Revealing the nature of HMXBs through multi-wavelength and statistical analyses

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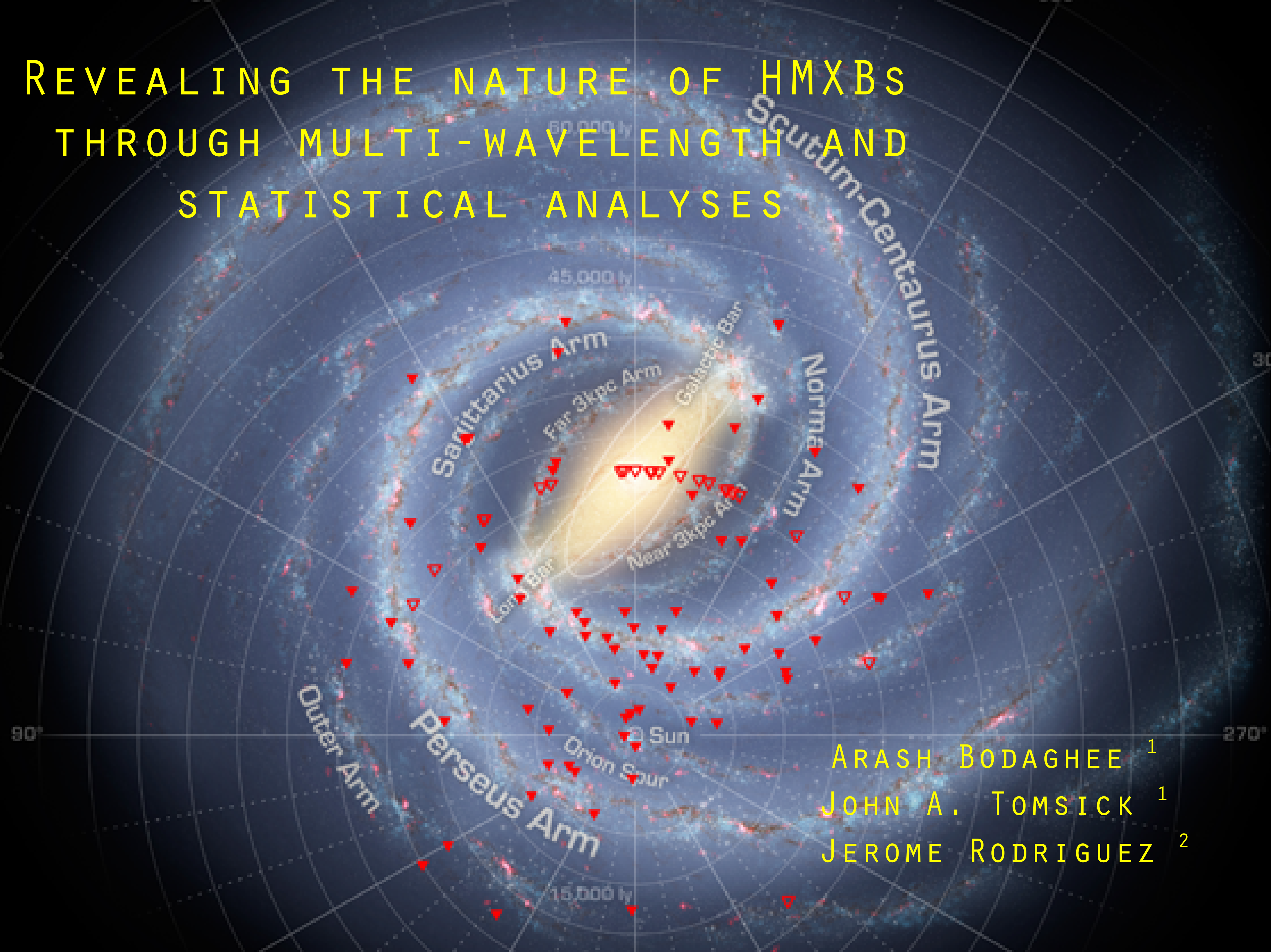
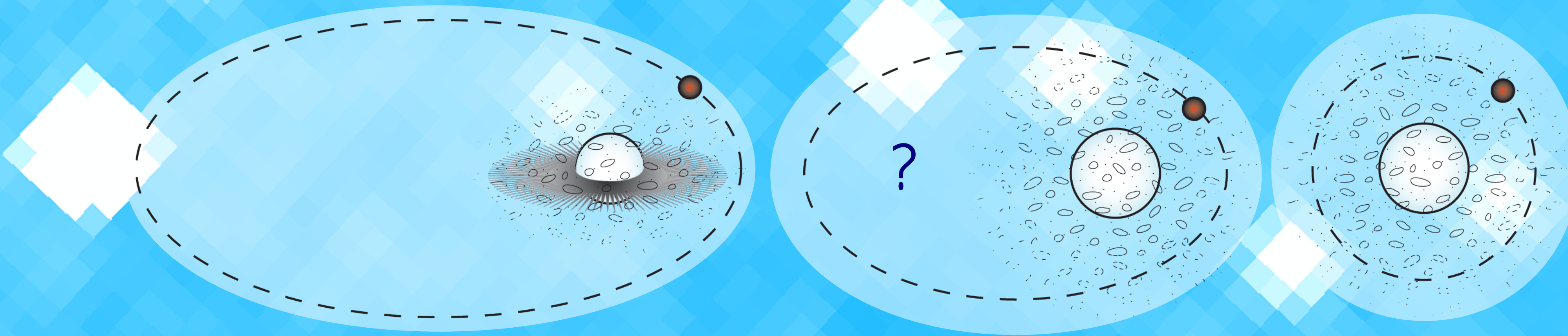
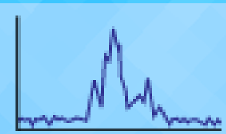
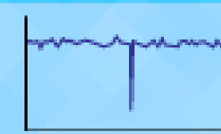
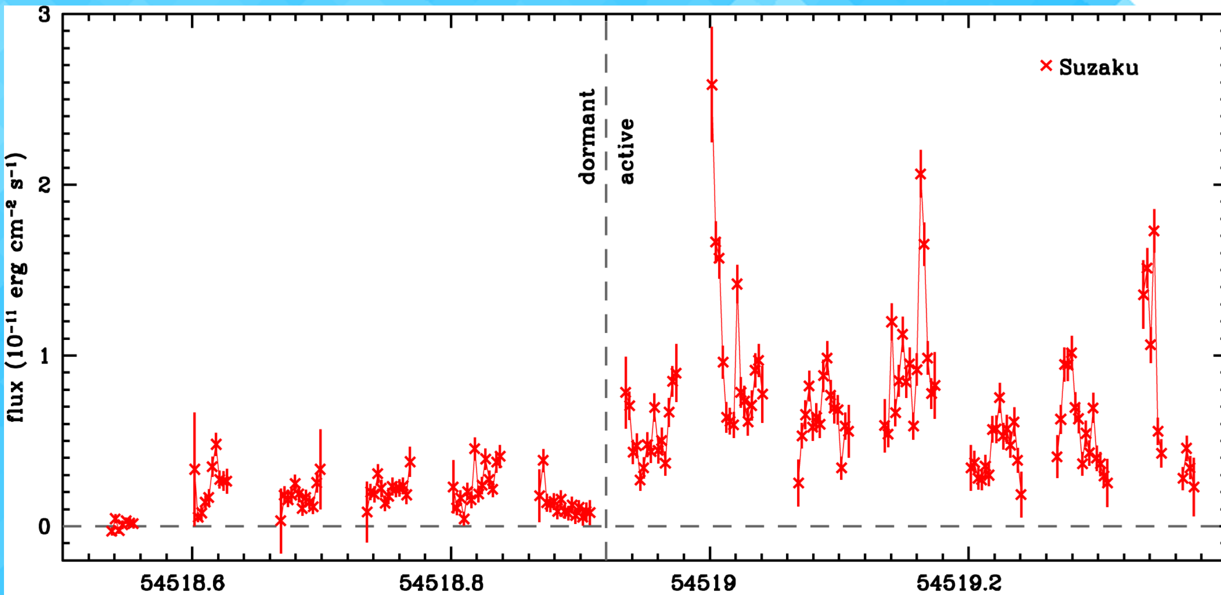


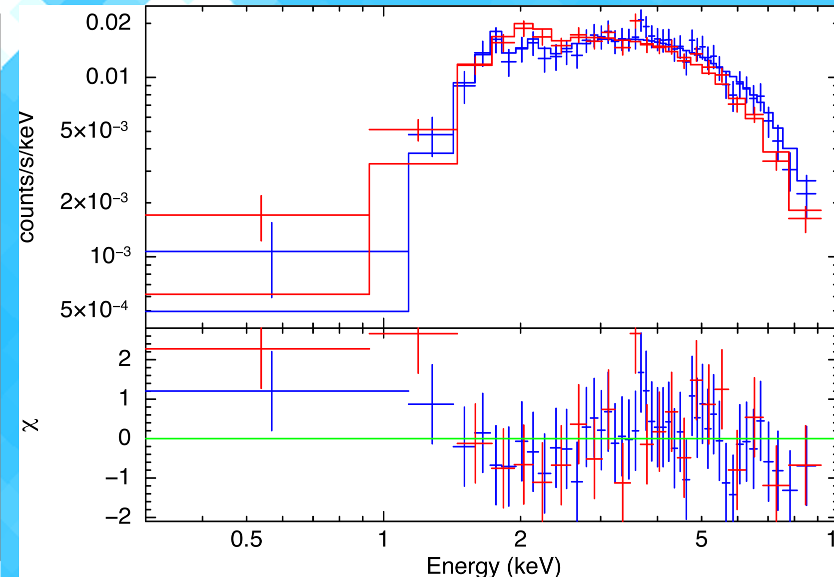
There are 3 known classes of HMXBs

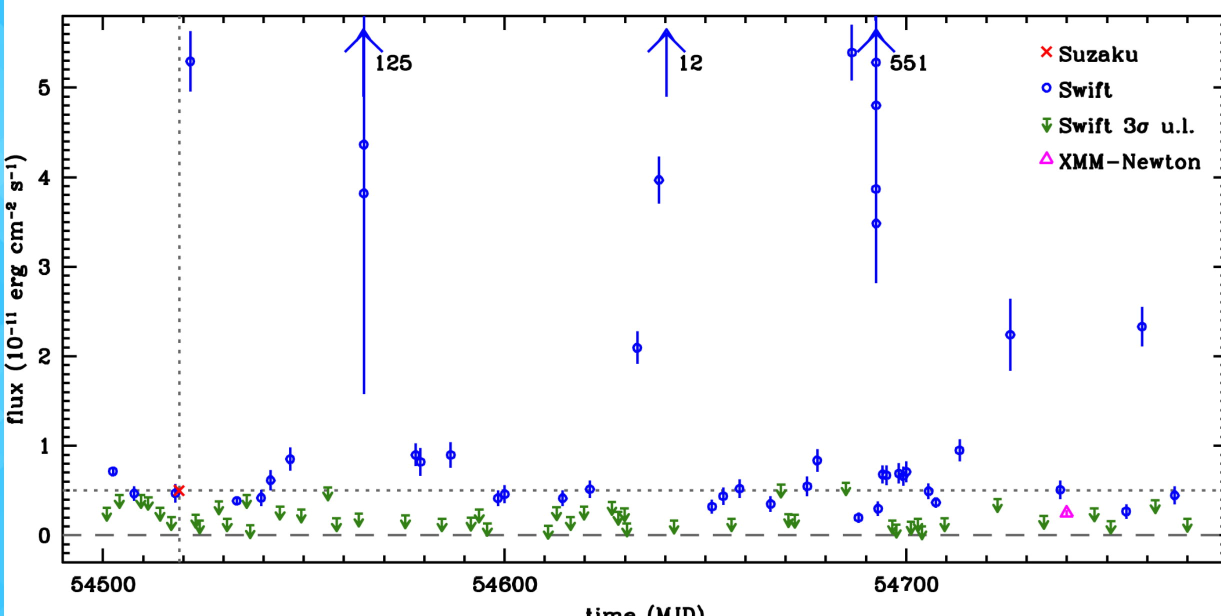


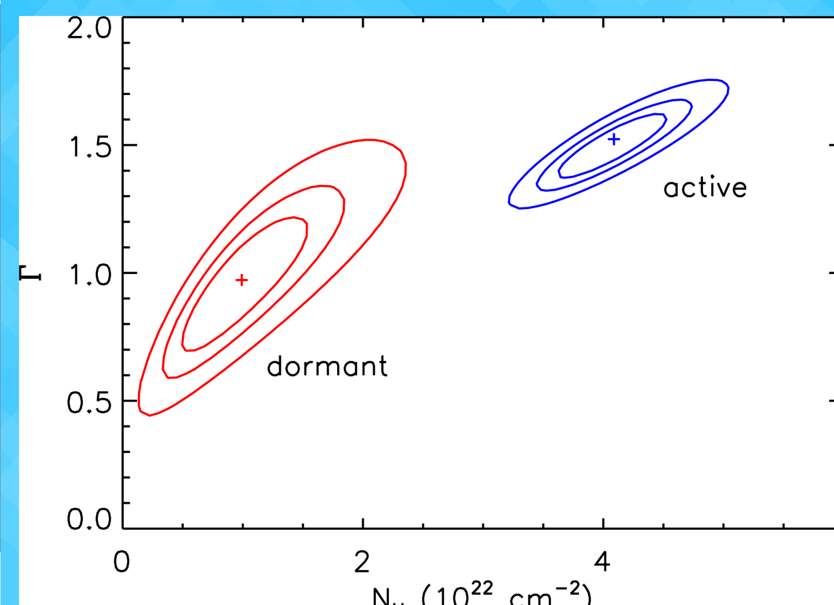
		BEXB Be X-ray Binary	SFXT Supergiant Fast X-ray Transient	SGXB Supergiant X-ray Binary
light curve				
L_X	(erg s^{-1})	10^{31}—10^{35}	10^{32}—10^{36}	10^{35}—10^{37}
dynamic range		10^4	10^4	10—100
on-timescale		days/weeks	hours/days	quasi-continuously
off-timescale		months/years	weeks/months	minutes
N_H	(cm^{-2})	$\leq 10^{23}$	10^{22}—10^{23}	$\geq 10^{23}$
spin period	(s)	1—1000	10—500	100—5000
orbital period	(d)	10—1000	10—200	1—50
number		46	12	33
prototype		V 0332+53	IGR J17391−3021	Vela X-1

Suzaku sees weak flares from the SFXT IGR J17391-3021



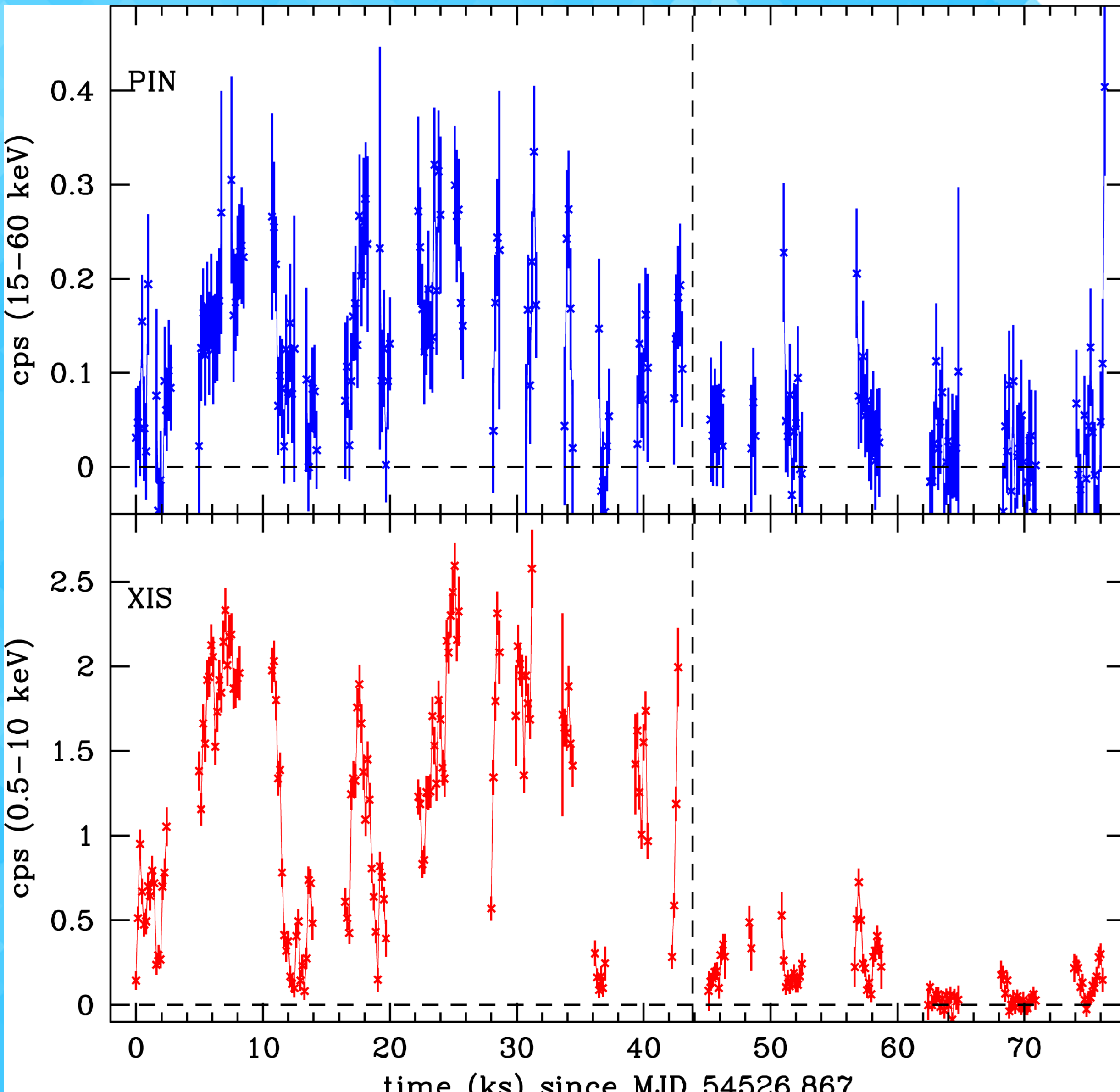


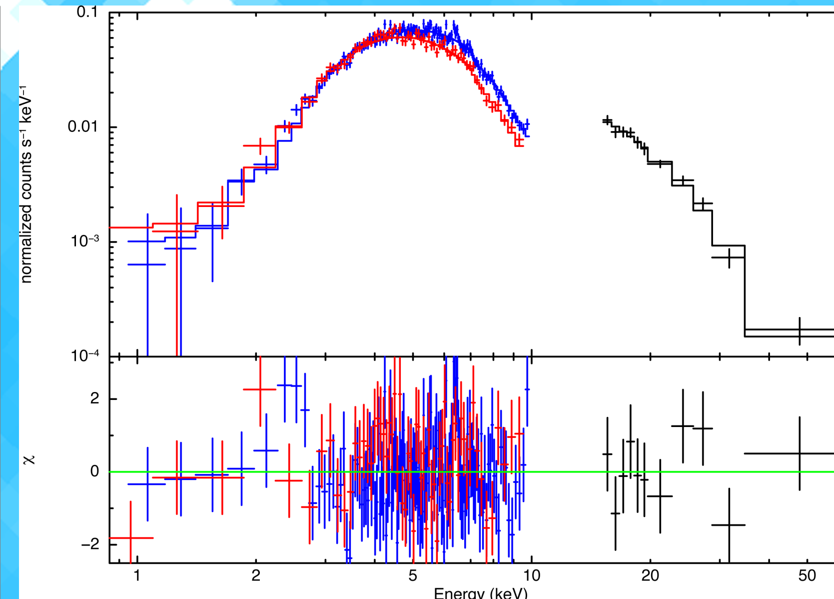


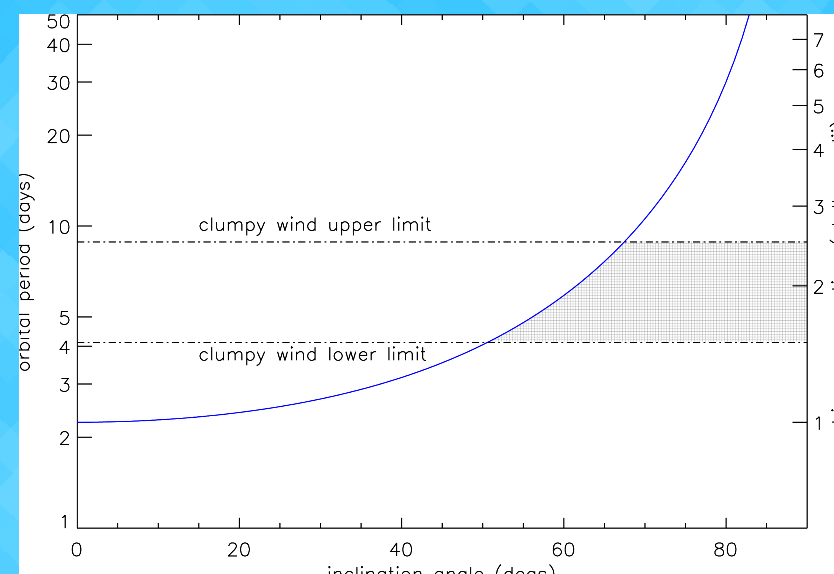


Bodaghee et al. 2010a

Did Suzaku see an eclipse in the SGXB IGR J16207-5129?







Bodaghee et al. 2010B
c.f. P15 Sasano et al.

The new crop of HMXBs are more obscured on average

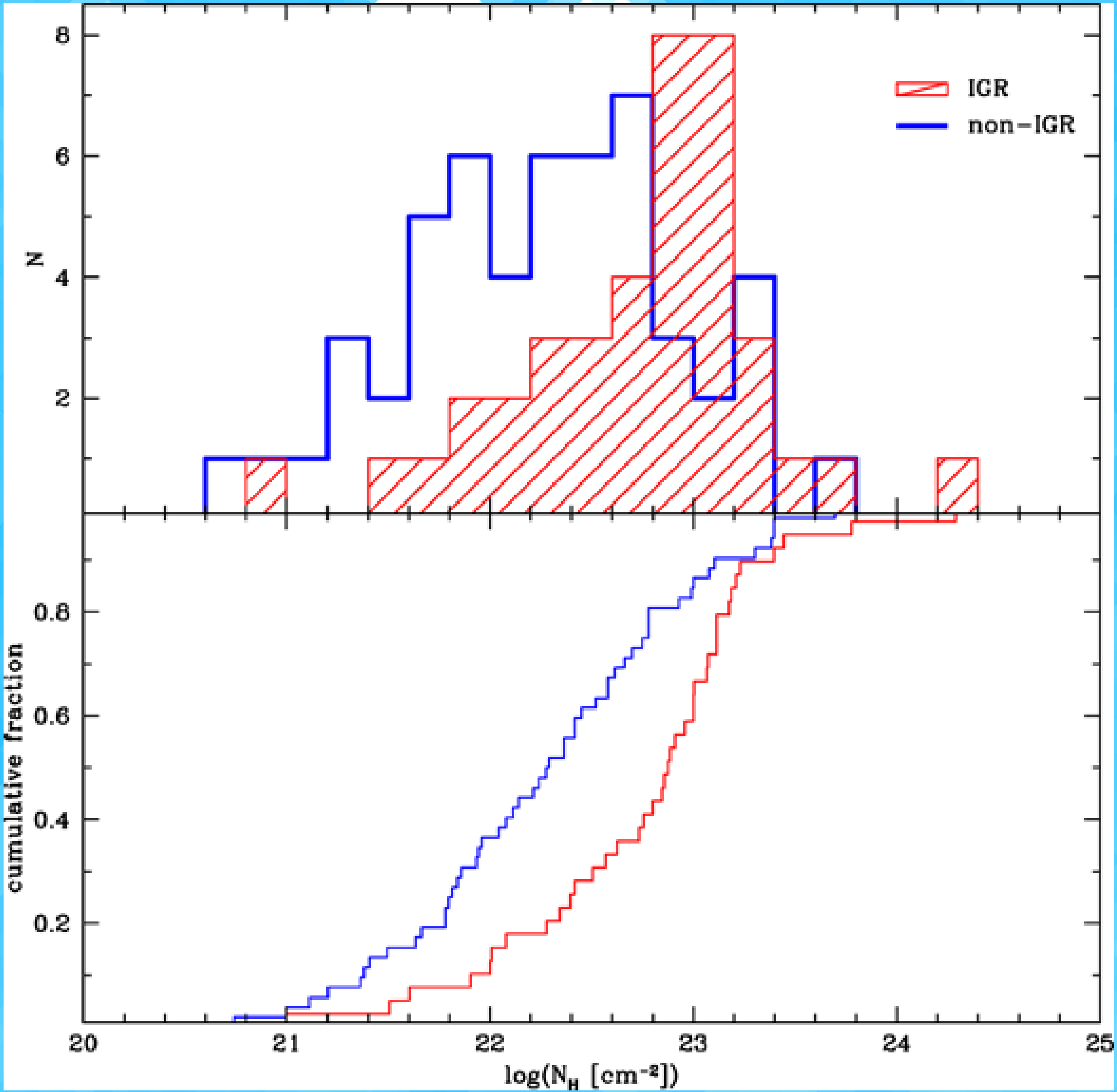
IGRs: $\langle N_H \rangle = 5.7\times10^{22}\ \mathrm{cm}^{-2}$

$\sigma = 0.6$

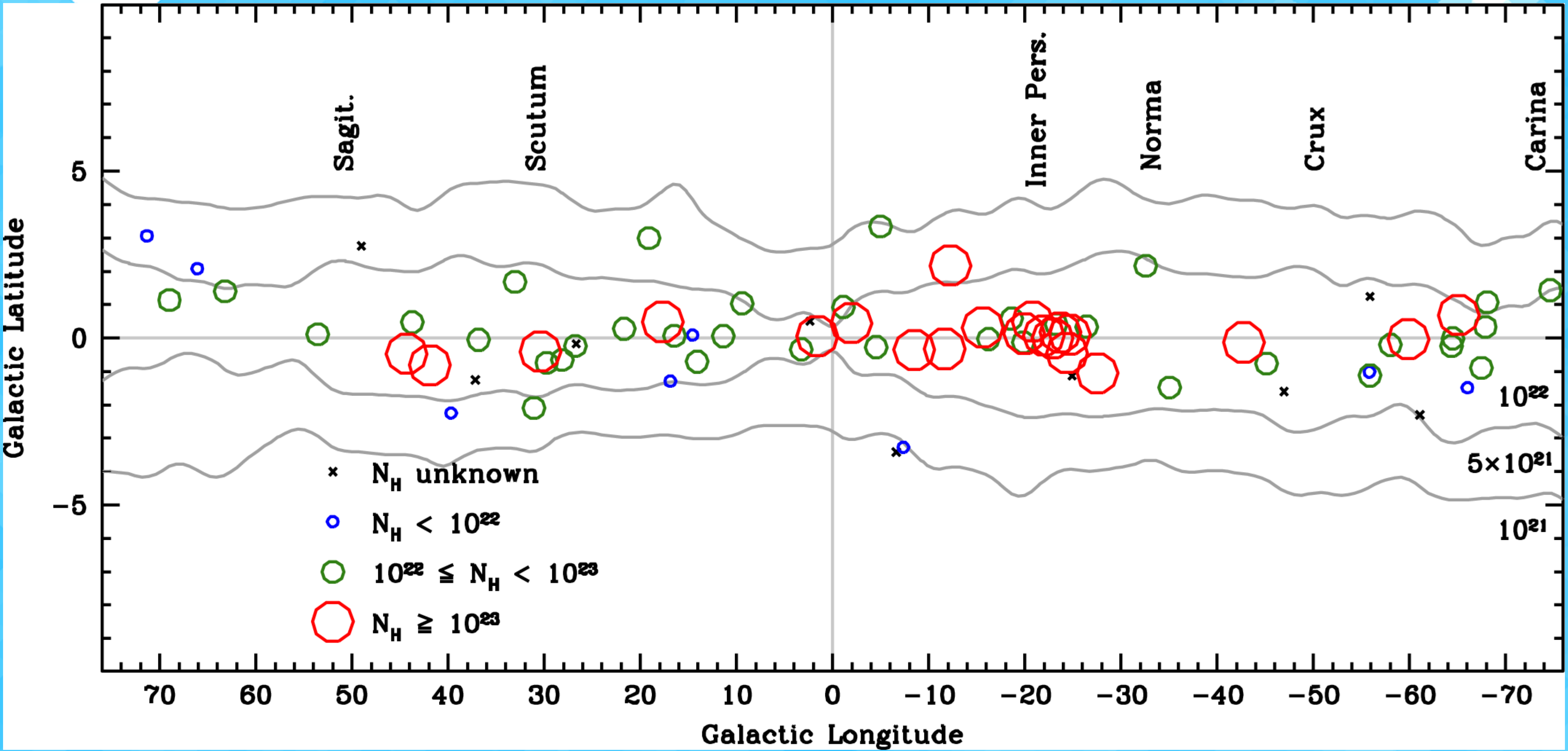
others: $\langle N_H \rangle = 1.9\times10^{22}\ \mathrm{cm}^{-2}$

$\sigma = 0.7$

KS-test prob.: 0.1%



Evidence of asymmetry & clustering in absorbed HMXBs



1 : 3 left : right

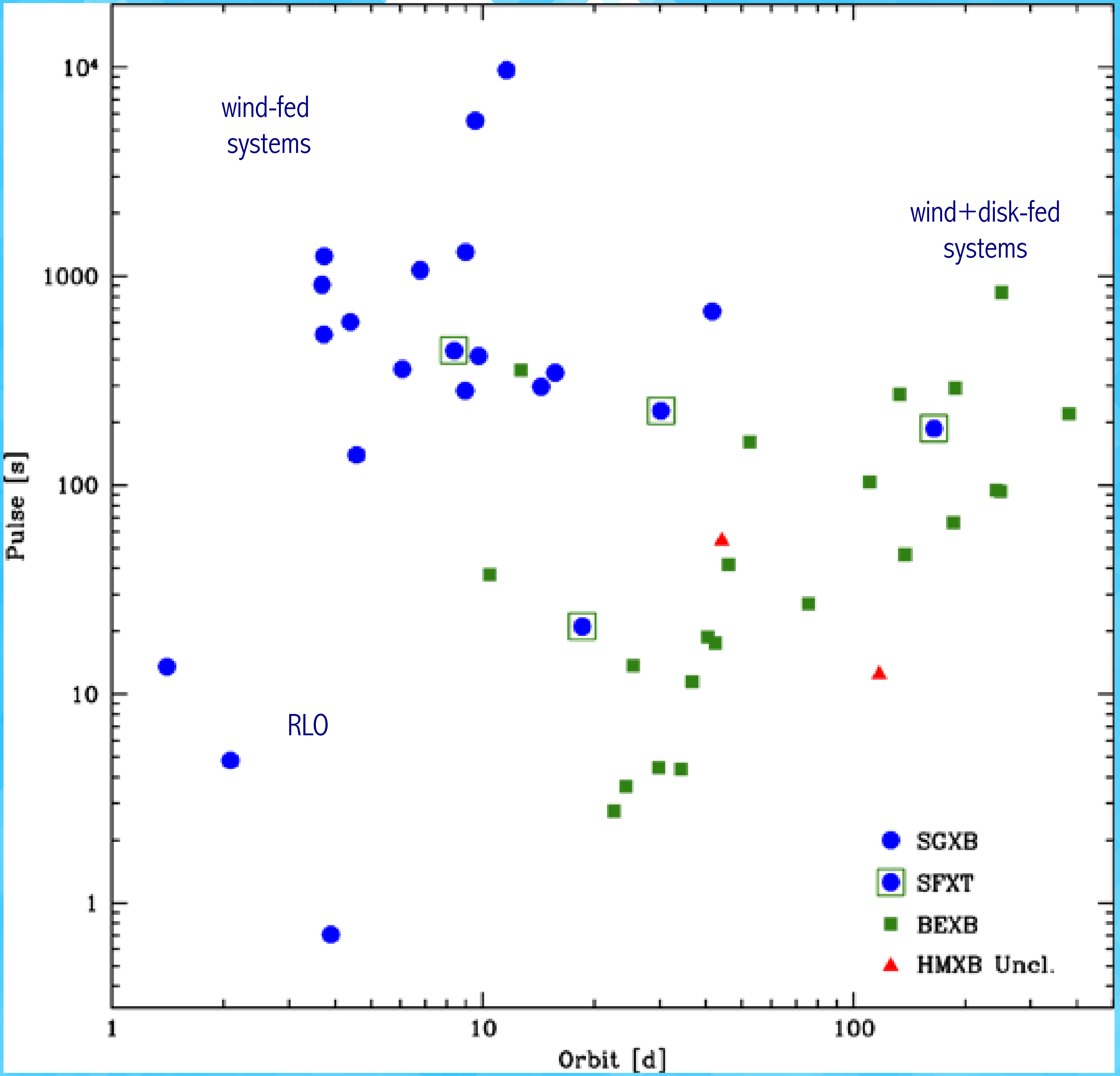
1 : 4 Scutum/Sagit. : Inner Perseus/Norma

Spin-orbital period diagram

segregation based on
dominant accretion mechanism

SFXTs span across populations

(adapted from Corbet 1986)



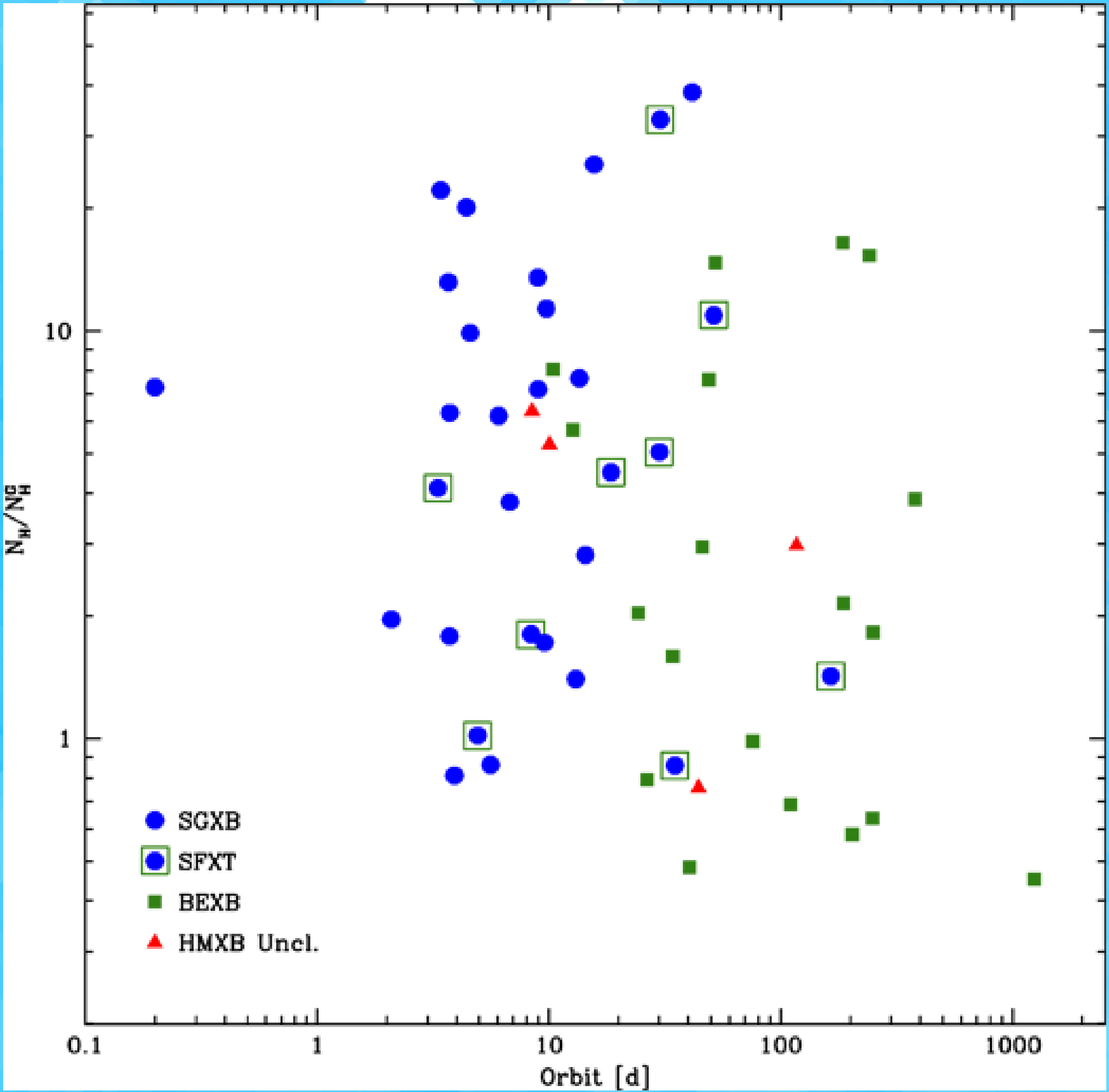
N_H-ORBITAL PERIOD DIAGRAM

segregation based on
dominant accretion mechanism

weak anti-correlation among HMXBs
Spearman rank: $R_S = -0.3$
Monte Carlo: 2% chance prob.

SFXTs occupy intermediate position
(Bodaghee et al. 2007)

some SFXTs evolved from Oe/Be
stars, i.e. they were once BEXBs!
(Liu et al. 2010)



N_H-SPIN PERIOD DIAGRAM

segregation based on
dominant accretion mechanism

weak correlation among HMXBs
Spearman rank: $R_S = +0.3$
Monte Carlo: 1% chance prob.

SFXTs occupy intermediate position
(Bodaghee et al. 2007)

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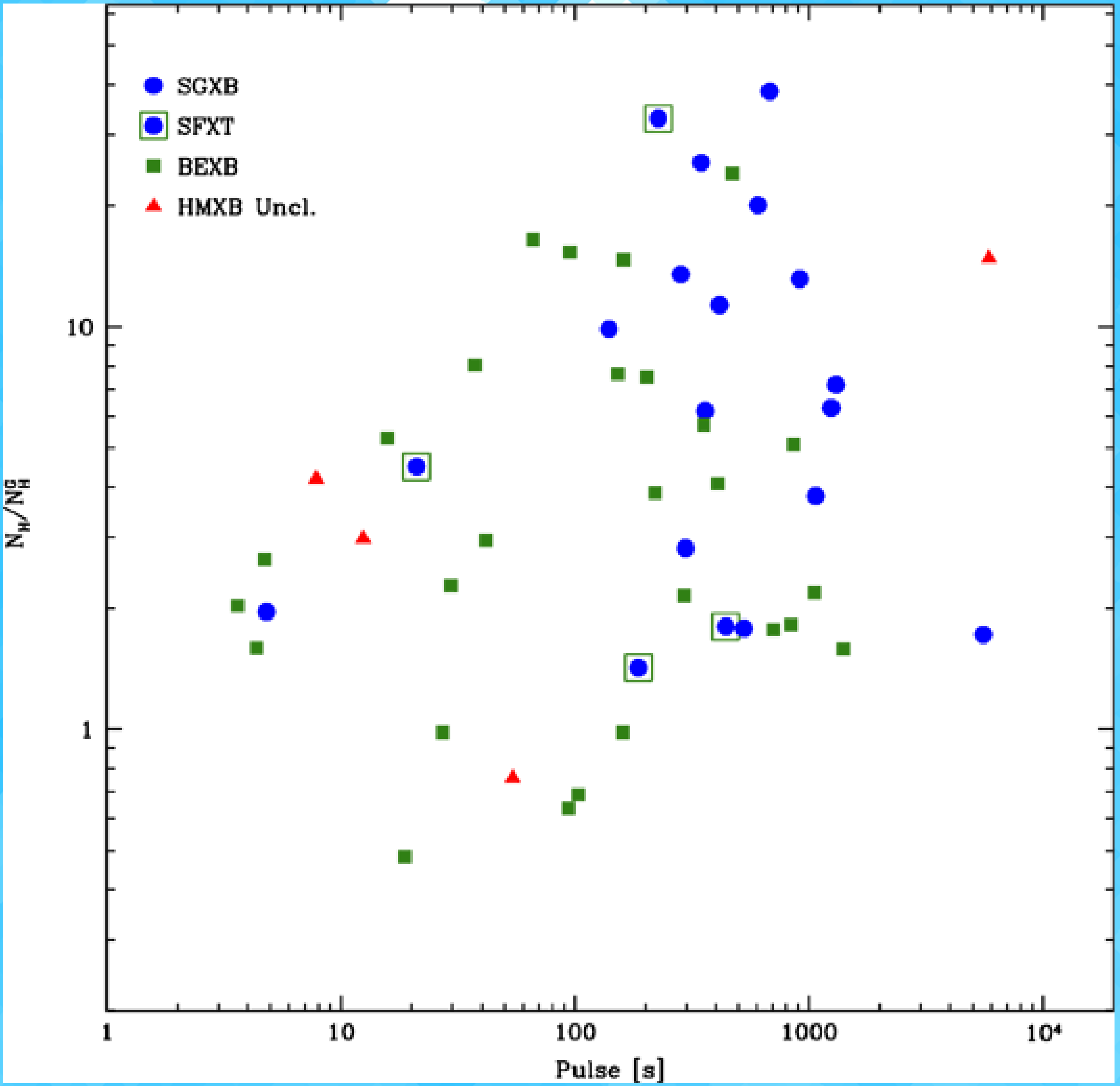
(Liu et al. 2010)



N_H-SPIN PERIOD DIAGRAM: CONSTRAINING NS MODELS

equilibrium spin periods from a wind-accreting pulsar model of Waters & van Kerkwijk 1989

$\dot{M}_w = 10^{-6}\, M_\odot y^{-1}$ $\quad v_w = 10^3\, \mathrm{km\ s^{-1}}$

$M_\star = 20\, M_\odot$ $\quad M_x = 1.4\, M_\odot$

$R_\star = 20\, R_\odot$ $\quad R_x = 10\, \mathrm{km}$

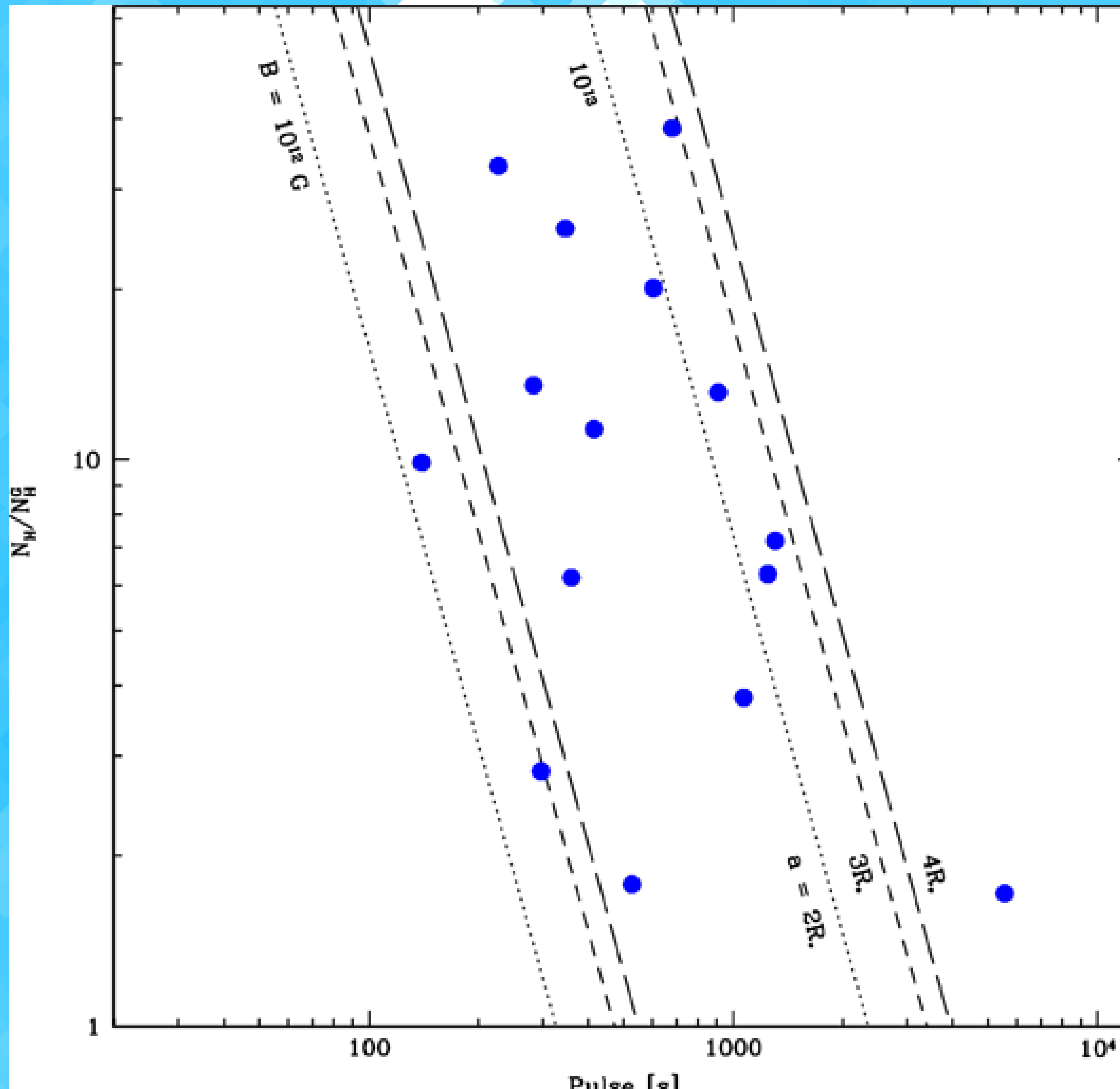
$\beta = \delta = \xi = 1$

$\dot{M}_{acc} = 4\pi\, R_{acc}^{\ 2} \rho_w v_w$

$$v(r) = v_\infty (1 - R_\star)^\beta$$

$$P_{eq} \sim C_{eq} (4\pi\rho)^{-3/7}\, [v_\infty (1 - R_\star)^\beta]^{9/7}$$

$$N_H \sim N_H^{\ G} + \int_\infty^{r=a} \rho(r)\, dr$$

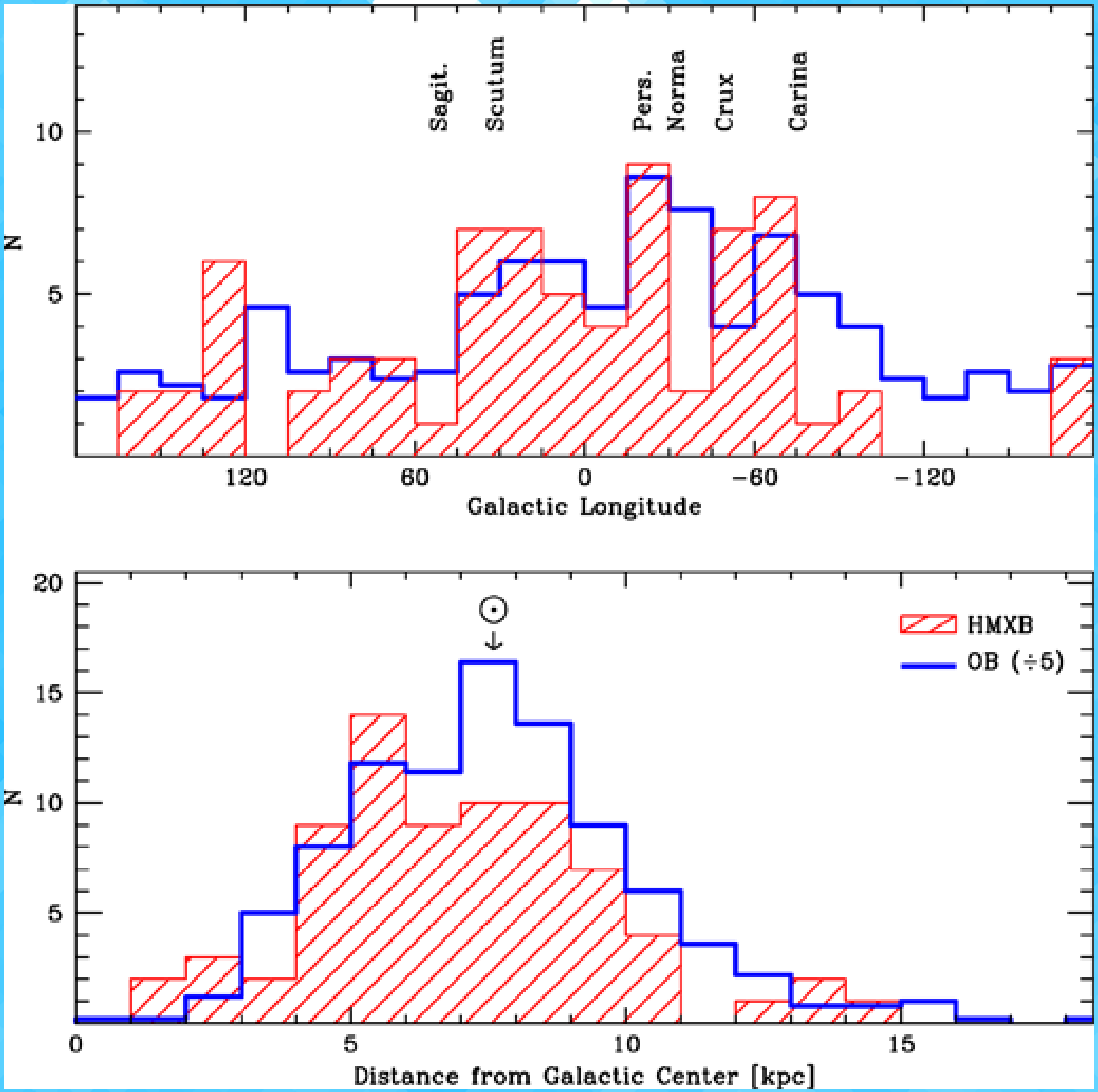


Galactic distribution

distribution of HMXBs is roughly compatible with young supergiants

KS-test probability:
5% and 8% (up to 60% for active)

problem: only a single spatial parameter studied at once

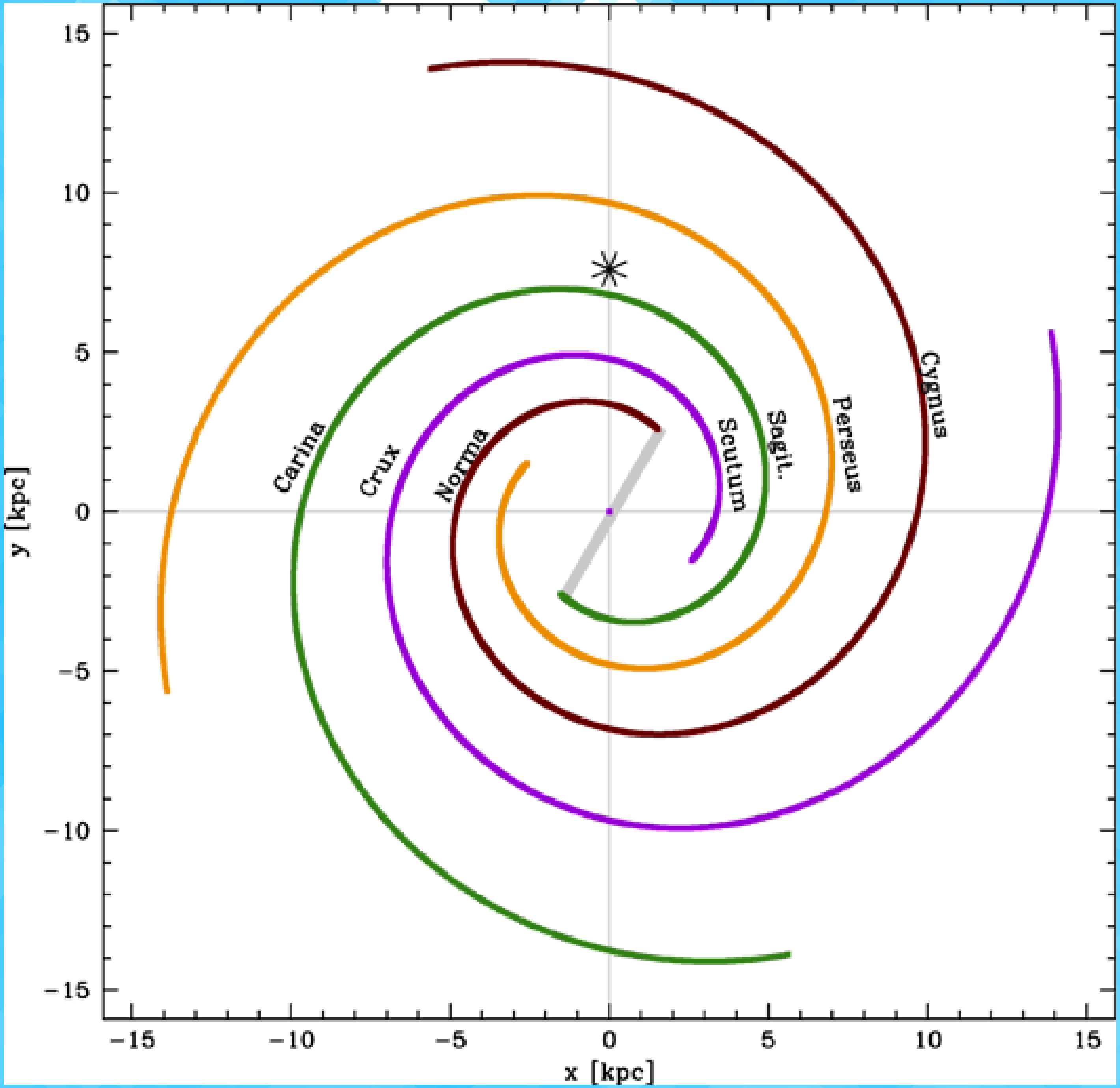


Galactic distribution

Best fitting 4-arm Galactic model to various observables (H I, pulsars, mol. clouds, etc.)

$R_{\odot} = 7.6$ kpc
pitch = 12°

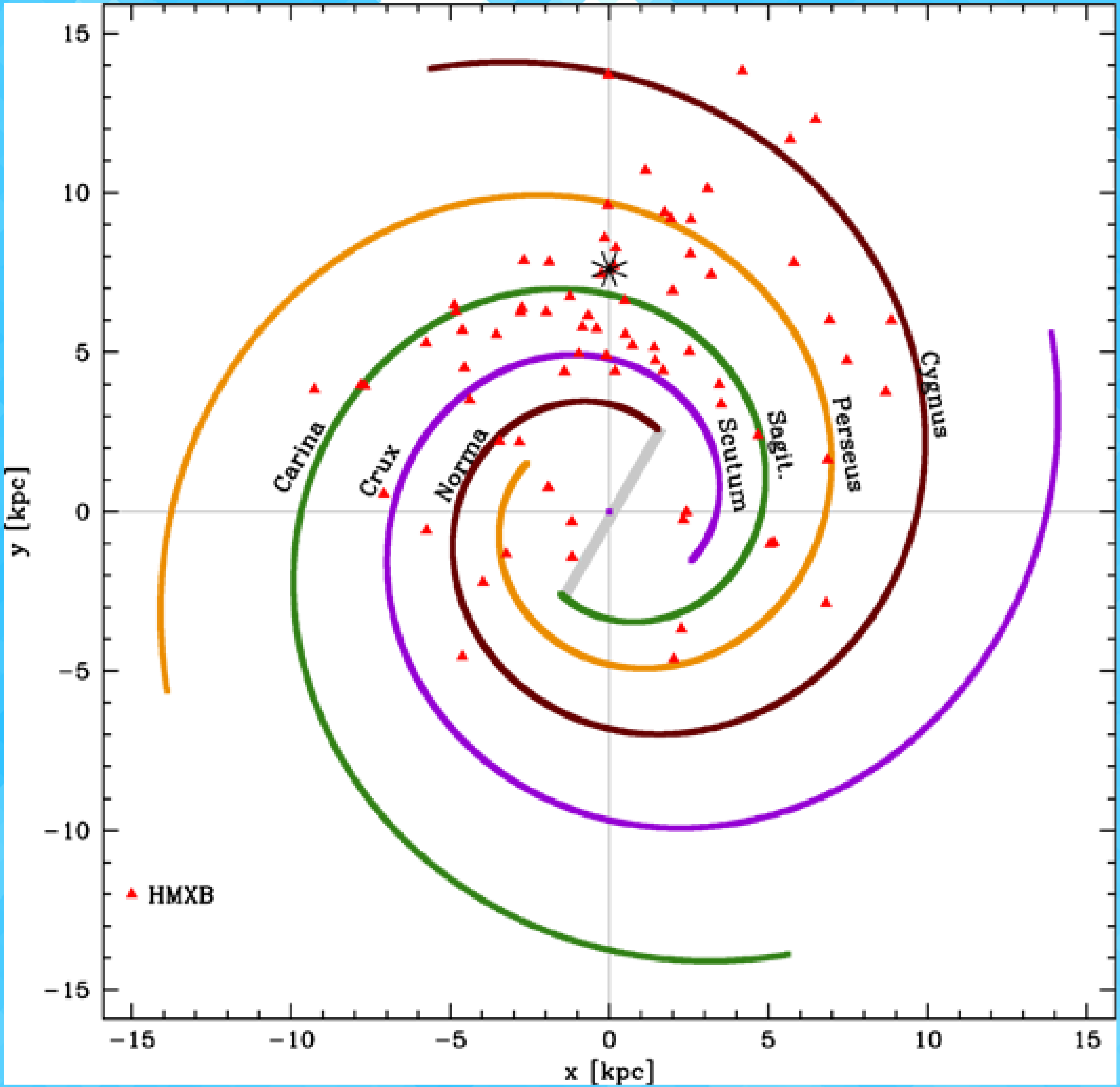
Vallée 2008



Galactic distribution

74 HMXBs have distances that are known from optical/IR observations

some uncertainties can exceed 1 kpc



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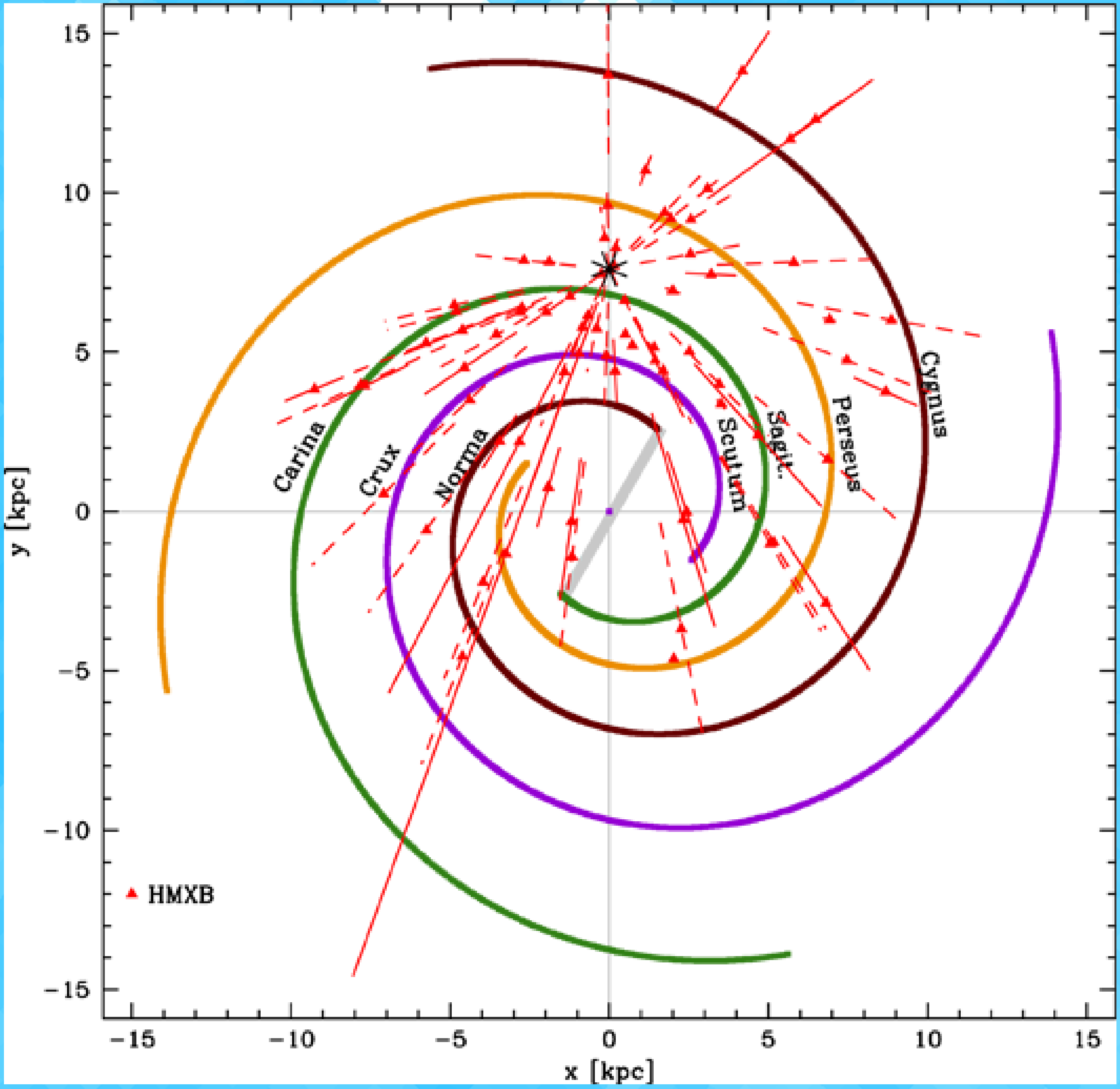
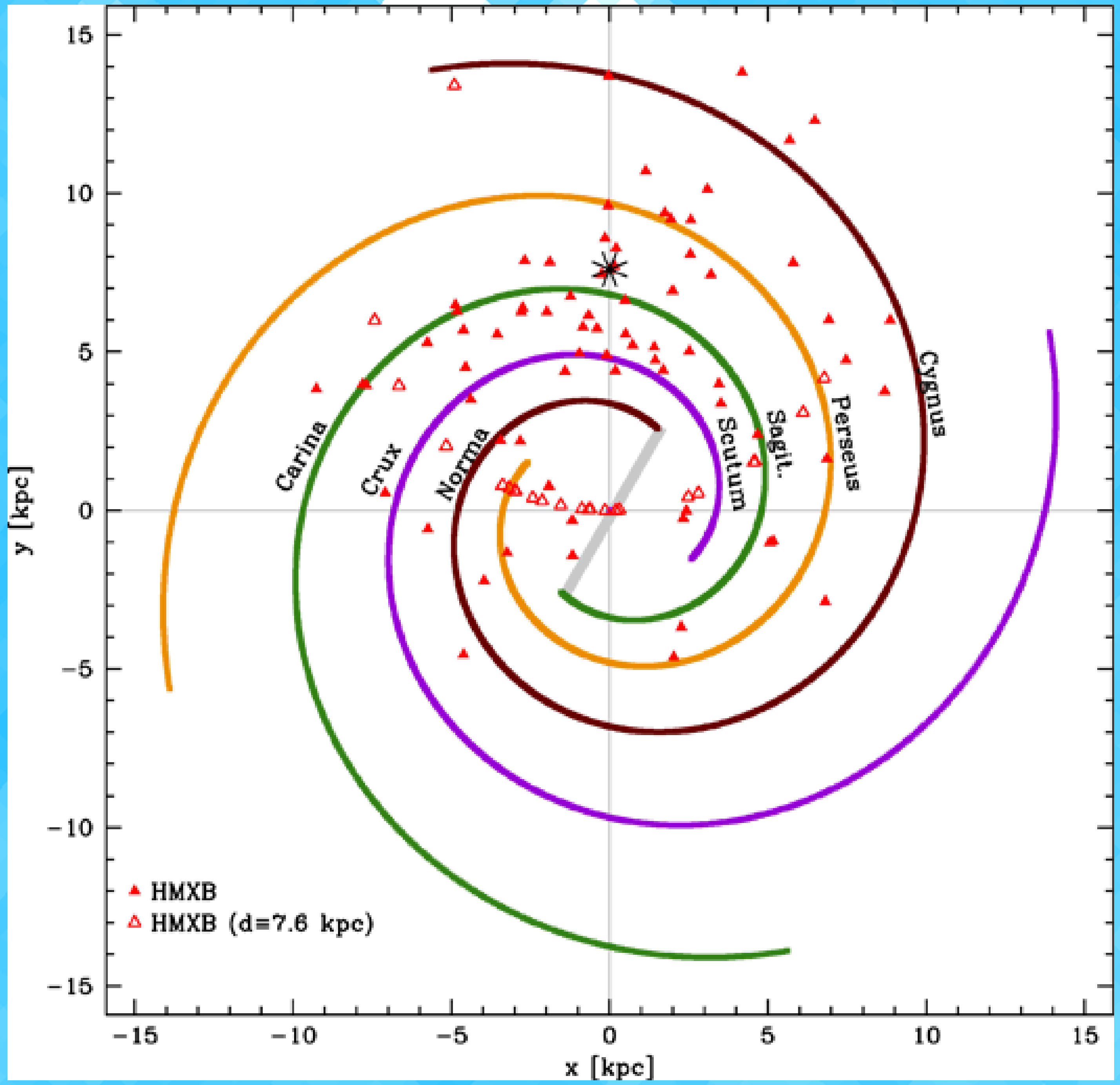


Galactic distribution

24 HMXBs have no reported distance measurement

assume they are at 7.6 kpc

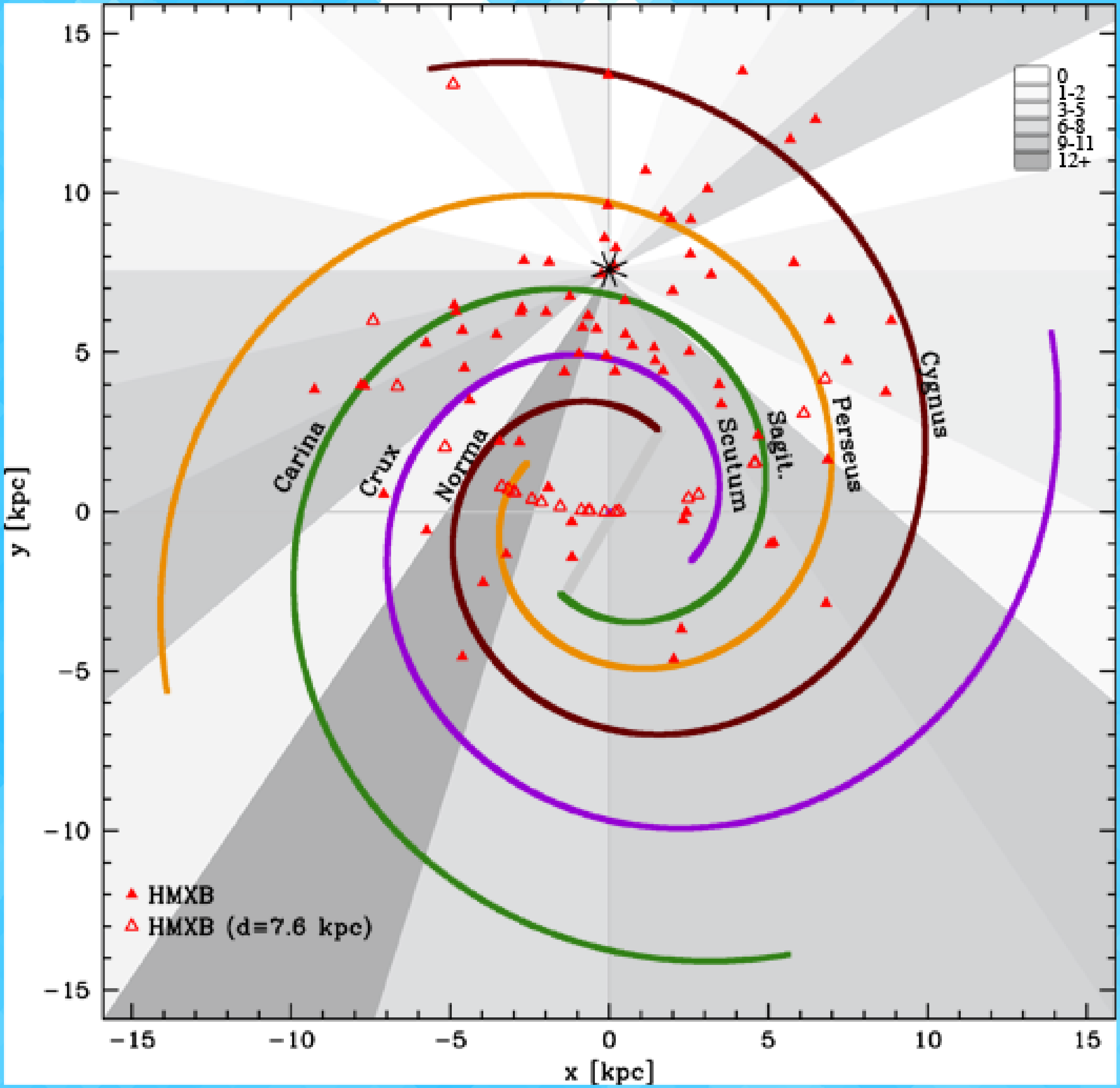


Galactic distribution

offset between peak HMXB density
and spiral arm tangents
c.f. Lutovinov et al. 2004
Dean et al. 2005

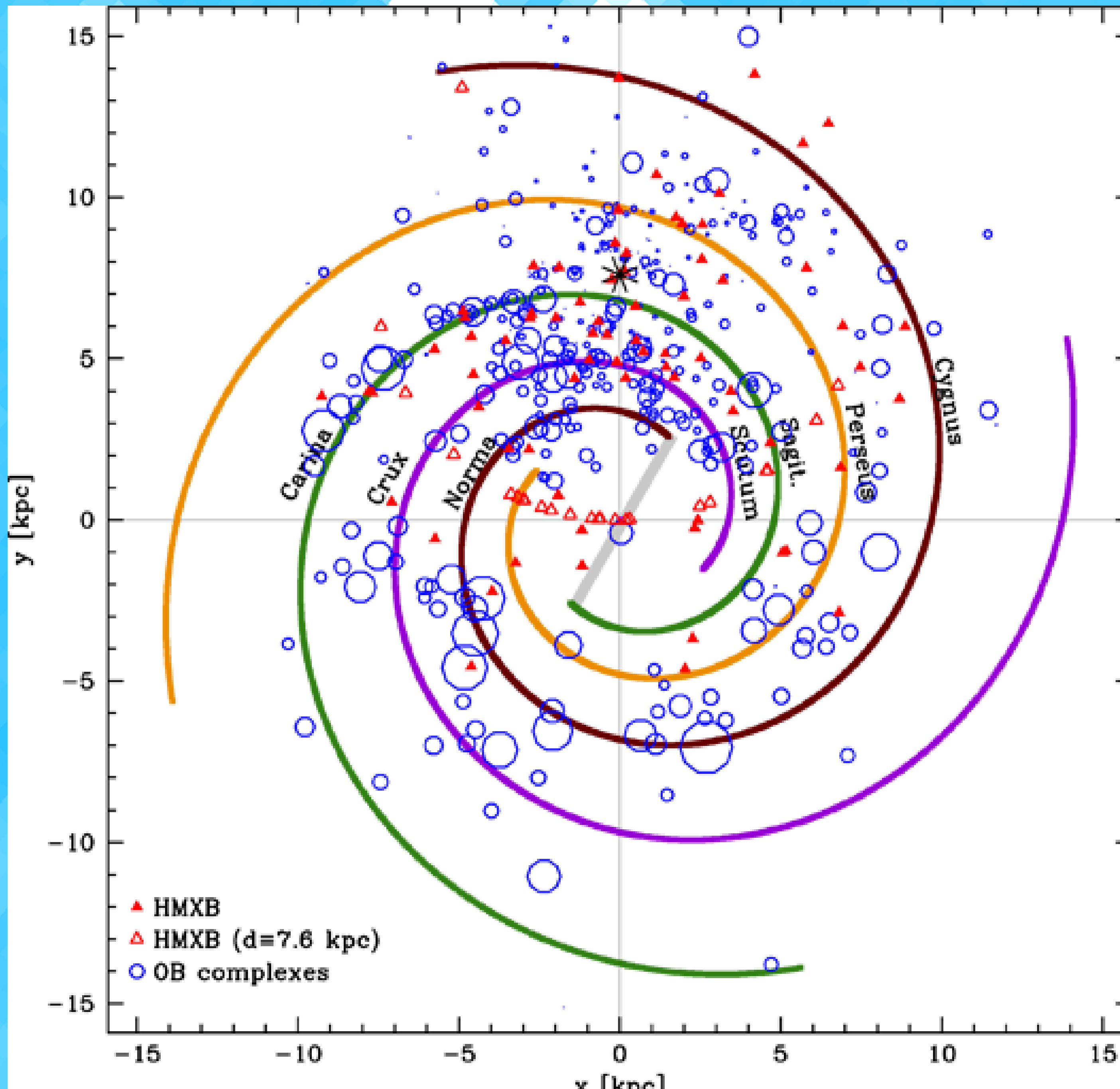
evolutionary effect?

model dependence:
offset affected by number
and location of arms



Galactic distribution

a better way would be to compare directly with massive-star forming regions in Cartesian space



Galactic distribution

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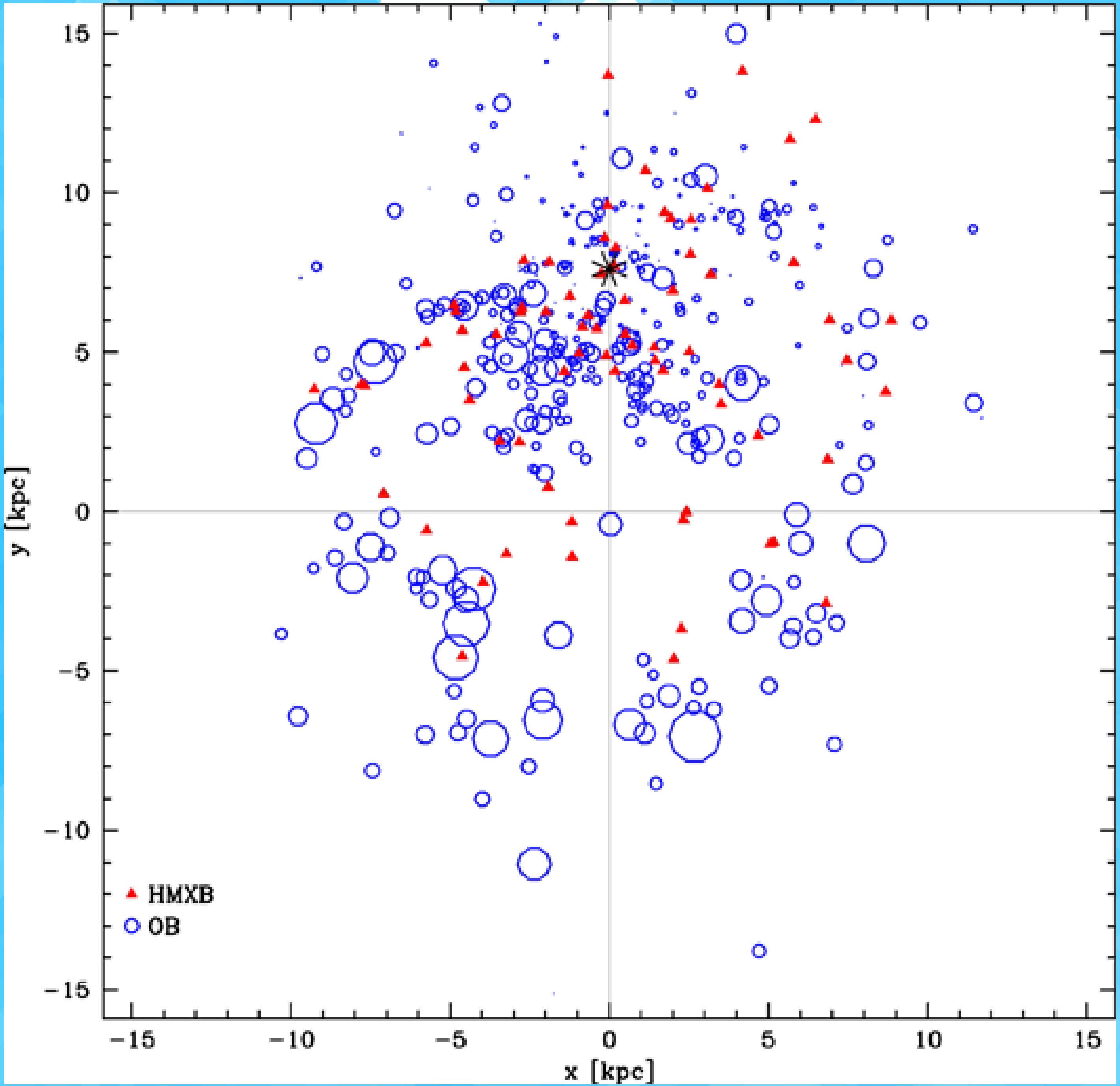


Spatial correlation function

For an HMXB in δV, the probability ($\geq$ Poisson) of finding an OB complex at a distance of r is:

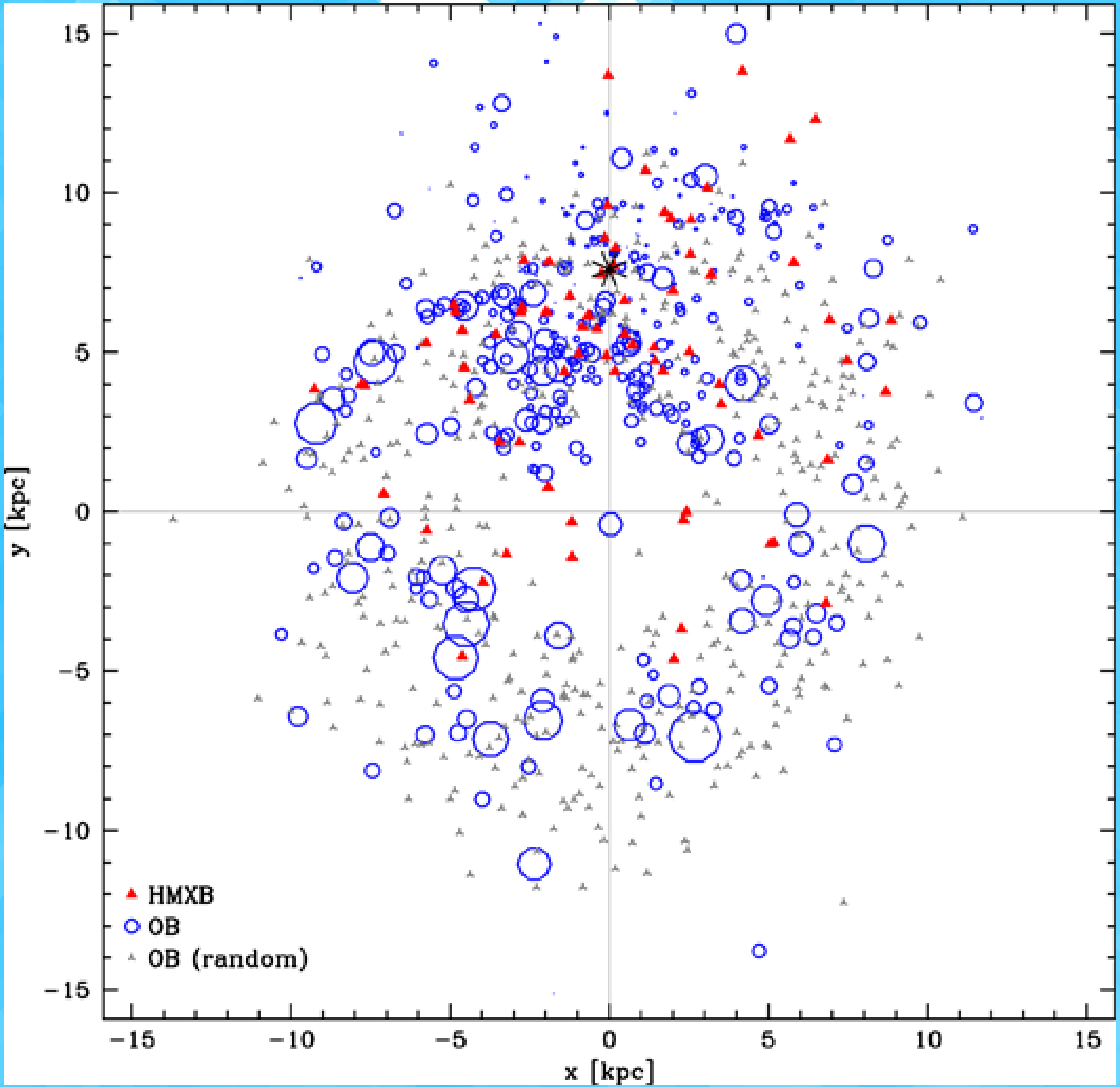
$$\delta P = n\,\delta V\,[1 + \xi(r)]$$

spatial correlation function:

$$\xi(r) = \frac{DD(r)}{DR(r)} - 1$$

DD $\equiv$ data-data pairs:
i.e. HMXB vs. OB (observed)

DR $\equiv$ data-random pairs:
i.e. HMXB vs. OB (random)



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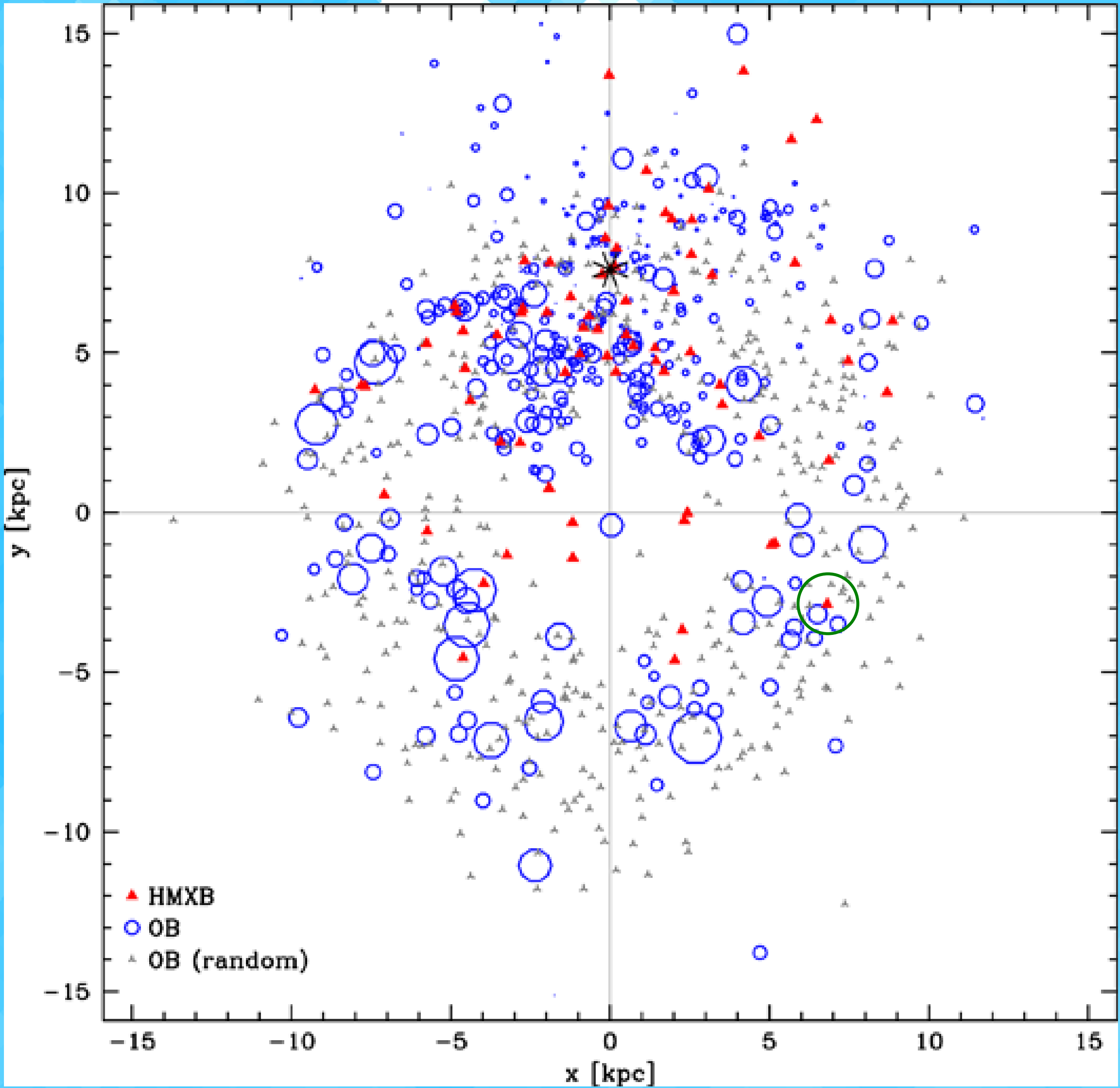

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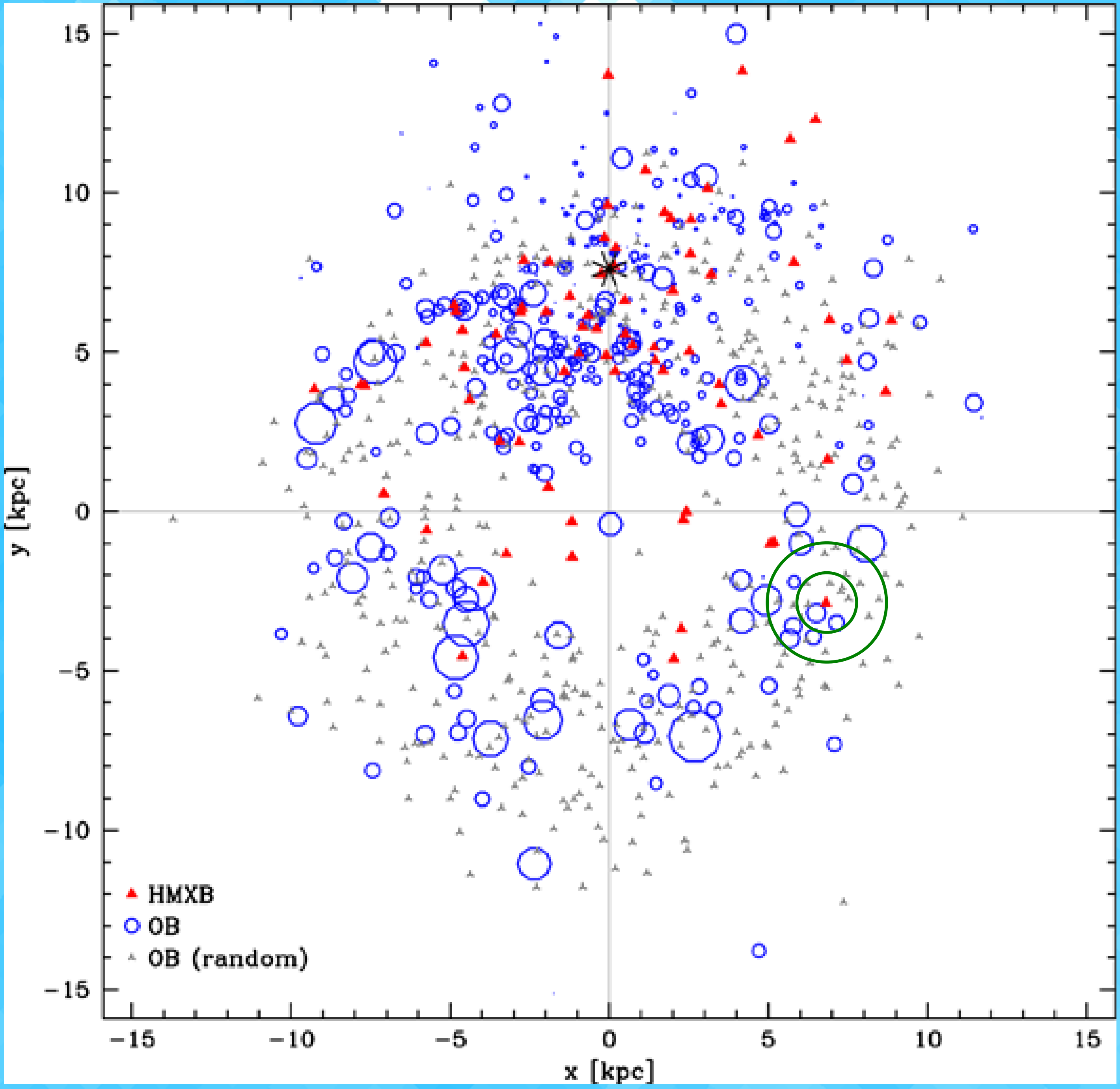

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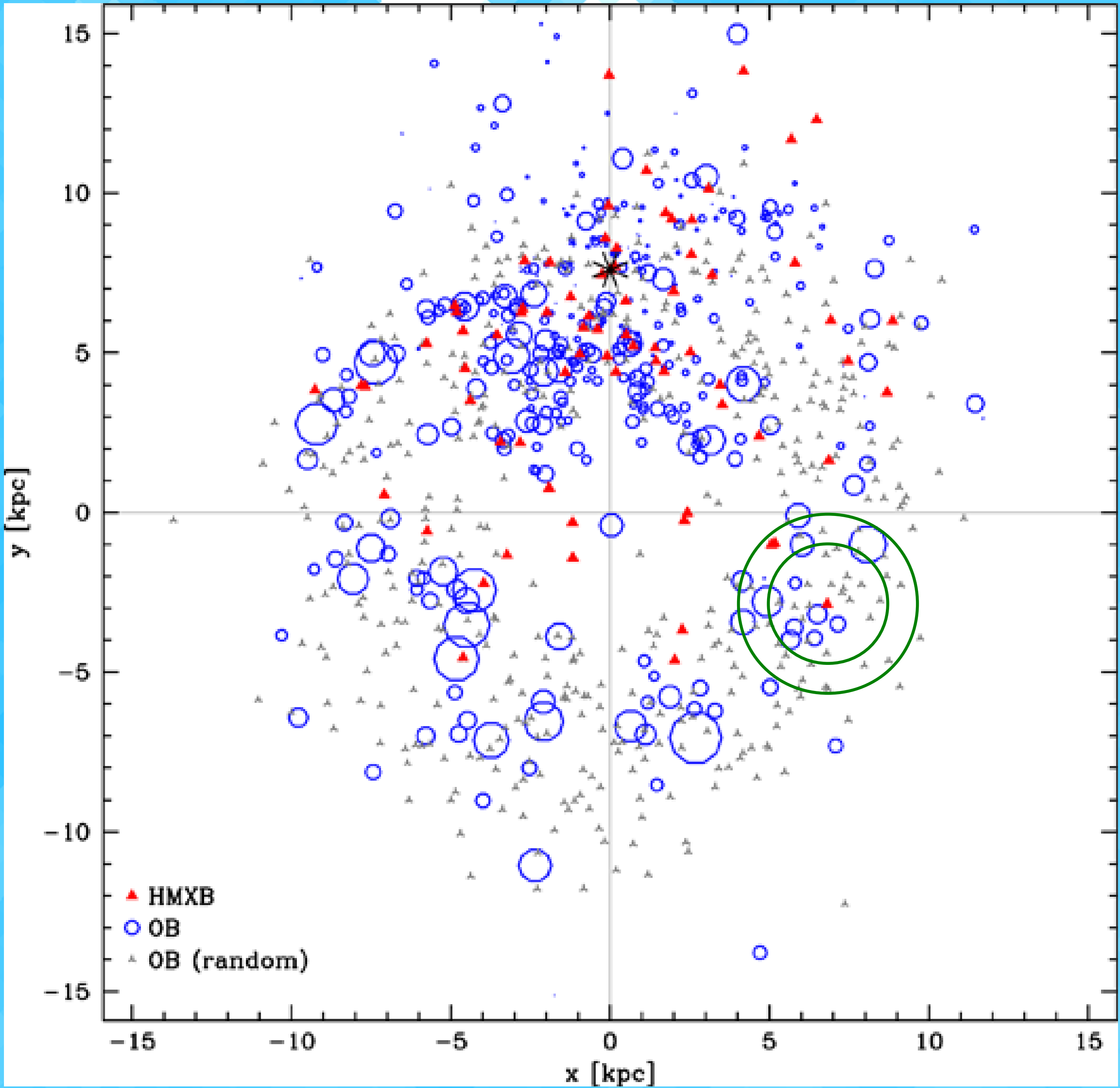

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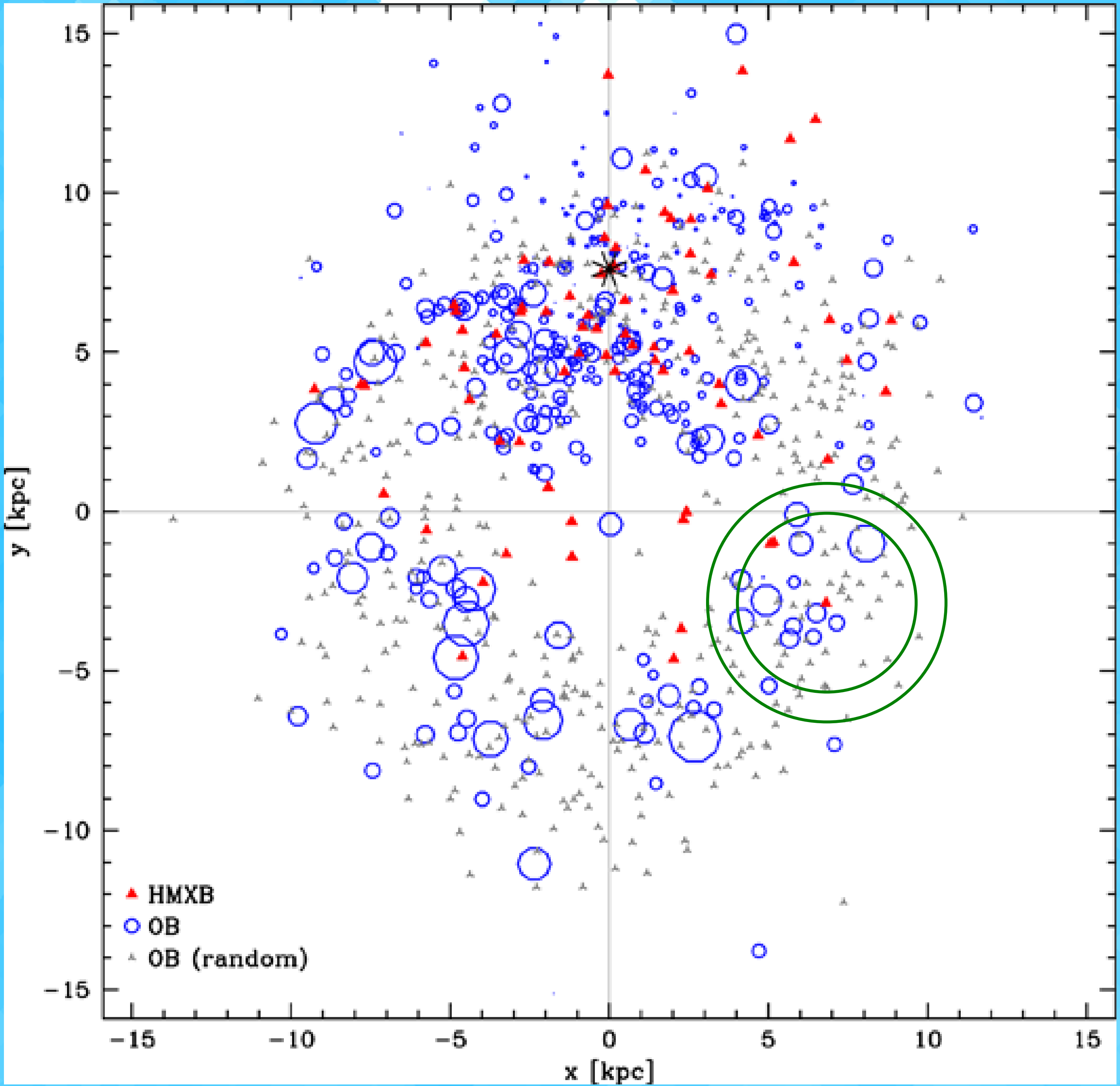

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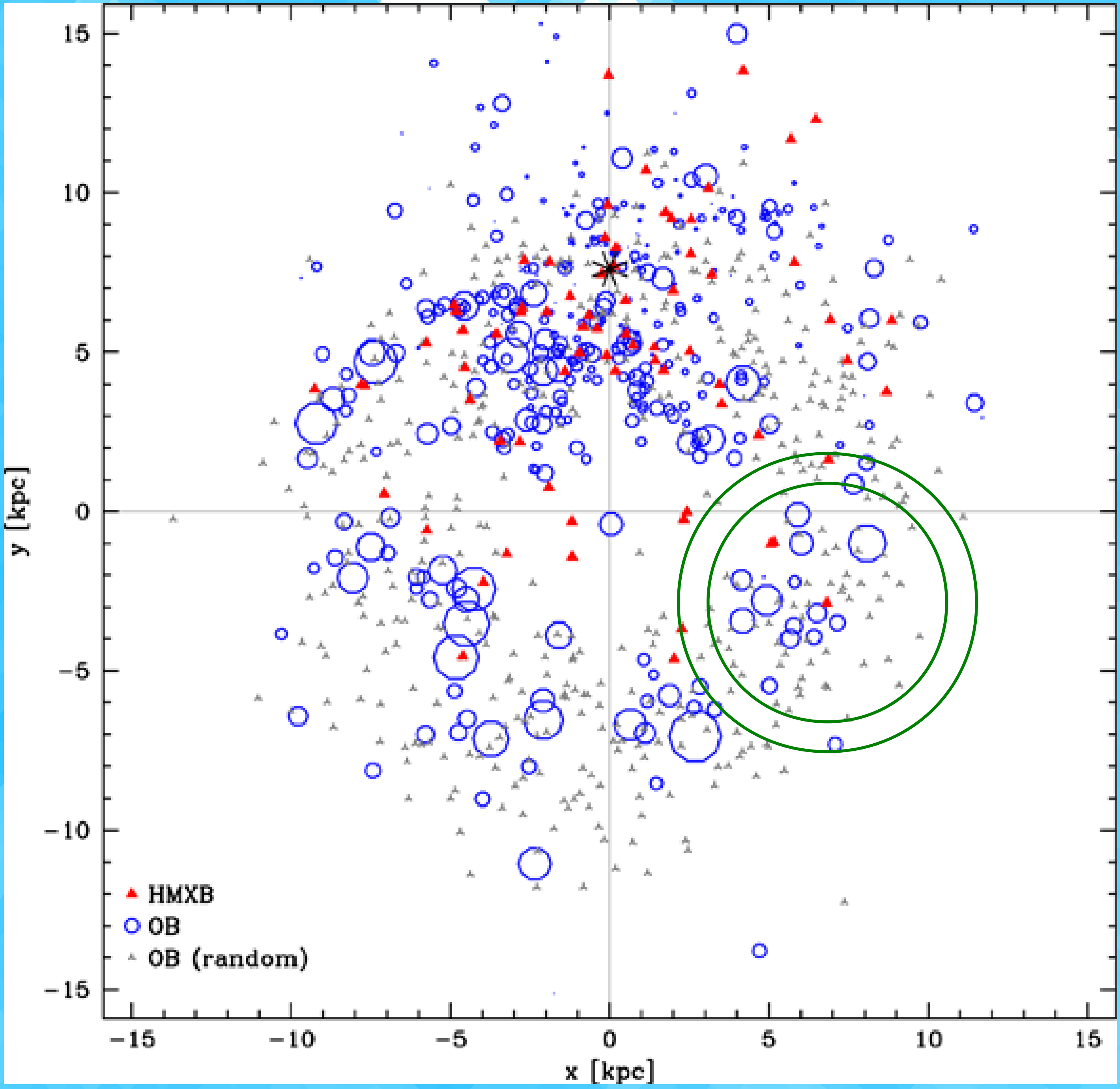


HMXBs and OB complexes are clustered together

For an HMXB in δV, the probability ($\geq$ Poisson) of finding an OB complex at a distance of r is:

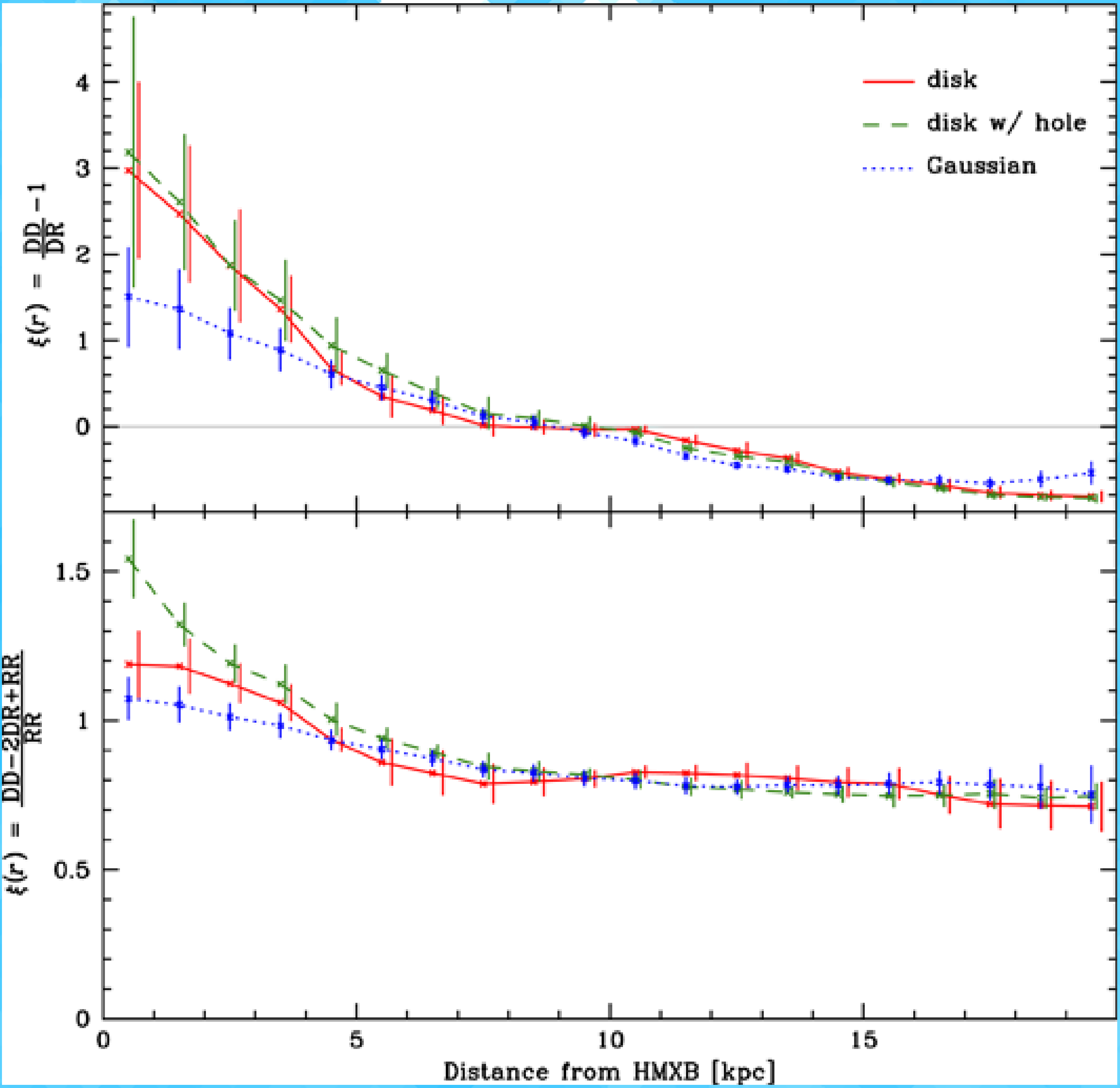
$$\delta P = n\,\delta V\,[1 + \xi(r)]$$

spatial correlation functions:

$$\xi(r) = \frac{D_1D_2}{D_1R_2} - 1$$

$$\xi(r) = \frac{D_1D_2 - D_1R_2 - R_1D_2 - R_1R_2}{R_1R_2}$$

significance of clustering signal:
~10 σ for $r \lesssim 1$ kpc



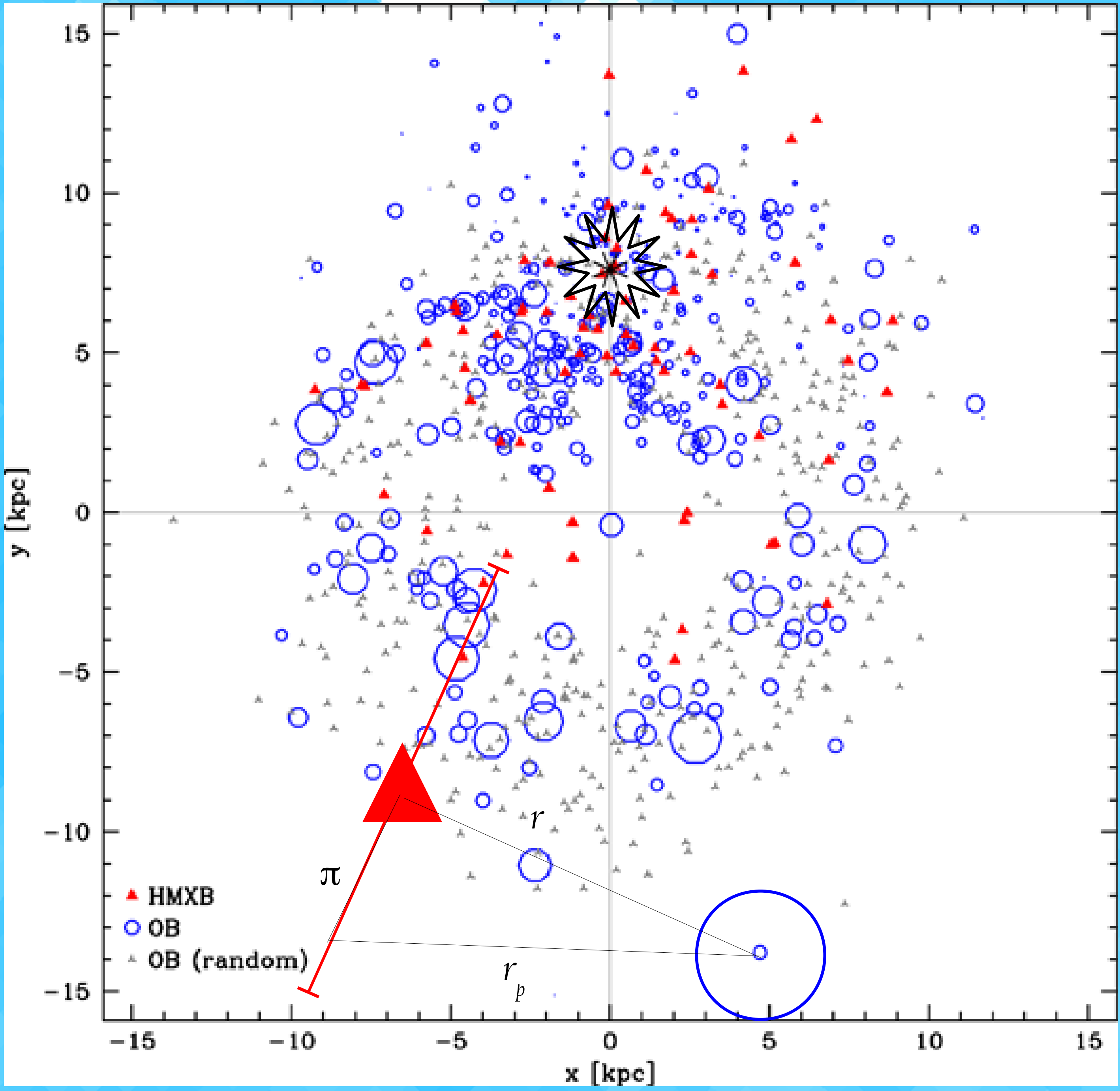
HMXBs and OB complexes are clustered together

the characteristic clustering scale (a few kpc) can help constrain the kick velocity of the binary system

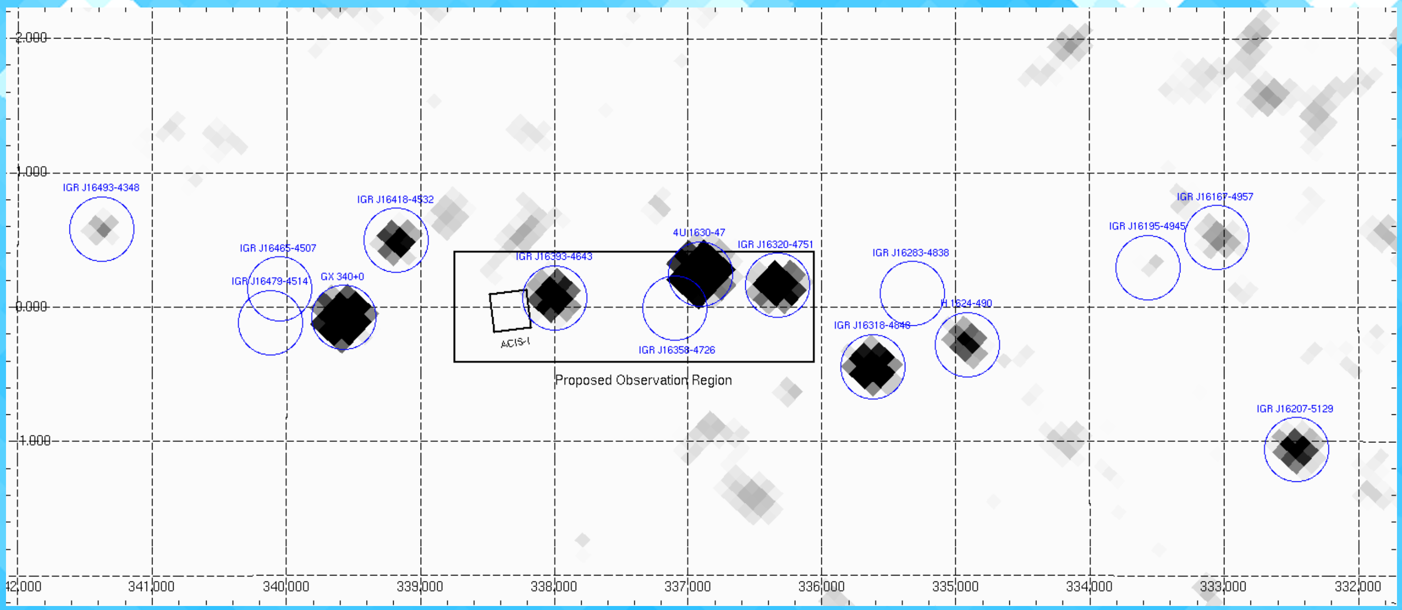
1) observational biases:
dust extinction, difficulty in finding HMXBs and OBs behind Galactic Bulge

2) systematic uncertainties:
reshuffle HMXBs within their distance uncertainties, also use projected correlation function $\xi(r_p,\pi)$

Bodaghee et al. 2011 (in prep.)



Chandra census of the Norma Arm



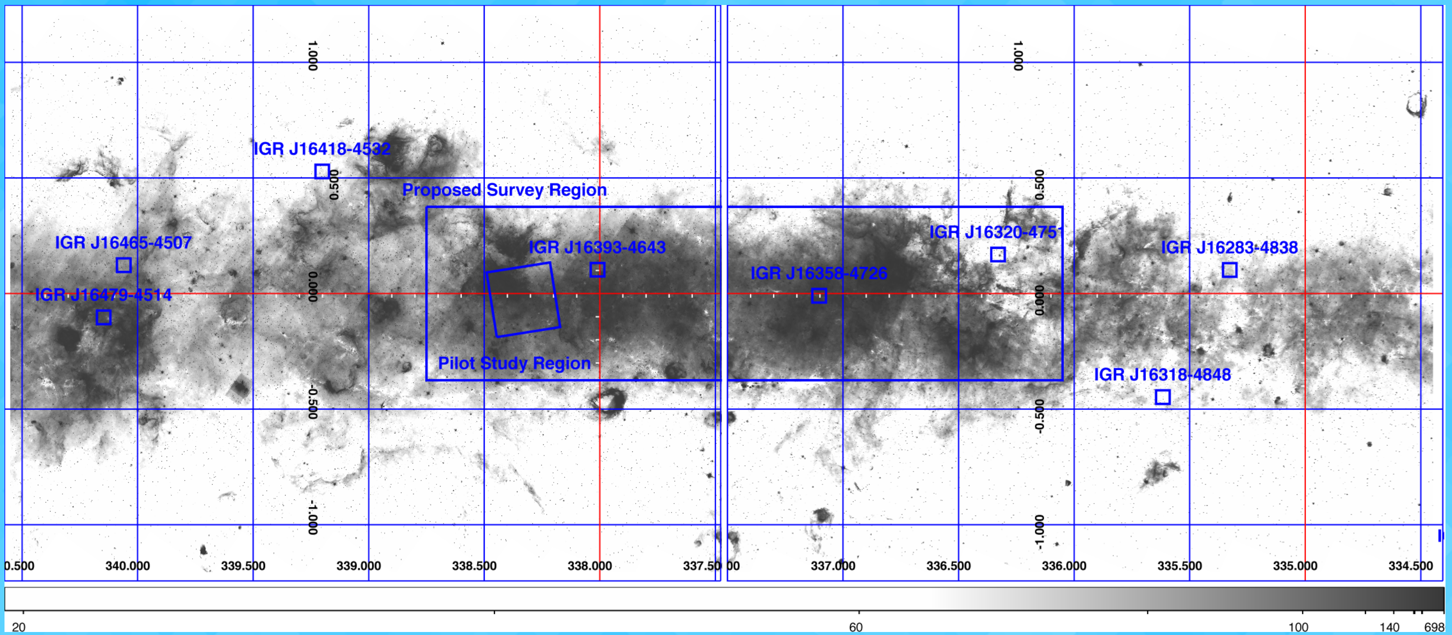
ISGRI 20—60 keV

500 ks beginning June, 2011

2°×0.8° field, 20 ks/pointing

numerous new HMXBs and
other source types
(galactic and extragalactic)

Spitzer 8 μm



other upcoming observations

XMM: 5 HMXB candidates
Chandra: 5 HMXB candidates
19 unclassified sources

Conclusions & perspectives

Don't miss the forest for the trees!

Population studies can go beyond the “simple” imaging, timing, and spectral analyses of individual sources

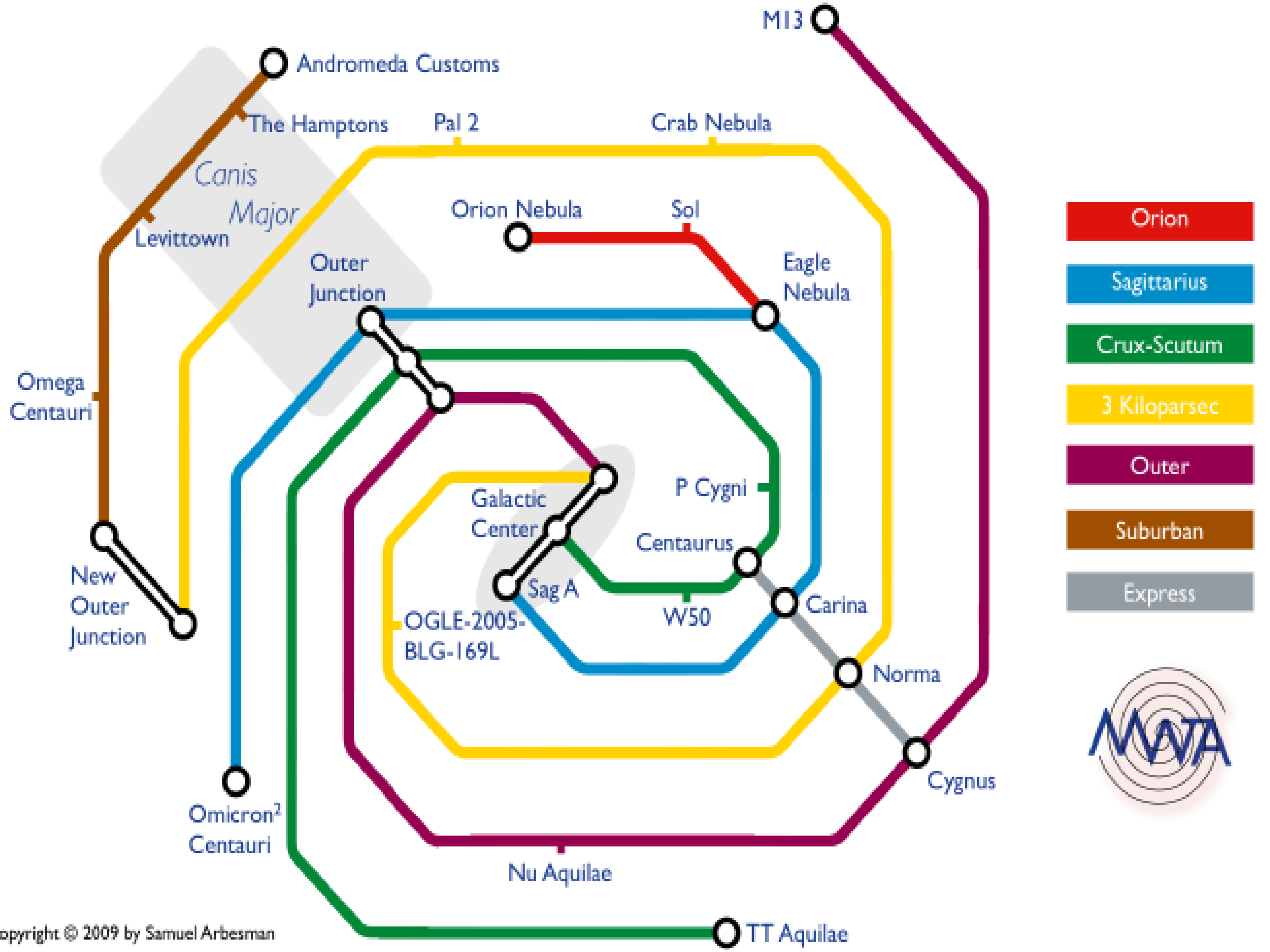
The expanded ranks of Galactic HMXBs provide:

- more reliable statistical analyses
- tighter constraints on models of wind-accreting pulsars
- a better understanding of the evolution of massive stars

For more information, please see:

Bodaghee et al. 2007, 2011 (in prep.)
Tomsick, Bodaghee, Rodriguez, et al. 2011 (coming up!)

irfu.cea.fr/Sap/IGR-Sources


M13
Andromeda Customs
The Hamptons
Pal 2
Crab Nebula
Canis Major
Levittown
Orion Nebula
Sol
Eagle Nebula
Outer Junction
Omega Centauri
P Cygni
Galactic Center
Centaurus
New Outer Junction
Sag A
W50
Carina
OGLE-2005-BLG-169L
Norma
Omicron² Centauri
Cygnus
Nu Aquilae
TT Aquilae
Orion
Sagittarius
Crux-Scutum
3 Kiloparsec
Outer
Suburban
Express
MWTA