

12/7/07

Fourth and last SkyWatch extra credit anytime before end of classes, December 7.

Reading: Chapter 13 (worm holes and time machines), 14 (quantum gravity, string theory, large extra dimensions).

Final Review Sheet posted

*Final Exam Information:* FRIDAY, DECEMBER 14, 9-12 N  
ART 1.102

News:

Pic of the day; 2 star clusters in Perseus



***Special Office Hours: RLM 15.216B***

***Monday, December 10, 12 - 1***

***Thursday, December 13, 12 - 1***

***Or by appointment with me or BiQing***

Worm Hole video

<http://home.actlab.utexas.edu/~dgilder/Wormholes.html>

In the 1990's, physicists discovered that 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.

In analogy to membranes, they are called *branes* of dimension  $p$ , or *p-branes*.

“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.

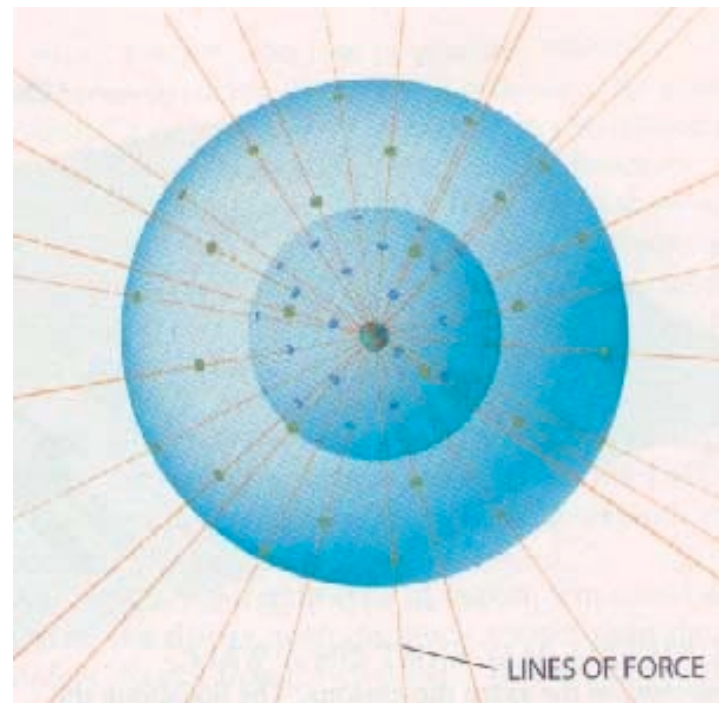
*This led to a revolution in our perspective on the Universe.*

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

Gravity probes all space, whatever its dimension. Gravity is a creature of space/time

Behavior of light and gravity in 3D

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



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 no where to go.

*New insight:* (1999) - Can have *large extra dimensions* and gravity will still leak only a little into that extra dimension, still weaken very nearly as  $1/r^2$ .

*Our 3D Universe could be a 3D brane in a 4D bulk*

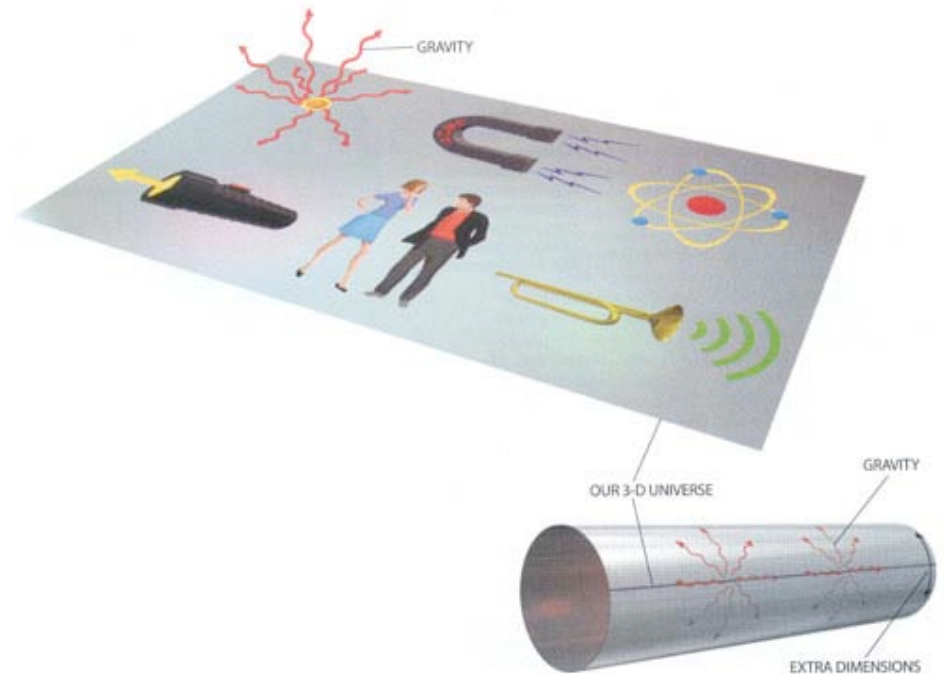
*There could be a real, large (infinite), four-dimensional hyperspace in which our 3D Universe is embedded.*

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.

Balls on 2D brane, sound into 3D bulk



Gravity corresponds to 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  $1/r^2$ .



***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 - could be a test.

*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...

Bubble Universes: When a black hole forms a “singularity” does a new Universe spring into existence “elsewhere” in 4D hyperspace?

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?

*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.

The Large Hadron Collider (LHC) is under construction at CERN, near Geneva, will begin to operate in 2008. Strong expectation that evidence for new physics, confirming or denying string theory ideas will be seen.

Take Away Message:

Hyperspace might be real...

Stay tuned!