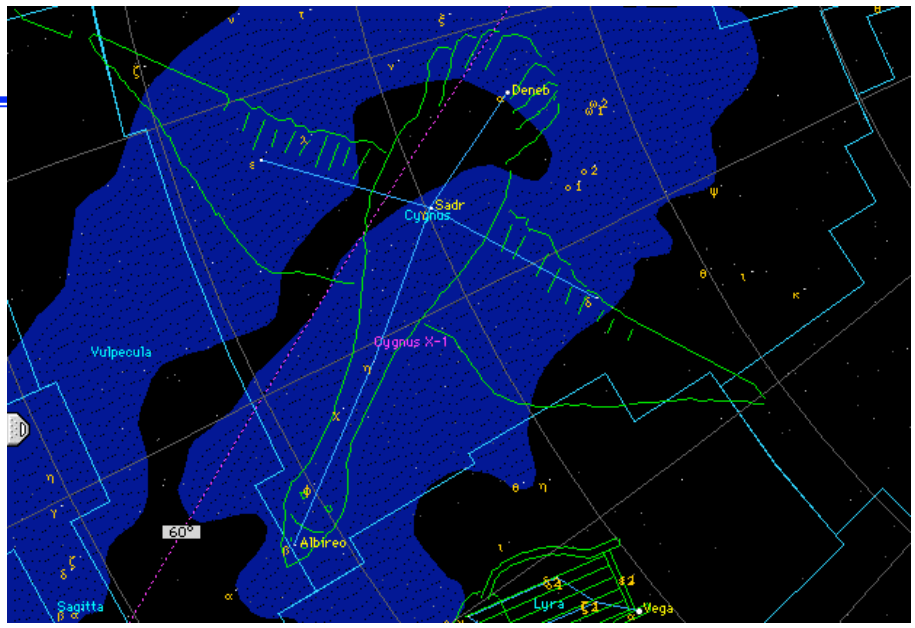
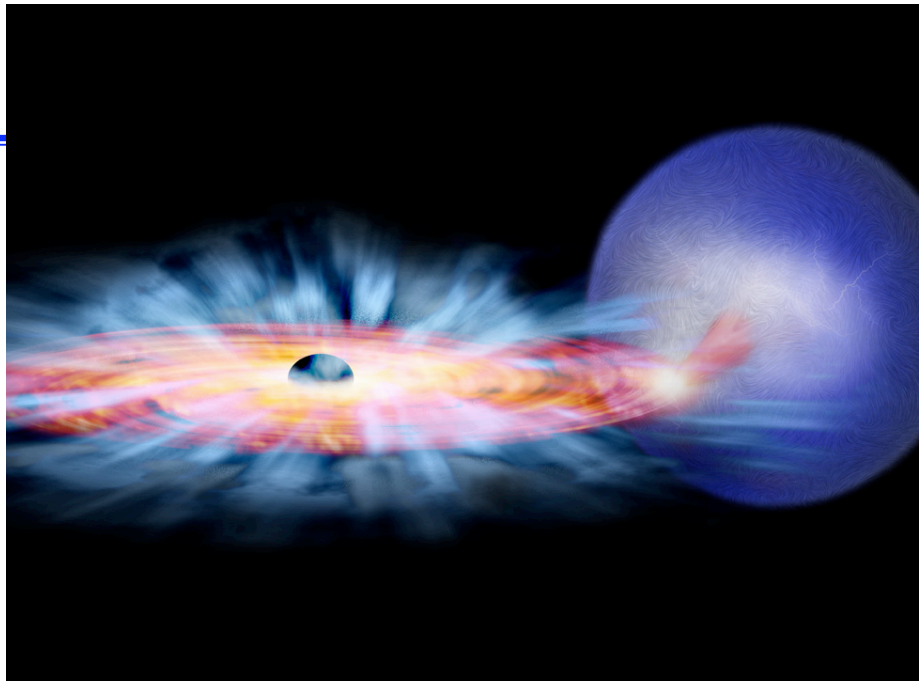
## Class 9 :
## X-ray binaries

- Black hole X-ray binaries
  - The discovery of stellar-mass black holes
- Neutron star X-ray binaries
  - Strongly magnetized systems: X-ray pulsars
  - Weakly magnetized systems

# I : Discovery of black holes

- First clear evidence for a black hole came from discovery of the X-ray source Cygnus X-1 by rocket experiments in 1965
- Cygnus X-1
  - Binary star system… black hole in orbit around a massive O-star
  - Black hole mass 7-13 Msun
  - X-rays produced due to accretion of stellar wind from O-star
  - 2kpc away



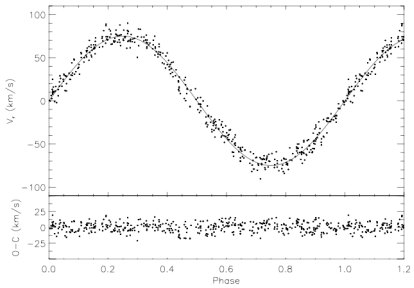


# How do we know the black hole mass?

- Can constrain black hole mass from orbit of companion star
  - Period 5.6 days
  - K = V sin i = 75km/s
  - Analysis of orbit shows that

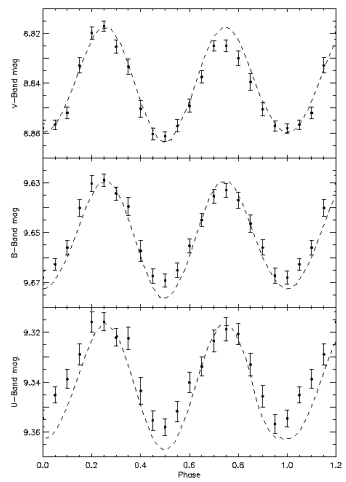
$$f = \frac{K^3 P}{2\pi G} = \frac{M_1^3 (\sin i)^3}{(M_1 + M_2)^2}$$

  - "Mass function" f can be measured…
  - $M_{BH}$>f
  - Cyg X-1… f=0.24$M_{BH}$




*Brocksopp et al. (1999)*

- Can we determine mass of black hole? Need to find inclination and mass of companion star
- Companion star:
  - Use spectroscopy to determine spectral type
  - Use knowledge of properties of stars to estimate mass based on spectral type
- Inclination
  - In best cases, use eclipse to determine that system is edge-on (i≈90 degrees)… can only do this in one case
  - Normal cases… use "ellipticity variations" to estimate inclination




- For Cygnus X-1…
  - Feed $M_1$ and i into mass function formula
  - Get $M_{bh}$=7-13 $M_{sun}$
  - Much more massive than maximum mass for a neutron star (~2-3 $M_{sun}$)
  - So this must be a black hole (there's no other known state of matter between neutron star and BH)
- Currently about 20+ "Galactic Black hole binaries" where similar arguments work
  - About 6 "golden cases" with f>3$M_{sun}$
  - In these systems, the conclusion that thes are black holes are inescapable no matter what inclination or companion star mass is assumed

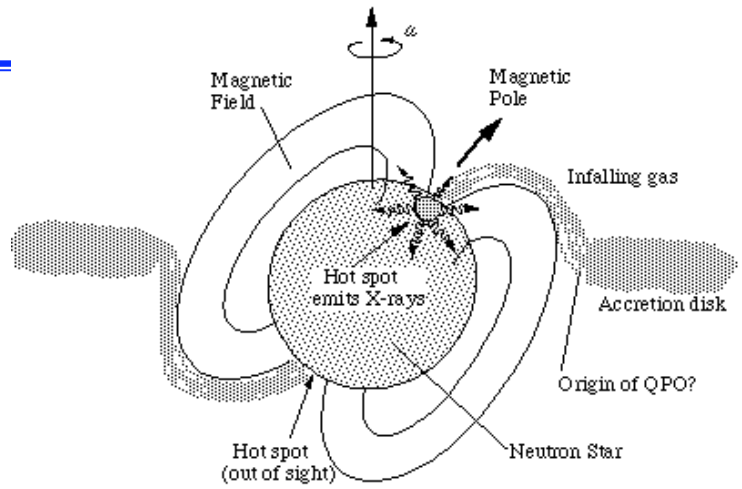
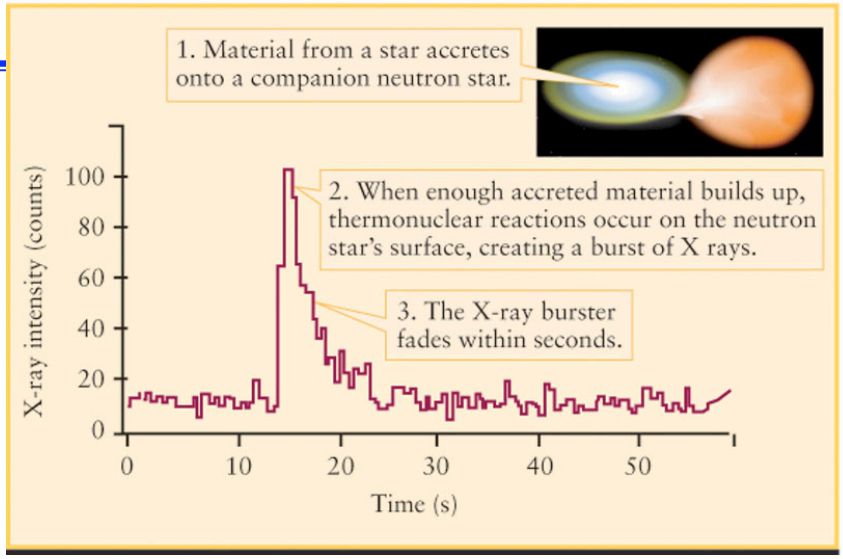
## Basic nature of these sources

- Gas from star flows towards black hole
  - Angular momentum of gas causes it to form an accretion disk
  - Turbulence in accretion disk causes the redistribution of angular momentum…
  - Most gas loses angular momentum and accretes into the black hole
  - Gravitational potential energy is released with incredible high efficiency (6-30%)
  - Much of this emerges in the X-ray band!

## II : Neutron star X-ray binaries

- Many X-ray binaries consist of a neutron star (rather than a black hole) orbiting a normal star
- Important new aspect…
  - Neutron star can have a magnetic field!
  - Appearance of source depends on magnetic field

- Strongly magnetized neutron star X-ray binaries…
  - Neutron star has a strong/large **magnetosphere**
  - Magnetosphere disrupts accretion disk…
  - Matter flows down field lines and strikes the magnetic poles of the neutron star… causes X-ray bright "**hot-spots**"
  - In hotspots, temperatures get high enough to fuse the incoming hydrogen to helium (continuously)
  - As poles spin around (due to NS rotation), the hot-spots flash in and out of view… get an **accretion-powered X-ray pulsar**.
  - Unlike case of the rotation-powered radio pulsars discussed before, these are **spinning-up** due to the action of the accretion disk



- Weakly magnetized neutron star X-ray binaries
  - Accretion disk extends all of the way to the neutron star surface… hydrogen gas is dumped onto surface and spreads around.
  - So… there's a growing layer of hot hydrogen gas on surface
  - Once layer grows thick enough, runaway fusion starts at base of layer… layer explodes!
  - Explosion lasts about 10s and blows most of the layer into space… "**X-ray burst**"