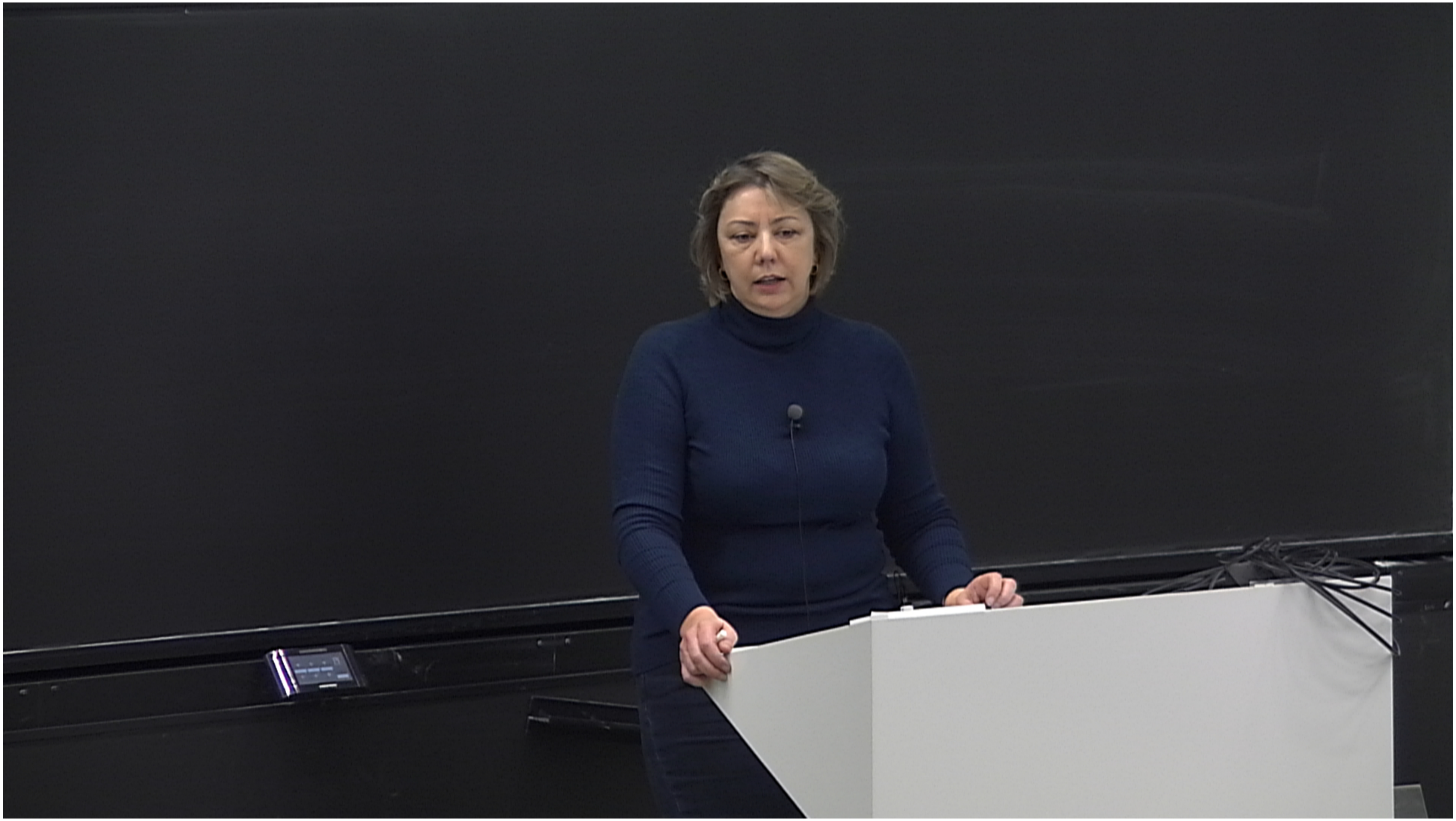
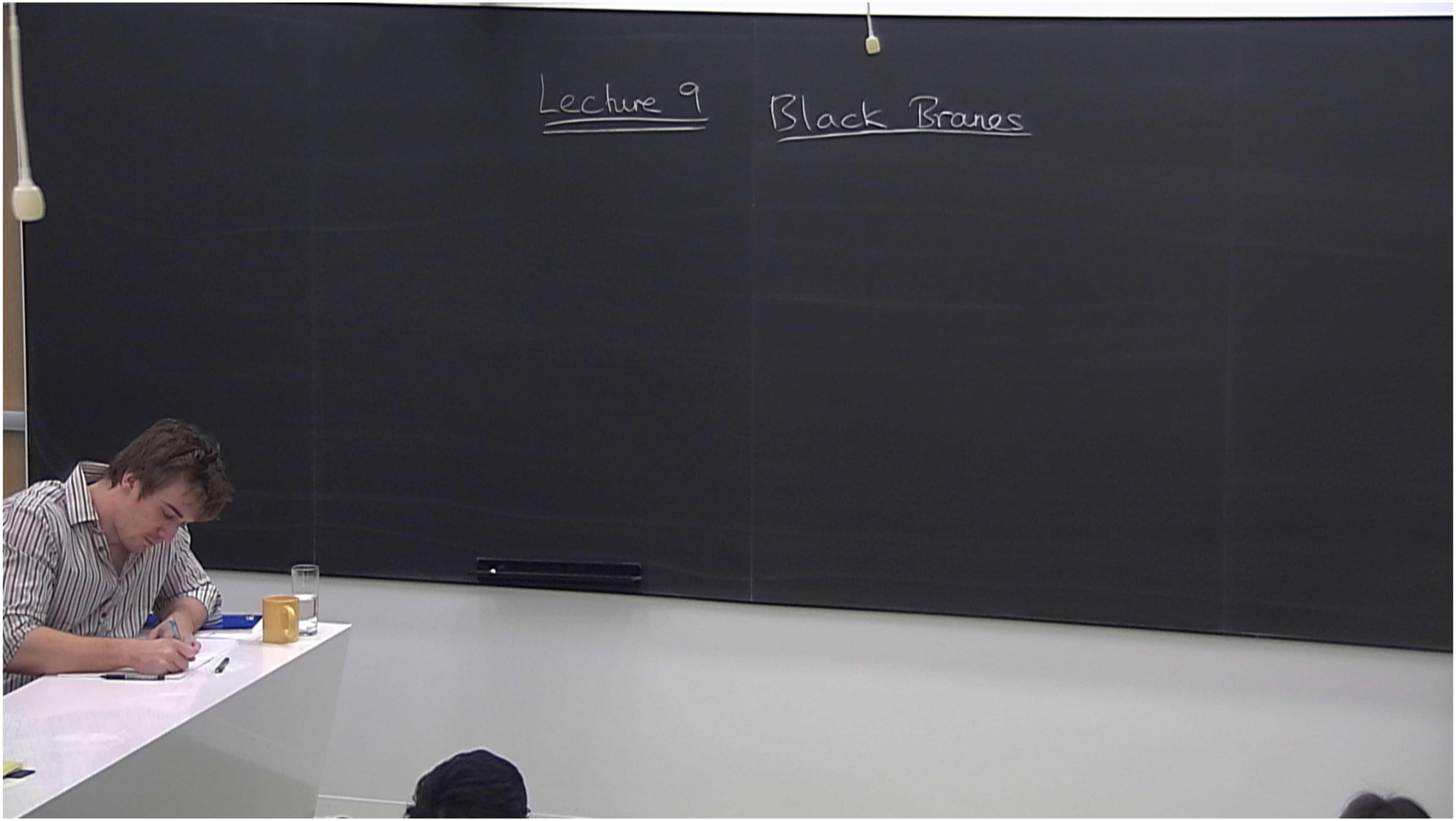
Title: Gravitational Physics (Review) - Lecture 9

Date: Feb 01, 2012 09:00 AM

URL: http://pirsa.org/12020011

Abstract:




Lecture 9
Black Branes

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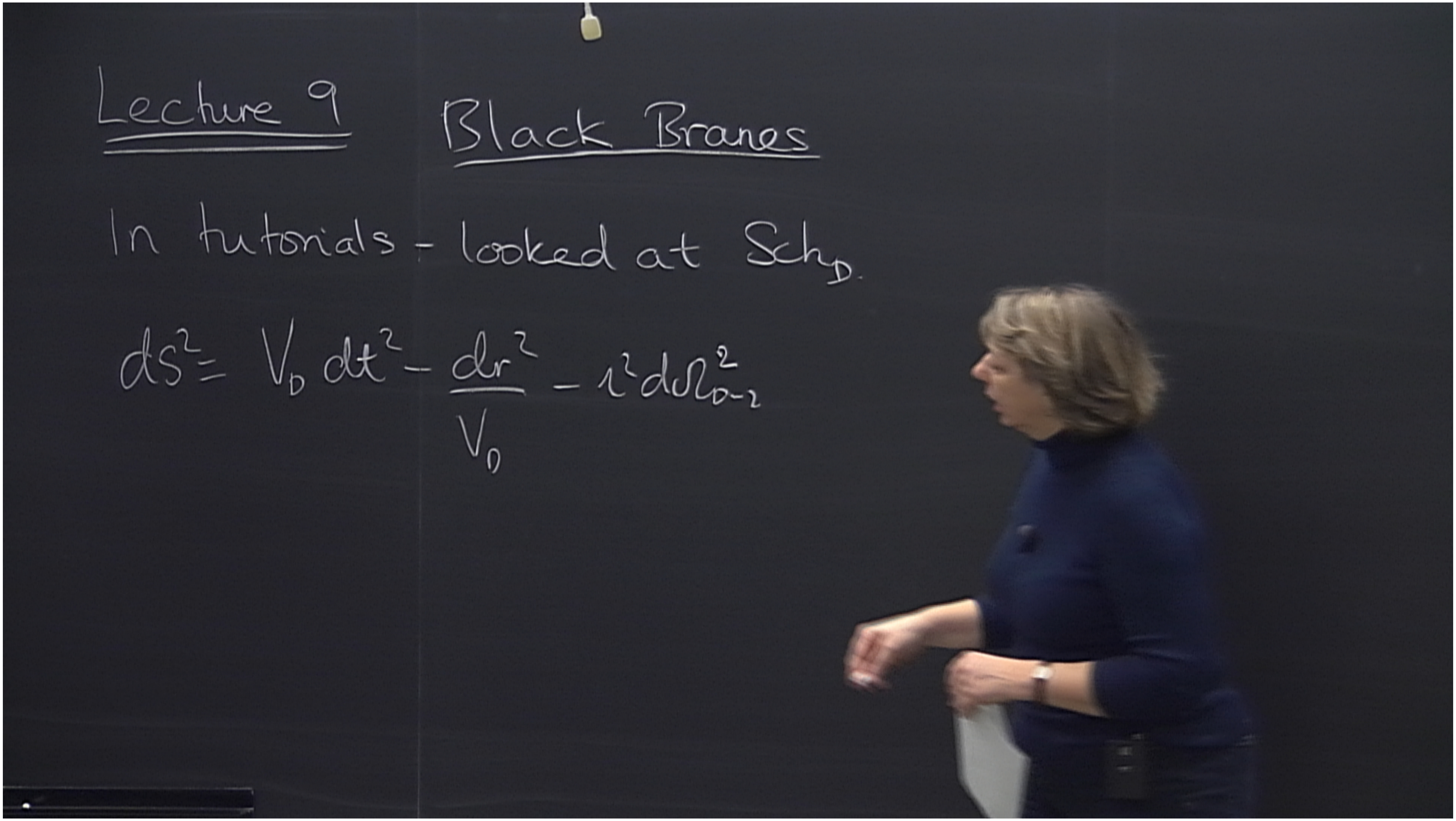
In tutorials - looked at Sch_D.


Lecture 9
Black Branes
In tutorials - looked at Sch_D.
$ds^2 = V_D\, dt^2 - \frac{dr^2}{V_D} - r^2 d\Omega^2_{D-2}$

Lecture 9

Black Branes

In tutorials - looked at Sch_D.

$$ds^2 = V_D\, dt^2 - \frac{dr^2}{V_D} - r^2 d\Omega^2_{D-2}$$

$$V_D = 1 - \left(\frac{r_+}{r}\right)^{D-3}$$

Black Branes

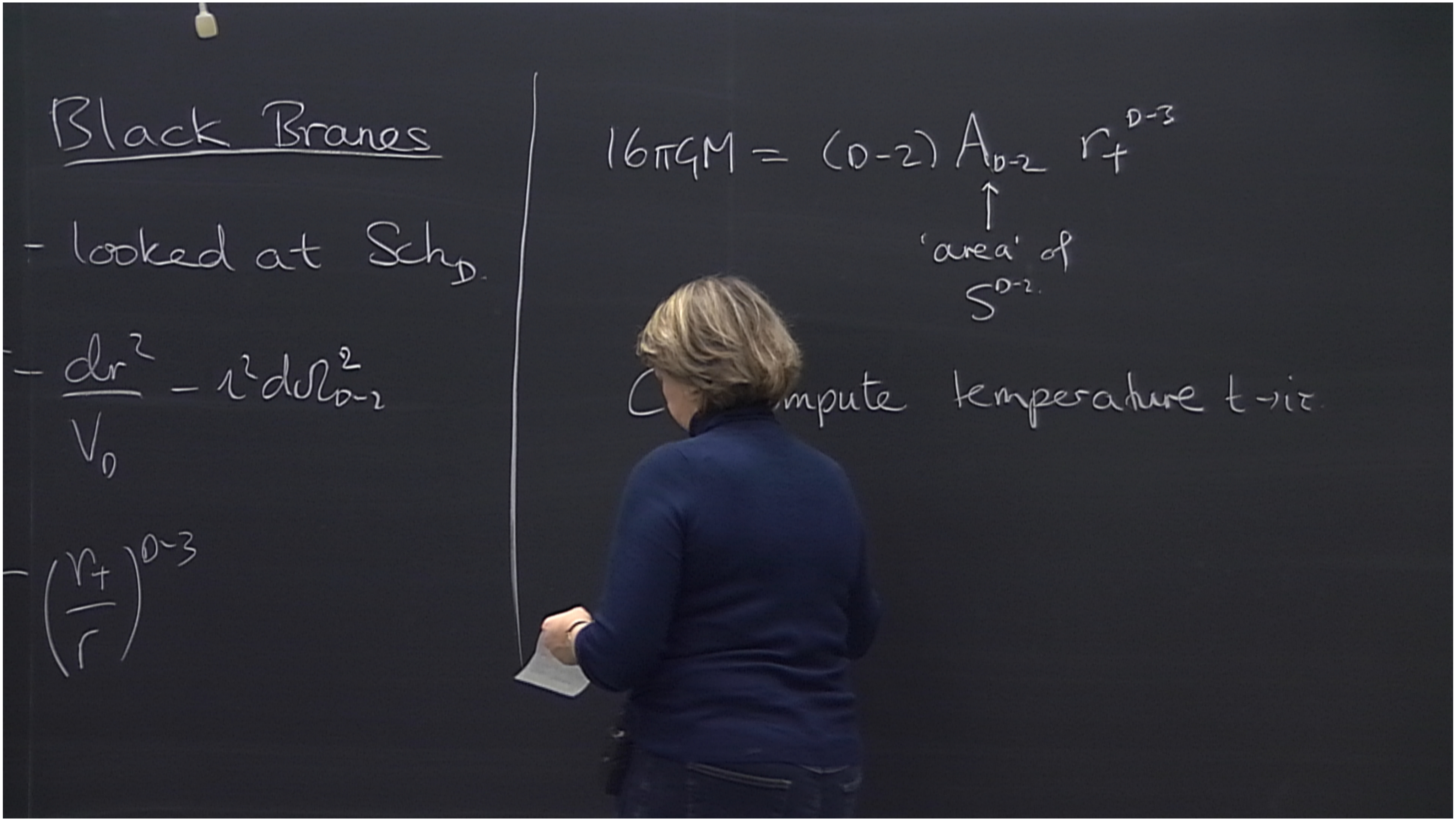
- looked at Sch_D.

$$- \frac{dr^2}{V_D} - r^2 d\Omega_{D-2}^2$$

$$- \left(\frac{r_+}{r}\right)^{D-3}$$

$$16\pi G M = (D-2)\, A_{D-2}\, r_+^{D-3}$$

'area' of S^{D-2}.


Black Branes
- looked at Sch_D.
'area' of S^{D-2}.
16πGM = (D-2) A_{D-2} r_+^{D-3}
mpute temperature t→iτ.

Black Branes

- looked at Sch_D

$-\frac{dr^2}{V_D} - r^2 d\Omega^2_{D-2}$

$-\left(\frac{r_+}{r}\right)^{D-3}$

$$16\pi G M = (D-2)\, A_{D-2}\, r_+^{D-3}$$

$\uparrow$ 'area' of S^{D-2}.

Can compute temperature $t \to i\tau$.

$$ds^2_{\tau, r} \sim V_0'(r_+)(r-r_+)\,d\tau^2 + \frac{dr^2}{V_0'(r_+)(r-r_+)}$$

Black Branes

- looked at Sch_D.

$- \frac{dr^2}{V_D} - r^2 d\Omega^2_{D-2}$

$- \left(\frac{r_+}{r}\right)^{D-3}$

$16\pi GM = (D-2) A_{D-2}\, r_+^{D-3}$

'area' of S^{D-2}.

Can compute temperature $t \to i\tau$.

$ds^2_{\tau,r} - V_0'(r_+)(r-r_+)d\tau^2 + \frac{dr^2}{V_0'(r_+)(r-r_+)}$

Letting $\rho^2 = \frac{4(r-r_+)}{V_0'(r_+)}$

Black Branes

- looked at Sch_D

$- \frac{dr^2}{V_D} - r^2 d\Omega^2_{D-2}$

$- \left(\frac{r_+}{r}\right)^{D-3}$

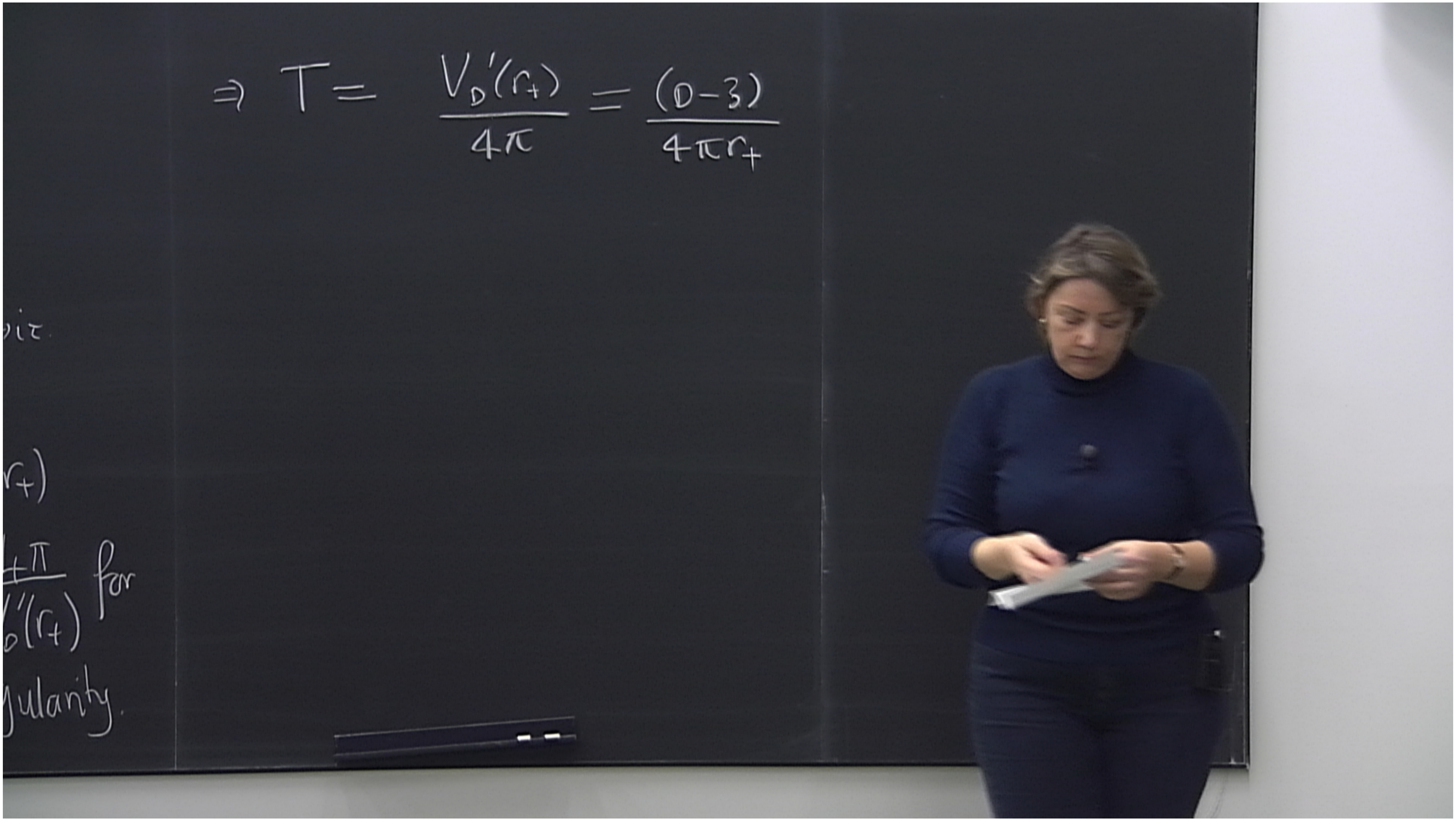
$$16\pi G M = (D-2) A_{D-2}\, r_+^{D-3}$$

A_{D-2}: 'area' of S^{D-2}.

Can compute temperature $t \to i\tau$.

$$ds^2_{\tau,r} - V_0'(r_+)(r-r_+)d\tau^2 + \frac{dr^2}{V_0'(r_+)(r-r_+)}$$

Letting $\rho^2 = \frac{4(r-r_+)}{V_0'(r_+)}$ gives $\Delta\tau = \frac{4\pi}{V_0'(r_+)}$ for regularity.


$\Rightarrow T = \frac{V_D'(r_+)}{4\pi} = \frac{(D-3)}{4\pi r_+}$

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$$= \left(\frac{(D-2)A_{D-2}}{16\pi G M}\right)^{1/D-3} \frac{(D-3)}{4\pi}$$

it.

$r_+)$

$\frac{4\pi}{V_D'(r_+)}$ for

gularity.

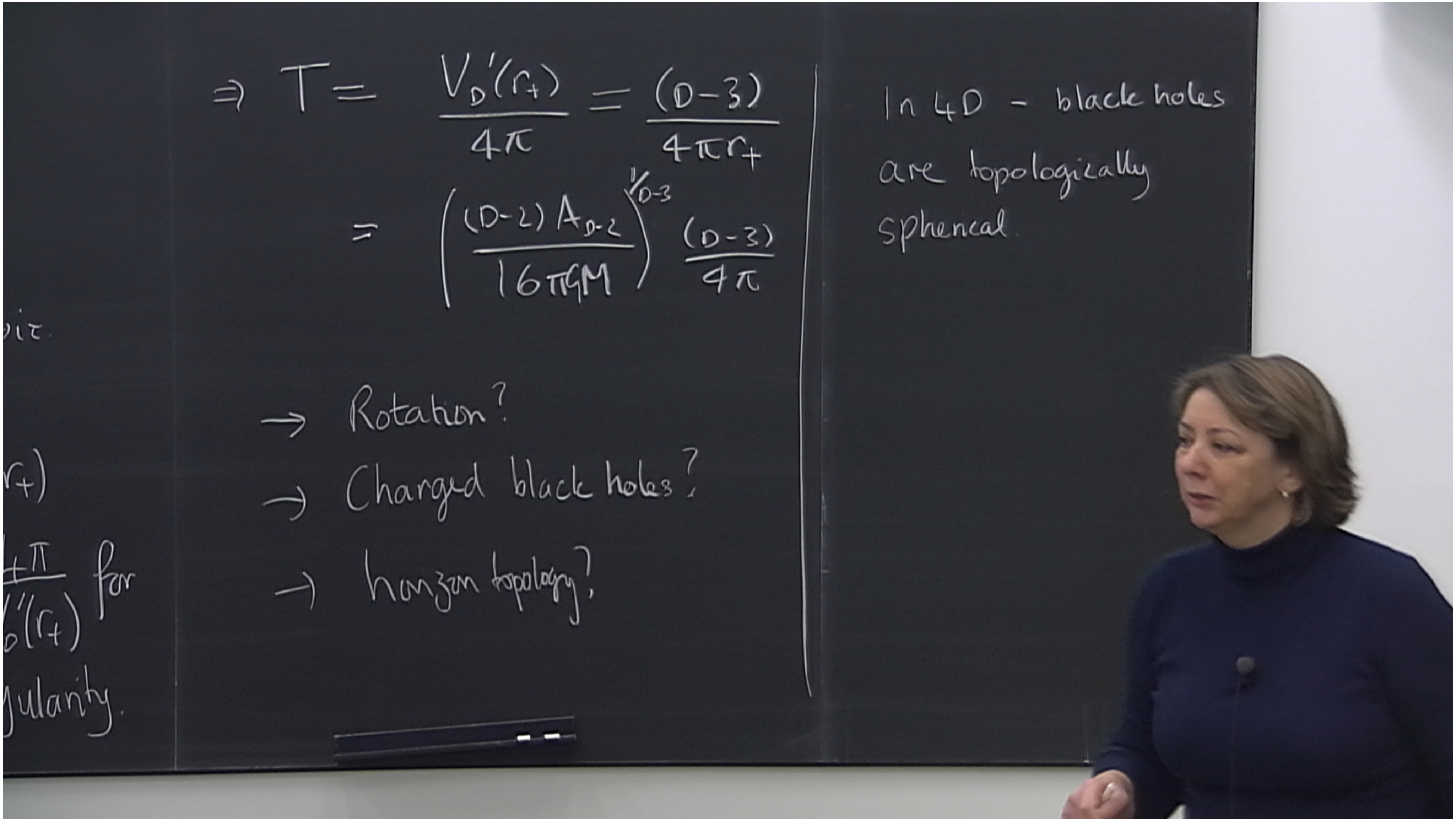
$$\Rightarrow T = \frac{V_D'(r_+)}{4\pi} = \frac{(D-3)}{4\pi r_+}$$

$$= \left(\frac{(D-2)\,A_{D-2}}{16\pi G M}\right)^{1/D-3} \frac{(D-3)}{4\pi}$$

→ Rotation?

→ Charged black holes?

→ horizon topology?



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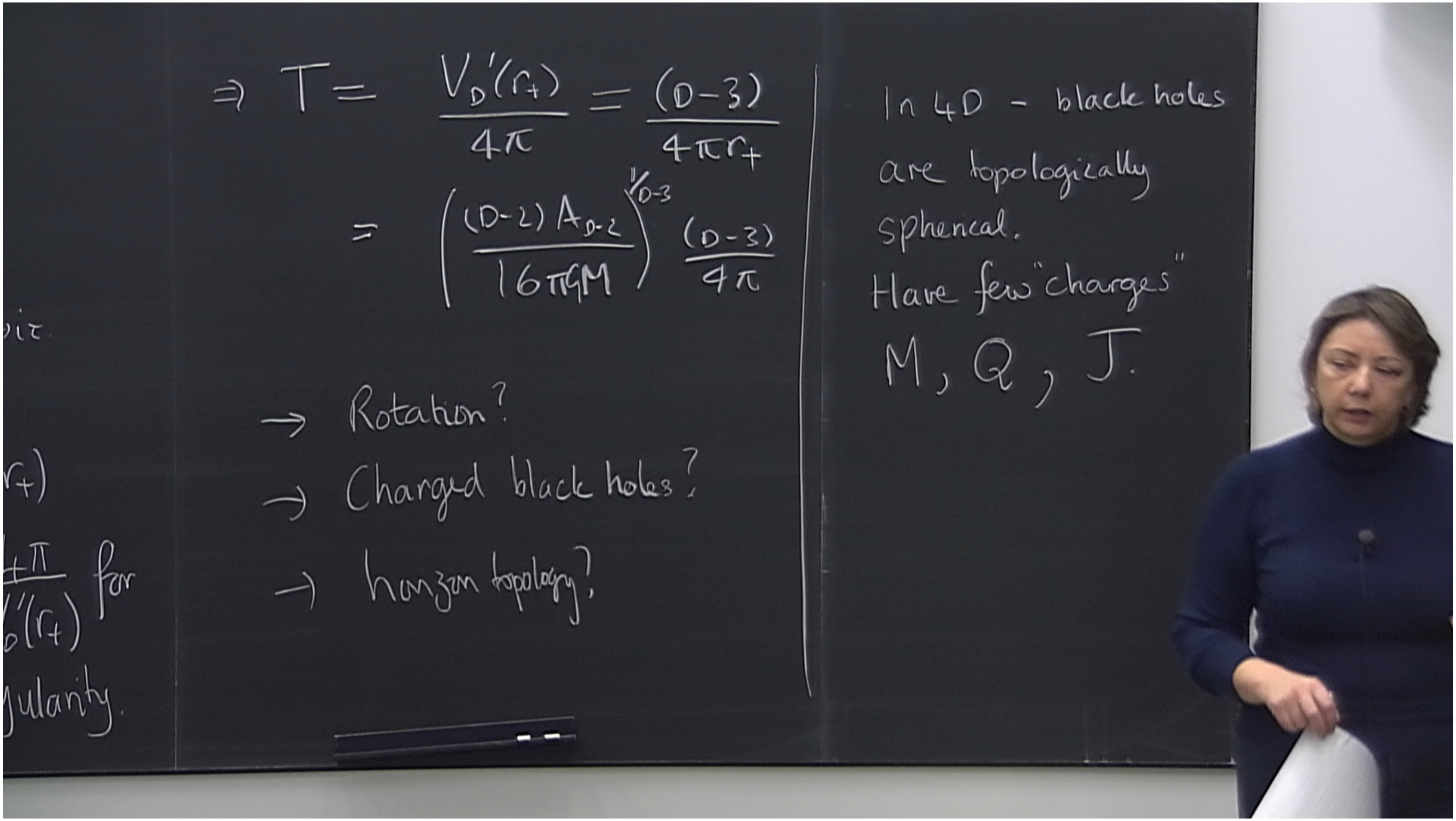
$= \left(\frac{(D-2)A_{D-2}}{16\pi GM}\right)^{1/D-3} \frac{(D-3)}{4\pi}$
→ Rotation?
→ Charged black holes?
→ horizon topology?
In 4D - black holes
are topologically
spherical.



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→ Rotation?
→ Charged black holes?
→ horizon topology?
In 4D - black holes
are topologically
spherical.
Have few "charges"
M, Q, J.

$$\Rightarrow T = \frac{V_D'(r_+)}{4\pi} = \frac{(D-3)}{4\pi r_+}$$

$$= \left(\frac{(D-2)\,A_{D-2}}{16\pi G M}\right)^{1/D-3} \frac{(D-3)}{4\pi}$$

→ Rotation?

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In 4D - black holes are topologically spherical.

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Don't have baryon number

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→ Rotation?

→ Charged black holes?

→ horizon topology?

In 4D - black holes are topologically spherical.

Have few "charges"

M, Q, J.

Don't have baryon number

"No hair theorems"

...it.

$r_+)$

$\frac{4\pi}{V_D'(r_+)}$ for

...gularity.

Rotating black holes (Myers-Perry).

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e.g.

$$d\cdots dt^2 - \left(\frac{r_+}{r}\right)^{D-3} \frac{r^2}{\rho^2}\left(dt + a\sin\theta\, d\varphi\right)^2 - r^2\cos^2\theta\, d\Omega_{D-4}^2$$

$$- \rho^2\left(\frac{dr^2}{\Delta} + d\theta^2\right) - (r^2+a^2)\sin^2\theta\, d\varphi^2.$$

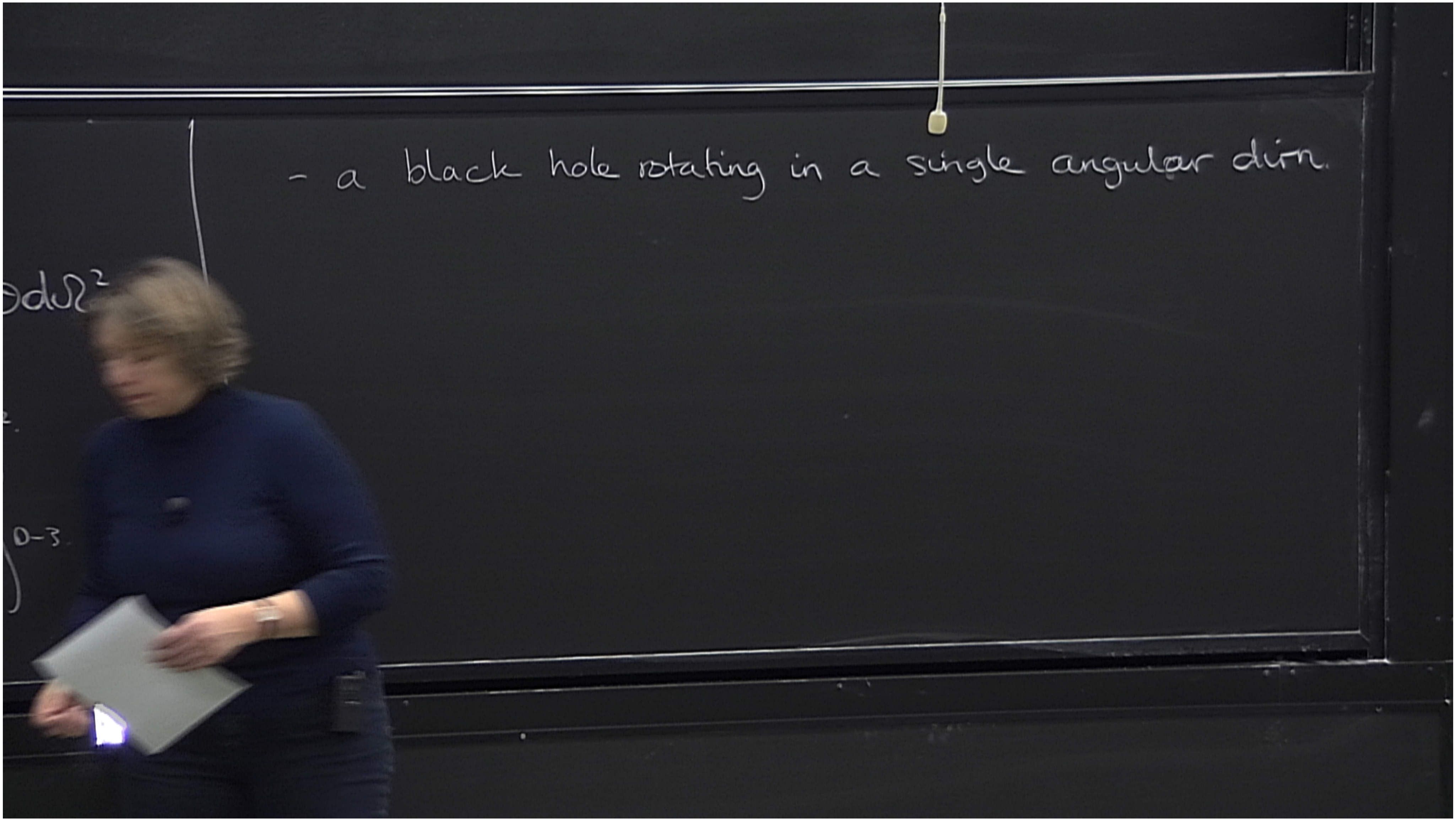
Rotating black holes (Myers-Perry).

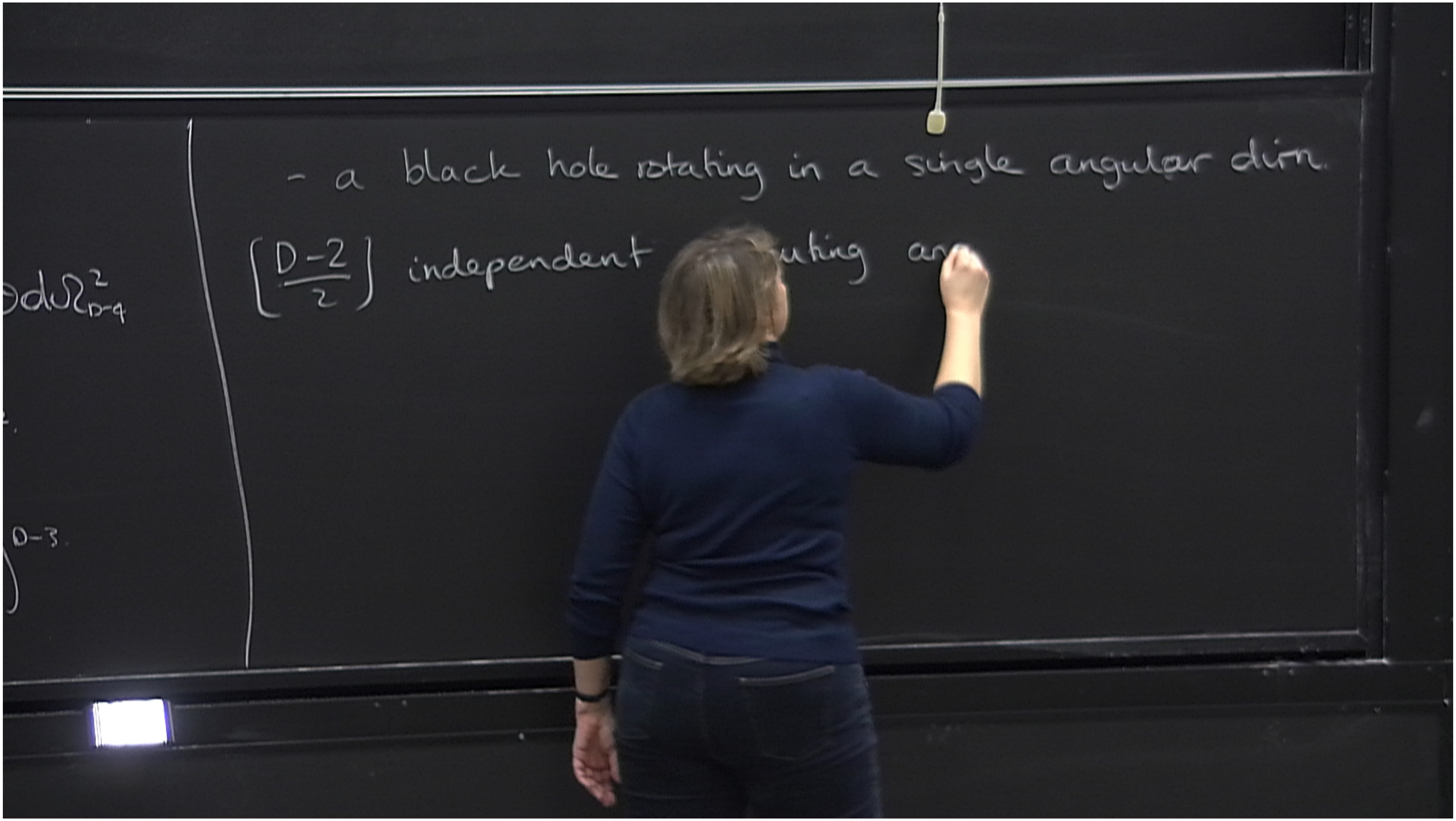
e.g.

$$ds^2 = dt^2 - \left(\frac{r_+}{r}\right)^{D-3} \frac{r^2}{\rho^2}\left(dt + a\sin\theta\, d\varphi\right)^2 - r^2\cos^2\theta\, d\Omega_{D-4}^2$$

$$- \rho^2\left(\frac{dr^2}{\Delta} + d\theta^2\right) - (r^2+a^2)\sin^2\theta\, d\varphi^2.$$

Where $\rho^2 = r^2 + a^2\cos^2\theta$; $\Delta = r^2 + a^2 - r^2\left(\frac{r_+}{r}\right)^{D-3}.$


- a black hole rotating in a single angular dirn.


- a black hole rotating in a single angular dirn.
[D−2 / 2] independent

$\theta\, d\Omega^2_{D-4}$

$)^{D-3}$.

- a black hole rotating in a single angular dirn.

$\left[\frac{D-2}{2}\right]$ independent commuting angular momenta.

$\ominus d\Omega^2_{D-4}$

$)^{D-3}$

- a black hole rotating in a single angular dirn.

$\left[\frac{D-2}{2}\right]$ independent commuting angular momenta.

Can have other "black" solutions:

$d\Omega^2_{D-1}$

$\left[\frac{D-2}{2}\right]$ independent commuting angular momenta.

Can have other "black" solutions:

e.g. black string

$$ds^2 = \left(1-\frac{2GM}{r}\right)dt^2 - \frac{dr^2}{1-\frac{2GM}{r}} - r^2 d\Omega_2^2 - dz^2.$$

$d\Omega^2_{D-4}$

$D-3$

- a black hole rotating in a single angular dirn.

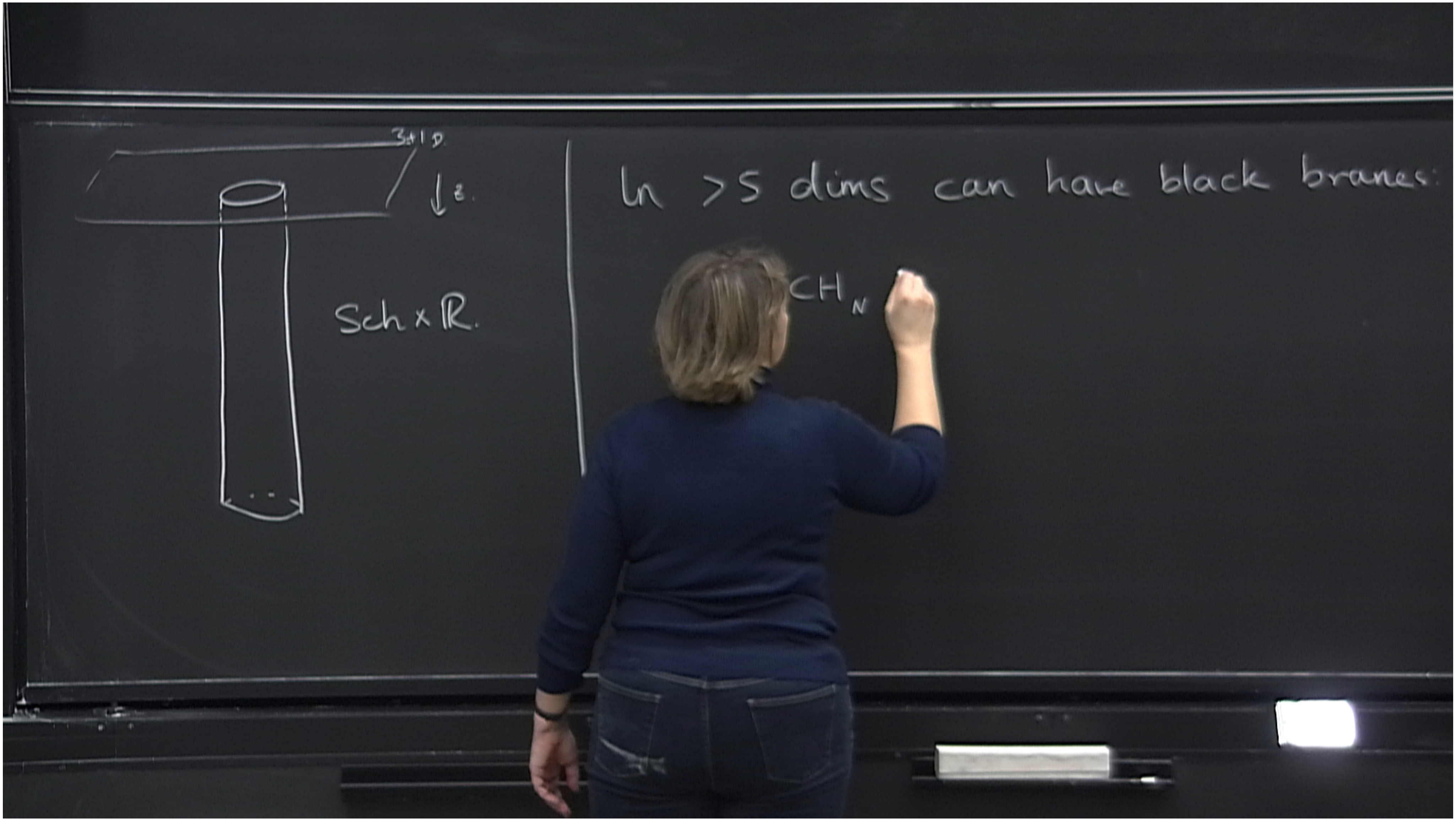
$\left\lfloor \frac{D-2}{2} \right\rfloor$ independent commuting angular momenta.

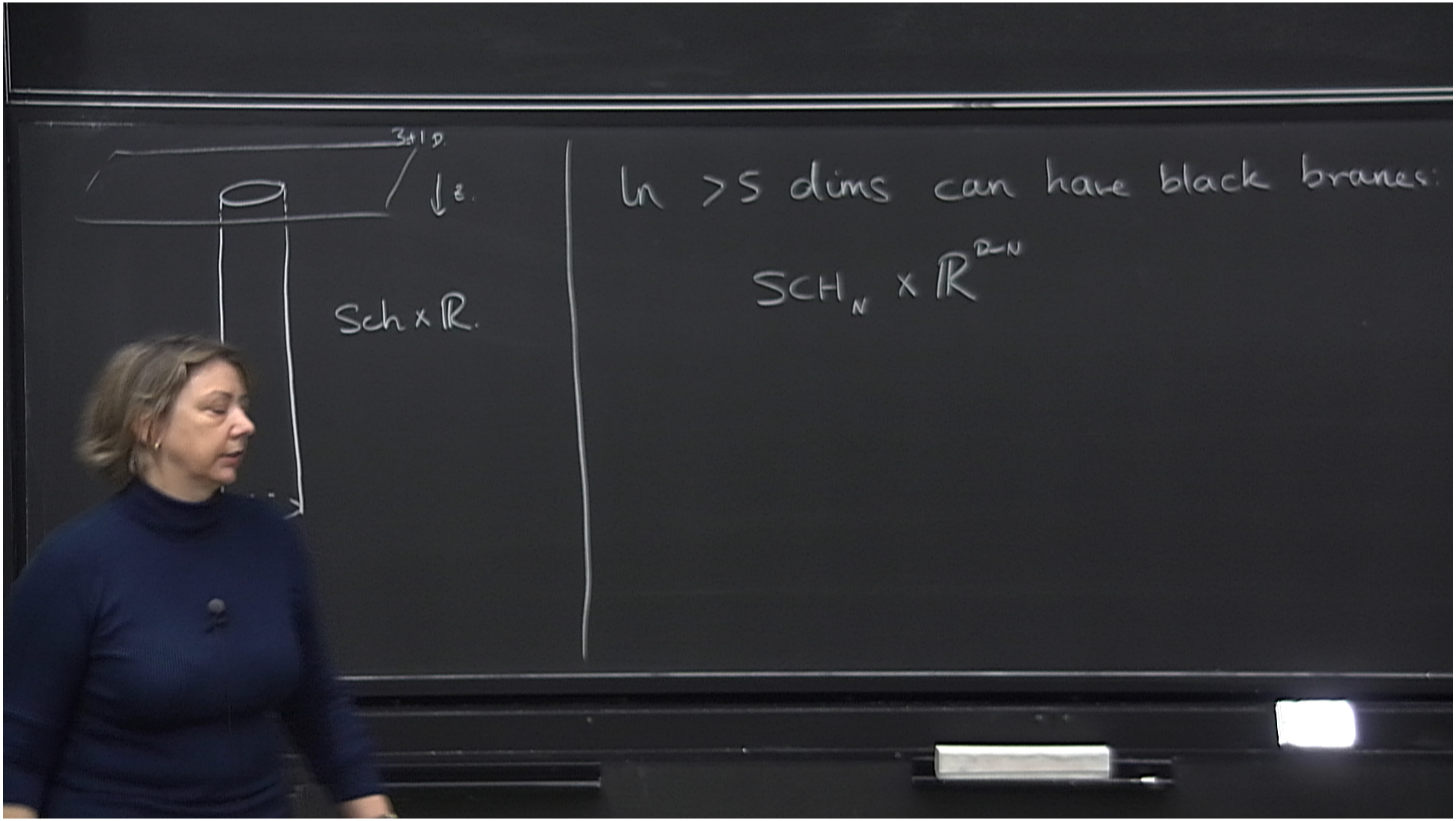
Can have other "black" solutions:

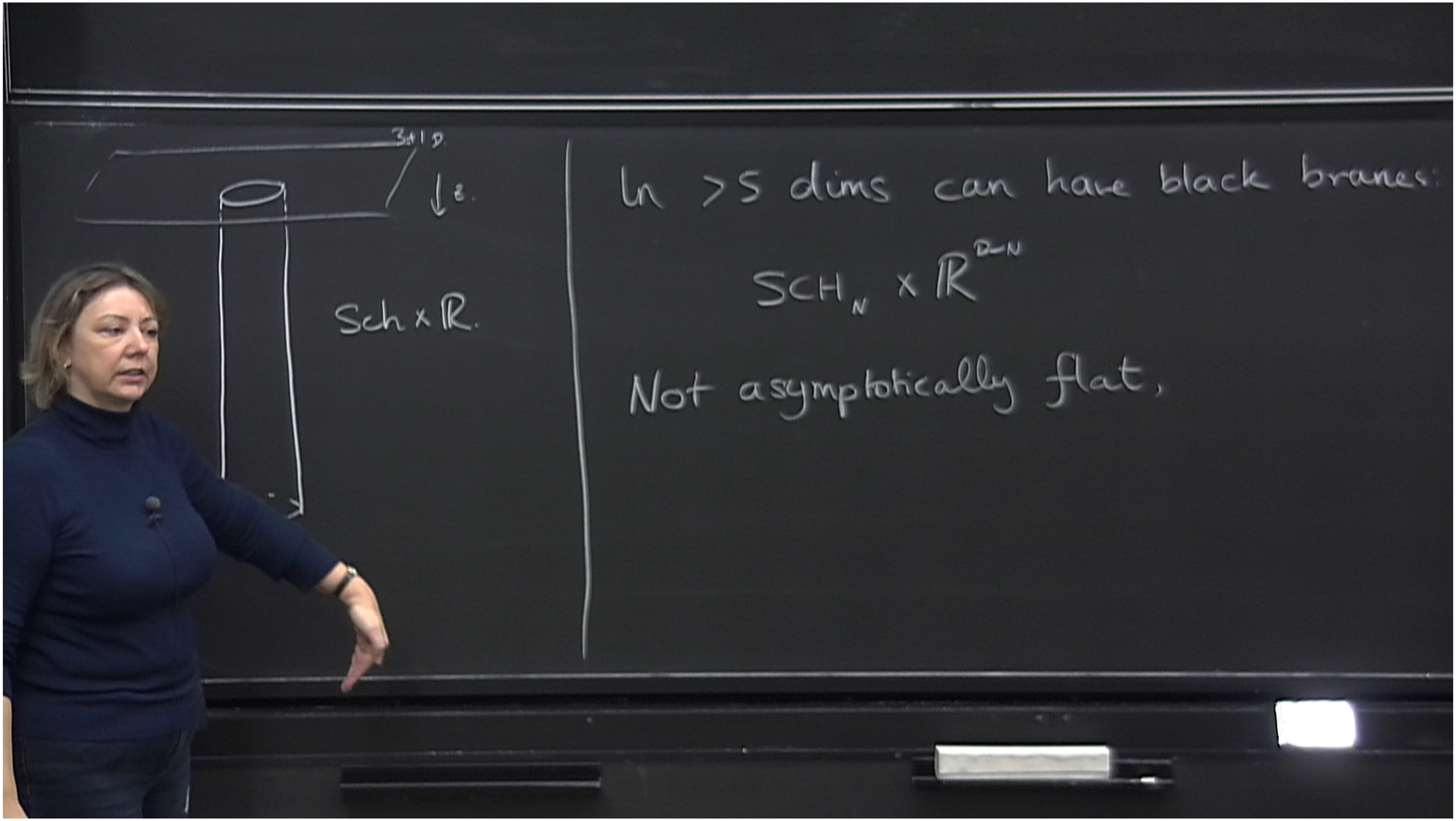
e.g. black string

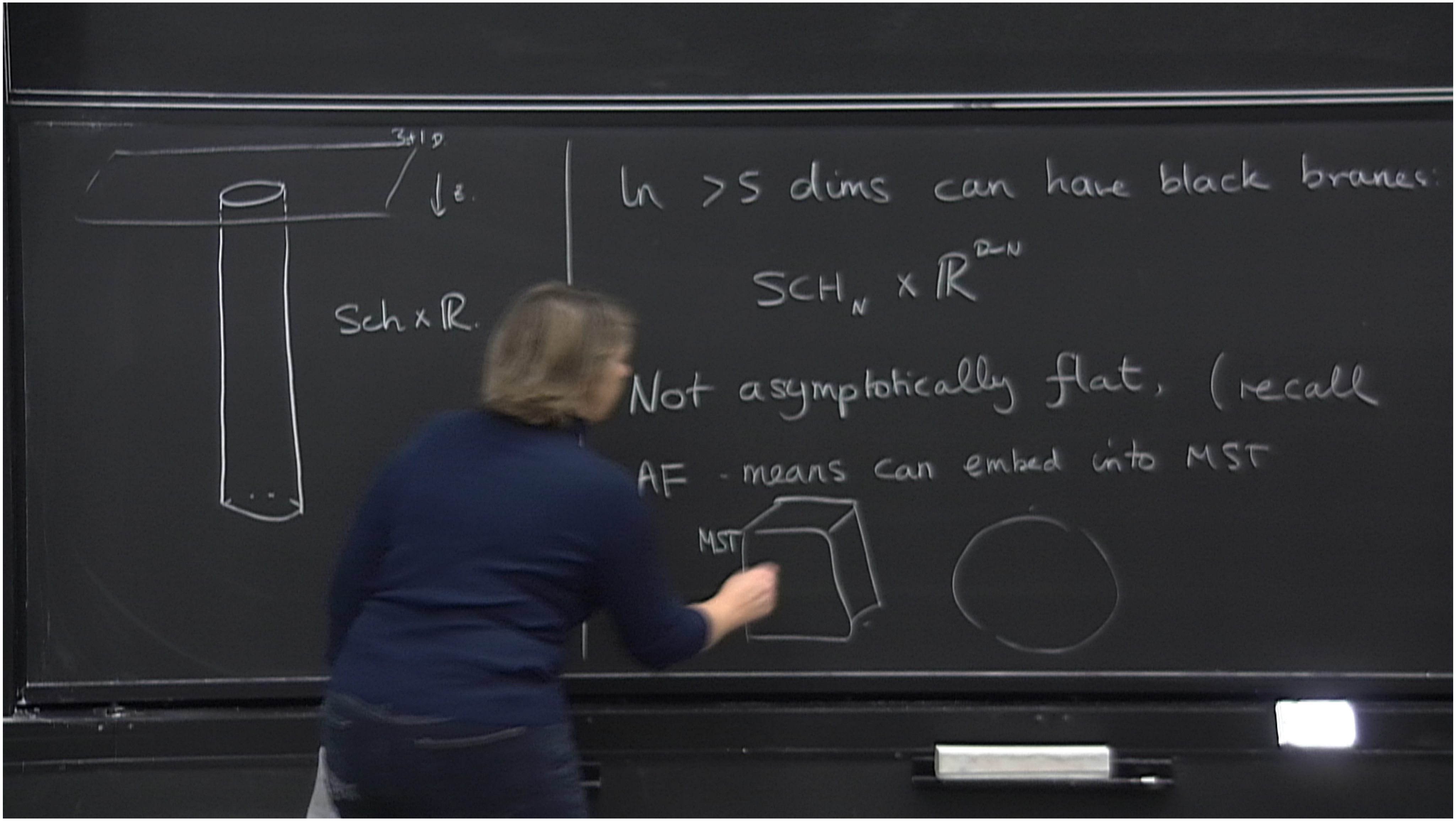
$$ds^2 = \left(1 - \frac{2GM}{r}\right) dt^2 - \frac{dr^2}{1 - \frac{2GM}{r}} - r^2 d\Omega_{II}^2 - dz^2.$$

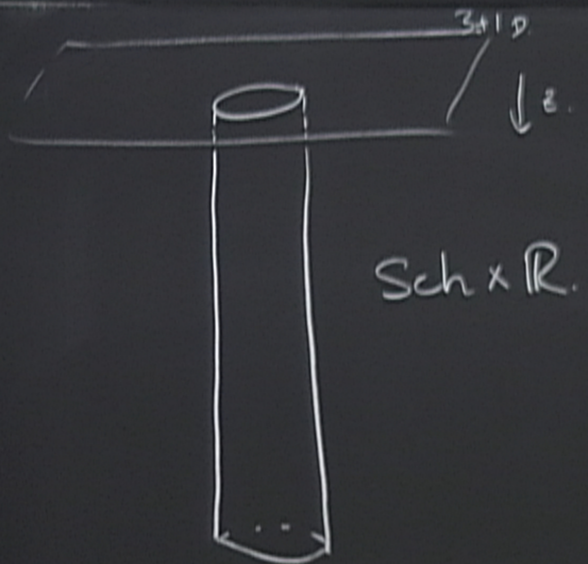

3+1 D


3+1 D
z
Sch x R.
In >5 dims can have black branes:
CH N


3+1 D.
z
Sch × R.
In >5 dims can have black branes:
SCH_N × R^{D-N}


3+1 D
Sch x R.
In >5 dims can have black branes:
SCH_N x R^{D-N}
Not asymptotically flat,


3+1 D
ε
Sch x R.
In >5 dims can have black branes:
SCH_N x R^(D-N)
Not asymptotically flat, (recall
AF - means can embed into MST
MST



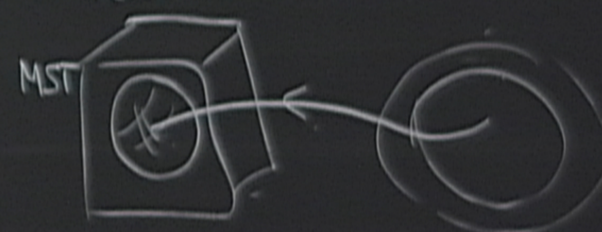
$Sch \times \mathbb{R}$.

In >5 dims can have black branes:

$$SCH_N \times \mathbb{R}^{D-N}$$

Not asymptotically flat, (recall

AF - means can embed into MST



ck branes:

(recall

ST

)

But is AF in the subset (N) directions

ck branes:

(recall

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)

But is AF in the subset (N) directions

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(recall

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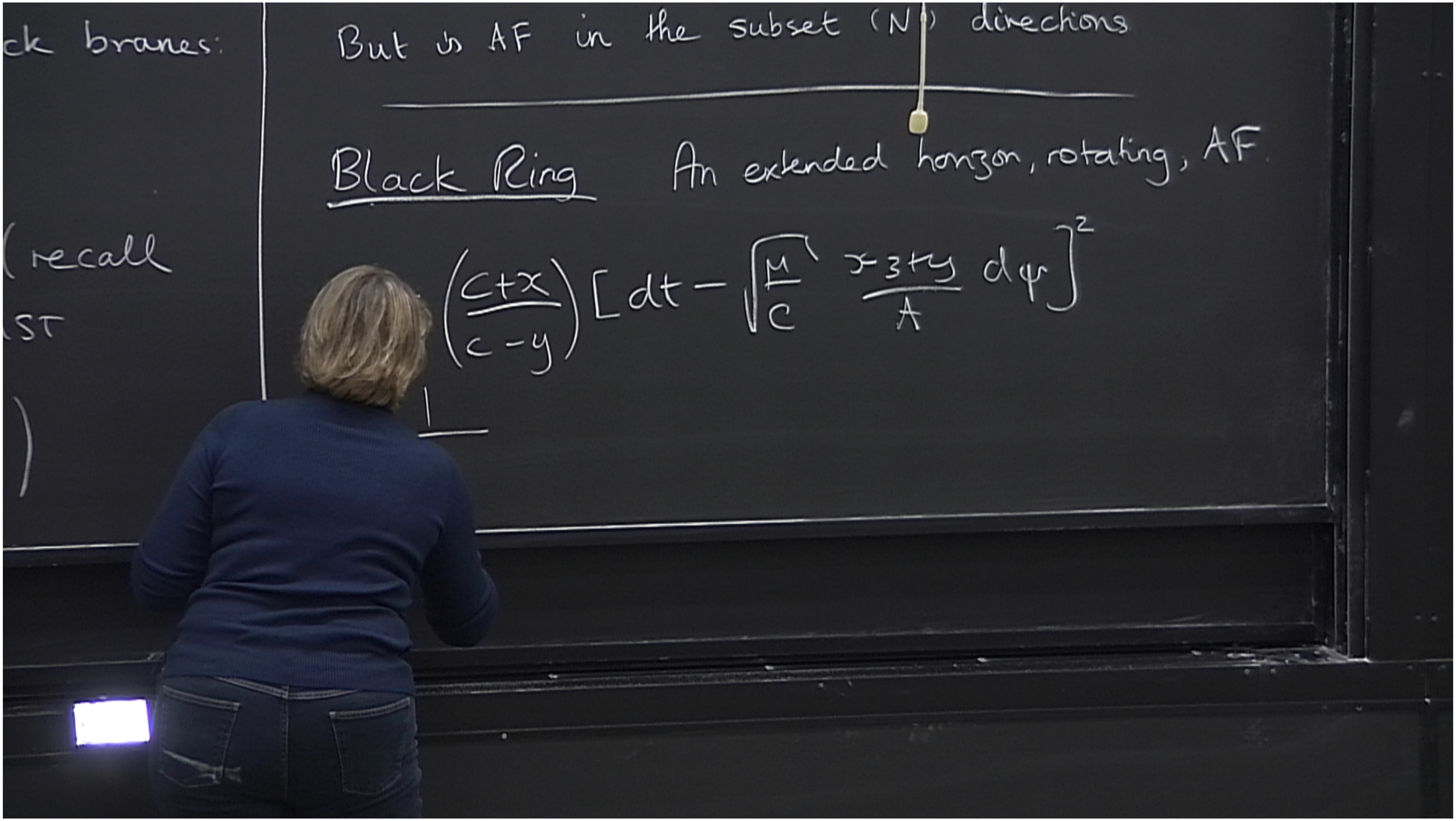
)

But is AF in the subset (N) directions

<u>Black Ring</u> An extended horizon, rotating, AF


ck branes:
But is AF in the subset (N) directions
Black Ring
An extended horizon, rotating, AF.
(recall
ST

recall

ST

Black Ring An extended horizon, rotating, AF

$$ds^2 = \left(\frac{c+x}{c-y}\right)\left[dt - \sqrt{\frac{\mu}{c}}\,\frac{x-3+y}{A}\,d\psi\right]^2$$

$$-\frac{1}{A^2(x+y)^2}\left(\begin{aligned}&\left(1+\frac{x}{c}\right)\left[F(y)\,d\psi^2 + (1-y/c)\,dy^2/F(y)\right]\\ &+\left(1-\frac{y}{c}\right)^2\left[\frac{dx^2}{G(x)} + \frac{G(x)}{1+x/c}\,d\varphi^2\right]\end{aligned}\right)$$

ck branes:

(recall

ST

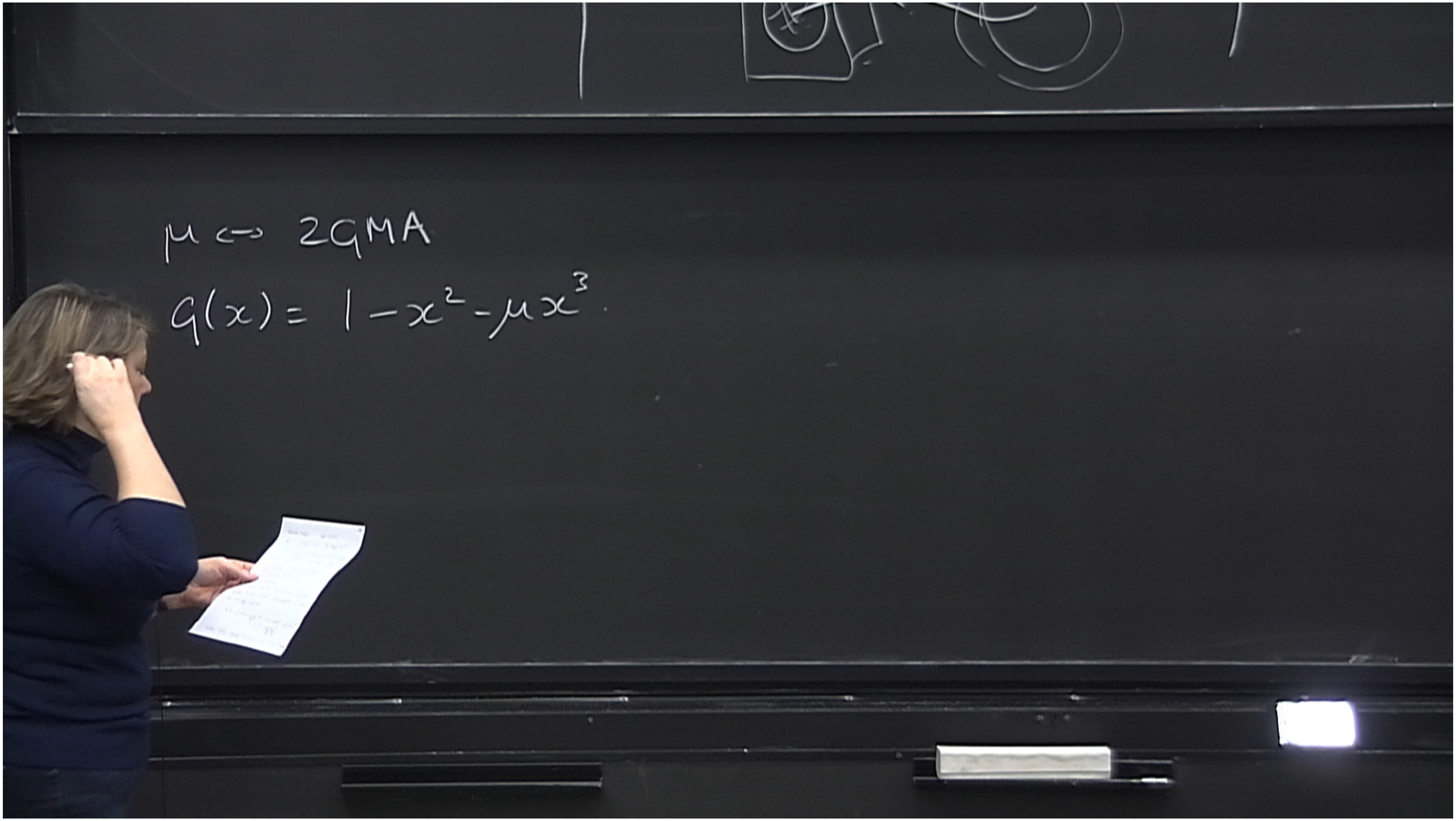
)

But is AF in the subset (N) directions

Black Ring An extended horizon, rotating, AF.

$$ds^2 = \left(\frac{c+x}{c-y}\right)\left[dt - \sqrt{\frac{\mu}{c}}\,\frac{x-3+y}{A}\,d\psi\right]^2$$

$$- \frac{1}{A^2(x+y)^2}\left[(1+\tfrac{x}{c})\left[F(y)\,d\psi^2 + (1-y/c)\,dy^2/F(y)\right] + (1-\tfrac{y}{c})^2\left[\frac{dx^2}{G(x)} + \frac{G(x)}{1+x/c}\,d\varphi^2\right]\right]$$


$\mu \leftrightarrow 2GMA$
$g(x) = 1 - x^2 - \mu x^3$

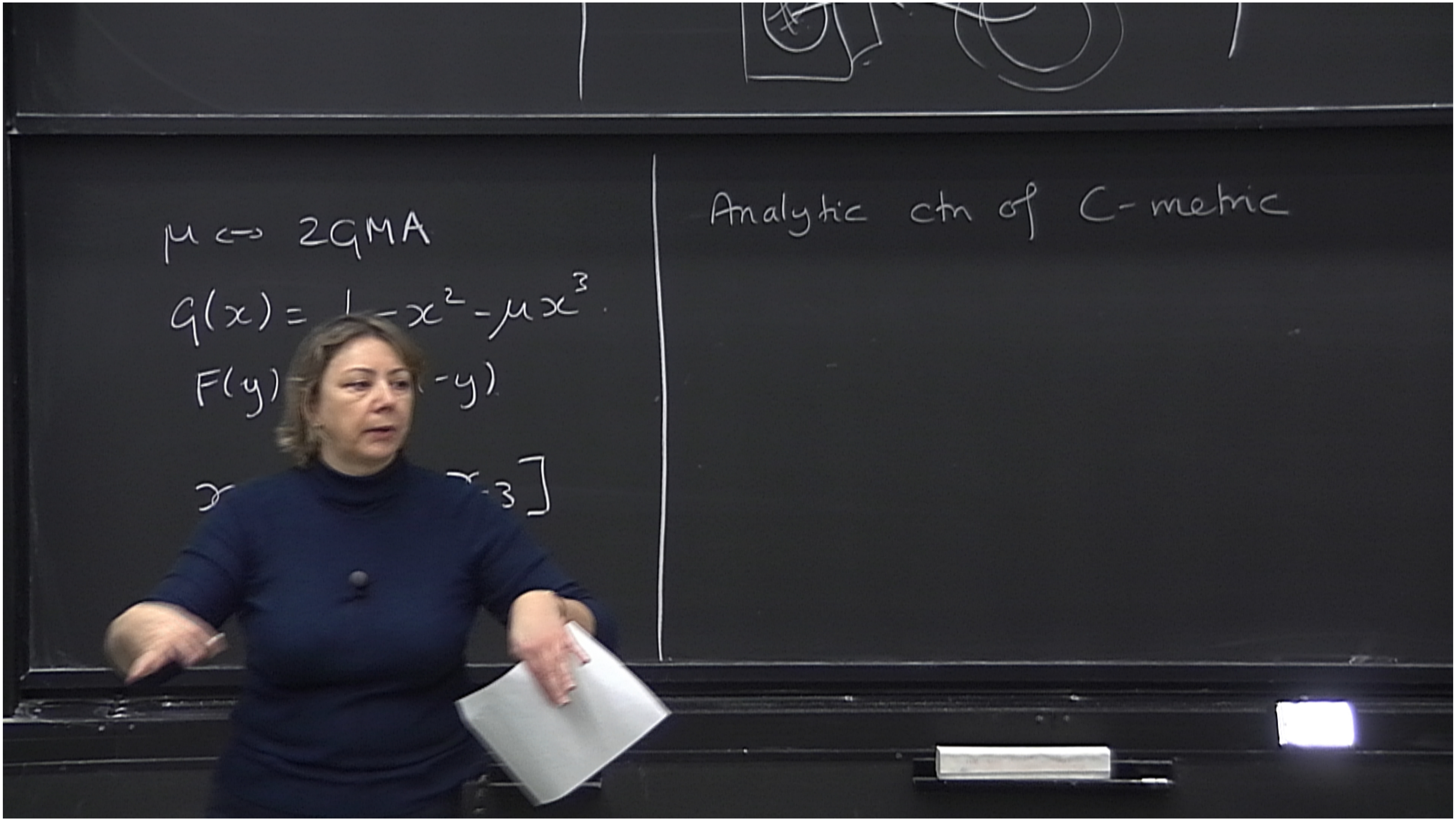
$\mu \leftrightarrow 2GMA$

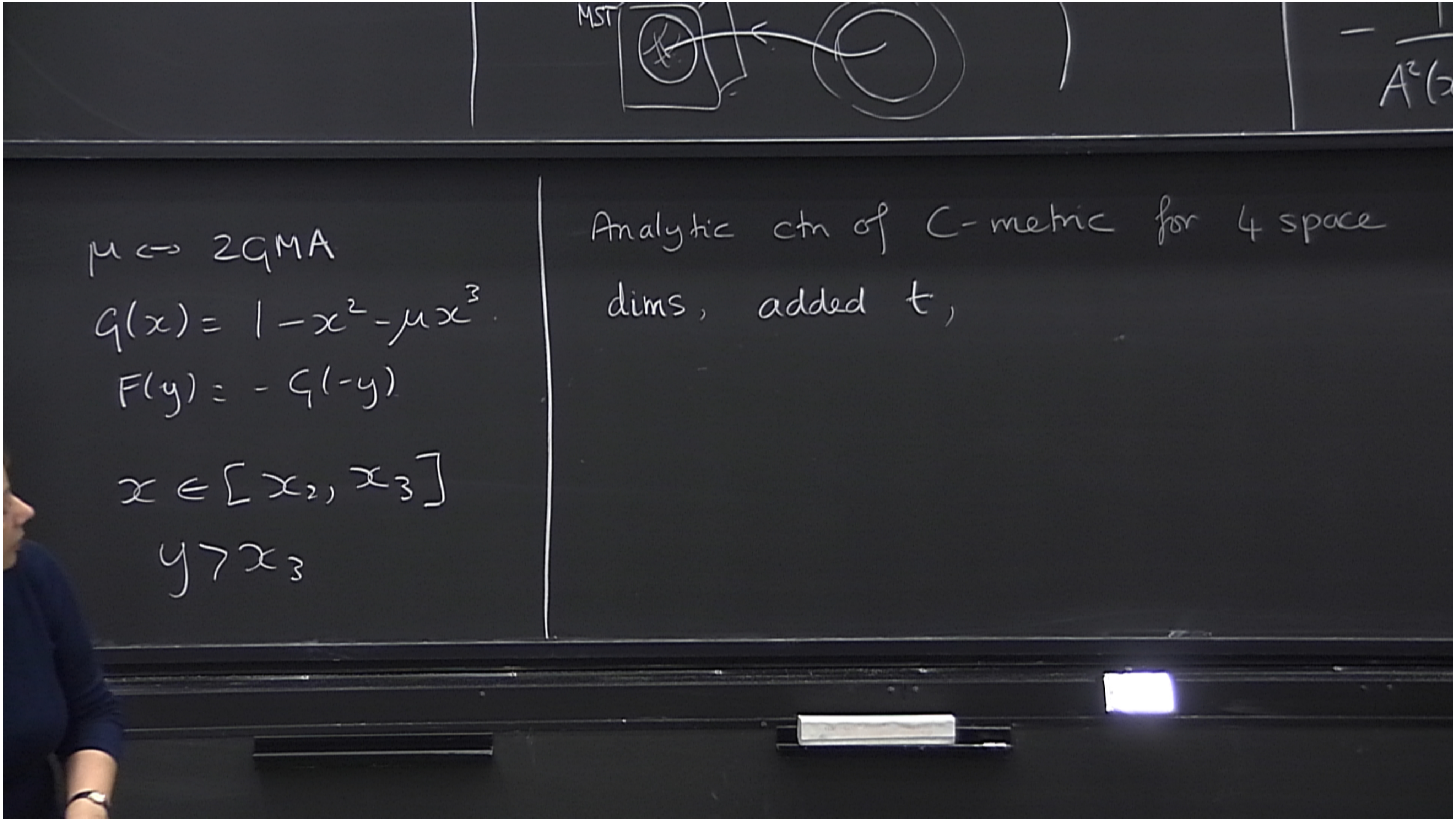
$G(x) = 1 - x^2 - \mu x^3$

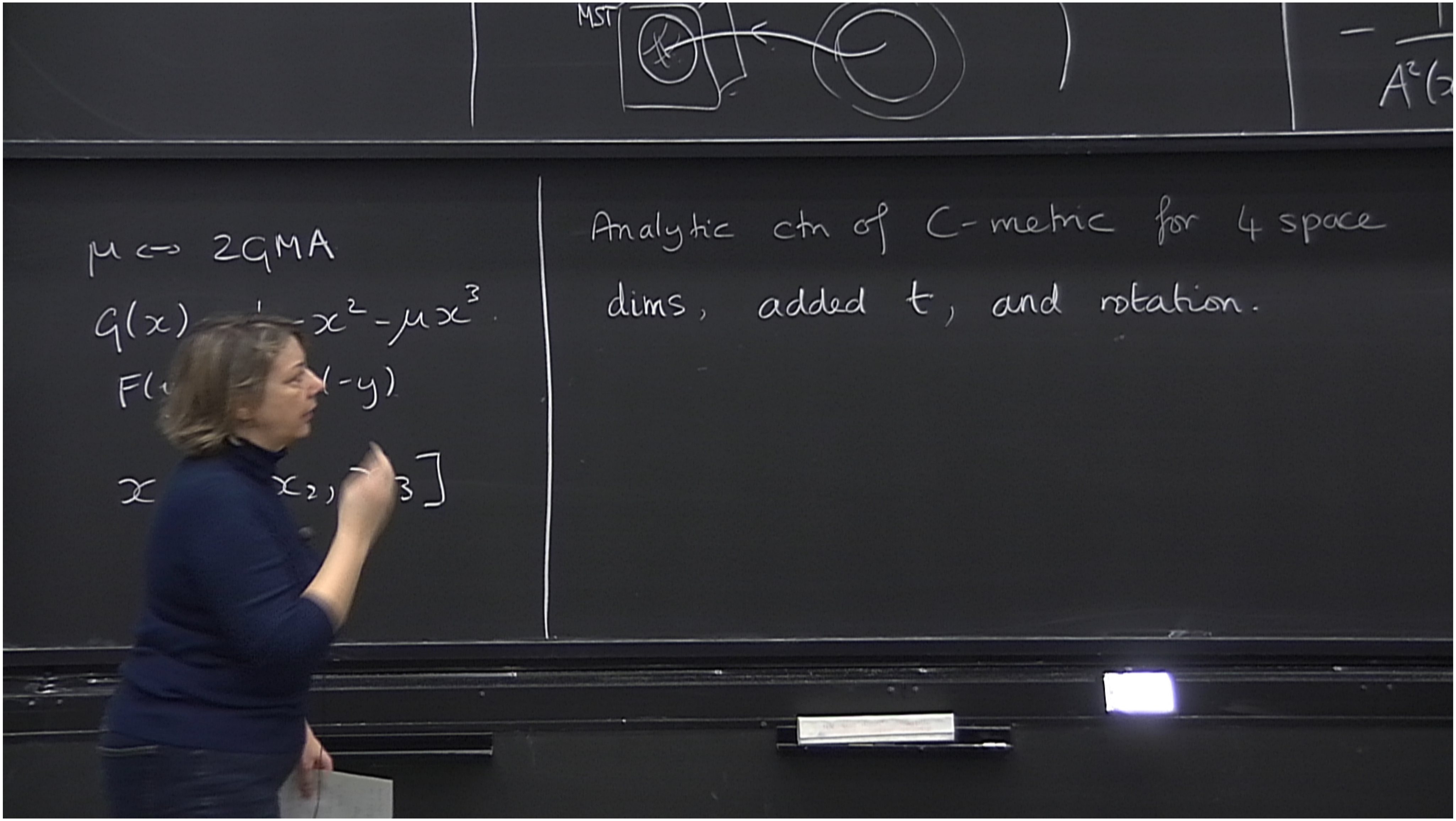
$F(y) = -G(-y)$

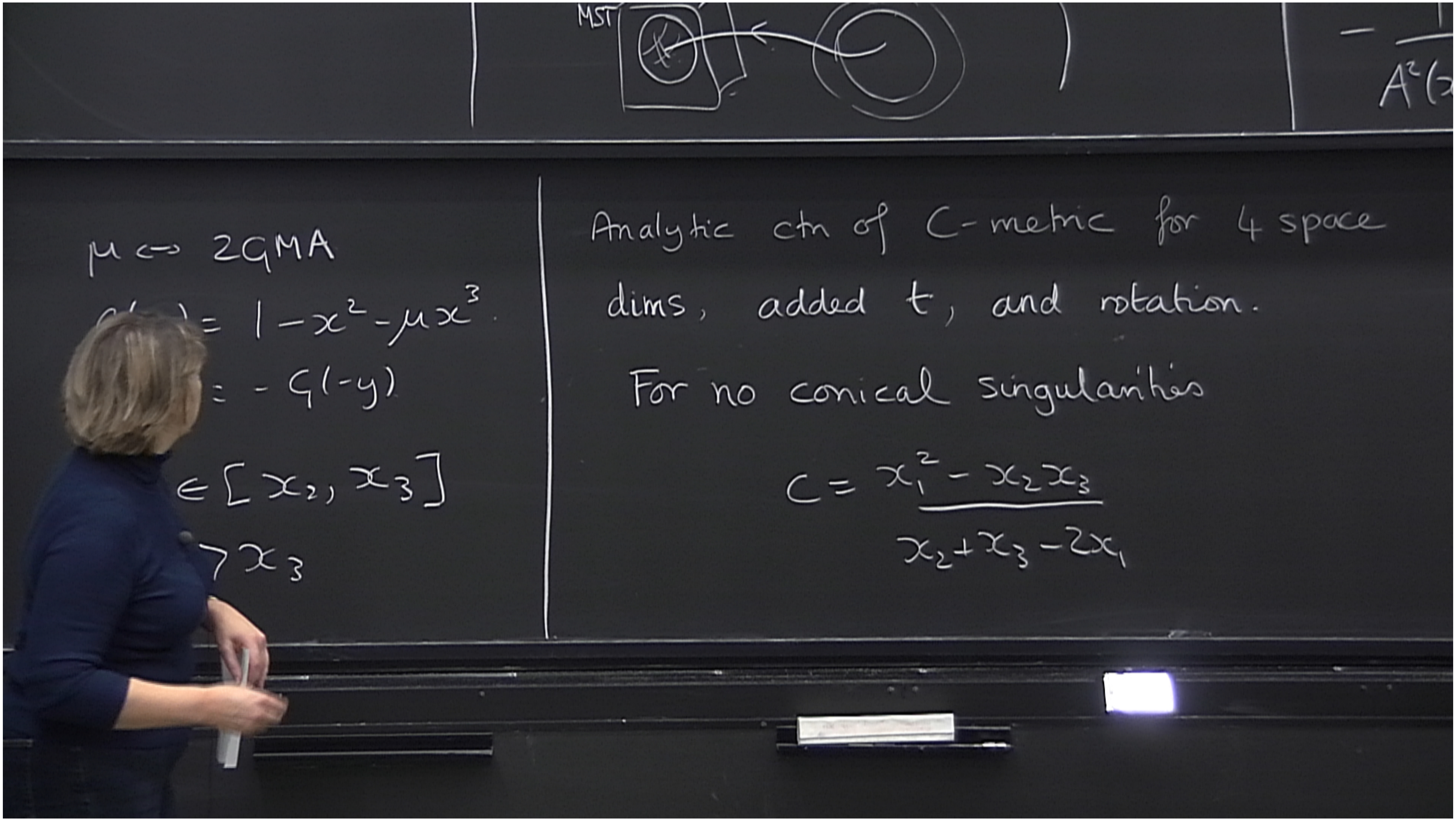
$x \in [x_2, x_3]$

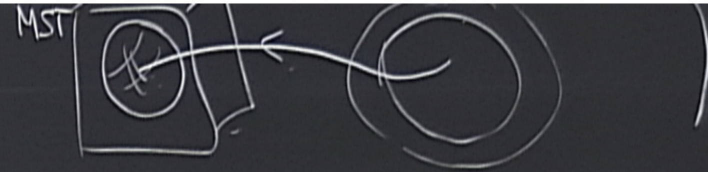
$y > x_3$


μ ⟷ 2GMA
G(x) = 1 - x² - μx³
Analytic ctn of C-metric


MST
$\mu \leftrightarrow 2GMA$
$G(x) = 1 - x^2 - \mu x^3$
$F(y) = -G(-y)$
$x \in [x_2, x_3]$
$y > x_3$
Analytic ctn of C-metric for 4 space dims, added t,


MST
μ ⟷ 2GMA
Analytic ctn of C-metric for 4 space
dims, added t, and rotation.


MST
$\mu \leftrightarrow 2GMA$
$= 1 - x^2 - \mu x^3$
$= -G(-y)$
$\in [x_2, x_3]$
$> x_3$
Analytic ctn of C-metric for 4 space dims, added t, and rotation.
For no conical singularities
$C = \frac{x_1^2 - x_2 x_3}{x_2 + x_3 - 2x_1}$



$- \frac{1}{A^2(x}$

$\mu \longleftrightarrow 2GMA$

$G(x) = 1 - x^2 - \mu x^3$

Roots

$F(y) = -G(-y)$ $\quad x_1 < x_2 < x_3$

$\ominus \qquad \oplus$

$x \in [x_2, x_3]$

$y > x_3$

Analytic ctn of C-metric for 4 space dims, added t, and rotation.

For no conical singularities

$$c = \frac{x_1^2 - x_2 x_3}{x_2 + x_3 - 2x_1}$$

$$A^2(x+y)^2\Big[+ (1-\tfrac{y}{c})^2 \Big[\frac{dx^2}{G(x)} + \frac{G(x)}{1+x/c} d\varphi^2 \Big] \Big)$$

etric for 4 space

nd rotation.

gularities

$$\frac{x_3}{-2x_1}$$

Emparan - Reall

$$A^2(x+y)^2\left[+ \left(1-\frac{y}{c}\right)^2 \left[\frac{dx^2}{G(x)} + \frac{G(x)}{1+x/c} d\varphi^2 \right] \right.$$

etric for 4 space

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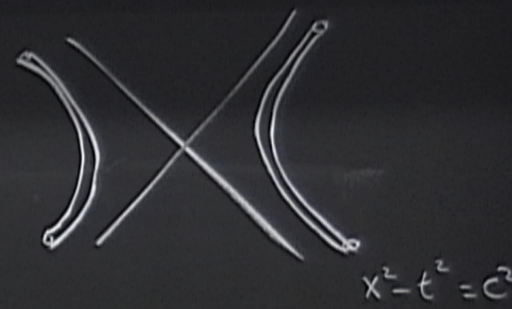
gularities

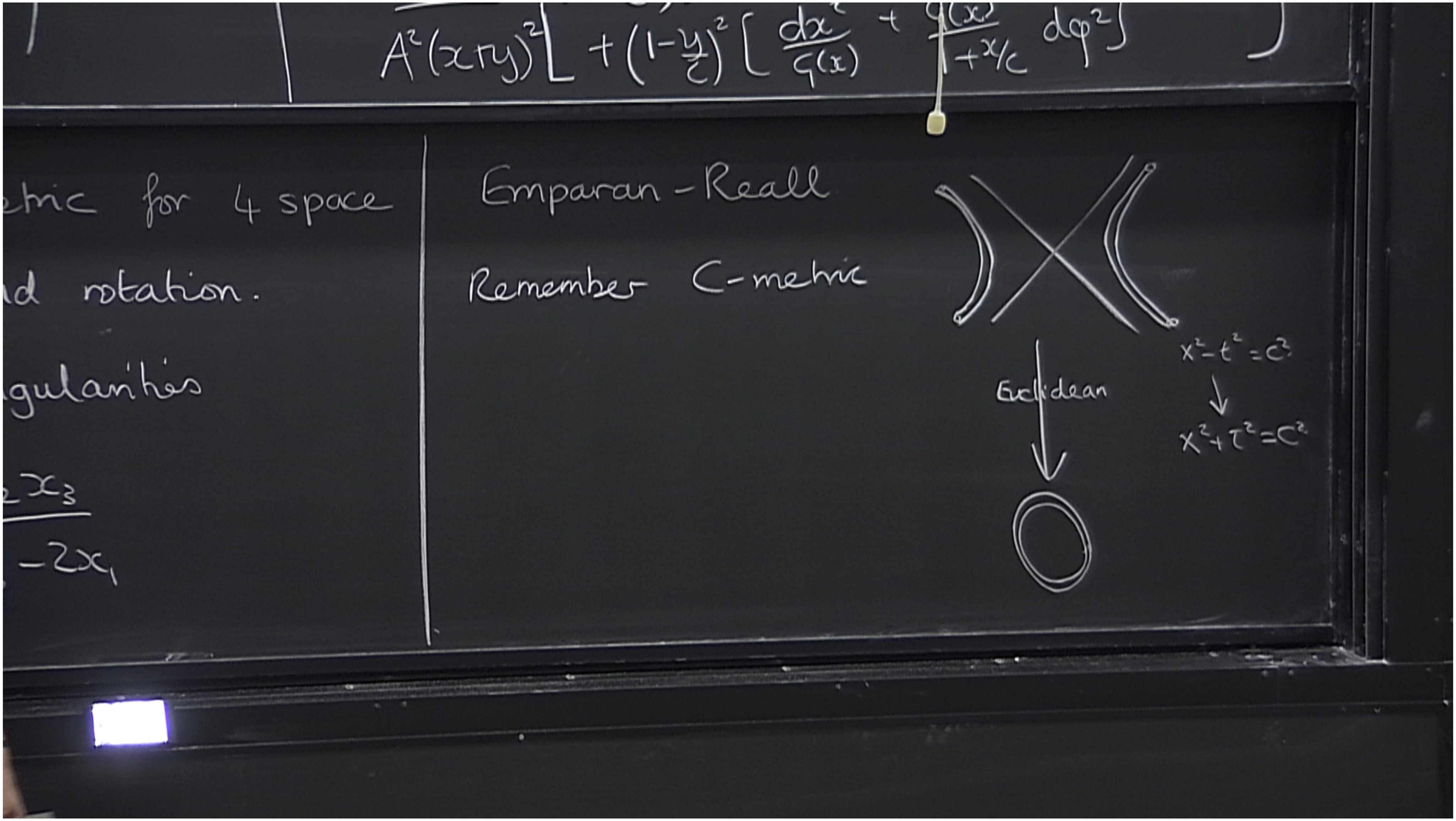
x_3

x_1

Emparan - Reall

Remember C-metric





$A^2(x+y)^2 \left[+ \left(1-\frac{y}{c}\right)^2 \left[\frac{dx^2}{G(x)} + \frac{G(x)}{1+x/c} d\varphi^2 \right] \right]$
etric for 4 space
nd rotation.
gularities
Emparan - Reall
Remember C-metric
Euclidean
$x^2 - t^2 = c^2$
$x^2 + \tau^2 = c^2$

$$A^2(x+y)^2 \Big[+ \left(1-\frac{y}{c}\right)^2 \Big[\frac{dx^2}{G(x)} + \frac{G(x)}{1+x/c}\, d\varphi^2 \Big] \Big]$$

etric for 4 space

nd rotation.

ngularities

x_3

$-2x_1$

Emparan - Reall

Remember C-metric

$x^2 - t^2 = c^2$

$\downarrow$

$x^2 + \tau^2 = c^2$

Euclidean

- alternative to rotating Myers-Perry b.h.

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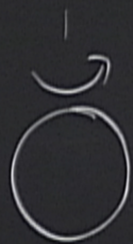
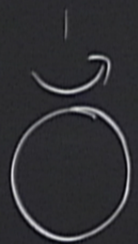
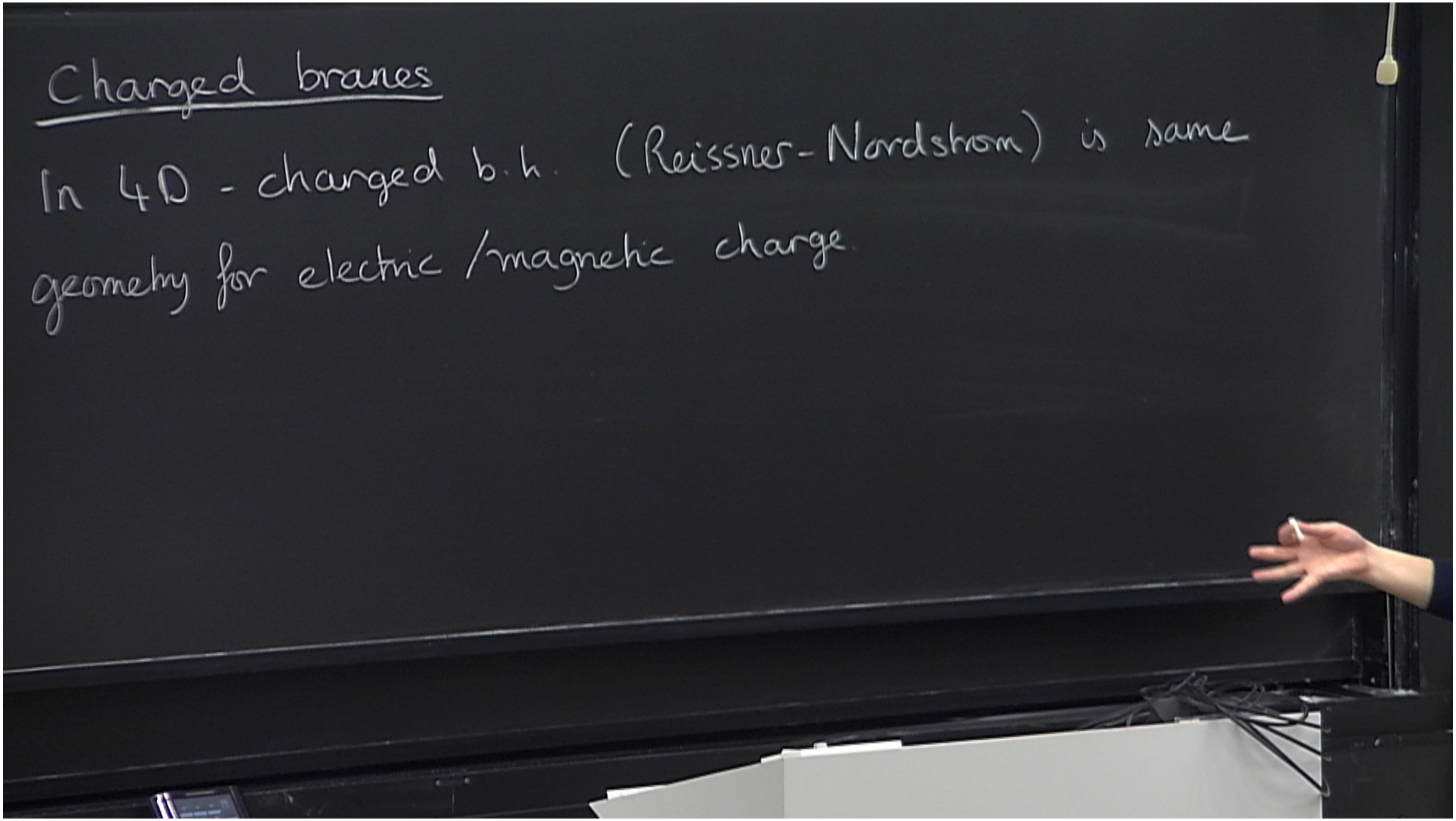
 or. 

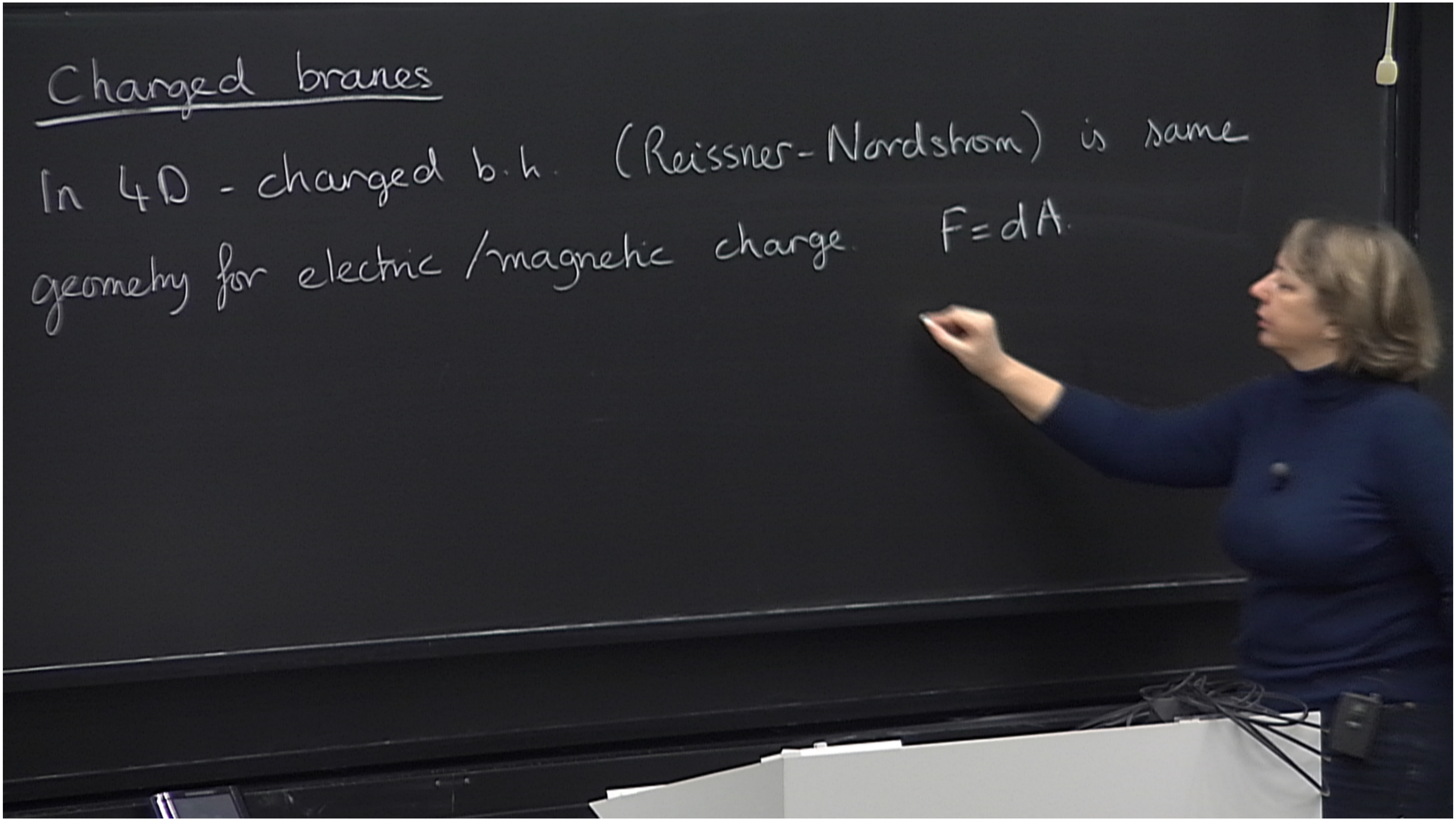
- alternatie to rotating Myers-Perry b.h.

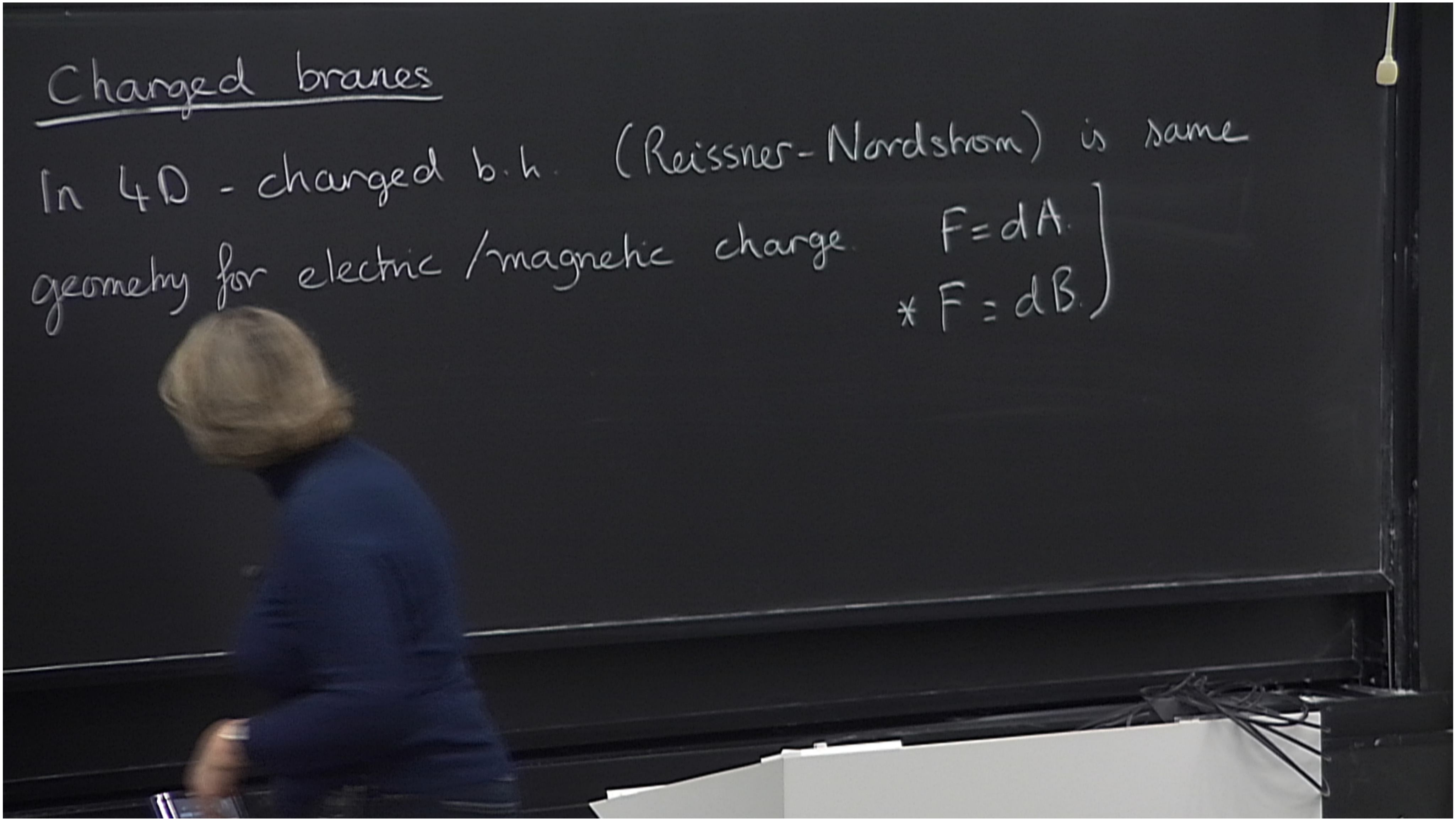
 or. 

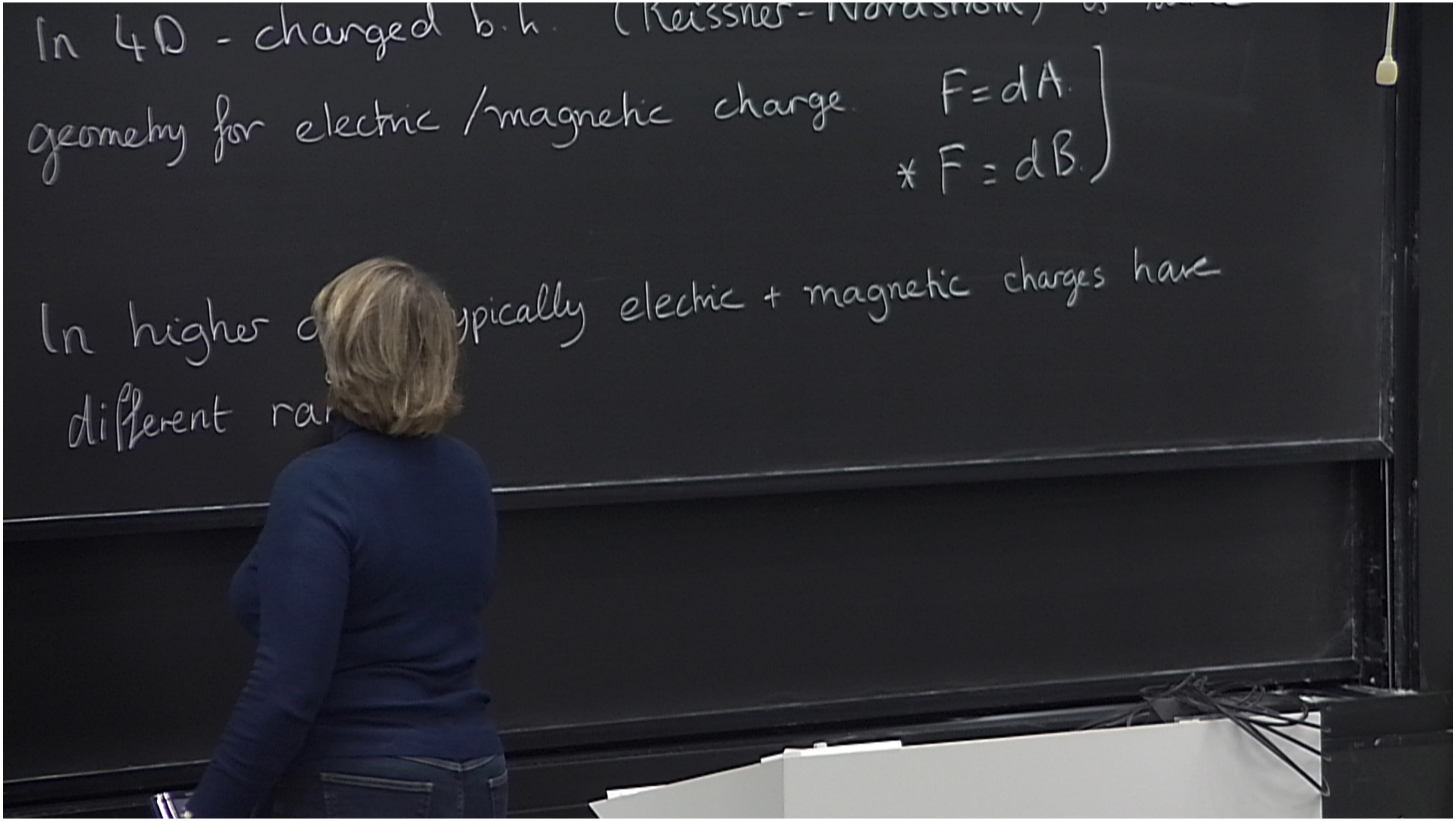
Black objects in higher dims have more degrees of freedom.

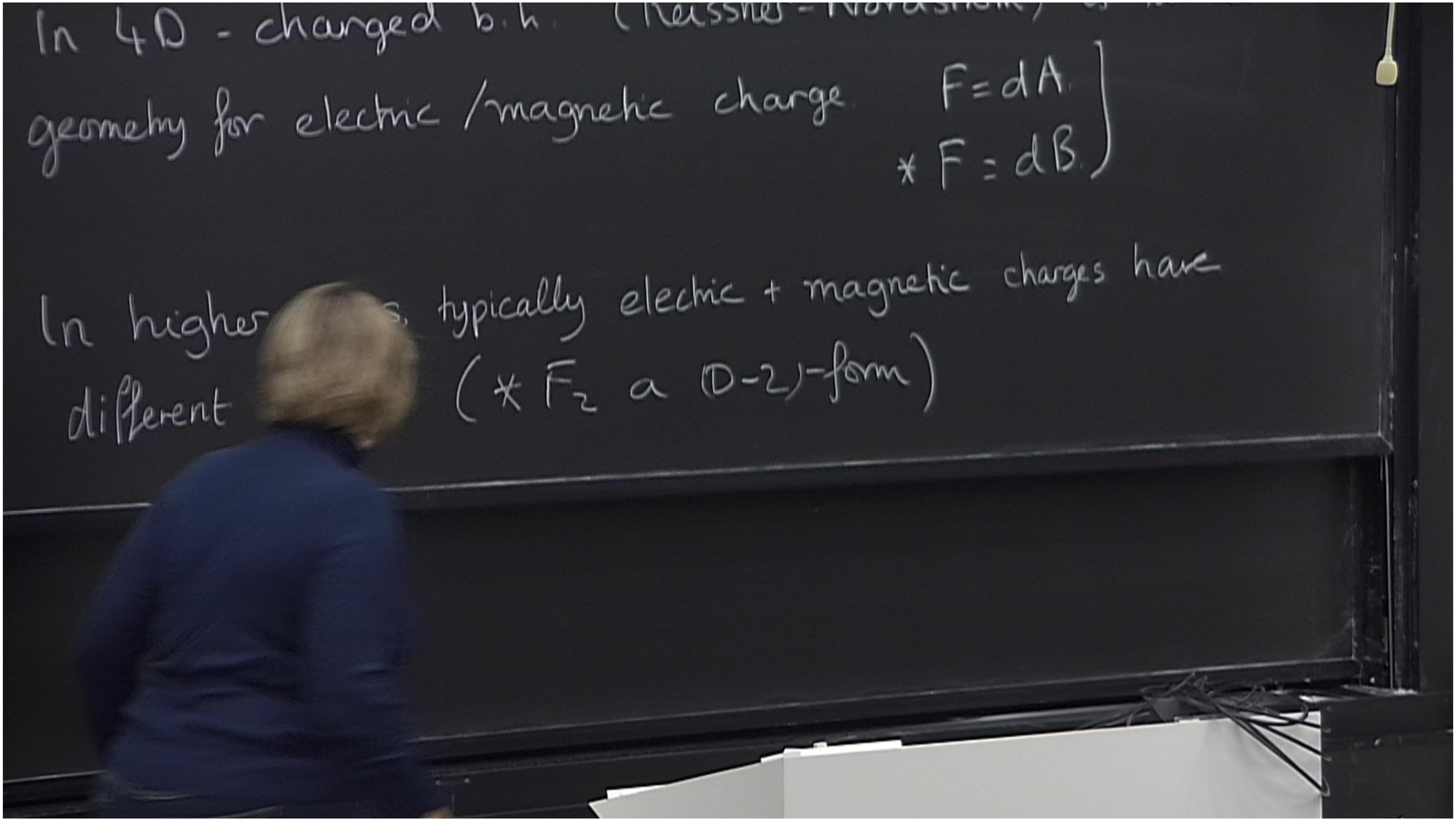

Charged branes


Charged branes
In 4D - charged b.h. (Reissner-Nordstrom) is same
geometry for electric /magnetic charge.


Charged branes
In 4D - charged b.h. (Reissner-Nordstrom) is same
geometry for electric /magnetic charge. $F = dA$.


Charged branes
In 4D - charged b.h. (Reissner-Nordstrom) is same
geometry for electric/magnetic charge. $F = dA$
$*F = dB$


In 4D - charged b.h.
geometry for electric / magnetic charge. F = dA
* F = dB
typically electric + magnetic charges have
different


In 4D - charged b.h.
geometry for electric /magnetic charge. F = dA
* F = dB
In higher
typically electric + magnetic charges have
different
(* F2 a (D-2)-form)

In string theory there are several propagating 'gauge' fields at low energy.

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$$S = -\int d^{10}x \sqrt{-g} \left\{ e^{-2\phi}\left[R + 4(\nabla\phi)^2 + H_{abc}^2\right] + \frac{2(dA_{(p+1)})^2}{(p+2)!} \right.$$

In string theory there are several propagating 'gauge' fields at low energy.

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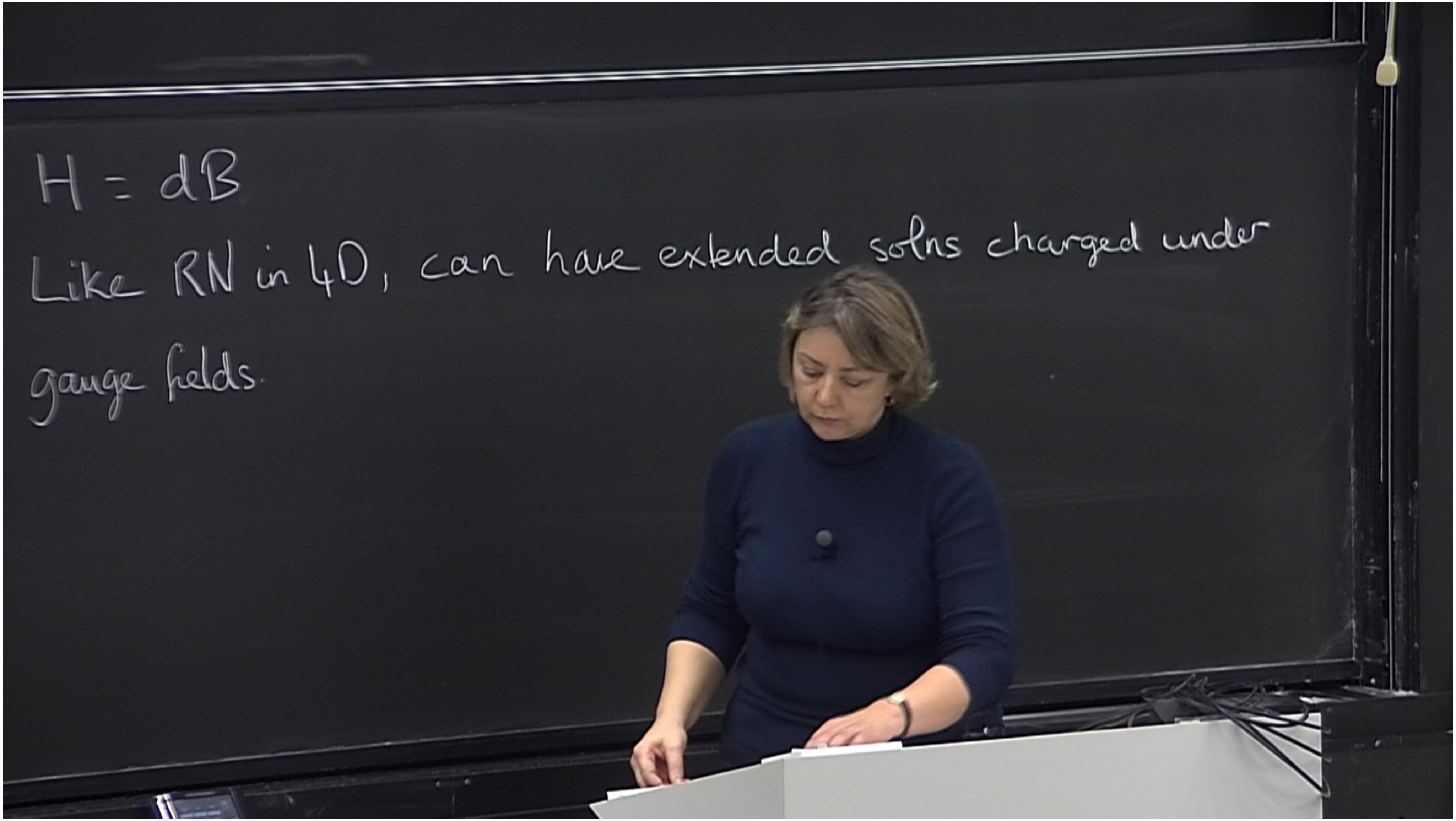
RR (p+1) forms.

$H = dB$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Like RN in 4D, can have extended solns charged under
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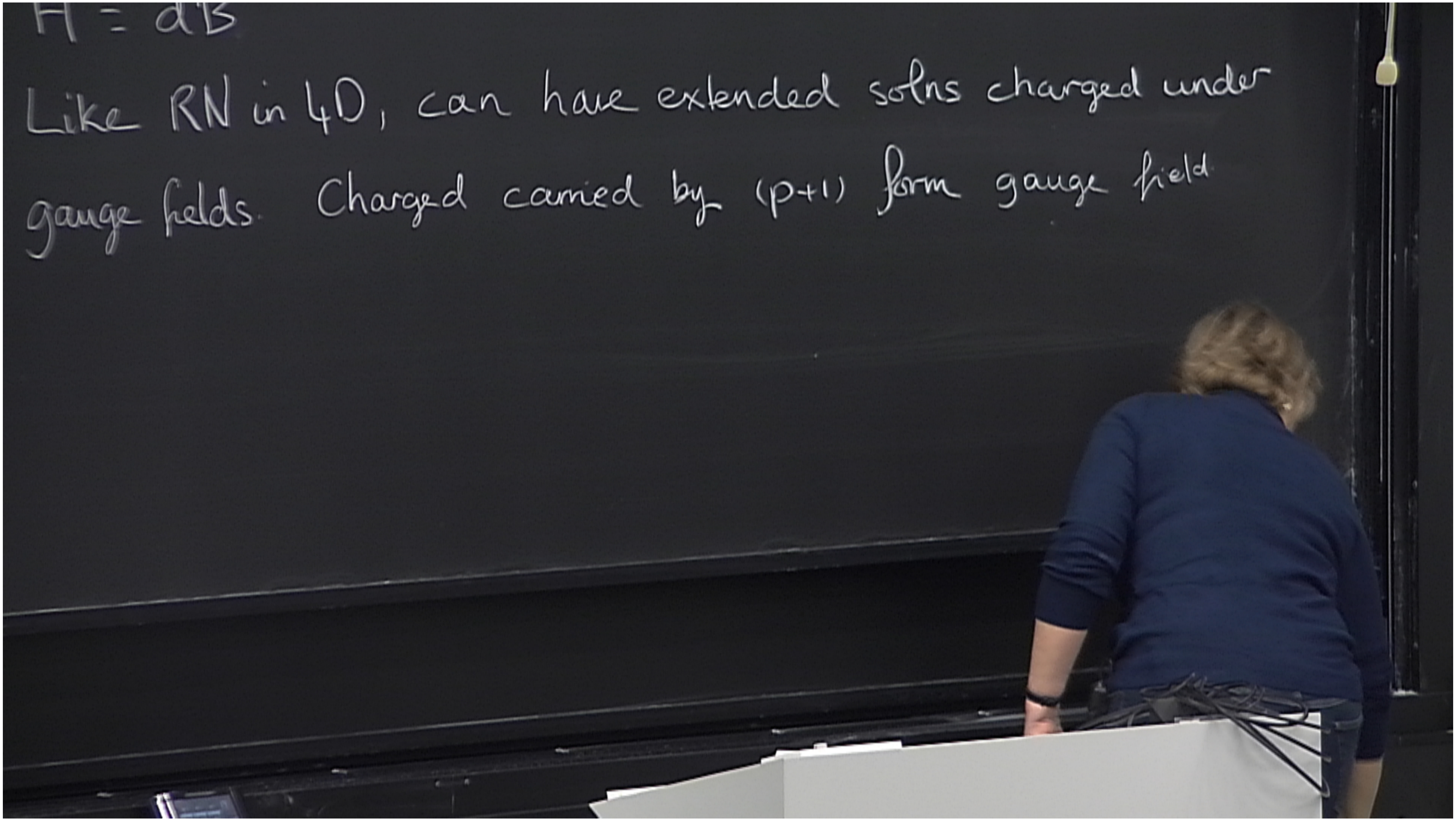
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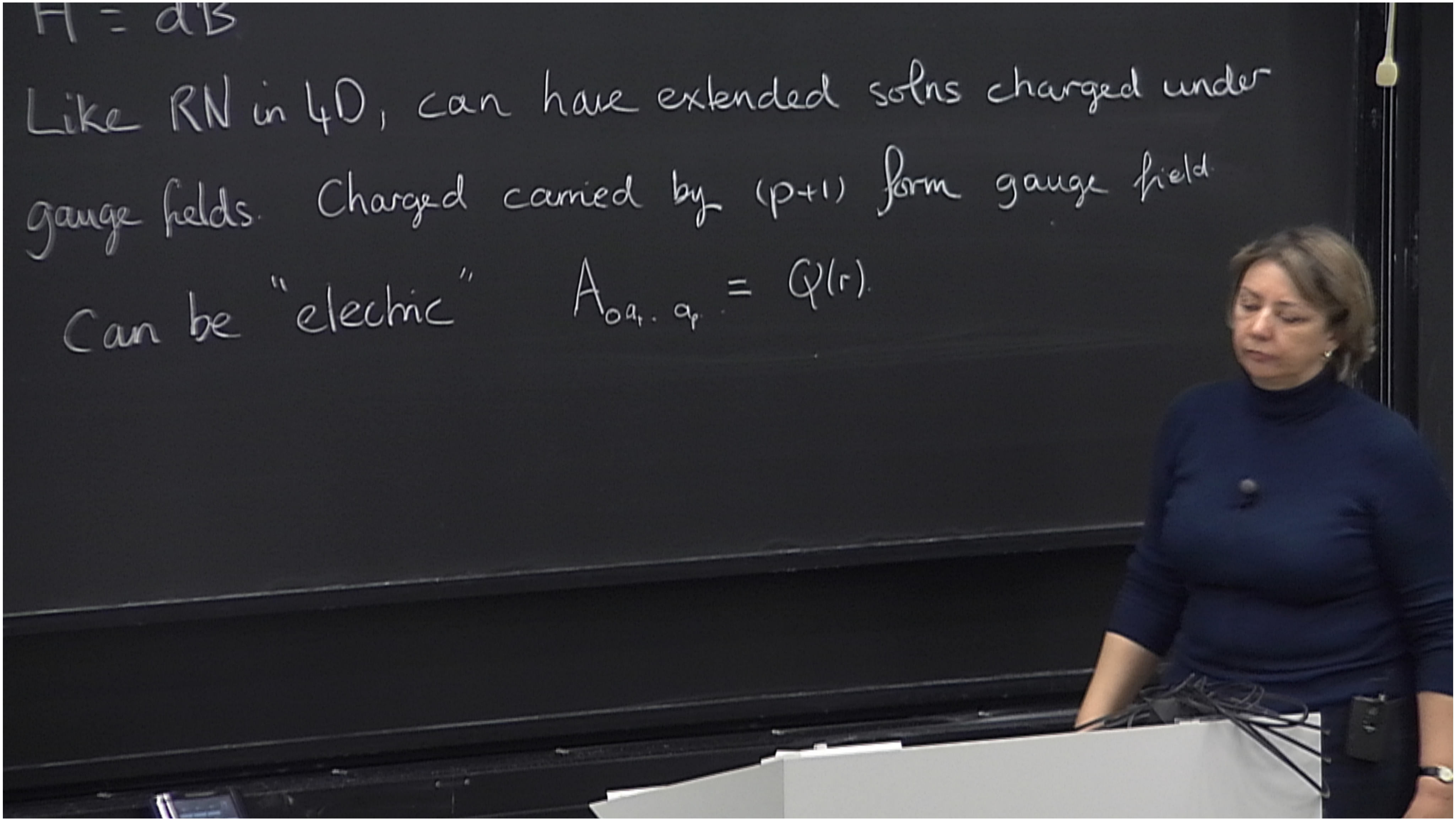
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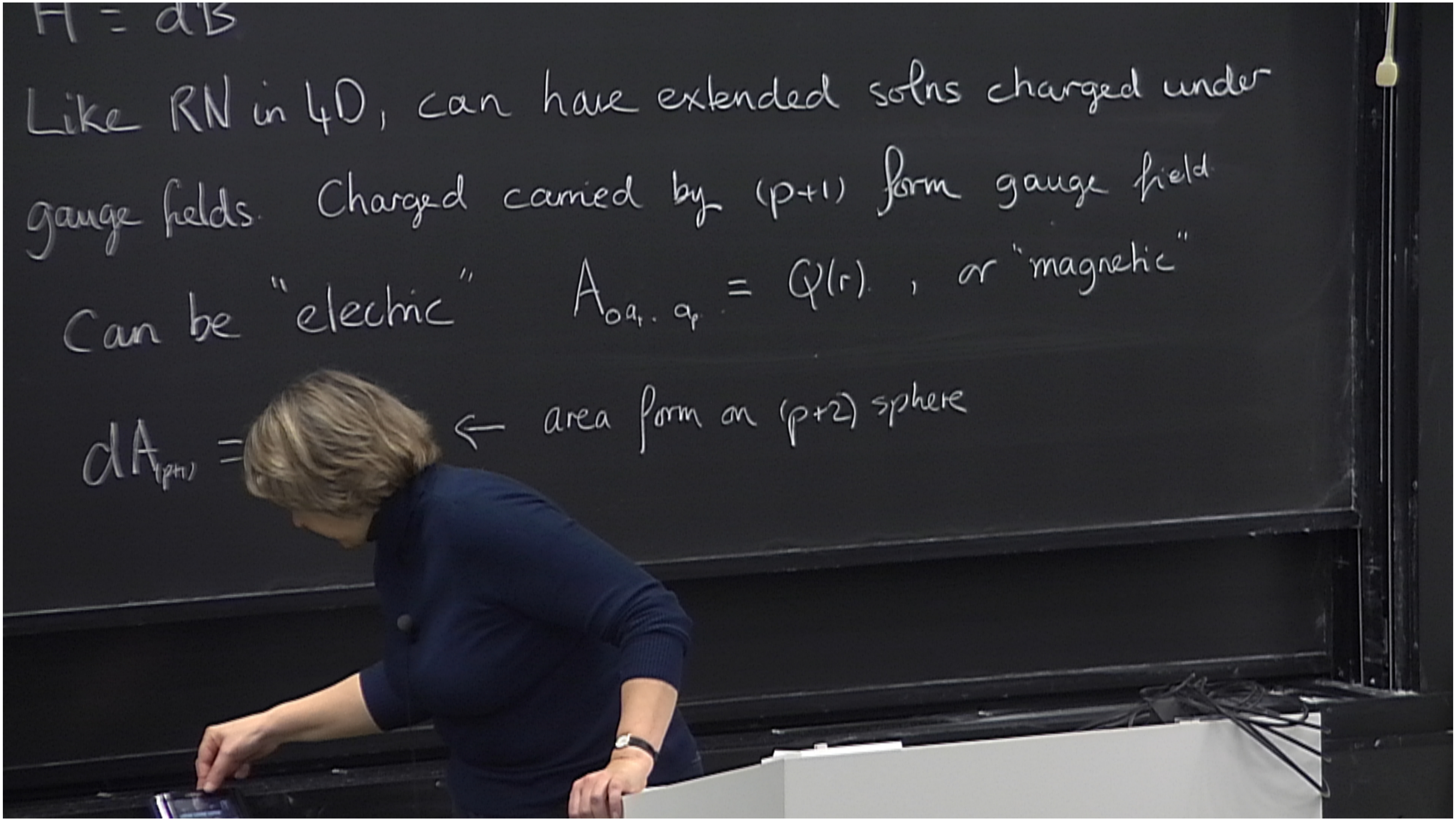
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$dA_{(p+1)} =$ ← area form on (p+2) sphere

different rank ($\star F_2$ a $(D-2)$-form)

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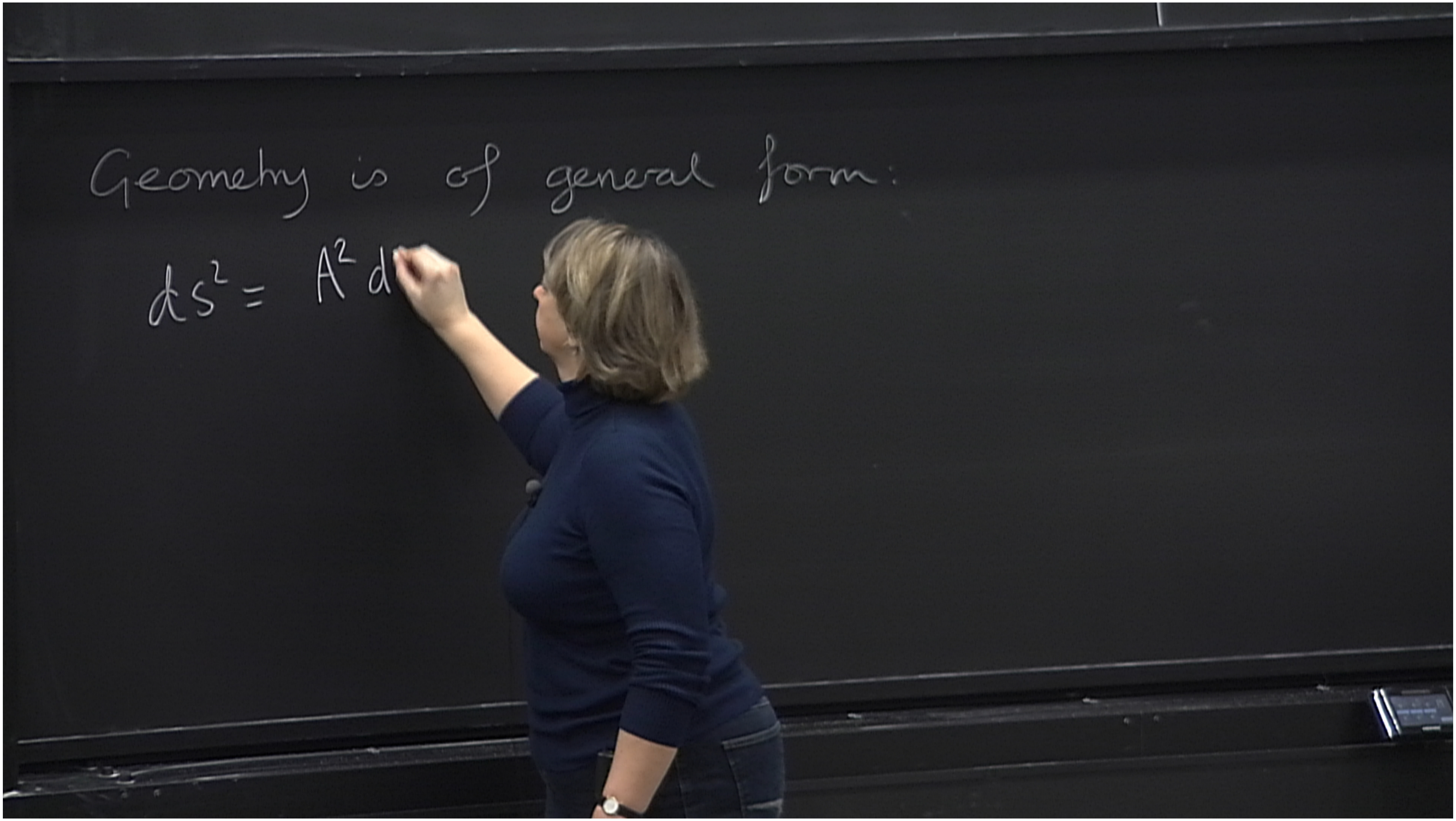
$dA_{(p+1)} = \epsilon_{p+2}$ ← area form on $(p+2)$ sphere


Geometry is of general form:
ds² = A² d

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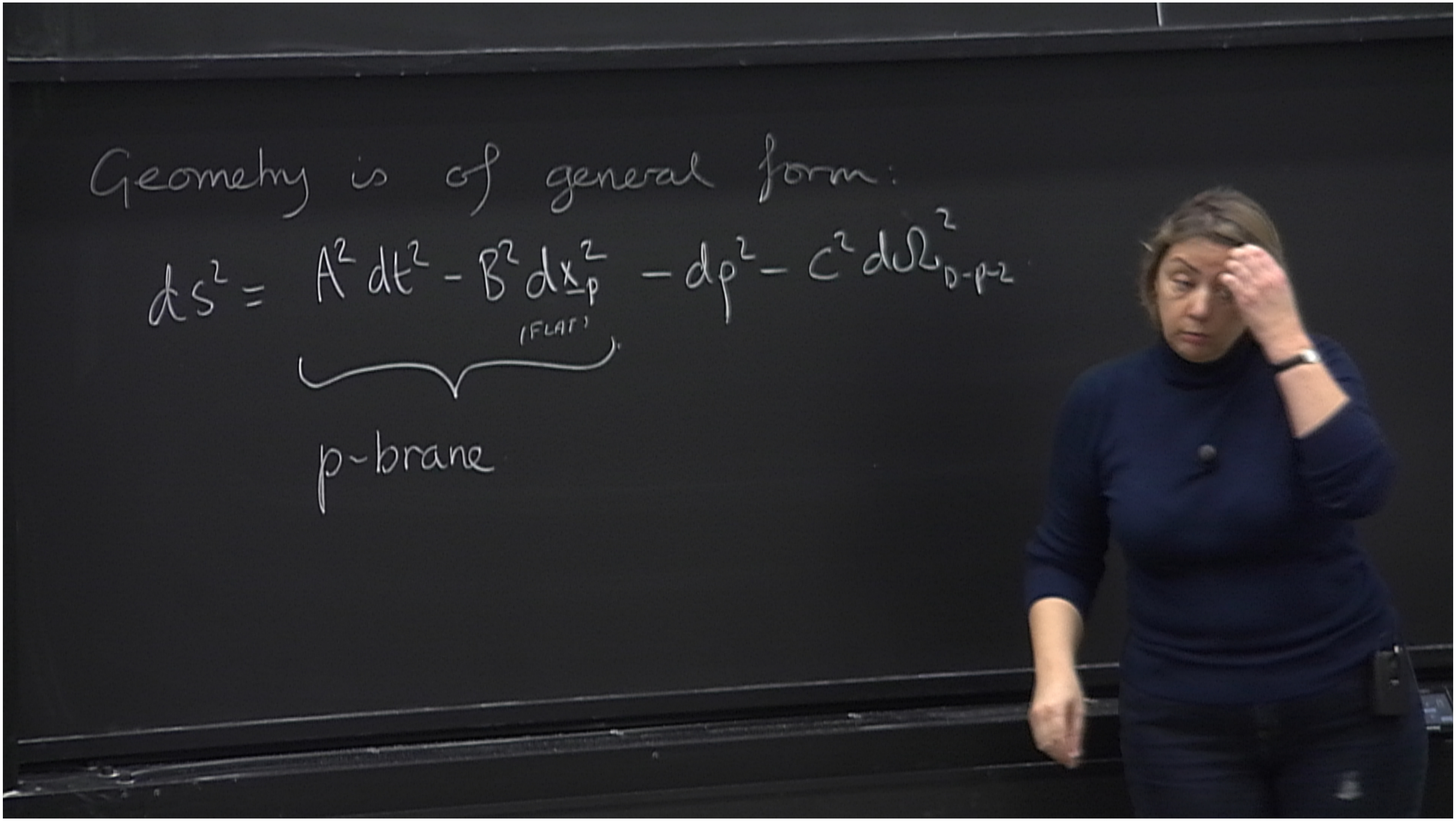
$$ds^2 = A^2 dt^2 - B^2 d\underline{x}_p^2 - d\rho^2 - C^2 d\Omega^2_{D-p-2}$$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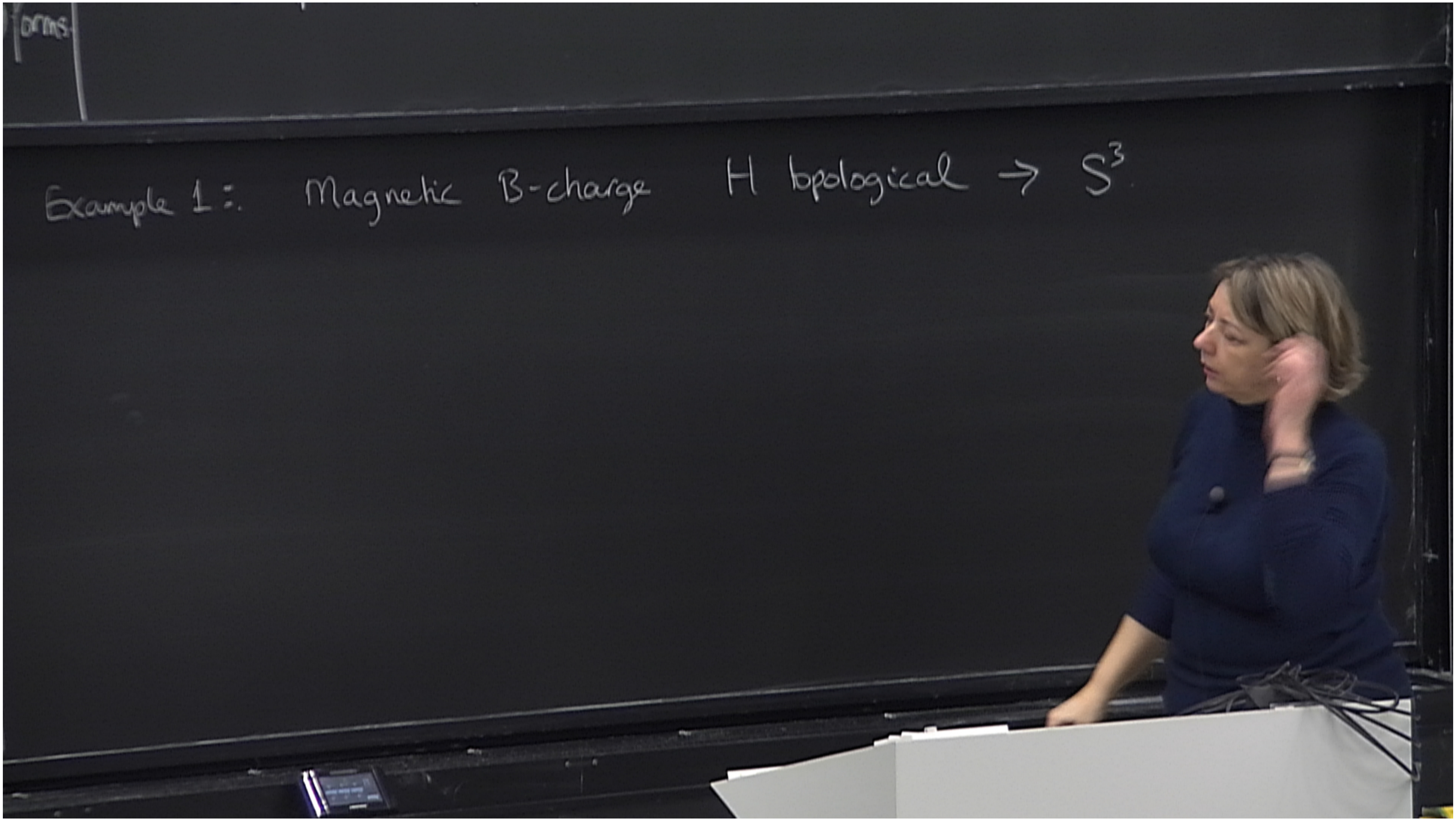
forms
Example 1 : Magnetic B-charge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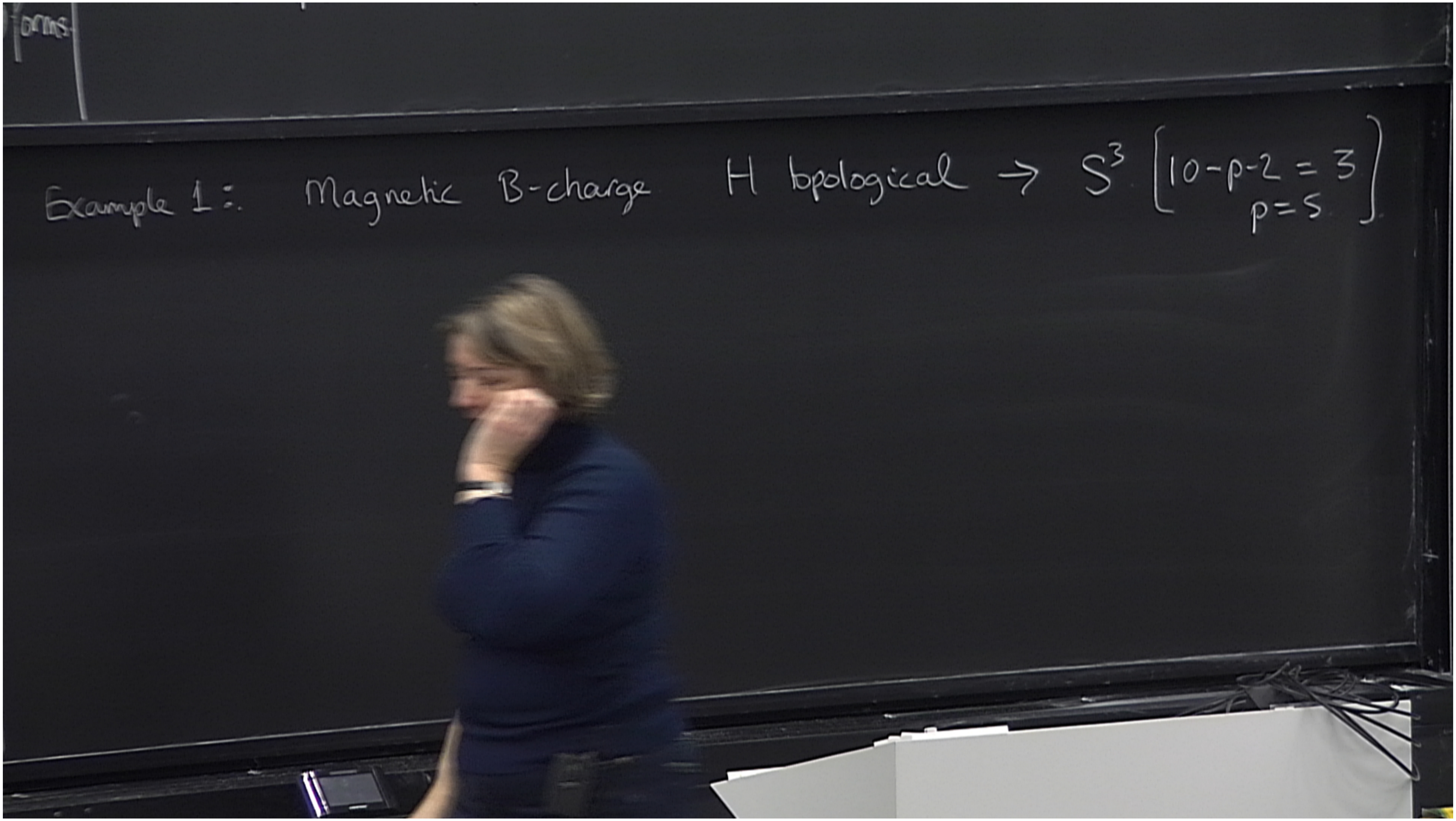
Example 1 :. Magnetic B-charge H topological → S³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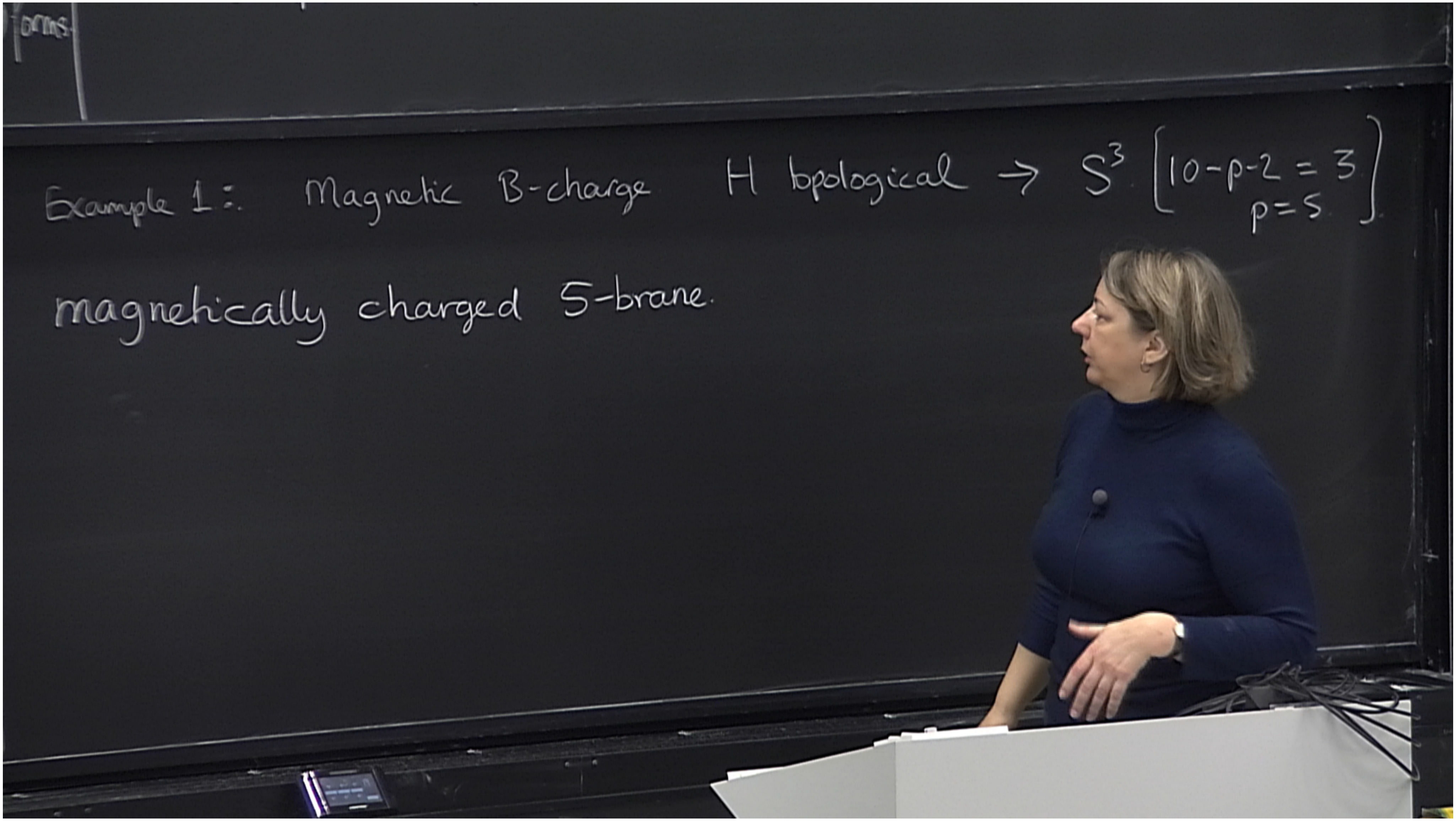
Example 1 : Magnetic B-charge H topological → S^3 [10-p-2 = 3
p=5]



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forms.

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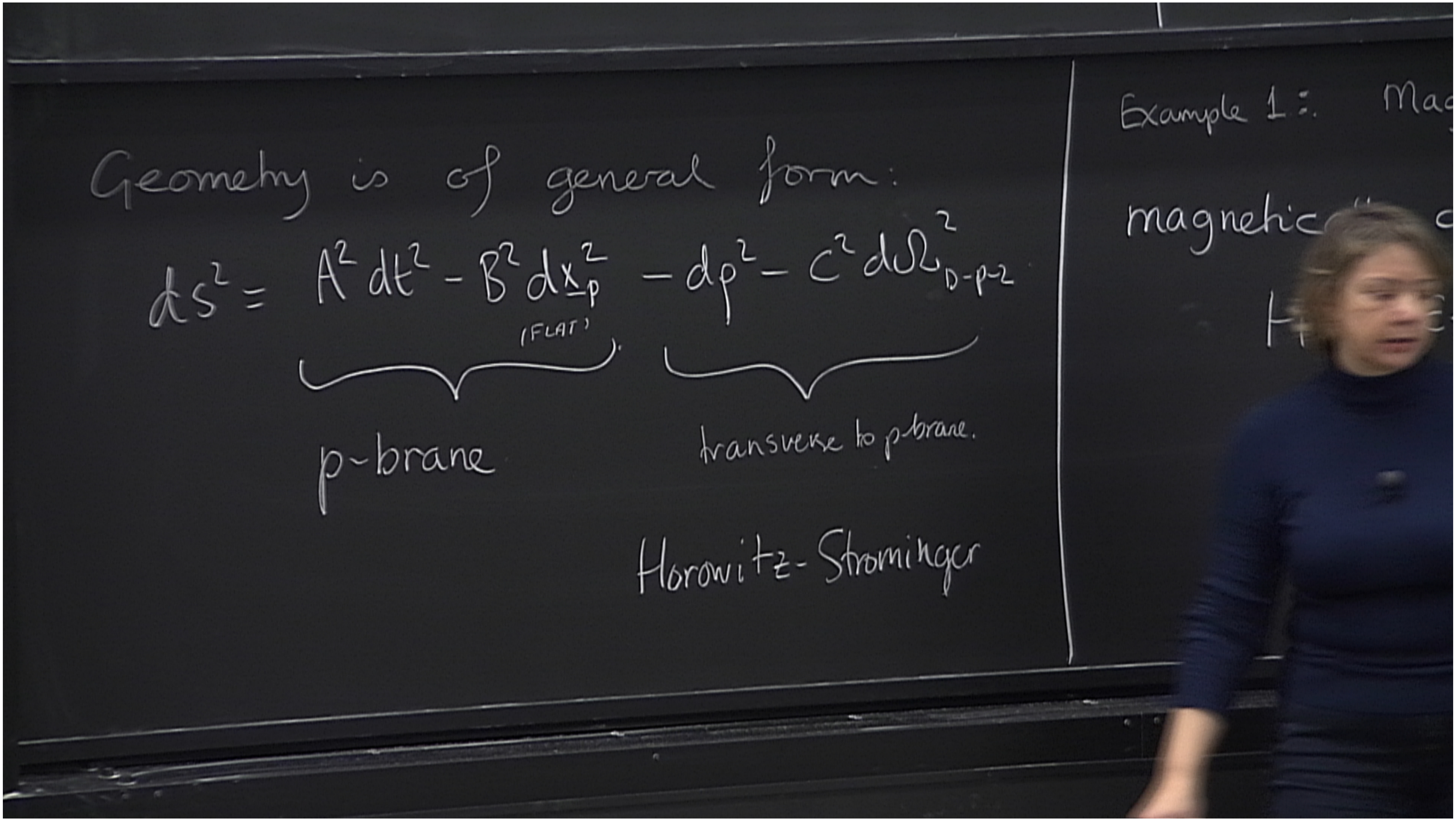
$$H = Q\,\epsilon_3\,, \qquad Q = r_+ r_-$$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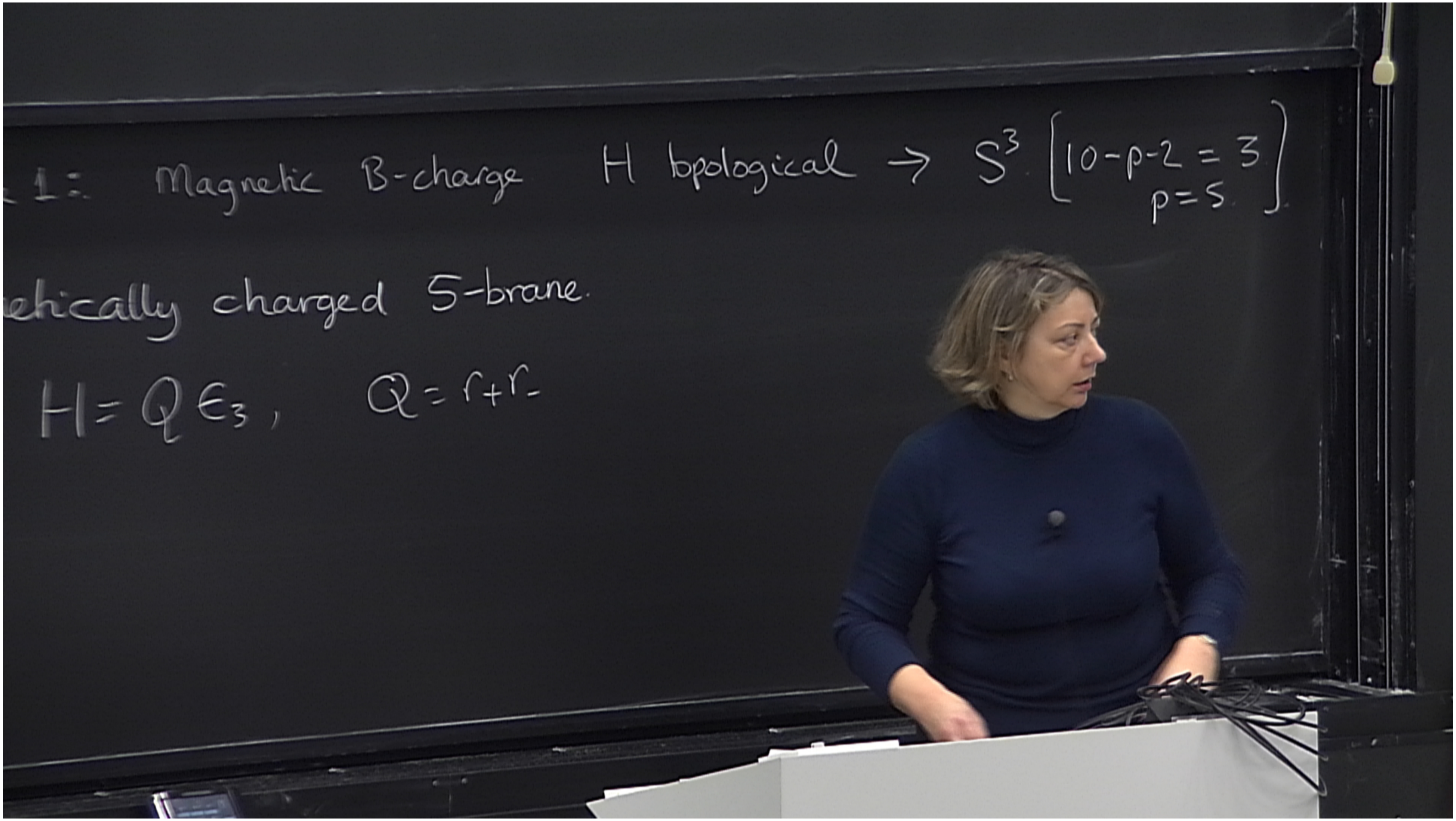
(FLAT)
p-brane
transverse to p-brane.
Horowitz-Strominger
Example 1: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$e^{-2\ldots}$

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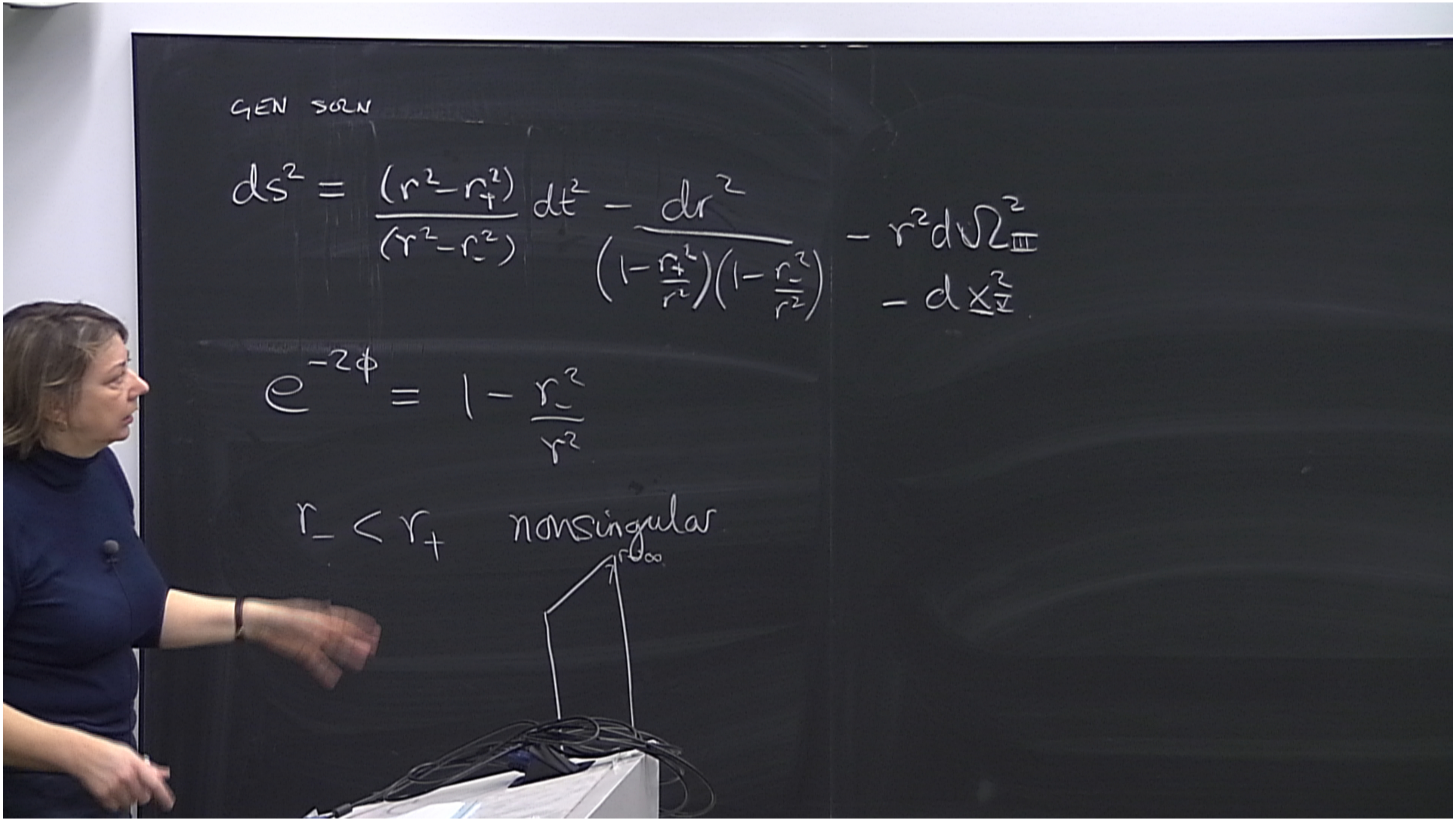
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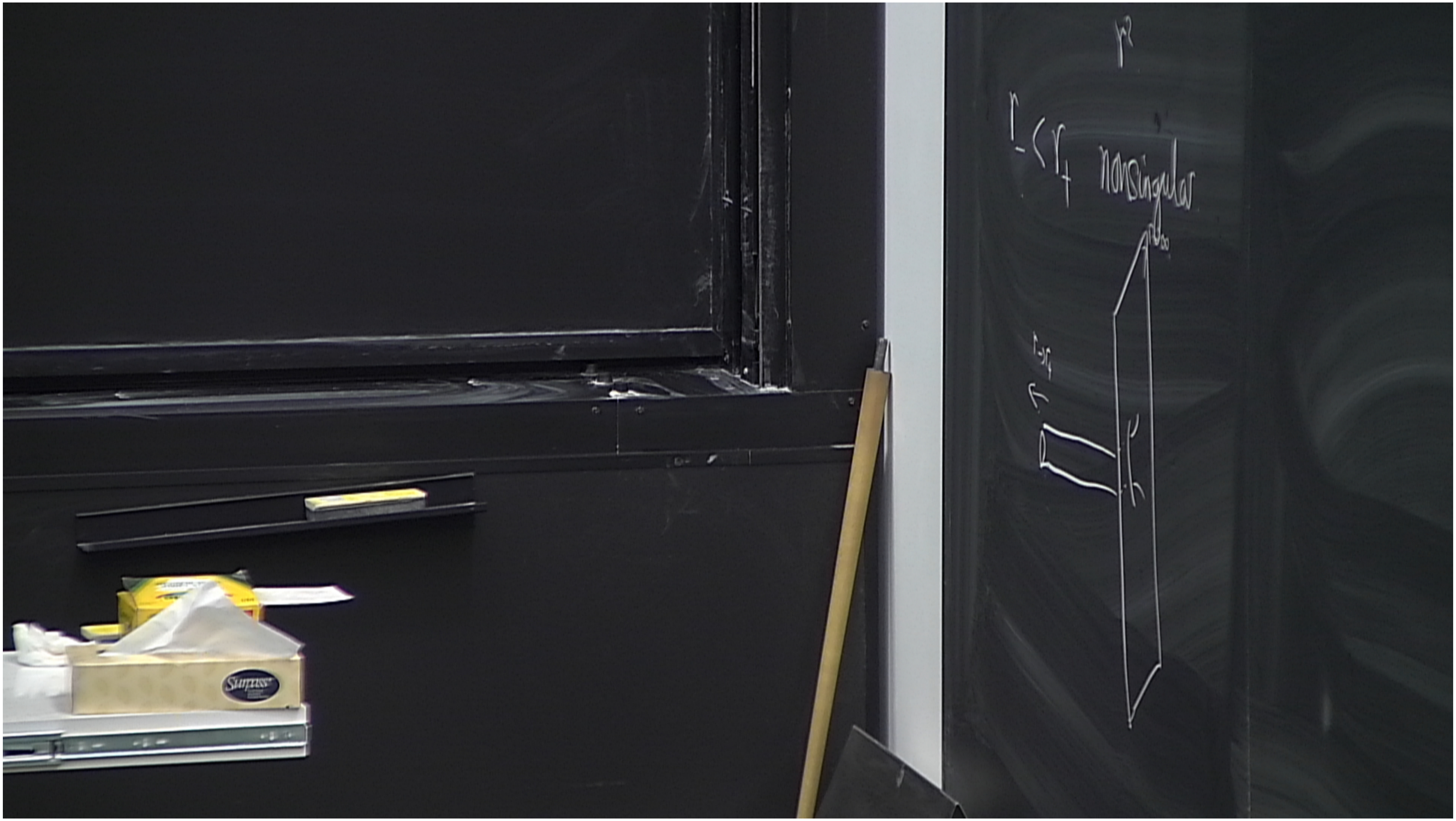
$r_- < r_+$ nonsingular
$r \to \infty$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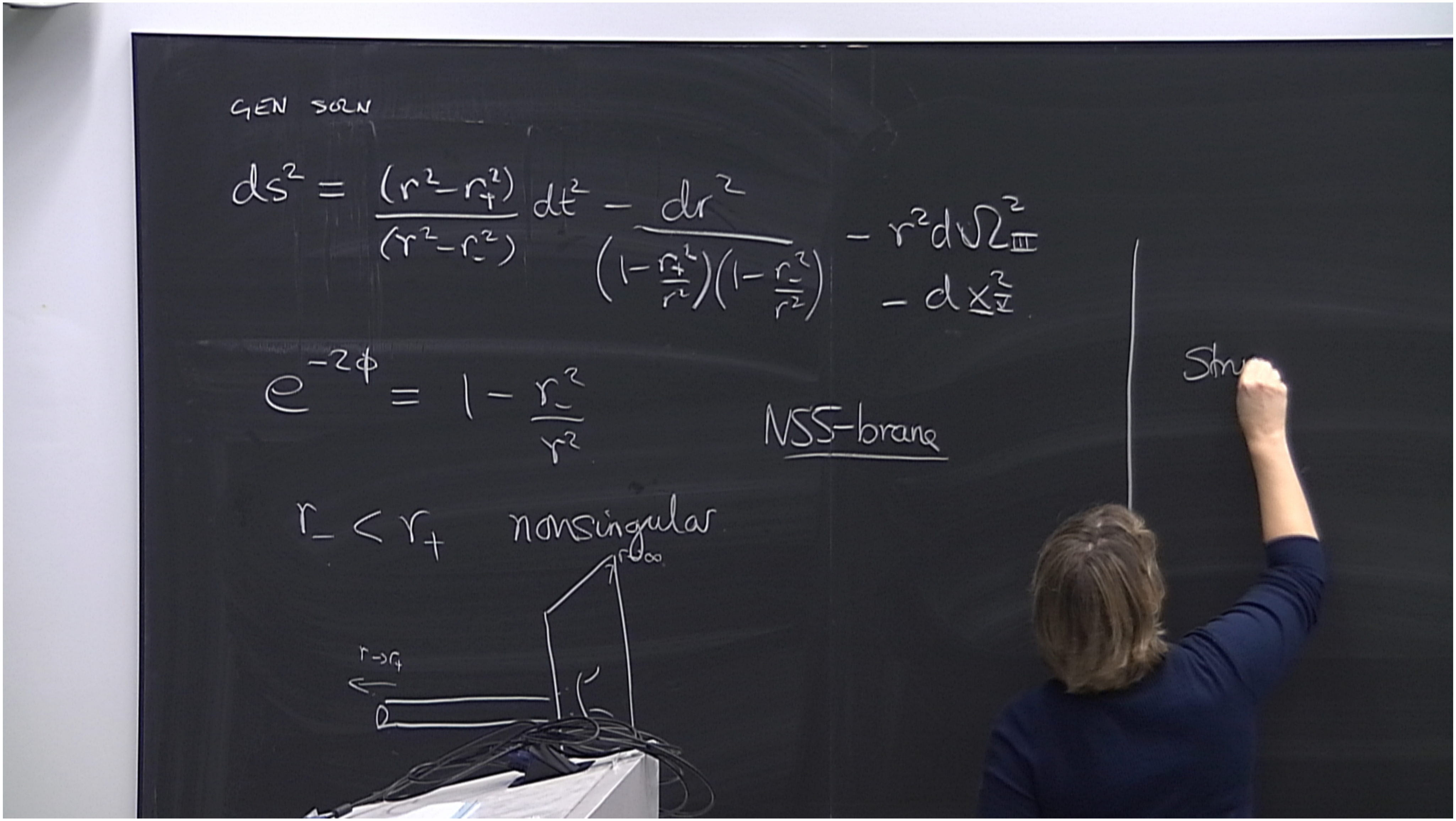
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NS5-brane
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$r \to r_+$

String is electrically charged

$$ds^2 = \frac{1-\Delta/y^6}{1+r_-^6/y^6} - \frac{dx^2}{1+r_-^6/y^6} - \frac{dy^2}{1-\Delta/y^6} - y^2 d\Omega_{VII}^2$$

$$e^{-2\phi} = \left(1+\frac{r_-^6}{y^6}\right) \qquad H_{txy} = \frac{Q e^{2\phi}}{y^7\left(1+r_-^6/y^6\right)}$$

Singular in extremal limit $\Delta \to 0$.

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F1 string

String is electrically charged

$$ds^2 = \frac{1-\Delta/y^6}{1+r_-^6/y^6}\,dt^2 - \frac{dx^2}{1+r_-^6/y^6} - \frac{dy^2}{1-\Delta/y^6} - y^2 d\Omega^2_{VII}$$

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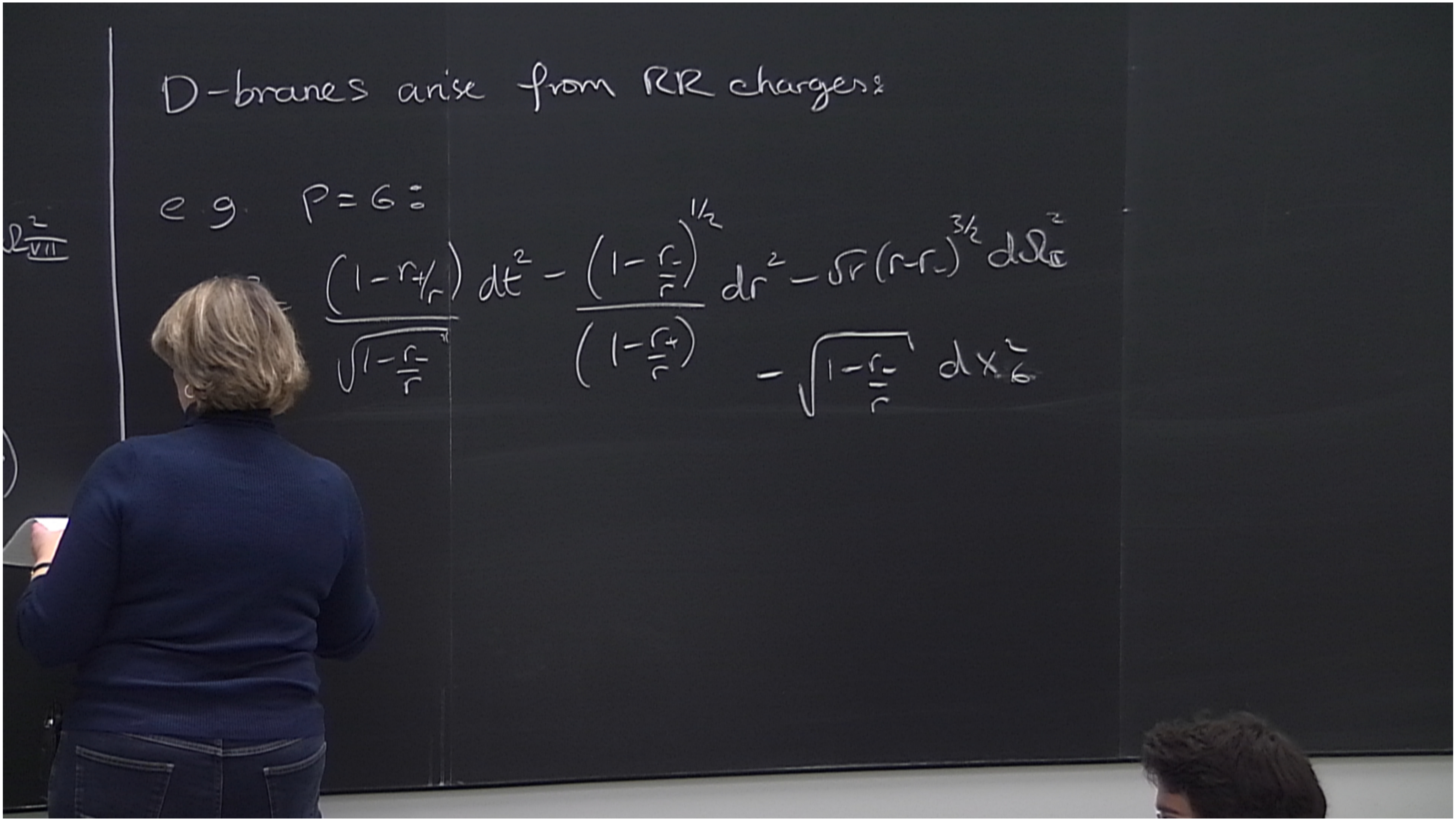
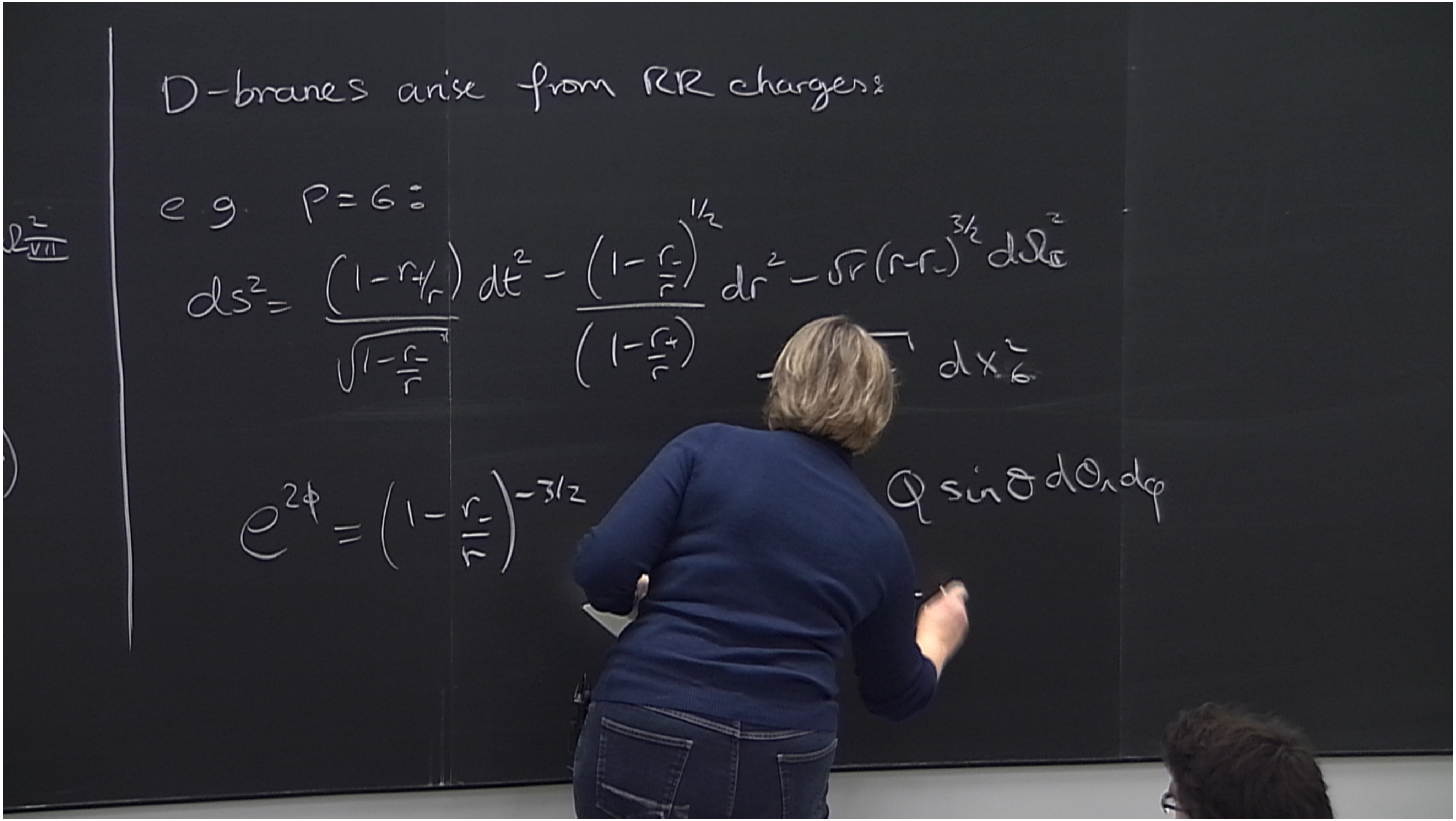
F1 string


D-branes arise from RR charges:
e.g. p = 6:
$ds^2 = \frac{(1 - r_+/r)}{\sqrt{1 - \frac{r_-}{r}}} dt^2 - \frac{(1 - \frac{r_-}{r})^{1/2}}{(1 - \frac{r_+}{r})} dr^2 - \sqrt{r}(r - r_-)^{3/2} d\Omega_2^2 - \sqrt{1 - \frac{r_-}{r}}\, dx_6^2$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dx_6^2
$e^{2\phi} = \left(1-\frac{r_-}{r}\right)^{-3/2}$
$Q \sin\theta \, d\theta \wedge d\varphi$

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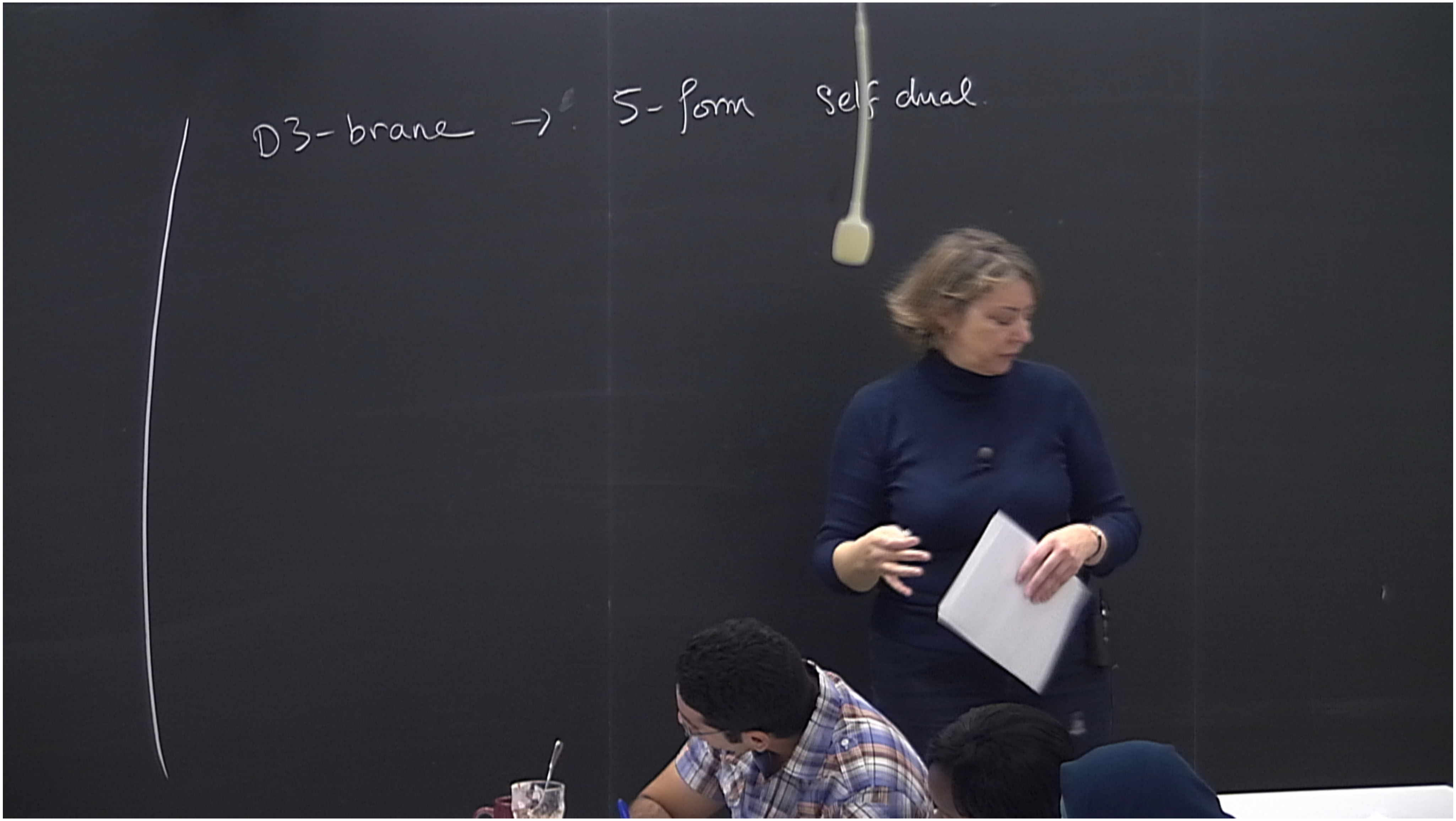
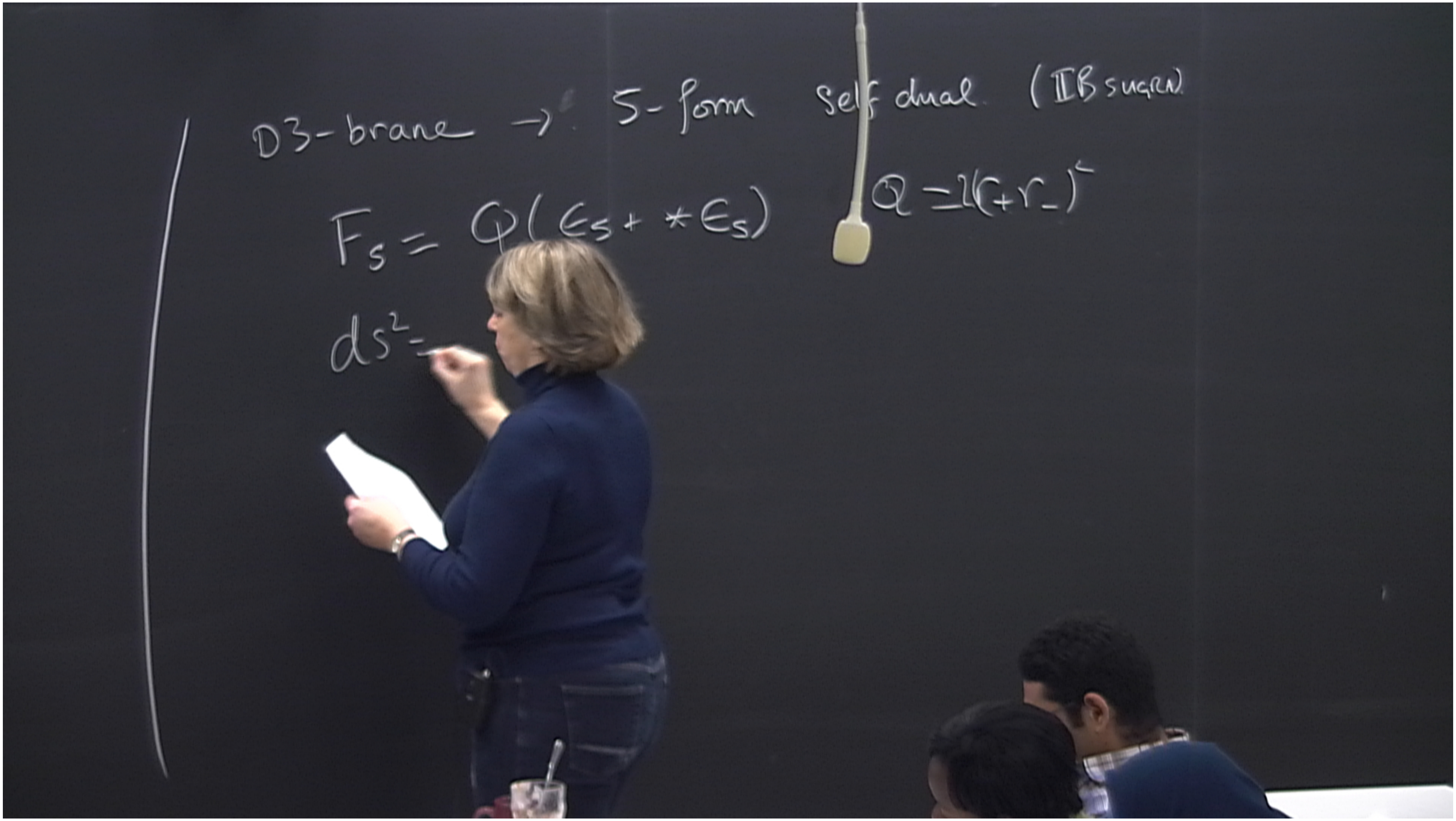
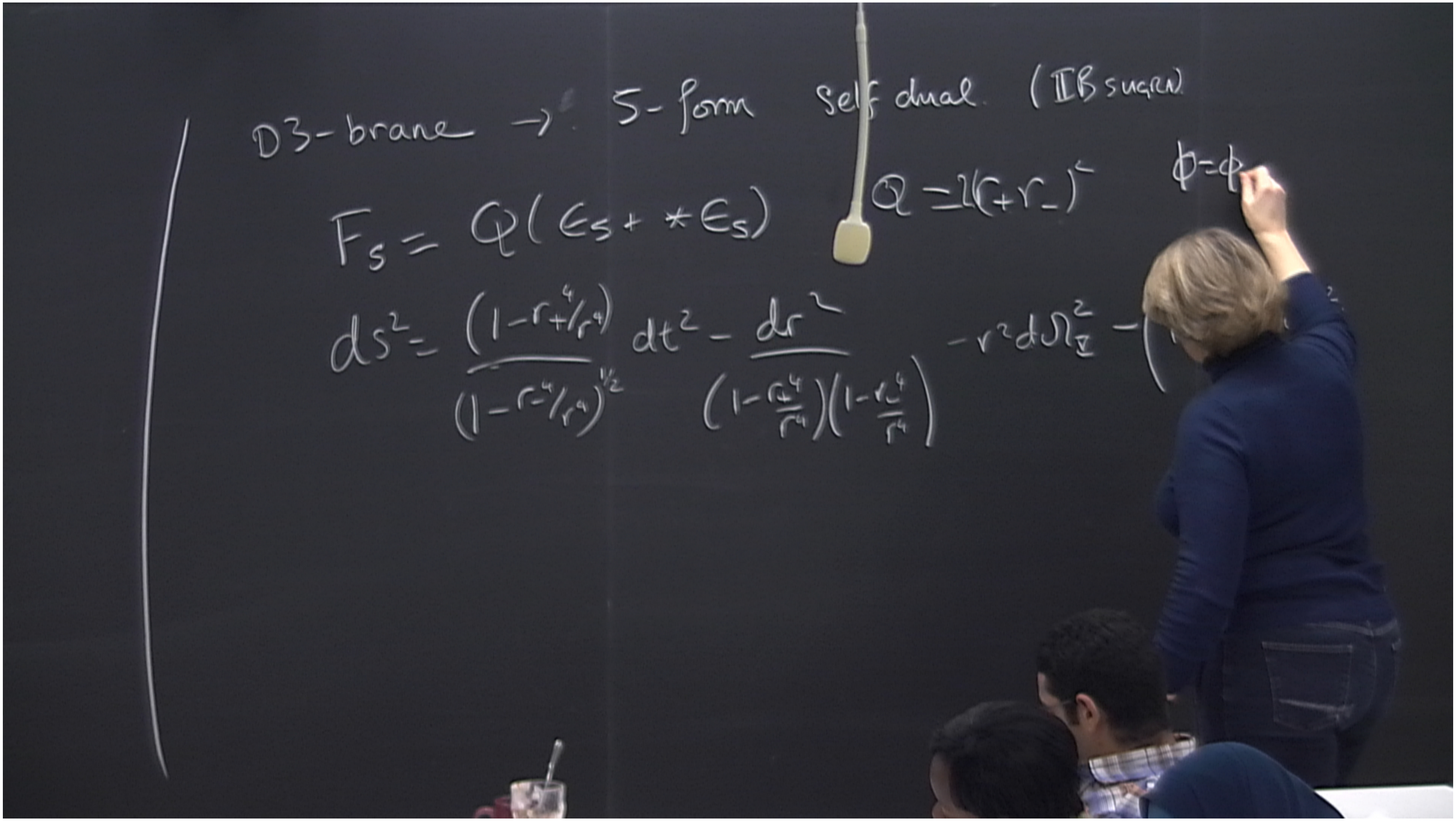
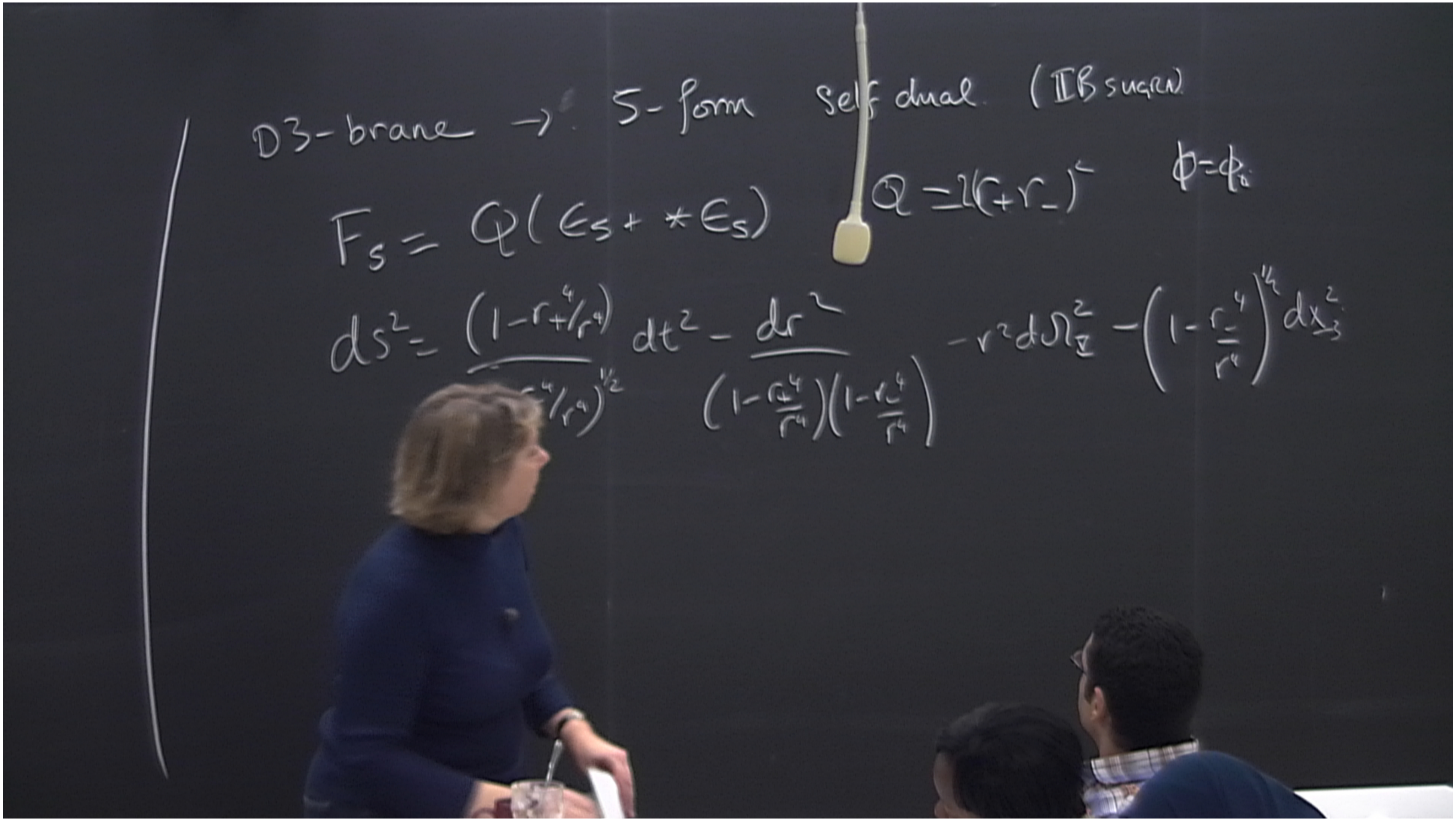
$$e^{2\phi} = \left(1 - \frac{r_-}{r}\right)^{-3/2} \qquad dA_6 = * \underbrace{Q}_{\frac{3}{2}(r_+ r_-)^{3/2}} \sin\theta\, d\theta \wedge d\varphi$$


D3-brane → 5-form self dual.


D3-brane → 5-form self dual (IIB SUGRA)
F5 = Q(ε5 + *ε5)
ds² =



D3-brane → 5-form self dual (IIB sugra)
$F_5 = Q(\epsilon_5 + *\epsilon_5)$
$Q = 2(r_+ r_-)^2$
$\phi = \phi$
$ds^2 = \frac{(1 - r_+^4/r^4)}{(1 - r_-^4/r^4)^{1/2}} dt^2 - \frac{dr^2}{(1-\frac{r_+^4}{r^4})(1-\frac{r_-^4}{r^4})} - r^2 d\Omega_5^2 -$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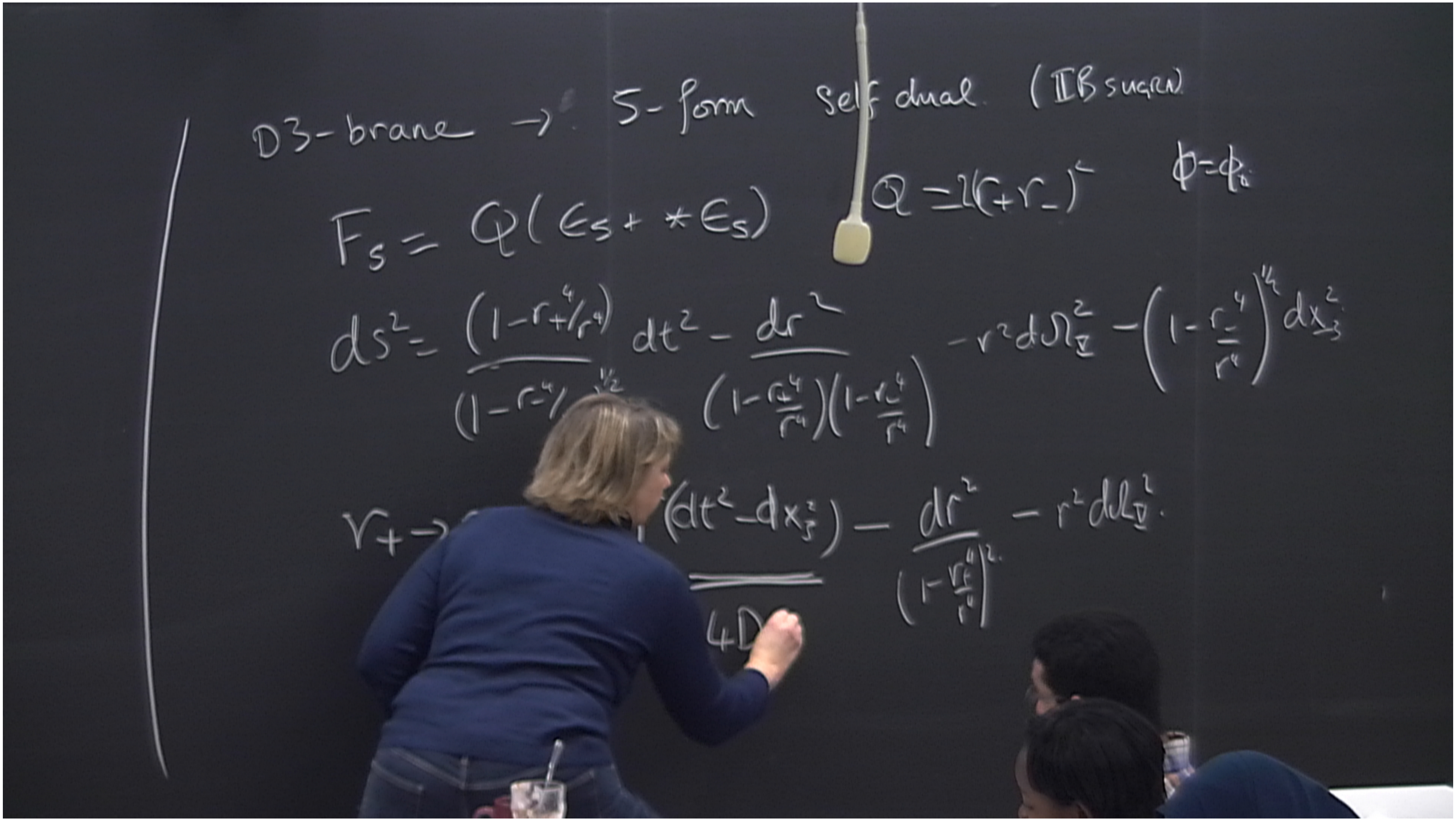
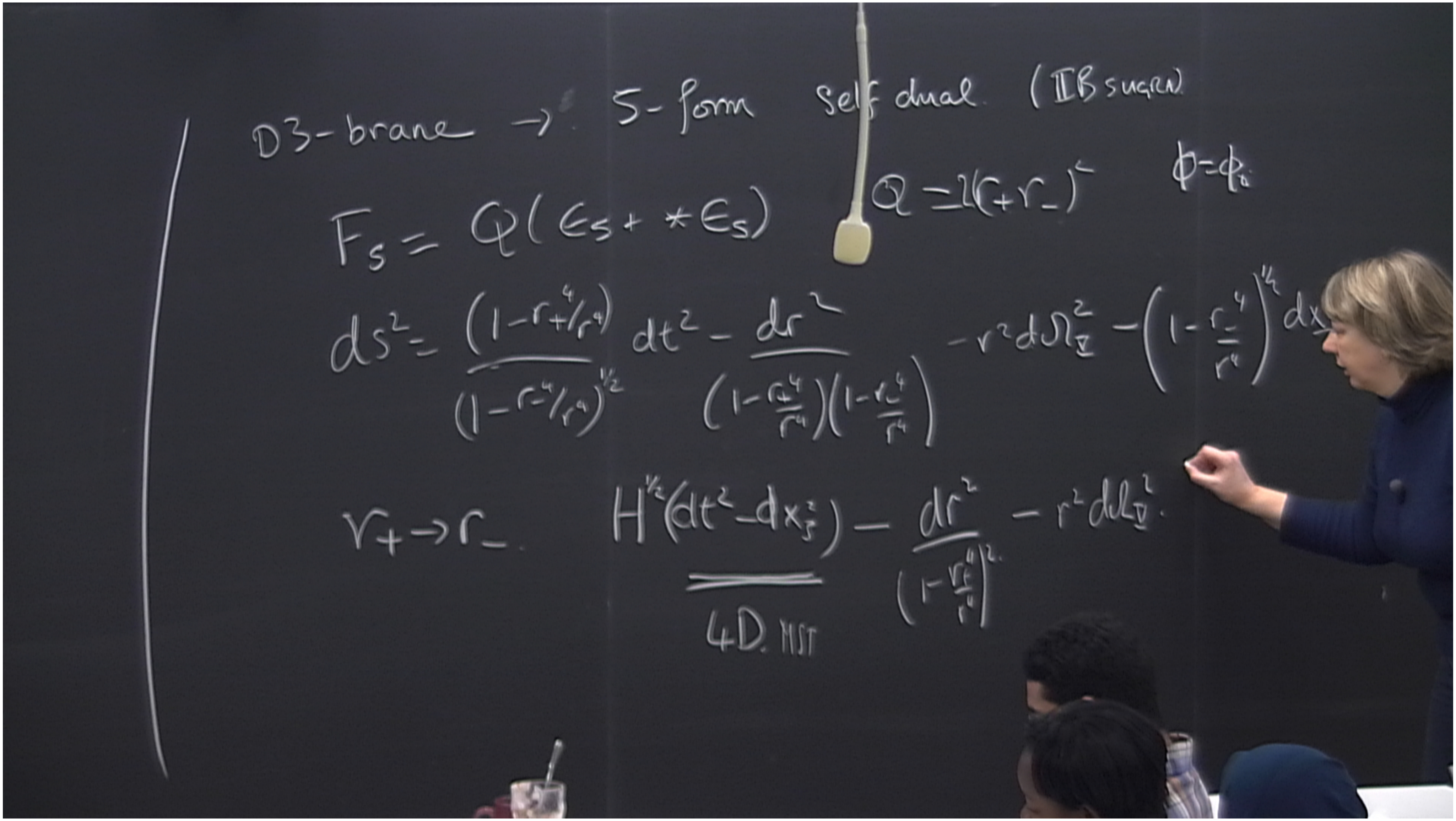
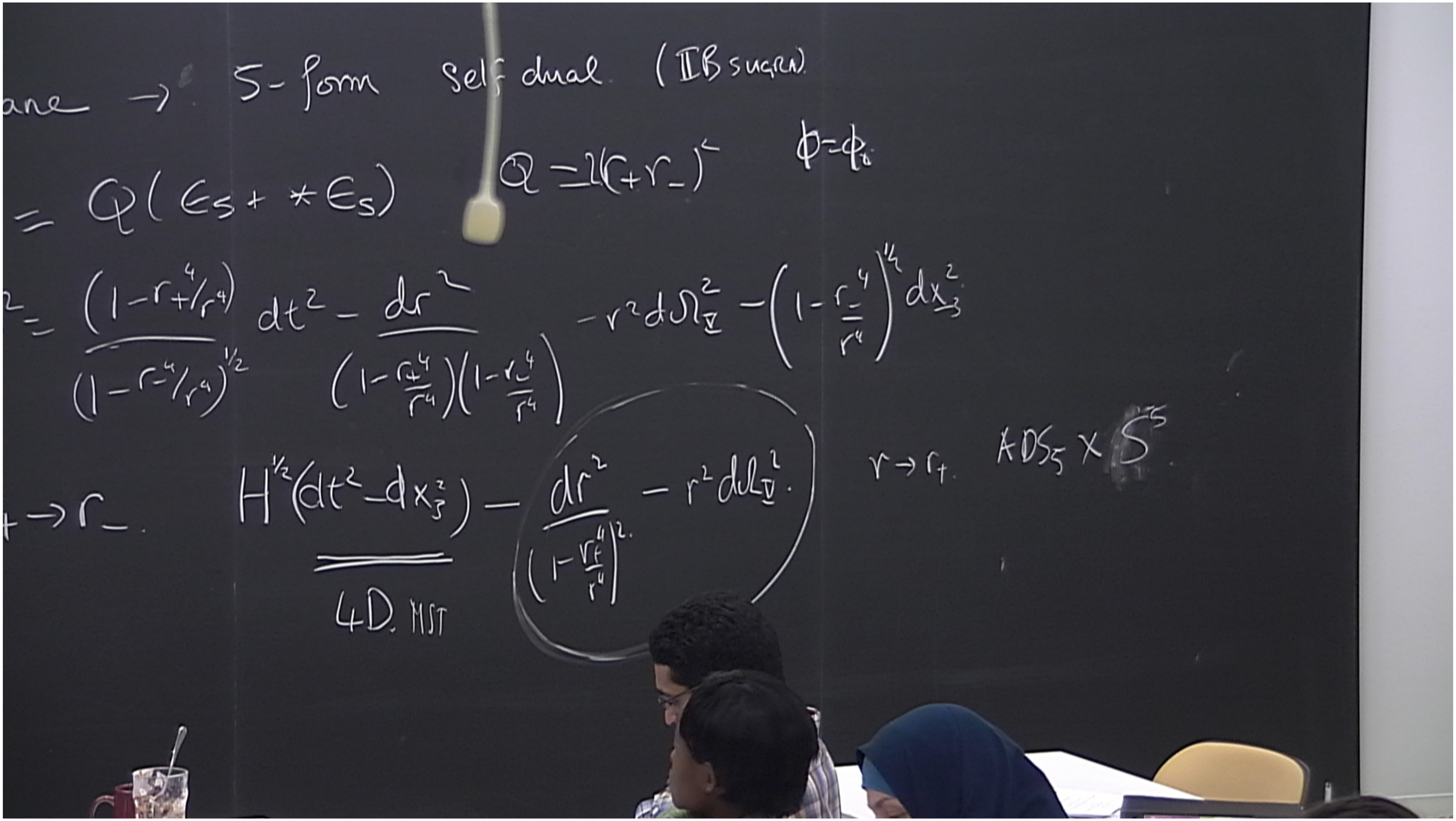

D3-brane → 5-form self dual (IIB SUGRA)
F5 = Q(ε5 + *ε5)
Q = 2(r+ r−)²
φ = φ0
ds² = (1 − r+⁴/r⁴) / (1 − r−⁴/r⁴)^½ dt² − dr² / ((1 − r+⁴/r⁴)(1 − r−⁴/r⁴)) − r² dΩ5² − (1 − r−⁴/r⁴)^½ dx3²
r+ → (dt² − dx3²) − dr² / (1 − r±⁴/r⁴)² − r² dΩ5²
4D


D3-brane → 5-form self dual (IIB SUGRA)
Q = 2(r₊ r₋)²   φ = φ₀
F₅ = Q(ε₅ + *ε₅)
ds² = (1 − r₊⁴/r⁴)/(1 − r₋⁴/r⁴)^{1/2} dt² − dr²/((1 − r₊⁴/r⁴)(1 − r₋⁴/r⁴)) − r² dΩ₅² − (1 − r₋⁴/r⁴)^{1/2} dx
r₊ → r₋   H^{1/2}(dt² − dx₃²) − dr²/(1 − r₋⁴/r⁴)² − r² dΩ₅²
4D. MST


ane → 5-form self dual (IIB sugra)
Q = 2(r+r_)²
φ = φ₀
= Q(ε₅ + *ε₅)
r → r₊ AdS₅ × S⁵
→ r_
4D MST