Title: Black Hole & Holography - Class 1

Date: Mar 15, 2007 10:30 AM

URL: http://pirsa.org/07030028

Abstract: <div id="Cleaner">Distinguished theoretical physicist Leonard Susskind, Professor of Physics at Stanford, will give a series of lectures on Black Holes and Holography at Perimeter Institute in Waterloo. This mini-course is open to all university professors and students.

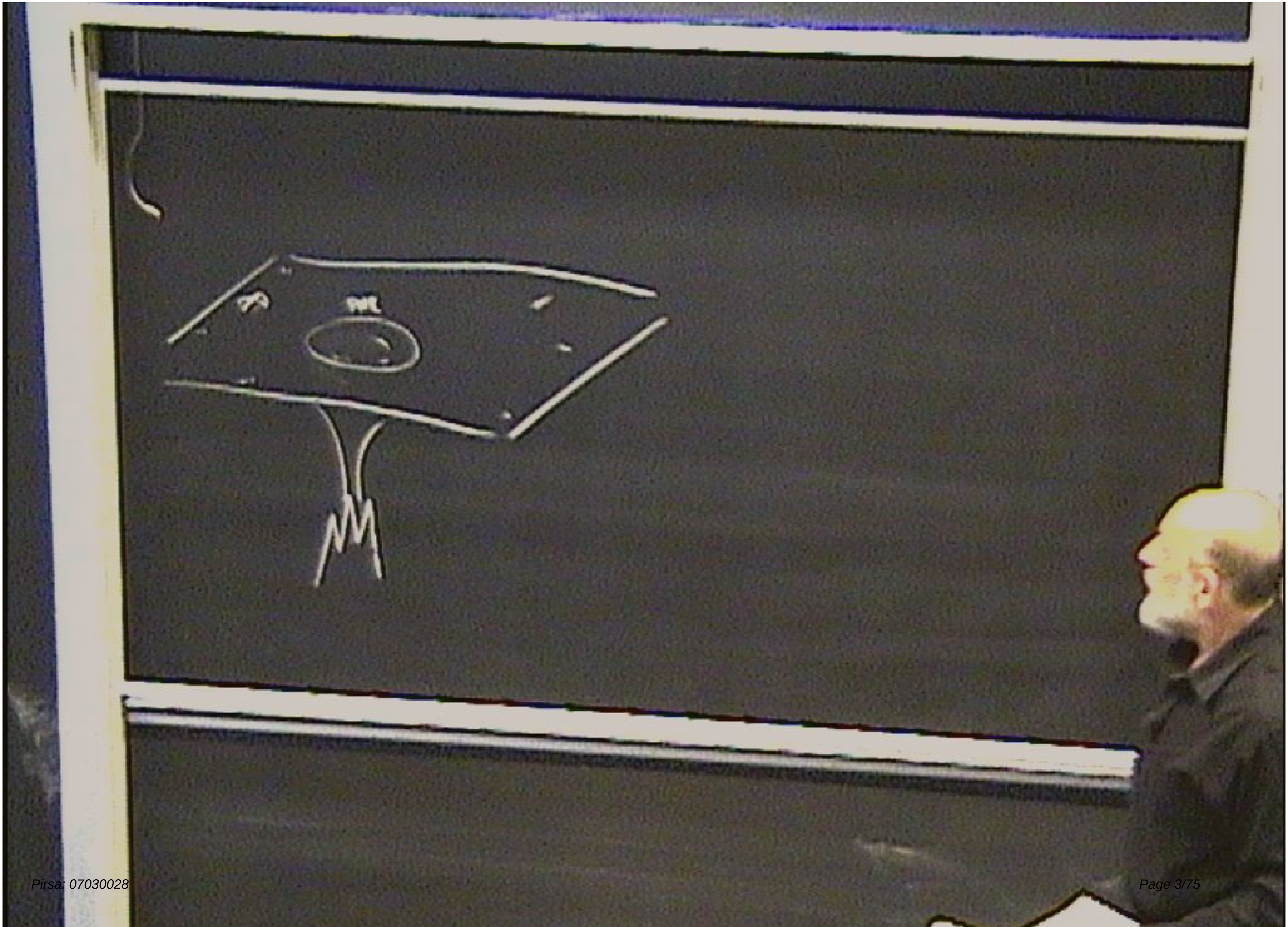
M R

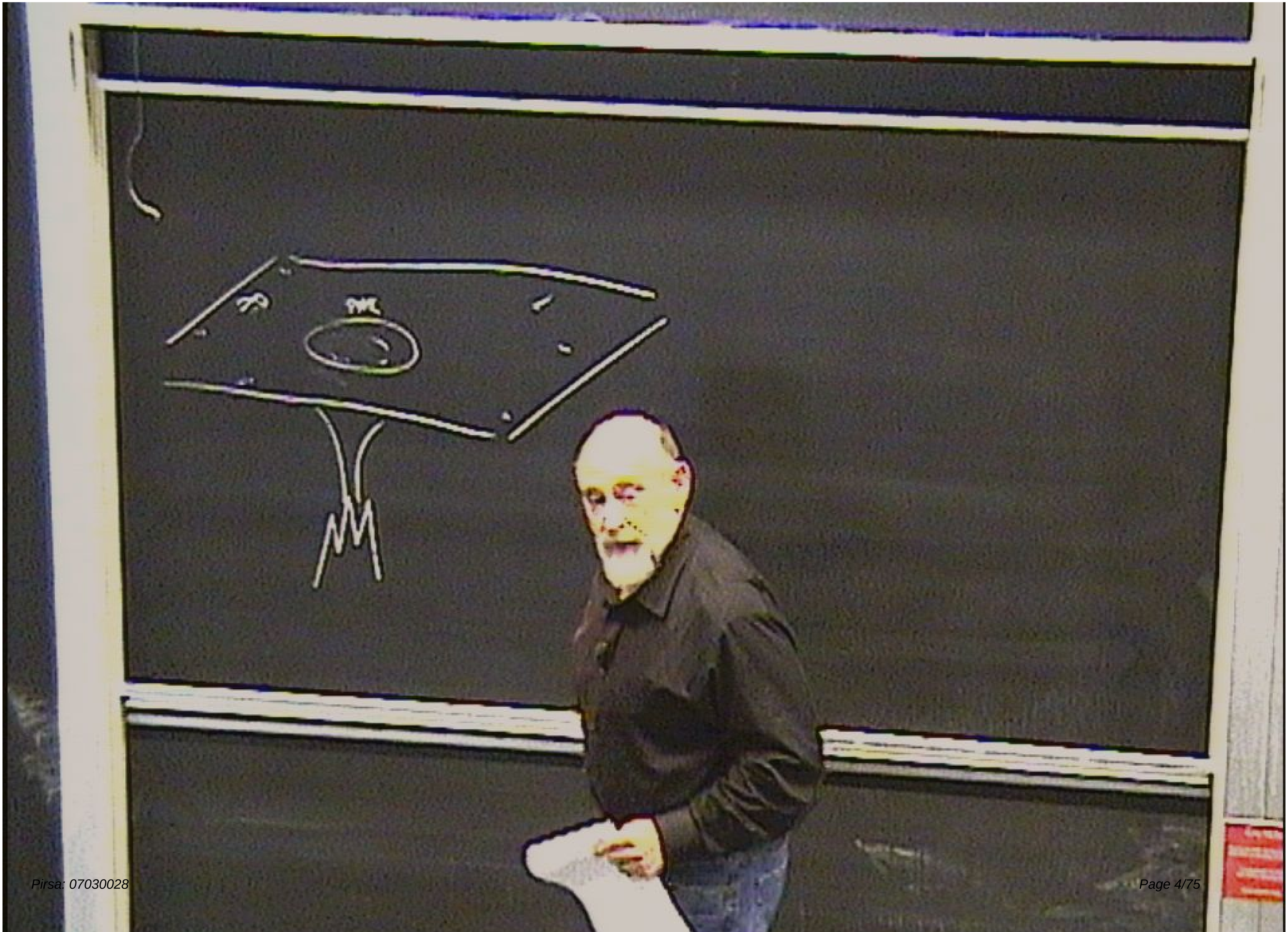
R

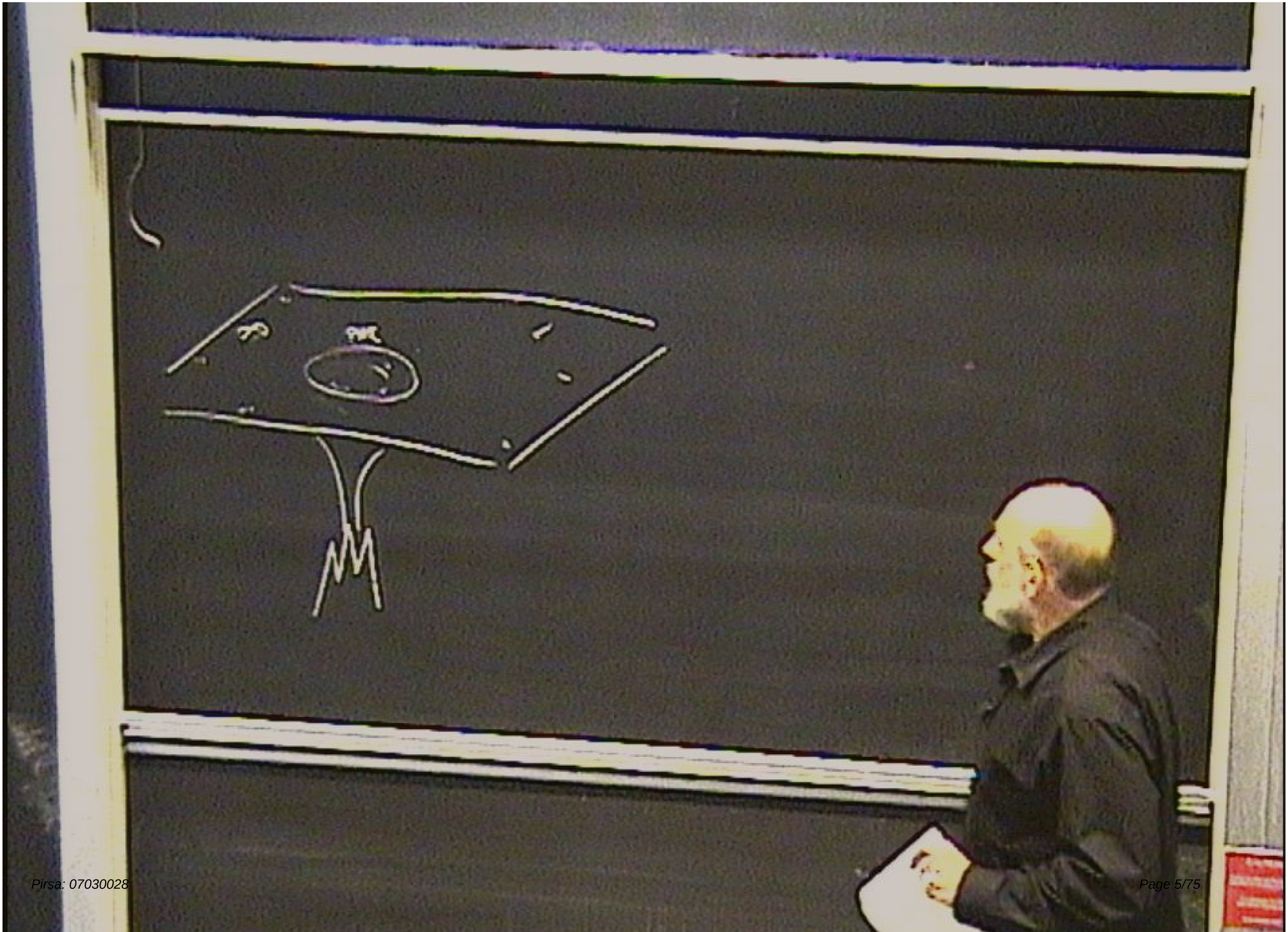
$$R_s = \frac{2MG}{c^2} \longrightarrow 3\,\text{KM}$$

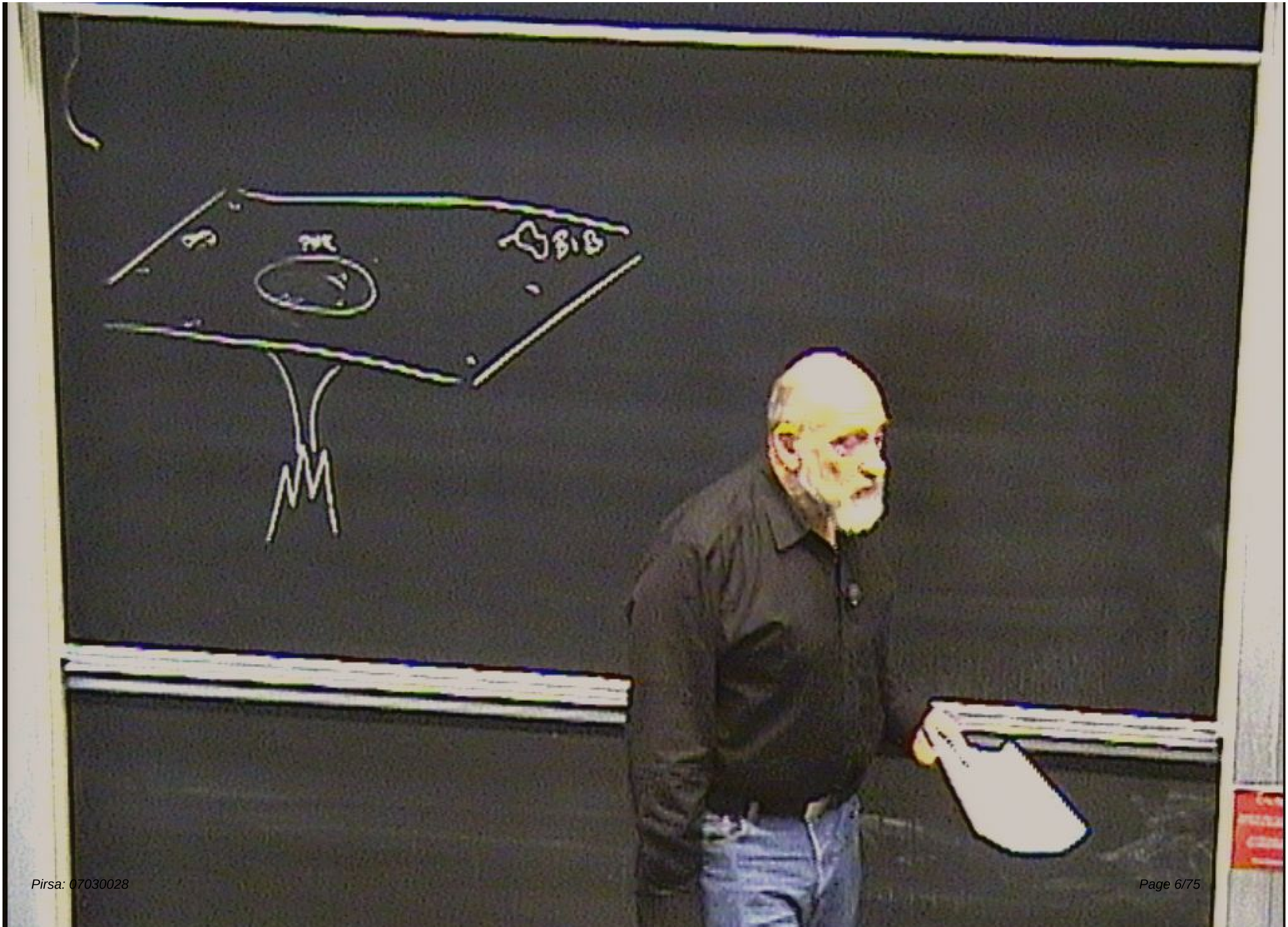
$$A = \frac{GM}{r^2}$$

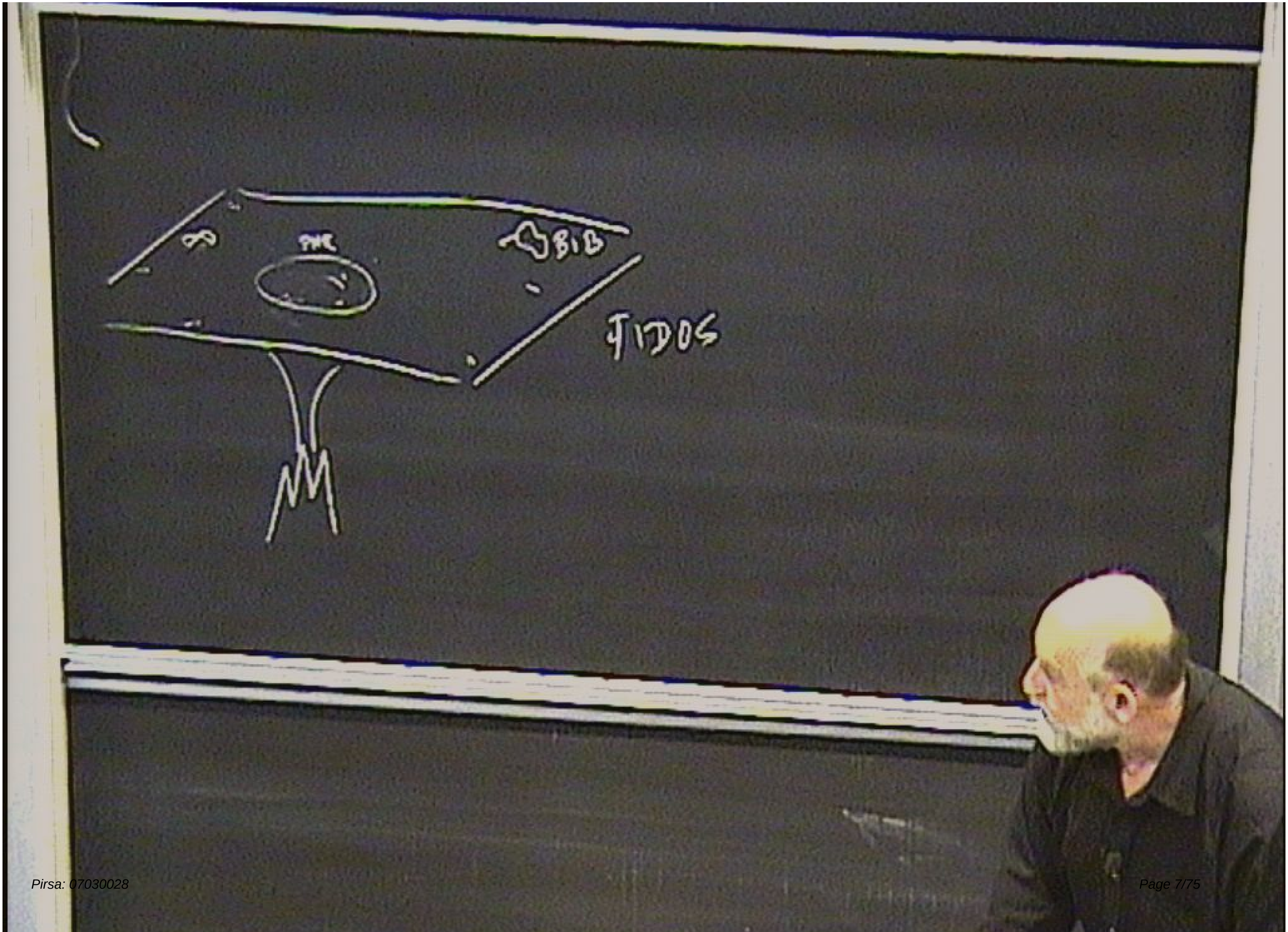
$$\frac{\partial A}{\partial r} = \frac{GM}{R_s}\,\frac{1}{R_s^2} = \frac{c^2}{R_s^2}\,\frac{10^{17}}{10^{8}} \sim 10^{1}$$

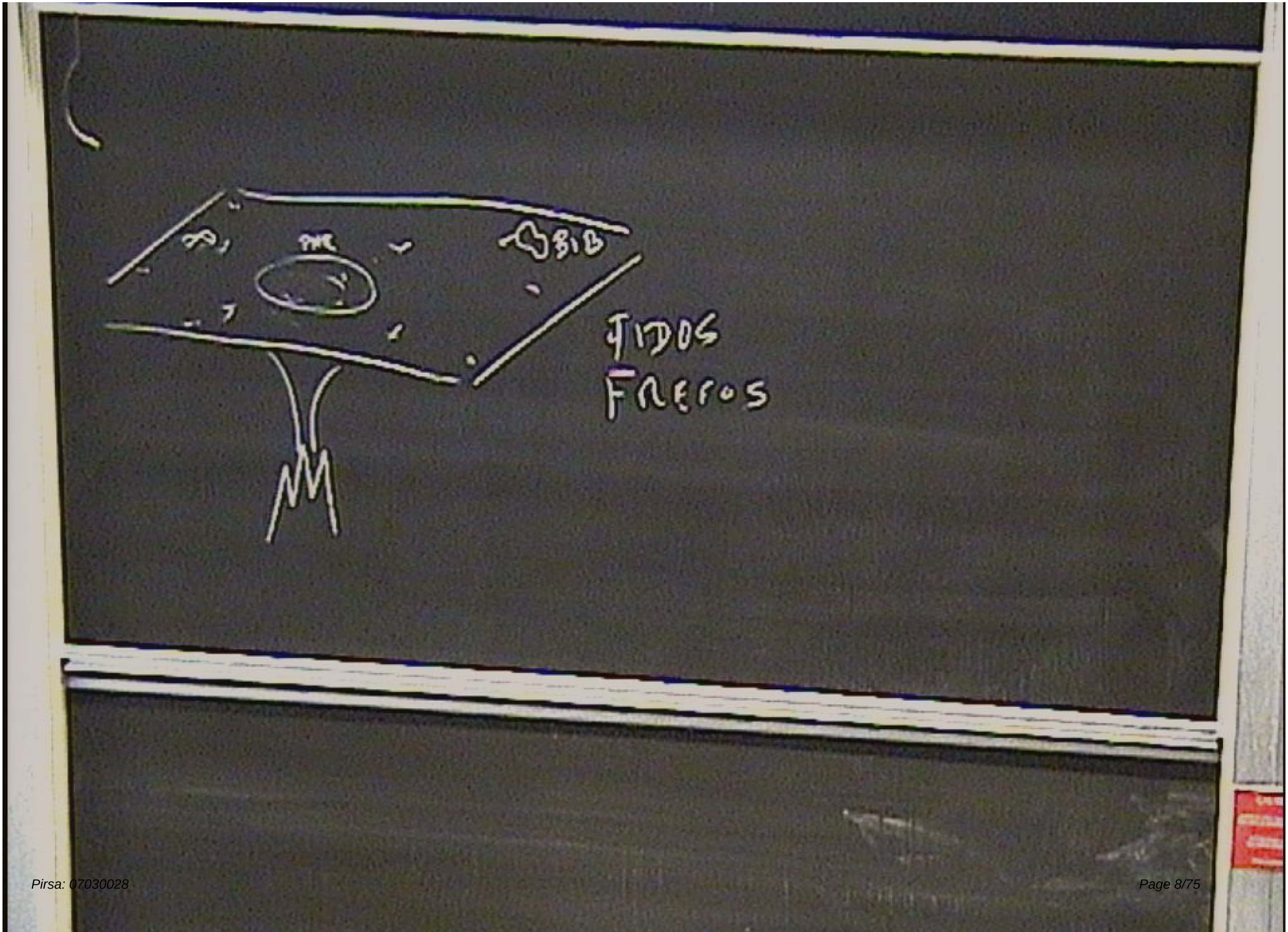


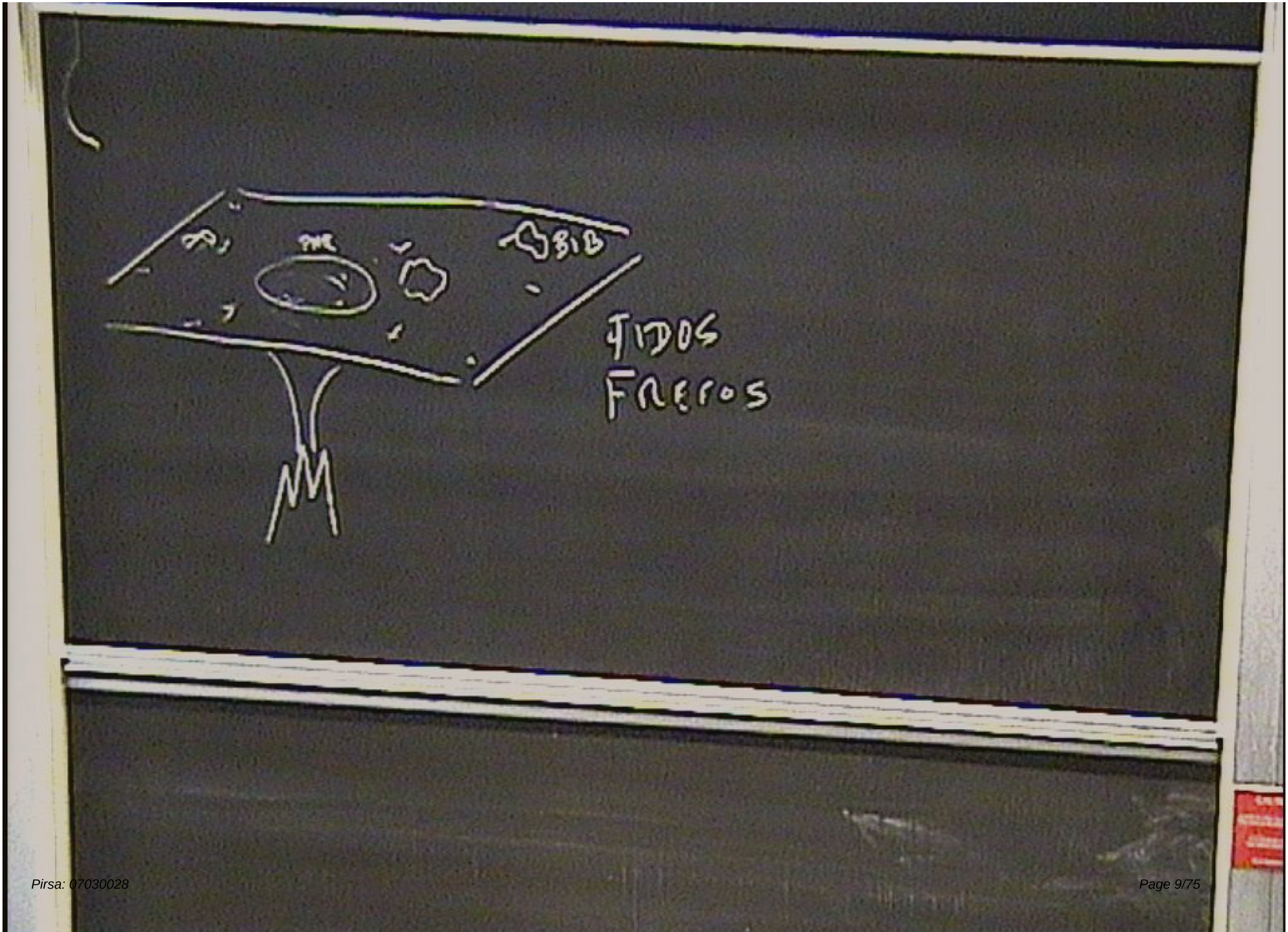


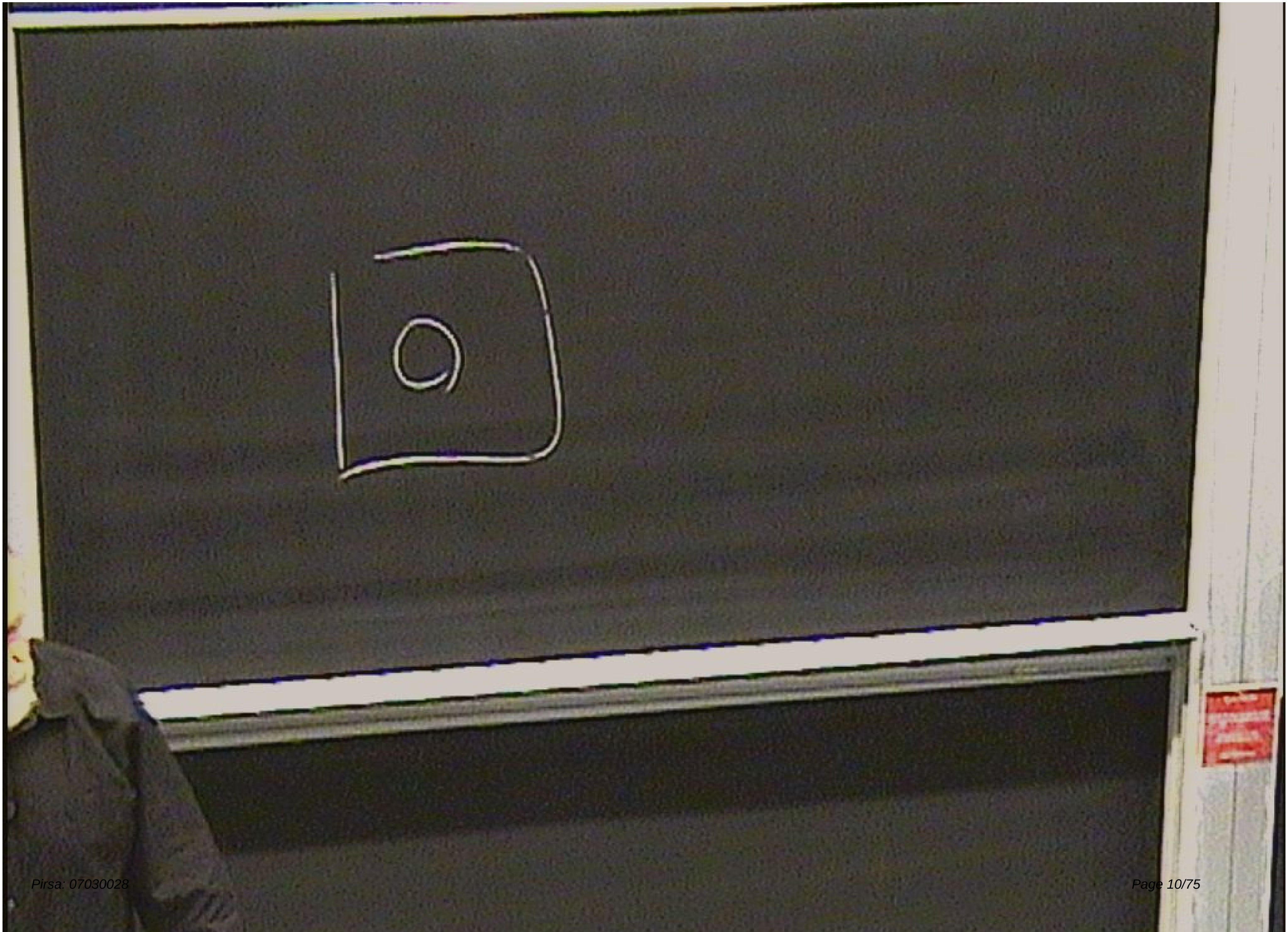


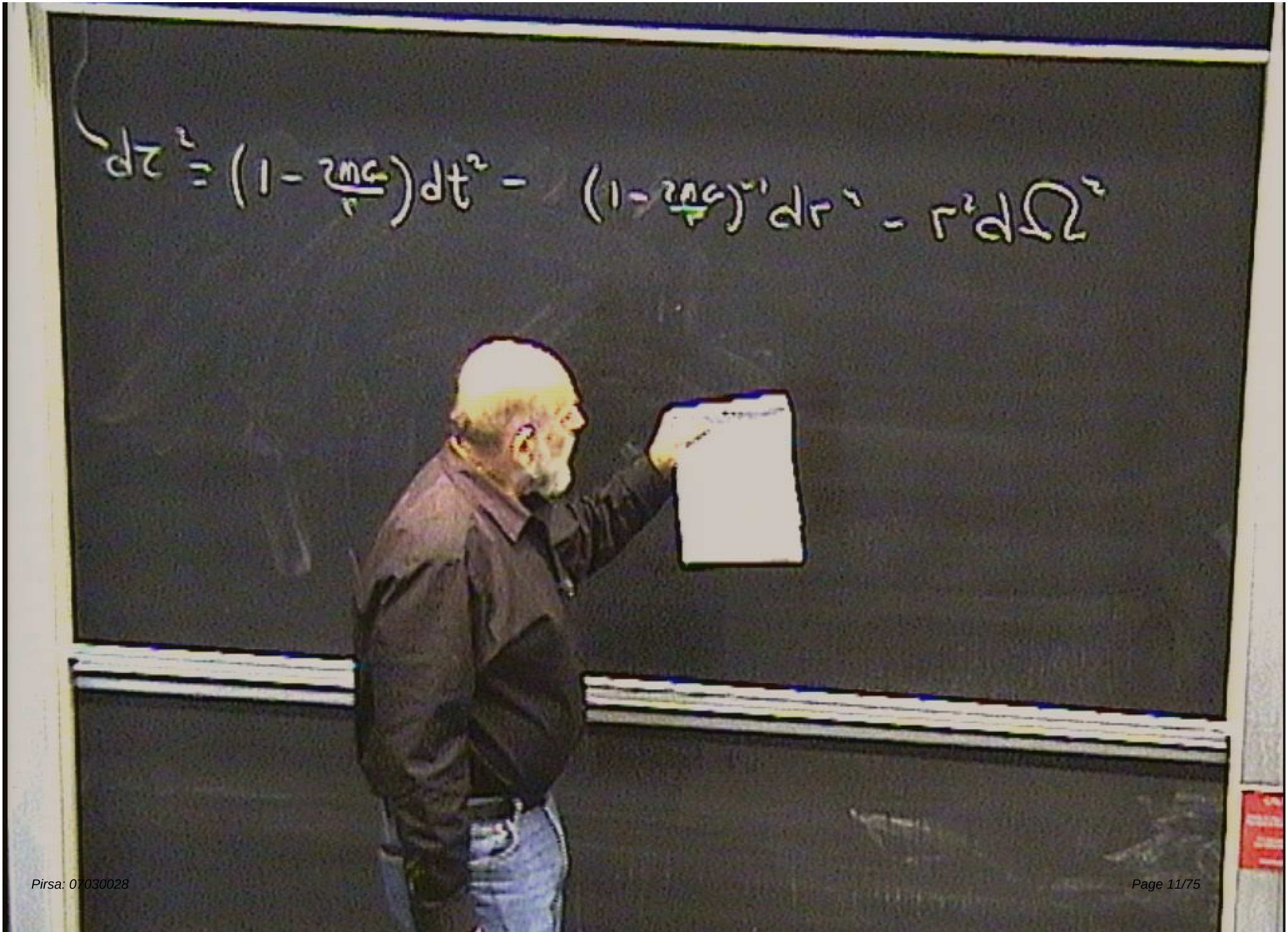


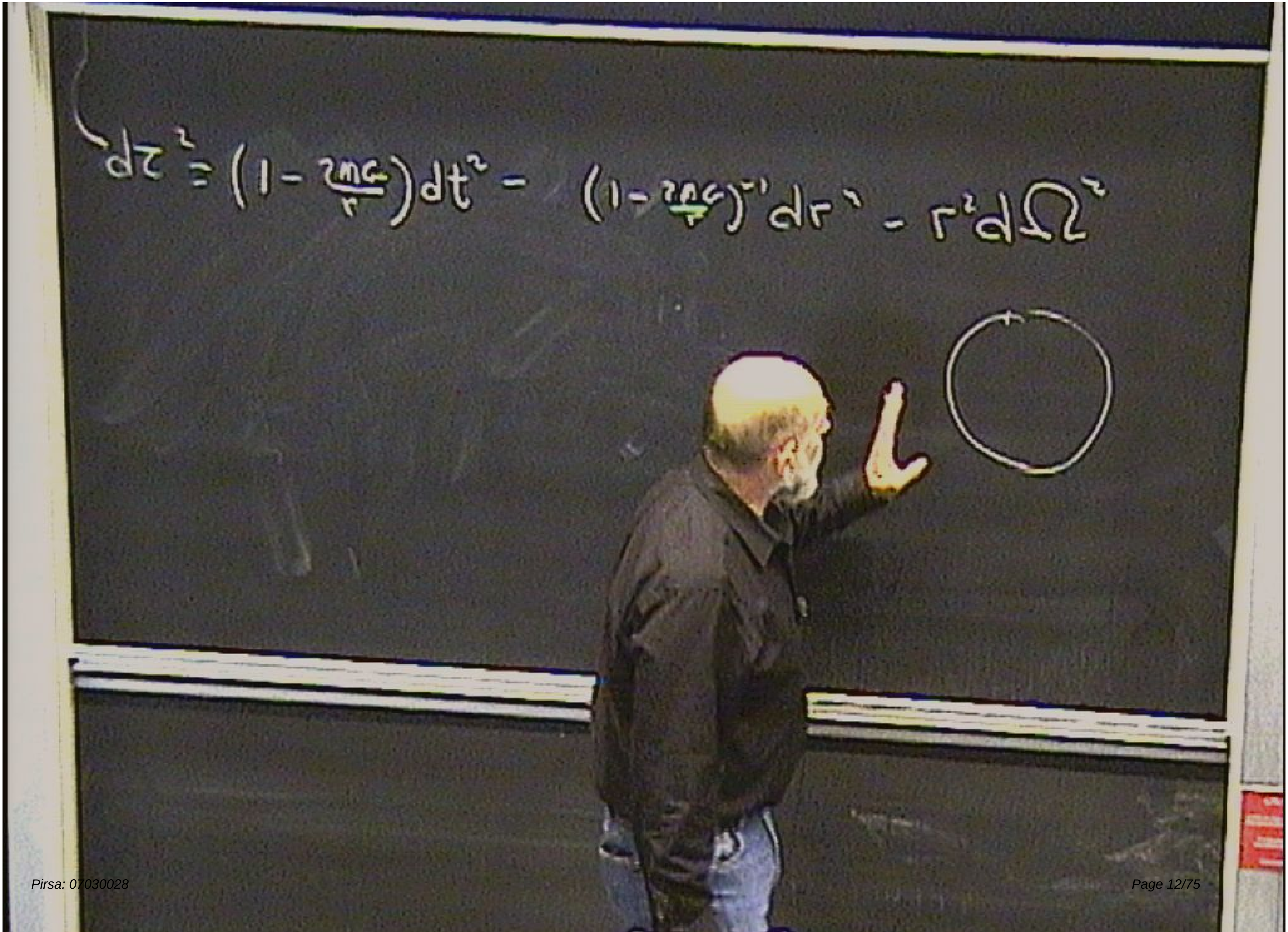









$d\tau^2 = \left(1 - \frac{2mG}{r}\right) dt^2 - \left(1 - \frac{2mG}{r}\right)^{-1} dr^2 - r^2 d\Omega^2$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$$d\tau^2 = \left(1 - \frac{2mG}{r}\right)dt^2 - \left(1 - \frac{2mG}{r}\right)^{-1}dr^2 - r^2 d\Omega^2$$

Horizon: $r = 2mG = R_S$

Sing $r = 0$

$$d\tau^2 = \left(1-\frac{2mG}{r}\right)dt^2 - \left(1-\frac{2mG}{r}\right)^{-1}dr^2 - r^2 d\Omega^2$$

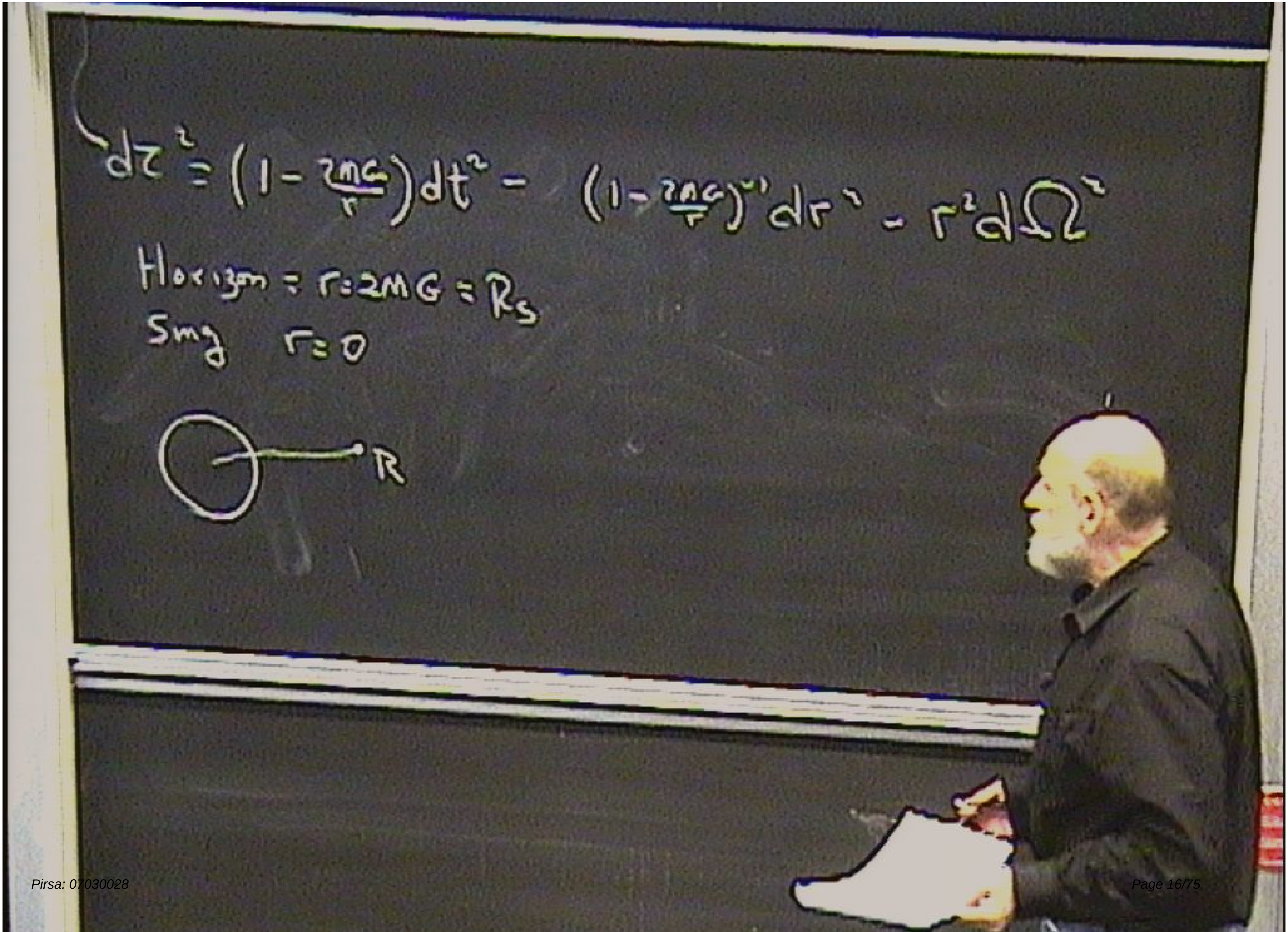
Horizon $= r = 2MG = R_s$

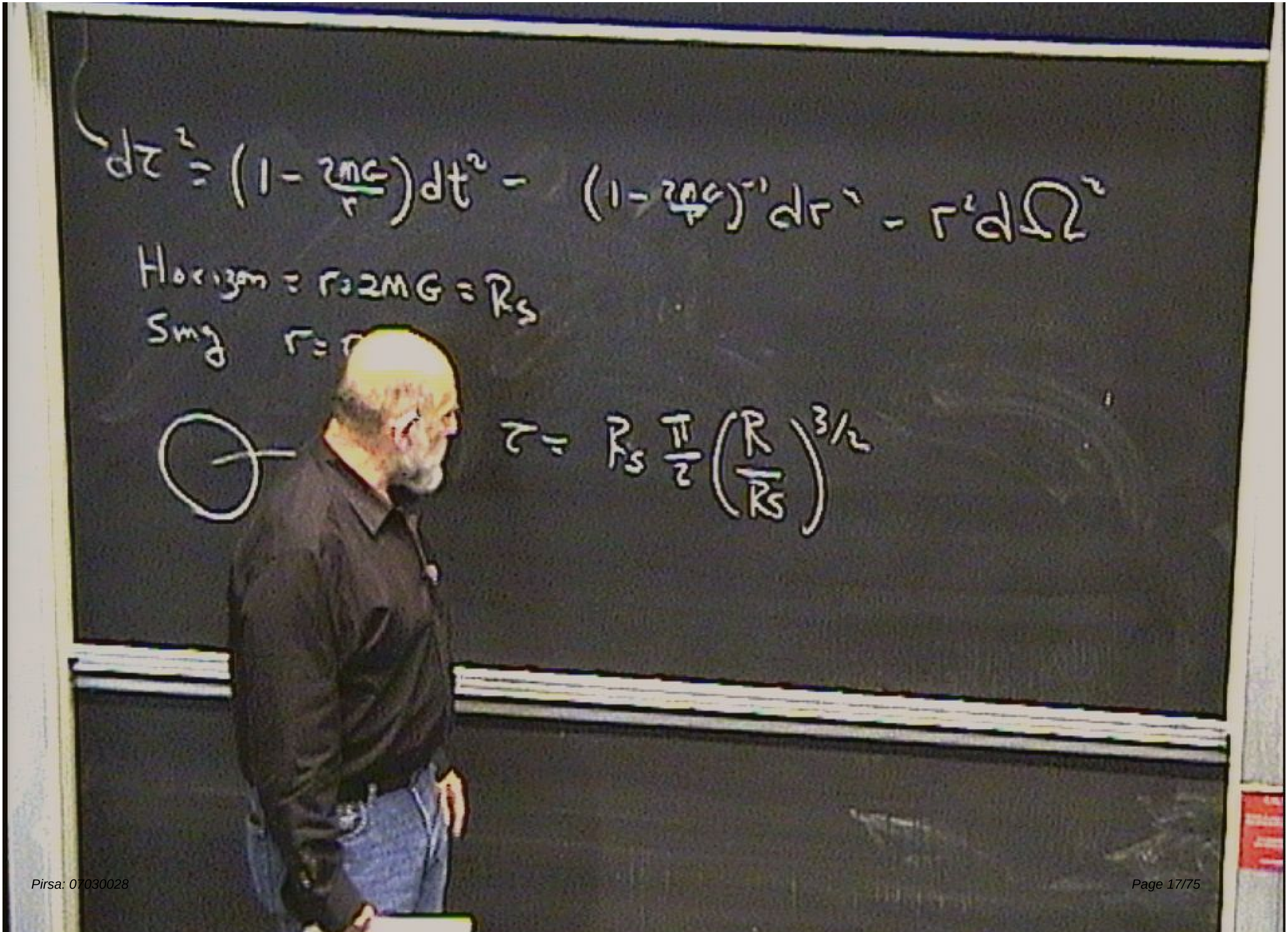
Sing $r = 0$

$$d\tau^2 = \left(1-\frac{2mG}{r}\right)dt^2 - \left(1-\frac{2mG}{r}\right)^{-1}dr^2 - r^2 d\Omega^2$$

Horizon $= r = 2mG = R_s$

Sing $r = 0$


$d\tau^2 = (1 - \frac{2mG}{r})dt^2 - (1 - \frac{2mG}{r})^{-1}dr^2 - r^2 d\Omega^2$
Horizon = r = 2MG = R_S
Sing r = 0
R

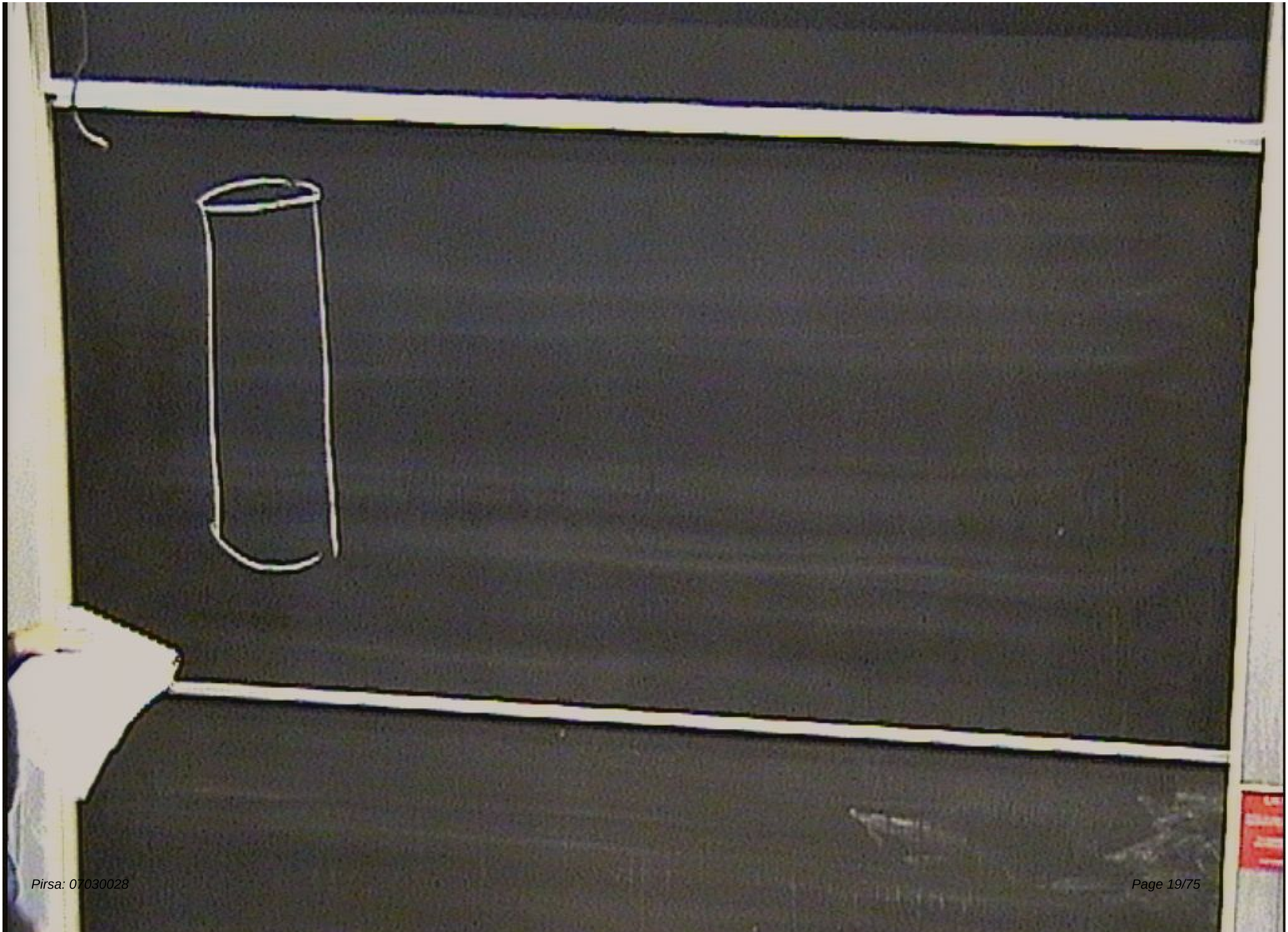

$d\tau^2 = \left(1 - \frac{2mG}{r}\right)dt^2 - \left(1 - \frac{2mG}{r}\right)^{-1}dr^2 - r^2 d\Omega^2$
Horizon = $r = 2mG = R_s$
Sing $r =$
$\tau = R_s \frac{\pi}{2}\left(\frac{R}{R_s}\right)^{3/2}$

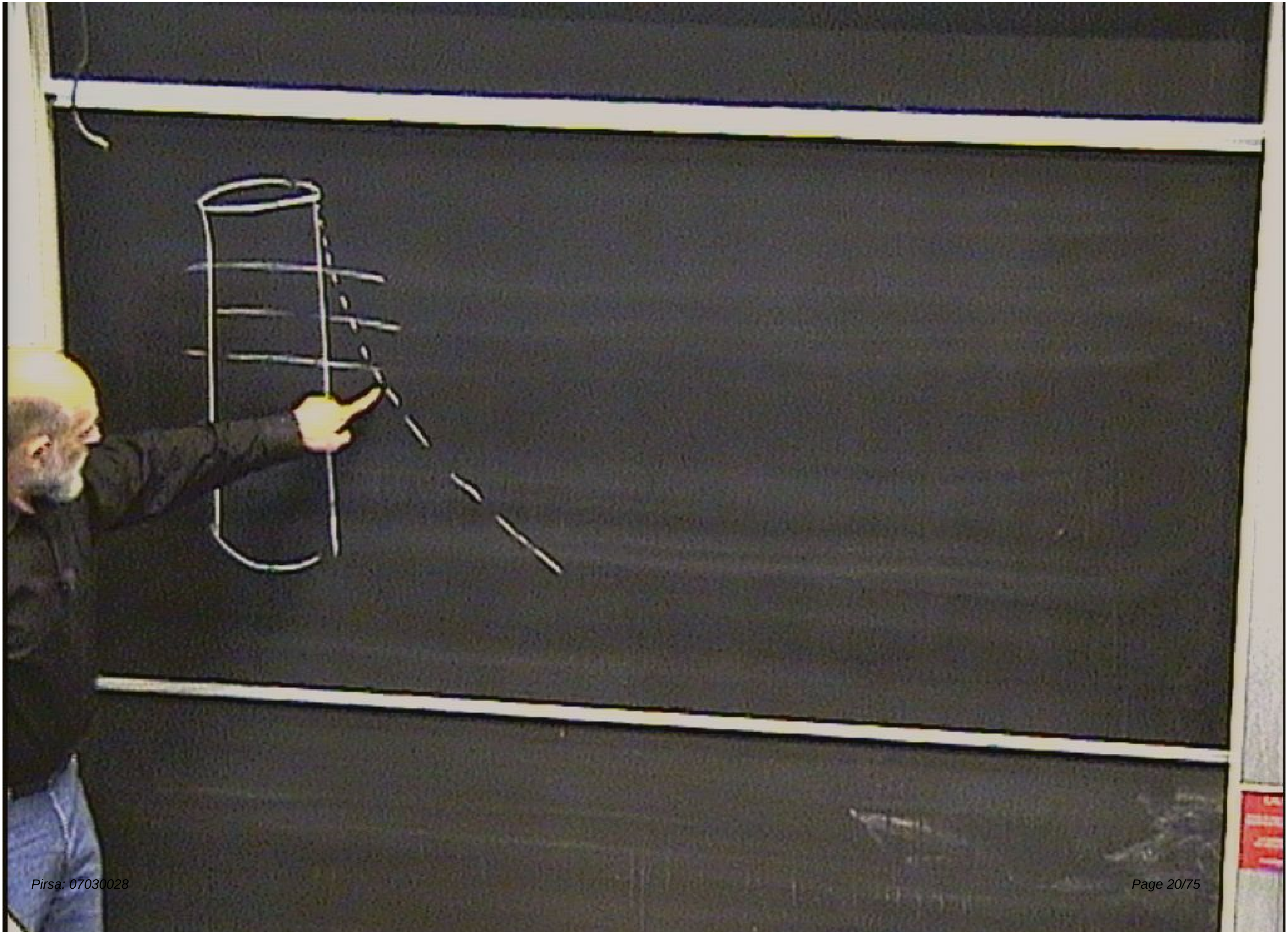
$$d\tau^2 = \left(1-\frac{2mG}{r}\right)dt^2 - \left(1-\frac{2mG}{r}\right)^{-1}dr^2 - r^2 d\Omega^2$$

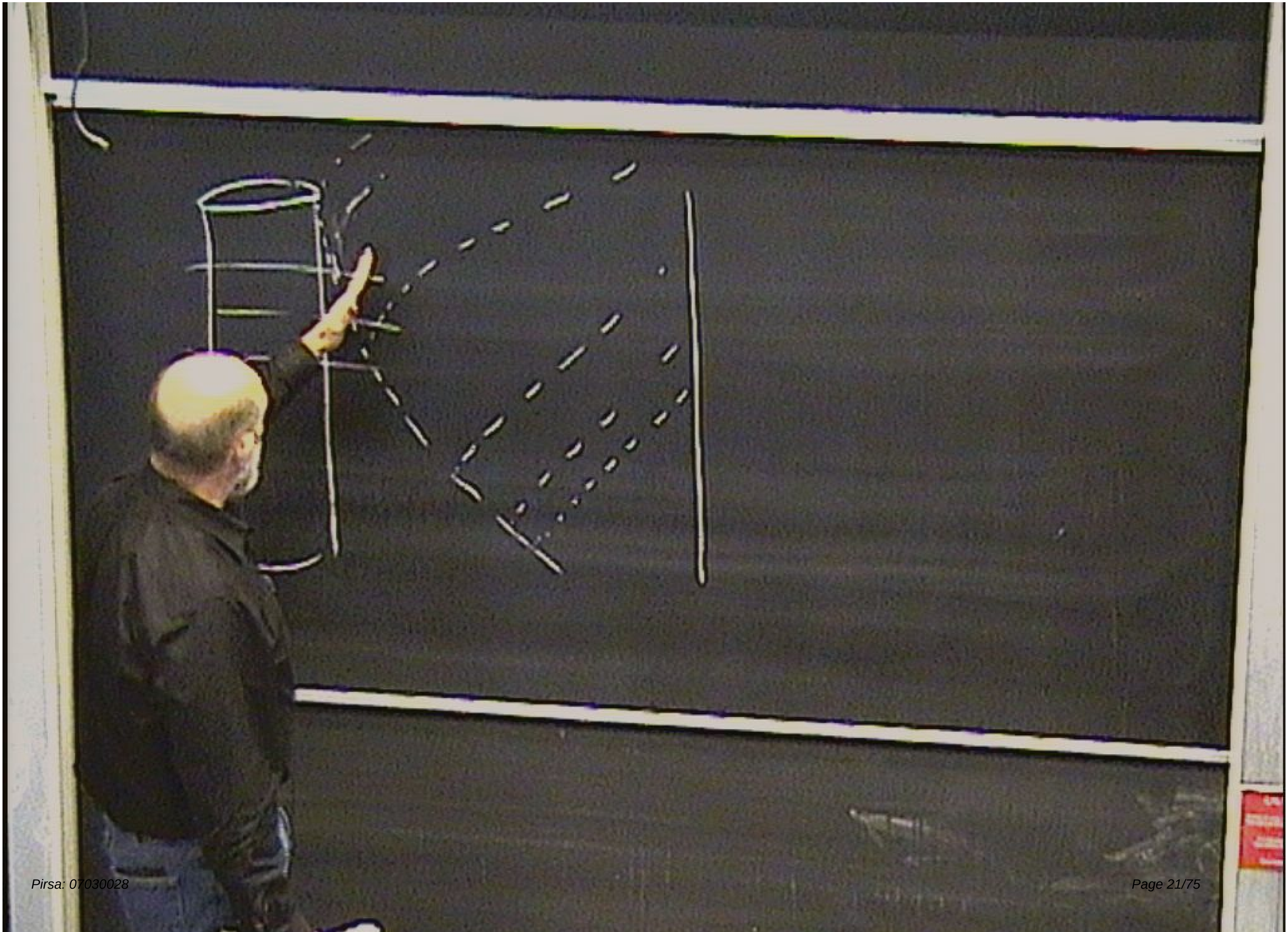
Horizon = $r = 2MG = R_S$

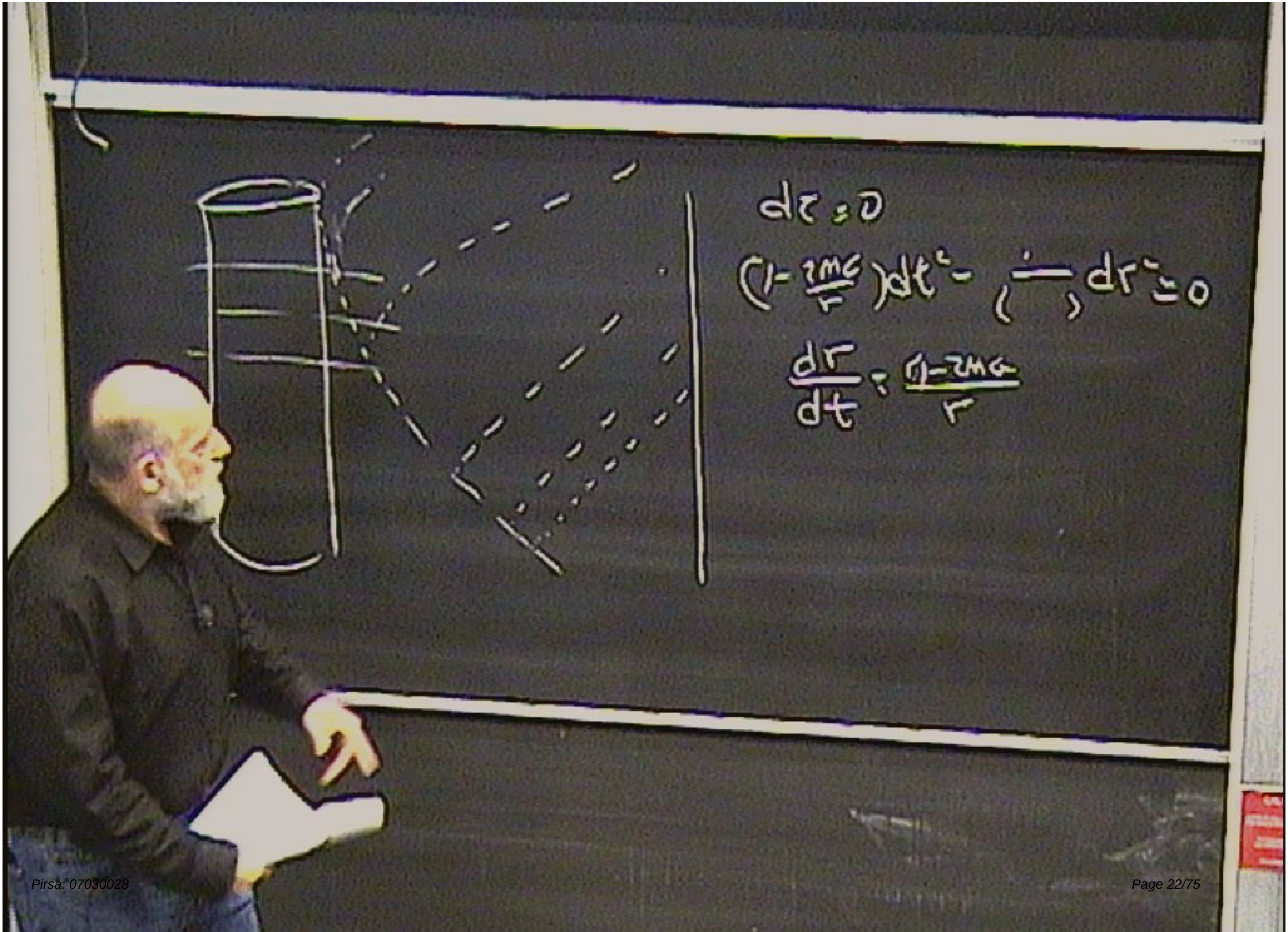
Sing $r = 0$

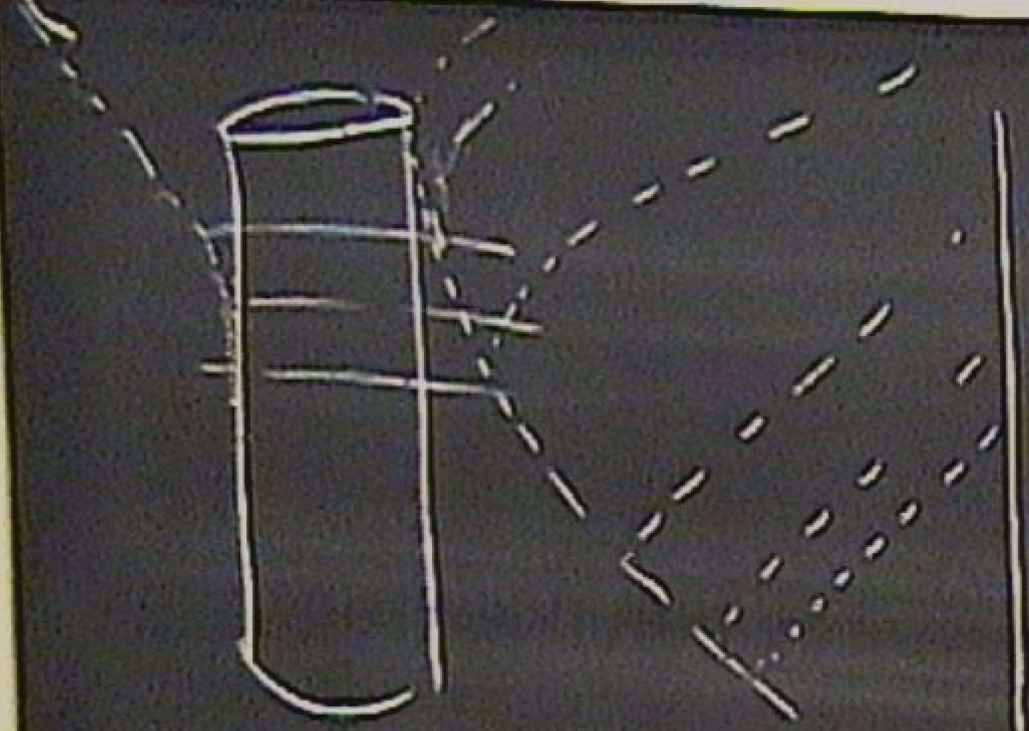
$$\tau = R_S \frac{\pi}{2}\left(\frac{R}{R_S}\right)^{3/2}$$







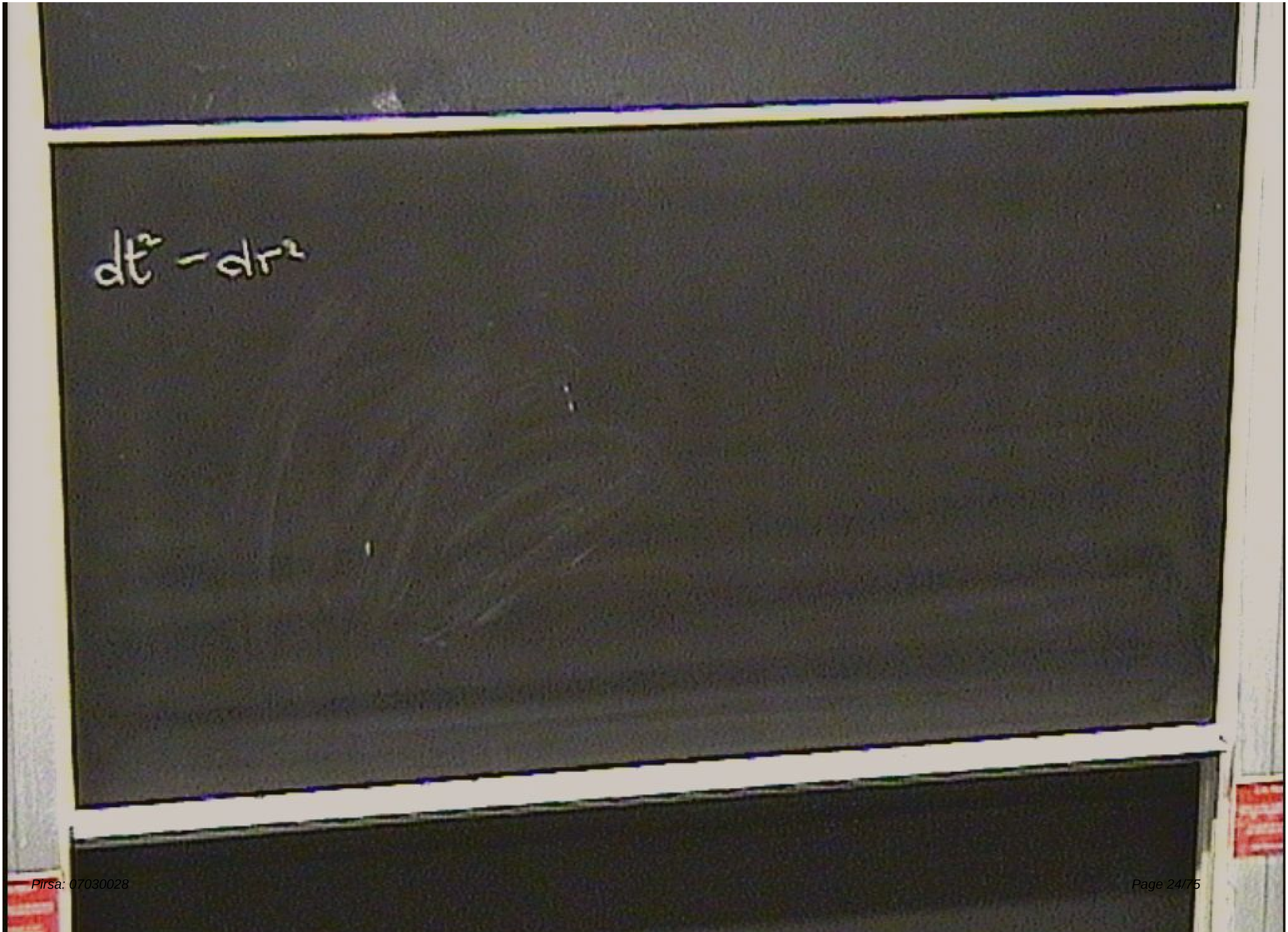

dτ = 0
(1 - 2MG/r) dt² - (1 / ( )) dr² = 0
dr/dt = (1 - 2MG/r)



$$d\tau = 0$$

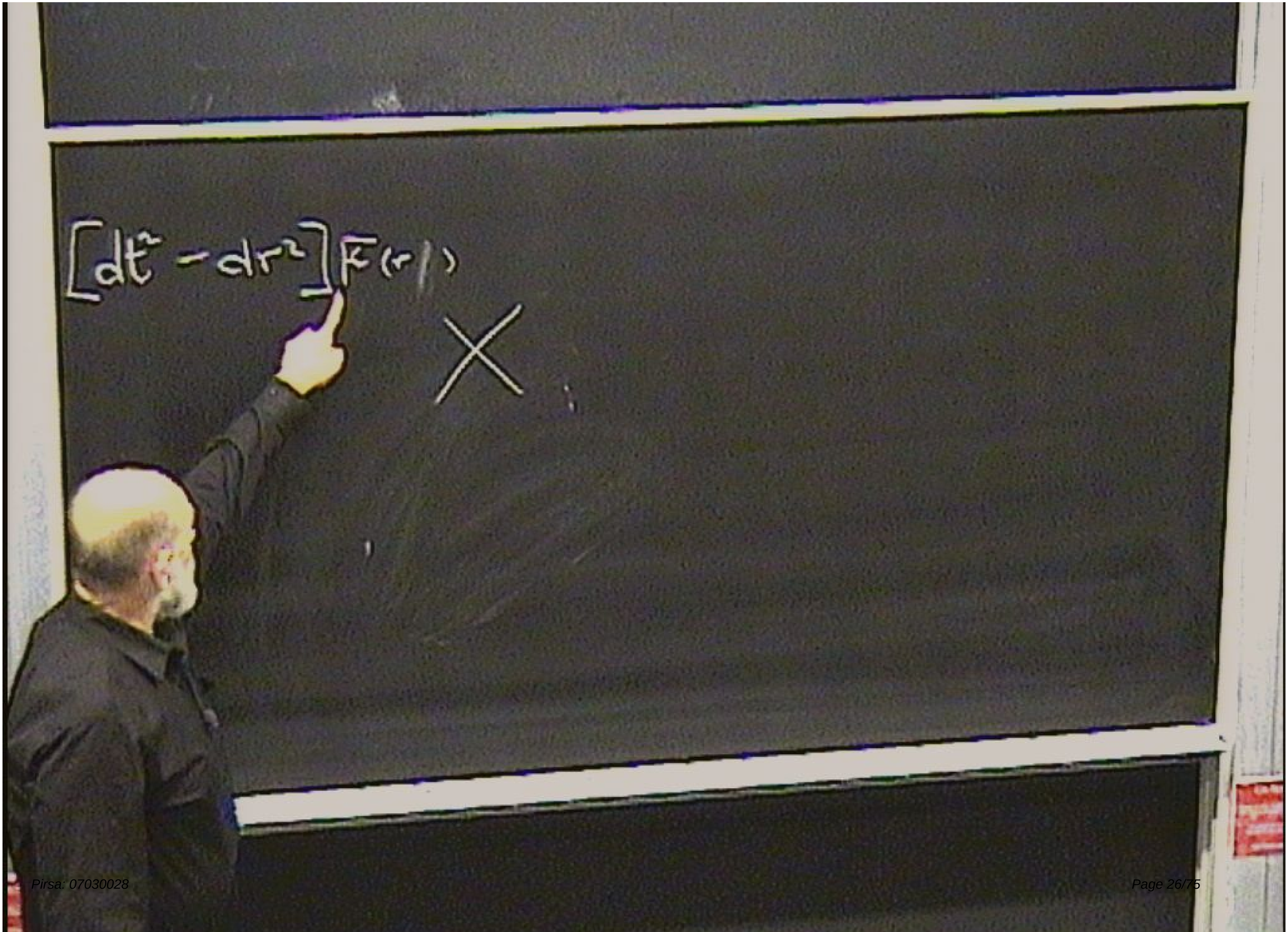
$$\left(1-\frac{2mG}{r}\right)dt^2 - \frac{1}{(\quad)}dr^2 = 0$$

$$\frac{dr}{dt} = \frac{\left(1-2mG\right.}{r}$$


$dt^2 - dr^2$

$$\left[dt^2 - dr^2\right] F(r,t)$$

$$\times$$


$[dt^2 - dr^2] F(r)$
X

$$[dt^2 - dr^2]\,F(r)$$

$$f = 1 - \frac{2mG}{r}$$

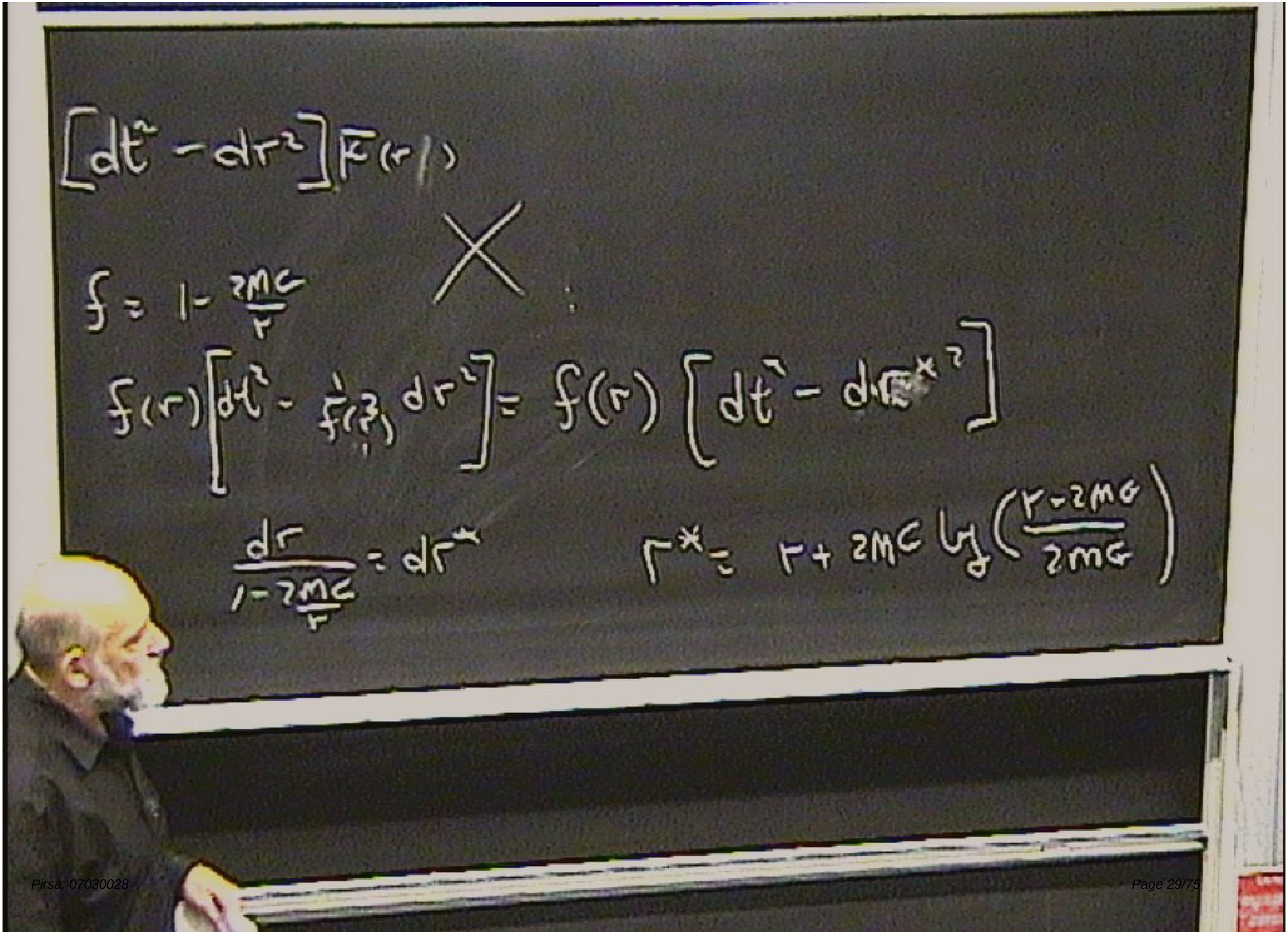
$$f(r)\,dt^2 - \frac{1}{f(r)}\,dr^2 = f(r)\left[dt^2 - dr^{*2}\right]$$

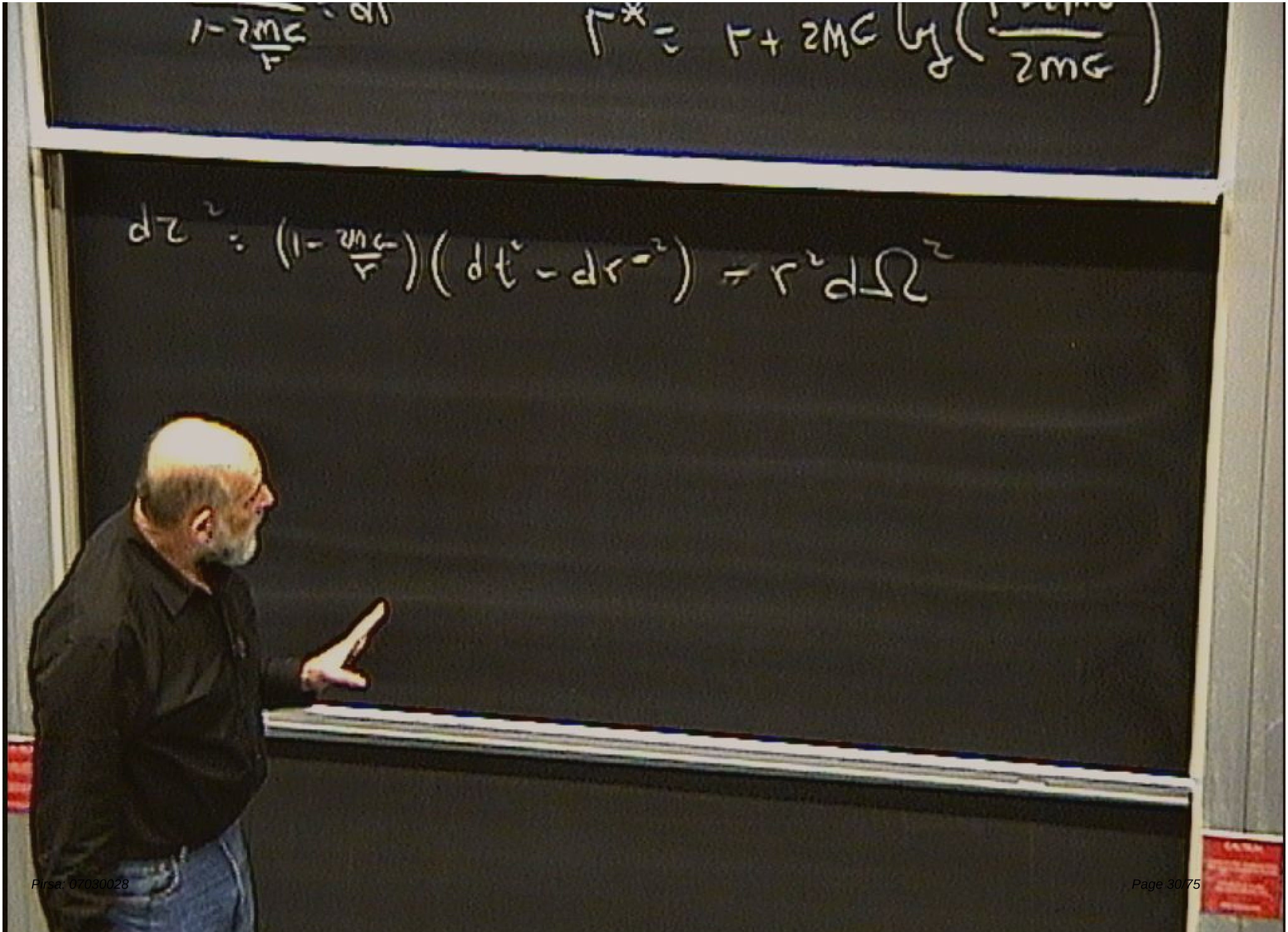
$$\left[dt^2 - dr^2\right] F(r)$$

$$f = 1 - \frac{2mG}{r}$$

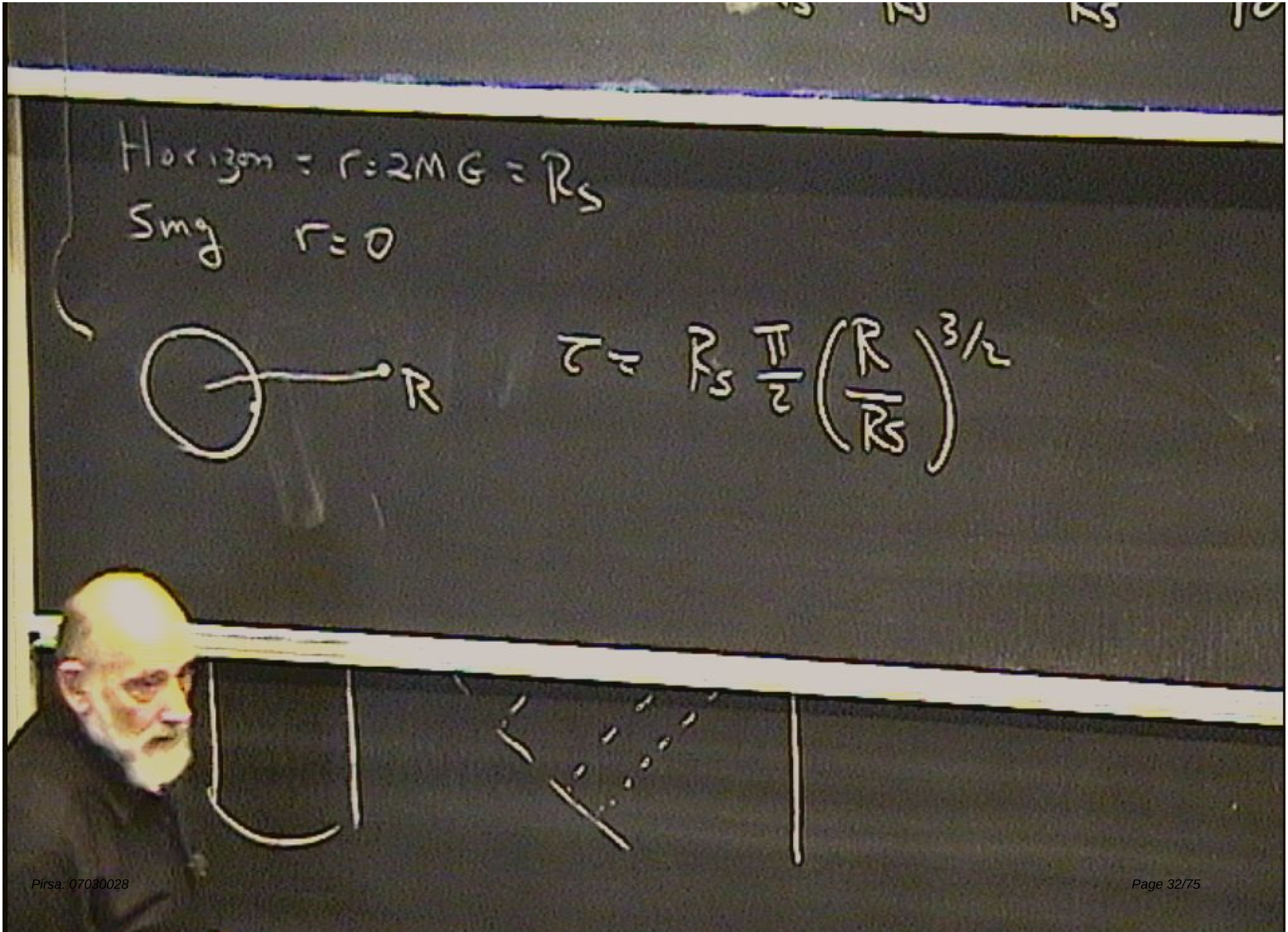
$$f(r)\left[dt^2 - \frac{1}{f(r)}\, dr^2\right] = f(r)\left[dt^2 - dr^{*2}\right]$$

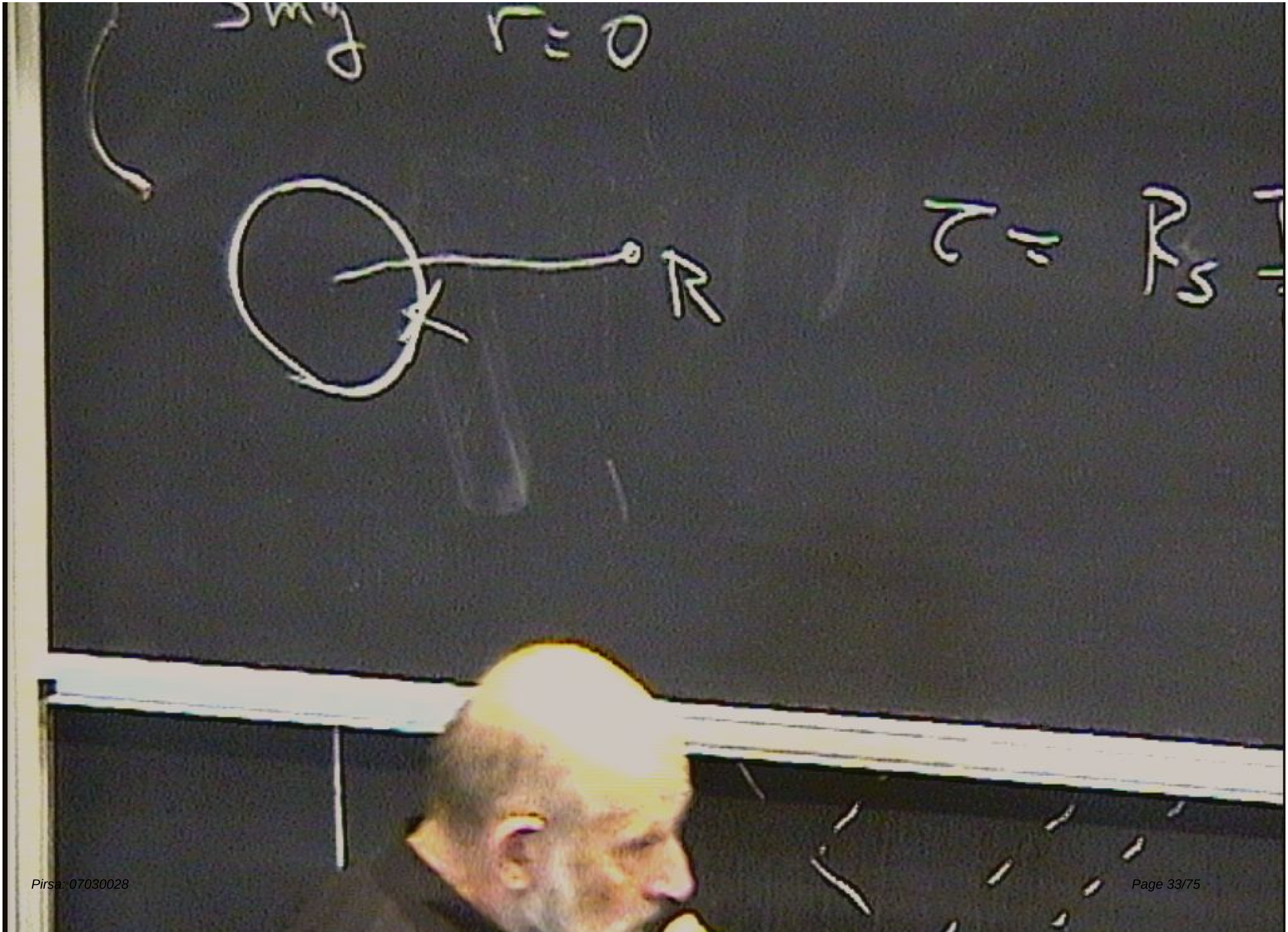
$$\frac{dr}{1 - \frac{2mG}{r}} = dr^*$$


$[dt^2 - dr^2]F(r)$
$f = 1 - \frac{2mG}{r}$
$f(r)\left[dt^2 - \frac{1}{f(r)} dr^2\right] = f(r)\left[dt^2 - dr^{*2}\right]$
$\frac{dr}{1-\frac{2mG}{r}} = dr^*$
$r^* = r + 2mG \log\left(\frac{r-2mG}{2mG}\right)$

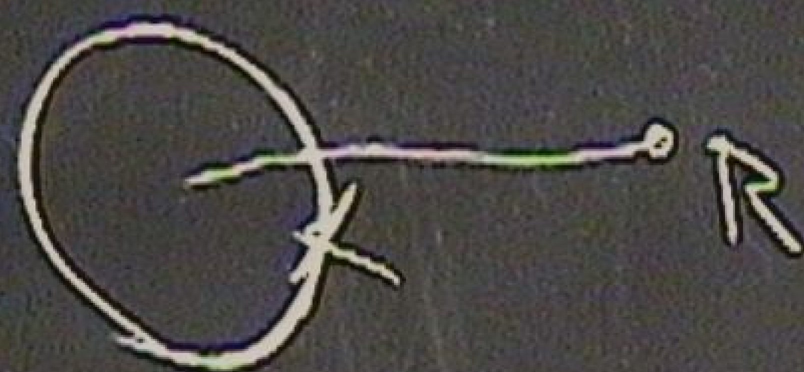

r* = r + 2MG log(/ 2MG)
dτ² = (1 - 2mG/r)(dt² - dr*²) - r² dΩ²

$$d\tau^2 = \left(1-\frac{2mG}{r}\right)\left(dt^2 - dr^{*2}\right) - r^2 d\Omega^2$$


Horizon = r = 2MG = R_S
Sing r = 0
R
τ = R_S π/2 (R/R_S)^{3/2}


r = 0
R
τ = R_s

sing $r=0$



$\tau = R_s$

$$\rho = \int_{2mG}^{r} \sqrt{g_{rr}}$$

$$\rho = \int_{2MG}^{r} \sqrt{g_{rr}}$$

$$\rho \cong 2\sqrt{2MG\,(r-2MG)}$$

$$\rho = \int_{2MG}^{r} \sqrt{g_{rr}}$$

$$\rho \cong 2\sqrt{2MG\,(r-2MG)}$$

$$d\tau^2 = \rho^2$$

$$\rho = \int_{2mG}^{r} \sqrt{g_{rr}}$$

$$\rho \cong 2\sqrt{2mG\,(r-2mG)}$$

$$d\tau^2 = \rho^2 \left(\frac{dt}{\text{[illegible]}}\right)^2 - d\rho^2$$

$$\rho = \int_{2MG}^{r} \sqrt{g_{rr}}$$

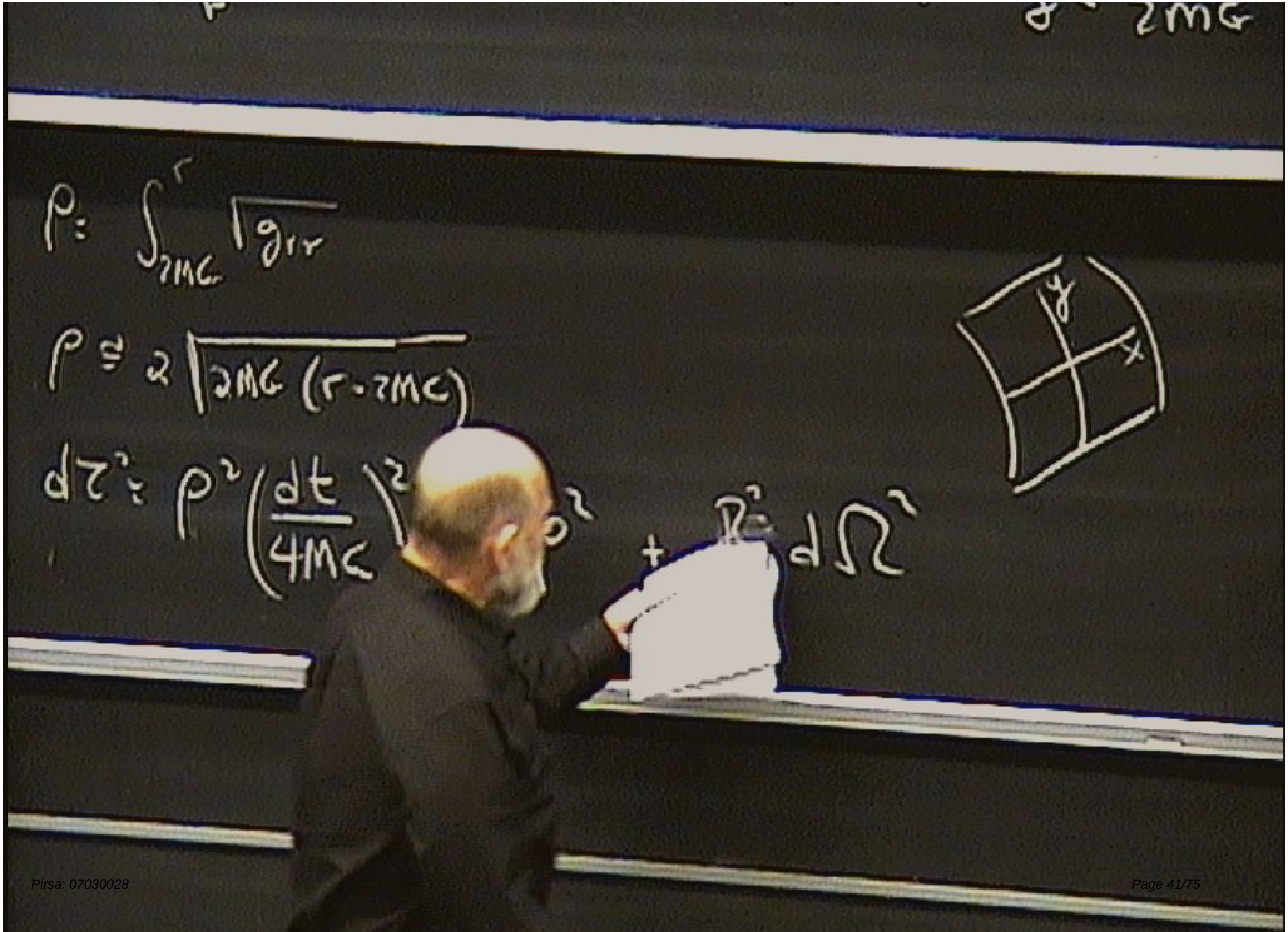
$$\rho \cong 2\sqrt{2MG\,(r-2MG)}$$

$$d\tau^2 = \rho^2 \left(\frac{dt}{4MG}\right)^2 - d\rho^2$$

$$\rho = \int_{2MG}^{r} \sqrt{g_{rr}}$$

$$\rho \cong 2\sqrt{2MG\,(r - 2MG)}$$

$$d\tau^2 = \rho^2 \left(\frac{dt}{4MG}\right)^2 - d\rho^2 + r^2 d\Omega^2$$


$\rho = \int_{2MG}^{r} \sqrt{g_{rr}}$
$\rho \cong 2\sqrt{2MG\,(r-2MG)}$
$d\tau^2 = \rho^2 \left(\frac{dt}{4MG}\right)^2$
$d\Omega^2$
y
x

$$\rho = \int_{2MG}^{r} \sqrt{g_{rr}}$$

$$\rho \cong 2\sqrt{2MG\,(r-2MG)}$$

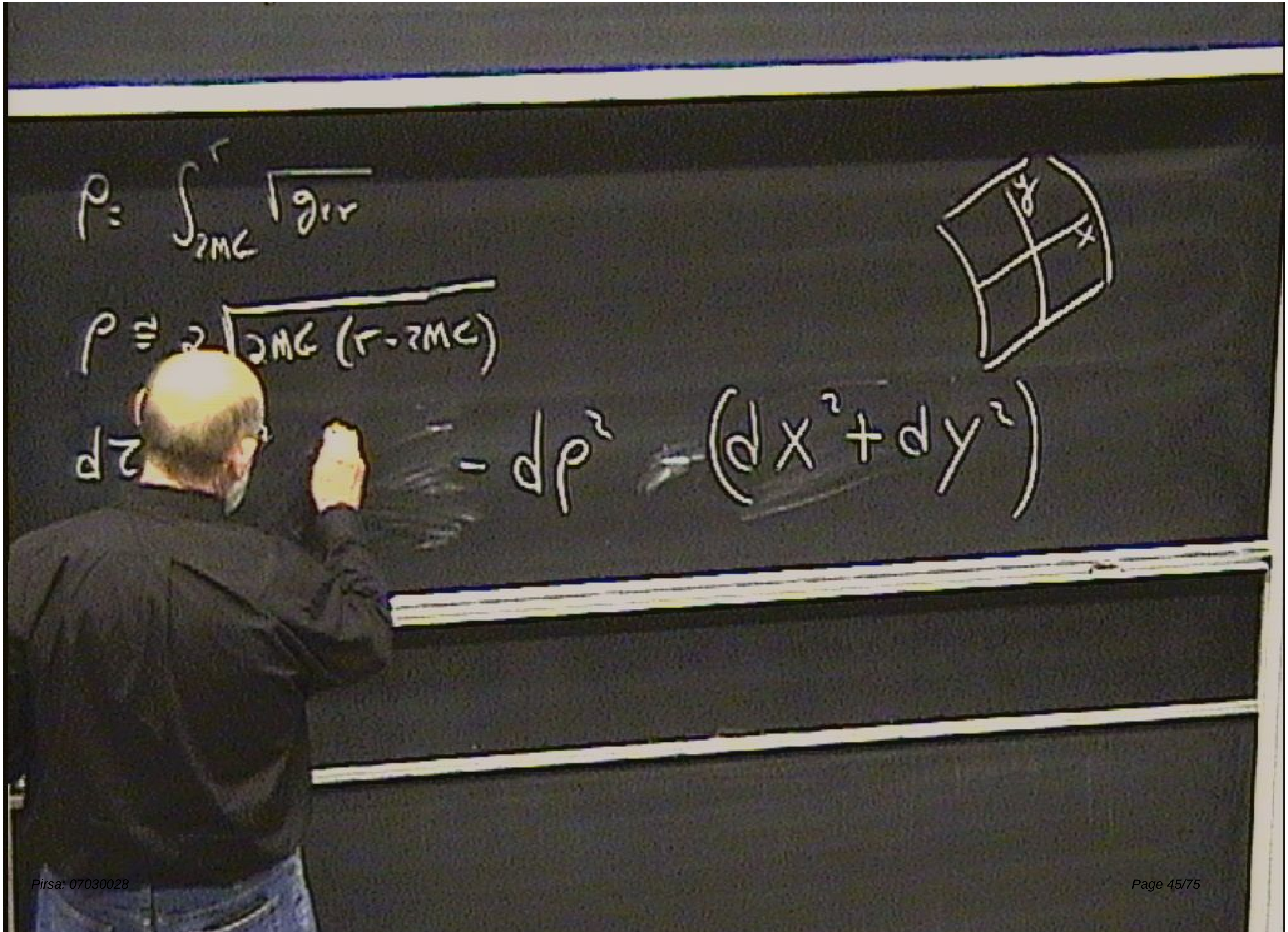
$$d\tau^2 = \rho^2\left(\frac{dt}{4MG}\right)^2 - d\rho^2 + r_s^2\, d\Omega^2$$

$$\rho = \int_{2MG}^{r} \sqrt{g_{rr}}$$

$$\rho \approx 2\sqrt{2MG\,(r-2MG)}$$

$$d\tau^2 = \rho^2\left(\frac{dt}{4MG}\right)^2 - d\rho^2 - \left(dx^2 + dy^2\right)$$

$$\frac{t}{4MG} = \omega$$


$\rho = \int_{2MG}^{r} \sqrt{g_{rr}}$
$\rho \cong 2\sqrt{2MG\,(r-2MG)}$
$d\tau$
$-\,d\rho^2 - (dx^2+dy^2)$
y
x

$$\rho = \int_{2MG}^{r} \sqrt{g_{rr}}$$

$$\rho \cong 2\sqrt{2MG\,(r-2MG)}$$

$$d\tau^2 = \rho^2\, d\omega^2 - d\rho^2 - (dx^2 + dy^2)$$

$$\rho = \int_{2MG}^{r} \sqrt{g_{rr}}$$

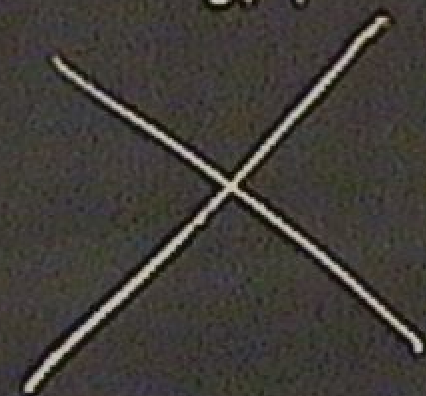
$$\rho \simeq 2\sqrt{2MG\,(r-2MG)}$$

$$d\tau^2 = \rho^2\, d\omega^2 + d\rho^2 + \left(dx^2 + dy^2\right)$$

$$d\tau^2 = \rho^2\, d\omega^2 - d\rho^2 - (dx^2 + dy^2)$$

$$z = \rho \cosh\omega \qquad dT^2 - dz^2 - dx^2 - dy^2$$

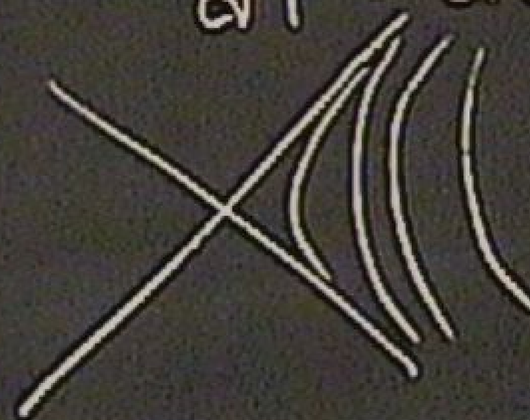
$$T = \rho \sinh\omega$$

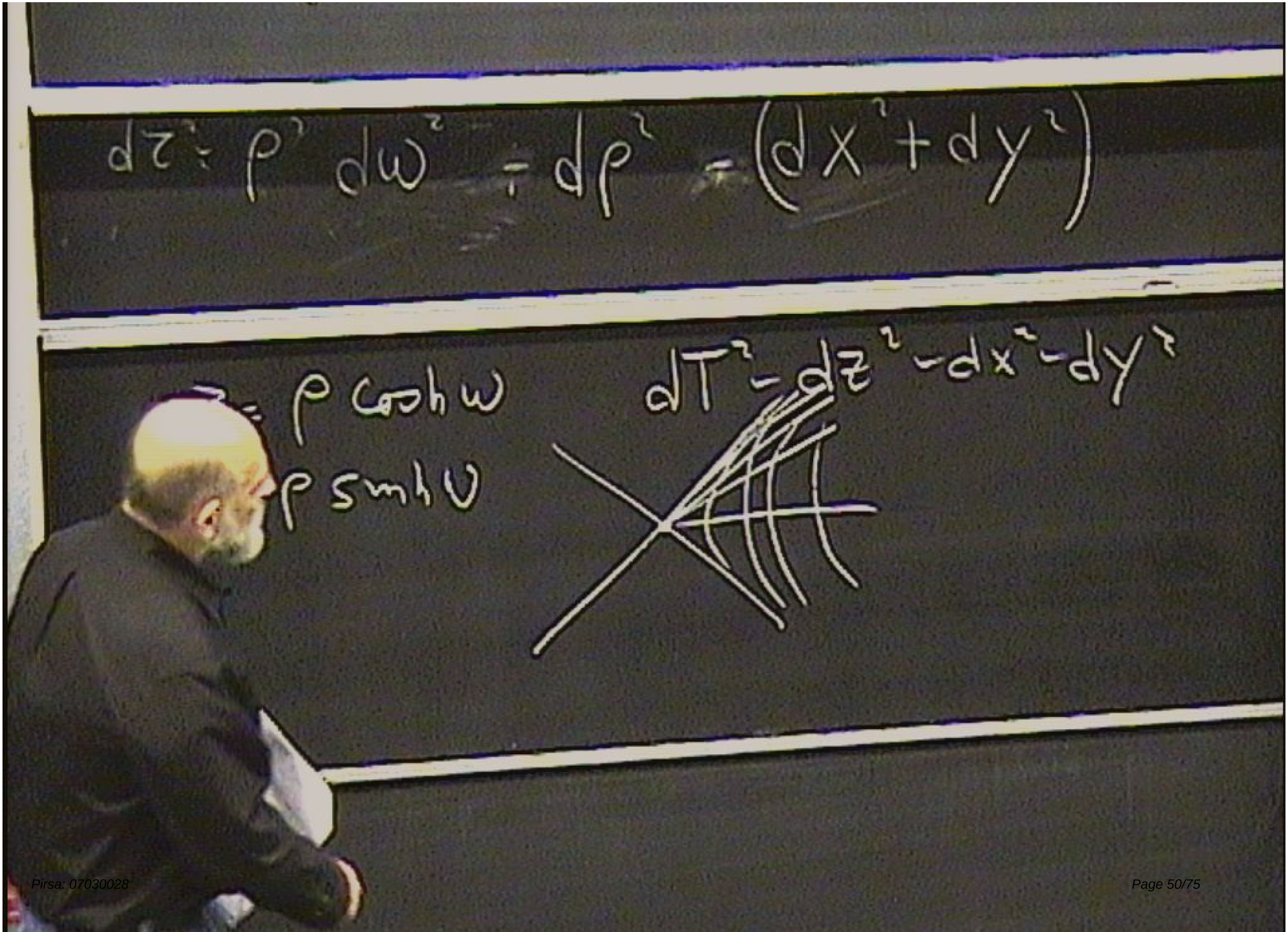


$$d\tau^2 = \rho^2\, d\omega^2 - d\rho^2 - (dx^2 + dy^2)$$

$$Z = \rho \cosh w$$
$$T = \rho \sinh w$$

$$dT^2 - dZ^2 - dx^2 - dy^2$$

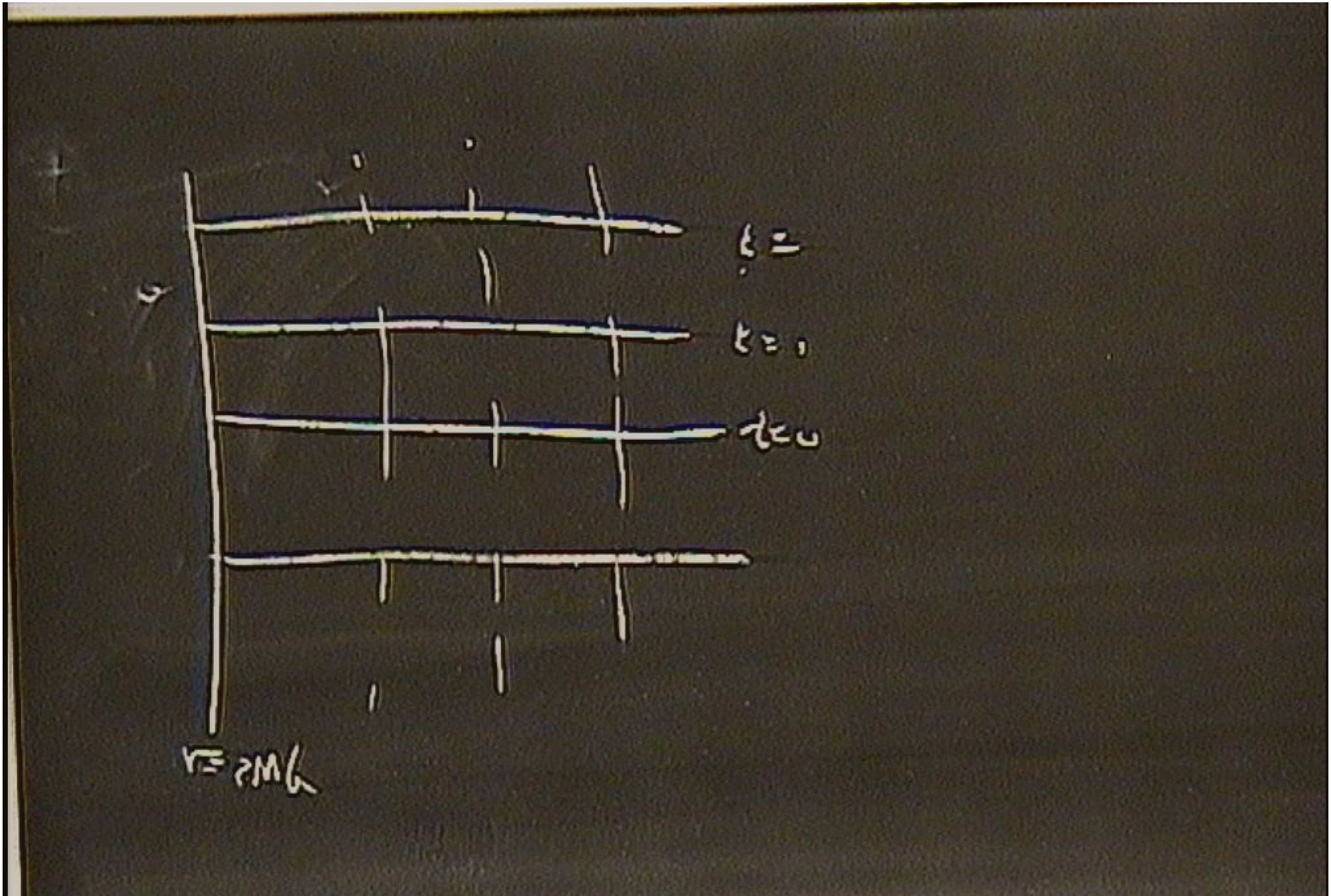


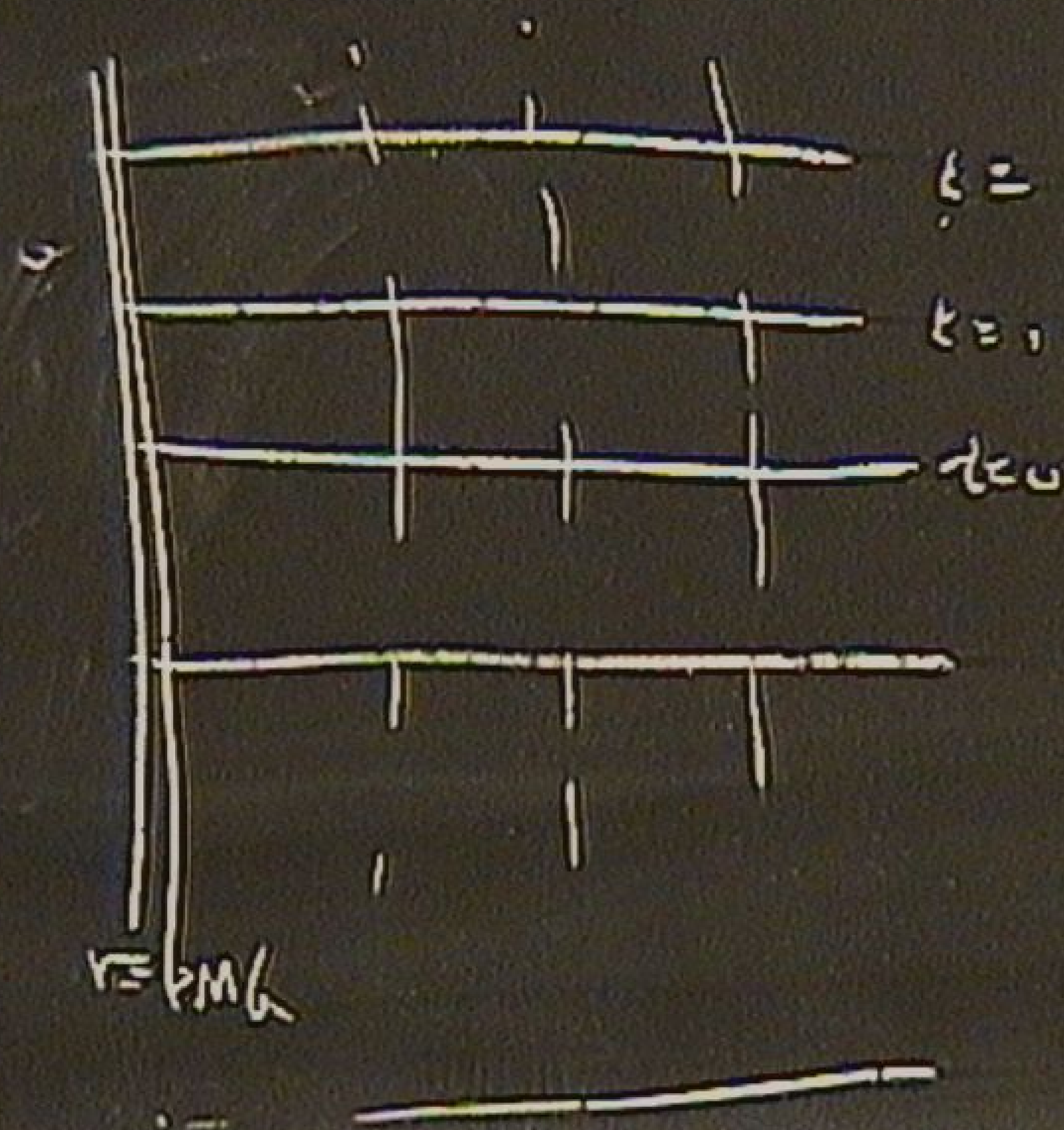

$d\tau^2 = \rho^2 d\omega^2 - d\rho^2 - (dx^2 + dy^2)$
$= \rho \cosh w$
$\rho \sinh w$
$dT^2 - dz^2 - dx^2 - dy^2$

$$d\tau^2 = \rho^2\, d\omega^2 - d\rho^2 - (dx^2 + dy^2)$$

$$z = \rho \cosh w$$
$$T = \rho \sinh w$$

$$dT^2 - dz^2 - dx^2 - dy^2$$


r=2MG



t =
t = 1
t = 0
r = 2MG

$$\rho^2 \, d\omega^2 - d\rho^2$$

$\longrightarrow 3\,\mathrm{km}$

$$F(R)\left[R^2\, dw^2 - dR^2\right] + \text{ang}$$

$$F(R)\left[R^2\, d\omega^2 - dR^2\right] + \text{ang}$$

$$\frac{dt^2}{(4MG)^2}$$

$F(R)R^2$

$$F(R)\left[R^2\, d\omega^2 - dR^2\right] + \text{ang}$$

$$\frac{dt^2}{(4MG)^2}$$

$$\frac{F(R)R^2}{(4MG)^2} = 1 - \frac{2MG}{r}$$

$$F(R)\left[R^2 d\omega^2 - dR^2\right] + \text{ang}$$

$$\frac{dt^2}{(4MG)^2}$$

$$\frac{F(R)}{} \left(1-\frac{2MG}{r}\right)(4MG)^2$$

$$F(\;)\,R^2 = \frac{1}{1-\frac{2MG}{r}}\,dr^2$$

$$F(R)\left[R^2\,d\omega^2 - dR^2\right] + \text{ang}$$

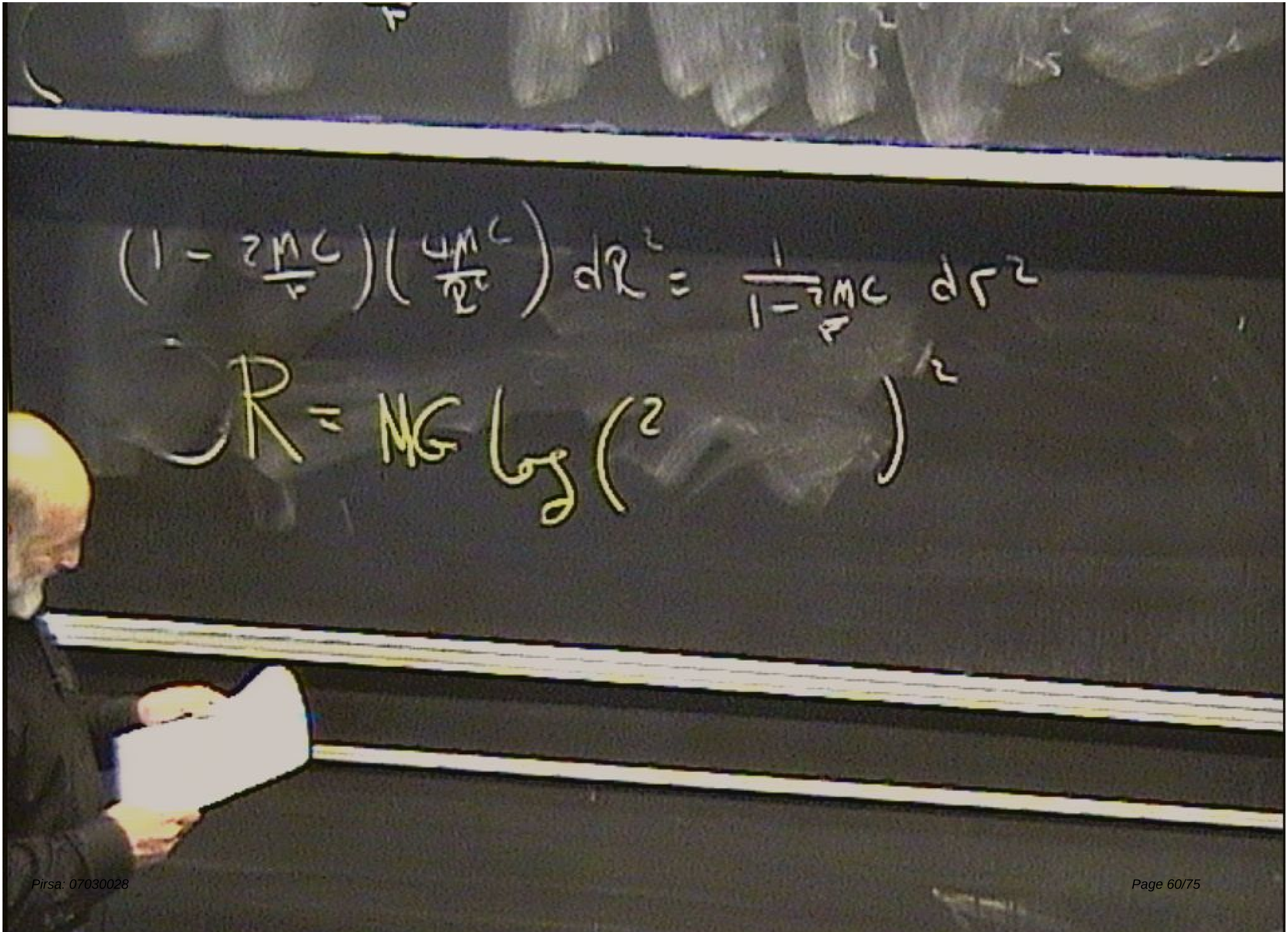
$$\frac{dt^2}{(4MG)^2}$$

$$F(R) = \left(1-\frac{2MG}{r}\right)\frac{(4MG)^2}{R^2}$$

$$F(R)\,dR^2 = \frac{1}{1-\frac{2MG}{r}}\,dr^2$$

Horizon =

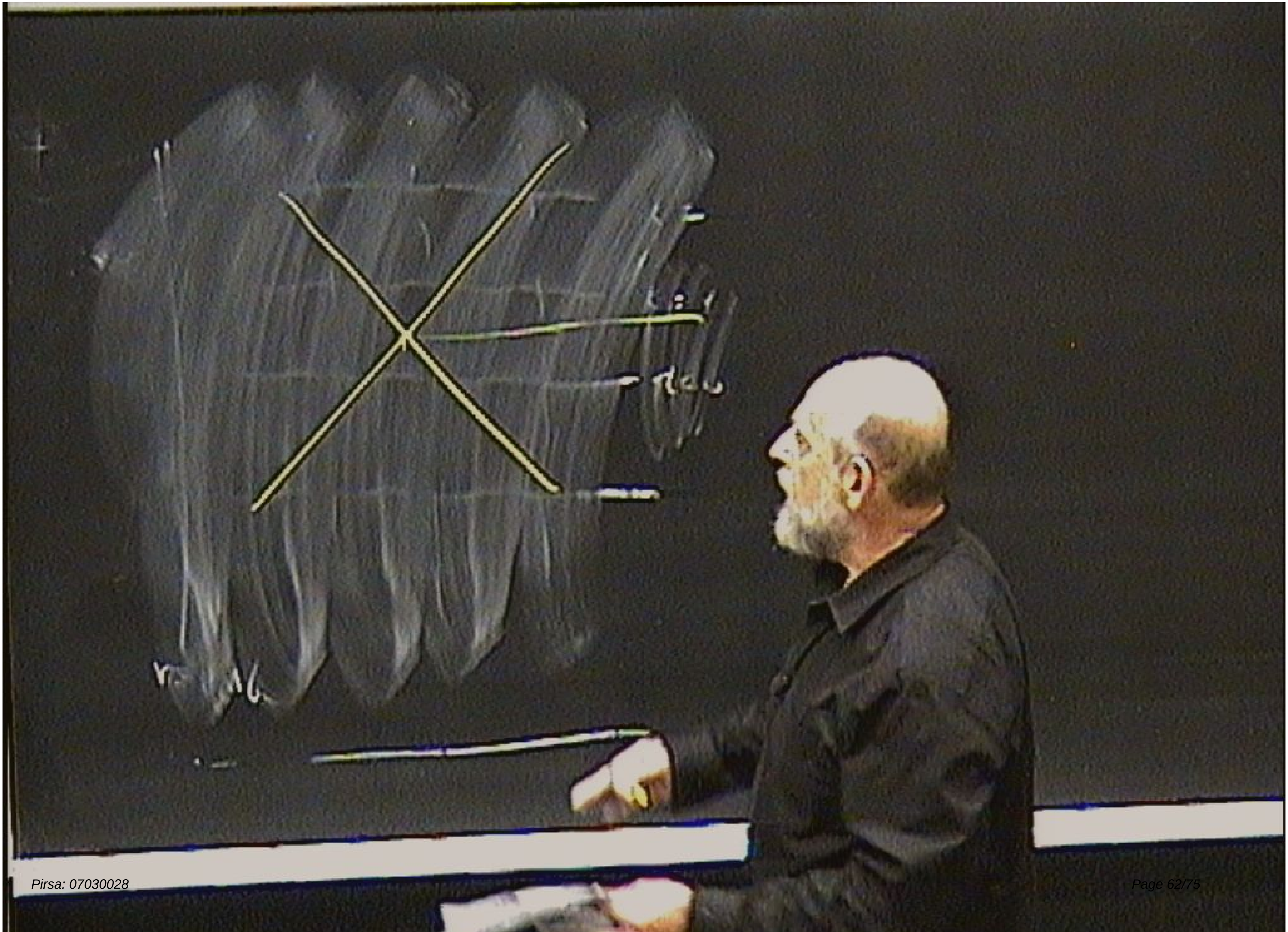
Smg

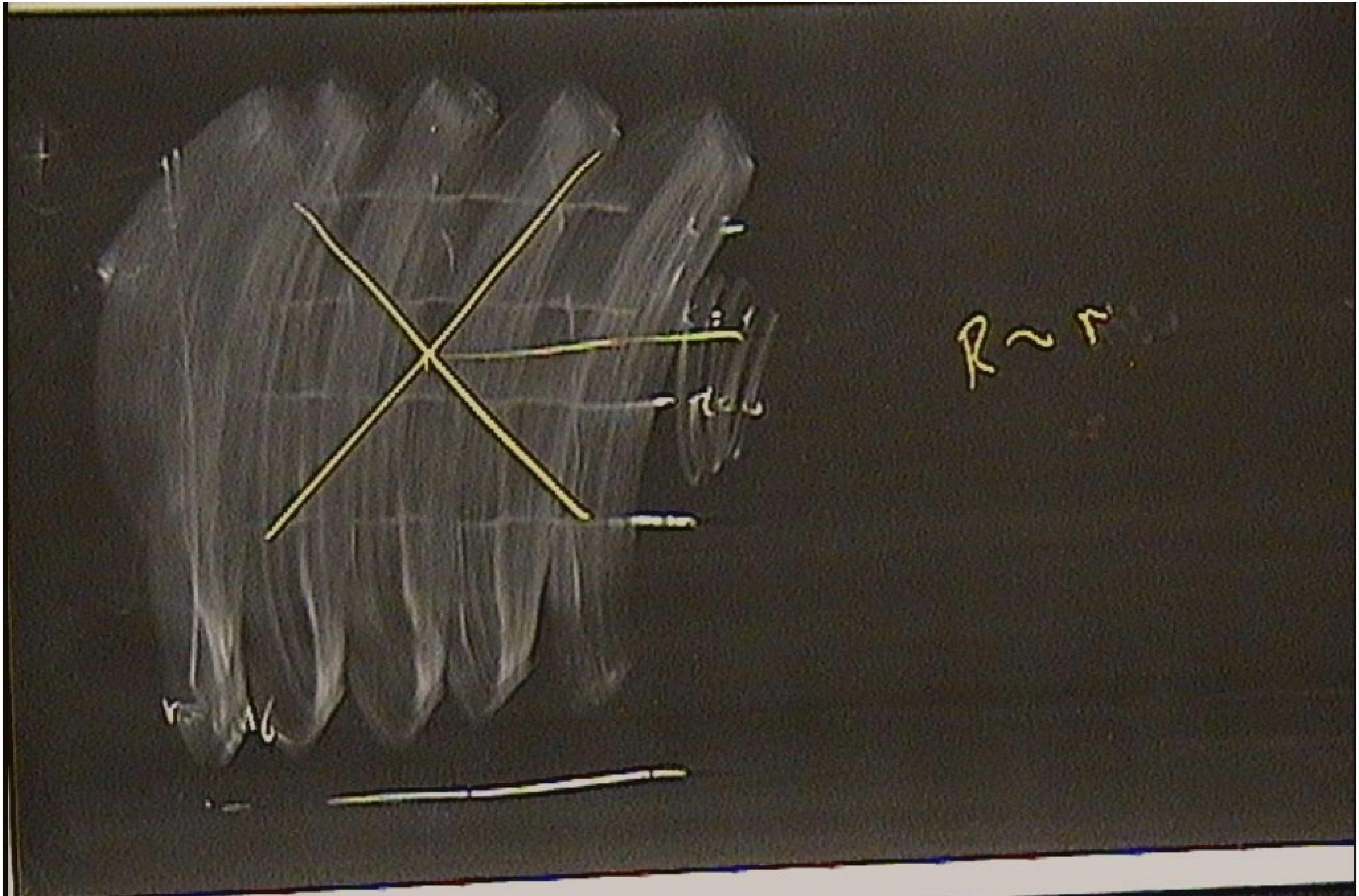

$(1 - \frac{2mc}{r})(\frac{4mc}{R^2}) dR^2 = \frac{1}{1-\frac{2mc}{r}} dr^2$
$R = NG \log(2 \quad)^2$

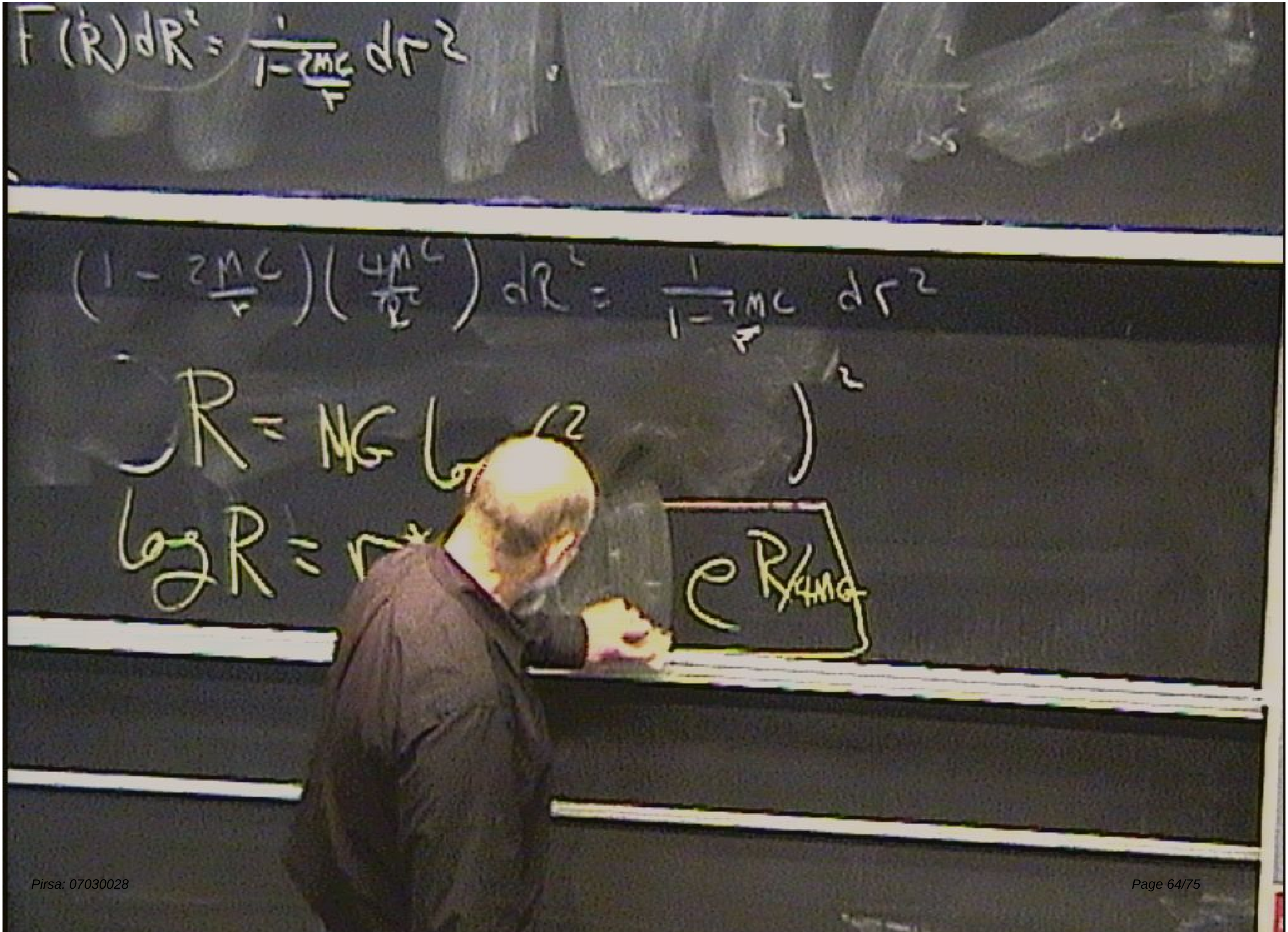
$$\left(1-\frac{2MG}{r}\right)\left(\frac{4MG}{R^2}\right)dR^2 = \frac{1}{1-\frac{2MG}{r}}\,dr^2$$

$$R = MG\log\left(2 \qquad\right)^{1/2}$$

$$\log R = r^*, \quad \boxed{r^* = e^R}$$




R ~ r



F(R) dR² = 1/(1 − 2mG/r) dr²
(1 − 2mG/r)(4m²G²/r²) dR² = 1/(1 − 2mG/r) dr²
e^{R/4mG}

$$F(R)\,dR^2 = \frac{1}{1-\frac{2mG}{r}}\,dr^2$$

$$\left(1-\frac{2mG}{r}\right)\left(\frac{4m^2G^2}{R^2}\right) dR^2 = \frac{1}{1-\frac{2mG}{r}}\,dr^2$$

$$R = NG\log\left(2 \qquad\right)^2$$

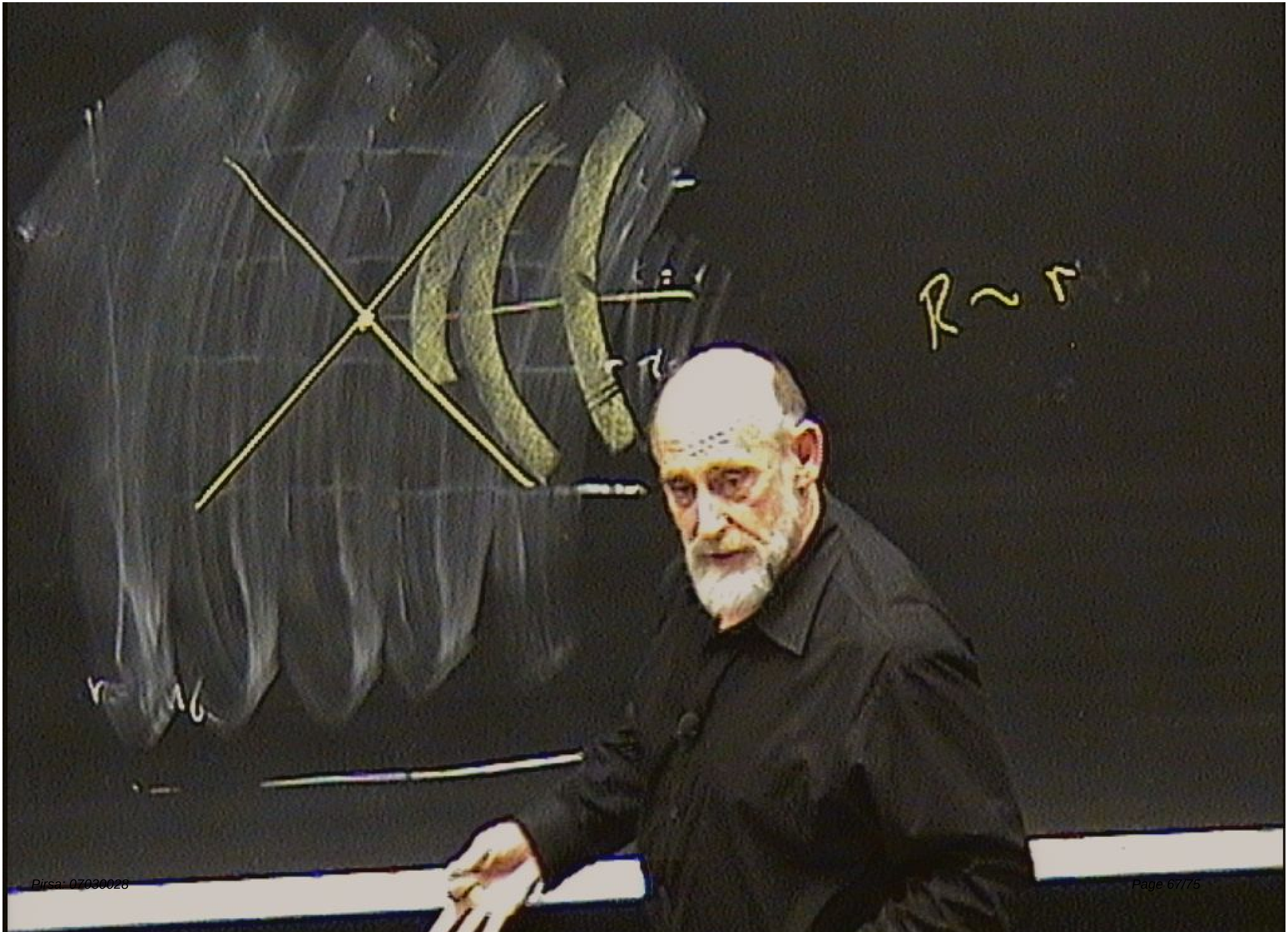
$$\log R = r^*$$

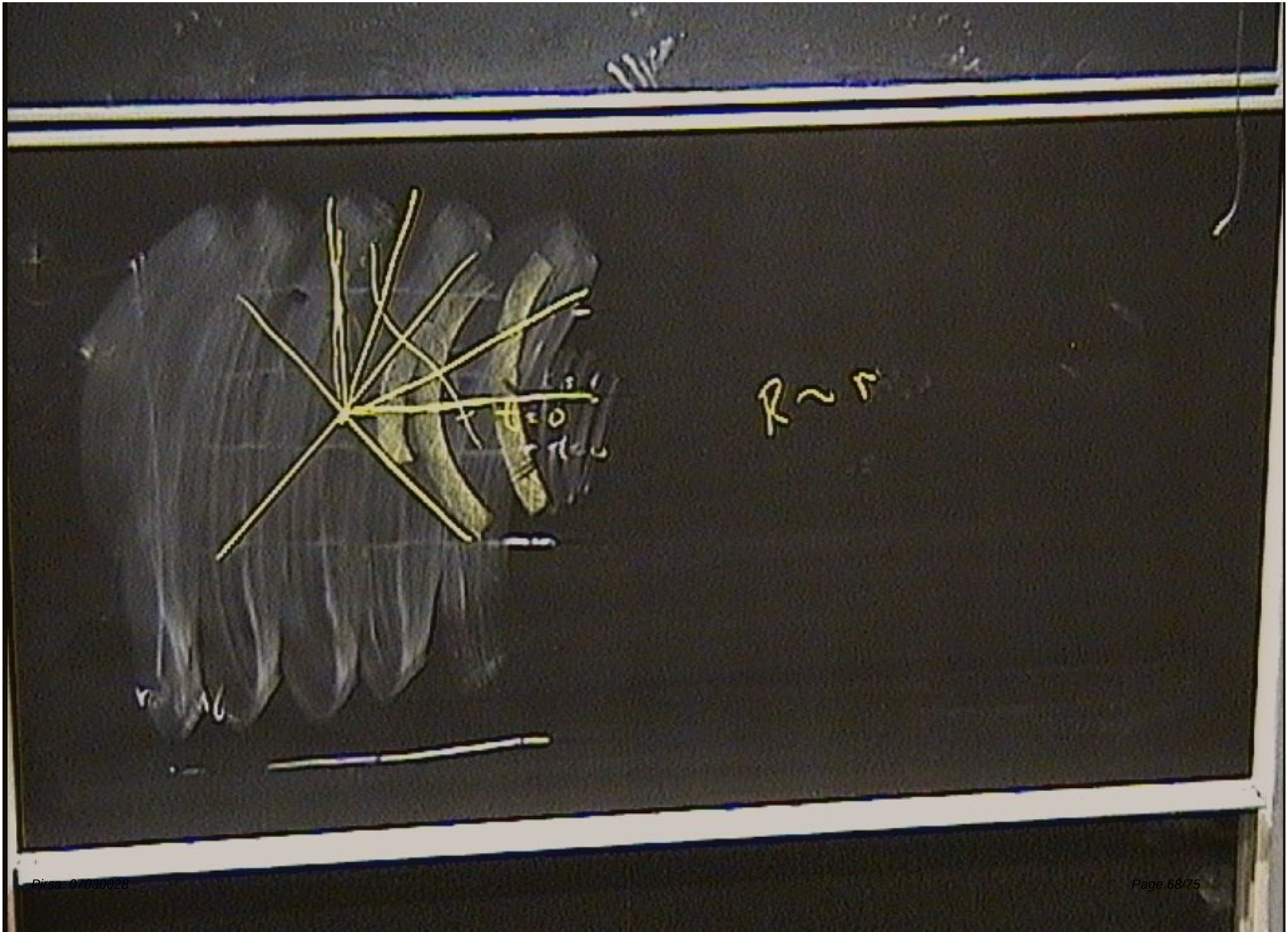
$$F(R)\,dR^2 = \frac{1}{1-\frac{2MG}{r}}\,dr^2$$

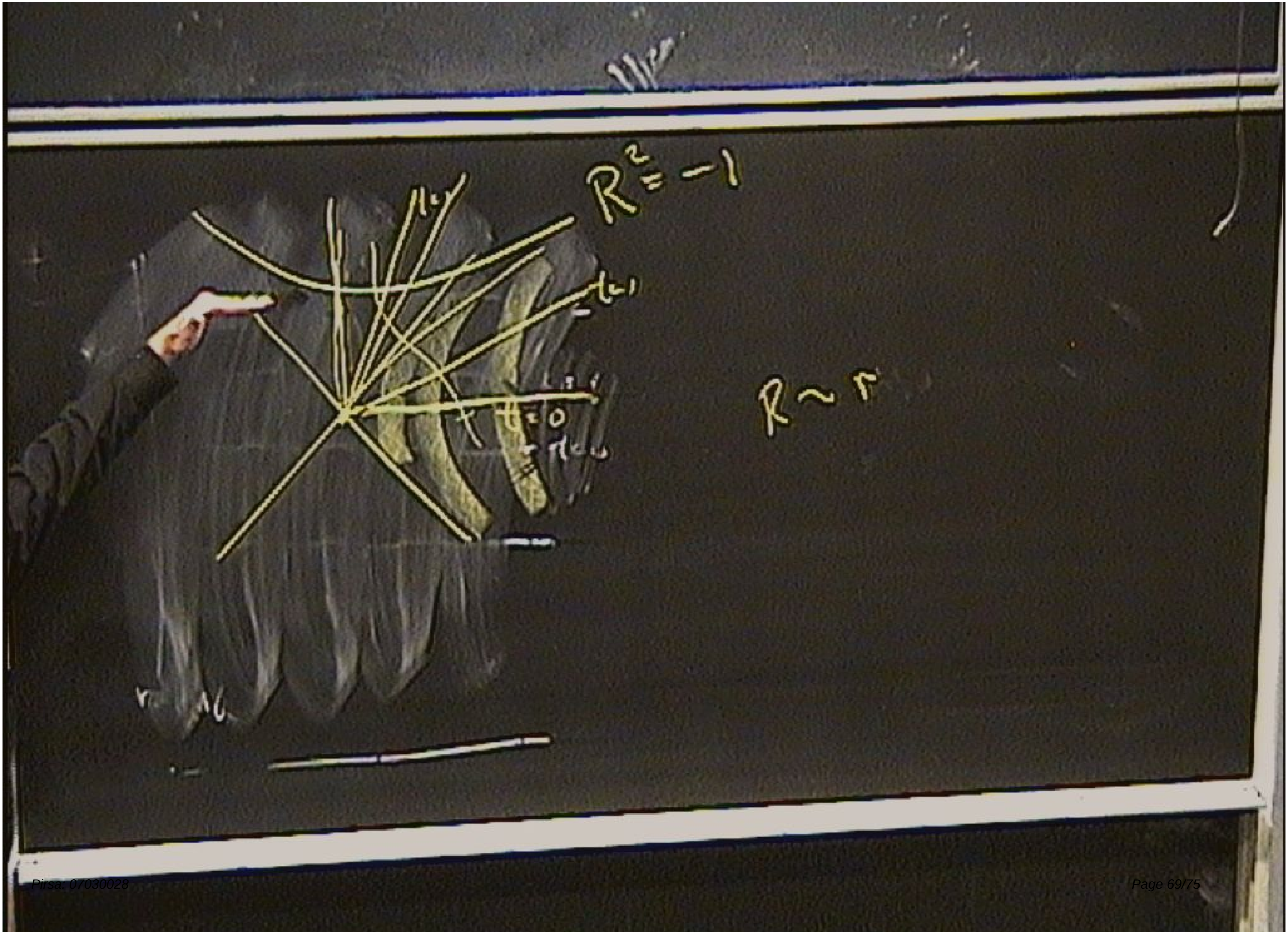
$$\left(1-\frac{2MG}{r}\right)\left(\frac{4M^2G^2}{R^2}\right)dR^2 = \frac{1}{1-\frac{2MG}{r}}\,dr^2$$

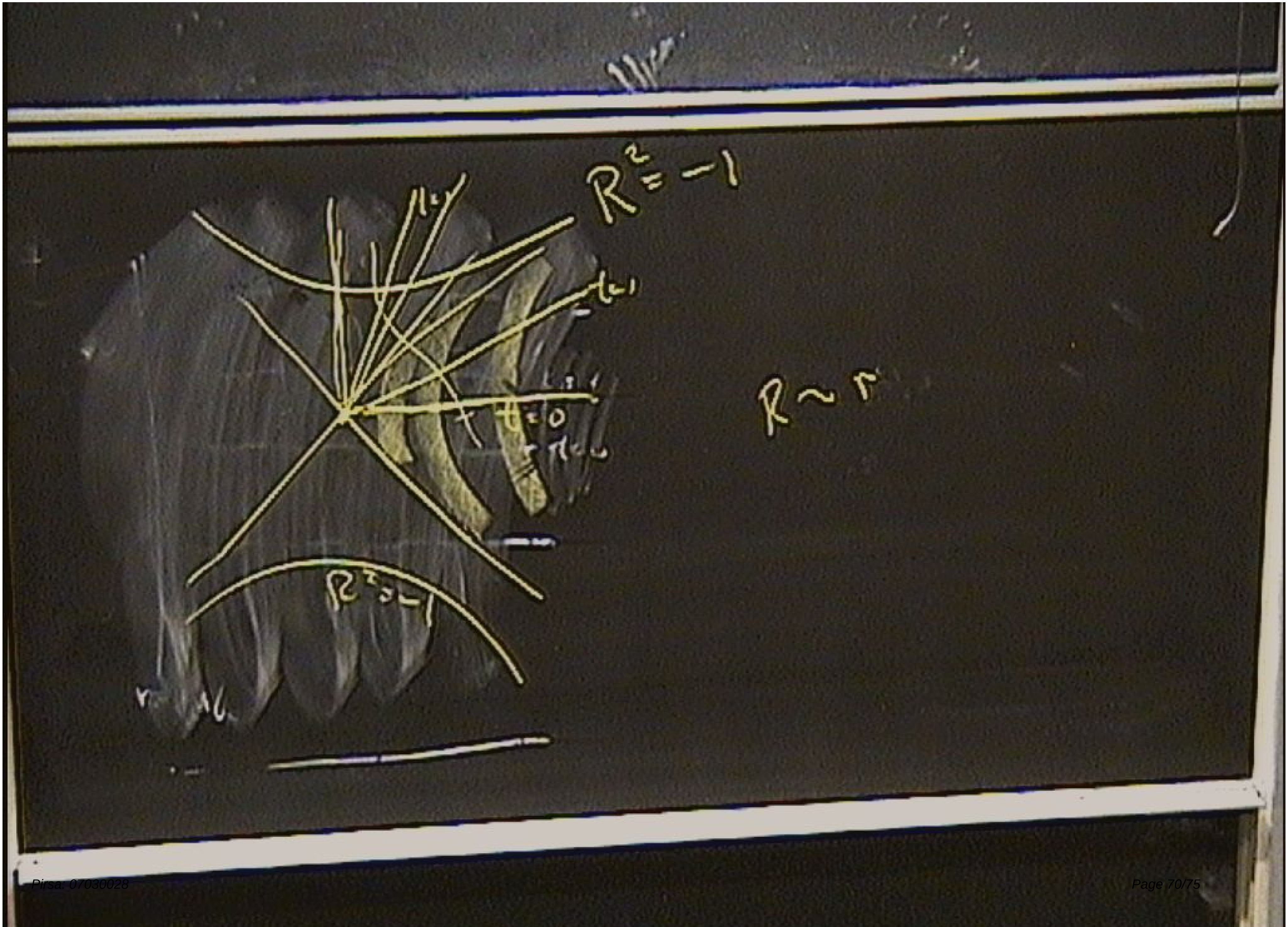
$$R = MG\log\left(2 \quad\right)^2$$

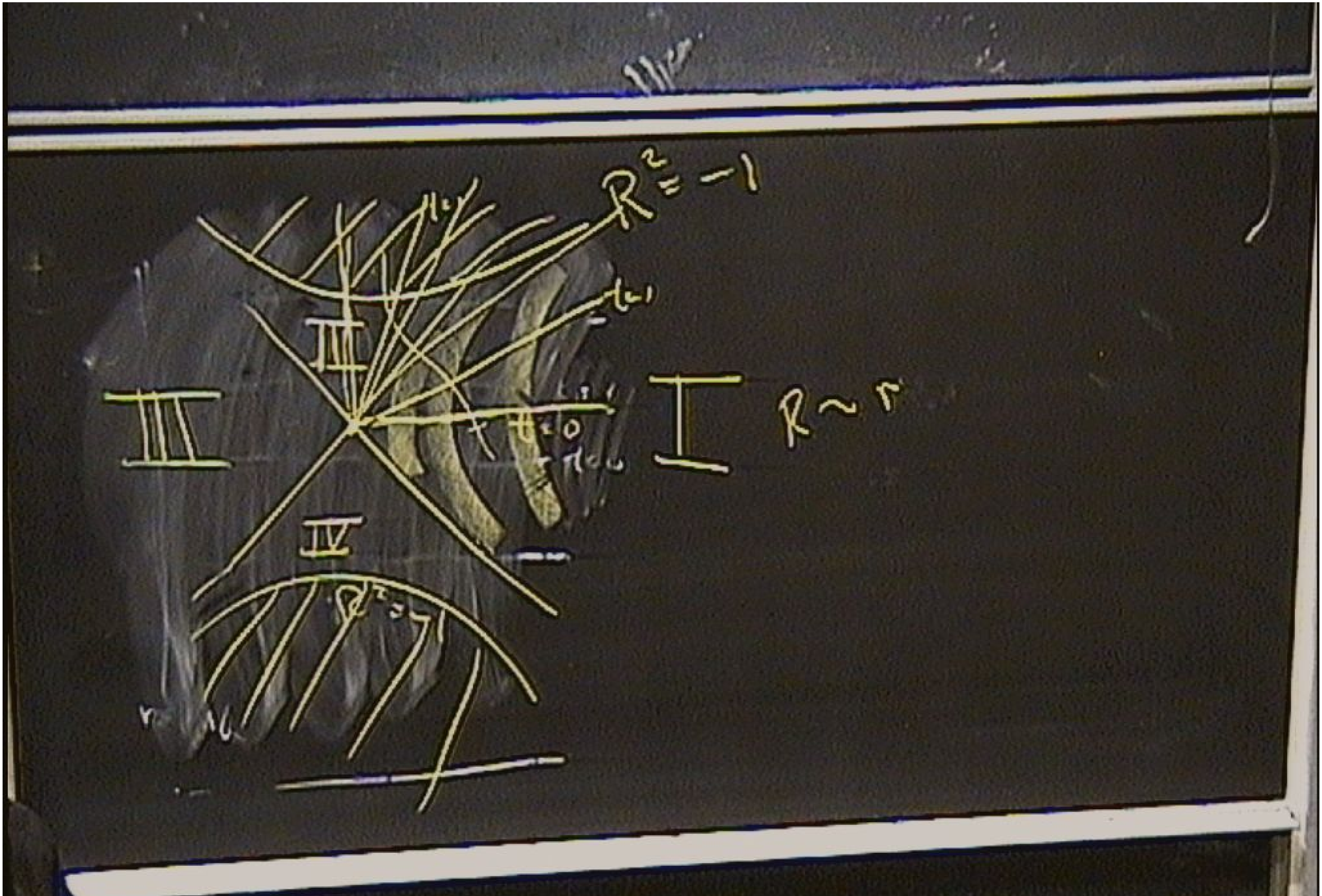
$$4MG\,\log\frac{R}{4MG} = r^*$$


R ~ r

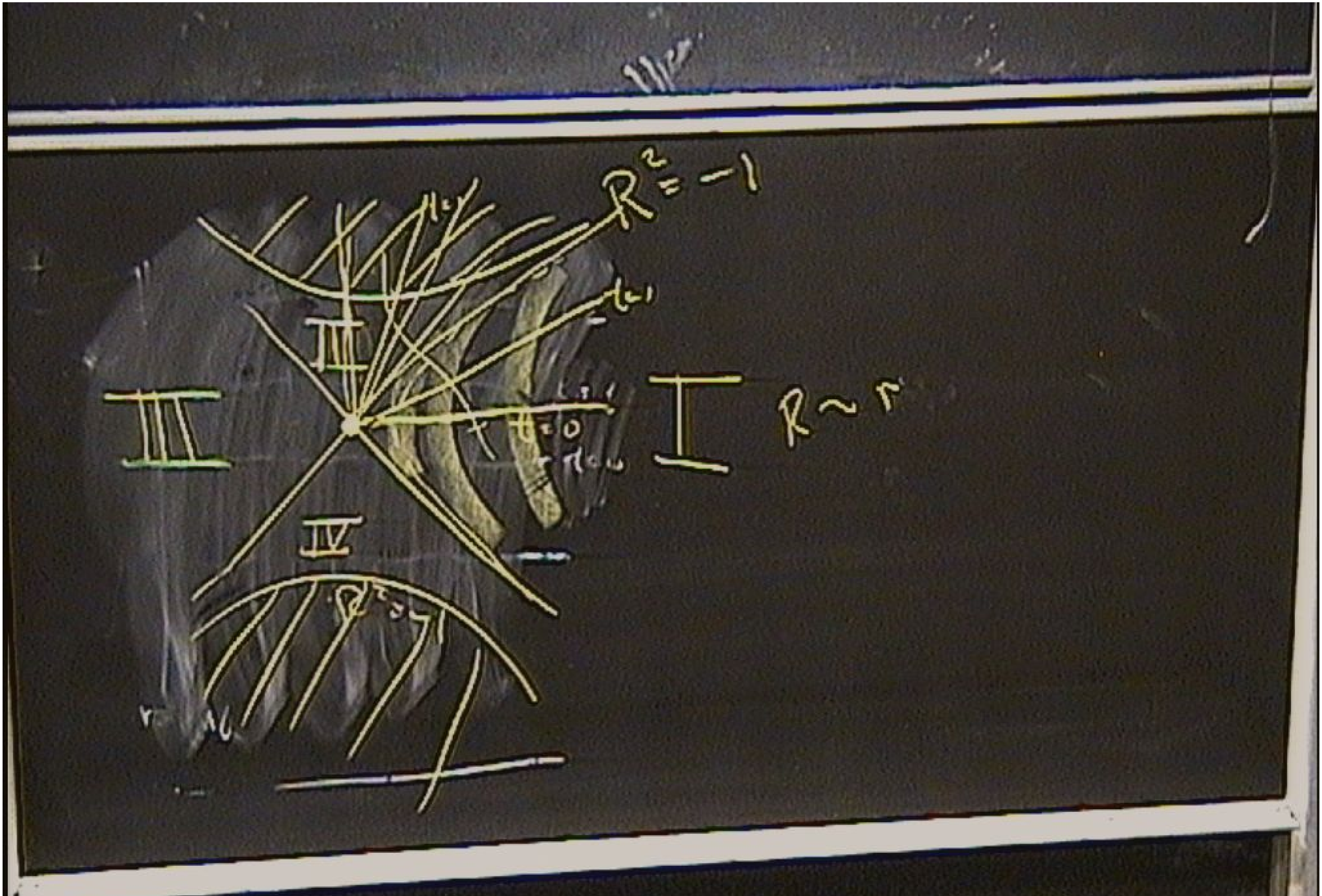

R ~ r

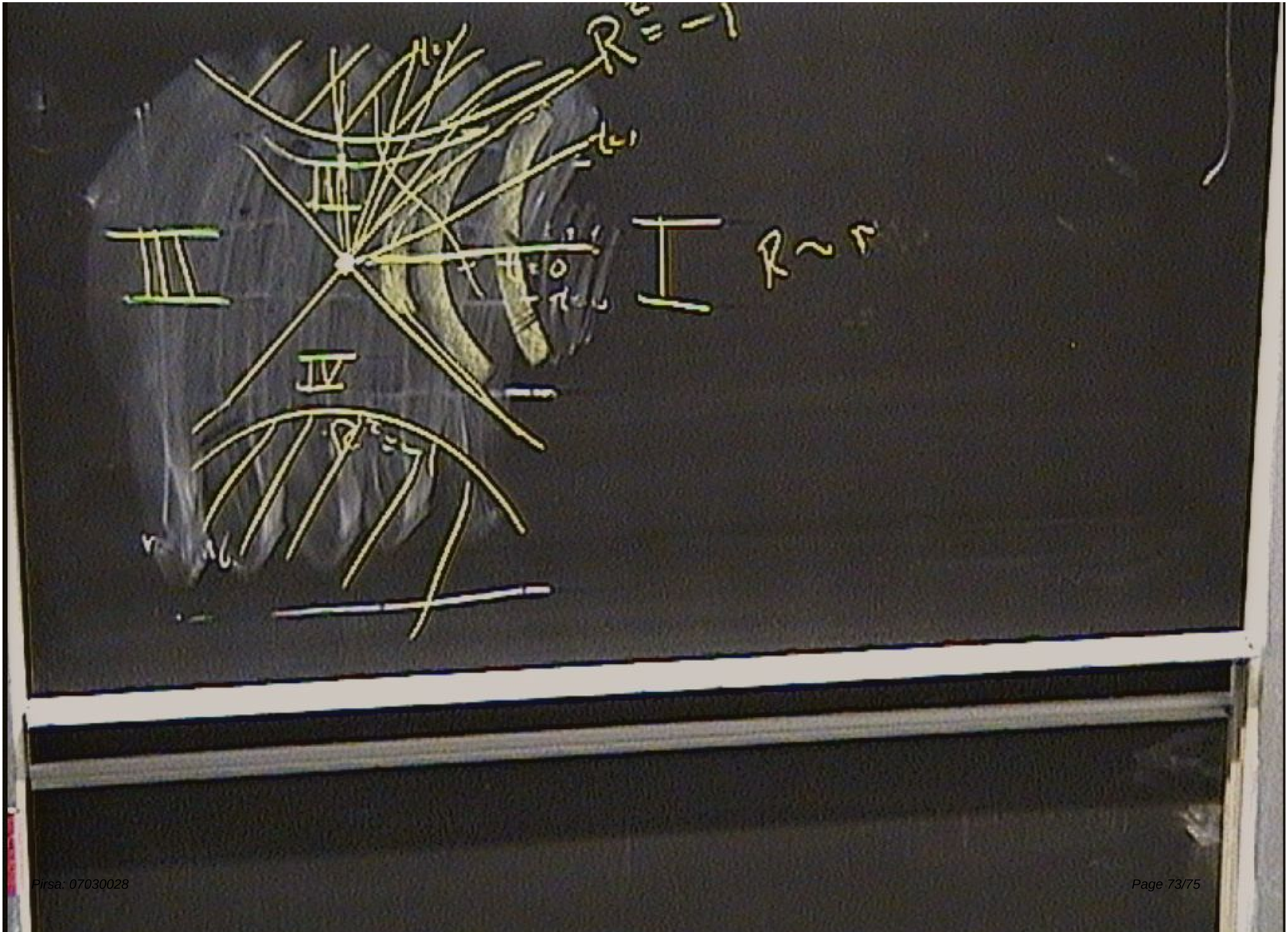

$R^2 = -1$
$R \sim r$

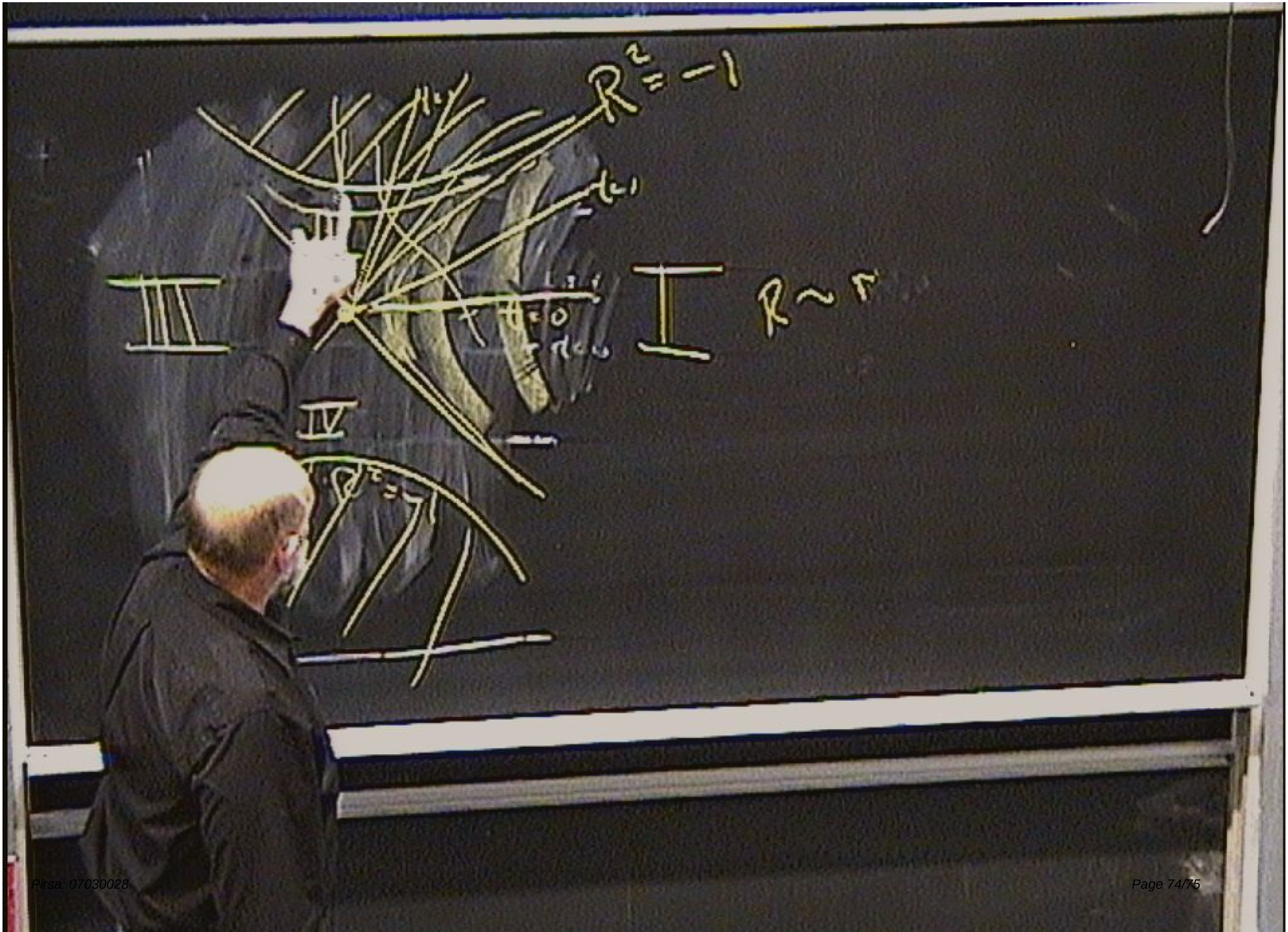

$R^2 = -1$
$t=0$
$R \sim r$
$R^2 = -1$



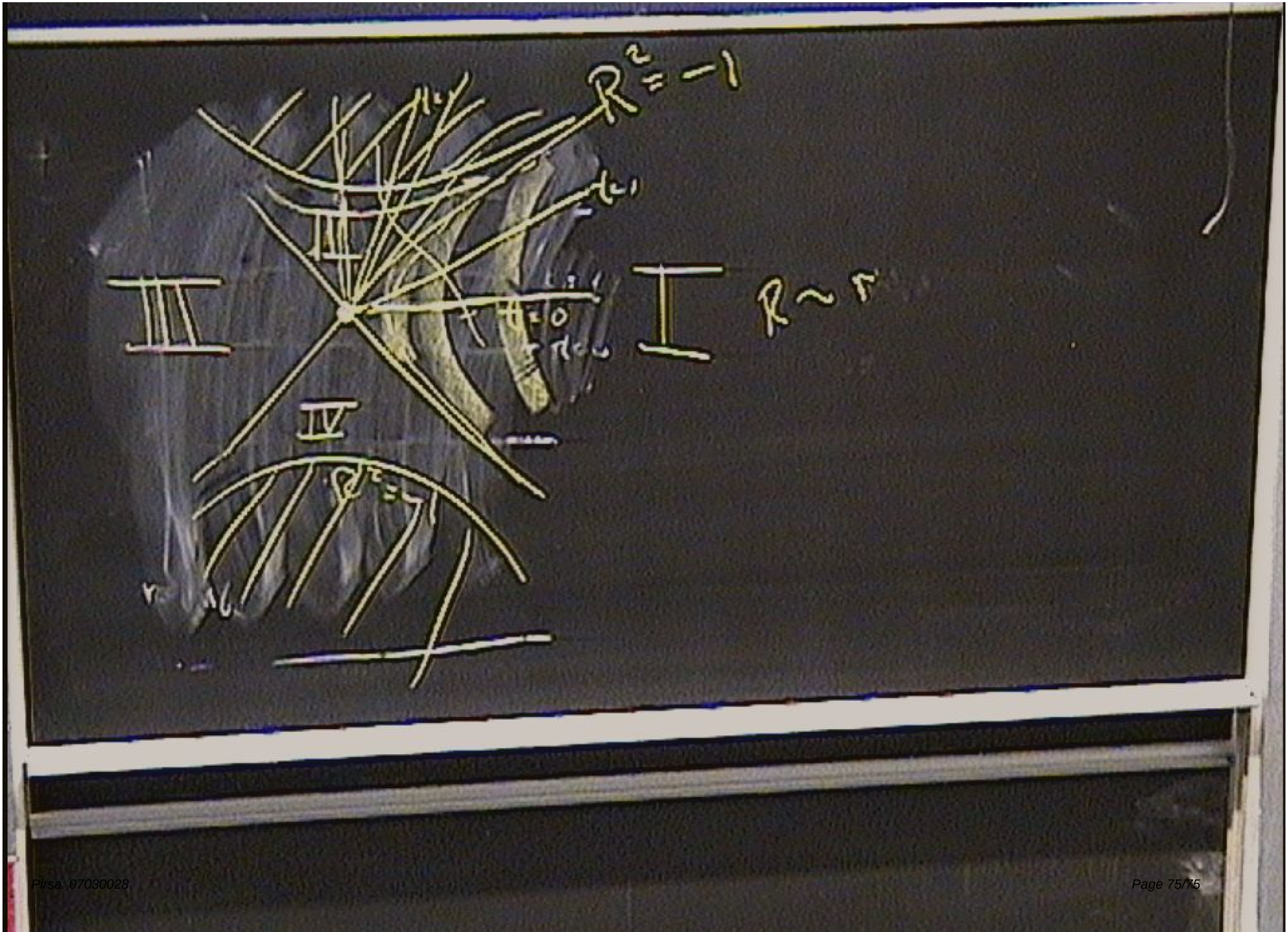
$R^2=-1$
t=1
III
II
I
$R\sim r$
t=0
IV
$R^2=-1$


$R^2=-1$
I
II
III
IV
$R\sim r$


III
II
I
R ~ r
IV



$R^2 = -1$
III
I
$R \sim r$
IV



$R^2 = -1$
I
II
III
IV
$R \sim r$