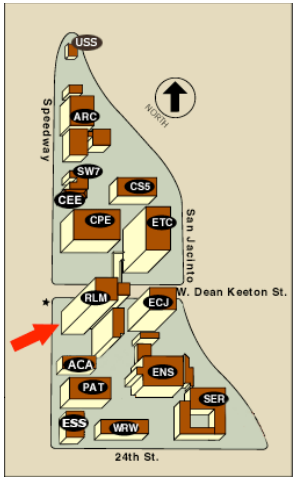
Wednesday, May 6, 2015

Exam 5, Sky Watch 5 on Friday, May 8.

Review sheet posted today.

Review Session Thursday 5 – 6 PM, RLM 6.104

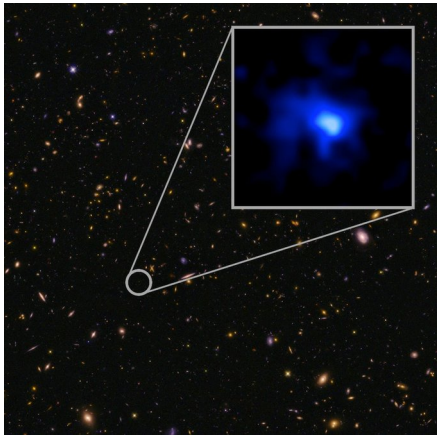


Electronic class reviews now available. Please respond. We find the feedback very valuable.

Fifth exam and sky watch, FRIDAY, May 8. Reading for Exam 5: Chapter 9 – Sections 9.6.1, 9.6.2, 9.7, 9.8; Chapter 10 - Sections 10.1-10.4, 10.9; Chapter 11 - all except Section 11.6 (abbreviated, focus on lectures); Chapter 12 - all; Chapter 13 (abbreviated); Chapter 14 - all

Astronomy in the news?

New record most distant galaxy found, born only 0.67 billion years after the big bang.

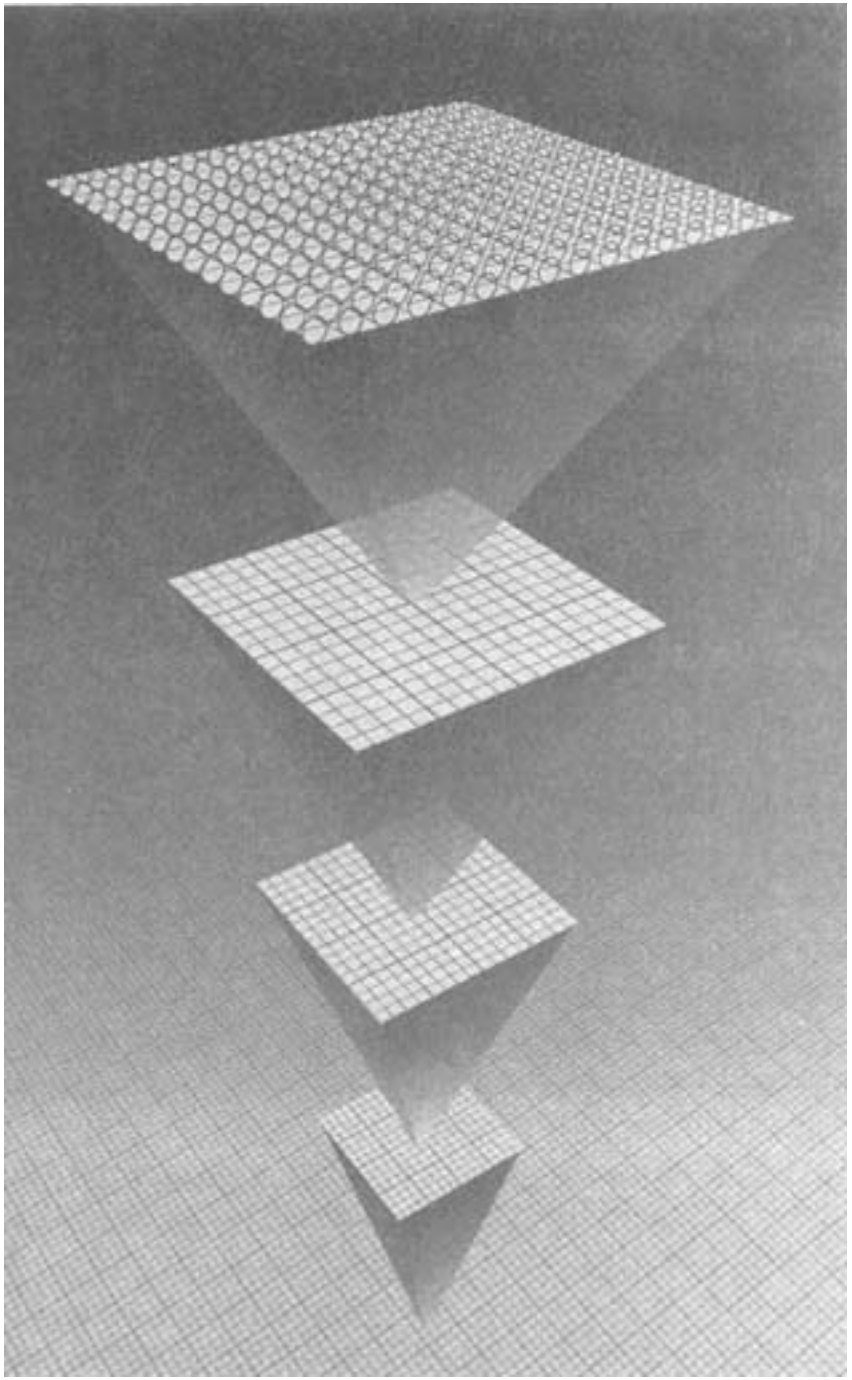


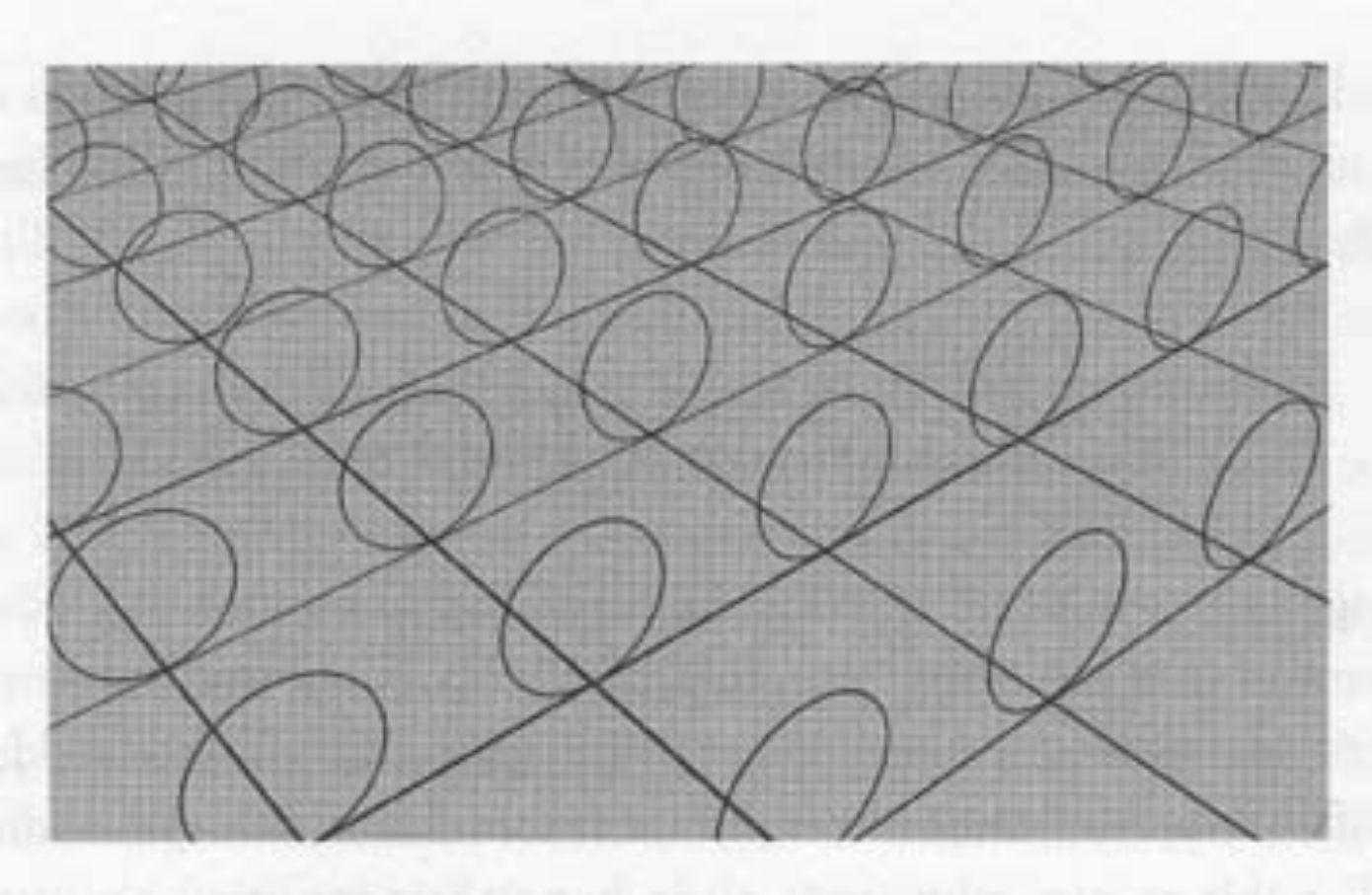
Goal:

To understand how string theory represents the current best candidate to be the needed theory of quantum gravity (Chapter 14)

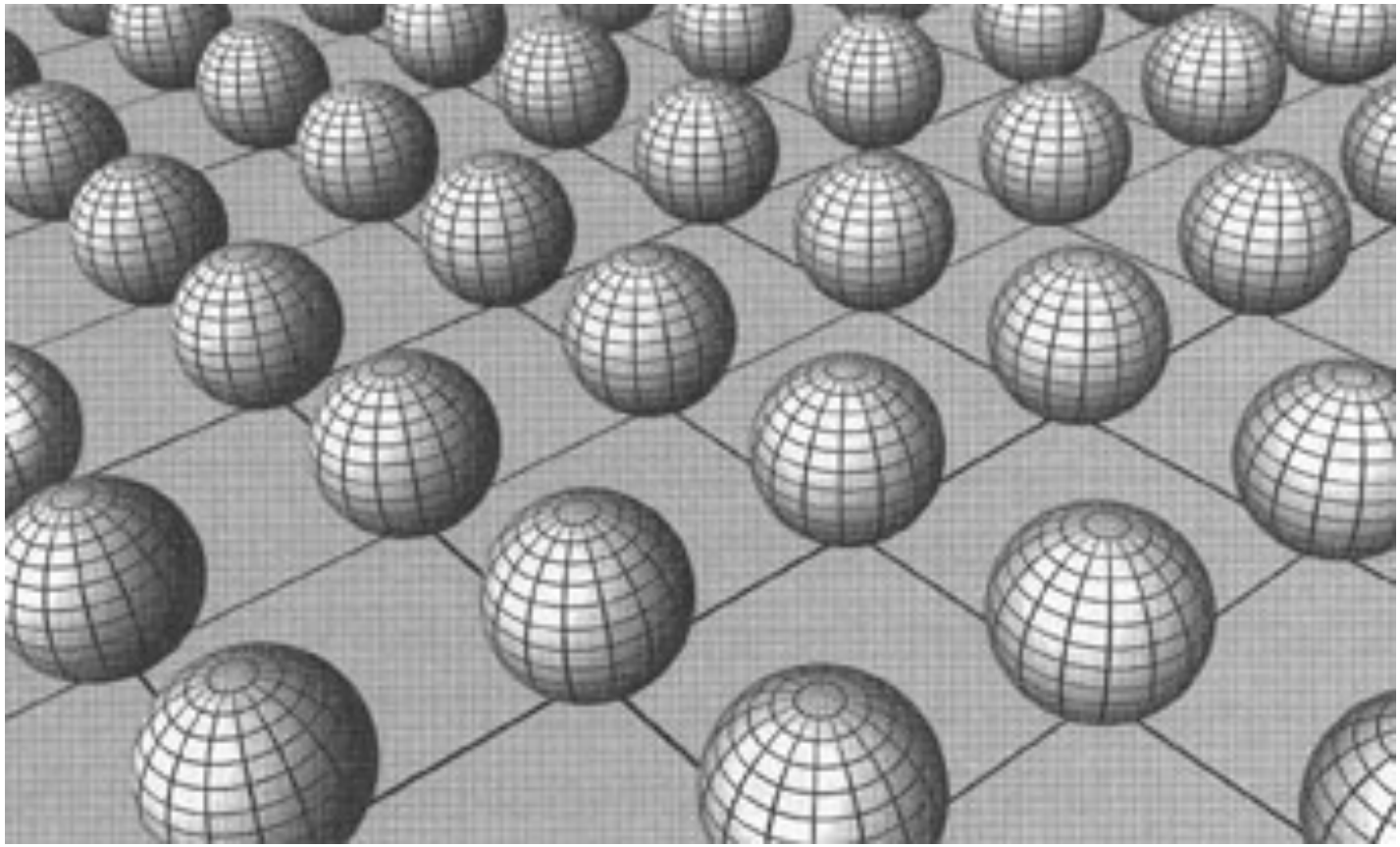
Schematic illustrations of how tiny “wrapped up” extra dimensions could be associated with our 3D space - something like an embedding diagram of the higher dimensional space, so our 3D space is reduced to 2D and the higher dimensional wrapped spaces are reduced to 3D.

From Brian Greene - The Elegant Universe

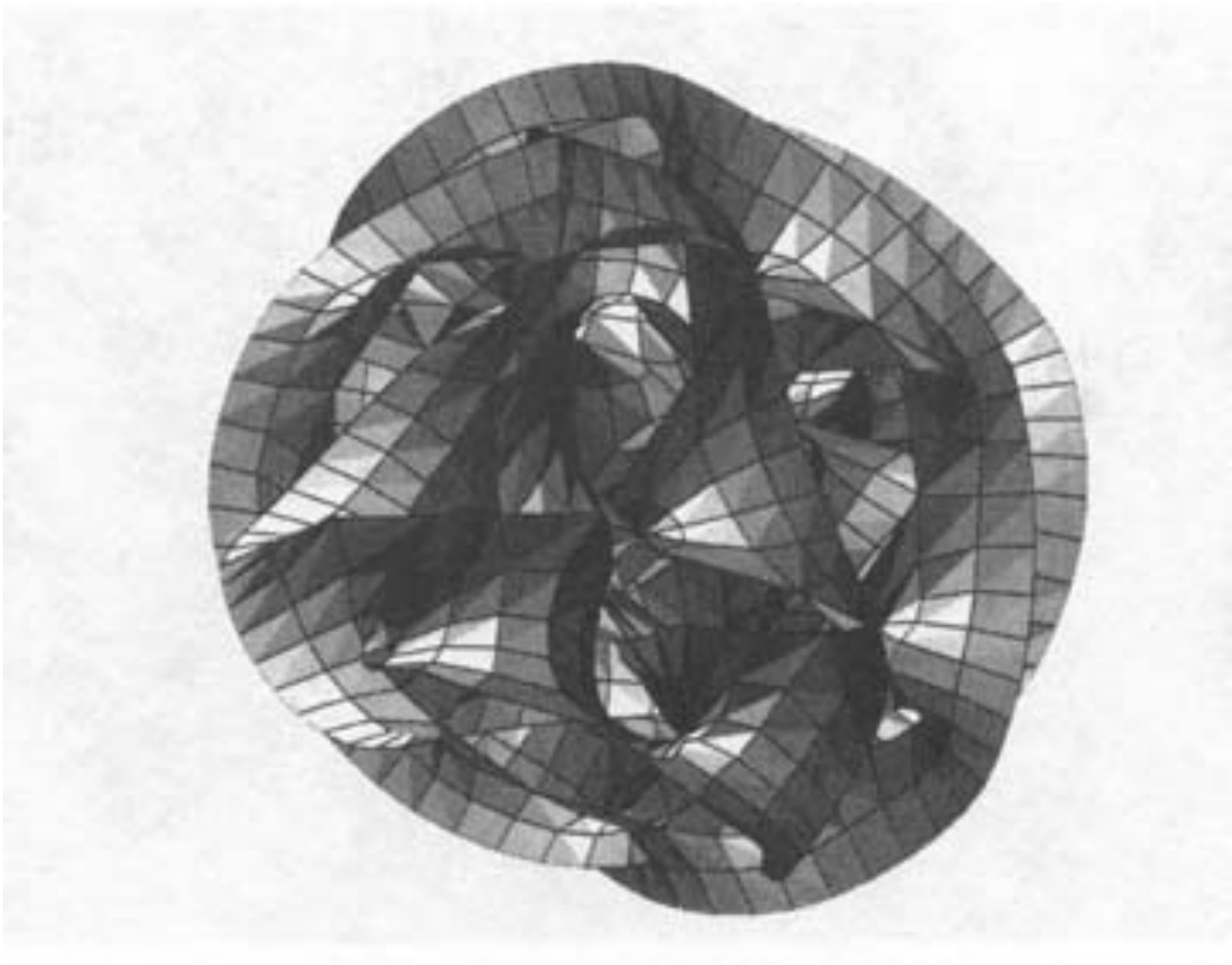




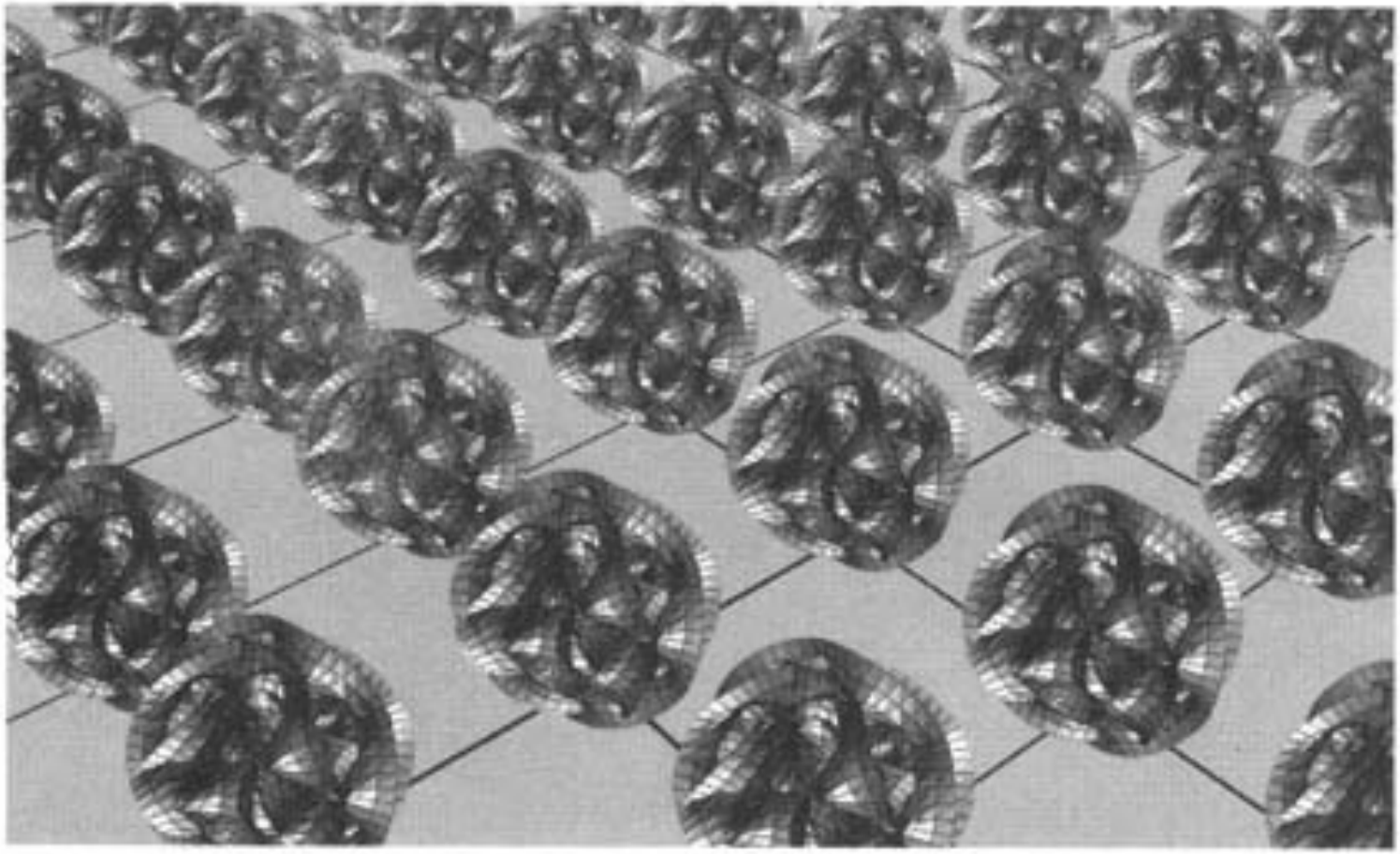
At each point in the 2D space (not just at the intersections of grid lines), there is a little 1D loop of one wrapped up extra dimension. From Brian Greene:The Elegant Universe



At each point in the 2D space (not just at the intersections of grid lines), there is a little 2D "sphere" of two wrapped-up extra dimensions. From Brian Greene: The Elegant Universe.



Representation of a Calabi-Yau space, with 6 wrapped-up extra dimensions. Calibi-Yau space gives string vibrations the properties of known particles. From Brian Greene: The Elegant Universe.



At each point in the 2D space (not just at the intersections of grid lines), there is a little 6D Calibi-Yau space of six wrapped-up extra dimensions.

From Brian Greene: The Elegant Universe.

Mathematics of string theory is complex.

Only approximate solutions so far, but:

String theory "contains" Einstein's Theory mathematically on large enough spatial scales that string "loops" are tiny, just as Einstein's theory "contains" Newton's mathematical theory of gravity on length scales where gravity is weak.

Can solve string theory near the event horizon (much larger than string scale) to determine the temperature of a black hole, get exactly Hawking's answer - deep connection between string theory and black holes.

Cannot yet solve for "singularity," but prospect to do so. Singularity would not be zero size and infinite density, but some behavior on the string length scale, not quantum foam, but some "stringy" nature.

Information fallen into black holes could be retained in string vibrations (or radiated away in "stringy" Hawking radiation).

Reprise – Newton, Einstein, and String Theory

Newton had the concept of a "force" of gravity.

Einstein's theory had the concept of gravity as curved space.

When gravity is weak, the mathematical description of gravity in Einstein's theory is exactly the same as the mathematics of Newton. The concept is different.

String theory is a quantum theory. String theory has the concept of gravity as a quantum force for which the messenger particles are "gravitons" propagating in 10 spatial dimensions.

For safe distances from a singularity (where the full string theory would be needed and remains unsolvable), the mathematical description of gravity is exactly the same as the mathematics of Einstein. The concept is different than both Newton and Einstein.

Although string theory is a quantum theory, it is built on concepts of curved space.

The equations of string theory predict not only 1D strings, but "surfaces."

These "surfaces" can be of any dimension less than the total of the space containing them, 10.

These surfaces can also wiggle and vibrate.

In analogy to membranes, they are called ***branes*** of dimension p, or ***p-branes***. A point is a zero-brane, a line a one-brane, etc.

The hyperspace "Volume" in which a brane is immersed is known as the ***bulk***.

Some strings are loops with their ends attached to branes.

Other strings are closed loops that can float off away from the brane, into the bulk.

This led to a revolution in our perspective on the Universe.

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.

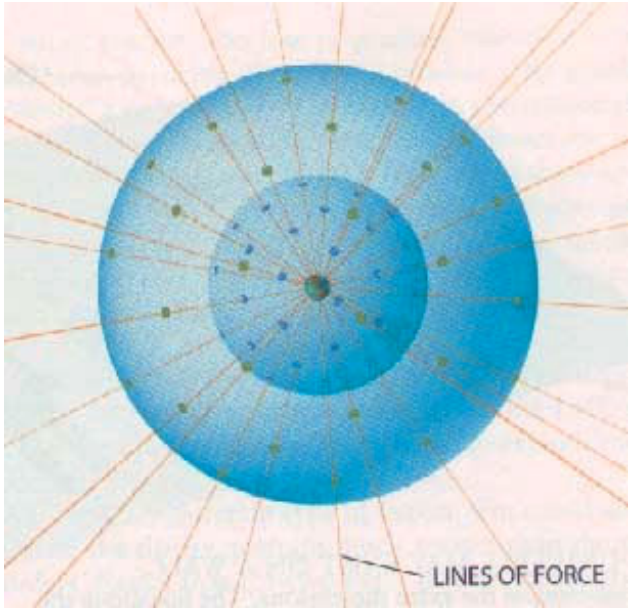
Old argument: there could ***not*** be a ***large*** 4th spatial dimension

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/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 space by 1/ "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" tightly so gravity has nowhere to go in that higher dimension.

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 any extra large dimension to be "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.

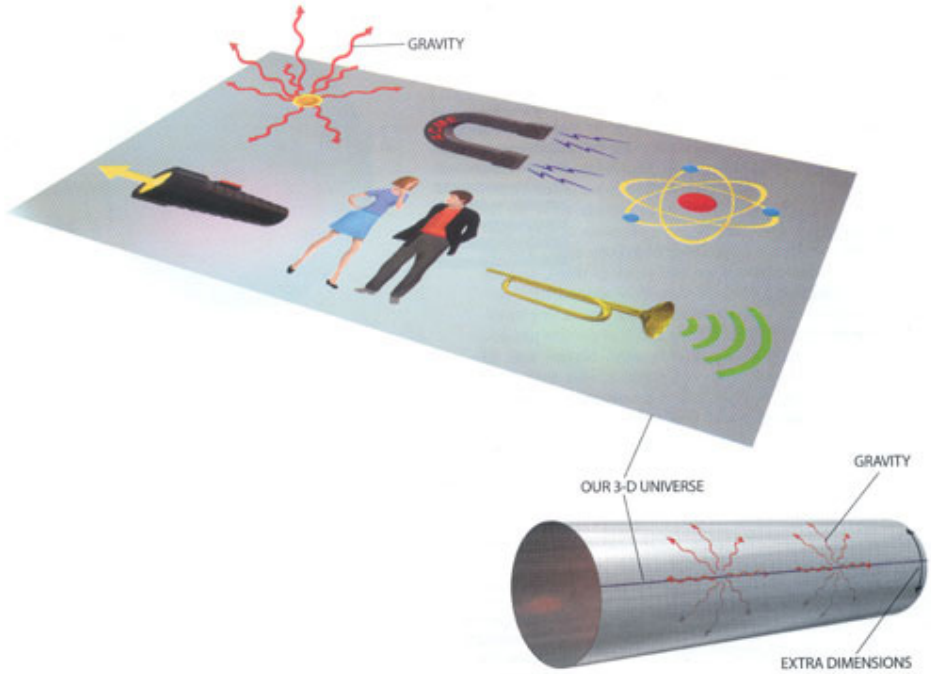
Plus tightly wrapped up dimensions.

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.

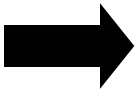
Gravity is based on "gravitons," closed loops of strings that are not stuck on the brane. They can float off into the bulk, but in a way that gravity still weakens very nearly like $1/r^2$.

Balls on 2D brane, sound into 3D bulk

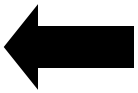


One minute exam

In string theory, our Universe is pictured as a



2 brane



3 brane

10 brane

3D bulk

Goal:

To understand how the notion of a large 4^{th} 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: Ekypyrotic Theory (Greek *ekypyrosis* = 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:

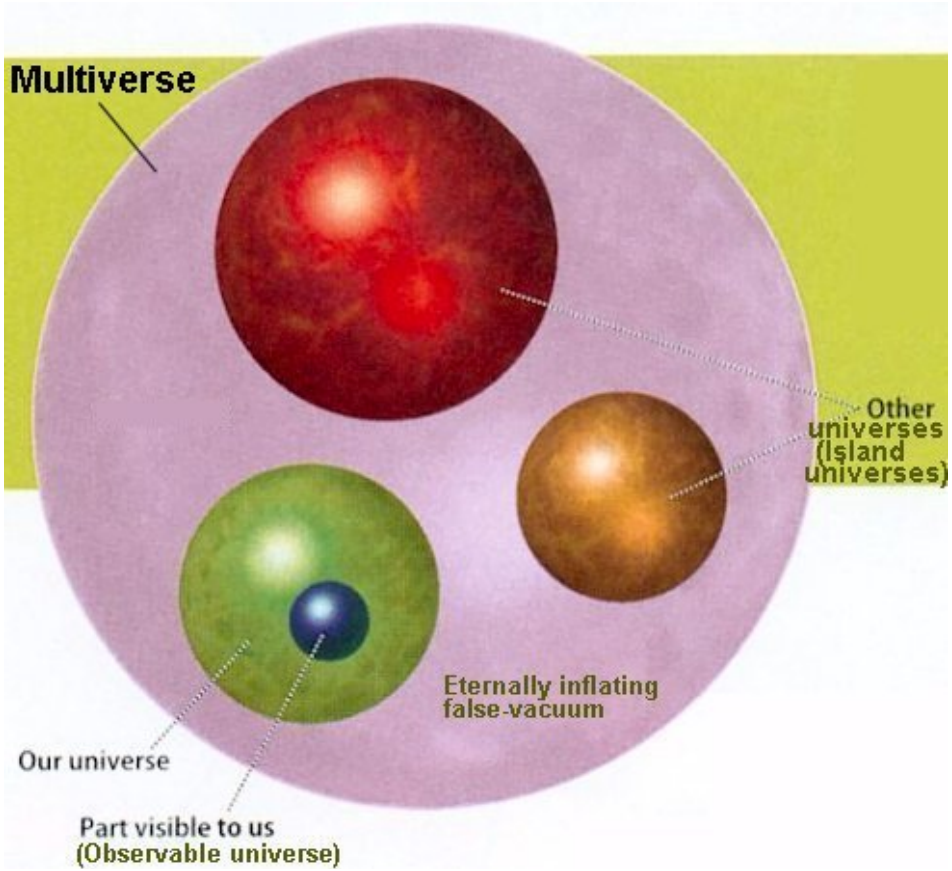
Singularity in black holes, quantum foam ⇒ nested "loops" of strings?

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?

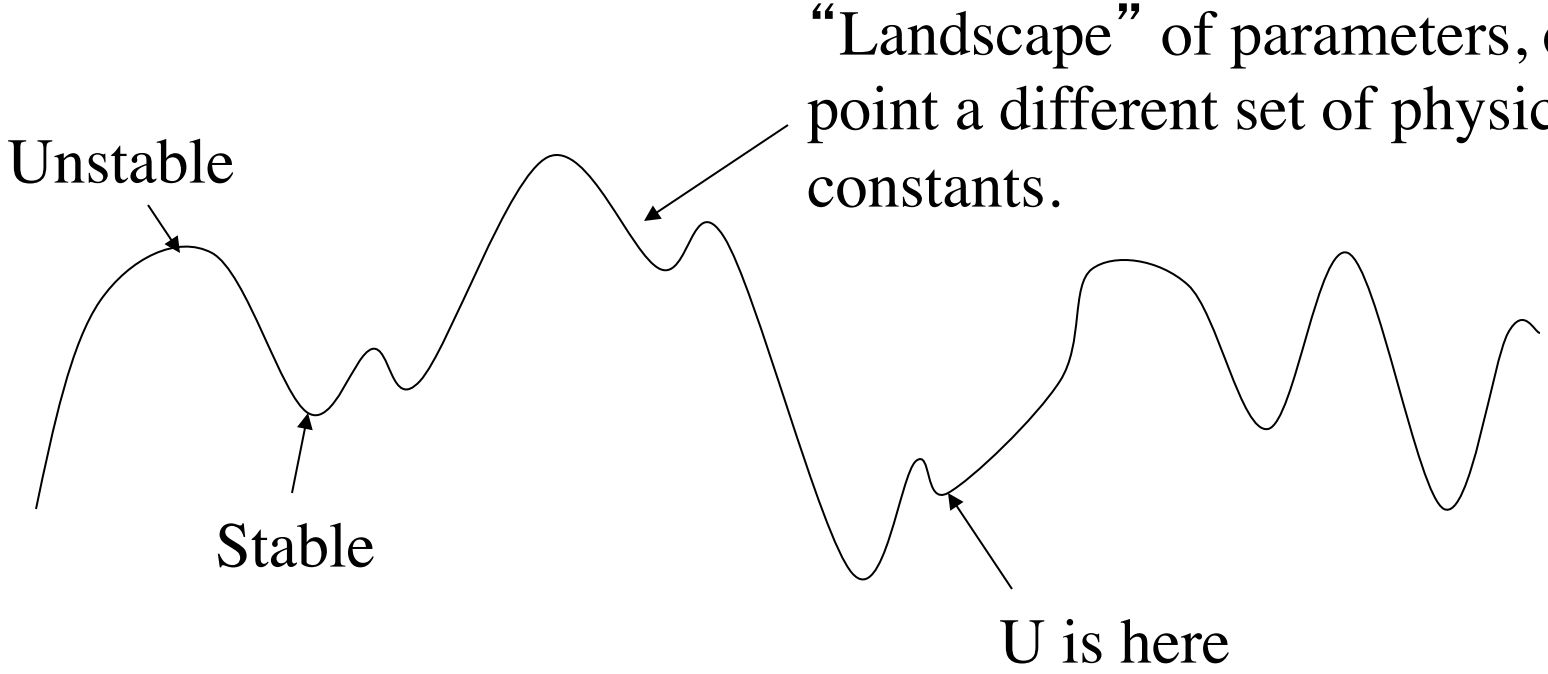
More current ideas:

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



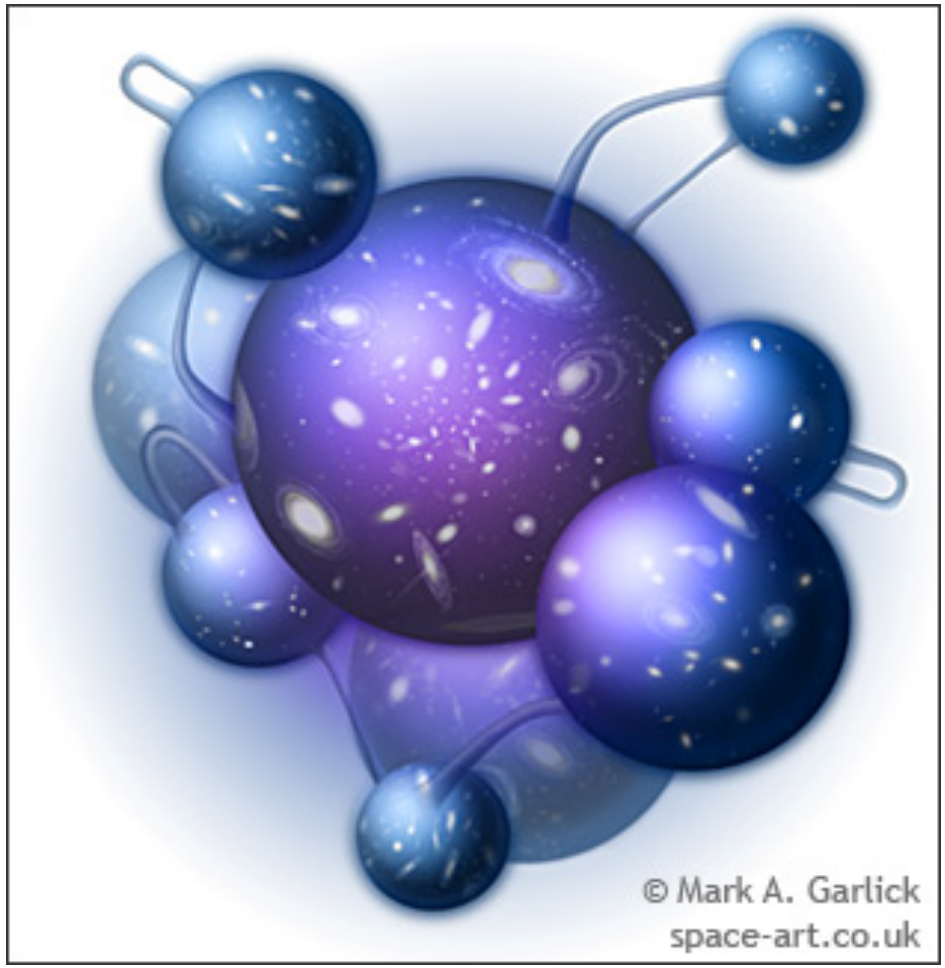
The String Landscape - current estimates are that string theory might provide 10^{500} different solutions, "universes," each with a different set of values of the physical constants, speed of light, the gravitational constant, Planck's constant that determines the size of quantum uncertainty, Einstein's 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.



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.

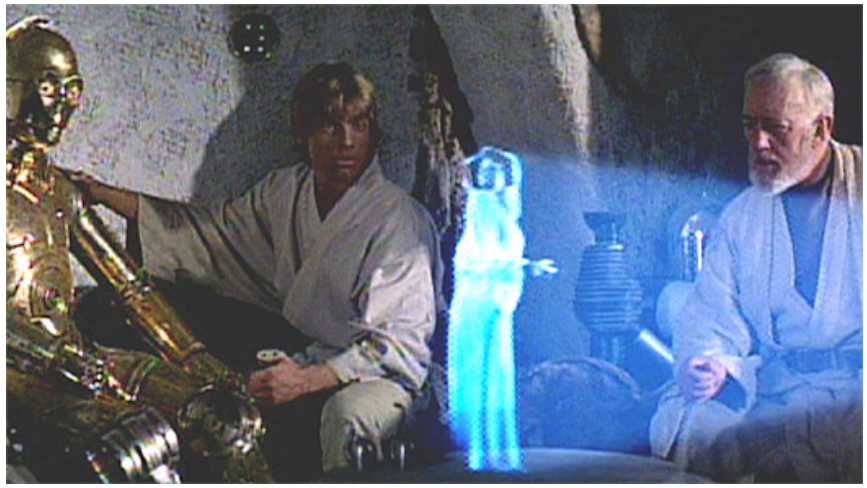
All this led to the idea that we live in a ***Holographic Universe***.

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?

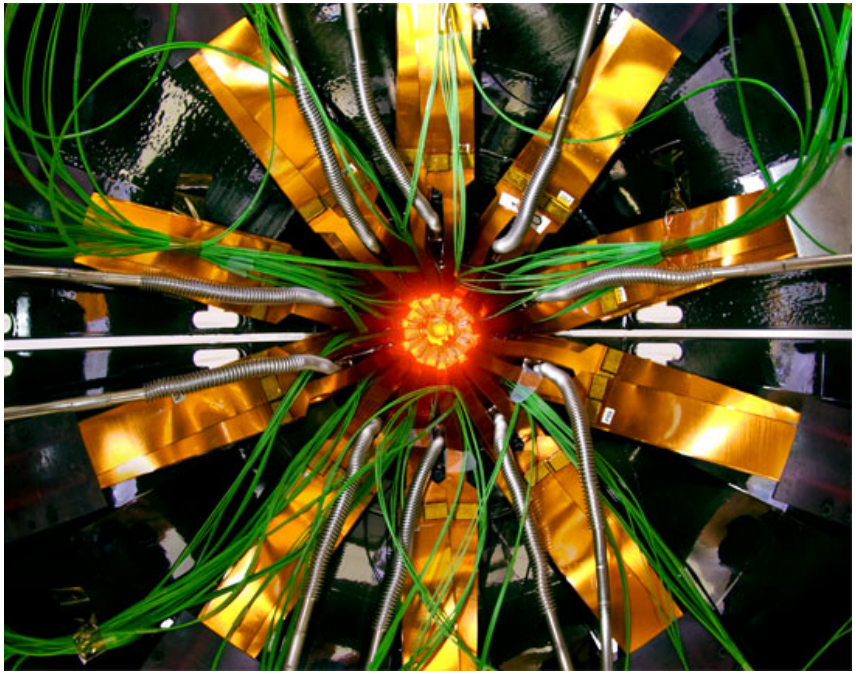
Curved space near event horizons of black holes might be different than standard Einstein gravity - can that be measured with X-rays?

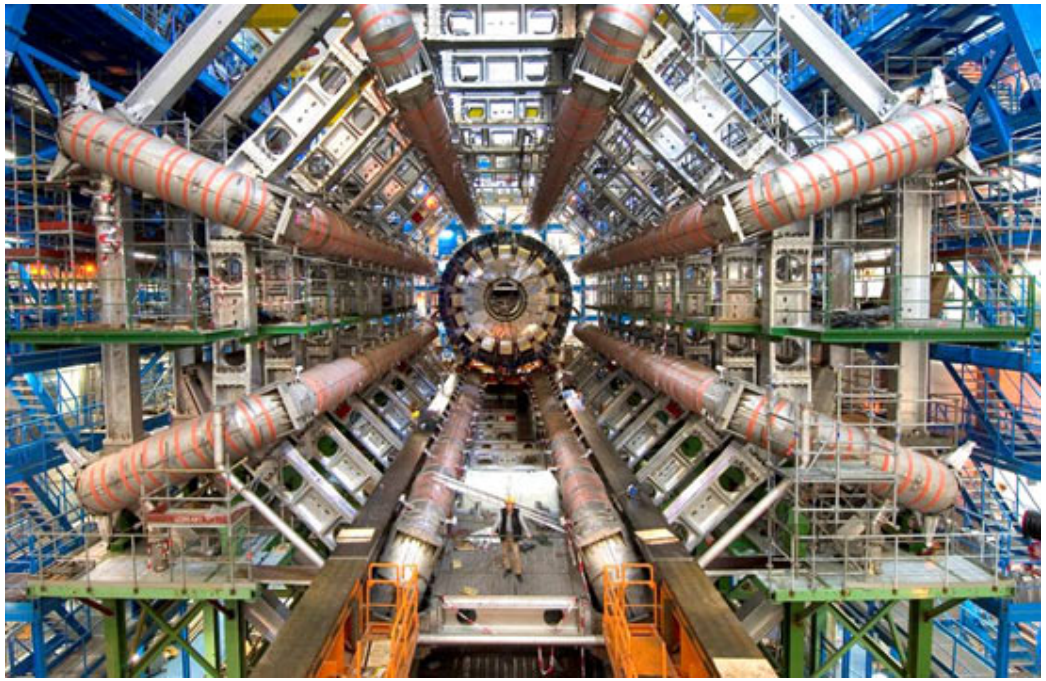
Interactions in particle accelerators could be different if some energy disappears into the 4D bulk (as closed string gravitons).

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!)