Populations of X-ray sources in galaxies

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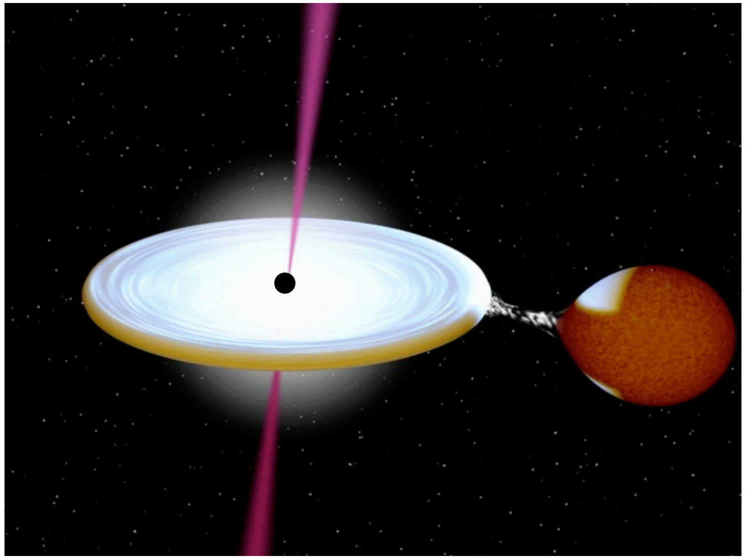
Outline

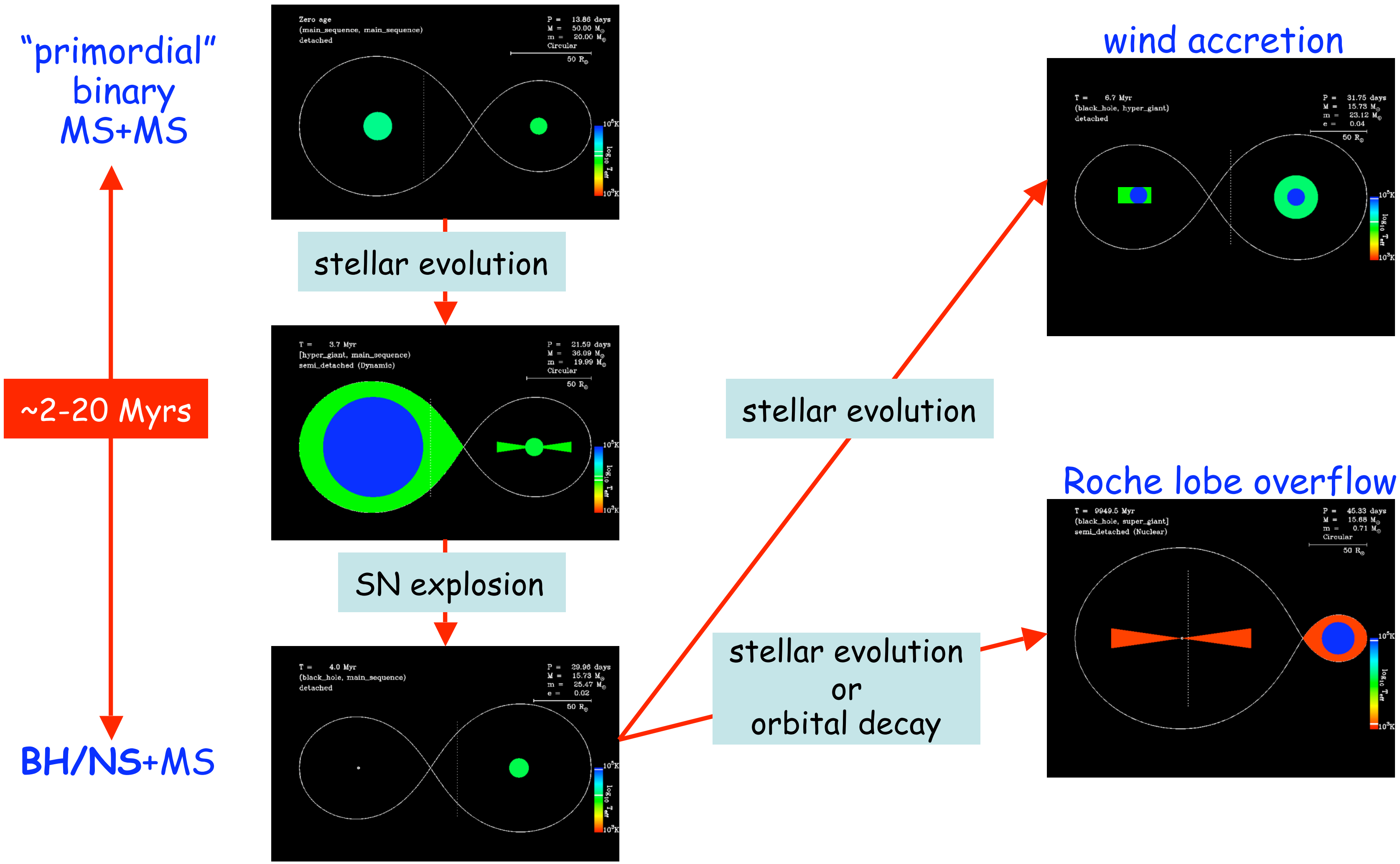
- ✓ overview of populations of X-ray binaries in galaxies
- ✓ constrains on IMF
- ✓ impact on the theory of binary formation and evolution
- ✓ primordial binaries, dynamical formation of binaries in dense stellar environment

X-ray binaries

- accretion onto BH or NS
- descendants of $M>8M_{sun}$ stars
- L_x~... 10^{35} - 10^{39}... erg/s
- dominate X-ray output of a normal galaxy (no AGN, no hot gas)
- primordial or newly formed



Binary evolution



Evolutionary time scales

HMXB

- $\tau \sim 10$ Myrs
- ~ duration of star formation event

Star formation tracer

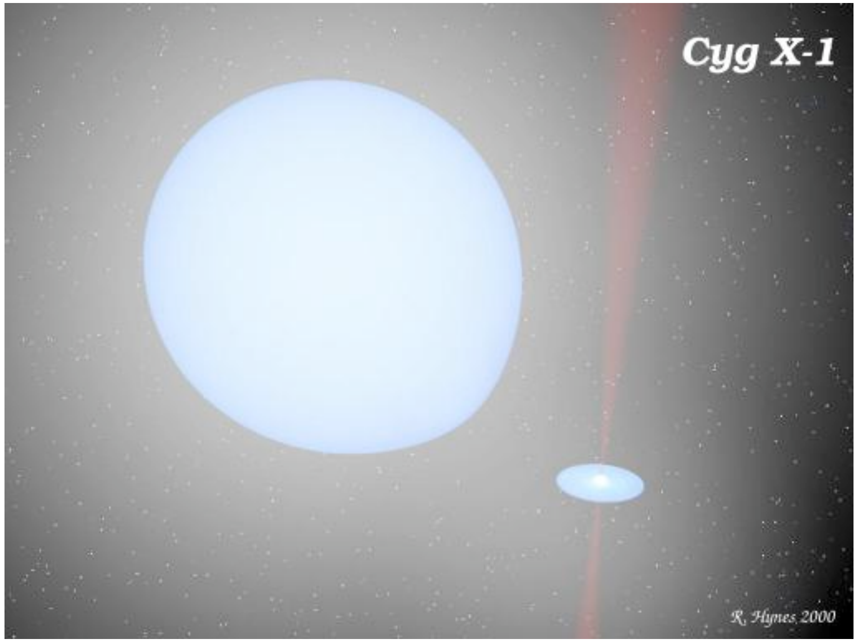
LMXB

- $\tau \sim 1\text{-}10$ Gyrs
- ~ live time of the host galaxy

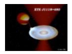
Stellar mass tracer

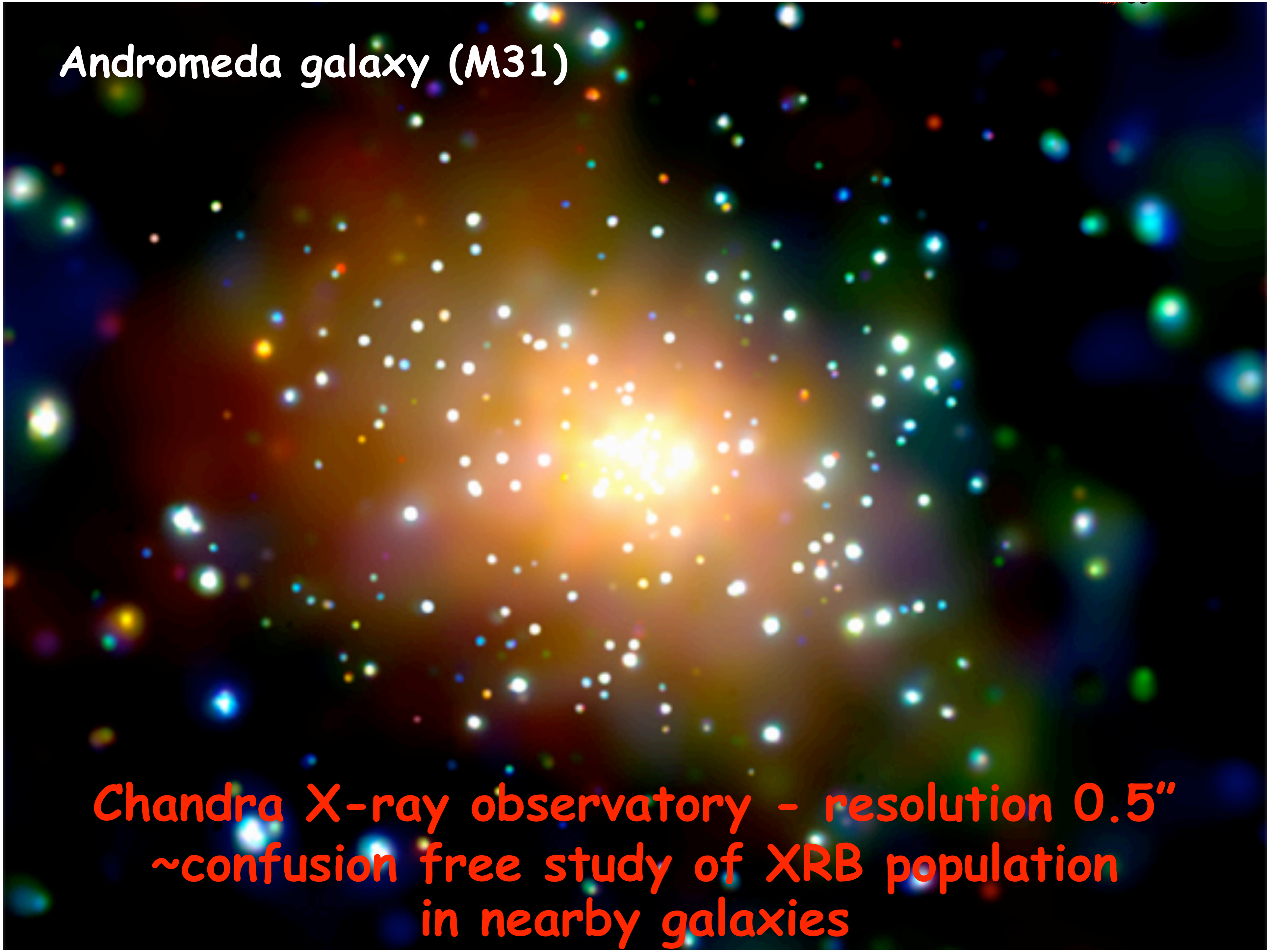
X-ray binaries

High mass



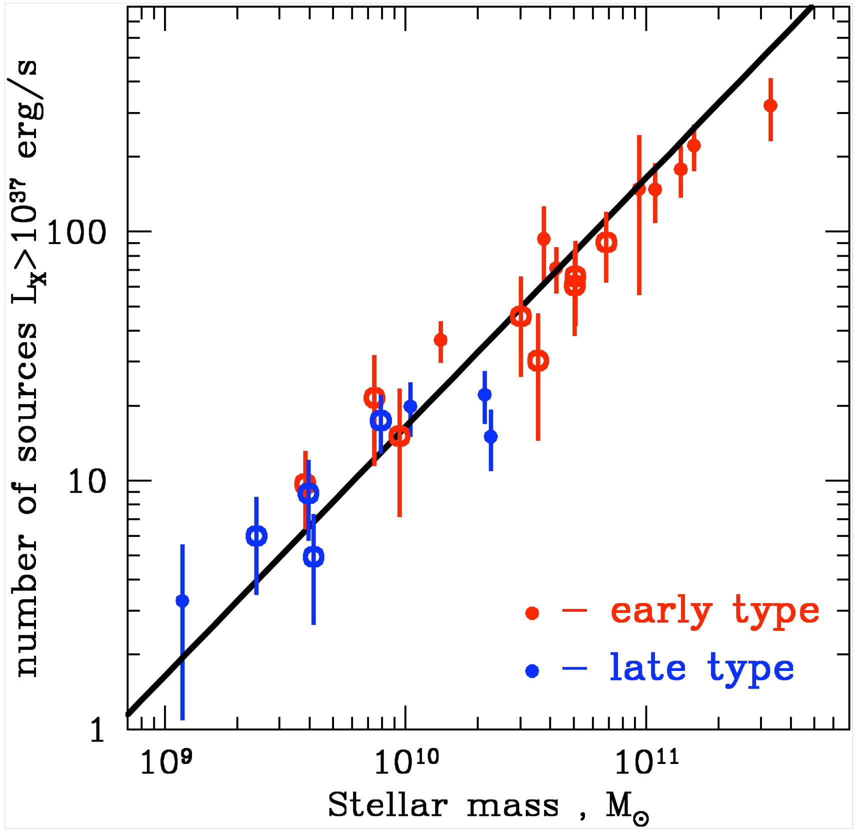
Low mass



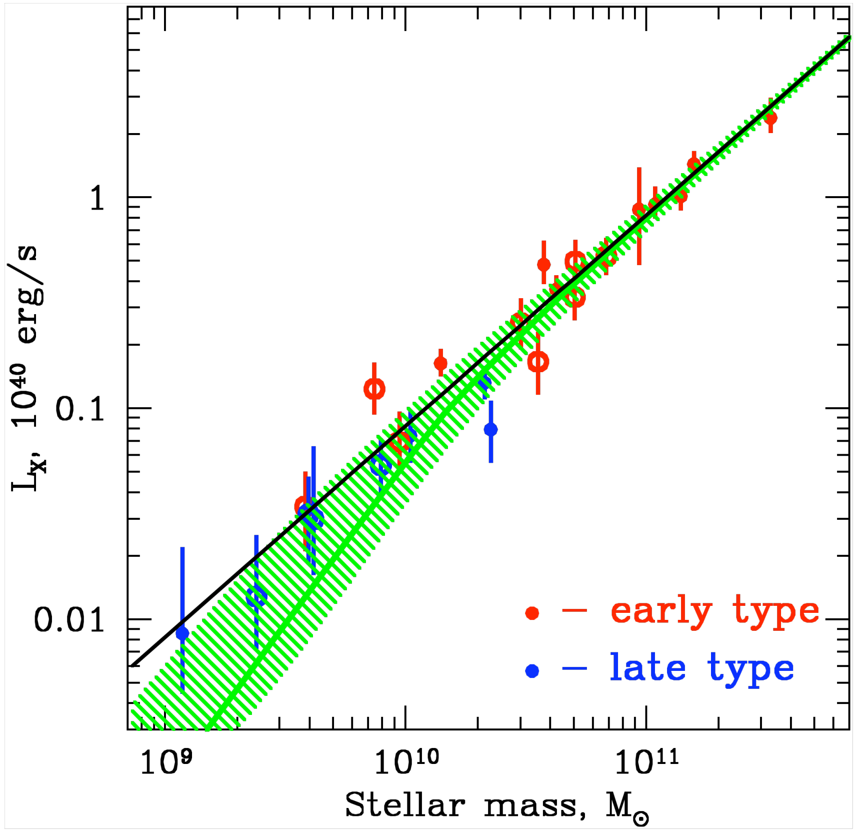

Andromeda galaxy (M31)
Chandra X-ray observatory - resolution 0.5"
~confusion free study of XRB population
in nearby galaxies

L_x-mass relation for LMXBs

number of sources

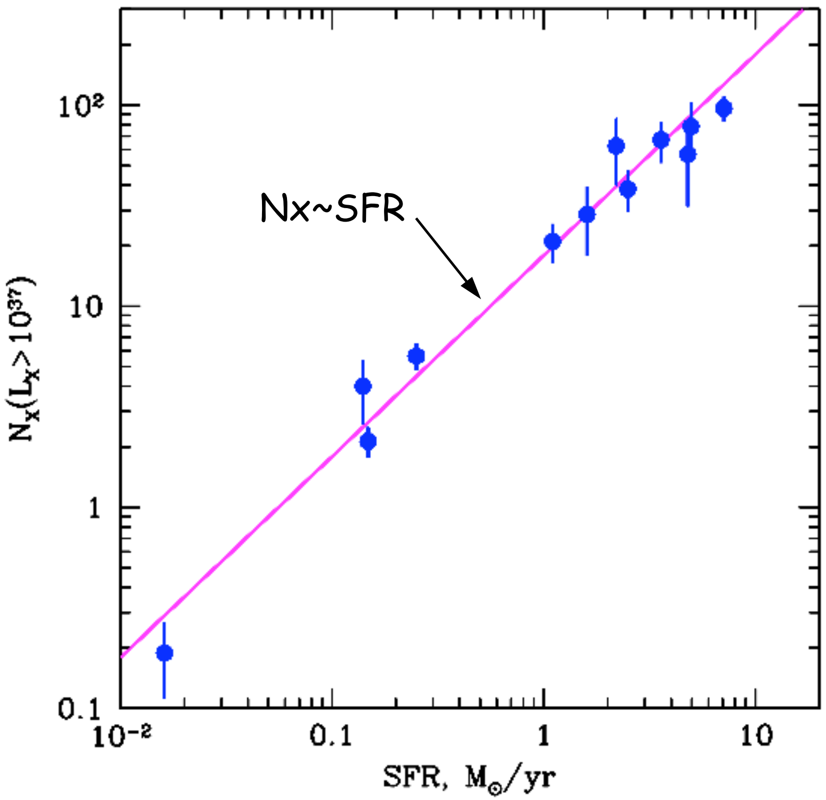


total X-ray luminosity

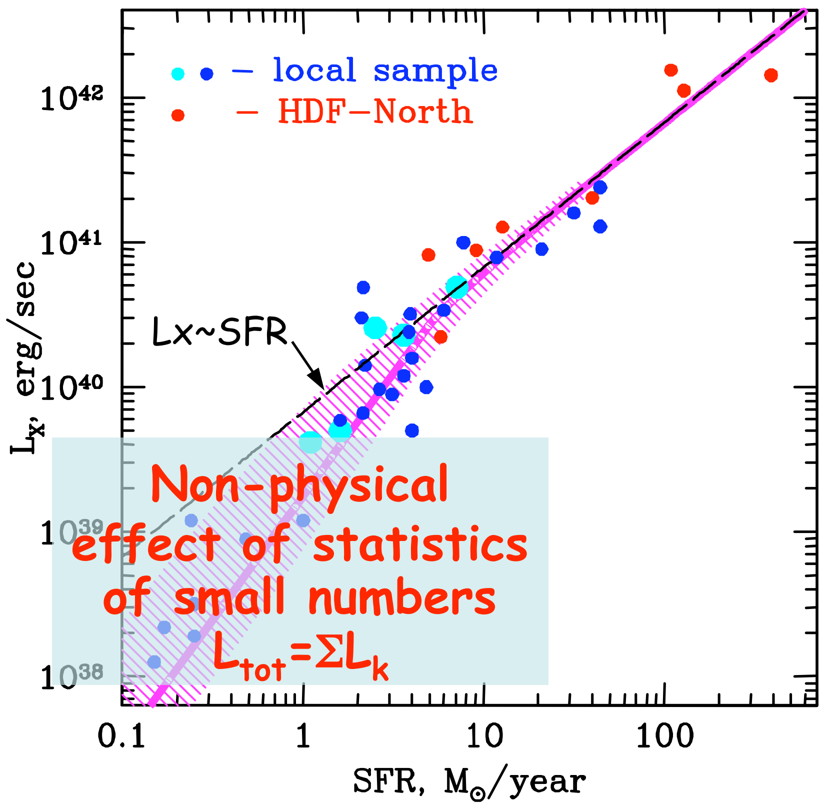


Lx-SFR relation for HMXBs

number of sources



total X-ray luminosity



Total luminosity of XRBs

$$L_x \sim 2\cdot 10^{39} \times SFR + 10^{39} \times M_*$$

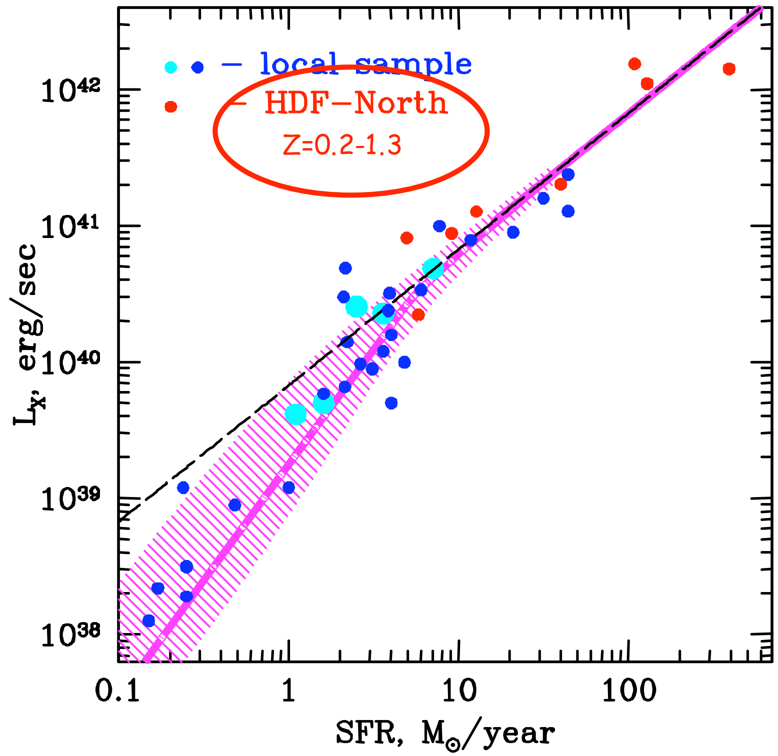
$$N_x(L_x>10^{37}) \sim 7 \times SFR + 10 \times M_*$$

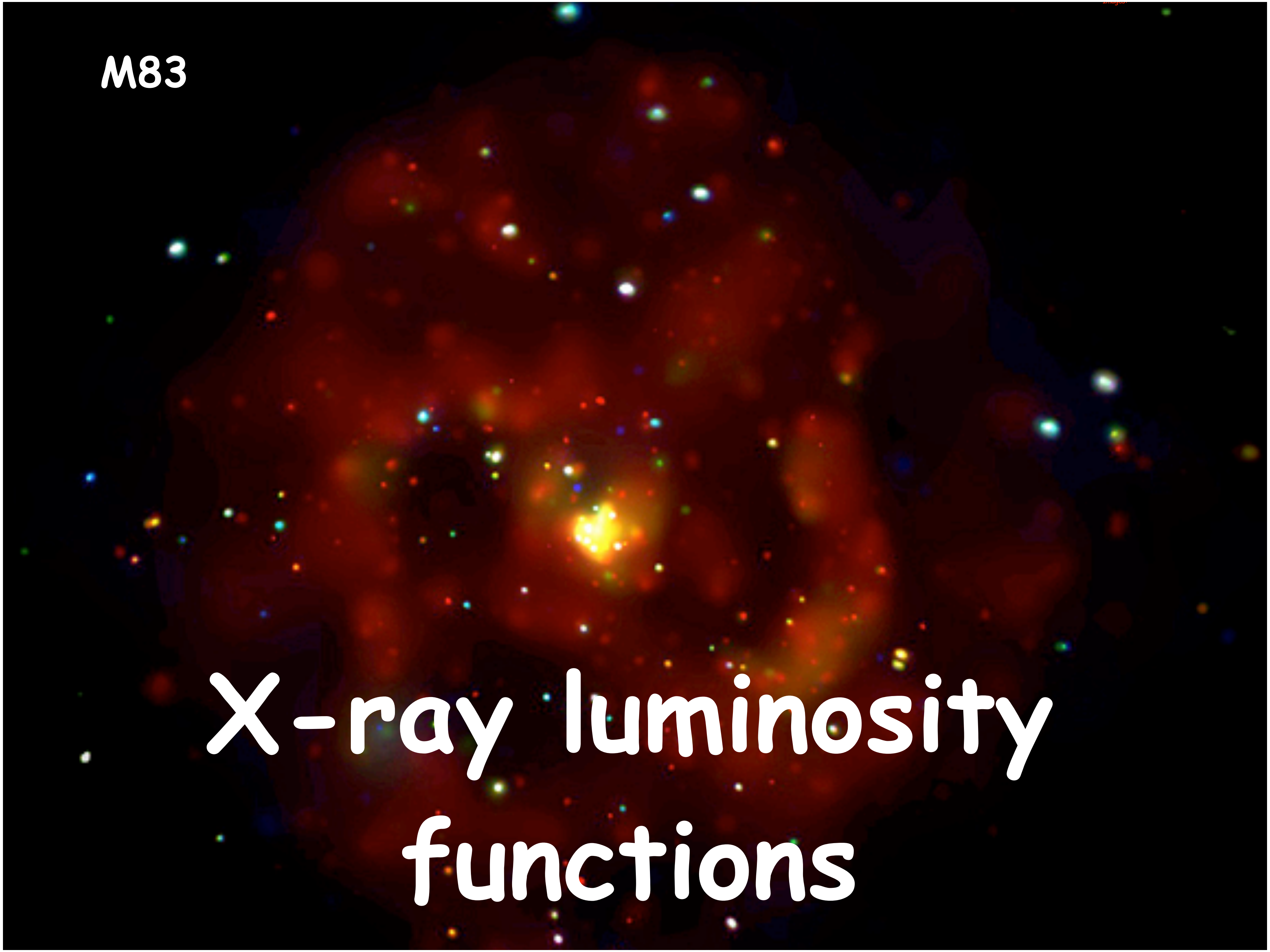
$[SFR] = M_\odot/yr$

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

XRBs can be used as SFR and stellar mass proxy

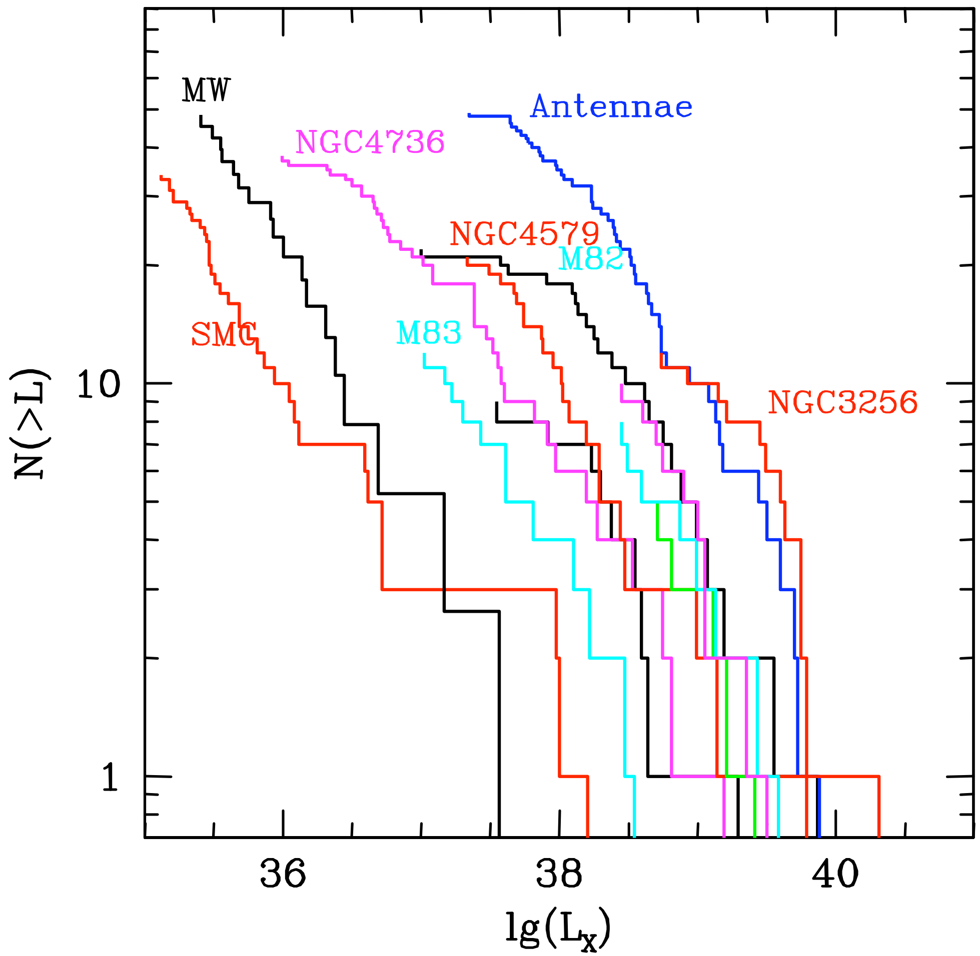
- new & independent method
- SFR (HMXBs) - high z
- contamination:
  - AGN
  - hot gas




M83
X-ray luminosity functions

HMXBs

X-ray luminosity functions:

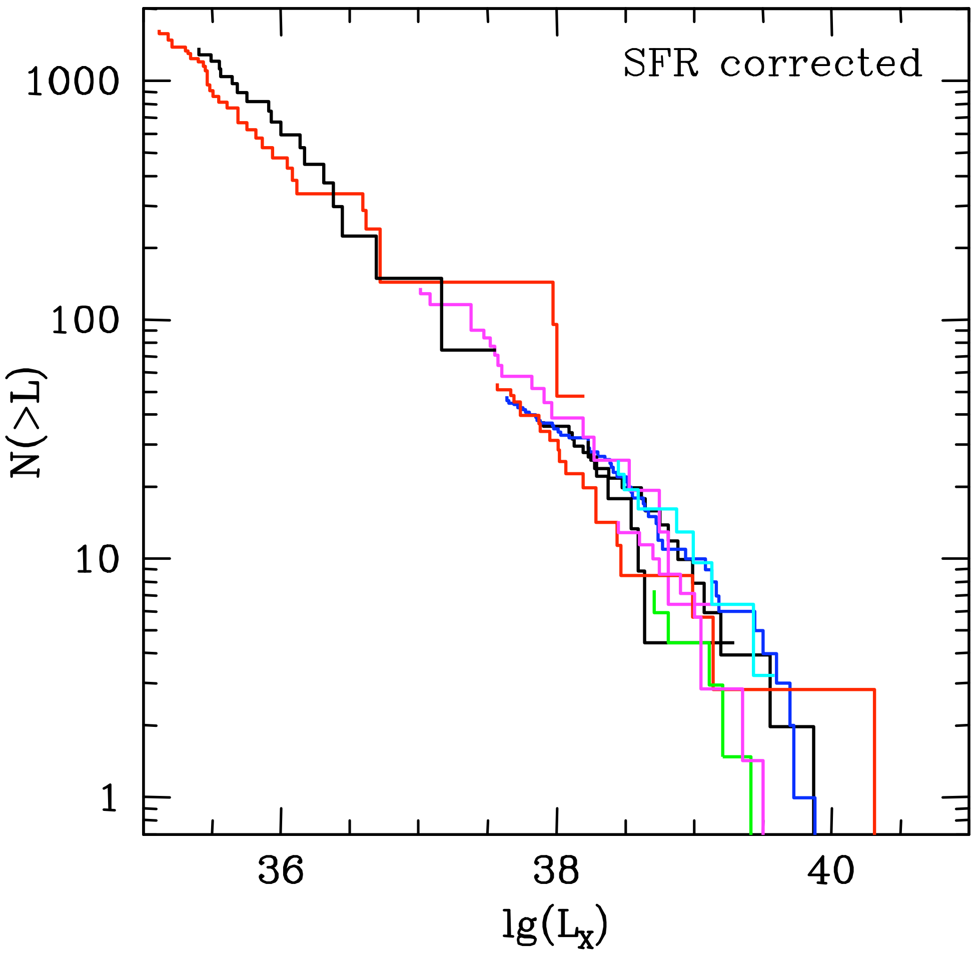


SFR~0.15-7 M_{sun}/yr

HMXBs

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

SFR~0.15-7 M_{sun}/yr

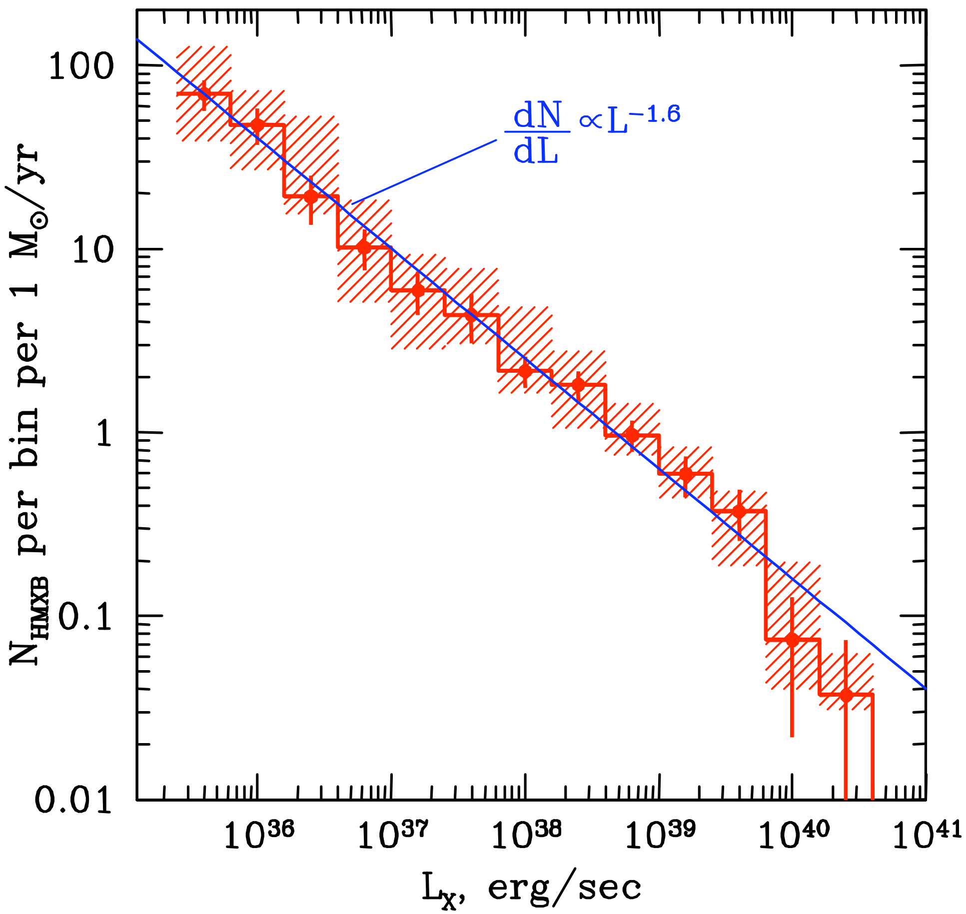


Universal XLF of HMXBs

- constant shape, normalization ~ SFR

$$\frac{dN}{dL_{38}} = 3.3 \times SFR \times L_{38}^{-1.6}$$

- cut-off @ $\log(L_x)$~40.5



HMXB XLF & IMF slope

- accretion of radiation pressure driven stellar wind

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

more accurate consideration (Bondi accr. etc):

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

$$\frac{dN}{dL_x} = \frac{dN}{dM_*} \times \frac{dM_*}{dL_x} \Rightarrow \alpha_{IMF} = 2.5 \times \alpha_{XLF} + 1.2$$

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

$$\alpha_{XLF} = 1.6 \pm 0.15 \Rightarrow \underline{\alpha_{IMF} = 2.5 \pm 0.3} \quad (\text{Salpeter}: \ \alpha_{IMF} = 2.35)$$

Formation of X-ray binaries

Abundance of HMXBs

number of HMXBs:

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

- **number of HMXB** (N_{HMXB})
- **birth rate of compact objects** ($\dot{N}_*$)
- **HMXB fraction** (f_{HMXB})
- **duration of HMXB phase** (τ_{HMXB})

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

Abundance of HMXBs

number of HMXBs:

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

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

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

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

Abundance of HMXBs

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

O,B binaries: τ_{HMXB}~10^4-10^5 yrs

X/Be binaries: τ_{HMXB}~10^5-10^6 (?) yrs

$$f_{HMXB} \geq 0.12 \times \left(\frac{\tau_{HMXB}}{0.5 \text{ Myr}} \right)^{-1}$$

Abundance of LMXBs

Per 10^{10} M_{sun}:

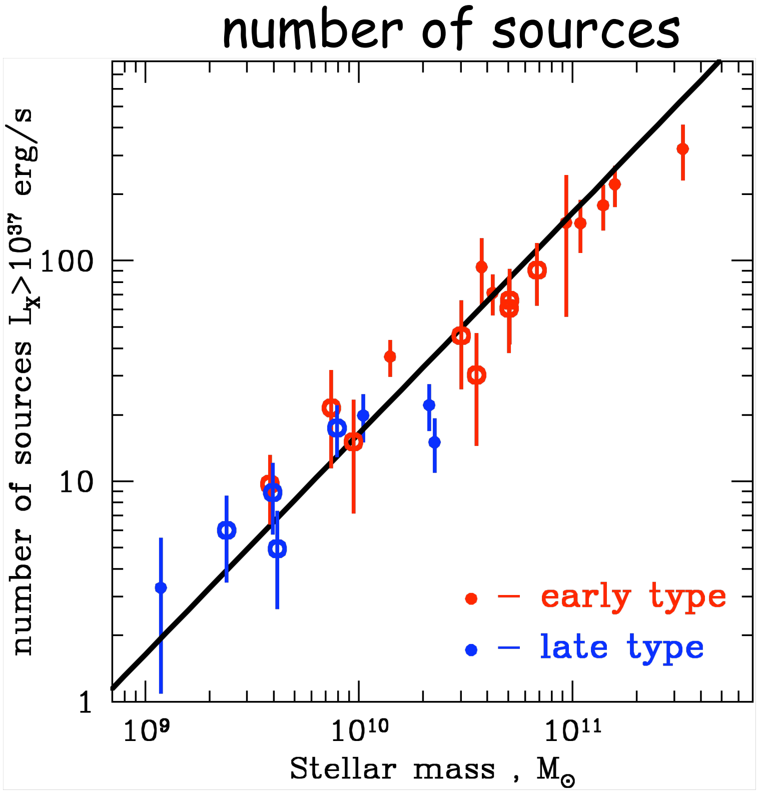
Salpeter IMF: ~$7.4 \cdot 10^7$ BH & NS

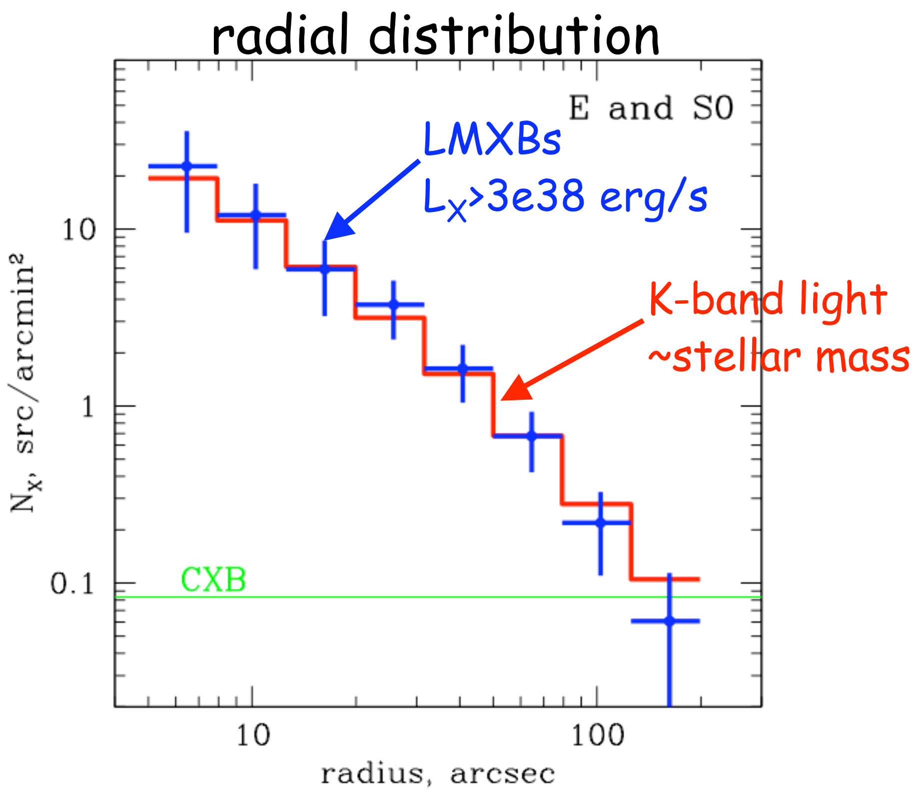
LMXB-M_{star} relation: $N_{LMXB}(L_X>10^{35})$~50 LMXBs

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

Dynamical formation of LMXBs in dense stellar environment.

LMXB ∝ stellar mass



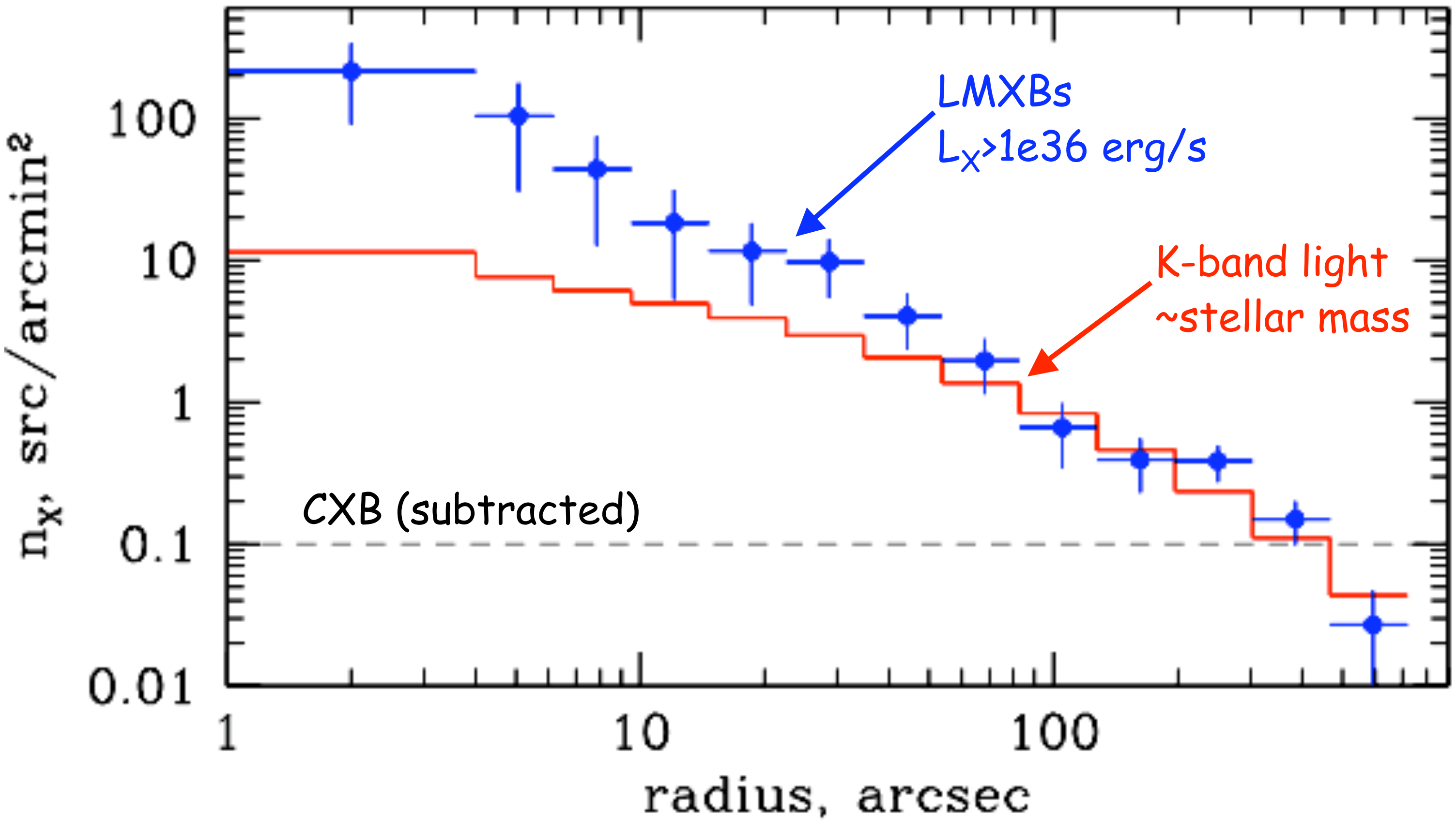


BUT: Globular clusters in the MW

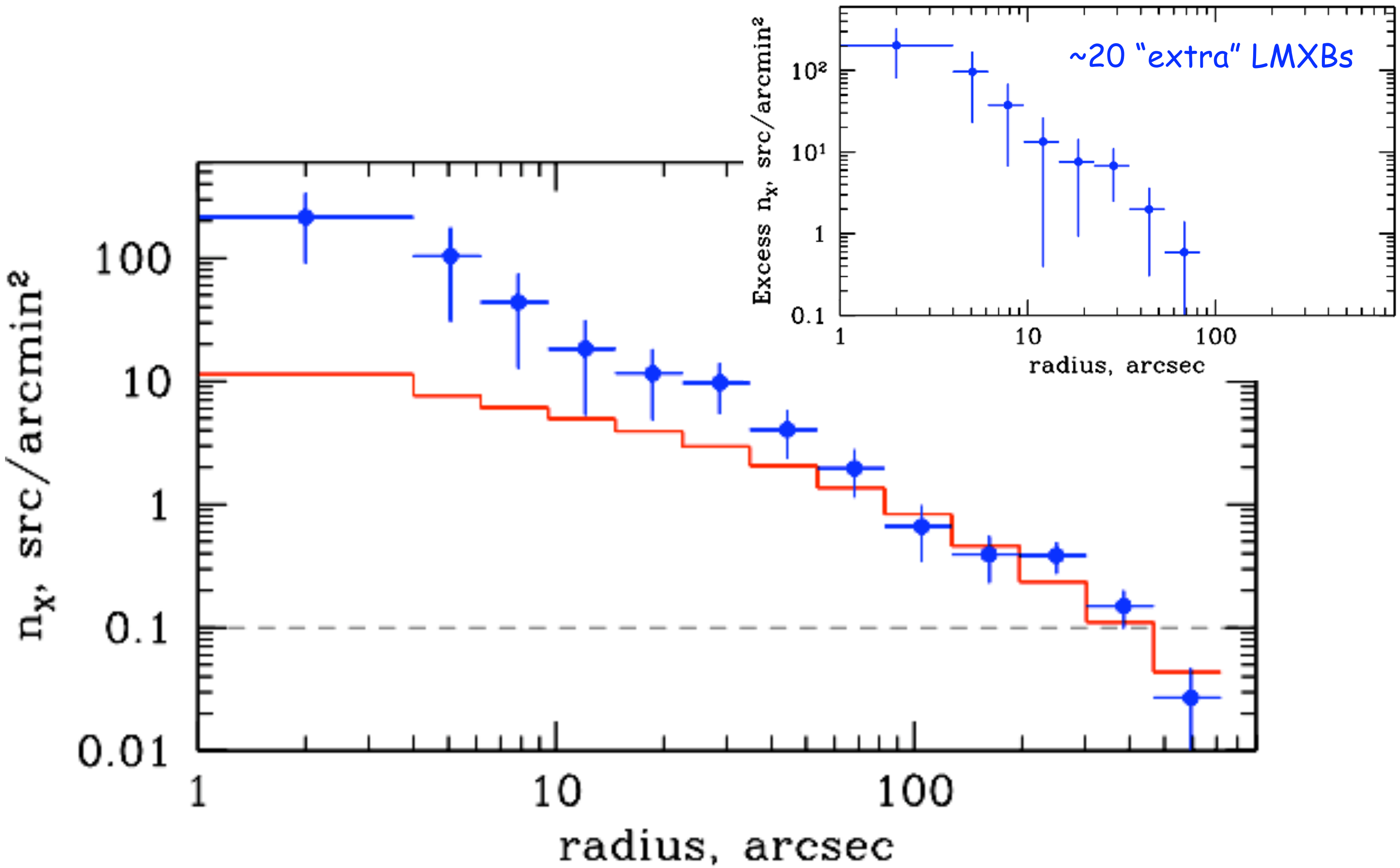
	total mass	N_{LMXB}	specific frequency
Globular clusters	$\sim 10^7$ Msun	13	**1 per $\sim 10^6$ M_{sun}**
Galaxy	$5 \cdot 10^{10}$ M_{sun}	~200	**1 per $\sim 10^8$ M_{sun}**

Clark 1975; Katz 1975; Fabian et al. 1975

M31, radial profile



M31, radial profile



What it takes to form a binary:

- binary is a bound system: $$E_{tot} = -\frac{GM_1M_2}{2a} < 0$$
- unbound NS(BH) + normal star: $$E_{tot} = +\frac{\mu v_{rel}^2}{2} > 0$$
- dissipation mechanism is needed

Possibilities:

- **tidal capture** (MS + NS -> LMXB)
- collisions with **red giants** (RG + NS -> UCXB)
- **exchange** reactions (primordial binary + NS -> LMXB)

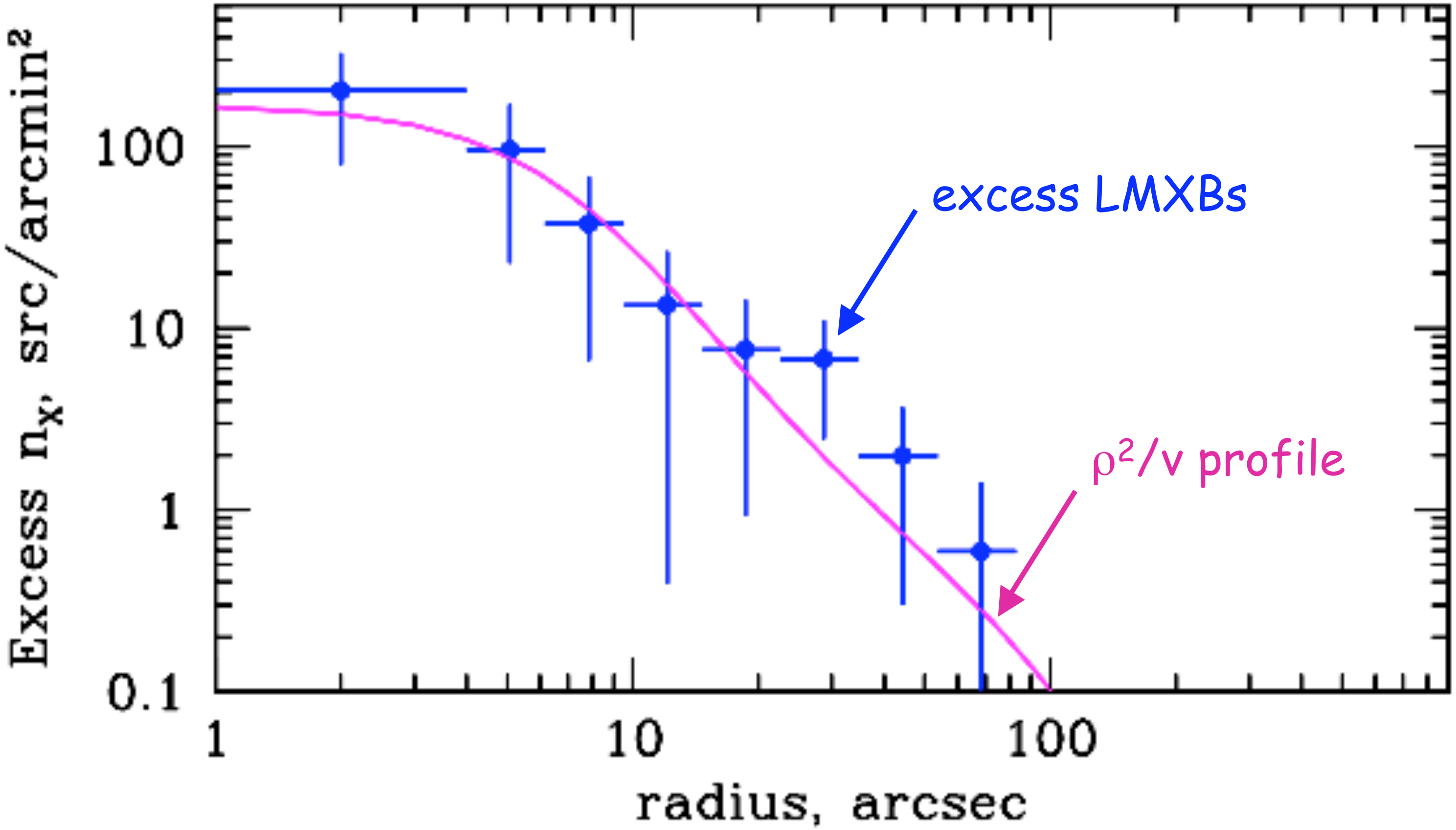
- crossection is enhanced by **gravitational focusing**

$$\sigma = \pi d^2 \left(1 + \frac{2G(m+M)}{\mathrm{v}^2 d}\right) \approx \pi d \frac{2G(m+M)}{\mathrm{v}^2}$$

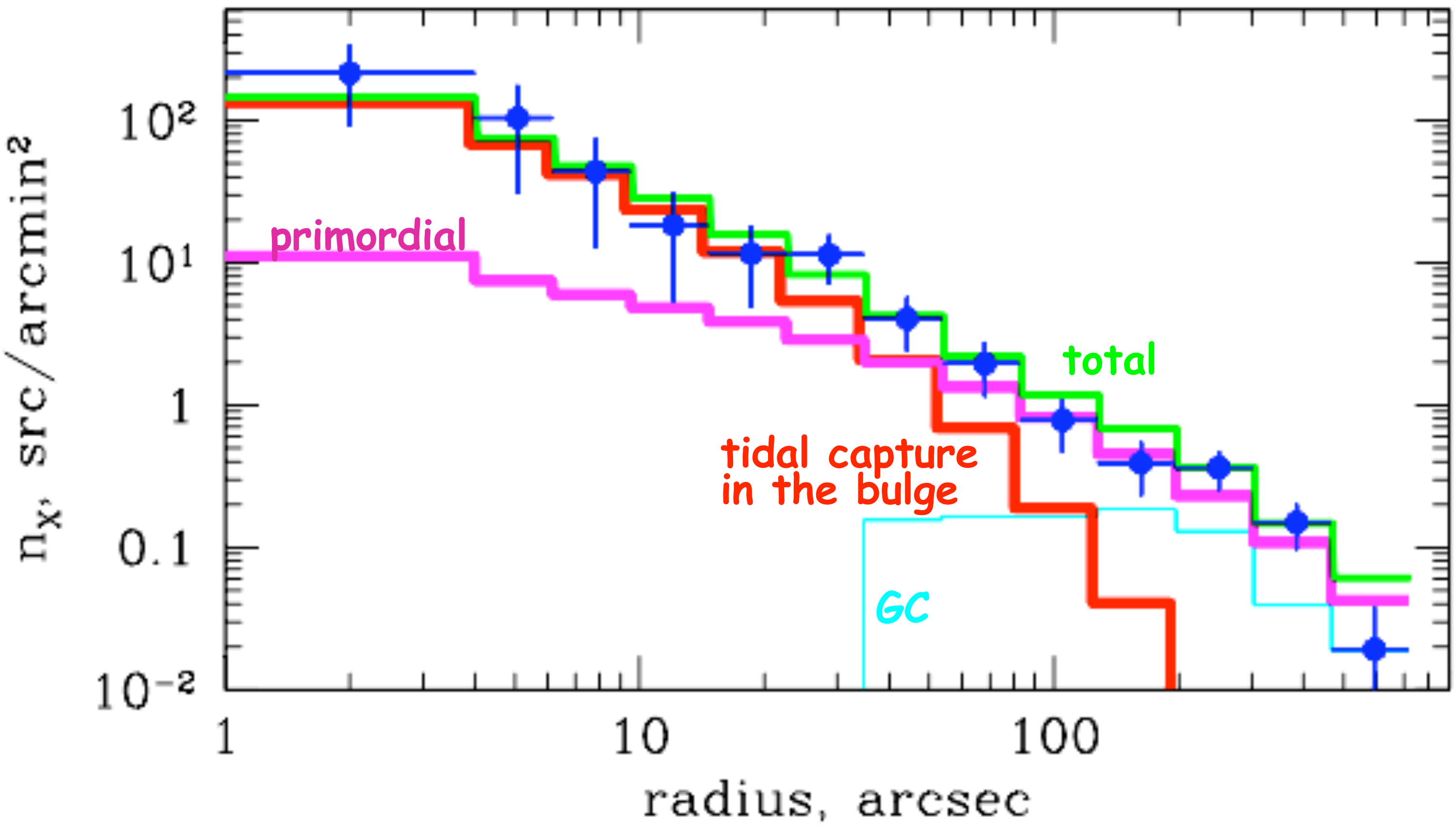
- **encounter rate**

$$\Gamma = n_{NS} n \sigma \mathrm{v} \propto \frac{\rho^2}{\mathrm{v}}$$

Radial distribution

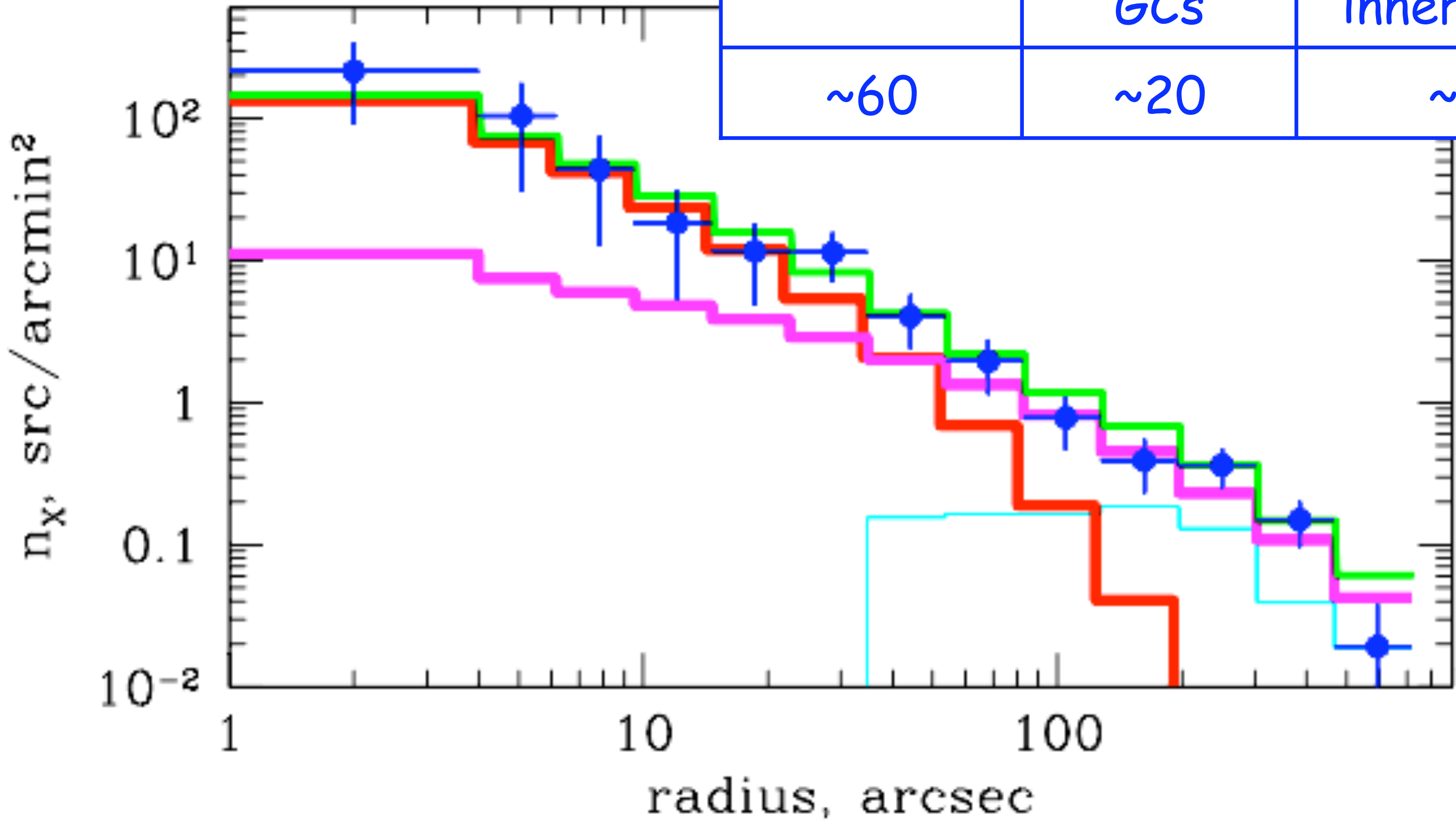


LMXBs in M31: overall picture



LMXBs in M31: overall picture

primordial	dynamical interaction	
	GCs	inner bulge
~60	~20	~20



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