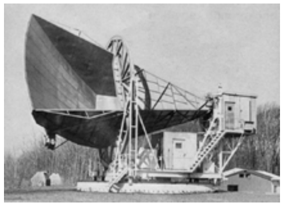
When Radiation Ruled—24 Oct

- Homework 7 is due on Wed, not Mon.
- Picture of Penzias & Wilson's equipment in Deutsches Museum, Munich, Germany (Thanks to Joel Adelsberg)

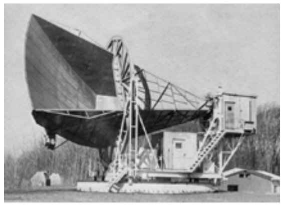


When Radiation Ruled—24 Oct

- 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

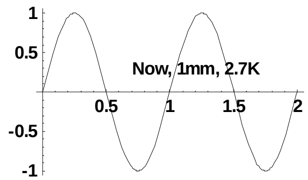
Rad: 0.6kg $T=0.8\times10^9$K

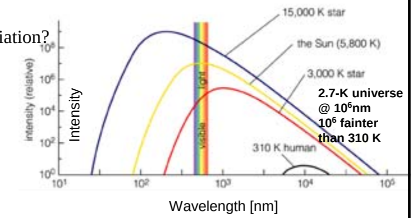
Expansion stretches wavelength of light

- We see black-body radiation with T=2.7 K, and wavelength at the peak intensity λ_{max}= 1 mm.

  λ_{max} = 2.7mm-K / T (Wein's Law)
- Principle: Wavelength of radiation stretches by the same factor as the universe expands.

1. When the U was half the present size, what was the wavelength at the peak intensity?
   A. 0.5 mm
   B. 1 mm
   C. 2 mm.
2. What was the temperature of the radiation?
   A. 1.3 K
   B. 2.7 K
   C. 5.4 K



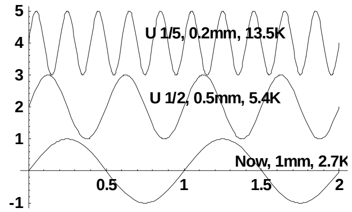


Expansion stretches wavelength of light

- Wavelength of radiation stretches by the same factor as the universe expands.

1. When the U was half the present size, what was the wavelength at the peak intensity? 0.5 mm
2. What was the temperature of the radiation? 5.4 K

- Key idea: When the universe was smaller (when the distance between us and some object was smaller), the temperature was hotter.



Book-burning Universe

- Key idea: When the universe was smaller (when the distance between us and some object was smaller), the temperature was hotter. There is no obvious limit to the temperature.
- At one time, the universe was too hot to have paper. (Paper burns.)
  – Occurs at 451 F = 500 K.
  – (In reality, there was no carbon and no paper at that time.)
- Define the expansion parameter a to be
  – a = distance between two objects/ present distance

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?
   A. 30 Mpc, a=1/10, T=2.7 * 10 = 27K
   B. 10 Mpc, a=1/30
   C. 3 Mpc, a= 1/100
   D. 1 Mpc, a= 1/300

Book-burning Universe

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1. What other familiar things were not possible at one time? What other reactions might have occurred when the universe was smaller & hotter.

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1. What other familiar things were not possible at one time? What other reactions might have occurred when the universe was smaller & hotter.

- U was too hot to have stars.
- U was too hot to have molecules.
- U was so hot that atoms were ionized.
- U was too hot to have nuclei other than hydrogen.

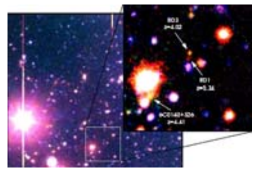
Book-burning Universe

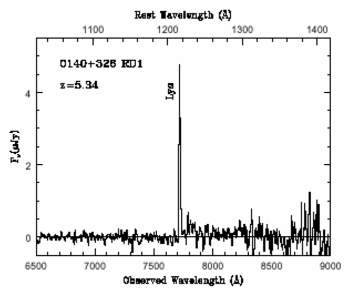
- Key idea: When the universe was smaller (when the distance between us and some object was smaller), the temperature was hotter. <u>There is no obvious limit to the temperature.</u>
- What other reactions might have occurred when the universe was smaller & hotter?
- Events in the universe's life
- First stars formed
  – When U cooled enough, gravity was able to overcome pressure.
- Recombination: U changed from opaque to transparent
  – Ionization & recombination
  – Free p + e → hydrogen atom
- Production of the first nuclei other than H
  – Nuclear reaction
  – Free protons + neutrons → helium nucleus

Expansion parameter & redshift

- Expansion parameter
  a = distance between two galaxies / present distance
  – The expansion parameter a changes from 0 at the Big Bang to 1 at the present.
- Universe expand the same as wavelength of light.

1. When the light that we see left galaxy 0140+326 RD1, its wavelength was 1215 Å (121.5nm). When the light that we see now left the galaxy, the expansion parameter of the universe was
   A. less than 1
   B. 1
   C. greater than 1.





Expansion parameter & redshift

- Expansion parameter
  a = distance between two galaxies / present distance
  – The expansion parameter a changes from 0 at the Big Bang to 1 at the present.
- Universe expand the same as wavelength of light.

1. When the light that we see left Galaxy 0140+326 RD1, its wavelength was 1215 Å (121.5nm). By what factor has the universe expanded since the time the light left that galaxy?
   - We see its wavelength to be 7710Å. U has expanded by a factor of 6.35 since the time the light left that galaxy.
   - a = 1215/7710 = 1/6.35.

- Redshift z
  z = 1/a – 1
  $z = \lambda_{received} / \lambda_{emitted} - 1$
  Speed = z × speed of light (for small z)
- For galaxy 0140+326 RD1,
  z=7710/1215 – 1 = 6.34 – 1 = 5.34