Title: What is String Phenomenology?

Date: Apr 11, 2005 02:45 PM

URL: http://pirsa.org/05040051

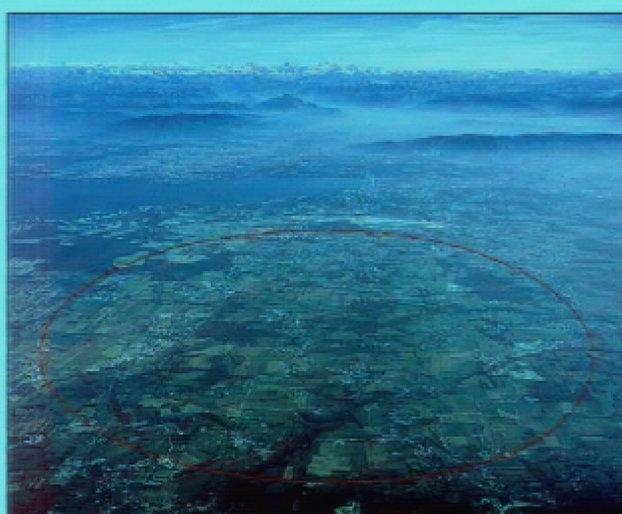
Abstract:

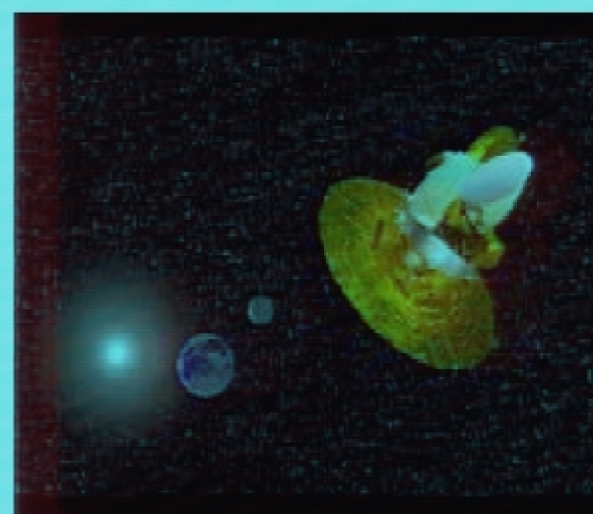
After a recent workshop here on String Phenomenology…

What is String Phenomenology?

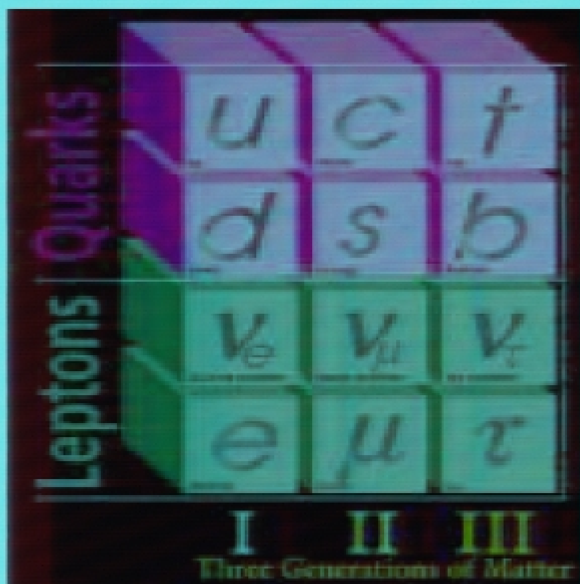
Particle Physics and Cosmology

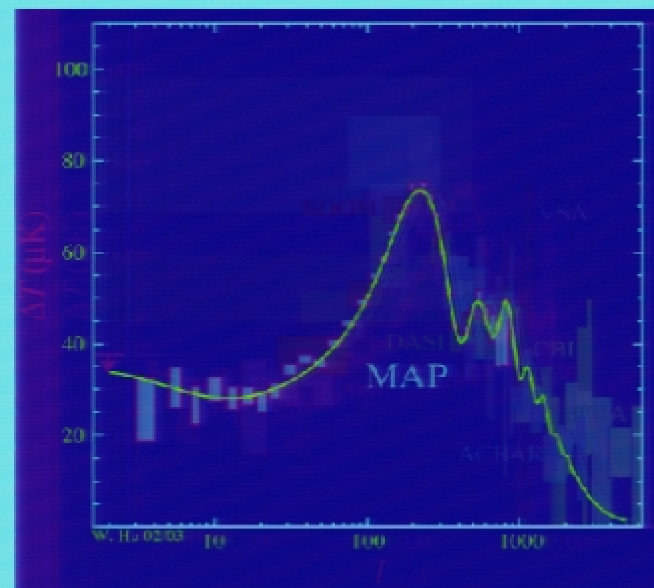
- Deep connection, e.g., inflation, dark matter, neutrinos…
- Both study the universe in the extreme conditions.





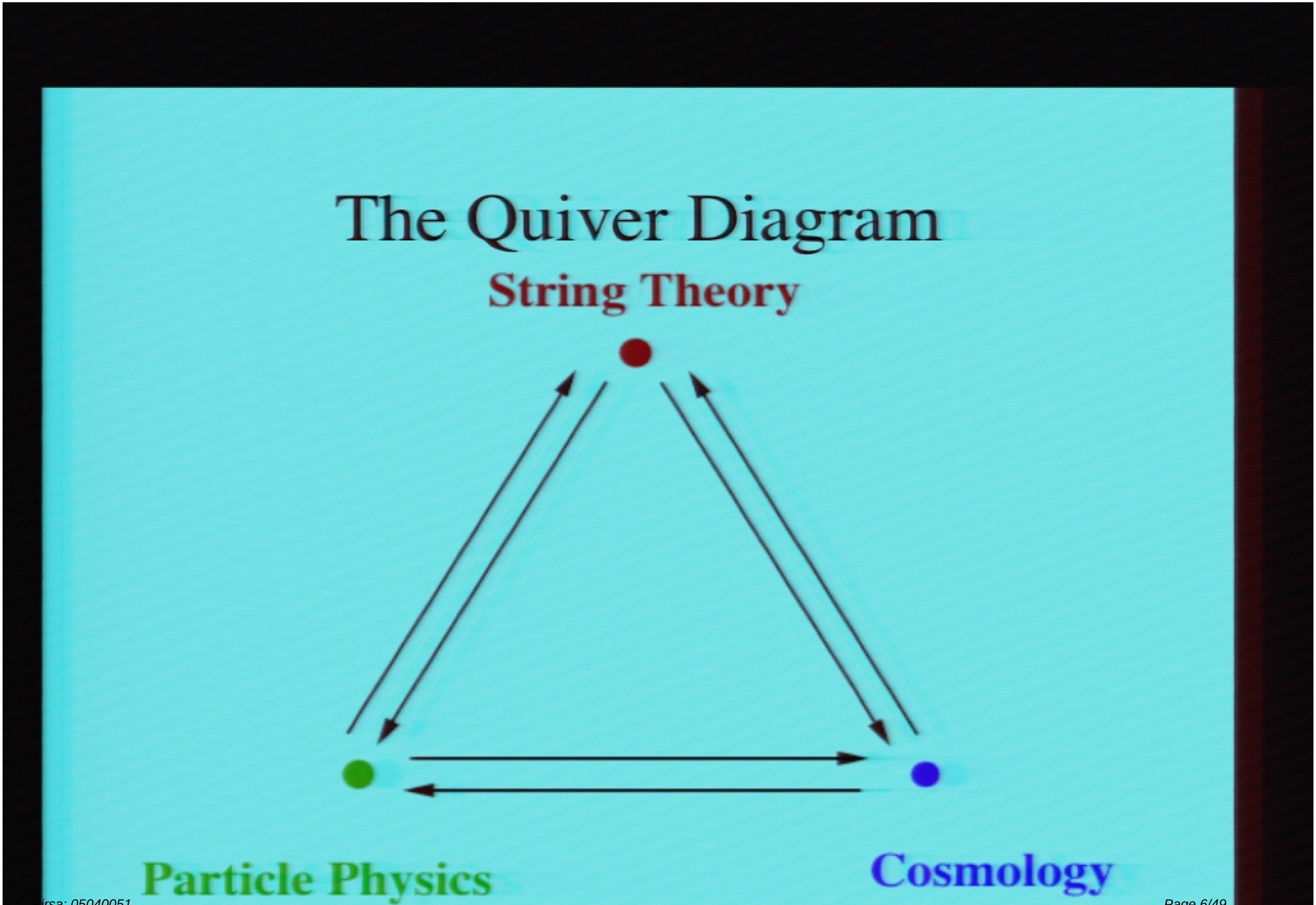
The Standard Model(s)



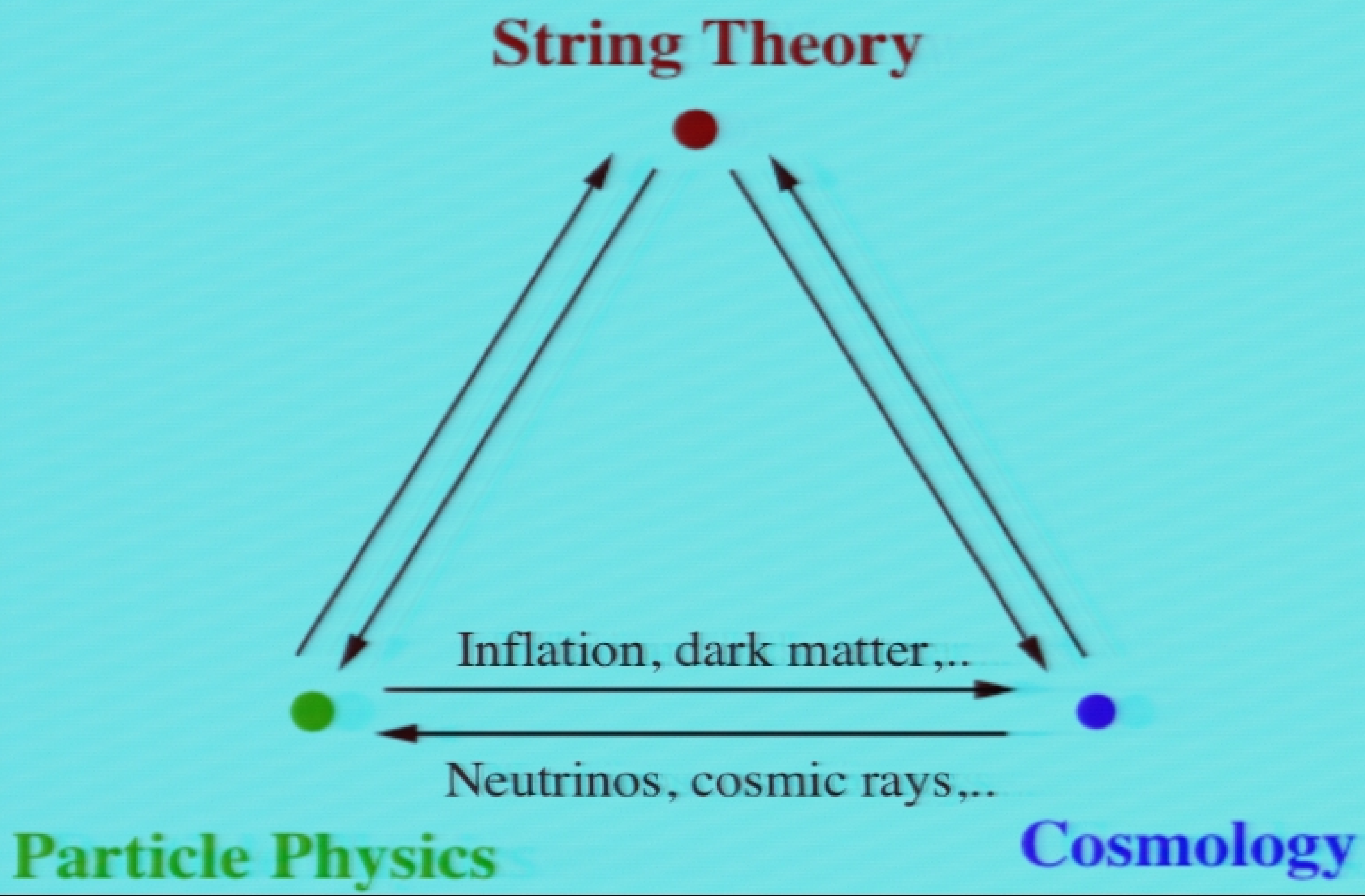


Hierarchy problem
SUSY?
….

Flatness, horizon, anisotropy
Inflation?
Dark energy?
…..


The Quiver Diagram
String Theory
Particle Physics
Cosmology

The Quiver Diagram



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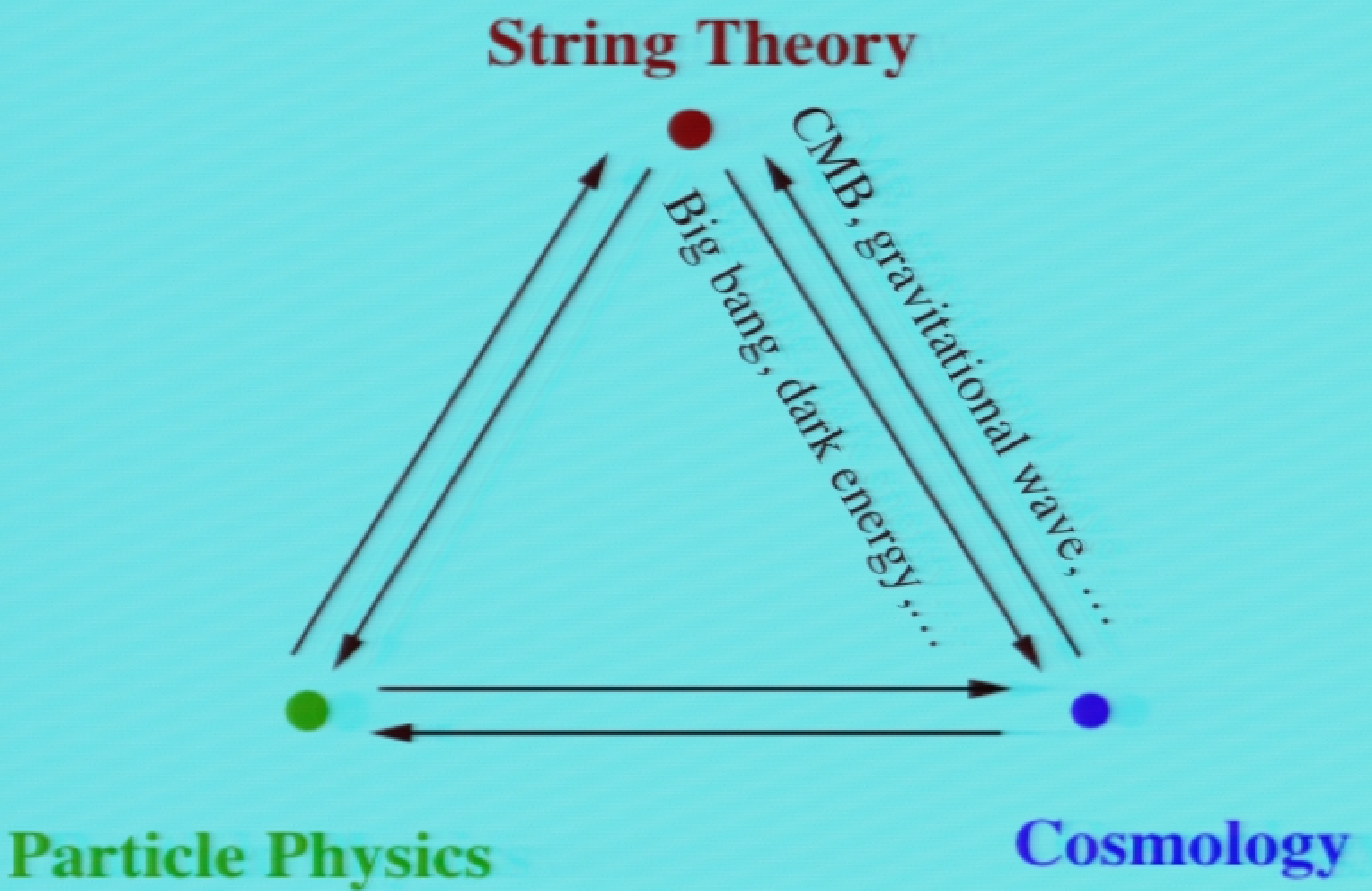
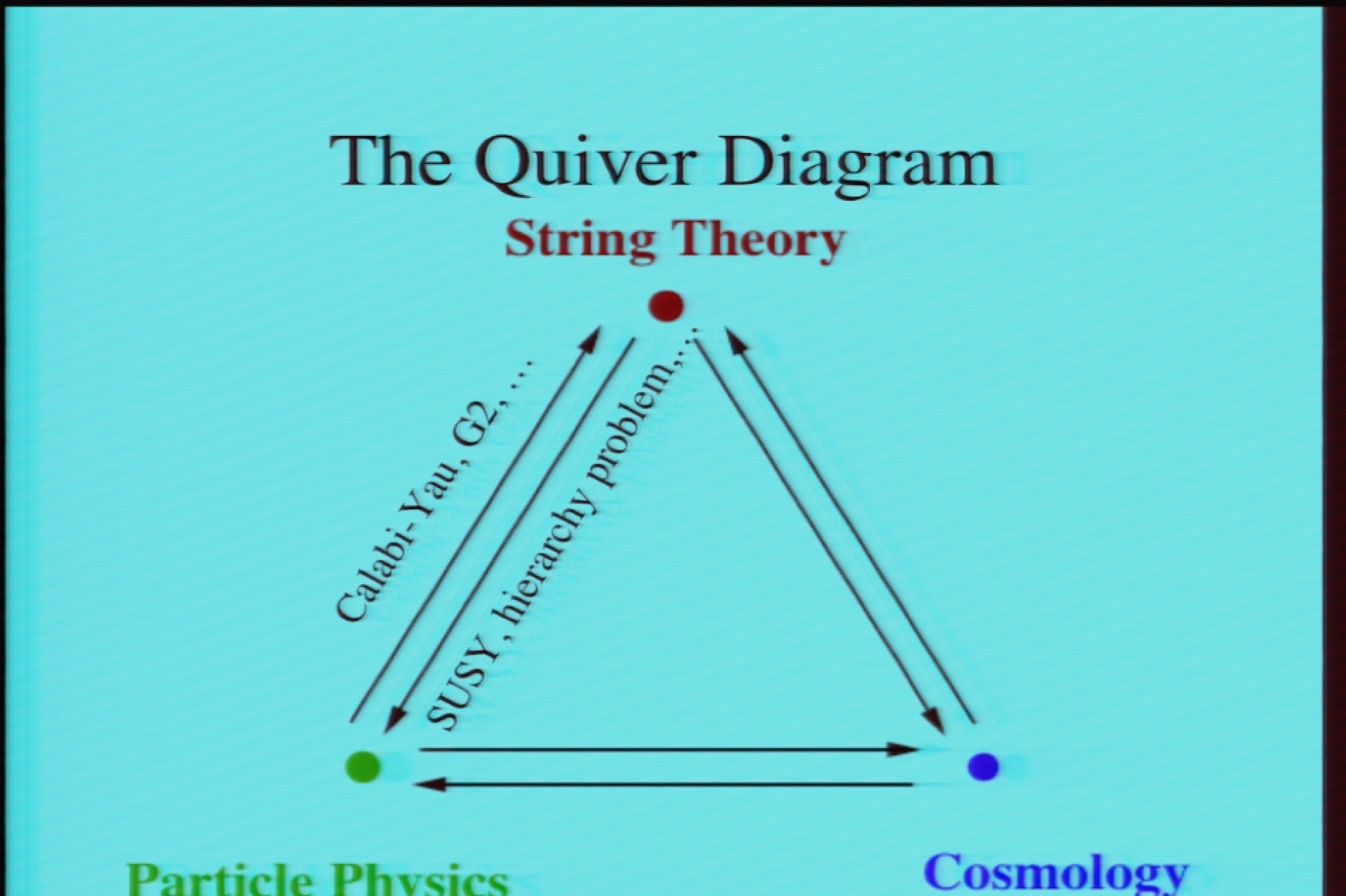
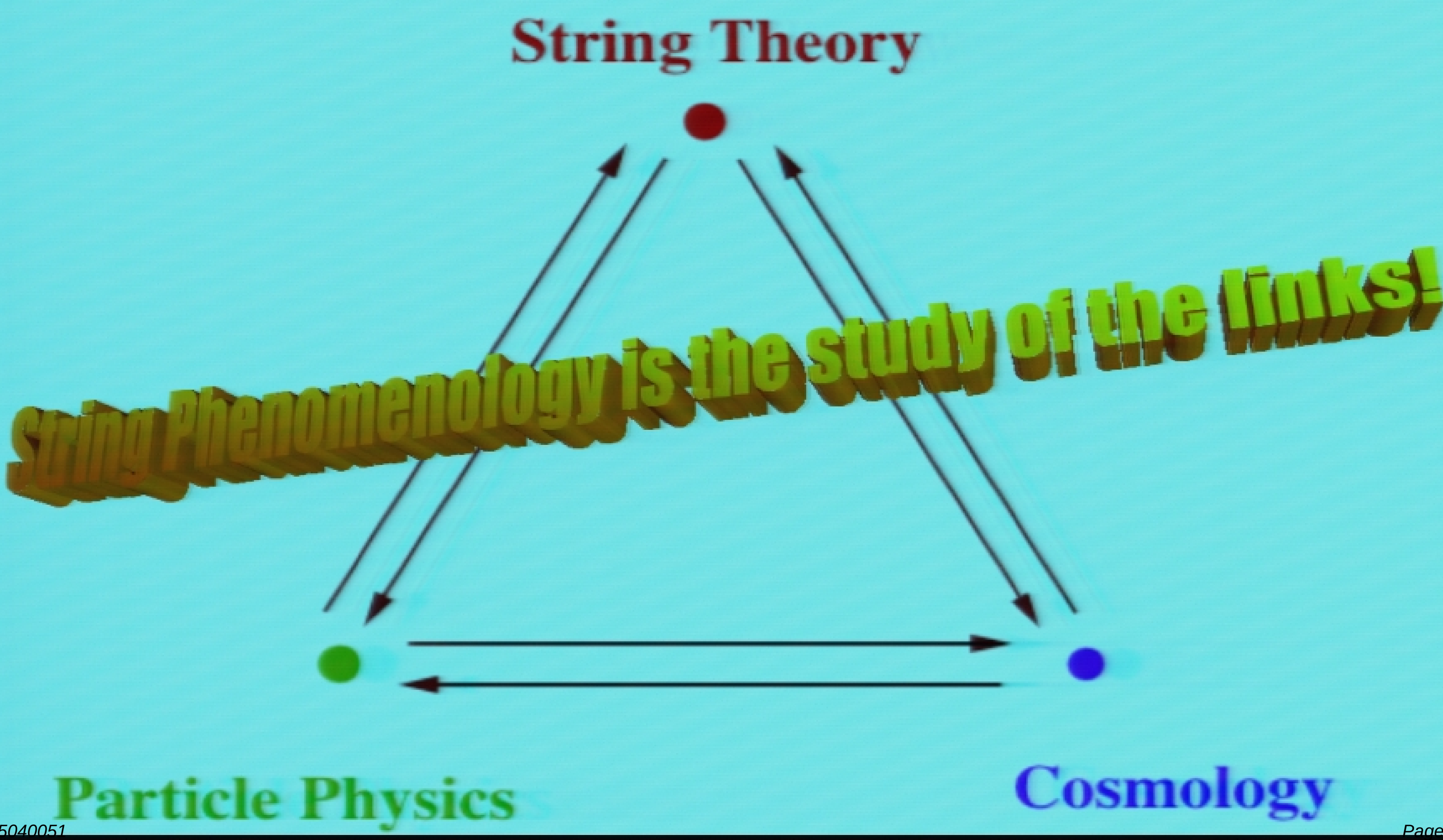


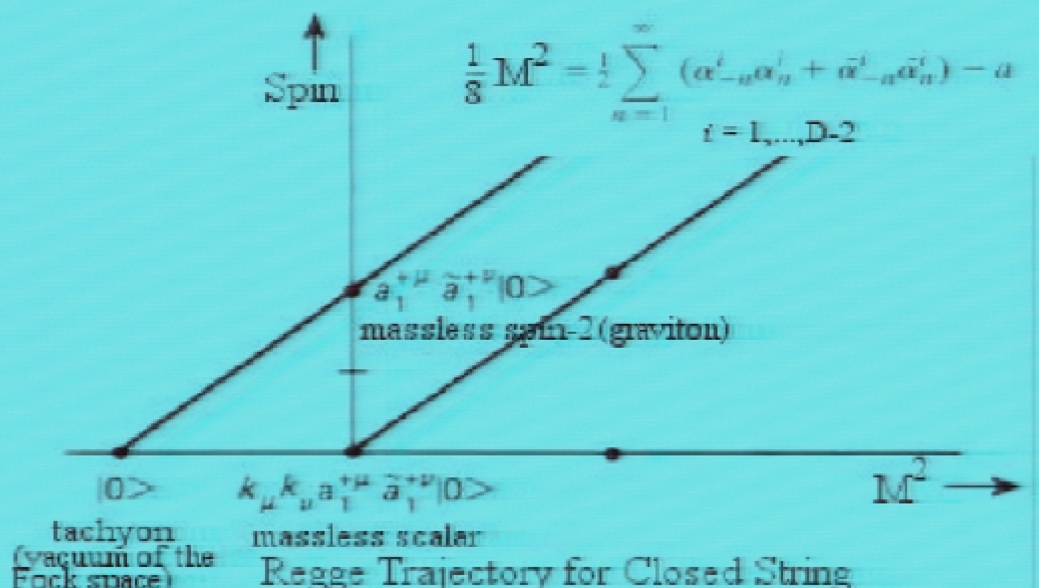

The Quiver Diagram
String Theory
Calabi-Yau, G2, ...
SUSY, hierarchy problem, ...
Particle Physics
Cosmology

The Quiver Diagram



The beginning of the unexpected...

Strings as a Theory of Hadrons



String theory began as a **phenomenological model**.

Massless spin 2 particle: **graviton!**

Meet the Quintuplets

Meet the Quintuplets

The Heterotic Supremacy

- **Type IIA/IIB:** difficult to implement non-Abelian gauge groups and chiral fermions.

In fact, a no-go theorem for the Standard Model.

Dixon, Kaplunovsky, Vafa

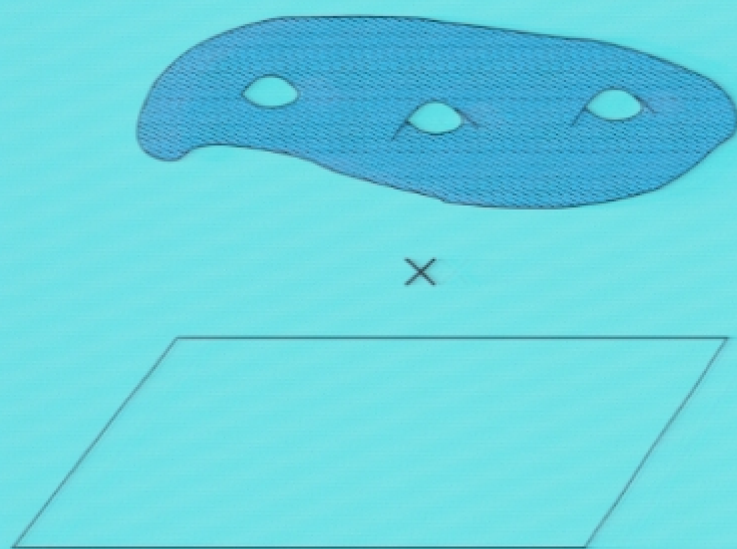
- **Heterotic E8xE8:** naturally contains GUT and hidden sector:

$$E_8 \supset E_6, SO(10), SU(5), \ldots$$

- **Heterotic SO(32) and Type I:** two other siblings that are largely ignored....

String Phenomenology Begins

Calabi-Yau Compactification



6D Compact space

M

$\mathcal{N} = 1$ SUSY $\Leftrightarrow$ Calabi-Yau

Our 4D

- **Low energy physics** (e.g., spectrum, couplings, ...) determined by topological + geometrical data of M.

- Building realistic heterotic string models: a huge industry in mid 80s to mid 90s....

The Good Side

- $M_s \simeq g_s M_P$
- Gauge unification
- Rank $\leq$ 22
- E6, SO(10), SU(5) GUTs, MSSM-like Models
- Non-trivial constraints on matter representations
- Exotic matter: Schellekens' theorem

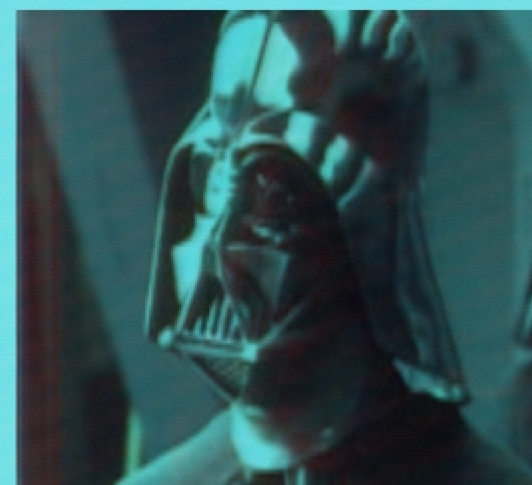
Internal consistencies + phenomenological constraints

$\Rightarrow$ A very tight system!

The Dark Side

Moduli Problem

SUSY Breaking



Moreover, $M_s \simeq g_s M_P \Rightarrow$ difficult to test or falsify . . .

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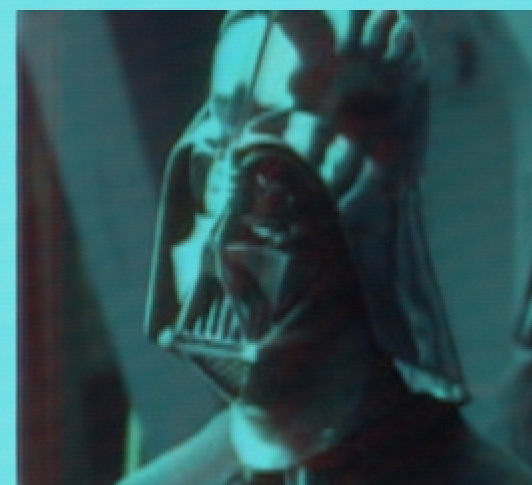

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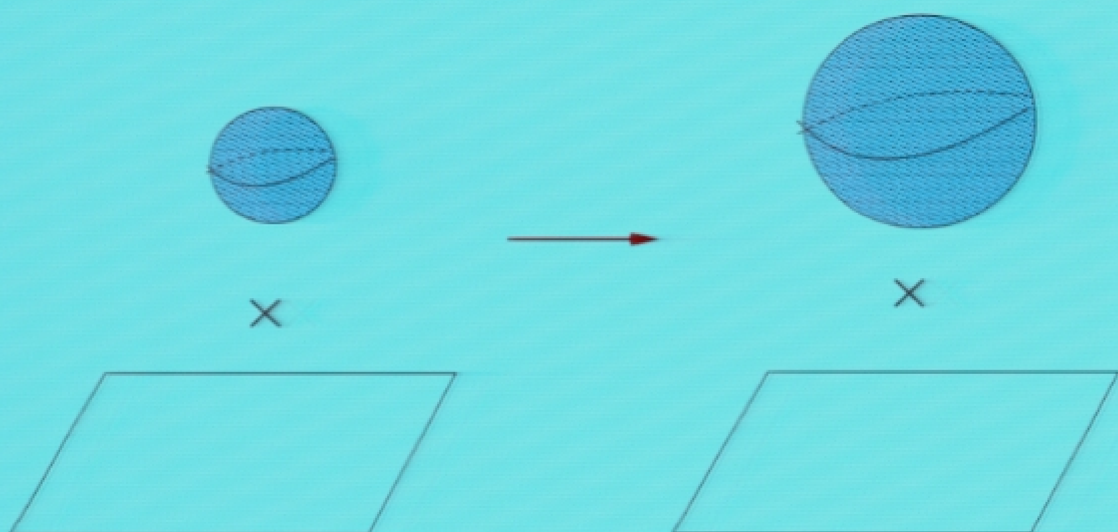


Varying the size/shape of M

In 4D physics, this freedom implies moduli: scalar fields ϕ_i

$$V(\phi_i) = 0 \qquad \forall \phi_i$$

The Moduli Problem II

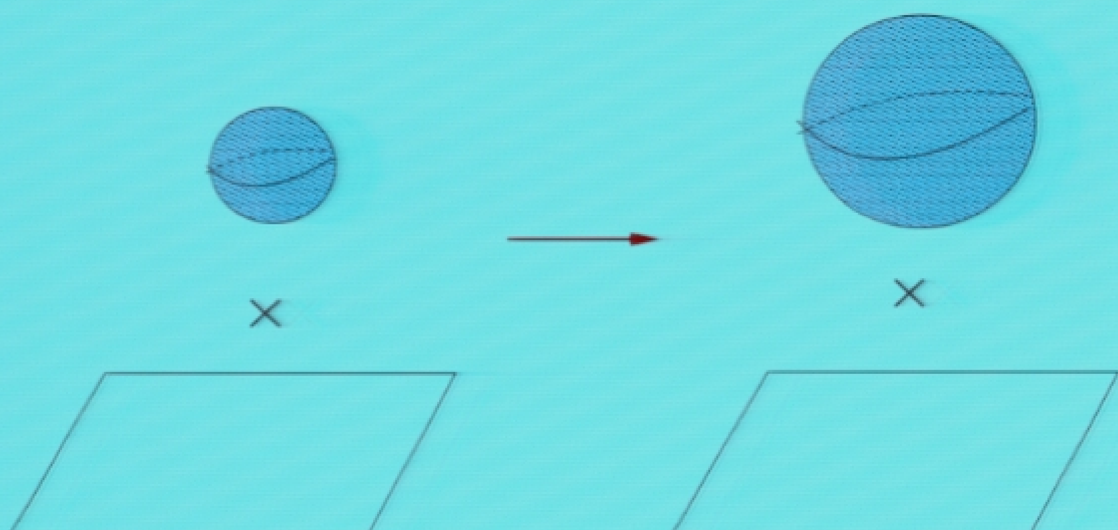
- Different $< \phi_i >$ $\Rightarrow$ inequivalent physics (e.g., Yukawa couplings, particle masses,..)

Loss of predictivity

- Existence of light scalars:
  - Equivalence principle violations?
  - Time varying α?
  - Energy in ϕ can ruin cosmology.

Phenomenological problems

The Moduli Problem



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Phenomenological problems

SUSY Breaking

- **Assumptions:**

  - Non-perturbative effects (e.g., gaugino and matter condensation) break SUSY.
  - The *same* NP effects also lift all moduli.

- **But …**

  SUSY breaking effects on SM and moduli lifting potential not readily computable in a *controlled* way.

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Return of the Lost Family

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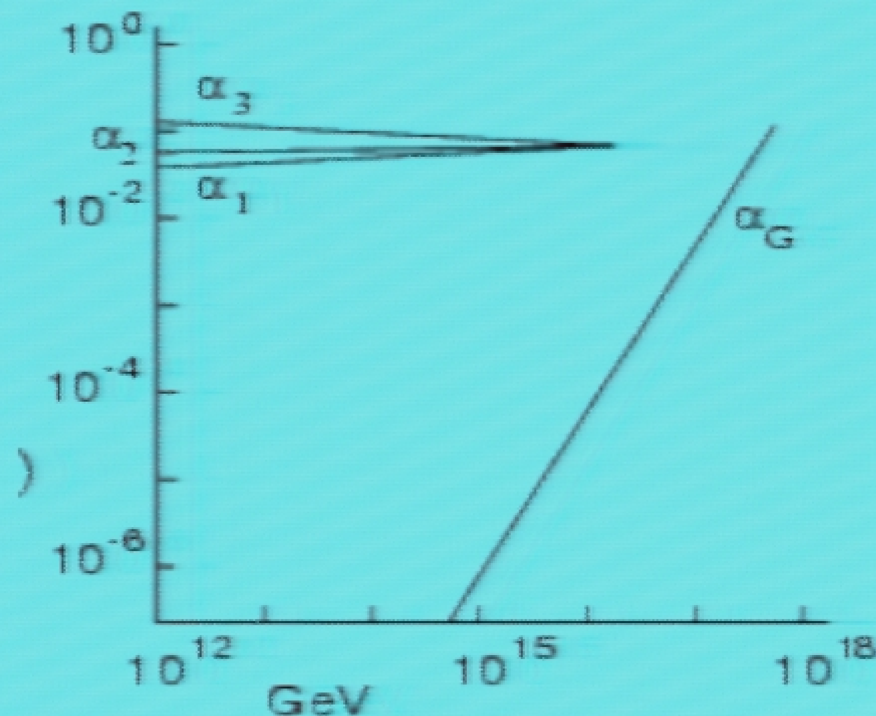
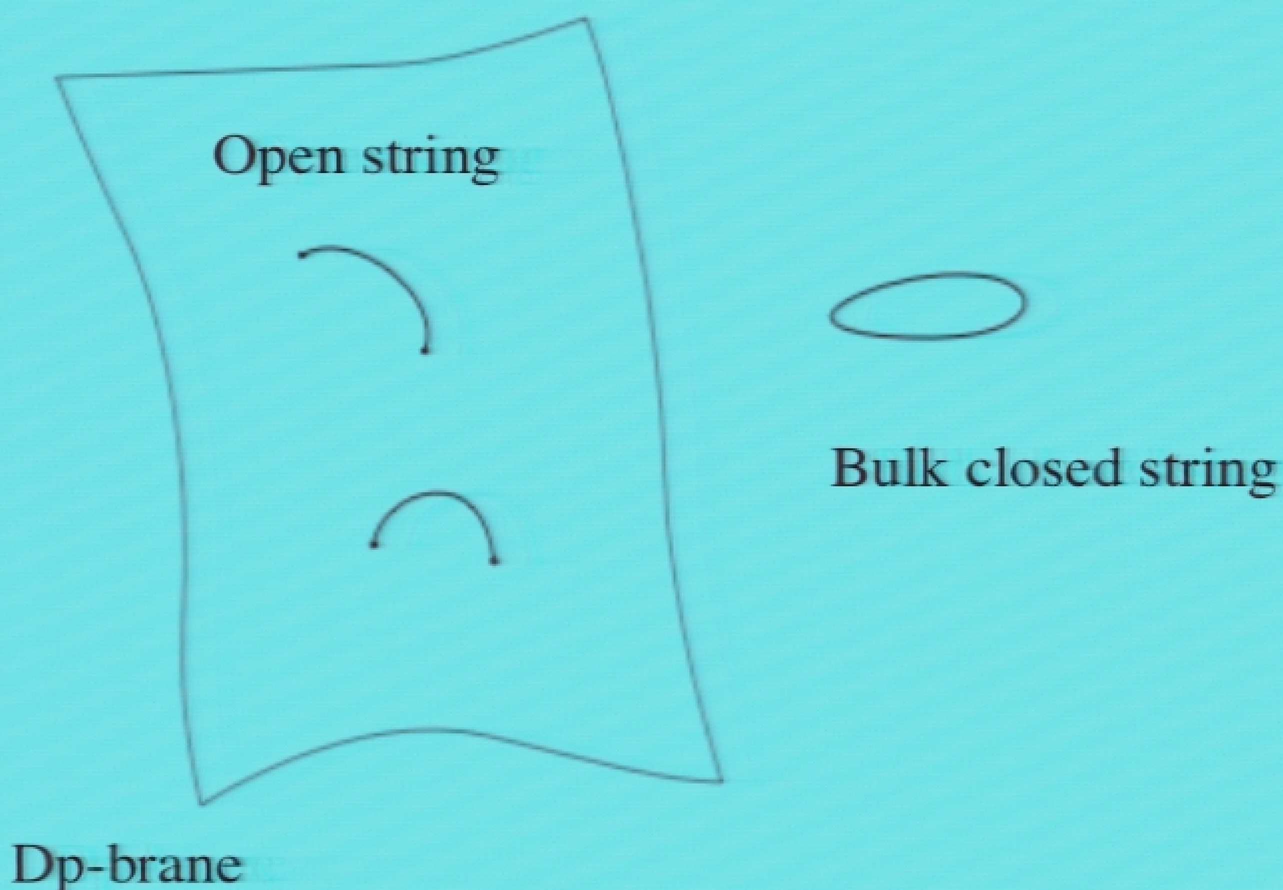
Return of the Lost Family

Including Gravity

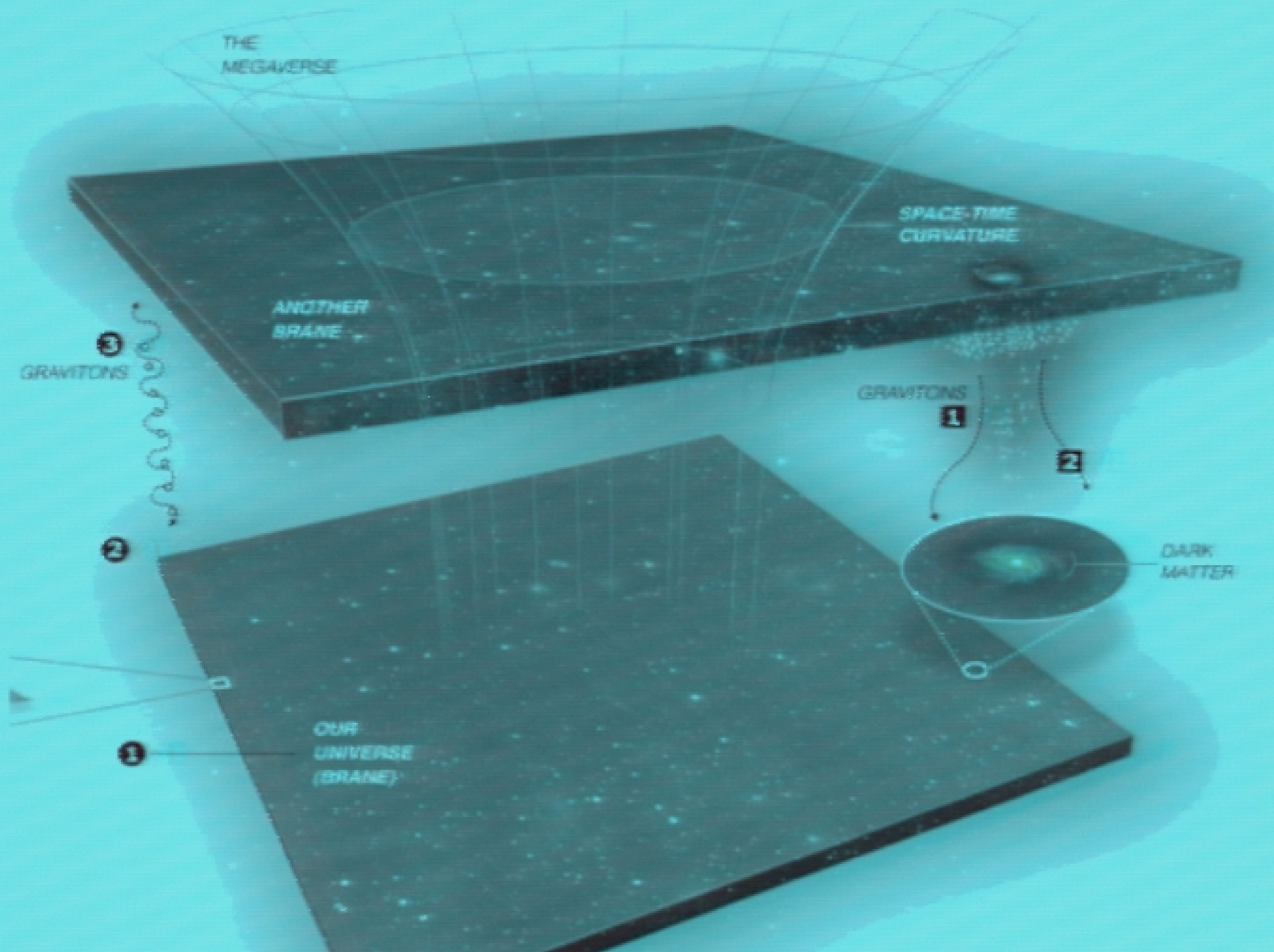


Dienes, Phys. Report

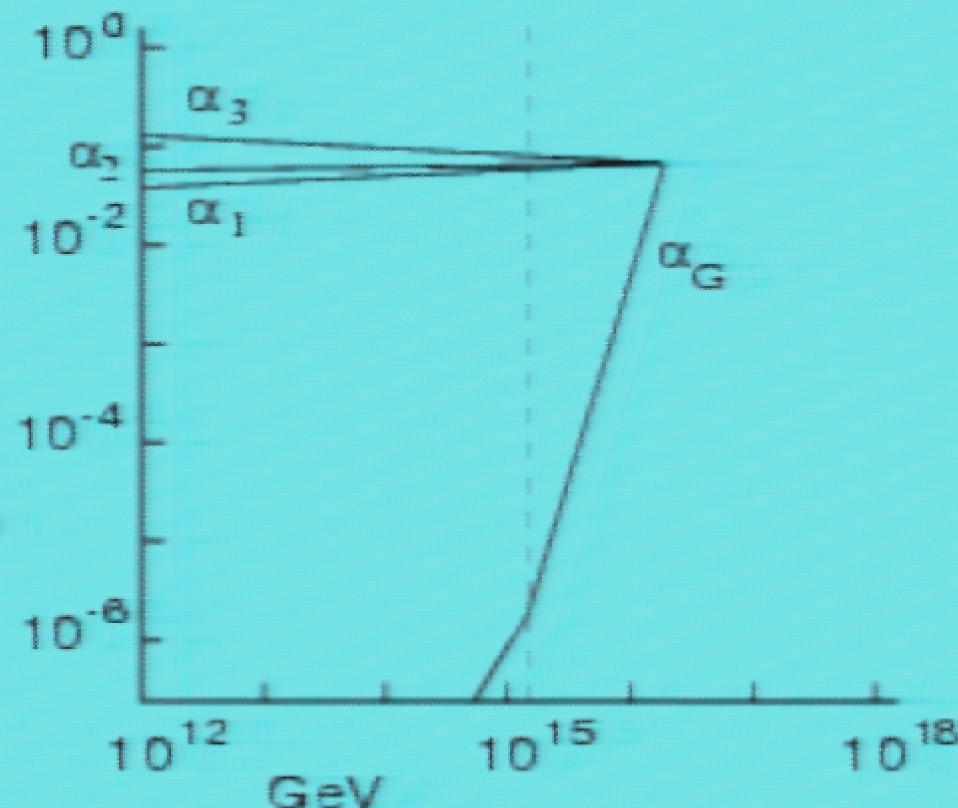
D-brane



Brane World


THE
MEGAVERSE
SPACE-TIME
CURVATURE
ANOTHER
BRANE
GRAVITONS
GRAVITONS
DARK
MATTER
OUR
UNIVERSE
(BRANE)

When all ends meet



Witten

Flux Compactification

- Just like particle couples to gauge field via

$$\int_{\text{worldline}} A$$

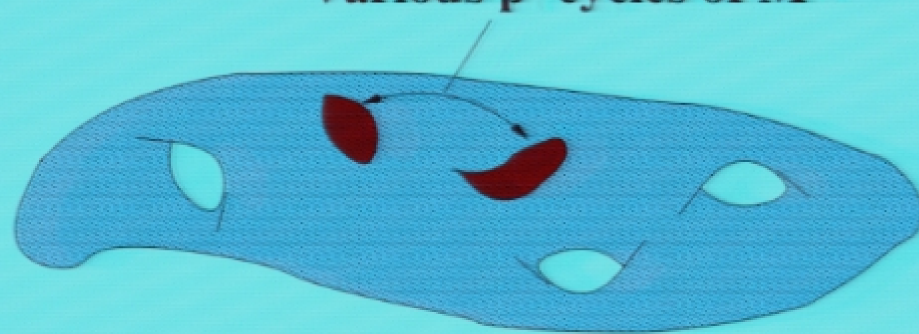
- Dp branes couple to p+1-index gauge fields:

$$\int_{\text{worldvolume}} A_{p+1}$$

- Thus (p+2)-form field strengths:

$$F_{p+2} = dA_{p+1}$$

Flux Compactification II



- For each p-cycle in M, we can turn on

$$\int_{\Sigma_p} F_p \in \mathbf{Z}$$

Dirac quantization

- Analogous to turning on a B-field

$$E \sim \frac{1}{8\pi} \int \left(E^2 + B^2\right)$$

Cost energy to turn on fluxes!

Moduli Stabilization

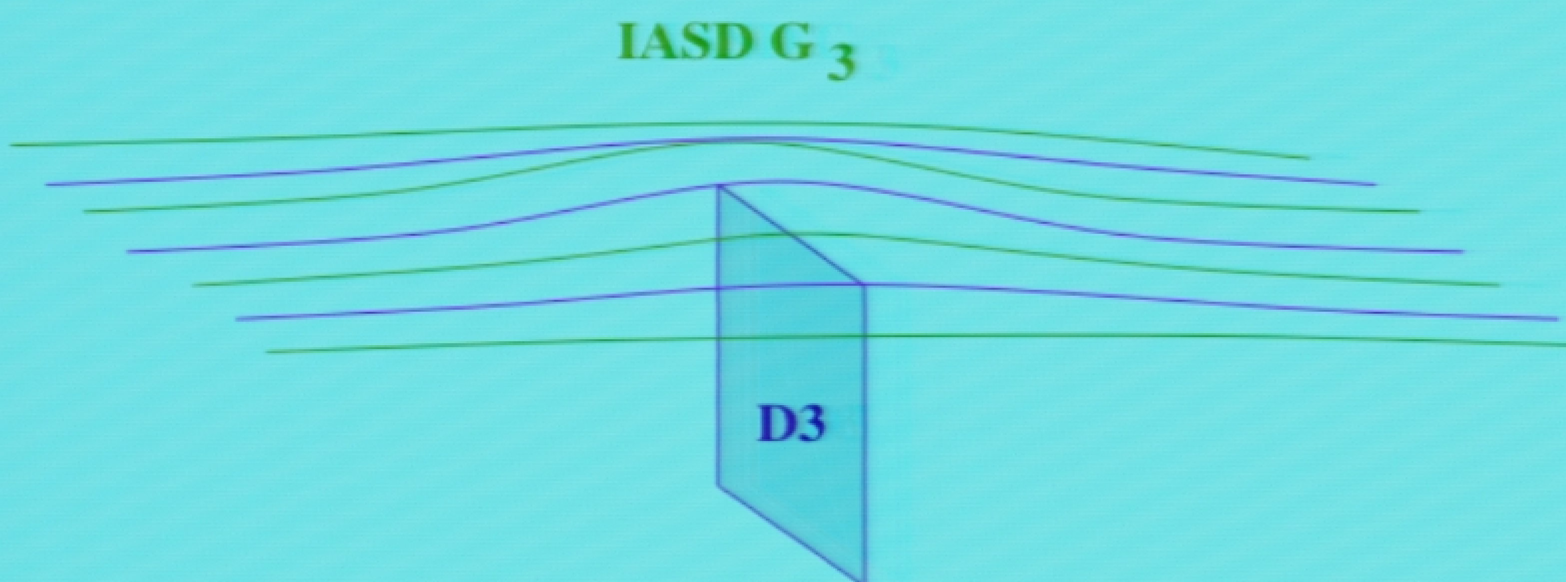
- The energy cost of a given flux depends on detailed geometry of M:

$$V_{n_1,n_2,\ldots,n_k}(\phi_i)$$ **Flux induced potential**

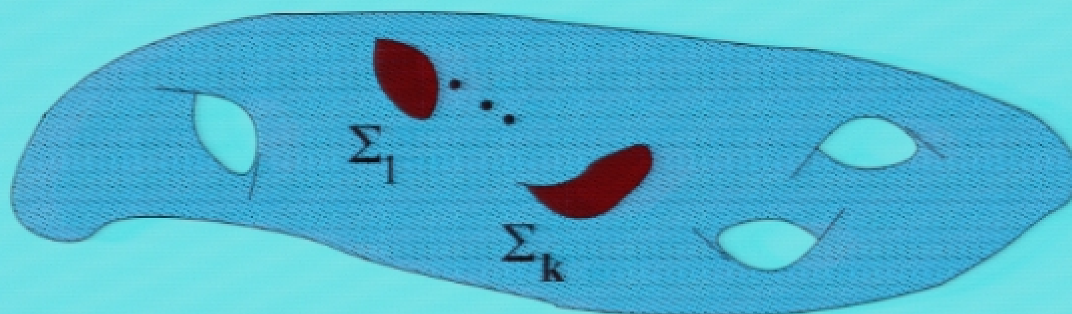
where $n_j = \int_{\Sigma_j} F \ , \quad j = 1, \ldots, k.$

- Lift the moduli ϕ_i!

Flux Induced SUSY Breaking



Number of vacua



$$\int_{\Sigma_j} F_p = n_j$$

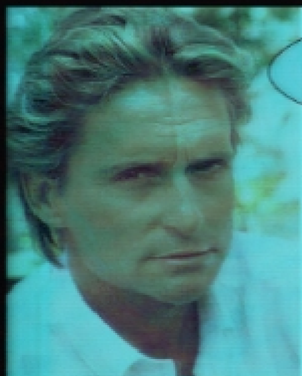
Gauss's Law: $$\sum_{j=1}^{k} n_j^2 \leq N^2$$

N^2 and k depend on the topology of $\mathcal{M}$, roughly $\mathcal{O}(100)$.

Assuming $V_{n_1,\ldots,n_k}(\phi)$ has a critical point for each $\{n_1, \ldots, n_k\}$

$$\#\ \text{vacua} \sim N^k$$ naively can exceed 10^{100}

The Landscape



The Landscape II

- By far the only convincing example where *all* moduli are stabilized is a simple AdS vacuum (with no matter fields!) constructed by Denef et al.

- The naive counting suppresses the D-brane sector which is the phenomenological relevant part:

$$N_{D3} + \sum_{j=1}^{k} n_j^2 = N^2$$

plus additional constraints on 7-branes.

Realistic Models are Rare …

Phenomenological constraints + internal consistencies impose strong cuts on the landscape.

Heterotic String (e.g., Ovrut et al, …)

Constructing stable equivariant bundles & computing their cohomology on non-simply connected Calabi-Yau…

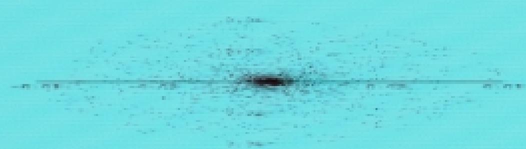
Type IIB Flux Vacua (e.g., Marchesano & Shiu, …)

Constructing magnetized D-branes with torsion K-theory charges in Calabi-Yau orientifolds…

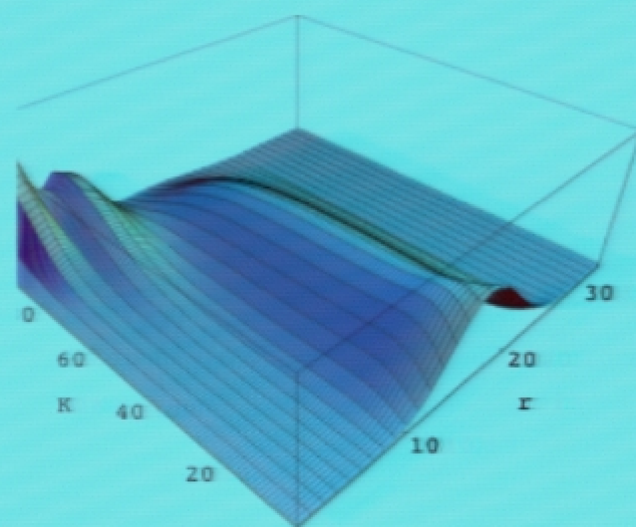
Intersecting D-brane Models (including Gepner orientifolds)

See review by Bluemenhagen et al.

Landscape: what is it good for?



Ashok & Douglas
Kachru et al
Conlon & Quevedo

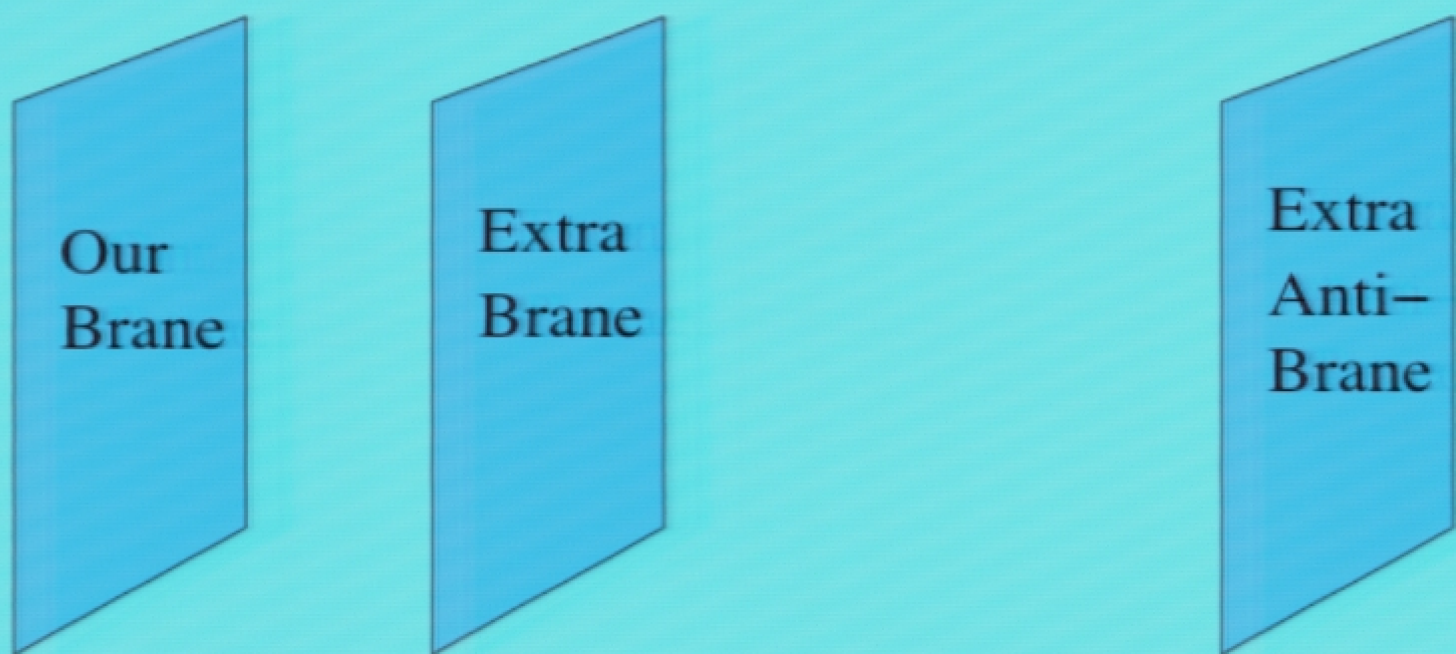


Blumenhagen et al

- Terrain by terrain instead of model by model.
- To guide us where to look and where to avoid.

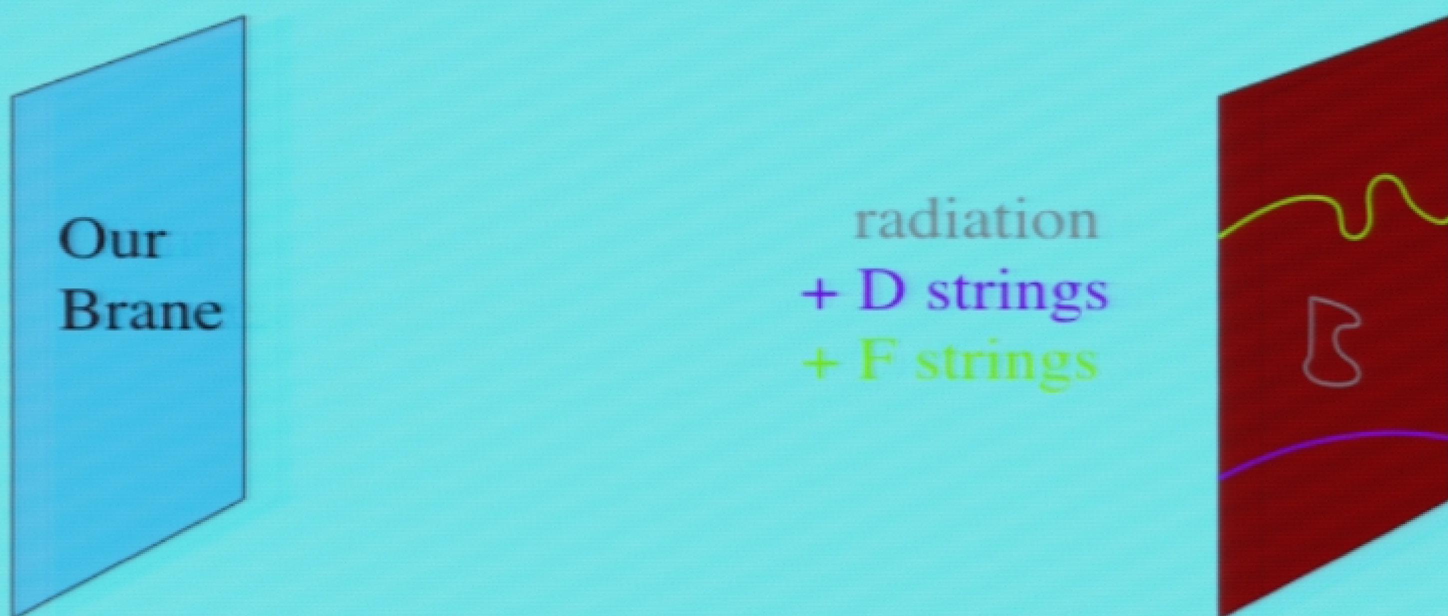
Brane Inflation & Cosmic Strings

Dvali & Tye
KKLMMT



Brane Inflation & Cosmic Strings

Stringy signatures, e.g., gravitational waves, …



Tye et al
Copeland, Myers, Polchinski

Summary

- **String Phenomenology** ~ 30 year old baby -- too young to be accomplished, too old to be naive.
- **Too early for string phenomenology?** An inspiring analogy: SM was developed before gauge theories were known to be renormalizable.
- **Spin-off results** (e.g, Calabi-Yau, G2, mirror symmetry, duality, topology change, …).

Summary II

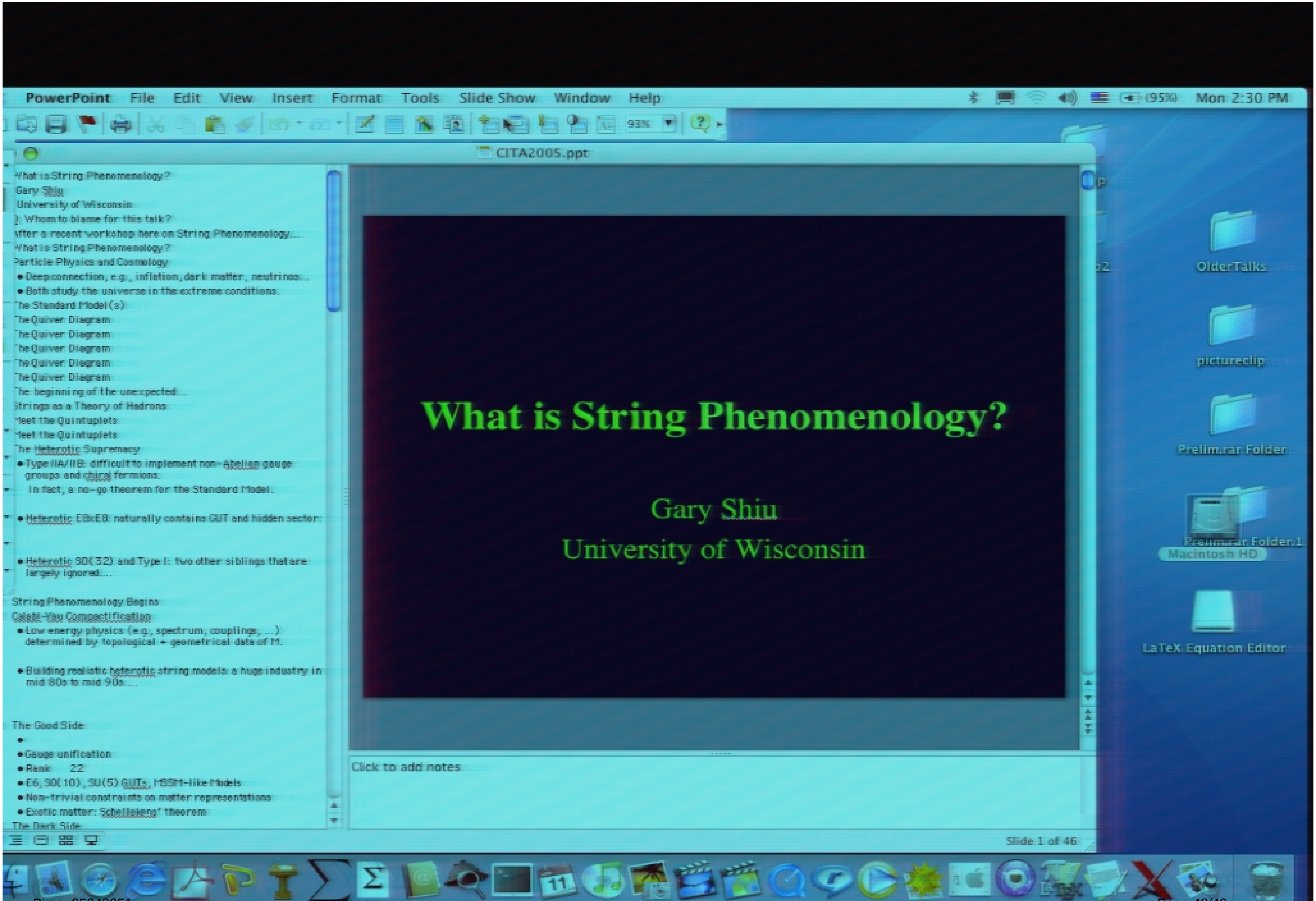
- Fountain of new ideas/scenarios for particle physics/cosmology:

  SUSY: low/high scale, split, ...

  Extra Dimensions: large/small, warp/unwarped,
  universal/brane world.

  Technicolor: the tip of a KS throat.

  and provide a consistent UV completion.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Gary Shiu
University of Wisconsin
Q: Whom to blame for this talk?
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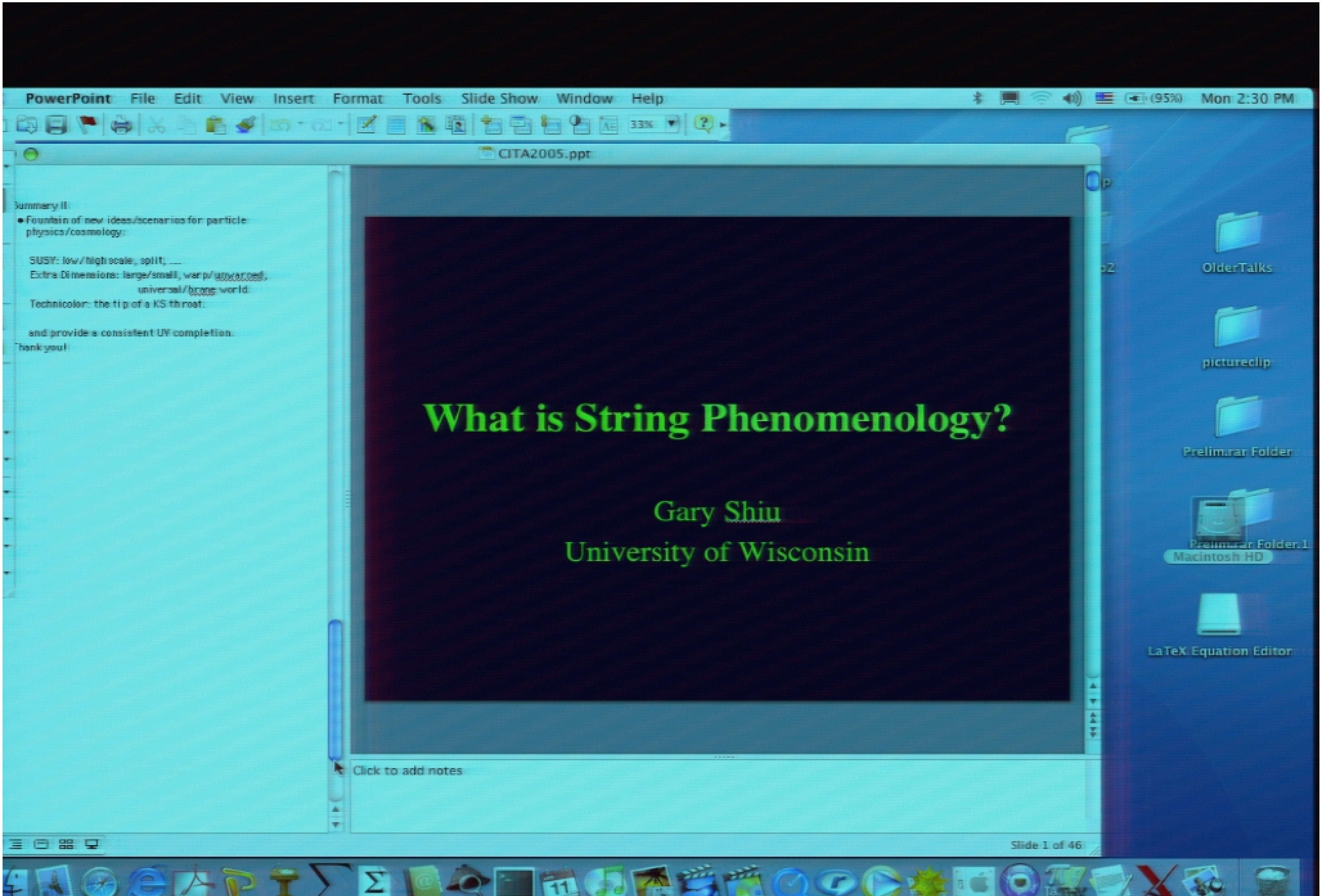

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