Stars, Galaxies & the Universe Announcements

- **Reading Quiz #13**– today in class
- **HW #11 available and due on Friday (12-3) by 5 pm!**
- **Final Exam will be cumulative; Thursday 16 Dec @7:30 am in VAN LR 1; 150 points – 50 questions @3 pts each! We will have a review session sometime during Finals Week.**

- Tuesday (12-14) evening @ 7 pm?

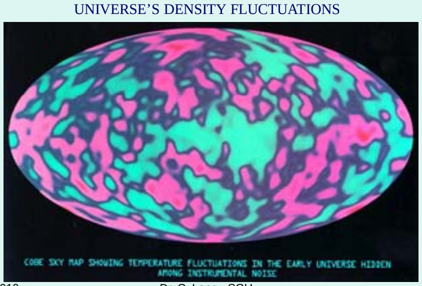
Stars, Galaxies & the Universe Lecture Outline

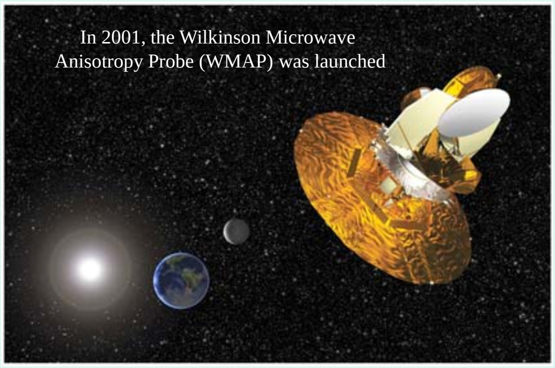
Cosmology (Ch. 26) – Part II

(1) Cosmic Microwave Radiation
(2) Structure of Early Universe
(3) Dark Matter
(4) Fate of Universe

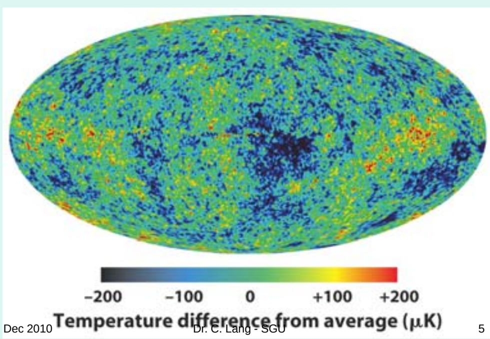
Further, very careful investigation of COBE data revealed that at small small levels, there were in fact temperature variations in the CMB

→hidden in the "noise" of the instrument
→scientists had to do careful calibration to see the variations
→physically, what do these variations mean? EARLY PICTURE OF UNIVERSE'S DENSITY FLUCTUATIONS





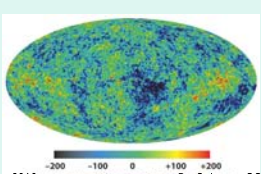
WMAP discovered that on small scales (better spatial resolution than previous observations), there were VERY SMALL fluctuations (changes) in the CMB temperature: 2.725 K +/- 0.0002 K!!



What can this discovery tell us about the early universe?

→ temperature warmer = regions of lower density
→temperature cooler = regions of higher density

→ preserved earliest record of universe's structure
→ there are structures of density in early universe which eventually evolved into galaxies, stars, etc.

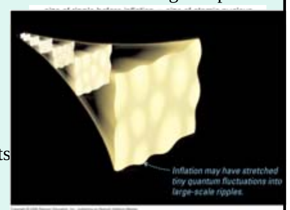


then

now

Where Does Structure Come from?

- The density of matter in the early Universe had to differ slightly from place to place.
  - otherwise, galaxies would never have formed
  - traditional Big Bang model does not tell what caused density enhancements
- Quantum Mechanics: energy fields must fluctuate at a given point.
- Energy distribution is irregular…
  - on microscopic spatial scales
- These quantum ripples would be greatly magnified by inflation.
- Large ripples in energy are the seeds for the density enhancements
  - they imposed a pattern about which structure formed



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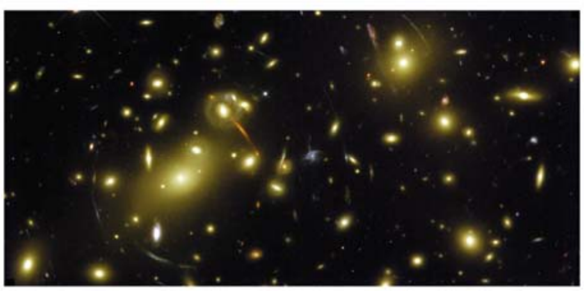

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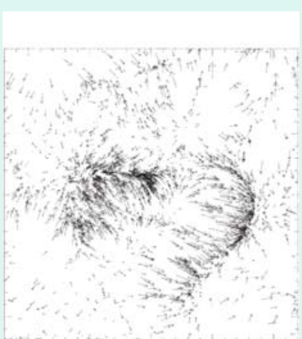
What is the role of dark matter in the formation of galaxies?



If dark matter is more common form of mass in galaxies then It must have provided most of the Gravitational attraction responsible For creating protogalactic clouds

Some clusters and superclusters sre still in the process of forming

Image (left) shows motions of halaxies due to gravity

Milky Way at Center – image is 600 Mly across; Virgo cluster is drawing Local Group into it to form a supercluster

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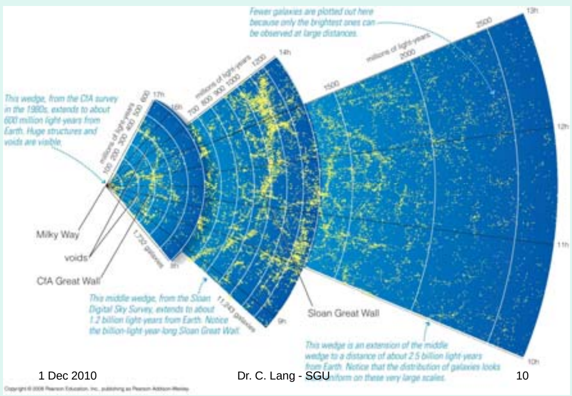
Large-scale Structures may mimic distribution of dark matter



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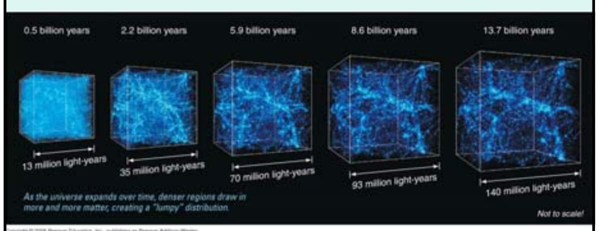
Simulation of structure formation:

→development of a region that is now 140 Mly across
→notice that the distribution of matter is only slightly lumpy to start with (at 0.5 Byr old) and grows more pronounced over time as matter is attracted to these density enhancements



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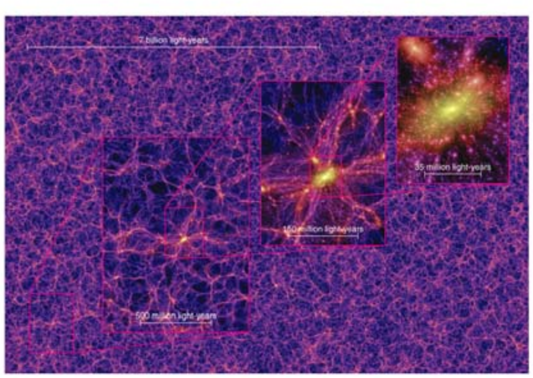

Distribution of dark matter in universe at early times

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What is Dark Matter Made Of?

- Dark matter could be made out of protons, neutrons, & electrons.
  - so-called "ordinary" matter, the same matter we are made up of
  - if this is so, then the only thing unusual about dark matter is that it is dim
- However, some or all of dark matter could be made of particles which we have yet to discover.
  - this would find this to be "extraordinary" matter
- Physicists like to call ordinary matter **baryonic matter**.
  - protons & neutrons are called baryons
- They call extraordinary matter **non-baryonic matter**.

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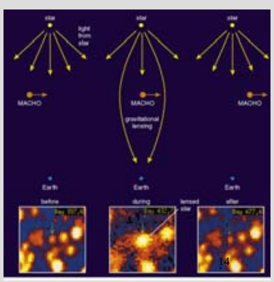
Ordinary Dark Matter Candidates

- Our Galactic halo should contain baryonic matter which is dark:
  - low-mass M dwarfs, brown dwarfs, and Jovian-sized planets
  - they are too faint to be seen at large distances
  - they have been called "MAssive Compact Halo Objects" or **MACHOs**
- We detect them if they pass in front of a star where they…
  - gravitationally lens the star's light
  - the star gets much brighter for a few days to weeks
  - we can measure the MACHO's mass
- These events occur to only one in a million stars per year.
  - must monitor huge numbers of stars
  - **Number of MACHOs detected so far does not account for the Milky Way's dark matter**



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Extraordinary Dark Matter Candidates

- We have already studied a nonbaryonic form of matter:
  - the **neutrino**…detected coming from the Sun
  - neutrinos interact with other particles through only two of the natural forces:
    - gravity
    - weak force (hence we say they are "weakly interacting")
  - their rest masses are so low & speeds so high, they will escape the gravitational pull of a galaxy…they can **not** account for the dark matter observed
- But what if there existed a *massive* weakly interacting particle?
  - physicists call them "Weakly Interacting Massive Particles" or **WIMPs**
  - these particles are theoretical; they have not yet been discovered
  - they would be massive enough to exert gravitational influence
  - they would emit no electromagnetic radiation (light) or be bound to any charged matter which could emit light
  - as weakly interacting particles, they would not collapse with a galaxy's disk
  - yet they would remain gravitationally bound in the galaxy's halo

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How will the Universe End?

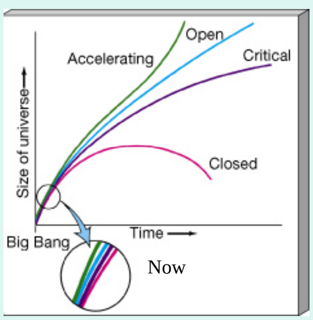
Robert Frost's "Fire & Ice"

Some say the world will end in fire,
Some say in ice.
From what I've tasted of desire
I hold with those who favor fire.
But if I had to perish twice,
I think I know enough of hate
To say that for destruction ice
Is also great
And would suffice.

How will the universe end?

Universe is presently Expanding
But…
mass is attractive, so it slows expansion.

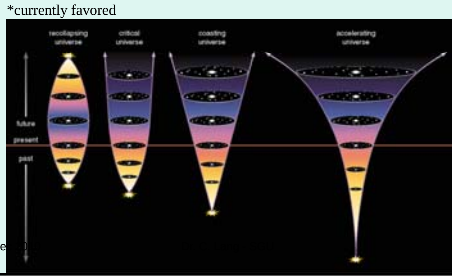
Questions:
(1) Is there enough mass to stop the observed expansion?
(2) Is the universe expanding rapidly enough to escape its own gravity?



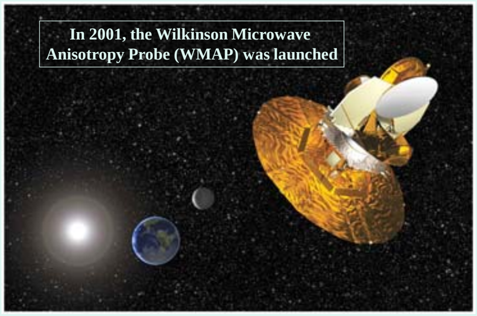
Four Models for the Future of the Universe

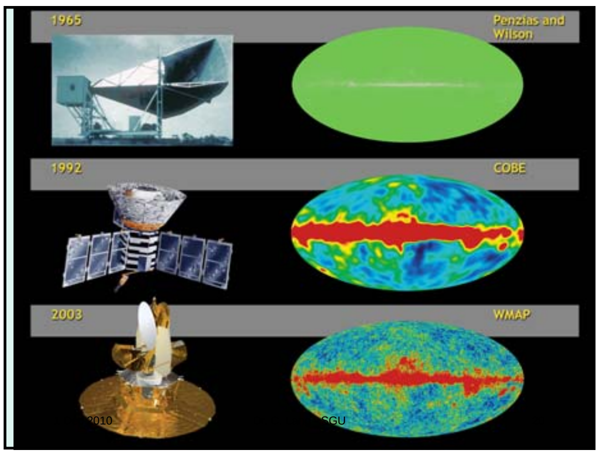
1. Recollapsing Universe: the expansion will someday halt and reverse
2. Critical Universe: will not collapse, but will expand more slowly with time
3. Coasting Universe: will expand forever with little slowdown
4. Accelerating Universe*: the expansion will accelerate with time

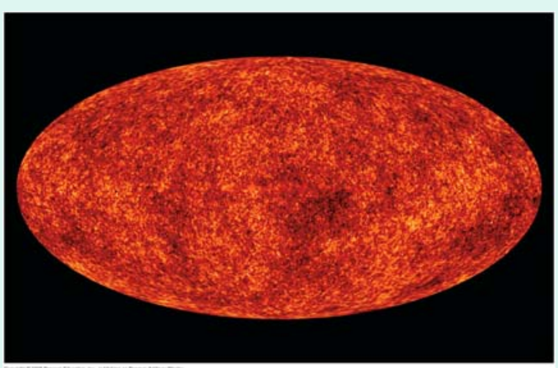
*currently favored



How can we test the idea of inflation?







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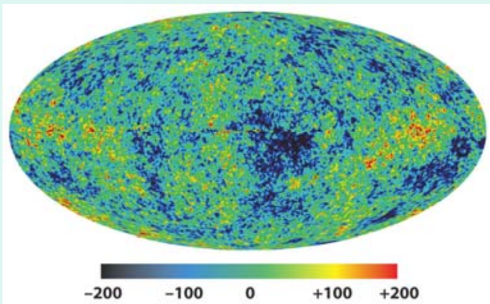

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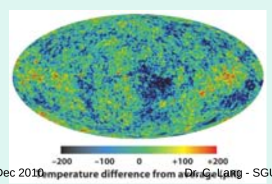

then

now

The shape and fate of the Universe:

- very small temperature variations in the CMB measured by the WMAP satellite tell us about early universe structure
- the curvature of our universe – open, closed or flat?
  - → determining the total average density of matter + radiation
  - → looking at size scale of fluctuations in early universe (from CMB)
- the fate of our universe
  - → distant SN can reveal how expansion of universe changes
- dark energy fills our universe!

The Critical Density

- **We have seen that gravitational attraction between galaxies can overcome the expansion of the Universe in localized regions.**
  - how strong must gravity be to stop the <u>entire</u> Universe from expanding?
  - it depends on the total mass density of the Universe
- We refer to the mass density required for this gravitational pull to equal the kinetic energy of the Universe as the **critical density**.
  - if mass < critical density, the Universe will expand forever
  - if mass > critical density, the Universe will stop expanding and then contract

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Omega is a measure of the density of the universe compared to the "critical density" (flat universe)

$$\Omega = \rho/\rho_{crit}$$

1. $\Omega > 1$ – more density than critical - CLOSED
2. $\Omega = 1$ – equal density to critical - FLAT
3. $\Omega < 1$ – less density than critical - OPEN

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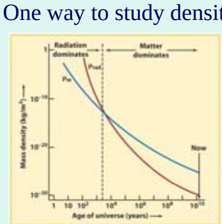
1. One way to study density of universe...



- is to study the *density* of both matter and radiation in the universe **now**
- density of radiation and matter has changed over time (radiation dominated in the early universe; matter dominates now)
- ρ_{matter} = 2.6 x 10^{-27} kg/m^3 (matter dominates now; dark matter incl'd)
- $\rho_{critical}$ = 9.5 x 10^{-27} kg/m^3
- density < critical density

→ universe should be OPEN!

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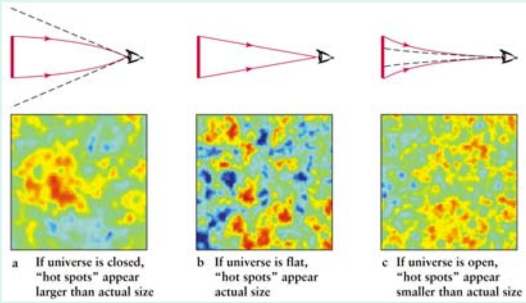
We can learn about the density (and geometry) of universe by looking at these fluctuations in the early universe



Theoretical astrophysicists have show that for a "flat" universe, the size scale of the fluctuations should be ~1 degree

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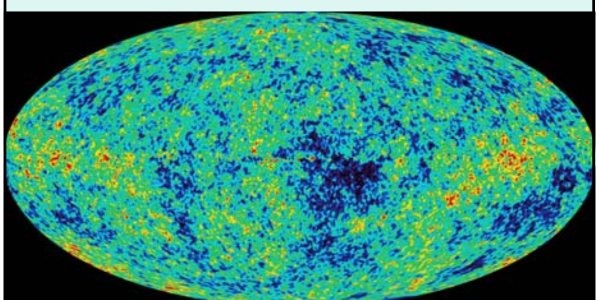
2. Second way: we can learn about the density of universe by looking at these fluctuations in the early universe



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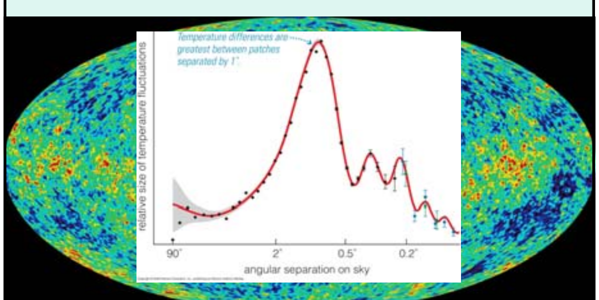
The results from the WMAP satellite show that the angular size scale of the fluctuations in the CMB radiation are about 1 degree across – **implying that the universe is indeed "flat" in its curvature**



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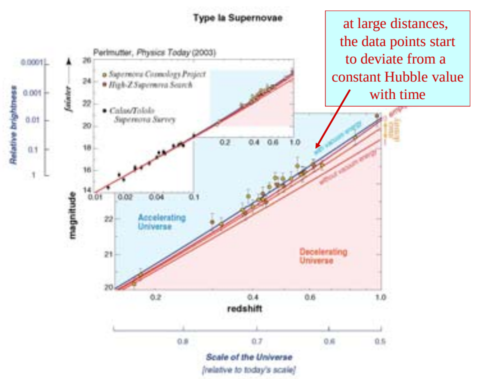
The "flatness" problem:

→ WMAP results indicate that the universe is **flat** (theoretical predictions for flat universe suggest that size scales of fluctuations should be 1 degree)

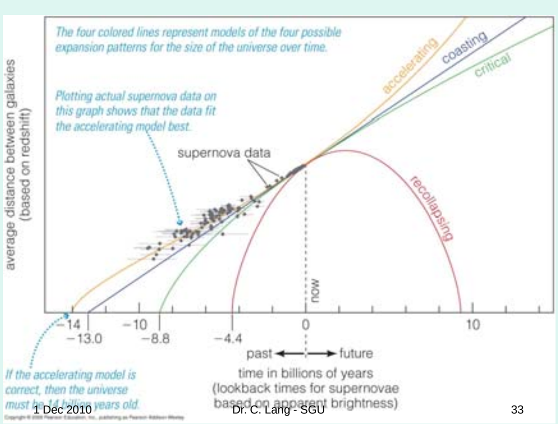
→The density of matter and radiation in the universe suggests that the universe should not be flat – but should be **open**

ONLY SOLUTION:

- universe is filled (73%) with the presence of dark energy
  - →can't be detected visually – it's not luminous matter
  - → can't be detected gravitationally – it's not dark matter



at large distances, the data points start to deviate from a constant Hubble value with time



• What is "Dark Energy"?

→ something which causes the universe to expand
→it makes up 73% of the universe and we are unable to detect it – therefore it is not something that current physics can describe very well
→ sort of an "antigravity"

• How will dark energy effect the fate of the universe?

→the universe will keep expanding FOREVER

→the rate of expansion of the universe will increase – acceleration!
→ 30 billion years from now, only 1000 nearby galaxies will be detectable from Earth
→ space will have expanded so far that visible light from these galaxies will be cosmologically redshifted into the infrared!

Moral: enjoy your night sky viewing now while galaxies are still visible!