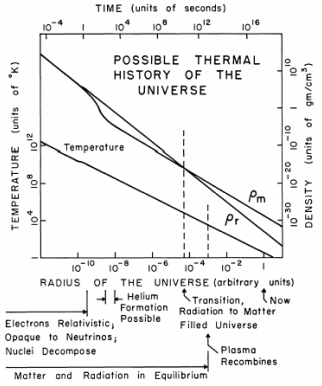
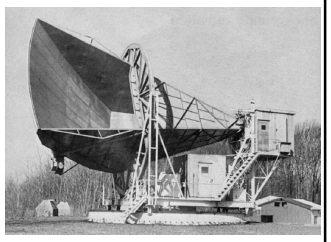
Radiation from the Big Bang—24 Oct

- Big 4 discoveries in cosmology
  - Expansion of Universe 1929
  - Radiation from BB 1965
  - Dark matter 1930s
  - 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?
- Discovery
- Radiation drives early history of the universe



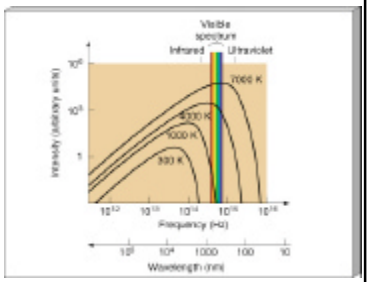
1965 Discovery of Radiation

- 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"
  - Total 6.7 K
  - Sky -2.3 K
  - Antenna -0.9 K
  - Unaccounted 3.4 K



Thermal Radiation

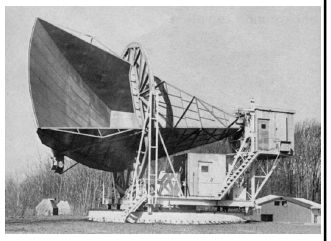
- Thermal radiation, also called black-body radiation
  - Emitted by anything warm
  - Wavelength changes with temperature
    - λpeak ×T=2.9mm K (Wien's Law)
    - For the sun, T=5700K and λpeak =2.9mm/5700K=.0005mm=500nm
    - For a person, T=273+37=310K. λpeak =2.9mm/310K=.01mm (infrared)
    - For universe, T=2.73K. λpeak =2.9mm/2.73K=1mm (microwave)
- A star or hot plate emits radiation. Energy emitted per second depends on Area×**emissivity**×T^4.
  - Emissivity = 1 for a black surface
  - Emissivity = 0 for a mirror



Antenna temperature

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

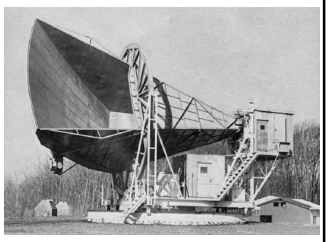
1. Why would "white material" raise the antenna temperature?



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
- Sky temperature

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.)



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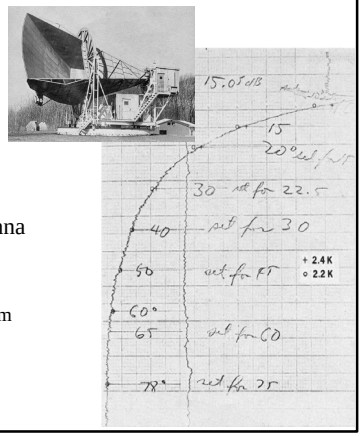
  - "The excess temperature is … isotropic, unpolarized, and free from seasonal variation."



Source of Radiation

- 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
- Free from seasonal variations means same intensity in summer and winter.

3. Is radiation from the sun isotropic? Explain.
4. Is radiation from the antenna free of seasonal variations? Explain.
5. Is radiation from the Big Bang isotropic?
6. Is radiation from the Big Bang free of seasonal variations?

Radiation is from 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?