Introductory Astronomy

Week 8: Cosmology

Clip 4: Our Universe: First Look

Cosmological Parameters

$$H^2 = \frac{8\pi G}{3}\rho - \frac{kR_0c^2}{a^2} + \frac{\Lambda c^2}{3}$$

$$-qH^2 = -\frac{4\pi G}{3}\left(\rho + \frac{3P}{c^2}\right) + \frac{\Lambda c^2}{3}$$

$$\Omega_0 - 1 = \frac{kR_0c^2}{H_0^2}$$

$$\Omega_0 = \Omega_{D,0} + \Omega_{R,0} + \Omega_{\Lambda,0}$$

$$q = \frac{1}{2}\Omega_D + \Omega_R - \Omega_\Lambda$$

- Measure $H_0 = 100h\frac{\mathrm{km/s}}{\mathrm{Mpc}}$ $h = 0.71$
- Parameterize density by

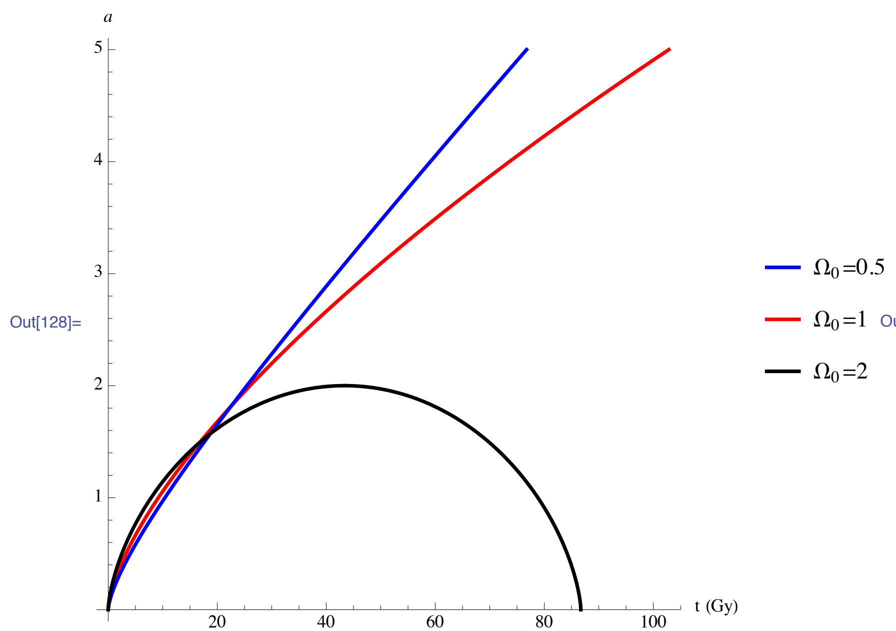
$$\Omega = \rho/\rho_c \qquad \rho_c = \frac{3H^2}{8\pi G}$$

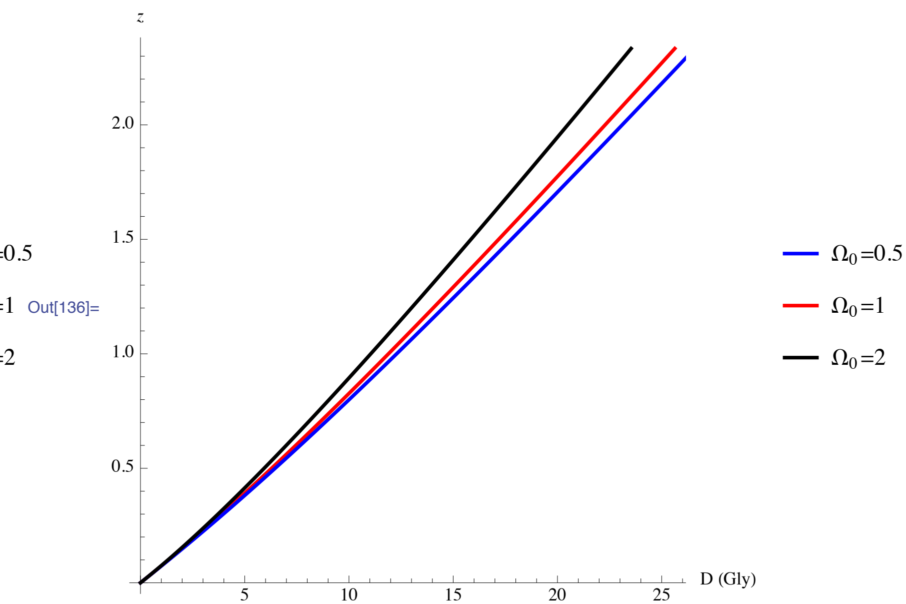
$$\rho_{c,0} = \frac{3H_0^2}{8\pi G} = 4.17 \times 10^{-28}\,\mathrm{kg/m^3}$$

- Best data:

$$\begin{aligned} \Omega_{Db,0} &= 0.044 \\ \Omega_{D,0} &= 0.256 \\ \Omega_{R,0} &= 4.765 \times 10^{-5} \\ \Omega_{\Lambda,0} &= 0.74 \end{aligned}$$

Dust Universe





$$a(t) = (3H_0 t/2)^{2/3} \quad H_0 t_0 = 2/3$$

First Look Back

- The past was denser $\rho_D(t) = \rho_{D,0} a(t)^{-3}$
- It was hotter $v(t) = v(t_0) a(t)^{-1}$
- Hydrogen ionized until $z_{ion} \sim 1000$ recombination $t_{ion} \sim 380\,\mathrm{ky}$
- Before that baryonic matter and radiation exchange energy rapidly maintaining thermal equilibrium
- Radiation dominated $\rho_R(t) = \rho_{R,0} a(t)^{-4}$ until

$$a_{RT} = \Omega_{R,0}/\Omega_{D,0} = 1.58 \times 10^{-4} \quad z_{RT} \sim 3300 \quad t_{RT} \sim 55\,\mathrm{ky}$$

- In radiation era $a(t) = a_{RT} \left(\frac{t}{t_{RT}} \right)^{1/2}$

Temperatures and Species

- Gas of particles at $T \gg \frac{mc^2}{k_B}$ will be relativistic
- Energy spectrum blackbody. Mean energy $\sim k_B T$
- Energy density $\rho = g\frac{\sigma T^4}{4c}$
- Cosmic expansion redshifts energies preserving blackbody spectrum $T(t) = T_0 a(t)^{-1}$
- Far in the past, everything is relativistic

Duke UNIVERSITY