High-mass X-ray Binaries: Illuminating the Passage from Massive Binaries to Merging Compact Objects
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Clarifying the population of HMXBs in the Small Magellanic Cloud

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Abstract. Almost all confirmed optical counterparts of HMXBs in the SMC are OB stars with equatorial decretion disks (OBe). These sources emit strongly in Balmer lines and standout when imaged through narrow-band Hα imaging. The lack of secure counterparts for a significant fraction of the HMXBs motivated us to search for more. Using the catalogs for OB/OBe stars (Maravelias *et al.* 2017) and for HMXBs (Haberl & Sturm 2016) we detect 70 optical counterparts (out of 104 covered by our survey). We provide the first identification of the optical counterpart to the source XTEJ0050-731. We verify that 17 previously uncertain optical counterparts are indeed the proper matches. Regarding 52 confirmed HMXBs (known optical counterparts with Hα emission), we detect 39 as OBe and another 13 as OB stars. This allows a direct estimation of the fraction of active OBe stars in HMXBs that show Hα emission at a given epoch to be at least $\sim 75\%$ of their total HMXB population.

Keywords. Magellanic Clouds, stars: early-type, stars: emission-line, Be, X-rays: binaries

1. Introduction

The Small Magellanic Cloud (SMC) has been a major target for X-ray surveys for a number of reasons: (i) due to the complete coverage of the galaxy, (ii) our ability to detect sources down to non-outbursting X-ray luminosities ($L_X \sim 10^{33}$ erg s^{-1}), and (iii) its impressive large number of High-Mass X-ray Binaries (HMXBs; Haberl & Sturm 2016). Thus, the SMC is a unique laboratory to examine HMXBs with a homogeneous and consistent approach. However, the X-ray properties alone cannot fully characterize the nature of each source. HMXBs consist of an early-type (OB) massive star and a compact object (neutron star or black hole), which accretes matter from the massive star either through strong stellar winds and/or Roche-lobe overflow in supergiant systems or through an equatorial decretion disk in, non-supergiant, OBe stars (Be/X-ray Binaries; BeXBs). Thus, to understand the nature of HMXBs in general we need to also study their optical counterparts. The OBe stars are massive stars that due to their decretion disks show Balmer lines in emission, of which Hα is typically the most prominent (e.g., see the review by Rivinius, Carciofi & Martayan 2013). Although the SMC is close enough to resolve its stellar population, we still lack the identification of the optical counterparts or their nature for many HMXBs. Out of the ~ 120 HMXBs (of which almost all are actually BeXBs; Haberl & Sturm 2016), the $\sim 40\%$ is listed as candidate systems of this class of objects. By taking advantage of the fact that OBe stars display Hα in emission (i.e., easily discernible in Hα narrow-band images), we performed a wide area Hα imaging survey of the SMC to reveal prime candidates for optical counterparts to HMXBs.

2. Survey and Catalog

We used the Wide Field Imager (WFI@MPG/ESO 2.2m, La Silla, on 16/17 November, 2011) and the MOSAIC camera (@CTIO/Blanco 4m, Cerro Tololo, on 15/16 December, 2011) to observe 6 and 7 fields in the SMC, respectively, covering almost the entire main body of the galaxy. Each field was observed in the R broad-band (the continuum) and Hα narrow-band filters, in order to ensure the proper removal of the continuum and the calculation of Hα excess (for details see Maravelias 2014; Maravelias *et al.* 2017). The exposure time was selected to achieve a similar depth ($R \sim 23$ mag) in both campaigns to cover all late B-type stars at the distance of the SMC.

Using the locus of OB stars (Antoniou *et al.* 2009) we selected the best OB candidate sources, for which we calculated their (H$\alpha - R$) index. From their corresponding distribution we estimate their mean (H$\alpha - R$) and their standard deviation σ. We consider as the most reliable Hα emitting candidates the sources with: $(\mathrm{H}\alpha - R) < \langle \mathrm{H}\alpha - R \rangle - 5 \times \sigma$, and SNR$> 5$ (Maravelias *et al.* 2017). The final catalog consists of ~ 8350 Hα emitting objects out of a parent population of ~ 77000 OB stars.

3. Results

In Maravelias *et al.* (2017) we have performed an initial analysis to derive the ratios of OB stars with emission (OBe) over their total parent OB population, as well as the HMXBs over the OBe population (OBe/OB$\sim 13\%$ and HMXBs/OBe$\sim 0.002 - 0.025\%$, respectively). In this work, we focus in a more detailed treatment of the HMXB population to identify the best optical counterparts. From the most recent census of HMXBs in the SMC by Haberl & Sturm (2016) we remove all rejected and unlikely HXMBs, along with 17 sources that lie outside our Hα survey. Thus, we are left with 104 HMXBs, which we cross-correlate with our catalog to identify the counterparts of 70 HMXBs (see Fig. 1 and its caption for their representation).

We find that the optical counterpart of the source XTE J0050-731 or SXP16.6 (ID#17 in the Haberl & Sturm 2016 catalog) is an Hα emitting OB star. This is the first identification of the optical counterpart of this source (not to be confused with RX J0051.8-7310), and spectroscopy is needed to verify its nature. Moreover, we verify the, previously uncertain, optical counterparts for 17 sources to be OBe (10) or OB (7) stars. Last, we have detected 52 HMXBs, which have confirmed optical counterparts known to display Hα in emission. Out of these sources we find 39 as Hα emitters, while another 13 sources are identified only as OB stars (probably inactive Be stars due to their transient nature). Given these numbers, we estimate that at a given epoch $\sim 75\%$ of HMXBs (BeXBs) are active. Although this is in general agreement with the fraction of active Be stars identified in open Galactic clusters ranging from 50-75% (Fabregat 2003; McSwain & Gies 2005; Granada *et al.* 2018), we point out that it is actually a lower limit of the overall OBe population. This is because our selection criteria for OBe stars are conservative and this photometric approach is not sensitive to OBe stars with relatively faint Hα emission. These results might differ from those based on the census of OB stars in clusters, as we examine a much larger OBe population covering both clusters and the field, in the environment of the SMC which has a much lower metallicity than the Galaxy. This consists a direct measurement of the actual fraction of active OBe stars in HMXBs (BeXBs) that show Hα emission, i.e., an active decretion disk, at a given epoch.

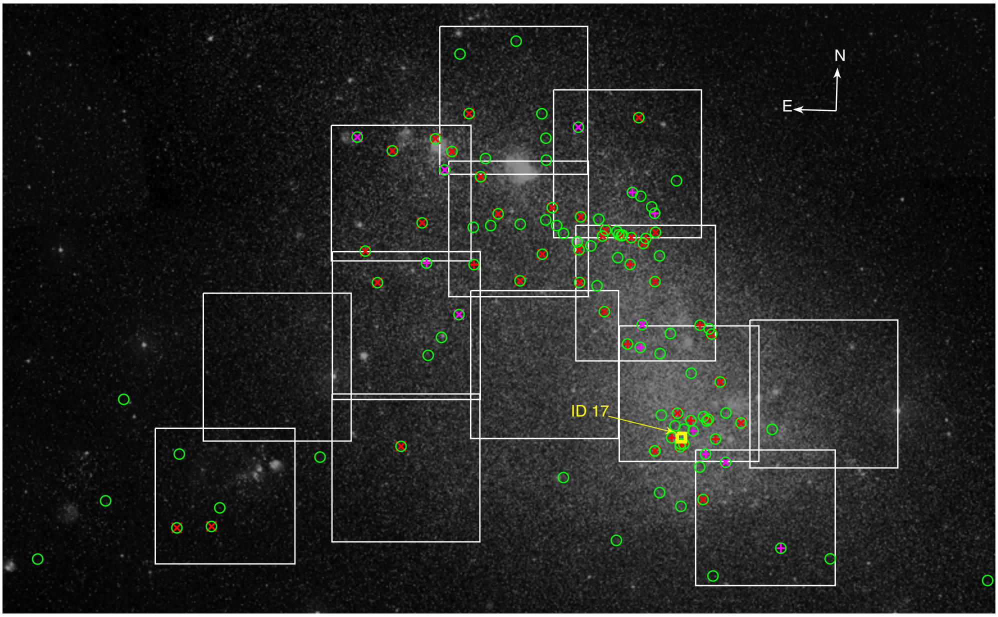

Figure 1. Our observed fields (white boxes) overplotted on a DSS image of the Small Magellanic Cloud. The green circles correspond to HMXBs from the census of Haberl & Sturm (2016), of which 104 lay within our fields and 70 have been identified. One of these is an Hα emitting OB (yellow arrow/box) coinciding with the HMXB ID#17 (Haberl & Sturm 2016; XTE J0050-731; SXP 16.6), an X-ray source without any optical identification previously. For 17 HMXBs we verify their, previously uncertain, optical counterparts to 7 OB stars (magenta crosses) and another 10 OB stars with Hα emittion (red crosses). From 52 HMXBs with confirmed Hα emitting counterparts we identify 39 sources (red X symbols) with Hα excess, and 13 sources (magenta X symbols) are identified as OB stars (inactive OBe, i.e., without Hα emission).

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