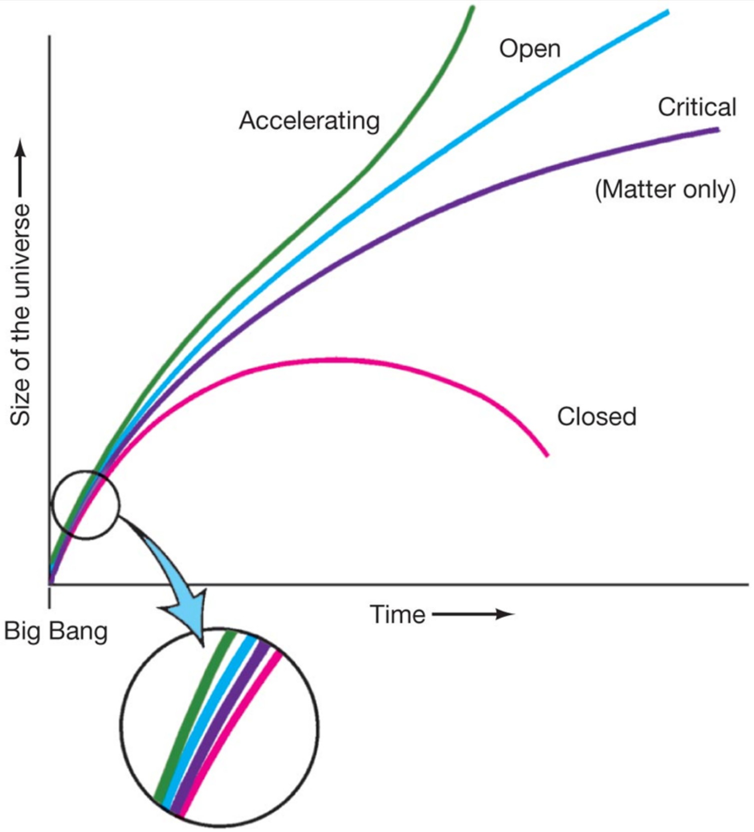
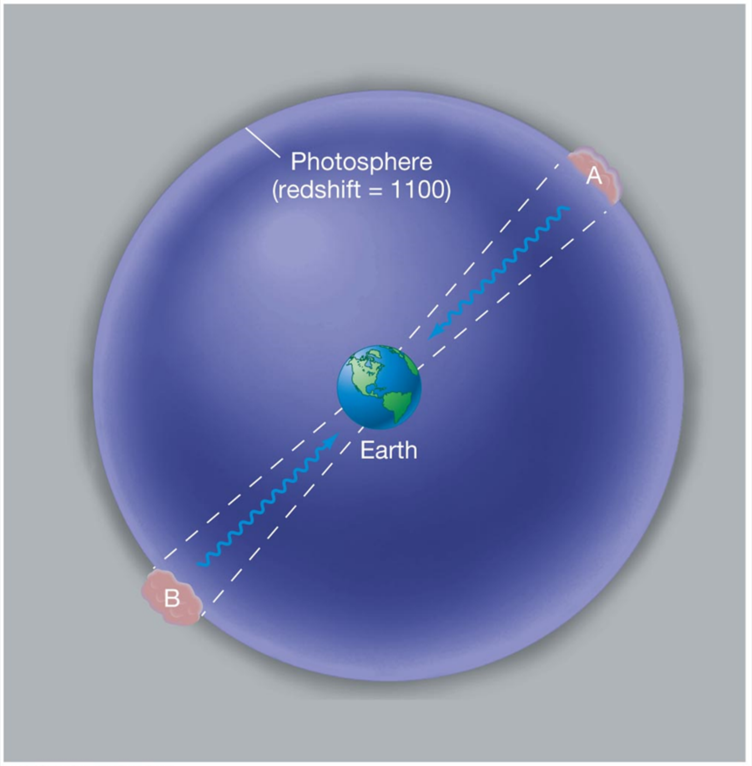
GEOMETRICAL PROBLEMS

- Two problems with the Big Bang are:
- (1) The Flatness Problem
  - The universe is very close to flat
  - If it was a little bit different from flat early on, things wouldn't have lasted this long
- Why should it be so very close to perfectly balanced?
  - More than 1 part in 10^{15} wipes out, does not stay balanced



(2) THE HORIZON PROBLEM

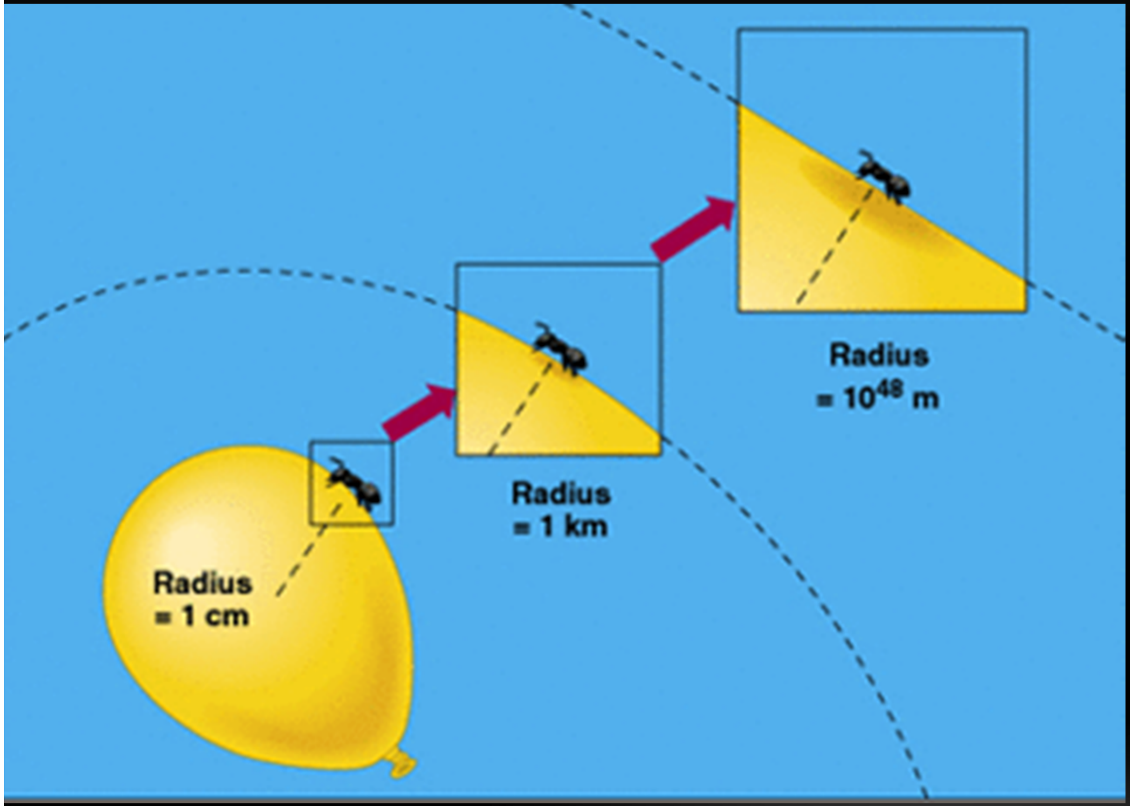
- The CMB is very uniform
  - This means that the glowing stuff was all about the same temperature
  - This will happen via normal heat conduction, radiation
- But, at short times, how could the light travel far enough to equalize the temperature on both sides of the sky?



INFLATION

- A way around these problems is called “Inflation”
  - Very early on, the universe expanded extremely rapidly (then slowed down to the “leisurely” pace of today)
  - From 10^{-35} to 10^{-32} seconds, the universe grew by a factor of 10^{50}
- Not as stupid as it sounds
  - people working on Grand Unified Theories have plausible reasons for this to happen
    - Energy released when strong force splits off

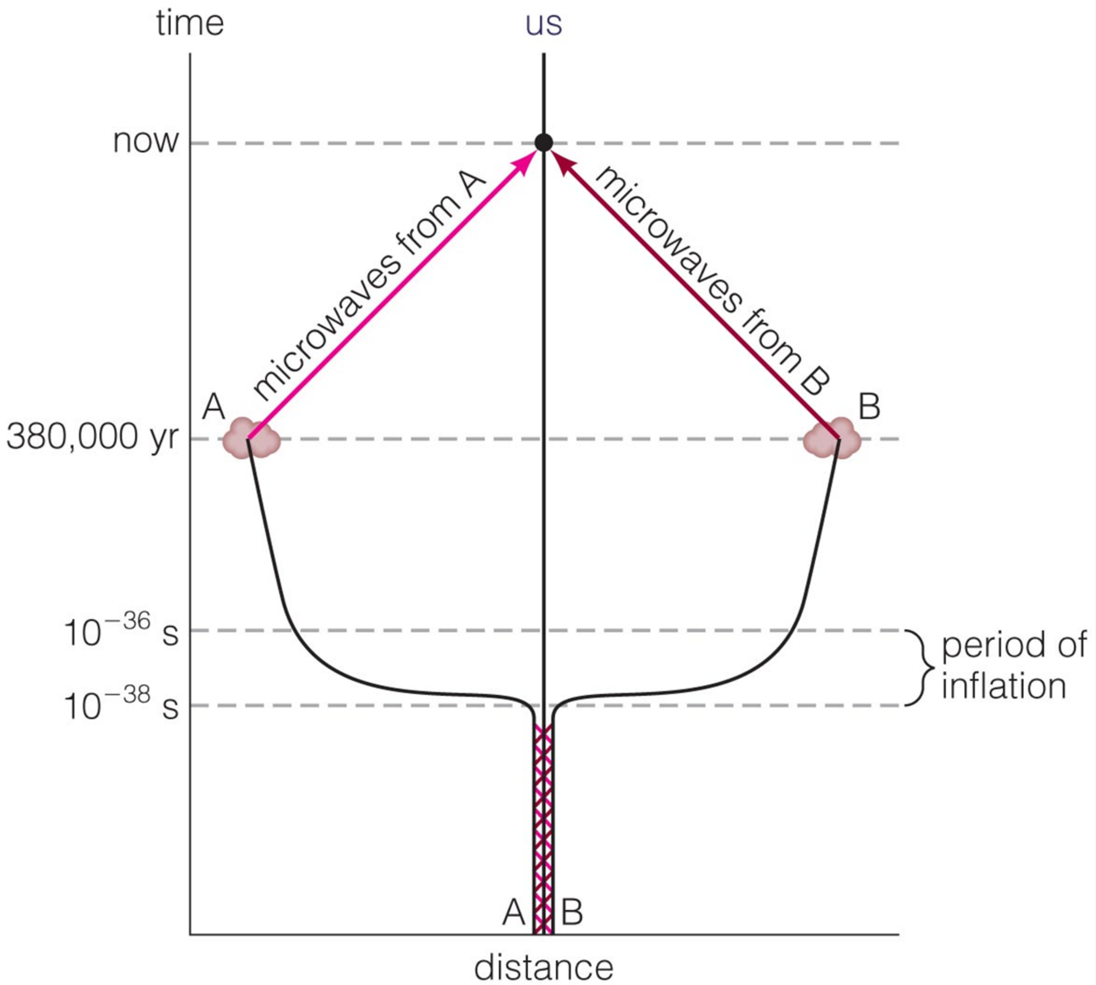
HOW DOES THIS HELP?



- Rapid expansion makes things appear more flat
  - Non-flat curvature "inflated away"

UNIFORM TEMPERATURE

- Regions now on opposite sides of the sky were close together before inflation pushed them far apart.
- So would be the same temperature to start off



LARGE SCALE STRUCTURE

- Does this also inflate away clumps of matter such that there are no lumps to form galaxies around?
- In fact, if things rapidly grew, then small quantum fluctuations in the early universe would be magnified and provide the lumps

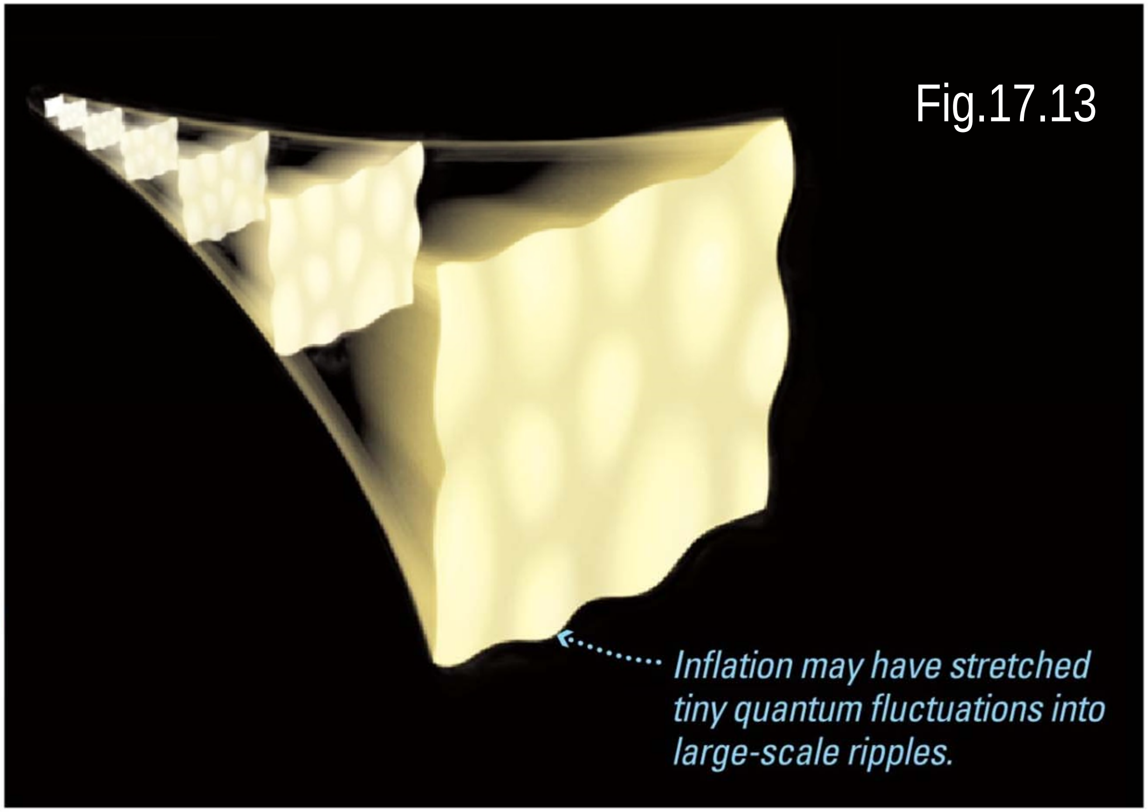
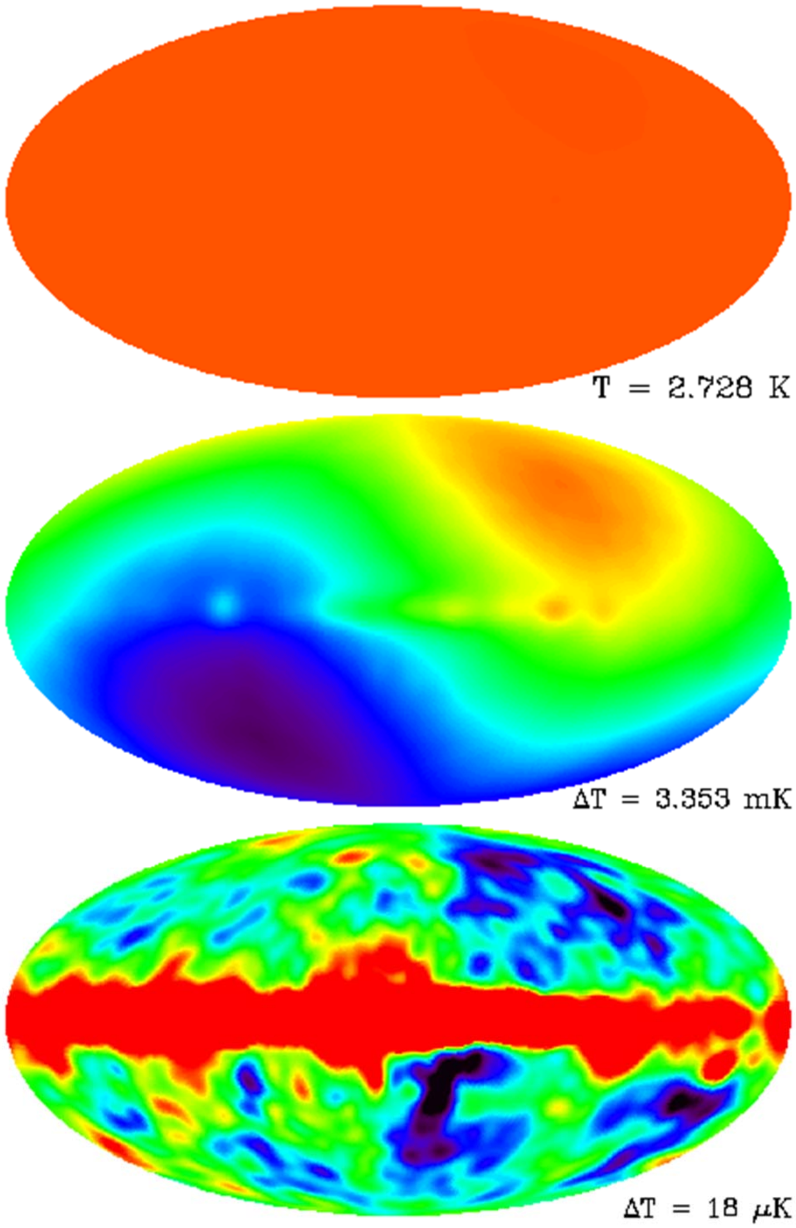


Fig.17.13

Inflation may have stretched tiny quantum fluctuations into large-scale ripples.

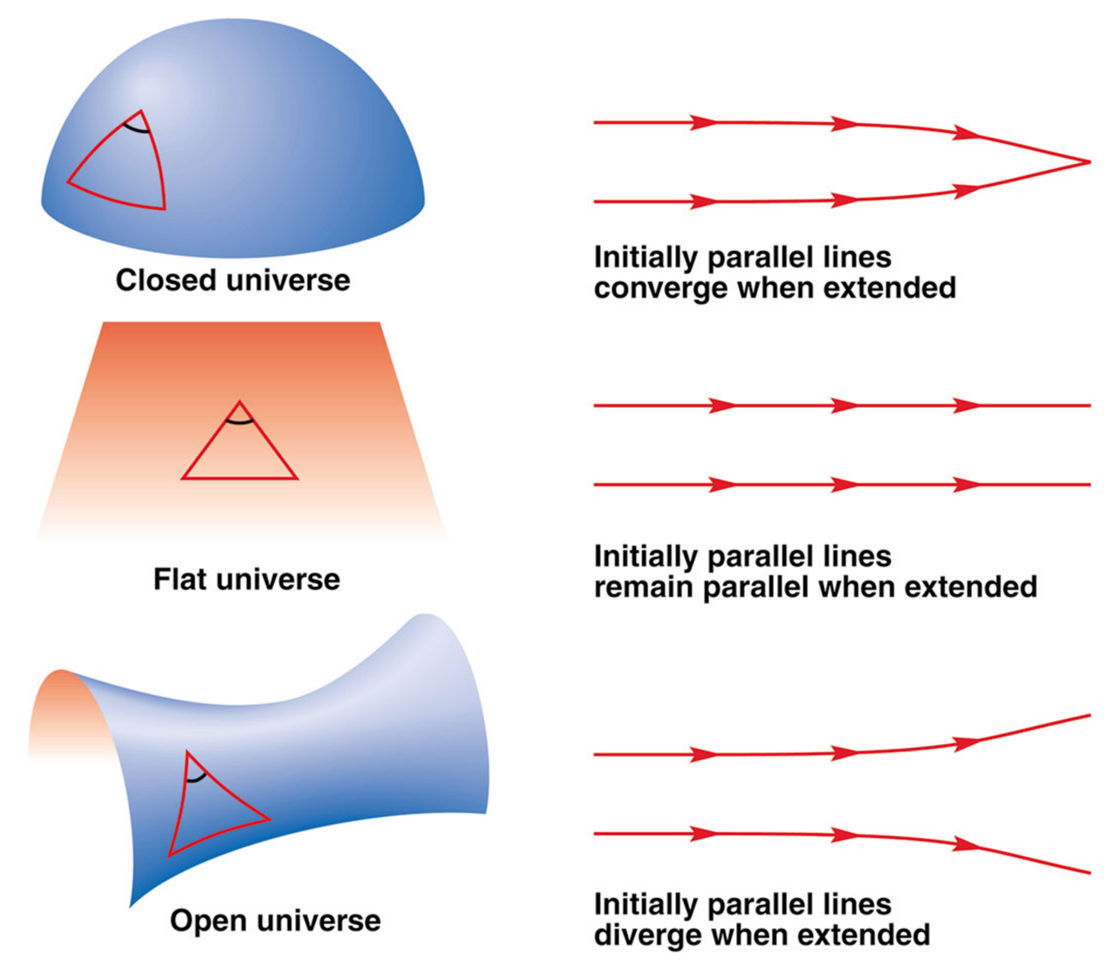
microsoft and apple not playing nicely together…



ANISOTROPIES

- We see these tiny fluctuations (COBE)
- Balloons and south-pole based antennae BOOMERANG, MAXIMA, and DASI have taken even more precise data
- WMAP satellite really cleaned things up
- Planck satellite doing even better right now

HOW DOES THIS HELP?

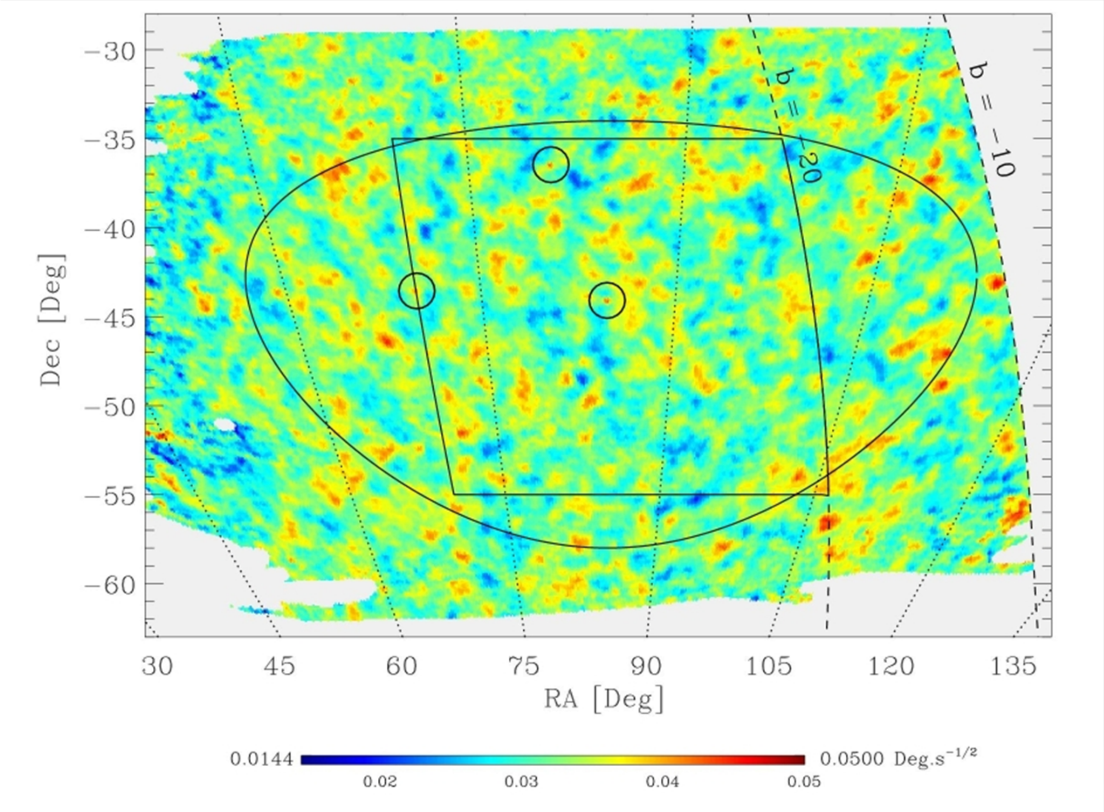


- Light and/or sound waves in the early universe would be influenced by the geometry
- Closed – spots magnified
- Open, spots shrunk
- Flat – spots should be about 1^{o} wide

GEOMETRY AND THE SPOTS

microsoft and apple not playing nicely together…

THE LUMPS

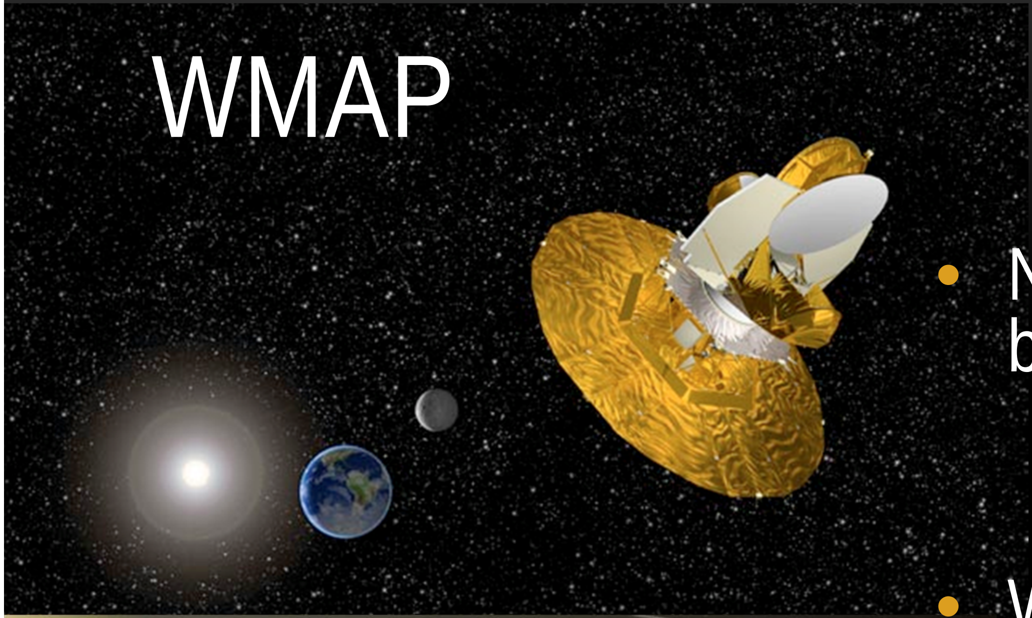


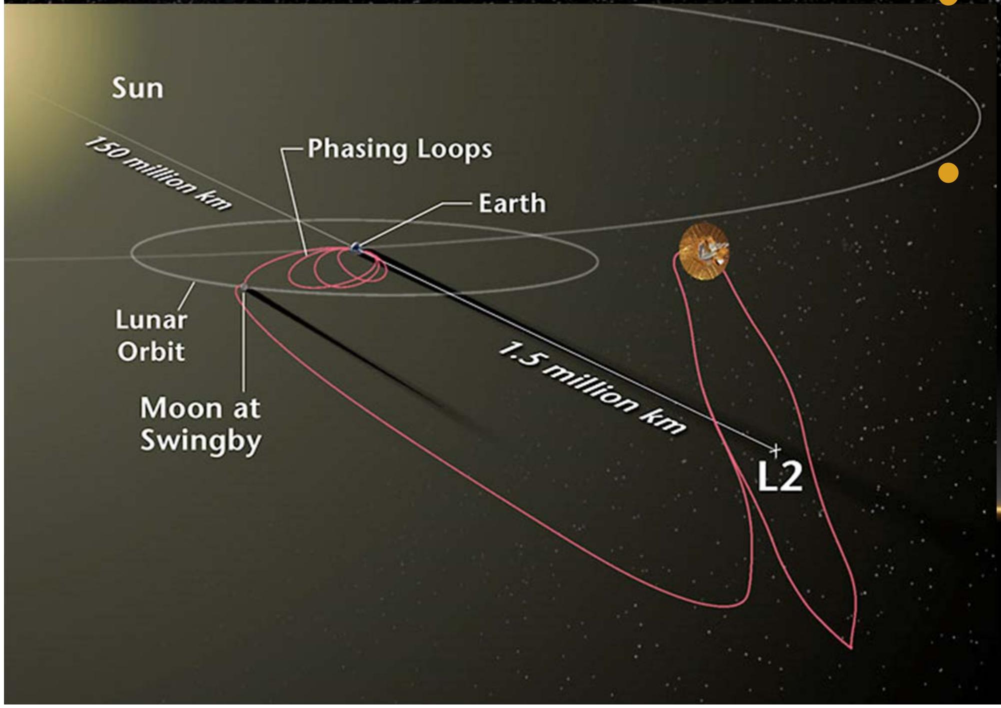
- BOOMERANG data shown at left
- Measure the angular sizes of the hot and cold spots

What are the spots?

microsoft and apple not playing nicely together…

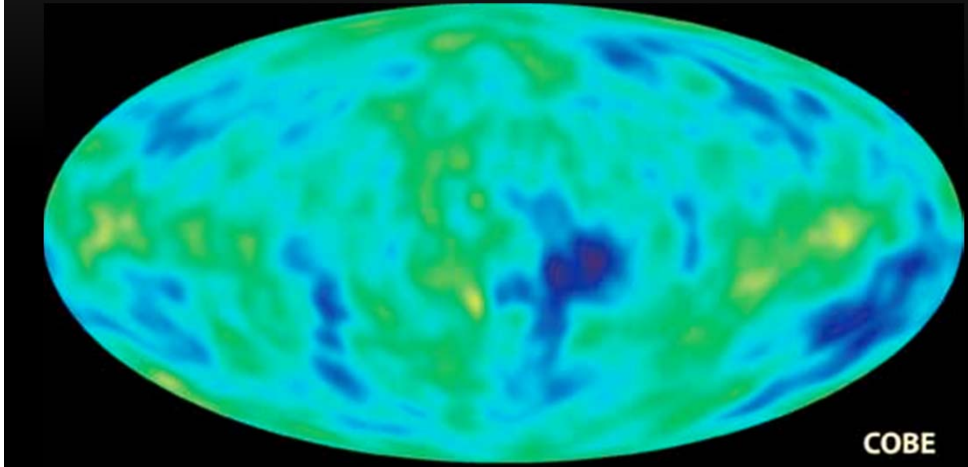
WMAP

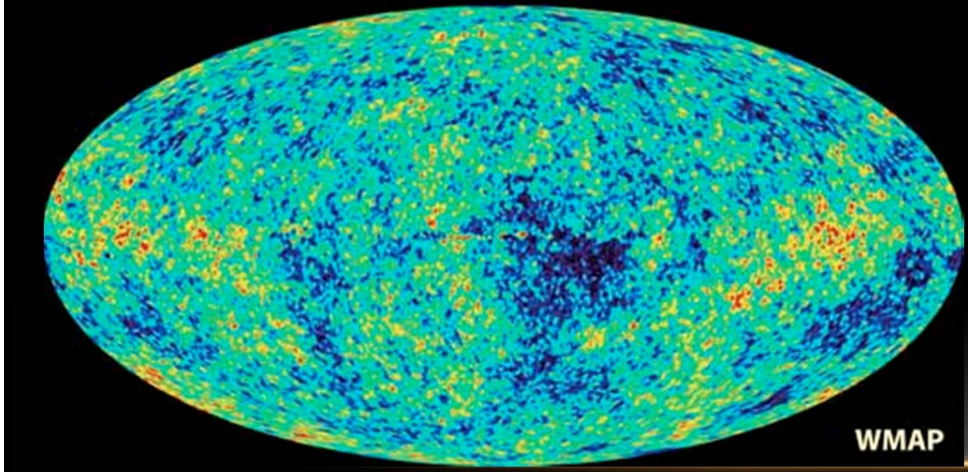




- Next satellite gives much better view
  - From “L2” point, 4x moon’s distance
- Wilkinson Microwave Anisotropy Probe
- Looks at same stuff in much better detail
  - Science often works this way

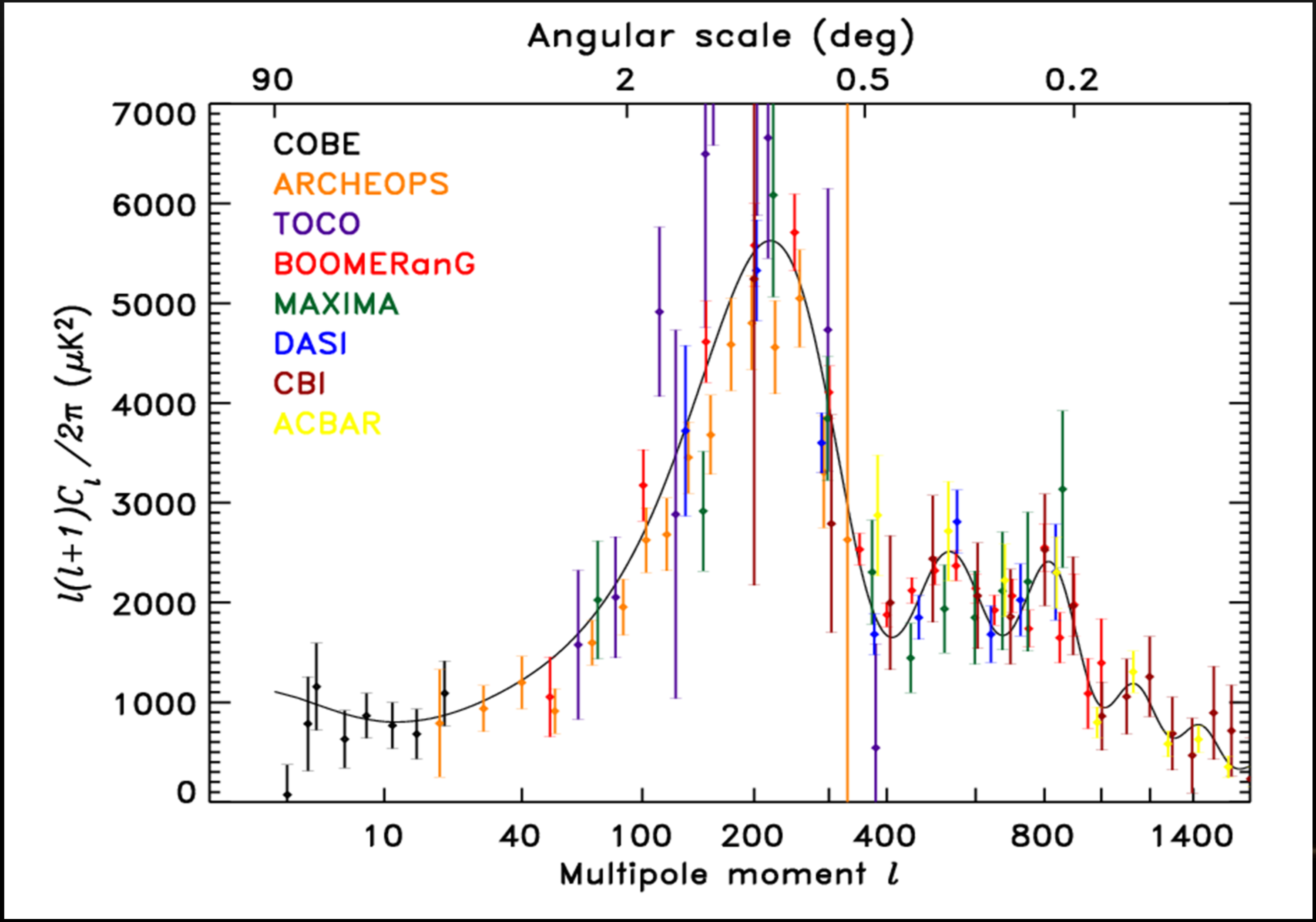
A MUCH MORE CLEAR BABY PICTURE





WMAP’s web site is full of great stuff, see class’ “links” page

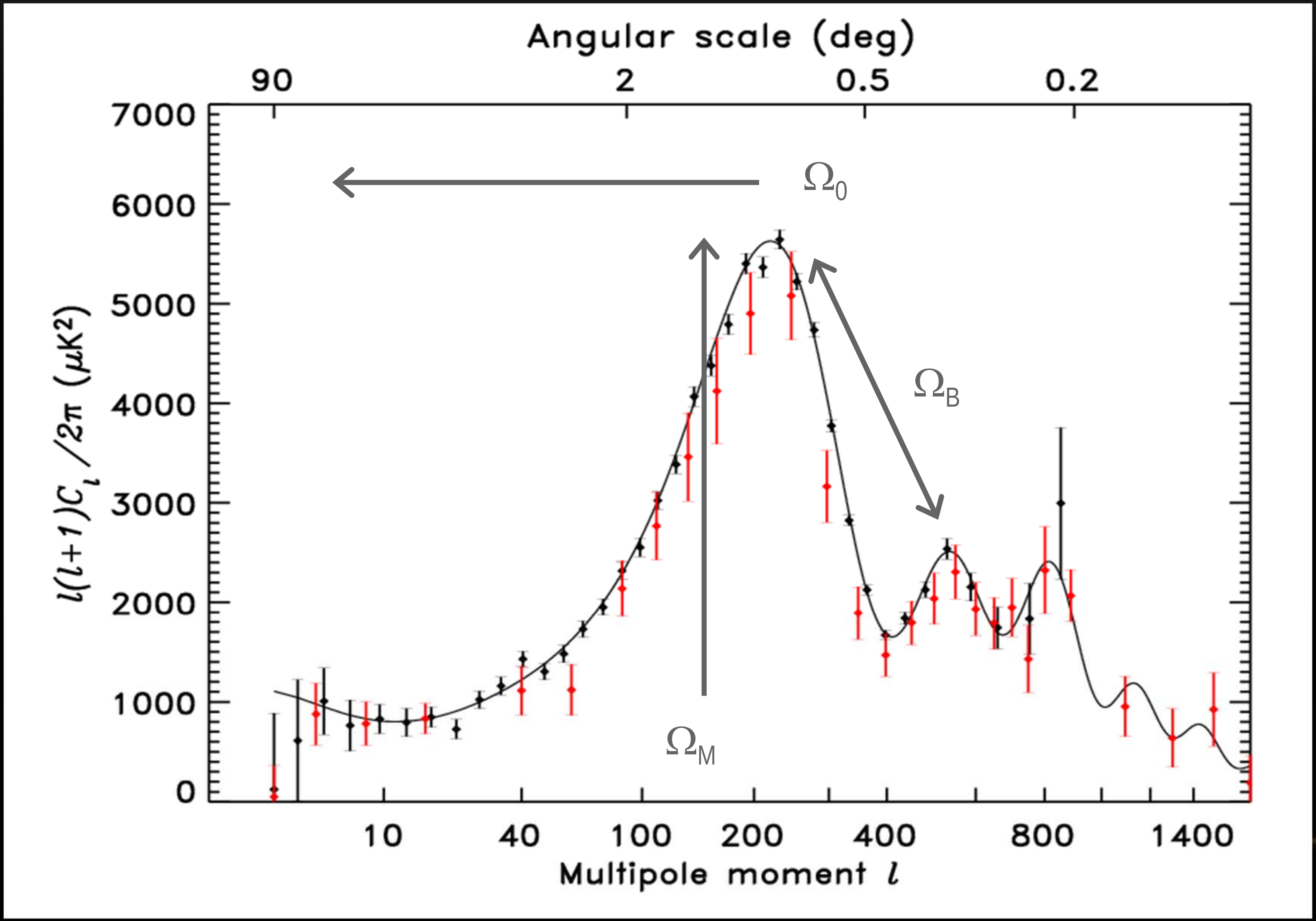
THE OLD DATA



Spot Sizes:

Black is WMAP Best fit

THE NEWER DATA



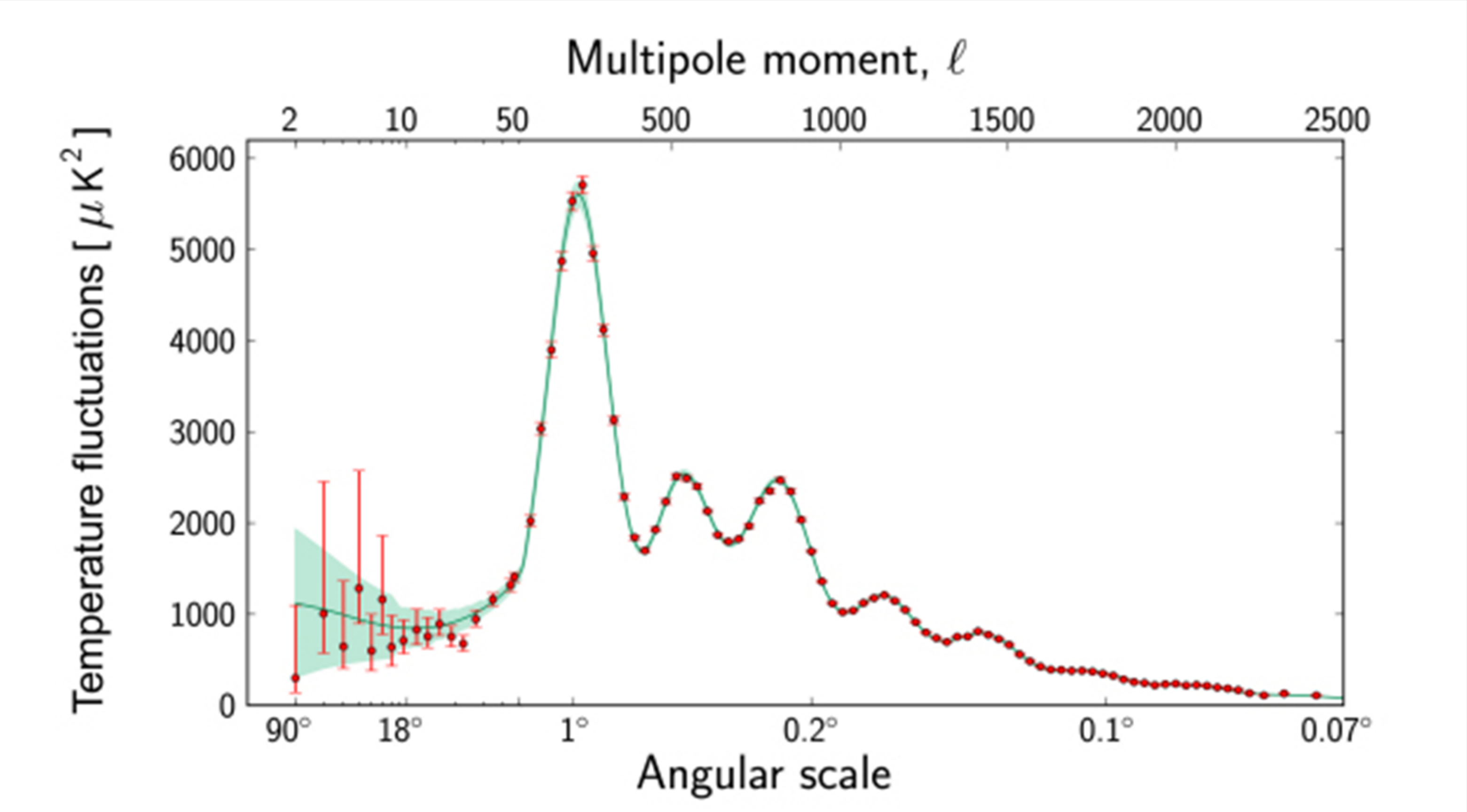
Line is best fit

Black are WMAP data

Red are all other data

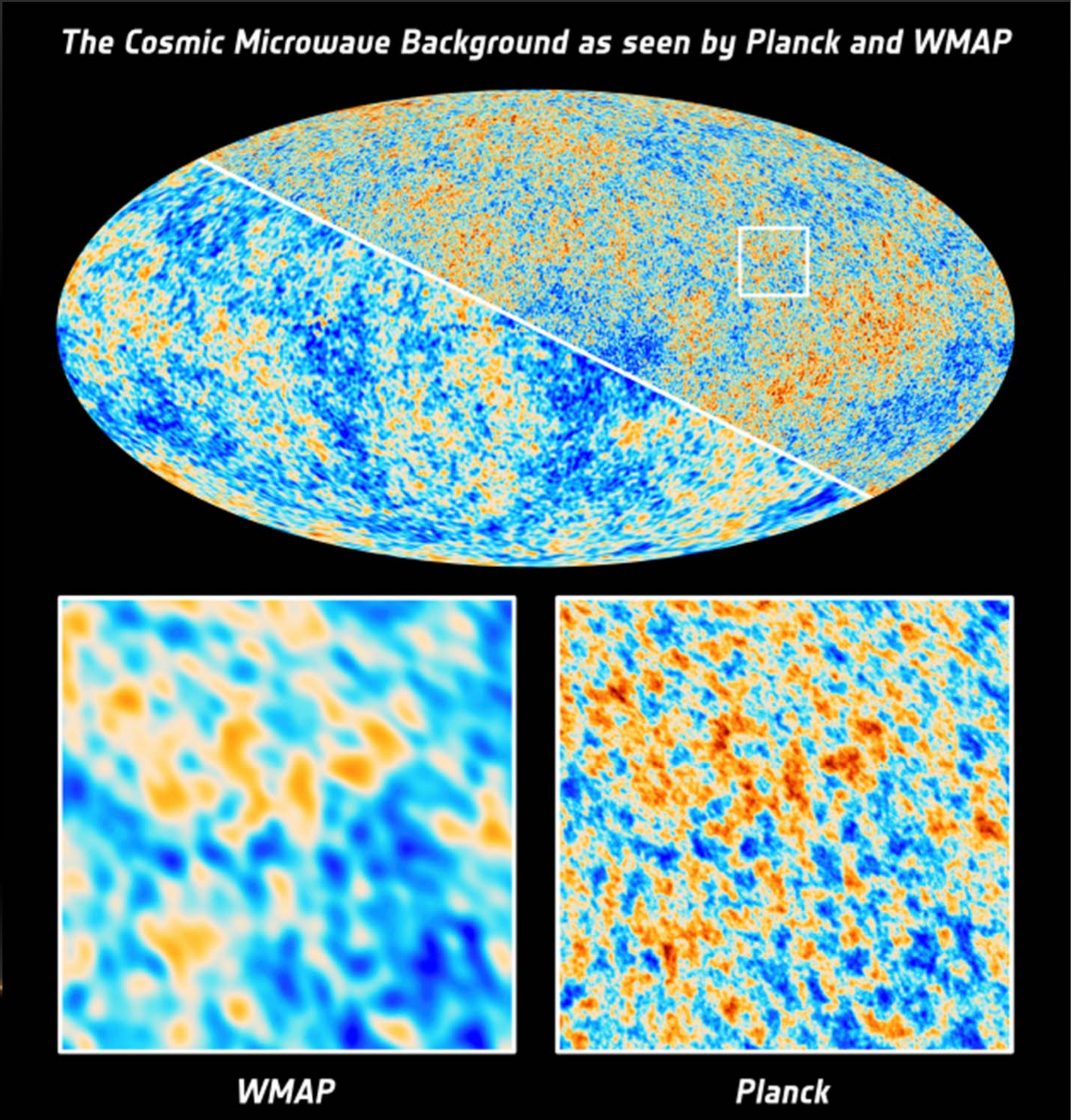
THE LATEST

- From Planck, as of 2013



THE LATEST STUFF

- The Planck satellite has recently measured everything even more precisely…



THE NUMBERS

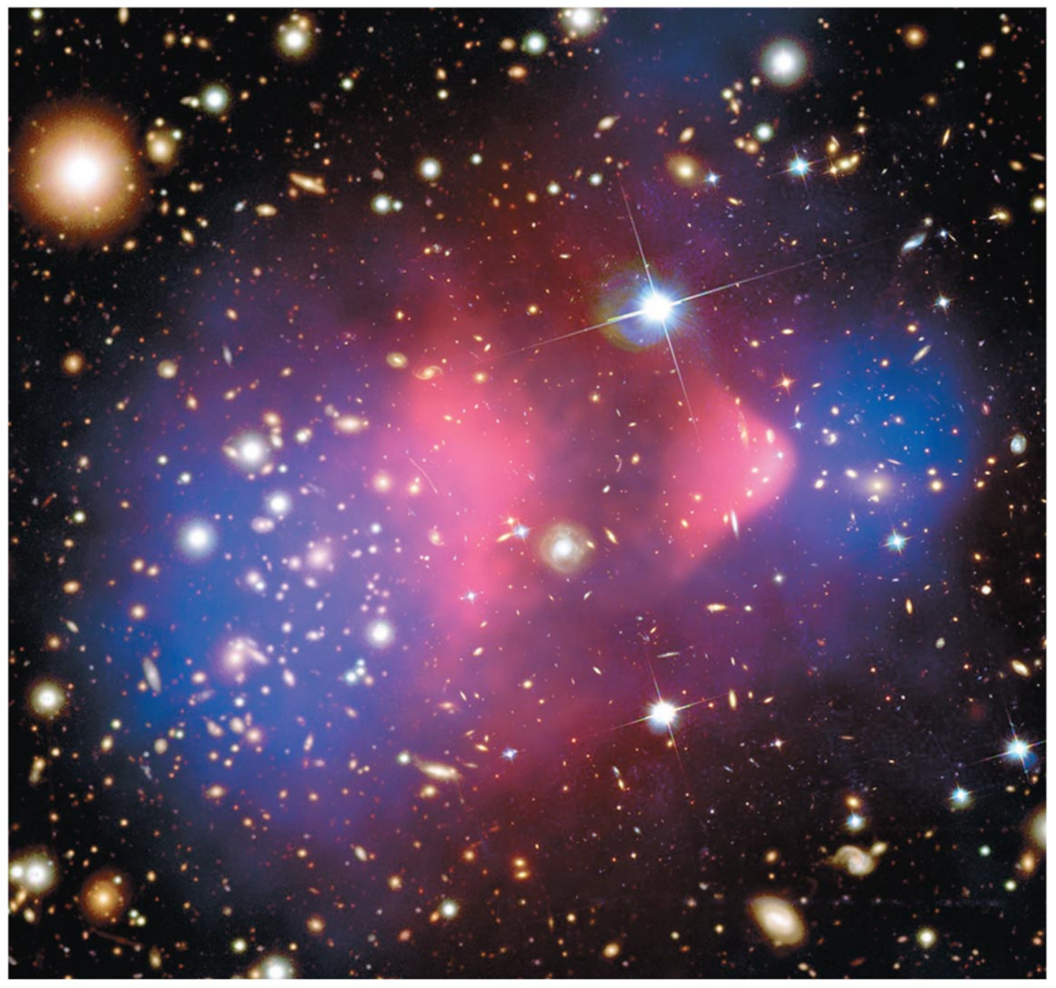
- 2015 WMAP numbers (which seem to agree with other measurements):
  - Age of universe $t_{0:}$ = 13.799±0.021 Gy
  - Masses: $\Omega_0 = 1.0000 \pm 0.0088$,
    $\Omega_m = 0.3089 \pm 0.062$, $\Omega_b = 0.04874 \pm 0.00031$,
    $\Omega_\nu \leq 0.0054$
  - Hubble constant $H_0 = 67.74 \pm 0.46$ km/s/Mpc
  - And many other numbers …

WAIT, THAT DOESN'T ADD UP…

- If total mass Ω_0=1.00 is 100% of what's needed to make the universe flat…
  - But Ω_m is the fraction of actual matter (30.89%), where's the rest?
- Ω_Λ=0.6911±0.0062
  - 69% of the stuff in the universe isn't even matter!
- Also note: if matter is 30.89% of the universe, but baryons (ordinary protons, neutrons etc) is only 4.874% of the total, what's the other 26.02% of the matter?

DARK MATTER, DARK ENERGY

- … and the Fate of the Universe



Ch.18

WHAT'S THAT?

- Sounds like Star Wars, but:
- *Dark matter:* An undetected form of mass that emits little or no light but whose existence we infer from its gravitational influence
- *Dark energy:* An unknown form of energy that seems to be the source of a repulsive force causing the expansion of the universe to accelerate

WHAT WE KNOW SO FAR

- Normal matter: ~ 5%
  - Normal matter inside stars: ~ 0.5%
  - Normal matter outside stars: ~ 4.5%
  - We've spent a whole semester on mostly that 0.5%! (*talked some about gas and dust etc too*)
- Dark matter: ~ 26%
- Dark energy: ~ 69%

THE OTHER 95%?

- What *is* it?
  - We don’t really know yet, so:
  - Dark matter is the name given to the unseen mass whose gravity governs the observed motions of stars and gas clouds.
  - Dark energy is the name given to whatever might be causing the expansion of the universe to accelerate.
- This chapter explains what we do know about it

DARK MATTER

- Luminous matter (Stars mostly) only makes up 0.5% of the total mass in the universe!
- Ordinary “Dark” Matter
  - Made of ordinary neutrons, protons, etc.
    - Ω_b where “b” is for “Baryon”
  - Gas, dusk, brown dwarfs
  - Together with luminous matter (stars etc) seems to make up only 5% the total mass of the universe
    - So $\Omega_b = 0.05$

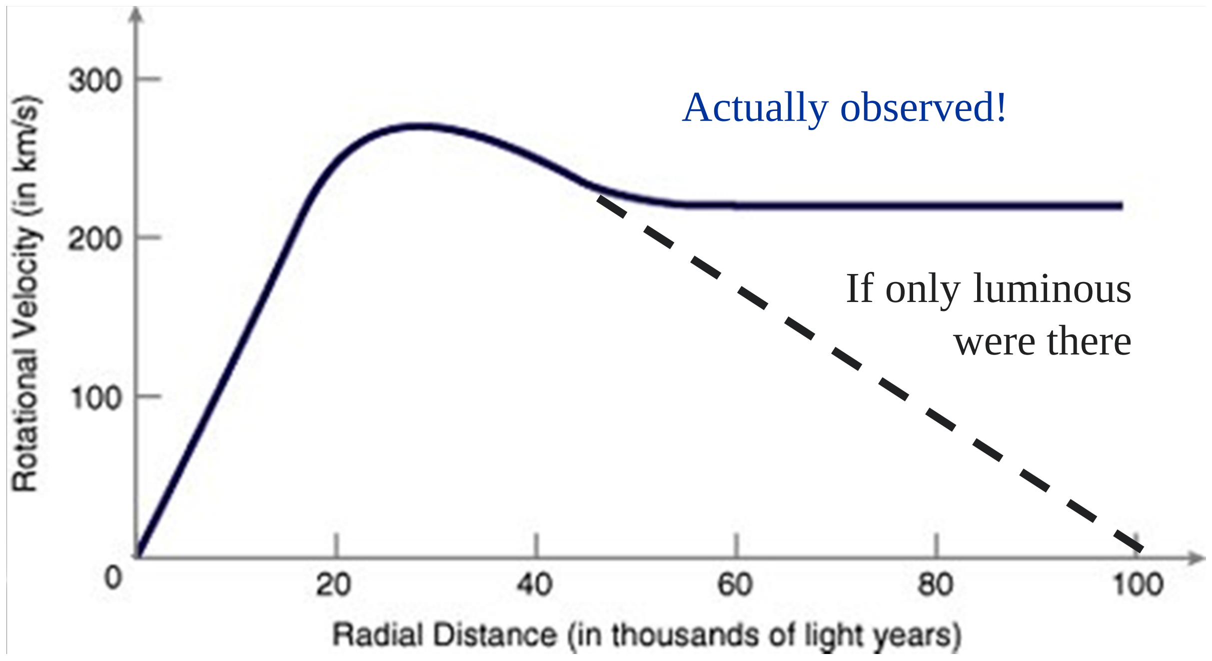
EXOTIC DARK MATTER

- Hot Dark Matter
  - Massive particles moving at high speeds
  - Neutrinos are this, could be 0.5% the total mass
- Cold Dark Matter
  - Massive particles moving slowly
  - WIMPS, Axions? People are looking hard!
  - Seems to be 26% of the total mass
- Total mass $\Omega_M = 0.31$
- The other 69% seems to be in “Dark Energy”
  - $\Omega_\Lambda = 0.69$

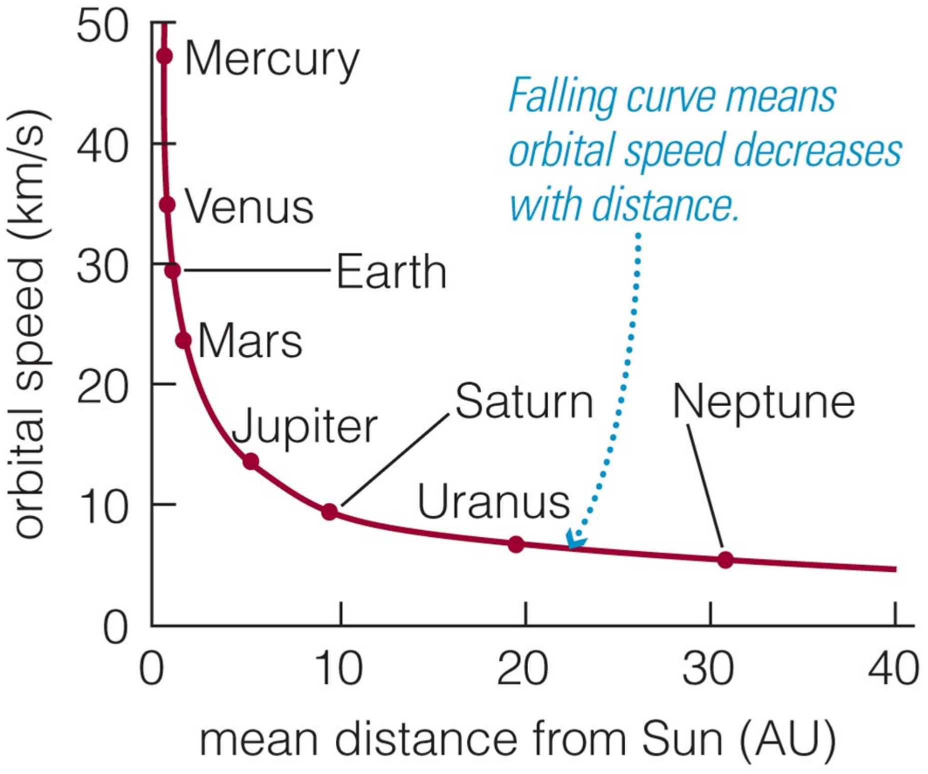
DARK MATTER

- Galactic rotation curves – luminous matter not enough
- (Disk stability also needs a Dark Matter halo)

Galaxy M31 image
by Jason Ware.



IN THE SOLAR SYSTEM



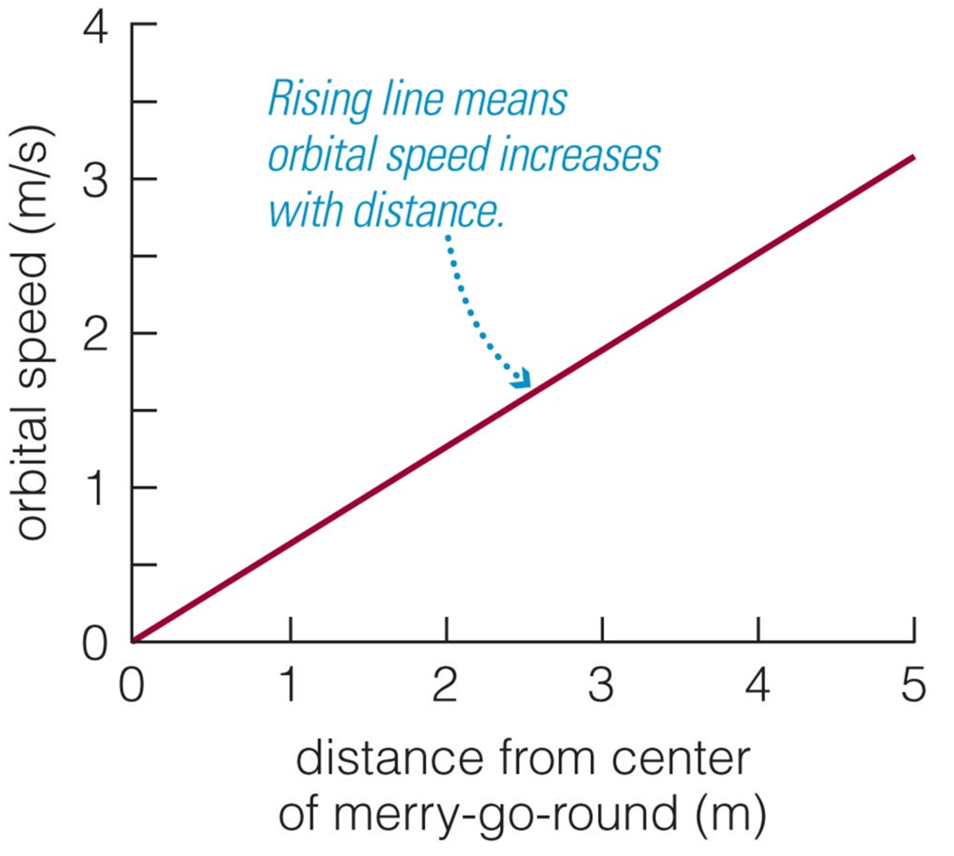
b The rotation curve for the planets in our solar system.

- Sun has nearly all the mass
- So, further out, gravity weaker because you’re further from all the mass, planets orbit more slowly
- Plot speed vs. distance

PLAY

Fig.18.1b

ON A MERRY-GO-ROUND



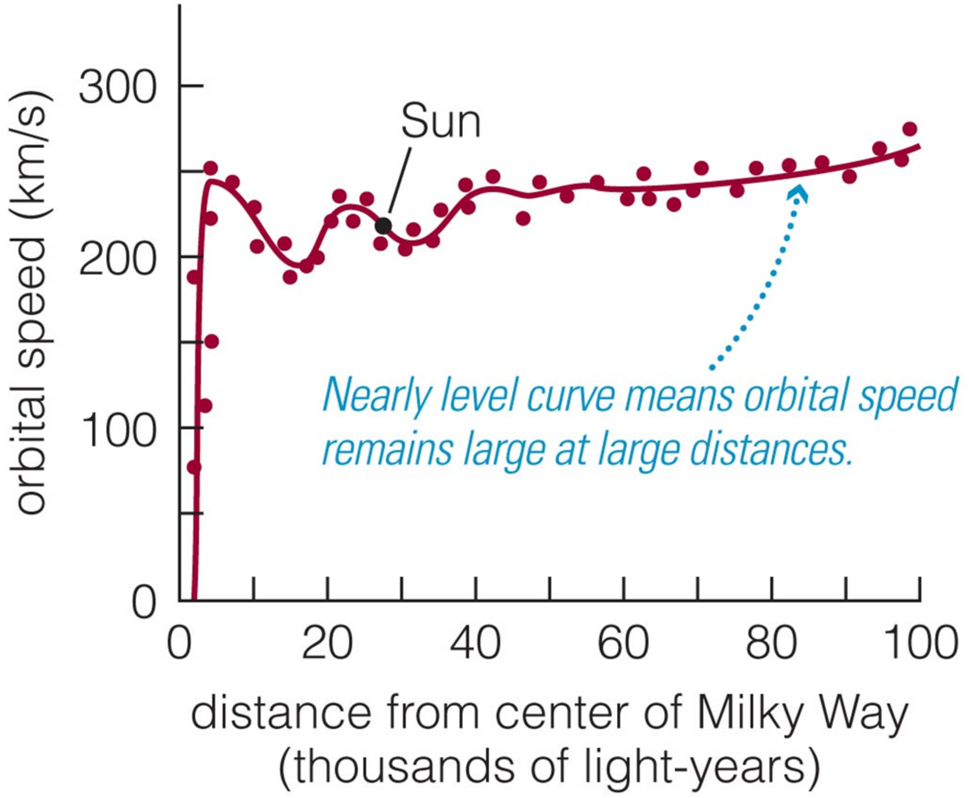
a A rotation curve for a merry-go-round is a rising straight line.

- Things farther out go faster, it's not gravity making things go round, it's a solid object

PLAY

Fig.18.1a

IN A GALAXY



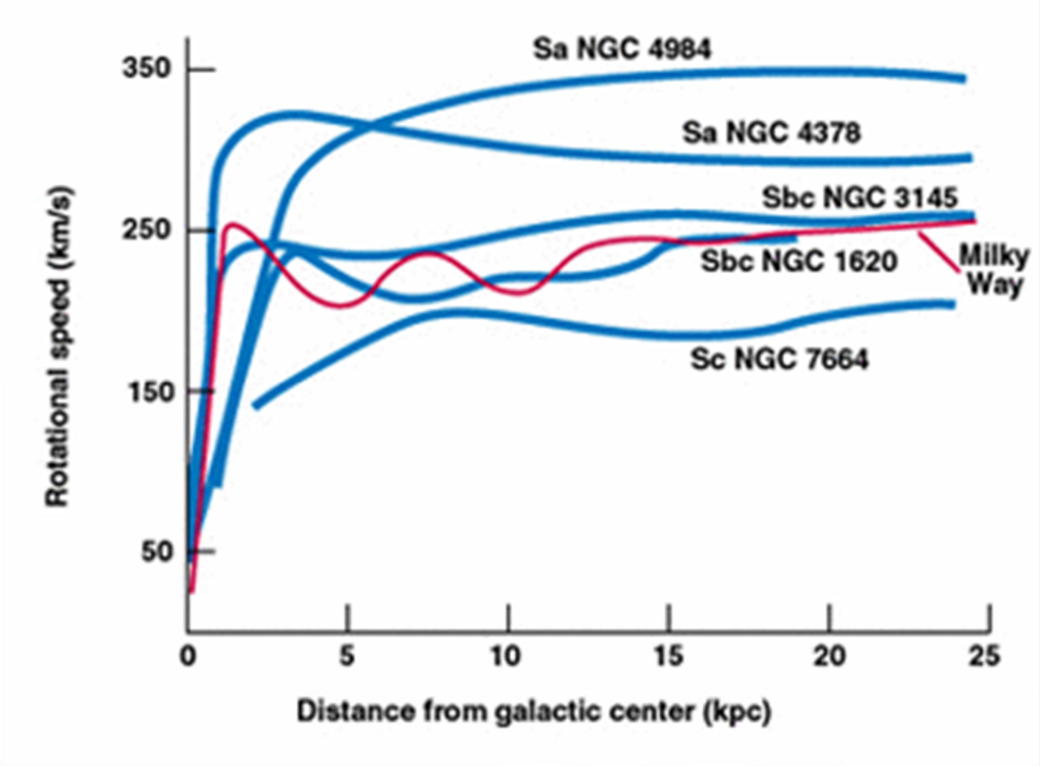
c The rotation curve for the Milky Way Galaxy. Dots represent actual data points for stars or gas clouds.

- We can make a rotation curve for galaxies too
- Here’s the Milky Way

PLAY

Fig.18.1c

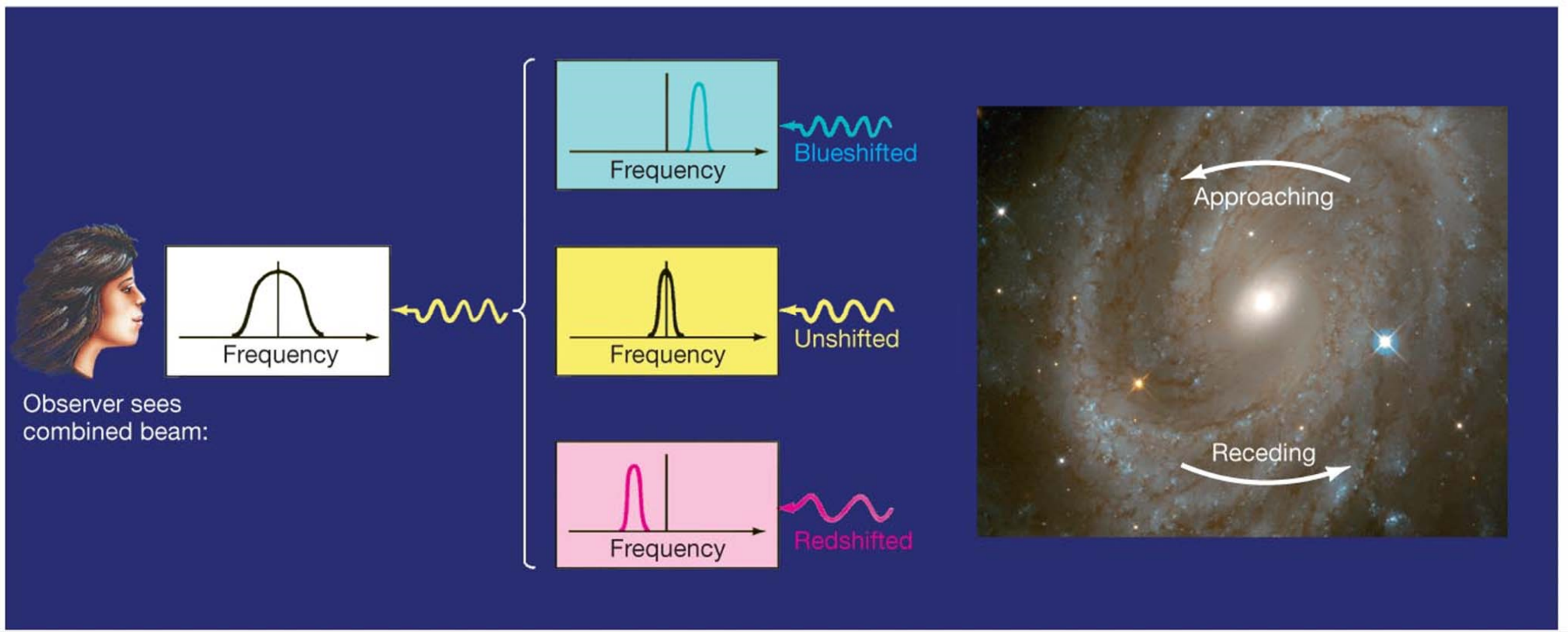
HOW WE “WEIGH” GALAXIES



- Kepler’s laws tell us faster rotators have more mass
  - which galaxy here is the most massive?

ROTATION?

- Just use the Doppler effect



HOW TO GET THIS SORT OF CURVE?

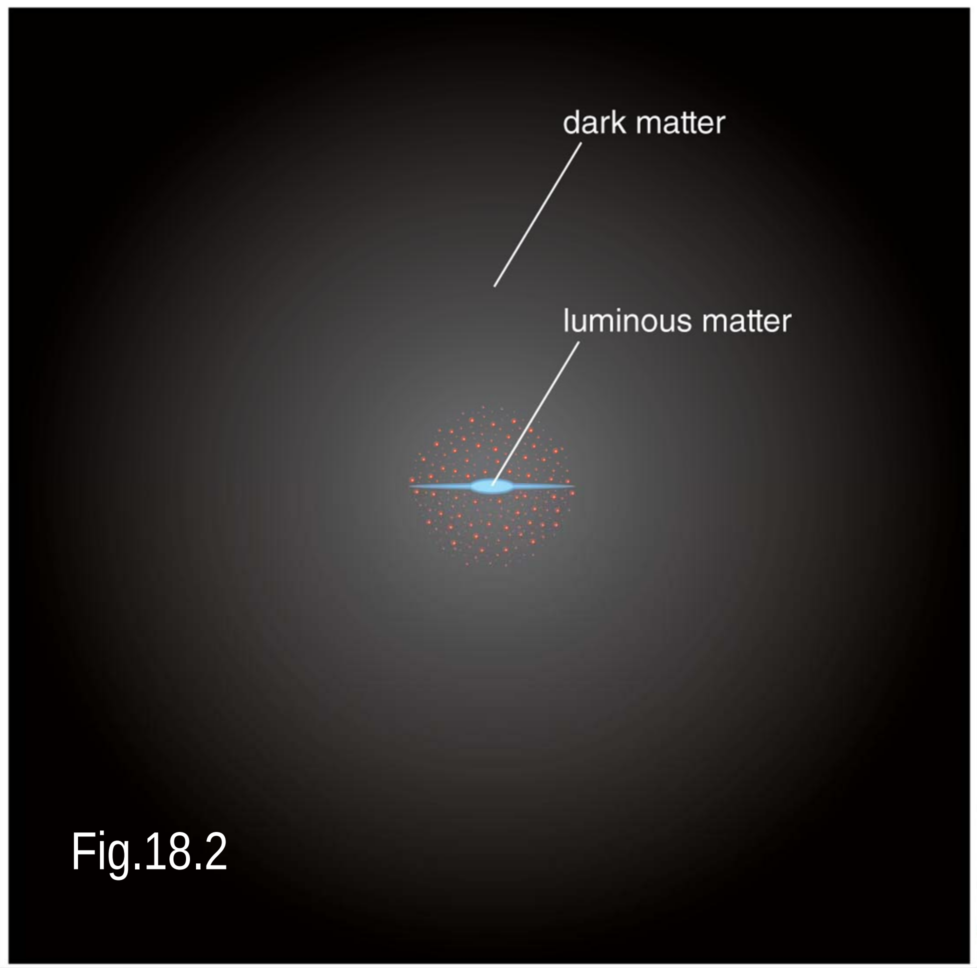
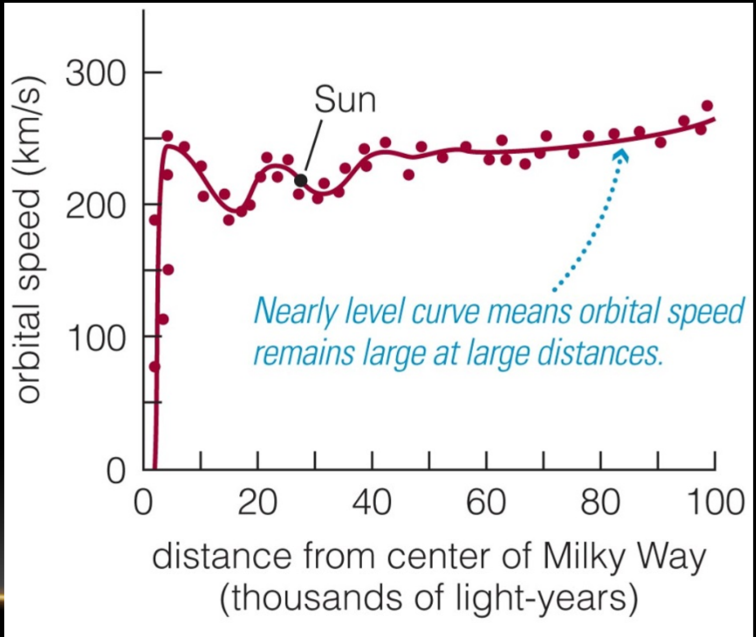


Fig.18.2

- Need mass spread out where we don't see it



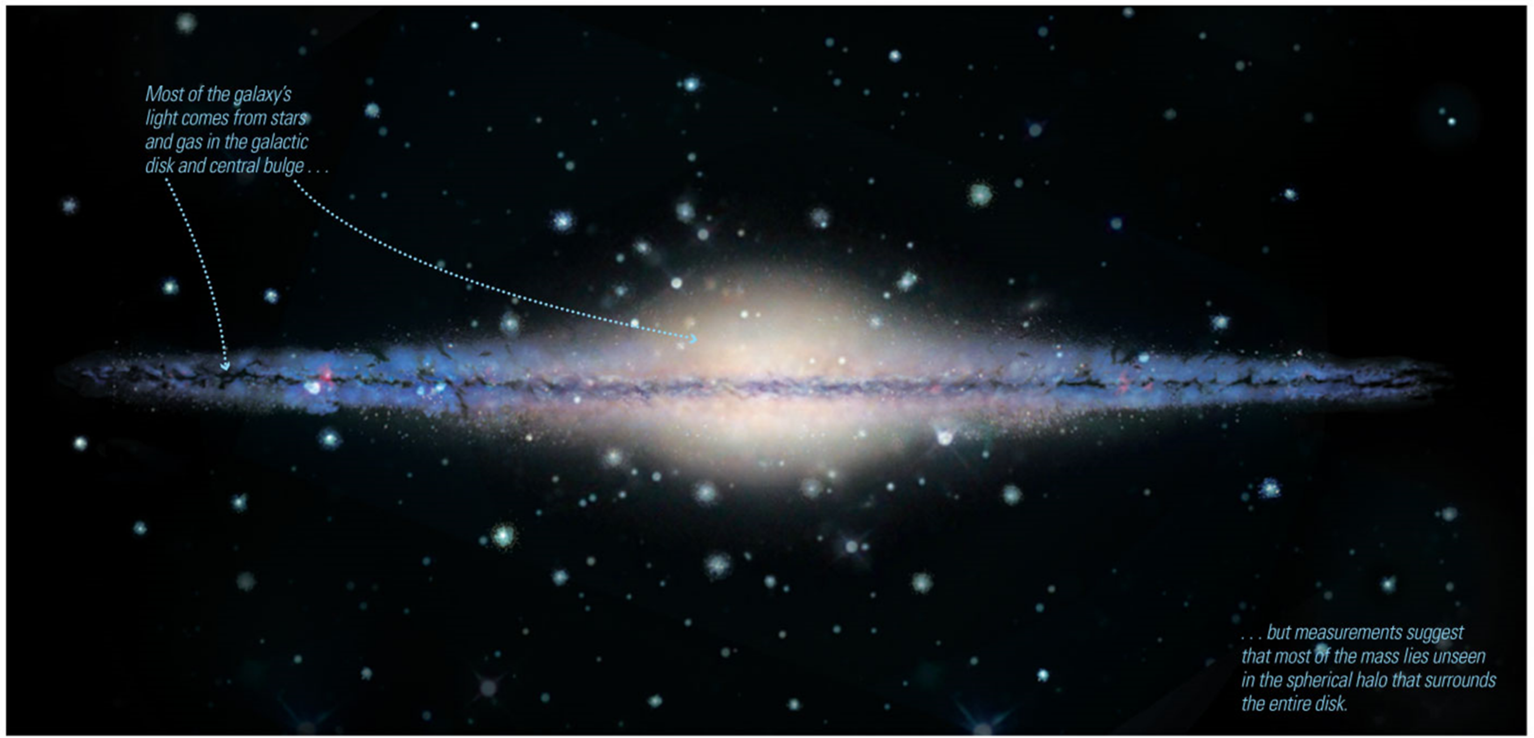
c The rotation curve for the Milky Way Galaxy. Dots represent actual data points for stars or gas clouds.

Fig.18.1c

PLAY

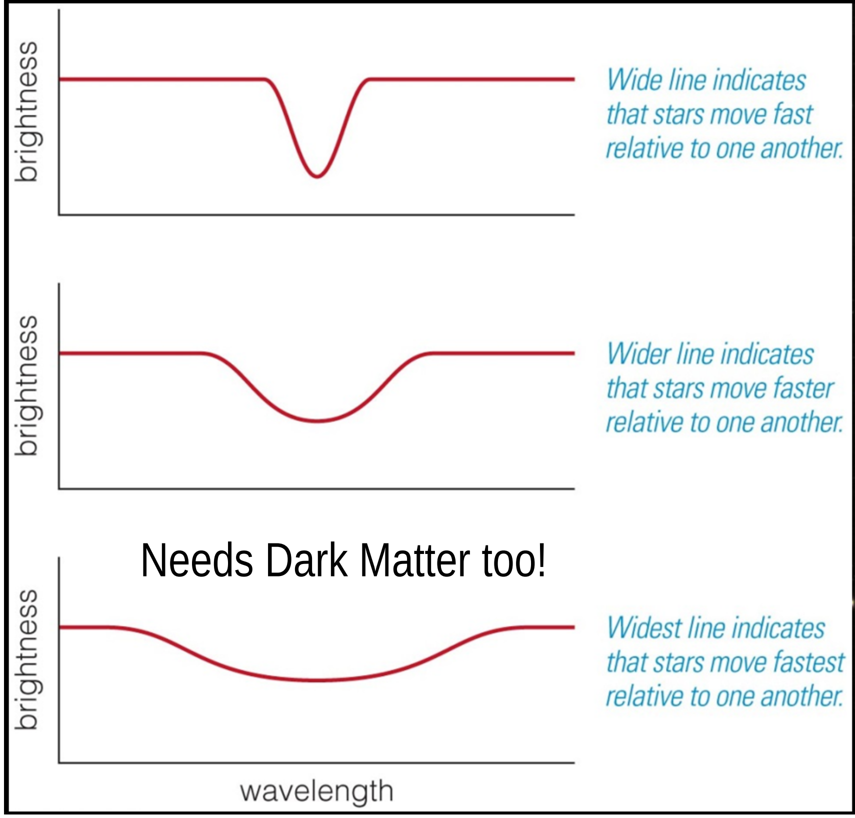
HOW MUCH MASS IN MILKY WAY?

- Mass in side Sun's orbit: 1.0x10^{11} $M_{\odot}$
- Total mass: ~10^{12} $M_{\odot}$



IN ELLIPTICAL GALAXIES?

- They don’t have a nice flat disk to measure “sides” of
- So measure the broadening of spectral lines
  - broader, more stars going faster in all directions

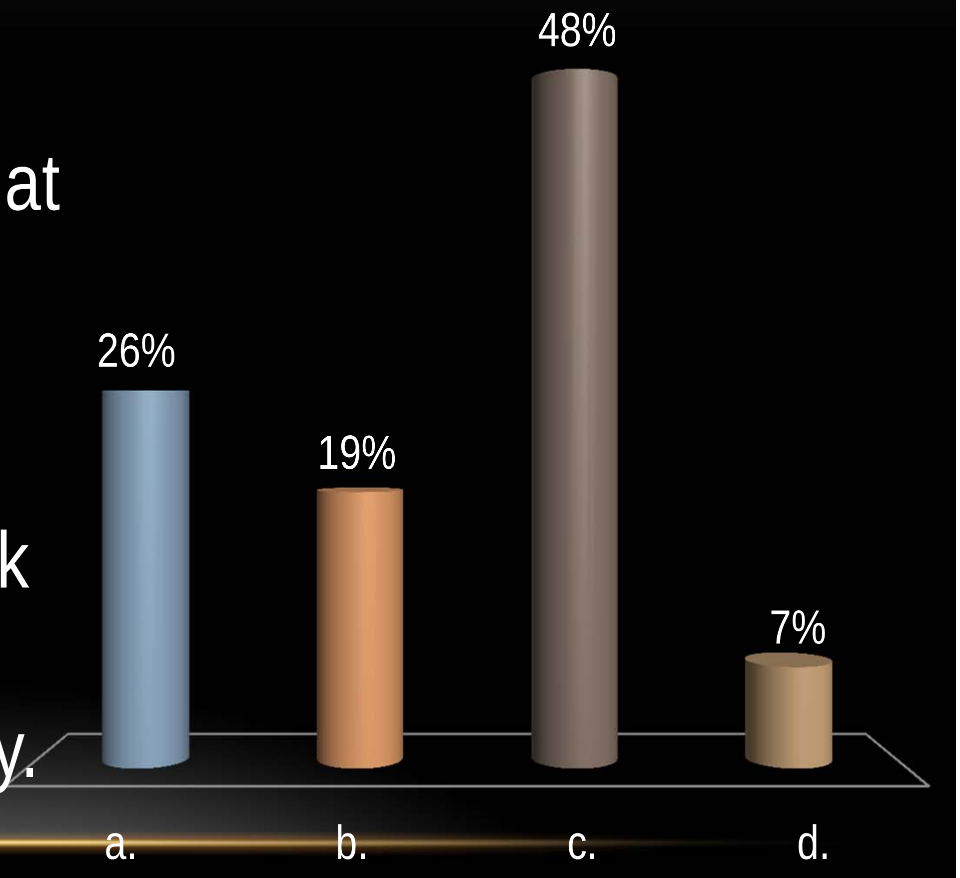


Needs Dark Matter too!

Elliptical Galaxy M87,
Adam Block, Mt. Lemmon SkyCenter, U. Arizona

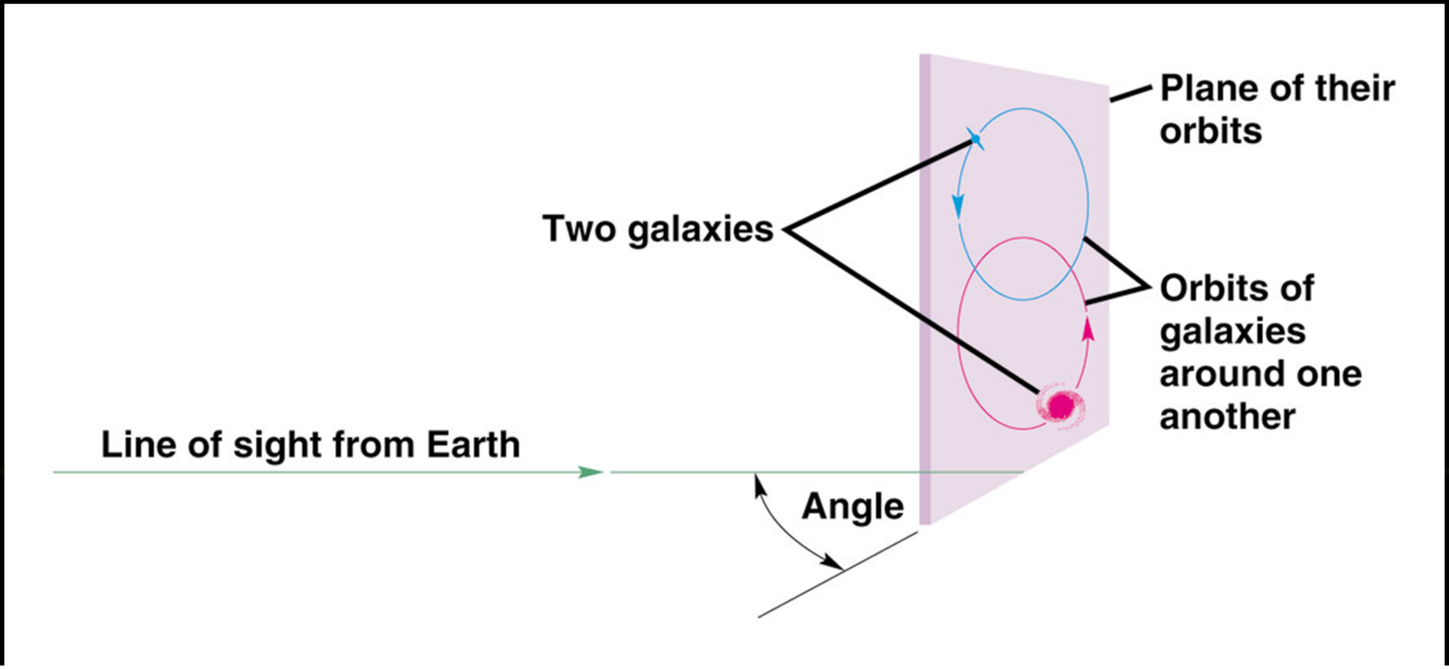
WHAT WOULD YOU CONCLUDE ABOUT A GALAXY IN WHICH ORBITAL VELOCITIES RISE STEADILY WITH DISTANCE BEYOND THE VISIBLE PART OF ITS DISK?

a. Its mass is concentrated at the center.
b. It rotates like the solar system.
[✓ c. It is especially rich in dark matter.]
d. It's just like the Milky Way.



ORBITING GALAXIES

- Just like binary stars, two orbiting galaxies can give us a hint to the mass, still using Kepler's Laws and Doppler shifts



SHOWS UP IN CLUSTERS TOO

- Looking at the motion of galaxies in their clusters, more dark matter!
  - Calculate escape velocity of cluster needed to keep the cluster together, need a lot more gravity than visible stuff provides
  - Need 50x as much mass as we see