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

The X-ray Sky
Feb. 96 - Nov. 99
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
  - $K = V \sin i = 75\text{km/s}$
  - 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...
- $M_{\text{BH}} > f$
- Cyg X-1... $f = 0.24 M_{\text{BH}}$

*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 ($\approx 90$ 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 $M_{bh} = 7-13 \, M_{\odot}$
- Much more massive than maximum mass for a neutron star ($\approx 2-3 \, M_{\odot}$)
- 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 $f > 3M_{\odot}$
- In these systems, the conclusion that they 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 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"