High-mass X-ray binaries

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50 years of X-ray astronomy

2002: Giacconi recieves NP from the king of Sweeden

1962 Bruno Rossi & Riccardo Giacconi

American Science & Engineering (AS&E)

A rocket with Geiger counter: to seach X-rays from the Moon

Rocket spans -
the field-of-view passed a bright source named Scorpius X-1

Sun: X-rays are 10^{-6} visible light intensity

Sco X-1: $L_X = 10^9\ L_X^{sun}$

www.nobelprize.org/nobel_prizes/physics/laureates/2002/giacconi-lecture.html

First discovery

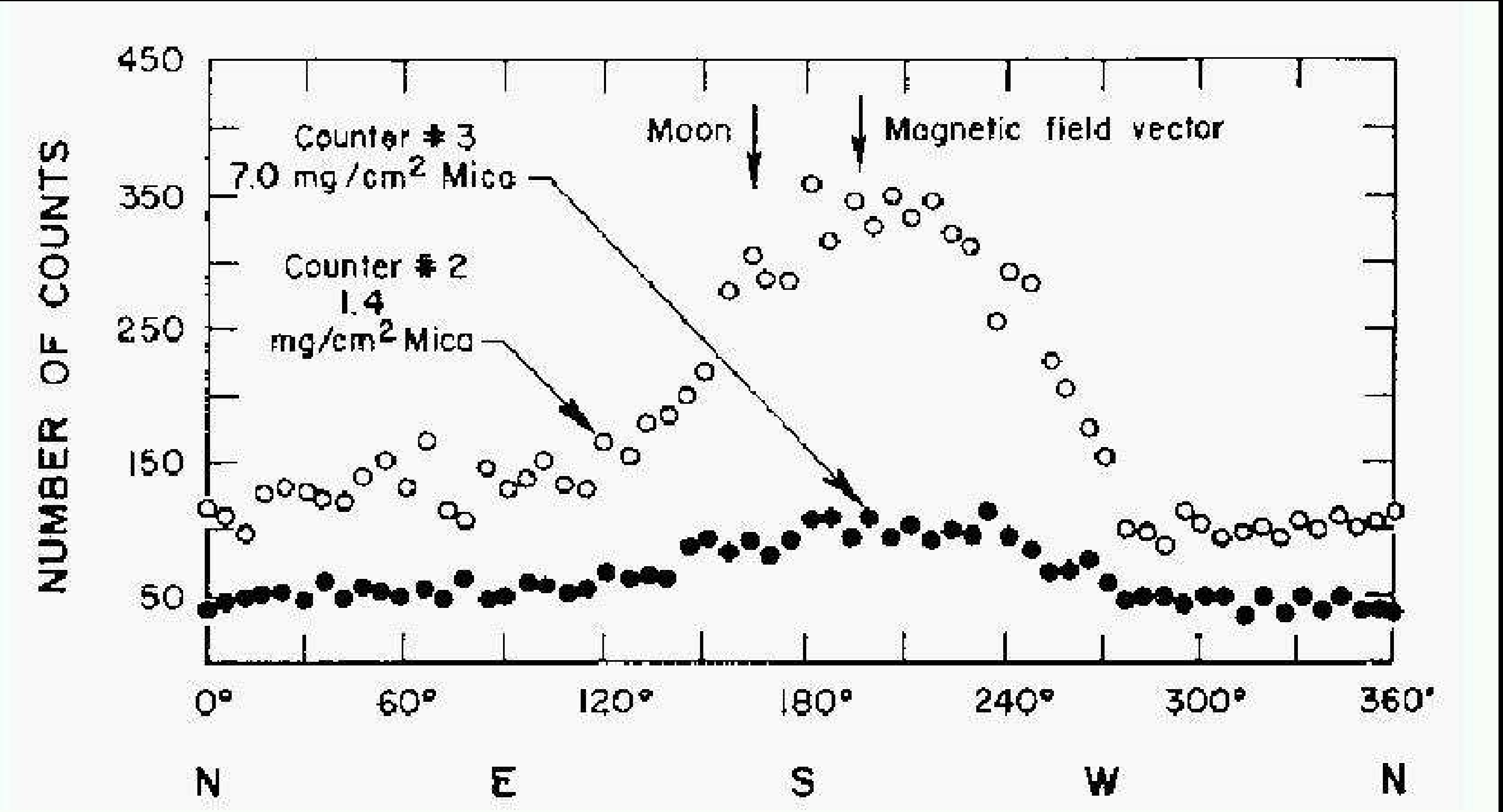


Figure 2. The first observation of Sco X–1 and of the x–ray background in the June, 12, 1962 flight. From Giacconi, *et al.*, 1962.

Sco X-1 is the first extrasolar X-ray source

Shklovsky 1967: Sco X-1 is a binary containing neutron star

1967: Hewish discovery of pulsars

Note the X-ray background

First X-ray Sky Survey: UHURU Dec 1970 - March 1973

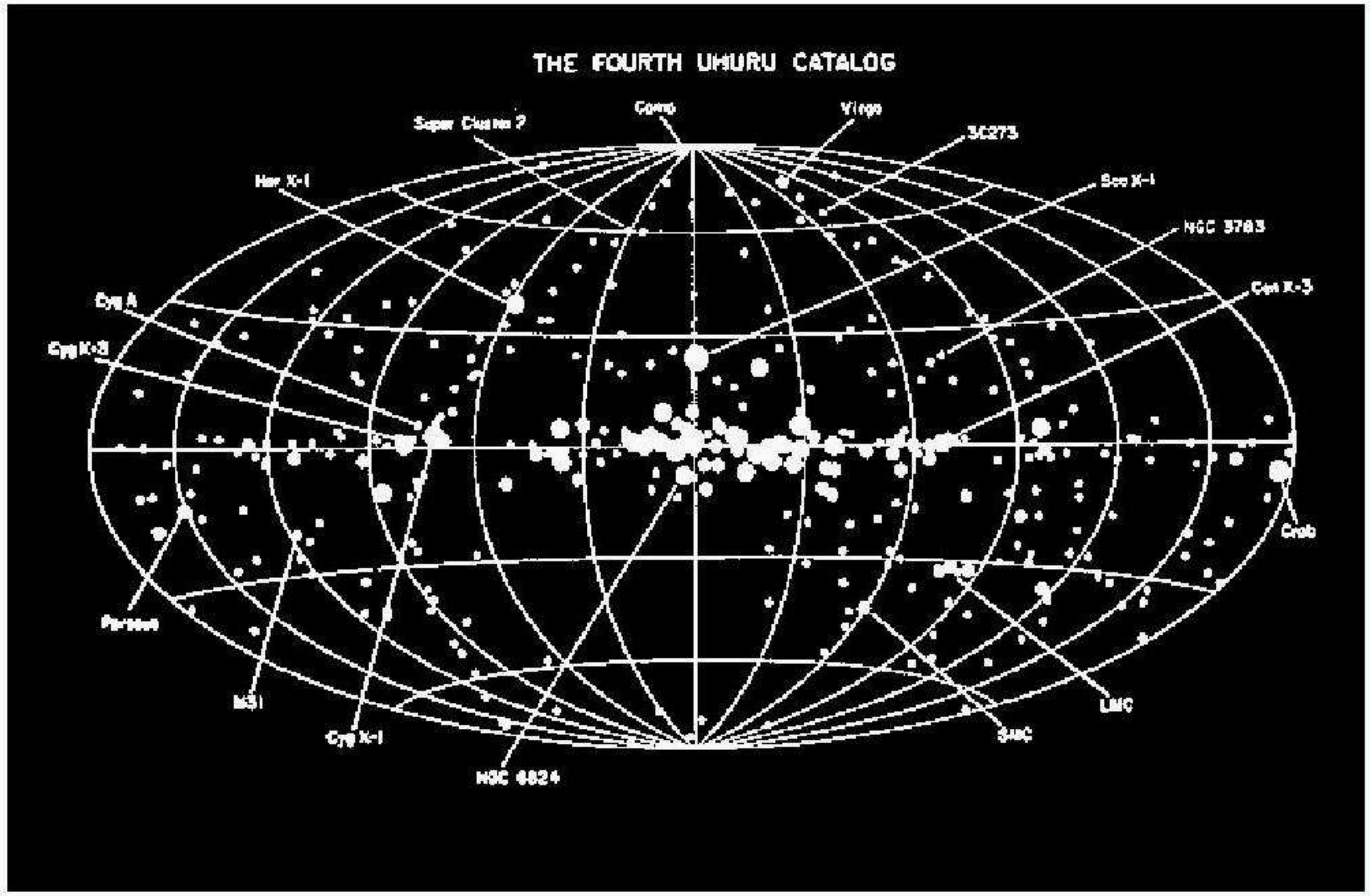


Figure 4. The x–ray sources observed by UHURU plotted in galactic coordinates. The site of the dot is proportional to intensity on a logarithmic time scale. From X-ray Astronomy (Eds. R. Giacconi, H. Gursky), 1974, Riedel, Dordrecht, p. 156.

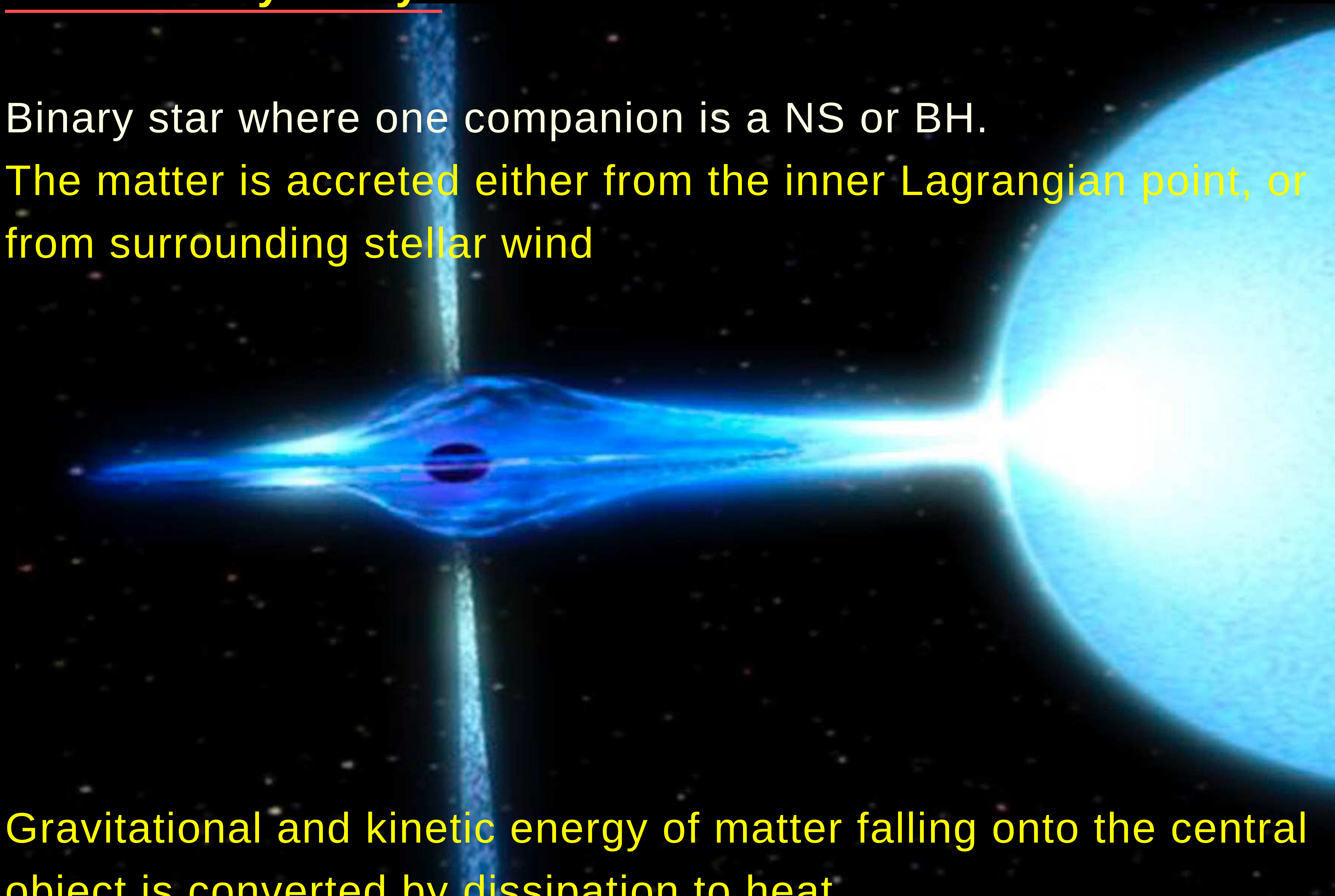
Band 2 .. 20 keV, flux 1/10,000th of Sco X-1, A = 0.084 m^2

First black holes Cyg X-1, Her X-1, X-ray pulsars

Galactic plane, AGNs, galaxy clusters

Total 339 sources, 4th Catalog names 4U1957+11 etc..

What is X-ray binary?



Binary star where one companion is a NS or BH.

The matter is accreted either from the inner Lagrangian point, or from surrounding stellar wind

Gravitational and kinetic energy of matter falling onto the central object is converted by dissipation to heat.

Accretion

The depth of potential well in compact objects is large → large ammount of energy is liberated in accretion process

The process of accretion at a rate $\dot{M}$ onto an object of mass M and radius R gives a luminosity of

$$L = GM\dot{M}/R$$

Heat is partially radiated out, partially converted to work on the disc expansion and (in the case of BH accretion) partially lost inside the hole.

Mass to energy conversion efficiency $\eta = L/Mc^2 = 0.1$ → **considerably greater than the efficiency of nuclear fusion**

Eddington limit

The accretion rate is limited by the Eddington limit. Defined by the balance between outward radiation pressure and inward gravitational force.

Any phenomenon lasting more than a few dynamical scales should have $L<L_{edd}$.

Force of radiation acting on an electron

$$F_{\rm rad} = \frac{L}{4\pi R^2 h\nu}\sigma_{\rm T}\frac{h\nu}{c}$$

Force of gravity on a proton $$F_{\rm grav} = \frac{GMm_{\rm p}}{R^2}$$

$$L_{\rm edd} = \frac{4\pi GMm_{\rm p}c}{\sigma_{\rm T}} \approx 10^{38} M \ \text{[erg/s/M}_\odot\text{]}$$

Maximum accretion rate

$$\dot{M}^{\rm edd}_{\rm acc} = \frac{L_{\rm edd}}{\eta c^2} \approx 2\times 10^{-8} M \ [\text{M}_\odot\text{/yr}]$$

Accretion disks

Matter's angular momentum is > than the Keplerian angular momentum → accreting matter will orbit a compact object.

Dissipation and friction: matter flattens and spreads equatorially into an accretion disk. The angular momentum is transported outward by friction and mass moves inward.

Newtonian gravity: angular momentum at a distance R from a spherical object with the mass M is $(GMR)^{1/2}$ → monotonically increasing → stability of all orbits.

Einstein gravity: angular momentum has a minimum at the radius of the innermost stable circular orbit (ISCO). Orbits above r_{ISCO} are stable, and below are unstable.

For a non- rotating black hole $r_{ISCO} = 6GM/c^2$

Shakura-Sunyaev ”standard” disk (1974)

Axially symmetric, stationary, local analytic model.

It is geometrically thin in the vertical direction and has a disc-like shape

Accretion rate is very sub-Eddington. Opacity is very high. High luminosity, high efficiency of radiative cooling.

Electromagnetic spectra is not much different from that of a sum of black bodies. α-viscosity prescription assuned, but weak dependence in final solution.

α-viscosity prescription is assumed ad hoc and not derived from the first principles

The gas goes down on tight spirals, approximated by circular, free (Keplerian, geodesic) orbits

11 Spherically symmetrical (Bondi) accretion

- Spherical accretion onto an object occurs e.g. in a star accreting from ISM or in a compact object immersed in stellar wind.

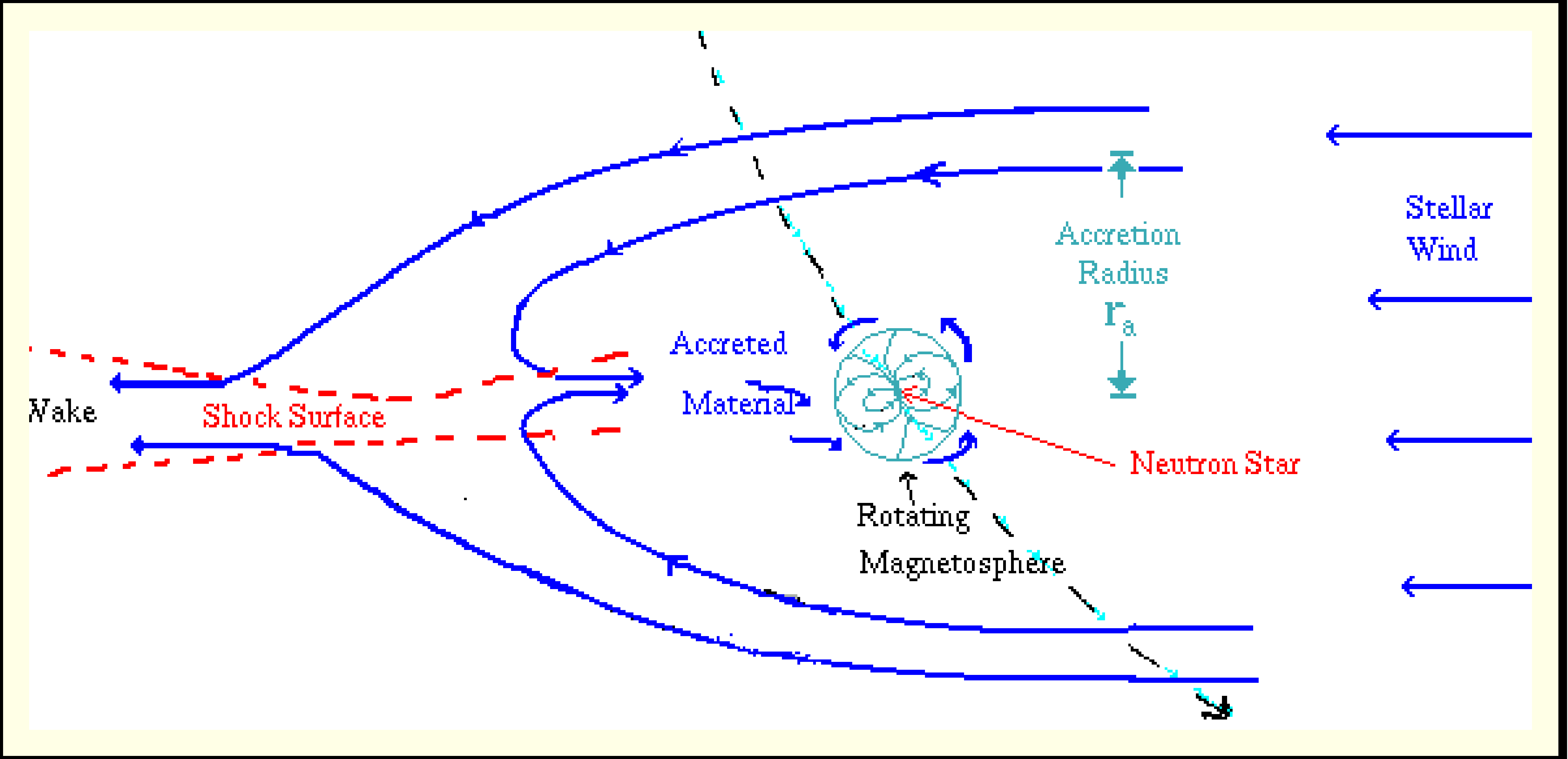
- This happening when angular momentum is not dynamically important

- Accretion rate $\dot{M}_{\rm acc} = 4\pi r_{\rm A}^2 \rho v$, velocity can be either sound speed (c_s) or motion speed of compact object through the medium.

- Accretion $E_{tpt}<0$ → r_A is effective radius such that escape velocity $\sqrt{\frac{2GM}{r_{\rm A}}} = v$

- $$r_{\rm A} = \frac{2GM}{v^2} \rightarrow \dot{M}_{\rm acc} = \frac{8\pi\rho G^2 M^2}{v^3}$$

Davidson & Ostriker (1973)

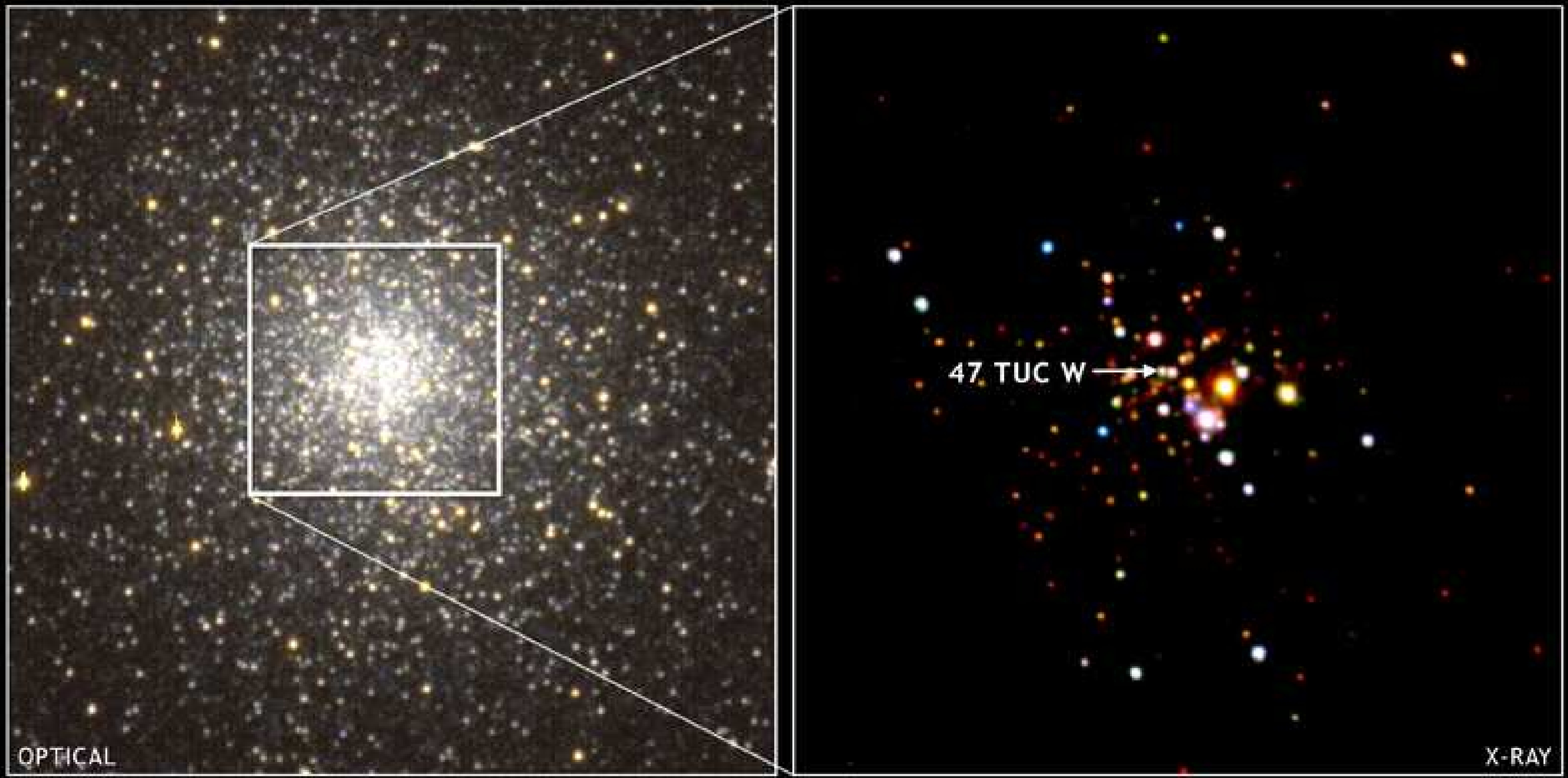


Accretion of stellar wind on a neutron star

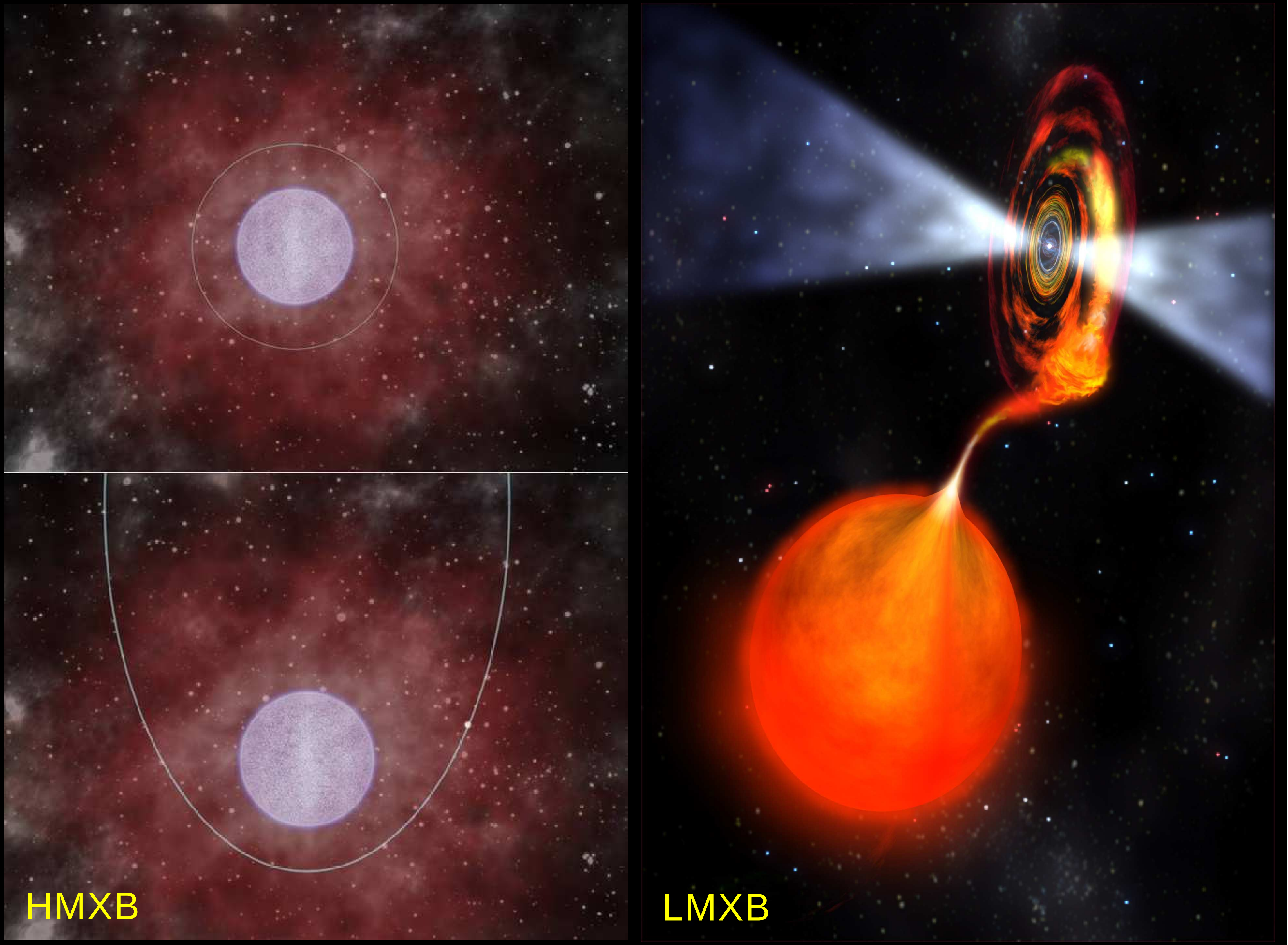
X-ray Binary Classification

Classified according to the type of donor

- High-mass X-ray binaries (HMXB): early-type star (OB or Wolf-Rayet). Stellar wind accretion. Located in star forming regions. Cyg X-1, Vela X-1, Her X-1
- Low-mass X-ray binary (LMXB): late type stars. Mass transfer via L1. Many types. Trace old population, globular clusters. Sco X-1



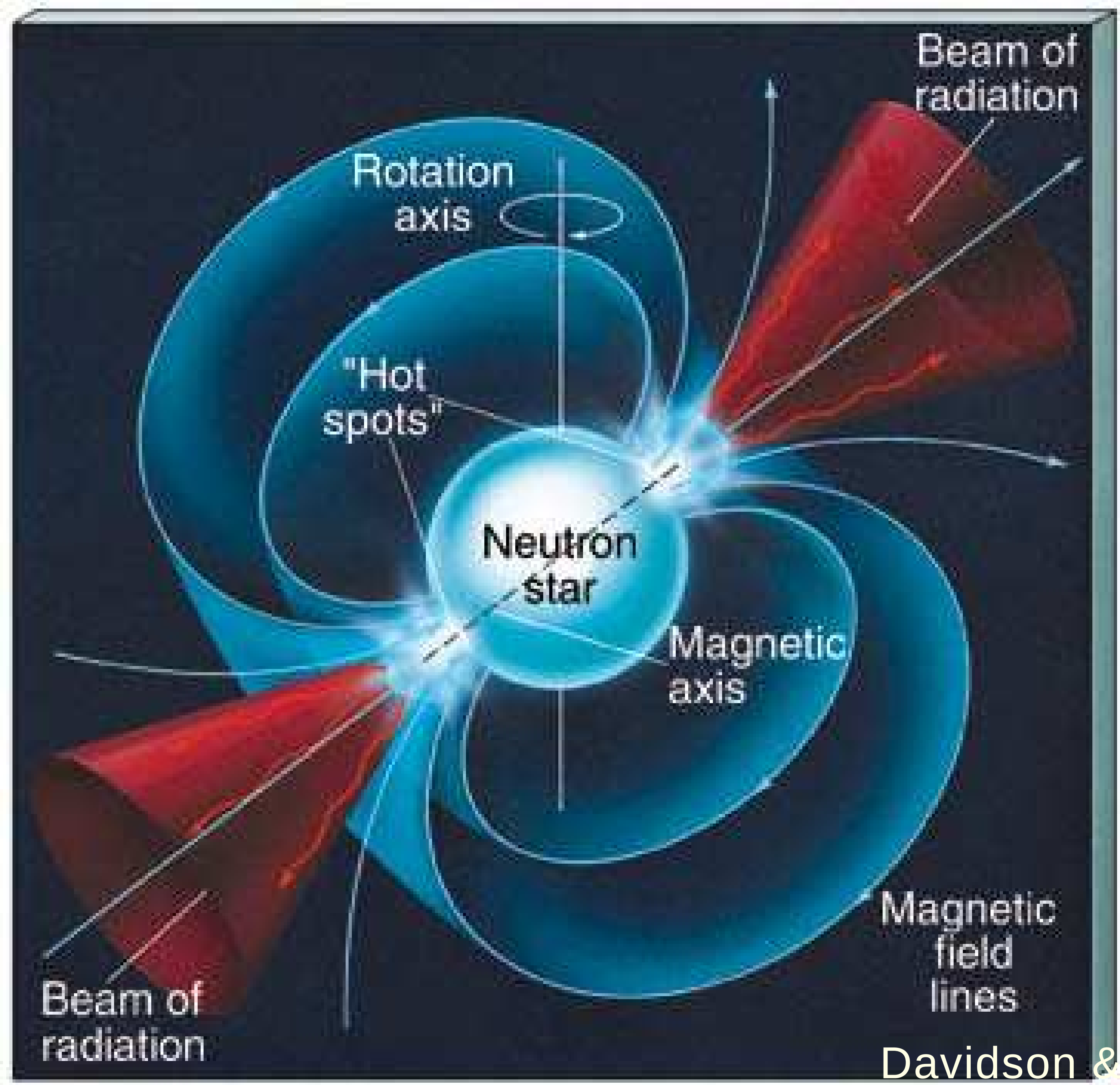
NASA/CXC/CfA/J.Grindlay C.Heinke; ESO/Danish 1.54-m/W.Keel


HMXB
LMXB

High Mass X-ray Binary Classification

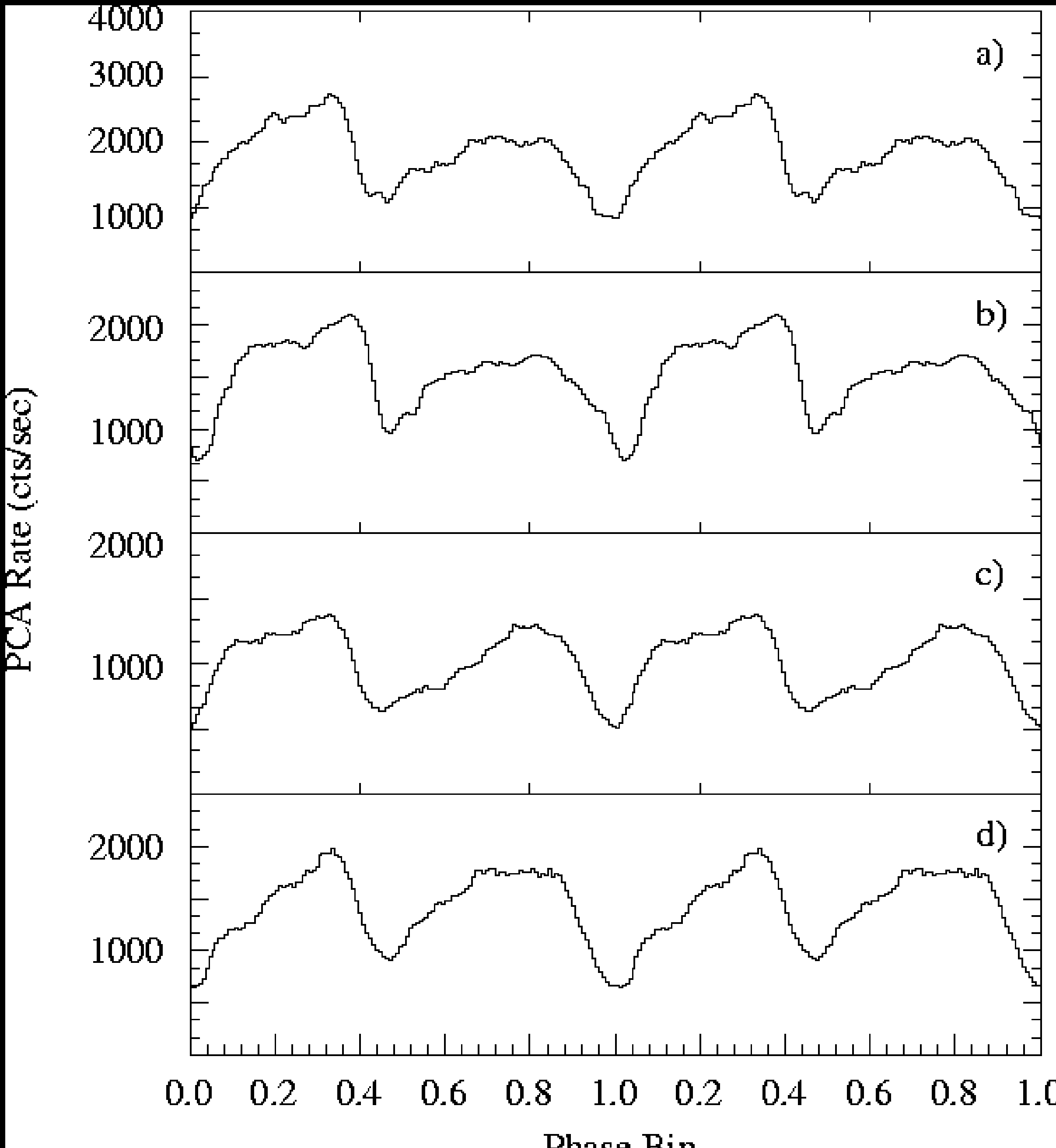
- Transients: exibit X-ray outbursts. Be-type donors. Her X-1
- Supergiant X-ray transients: OB-type donors, huge flares, physics is not understood discovered with Integral γ-ray observatory, many are highly-obscured
- Persistent sources: persistently bright X-ray sources. Vela X-1

  - Type of accretor: BH or Neutron Star
  - Neutron Star accretor: X-ray pulsars



Davidson & Ostriker 1973

X-ray Pulsars



Kreykenbohm et al. A&A 341, 141 P=283.4 s

- The rotation rate of the NS is held near equilibrium, depending on the B_0 and rotation rate
- If NS is spinning too fast $R_M > R_{sy}$, matter cannot fall through the magnetosphere
- Material is flung out of the system, inducing a braking torque. **Spin-down of a pulsar long period pulsars**
- If is spinning too slow $R_M < R_{sy}$. Density gradient in stellar winds → a side closer to the star accretes more → a torque → **spin up millisecond pulsars**

New NASA X-ray telescope

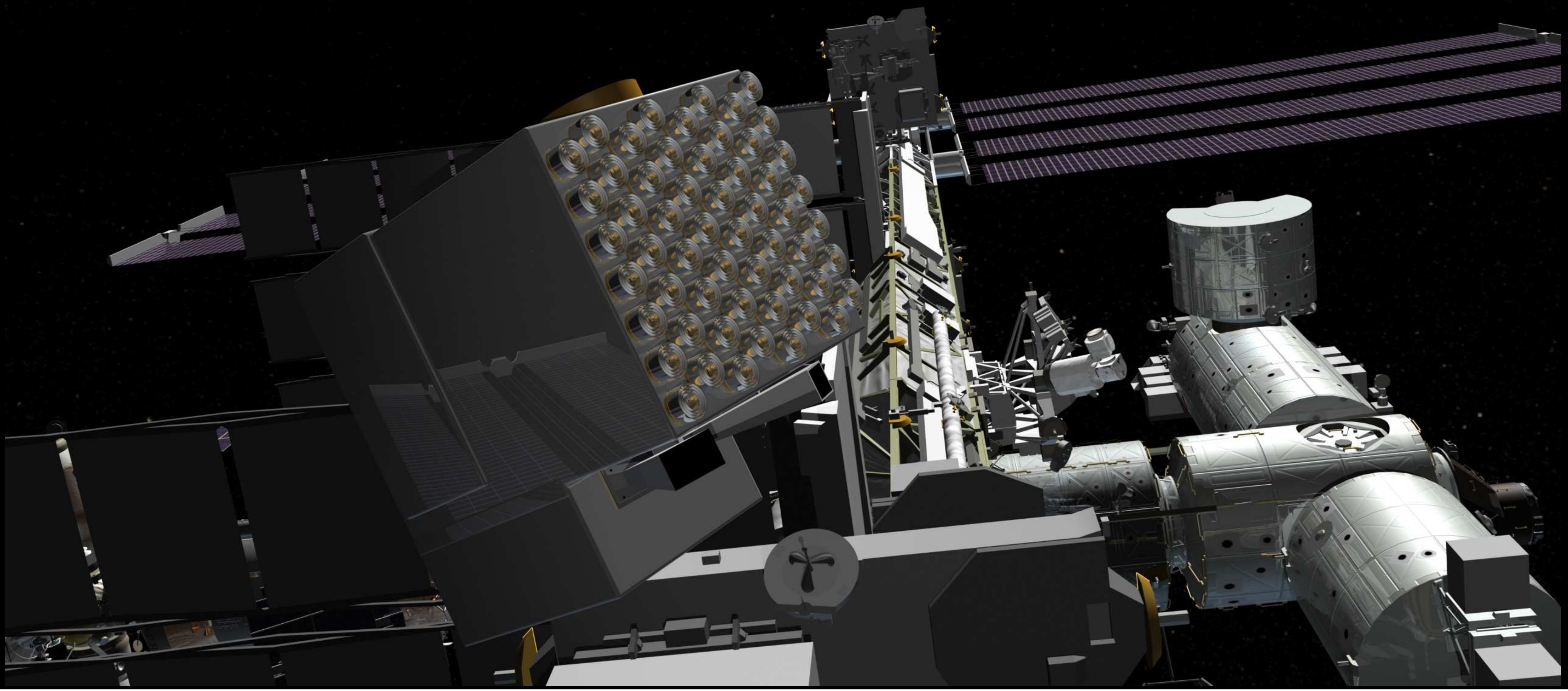
- Array of 56 telescopes mounted on the ISS

Measure X-ray pulsars X-ray light curves

Shape of the light-curve is affected by the gravity

Means to determine the equation of state

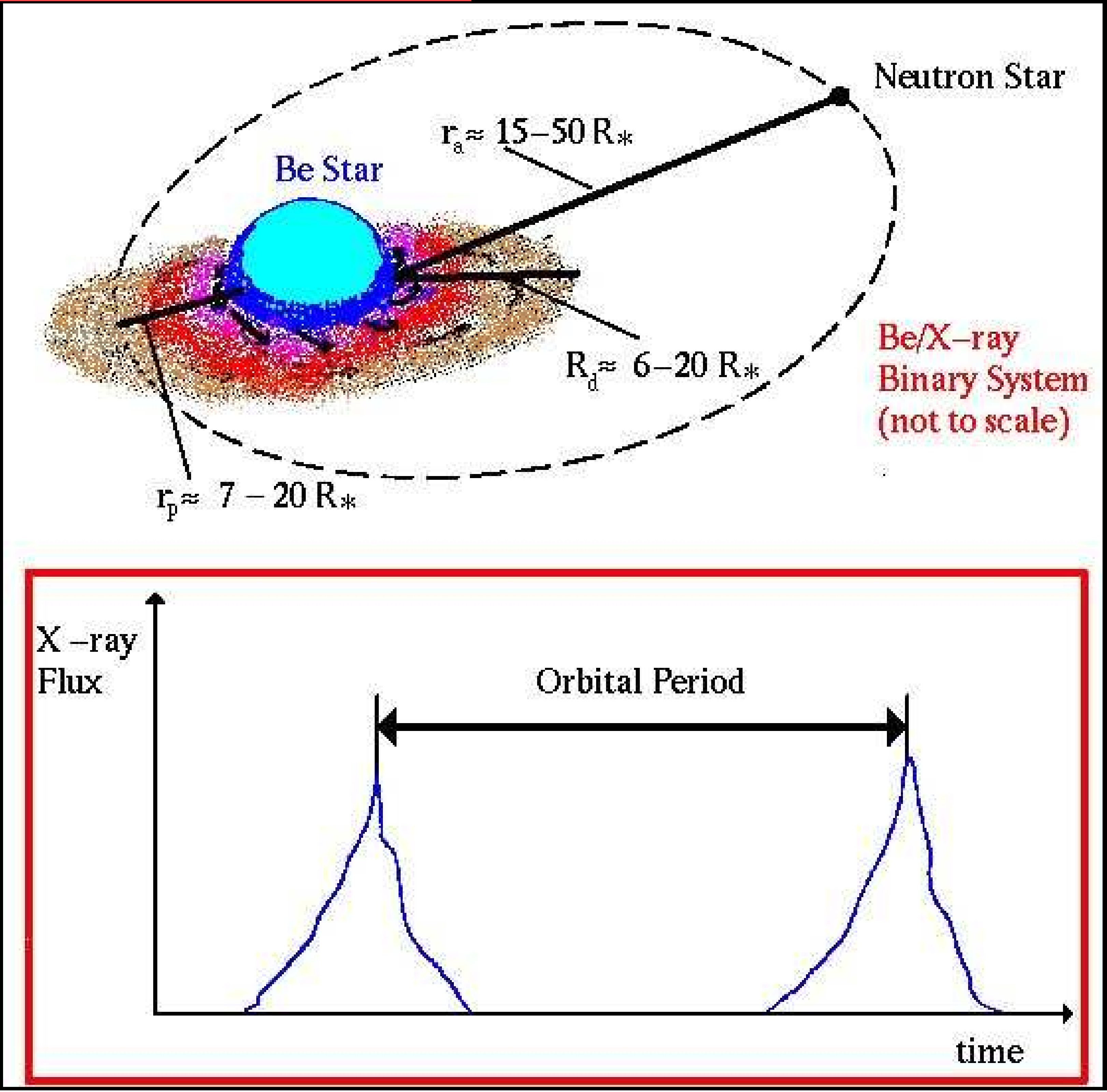
- Selected by NASA for launch in 2017



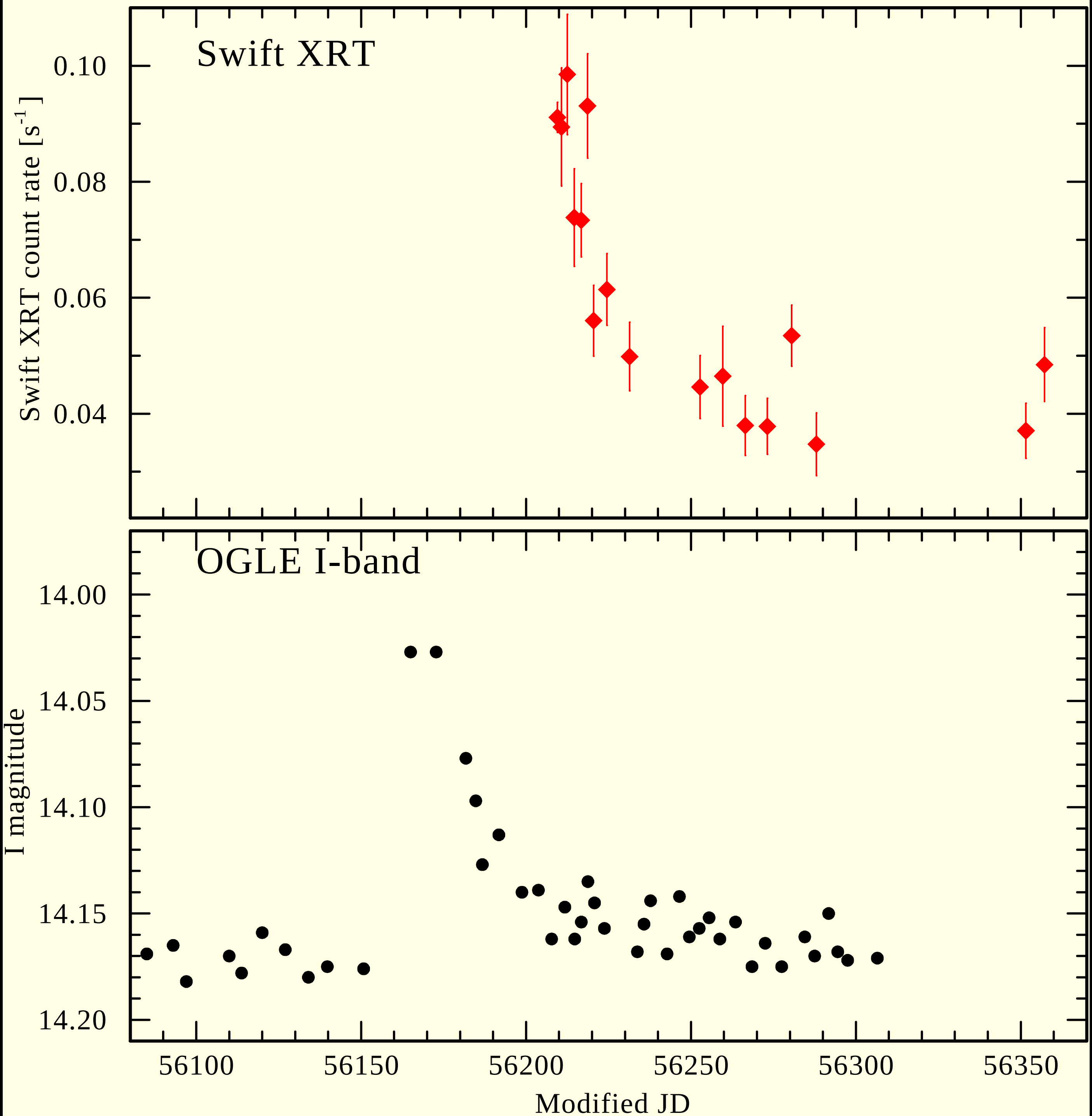
A walk through different types of HMXBs

- BeXRB
- SgHMXB
- SFXT
- RL-XRB

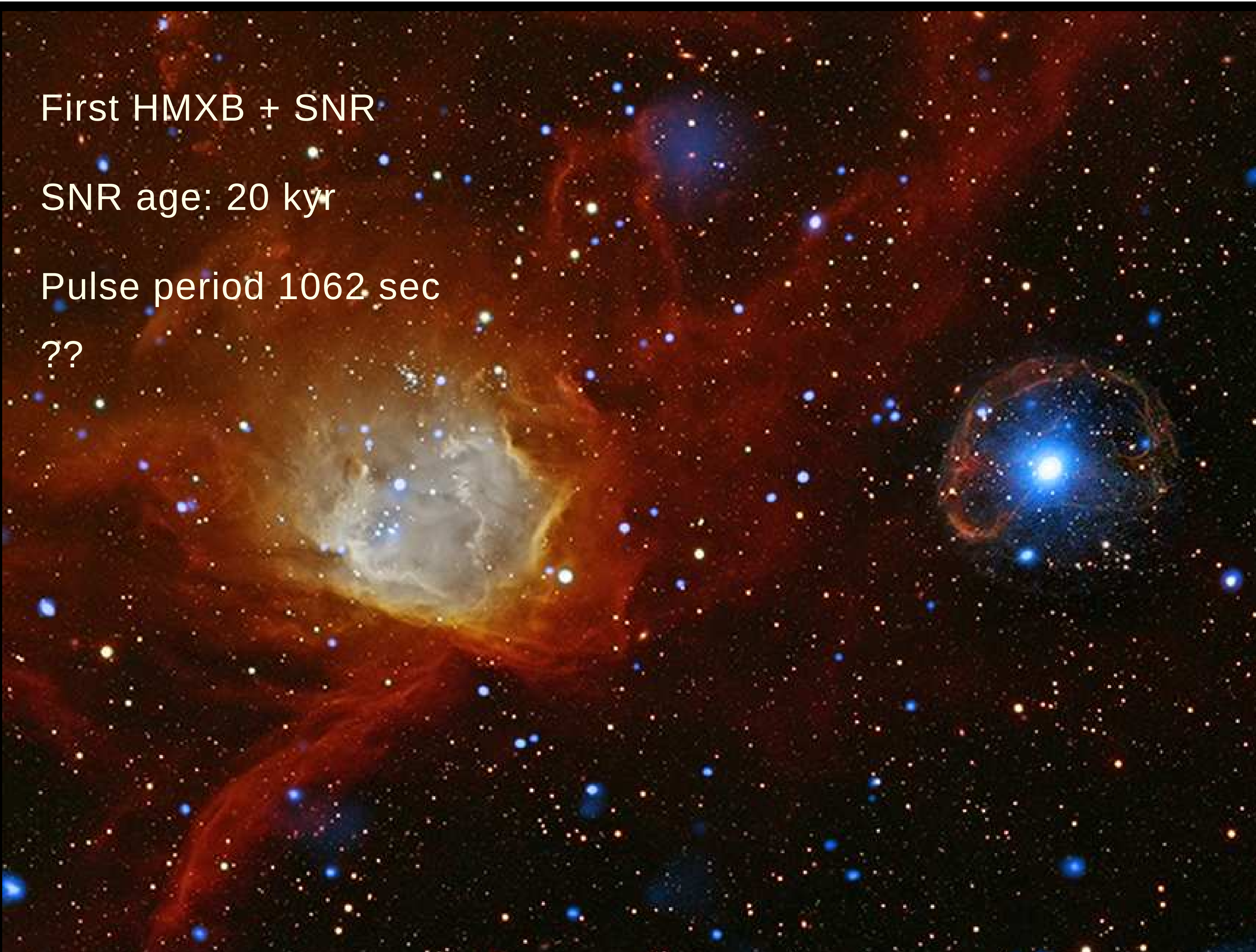
BeXRBs: transient HMXB



An example: SXP 1062 in the SMC



- Most common type of HMXB
- All but one HMXB in the SMC are BeXRB
- Some of them γ-ray sources
- Not well understood: physics, census, formation
- An example: SMC SXP 1062


First HMXB + SNR
SNR age: 20 kyr
Pulse period 1062 sec
??

Persistent HMXBs

- OB-type donor (usually a supergiant). NS is immersed in a stellar wind. Orbital separation is typically $2R_{star}$.

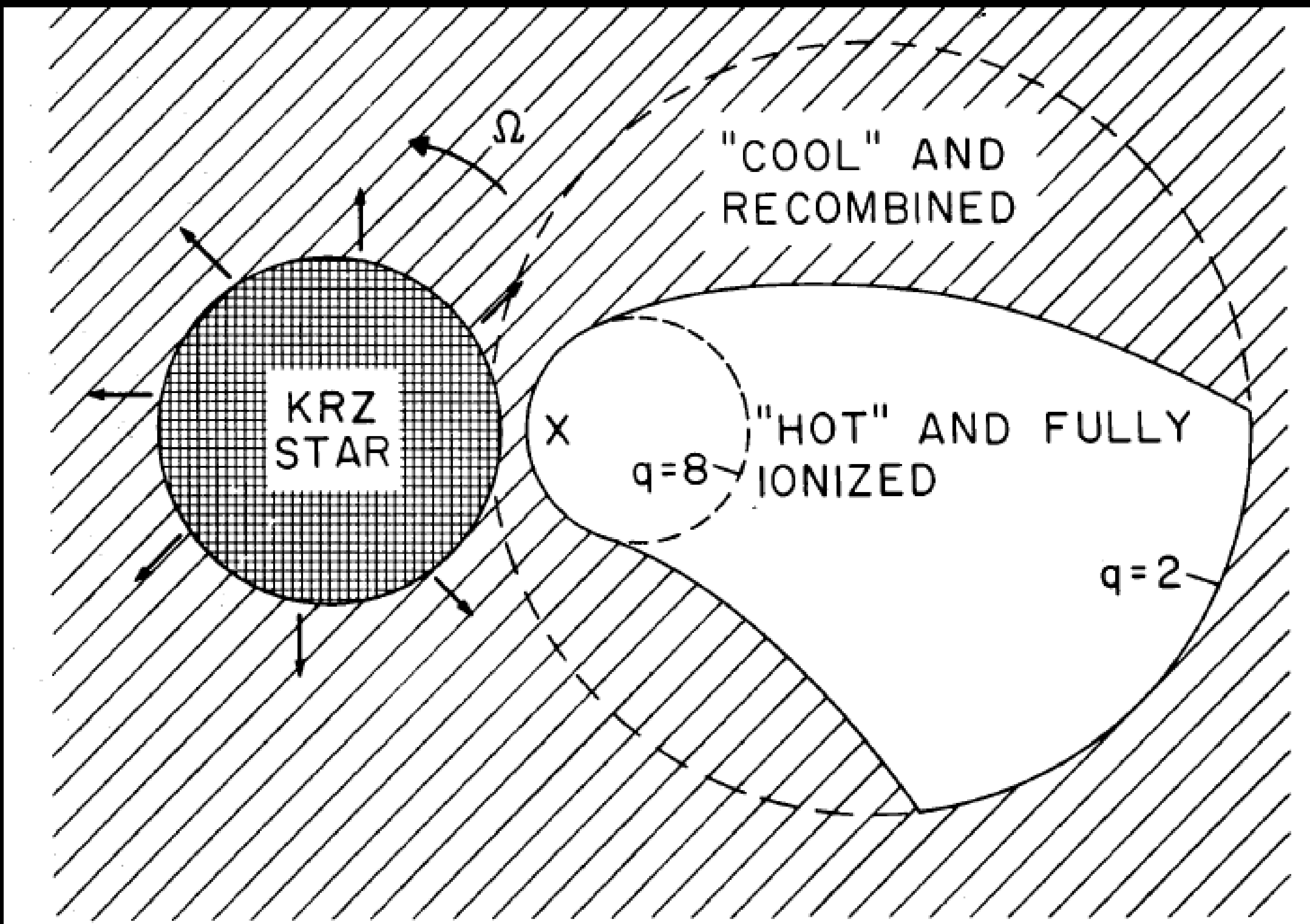
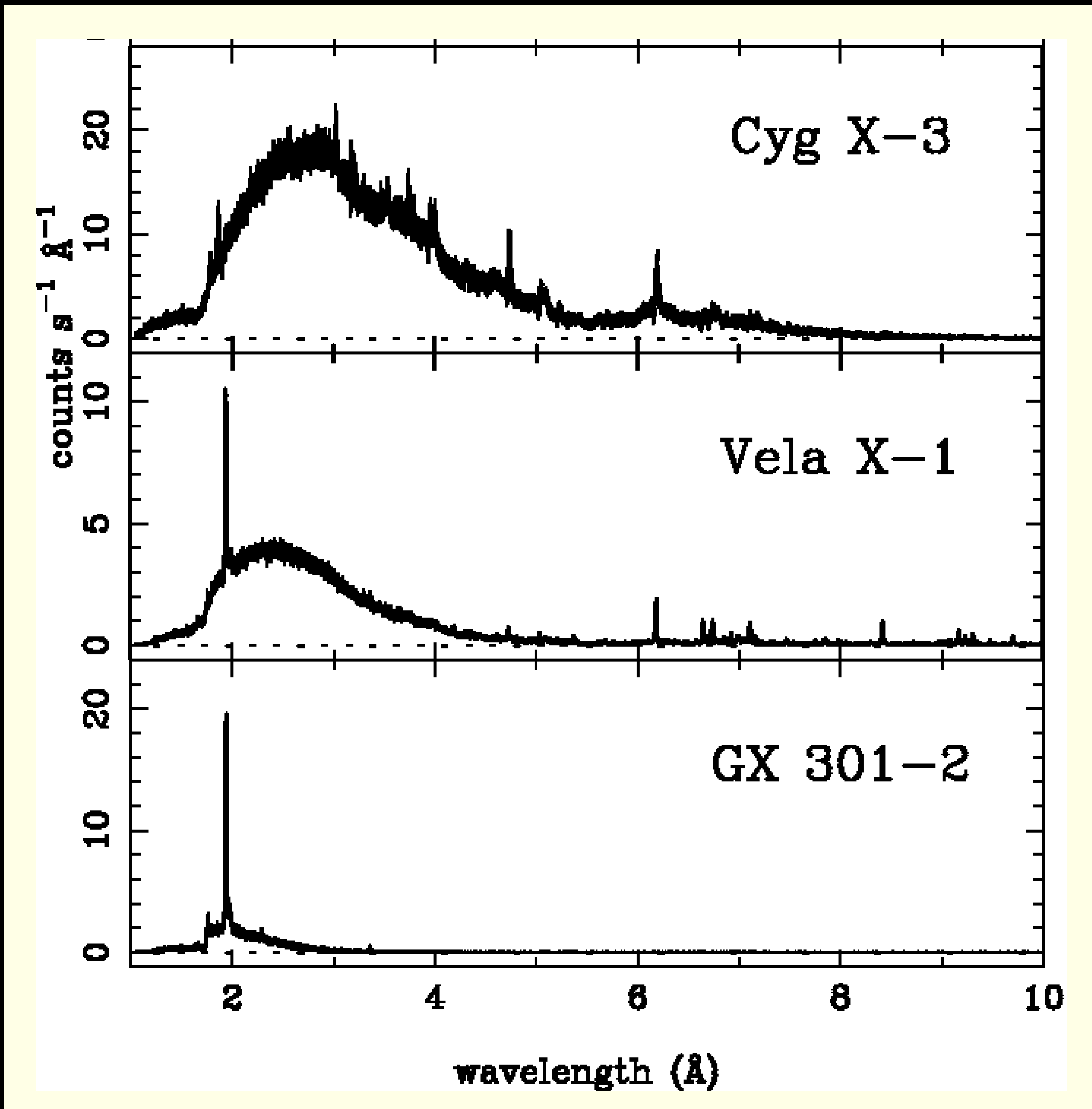


FIG. 4.—A model for the system Cen X-3/Krzeminski's star during the turn-on of 1972 July.

Hatchett & McCray 1977

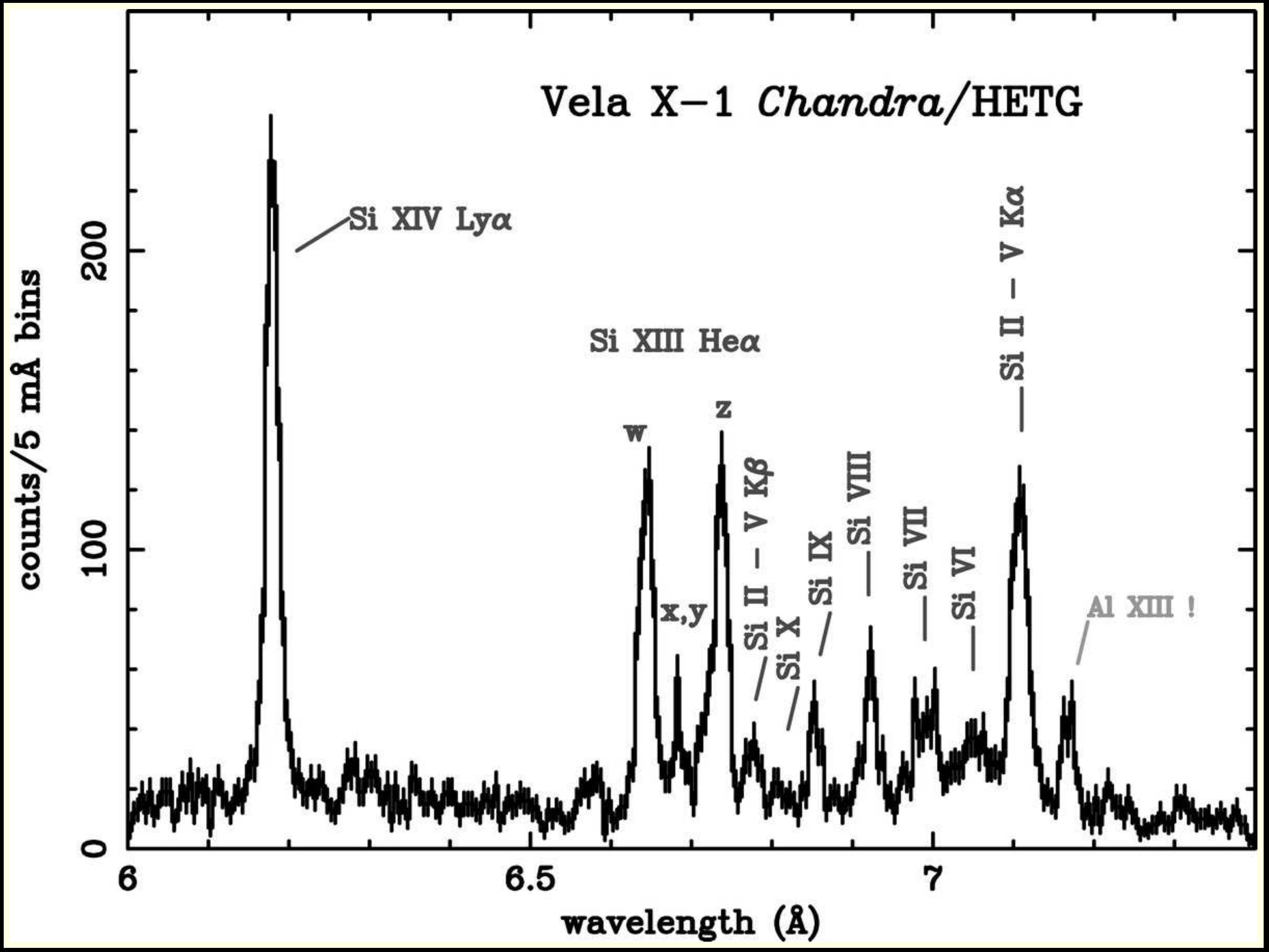
- Some host X-ray pulsars
- Sensitive to the properies of donor winds
- About a dozen known in the Galaxy

X-ray spectra



- Strongly absorbed power-law
- Absorption depends on orbital phase
- Compact object distorts wind
- X-ray field distorts the wind

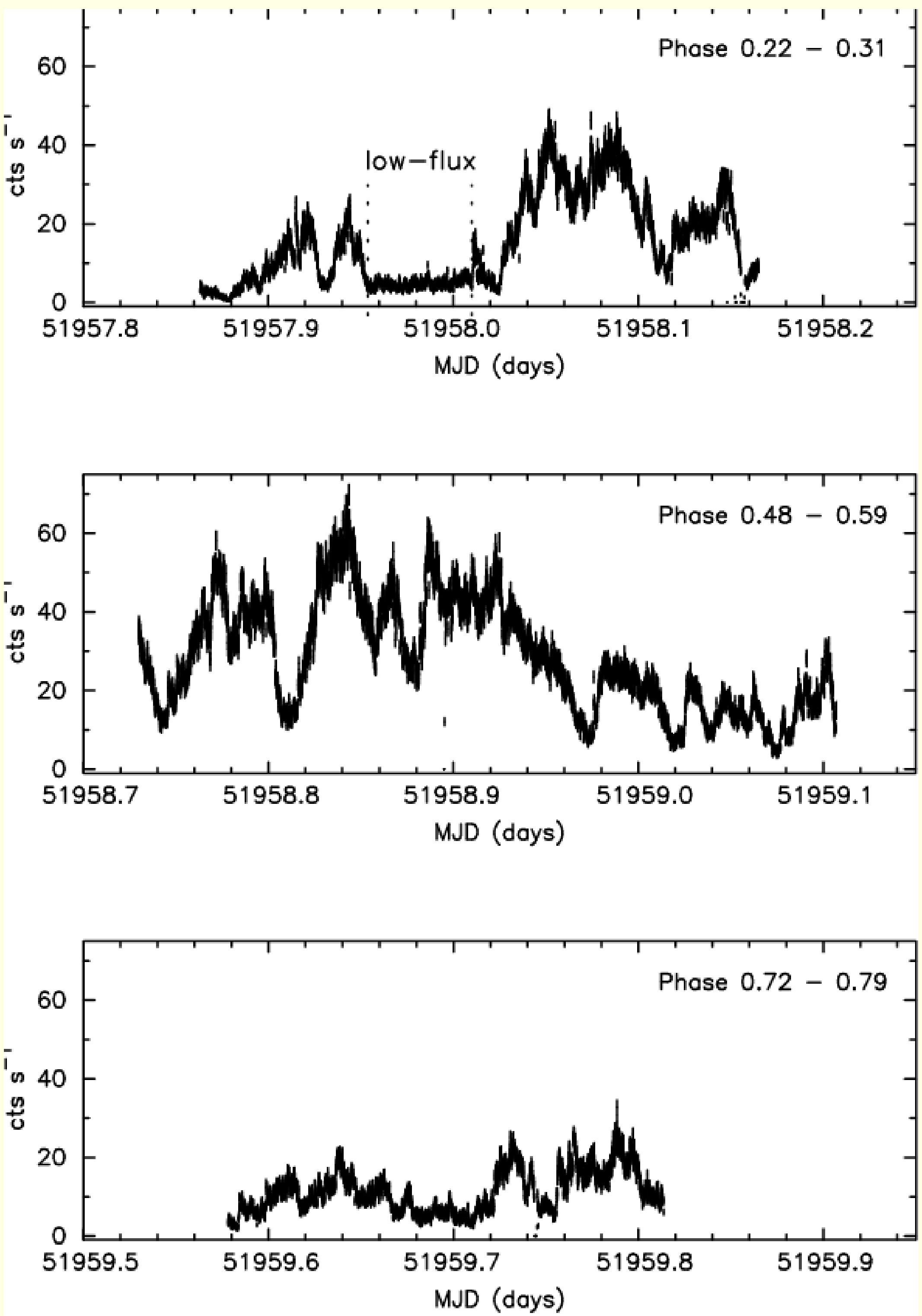
High-resolution spectrum of Vela X-1



Vela X-1 spectrum (Sako et al. 1999)

Huge variety of ionization stages: inhomogeneity

Stochastic variability



- 4U 1700-37/HD 153919 O6I+NS
- XMM Light Curves
  van der Meer et al. 2005
- Varying density and/or velocity structure
- Flaring/stochastic variability common among HMXBs
- Clumped wind
- Clump: velocity is MUCH higher before the clump comes. Can light-curve reflect rather velocity structure?

Accretion in a clumped wind

4 *L. Ducci et al.*

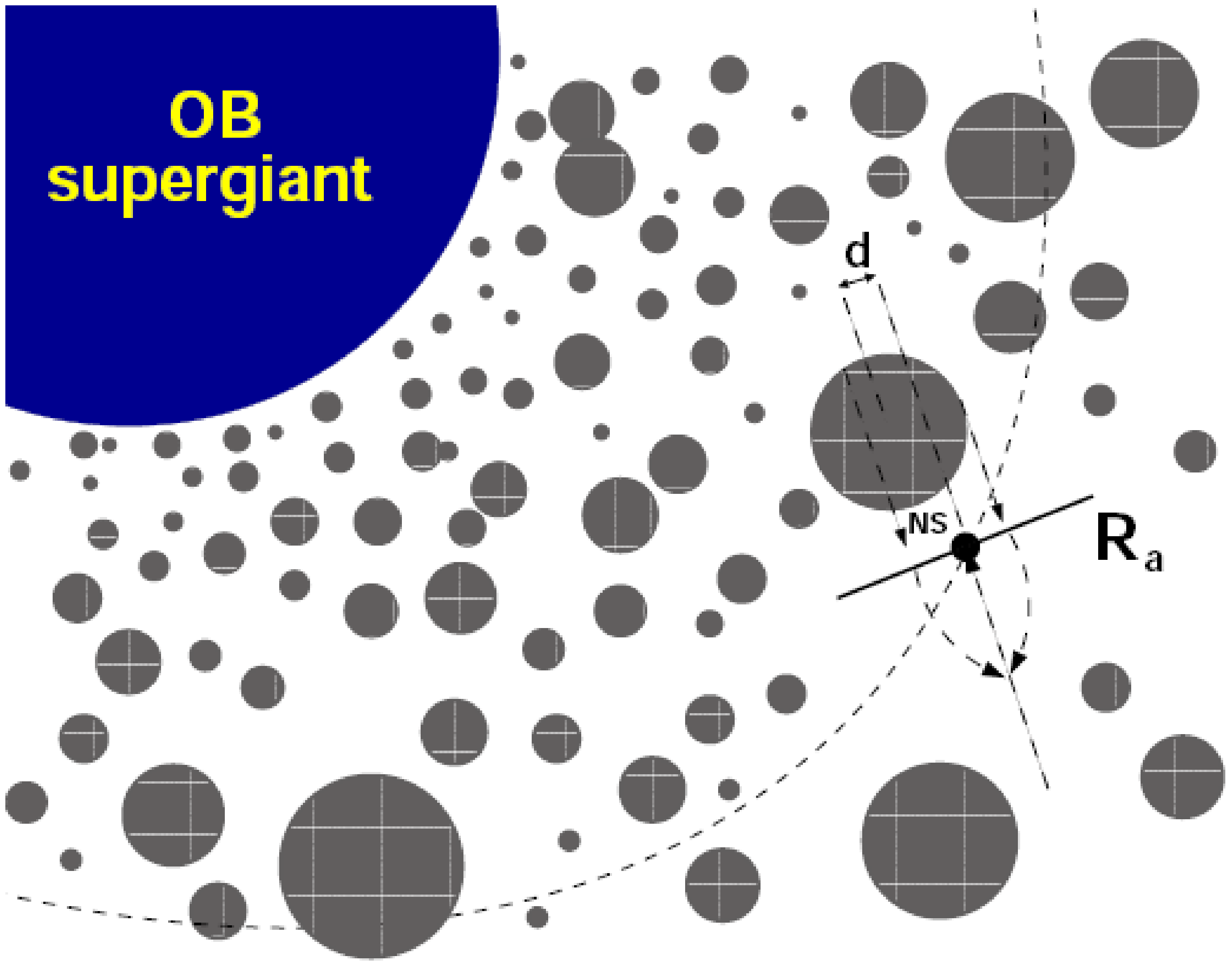
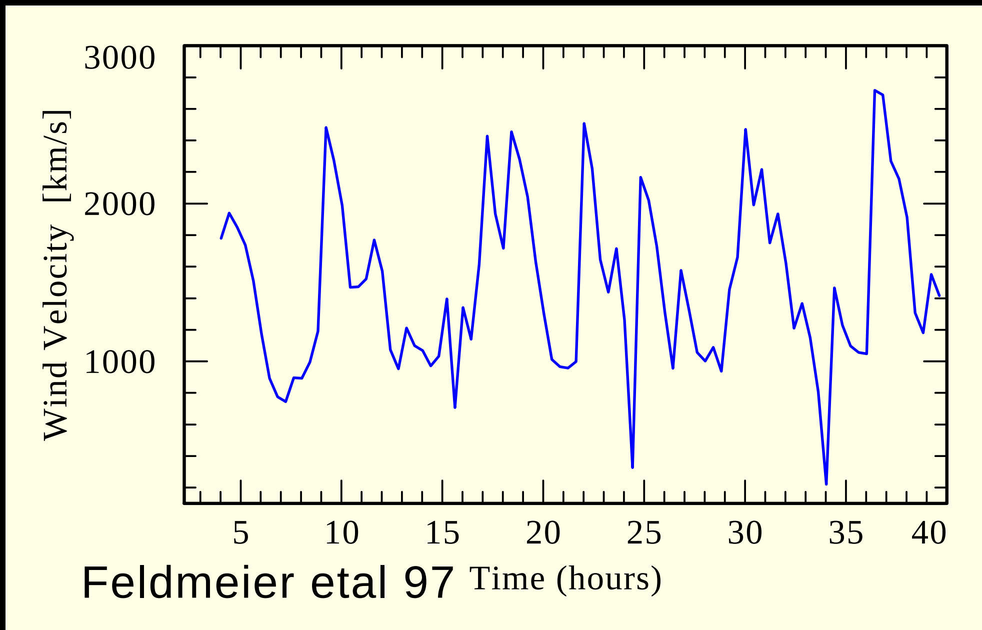


Figure 1. Schematic representation of our clumpy wind model. d is the distance between the centre of the clump and the cen
R_a is the accretion radius.

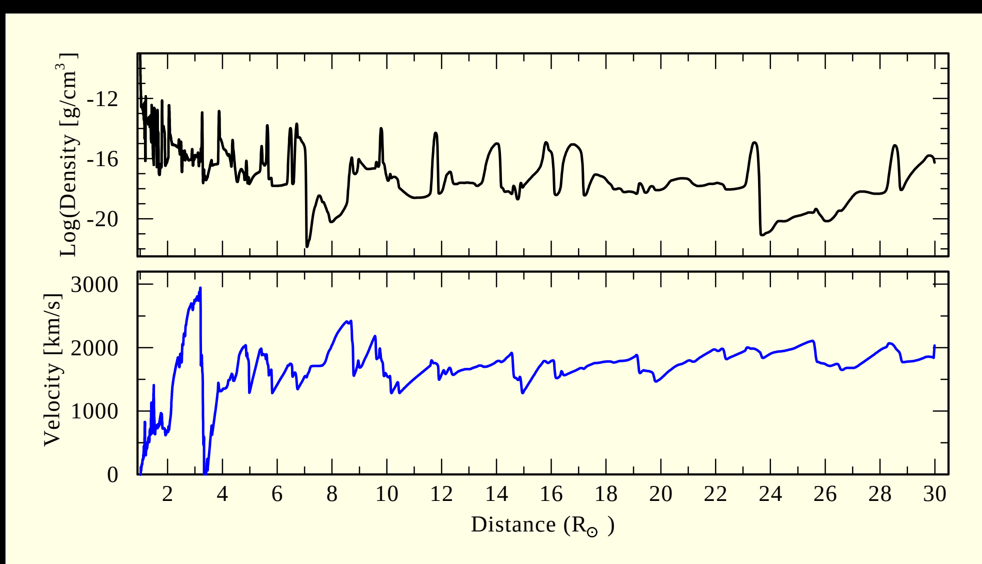
Bondi-Hoyle accretion: RHD stellar wind model

(RHD) Velocity at 2.5 R*



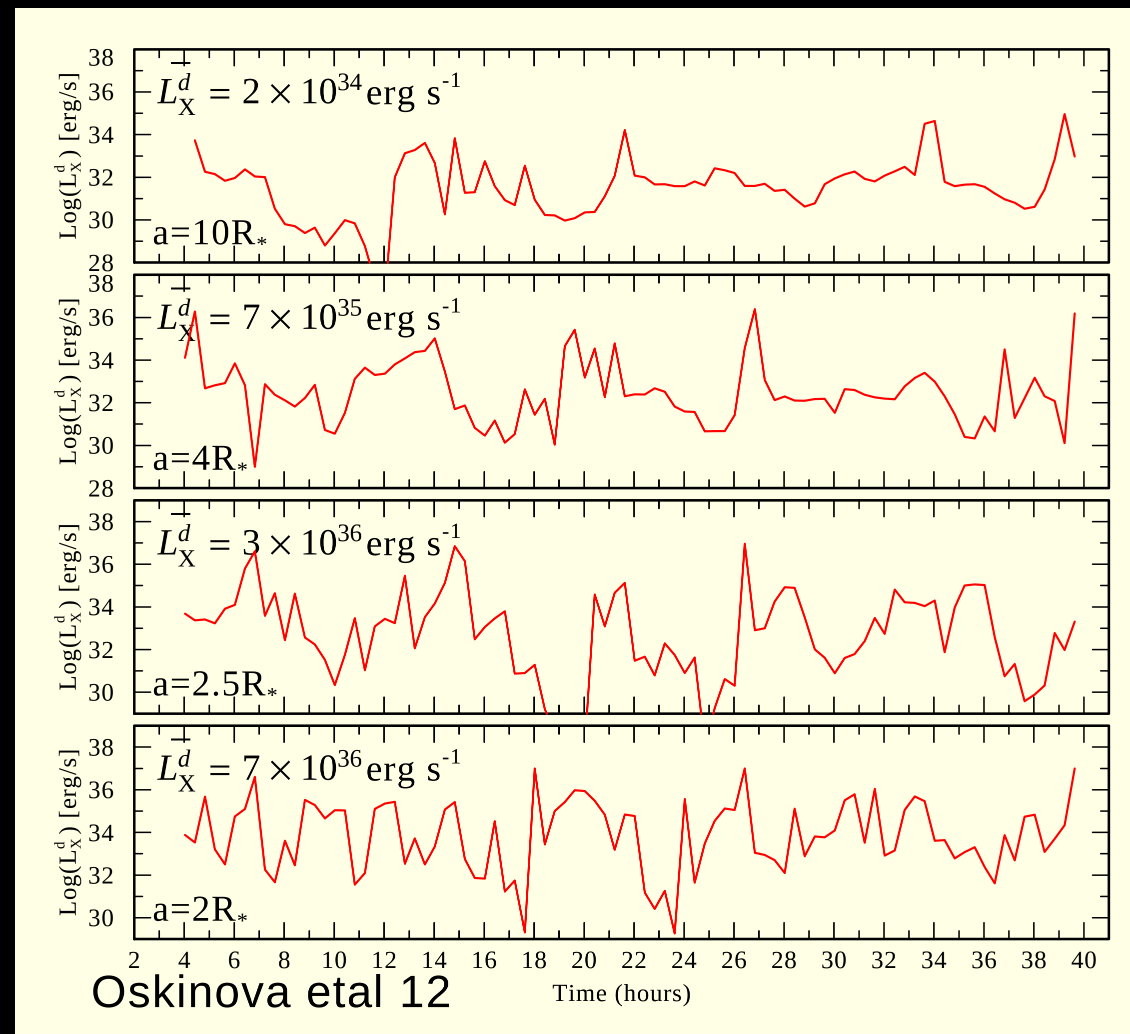
Feldmeier etal 97

(RHD) Radial wind structure



Model X-ray light curves

or different orbital separations

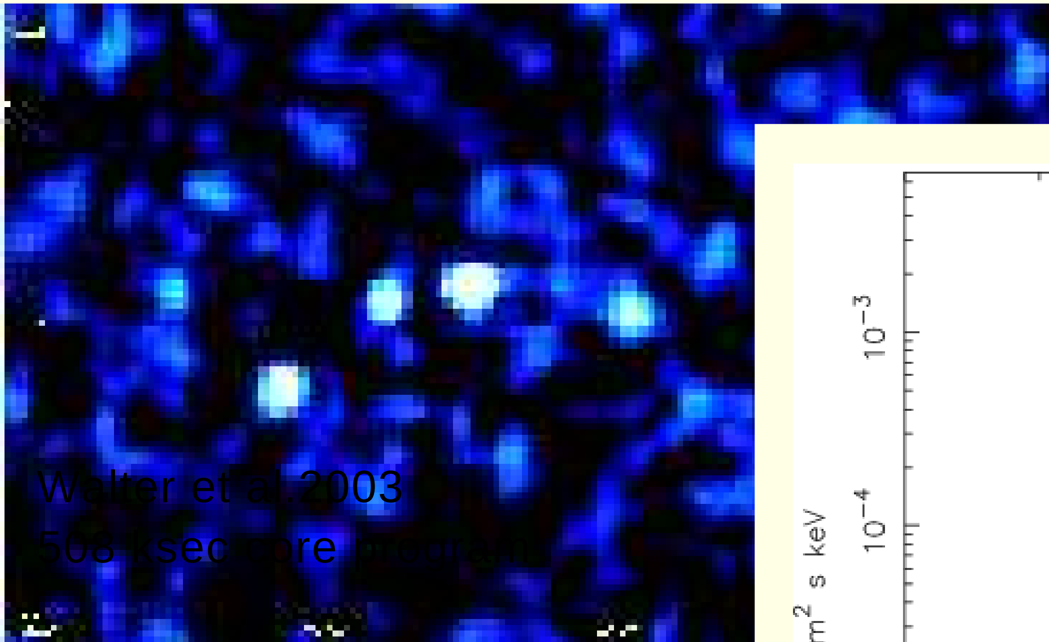


Oskinova etal 12

Very strong variability

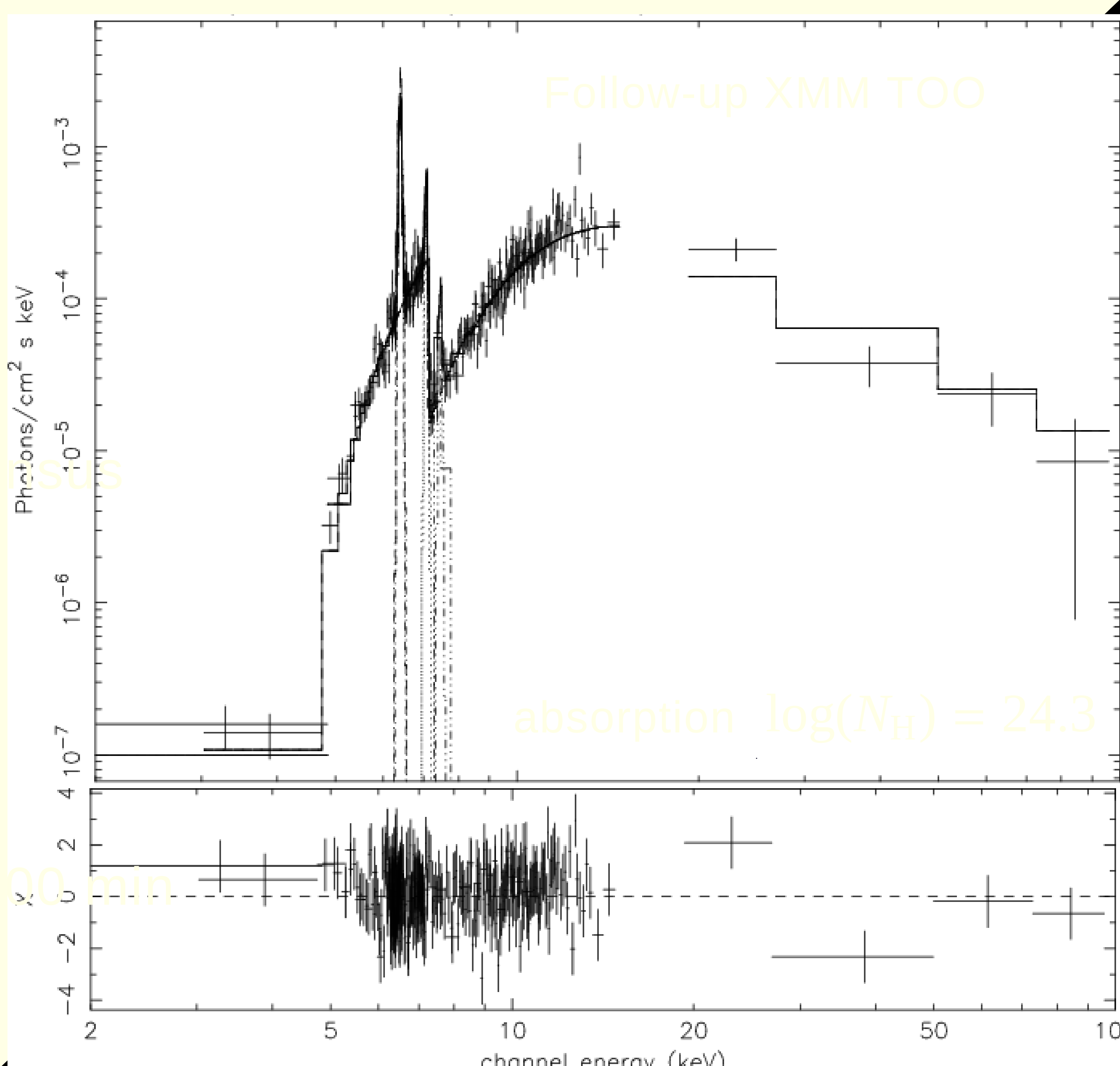
not-observed

New, absorbed Integral sources: Supergiant Fast X-ray transients



IGR J16318-4848

01/03 beginning of science operation



- Doubled the HMXB census

$\log(N_H) \geq 23$

Galactic value $\log(N_H) \approx 2$

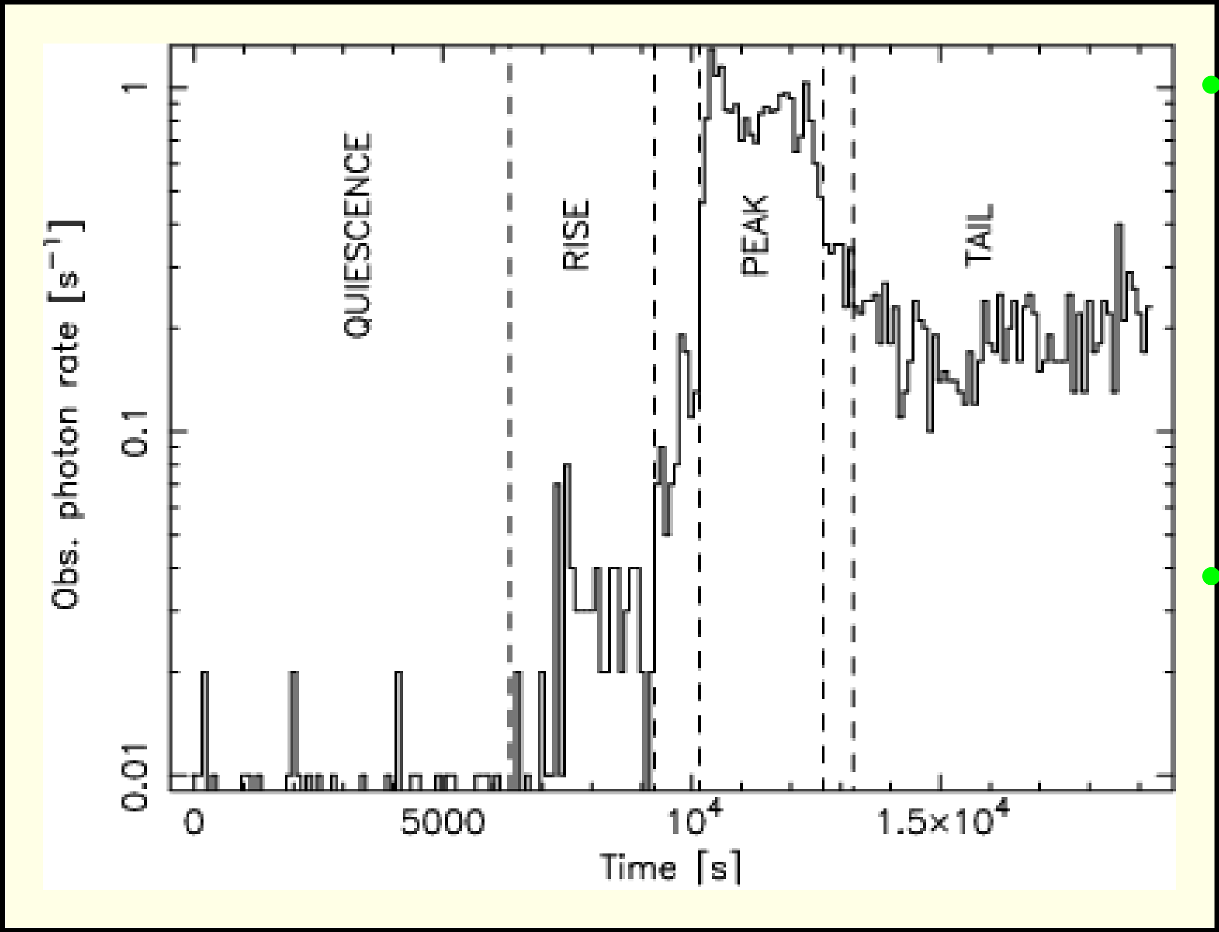
- Hard X-rays

power-law ($\Gamma \leq 2$)

emission lines

- 4 IGRs: pulses (?) 4-[illegible]00 min

IGRs with optical identifications



- IGR J17544-2619
  O9Ib
  Brief outbursts 100x
  in 't Zand '05: **clumps**
  $L_X \approx 5 \times 10^{32}$ erg/s
- IGR J19140+0951
  OB stars (in 't Zand '06)
  ISM reddening
  Source $A_V = 17.4$
- XTE J1739-302
  O8Iab(f) optic $\log N_H = 22.3$,
  X-ray spectra $\log N_H = 22.54$
  variable absorption (Neg. + '06)
  NB! Absorption in OI stars
  is $\log N_H \approx 20 \approx$ ISM

Supergiant Fast X-ray Transients

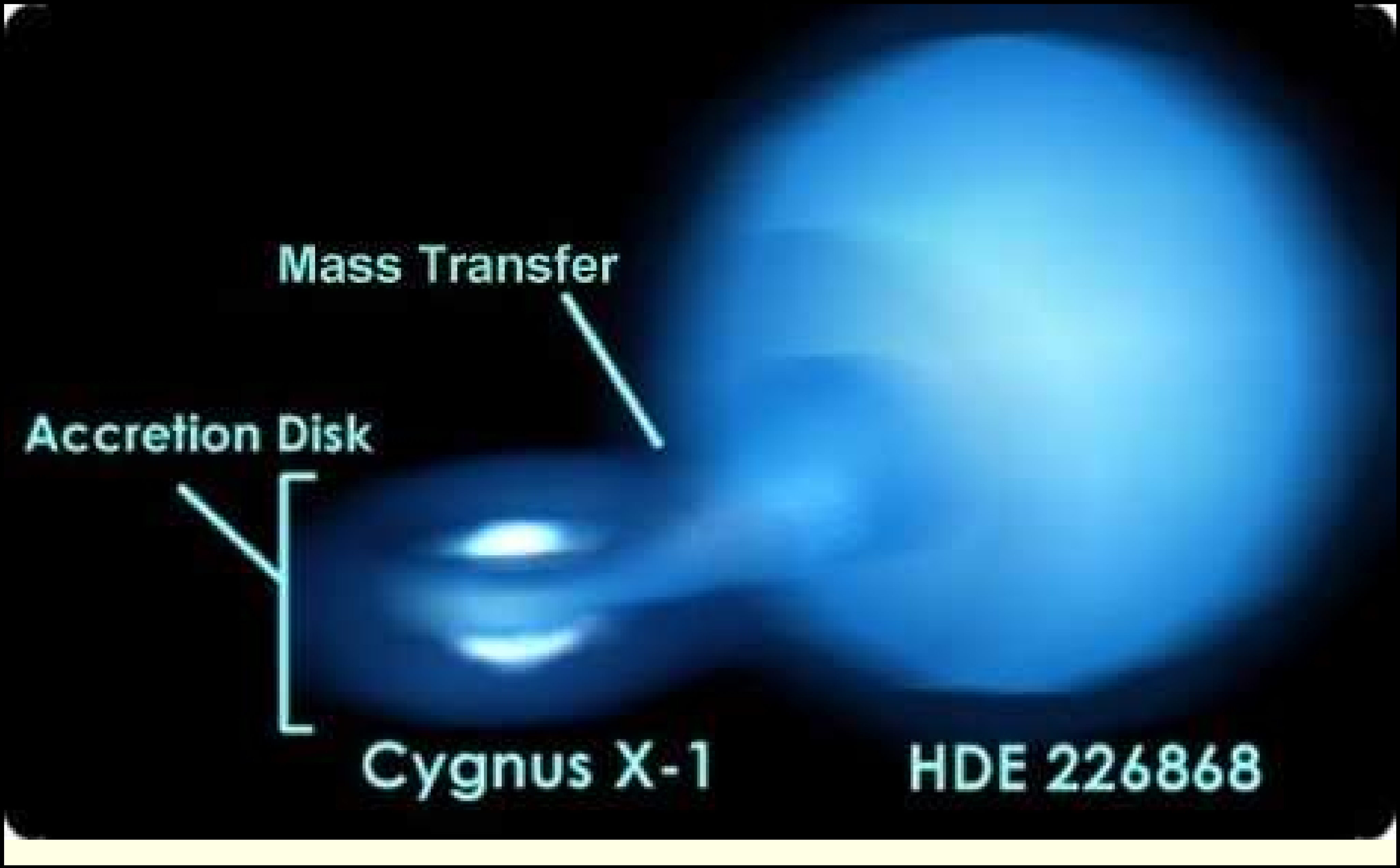
- OB supergiant donors
- High-photoabsorption
- Flaring
- Low-quiescence X-ray luminosity

Clumped stellar winds?

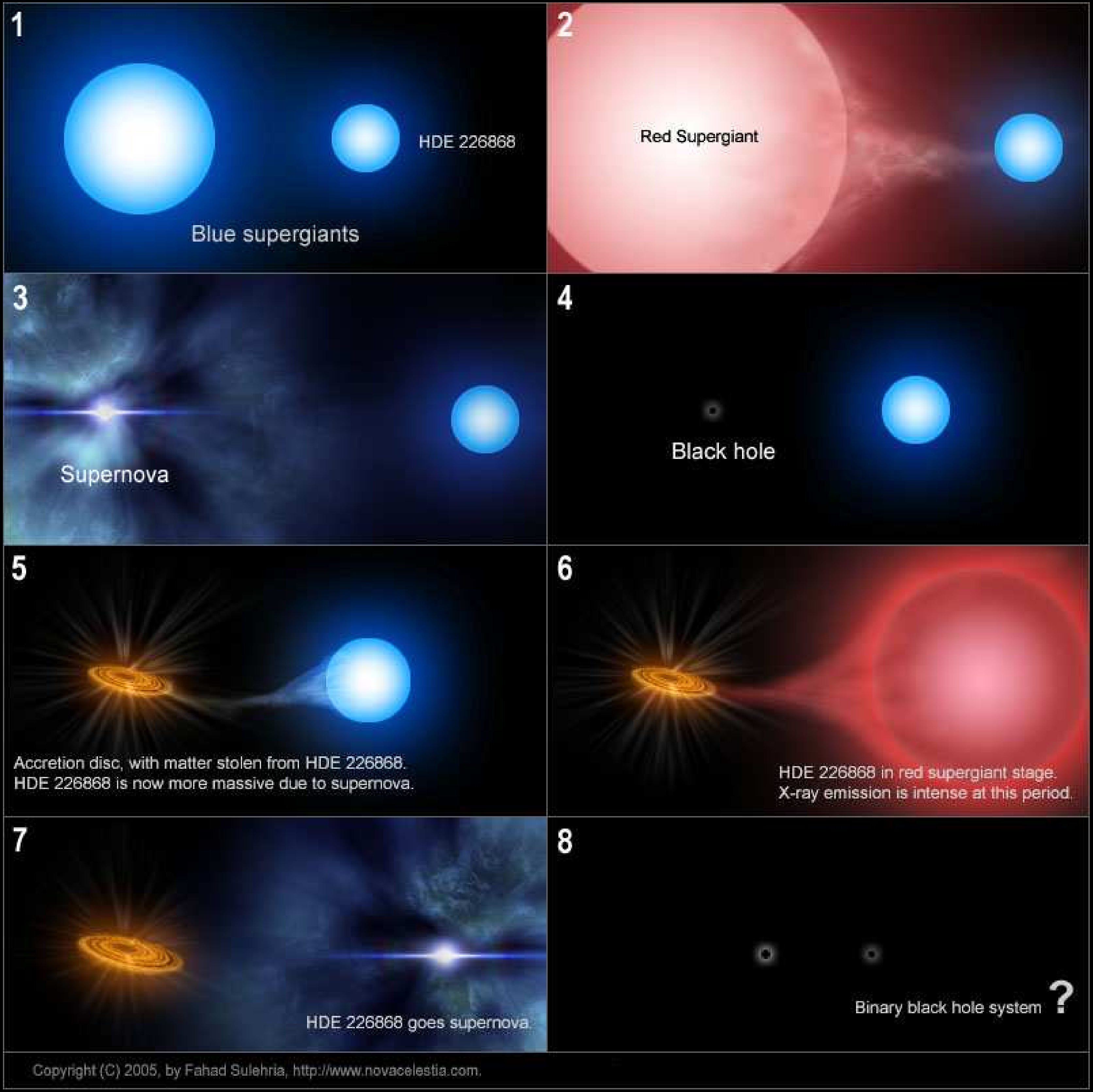
Magnetosphere Gating?

Bozzo et al. 2011

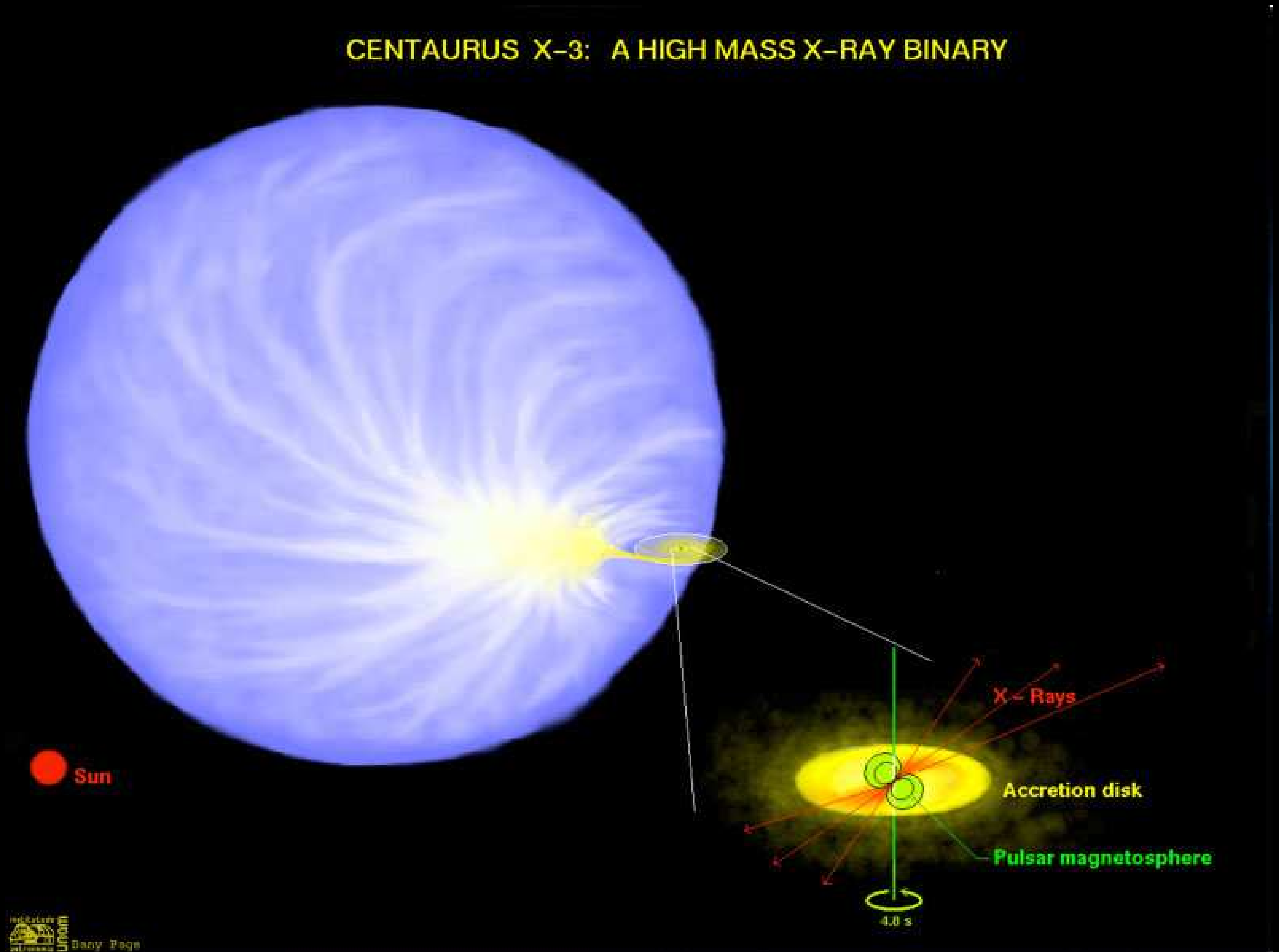
Roche Lobe filling HMXB



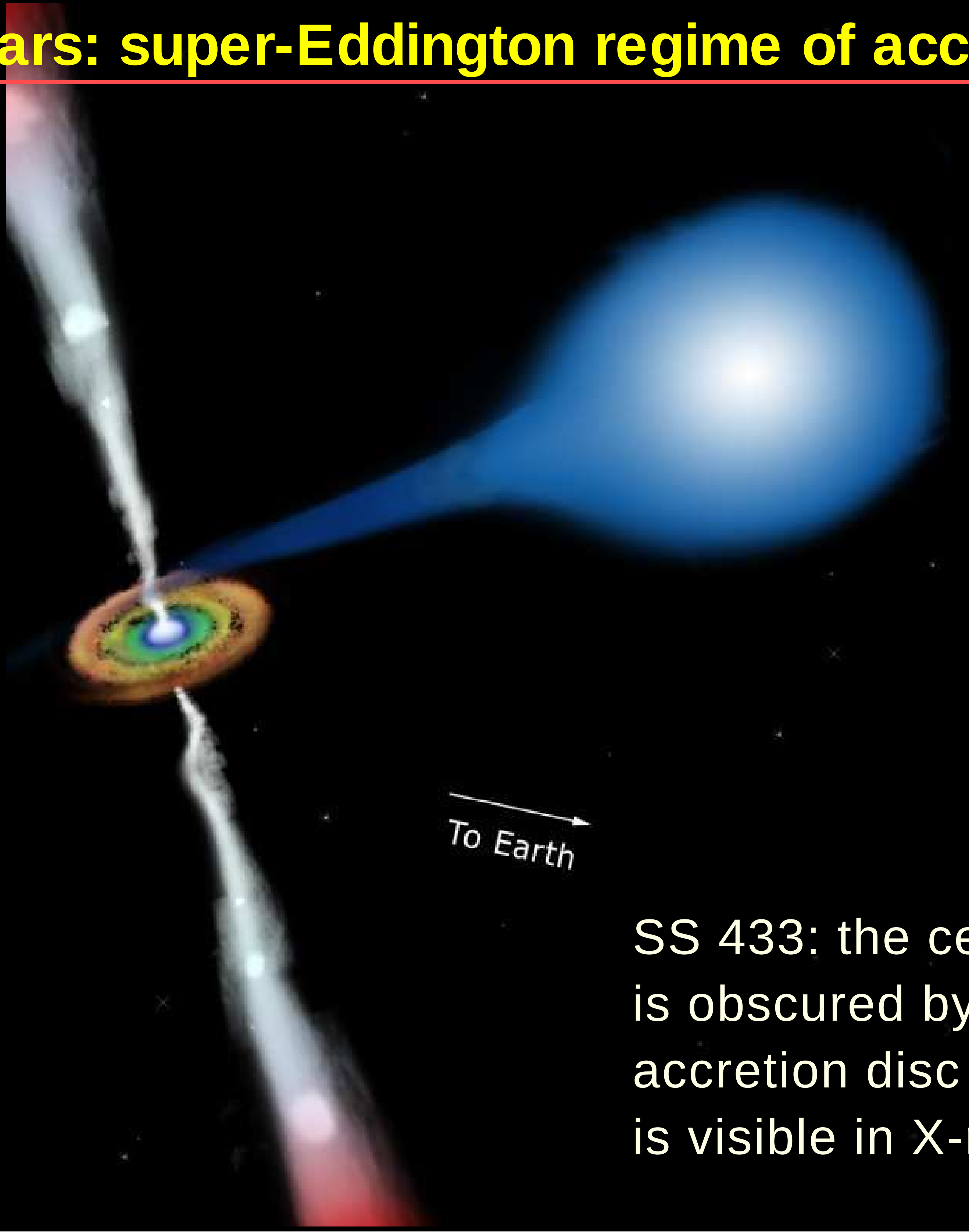
High $L_X > 10^{38}$ erg/s; hard and soft spectral states; Cyg X-1 black hole


1
HDE 226868
Blue supergiants
2
Red Supergiant
3
Supernova
4
Black hole
5
Accretion disc, with matter stolen from HDE 226868.
HDE 226868 is now more massive due to supernova.
6
HDE 226868 in red supergiant stage.
X-ray emission is intense at this period.
7
HDE 226868 goes supernova.
8
Binary black hole system ?
Copyright (C) 2005, by Fahad Sulehria, http://www.novacelestia.com.

RL-HMXB with neutron star companion

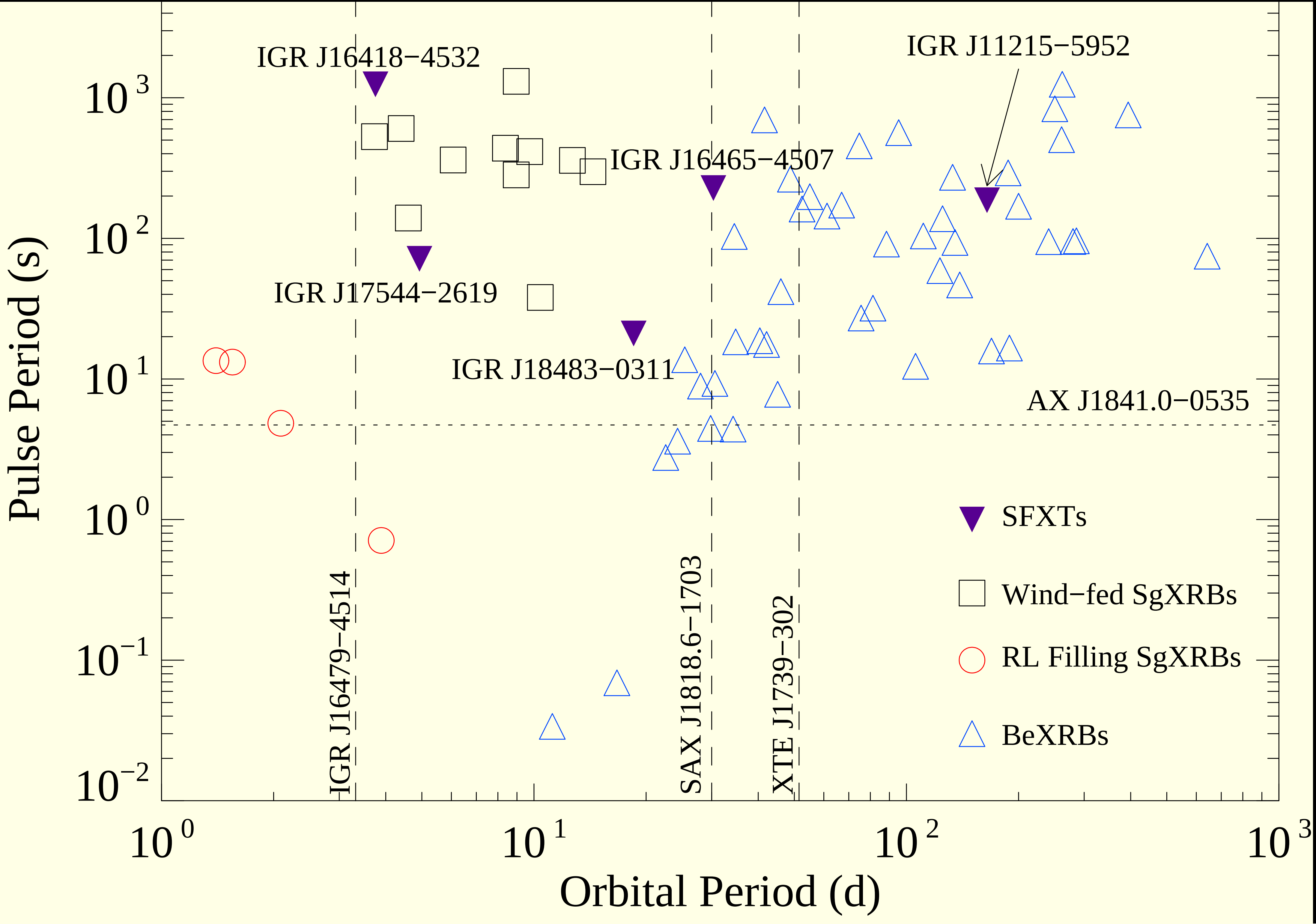


Micro-quasars: super-Eddington regime of accretion

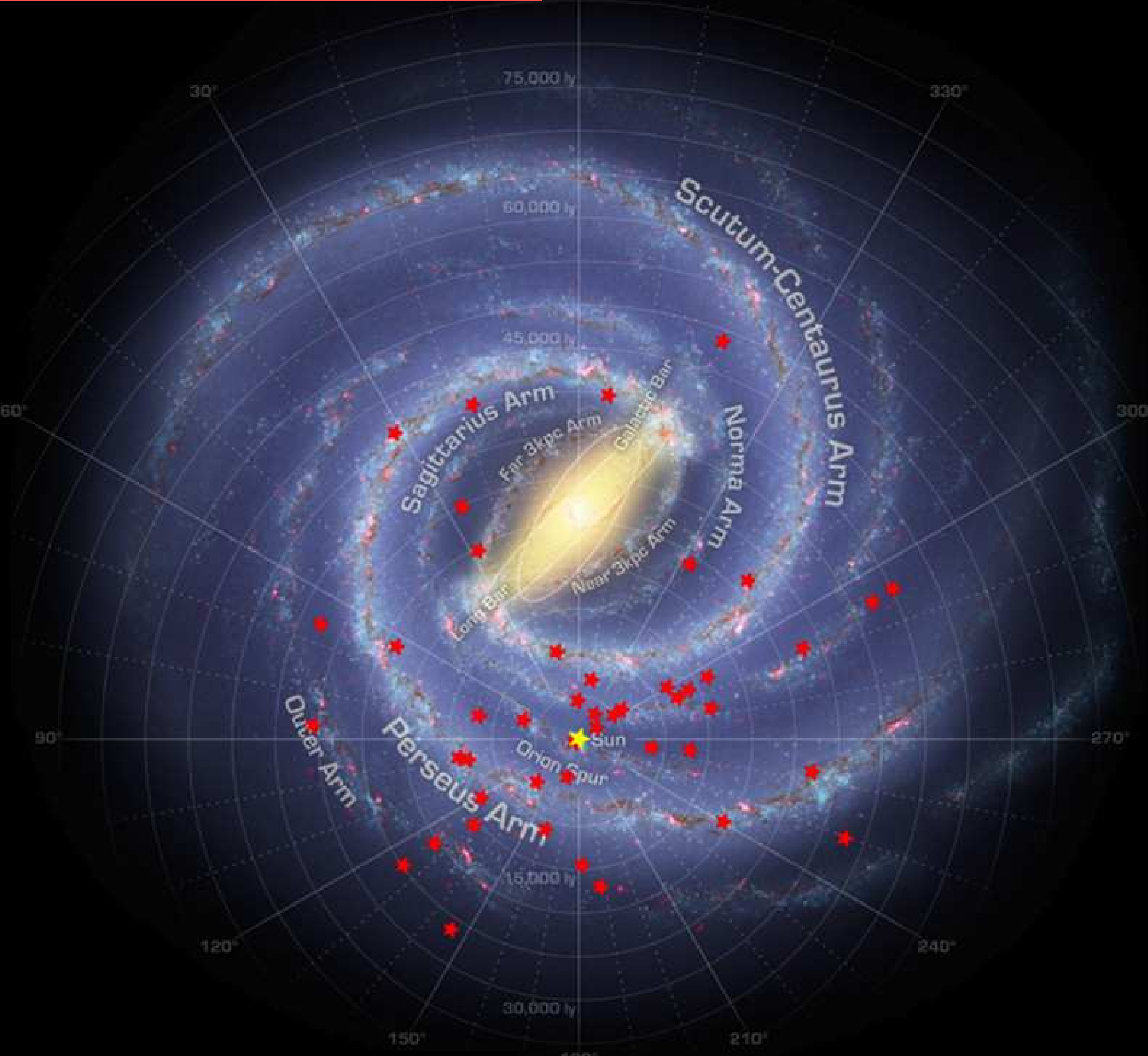


SS 433: the central engine is obscured by the accretion disc and only jet is visible in X-rays

Corbet Diagram (MNRAS 1986)

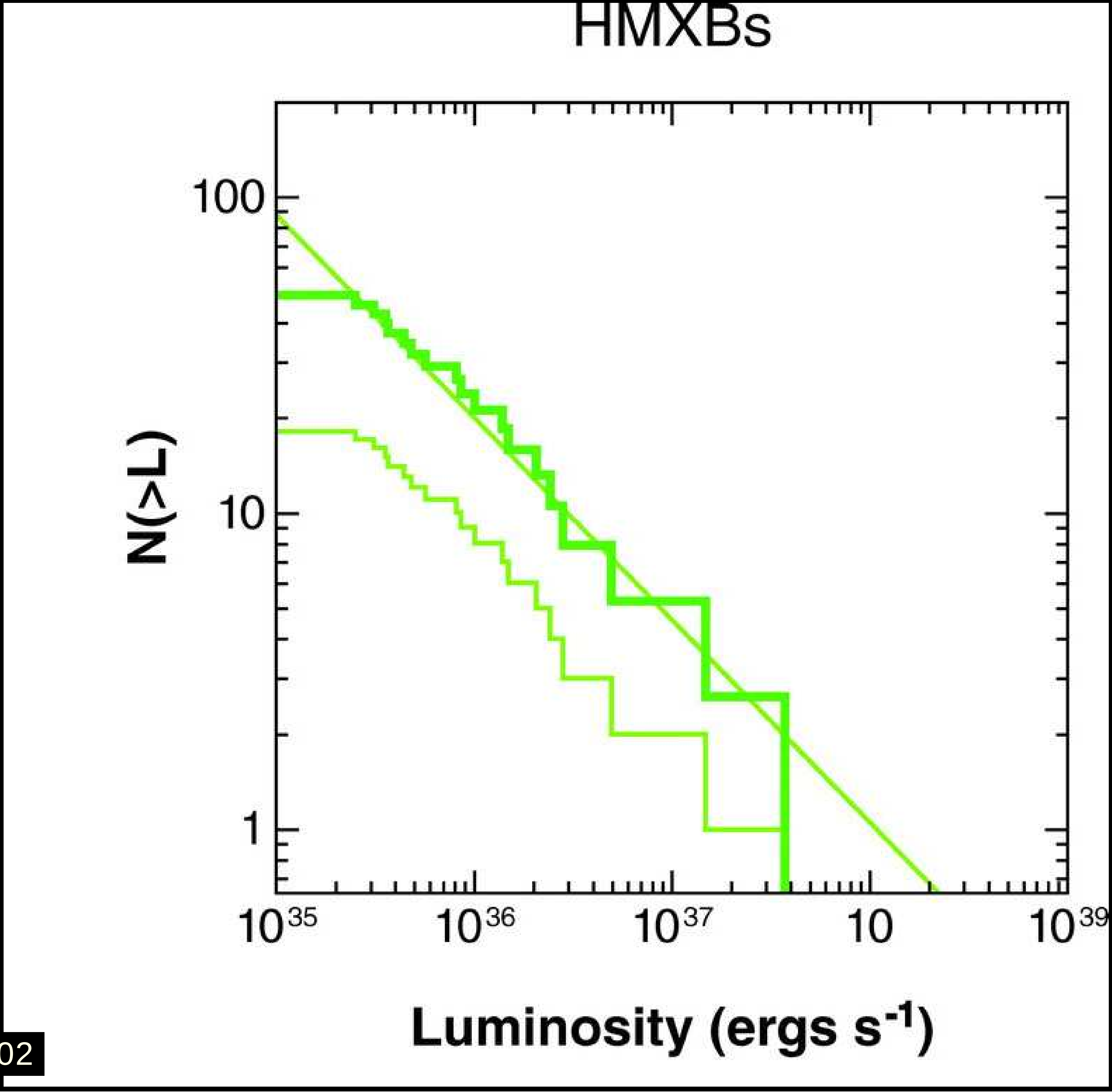


HMXB Galactic Distribution



NASA/Adler/U. Chicago/Wesleyan/JPL-Caltech

HMXB Luminosity Function

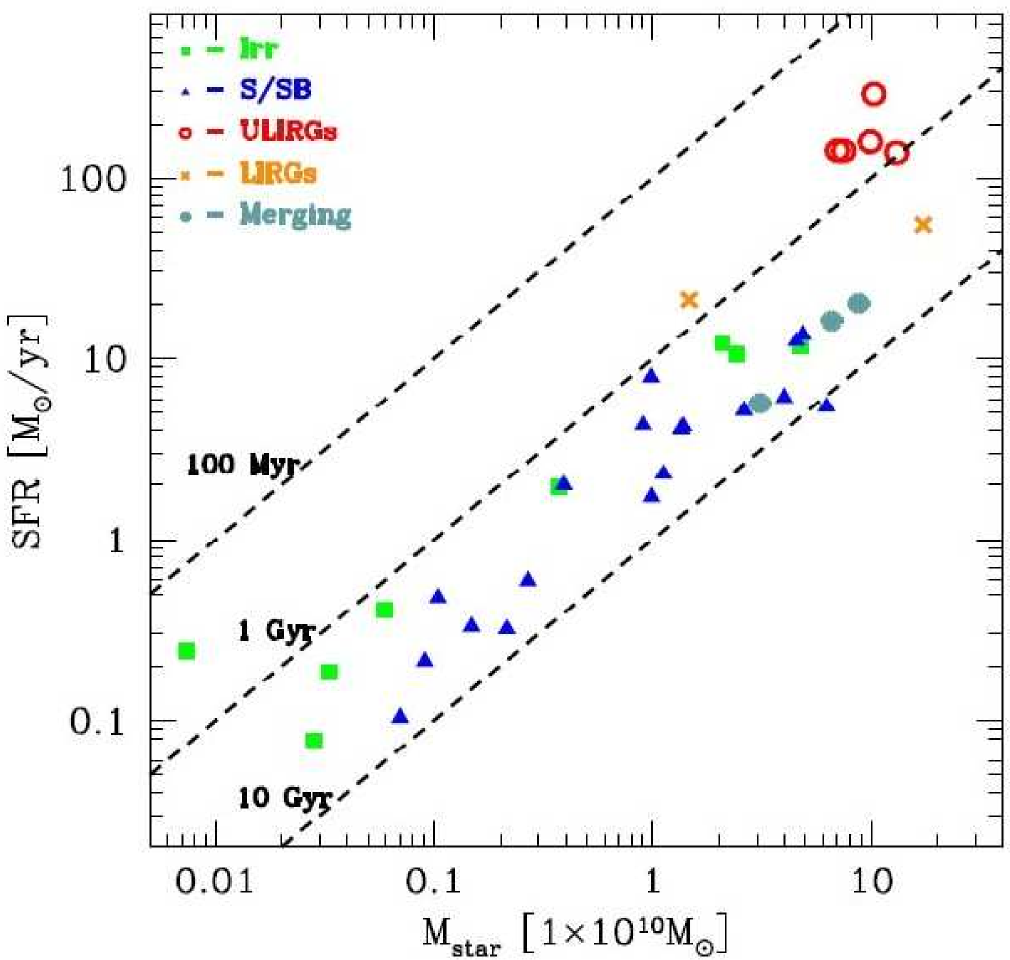


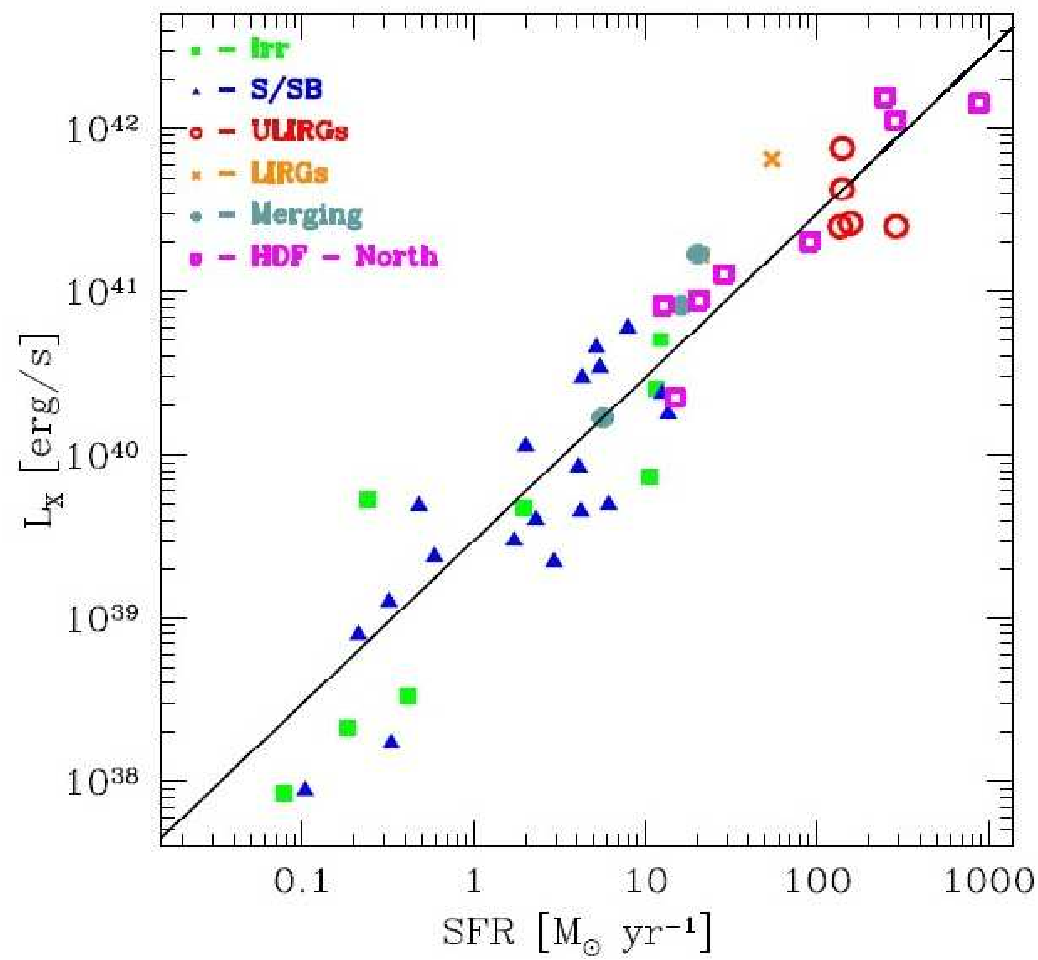
Grimm et al. 2002

HMXRBs as star-formation rate indicators (?)

SFR vs galaxy masses

SFR vs X-ray luminosity





Mineo et al. 2011

BeXRB - SgXRB - SFXT - RLHMXB

Very complex systems: relativity, stellar physics, stellar and galactic evolution, hydrodynamic. etc....

- Matter in extreme conditions

- Stellar winds from massive stars

Neutron stars (X-ray pulsars) - Black Holes