Highly-absorbed X-ray binaries in the Small Magellanic Cloud

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ABSTRACT

Many of the high mass X-ray binaries (HMXRBs) discovered in recent years in our Galaxy are characterized by a high absorption, most likely intrinsic to the system, which hampers their detection at the softest X-ray energies.
We have undertaken a search for highly-absorbed X-ray sources in the Small Magellanic Cloud (SMC) with a systematic analysis of 62 XMM-Newton SMC observations.
We obtained a sample of 30 sources showing evidence for an equivalent hydrogen column density larger than 3×10^{23} cm^{-2}.
Five of these sources are clearly identified as HMXRBs: four were already known (including three X-ray pulsars) and one, XMM J005605.8-720012, reported here for the first time.
For the latter, we present optical spectroscopy confirming the association with a Be star in the SMC.
The other sources in our sample have optical counterparts fainter than magnitude ~16 in the V band, and many of them have possible NIR counterparts consistent with highly reddened early type stars in the SMC.
While their number is broadly consistent with the expected population of background highly-absorbed active galactic nuclei, a few of them could be HMXRBs in which an early type companion is severely reddened by local material.

Scientific context

Many observations of the Small Magellanic Cloud (SMC) in the X-ray energy band have led to the discovery of a large number of High Mass X-ray Binaries (HMXRBs). The number of known HMXRBs in the SMC (about one hundred, Liu et al. 2005) is much larger than what would be expected by scaling the number of these sources seen in the Milky Way for the mass ratio of the two galaxies (M_{MW}/M_{SMC} ~ 50). This has been interpreted as evidence for a recent episode of star formation in the SMC (Majid et al. 2004, Shtykovskiy et al. 2007, Antoniou et al. 2010). It is also remarkable that the SMC contains only one supergiant system, SMC X-1. All the other HMXRBs in the SMC consist of neutron stars accreting from Be-type companions. Be/X-ray binaries constitute the largest class of HMXRBs also in our Galaxy, but the relative number of supergiant systems is much higher than in the SMC, since 30 of the 114 Galactic HMXRBs (Liu et al. 2006) are confirmed or suspected supergiant systems.
Many new Galactic HMXRBs have been discovered in the last few years with the INTEGRAL satellite, thanks to good sensitivity in the hard X-ray range, coupled with an extensive monitoring of the Galactic plane. These observations led to the recognition of the new subclass of Supergiant Fast X-ray Transients (SFXT) and to the discovery of persistent supergiant systems characterized by a high absorption (equivalent column density above a few 10^{23} cm^{-2}), which escaped an earlier discovery because the high absorption severely suppresses their flux below 10 keV (see, e.g., Sidoli et al. 2010, for a recent review).
In order to look for the presence of highly-absorbed HMXRBs in the SMC, we have carried out a dedicated analysis of the XMM-Newton data collected during the Large Program for the SMC Survey (Haberl & Pietsch 2008) and other observations of the SMC targets.

XMM/EPIC observations and selection criteria

In order to look for the presence of highly-absorbed HMXRBs in the SMC we have carried out a dedicated analysis of the 62 XMM-*Newton* pointings performed from 2001 May 31 to 2010 March 16:

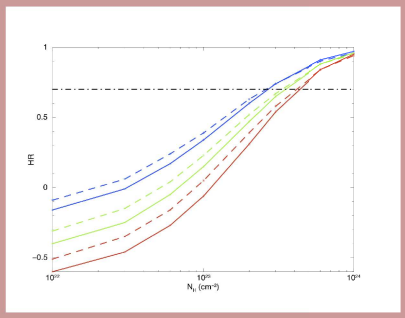
- MOS1 → full frame → net exposure time of 1572 ks
- MOS1 → full frame → net exposure time of 1598 ks
- pn → full frame → net exposure time of 1361 ks

We optimized our source detection strategy in order to select highly absorbed X-ray sources. To this aim we simulated the EPIC count distributions for absorbed power-law spectra with photon-index in the range 1-2 and with:

- an absorbtion component which accounts for absorption in the SMC and intrinsic to the source (N_H = 10^{22} - 10^{24} cm^{-2}, metal abundances = 0.2)
- an abscrbtion component which accounts for foreground absorption in our Galaxy (N_H = 6×10^{20} cm^{-2}, elemental abundances from Wilms et al. 2000)

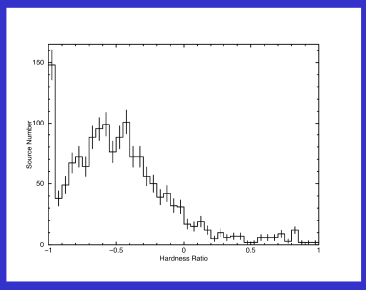
We defined the *Hardness Ratio* HR = (H - S)/(H + S) based on the count rates in the soft (S, 1-3 keV) and hard (H, 3-10 keV) energy ranges and estimated the HR values as function of N_H, for both the pn and MOS cameras and different values of photon-index.

On the basis of these simulations, we adopted a HR threshold value of 0.7, in order to select sources with $N_H > 3 \times 10^{23}$ cm^{-2}



Highly - absorbed X-ray sources

The HR distribution of the ~ 1500 detected sources shows that most of them have HR < 0, with a peak around -0.5, therefore they are characterized by non-absorbed soft spectra. In our final source list there are 30 objects with HR > 0.7, which we consider as highly-absorbed sources with $N_H > 3 \times 10^{23}$ cm^{-2}.



The fluxes of the 30 highly-absorbed X-ray sources have been computed in the 3-10 keV energy range assuming a power-law with photon index of 1.5 and $N_H = 3 \times 10^{23}$ cm^{-2}.
The brightest source has an absorbed flux of 9×10^{-12} erg cm^{-2} s^{-1}, while the faintest sources in the sample have fluxes of ~ 4×10^{-14} erg cm^{-2} s^{-1}, which corresponds to a source luminosity of ~ 2×10^{34} erg s^{-1} for a SMC distance of 60 kpc (Hilditch et al. 2005).

Four already known HMXRBs

Some of our selected sources were already reported in other studies of the SMC. Four sources, including three pulsars, were already known as HMXRBs: SXP25.5 (Haberl et al. 2008a), SXP34 (Shtykovskiy & Gilfanov 2005), SXP293 (Macomb et al. 2003), and SXP323 (Haberl et al. 2008b).

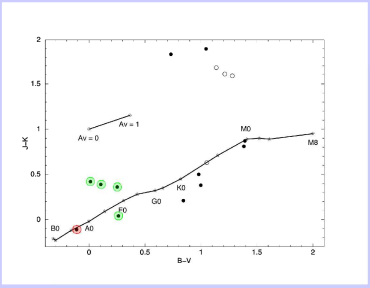
X-ray source	SXP25.5	SXP34	SXP293	SXP323
Rate (3-10 keV, x 10^{-4} cts s^{-1})	35.4 ± 6.2	10.8 ± 3.1	21.4 ± 4.5	13.80 ± 3.0
f_x (3-10 keV, erg cm^{-2} s^{-1})	3.49×10^{-11}	6.81×10^{-12}	1.45×10^{-11}	8.78×10^{-12}
HR	0.72 ± 0.12	0.81 ± 0.28	1.00 ± 0.18	0.77 ± 0.21

The spectrum of the 25 s pulsar SXP25.5 was well fit with a power law of photon index 1.33 ± 0.27 and $N_H = 5 \times 10^{22}$ cm^{-2}, confirming our conclusion that is a highly absorbed source.

The brightest source is the 293 s pulsar SXP293, for which Haberl et al. 2008b reported an absorption $N_H = (1.35 \pm 0.32) \times 10^{22}$ cm^{-2}, considerably smaller than the value we inferred from the hardness ratio. This might be due to the fact that the Haberl et al. 2008b results were obtained from the June 2007 XMM-Newton observation, while our results for this source are based on the SMC Survey pointing carried out in October 2009, when the source was a factor ~ 10 brighter.

Search for optical / NIR counterparts

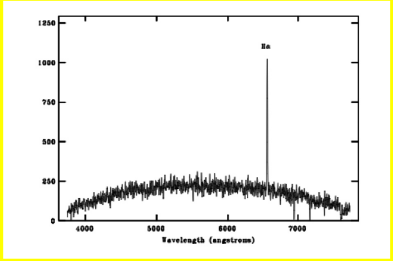
We searched for possible counterparts of our 30 highly-absorbed sources using the optical MCPS catalogue, which is based on observations performed in the U, B, V, and I filters (Zaritsky et al. 2002), and the IRSF Magellanic Cloud catalogue (Kato et al. 2007) for the NIR (J, H, K filters). For five sources no catalogued optical or NIR counterparts were found down to limits of V ~ 23 mag and K ~ 17 mag.
The plot of the NIR vs. optical colors shows that the four already known HMXRBs of our sample are located in the region corresponding to J-K < 0.5 mag and B-V < 0.5 mag (green circles).



Three of these sources are well above the position of the main-sequence stars (Johnson et al. 1966). If they are affected by an IR excess (which could be due to the decretion disk of the Be star), their optical/NIR colors are consistent with early type stars with moderate optical reddening (A_V ~ 2-3 mag). On the other hand, HMXRBs in which also the optical companion is affected by a high local absorption would show much redder colors. Therefore, we cannot exclude that also some of the other sources plotted, or for which no optical and NIR counterparts have been detected, are highly-absorbed HMXRBs.
The five sources at the top of the plot are far from the main-sequence stars, therefore it is difficult to suggest a reliable classification for them. This is particularly true for the three sources shown as open circles, for which also a different counterpart could be suggested.
These five sources could be early-type stars only if they are characterized by both a large IR excess and a high reddening. On the other hand, since for AGNs J-K > 0.5 (Kouzuma & Yamaoka 2010) and -0.4 < B-V < 0.7 (Hatziminaoglou et al. 2002), these sources could be best classified as reddened AGNs.
Of course we do not expect that all the source in our sample are HMXRBs in the SMC. A large fraction of them will turn out to be background absorbed AGNs. On the other hand the sample should not contain foreground stars belonging to our Galaxy, which would show softer and less absorbed X-ray spectra.

XMMU J005605.8-720012: A new Be HMXRB in the SMC

This source has been detected with a total of 68 counts in the hard energy range (3-10 keV) and a HR value of 0.71. It has a relatively bright (V = 16.71 mag) optical counterpart, with color B-V = -0.11 mag, and with a quality flag in the MCPS indicating a successful fit with a stellar atmosphere model. Its candidate NIR counterpart has a K magnitude of 17.18 mag, with color J-K = -0.11 mag. This source falls in the region corresponding to J-K < 0.5 mag and B-V < 0.5 mag in the plot of NIR vs. optical colors (red circle), as the four already known HMXRBs. It has an unabsorbed luminosity, in the energy range 3-10 keV, of 4.4 x 10^{34} erg s^{-1}.



Optical spectral observations of the source XMMU J005605.8-720012 were obtained in September 2010, using the 1.9-meter telescope and the Cassegrain spectrograph at the South African Astronomical Observatory (SAAO) in Sutherland. We used grating number 7 (300 lines per mm) to obtain spectra between 3700 and 7700 angstrom having a resolution of 5 angstrom. The resulting spectrum, which has a single H_{alpha} emission line with equivalent width EW= -37.44 angstrom, is shown in the above figure.
These findings indicate that this new source is a Be HMXRB

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