May 2, 2011

Exam 5, Friday, May 6. Review Thursday, 5 – 6 PM, room WEL 1.308.

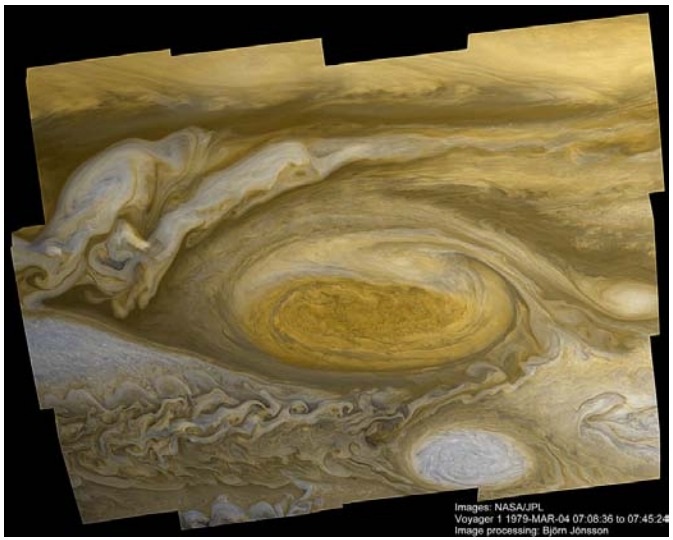
Review Sheet posted.

Reading: Chapters 12, 13, 14

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

Astronomy in the news: shuttle launch delayed, maybe a week.

Pic of the day: Jupiter's Great Red Spot, turbulence and its effects are a great problem in many areas of astronomy



We failed to record some grades for 4th sky watch. Please check your grade online. If it is incorrect, return your sky watch and we'll fix it.

If you have a "zero" but did a skywatch, please return it.

The grades are written in the lower right hand corner of the first page.

Goal:

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

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.

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?

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:

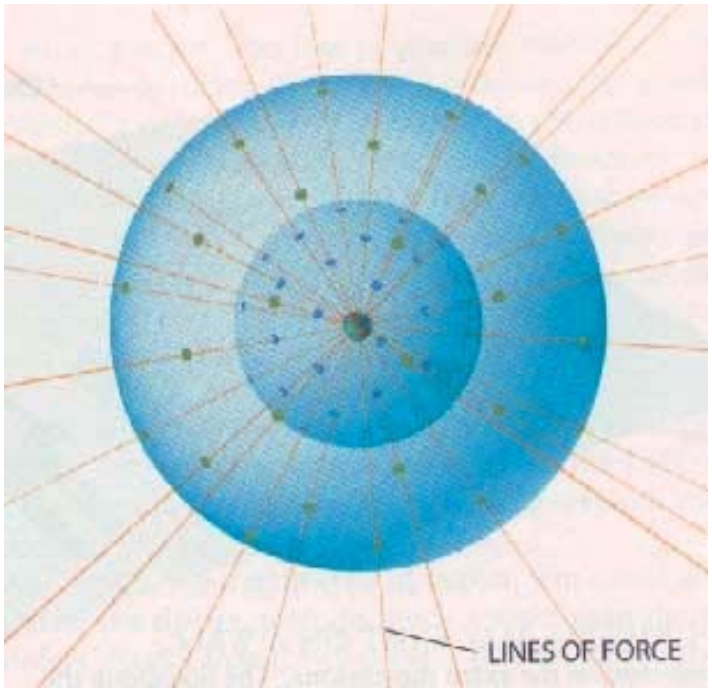
What is the “inverse r-squared law?”

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/area $\propto 1/r^2$ in 3D. Area is one dimension less than volume; the "2" 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/ “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: (1999) - Can have ***large extra dimensions*** and gravity will still leak only a little into those extra dimensions, still weaken very nearly as $1/r^2$.

Leakage could account for why gravity seems "weaker" than other forces.

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

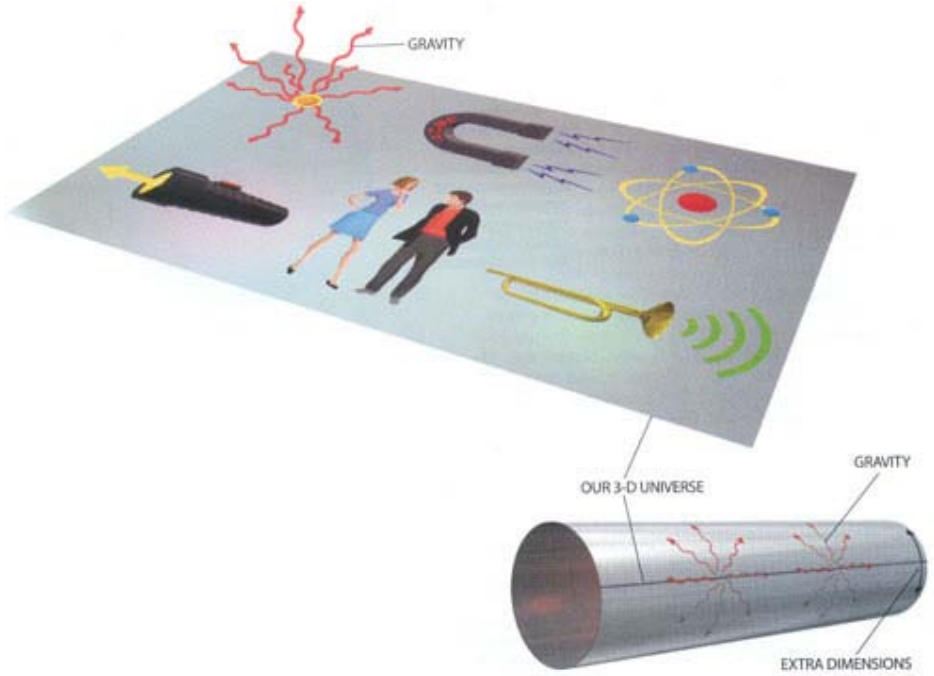
There could be a real, large (infinite), four-dimensional hyperspace in which our 3D Universe is embedded.

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.

Balls on 2D brane, sound into 3D 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 $1/r^2$.

One minute exam:

If gravity reached into the 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