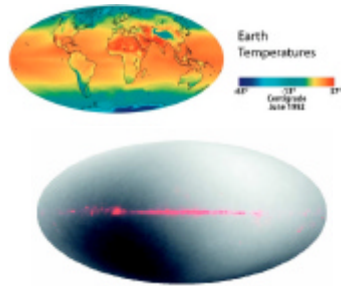


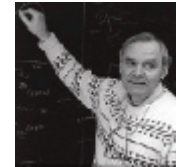
Universe at 300,000yr—7 Dec

- CBR is a snapshot of U at 300,000 yr.
 - Radiation from the Big Bang separated from matter when universe became neutral (not ionized) at $a=0.001$.
- What is in the snapshot?
 - History of MW & local group: motion of 300km/s
 - Growing clumps of mass
 - $\Omega_{total} = 1$
 - Evidence of first stars

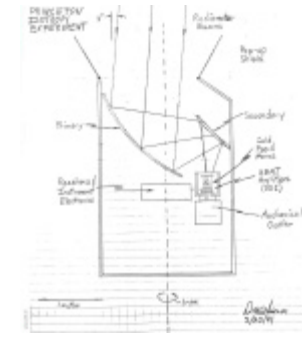


Temperature of radiation from BB from WMAP

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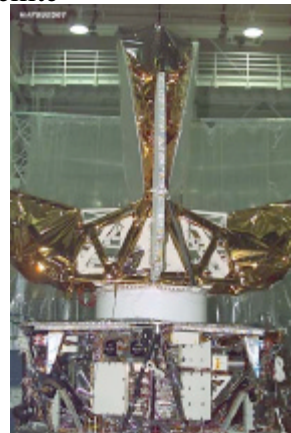
Dave Wilkinson
1935-2002, b., Hillsdale MI



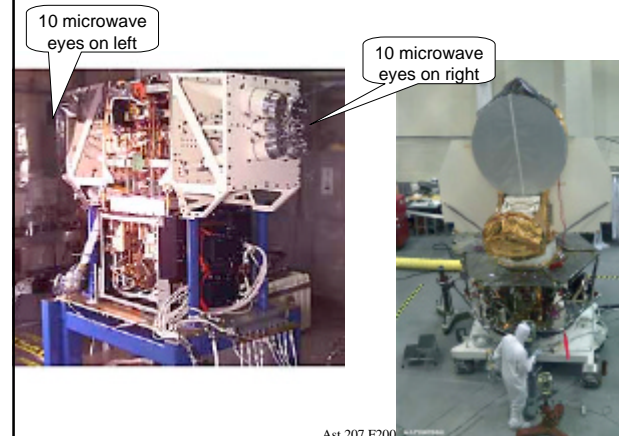
Dave's notebook 3/20/1991, Greg Tucker

Wilkinson Microwave Anisotropy Probe (WMAP) Satellite

- Measure spatial variations in temperature of the CBR
- Sensitivity is a part in 100,000. (35/1,000,000 K)
- Anything in the instrument even 0.0001K warmer is fatal.
- Symmetric design
 - Compare temperature between left & right channels



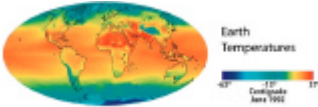
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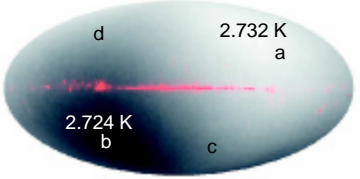
Local Motion

- 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.



Earth Temperatures
0.1 K 1 K
Compendium Area 1992

1. The earth, sun, and Milky Way are moving toward which direction? In which direction is wavelength compressed?

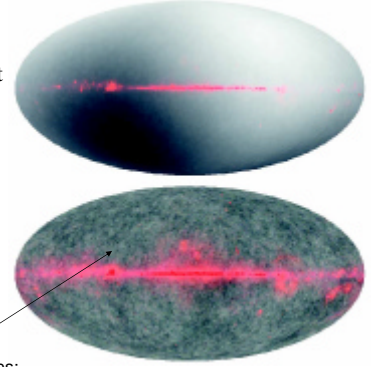


2.732 K a
2.724 K b
c d

Remove motion

- Remove motion and show with increased contrast
- Largest fluctuations are at an angular scale of 1°.
- Fluctuations are growing dense & sparse regions

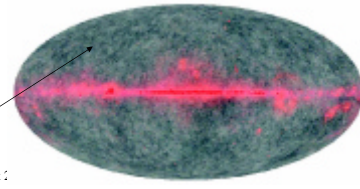
2. How long have these regions been growing?
3. Radiation dominates pressure. How big are these regions?



Temperature fluctuations:
Light & dark mottling Ast 207 F2005

Angular scale ⇒ Weighing the Universe

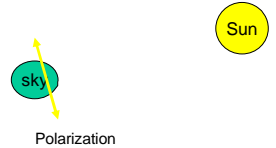
- Regions have been growing for 300,000 yr.
 - Size $L = 1/3$ speed of light * 300,000 yr
- Largest fluctuations are at an angular scale of 1°.
- This is a method to weigh the universe.
- A “yardstick” is like a standard candle.
 - Flux = Luminosity/D².
 - Angle = Length/D.
- Result: Density parameter
 $\Omega_{\text{matter}} + \Omega_{\text{DM}} + \Omega_{\text{cc}} = 1$



Temperature fluctuations:
Light & dark mottling Ast 207 F2005

First Stars

- WMAP finding
 - Cosmic radiation is weakly polarized for points in the sky separated by 40deg.
- Scattering creates polarization.
- Universe became un-ionized at decoupling.
- First stars and quasars emit ultraviolet radiation and re-ionized matter.
- Re-ionized matter scatters light strongly.
- Largest effect for points separated by
 - Speed of Light * age at re-ionization
- First stars & quasars turned on at 200Myr.



Polarization

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