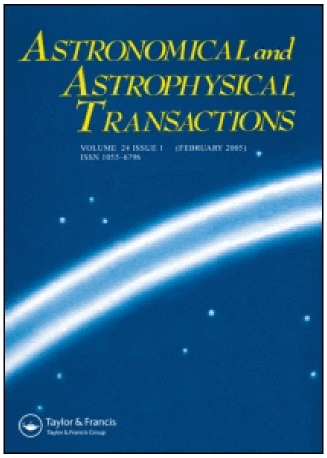

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A. N. Gerashchenko [a]; Z. Kadla [a]
[a] Main Astronomical Observatory, Russian Academy of Sciences, Saint Petersburg, Russia

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AN INVESTIGATION OF THE STRUCTURE OF NON-UNIFORMITIES OF INTERSTELLAR ABSORPTION USING PHOTOMETRY OF GLOBULAR CLUSTERS

A. N. GERASHCHENKO* and Z. KADLA

Main Astronomical Observatory, Russian Academy of Sciences, Pulkovo, Saint Petersburg 196140, Russia

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Charge-coupled device photometric investigations of the central regions of the globular clusters NGC 4372 ($r < 4'$) and NGC 6266 ($0.5' < r < 2'$) were used to obtain detailed maps of the distribution of differential reddening. In both clusters the reddening is non-uniform on angular scales less than $1'$ and varies by magnitudes of 0.15 and 0.20 within the investigated fields of NGC 4372 and NGC 6266 respectively. For these clusters the average $E(B - V)$ values of magnitudes 0.34 and 0.43 are smaller than those found previously.

Keywords: Interstellar absorption; Globular cluster

1 INTRODUCTION

An accurate analysis of the colour-magnitude diagrams (CMDs) of globular clusters requires knowledge of interstellar absorption. The obtained fundamental parameters of a cluster depend on the precision with which the interstellar absorption is determined. In order to estimate the applicability of the assumption of uniform absorption in the field of a globular cluster, which is usually used to correct the photometric data, it is necessary to know the structure of the variation in interstellar absorption across the field of the cluster.

For most high-latitude clusters with small extinction due to clouds in the galactic plane, the model of uniform absorption is applicable. The scale of the variation in extinction is of the order of tens arcminutes (Minniti *et al.*, 1992). For low-latitude globular clusters the scale of absorption variations can be much smaller as the integrated contribution of all the clouds along the line of sight is taken into account. The apparent size of the latter is inversely proportional to distance. According to Minniti *et al.* (1992), the size of interstellar absorption non-uniformities is of the order of arcminutes for low- and moderate-latitude clusters. The same scale follows from the distribution of interstellar dust emission (Schleger *et al.*, 1998) and interstellar H I (Burstein and Heiles, 1982), which is probably due to the spacial resolution of the observations.

* Corresponding author. E-mail: ger@gao.spb.ru

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TABLE I Estimates of the Magnitudes of $\Delta E(B-V)$.

Reference	*Investigated region*	$\Delta E(B-V)$
Hartwick and Hesser (1973)	$r < 4'$	0.06
Alcaino *et al.* (1991)	$3.4' \times 3.4'$ to the west $5'$ from the cluster centre	0.03
Minniti *et al.* (1992)	$r < 3.5'$	0.17
Kaluzny and Krzeminski (1993)	$10' \times 10'$ to the east $2.3'$ from the cluster centre	0.08

Results obtained by Kemp *et al.* (1995) from an analysis of high-resolution observations of interstellar lines (K I and Na I) in stars of the moderate-latitude globular cluster NGC 6121 revealed a more fine-scale structure. In two stars $17''$ apart the interstellar K I column density difference is about 40%.

In this paper the non-uniformities of interstellar absorption for two southern globular clusters NGC 4372 and NGC 6266 are investigated. Both clusters are located in regions with a non-uniform interstellar medium.

The globular cluster NGC 4372 (C1223-724; $l = 301.0°$, $b = -0.9°$) is one of the few clusters located in or near known dark nebulae. The light of stars of the cluster is dimmed by one of the long dark streamers from the Coal Slack (Shapley, 1939). The cluster NGC 6266 (M 62; C1658-300; $l = 353.6°$; $b = +7.3°$) is located in a region of the galactic centre rich with stars and dust.

The researchers who made the first photographic investigations of these clusters [Hartwick and Hesser (1973) and Alcaino (1974) for NGC 4372, and Van Agt and Oosterhoff (1959), Gascoine and Ford (1967) and Alcaino (1978) for NGC 6266] concluded that differential absorption is evident in the fields of the clusters and results in a large dispersion of their CMDs. This conclusion was later confirmed by charge-coupled device (CCD) photometric NGC 4372 (Alcaino *et al.*, 1991; Kaluzny and Krzeminski, 1993; Brocato *et al.*, 1996) and NGC 6266 (Caloi *et al.*, 1987) and polarimetric (Minniti *et al.*, 1992) observations. However, only estimates of the values and direction of possible variations within the limits of the studied regions were obtained. These are summarized for NGC 4372 in Table I. It was found that the reddening is smallest in the southern part of the cluster and increases towards the north.

Interstellar reddening in the southeastern part of NGC 6266 has a magnitude about 0.2 larger than in other parts of the cluster. This cluster has the largest differential absorption of clusters with known variable absorption. However, no attempt had been made to investigate the distribution of the latter in more detail.

2 OBSERVATIONS AND REDUCTION

The CCD observations made by Brocato *et al.* with the ESO 0.9 m Danish telescope were used in the present investigation. Details and reduction of the observations have been given by Brocato *et al.* (1996). Four ($3.7' \times 3.7'$) overlapping areas located in the central region ($r < 4'$) of NGC 4372 were investigated. The low concentration of stars towards the centre of the cluster (Webbink, 1985) permitted reliable photometric measurements of stars in the cluster centre.

The investigated field of NGC 6266 is also located in the central part of the cluster. This cluster is one of the galactic clusters with the highest concentration of stars towards the cluster centre (Webbink, 1985), and the area with $r < 0.5'$ was not considered. In the CMD the B and V magnitudes of the RR Lyr stars obtained at almost the same phase were used. The variables are thus located in the instability strip and therefore will not increase the scatter of points in the CMD. This is of special importance in the case of NGC 6266 which has

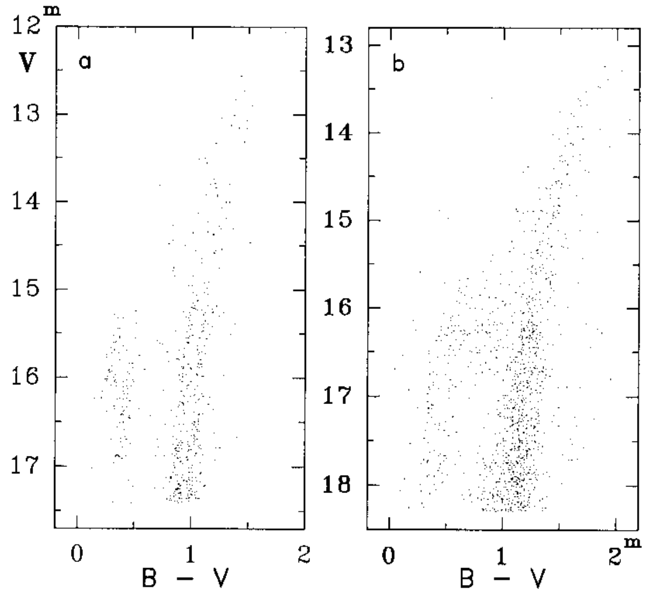

FIGURE 1 CMDs of globular clusters: (a) NGC 4372 ($r < 4'$); (b) NGC 6266 ($0.5' < r < 2'$).

many RR Lyr variables (Clement *et al.*, 2001). The magnitudes of stars brighter than 18 were determined with a magnitude error of 0.03 in the central region ($r < 0.7'$) of NGC 4372 and 0.02 in the outermost regions of both clusters.

The CMDs obtained for the two clusters are shown in Figure 1. A striking feature of the figure is the large spread of stars forming the principal sequences of the cluster CMDs. The spread is significantly larger than expected on the basis of the formal accuracy of the photometry.

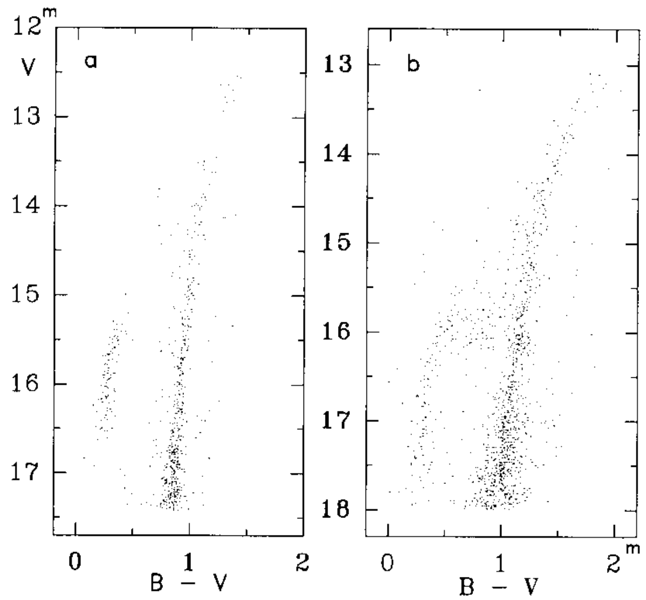

FIGURE 2 The CMDs corrected for differential absorption: (a) NGC 4372 ($r < 4'$); (b) NGC 6266 ($0.5' < r < 2'$).

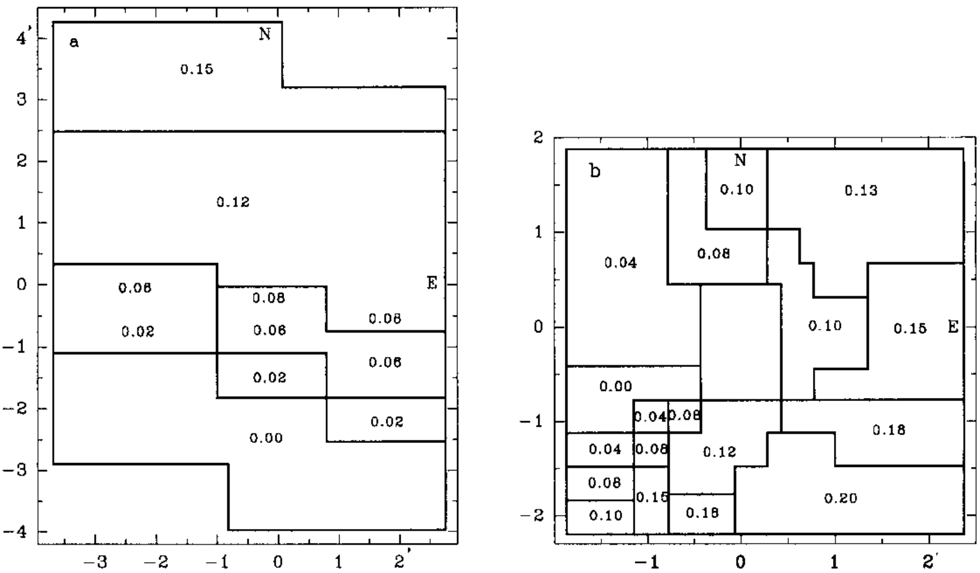

FIGURE 3 Maps of the distribution of differential absorption of the globular clusters: (a) NGC 4372; (b) NGC 6266. The values of ΔE are given in each area.

The known RR Lyr variables have not been included in the diagrams. However, the instability strip of NGC 6266 is heavily populated by stars, possible RR Lyr variable star candidates. The large width of the CMD branches of both clusters is due mainly to different absorption. In addition the CMD of NGC 6266 is contaminated by field stars which according to Caloi *et al.* (1987) can contribute up to 30%.

The description of the method for correcting the CMD for differential interstellar absorption has been given by Gerashchenko *et al.* (1999) using the cluster NGC 4372 as an example. The CMDs of the globular clusters NGC 4372 and NGC 6266 corrected for differential reddening by this method are shown in Figure 2. The branches of the CMDs are much narrower than those in Figure 1, which favours the assumption that the large scatter in Figure 1 is due to differential reddening.

The results of the present investigation on the distribution of differential interstellar reddening is represented in graphical form in Figure 3.

3 THE REDDENING ZERO POINT

Two methods were used to determine the lowest values of $E_0(B-V)$ (the reddening zero point) in the investigated regions of the two clusters, which are to be added to $\Delta E(B-V)$. In the first the dereddened CMDs of the investigated clusters are compared with those of clusters with the same metallicity and small constant absorption. NGC 4372 is a low-metallicity cluster with estimates of [Fe/H] ranging from −1.66 (Bica and Paltoriza, 1983) to −2.08 (Zinn, 1985). The [Fe/H] values for NGC 6266, which is a cluster with a higher value of metallicity, range from −1.07 (Carretta and Gratton, 1997) to −1.29 (Zinn, 1985).

We used the metallicities [Fe/H] of galactic clusters given in the paper by Ferraro *et al.* (1999). These are based on the results of an analysis of high-dispersion spectra of giants in 24 galactic clusters (Carretta and Gratton, 1997). According to these estimates the metallicities are −1.94 for NGC 4372 and −1.07 for NGC 6266. The best fit of the CMD of NGC 4372

TABLE II Magnitudes of $E_0(B-V)$.

	First method		*Second method*		*Mean*
NGC	$E_0(B-V)$	$(m-M)_V$	$E_0(B-V)$	*[Fe]/[H]*	$E_0(B-V)$
4372	0.26	15.0	0.27	−2.08	0.26
6266	0.34	15.4	0.32	−0.95	0.33

with those of three galactic clusters with similar metallicities (M 15, M 30 and M 92) occurs when the magnitudes of ΔV are −0.4, 0.2 and 0.2 and those of $\Delta(B-V)$ are 0.16, 0.24 and 0.20 respectively. Adopting $E(B-V)$ magnitudes of 0.10 (M 15) (Durrell and Harris, 1993), 0.07 (M 30) (Bergbush, 1996) and 0.02 (M 92) (Buonanno *et al.*, 1985) the zero point of NGC 4273 has a magnitude of $E_0(B-V)$ of 0.26. From a similar comparison of NGC 6266 with NGC 1261 the magnitude of $E_0(B-V)$ is 0.32 for the former (Table II). The second method for determining the zero point of $E_0(B-V)$ uses the statistical relations derived by Ferraro *et al.* (1999) (Table IV in their paper) for the known parameters of the upper part of the CMD (ΔV, S, and $(B-V)_{(0,g)}$). The best fits of the red-giant branch of the dereddened CMDs by exponential functions were used to determine the above parameters. The magnitudes of $E_0(B-V)$ determined by the two methods and the mean values are given in Table II.

4 RESULTS AND CONCLUSIONS

Using the values of $E_0(B-V)$ (the last column of Table II) and taking into account the obtained intervals of change in the values of differential absorption (magnitudes of 0.15 for NGC 4372 and 0.20 for NGC 6266) we found that within the investigated regions of

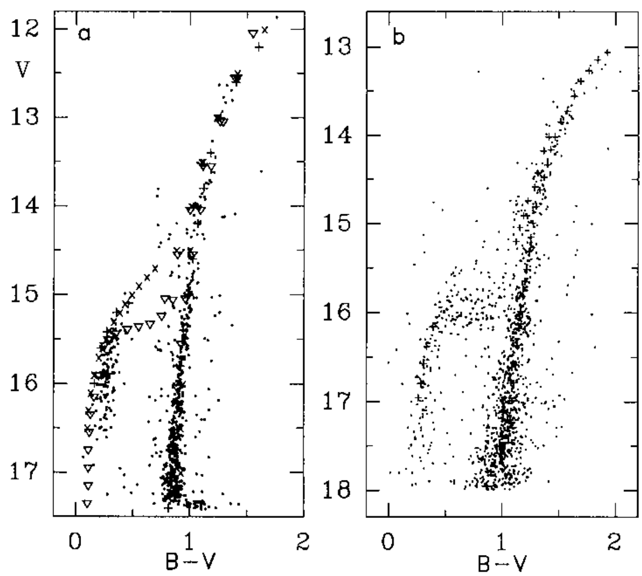

FIGURE 4 (a) A comparison of the CMD of NGC 4372 (·) with those of M 15 (▽), M 92 (+) and M 30 (×). (b) A comparison of the CMD of NGC 6266 (·) with that of NGC 1251 (+).

these clusters the magnitudes of $E(B-V)$ change from 0.26 to 0.41 for NGC 4372 and from 0.33 to 0.53 for NGC 6266. Correspondingly the average magnitudes of $E(B-V)$ are 0.34 and 0.43 for these clusters. These values are smaller than the previous smallest estimates: magnitudes of 0.42 (Hartwick and Hesser, 1973) for NGC 4372 and 0.50 (Alcaino, 1978) for NGC 6266.

Simultaneously the method of comparison of the CMDs permitted the determination of the apparent distance modulus $(m-M)_V$. The narrowness of the main branch of the dereddened CMDs resulted in more accurate fits. Taking the magnitudes of $(m-M)_V$ of the clusters as 15.40 ± 0.15 for M 15 (Durrell and Harris, 1993), 14.83 for M 92 (Buonanno *et al.*, 1985) and 14.83 for M 30 (Bergbush, 1996) we obtained for NGC 4372 $(m-M)_V$ magnitude of 15.02 ± 0.20. As there is no error associated with the distance modulus for M 92 and M 30 we assumed for them a typical magnitude error of 0.20. Using the obtained $E_0(B-V)$ magnitude of 0.26 we determined the magnitude of the absolute distance moduli $(m-M)_{0V}$ as 14.19 ± 0.20. Similarly, magnitudes of the apparent and absolute distance moduli for NGC 6266 are 15.40 ± 0.23 and 14.54 ± 0.23, adopting the apparent distance modulus magnitude for the comparison cluster NGC 2161 as 16.00 ± 0.23.

An analysis of the distributions of differential interstellar reddening leads to the following conclusions.

(i) We have obtained the detailed distributions of reddening in the fields of both clusters which were found to have a complex structure. The reddening can vary within angular distances $r < 1'$. The non-uniformity for NGC 6266 is more pronounced. In the northern part of NGC 4372 the reddening is more uniform than in the southern part.

(ii) The reddening varies considerably in the investigated regions: $\Delta E(B-V)$ magnitudes of 0.15 for NGC 4372 ($r < 4'$) and 0.20 for NGC 6266 ($r < 2'$). The former value agrees with the data of Minniti *et al.* (1992) but is considerably larger than those determined by other workers. The value for NGC 6266 agrees on the whole with the results published earlier.

(iii) The average values of the reddening are smaller than those found in previous investigations of these clusters.

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