

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?

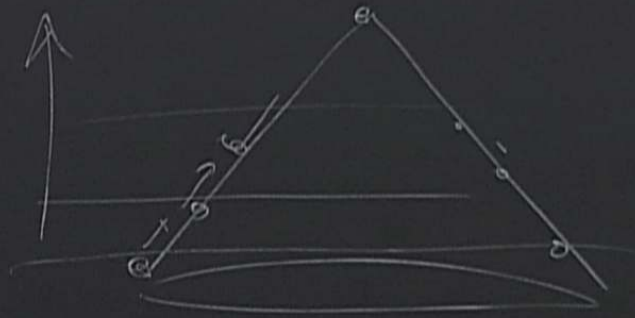
* Acceleration of the universal
expansion.

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

$$H = \frac{\dot{a}}{a}$$

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

ersal



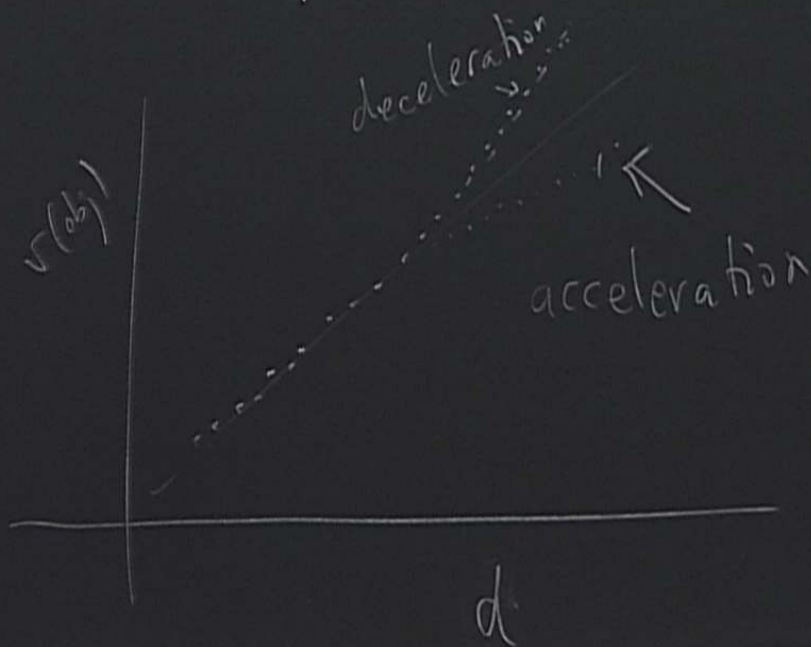
$d(z)$ DISTANCE - REDSHIFT

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

d vs z for small z

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

Most distant d_L vs z measurements
use Type Ia supernovae



$$v = H d \quad \text{Hubble}$$

$$\ddot{a} > 0$$

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

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

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

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

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

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

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

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

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

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

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

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

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

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 $p \approx -V \approx -\rho$

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



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

0 matter

-1 DE

$\dot{\phi}^2 \ll V$ slow-roll regime
(usually requires V to "shallow")

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$\dot{\phi}^2 \ll V$ slow-roll regime
 (usually requires V to "shallow")

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



$q > 0$ is possible

$$w = \frac{P}{\rho} \rightarrow \begin{cases} \frac{1}{3} \text{ rad.} \\ 0 \text{ matter} \\ -1 \text{ DE} \end{cases}$$

$\dot{\phi}^2 \ll V$ slow-roll regime
(usually requires V to "shallow")

$w = -1$ $\rho(a) = \text{independent of } a$. (How is this possible given expansion?)
 $p = -\rho$ does right amount of work.

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

allow")

2 given

$\rho = \text{const}$ smells like the vacuum energy density

- Good evidence that the vacuum now is Lorentz invariant.

- only Lorentz invariant p.o.s. is $w = -1$. ($T_{\mu\nu} = \lambda g_{\mu\nu}$) with $\lambda = \text{const}$.

$SO(3,1)$

η_{ab} ϵ_{abcd}

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

invariant.

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



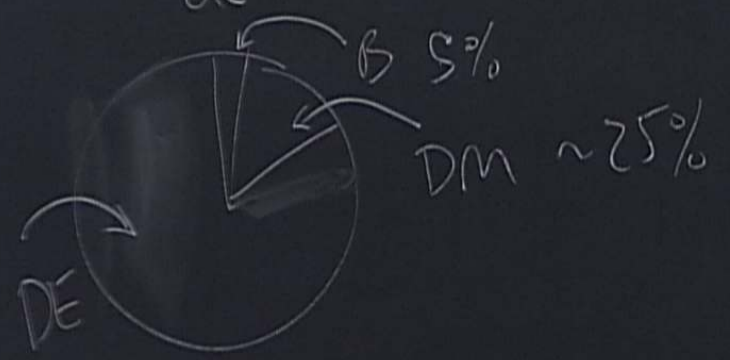
$$e_{\mu}^a$$



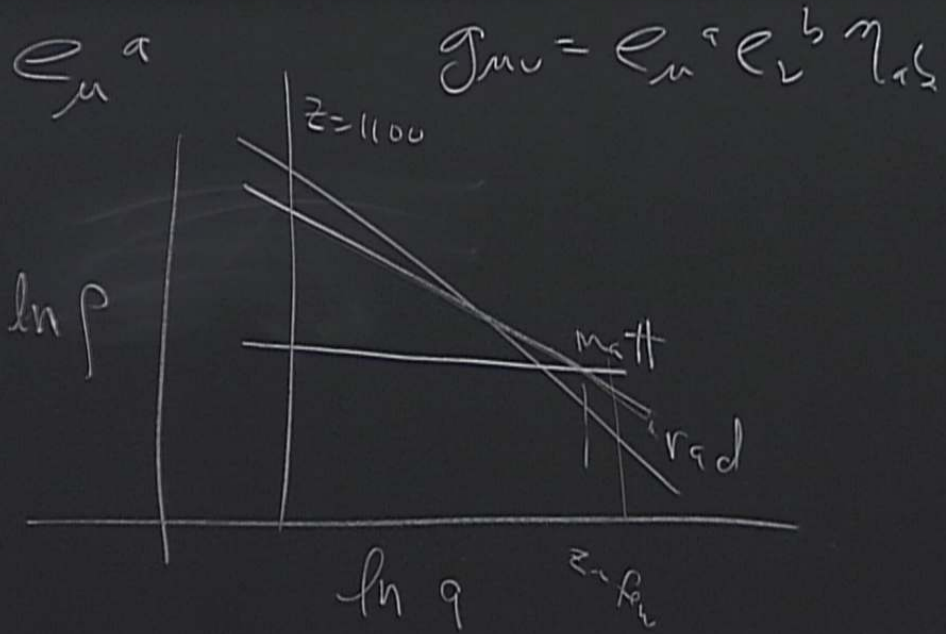
$$g_{\mu\nu} = e_{\mu}^a e_{\nu}^b \eta_{ab}$$

...
"shallow")
... given
)

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

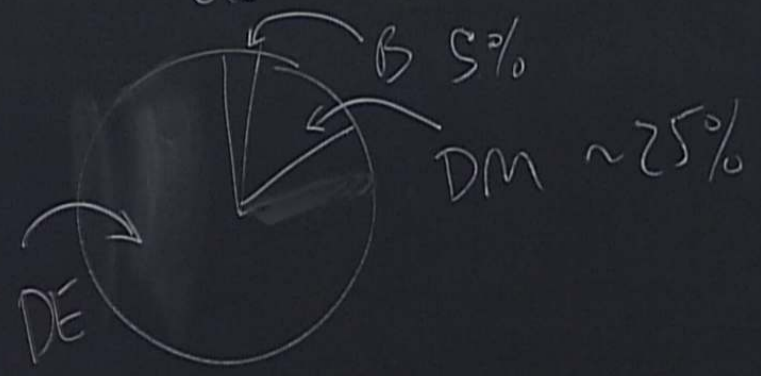


const.



engine
to "shallow")
possible given
n?)

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



"Concordance" Λ CDM
cosmology

the vacuum energy density
 at the vacuum now is
 recent e.o.s. is $w = -1$

