Title: Accelerated Universe and Gravity at Smallest and Largest

Date: Oct 25, 2006 02:00 PM

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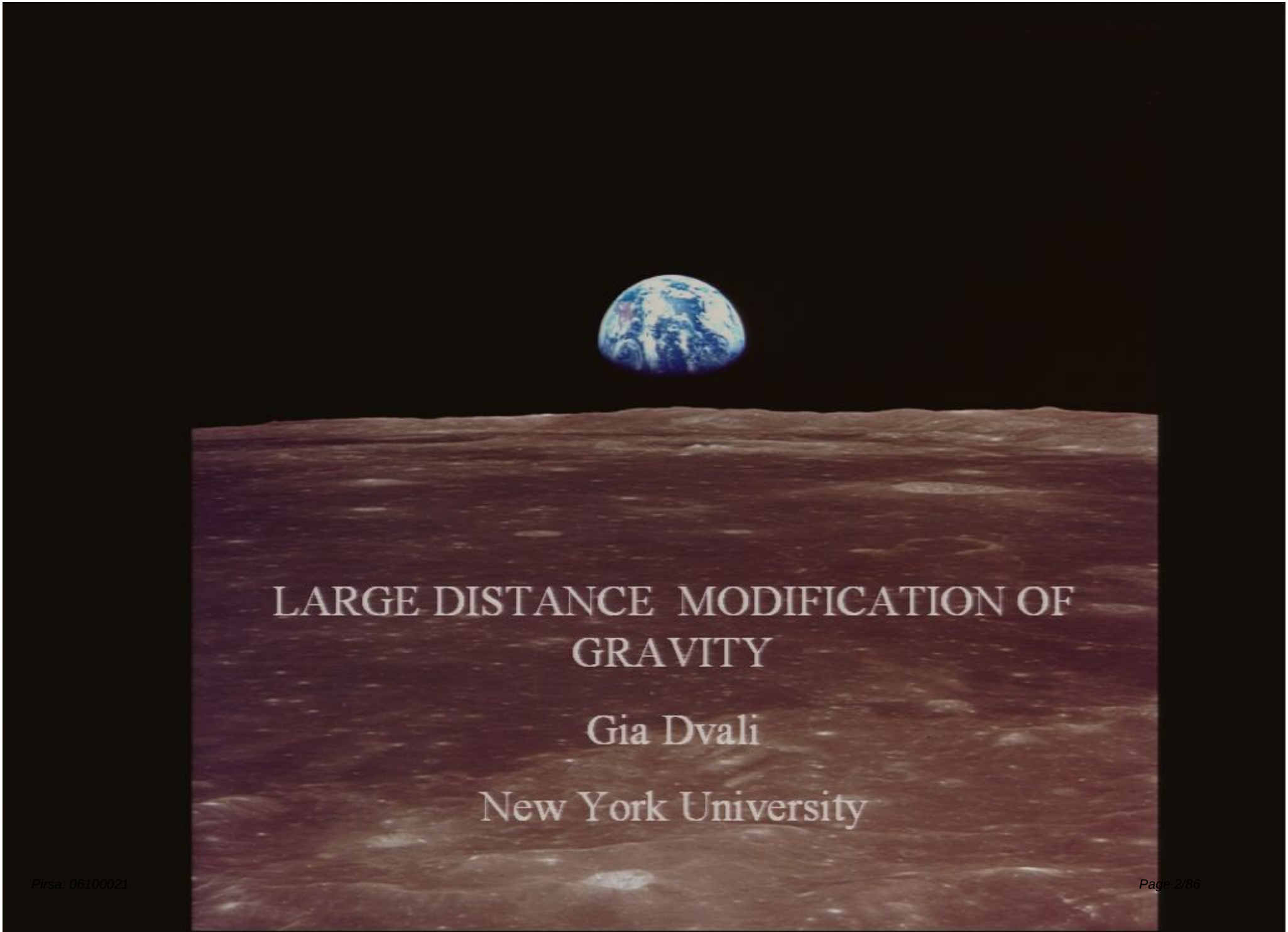
Abstract: We discuss motivations, observational constraints and consequences of modifying the fundamental laws of gravity at large distances. Such modifications of gravity can be the reason for the observed late-time acceleration of the Universe, and can be differentiated from conventional dark energy via precision cosmology. The inevitable additional polarizations of graviton lead to observably large perihelion precession of the Lunar and Martian orbits. These theories also have potentially observable consequences at LHC .


LARGE DISTANCE MODIFICATION OF GRAVITY
Gia Dvali
New York University

Modified gravity versus dark energy

Dvali, Gabadadze, Porrati;
Dvali, Gabadadze;

Deffayet, Dvali, Gabadadze;

Dvali, Gruzinov and Zaldarriaga;
Dvali, Turner;

Modified Gravity and Cosmological Constant

Dvali, Gabadadze, Shifman;

Adams, McGreevy, Silverstein;

Arkani-Hamed, Dimopoulos, Dvali, Gabadadze

Universe's acceleration:

Hubble parameter: $H \equiv \left(\frac{\dot{a}}{a}\right) \longrightarrow$ const

Friedmann equation (flat universe)

$$H^2 + \ldots = \frac{8\pi}{3} G_N \rho_{Matter} + \ldots$$

Dark energy or Modified Gravity?

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Dark energy or Modified Gravity?

Discontinuity

Crossover distance $r_c \sim 10^{28}$cm

$\lim_{r_c \to \infty}$ New Gravity $\neq$ Einstein

New gravity is no longer mediated by a massless spin-2 graviton!

$$h_{\mu\nu}^{\text{New}} = h_{\mu\nu}^{\text{Einstein}} + ?$$

Why: modified gravity → universes acceleration?

Universe's acceleration at a constant rate implies:

CONSTANT CURVATURE = GRAVITON "CONDENSATE"

↓

$$R = 12\,H^2 = \text{constant}$$

Because of acceleration our Universe is filled with a minuscule nearly-constant graviton condensate ~ 10^{-29}g/cm^3

BUT, MASSLESS BOSONS DO NOT CONDENSE WITHOUT A SOURCE

This is why in Einstein's gravity the Universe's acceleration requires a dark energy source!

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But, in modified gravity gravitons are no longer massless, and can condense without any dark energy source!

Resulting into the self-accelerated Universe

Friedmann equation for flat and empty universe:

$$H^2 = 0$$

$$\downarrow$$

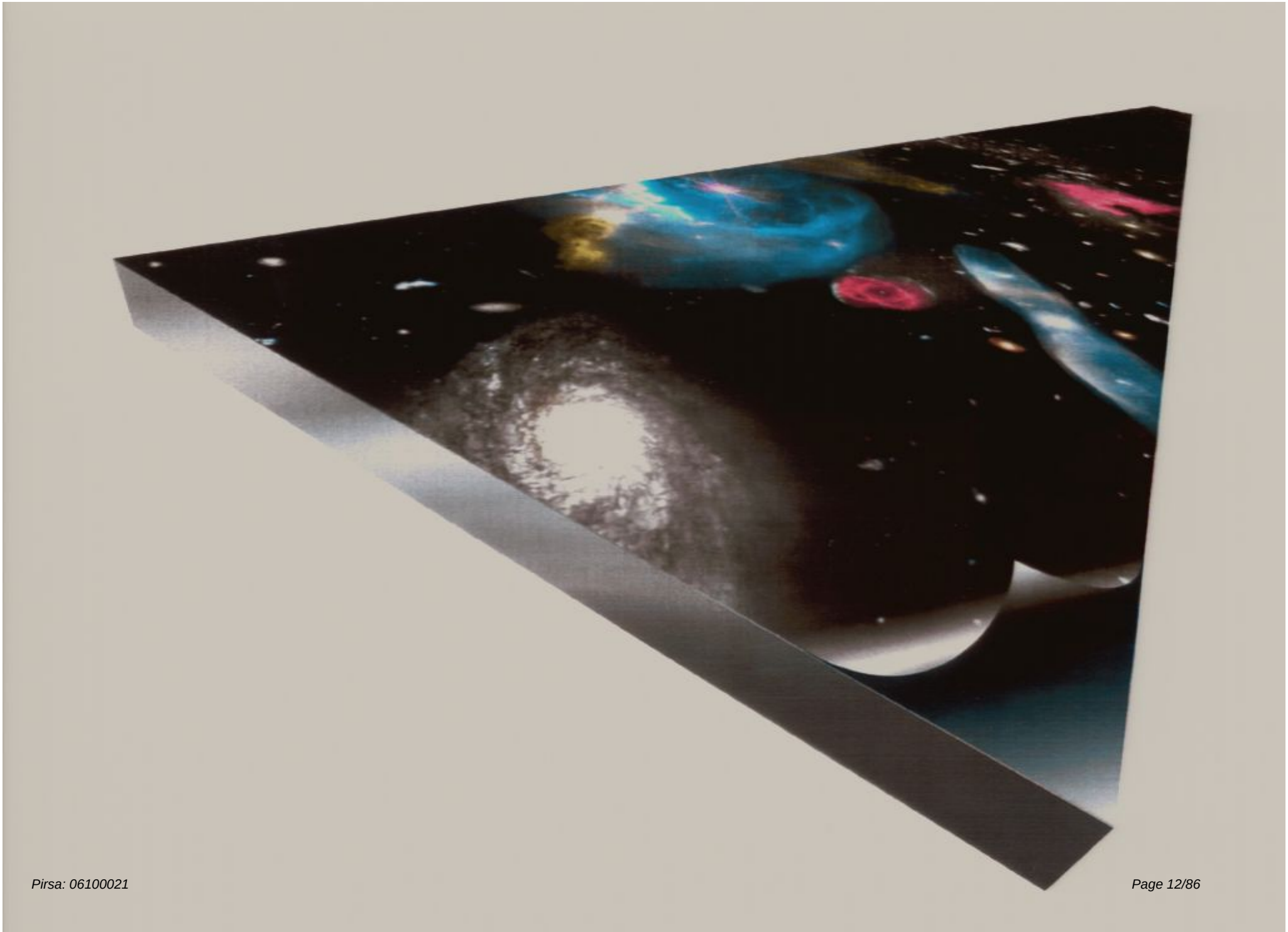
No expansion

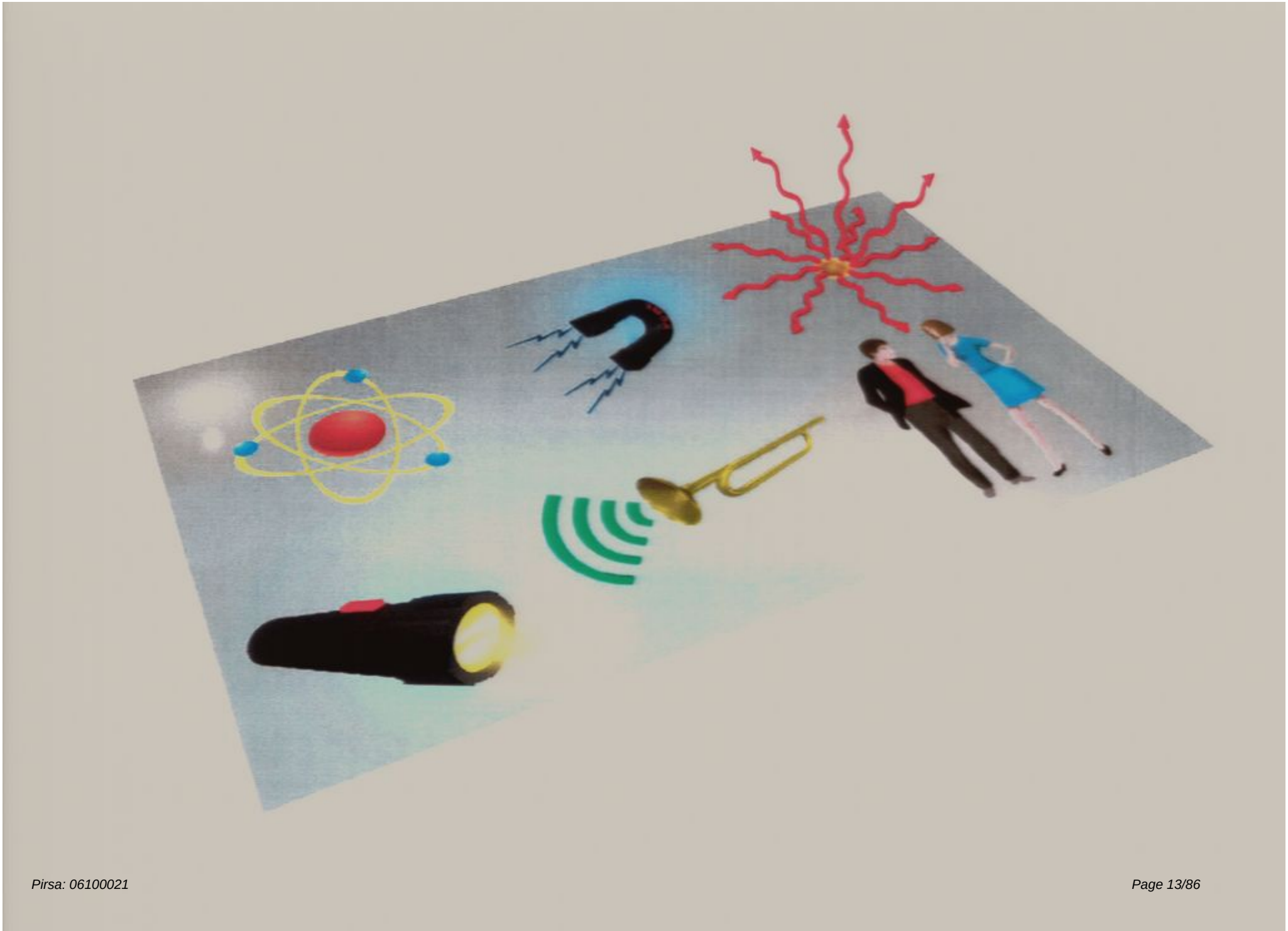
Modified Friedmann equation for flat and empty Universe:

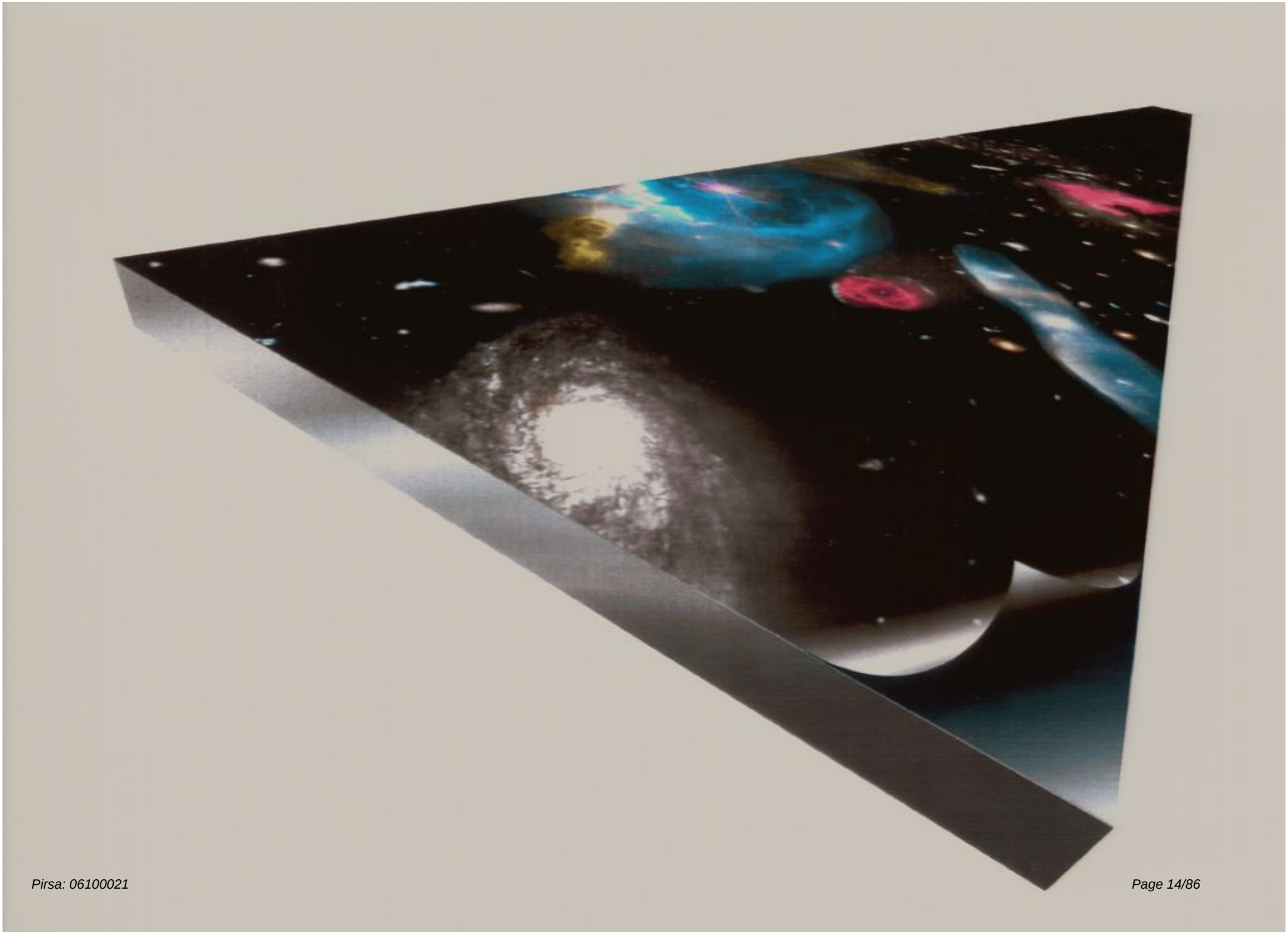
$$H^2 - H/r_c = 0$$

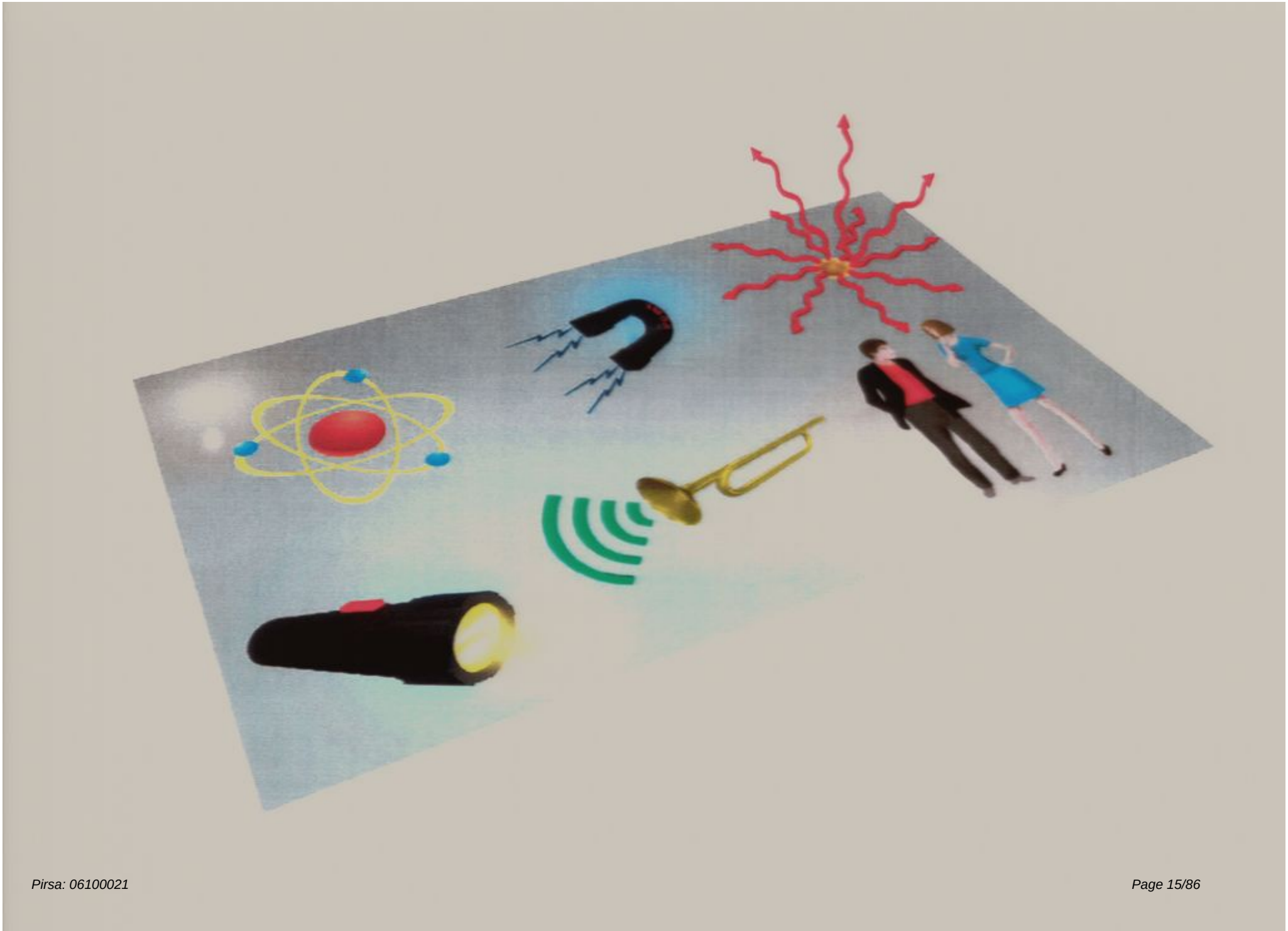
$$\downarrow$$

Acceleration at a constant rate: $H=1/r_c$

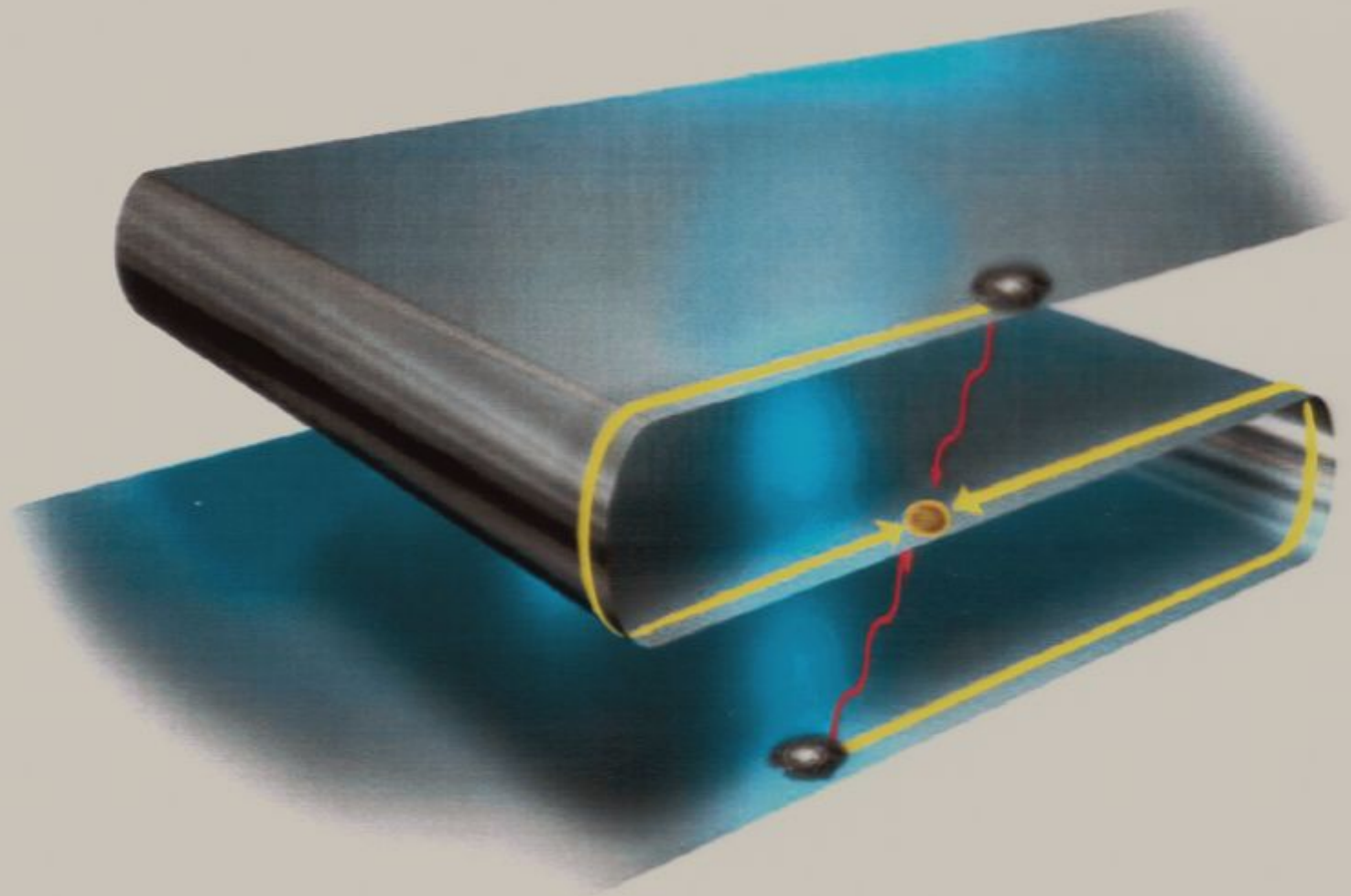


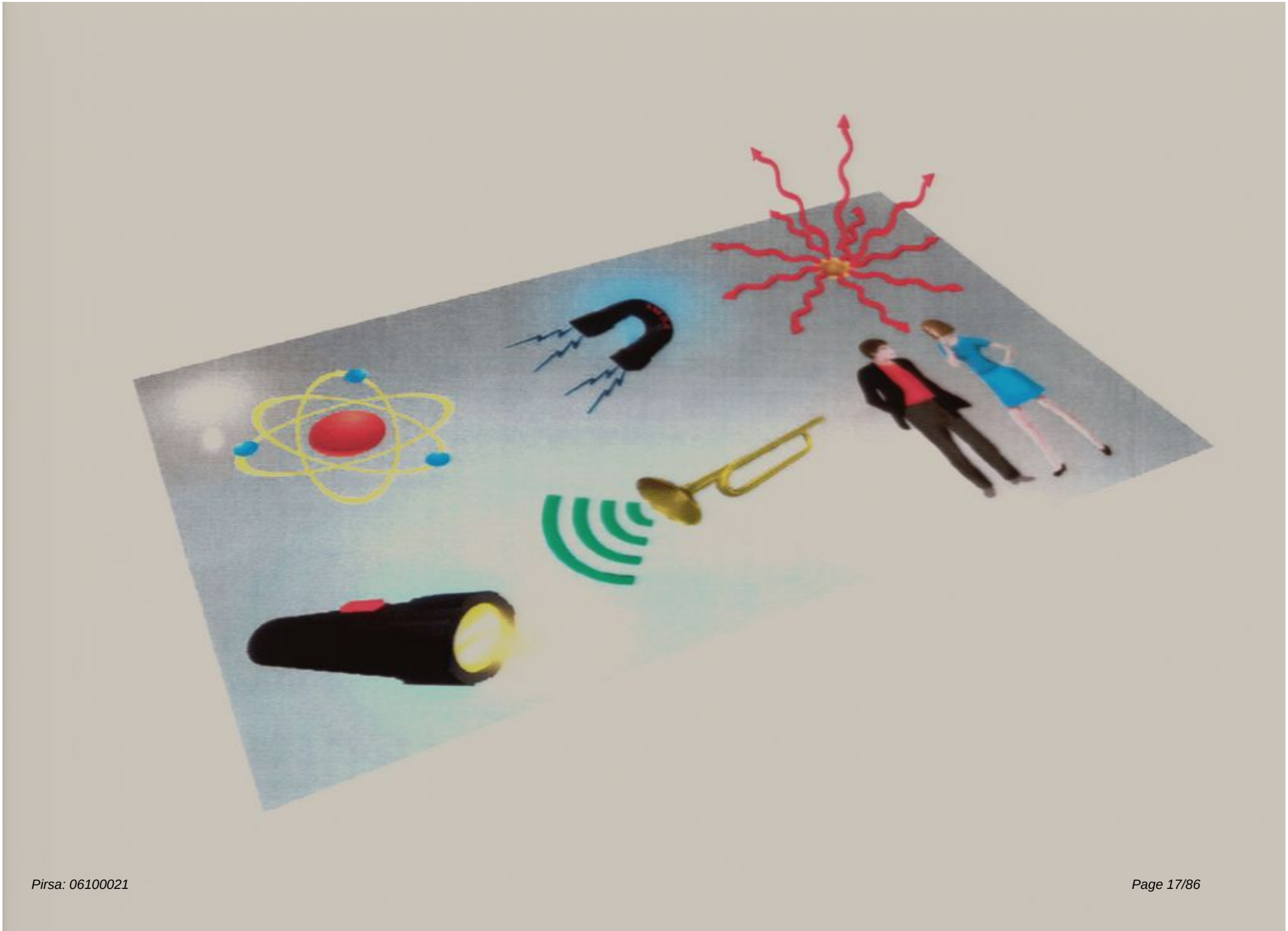






Gravitational shortcut





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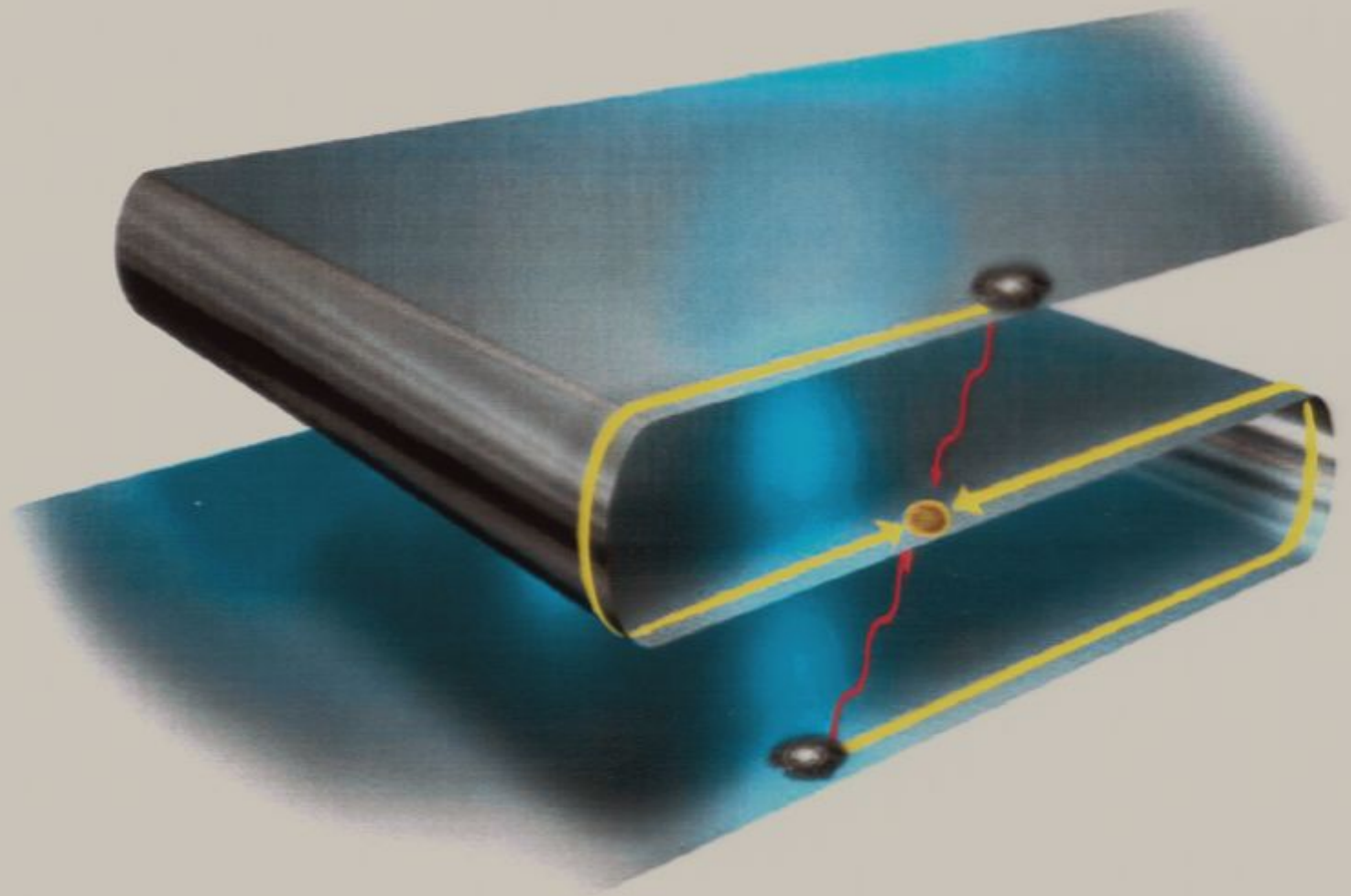
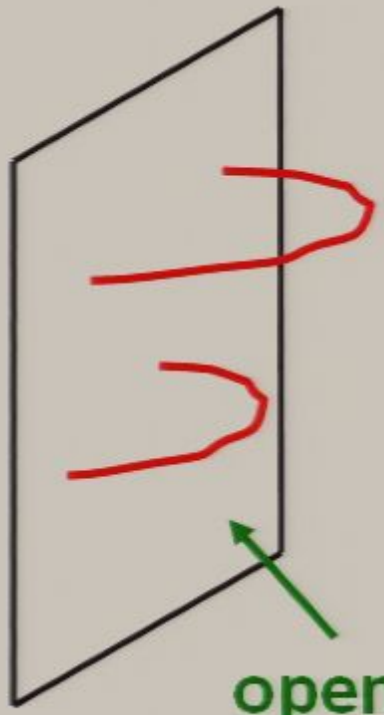
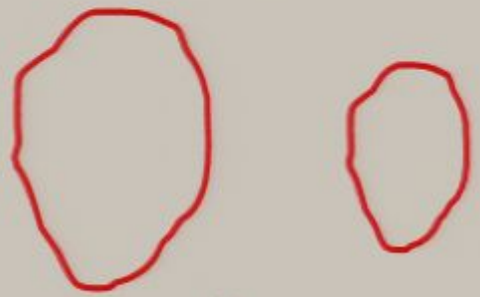


STRING THEORY PICTURE



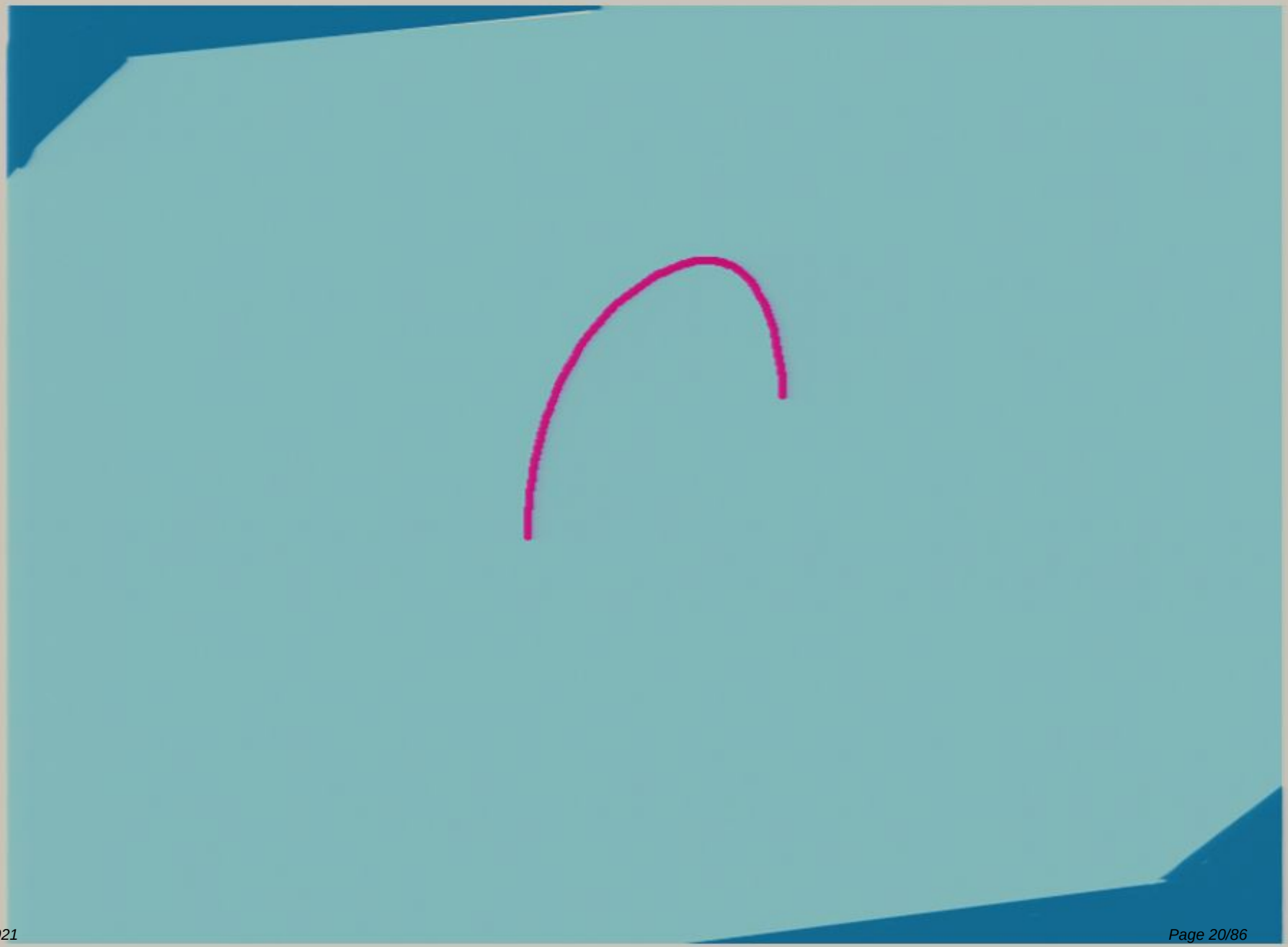
open strings

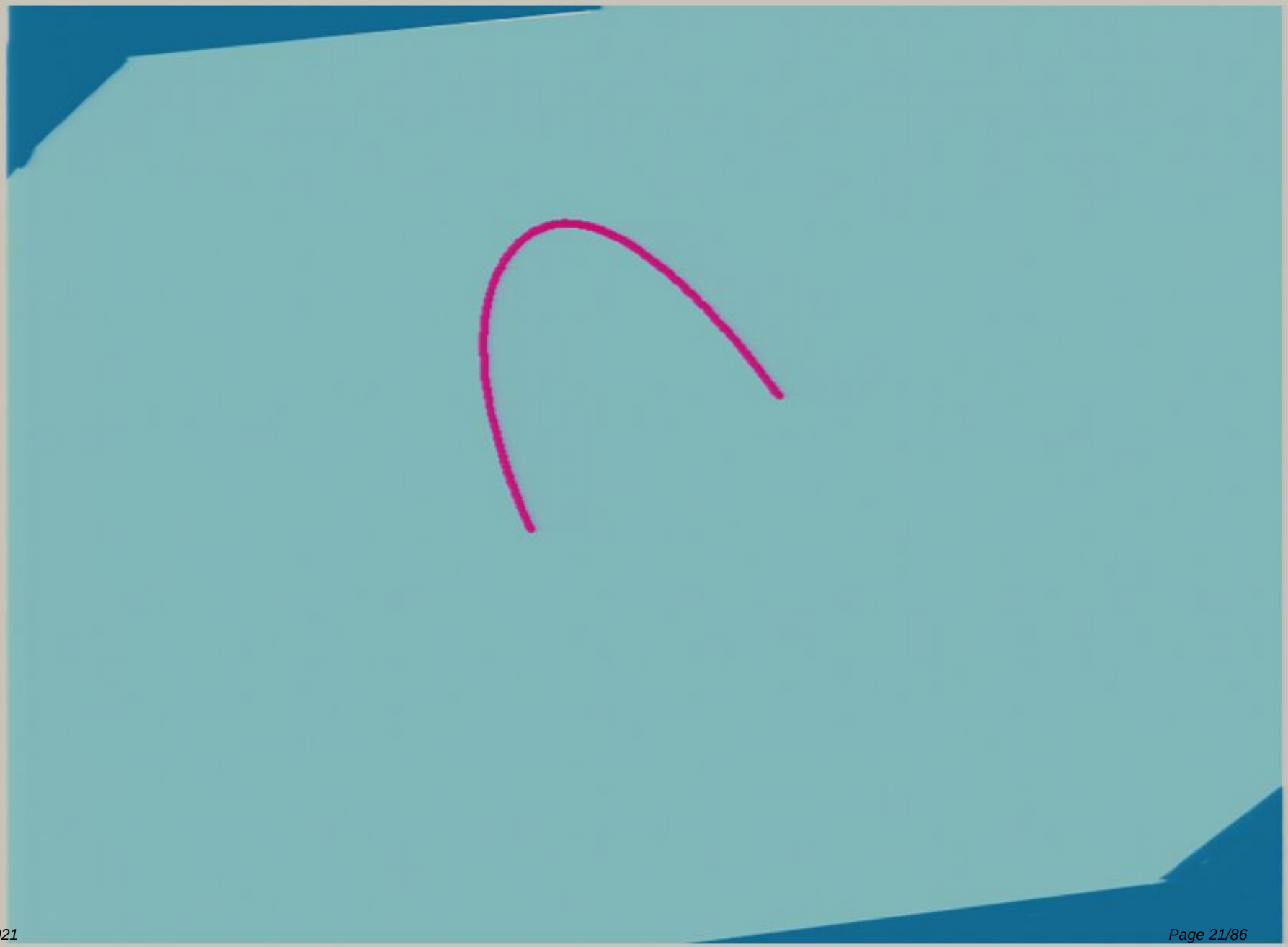
ordinary particles

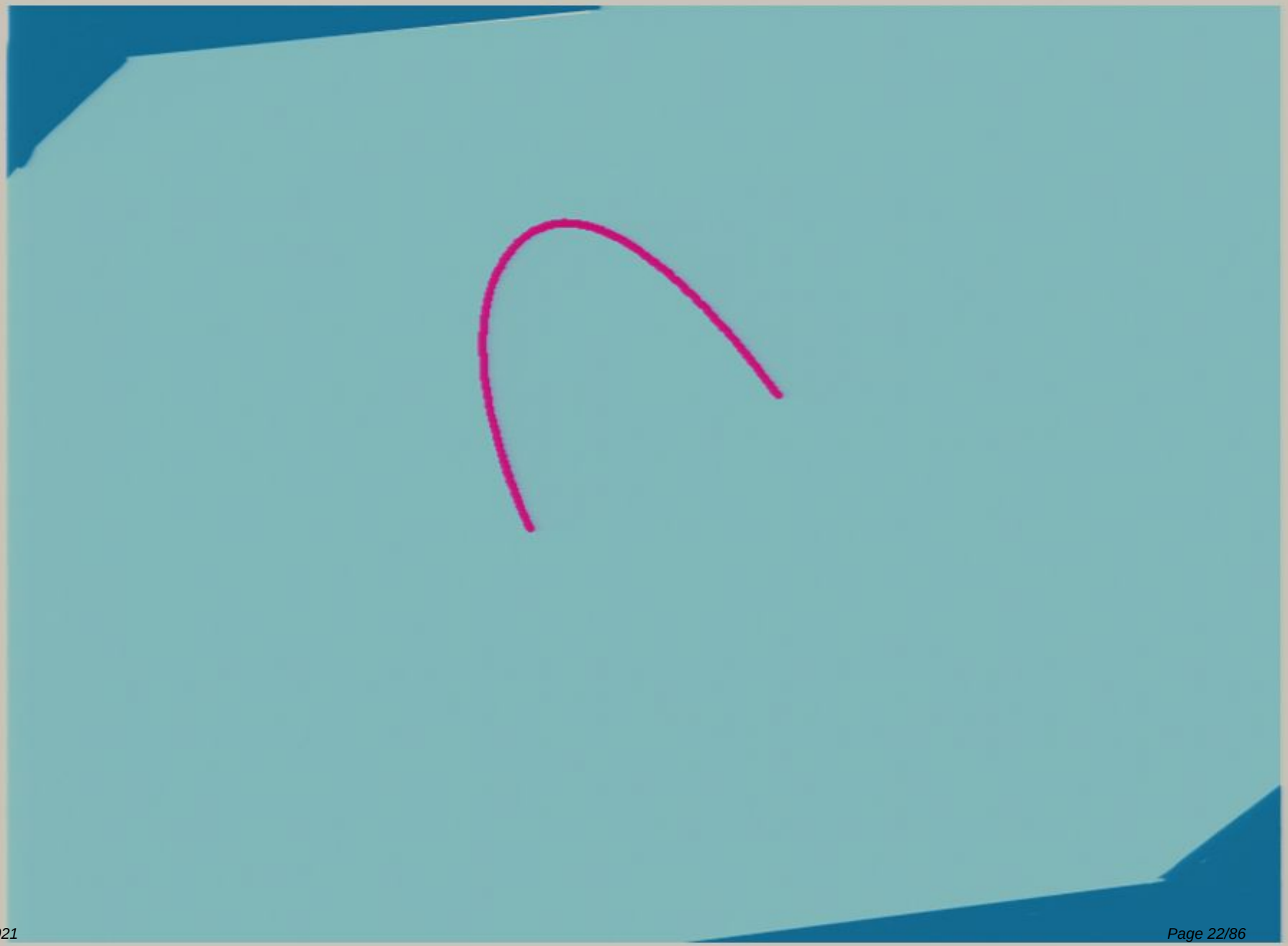


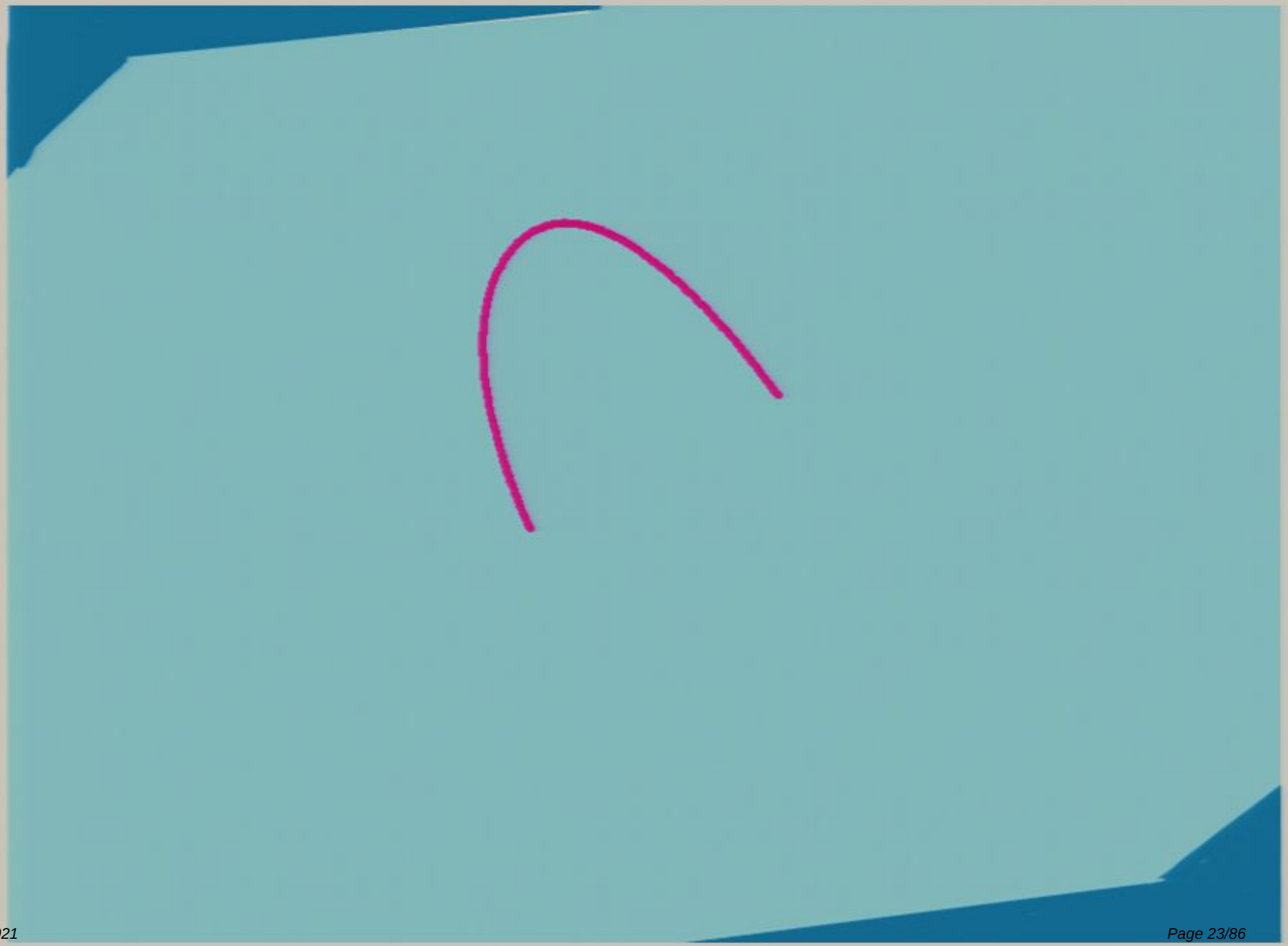
closed strings

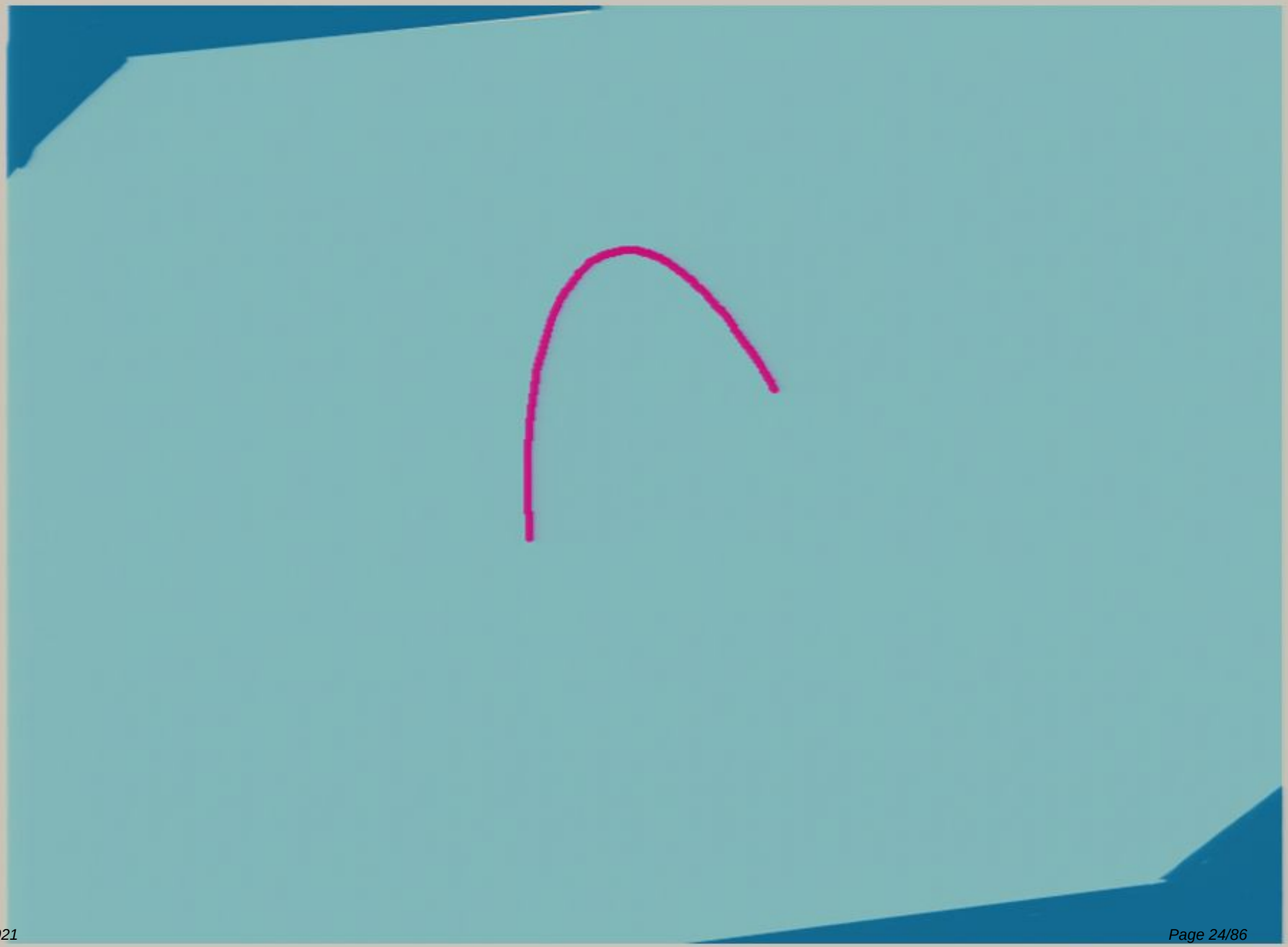
gravity

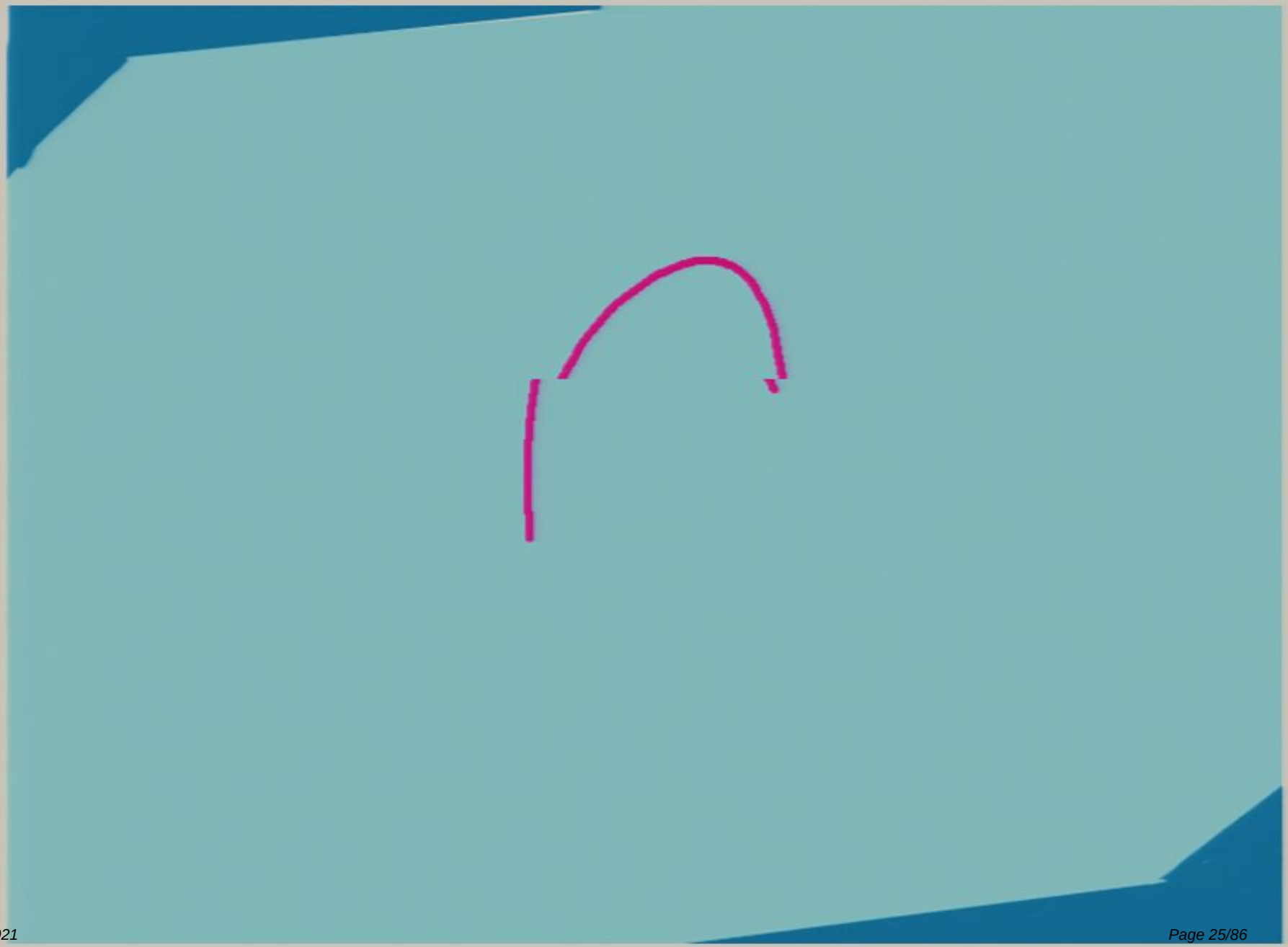


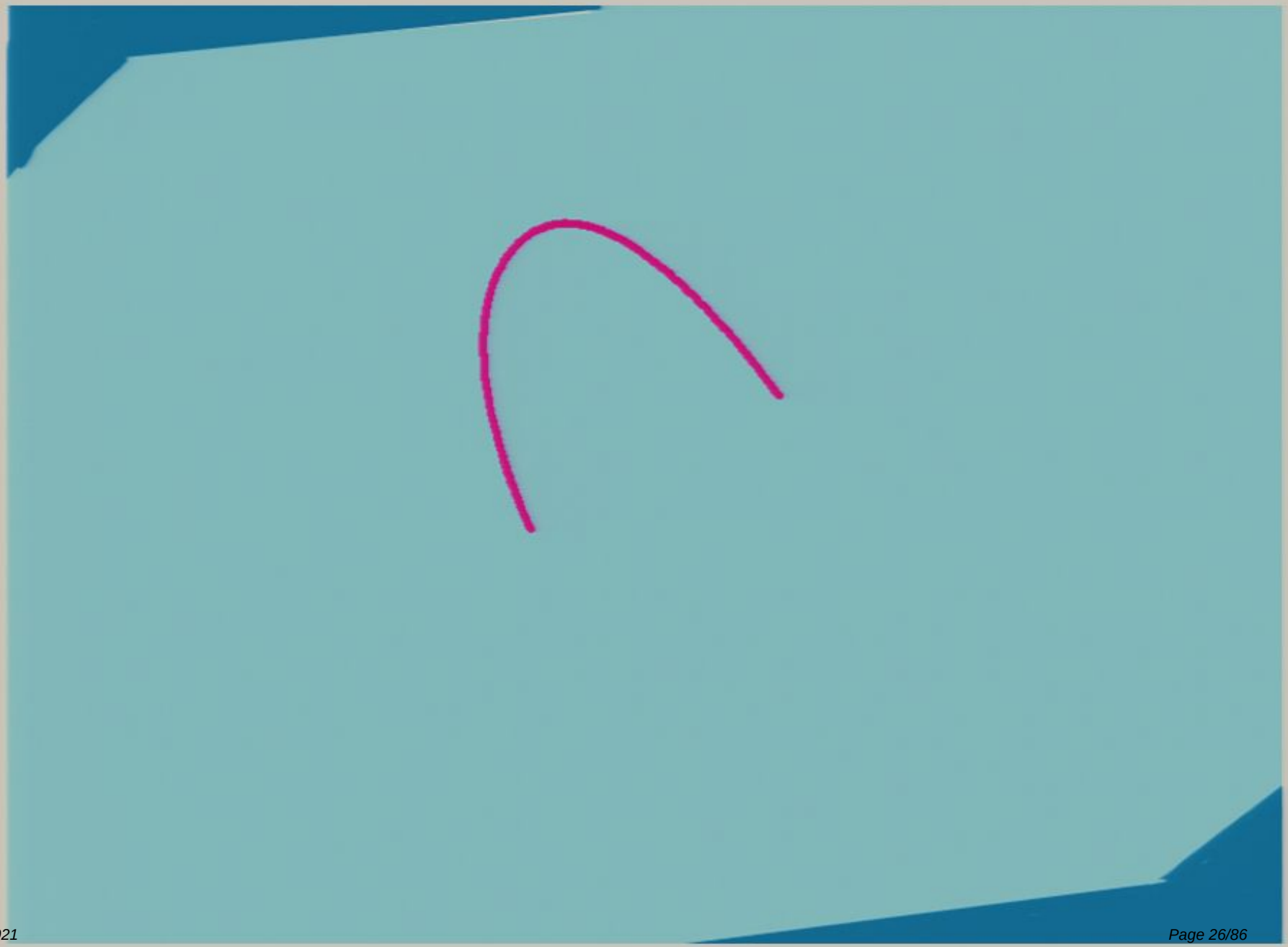


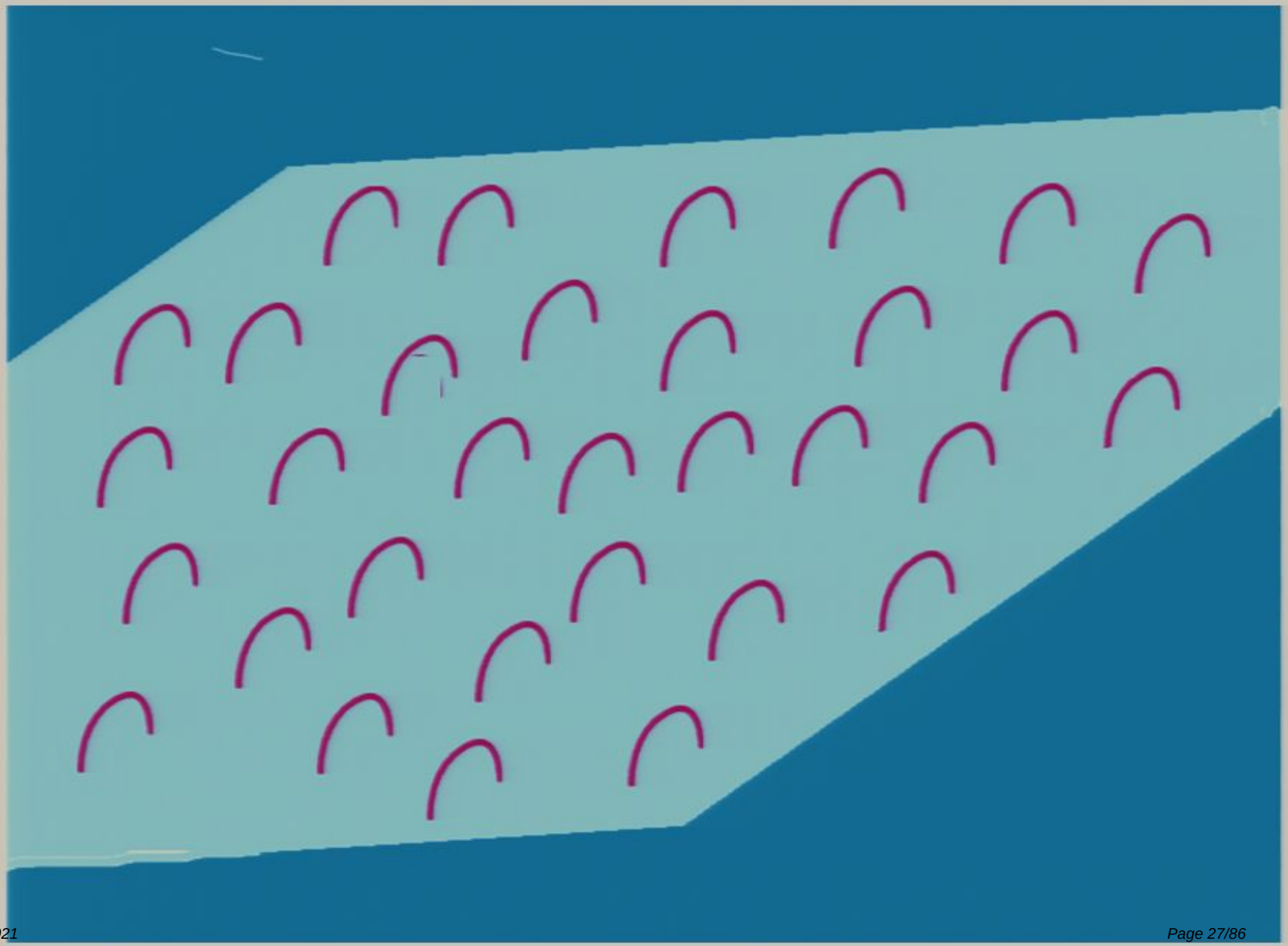


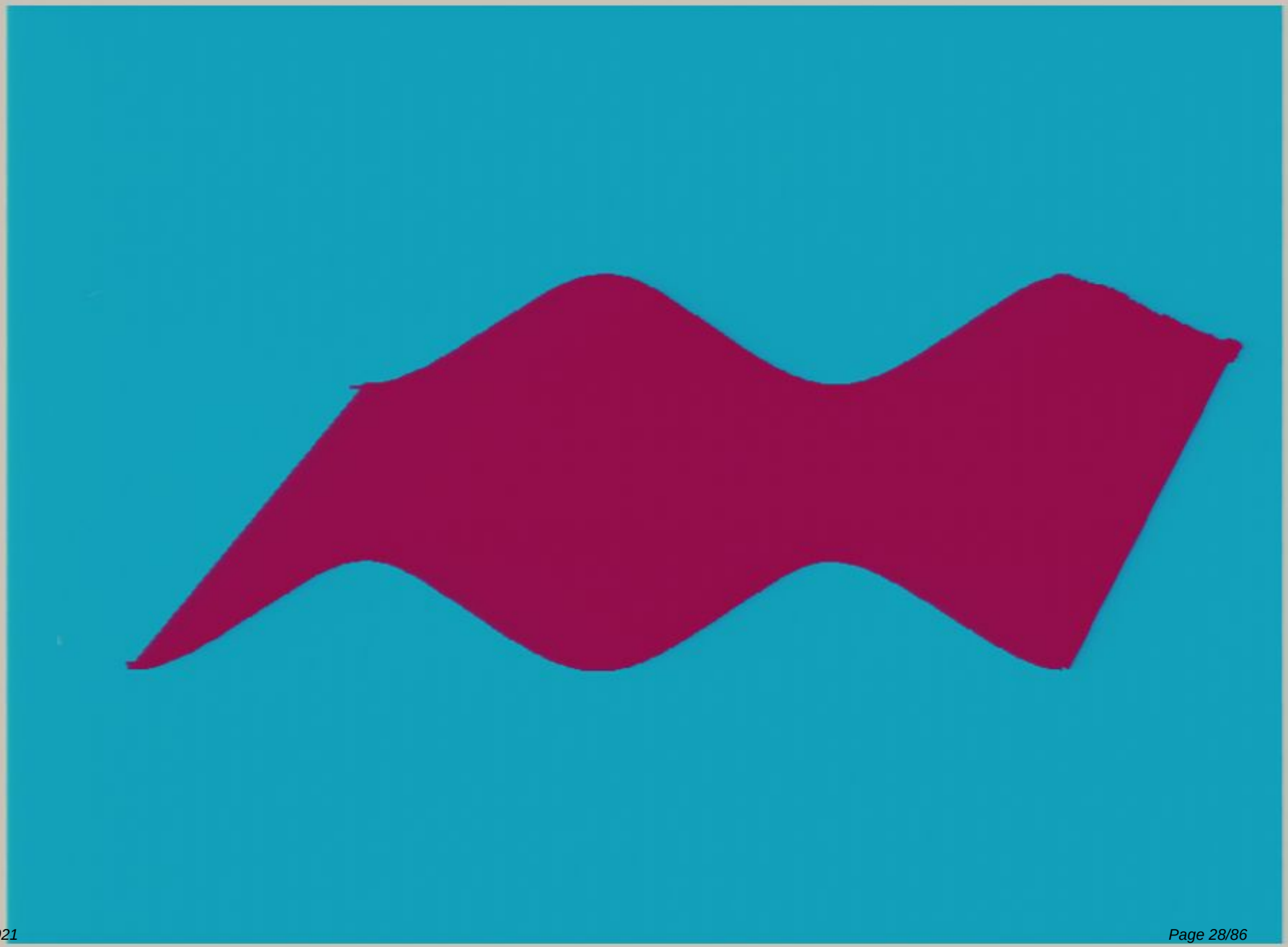


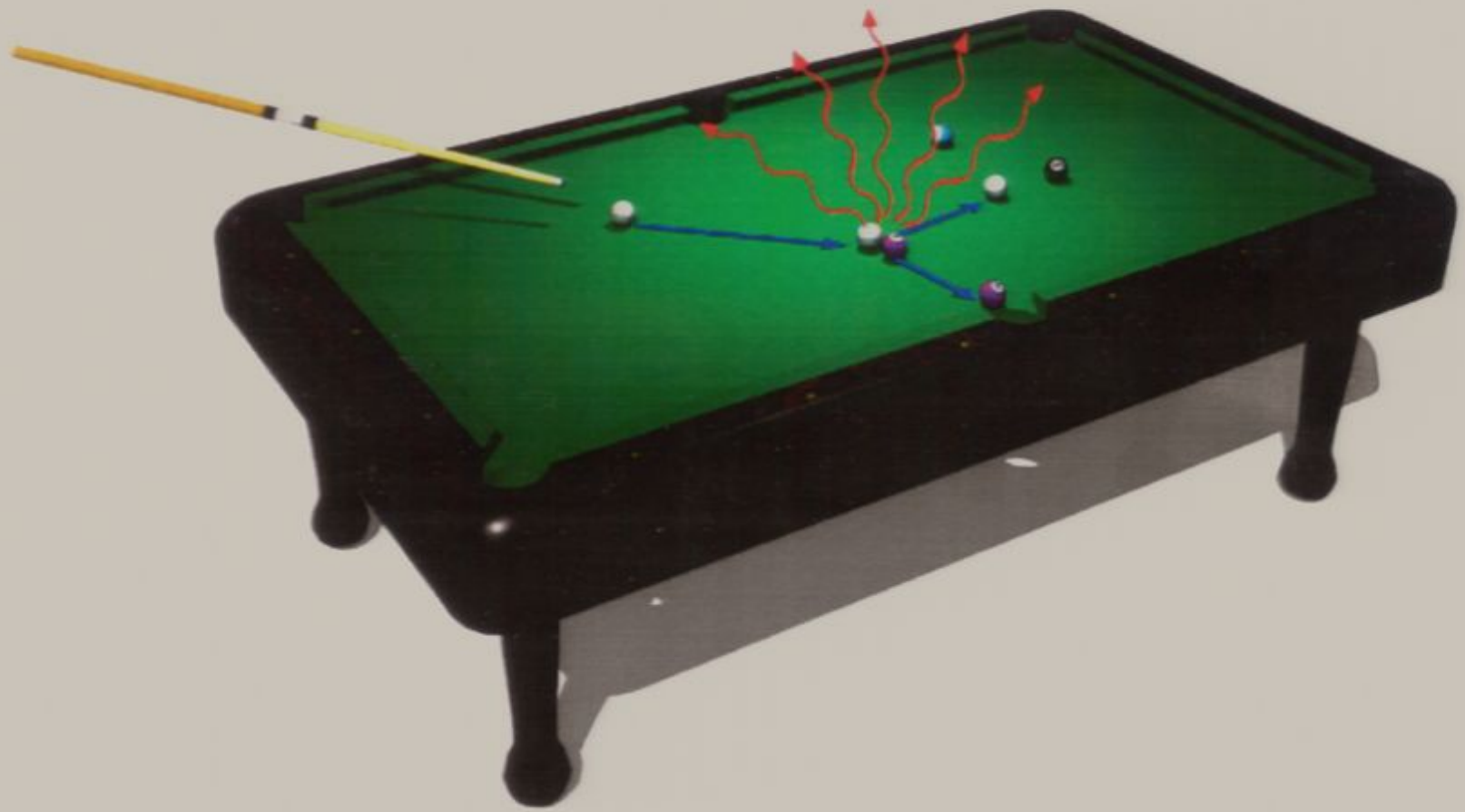


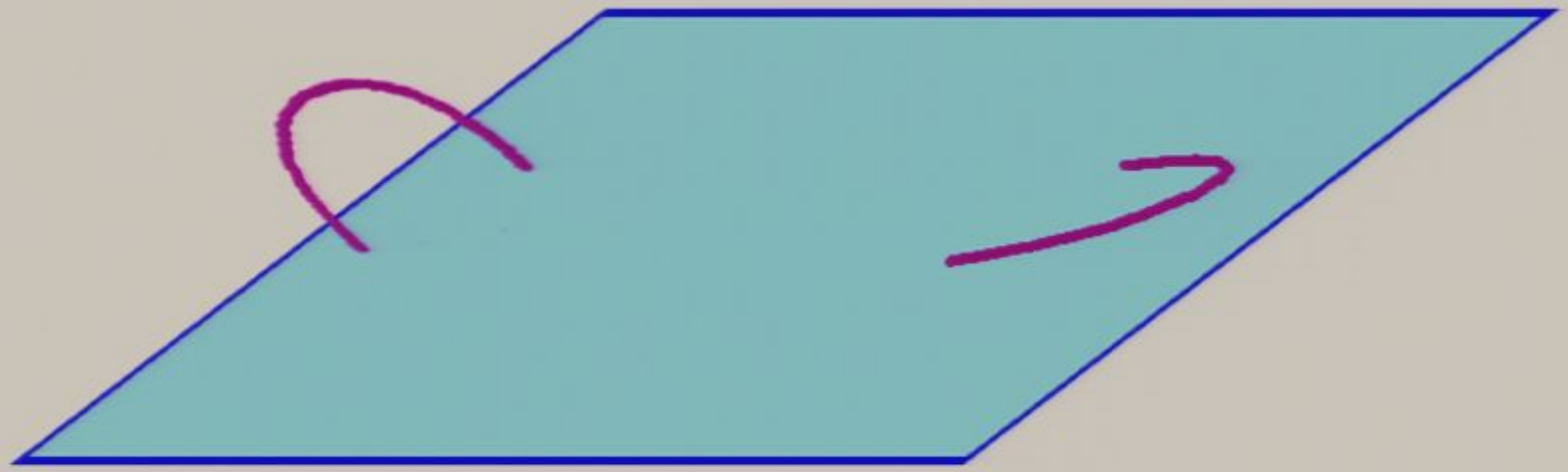


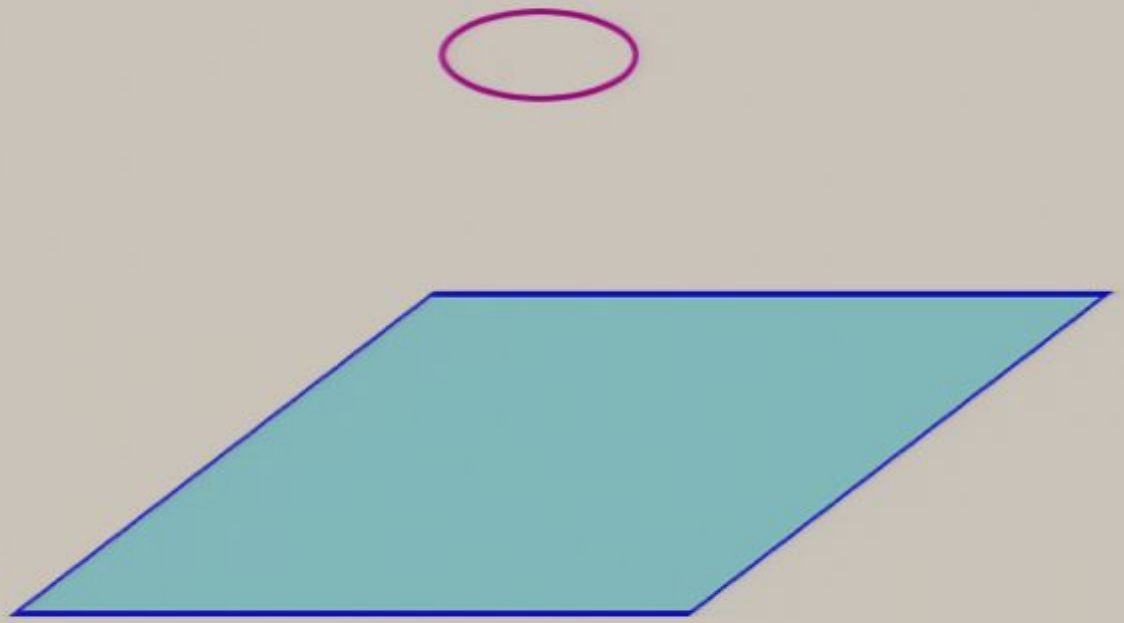


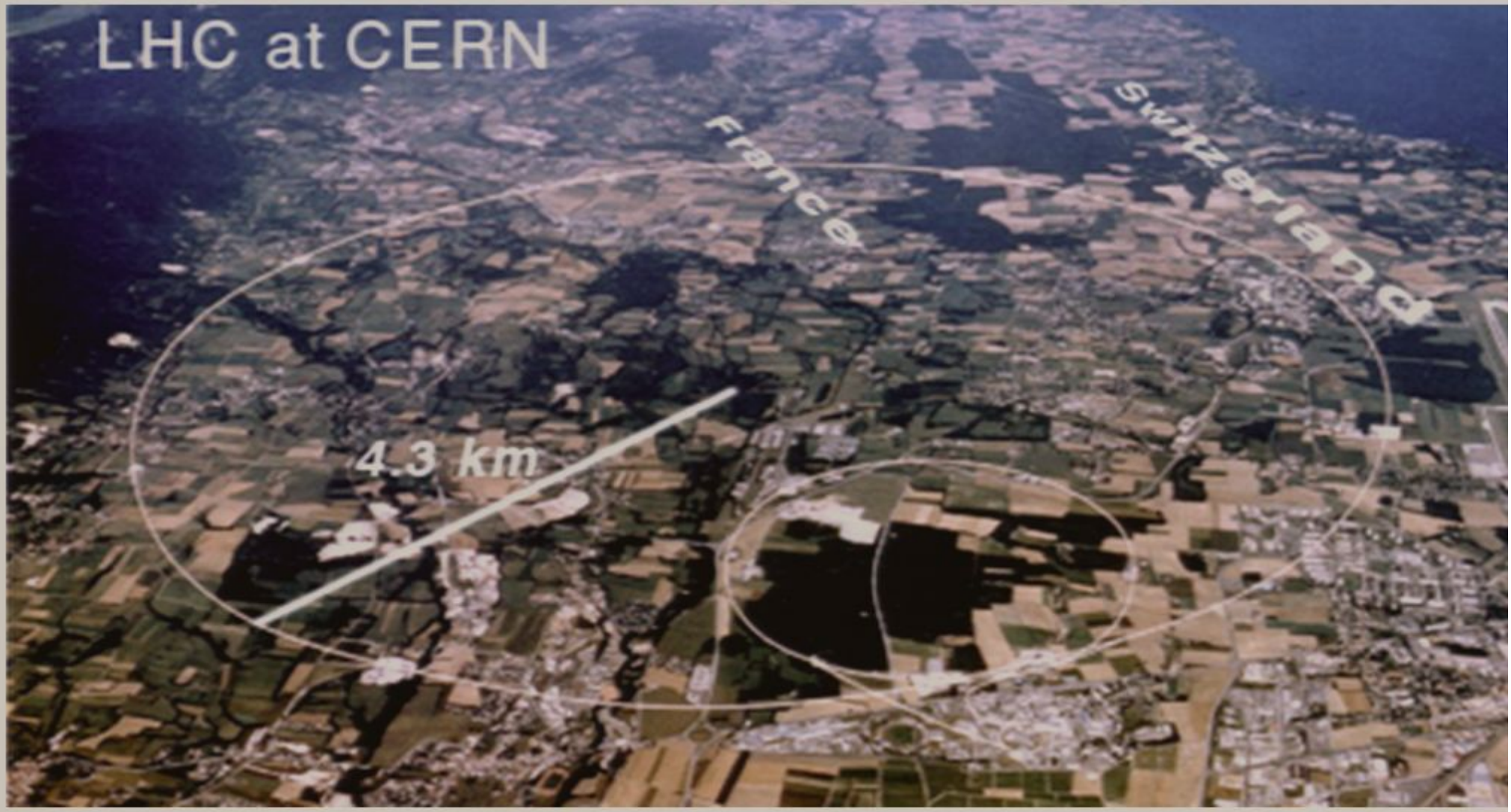


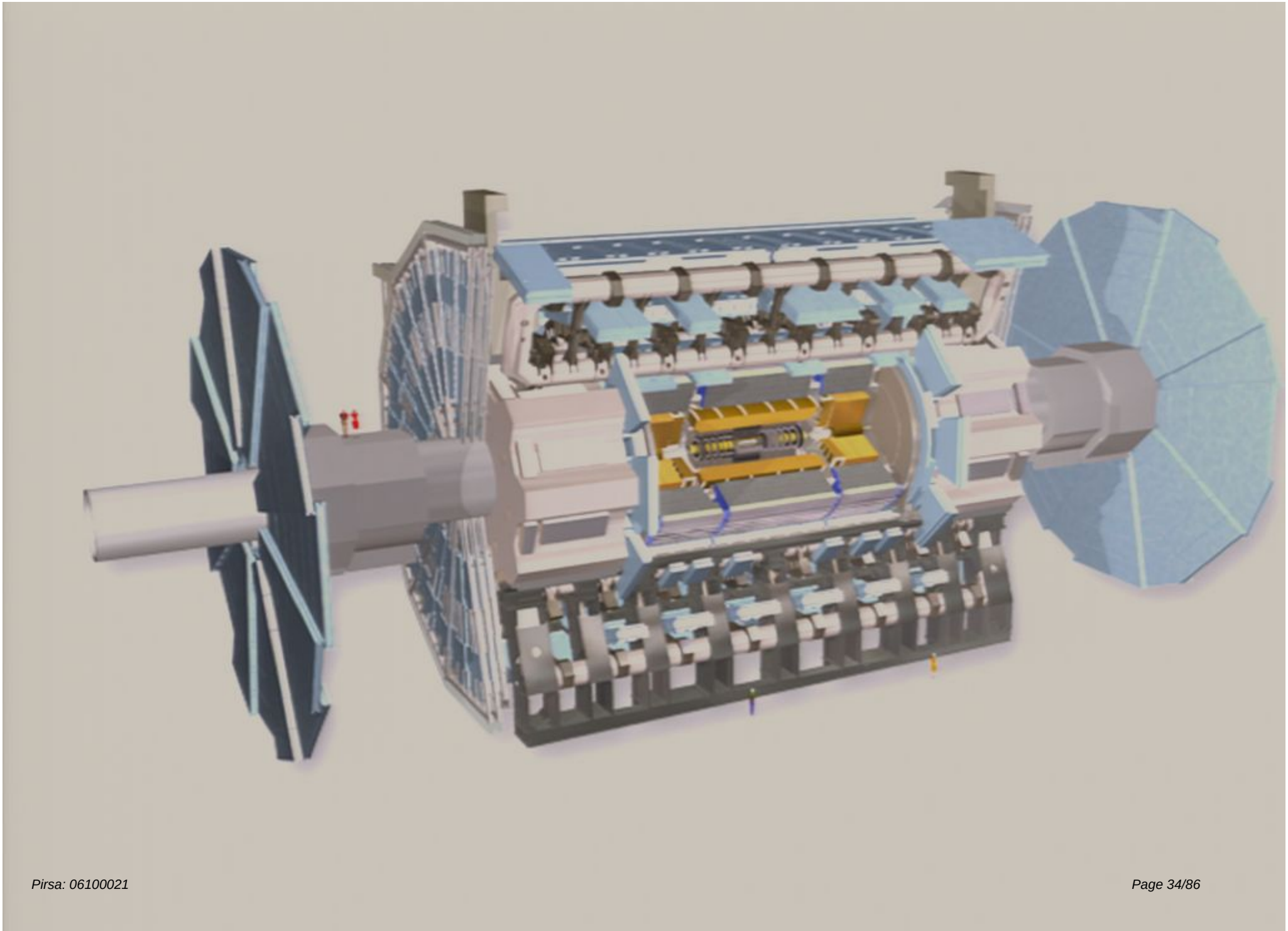


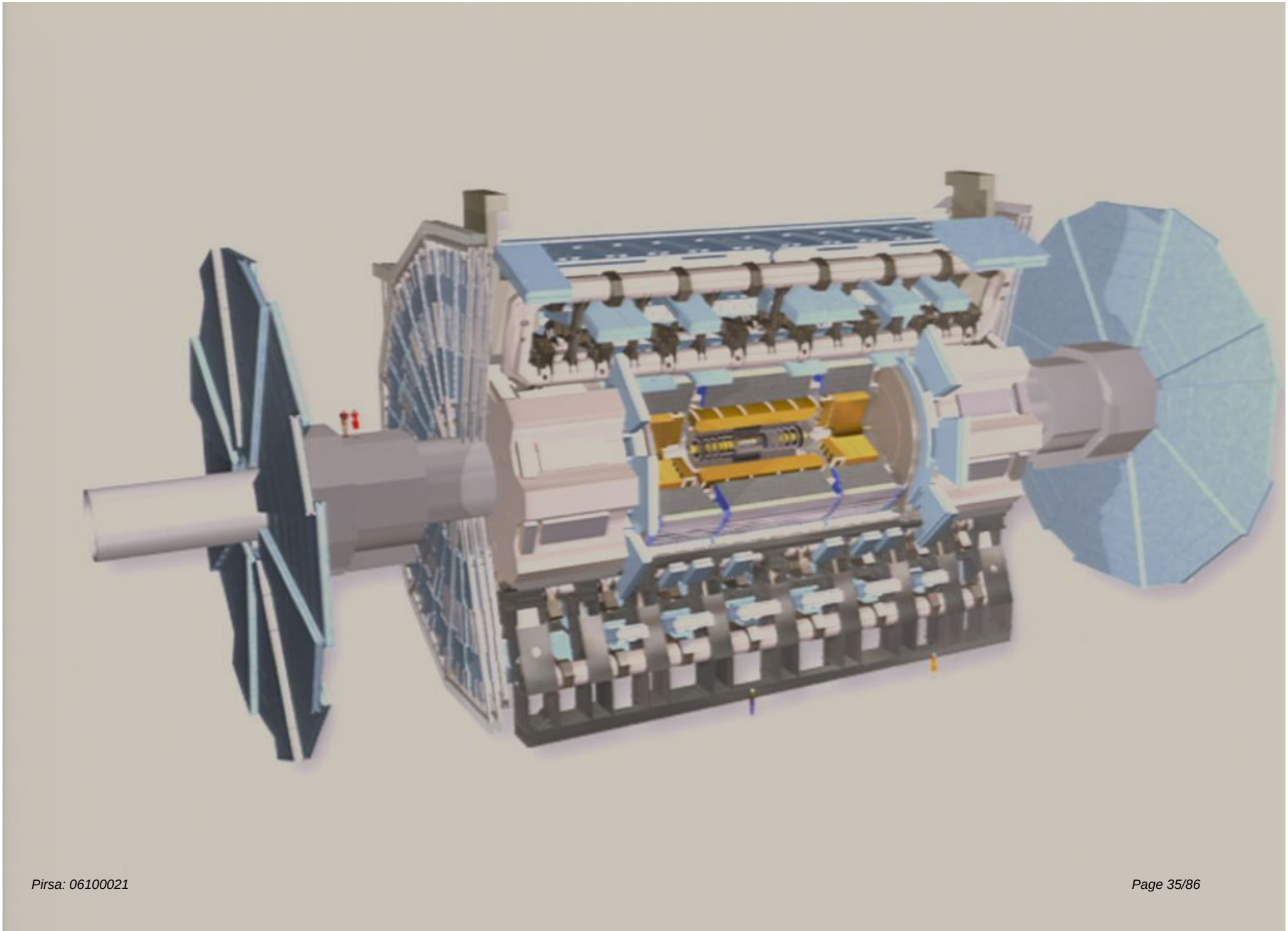


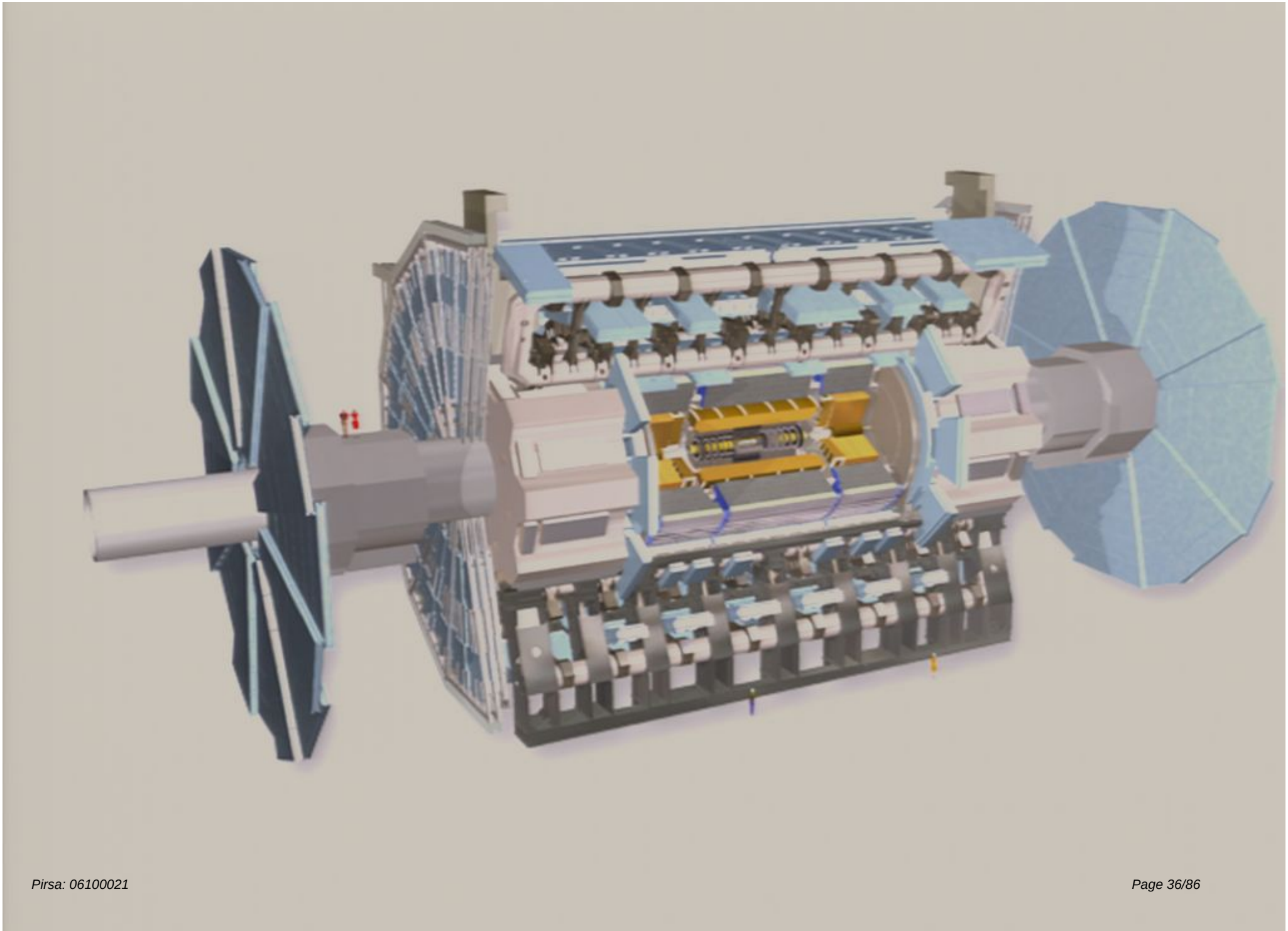


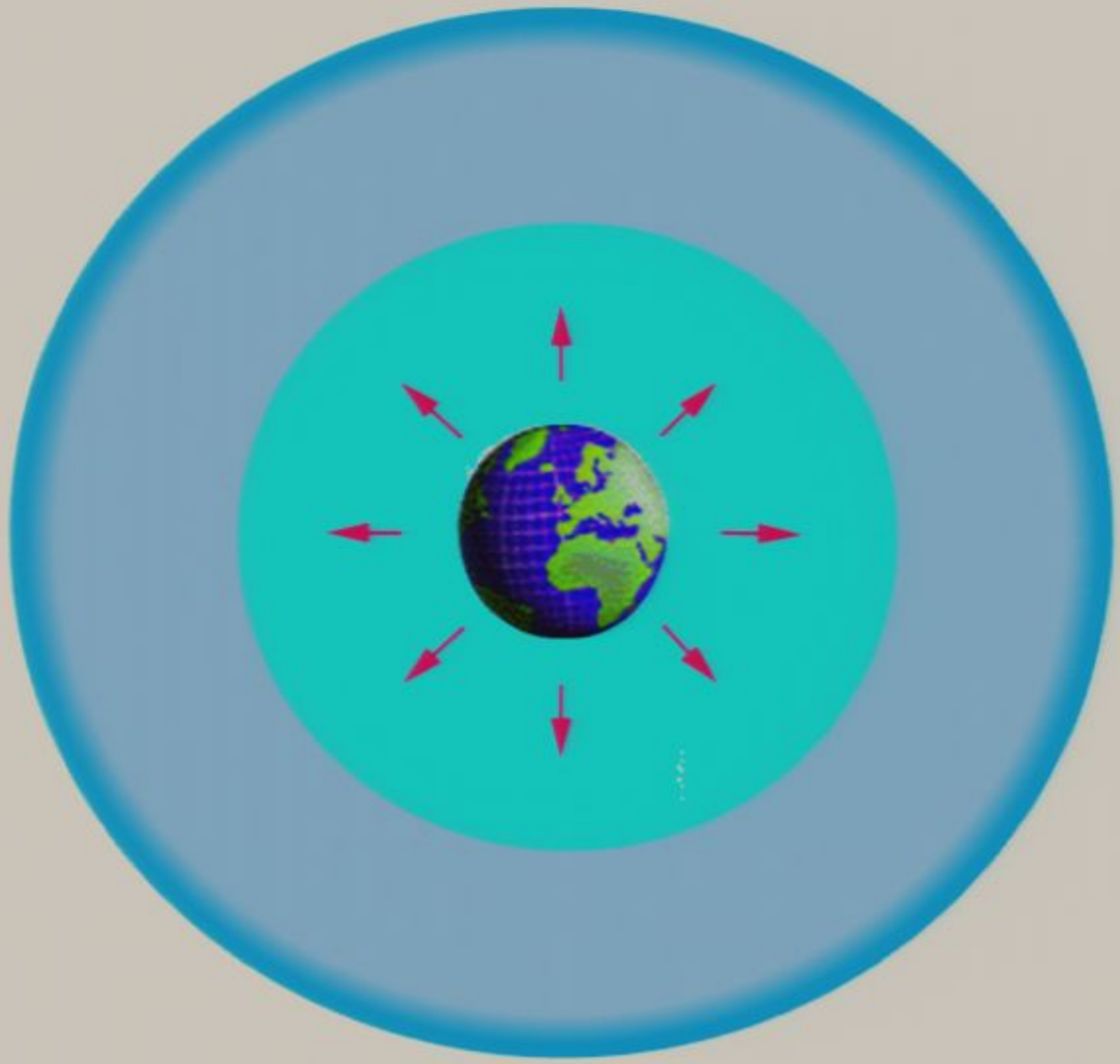


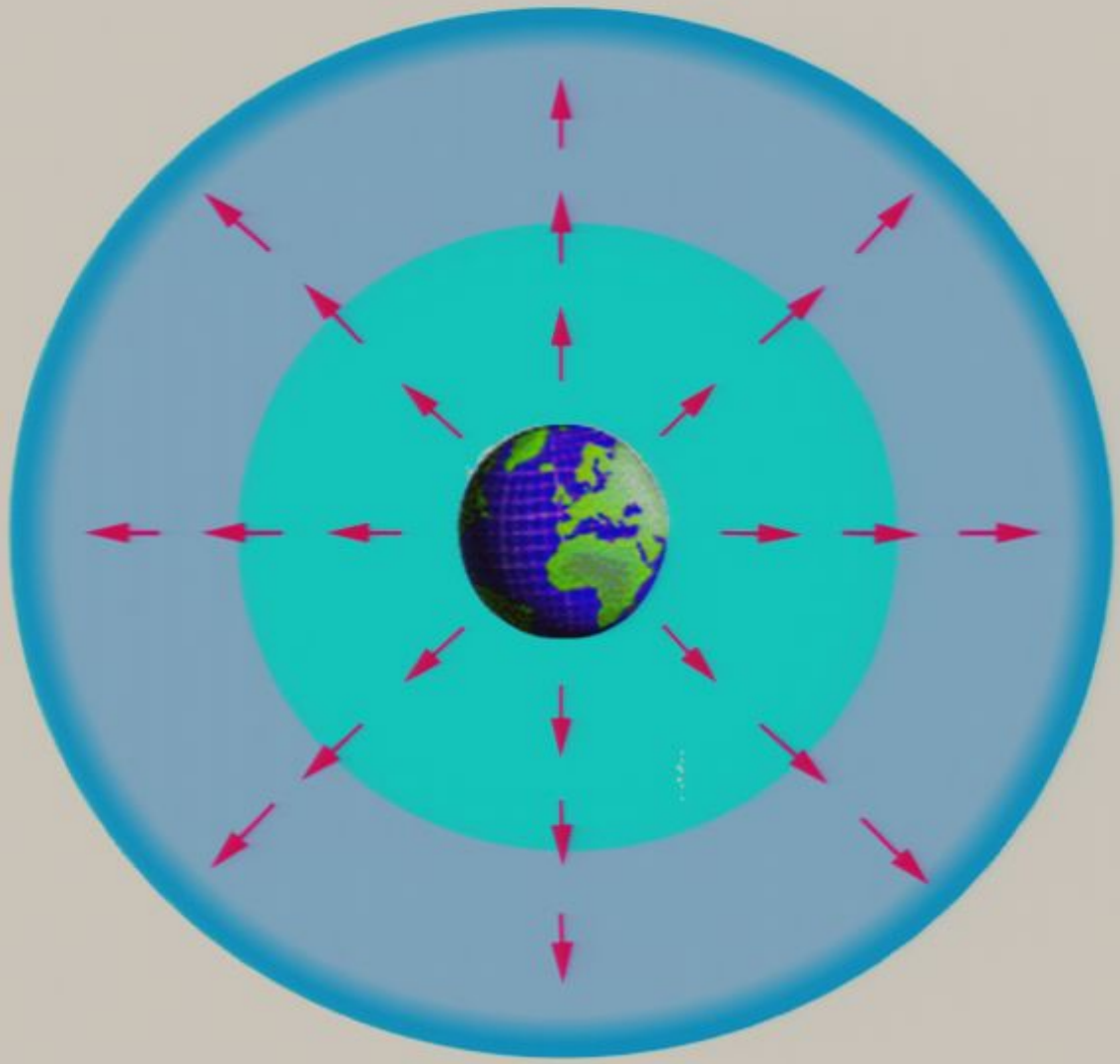

LHC at CERN
France
Switzerland
4.3 km

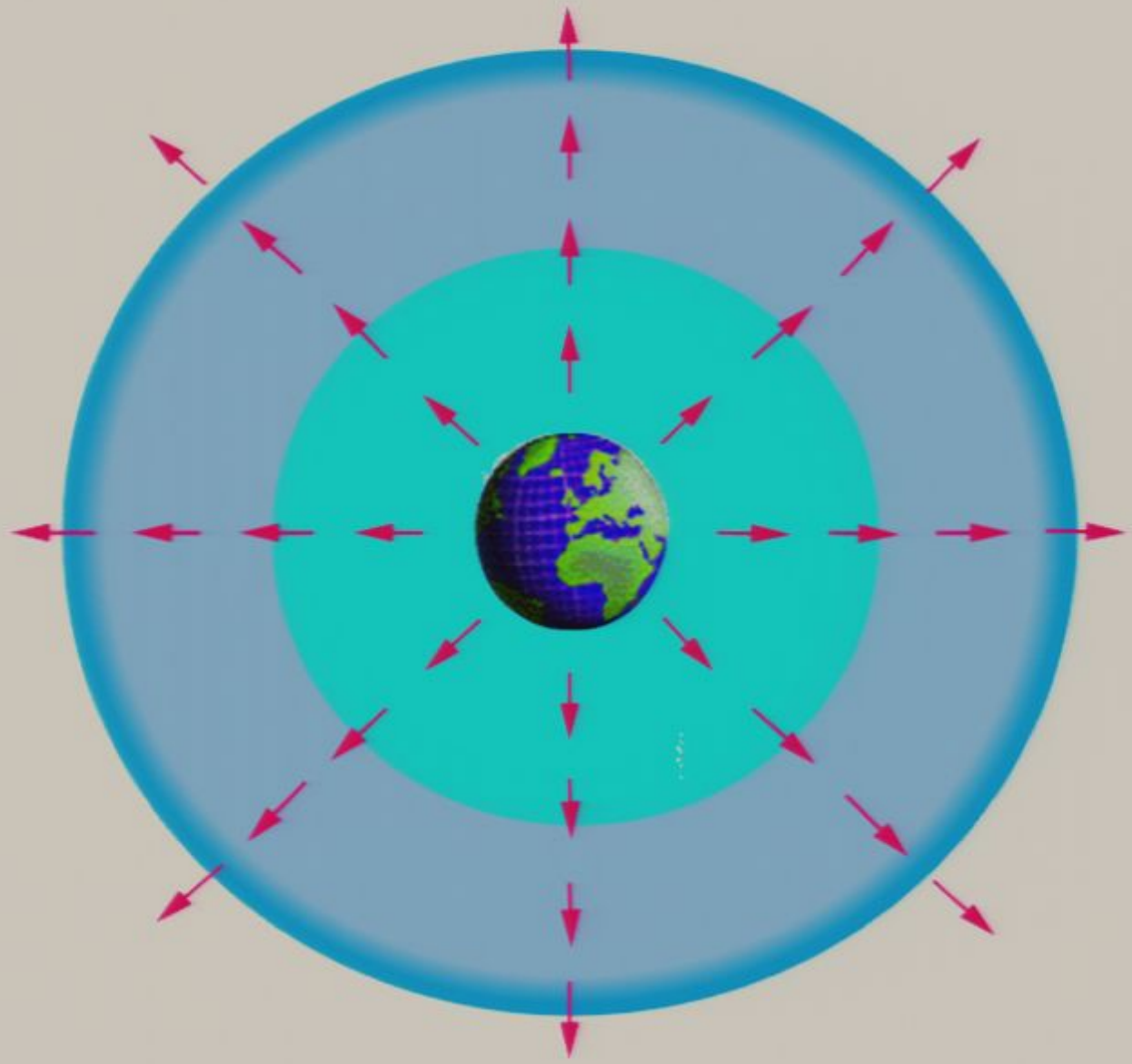


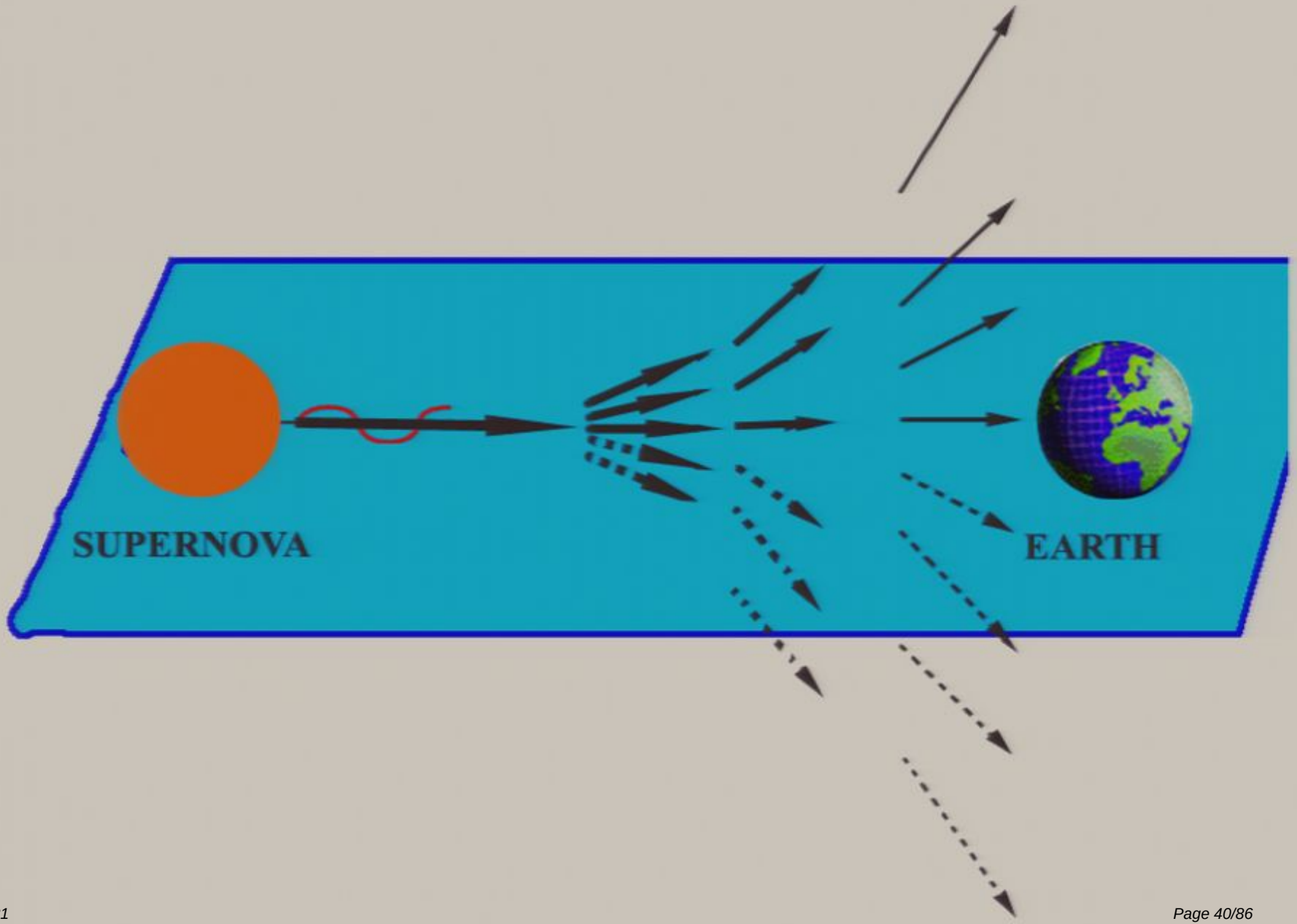


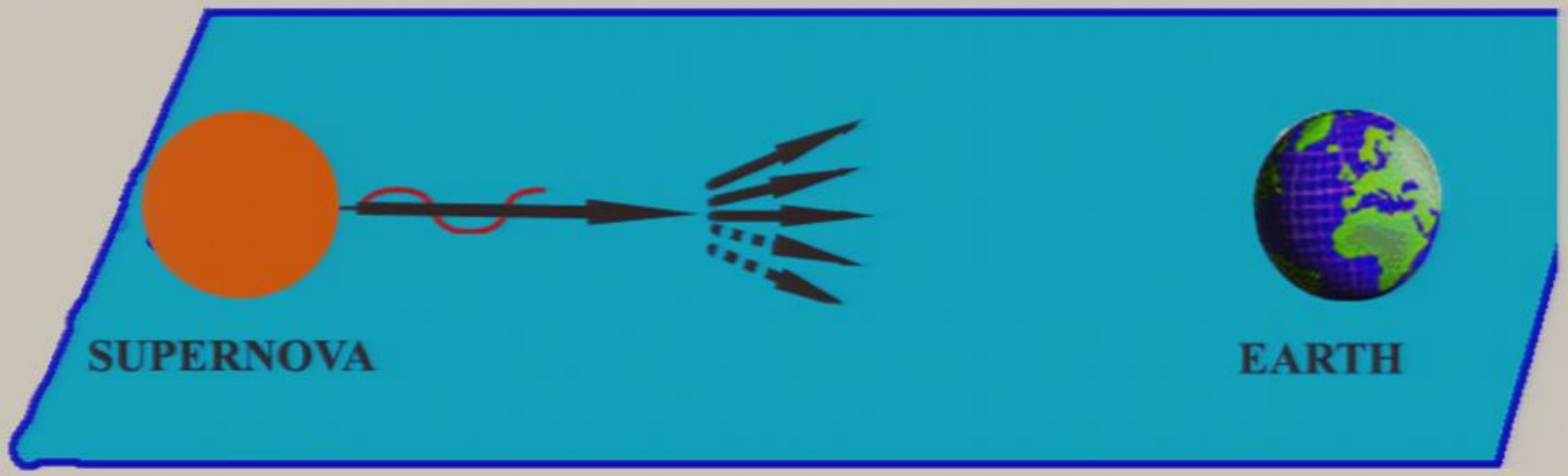









SUPERNOVA
EARTH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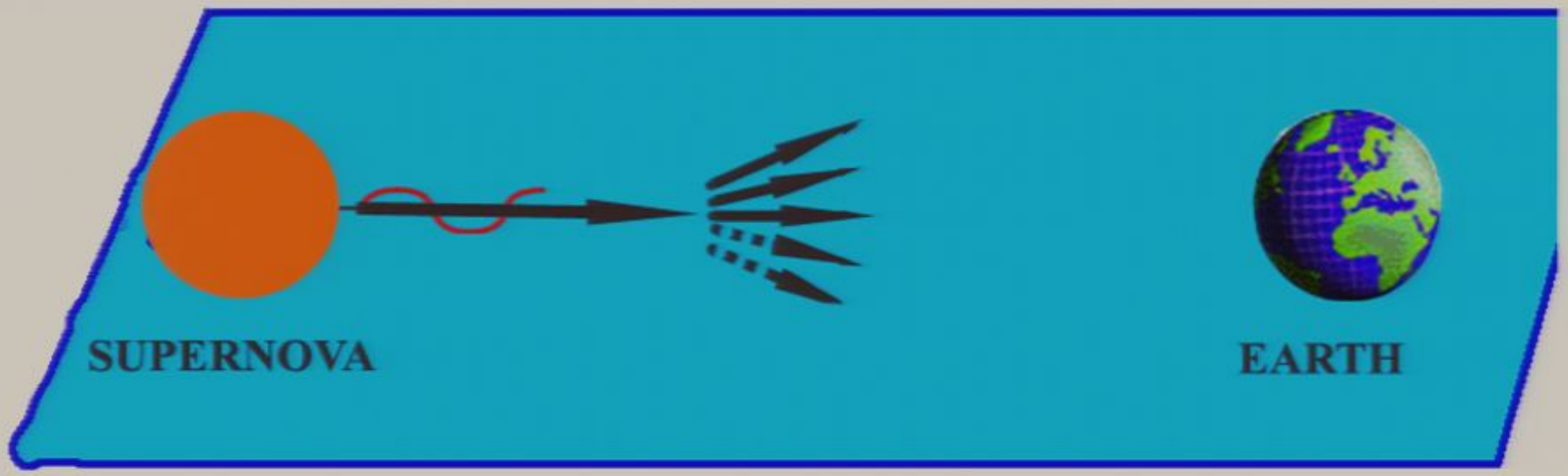
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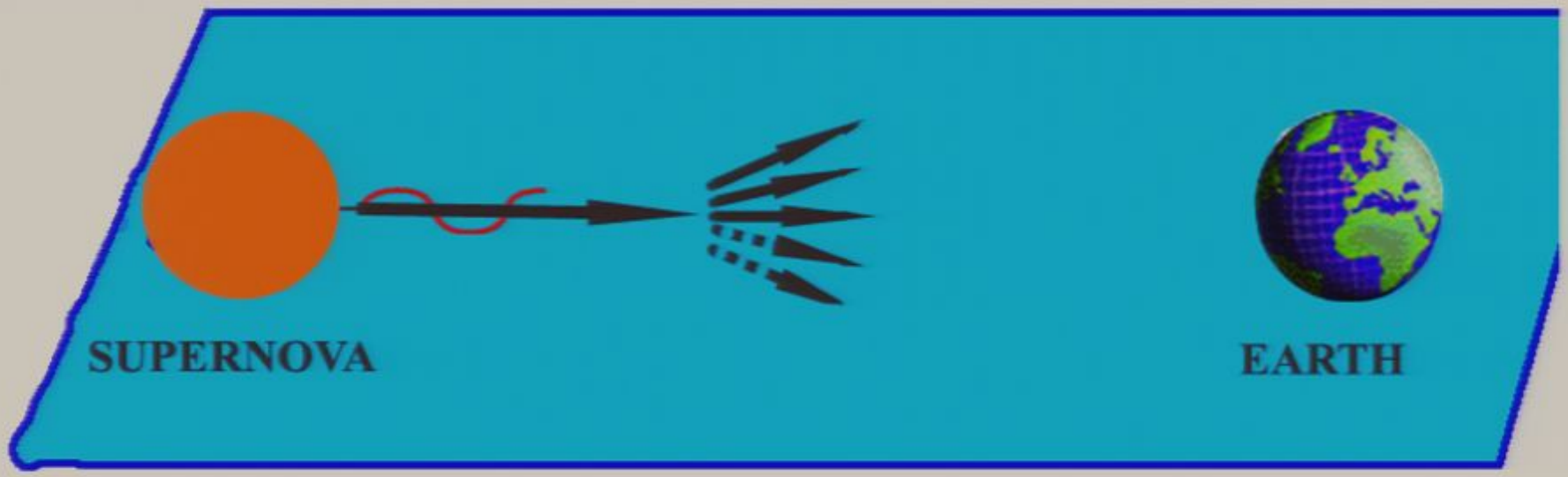
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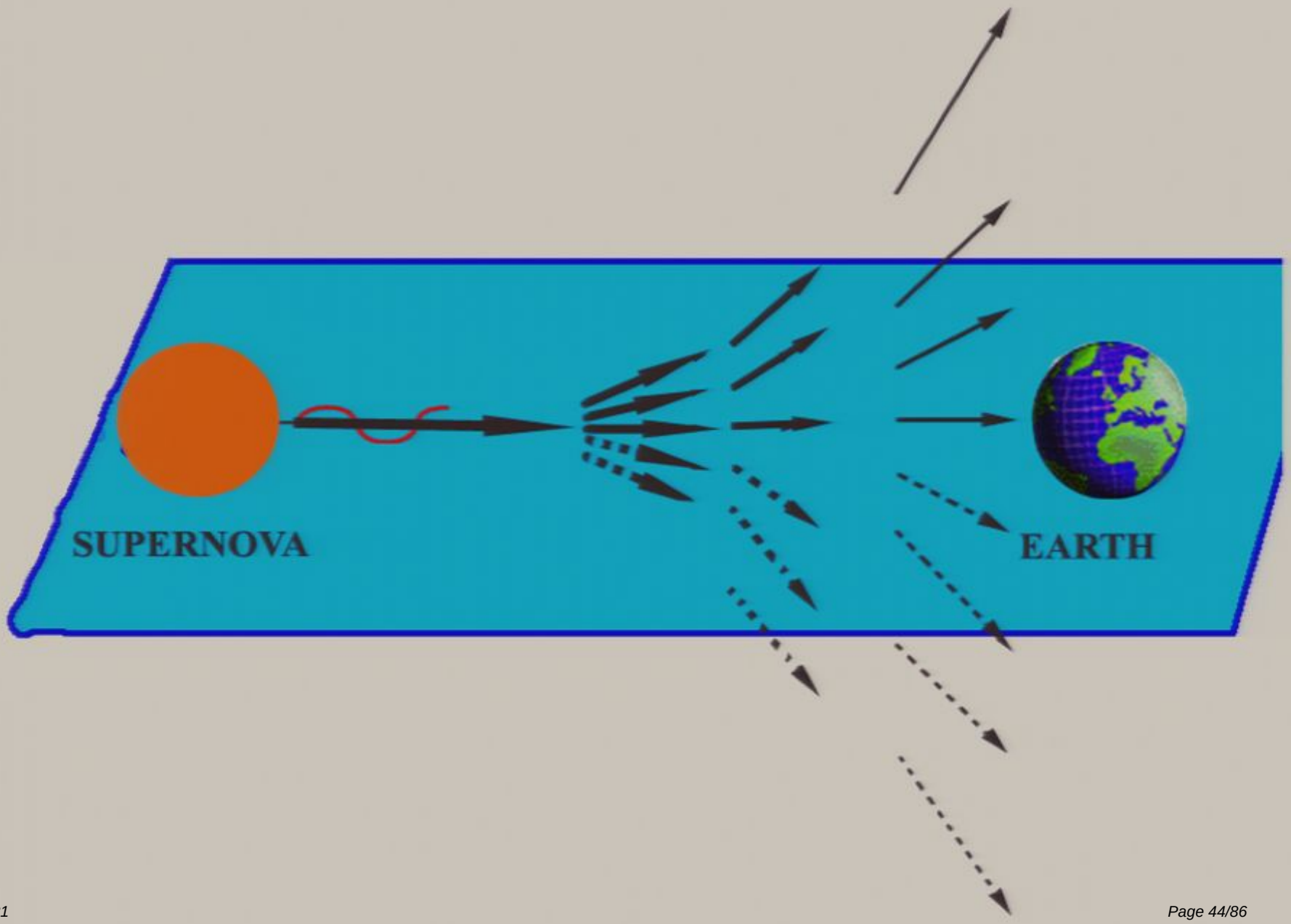
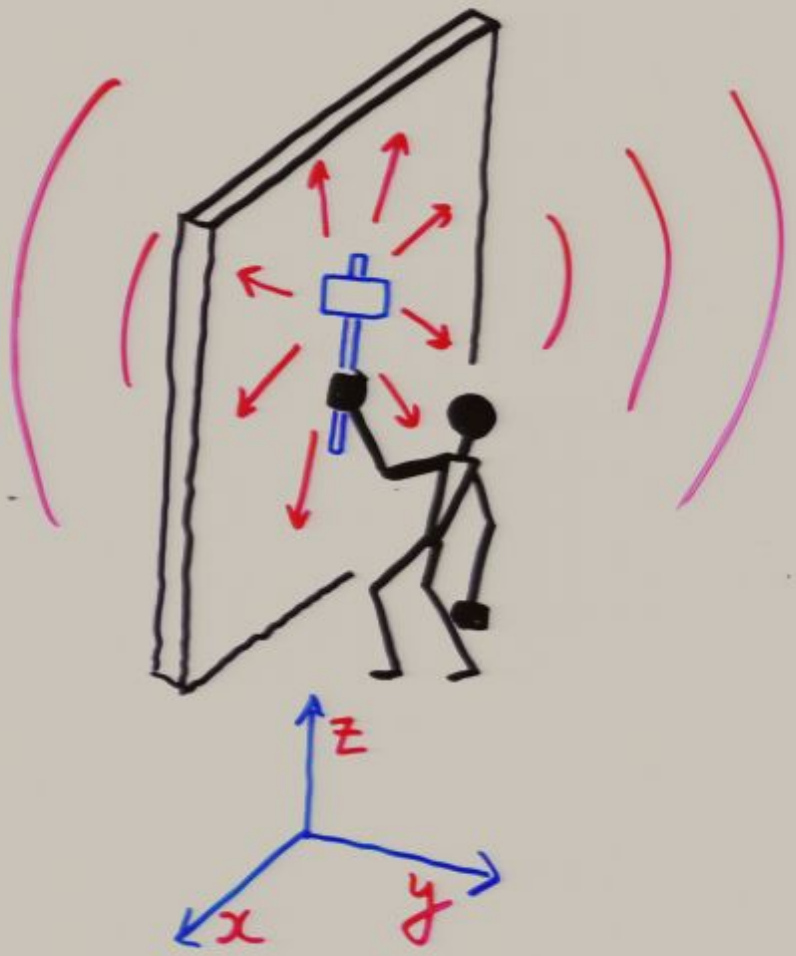

SUPERNOVA
EARTH

SOUND WAVE

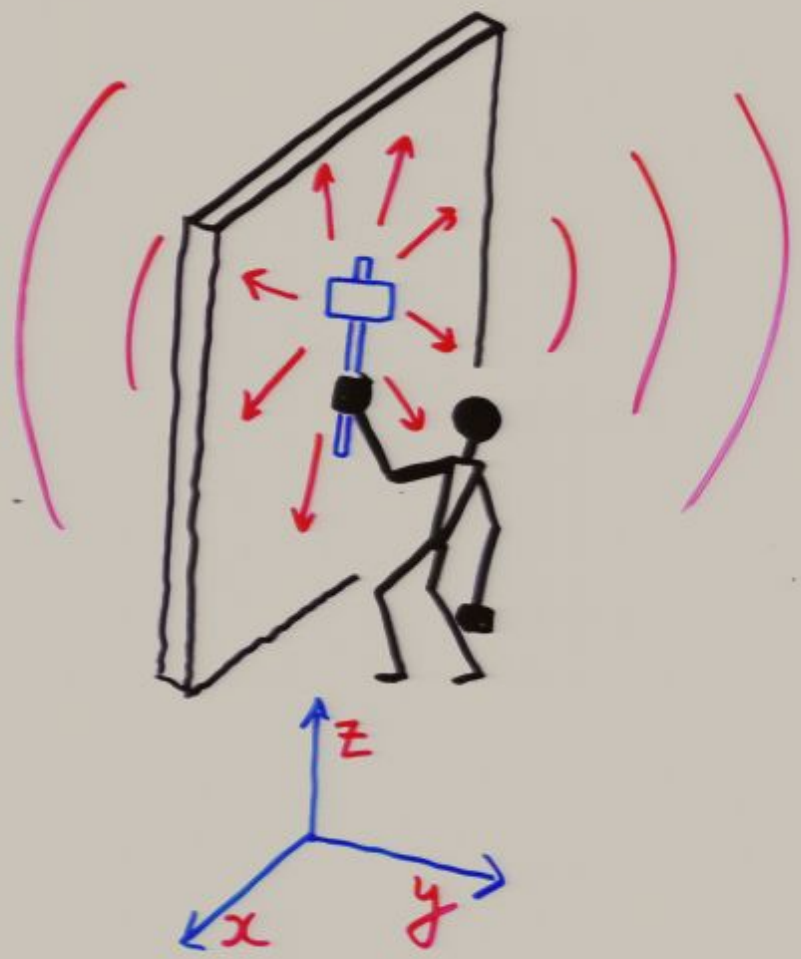
DGP '00



$$\left\{ \delta(y) \Box_{2+1} + \frac{1}{r_c} \Box_{3+1} \right\} \psi = \delta^4(x)$$

SOUND WAVE

DGP '00



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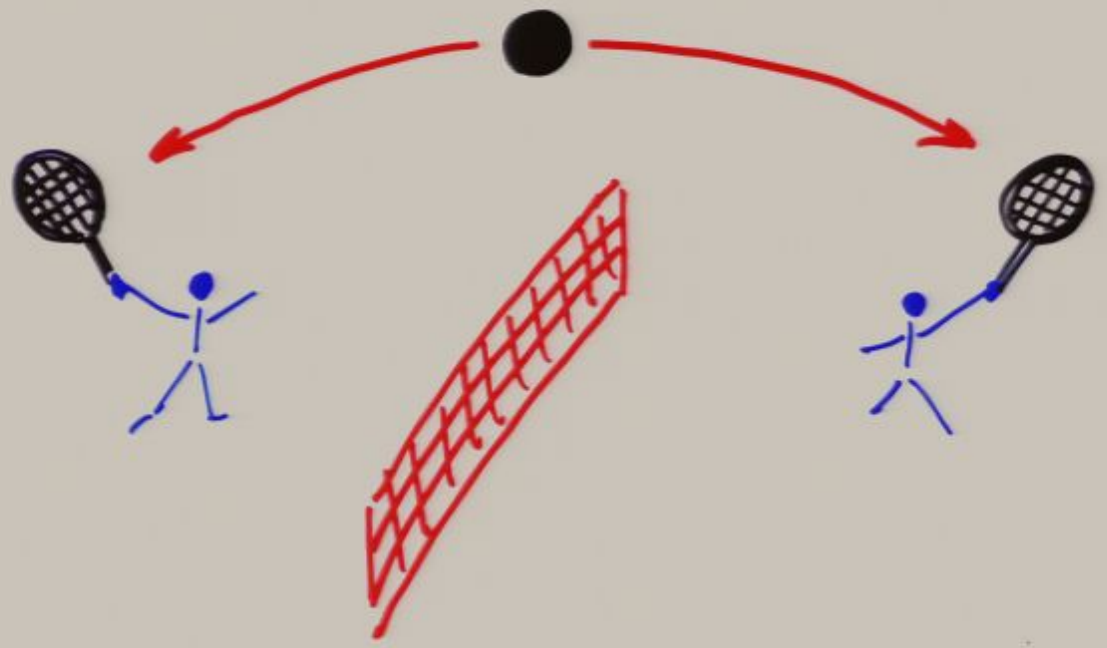

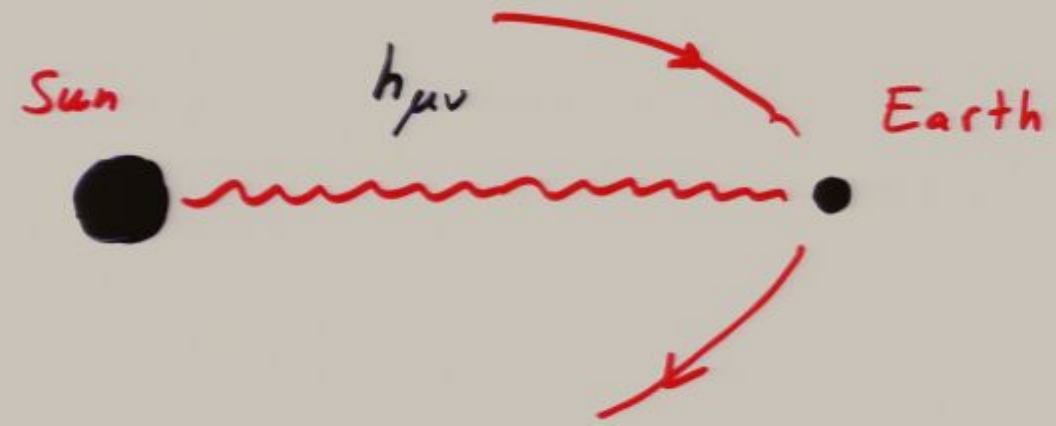
Sun
$h_{\mu\nu}$
Earth

FRW Equation is modified

$$H^2 - H/r_c = \frac{8\pi}{3} G_N \rho$$

Early cosmology in normal $H >> r_c^{-1}$

Late cosmology $H \to H = r_c^{-1}$

At late times Universe is self-accelerating!

NO NEED IN DARK ENERGY.

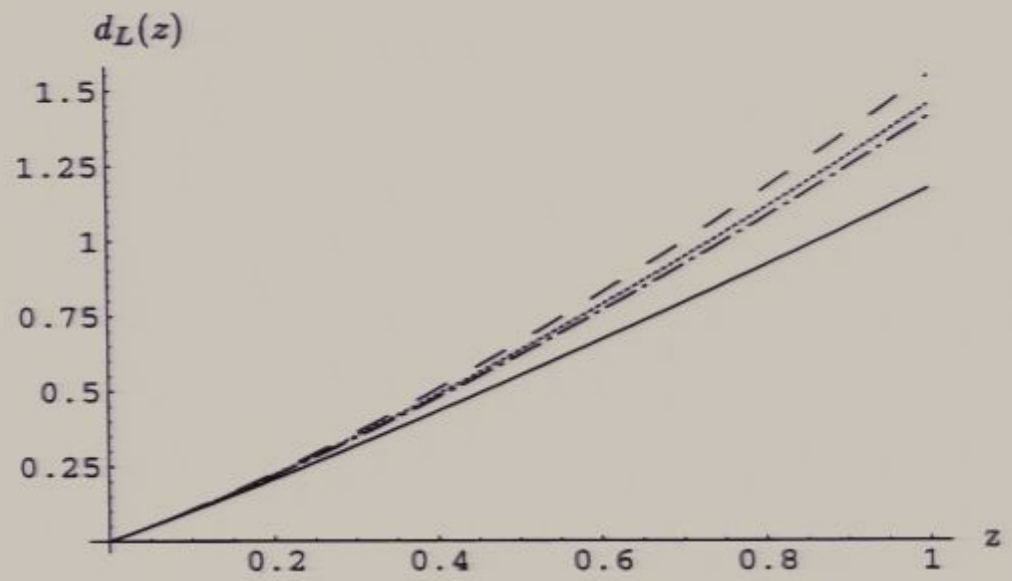

Figure 2: Luminosity distance as a function of red-shift for ordinary cosmology with $\Omega_\Lambda = 0.7, \Omega_M = 0.3, k = 0$ (dashed line), $\Omega_\Lambda = 0, \Omega_M = 1, k = 0$ (solid line), and dark energy with $\Omega_X = 0.7, w_X = -0.6, \Omega_M = 0.3, k = 0$ (dotted-dashed line) and in our model (dotted line) with $\Omega_M = 0.3$ and a flat universe (for which one gets from equation (28) $\Omega_{r_c} = 0.12$ and $r_c = 1.4 H_0^{-1}$).

FRW Equation is modified

$$H^2 - H/r_c = \frac{8\pi}{3} G_N \rho$$

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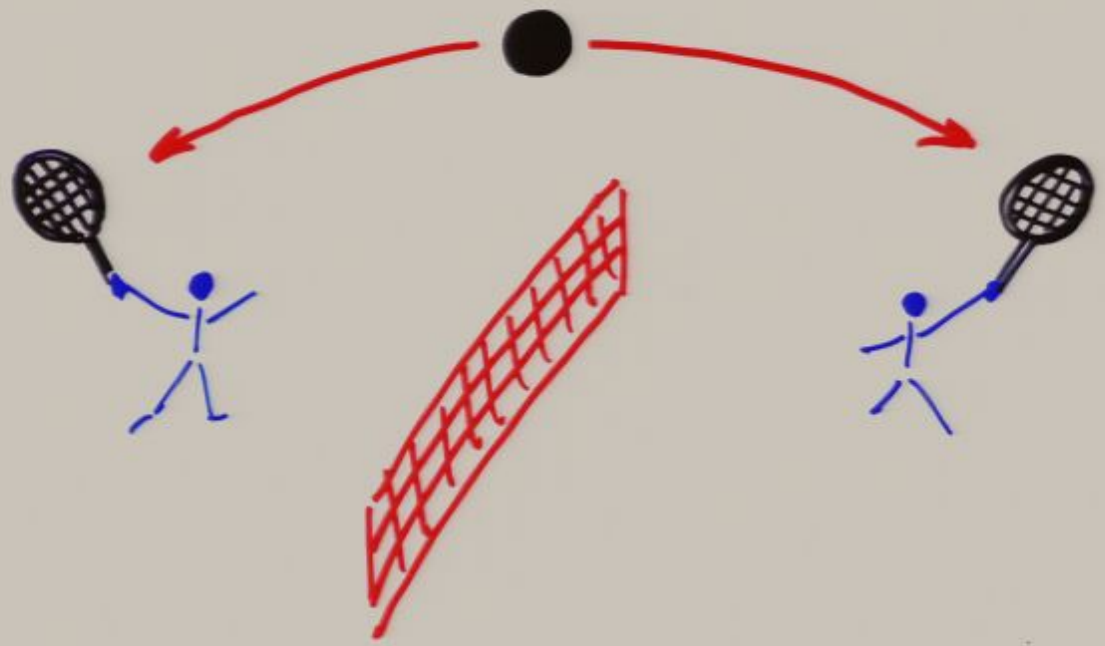
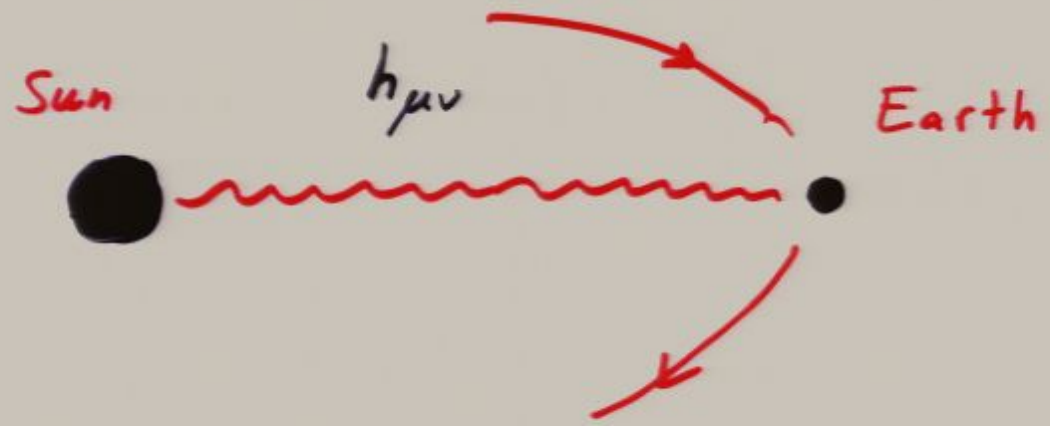
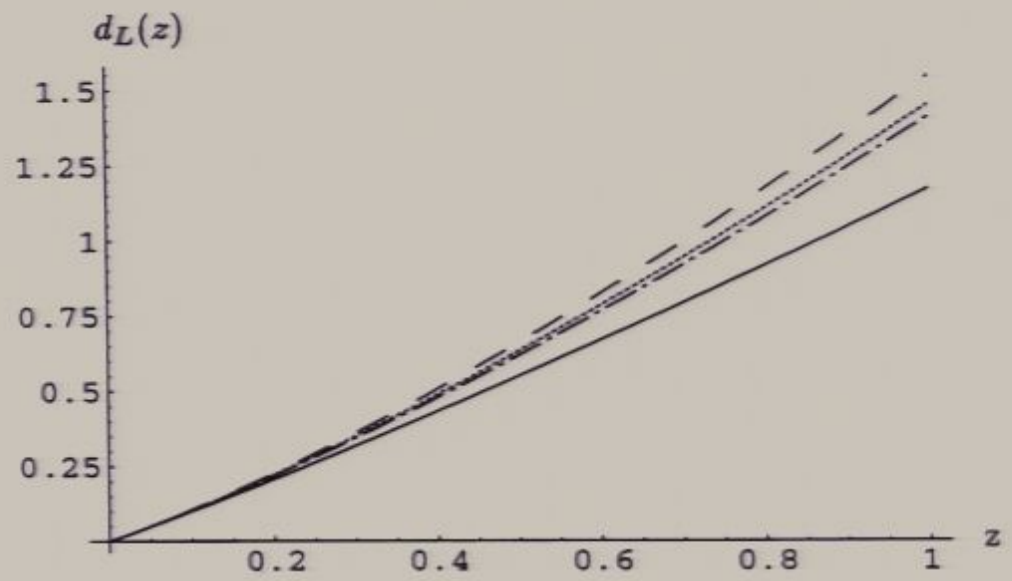



Sun
$h_{\mu\nu}$
Earth



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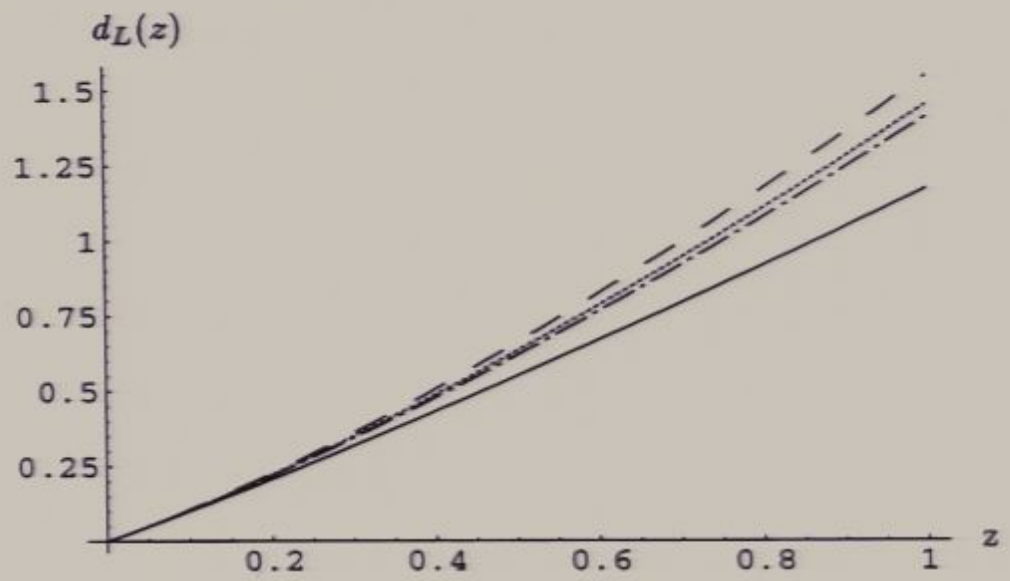

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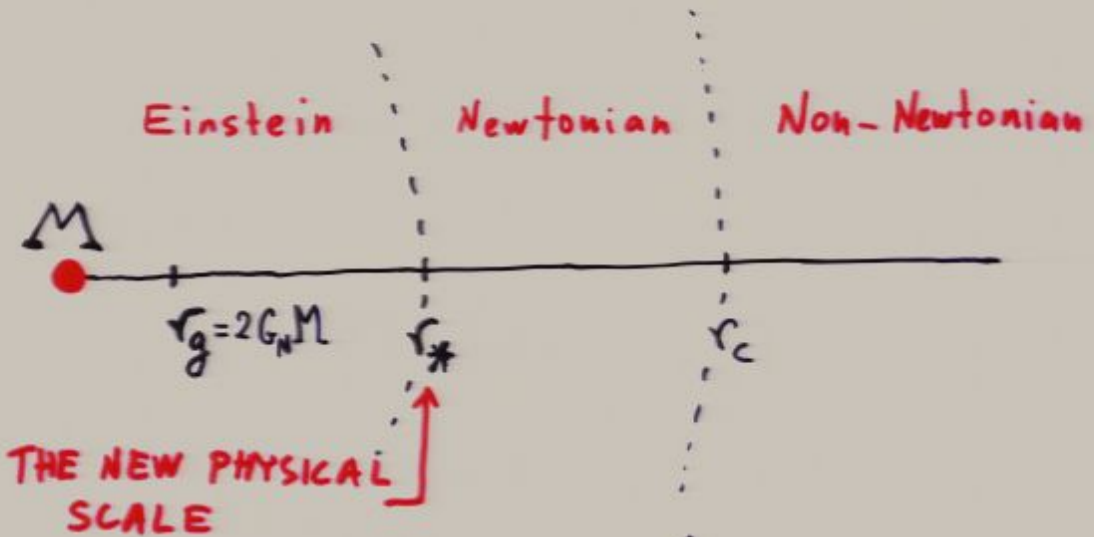
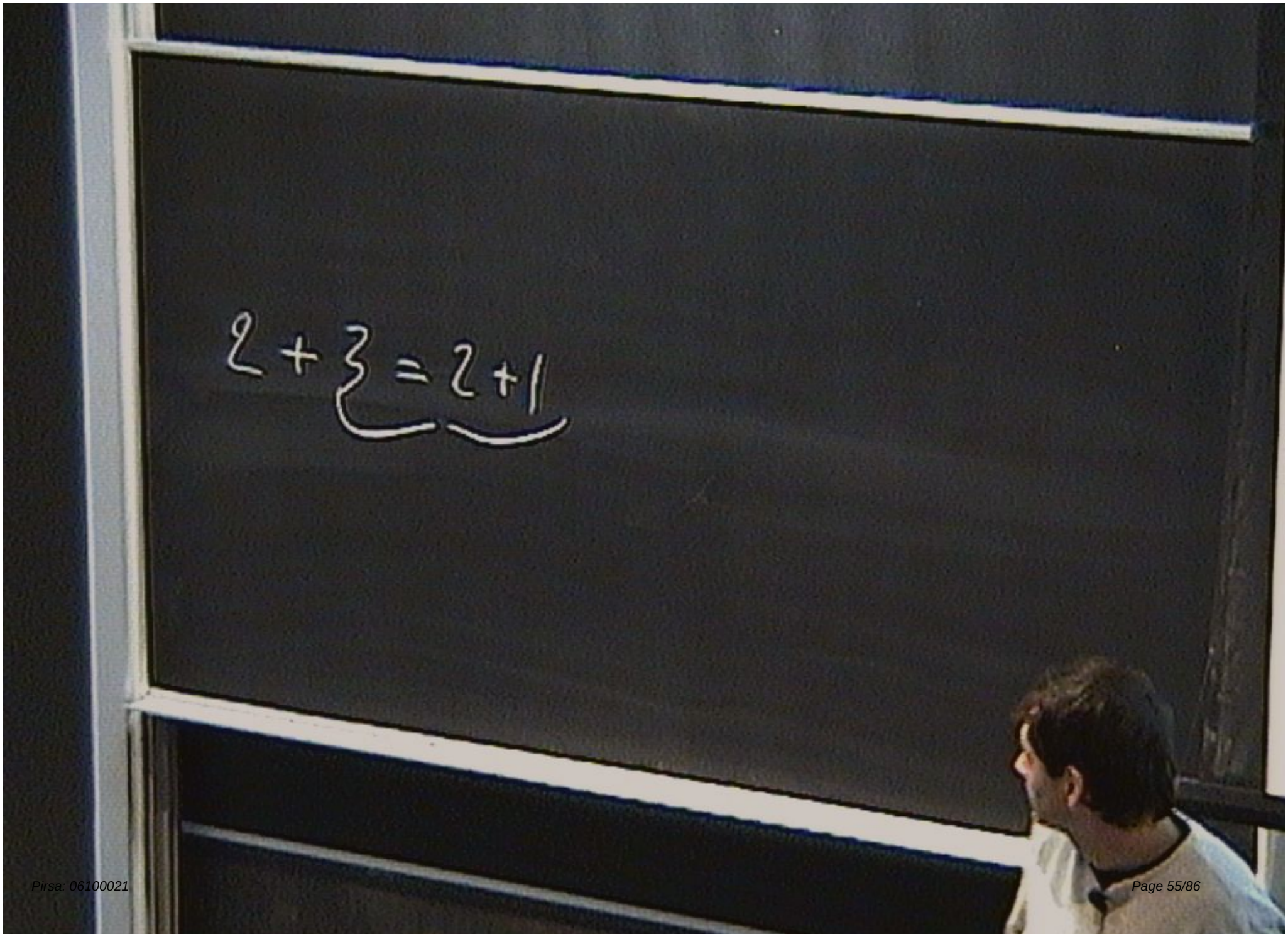
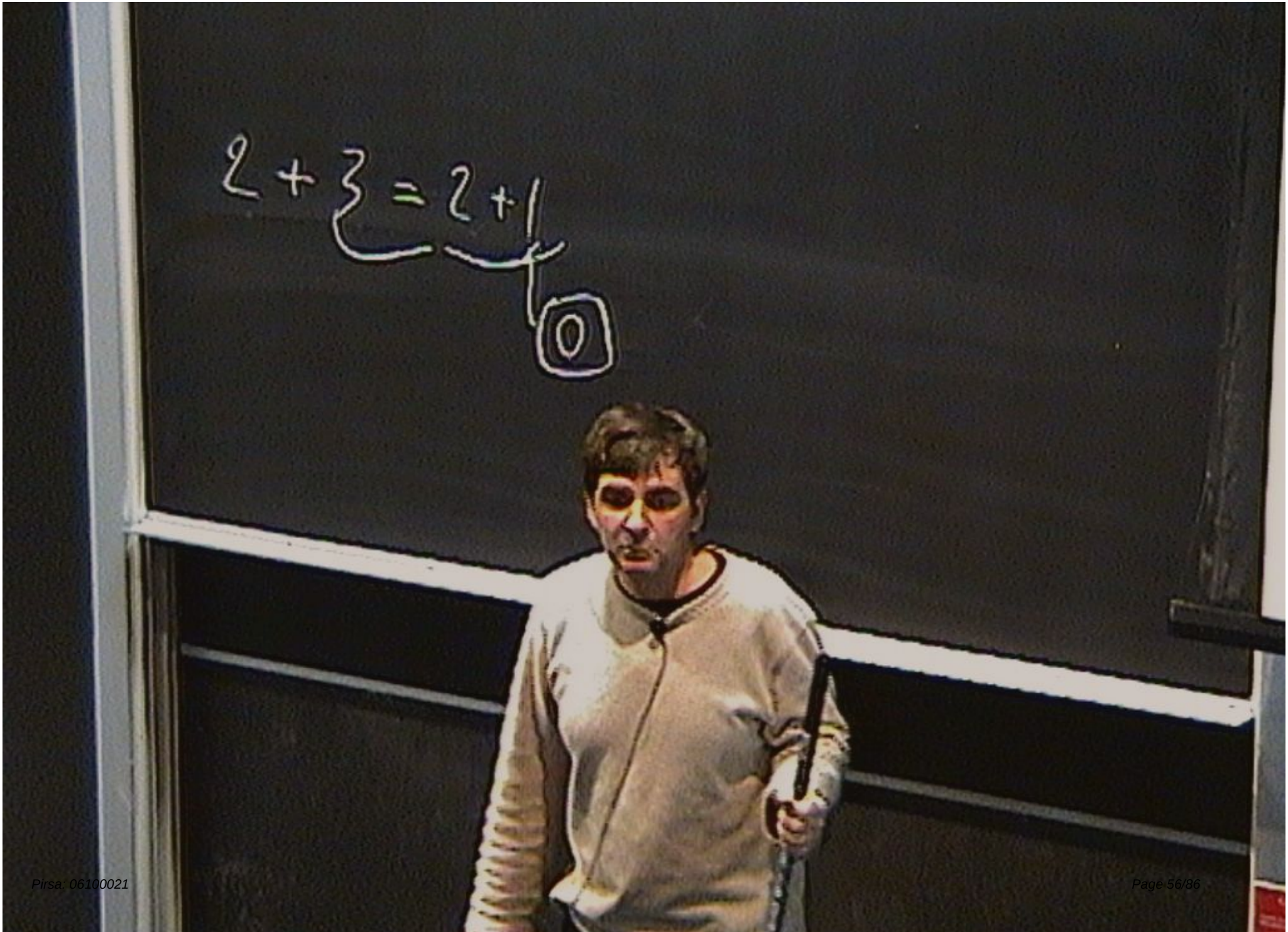
Corrections to Einstein are Source-dependent

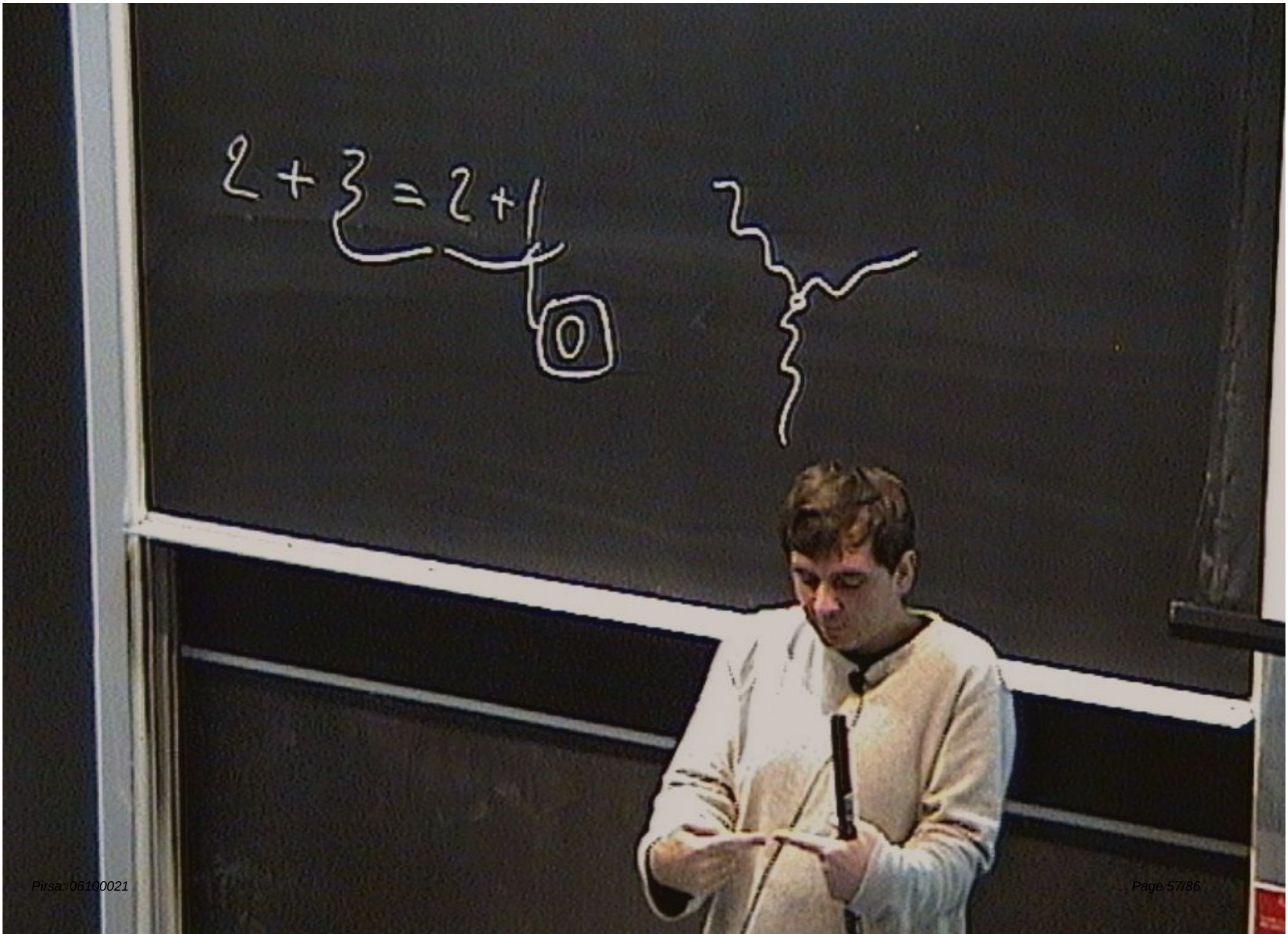
Corrections to Einstein $\begin{cases} \neq \dfrac{r}{r_c} \\ = \left(\dfrac{r}{r_*}\right)^{3/2} \end{cases}$ $r_* \ll r_c$

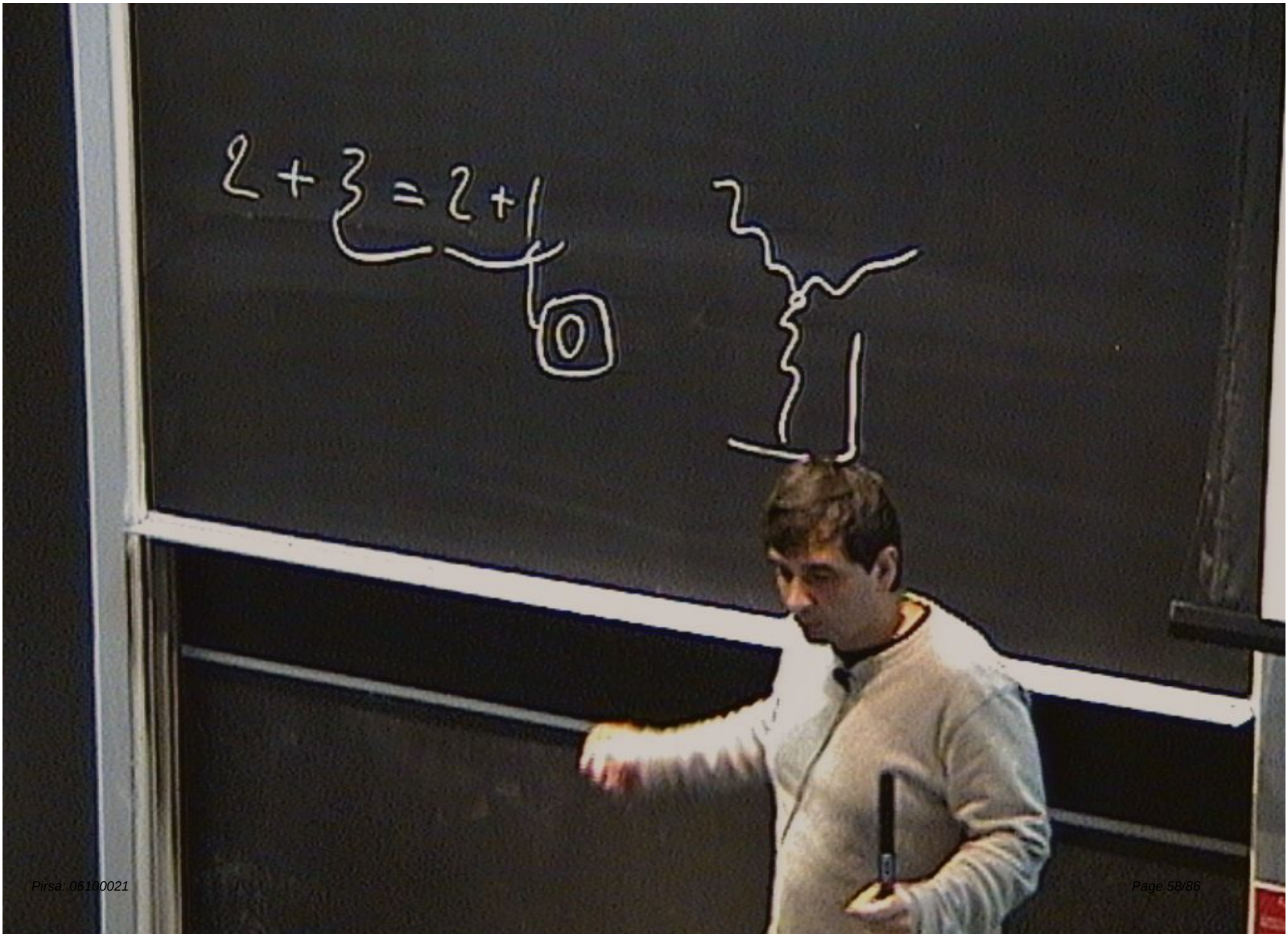


$$r_* = \left(r_c^2 r_g\right)^{\frac{1}{3}}$$


2 + 3 = 2 + 1


2 + 3 = 2 + 1
0


2 + 3 = 2 + 1
0


2+3=2+1
0
2
1

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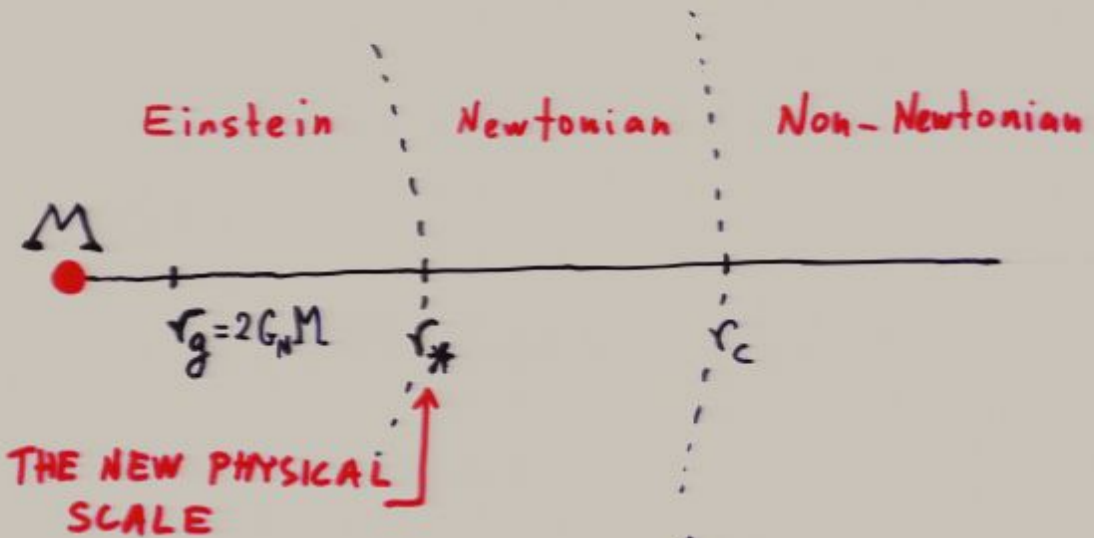

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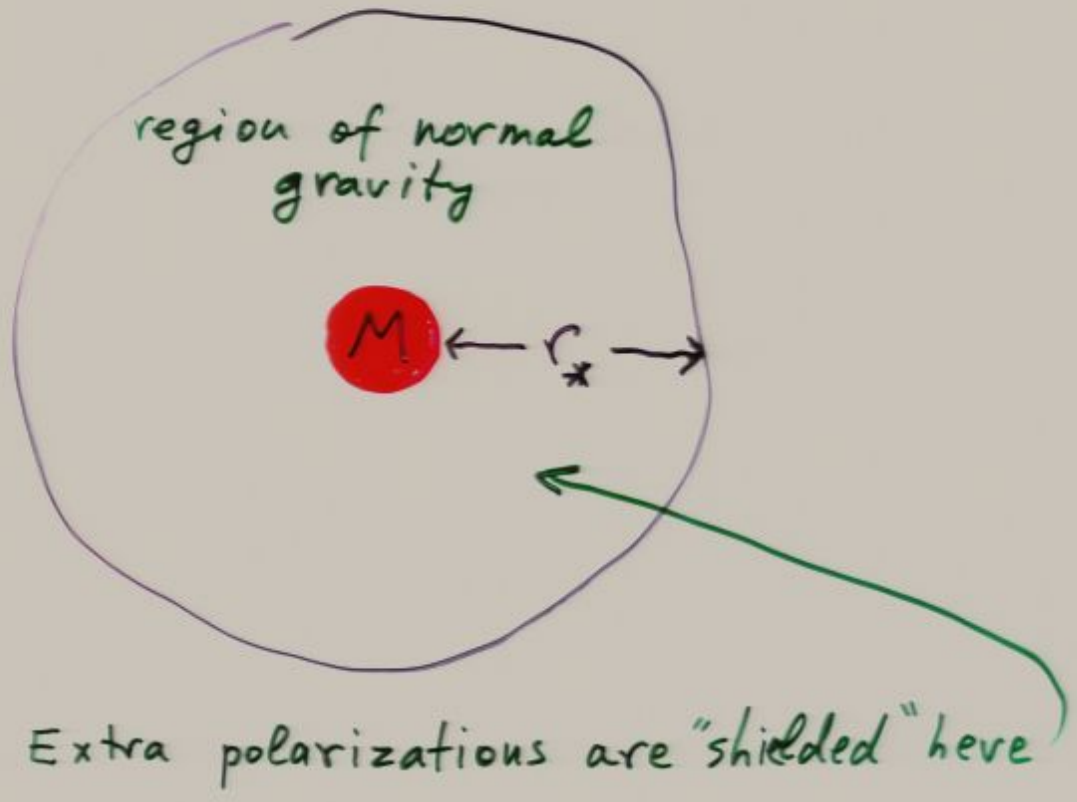
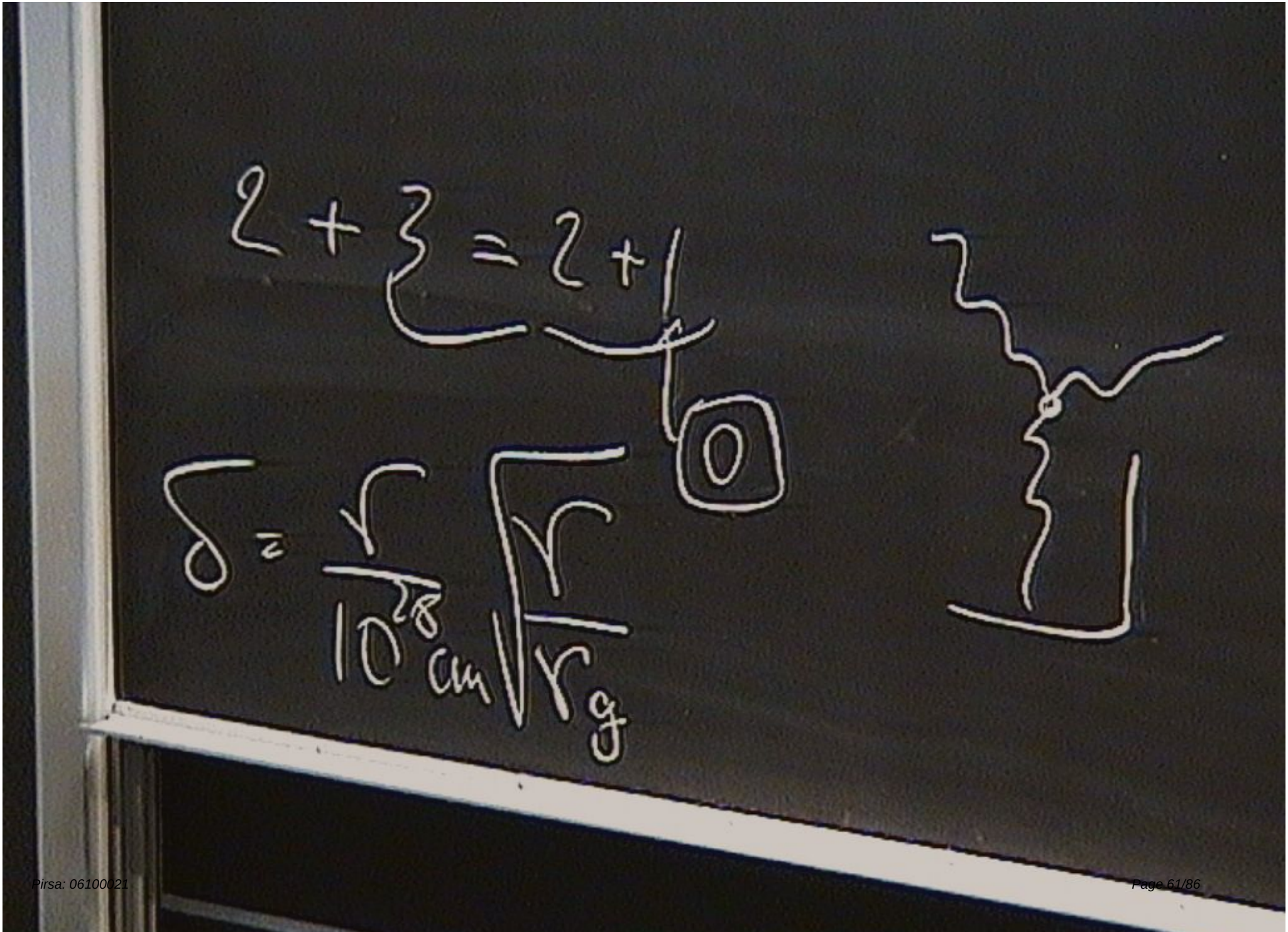
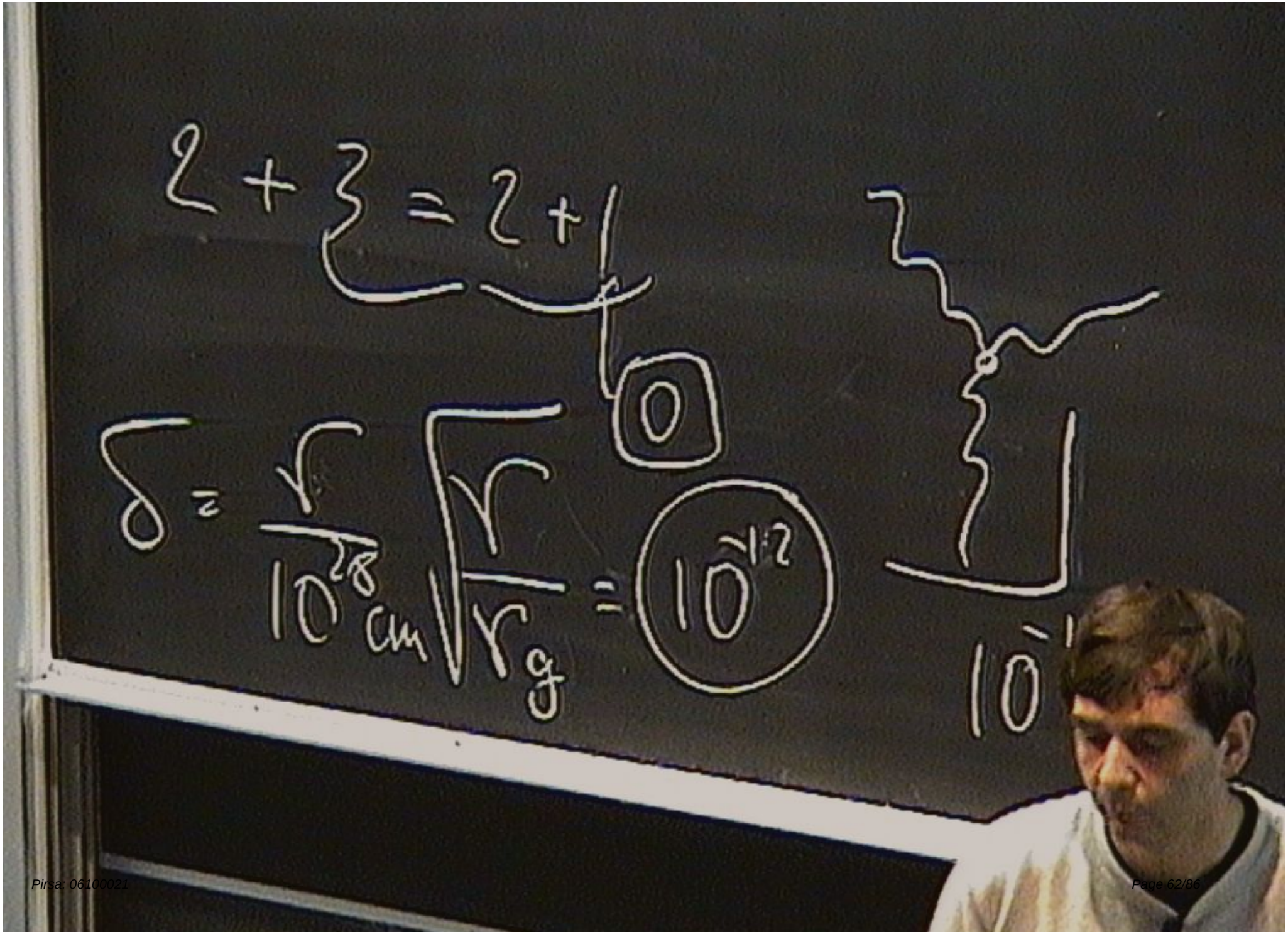
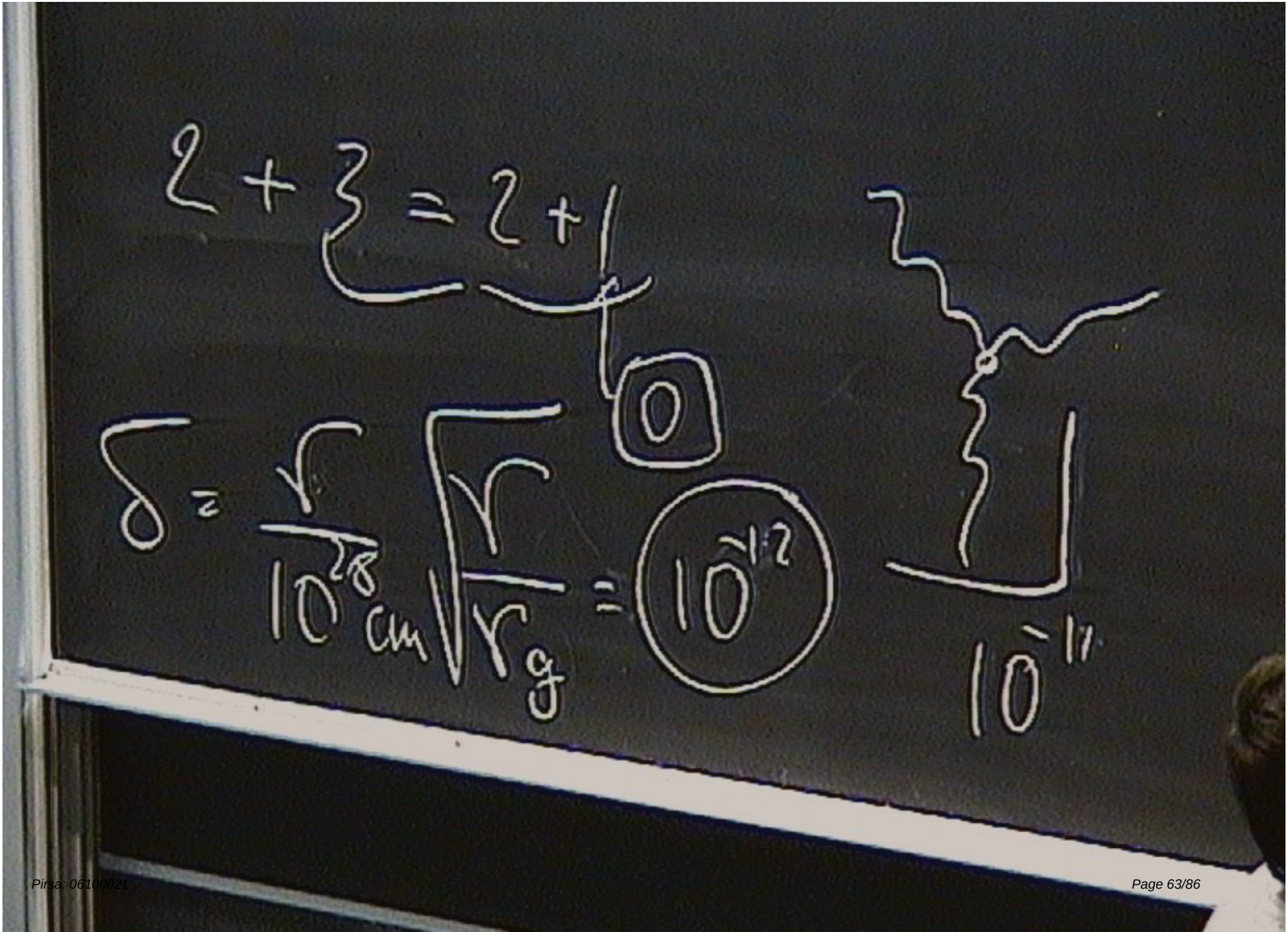


$$r_* \sim (r_c^2 r_g)^{\frac{1}{3}} \ll r_c \,!$$

$$r_g \equiv 2 G_N M$$


2 + ξ = 2 + 1
δ = r / 10^28 cm √(r / r_g)
0


2 + ξ = 2 + 1
0
δ = r / 10^28 cm √(r / r_g) = 10^-12
10^-1


2 + 3 = 2 + 1
δ = r / 10^28 cm √(r / r_g) = 10^-12
0
10^-11

LUNAR RANGING TEST OF MODIFIED GRAVITY

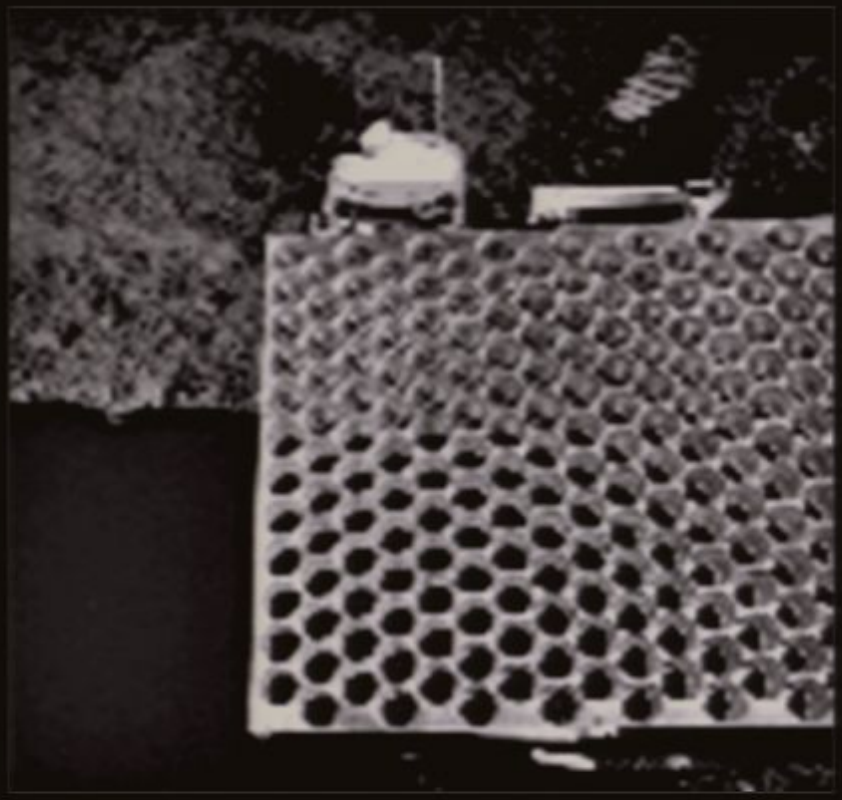
Predicted anomalous perihelion precession of the lunar orbit

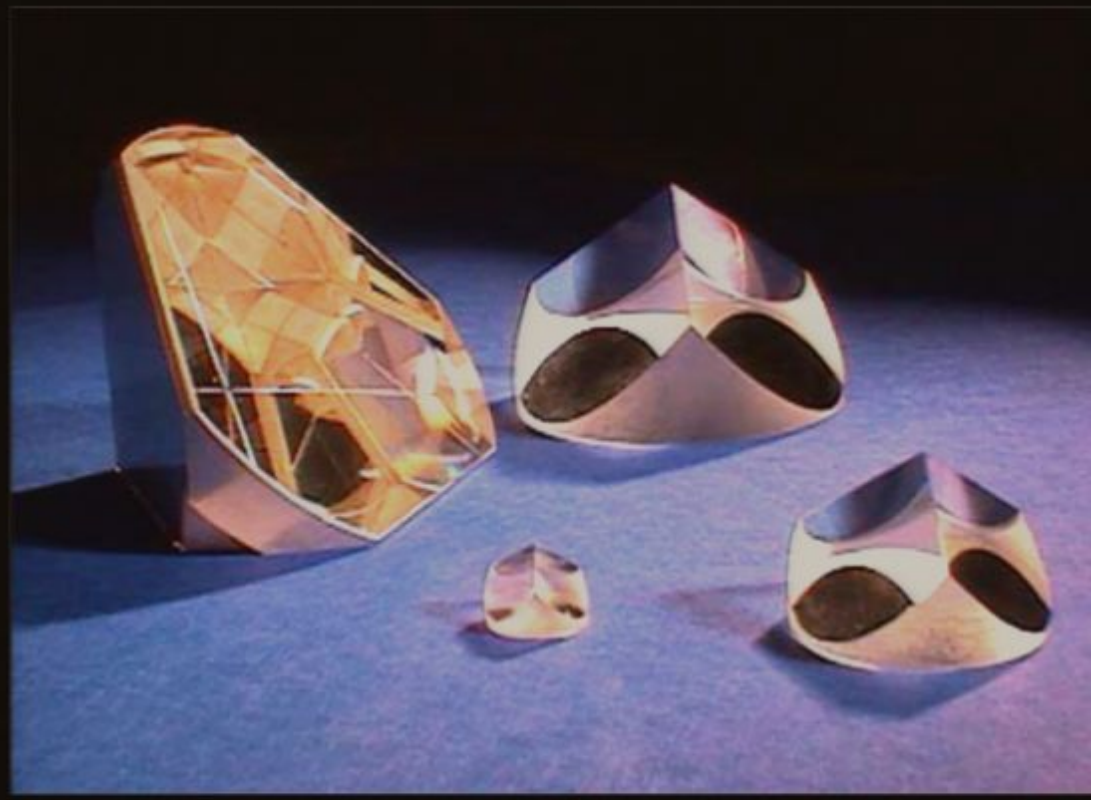
$$\delta\phi = 1.4 \times 10^{-12}$$

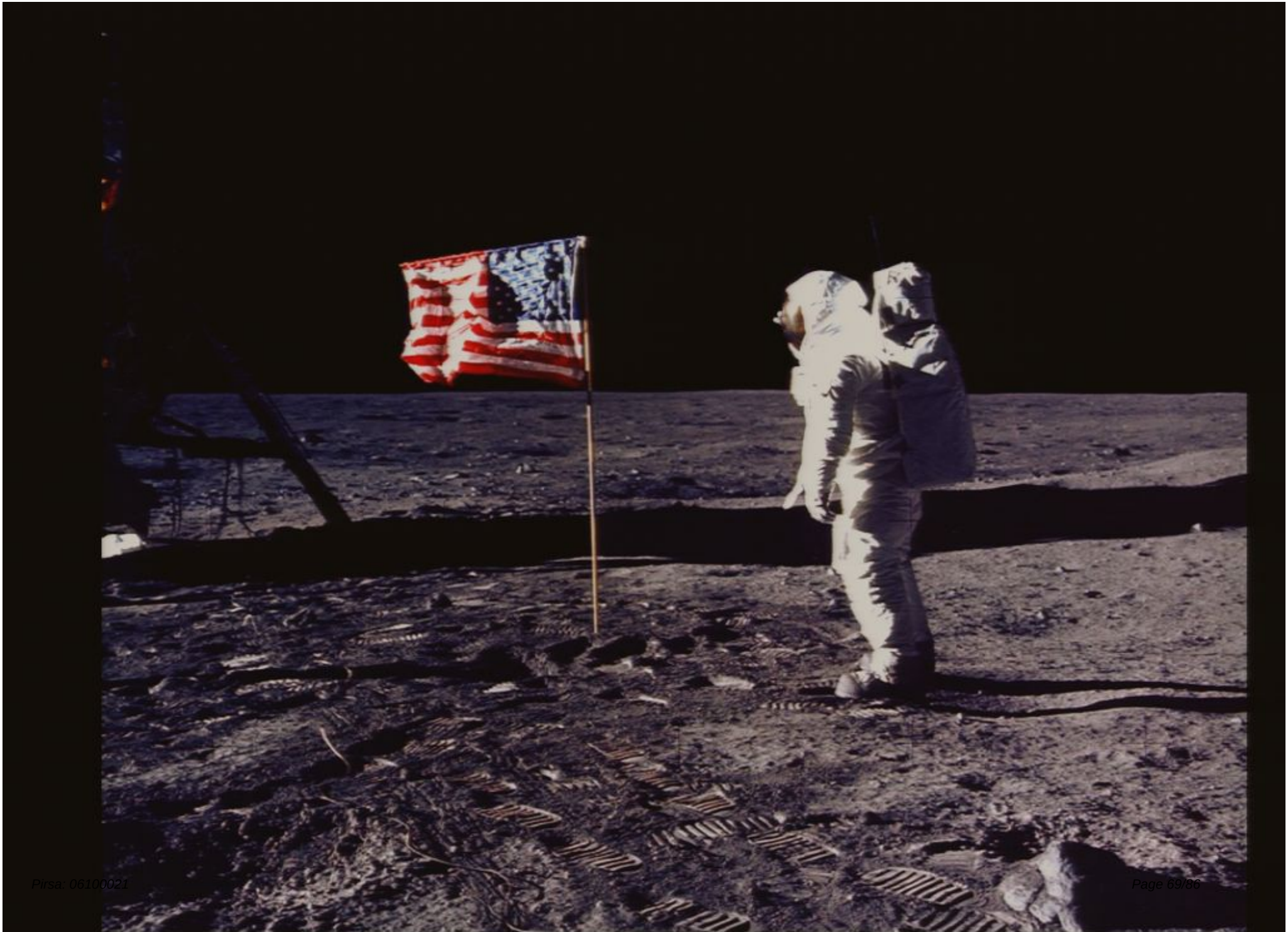
Todays accuracy:

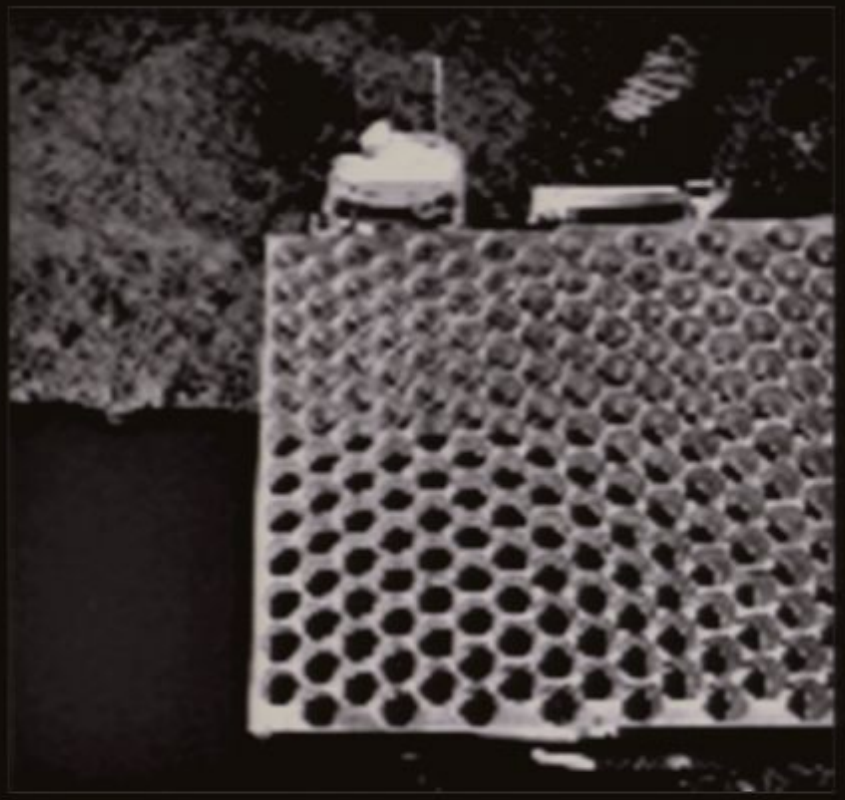
$$\sigma_{\phi} = 2.4 \times 10^{-11}$$

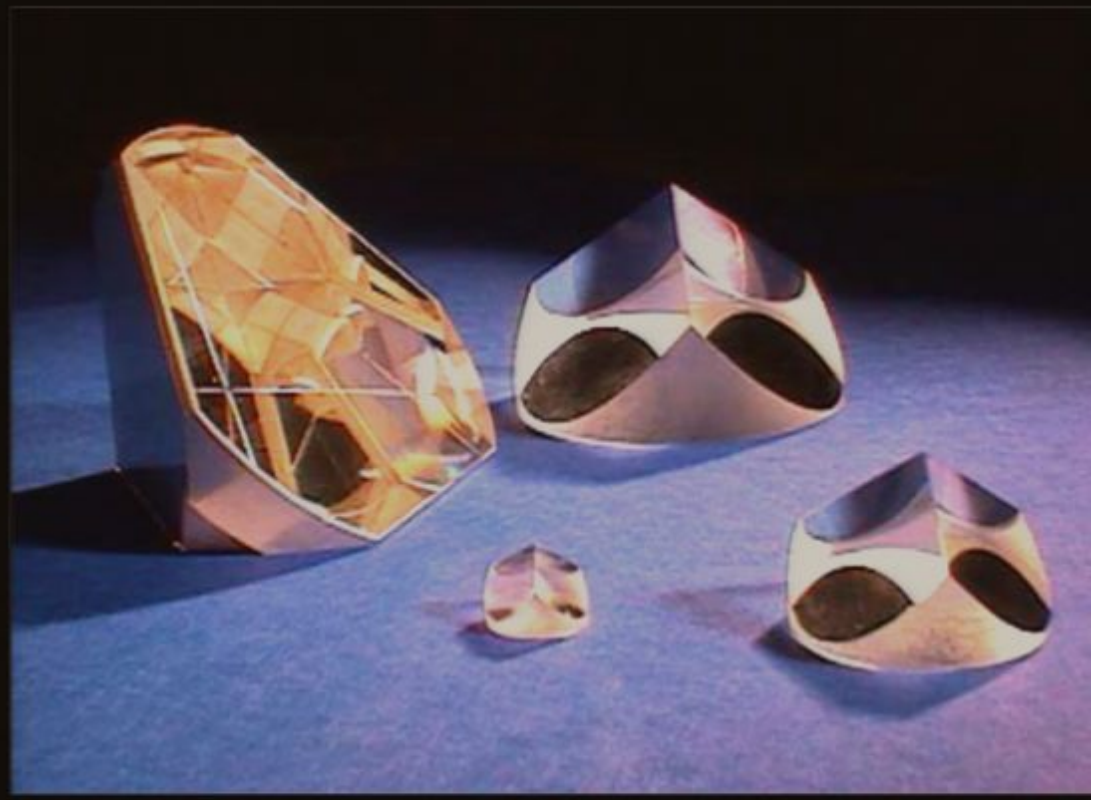
10-fold improvement is expected











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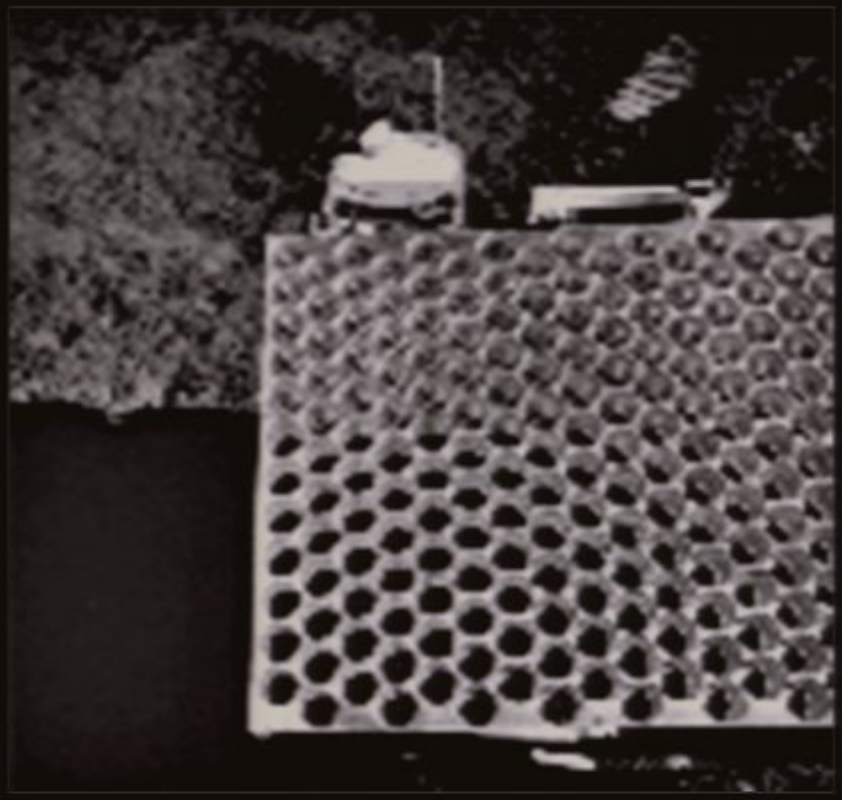
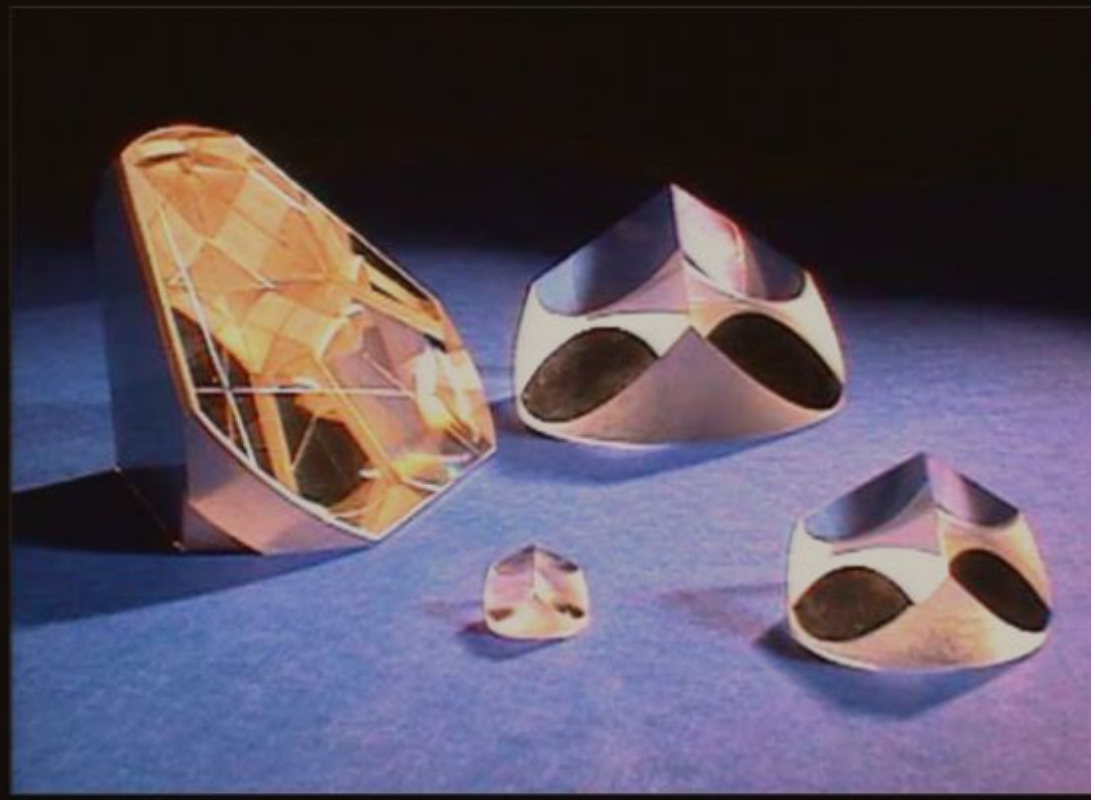
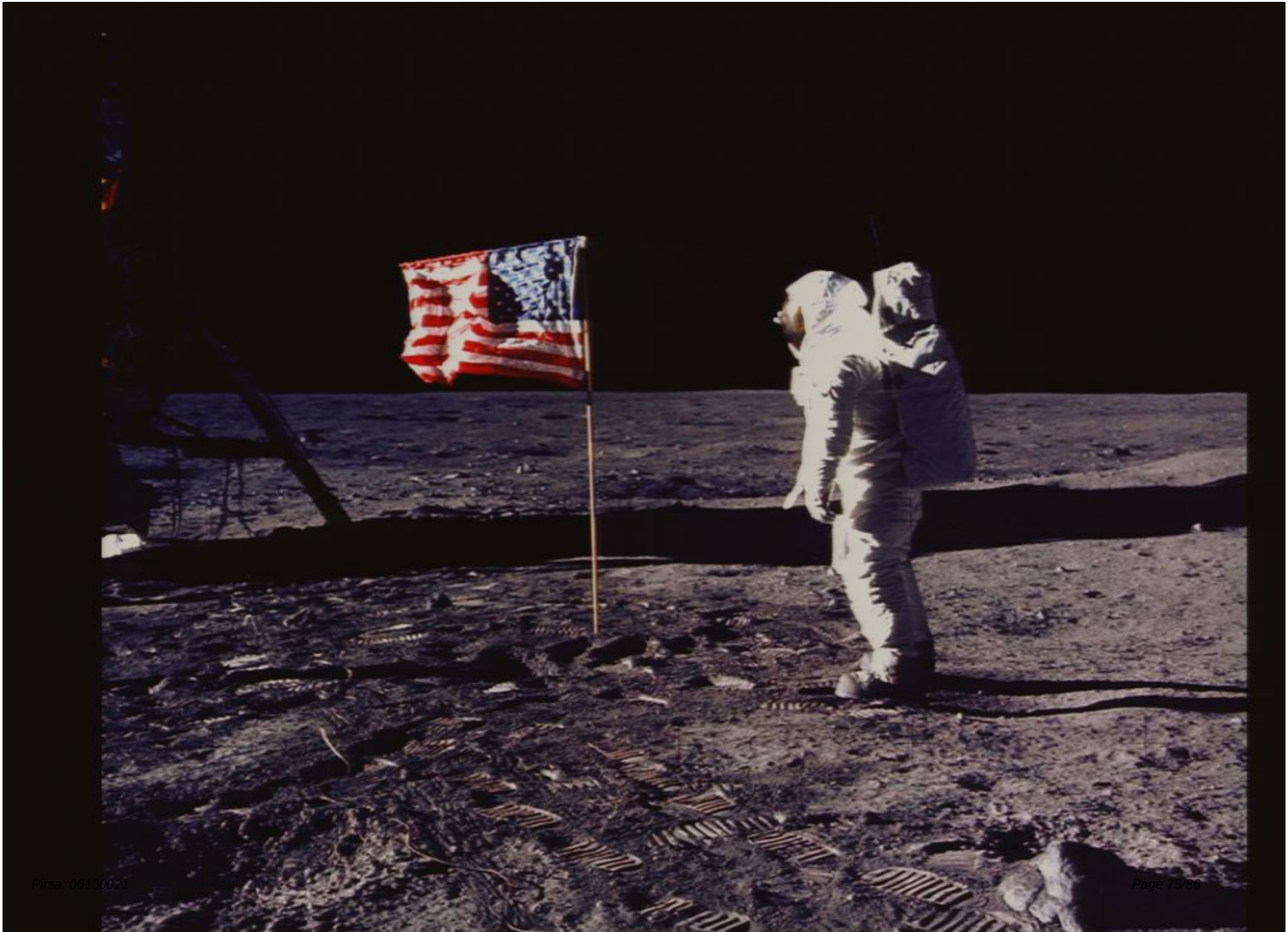
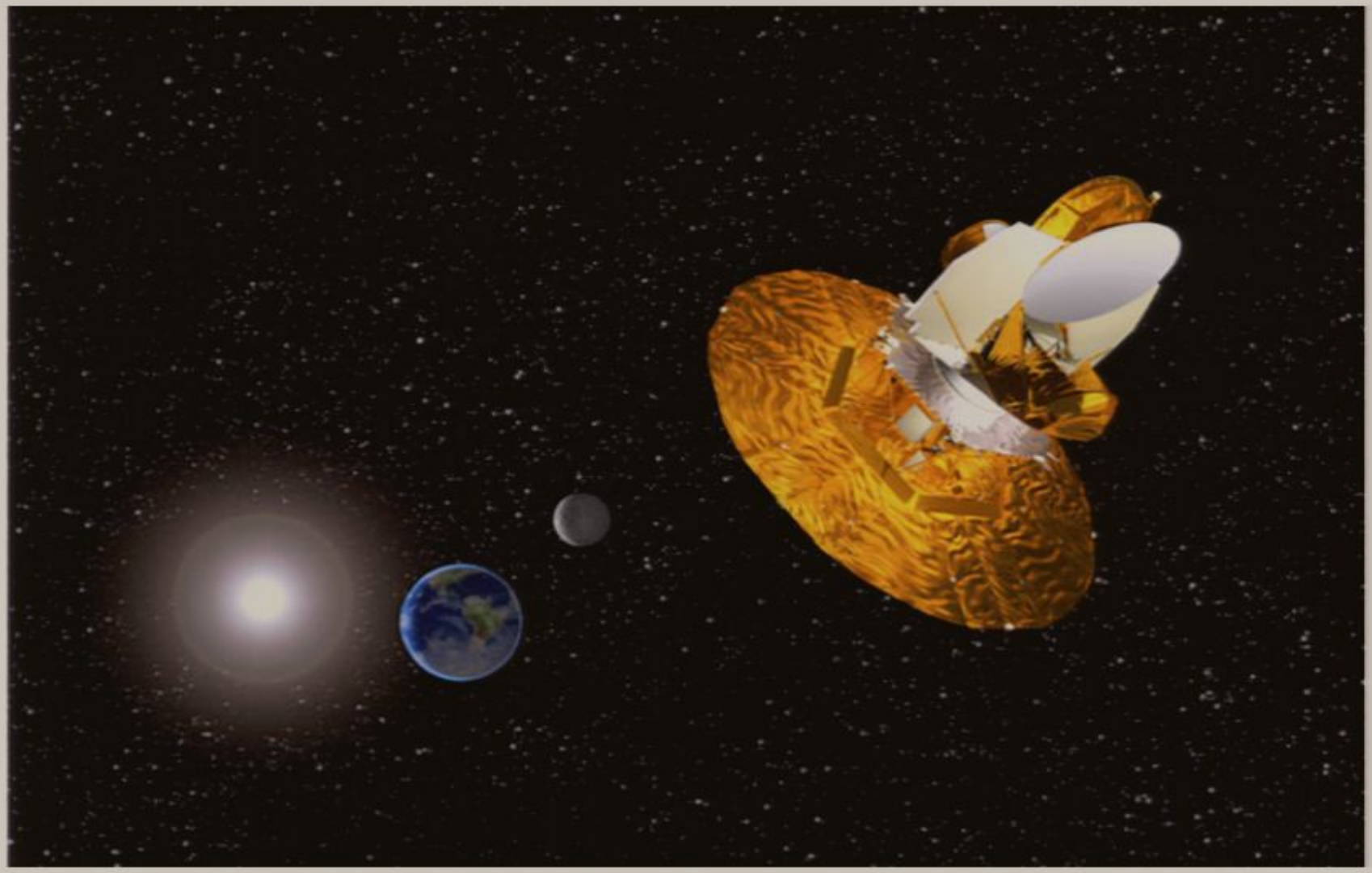
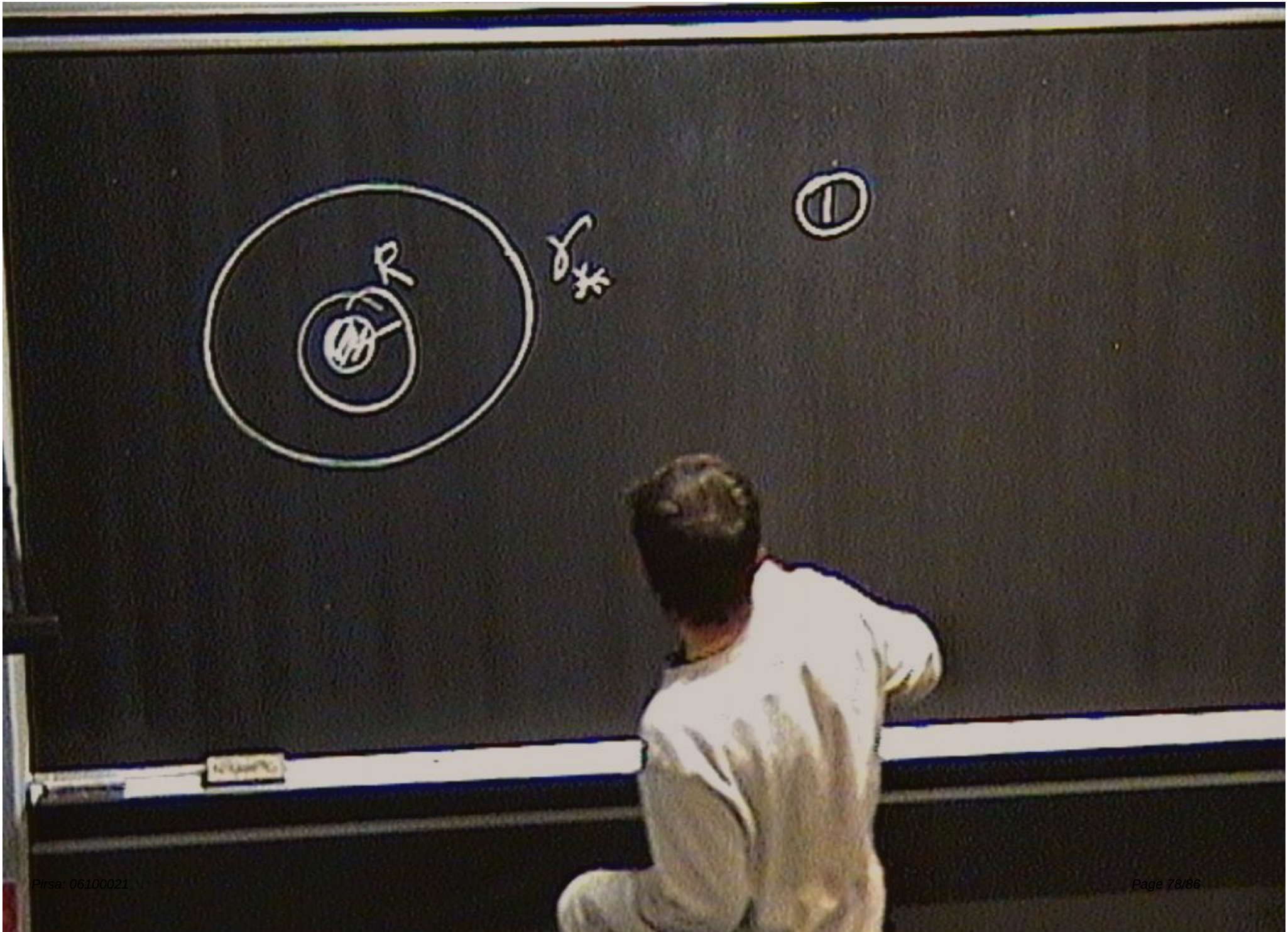
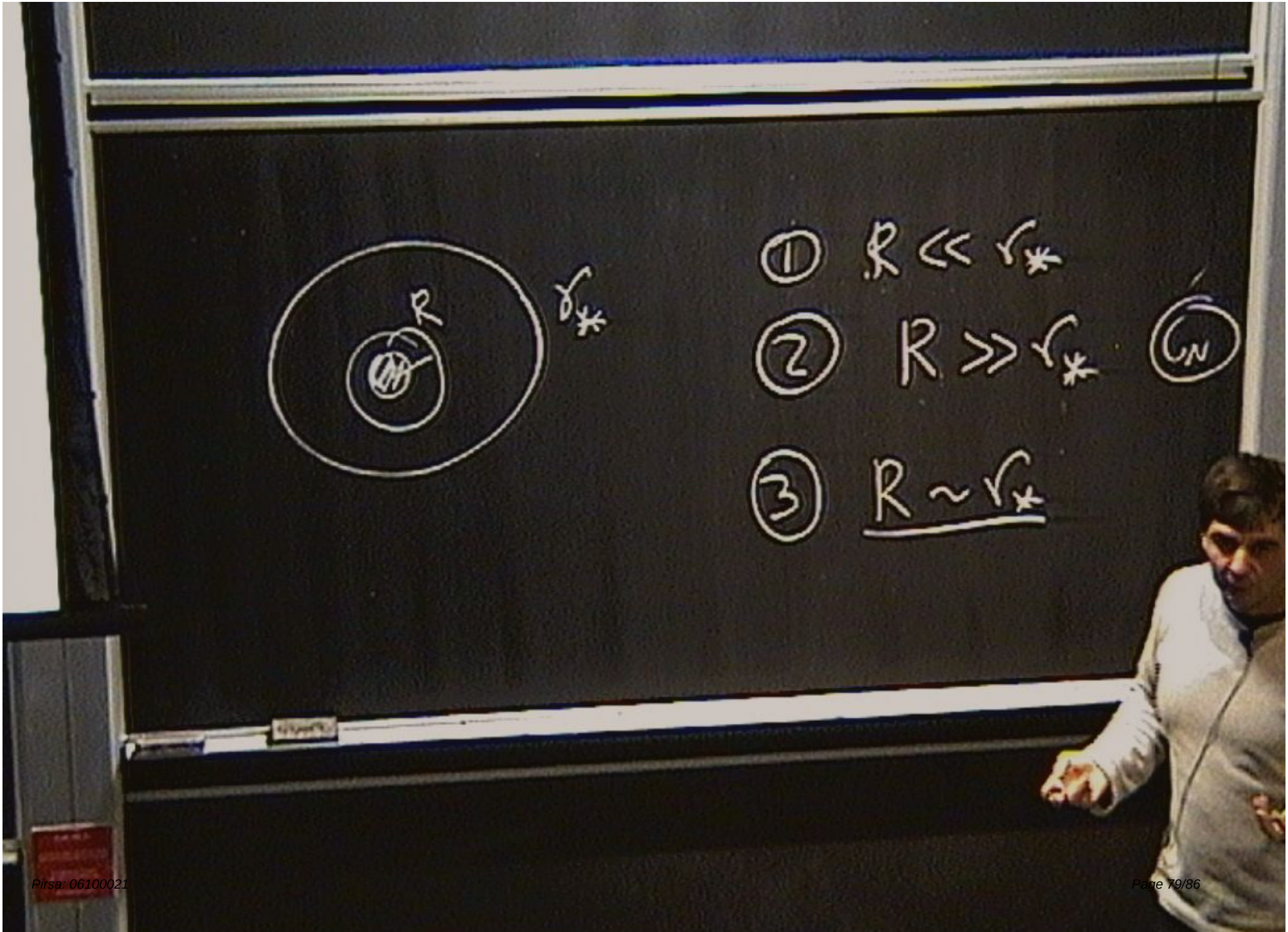


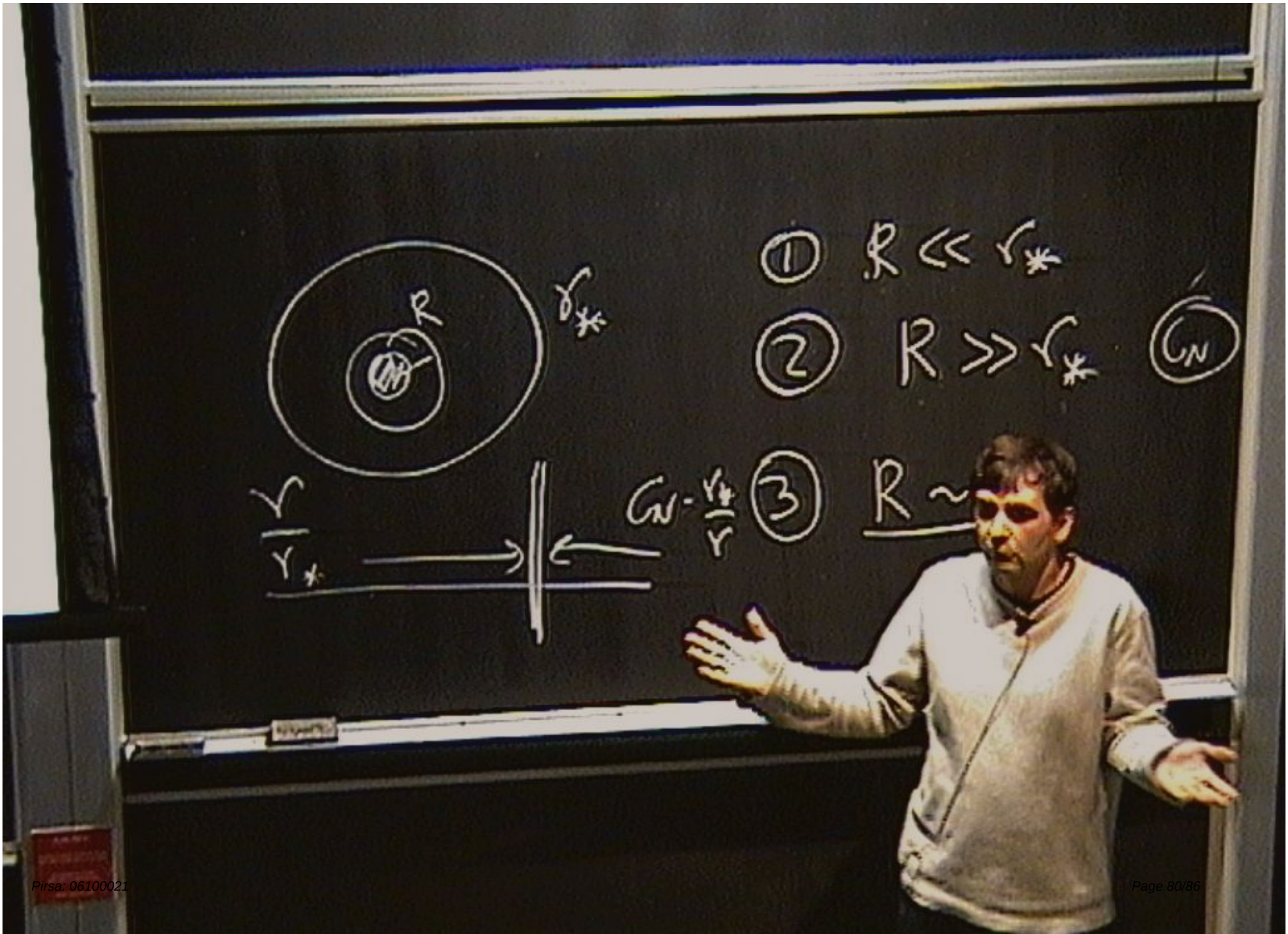


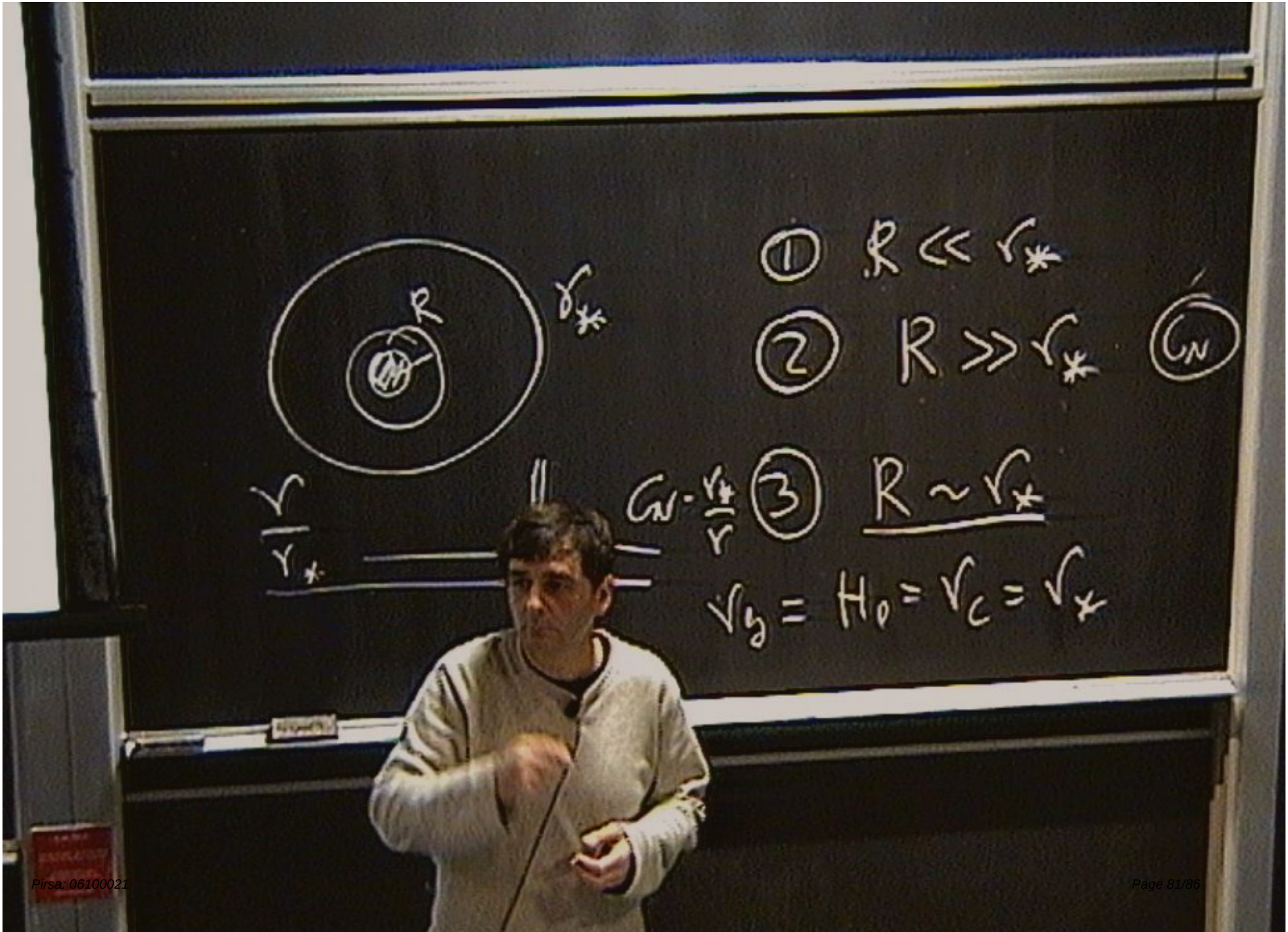





R
γ_*
1

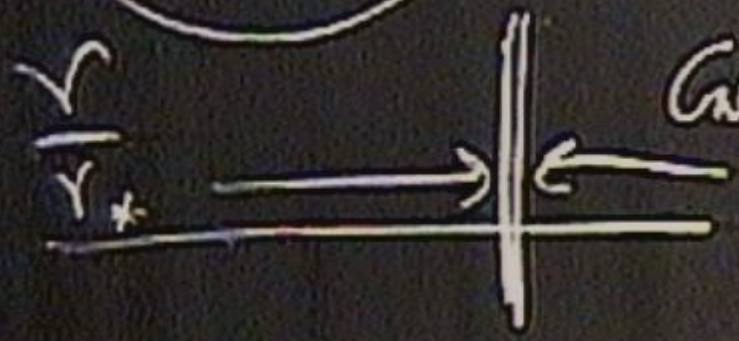

R
r_*
① $R \ll r_*$
② $R \gg r_*$
③ $R \sim r_*$


R
r_*
① $R \ll r_*$
② $R \gg r_*$ G_N
③ $R \sim$
$G_N \cdot \frac{r}{r_*}$
$\frac{r}{r_*}$


R
r_*
① $R \ll r_*$
② $R \gg r_*$
G_N
$\frac{r}{r_*}$
$G_N \cdot \frac{r_*}{r}$
③ $R \sim r_*$
$v_g = H_0 = r_c = r_*$

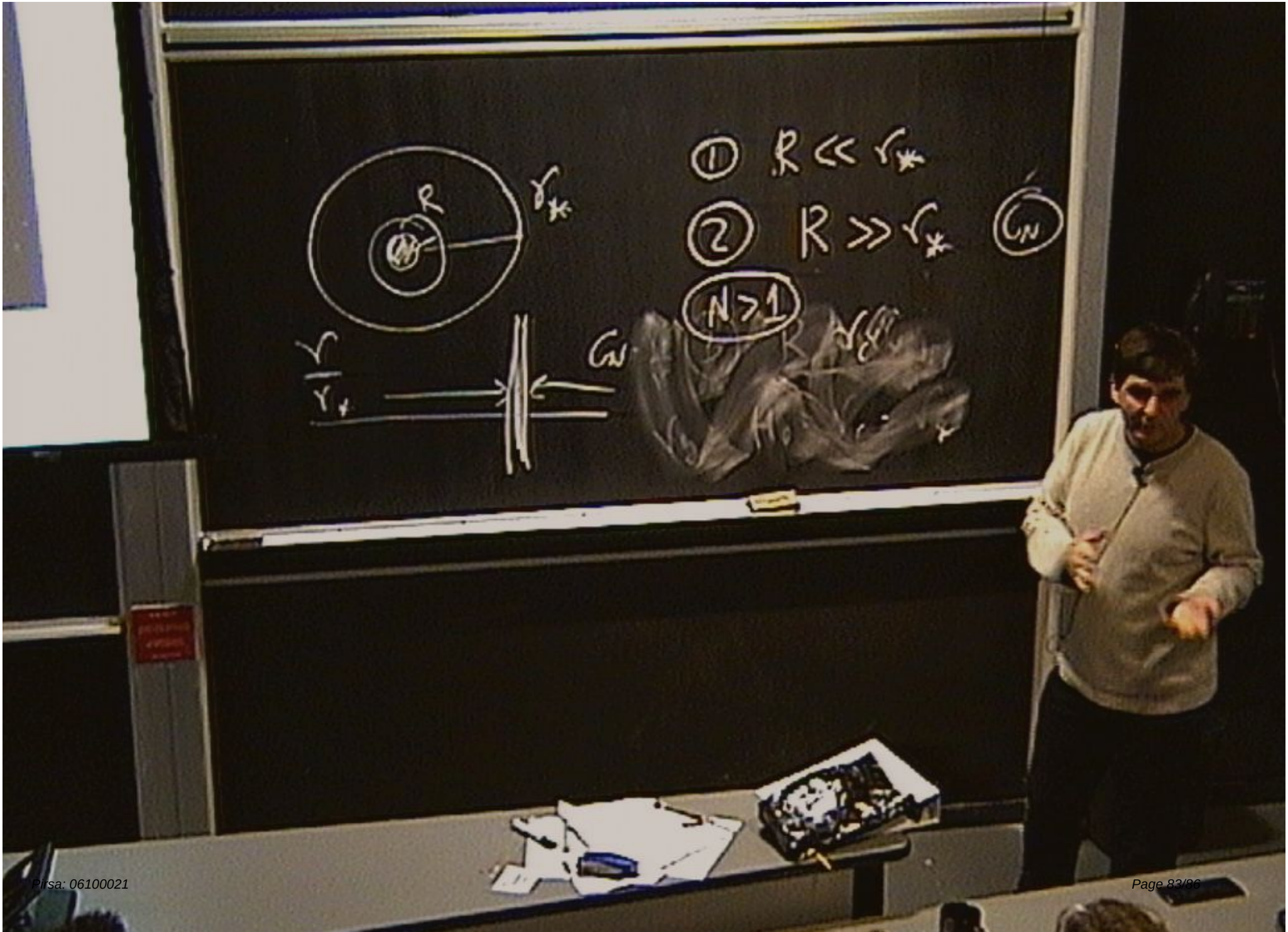
① $R \ll r_*$

② $R \gg r_*$ G_N

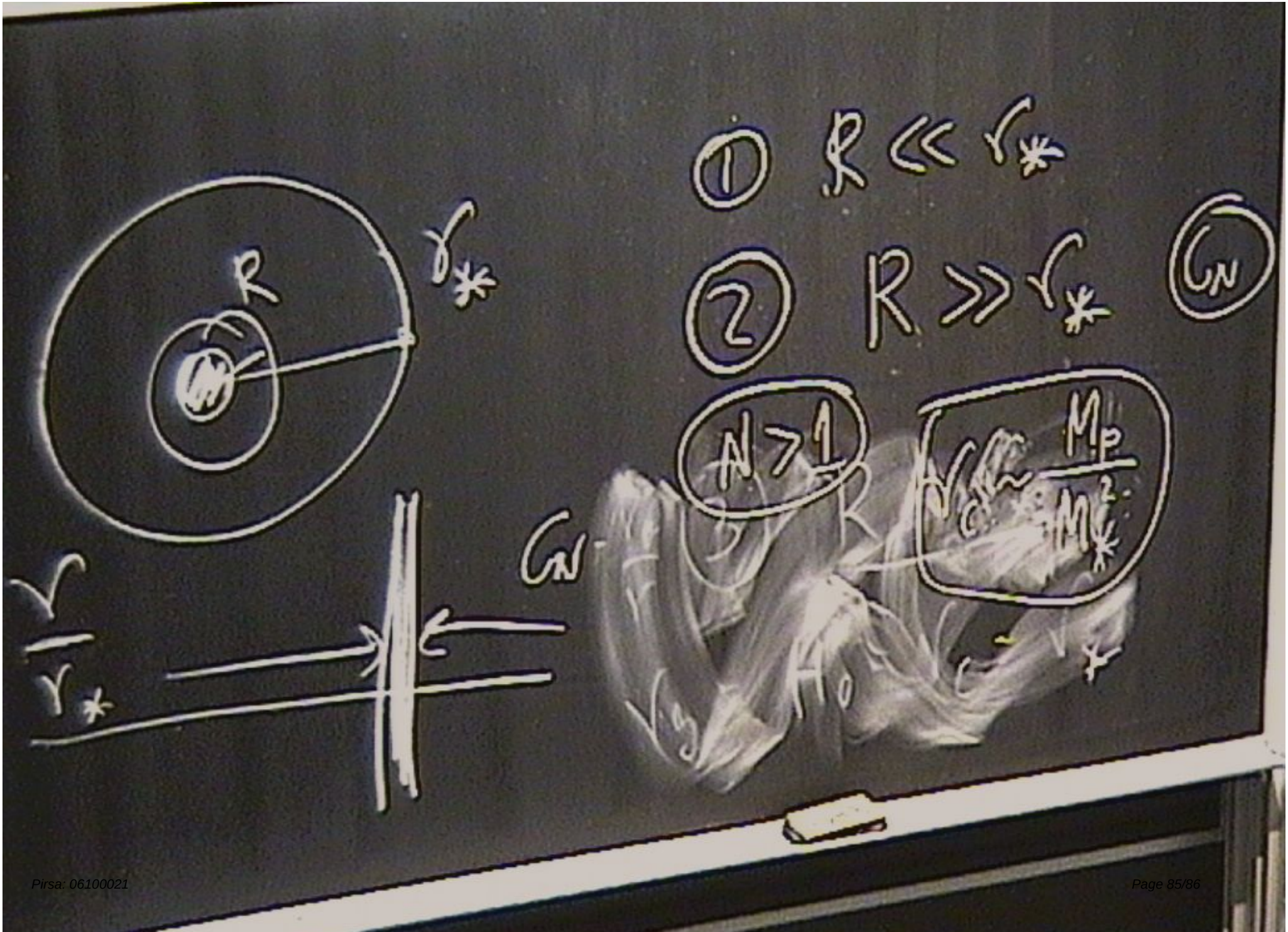


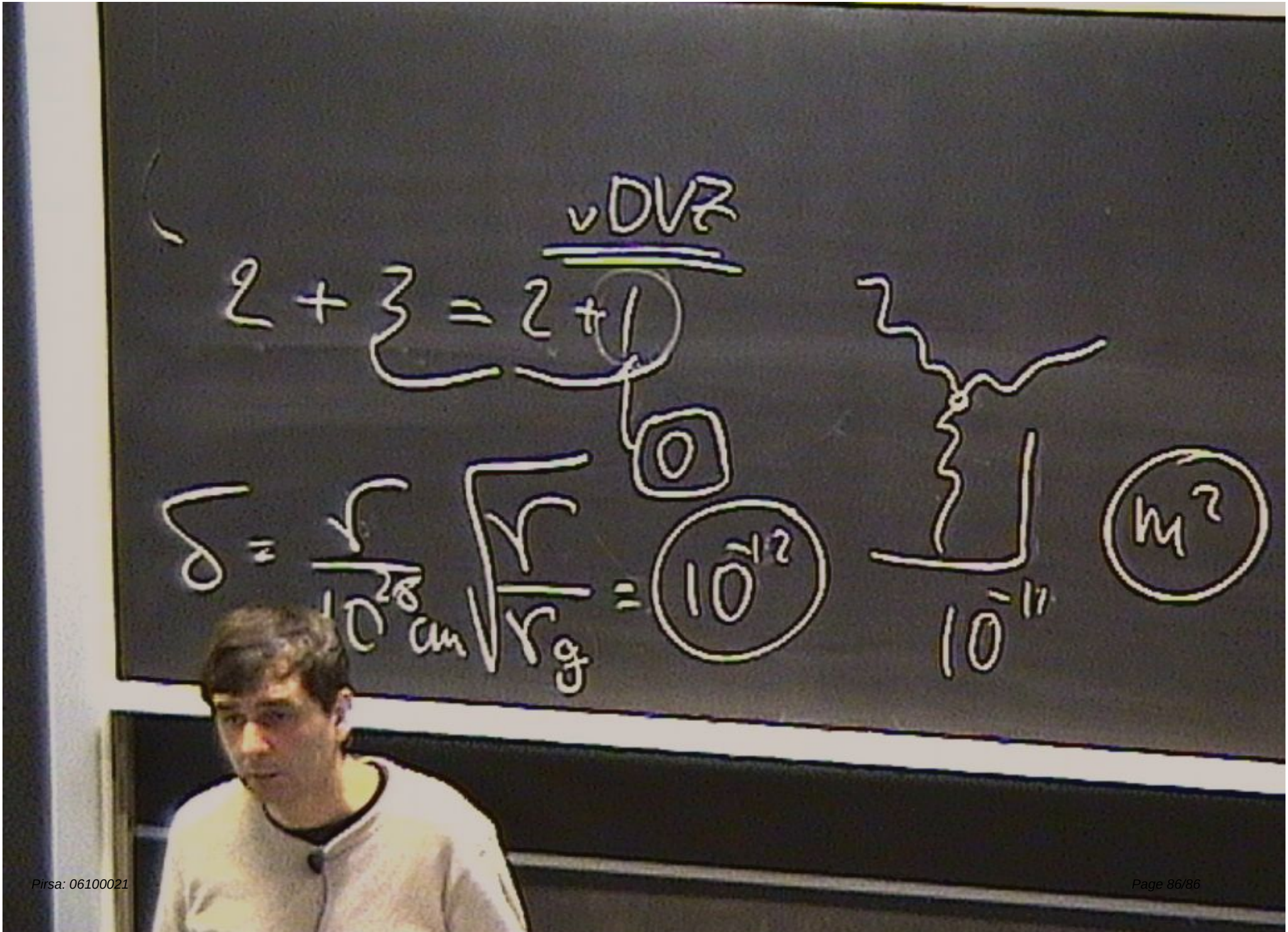
③ $R \sim r_*$

$v_g = H_0 = r_c = r_*$


R
① R << r*
② R >> r*
N>1

R
r_*
① $R \ll r_*$
② $R \gg r_*$
GN
$N > 1$
M
GN
r_*


① R ≪ r*
② R ≫ r*
GN
R
r*
N > 1
Mp
M*
GN
r
r*


vDVZ
2 + ξ = 2 + 1
0
δ = r / 10^28 cm √(r / r_g) = 10^12
10^-17
M^2