Title: SUSY Breaking in a Field Theory with a Dual

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Abstract: TBA

SUSY breaking in a field theory with a dual geometry

Dušan Simić

Stanford University

Based on: arxiv:1009.0023, 1009.3034; DS.

Supersymmetry:

- Candidate solution to the hierarchy problem of the electroweak theory.
- Naturally arises in string theory.

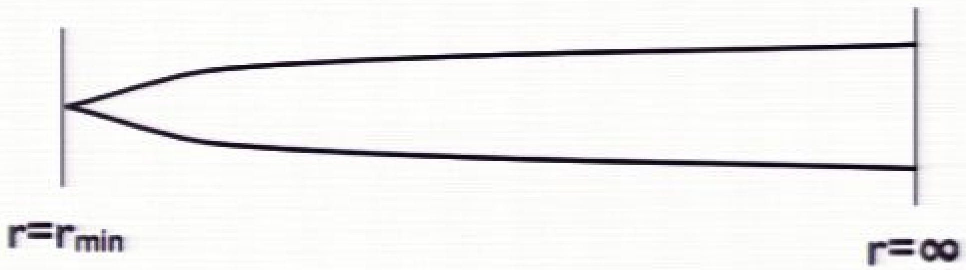
This makes it interesting to study susy breaking in a variety of contexts – in particular the exploration of new mechanisms.

Gauge-gravity duality:

$$\int_{\partial M} \mathrm{Tr} F^2 \sim \int_M \sqrt{-g} R$$

Allows for the approximate solution of a variety of quantum field theories at strong coupling through the study of classical gravity equations.

The field theory is dual to a warped throat geometry:



By the gauge-gravity correspondence string theory on a 10d non-compact warped throat geometrizes the renormalization group flow of a 4d field theory. If μ is the RG scale then:

$$\mu = r/l_s^2$$

where r is the radial coordinate of the throat.

Gravity dual of supersymmetry breaking:

Because the SUSY breaking is spontaneous by considerations in QFT the susy breaking effects should fall off as some power of $1/r$ away from the tip.

Thus the gravity dual of a field theory with a supersymmetry breaking vacuum (metastable or otherwise) is dual to a supersymmetric warped throat with a super-symmetry breaking region localized near the bottom.

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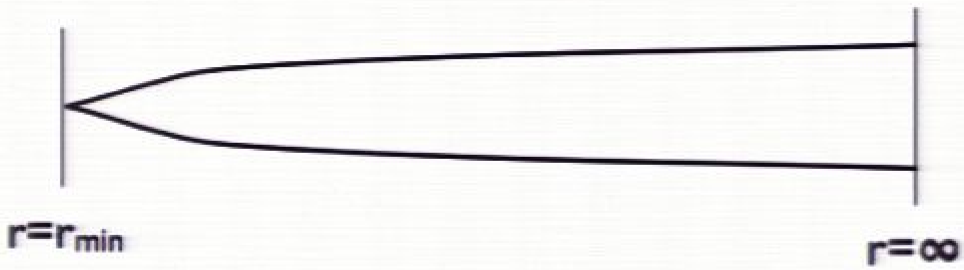

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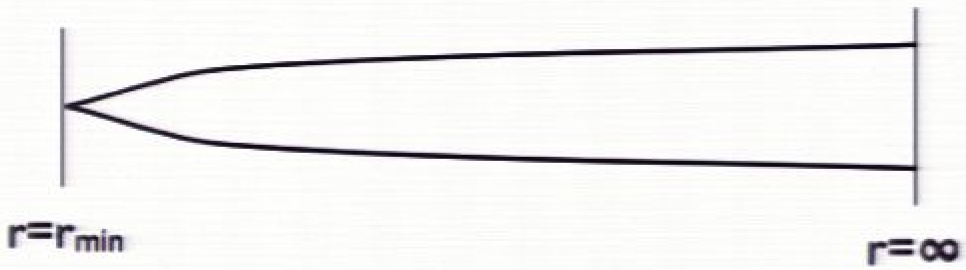

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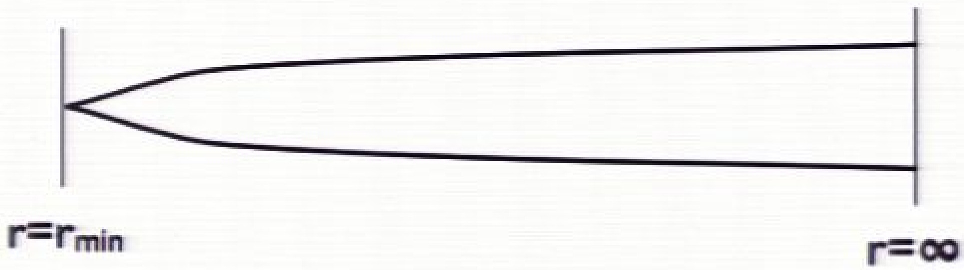

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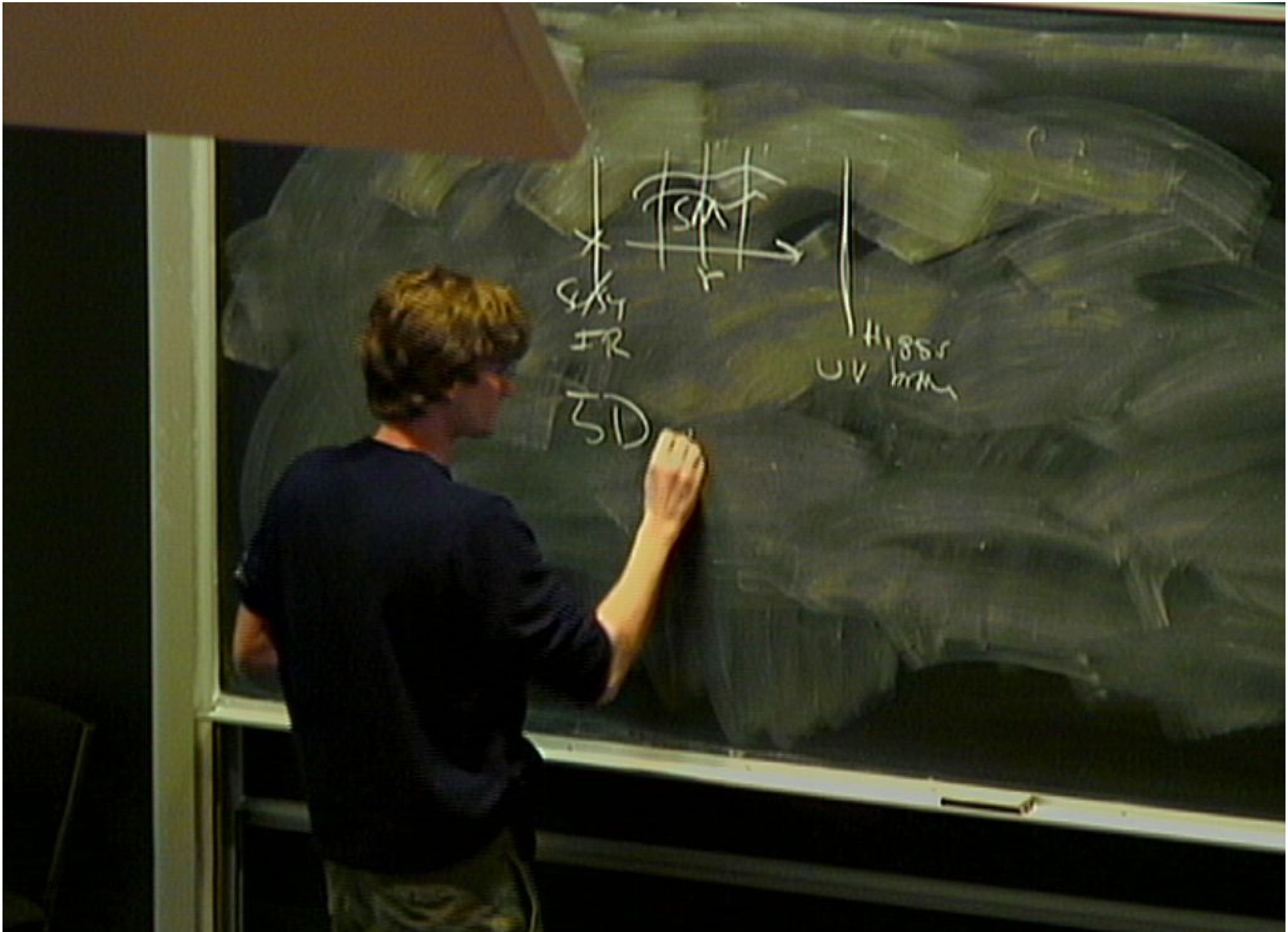
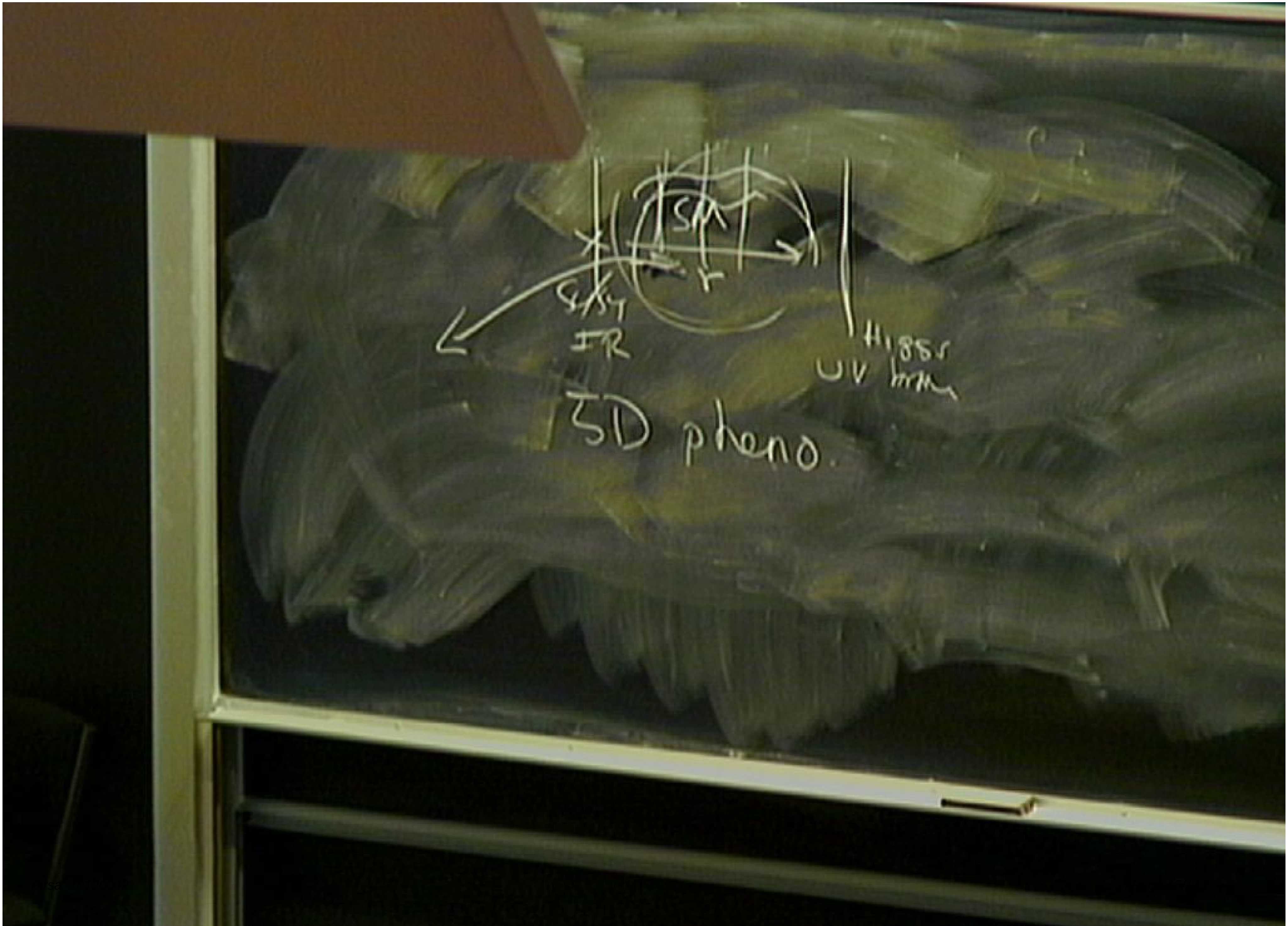
What are such objects good for?

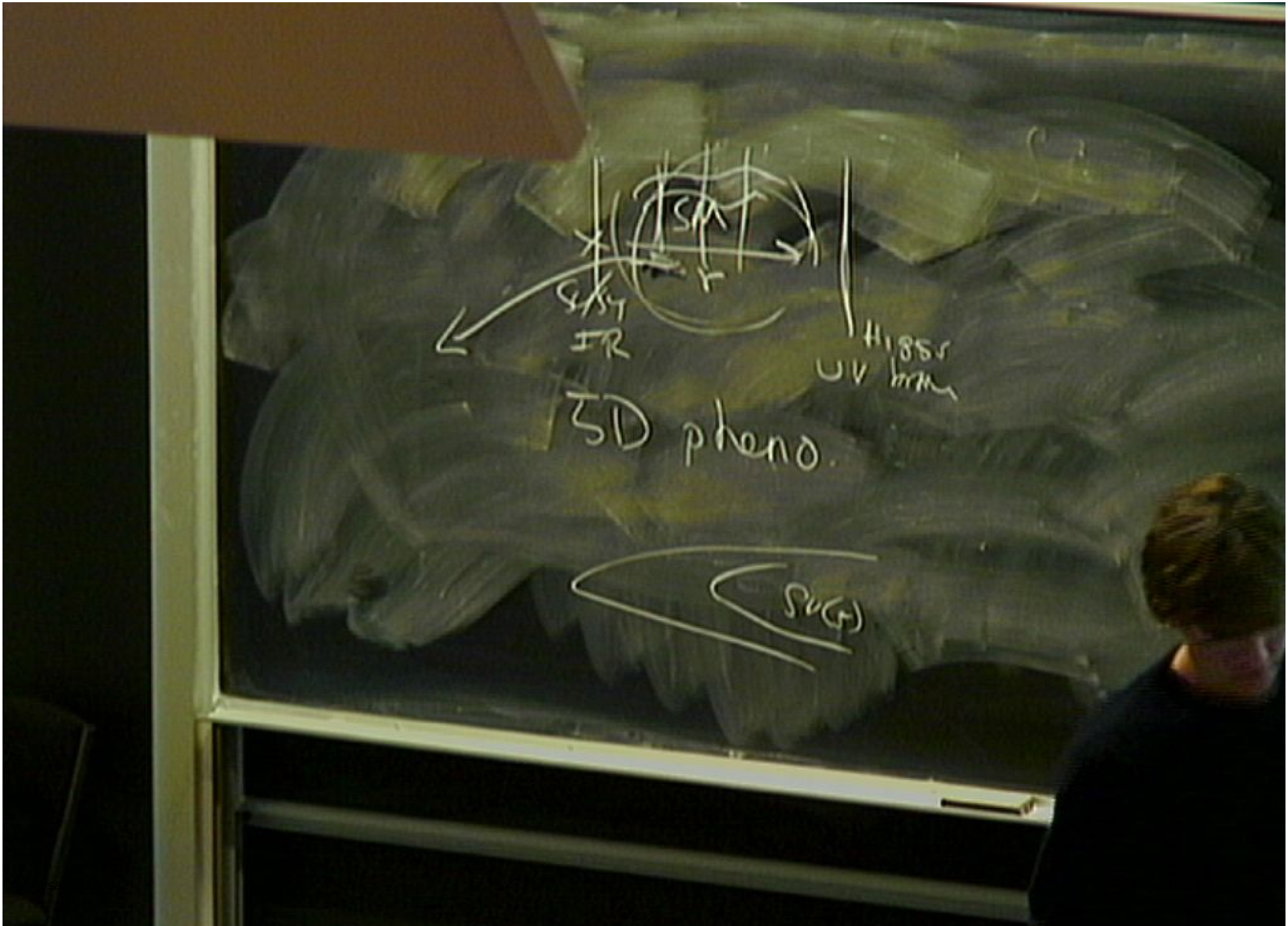
Warped model building from a top-down (microscopic) context:

- Models of particle physics. (Gherghetta et al; Benini, Dymarsky, Franco, Kachru, DS, Verlinde; ...) (Kachru, DS, Trivedi)
- Inflation.(Baumann, Dymarsky, Kachru, Klebanov, Maldacena, McAllister, ...)

So this is one reason to motivate this kind of a construction.


SM
SUSY
IR
5D
Higgs
UV


SM
IR
5D pheno.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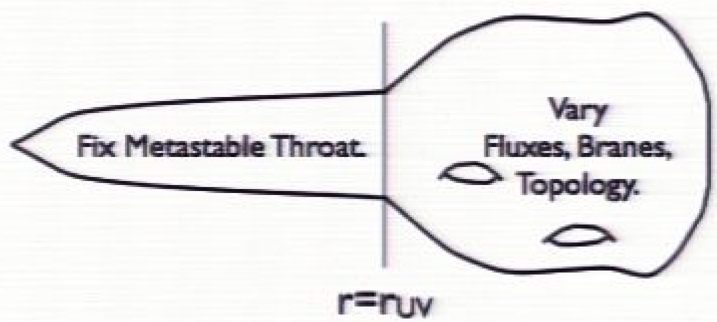
A second, related reason:

Throats can be compactified in a number of ways. A given throat may arise in a multitude of flux compactifications.



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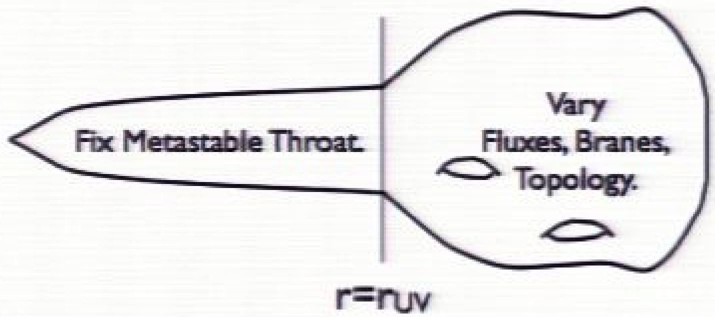

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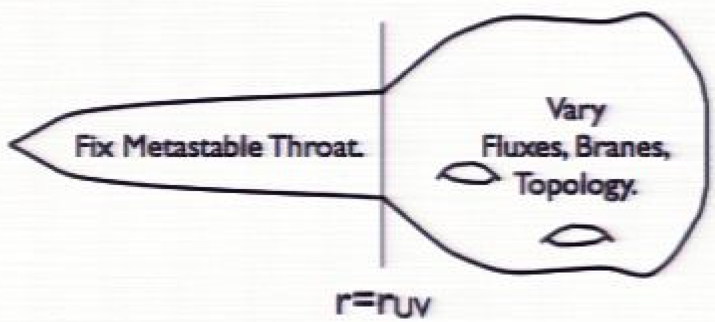

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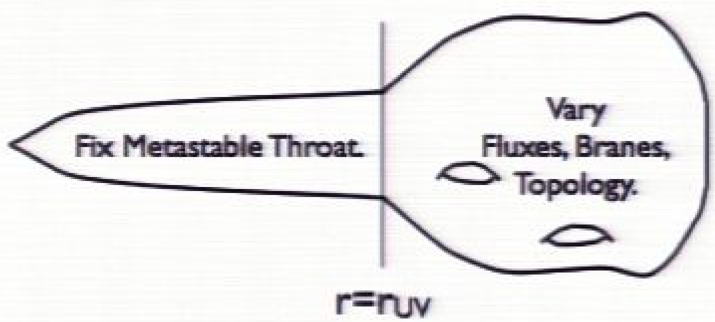

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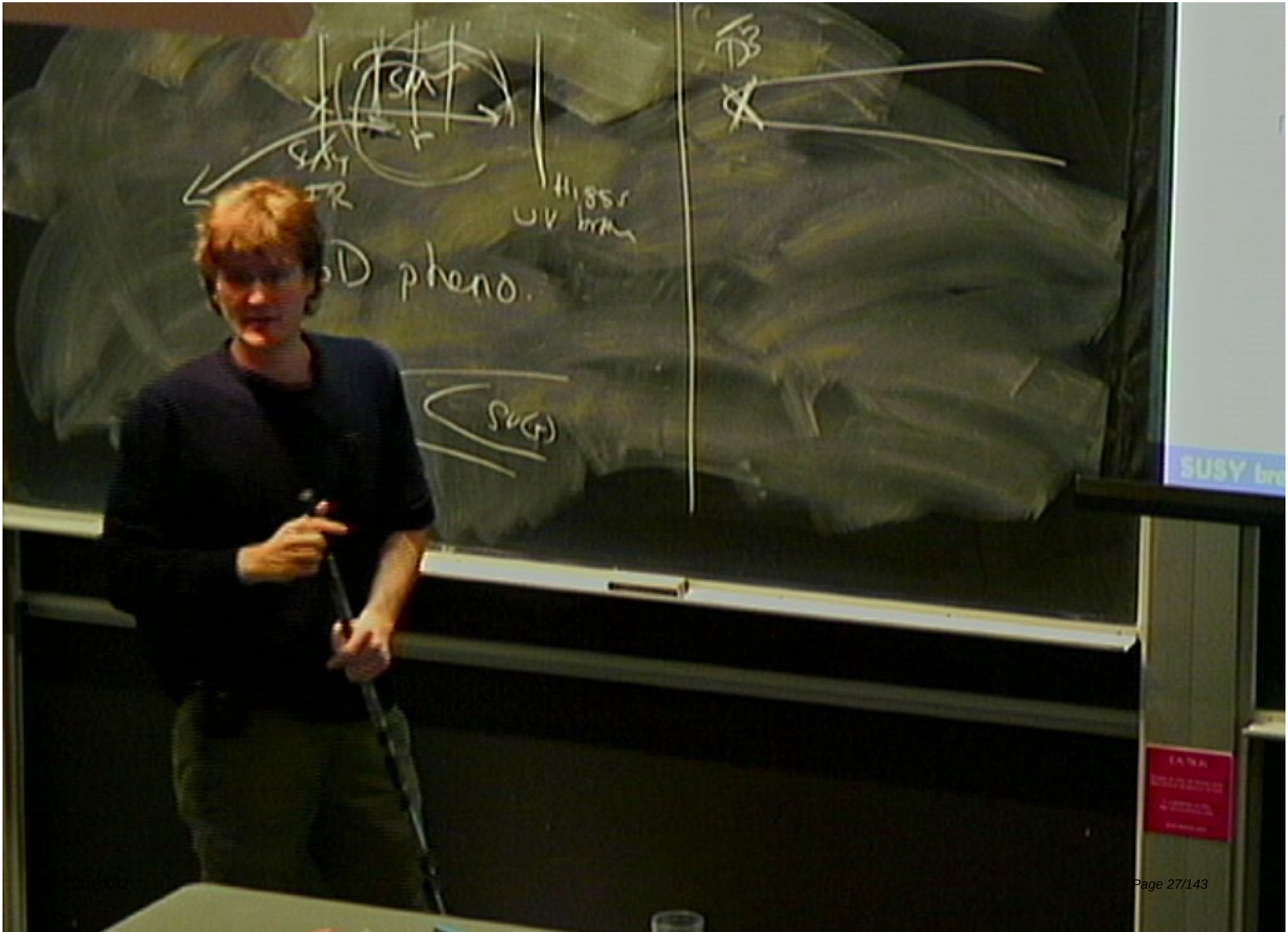
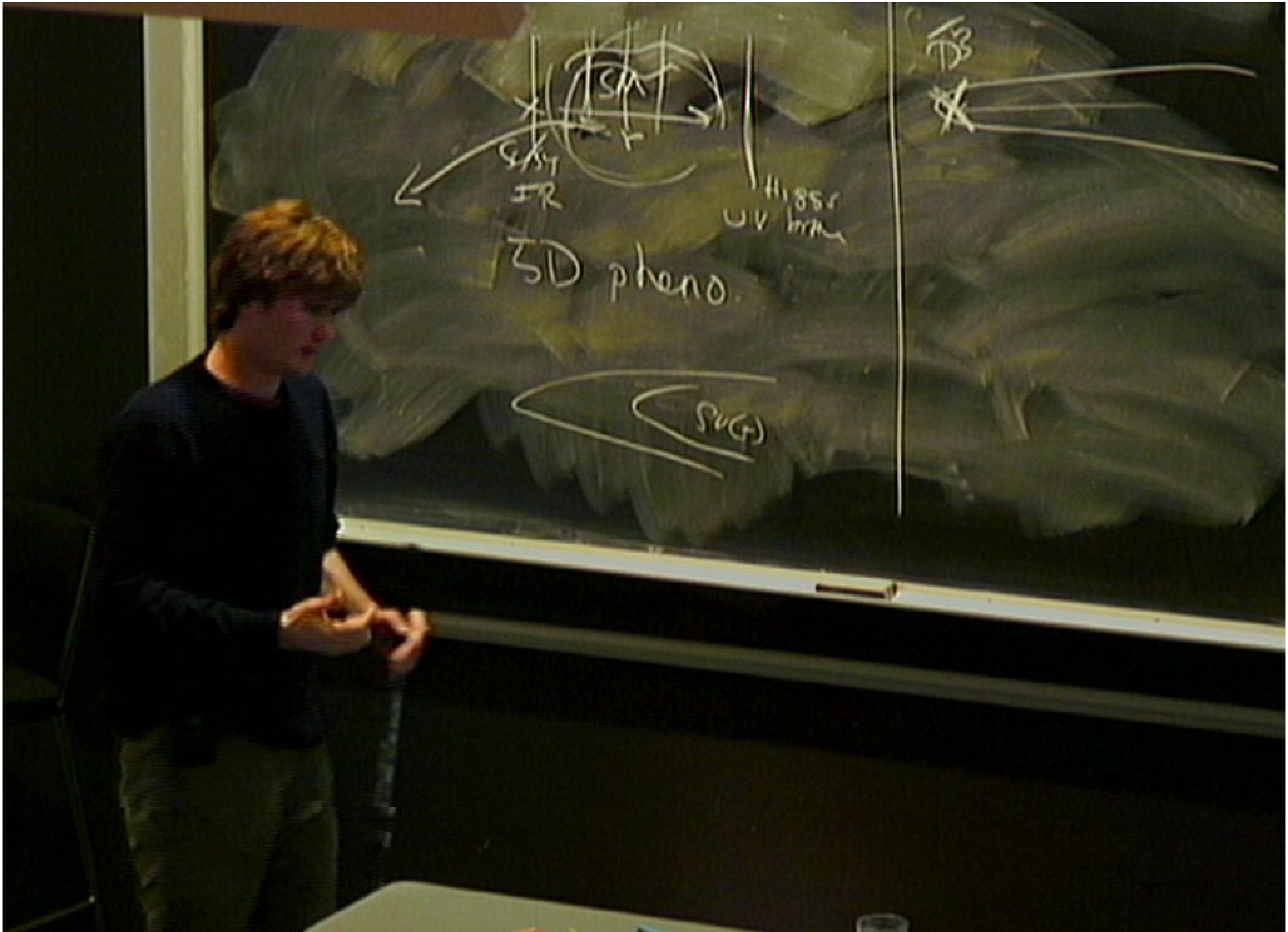
Currently there is already one class of examples which are strong candidates. This involves placing anti-branes at the bottom of an otherwise supersymmetric warped throat. (Kachru, Pearson & Verlinde '01)

Currently there is no understanding of this in terms of FT (all arguments on the gravity side).

This is a very interesting problem about which I won't say too much more about in this talk.


pheno.
SUSY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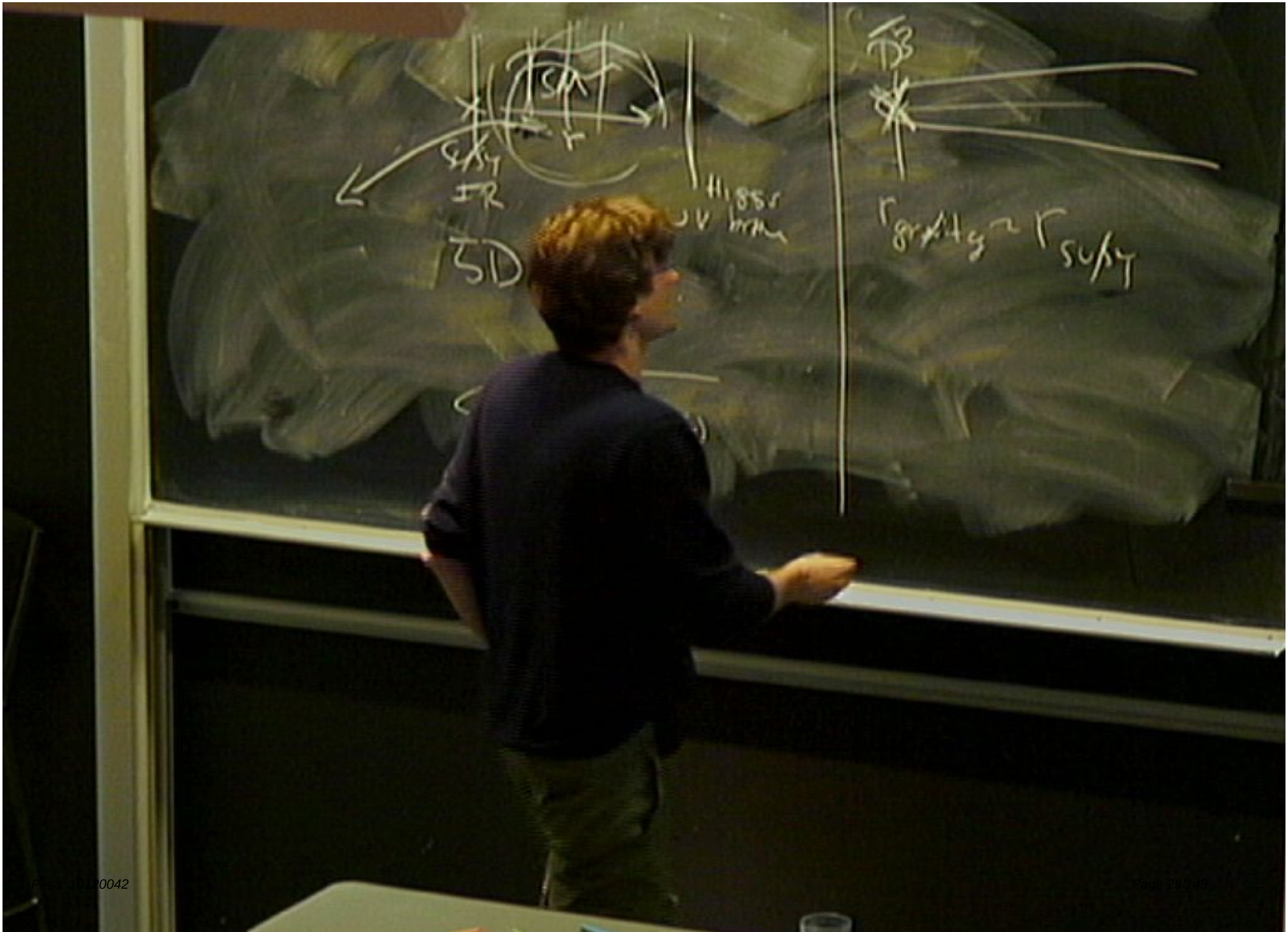
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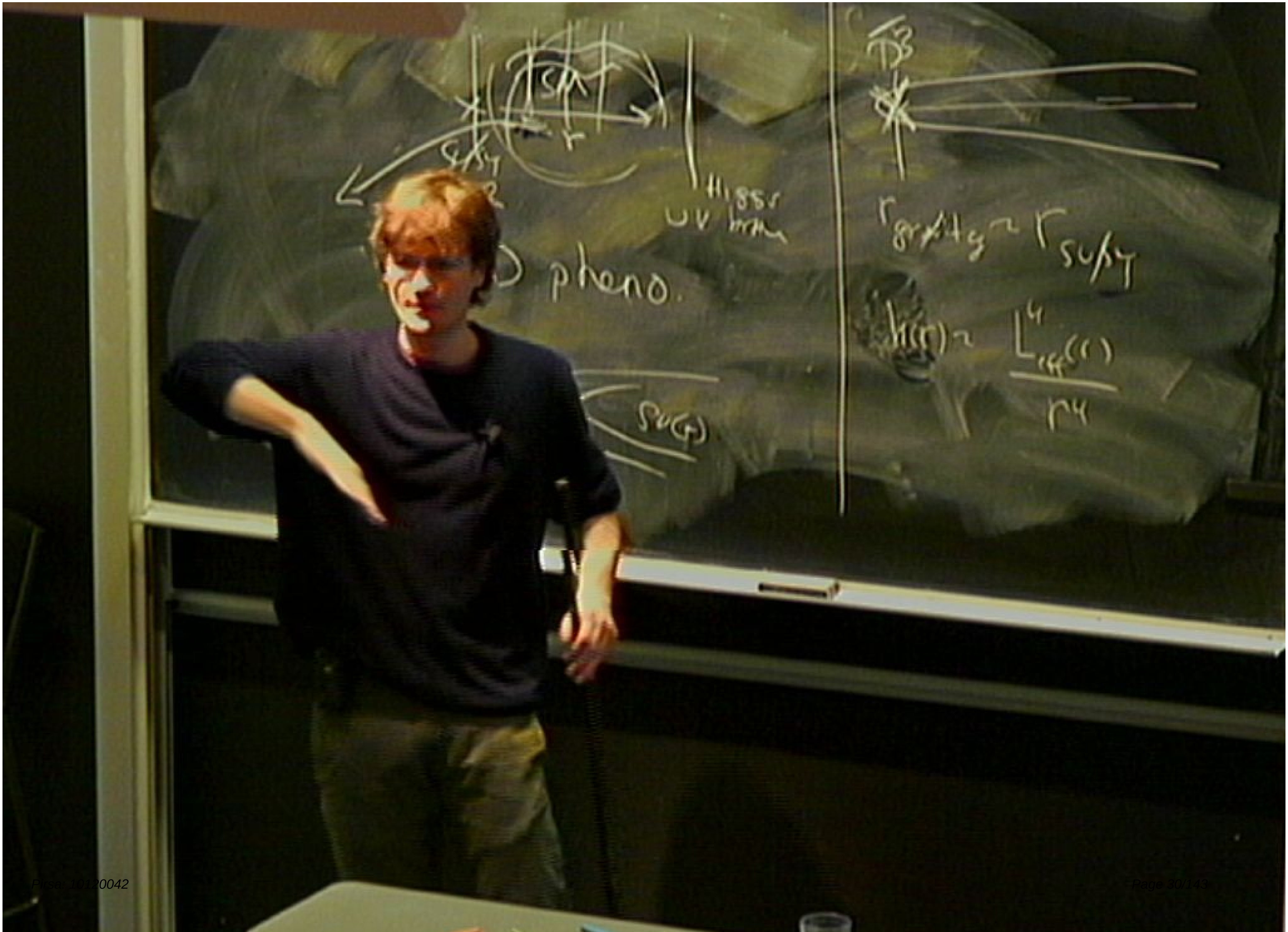
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Instead I will construct examples of warped throats with susy breaking whose existence can be argued from FT theory.

Constructing such new classes may be interesting because it may yield different phenomenology (low energy spectra may turn out to be different).

(also theoretically interesting.)

But why should this have any hope of working?

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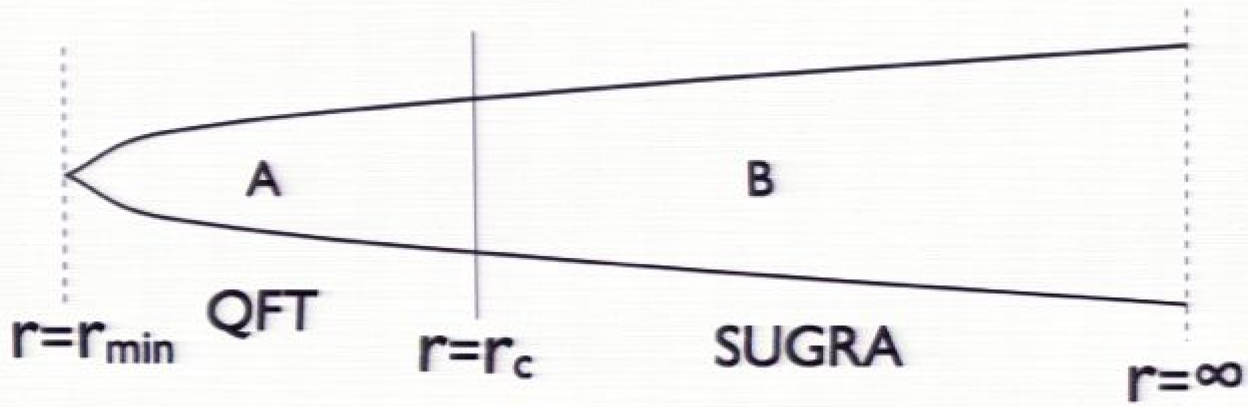
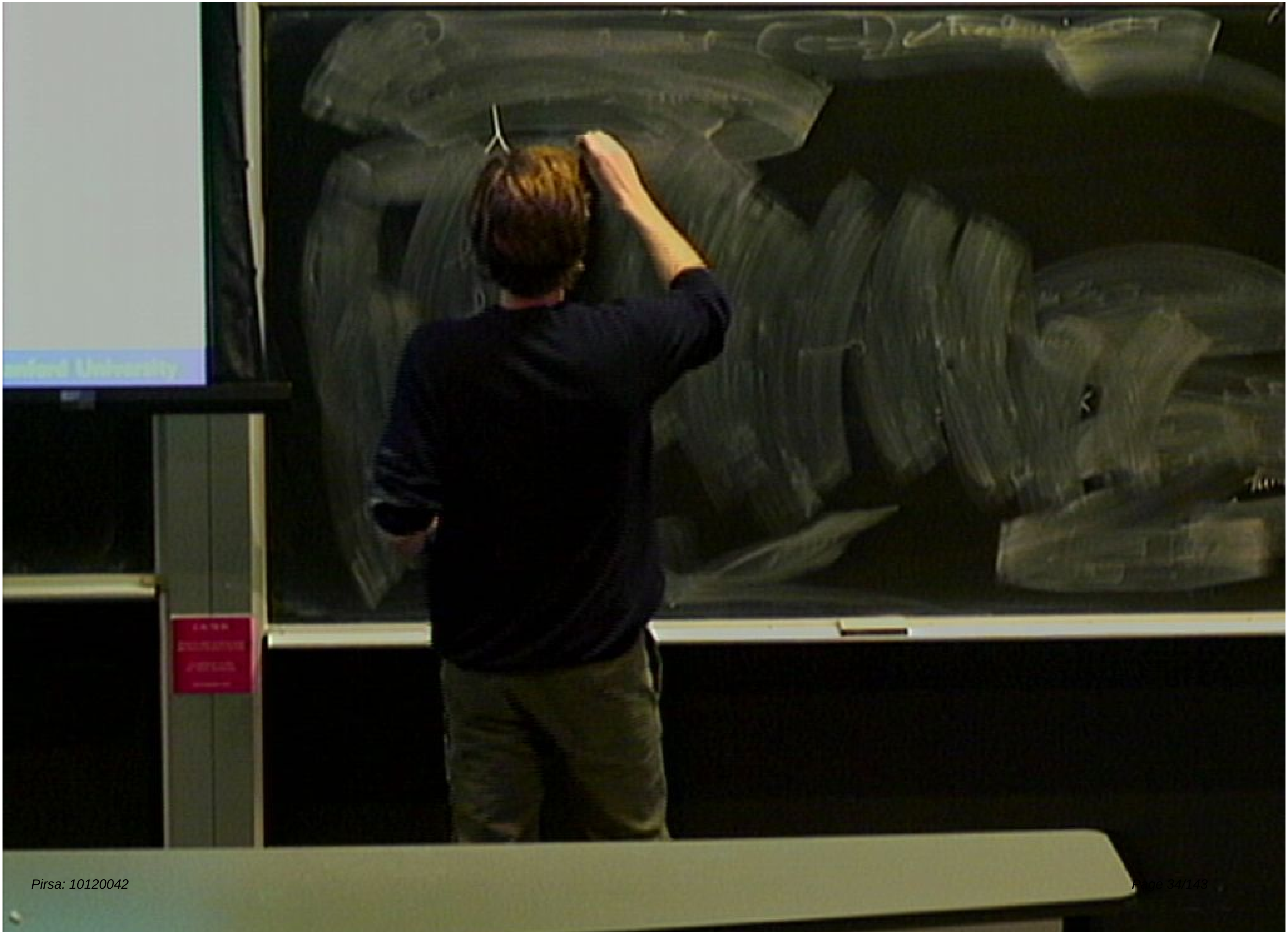
For this to work we need the following set-up:

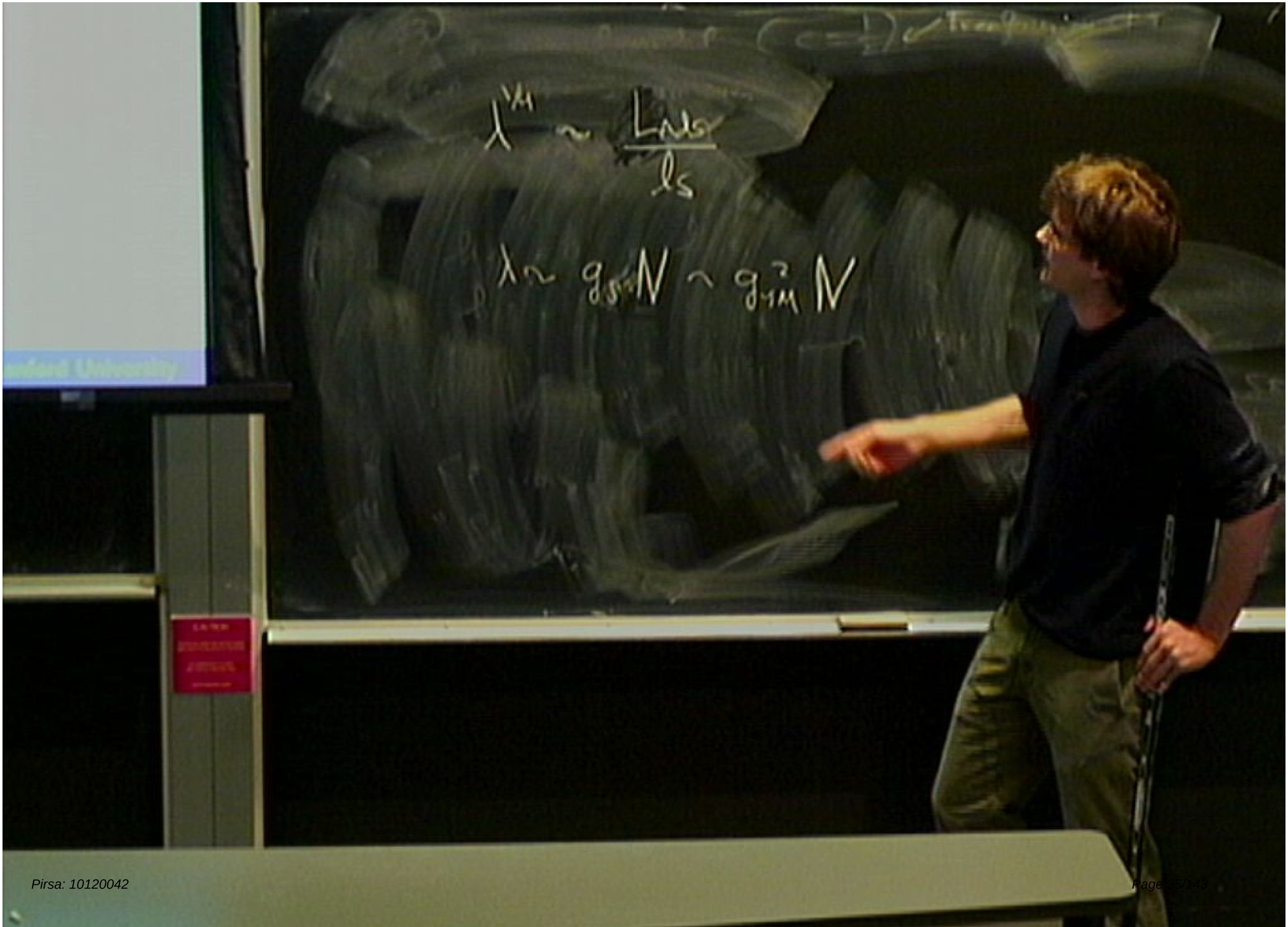


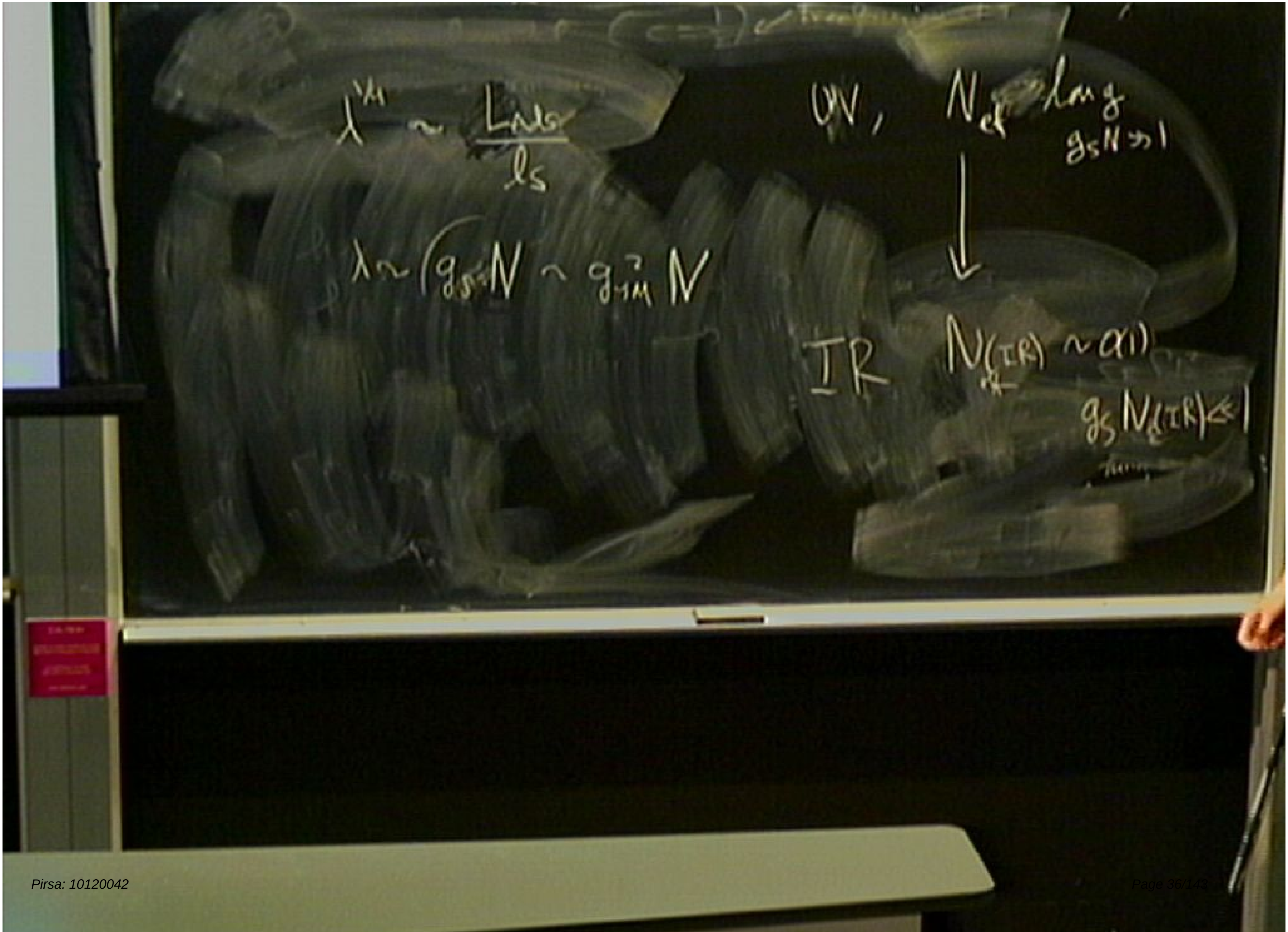
In region B supergravity is valid.

In region A perturbative quantum field theory is valid.

The supersymmetry breaking occurs deep within region A.




$\lambda^{1/4} \sim \frac{L_{AdS}}{l_s}$
$\lambda \sim g_s N \sim g_{YM}^2 N$


λ^{1/4} ~ L_AdS / l_s
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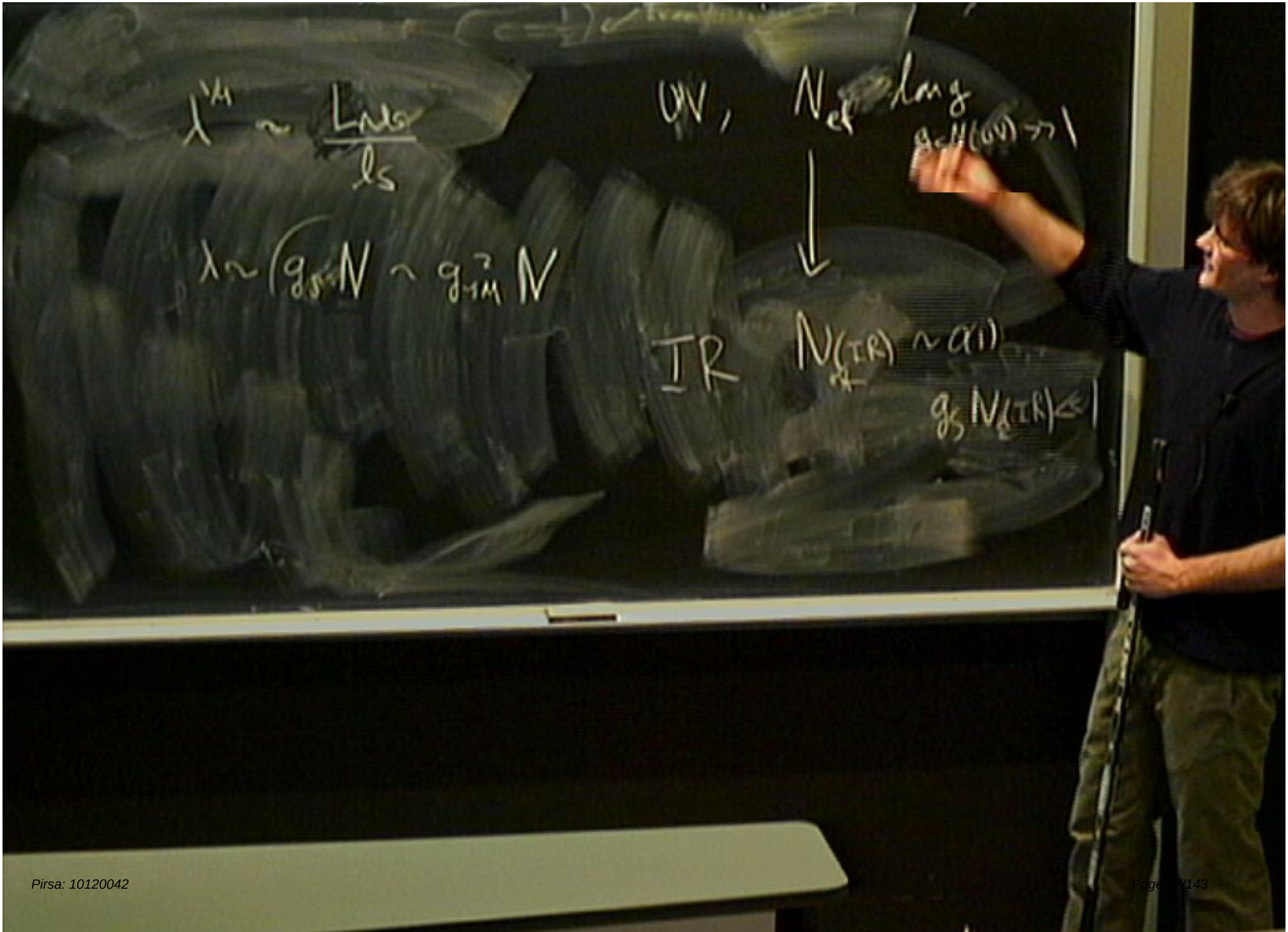
UV, N_eff large
g_s N >> 1
IR N_eff(IR) ~ O(1)
g_s N_eff(IR) << 1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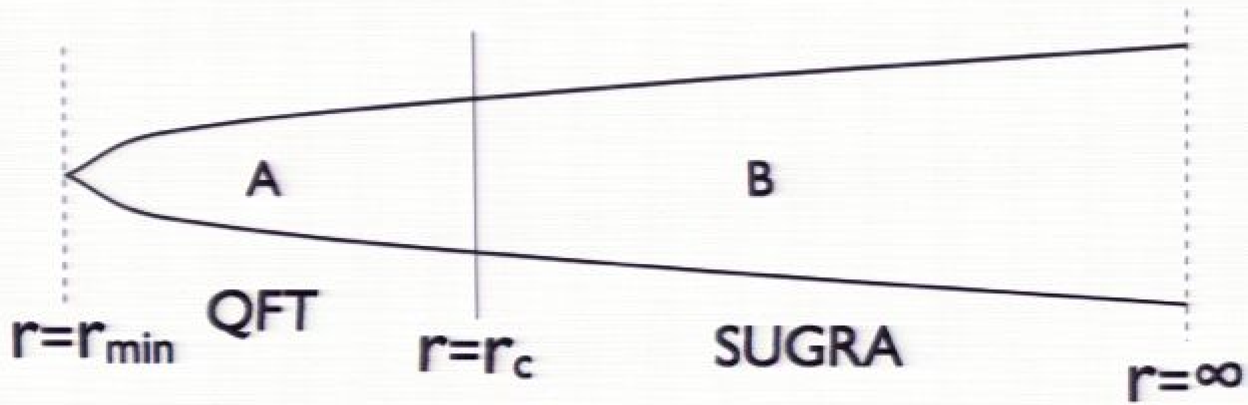

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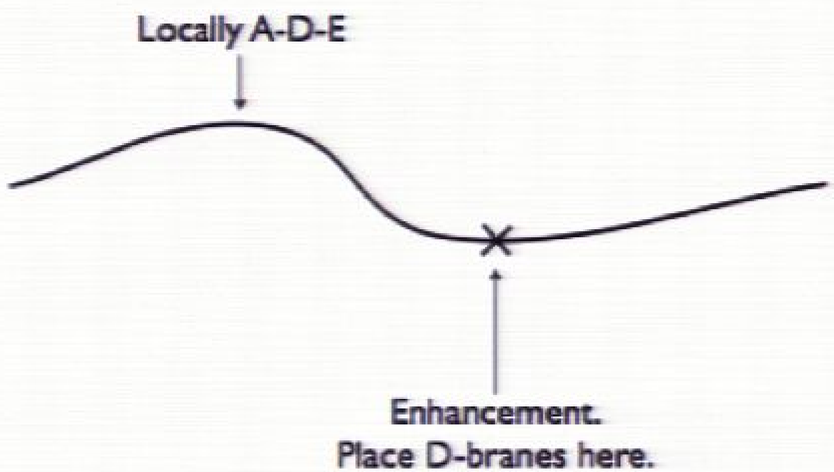
How to proceed?

A large class of supersymmetry breaking configurations in string theory can be achieved by placing a small number of fractional branes at non-isolated singularities.(Buican, Malyshev and Verlinde '08)



Give rise to quiver gauge theories with metastable susy breaking vacua.

An example of a field theory constructed in such a manner:

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Φ	adj	1	1
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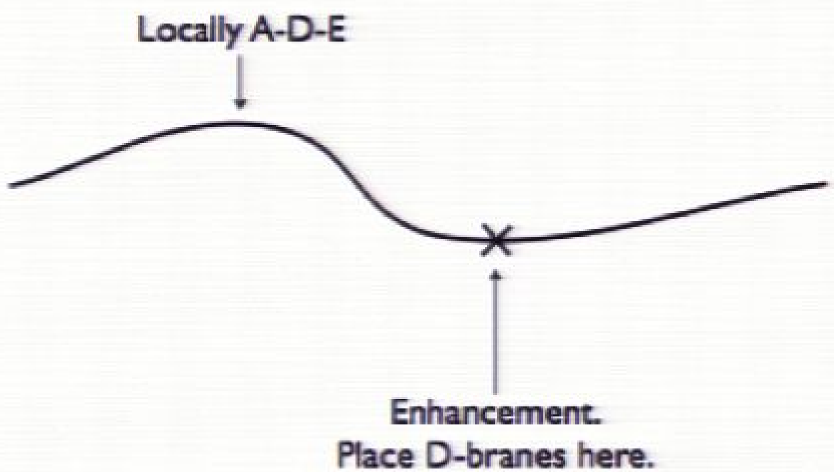

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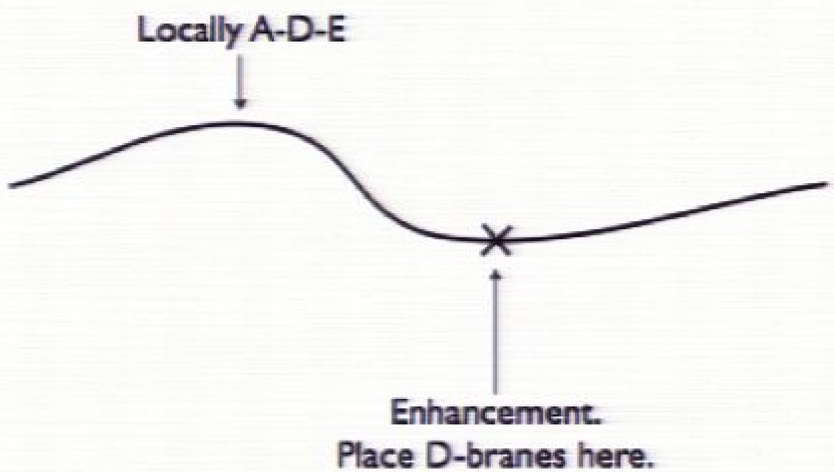

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When $M_1 > M_2 + M_3$, the F-term constraint:

$$\frac{\partial \mathcal{W}}{\partial \Phi} = \tilde{Y} Y - X \tilde{X} - \xi = 0, \tag{2}$$

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However, such models provide "target models" to realize as the endpoint of a cascade. The latter is engineered to have a description in terms of supergravity above some scale much larger than the scale of supersymetry breaking and a calculable field theory description below it.

The ranks gradually decrease until the effective 't Hooft coupling is small and the dual geometry becomes highly curved.

In the ultra-violet, we start with the model:

$\mathcal{G}$	$U(N)_1$	$U(N+M_2)_2$	$U(N+M_3)_3$
Φ	adj	1	1
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with $N >> M_2, M_3$.

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As we flow towards the infrared, the ranks should gradually reduce due to a sequence of dualities to the small rank version which is itself weakly coupled and known to harbor a supersymmetry breaking vacuum.

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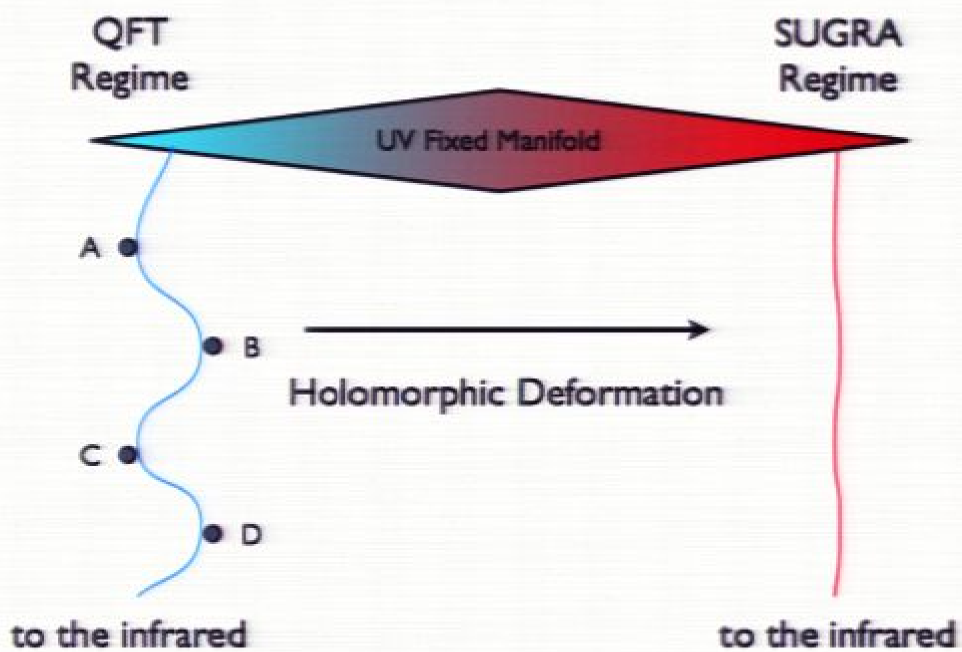

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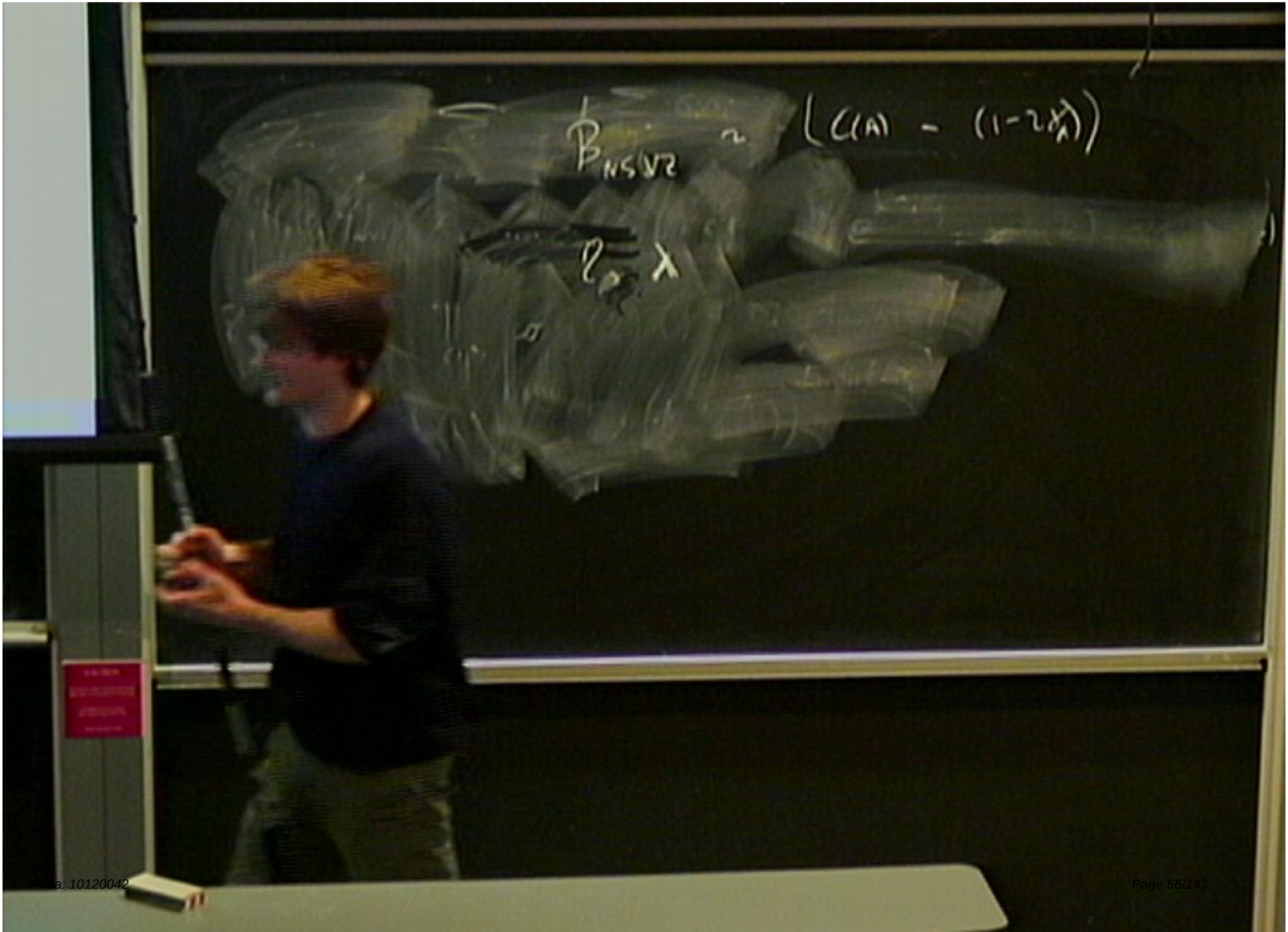

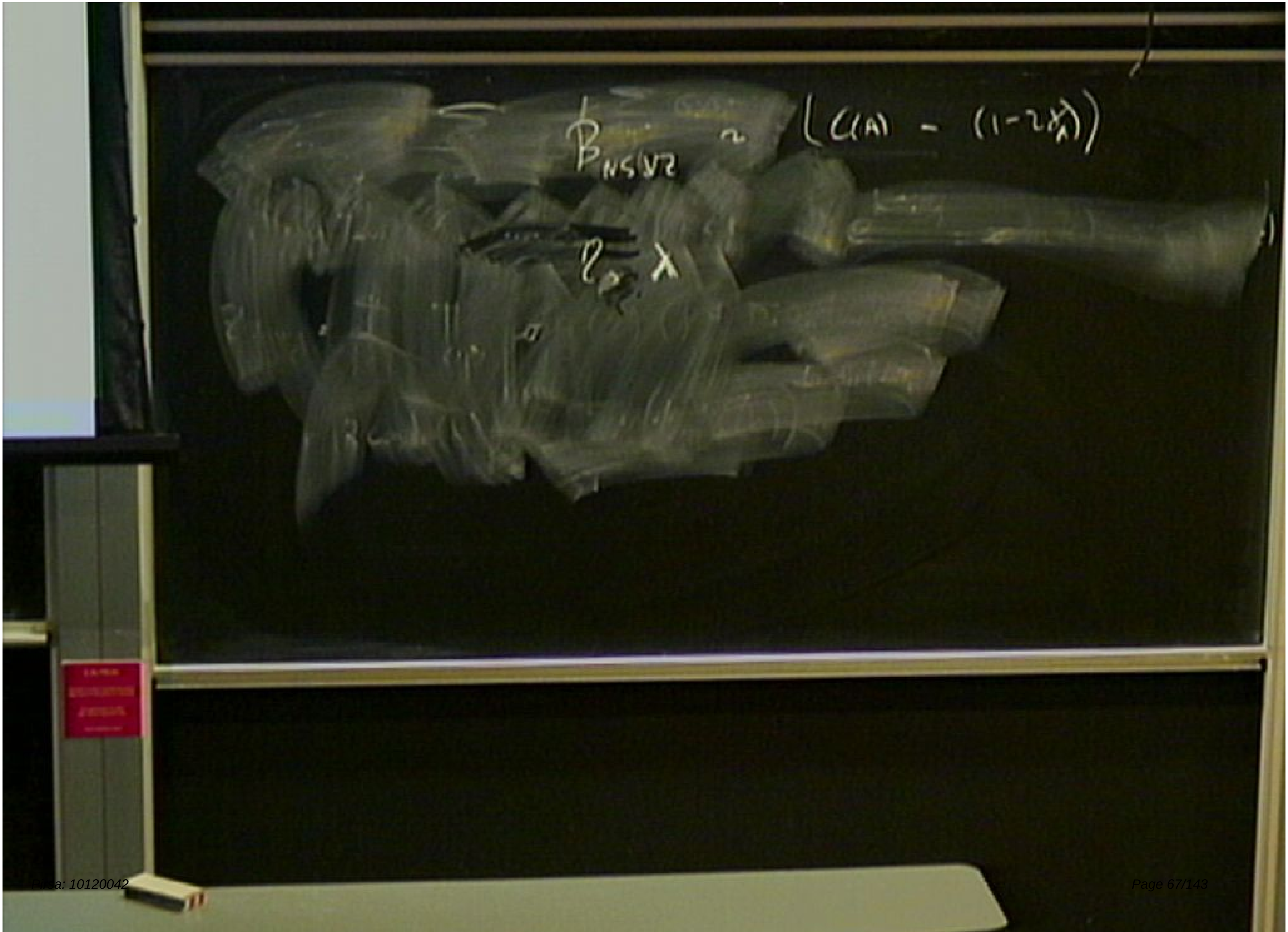

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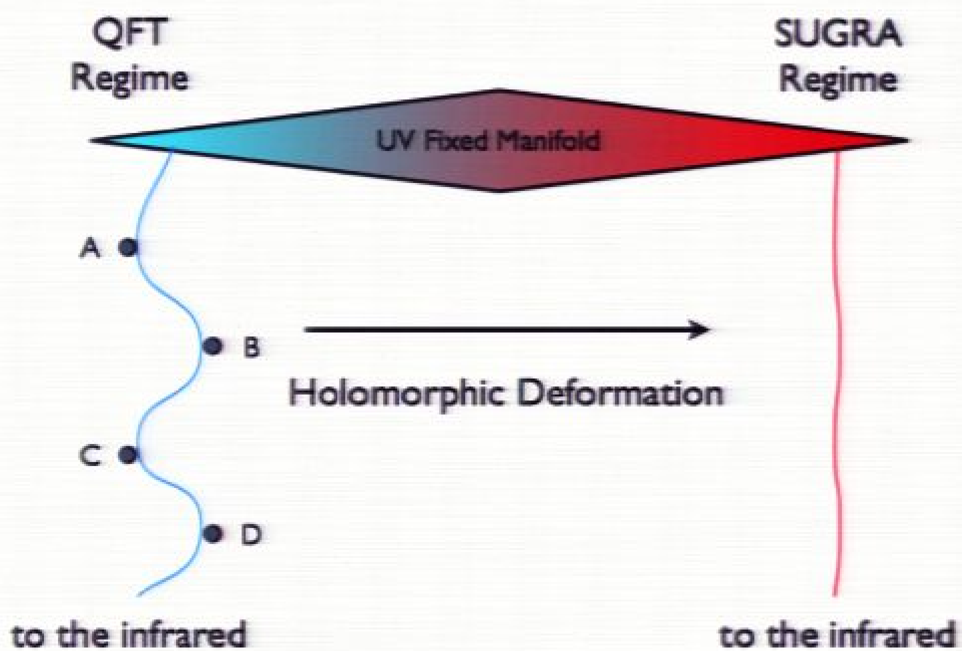

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Having weakly coupled field theory descriptions, these constructions are not directly dual to weakly curved geometries.

However, such models provide "target models" to realize as the endpoint of a cascade. The latter is engineered to have a description in terms of supergravity above some scale much larger than the scale of supersymetry breaking and a calculable field theory description below it.

The ranks gradually decrease until the effective 't Hooft coupling is small and the dual geometry becomes highly curved.

When $M_1 > M_2 + M_3$, the F-term constraint:

$$\frac{\partial \mathcal{W}}{\partial \Phi} = \tilde{Y} Y - X \tilde{X} - \xi = 0, \tag{2}$$

cannot be satisfied due to a mismatch of ranks, and thus SUSY is broken.

The resulting vacuum is "stabilized" by a one-loop effective potential (all scalars which are not Goldstones get a positive mass squared at one loop) when the couplings are weak. (Intriligator, Seiberg & Shih '07)

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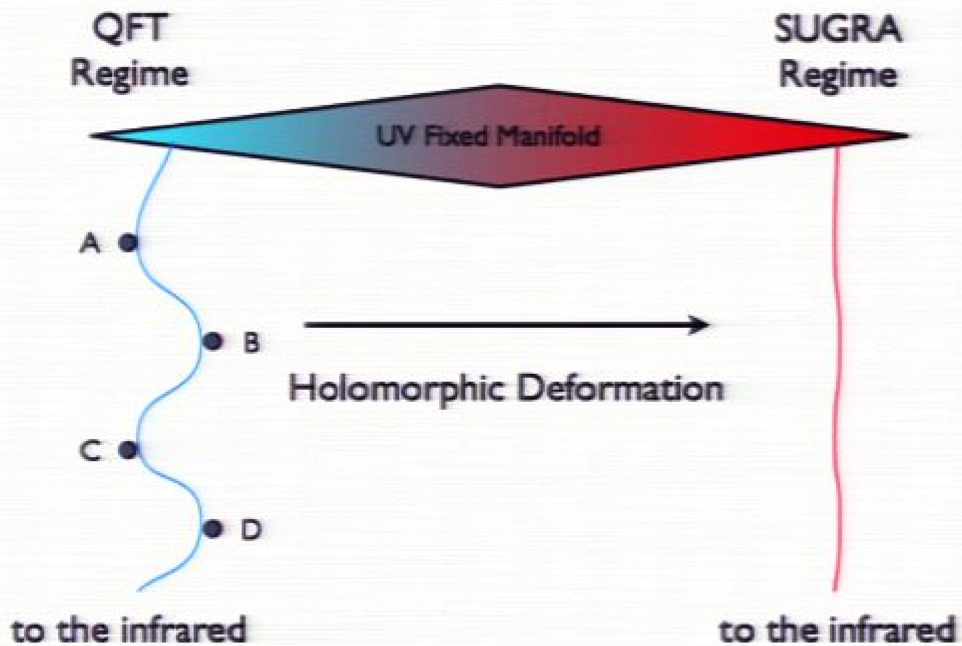

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The adjoint node formally has the matter content of an $\mathcal{N}=2$ theory, and the adjoint has the usual $\mathcal{N}=2$-like cubic superpotential couplings to the rest of the theory.

This leads to the prescription that the strong coupling singularity of an adjoint node at a cascade in a general non-isolated singularity is dealt with by approximating the strongly coupled adjoint node by N=2 SQCD on its Coulomb branch.

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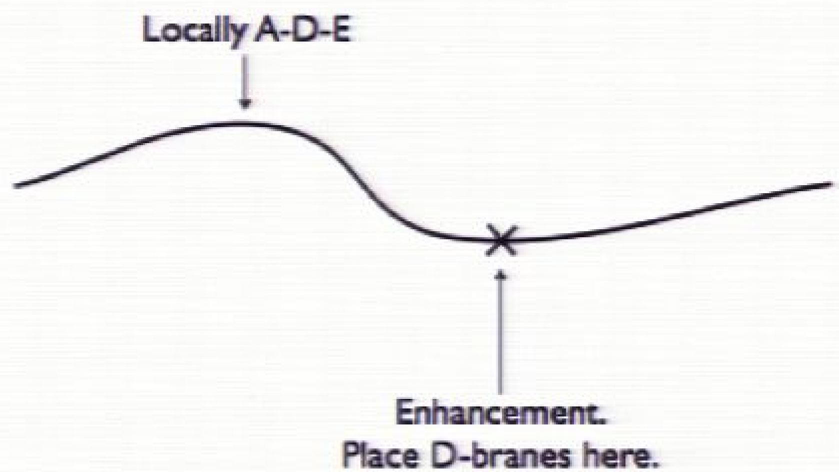
A large class of supersymmetry breaking configurations in string theory can be achieved by placing a small number of fractional branes at non-isolated singularities.(Buican, Malyshev and Verlinde '08)



Give rise to quiver gauge theories with metastable susy breaking vacua.

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An example of a field theory constructed in such a manner:

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It arises at the so-called "suspended-pinch-point singularity" (SPP). (actually a deformation thereof.)

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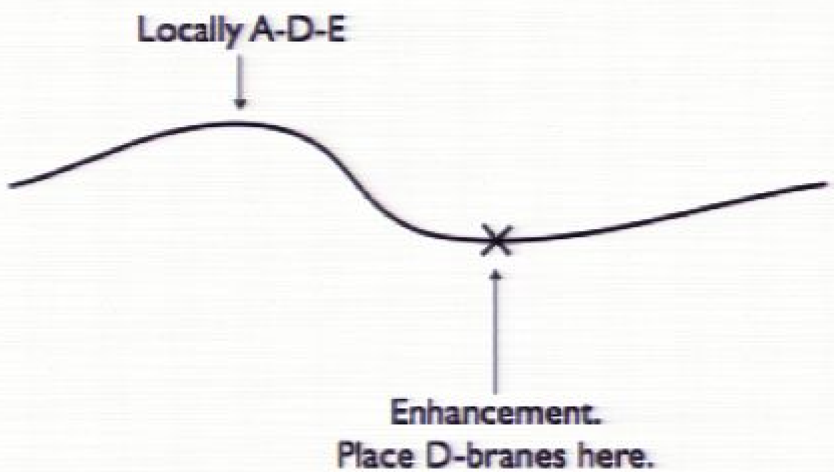

Give rise to quiver gauge theories with metastable susy breaking vacua.

An example of a field theory constructed in such a manner:

$\mathcal{G}$	$U(M_1)_1$	$U(M_2)_2$	$U(M_3)_3$
Φ	adj	1	1
$X, \tilde{X}$	$\square, \bar{\square}$	1	$\bar{\square}, \square$
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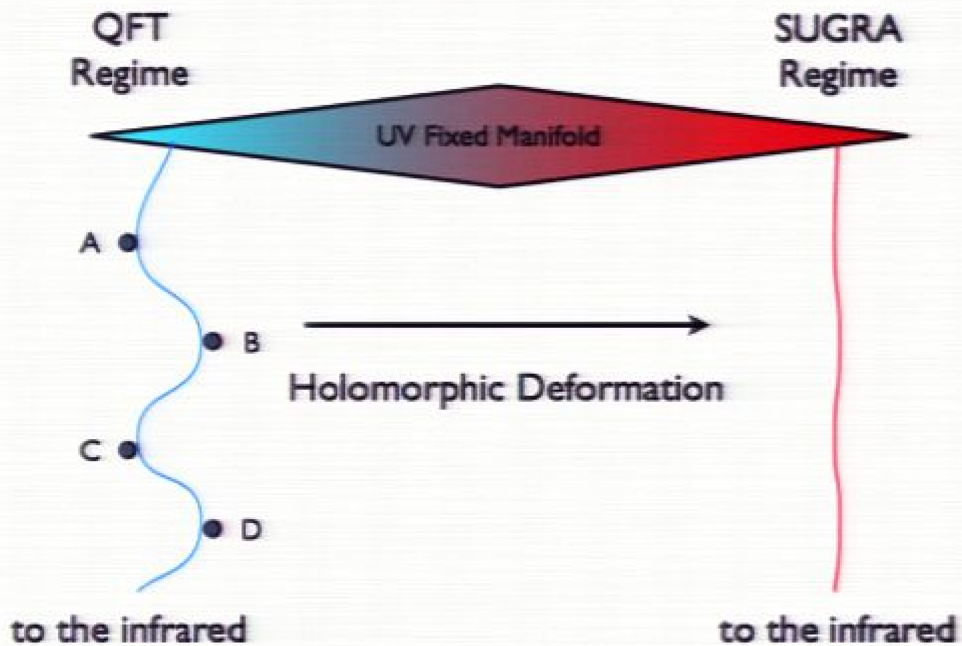
When $M_1 > M_2 + M_3$, the F-term constraint:

$$\frac{\partial \mathcal{W}}{\partial \Phi} = \tilde{Y} Y - X \tilde{X} - \xi = 0, \tag{2}$$

cannot be satisfied due to a mismatch of ranks, and thus SUSY is broken.

Basic strategy of solution:



Because supersymmetric gauge theories undergo no phase transitions - we can study the fate of the adjoint coupling singularities in the QFT regime. **

Result: Approximate the strongly coupled adjoint node by N=2 SQCD on its Coulomb branch.

This could have been expected, as there is suggestive $\mathcal{N}=2$ structure in quiver gauge theories arising at non-isolated singularities. This is easily seen in SPP:

$$\mathcal{W} = \mathrm{Tr}\{\Phi\tilde{Y}Y\} - \mathrm{Tr}\{\Phi X\tilde{X}\} + \mathrm{Tr}\{Z\tilde{Z}\tilde{X}X - \tilde{Z}ZY\tilde{Y}\} - \xi\mathrm{Tr}\{\Phi - \tilde{Z}Z\}. \quad (5)$$

The adjoint node formally has the matter content of an $\mathcal{N}=2$ theory, and the adjoint has the usual $\mathcal{N}=2$-like cubic superpotential couplings to the rest of the theory.

This leads to the prescription that the strong coupling singularity of an adjoint node at a cascade in a general non-isolated singularity is dealt with by approximating the strongly coupled adjoint node by N=2 SQCD on its Coulomb branch.

Having weakly coupled field theory descriptions, these constructions are not directly dual to weakly curved geometries.

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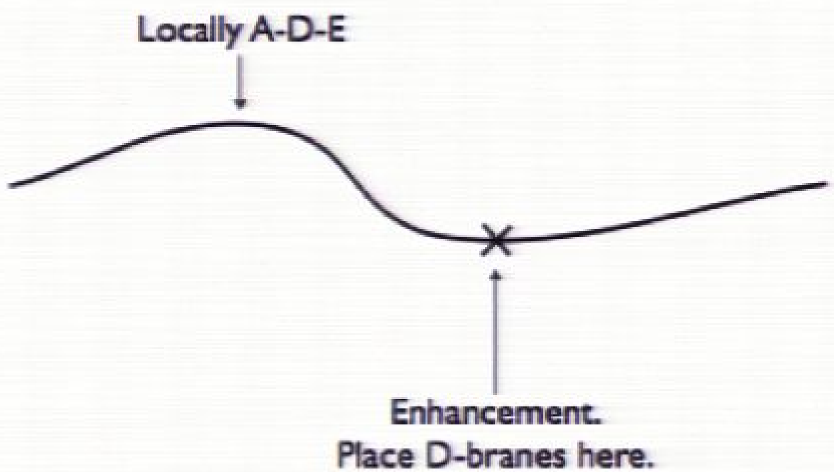

Give rise to quiver gauge theories with metastable susy breaking vacua.

This is due to the self-similar nature of duality cascades. When a gauge coupling hits a strong coupling singularity one performs a Seiberg duality, bringing the theory back to a similar form, except with reduced ranks.

$\mathcal{G}$	$U(N''-M_2)_1$	$U(N'')_2$	$U(N''-M_1)_3$
Φ	1	adj	1
$z, \tilde{z}$	$\square, \overline{\square}$	1	$\overline{\square}, \square$
$X, \tilde{X}$	$\overline{\square}, \square$	$\square, \overline{\square}$	1
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Here: $N'' = N - M_2$.

However, this does not apply when the gauge coupling hitting the singularity is one under-which the adjoint is charged, as Seiberg duality does not hold.

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Furthermore, the generic cascade is bound to hit such strong coupling singularities every $O(1)$ cascade steps, and all cascades based on non-isolated singularities seem to have this feature. (Argurio et al; Franco et al; DS)

Therefore in order to derive the low energy field theory and prove that it harbors a metastable vacuum, these strong coupling singularities in the adjoint nodes must be understood.

This leads to the prescription that the strong coupling singularity of an adjoint node at a cascade in a general non-isolated singularity is dealt with by approximating the strongly coupled adjoint node by N=2 SQCD on its Coulomb branch.

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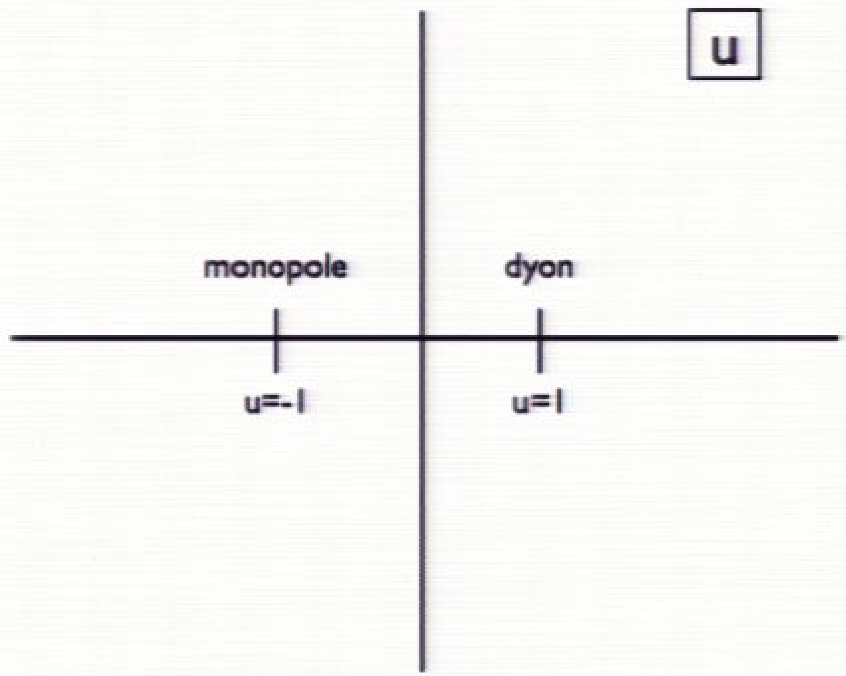
Earlier work on SUGRA side. (Argurio, Benini, Bertolini, Closset & Cremonesi)

**

In asymptotically free N=2 SQCD theories, the strong coupling singularity is resolved by the spontaneous breakdown of the gauge group to a conformal or infra-red free subgroup.

Seiberg-Witten ($\mathcal{N} = 2$ SU(2) SYM):



where $u \sim \mathrm{Tr}\ \phi^2$.

N=2 SQCD has rich Coulomb branch, with special monopole points.

In the generalization to $SU(N_c)$ the coulomb branch is locally $\mathbb{C}^{N_c-1}$, and is coordinatied by:

$$\vec{u} = (\mathrm{Tr}\ \phi^2, \mathrm{Tr}\ \phi^3, \dots) \tag{6}$$

And N=2 SQCD has rich a Coulomb branch, with special monopole points, just as in Seiberg-Witten, except more complexity. There is also a Seiberg-Witten curve:

$$y^2 = \prod_{i=1}^{N_c} (x - \phi_i)^2 + 4\Lambda^{2N_c - N_f} x^{N_f} \tag{7}$$

Remarkably, in a large class of examples, it can be shown that the deformation to the N=1 theories we are interested in introduces only trivial corrections to this curve. Thus the flat moduli directions and the special monopole points survive in the N=1 theory.

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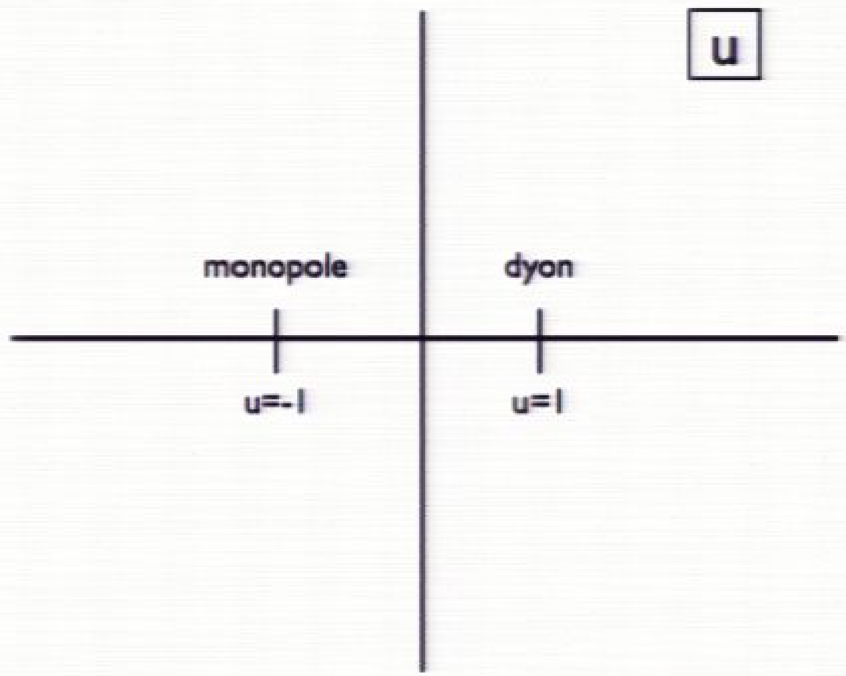

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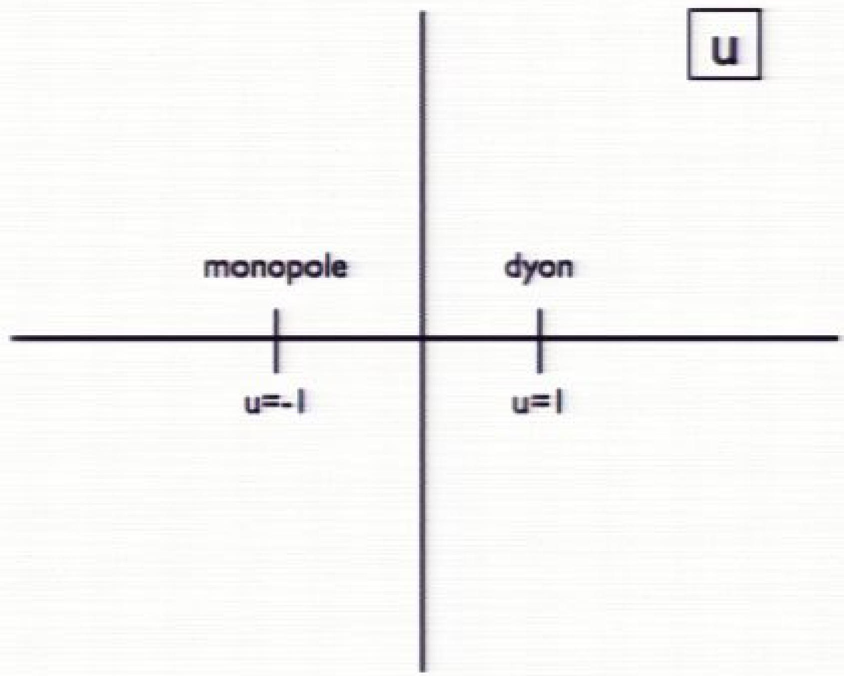

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Let's take it from the top again. In the ultra-violet, we start with the model:

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with $N >> M_2, M_3$.

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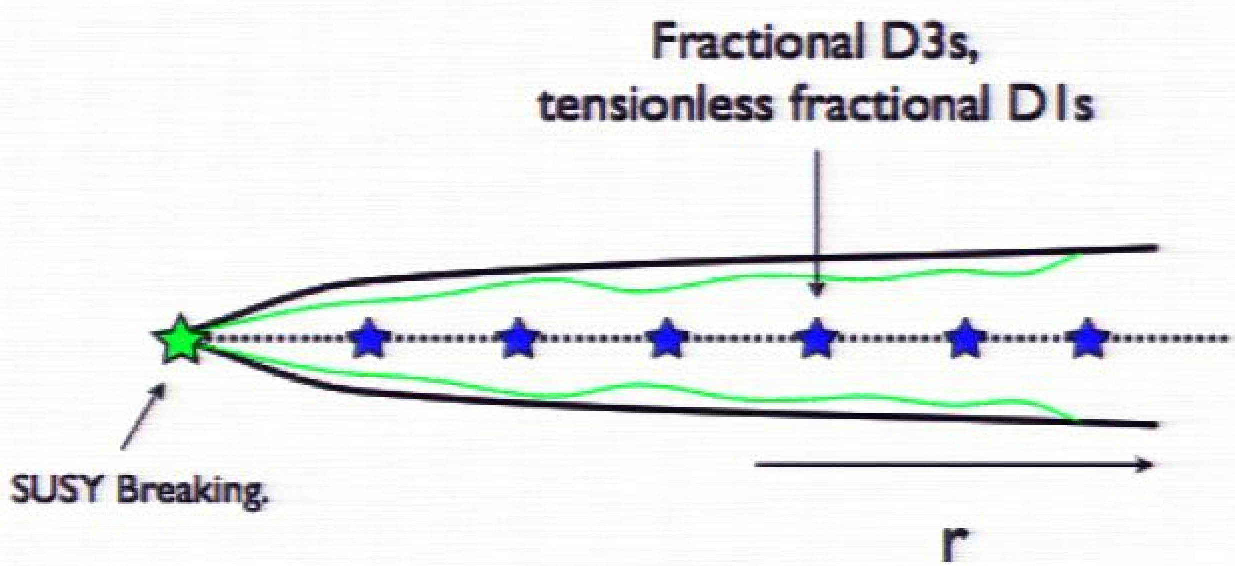
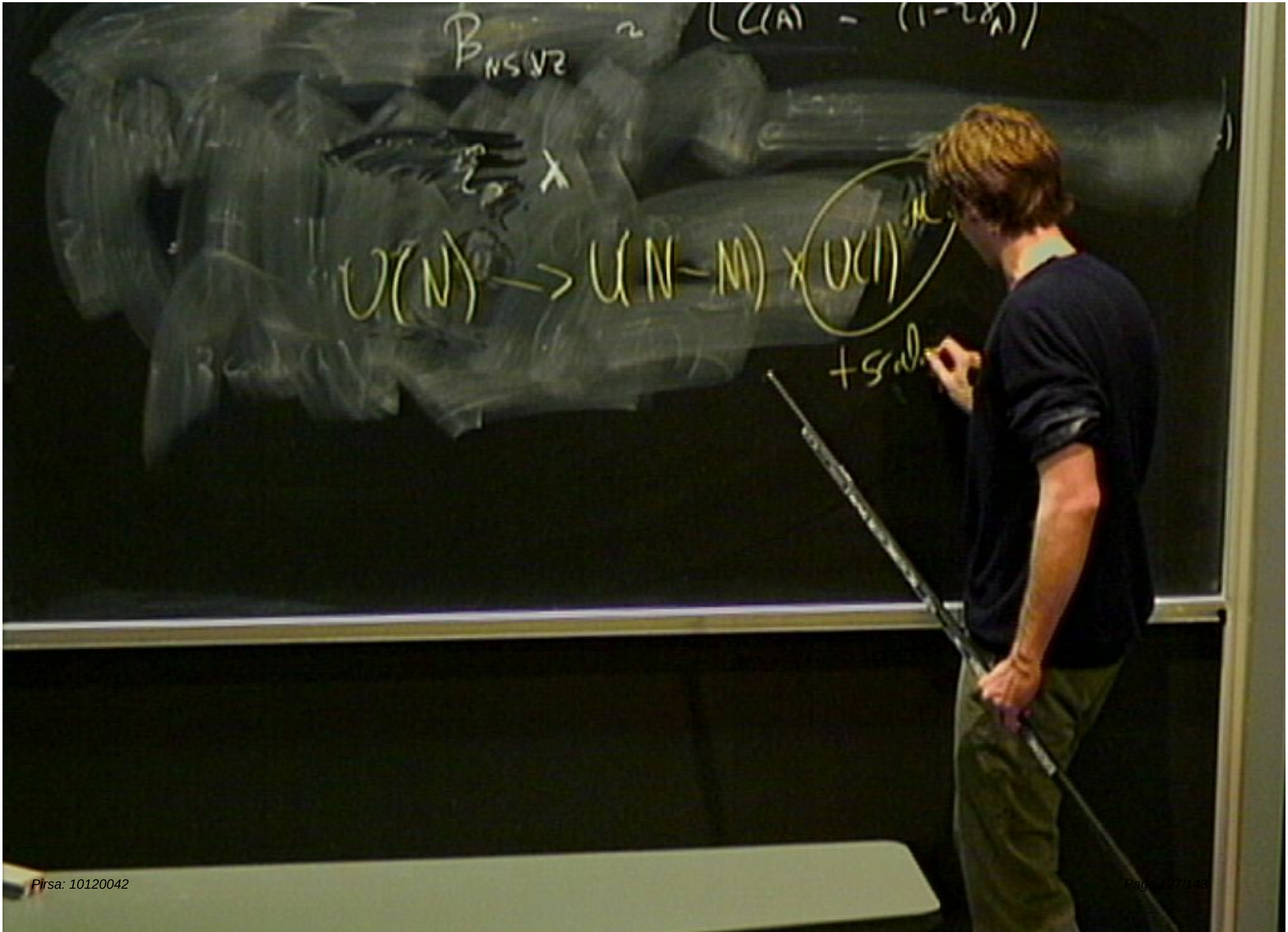
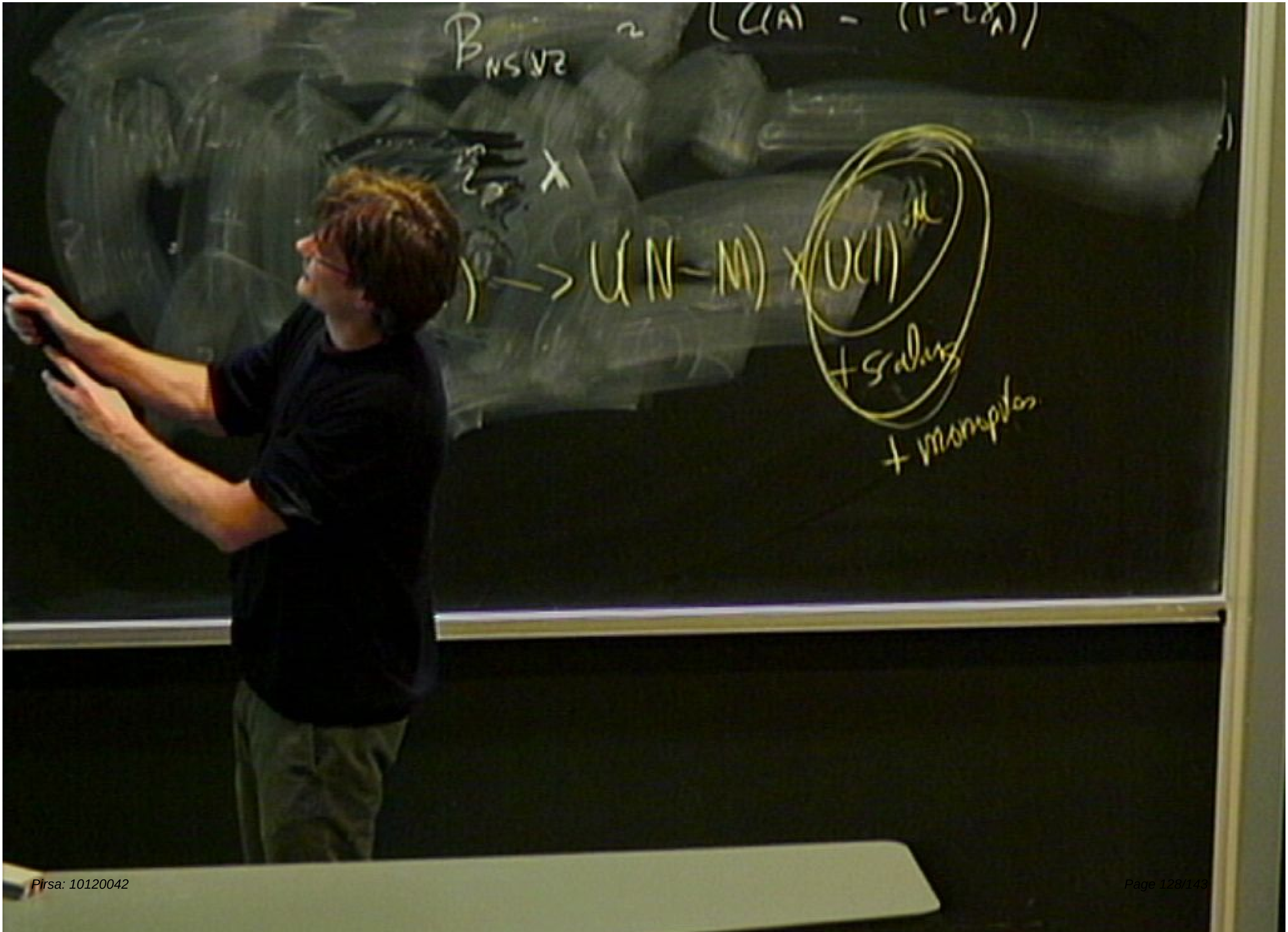
Geometric picture

The final geometric picture of the metastable warped throat:



Moduli are fractional D3s, monopoles are wrapped D3s, leading to fractional D1s. The fractional D3 positions are constrained by an enhancon mechanism - dual to the "removal of the origin" in Seiberg-Witten.


U(N) → U(N−M) × U(1)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+ scaling
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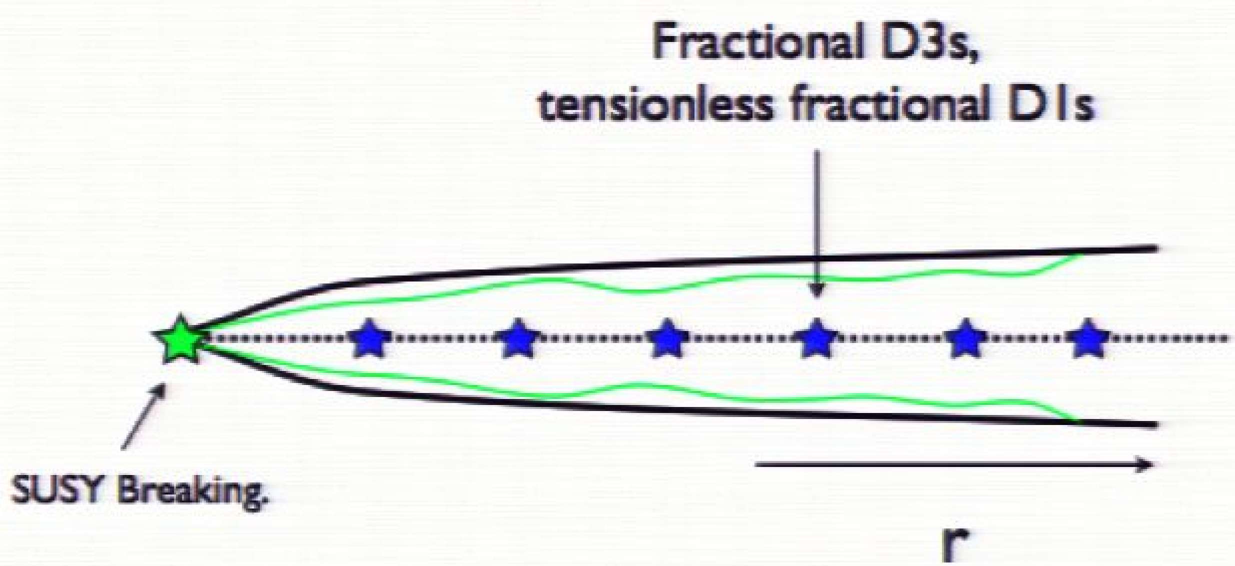

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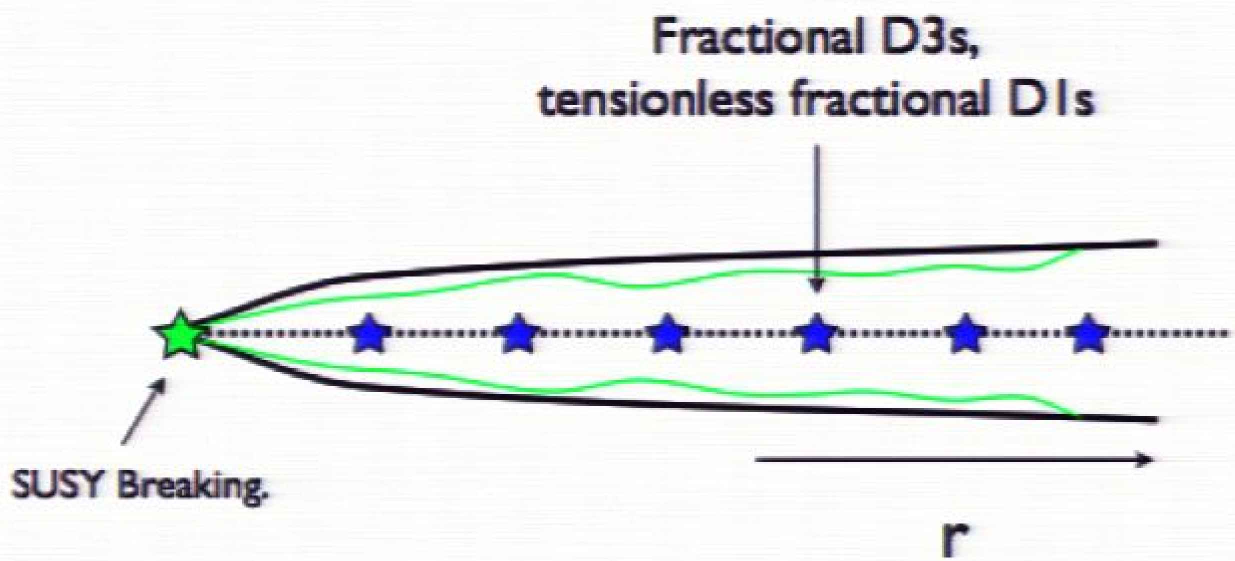

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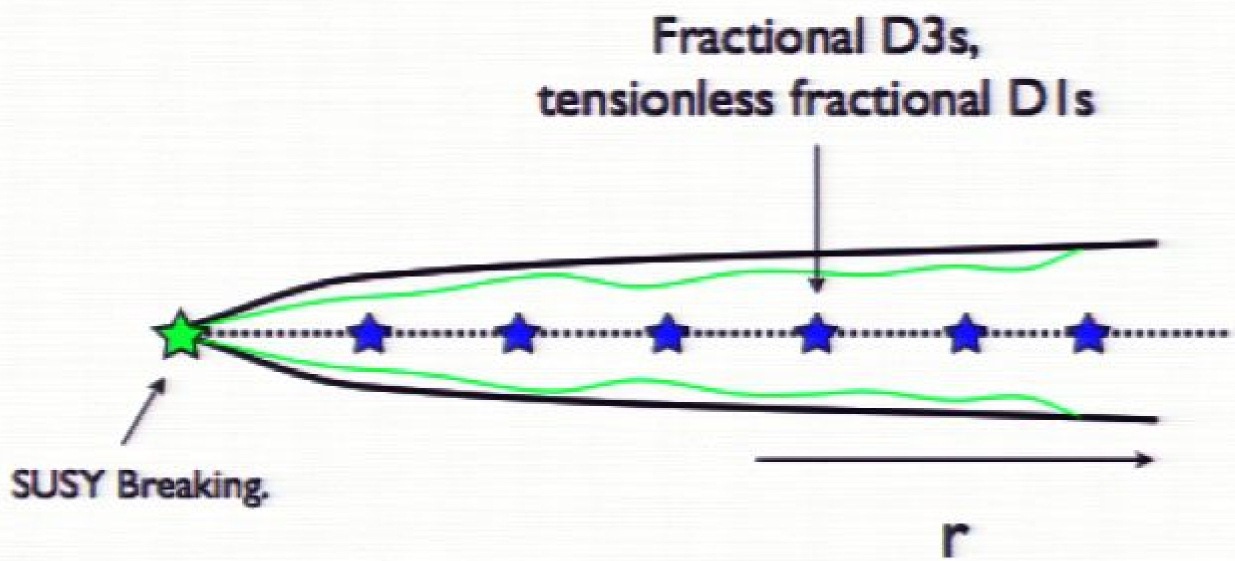

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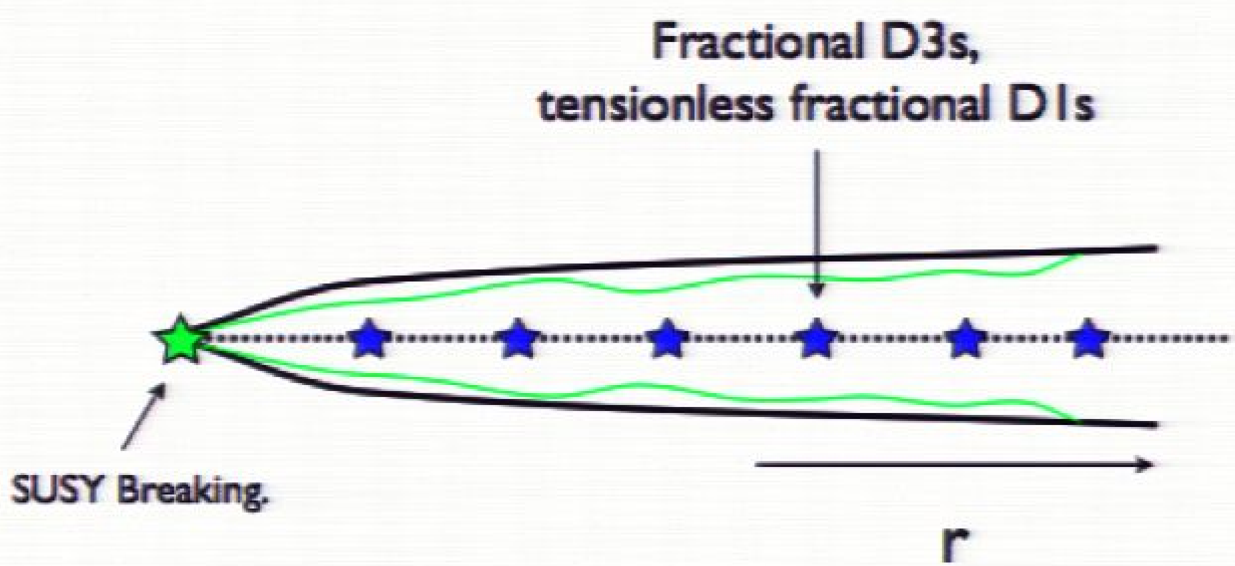

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