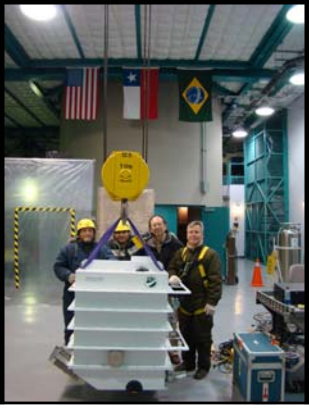
Spartan Infrared Camera at the SOAR Telescope

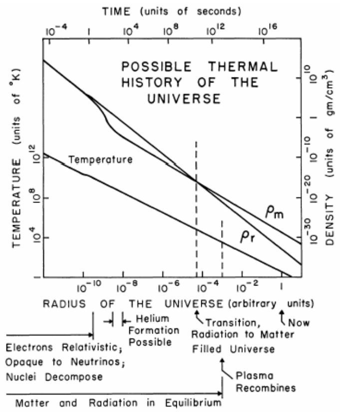


Radiation from the Big Bang—20 Oct

1. Your parents ask you, “How do you know the Big Bang occurred?”

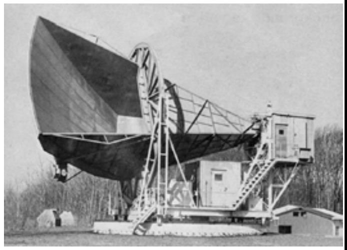
Radiation from the Big Bang—20 Oct

- Four big 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 (today)
- Radiation drives early history of the universe (rest of week)



1965 Discovery of Radiation

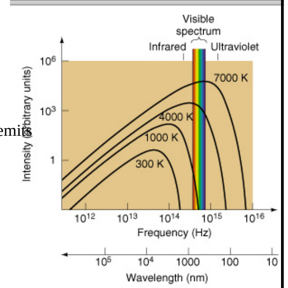
- Arno Penzias & Bob Wilson at Bell Labs in Holmdel, NJ, postdocs, wanted to use the 20-foot horn antenna from Echo Satellite program to do astronomy.
  - Boss says, “Arno & Bob, go measure the noise of the radio receiver.”
- Measured the “noise temperature” of 6.7 K.



Thermal Radiation

- Thermal radiation, also called black-body radiation
  - Emitted by anything warm
  - Wavelength changes with temperature
    - λpeak ×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)
- 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

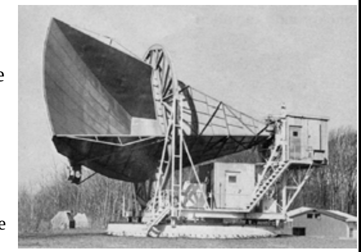
1. I shine light on a surface, and 10% is absorbed. This surface emits more like
   A. a mirror
   B. a black surface.
2. I shine light out into space. This surface emits more like
   A. a mirror
   B. a black surface



1965 Discovery of Radiation

- Measured the "noise temperature" at wavelength 30cm. 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

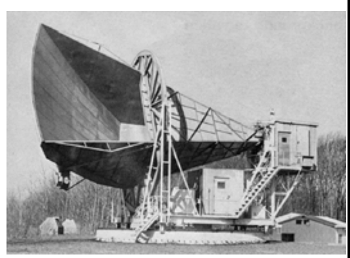
1. On a summer day, the temperature of the antenna is about 300K, and yet they measured its "noise temperature" to be 0.9K. The two temperatures disagree because
   A. The antenna is almost black.
   B. The antenna is nearly a mirror.
   C. A 300 degree black body emits very little light at wavelength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

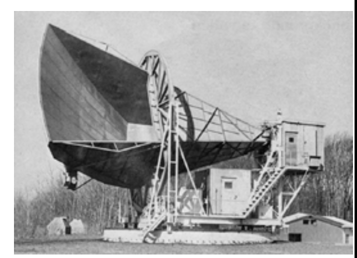
1. "White material" would raise the antenna temperature, because
   A. it absorbs light with wavelength 30 cm.
   B. it reflects light with wavelength 30 cm.
   C. it is hotter than the antenna.



How P&W measured sky temperature

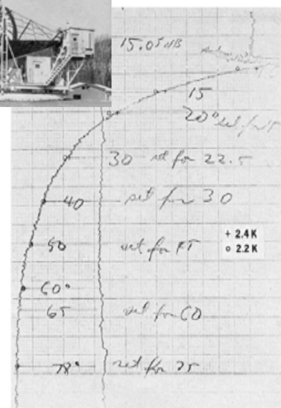
- P & W measured the "noise temperature"
  - Total 6.7 K
  - Sky 2.3 K
  - Antenna <u>0.9 K</u>
  - Unaccounted 3.4 K
- Sky temperature

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.)



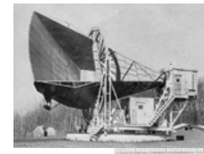
How P&W measured sky temperature

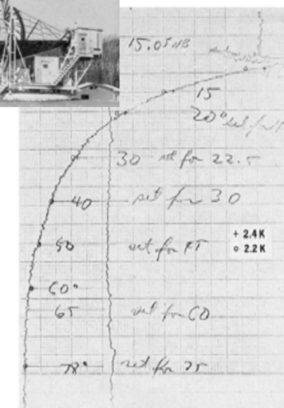
- P & W measured the “noise temperature”
  - Total 6.7 K
  - Sky 2.3 K
  - Antenna 0.9 K
  - Unaccounted 3.4 K
- They pointed the antenna
  - almost straight up
  - at 15° from the horizon and got more light.
- How is this possible?



Penzias & Wilson’s conclusion

- P & W measured the “noise temperature”
  - Total 6.7 K
  - Sky 2.3 K
  - Antenna 0.9 K
  - Unaccounted 3.4 K
- We can account for radiation equivalent to a black body with temperature 3.2 K. We cannot account for radiation equivalent to a black body with temperature 3.4 K.





What Penzias & Wilson wrote

- 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.
- We are Bob Dicke in 1965 analyzing P & W’s measurement. (Since Bob Dicke was building equipment to do what P & W had already done, it took him 1s to do this analysis.) What are possible sources of the radiation?