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CCD PHOTOMETRY OF THE GLOBULAR CLUSTER NGC 4372 [1]

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ABSTRACT

We present a deep (B, V) color-magnitude diagram (CMD) of the Galactic globular cluster NGC 4372. According to the recent inside-out picture of Galaxy formation, this cluster is predicted to be one of the oldest globular clusters in the Galaxy. Our CMD shows a well defined main-sequence extending ~ 2 magnitudes below the turnoff. Despite the uncertainty that stems from the small sample size of bright stars, comparison with the Revised Yale Isochrones suggests that this cluster may indeed be one of the oldest ($\sim$ 16.6 Gyrs) globular clusters in our Galaxy.

1. INTRODUCTION

Until recently, the available observations for Galactic globular clusters were generally interpreted as indicating very little variation about a mean cluster age of approximately 15 Gyrs. This lack of an age variation was taken as support for the rapid initial collapse picture of the protogalaxy originally suggested by Eggen, Lynden-Bell and Sandage (1962). However, new results suggest that there is, in fact, a substantial age range among the Galactic globular clusters, both as a function of abundance, with the more metal-poor clusters being older (Lee *et al.* 1990), and at a fixed abundance (Lee *et al.* 1988, 1994, Stetson *et al.* 1989, VandenBerg *et al.* 1990, Buonnano *et al.* 1993). This suggests a very different picture of the early stages of the Galaxy's evolution: a prolonged and chaotic formation process, perhaps along the lines first sug ted by Searle and Zinn (1978).

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Expanding on this, in his recent investigation of the RR Lyrae stars in the Galactic nuclear bulge, Lee (1992) has shown that the oldest stellar population in the Galactic nuclear bulge is older than that in the halo. The inferred radial gradient in age implies that the bulge was the first part of our Galaxy to form, and then served as a nucleus around which the rest of the Galaxy was built up from the inside out (see also Larson 1990; van den Bergh 1993). According to this inside-out picture of Galaxy formation, star formation and the accompanying nucleosynthesis probably commenced first near the Galactic center so that among the most metal-poor star clusters in this region the very oldest objects in the Galaxy sould be found.

NGC 4372 is one such cluster in the inner halo of the Galaxy. It is one of the most metal poor clusters in the inner halo ([Fe/H] = −2.08; Zinn 1985), and also it possess only blue horizontal-branch (HB) stars: a sign that it may be indeed old according to the age interpretation of the second parameter phenomenon of the HB (Lee *et al.* 1994). The purpose of the present paper is to report the first result of our CCD photometry for this cluster.

2. OBSERVATIONS AND DATA REDUCTION

The observations consist of 14 B and V frames of the NGC 4372. These frames were obtained on February 24, 1987 by one of us (Y.-W. Lee) using the direct RCA CCD camera on the 0.9-m telescope at Cerro Tololo Inter-American Observatory (CTIO). The frames have an image scale of 0″.495/pixel and cover an area approximately 4.2 × 2.6 arcmin on the sky. The median seeing was 1″.7, as estimated from the full width at half-maximum (FWHM) of the stellar images. Preliminary reductions of the CCD frames, including debiasing, trimming, and flat fielding, were carried out with the standard mountain CCD reduction package at CTIO. The frames were then reduced using the multiple-star profile fitting program DAOPHOT (Stetson 1987). Figure 1 displays the V frame of NGC 4372.

The final instrumental magnitudes were transformed to the standard B, V system, using 18 standard stars from Graham (1982) and Landolt (1983). These standard stars were reduced with the aperture photometry routine of IRAF. The derived transformation equations are

$$(B - V) = 1.265(b - v) - 0.105,$$
$$V - v = -0.030(B - V) - 2.690,$$

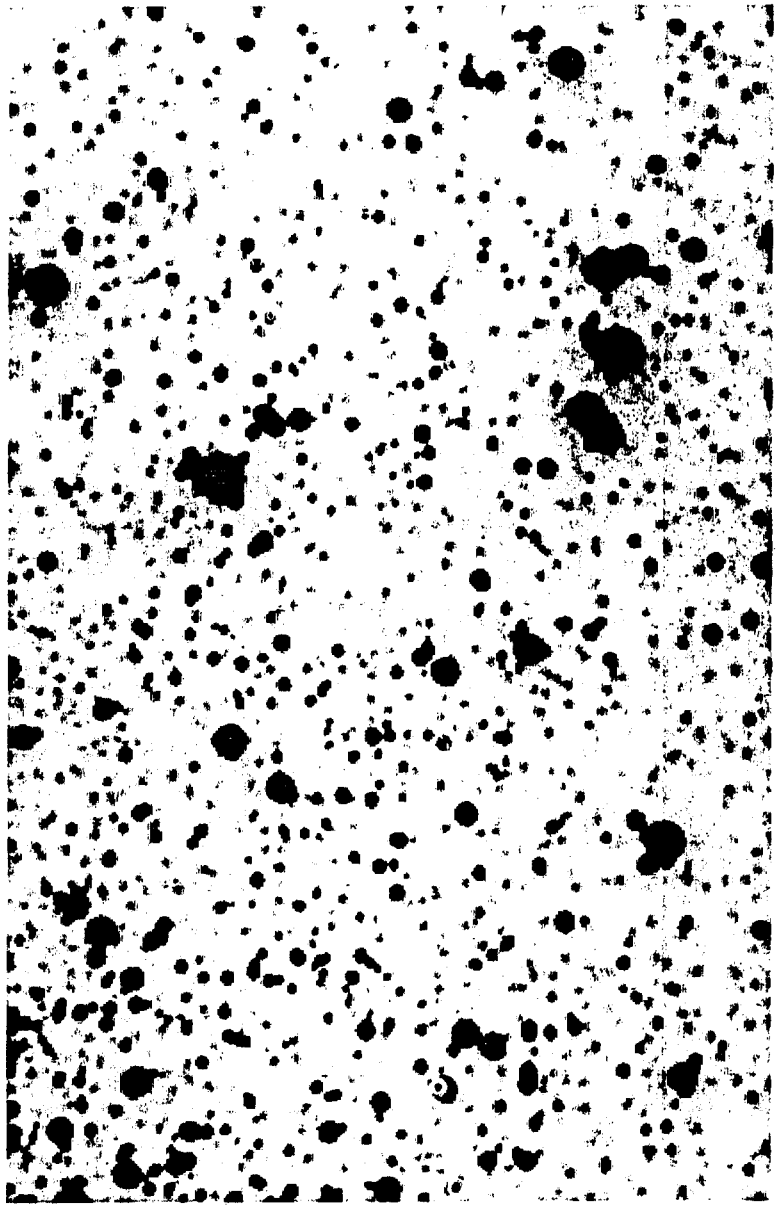

Figure 1. The V CCD frame of NGC 4372. The exposured time is 1200 secs.

and are shown in Figures 2 and 3. The brightest, not saturated, and most isolated cluster stars were used to tie together the aperture photometry instrumental magnitudes and those given by the multiple PSF fitting routine. This matching introduces zero-point uncertainties of $\pm$ 0.004 mag in the V band, and $\pm$ 0.005 mag in the B band. Fully reduced stars in each frame were cross-identified in B and V frames to produce a final CM diagram.

3. THE COLOR-MAGNITUDE DIAGRAM

In Figure 4, we present our $(V, B-V)$ color-magnitude diagram for 739 stars in the NGC 4372, after rejection of poorly fit stars $[\sigma(B-V) > 0.050]$ on the basis of error indicatiors returned by DAOPHOT. The scatter about the main sequence locus is in excess of that expected from observational error alone. We suspect that this is the effect of differential interstellar reddening that may present across the NGC 4372 field. Inspection of the ESO Southern Sky Survey films for the region around NGC 4372 indicates that interstellar absorption toward NGC 4372 may be somewhat patchy. It is unlikely therefore that a single reddening correction will apply perfectly for all NGC 4372 stars. In fact, Hartwick and Hesser(1983) suggested that E$(B-V)$ ranges from 0.42 to 0.48 based on their UBV photometry for bright stars in this field.

Despite the scatter, the CMD shows well defined main sequence turnoff at V=19.1 $\pm$ 0.1. The estimation of the level of the HB, however, is not straight-forward, given the small sample size of bright stars (i.e, HB and RGB stars). Despite this uncertainty, we estimate the mean level of the NGC 4372 HB to be $V = 15.40 \pm 0.20$, close to the value found by Hartwick and Hesser (1973). According to the synthetic HB models of Lee (1990), the absolute magnitude of the HB for the metallicity of NGC 4372 (i.e. [Fe/H] = -2.08) is predicted to be $M_V(HB) = 0.57$. We therefore derive the apparent distance modulus as $V - M_V = 14.83 \pm 0.20$.

The distance modulus estimated above and the mean interstellar reddening of E$(B-V)$ = 0.45 (Zinn 1985) were used in Figure 5 in order to compare the observations with the Revised Yale Isochrones (Green *et al.* 1987). This comparison suggests that the age of NGC 4372 may be as old as 18 $\pm$ 3 Gyrs. Taking the effect of alpha-element enhancement ([α /Fe] $\approx$ 0.4; Spite & Spite 1991) in Population II stars ($-$1.4 Gyrs; VandenBerg 1985), we obtain 16.6 $\pm$ 3 Gyrs for our best estimate of the age of NGC 4372. The difference in $(B-V)$ between the turnoff and the base of the red giant-branch (RGB) - a new age indicator suggested by VandenBerg *et al.*(1990) - also indicates that this cluster may be one of the oldest globular clusters in the Galaxy. The major uncertainty of this age estimation stems from the small sample size of HB and RGB stars in our CMD. Additional CCD photometry

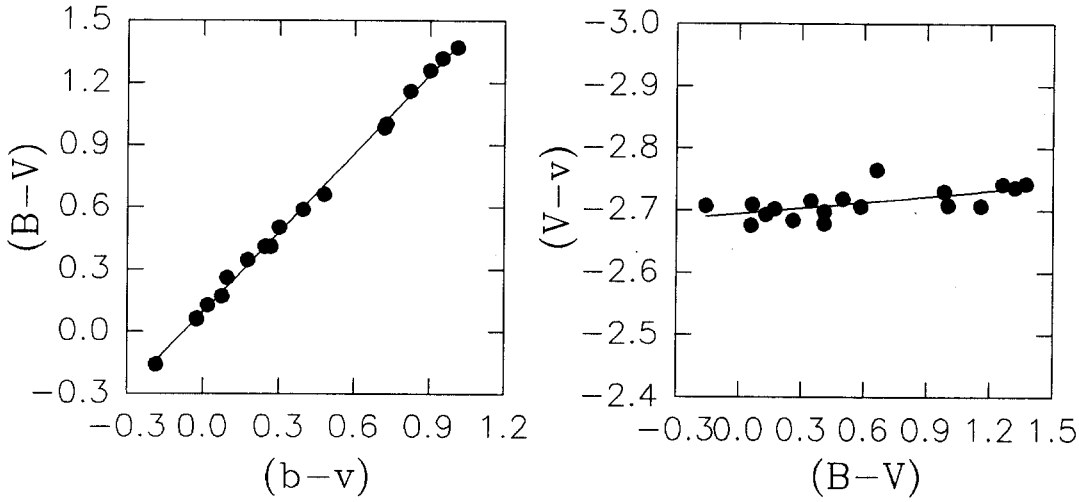

Figure 2. The colrrelations between our instrumental magnitudes (b, v) and the magnitudes on the standard systems (B, V) from Landolt (1983) and Graham (1982).

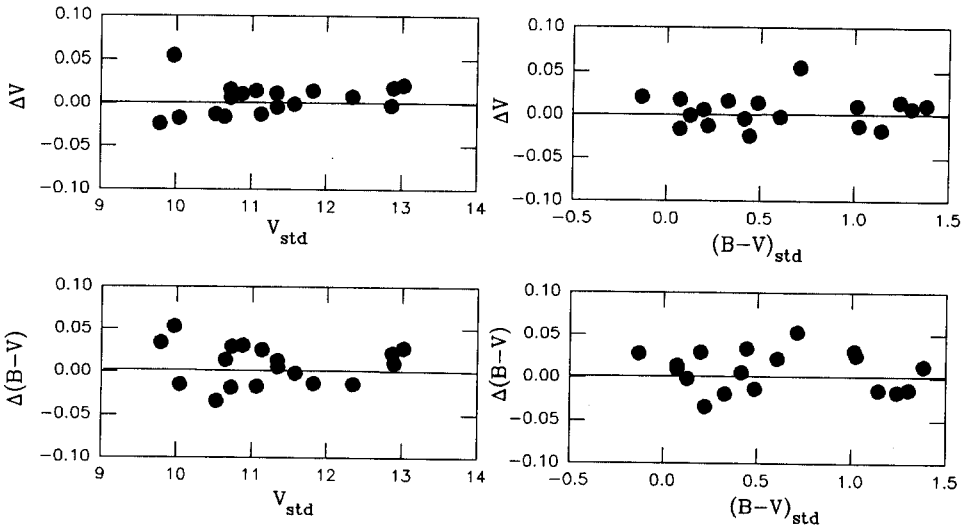

Figure 3. Transformation residuals of our photometry for standard stars with respect to values from Landolt (1983) and Graham (1982).

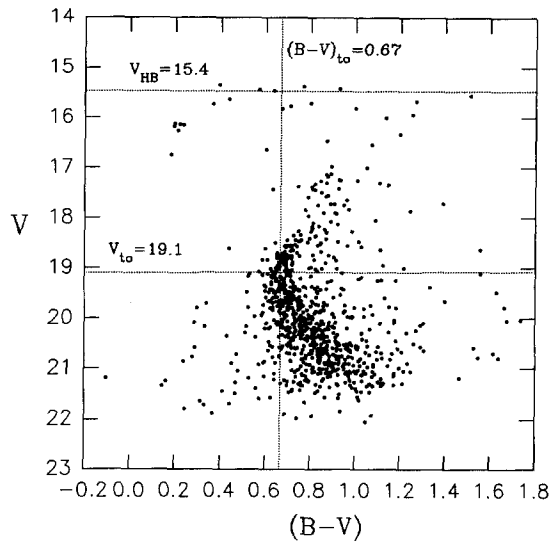

Figure 4. The color-magnitude diagram of NGC 4372 obtained from the median filtered long exposure frames. There are 739 stars in this diagram.

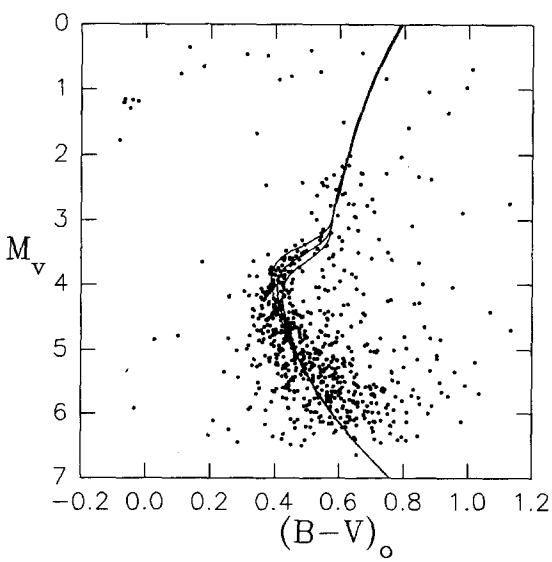

Figure 5. Comparison of our CMD with the Revised Yale Isochrones for ages of 16, 18 & 20 Gyrs (left to rifht). The CMD has been adjusted for $(m-M)_v = 14.83$ and $E(B-V) = 0.45$. Isochrones are for Z = 0.00015 and Y = 0.24.

for bright stars in NGC 4372, now in progress at the Yonsei University Observatory, will undoubtedly help to resolve this problem in the near future.

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