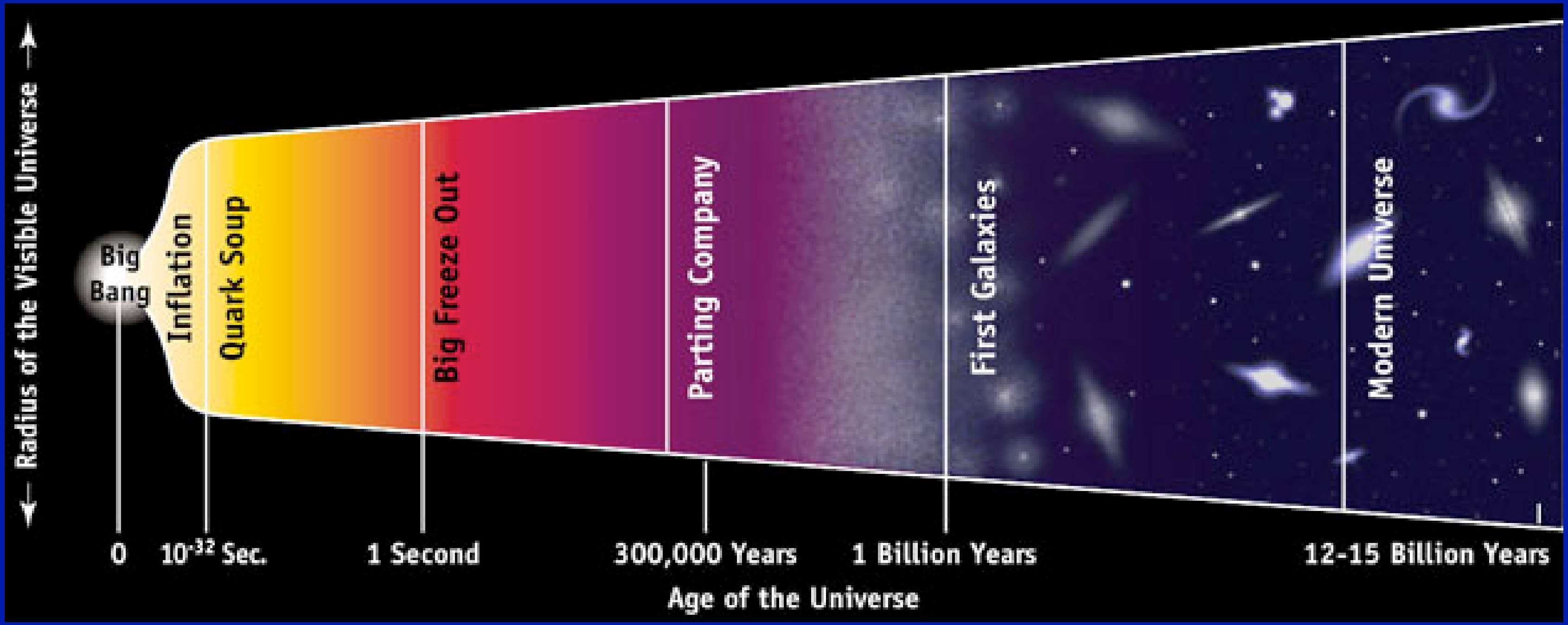
Expanding Universe
ASTR 301 G
NMSU



http://archive.ncsa.uiuc.edu/Cyberia/Cosmos/CosmicMysteryTour.html

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Concepts which you should be comfortable with:

- Basic differences between: a planet, a star, a solar system, a galaxy, the Universe (scale?)
- We live in a galaxy called the Milky Way (what does it look like? we have a good idea even though we can only see it from the inside)
- Our galaxy (like billions of others) is made up of about 400 billion stars
- Our galaxy is one of several billion galaxies, many which we can't even detect (many galaxies are 'dwarfs')
- The ones we can detect: we look at their images and spectra to get physical information; either of these can be any type of light (visible, radio, X-ray, etc.) given the proper equipment (telescope, camera, spectrograph)

steady-state universe: 1948
(Bondi, Gold, Hoyle)

- *This theory is no longer accepted by the astronomical community, but here's what it meant:*
- On large scales, the universe looks the same from every vantage point, and it has no beginning or end
- Further confirmation of expanding universe (mid 1900s) meant that in order for steady-state model to be correct, new matter had to spontaneously be created 'out of nothing'
- This way, Universe maintained a constant density by increasing its mass as its volume increased (density = mass/volume)
- Steady-state theory proven incorrect by further discoveries (more later)

The Expanding Universe

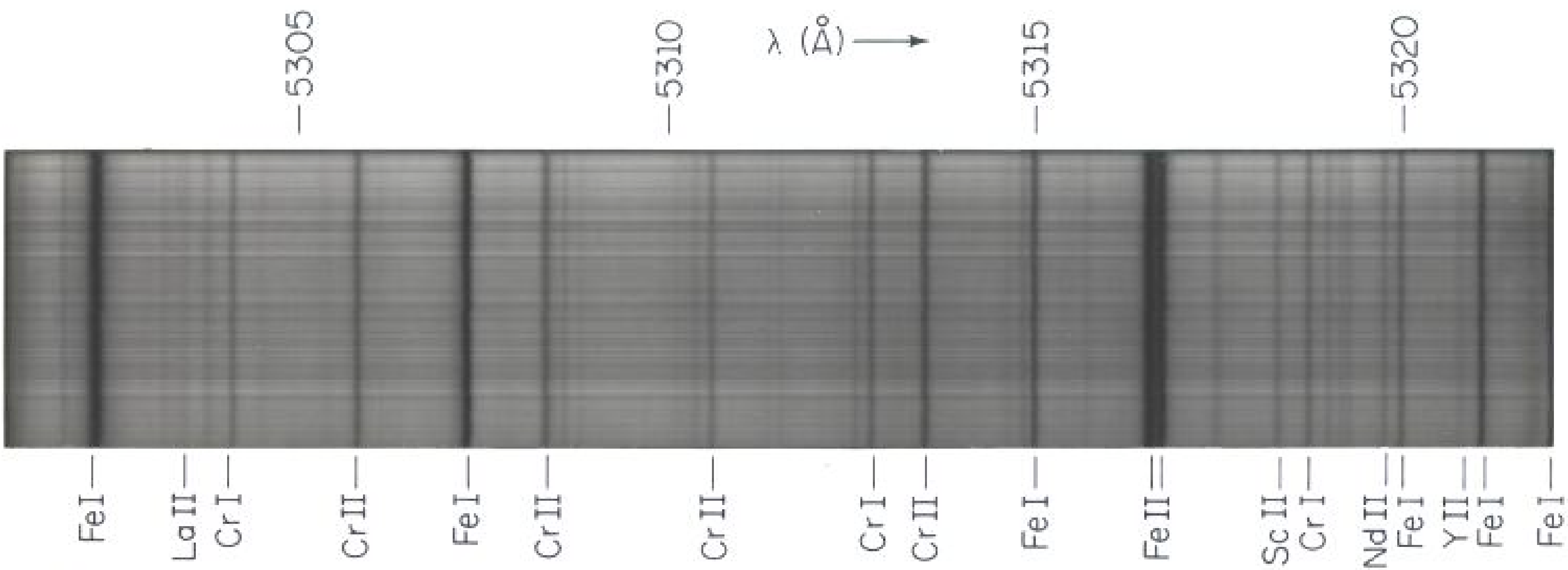
- Hard to envision: sort of analogous to a raisin bread baking; raisins stay the same size, but the dough (space) between them increases. Raisins move *with* the dough
- One major difference: the raisin cake has a centre; the Universe HAS NO CENTRE
- In this case, the cake would be baking such that as time went on, the cake expands faster and faster, and the raisins grow farther and farther apart faster all the time

(other major difference: cake may be delicious)

How did they know that the universe was expanding?

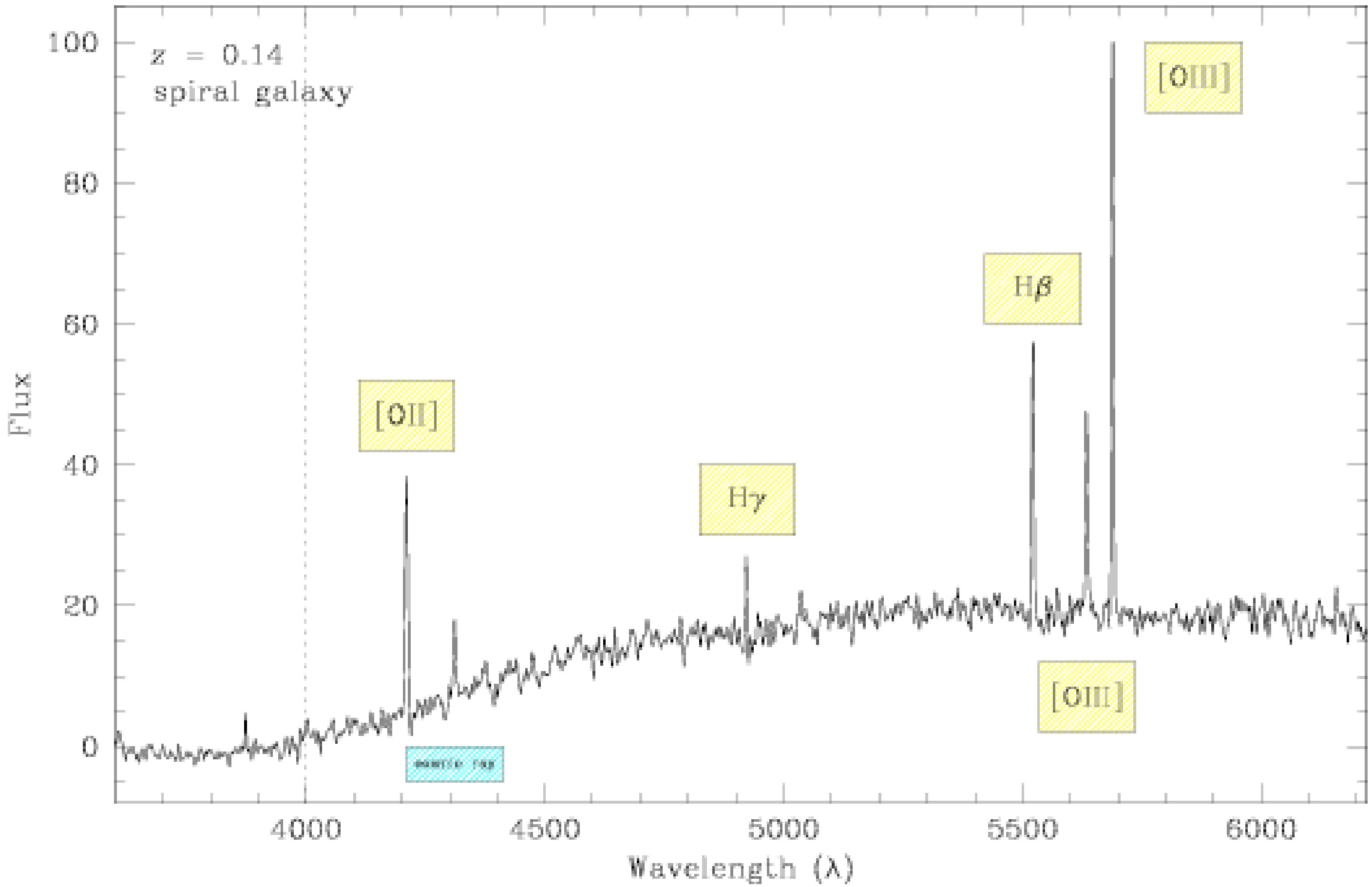
- Certain spectral features in galaxies are well-known; different stars which make up a galaxy have ‘signatures’ that they leave as emission or absorption lines on a spectrum (below: Sun’s spectrum)

- These features will be ‘shifted’ toward the red (redshifted) if the distance between us and them is increasing. **DOPPLER EFFECT**.



http://www.astro.uiuc.edu/~kaler/sow/spectra.html

Example of a galaxy spectrum:



bluer redder

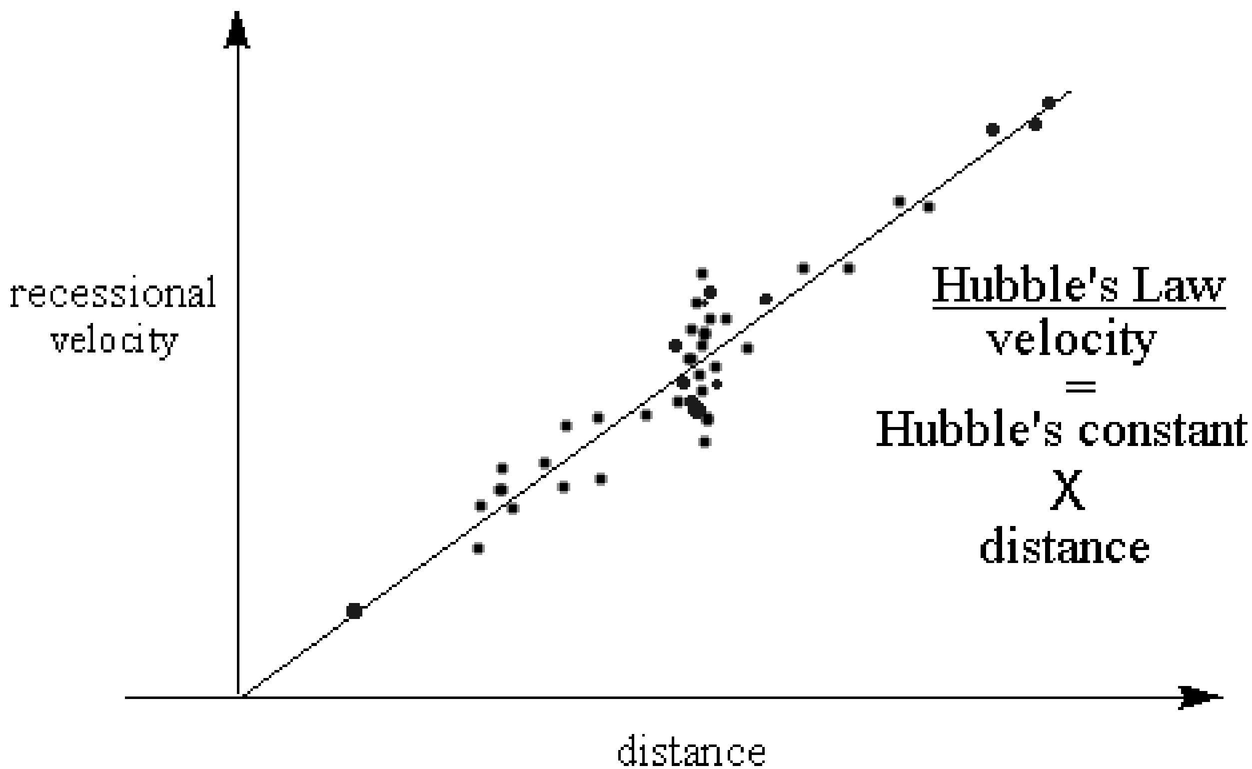
- Spectrum of a spiral galaxy. The more distant the galaxy, the more 'redward' the spectrum will lie, since everything is 'receding' from us (expanding universe). Graphic courtesy of Dr. Nicole Vogt, NMSU.

Discovery of expanding universe

- It was assumed that observed 'spiral nebulae' were a part of our galaxy (when they were really other very distant galaxies)
- Edwin Hubble determined distances to these objects, concluding they had to be outside of the MW
- 1929: Hubble compared galaxy measured distances with corresponding galaxy redshifts (spectra), and there was a pattern: the farther the galaxy, the higher the redshift!
- This implied that the relative velocity between us and the most distant galaxies was higher than for nearby galaxies...

Hubble's Law

- Plot of radial (recessional) velocity vs. distance for several galaxies
- Why is there scatter?
- Slope of line gives you the *Hubble constant*



Hubble's Law

- recessional velocity = Hubble const x distance, or $V = H_0 \times D$
- H_0 is a constant, thought to be about 70 $kms^{-1}Mpc^{-1}$ (km per s per megaparsec; units of inverse time)
- The inverse (recipricol) of H_0 is the 'Hubble Time'; a rough estimate of the age of the universe. BUT must keep track of units (convert km to Mpc or vice versa)
- UNITS: 1 parsec (pc) = 3.26 light years; 1 ly = 9.46×10^{12} km

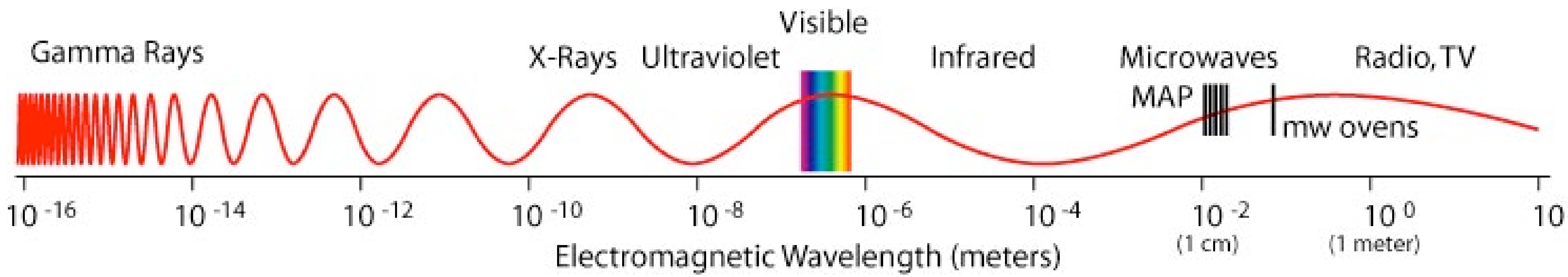
Implications...

- If the galaxies are all moving away from each other, that would imply that at one time things were very close together (a ‘Hubble Time’ ago)
- There is actually evidence of this: the Cosmic Microwave Background Radiation

A very cold radio show: the CMB

- The steady-state theory could not explain one of the most (the most?) important discoveries in astronomy: the Cosmic Microwave Background (CMB)
- Penzias & Wilson at Bell Labs discovered a strange signal. As it turns out the signal had a frequency range of ~0.3 - 630 GHz
- Microwave ovens operate at a frequency of about 2.45 GHz; cell phones around 0.83 GHz

The electromagnetic spectrum



Light 'waves' are characterized by their *wavelength* and/or their *frequency*.

speed of light c = frequency x wavelength.

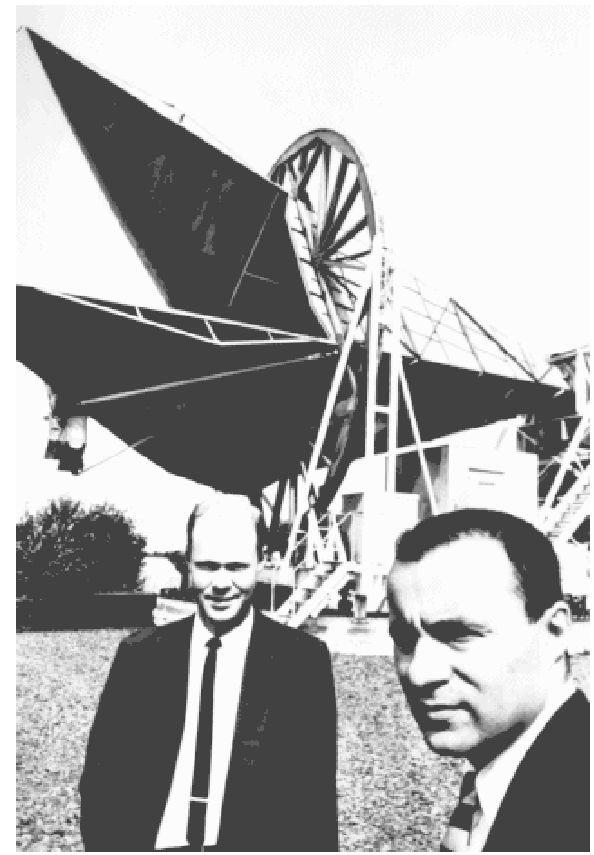
c is constant, so the lower the frequency, the longer the wavelength.

$c = 3 \times 10^8$ m/s in a vacuum.

http://map.gsfc.nasa.gov/m_mm/mr_whatsthat.html

More on the CMB...

- 1965: In trying to pick up galactic radio emissions with their antenna, Penzias & Wilson picked up 'noise' that was fairly uniform in signal no matter where they pointed their detector
- It was soon after discovered that this noise was coming from well beyond our galaxy; it was very 'old' radiation, dating back to the early universe

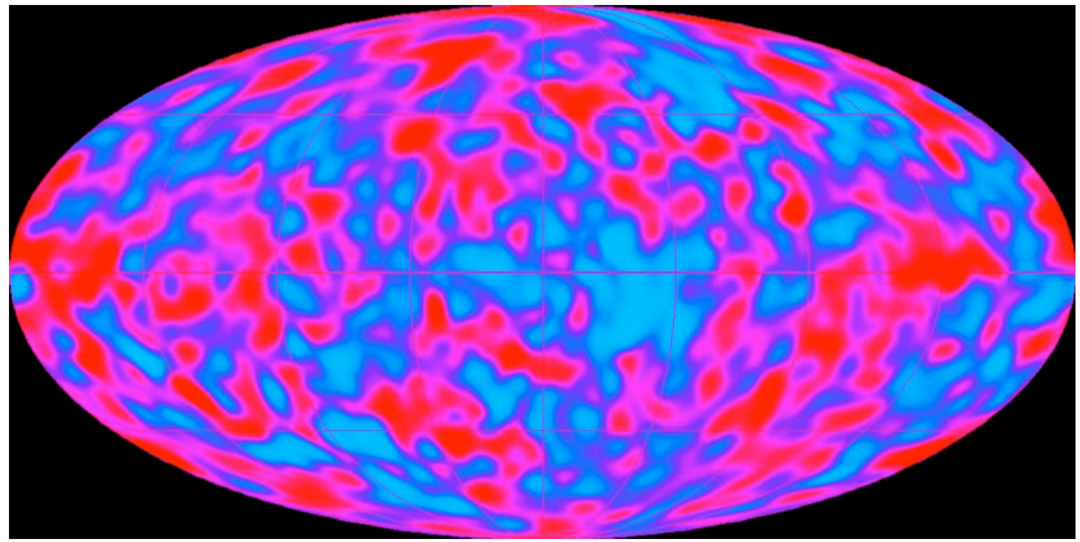


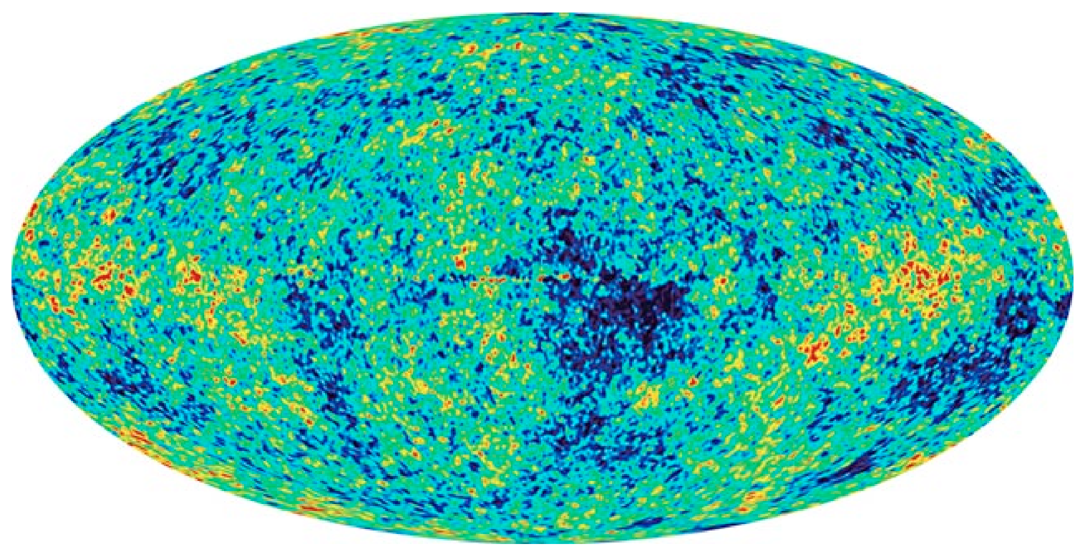
...More on the CMB

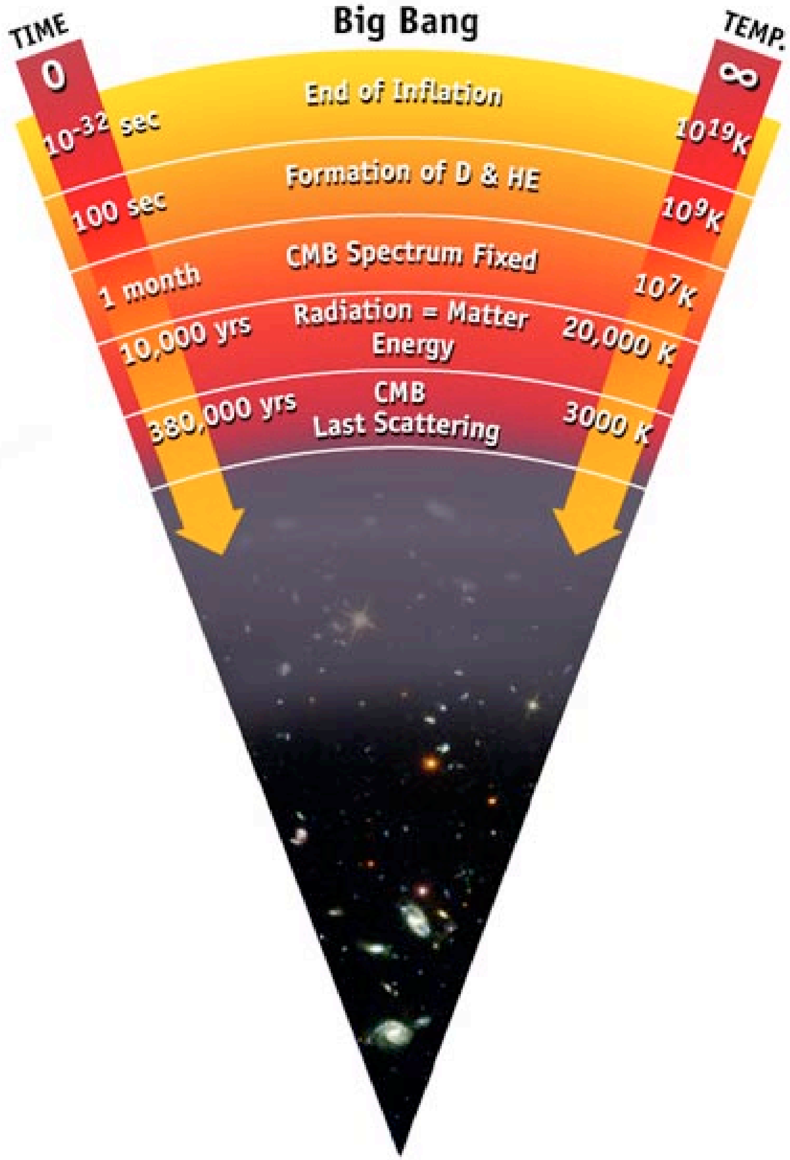
- The CMB is COLD, temperature of 2.7 K
- The early universe was extremely hot, but has cooled due to the expansion
- When we ‘see’ the CMB, we are not seeing the Big Bang, but a point in time roughly 300,000 years after the Big Bang
- 300,000 years after the Big Bang, the universe was cool enough such that electrons could start to combine with neutrons and protons, creating the first atoms (mostly hydrogen)

Coming all the way from more than 120,000,000,000,000,000,000,000 km: It's the CMB!

- COBE satellite map (top)
- WMAP satellite map (bottom)

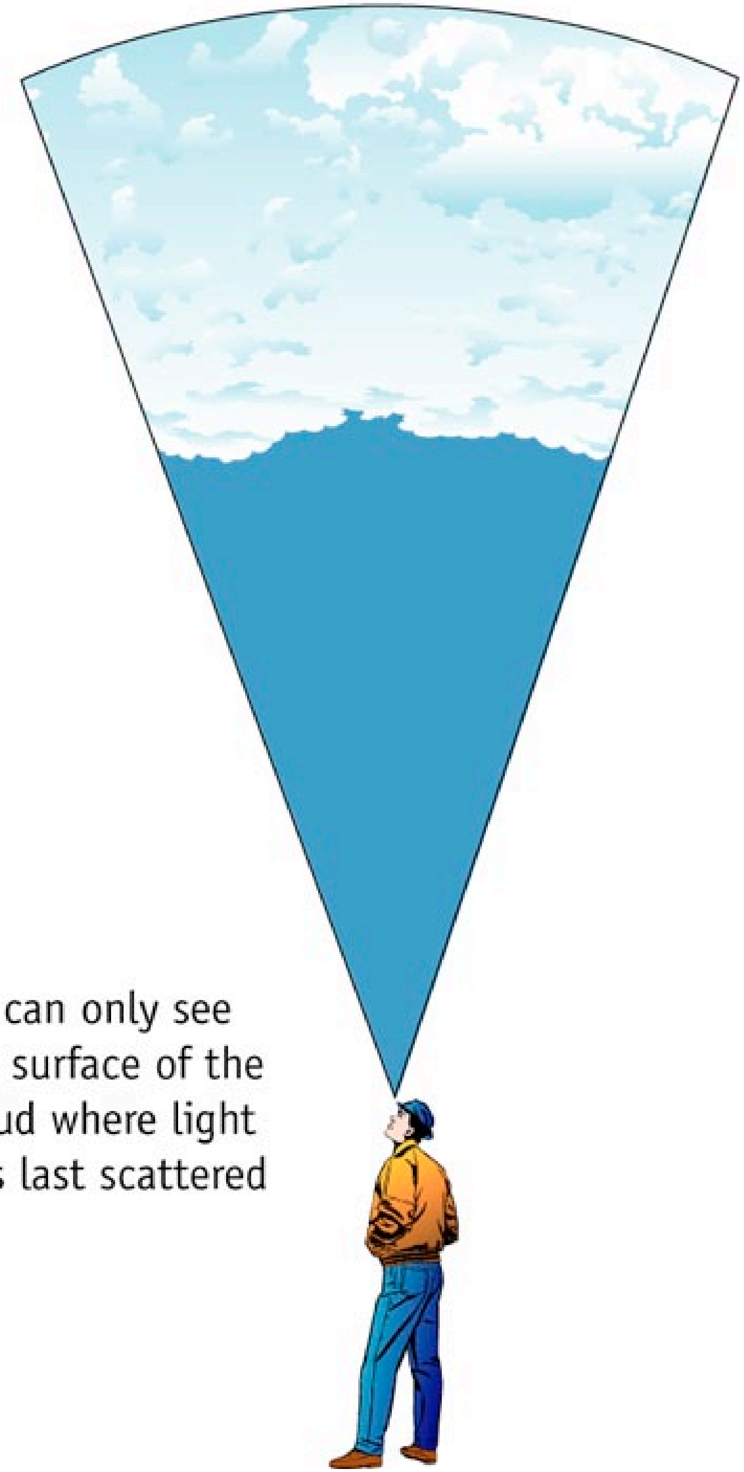






PRESENT
13.7 Billion Years
after the Big Bang

The cosmic microwave background Radiation's "surface of last scatter" is analogous to the light coming through the clouds to our eye on a cloudy day.



We can only see the surface of the cloud where light was last scattered

http://map.gsfc.nasa.gov/m_uni/uni_101bbtest3.html

further implications

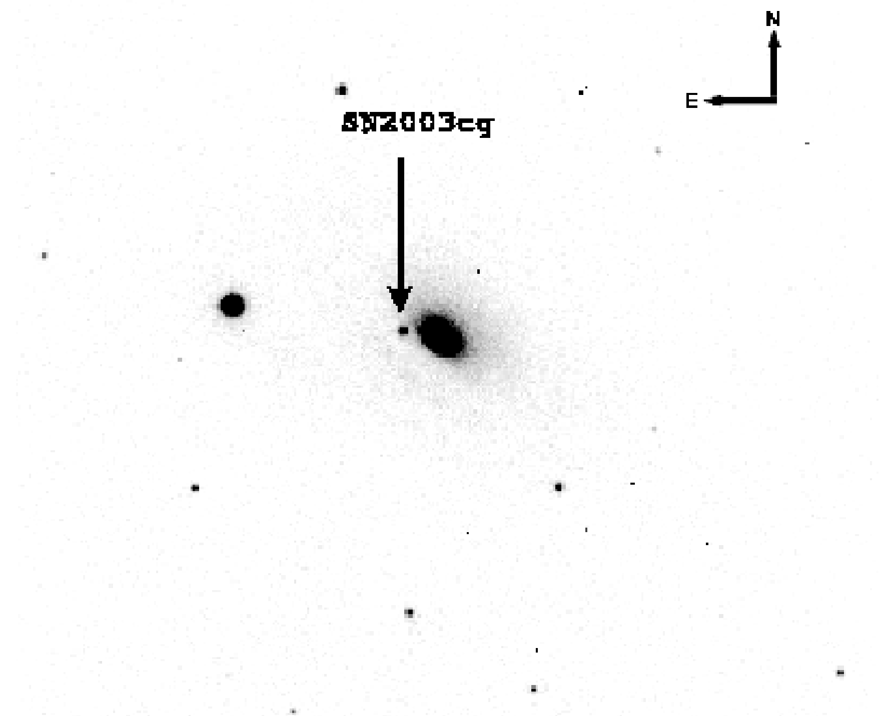
- Confirmation that the universe was not in a ‘steady-state’, but that it has grown (expanded) since the time of the 300,000 year-old CMB light (and before this, but we can’t ‘see’ it)
- So is the Universe expanding at at constant rate? Or speeding up? Slowing down?
- Seems to be accelerating...

Accelerating Universe

- It is now thought that the rate of expansion of the Universe is speeding up
- This could be true if there is some ‘energy’ or force that acts to counter gravitational (attractive) effects
- The acceleration has been inferred from measurements of type Ia supernovae, which have distinctive light curves

Type Ia Supernovae

- Not like type II SNe; type I involve binary star (usually white dwarf and red giant; red giant loses mass to white dwarf)
- When these things (WDs) blow up, they have a signature behaviour in terms of their spectra



http://www.mpa-garching.mpg.de/~rtn/

Observations

- Type Ia supernovae; very energetic... can be detected from far away
- In looking for SNe type Ia at high redshift (distance), can compare the ‘expected’ brightness to ‘observed’ brightness
- The SNe tend to appear more dim than predicted, implying (maybe) that they are farther away than expected
- Possible explanation for this is that the Universe is accelerating as it expands

What is making the expansion rate accelerate?

- Hypothesized 'dark energy'; NOT the same as 'dark matter'!!!
- Dark Matter: more than 90% of *matter* in the universe has thus far not been directly observed (but we know it's there; how?)
- Dark Matter and 'normal' matter together only make up about 30% of the known universe; other 70% is Dark Energy (vacuum energy; 'negative pressure')
- In cosmological calculations, this dark energy term is called 'the cosmological constant', Λ

The next few slides describe very briefly ‘what went down’ in the early universe. Some of the concepts (like cosmology in general) are complicated and you aren’t expected to know them thoroughly.

If you are interested in learning more, additional sources can be recommended. A good place to start is
http://en.wikipedia.org/wiki/Cosmological_constant
and links therein.

Timeline of events according to Big Bang (BB) theory

- 10^{-43} s after BB: this is called the Planck Time. Before this time, physics cannot explain theoretically what went on. Universe had a diameter of about 10^{-33} cm, T= 10^{32} K. The four fundamental forces (gravity, electromagnetic, weak and strong) are 'unfied'. Then *Gravitational* force 'diverges' from *Electronuclear* force.

- 10^{-35} - 10^{-32} s: Inflation. T = 10^{28} K. *Electronuclear* force diverges into *Strong* and *Electroweak* forces

- 10^{-32} - 10^{-12} s: Universe is size of an orange; cool enough for quarks (and antiquarks) to form. T= 10^{25} K

- 10^{-12} - 10^{-6} s: First formation of electrons, neutrinos (matter & antimatter). T= 10^{15} K. *Electroweak* force diverges into *Weak* and *Electromagnetic* forces.

- 10^{-6} - 10^{-4} s: T = 10^{13} K. First formation of protons and neutrons (matter and antimatter). Universe solar-system size.

separation of forces video:

http://archive.ncsa.uiuc.edu/Cyberia/Cosmos/InTheBeginning.html

Check out some of the other cool videos on this site!

timeline cont'd...

- 10^{-4} - 1 s: matter-antimatter collisions (result in photons); slight over abundance of matter over anti-matter
- First few seconds: T ~ 1,000,000 K. First formation of atomic nuclei (nuclei, not atoms). Universe consists of ~3/4 H, 1/4 He, and trace amounts Li and deuterium nuclei
- Few minutes - ~300,000 yrs: T reaches 10,000 K, density low enough that now photons can propagate (not always continually absorbed by matter), i.e. the Universe became 'transparent'. We see these photons as the CMB

  http://archive.ncsa.uiuc.edu/Cyberia/Cosmos/PartingCompany.html
- It was after 300,000 years from the BB that atoms began to form