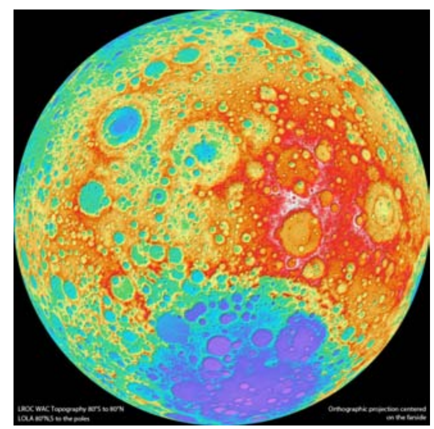
Friday, November 18, 2011

Reading: Chapter 12, Chapter 13, Chapter 14

Astronomy in the news? Fabric of the Cosmos, Quantum Leap, weird world of quantum uncertainty, quantum entanglement (instantaneous action at a distance), quantum computing.

The Fabric of the Cosmos, fourth installment, Universe or Multiverse, Wednesday, November 23, PBS (KLRU) 8 PM (re-runs http://www.klru.org/schedule/viewProgram.php?id=246736).

Pic of the day: false color topographical map from Lunar Reconnaissance Orbiter



Goal:

To understand what the Dark Energy implies for the shape and fate of the Universe.

Nature of Dark Energy

Energy of vacuum - quantum fluctuations, particle/anti-particle (recall role in Hawking radiation) predict an acceleration that is too large by a factor x 10^{120}. It works on Earth, but not, somehow, in deep space.

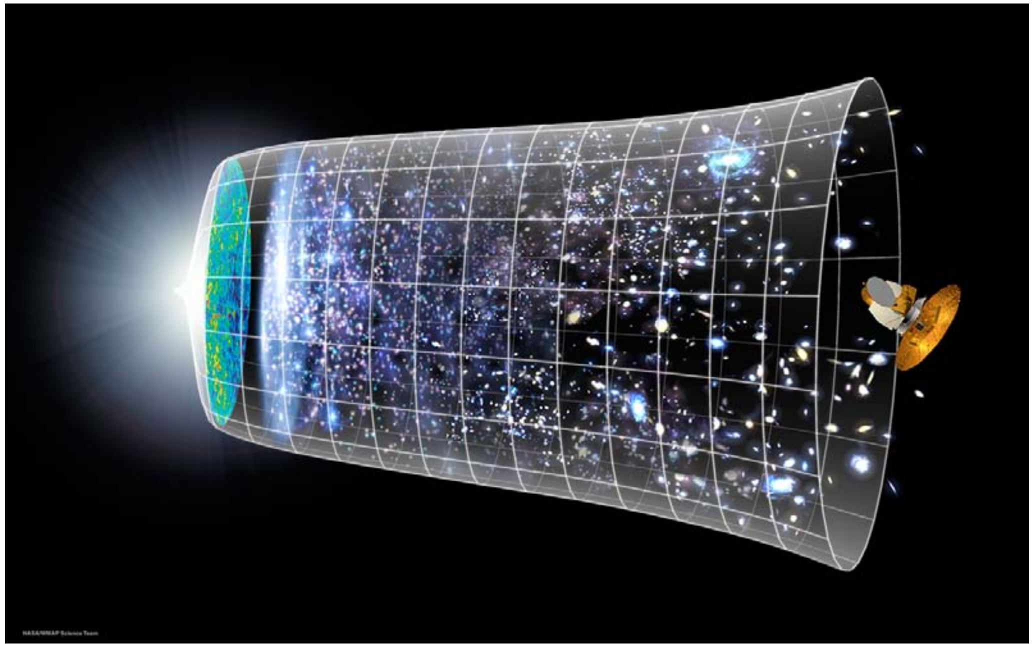
"Worst prediction ever in physics,"
Steven Weinberg (UT Nobel Laureate)

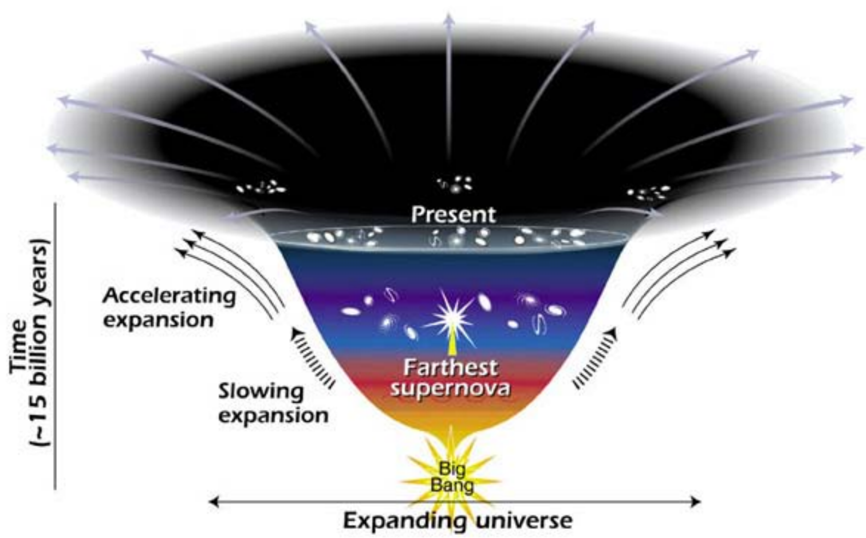
Related phase early in Big Bang, when the Universe was a fraction of a second old,

A huge "inflation" by anti-gravitating vacuum force blows the Universe so big that it is essentially flat (like the surface of the Earth appears to us, only moreso!)

Anti-gravitating energy went away - has come back gently in the last 5 billion years. ***What is it???***

“Space-time diagrams” illustrate how the Big Bang led to inflation, then deceleration, and now acceleration





The Fate of the Universe?

If the acceleration stays constant, the fate is rather dismal: galaxies will be pulled infinitely far apart, then even small mass, long-lived stars age and die, protons, neutrons and electrons will decay to photons, black holes will evaporate by Hawking radiation.

The result would be an empty Universe filled with dilute radiation.

We know so little about the Dark Energy, that it could do other things.

It could get stronger, leading to a ***Big Rip*** with atoms and the very fabric of space being pulled apart (most physicists think this unlikely)

It could reverse sign and gravitate, leading to the recollapse of the Universe in a ***Big Crunch***.

Goal:

To understand how physicists are attempting to cope with the existence and nature of the acceleration of the Universe driven by Dark Energy.

Einstein’s theory of the behavior of the Universe contained a “Cosmological Constant” that could be positive, negative, or zero.

Einstein first argued it was positive in order to provide an anti-gravitating force to counteract gravity to keep the Universe from expanding or contracting. Then the expansion of the Universe was discovered and he called it a “blunder.”

Current results on the expansion are consistent with the Dark Energy behaving in accord with Einstein’s Cosmological Constant.

Even if true, we still need to know what it is, physically! Why does this “constant” have the value it does? Sort of like asking why the speed of light has the value it does.

Theories of **quantum fields** suggest that the Dark Energy could or should vary with time and space.

One theory called “quintessence” (the fifth essence, after the Greek earth, air, fire, and water) would have that property.

Other theories call for interaction with other 3D Universes “elsewhere” in hyperspace.

The race is on to determine whether the Dark Energy is constant (Einstein’s cosmological constant) or not (some quantum field).

Texas astronomers will be doing the Hobby-Eberly Telescope Dark Energy Experiment (HETDEX) starting next summer for three years to try to answer this question.

Goal:

To understand why we need a new theory of Quantum Gravity and the ideas involved in the attempt to construct that theory.

Quantum Gravity - The Final Frontier

The remainder of the class will be spent exploring various aspects of the most fundamental issue of modern physics: reconciling ***Einstein's theory of gravity*** as curved space with the ***quantum theory*** of how things behave at a fundamental microscopic level.

The problem - each of these great theories of 20th century physics contradict one another at a fundamental level.

Einstein's theory predicts ***singularities*** at the beginning of the Big Bang and in the centers of black holes where matter is crushed to a point with infinite density, time and space come to a halt. Quantum theory says the position of nothing, not even a singularity, can be specified exactly (the Uncertainty Principle applied to singularities).

Quantum theory is designed to work in flat, or gently curving space. It does not make sense when the curvature of space is tighter than the "wavelength," the uncertainty in position, of a particle.

Each great theory of 20th century physics contradicts the other!

Can use current theories to "predict" the conditions for which the theoretical collision occurs, where the theory of quantum gravity is most crucially needed, effectively the **scale of length where quantum uncertainty and space-time curvature are equal**.

Planck length - about 10^{-33} centimeters, vastly smaller than any particle, but still not zero!

Planck density - about 10^{93} grams/cubic centimeter, huge, but not infinite!

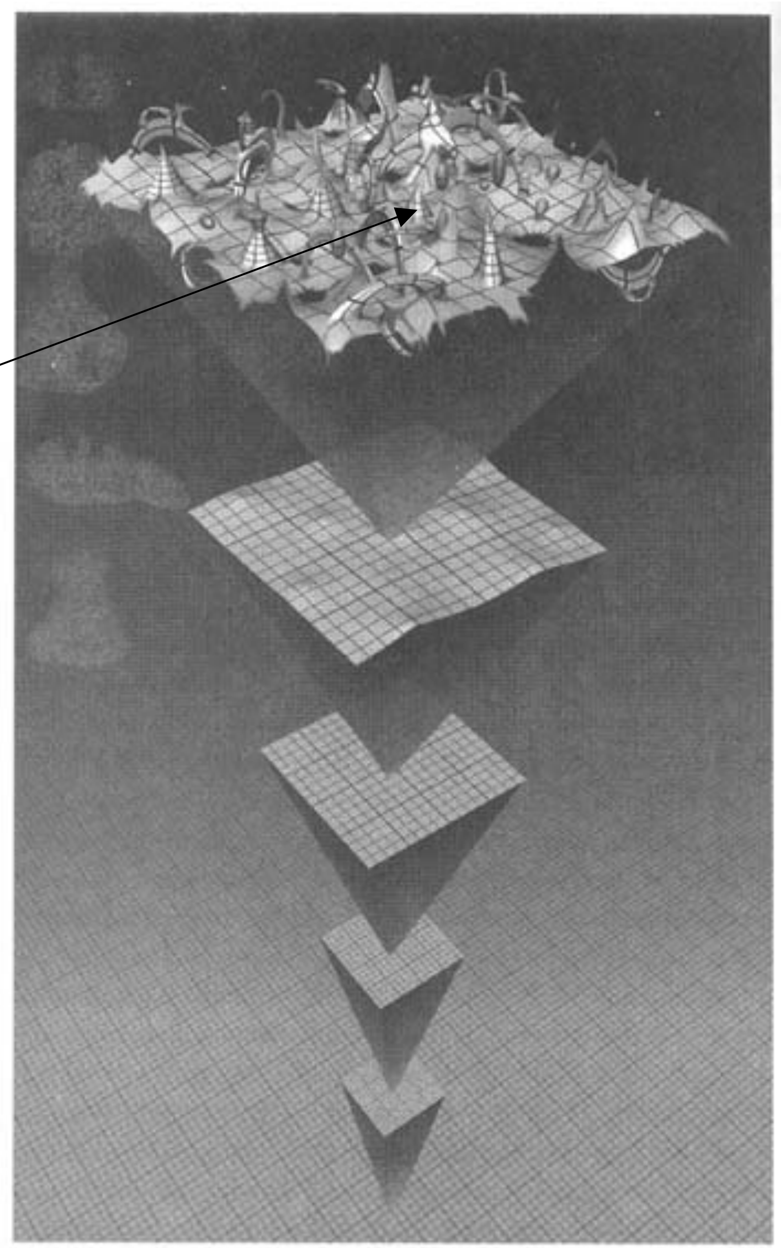
Planck time - about 10^{-43} seconds, short, but not zero! Cannot predict earlier times in the Big Bang.

On the Planck scale, space and time themselves could be quantum uncertain, "up" "down" "before" "after" difficult if not impossible to define.

Spacetime becomes a "quantum foam" (a poetic concept without a mathematical/physical framework).

Quantum Foam

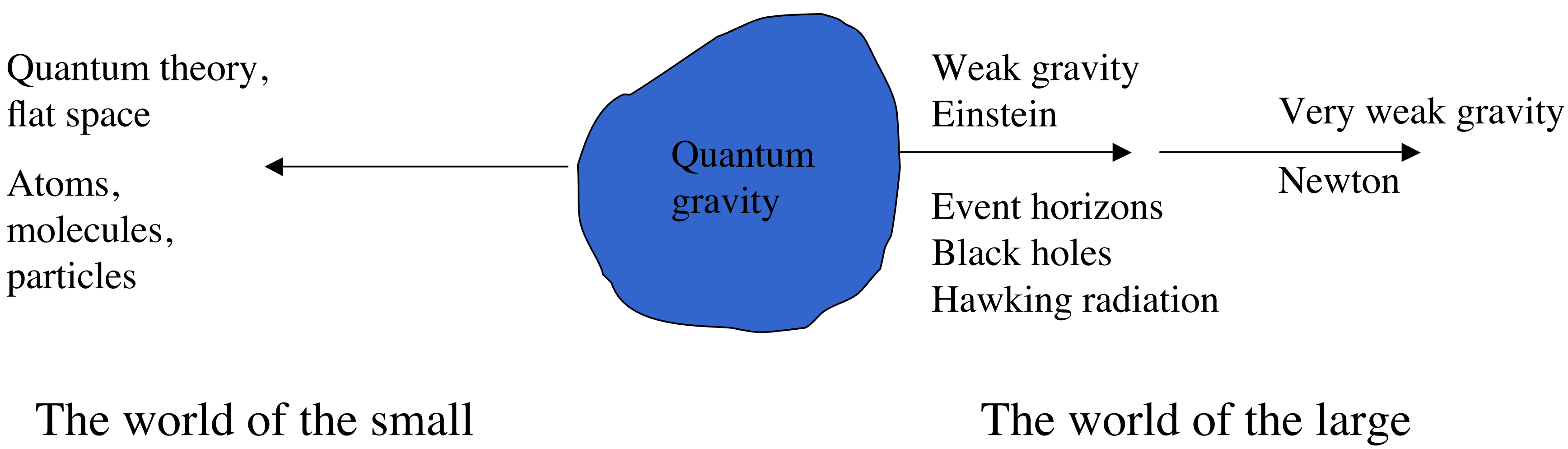
At the Planck length scale



From Brian Greene

The Elegant Universe

We need an embracing theory of ***quantum gravity*** that will reduce to ordinary gravity and ordinary quantum theory where they work well (away from singularities and with non-severe curvature - same thing!), but will also tell us what a "singularity" really is.



One Minute Exam

As an explanation for the Dark Energy, a quantum field would be different from Einstein's Cosmological Constant because a quantum field would

➡ Be constant in space

⬅ Vary in time

⬆ Gravitate

⬇ Anti-gravitate

One Minute Exam

In a theory of quantum gravity, the singularity in a black hole would have a density of

➡ infinity

⬅ about 10^{93} grams/cubic centimeter

⬆ about 10^{-33} grams/cubic centimeter

⬇ about 10^{-43} grams/cubic centimeter

Goal:

To understand how Einstein's theory predicts worm holes and time machines and how we need a theory of quantum gravity to understand if those are really possible.