

Monday, April 30, 2012

Fifth Exam, Friday, May 4

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, CPE 2.214

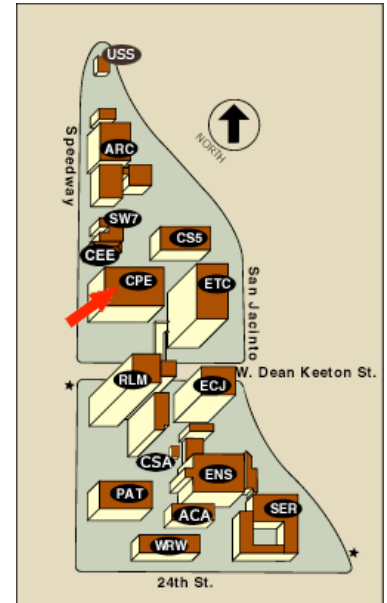
Reading: Chapters 11 (omit 11.6), 12, 13, 14

Electronic class evaluations. Please respond. This feedback is very valuable to me and to the TAs.

Astronomy in the news?

Stars near the Sun don't seem to indicate any dark matter.

<http://news.sciencemag.org/sciencenow/2012/04/has-dark-matter-gone-missing.html?ref=hp>



News:

Goal:

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

Concept check:

Can you explain what it means to have a wrapped up, closed dimension in 3D? What are examples?

Can you explain what it means to have tiny, wrapped up higher dimensions?

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, 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.

“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.

Concept check:

What is the “inverse r-squared law?”

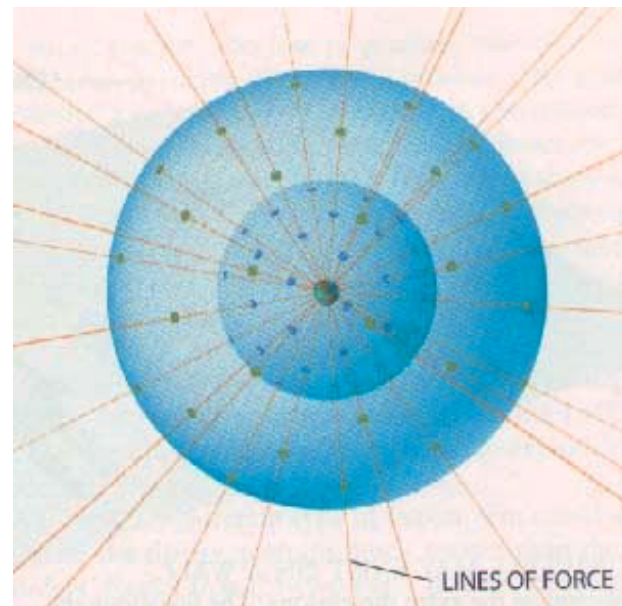
Old argument: there could *not* be a *large* 4th spatial dimension

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.

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 $1/\text{distance}^2$ 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.

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.

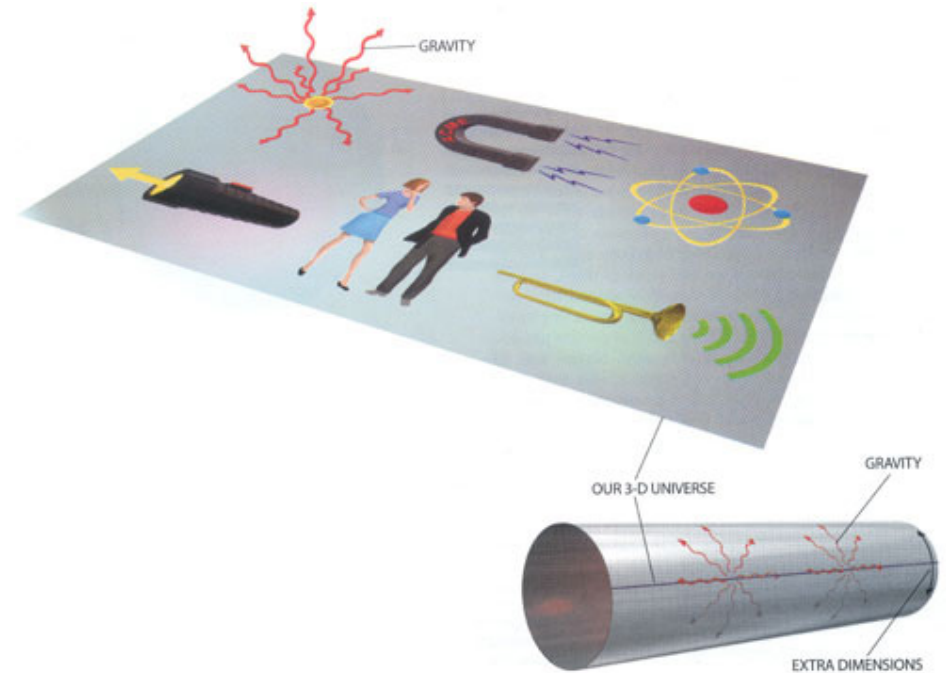
Plus tightly wrapped up dimensions.

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

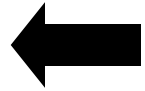


One minute exam:

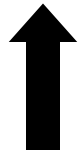
If gravity reached into a 5D space as easily as it penetrates our ordinary three-dimensional space, then it would get weaker with distance from the source as



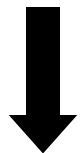
$$1/(\text{distance})^2$$



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



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



Our 3D brane expands

One minute exam

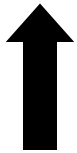
In string theory, our Universe is pictured as a



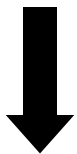
2 brane



3 brane



10 brane



3D bulk

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.