Theoretical Physics

overview

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Theoretical Theory

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"String Theory" overview

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QUESTION:

What are "string theorists" working on these days?

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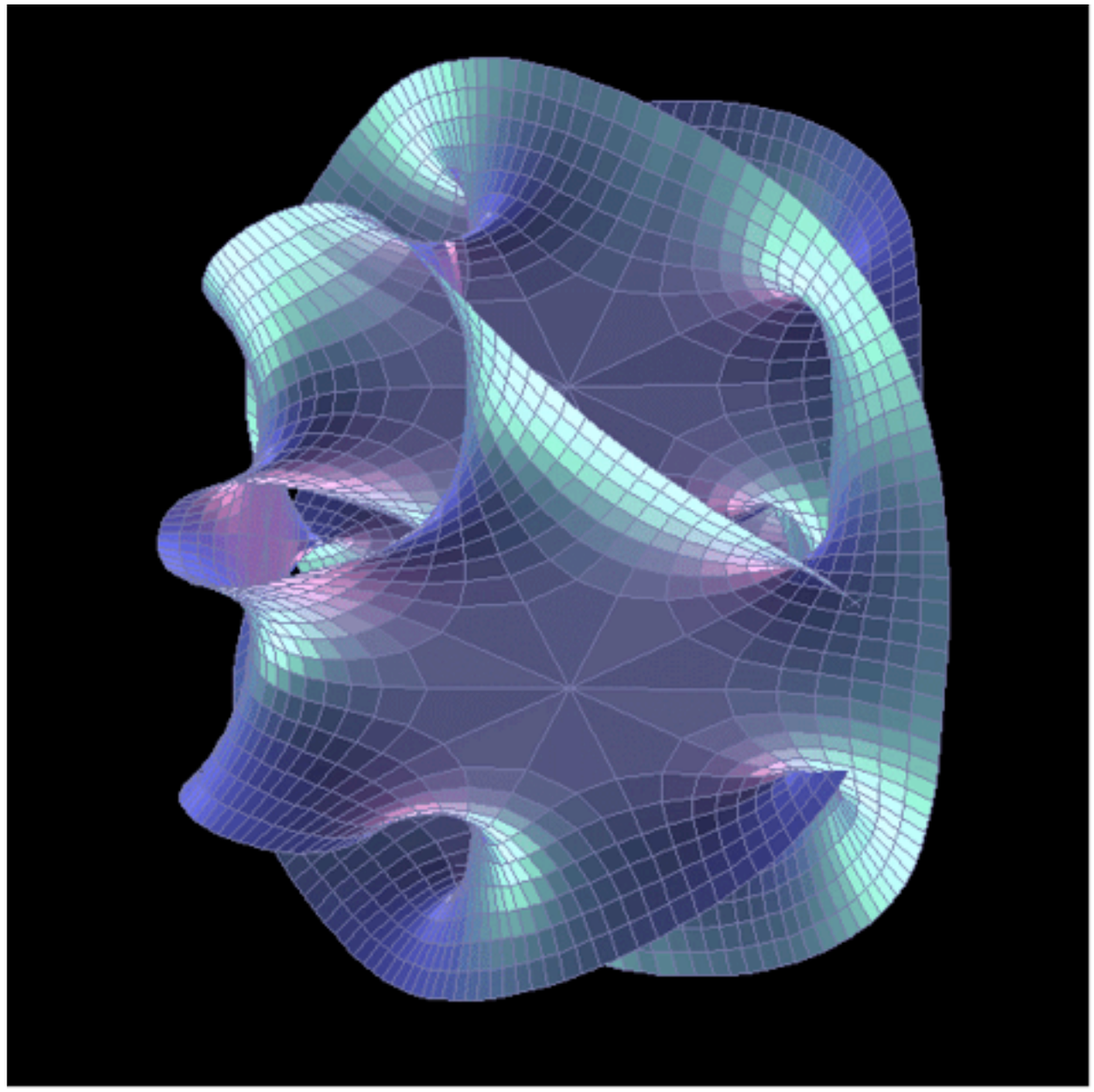
ANSWER:

They are still playing with its many

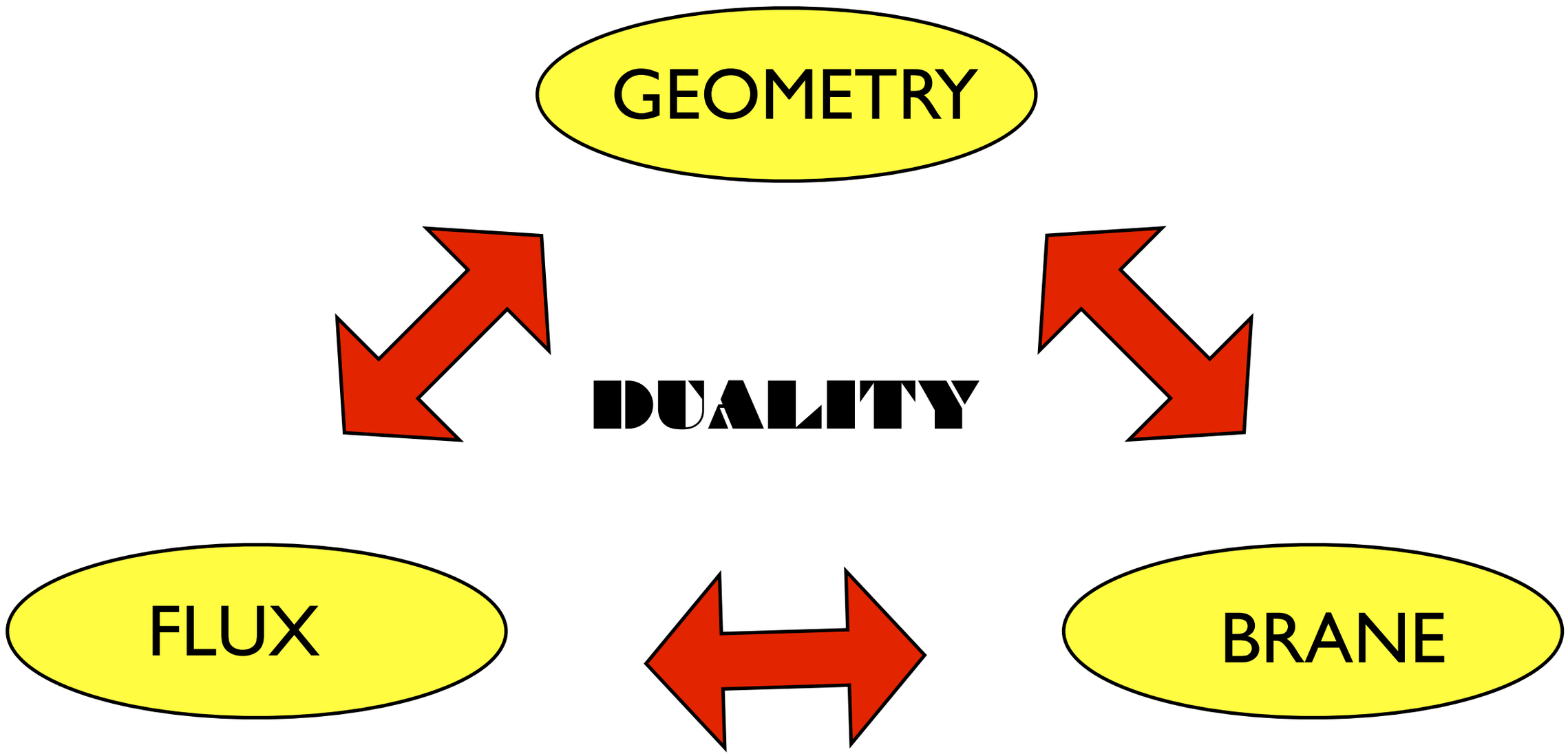
MOVING PARTS

First example of "moving parts" in the 80's

String-SUSY geometries: $CY_6 \longleftrightarrow CFT_2$ ...

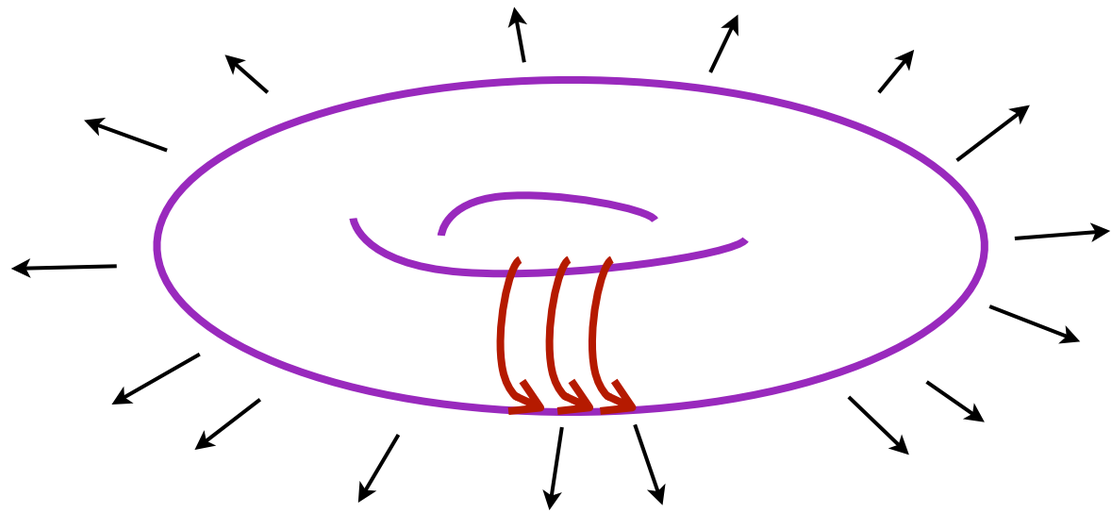


More to come in the 90's:
Fluxes and branes



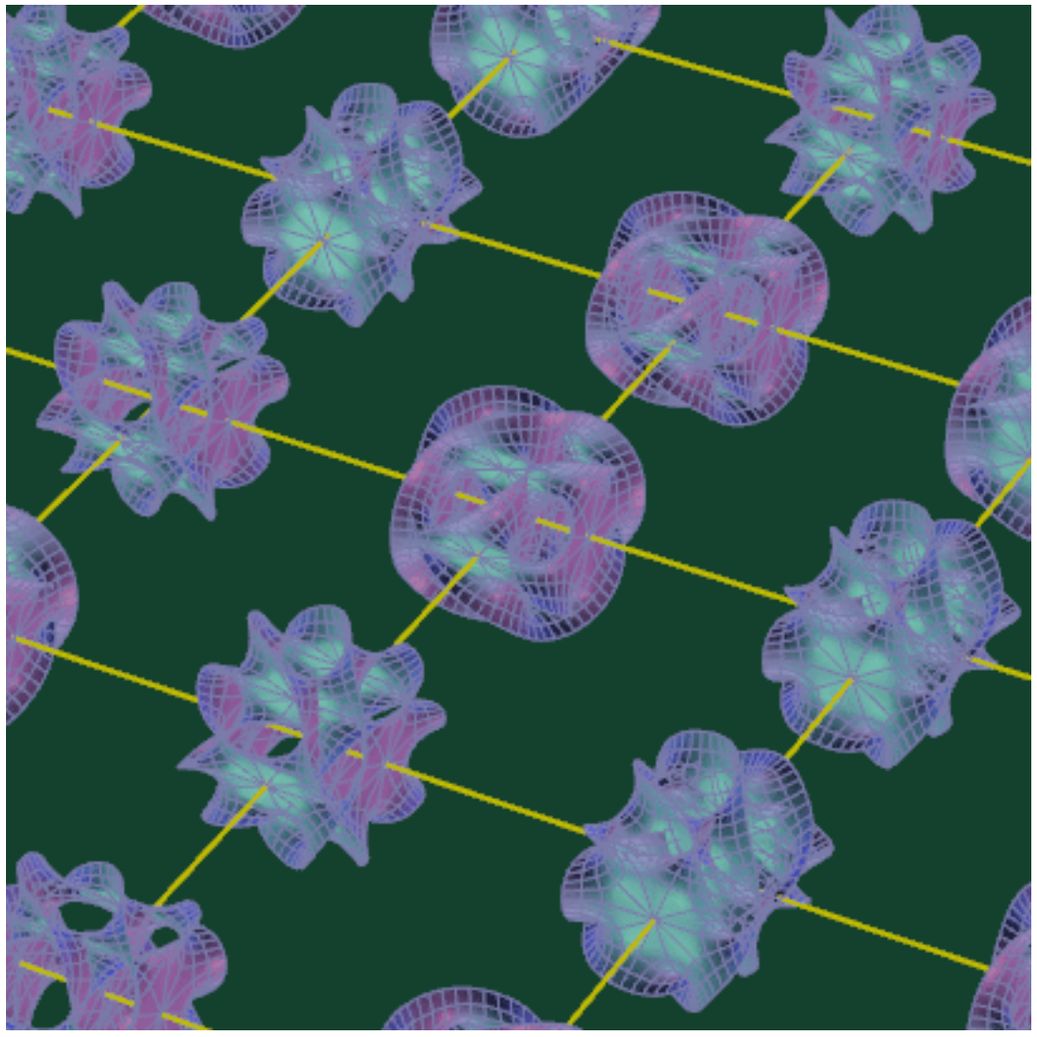
Combining them as in a

XIX-century "mechano"...



we can break SUSY and stabilize the size/shape of internal geometries

We use them to build semiclassical states



(A) almost SUSY "vacua"

(B) almost SUSY
"localized black hole states"

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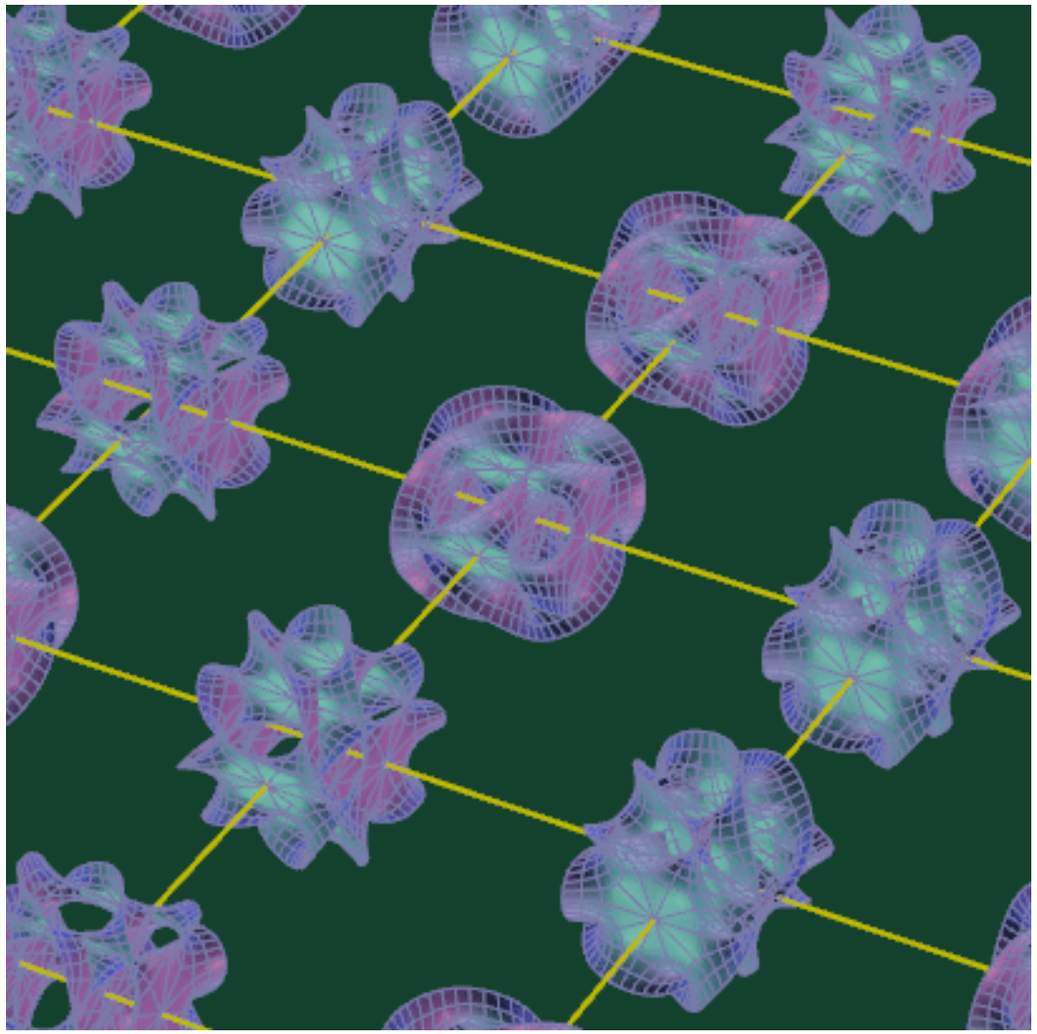
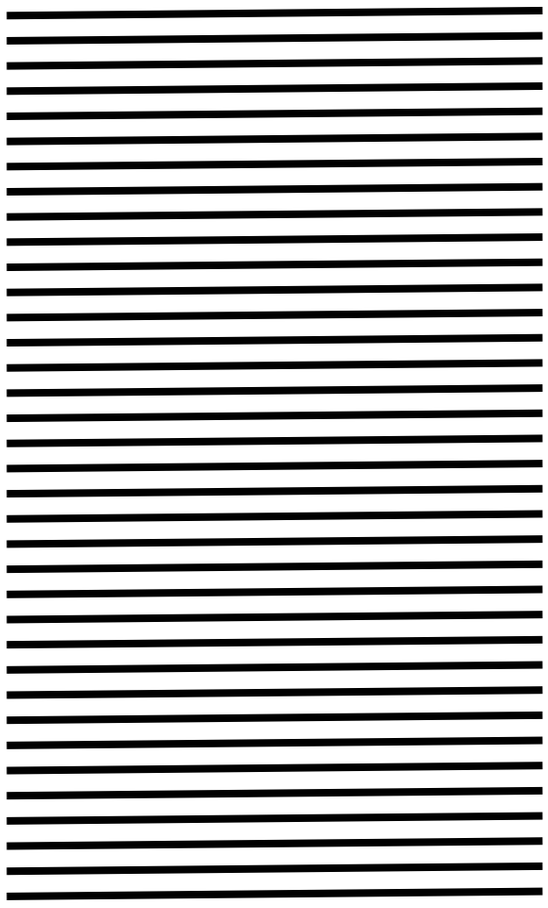


(A) almost SUSY "vacua"

(B) almost SUSY
"localized black hole states"

$$L_{\cancel{\text{SUSY}}} > \mathcal{O}(\ell_P)$$

With so many moving parts, we get naturally
a HUGE degeneracy of semiclassical states

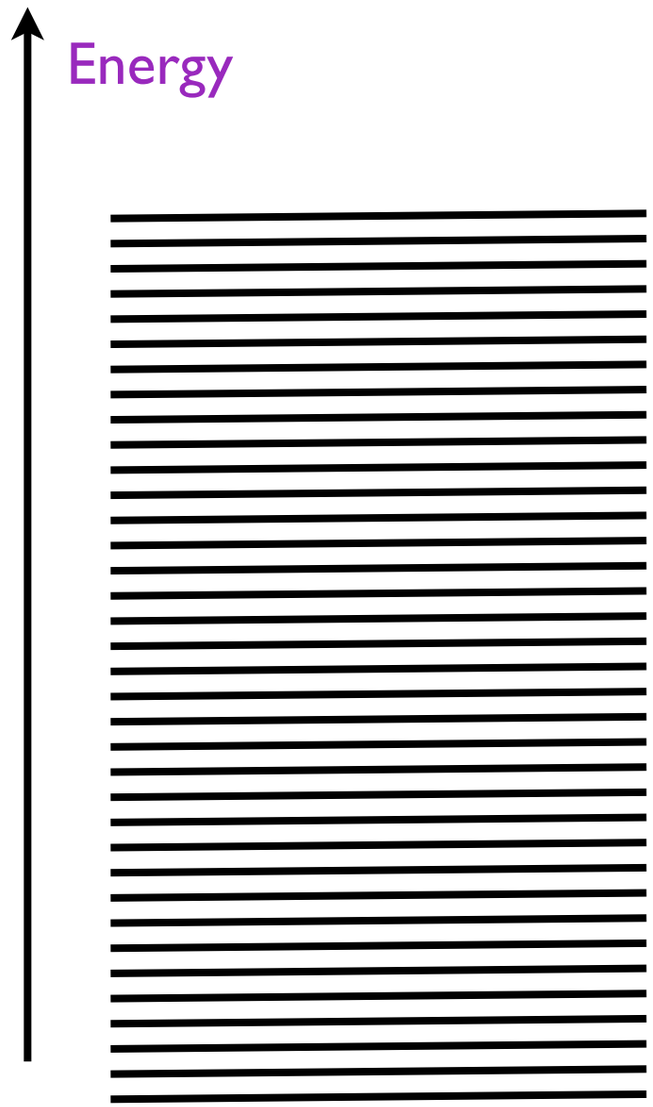


$$\text{Degeneracy} \approx (n_{\text{moving}})^{N_{\text{parts}}}$$

Recognize the famous 10^{500} ?

A crucial test of this huge degeneracy

For almost-SUSY black holes this is the spectrum of some Hamiltonian:



Its density of states is constrained by general low-energy physics arguments, due to Bekenstein and Hawking

$$S(E) \equiv \log\, \Omega(E)$$

It is a famous result that

(Strominger & Vafa)

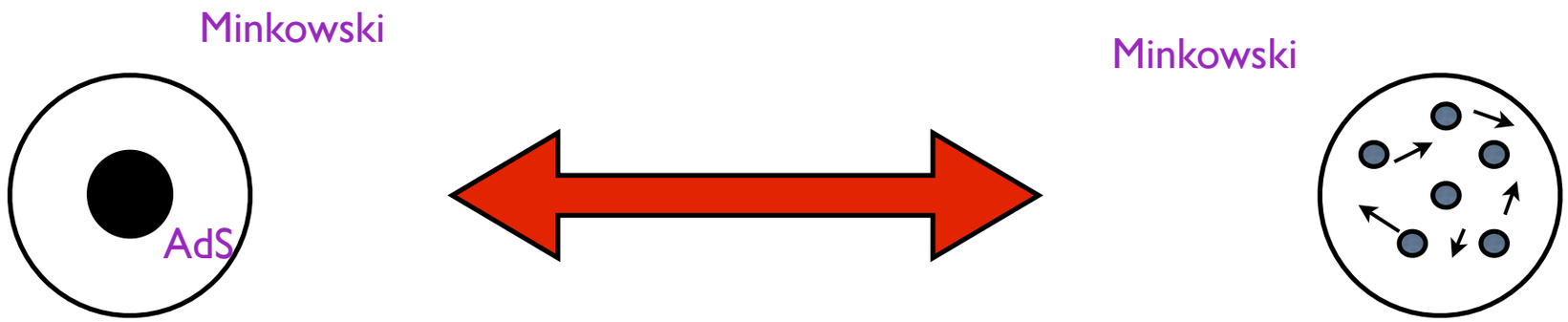
$$S(E)_{\rm BH} = \frac{A_{\rm horizon}}{4G} = \log\left[(n_{\rm moving})^{N_{\rm parts}}\right]$$

Exactly, in the WKB approximation for the right-hand side down to the precise factor of 1/4

Literally, micro-states of almost SUSYc black holes are given by the stringy "moving parts"

In some sense, this proves that the "number of moving parts" is basically the "right" number

Maldacena saw an even more important consequence

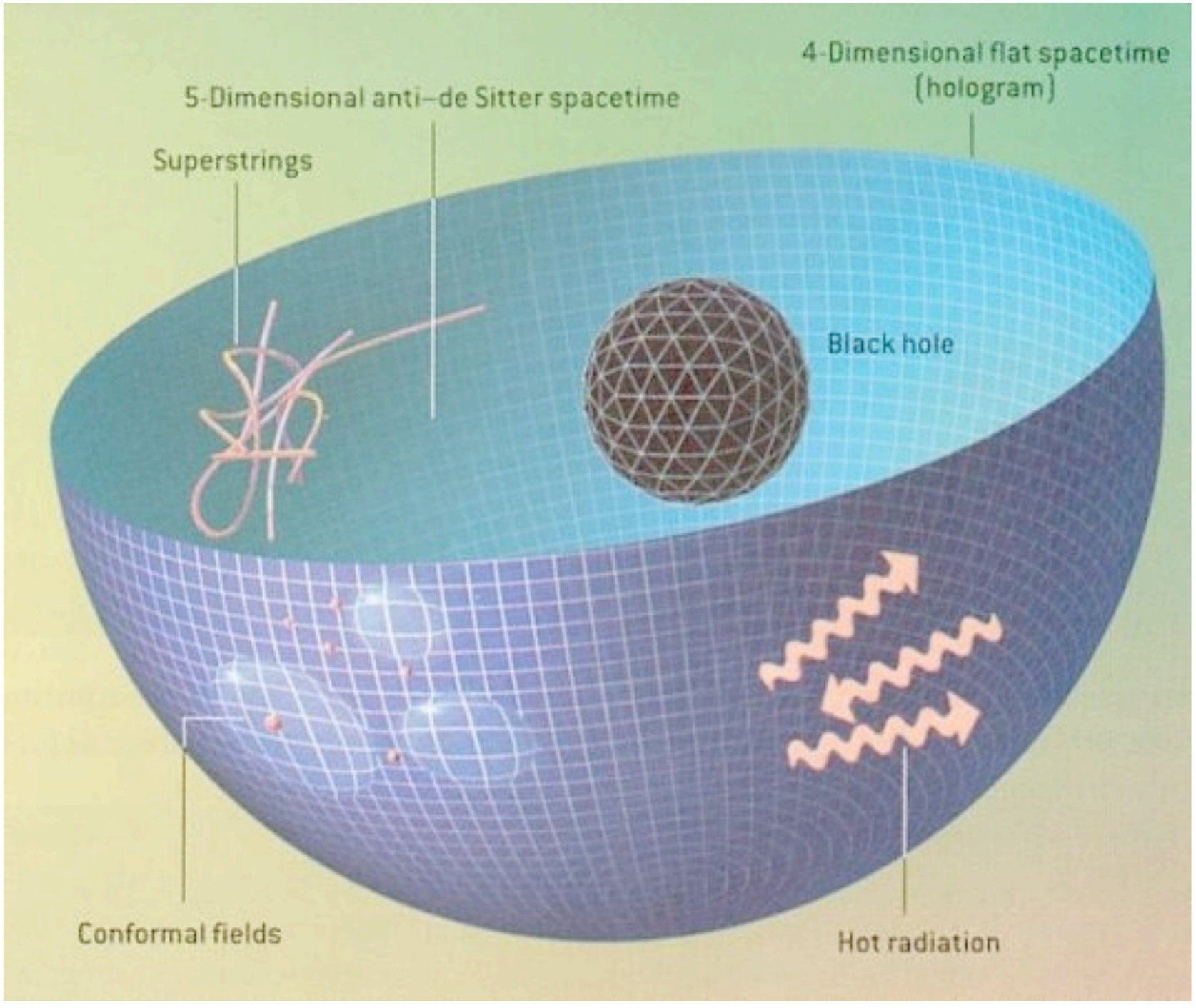


The black hole mass is the energy of the moving parts

Therefore:

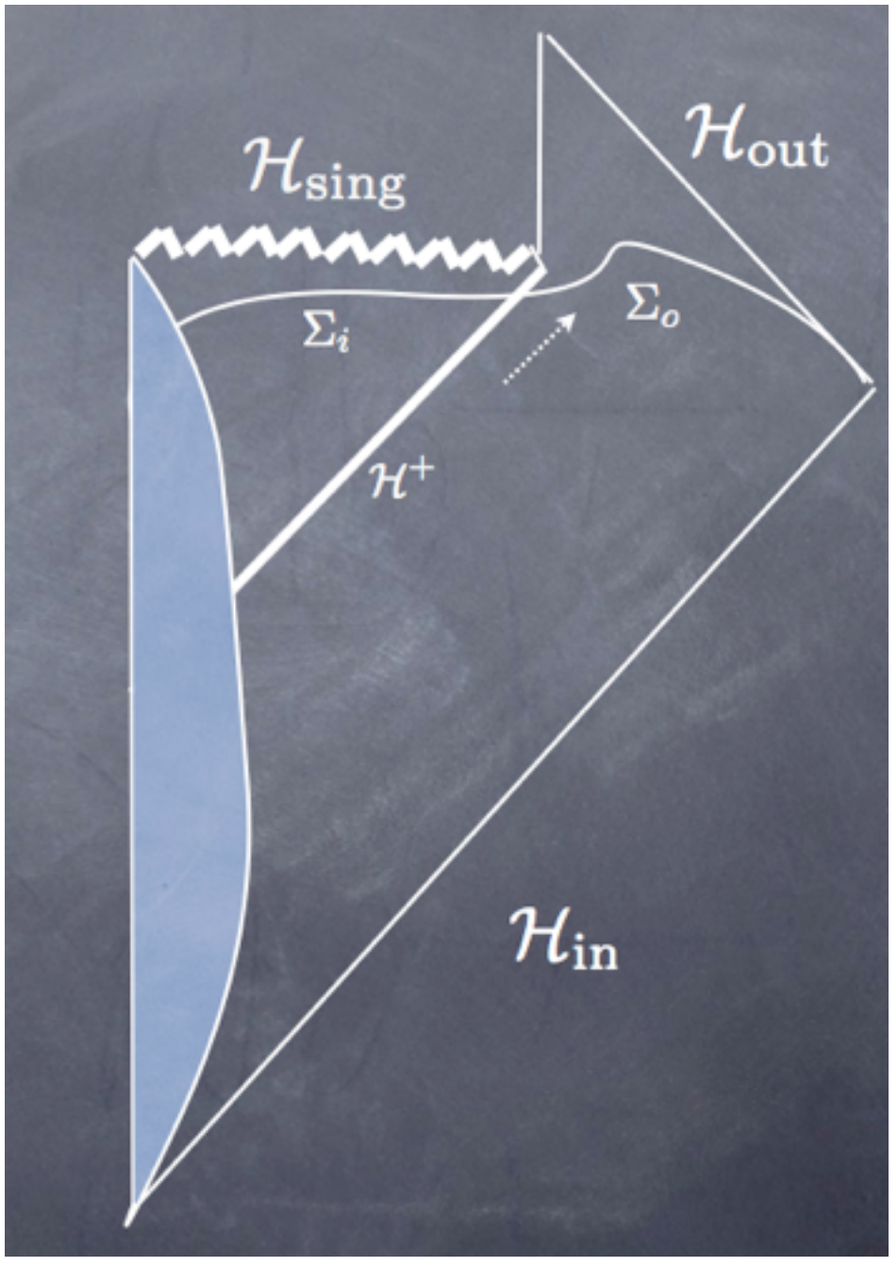
The moving-parts ground state is mapped to the negative curvature AdS region

AdS/CFT


4-Dimensional flat spacetime
(hologram)
5-Dimensional anti–de Sitter spacetime
Superstrings
Black hole
Conformal fields
Hot radiation

The quantum black hole will be decoded...

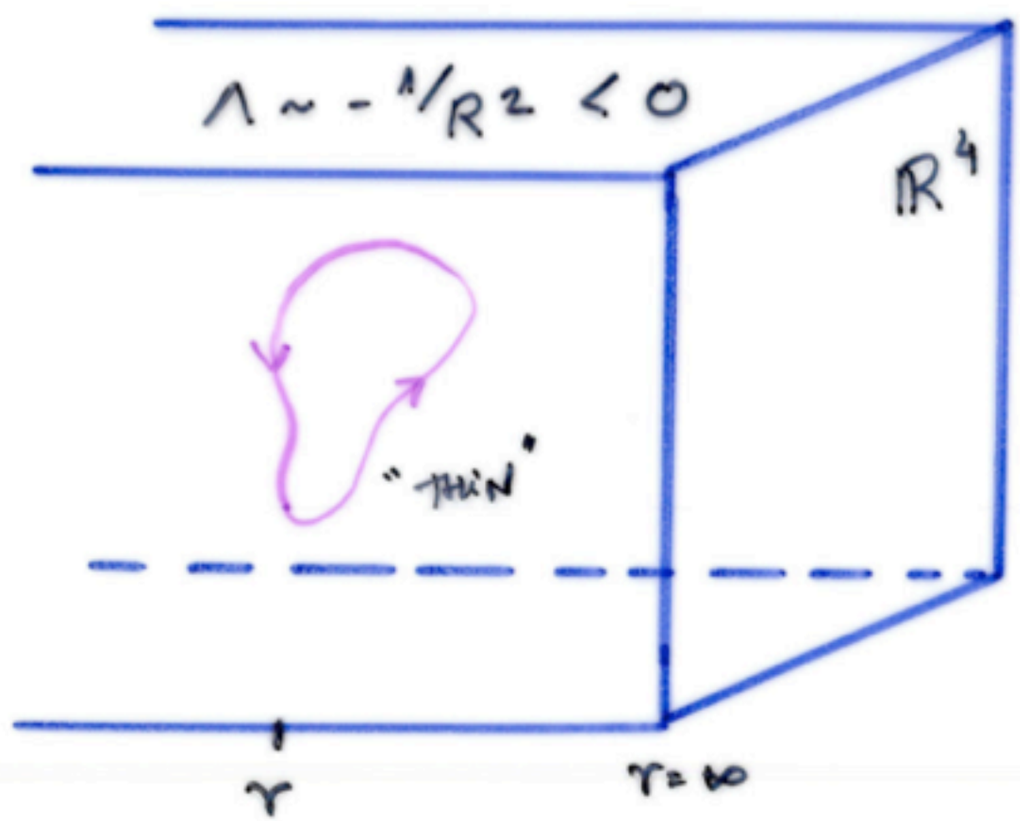
Bekenstein, 't Hooft, Susskind...

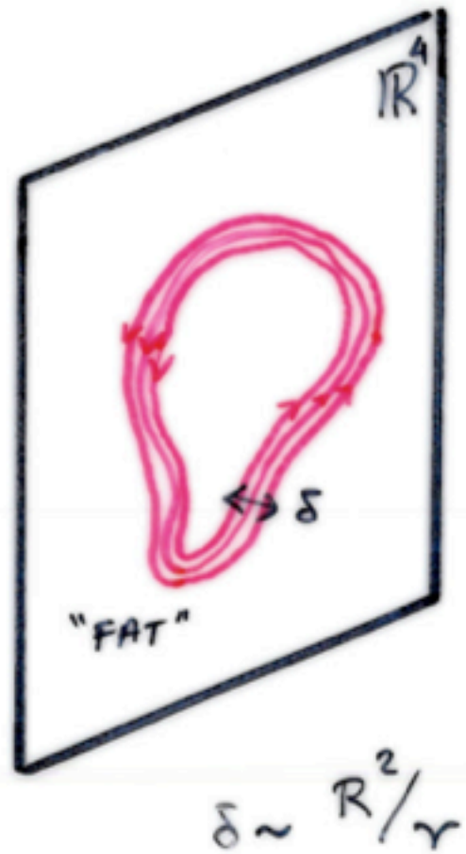


Physics of the crunch/bang singularity is deeply scrambled in the CFTs Hilbert space... but it is there!

The elusive confining-string unveiled...

Nambu, Wilson, 't Hooft, Polyakov...





The "fatty" confining string is nothing but a "skinny" fundamental string floating in an extra-dimensional AdS box

Main open problem!

Calculations are carried out as a strong-coupling expansion

$$\langle \mathcal{O} \rangle = \sum_n \left(\frac{1}{\sqrt{\alpha_s}} \right)^n \langle \mathcal{O} \rangle_n$$

Not easily matched to the actual dynamical regime of real QCD

So far, great solace came from looking at universal behavior of high-T regime (thermodynamics and transport)

$$\frac{\text{shear viscosity}}{\text{entropy density}} = \frac{\eta}{s} = \frac{1}{4\pi} + \mathcal{O}\left(\frac{1}{\sqrt{\alpha_s}}\right)$$

(Policastro, Son & Starinets)

A "perfectish" quark-gluon plasma fluid, a good starting point to model RHIC & LHC data?

STILL...

The UV theory was not exactly QCD...

so systematics are not under control, and the method remains just a qualitative guide to strong-coupling plasma dynamics

Recently, a new tool was added to the box

If the AdS black hole carries a U(1) charge,
the CFT is in a finite T and finite μ state

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The $\mu >> T$ limit

sends us into Condensed-matter physics

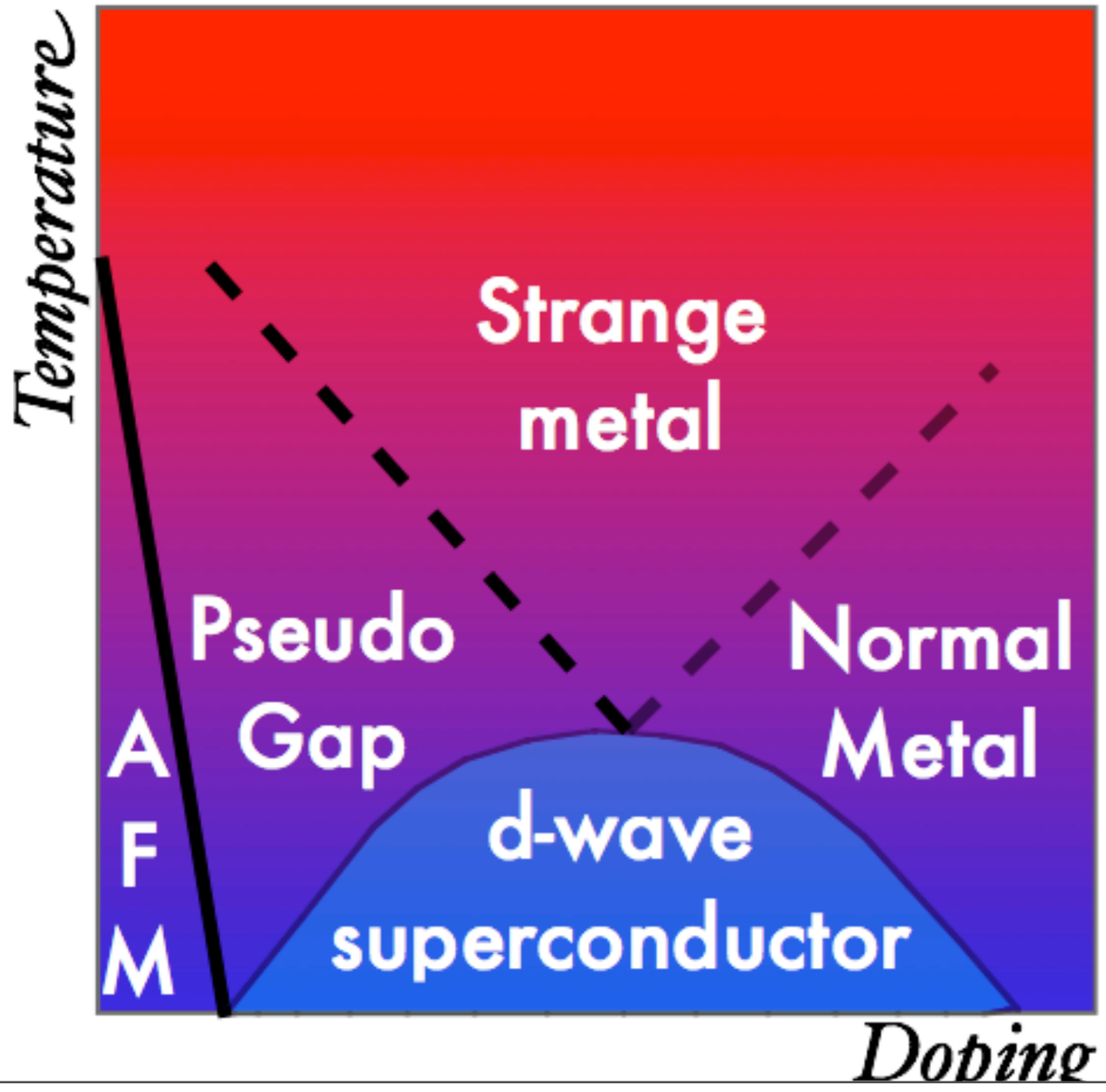
The exciting hint: the charged black hole gives, effortlessly:

$$C_V \propto T$$

The landmark of a Fermi liquid

On closer inspection, one does find evidence for a Fermi surface, albeit a non-Landau one

Some famous CM-Theorists are quite excited about this...

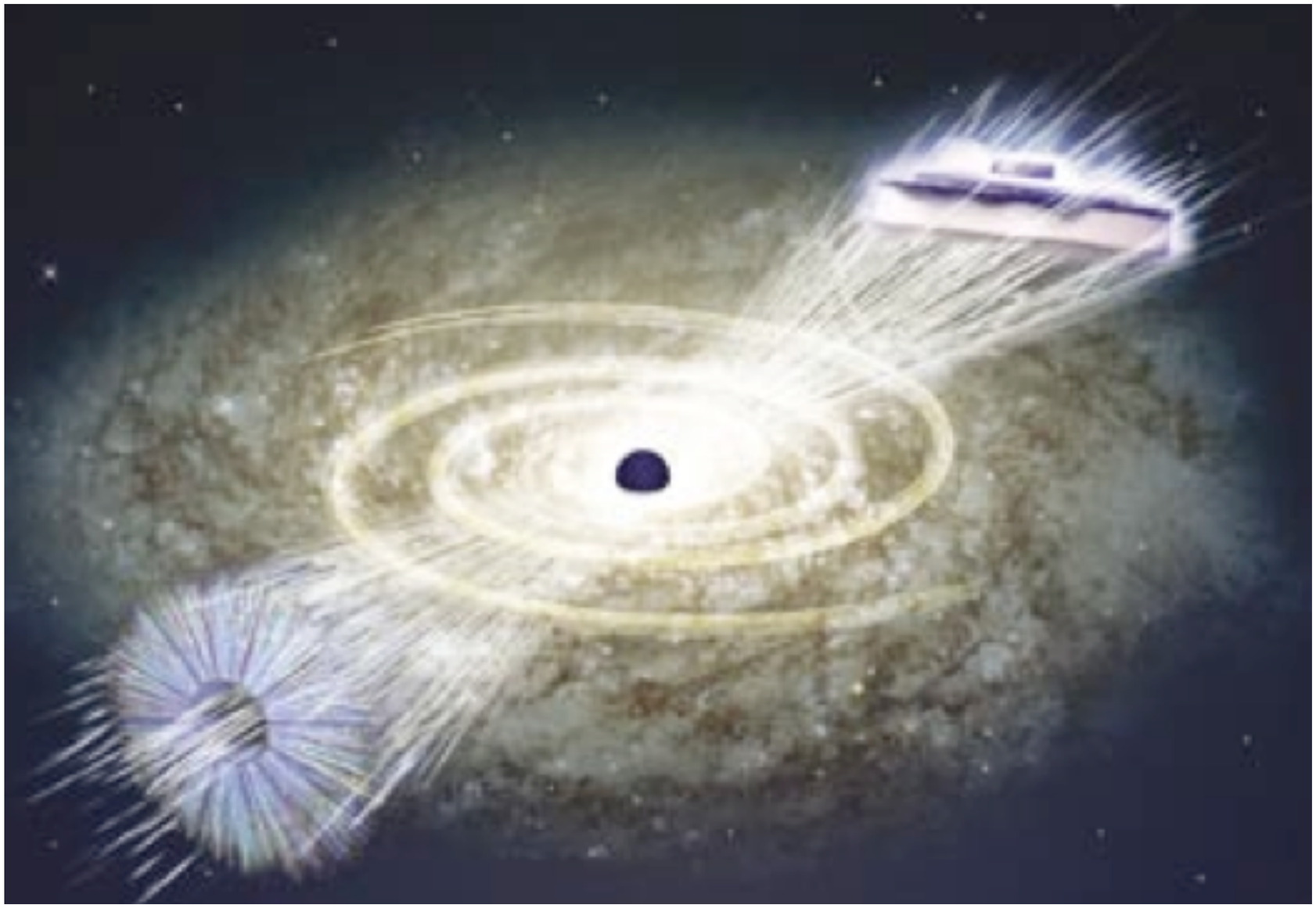


Future of this idea will depend on getting the peculiar linear resistivity of strange metals, just coming out from the geometry

$$\text{Resistivity} = \rho \propto T$$

A "holy grail" of High-T_c superconductivity

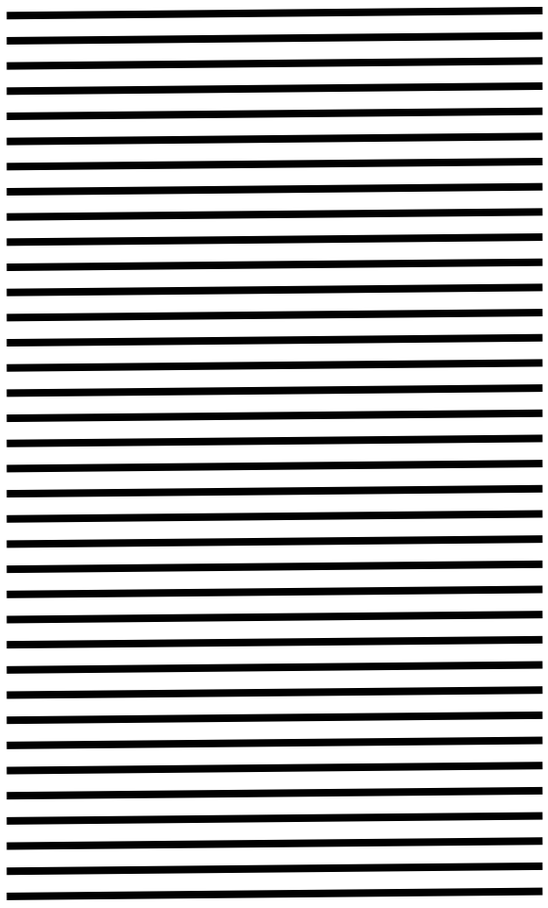
The black hole at the center of the galaxy...



...of theoretical methods (cf. Jan Zaanen)

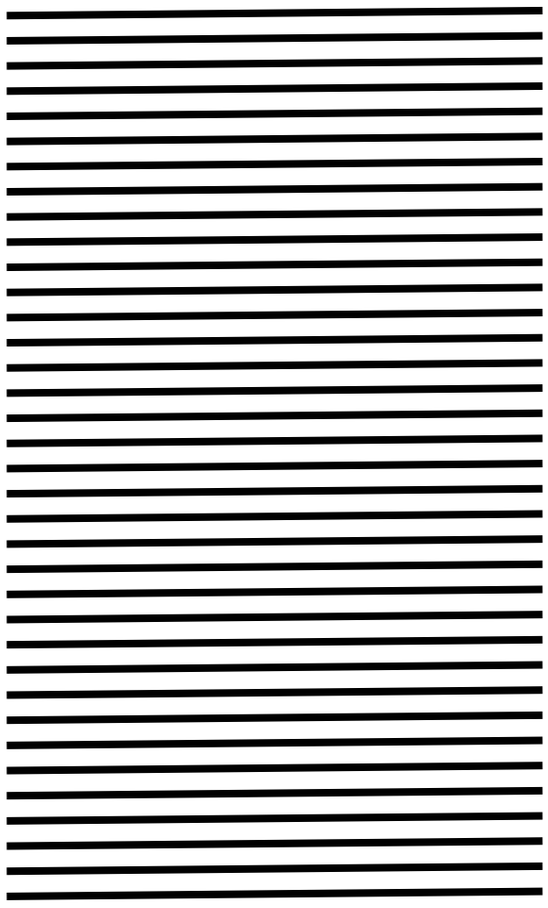
The "moving parts" of string theory are also crucial for particle-physics model building...

BACK TO THE DISCRETUUM



Can construct semiclassical states looking like 4-dimensional "vacua"

BACK TO THE DISCRETUUM

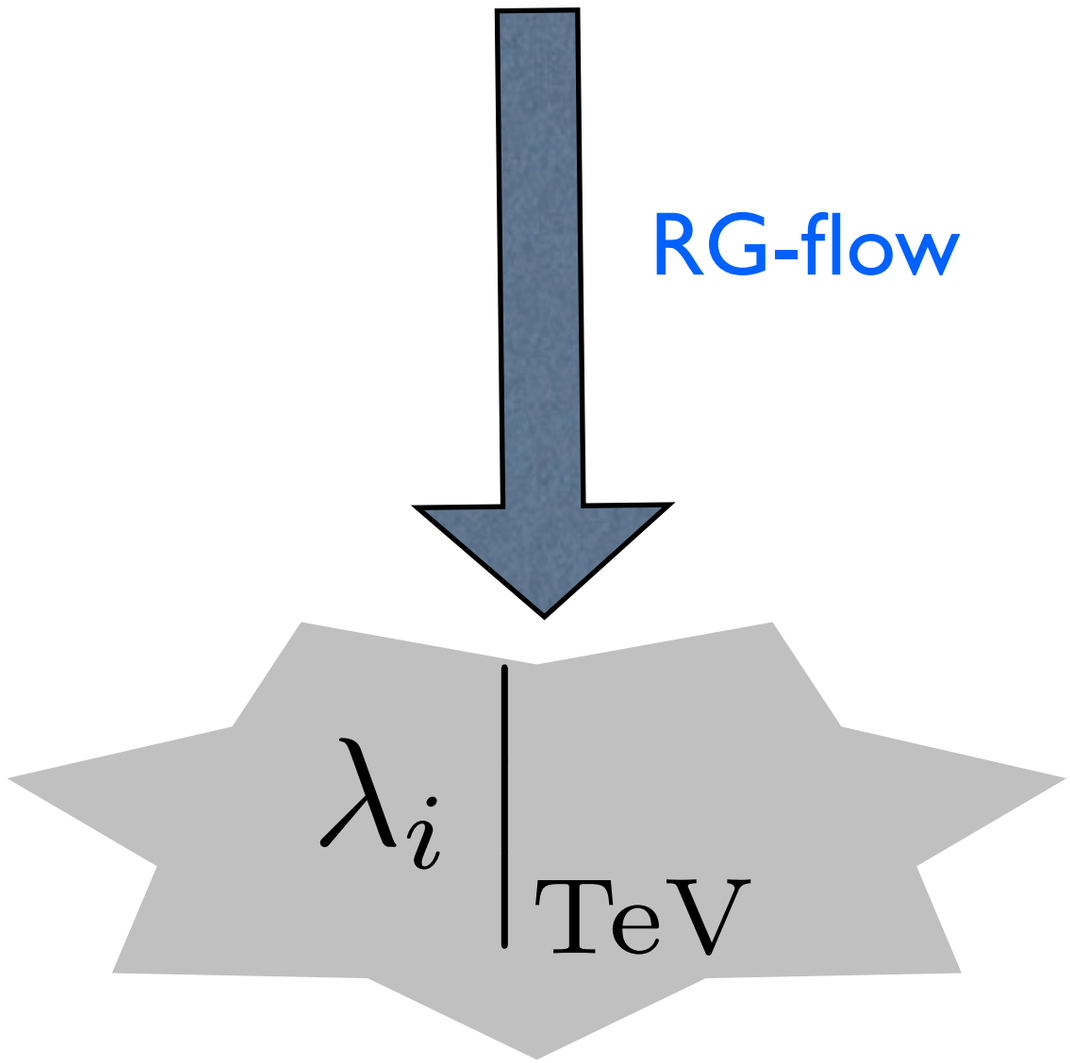


Can construct semiclassical states looking like 4-dimensional "vacua"

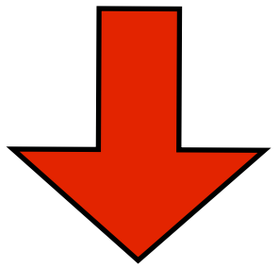
Each equipped with a 4-dim effective Lagrangian

$$\mathcal{L}_{\rm eff} = \frac{1}{2} M_P^2 \, R + \sum_i \frac{\lambda_i}{M_P^{d_i - 4}} \mathcal{O}_i$$

$$\lambda_i\Big|_{\rm UV} = f(\text{moving parts})$$



We say "vacua" because they are actually generically metastable quantum-thermal tunneling effects



The resulting cosmologies are of the "eternal inflation" type

THE FIRST QUESTIONS:

- Is the SM "in the list"?
- How to find it?
- Can we test some predictions?
- Can we make sense of the cosmology?

Historically, looked for $\mathcal{L}_{\rm eff}[Standard\ Model]$ under some "lamp-posts" amenable to calculation

- Heterotic E_8 X E_8
- M5-brane models
- Type IIA brane intersections
- Type IIB orientifolds
- F-theory models
- ...

All of them provide good caricatures of the real world, most bottom-up ideas can be embedded but...

Detailed description is too qualitative to really nail the O(20) values of λ_i that we have measured below the TeV

And one outstanding problem remains...

$$\lambda_0 = G\Lambda \sim 10^{-120}$$

Who is going to compute this?

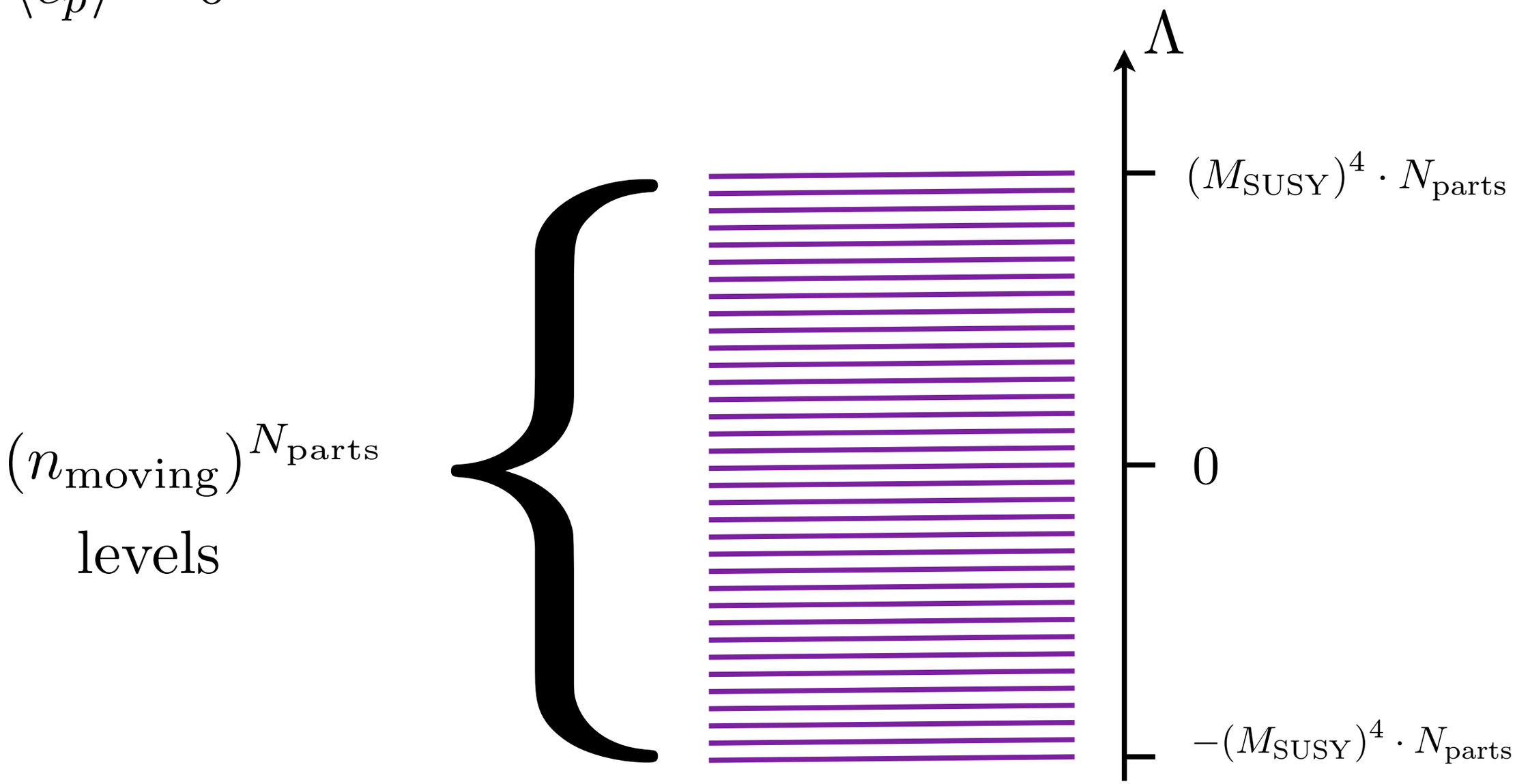
Understood as a result of an accidental cancellation, thanks to the many moving parts

A generic estimate:

$$\Lambda = \sum_{p}^{N_{\rm parts}} c_p \, (M_{\rm SUSY})^4$$

$$c_p \in \Big[-n_{\rm moving}, n_{\rm moving} \Big]$$

$$\langle c_p \rangle = 0$$



This suggests that we look for the Standard Model in a region of the Discretuum in which Λ scans with a random and dense distribution

Then our value of Λ would be a contingency

(Weinberg)

PROBLEM!

In simple, unrealistic models, once λ_0 scans, all other λ_i tend to scan as well!

Random variables in practice?

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all other λ_i tend to scan as well!

Random variables in practice?

its the **PANDORA** box!

Are we prepared to give up our theoretical prejudices?

$$\frac{\Lambda}{M_P^2}$$

$$\frac{m_H}{M_P}$$

$$Y\ ,\ \ \theta_{\rm QCD}$$

$$\alpha_s\ , \alpha_W\ , \alpha_{em}$$

$$\frac{m_p}{M_P}$$

$$\frac{M_{\rm SUSY}}{M_P}$$

OF COURSE...

this could be severely simplistic

After all, something important was left inside Pandoras' box...

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HOPE

I have argued that the "moving parts" of string theory are crucial but...

WHO ORDERED THEM?

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SUSY !!!

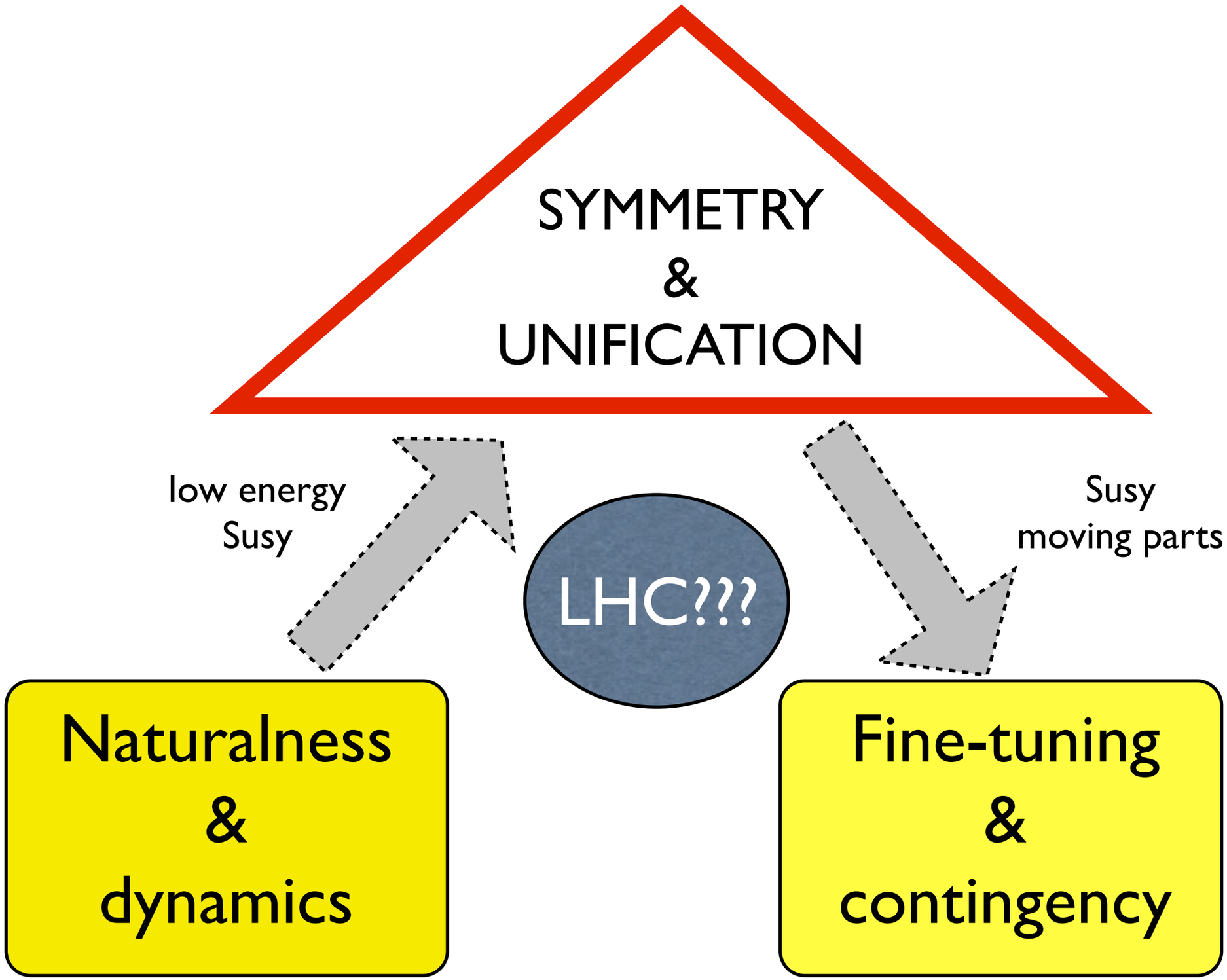
l'éminence grise

From the maximal SUSY$_{11}$ algebra:

$$\{Q, Q\} = \gamma^{\mu} P_{\mu} + \sum \gamma^{[\mu\nu\ldots]} Z_{[\mu\nu\ldots]}$$

The natural representation of the
antisymmetric central charges
is in terms of branes, which source fluxes,
and wrap topological cycles

A historical irony?



THANK YOU