Title: (almost) Stable Islands in the Landscape

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Abstract: We will consider stability in the string theory landscape. A survey over several classes of flux vacua with different characteristics indicates that the vast majority of flux vacua with small cosmological constant are unstable to rapid decay to a big crunch. Only vacua with large compactification radius or (approximately) supersymmetric configurations turn out to be long lived. We will speculate that regions of the landscape with approximate R-symmetry, while rare, might be cosmological attractors.

(almost) Stable Islands in the Landscape

M. Dine, G. Festuccia, A. Morisse, KvdB, work in progress

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Piscataway, NJ

Young Researchers Conference - PI
December 6, 2007

Sad news for string theory...

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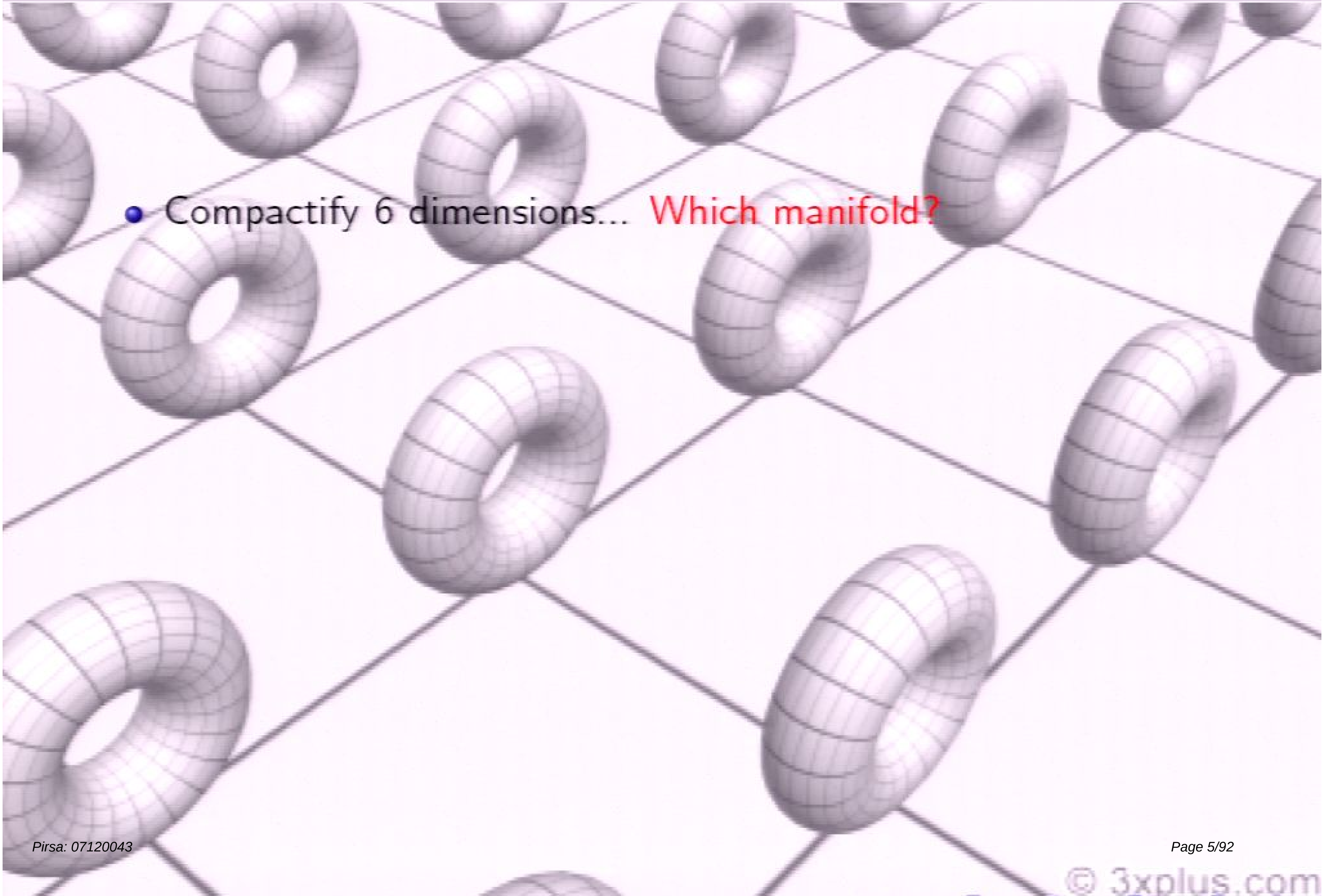
$$10 = 4 + 6$$

- Compactify 6 dimensions... Which manifold?



- Compactify 6 dimensions...
- Many manifolds consistent with string theory (Calabi-Yau) parametrized by moduli fields (massless)
  eg. z (shape), $\rho \sim V^{2/3}$ (size), $\tau, \ldots$

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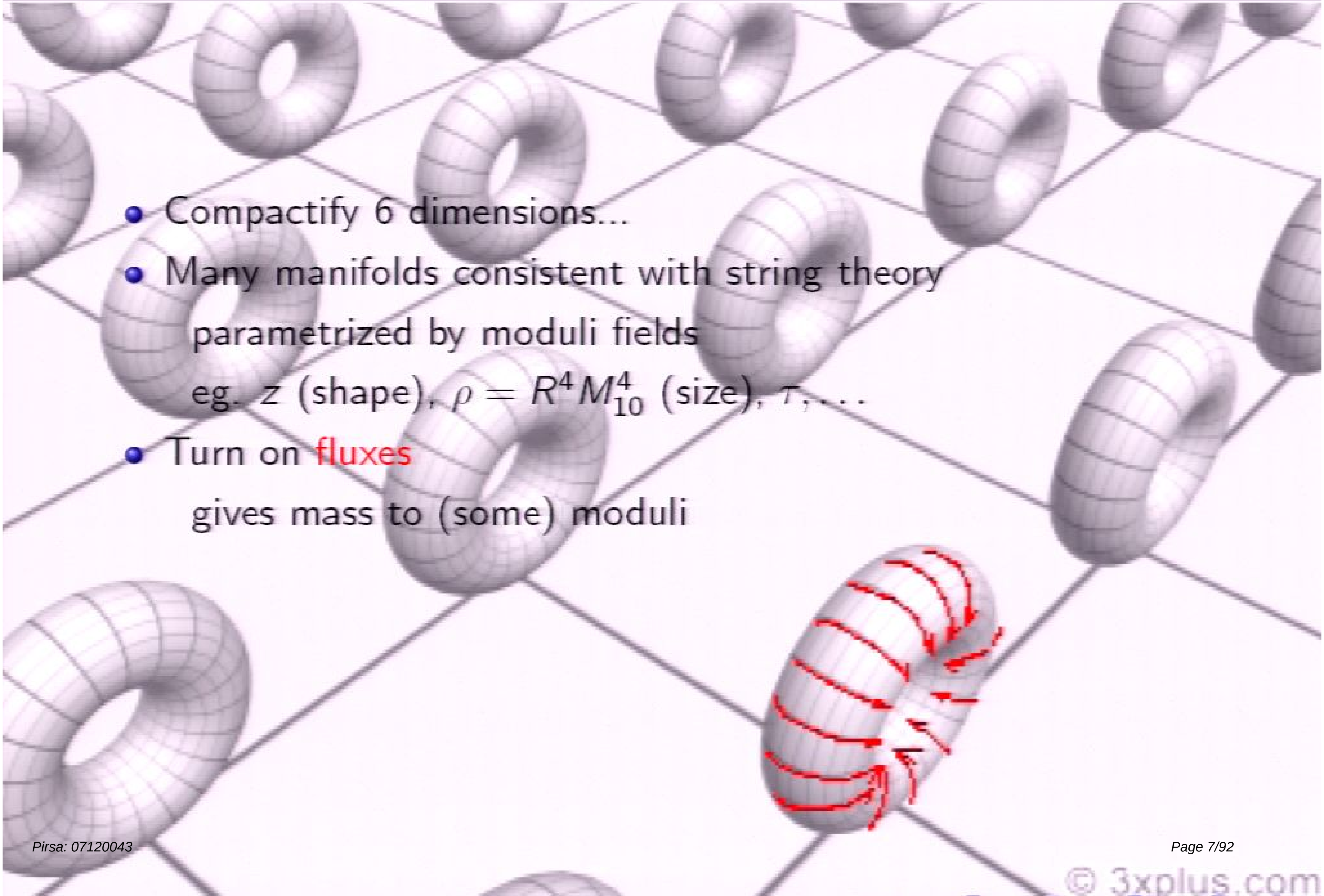

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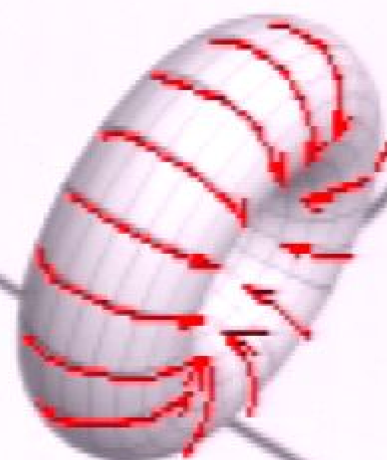

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  eg. z (shape), $\rho = R^4 M_{10}^4$ (size), $\tau, \ldots$
- Turn on fluxes

  gives mass to (some) moduli

  flux is quantized by integer N

  total charge is zero (tadpole condition)

How to study these flux compactifications?

- 10 dimensional point of view:
  study a particular 10d geometry with
  particular fluxes in supergravity
  eg. GKP, KKLT, DGKT,...
- 4 dimensional point of view:
  integrate out the heavy effects of the compact manifold
  leaves a 4d (supersymmetric) effective theory

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4 dimensional $\mathcal{N} = 1$ supergravity

- Theory is determined by two functions:
  Kahler potential K (kinetic terms)
  Superpotential W
- The scalar fields (moduli) feel a potential:

$$V = e^{K/M_4^2}(K^{i\bar{j}} D_i W D_{\bar{j}} W - 3\frac{|W|^2}{M_4^2})$$

with

$$D_i W = \partial_i W + W \partial_i K / M_4^2$$

and M_4 the 4d Planck length

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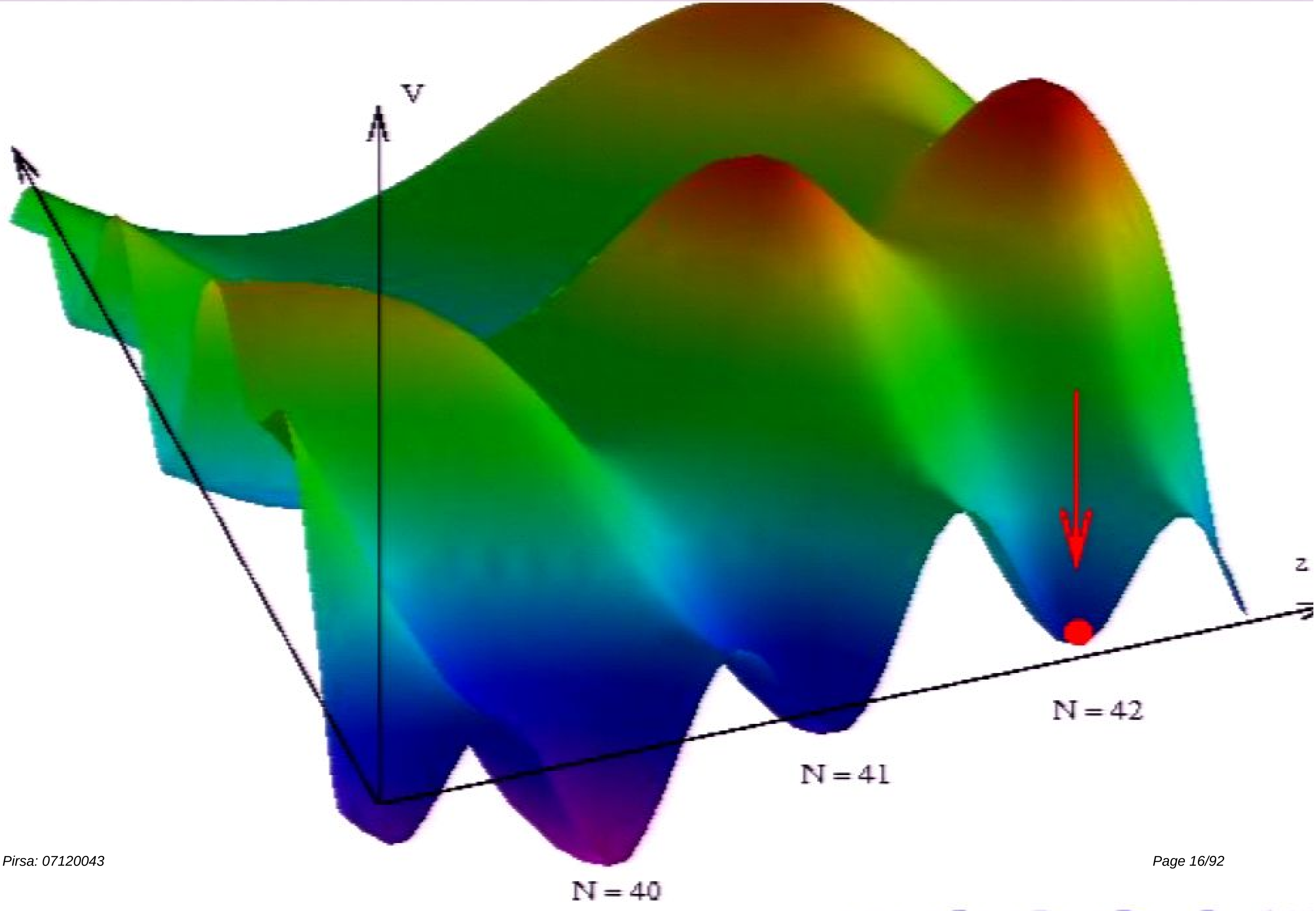
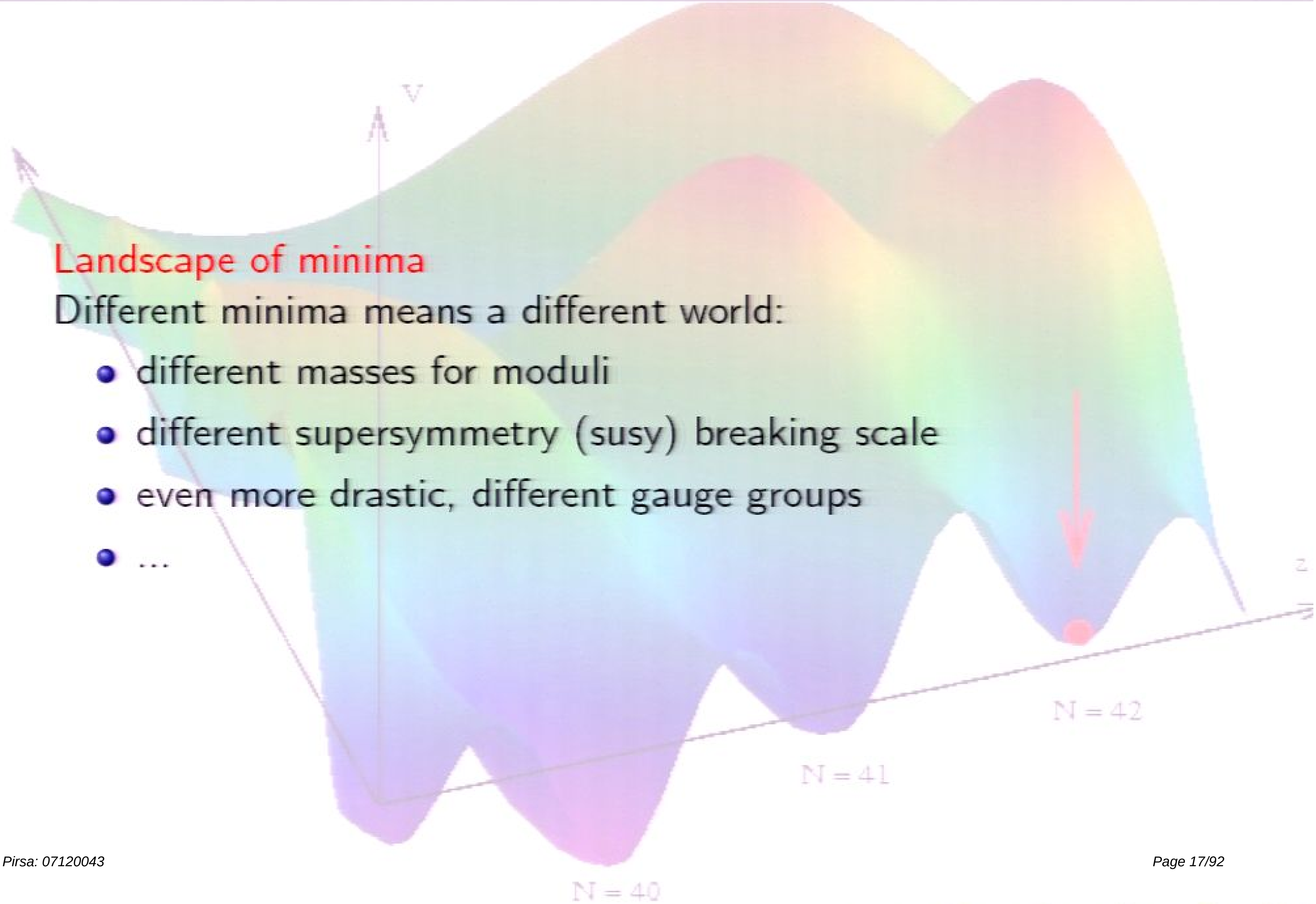
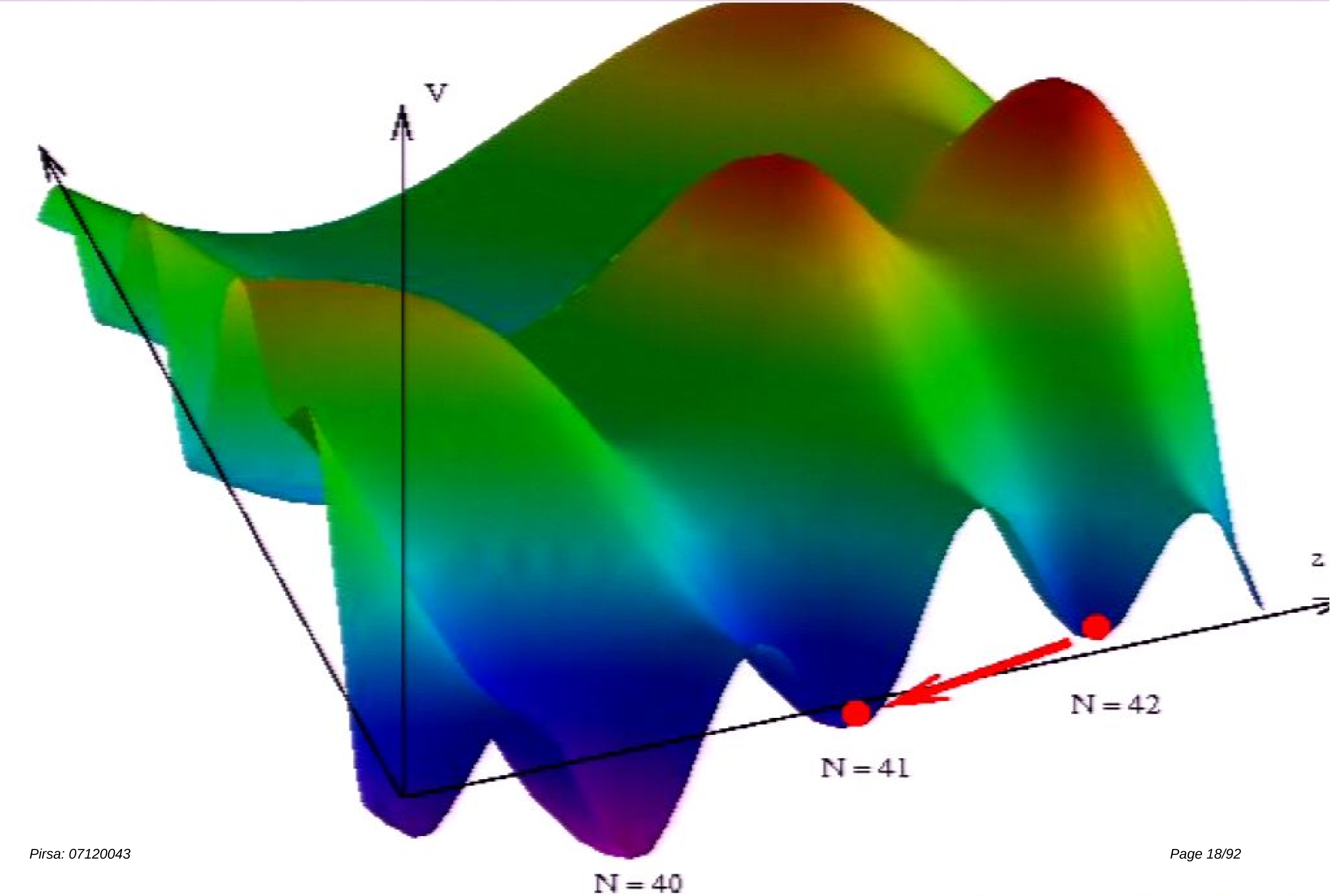

V
z
N = 42
N = 41
N = 40



Landscape of minima

Different minima means a different world:

- different masses for moduli
- different supersymmetry (susy) breaking scale
- even more drastic, different gauge groups
- ...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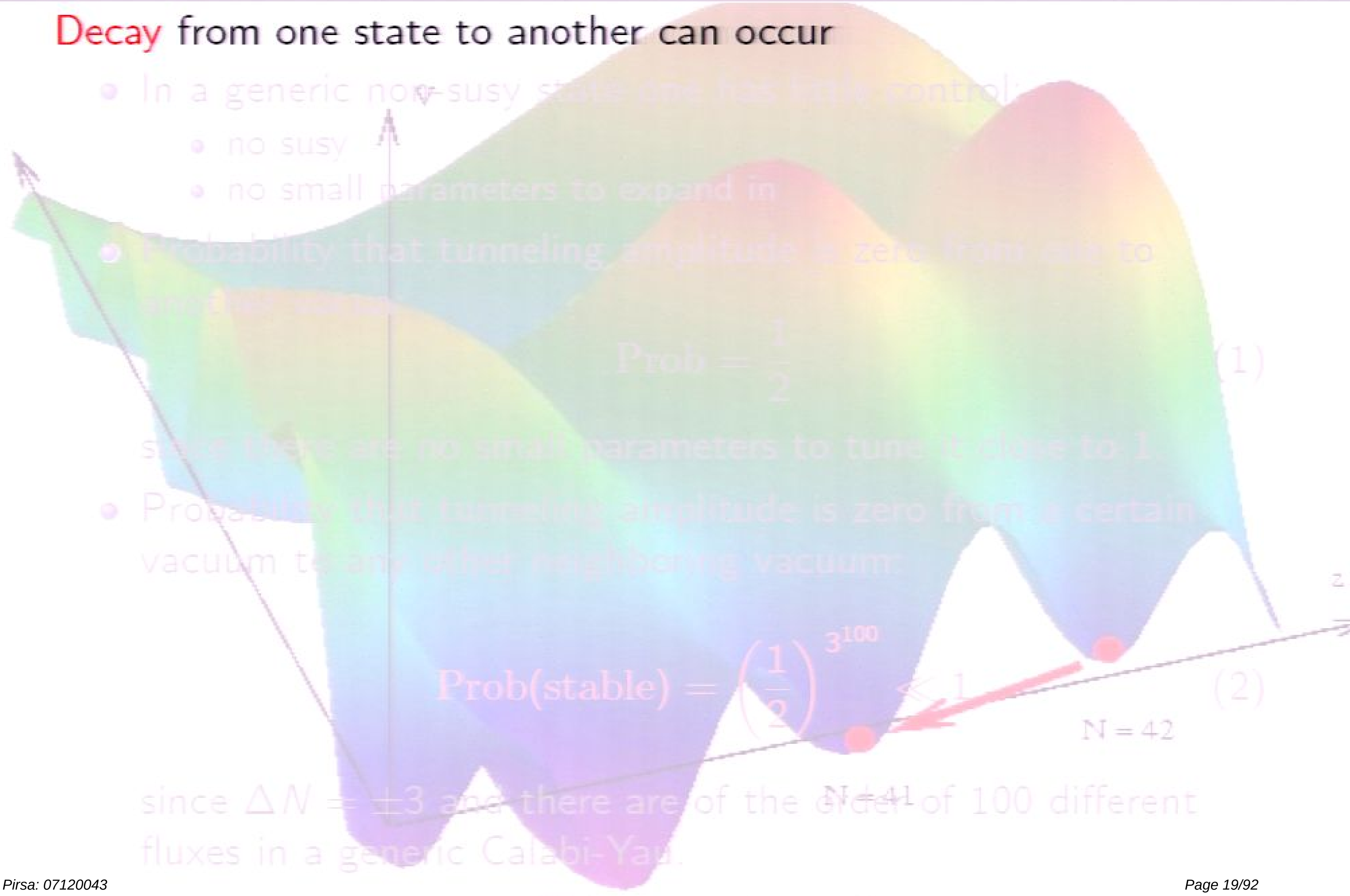
Decay from one state to another can occur



- In a generic non-susy state one has little control:
  - no susy
  - no small parameters to expand in
- Probability that tunneling amplitude is zero from one to another state:

$$\mathrm{Prob} = \frac{1}{2} \quad (1)$$

since there are no small parameters to tune it close to 1.

- Probability that tunneling amplitude is zero from a certain vacuum to any other neighboring vacuum:

$$\mathrm{Prob(stable)} = \left(\frac{1}{2}\right)^{3^{100}} \ll 1 \quad (2)$$

since $\Delta N = \pm 3$ and there are of the order of 100 different fluxes in a generic Calabi-Yau.

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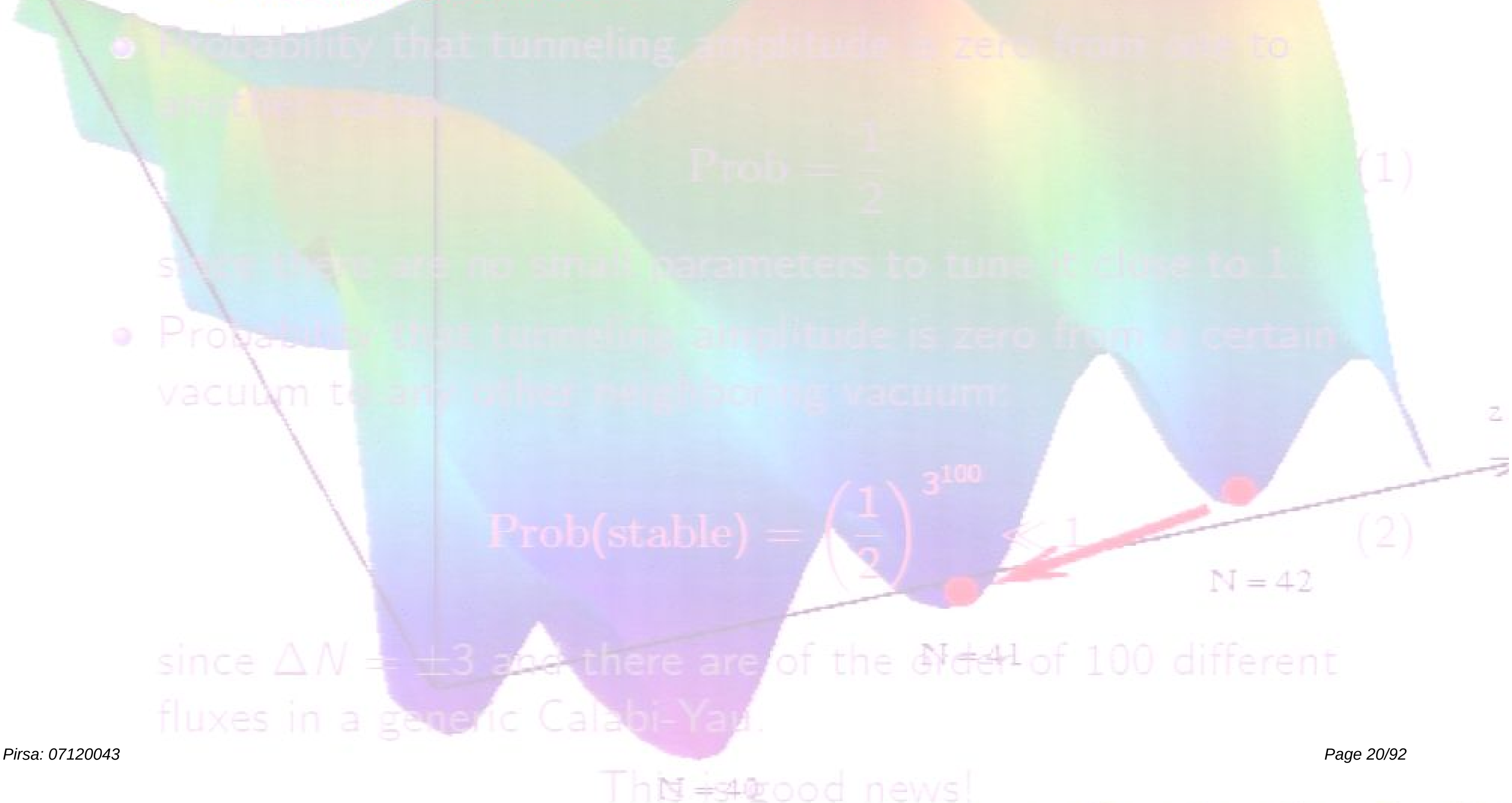

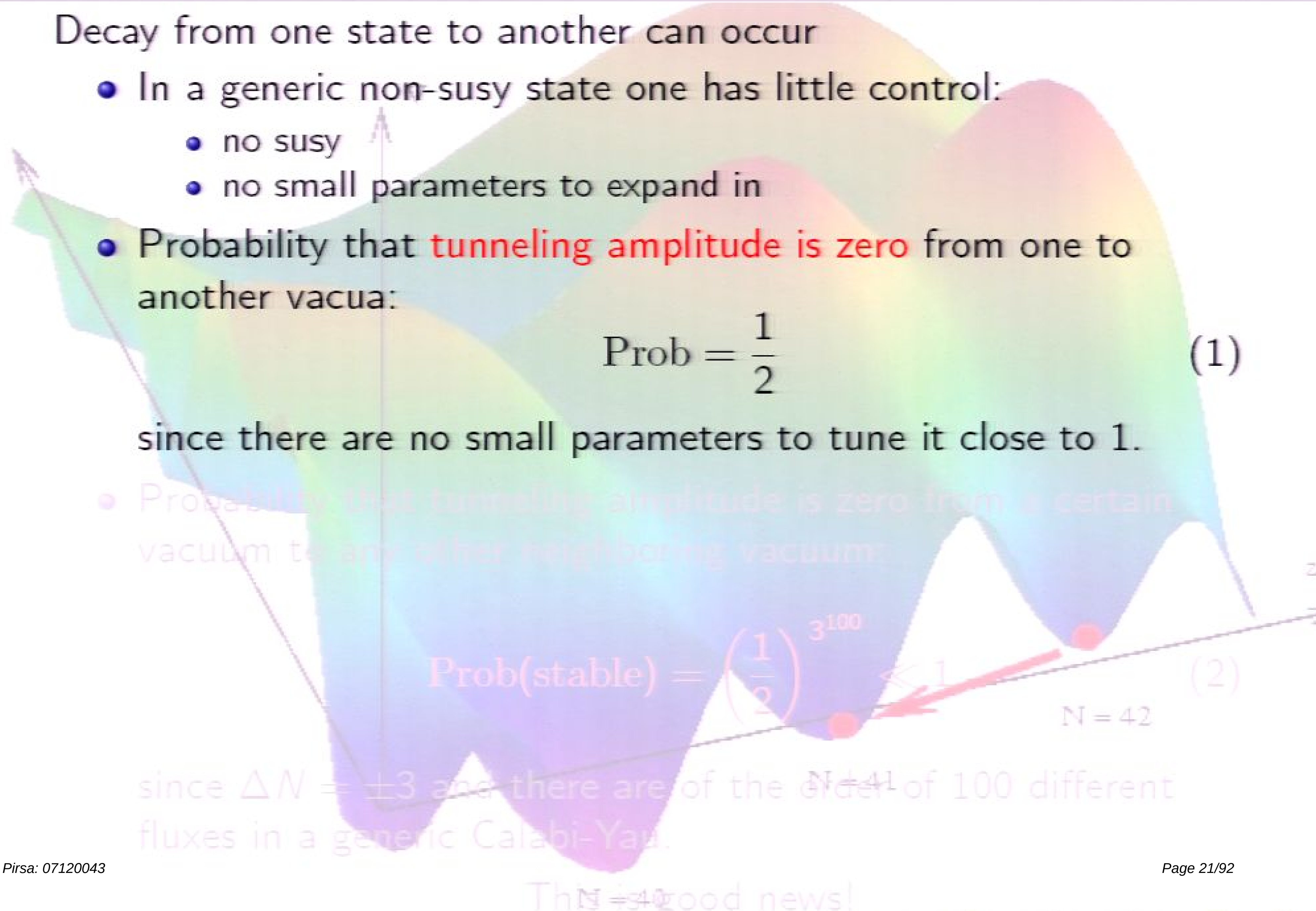

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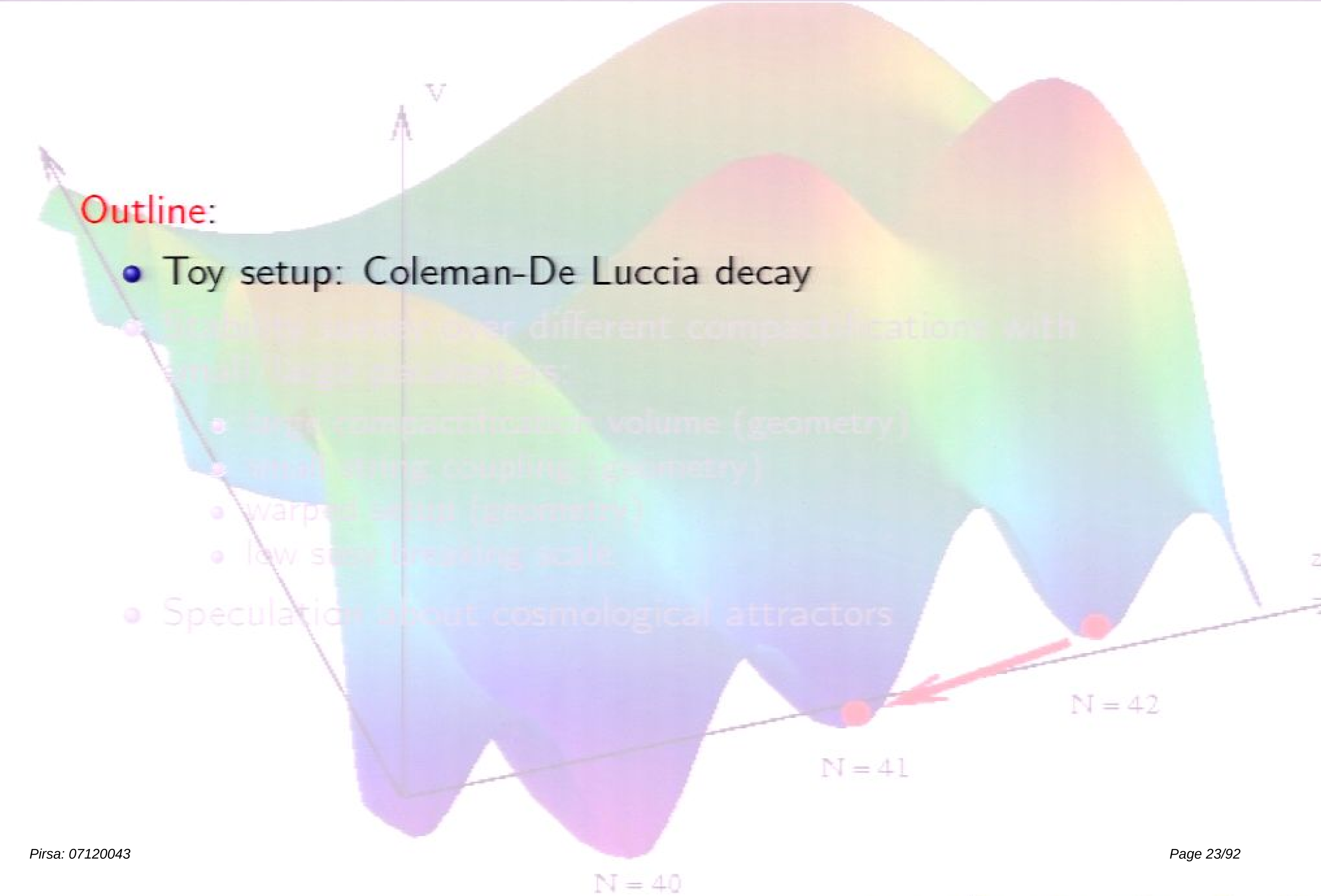

Outline:

- Toy setup: Coleman-De Luccia decay
- Stability survey over different compactifications with small/large parameters:
  - large compactification volume (geometry)
  - small string coupling (geometry)
  - warped setup (geometry)
  - low susy breaking scale
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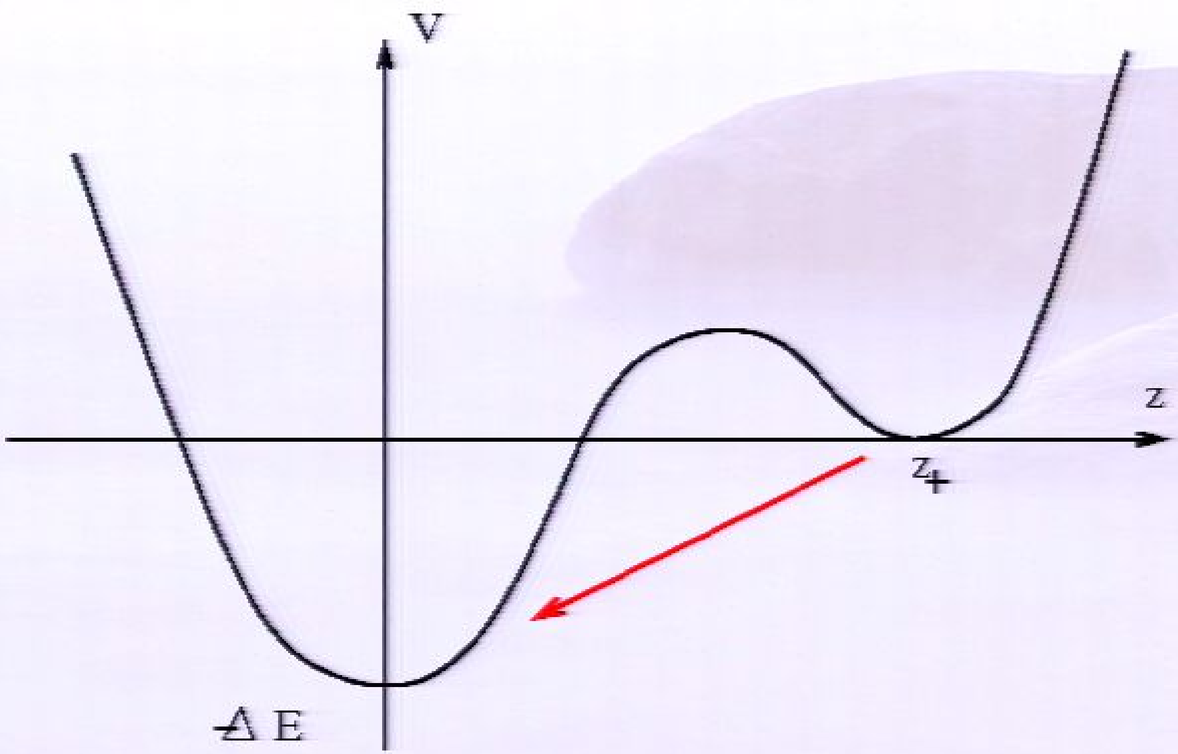
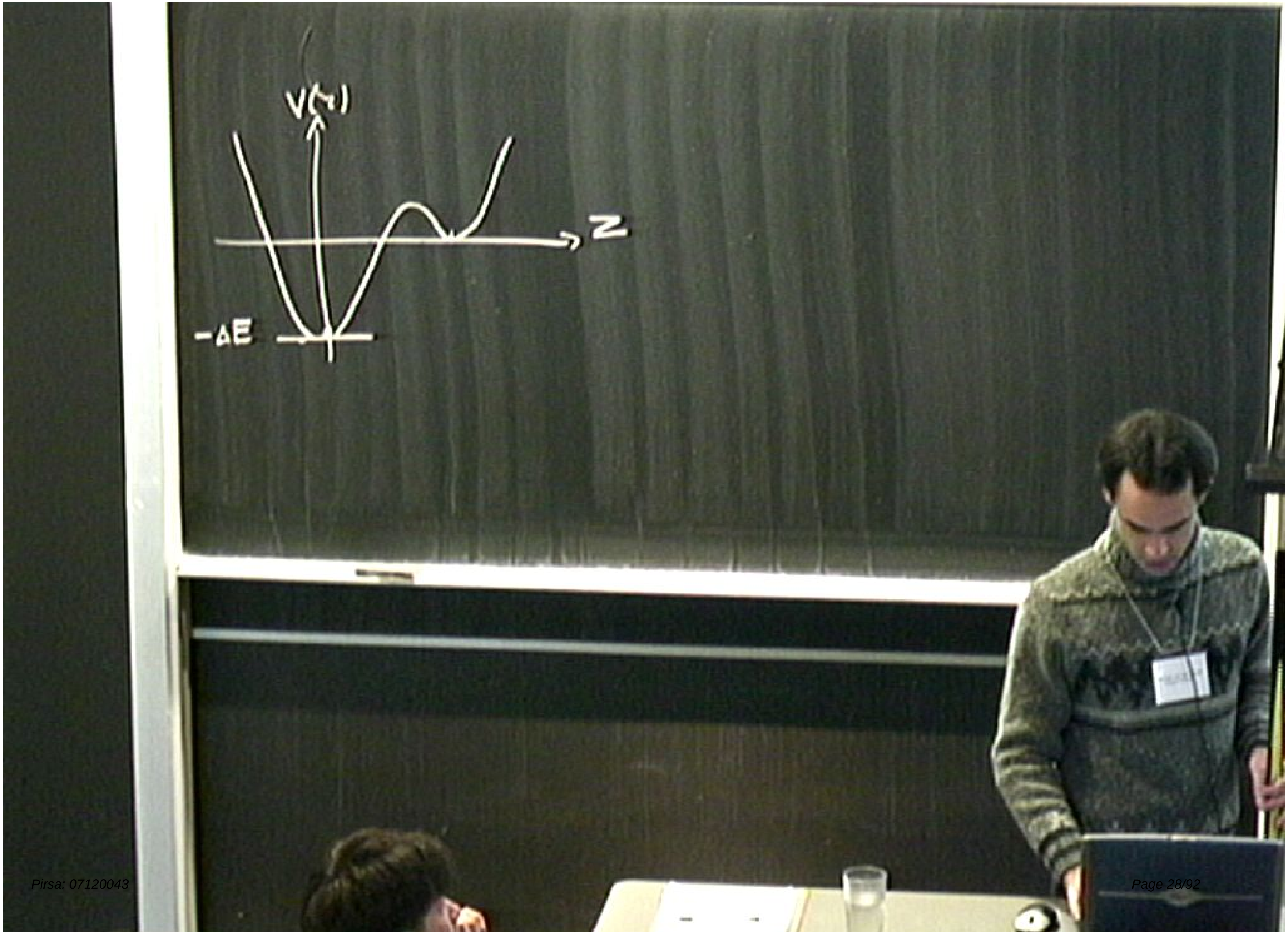
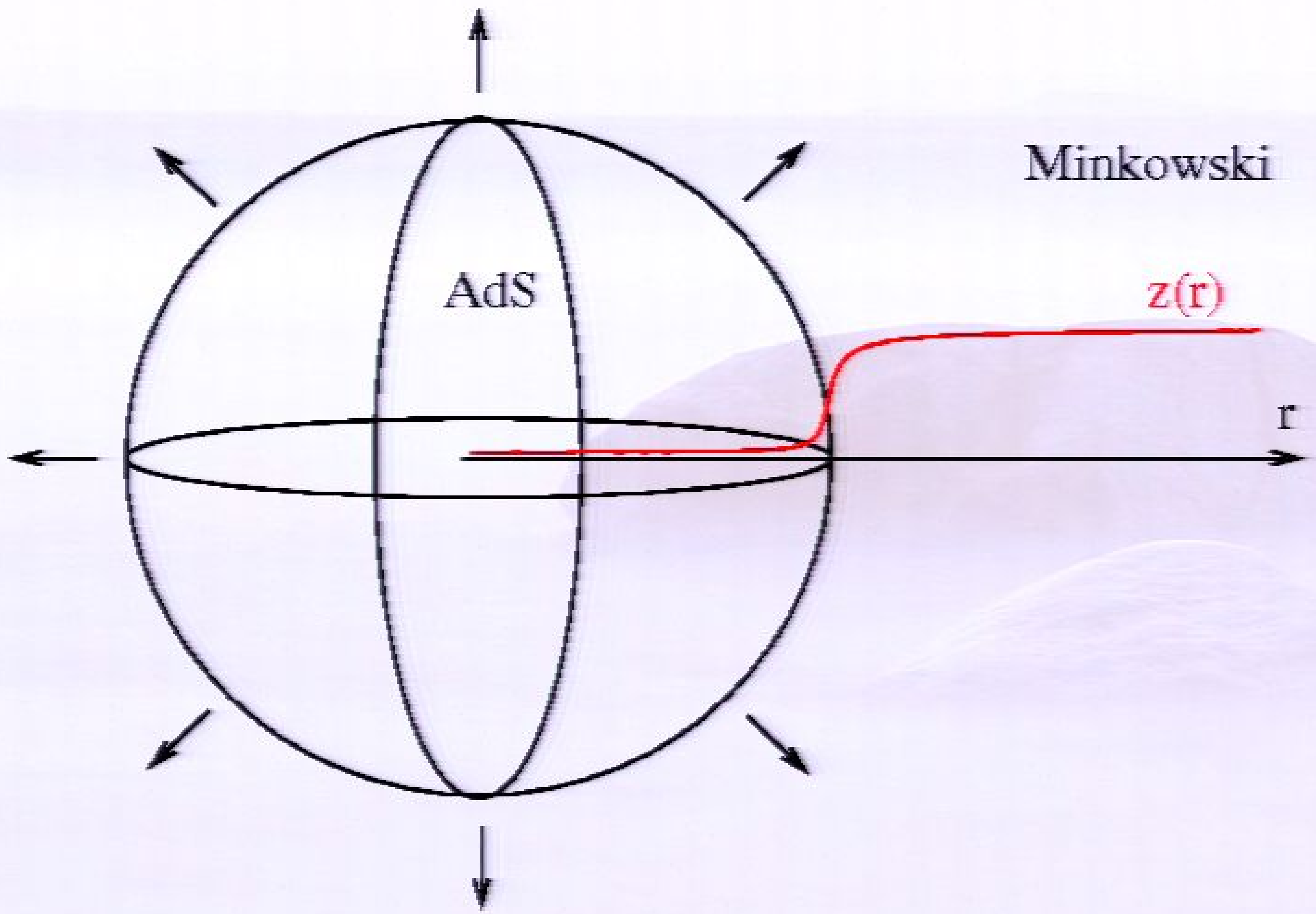
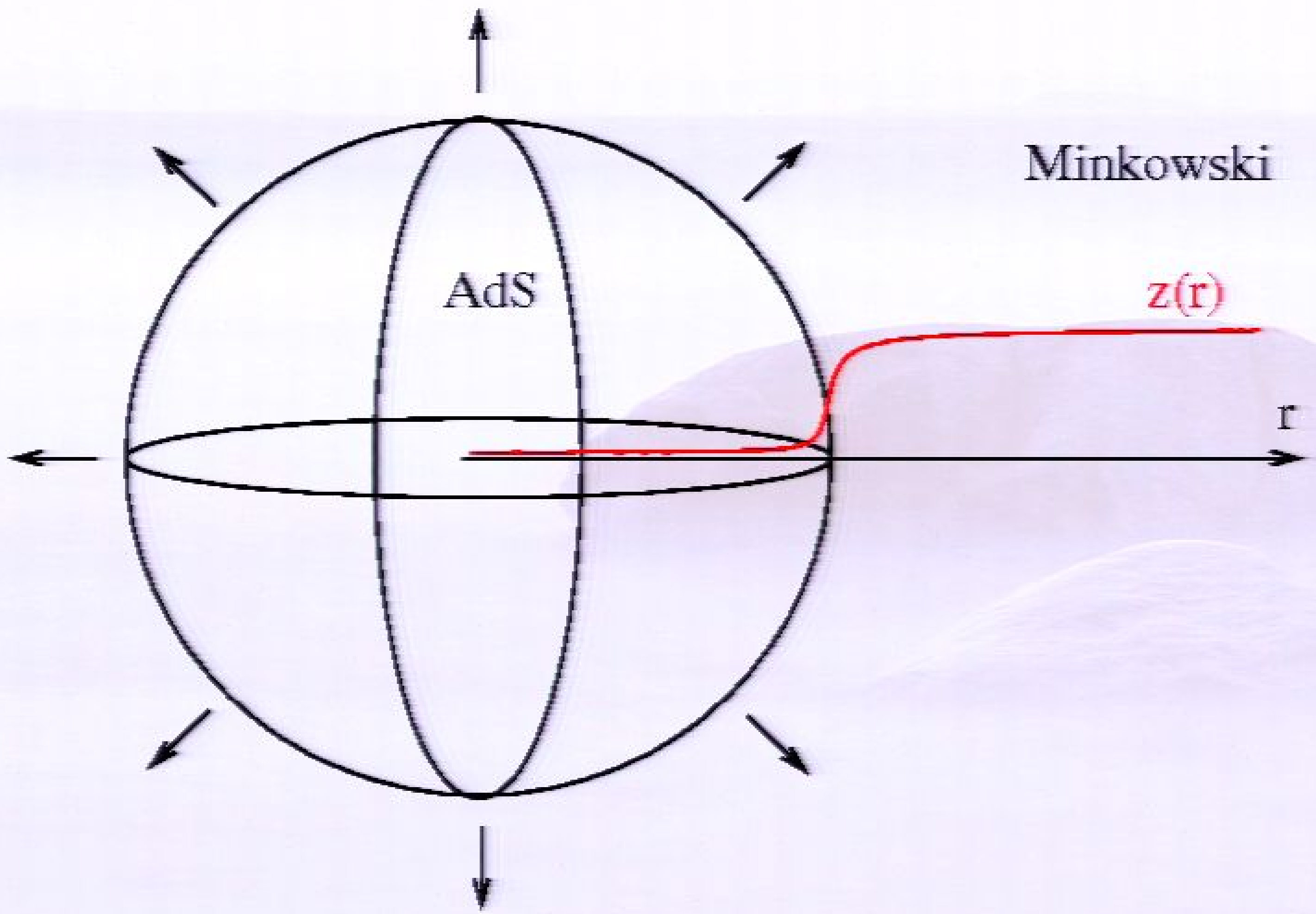
Consider the scalar field theory:

$$S = \int d^4x \left\{ \frac{1}{2}(\partial_\mu z)^2 - V(z) \right\} \quad (3)$$




V(z)
Z
−ΔE


Minkowski
AdS
z(r)
r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Energetics for bubble nucleation (thin wall):

$$E = -\frac{4\pi}{3}\Delta E\, r^3 + 4\pi T\, r^2 \tag{4}$$

with the tension

$$T = \int_{z_-}^{z^+} dz \sqrt{2V(z)} \tag{5}$$

Energy conservation, $E =$

$$R_b \sim \frac{T}{\Delta E} \tag{6}$$

The decay probability per unit time and volume is given by

$$\frac{\Gamma}{V} \sim e^{-S_b} \quad \text{with} \quad S_b \sim \frac{T^4}{\Delta E^3} \tag{7}$$

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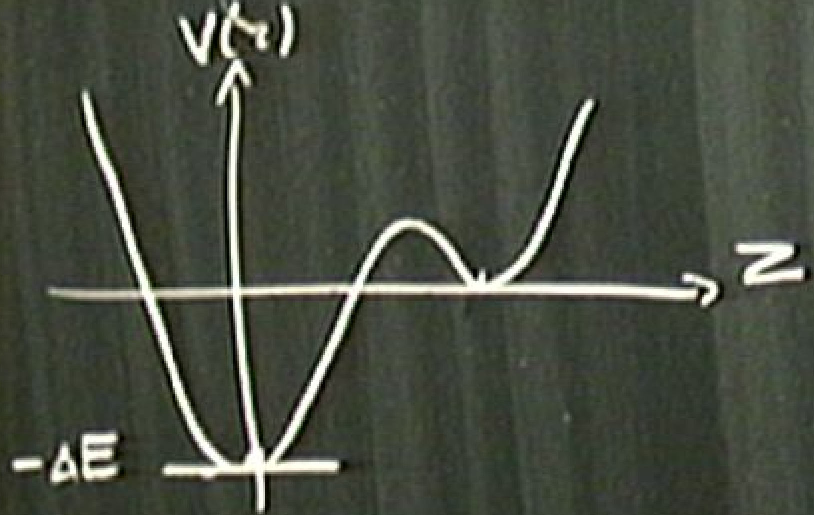
$$S_b \sim \frac{T^4}{\Delta E^3} \quad ; \quad R_b \sim \frac{T}{\Delta E} \tag{8}$$



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- gravitational potential energy of the bubble
- volume of the bubble is corrected

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$$S_b \sim \frac{T^4}{\Delta E^3}\frac{1}{(1-(R_b/2R_{\mathrm{AdS}})^2)^2} \quad ; \quad R_b \sim \frac{T}{\Delta E}\frac{1}{1-(R_b/2R_{\mathrm{AdS}})^2} \tag{8}$$

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Let us redo the Coleman-De Luccia exercise but with stringy input.
Let us for now take all fluxes of order N:

$$\begin{aligned} W &= \int G_3 \wedge \Omega && \sim N \\ K &= -3\ln(\rho+\bar{\rho}) + \ldots && \sim \ln V^{-2} \end{aligned} \tag{11}$$

This gives for a decay $\Delta N = \pm 1$

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Conclusion: For decay to be suppressed we need the volume V to scale as $N^{3/2}$
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$$S_b \sim \frac{V^2}{N^3} \quad ; \quad R_b \sim \frac{V}{N} \quad ; \quad [illegible] \tag{13}$$

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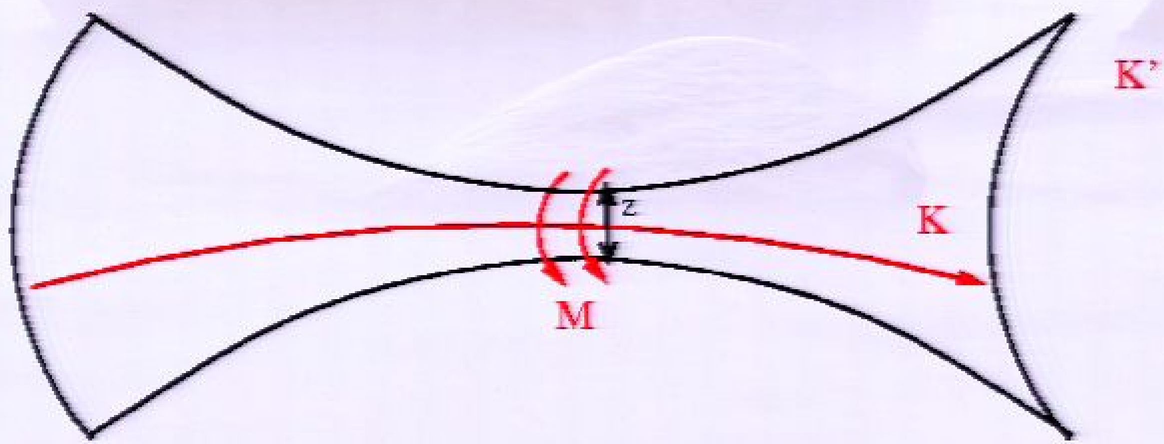
Let us now consider the GKP setup (type IIB)
(with ρ considered fixed and large):

$$W = M\mathcal{G}(z) - K\tau z - K'\tau h(z) \quad (14)$$
$$K = -3\ln(\rho + \bar{\rho}) - \ln(-i(\tau - \bar{\tau})) + k(z, \bar{z}) \quad (15)$$

with M, K and K' the flux quanta of F_3, H_3 and H_3 flux respectively.



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with M, K and K' the flux quanta of F_3, H_3 and H_3 flux respectively.
Imposing susy leads to

$$
\begin{aligned}
D_\tau W &= 0 \Rightarrow g_s \sim \frac{K'}{M}\\
D_z W &= 0 \Rightarrow z \sim e^{-\frac{2\pi K}{g_s M}}
\end{aligned}
\qquad (18)
$$

We take $M \gg K'$ to get a small string coupling g_s.

Let us focus on the decay $\Delta M = \pm 1$:

$$\Delta E \sim \frac{M}{V^2} g_s \quad ; \quad T \sim \frac{1}{V}\sqrt{g_s} \tag{19}$$

Notes:

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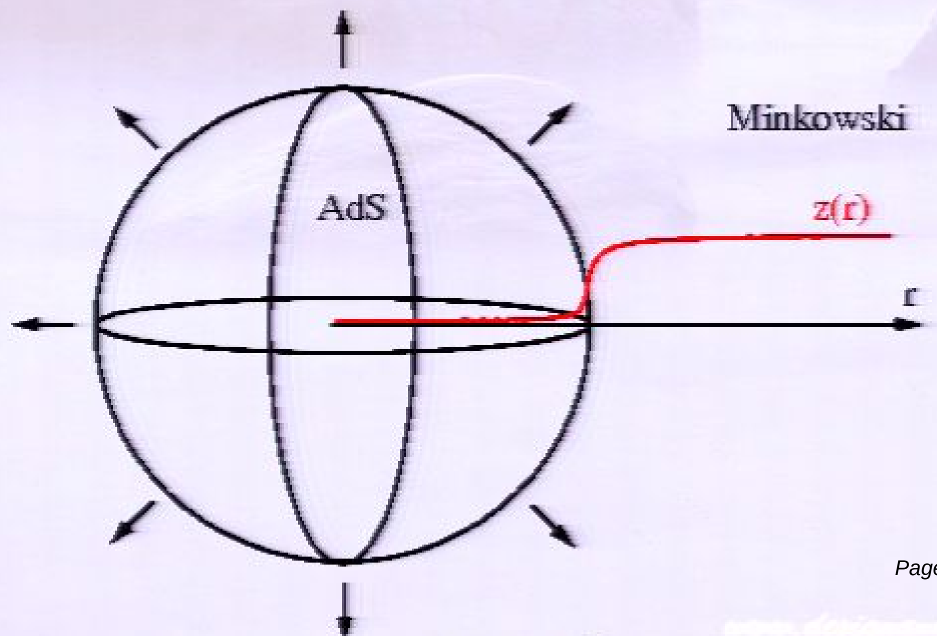

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- The tadpole constraint

$$N_{\mathrm{D3}} - \frac{1}{2} N_{\mathrm{O3}} + \int H_3 \wedge F_3 = 0 \tag{24}$$

indicates D3 brane emission since F_3 changes (estimate ΔE unchanged).

We find for the $\Delta M = \pm 1$ decay:

$$S_b \sim \frac{V^2}{M^3 g_s} \sim \frac{V^2}{M^2 K'} \quad ; \quad R_b \sim \frac{V}{M\sqrt{g_s}} \ll R_{\mathrm{AdS}} \sim \frac{V}{\sqrt{M g_s}} \qquad (25)$$

Conclusions:

- For decay suppression we need [illegible] the flux quanta.
- Warping does not seem to suppress the decay.
- Small string coupling, $g_s \sim K'/M$, does not suppress the decay.

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Let us consider the DGKT setup (type IIA):

$$g_s \sim N^{-3/4} \quad ; \quad V \sim N^{3/2} \quad ; \quad R_{\mathrm{AdS}} \sim N^{9/4} \qquad (26)$$

this gives,

(27)

and thus

(28)

Conclusion: decay suppression!

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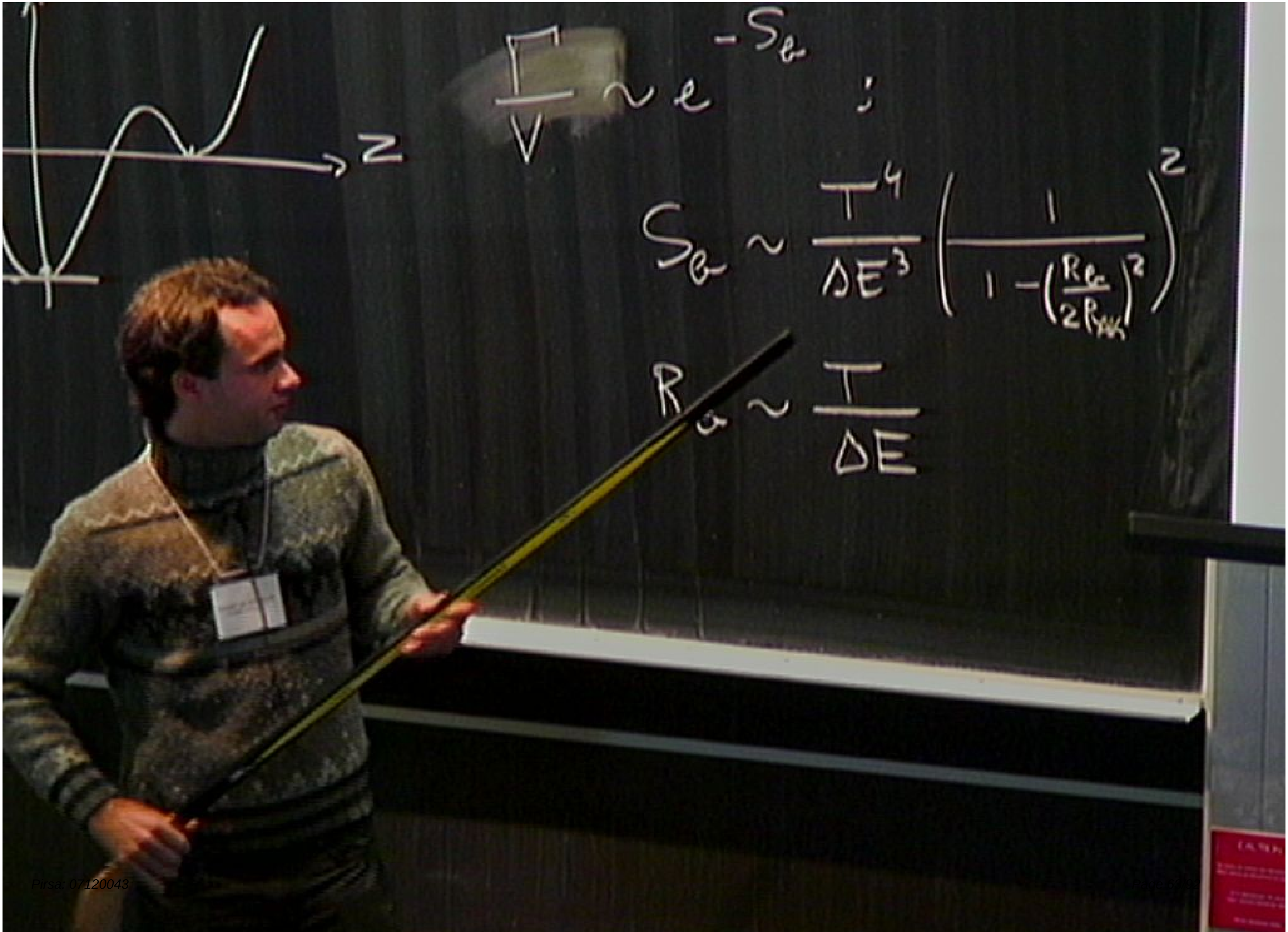
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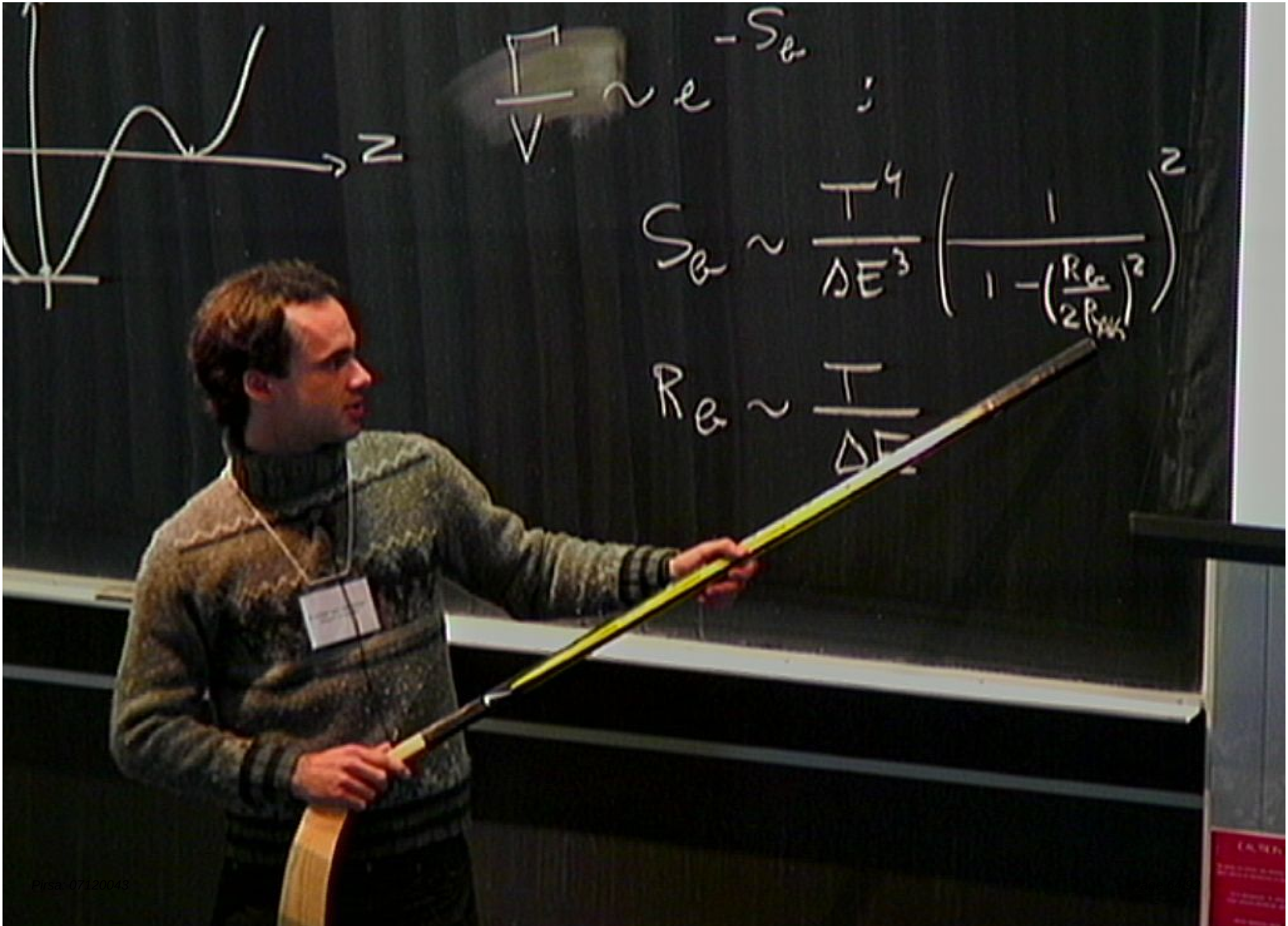
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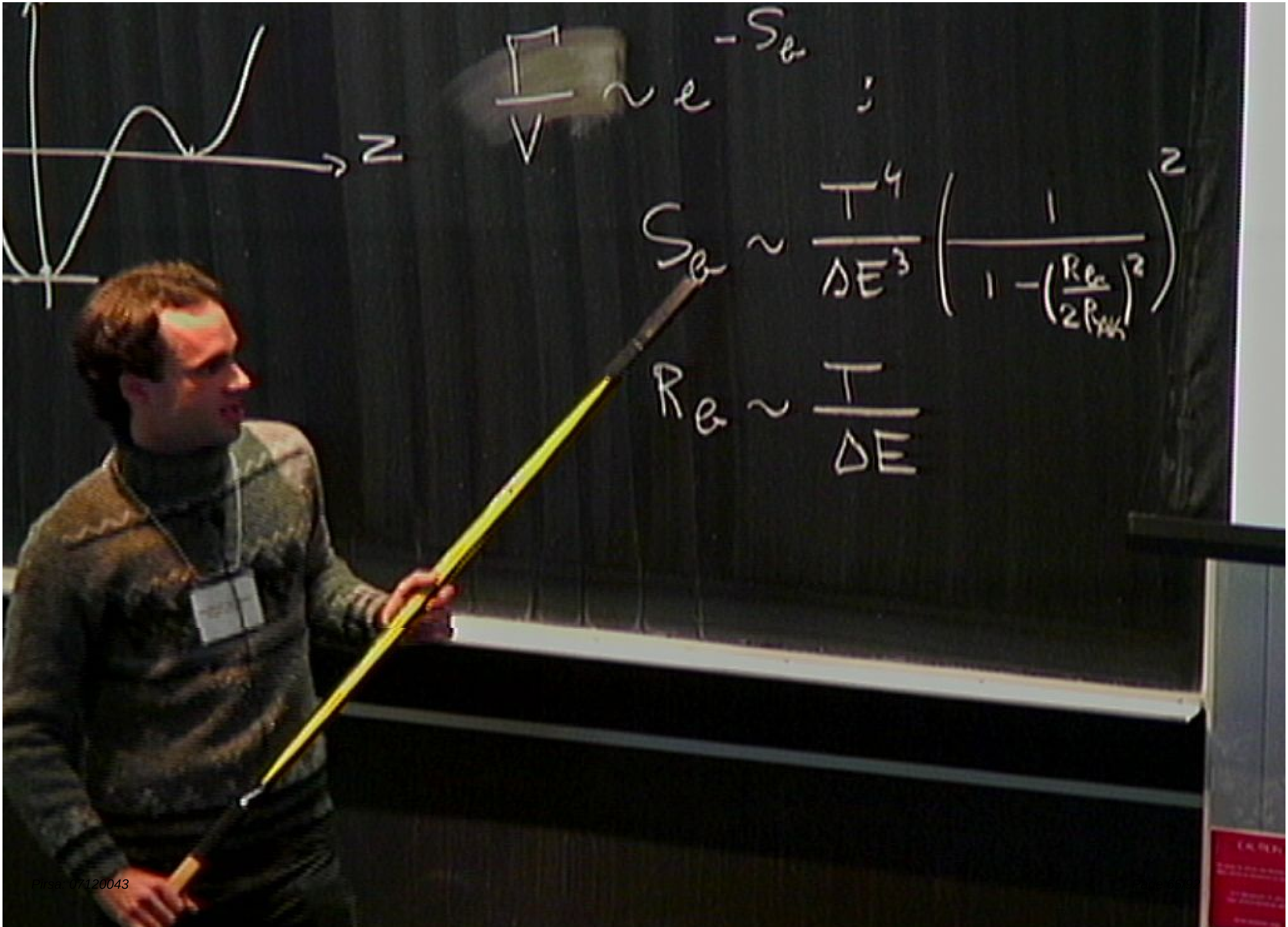
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Configurations with low energy susy breaking:

- KKLT:

$$W = W_0 + e^{-\rho} \tag{35}$$

  where W_0 is tuned to be small such that sugergravity is valid (large ρ).
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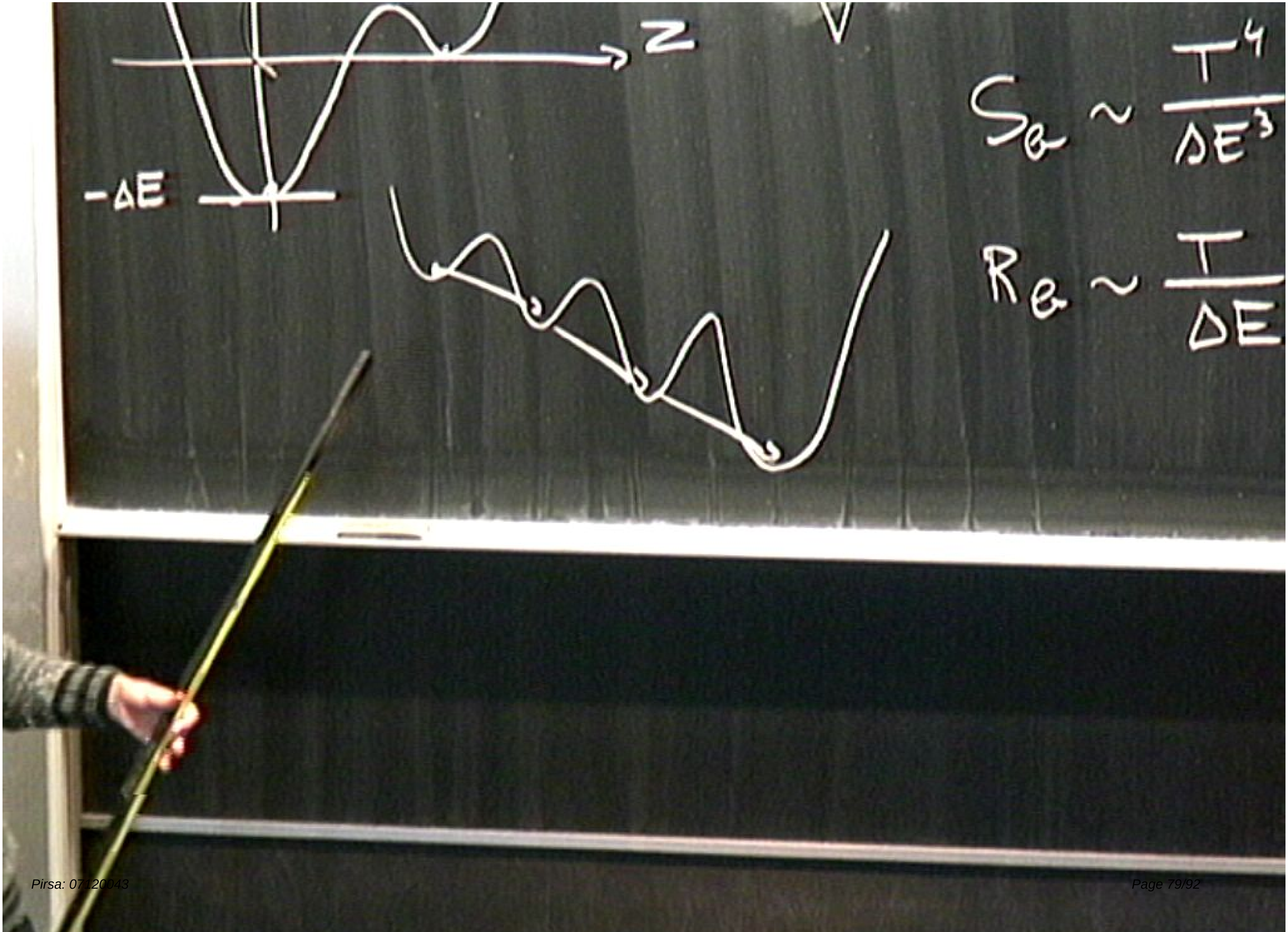
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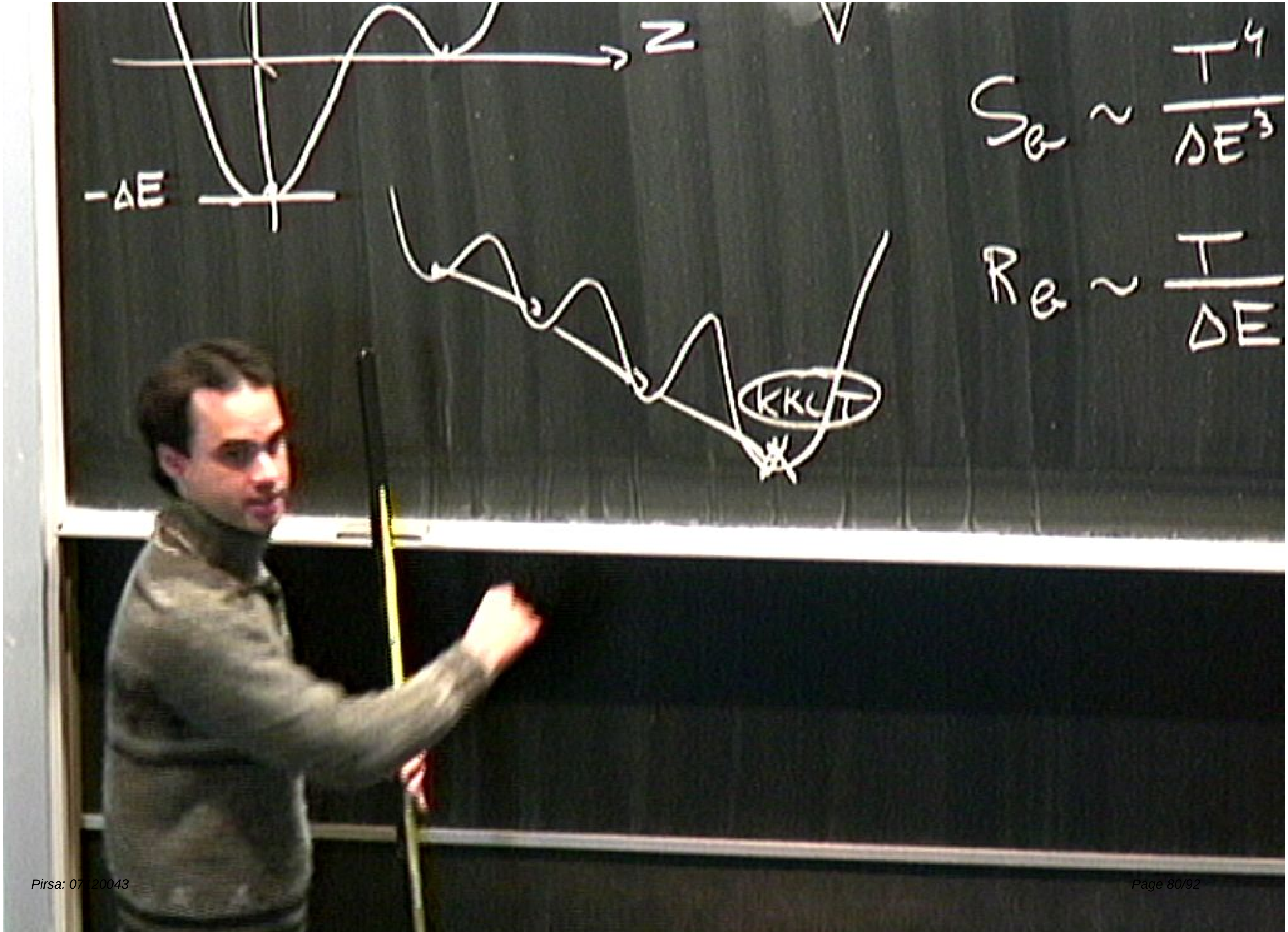
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KKLT

[redacted]

Configurations with low energy susy breaking:

- Discrete R-symmetry: Rare in the landscape, since all fluxes which break the symmetry have to be zero.
  Turning on a small amount n of the fluxes that break the symmetry contributes to the cosmological constant:

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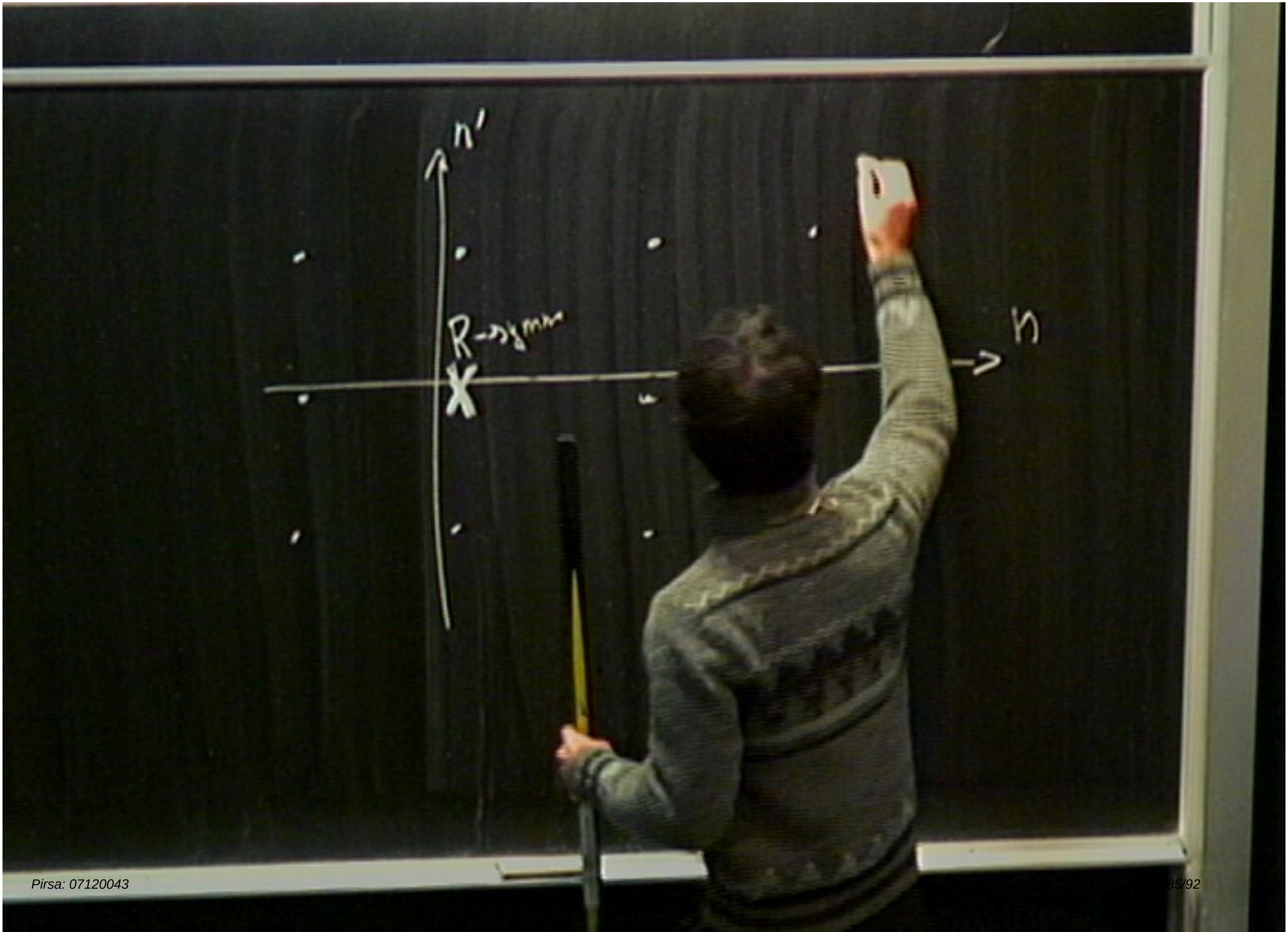
n'
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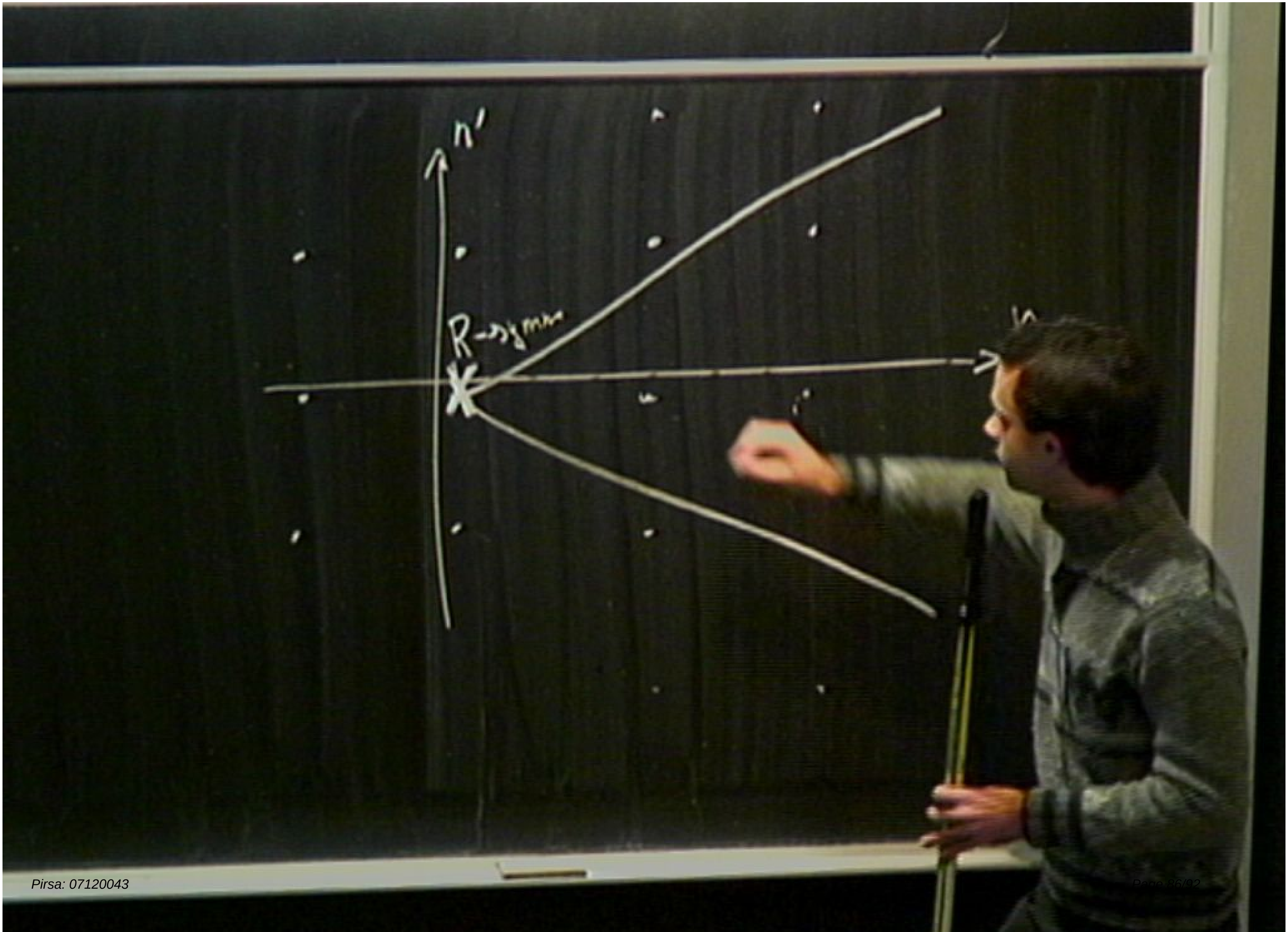
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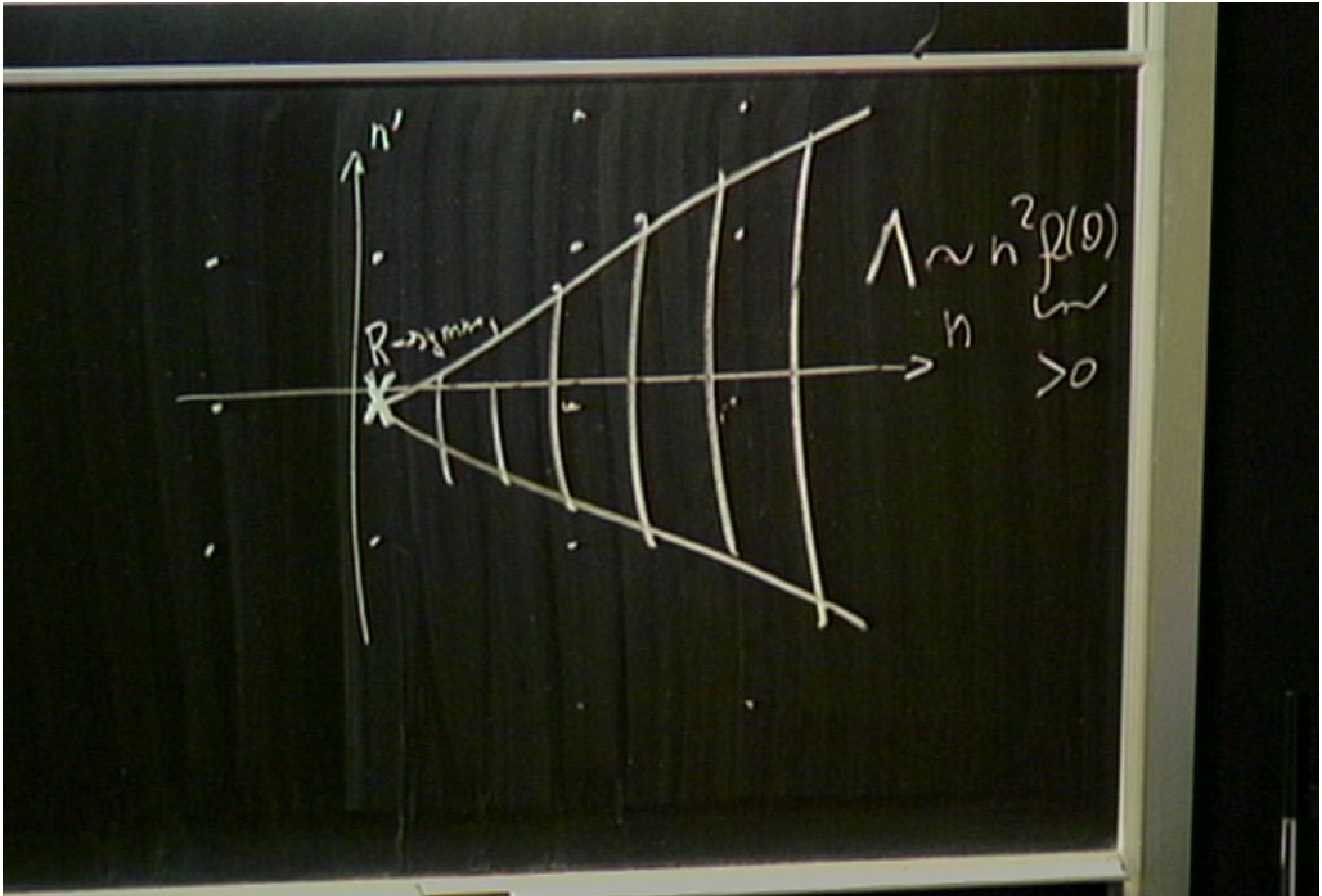
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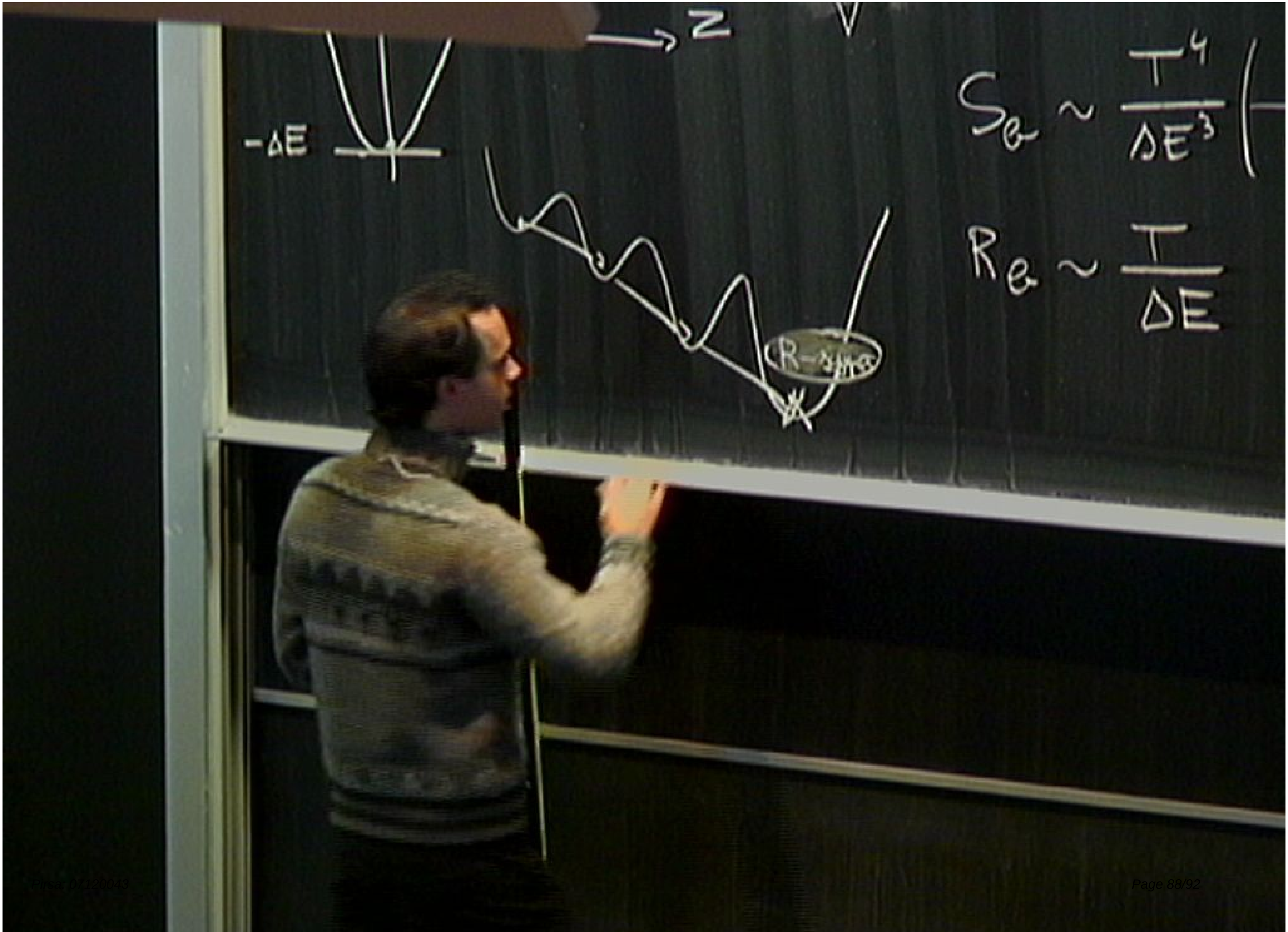

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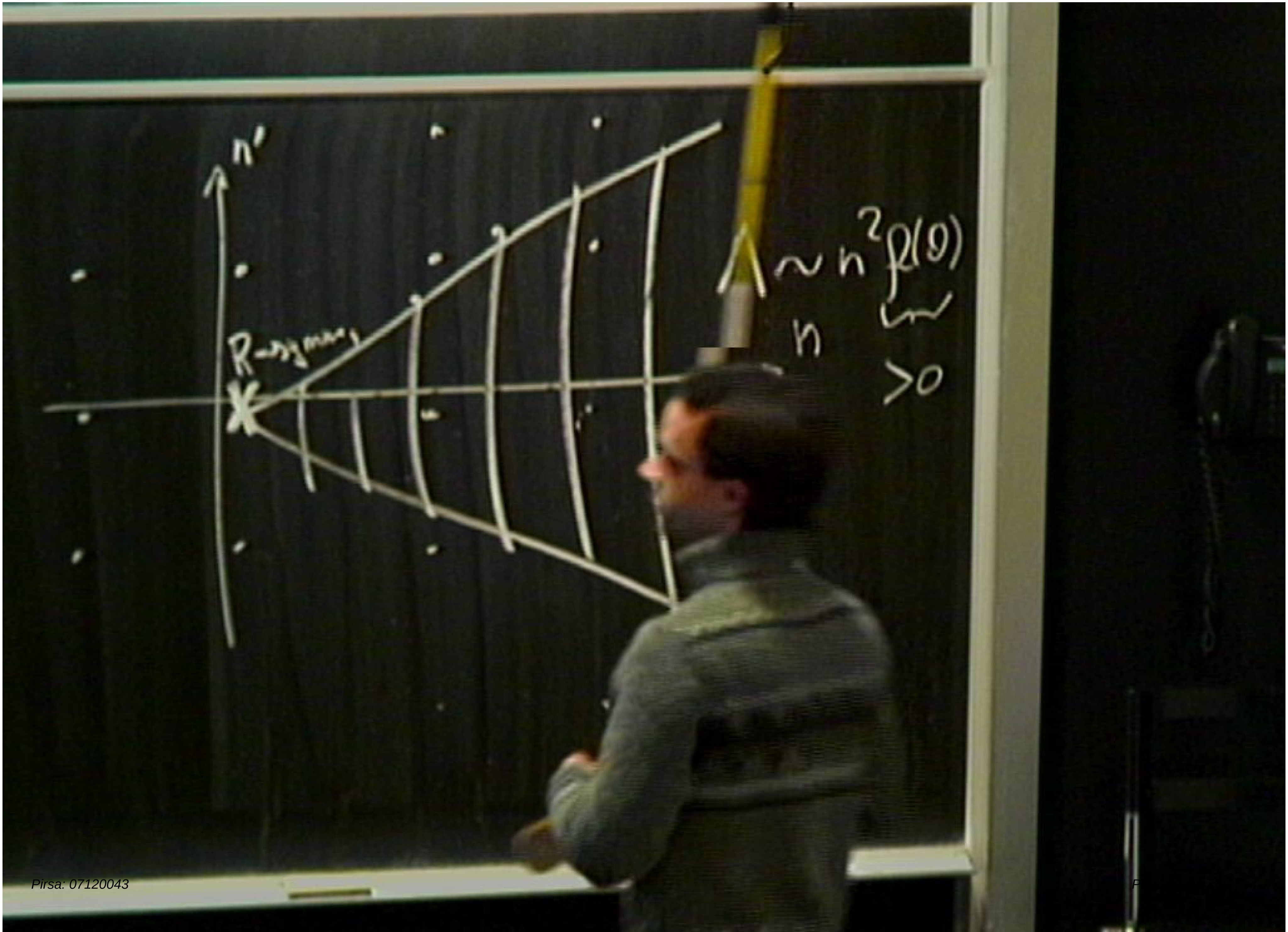
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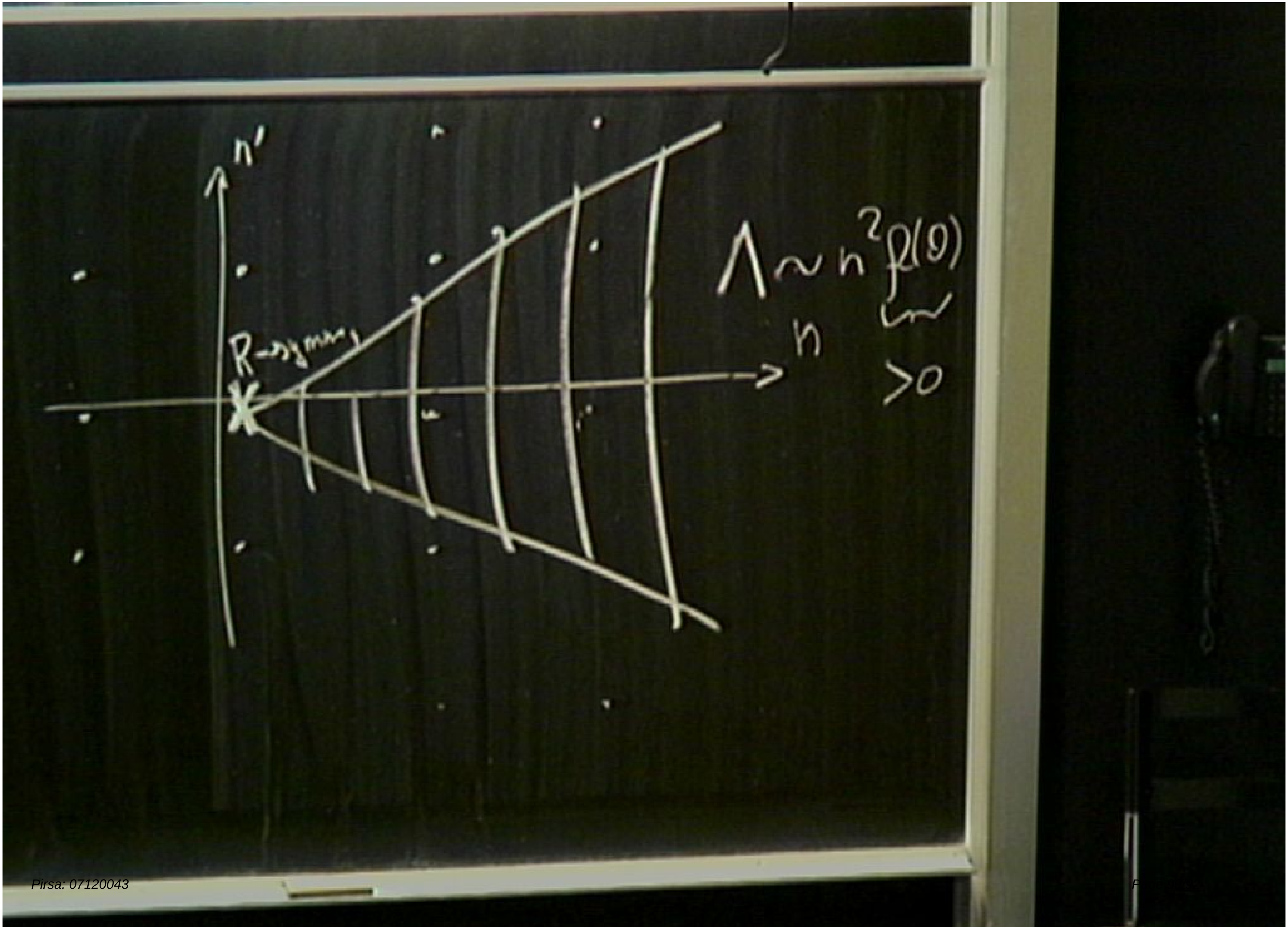

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