time Evolution of the Universe



- Find time for transition from radiation to matter dominated and age of universe on board.

Homework

- For next class:
  - Problem 8.1