High-mass X-ray binary systems through the eyes of INTEGRAL

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Understanding of HMXB population:

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

2) Formation and evolution of binaries, spatial distribution, luminosity function

3) Application for cosmological surveys (distant galaxies, contribution of HMXBs to observed X-ray luminosities)
Nature of a vast majority of XRBs in other galaxies are unknown. Only investigations in our Galaxy can help to answer to above questions about XRBs.

It is not possible to trace the “history” of one system, it is needed to study the population as a whole.

Surveys with the high coverage, sensitivity, completeness of the detection and identifications are required. ROSAT, ASCA, Chandra, XMM-Newton, ASM/RXTE have limitations.

INTEGRAL or Swift have certain advantages.
INTEGRAL/IBIS
All-sky survey
(Krivonos et. al., 2010, current state)

~830 detections (42% IGRs):
  ~50% Galactic (45% IGRs)
  ~40% ExtraGal.
  ~10% Unident.

SWIFT/BAT 70 m
all-sky survey
(Baumgartnet et al., 2013)

~1200 detections:
  ~21% Galactic
  ~60% ExtraGal.
  ~19% Unident.
INTEGRAL/IBIS exposure map

SWIFT/BAT sensitivity map:
Highlights of INTEGRAL in the Galaxy

Discovery more than hundred new sources

New population of HMXBs

Heavily absorbed systems  Supergiant fast X-ray transients

Broadband spectroscopy of XRBs

Discovery and detailed study cyclotron lines

Long term studies of accreting black holes

Populations study of XRBs
V0332+53 – natural laboratory

13.5 years history

High state
\( \alpha = -0.09 \pm 0.01 \)
\( E_{\text{cut}} = 9.15 \pm 0.03 \text{ keV} \)
\( E_{\text{cyc1}} = 26.21 \pm 0.15 \text{ keV} \)
\( E_{\text{cyc2}} = 50.66 \pm 0.30 \text{ keV} \)
\( E_{\text{cyc3}} = 73.8 \pm 1.8 \text{ keV} \)
\( E_{\text{cyc1}}/E_{\text{cyc2}}/E_{\text{cyc3}} = 1/1.93/2.82 \)

Kreykenbohm et al. 2005
Number of known HMXBs is increased significantly
Population study at new level

Walter et al. 2015
HMXB peaked away of the Galactic Center and concentrated towards the spiral arms, but not one-to one. Possible reasons:

Active HMXBs – few Myr to 20-30 Myr -> current SF regions are displaced in a relation to HMXBs due to different angular velocities of stars and spiral arm structure!
Density wave

M 51 HST image

Stars rotation

$\Delta \Theta = (\Omega(r) - \Omega_p) \tau$

Young systems

40 Myr

Shtykovskiy & Gilfanov 2007
HMXBs in the Galaxy
Real sensitivity:
$2 \times 10^{35}$ erg/s

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

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

\( > 2 \times 10^{35} \text{ erg/s} \)
completeness 13 kpc

\( \gamma_{\text{bright}} = 2.0 \pm 0.3 \)

\( > 2 \times 10^{34} \text{ erg/s} \)
completeness 4.1 kpc

\( \gamma_{\text{faint}} = 1.49 \pm 0.21 \)

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

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

Cash (1979)
Density distribution of the HMXBs vs SFR

$N \approx 5 \times 10^{-2} \frac{\text{SFR}}{\text{SFR}_\odot}$

Guesten & Mezger 1982; Lyne, Manchester, & Taylor 1985; Chiappini, Matteucci, & Romano 2001
Our statistically complete flux-limited sample provides clues—what determines the HMXB population:

1) $P_{\text{orb}}$ distribution
2) $M_c$ distribution
\[ \frac{dN}{dM_c} \sim M_c^{-2.35} \] (Salpeter)
\[ \frac{dN}{d\log P} = \text{const} \] (Bhattacharia, Ghosh, 2012)

Orbital parameters
90\% completeness

Lutovinov et al. (2013)
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 (Shakura et al. 2013, 2014)

see talk P.Romano!
\frac{dN}{dM_c} \sim M_c^{-2.35} \quad (\text{Salpeter})

\frac{dN}{d\log P} = \text{const} \quad (\text{Bhattacharia, Ghosh, 2012})
Open issues

- Determination of distances to HMXBs candidates in further part of the Galaxy
- Search for HMXBs in the Galactic bulge
- Total number of HMXBs in the Galaxy

2S1553-542, d≈20 kpc
Tsygankov+ 15,
Lutovinov+ 15
Number of HMXBs in Galaxy, predictions
Figure 19. The observed number-flux distribution compared to the combined estimates of the expected AB/CV, HMXB, and AGN flux distributions based on the luminosity functions of these populations from other surveys. 

Fornasini et al. 2014
Future surveys.
Spectrum-Rentgen-Gamma

Launch 2017
Future surveys, SRG predictions

Large area, sensitivity $\sim 1.18 \times 10^{-13}$ erg/s/cm$^2$

$\sim 130$ persistent HMXBs in MW
Conclusions

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

2) Displacement between maximums of the HMXBs distribution and spiral structure

3) Curved shape of HMXB LF

4) Surface density distribution \rightarrow SFR

5) Predictions for future surveys, search for HMXBs in the Galactic bulge and large distances