

# Physics 102 - December 7, 2009

- Projects due Friday, Dec. 11
- Final EXAM - Wed., Dec. 16, 4pm

B+L 109

index card okay

cumulative

Q+A session . . . need to schedule

# The Cosmic Landscape

In String theory -

Laws of Physics  
Particle Spectrum  
Nature of forces

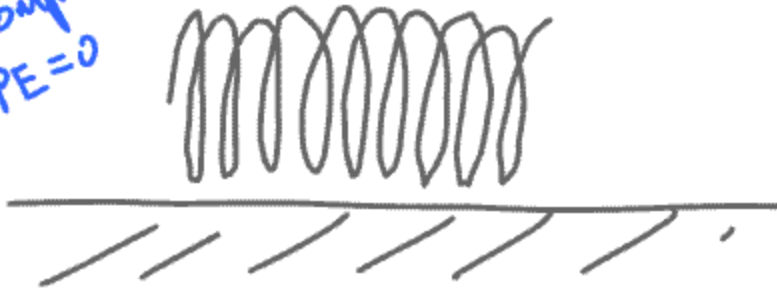
Shades of the Ancient Greeks!  
geometry

dictated by  
Shape + size of  
Extra dimensions

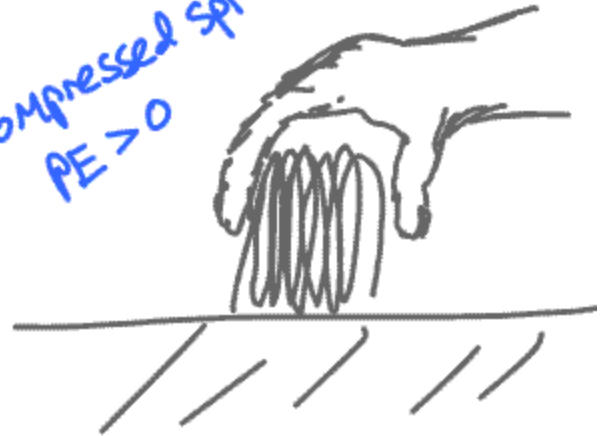
Depends on details of the compactification

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

uncompressed spring  
 $PE=0$

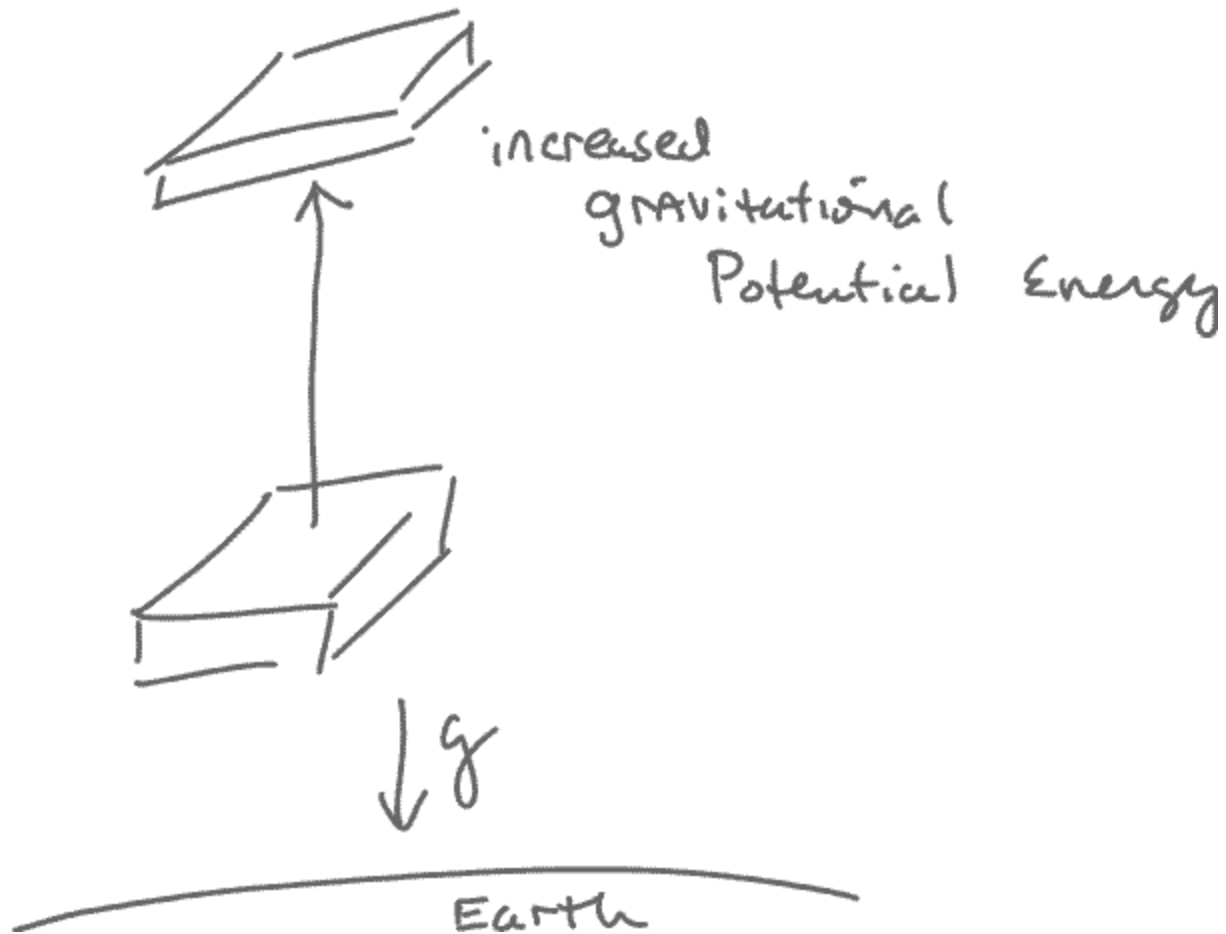


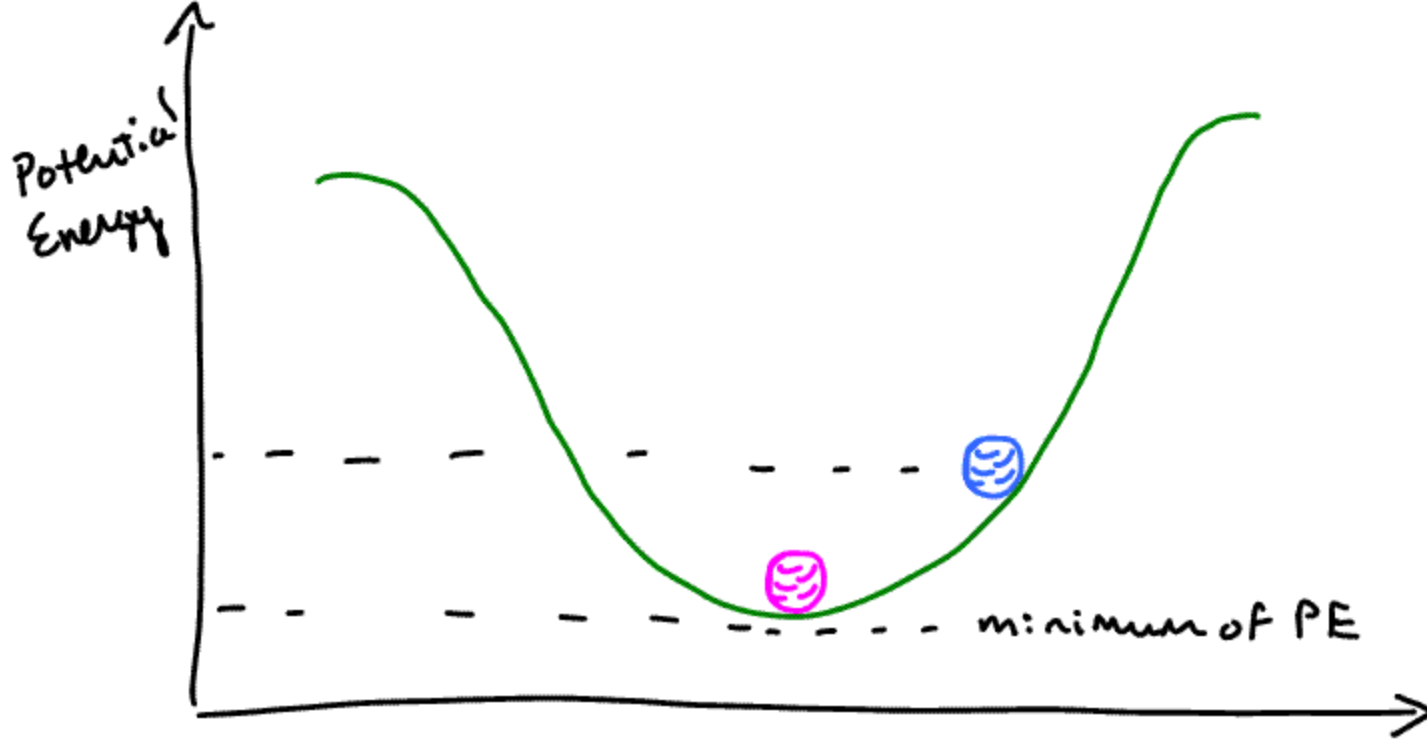
Compressed spring  
 $PE > 0$



Springs and Potential energy

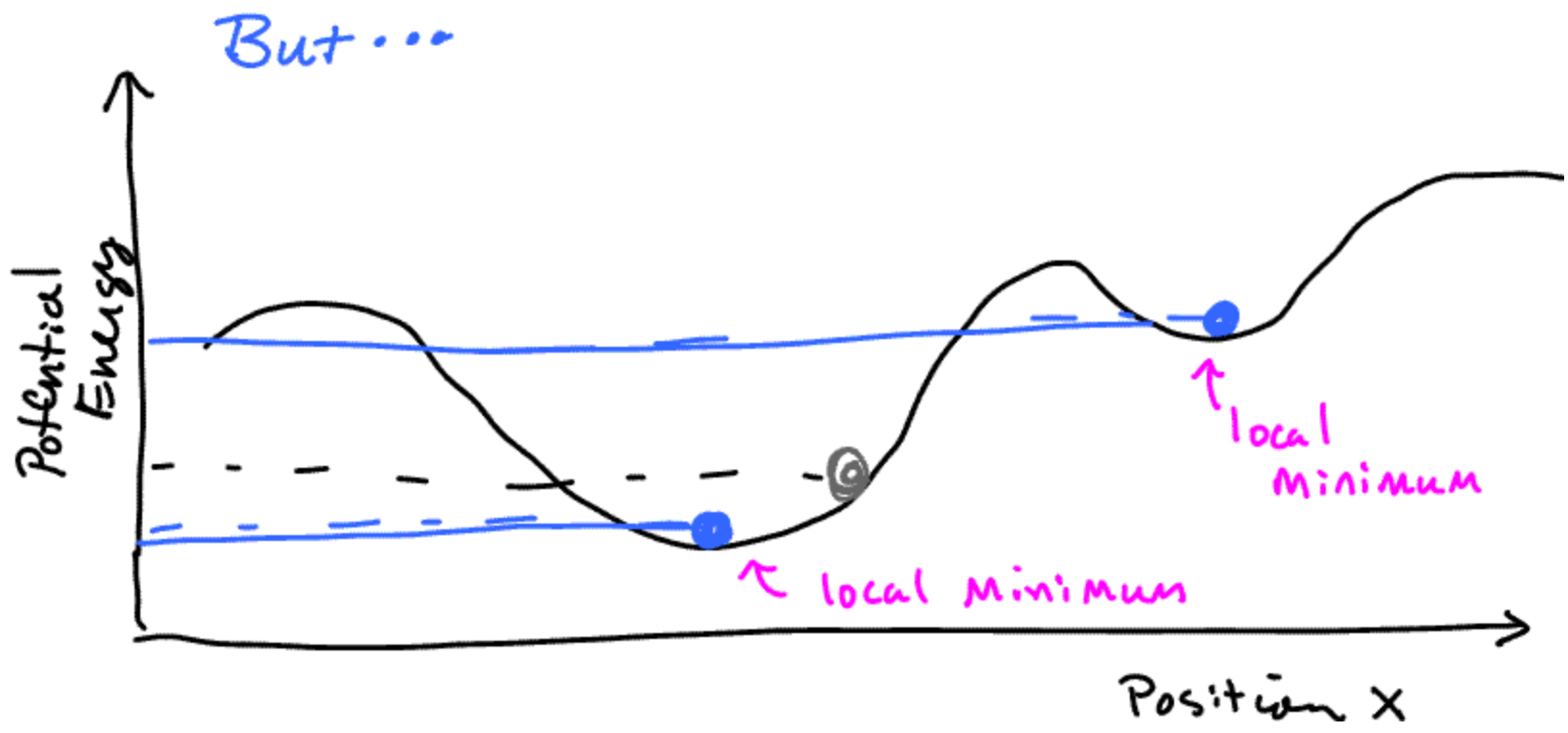
# gravitational Potential Energy





### 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!!



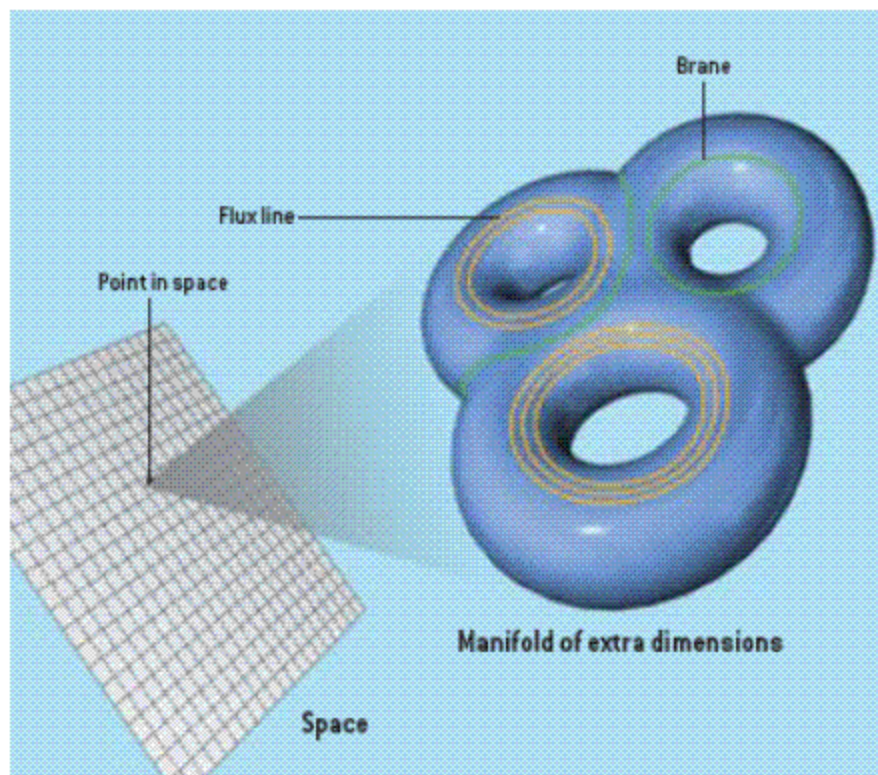


Fig from —  
Bousso + Polchinski:  
The String Theory Landscape  
Sci. Am. 2004

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

The "vacuum energy" depends on this.

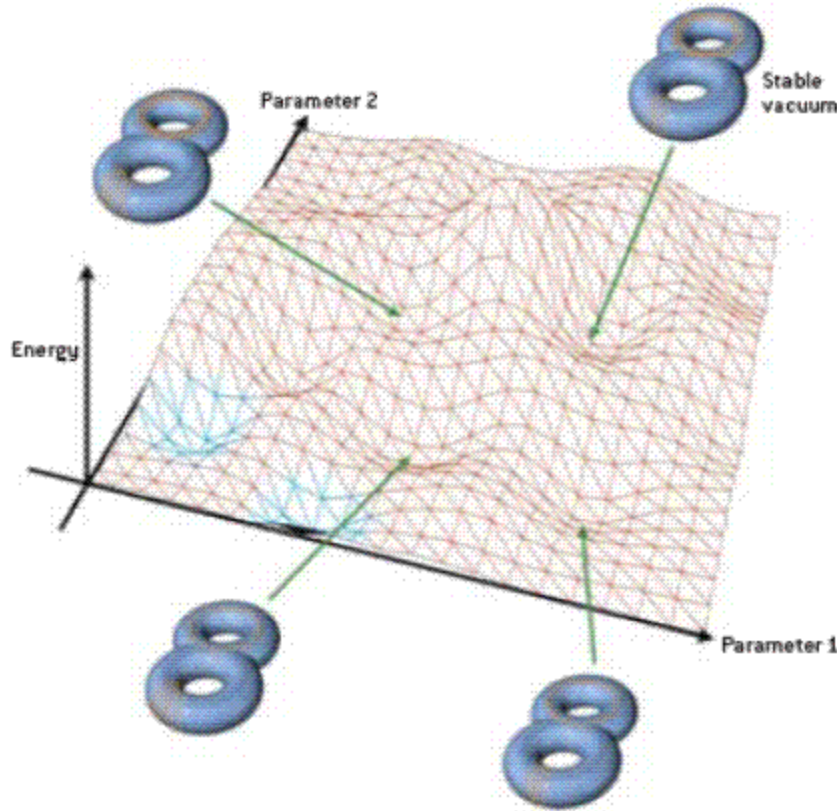
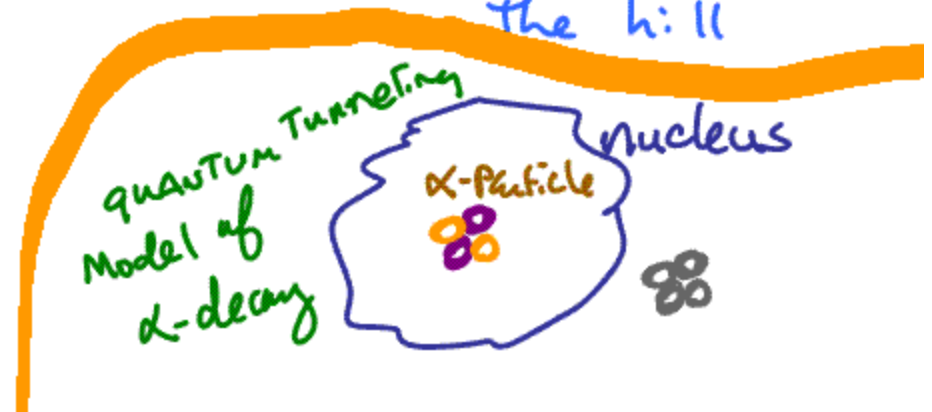
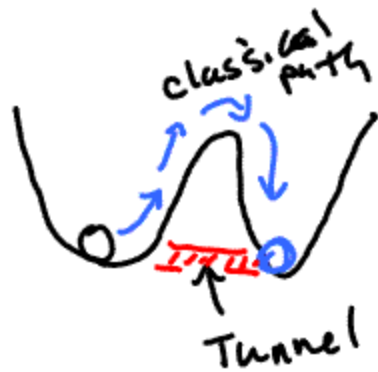
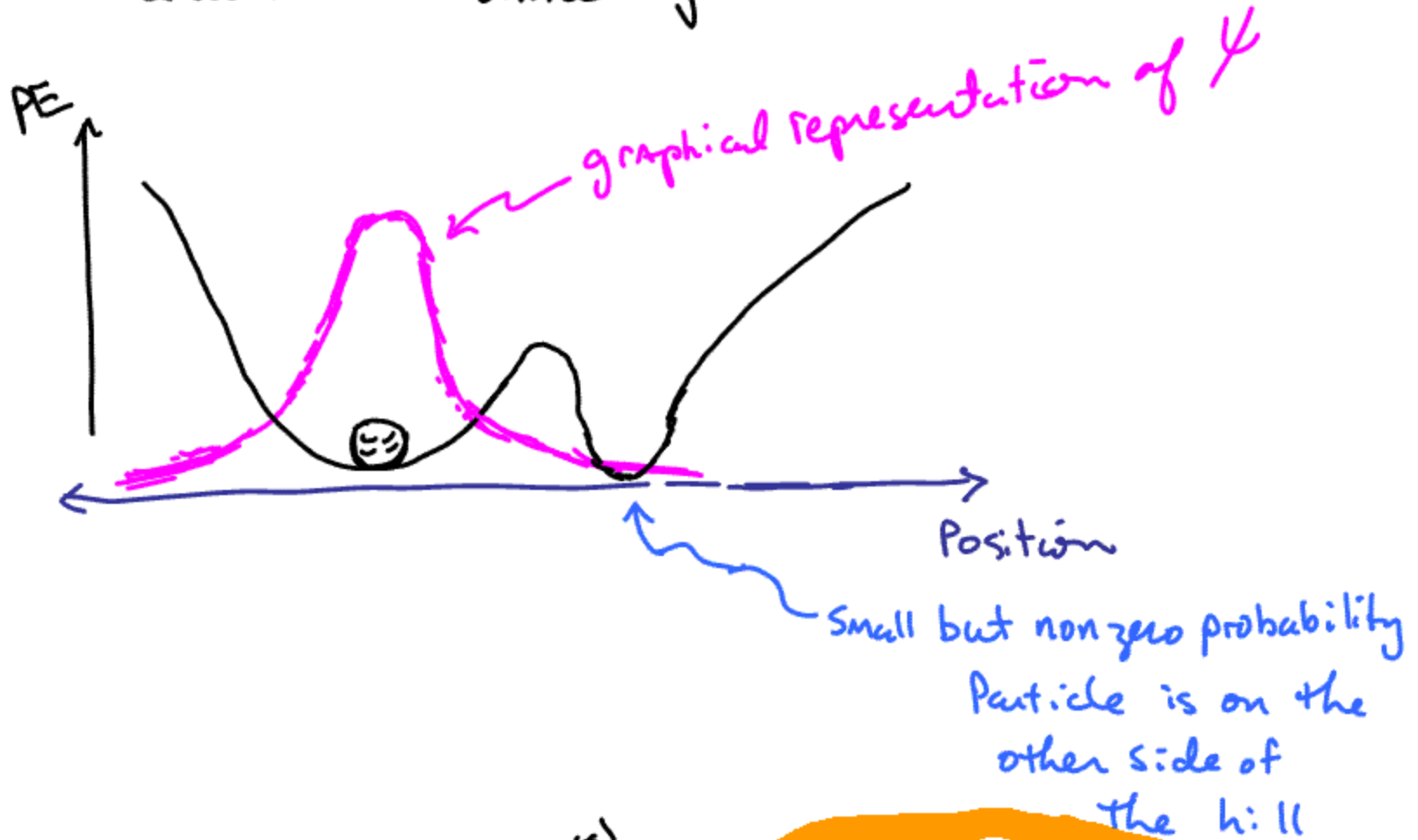


Fig from —  
Bousso + Polchinski:  
The String Theory Landscape  
Sci. Am. 2004

Different configurations  $\rightarrow$  Different energies  
 $\rightarrow$  Different locations in  
the landscape of  
Possibilities



# Quantum Tunneling



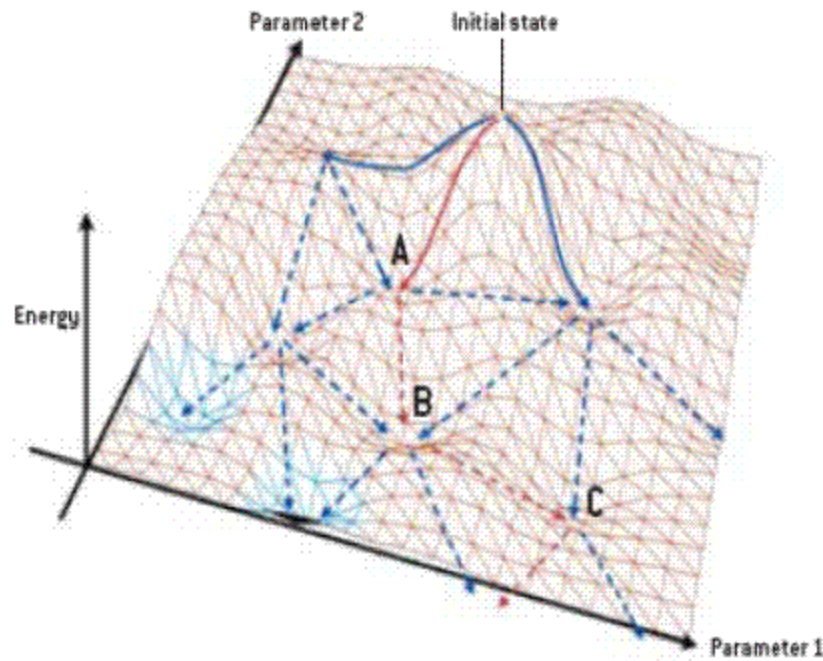
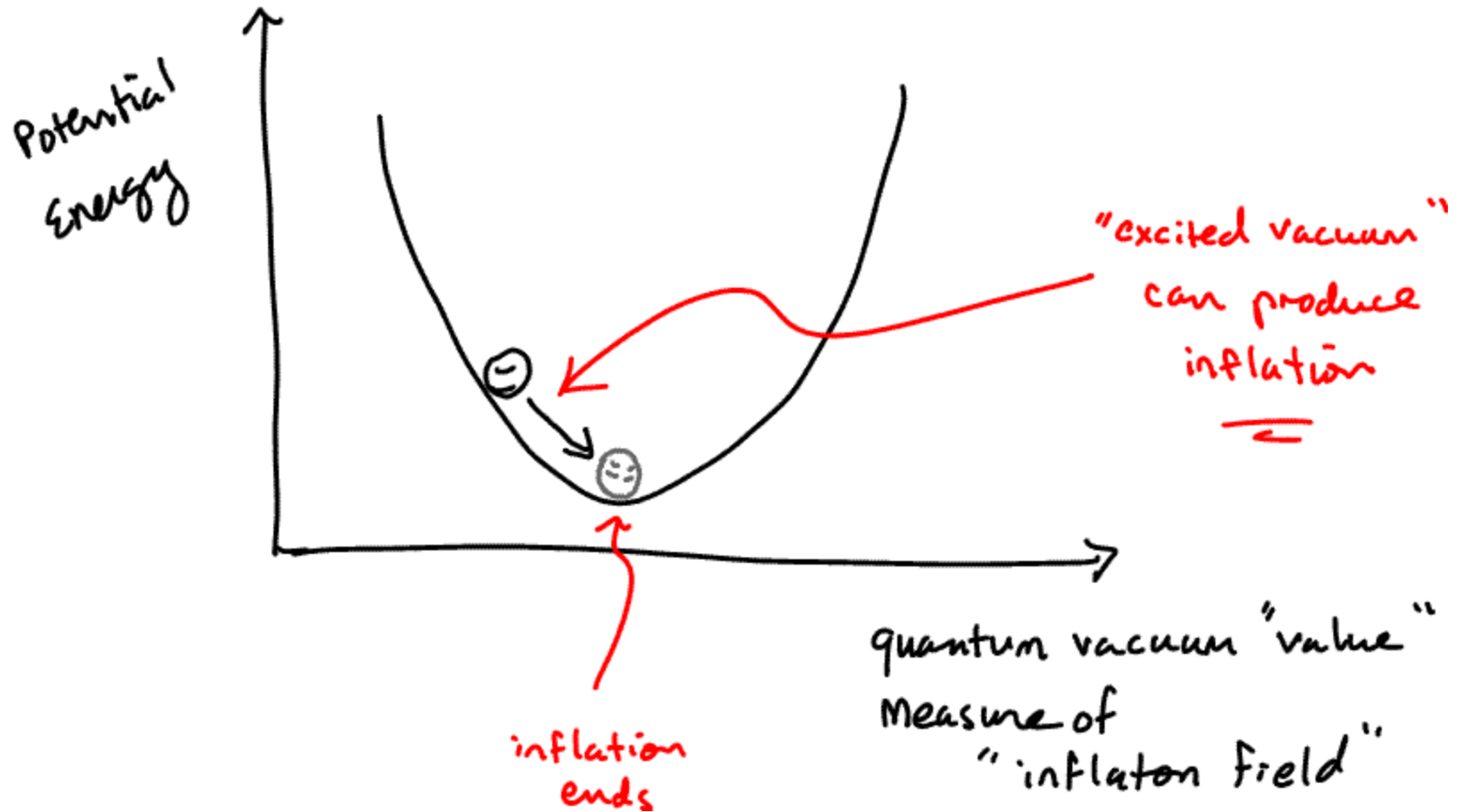


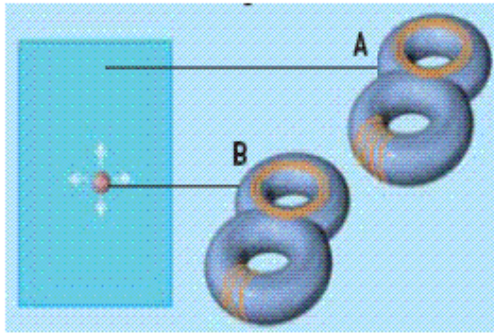
Fig from —  
 Bousso + Polchinski:  
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 Sci. Am. 2004

- Different configurations of the string theory vacuum are  $\sim$  stable
- Quantum mechanics allows one configuration to decay / fluctuate / tunnel to another configuration locally

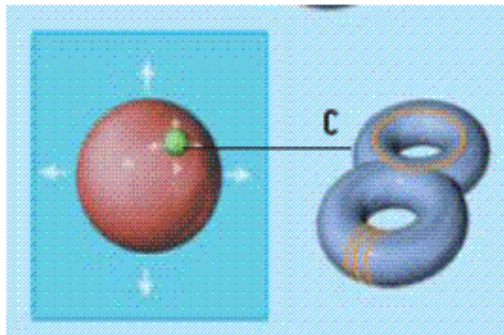
# "False vacuum" and inflation



# The cosmic Landscape of the Multiverse in String Theory



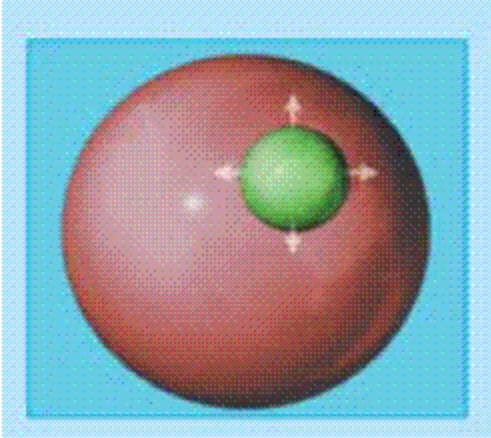
Tunneling from one stable vacuum to another would not occur everywhere in the universe at once. Instead it would occur at one random location, producing an expanding bubble of space (*arrows*) having the new vacuum. In this example, the blue region of space has vacuum A, whose manifold of small extra 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.



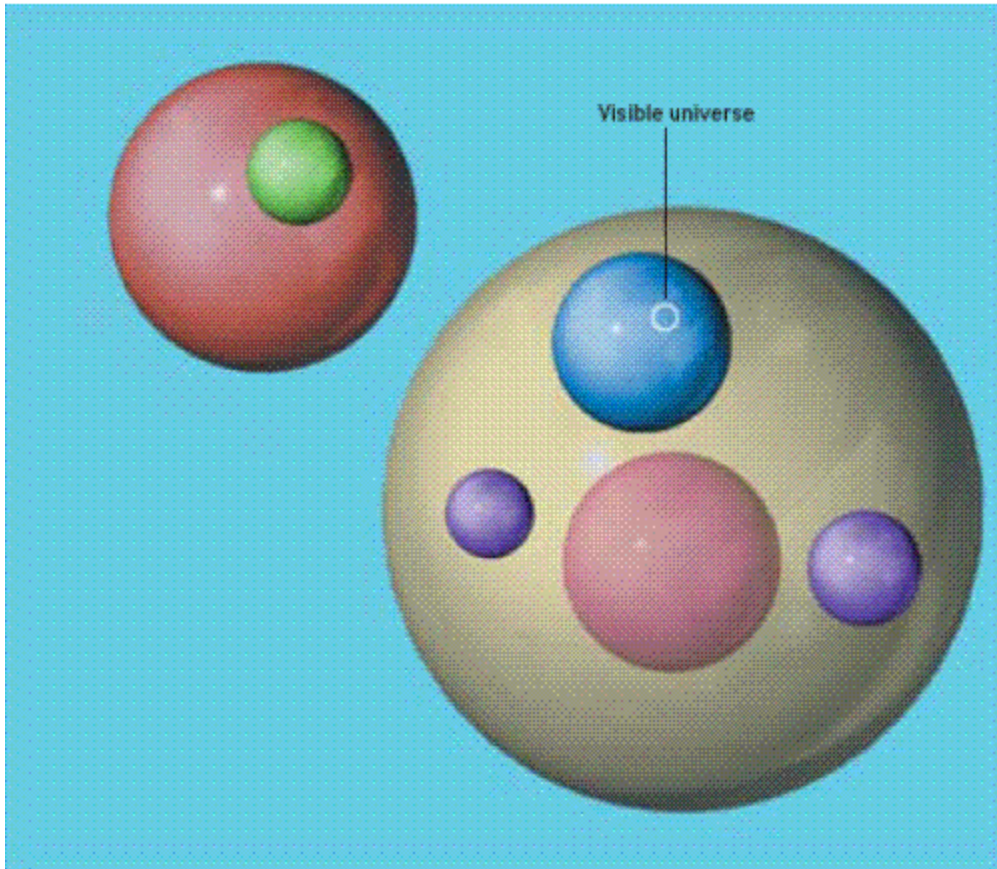
The red region grows rapidly, potentially becoming billions of light-years in diameter. Eventually another transition occurs within the red region, this time a decay of one of the two flux lines. This decay generates the green region, which has vacuum C and still another set of particles and forces.

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  $\rightarrow$  many different potential energies and characteristics of the vacuum  $\swarrow$  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?

# The Mathematical Universe Hypothesis



Max Tegmark  
ArXiv: 0704.0646  
95-9c

## External Reality Hypothesis:

There exists an external reality completely independent of us humans.

EIRH 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  $\equiv$  TOE

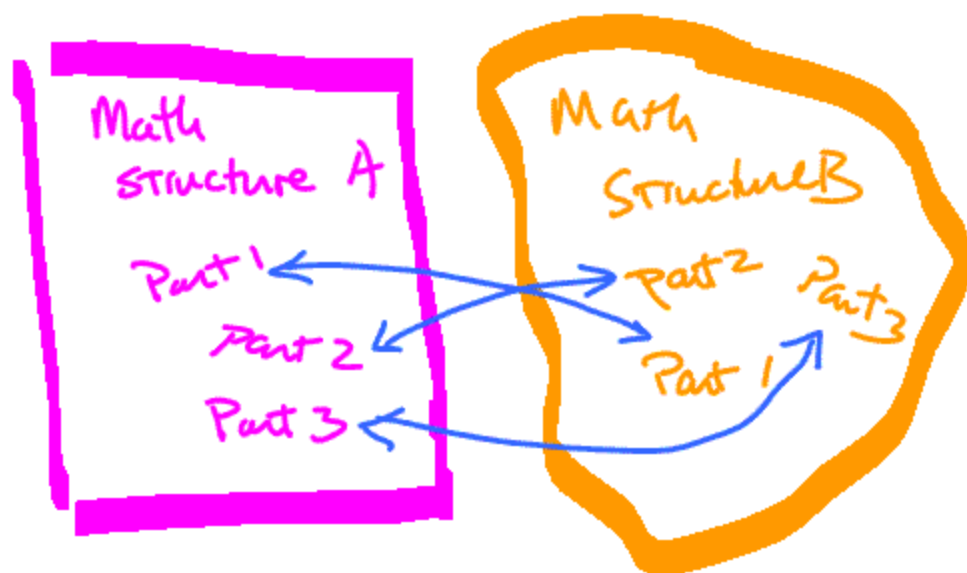
TDE MUST NOT have Ambiguities  
or human-related "baggage"



Mathematical Structure

In Mathematics

IF  $\left\{ \begin{array}{l} \text{Part 1 same as Part 1} \\ \text{Part 2 same as Part 2} \\ \text{Part 3 same as Part 3} \end{array} \right\}$



Then

Math Structure A and Math Structure B  
are one and the same



Mathematical  
Structure that is  
The TOE



External  
Reality

The External Reality is a Mathematical Structure

Mathematical Universe Hypothesis

Could Have Many  
Different complete and  
self-consistent and independent  
irreducible Mathematical  
Structures

Does each correspond  
to a different universe?  
→ Multiverse

Not quite the same as "Anything goes".

If discover TOE

Why these equations

and NOT others?

(Wheeler / Hawking)

MUH  $\rightarrow$  why NOT others?

Multiverse

Extreme Copernican Revolution --,