Tuesday, December 1, 2009
Fourth Exam, Thursday; Review Sheet Posted, **No Final**
Review Session Wednesday, 5:00 PM, **RLM 15.216B (NOTE ROOM)**
Final Sky Watch, IYA reports due on Sunday, December 6 **in Wheeler's office, RLM 17.230** (Other Worlds Exhibit at HRC for IYA)

Course Evaluation Online - please do that. The TA's and I pay close attention to comments.

Informal office hours for Wheeler - Wednesday, 1 - 2 PM

Astronomy in the News: Space Shuttle and the Russian Cosmos returned from the International Space Station.

Pic of the day - Veil nebula, part of the expanding rim of the Cygnus loop, the remnant of the explosion of a massive star 7500 years previously

Reading for Fourth Exam:

Chapter 10, Sections 10.1-10.6, **10.9**-10.10
Chapter 11, Sections 11.1-11.5, **11.8**
Chapter 12, all

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.

Dark Matter

Previously known surprising result:

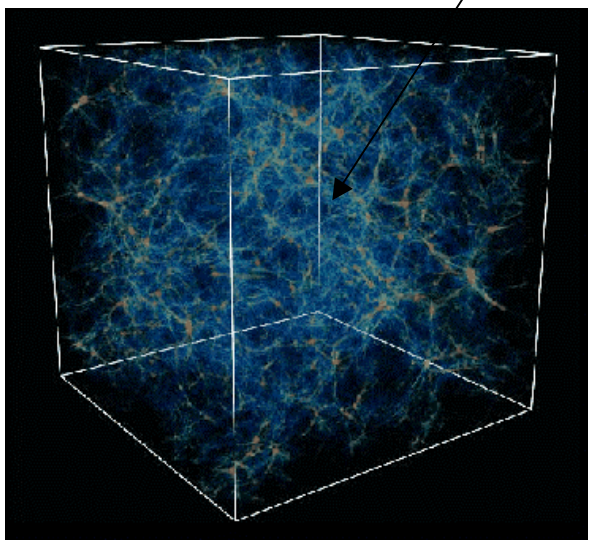
Most ***gravitating*** matter in the Universe is mysterious ***Dark Matter***

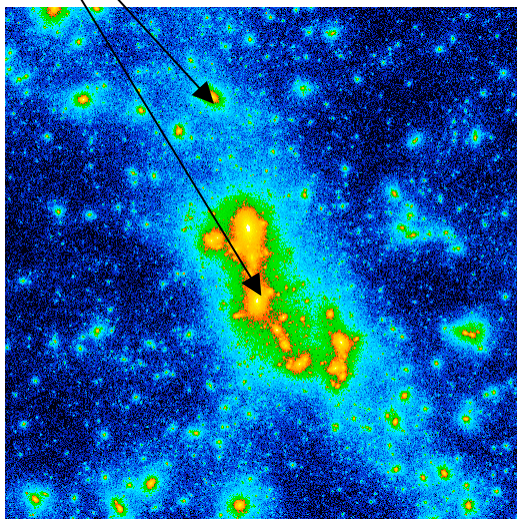
Not composed of p, n, e - the stuff of stars, galaxies, planets, and people

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.

Density of Dark Matter is not enough to close the Universe
$\Rightarrow$ Universe is "open?" (3D Pringle).

Nature threw us a curve ball

SN were the key!

Use Type Ia supernovae (brightest, ~ uniform behavior)

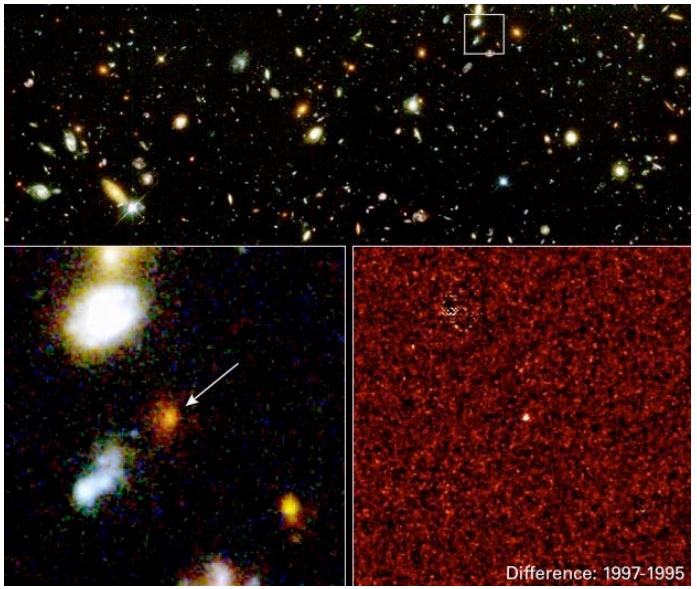
Carefully map ***distances*** (dimmer appearance means further away), ***velocities*** (Doppler red shifts) in all directions

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

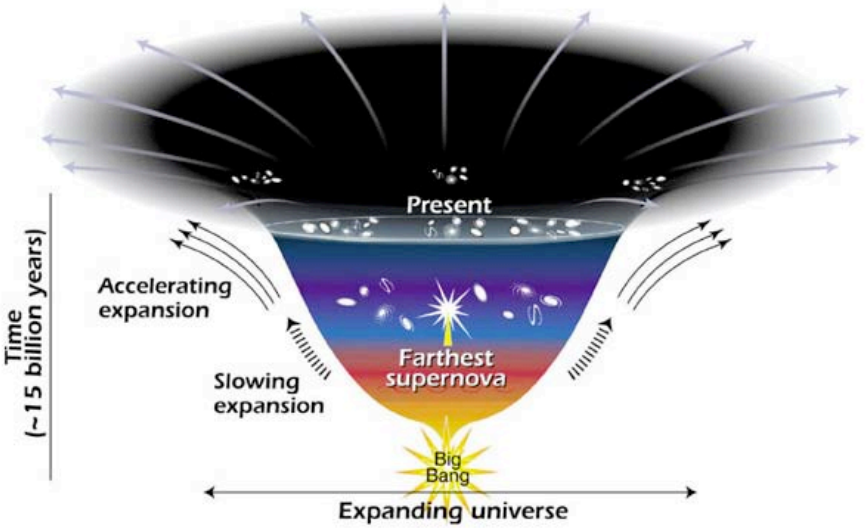
More subtle techniques than making parallel lines or drawing triangles, but still amounts to “doing 3D geometry.”

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 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 in a given time?

⇒ 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.

⇒ 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!

Add up all the normal matter (not much), Dark Matter and the mass equivalent of the Dark Energy ($E = mc^2$) 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.

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

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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,"
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???***

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.

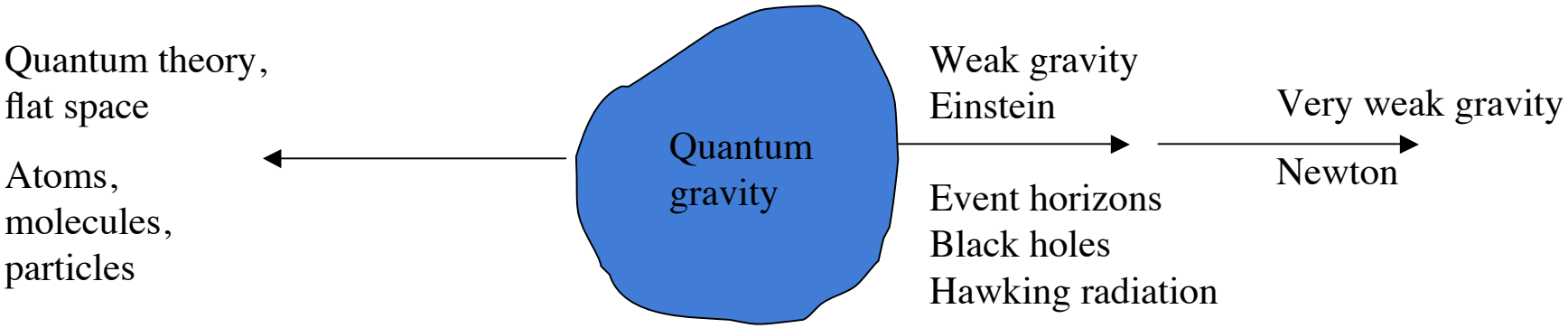
The result would be an empty Universe filled with dilute radiation.

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***.

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.



The world of the small

The world of the large

Need quantum gravity theory of singularity, quantum foam, worm holes and Dark Energy

The best current candidate for a theory of Quantum Gravity is String Theory

See Brian Green - The Elegant Universe

(http://www.pbs.org/wgbh/nova/elegant/)

Read ***The Universe on a String*** editorial by Brian Green posted under links -> string theory (for fun, not for class!)

Hyperspace is an intrinsic aspect of string theory - 10 dimensions of space, plus time.

Take Away Message:

Hyperspace might be real…

Stay tuned!

(and remember to keep an eye on Betelgeuse!)