Notes on Teaching Company *Understanding the Universe: An Introduction to Astronomy* 2nd edition
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Cosmology sections

Lecture 86: the stuff of the cosmos
The Concordance model of 2001 provides a convergence of several sets of data all of which suggests that
"30% of the universe is normal mater, dark matter, and normal energy. 70% is weird stuff." Called dark energy. This weird stuff has a repulsive effect and is accelerating the expansion of the universe.

Luminous galaxies tend to form at the peaks of dark matter, just as snow is seen at the peaks of mountains. Dark energy effects the growth of large scale structure. Simulations which include "dark energy" look a lot more like our observed universe than simulations which include only cold dark matter. Omega x, representing dark energy, sort of represents the cosmological constant.

Lecture 87: dark energy: quantum (zero point energy) fluctuations
Dark NRG is shaking the foundations of theoretical physics.
Simplist candidate is the cosmological constant
In general relativity, normal outward pushing pressure adds to the gravitational effect on a body: you will be a little heavier if you take the outward pressure of the earth on you into account.
Matter and energy density and pressure all contribute to the gravitational field of an object.
Expansion of universe for
Normal matter and energy have a positive energy density and positive pressure, resulting in expansion of universe.
Dark energy may have a "normal" positive energy density but a negative pressure, which would result in greater expansion; ie acceleration of expansion.
What could dark energy be? May result from imperfect cancellation of quantum fluctuations (ZPF)

Theory of Quantum electrodynamics of Fenyman et al said the quantum fluctuations are really occurring and effect the structure of atoms. The theory of QED basically says the interaction between two particles is mediated by virtual particles. for example, the virtual particle for electrons is the photon; the electrons feel each other by exchanging virtual photons.

Willis Lamb in 1947 found that the energy levels in the hydrogen atom are not exactly where you would expect them to be based on classical physics. The mismatch is called the Lamb Shift. QED explains the Lamb Shift: unless you include the effects of the virtual particles, you will not get the classically expected values. For hydrogen, the virtual photons interact with the electrons, changing its mass. If had slight excess of positive energy virtual particles: this would account for the observed acceleration of expansion of the universe via negative pressure.

The Casimir effect shows that 2 thin plates placed on one another attract one another. In the space between the two plates the wavelengths have to be such that they form nodes on the two plates (standing waves). Even though the number of waves between the plates and outside the plates is infinite, the infinity between the plates is smaller (less dense) than the infinity outside the plates, so there is a net attractive force between the plates. [This is a net attractive force however, not a repulsive force]. This illustrates how the vacuum might exhibit a macroscopic effect.

Lecture 88: dark energy Quintessence??
2 major problems with quantum (zpf) fluctuations theory of dark energy
1st: the cosmological constant is small: omega lambda = energy density= 0.75
Back of envelope theoretical calc of what omega lambda should be is 10 to the 120th power
Value measured by astronomers is .75
If all quantum fluc cancelled exactly, the value would be exactly zero.
We know energy density can't be too big; else no galaxies would have formed; we would not have formed
2nd why are WL (energy density) and W matter (energy density of matter) roughly equal right now?
Fractional energy density for WL and WM: WM is decreasing; WL is increasing; at this time (the time of humanity)
The ratio is roughly the same. Why? Suggests a fine tuning. The theory of quantum fluctuations gives no insight into that.

Other possible mechanisms aside from cosmological constant; main alternative is called "Quintessence", after Aristotle's fifth element. This is a new energy field; repulsive. Can be thought of as a 'latent heat of space associated with an unbroken or recently broken symmetry".

Liquid droplets are more symmetric than crystals.

"easy heat:" contains a supercooled chemical (sodium acetate) in liquid form at room temperature that has latent heat in it, similar to super cooled water. If perturb the liquid crystals form and heat is released. The supercooled solution represents an unbroken symmetry. The breaking of symmetry of going to a less symmetric state and releasing heat is analogous to breaking symmetry in something in the universe, and the expansion of the universe (not release of heat)

Hundreds of quintessence models.
An equation of state parameter W can be defined for the universe: inversely proportional to density times c squared and directly proportional to pressure. The theoretical value of w can be calculated for different theories of dark energy.

Measure W by measuring lots of super nova at high red shift.
Based on the current data, the measured value is the value of the cosmological constant theory of dark matter is -1. So, the vacuum or quantum fluctuation theory is most consistent with measured values. Can rule out quintessence models that have W values different from -1.

Lecture 89: Grand Unification and theories of everything

To understand dark energy, we will probably need a theory of everything. Dark energy provides a good test of any potential TOE. Strong force is residual of the color force that binds quarks together. EM and weak force have been unified. In high energy interactions, cant tell the EM force from the weak force. Steven Weinberg et al got Nobel Prize for "electro-weak" in 1979.

GUT: unify electro-weak and strong nuclear
TOE: unify electro-weak and strong nuclear and gravity.

Two issues with TOE:
G so weak it cannot relate to the other forces
QM & Relativity, though each is good in its own area, are incompatible;
QM very small
Rel very large
Large mass in small volume: need quantum theory of gravity to understand black holes.
Uncertainty Principle shows quantum vacuum: tiny distance and time implies large uncertainty in energy.
Space time curvature in this situation is extreme and chaotic. Gen relativity can only deal with smooth variations in space time. At point size time and space, get infinite fluctuations in energy infinite curvature in space time.
We reach the unknown at scales of the Plank length of 10-33 cm. At that scale the associated particle energies are like 10 to the 19^{th} time the mass of the proton. This mass is the Plank mass. (matter and energy related by e=mc2) At that mass, gravity becomes just as important as the other forces, which means the TOE must deal with this situation.

Even if fluctuations only occur at the plank scales, omega lambda, energy density, is10^{-120}

If manifest quantum fluctuation is cancelled out by it's "hole" inside the vacuum, should have lambda exactly 0.0.
But the measured value is .75.

String theory says can't talk about infinitesimal regions of space; space itself and the particles in it have a minimum length on the order of the plank length. Fundamental particles are energy packets; strings of energy in different modes of vibration, which are manifest as different types of particles. String theory gets rid of the infinitesimal, therefore the infinites, which is its great triumph. String theory is a proposed GUT or TOE.

These particles are of plank mass; not observed, and how do you get the masses of observed particles from them?
Vibrations cancel out, this tends to lower the expected masses.
Still, have not obtained any existing particle masses. No observations support string theory. No testable predictions.

What is so alluring about ST? its math elegance; its aesthetics; some scientists think that certain relationships are so appealing that they must be right.

Lecture 90: looking for hidden dimensions
For math in string theory to work, the vibrations have to occur in hidden dimensions.
M theory is a type of string theory 11 d; M for Membrane theory rather than string.

There is a historical president for multiple dimensions. In 1919, Theodor Kaluza suggested there are four dimensions. He had found that electromagnetism comes out of the equations of General Relativity if those equations are expressed in four spatial dimensions rather than three. Seven years later, Oscar Klein refined this idea; said the reason we don't see the 4^{th} spatial dimension is that it is curled up on very small Plank scales. Kaluza Klein theory.

7 curled up spatial dimensions make a generic class of Calabi-Yau spaces developed independent of string theory; may be relevant to string theory.

All string theories, as well as some other theories predict the graviton, the carrier particle of gravity.

In QM there is always a carrier particle. This may be a link to connecting gravity and the other 3 forces.

Graviton may act only in the hidden dimensions, but some leaks into the three dimensional world. This may explain weakness of gravity.

If this were true, might see apparent energy losses when gravitons escape from the 3 dimensions into their preferred hidden dimensions. To see this, would need a large collider, such as Fermilab are CERN. No energy losses found yet.