IC 1257: A New Globular Cluster in the Galactic Halo

William E. Harris
Department of Physics & Astronomy, McMaster University, Hamilton ON L8S 4MI Canada
Electronic mail: harris@physics.mcmaster.ca

Randy 1,. l'helps
Carnegie Observatories, 813 Santa Barbara Street, Pasadena, CA 91101
Electronic mail: phelps@ociw.edu

Barry II'. Madore
NASA/IPAC Extragalactic Database, Jet Propulsion Laboratory, California Institute of Technology, Pasadena CA 91125
Electronic mail: barry@ipac.caltech.edu

Olga Pevunova
Infrared Processing and Analysis Center, California Institute of Technology, Pasadena, CA 91125
Electronic mail: olga@ipac.caltech.edu

Brian A. Skiff
Lowell Observatory, Flagstaff AZ 86001
Electronic mail: bas@lowell.edu

Czernic Crute
Los Angeles Astronomical Society and Western Observatorium

Barbara Wilson
George Observatory, Houston Museum of Natural Science, and
Houston Astronomical Society, Houston, Texas
Electronic mail: bwilson2@ix.netcom.com

ABSTRACT

New CCD photometry of the faint, compact star cluster IC 1257 (ℓ = 17°, b = +15°), obtained with the Palomar 5m telescope[1], reveals that it is a highly reddened globular cluster well beyond the Galactic center. With an apparent distance modulus $(m - M)_V$ = 19.2 and a foreground reddening $E(B - V)$ = 0.75, it is 24 kpc from the Sun and $\sim$ 16 kpc beyond the Galactic center. The morphology of its color-magnitude diagram is similar to that of M13, and suggests that it has moderately low metallicity ([l'c'/}]] $\sim$ -1.'().

[1] The Palomar 5m telescope is operated in a joint agreement among the California Institute of Technology, the Jet Propulsion Laboratory, and Cornell University.

Subject headings: Globular Clusters

1. introduction

It is generally believed that the great majority of the globular c-lusters in the Milky Way have now been found. The most recent catalog (Harris 1996) includes 146 such objects, and the total number of confirmed globulars has grown by only a few percent over the past two decades, despite careful searching of the outer halo and Galactic-bulge regions where most missing clusters are probably hiding. But though it is highly unlikely that any luminous, massive NGC-type clusters remain to be found, smaller clusters have kept turning up in surprising places. Recent examples are the very sparse Pyxis system in the outer halo discovered by Irwin *et al.* (1995), and the Galactic-disk object Lynga 7, once thought to be an old open cluster (Ortolani *et al.* 1993; Tavarez & Friel 1995).

A new finding in this category is IC 1257. This object lies at $\ell = 17^o, b = +15^o$ (equatorial 1950 coordinates $\alpha =$ 17''24'''27^s, $\delta =$ 070 °3'05"; it is also listed in the Guide Star Catalog as GSC 5079-0033, at J2000 coordinates 17''2?7'''08.5^3, 07 °05'35") in a field of moderately heavy but uniform reddening above the Galactic center. It shows up on the 1'OSS and Digital Sky Survey images as a faint, very compact, and obviously distant star cluster (the visual contrast between it and the much nearer globular cluster NGC 6366, 011 the same Sky Survey field, is quite striking). It was discovered more than a century ago by Spitaler *(1890)*. Despite the heavy foreground absorption, it is more easily visible than many of the remote, sparse Palomar-type globular clusters that were found in the systematic search by Abell (1955). Wherever 1(; 1257 has been cataloged, it has always been listed as an open cluster (*e.g.* Shapley 1930; Lynga 1987), though a few publications (notably Burnham 1978) remark that its classification is uncertain and that it may in fact be a globular. Certainly, its moderately high latitude and optical morphology are more in favor of the globular category, but its unfortunate early inclusion in the open-cluster lists served only to divert attention from it, and it has eluded all detailed investigation since its discovery.

The color-magnitude diagram (CMD) of a star cluster usually provides a definitive way to establish its nature, and the photometric study that we report here shows immediately that IC 1257 is a globular cluster on the far side of tile Galaxy. In the previous literature, probably the closest analog of this somewhat accidental re-identification process is for the bulge cluster NGC 6540, which was independently discovered as a globular cluster by Djorgovski (1987) and then later cross-identified by Bica *et al.* (1994) as an NGC object which hat] been previously listed as an open cluster. It is natural to wonder how many other such objects still wait to be correctly identified.

2. Observations and Data Analysis

By inspection of the cluster catalog lists and Sky Survey fields, we recently became aware that IC 1257 might be a globular cluster, and took the earliest opportunity to obtain deep CCD exposures of it. Images in *BVI* were acquired with the Palomar 5-m telescope on the night of 1996 8 Sept. We used the COSMIC 2048 x '2048 CCD array at prime focus, with a corresponding image scale of $0''.2846$ per pixel. Single exposures were taken in each filter, with integration times of 900 sec (*B*), 600 sec (V), and 300 sec (*I*). The *B* image of IC1257 is shown in Fig. I .

Observing conditions were photometric, and frames of four standard-star fields from Landolt (1 992) were taken to calibrate the photometry. The seeing quality on the cluster frames (taken at moderately high airmass) was $1''.4$ FWHM. From the internal scatter of the standard-star measurements, we judge the zeropoints of our photometric *BVI* scales to be established to within :10.02 mag in each filter.

All the image measurement was done with the standard 1 RAF version of the crowded-field DAOPHOT code (Stetson *et al.* 1990). Complete lists of the final data carr be sent to any interested reader on request to WEH. The resulting CMDs in $(V, B - V)$ and $(I, V I)$ are shown irr Fig. 2. At radii larger than ~ 1' from the cluster center, the cluster population drops off rapidly arid the contamination of the CMD by field stars becomes dominant. Experimentation with various radial binnings showed that a dividing line around r : $50''$ gave a near-optimum separation between cluster and field, as shown in the panels of Fig. 2. For the brighter parts of the CMD ($V < 20$, *i.e.* brighter than the HB level), the internal errors of the photometry from the DAOPHOT reductions are less than 0.02 mag in either magnitude or color; these internal uncertainties increase to $\sigma(V) \simeq 0.05, \sigma(V I)$, :I 0.08 at V $\simeq$ 22.

3. Results and Interpretation

The (*B*, V) frame pair gave the best definition of the cluster sequences in the CMD. From the inner region shown in Fig. 2(a), it is immediately clear that IC 1257 exhibits at least two trademarks of a normal halo cluster with low or moderately low metallicity: an extremely blur horizontal branch (111111), apparently with few or no RR Lyrae stars, and a steep red-giant branch (RGB). A close analog among the normal, well-studied halo clusters is probably M 13 (*e.g.* Sandage 1969, 1 970), which exhibits the same basic features,

Our data become severely incomplete past V ~ 22 and thus fall well short of the subgiant region or main-sequence turnoff. Never theless, the brighter parts of the CMD allow us to deduce much essential information about the cluster. The CMDs of both the inner and outer field clearly confirm that the foreground absorption is high, arid the field star population is seen to set in rather sharply redward of a 'wall' at B $V \simeq 1$ .3, V $1 \simeq 1.7$. We use two ways to estimate the cluster reddening:

(1) The red edge of the BHB (or equivalently, the blue edge of the RR Lyrae gap) falls at a well determined color $(B-V)_0 = 0.18 \pm 0.02$ in metal-poor clusters (*e.g.* Sandage 1969). Taking $(B-V) = 0.95 \pm 0.05$ for the apparent color of this fiducial feature in our CMD, we derive $E(B-V) = 0.77 \pm 0.05$. This estimate should actually be considered an upper limit, since the BHB may not reach all the way to the actual RR Lyrae blue edge.

(2) The integrated colors of low-metallicity globular clusters are not very sensitive to metallicity (Racine 1973; Reed *et al.* 1988), and to first order, we can assume $(B-V)_0 = 0.65 \pm 0.05$, $(V-I)_0 = 0.9 \pm 0.1$ for any such cluster. For *highly* reddened clusters, the integrated color itself thus provides an accurate reddening indicator. To obtain the cluster color, we smoothed the original images with a simple boxcar filter to reduce stochastic effects of individual bright stars, and then measured the intensity of the cluster light through a 15″ circular aperture centered on the cluster. This procedure gave integrated colors of $B-V = 1.38 \pm 0.02$, $V-I = 1.83 \pm 0.02$. Subtracting the assumed intrinsic colors quoted above then gives $E(B-V) = 0.73 \pm 0.05$, $E(V-I) \simeq 1.3\,E(B-V) = 0.93 \pm 0.1$.

The two methods give entirely consistent results, and we adopt a mean estimate $E(B-V) = 0.75 \pm 0.04$ for the following discussion. The observed scatter in color (typically ± 0.1 mag) along the red-giant branch and horizontal branch is larger than the internal errors of the photometry (see above), and is thus probably due to a modest amount of differential reddening across the face of the cluster. However, given the relatively large amount of foreground absorption, the differential reddening is surprisingly small.

Taking the reddest part of the BHB as defining the RR Lyrae gap level, we adopt $V_{HB} = 19.8 \pm 0.2$. The metallicity of the cluster can be gauged only roughly with the limited data we have at present; the most effective method we can apply is to use $(B-V)_{0,g}$, the color of the RGB at the HB level (Zinn & West 1984). From Fig. 2(a), we obtain $(B-V)_g = 1.50 \pm 0.05$ and thus $(B-V)_{0,g} = 0.75$. The Zinn-West calibration then gives $[Fe/H] \simeq -1.7 \pm 0.3$. This estimate should be treated with caution given the high reddening and the rather sparsely populated CMD we have at present; the only truly reliable conclusion we can make at this stage is that the cluster is neither metal-rich nor extremely metal-poor.

Assuming $M_V(HB) = 0.6$ for a moderately metal-poor cluster (e.g. Carney *et al.* 1992; VandenBerg *et al.* 1996; Layden *et al.* 1996), we estimate an apparent distance modulus $(m-M)_V = 19.2 \pm 0.2$ and thus $(m-M)_0 = 16.9$ with $A_V = 3.1\,E(B-V)$. A rough check on this distance can be obtained from the tip of the red-giant locus, which lies at $M_I(\mathrm{tip}) = -4.0 \pm 0.1$ for all low-metallicity old stellar populations (Lee *et al.* 1993). From Fig. 2(b), we find that the brightest red-giant star observed in the cluster is at $I \sim 15.75$, which with $M_I > -4.0$ gives $(m-M)_I < 19.75$, or $(m-M)_V < 20.7$, which is comfortably above the estimate from the HB. Since the cluster is not heavily populated, it is likely that the observed giant branch does not extend all the way to the true RGB tip and that this method can give only a generous upper limit

The distance of IC 1257 from the Sun is then 24 ± 2 kpc, or (with $R_0 = 8$ kpc) 16 kpc from the Galactic center. Its location in the halo is indicated in Fig. 3. Interestingly and unlike the great majority of Milky Way globular clusters that have been discovered in the past few decades it is not in either the Galactic. bulge or the outermost halo, but rather in the mid-halo region.

The large distance of the cluster and its compact structure, coupled with the indifferent seeing quality of our CCD images, prevents our photometry from reaching into the innermost $\sim 10''$ (1 pc). Thus any quantitative statements about its core radius or central concentration must await higher-resolution imaging. We can, however, estimate the Cluster luminosity by direct integration from our frames. The B image of the cluster is the most free of saturated star images (either bright foreground stars at large radii, or the brightest RGB stars in the cluster core) and thus the most suitable for the purpose. Large-aperture photometry of the smoothed B image yielded B_t - 14,5 within a radius of 2!6, beyond which we could find no further measurable growth in the cluster light. With the integrated color given above, we then deduce V_t = 13.1, and hence M_V^t = 6.1. This luminosity is distinctly fainter than the average of all globular clusters in the Milky Way ($\langle M_V^t \rangle$ = 7.5; Harris 1991), but still significantly more luminous than the }'alc)]nar-type clusters that inhabit the outermost halo.

l'ills.lly, wc note the presence of an unusually bright star (or starlike object) which appears to lie within $\sim 2''$ of the geometric center of the cluster. '1'bough it is clearly saturated on our I- band image, measurement of this central object through a $2''$-diameter aperture on the B and V frames (extrapolated through the standard curve of growth to the equivalent large- aperture magnitudes) gives approximate photometry of V = 17.12, B V $\simeq$ 1.4. From its placement on the CMD, it could then be a post-AGB star, an RGB-tip star for which the photometry is badly contaminated, or some other kind of compact source. Again, higher-resolution imaging will be necessary to measure it accurately.

In summary, we find that IC 1257 can safely be added to the census of Milky Way globular clusters. It is a moderately low-luminosity halo cluster about 16 kpc beyond the Galactic center, with a CMD morphology and metallicity that are normal for its location. It would be of great interest to obtain a radial velocity and spectroscopic metallicity for it, as well as higher-resolution imaging.

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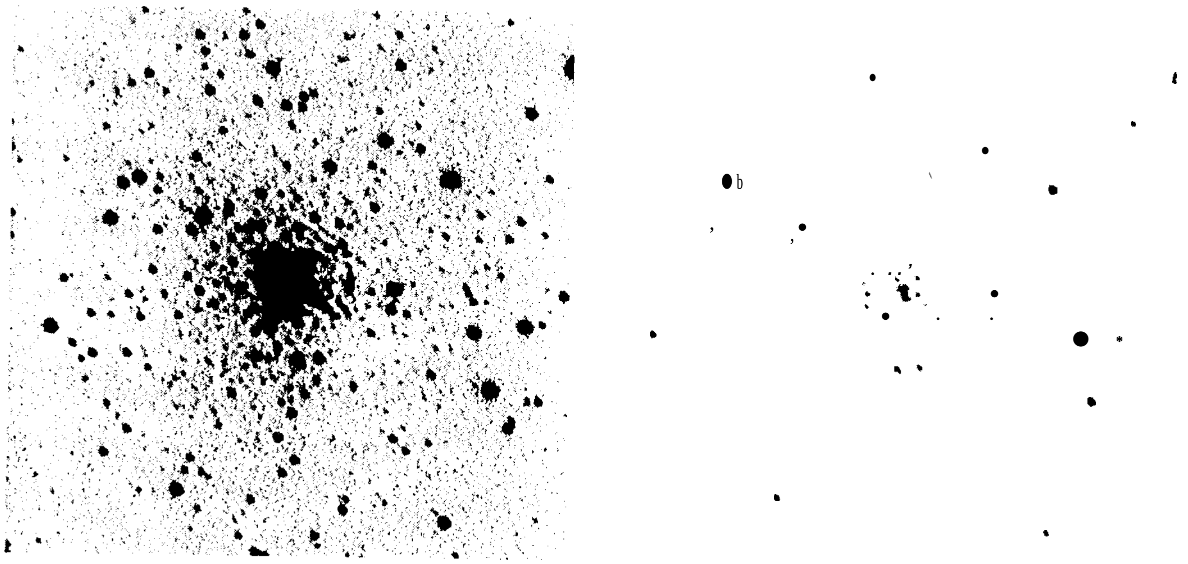
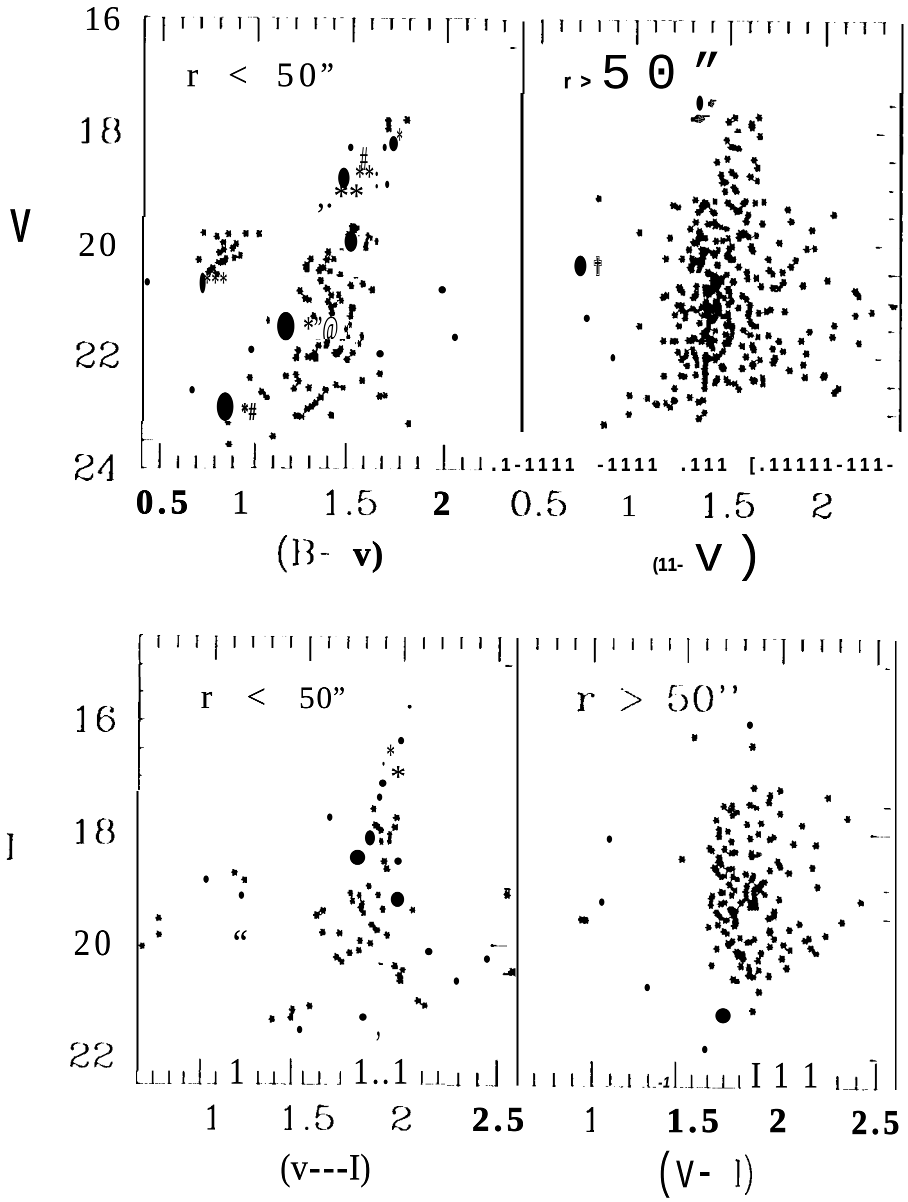
Fig. 1.- A 900-sec exposure in B of the cluster IC 1257, taken at the prime focus of the Hale 5 meter telescope. The field of view displayed is 2.'8 x 2.'8; North is up and East to the left. The outer parts of the cluster are shown in the left panel, and the inner parts in the right panel.

Fig. 2. (a) Color-magnitude diagram in V, $(B - V)$ for IC1257. The *left panel* shows the measured stars in the inner region (< 50" from cluster center, excluding the innermost ~ 10" for which crowding prevented any measurement), while the *right panel* shows the CMD for the region outside 50" radius. The interior region contains primarily cluster stars, while the outer region is mostly field stars. (b) Color-magnitude diagram in I, $(V - I)$ for IC 11257. Panels are the same as for part (a).

Fig. 3.- Location of IC 1257 in the Milky Way halo, in the X, Z Galactic coordinate plane. In this plot the Sun is at (O, O) and the Galactic center at (8, O) kpc. Data for other globular clusters (small symbols) are taken from Harris (1996).

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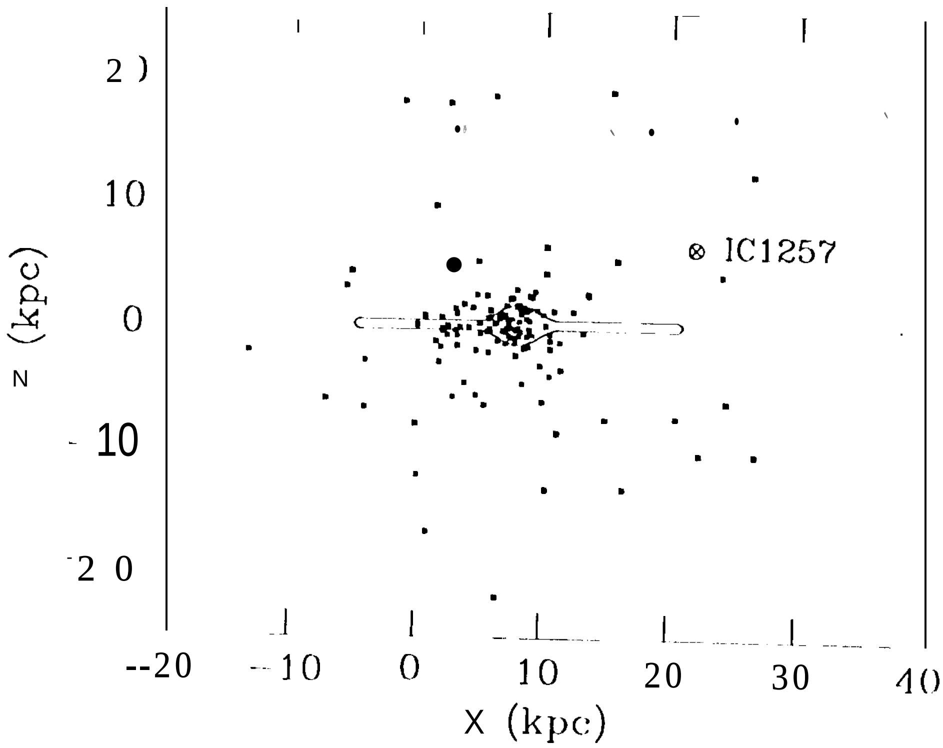

IC1257
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Z (kpc)
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