Title: On the geometry of the gauged ISS model

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Abstract: TBA

On the geometry of the gauged ISS model

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Plan

1. Motivations for SUSY breaking in a "hidden" sector
2. Geometry of gauged ISS model
3. Interpretation of ISS superpotential
4. R-symmetry problem
5. Conclusions

References

Buican, Malyshev, Verlinde, On the geometry of metastable supersymmetry breaking, arXiv:0710.5519

Aganagic, Beem, Kachru, Geometric transitions and dynamical SUSY breaking, arXiv:0709.4277

Intriligator, Seiberg, Shih, Dynamical SUSY breaking in meta-stable vacua, hep-th/0602239

Morrison, Plesser, Nonspherical horizons, hep-th/9810201

Douglas, Moore, D-branes, quivers, and ALE instantons, hep-th/9603167

Giudice, Rattazzi, Theories with gauge mediated supersymmetry breaking, hep-ph/9801271

SUSY breaking in a hidden sector

Supersymmetry is a powerful tool to solve some problems such as the hierarchy between the weak scale and the Planck scale.

The problem is how to break it in a realistic way.

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- Introduce soft terms by hand: why are they much smaller than M_{Pl}?
- Spontaneous breaking at tree level: since $STrM^2 = 0$ there should exist very light superpartners.
- Spontaneous breaking in a hidden sector with the generation of the masses at one loop: works best so far.

Mediation of SUSY breaking

There have been a lot of constructions of Standard Model-like theories in String theory:

- Heterotic strings
- Intersecting branes
- D-branes at CY singularities

The next question is how to get SUSY breaking in model building.

ISS in String theory

One of the goals of my talk will be to motivate why the ISS model might be a convenient choice for studying SUSY breaking.

The main objectives are:

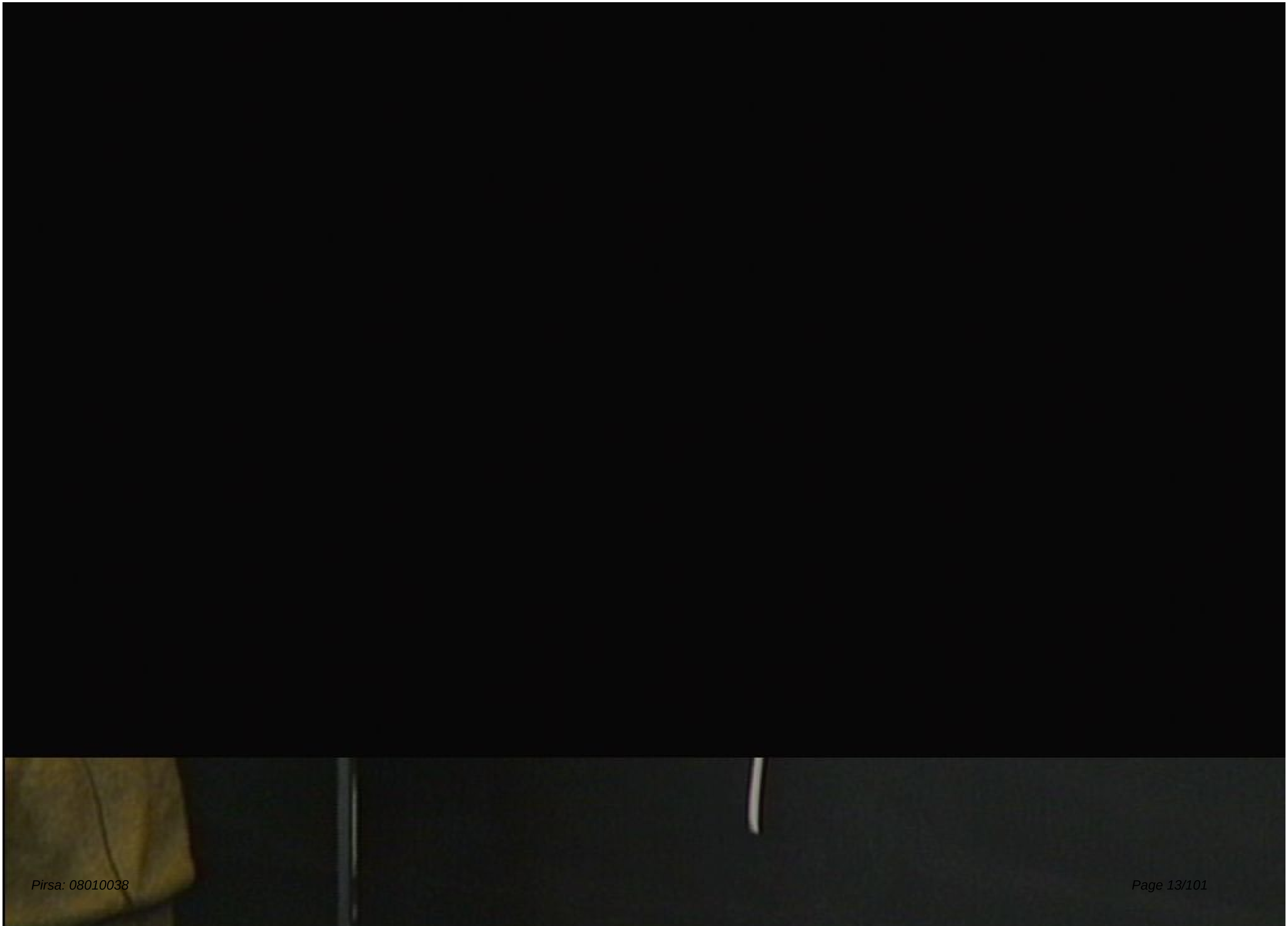
- Existence of a good field theoretic description
- The possibility of a geometric interpretation of various features of the model
- Rather generic in field theory and string theory

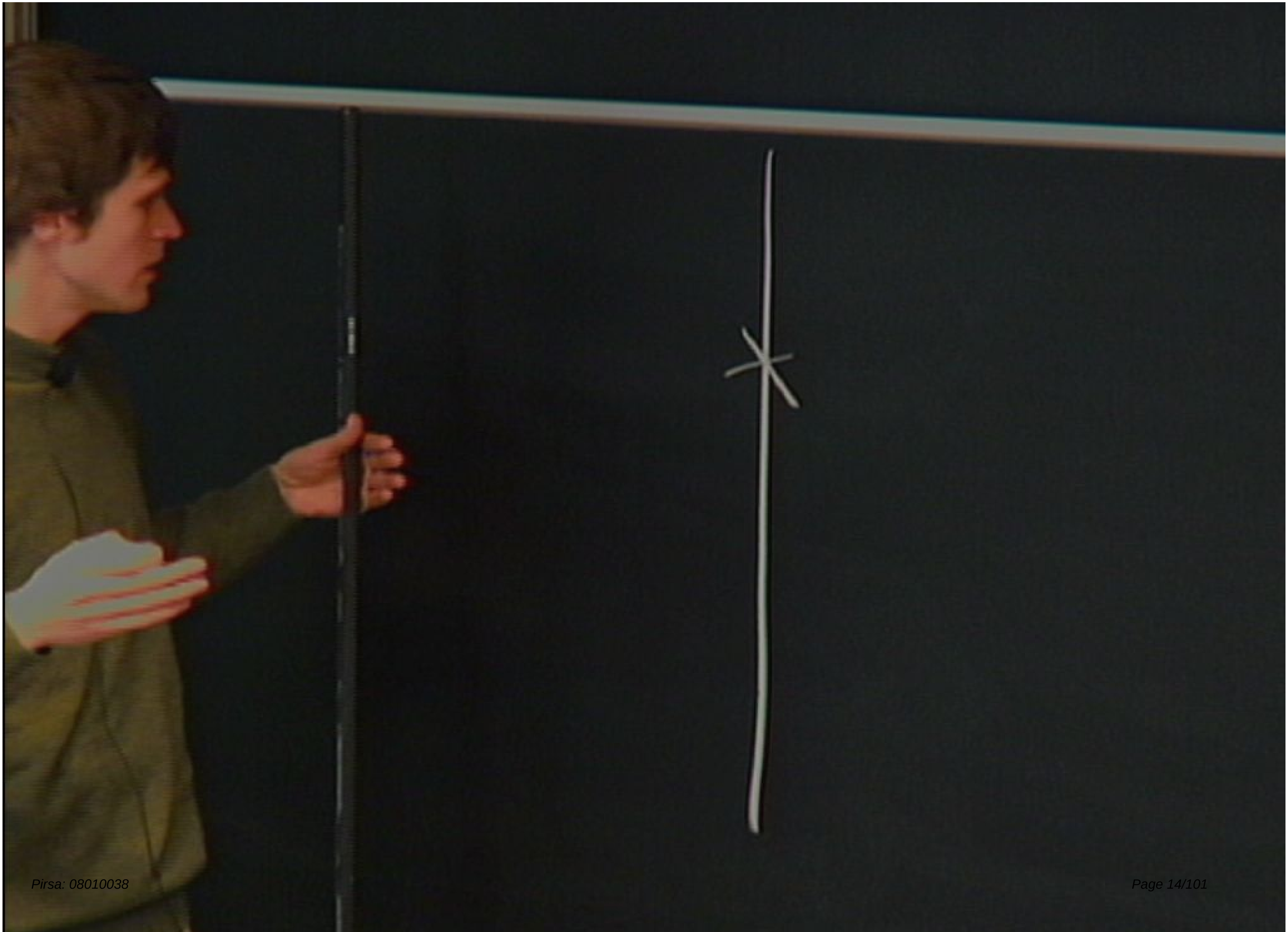
Highlights of stringy ISS construction

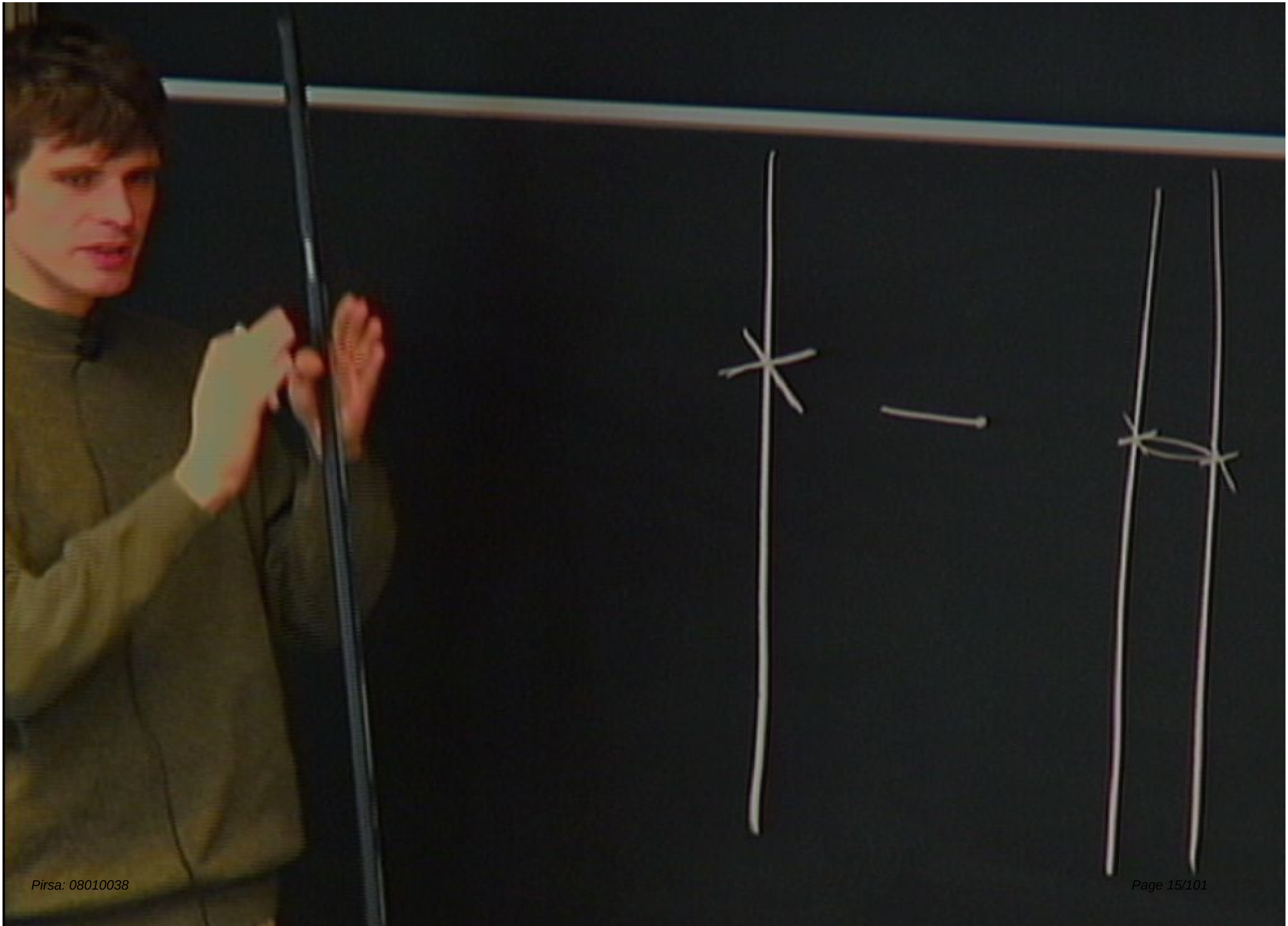
One of the goals for this talk will be to find the minimal requirements for ISS-like SUSY breaking vacua in quiver gauge theories.

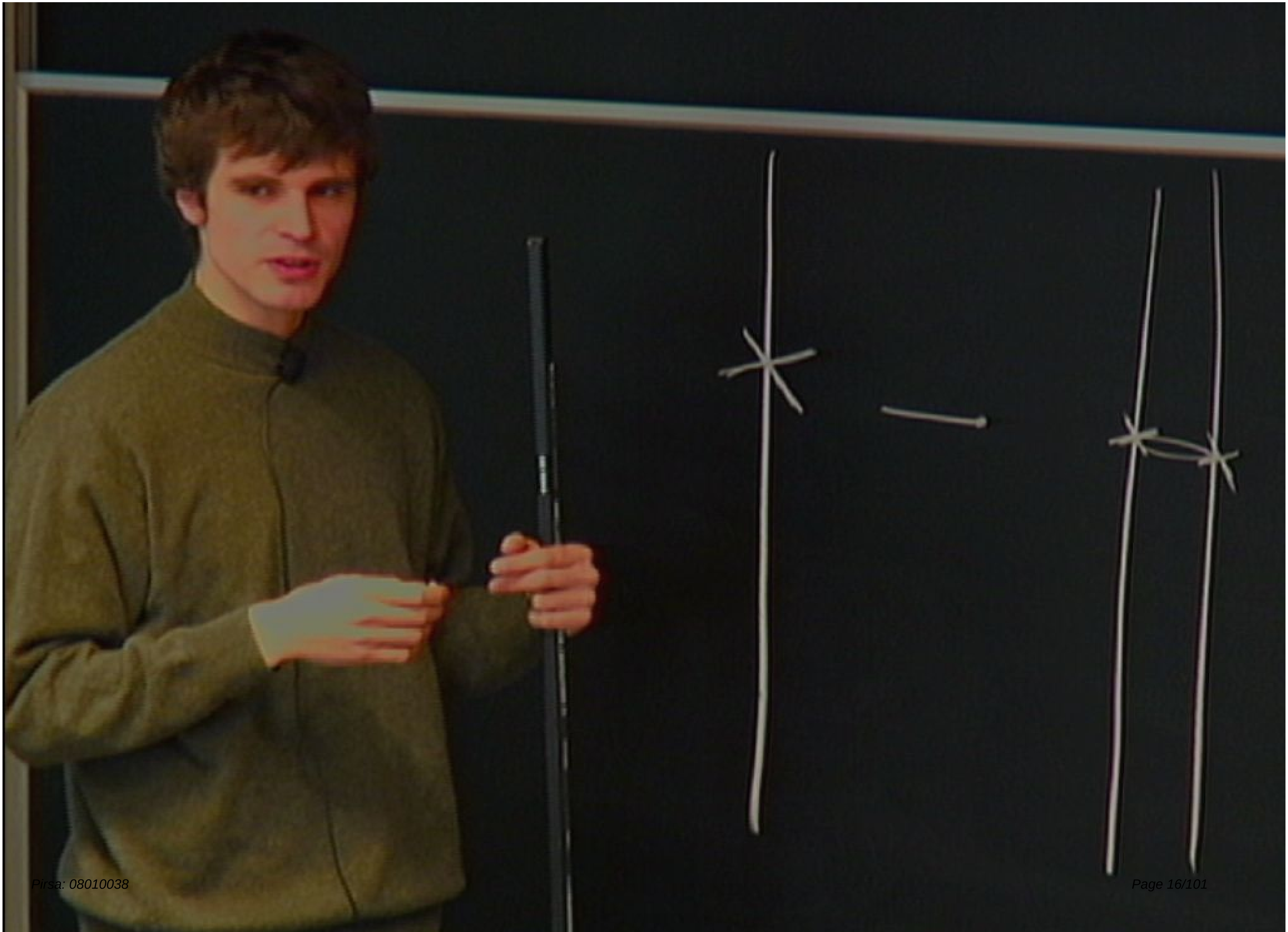
The final result will be the following:

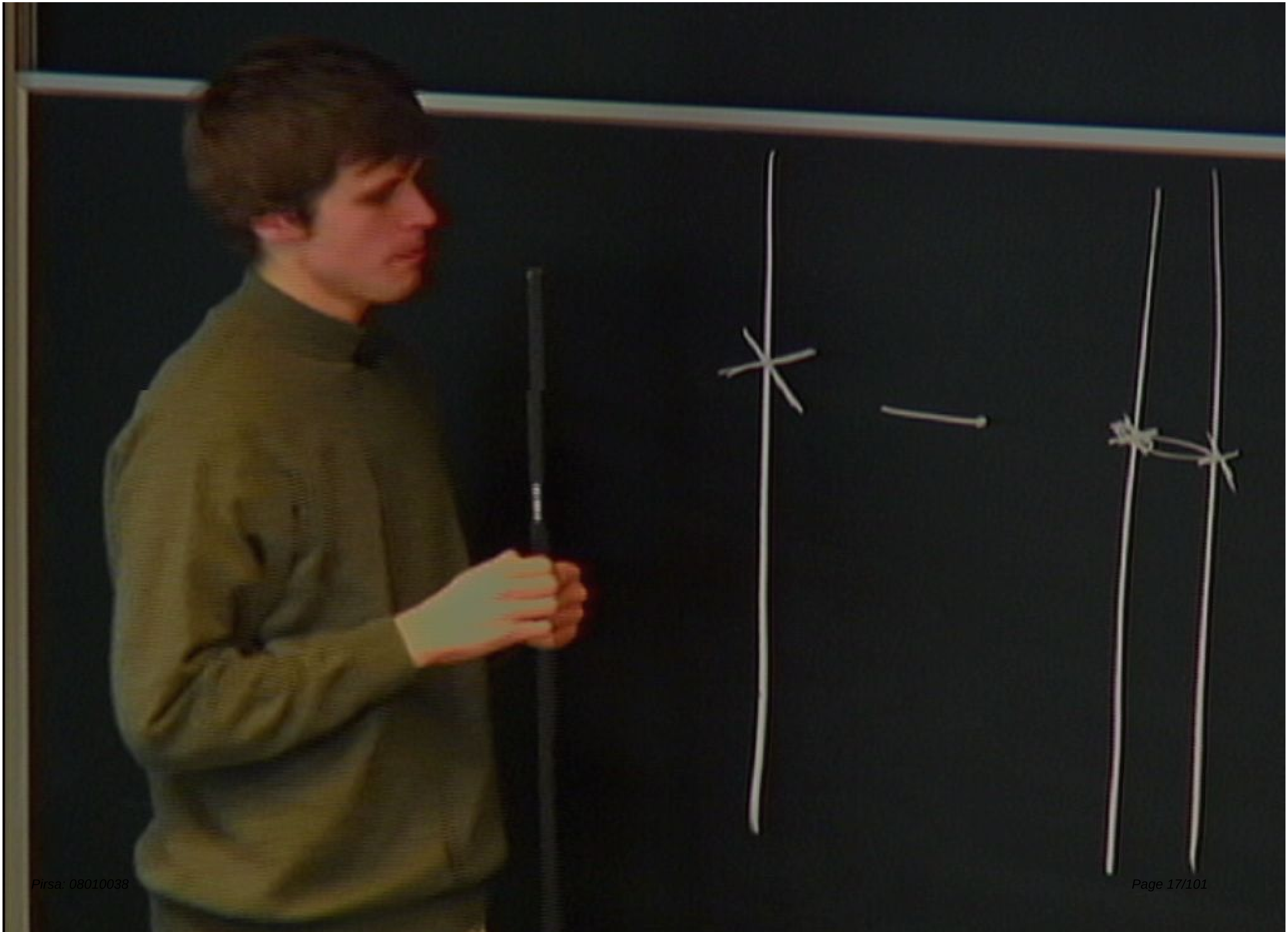
- the background CY manifold has a non-isolated singularity passing through an isolated singularity;
- the non-isolated singularity is slightly deformed;
- SUSY is broken by fractional branes wrapping "hidden" cycles in both isolated and non-isolated singularities.

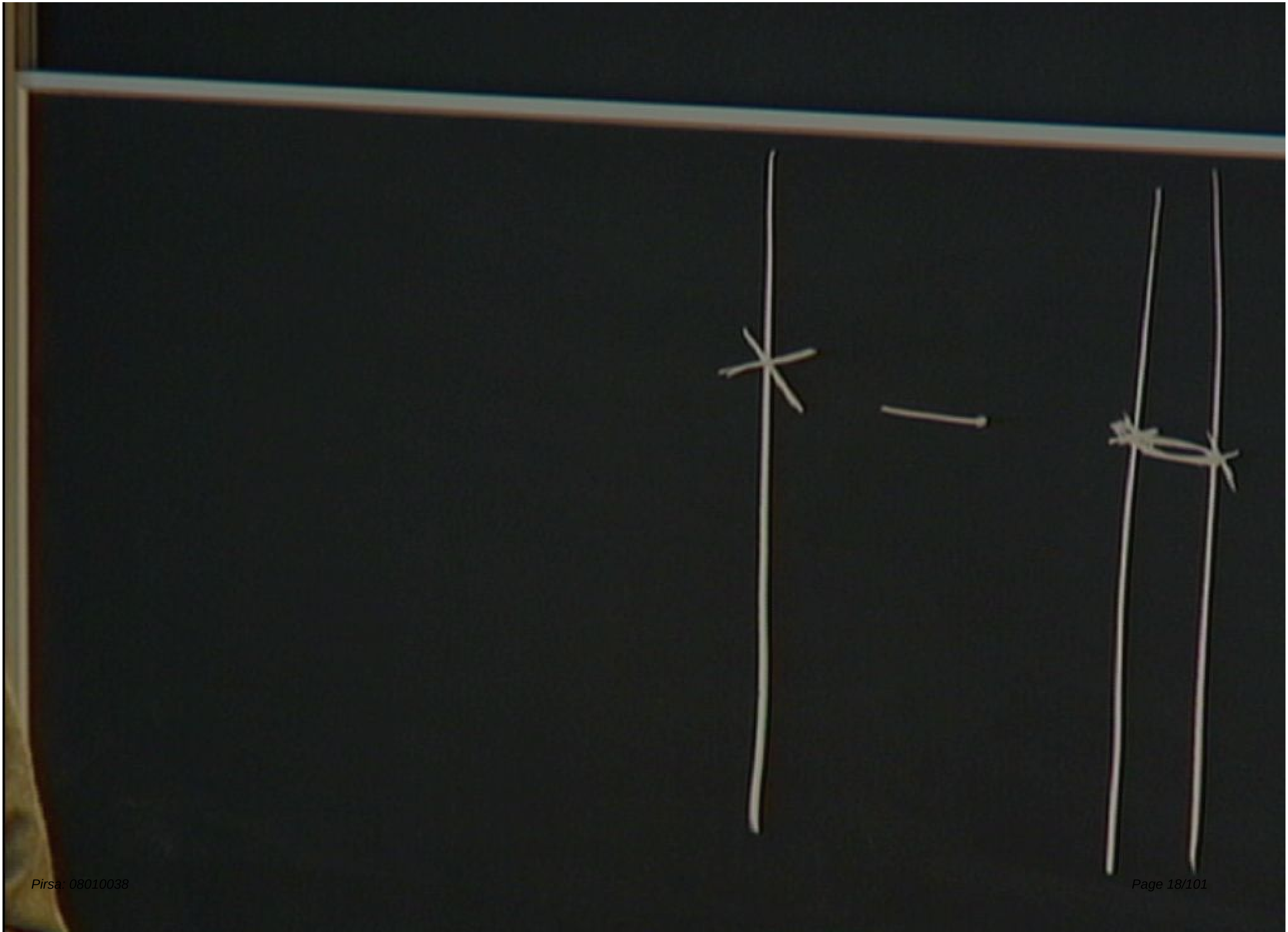




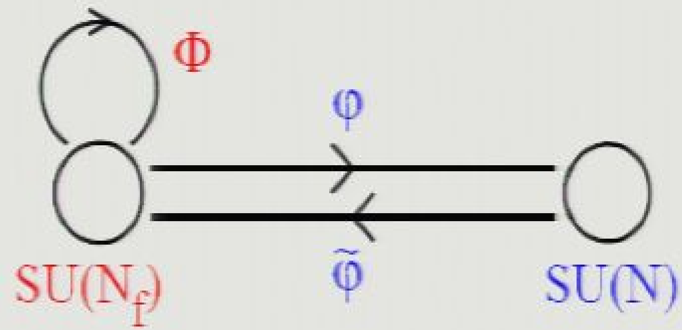








The ISS quiver



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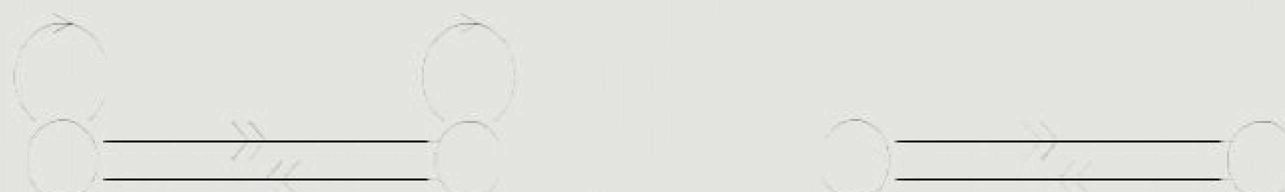

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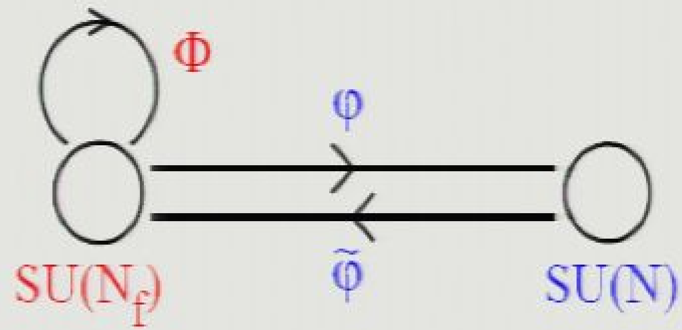

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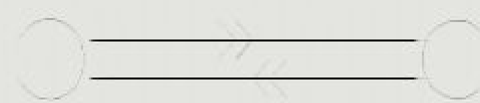

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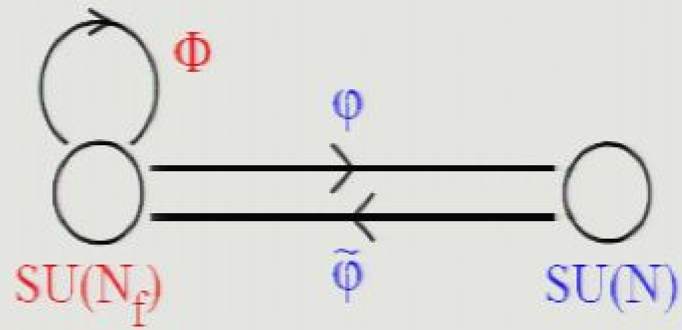

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SUSY breaking in ISS model

In the low energy theory, the ISS superpotential is

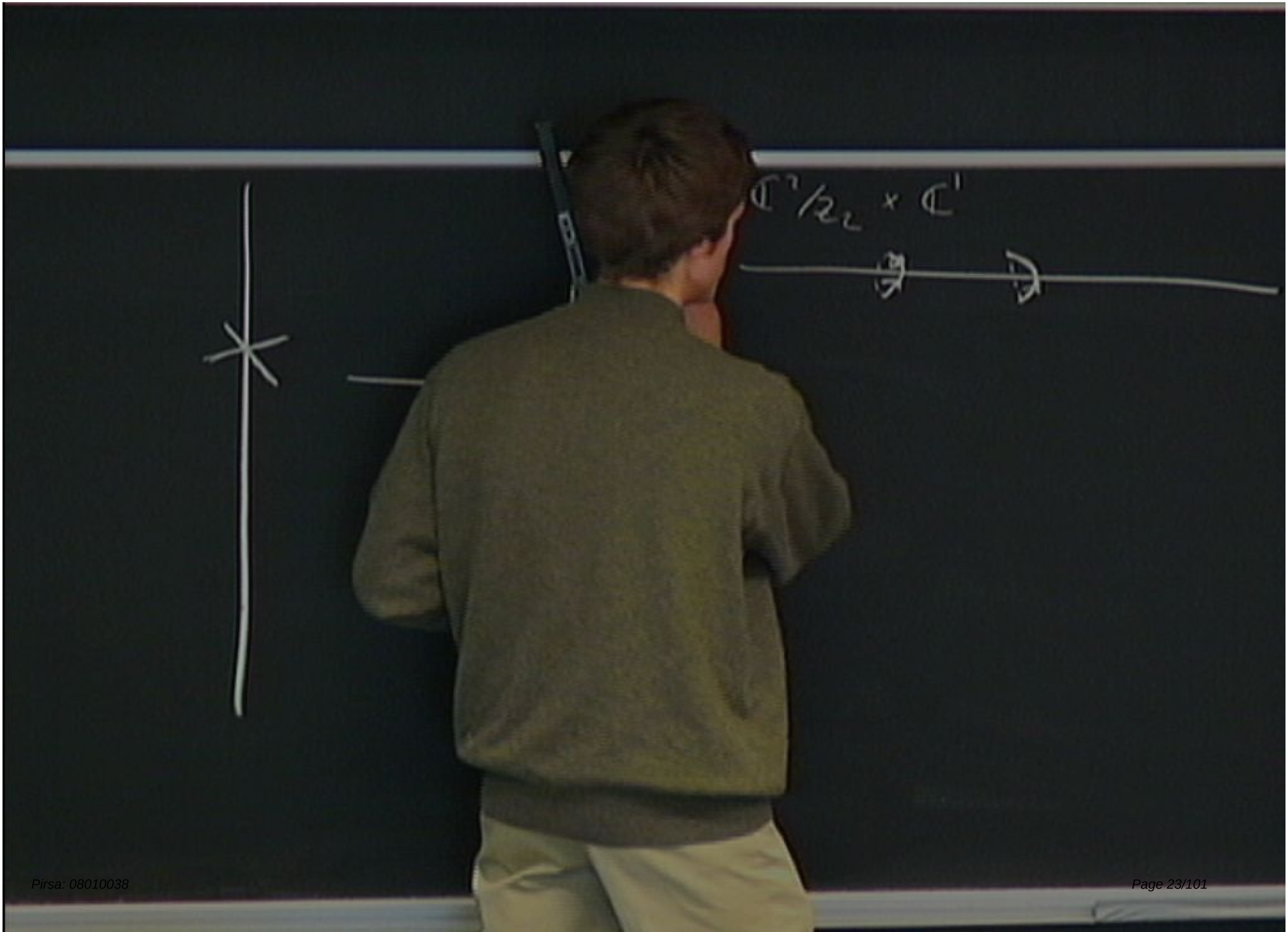
$$W = h\mathrm{Tr}(\tilde{\varphi}\Phi\varphi) - h\mu^2\mathrm{Tr}\Phi$$

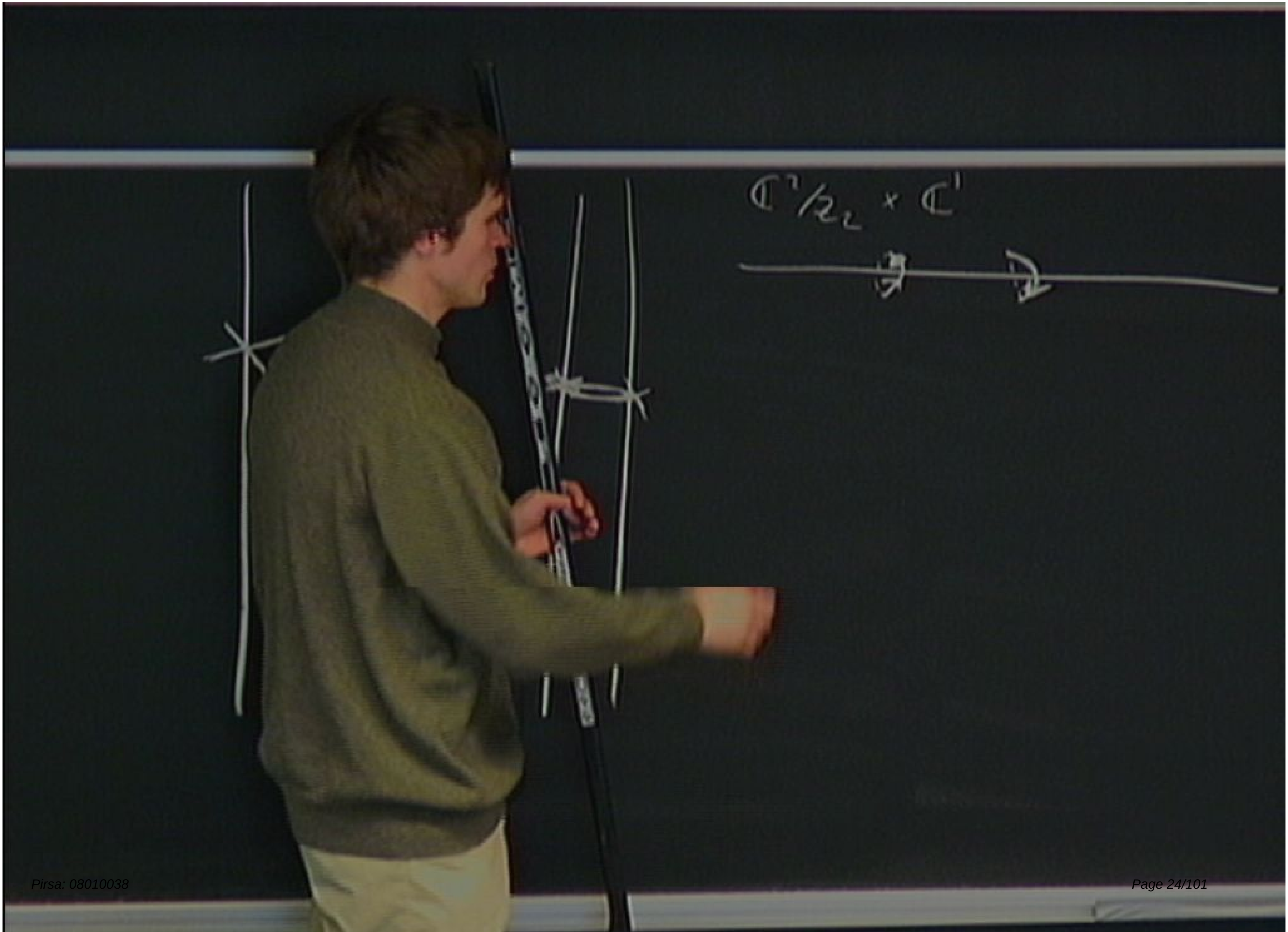
where Φ is $N_f \times N_f$ and φ, $\tilde{\varphi}^T$ are $N_f \times N$ matrices.

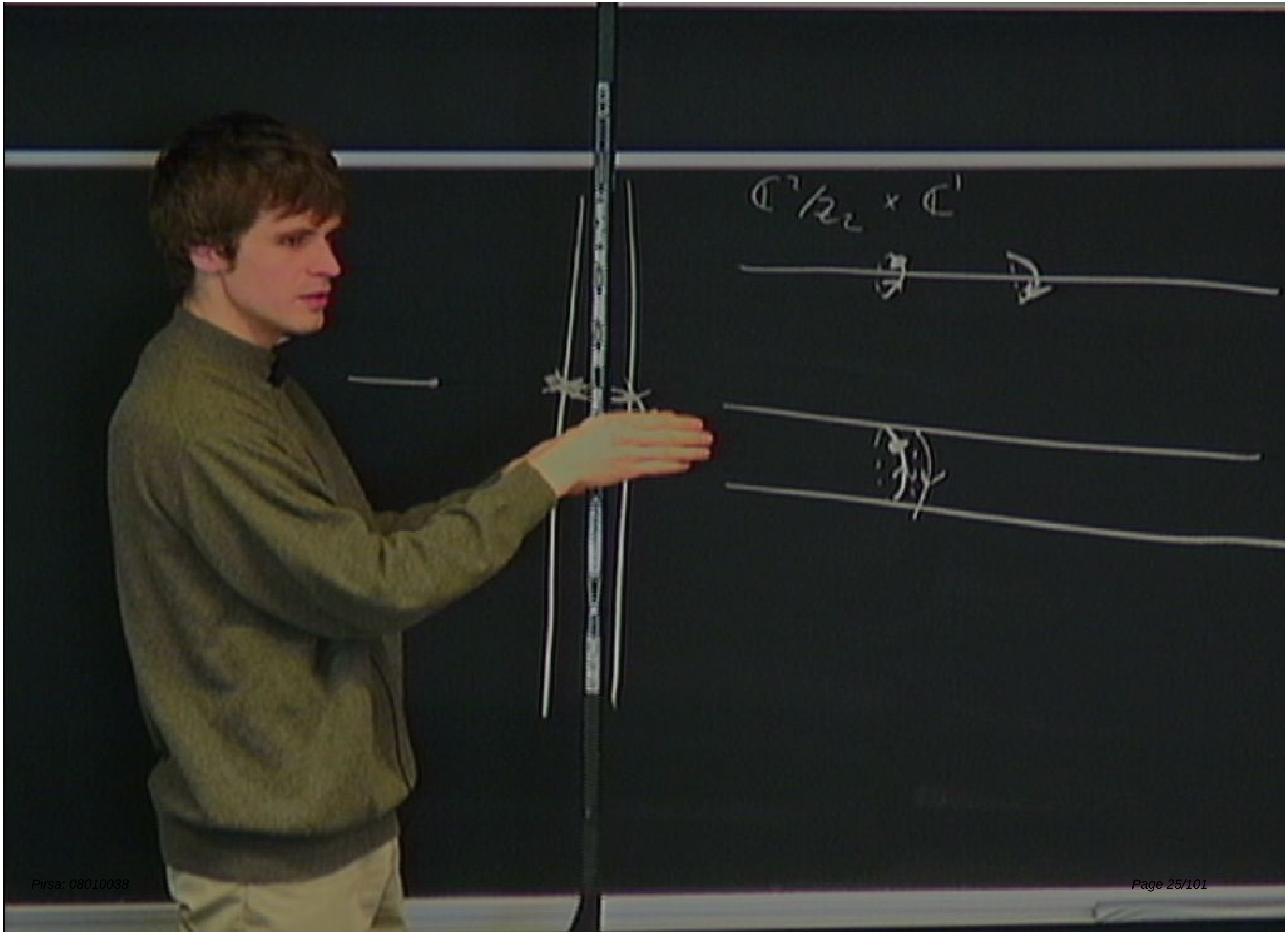
If $N_f > N$, then SUSY is broken by the F-term equations for the Φ_{ij} fields

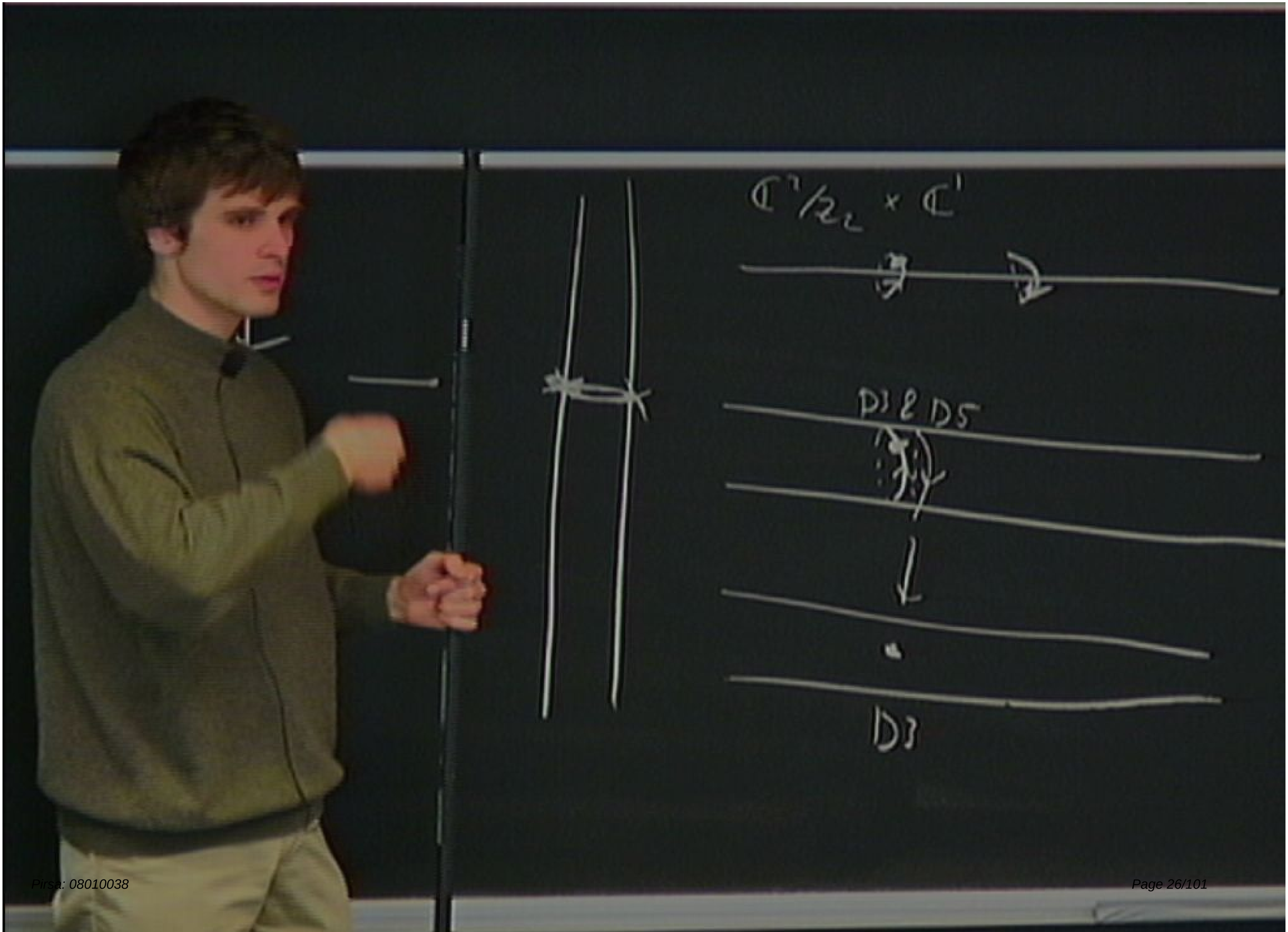
$$\varphi_{ik}\tilde{\varphi}_{kj} = \mu^2\delta_{ij}$$

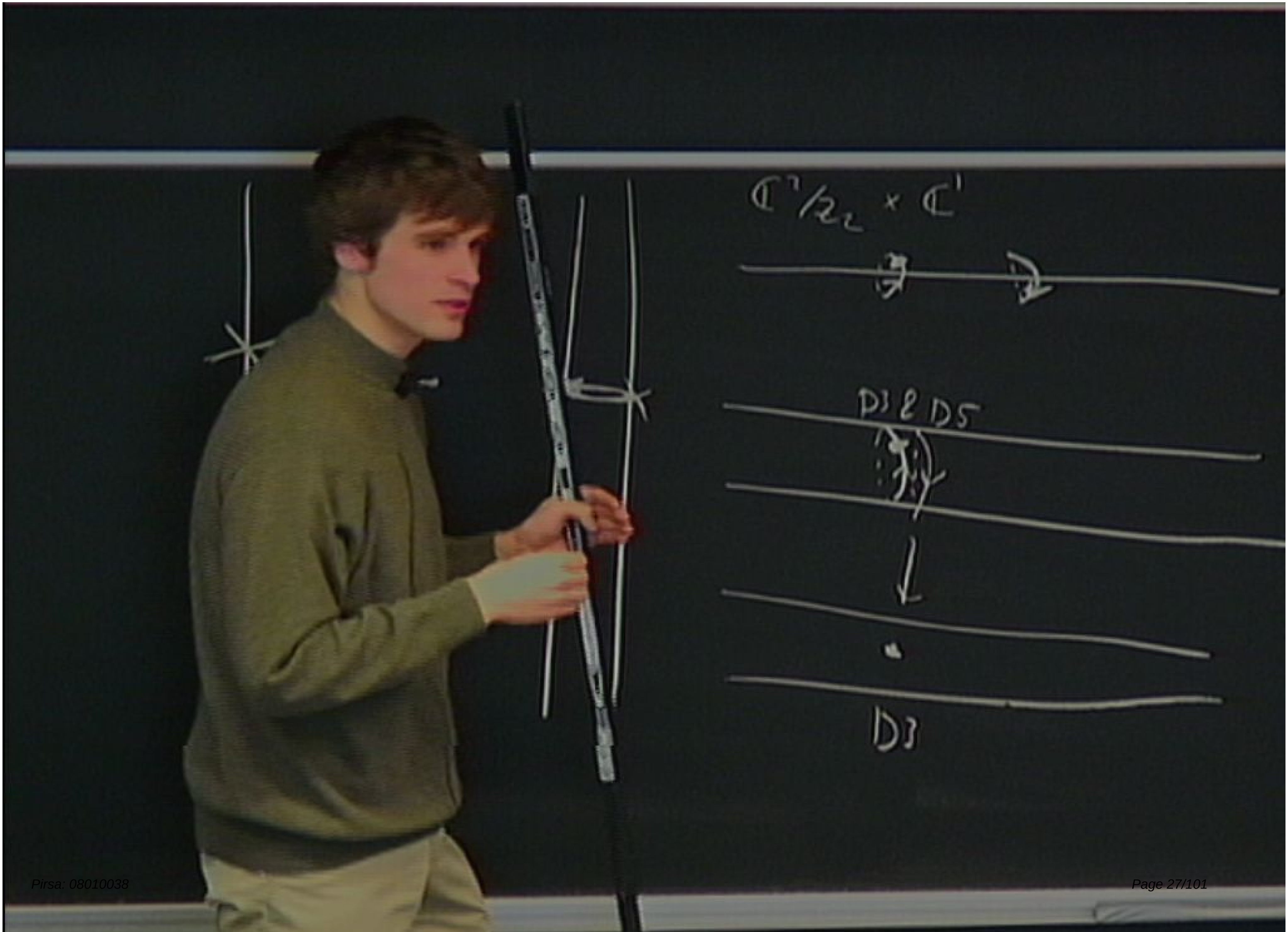
since the product of φ and $\tilde{\varphi}$ matrices has at most rank N and the matrix on the right has rank N_f.

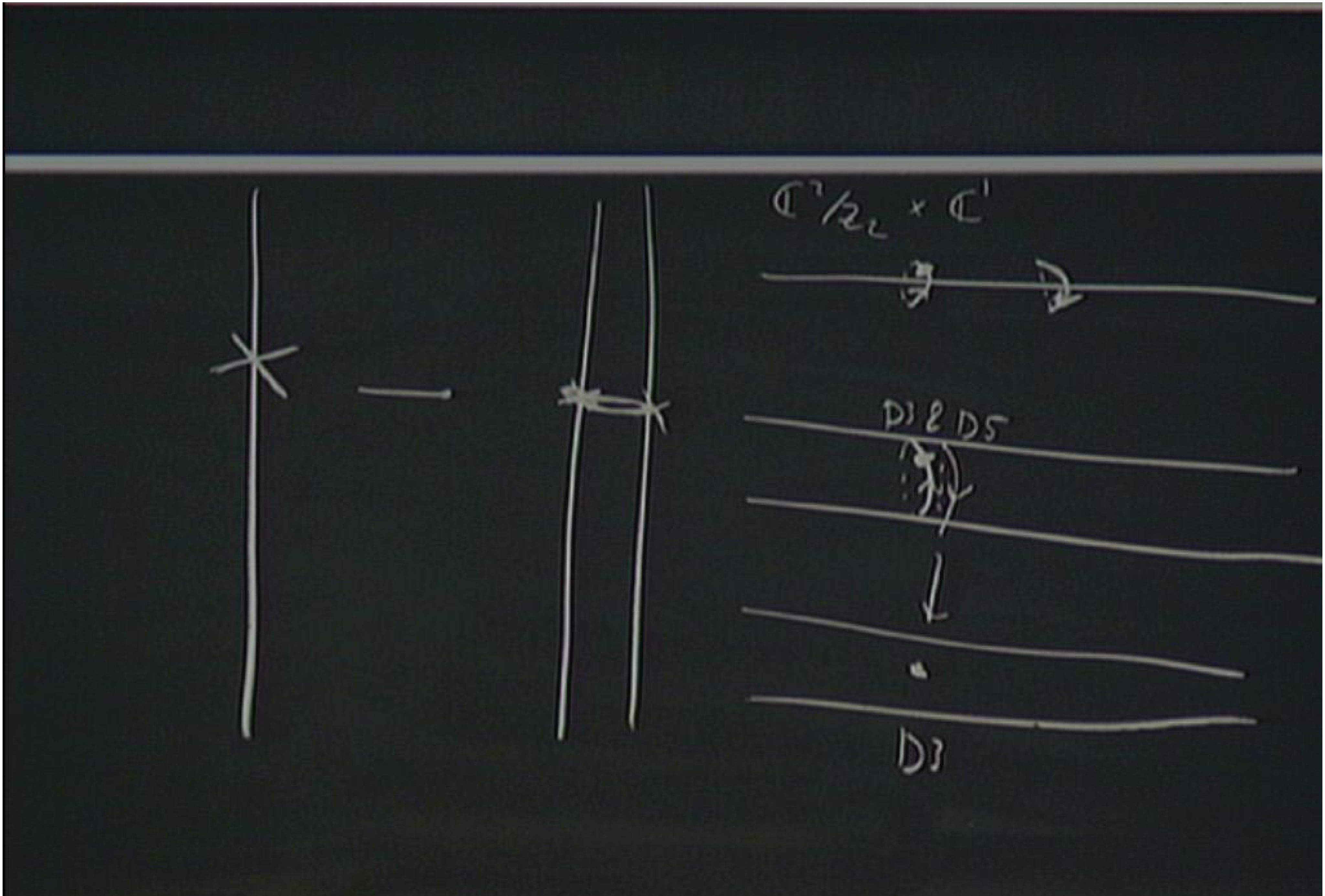



$\mathbb{C}^2/\mathbb{Z}_2 \times \mathbb{C}^1$


$\mathbb{C}^1/\mathbb{Z}_2 \times \mathbb{C}^1$


$\mathbb{C}^2/\mathbb{Z}_2 \times \mathbb{C}^1$
D3 & D5
D3


C²/Z₂ × C¹
D3 & D5
D3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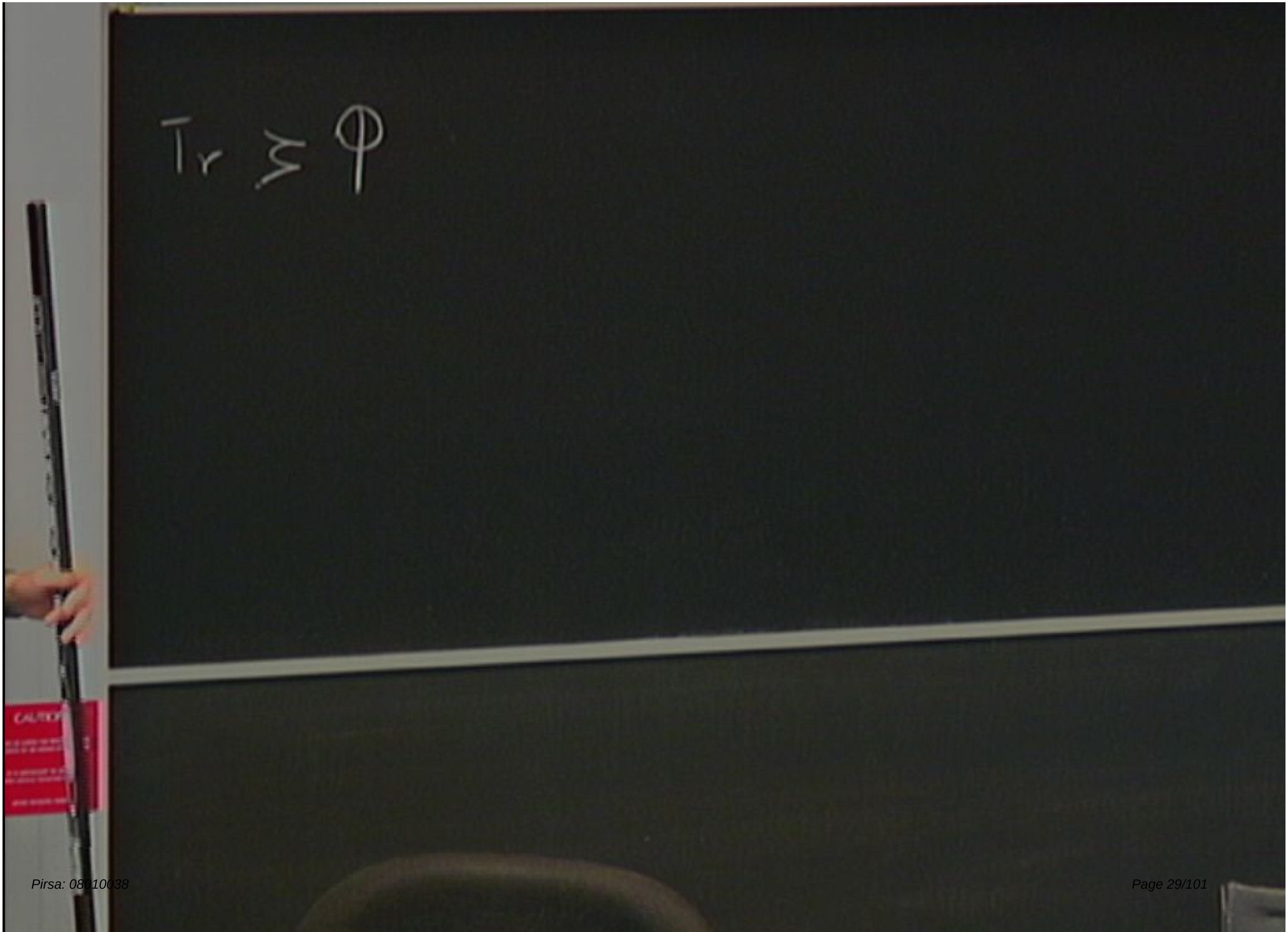
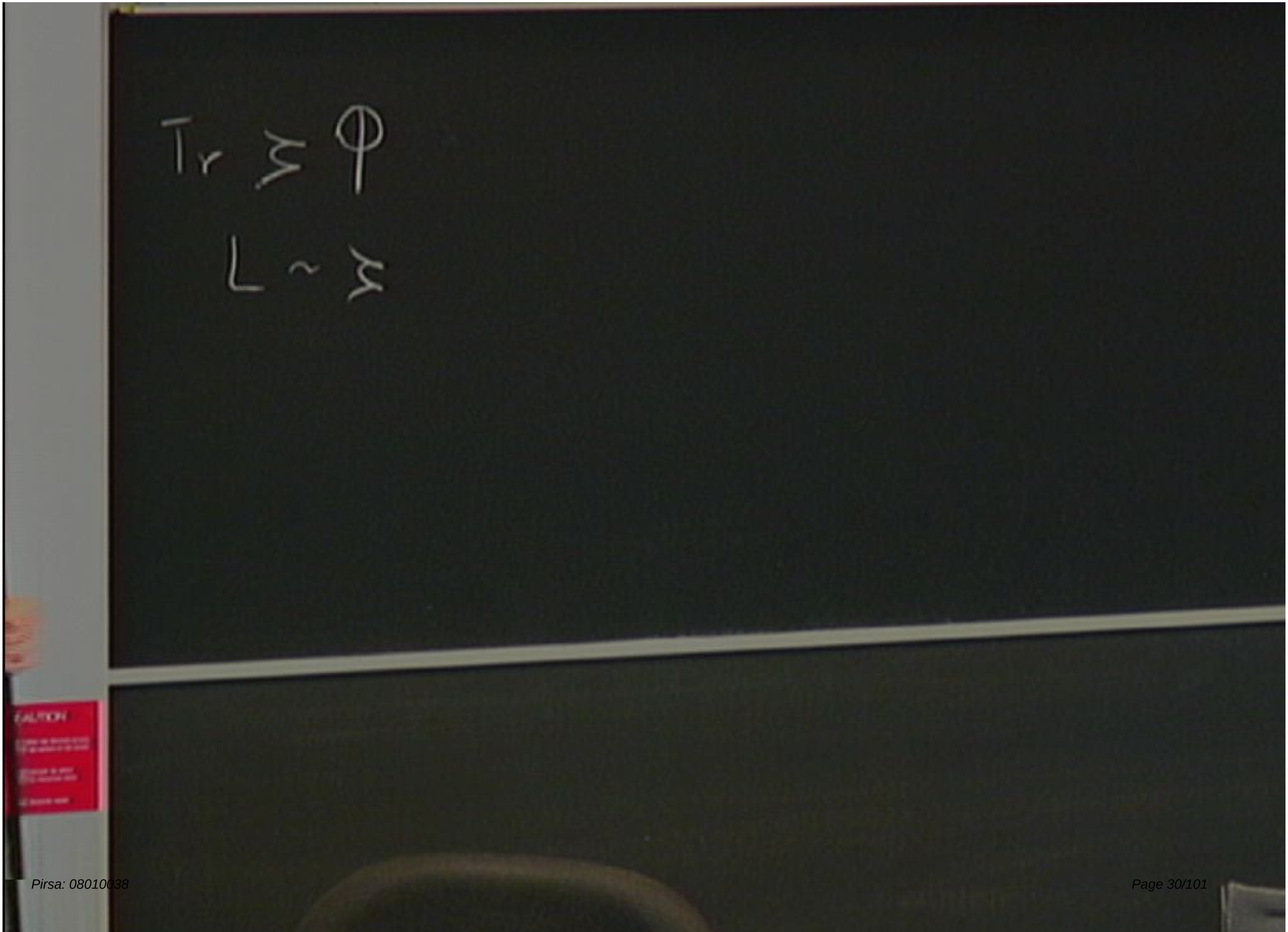
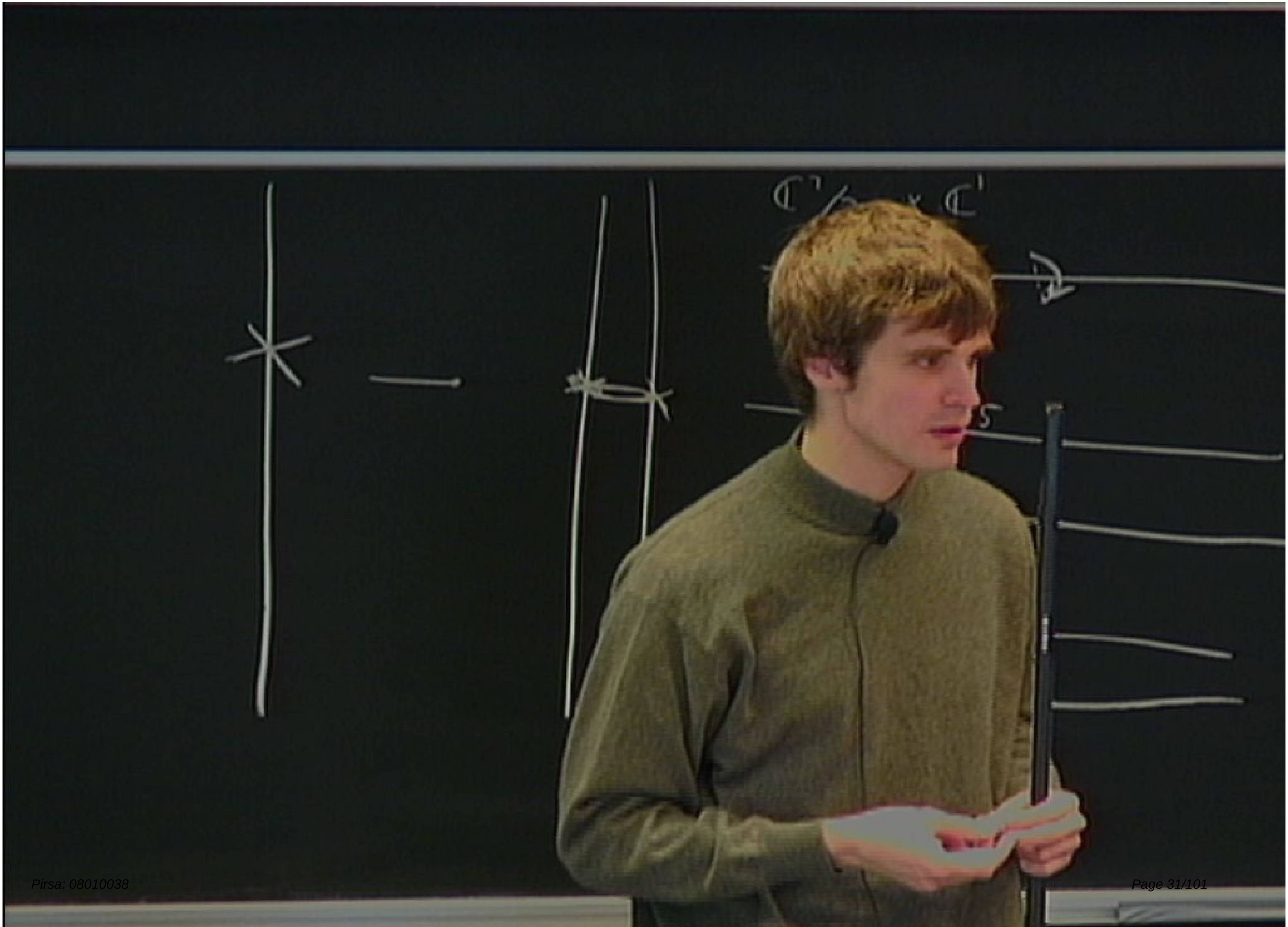
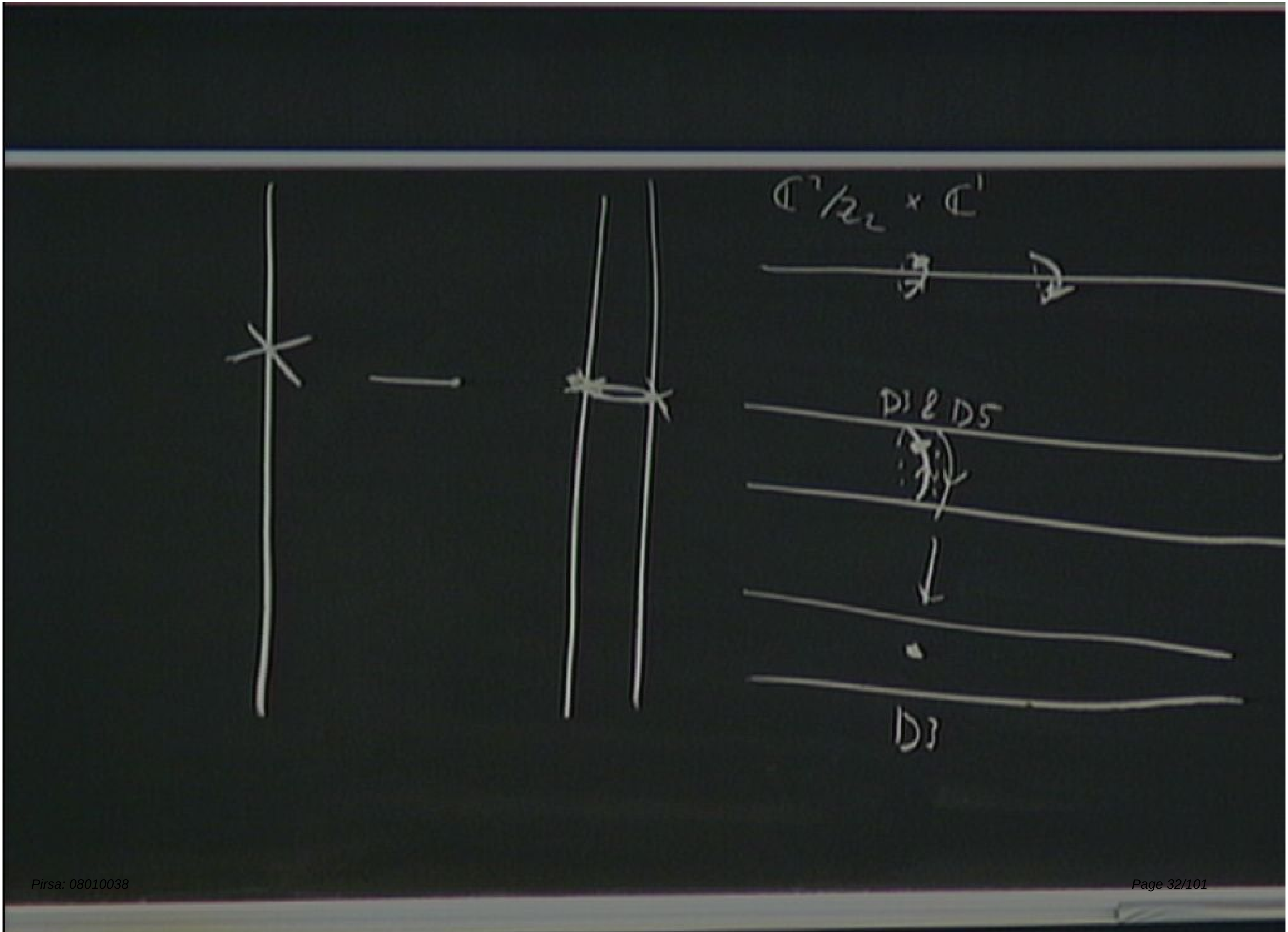
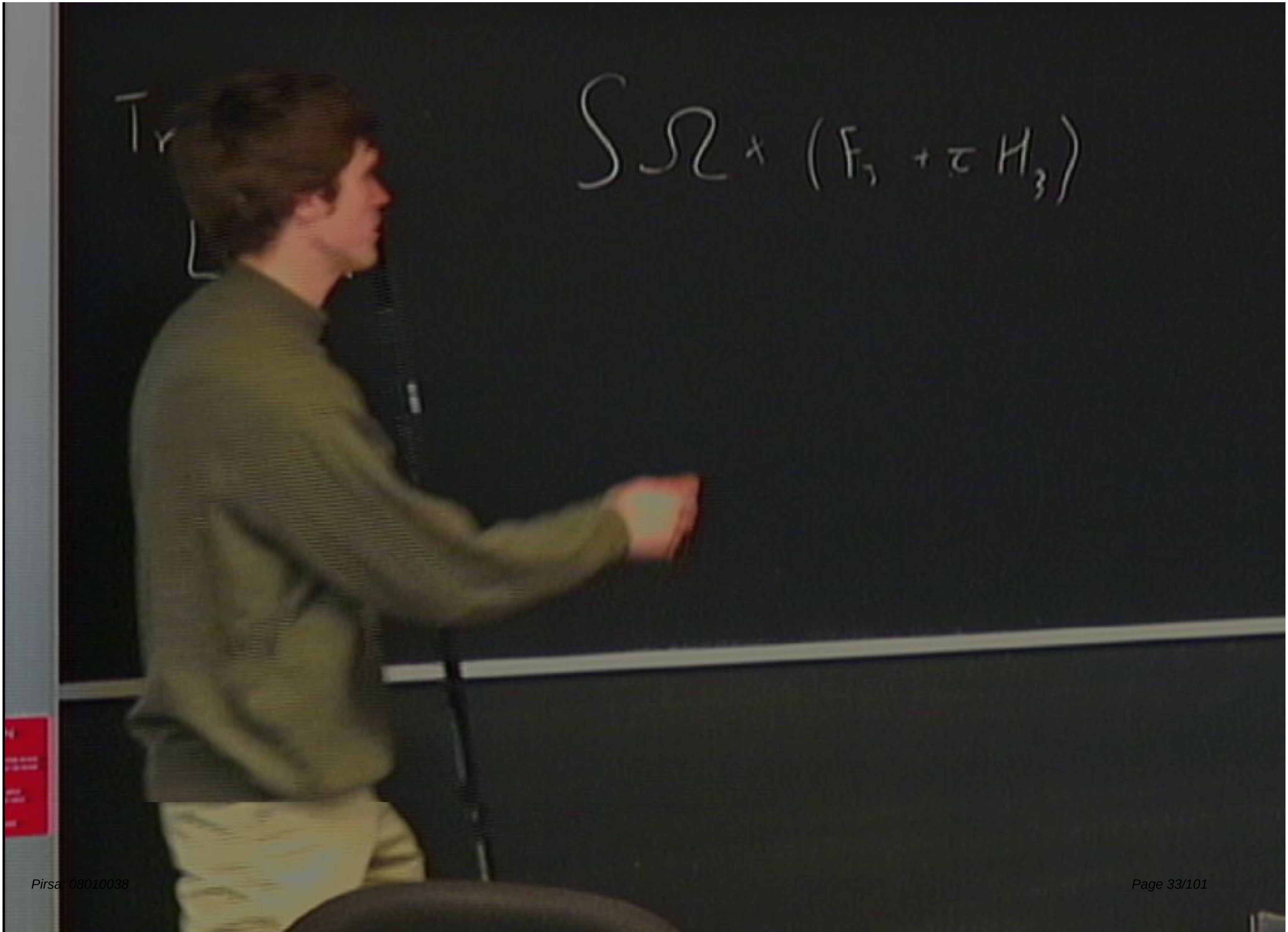
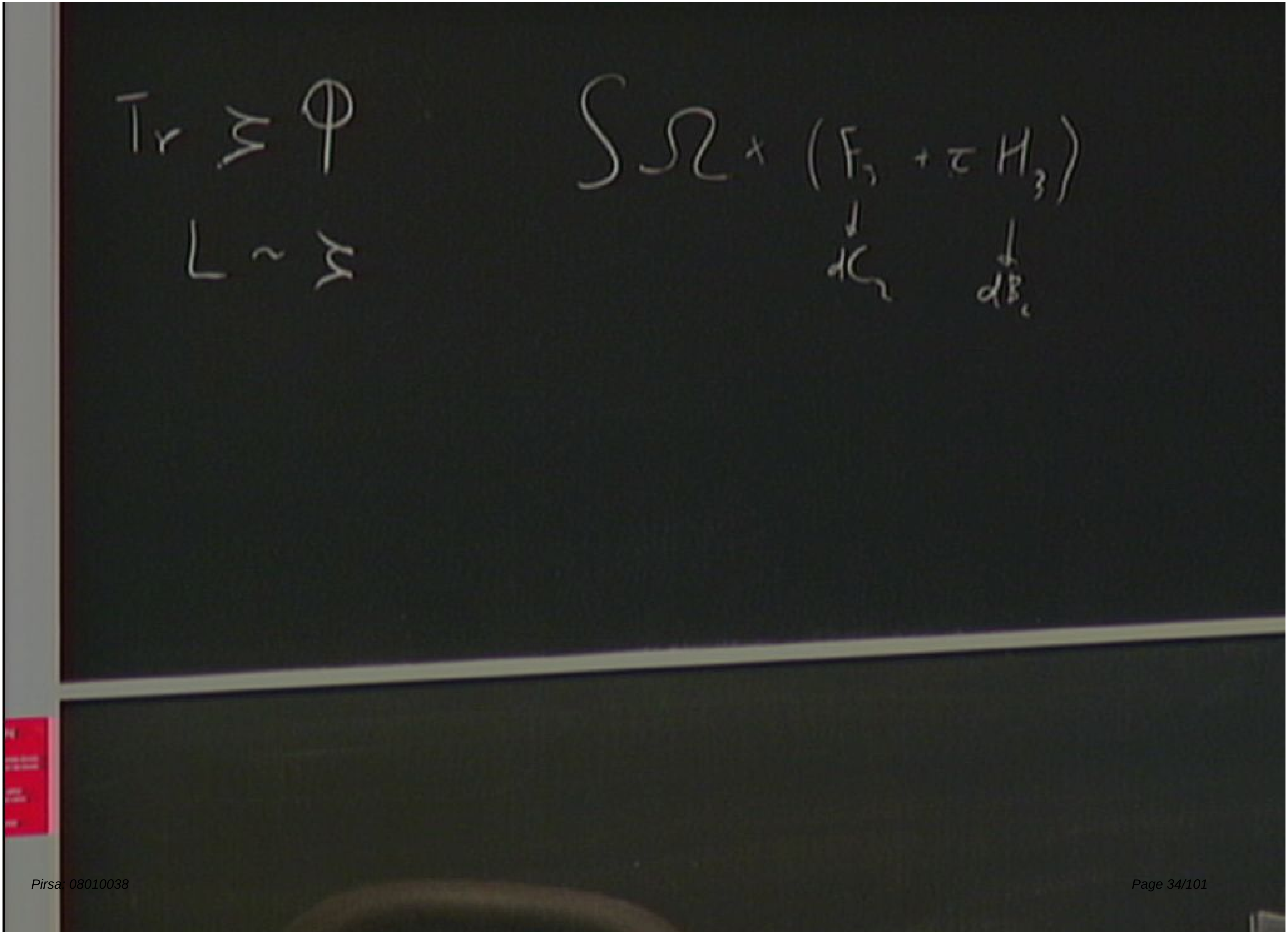

Tr ξ φ

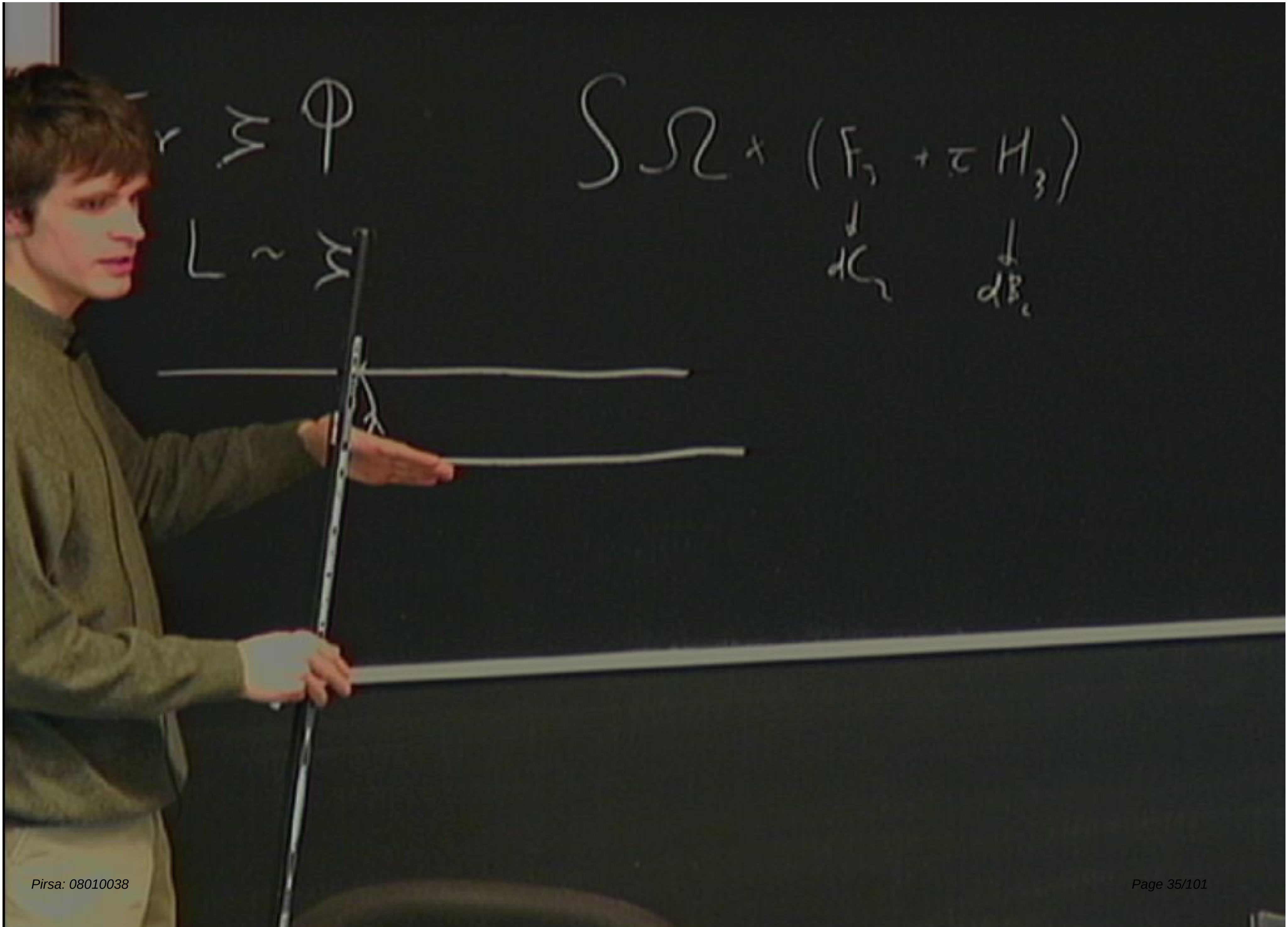

$\mathrm{Tr}\ \xi\ \phi$
$L \sim \xi$



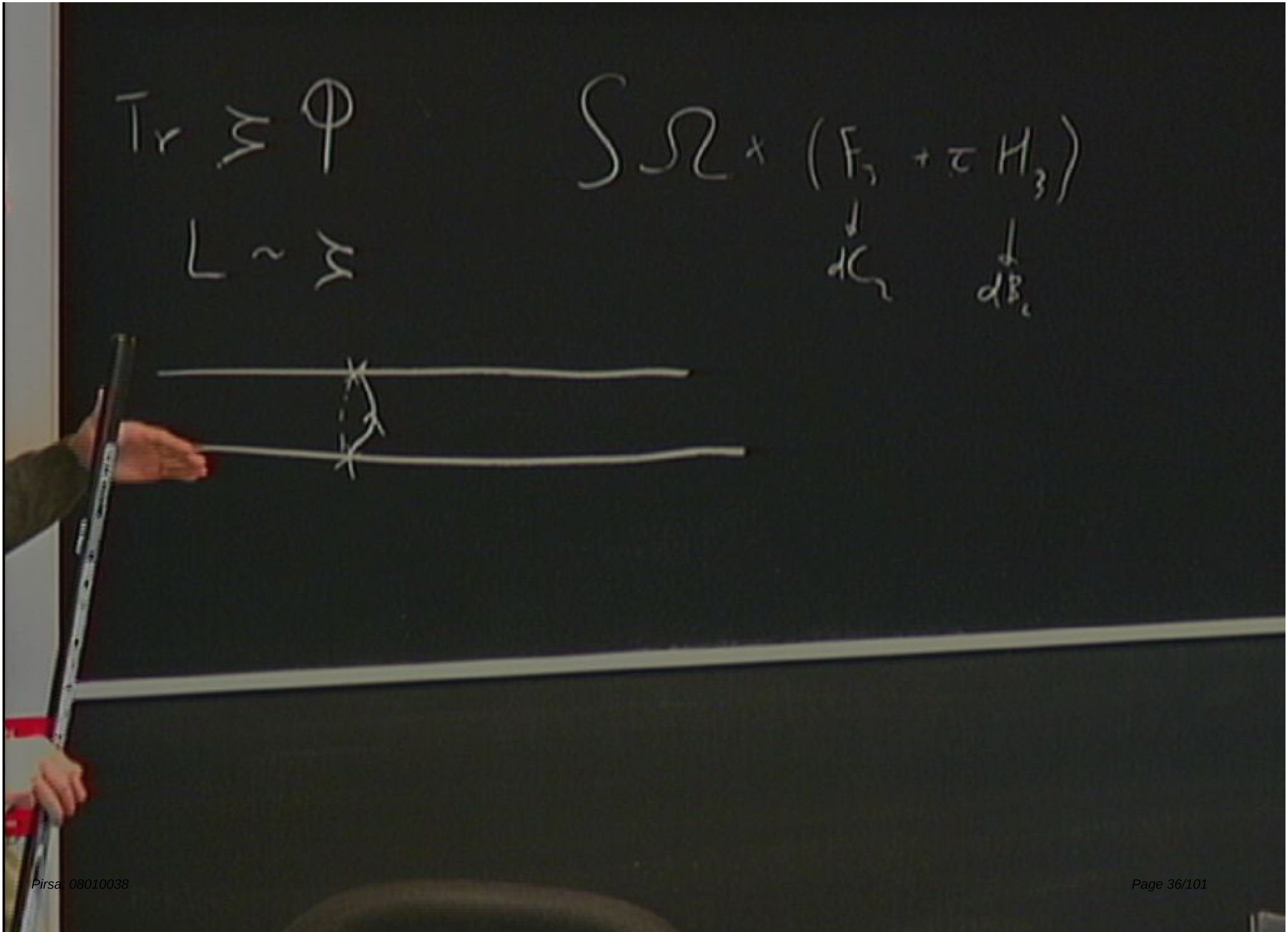

$\mathbb{C}^2/\mathbb{Z}_2 \times \mathbb{C}^1$
D1 & D5
D3


Tr
∫ Ω ∧ (F_3 + τ H_3)


$\mathrm{Tr}\, \xi\, \Phi$
$L \sim \xi$
$\int \Omega \wedge (F_3 + \tau H_3)$
dC_2
dB_2



∫ Ω ∧ (F₃ + τ H₃)
dC₂
dB₂
L ~ ξ


$Tr\, \xi\, \Phi$
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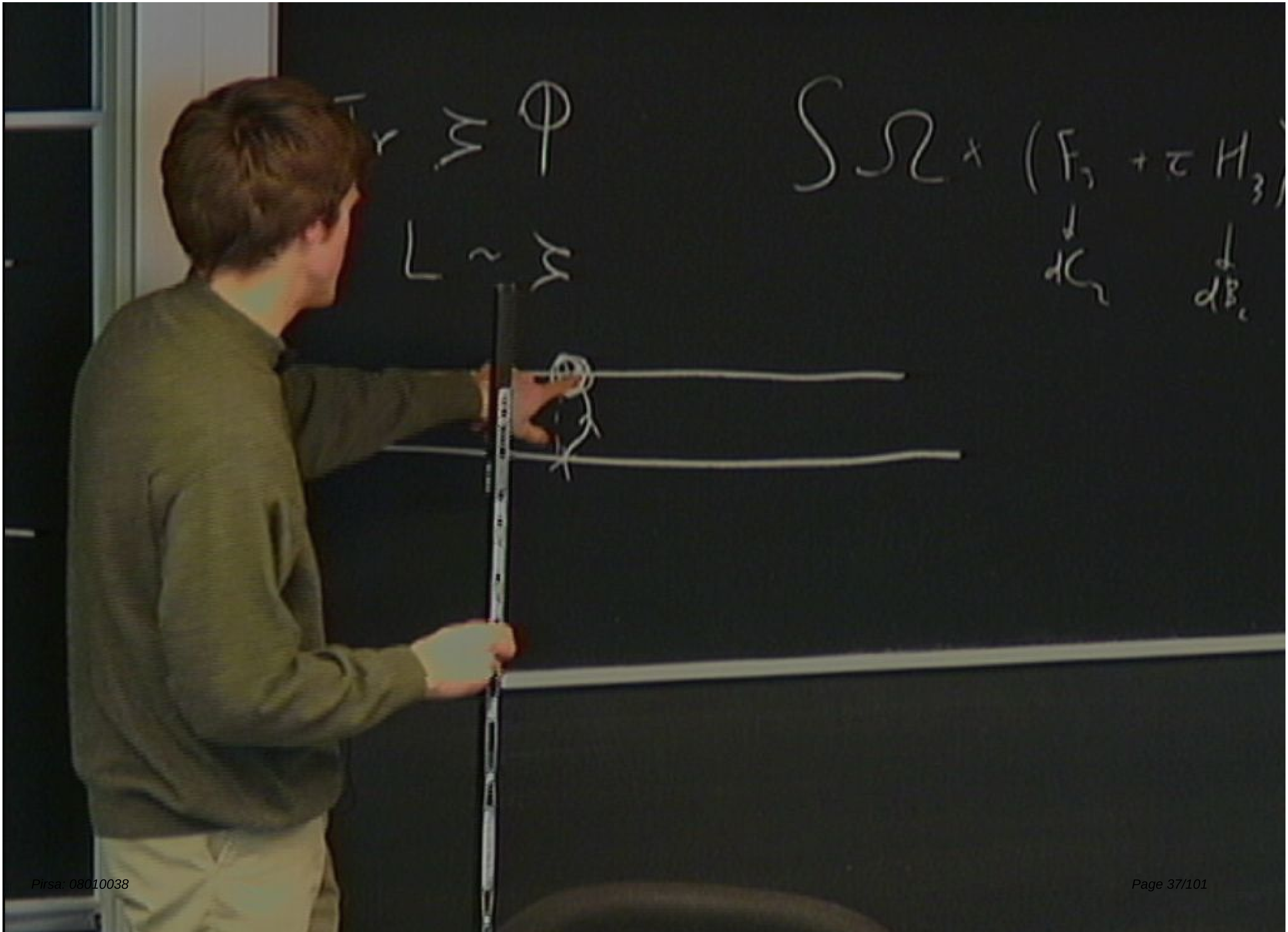

L ~ ξ
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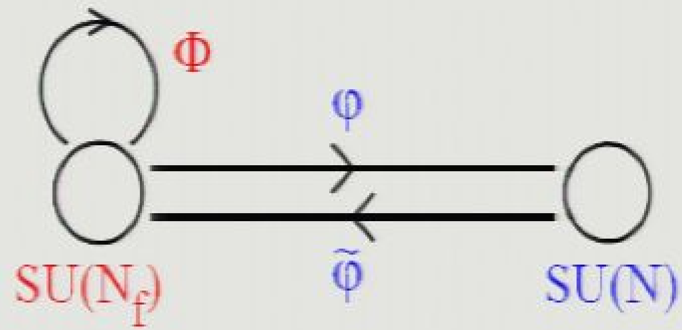
The ISS quiver



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Suspended Pinch Point singularity

The simplest suitable singularity is the Suspended Pinch Point (SPP) singularity.

This singularity is obtained by a deformation of the $\mathbb{C}^2/Z_3$ singularity. The equation of SPP singularity in $\mathbb{C}^4$ is

$$cd = a^2 b$$

It has a non-isolated $\mathbb{C}^2/Z_2$ singularity along $b \neq 0$. If we deform the $\mathbb{C}^2/Z_2$ singularity

$$cd = a(a - \zeta)b.$$

then we get two conifold singularities at $a = 0$ and $a = \zeta$.

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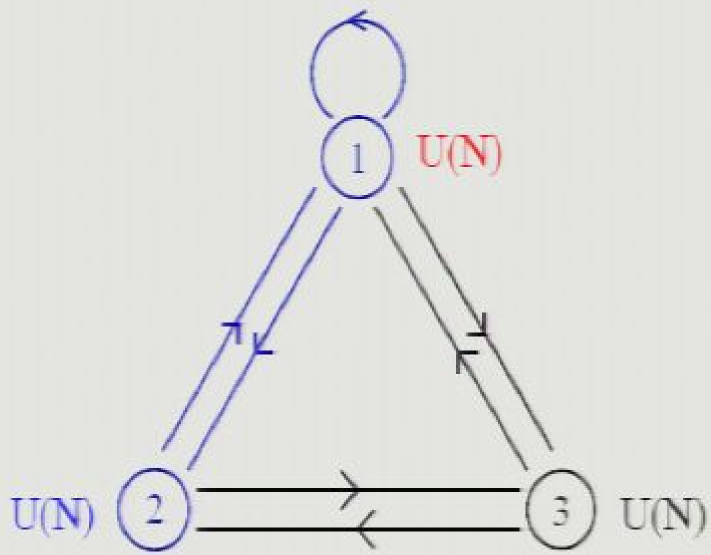
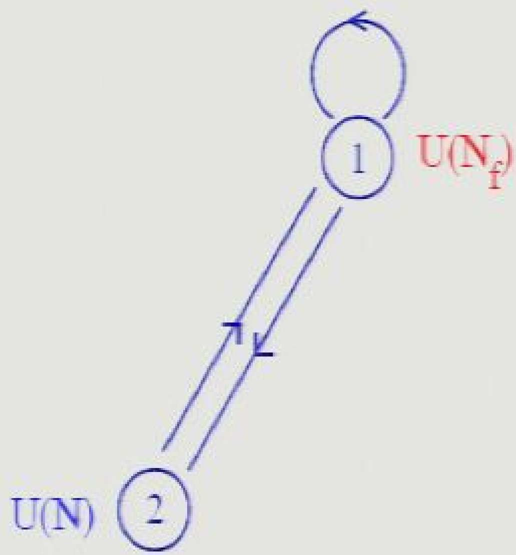


By adding the fractional branes to the SPP quiver we can obtain the ISS quiver.

The ISS quiver



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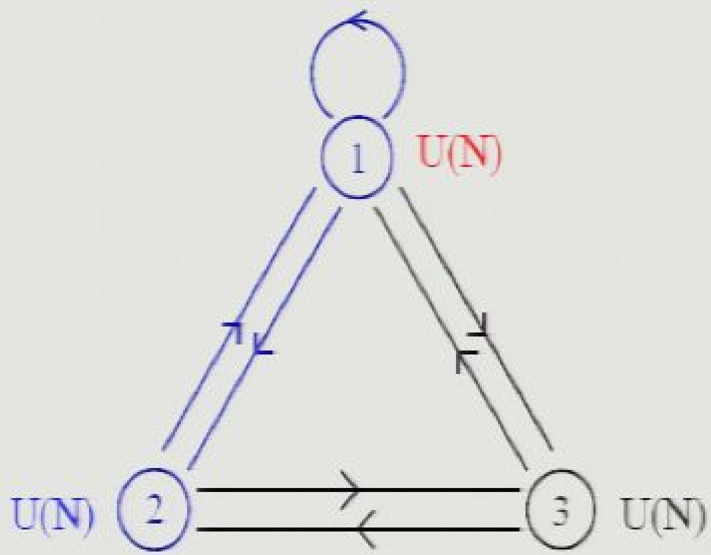

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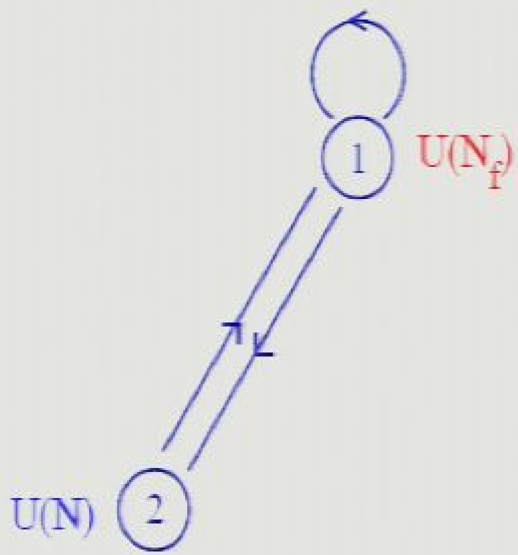

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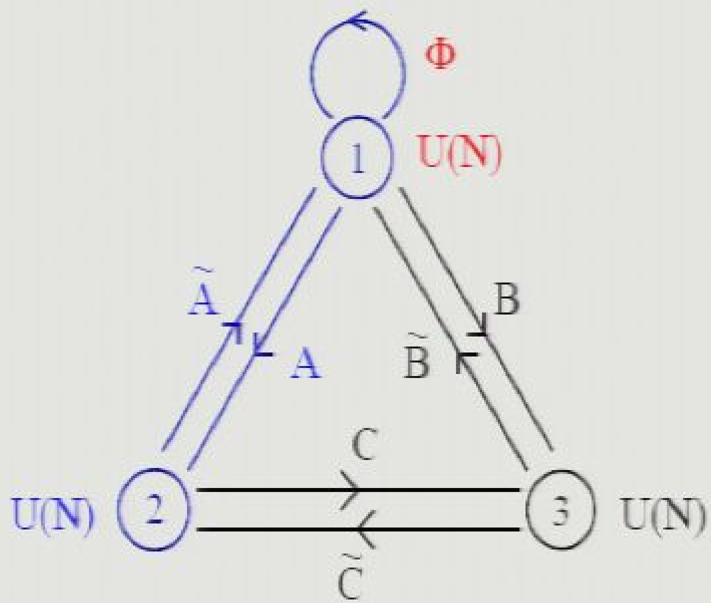
The SPP superpotential



The superpotential for N D3-branes at the SPP singularity (Morrison & Plesser '98)

$$W = \mathrm{Tr}\left(\Phi(A\tilde{A} - B\tilde{B}) + \lambda(\tilde{C}C\tilde{B}B - C\tilde{C}\tilde{A}A)\right)$$

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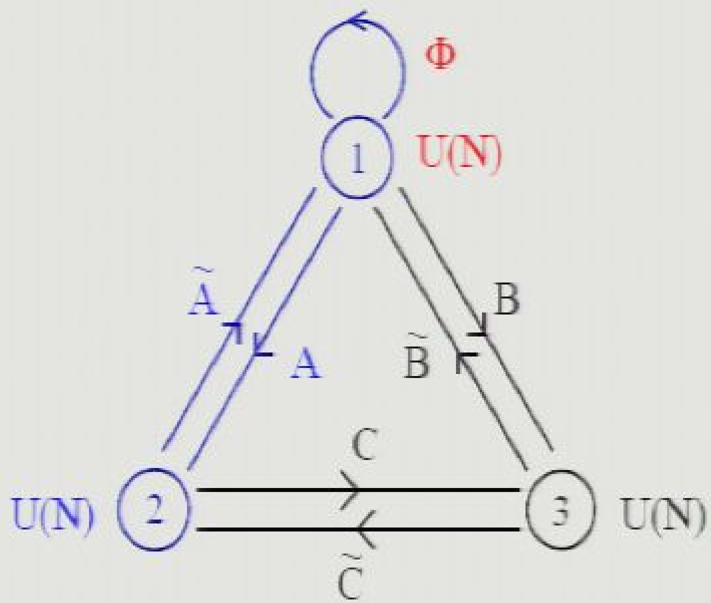

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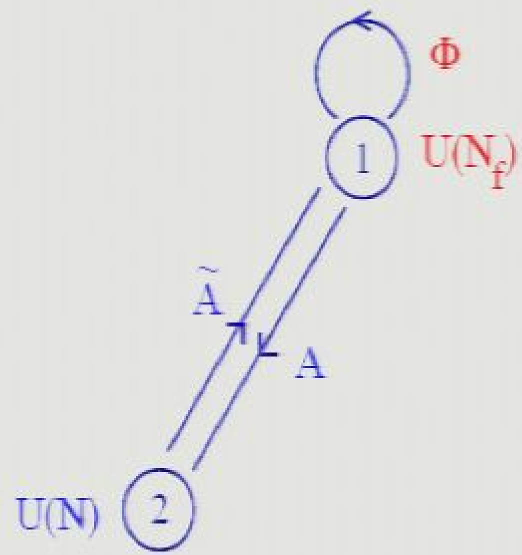
Almost ISS superpotential



The reduced SPP quiver theory is the (gauged) ISS model

$$W = \mathrm{Tr}\left(\Phi A \tilde{A}\right)$$

But the F-term is missing so far.

F-term for SPP singularity

We can add the following deformation of the SPP superpotential

$$\delta W = -\zeta \mathrm{Tr}(\Phi - \lambda \tilde{C} C)$$

it corresponds to the deformation of the $\mathbb{C}^2/Z_2$ singularity within the SPP.

Denote the gauge invariant combinations $a = \tilde{A}A$, $a' = \tilde{B}B$, $b = \tilde{C}C$, $c = \tilde{A}B\tilde{C}$, and $d = AC\tilde{B}$. Before the deformation the F-term equation for Φ sets $\tilde{A}A = \tilde{B}B$ and the fields satisfy the constraint $cd = a^2 b$. After the deformation $\tilde{A}A = \tilde{B}B + \zeta$ and the fields satisfy $cd = a(a-\zeta)b$ – the deformed SPP equation.

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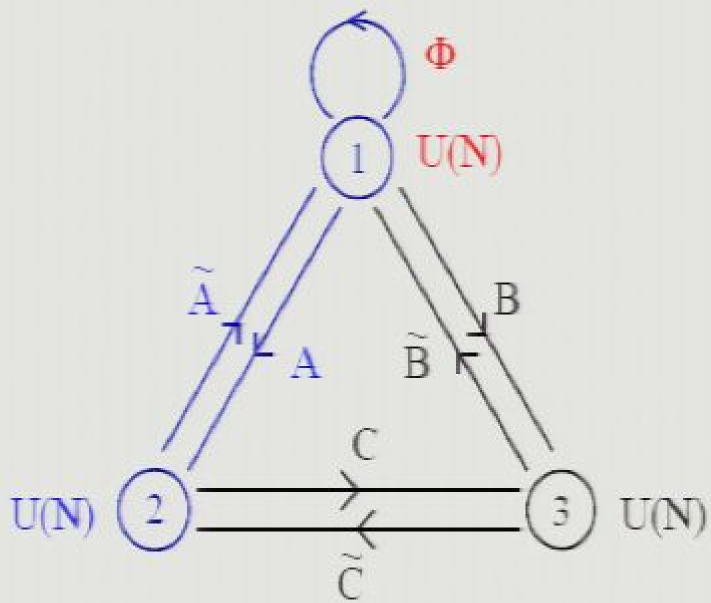

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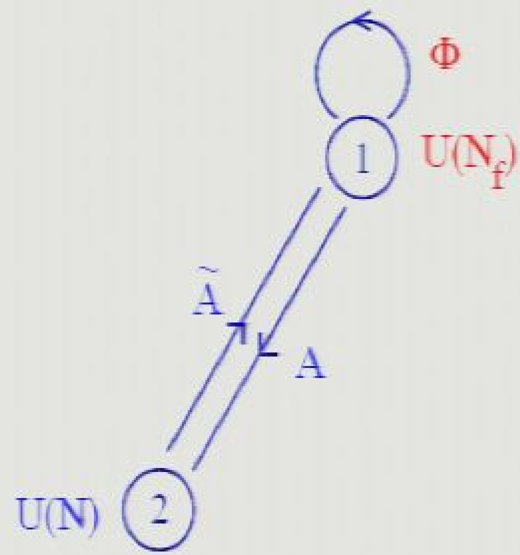

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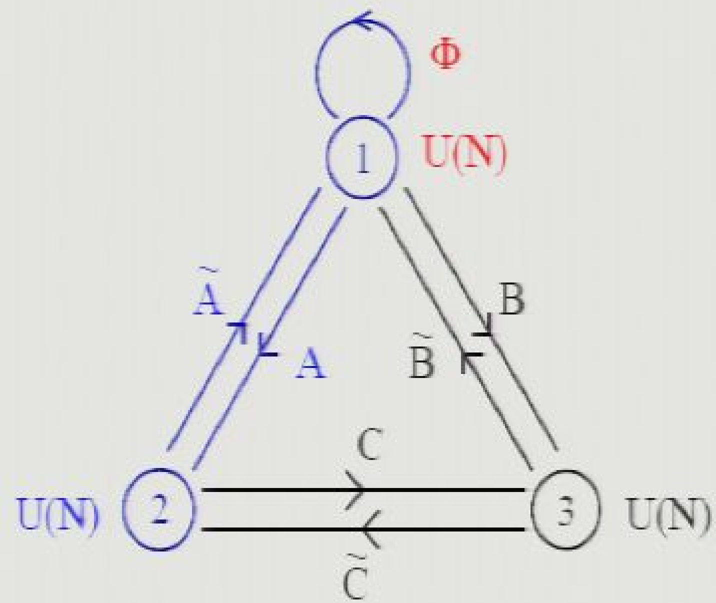

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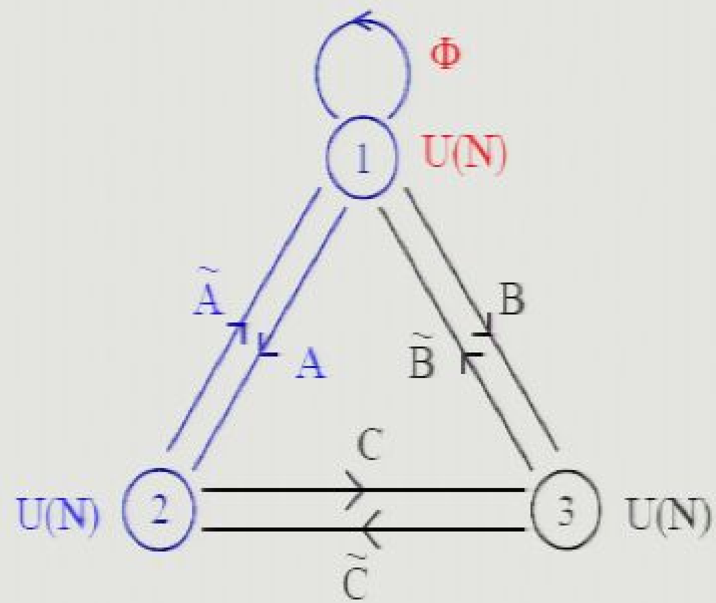

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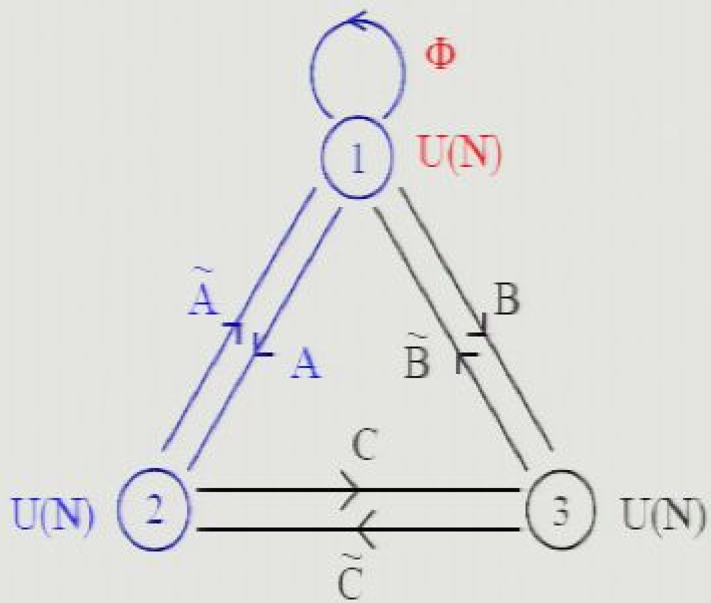

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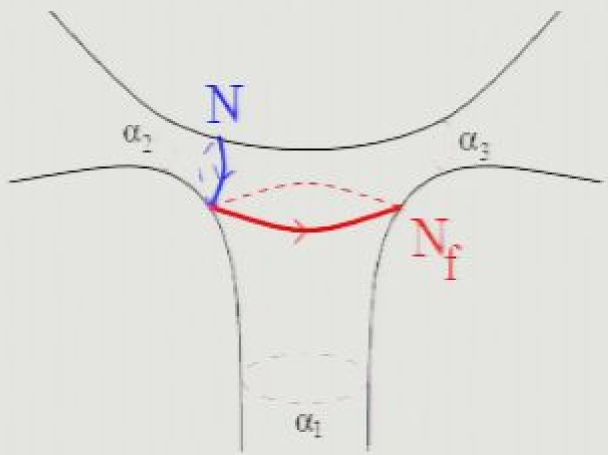
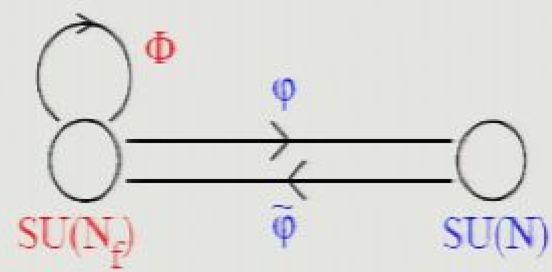
Geometry of gauged ISS model

Our basic claim is that the gauged ISS model is represented in type IIB theory by a set of fractional branes on a slightly deformed SPP singularity.





Here α_1 represents the two-cycle of the deformed Z_2 singularity and the α_2, α_3 cycles represent the two conifolds remaining after the deformation,

$\alpha_1 + \alpha_2 + \alpha_3 = 0.$

Structure of SUSY breaking vacuum

Near the vacuum the fields can be represented as

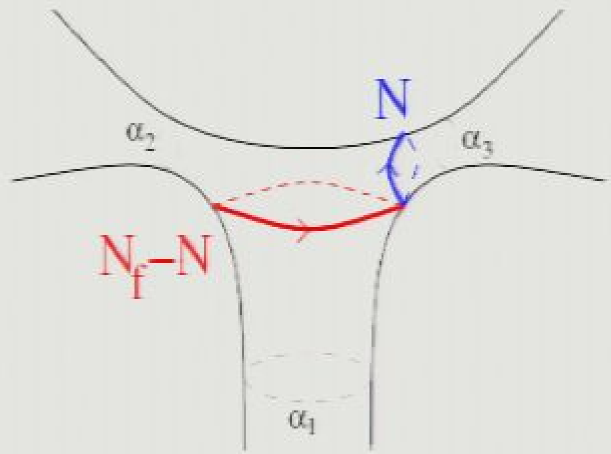
$$\Phi = \begin{pmatrix} Y & \tilde{Z} \\ Z & X \end{pmatrix} \qquad \varphi = \begin{pmatrix} \mu + \chi \\ \rho \end{pmatrix} \qquad \tilde{\varphi} = (\mu + \tilde{\chi} \quad \tilde{\rho})$$

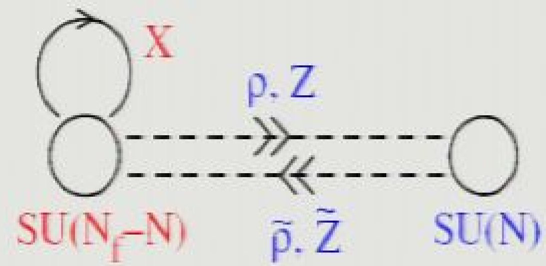
The blue fields are massive, the field X is a pseudo-modulus. Some combination of the χ fields is a pseudo-modulus too. It is massive if we gauge the flavor group $SU(N_f)$. The superpotential near this vacuum is an O'Raifeartaigh type model

$$W = h\mathrm{Tr}(\tilde{\rho}X\rho + \mu\tilde{Z}\rho + \mu\tilde{\rho}Z - \mu^2 X) + \ldots$$

the dots denote extra fields and interactions.

Geometry of SUSY breaking

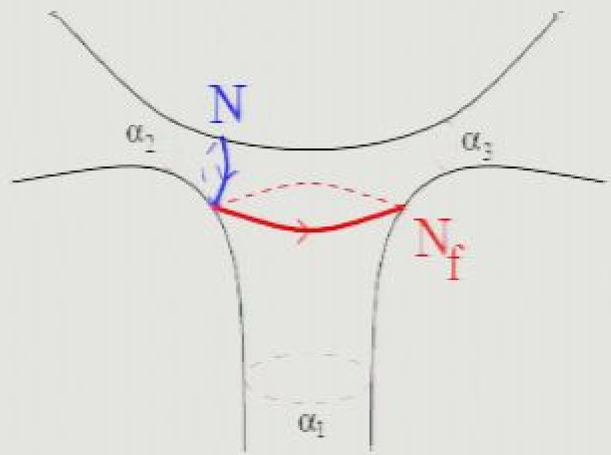


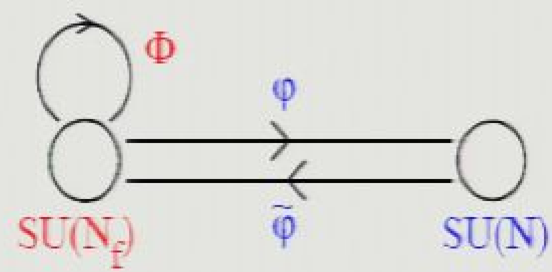


The fractional D-branes on α_1, the deformed cycle of Z_2 singularity, have a non-zero volume. In order to reduce their volume, N D-branes annihilate with N D-branes on α_2 to produce N D-branes wrapping $-\alpha_3$. The remaining $(N_f - N)$ D-branes on α_1 make up the vacuum energy that breaks SUSY.

Geometry of gauged ISS model

Our basic claim is that the gauged ISS model is represented in type IIB theory by a set of fractional branes on a slightly deformed SPP singularity.





Here α_1 represents the two-cycle of the deformed Z_2 singularity and the α_2, α_3 cycles represent the two conifolds remaining after the deformation,

$\alpha_1 + \alpha_2 + \alpha_3 = 0.$

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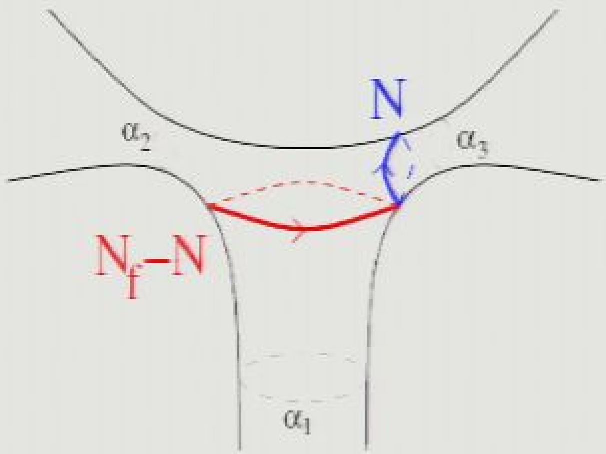

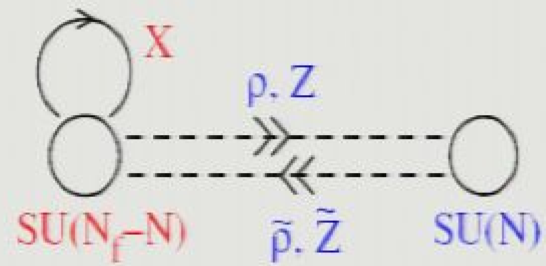

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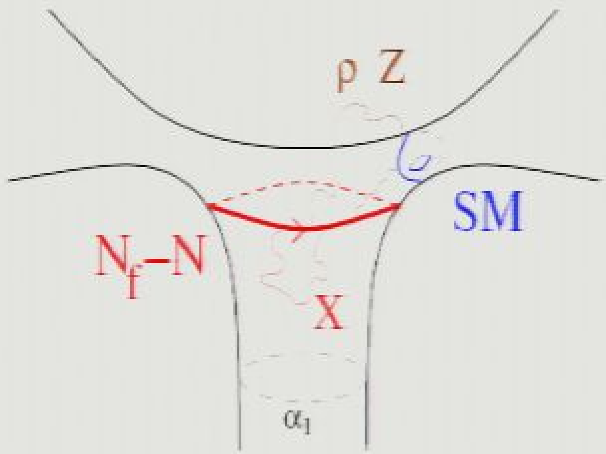
The dictionary

Field theory	Geometry
F-term $\zeta \mathrm{Tr}\Phi$	deformation $cd = a(a-\zeta)b$ of SPP
vevs of bifundamental fields	"annihilation" of fractional D-branes
flat direction for adjoint X field	motion of $(N_f - N)$ D-branes along the deformed Z_2 cycle
F-term vacuum energy $(N_f - N)\lvert\zeta\rvert^2$	tension of $(N_f - N)$ D-branes on a two-cycle of size ζ

Gauge mediation of ISS



The general geometrical prescription can be used to mediate the F-term SUSY breaking to the Standard Model. We just need to engineer a geometry with a slightly deformed non-isolated singularity passing through an isolated singularity that reproduces the Standard Model.

R-symmetry and SUSY breaking

In conventional gauge mediation SUSY breaking is transmitted through the masses of mediators

$$W = \mathcal{M}\varphi\tilde{\varphi}. \qquad \mathcal{M} = M + \theta^2 F$$

"Mass matrix" $\mathcal{M}$ is a field overlapping with the goldstino. Usually it is assumed that non-zero F breaks both supersymmetry and R-symmetry.

In ISS the field X plays the role of $\mathcal{M}$. However $R(X) = 2$ and $R(F_X) = 0$, i.e. the non-zero F-term doesn't break R-symmetry. Moreover the existence of an R-symmetry is a general property of F-term SUSY breaking.

Gaugino masses and R-symmetry

The gaugino mass term breaks the R-symmetry

$$V = m\lambda\lambda$$

since $R(\lambda) = 1$. Thus in order to generate the gaugino masses perturbatively, one needs to break the R-symmetry. The gauginos lighter than about $100GeV$ are ruled out by experiments.

On the other hand, in order to avoid fine tuning in generating the electro-weak scale, it is assumed that the stop mass is of the order of several hundred GeV. Thus, R-symmetry should be broken at approximately the same scale as SUSY breaking.

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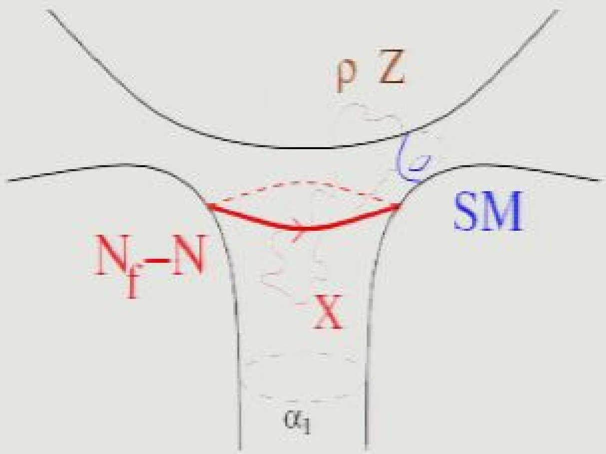

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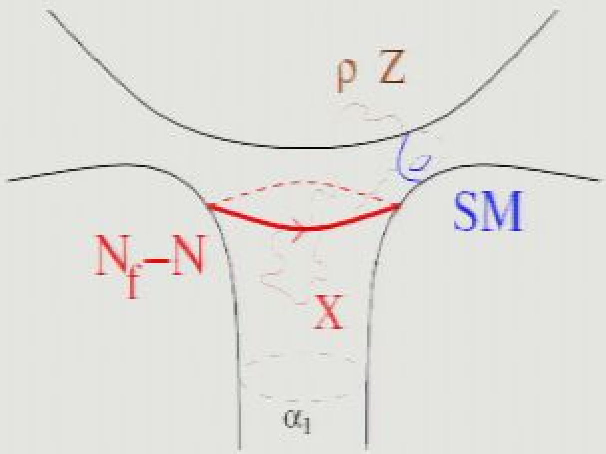

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Structure of SUSY breaking vacuum

Near the vacuum the fields can be represented as

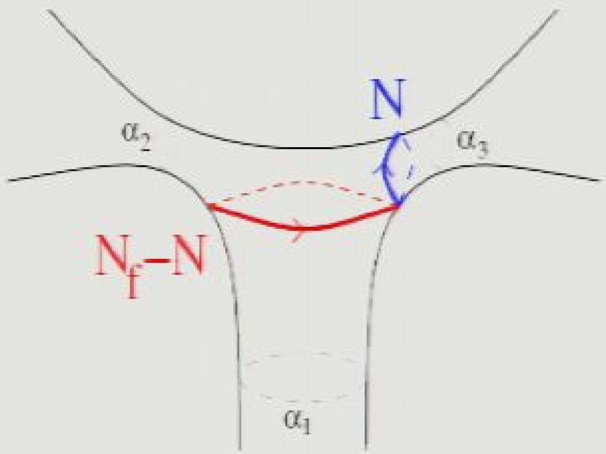
$$\Phi = \begin{pmatrix} Y & \tilde{Z} \\ Z & X \end{pmatrix} \qquad \varphi = \begin{pmatrix} \mu + \chi \\ \rho \end{pmatrix} \qquad \tilde{\varphi} = (\mu + \tilde{\chi} \quad \tilde{\rho})$$

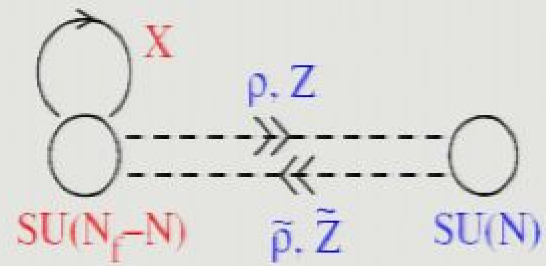
The blue fields are massive, the field X is a pseudo-modulus. Some combination of the χ fields is a pseudo-modulus too. It is massive if we gauge the flavor group $SU(N_f)$. The superpotential near this vacuum is an O'Raifeartaigh type model

$$W = h\mathrm{Tr}(\tilde{\rho} X \rho + \mu \tilde{Z} \rho + \mu \tilde{\rho} Z - \mu^2 X) + \ldots$$

the dots denote extra fields and interactions.

Geometry of SUSY breaking





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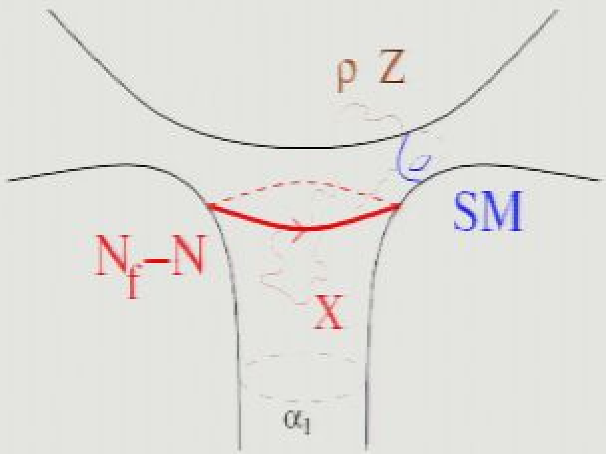

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The contradiction and possible solution

The need to break both SUSY and R-symmetry at approximately the same scale poses a contradiction for the F-type of SUSY breaking since the breaking of R-symmetry generically restores SUSY.

- In general, the scale of explicit R-symmetry breaking should be smaller than the one-loop mass of the pseudo-modulus.
- However it it possible that small explicit R-symmetry breaking induces a large spontaneous breaking that doesn't destabilize the vacuum.

Mass deformation of ISS model

Consider the mass deformation of ISS model

$$W = h\mathrm{Tr}(\tilde{\varphi}\Phi\varphi) - h\mu^2\mathrm{Tr}\Phi + \frac{1}{2}hm\Phi^2$$

in order to preserve metastability, we assume that $m \ll \mu$.

The deformation affects the pseudo-modulus X. The one-loop potential is

$$V(X) = h^2|mX - \mu^2|^2 + m_{1l}^2|X|^2.$$

where m_{1l} is the one-loop mass for X.

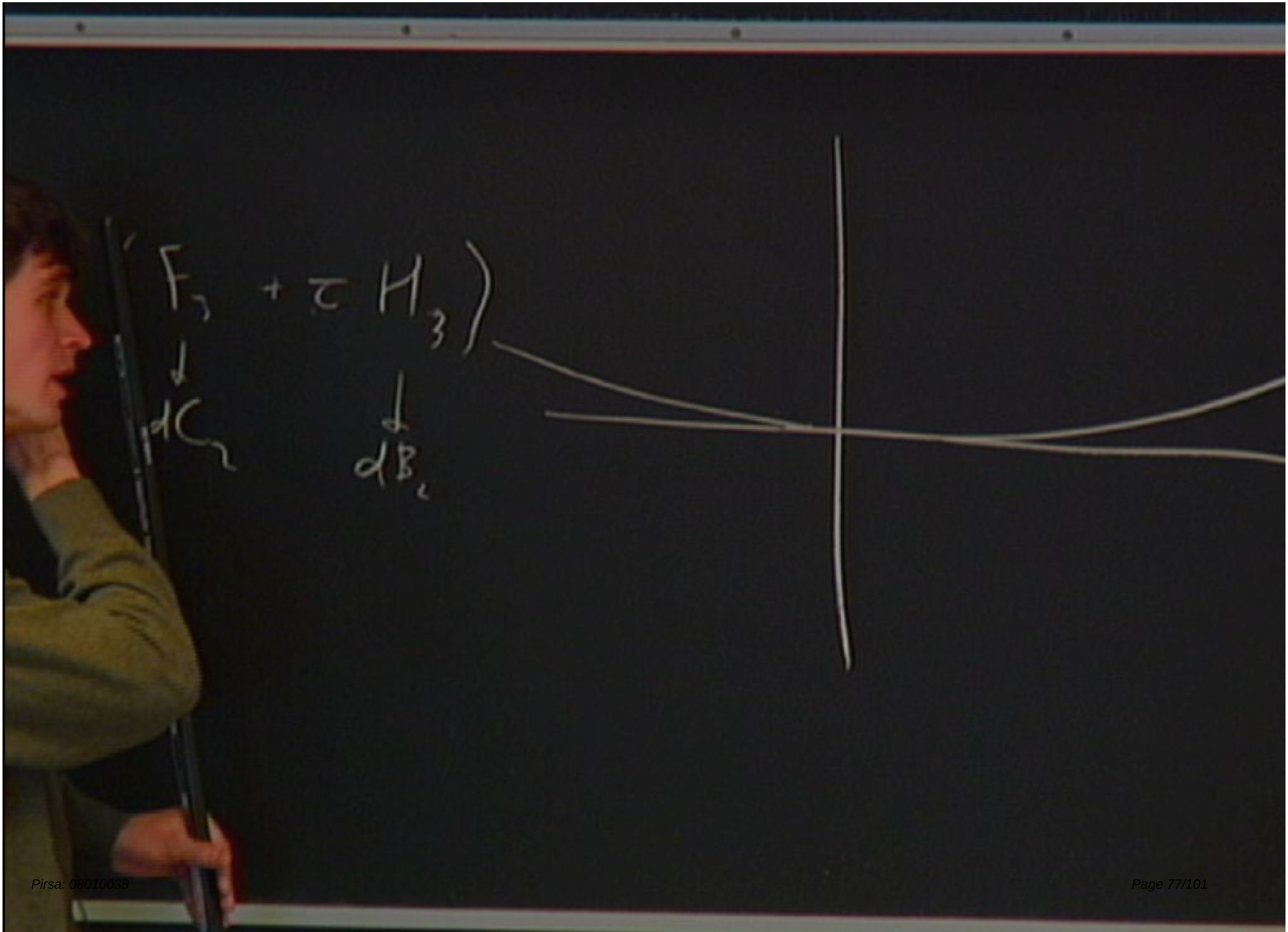
R-symmetry breaking minimum

The new minimum is at

$$X = \frac{h^2 m \mu^2}{m_{1l}^2}$$

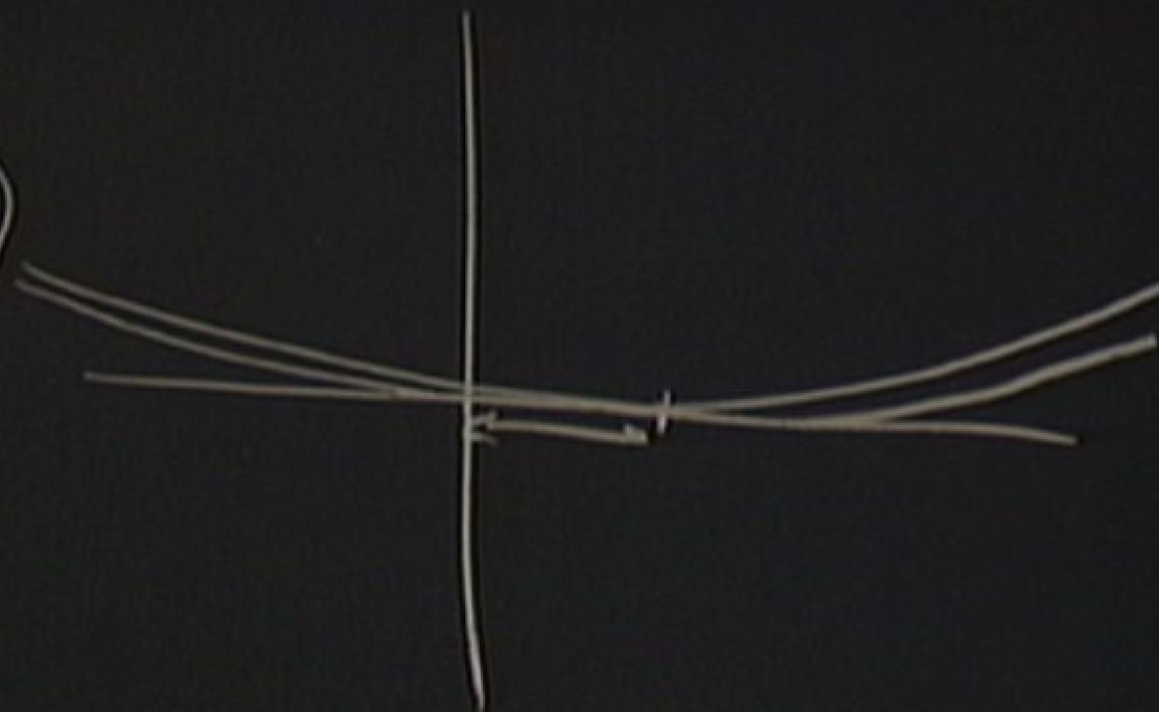
For $m \sim m_{1l}^2/h^2\mu$ we have $X \sim \mu$. Note that in this case $m \ll m_{1l}$ and $X \ll \mu^2/m$, i.e. the new vacuum is metastable and far away from the SUSY restoring vacuum.

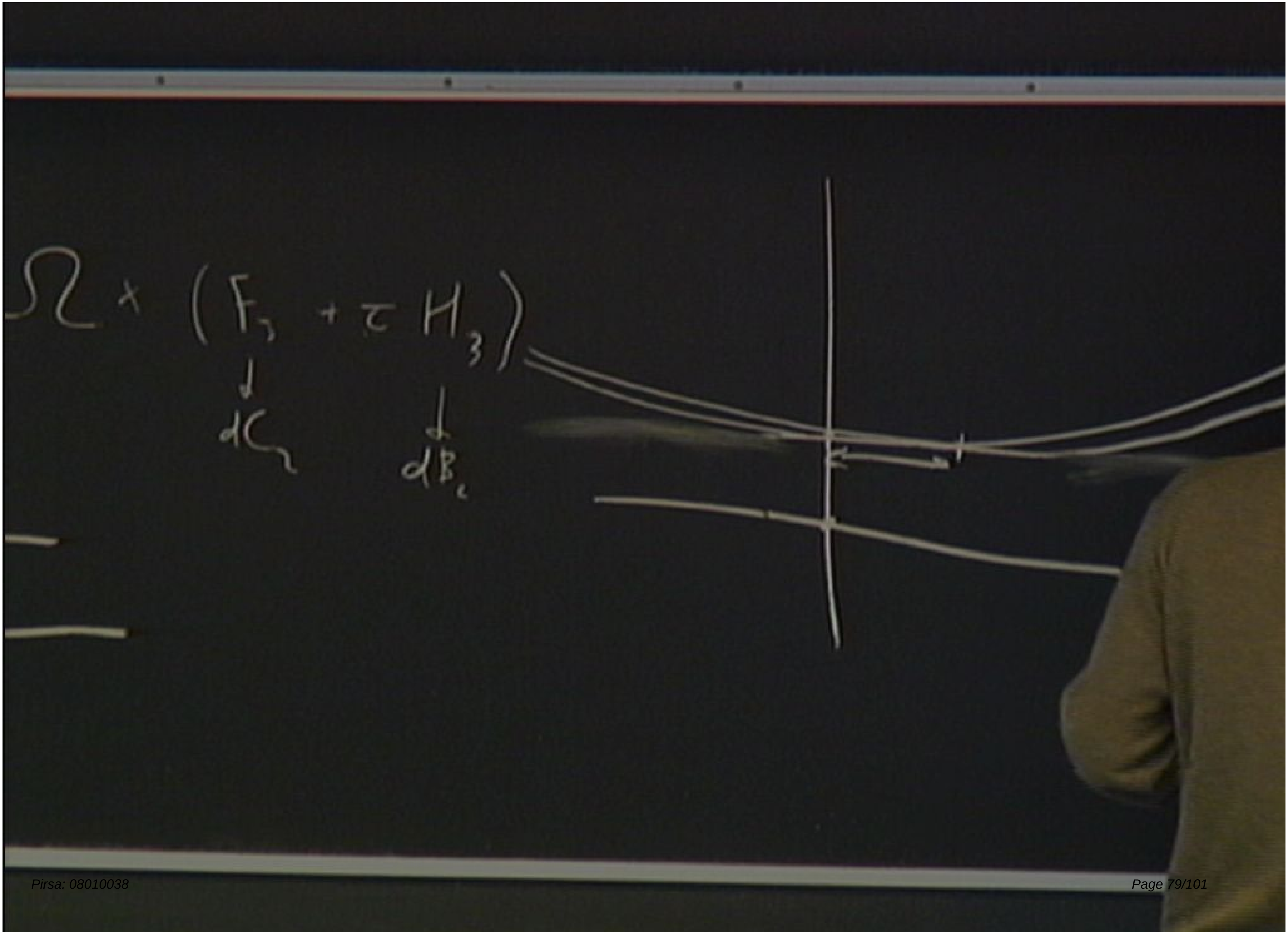
In this example the small mass deformation m that breaks R-symmetry explicitly induces a large vev for X that breaks the R-symmetry spontaneously.

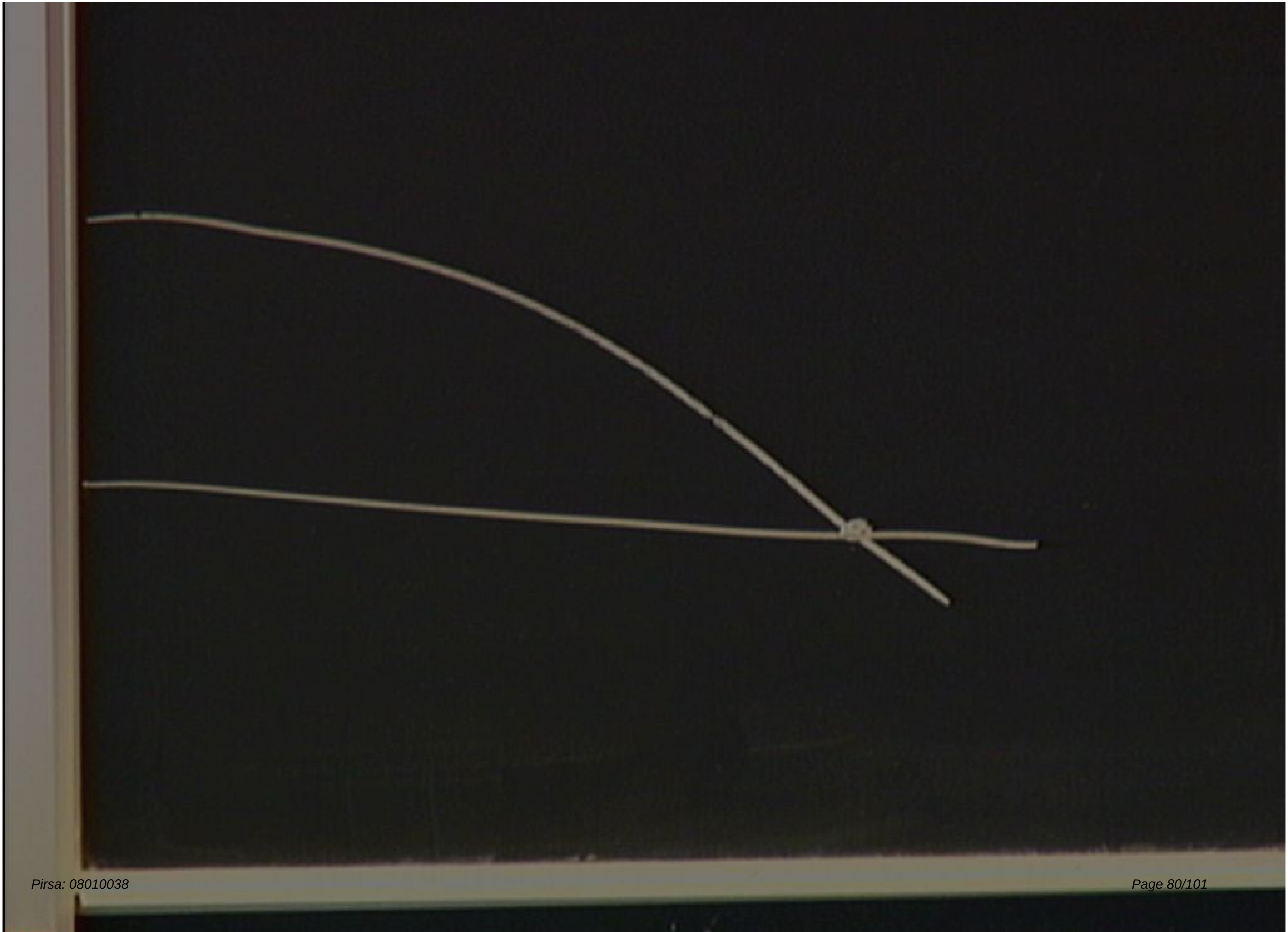

(F_3 + τ H_3)
dC_2
dB_2

$$\int \Omega \wedge (F_3 + \tau H_3)$$

$$F_3 \downarrow dC_2 \qquad H_3 \downarrow dB_2$$




Ω × (F3 + τ H3)
dC2
dB2



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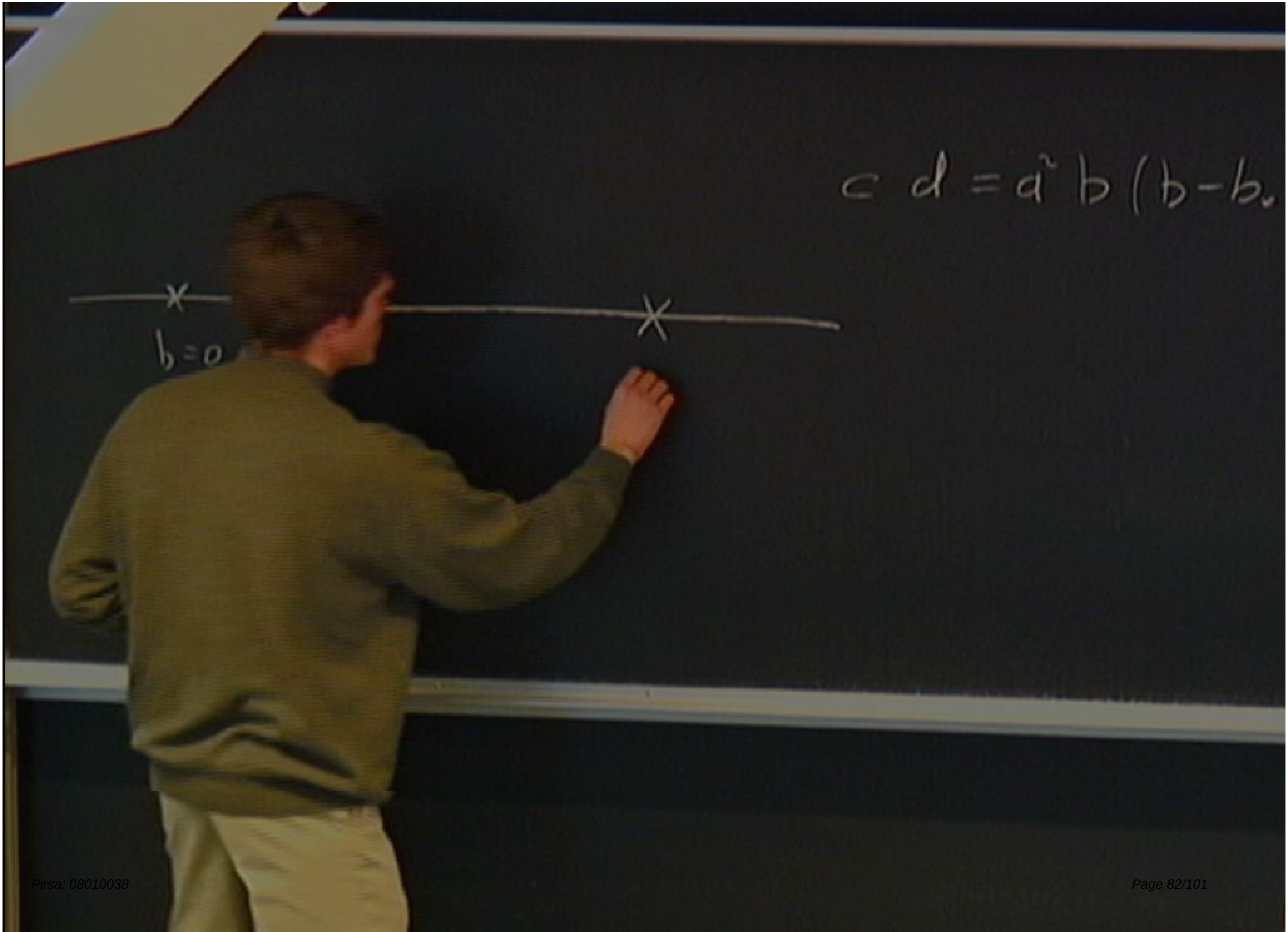
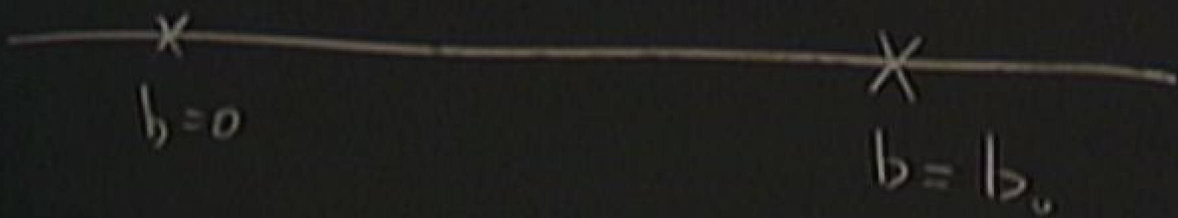
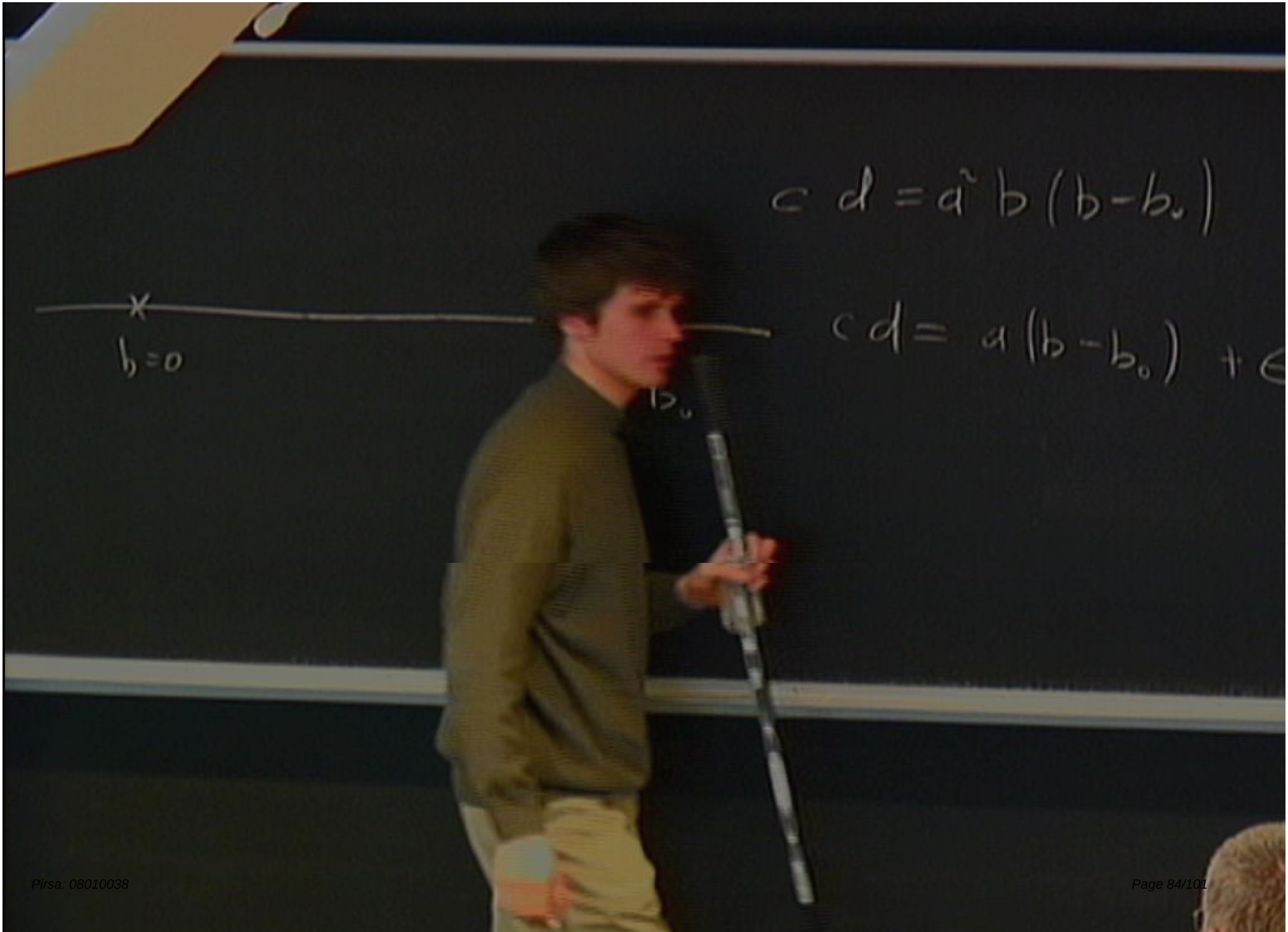
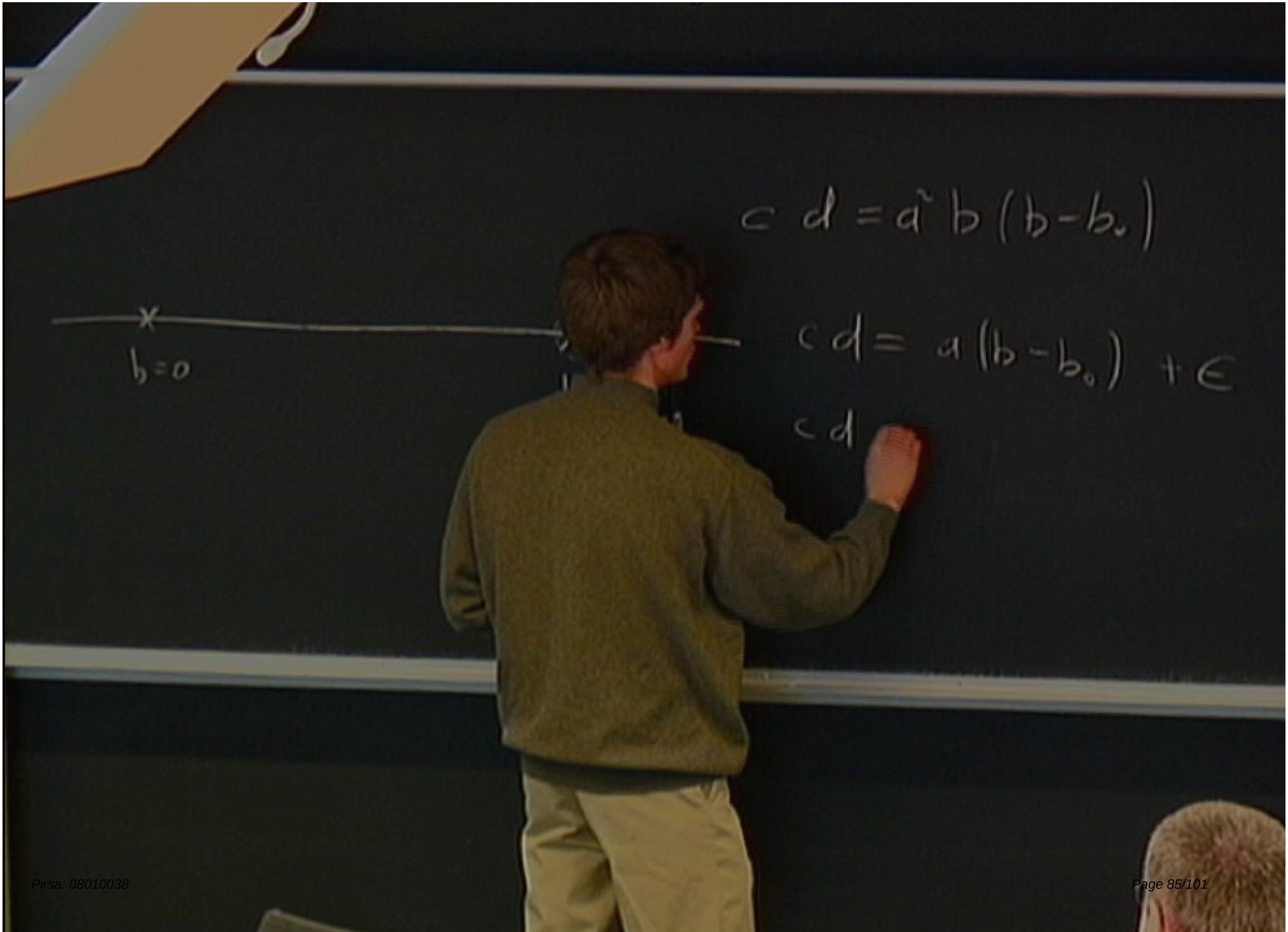
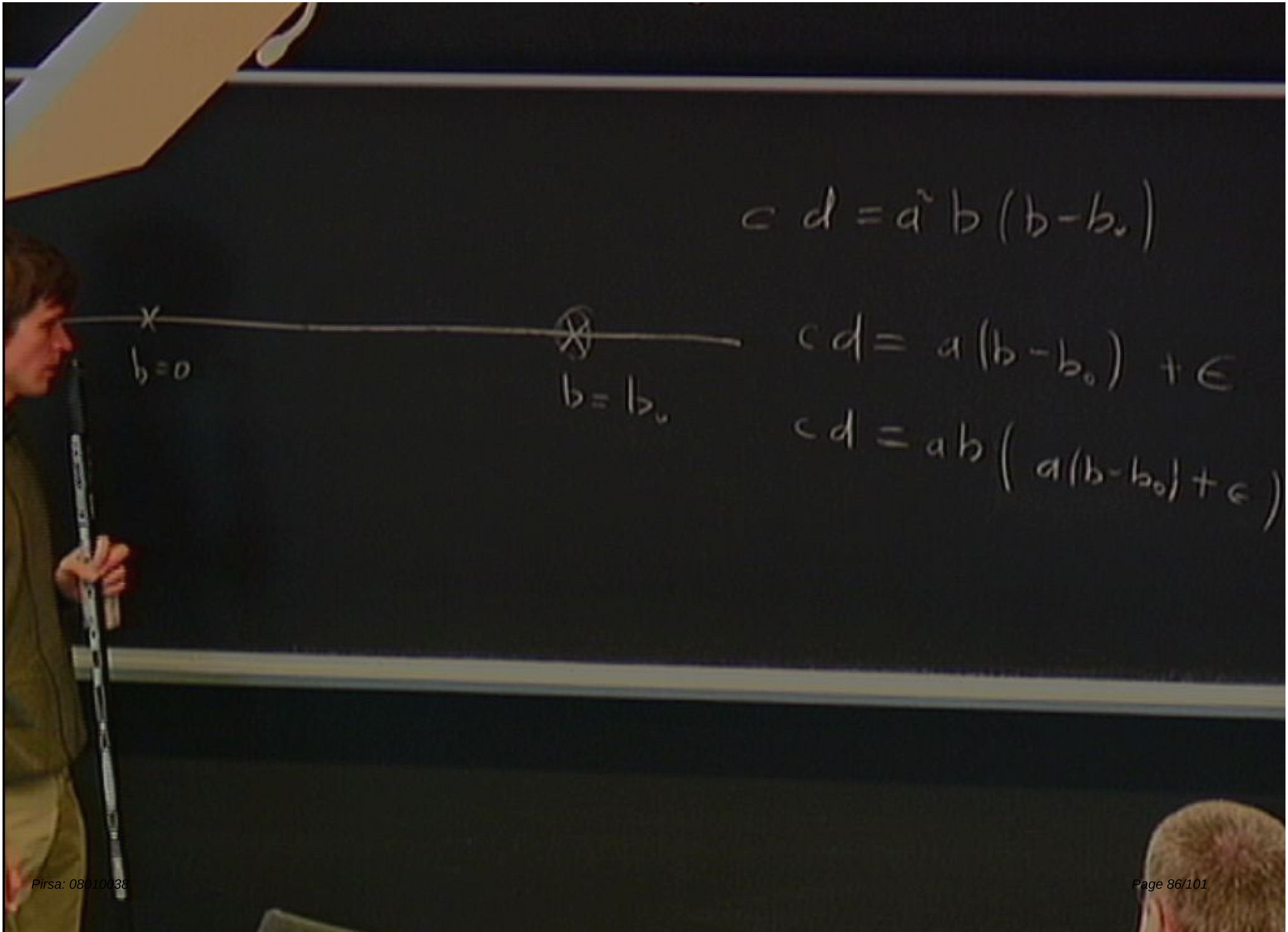

c d = a² b (b - b₀
b=0

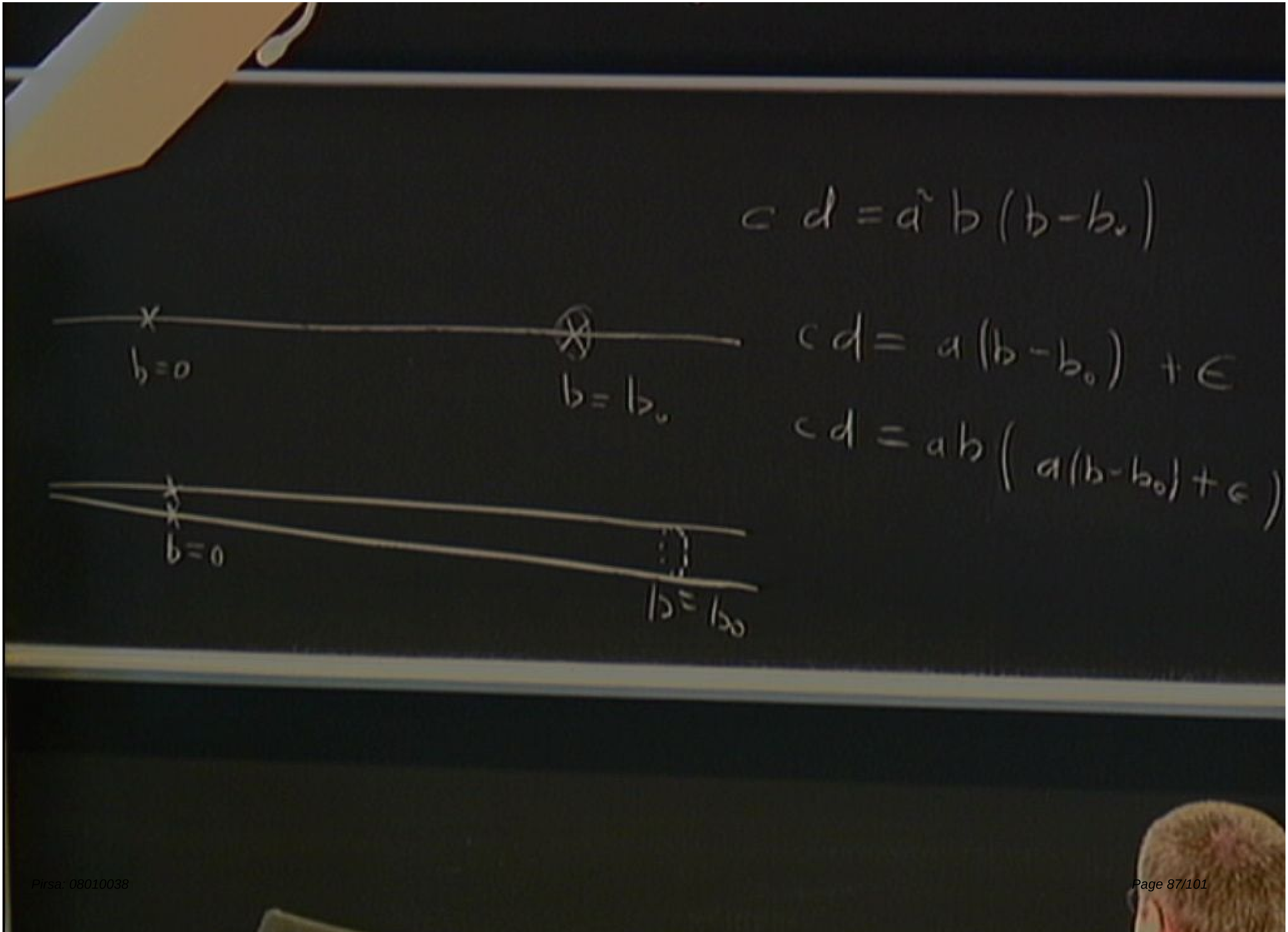
$$c\,d = a^2\, b\,(b - b_0)$$

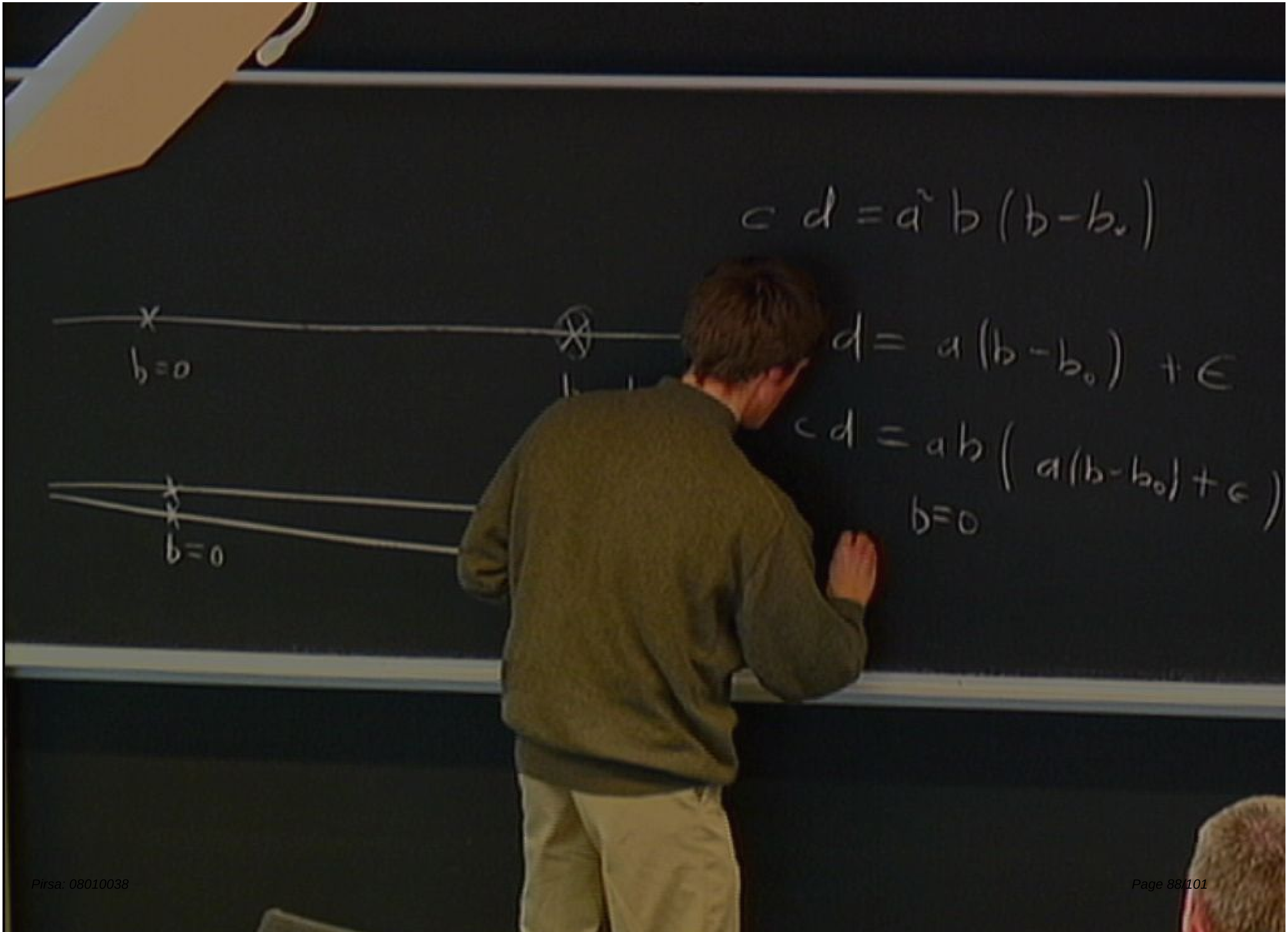


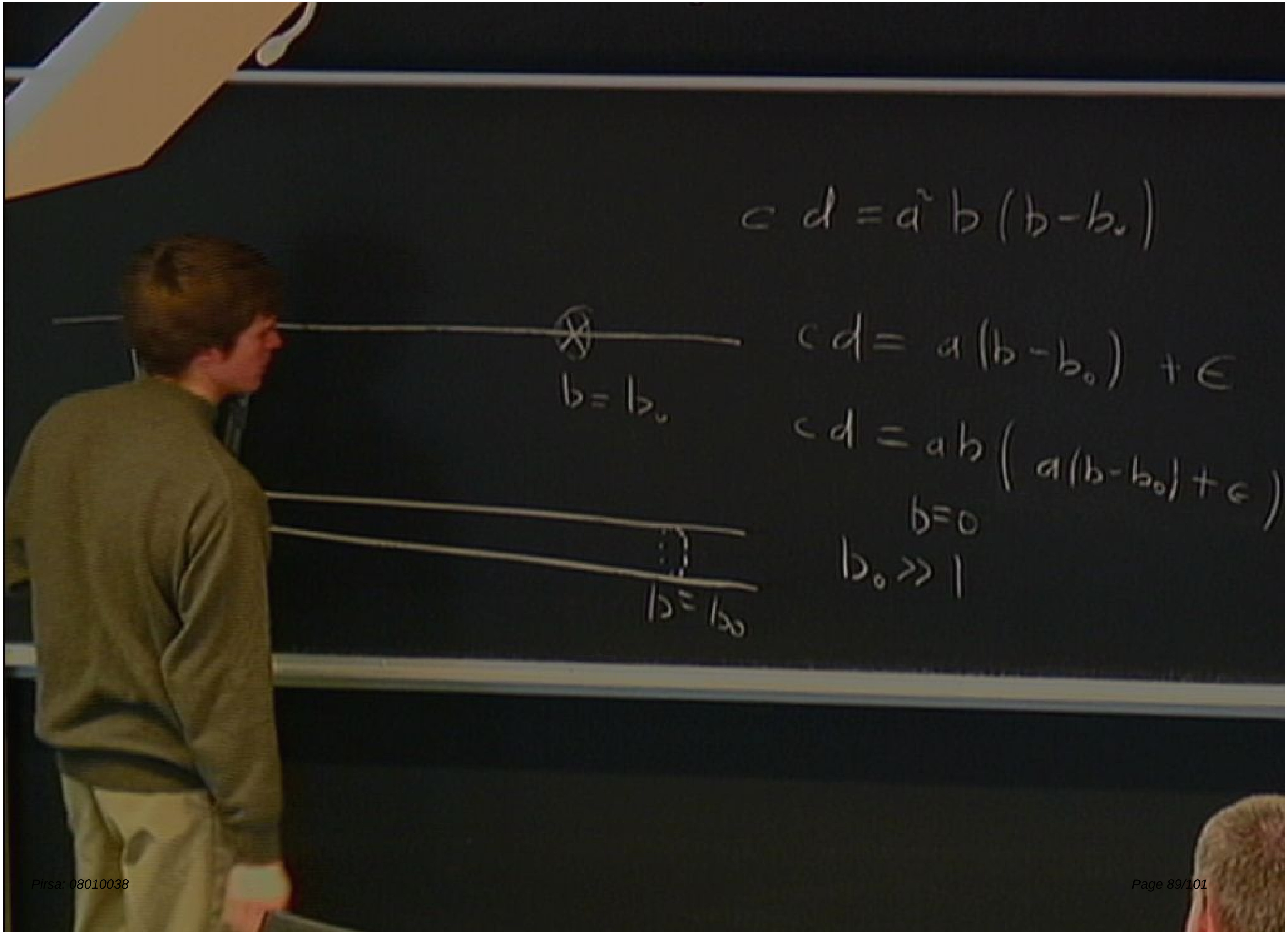

c d = a² b (b − b₀)
c d = a (b − b₀) + ϵ
b = 0
b₀

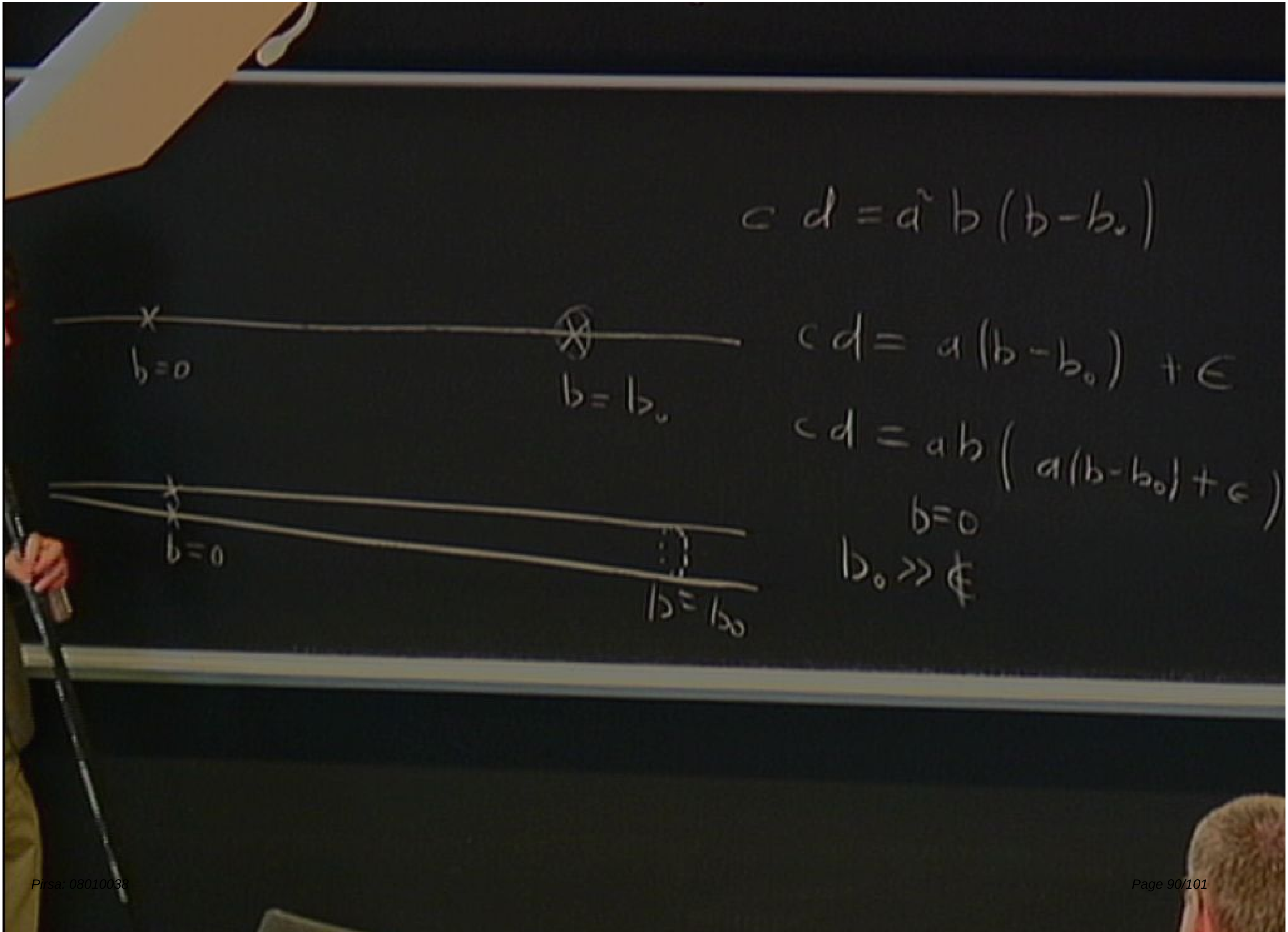

c d = a b (b - b₀)
c d = a (b - b₀) + ∈
c d
b = 0

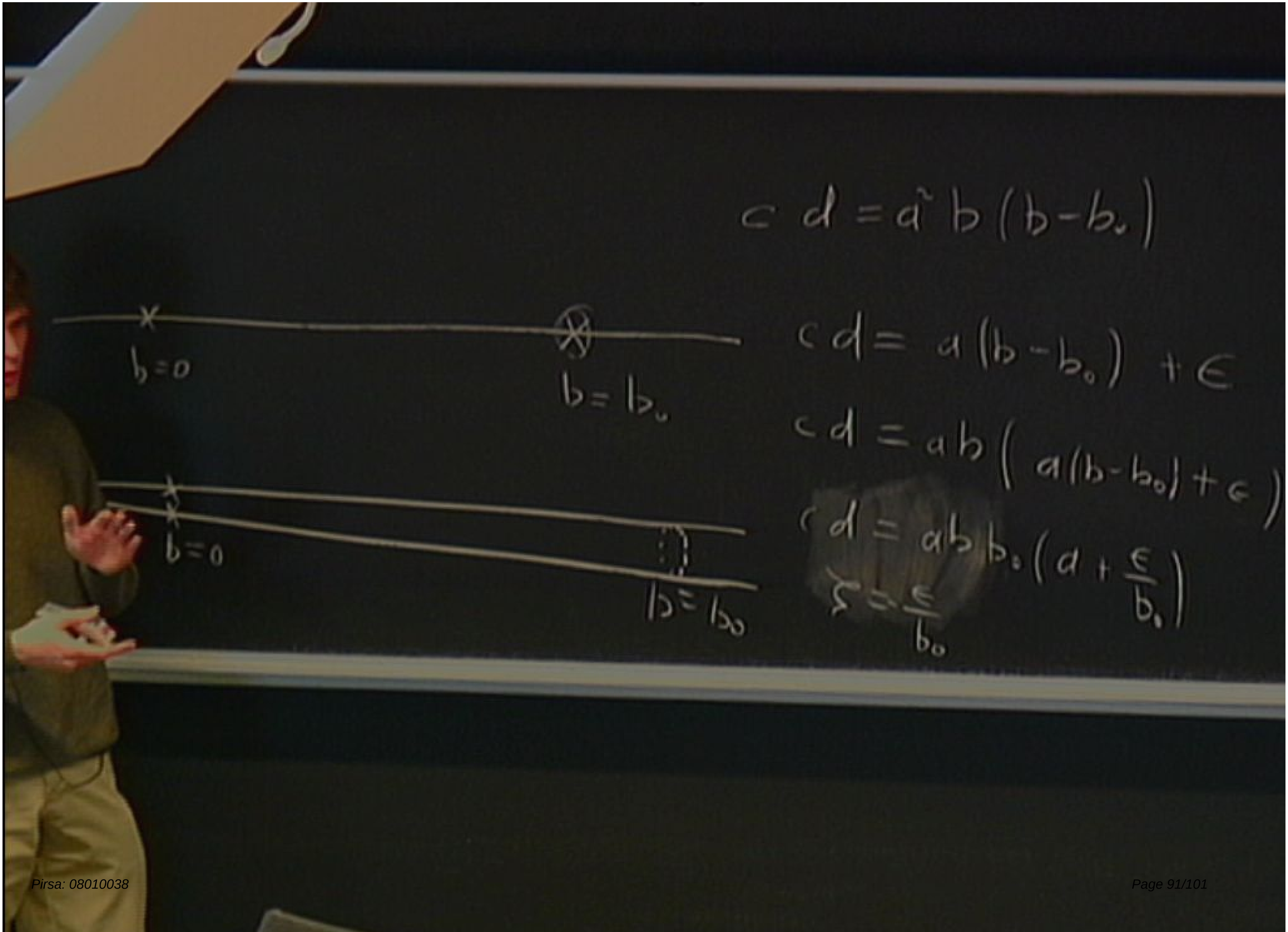

$c\,d = a^2 b\,(b - b_0)$
$b=0$
$b=b_0$
$c\,d = a\,(b - b_0) + \epsilon$
$c\,d = a\,b\,(\,a(b - b_0) + \epsilon\,)$


c d = a² b (b - b₀)
c d = a (b - b₀) + ε
c d = a b (a (b - b₀) + ε)
b = 0
b = b₀
b = 0
b = b₀


c d = a² b (b - b₀)
d = a (b - b₀) + ε
c d = a b (a (b - b₀) + ε)
b=0
b=0
b=0


c d = a² b (b - b₀)
c d = a (b - b₀) + ε
b = b₀
c d = a b (a (b - b₀) + ε)
b = 0
b₀ >> 1
b = b₀


c d = a^2 b (b - b_0)
b=0
b= b_0
cd = a (b - b_0) + ε
c d = a b (a(b - b_0) + ε)
b=0
b_0 >> ε
b=0
b= b_0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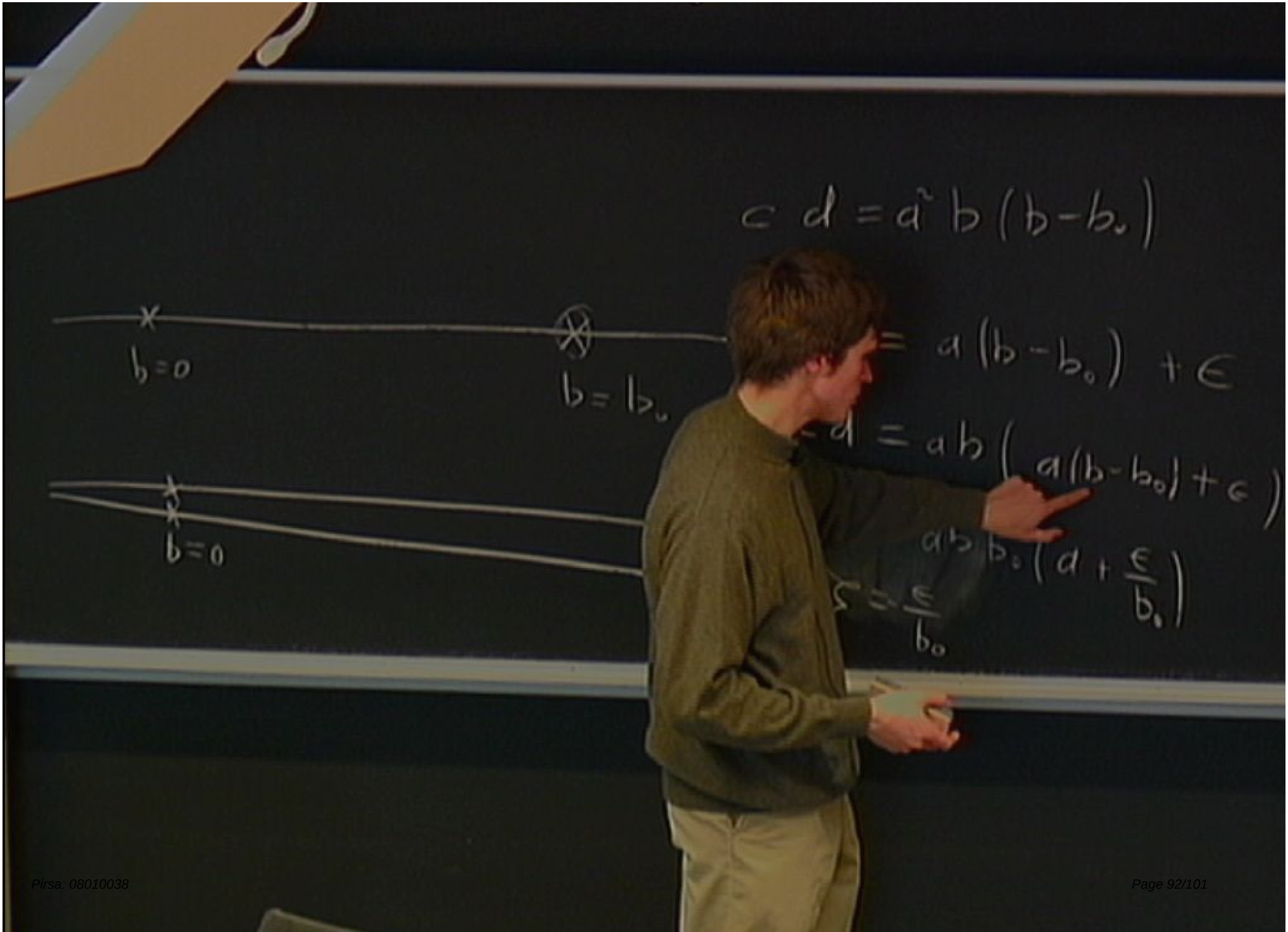
$c\,d = a b (a(b - b_0) + \epsilon)$
$c\,d = a b b_0 (a + \frac{\epsilon}{b_0})$
$\xi = \frac{\epsilon}{b_0}$
$b = 0$
$b = b_0$
$b = 0$
$b = b_0$


c d = a² b (b − b₀)
b=0
b = b₀
= a (b − b₀) + ε
d = a b (a(b − b₀) + ε)
a b b₀ (d + ε/b₀)
b=0
= ε/b₀

$$cd = a^2 b (b - b_0)$$

$$cd = a(b - b_0) + \epsilon$$

$$cd = ab\left(a(b - b_0) + \epsilon \right)$$

$$cd = ab\, b_0 \left(a + \frac{\epsilon}{b_0} \right)$$

$$\xi = \frac{\epsilon}{b_0}$$

Why stringy ISS?

Advantages:

- dynamical generation of SUSY breaking
- simple geometrical interpretation – a plus for model building
- possibility of extension beyond small coupling

Future directions:

- dynamical R-symmetry breaking
- geometric proof of meta-stability (large coupling, AdS/CFT?)

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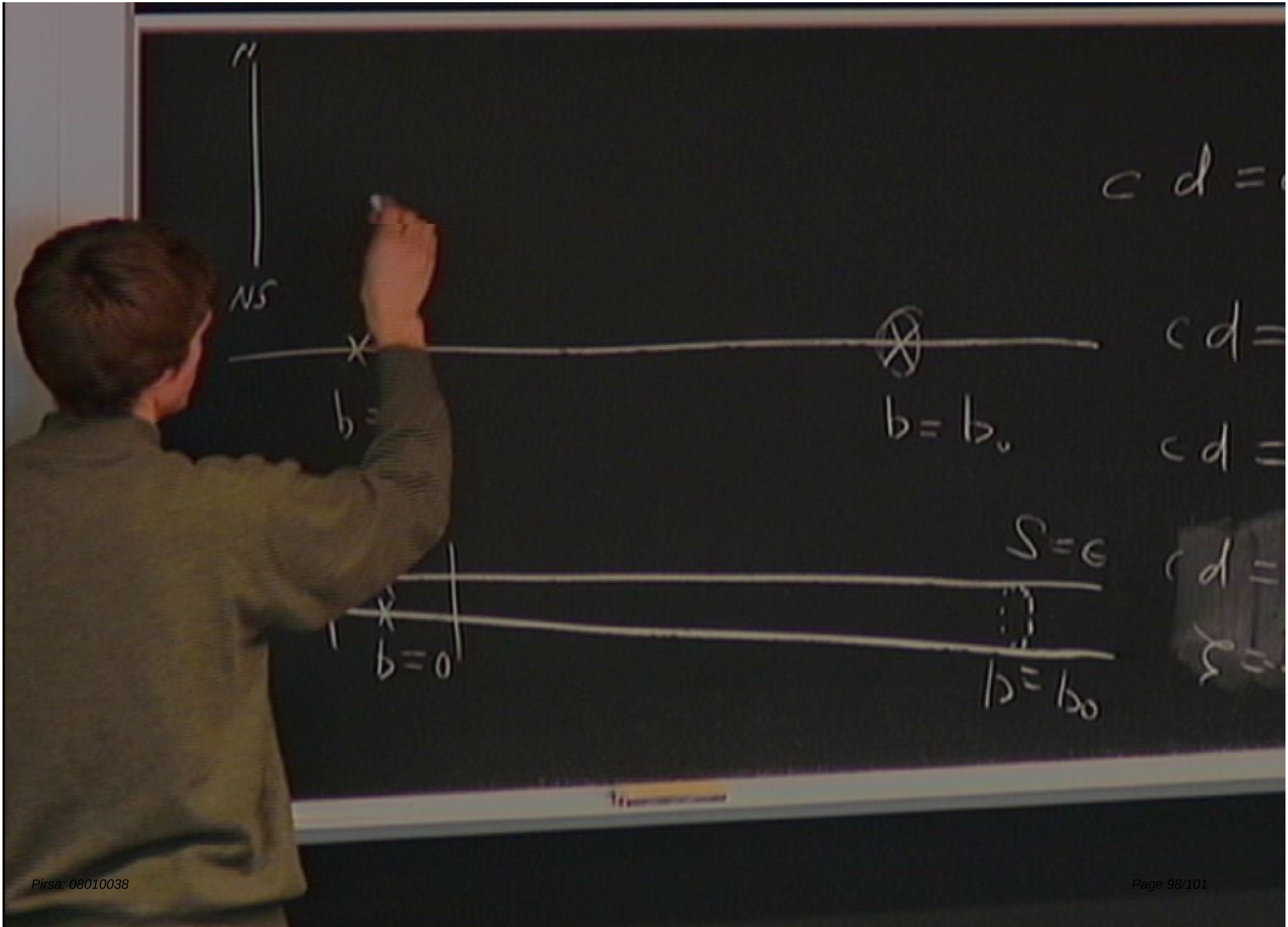
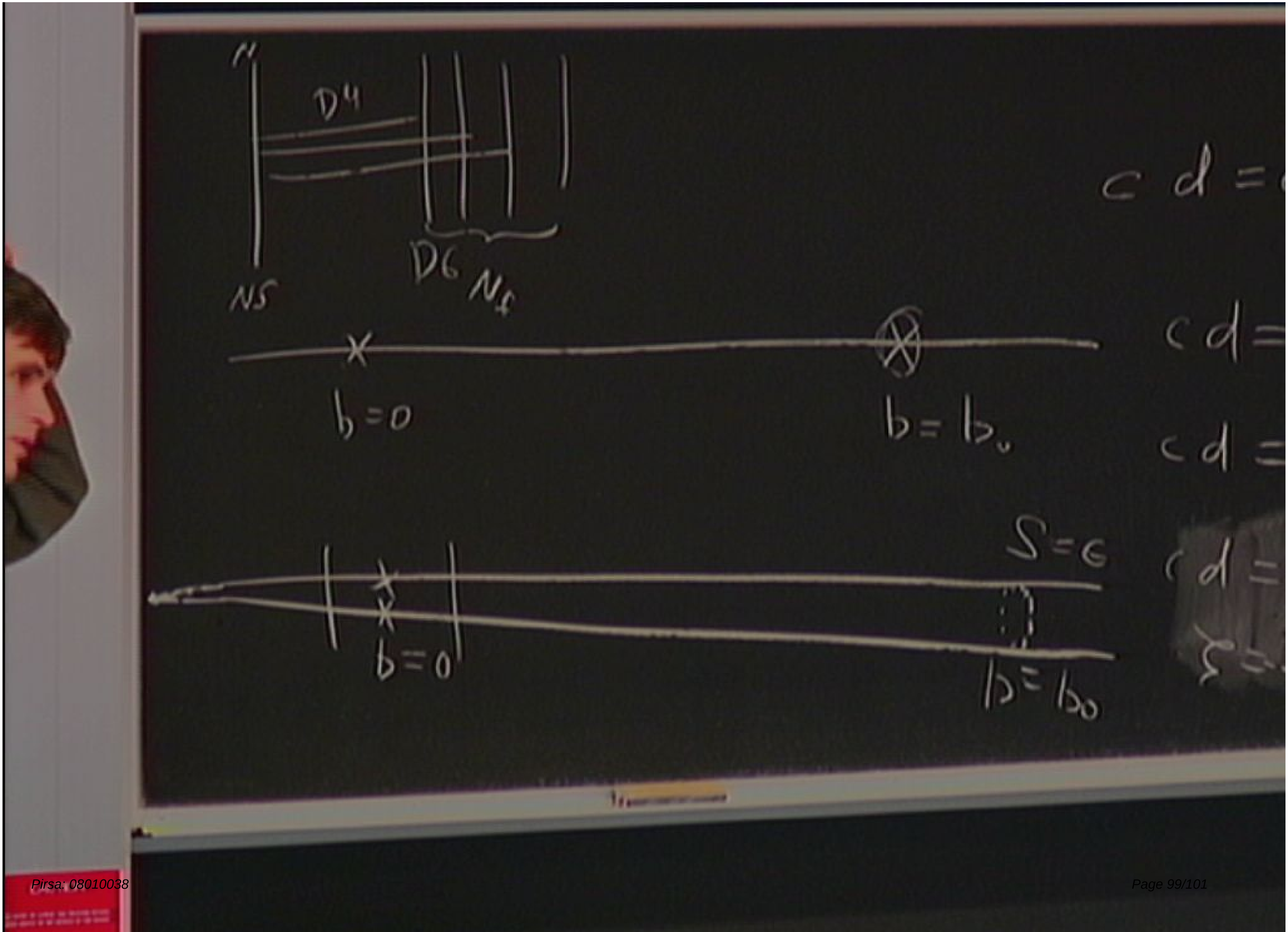
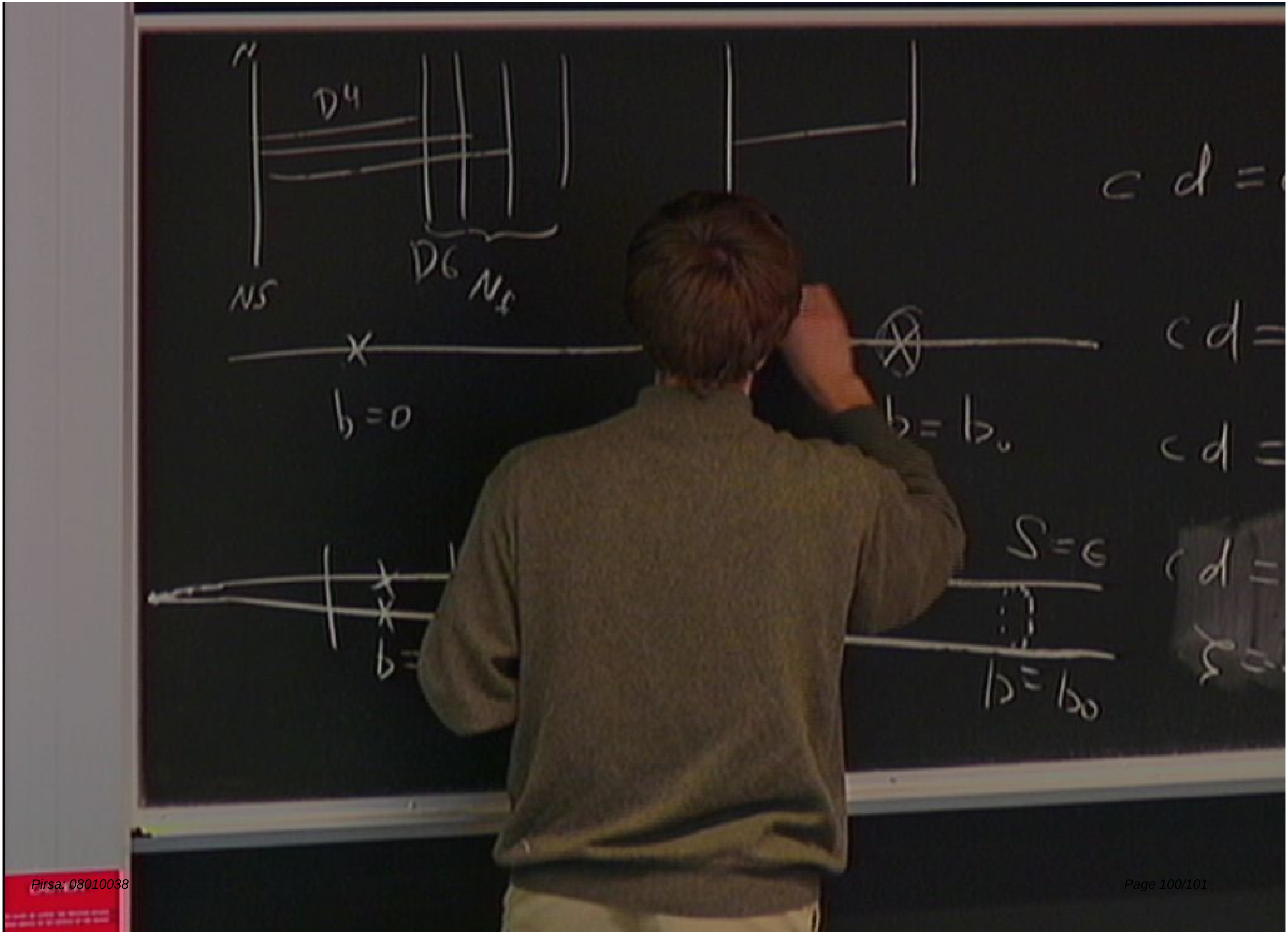
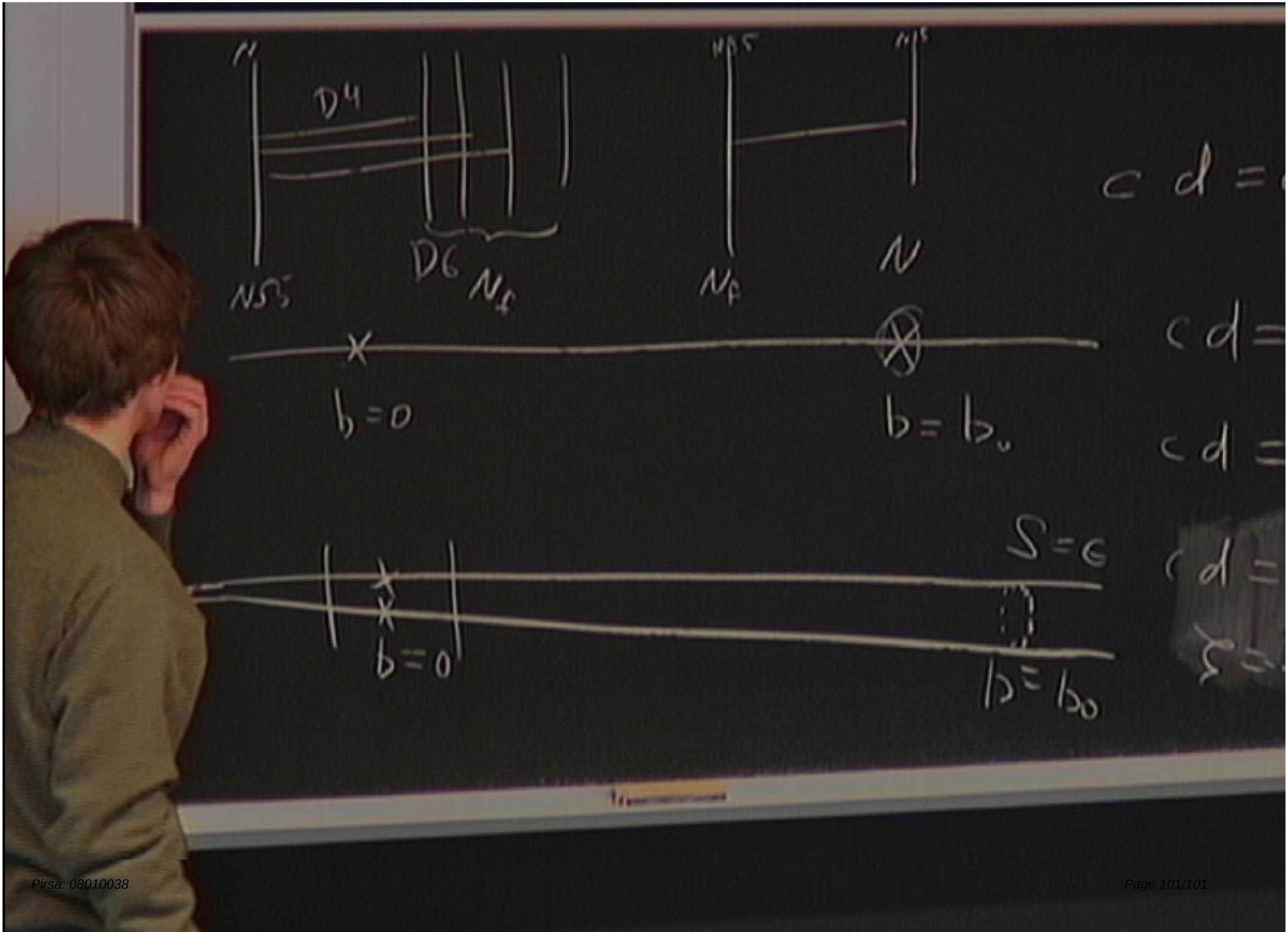

NS
c d =
b= b0
S=6
b=0
b= b0


D4
D6
NS
Nf
b=0
b= b0
S=6
b=0
b= b0
cd =
cd =
cd =
cd =


D4
D6
NS
N_f
b=0
b=b₀
S=6
cd=
b=b₀


D4
NS5
D6
N_f
N_f
N
b=0
$b = b_0$
b=0
$b = b_0$