Black holes in X-ray binaries

Suppose we have a binary in which we can measure:

- the period P
- the amplitude of the observed radial velocity of both stars v_{r1} and v_{r2}
- the inclination i (e.g. because we see an eclipse)

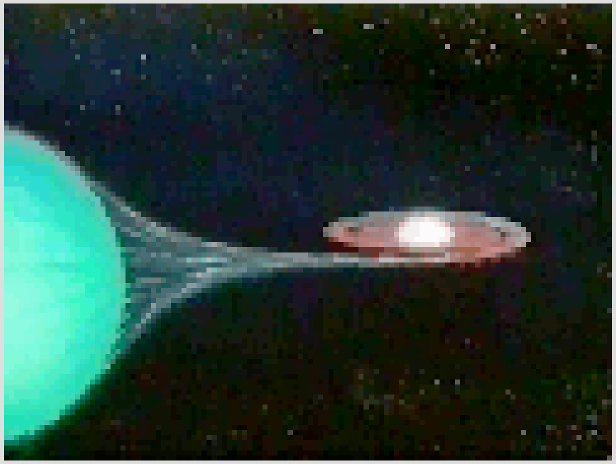
Then we showed (lecture #13) that:

$$\frac{M_1}{M_2} = \frac{v_{r2}}{v_{r1}}, \quad M_1 + M_2 = \frac{P}{2\pi G} \frac{\left(v_{r1} + v_{r2}\right)^3}{\sin^3 i}$$

Two equations for the two unknown masses, so both can be determined

Binaries containing black holes are rare, and it's never possible to measure the radial velocity `of the black hole' (gas near the black hole is moving with v~c!). No examples of double-lined eclipsing spectroscopic binaries.

Also no examples of black hole - pulsar binaries.



Binary containing a black hole in a mass transfer system. Donor star may be:

- massive star - a High Mass X-ray binary
- a low mass star undergoing Roche lobe overflow - Low Mass X-ray binary

If the **mass-losing star** can be detected, then we can measure:

- radial velocity amplitude of the donor star v_{r1}
- the period of the binary P

In practice this may not be easy - many X-ray binaries are distant and measuring the spectrum of the donor star is difficult - especially if it's a low mass star.

One velocity plus period yields a **lower limit** to the mass

Start with previous equations

$$\frac{M_1}{M_2} = \frac{v_{r2}}{v_{r1}}, \quad M_1 + M_2 = \frac{P}{2\pi G} \frac{(v_{r1} + v_{r2})^3}{\sin^3 i}$$

Substitute for the unknown velocity v_{r2}

$$M_1 + M_2 = \frac{P}{2\pi G} \frac{\left(v_{r1} + v_{r1}\frac{M_1}{M_2}\right)^3}{\sin^3 i}$$

Simplify

$$M_2\left(1 + \frac{M_1}{M_2}\right) = \frac{P}{2\pi G} \frac{v_{r1}^3}{\sin^3 i}\left(1 + \frac{M_1}{M_2}\right)^3$$

$$M_2 = \frac{P v_{r1}^3}{2\pi G} \frac{(1 + M_1/M_2)^2}{\sin^3 i}$$

$$M_2 = \frac{P v_{r1}^3}{2\pi G} \frac{\left(1 + M_1/M_2\right)^2}{\sin^3 i}$$

Measure the radial velocity amplitude of mass losing star, v_{r1}, and period P, so this term is known.

Term is unknown, but as $M_1/M_2 > 0$ and $\sin(i) < 1$ the value must be **greater** than unity.

Minimum mass of the binary companion: $\frac{P v_{r1}^3}{2\pi G}$

If in an X-ray binary this minimum mass exceeds 3 Solar masses, deduce that the compact object is likely to be a black hole rather than a neutron star.

To date, there are around 10 X-ray binaries known which have values of $Pv_{r1}^{3}/2\pi G$ that exceed 3 M_{sun}.

Using also other observational evidence (e.g. the estimated mass of the donor star based on its spectrum), 18 systems are strongly believed to harbor stellar mass black holes.

Typical masses for the black holes are 7 - 10 M_{sun}.

These systems comprise about 10% of all X-ray binaries, though they are a very small fraction of the estimated 300 million black hole remnants in the Galaxy.

Most are transient sources - **X-ray novae**.

- Cygnus X-1 (1972)
- LMC X-3 (1983)
- A0620-00 (1986)
- …

discoveries of galactic black hole candidate sources

Properties of galactic black hole candidates include:

- high luminosity in X-ray waveband
- complex pattern of variability
- relativistic (v ~ c) jets

Neutron stars in X-ray binaries are also luminous and variable X-ray sources, though jet velocities from neutron stars are probably smaller (~0.5 c).

<u>High luminosity</u>

Easiest property to explain: as gas spirals in through the accretion disk gravitational potential energy is dissipated and radiated.

Note: in principle gas on radial trajectory can be swallowed by the black hole without emitting *any* radiation - usually there's enough angular momentum that this doesn't happen.

Can make a crude Newtonian estimate of the efficiency of gas accretion onto a black hole:

$$L = \frac{GM\dot{M}}{R} \sim \frac{GM\dot{M}}{2GM/c^2} = \frac{\dot{M}c^2}{2}$$

This would give a radiative *efficiency* (the fraction of the rest mass energy of the accreted gas that is converted to radiation):

$$\eta = \frac{L}{\dot{M}c^2} \sim 0.5$$

More detailed estimates give:

- η = 0.06 (Schwarzschild black hole)
- η = 0.42 (Kerr black hole with spin parameter a = 1, accreting from gas in a prograde equatorial orbit)

Extremely efficient - high luminosity.