

Title: Review on Proposed Models for Dark Energy 1

Date: May 05, 2010 10:30 AM

URL: <http://pirsa.org/10050011>

Abstract:

Cosmological constant (C.C.)

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Einstein (1917) → Λ

de Sitter → Expansion
no matter

Cosmological constant (C.C.)

Einstein (1917) → Λ

Friedmann (1922)

→ Expanding Sol's

de Sitter → Expansion
no matter

Hubble

(1929) → obs. → Univ. is Expanding

Cosmological constant (C.C.)

Einstein (1917)

$$\rightarrow \Lambda$$

de Sitter

\rightarrow Expansion
no matter

Friedman (1922)

\rightarrow Expanding Sol's

\nearrow Hubble (1929)

\rightarrow Obs. \rightarrow Univ. is Expanding

Zel'dovich

$$\rightarrow \langle T_{ik} \rangle_{vac} = \Lambda g_{ik} / 8\pi G$$

Cosmological constant (C.C.)

Einstein (1917) → Λ

Friedmann (1922)

→ Expanding Sol's

de Sitter → Expansion
no matter

Hubble

(1929)

→ obs. → Univ. is Expanding

L'davich (1968)

$$\langle T_{ik} \rangle_{UV} = \Lambda g_{ik} / 8\pi G$$

1970-1980

Cosmological constant (C.C.)

Einstein (1917)

$$\rightarrow \Lambda$$

de Sitter

\rightarrow Expansion
no matter

(1922)

\rightarrow Expanding Sol's

(1929)

\rightarrow Obs. \rightarrow Univ. is Expanding

(1958)

$$\rightarrow \langle T_{ik} \rangle_{vac} = \Lambda g_{ik} / 8\pi G$$

$$\int_0^{t_{now}} \sqrt{\dot{a}^2 + k^2} dt$$

1970-1980

\rightarrow Inflation

$$\hookrightarrow \langle \dot{m}_p^2 \rangle \sim \Lambda$$

2003

WMAP

2004

BAO

$\Rightarrow \rho_{\Lambda}$

\downarrow

quint

DGP

$\rho_{\Lambda} \rightarrow$ Implication

$\langle m_{\nu}^2 \rangle \sim \delta_{\nu}$

1998 - 1999 \rightarrow Supernova Observations $\rightarrow \ddot{a} > 0$

2003 WMAP

2004 BAO

$\Rightarrow \rho_{\Lambda}$
 \downarrow
Quant.
DCP
k Ess

$\rho_{\text{vac}} \rightarrow$ Inflation

$\langle m_{\nu}^2 \rangle \sim \rho_{\Lambda}$

Back reaction

Cosmological constant (C.C.)

Einstein (1917) → Λ
Friedmann (1922)

de Sitter → Expansion
no matter

→ Expanding Sol's

Hubble (1929) → obs. → Univ. is expanding

2.

$$\langle T_{ik} \rangle_{\text{vac}} = \Lambda g_{ik} / 8\pi G$$

1980

→ Inflation

$$\int_0^{k_{\text{hor}}} \sqrt{g_{ik}} k^3 dk$$

$$\langle n_{\nu}^2 \rangle \sim \int$$

$\Lambda = 0$

$$\ddot{a} > 0$$

$$\left\{ \begin{array}{l} H^2 \frac{1}{3M_p^2} (\rho_i + p_i) \\ \frac{\ddot{a}}{a} = -\frac{1}{6M_p^2} (\rho_i + 3p_i) \end{array} \right.$$

$$\ddot{a} > 0 \quad \equiv \quad \ddot{a} > 0$$



$$\left\{ \begin{aligned} H^2 &= \frac{1}{3M_p^2} (\rho_i + p_i) \\ \frac{\ddot{a}}{a} &= -\frac{1}{6M_p^2} (\rho_i + 3p_i) \end{aligned} \right.$$

$$\ddot{a} > 0 \quad H = \frac{\dot{a}}{a}$$



$$\left\{ \begin{aligned} H^2 &= \frac{1}{3M_p^2} (\rho_i + \rho_k) \\ \frac{\ddot{a}}{a} &= -\frac{1}{6M_p^2} (\rho_i + 3p_i) \end{aligned} \right.$$

$$\ddot{a} > 0 \quad H = \frac{\dot{a}}{a}$$



$$\begin{cases} H^2 = \frac{1}{3M_p^2} (\rho_s + \rho_\Lambda) \\ \frac{\ddot{a}}{a} = -\frac{1}{6M_p^2} (\rho_s + 3\rho_\Lambda) \\ \dot{\rho}_\Lambda = -3H(\rho_\Lambda) \end{cases}$$

$$\ddot{a} > 0 \quad H = \frac{\dot{a}}{a}$$



$$\left\{ \begin{aligned} H^2 &= \frac{1}{3M_p^2} (\rho_s + \rho_r) \end{aligned} \right.$$

$$\frac{\ddot{a}}{a} = -\frac{1}{6M_p^2} (\rho_s + 3\rho_r)$$

$$\dot{\rho}_s = -3H(\rho_s + p_s) \quad \rho_s + 3p_s > 0$$

$$p_r = w\rho_r$$

$$s > 0$$

$$\ddot{a} > 0 \quad H = \frac{\dot{a}}{a}$$



$$\left\{ \begin{aligned} H^2 &= \frac{1}{3M_p^2} (\rho_s + \rho_r) \end{aligned} \right.$$

$$\frac{\ddot{a}}{a} = \frac{1}{6M_p^2} (\rho_s + 3\rho_r) = \frac{1}{6M_p^2} (1+3w)\rho_s$$

$$\dot{\rho}_s = -3H(\rho_s + p_s)$$

$$\rho_s + 3p_s > 0$$

$$p_s = w\rho_s$$

$$s > 0$$

$$w < -\frac{1}{3}$$

$$w = -1$$

$$s = -P$$

$$\ddot{a} > 0 \quad H = \frac{\dot{a}}{a}$$



$$\left\{ \begin{aligned} H^2 &= \frac{1}{3M_p^2} (\rho_s + \rho_r) \end{aligned} \right.$$

$$\frac{\ddot{a}}{a} = -\frac{1}{6M_p^2} (\rho_s + 3\rho_r) = -\frac{1}{6M_p^2} (1+3w)\rho_s$$

$$\dot{\rho}_s = -3H(\rho_s + p_s)$$

$$\dot{\rho}_s = -3H(1+w)\rho_s$$

$$\rho_s + 3p_s > 0$$

$$p_s = w\rho_s$$

$$\rho_s > 0$$

$$w < -\frac{1}{3}$$

$$w = -1$$

$$\rho_s = -p_s$$

$$\ddot{a} > 0 \quad H = \frac{\dot{a}}{a}$$



$$\left\{ \begin{aligned} H^2 &= \frac{1}{3M_p^2} (\rho_s + \rho_r) \end{aligned} \right.$$

$$\frac{\ddot{a}}{a} = \frac{1}{6M_p^2} (\rho_s + 3\rho_r) = \frac{1}{6M_p^2} (1+3w)\rho_s$$

$$\dot{\rho}_s = -3H(\rho_s + p_s)$$

$$\dot{\rho}_s = -3H(1+w)\rho_s$$

$$\dot{\rho}_s = -3H(1+w)\rho_s$$

$$\rho_s + 3p_s > 0$$

$$p_s = w\rho_s$$

$$\rho_s > 0$$

$$w < -\frac{1}{3}$$

$$w = -1$$

$$\rho_s = -p_s$$

$\langle \ddot{a} \rangle$



\rightarrow

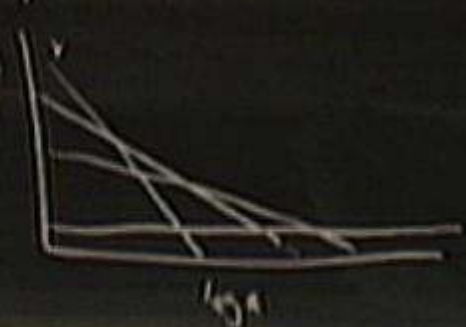
$$H^2 = \frac{1}{3M_p^2} \left(\sum_i \rho_i a^{-3(1+w)} + \rho_{\Lambda} a^{-2} \right)$$

$$3P_i = -\frac{1}{\epsilon M_p^2} (1+3w) \rho_i$$

$S + 3P > 0$
 $P_i = w \rho_i$
 $S > 0$

$w < -1/3$
 $w = -1$
 $S = -P$

$$= \frac{1}{3M_p^2} \left(\rho_{\Lambda} a^{3\epsilon}, \rho_{\Lambda} a^6 + \rho_{\Lambda} a^{12} + \rho_{\Lambda} a^{\dots} \right)$$



30/9-2011



$$\sigma_{1/2} = (1, 2)$$



$$\frac{a}{a} = (1+z) \quad a, c$$

$$H_0^2 \frac{1}{3M^2} \left(\sum s_{ii} (1+z)^{3(1+w)} + \sum_{ii} (1+z)^2 \right)$$

$$\frac{a}{a_0} = (1+z)^{-1} \quad a_0 = \boxed{H_0}$$

$$H_0^2 = \frac{1}{3M_p^2} \left(\sum \rho_{i,c} (1+z)^{3(1+w_i)} + \rho_{\Lambda} (1+z)^2 \right)$$

$$H^2 = H_0^2 \left(\sum \Omega_{i,c}(1+z)^{3(1+w_i)} + \Omega_{\Lambda} \right), \quad \Omega_{i,c} = \frac{\rho_{i,c}}{H_0^2 M_p^2}$$

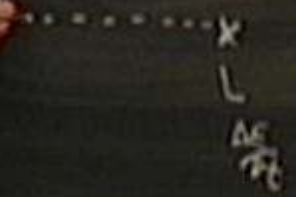
$3 \log a - x \log a$



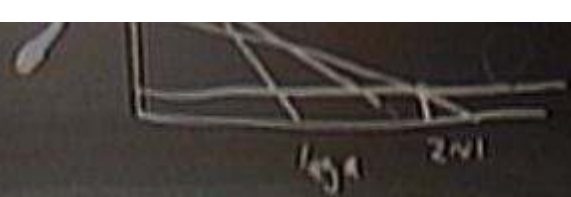
$$\frac{a}{2} = (1+z) \quad a=1 \quad \boxed{H.}$$

$$e^{-\frac{1}{2}} \frac{1}{3A^2} \left(\sum S_{i,j} (1+z)^{3(1+w)} + S_{i,k} (1+z)^2 \right)$$

$$H_i^2 \left(\sum \Omega_k (1+z)^{3(1+w)} \right) \quad \Omega_i = \frac{S_{i,j}}{H_i^2 \Omega_j} \quad \sum \Omega_i + \Omega_k = 1$$



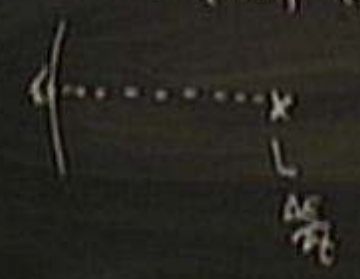
3.5.9 - 2.1.1



$$\frac{a}{L} = (1+z) \quad a=1 \quad \boxed{H}$$

$$H^2 = \frac{1}{3A^2} \left(\sum s_{ij} (1+z)^{3(1+w)} + s_{ik} (1+z)^2 \right)$$

$$H^2 = H_0^2 \left(\sum \Omega_k (1+z)^{3(1+w)} \right) \quad \Omega_k = \frac{s_{ij}}{H_0^2 A^2} \quad \sum \Omega_k = 1$$



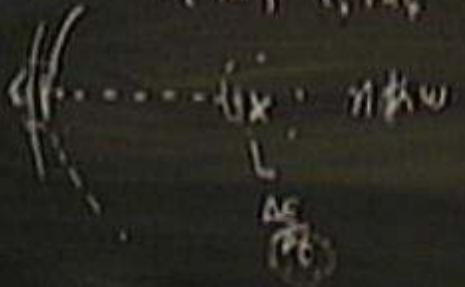
$\frac{1}{\rho} = \frac{1}{\rho_0} (1+z)$



$\frac{1}{\rho} = (1+z)$ $a=1$ $[H.]$

$$H^2 = \frac{1}{3A^2} \left(\sum \rho_{i,c} (1+z)^{3(1+\nu)} + \rho_{i,k} (1+z)^2 \right)$$

$H^2 = H_0^2 \left(\sum \Omega_k (1+z)^{3(1+\nu)} \right)$ $\Omega_k = \frac{\rho_{i,c}}{H_0^2 A^2}$ $\sum \Omega_k + \Omega_k = 1$



$$\tilde{\rho} = \frac{\rho_0}{\Delta \epsilon \rho_0}$$

$$\frac{1}{4R^2}$$

30/9-2011



$$\frac{a}{\lambda} = (1+z) \quad a=1 \quad \boxed{H.}$$

$$H_0^2 = \frac{1}{3M_{pl}^2} \left(\sum S_{ic} (1+z)^{3(1+w)} + S_{\Lambda} (1+z)^2 \right)$$

$$H^2 = H_0^2 \left(\sum \Omega_i (1+z)^{3(1+w)} + \Omega_{\Lambda} \right) \quad \Omega_i = \frac{\rho_i}{H_0^2 M_{pl}^2} \quad \sum \Omega_i + \Omega_{\Lambda} = 1$$



$$\tilde{p} = \frac{\hbar \omega}{4\pi \Delta x^2 \omega^2 (1+z)} = \frac{\Delta E}{4\pi \Delta x^2 (1+z)^2} = \frac{L}{4\pi \Delta x^2 (1+z)^2}$$

$$\frac{a_0}{a} = (1+z) \quad a_0 = 1 \quad \boxed{H_0}$$

$$H_0^2 = \frac{1}{3M_p^2} \left(\sum_i \rho_{i,0} (1+z)^{3(1+w)} + \rho_{\Lambda,0} (1+z)^2 \right)$$

$$H^2 = H_0^2 \left(\sum_i \Omega_{i,0} (1+z)^{3(1+w)} + \Omega_{\Lambda,0} (1+z)^2 \right) \quad \Omega_{i,0} = \frac{\rho_{i,0}}{H_0^2 M_p^2} \quad \sum_i \Omega_{i,0} + \Omega_{\Lambda,0} = 1$$

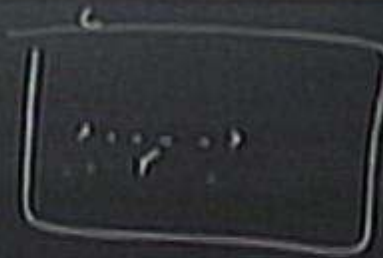


$$\dot{\rho} = \frac{\rho H_0 \omega}{(1+z)^3} = \frac{\Delta E}{\Delta t (M_p^2 (1+z)^3)} = \frac{L}{4\pi r^2 (1+z)^3} \frac{dE}{dE}$$

$$d_2 = r_c(t)$$



$$d_2 = r_c(1+z)$$



$$d_{\perp} = \gamma_c (1+z)$$

$$dt' = dt^2 - a^2 dr^2$$

$$dr = \frac{dt}{a} = \frac{dt}{da} \cdot da = \frac{1}{Ha^2}$$

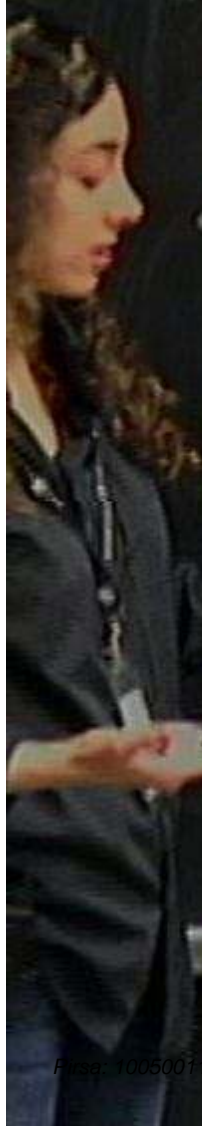


$$d_L = \gamma_c(1+z) = -(1+z) \int \frac{dz}{H(z)}$$



$$dc^i = dc^z - a^i dr^z$$

$$dr = \frac{dt}{a} = \frac{dt}{da} \cdot da = \frac{1}{H a^2} \left(\frac{-dz}{(1+z)^2} \right) = -\frac{dz}{H(z)}$$



$$d_L = \gamma_c(1+z) = r(1+z) \int_0^z \frac{dz}{H(z)}$$



$$= dt^2 - a^2 dr^2$$

$$dr = \frac{dt}{a} = \frac{dt}{da} \cdot da = \frac{1}{H a^2} \left(\frac{-dz}{(1+z)^2} \right) = -\frac{dz}{H(z)}$$

$$\frac{a}{a_0} = (1+z)^{-1}$$

$$q_0 = \frac{-\dot{a}}{H a} \Big|_{t=t_0}$$

$$d_L = \frac{(1+z)}{H_0} \left(z - \frac{1}{2} q_0 z^2 \right)$$

$$= \frac{1}{H_0} \left(z + \left(\frac{1}{2} (1-q_0) \right) z^2 \right)$$

$z < 1$

$$H_0 + \frac{dH}{dz} z = H_0 \left(1 + \frac{1}{H_0} \frac{dH}{dz} z \right) = H_0 \left(1 + \left(\frac{\dot{a}}{H_0 a} - 1 \right) z \right) = H_0 \left(1 + (q_0 + 1) z \right)$$

$$\frac{dH}{dz} = -\frac{H_0}{a} = -\frac{H_0}{H_0} = -\frac{(\dot{a}/a - H_0)}{H_0}$$

$$d_L = \gamma_c(1+z) = r(1+z) \int_0^z \frac{dz}{H(z)}$$



$$d_L = dt^2 - a^2 dr^2$$

$$q = \frac{-\dot{a}}{H a} \Big|_{t=t_0}$$

$$dr = \frac{dt}{a} = \frac{dt}{da} \cdot da = \frac{1}{H a^2} \left(\frac{-dz}{(1+z)^2} \right) = -\frac{dz}{H(z)}$$

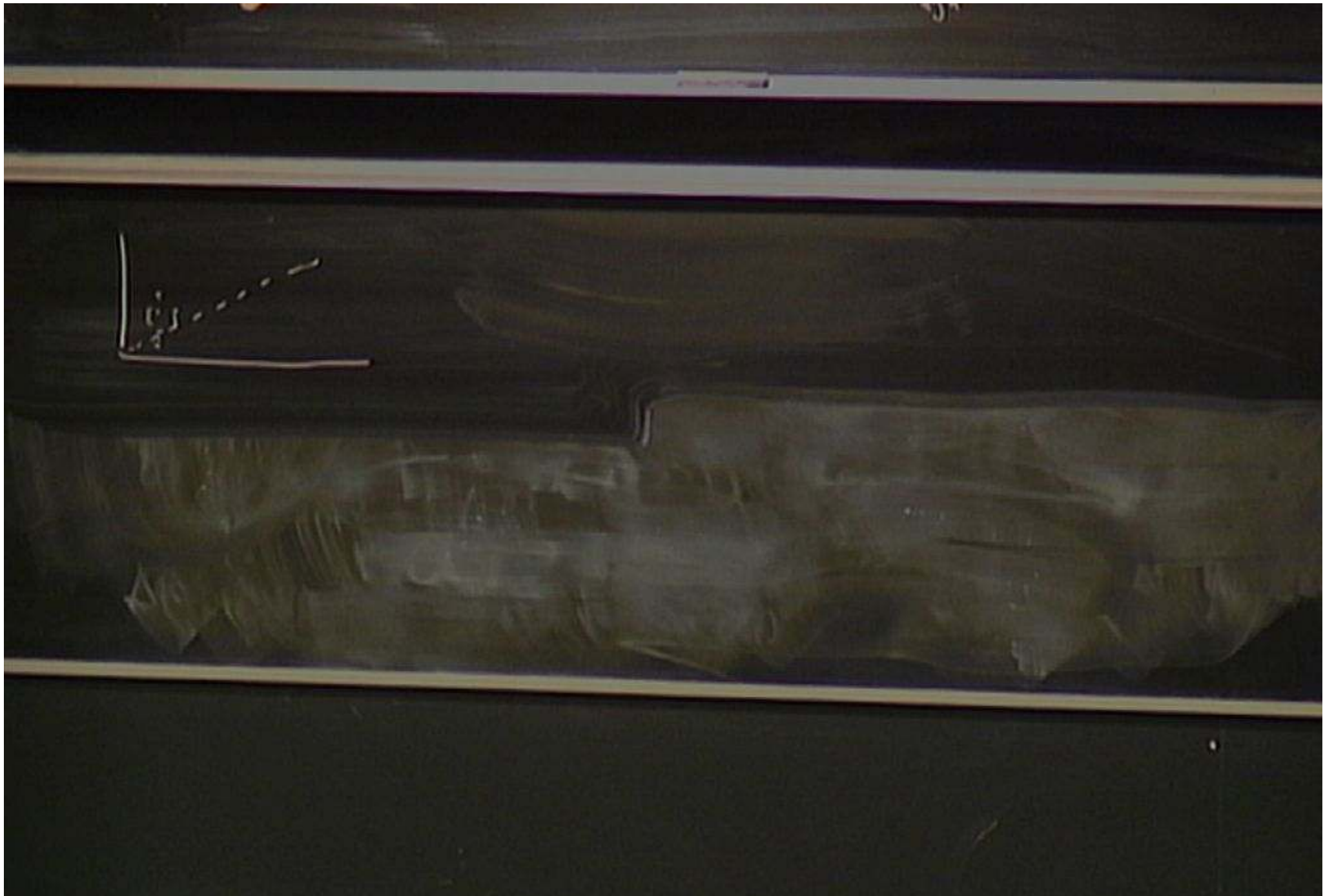
$$\frac{a}{a_0} = (1+z)^{-1}$$

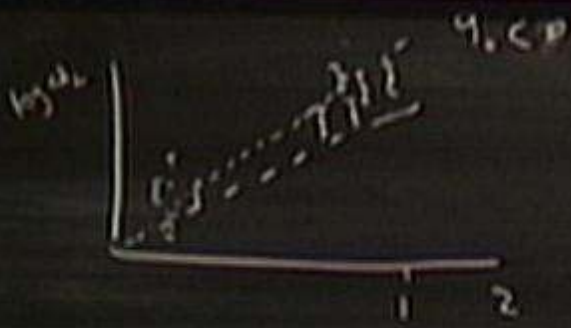
$$d_L = \frac{(1+z)}{H_0} \left(z - \frac{1}{2} \left(\frac{q}{H_0} + 2 \right) z^2 + \frac{1}{6} \left(\frac{q}{H_0} + 1 \right) z^3 \right)$$

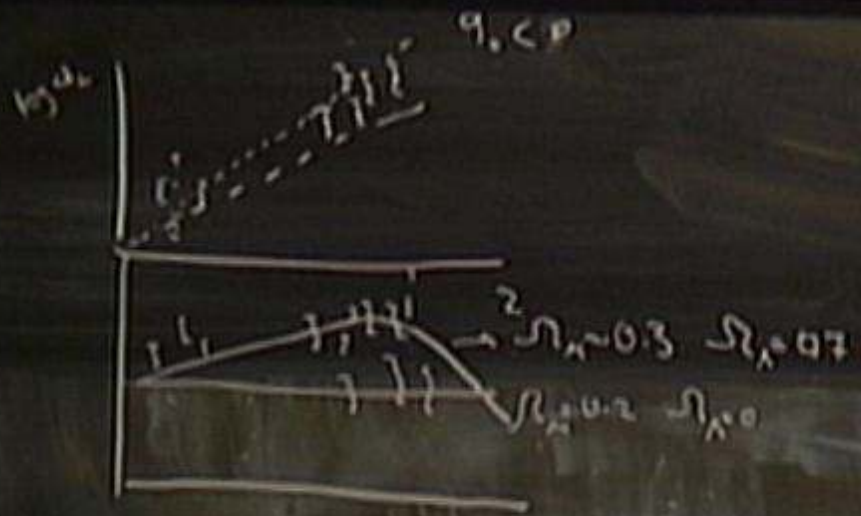
$z < 1$

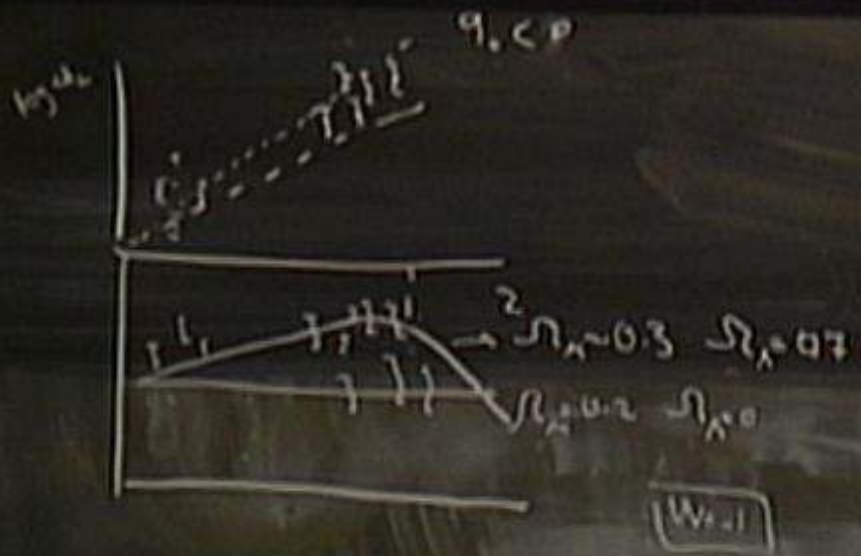
$$H_0 + \frac{dH}{dz} \Big|_z = H_0 \left(1 + \frac{1}{H_0} \frac{dH}{dz} z \right) = H_0 \left(1 + \left(\frac{\dot{a}}{H_0 a} - 1 \right) z \right) = H_0 \left(1 + (q_0 + 1) z \right)$$

$$\frac{d}{da} \frac{da}{dz} = -\frac{H}{a} = -\frac{H(z)}{H_0} = -\frac{\left(\frac{\dot{a}}{a} - H \right)}{H_0}$$











$$C_3 = \frac{C}{\sqrt{3(1+R)}} \frac{3k}{5r}$$





$$G_3 = \frac{c}{\sqrt{3(1+R)}} \frac{3k}{5r}$$

$$\phi = \frac{Hf + \phi}{(1+w)H}$$



$$c_s = \frac{c}{\sqrt{3(1+R)}} \sim \frac{c}{s_r}$$

$$\zeta = \left(\phi + \frac{H\dot{\phi} + \dot{\phi}}{(1+w)H} \right)$$

$$\nabla^2 \phi \propto \delta\rho$$

$$\propto \delta T$$

$$\int \sqrt{-g} (\zeta'^2 - c_s^2 (\nabla \zeta)^2)$$

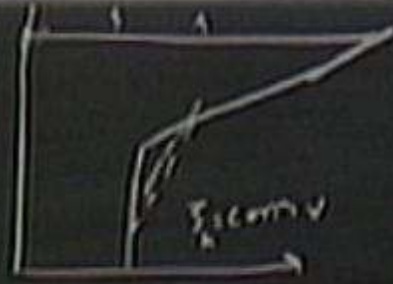
$$d\eta = \frac{dt}{a}$$





$$C_3 = \frac{c}{\sqrt{3(1+R)}} \sim \frac{1}{5}$$

$\frac{3k}{s_r}$



$$\zeta = \left(\phi + \frac{H(\phi + \dot{\phi})}{(1+w)\mu} \right)$$

$$\nabla^2 \phi \propto \delta\rho$$

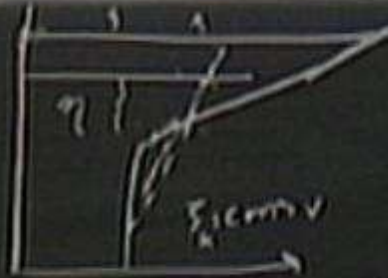
$$\propto \delta T$$

$$\int \sqrt{-g} (\zeta'^2 - C_s^2 (\nabla \zeta)^2) \Rightarrow \zeta''_k - k^2 C_s^2 \zeta = 0 \Rightarrow \zeta_k \propto \cos(k \int dt)$$

$$d\eta = \frac{dt}{a}$$



$$c_s = \frac{c}{\sqrt{3(1+R)}} \sim \frac{1}{5}$$



$$H^2 = H_0^2 a^{-4} \sim H_0^{-1} = H_0^{-1} a^{+2}$$

$$\zeta = \left(\phi + \frac{H\dot{\phi} + \dot{\phi}^2}{(1+w)H} \right)$$

$$\nabla^2 \phi \propto \delta\rho \propto \delta T$$

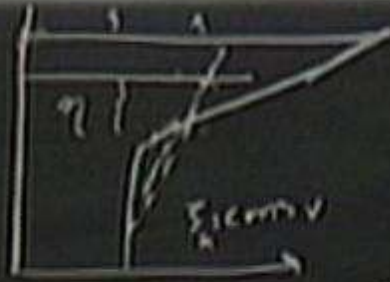
$$\eta = \int \frac{dt}{a} = \int \frac{da}{Ha^2} = \frac{1}{H_0}$$

$$\int \sqrt{g} (\zeta'^2 - c_s^2 (\nabla \zeta)^2) \Rightarrow \zeta_k'' - k^2 c_s^2 \zeta = 0 \Rightarrow \zeta_k \propto \cos(k c_s \eta)$$

$$d\eta = \frac{dt}{a}$$



$$c_s = \frac{c}{\sqrt{3(1+R)}} \approx \frac{1}{5}$$



$$H^2 = H_0^2 a^{-4} \sim H_0^{-1} = H_0^{-1} a^{+2} \Rightarrow R$$

$$\zeta = \left(\phi + \frac{H\dot{\phi} + \dot{\phi}^2}{(1+w)H} \right)$$

$$\nabla^2 \phi \propto \delta\rho \propto \delta T$$

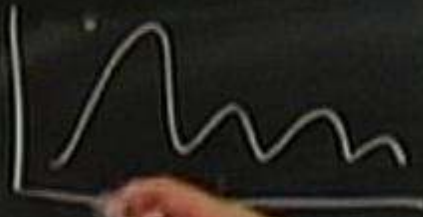
$$\eta = \int \frac{dt}{a} = \int \frac{da}{Ha^2} = \frac{1}{H_0} \int \frac{da}{a} = \frac{a_{eq}}{H_0} \Rightarrow R$$

$$\int \sqrt{g} (\zeta'^2 - c_s^2 (\nabla \zeta)^2) \Rightarrow \zeta_k'' - k^2 c_s^2 \zeta = 0 \Rightarrow \zeta_k \propto \cos(kc_s \eta) \propto \cos(kc_s R_H)$$

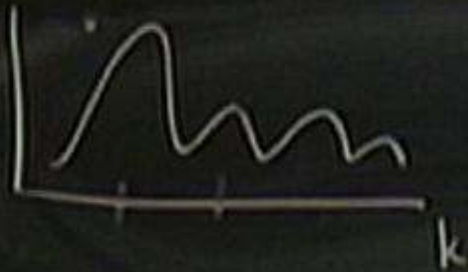
$$d\eta = \frac{dt}{a}$$

$$\sqrt{\langle \delta T_k^2 \rangle} \propto \sqrt{\langle \delta S_k^2 \rangle}$$

$$\langle \delta T_k^2 \rangle \propto \langle \delta \zeta_k^2 \rangle$$



$$\langle \delta T_k^2 \rangle \propto \sqrt{\langle \delta \epsilon_k^2 \rangle}$$



$$\langle \delta T_N^2 \rangle \propto \langle \delta S_N^2 \rangle$$

