Friday, November 22, 2013

Reading: Chapter 12 – all

Astronomy in the news?

IceCube, giant array of phototubes buried in the clear ice of Antarctica, has detected 28 very high energy neutrinos (of maybe 30 million that have passed through the detector), the first from beyond the Solar System since SN 1987A. The few neutrinos are named after Sesame Street characters, Bert, Ernie, …

Historical note: 50^{th} Anniversary of the death of President Kennedy.

Goal:

To understand the origin, shape, and fate of the whole Universe and how Type Ia supernovae have helped to revolutionize that understanding.

One Minute Exam

Einstein says that more distant galaxies move away from us more rapidly because:

➡ The Earth is in the center of the Universe.

⬅ The Universe blew up in the Big Bang like a bomb blowing up in three-dimensional space.

⬆ Our 3D Universe expands into a 4D hyperspace.

⬇ Space expands, carrying all distant galaxies further apart from one another.

Age and Fate of the Universe

All distances between distant galaxies are proportional to the time elapsed; distance = velocity x time.

Distance divided by the Velocity from the Doppler red shift

$\Rightarrow$ Age of Universe ~13.8 billion years

Fate of the Universe is intimately tied to the shape (we thought!)

Simplest choices:

finite age, re-collapse (***closed***, "sphere," **high density**, high gravity)
expand forever, v > 0 (***open***, "Pringle," **low density**, low gravity)
Special Case: expand forever, v → 0 as reach infinity (***flat***, **very special density** and gravity)

In principle, we can figure out the shape and fate of our Universe by doing 3-D geometry in our 3-D Universe, in practice we often try to measure the density of the matter.

Goal:

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

Dark Matter

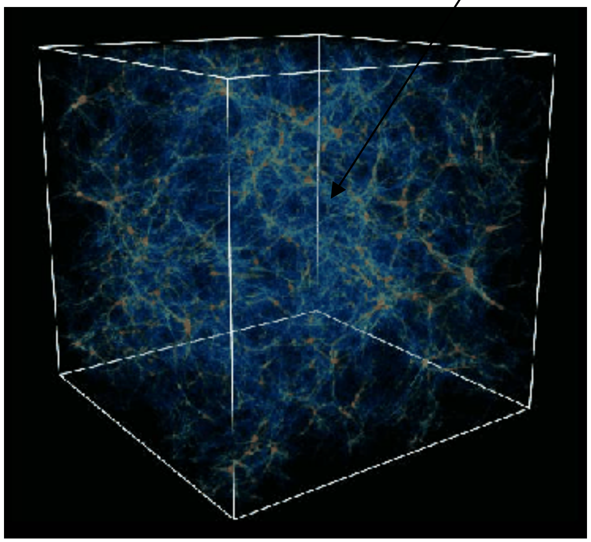
Previously known surprising result:
Most ***gravitating*** matter in the Universe is mysterious ***Dark Matter***

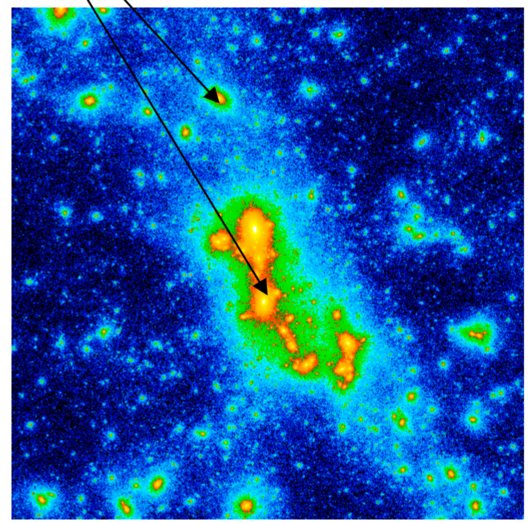
Not composed of p, n, e - the stuff of stars, galaxies, planets, and people

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:
5 × more total density and 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
$\Rightarrow$ 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

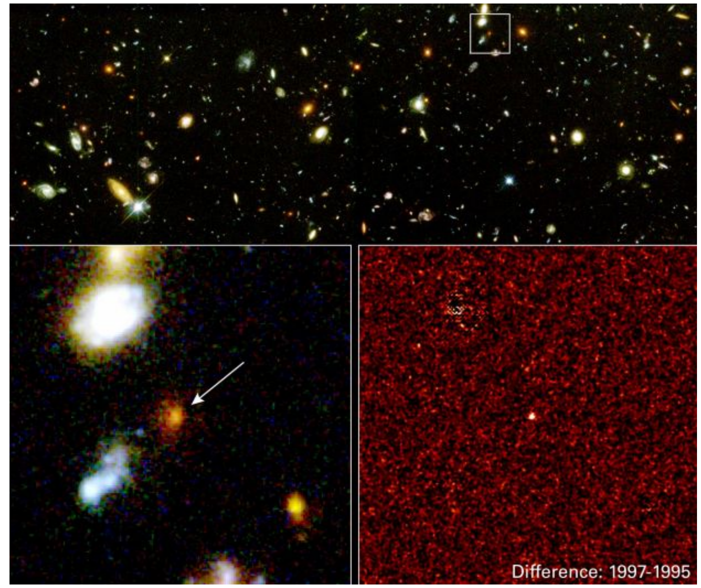
High Density, closed

Very special density, flat

Low density, open

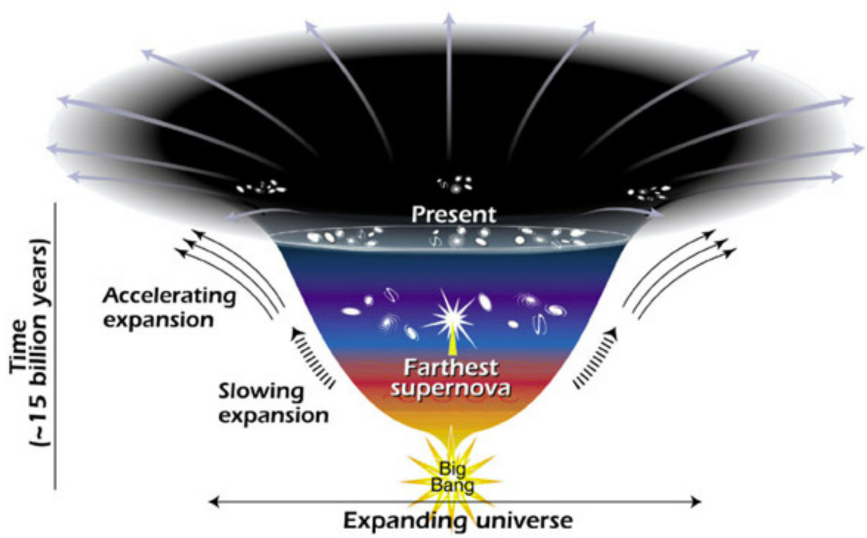
More subtle techniques than making parallel lines or drawing triangles, but still amounts to "doing 3D geometry."

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.

$\Rightarrow$ 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.

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

⬅ The dark space between stars and galaxies

⬆ 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 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???***