*The Stellar Content of Local Group Galaxies*
*IAU Symposium, Vol. 192, 1999*
*Patricia Whitelock and Russell Cannon, eds.*

# Optical Counterparts to Be/X-ray Binaries in the Magellanic Clouds

David A. H. Buckley

*South African Astronomical Observatory, PO Box 9, Observatory 7935, South Africa*

James B. Stevens and Malcolm J. Coe

*Dept. of Physics & Astronomy, University of Southampton,*
*Southampton SO17 1BJ, UK*

**Abstract.** We discuss the optical identification of 9 Be/X-ray binary optical counterparts of X-ray sources in the Magellanic clouds, most of them discovered in *ROSAT* observations. Imaging CCD photometry (using $BVR_C$ and H$\alpha$ filters) was employed to search the typically 20 arcsec radius error circles for early-type stars exhibiting H$\alpha$ emission. Spectroscopy of 5 candidates confirmed the presence of H$\alpha$ emission. Based on the positional coincidences, we propose Be star optical counterparts to all of 9 X-ray sources: 6 from *ROSAT* and one each from *ASCA*, *EXOSAT* and *HEAO-1*. All of the sources exhibit the typical X-ray characteristics of Be/neutron star X-ray binaries: transient nature or strong variability, relatively hard X-ray spectra and, in 5 cases, detections of probable neutron star spin periods in the range 8.9 to 91.1 seconds.

## 1. Introduction

Accretion onto a compact object invariably results in X-ray emission, with the luminosity determined by such important parameters as the size and mass of the accreting object and the mass accretion rate. Binaries represent the best laboratories for the study of the accretion process, and the majority (~80%) of the higher mass systems (High Mass X-ray Binaries, or HMXBs) consist of luminous O-B stars ($\gtrsim 8\,M_\odot$) losing mass to neutron star companions.

A substantial fraction of the X-ray sources detected in the Magellanic Clouds are thought to be HMXBs. For example, in the *ROSAT* PSPC survey of the Small Magellanic Cloud (Kahabka et al. 1998), ~30% of the 248 sources detected to a completeness limit of $1-4\times10^{34}$ erg s$^{-1}$ (0.1-2.4 keV) are thought to be hard X-ray binaries (see also Cowley et al., these Proceedings). This conclusion has been reached mainly on the basis of their X-ray properties (e.g. spectral hardness and variability), through a comparison to the Galactic population of HMXBs.

## 2. The Be/X-ray Binaries

The majority of HMXBs are binaries in wide and eccentric orbits, with orbital periods ranging from $10^1$ to $10^3$ days. They typically consist of rapidly rotating Be stars, which are shedding mass in an equatorial disc and a wind. This mass loss powers the weak (by comparison to Roche lobe overflow-driven mass loss), hard, X-ray emission. However, at certain epochs the X-ray luminosity can increase substantially, and is often associated with the periastron passage of the neutron star. At this phase the neutron star may actually 'plough' through the Be star's disc, or even undergo direct Roche lobe overflow from its companion. Many other systems show less regular transient X-ray behaviour, probably due to variations in mass loss from the Be star.

Much progress in understanding the physics of these systems has resulted from recently conducted multi-wavelength (IR–optical–UV–X-rays– $\gamma$-rays) campaigns. Observations in the optical–IR domain shed light on the physical conditions of the Be star discs, and particularly the mass loss rates. In addition, with contemporaneous X-ray observations, which provide direct information on the accretion process, it is possible to investigate the correlation between the mass loss rate of the Be star and the mass accretion rate of the neutron star. Thus it should be possible, through long-term multi-wavelength programs, to build a more complete picture of the accretion process, and to study it as a function of time.

## 3. The Magellanic Cloud Be/X-ray Binaries

Observations of the HMXBs in the Magellanic Clouds show marked differences in the populations. The X-ray luminosity distribution appears to be shifted to higher luminosities relative to the Galactic population. There also seems to be a higher incidence of sources suspected to harbour black holes (e.g. Schmidtke et al. 1994, and references therein). Explanations for this difference have generally invoked lower metallicities.

In order to study the differences between the HMXB populations in the Magellanic Clouds and the Galaxy, it is desirable to determine the physical parameters of as many systems as possible. We can then investigate whether the distributions of mass, orbital period, or spectral type are significantly different.

Most of the sources we have studied are derived from the *ROSAT* survey of the SMC (Kahabka & Pietsch 1996). In some cases these sources have also appeared in the much older *Einstein* survey (Bruhweiler et al. 1987; Wang & Wu 1992), but have remained unidentified until now.

## 4. Identifications of optical counterparts

We present in Table 1 a list of the sources for which we have discovered Be stars as possible optical counterparts. The sample was chosen to include unidentified X-ray sources from which pulsations, variability or transient behaviour has been detected, or X-ray spectral characteristics indicative of HMXB status.

Candidates were selected on the basis of CCD photometry of the X-ray error circles. From $B$, $V$, $R_\mathrm{C}$, $I_\mathrm{C}$ and H$\alpha$ CCD frames, an *H$\alpha$ emission – colour*

Table 1. Magellanic Cloud X-ray sources suspected to be Be/neutron binaries

| Source | Error radius[a] (arcsec) | Pulse Period[b] (s) | No. of candidates | E.W.$_{H\alpha}$ (Å) |
|---|---|---|---|---|
| RX J0032.9-7348 | 62 | | 1 | -35 |
| RX J0049.1-7250 | 22 | 74.7 | 2 | |
| AX J0051-722 | 10 | 91.1 | 1 | -22 |
| RX J0051.8-7231 | 11 | 8.9 | 3 | |
| 1WGA J0053.8-7226 | 15 | 46.6 | 2 | -13 |
| 1WGA J0054.9-7226 | 11 | 59.1 | 1 | -25 |
| RX J0101.0-7206 | 10 | | 1 | -60 |
| EXO 0531.1-6609 | 9 | | 1 | |
| H 0544-665 | 30 | | 1 | |

[a] the radius of the 90% confidence error circle
[b] X-ray pulse period, if detected

diagram was constructed, with $(r_c - H\alpha)$ plotted vertically, and $(b - v)$ plotted on the horizontal axis. In this way relatively blue objects exhibiting an H$\alpha$ excess could be located. Emission candidates for five of the sources were subsequently observed spectroscopically, confirming them to be Be stars.

## 5. Results, summary and discussion

Detailed results will appear in two forthcoming papers (Buckley et al. 1999; Stevens, Coe & Buckley 1999). In most cases only one emission line object has been located in the X-ray error circle (see Table 1), and is therefore a strong candidate for the optical counterpart. Furthermore, the X-ray properties (e.g. variability, spectra, pulses) lend additional support to their classification as HMXBs of the Be/neutron star X-ray binary class.

For five of the SMC sources, recent detections of X-ray pulsations (e.g. by the *Rossi X-ray Timing Explorer* or *ASCA* satellites: Corbet et al. 1998a,b; Israel et al. 1997; Marshall & Lochner 1998) in periods ranging from 9 s to 91 s establish them to be X-ray pulsars, further evidence for their classification as Be/X-ray binaries.

It appears that, especially for the SMC, there is an abnormally large number of Be/X-ray binaries. The log$N$-log$S$ plot for the 71 SMC hard X-ray binaries (Kahabka et al. 1998) implies numbers somewhat in excess of the predictions based on the population synthesis calculations of Dalton & Sarazin (1995). The lower luminosity ($\lesssim 10^{36}$ erg s$^{-1}$) systems may be older from an evolutionary point of view, with slow neutron star rotators in long orbital period Be-systems. This is in accord with the recent discoveries of 8 'slow' X-ray pulsars ($P_{spin}$ ~40–350 s), one with a likely orbital period of 110–120 days (AX J0051-722).

In addition, studies of cluster populations in the SMC show a higher proportion of Be stars amongst earlier spectral types than in the Galaxy, perhaps due to metallicity effects on radiatively driven winds. For a given population of B-star/neutron star binaries, more SMC systems would therefore contain Be stars, leading to accretion-powered X-ray emission.

Alternatively, the star formation history of the SMC may have resulted in a peak in the stellar age distribution, triggered by an SMC/LMC encounter $\sim 10^7$ years ago. This might have led to enhanced formation of binaries of the right mass, which have since had time to evolve into Be/X-ray binaries.

## References

Bruhweiler, F.C., Klinglesmith, D.A. III, Gull, T.R., Sofia, S. 1987, ApJ, 317, 152

Buckley, D.A.H., Stevens, J.B., Coe, M.J., Angelini, L., White, N.E., Giommi, P. 1998b, MNRAS, in press

Corbet, R., Marshall, F.E., Lochner, J.C., Ozaki, M., Ueda, Y. 1998a, IAUC 6803

Corbet, R., Marshall, F.E., Lochner, J.C., Ozaki, M., Ueda, Y. 1998a, IAUC 6788

Dalton, W.W., Sarazin, C.L. 1995, HMXB Modelling: The Magellanic Cloud Populations (preprint).

Israel, G.L., Stella, L., Angelini, L., White, N.E., Giommi, P., Covino, S. 1997, ApJ, 484, L141

Kahabka, P., Pietsch, W. 1996, A&A, 312, 919

Kahabka, P., Pietch, W., Filipovic, M.D., Haberl, F. 1998, A&A, in press

Marshall, F.E., Lochner, J.C. 1998, IAUC 6818

Schmidtke, P.C., Cowley, A.P., Frattare, L.M., McGrath, T.K., Hutchings, J.B., Crampton, D. 1994, PASP, 106, 843

Steven, J.B., Coe, M.J., Buckley, D.A.H. 1999, MNRAS, submitted

Wang, Q., Wu, X. 1992, ApJS, 78, 391

## Discussion

*Hutchings:* Can you comment on the chance of finding a Be star in any random circle of this size in the LMC or SMC? (i.e. is the existence of a Be star inside an error circle a good reason to believe it is the correct identification?)

*Buckley:* The X-ray properties of the sources are all consistent with their classification as Be/X-ray binaries. However, the occurance of emission in B-stars is quite high in the Magellanic Clouds. From our CCD photometry, we find that the average density of H$\alpha$ emission objects is $\sim$0.2 arcminute$^{-2}$. This implies a probability of a normal Be star falling by chance inside an error circle of $\lesssim$5% for most of our sources. Confirmation of the optical counterpart can of course only really be achieved with higher spatial resolution X-ray observations (e.g. with *AXAF*).