Title: Cosmology - Review (PHYS 621) - Lecture 15

Date: Dec 18, 2009 10:00 AM

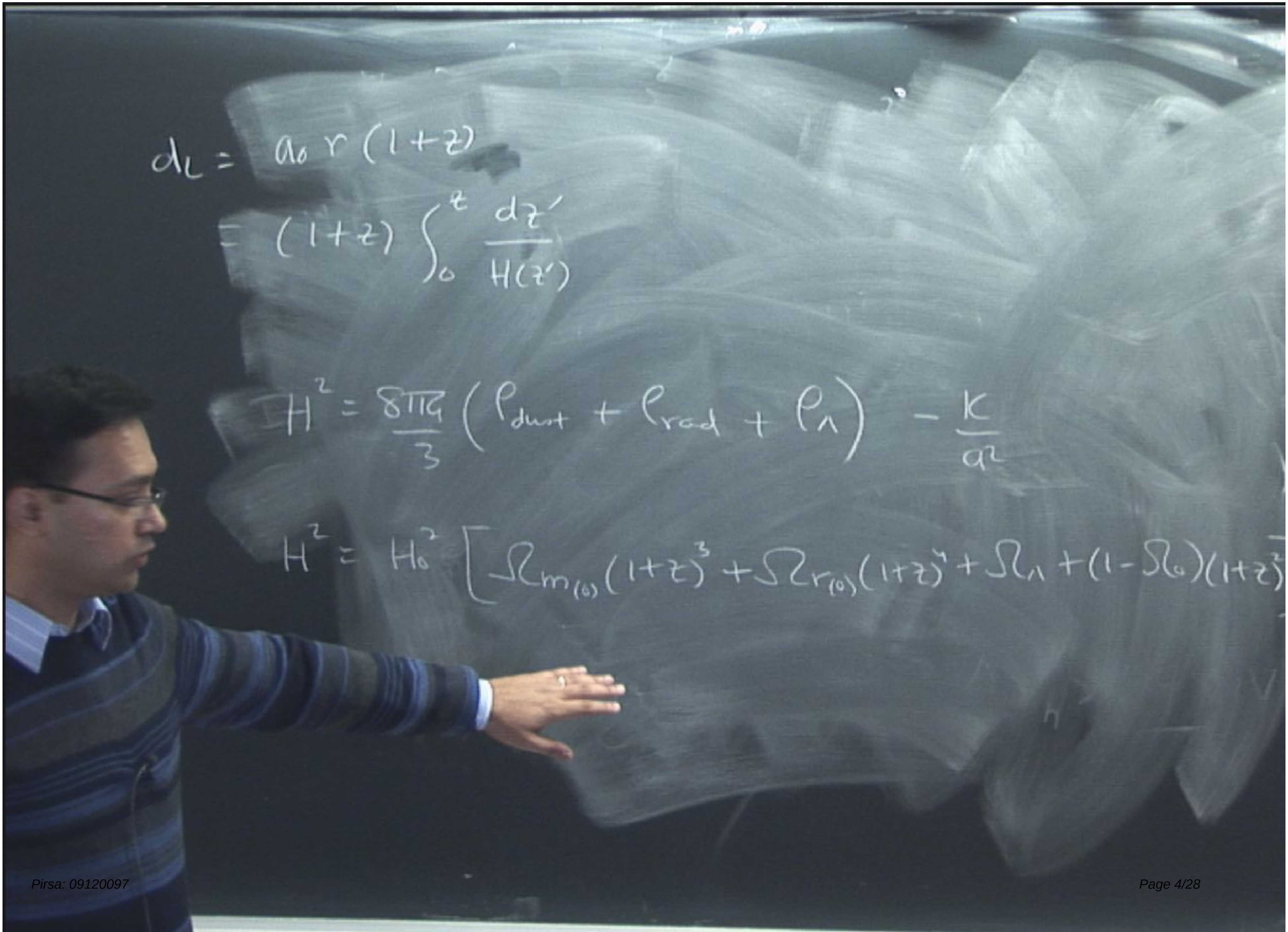
URL: http://pirsa.org/09120097

Abstract:

perimeter scholars
international

$$d_L = a_0 r (1+z)$$

$$= (1+z) \int_0^z \frac{dz'}{H(z')}$$


$d_L = a_0 r (1+z)$
$= (1+z) \int_0^z \frac{dz'}{H(z')}$
$H^2 = \frac{8\pi G}{3} \left(\rho_{dust} + \rho_{rad} + \rho_\Lambda \right) - \frac{K}{a^2}$
$H^2 = H_0^2 \left[\Omega_{m(0)} (1+z)^3 + \Omega_{r(0)} (1+z)^4 + \Omega_\Lambda + (1-\Omega_0)(1+z)^2 \right.$

$$d_L = a_0 r (1+z)$$

$$= (1+z) \int_0^z \frac{dz'}{H(z')}$$

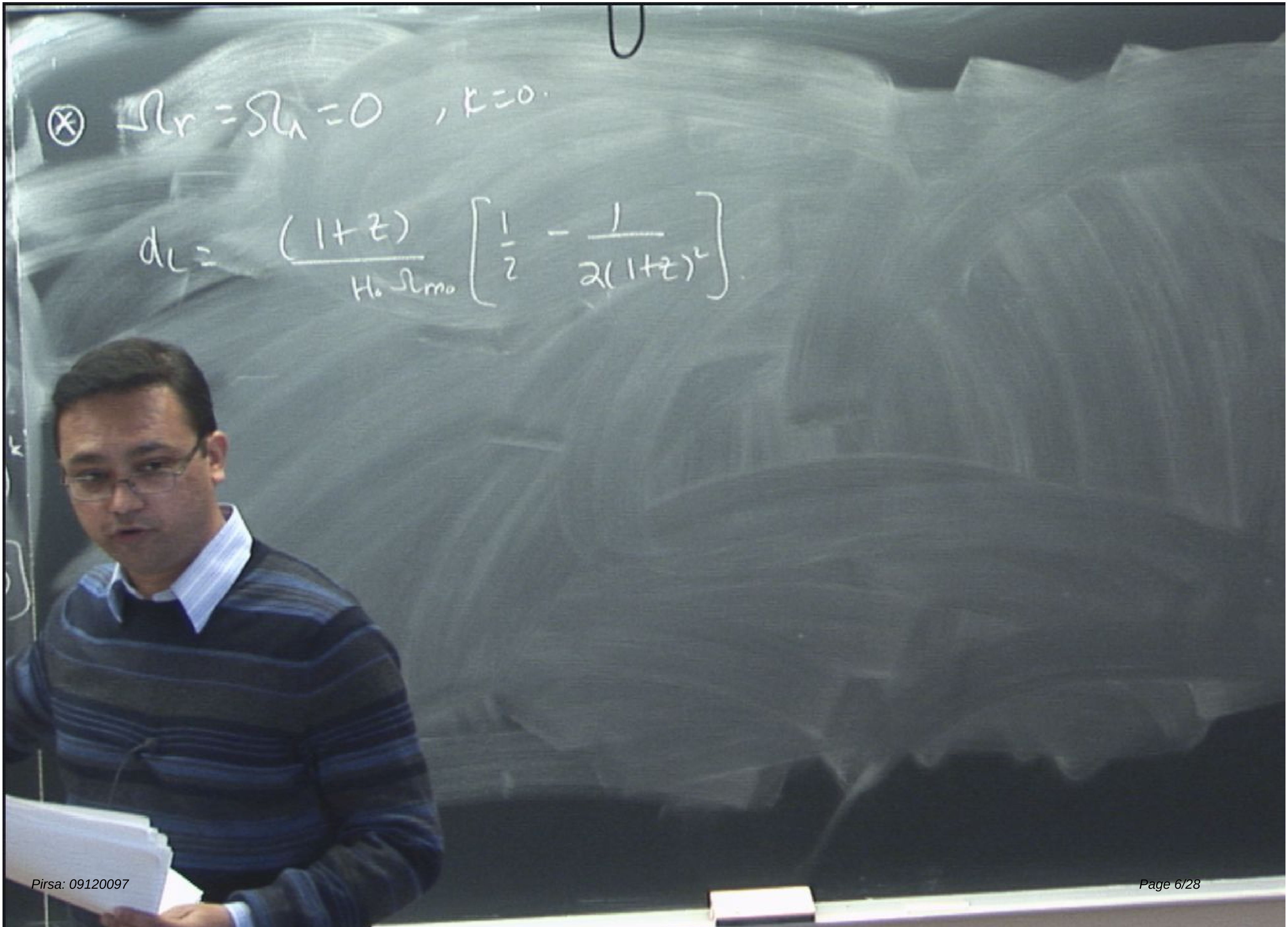
$$\Omega = \frac{\rho}{\rho_c}$$

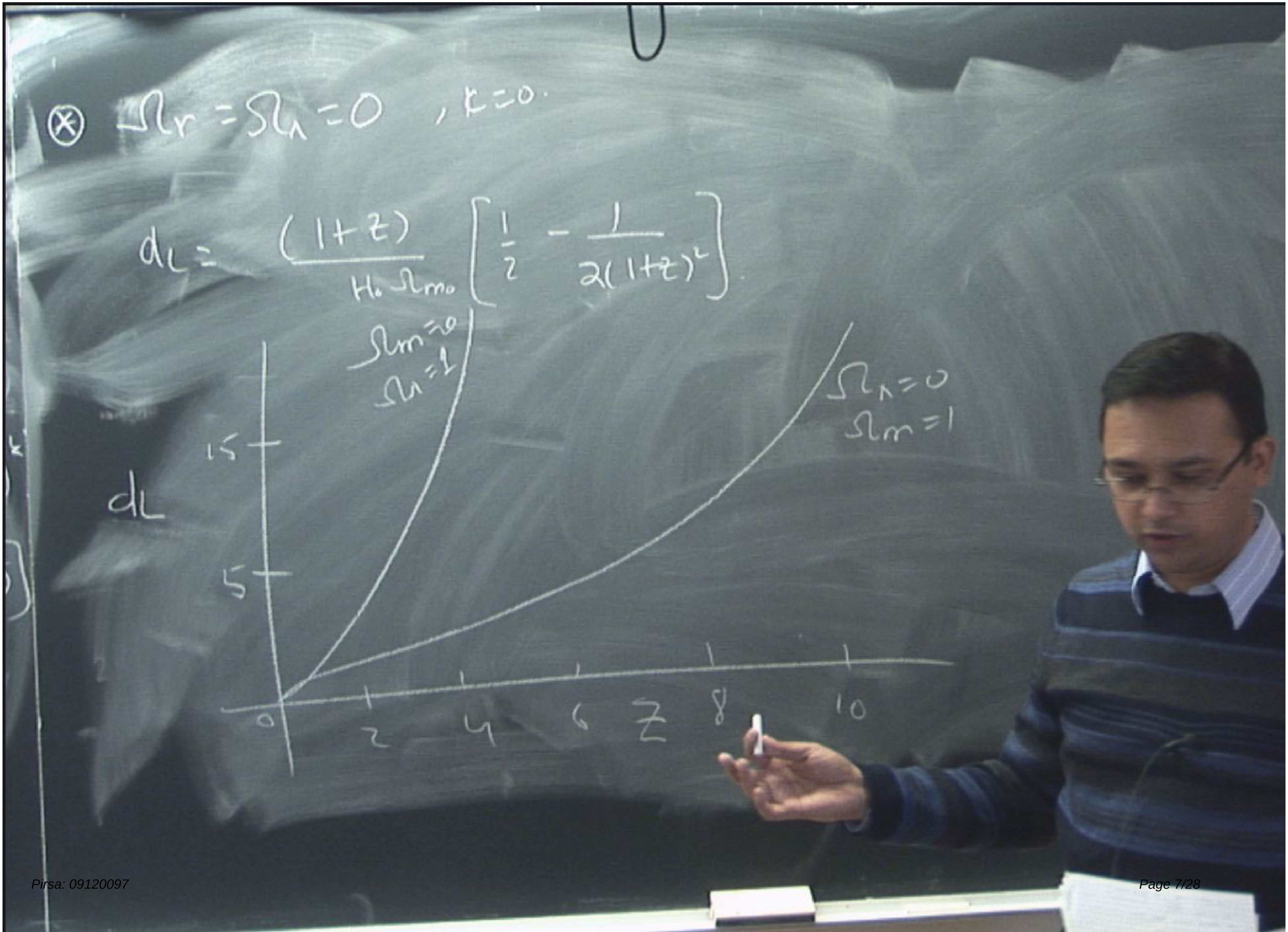
$$H^2 = \frac{8\pi G}{3}\left(\rho_{dust} + \rho_{rad} + \rho_\Lambda\right) - \frac{K}{a^2}$$

$$H^2 = H_0^2\left[\Omega_{m(0)}(1+z)^3 + \Omega_{r(0)}(1+z)^4 + \Omega_\Lambda + (1-\Omega_0)(1+z)^2\right.$$

(*) $K=0$, $\Omega_\Lambda = 1$, $\Omega_r = \Omega_{dust} = 0$, $\Omega_0 = 1$

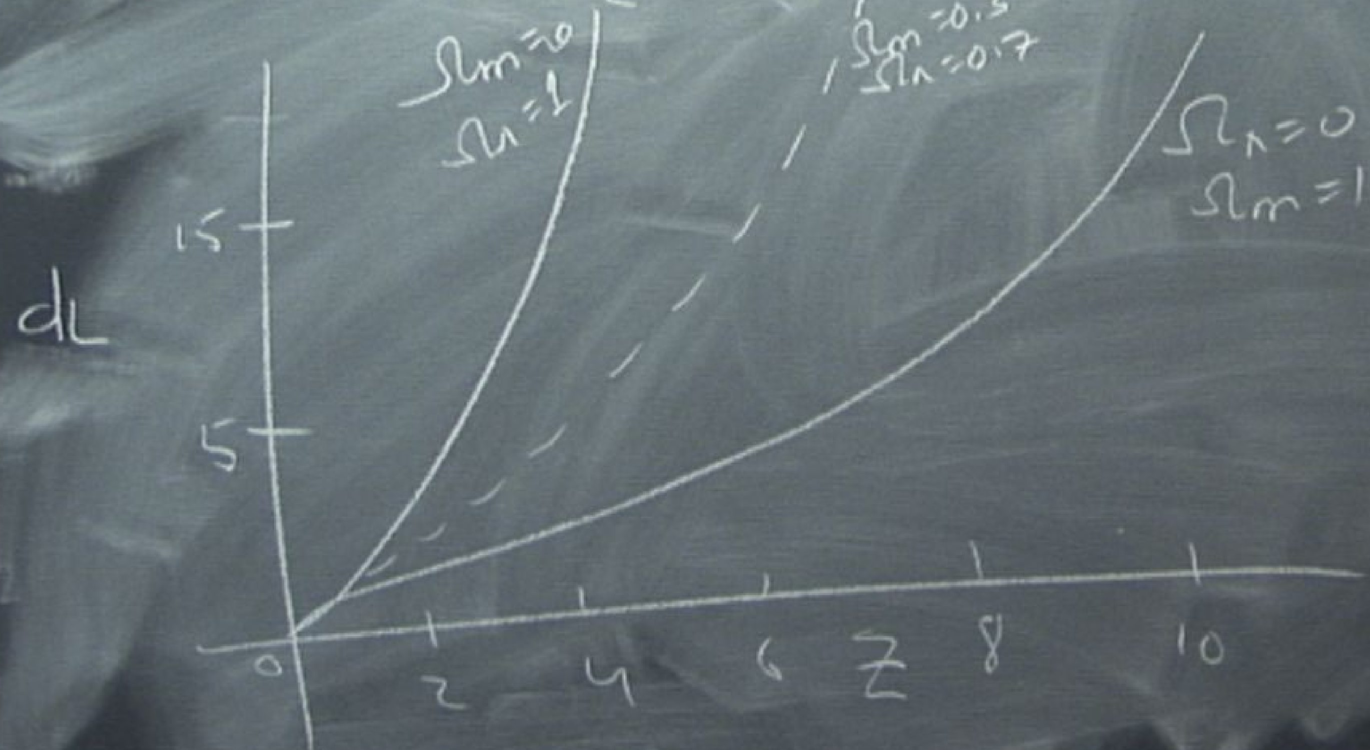
$$d_L = (1+z)\int_0^z \frac{dz'}{H_0\sqrt{\Omega_\Lambda}} = \frac{(z^2+z)}{H_0}$$


$\Omega_r = \Omega_\Lambda = 0 \,, k = 0.$
$d_L = \frac{(1+z)}{H_0 \Omega_{m0}} \left[\frac{1}{2} - \frac{1}{2(1+z)^2} \right]$


$\Omega_r = \Omega_\Lambda = 0$, $k = 0$.
$d_L = \frac{(1+z)}{H_0 \Omega_{m0}} \left[\frac{1}{2} - \frac{1}{2(1+z)^2} \right]$
$\Omega_m = 0$
$\Omega_\Lambda = 1$
$\Omega_\Lambda = 0$
$\Omega_m = 1$
d_L
15
5
0
2
4
6
z
8
10

$\otimes$ $\Omega_r = \Omega_\Lambda = 0$, $k = 0$.

$$d_L = \frac{(1+z)}{H_0 \Omega_{m0}} \left[\frac{1}{2} - \frac{1}{2(1+z)^2} \right]$$



$$* \quad \ell = \frac{L}{4\pi d_L^2}$$

$$H^2 = H_0^2 \left[\Omega_{m(0)}(1+z)^3 + \Omega_{r(0)}(1+z)^4 + \Omega_\Lambda + (1-\Omega_0)(1+z)^2 \right.$$

$$* \quad k=0, \quad \Omega_\Lambda = 1, \quad \Omega_r = \Omega_{dust} = 0, \quad \Omega_0 = 1$$

$$d_L = (1+z)\int_0^z \frac{dz'}{H_0\sqrt{\Omega_\Lambda}} = \frac{(z^2+z)}{H_0}$$

* $l = \dfrac{L}{4\pi d_L^2}$

* 1998. Type Ia SN

Perlmutter et al. SN Cosmology Project.

Riess et al High Z SN.

$$* \quad \ell = \frac{L}{4\pi d_L^2}$$

$$* \quad q = -\frac{\ddot{a}}{aH^2}$$

$k=0$.

$$q(t) = \Omega_{r(t)} + \frac{1}{2}\Omega_{m(t)} - \Omega_\Lambda$$

$$\simeq \frac{\Omega_{m(0)}}{2a^3} - \Omega_\Lambda = \frac{1}{2}\Omega_{m(0)}(1+z)^3 - \Omega_\Lambda$$

$$* \quad l = \frac{L}{4\pi d_L^2}$$

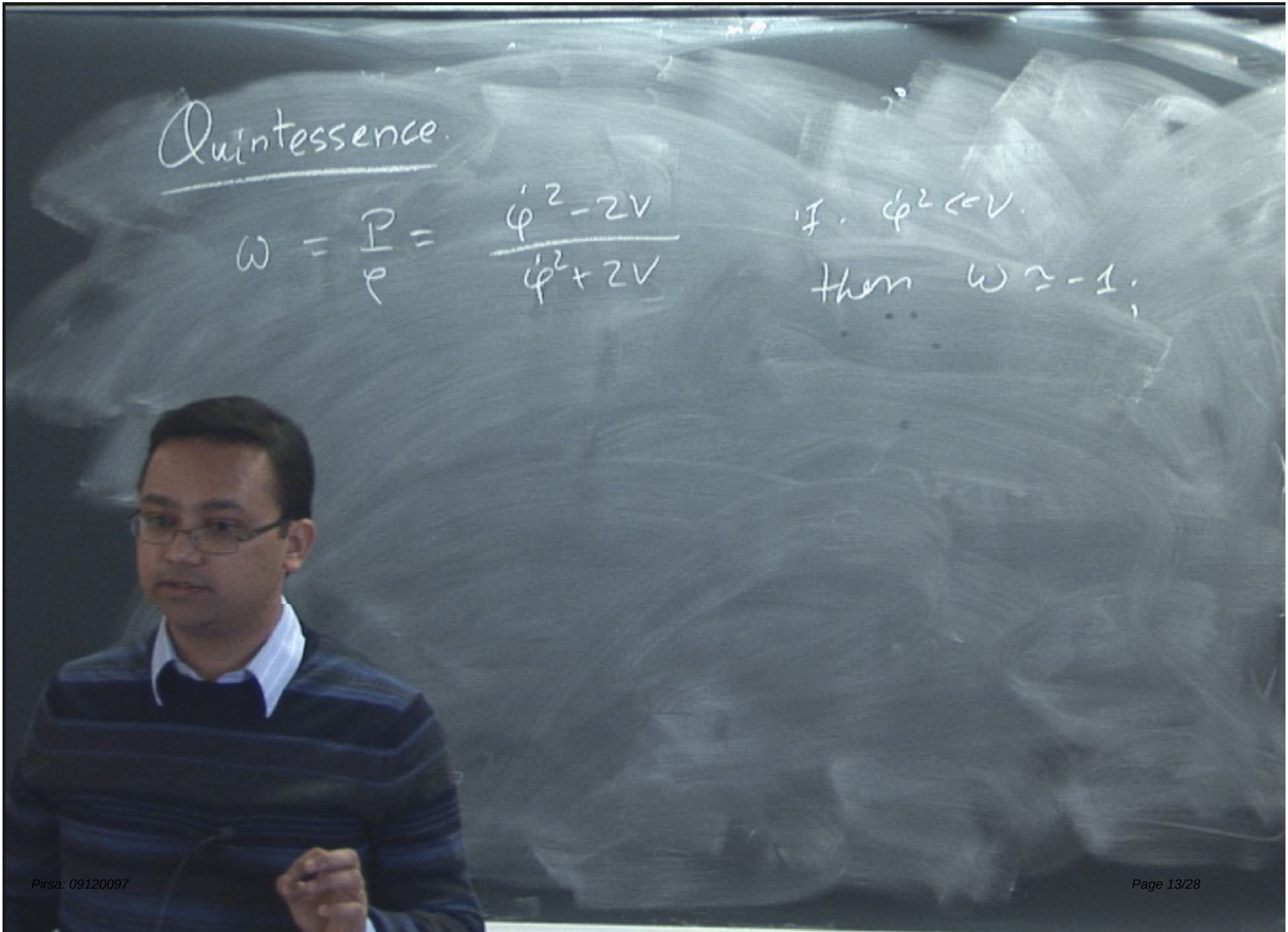
$$\circledast \quad q = -\frac{\ddot{a}}{aH^2}$$

$k=0.$

$$q(t) = \Omega_{r(t)} + \frac{1}{2}\Omega_{m(t)} - \Omega_\Lambda$$

$$\simeq \frac{\Omega_{m(0)}}{2a^3} - \Omega_\Lambda = \frac{1}{2}\Omega_{m(0)}(1+z)^3 - \Omega_\Lambda$$

$$(1+z)^3 = \frac{2\Omega_\Lambda}{\Omega_{m(0)}} \Rightarrow 1+z = 1.67 \quad \boxed{z = 0.67}$$


Quintessence.
$\omega = \frac{P}{\rho} = \frac{\dot\varphi^2 - 2V}{\dot\varphi^2 + 2V}$
If $\dot\varphi^2 \ll V$
then $\omega \simeq -1$;

Quintessence

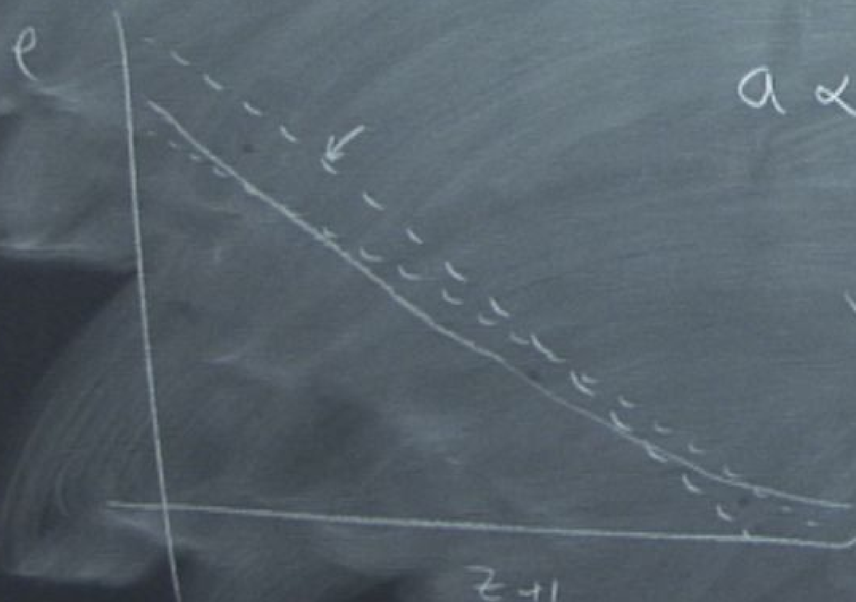
$$\omega = \frac{P}{\rho} = \frac{\dot{\varphi}^2 - 2V}{\dot{\varphi}^2 + 2V}$$

If $\dot{\varphi}^2 \ll V$ then $\omega \simeq -1$;

Quintessence.

$$\omega = \frac{P}{\rho} = \frac{\dot\varphi^2 - 2V}{\dot\varphi^2 + 2V}$$

If $\dot\varphi^2 \ll V$ then $\omega \simeq -1$.



$$a \propto t^p$$

$$\ddot a > 0$$

$$p > 1$$

$$V = \frac{3H^2}{8\pi G}\left(1 + \frac{\dot H}{3H^2}\right)$$

$$\dot H = -4\pi G \dot\varphi^2$$

$$\phi = \int dt \left(-\frac{\dot H}{4\pi G}\right)^{1/2}$$

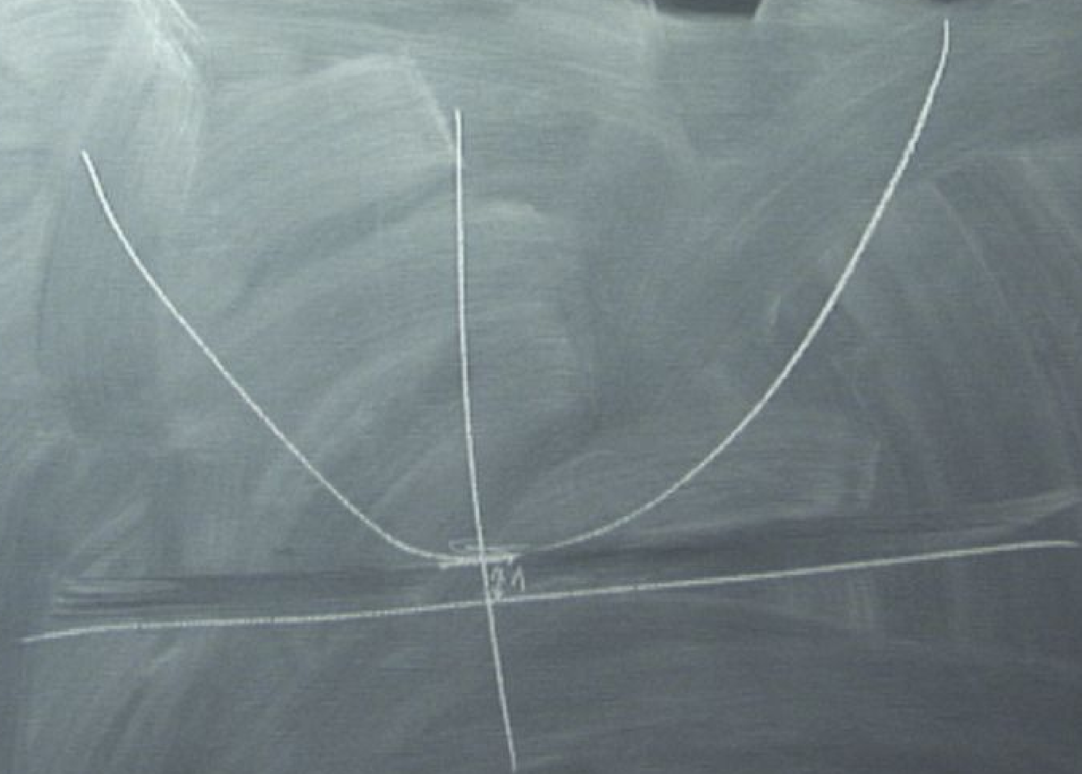
$$V = V_0 \exp\left(-\sqrt{\frac{16\pi}{p}}\;\frac{\varphi}{m_{pl}}\right)$$

$$V = V_0 \exp\left(-\sqrt{\frac{16\pi}{p}}\,\frac{\varphi}{m_{pl}}\right)$$

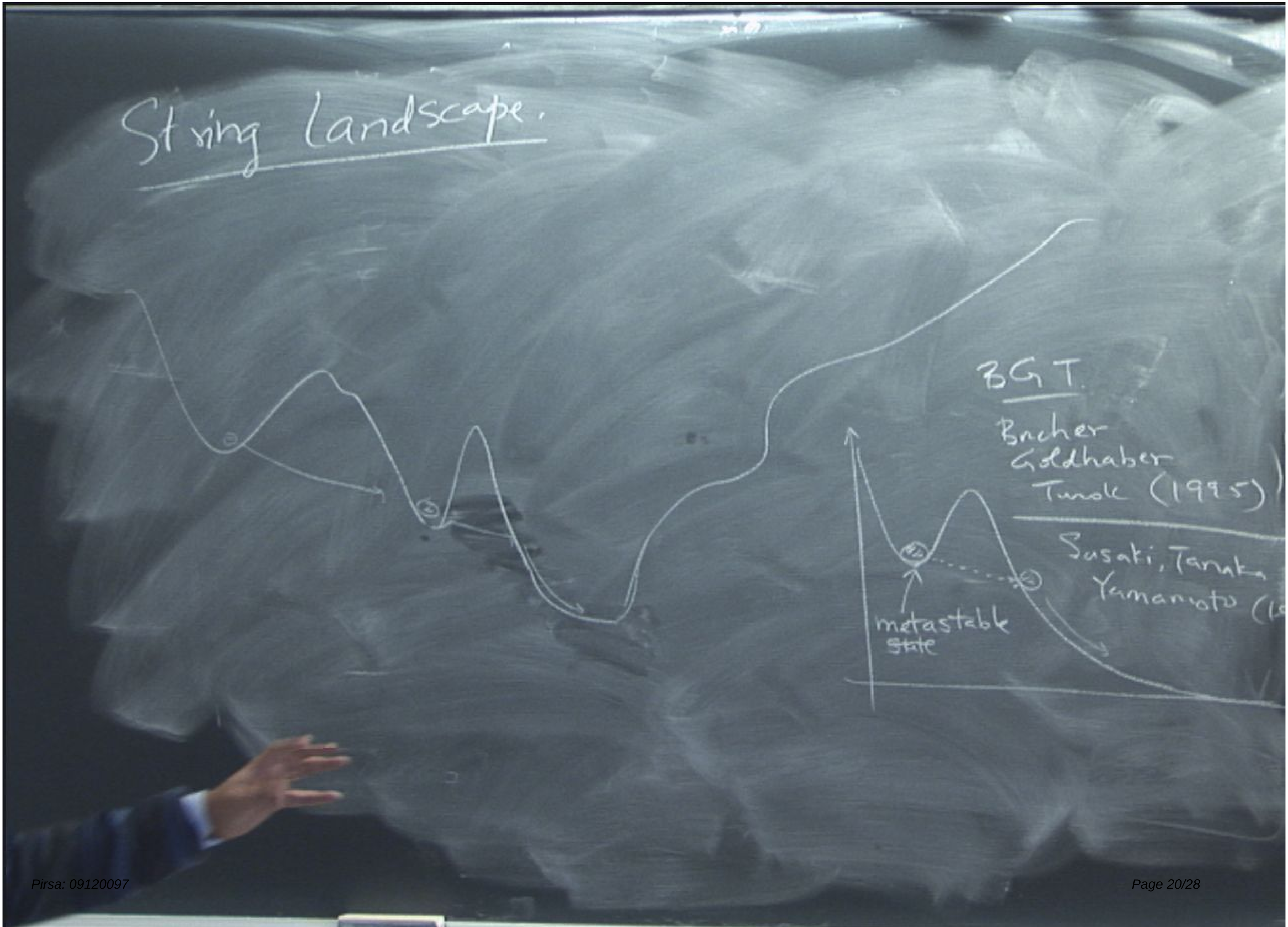
$$V(\varphi) = \frac{V_0}{\varphi^{\alpha}}$$

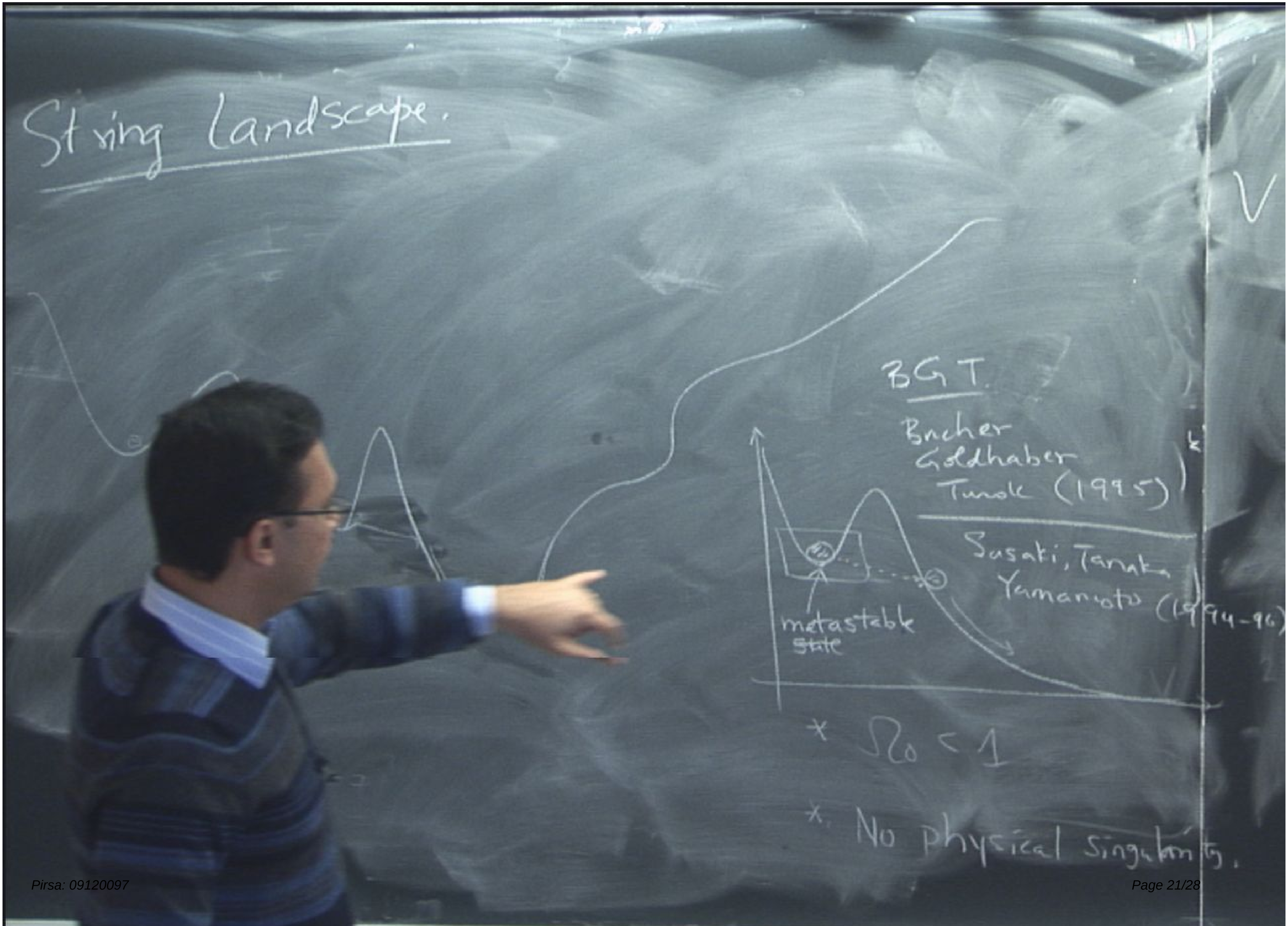
$$V = V_0 \exp\left(-\sqrt{\frac{16\pi}{p}}\,\frac{\varphi}{m_{pl}}\right)$$

$$V(\varphi) = \frac{V_0}{\varphi^{\alpha}}$$



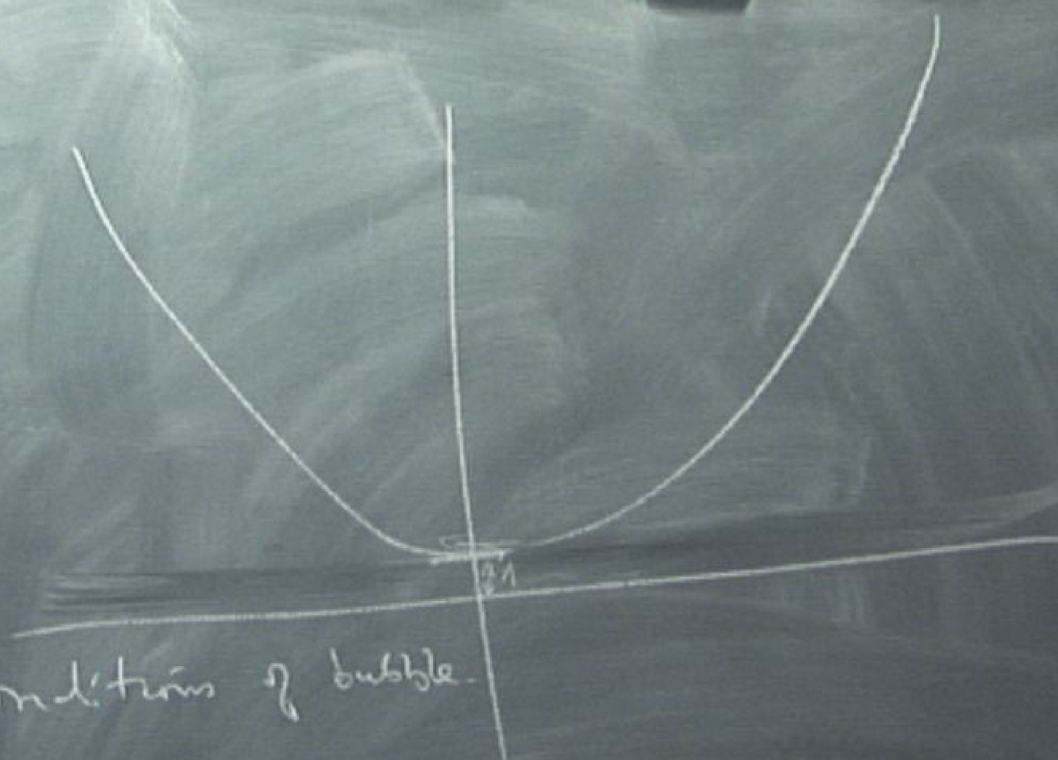
String landscape.


String landscape.
BGT
Bucher
Goldhaber
Turok (1995)
Sasaki, Tanaka
Yamamoto
metastable state


String landscape.
V
BGT
Bucher
Goldhaber
Turok (1995)
Sasaki, Tanaka
Yamamoto (1994-96)
metastable
state
* Ω0 < 1
* No physical singularity.

$$V = V_0 \exp\left(-\sqrt{\frac{16\pi}{p}}\ \frac{\varphi}{m_{pl}}\right)$$

$$V(\varphi) = \frac{V_0}{\varphi^{\alpha}}$$



* Initial conditions of bubble.

$$\dot{a} = 1,\ a = 0,\ \dot{\varphi} = 0$$

$$\Omega - 1 = \frac{k}{a^2 H^2} = \frac{k}{\dot{a}^2} \Rightarrow \Omega - 1 = k = -1$$

$$\Omega = 0$$

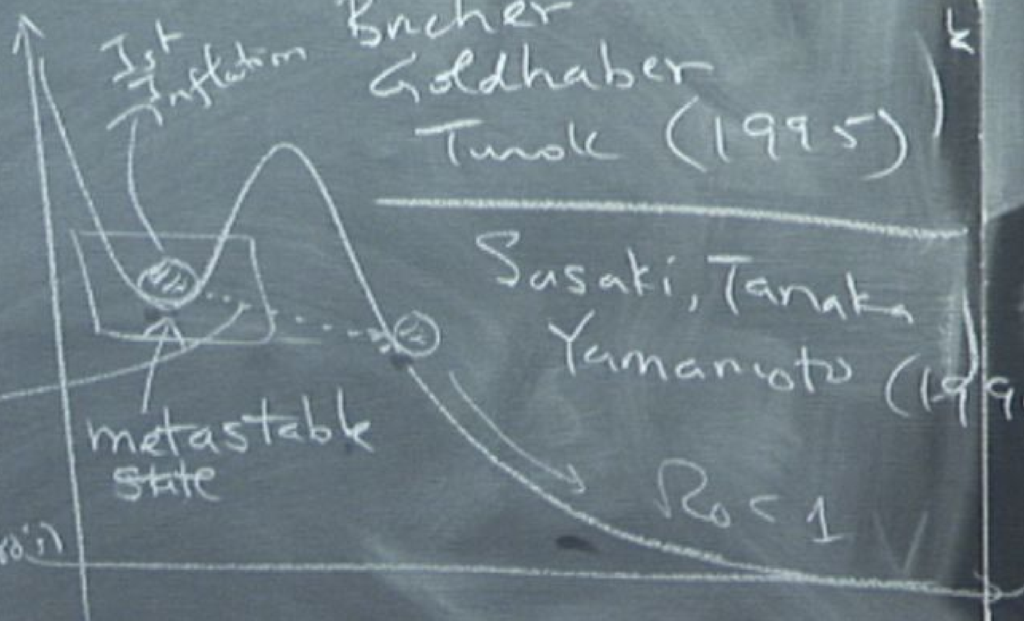
k

(1994-96)

nity.

BGT.

Bucher
Goldhaber
Turok (1995)



Sasaki, Tanaka
Yamamoto (1994-96)

Coleman
de Luccia (1980's)

* $\Omega_0 < 1$

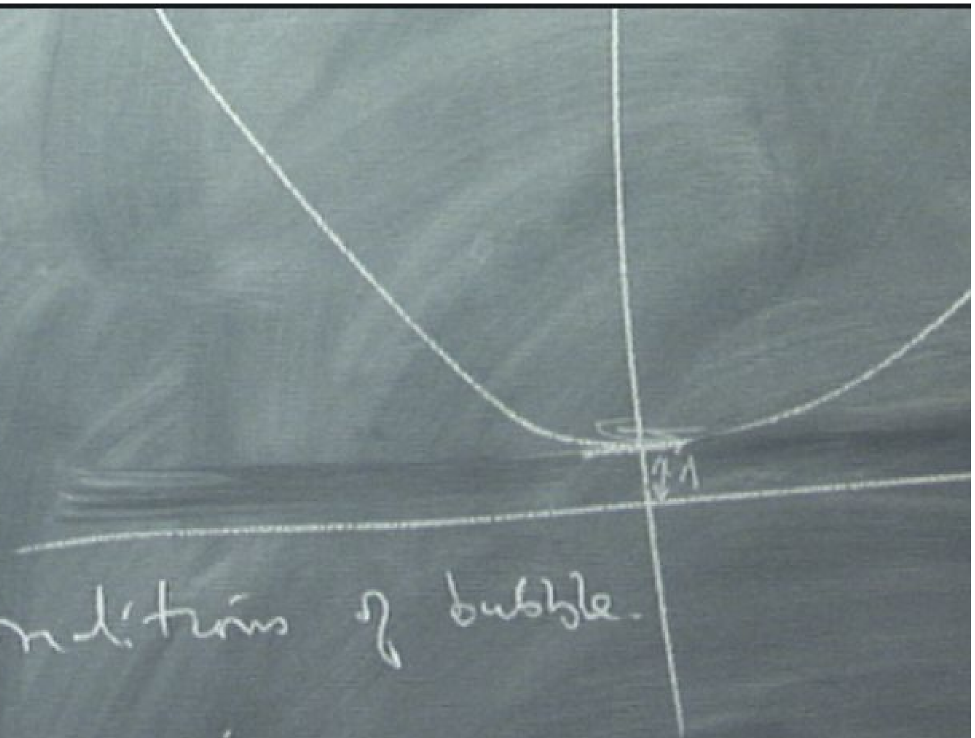
* No physical singularity.

$V(\varphi) = \frac{V}{\varphi}$

* In

$\dot{a}$

$$V(\varphi) = \frac{V_0}{\varphi^{\alpha}}$$



* Initial conditions of bubble.

$$\dot{a} = 1, \quad a = 0, \quad \dot{\varphi} = 0$$

(1994–96)

$$\Omega - 1 = \frac{k}{a^2 H^2} = \frac{k}{\dot{a}^2} \Rightarrow \Omega - 1 = k = -1$$

$$\Omega = 0$$

...tarity.

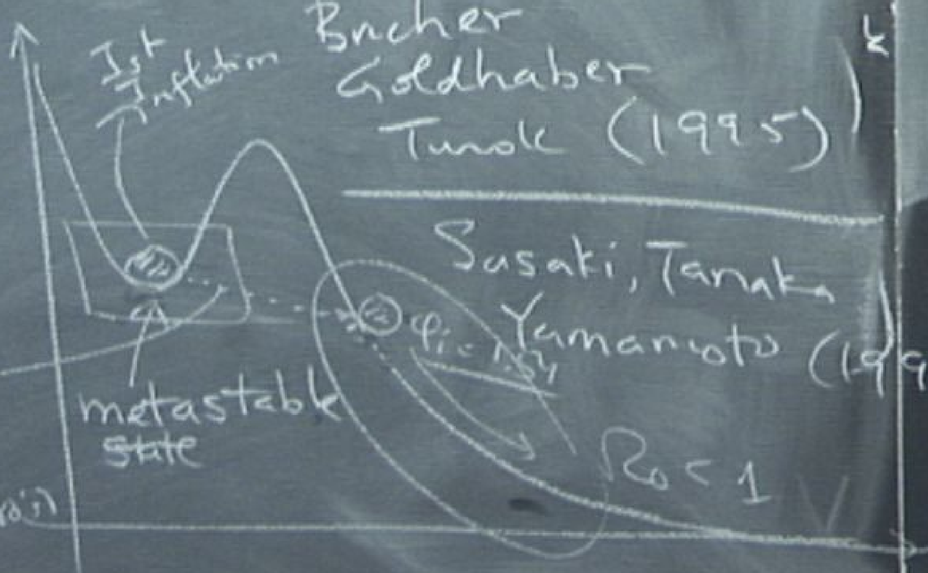
$$V = V_0 \exp\left(-\sqrt{\frac{16\pi}{p}}\ \frac{\varphi}{M_{pl}}\right)$$

BGT.

Bucher
Goldhaber
Turok (1995)

Sasaki, Tanaka
Yamamoto (1994-96)

...man
... Luccia (1980)



$$V(\varphi) = \frac{V_0}{\varphi^\alpha}$$

* Initial

$\dot a = 1$, ...

$\Omega - 1 =$ ...

$V \propto \phi$

$$\phi_i^2 = \frac{m_p^2}{8\pi}$$

* $\Omega_0 < 1$

* No physical singularity.

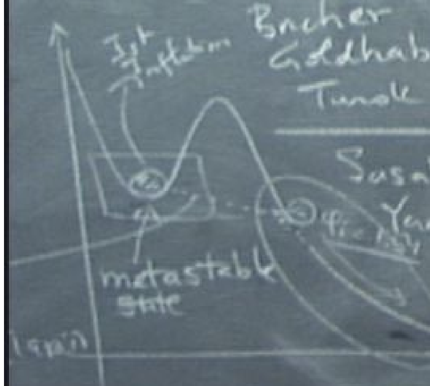
$$V = V_0 \exp\left(-\sqrt{\frac{16\pi}{p}}\,\frac{\varphi}{m_{Pl}}\right)$$

$$V(\varphi) = \frac{V_0}{\varphi^{\alpha}}$$

BGT

Bucher, Goldhaber, Turok (1995)

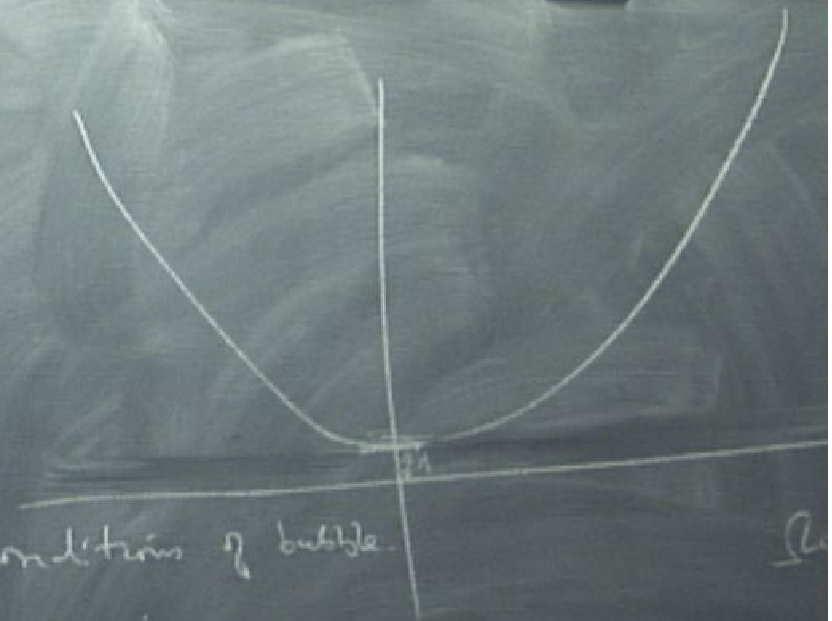
Sasaki, Tanaka, Yamamoto (1994-96)



$\Omega_0 < 1$

* $\Omega_0 < 1$

* No physical singularity.



* Initial conditions of bubble.

$$\dot a = 1,\ a = 0,\ \dot\varphi = 0$$

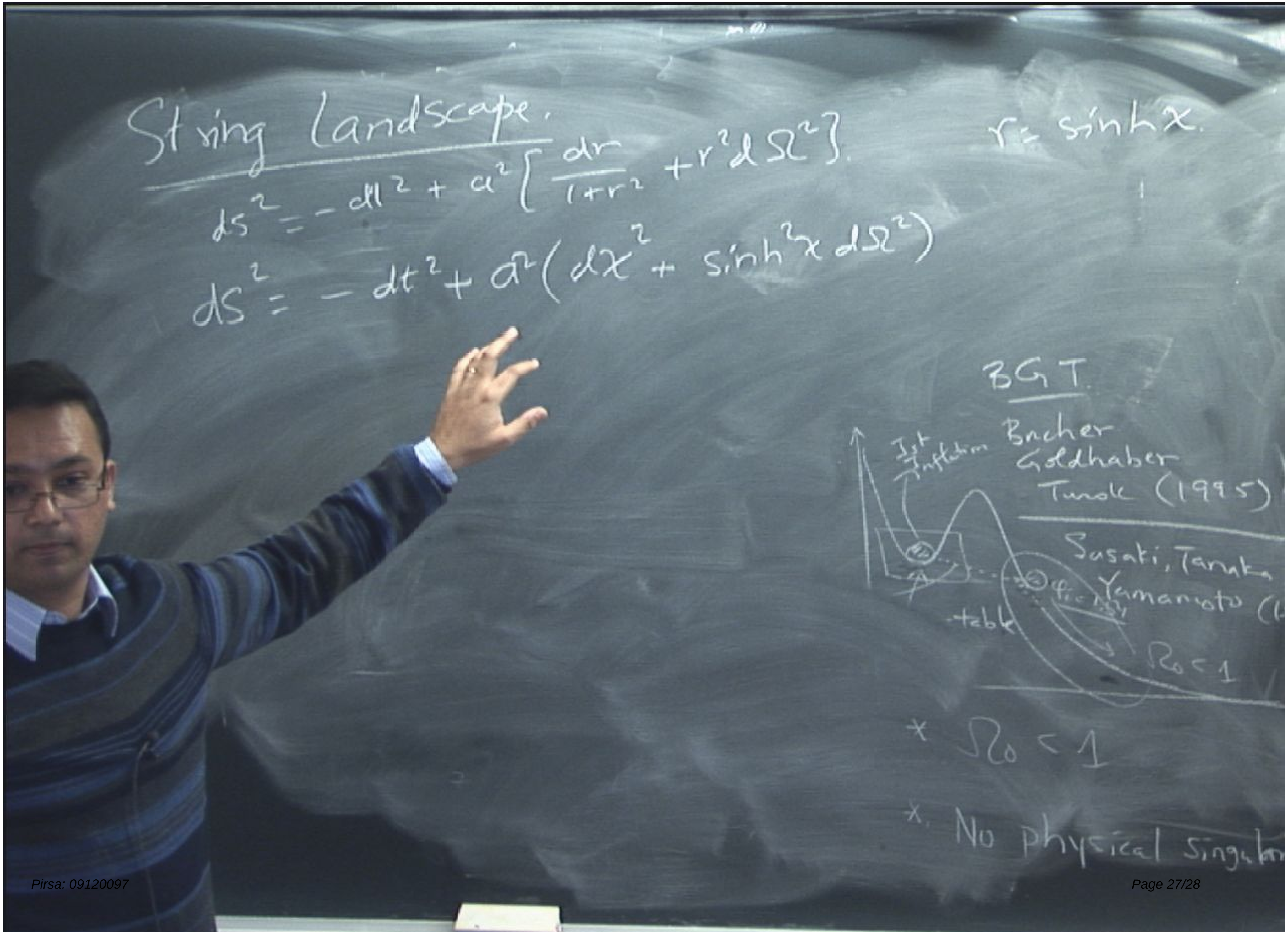
$$\Omega - 1 = \frac{k}{a^2H^2} = \frac{k}{\dot a^2} \Rightarrow \Omega - 1 = k = -1$$

$$\Omega = 0$$

$V\ a\ \phi$

$$\phi_i^2 = \frac{m_P^2}{8\pi}\ln\left[\frac{\alpha}{\Omega_0^{-1}-1}\right],$$

$A \sim 10^{25}$


String landscape.
$ds^2 = -dt^2 + a^2\left[\frac{dr}{1+r^2} + r^2 d\Omega^2\right]$
$r = \sinh\chi$
$ds^2 = -dt^2 + a^2(d\chi^2 + \sinh^2\chi\, d\Omega^2)$
BGT
Bucher
Goldhaber
Turok (1995)
Sasaki, Tanaka
Yamamoto
$\Omega_0 < 1$
× $\Omega_0 < 1$
× No physical singular

String landscape.

$$ds^2 = -dt^2 + a^2\left[\frac{dr}{1+r^2} + r^2 d\Omega^2\right] \qquad r = \sinh\chi$$

$$ds^2 = -dt^2 + t^2\left(d\chi^2 + \sinh^2\chi\, d\Omega^2\right)$$

Near the singularity

Milne metric

$$T = t\cosh\chi$$

$$R = t\sinh\chi$$

$$ds^2 = -dT^2 + \left(dR^2 + R^2 d\Omega^2\right)$$

BGT.

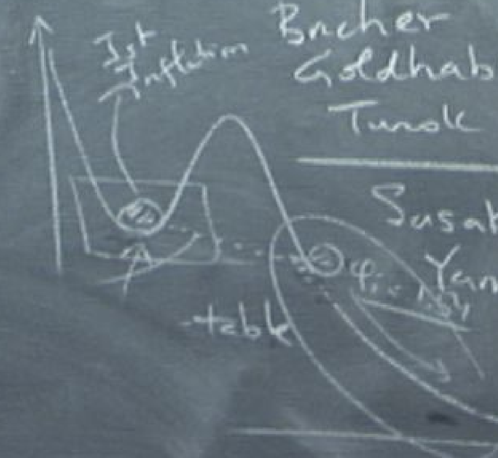
Bucher

Goldhaber

Turok (1995)

Sasaki, Tanaka

Yamamoto (1...



× $\Omega_0 < 1$

× No physical singular...