

Title: What's blowing up the Universe?

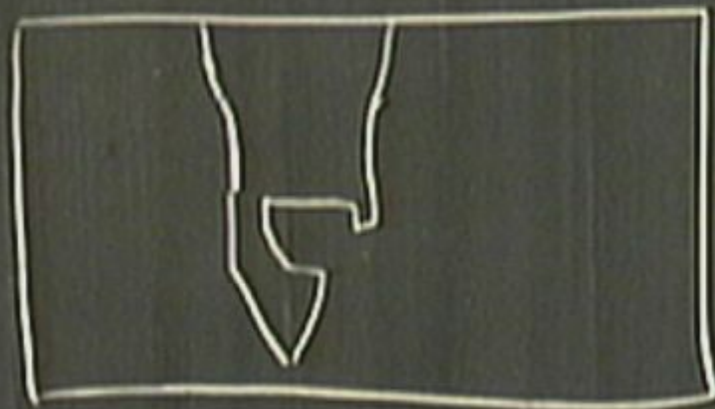
Date: Aug 19, 2008 09:00 AM

URL: <http://pirsa.org/08080026>

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.

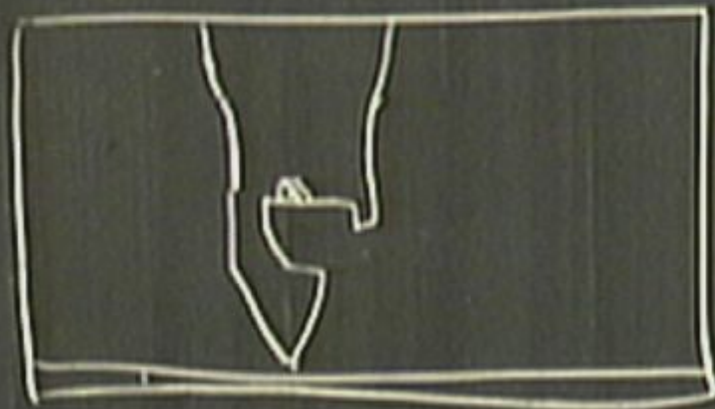
Mark Wymon

Mark Wyman

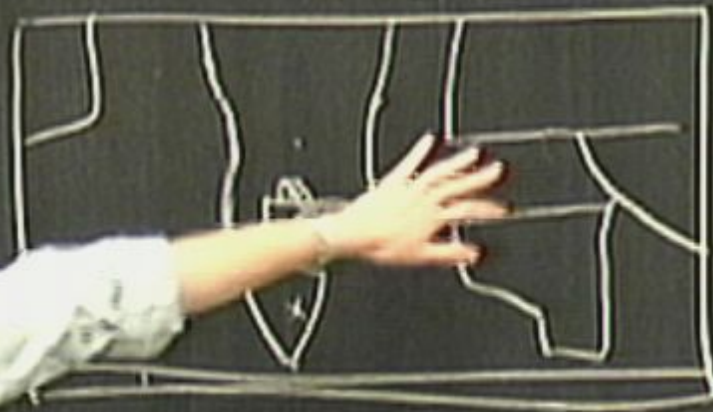




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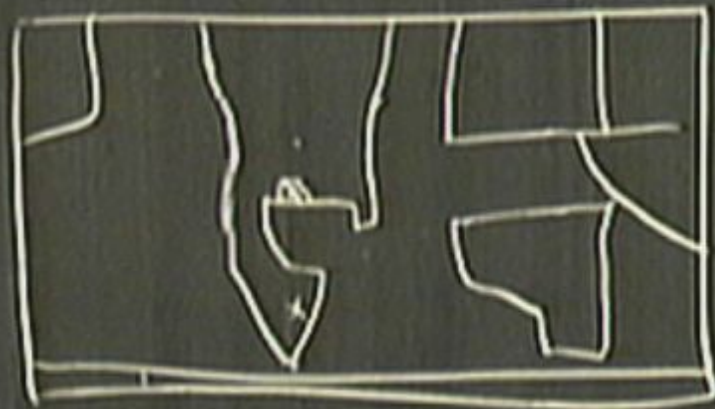


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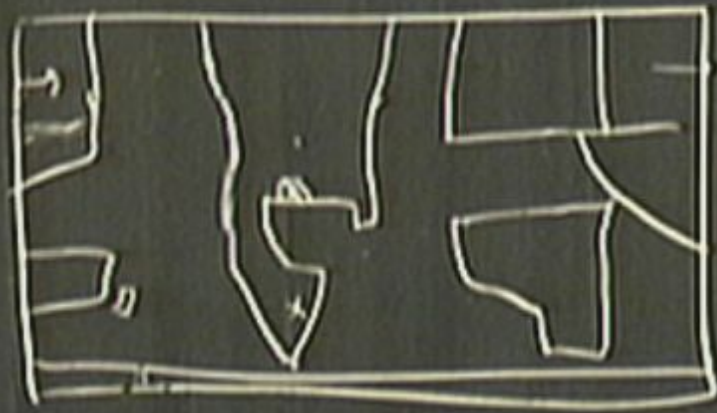




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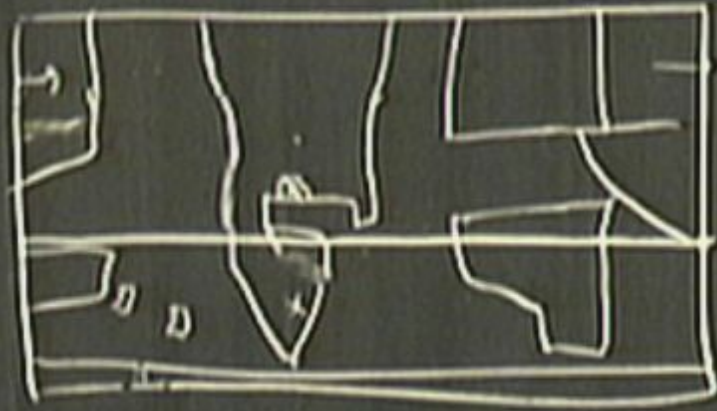


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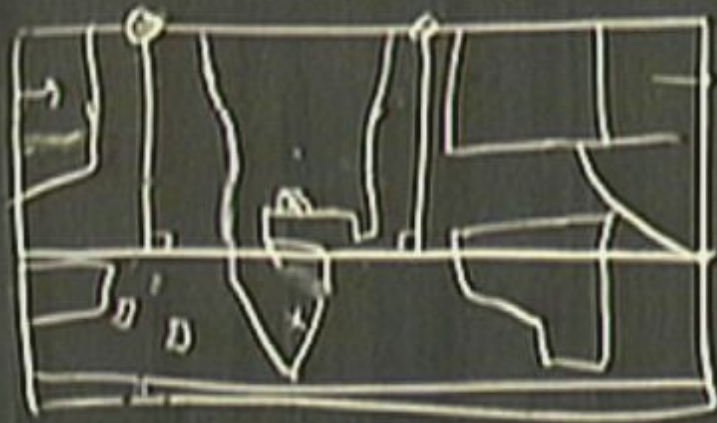


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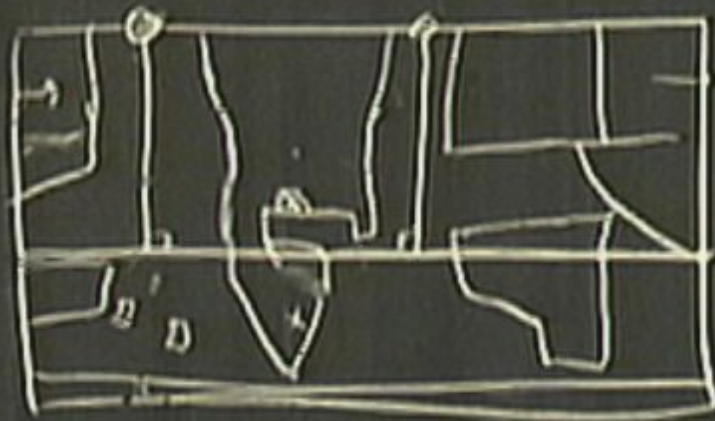




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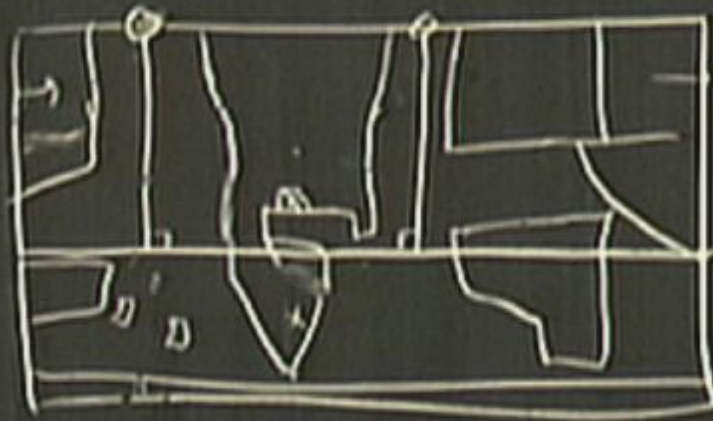


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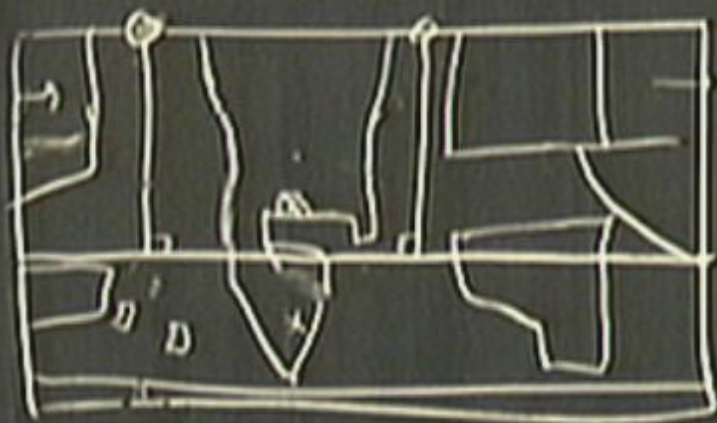





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$$\mu \sim \text{g/cm} \sim 10^{20} \text{ g/cm}$$

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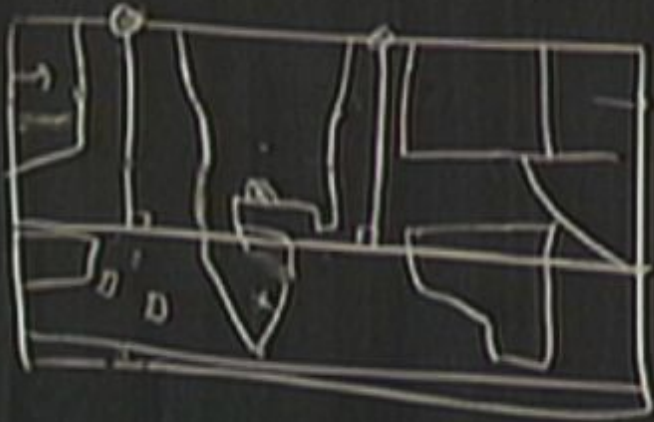
Curvature = Energy density





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Curvature = # Energy density  
 $G_{ii}$




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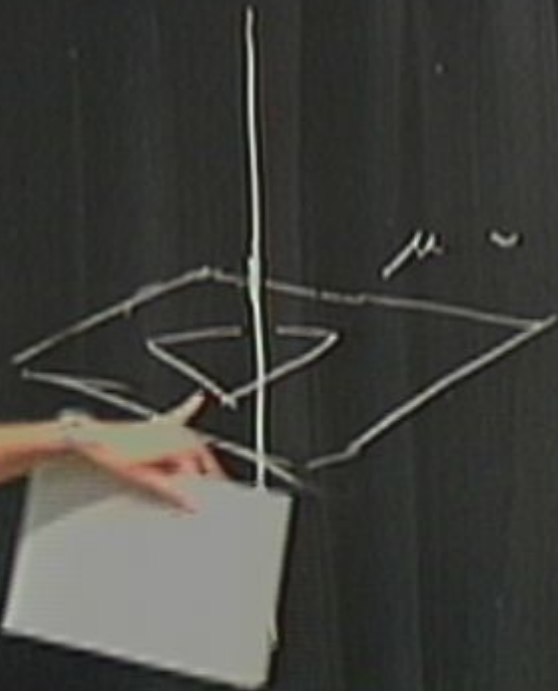
Curvature =  $\frac{1}{2}$  Energy density  
 $G_{\mu\nu}$





A person's arm and hand are visible on the left side of the image, pointing towards a vertical white line drawn on the chalkboard. The person is wearing a light-colored, patterned shirt.
$$\mu \sim \text{g/cm} \sim 10^{20} \text{ g/cm}$$

$$\mu \sim 9/\text{cm} \sim 10^{20} \text{ g/cm}$$







$$\mu \sim 9/\text{cm} \sim 10^{20} \text{ g/cm}$$

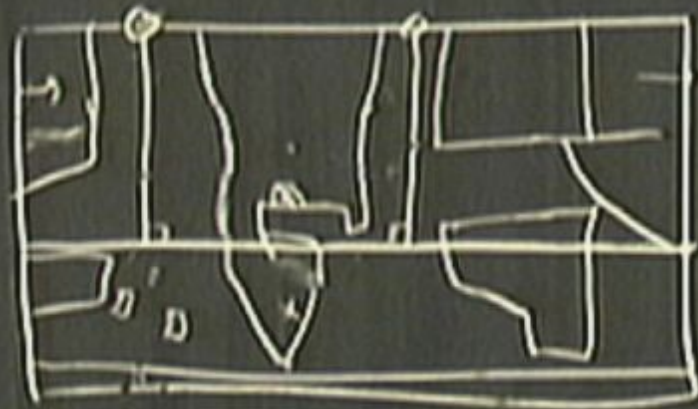
Cosmic strings

$$\mu \sim \text{g/cm} \sim 10^{20} \text{ g/cm}$$





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Curvature =  $\frac{\# \text{ Energy density}}{G_{11}}$



Energy = everything

Cosmology: Study of the Universe as  
a whole



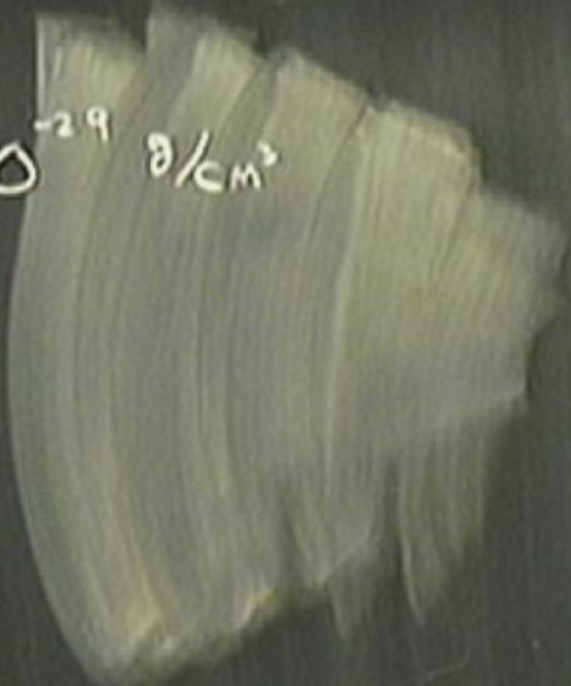
Cosmology: Study of the Universe as  
a whole



c.g.s

-1/2

$$\rho \approx 10^{-29} \text{ g/cm}^3$$



cgs  
kms

-12

$$\rho \approx 10^{-29} \text{ g/cm}^3$$



cgs  
kms

-12

$\rho \approx 10^{-29} \text{ g/cm}^3$





cgs  
kms

-12

$\rho \approx 10^{-29} \text{ g/cm}^3$



c.g.s  
k.m.s

-12

$\rho$

$\rho/cm^3$



Standard  
ruler



c.g.s  
kms

-12

$$\rho \approx 10^{-29} \text{ g/cm}^3$$



Standard  
ruler

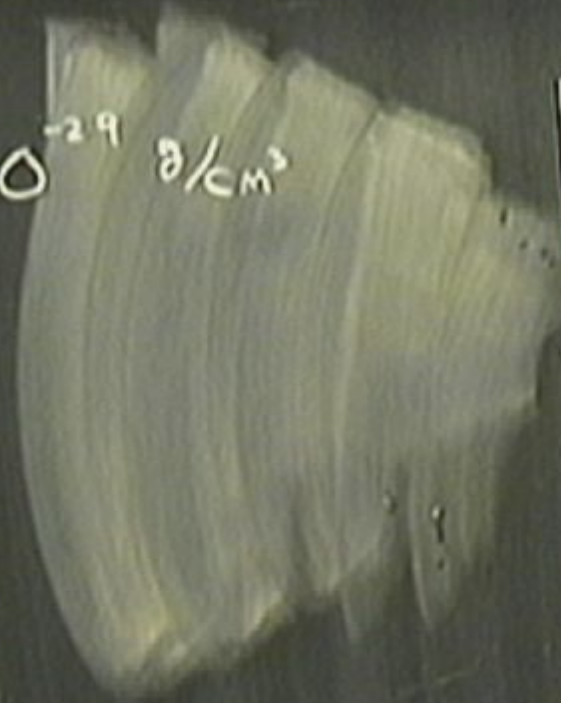
$d \sim 100$  million light  
years



cgs  
kms

-12

$$\rho \approx 10^{-29} \text{ g/cm}^3$$



Standard  
ruler

$d \approx 100$  million light  
years

c.g.s  
kms

-12

$10^{-29} \text{ g/cm}^3$



Standard  
ruler

$d \sim 100$  million light  
years





cgs  
kms

-12

$$\rho \approx 10^{-29} \text{ g/cm}^3$$



Standard  
ruler

$d \sim 100$  billion light  
years

$$\frac{t_1}{t_2} = \frac{m_1}{m_2}$$



cgs  
KMS

-12

$$\rho \approx 10^{-29} \text{ g/cm}^3$$



Standard  
ruler

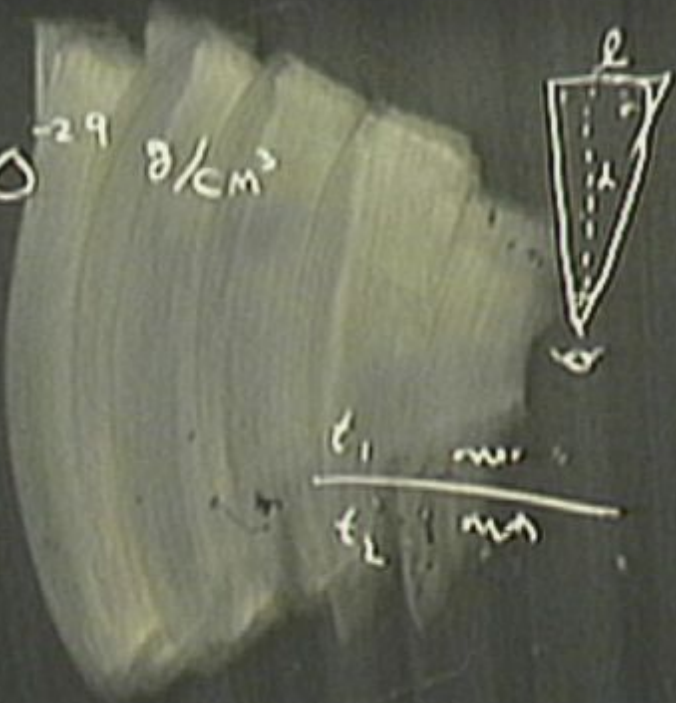
$d \sim 100$  million light  
years

$$\frac{t_1 \text{ m}}{t_2 \text{ m}}$$

cgs  
kms

-12

$$\rho \approx 10^{-29} \text{ g/cm}^3$$



Standard  
ruler

$d \sim 100$  million light  
years

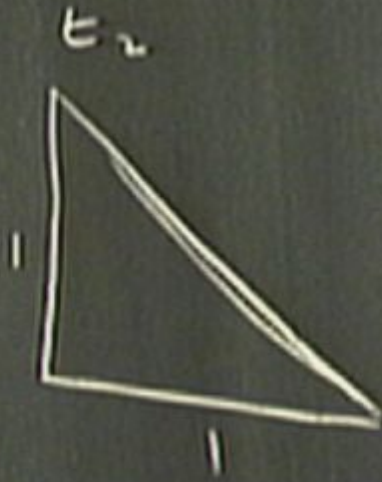
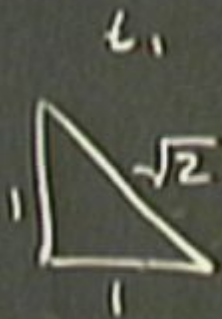
$$\frac{t_1 \text{ yr}}{t_2 \text{ yr}}$$







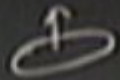




↑

x you  
am  
here





$$H \sim \frac{\text{velocity}}{\text{distance}}$$

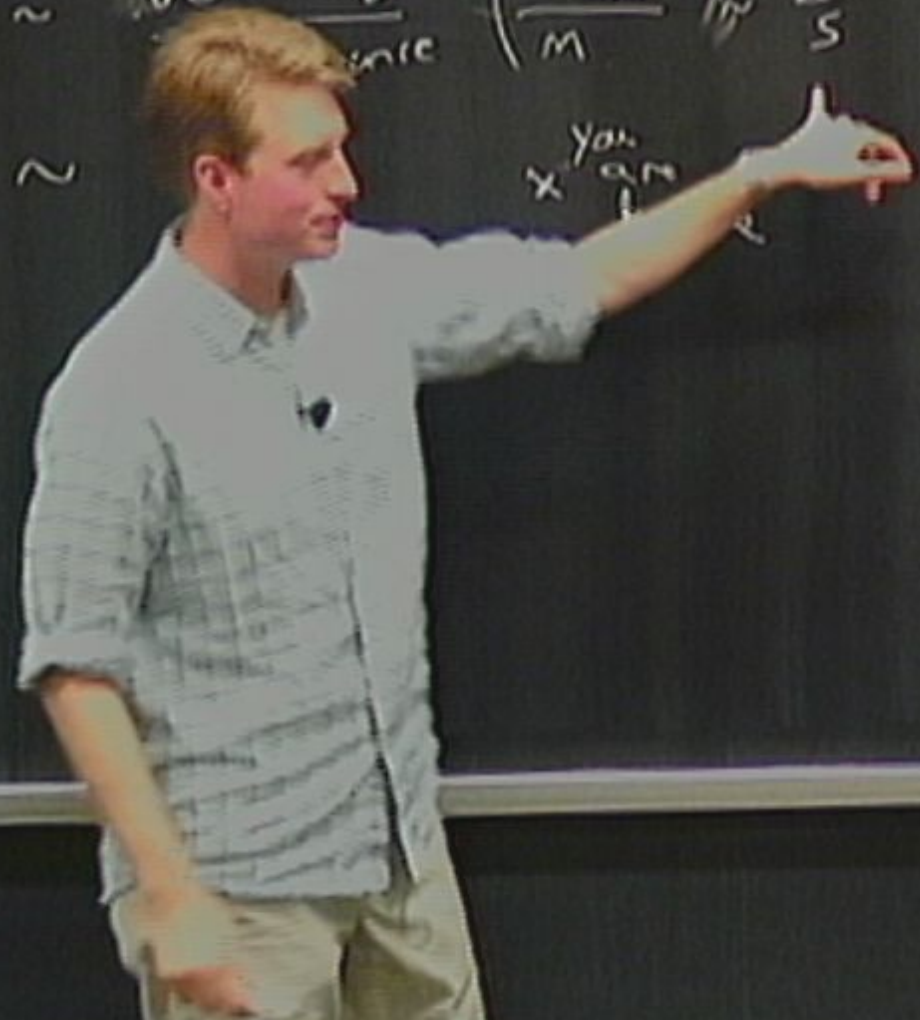
x you  
am  
here

↑

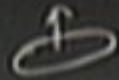
$$H \sim \frac{\text{velocity}}{\text{wavelength}} \left( \frac{m/s}{m} \right) \sim \frac{1}{s}$$

2

x you  
am



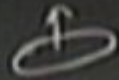




$$H \sim \frac{\text{velocity}}{\text{distance}} \left( \frac{\text{m/s}}{\text{m}} \right) \sim \frac{1}{\text{s}}$$

$$\sim 711 \frac{\text{km/s}}{\text{Mpc}} \quad \times \begin{matrix} \text{you} \\ \text{are} \\ \text{here} \end{matrix}$$

Mpc = Mega parsec  
↑  
~3 light year



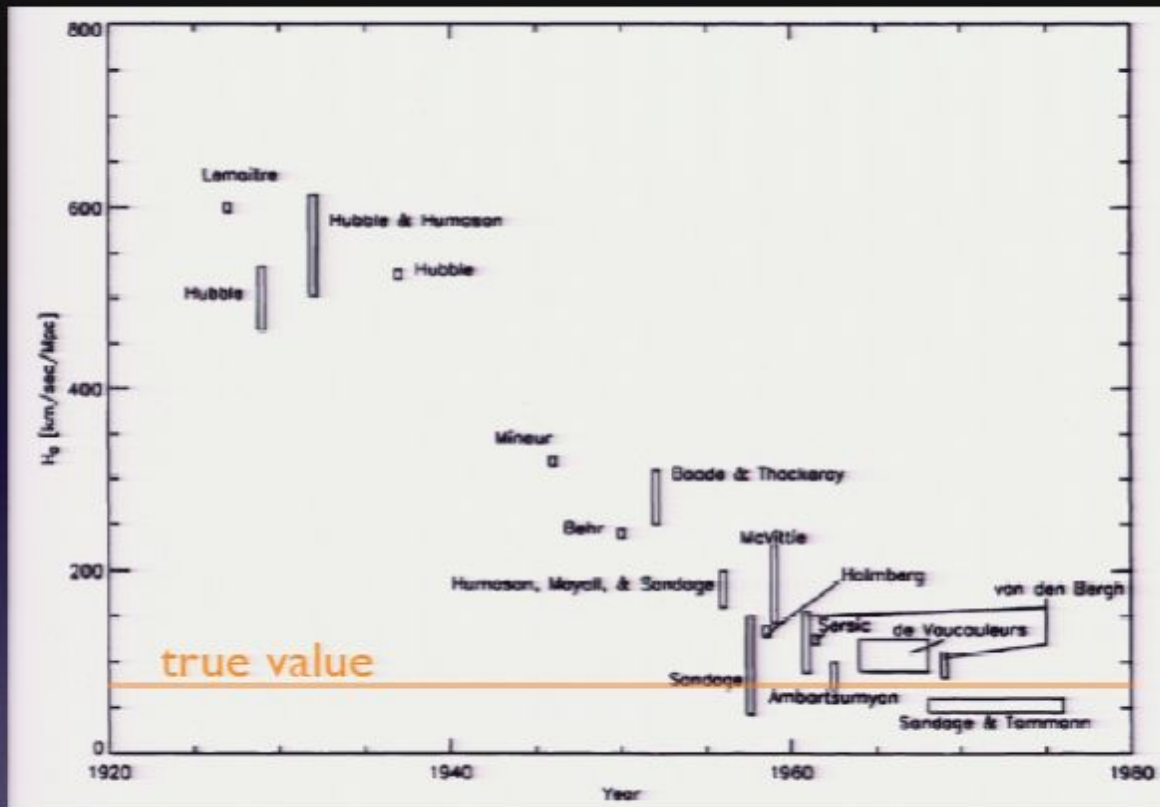
$$H \sim \frac{\text{velocity}}{\text{distance}} \left( \frac{\text{m/s}}{\text{m}} \right) \approx \frac{1}{\text{s}}$$

$$\sim 70 \frac{\text{km/s}}{\text{Mpc}} \quad \times \begin{matrix} \text{you} \\ \text{are} \\ \text{here} \end{matrix}$$

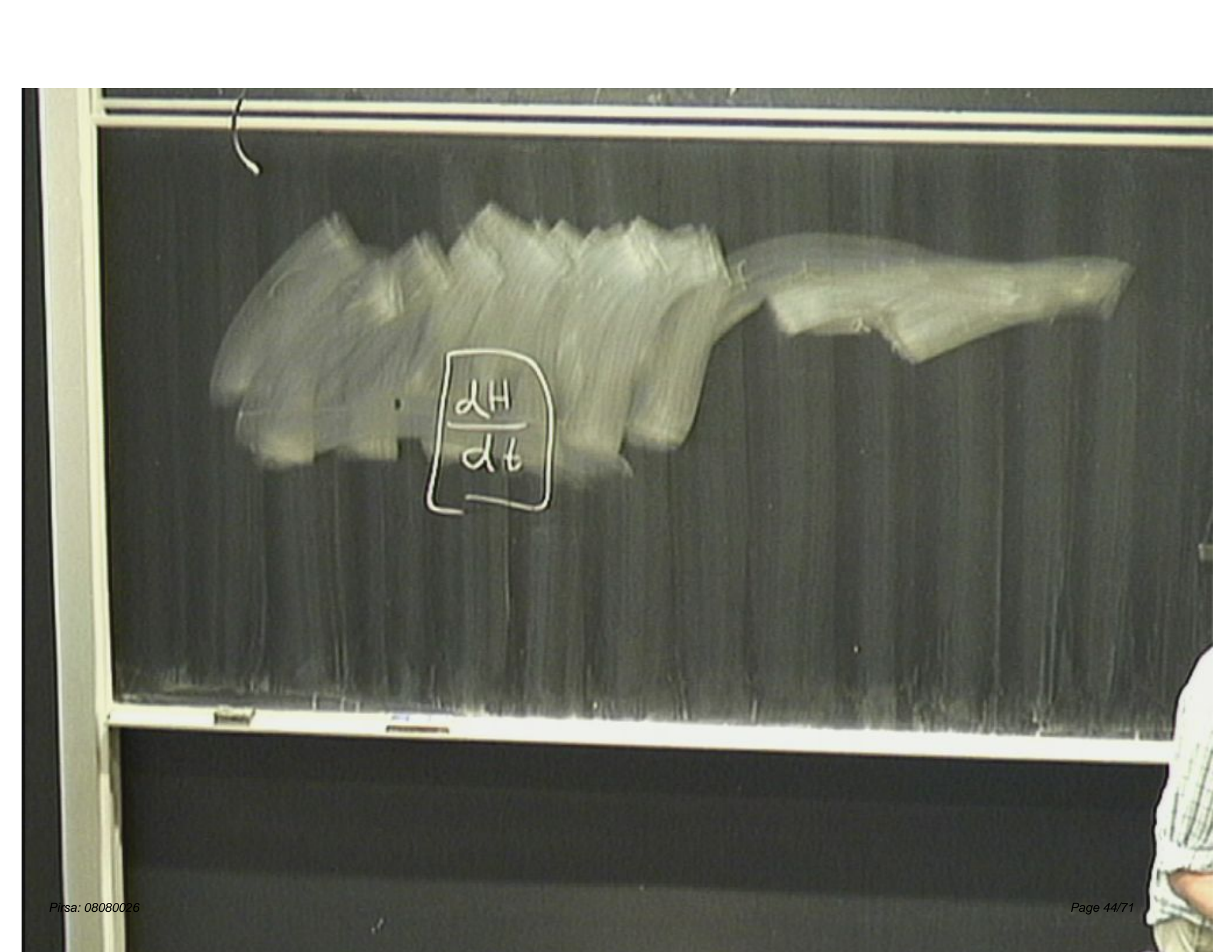
Mpc = Mega parsec  
↑  
10<sup>6</sup>      ↑  
            ~3 light year



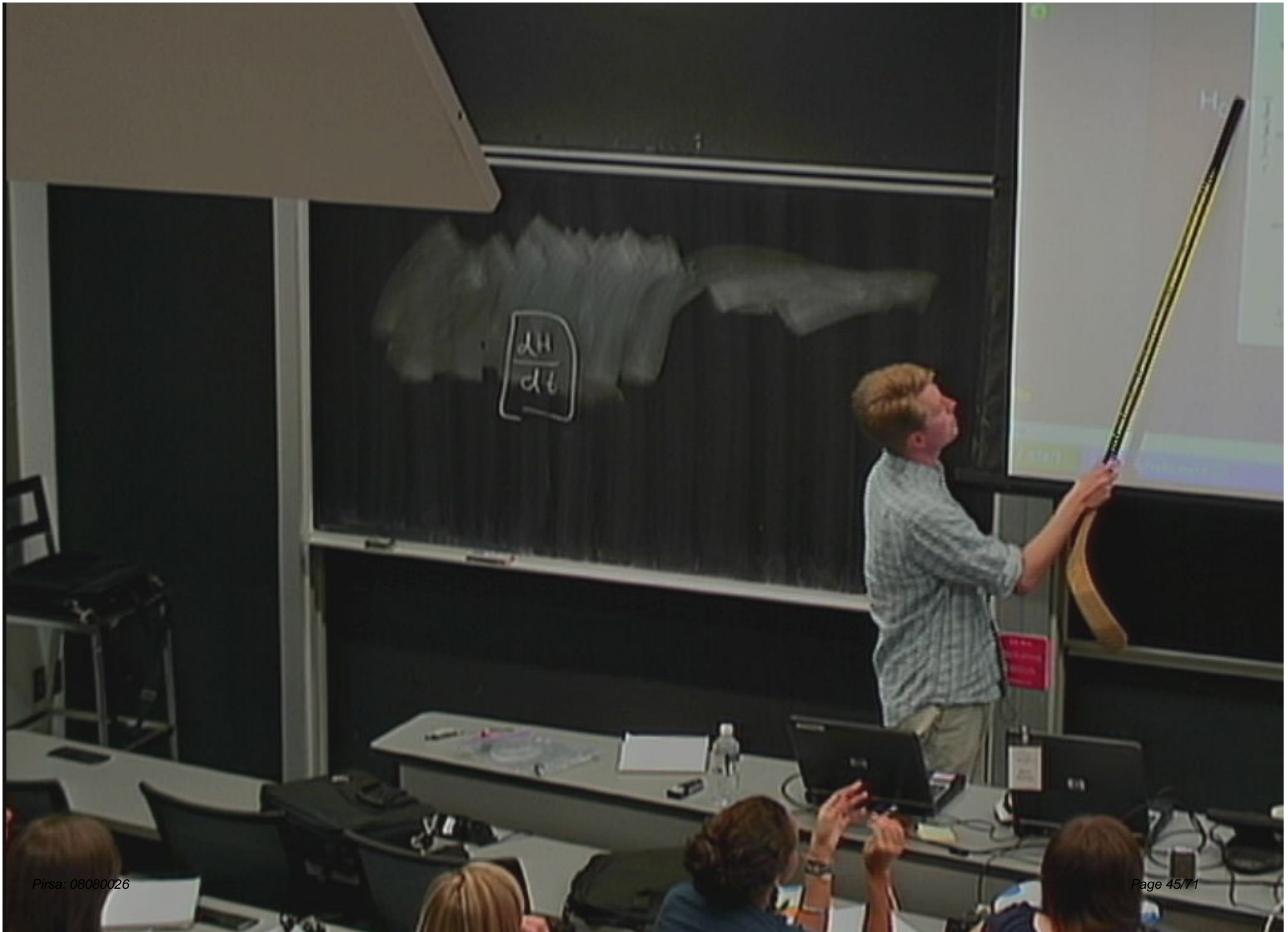
$H_0$



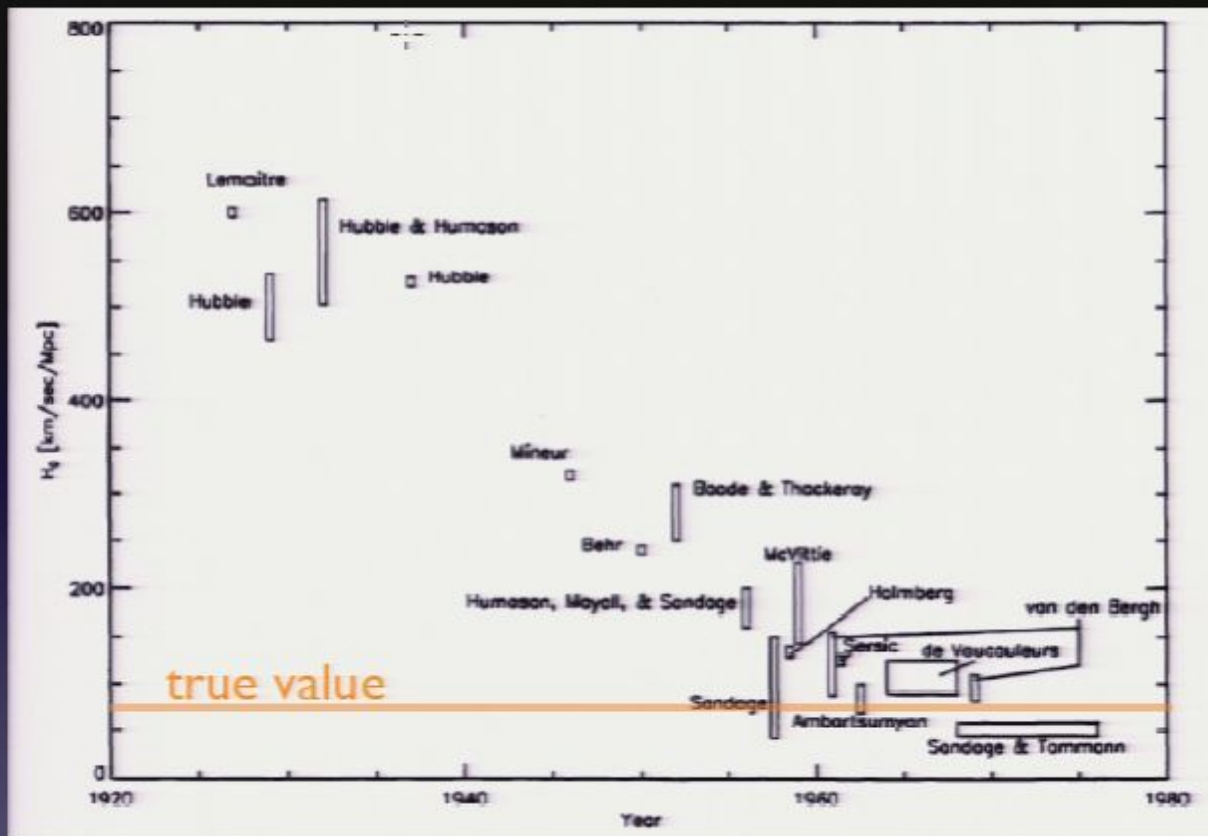
Year of Measurement

A chalkboard with a large white smudge in the upper left quadrant. In the center of the smudge, the mathematical expression  $\frac{dH}{dt}$  is written in white chalk. The expression consists of 'dH' over a horizontal line, with 'dt' below it. The entire expression is enclosed in a hand-drawn white rectangular box with rounded corners.
$$\frac{dH}{dt}$$





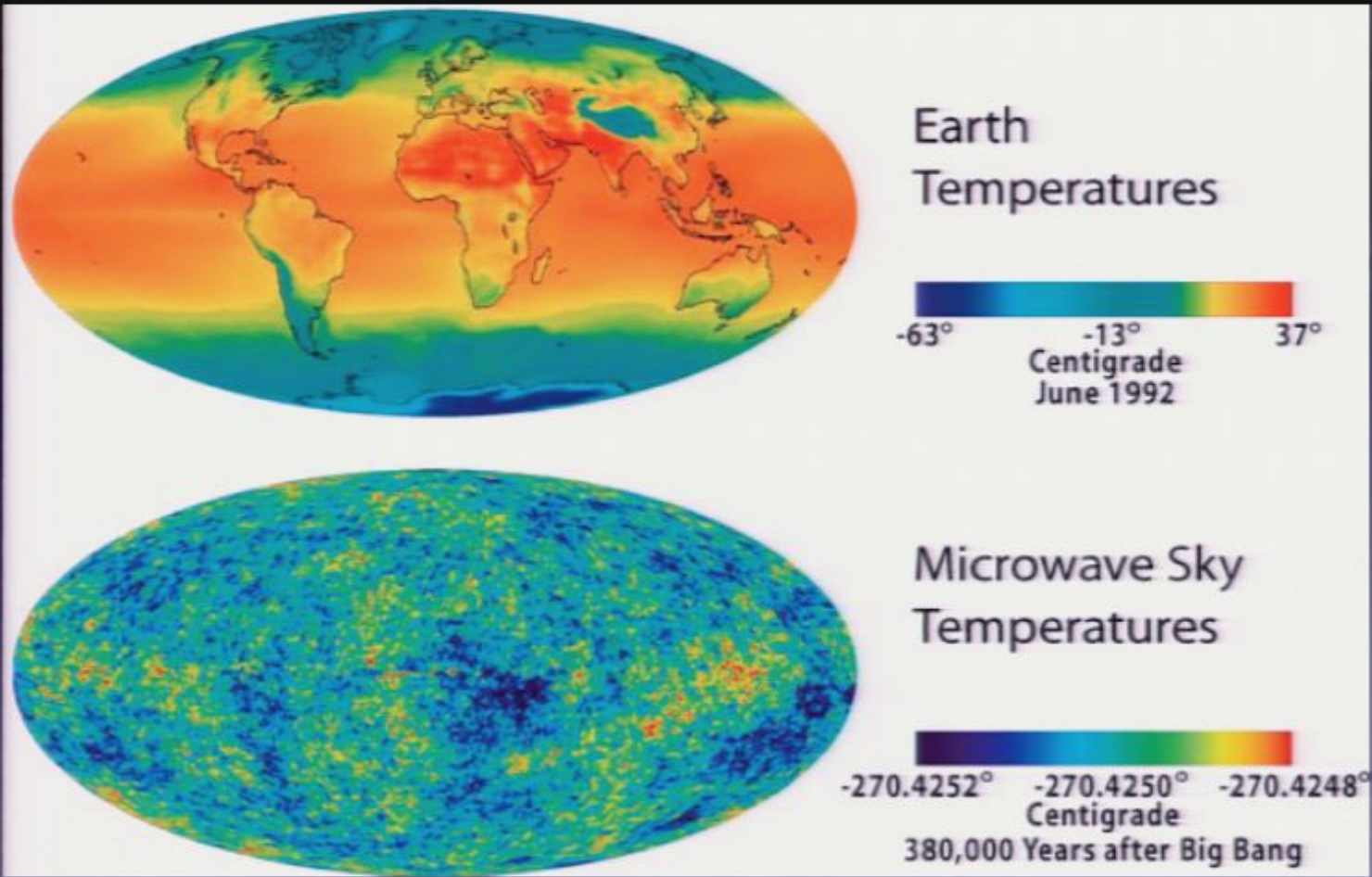
$H_0$



Year of Measurement

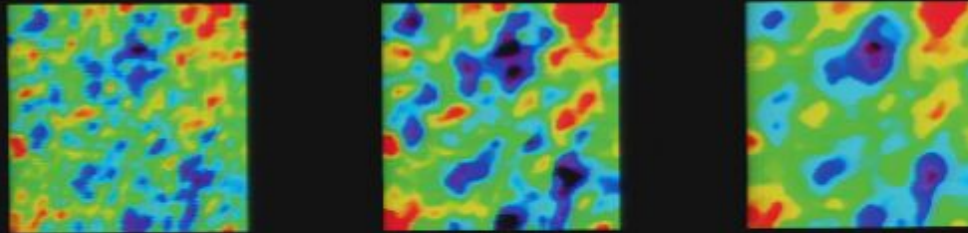


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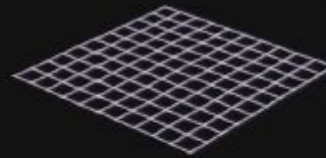


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# GEOMETRY OF THE UNIVERSE



**OPEN**

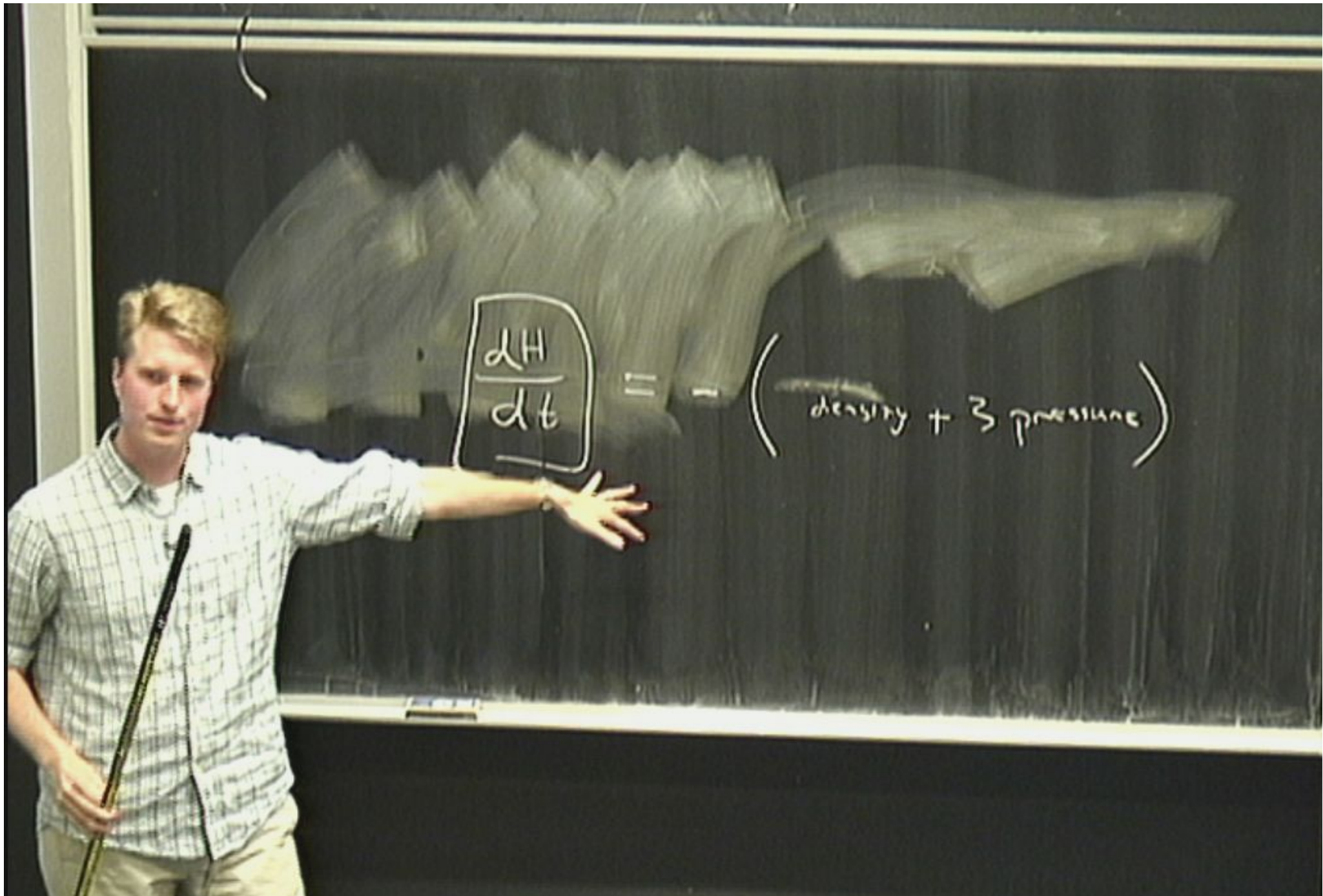


**FLAT**



**CLOSED**





$$\frac{dH}{dt}$$

=

(~~density~~ + 3 pressure)



cgs  
kms

$$\rho \approx 10^{-29} \text{ g/cm}^3$$



Standard  
ruler

$d \approx 100$  million light  
years

$$\frac{c_1}{t_2} \approx \frac{m_1}{m_2}$$



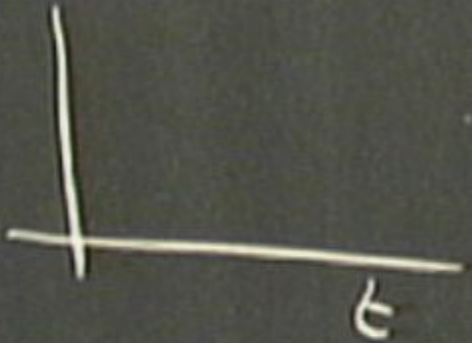
$$\frac{dH}{dt} > 0$$



White  
dwarfs

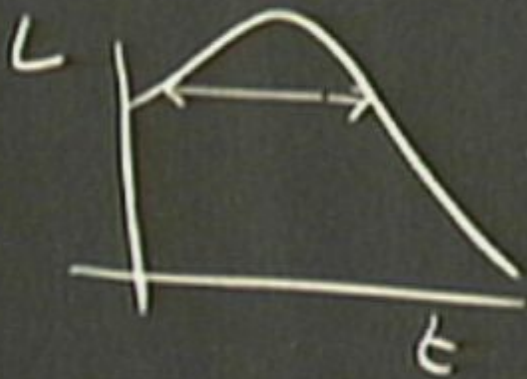
CAUTION  
NO FLAMMABLES  
OR OILS  
HERE

White  
dwarfs

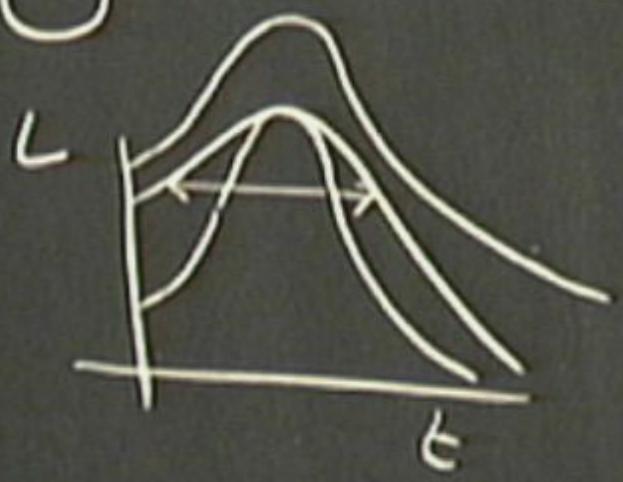




White  
dwarfs

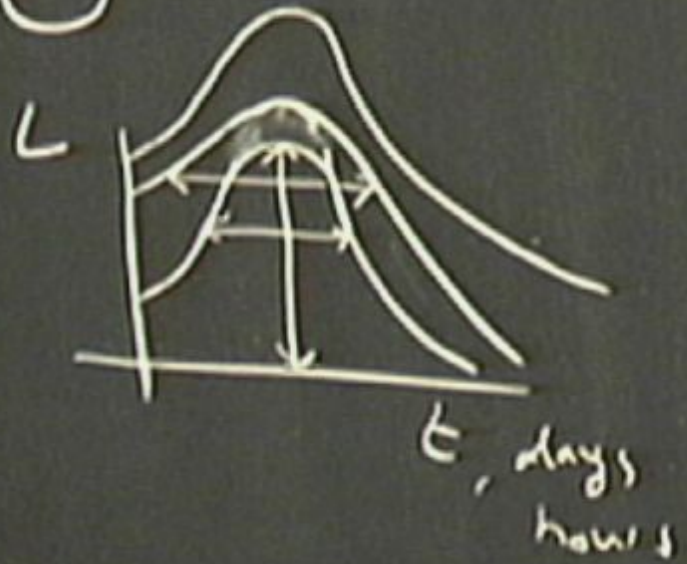


white  
dwarfs

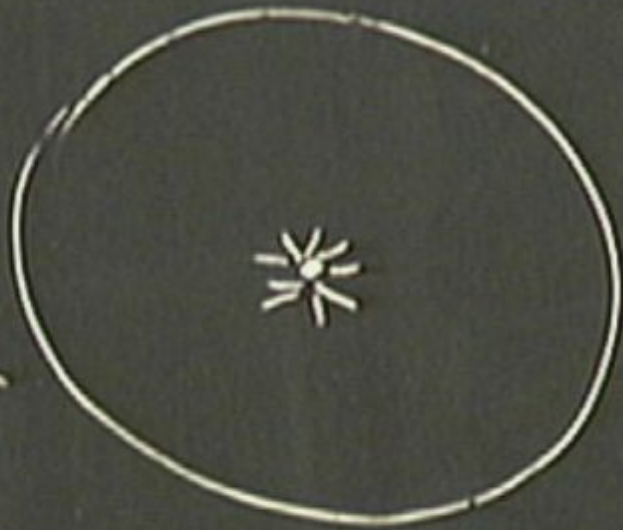
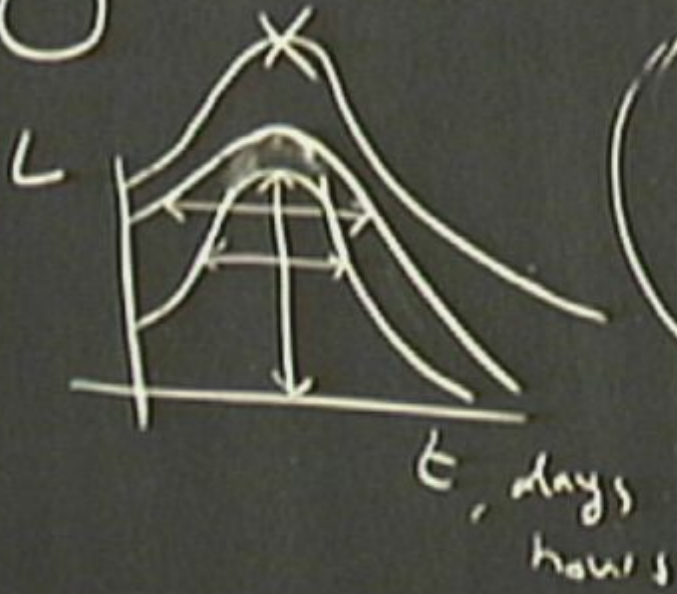




White  
dwarfs

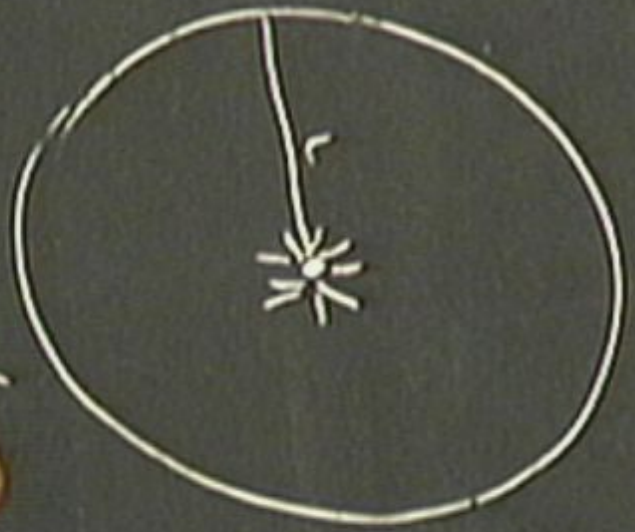
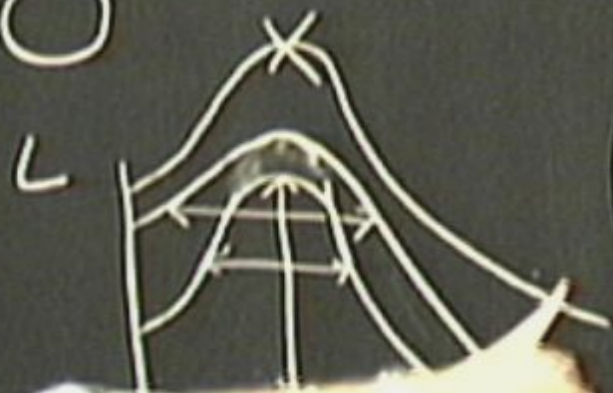


White  
dwarfs





White  
dwarfs

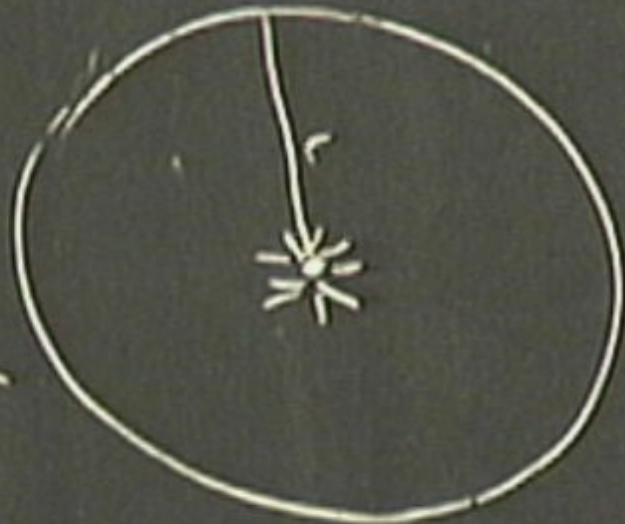


days  
hours

White  
dwarfs

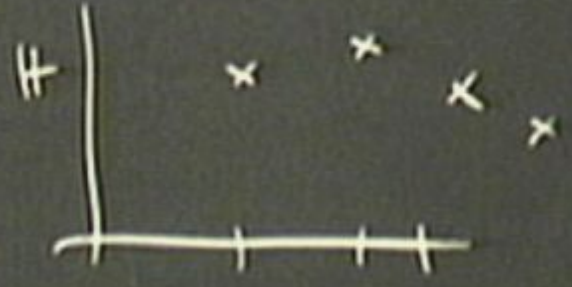
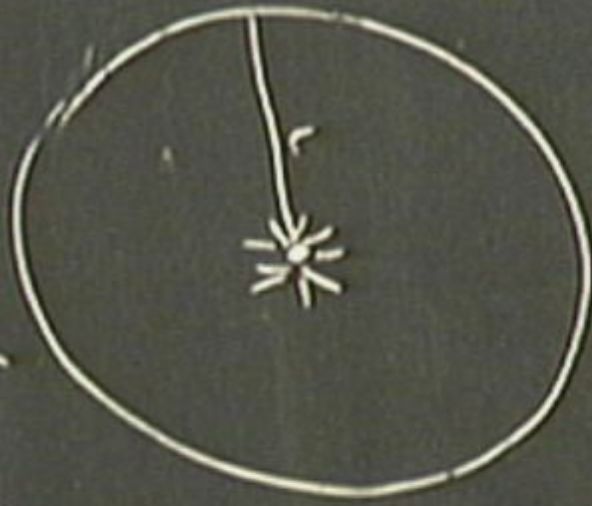
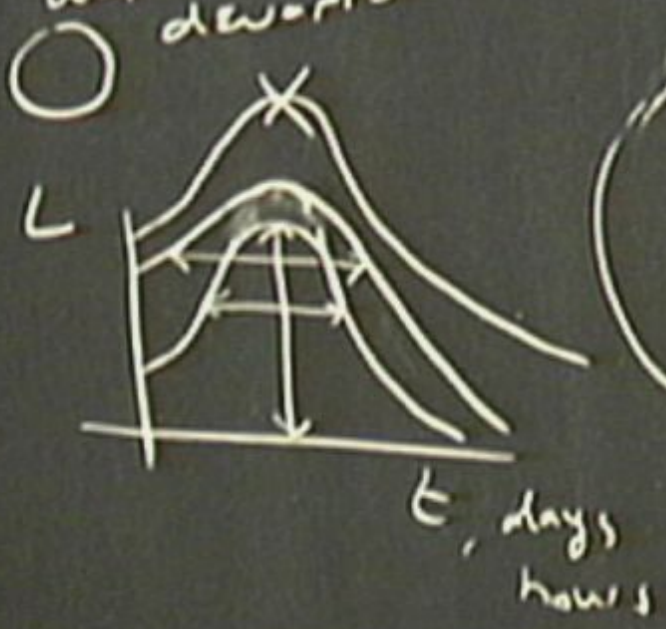


$t$ , days  
hours





White  
dwarfs



$$\left( \frac{dH}{dt} \right) > 0$$



$\Gamma R$

$H^2$

$$\left[ \frac{dH}{dt} \right]$$

=

$- \left( \text{density} + 3 \text{ pressure} \right)$

$\gamma R$

$H^2$

$$\left[ \frac{dH}{dt} \right] = -$$

$$\left( \text{density} + 3 \text{ pressure} \right)$$



$\Gamma R$   
 $H^2$

$$\frac{dH}{dt}$$

cosmological constant  
density + 3 (pressure)

$g/cm^3$

$\hookrightarrow R$   
 $\frac{1}{H^2}$

$$\left[ \frac{dH}{dt} \right] = -$$

$\Lambda$  cosmological constant  
density + 3 (pressure)

$$\rho = 10^{-29} \text{ g/cm}^3$$

$$\rho_{\Lambda} = 70\% \rho_{\text{tot}}$$



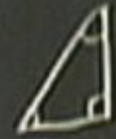
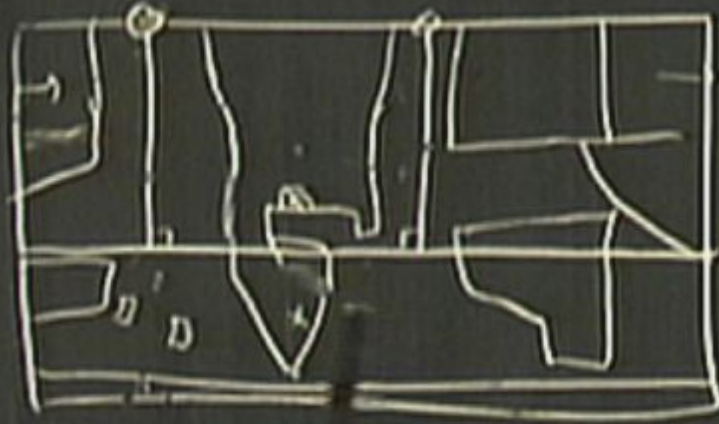



$$\lambda_{\Delta} = \frac{H}{-}$$



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$\Lambda + \text{Curvature} = \text{Energy density}$   
 $G_{\mu\nu}$



Energy = everything  
density

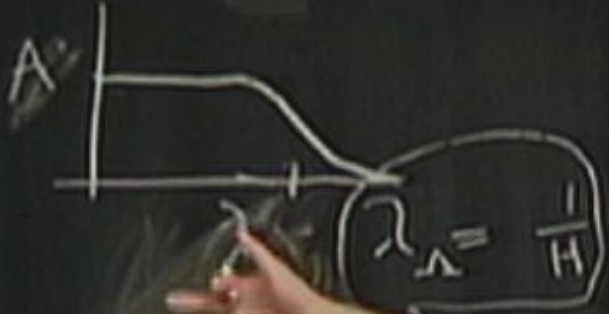




$$\lambda_{\Delta} = \frac{1}{H}$$







$\hookrightarrow R$

$H^2$

$$\left[ \frac{dH}{dt} \right] =$$

$=$

density + 3

$\Lambda$  cosmological constant

pressure

$$\rho = 10^{-29} \text{ g/cm}^3$$

$$\rho_{\Lambda} = 70\% \rho_{\text{tot}}$$