

Title: 12/13 PSI - Cosmology Review Lecture 7

Date: Feb 27, 2013 11:30 AM

URL: <http://pirsa.org/13020107>

Abstract:

D.G.

G.R.

Max. Sym.

FRW

BH

→ Thermo/SM
in FRW]

FRW

$P \propto \frac{1}{a} \rightarrow$ Hubble Friction

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G.R.

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Thermo/
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FRW

$$P \propto \frac{1}{a}$$

→ Hubble Friction

→ Redshift $\lambda \propto a(t)$

D.G.

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Thermo/SM
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$P \propto \frac{1}{a}$ → Hubble Friction

Redshift $\lambda \propto a(t)$

Horizons → "Future" ← ("Event") → $\ddot{a} > 0$

"Past" ← ("Particle") → $\ddot{a} < 0$

Dynamics: $H^2 = \dots$

$\dot{\rho} = \dots$

$p \propto \frac{1}{a}$ → Hubble Friction
 → Redshift $\lambda \propto a(t)$

Horizons → "Future" ← ("Event") → $\ddot{a} > 0$
 → "Past" ← ("Particle") → $\ddot{a} < 0$

Dynamics: $H^2 = \dots$
 $\dot{p} = \dots$

$$H^2 = \frac{16\pi G \rho + 2\Lambda}{n(n-1)} = \frac{K}{a^2}$$

$$\dot{p} = -nH(p + \rho)$$

$$H^2 = \frac{16\pi G \rho + 2\Lambda}{n(n-1)} - \frac{K}{a^2}$$

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

$$\rho_{vac} = \frac{\Lambda}{8\pi G}$$

$$\rho_{tot} = \rho + \rho_{vac}$$

$$\dot{\rho} = -nH(\rho + p) \rightarrow$$

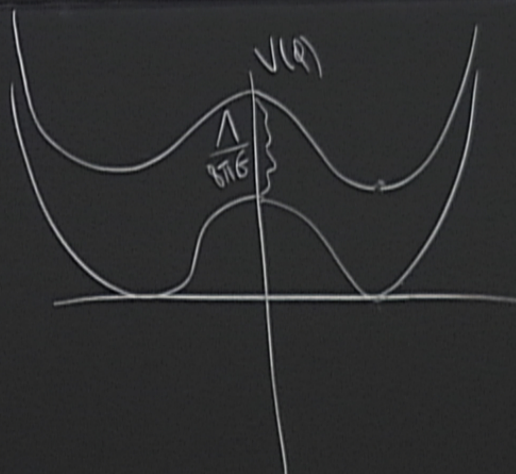
$$\dot{\rho} = -3H(\rho + p)$$

$$\rightarrow H^2 = \frac{8\pi G}{3} \rho_{tot} - \frac{K}{a^2}$$

$$S = \int d^4x \sqrt{-g} \left\{ \frac{R - 2\Lambda}{16\pi G} - \frac{1}{2} (\partial\phi)^2 - V(\phi) \right\}$$

$$\frac{\Delta}{8\pi G}$$

$$p + p_{vac}$$



$$H^2 = \frac{16\pi G \rho + 2\Lambda}{n(n-1)} - \frac{K}{a^2} \rightarrow H^2 = \frac{8\pi G}{3} \rho + \frac{\Lambda}{3} - \frac{K}{a^2}$$

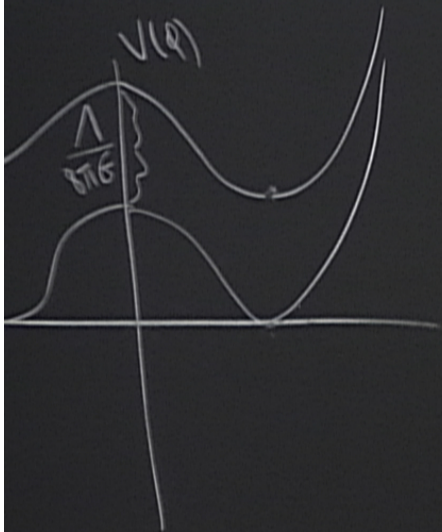
$$\dot{\rho} = -nH(\rho + p) \rightarrow \dot{\rho} = -3H(\rho + p)$$

$$H^2 = \frac{8\pi G}{3} \rho_{\text{tot}} - \frac{K}{a^2}$$

$$\rho_{\text{vac}} = \frac{\Lambda}{8\pi G}$$

$$\rho_{\text{tot}} = \rho + \rho_{\text{vac}}$$

$$S = \int d^4x \sqrt{-g} \left\{ \frac{R - 2\Lambda}{16\pi G} - \frac{1}{2} (\partial\phi)^2 - V(\phi) \right\}$$



$$\underline{G_m + \Lambda g_m} = \underline{T_{m\nu}}$$

$$\uparrow$$

$$T_{m\nu}^{\nu} = 0$$

$$\rho_{cr}(t) = \Omega(t) = \frac{3H^2(t)}{8\pi G_N}$$

$$\rho_0 = \rho_{cr} \pm 1\%$$

Flatness Puzzle

$$\rho_{cr}(t) = \rho(t) = \frac{3H^2(t)}{8\pi G_N}$$

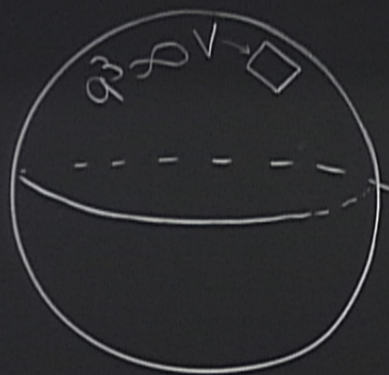
$$\rho_0 = \rho_{cr} \pm 1\%$$

Flatness Puzzle

$$\dot{\rho} = -3H(\rho + p) \quad p = w\rho$$

$$\rho \propto a^{-3(1+w)}$$





$$dE = \cancel{TdS} - PdV$$

$$d(gV) = -PdV \Rightarrow g dV + V dg = -w g dV \Rightarrow \frac{dg}{g} = -(1+w) \frac{dV}{V}$$

$$dE = \cancel{TdS} - PdV$$



$$d(gV) = -PdV \Rightarrow \rho dV + Vd\rho = -w\rho dV \Rightarrow \frac{d\rho}{\rho} = -(1+w) \frac{dV}{V}$$

$$\ln \rho = -(1+w) \ln V + C$$

$$\rho \propto V^{-(1+w)}$$

$$\propto a^{-3(1+w)}$$

$$\int \rho \times V - g \left\{ \frac{1}{16\pi G} - \frac{1}{2} (\partial\phi)^2 - V(\phi) \right\}$$

$$dE = T dS - P dV$$

$$d(gV) = -P dV \Rightarrow \rho dV + V d\rho = -w \rho dV \Rightarrow$$

$$\frac{d\rho}{\rho} = -(1+w) \frac{dV}{V}$$

$$\ln \rho = -(1+w) \ln V + C$$

$$\rho \propto V^{-(1+w)}$$

$$\propto a^{-3(1+w)}$$

$$\underline{w=0} \quad (\text{NR matter})$$

$$\underline{w=\frac{1}{3}} \quad (\text{Radiation})$$

$$\underline{w=-1} \quad (\text{DE, V.E.})$$

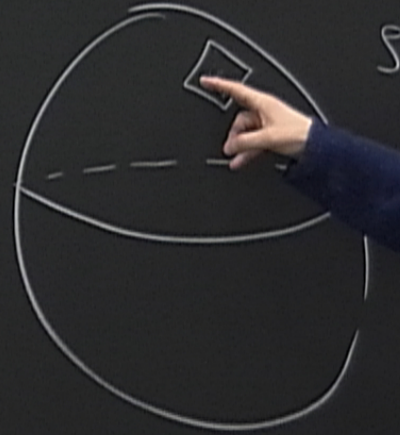
NR Matter

$$\underline{w=0} \quad (\text{NR matter})$$

$$\underline{w=\frac{1}{3}} \quad (\text{Radiation})$$

$$\underline{w=-1} \quad (\text{DE, V.E.})$$

NR Matter

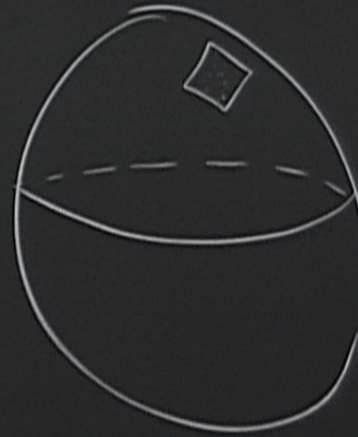


$$\underline{w=0} \quad (\text{NR matter})$$

$$\underline{w=\frac{1}{3}} \quad (\text{Radiation})$$

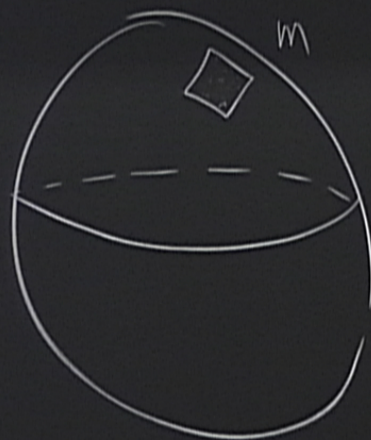
$$\underline{w=-1} \quad (\text{DE, V.E.})$$

NR Matter



$$\rho \propto a^{-3} = a^{-3(1+w)} \quad w=0$$

NR Matter



$$\rho \propto a^{-3} = a^{-3(1+w)} \quad w=0$$

$$hw \propto \frac{1}{a} \quad p = \frac{E}{V} \propto a^{-4} = a^{-3(1+w)} \quad w = \frac{1}{3}$$

$$a^{-3(1+w)} \quad w=0$$

$$\propto \frac{1}{a} \quad \rho = \frac{E}{V} \propto a^{-4} = a^{-3(1+w)} \quad w = \frac{1}{3}$$

$$G_{\mu\nu} + \Lambda g_{\mu\nu} = 8\pi G_N T_{\mu\nu} + 8\pi G_N T_{\mu\nu}^{\text{vac}}$$

$$T_{\mu\nu} = \rho g_{\mu\nu} + (\rho + p) u^\mu u^\nu$$

$$p_{\text{vac}} = -\frac{\Lambda}{8\pi G} = a^{-3(1+w)}$$

$$p_{\text{vac}} = -\frac{\Lambda}{8\pi G} = -p_{\text{vac}}$$

$$H^2 = \frac{8\pi G}{3} \rho - \frac{K}{a^2} \quad \rho = w\rho, \quad K = \begin{pmatrix} +1 \\ -1 \\ 0 \end{pmatrix}$$

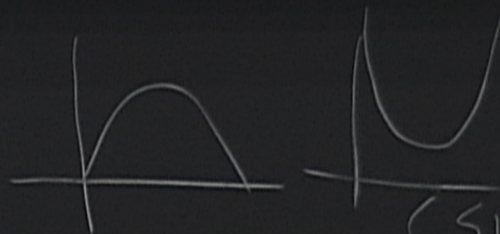
$$a(\eta) = (\dots) S_K^\alpha(\eta/\alpha) \quad \alpha = \frac{2}{1+3w}$$

$$S_K(x) = \begin{cases} \sin x \\ \end{cases}$$

$$-\frac{K}{a^2} \quad p = w p, \quad K = \begin{pmatrix} +1 \\ -1 \\ 0 \end{pmatrix}$$

$$(\dots) \underline{S_K^\alpha(\eta/\alpha)}$$

$$\alpha = \frac{2}{1+3w}$$



$$S_K(x) = \begin{cases} \sin x & K=+1 \\ x & K=0 \\ \sinh x & K=-1 \end{cases}$$

$$a \propto t^{\frac{2}{3(1+w)}} \propto \eta^{\frac{2}{1+3w}}$$

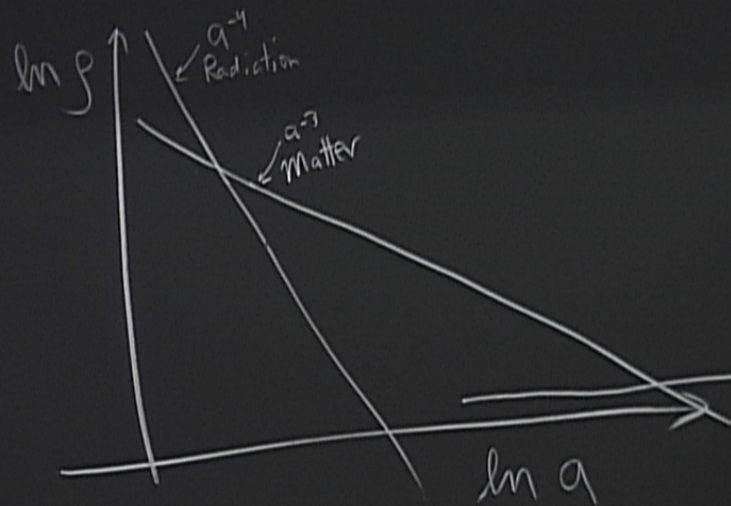
$$H = \frac{\dot{a}}{a} = \frac{2}{3(1+w)t} \quad w=0$$



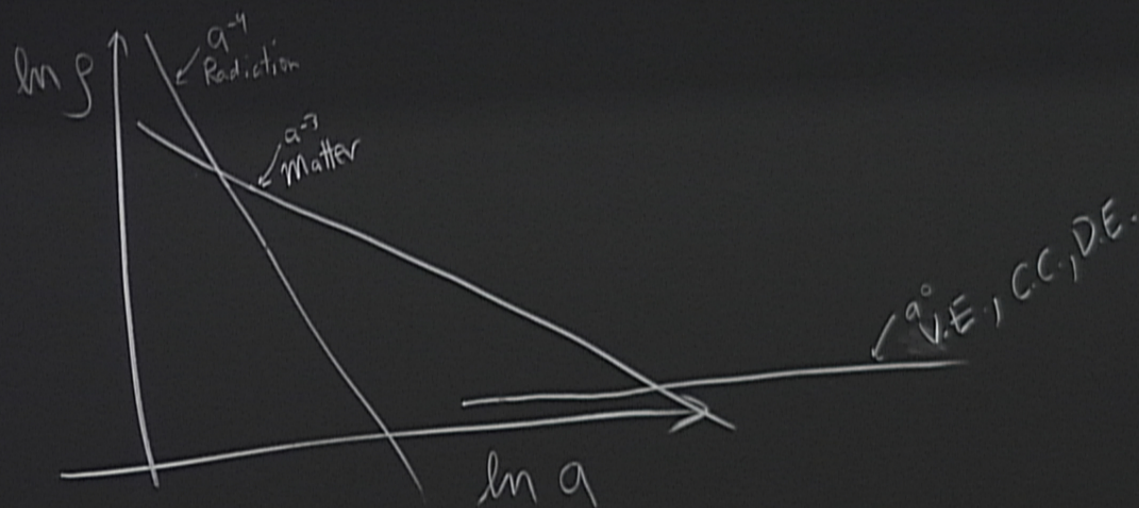
$$K(x) = \begin{cases} \sin x & K=+1 \\ x & K=0 \\ \sinh x & K=-1 \end{cases}$$

$$H^2 = \frac{8\pi G}{3} \rho - \frac{K}{a^2}$$

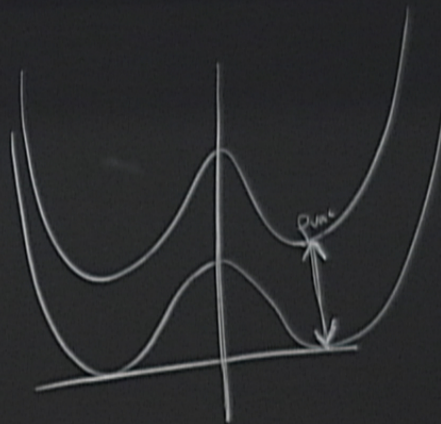
$\uparrow$
 $\rho \begin{cases} \propto a^{-4} \\ \propto a^{-3} \end{cases}$

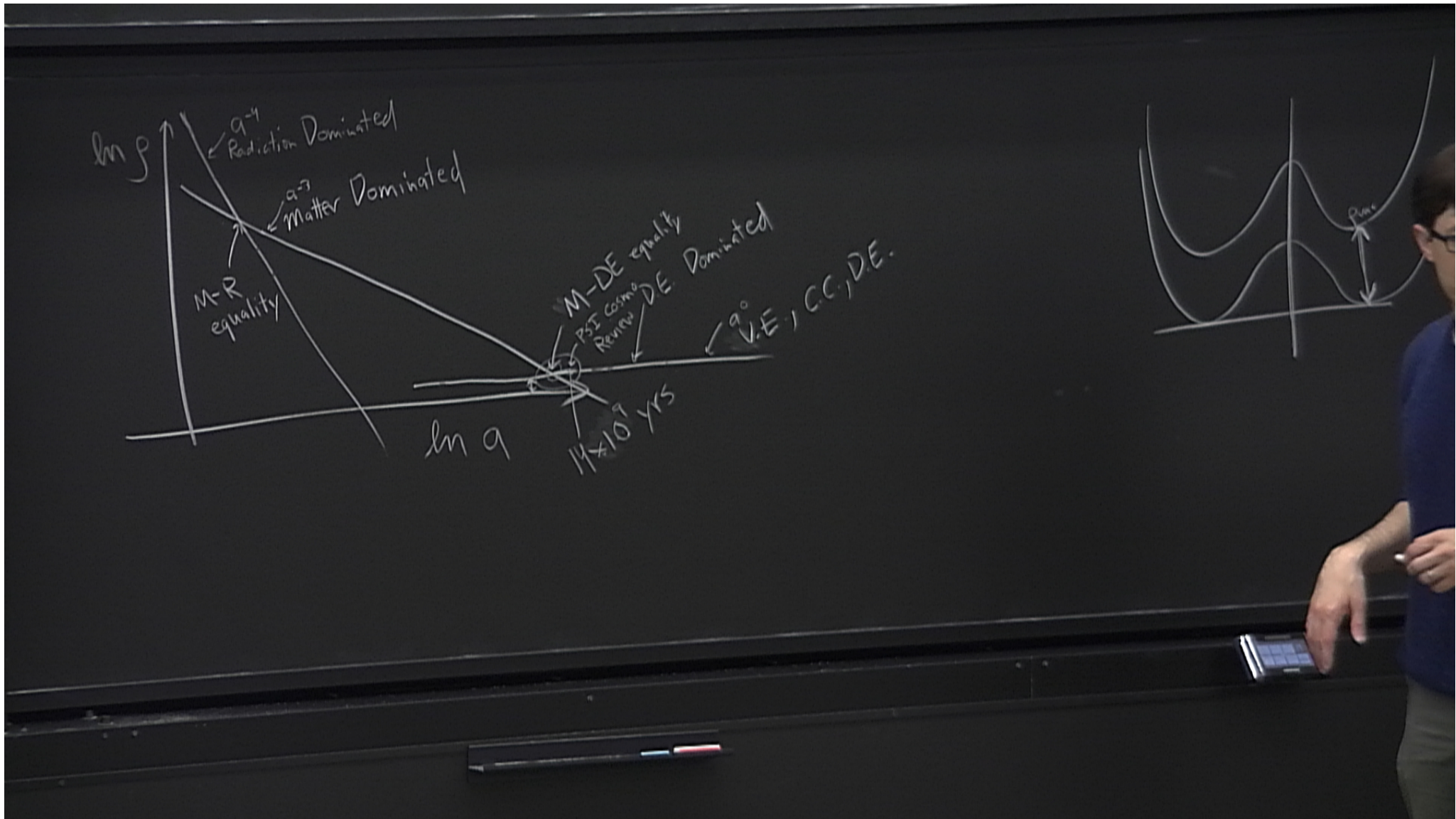


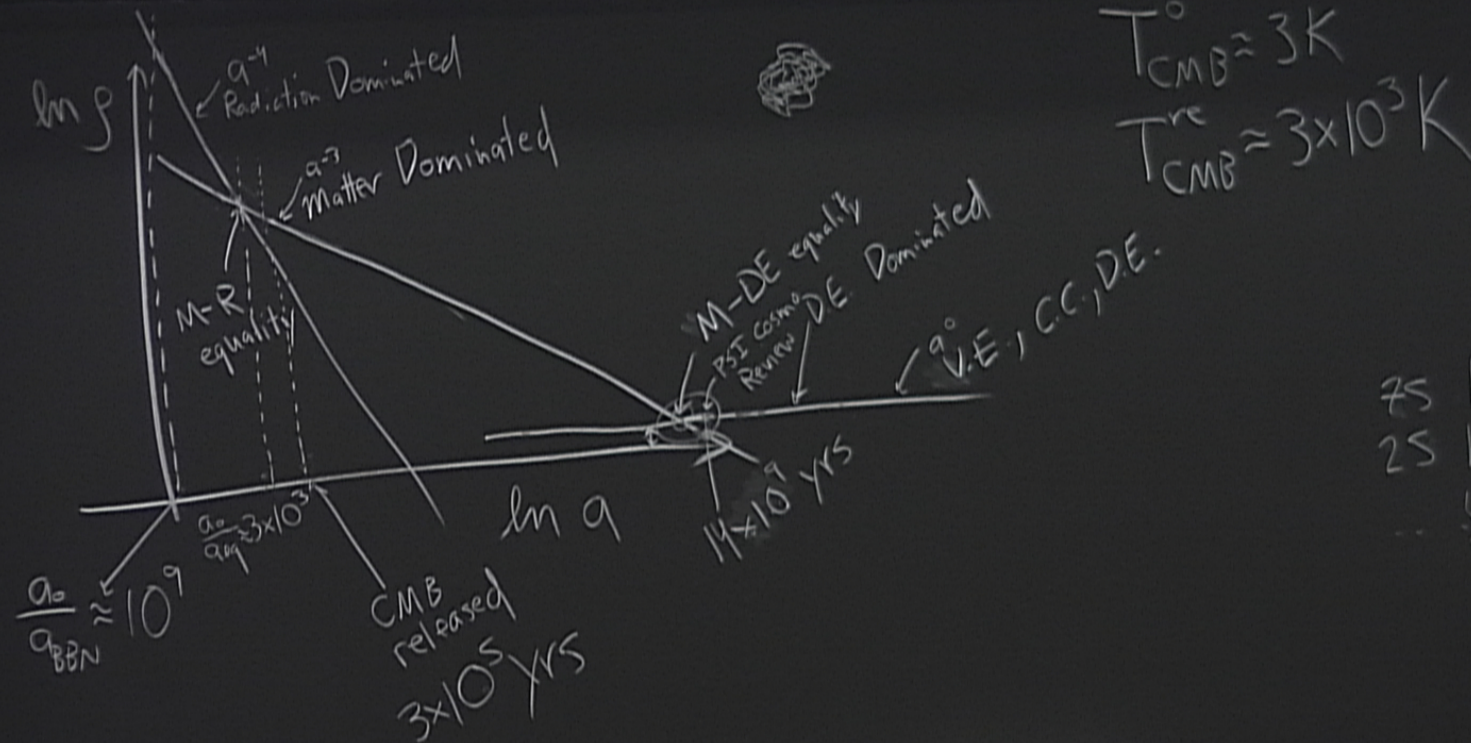
$\rho_{\text{DE}} \propto \rho_{\text{M}}^{1/3}$



✓ ∇^0 V.E., C.C., D.E.







75 H
 25 He
 ...
 ...
 ...

