

Wednesday, April 18, 2012

Exam back

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

Astronomy in the news?

Retired space shuttle Discovery delivered to the Smithsonian Udvar-Hazy Museum at Dulles airport on the back of a specially-rigged Boeing 747.



News:

Wonderful poster exhibit in the Welch hallway on the contributions of the Muslim culture to science, math, and astronomy.

One thing I knew: the word “algorithm” is derived from the name of the 8<sup>th</sup> century scholar Muḥammad ibn Mūsā al-Khwārizmī. “Algebra” is derived from *al-jabr*, one of the two operations he used to solve quadratic equations.



One thing I did not know: a 7<sup>th</sup> century Syrian woman engineer whose surname was al Astrulab worked on early astrolabes. The origin of the word “astrolabe” is murky (<http://en.wikipedia.org/wiki/Astrolabe>), but the surname probably has its origin as “maker of astrolabes.”

Goal:

To understand the nature of dark matter and how it affects the Universe.

# *Dark Matter*

Previously known surprising result:

Most *gravitating* matter in the Universe is mysterious *Dark Matter*

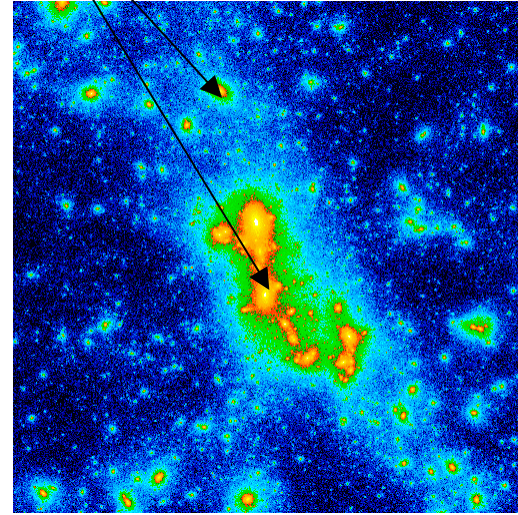
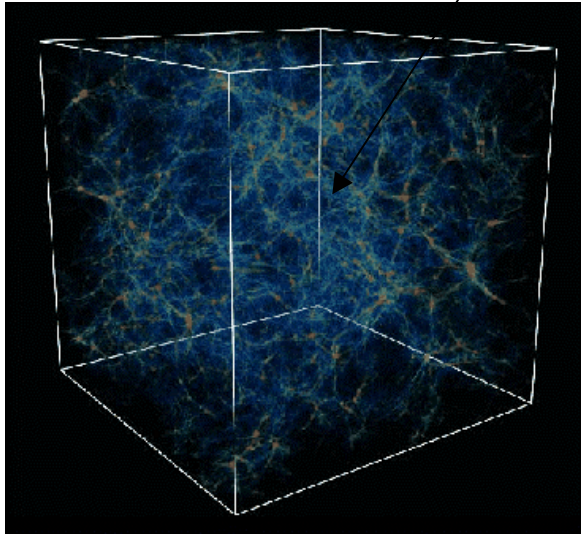
Not composed of p, n, e - the stuff of stars, galaxies, planets, and people

Dark Matter was *never* composed of that stuff (or would upset observed mix of hydrogen and helium from the Big Bang), so also not black holes once made from ordinary star stuff.

Some yet undiscovered particles that only interact by gravity and by the weak nuclear force, no electrical force, no strong nuclear force:

*10 × more total mass than “normal” stuff stars, gas, etc.*

# Dark Matter



Computer simulations show that from the tiniest wrinkles of quantum uncertainty in the Big Bang, the Dark Matter agglomerates to form all the ***Large Scale Structure***, galaxies, clusters of galaxies of the Universe.

Ordinary matter, protons, electrons, settles to center of Dark Matter lumps to form galaxies and clusters of galaxies. **Our familiar Universe of stars and galaxies would not exist without the Dark Matter.**

Density of Dark Matter is not enough to close the Universe  
⇒ Universe is “open?” (3D Pringle).

Goal:

To understand how Type Ia supernovae taught us a dramatic new lesson about the Universe and what that lesson was.

We thought we were trying to determine the density of the Universe to determine how strongly it was **decelerated** by gravity and hence whether it were open, closed, or flat.

Nature threw us a curve ball

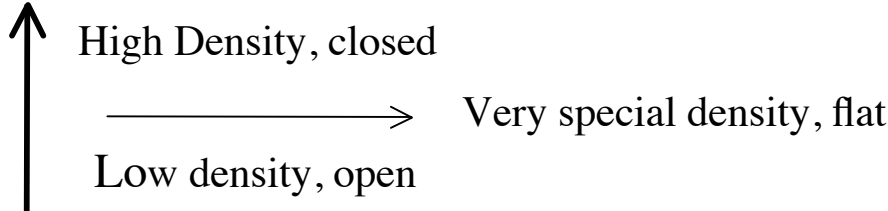
SN were the key!

Use Type Ia supernovae (brightest ~ uniform behavior)

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

Density of the Universe

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

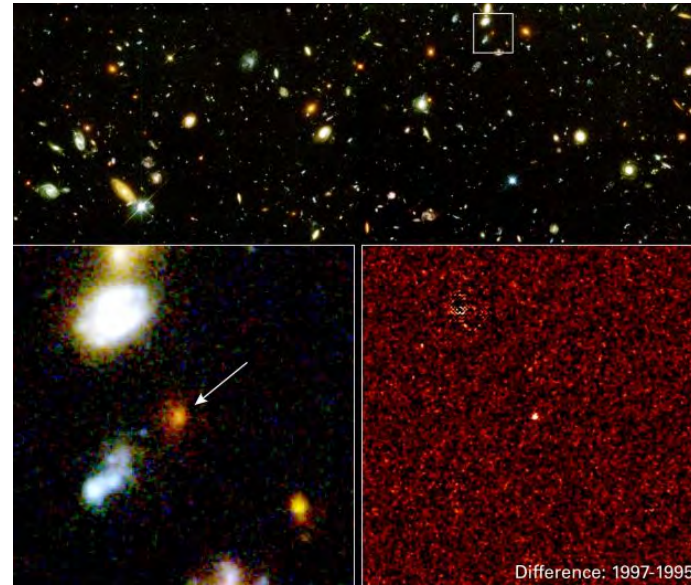


High Density, closed  
—————> Very special density, flat  
Low density, open

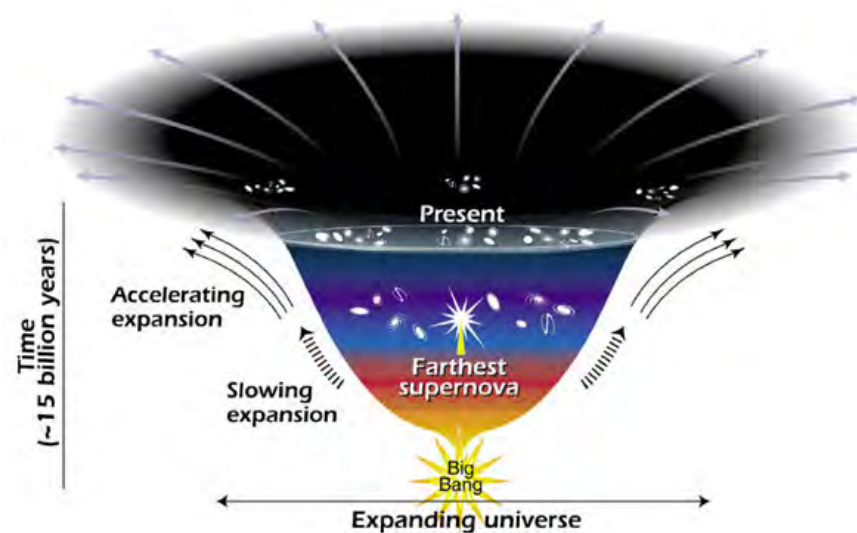
More subtle techniques than making parallel lines or drawing triangles, but still amounts to “doing 3D geometry.”

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

⇒ Further away than expected for a “normal” gravitating Universe

How do you get further away at a given current velocity?

⇒ Universe has been *accelerating*!! (and it is somewhat older than a coasting Universe would have been)

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.

=> 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.

***Dark Energy 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!

And why this discovery was awarded the Nobel Prize for Physics in October 2011.



Saul Perlmutter  
UC Berkeley



Brian Schmidt  
Mt. Stromlo  
Observatory,  
Canberra, Australia



Adam Riess  
Johns Hopkins  
University



## One Minute Exam

The type of supernova used to discover the acceleration of the Universe was

 Type Ia

 Type Ib

 Type Ic

 Type II

## One Minute Exam

Dark Matter is responsible for



The acceleration of the Universe



The dark space between stars and galaxies



The clumping of matter to form stars and galaxies



The Dark Ages after the initial Big Bang

## One Minute Exam

Dark Energy is responsible for



The acceleration of the Universe



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The clumping of matter to form stars and galaxies



The Dark Ages after the initial Big Bang

Goal:

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



Add up all the normal matter (not much, about 4%), Dark Matter (about 23%) and the mass equivalent of the Dark Energy ( $E = mc^2$ , about 73%) and find the Universe has just the very special density to be flat!

***The Universe is Flat (in 3D) 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.

Just as a table top is composed of atoms and molecules on small scales, but is flat for all practical purposes when we sit down to eat.

***The best current guess is that our real 3D Universe is essentially 3D flat - but accelerating!***

# *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  $\times 10^{120}$ . 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???*