

Monday, December 2, 2013

Fifth exam, Friday, December 6

Fifth sky watch due. You can do any object mentioned throughout the term that you have not done before.

Review sheet posted

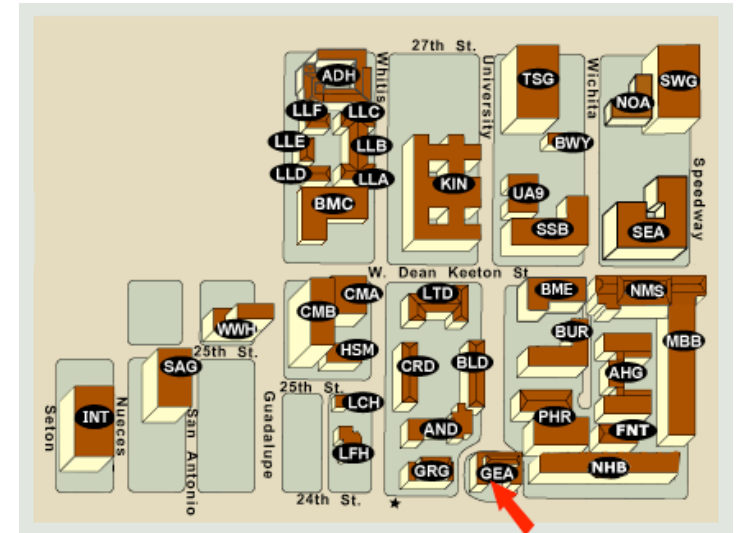
Review Session Thursday, 5 – 6 PM, GEA 105

NOTE – different room than either before

Reading: Chapters 11 (omit 11.6), 12, 13, 14

Electronic class evaluations. Please respond.

This feedback is very valuable to me and to the TAs.



Goal:

To understand why physicists argued that any “extra” dimensions had to be tiny and wrapped up, how that restriction was removed, and what that means for our view of the Universe.

Concept check:

What is the “inverse r-squared law?”

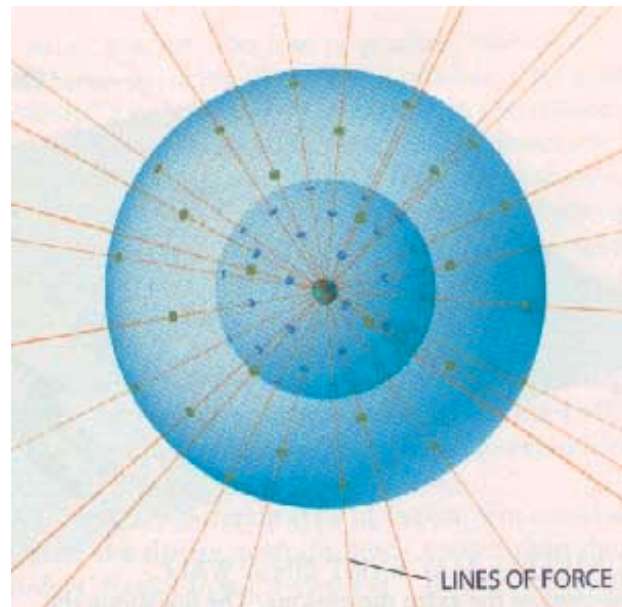
Old argument: there could *not* be a *large* 4th spatial dimension

Behavior of light, electrical force, and gravity in 3D

The luminosity or lines of force flow out through larger *area* at larger distance. The strength (brightness or lines of force per unit area) is thus diluted by $1/\text{area} \propto 1/r^2$ in 3D.

Area is one dimension less than volume.

The “2” in the inverse square law is exactly “1” less than the total number of large dimensions, “3”



Light and electricity might be stuck in 3D, but gravity probes all space, whatever its dimension. Gravity is a creature of space/time

Extend the argument to higher dimensions than 3.

An “area” is one dimension less than the total “volume” corresponding to a given dimension of space.

If gravity extends to a fourth dimension, where “volumes” scale like r^4 and “surfaces” scale like r^3 , then gravity would be diluted in 4D by $1/\text{“area”} \propto 1/r^3$ in 4D.

Obviously wrong! Even Newton knew that gravity weakens as the inverse of distance squared, not as distance cubed!

Implication (it was long thought): IF there is a 4th (or higher) dimension it must be “wrapped up” so gravity has nowhere to go.

New insight: (Lisa Randall 1999) - Can have *large extra dimensions* and gravity will still leak only a little into those extra dimensions, still weaken very nearly as $1/r^2$. Had assumed extra dimension was “flat” - it needn’ t be.

Leakage into higher dimensions could account for why gravity seems “weaker” than other forces.

Our 3D Universe could be a 3D brane in a large, extended, 4D bulk

There could be a real, large (infinite), four-dimensional hyperspace in which our 3D Universe is embedded.

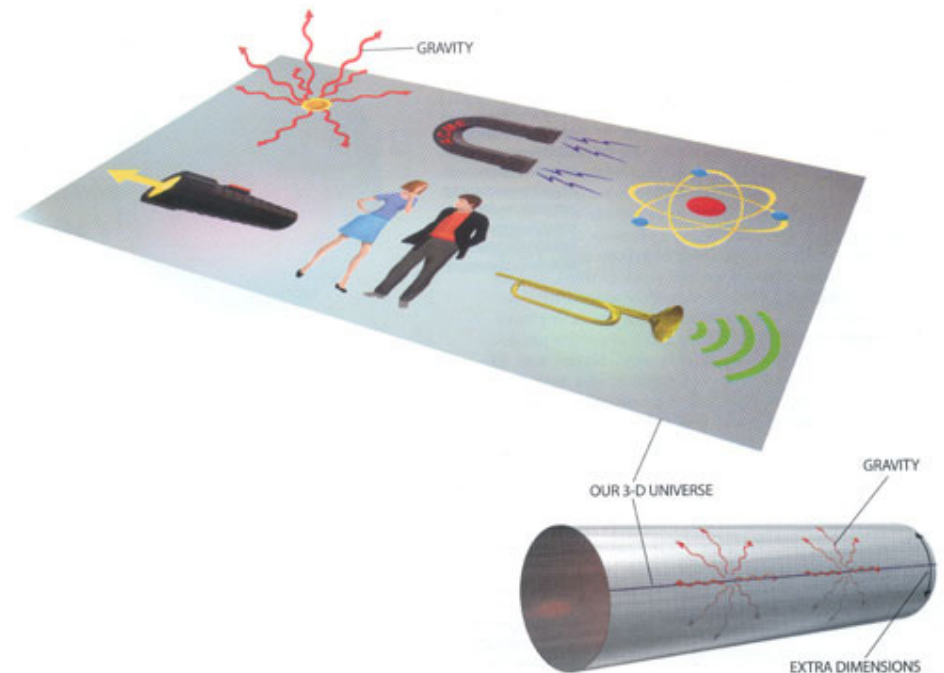
Plus tightly wrapped up dimensions.

In this picture, ordinary forces, electromagnetism, nuclear forces, correspond to “open” strings that have ends stuck on the 3D brane,

These strings cannot “go” into the 4D bulk, we cannot “see” the 4D bulk.

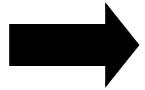
Gravity is based on “gravitons,” closed loops of strings that are not stuck on the brane. They can float off into the bulk, but in a way that gravity still weakens very nearly like $1/r^2$.

Balls on 2D brane, sound into 3D bulk



One minute exam

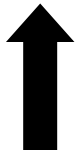
In string theory, our Universe is pictured as a



2 brane



3 brane



10 brane



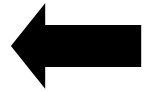
3D bulk

One minute exam:

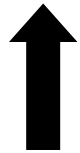
If gravity reached into a 5D space as easily as it penetrates our ordinary three-dimensional space, then it would get weaker with distance from the source as



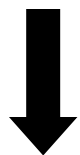
$$1/(\text{distance})^2$$



$$1/(\text{distance})^3$$



$$1/(\text{distance})^4$$



$$1/(\text{distance})^5$$

Goal:

To understand how the notion of a large 4th dimension led to notions of multiverses and what string theory has to say about black holes and information.

Brane World cosmologies: exploring the theoretical possibility that our Universe is a 3D brane floating in a 4D bulk, with 6 wrapped-up dimensions, plus time

Example: Ekpyrotic Theory (Greek *ekpyrosis* = conflagration)

Two 3D branes collide in 4D bulk

hot, dense “Big Bang” but not infinite density

no singularity

different gravity waves than standard “inflation” theory - could be a test.

More Brane World ideas:

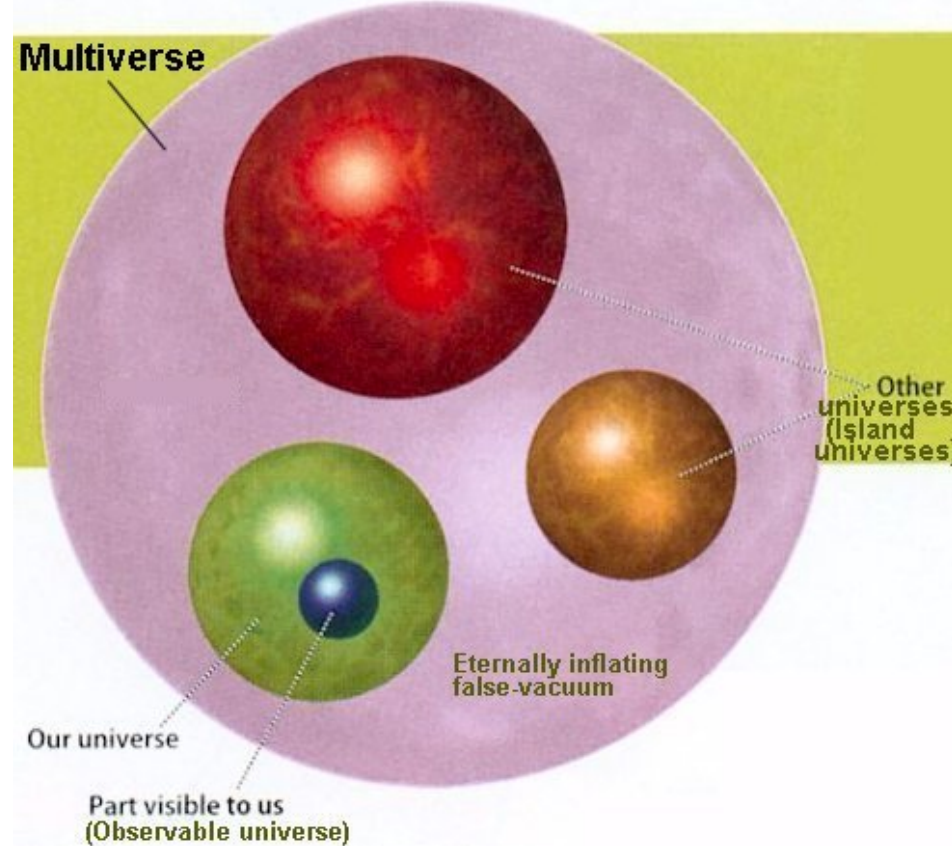
Singularity in black holes, quantum foam \Rightarrow nested “loops” of strings?

The 4D Bulk: is this where our Universe curves to when it curves, expands to when it expands – Maybe...

Is the Dark Energy that drives the acceleration of the Universe some manifestation of a “nearby” 3D Universe only a little distance away from our Universe in the 4D bulk?

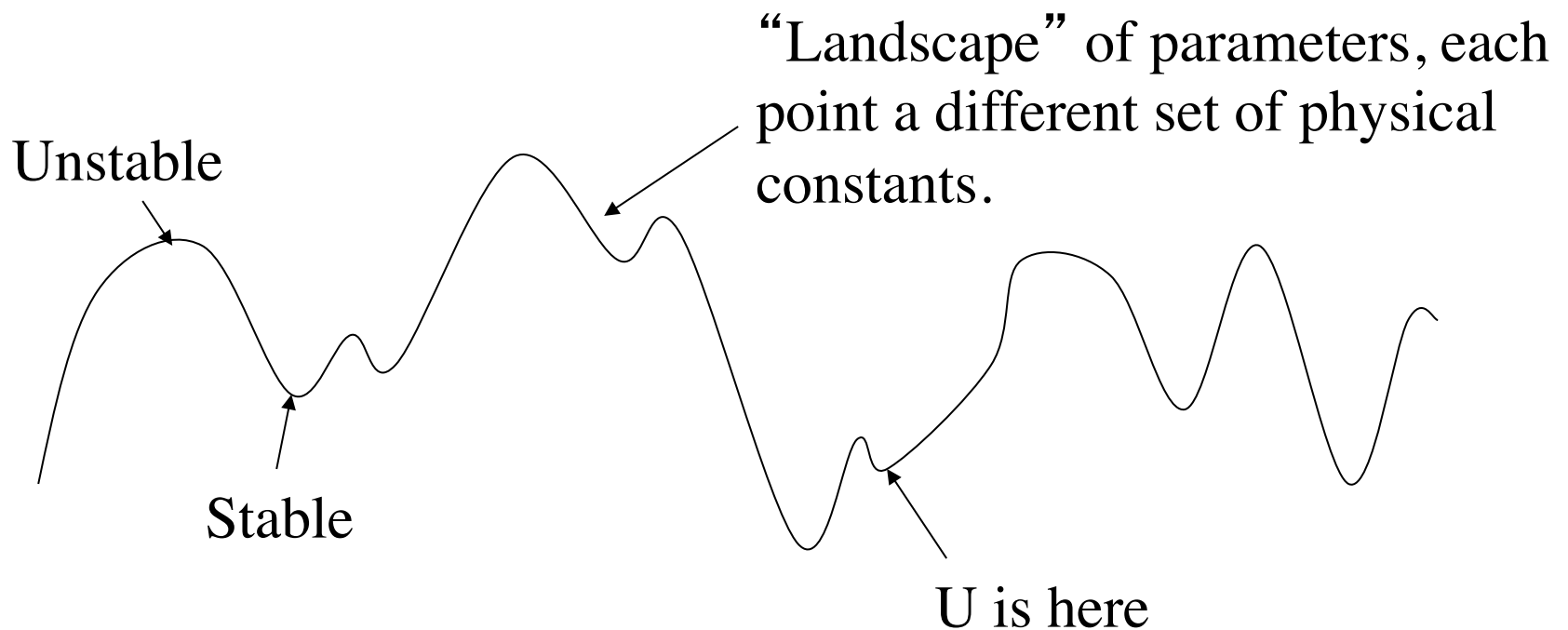
More current ideas:

The Multiverse - the idea that there could be many 3D universes separated in 4D hyperspace.



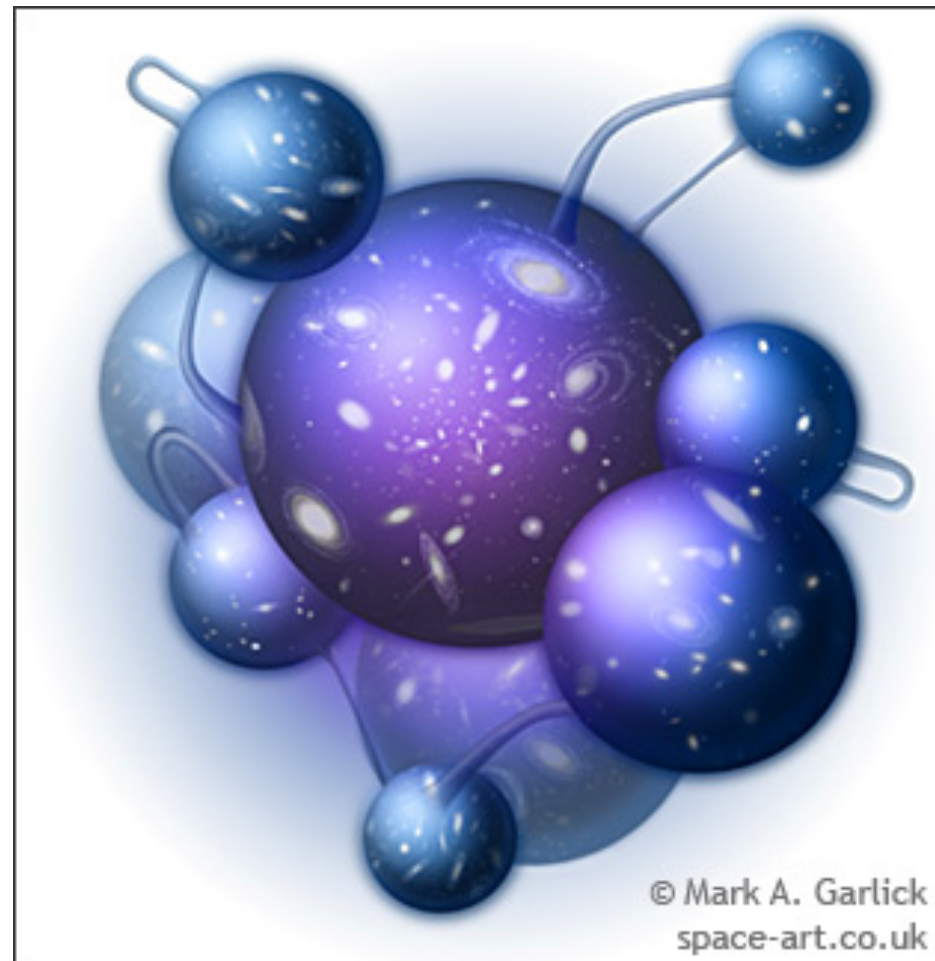
The String Landscape - current estimates are that string theory might provide 10^{500} different solutions, “universes,” each with a different set of values of the physical constants, speed of light, the gravitational constant, Planck’s constant that determines the size of quantum uncertainty, Einstein’s Cosmological Constant, masses and charges of particles.

Only some universes could make stars, galaxies, and life.



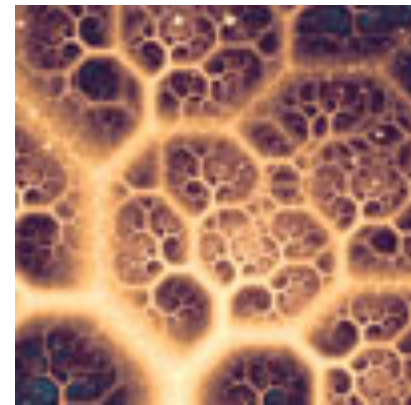
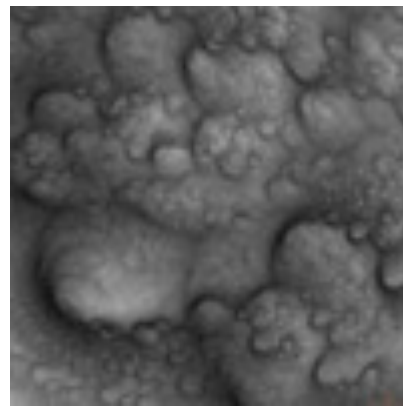
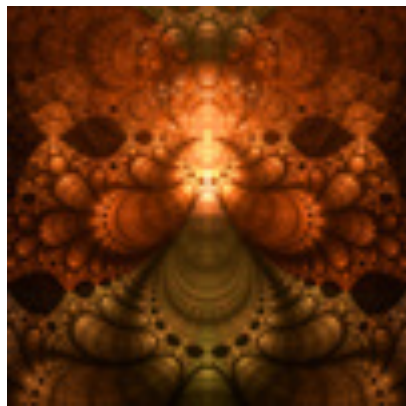
Bubble Universes - the individual universes created from the parameters of the String Landscape that populate the Multiverse.

One idea:
when a black
hole forms a
“singularity”
in one
universe, a
new universe
is born
“elsewhere” in
hyperspace.



Eternal Inflation - the notion that new bubble universes are constantly being born, “inflated” from the quantum foam or stringy space-time.

Chaotic Inflation - a variation on eternal inflation in which new bubble universes are constantly being born and the multiverse is fractal on large scales.



New insights into information

Derivation of the temperature of a black hole from string theory got exactly Hawking's answer.

But string theory is a quantum theory and exactly preserves information.

The implication is that Hawking was wrong that information is destroyed in a black hole and that black holes have only mass, charge and spin.

The information must be retained in string vibrations **at the event horizon** (not within the black hole).

Surfaces are the true repository of information, not volumes.

In a hologram, the information is stored as patterns on a 2D surface. With exposure to a laser, a 3D representation of the 2D information can be restored.

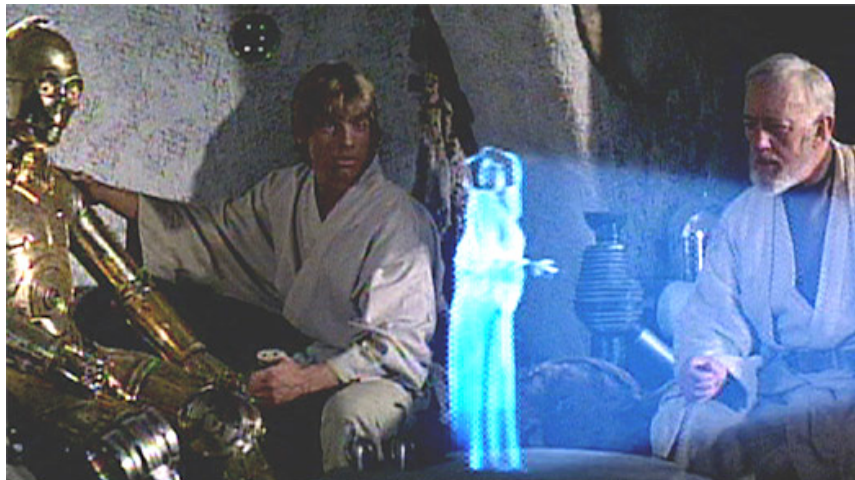
All this led to the idea that we live in a *Holographic Universe*.

The Holographic Universe - the notion that the real information content is imprinted in quantum bits on the surface, the event horizon, of the observable universe.

What we regard as the physics (and chemistry and biology) in our 3 dimensions, is fundamentally set and controlled by information and physics on the 2D surface around us.

Closely related to the understanding that the information of what fell into a black hole is retained in string vibrations at the event horizon surface of a black hole.

We are just 3D hologram projections from the 2D surface.



The origin of space and time

In principle, a true “theory of everything” should tell us the nature of space and time.

String theory assumes the existence of 10 dimensional spaces and time, so the fundamental question of how and why space and time exist remains elusive.

Is this real, or just mathematical fantasy?

Must be able to test: Physicists are straining to devise such tests.

Does gravity behave a little differently than $1/r^2$, for instance like $1/r^{2.0001}$, that would be hint of higher dimensions?

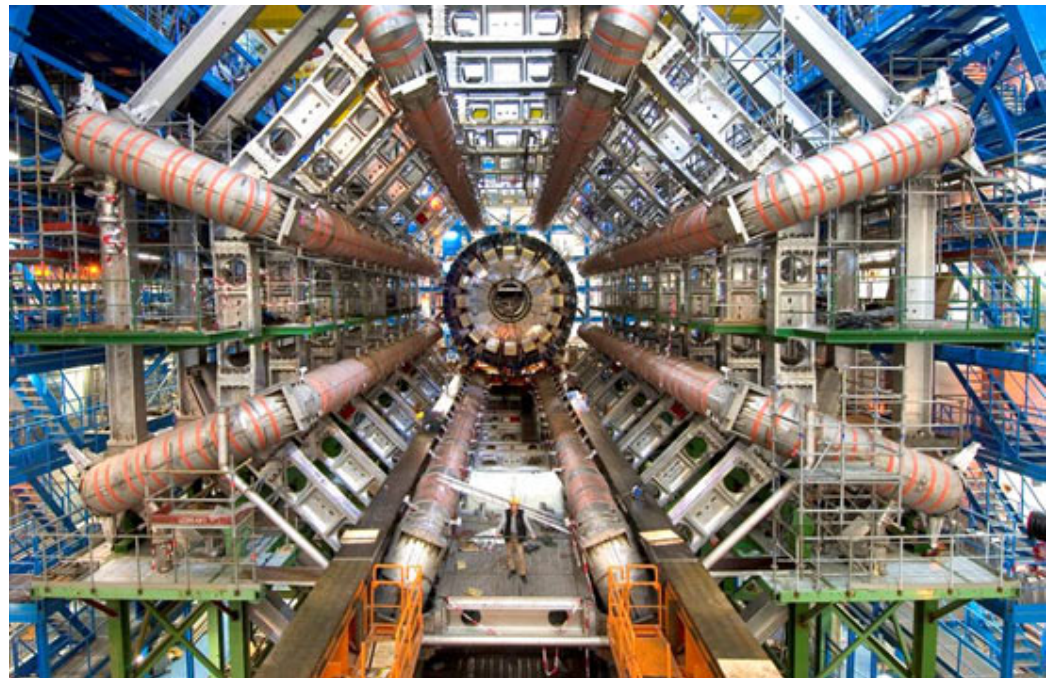
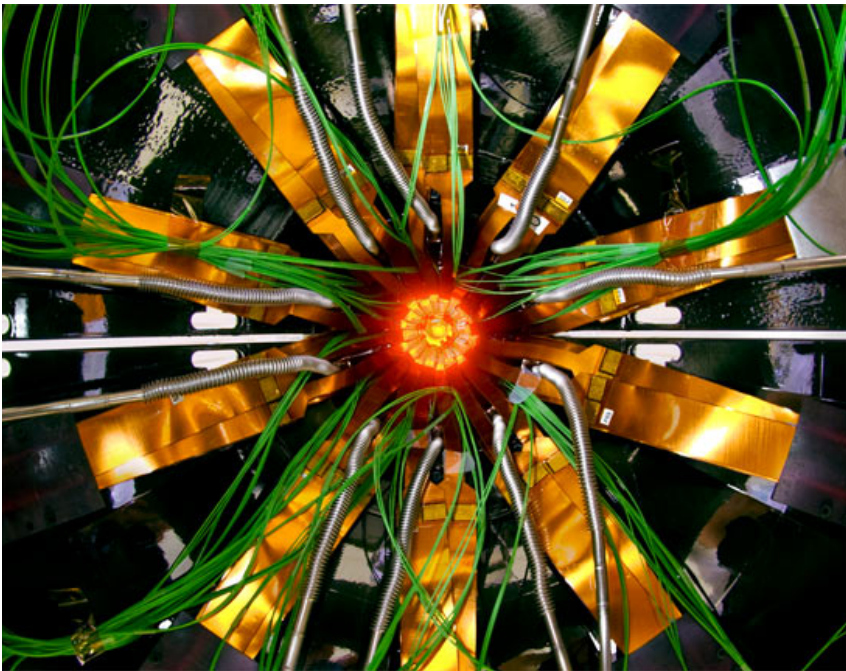
Curved space near event horizons of black holes might be different than standard Einstein gravity - can that be measured with X-rays?

Interactions in particle accelerators could be different if some energy disappears into the 4D bulk (as closed string gravitons).

The Large Hadron Collider (LHC) at CERN, near Geneva, is operating. Strong expectation that evidence for new physics, confirming or denying string theory ideas, will be seen.

Not yet, the physics community is holding its collective breath...

The **Large Hadron Collider** at CERN in Switzerland may see the first hints of extra dimensions.



Take Away Message:

Hyperspace might be real...

Stay tuned!

(and remember to keep an eye on Betelgeuse!)

Reprise

Einstein predicts black holes, astronomers have found them.

Einstein predicts black holes have singularities, but singularities violate quantum theory. Need a theory of quantum gravity.

String theory is the best current candidate for a theory of quantum gravity.

String theory demands 10 mutually perpendicular directions, dimensions, of space; two different kinds of strings, those attached to themselves, those attached to branes; some of the higher dimensions are curved up into Calabi-Yau spaces to give known particles by string vibrations.

Physicists argued that since gravity declines with distance like 1 over distance² all higher dimensions must be tiny and wrapped up, so there was no “volume” beyond 3D where gravity could penetrate.

New insight: (Lisa Randall 1999) - Can have *large extra dimensions* and gravity will still leak only a little into those extra dimensions, still weaken very nearly as $1/r^2$. Had assumed extra dimension was “flat” - it needn’ t be.

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Brane World cosmologies: exploring the theoretical possibility that our Universe is a 3D brane “surrounded” by a 4D bulk, with 6 wrapped-up dimensions, plus time

Latest String Landscape idea:

10^{500} different solutions is a lot, but if the universe is infinite, then every solution must be repeated an infinite number of times.

⇒ An exact copy of us is having this lecture elsewhere in hyperspace.

Can you spot a potential flaw in this argument?