permanent adress: $\vec{r}_c$ (dimension less)

distance $D = a(t)\,|\vec{r}_c|$

$V_r(t) = H(t)\,D(t)$

$H_0 = H(t_0) = \text{Hubble constant} \simeq \frac{70\ \text{km/s}}{1\ \text{Mpc}} = \frac{1}{14 \cdot 10^9\ \text{yr}}$

$H(t) = \frac{\dot{a}(t)}{a(t)}$

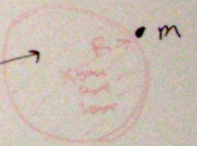
$\left.\frac{dr_c}{dt}\right|_{\text{light}} = \frac{c}{a(t)} \implies z = \frac{\overset{=a(t_0)}{a_0}}{a(t)} - 1$

$r_c(\text{emit}, t) = \int_t^{t_0} \frac{c}{a(t')}\,dt'$

$D(\text{emit}, t) = a(t) \cdot r_c(\text{emit}, t)$

$D(\text{emit}, t_0) = a_0 \cdot r_c(\text{emit})$

$\rho(t)$



$M = \frac{4\pi}{3}\rho(t) R^3$

$V_{pot} = -\frac{GMm}{R} = -\frac{4\pi R^2 G}{3}\rho(t) \cdot m$

$T_{kin} = \frac{m}{2} v^2$

$V_{pot} + T_{kin} = E \quad \Big| :m \quad -V_{pot}$

$\frac{v^2}{2} = \frac{4\pi G}{3} R^2 \rho(t) + \frac{E}{m}$

$\frac{\dot{a}^2 r_c^2}{2} = \frac{4\pi G}{3} a^2 r_c^2 \rho(t) + \frac{E}{m}$

$$\dot{a}^2 = \frac{8\pi G}{3}\rho(t)\,a^2 + \frac{2E(r_c)}{m r_c^2}$$ | assume $E \sim r_c^2$

$$\qquad \overset{\shortparallel}{-Kc^2}$$ | fiddle with a

$a = R_{curvature}$

until $K = $
- $-1 \rightarrow$ unbounded "open", negative curvature
- $0 \rightarrow \infty$, flat
- $+1 \rightarrow$ finite "closed", positive curvature

$a = R_{curvature}$

$$H^2(t) = \frac{\dot{a}^2(t)}{a^2(t)} = \frac{8\pi G}{3}\rho(t) - \frac{Kc^2}{a^2(t)}$$

$$H_0^2 = \frac{8\pi G}{3}\rho(t_0) - \frac{Kc^2}{a_0^2}$$

$$1 = \underbrace{\frac{8\pi G}{3H_0^2}}_{=\frac{1}{\rho_c(0)}}\rho(t_0) - \frac{Kc^2}{a_0^2 H_0^2}$$

$$\frac{\rho^{(0)}_{Baryons}}{\rho_c(0)} \simeq 4\text{-}5\% \qquad \frac{\rho^{(0)}_{Dark\,Matter}}{\rho_c(0)} \simeq 26\%$$

$$\Omega_M = 30\% \sim \frac{a_0^3}{a^3}$$

$$\Omega_\Lambda = 70\% \sim 1$$

$$\Omega_R = \frac{\frac{\varepsilon(\gamma)}{c^2}}{\rho_c} = 8\cdot 10^{-5} \sim \frac{a_0^4}{a^4}$$

$$T \sim \frac{1}{a}$$