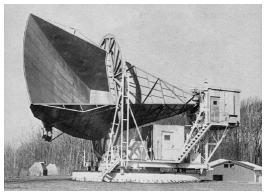
When Radiation Ruled—26 Oct

- At present, radiation from the Big Bang is weak
  - T = 2.7 K
  - Has no affect on history of universe
- In past, radiation from the Big Bang was
  - Hot enough to change matter
  - Denser than matter
- Temperature and expansion
  $T / T_{now} = 1/a$
  $a = Dist / Dist_{now}$



Universe now

Universe at 3min

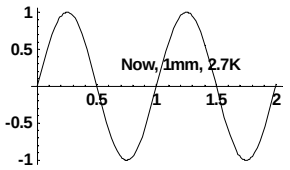
Matter: 0.1mg
$T=0.8\times10^9$K

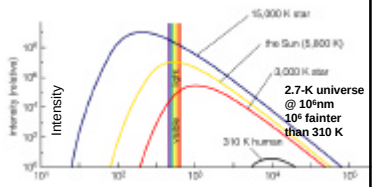
Rad: 0.6kg
$T=0.8\times10^9$K

Expansion stretches wavelength of light

- We see black-body radiation with T=2.7 K, and wavelength at the peak intensity $\lambda_{max} = 1$ mm.
  $\lambda_{max} = 2.7\text{mm-K} / T$ (Wein's Law)
- Wavelength of radiation stretches same as universe expands.

1. When the U was half the present size, what was the wavelength at the peak intensity and what was the temperature of the radiation? Not graded: What principle did you use?





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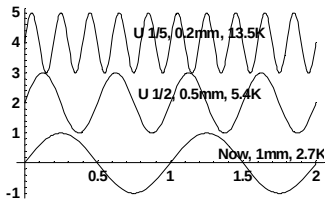


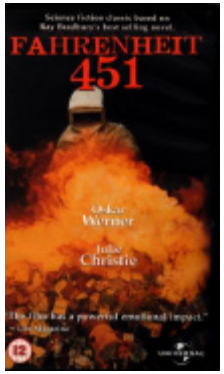
Book-burning Universe

- At one time, the universe was hot enough to burn paper
  - Occurs at 451 F = 500 K.
  - (In reality, there was no carbon and no paper at that time.)

2. Hoag's object is 300 Mpc from the Milky Way. How far was it when the U was just hot enough to burn paper?
3. What other reactions might have occurred when the universe was smaller & hotter?

Book-burning Universe

- What other reactions might have occurred when the universe was smaller & hotter?
- Events in the universe's life
- Recombination: U changed from opaque to transparent
  - Chemical reaction
  - Free p + e → hydrogen atom
- Production of helium
  - Nuclear reaction
  - Free protons + neutrons → helium nucleus



How mass density changes

- Fill a 2-L bottle with an average of the present universe
- Matter
  - Mass = 2×10^{-27}kg
    - Same mass as hydrogen atom
- Radiation (Light) has mass because radiation has energy
  - $E = m c^2$
- Radiation
  - 32 M photons in the bottle
  - Mass of each photon= 1.1×10^{-39}kg
  - Mass of light = 3.6×10^{-32}kg
    - Same mass as 1/50,000 hydrogen atom

Matter: 2×10^{-27}kg
Rad: 4×10^{-32}kg

How mass density changes

- Mass of matter = 2×10^{-27}kg
  - Same mass as 1 hydrogen atom
- Define expansion parameter

  a = distance between two galaxies / present distance

4. The expansion parameter a changes from ___ at the Big Bang to ___ at the present.

—End of class—

5. (2 pts.) The matter in the 2-L bottle used to occupy a smaller volume. When universe half the present size, how much volume did the matter in the 2-L bottle fill? The mass density at that time was ___ that of the present mass density.

Then

Matter: 2×10^{-27}kg
Rad: 4×10^{-32}kg