4/27/05

Exam 4, Friday

Chapters 9 [Sections 5.2. 6 (not 6.4 white holes), 7, 8], 10, 11

Review sheet posted, Wheeler available as much as possible.

Review, Tomorrow, 5:00 PM RLM 15.216B

Supplementary reading - Draft of new, revised chapters for second edition, under “reading assignments” link

News: Philip Morrison of MIT 89: Atomic Bomb, Powers of 10, Tycho’s nose

Pic of the day:

Hercules cluster of galaxies

Nature recently threw us a curve ball

SN were the key!

Use Type Ia supernovae (brightest, ~ uniform behavior)

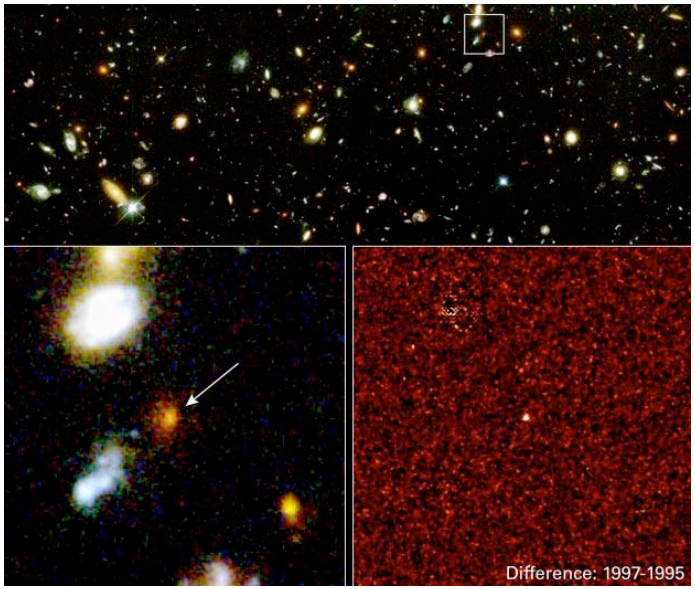
Carefully map ***distances*** (dimmer appearance means further away), ***velocities*** (Doppler red shifts) in all directions

Do geometry - measure curvature - “sphere”, “Pringle”, “flat”
closed, open, flat

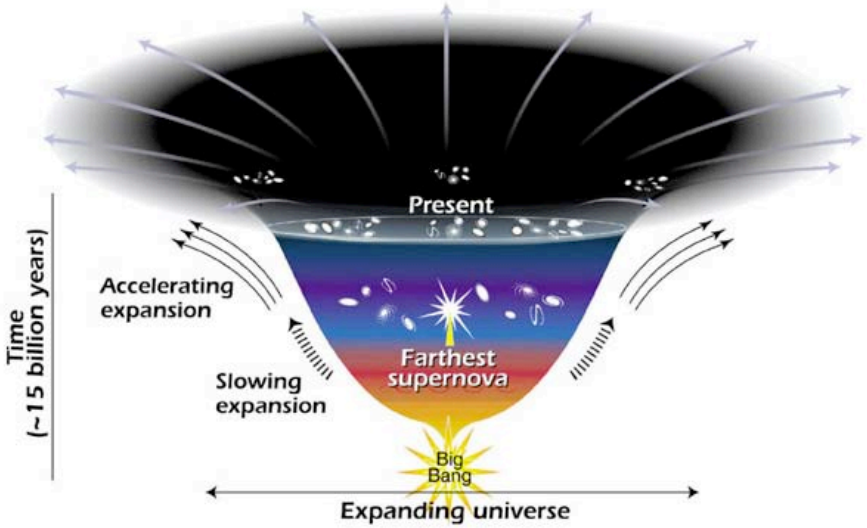
More subtle techniques than making parallel lines or drawing triangles, but still amounts to “doing 3D geometry.”

Type Ia supernovae are generally the brightest and can be seen at cosmological distances.

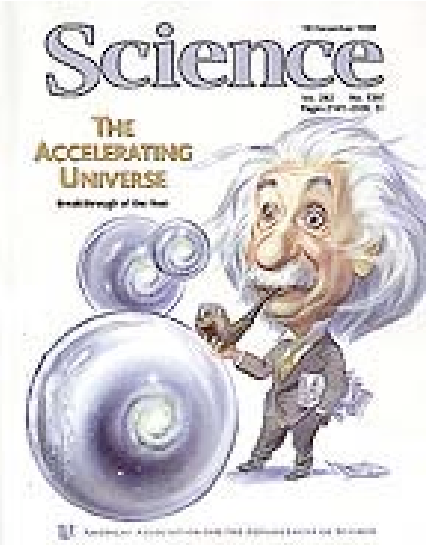
They were used as cosmological probes...



to discover the ***acceleration*** of the Universe...



the Science Magazine scientific Breakthrough of the Year in 1998



The supernovae were found to be a little too dim at given expansion velocity (red shift)

$\Rightarrow$ Further away than expected for a "normal" gravitating Universe

How do you get further away in a given time?

$\Rightarrow$ Universe has been *accelerating*!!

Throw ball

Other arguments, especially careful study of the small irregularities of the temperature of the cosmic background radiation left over from the Big Bang, confirm the evidence from supernovae

=> Accelerating Universe - confirmed by all tests applied so far.

$\Rightarrow$ Universe is filled with an even more mysterious ***Dark Energy***,

The dark energy seems to be some sort of force field (like a magnetic field, only different), that permeates the vacuum, empty space, and that that *pushes*, ***anti-gravitates!***

As space expands there is just more vacuum filled with this force field, so the effect is not diluted by the expansion.

Anti-gravitates: cannot be any particle, “normal” (p, n, e) or dark matter, that gravitates.

Dark Energy force field is not accounted for by any currently known physics.

A major challenge to fundamental physics!

Pressure Gravitates	Tension Anti-Gravitates
Dark Matter Gravitates	Dark Energy Anti-Gravitates
1/3 of that needed to be flat (3D)	2/3 of that needed to be flat (3D)

Total 1/3 + 2/3 = 1 just the right total mass/energy to be flat (3D)

The stuff that we and the Sun and stars are made of is essentially irrelevant to this argument, there is too little of it in the Universe.

Most of the stuff of which the Universe is composed is substances, Dark Matter, Dark Energy, completely unlike us.

The best current guess is that our real 3D Universe is essentially flat

But accelerating!

Flat on average

Still have individual stars, neutron stars, black holes, galaxies, that curve the space around them causing the small scale, local effects of gravity.

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}

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

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.
What is it???

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 a force to counteract gravity to keep the Universe from expanding or contracting, but 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 being just the value set by Einstein.

Even if true, still need to know what it is, physically!

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.

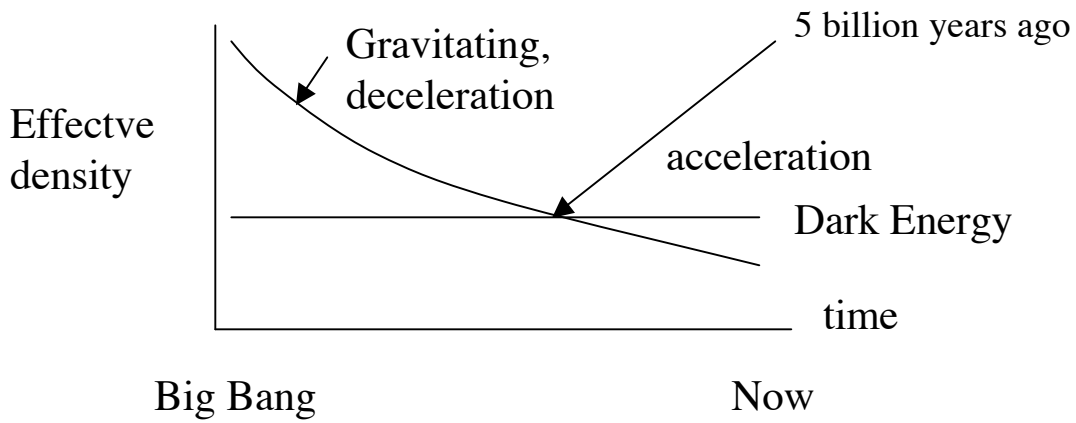
The race is on to determine whether the Dark Energy is constant or not.

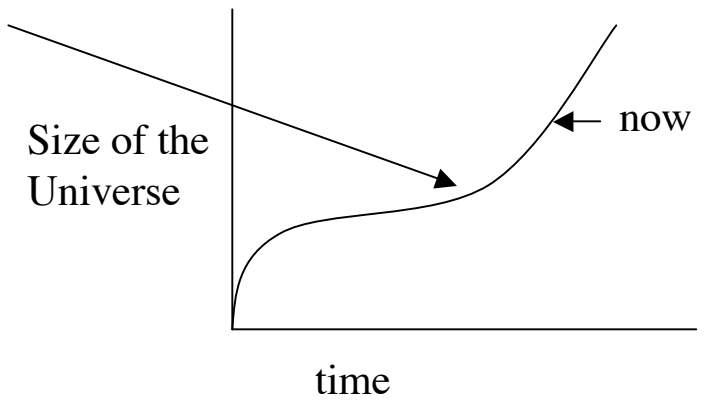
If the Dark Energy is roughly constant, as the Universe expands, the density of gravitating stuff (Dark Matter and normal matter) decreases in a given volume, but the Dark Energy, a property of empty space, stays the same.

The Dark Matter and gravity would be strongest early on, but Dark Energy, anti-gravity and acceleration would come to dominate.

Recent results from the Hubble Space Telescope suggest the Universe switched to acceleration about 5 billion years ago.

Why now?





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***.