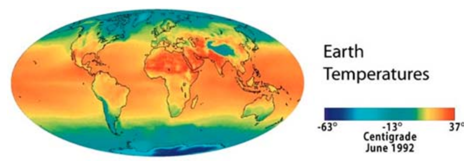
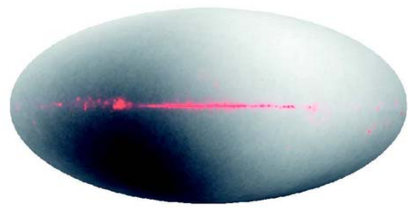
Universe at 400,000yr—1 Dec

- Cosmic background radiation is a snapshot of U at 400,000 yr.
- What is in the snapshot?
  - History of MW & local group: motion of 300km/s
  - Fluctuations at an angular scale of 1°.
  - Growing clumps of mass ⇒ mass density of the universe
  - Evidence of first stars





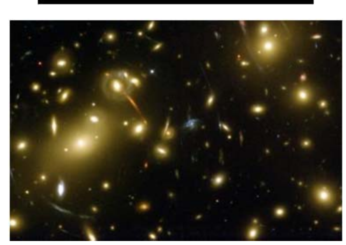
Temperature of radiation from Big Bang, measured by WMAP satellite

Universe at 13.7Byr & 11.7Byr

- M101 is a snapshot of the universe.
  - v=1050km/s
  - D=v/H=1050/60=18Mpc=18 *3.2=56MillionLight year
  - Light took 18Myr to get to us.

1. Light from Abell2218 took 2Byr to get to us. Are all of the objects in the picture of Abell 2218 from the time when the universe was 11.7Byr old?
   A. Y
   B. N

M104



Abell2218

Universe at 4min

- At 3min
  - Neutrons got incorporated into ^{4}He.
  - Temperature was 1BK.

1. If you could go back in time to when the U was 4min old and take a picture, what would you see? Stars. Very hot black-body radiation.
   A. S and V
   B. S only
   C. V only
   D. Neither S nor V.

Universe at 4min

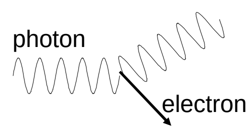
- At 4min, U was slightly cooler than 1BK.
- There were no stars, no galaxies, no planets. These could not form when the temperature was so hot.

Ionized/un-ionized gas

- Ionization is the loss of an electron.
  H atom → p + e^-
- Recombination is when electron and nucleus combine.
  p + e^- → H atom
- Ionization occurs if the temperature is hot enough.

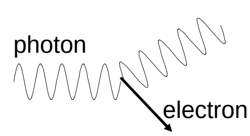
1. Name one thing in this room that is/has ionized gas.
   A. Gas in fluorescent light
   B. Air
   C. Air in my lungs

- Light scatters poorly off of electrons bound in an atom or molecule.
- Light scatters readily off of free electrons.



- If the air were ionized, light would travel 500m before it is scattered. Light scatters nearly equally in all directions.

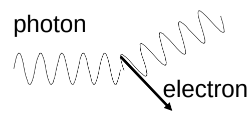
1. If the air were ionized, could you, sitting in Michigan Stadium, watch the Spartans beating Michigan? Could you see stars at night?
   A. YY
   B. YN
   C. NY
   D. NN



- If the air were ionized, the air would be a fog.
- We do not have a picture of the U at 4min, because at such a high temperature, the U is ionized. Light could travel only a short distance before scattering of an electron.

Matter and Radiation Decoupled

- Early, hot universe
  - Hydrogen is ionized.
    - Protons and electrons are free
  - Universe is opaque.
    - Photons travel only short distances.
    - Scattered by free electrons.



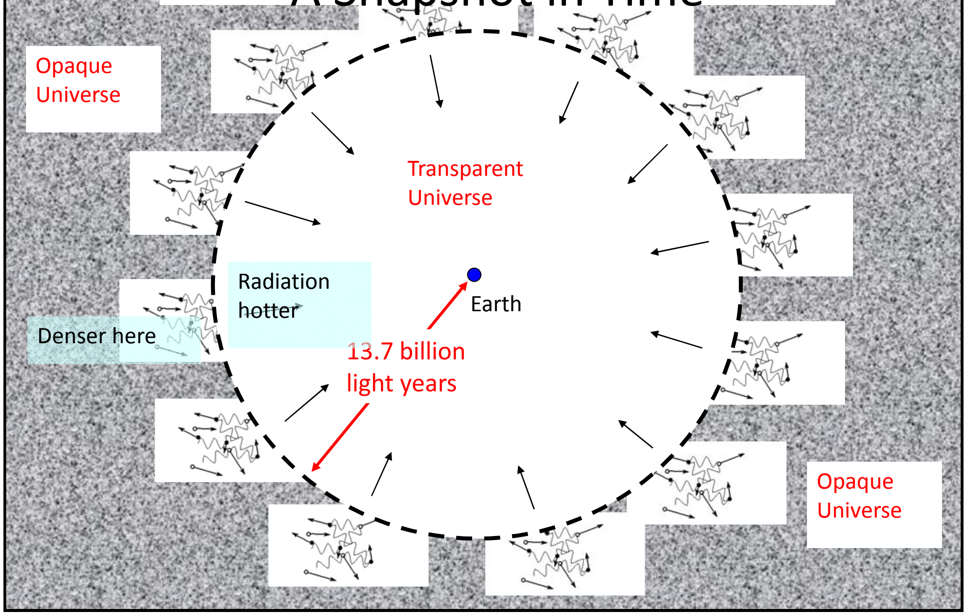
- Decoupling: $p + e^- \rightarrow$ H atom
  - T = 3000 K; universe 400,000 yr old.
  - Universe becomes transparent
    - Photons decouple from matter, continue in whatever direction they were moving.
- After decoupling
  - Photons travel in same direction. Preserves information about the matter at decoupling.
  - In certain directions, matter & light were slightly more dense. Light preserves that information.

Before & after decoupling

- Adam was sent back in time to when the U was 300,000yr old. Noah was sent back to when the U was 500,000yr old. A & N sent us a message that they are toasty warm.

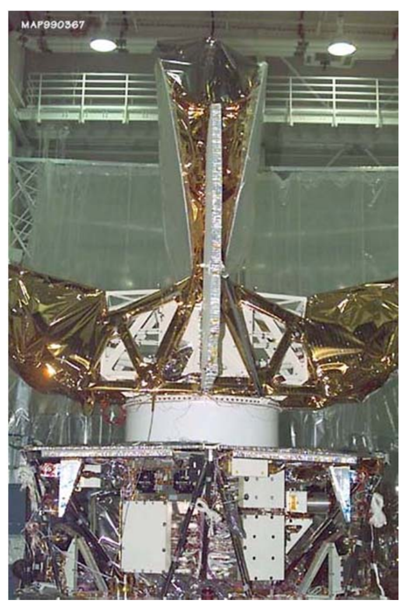
1. Can we get their messages?
   A. Y for both
   B. Y for A, N for N
   C. N for A, Y for N
   D. N for both.

A Snapshot in Time



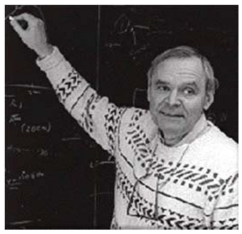
Wilkinson Microwave Anisotropy Probe (WMAP) Satellite

- Goal: Take a picture of the U when it was 400,000yr old.
  - Measure spatial variations in temperature of the CBR.
- Measure anisotropy
  - Penzias & Wilson found radiation to be isotropic.
  - Goal is to measure small deviations.
- Sensitivity is 0.000035K (a part in 100,000).
- Anything in the instrument even 0.0001K warmer is fatal.
- Symmetric design
  - Record temperature difference between left & right channels. Temperature difference is small.
  - Rotate entire instrument.
    - Instrumental problems do not change; radiation from the sky does change.

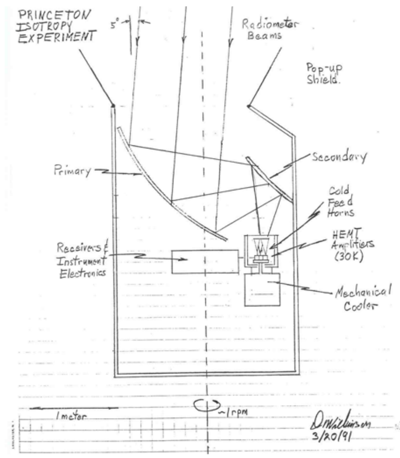


Ast 207 F2010

Wilkinson Microwave Anisotropy Probe (WMAP) Satellite



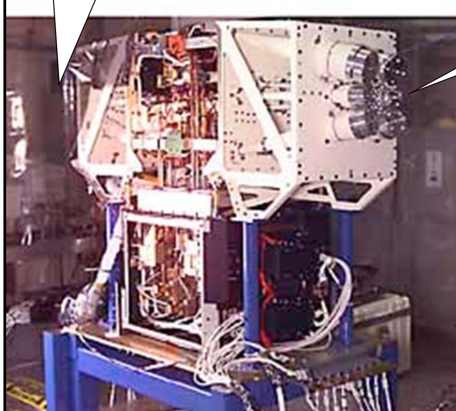
Dave Wilkinson
1935-2002, b. Hillsdale MI



Dave's notebook 3/20/1991, Greg Tucker

10 microwave eyes on left

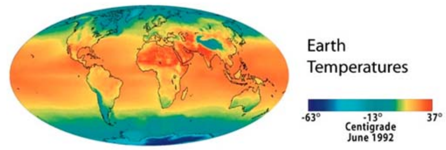
10 microwave eyes on right

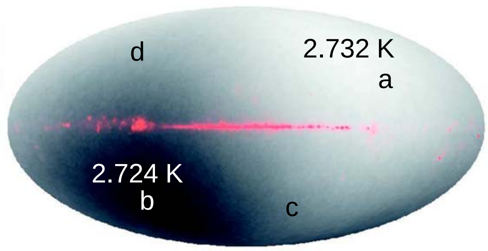


Local Motion

- WMAP: Temperature of CBR across whole sky
- Notice Milky Way (pink)
- Earth, sun, MW, & local group of galaxies move at 300 km/s with respect to whole universe.

1. The earth, sun, and Mil Way are moving towarc which direction? In whi direction is wavelength compressed?

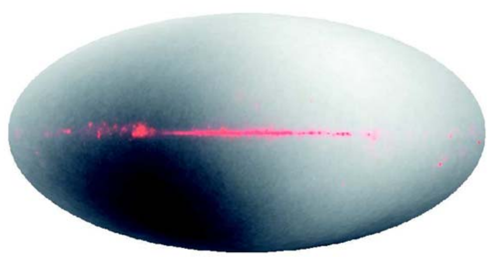


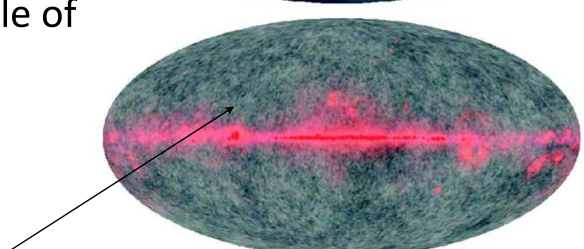


Ast 207 F2010

Remove motion

- Remove motion and show with increased contrast
- Largest fluctuations are at an angular scale of 1º.





Temperature fluctuations:
Light & dark mottling

Ast 207 F2010