X-ray binaries

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MPA, Garching

Outline

- ✓ observational appearance
- ✓ populations in galaxies
- ✓ relation to star-formation history
- ✓ numbers, luminosity distributions, IMF

Hans-Jakob Grimm (CfA)

Igor Prokopenko (IKI)

Pavel Shtykovskiy (IKI/MPA)

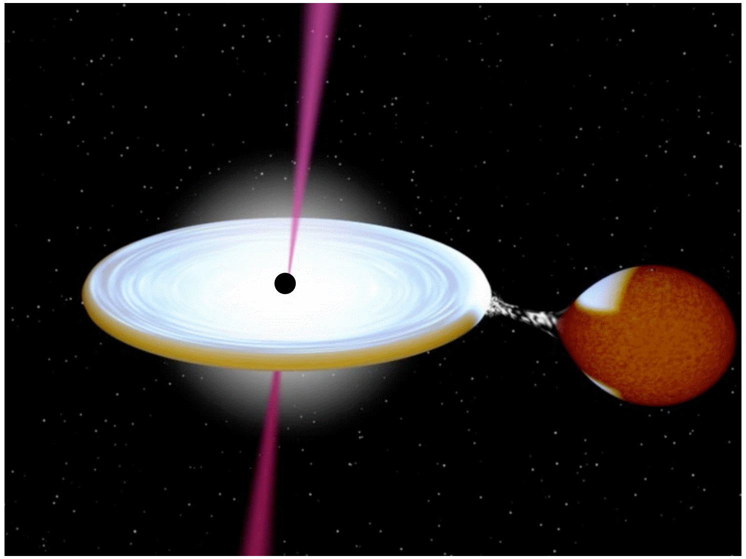
Rashid Sunyaev (MPA/IKI)

Rasmus Voss (MPA, MPE)

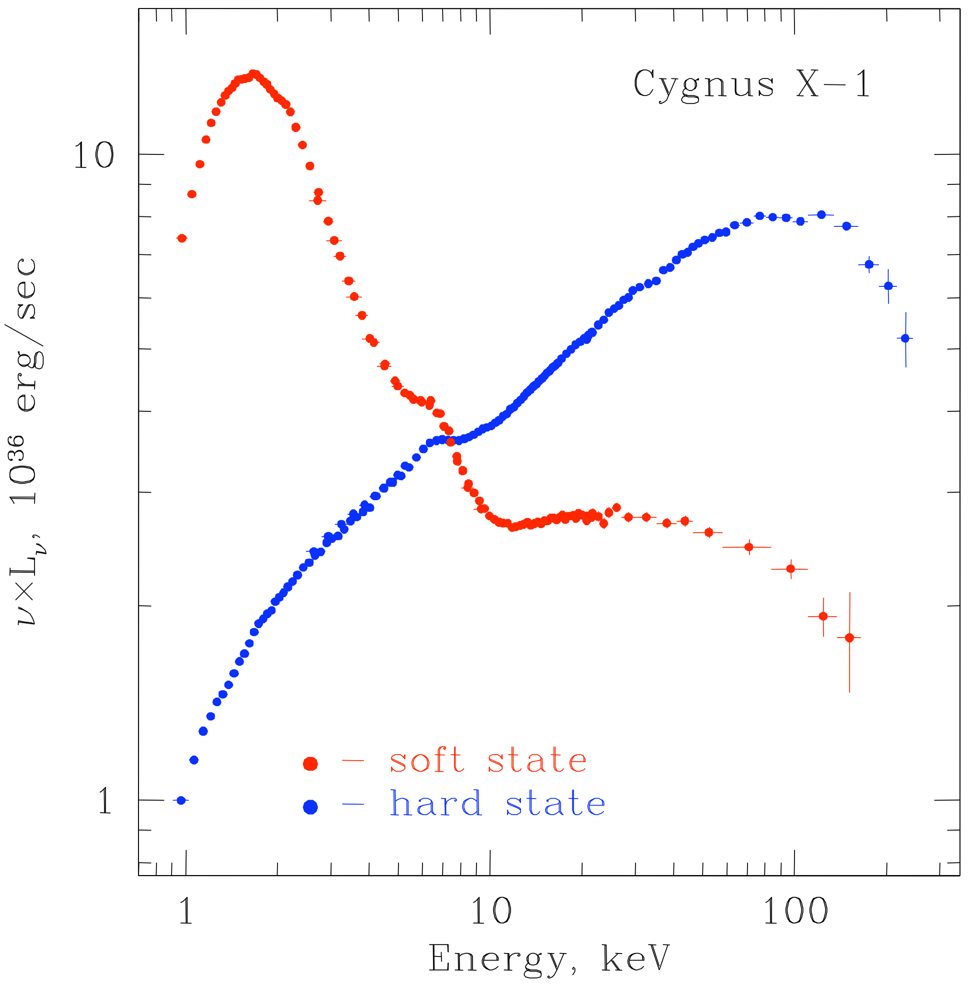
Akos Bogdan (MPA)

X-ray binaries

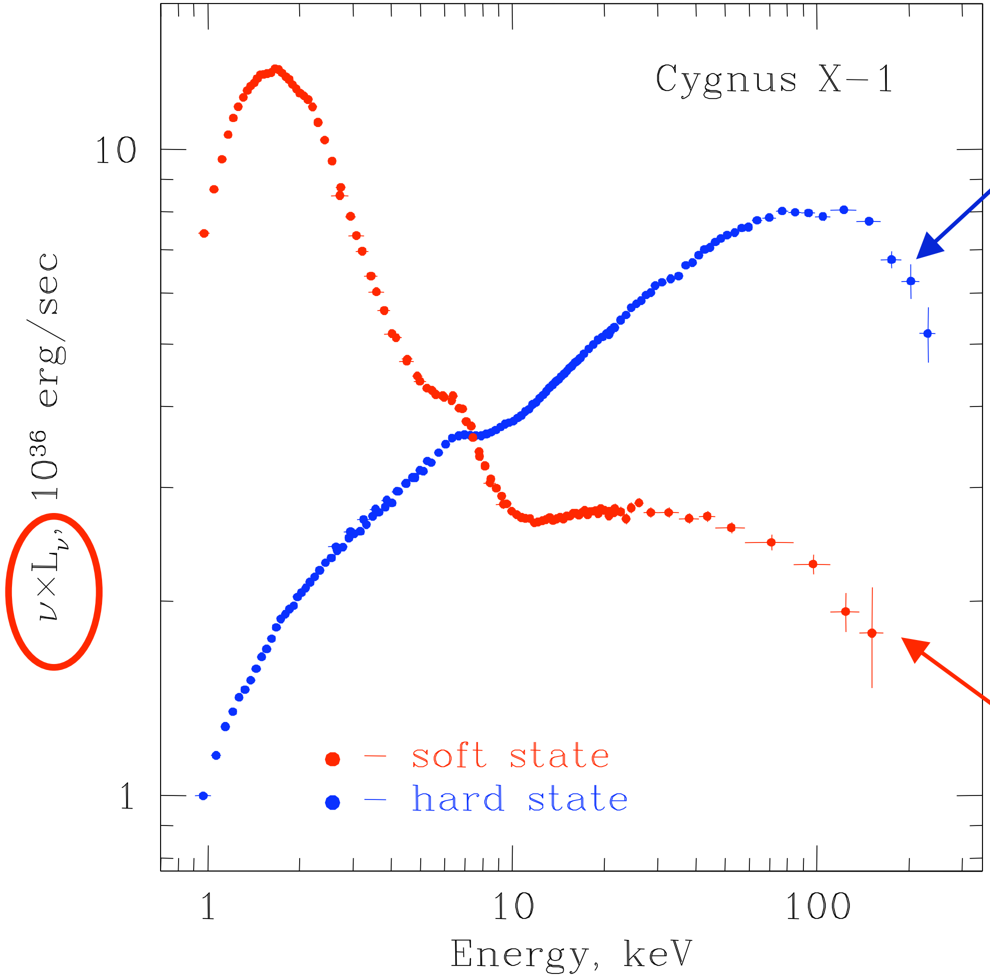
- accretion onto BH or NS in a binary system
- brightest stellar mass X-ray sources
- L_x~... 10^{35} - 10^{39}... erg/s in the X-ray band
- ~200 bright X-ray binaries in the Milky Way



X-ray spectra of accreting BH



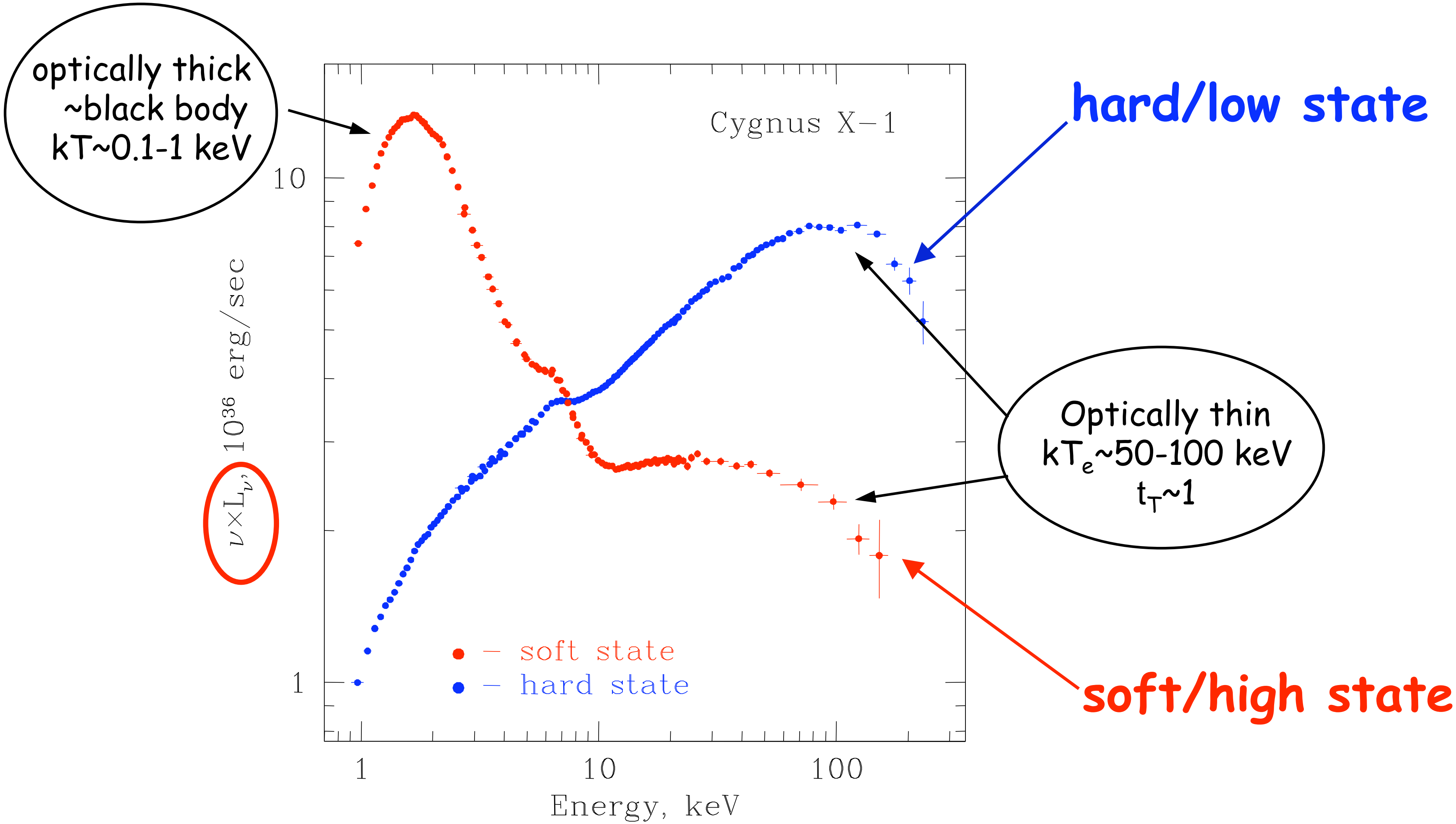
Spectral states



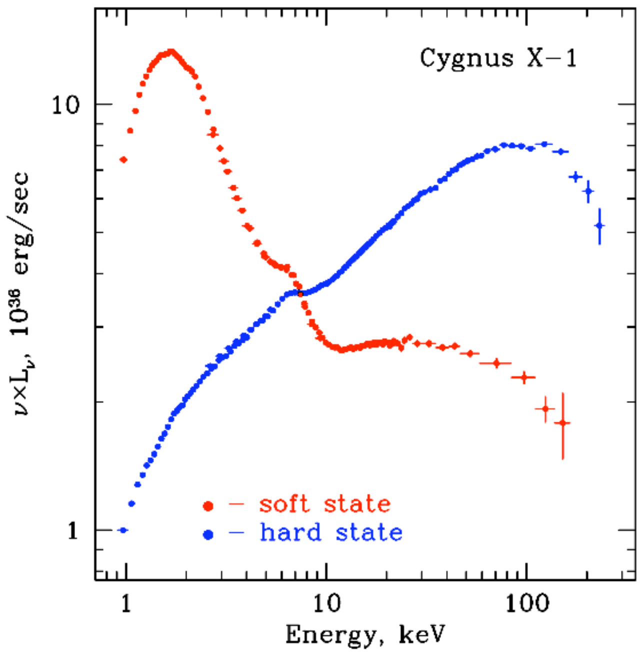
hard/low state

soft/high state

Spectral states

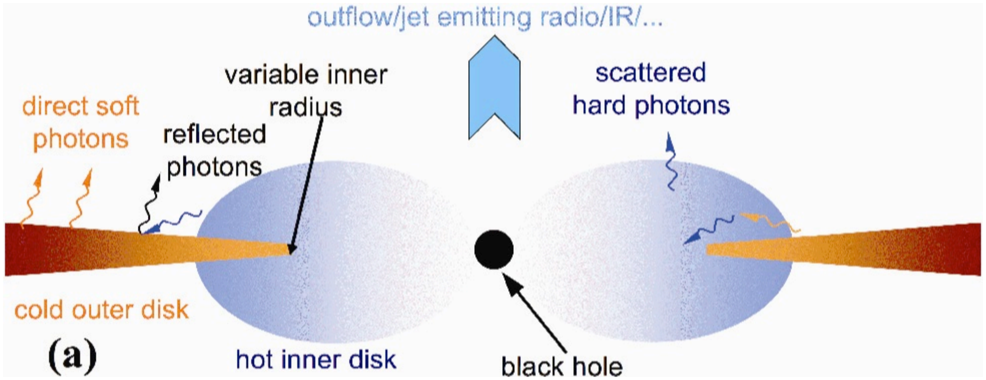


Geometry



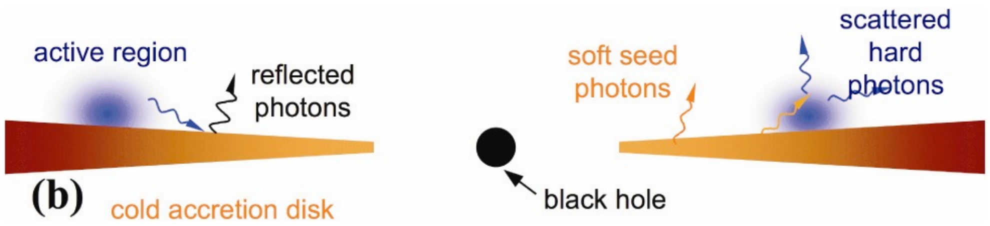
hard state

truncated disk + inner hot flow



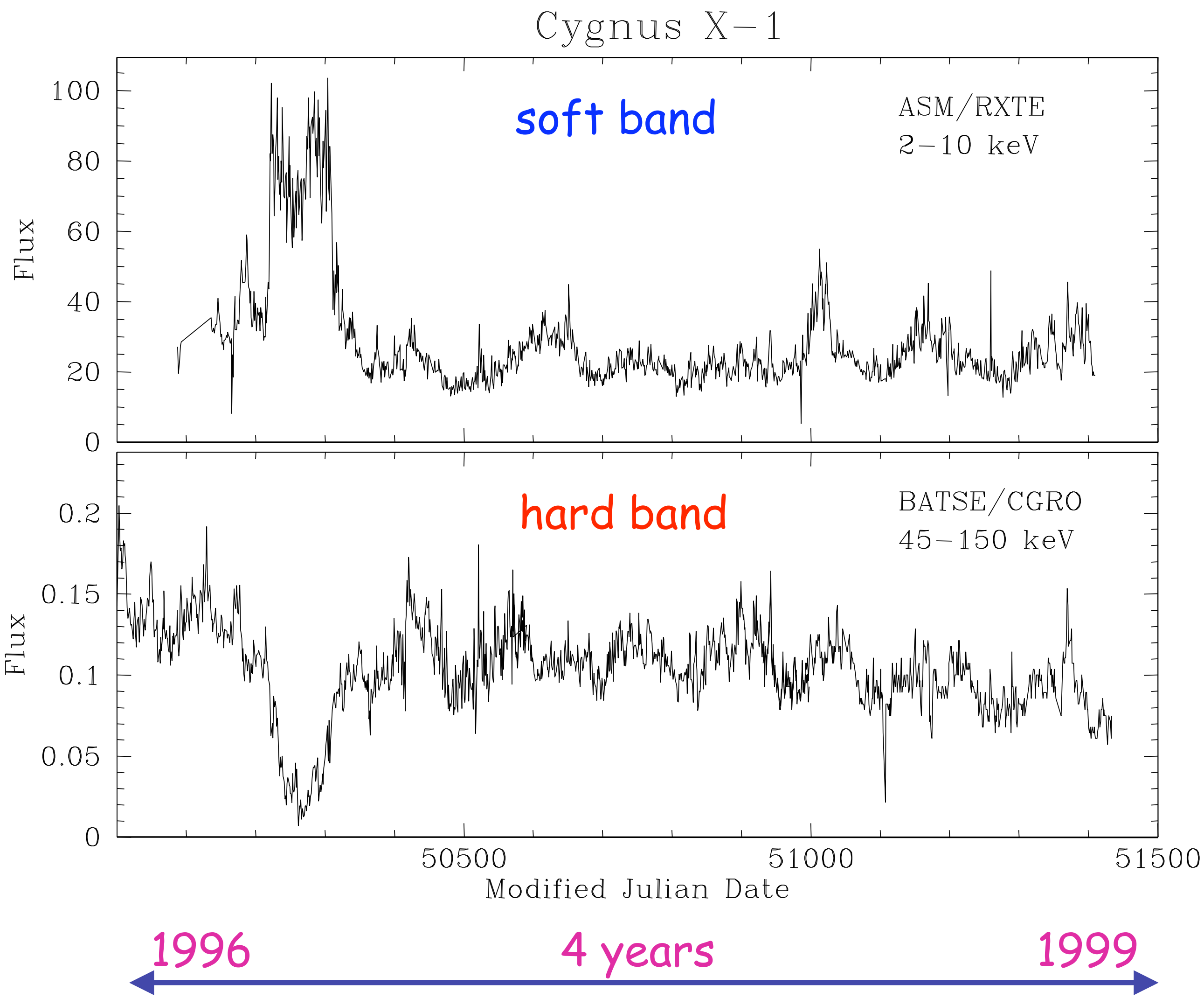
soft state

disk extends to last stable orbit

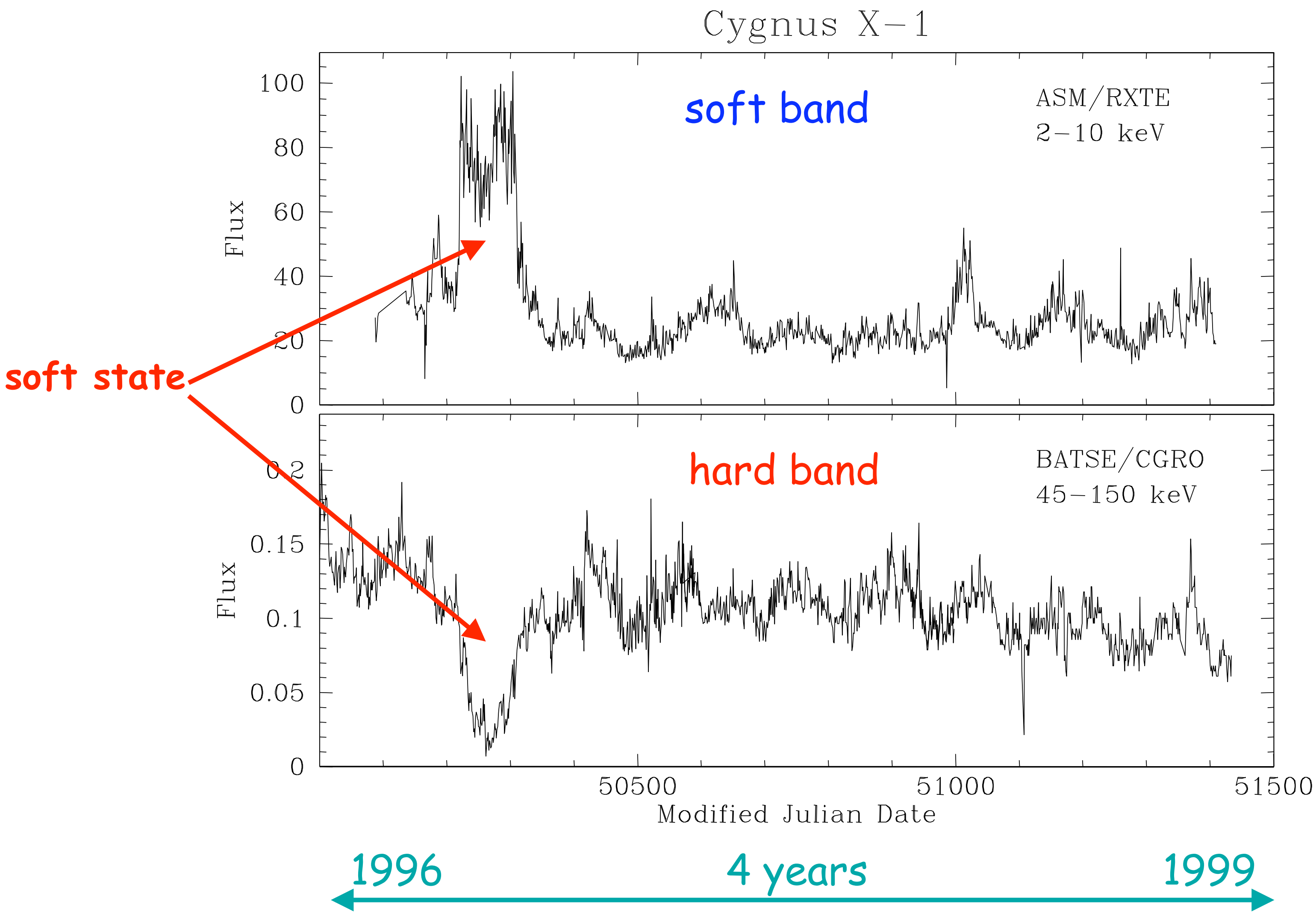


from Zdziarski & Gierlinski, 2004

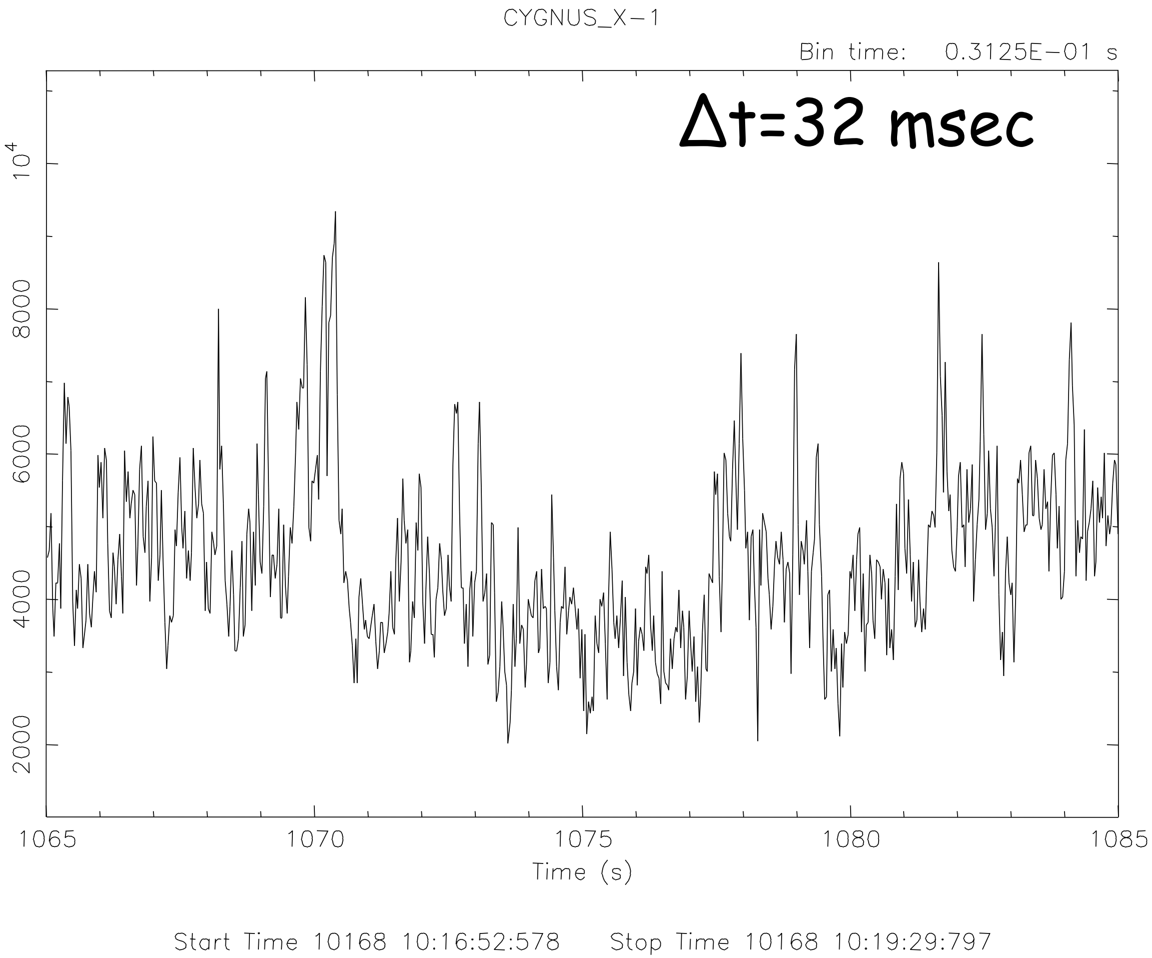
Variability



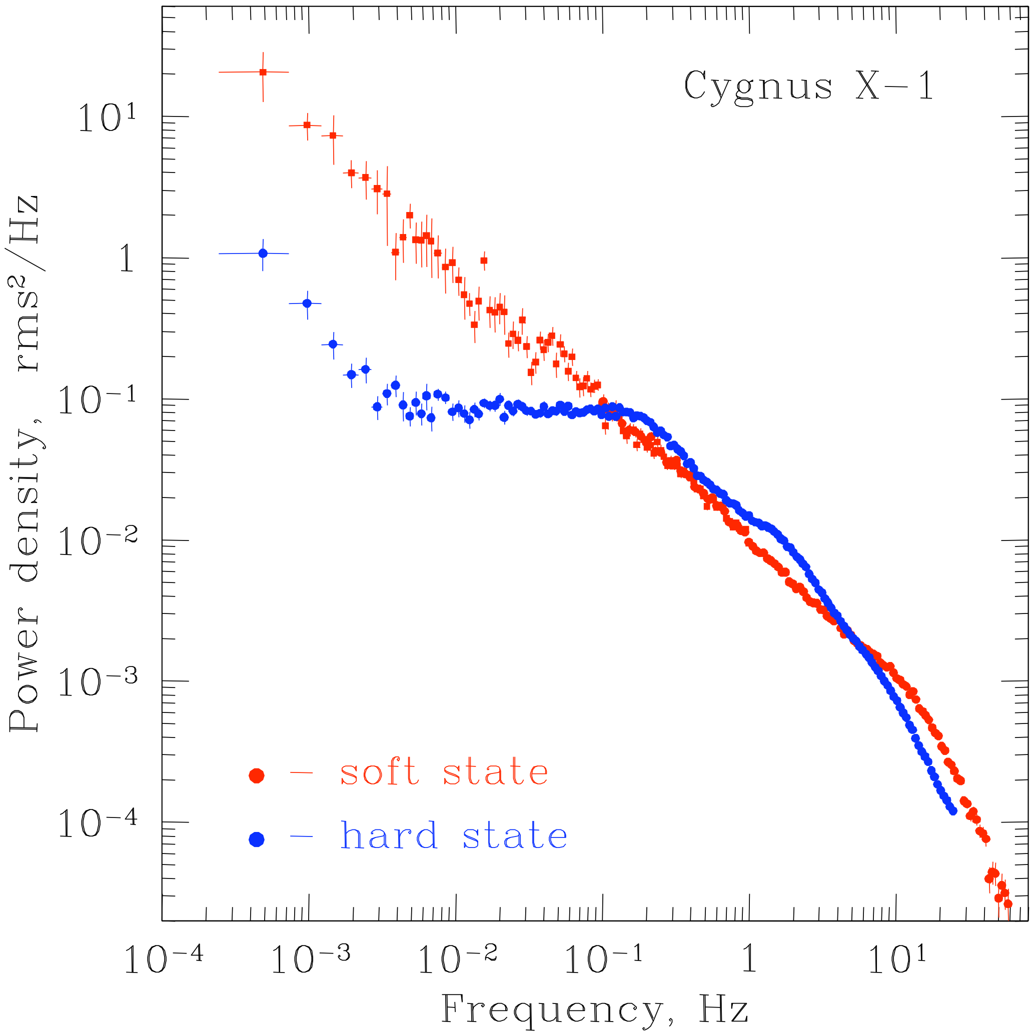
Variability



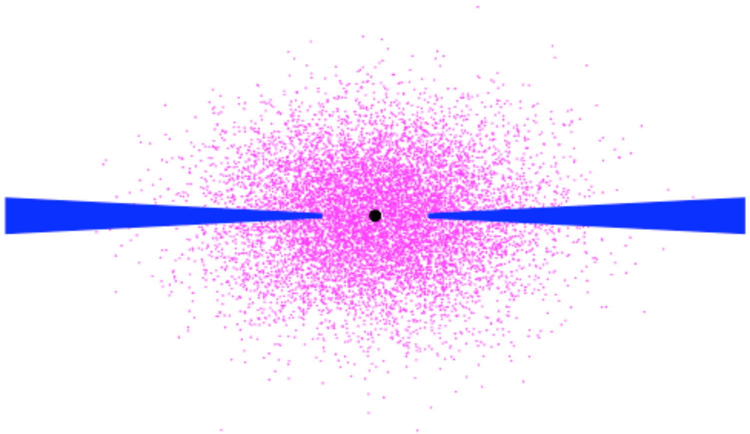
Variability



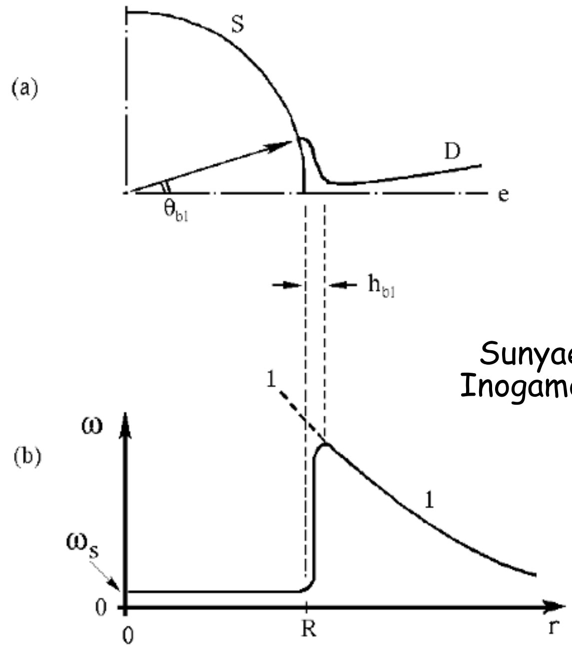
Power density spectra



BH



NS



Sunyaev & Shakura, 1986
Inogamov & Sunyaev, 1999

NO boundary layer

$L_{tot}=L_{disk}$

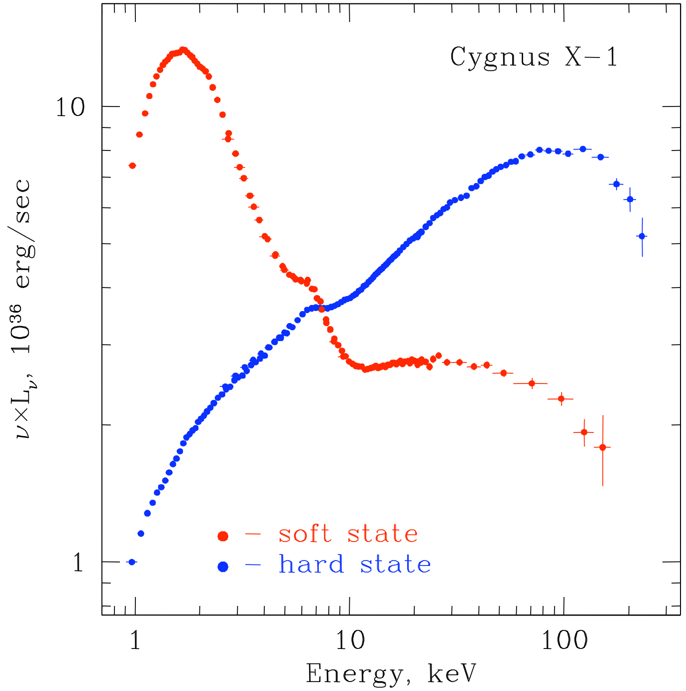
boundary layer

$L_{BL} \sim L_{disk}$

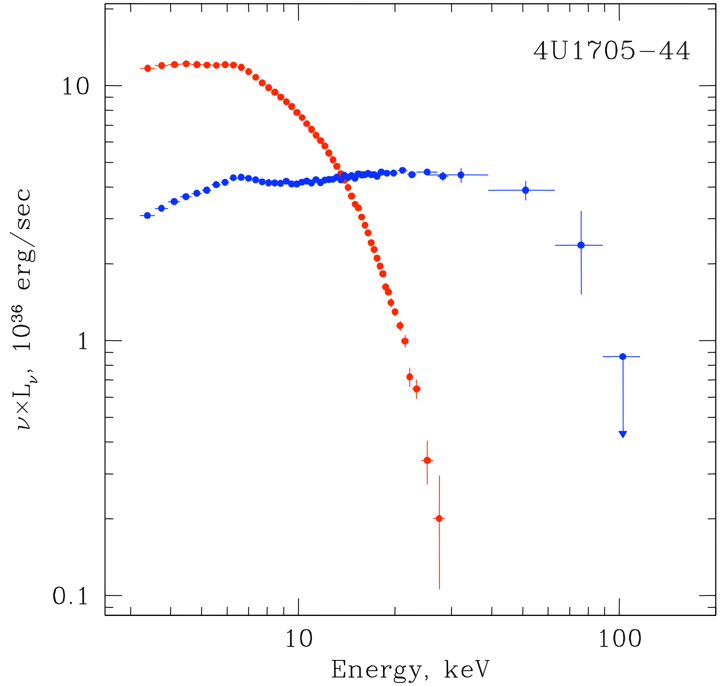
$L_{tot}=L_{disk}+L_{BL}$

X-ray spectra: BH and NS

black hole



neutron star



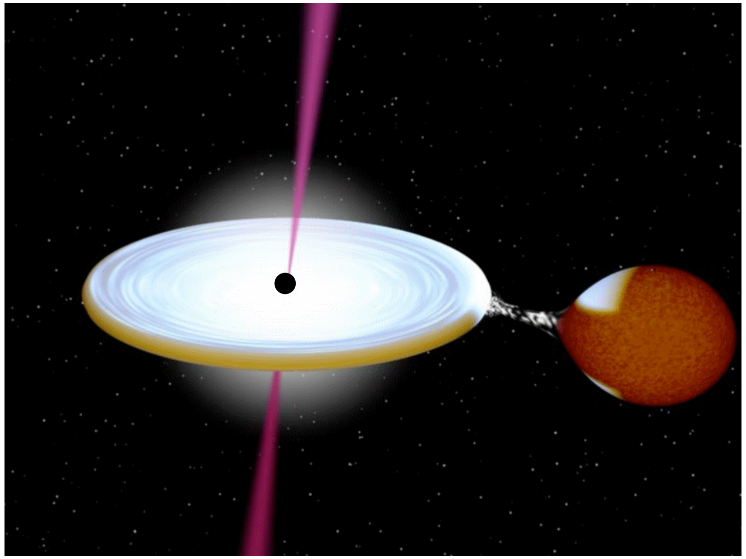
Disk: $kT_{NS} > kT_{BH}$ (difference in size + BL emission in NS)

Comptonization: $y_{NS} < y_{BH}$ $kTe_{NS} < kTe_{BH}$ (hard surface in NS)

Populations of compact objects

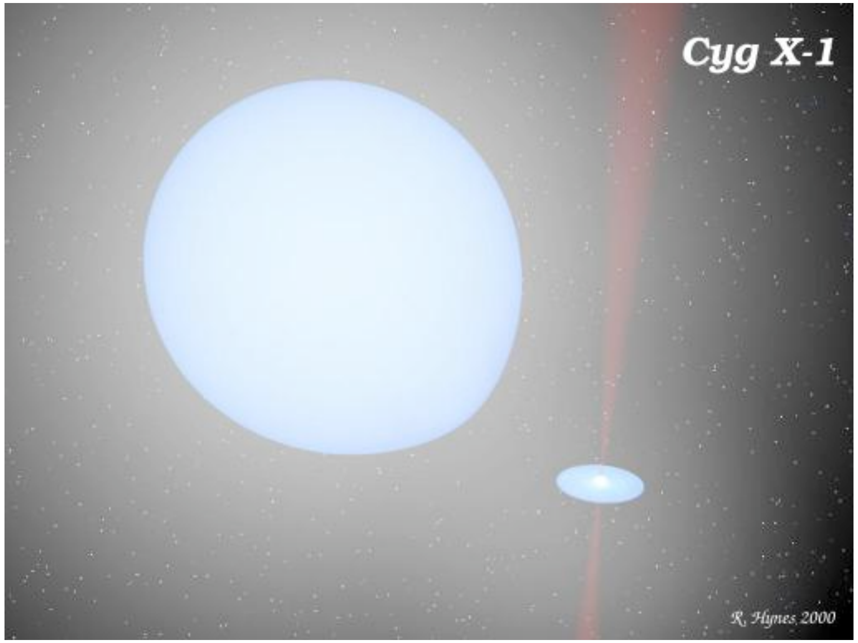
X-ray binaries

- ~200 bright X-ray binaries in the Milky Way
- dominate X-ray output in the majority of galaxies
- two kinds: high- and low-mass X-ray binaries

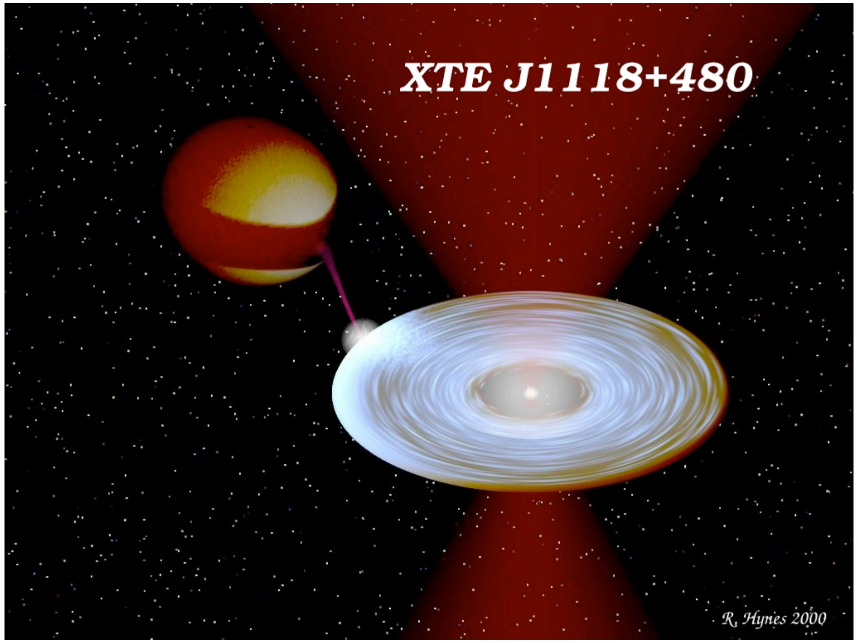


X-ray binaries

High mass

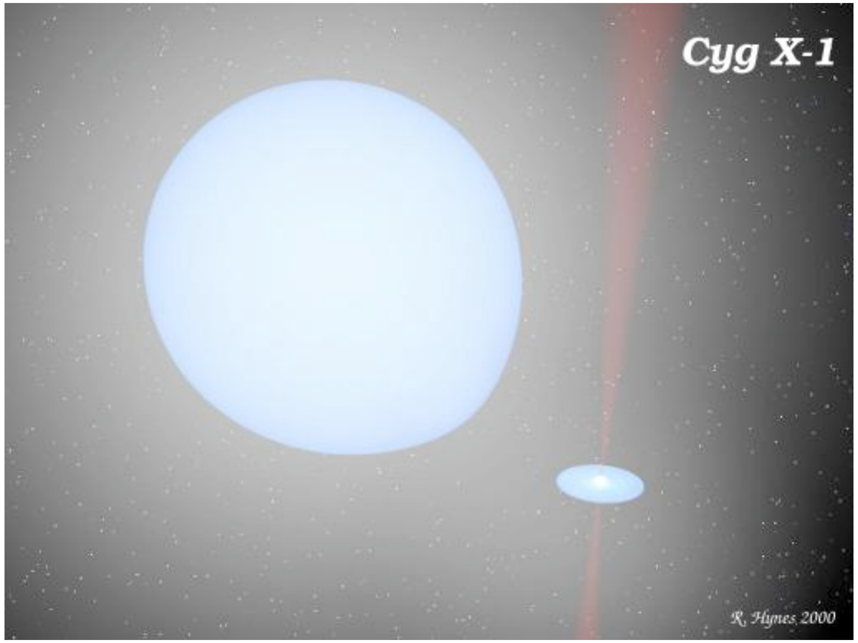


Low mass

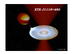


X-ray binaries

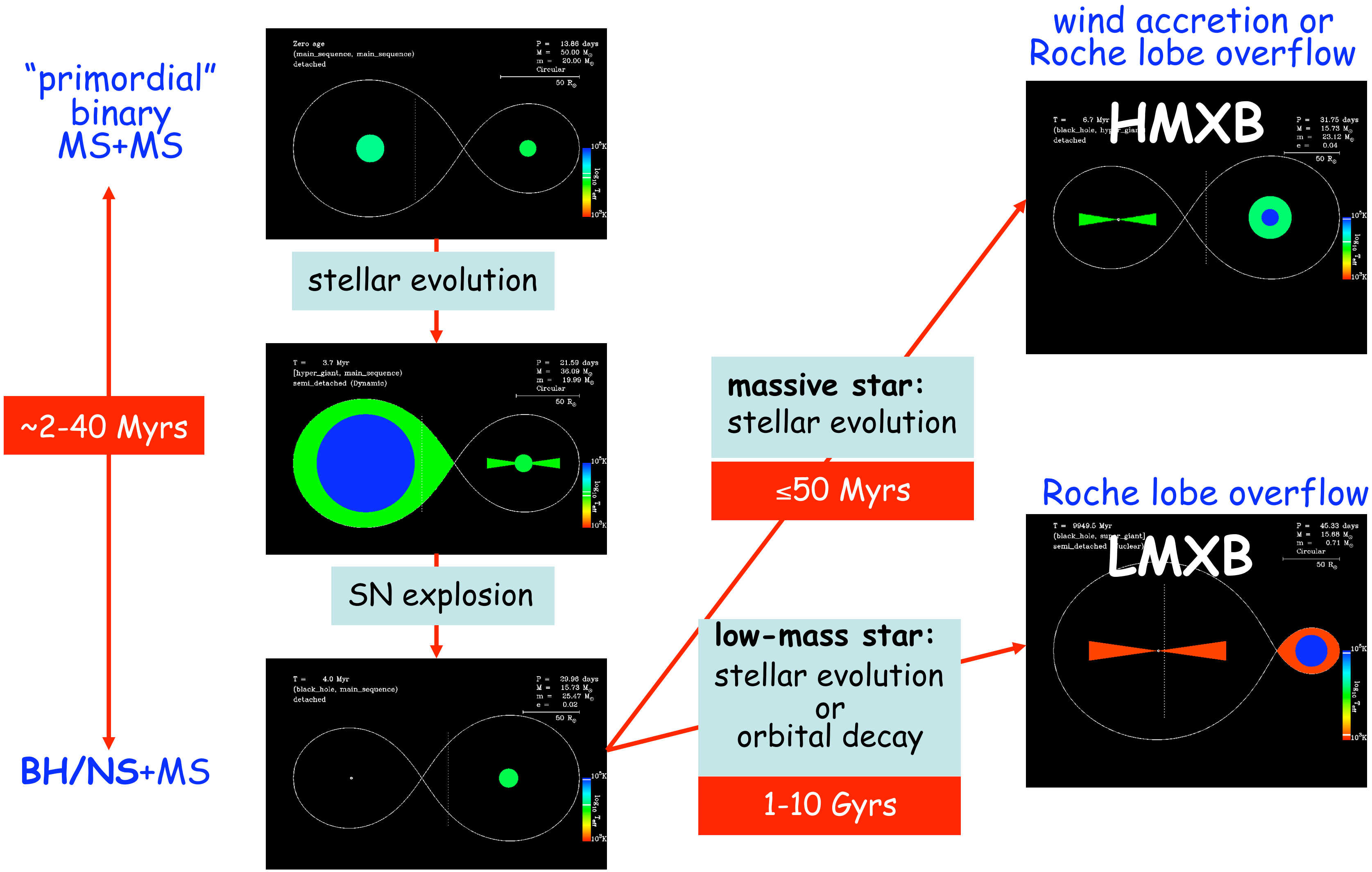
High mass



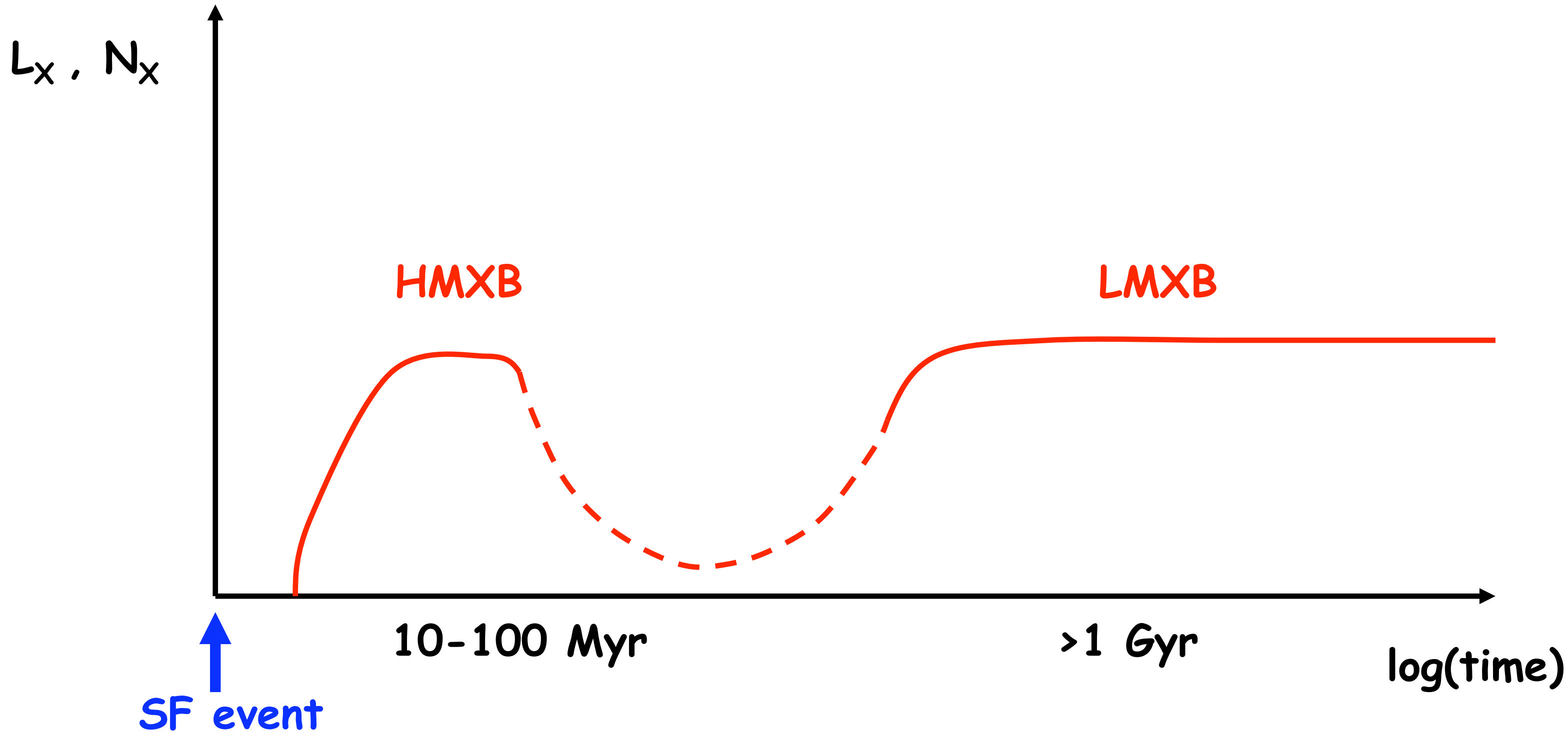
Low mass



Simple (and incorrect) sketch of binary evolution



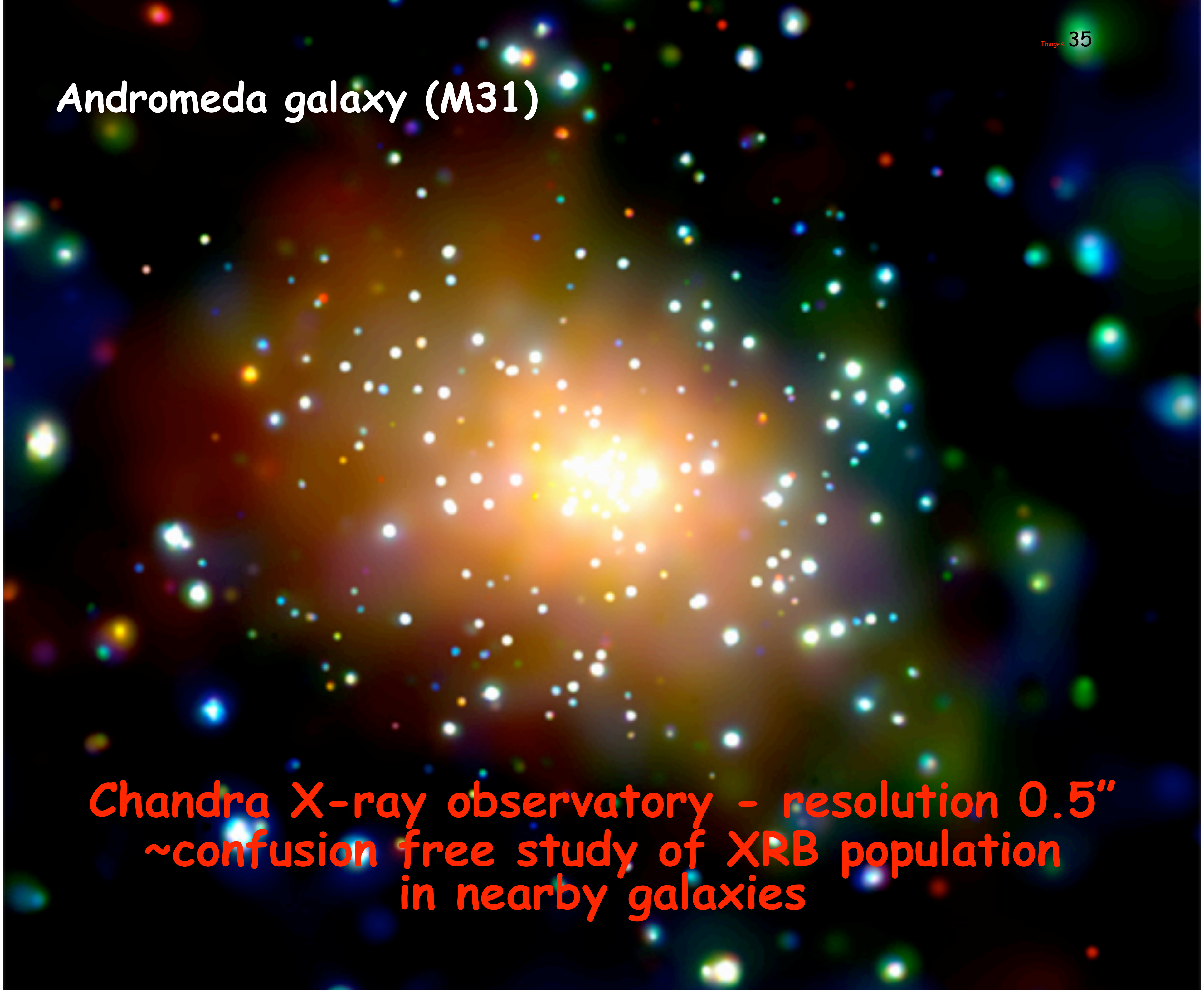
Time dependence of XRB populations



Evolutionary time scales

HMXB	LMXB
▪ t~10-50 Myrs	▪ t~1-10 Gyrs
▪ ~ duration of star formation event	▪ ~ live time of the host galaxy
Star formation tracer	**Stellar mass tracer**

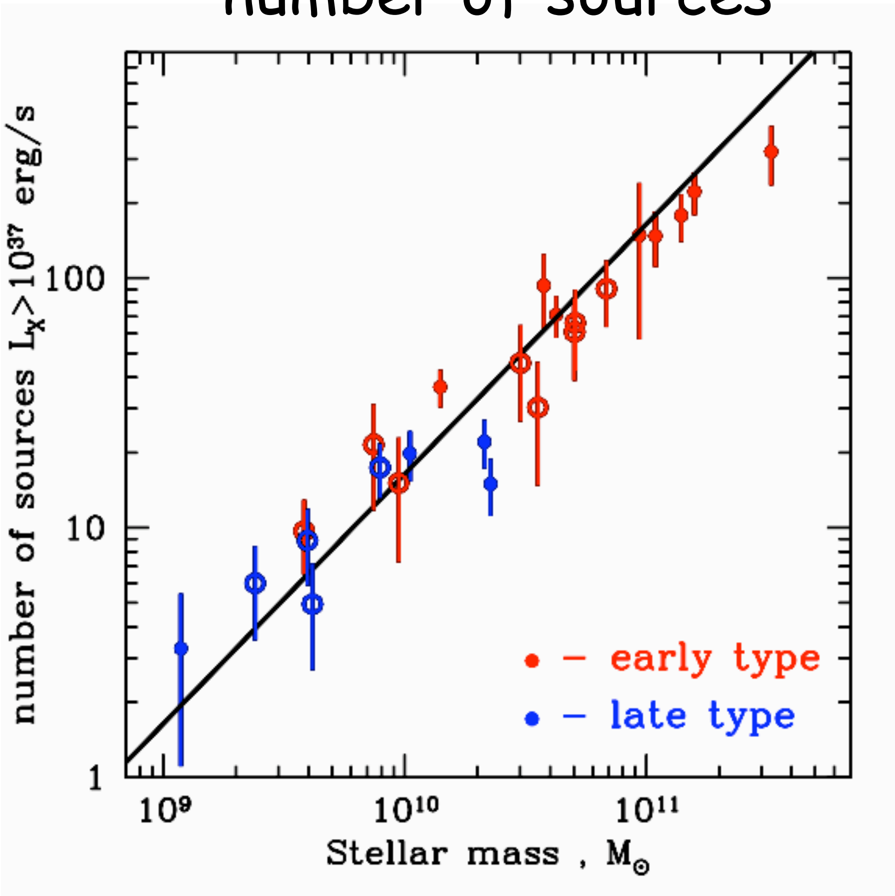
Andromeda galaxy (M31)



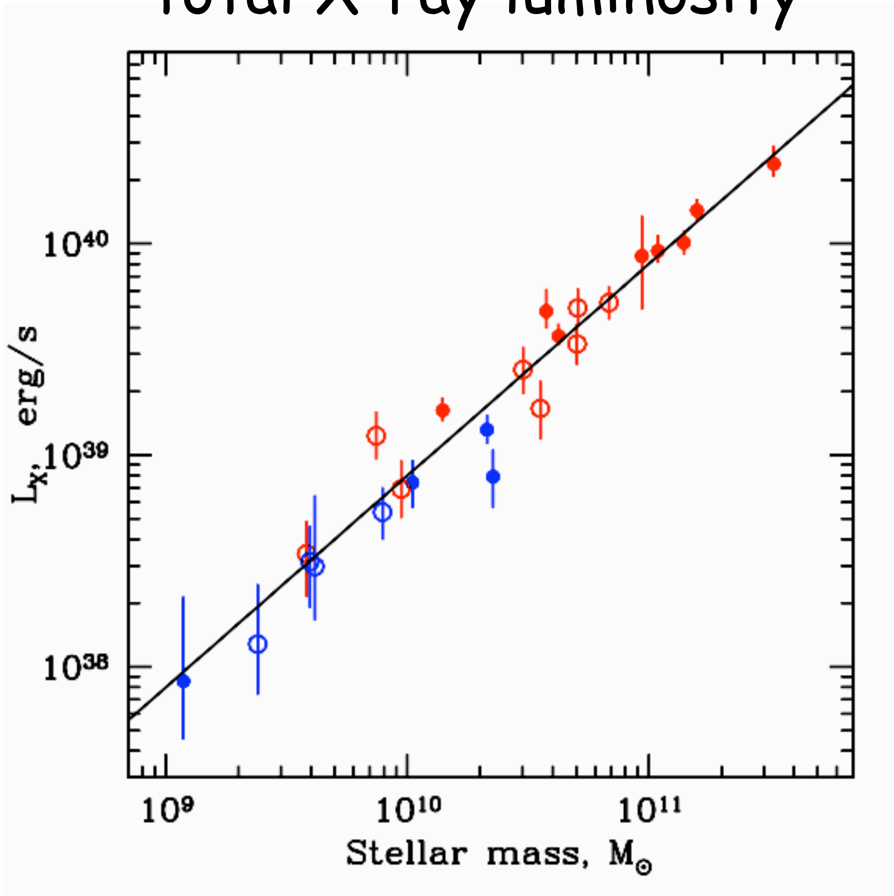
Chandra X-ray observatory - resolution 0.5"
~confusion free study of XRB population
in nearby galaxies

L_x-mass relation for LMXBs

number of sources

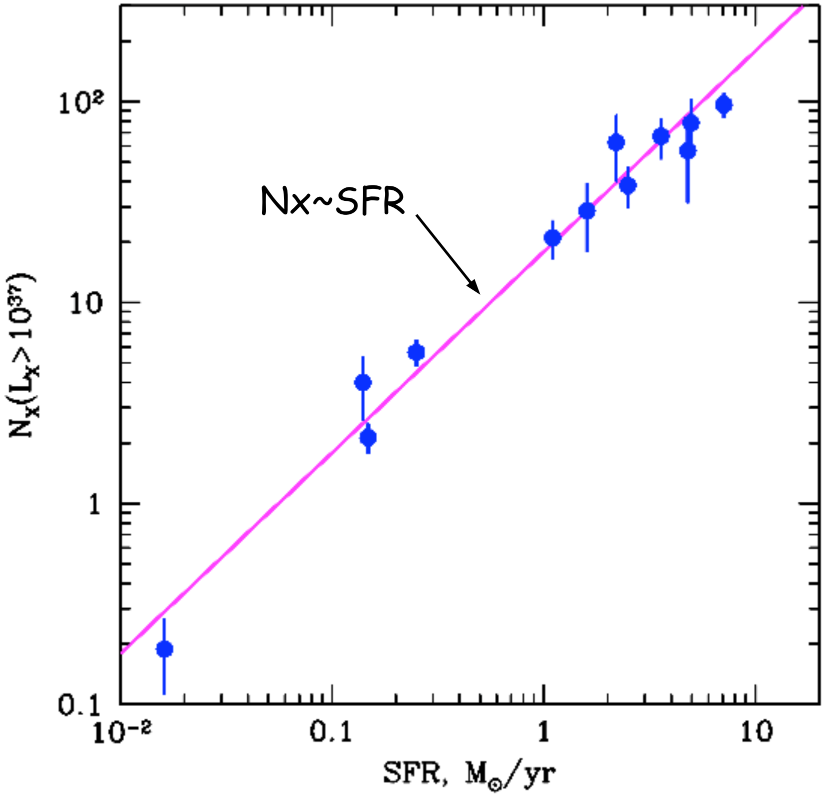


total X-ray luminosity

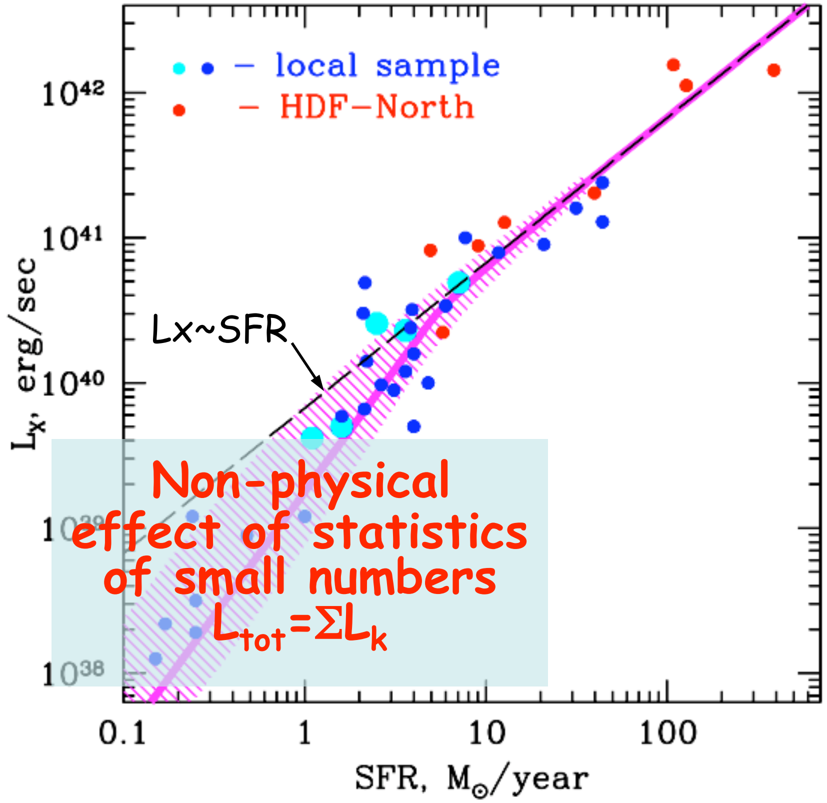


L_x-SFR relation for HMXBs

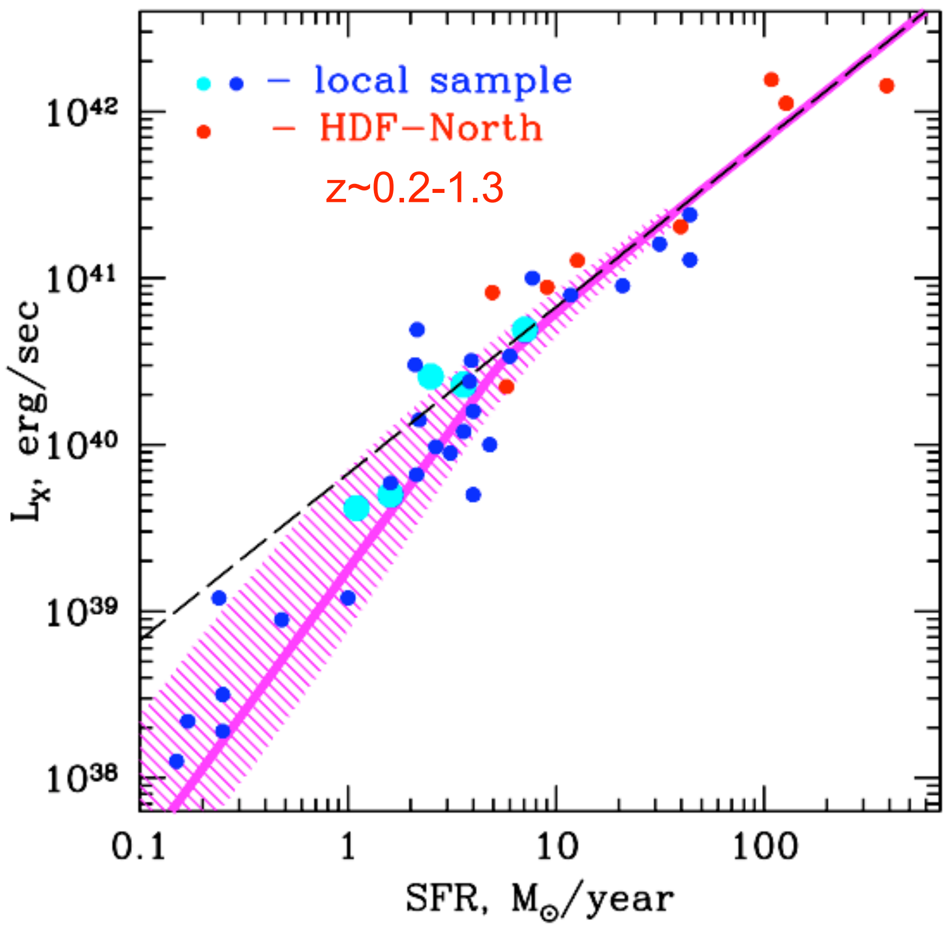
number of sources



total X-ray luminosity



A method to measure star-formation rate in (distant) galaxies



Total number and luminosity of X-ray binaries

$$L_x \sim 2\cdot10^{39}\times \mathbf{SFR} + 1\cdot10^{39}\times \mathbf{M_*}$$

$$N_x(L_x>10^{37}) \sim 7\times \mathbf{SFR} + 10\times \mathbf{M_*}$$

$[SFR]= M_\odot/yr$

$[M_*]=10^{10}\ M_\odot$

How many black holes and neutron stars become X-ray sources?

Number of HMXBs observed at any given time:

$$N_{HMXB} \sim \dot{N}_*(M > 8M_{sun}) \times f_{HMXB} \times \tau_{HMXB}$$

number of HMXB

birth rate of compact objects

HMXB fraction

duration of X-ray active phase

$$f_{HMXB} \propto f_{bin} \times f_{surv} \ \ldots$$

Number of HMXBs observed at any given time:

$$N_{HMXB} \sim \dot{N}_*(M > 8M_{sun}) \times f_{HMXB} \times \tau_{HMXB}$$

Salpeter IMF: $\dot{N}_*(M > 8M_{sun}) \approx 7.4 \cdot 10^{-3} \times \mathrm{SFR}$

Nx-SFR relation: $N_{HMXB}(L > 10^{34}) \approx 500 \times \mathrm{SFR}$

$$\boxed{f_{HMXB} \times \tau_{HMXB} \sim 0.07\ \mathrm{Myr}}$$

Fraction of compact objects X-ray active once in their lifetime

$$f_{HMXB} \times \tau_{HMXB} \geq 0.07 \text{ Myr}$$

O,B binaries: $\tau_{HMXB} \sim 10^4 - 10^5$ yrs

X/Be binaries: $\tau_{HMXB} \sim 10^5 - 10^6$ (?) yrs

$$\boxed{f_{HMXB} \geq 0.7 \times \left(\frac{\tau_{HMXB}}{0.1 \text{ Myr}} \right)^{-1}}$$

…in LMXBs

Per 10^{10} M_{sun}:

Salpeter IMF: ~$7.4 \cdot 10^7$ BH & NS

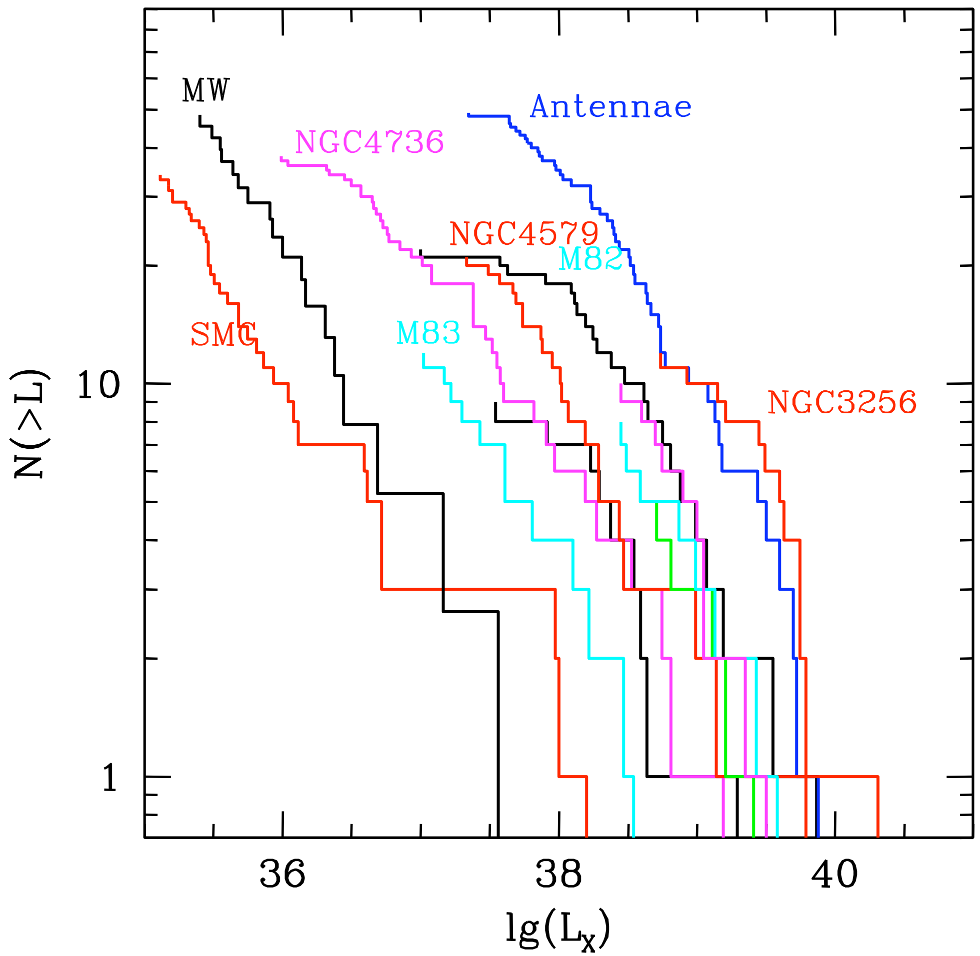
LMXB-M_{star} relation: $N_{LMXB}(L_X > 10^{35})$~50 LMXBs

$$\boxed{f_{LMXB} \sim 7 \cdot 10^{-6} \left(\frac{f_{tr}}{0.1} \right)^{-1}}$$

Luminosity functions

HMXBs

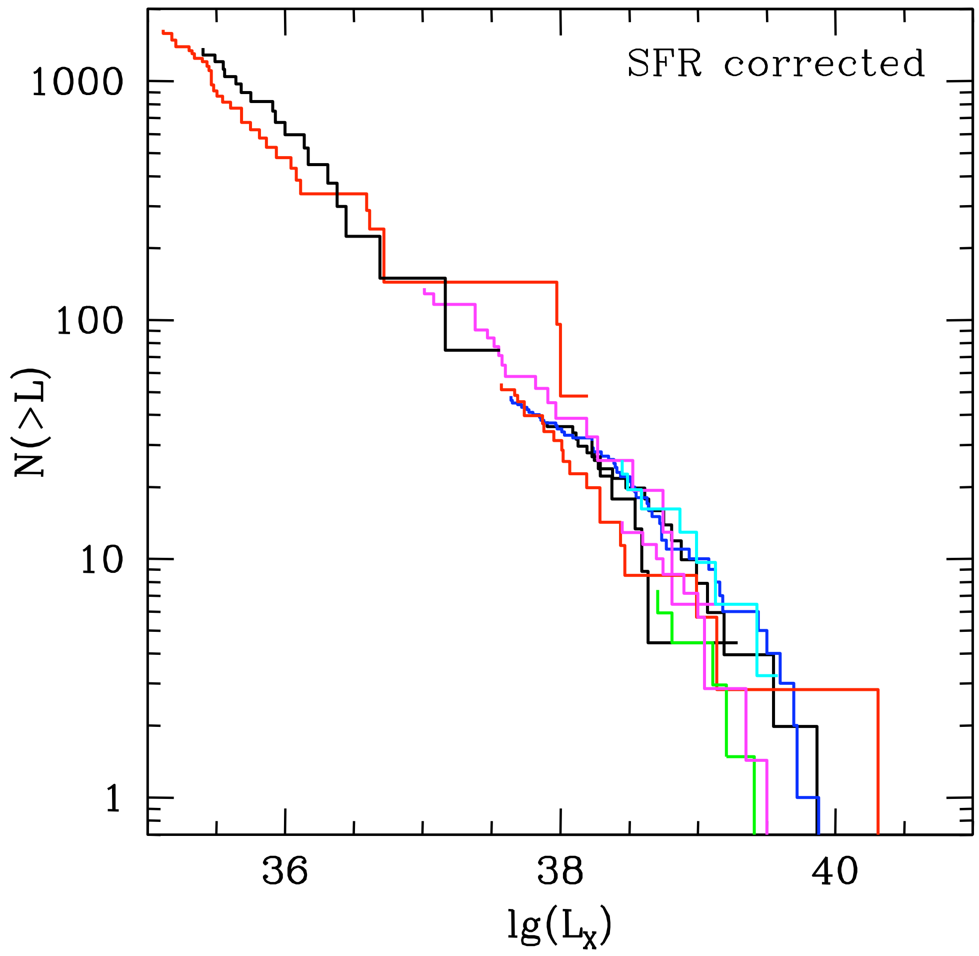
X-ray luminosity functions:



SFR~0.15-7 M_{sun}/yr

HMXBs

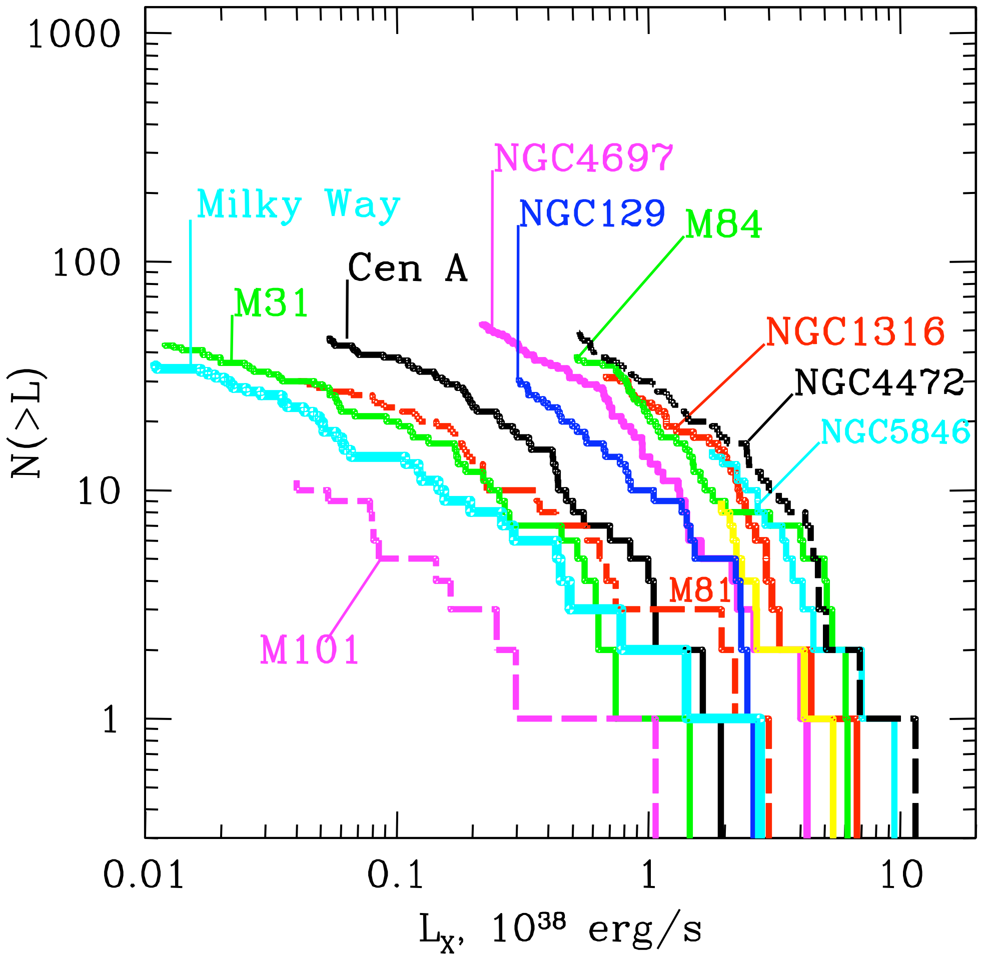
X-ray luminosity functions **scaled to the same SFR**



SFR~0.15-7 M_{sun}/yr

LMXBs

X-ray luminosity functions:

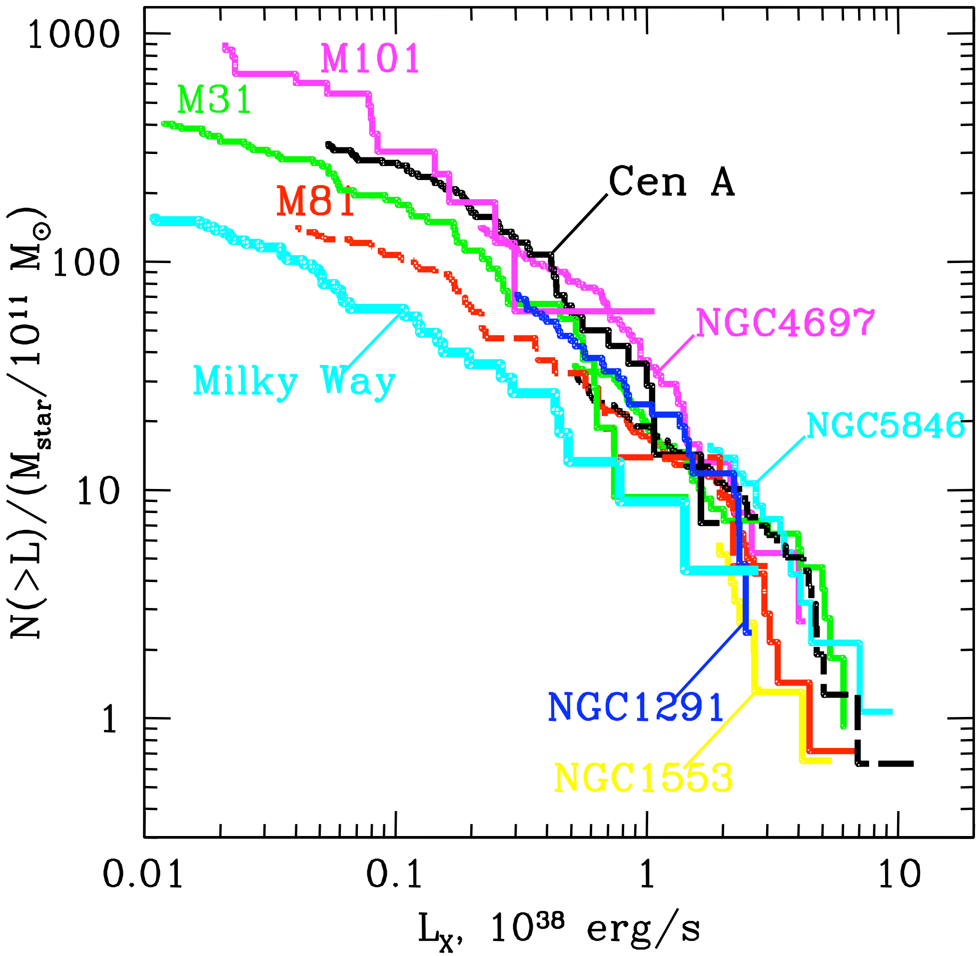


Stellar mass range: 10^9-3×10^{11} Msun

LMXBs

X-ray luminosity functions: **scaled to the same mass**

Stellar mass range: 10^9-3×10^{11} Msun



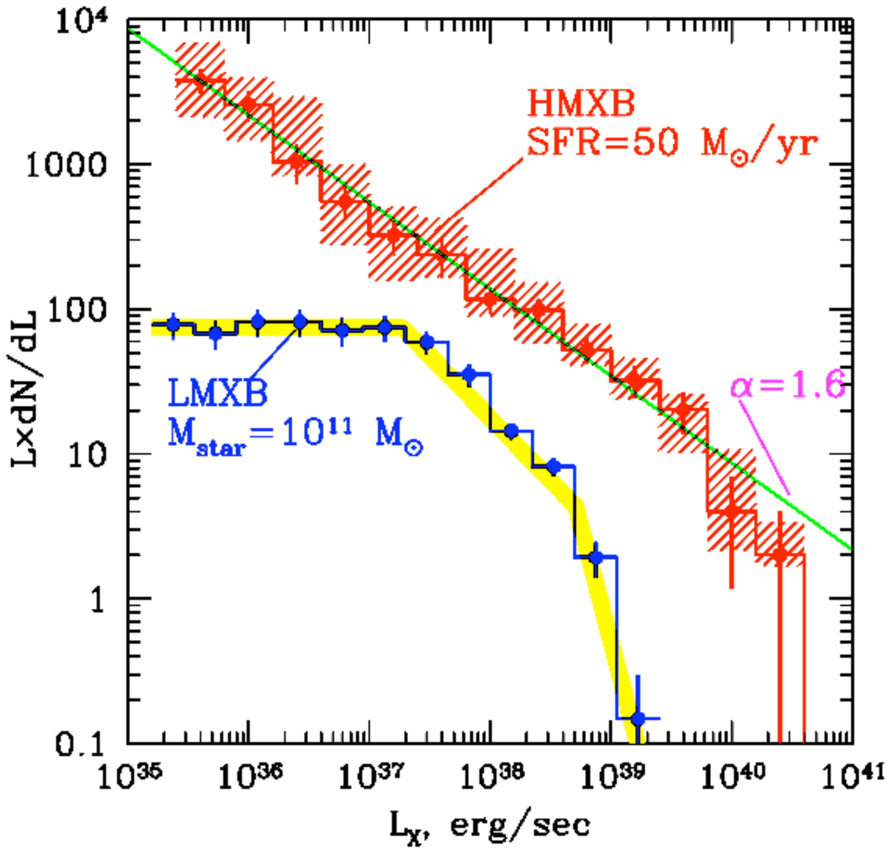
Luminosity functions

HMXBs and LMXBs:

different **shapes/slopes**

different **accretion regimes:**

- wind accretion
- Roche-lobe overflow



HMXB XLF & IMF slope

accretion of radiation pressure driven stellar wind

$$\left.\begin{aligned} \dot{M}_{wind} &\propto L_* \\ L_* &\propto M_*^3 \end{aligned}\right\} \Rightarrow \dot{M}_{wind} \propto M_*^3 \Rightarrow \dot{M}_{acc} \propto \dot{M}_{wind} \propto M_*^3$$

more accurate consideration (Bondi accr. etc):

$$\dot{M}_{acc} \propto M_*^{2.5} \Rightarrow L_x \propto M_*^{2.5} \qquad \text{(Postnov, 2004)}$$

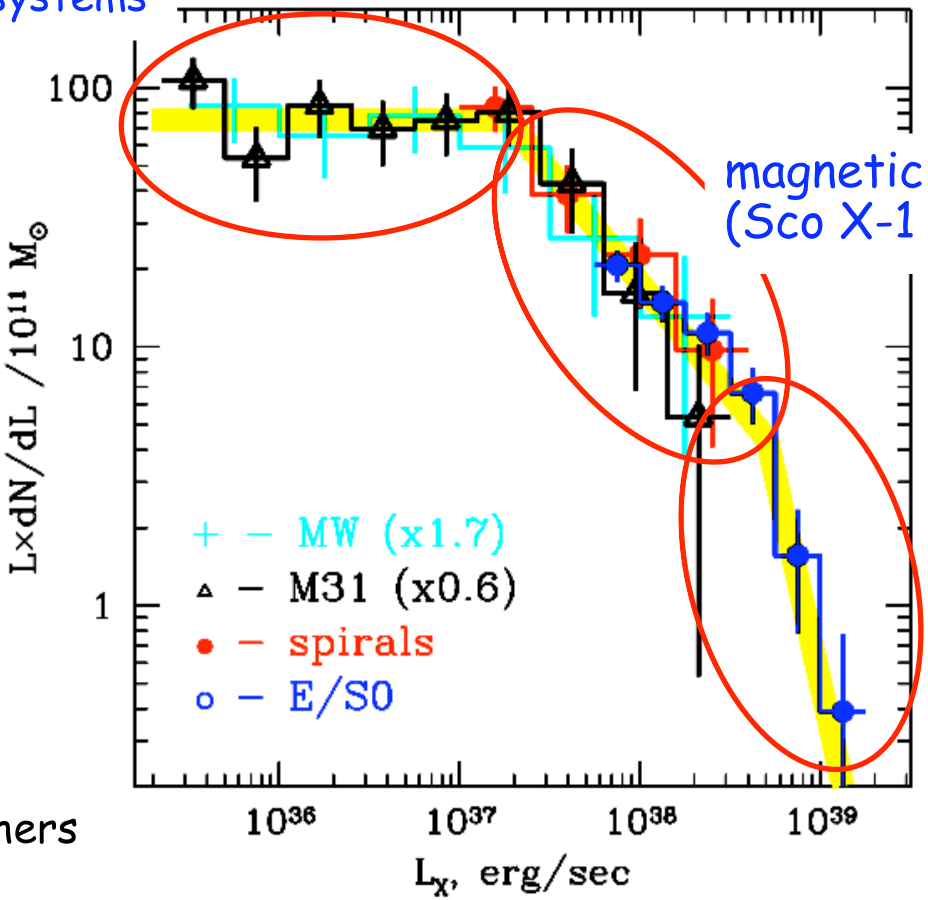
$$\frac{dN}{dL_x} = \frac{dN}{dM_*} \times \left(\frac{dL_x}{dM_*}\right)^{-1} \Rightarrow \alpha_{IMF} = 2.5 \times \alpha_{XLF} - 1.5$$

$$\alpha_{IMF}, \alpha_{XLF} - \text{ IMF and XLF slopes: } \quad \frac{dN}{dL_X} = M_*^{-\alpha_{XLF}}; \quad \frac{dN}{dM_*} = M_*^{-\alpha_{IMF}}$$

$$\alpha_{XLF} = 1.6 \pm 0.15 \Rightarrow \underline{\alpha_{IMF} = 2.5 \pm 0.4} \quad \text{(Salpeter: } \alpha_{IMF} = 2.35\text{)}$$

LMXB XLF

gravitational braking
in longer Porb systems



magnetic braking
(Sco X-1 etc.)

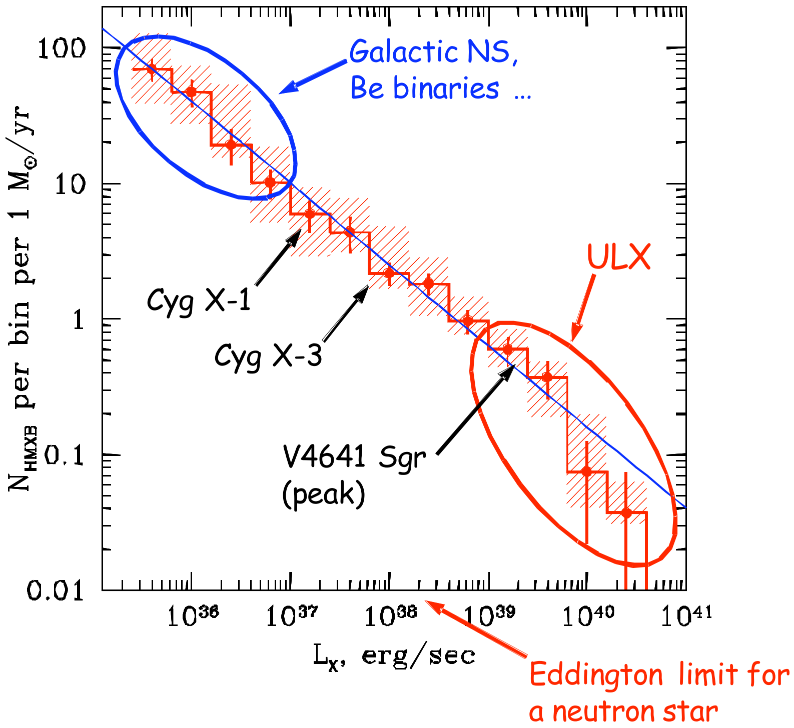
Evolved companion
and/or
Gravitational braking in
ultracompact binaries
NS+WD, Porb~10 min

short life-time problem

King, Bildsten,
Postnov and others


Thank you!
image: Li & Wang

ULX and HMXB



lg(Lx)<40

- ~**featureless** power law
  smooth extension of ordinary HMXB population
- different population – **unlikely;**
  high M, high Mdot tail ?

lg(Lx)>40

- the **brightest ULXs - different nature ?**