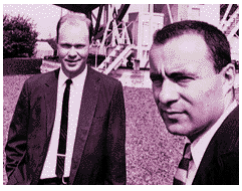
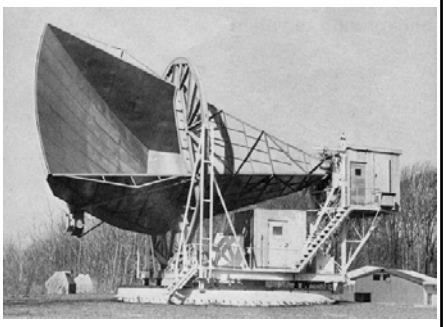
Radiation from the Big Bang—7 Nov

- Four most important discoveries in cosmology
  - Hubble's Law, expansion of universe 1929
  - Radiation from BB 1965
  - Dark matter 1930s, 1970s
  - Accelerated expansion 1998
- Outline
  - Discovery of cosmic background radiation (today)
    - Did the radiation that Penzias & Wilson discover come from the Big Bang?
    - Objective: To interpret evidence & draw conclusions. What is the evidence?
  - Radiation determines the early history of the universe (Wed)

1965 Discovery of Radiation from the Big Bang

- 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 a "noise temperature" of 6.7 K.



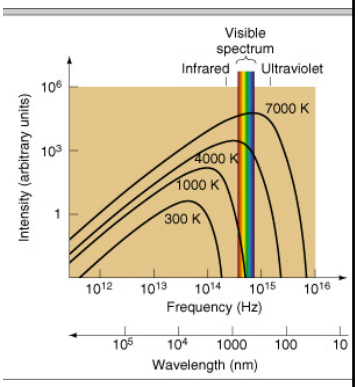


Thermal Radiation

- Thermal radiation, also called black-body radiation
  - Emitted by anything warm
  - Wien's Law: Wavelength changes with temperature

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

    - For the sun, T=5700K
      λpeak =2.9mm/5700K=500nm
    - For a person, T=273+37=310K.
      λpeak =.01mm (infrared)
    - For universe, T=2.73K.
      λpeak =1mm (microwave)

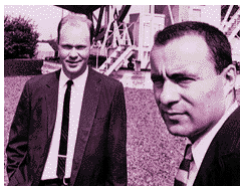


Thermal Radiation: emissivity

- 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×**emissivity**×T^4.
  - For mirror, energy emitted is zero.
  - For black surface, energy emitted is AreaT^4

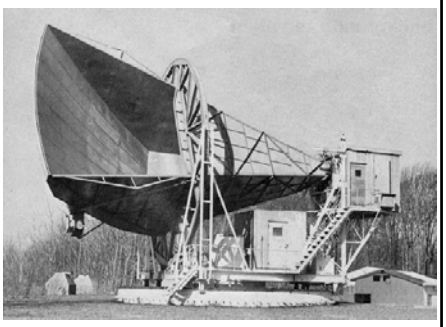
1. I shine light on a surface, and 10% is absorbed. This surface emits more like ___. I shine light out into space. Space emits more like ___.
   A. a mirror for both
   B. mirror. black surface.
   C. black surface. mirror.
   D. a black surface for both

1965 Discovery of Radiation



- Penzias & Wilson's measured the radiation at wavelength 30cm.
- They reported the amount of radiation as a temperature. If the sources are black (emissivity =1), then the temperatures are:

Source	Radiation
Total	6.7K
Sky	2.3K
Antenna	0.9K
Unaccounted	3.4K

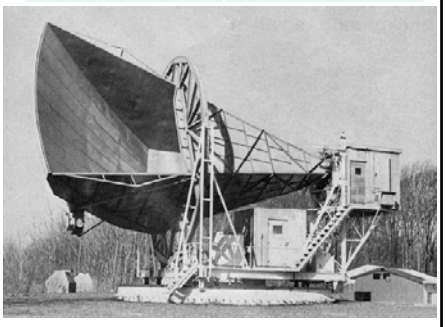


Meaning of "Antenna temperature"

Source	Radiation
Total	6.7K
Sky	2.3K
Antenna	0.9K
Unaccounted	3.4K

- P&W reported the amount of radiation as a temperature. If the sources are black (emissivity =1), then the temperatures are in the table.

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

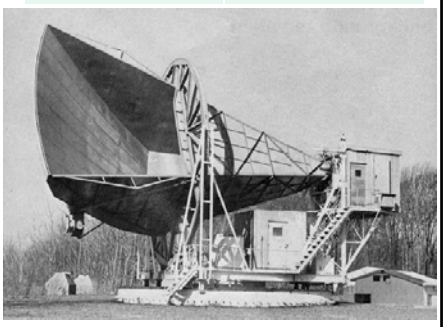


Antenna temperature

Source	Radiation
Total	6.7K
Sky	2.3K
Antenna	0.9K
Unaccounted	3.4K

- 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."

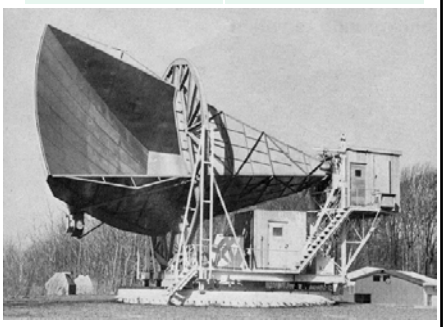
1. "White material" raises the antenna temperature, because
   A. it absorbs light with wavelength 30 cm.
   B. it reflects light with wavelength 30 cm.
   C. it is hotter than the antenna.



How P&W measured sky temperature

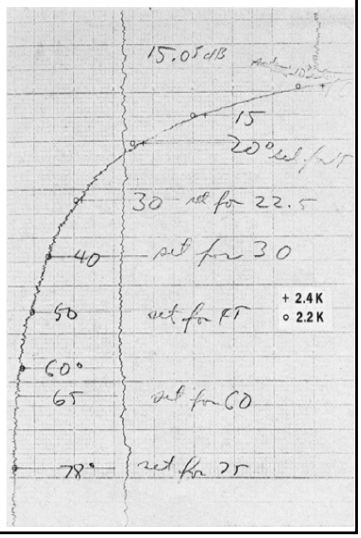
Source	Radiation
Total	6.7K
Sky	2.3K
Antenna	0.9K
Unaccounted	3.4K

- P & W measured the sky to emit the same radiation as a 2.3-K blackbody.
- By "sky," they mean the radiation emitted by the air molecules.
- How did they measure the amount of radiation that the air molecules emit? (They did not use a thermometer.)



How P&W measured sky temperature

- The effect:
  - When the antenna is pointed straight up, the antenna collects radiation from 1 layer of air.
  - When the antenna is toward the horizon, the antenna collects radiation from a thicker layer of air.
- Have you observed this effect?
- 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 total "temperature" and the temperature of two known sources.
- They report: 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.

Source	Radiation
Total	6.7K
Sky	2.3K
Antenna	0.9K
Unaccounted	3.4K

Is radiation from the Big Bang?

Bob Dicke

- 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.

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.