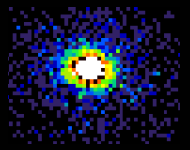
Black Holes & Quasars—7 Nov

- Open house at MSU Observatory
  - Fri & Sat, 9:00-11:00 if not cloudy
- Black hole
  - Mass is so concentrated that nothing escapes
- Quasar
  - Black holes in the center of galaxies

BH in center of Milky Way



BH Cyg X1

Jet in galaxy M87

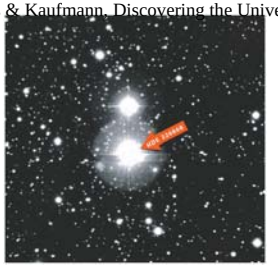
Black hole

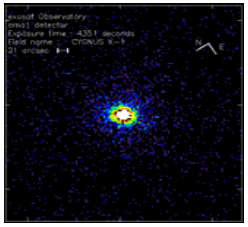
- Escape from earth
  - To escape from earth's gravity, a molecule must go faster than 11 km/s.
- Escape speed v depends on mass and radius
  $v^2 = G \text{ mass} / \text{radius}$
- If mass is big enough or radius is small enough, escape speed is greater than speed of light: nothing can escape.
- If sun were squeezed to 3-km radius, light could not escape from it.
- If Earth were squeezed to 1-cm radius, light could not escape from it.
- Schwarzschild radius is boundary between inside & outside of a black hole.
  - Light can escape if outside Schwarzschild radius.

Comis & Kaufmann, Discovering the Universe

Black hole

- How can we detect a black hole if light cannot escape from it?
  - Look at something that orbits around it
  - Look at the mass that is falling into it.
- Objects that emit little or no light
  - Black hole
  - White dwarf
    - Degenerate electrons cause pressure.
    - Max mass is $1.4M_\odot$.
  - Neutron star
    - Degenerate neutrons cause pressure.
    - Max mass is $3M_\odot$.
- Cygnus X1
  - Bright source of X rays
  - In visible, star HD226868
  - HD226868 moves around something at 50km/s with 5 day period

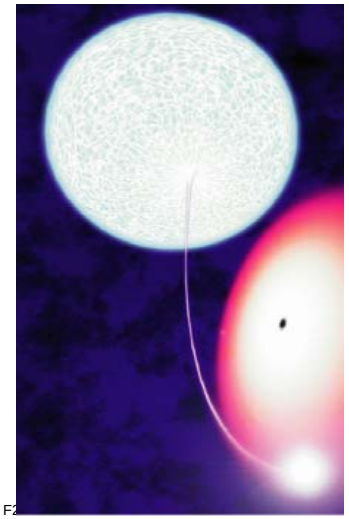




heasarc.gsfc.nasa.gov/ Images/exosat/cygx1.gif

Cygnus X1

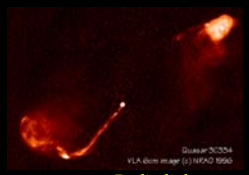
- HD226868, a giant, donates mass to BH
  - Mass falls toward BH, moves fast, gets hot.
  - Hot gas emits X rays
- Mass of companion
  - Kepler's 3rd law: Radius & period ⇒ total mass of two stars.
    - P=5da
    - 5da & 50km/s ⇒ R.
  - Speed ⇒ mass of companion
  - Mass of companion is $10M_\odot$.
- Companion is compact
  - A $10\text{-}M_\odot$ star would be seen in visible.
- Cygnus X1 is a black hole



Discovery of quasars (quasi-stellar objects)

- Some sources of radio waves are coincident with stars.
- Stars do not emit light at radio wavelengths.
- Are they some kind of weird star within the Milky Way Galaxy?

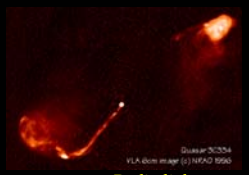

Visible light


Radio light

Discovery of quasars (quasi-stellar objects)

- Are they some kind of weird star within the Milky Way Galaxy?
- Maarten Schmidt gets a spectrum.
  - "Star" was moving away at 40,000 km/s. Fastest stars in Milky Way move at 200km/s.
- Why is it moving so fast?


Visible light

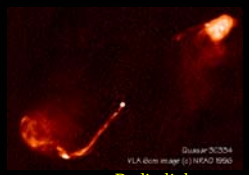

Radio light

Discovery of quasars (quasi-stellar objects)

- Maarten Schmidt gets a spectrum.
  - "Star" was moving at 40,000 km/s. Fastest stars in Milky Way move at 200km/s.

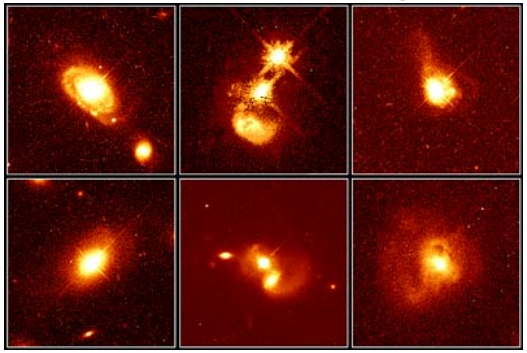
1. Why is it moving so fast?
   A. It is in a distant galaxy.
   B. It was shot out of the MW.


Visible light


Radio light

Quasars: events in centers of galaxies

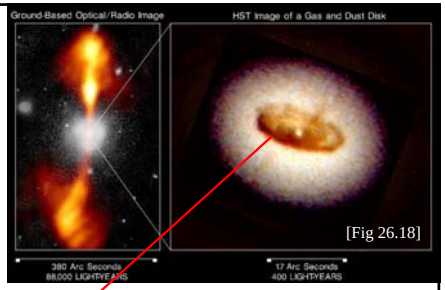
[Fig. 26.6]



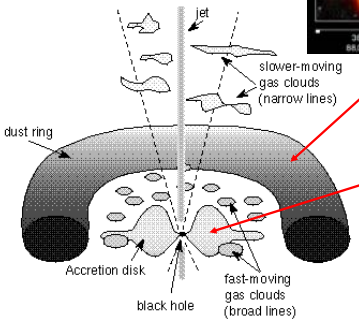
- Hubble Space Telescope images.
  - bright star-like objects at centers of faint galaxies.

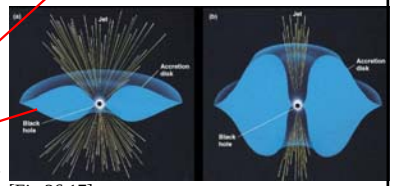
Energy Source:

- Gas, stars fall into 10^8 $M_\odot$ black hole.
- Gravitational potential energy ➔ thermal energy ➔ light



[Fig 26.18]

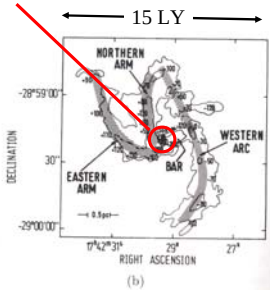




[Fig 26.17]

Accretion disk + Black Hole + Jets

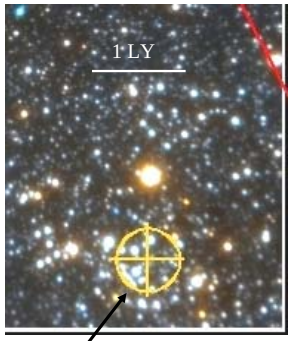
Sagittarius A*



Radio observations with higher angular resolution.

Small oval is the point source Sagittarius A* = center of galaxy

Infrared Images of the Galactic Center

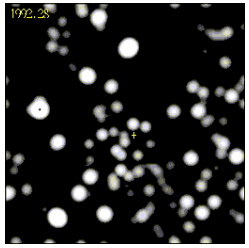


Using "adaptive optics" technique on Gemini 8m telescope.

Galactic Center (Sagittarius A*)

300,000 x more stars per unit volume than in vicinity of Sun

The Black Hole at the the Galactic Center



Infrared observations over 6 years.

Velocities of stars in very center ➔ 1 million $M_\odot$ black hole at position of Sagittarius A*