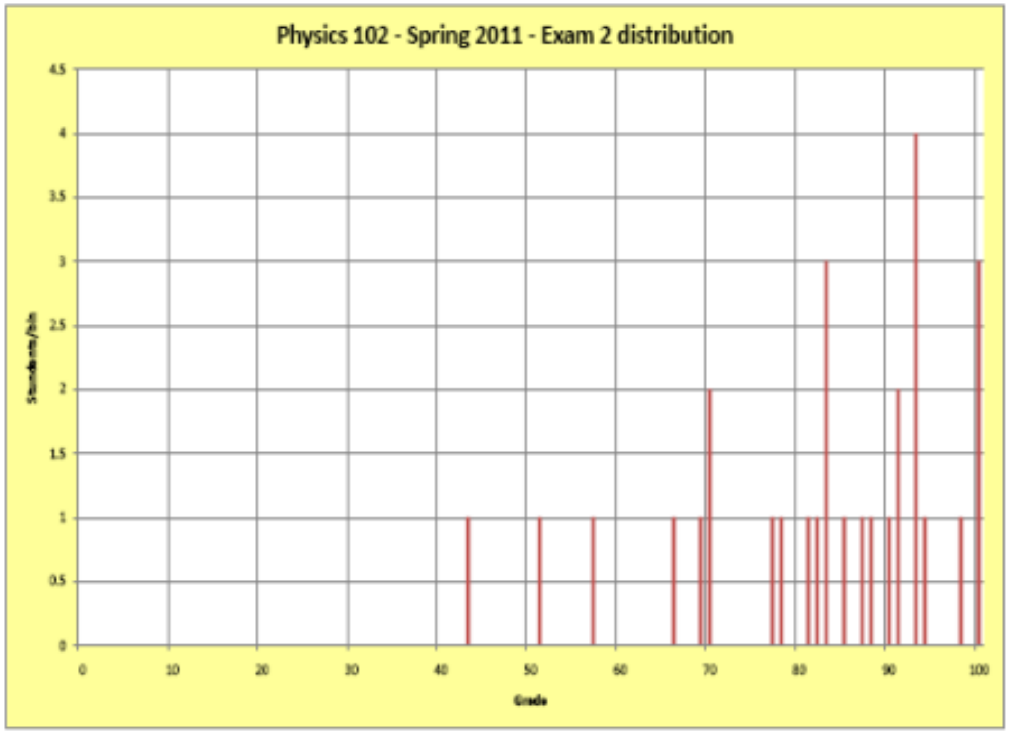
Physics 102 - April 25, 2011

- No recitations this week
- There is reading for this week
- I'll send out some thoughts/questions to consider abt reading/lectures since last recitation
- Final Exam - May 3 4pm
  - Location TBA
  - 8.5 x 11 inch sheet
  - Calculator
- Exam 2 is graded



Mean grade

→ 82

String Theory

or

Particle spectrum consists of different excitations of fundamental string-like objects

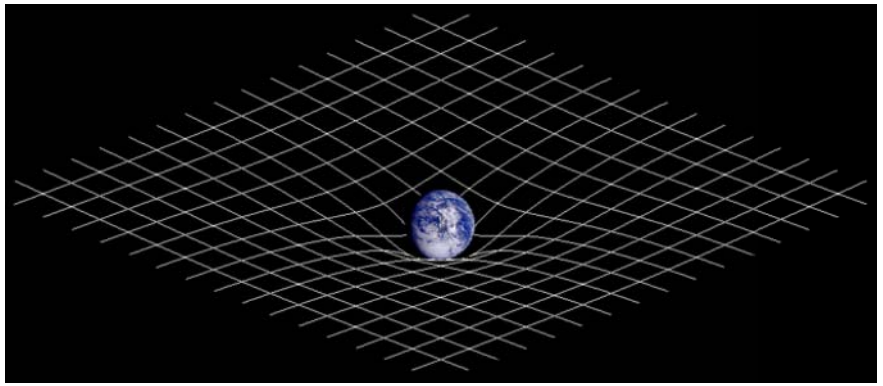
vs.

point-like particles in quantum field theory

Excitement about String theory

Small distance Behavior Better

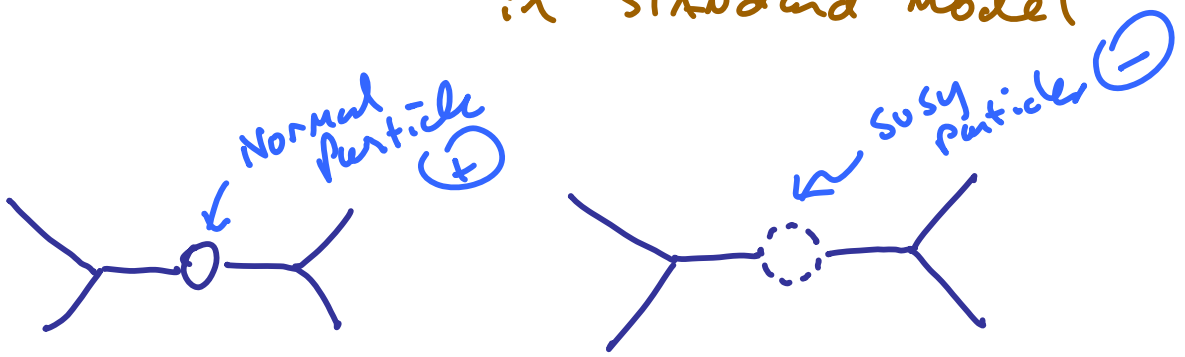
Quantum Gravity Seems Practical



	Spin		Spin
e^-	$\frac{1}{2}$	$\tilde{e}^-$	0
ν_e	$\frac{1}{2}$	$\tilde{\nu}_e$	0
u	$\frac{1}{2}$	$\tilde{u}$	0
d	$\frac{1}{2}$	$\tilde{d}$	0
γ	1	$\tilde{\gamma}$	$\frac{1}{2}$

Supersymmetry Natural

→ Can provide mechanism to solve Missing Higgs problem in Standard model



→ can Help theorists greatly w/ cancellation of "radiative corrections"

→ Sort of a natural symmetry to expect

String theory
Bosons only
misbehaves
(ghost particles)
unless done in
26 dimensions mathematically

NOT like the real world

String theory
Bosons + Fermions
misbehaves
(ghost particles)
unless done in
10 dimensions mathematically
plus
Supersymmetry

like real world?
Maybe

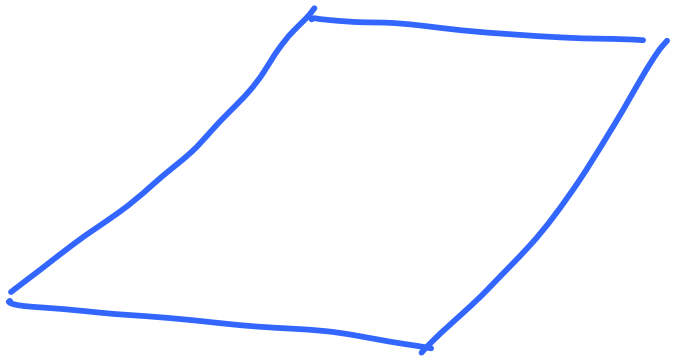
Extra Dimensions
yikes!

Must concoct ways for those Extra Dimensions to exist in the theory But be imperceptible

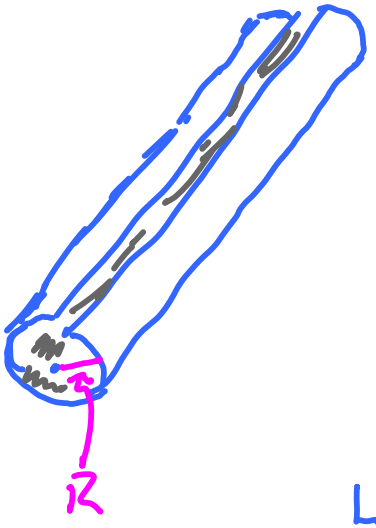
→ Compactification

→ limit where particles can go

Compactification

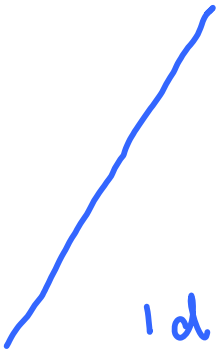


2d



R

3d



1d

Let R → small

"Strings" are a special case

Structures in String theory

P-Branes

0-Brane	Point
1-Brane	String
2-Brane	Membrane
3-Brane	
⋮	
9-Bran	

D-Brane (Dai, Leigh, Polchinski + indep by Horava)
1989

P-Brane where on end of an open string is attached.

Limit where particles can go

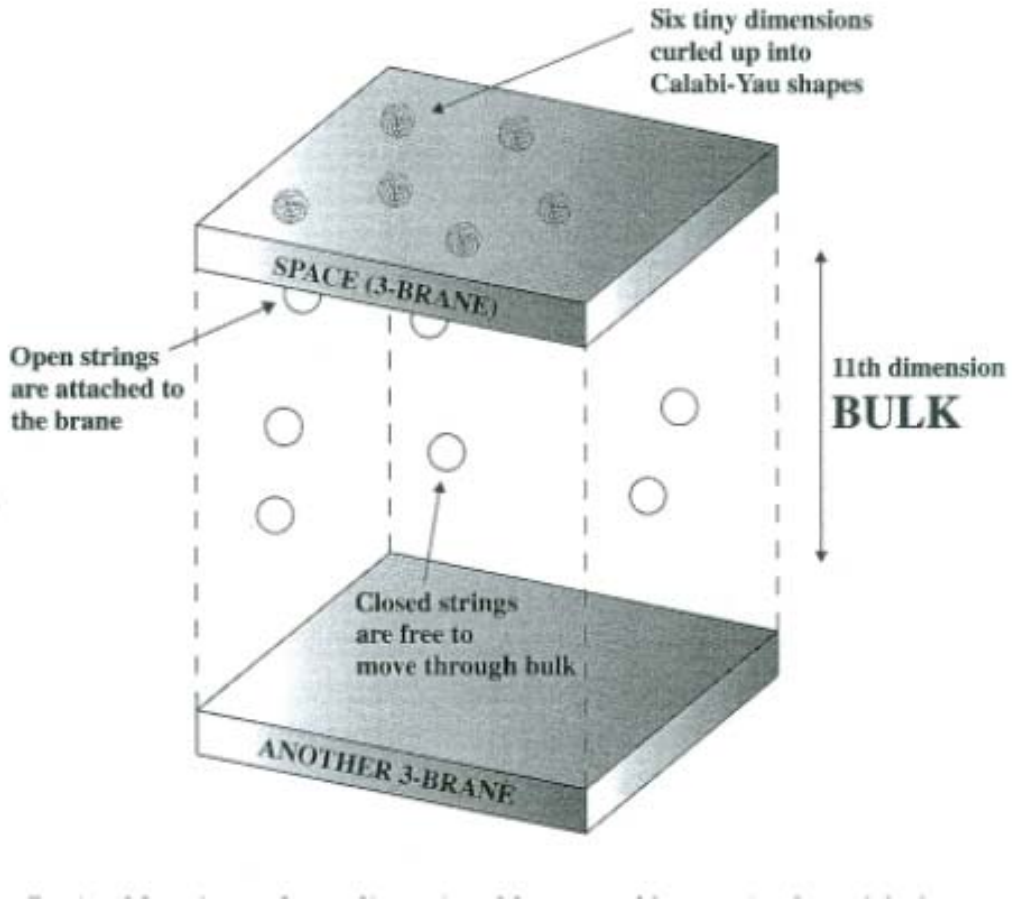
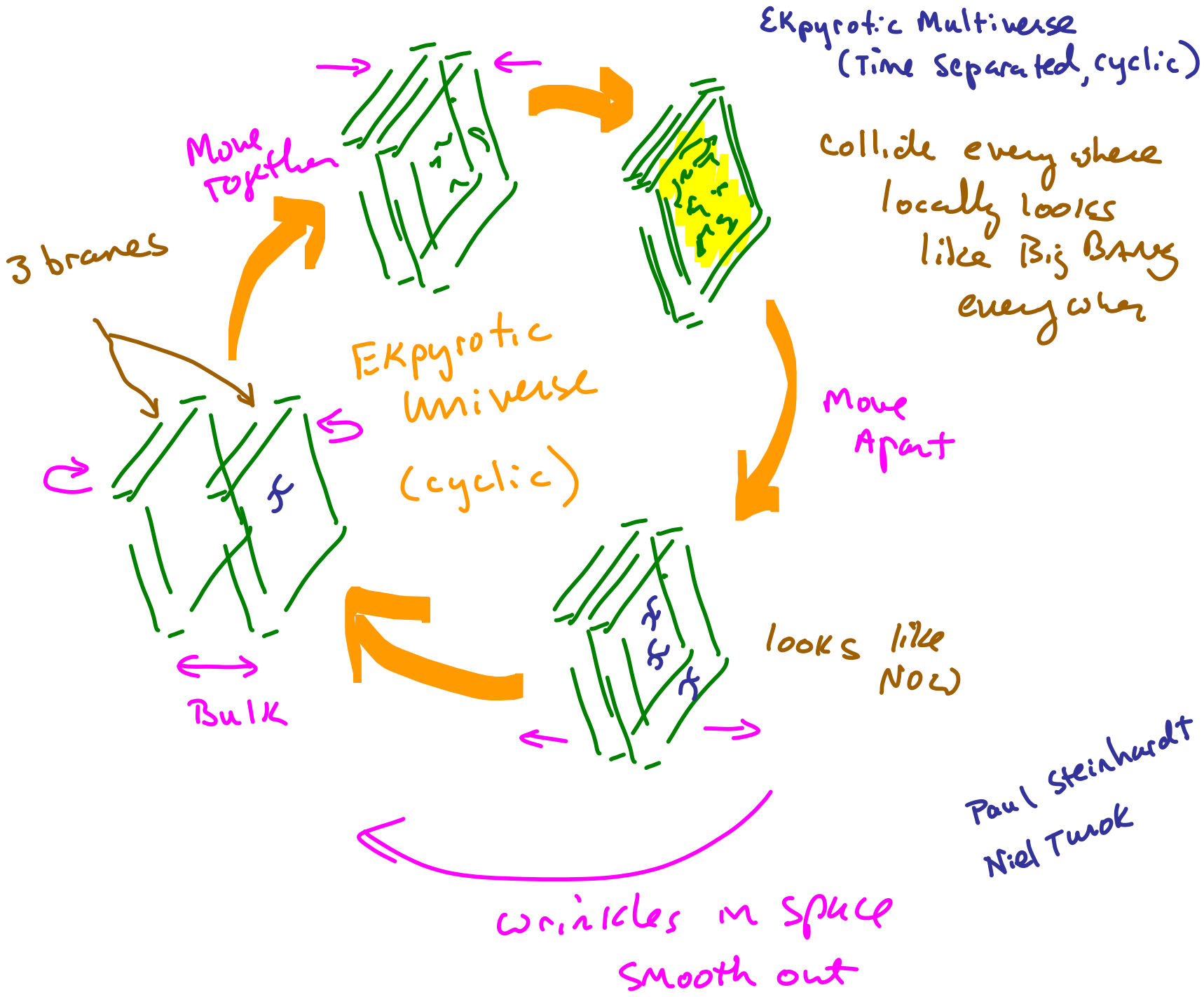


image from http://abyss.uoregon.edu/~js/qc/qc.html


Ekpyrotic Multiverse
(Time separated, cyclic)
Collide everywhere
locally looks
like Big Bang
everywhere
Move
Apart
looks like
Now
wrinkles in space
smooth out
Move
Together
3 branes
Ekpyrotic
Universe
(cyclic)
Bulk
Paul Steinhardt
Neil Turok

The Cosmic Landscape

In String theory –

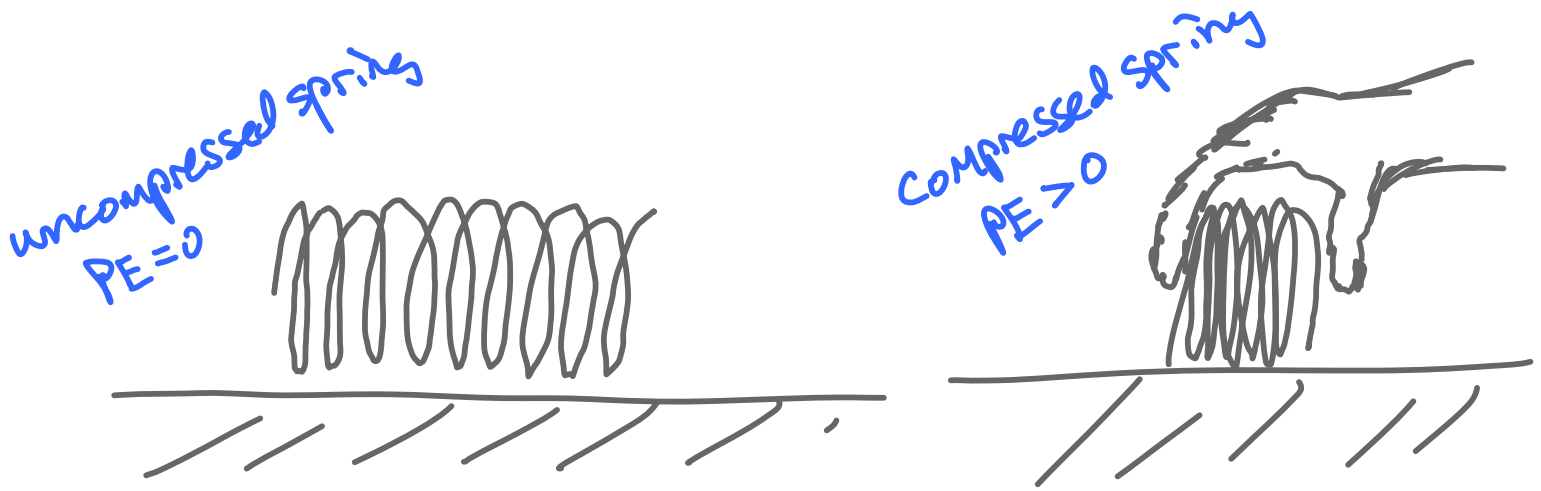
Laws of Physics
Particle spectrum
Nature of forces

} dictated by Shape + Size of Extra dimensions

Shades of the Ancient Greeks! geometry

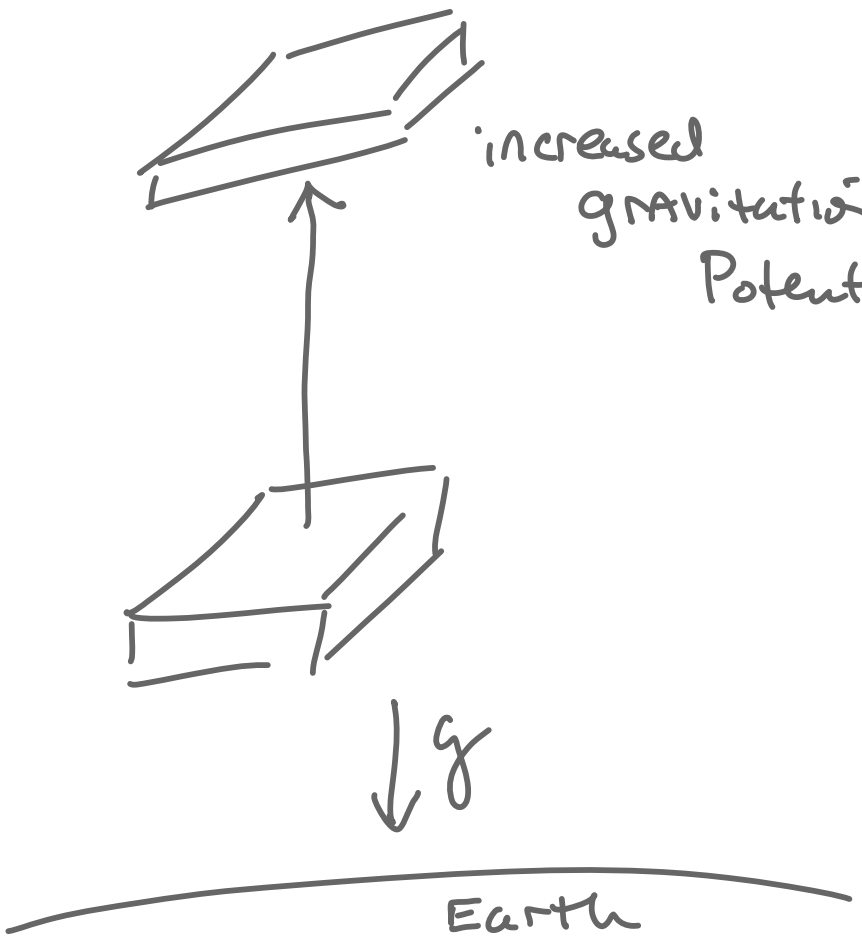
Depends on details of the compactification

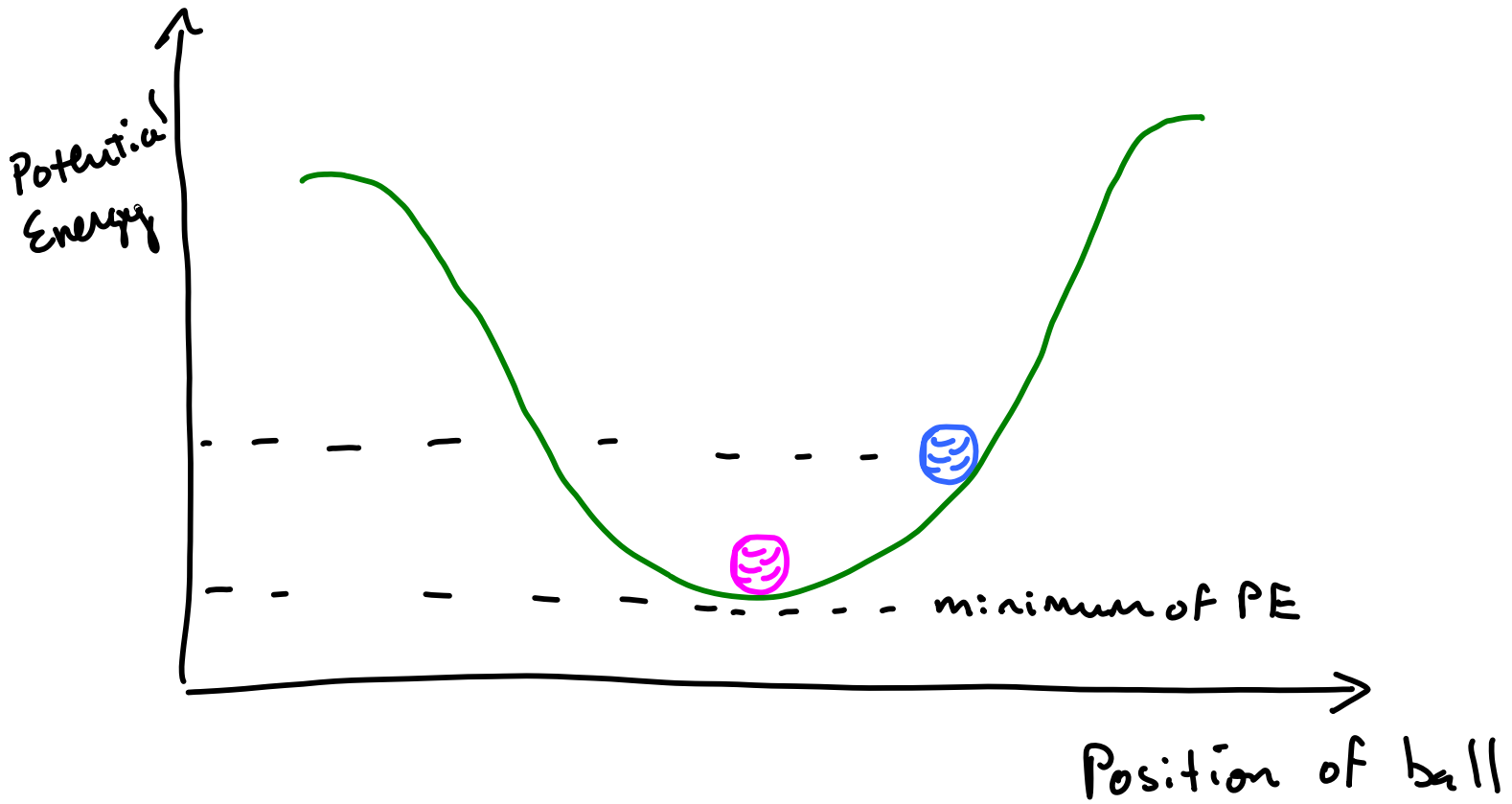
Vacuum "potential energy" depends on the details of the configuration of the different dimensions



Springs and Potential energy

gravitational Potential Energy



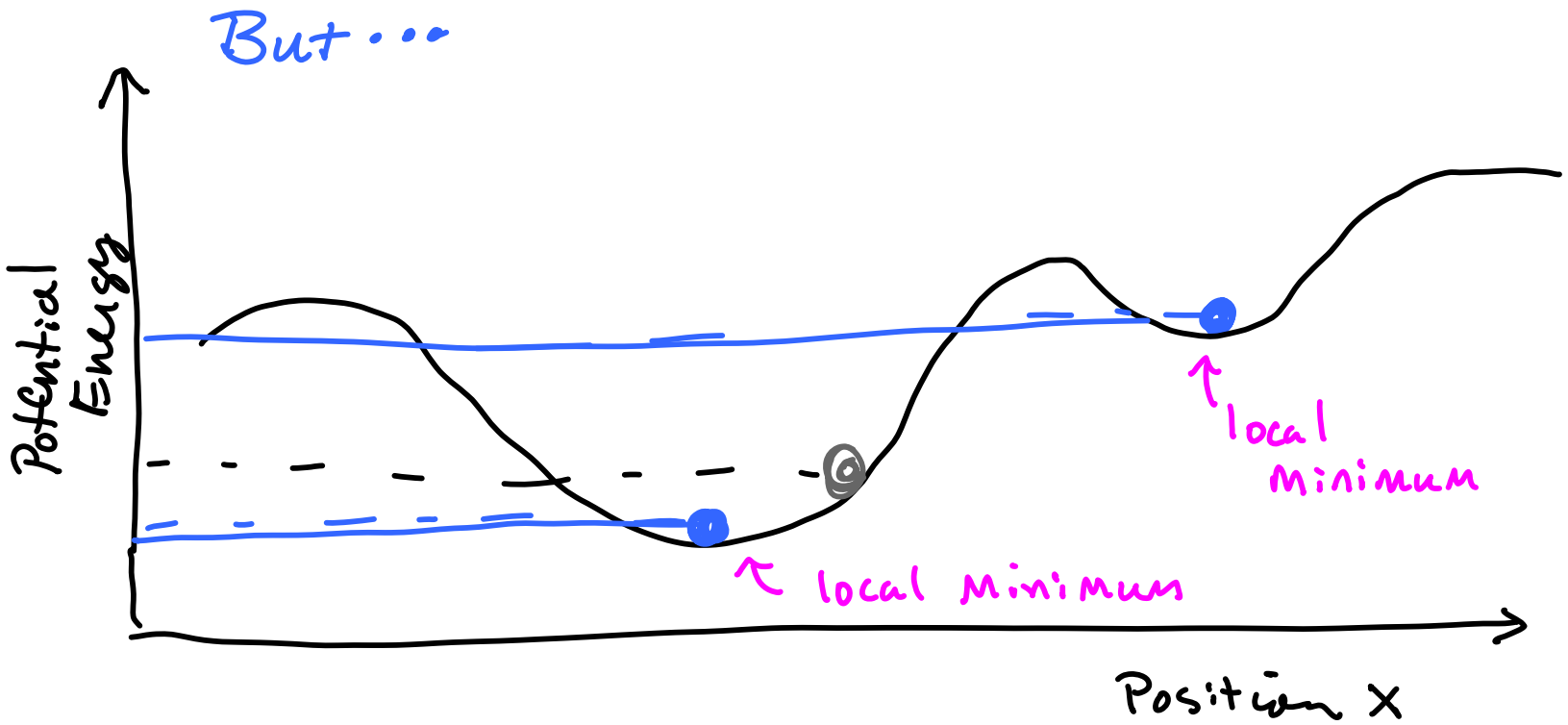


Different compactification schemes involve different degrees of potential energy stored in the "vacuum"

The String theorist's fantasy:

There is a single, particular Model Compactification that leads to a Minimum in the total energy of the System ... Corresponds to the particle spectrum, Cosmological constant, forces we see

→ The Theory of Everything!!



Expect a huge # of compactification schemes to lie at local minima of the "potential energy" function

→ should be quasi stable or stable

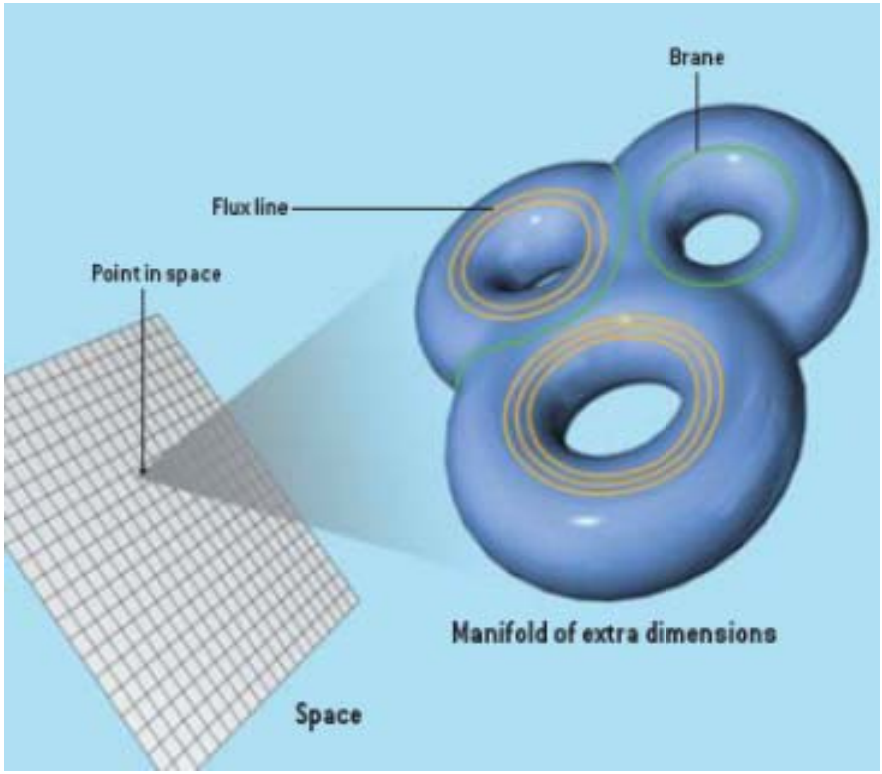
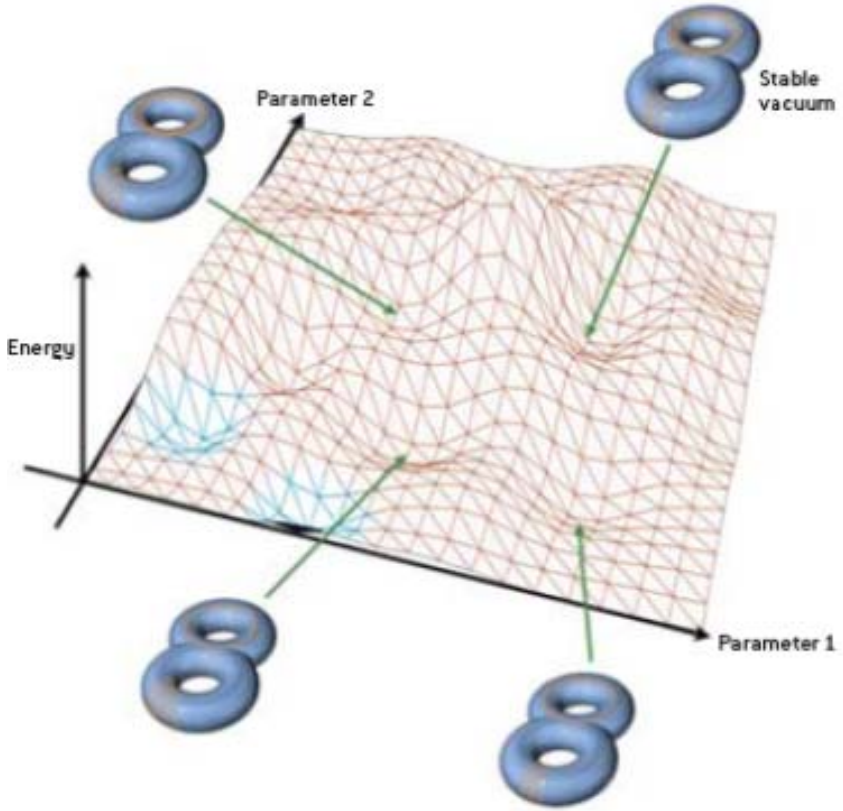


Fig from —
Bousso + Polchinski:
The String Theory Landscape
Sci. Am. 2004

What does the space look like on a very small scale?

The "vacuum energy" depends on This.



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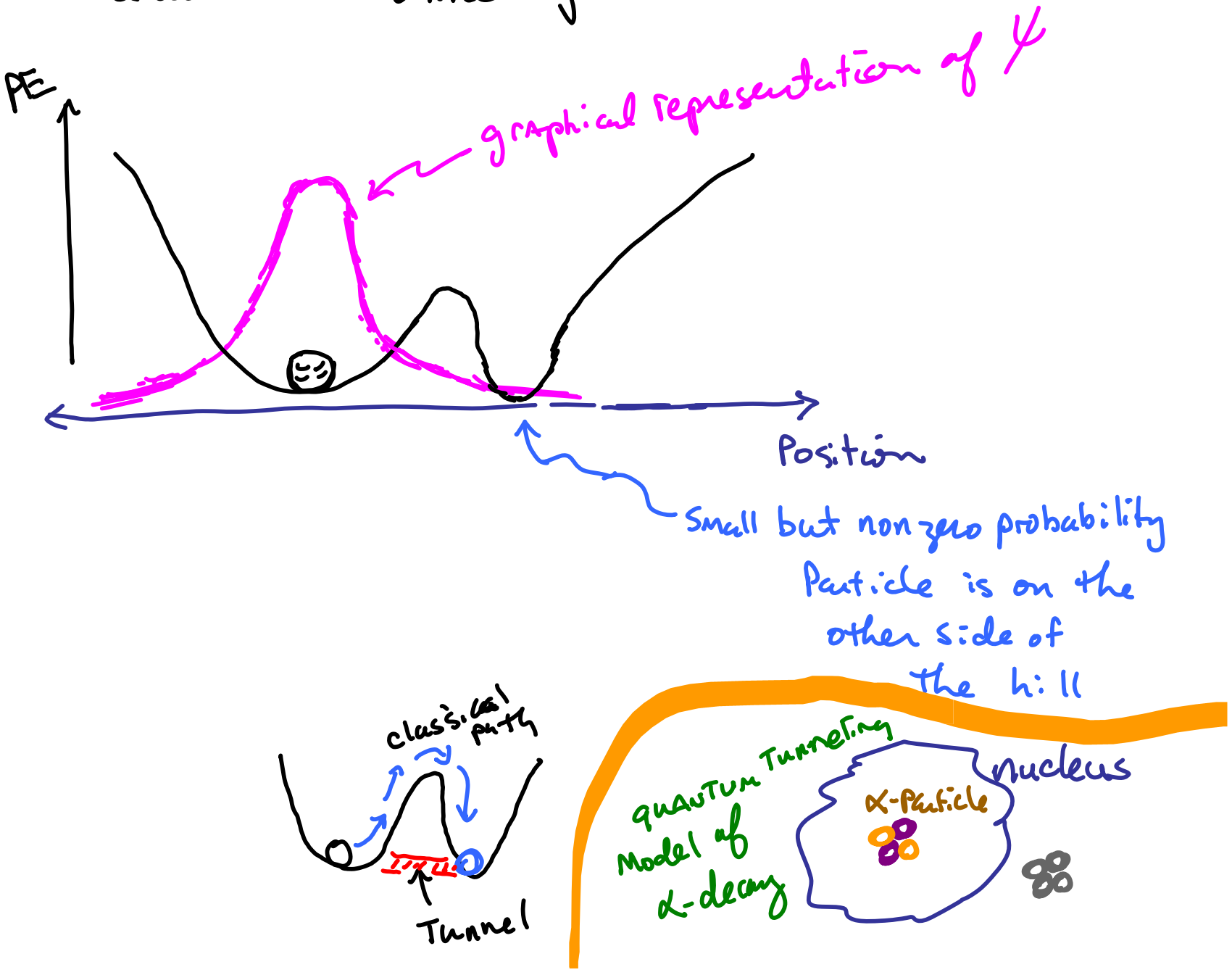
Different configurations → Different energies
→ Different locations in
the landscape of
Possibilities

Quantum Tunneling



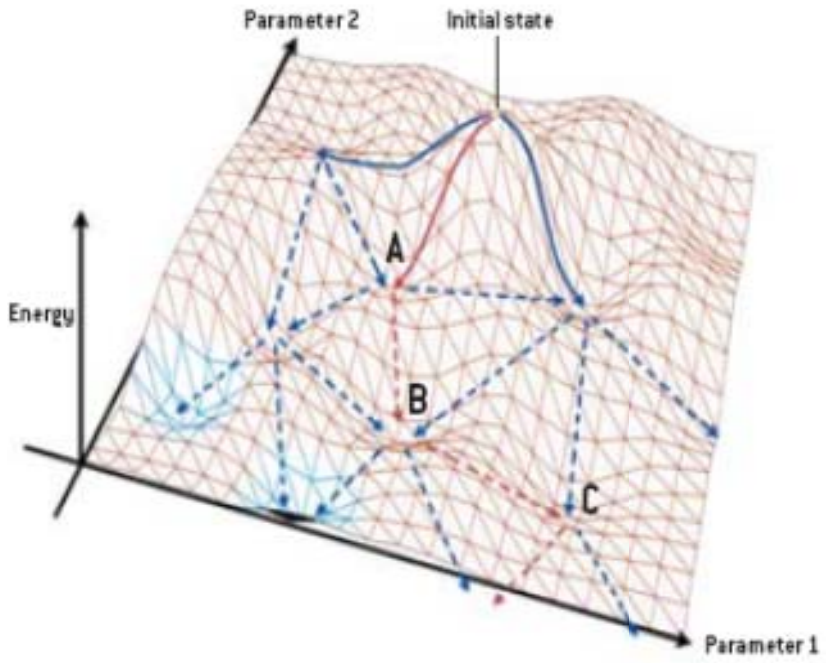


Fig from —
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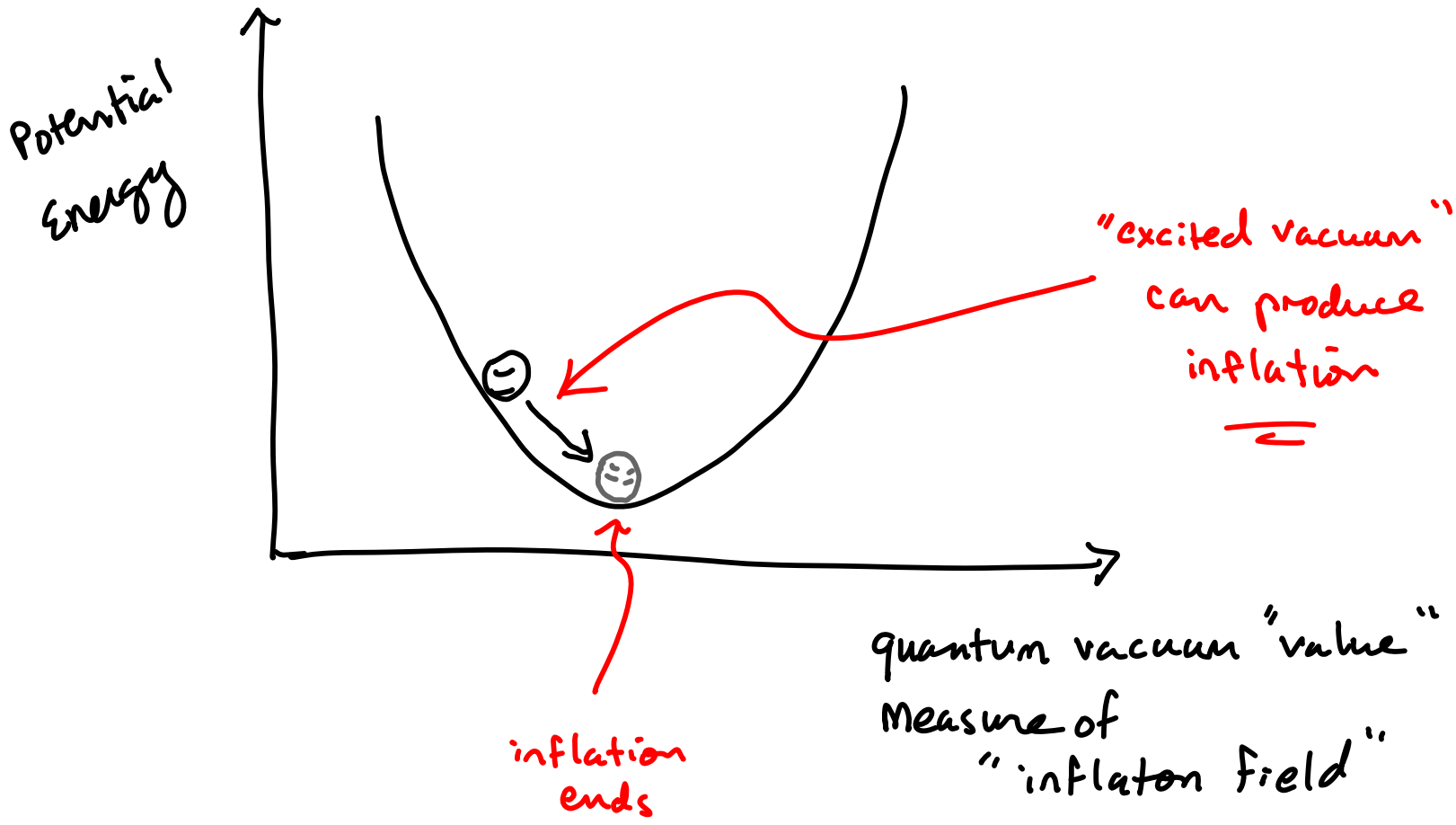
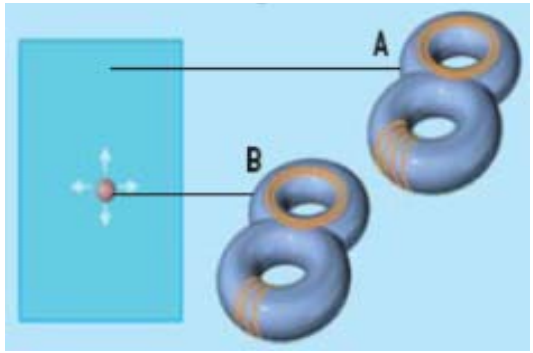
Sci. Am. 2004

- Different configurations of the String Theory vacuum are ~ stable
- Quantum mechanics allows one configuration to decay / fluctuate / tunnel to another configuration locally

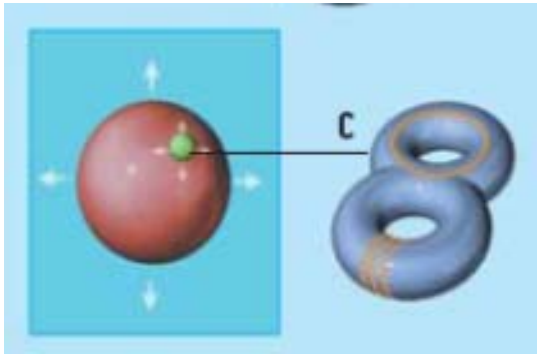
"False vacuum" and inflation



The cosmic Landscape of the Multiverse in String Theory



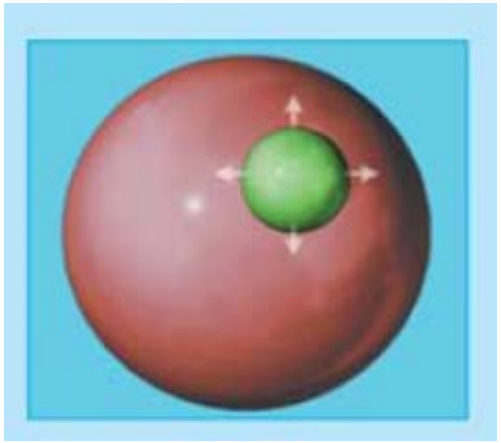
Tunneling from one stable vacuum to another would not occur everywhere in the universe at once. Instead it would occur at one random location, producing an expanding bubble of space (*arrows*) having the new vacuum. In this example, the blue region of space has vacuum A, whose manifold of small extra dimensions consists of a two-handled doughnut with groups of two and four flux lines wrapped around the handles. The red region, which has vacuum B, emerges when one of the four flux lines decays. Corresponding to their different manifolds, the two regions will have different kinds of particles and forces and thus different laws of physics.



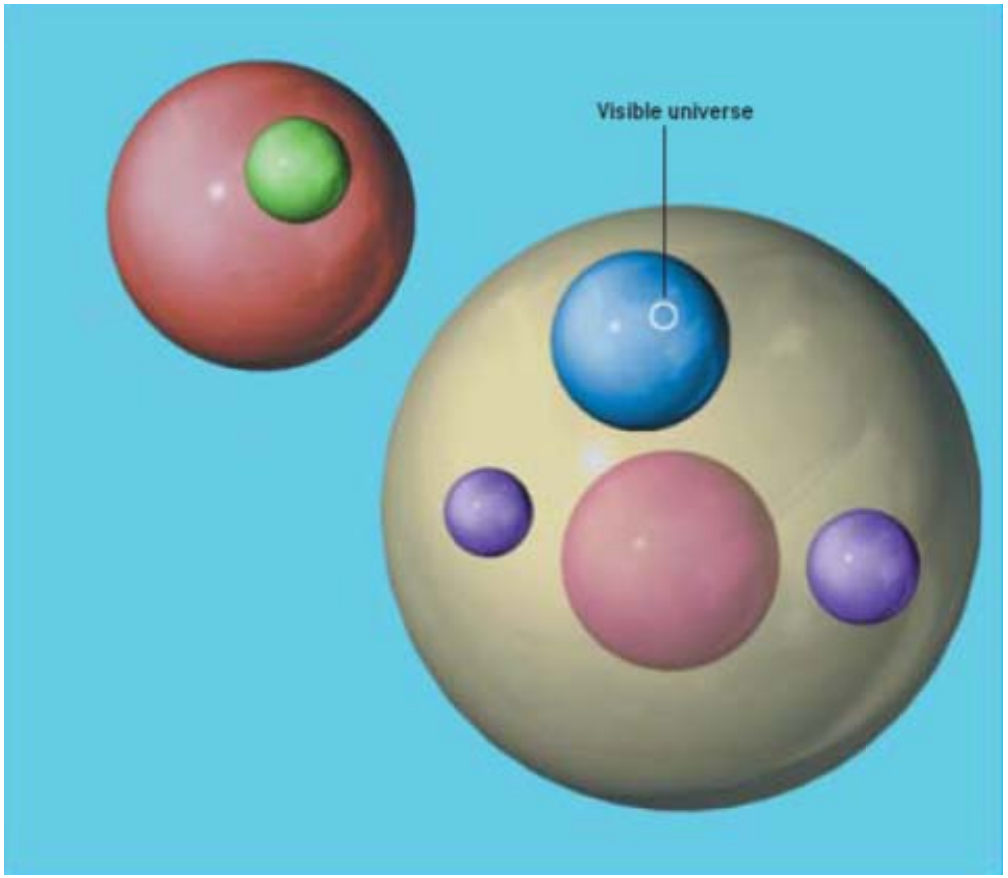
The red region grows rapidly, potentially becoming billions of light-years in diameter. Eventually another transition occurs within the red region, this time a decay of one of the two flux lines. This decay generates the green region, which has vacuum C and still another set of particles and forces.

Figures + text from

Bousso + Polchinski, "The String Theory Landscape", Sci. Amer. 2004



The green region also grows rapidly, but it never catches up with the red region. Similarly, the red region never completely replaces the original blue vacuum.



Because the quantum tunneling is a random process, widely separated locations in the universe will decay through different sequences of vacua. In this way, the entire landscape is explored; every stable vacuum occurs in many different places in the universe.

The whole universe is therefore a foam of expanding bubbles within bubbles, each with its own laws of physics. Extremely few of the bubbles are suitable for the formation of complex structures such as galaxies and life. Our entire visible universe (more than 20 billion light-years in diameter) is a relatively small region within one of these bubbles.

The cosmic landscape

Many (10^{500}) ways to compactify the extra dimensions → many different Potential energies and characteristics of the vacuum

particles
forces

All are possible?

So – it is certainly true that a universe like ours – seemingly fine-tuned and suitable for life as we know it – Should exist

Scientific?

What does this mean for the Theory of Everything?

How does this relate to intelligent design?

The Mathematical Universe Hypothesis

Max Tegmark
ArXiv: 0704.0646
gr-qc

External Reality Hypothesis:

There exists an external reality completely independent of us humans.

ERH reasonable to most folks but NOT universally accepted – even among scientists ... extreme Copenhagenists for example.

Ultimate goal of theoretical physics

Develop/Discover Theory that completely describes this External Reality

Theory of Everything ≡ TOE