When radiation ruled—9 Nov

- Announcements
  - No class on Wed., 23rd.
  - Missouri Club?
- Outline
  - Evidence that Penzias & Wilson detected radiation from the Big Bang. (Finish discussion from Mon.)
  - Radiation dominated the universe at early times.
    - Objectives
      - Why did radiation rule?
      - How does radiation change the universe?

Is the radiation from the Big Bang?

- Penzias & Wilson, 1965, "A measurement of the excess antenna temperature at 4080Mc/s," ApJ 142, 419
  - "The excess temperature is … isotropic, unpolarized, and free from seasonal variation."
- Isotropic means <u>we observe</u> the same intensity in all directions.
  - Stars or nearby galaxies cannot be the source of the radiation, since they are not isotropic in the sky.
  - Radiation from the Big Bang is isotropic
    - An expansion that follows Hubble's Law has no unique center or every galaxy is at the center.
    - If you are at the center, no direction looks special.

Is the radiation from the Big Bang?

- Penzias & Wilson, 1965, "A measurement of the excess antenna temperature at 4080Mc/s," ApJ 142, 419
  - "The excess temperature is … isotropic, unpolarized, and free from seasonal variation."
- Free from seasonal variations means same intensity in summer and winter.

1. Is radiation from sources near the antenna (such as from some trees) free of seasonal variations? Is radiation from the Big Bang free of seasonal variations?
   A. YY
   B. YN
   C. NY
   D. NN

Is the radiation from the Big Bang?

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1. Is radiation from near the antenna (such as from some trees) free of seasonal variations? Is radiation from the Big Bang free of seasonal variations?
   - Trees or a farmer's cannot be the source of the radiation, since they are hotter in summer.
   - Radiation from the Big Bang is the same in summer and winter. Why?

The radiation is from the Big Bang

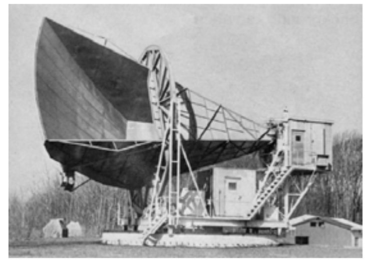
- Could many distant galaxies with a high temperature emit this radiation?
  - Since there is no galaxy in every line of sight, the emissivity is less than 1.
- Later, in 1967, Dicke, Roll, & Wilkinson showed that the spectrum of the radiation is thermal. The source is “black.”
- The only source that is black in every direction is the Big Bang.
  - In every direction, there is some matter.
- The radiation comes from the Big Bang.

When radiation ruled

1. Is the radiation from the universe hot enough to cook a turkey? Explain.
   A. No
   B. Yes

When Radiation Ruled

- 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
- How temperature and expansion are related.



Universe now

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

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

Universe at 3min

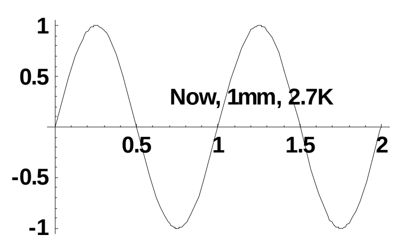
Expansion stretches wavelength of light

- Wein's Law

  $$\lambda\text{peak} = 2.9\text{mm K}/T$$

- 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



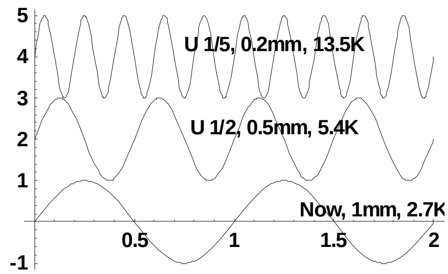
Expansion stretches wavelength of light and cools the radiation from the Big Bang

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

$$\lambda \text{peak} = 2.9\text{mm K} / T$$

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.



Expansion parameter

- Define the expansion parameter a
  a = (distance between two objects) / (present distance)
  - Two objects must be moving apart with the expansion of the universe. Eg., this does not apply for us & Andromeda.
  - a = $\lambda_{emit} / \lambda_{obs}$

1. The value of the expansion parameter is
   A. 1 at BB and 0 at present.
   B. 1 at present and 0 at BB
   C. 1 at both present time and at BB.
   D. None of other answers are correct.

- We found this relationship between temperature of the radiation from the Big Bang and expansion of the universe

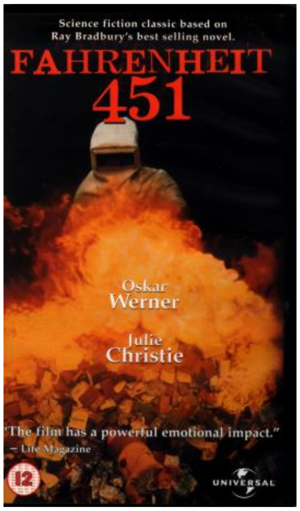
$$T = 2.7\text{K}/a$$

- Why does the radiation from the Big Bang affect the universe?

Book-burning Universe

- When the universe was smaller by a factor a (when the distance between us and some object was smaller), the temperature was hotter by a factor 1/a.
  $T = 2.7\text{K}/a.$
- At one time, the universe was too hot to have paper.
  - Paper burns 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?
   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

- 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.

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