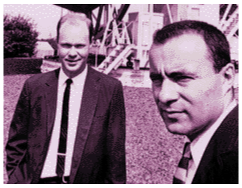
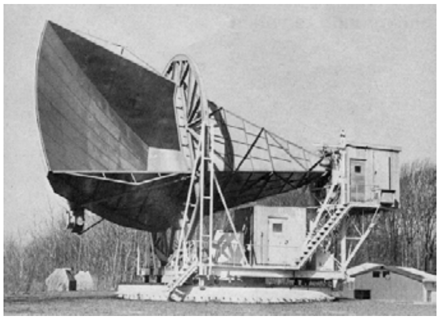
Radiation from the Big Bang—4 Nov

- Four most important discoveries in cosmology
  - Hubble's Law, expansion of universe 1929
  - Radiation from BB 1965
  - Dark matter 1930s
  - Accelerated expansion 1998
- Discovery (today)
- Radiation determines the early history of the universe (Fri & Mon)
- Observing if weather is clear
  - Wed & Thurs, Nov 18 & 19, from 6:30-10:00pm
  - Attend only if stars are visible. See angel after 5:00pm, if weather is ambiguous.
  - Quiz. You will be asked to locate a star using the Abrams Planetarium star chart. Quiz counts as one clicker assignment.
  - Go to the south end of the building (toward Wilson Rd.) & take the elevator up to the penthouse. Elevator cannot go up after 10:00.

1965 Discovery of Radiation

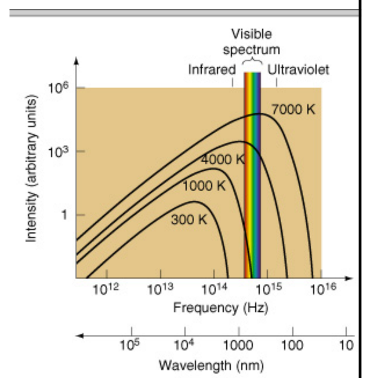
- Arno Penzias & Bob Wilson at Bell Labs in Holmdel, NJ, postdocs, wanted to use the 20-foot horn antenna from Echo Satellite program to do astronomy.
  - Boss says, "Arno & Bob, go measure the noise of the radio receiver."
- Measured the "noise temperature" of 6.7 K.





Thermal Radiation

- Thermal radiation, also called black-body radiation
  - Emitted by anything warm
  - Wavelength changes with temperature
    - λpeak $\times$T=2.9mm K (Wien's Law)
    - For the sun, T=5700K and λpeak =2.9mm/5700K=.0005mm=500nm
    - For a person, T=273+37=310K. λpeak =2.9mm/310K=.01mm (infrared)
    - For universe, T=2.73K. λpeak =2.9mm/2.73K=1mm (microwave)

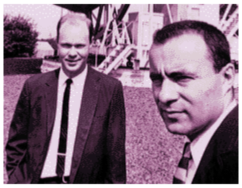


Thermal Radiation: emissivity

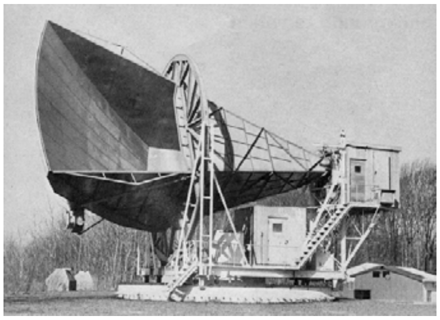
- Amount of radiation depends on emissivity.
- Shine light on a surface. Emissivity = fraction of light absorbed. (The rest is reflected.)
  - Emissivity = 1 for a black surface
  - Emissivity = 0 for a mirror
- Energy emitted per second depends on Area$\times$**emissivity**$\times T^4$.
  - For mirror, energy emitted is zero.
  - For black surface, energy emitted is AreaT^4

1. I shine light on a surface, and 10% is absorbed. This surface emits more like ___. I shine light out into space. Space emits more like ___.
   A. a mirror for both
   B. <u>mirror. black surface</u>.
   C. black surface. mirror.
   D. a black surface for both

1965 Discovery of Radiation



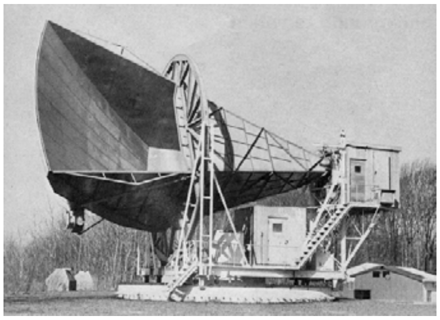
- Measured the “noise temperature” at wavelength 30cm. (A perfectly black source of the “noise temperature” emits an amount of radiation equal to the measured amount.) Their result: If the sources are black (emissivity =1), then the temperatures are
  - Total 6.7 K
  - Sky 2.3 K
  - Antenna <u>0.9 K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



1. On a summer day, the temperature of the antenna is about 300K, and yet they measured its “noise temperature” to be 0.9K. The two temperatures disagree because
   A. The antenna is almost black.
   B. <u>The antenna is nearly a mirror</u>.
   C. A 300 degree black body emits very little light at wavelength 30 cm.

Antenna temperature

- P & W measured the “noise temperature”
  - Total 6.7 K
  - Sky 2.3 K
  - Antenna <u>0.9 K</u>
  - Unaccounted 3.4 K
- Could not account for 3.4 K
  - “Pigeons… had covered the inside with a white material familiar to all city dwellers. We…cleaned up their mess, but obtained only a small reduction in antenna temperature.”

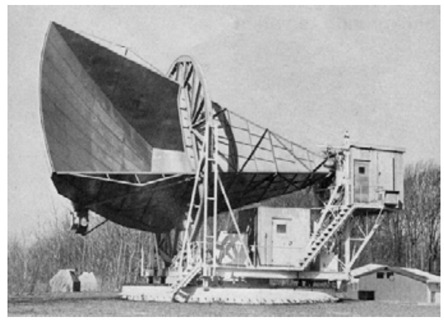


1. “White material” raises the antenna temperature, because
   A. <u>it absorbs light with wavelength 30 cm</u>.
   B. it reflects light with wavelength 30 cm.
   C. it is hotter than the antenna.

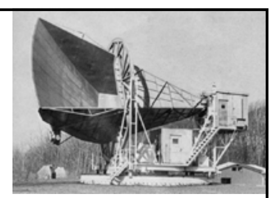
How P&W measured sky temperature

- P & W measured the "noise temperature"
  - Total 6.7 K
  - Sky 2.3 K
  - Antenna 0.9 K
  - Unaccounted 3.4 K

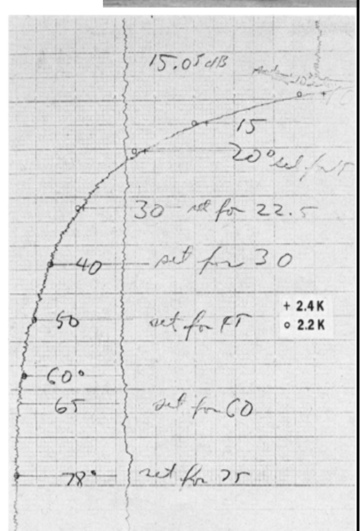
2. P & W measured the sky to emit the same radiation as a 2.3-K blackbody. How did they measure the amount of radiation that the sky emits? (They did not use a thermometer.)



How P&W measured sky temperature

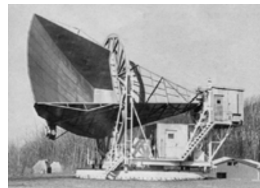


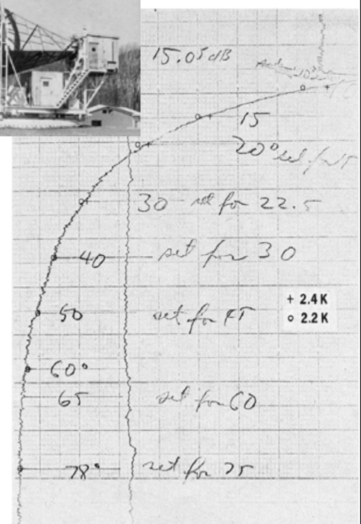
- P & W measured the "noise temperature"
  - Total 6.7 K
  - Sky 2.3 K
  - Antenna 0.9 K
  - Unaccounted 3.4 K
- They pointed the antenna
  - almost straight up (78°).
  - and then at 15° from the horizon and got more light.
- How is this possible?



Penzias & Wilson's conclusion

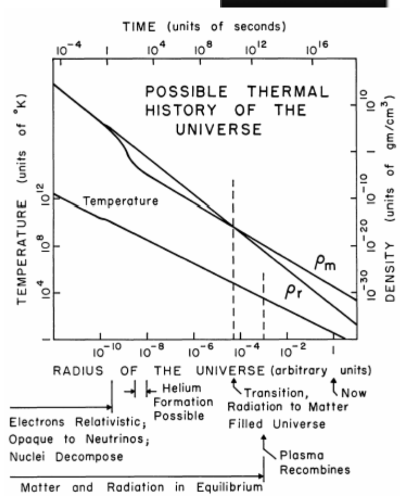
- P & W measured the "noise temperature"
  - Total 6.7 K
  - Sky 2.3 K
  - Antenna <u>0.9 K</u>
  - Unaccounted 3.4 K
- The total amount of radiation is equivalent to a black body with temperature 6.7K. We can account for 3.2 K of it. We cannot account for 3.4 K of it.





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 we observe 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.

3. 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
4. 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? NY

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 we observe 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.

Summarizing questions

- Your parents ask you, “How do you know the Big Bang occurred?” (We know two answers.)
- What is the evidence that the radiation that P&W discovered comes from the Big Bang?