Radiation from the Big Bang

- Four big discoveries in cosmology
  - Hubble's discovery of the expansion of universe. 1929
  - Radiation from BB. 1965
  - Dark matter. 1930s, 1970s
  - Accelerated expansion. 1998
- BB radiation inspires questions and offers some answers
  - Where did helium come from?
  - Where did radiation come from?
  - What is universe made of?
  - When did the first stars form?
- How did the radiation affect the history of the universe?

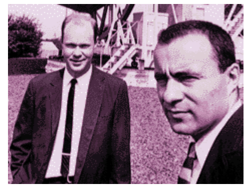
- Homework 7
  - Due 6:00 pm on Tues, April 28th
  - Just before Missouri Club
- Missouri (Show Me) Club
  - Tues, April 28th, 7:00-8:00pm
  - Room 1415.
- Final Exam
  - Wed, May 6th, 3:00-5:00
  - Room 1410 (our classroom)
  - One 8½ ×11 cheat sheet.
  - Covers entire course with more emphasis on galaxies & cosmology.
- Please rate your class at
  - rateyourclass.msu.edu
  - Closes on May 8th.

Test 3

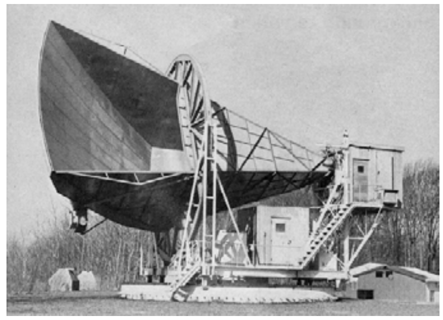
- Your test
  - loncapa.msu.edu
- Your grades
  - "Report" tab on angel.msu.edu
- Class
  - average: 27/41 (66%)
  - 75% scored above 23 (56%)
  - 25% scored above 32 (78%)

- Average has increased significantly
  - Test 1: 58%
  - Test 2: 61%
  - Test 3: 66%
  - Score of top 25% on Test 1 = average score on Test 3.
- Your grade at end of the course may change.
  - For 52% of students, grade changed by at least 0.5 since midterm.
  - Final exam counts for 35% of grade.

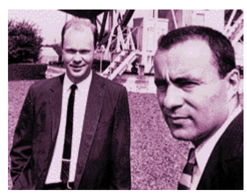
1965 Discovery of Radiation



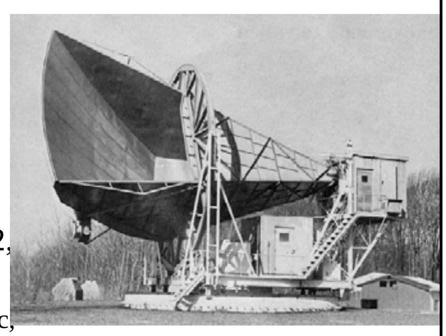
- Arno Penzias & Bob Wilson at Bell Labs in Holmdel, NJ, postdocs, wanted to use the 20-foot horn antenna from Echo Satellite program to do astronomy.
  - Boss says, “Arno & Bob, go measure the noise of the radio receiver.”
- Measured the “noise temperature” of 6.7 K.



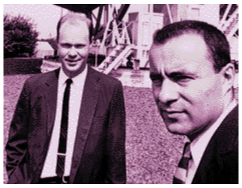
1965 Discovery of Radiation



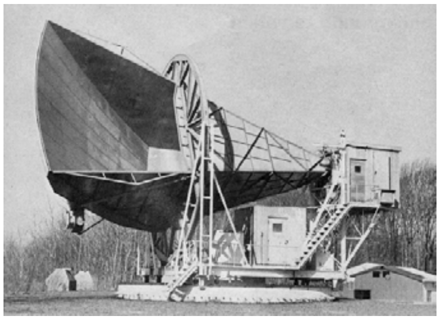
- Measured the “noise temperature” at wavelength 30cm. Their result: the temperatures are
  - Total 6.7 K
  - Sky 2.3 K
  - Antenna 0.9 K
  - Unaccounted 3.4 K
- Penzias & Wilson, 1965, “A measurement of the excess antenna temperature at 4080Mc/s,” ApJ 142, 419
  - “The excess temperature is … isotropic, unpolarized, and free from seasonal variation.”



1965 Discovery of Radiation from Big Bang

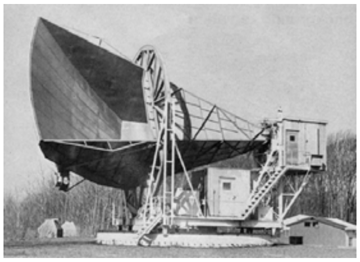


- What does radiation from the Big Bang look like?
  - Radiation was emitted when the universe was much smaller. (Coma is now 300M light-years from us. Distance was miniscule then.)
  - Light traveled 13Byr and reached us.
  - There is no unique center of the universe. We are a center.



1. Is the radiation from the Big Bang isotropic (look the same in all directions)? Would radiation from the BB change with the seasons?
   A. Yes. Yes
   B. No. No
   C. Yes. No
   D. No Yes.

When Radiation Ruled



Universe now

- 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 at 3min

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

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

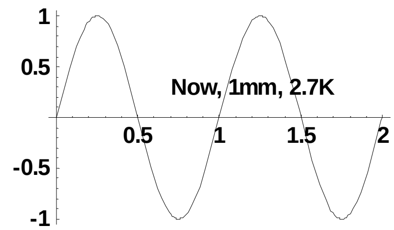
Expansion stretches wavelength of light

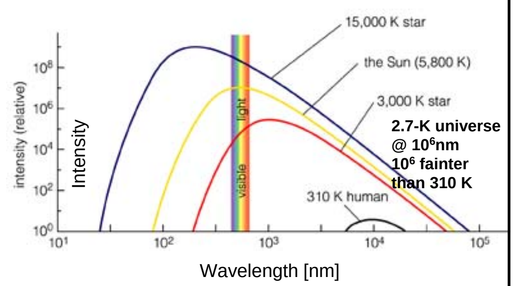
- We see black-body radiation with T=2.7 K, and wavelength at the peak intensity

  $\lambda_{max} = 1$ mm.

  $\lambda_{max} = 2.7$mm-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
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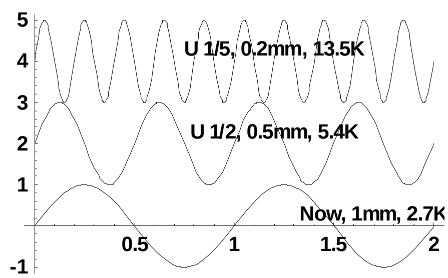
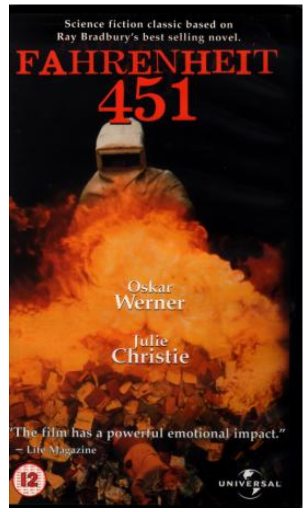
- Key idea: When the universe was smaller (when the distance between us and some object was smaller), the temperature was hotter.



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 expansion parameter was ½?
   A. 600 Mpc
   B. 300 Mpc
   C. 150 Mpc
   D. 1200 Mpc



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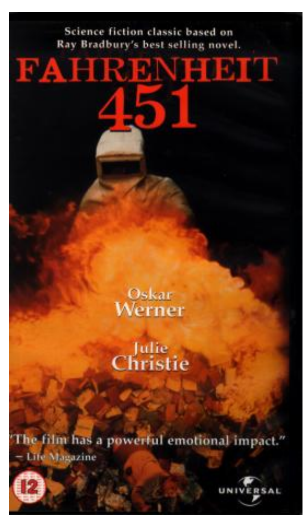
- Define the expansion parameter a to be
  - a = distance between two objects/ present distance

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

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