HIGH MASS X-RAY BINARIES AND RECENT STAR FORMATION HISTORY

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ABSTRACT

Based on the XMM-Newton observations of Magellanic Clouds we consider the dependence of population of high mass X-ray binaries on the recent star formation history in the host galaxy. Simple N$_{HMXB}$ - SFR linear relation, although applicable on average, fails to explain the spatial distribution of HMXBs over individual star formation complexes in the LMC. Using archival optical observations of the Magellanic Clouds we reconstruct their star-formation histories. Combining these with the X-ray data we determine the N$_{HMXB}$(t) dependence for the SMC, compare results with the predictions of simple model based on supernovae rate and perform the comparison of HMXB formation efficiencies in Large and Small Magellanic Clouds.

Key words: high mass X-ray binaries; Magellanic Clouds.

1. INTRODUCTION

High mass X-ray binaries represent a class of objects composed of a neutron star or a black hole, accreting matter from an early-type massive star. Since life time of a massive star is small, HMXBs are young objects and thus should trace recent star forming activity. As a result, in a simple qualitative picture their number should scale with the star formation rate of the host galaxy. Indeed, based on Chandra observations of nearby galaxies, Grimm et al. [3] have shown, that the X-ray luminosity function (XLF) of HMXBs obeys the universal powerlaw distribution, whose normalization is proportional to the star formation rate of the host galaxy. However, while this simple model agrees well with the observations of populations of HMXBs in nearby galaxies, in the individual stellar complexes the behaviour of N$_{HMXB}$-SFR dependence seems to be more complicated. For instance Shtykovskiy & Gilfanov [4] have shown that universal model fails to explain the spatial distribution of HMXBs over the Large Magellanic Cloud as the spatial density of HMXBs in this galaxy do not correlates with the pattern of the SFR. Instead, the majority of HMXBs are observed in the region of moderate star forming activity (LMC 4), while in the most active star forming region 30 Dor almost none are present. Shtykovskiy & Gilfanov [4] proposed that the observed discrepancy may result from the different ages of these regions and hence different evolutionary phases of the HMXB populations. Indeed, the central region of 30 Dor has a very young age, $\approx 1-2$ Myr. This is insufficient to form compact objects – neutron stars or black holes. On the other hand, sg. shell LMC 4 has more aged population, $t \approx 10-30$ Myr which is more favorable for formation of HMXBs.

From this point of view, the observed universal N$_{HMXB}-$SFR relation is a result of averaging over an overall smooth star formation history (SFH) of the galaxy. On the other hand, in the individual stellar complexes or in galaxies with significantly non-uniform star formation history, the universal relation breaks and an age of the HMXBs population should be taken into account. Based on the XMM-Newton observations of high mass X-ray binaries in Magellanic Clouds, we investigate in details the connection between the population of high mass X-ray binaries and recent star formation history and thus put constraints on the evolution of population of HMXBs after the star formation (SF) event.

2. NUMBER OF HMXBS AS A FUNCTION OF TIME ELAPSED SINCE THE STAR FORMATION EVENT

The evolution of HMXBs population after the star formation event is naturally represented by the time-dependent specific number of HMXBs, defined as the number of HMXBs present after time t elapsed since the SF event, normalized to the mass of massive stellar population formed during this event. In a simplified model the time-dependent behaviour of specific number of HMXBs may be constrained using the rate of supernovae resulting in a compact object:

$$\eta(t) \equiv \frac{N_{HMXB}(t)}{M(>8M_\odot)} \propto (\frac{dN}{dt})_{SN} \cdot f_{opt} \cdot f_{active}, \quad (1)$$

where f_{opt} – fraction of compact objects with proper optical companions, f_{active} – fraction of active systems (in case of transients), $M(>8M_\odot)$ – mass of massive stellar population formed in SF event.

This model is of course oversimplified. More sophisticated calculations concerning the evolution of population of HMXBs should rely on population synthesis models taking into account detailed evolution of stars, the effects of binary evolution etc.

On the other hand, the number of HMXBs observed in some region is a convolution of specific number of HMXBs with the star formation rate (SFR) history in this region:

$$\int SFR(t) \times \eta(t) dt = N_{HMXB} \qquad (2)$$

Given the spatial distribution of HMXBs over MCs and spatial-dependent SFH of the stellar population it is possible to solve the inverse problem posed by this equation and thus reconstruct the behaviour of specific number of HMXBs as a function of time.

3. STAR FORMATION HISTORY IN MAGELLANIC CLOUDS

Star formation history can be obtained directly from the observed stellar populations, provided that one has stellar photometry with sufficient quality in at least two bands. Indeed, as stellar populations of different ages occupy different areas on the color-magnitude diagrams (CMD), it is possible to reconstruct the SFH via the comparison of the observed disribution of stars over the CMD and a model based on the combination of coeval synthetic stellar populations of different ages [1].

Our procedure of the SFH reconstruction consists of the following steps.

(i) Based on a Padua stellar evolution libraries [2] we generate a set of synthetic CMDs covering desired age and metallicity ranges. Each synthetic CMD represents a probability distribution for a model population of coeval stars in a color-magnitude space.

(ii) We then apply correction for interstellar extinction and distance modulus.

(iii) Finally, we approximate the observed CMDs of stars in the Magellanic Clouds from the MCPS catalogue [6, 7] with the linear combination of synthetic CMDs and calculate the uncertainties of the solution.

4. HMXBS AND RECENT STAR FORMATION IN MAGELLANIC CLOUDS

4.1. Small Magellanic Cloud

Given the star formation history of Magellanic Clouds reconstructed in previous section (fig. 1), it is now possible to solve the problem posed by eq. 2 and thus to obtain observational constraints on the N$_{HMXB}$ – t behaviour. Using Lucy-Richardson method and list of HMXB candidates obtained by Shtykovskiy & Gilfanov [5], we solve the inverse problem and obtain constraints on the evolution of specific number of HMXBs. The results are presented on fig. 2. The theoretical behaviour of specific number of HMXBs on this plot is simply a supernovae rate calculated using eq. 1 and renormalized according to calibration of the N$_{HMXB}$–SFR relation [3]. As is clear from figure, the total number of HMXBs in the SMC is consistent in general with predictions of the universal N$_{HMXB}$–SFR relation of Grimm et al. [3]. This appeares to contradict with the common beleive that the SMC is unnaturally overabundant in HMXBs, the high number of HMXBs in the SMC on the contrary simply reflects the intensity of the recent star formation in the SMC. The time behaviour of the curve is also in agreement with the simple model based on the supernova rate, though there is a deficit of young HMXBs.

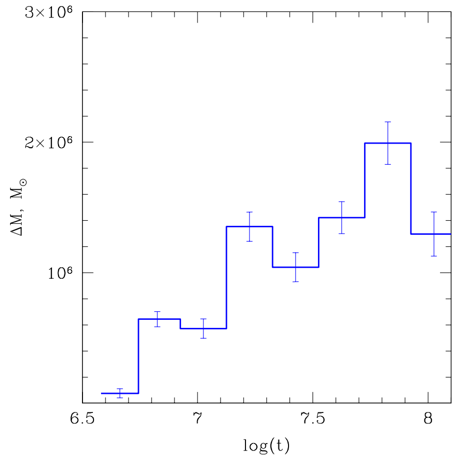

Figure 1. The star formation history of the Small Magellanic Cloud calculated as described in sec. 4.1.

4.2. Large Magellanic Cloud

Due to small number of HMXBs in the LMC the reconstruction of meaningful behaviour of time-dependent specific number of HMXBs is impossible. To get an idea of it's properties, we reconstruct the SFH of the LMC and convolve it with the time-dependent behaviour of specific number of HMXBs for the SMC obtained in previous section. This gives us predictions on the number of HMXBs in the individual regions of the LMC which we compare with observations. The results presented on fig. 3 reveal striking scatter in the observed and expected number of HMXBs, as opposite to results for the SMC where clear correlation is observed. Indeed, while in general the HMXBs in the LMC are underabundant as compared to the SMC by a factor of ≈3, the HMXB formation efficiency in the northern region of the supergiant shell LMC 4 hosting ≈ 8 systems is comparable with the one in the SMC. The results become even more strik-

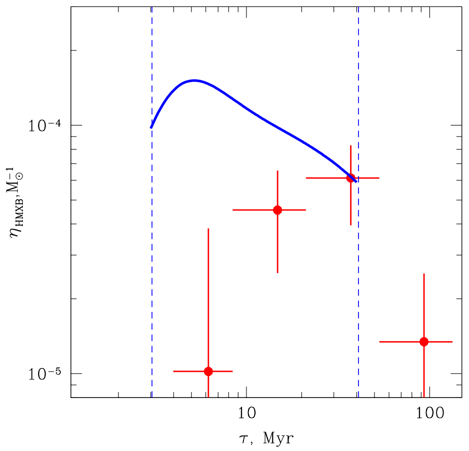

Figure 2. The time dependence of the specific number of HMXBs (red crosses) obtained as described in sec. 4.1 using the spatial distribution of HMXBs over the SMC and the spatially-resolved SFH of this galaxy. The solid line (blue) shows a simple model based on the supernovae rate and normalised according to N_{HMXB}-SFR relation of Grimm et al. [3]

ing when we calculate the expected number of HMXBs, $N_{HMXB}^{exp} \approx 0.5$ for one of the XMM pointings to the LMC 4 well-known for its HMXBs abundance, where 5 out of 8 systems are located.

The reasons for HMXB formation efficiency variations across the LMC and for the discrepancy of total number of HMXBs in Magellanic Clouds are unclear. They may result either from observational effects, such as incompleteness of the HMXB list or distortion of HMXBs spatial distribution due to kicks or due to more fundamental reasons, e.g. variations of the IMF, metallicity dependence of HMXBs etc.

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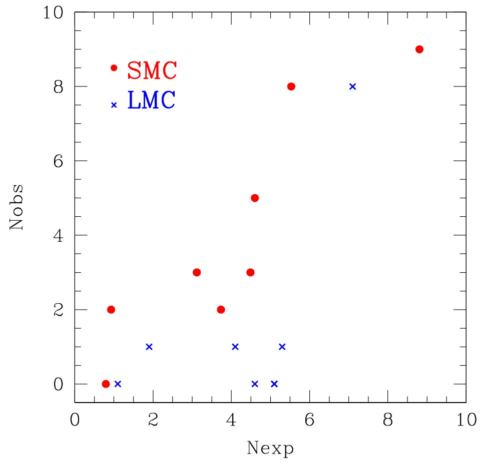

Figure 3. Observed number of HMXBs vs expected number of HMXBs in the individual SMC (points) and LMC (crosses) regions as predicted by the star formation history and time-dependent specific number of HMXBs obtained from the SMC observations.