4/25/05 Exam 4, Friday

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

Review sheet posted today, Wheeler available as much as possible.

Review, Thursday, 5:00 PM RLM 15.216B

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

News:

Pic of the day: Eagle Nebula





Chapter 11 Our Expanding Universe

Expanding Universe - we observe all distant galaxies (so far away we cannot sense their individual gravity) moving away from us with speed proportional to distance: as if we were in the center of an explosion.

Our Universe is not a bomb in pre-existing empty 3-D space!

Lesson from Einstein - *space itself can expand carrying the* (almost motionless) *galaxies*

All distant galaxies move away from all other distant galaxies. No galaxy, certainly not us, is in the center.

The result: speed proportional to distance

Our Expanding Universe

Expanding *surface* of a balloon as an example

2D embedding diagram of 3D expanding Universe

No 2D center, no 2D edge, no 2D outside

There is a 3D center, a 3D edge, a 3D outside, in 3D hyperspace

All 3D space expands - carrying essentially motionless matter (galaxies)

No 3D center, no 3D edge, no 3D outside

As 3D astronomers, we don't have to ask what the Universe is expanding into, but if anything it is a 4 (or more) D hyperspace, just as a 2D balloon expands into 3D hyperspace.

Infinite flat rubber sheet could expand without expanding into any hyperspace (2D embedding diagram example).

Einstein's theory says that for a Universe that is the same, on average, everywhere, there are only three basic shapes it can have The 3D analog of a spherical surface - *Closed Universe* The 3D analog of a "saddle" or "Pringle" shape - *Open Universe* The 3D analog of a flat plane - *Flat Universe*

The 2D embedding diagrams of these 3D Universes are, respectively, a sphere, an infinite saddle or Pringle, and an infinite flat plane.

A closed universe is finite in space and time, the other two are infinite in space and time, but all must have started 14 billion years ago in the Big Bang.







Age and Fate of the Universe

All distances between distant galaxies are proportional to the time elapsed. Distance plus Velocity from the Doppler red shift ⇒ Age of Universe ~14 billion years

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

Simplest choices:finite age, recollapse ("sphere," high density, high
gravity)expand forever, v > 0 (Pringle, low density, low
gravity)Special Case: expand forever, $v \rightarrow 0$ as reach
infinity (flat, very special density, gravity)

In principle, we can figure out the shape and fate of our Universe by doing 3-D geometry in our 3-D 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:100 × more total mass than normal stuff stars, gas, etc.



Computer simulations show that from the tiniest wrinkles the Dark Matter agglomerates to form all the *Large Scale Structure* of the Universe

Ordinary matter, protons, electrons, settle to center of Dark Matter lumps to form galaxies and clusters of galaxies

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