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Astrometric detection of Neutron Star Companions to High Mass X-ray Binaries

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Abstract. We consider the feasibility of detecting neutron star companions to High Mass X-ray Binaries (HMXBs) using astrometric techniques, specifically for accuracies expected for the upcoming Gaia satellite. The direct determination of orbital parameters of HMXBs will increase the census of measured neutron star masses.

Keywords. X-rays: binaries, Stars: neutron, Astrometry

The brightest X-ray sources in the Galaxy are X-ray binaries, where a compact object such as a black hole, neutron star or white dwarf accretes matter from a normal stellar companion either by Roche Lobe overflow or a stellar wind. The mass of the companion and the parameters of the system can be derived or estimated if an eclipse occurs or through radial velocity variations. However, a more accurate determination is provided by a direct astrometric measurement of the non-linear motion of the stellar companion due to the hidden compact object. What we seek to do is to use the very high positional accuracies which the Gaia satellite will achieve for a large number of HMXRBs to investigate the masses of the compact companions. We take a number of representative HMXRBs and estimate their masses and distances. We then estimate their initial masses and a corresponding expected range of possible orbital separations. Finally we determine the range of orbital separation within which Gaia's positional accuracy would be sufficient to infer the presence of a hidden companion for these specific cases. Hence we can determine a probability of neutron star detection.

Table 1. HMXBs with known orbital periods

Name	Name	Name	Name	Name
QV Nor	V801 Cen	V635 Cas	0834-430	J0535.0-6700(LMC)
Vela X-1	Cen X-3	BQ Cam	1657-415	SMC 34
LS 5039	BP Cru	V572 Pup	J2103.5+4545	SMC 37
V725 Tau	X Per	V830 Cen	0535-668	J0053.8-7226(SMC)
V441 Pup	V662 Cas	V850 Cen	LMC X-4	SMC X-1
V884 Sco	γ Cas	J2239.3+6116	LMC 218	SMC 58
V615 Cas				

[a] Orbital period from (Harmanec *et al.* 2000). [b] Values taken from (McSwain *et al.* 2004). We adopt distances of 49kpc to the LMC and 58kpc to the SMC (Mateo 1998).

As an illustrative example and comparative base we use the the HMXB catalogue of Liu *et al.* (2000) and restrict ourselves to those systems for which an orbital period is known. These include two systems for which we found the orbital period listed in the literature: γ Cas (Harmanec *et al.* 2000) and LS 5039 (McSwain *et al.* 2004).Three of the

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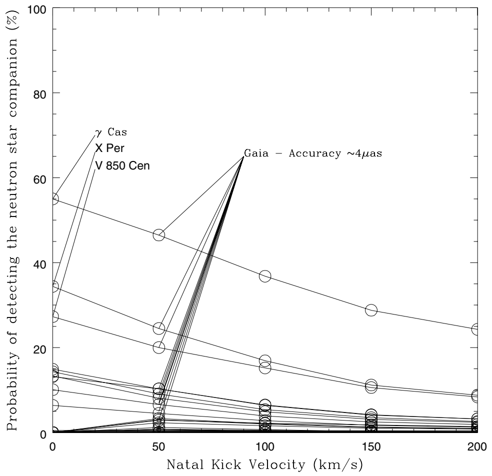

Figure 1. Percentage probability of Gaia detecting a neutron star companion to each of the HMXB sample stars, considering a theoretical set of possible system configurations that survive the supernova. The probabilities are shown as a function of the natal kick velocity to the neutron star, due to asymmetries in the supernova explosion

objects are left out even though they meet our criteria: Cyg X-1, LMC X-1, LMC X-3, which are black-hole binaries, for the reason that the ideas developed for determining the theoretical range of separations apply specifically to neutron star companions. This gives a total of 31 objects, 22 galactic and 9 extragalactic, see Table 1. Using their observed quantities such as magnitude, colour index and spectral type we calculated their approximate distances and estimated their masses.

From the estimated masses we can calculate what the likely initial masses were. Then, using an initial distribution for the semi-major axis we determine what the likely final separation distribution might be due to the effects of mass transfer and the supernova explosion of the primary (initially most massive star). Next we can determine what range of detectable separations Gaia will have. The presence of a compact companion can be inferred due to the non-linear motion of the bright stellar component of the binary. This means that the semi-major axis must be greater than some threshold value in order for the perturbation to normal straight line motion to be detectable. There is also a maximum semi-major axis due to the finite length of the mission resulting in possibly only a partial part of the orbit being sampled within this time. Thus giving us the limits for our detection range specific to each of our sample cases. For more details see Ó Maoiléidigh *et al.* (2005). Figure 1 illustrates the percentage probability of detection for our sample stars.

As is evident from Figure 1 the probability of detection is significant for a number of systems. Since we have known orbital periods for our sample we can see which system would actually be detected. γ Cas and X-Per have a sufficiently long period and are close enough to be detected astrometrically. This is about a 6% detection rate from our sample. However if we only consider galactic objects then this improves to about 9%.

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