An estimate of the SN kick velocities for High Mass X-ray Binaries in the SMC

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ABSTRACT

This work investigates the possible supernova kick velocities imposed on HMXB systems in the Small Magellanic Cloud. Comparisons are made between the location of such systems and the locations of young, stellar clusters on the premise that these may represent the birthplace of many of these systems. Measurements of the separation of clusters and HMXBs, and an estimate of the typical lifetimes of these systems, leads to a minimum average space velocity 30 km/s. This value is compared to theoretical estimates.

Key words: stars: neutron - X-rays: binaries - Magellanic Clouds

1 INTRODUCTION AND BACKGROUND

The Be/X-ray systems represent the largest sub-class of massive X-ray binaries. A survey of the literature reveals that of the 115 identified massive X-ray binary pulsar systems (identified here means exhibiting a coherent X-ray pulse period), most of the systems fall within this Be counterpart class of binary. The orbit of the Be star and the compact object, presumably a neutron star, is generally wide and eccentric. X-ray outbursts are normally associated with the passage of the neutron star close to the circumstellar disk (Okazaki & Negueruela, 2001). A recent review of these systems may be found in Coe (2000).

X-ray satellite observations have revealed that the Small Magellanic Cloud (SMC) contains an unexpectedly large number of High Mass X-ray Binaries (HMXB). At the time of writing, 47 known or probable sources of this type have been identified in the SMC and they continue to be discovered at a rate of about 2-3 per year, although only a small fraction of these are active at any one time because of their transient nature. Unusually (compared to the Milky Way and the LMC) all the X-ray binaries so far discovered in the SMC are HMXBs, and equally strangely, only one of the objects is a supergiant system, all the rest are Be/X-ray binaries.

Portegies Zwart (1995) and Van Bever & Vanbeveren (1997) investigate the evolutionary paths such systems might take and invoke kick velocities of the order 100 - 400 km/s. In an investigation into bow shocks around galactic HMXBs Huthoff & Kaper (2002). They then used Hipparcos proper motion data used to derive associated space velocities for Be/X-ray and supergiant systems. From their results, an average value of 48 km/s is found for the 7 systems that they were able to fully determine the three dimensional motion. Since this is rather lower than the theoretical values it is important to seek other empirical determinations of this motion.

This paper addresses what may be learnt about kick velocities by looking at the possible association of HMXBs in the SMC with the nearby young star clusters from which they may have emerged as runaway systems. A review of the properties of the optically (and/or IR) identified counterparts to the X-ray pulsars is presented in Coe et al. (2005). In that paper the authors introduce the nomenclature of SXPnnn for the systems, where SXP stands for Small Magellanic Cloud X-ray Pulsar, and the numbers nnn identify the X-ray pulse period in seconds. This simplified identification is used here. The SMC cluster data come from an extensive review of the spatial location of stars by Rafelski & Zaritsky (2004). Clusters from this paper are hereafter referred to as RZ clusters.

2 BIRTHPLACES AND KICK VELOCITIES

There is considerable interest in the evolutionary path of High Mass X-ray binary systems (HMXBs), and, in particular, the proper motion of these systems arising from the kick velocity imparted when the neutron star was created.

3 ANALYSIS

It is critical to use the exact position for the SXP sources if distances are to be measured - some have X-ray positional
errors of a few arcminutes. Consequently, only the SXP objects from Coe et al. (2005) which had precise optical counterparts were selected for this work. This resulted in an SXP list of 17 objects.

Firstly the spatial distributions of SXPs and the RZ clusters within the SMC were checked to ensure adequate matching coverage around the regions occupied by the SXP objects. This was found to be satisfactory - see Figure 1. The OGLE catalogue of SMC clusters (Pietrzynski et al., 1998) was also considered, but this has restricted coverage and several of the SXP sources fell outside the OGLE region.

In order to determine whether the SXP sources may have originated from a nearby stellar cluster, the coordinates of the SXP objects were compared to those of the RZ clusters. For every SXP its position was compared to the location of all of the RZ clusters and the identification of the nearest cluster neighbour obtained. The results from this search are presented in Table 1.

The average distance between the pairs of objects listed in Table 1 was found to be 3.85 arcminutes. The histogram of the distances between each SXP source and the nearest RZ cluster is shown in the upper panel of Figure 2. Obviously it is important to ensure that the SXP-RZ cluster distances are significantly closer than a sample of randomly distributed points. One way to determine this is simply to just use the RZ cluster data and find the average cluster-cluster separation. This gives a value of 6.13 arcminutes. Alternatively, the rectangular region indicated in Figure 1 was used, and the minimum distance between 100,000 random points and, in each case, the nearest RZ cluster was found. The average value was found to be 5.30 arcminutes and the corresponding histogram is shown in the lower panel of Figure 2. From comparing the two histograms it is clear that there does exist a much closer connection between SXP sources and RZ clusters than expected randomly.

This conclusion may be tested further using either the Kolmogorov-Smirnov (K-S) test or the Student t-test to quantify the probability that the two distributions are distinctly different. The K-S test gives a probability of 9% that the two distributions are the same, whereas the t-test gives a value of 3% that the means are the same. Thus the above conclusion (that the SXP sources are closer to the clusters than random) is well supported, but not overwhelmingly so.

A sample of 4 SXP objects and their nearest RZ cluster is shown in Figure 3. The image shown is from the digitised sky survey red band.

Figure 1. Distribution of SXPs (shown as crosses) and RZ clusters (shown as squares) in the SMC. The rectangular box indicates the region used for the random sampling comparison - see text.

Table 1. Table of optically identified SXP objects and, in each case, the nearest RZ cluster and its distance away from the SXP source.
4 DISCUSSION

If the distance of 3.85 arcminutes is indicative of the distance the SXP pulsar systems have travelled on average since birth, then this value may be used to estimate the kick velocity of the systems. To do this one first needs to convert the angular separation into a real distance. Using a value of 60 kpc for the distance to the SMC, then 3.85 arcminutes corresponds to 65 pc. To compute a velocity one has to have some estimate of the likely travel time of the SXP system since birth. An upper limit on this may be taken from the evolutionary models of Savonije & van den Heuvel (1977) who estimate the maximum possible lifetime of the companion Be star after the creation of the neutron star to be 5 million years. However, in the same paper they estimate the spin down time of the pulsar since creation to be less than 600,000 years. If we take the lower limit (the spin down time) then the minimum average velocity of the SXP...
systems projected on to the sky is 130 km/s. This number is significantly higher than the numbers presented by other authors, for example van den Heuvel et al. (2000). Those authors interpreted the Hipparcos results for galactic HMXBs (Chevalier & Ilovaisky, 1998) in terms of models for kick velocities, and concluded that values around 15 km/s were more appropriate for such systems. So if, instead, the lifetime number of 5 million years is used, then transverse velocity components of 16 km/s are obtained.

In either case, assuming the systems are moving in completely random directions compared to our line of sight, then the true average space velocity will be a factor $\sim 2$ greater, i.e. an average of 32 km/s in the second case.

Finally, the ages of the RZ clusters associated with the SXP sources are of significant interest. Using the extinction corrected ages presented in Table 2 of Rafelski & Zaritsky (2004) it is possible to determine the mean age to be $130 \pm 140$ Myrs. As can be seen from the histograms presented in their paper, this is very much at the young end of their sample distribution. It therefore reinforces the suggestion that the clusters identified with the SXP sources are very likely to be the correct parent clusters for these objects.

5 CONCLUSIONS

As a result of the study of HMXBs in the SMC it has been shown that there exists a convincing link between the these systems and nearby stellar clusters. Accepting this link, leads to a determination of the average space velocity of the systems arising from the SN kick to be $\sim 30$ km/s. This value is in good agreement with observational and theoretical values.

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