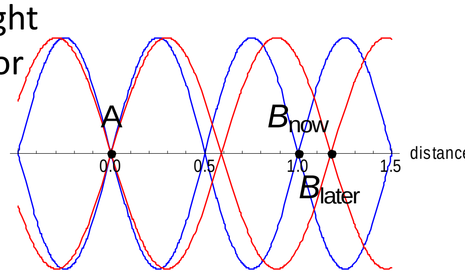
# Radiation from the Big Bang—3 Nov

- Examples of distant objects
  - Objective: How is redshift related to the expansion of the universe?
- Four most important discoveries in cosmology
  - Hubble's Law, expansion of universe 1929
  - Radiation from BB 1965
  - Dark matter 1930s, 1970s
  - Accelerated expansion 1998
- Discovery of cosmic background radiation (today)
- Radiation determines the early history of the universe (Fri & Mon)

## Expansion stretches wavelength of light

- Principle: Wavelength of light stretches by the same factor as the universe expands.

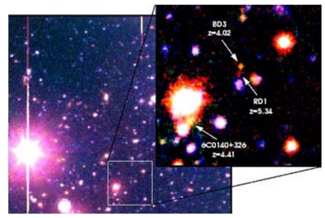


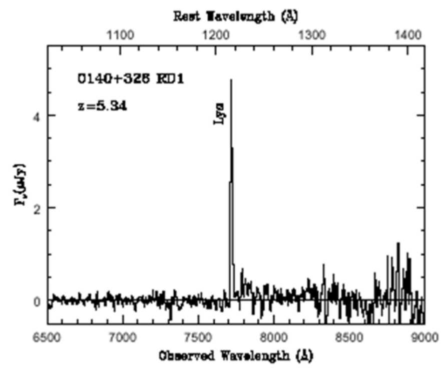
## Example: Very distant galaxy

- Galaxy found by looking for red objects
- Key idea: Universe expands the same as wavelength of light.

1. When the light that we see left Galaxy 0140+326 RD1, its wavelength was 1215 Å (121.5nm). We see its wavelength to be 7710Å. By what factor has the universe gotten bigger?
   A. About 6500
   B. between 3 & 4
   C. between 4 & 5
   D. between 5 & 6
   E. between 6 & 7

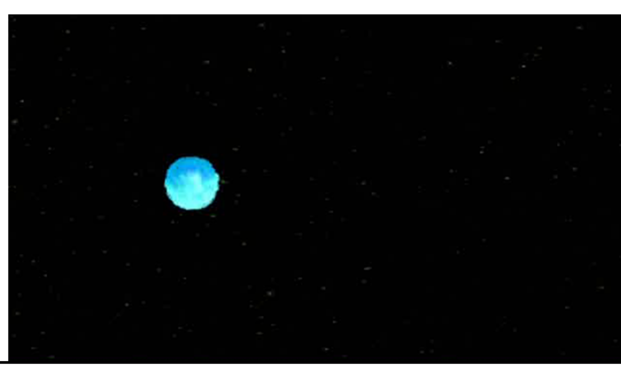
- U has expanded by a factor of 6.35 since the time the light left that galaxy.
  $D_{now}/D_{lightEmitted} = \lambda_{received}/\lambda_{emitted}$
  $= 7710/1215 = 6.35.$
- Redshift $z = \lambda_{received}/\lambda_{emitted} - 1$
- $D_{now}/D_{lightEmitted} = 1+z$






## Example: Gamma ray burst

- Gamma-ray burst is a short pulse of gamma rays (more energetic than X-rays).
- Some gamma-ray bursters are stars that collapse at the end of their life to produce a black hole.
  - Animation http://www.nasa.gov/mission_pages/swift/bursts/cosmic_record.html



## Gamma ray burster 090423

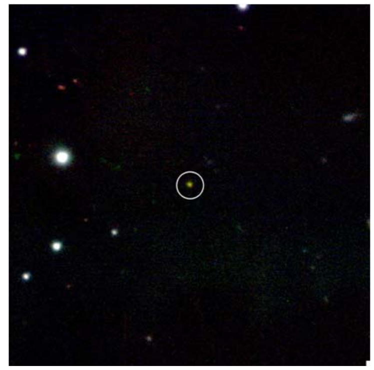
"Light coming to us from such a distance is stretched because the universe is expanding. The greater the stretching — called redshift — the more distant the object. The previous most-distant object, a galaxy, has a redshift of 6.96. GRB 090423 has a redshift of 8.2 and appears to observers as an extremely red point of light. When that explosion took place, the universe was more than ___ times smaller than it is now. It's one thing to explore such remote recesses of time in theory. It's something else again to witness their afterglow. And GRB 090423 is an invitation for all of us to unfetter our imaginations. We imagine looking outward from that distant point knowing that our own exploration still lies some 13 billion years in the future."—NY Times Editorial 10/30/09

- How big was the universe when the star died?
  - Key idea: U expands the same as wavelength of light
  - Definition of redshift z

    $1+z = \lambda_{received} / \lambda_{emitted}$.

1. By what factor has the universe gotten bigger?
   A. between 5 & 6 times bigger
   B. between 6 & 7
   C. between 7 & 8
   D. between 8 & 9
   E. between 9 & 10

- $D_{today}/D_{starDied} = 1+z = 1+8.2 = 9.2$



Gemini Observatory/NSF/AURA/D. Fox, A. Cucchiara (Penn State), & E. Berger (Harvard)

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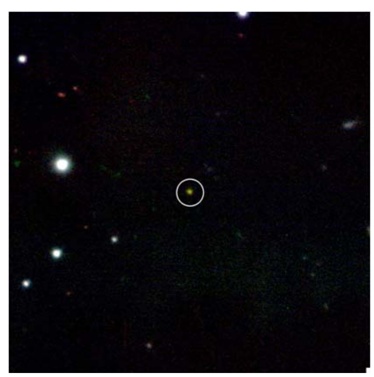
  - Key idea: U expands the same as wavelength of light
  - Definition of redshift z

    $1+z = \lambda_{received} / \lambda_{emitted}$.
- By what factor has the universe gotten bigger?
- $D_{today}/D_{starDied} = 1+z = 1+8.2 = 9.2$
- How old was the universe when the star died?
  - Key idea: H's Law: v = H D
  - Key idea: speed does not change much.
  - Key idea: Age of U is approx. 1/H.
  - Present age of U is 13Byr.

1. Hubble's constant was
   A. same as present value
   B. 9.2 times its present value
   C. 1/9.2 of its present value

- Not completely accurate b/c speed changes.
- The U was younger by a factor of 9.2 when star died b/c of key idea that age of U is approx. 1/H.
  - A better calculation: U was 600Myr old when star died.



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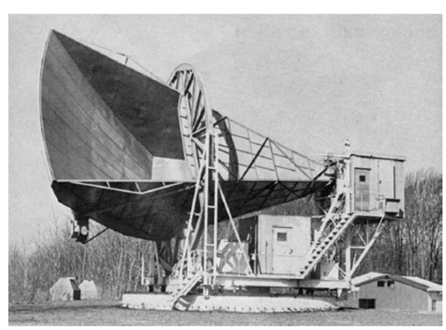
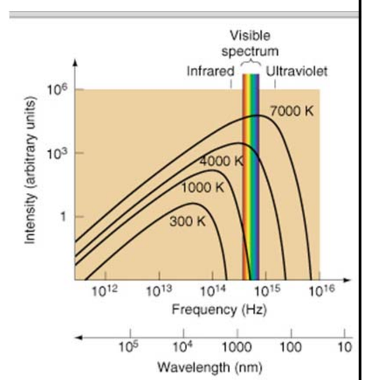
## 1965 Discovery of Radiation from the Big Bang

- 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
  - Wavelength changes with temperature
    - $\lambda$peak $\times$T=2.9mm K (Wien's Law)
    - For the sun, T=5700K and $\lambda$peak =2.9mm/5700K=.0005mm=500nm
    - For a person, T=273+37=310K. $\lambda$peak =2.9mm/310K=.01mm (infrared)
    - For universe, T=2.73K. $\lambda$peak =2.9mm/2.73K=1mm (microwave)



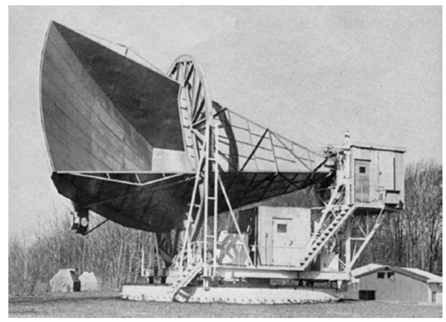

## Thermal Radiation: emissivity

- 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 Area$T^4$

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

- 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



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.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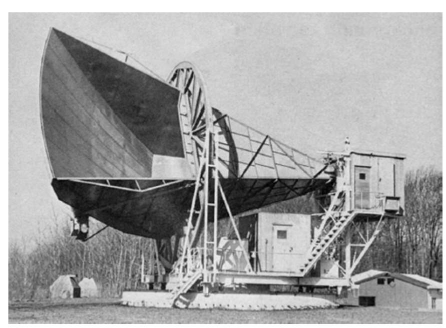


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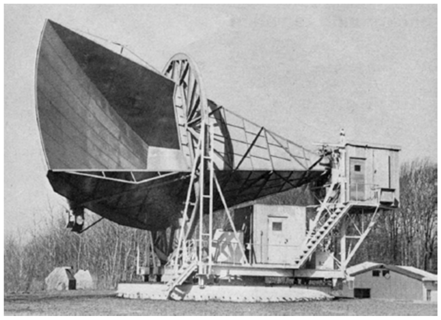
# Antenna temperature

- 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. "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.