Title: PSI 2015/2016 Explorations in Particle Theory - Burgess - 9

Date: Apr 21, 2016 09:00 AM

URL: http://pirsa.org/16040028

Abstract:

DARK ENERGY

- Many Lines of Evidence for its existence?

* Acceleration of the universal expansion.

$$ds^2 = -dt^2 + a^2(t)\, \gamma_{ij}\, dx^i dx^j$$

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

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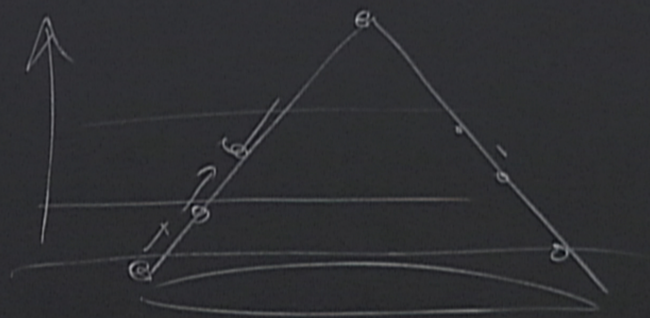


$d(z)$ DISTANCE - REDSHIFT

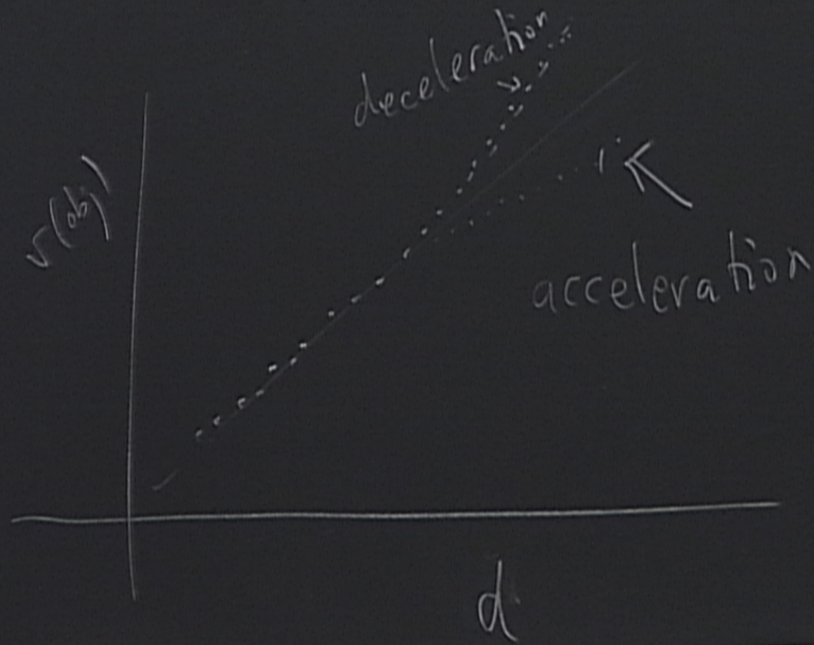
$(1+z) = \frac{a_0}{a}$

d vs z for small z

$d = H_0 z + c z^2 + \ldots$

Most distant d_L vs z measurements

use Type Ia supernovae



$v = Hd$ Hubble

$\ddot{a} > 0.$

$$\frac{d}{dt}\left(H^2 = \frac{8\pi G}{3}\rho \right)$$

$$\dot{\rho} + 3H(\rho + p) = 0$$

$$\frac{d}{dt}(\rho a^3) + p\frac{d}{dt}(a^3) = 0$$

$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3}(\rho + 3p)$$

$$\frac{d}{dt}\left(H^2 = \frac{8\pi G}{3}\rho \right)$$

if $p < -\frac{1}{3}\rho$.

$$\dot{\rho} + 3H(\rho + p) = 0$$

$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3}(\rho + 3p)$$

$\ddot{a} > 0$ is possible with $\rho > 0$

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

Do reasonable systems give you $\rho < 0, p < 0$?

u^μ = 4-velocity of the rest frame of the cosmic fluid

eg $\rho < 0$ $\quad$ $\mathcal{L} = \sqrt{-g}\left[-\frac{1}{2}(\partial\phi)^2 - V(\phi)\right]$

$\rho = \frac{1}{2}\dot{\phi}^2 + V$

$\phi = \phi(t)$ $\quad$ $T_{\mu\nu} = p g_{\mu\nu} + (p+\rho)u_\mu u_\nu$

$p = \frac{1}{2}\dot{\phi}^2 - V$

$d = H_0 z + c z^2 + \dots$

u^μ = 4-velocity of the rest frame of the cosmic fluid

$\rightarrow \rho = \frac{1}{2}\dot{\phi}^2 + V$

$\rightarrow p = \frac{1}{2}\dot{\phi}^2 - V$

stability demands V bounded from below, not $V > 0$

a vacuum exists

if $\dot{\phi}^2 \ll V$ (with $V > 0$) then $p \simeq -V \simeq -\rho$

$w = \frac{P}{\rho}$

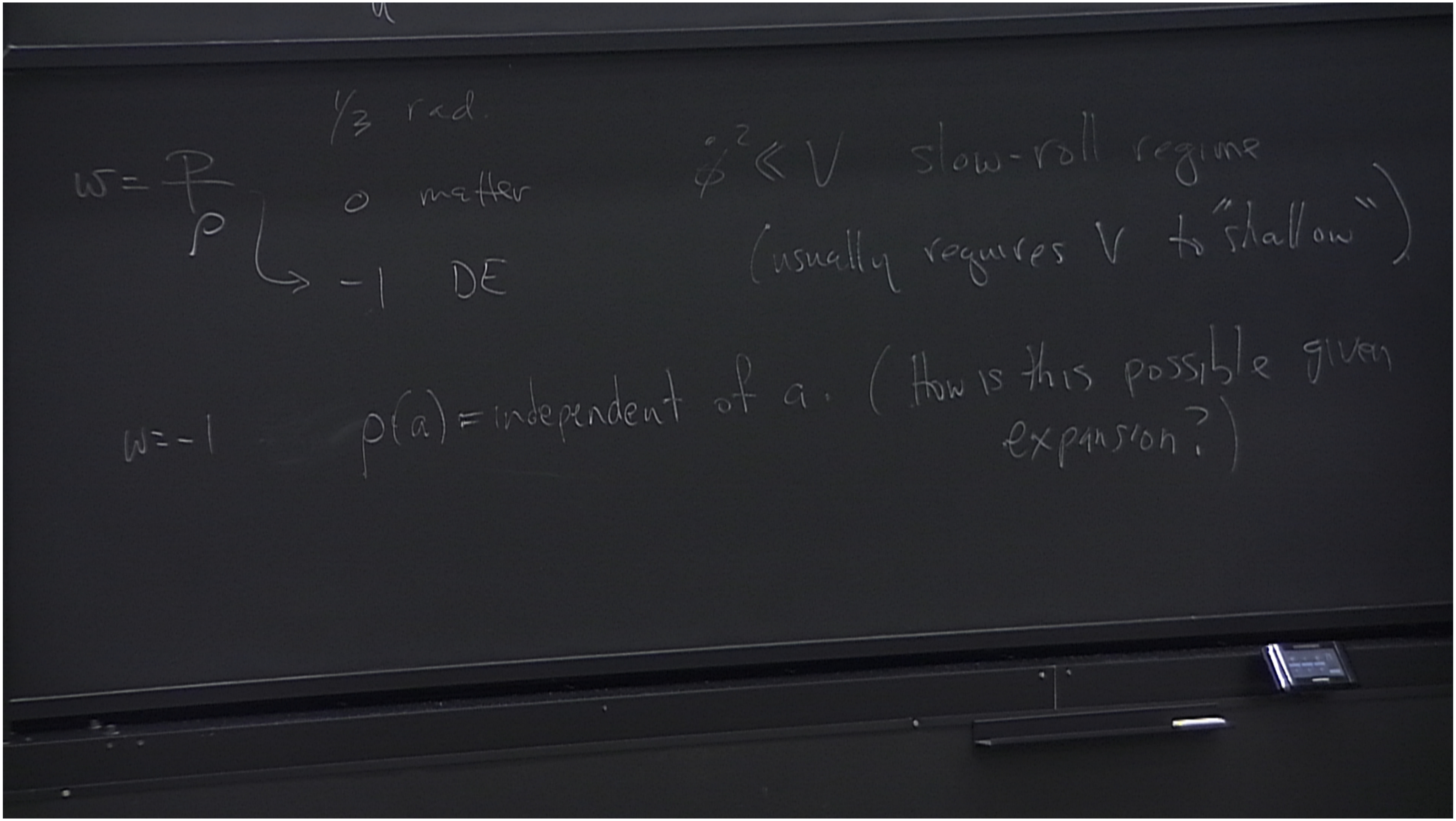
$\frac{1}{3}$ rad.

0 matter

$\rightarrow -1$ DE

$\dot{\phi}^2 \ll V$ slow-roll regime

(usually requires V to "shallow")


$w = \frac{P}{\rho}$
1/3 rad.
0 matter
-1 DE
$\dot{\phi}^2 \ll V$ slow-roll regime
(usually requires V to "shallow")
$w = -1$
$\rho(a)$ = independent of a. (How is this possible given expansion?)

$\ddot{a} > 0$ is possible

d

$w = \frac{P}{\rho}$

- $1/3$ rad.
- 0 matter
- -1 DE

$\dot{\phi}^2 \ll V$ slow-roll regime

(usually requires V to "shallow")

$w = -1$ $\rho(a)$ = independent of a. (How is this possible given expansion?)

$p = -\rho$ does right amount of work.

$$\frac{d}{dt}(\rho a^3) + P\frac{d}{dt}(a^3) = 0$$

allow")

e given

$\rho =$ const smells like the vacuum energy density

- Good evidence that the vacuum now is Lorentz invariant.
- only Lorentz invariant e.o.s. is $w = -1$. $\left(T_{\mu\nu} = \lambda g_{\mu\nu} \right)$ with $\lambda = \text{const}$.

$SO(3,1)$

η_{ab} $\quad \epsilon_{abcd}$

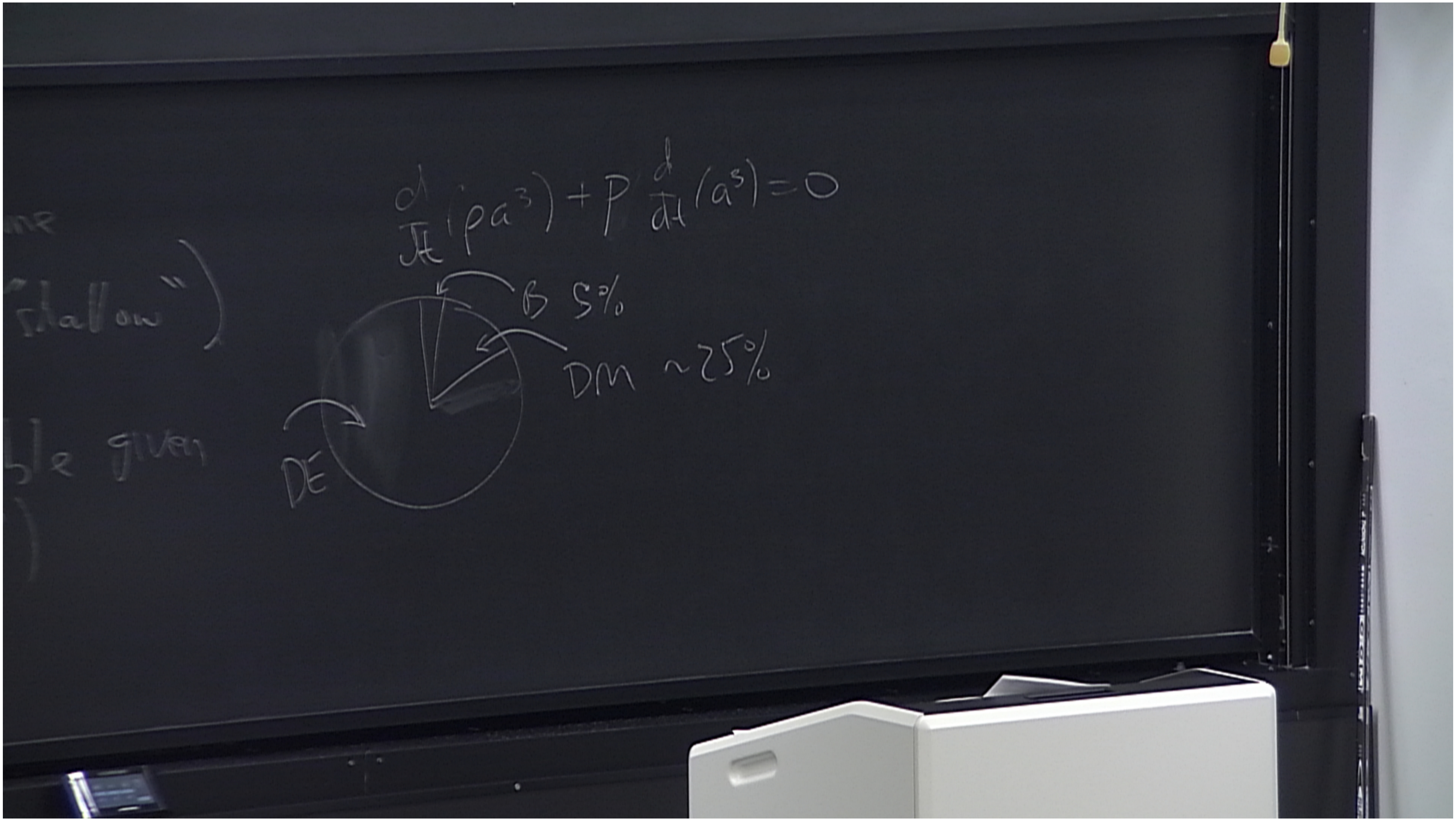
$\nabla_\mu T^{\mu\nu} = 0$

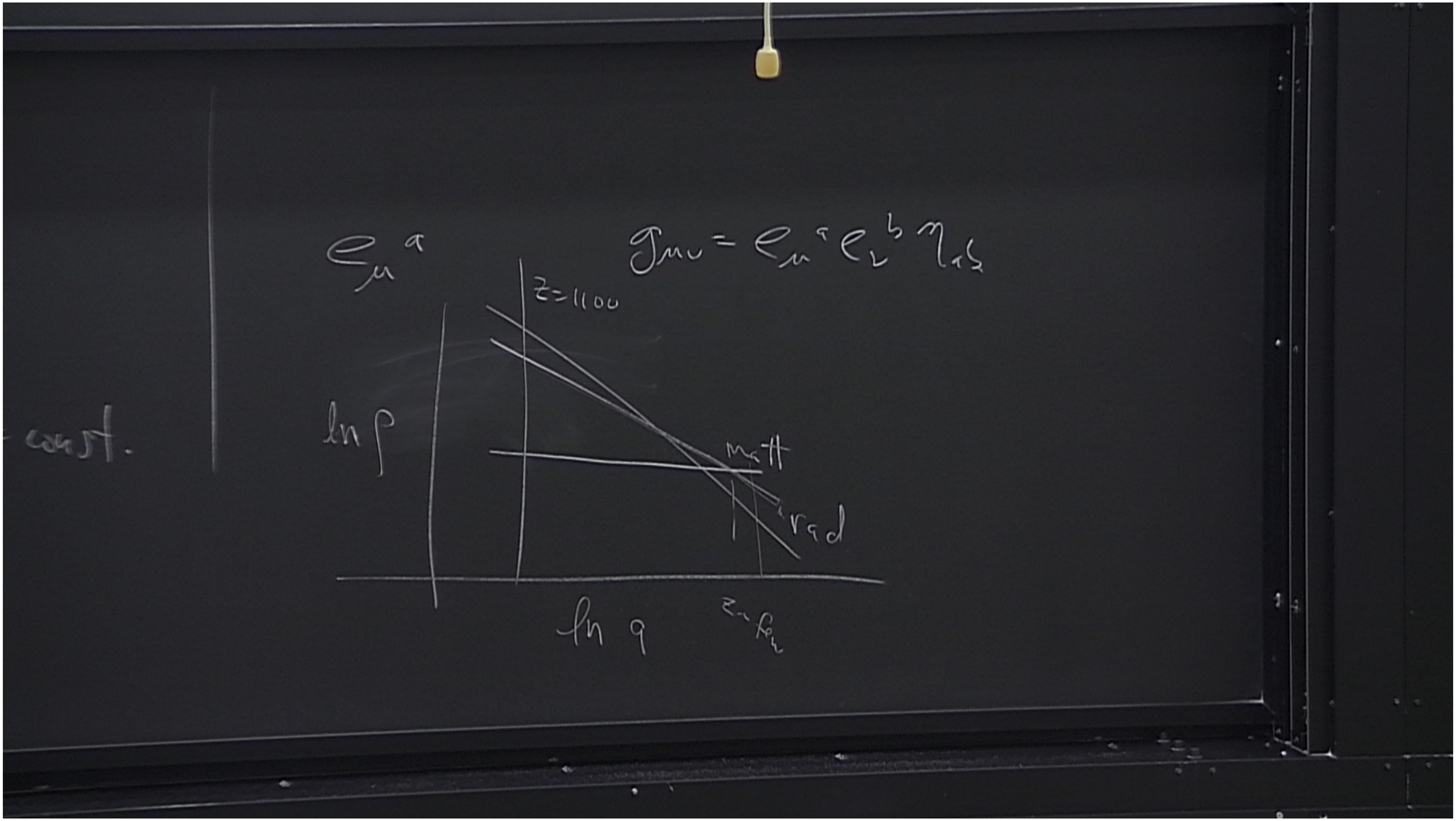
...riant.

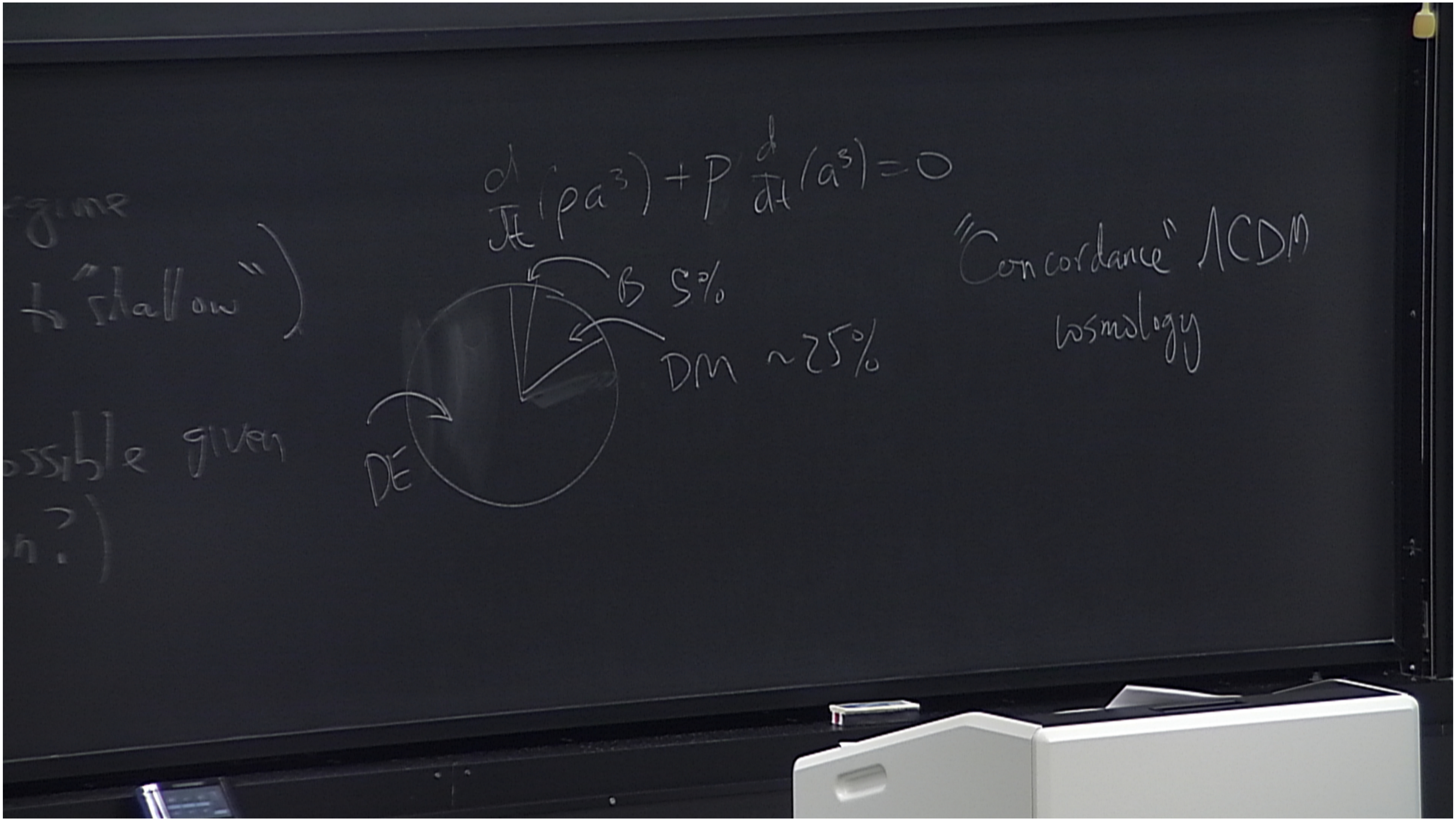
...) with $\lambda = \text{const.}$

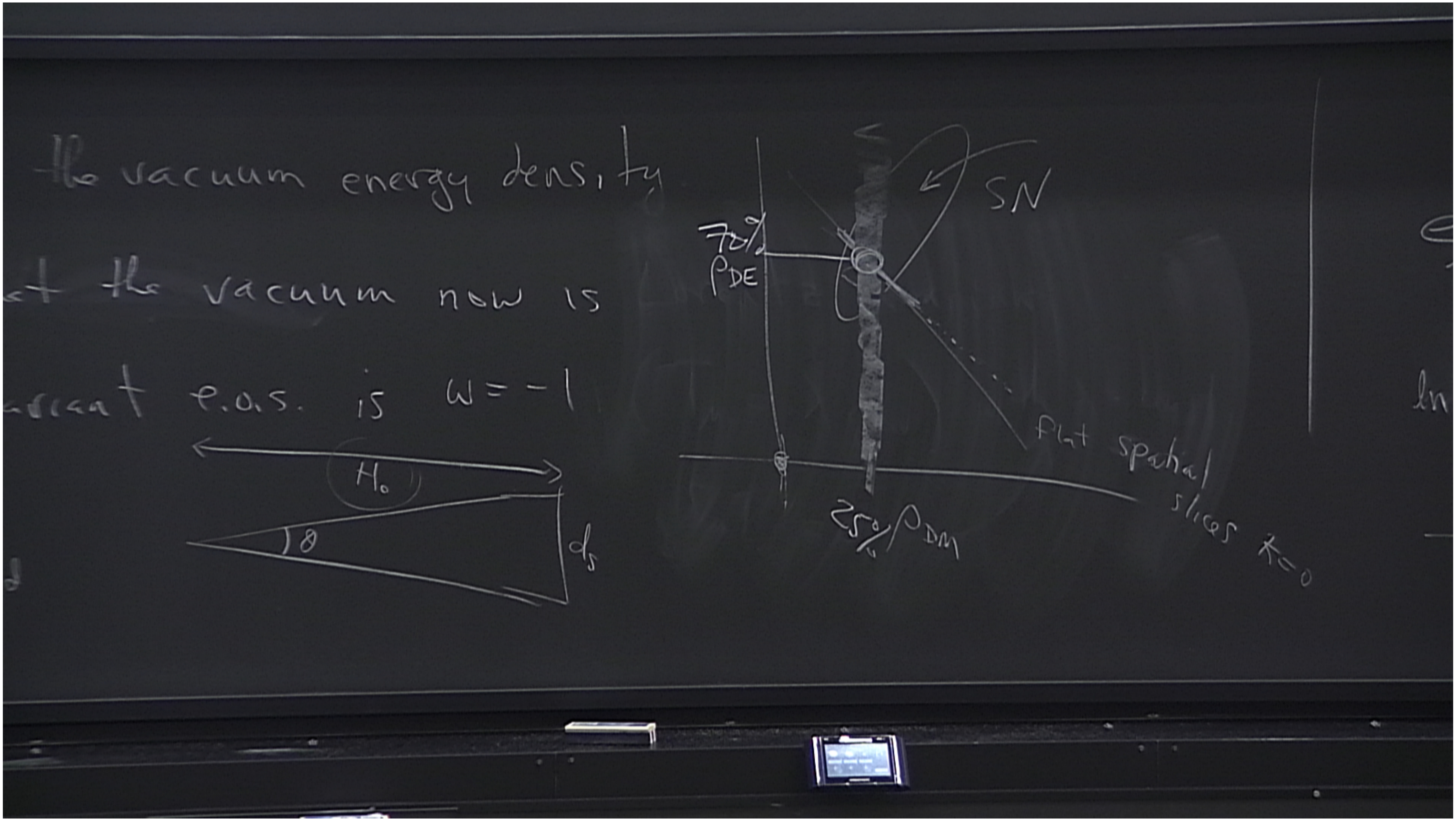
$e_\mu{}^a$

$g_{\mu\nu} = e_\mu{}^a e_\nu{}^b \eta_{ab}$


$\frac{d}{dt}(\rho a^3) + P\frac{d}{dt}(a^3) = 0$
"shallow"
B 5%
DM ~25%
DE


const.
$e_\mu{}^a$
$g_{\mu\nu} = e_\mu{}^a e_\nu{}^b \eta_{ab}$
z=1100
ln ρ
matt
rad
ln a


d/dt (ρa³) + P d/dt (a³) = 0
B 5%
DM ~25%
DE
"Concordance" ΛCDM
cosmology
to "shallow")
ossible given


the vacuum energy density
at the vacuum now is
ariant e.o.s. is w = -1
H₀
θ
SN
70%
ρDE
25%
ρDM
flat spatial
slices k=0