

Title: What's Blowing up the Universe?

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Abstract: The reason cosmologists have a job is that the Universe as a whole -- the stuff between planets and stars and galaxies -- is, despite first appearances, a pretty interesting place. The strangest fact about it is that it's expanding, and always has been, as far as we know (and though Einstein's theory of gravity predicts this, Albert himself didn't much care for the idea, at least at first). After about seventy years -- it was discovered in 1929 -- this expansion was kind of old hat, but then new observations came around that shattered the old complacency. The old idea was that the Universe was expanding, but slowing down as it went -- since gravity, as far as anyone knew, could only cause attractive forces. What the new observations demonstrated is that the Universe's expansion is, in fact, accelerating -- getting faster with time. This is so shocking that most astronomers and cosmologists couldn't believe it at first, and some still don't. In this talk, I'll explain a bit about how we know this, why it's so shocking, and tell you something about the crazy ideas people at Perimeter have for what's going on.

Welcome Mark Wyman
~~member~~

Talk title: What is the weight
of nothing?

Cosmology

Cosmology

is the Universe
as a whole



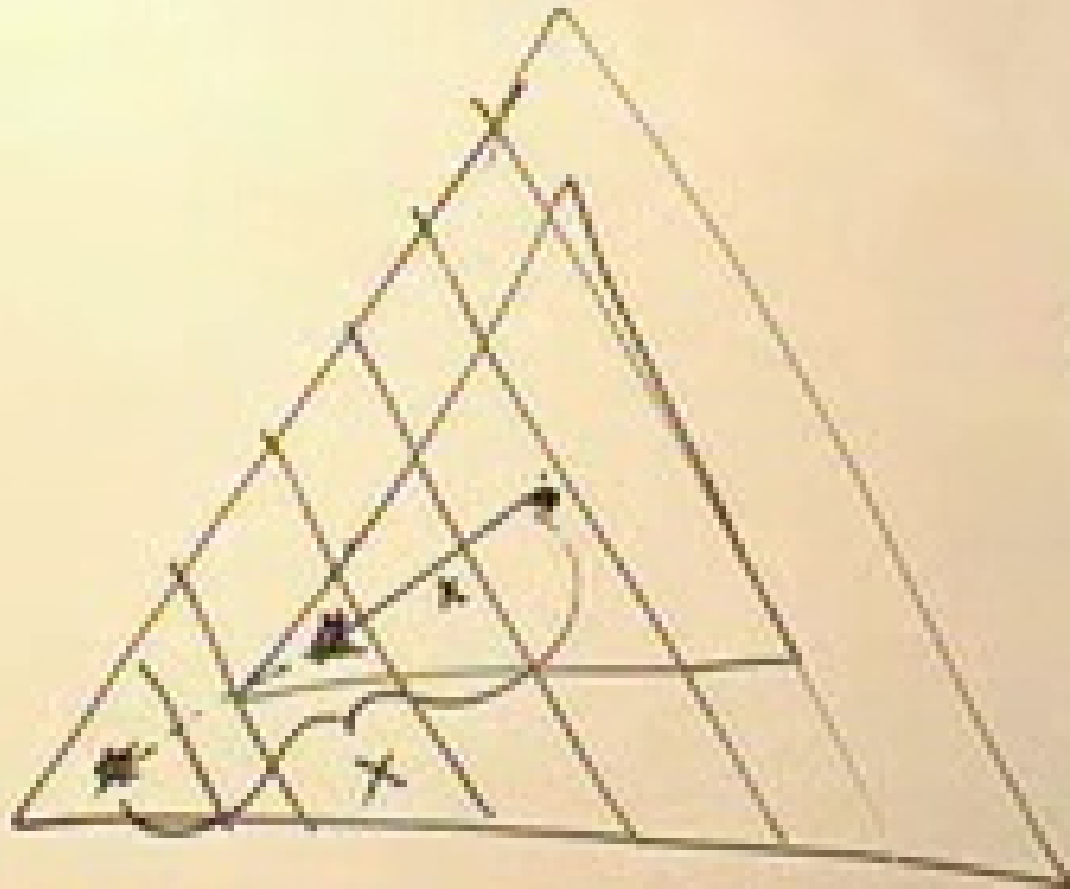
PHYSICS. WHAT IS THE WEIGHT
of Nothing

Vacuum



that state

that has no
excitations



$$V = \frac{d\phi}{dt}$$

$$\frac{d}{dt} (Fg)$$

$$\vec{v} = Q \times \vec{\omega}$$

↑

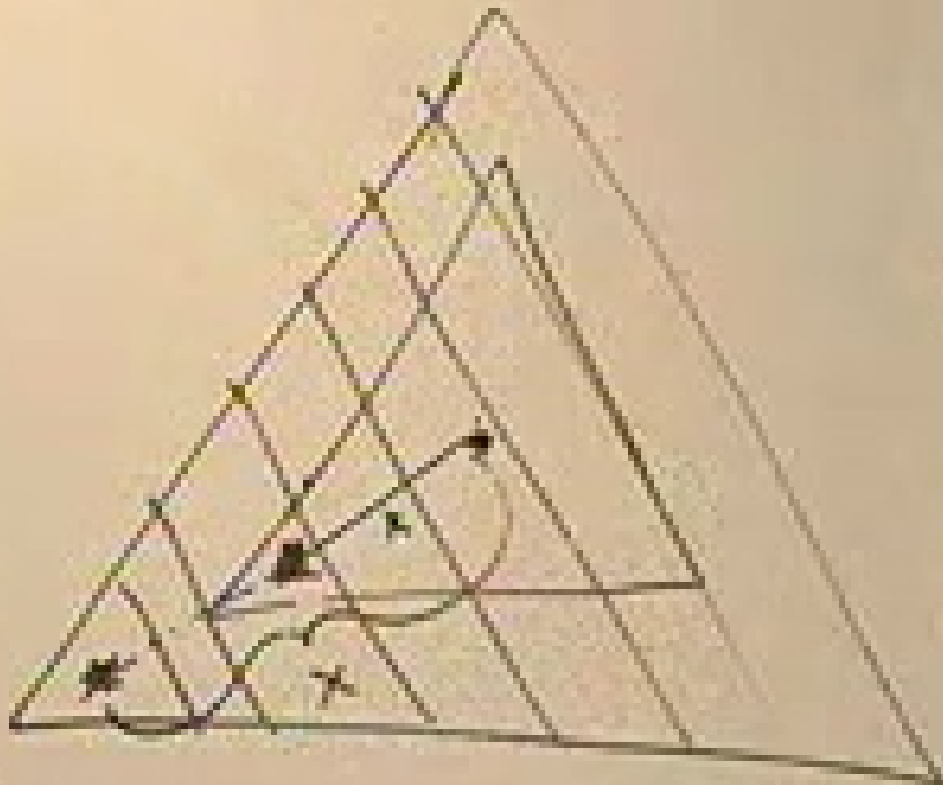
$$\dot{V} = \frac{dV}{dt} = \frac{d}{dt} \left(\frac{1}{2} \dot{x}^2 + \frac{1}{2} kx^2 \right) + \frac{d}{dt} \left(\frac{1}{2} m \dot{x}^2 \right)$$

$$= \left(\frac{d}{dt} \left(\frac{1}{2} \dot{x}^2 + \frac{1}{2} kx^2 \right) \right) + \frac{d}{dt} \left(\frac{1}{2} m \dot{x}^2 \right)$$

$$v = \frac{dr}{dt} = \frac{da}{dt} \chi(t) + \cancel{\frac{a}{dt} \chi(t)}$$

$$v = a \left(\frac{d\chi}{dt} \right) \chi(t)$$

Hubble's Law



$$V = \frac{d\Phi}{dt}$$

$\lambda = \frac{p}{h}$

$$\frac{d}{dt}(F \cdot g) =$$

$$\vec{v} = \vec{p} \times \vec{\omega}$$

$$v = \frac{dr}{dt} = \frac{da}{dt} X(a) + g$$

$$v = \left(\frac{d|a|}{dt} \right) \hat{r}(t)$$

Huygens Law

$Q = \text{scale}$
 factor

$\frac{dQ}{dt}$

$X = \frac{1}{R}$

$$\frac{d^2 a}{dt^2}$$

V_{app}

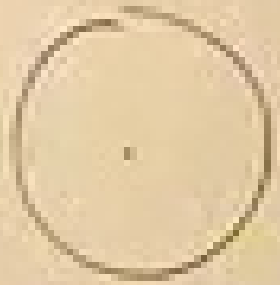
r

variables

$$\frac{da}{dc} \propto -(\rho + 3p)$$

↑
density

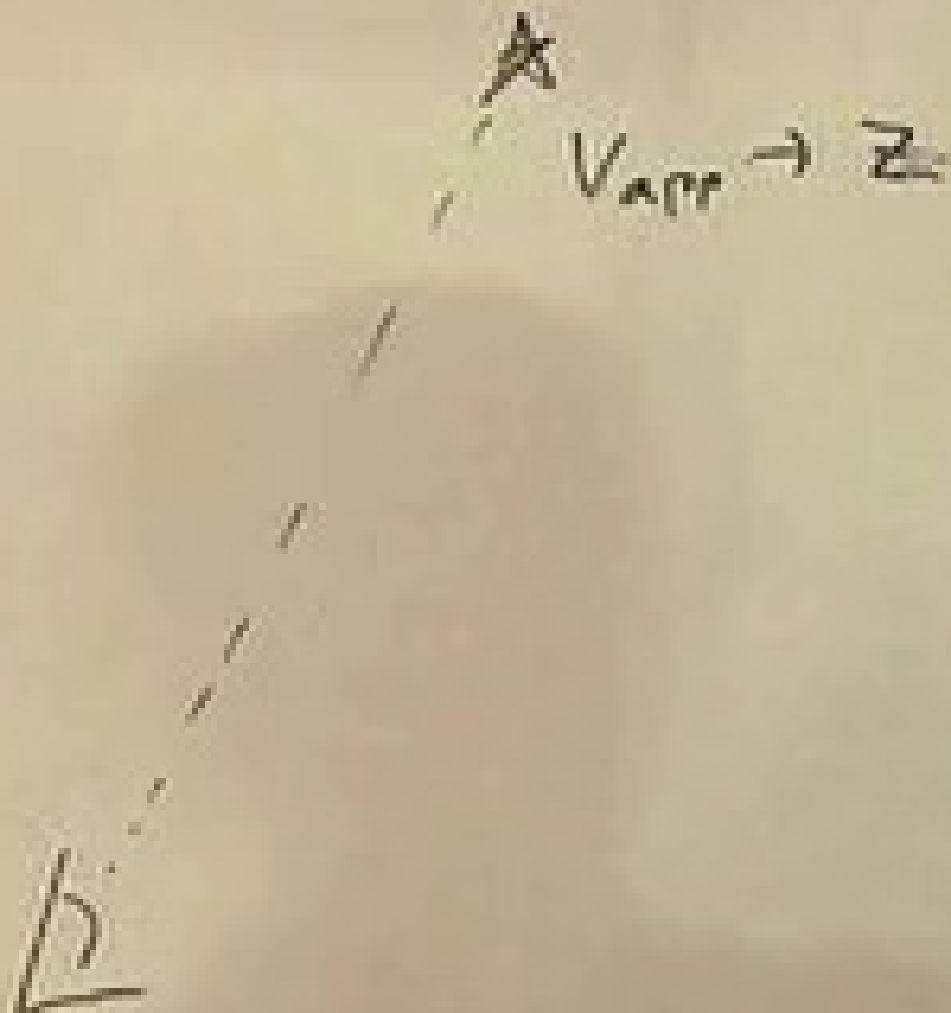
↙
pressure



$$A = 4\pi r^2$$

$$L = \frac{A}{r}$$

Z





Handwritten text at the top of the whiteboard, possibly a name or title.



$$A = V_{eff} + Z$$

Handwritten symbol, possibly a bracket or a specific variable.

Handwritten symbol, possibly a bracket or a specific variable.

Handwritten symbol, possibly a triangle or a specific variable.

$$\frac{\Delta r}{\Delta z} = \dots$$

$$\frac{\partial}{\partial z} \left(\frac{\partial r}{\partial z} \right)$$

$$\frac{\partial}{\partial z}$$

Astronomy Night

$$P_{\text{string}} = \frac{1}{2} \rho$$

$$P_{\text{star}} = \frac{1}{2} \rho$$

$$P_{\text{space}} = \rho$$

red work
brown...

green

red 2...

black /

orange

$$\frac{d^2 a}{dt^2} = -\left(\rho + \frac{3}{2} p\right)$$

$$G_{\mu\nu} = 8\pi S_{\mu\nu} + \Lambda g_{\mu\nu}$$

Space Curves \rightarrow $G_{\mu\nu}$
 $S_{\mu\nu}$ \rightarrow Matter & energy
 $\Lambda g_{\mu\nu}$

$\mu = \nu \sigma$

$$\frac{d^2 a}{dt^2} - \frac{v^2}{a^3} = -3p,$$

$$G_{\mu\nu} = 8\pi G T_{\mu\nu} + \Lambda g_{\mu\nu}$$

where $G_{\mu\nu}$ is the Einstein tensor, $T_{\mu\nu}$ is the stress-energy tensor, Λ is the cosmological constant, and $g_{\mu\nu}$ is the metric tensor.

Labels in the image:
- $G_{\mu\nu}$ is labeled "Einstein tensor"
- $8\pi G T_{\mu\nu}$ is labeled "matter + energy"
- $\Lambda g_{\mu\nu}$ is labeled "cosmological constant"

①

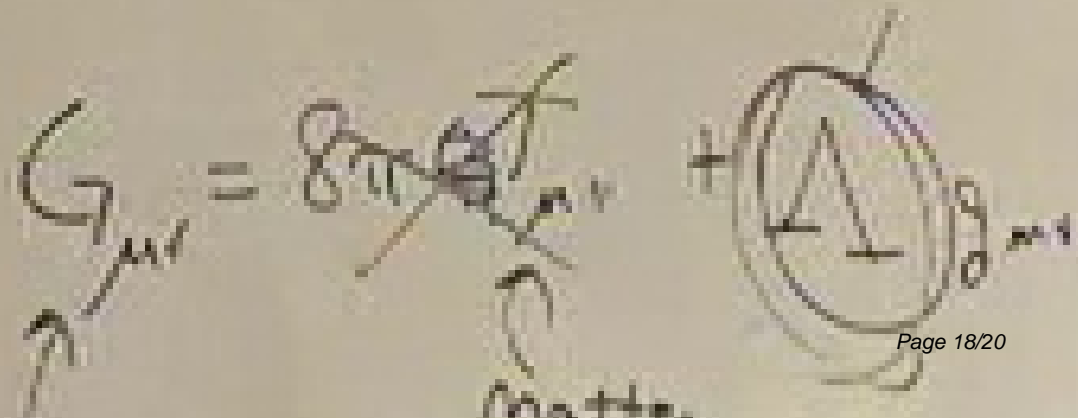
10

$$\begin{pmatrix} \cdot \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ \cdot \end{pmatrix} \cdot \begin{pmatrix} \frac{d^2 \theta}{dt^2} \\ \frac{d^2 \theta}{dt^2} \\ \frac{d^2 \theta}{dt^2} \\ \frac{d^2 \theta}{dt^2} \\ \frac{d^2 \theta}{dt^2} \\ \frac{d^2 \theta}{dt^2} \\ \frac{d^2 \theta}{dt^2} \\ \frac{d^2 \theta}{dt^2} \\ \frac{d^2 \theta}{dt^2} \\ \frac{d^2 \theta}{dt^2} \end{pmatrix} = \text{const}$$

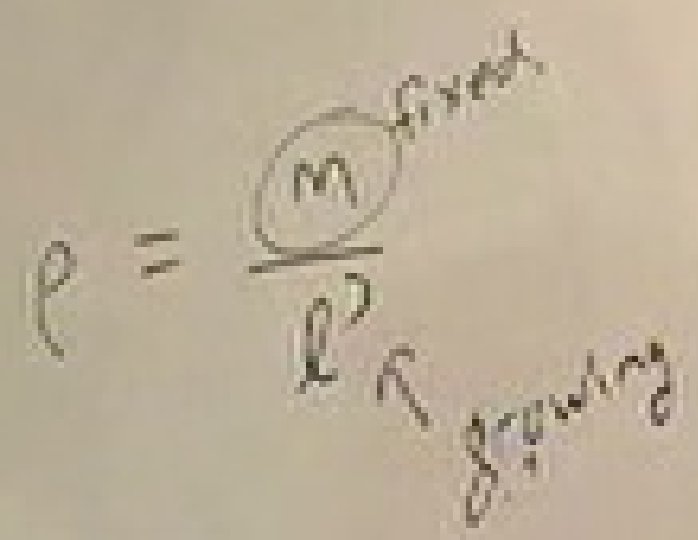
accel. rate

$\mu =$
 $\mu = \mu \cdot \mu \cdot \mu$

$$\frac{d^2 \theta}{dt^2} = \left(\rho + \frac{3}{2} \rho \right)$$



11
2014 x 11



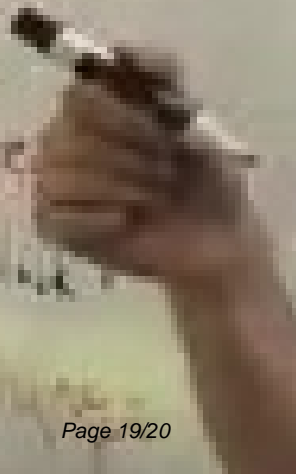
2 → shrinks



- Farewell sheet
- SNO LAB journal
- PI t-shirts
labring Fri.
- Departures
- Astronomy
Night

red words
blue words

red
blue



$$\rho = \frac{M^{\text{fixed}}}{L^{\text{growing}}}$$

$\rho \rightarrow$ shrinks

$$\rho_{\text{DE}, \Lambda} = \frac{M^{\text{fixed}}}{L^{\text{fixed}}}$$

- SNOLAB period
- PI t-shirts
to bring Fri.
- Departures
- Astronomy
Night

red wavy

blue wavy

green

red

blue