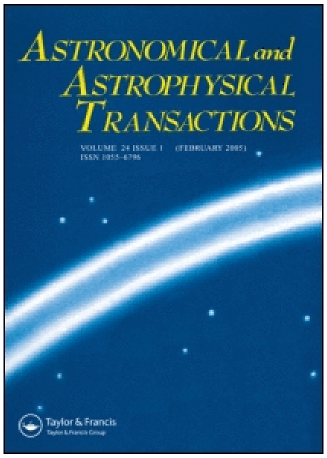

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Using the values of N_{HI} and A_V to improve the distances to some X-ray binaries and supernova remnants

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USING THE VALUES OF $N_{\rm HI}$ AND A_v TO IMPROVE THE DISTANCES TO SOME X-RAY BINARIES AND SUPERNOVA REMNANTS

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We chose some X-ray binaries and supernova remnants each of which has a direction in which more than four early type stars with known values of neutral hydrogen column density and interstellar optical absorption are located. These data give us the chance to improve the distances to two X-ray binaries and one supernova remnant.

KEY WORDS Neutral hydrogen column density, optical absorption coefficient

1 INTRODUCTION

There are several methods to determine the distances to galactic supernova remnants (SNRs), but the errors for the distance values are large in all cases and the reliabilities of these methods vary greatly from one to another. The average sample error is about 50% for SNR distances, but for some SNRs the error may be more than 100%. Only in a few cases are the distances well known.

For X-ray binaries with identified optical components the determinations of distances are possible, but these distance values are less reliable compared to the distance values of single stars, because the optical components are in the mass-loss stage and because of the influences of the X-ray irradiation.

It is known that among all objects in the galaxy the best distance values can be obtained only for stars on the main sequence and for giants. Therefore, comparing the optical absorption coefficient, A_v, and neutral hydrogen column density, $N_{\rm HI}$, values of X-ray sources and SNRs with the values of stars having the same directions with the X-ray sources and the SNRs may help us to estimate the distances.

In our Galaxy the scale height of dust clouds is about 60–70 pc. For H I clouds the scale height is about three times greater than that of the dust clouds. Because of this, it is not useful to try to find relations between A_v and $N_{\rm HI}$ for regions with Galactic latitudes greater than about 3–5° for distances greater than about 700–1000 pc.

H I is more homogeneous with respect to dust, but its density is also very different in H I, H II regions and in intergalactic-arm regions. Also, we must not forget that there may be some huge changes in dust density with distance in the line of sight. So, A_v–$N_{\rm HI}$ relations for the whole Galactic plane are not useful. If we want to find better relations between A_v and $N_{\rm HI}$ then we have to look at regions with small angular sizes.

As the distance increases the value of A_v also increases in the Galactic plane, but differently for different distances. If we increase the widths of the regions to increase the number of data points then we can find A_v–$N_{\rm HI}$ relations with relatively small errors for all distances, but this has no physical significance. We must remember that we can always find some relations between any two quantities that are time or distance dependent even if there is no real relation between them.

2 DISTANCES TO SOME SNRs AND X-RAY BINARIES

It is known that A_v values may considerably differ for stars at the same distances with angular separation of about 1° or more (Neckel and Klare, 1980). The characteristic size of inhomogeneity for the H I distribution is several times larger than for the dust. So, we may combine the stars with angular separation up to about 4°, as we do not have large number of stars in each direction. There are more than 700 stars with known $E(B-V)$ and $N_{\rm HI}$ values (Diplas and Savage, 1994; Fruscione *et al.*, 1994). We chose some of these stars and made several groups which contain four or more stars having small angular separations. We used the values of A_v and $N_{\rm HI}$ of the chosen stars to estimate the distance values of X-ray binaries and SNRs with known A_v and/or $N_{\rm HI}$ values.

We considered the data of SNR W28 (Green, 1996), the low mass X-ray binary (LMXB) 2318+620 and the high mass X-ray binary (HMXB) 1145–619 (van Paradijs, 1993) located in or very close to the directions of the chosen stars and we directly compared those values with the A_v and $N_{\rm HI}$ values of the stars. We tried to use our A_v–$N_{\rm HI}$ relations for each of the groups of stars to check A_v and $N_{\rm HI}$ values of the X-ray binaries and the SNR, too. We also used the data given by Neckel and Klare (1980). We compare the A_v values given in that paper with the A_v values of the X-ray binaries and the SNR to criticize the distance values of these objects given in the literature. We included some other hot stars which are not members of our groups of stars, but have directions close to the directions of the X-ray binaries and the SNR. The data of these hot stars are also taken from Diplas and Savage (1994) and Fruscione *et al.* (1994).

2.1 Direction 1

In this direction there are eight stars and all of them are at the same distance from the Sun: $d = 1.6$ kpc. Stars with numbers 2, 4, 5, 7 and 8 belong to SGR OB1 which has a distance of 1.6 kpc (Humphreys, 1978). Melnik and Efremov (1995) give a distance of 1.5 kpc for this association. Stars with numbers 2,4 and 5 simultaneously belong to the open cluster (OC) NGC 6530 (C1801–243) which has a distance of 1.6 kpc (Lynga, 1987). According to Ahumada and Lapasset (1995) NGC 6530 has $E(B-V) = 0.35$ mag. It is possible that all of the stars in this direction belong to SGR OB1. A simple (linear) relation between A_v and $N_{\rm HI}$ for this direction is $A_v = 4.4 \times 10^{-22} \times N_{\rm HI}$ cm^2 mag $+0.18$ mag. It is necessary to remember that all the stars have the same distance, therefore different values of A_v and $N_{\rm HI}$ are due to small differences in the directions of the stars.

SNR W28 is located in this direction, but it is considerably farther away with respect to the OB association, SGR OB1. If we want to compare the values of A_v for SNR W28 (G6.4–0.1) with the values of A_v given by Neckel and Klare (1980) for this direction, the most convenient region is No. 240 (centred at $l = 8°$, $b = 0°$). In that paper, the dependence of A_v on distance is given up to 3 kpc in this direction. For the region No. 240 the average value of A_v may be close to 1 mag up to 3 kpc. The value of A_v for SNR W28 is equal to 3.2–4.2 mag according to Long *et al.* (1991) and is about 3.2 mag according to Fesen and Hurford (1995). The distance values given for W28 are: 2.5 kpc (Sahibov and Smirnov, 1983), 2 kpc (Allakhverdiyev *et al.*, 1986), 2 kpc (Frail *et al.*, 1994, using the interaction of the SNR with an OH maser source) and 3.5–4 kpc (Green, 1996). For W28 Long *et al.* (1991) give $N_{\rm HI} = (7\text{–}11) \times 10^{21}$ cm^{-2} and adopt 8×10^{21} cm^{-2}. If we use the relation between A_v and $N_{\rm HI}$ for this direction and the value of $N_{\rm HI} = 9 \times 10^{21}$ cm^{-2} then we find $A_v = 4.14$ mag which is in good agreement with the values given by Long *et al.* (1991) and Fesen and Hurford (1995). Therefore, if we take into account all the data given above, then we may adopt the distance value of 3.5–4 kpc given by Green (1996) for W28.

Kaspi *et al.* (1993) discussed a possible association of W28 with pulsar PSR J1801–2306 for which the value of the dispersion measure (DM) is equal to 1074 pc cm^{-3}. There is no other known PSR with such a large DM and for a distance of about 12–13 kpc the number density of electrons in the line of sight is greater than for all other known PSRs in this direction. According to Frail *et al.* (1993) W28 and the PSR can be at the same distance, but according to Allakhverdiev *et al.* (1996) this is not possible. So, checking the distance of W28 is important. It is difficult to give a distance value greater than 4–5 kpc for W28, because beyond this distance there is a large discrepancy between the diameter and the surface brightness of the SNR.

2.2 Direction 2

This direction contains only four stars and all of these stars belong to CEP OB3 which has a distance of 0.87 kpc according to Humhreys (1978), about 0.8 kpc according to Garmany and Stencel (1992) and 0.9 kpc according to Melnik and Efremov (1995).

LMXB 2318+620 has a direction which is very close to this direction. The $N_{\rm HI}$ value of LMXB 2318+620 is 1.5×10^{21} cm^{-2} and from the relation between A_v and

Table 1. Data of stars, X-ray binaries and SNR

No.	*HD/name*	*l* (*degrees*)	*b* (*degrees*)	A_v (*mag*)	$N_{HI} \times 10^{21}$ (cm^{-2})	*Distance* (*kpc*)
			Direction 1			
1	CPD-246121	5.97	−0.91	0.83	1.4	1.6
2*	164794	6.00	−1.20	1.12	2.2	1.6
3	315032	6.02	−1.29	0.90	1.8	1.6
4*	164816	6.06	−1.20	0.93	1.5	1.6
5*	165052	6.12	−1.48	1.31	2.3	1.6
6	315021	6.12	−1.33	0.99	1.9	1.6
7*	163892	7.15	0.62	1.28	2.1	1.6
8*	164402	7.16	−0.03	0.80	2.0	1.6
	SGR OB1					1.6, 1.5
	OC NGC 6530			1.12		1.6
	SNR W28	6.4	−0.1	3.2–4.2	7–11	2.0, 2.5
				~ 3.2		3.5–4.0
			Direction 2			
9*	217035	110.25	2.86	2.43	2.9	0.9
10*	217312	110.56	2.95	2.14	3.0	0.9
11*	217297	110.82	3.52	1.82	3.0	0.9
12*	218342	111.39	2.73	2.27	3.3	0.9
	CEP OB3					0.9,0.8,0.9
	LMXB 2318+620	112.6	1.3	1.00	1.5	3.0–6.0
			Direction 3			
13*	99953	293.93	−2.13	1.57	3.0	2.4
14	100444	294.35	−2.09	1.50	2.5	4.3
15*	101008	294.71	−1.72	0.93	1.7	2.4
16*	101190	294.79	−1.49	1.15	1.4	2.4
17	308813	294.79	−1.61	0.96	1.4	2.4
18*	101205	294.85	−1.65	1.22	1.6	2.4
19*	101298	294.85	−1.69	1.22	1.8	2.4
20*	101413	295.03	−1.71	1.15	1.7	2.4
21*	101436	295.04	−1.71	1.22	1.7	2.4
	CRU OB1					2.4, 2.7
	HMXB 1145-619	295.6	−0.2	1.1	3.0	2.1, 1.5
	102475	295.59	−0.48	0.70	1.1	4.5
	103779	296.85	−1.02	0.67	1.4	4.1
	104705	297.45	−0.34	0.83	1.3	3.9

$N_{\rm HI}$ the value of A_v is 1.0 mag (Taylor *et al.*, 1991). This value is in good agreement with the data given in Table 1 for this direction. Therefore, the distance of this LMXB is probably not greater than the distance of CEP OB3 (see Table 1), but according to Taylor *et al.* (1991) its distance which is found from the Galactic rotation model using the radio line is 3–6 kpc.

When we also compare the value of A_v of LMXB 2318+620 with the dependence of A_v on distance for the region No. 351 (centred at $l = 111.5°$, $b = 0.5°$) (Neckel and Klare, 1980) we see that this X-ray source must be at a distance between 0.5 kpc and 1 kpc. The luminosity of LMXB 2318+620 changes between 10^{34} and 10^{35} erg s^{-1} (Taylor *et al.*, 1991). If the distance value of this X-ray source is between 0.5 and 1 kpc then its luminosity must be 1–2 orders smaller, so that this source may not be a LMXB but a cataclysmic variable.

2.3 Direction 3

This direction contains nine stars, seven of which belong to CRU OB1 with a distance of 2.4 kpc (Humphreys, 1978) or 2.7 kpc (Melnik and Efremov, 1995). The star HD 100444, with a distance of about 4.2 kpc, has A_v and $N_{\rm HI}$ values close to the values of HD 99953 for which the distance is only about 2.4 kpc. For this direction the relation between A_v and $N_{\rm HI}$ may be represented as: $A_v = 3.5 \times 10^{22} \times N_{\rm HI}$ cm^2 mag+0.57 mag.

Close to this direction there is HMXB 1145–619 with a distance of about 1.5 kpc (Dower *et al.*, 1978). Van Oijen (1989) gives a distance of 2.1 kpc for this X-ray binary. But if we compare $A_v = 1.1$ mag (using the data $E(B-V) = 0.35$ mag given by Waters *et al.* (1988)) and $N_{\rm HI} = 3.0 \times 10^{21}$ cm^{-2}, $d \cong 8$ kpc (Mereghetti *et al.*, 1987) values of this X-ray binary with the data of the stars in this direction we see that the distance of this binary must be close to 3 kpc. The A_v and $N_{\rm HI}$ values of this HMXB fit well to the A_v–$N_{\rm HI}$ relation for this direction. To check this result, in Table 1 we give the data of three stars which do not belong to this group of stars but have directions close to the direction of HMXB 1145–619. We can easily see that in the direction of the three stars the A_v and $N_{\rm HI}$ values are very small for a distance of about 4 kpc. The average values for these three stars are: $A_v = 0.73$ mag and $N_{\rm HI} = 1.3 \times 10^{21}$ cm^{-2}. HD 102475 has l and b coordinates very close to the coordinates of HMXB 1145–619. This star has A_v, $N_{\rm HI}$ and d values of 0.70 mag, 1×10^{21} cm^{-2} and 4.5 kpc, respectively, so the distance of HMXB 1145–619 may be about 4 kpc.

If we also consider the data for the regions No. 149 (centred at $l = 295°$, $b = -1.5°$) and No. 151 (centred at $l = 296°$, $b = -1°$) given by Neckel and Klare (1980) then we see that the value of A_v is about 1 mag and does not exceed 2 mag up to 4–5 kpc. Therefore, HMXB 1145–619 may have a distance of aboat 4 kpc.

3 CONCLUSION

We criticized the distance values of two X-ray binaries, LMXB 2318+620 and HMXB 1145–619, and one SNR, W28, which are located in or close to the directions of some stars with known values of A_v and $N_{\rm HI}$.

In the discussion of the distance values of the X-ray binaries and the SNR:

(1) We used our A_v–$N_{\rm HI}$ relations to find or to check A_v or $N_{\rm HI}$ values of the X-ray binaries and the SNR with known A_v and/or $N_{\rm HI}$ values.

(2) We compared A_v and $N_{\rm HI}$ values of the stars in the groups with the values of the X-ray binaries and the SNR.

(3) We also compared A_v and $N_{\rm HI}$ values of some other hot stars which are not members of our groups but have directions very close to the directions of the X-ray binaries and the SNR with A_v and $N_{\rm HI}$ values of the X-ray binaries and the SNR.

(4) We used the dependence of A_v on distance for some regions given in Neckel and Klare (1980).

We have obtained some specific results for the distances of the X-ray binaries and the SNR. It is necessary to remember that estimating the distance values of these objects with different methods is very important. We enumerate these objects in the order of the numbers of the directions to which they belong:

(1) The best distance value for SNR W28 may be about 3.5–4 kpc given by Green (1996). The association of W28 with PSR J1801–2306 (d = 13.5 kpc) does not have a serious basis.

(2) LMXB 2318+620 may have a distance value less than or approximately equal to 1 kpc instead of 3–6 kpc given by Taylor *et al.* (1991). In this case, its luminosity may be about 10^{32}–10^{33} ergs s^{-1} so that it may not contain a neutron star but a white dwarf.

(3) The distance to HMXB 1145–619 may be about 4 kpc instead of 1.5 kpc (Dower *et al.*, 1978), 2.1 kpc (van Oijen, 1989) and $\sim$ 8 kpc (Mereghetti *et al.*, 1987).

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