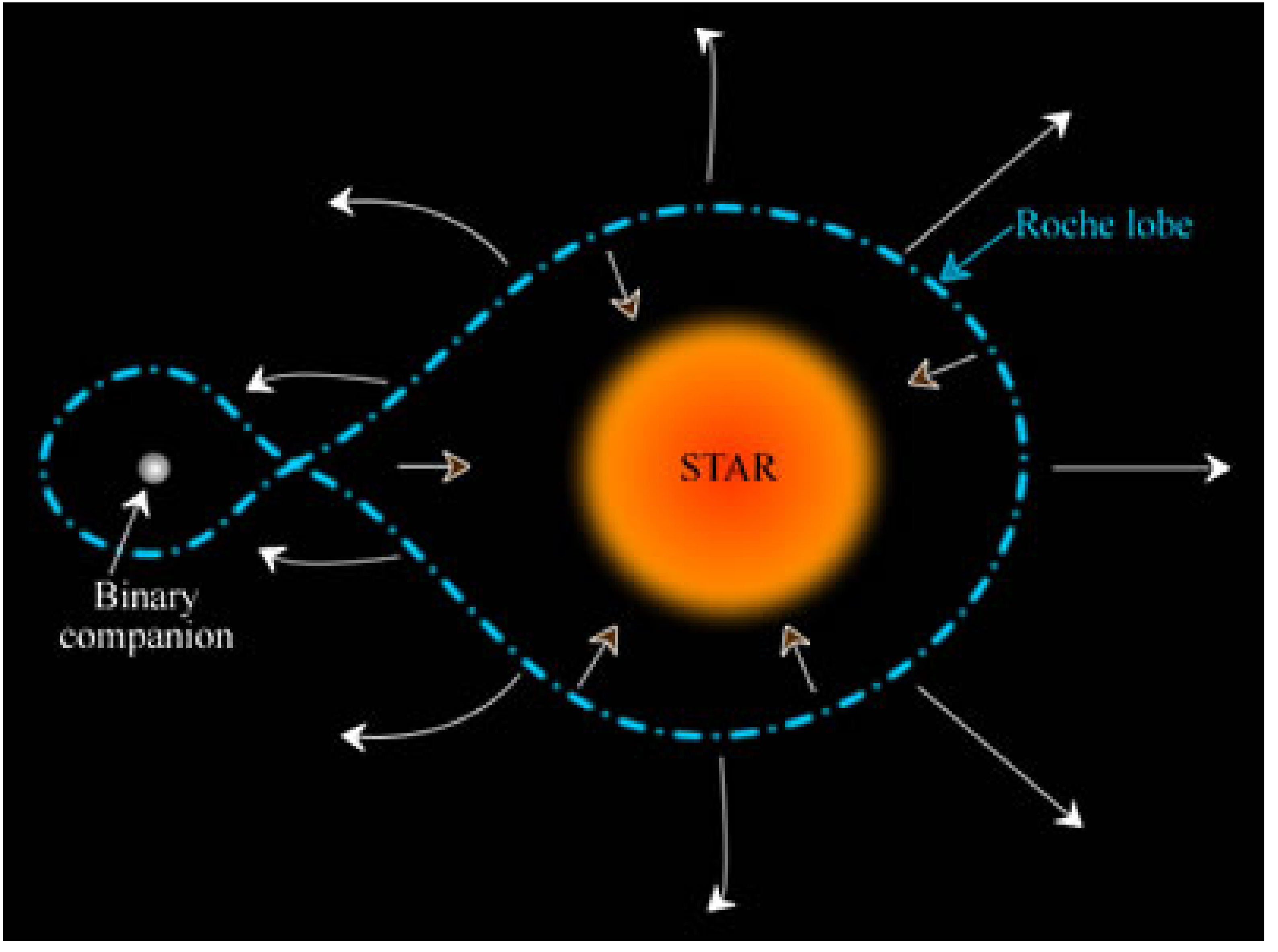
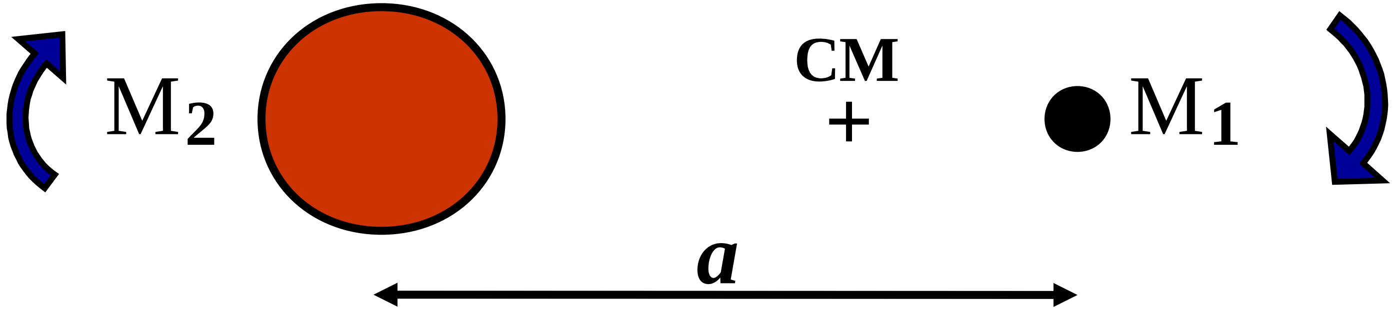
Accretion in Binaries

- Two paths for accretion
  - Roche-lobe overflow
  - Wind-fed accretion
- Classes of X-ray binaries
  - Low-mass (BH and NS)
  - High-mass (BH and NS)
  - X-ray pulsars (NS)
  - Be/X-ray binaries (NS)

Roche Lobe Overflow



Binary Orbit



Compact star mass = $M_1 M_\odot$

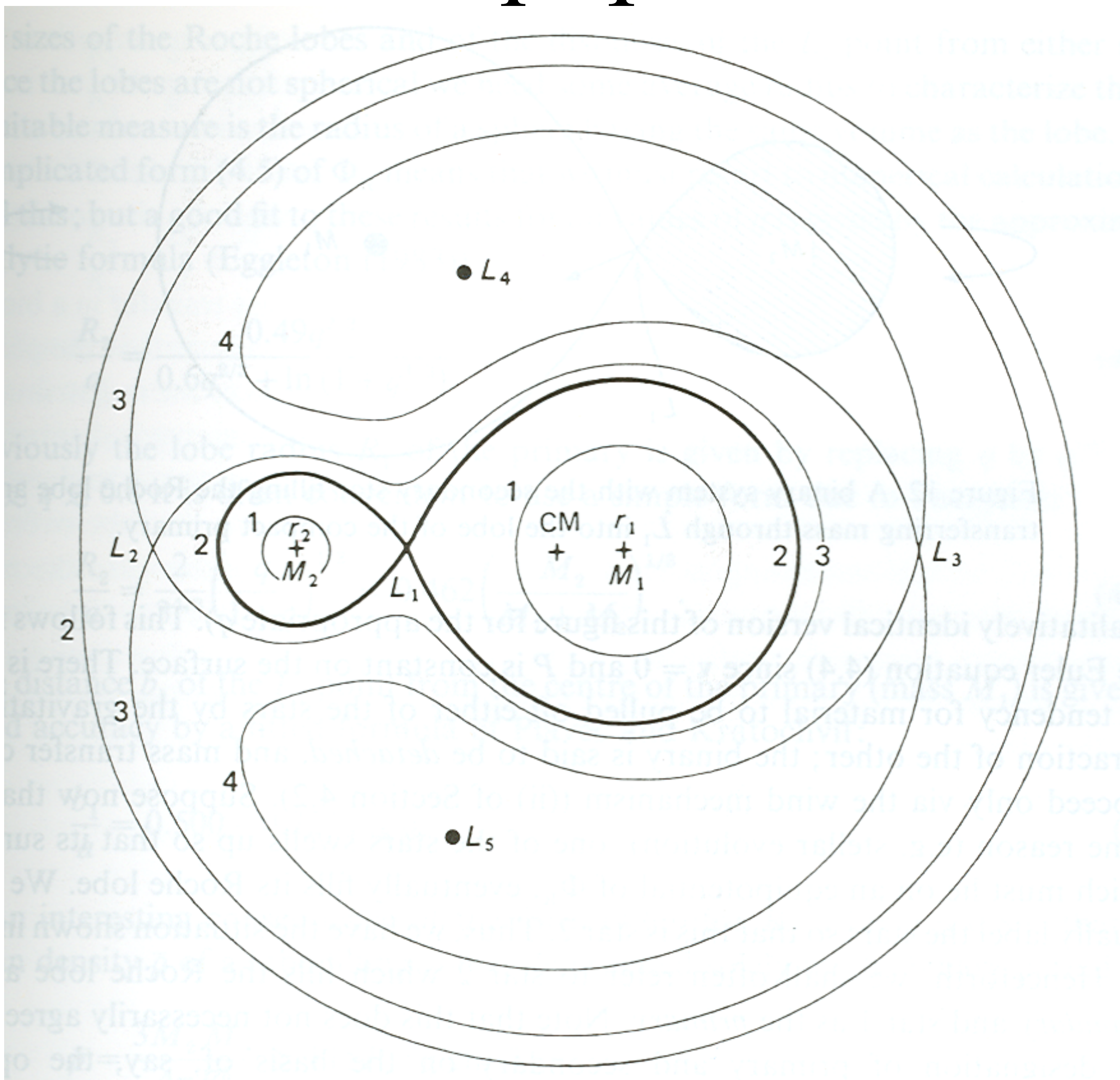
Normal star mass = $M_2 M_\odot$

Binary separation = a, mass ratio q = M_2/M_1

$$\text{Kepler's law: } 4\pi^2 a^3 = G(M_1 + M_2)M_\Theta P^2$$

$$a = 3.5\times10^{10} M_1^{1/3}(1+q)^{1/3} P_{hr}^{2/3} \text{ cm}$$

Roche equipotentials



Roche lobe radius

$$\frac{R_2}{a} = \frac{0.49q^{2/3}}{0.6q^{2/3} + \ln(1+q^{1/3})}$$

From fits to numerical calculations of lobes (Eggleton 1984)

For 0.1 < q < 0.8 is approximately

$$\frac{R_2}{a} = 0.462\left(\frac{M_2}{M_1+M_2}\right)^{1/3}$$

Average density is then

$$\bar{\rho} = \frac{3\mathrm{M}_2 M_\odot}{4\pi\mathrm{R}_2^3} \simeq 115\mathrm{P}_{hr}^{-2}\,\mathrm{g\ cm}^{-3}$$

Evolution of orbit

Angular momentum: $$J = M_1 M_2 \left(\frac{Ga}{M_1 + M_2} \right)^{1/2} M_\Theta^{3/2}$$

Evolution:

$$\frac{\dot{a}}{a} = \frac{2\dot{J}}{J} + \frac{2(-\dot{M}_2)}{M_2} \left(1 - \frac{M_2}{M_1} \right)$$

Assuming $\dot{M}_1 + \dot{M}_2 = 0$

$\dot{M}_2 < 0$ in order to make X-rays

Binary expands if mass flows from less massive to more massive star, contracts if flow is from more massive to less massive star.

Evolution of Roche lobe

$$\frac{\dot{R}_2}{R_2} = \frac{\dot{a}}{a} + \frac{\dot{M}_2}{3M_2}$$

$$\frac{\dot{R}_2}{R_2} = \frac{2\dot{J}}{J} + \frac{2(-\dot{M}_2)}{M_2}\left(\frac{5}{6} - \frac{M_2}{M_1}\right)$$

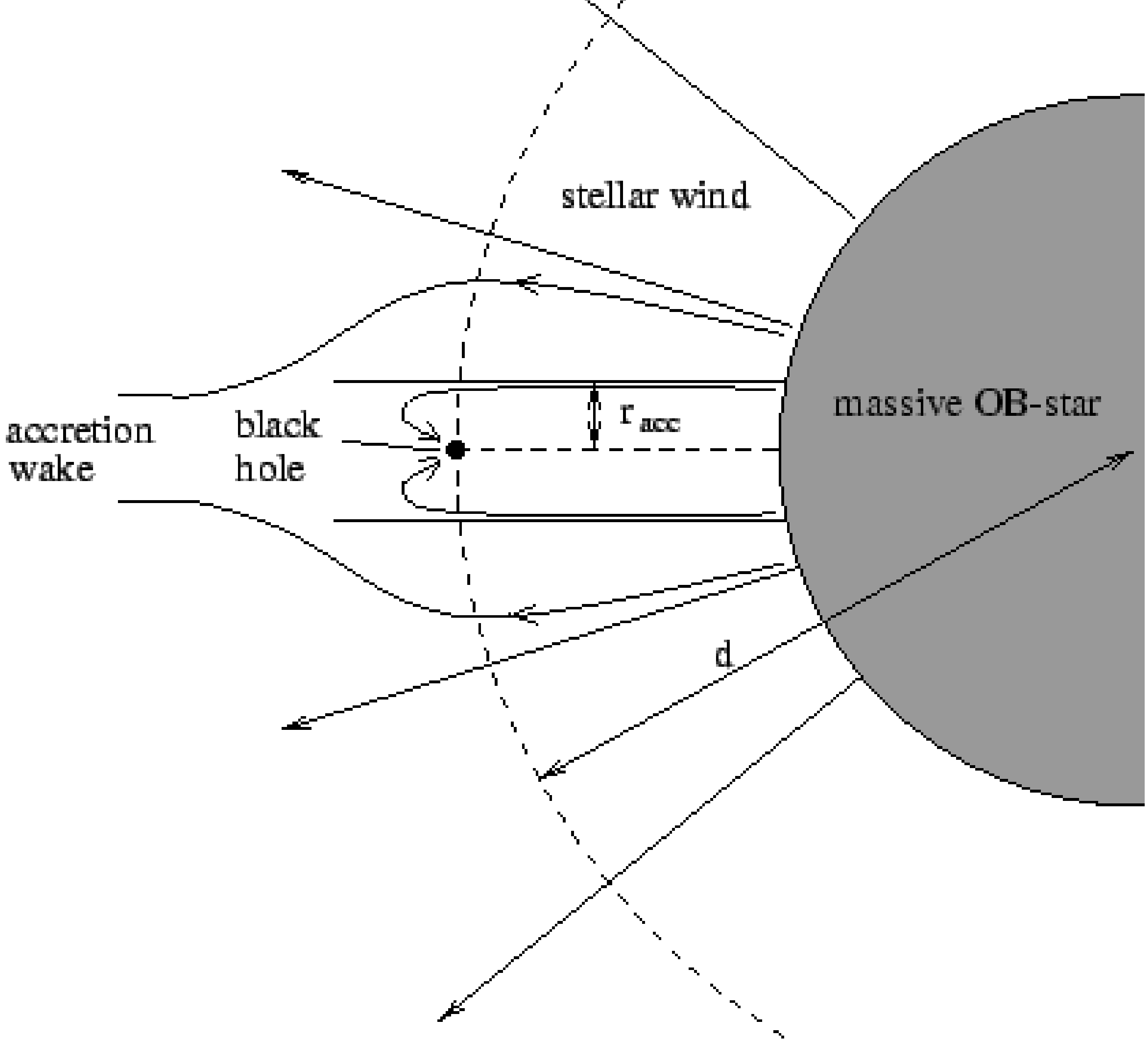
Roche lobe shrinks if $q > 5/6$: rapid and violent accretion,

Roche lobe expands if $q < 5/6$, need either star to expand or some process to lose angular momentum to continue accretion.

Binary evolution

- Radius of star expands as star loses mass.
  - Occurs when star evolves off main sequence and expands to be giant
  - Occurs if mass/radius relation for star is inverted
- Angular momentum loss
  - Gravitational radiation
  - Magnetic braking
  - Tidal synchronization
  - Winds

Wind Fed Accretion



Wind Fed Accretion

Matter in wind will accrete if its speed is less than the escape speed from the compact object at the radius of closest approach

V_w = wind velocity

V_x = velocity of compact object

R_c = capture radius

$$R_c = \frac{2GM_X}{V_X^2 + V_W^2}$$

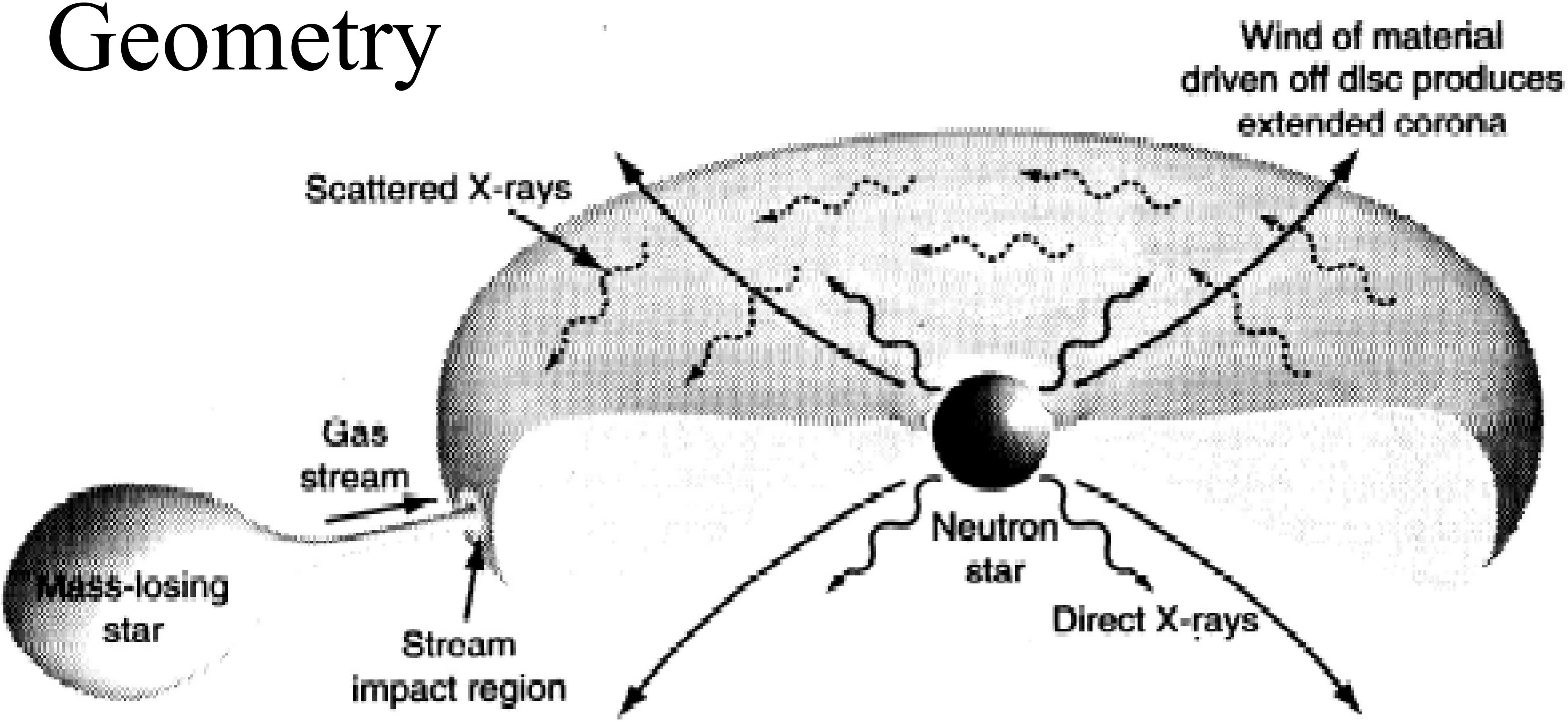
X-Ray Binaries

- Low mass: companion star mass less than one solar mass
- High mass: companion star mass greater than one solar mass.

Low Mass X-ray Binaries

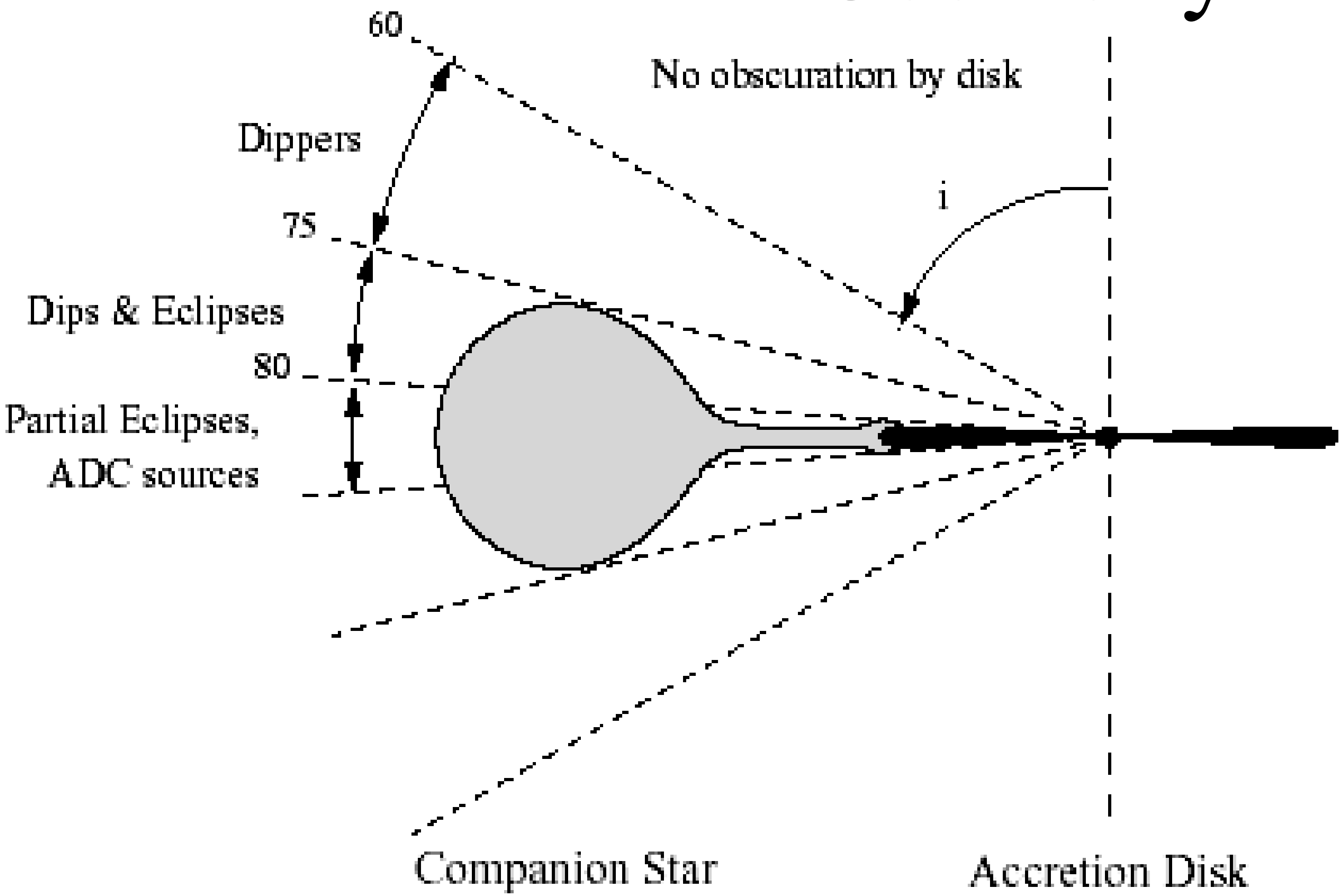
- Include both neutron star and black hole candidates for the compect objects.
- They are the brightest X-ray sources in our Galaxy.
- Powered by accretion via Roche lobe overflow.
- The companion stars are optically faint and in many cases have the spectra of low-mass stars.
- The ratio of X-ray to optical luminosity is high.
- Some produce X-ray bursts.

Geometry



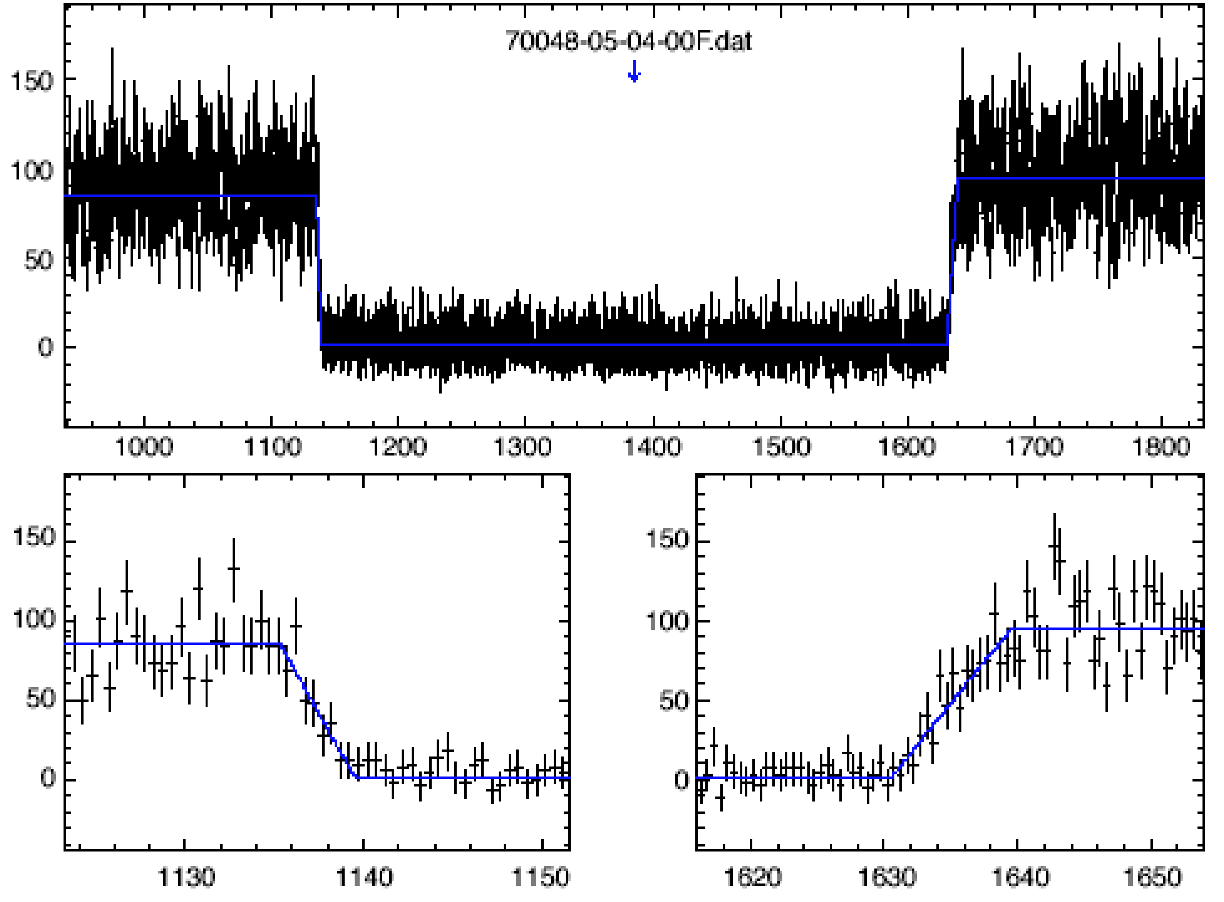
For BH, X-ray emission is from disk. For NS, there is also emission from boundary layer where disk meets NS and surface of NS. Optical emission arises from outer disk, companion star, and X-rays reprocessed by disk or companion.

Geometry



Observed phenomenology depends on viewing angle.

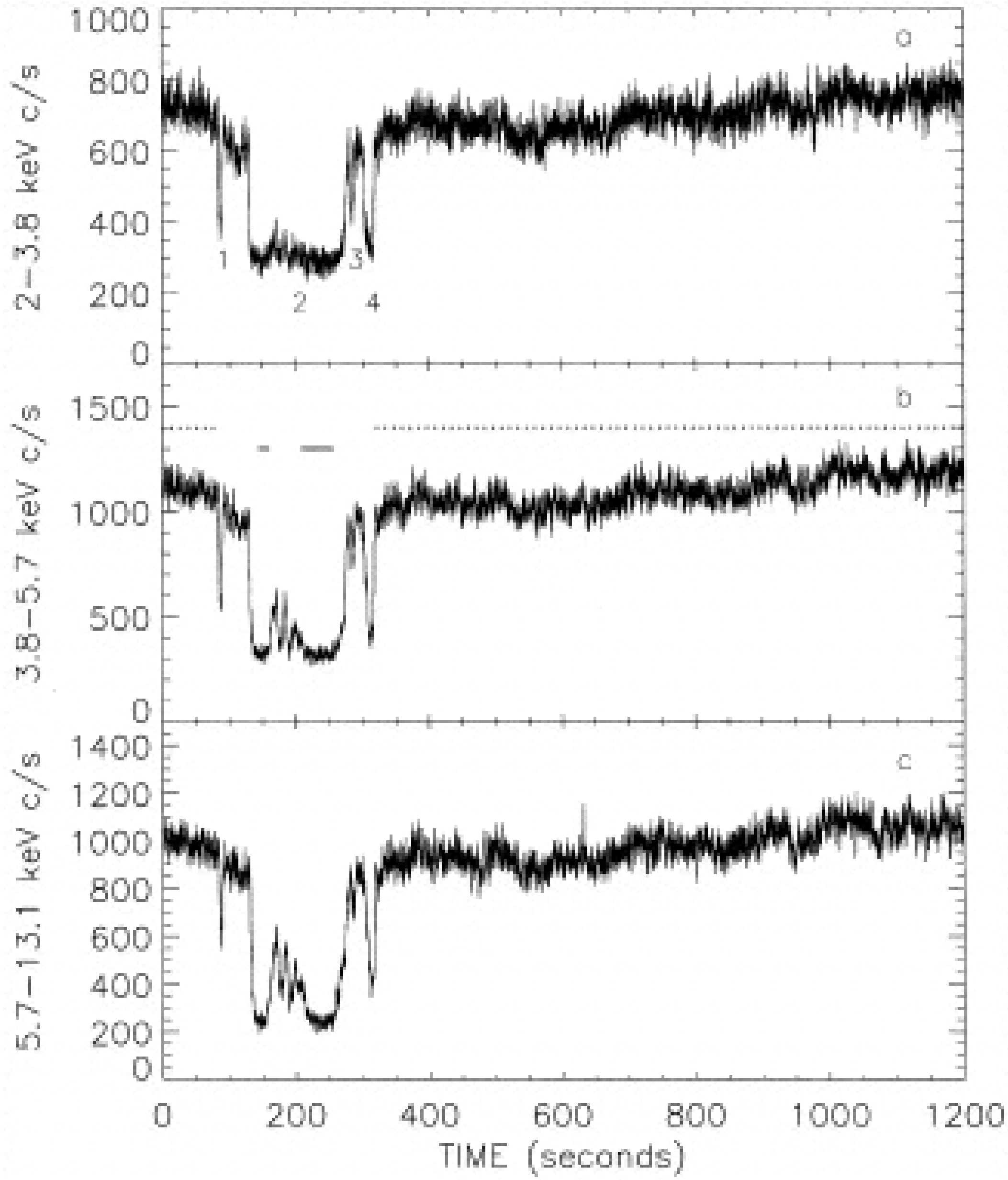
X-ray Eclipse



An eclipse of EXO 0748-676 (Hertz, Wood, Cominsky 1997).

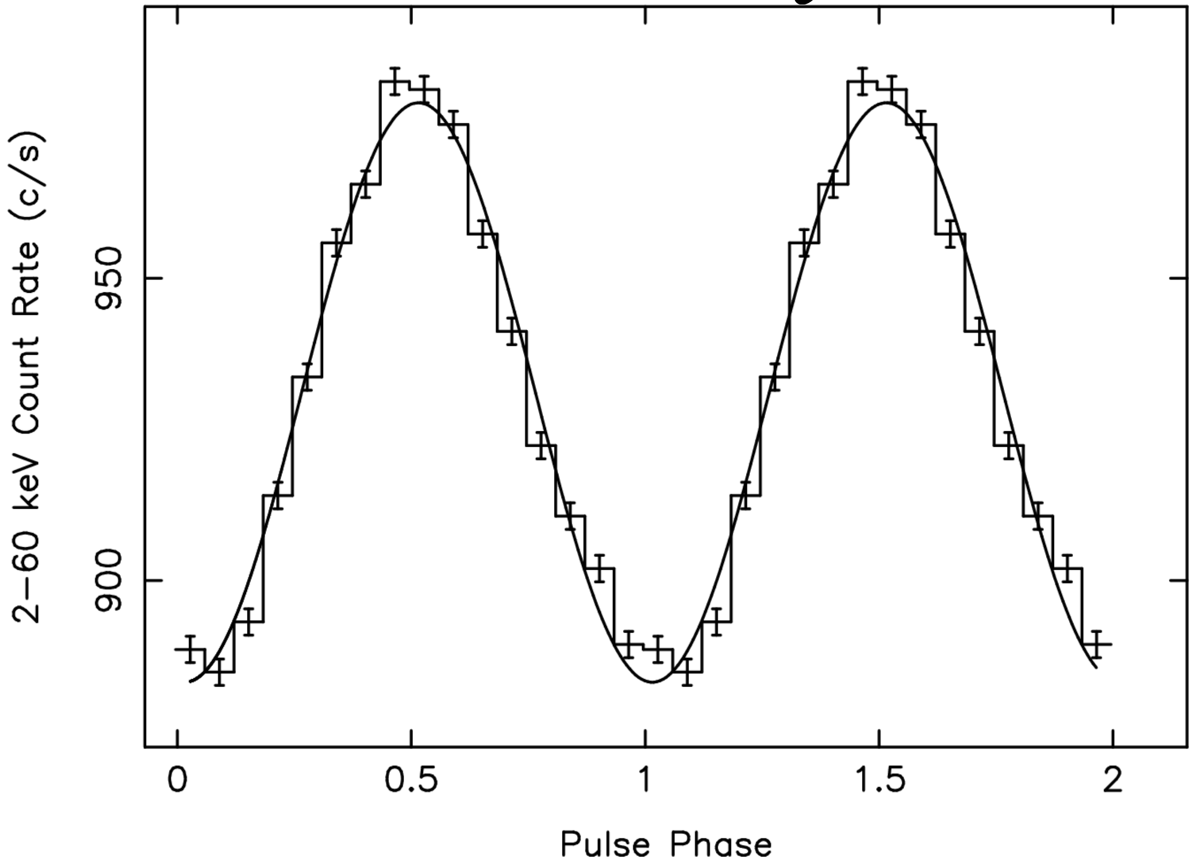
X-ray Dips

Can be used to constrain size of X-ray emitting region(s).



Dips from 4U1630-47 (Tomsick, Lapshov, Kaaret 1998).

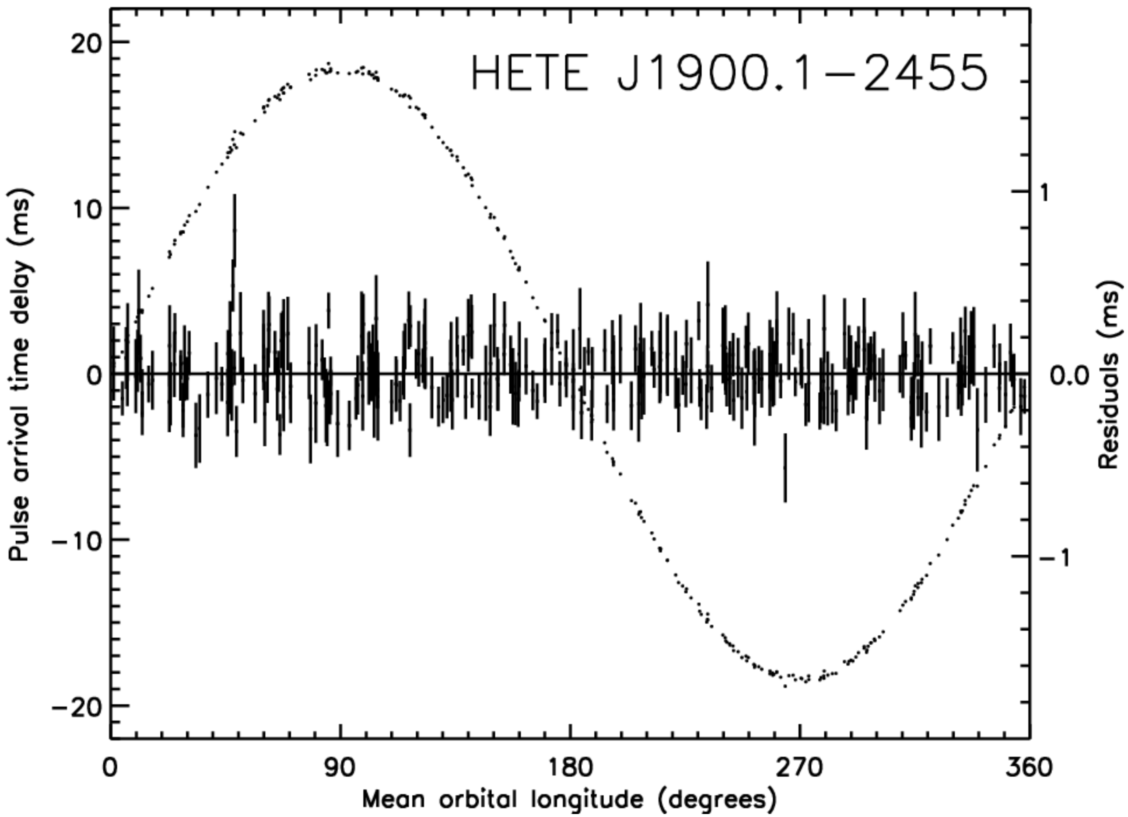
Millisecond X-Ray Pulsars



Millisecond pulsations were discovered from one LMXB in 1998 (Wijnands & van der Klis; Chakrabarty & Morgan).

Pulse period is 2.49 ms, indicated neutron star spin rate.

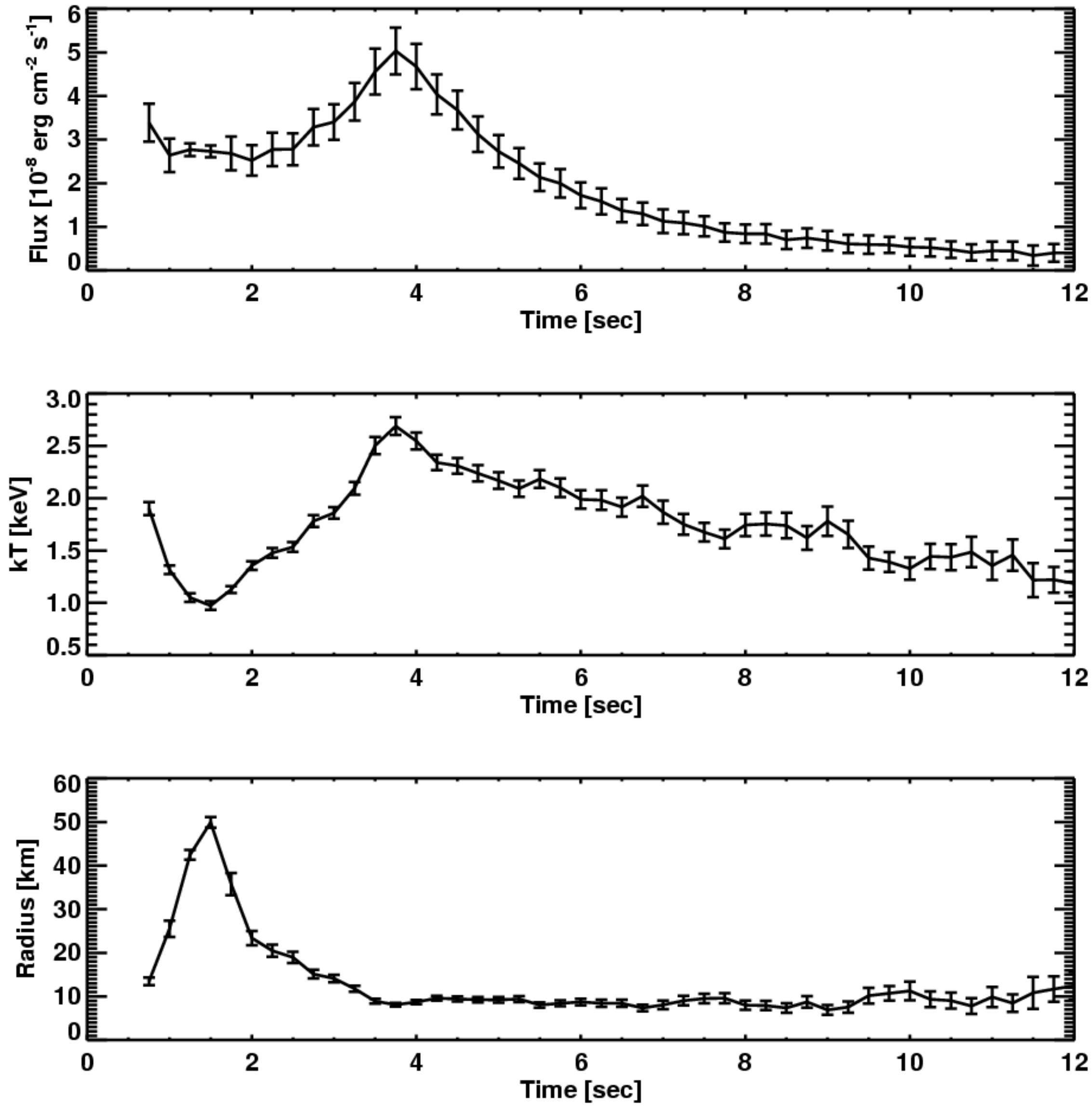
Orbital Modulation



Pulse period is modulated by orbital motion. Using pulsations one can measure the orbit. For HETE J1900 the orbit is 83 minutes and the companion star between 0.016 and 0.07 solar masses (Kaaret et al. 2005).

X-ray Bursts

Spectrum is a simple blackbody.
Emission is due to nuclear fusion on neutron star surface.



Radius expansion X-ray burst from LMXB in globular cluster NGC 6440 (Kaaret et al. 2003)

Burst Energetics

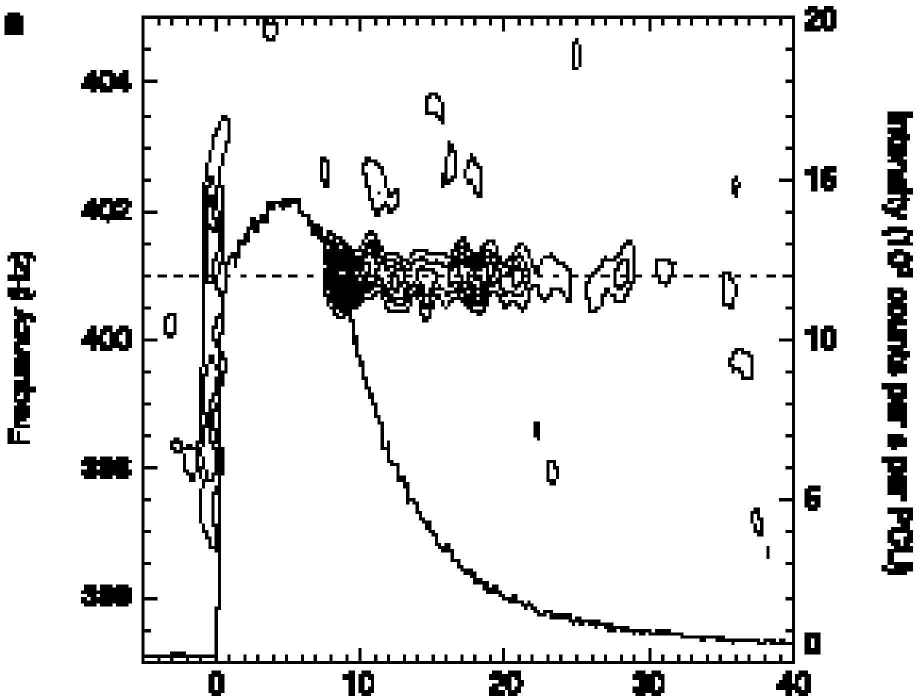
α parameter: the ratio of average energy emitted in the persistent X-ray emission (between bursts) to that emitted in bursts

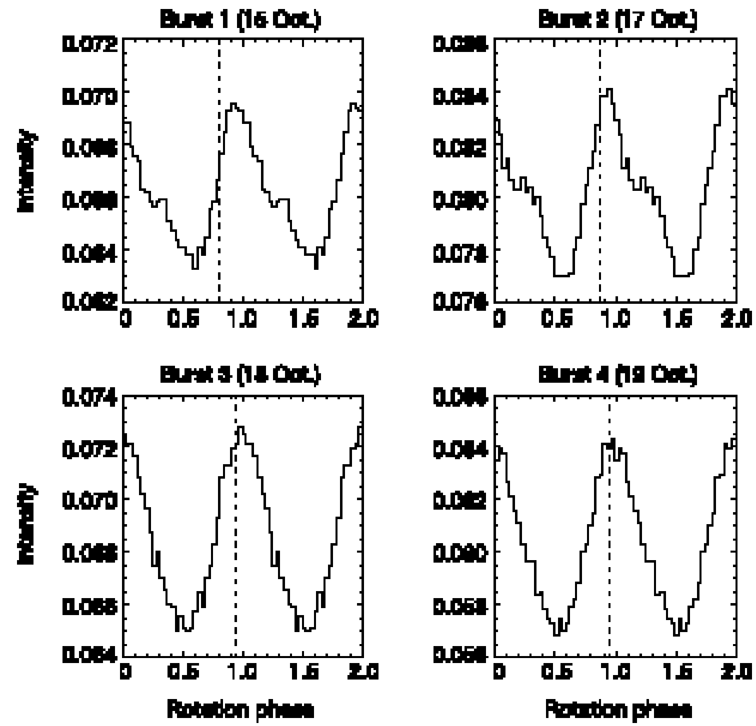
If Type I bursts are due to thermal nuclear processes, α should be equal to the ratio of accretion power to nuclear power,

$$\alpha = \frac{\varepsilon_a}{\varepsilon_n} \approx (25 - 100) \frac{M_*}{M_\odot} \left(\frac{R_*}{10^6\,cm} \right)^{-1}$$

The observed values range from ~10-1000, with a maximum in the distribution around 100, in good agreement with the model.

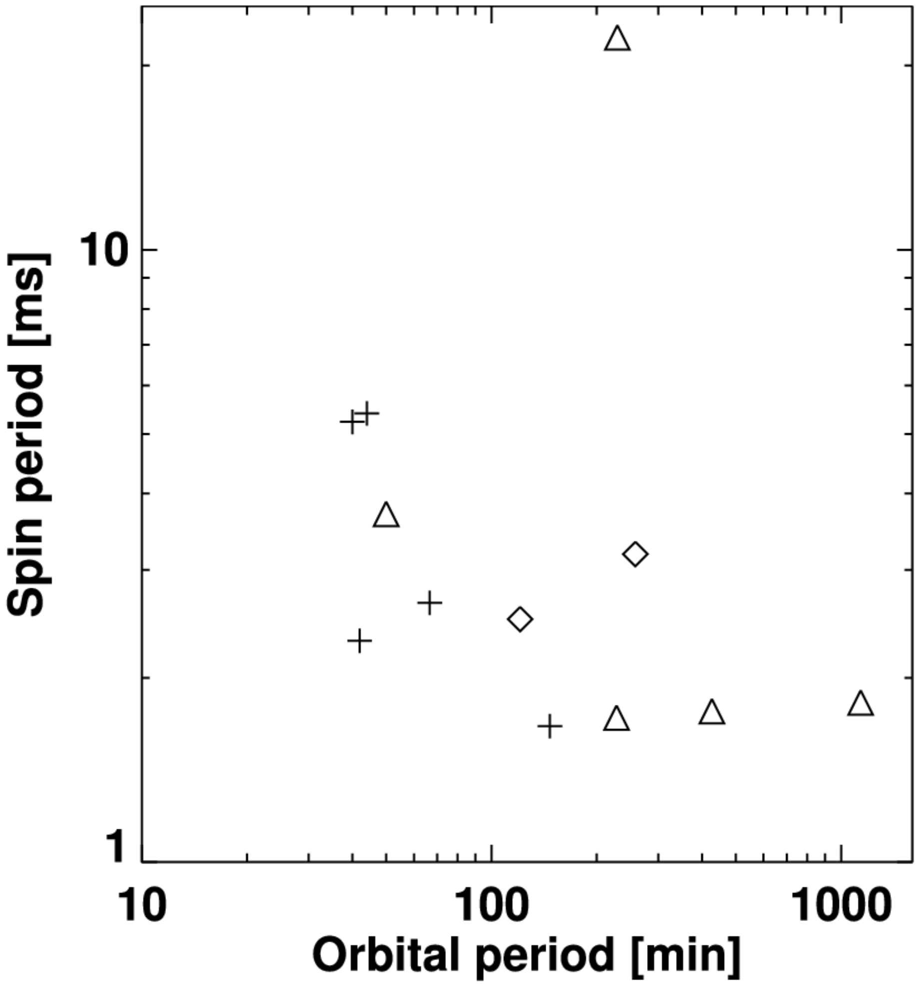
Burst Oscillations





Oscillations sometimes appear in bursts. Burst oscillations and coherent persistent oscillations in SAX J1808.4-3658 are at the same frequency. Both indicate spin frequency of neutron star.

Spin and orbital periods



Minimum measured spin period is 1.6 ms.

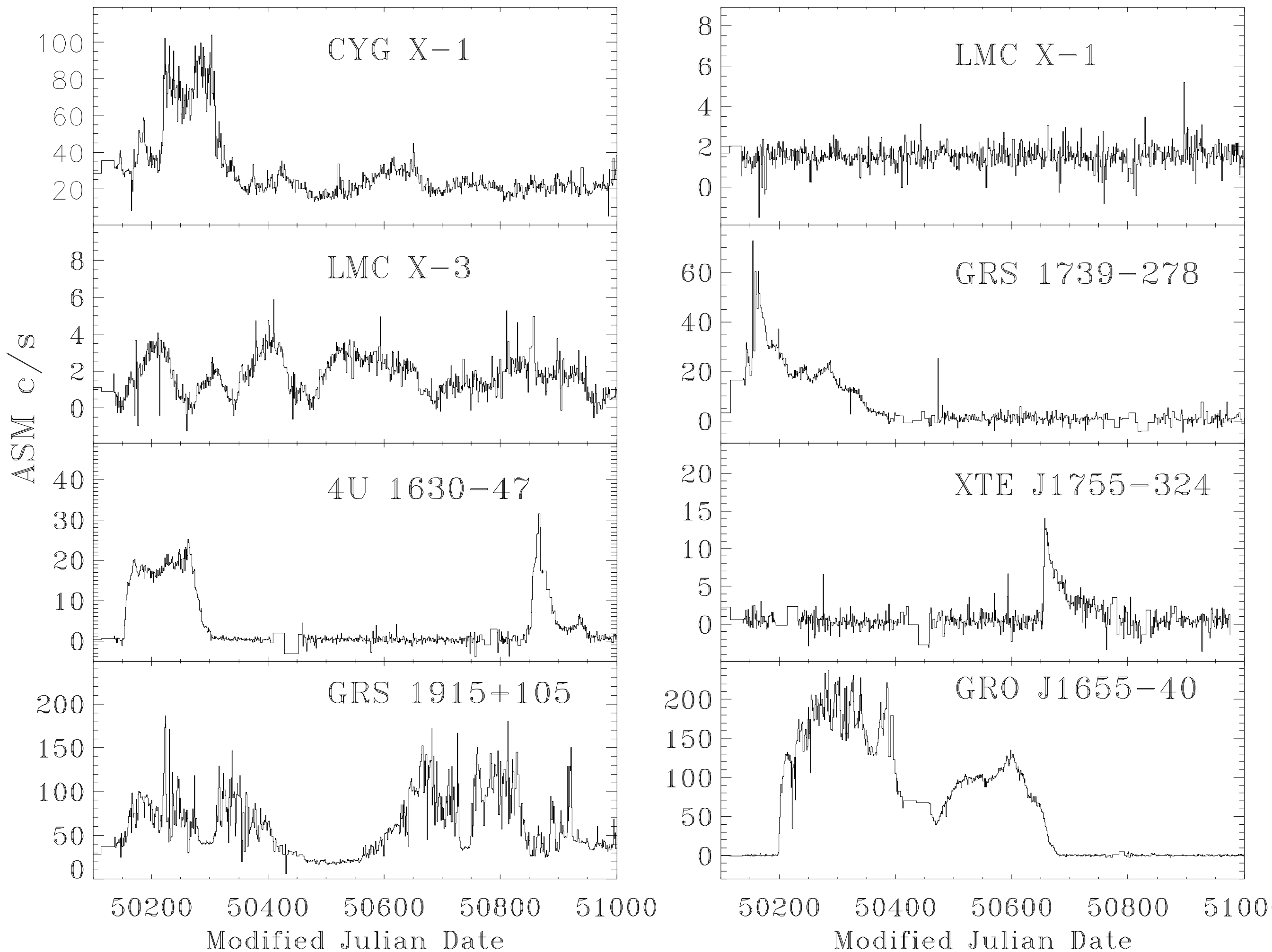
NS should be able to rotate faster than this.

Period limit may be due to gravitational radiation.

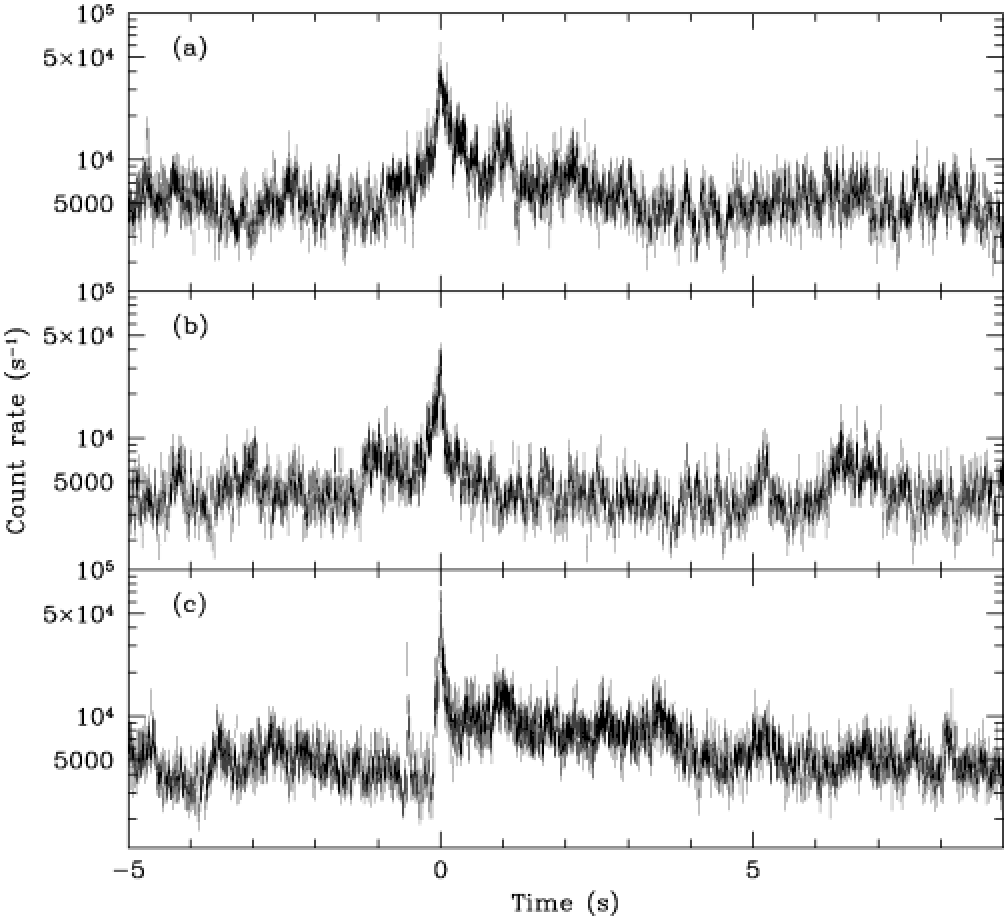
LMXB and MS Pulsars

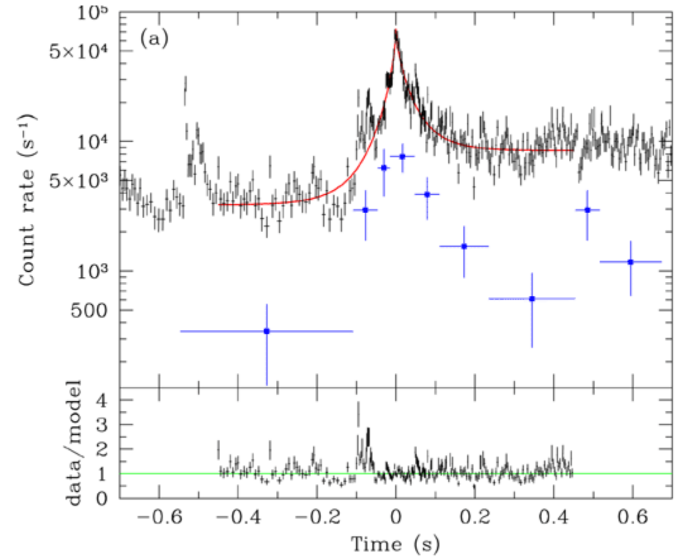
- LMXBs are the progenitors of millisecond radio pulsars.
  - LMXBs are very old systems.
  - Neutron stars are spun up by accretion over a long time.
  - Radio pulsars emerge when accretion ceases.
  - Companion stars probably evaporate by irradiation from pulsars or are accreted away.

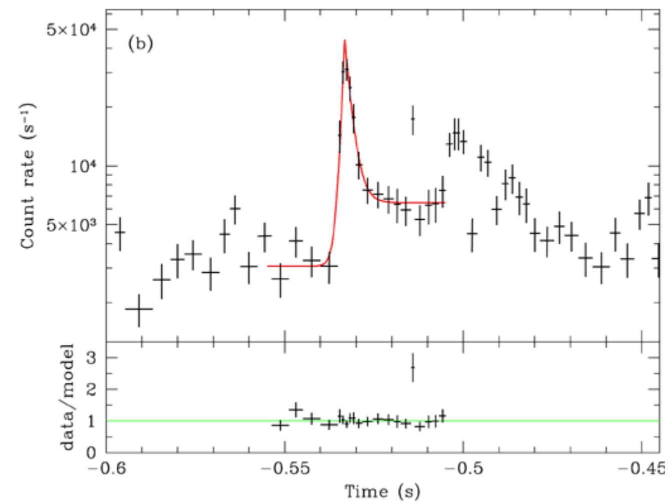
Variabilities of Black Holes



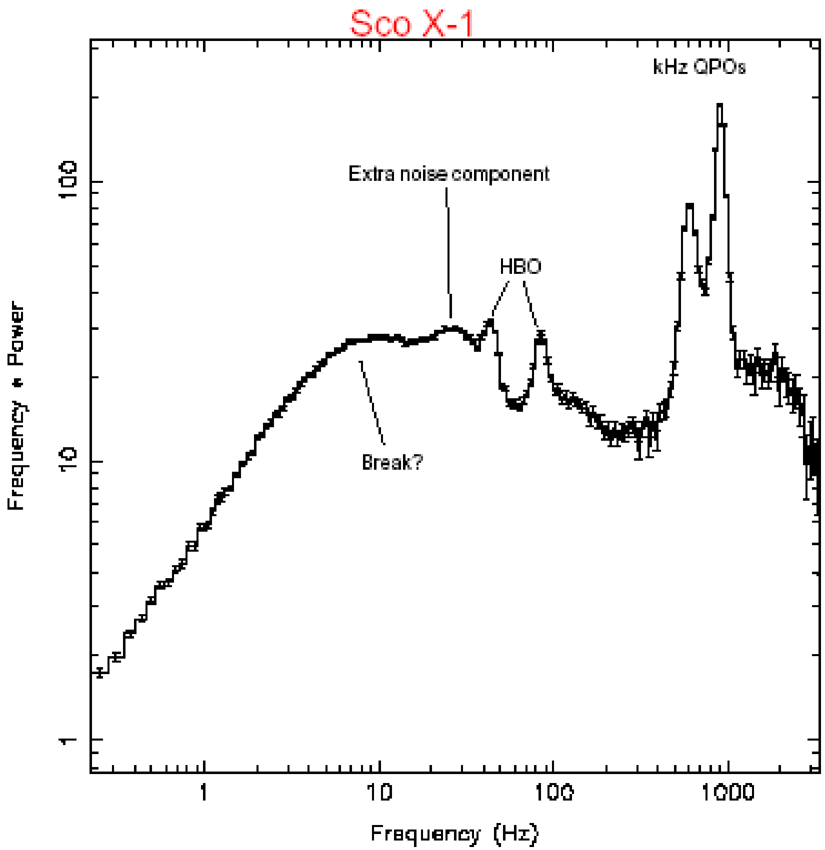
Rapid Variability







Quasi-Periodic Oscillations



KiloHertz QPOs:

Time scale is orbital time scale at inner edge of accretion disk.

Two peaks which tend to move together, frequency difference is equal to or half the spin frequency.

Several lower frequency QPOs, tend to move with kHz QPOs.

Not understood!