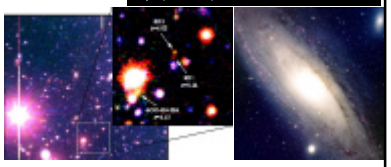
Far, Far Away—28 Oct

- Distant objects
  - Galaxies
  - Quasars (black hole in center of galaxies)
  - Distant objects are younger
  - Redshift
- At some time, there were no objects.
  - Pressure of radiation prevents gravity from forming stars and galaxies.

Many numerical errors on 26 Oct. Download corrected slides.

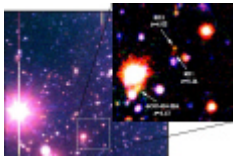


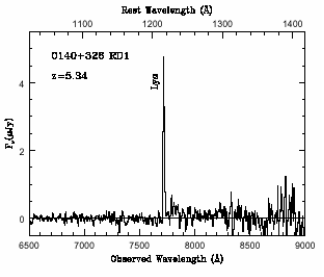
http://antwrp.gsfc.nasa.gov/apod/ap980324.html

Expansion parameter & redshift

- Expansion parameter
  a = distance between two galaxies / present distance
  - The expansion parameter a changes from 0 at the Big Bang to 1 at the present.
- Universe expand the same as wavelength of light.
- Program to look for the most distant galaxies. Dey et al. found galaxy 0140+326 RD1.

1. When the light that we see left Galaxy 0140+326 RD1, its wavelength was 1215 Å (121.5nm). By what factor has the universe expanded since the time the light left that galaxy?



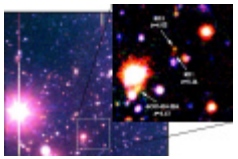


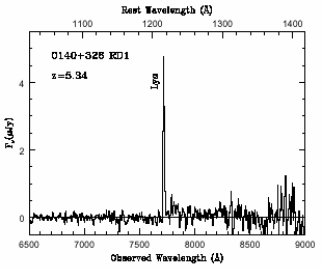
Expansion parameter & redshift

- Expansion parameter
  a = distance between two galaxies / present distance
  - The expansion parameter a changes from 0 at the Big Bang to 1 at the present.
- Universe expand 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. U has expanded by a factor of 6.35 since the time the light left that galaxy. a=1/6.35.

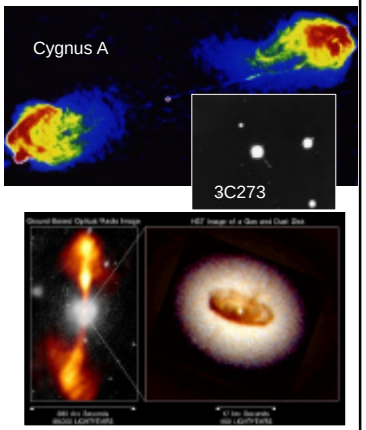
- Redshift z
  - $z = 1/a - 1$
  - $z = \lambda_{received} / \lambda_{emitted} - 1$
  - Speed = z × speed of light (for small z)



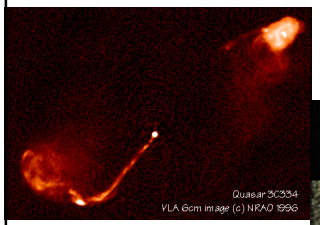


Quasars & Active Galactic Nuclei

- Most big galaxies have a black hole in the nucleus.
- In quasars, the nucleus is so bright that that the galaxy looks like a point.
- Mass of the black hole
  3,000,000,000$M_\odot$ in M87
  3,000,000$M_\odot$ in Milky Way
- Material can be ejected along the spin axis.

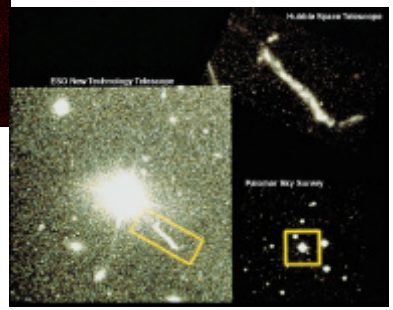


Quasars: Quasi-Stellar Radio Sources



Radio image

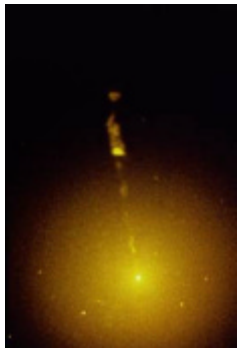
- But most are *not* radio sources
  - Quasi-Stellar Objects (QSOs)



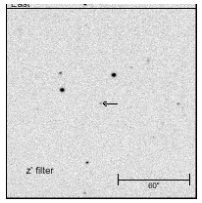
Optical image

Black Holes

- The mass is so concentrated that light cannot escape from within the Schwarzschild radius of a black hole.
- R_S=3km $M/M_\odot$.
- R_S=3km if $M=M_\odot$.
- $R_S=3\times10^6$km (3 times moon's orbit) if $M=10^6M_\odot$.
- $R_S=3\times10^9$km (Saturn's) if $M=10^9M_\odot$.

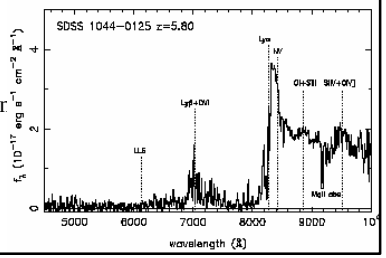


A very distant quasar



- Fan et al, 2000, Astron. Jour., **120**, 1167.

2. When quasar SDSS 1044-0125 emitted the light that we see now, what was the temperature of the radiation from the Big Bang? Was the radiation hot enough to burn paper?



How mass density changes

- Mass of matter = 2×10^{-27}kg
  - Same mass as 1 hydrogen atom

3. (2 pts.) The matter in the 2-L bottle used to occupy a smaller volume. When universe half the present size, how much volume did the matter in the 2-L bottle fill? The mass density at that time was ___ that of the present mass density.

Then

Matter: 2×10^{-27}kg
Rad: 4×10^{-32}kg

How mass density changes

- Define expansion parameter
  a = distance between two galaxies / present distance

3. The matter in the 2-L bottle used to occupy a smaller volume. When universe half the present size, how much volume did the matter in the 2-L bottle fill? <u>1/8 of present volume</u>. The mass density at that time was <u>8</u> times that of the present mass density.

- Mass density of matter changes as
  - $\rho = \rho_{now}\, a^{-3}$
  - One power for each dimension

Then

Matter: 2×10^{-27}kg
Rad: 4×10^{-32}kg