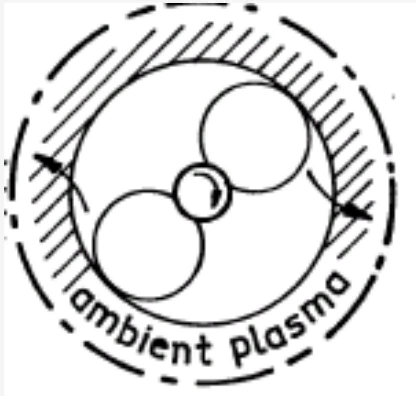
Population of High-Mass X-ray Binaries in the Milky Way. INTEGRAL Legacy Survey

Lutovinov A.

Revnivtsev M., Tsygankov S., Krivonos R.

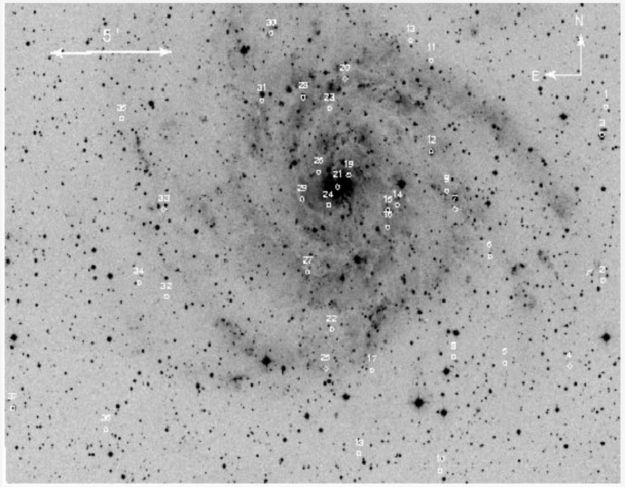
Understanding HMXB population:

1)properties of compact objects (NS magn. field, magnetosphere interactions, spin period, etc)



2) Formation and evolution of binaries

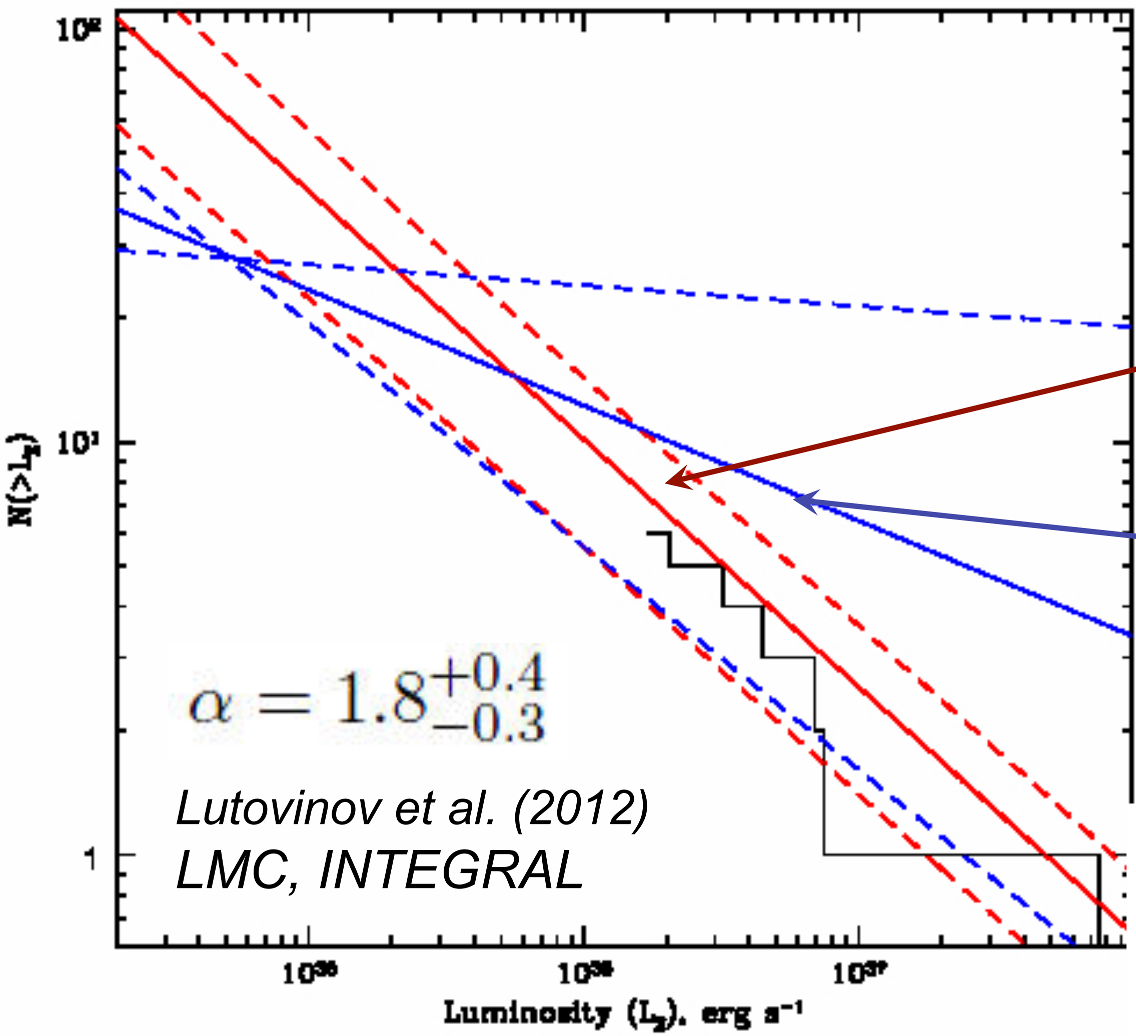
3) Application for cosmological surveys (distant galaxies, contribution of HMXBs to observed X-ray luminosities)



$$\frac{dN}{dL} \propto \mathrm{SFR} \times L^{-\alpha}$$

Universal form

a~1.6 *Grimm et al. (2003)*
Postnov (2003)



$$\alpha = 1.8^{+0.4}_{-0.3}$$

Lutovinov et al. (2012)
LMC, INTEGRAL

$$\alpha = 1.28^{+0.26}_{-0.23}$$

Shtykovskiy, Gilfanov (2005)
LMC, XMM-Newton

Indication of a flatness of LFat low luminosities

Shtykovskiy, Gilfanov (2007)
SMC, XMM-Newton

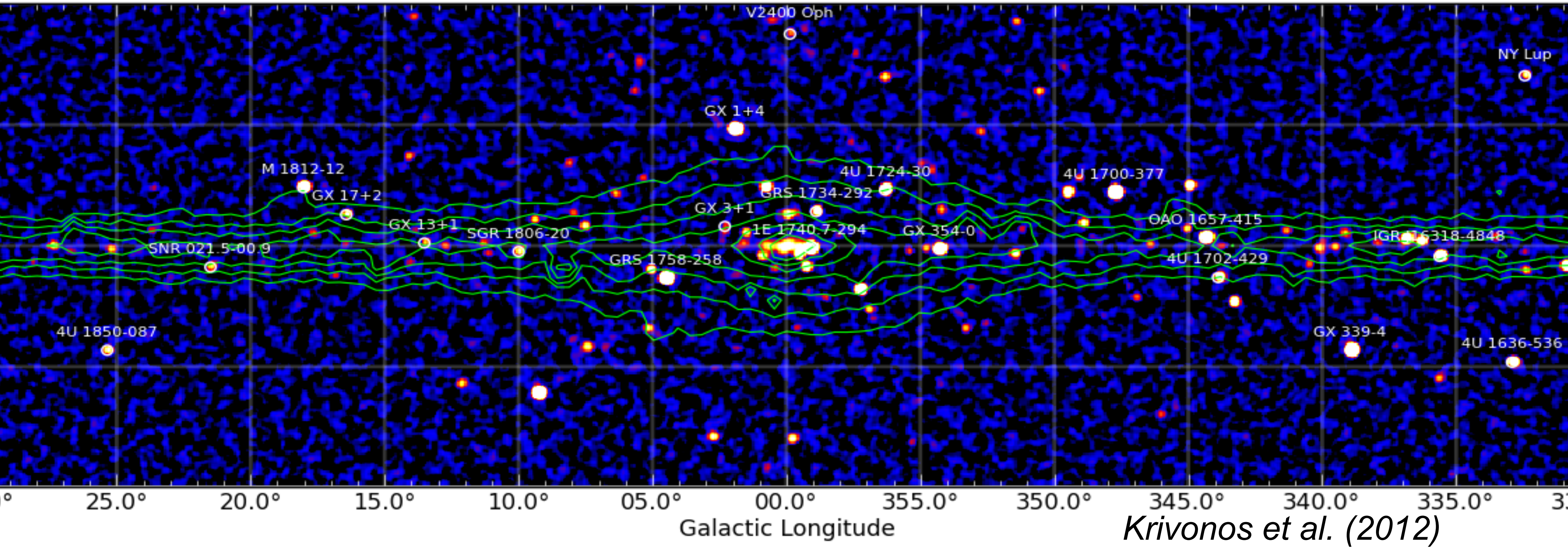
Is the LF of HMXBs really universal?
Only study of MW can help to answer

9 years Galactic plane survey with INTEGRAL

Dec 2002 – Jan 2011,
total exposure 132 Msec,
peak sensitivity in 17-60 keV
2.9×10^{-12} erg/s/cm^2 (0.2 mCrab)

Total – 402 sources on the average map, galactic – 252 (108 LMXBs, 75 HMXBs, 36 CVs), Extragalactic – 115 (112 AGNs, 3 GCs)

Identification completeness – 91% thanks to efforts of number of groups: *Masetti+, Burenin+, Bikmaev+, Nespoli+, Chaty+, Bodaghee+ Rodrigues+, Tomsick+, Landi+, Malizia+, and many others*



Krivonos et al. (2012)

Complete, flux-limited sample of HMXBs

|b|<5º

Only sources with known distances and spectral class

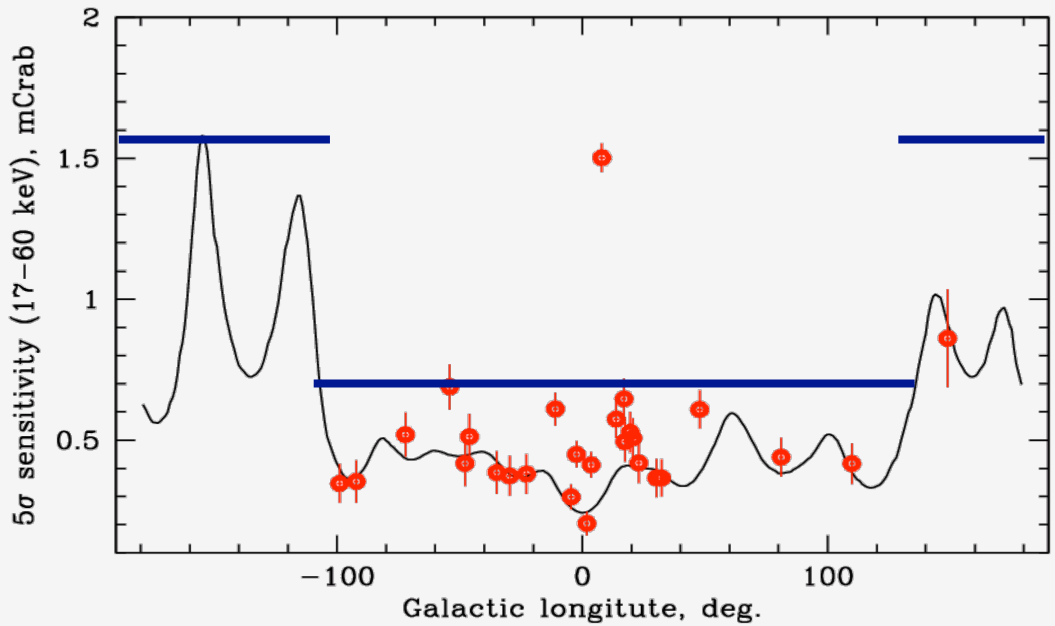
Exclude BH, gamma-loud binaries (Cyg X-1, Cyg X-3, LSI +61 303, etc)

Exclude transient sources

criteria

F_p/F_{mean} > 0.5

Flux limited 0.7 mCrab (10^{-11} erg/s/cm^2)



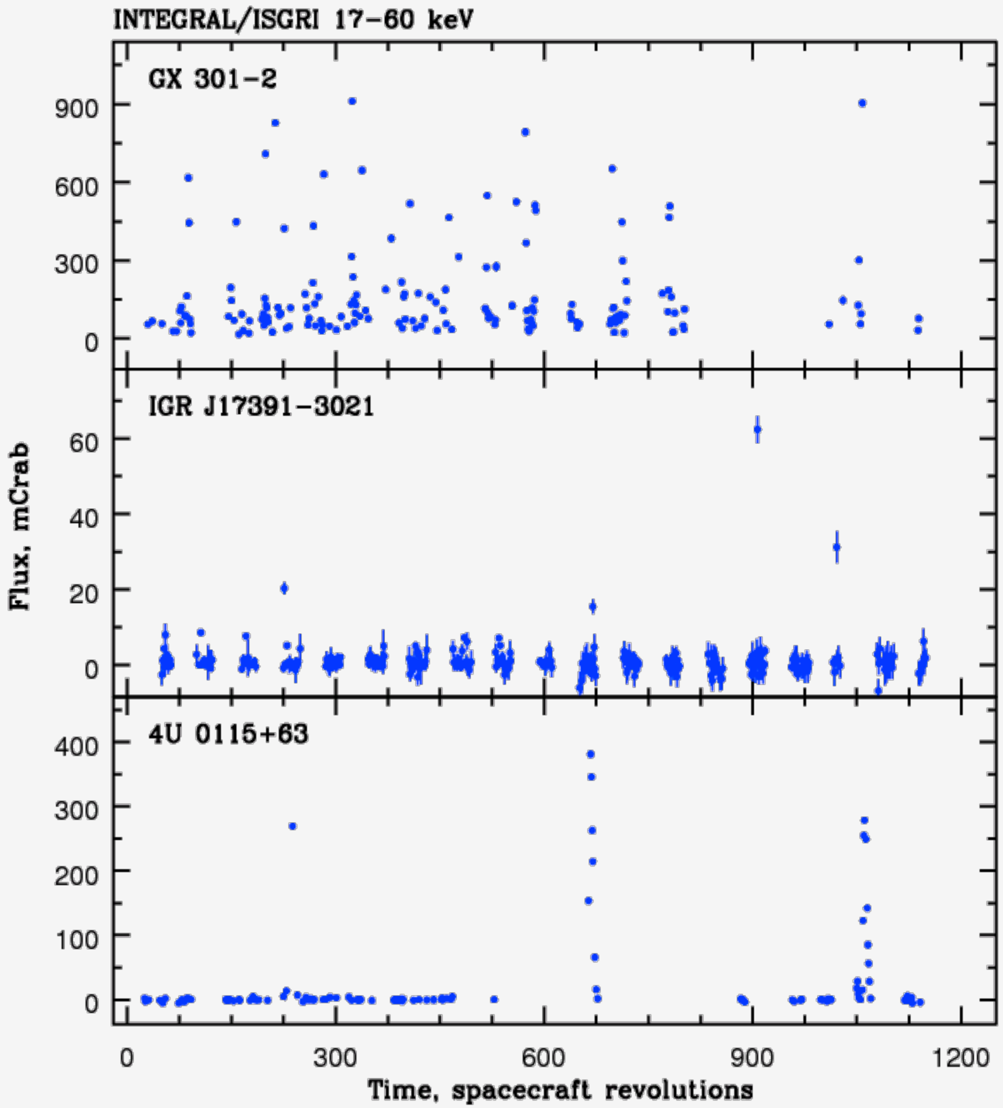
Final sample includes 37 sources

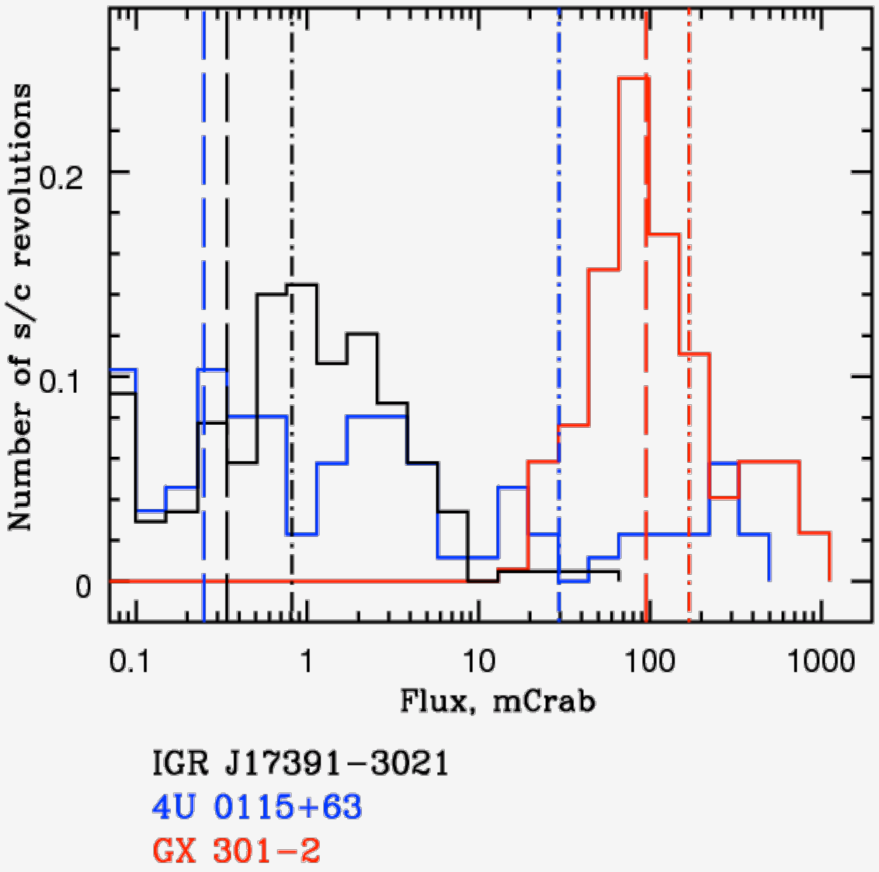
Wind-fed binaries with NS

Exclude transient sources

criteria

$\mathbf{F_p/F_{mean} > 0.5}$

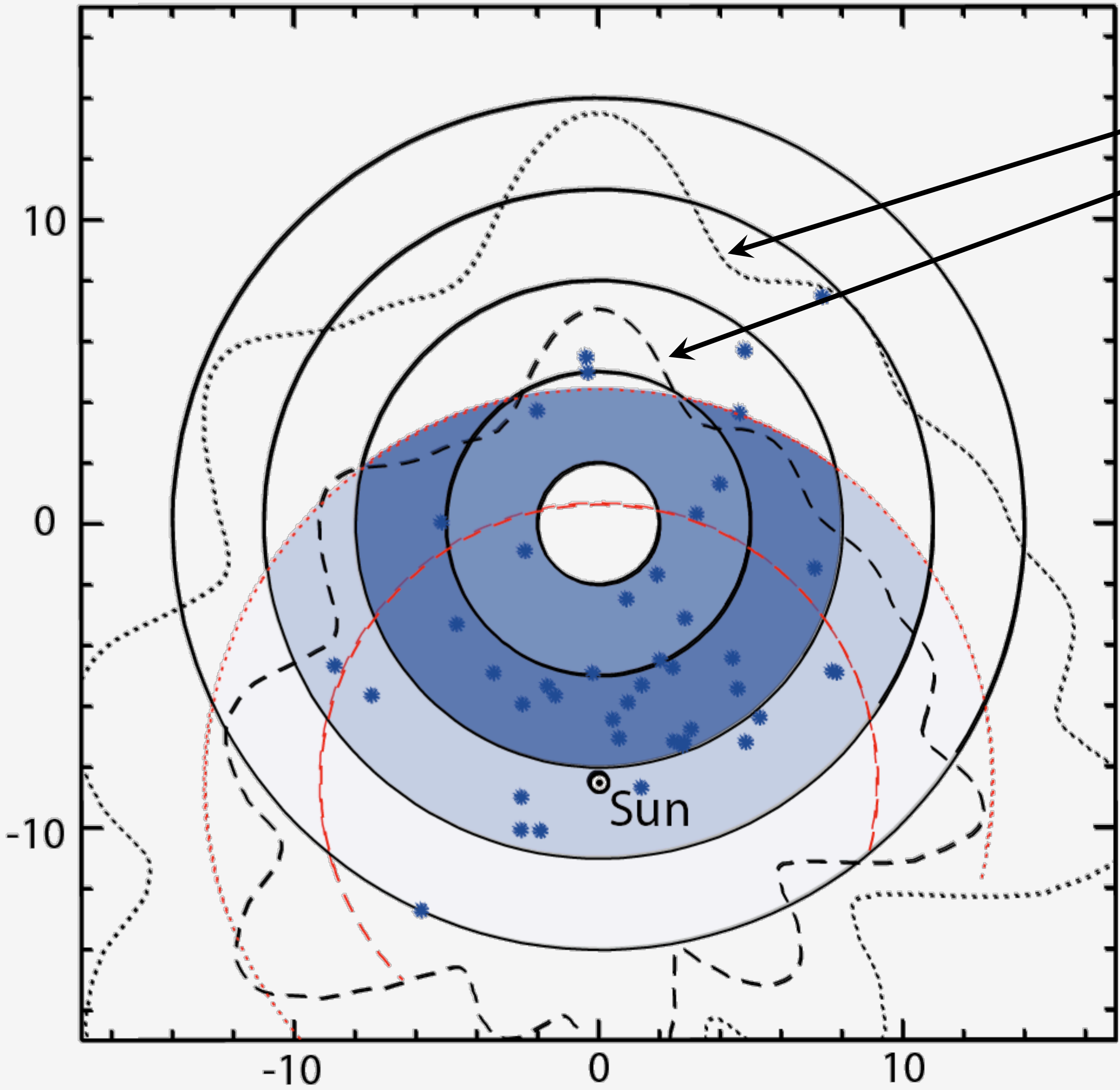




Name	l, deg	b, deg	$L_{X,17-60keV}$, 10^{35} erg s^{-1}	Distance, kpc	P_{orb}, days	Class
Vela X-1	-96.93	3.93	5.868 ± 0.003	1.40	8.960	B0.5Ib
3U 1022-55	-74.64	1.49	0.311 ± 0.033	5.00	0.000	B0 III-Ve
Cen X-3	-67.90	0.33	24.51 ± 0.041	5.70	2.090	O6-7II-III
IGR J11305-6256	-66.05	-1.48	0.299 ± 0.012	3.00	0.000	B0IIIe
IGR J11435-6109	-65.12	0.68	3.165 ± 0.097	8.60	52.460	B2III or B0V
A 1145.1-6141	-64.50	-0.02	20.14 ± 0.095	8.50	14.400	B2 Iae
X 1145-619	-64.38	-0.24	0.271 ± 0.012	3.10	187.500	B1Ve
1ES 1210-646	-61.13	-2.31	0.105 ± 0.011	2.80	0.000	B2V
GX 301-2	-59.90	-0.03	31.53 ± 0.016	3.50	41.500	B1Ia+
1RXP J130159.6-635806	-55.91	-1.12	0.765 ± 0.041	5.50	0.000	O9V or B1III
4U 1416-62	-46.98	-1.57	0.438 ± 0.048	6.00	42.200	B1Ve
IGR J14331-61[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4U 1538-522						
IGR J16207-51[illegible]						
!!! IGR J16207-[illegible]						
IGR J16195-49[illegible]						
IGR J16283-48[illegible]						
IGR J16318-48[illegible]						
IGR J16320-47[illegible]						
AX J163904-46[illegible]						
IGR J16418-45[illegible]						
IGR J16465-45[illegible]						
!!! IGR J16465-[illegible]						
IGR J16479-45[illegible]						
!!! IGR J16479-[illegible]						
IGR J16493-43[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
OAO 1657-415	-15.63	0.32	48.72 ± 0.058	7.10	10.400	B0-6sg
4U 1700-377	-12.24	2.17	12.98 ± 0.004	2.12	3.410	O6.5Iaf+
EXO 1722-363	-8.50	-0.35	3.996 ± 0.032	6.10	9.740	B0-B1 Ia
AX J1749.1-2733	1.58	0.06	3.285 ± 0.128	13.50	0.000	B1-3
AX J1749.2-2725	1.70	0.11	2.760 ± 0.137	14.00	0.000	B3
IGR J17544-2619	3.24	-0.32	0.130 ± 0.010	3.60	4.930	O9Ib
IGR J18027-2016	9.43	1.03	10.24 ± 0.140	12.40	4.600	OBsg
!!! IGR J18027-2016	9.43	1.03	10.24 ± 0.140	12.40	4.600	B1b
IGR J18214-1318	17.67	0.48	1.377 ± 0.076	8.00	0.000	O9I
IGR J18410-0535	26.78	-0.23	0.113 ± 0.011	3.20	0.000	B1Ib
AX J1845.0-0433	28.14	-0.66	0.255 ± 0.015	3.60	0.000	O9.5I
XTE J1855-026	31.07	-2.09	14.44 ± 0.114	10.00	6.070	B0 Iaep
X 1908+075	41.89	-0.81	9.658 ± 0.047	7.00	4.400	O7.5-9.5sg
4U 1907+097	43.74	0.47	4.389 ± 0.024	5.00	8.380	O8-9Ia
IGR J19140+0951	44.29	-0.46	1.687 ± 0.012	3.60	13.560	B1I
!!! IGR J19140+0951	44.29	-0.46	1.687 ± 0.012	3.60	13.560	B0.5I
SWIFT J2000.6+3210	68.98	1.13	2.108 ± 0.092	8.00	0.000	early BV or mid BIII
4U 2206+543	100.60	-1.10	0.852 ± 0.010	2.60	9.570	O9.5V
IGR J00370+6122	121.21	-1.42	0.084 ± 0.010	3.00	15.665	BN0.5II-IIIb
1A 0114+650	125.71	2.55	6.642 ± 0.063	7.20	11.600	B1Ia
R J0146.9+6121	129.52	-0.80	0.096 ± 0.010	2.50	0.000	B1Ve

Majority of sources do not have Be companions

INTEGRAL view through the whole Galaxy



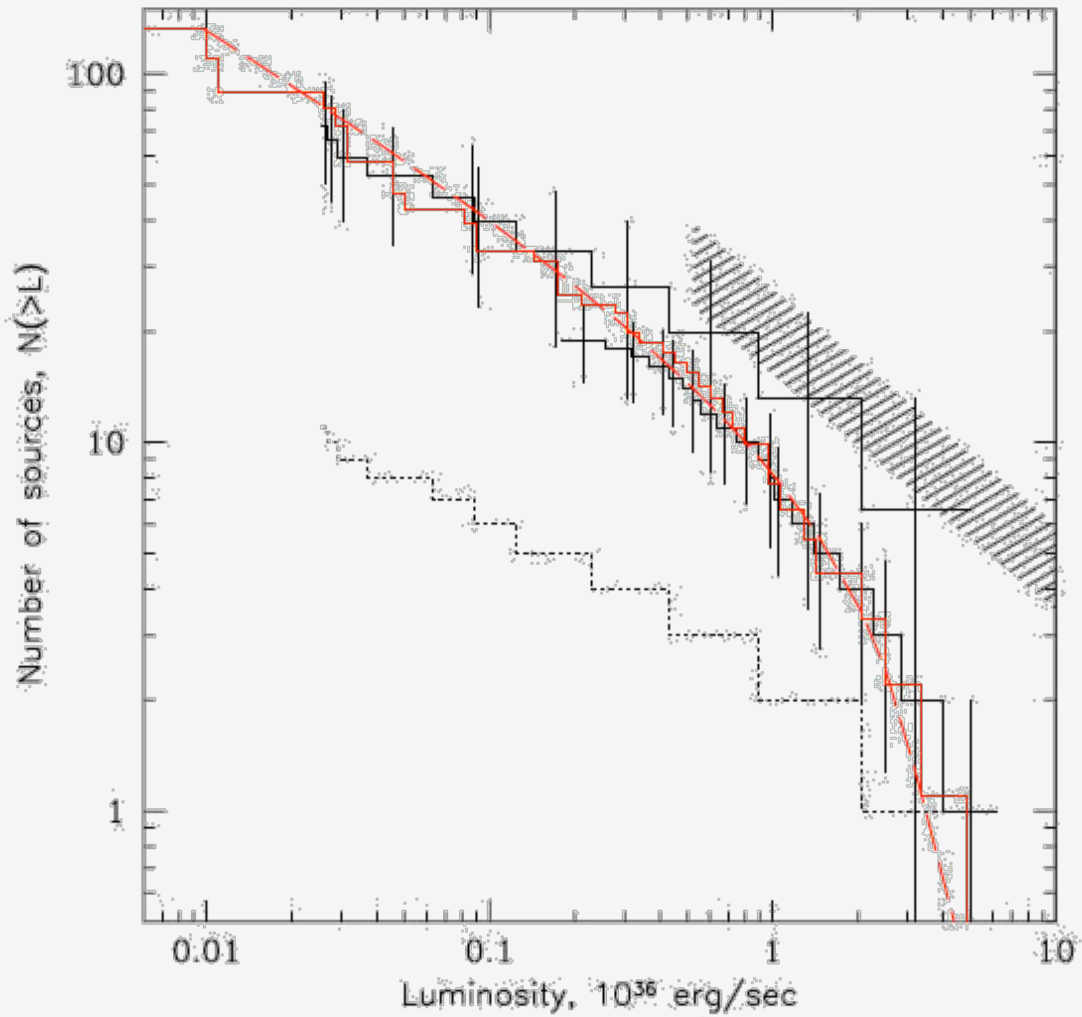
Real sensitivity:
2×10^{35} erg/s
10^{35} erg/s

Limited flux
0.7 mCrab
(10^{-11} erg/s/cm^2)
2×10^{35} erg/s
10^{35} erg/s

The Galaxy was divided into 5 rings
0-2,2-5,5-8,
8-11 and 11-14 kpc

Key tasks: 1) LF and 2) Surface density

Luminosity Function



First step (volume limited):

The available luminosity range of HMXBs was divided into two intervals – above 2x10^{35} erg/s (for the limit of our survey 10^{-11} erg/s/cm^2 this sample is complete up to 13 kpc from the Sun) and above 2x10^{34} erg/s (complete up to 4.1 kpc from the Sun). For both luminosity intervals we calculate luminosity distribution of sources (ML).

$$\gamma_{\rm faint} = 1.49 \pm 0.21$$

$$\gamma_{\rm bright} = 2.0 \pm 0.3$$

Renormalization both samples, using calculated density distribution

Second step: the whole sample

$$\frac{dN}{dL} = \begin{cases} A_j (L/L_*)^{-\alpha_1} & \text{if } L < L_* \\ A_j (L/L_*)^{-\alpha_2} & \text{if } L > L_* \end{cases}$$

$$C = 2\sum_j \left(\int \phi(L) S_{\max,j}(L) dL - \sum_{i=1}^{N_j} \ln\left[\phi(L_{i,j}) S_{\max,j}(L_{i,j})\right] \right)$$

$$\phi(L) = dN/dL$$

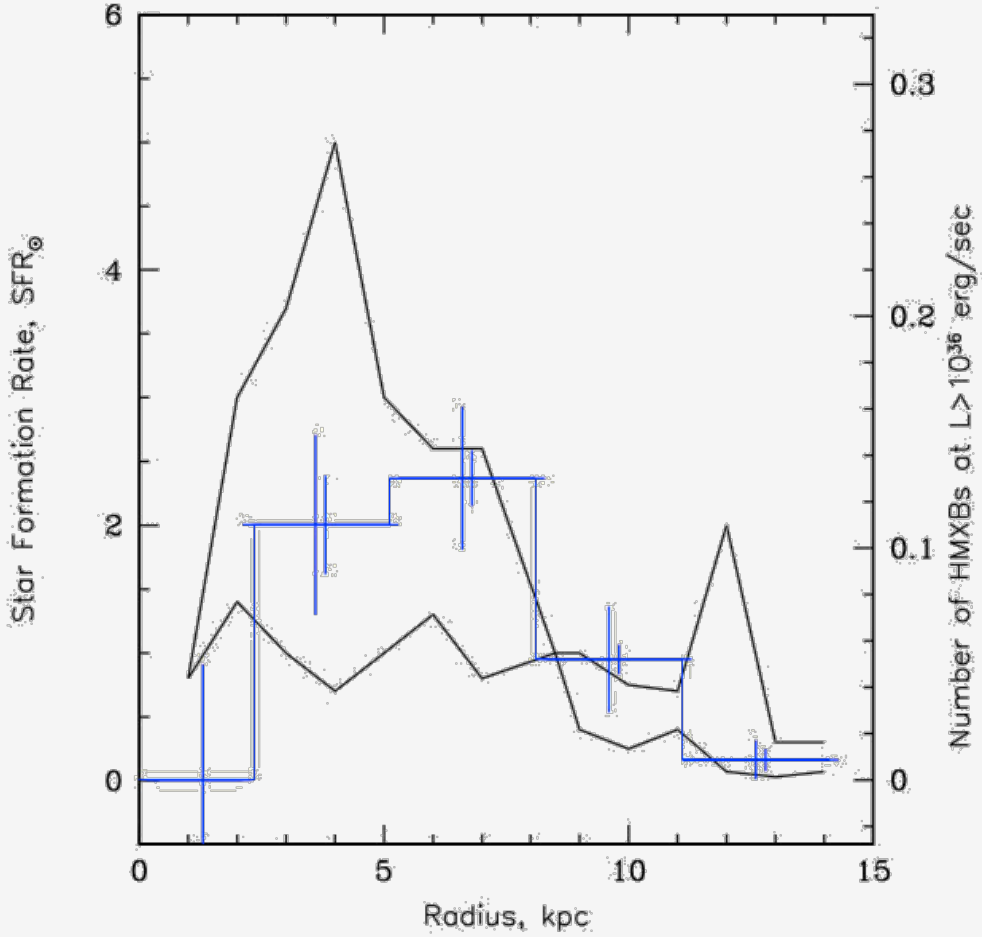
Cash (1979)

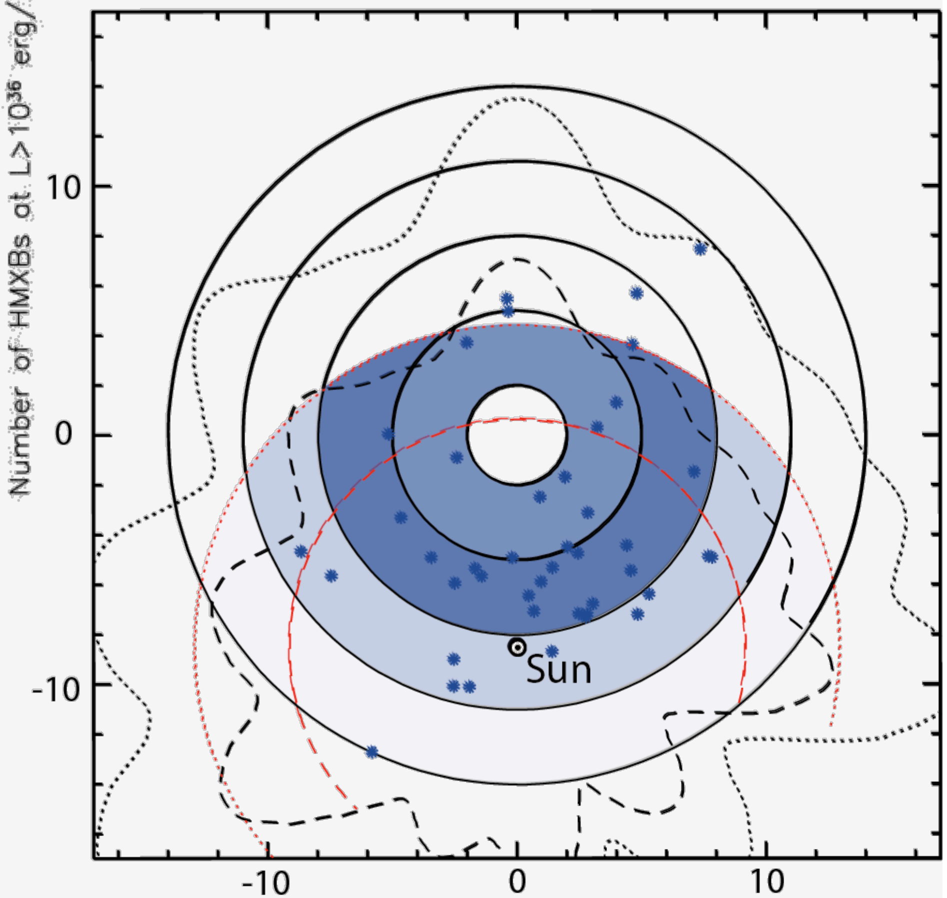
Table 2. Best fit parameters of the HMXB luminosity function

Parameter	Value and 1σ error
α_1	$1.43^{+0.11}_{-0.15}$(stat.)± 0.06(syst.)
α_2	> 2.2
L_*	$2.5^{+2.5}_{-1.5}$(stat.)± 1 (syst.)
$R_{\rm GC}$,kpc	$N(L > 10^{35}$erg/sec$)$/kpc^2
0-2	0.0 ± 0.05(syst.)
2-5	$0.11^{+0.05}_{-0.04}$(stat.)± 0.02(syst.)
5-8	$0.13^{+0.04}_{-0.04}$(stat.)± 0.01(syst.)
8-11	$(5.2^{+2.4}_{-2.3}) \times 10^{-2}$(stat.)$\pm 6.5 \times 10^{-3}$(syst.)
11-14	$(8.8^{+10.5}_{-6.6}) \times 10^{-3}$(stat.)$\pm 4.8 \times 10^{-3}$(syst.)

Main uncertainty is due to poor knowledge of distances to sources.
We have varied around known values with assuming a Gaussian distribution with σ=20% of the source distance. -> Systematical uncertainty

HMXB density distribution vs SFR





Guesten & Mezger 1982; Lyne, Manchester, & Taylor 1985; Chiappini, Matteucci, & Romano 2001.

Vertical distribution of HMXBs

h≈85-90 пк

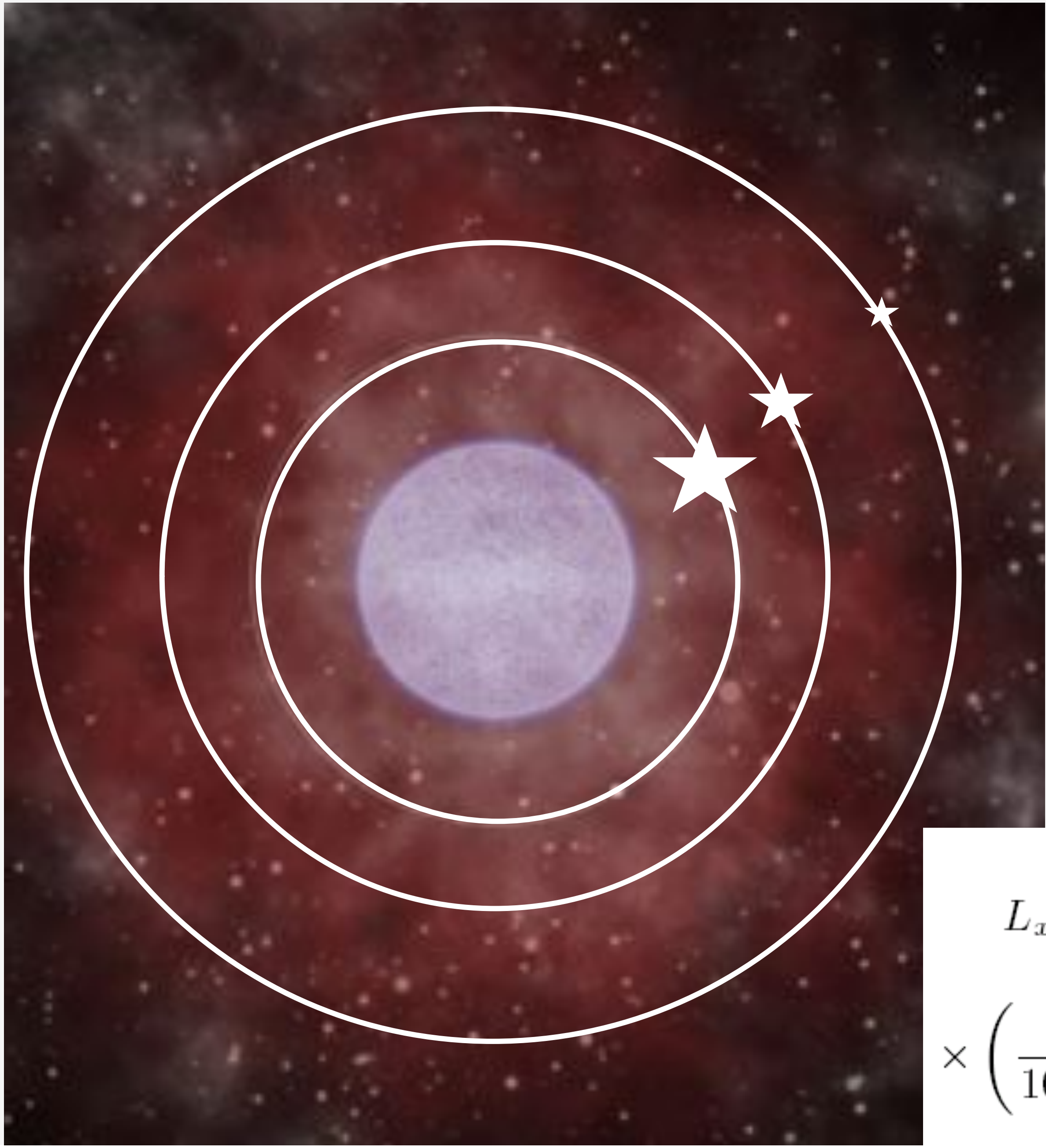
WR ~45 pc *(Conti & Vacca 1990)*
OB assiciations ~30 pc *(Bronfman et al. 2000)*
Open clusters ~50 pc *(Joshi 2005)*

Kinematic age

$$\tau \simeq 50\ \mathrm{pc}/\underbrace{(50-90)}_{\text{HMXB systemic velocity}}\ \mathrm{km}\,s^{-1} \simeq 0.5-1\ \mathrm{Myr}$$

(Kaper et al. 1997; Hutoff & Kaper 2002)

Simple model of wind-accreting NS



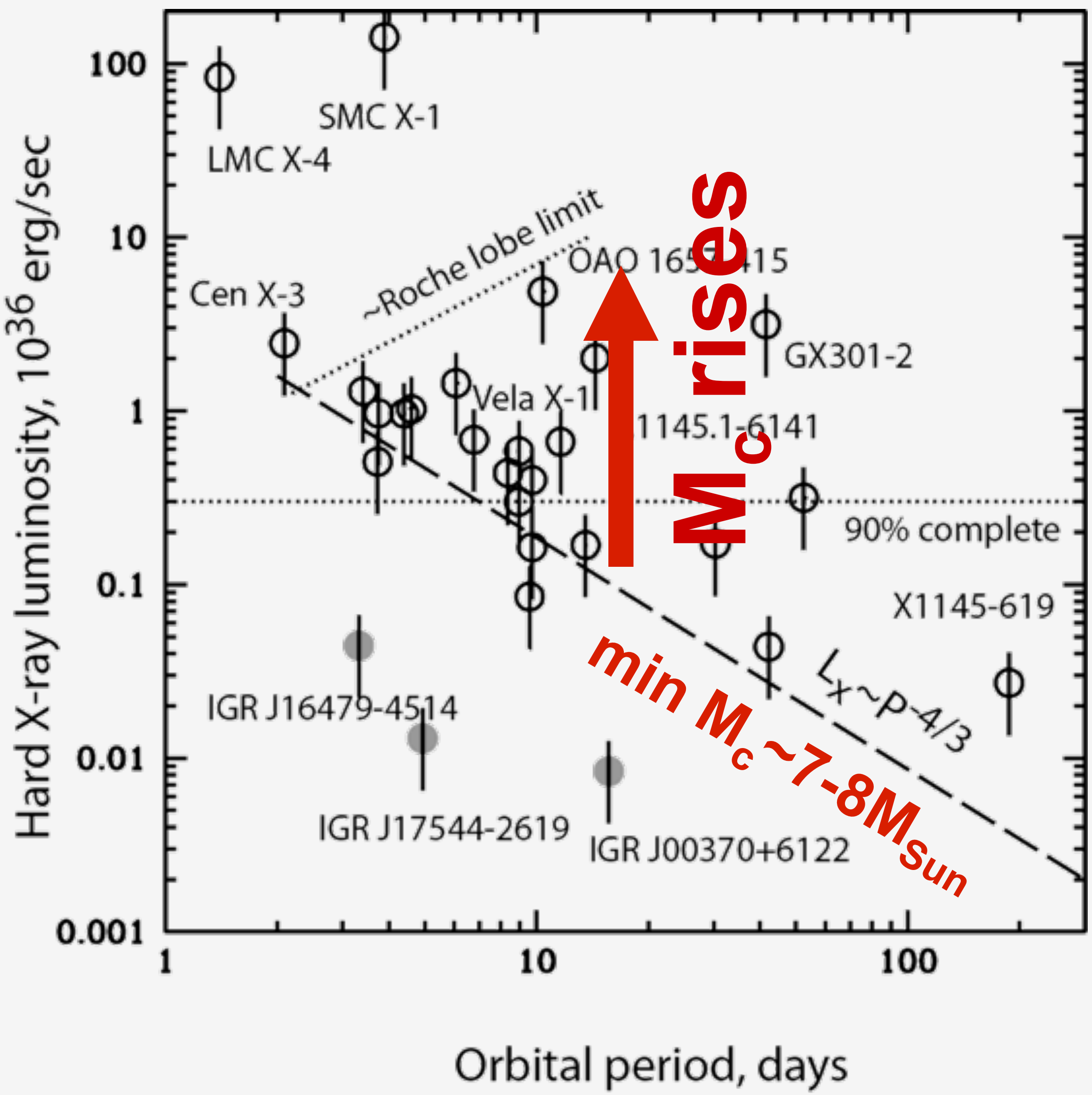
NS luminosity depends on:

Companion mass (Mdot_wind)

Orbital period

$$L_x \approx 5.4k \times 10^{35} \left(\frac{M_2}{10\ M_\odot}\right)^{2.76} \times$$
$$\times \left(\frac{a}{10\ R_\odot}\right)^{-2} \left(\frac{v_{\rm w}[1 - R_2/a]^{1/2}}{1000\ {\rm km}\ s^{-1}}\right)^{-5}$$

Formation and evolution



Our statistically complete flux-limited sample provides clues –

what determines the HMXB population

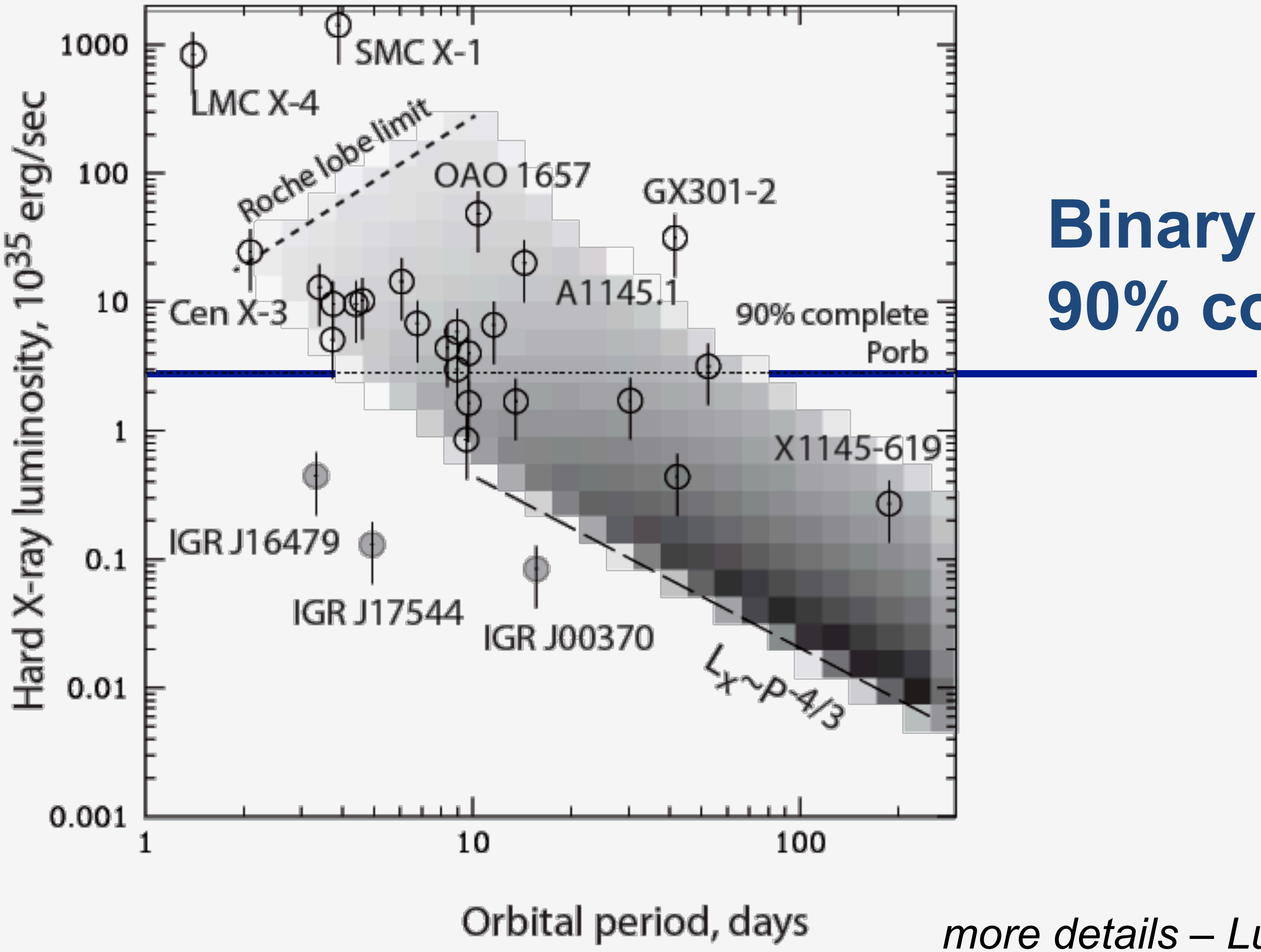
1)P_{orb} distribution

2)M_c distribution

$dN/dM_c \sim M_c^{-2.35}$ (Salpeter)

$dN/d\log P$ = const

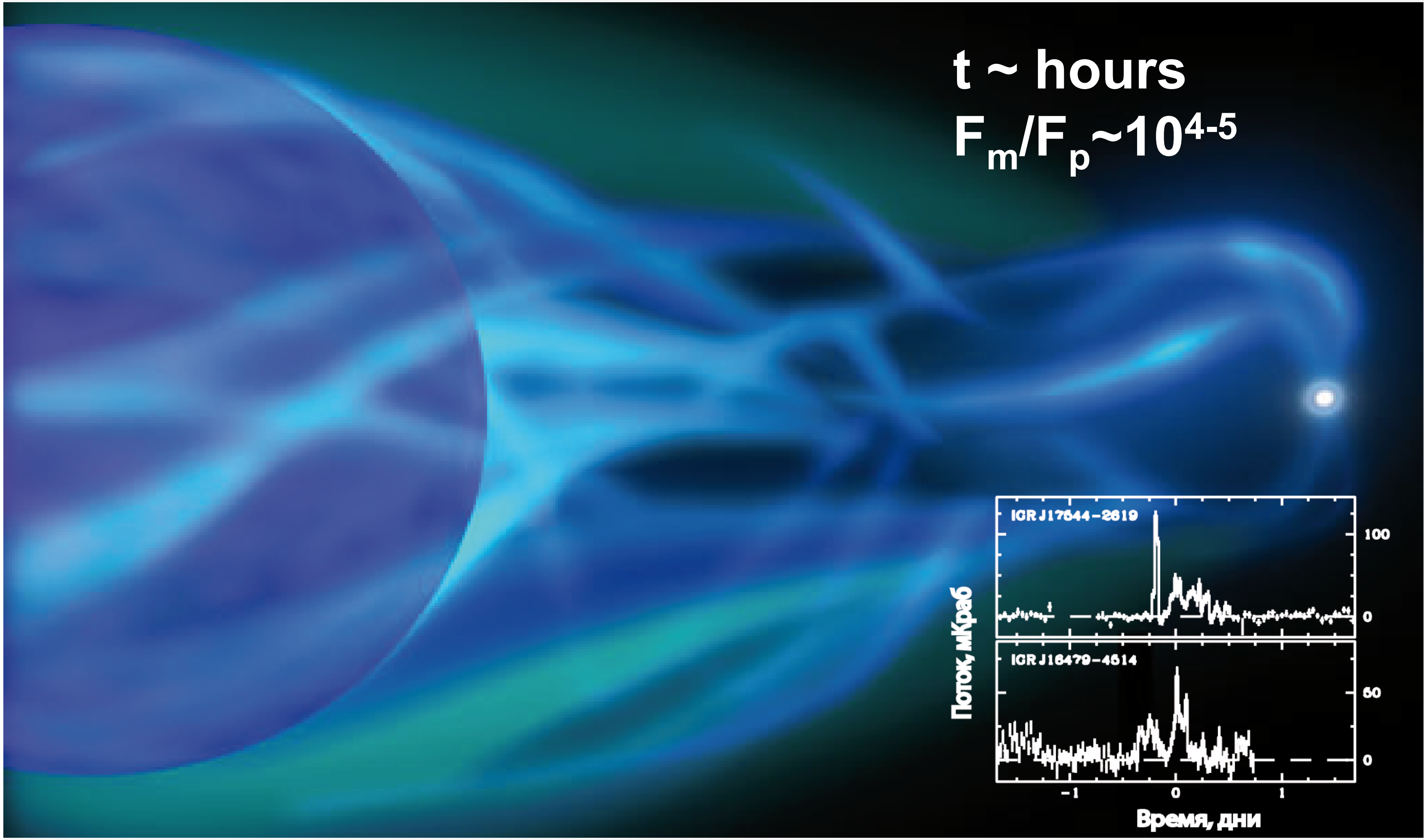
Similar analytic consideration *(Bhattacharia, Ghosh, 2012)*



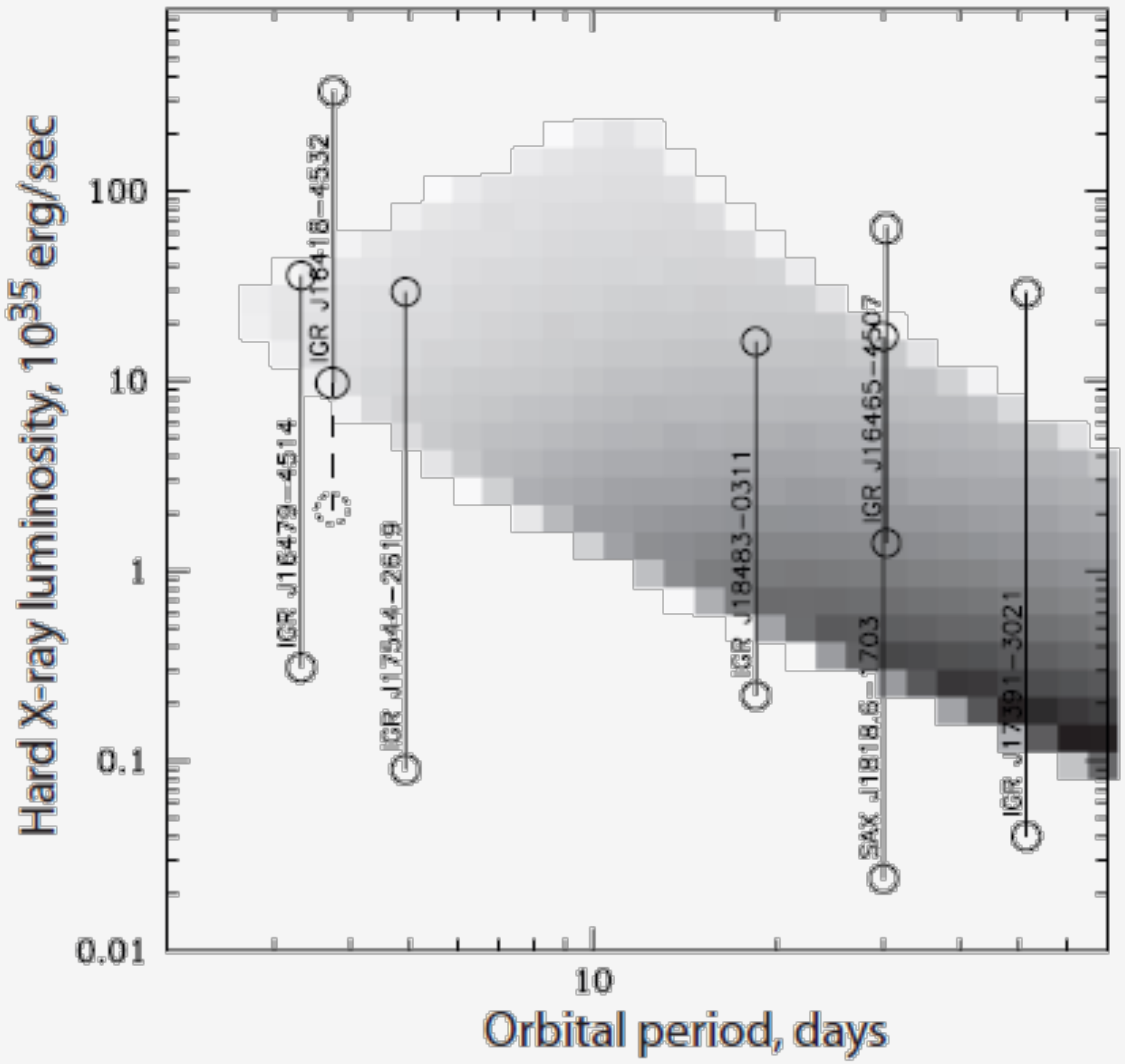
Binary parameters 90% complete here

more details – Lutovinov et al. (2012b)

SFXT (Supergiant Fast X-ray Transients)



SFXT (outbursts mechanisms)



~~Clumpy wind~~

~~(Walter et al. 2006, Sidoli et al. 2011)~~

Inhibition of the Accretion

(Grebenev & Sunyaev 2007, Bozzo et al. 2008)

Flaring activity due to transition from (stable) radiative cooling to (unstable) Compton cooling

(K.Postnov talk, L.Sidoli talk)

Surveys perspectives

[NuSTAR]

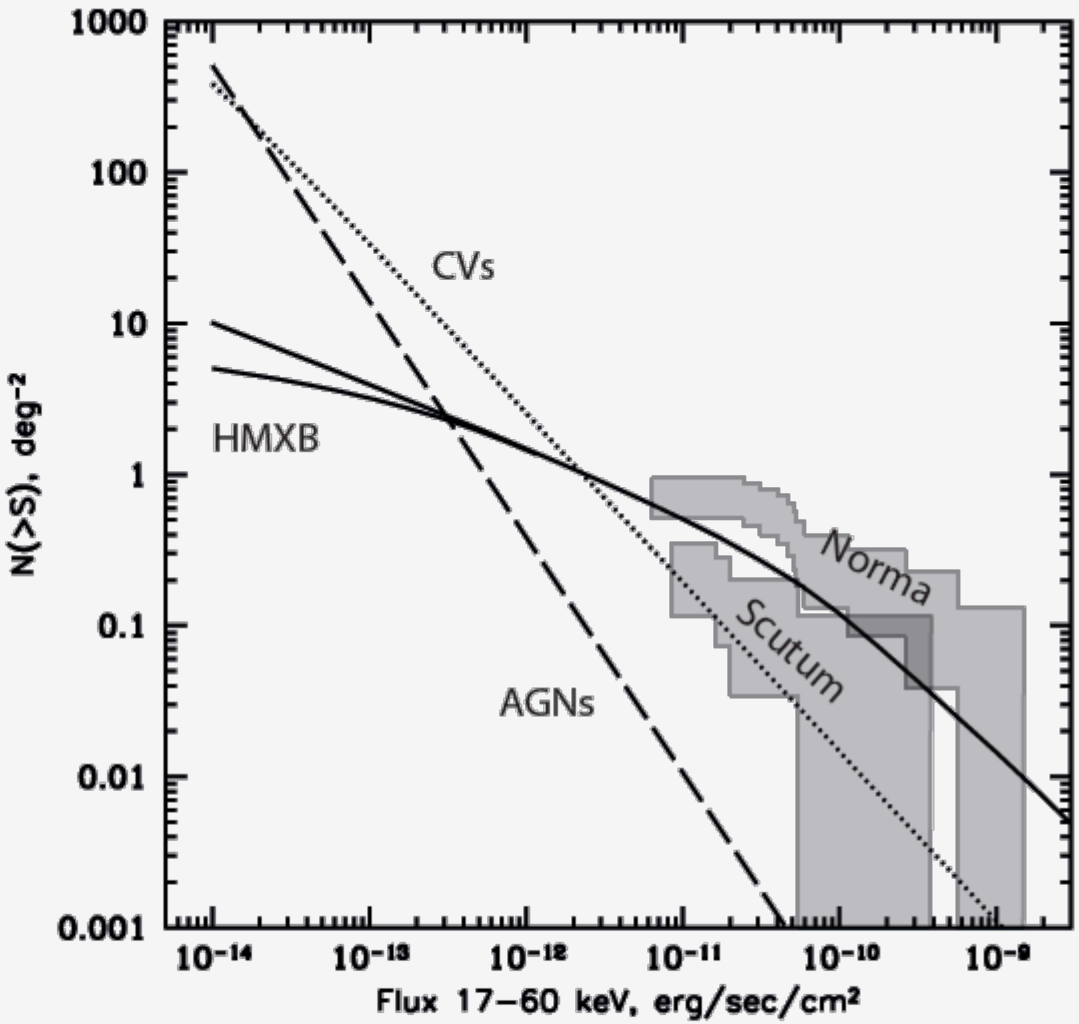
Deep over small area. Not large amount of HMXBs

[Spectrum XG]

Large area

1.18×10^{-13} erg/s/cm^2

130 persistent HMXB in MW



Conclusions

1)INTEGRAL Legacy: first complete survey of HMXB in Milky Way (absorption ignorant)

2)Dominance of SG systems among persistent sources!

3) Curved shape of HMXB LF

4)Surface density distribution - > SFR

5) Emerging of the global picture of HMXB formation

6)Clues to mechanism of SFXT outbursts