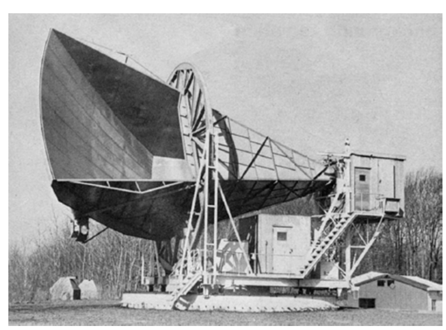
Radiation from the Big Bang—5 Nov

- Homework 8 is on angel. Due noon, Mon, 15 Nov.
- Homework 9 will be due Fri, 19 Nov at start of class. No late papers. Covered on Test 3.
- Test 3 is Mon, 22 Nov.
- No class on Wed before Thanksgiving.

- Four most important discoveries in cosmology
  - Hubble's Law, expansion of universe 1929
  - Radiation from Big Bang 1965
  - Dark matter 1930s, 1970s
  - Accelerated expansion 1998
- Did the radiation that Penzias & Wilson discover come from the Big Bang?
  - Objectives:
    - To interpret evidence & draw conclusions. What is the evidence?
    - To answer an important question in a simple way. Your parents ask you, "How do you know the Big Bang occurred?" (We know two answers.)
- When radiation ruled the early history of the universe.

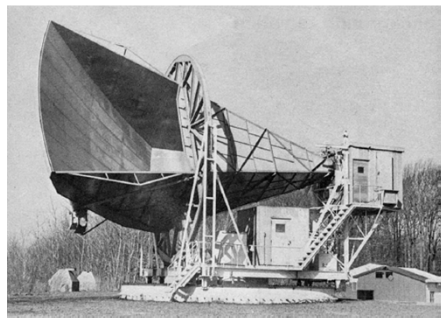
1965 Discovery of Radiation

- Measured the "noise temperature" at wavelength 30cm. (A perfectly black source of the "noise temperature" emits an amount of radiation equal to the measured amount.) Their result: If the sources are black (emissivity =1), then the temperatures are
  - Total 6.7 K
  - Sky 2.3 K
  - Antenna 0.9 K
  - Unaccounted 3.4 K

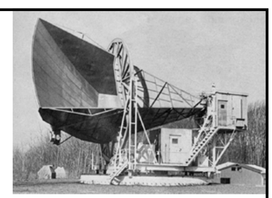


How P&W measured sky temperature

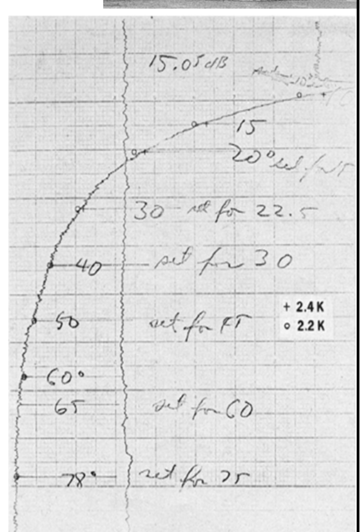
- P & W measured the "noise temperature"
  - Total 6.7 K
  - Sky 2.3 K
  - Antenna 0.9 K
  - Unaccounted 3.4 K
- P & W measured the sky to emit the same radiation as a 2.3-K blackbody. How did they measure the amount of radiation that the sky emits? (They did not use a thermometer.)



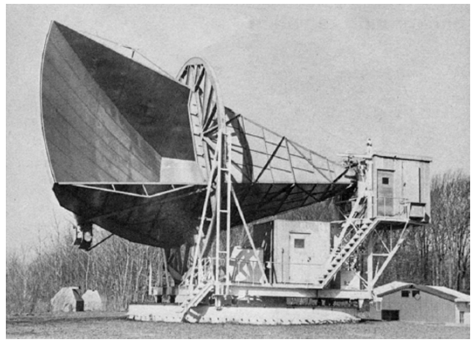
How P&W measured sky temperature



- They pointed the antenna
  - almost straight up (78°).
  - and then at 15° from the horizon and got more light.



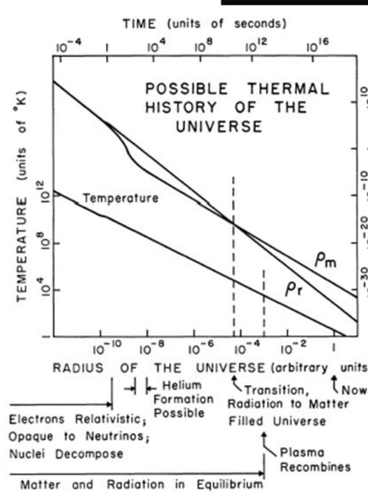
Penzias & Wilson's conclusion



- P & W measured the "noise temperature"
  - Total 6.7 K
  - Sky 2.3 K
  - Antenna 0.9 K
  - Unaccounted 3.4 K
- The total amount of radiation is equivalent to a black body with temperature 6.7K. We can account for 3.2 K of it. We cannot account for 3.4 K of it.

Is radiation from the BB?

- 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."
- Dicke, Peebles, Roll, & Wilkinson, 1965, "Cosmic Black-body Radiation," ApJ 142, 414.
  - "Could the universe have been filled with black-body radiation from this possible high-temperature state?
- The excitement was that this radiation could be from the Big Bang. Was there evidence in support or evidence that refutes?



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. It does not means the source emits the same in all directions.
- Free from seasonal variations means the intensity in summer and winter are the same.

1. Would we observe radiation from the sun to be isotropic? Is radiation from the Big Bang isotropic?
   A. YY
   B. YN
   C. NY
   D. NN
2. 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? Same foils.

Radiation is from the Big Bang

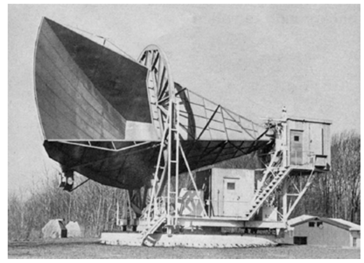
- Penzias & Wilson, 1965, "A measurement of the excess antenna temperature at 4080Mc/s," ApJ 142, 419
  - "The excess temperature is … isotropic, unpolarized, and free from seasonal variation."
- Isotropic means <u>we observe</u> the same intensity in all directions.
  - Stars or nearby galaxies cannot be the source of the radiation, since they are not isotropic in the sky.
- Free from seasonal variations means same intensity in summer and winter.
  - The environment (trees, grass, antenna) cannot be the source of the radiation, since their temperatures vary with the seasons.
- 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.
- The radiation comes from the Big Bang.

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
- 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

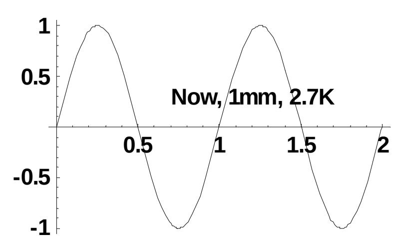
Rad: 0.6kg $T=0.8\times10^9$K

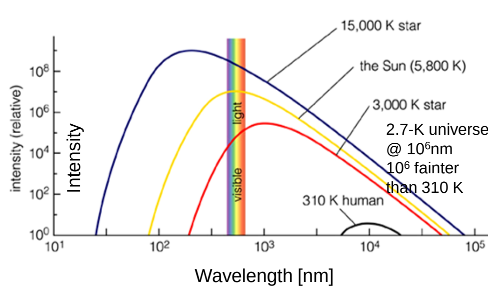
Expansion stretches wavelength of light

- 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





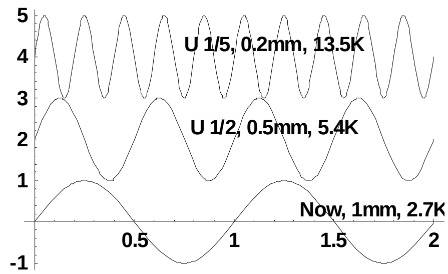
Expansion stretches wavelength of light and cools the radiation from the Big Bang

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

  λ_{max} = 2.7mm-K / T (Wein's Law)

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.



How much hotter was the universe?

- Key idea: When the universe was smaller (when the distance between us and some object was smaller), the temperature was hotter.
- 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 = 1/(1+z)
  – 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.

- Key idea, stated more precisely: 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=2.7K/a.