

Hubble's Law & Black Holes at a Galaxy's Center

- Questions about Hubble's Law
- Quasars, active galaxies, & black holes in centers of galaxies
- Astronomical Horizons Public Talks
 - First Light for the Spartan Infrared Camera
 - Ed Loh
 - Abrams Planetarium
 - Today at 7:30pm



Edwin Hubble 1889-1953

Simplicio's questions about Hubble's Law

- Hubble's law
 - $v = H D$
 - $H = 100 \text{ km/s/Mpc}$ (approx)
- Coma is 300MLy from us, and it is moving away from us at 6000km/s.
Simplicio: Galaxy NGC 2323, which is 600MLy away, moves at 12,000km/s.
- 1. What is the basis of Simplicio's reasoning?
 - a. Simplicio is guessing
 - b. Big objects move fast
 - c. Simplicio recalls how fast NGC2323 is moving
 - d. Hubble's Law



Sagredo, Simplicio, and Salviati
Galileo's *Dialogue Concerning Two Chief World Systems*

- Simplicio: (a) Coma is 300MLy from us, and (b) it is moving away from us because of the Big Bang. (c) The sun is 1 AU from us, and (d) it is moving away from us because it is part of the universe.
2. Is Simplicio's thinking correct?
 - a. No, (a) is incorrect.
 - b. No, (b) is incorrect.
 - c. No, (c) is incorrect.
 - d. No, (d) is incorrect.
 - e. Yes

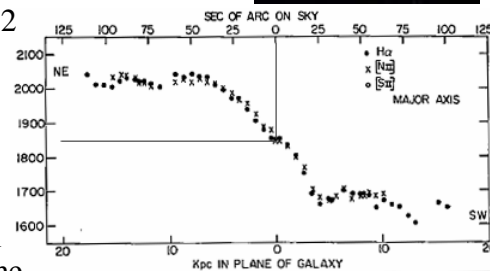
- Simplicio: You tell me the universe is expanding, and some things do move away but other things do not. How does a thing know what to do?
3. Sagredo explains: The fundamental reason is
 - a. Galaxies move away; other things do not.
 - b. Big objects move away; little objects do not.
 - c. If the force holding the object is big enough, it does not move away.
 - d. Nearby objects do not move away; distant objects do.

- The Andromeda galaxy is coming toward us, not moving away. Simplicio: That must be a mistake.
4. Sagredo explains: The reason is
- a. Part of the Big Bang went the wrong way.
 - b. Andromeda is a little galaxy.
 - c. Over time, the gravitational force between Andromeda & the Milky Way has slowed and reversed the expansion.
 - d. Andromeda is nearby.

Galaxy NGC3672



1. Why is the center of NGC3672 moving away from us? (It moves at 1850km/s.)
 - A. The gas orbits.
 - B. The universe expands.
2. Why is the northeast part of NGC3672 moving away from us faster than the center and the southwest part slower than the center? (Same foils)
3. The distance to NGC3672 is
 - A. 19 Mpc
 - B. 1850 Mpc
 - C. 0.054 Mpc



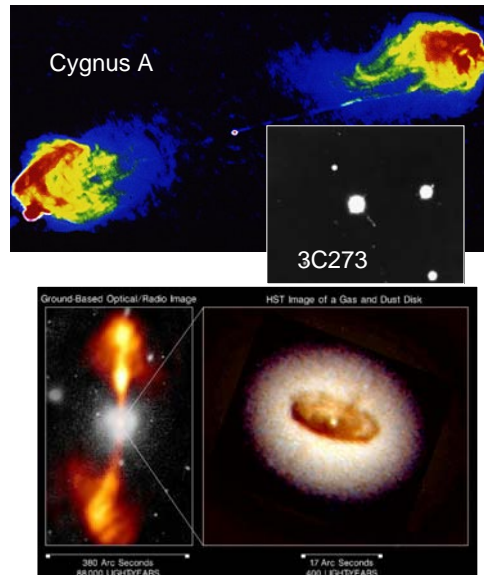
Velocities measured with Doppler effect
Rubin, Ford, Thonnard, jr

Age of the universe

- I am driving down I96 at 50mph. I am 50mi from home. How long have I been driving?
 - Time = distance / speed
- Hubble's Law: $v = H D$
- 1. How old is the universe?
 - A. H
 - B. $1/H$
 - C. H^2
 - D. $1/H^2$
- Measuring Hubble's constant is a key step in finding the age of the universe.
- This method is not perfectly accurate because galaxies may slow down or speed up. Need to measure slowing or speed-up.
- Age is 13Byr.
 - Age of solar system is 4.5Byr. SS is 1/3 age of universe.

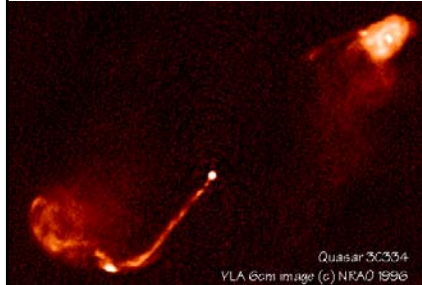
Quasars & Active Galactic Nuclei

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

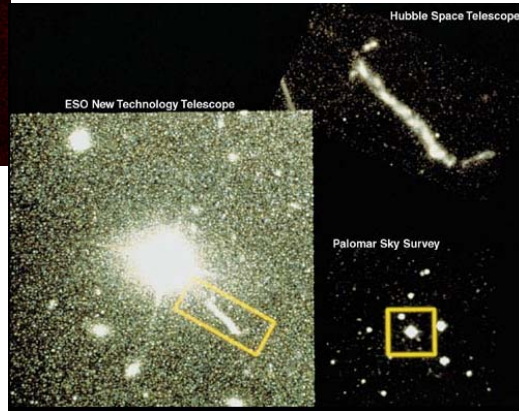


Quasars: Quasi-Stellar Radio Sources [26]

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



Radio image

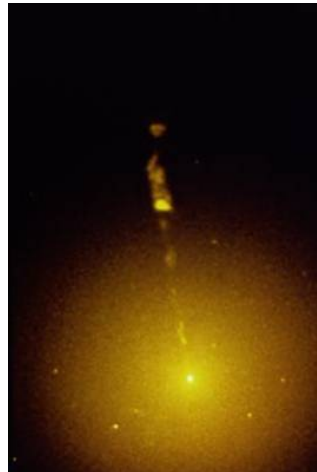


Optical image

[Fig 26.3]

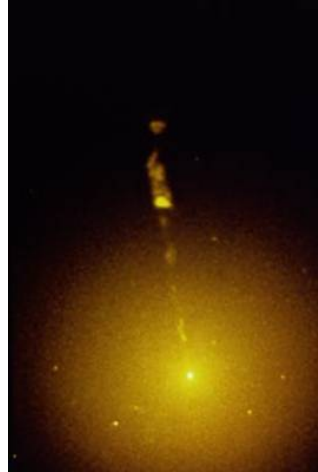
Black Holes

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



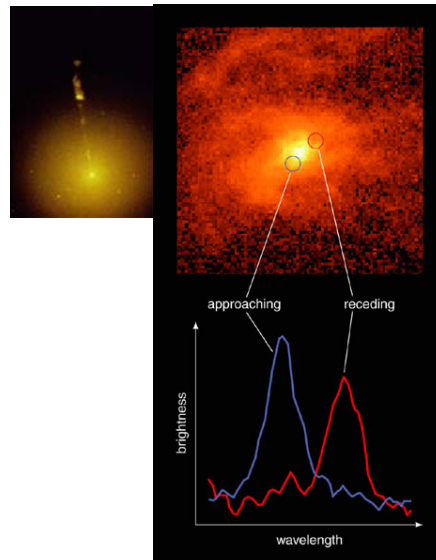
Measurement of Mass of Black Hole

- The bright center may be a dense concentration of stars.
- 1. What must you measure to find the mass of black hole in M87, a big elliptical galaxy?
 - a. Luminosity of nucleus
 - b. Distance to M87
 - c. Size of orbit & speed of something in orbit
 - d. Speed of ejected material

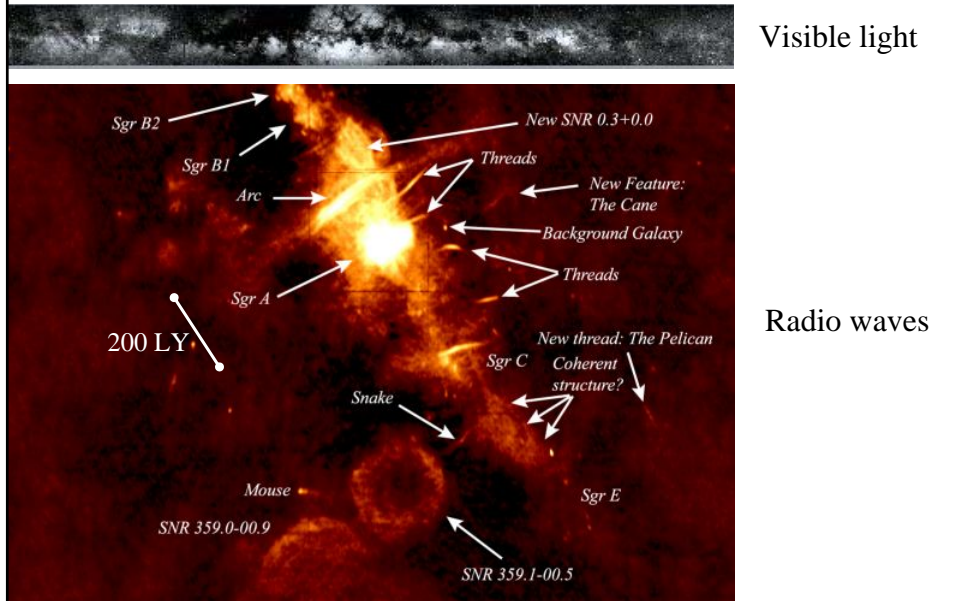


Measurement of Mass of Black Hole

- To find the mass of black hole in M87, a big elliptical galaxy, use Kepler's 3rd Law.
$$\text{Mass} = R^3/P^2 = RV^2$$
$$R = 60\text{ly}$$
$$V = 800\text{km/s}$$
$$M = 3\text{Billion}M_{\odot}$$
$$= 3,000,000,000M_{\odot}$$
- If the mass were stars, density is 15,000 times that in sun's neighborhood.



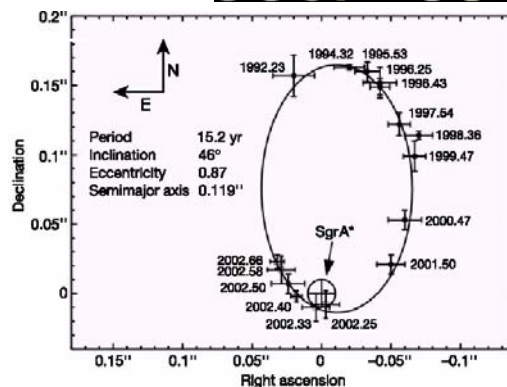
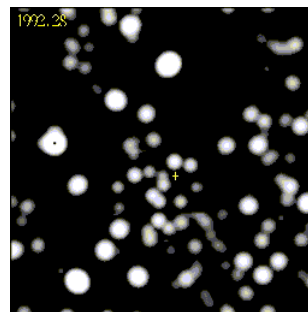
The Center of our Milky Way Galaxy



Black Hole at the Center of the Milky Way Galaxy

- From 2002.25 to 2002.40 (0.15yr), star moved same as it did from 1995.53 to 1996.43 (0.9yr).
- 2. Why did the star move so fast when it was near Sgr A*?
 - a. Kepler's law of equal areas
 - b. It got sucked in by the black hole.
 - c. The black hole spit it out.
 - d. There is mass near the black hole

Infrared observations over 6 years.



Black Hole at the Center of the Milky Way Galaxy

- Orbit is a ellipse tilted by 46°
 - $P=15\text{yr}$
 - $R=900\text{AU}$
- Data from 2002 goes within 60AU from black hole. [Orbit of Pluto is 40AU.]
- $\text{Mass} = R^3/P^2$
 $= 3,000,000 M_\odot$
- Within 60AU, the mass at SgrA* acts like a point.

Infrared observations over 6 years.

