

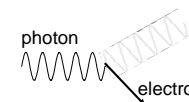
Decoupling between radiation and matter—10 Nov

- Homework
 - Average of Hwk 6: 32/36
 - Average of Hwk 7: 24/29
 - One paper without a name
- Important events in the history of the universe
 - Formation of helium (Done)
 - Universe becomes un-ionized. Radiation and matter decoupled (Today)
 - Galaxies and stars form (Later)
- Decoupling is when universe changed from ionized to neutral and opaque to transparent
- CBR is snapshot of universe at 300,000yr.
- WMAP satellite measured fluctuations in CBR

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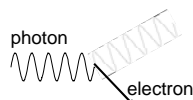
Ionized/un-ionized gas

- Ionization is the loss of an electron.
 $\text{H atom} \rightarrow \text{p} + \text{e}^-$
 - Recombination is when electron and nucleus combine.
 $\text{p} + \text{e}^- \rightarrow \text{H atom}$
 - Ionization occurs if the temperature is hot enough.
1. Name one thing in this room that is/has ionized gas.
 - A. 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.



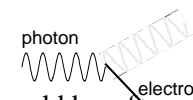
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- If the air were ionized, light would travel 500m before it is scattered. Light scatters nearly equally in all directions.
1. If the air were ionized, could you, sitting in Spartan Stadium, watch the Spartans beating Purdue? Could you see stars at night?
 - A. YY
 - B. YN
 - C. NY
 - D. NN



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- 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 Spartan Stadium, watch the Spartans beating Purdue? 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.

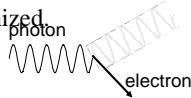


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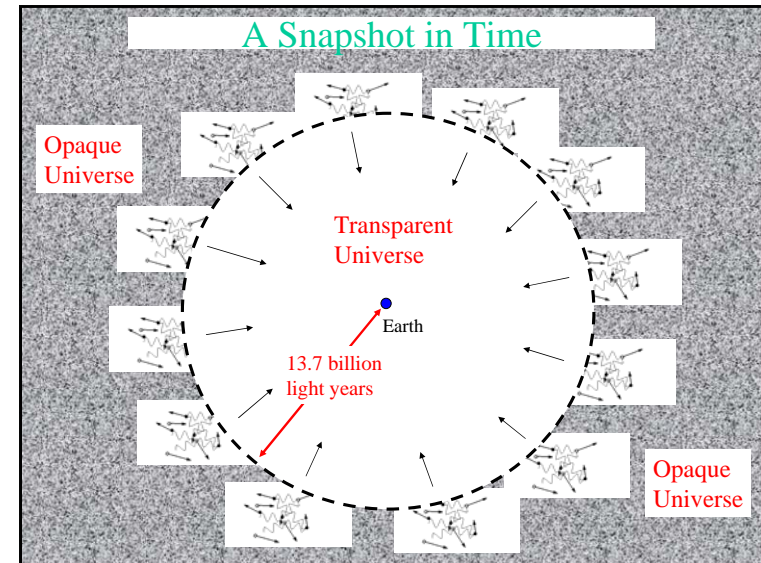
Matter and Radiation Become Decoupled

History

- In 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 300,000 yr old.
- Universe becomes transparent
 - Photons decouple from matter, continue in whatever direction they were moving.



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Cosmic background radiation

- Decoupling is when universe changed from ionized to neutral and opaque to transparent
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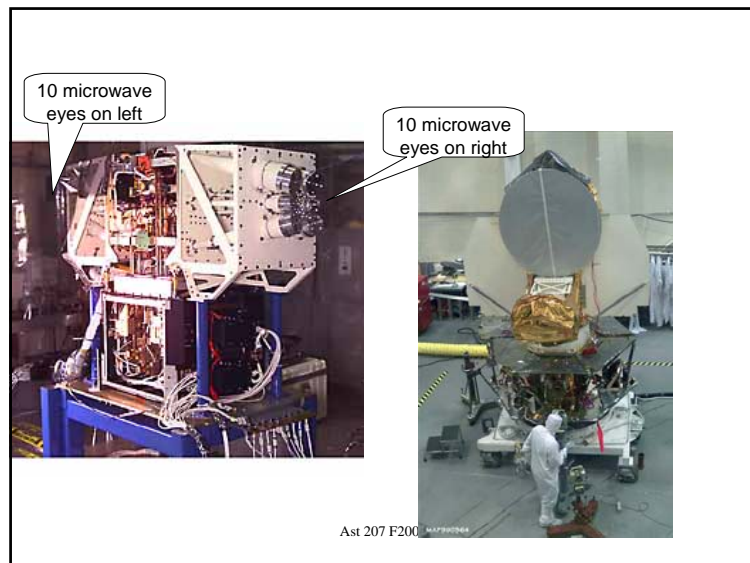
WMAP: Temperature of CBR

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

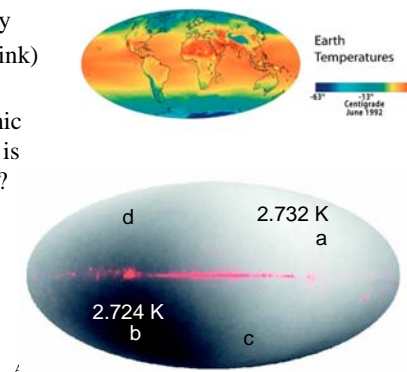


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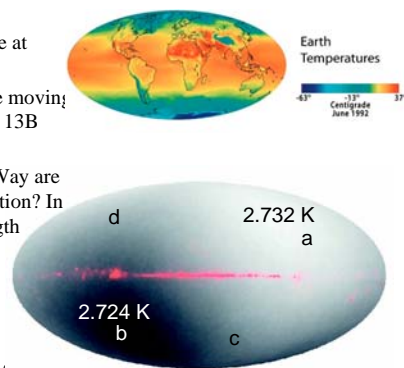
WMAP Results

- WMAP: Temperature of CBR across whole sky
 - Notice Milky Way (pink)
1. What are possible reasons that the Cosmic background radiation is hotter in direction (a)?



WMAP Results

- WMAP: Temperature of CBR across whole sky
 - CBR is snapshot of universe at 300,000 yr.
 - The earth, sun, and MW are moving with respect to the universe 13B light-years from us (now).
1. The earth, sun, and Milky Way are moving toward which direction? In which direction is wavelength compressed?
- Speed is 400 km/s



Cosmic background radiation

- Decoupling is when universe changed from ionized to neutral and opaque to transparent
- CBR is snapshot of universe at 300,000yr.
- WMAP satellite measured fluctuations in CBR
- More results of WMAP at the end of the term



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WMAP: Temperature of CBR