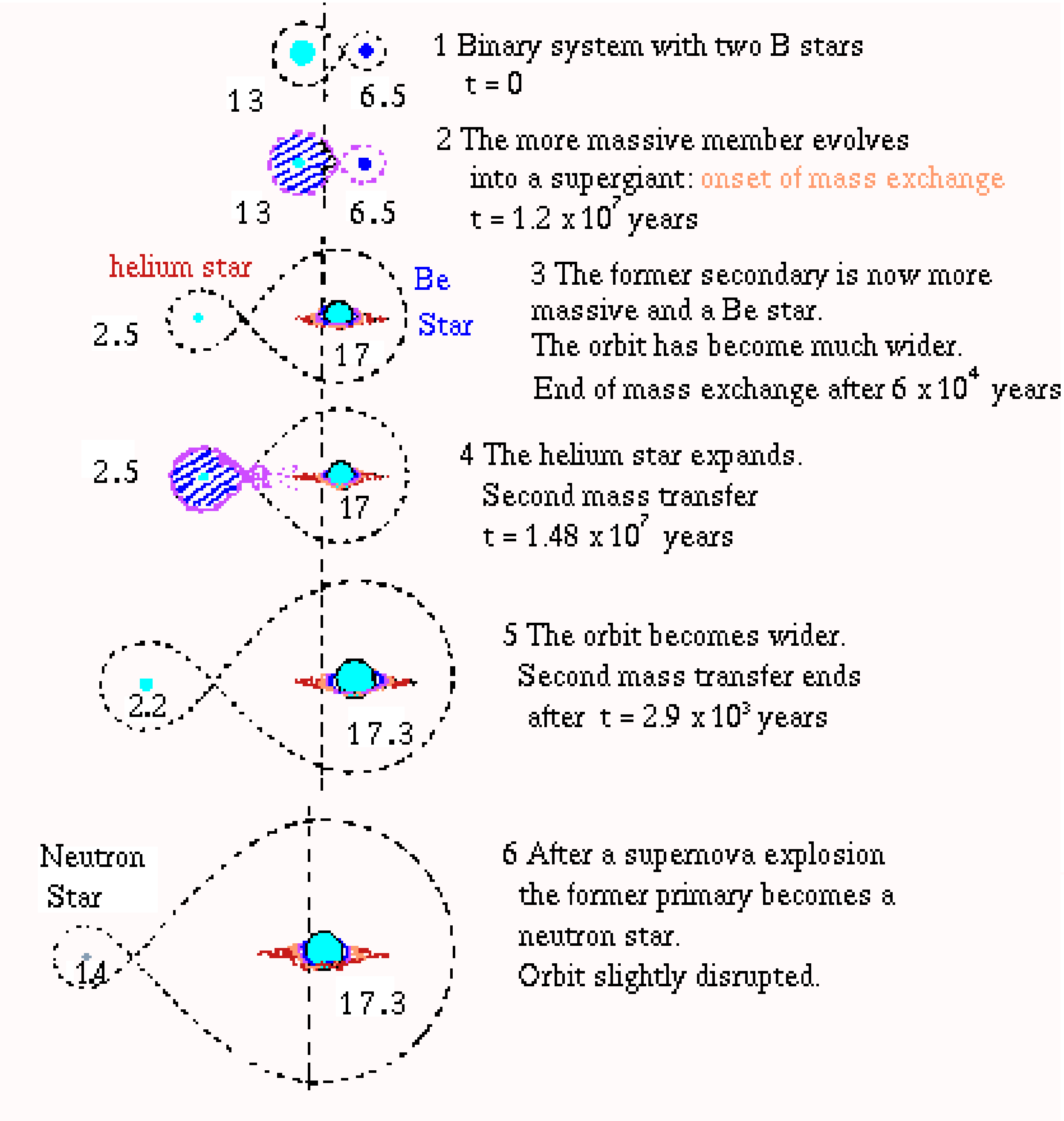
Accretion in Binaries II

- Classes of X-ray binaries
  - Low-mass (BH and NS)
  - High-mass (BH and NS)
  - X-ray pulsars (NS)
  - Be/X-ray binaries (NS)
- Distinguishing NS versus BH binaries

X-Ray Binaries

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

HMXB Formation



1 Binary system with two B stars
t = 0

2 The more massive member evolves
into a supergiant: onset of mass exchange
t = 1.2 x 10^7 years

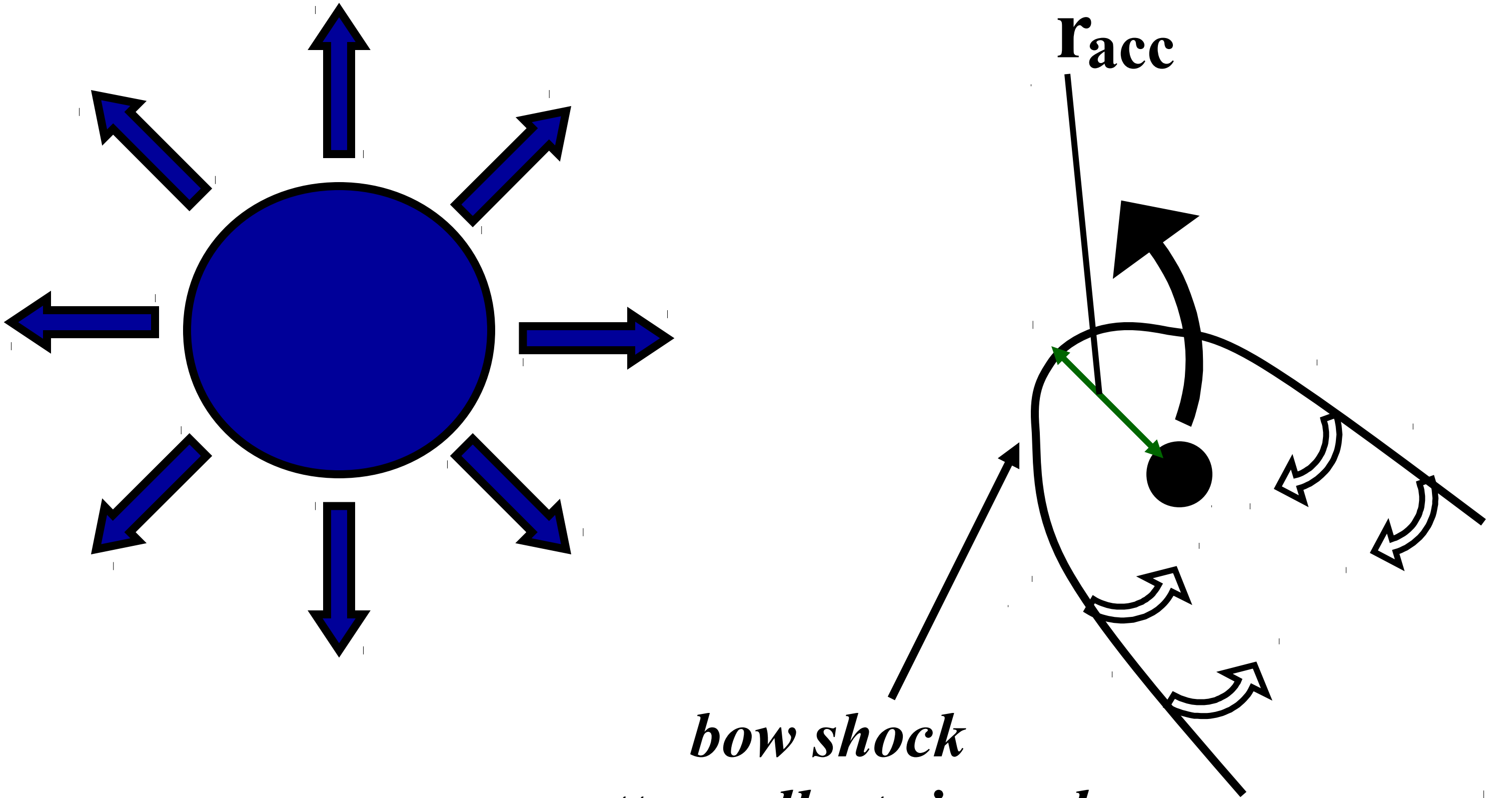
3 The former secondary is now more
massive and a Be star.
The orbit has become much wider.
End of mass exchange after 6 x 10^4 years

4 The helium star expands.
Second mass transfer
t = 1.48 x 10^7 years

5 The orbit becomes wider.
Second mass transfer ends
after t = 2.9 x 10^3 years

6 After a supernova explosion
the former primary becomes a
neutron star.
Orbit slightly disrupted.

Wind Fed Accretion



bow shock

matter collects in wake

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

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

Luminosity

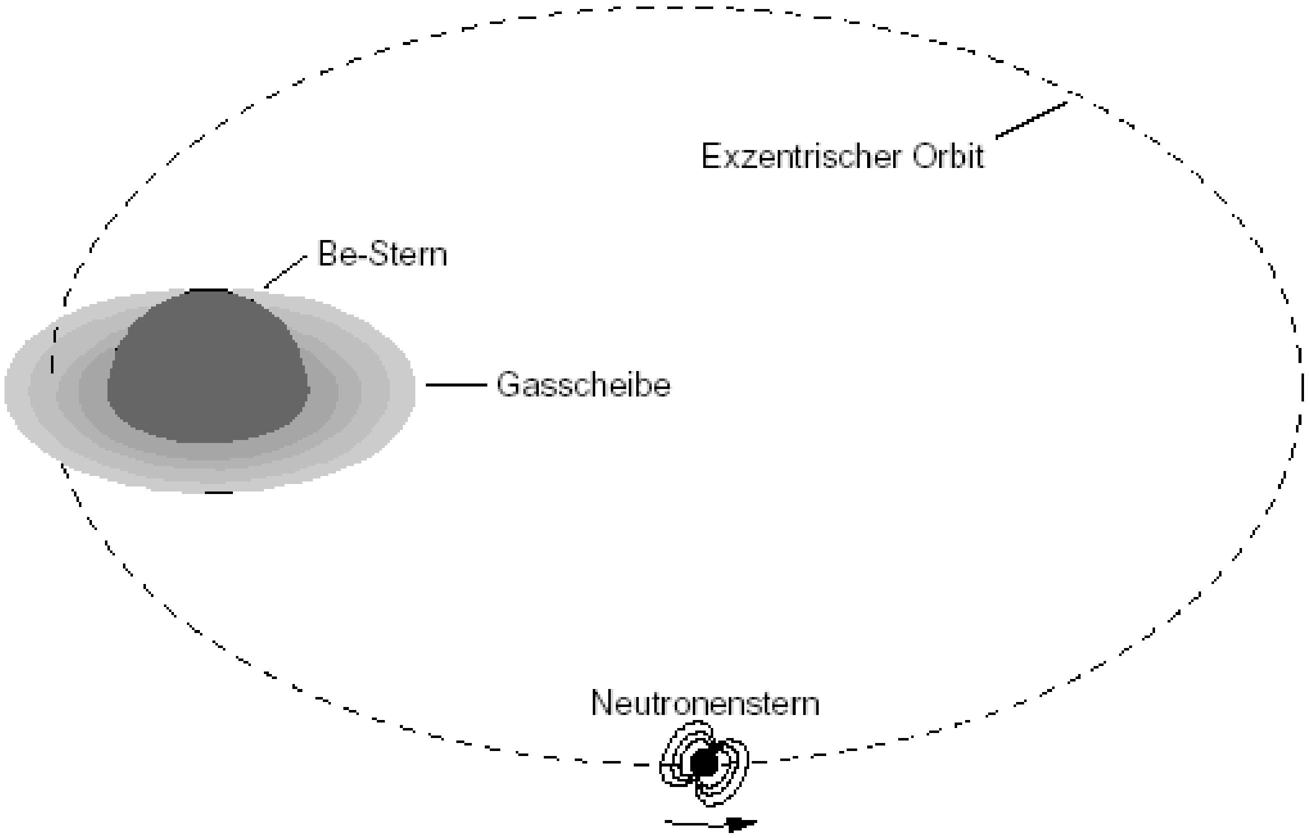
$$\dot{m} = \frac{\dot{m}_w}{4}\left(\frac{r_{acc}}{D_{orb}}\right)^2 \Rightarrow$$

$$L = \xi \dot{m} c^2 \approx \frac{\xi \dot{m}_w c^2}{4}\left(\frac{2GM}{D_{orb}}\right)^2 v_w^{-4},\ if\ v_w >> v_X$$

If a neutron star binary has the following parameters, $D_{orb}=10^{12}$ cm, v_w= 1000 km/s,

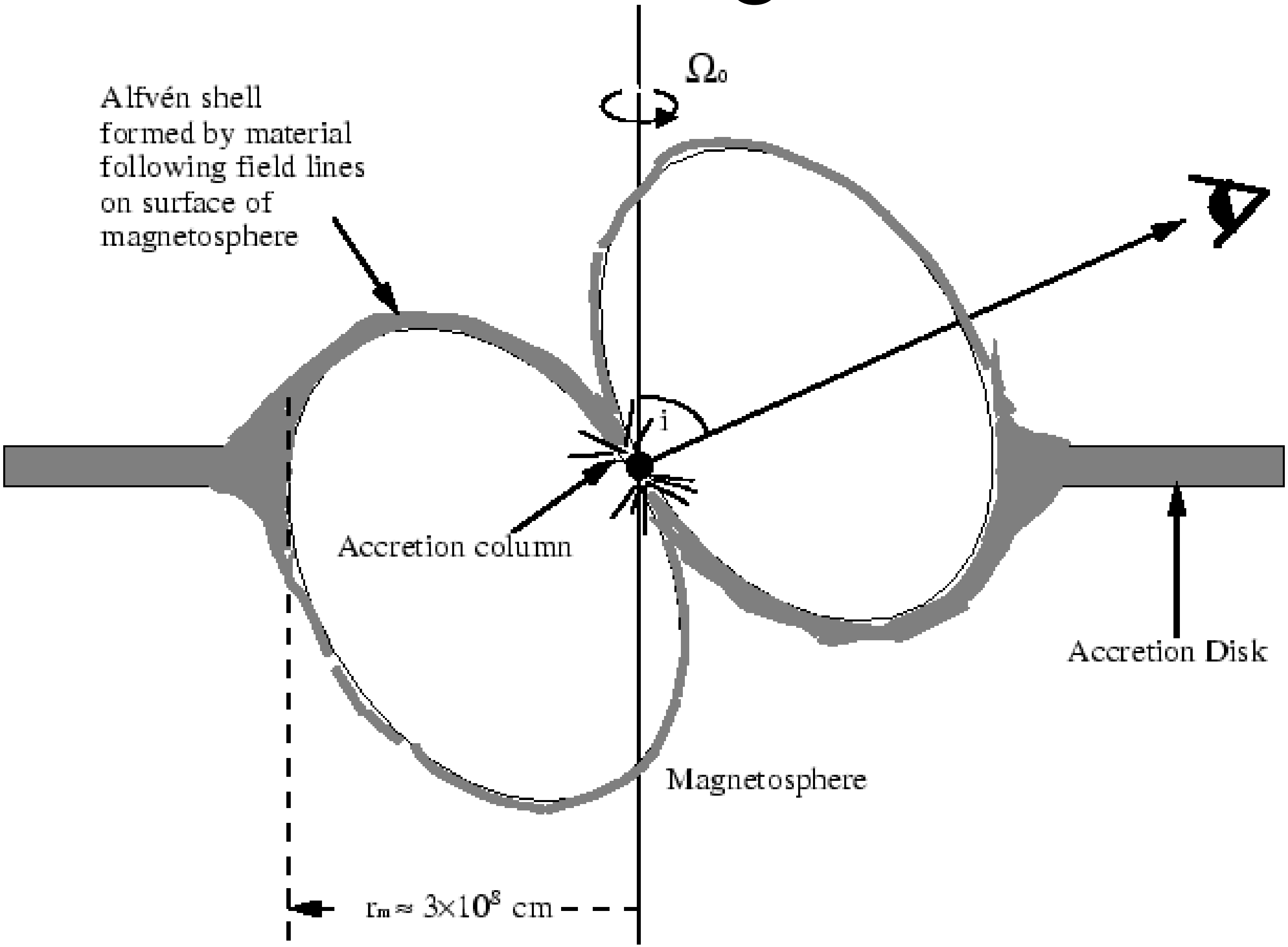
$$L \approx \left[\frac{1}{4}\left(\frac{R_s}{D_{orb}}\right)^2\left(\frac{c}{v_w}\right)^4\right] \xi \dot{m}_w c^2 = 4\times 10^{-4}\left(\xi \dot{m}_w c^2\right)$$

Accreting Pulsars



High mass X-ray binary

Accretion in magnetic field



Magnetosphere boundary

Magnetopheric boundary, r_M, is where the magnetic pressure balances the ram pressure of accreted matter

$$p_{mag} = \frac{B^2}{8\pi} = p_{ram} = \rho v^2$$

Assuming spherical accretion and a dipole field with the dipole moment $\mu = B_S R_S^3$, where R_S and B_S are the radius of the star and the field strength at the surface.

$$r_M = 5.1 \times 10^8 \,\mathrm{cm} \left(\frac{\dot{m}}{10^{16}\,\mathrm{g/s}} \right)^{-2/7} \left(\frac{M}{M_\Theta} \right)^{-1/7} \left(\frac{\mu}{10^{30} G \cdot \mathrm{cm}^3} \right)^{4/7}$$

Accretion Torque

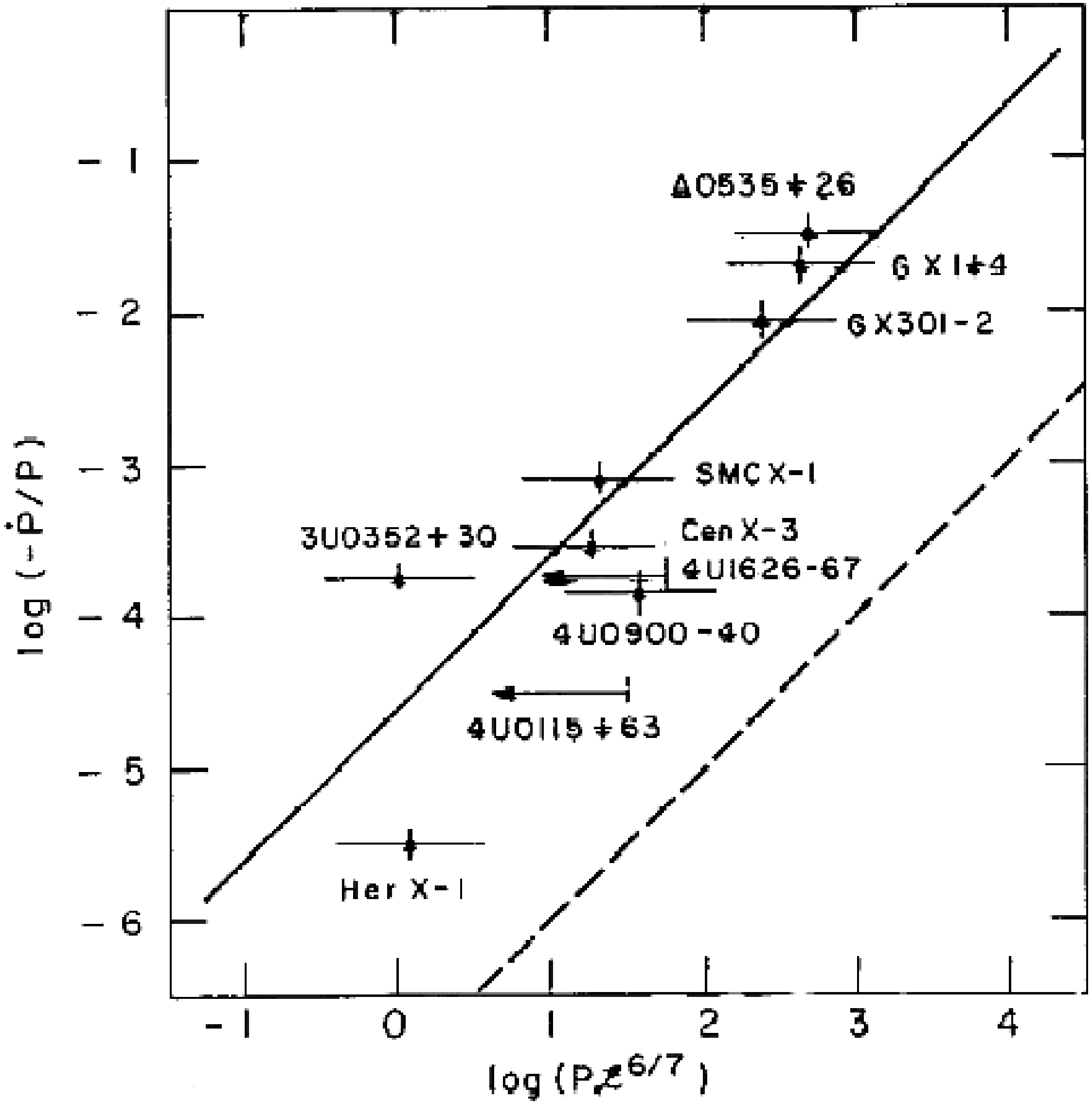
Angular momentum transport $= \dot{m} v_{\varphi} r$

Torque on star $= I \dot{\omega} = \dot{m} v_{\varphi} r_{m}$

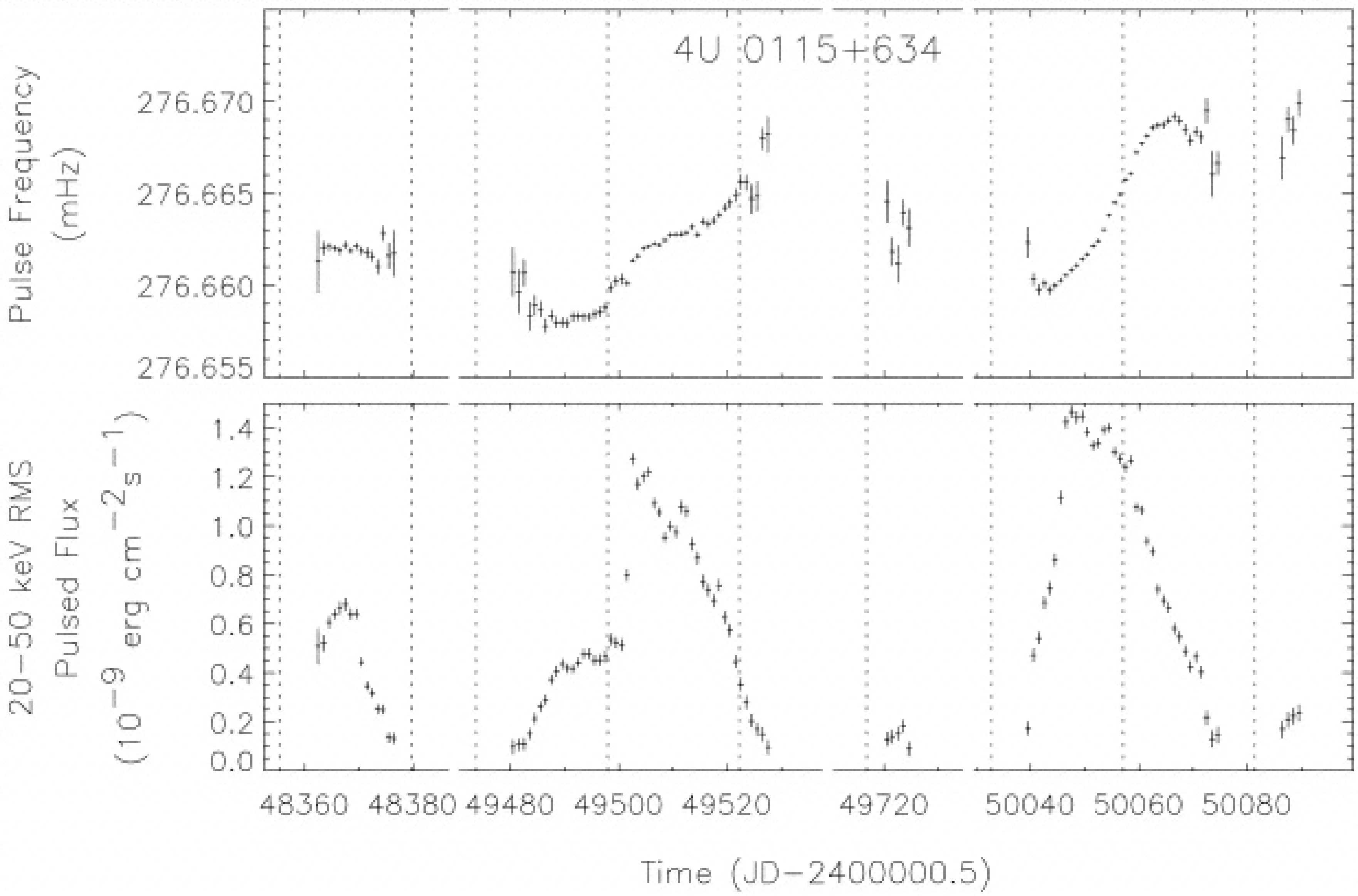
Note $L = \frac{GM \dot{m}}{r_{M}}$ and $\dot{\omega} = \frac{-2\pi}{P^2} \dot{P}$

Find $\frac{\dot{P}}{P} \propto P L^{6/7}$

Accretion Torque



Pulse Period Variations



What happens if the spin rate of the pulsar is faster than Keplerian rotation rate at the magnetospheric boundary?

Corotation radius lies outside magnetopheric boundary

Equilibrium Period

The accreted matter ceases to transfer angular momentum to the neutron star when

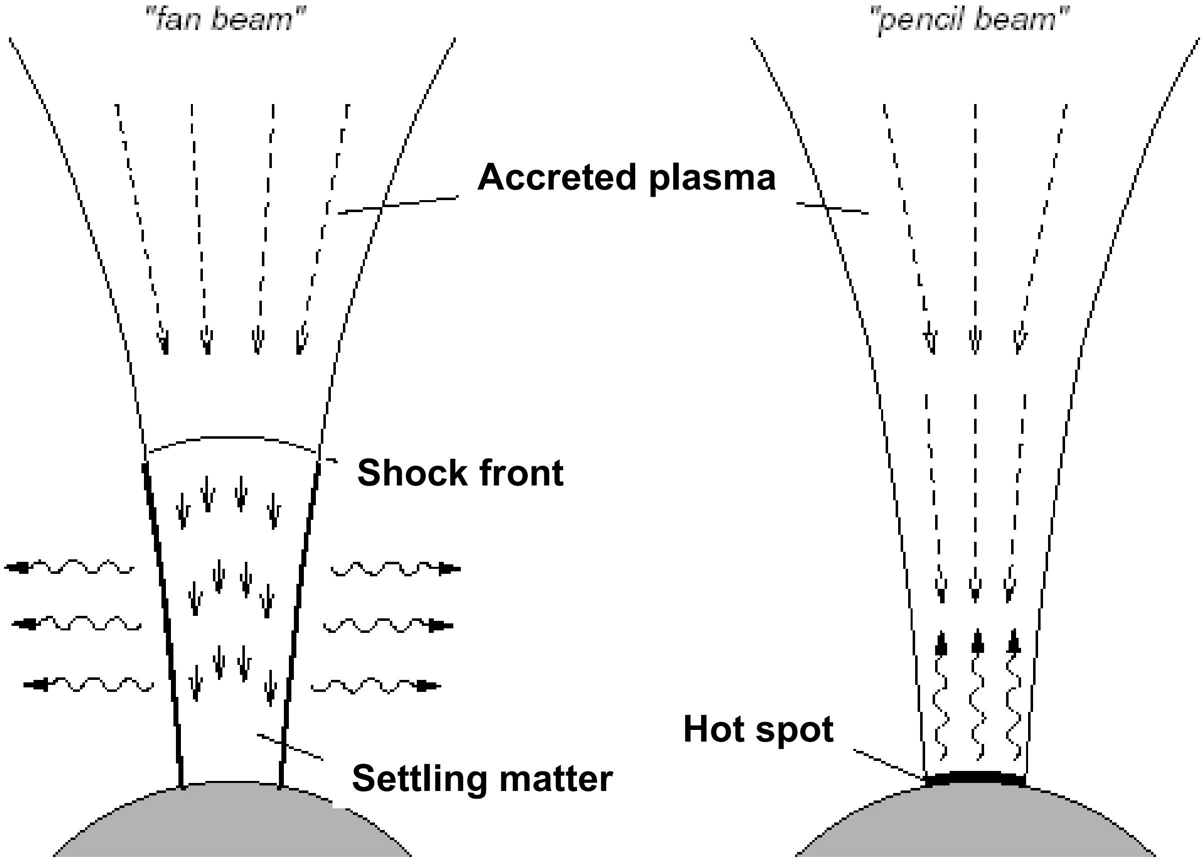
$$\omega = \Omega_K(r_M)$$

$$P_{eq} = 2\pi \left(\frac{r_M^3}{GM} \right)^{1/2} = \frac{2\pi}{(GM)^{1/2}} \left(\frac{R^{12}}{8\pi GM \dot{m}} \right)^{3/14} B_S^{6/7}$$

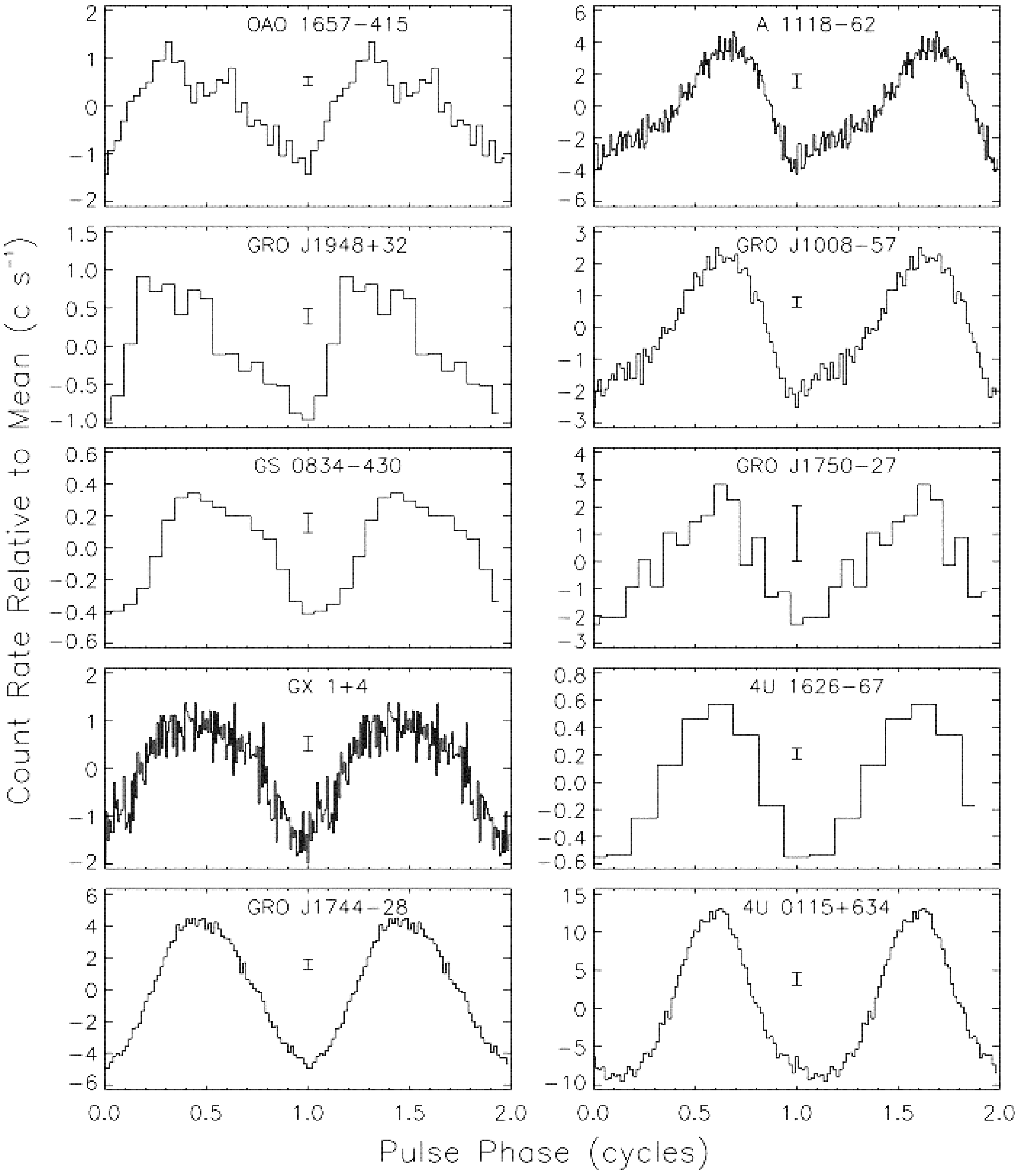
For a maximum (Eddington) luminosity and typical neutron star mass and radius, we have

$$\frac{P_{\min}}{0.002\,s} \approx \left(\frac{B}{10^9 G} \right)^{6/7}$$

Emission Geometry



Pulse Profiles



Landau Levels

Quantization of energy due to magnetic field:

$$E_n = m_\mathrm{e} c^2 \sqrt{1 + \left(\frac{p_\parallel}{m_\mathrm{e} c}\right)^2 + 2n\frac{B}{B_\mathrm{crit}}}$$

Landau levels

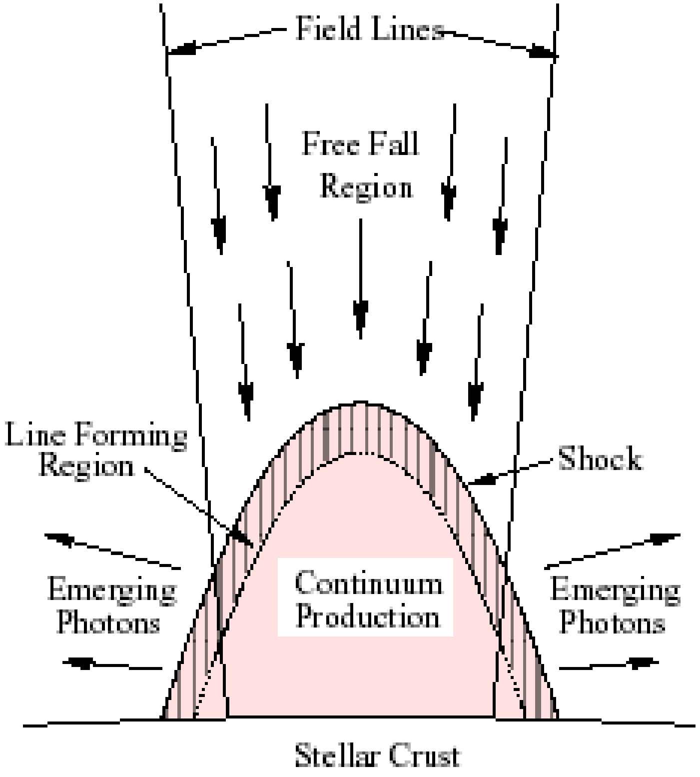
where $p_\parallel$ is the momentum of the electron parallel to the field, n is the quantum number, and B_{crit} is the critical field,

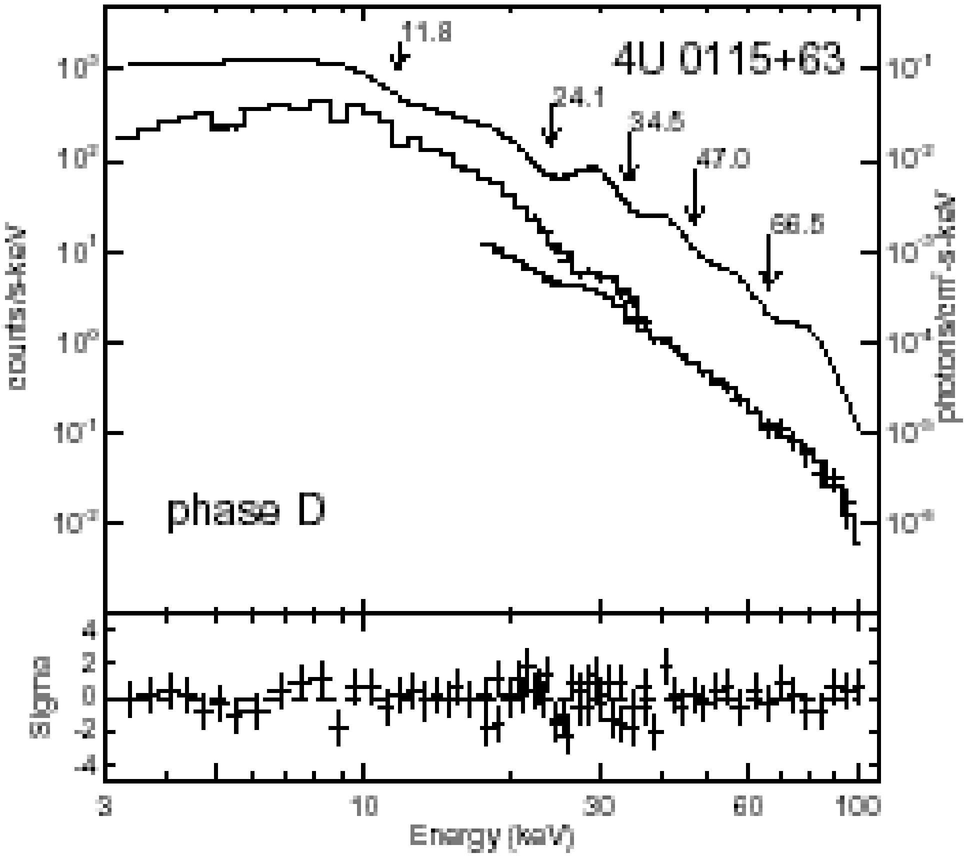
$$B_{crit} = \frac{m_e^2 c^3}{e\hbar} \approx 4.4 \times 10^{13} G$$

For $B \ll B_{crit}$, the spacing between adjacent levels is

$$E_{cyc} = E_{n+1} - E_n = \frac{\hbar e}{m_e c} B = 11.6\, keV \left(\frac{B}{10^{12} G}\right)$$

Cyclotron Lines





X-Ray Pulsar Cen X-3

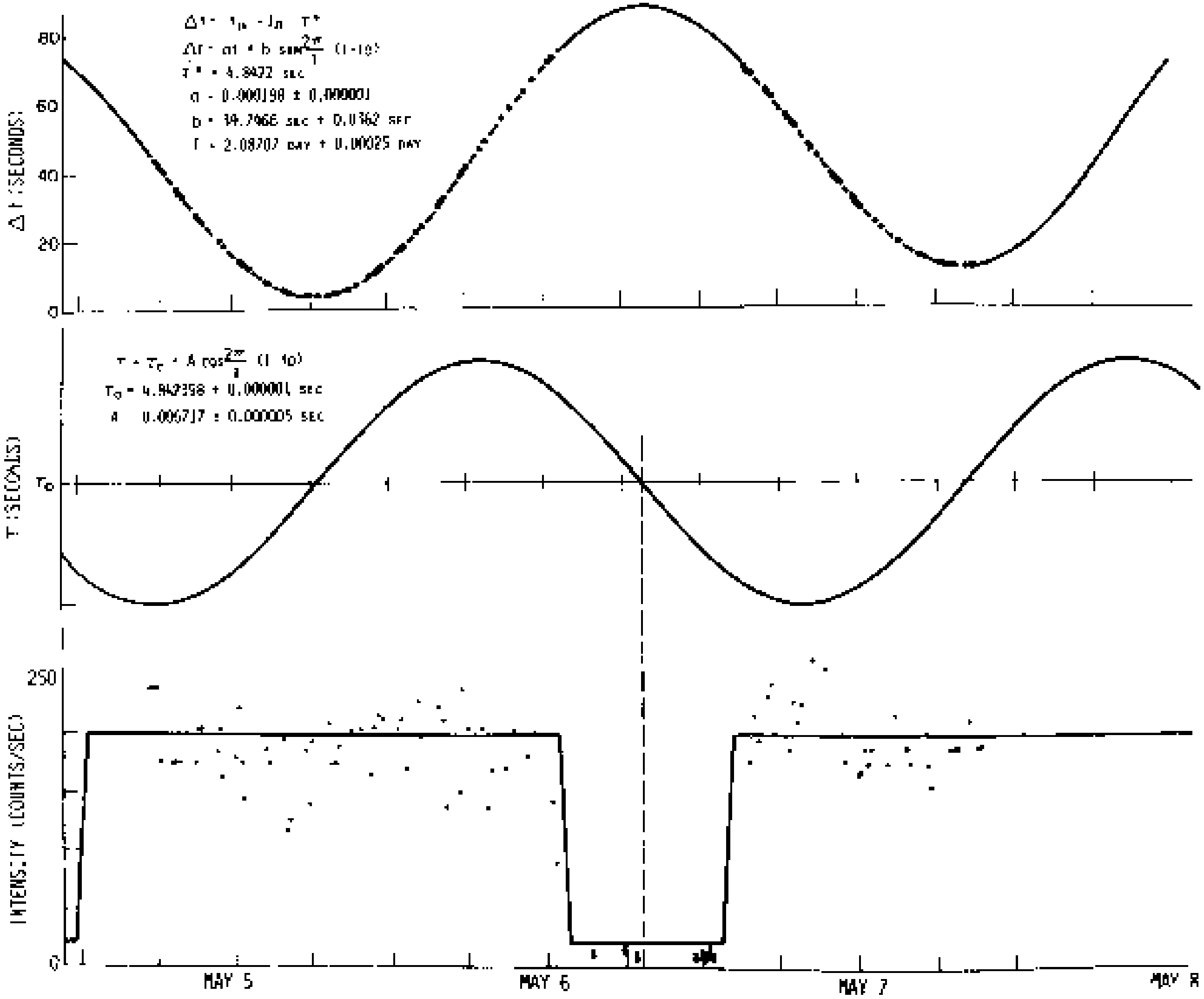
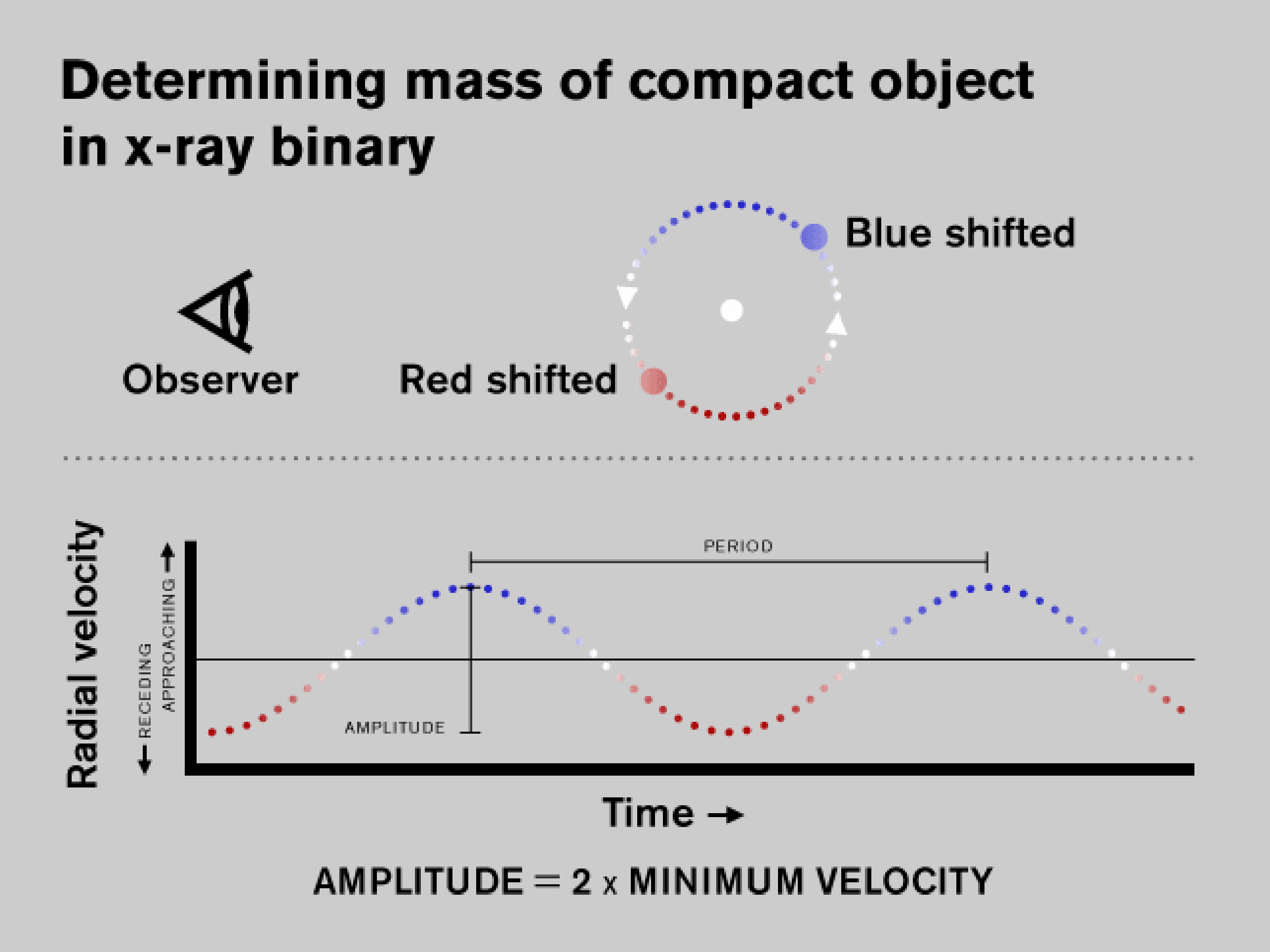


Figure 6. Period variations and occulations of Cen X–3. From Giacconi, 1974.

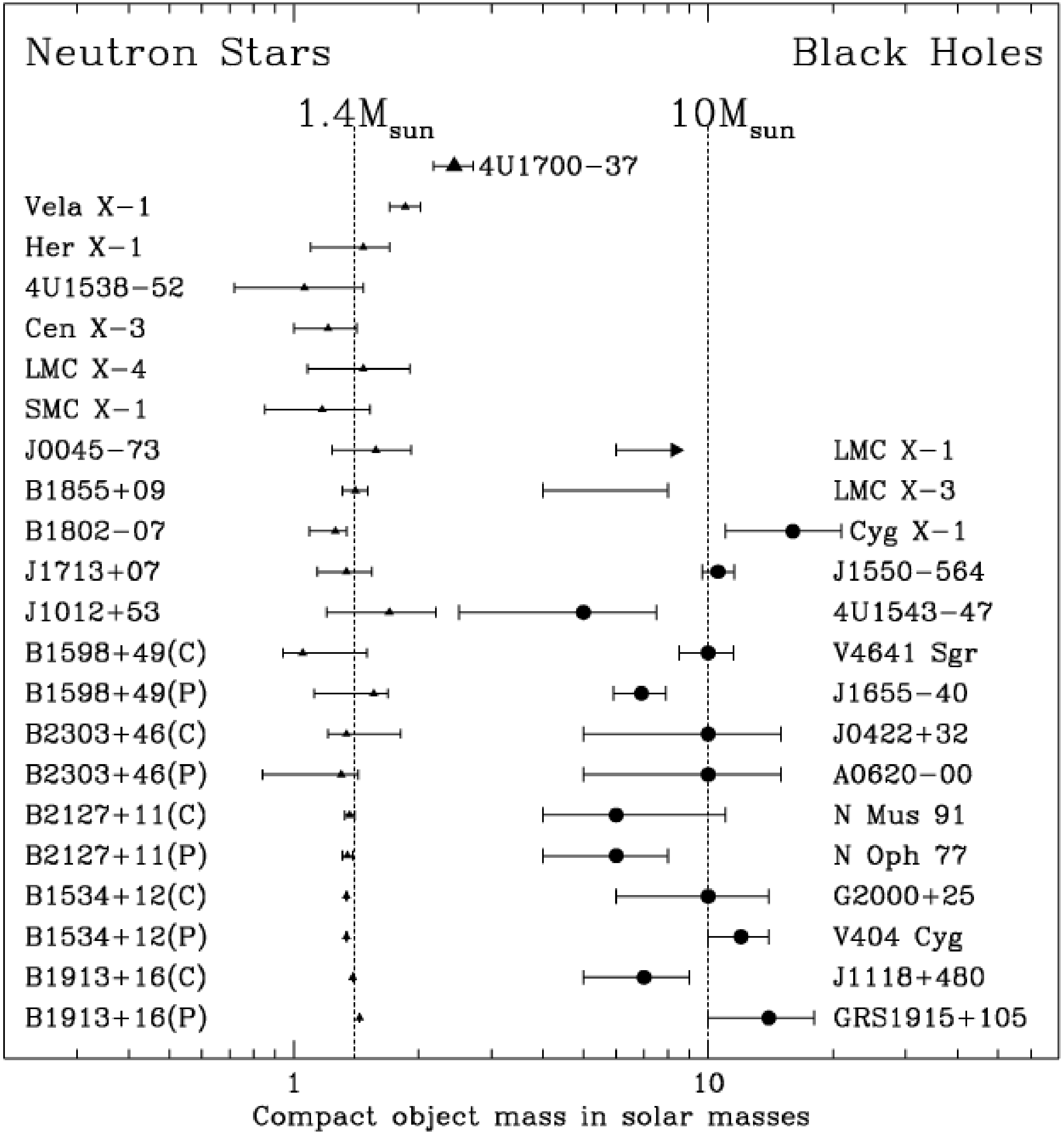
Pulses are modulated at orbital period of 2.09 days

Distinguishing BH vs NS



Mass function

$$f_0 \equiv \frac{M_X^3 \sin^3 i}{(M_X + M_0)^2} = \frac{P_0 K_0^3}{2\pi G} \qquad f_0 \leq M_X$$


Neutron Stars
Black Holes
1.4M_sun
10M_sun
4U1700-37
Vela X-1
Her X-1
4U1538-52
Cen X-3
LMC X-4
SMC X-1
J0045-73
B1855+09
B1802-07
J1713+07
J1012+53
B1598+49(C)
B1598+49(P)
B2303+46(C)
B2303+46(P)
B2127+11(C)
B2127+11(P)
B1534+12(C)
B1534+12(P)
B1913+16(C)
B1913+16(P)
LMC X-1
LMC X-3
Cyg X-1
J1550-564
4U1543-47
V4641 Sgr
J1655-40
J0422+32
A0620-00
N Mus 91
N Oph 77
G2000+25
V404 Cyg
J1118+480
GRS1915+105
1
10
Compact object mass in solar masses