

Title: Physics Beyond the Horizon 1

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Abstract:

Maldacena 010622

Filkowski, Huber, Kleban, SS

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03-06-170



Horizon

∞

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Horizon

∞

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Horizon

∞

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Horizon

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Horizon



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fix
understand
locality

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Horizon

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understand
locality

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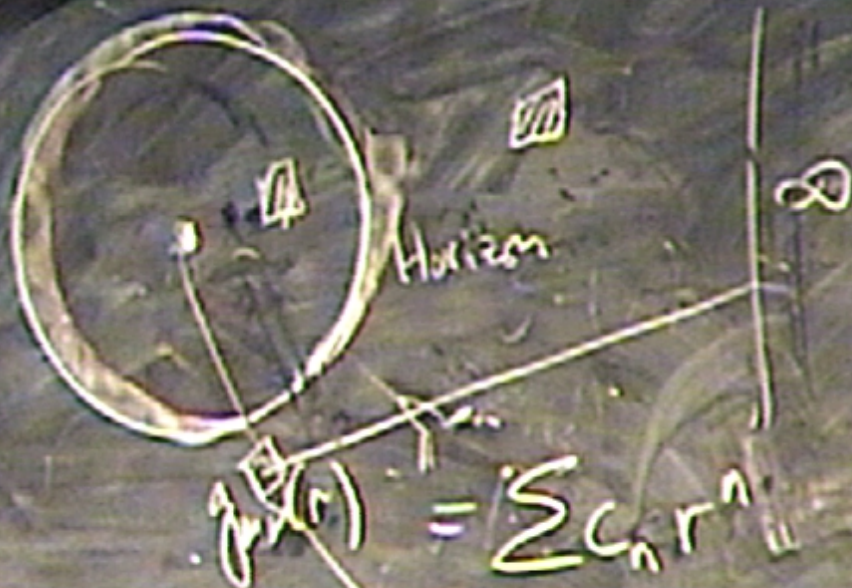


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locality

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understand
locality

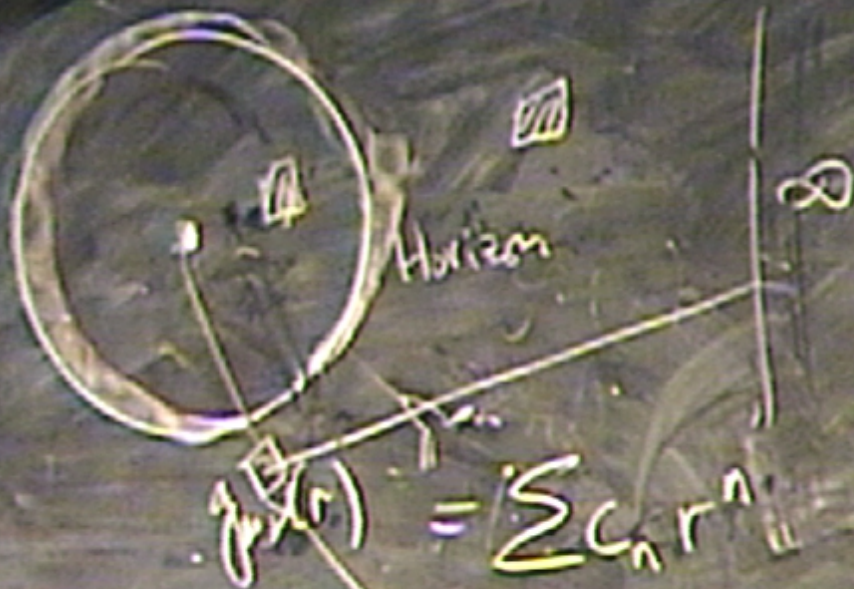
$$f(r) = \left(1 - \frac{2GM}{r}\right)$$

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fix
understand
location

$f(r)$



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$g(r) = \frac{1}{2}$

fix
understand
locality

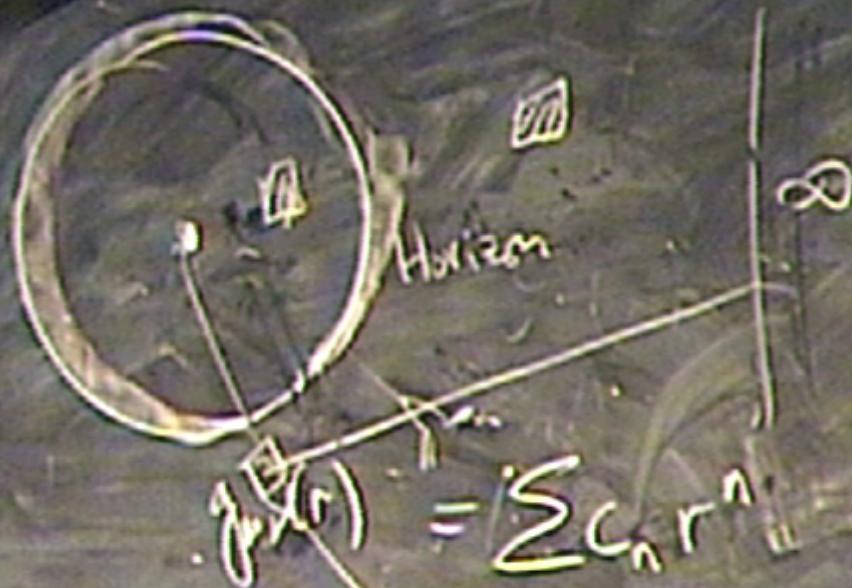
$f(r)$



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understand
locality

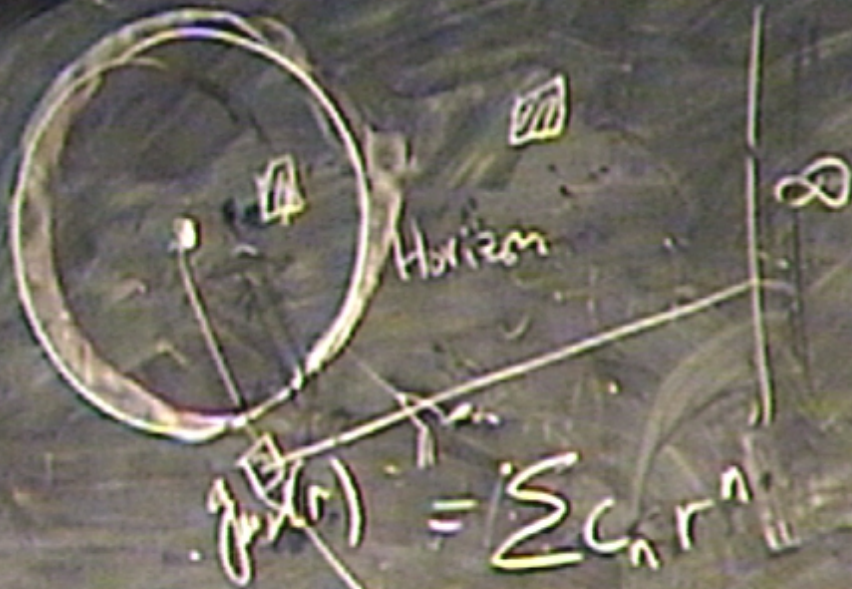
$f(r)$

derivative

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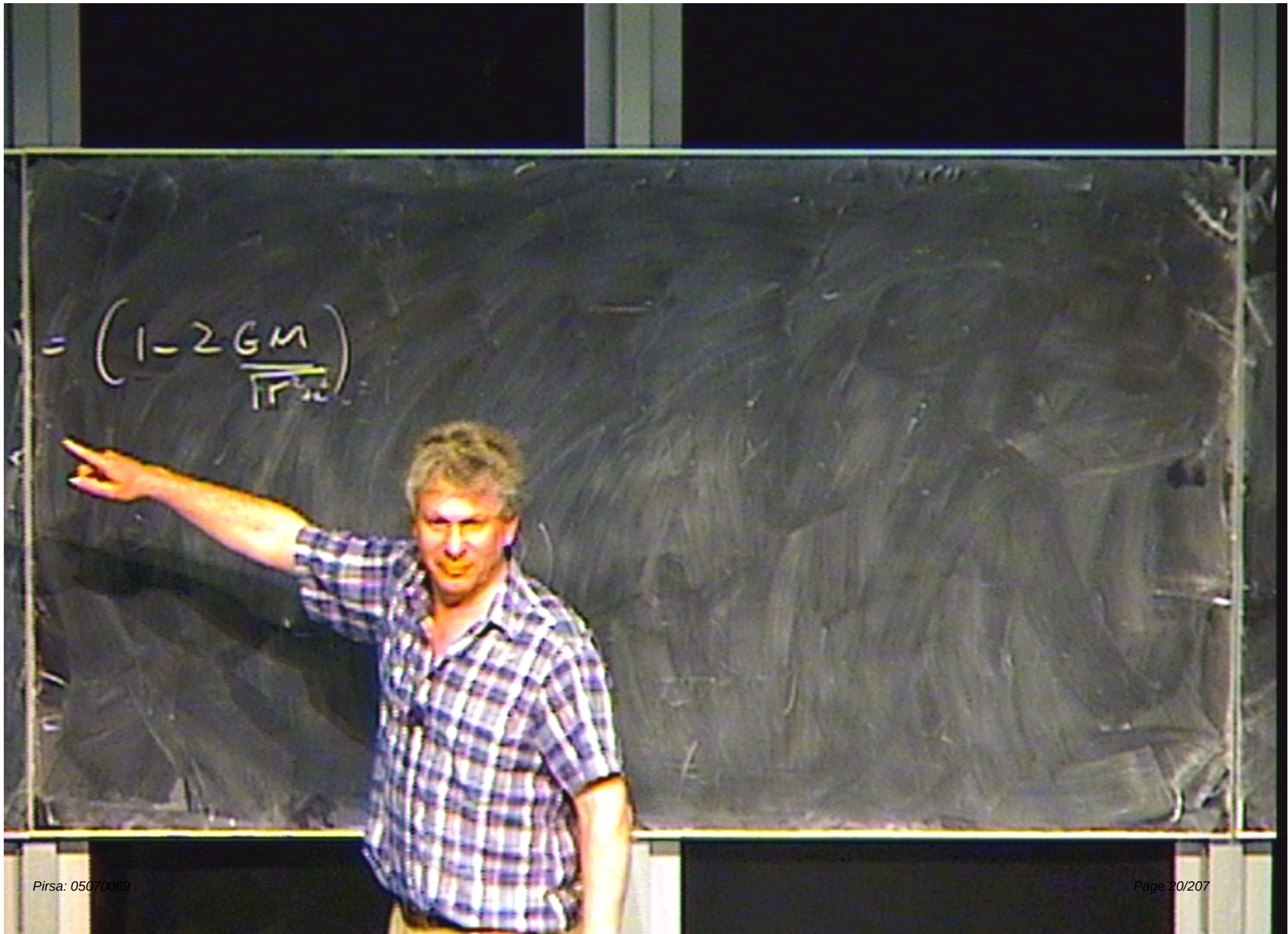
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fix
understand
locality

$f(r)$





$$= \left(1 - \frac{2GM}{r_{ph}} \right)$$

$$= \left(1 - \frac{2GM}{r_{\text{sc}}}\right)$$

use D-branes as probes
of geometry

$$\frac{m_s}{\delta \neq}$$

$$= \left(1 - \frac{2GM}{r^2}\right)$$

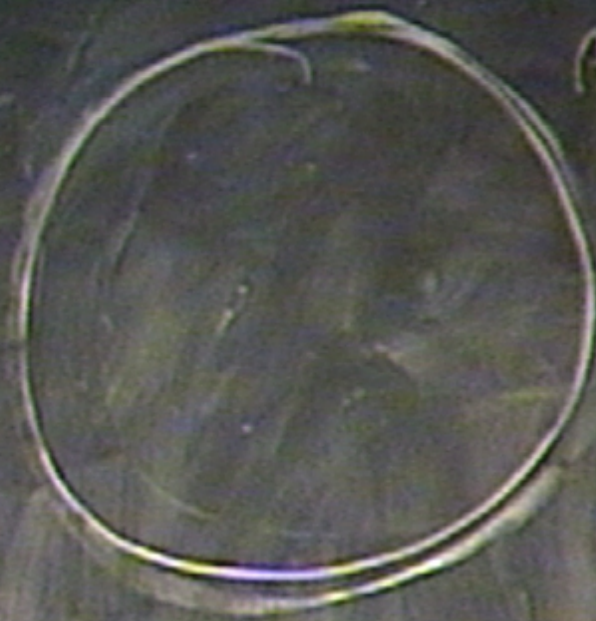
use D-branes as probes
of geometry $\frac{m_s}{\hbar}$

$$= \left(1 - \frac{2GM}{r c^2}\right)$$

use D-branes as probes
of geometry $\frac{m_s}{\hbar}$

$$= \left(1 - \frac{2GM}{r_{\text{Sch}}}\right)$$

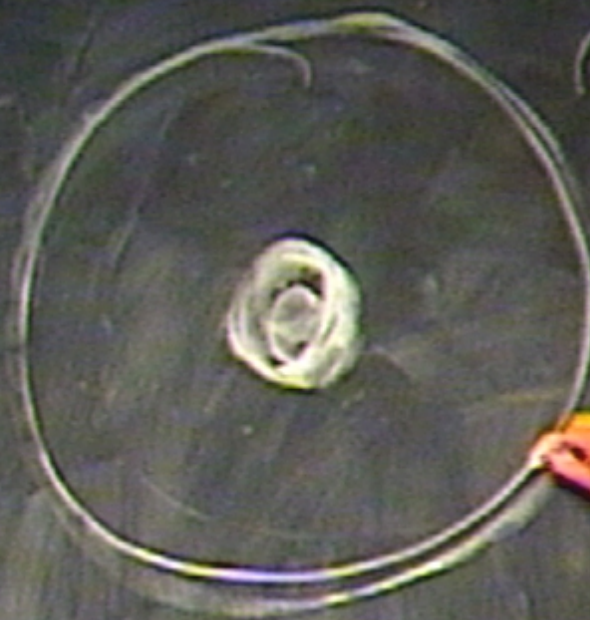
use D-branes as probes
of geometry $\frac{m_s}{\hbar}$



ANSK F

$$= \left(1 - \frac{2GM}{r c^2}\right)$$

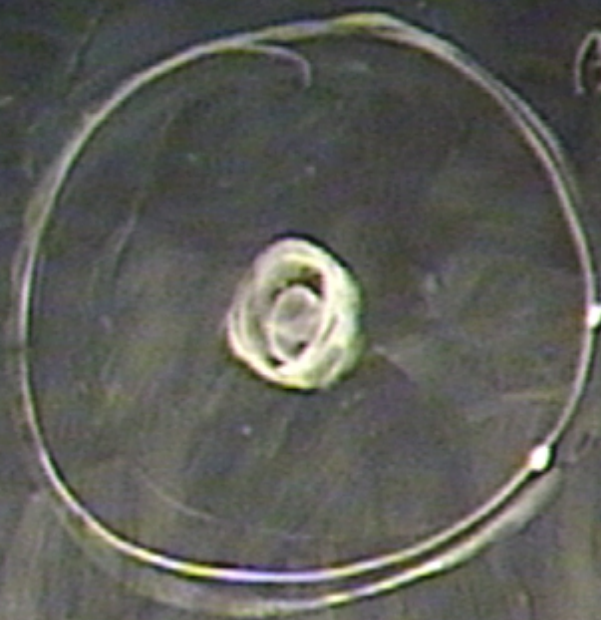
use D-branes as probes
of geometry $\frac{m_s}{\hbar}$



ASK F

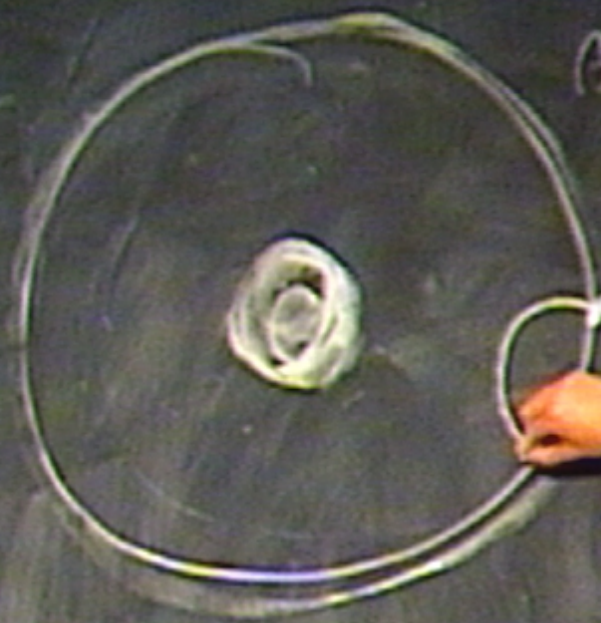
$$= \left(1 - \frac{2GM}{r c^2}\right)$$

use D-branes as probes
of geometry $\frac{m_s}{\hbar}$

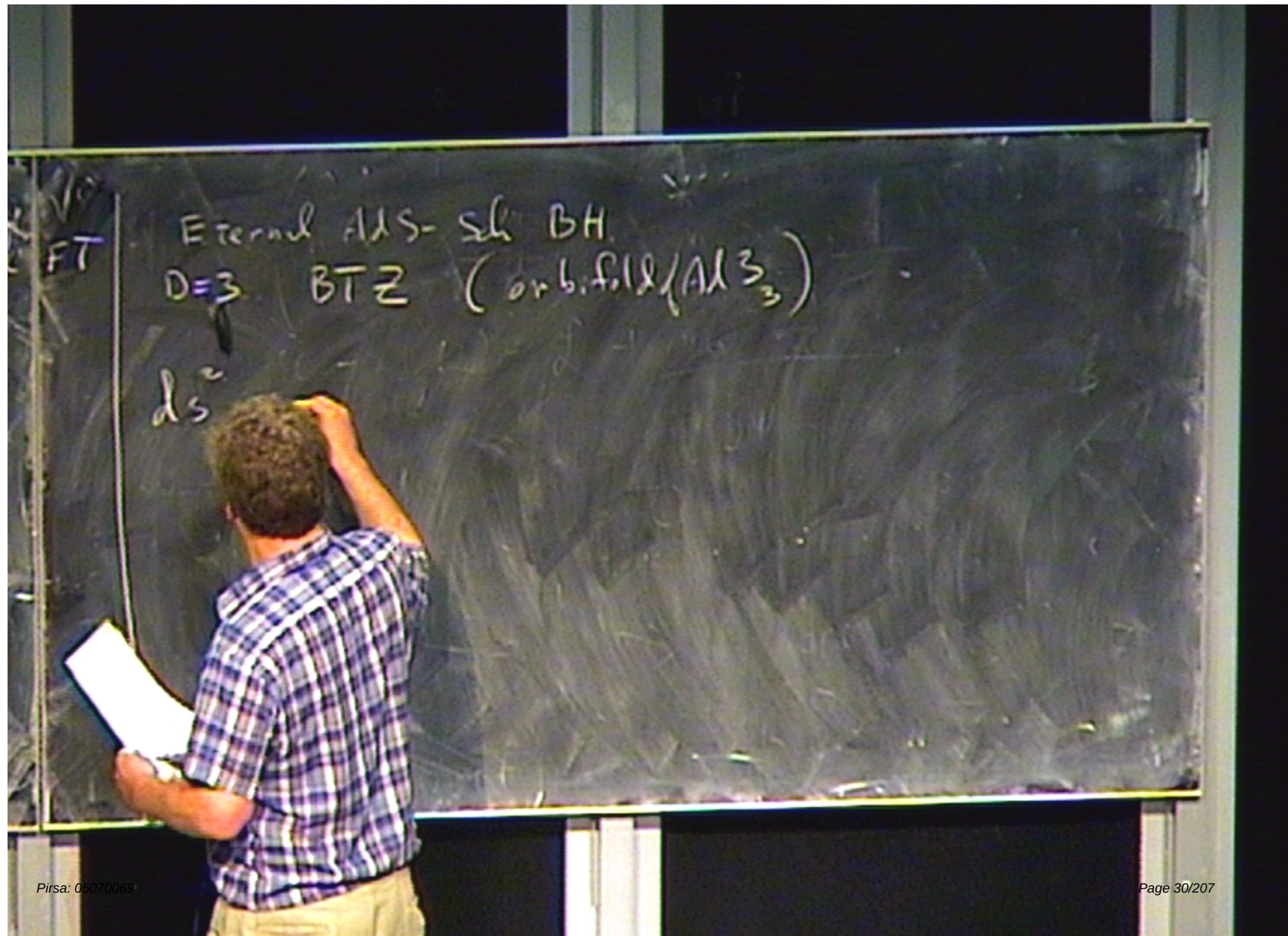


$$= \left(1 - \frac{2GM}{r c^2}\right)$$

use D-branes as probes
of geometry $\frac{m_s}{\hbar}$



FT
Eternal AdS- S_L BH
 $D=3$ BTZ (



FT
External AdS- sol BH
 $D=3$ BTZ (orbifold AdS_3)

$$ds^2 = R_{\text{AdS}}^2 \left(-f(r) dt^2 + \frac{1}{f(r)} dr^2 + r^2 d\theta^2 \right)$$

$$f(r) = (r^2 - r_+^2) \quad f(r_+) = 0$$

FT
Eternal AdS- sol BH
D=3 BTZ (orbifold AdS_3)

$$ds^2 = R_{AdS}^2 \left(-f(r) dt^2 + \frac{1}{f(r)} dr^2 + r^2 d\theta^2 \right)$$

$$f(r) = (r^2 - r_+^2)$$

$$R_{AdS} = 1$$

FT
Eternal AdS-Sch BH
 $D=3$ BTZ (orbifold AdS_3)

$$ds^2 = R_{AdS}^2 \left(-f(r) dt^2 + \frac{1}{f(r)} dr^2 + r^2 d\theta^2 \right)$$

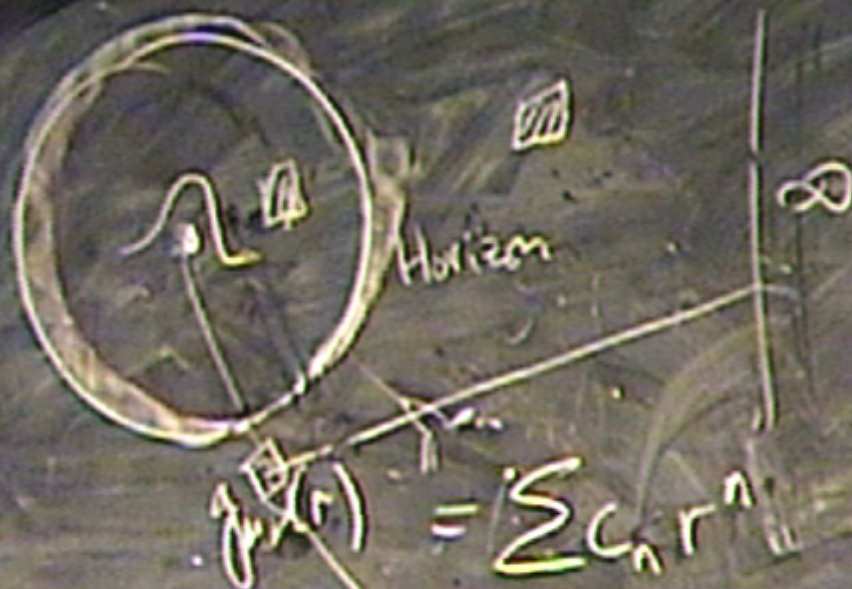
$$f(r) = (r^2 - r_+^2), \quad f(r_+) = 0$$

$$R_{AdS} = 1 \xrightarrow{\text{rescaling}} f(r) = r^2 - 1$$

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fix
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locality

$f(r)$



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ALS-Sch₃

$f(r)$

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ALS-Sch₃

$f(r)$



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Also Sch₃

$f(r)$

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ALS-Sch₃



Flare-up

$f(r)$

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ALS-Sch₃

ALS (rem)

$f(r)$

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ALS-Sch₃

ALS (ram)

$f(r)$

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$f(r)$

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ALS-Sch₃

ALS (ram)

$f(r)$

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ALS-Sch₃

ARS
Weyl₂



Al
b₂

$f(r)$

ALS-Sch₃

ALS
blary₂
cft₂



ALS (r=∞)
blary₁
cft₁

ALS-Sch₃

ALS
blary₂
cft₂



AdS ($r=\infty$)
blary₁
cft₁

0106112

Hu, Yang, Kleban, SS

Sch₃



ALS (rem)
bary
cf

$$|\psi\rangle_{HH} =$$

$$= \sum -\beta E_n/2$$

$$|n\rangle_1$$

$$|n\rangle_2$$

0106112

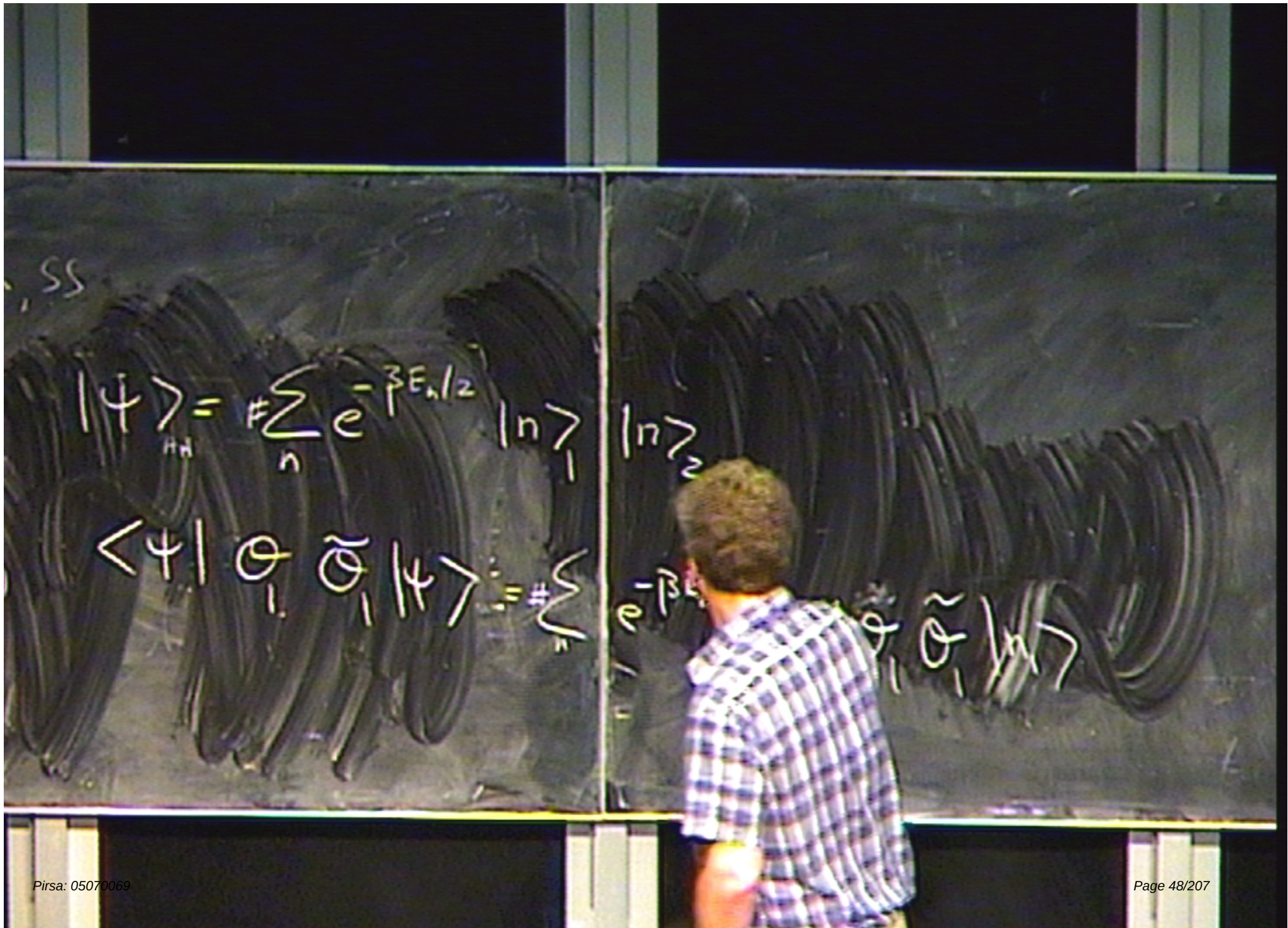
Hu, Berg, Kleban, SS

Sch₃



ALS (rem)
blng
ctt

$$|\psi\rangle_{HH} = \sum_n e^{-\beta E_n/2} |n\rangle_1 |n\rangle_2$$



SS

$$|\psi\rangle_{HH} = \# \sum_n e^{-\beta E_n/2} |n\rangle_1 |n\rangle_2$$

$$\langle \psi | \Theta_1 \tilde{\Theta}_1 | \psi \rangle = \# \sum_n e^{-\beta E_n} \langle \Theta_1 \tilde{\Theta}_1 | n \rangle$$

$$|\psi\rangle = \frac{1}{\mathcal{N}} \sum_n e^{-\beta E_n/2} |n\rangle_1 |n\rangle_2$$

$$\langle \psi | \hat{\Theta}_1 \tilde{\Theta}_1 | \psi \rangle = \frac{1}{\mathcal{N}^2} \sum_n e^{-\beta E_n} \langle n_1 | \hat{\Theta}_1 \tilde{\Theta}_1 | n_1 \rangle$$

SS

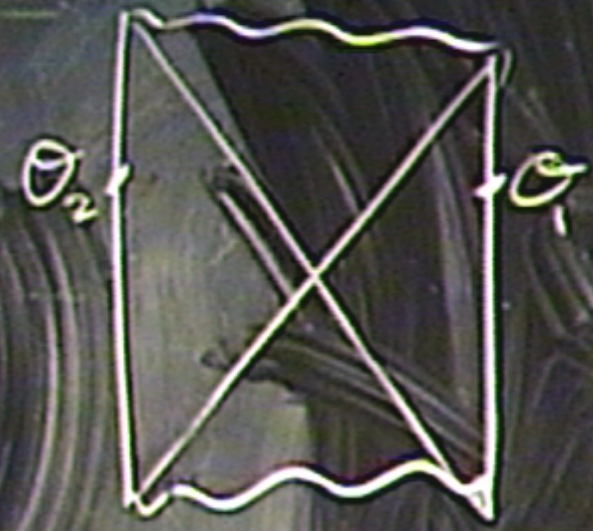
$$|\psi\rangle_{HH} = \# \sum_n e^{-\beta E_n/2} |n\rangle_1 |n\rangle_2$$

$$\langle \psi | \Theta_1 \tilde{\Theta}_1 | \psi \rangle = \# \sum_n e^{-\beta E_n} \langle n, 1 | \Theta_1 \tilde{\Theta}_1 | n \rangle$$

$$|n\rangle_2$$

$$e^{-\beta E_n}$$

$$\langle n, | \theta, \tilde{\theta} \rangle | n \rangle$$

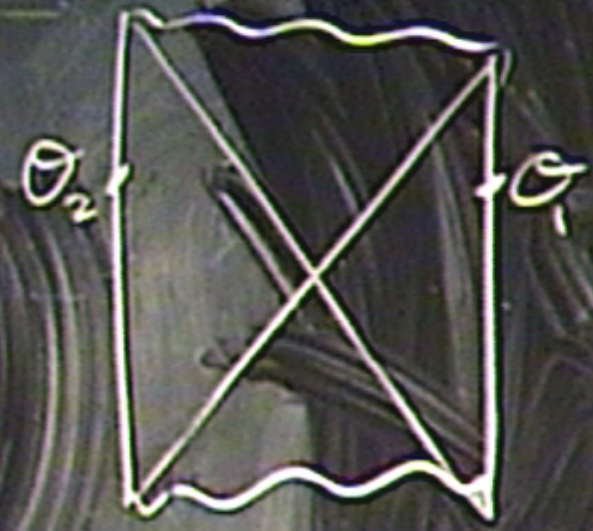


$$\langle + | \sigma_z | \sigma_z \rangle$$

$$|n\rangle_2$$

$$e^{-\beta E_n}$$

$$\langle n, | \theta, \tilde{\theta} \rangle | n \rangle$$

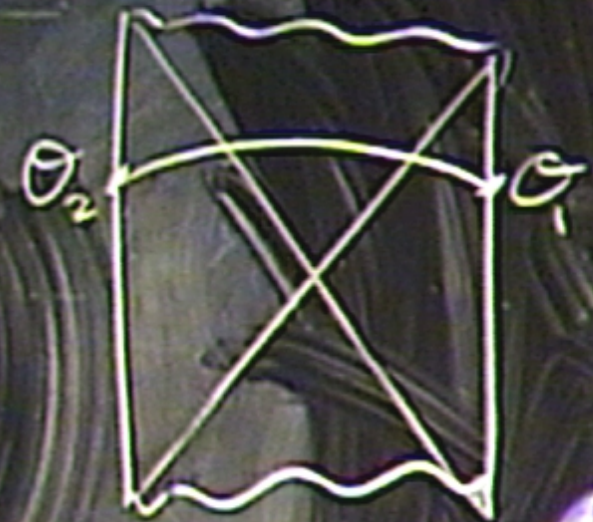


$$\langle + | \theta_2, \theta_1 | + \rangle$$

$$\ln Z$$

$$e^{-\beta E_n}$$

$$\langle n, | \theta, \tilde{\theta} | n \rangle$$



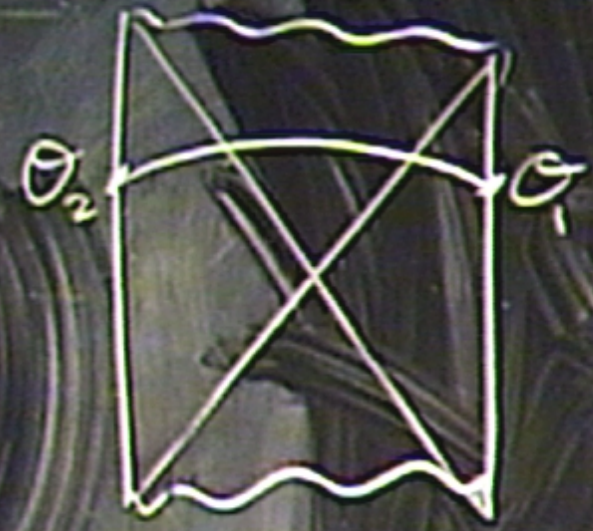
$$\langle + | \sigma_z | \sigma_1 \rangle$$



$$|n\rangle_2$$

$$e^{-\beta E_n}$$

$$\langle n, | \theta, \tilde{\theta} \rangle | n \rangle$$

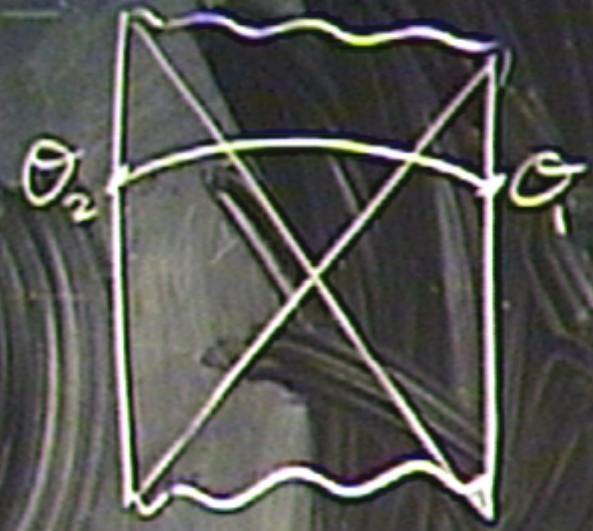


$$\langle + | \theta_2, \theta_1 | + \rangle$$

$$|n\rangle_2$$

$$e^{-\beta E_2}$$

$$\langle n, | \theta_1, \tilde{\theta}_1 | n \rangle$$



$$\langle + | \theta_2, \sigma_1 | + \rangle$$

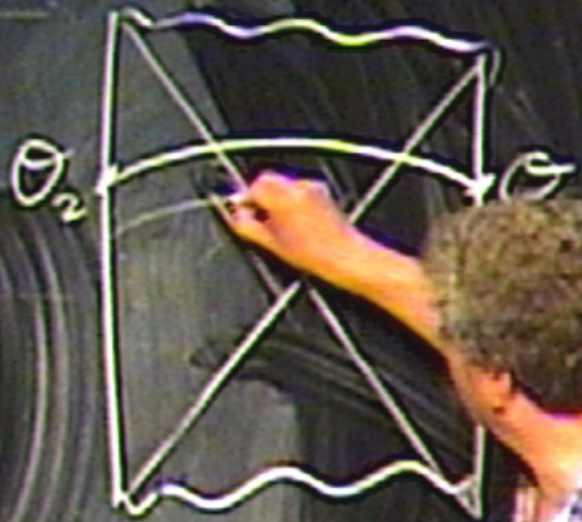
$$T_{12}$$



$$|n\rangle_2$$

$$e^{-\beta E_n}$$

$$\langle n, | \theta, \tilde{\theta} | n \rangle$$



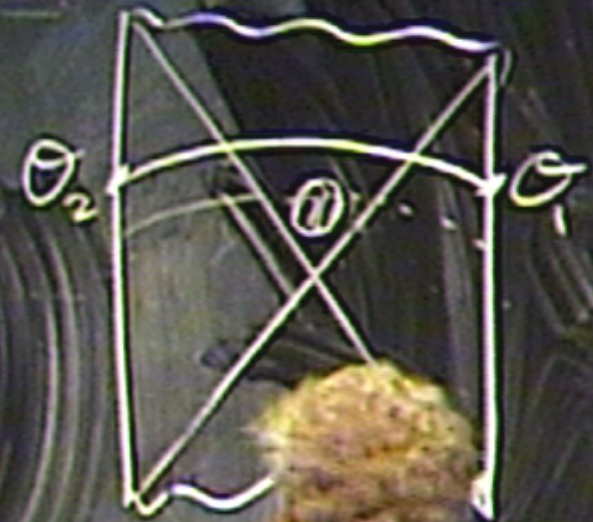
$$\langle + | \sigma_z | \sigma_z | + \rangle$$



$$|n\rangle_2$$

$$e^{-\beta E_n}$$

$$\langle n, | \theta, \tilde{\theta} \rangle | n \rangle$$



$$\langle + | \sigma_z | + \rangle$$

$$T_{12}$$



$$|n\rangle_2$$

$$e^{-\beta E_n}$$

$$\langle n, | \theta_1, \tilde{\theta}_1 | n \rangle$$



$$\langle + | \sigma_z | + \rangle$$

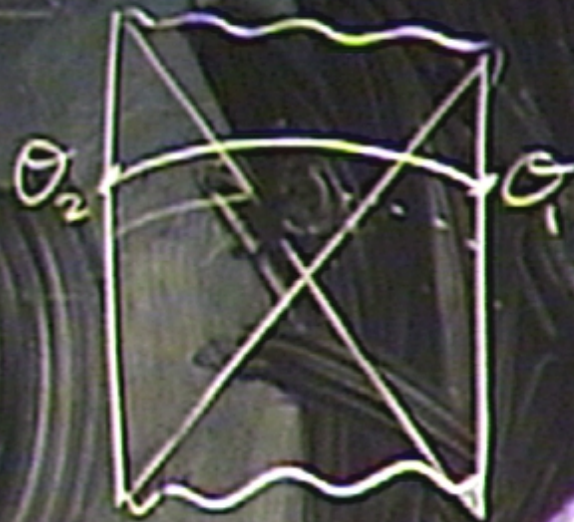
$$T_{12}$$



$$|n\rangle_2$$

$$e^{-\beta E_n}$$

$$\langle n, |\theta, \tilde{\theta}| n \rangle$$



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ALS-Sch₃

ARS

W₁
c

ALS (real)
bilinear
cf₁

$$|\psi\rangle = \# \sum_n e^{-\beta E_n/2} |n\rangle$$

$$\langle \psi | \phi_i \phi_i | \psi \rangle = \# \sum_n$$

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ALS-Sch₃

ARS

ALS (real)
baryon
cf

$$|4\rangle_{HH} = \# \sum_n e^{-\beta E_n/2} |n\rangle$$

$$\langle 4 | \Theta_i \tilde{\Theta}_i | 4 \rangle = \# \sum_n$$

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AdS-Sch₃

AdS
Weyl₂
CFT₂



AdS (near)
Hubeny
CFT₁

$$|n\rangle = \frac{1}{\sqrt{Z}} \sum_n e^{-\beta E_n/2} |n\rangle$$

(t +

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AdS-Sch₃

$$| \psi \rangle_{HH} = \# \sum_n e^{-\beta E_n/2} | n \rangle_1$$

AdS
Weyl₂
cft₂

AdS (near)
holog₁
cft₁

$\phi_1(t+)$

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ALS-Sch₃

$$|\psi\rangle_{HH} = \# \sum e^{-\beta E_n/2} |n\rangle_1$$

ALS
blary₂
cft₂



ALS (real)
blary₁
cft₁

ϕ

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AdS-Sch₃



$$|4\rangle = \# \sum_n e^{-\beta E_n/2} |n\rangle$$

$$t + i\beta$$

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AdS-Sch₃

$$|\psi\rangle_{HH} = \# \sum_n e^{-\beta E_n/2} |n\rangle_1$$

$$\phi_1(t + i\frac{\beta}{2}) = \phi_2$$

AdS

Hubeny

AdS (near)

Hubeny

cf

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ALS-Sch₃



$$|\psi\rangle_{HH} = \# \sum_n e^{-\beta E_n/2} |n\rangle_1$$

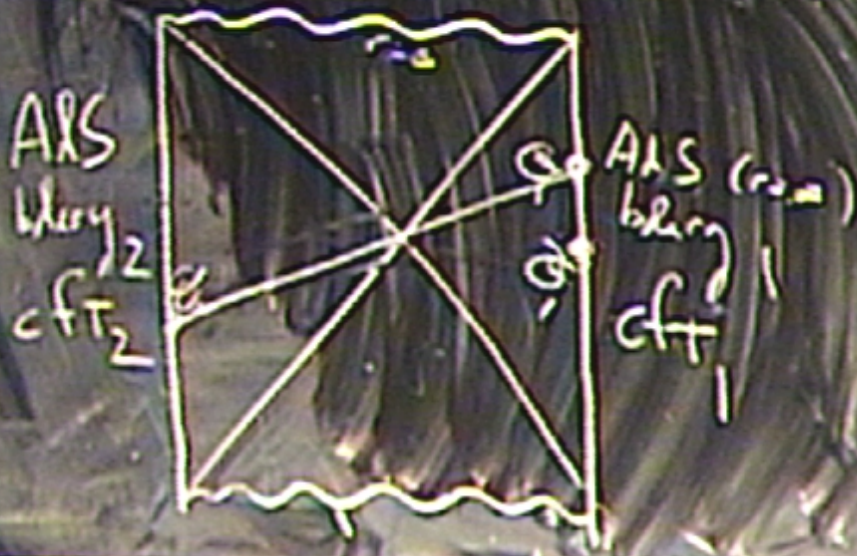
$$\phi_1(t + i\frac{\beta}{2}) = \phi_2$$

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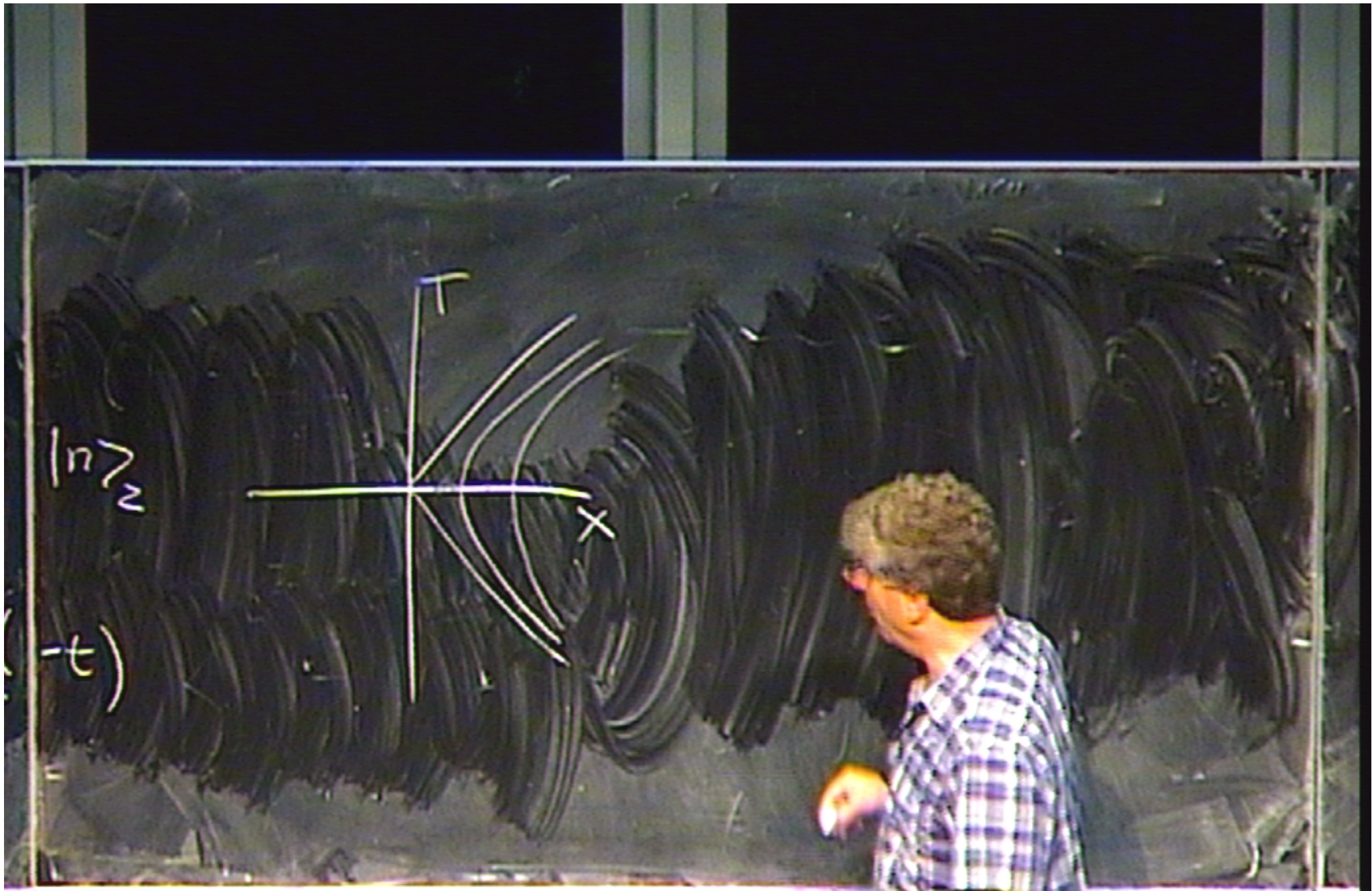
ALS-Sch₃

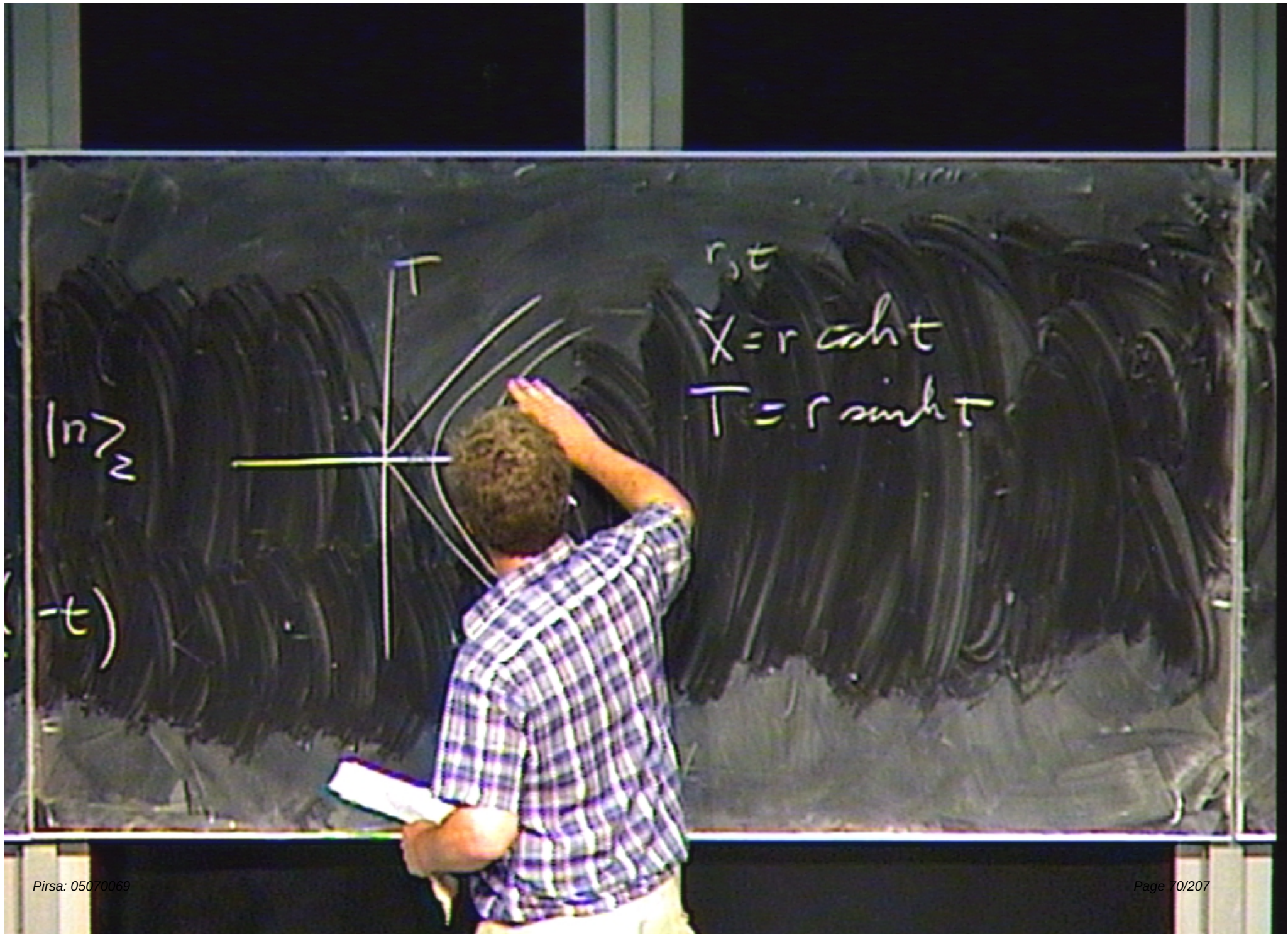


$$|4\rangle_{HH} = \# \sum_n e^{-\beta E_n/2} |n\rangle_1$$

$$\phi_1(t + i\frac{\beta}{2}) = \phi_2$$

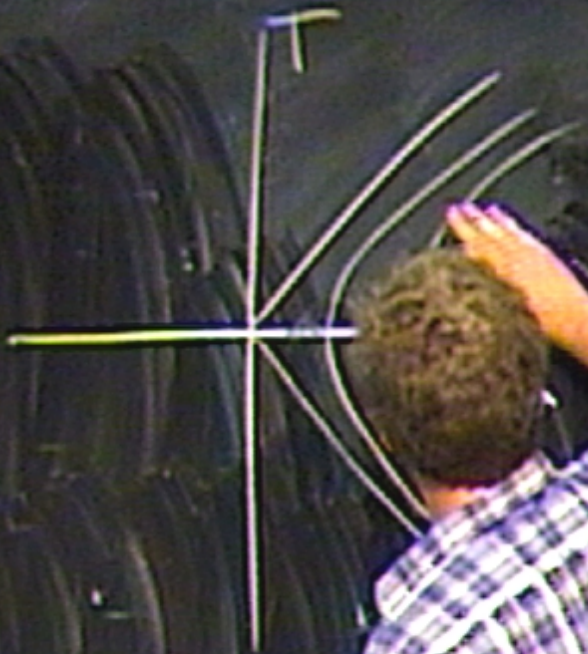
in $|4\rangle$





$\ln z_2$

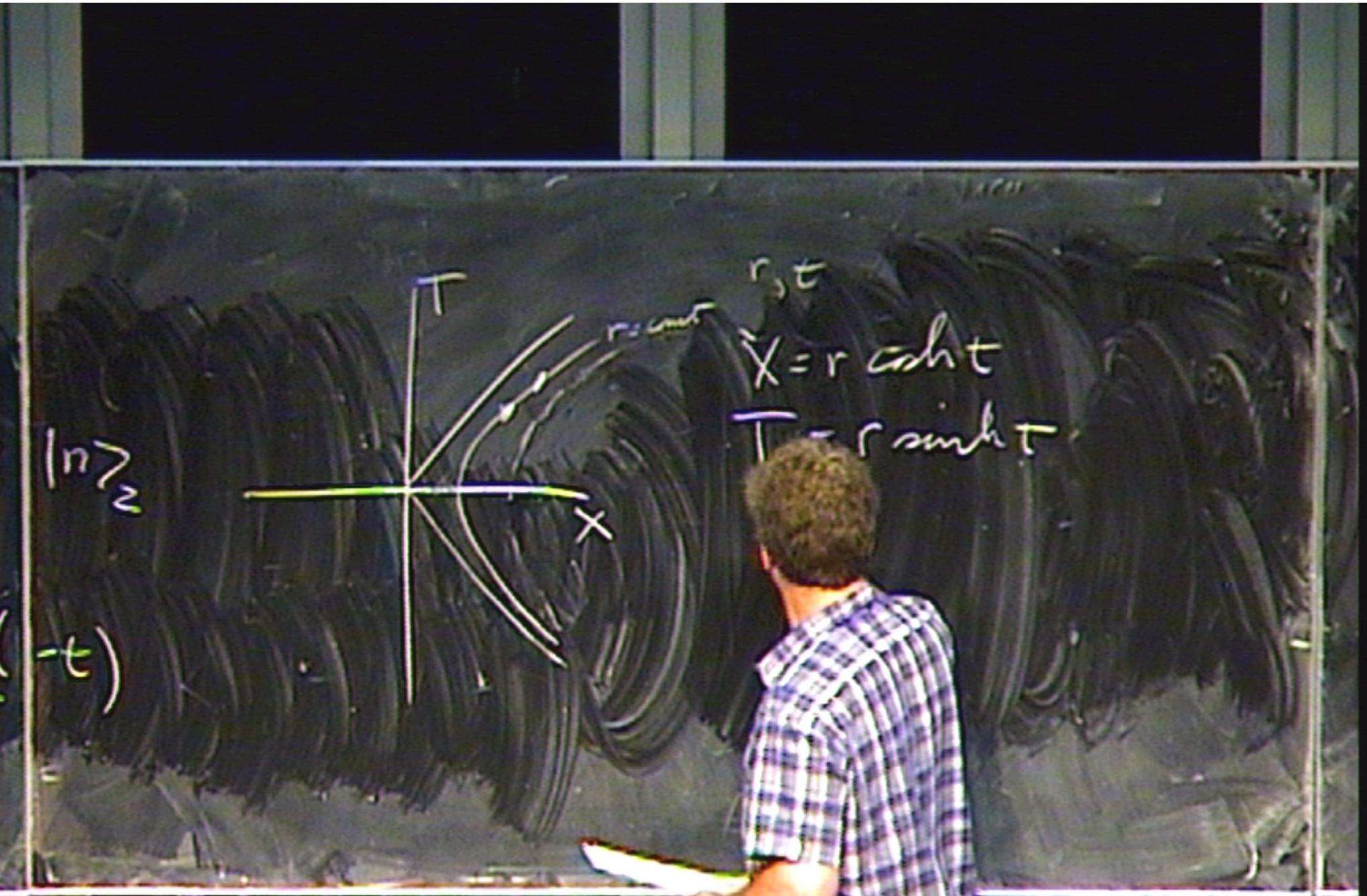
$(-t)$

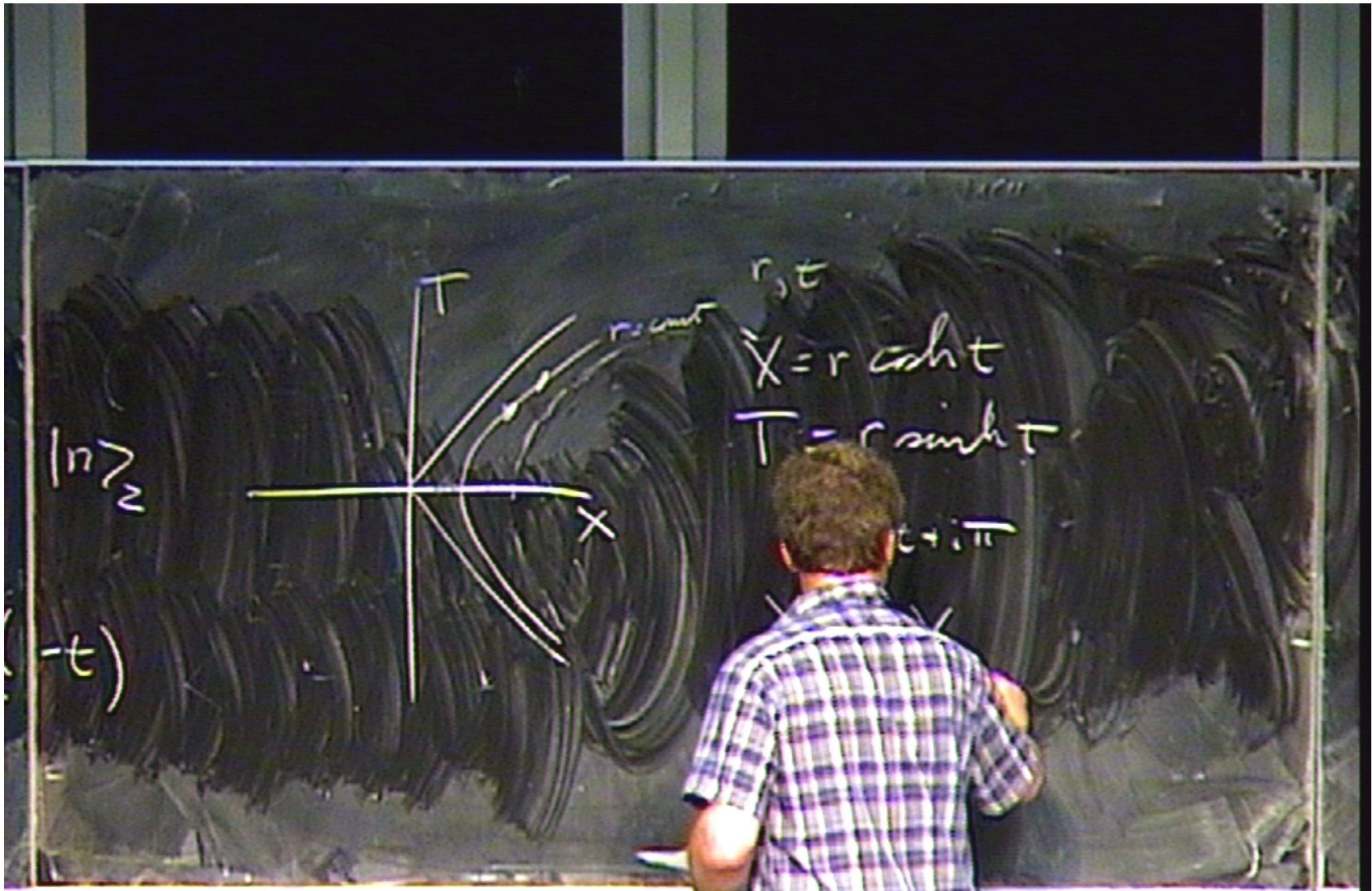


r, t

$$X = r \cosh t$$

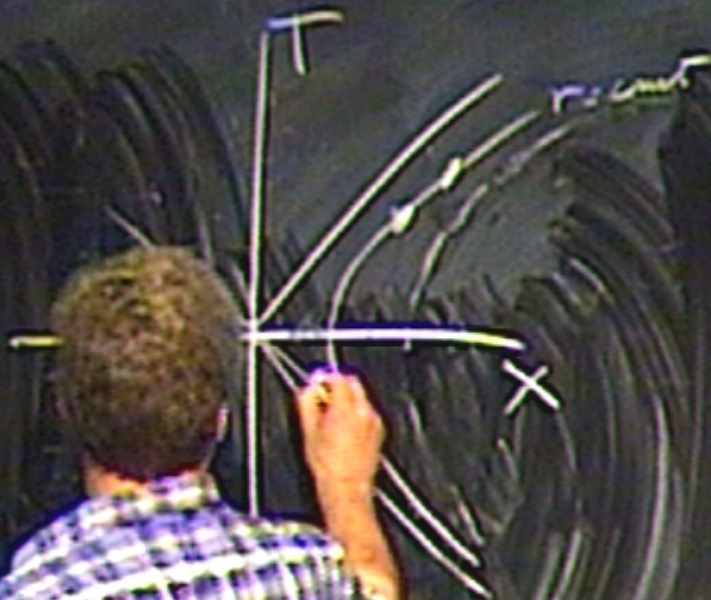
$$T = r \sinh t$$





$\ln z$

$(-t)$



r, t

$$X = r \cosh t$$

$$T = r \sinh t$$

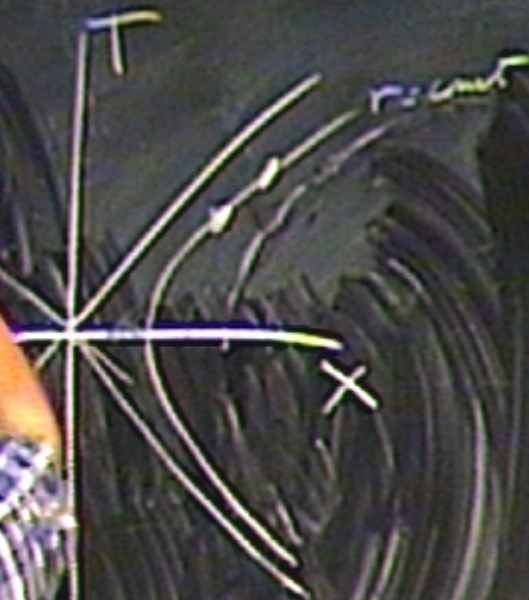
$$t \rightarrow t + i\pi$$

$$X \rightarrow -X$$

$$T \rightarrow -T$$

$\ln z$

$(-t)$



r, t

$$X = r \cosh t$$

$$T = r \sinh t$$

$$t \rightarrow t + i\pi$$

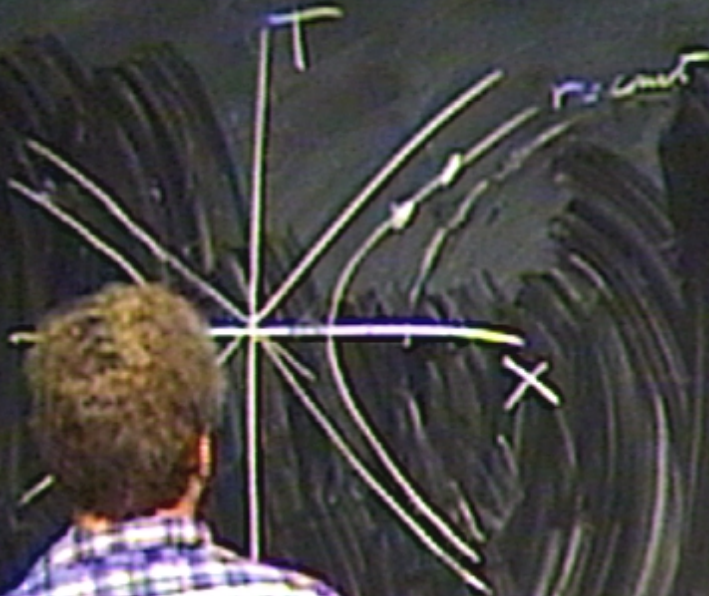
$$X \rightarrow -X$$

$$T \rightarrow -T$$



$\ln z$

$(-t)$



r, t

$$X = r \cosh t$$

$$T = r \sinh t$$

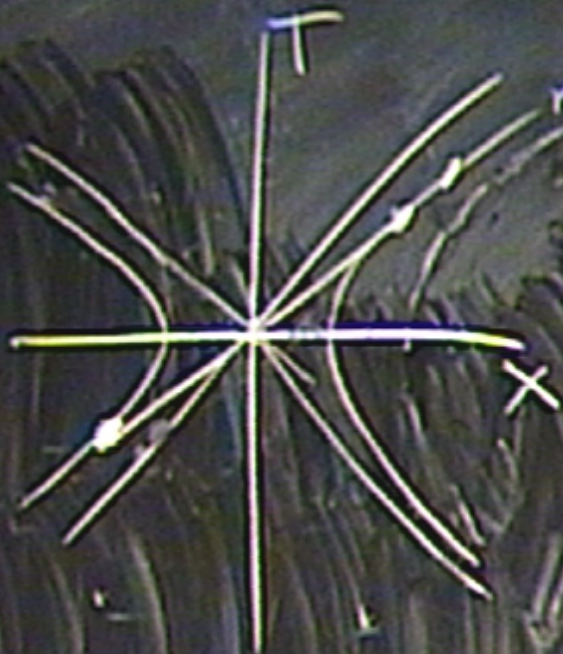
$$t \rightarrow t + i\pi$$

$$X \rightarrow -X$$

$$T \rightarrow -T$$

$\ln \gamma_2$

$-t)$



r, t

$$X = r \cosh t$$

$$T = r \sinh t$$

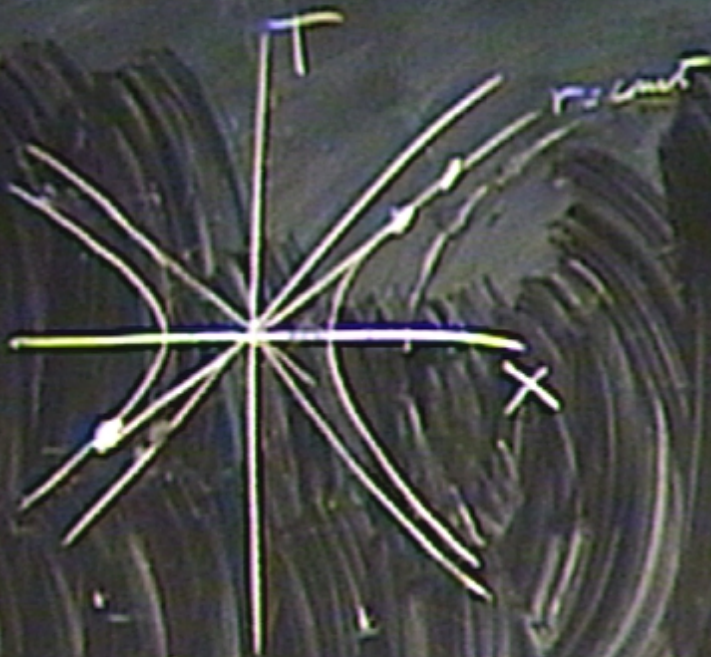
$$t \rightarrow t + i\pi$$

$$X \rightarrow -X$$

$$T \rightarrow -T$$

$\ln z$

$-t)$



r, t

$$X = r \cosh t$$

$$T = r \sinh t$$

$$t \rightarrow t + i\pi$$

$$X \rightarrow -X$$

$$T \rightarrow -T$$

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ALS-Sch₃

$$|\psi\rangle = \sum_n e^{-\beta E_n/2} |n\rangle$$

ARS
Weyl₂
cft₂



ALS (real)
Weyl₁
cft₁

$$\psi_1(t + i\frac{\beta}{2})$$

in $|\psi\rangle$

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ALS-Sch₃



$$|4\rangle_{HH} = \# \sum_n e^{-\beta E_n/2} |n\rangle_1$$

$$\phi_1(t + \frac{i\beta}{2}) = \phi_2$$

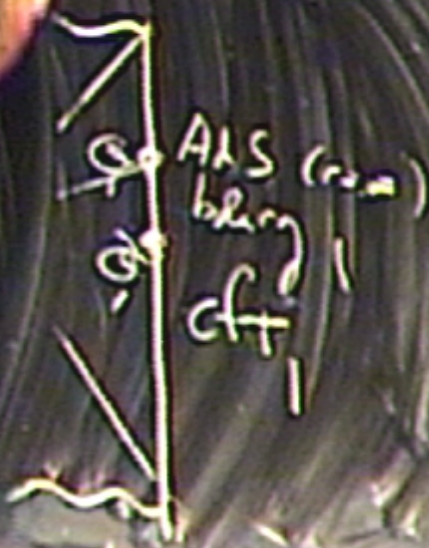
in $|4\rangle$

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ALS-Sch₃



$$| \psi \rangle_{HH} = \# \sum_n e^{-\beta E_n / 2} | n \rangle_1$$

$$\phi_1(t + i\frac{\beta}{2}) = \phi_2$$

in $| \psi \rangle$

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ALS-Sch₃

$$|4\rangle_{HH} = \# \sum_n e^{-\beta E_n/2} |n\rangle_1$$

ALS (real)
along
f₁

$$\phi_1(t + i\frac{\beta}{2}) = \phi_2$$

in $|4\rangle$

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ALS-Sch₃

$$= \# \sum_n e^{-\beta E_n/2} |\ln \rangle_1$$

$$\gamma_1(t + i\frac{\beta}{2}) = \phi_2$$

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$$\sim e^{-\beta E_n/2} \ln \gamma_1$$

$$\left(\frac{i\beta}{2} \right) = \phi_2$$

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$\frac{1}{2} \ln \gamma_1$

$= \phi_2$

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AlS-Sch₃

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ALS-Sch

| Geodesics in ALS-Sch

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AdS-Sch₃

Geodesics in AdS-Sch

Extremal action

$x^\mu(\tau)$

$$S = \int d\tau \dot{x}^2 \quad \cdot = \frac{d}{d\tau}$$

and AdS-Sch BH
BTZ (orbifold AdS_3)

$$R_{AdS}^2 \left(-f(r) dt^2 + \frac{1}{f(r)} dr^2 + r^2 d\phi^2 \right)$$

$$f(r) = (r^2 - r_+^2), \quad f(r_+) = 0$$

$$= 1 \xrightarrow{\text{rescaling}} f(r) = r^2 - 1$$

and AdS-Sch BH

BTZ (orbifold (AdS_3))

$$R_{AdS}^2 \left(-f(r) dt^2 + \frac{1}{f(r)} dr^2 + r^2 d\theta^2 \right)$$

$$f(r) = (r^2 - r_+^2), \quad f(r_+) = 0$$

$$= 1 \xrightarrow{\text{rescaling}} f(r) = r^2 - 1$$

and AdS-Sch BH

BTZ (orbifold AdS_3)

$$R_{AdS}^2 \left(-f(r) dt^2 + \frac{1}{f(r)} dr^2 + r^2 d\theta^2 \right)$$

$$f(r) = (r^2 - r_+^2), \quad f(r_+) = 0$$

$$= 1 \xrightarrow{\text{rescaling}} f(r) = r^2 - 1$$

radial geodesics
 $r(\tau), t(\tau)$

radial geodesics

$r(\tau), t(\tau)$

$\mathcal{G}_1$

radial geodesics

$r(t), t(t)$

$$S = \int dt - f(t) \dot{r}^2 + \frac{1}{f(t)} \dot{t}^2$$

radial geodesic

$r(\tau), t(\tau)$

$$15: \quad \left(\frac{dr}{d\tau} \right)^2 - f(r) \dot{t}^2 + \frac{1}{f(r)} \dot{r}^2 = 0$$

radial geodesics

$r(\tau), t(\tau)$

$$S = \int d\tau \left(-c(t) \dot{t}^2 + \frac{1}{f(r)} \dot{r}^2 \right)$$

radial geodesic

$r(\tau), t(\tau)$

$$S = \int d\tau \left(-f(r) \dot{t}^2 + \frac{\dot{r}^2}{f(r)} \right)$$

$$E = f(r) \dot{t}$$

radial geodesics

$r(\tau), t(\tau)$

$$S = \int d\tau \left(-f(r) \dot{t}^2 + \frac{1}{f(r)} \dot{r}^2 \right)$$

$$E = f(r) \dot{t} \quad \text{const on geodesics}$$

$$\dot{x}_\mu \dot{x}^\mu = 1 = -f(r) \dot{t}^2 + \frac{1}{f(r)} \dot{r}^2$$

radial geodesics

$r(\tau), t(\tau)$

$$E^2 = -f(r) +$$

$$S = \int d\tau \left(-f(r) \dot{t}^2 + \frac{1}{f(r)} \dot{r}^2 \right)$$

$$E = f(r) \dot{t} \quad \text{const on geodesic}$$

$$\dot{x}_\mu \dot{x}^\mu = \dot{t}^2 = -f(r) \dot{t}^2 + \frac{1}{f(r)} \dot{r}^2 = -$$

radial geodesics

$r(\tau), t(\tau)$

$$E^2 = -f(r) +$$

$$S = \int d\tau \left(-f(r) \dot{t}^2 + \frac{1}{f(r)} \dot{r}^2 \right)$$

$$E = f(r) \dot{t} \quad \text{const on geodesic}$$

$$\dot{x}_\mu \dot{x}^\mu = 1 = -f(r) \dot{t}^2 + \frac{1}{f(r)} \dot{r}^2$$

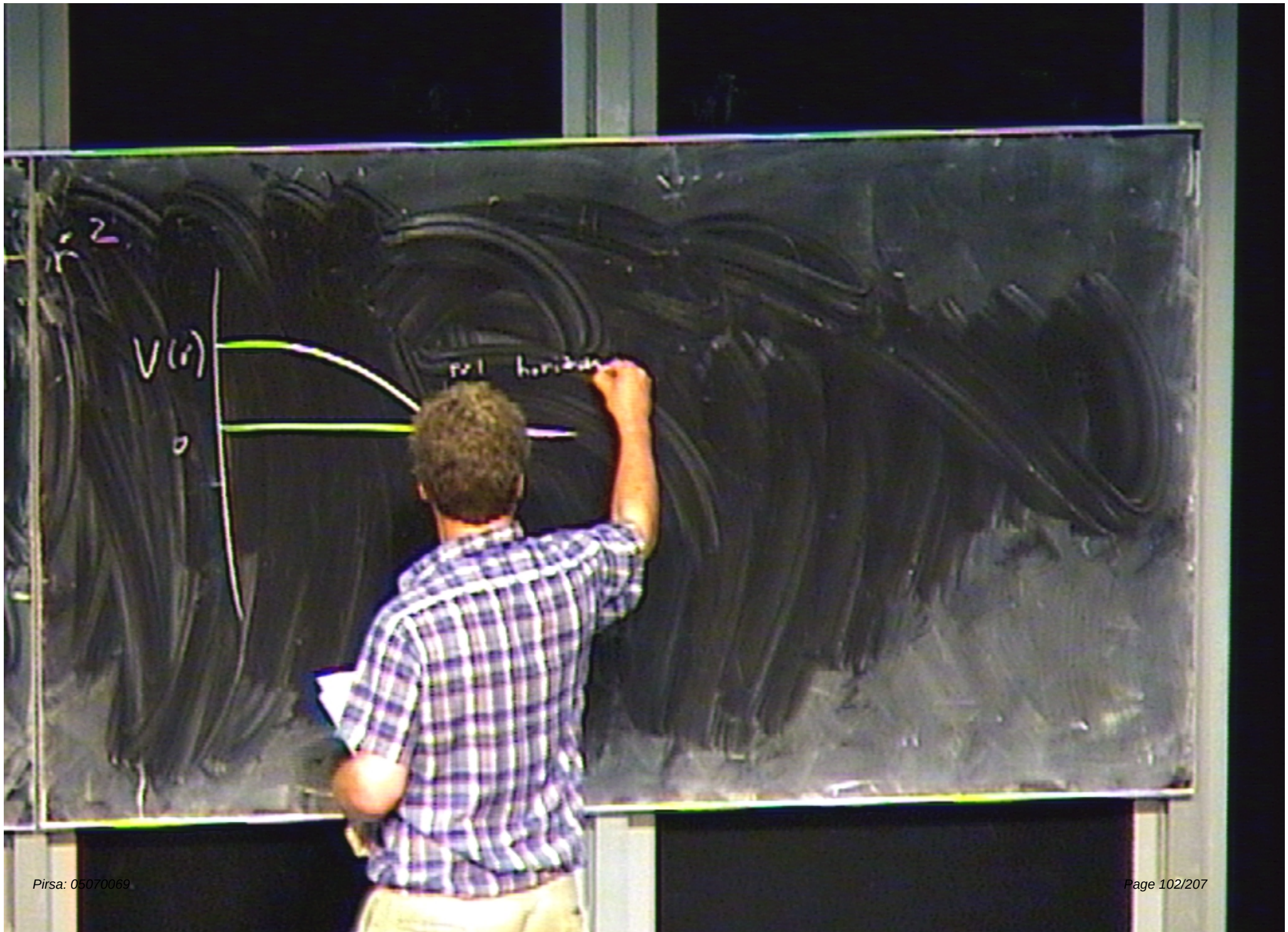
radial geodesic
 $r(\tau), t(\tau)$

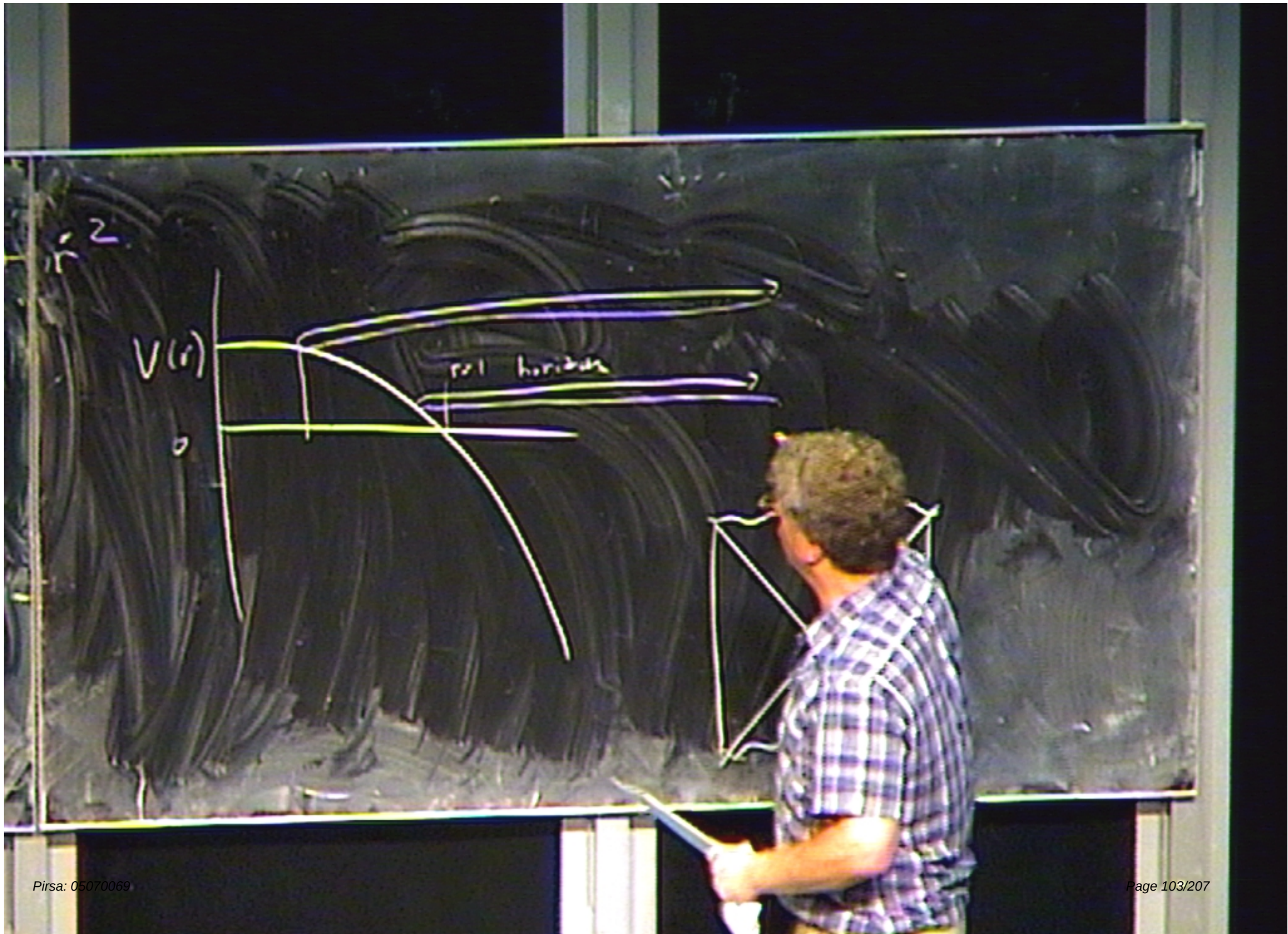
$$E^2 = -f(r) + \frac{\dot{r}^2}{f(r)}$$

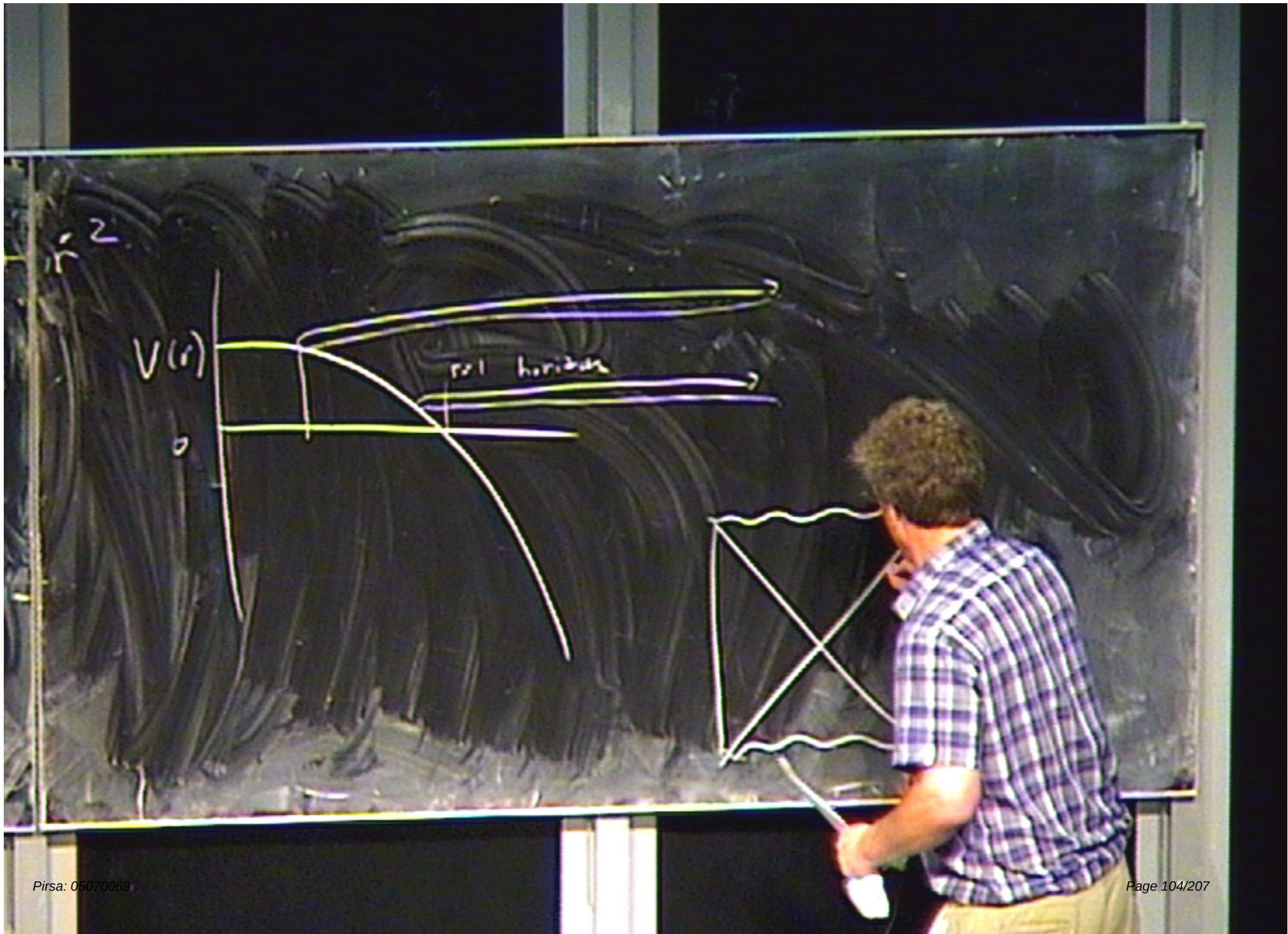
$$S = \int d\tau \left(-f(r) \dot{t}^2 + \frac{1}{f(r)} \dot{r}^2 \right)$$

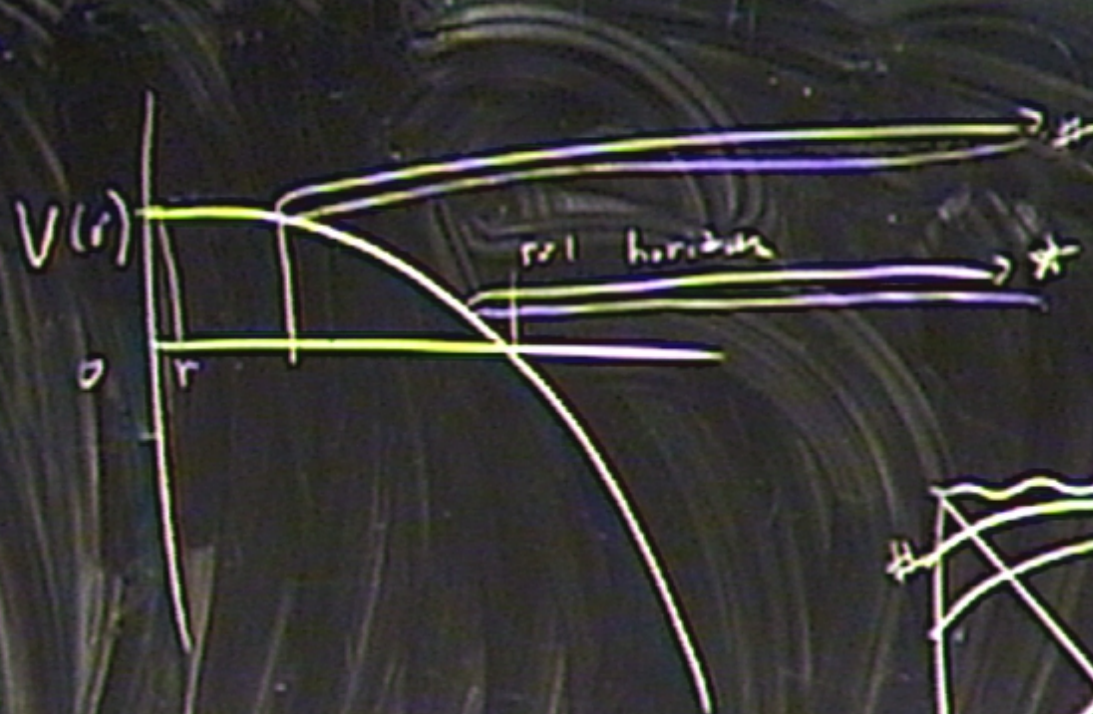
$$E = f(r) \dot{t} \quad \text{const on geodesic}$$

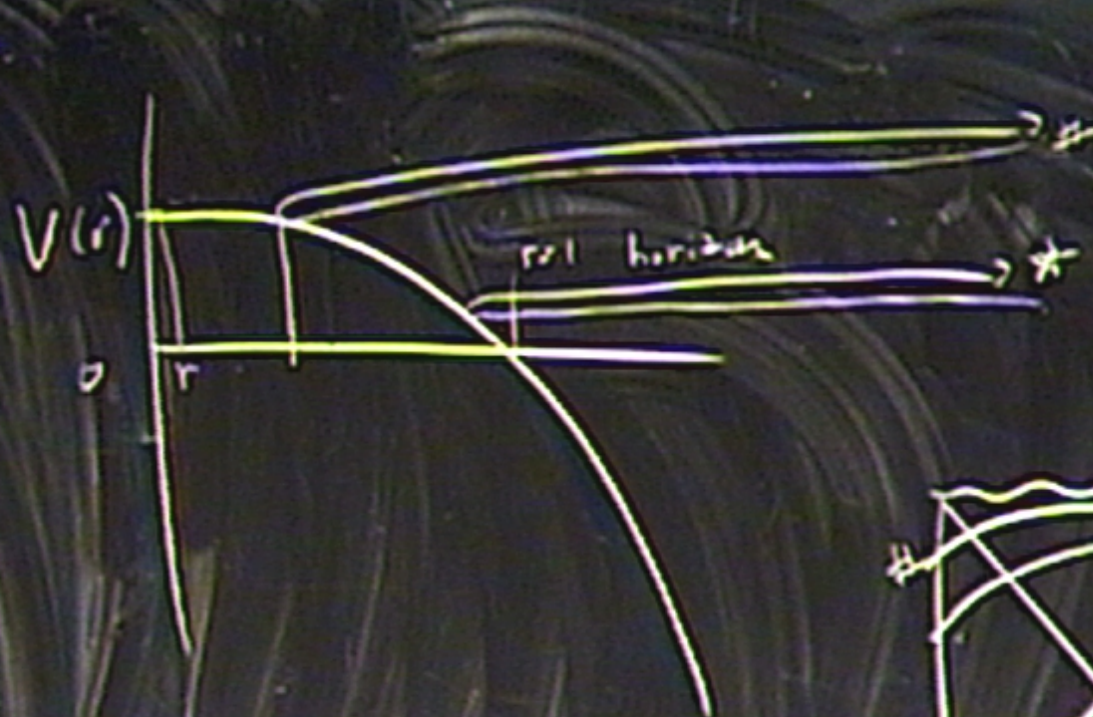
$$\dot{x}^\mu \dot{x}_\mu = 1 = -f(r) \dot{t}^2 + \frac{1}{f(r)} \dot{r}^2 = -\frac{1}{f} E^2 + \frac{1}{f} \dot{r}^2$$













0106112

heng, Kleban, SS

ch₃

$$L = z \log \cosh(t) + \text{const}$$

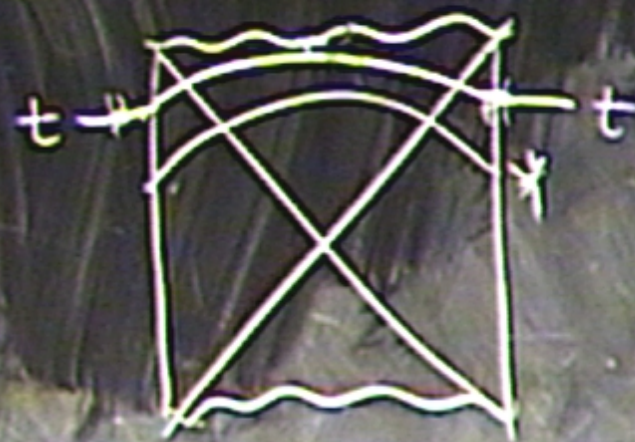
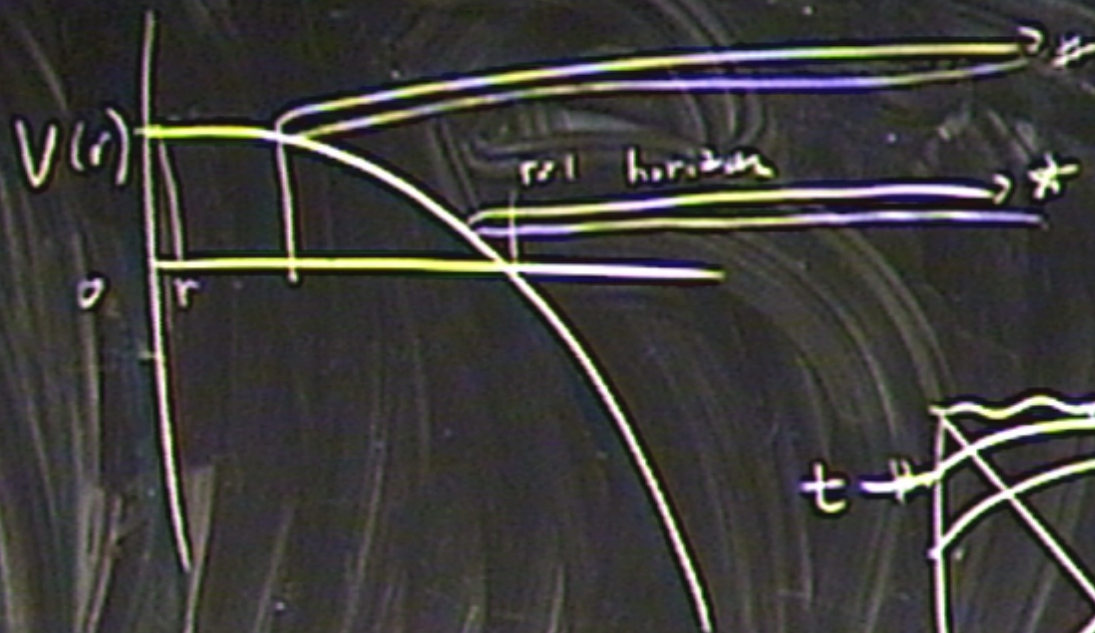
0106112

beny, Kleban, SS

ch₃

$$L = z \log \cosh(t) + \text{const}$$

$$\langle \phi \phi \rangle(t)$$



Maldacena 0106112

Filkowski, Hubeny, Kleban, SS

0306170

AdS-Sch₃

$$\mathcal{L} \Rightarrow \log \cosh(t) + \text{const}$$

$$\langle \phi \phi \rangle = e^{-m \mathcal{L}}$$

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Fidkowski, Hubeny, Kleban, SS

0306170

AdS-Sch₃

$$\mathcal{L} = z \log \cosh(t) + \text{const}$$

$$\langle \phi \phi \rangle(t) = e^{-m \mathcal{L}}$$

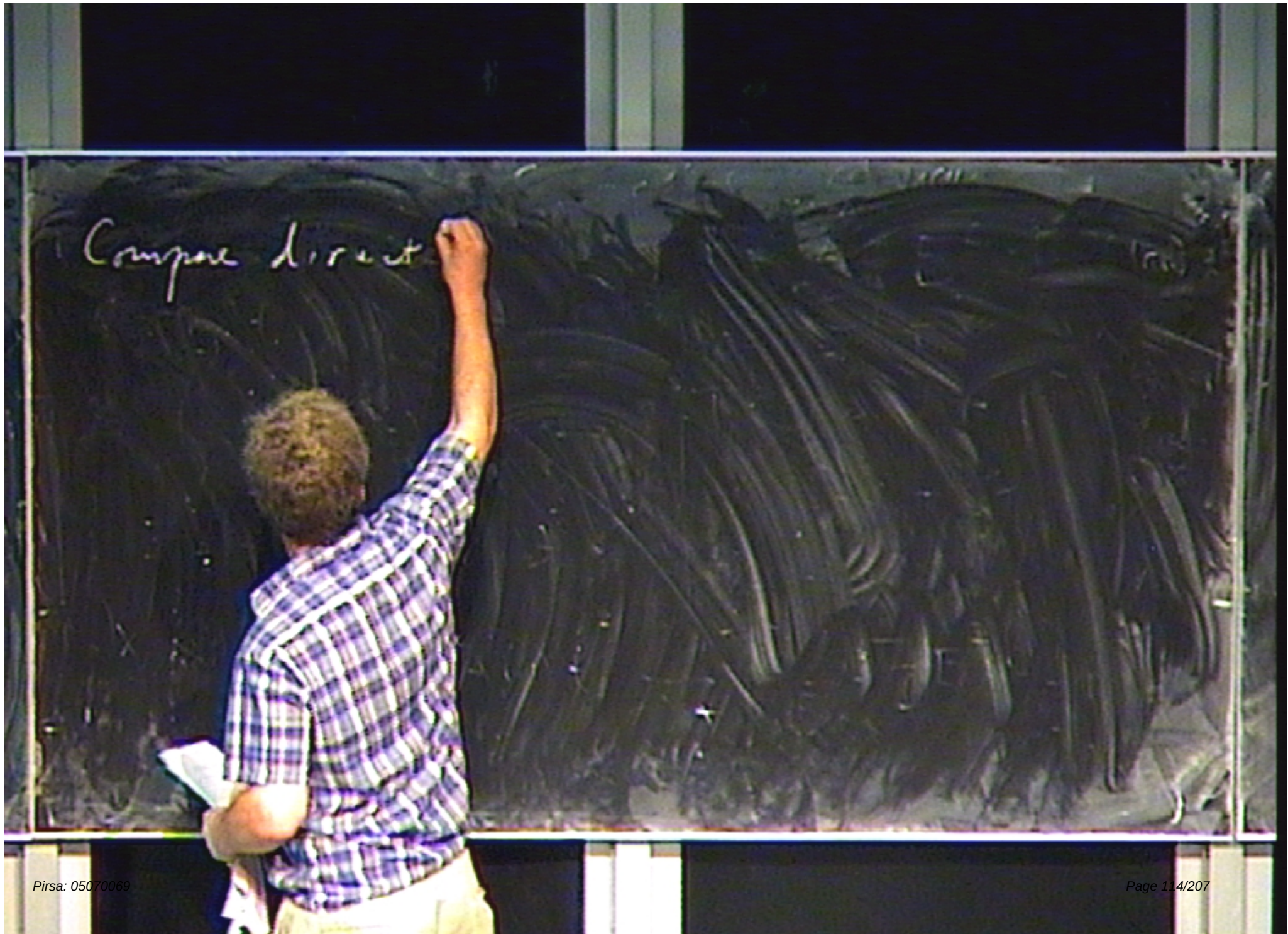
112

Kleban, SS

$$L = z \log \cosh(t) + \text{const}$$

$$\langle \phi \phi \rangle(t) = e^{-m L}$$

$$= \frac{1}{(\cosh t)^{2m}}$$



Compose directly to CPT

Compose directly to CFT

Compare directly to CFT

$\langle 44 \rangle$
 β

Compose directly to CFT

$\langle 44 \rangle_\beta$

Compose directly to CFT

$\langle 44 \rangle_\beta$



Compose directly to CFT

$\langle 44 \rangle_\beta$



Compose directly to CFT

$\langle 44 \rangle$



Compare directly to CFT

$$\langle \phi \phi \rangle_\beta$$

$$r_+ \rightarrow \infty$$

$$T \rightarrow \infty$$



Compose directly to CFT

$$\langle \phi \phi \rangle_\beta$$

$$r_+ \rightarrow \infty$$

$$T \rightarrow \infty$$

$$\theta \rightarrow \chi$$



Compose directly to CFT

$\langle 44 \rangle_\beta$

$r_+ \rightarrow \infty$

$T \rightarrow \infty$

$\theta \rightarrow \chi$



Compare directly to CFT

$$\langle \phi \phi \rangle_\beta$$

$$r_+ \rightarrow \infty$$

$$T \rightarrow \infty$$

$$\theta \rightarrow \chi$$



plane

Compare directly to CFT

$$\langle \phi \phi \rangle_\beta$$

$$r_+ \rightarrow \infty$$

$$T \rightarrow \infty$$

$$\theta \rightarrow \chi$$



exp



Compare directly to CFT

$$\langle \phi \phi \rangle_\beta$$

$$r_+ \rightarrow \infty$$

$$T \rightarrow \infty$$

$$\theta \rightarrow \chi$$



exp



Compare directly to CFT

$$\langle \phi \phi \rangle_\beta$$

$$r_+ \rightarrow \infty$$

$$T \rightarrow \infty$$

$$\theta \rightarrow \chi$$



exp



Compare directly to CFT

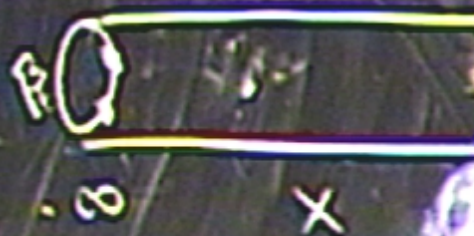
$$\langle \psi \psi \rangle_\beta$$



$\exp$
?



$$\frac{i\Gamma}{(\cosh t)^2 \Delta}$$



Compare directly to CFT

$$\Delta = m + O\left(\frac{1}{m}\right)$$

$$\langle \phi \phi \rangle_\beta$$



exp
?

plane

$$\frac{i\Gamma}{(\cosh t)^2 \Delta}$$



Compare directly to CFT

$$\Delta = m + O\left(\frac{1}{m}\right)$$

$$\langle 44 \rangle_{\beta}$$



exp



$$\frac{i\Gamma}{(\cosh t)^2 \Delta}$$



Compare directly to CFT

$$\Delta = m + O\left(\frac{1}{m}\right)$$

$$\langle \phi \phi \rangle_\beta$$

$$r_+ \rightarrow \infty$$

$$\frac{i\Gamma}{(\omega h + \epsilon)^2 \Delta}$$



exp
?



Compare directly to CFT

$$\Delta = m + O\left(\frac{1}{m}\right)$$

$$\langle \phi \phi \rangle_{\beta}$$

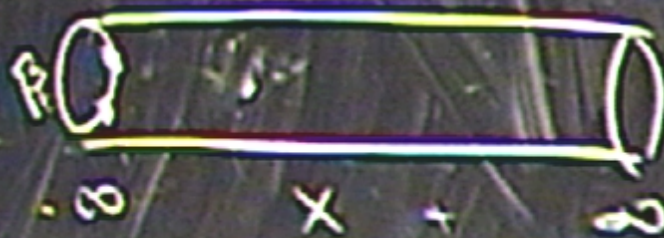
$$r_+ \rightarrow \infty$$

$$\frac{i\Gamma}{(\cosh t)^{2\Delta}}$$



exp
?

plane



Compare directly to CFT

$$\Delta = m + O\left(\frac{1}{m}\right)$$

$$\langle \phi \phi \rangle_\beta$$

$$r_+ \rightarrow \infty$$

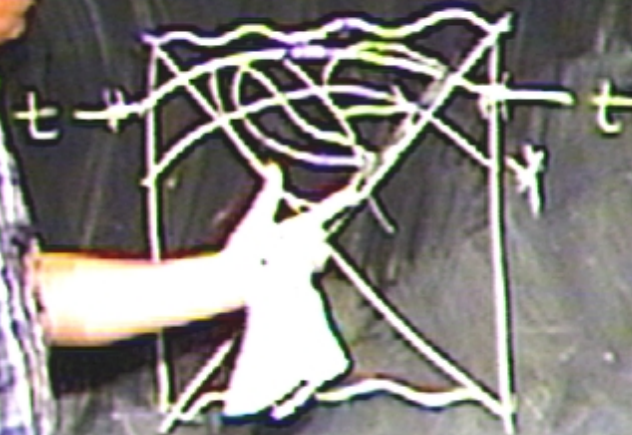
$$\frac{i\Gamma}{(\cosh t)^{2\Delta}}$$



exp
?



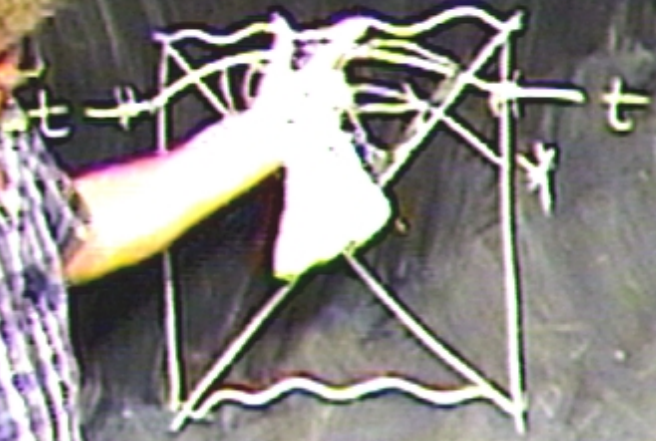
$t \sim s$
 $t \sim e s$





$$t \sim S$$

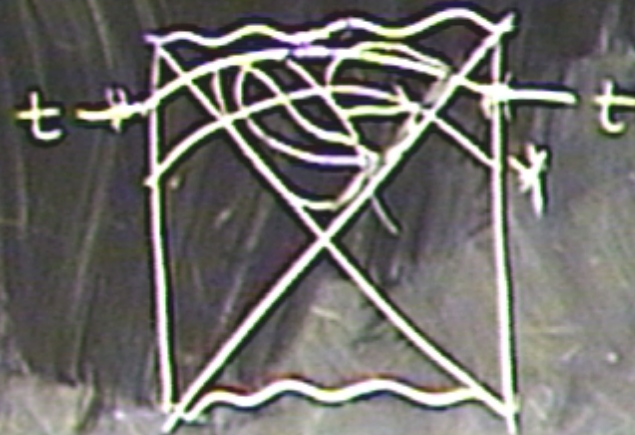
$$t \sim e^S$$





$$t \sim S$$

$$t \sim e^S$$



Maldacena 0106112

Filkowski, Hubeny, Kleban, SS
0306170

AdS-Sch₃

$$L = r^2 \dot{r}^2 \dot{\Theta}$$

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Falkowski, Hubeny, Kleban, SS

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AdS-Sch₃

$$L = r_+^2 \dot{\Theta}$$

$$- \frac{L^2}{r_+^2 r^2}$$

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ALS-Sch₃

$$L = r^2 \dot{r}^2 \dot{\Theta}$$

$$(r) = \frac{L^2}{r_+^2 r^2}$$



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AdS-Sch₃



$$L = r_+^2 \dot{\Theta}$$

$$\rightarrow V(r) = \frac{L^2}{r_+^2 r^2}$$



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AdS-Sch₃



$$L = r^2 \dot{\varphi}^2 \dot{\theta}$$

$$\rightarrow V(r) = \frac{L^2}{r^2}$$

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AdS-Sch₃



$$L = r^2 \dot{r}^2 \dot{\Theta}$$

$$\rightarrow V(r) = \frac{L^2}{r^2 r^2}$$

Maldacena 0106112

Filkowski, Hubeny, Kleban, SS

0306170

ALS-Sch₃



$$L = r^2 \dot{\varphi}^2 \dot{\Theta}$$

$$\rightarrow V(r) = \frac{L^2}{r^2 r^2}$$



Compare directly to CFT

$$\Delta = m + O\left(\frac{1}{m}\right)$$

$$\langle \phi \phi \rangle_\beta$$

$$r_+ \rightarrow \infty$$

$$\frac{iT}{(\cosh t)^{2\Delta}}$$



exp?



r_+ finite



12

Kleban, SS

A1S-Sch 5

12

Kleban, SS

A1S-Sch 5

ds^2

12

Kleban, SS

A1S-Sch 5

12

Kleban, SS

AUS-Sch 5

$$T \rightarrow \infty$$

$$r_+ \rightarrow \infty$$

12

Kleban, SS

AUS-Sch 5

$$T \rightarrow \infty$$

$$r_+ \rightarrow \infty$$

12

Kleban, SS

AUS-Sch 5

$$T \rightarrow \infty$$

$$r_+ \rightarrow \infty$$

$$ds^2 = - - dt$$

12

Kleban, SS

AUS-Sch 5

$$T \rightarrow \infty$$

$$r_+ \rightarrow \infty$$

$$ds^2 = -f(r) dt^2 + \frac{1}{f(r)} dr^2 + r^2 d\Omega^2$$

$\tilde{f}(r)$

12

Kleban, SS

AUS-Sch 5

$$T \rightarrow \infty$$

$$r_+ \rightarrow \infty$$

$$ds^2 = -f(r) dt^2 + \frac{1}{f(r)} dr^2$$

12

Kleban, SS

AUS-Sch 5

$$T \rightarrow \infty$$

$$r_+ \rightarrow \infty$$

$$ds^2 = -f(r) dt^2 + \frac{1}{f(r)} dr^2$$

AUS-Sch 5

$$T \rightarrow \infty$$

$$r_+ \rightarrow \infty$$

$$ds^2 = -f(r) dt^2 + \frac{1}{f(r)} dr^2 + r^2 r_+^2 d\Omega^2$$

SS / Aus-Sch 5

$$T \rightarrow \infty$$

$$r_+ \rightarrow \infty$$

$$ds^2 = -f(r) dt^2 + \frac{1}{f(r)}$$

$$f(r) = r^2 - \frac{1}{r^2}$$

radial
gerades, Ω const

$$dr^2 + r^2 r_+^2 d\Omega^2$$

SS / AUS-Sch 5

$$T \rightarrow \infty$$

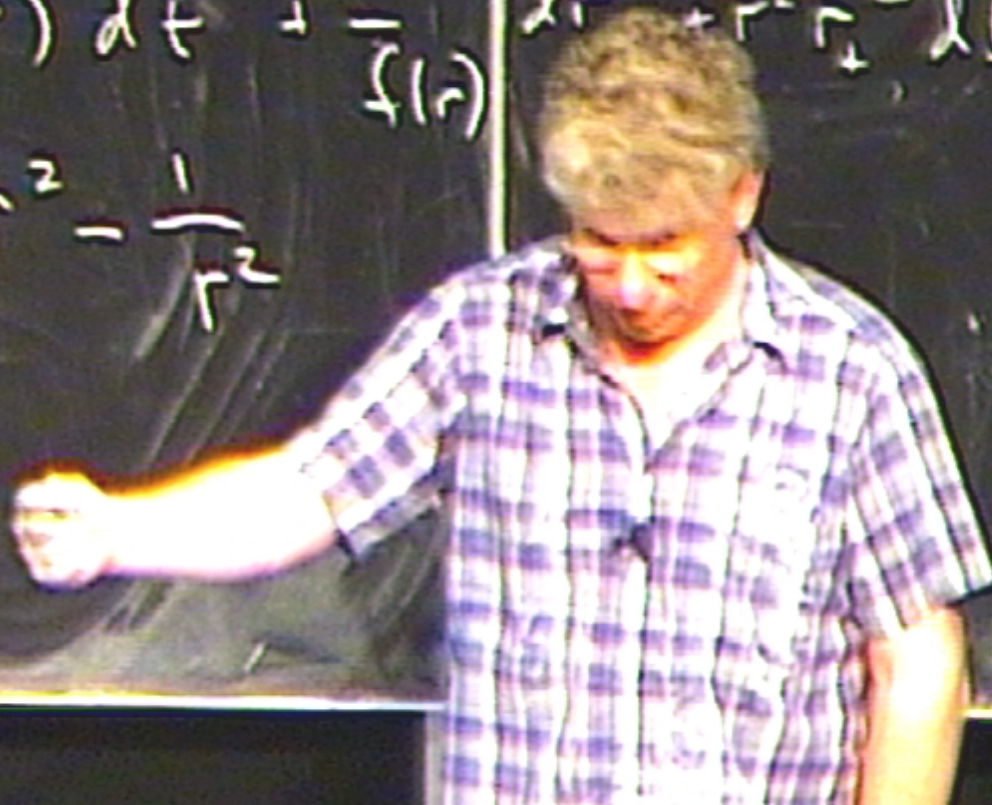
$$r_+ \rightarrow \infty$$

$$ds^2 = -f(r) dt^2 + \frac{1}{f(r)} dr^2 + r^2 d\Omega^2$$

$$f(r) = r^2 - \frac{1}{r^2}$$

radial
gerades, Ω const

$$dr^2 + r^2 d\Omega^2$$



SS / Ans-Sch 5

$$T \rightarrow \infty$$

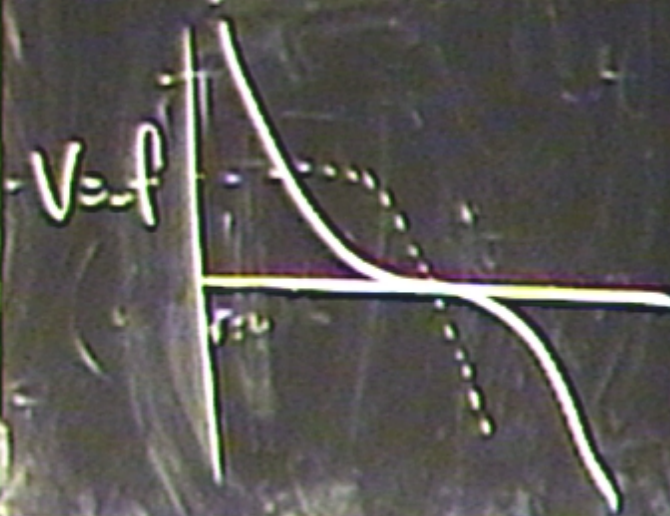
$$r_+ \rightarrow \infty$$

$$ds^2 = -f(r) dt^2 + \frac{1}{f(r)} dr^2$$

$$f(r) = r^2 - \frac{1}{r^2}$$

radial
geodesics, Ω const

$$dr^2 + r^2 \dot{r}^2 = d\Omega^2$$



SS / Ans - Soln 5

$$T \rightarrow \infty$$

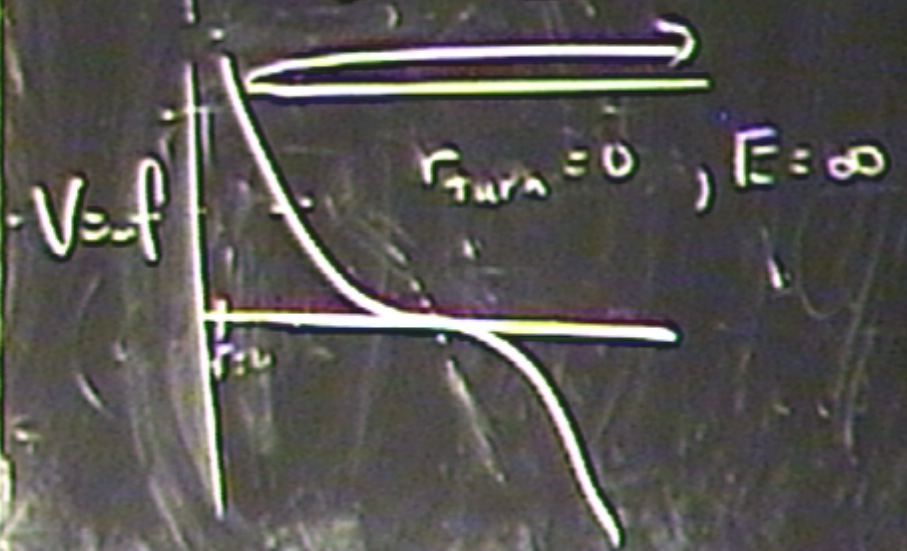
$$r_+ \rightarrow \infty$$

$$ds^2 = -f(r) dt^2 + \frac{1}{f(r)}$$

$$f(r) = r^2 - \frac{1}{r^2}$$

radial geodesics, Ω const

$$dr^2 + r^2 \dot{r}^2 = d\Omega^2$$



SS / A1 S-Sch 5

$$T \rightarrow \infty$$

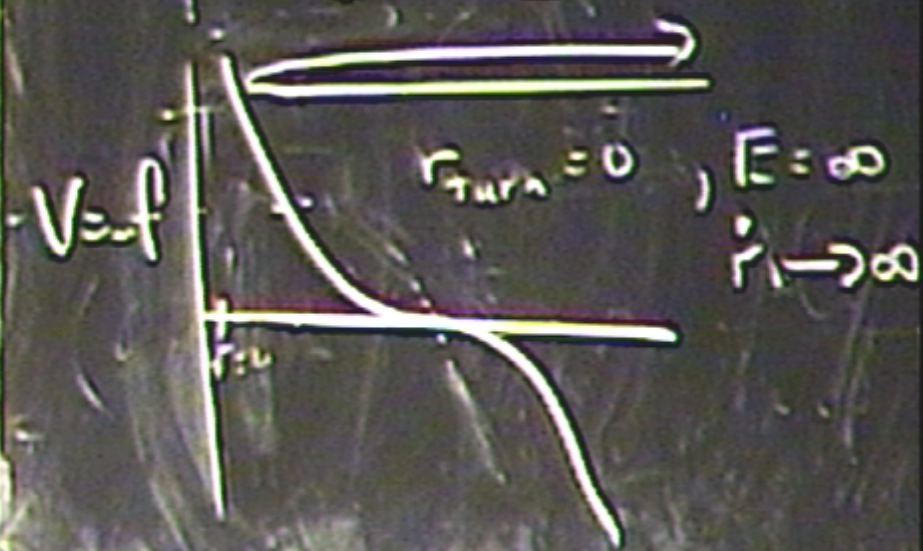
$$r_+ \rightarrow \infty$$

$$ds^2 = -f(r) dt^2 + \frac{1}{f(r)} dr^2$$

$$f(r) = r^2 - \frac{1}{r^2}$$

radial geodesics, Ω const

$$dr^2 + r^2 \dot{r}^2 = d\Omega^2$$



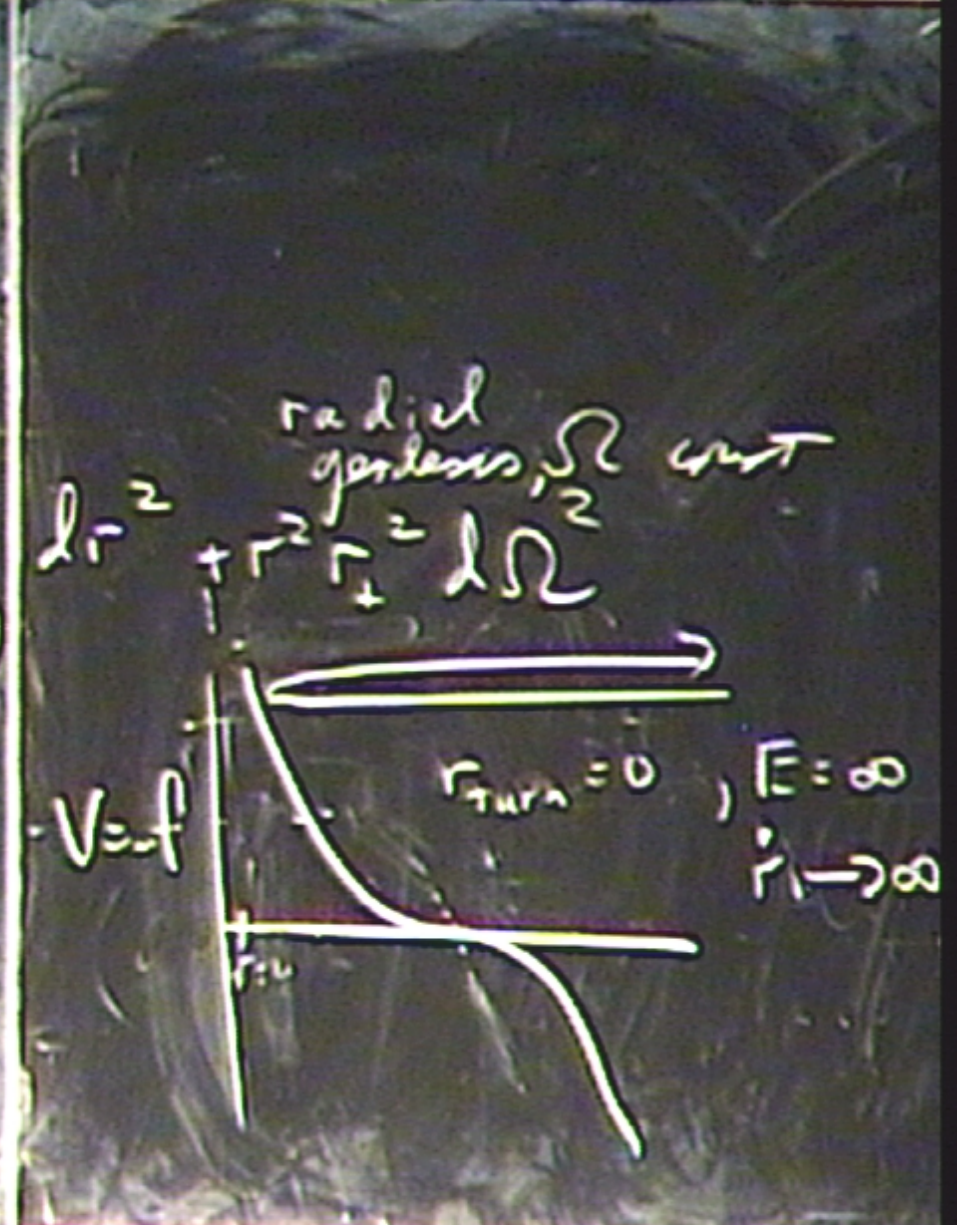
SS / AUS-Sch

$T \rightarrow \infty$

$r_+ \rightarrow \infty$

$$ds^2 = -f(r) dt^2 + \frac{1}{f(r)} dr^2$$

$$f(r) = r^2 - \frac{1}{r^2}$$



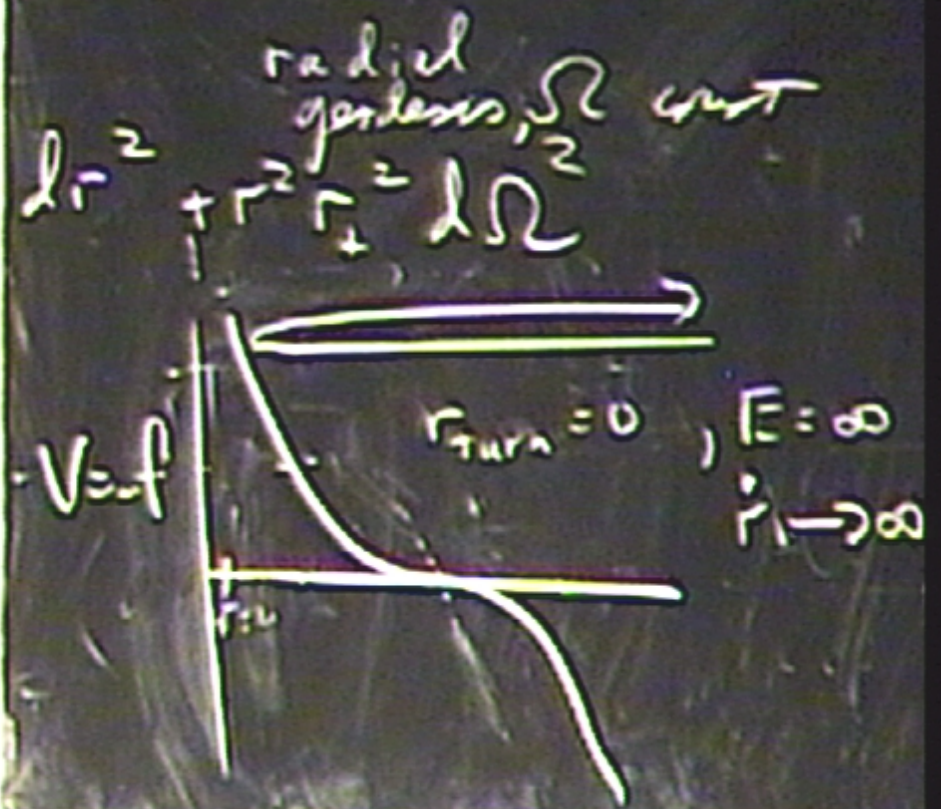
SS / AUS-Sch

$T \rightarrow \infty$

$r_+ \rightarrow \infty$

$$ds^2 = -f(r) dt^2 + \frac{1}{f(r)} dr^2$$

$$f(r) = r^2 - \frac{1}{r^2}$$



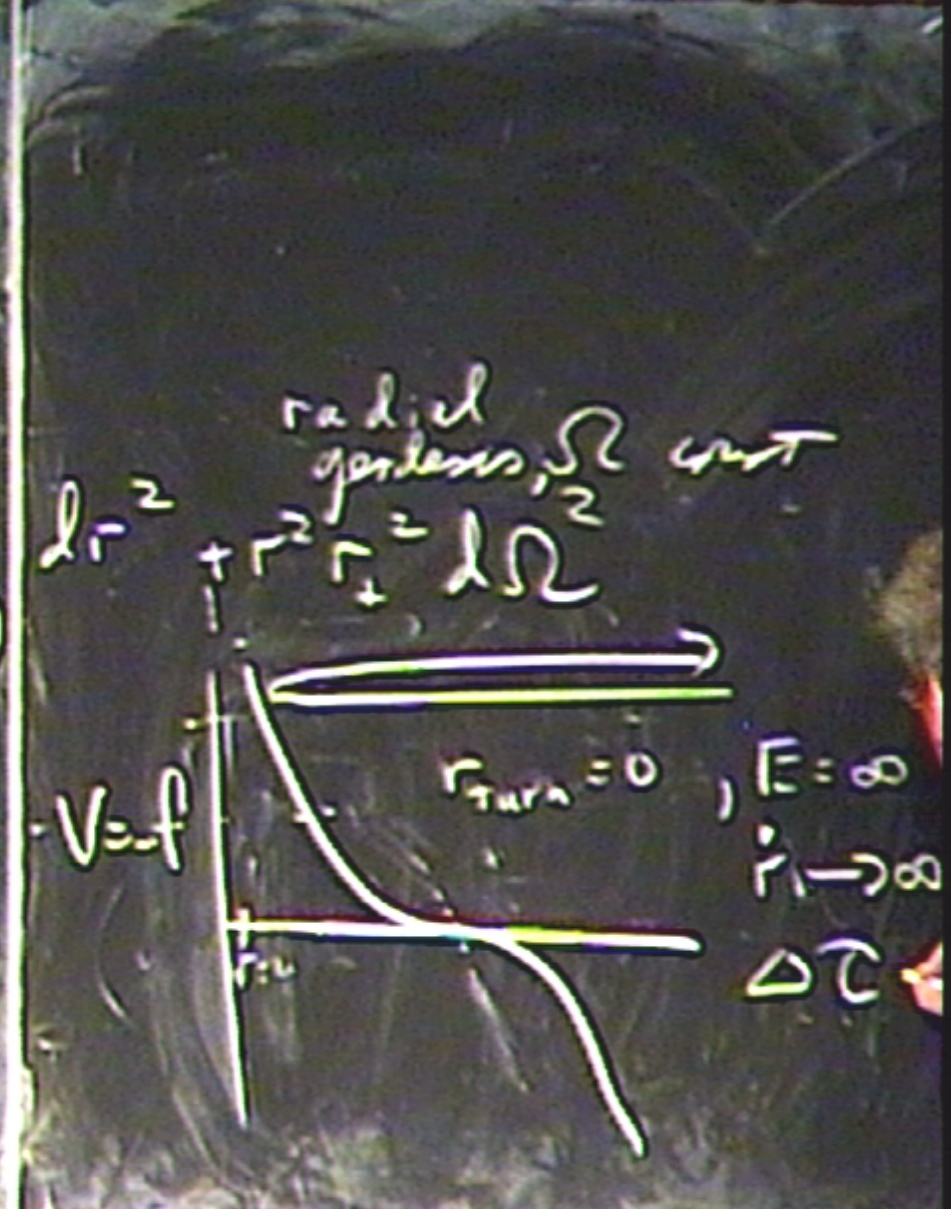
SS / AUS-Sch 5

$T \rightarrow \infty$

$r_+ \rightarrow \infty$

$$ds^2 = -f(r) dt^2 + \frac{1}{f(r)} dr^2$$

$$f(r) = r^2 - \frac{1}{r^2}$$



SS / AHS-Sch 5

$$T \rightarrow \infty$$

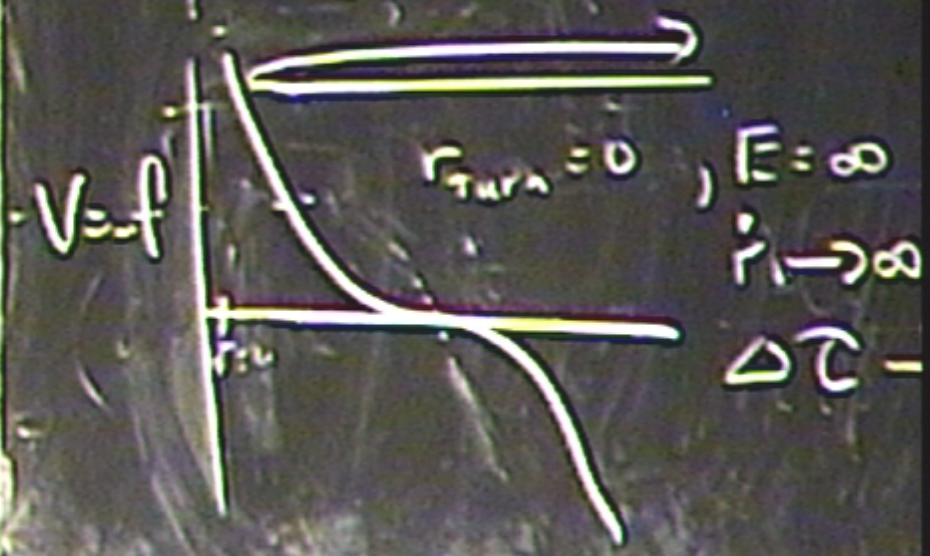
$$r_+ \rightarrow \infty$$

$$ds^2 = -f(r) dt^2 + \frac{1}{f(r)} dr^2$$

$$f(r) = r^2 - \frac{1}{r^2}$$

radial geodesics, Ω const

$$dr^2 + r^2 \dot{r}^2 = d\Omega^2$$



Ans - Sol₅

$$T \rightarrow \infty$$

$$r_+ \rightarrow \infty$$

$$ds^2 = -f(r) dt^2 + \frac{1}{f(r)}$$

$$f(r) = r^2 - \frac{1}{r^2}$$

radial geodesics, Ω const

$$dr^2 + r^2 r_+^2 d\Omega^2$$



$$r_{turn} = 0, E = \infty$$

$$r_+ \rightarrow \infty$$

$\Delta C \rightarrow 0$
nearly
null

Ans - Sol₅

$$T \rightarrow \infty$$

$$r_+ \rightarrow \infty$$

$$ds^2 = -f(r) dt^2 + \frac{1}{f(r)}$$

$$f(r) = r^2 - \frac{1}{r^2}$$

radial geodesics, Ω const

$$dr^2 + r^2 r_+^2 d\Omega^2$$



$$r_{\text{turn}} = 0, E = \infty$$

$$r_+ \rightarrow \infty$$

$\Delta\tau \rightarrow 0$
nearly
null

Ans - Sol₅

$$T \rightarrow \infty$$

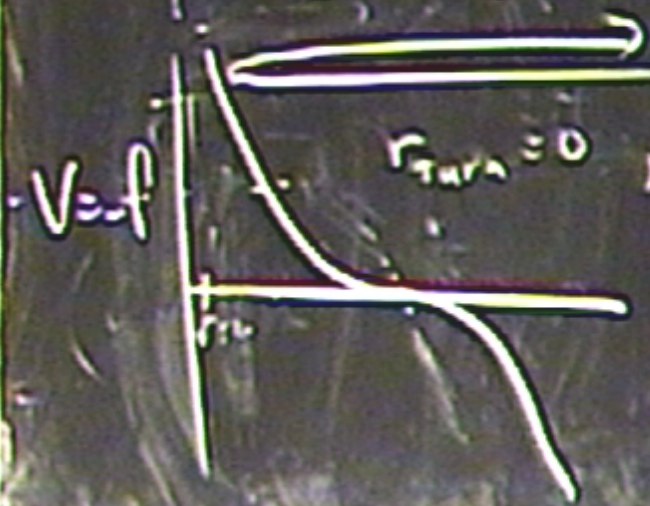
$$r_+ \rightarrow \infty$$

$$ds^2 = -f(r) dt^2 + \frac{1}{f(r)}$$

$$f(r) = r^2 - \frac{1}{r^2}$$

radial geodesics, Ω const

$$dr^2 + r^2 \dot{r}^2 d\Omega^2$$



$$r_{\text{turn}} = 0, E = \infty$$

$$r_+ \rightarrow \infty$$

$\Delta C \rightarrow 0$
nearly
null

Ans - Sch 5

$$T \rightarrow \infty$$

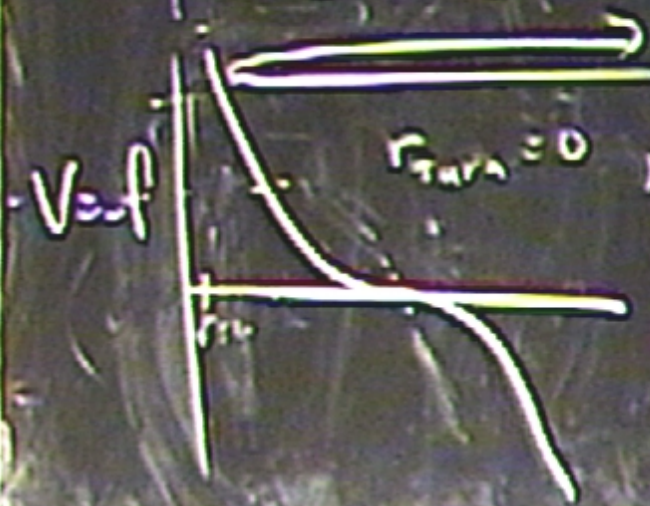
$$r_+ \rightarrow \infty$$

$$ds^2 = -f(r) dt^2 + \frac{1}{f(r)} dr^2 + r^2 d\Omega^2$$

$$f(r) = r^2 - \frac{1}{r^2}$$

radial geodesics, Ω const

$$dr^2 + r^2 d\Omega^2$$

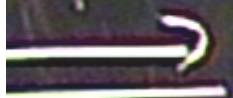


$$r_{turn} = 0, E = \infty$$

$$r \rightarrow \infty$$

$\Delta C \rightarrow 0$
nearly
null

Ω const

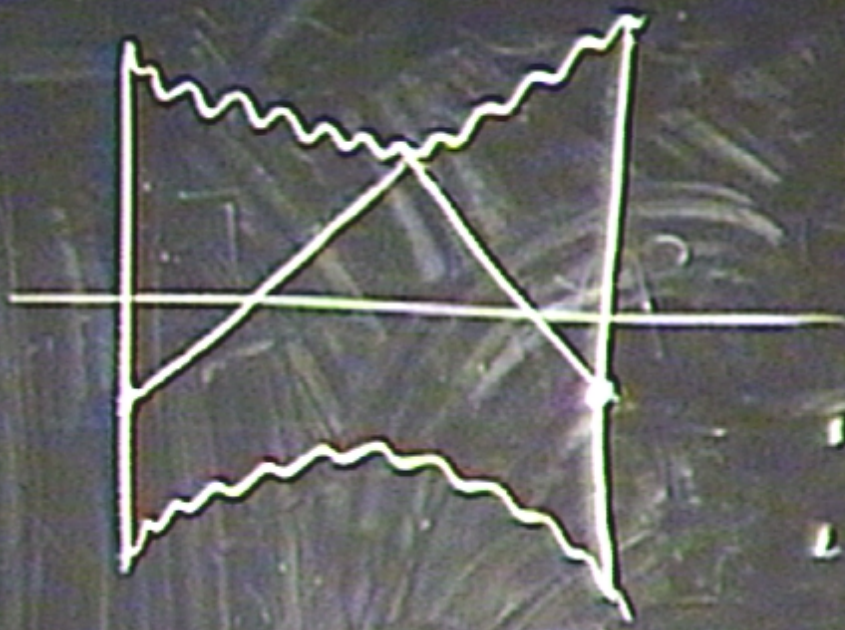


$\Omega = 0, E = \infty$

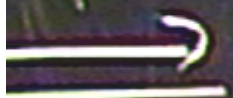
$\dot{r}_1 \rightarrow \infty$

$\Delta \tau \rightarrow 0$

nearly
null



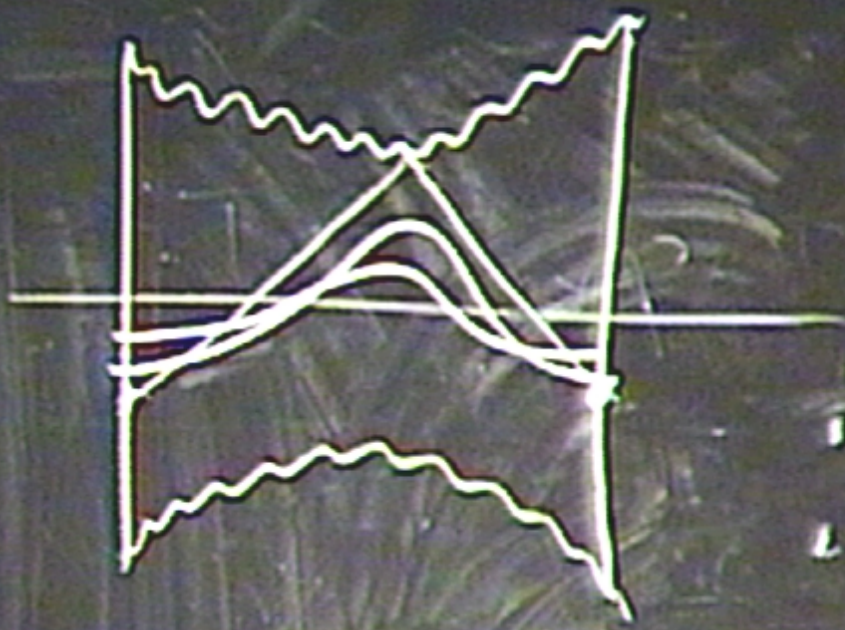
Ω const



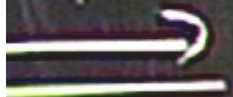
$\dot{r}_1 \rightarrow \infty$

$\Delta \tau \rightarrow 0$

nearly
null



Ω const



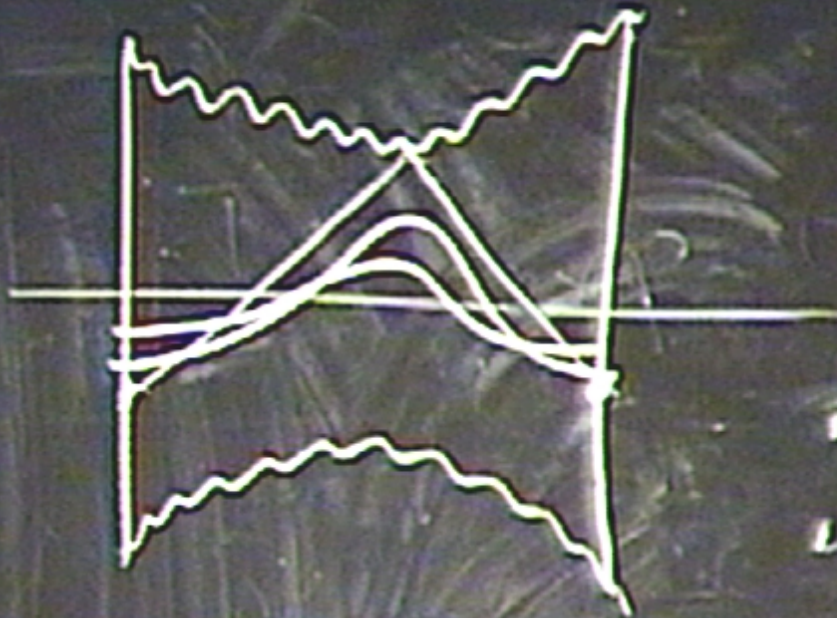
$\alpha = 0, E = \infty$

$\dot{r}_1 \rightarrow \infty$

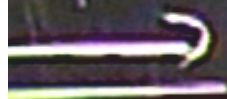
$\Delta \tau \rightarrow 0$

nearly

null



Ω const

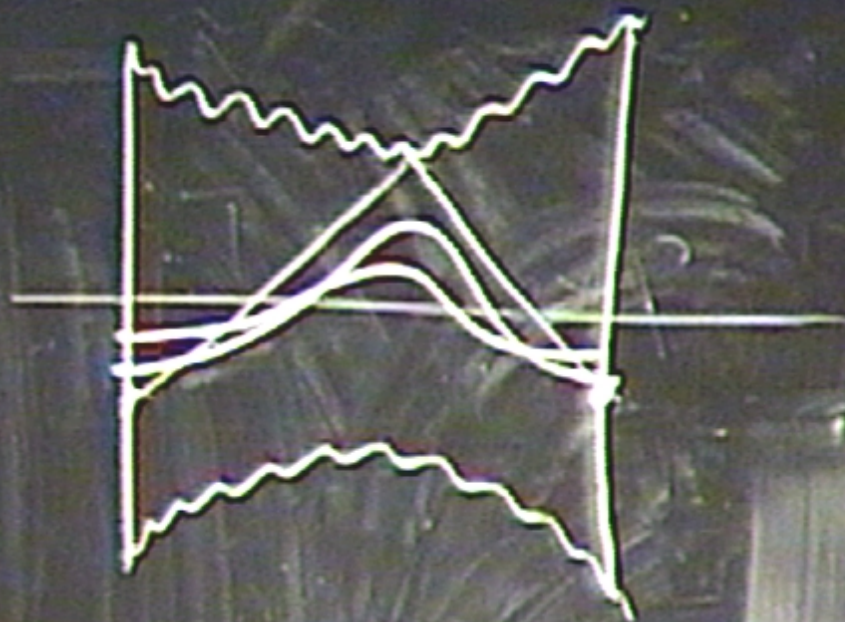


$\dot{r}_1 \rightarrow \infty$

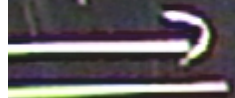
$\Delta \tau \rightarrow 0$

nearly

null



Ω_{cut}

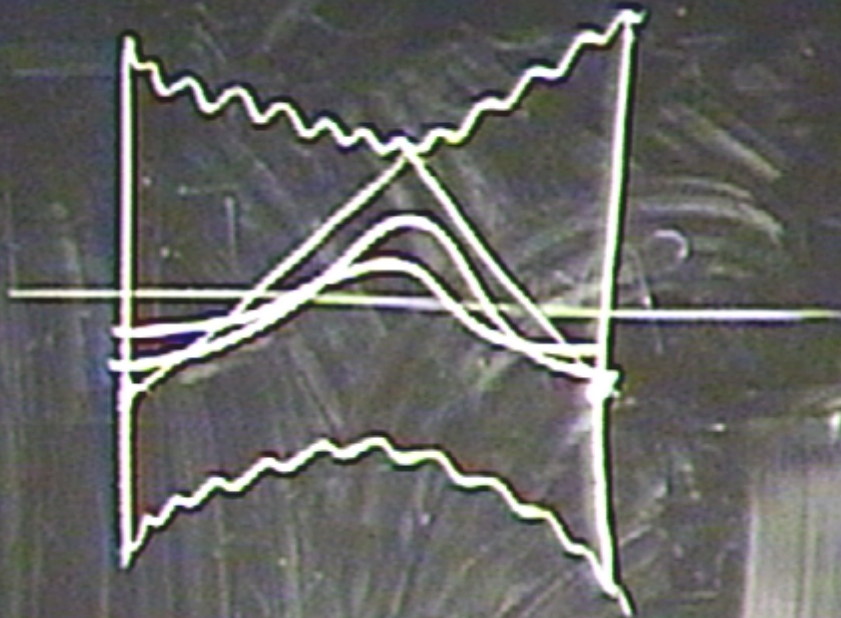


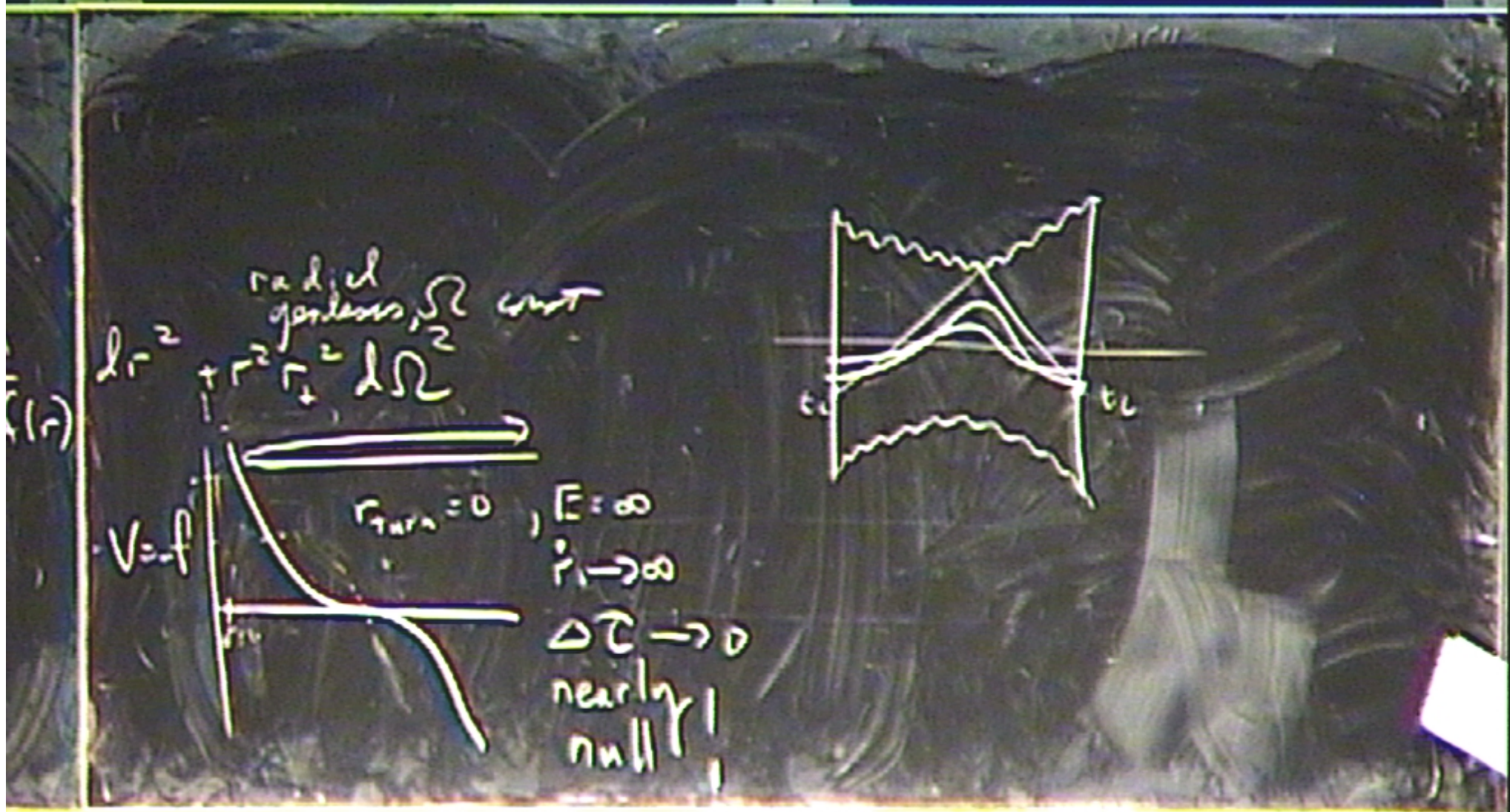
$\alpha = 0, E = \infty$

$\dot{r}_1 \rightarrow \infty$

$\Delta \tau \rightarrow 0$

nearly
null





$$\langle \phi \phi \rangle(t_i)$$

$$\sim e^{-mL}$$



$$t \sim S$$

$$t \sim e^S$$



$$\langle \phi \phi \rangle$$

$$\sim e^-$$

$$\sim t$$



$$\begin{array}{l} t \sim S \\ t \sim e^S \end{array}$$



$$\langle \phi \phi \rangle(t)$$

$$\sim e^{-m_1 t}$$

$$\sim \frac{1}{(t - \tau_c)^{2m_2}}$$



$$\begin{array}{l} t \sim S \\ t \sim e^S \end{array}$$



$$\langle \phi \phi \rangle(x, t)$$

$$\sim e^{-m_1 t}$$

$$\sim \frac{1}{(t - \tau_c)^{2m_2}}$$



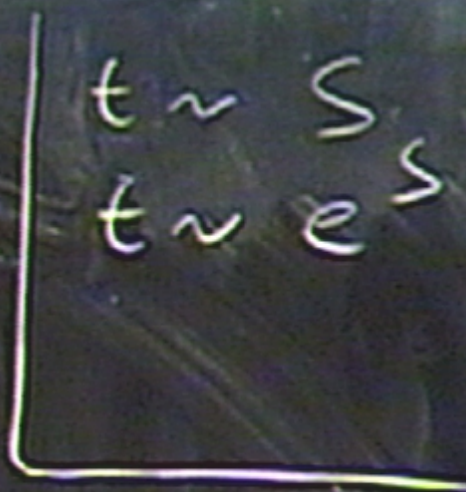
$$\begin{array}{l} t \sim S \\ t \sim e^S \end{array}$$



$$\langle \phi \phi \rangle(t)$$

$$\sim e^{-m_1 t}$$

$$\sim \frac{1}{(t - \tau_c)^{2m_2}}$$



$$\langle \phi \phi \rangle(t)$$

$$\sim e^{-m_1 t}$$

$$\sim \frac{1}{(t - \tau_c)^{2m_2}}$$



$$\begin{array}{l} t \sim S \\ t \sim e^S \end{array}$$



$$\langle \phi \phi \rangle(t)$$

$$\sim e^{-mL}$$

$$\sim \frac{1}{(t-\tau_c)}$$



$$\langle \phi \phi \rangle(x_t)$$

$$\sim e^{-mL}$$

$$\sim \frac{1}{(t - \tau_c)^{2m}}$$



$$\langle \phi \phi \rangle(t)$$

$$\sim e^{-mL}$$

$$\sim \frac{1}{(t-\tau_c)^{2m}}$$



$$\langle \phi \phi \rangle(t) \sim$$

$$e^{-m_1 t}$$

$$\sim \frac{1}{(t - \tau_c)^{2m_2}}$$



$$\langle \phi \phi \rangle(t) \sim$$

$$e^{-m_1 t}$$

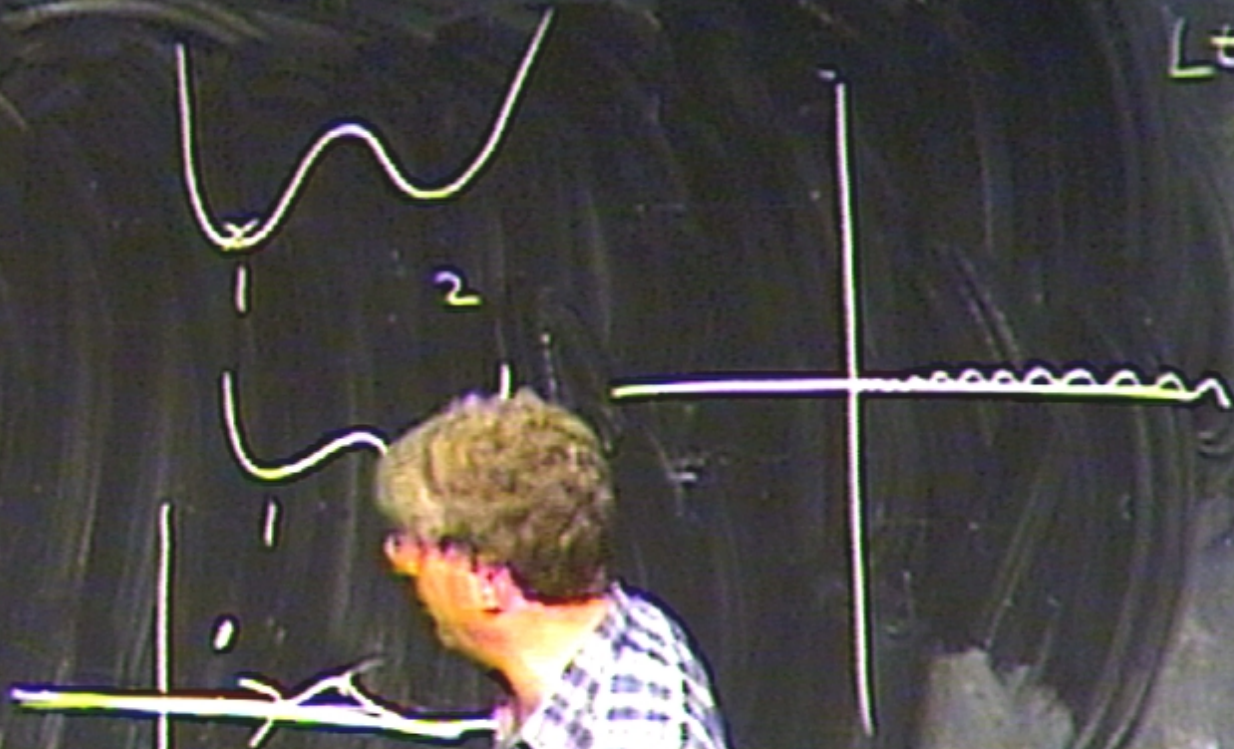
$$\sim \frac{1}{(t - \tau_c)^{2m_2}}$$



$$\langle \phi \phi \rangle(t)$$

$$\sim e^{-mL}$$

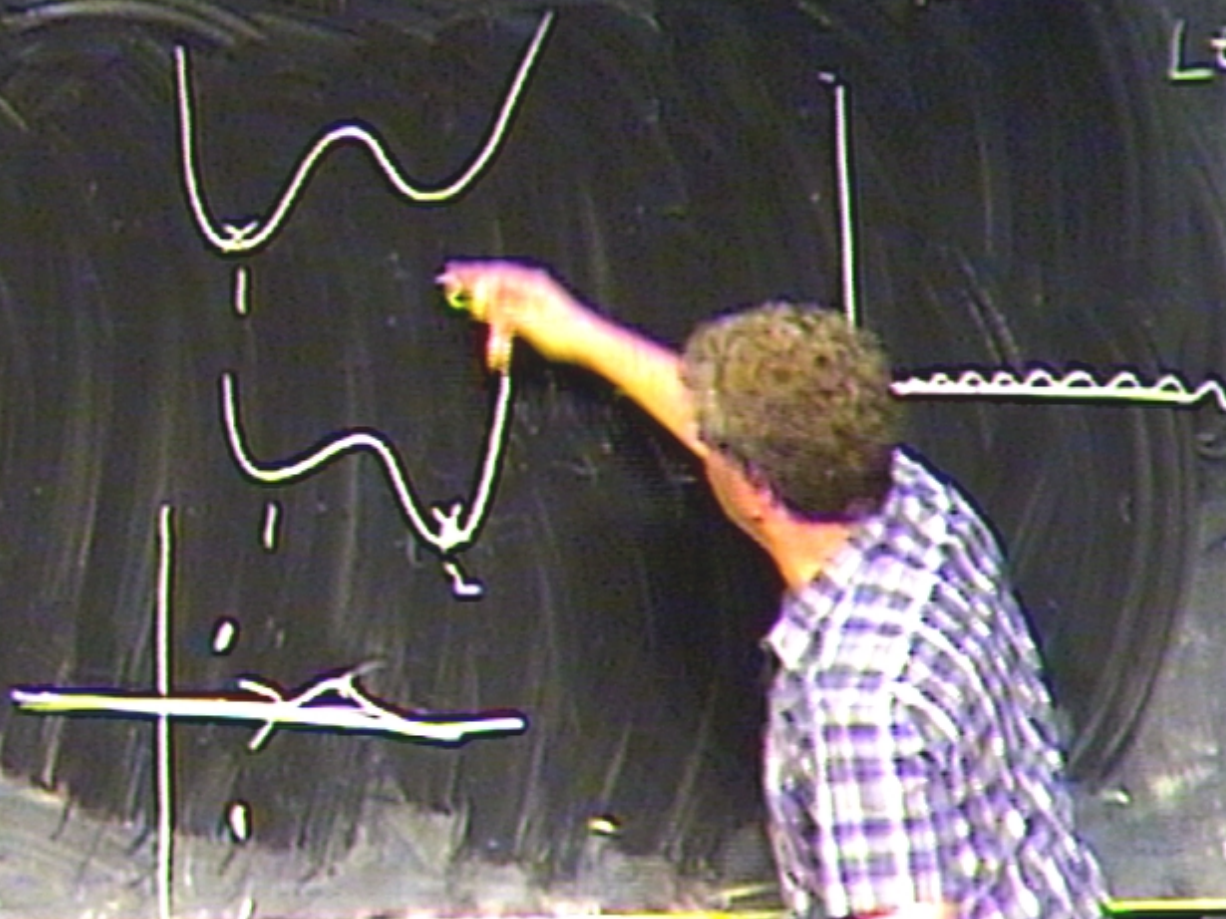
$$\sim \frac{1}{(t-\tau_c)^{2m}}$$



$$\langle \phi \phi \rangle(t)$$

$$\sim e^{-mL}$$

$$\sim \frac{1}{(t-\tau_c)^{2m}}$$



$$\gamma_s \rightarrow 0$$

$$m \rightarrow \infty$$

Lt

$$\langle \phi \phi \rangle(t)$$

$$\sim e^{-mL}$$

$$\sim \frac{1}{(t-\tau_c)^{2m}}$$



$$\gamma_s \rightarrow 0$$

$$m \rightarrow \infty$$

Lt

$$\langle \phi \phi \rangle(t, t)$$

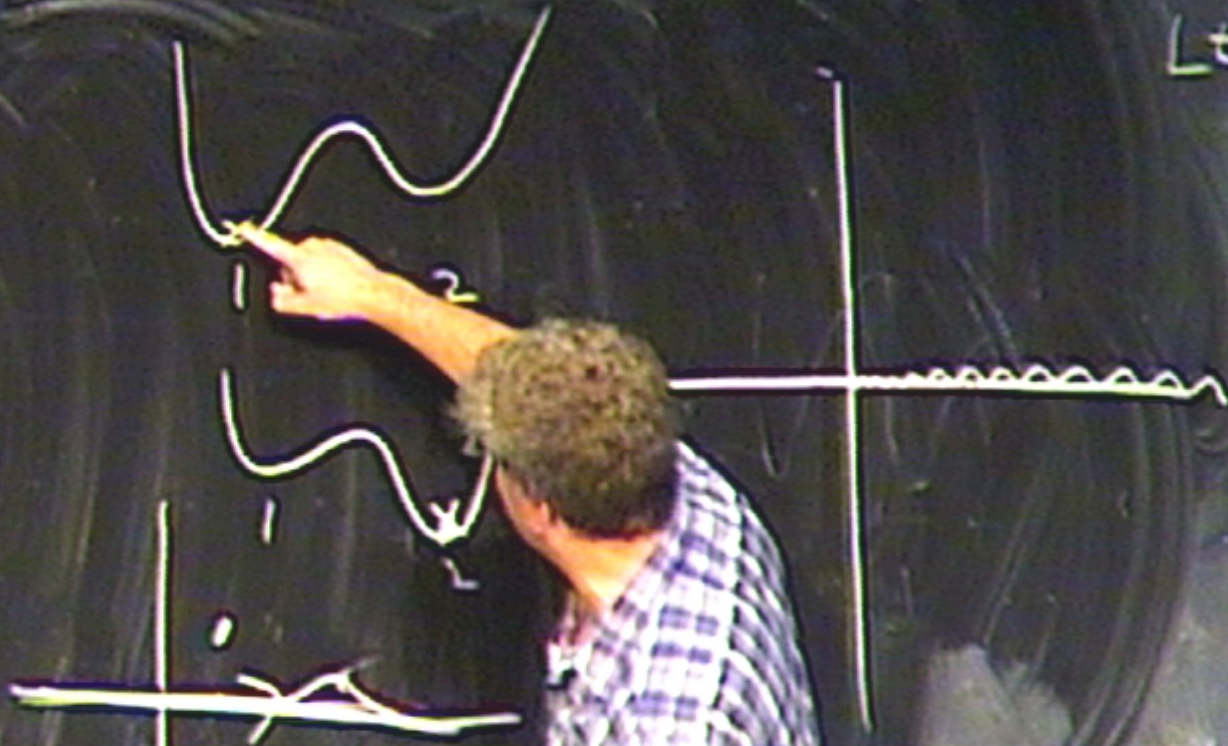
$$\sim e^{-mL}$$

$$\sim \frac{1}{(t - \tau_c)^{2m}}$$

$$\gamma_s \rightarrow 0$$

$$m \rightarrow \infty$$

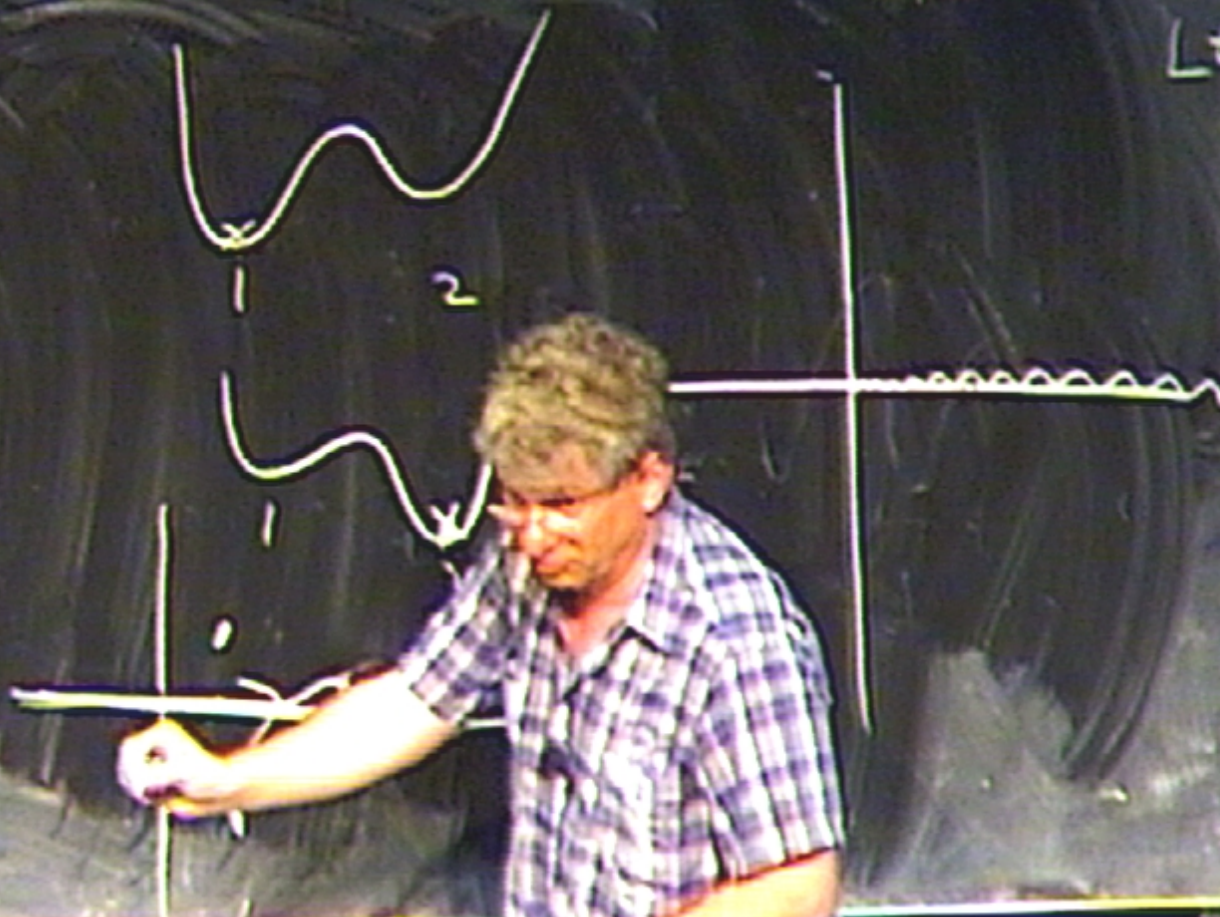
Lt



$$\langle \phi \phi \rangle(t)$$

$$\sim e^{-mL}$$

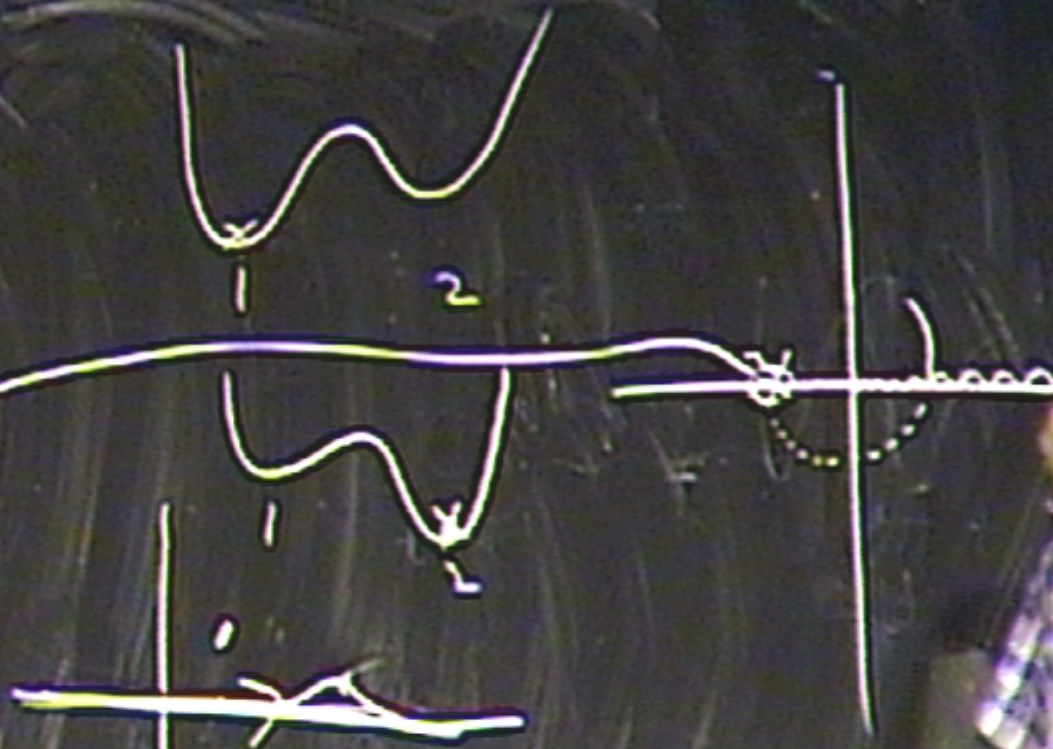
$$\sim \frac{1}{(t-\tau_c)^{2m}}$$



$$\langle \phi \phi \rangle(t)$$

$$\sim e^{-mL}$$

$$\sim \frac{1}{(t-\tau_c)^{2m}}$$



$$\gamma_s \rightarrow 0$$

$$m \rightarrow \infty$$

Lt

$$\sim \frac{1}{(t - \tau_c)^{2m}}$$



$$\langle \phi \phi \rangle(t)$$

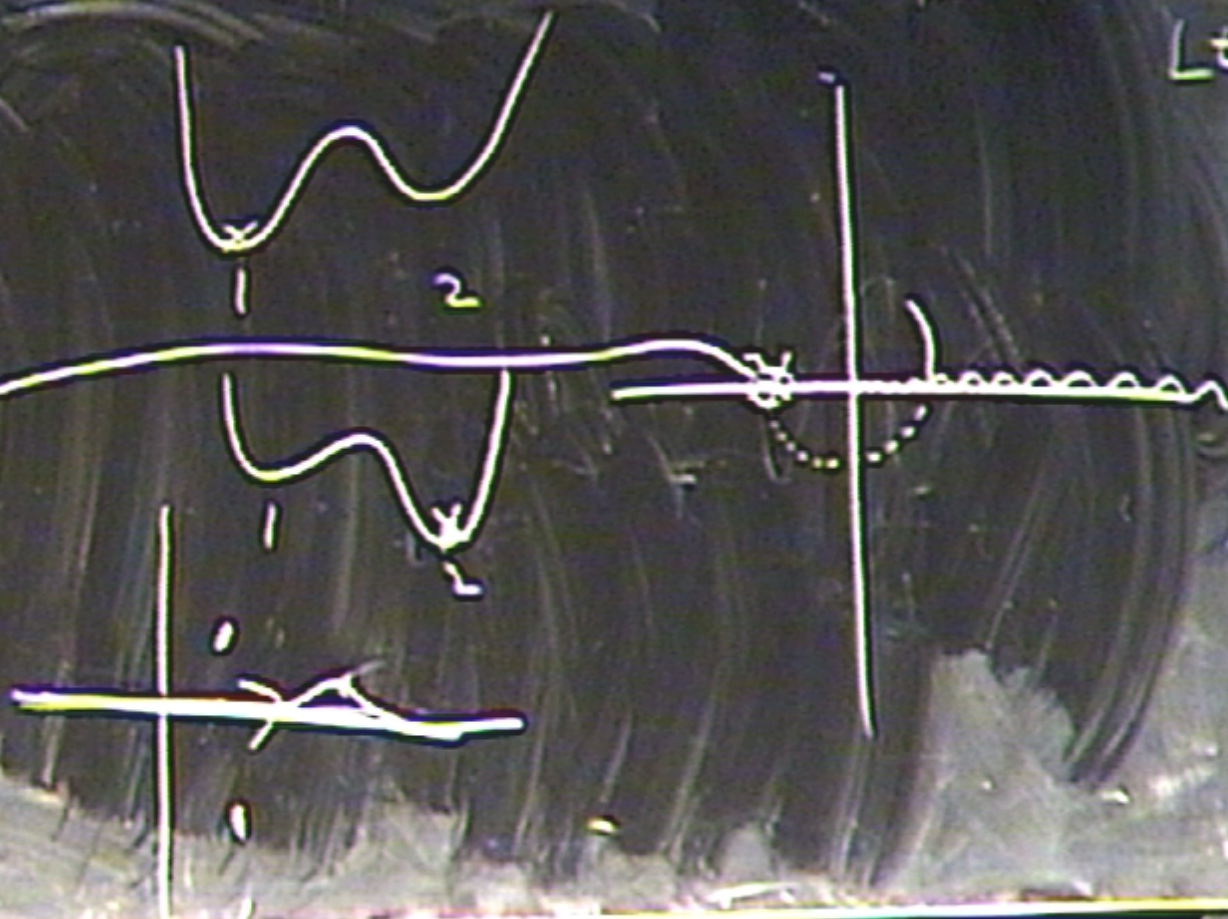
$$\sim e^{-m_1 t}$$

$$\sim \frac{1}{(t-\tau_c)^{2m_2}}$$

$$\gamma_s \rightarrow 0$$

$$m \rightarrow \infty$$

Lt



$$\langle \phi \phi \rangle(t)$$

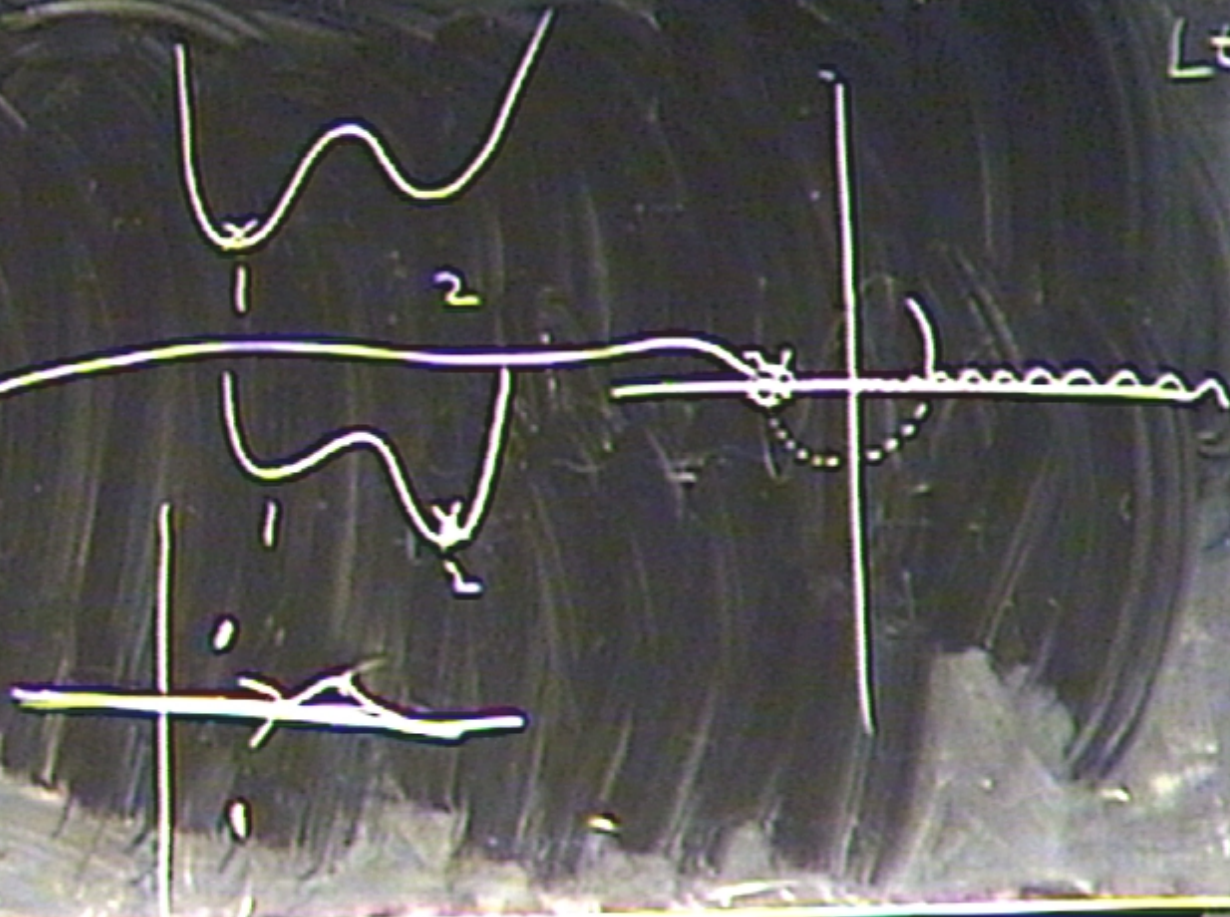
$$\sim e^{-m_1 t}$$

$$\sim \frac{1}{(t - \tau_c)^{2m_2}}$$

$$\gamma_s \rightarrow 0$$

$$m \rightarrow \infty$$

Lt



$$\langle \phi \phi \rangle(t, t)$$

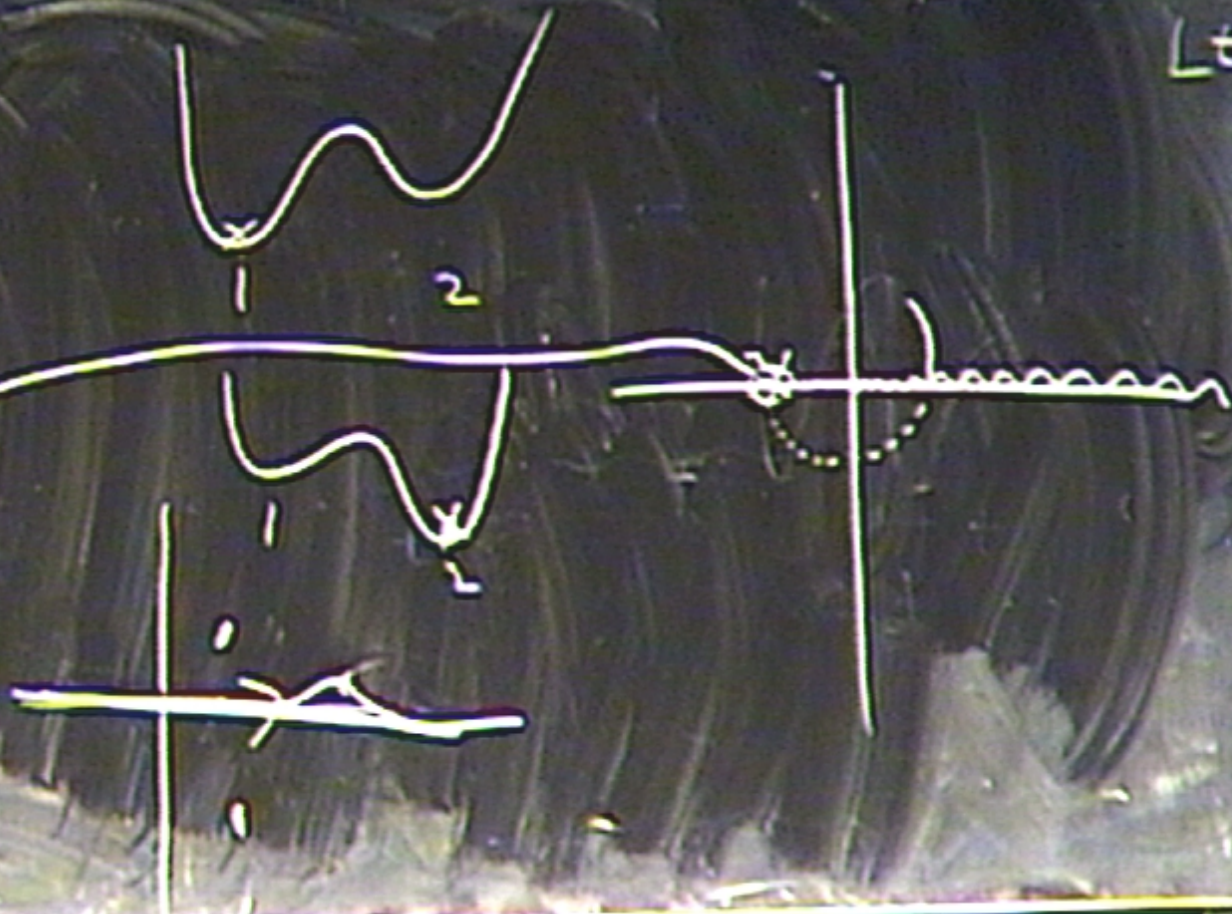
$$\sim e^{-m_1 L}$$

$$\sim \frac{1}{(t - \tau_c)^{2m_2}}$$

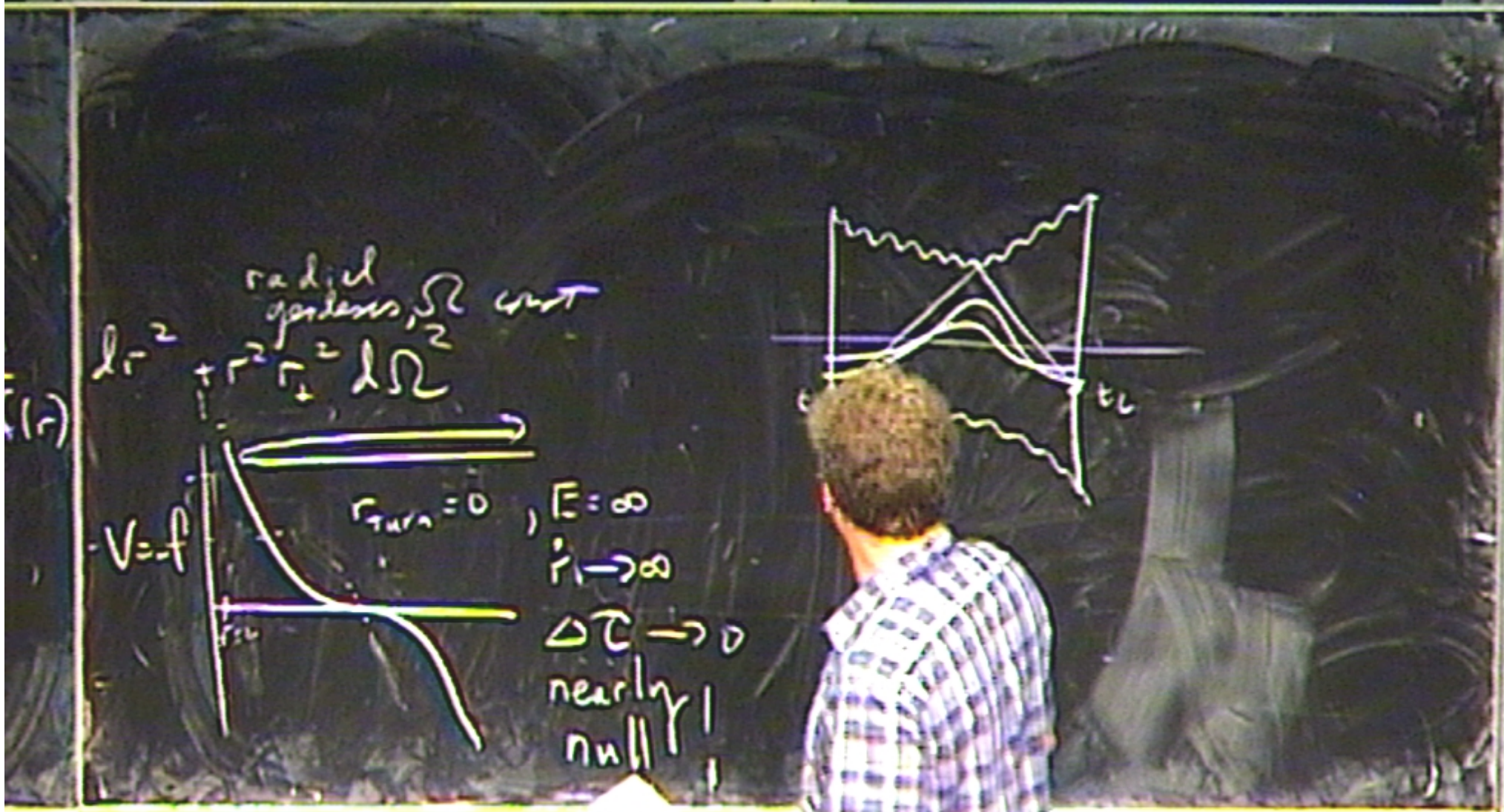
$$\gamma_s \rightarrow 0$$

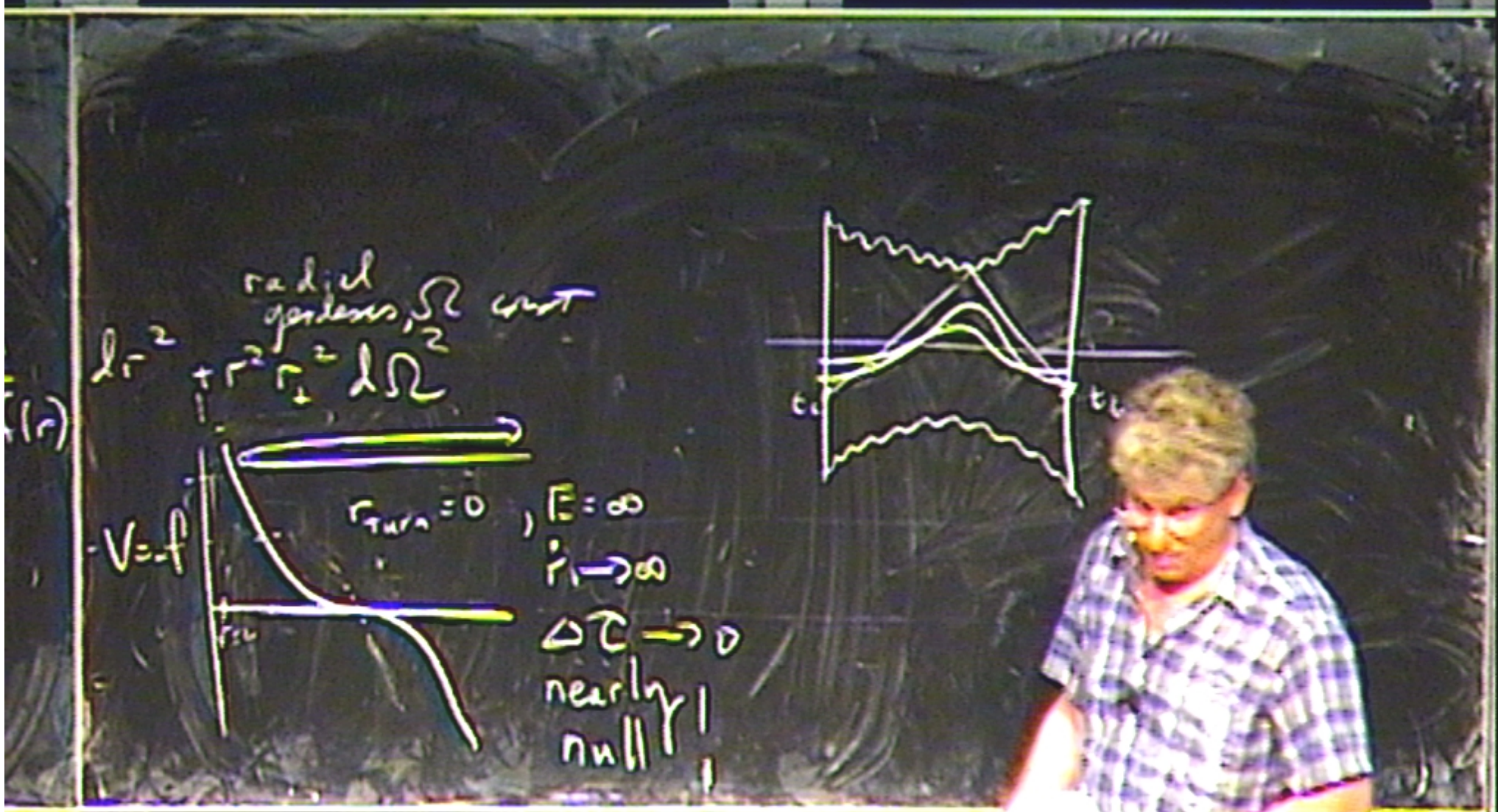
$$m \rightarrow \infty$$

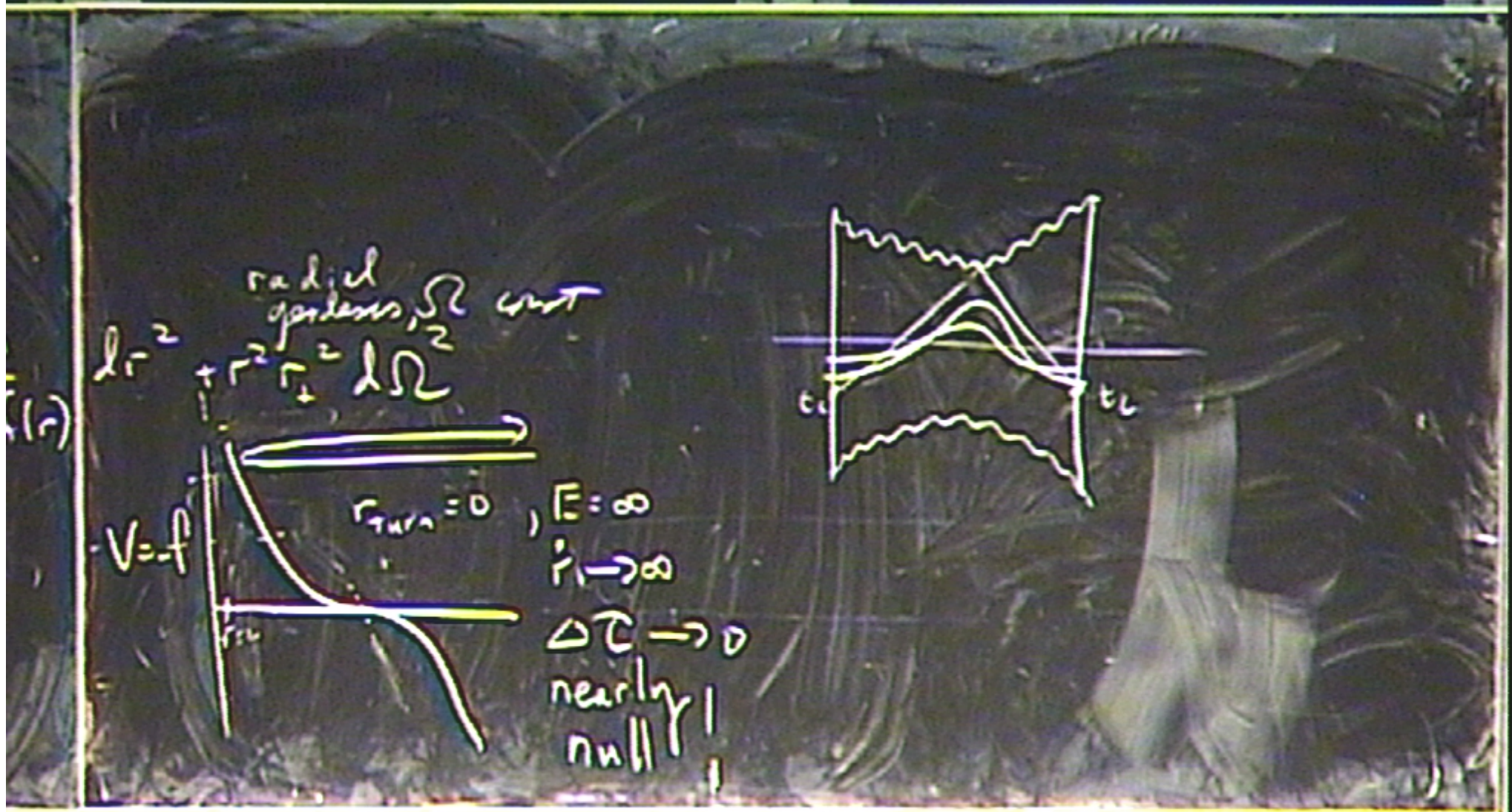
Lt











$$\langle \phi \phi \rangle(t)$$

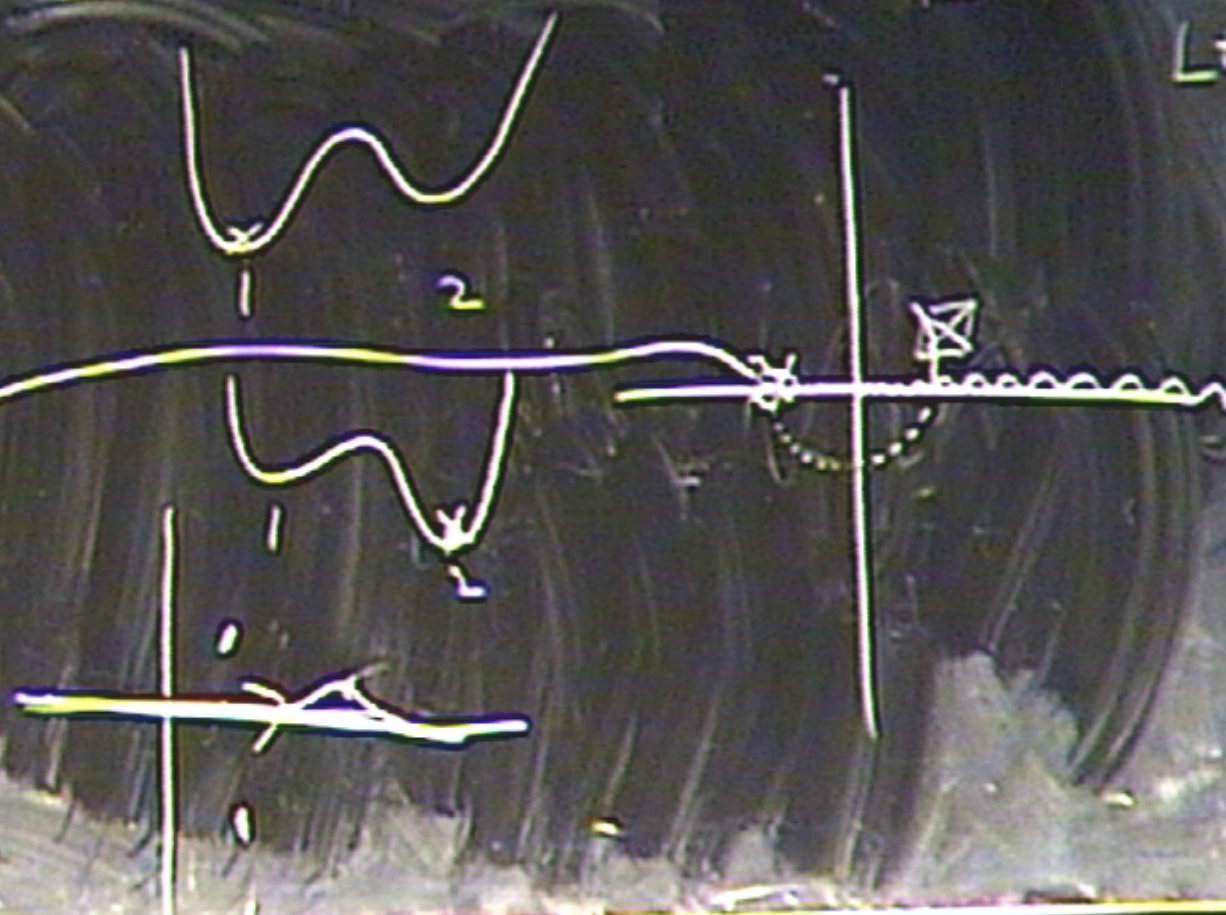
$$\sim e^{-m_1 t}$$

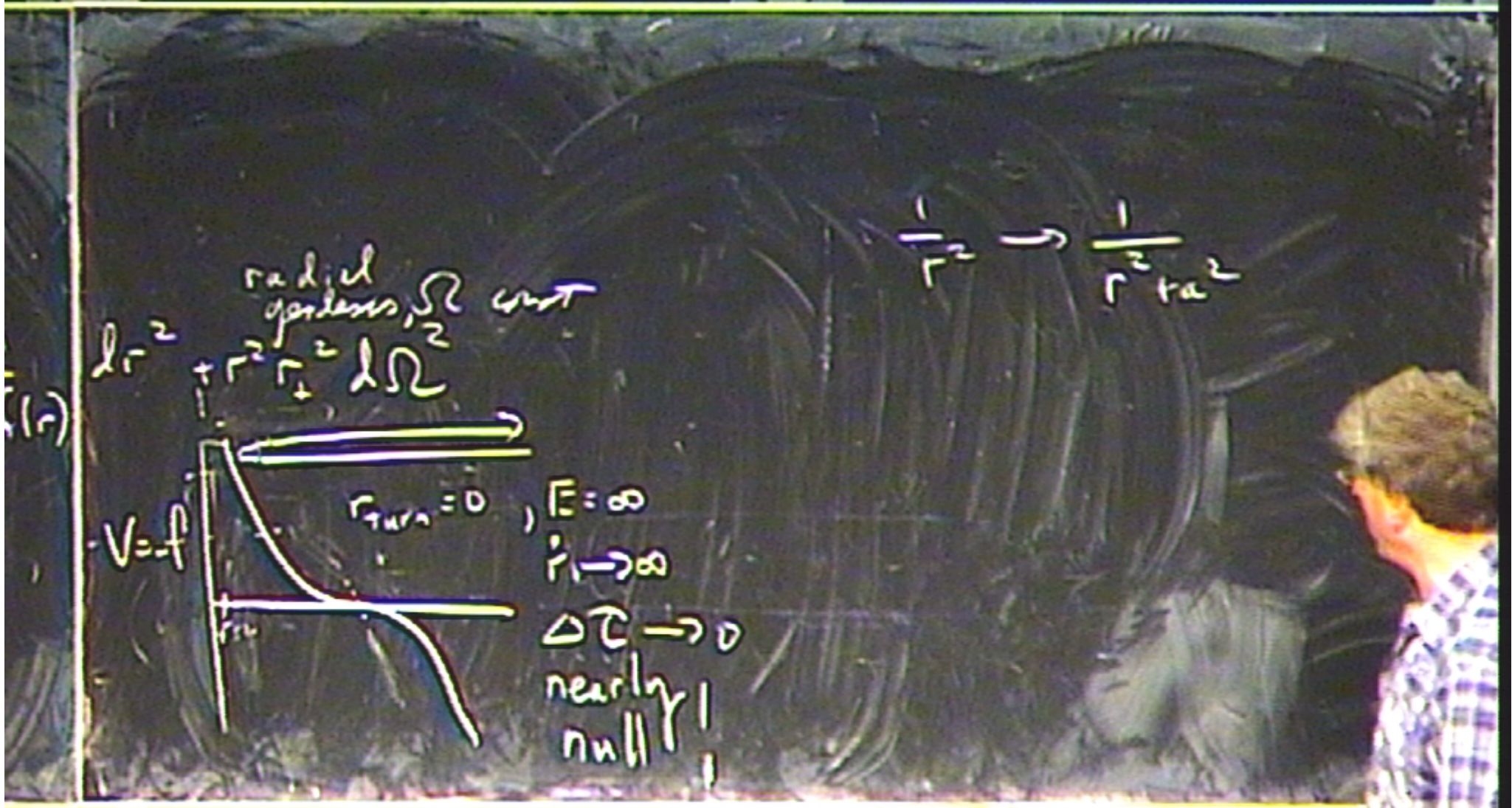
$$\sim \frac{1}{(t - \tau_c)^{2m_2}}$$

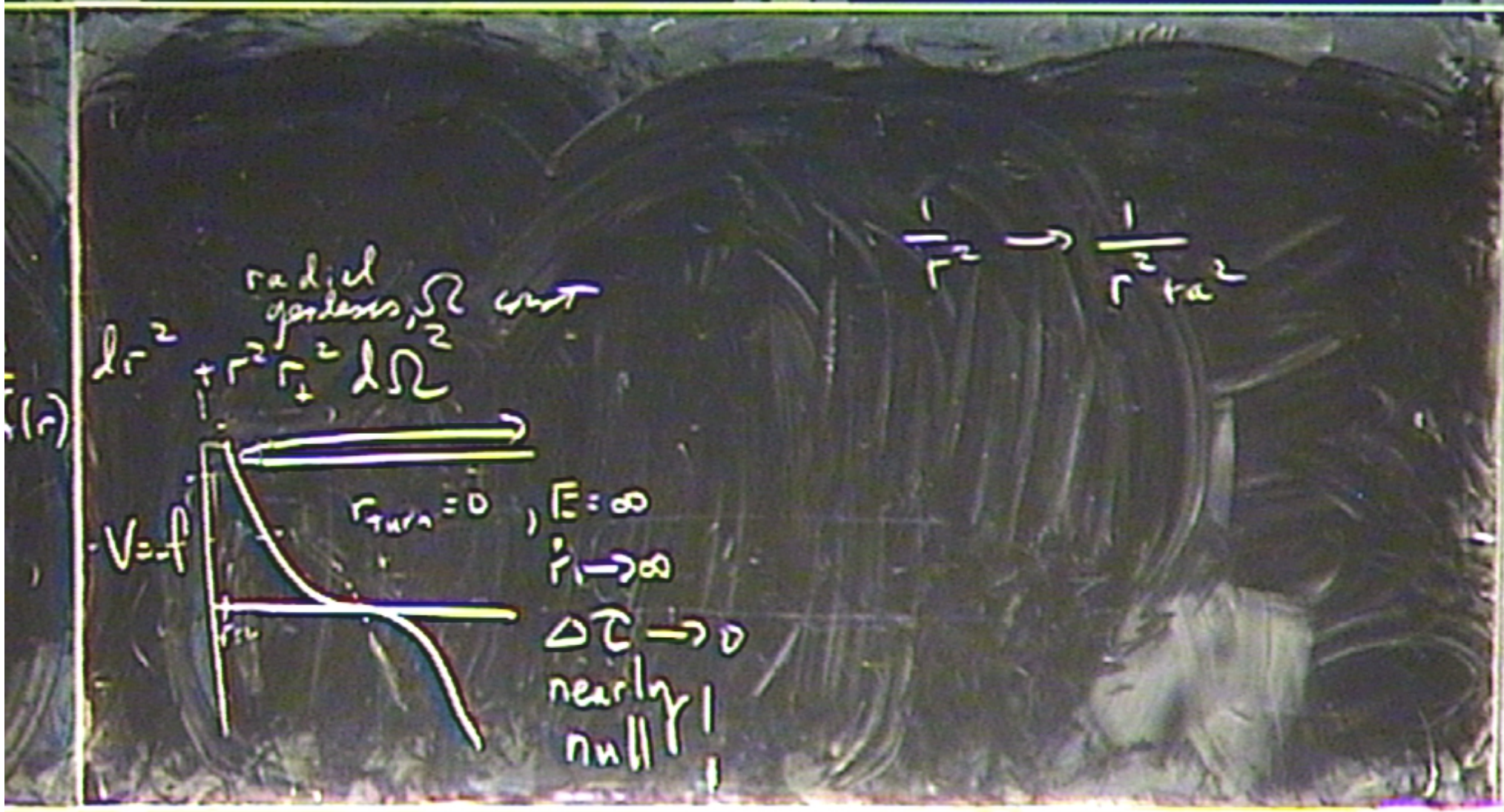
$$\gamma_s \rightarrow 0$$

$$m \rightarrow \infty$$

Lt







radial
spines, Ω unit

$$Lr^2 + r^2 Lr^2 + \lambda \Omega^2$$

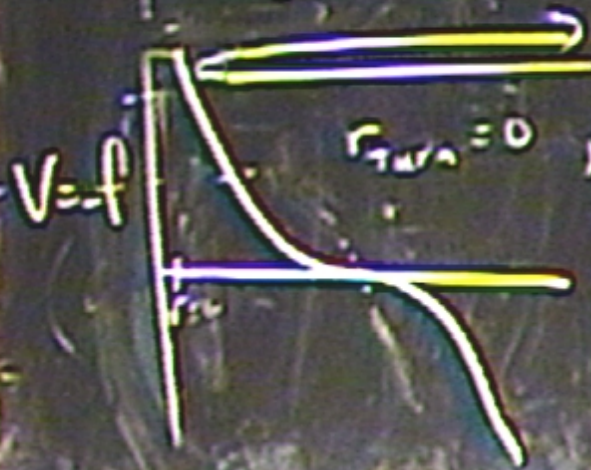

$$r_{TMR} = 0, E = \infty$$

Figure 1

 $\Delta T \rightarrow 0$

nearly null

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- 1) We miss ... ing.
- 2) There's ...

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- 1) We missed sing.
- 2) There's a phase transition
as we varies λ at
finite T

- 1) We missed Sing.
- 2) There's a phase transition as μ varies λ at finite T
- 3) Sing is smoothed out by α' effects