

Thursday, April 23, 2009

Fourth, and last, noncumulative exam on Thursday, May 7.  
Remainder of book. No Final.

Astronomy in the News -

Pic of the day - bubble blown by  
wind from massive star



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 13.7 billion years ago in the Big Bang.

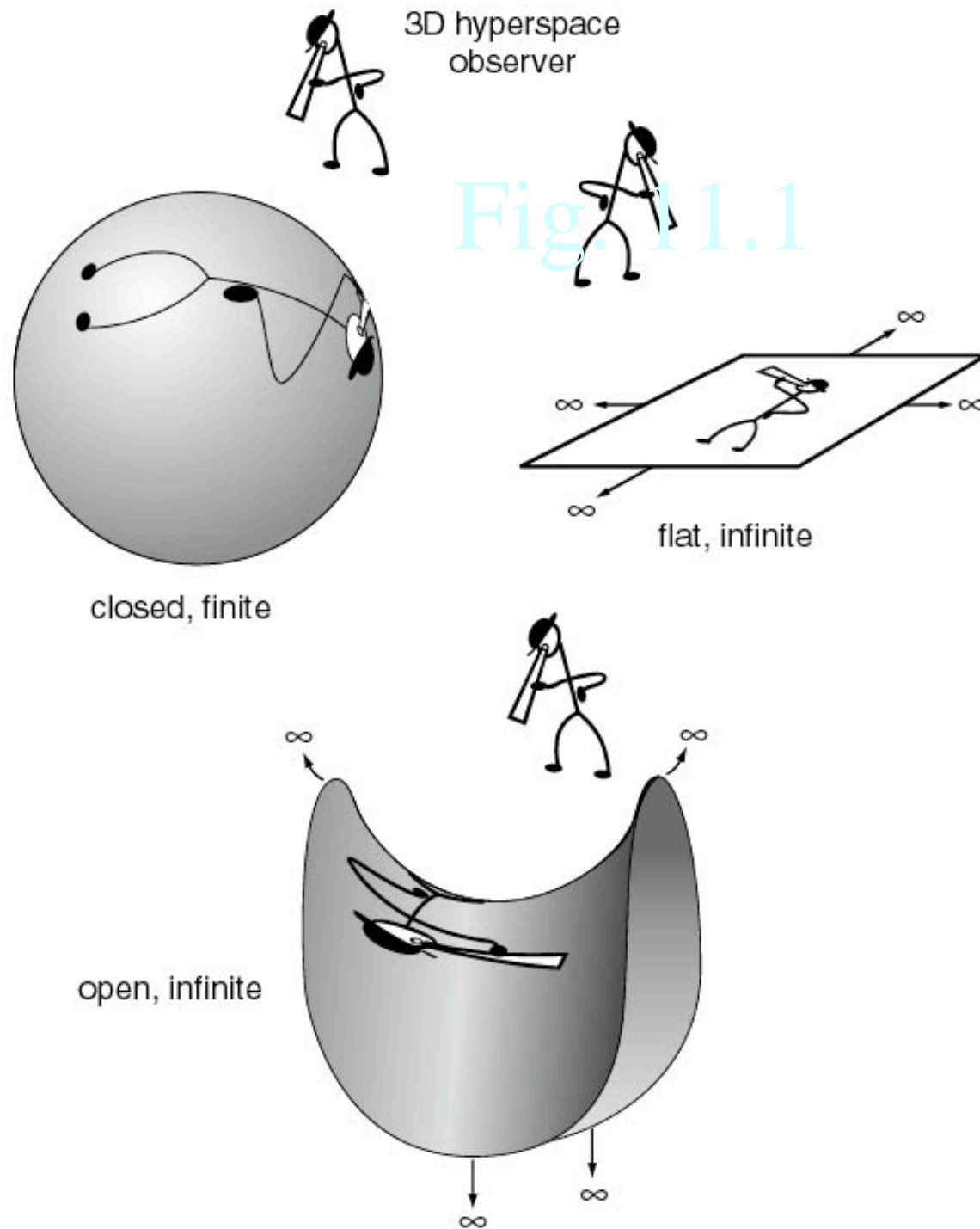


Fig. 11.1

2D  
embedding  
diagrams of  
possible  
shapes of our  
3D Universe

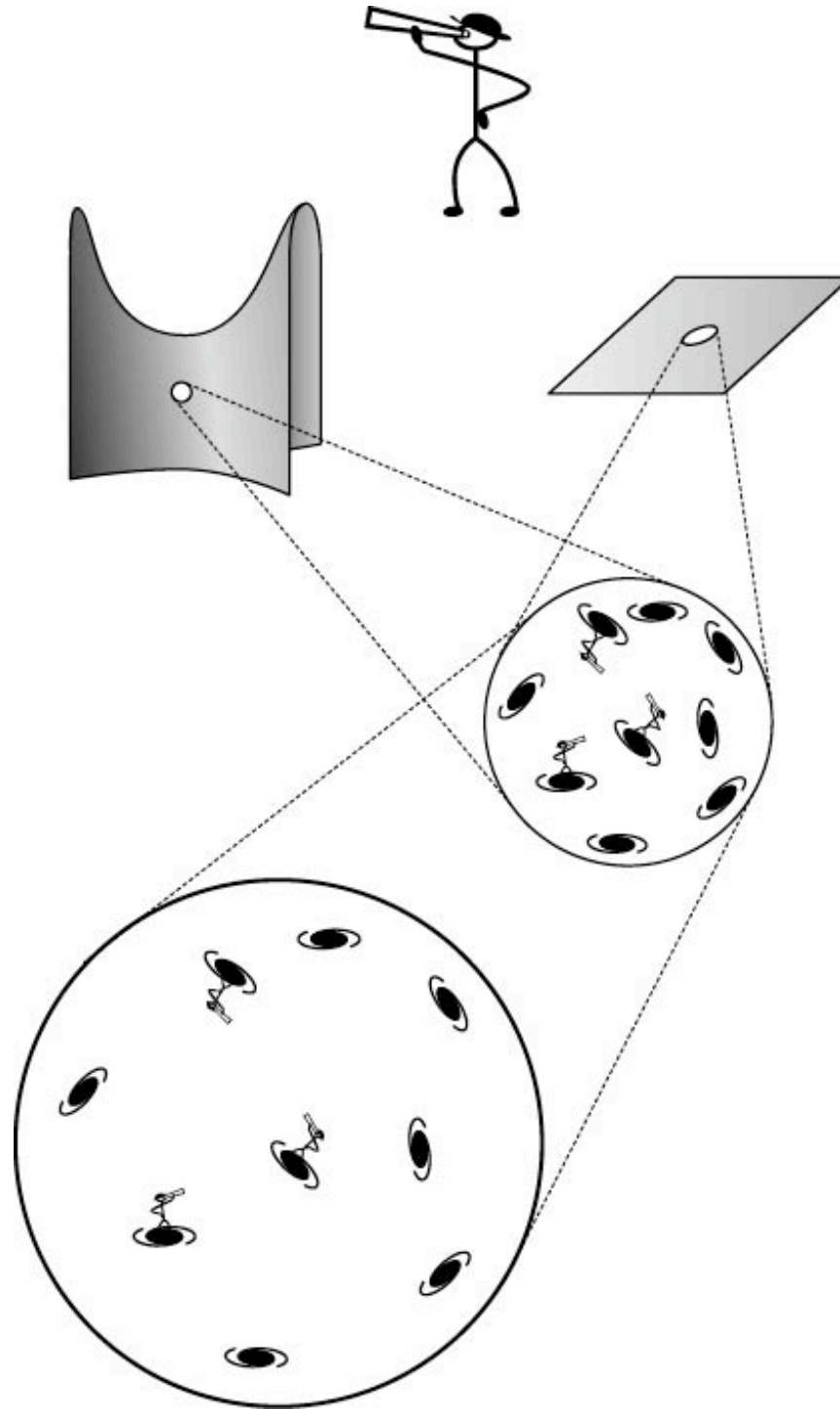


Fig 11.2

A patch of the space in a universe expands, drawing all galaxies away from all others, independent of the overall shape of the curvature of the universe.

# Age and Fate of the Universe

All distances between distant galaxies are proportional to the time elapsed. Distance divided by the Velocity from the Doppler red shift  $\Rightarrow$  Age of Universe  $\sim 13.7$  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,  $v \rightarrow 0$  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.*

## One Minute Exam:

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

- A) The Earth is in the center of the Universe.
- B) The Universe blew up in the Big Bang like a bomb blowing up in three-dimensional space.
- C) Our 3D Universe expands into a 4D hyperspace.
- D) 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*

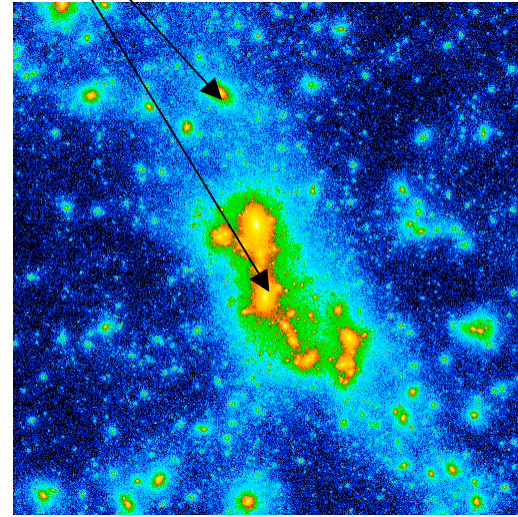
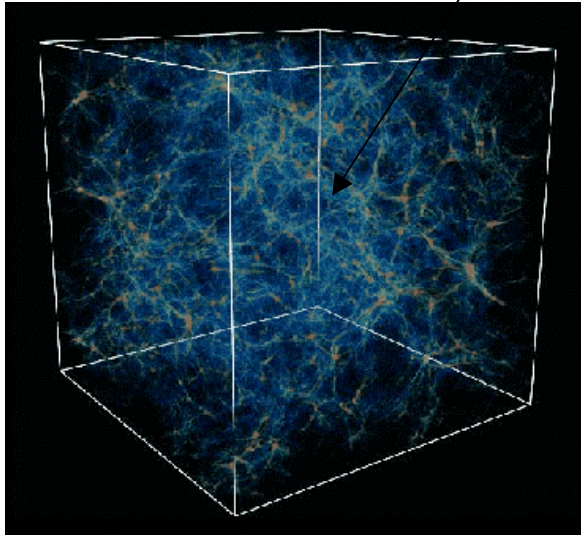
Not composed of p, n, e - the stuff of stars, galaxies, planets, and people

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  
⇒ Universe is “open?” (3D Pringle).



Nature threw us a curve ball

SN were the key!

Use Type Ia supernovae (brightest,  $\sim$  uniform behavior)

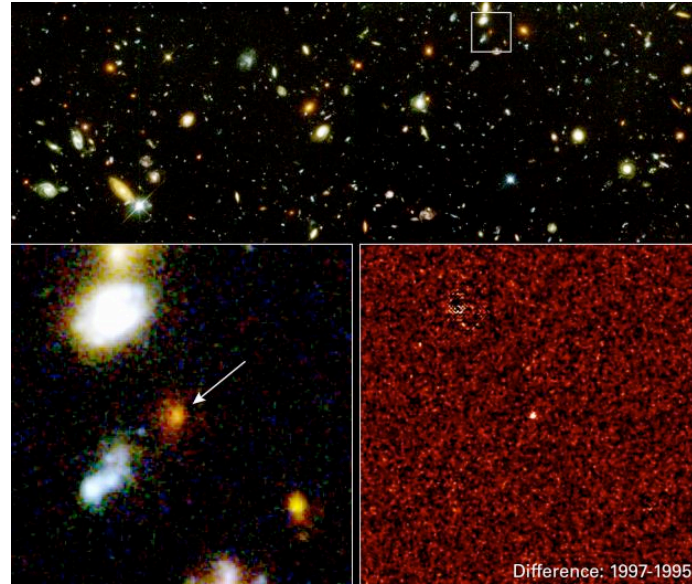
Carefully map *distances* (dimmer appearance means further away), *velocities* (Doppler red shifts) in all directions

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

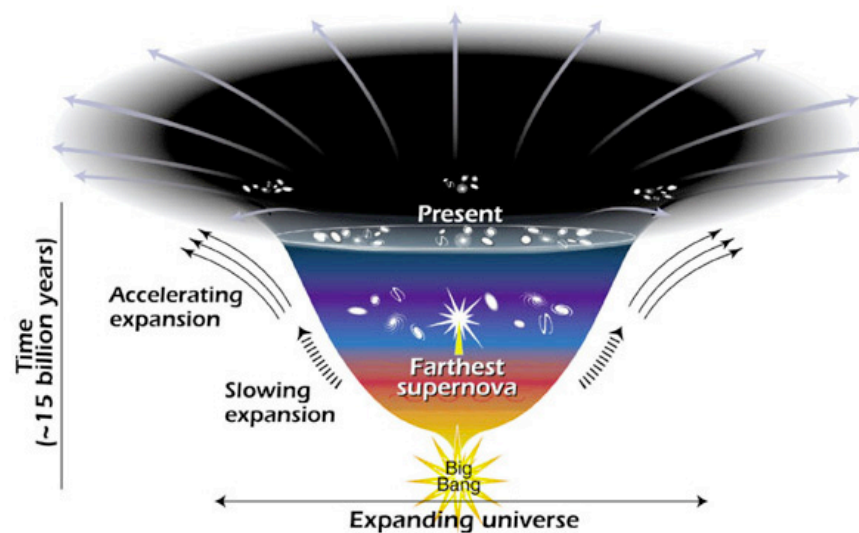
More subtle techniques than making parallel lines or drawing triangles, but still amounts to “doing 3D geometry.”

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.