1 Determination of Distance

In this study, we use the hydrogen column densities (N_H) taken from the literature and convert them to extinction in visual band (A_V). Since we need NIR extinction (A_{K_s}) for each source, we derive it using the $A_{K_s} = R_{K_s} \times A_V$ relation. We determine the distances to sources by means of red clump giants (RCG).

1.1 Estimation of Extinction to Sources

In order to determine Near-Infrared (NIR) extinction we collected hydrogen column densities toward the sources and convert them to A_V using the $N_H = (2.21 \pm 0.09) \times 10^{21} \times A_V$ relation given by Güver & Özel (2009). The values of N_H for each source along with the Galactic coordinates are listed in Table 1. The sources of which distances are determined are taken from Ford (2005).

Table 1: Galactic coordinates of the sources and their hydrogen column densities taken from which references.

Source	l°	b°	N_H (10^{22} cm^{-1})	Reference
4U 1608-522	343.8900	-1.3200	1.500 ± 0.100	Penninx et al. (1989)
4U 0614+09	200.8774	-3.3635	0.340 ± 0.030	Migliari et al. (2010)
Aql X-1	35.7184	-4.1432	0.348 ± 0.008	Raichur, Misra, Dewangan (2011)
4U 1702-42	343.8868	-1.3183	1.950	Güver, Psaltis, Özel (2012)
4U 1728-34	354.3034	-0.1507	2.600 ± 0.070	D'Aí et al. (2006)
4U 1636-53	332.9149	-4.8180	0.320 ± 0.010	Mück, Piraino, Santangelo (2013)
KS 1731-260	1.0730	3.6526	1.060 ± 0.080	Rutledge et al. (2002)
4U 1820-30	2.7882	-7.9138	0.160 ± 0.003	Sidoli et al. (2001)
4U 1705-44	343.3208	-2.3419	1.420 ± 0.060	Di Salvo et al. (2005)
Cyg X-2	87.3282	-11.3163	0.196 ± 0.004	Piraino, Santangelo, Kaaret (2002)
GX 17+2	16.4322	1.2776	2.000 ± 0.050	Farinelli et al. (2005)
GX 340+0	339.5881	-0.0794	5.700 ± 0.100	Seifina, Titarchuk, Frontera (2013)
GX 5-1	5.0778	-1.0182	3.000	Jackson, Church, Bałucińska-Church (2009)
Sco X-1	359.0942	23.7844	0.200 ± 0.015	de Vries et al. (2003)

These optical extinctions should be converted into NIR extinction since our distance calculations depend on A_{K_s}. There are many R_{K_s} coefficients which are empirically found such as 0.062, 0.085, 0.112 given by Nishiyama et al. (2008), Nishiyama et al. (2006), and Rieke & Lebofsky (1985), respectively. We used Galactic open clusters in order to determine the most precious coefficient.

By comparing the observations with the stellar models, the fundamental parameters of stellar clusters such as reddening, distance can be precisely calculated. We selected Galactic open clusters near the Galactic plane with well-known distance, and reddening in Kharchenko et al. (2005) catalogue. By using different R_{K_s} coefficients, distance determination is carried out as mentioned in the following section. As seen in Figure 1, the most accurate coefficient is found to be $R_{K_s} = 0.085$ which is given by Nishiyama et al. (2006). Thus, we calculate NIR extinction values using the $AK_s = 0.085 \times AV$.

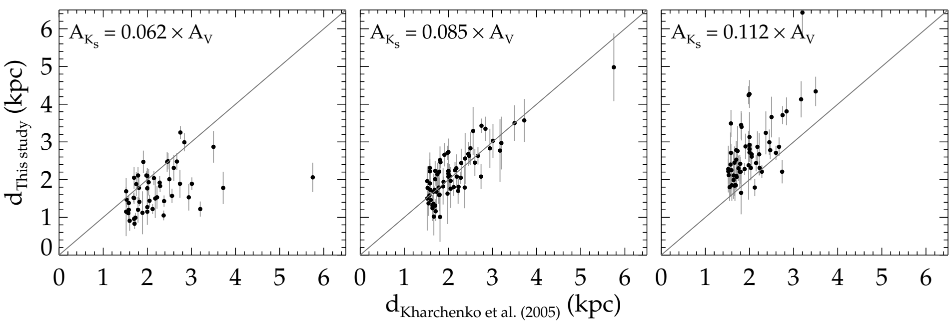

Figure 1: Comparison of the distances of the Galactic open clusters calculated different coefficients with the literature. The clusters are selected from Kharchenko et al. (2005) and the coefficients shown in left, middle, and right panels are taken from Nishiyama et al. (2008), Nishiyama et al. (2006), Rieke & Lebofsky (1985), respectively.

1.2 RCGs as a Distance Indicator

RCGs are core helium-burning stars and located the red side of horizontal branch in the H-R diagram. Their age and metallicity dependences of the luminosity are negligible and these giants have a very narrow luminosity function so that one can assume that the absolute magnitude of these stars is constant (Stanek & Garnavich, 1998; Salaris & Girardi, 2002). The absolute magnitude and intrinsic color of the RCGs in the NIR bands are well-known (Alves, 2000; Salaris & Girardi, 2002; Laney, Joner, & Pietrzyński, 2012; Yaz Gökçe et al., 2013). We use $M_{K_s} = -1.595 \pm 0.025$ mag, $(J - K_s) = 0.612 \pm 0.003$ mag given by Yaz Gökçe et al. (2013).

We used the 2MASS data (Skrutskie et al., 2006; Cutri et al., 2003) in the field of view of the sources listed in Table 1. For a given radius, we selected all of the stars and separated the RCGs using Galaxia extinction model (Sharma et al., 2011). Since the absolute magnitude of RCGs is known, the extinction in terms of distance and coordinates should be estimated. In order to do that in the 2MASS color-magnitude diagram (CMD), we used the dust distribution of Galaxia model (Sharma et al., 2011). According to Galaxia model, the density of dust in terms of distance and Galactic coordinates can be given as follows:

$$\rho_{dust}(R,z) = \frac{\rho_0}{k_{fl}} \exp\left[\frac{R_0 - R}{h_R} - \frac{|z - z_W|}{k_{fl} h_z}\right]. \tag{1}$$

Here, ρ_{dust} is the density of dust, $R_0 = 8.0$ kpc, $\rho_0 = 0.54$ mag kpc^{-1}, $h_R = 4.2$ kpc, $h_z = 88$ pc, k_{fl} and z_W are flaring and warping properties of the Galaxy (Sharma et al., 2011). The extinction for given distance and coordinates can be calculated as stated below.

$$A_\lambda(r) = A_\lambda^f \frac{\int_0^r \rho(R(r),\ z(r))dr}{\int_0^\infty \rho(R(r),\ z(r))dr}. \tag{2}$$

Where $A_\lambda^f = A_\lambda^i \times C(A_\lambda^i)$ and A_λ^i is adopted from Schlegel, Finkbeiner, Davis (1998). Hence the extinction calculated by Schlegel, Finkbeiner, Davis (1998) is over-estimated (Arce & Goodman, 1999; Schlafly & Finkbeiner, 2011), we used the following coefficient given by Binney et al. (2014) to correct the extinction:

$$C(A_\lambda^i) = 0.6 + 0.2 \times \left[1 - \tanh\left(\frac{A_\lambda^i - 0.15}{0.3}\right)\right]. \tag{3}$$

In Figure 2a, the 2MASS CMD centered around 4U 1608-522 with a radius of $10'$ is shown. In this panel, the dashed line represents the intrinsic color of RCGs, $(J - K_s) = 0.612$ mag, while the solid lines indicate the selection of RCGs with Galaxia model. We assume that all of the stars within these solid lines are RCGs. The contamination by another stars is negligible. Similarly to this method, López-Corredoira et al. (2002) used another approach called "SKY" extinction model to extract RCGs. They showed that the dwarf contamination mostly started at $m_K > 13^m$. In addition, the dwarf contamination reaches 45% at $m_K = 14^m$. In our case this is not important since the RCGs are brighter than this magnitude when they are at the distance of sources.

To determine the distances, we used the 2MASS JHK_s photometry (Skrutskie et al., 2006). Our sample given in Table 1 consists some sources whose distances exceed the limit magnitude of the 2MASS photometry. In this case, we used the UKIDSS data (Lucas et al., 2008). Even though this data set is only available for some fields around the Galactic plane, its limit magnitude is ~ 3 mag fainter than the 2MASS photometry. For some distant sources, which are beyond the limiting magnitude of 2MASS, we used the UKIDSS data.

The RCGs are extracted using the Galaxia extinction model as shown in Figure 2a. Once we isolate the RCGs, we split the data according to m_{K_s} magnitudes in 0.2 mag bins. We calculate the mean $(J - K_s)$ colors for each bin. Thus, the $A(K_s)$ extinction can be determined as follows:

$$A(K_s) = R_{K_s} \times [(J - K_s) - (J - K_s)_0], \tag{4}$$

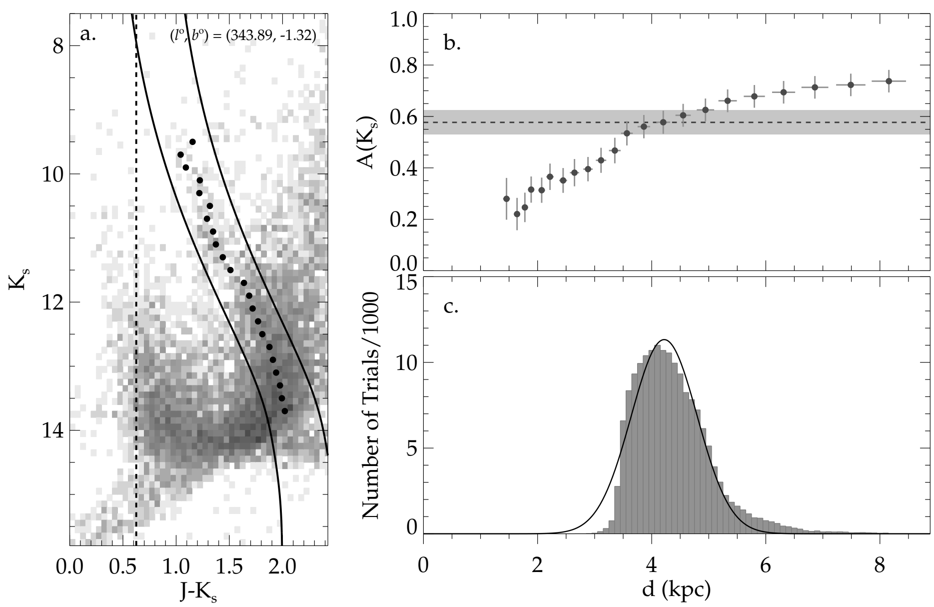

Figure 2: (a) the 2MASS CMD centered around 4U 1608-522 with a radius of $r = 10'$, (b) the $A(K_s)$ extinction-distance relation for the field, (c) the results of MCMC simulation for the source. The best distance solution is found to be 4.22 ± 0.58 kpc. In panel (a), the dashed line is the intrinsic color of the RCGs which is assumed $(J - K_s) = 0.612$ mag (Yaz Gökçe et al., 2013) whereas the solid lines represent the mos probable RCGs. In panel (b), the horizontal dashed line shows the K_s-band extinction value of the source and the gray field infers its uncertainty.

where $R_{K_s} = 0.528$ (Nishiyama et al., 2009) and $(J - K_s)_0 = 0.612$ mag (Yaz Gökçe et al., 2013). The uncertainty of the mean color for each bin is estimated as described:

$$\sigma_{(J-K_s)_i} = \frac{\sigma_i}{\sqrt{N_i}}, \tag{5}$$

where σ_i is the standard deviation of color, whereas N_i is the number of RCGs in each bin. In order to estimate the total uncertainty in $A(K_s)$, we take the uncertainty of the intrinsic color into account so that we find the total uncertainty of the extinction similar to Güver et al. (2010):

$$\sigma^2_{A(K_s)_i} = \sigma^2_{(J-K_s)_i} + \sigma^2_{(J-K_s)_0}, \tag{6}$$

here, $\sigma_{(J-K_s)_0} = 0.03$ mag (Yaz Gökçe et al., 2013). We calculate the uncertainty of the distance by means of distance modulus since the distance can be determined from the distance modulus:

$$m_{K_s} - M_{K_s} - A(K_s) = 5 \times \log\left(\frac{d}{\mathrm{pc}}\right) - 5 \tag{7}$$

here, $\mu_{K_s} = m_{K_s} - M_{K_s} - A(K_s)$ is the distance modulus and its uncertainty can be estimated:

$$\sigma^2_{\mu_{K_{s_i}}} = \sigma^2_{m_{K_{s_i}}} + \sigma^2_{M_{K_s}} + \sigma^2_{A(K_s)_i}, \tag{8}$$

where $\sigma_{M_{K_s}} = 0.025$ mag (Yaz Gökçe et al., 2013) and $\sigma_{m_{K_{s_i}}}$ is the mean value of apparent magnitude errors in each bin. In Figure 2b, the $A(K_s) - d$ relation for 4U 1608-522 is given. By using the relation as a model, we calculated the distance of sources and its error performing a MCMC simulation with 200000 trials. We fitted a Gaussian function over the MCMC results so that we determined the distance and its error as shown in Figure 2c. The details of the method are explained by Ford (2005); Janes et al. (2013). The distance of sources are tabulated in Table 2 with the calculated K_s-band extinction and the adopted radius for extracting stars in the field of view of the sources.

Table 2: The distance of sources, calculated K_s-band extinctions, used data for given radius, distances in the literature and their references.

Source	A_{K_s}	d (kpc)	Data	r ($'$)	$d_{\rm lit}$ (kpc)	Referance
4U 1608-522	0.577 ± 0.047	4.22 ± 0.58	2MASS	10	$2.8 - 3.8$	Jonker & Nelemans (2004)
4U 0614+09	0.131 ± 0.041				$1.4 - 3.0$	Jonker & Nelemans (2004)
Aql X-1	0.134 ± 0.041				$4.4 - 5.9$	Jonker & Nelemans (2004)
4U 1702-42	0.750 ± 0.041	6.10 ± 0.71	2MASS	20	$5.3 - 7.1$	Jonker & Nelemans (2004)
4U 1728-34	1.000 ± 0.044	4.34 ± 0.20	2MASS	20	$4.5 - 6.1$	Jonker & Nelemans (2004)
4U 1636-53	0.123 ± 0.041	4.73 ± 3.39	2MASS	20	$3.7 - 4.9$	Jonker & Nelemans (2004)
4U 1735-44	0.127 ± 0.041				$8.0 - 10.8$	Jonker & Nelemans (2004)
KS 1731-260	0.408 ± 0.045	5.38 ± 2.91	2MASS	20	$5.3 - 7.1$	Jonker & Nelemans (2004)
4U 1820-30	0.062 ± 0.041				$7.2 - 8.0$	Heasley et al. (2000)
4U 1705-44	0.546 ± 0.043	9.05 ± 3.18	2MASS	20	$7.2 - 9.6$	Jonker & Nelemans (2004)
Cyg X-2	0.075 ± 0.041				$11.4 - 15.3$	Jonker & Nelemans (2004)
GX 17+2	0.769 ± 0.042	9.93 ± 0.84	UKIDSS	20	$11.9 - 16.0$	Jonker & Nelemans (2004)
GX 340+0	2.192 ± 0.047				$10.7 - 11.3$	Penninx et al. (1993)
GX 5-1	1.154 ± 0.047	8.84 ± 0.31	UKIDSS	20	$6.3 - 11.7$	Christian & Swank (1997)
Sco X-1	0.077 ± 0.041	1.86 ± 3.12	2MASS	40	$2.5 - 3.1$	Jonker & Nelemans (2004)

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