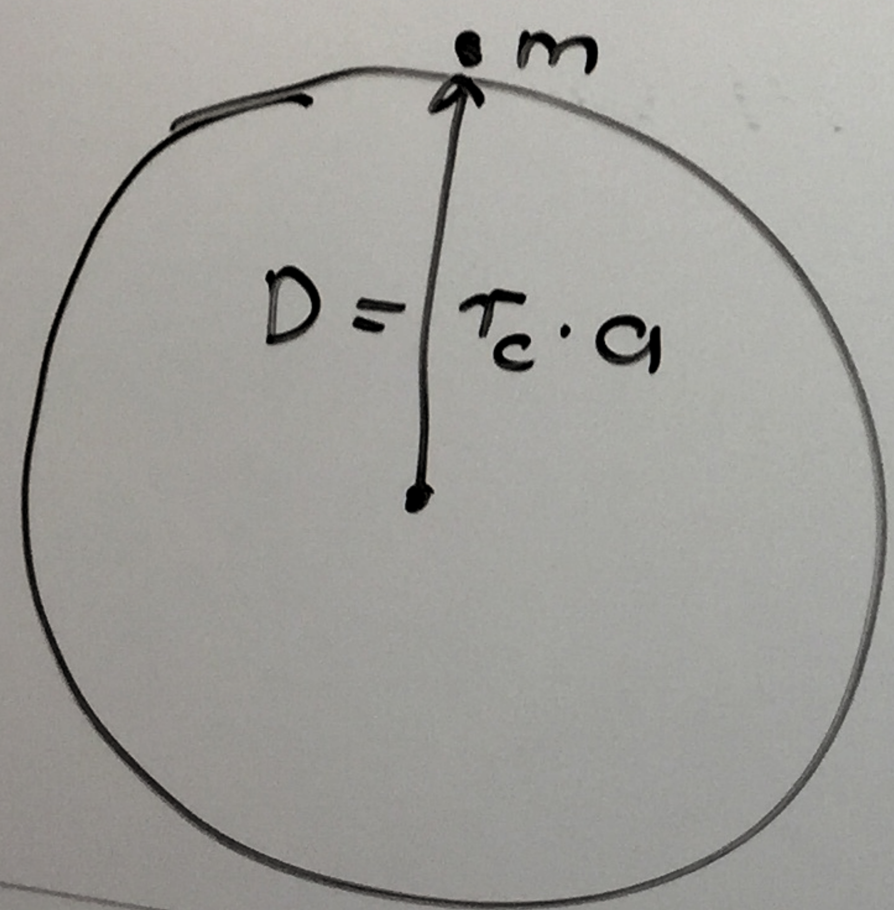
$a(t)$ → if Universe curved ⇒ $a$ = radius of curvature

→ if flat → $a = \frac{c}{H_0}$




$$T_{kin} = \frac{1}{2} m r_c^2 \dot{a}^2(t)$$

$$U_{grav} = - \frac{G \rho \cdot \frac{4\pi}{3} r_c^3 a^3}{r_c a}$$

$$\frac{E_{tot}}{m} = \frac{1}{2} r_c^2 \dot{a}^2 - G\rho \frac{4\pi}{3} r_c^2 a^2$$

$$\frac{E_{tot}}{\frac{1}{2} m r_c^2 \dot{a}^2} = 1 - G\rho \frac{4\pi}{3} 2 \frac{a^2}{\dot{a}^2}$$

$H(t) = 0$ ? ⇒ $K = +1$

Dark Energy : $\rho$ = const

1) $E_{tot} = 0$ (≤ 1.)

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

$$\rho = \rho_{crit} = \frac{3}{8\pi G} \cdot H^2(t)$$

today : $\rho^0_{crit} = \frac{3}{8\pi G} \cdot H_0^2$ ← $H^2(t=t_0)$ $= 6\ m_p / m^3$

$\rho^0_{BM} \simeq 0.3\ m_p / m^3$

$\rho^0_{DM} \simeq 1.5\ m_p / m^3$

$\rho_{DE} = 4.5\ m_p \cdot c^2 / m^3$

2) $E_{tot} > 0$ → Universe is curved

3) $E_{tot} < 0$ → "

$$\rho = \rho_{Matter} + \frac{\varepsilon}{c^2}$$

$\sum_{matter} \gamma m$ / unit volume

$T_{kin} \ll mc^2$ : cold matter : $\rho \sim \frac{1}{a^3}$

$T_{kin} \gg mc^2$ : radiation : $\rho \sim \frac{1}{a^4}$

ν's, γ's …

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

$$H^2(t) \cdot \frac{E_{tot}}{T_{kin}}$$

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