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WHITING 1: A NEW HALO YOUNG GLOBULAR CLUSTER

Giovanni Carraro[1,2,3]
Departamento de Astronomía, Universidad de Chile, Casilla 36-D, Santiago, Chile; gcarraro@das.uchile.cl
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ABSTRACT

We report on *BVI* CCD photometry of a field centered in the region of the Galactic star cluster Whiting 1 down to $V = 23.0$. This cluster has never been studied insofar, and we provide for the first time estimates of its fundamental parameters, namely, radial extent, age, distance, and reddening. Whiting 1 turns out to be a compact star cluster with a diameter of about 1′. We find that the cluster is about 5 Gyr old and has a probable metal abundance around [Fe/H] = −1.20. Its position at $b = -60.^{\circ}64$ and at a heliocentric distance of about 45 kpc makes the cluster a rather strange object, surely not a disk old open cluster, but perhaps the youngest halo globular cluster insofar known.

Subject headings: open clusters and associations: general — open clusters and associations: individual (Whiting 1)

1. INTRODUCTION

Whiting 1 (WHI B0200−03; $l = 161.^{\circ}62$, $b = -60.^{\circ}64$; $\alpha = 2^{\rm h}02^{\rm m}57^{\rm s}$, $\delta = -3^{\circ}15'10''$ [J2000 .0]) was discovered by Whiting et al. (2002) during a search for Local Group dwarf galaxies in the southern hemisphere. A 1200 s *V*-band image (their Fig. 4) reveals that this object is a star cluster very well resolved. The authors comment that it is a cluster of blue stars with a distant galaxy cluster in the background. This is probably the reason for which Whiting 1 was later on classified as a Galactic open cluster (Dias et al. 2002). However, its faintness and the particular location in the Milky Way in the anticenter direction at $b = -60.^{\circ}64$ cast some doubts on its open cluster nature.

In this Letter, we provide new photometric data with the aim to clarify the cluster nature and to derive the first estimates of its fundamental parameters. The layout of the Letter is as follows. Section 2 illustrates the observation and reduction strategies. An analysis of the geometrical structure and star counts in the field of the cluster are presented in § 3, whereas a discussion of the color-magnitude diagrams (CMDs) is performed in § 4. Section 5 deals with the determination of cluster reddening, distance, and age, and, finally, § 6 summarizes our findings.

2. OBSERVATIONS AND DATA REDUCTION

CCD *BVI* observations were carried out with the eight-CCD camera on board the 1.0 m telescope at Cerro Tololo Inter-American Observatory (Chile), in the nights of 2004 December 15–16. With a pixel size of $0.''469$, and a CCD size of 512 × 512 pixels, this samples a $4.'1 \times 4.'1$ field in the sky. The details of the observations are listed in Table 1, where the observed fields are reported together with the exposure times, the average seeing values, and the range of air masses during the observations. Figure 1 shows a 900 s *I*-band image of the area of Whiting 1. In the figure, east is up, and north is on the right.

The data have been reduced with the IRAF[4] packages CCDRED, DAOPHOT, ALLSTAR, and PHOTCAL using the point-spread function method (Stetson 1987). The two nights turned out to be photometric and very stable, and therefore we derived calibration equations for all 130 standard stars observed during the two nights in the Landolt (1992) fields SA 95-41, PG 0231+051, Rubin 149, Rubin 152, T Phe, and SA 98-670 (see Table 1 for details).

The calibration equations turned out to be of the form

$$b = B + b_1 + b_2 \times X + b_3(B - V),$$
$$v = V + v_1 + v_2 \times X + v_3(B - V),$$
$$i = I + i_1 + i_2 \times X + i_3(V - I),$$

where *BVI* are standard magnitudes, *bvi* are the instrumental ones, and *X* is the air mass; all the coefficient values are reported in Table 2. The standard stars in these fields provide a very good color coverage. The final rms of the calibration is 0.049, 0.034, and 0.033 for the *B*, *V*, and *I* filters, respectively.

Photometric errors have been estimated following Patat & Carraro (2001). It turns out that stars brighter than $V \approx 22$ mag have internal (ALLSTAR output) photometric errors lower than 0.10 mag in magnitude and lower than 0.18 mag in color. The final photometric catalog for Whiting 1 (coordinates, *B*, *V*, and *I* magnitudes, and errors) consists of 1757 stars and is available in electronic form at the WEBDA[5] Web site maintained by J.-C. Mermilliod.

3. STAR COUNTS AND CLUSTER SIZE

Dias et al. (2002) report a preliminary estimate of the Whiting 1 diameter amounting to $1.'2$. By inspecting Figure 1, we can recognize that the Dias et al. estimate is surely a reasonable one. Since our photometry covers entirely the cluster's area and part of the surroundings, we performed star counts to obtain an improved estimate of the cluster's size. We derived the surface stellar density by performing star counts in concentric

[1] Visiting Astronomer, Cerro Tololo Inter-American Observatory. CTIO is operated by the Association of Universities for Research in Astronomy (AURA), Inc., under contract to the National Science Foundation.

[2] Astronomy Department, Yale University, P.O. Box 208101, New Haven, CT 06520-8101.

[3] On leave from Dipartimento di Astronomia, Università di Padova, Vicolo Osservatorio 2, I-35122, Padua, Italy.

[4] IRAF is distributed by NOAO, which is operated by AURA, Inc., under cooperative agreement with the NSF.

[5] See http://obswww.unige.ch/webda/navigation.html.

TABLE 1
Journal of Observations of Whiting 1 and Standard Star Fields
(2004 December 15–16)

Field	Filter	Exposure Time (s)	Seeing (arcsec)	Air Mass
Whiting 1	*B*	120, 1200, 1800	1.2	1.12–1.20
	V	30, 600, 900	1.3	1.12–1.20
	I	30, 600, 900	1.2	1.12–1.20
SA 98-671	*B*	3 × 120	1.2	1.24–1.26
	V	3 × 40	1.4	1.24–1.26
	I	3 × 20	1.4	1.24–1.26
PG 0231+051	*B*	3 × 120	1.2	1.20–2.04
	V	3 × 40	1.5	1.20–2.04
	I	3 × 20	1.5	1.20–2.04
T Phe	*B*	3 × 120	1.2	1.04–1.34
	V	3 × 40	1.3	1.04–1.34
	I	3 × 20	1.3	1.04–1.34
Rubin 152	*B*	3 × 120	1.3	1.33–1.80
	V	3 × 40	1.2	1.33–1.80
	I	3 × 20	1.2	1.33–1.80
Rubin 149	*B*	3 × 120	1.1	1.21–1.96
	V	3 × 40	1.2	1.21–1.96
	I	3 × 20	1.2	1.21–1.96
SA 95-41	*B*	3 × 120	1.2	1.05–1.48
	V	3 × 40	1.2	1.05–1.48
	I	3 × 20	1.1	1.05–1.48

rings around the cluster's nominal center and then dividing by their respective surfaces. Poisson errors have also been derived and normalized to the corresponding surface. Poisson errors in the field star counts turned out to be very small, and therefore we are not going to show them. The final radial density profile for Whiting 1 is shown in Figure 2 as a function of *V* magnitude. The contribution of the Galactic disk field has been estimated by considering all the stars in the corresponding magnitude bin, located outside 1′.6 from the cluster center, and by normalizing counts over the adopted area.

The cluster seems to be populated by stars of magnitude in the range $18 \le V \le 24$, where it clearly emerges from the background. In this magnitude range, the radius is not larger than 0′.5. In conclusion, we adopt the value of 0′.5 as the Whiting 1 radius throughout this Letter. This estimate is in good agreement with the value of 1′.2 reported by Dias et al. (2002) for the cluster diameter.

TABLE 2
Coefficients of the Calibration Equations

$b_1 = 3.465 \pm 0.009$	$b_2 = 0.25 \pm 0.02$	$b_3 = -0.145 \pm 0.008$
$v_1 = 3.244 \pm 0.005$	$v_2 = 0.16 \pm 0.02$	$v_3 = 0.021 \pm 0.005$
$i_1 = 4.097 \pm 0.005$	$i_2 = 0.08 \pm 0.02$	$i_3 = 0.006 \pm 0.005$

4. THE COLOR-MAGNITUDE DIAGRAMS

In Figure 3, we present the CMDs of Whiting 1 for all the detected stars. In the left panel of the same figure, we show the CMD in the *V* versus $(B - V)$ plane, whereas in the right panel we show the CMD in the *V* versus $(V - I)$ plane. These CMDs are not very easily interpreted, because of the faintness of the stars. However, we can recognize a wide main sequence (MS) in both CMDs, extending from $V \approx 21$, where the turnoff (TO) point is located, down to $V \approx 23.5$. The upper part of the CMD is more confusing. It seems that a subgiant branch is actually present and that the red giant branch (RGB) starts rising at $V \approx 20.8$, $(B - V) \approx 0.9$. The RGB, however, is poorly populated. A group of stars at $18.0 \le V \le 18.3$, $(B - V) \approx 1.0$ may indicate the presence of a clump.

Better information can be derived from Figure 4, where we show the CMDs of Whiting 1 as a function of the distance from the cluster nominal center. Here we consider only stars having errors in the *V* band lower than 0.15 mag (see § 2). In the left panel, all the stars are plotted, whereas in the middle panel, we only plot the stars that lie within the cluster radius (see § 3). Finally, in the right panel, we plot the stars outside the cluster region, to show what the Galactic field toward the cluster looks like. Interestingly, the MS in the middle panel gets much thinner, and we can locate the TO point at $V \approx 21.0$, $(B - V) \approx 0.5$. The RGB is scarcely populated, and the presumed clump disappears. Most of the stars in the left panel

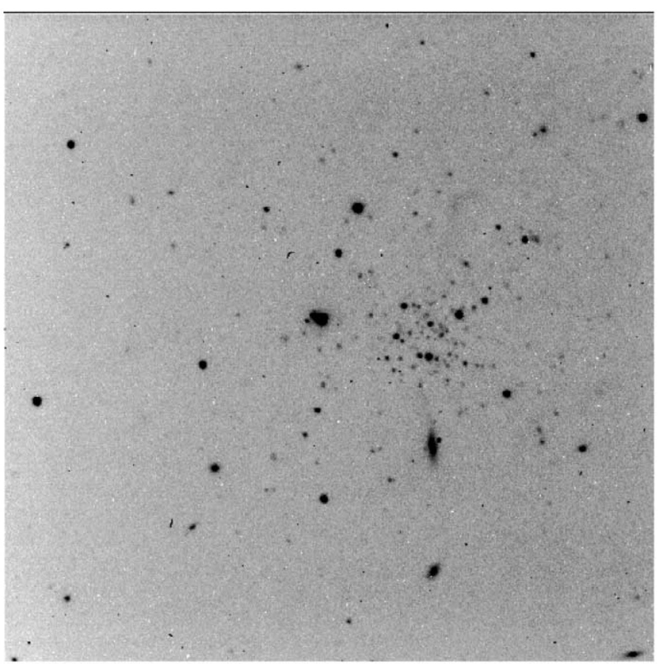

Fig. 1.—The 900 s *I*-band image of the observed area in the region of the open cluster Whiting 1. East is up, north is on the right, and the covered area is 4′.1 × 4′.1.

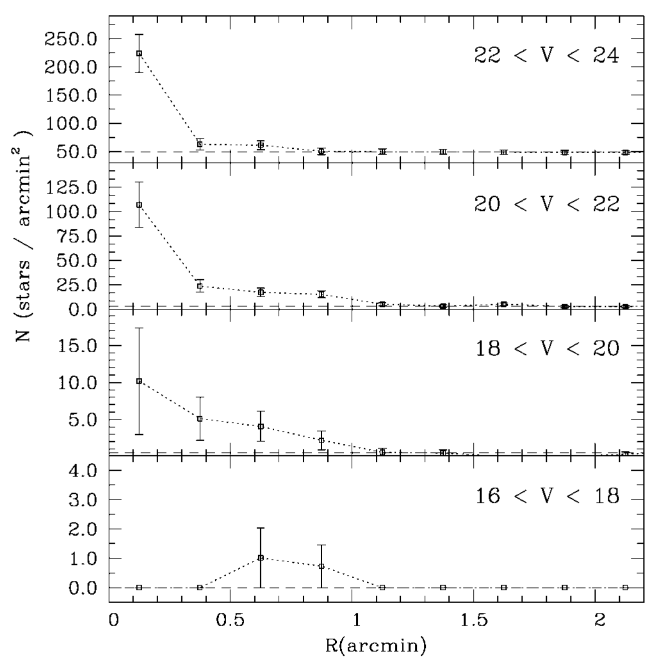

Fig. 2.—Star counts in the area of Whiting 1 as a function of radius and magnitude. The dashed lines represent the level of the control field counts estimated in the surroundings of the cluster in that magnitude range.

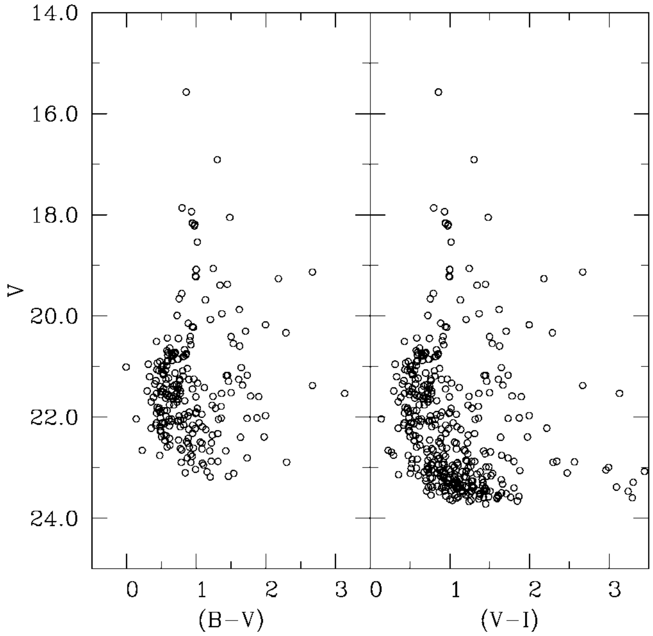

FIG. 3.—V vs. $(B - V)$ (*left panel*) and V vs. $(V - I)$ (*right panel*) CMDs of Whiting 1.

located in the RGB region and in the red edge of the MS come from the field shown in the right panel. In conclusion, the overall shape of the CMD in the middle panel is reminiscent of an old cluster.

5. CLUSTER FUNDAMENTAL PARAMETERS

In this section, we provide estimates of Whiting 1 basic parameters. We start deriving a first guess of the cluster reddening by using far-IR background maps by Schlegel et al. (1998). We obtain $E(B - V) = 0.026$, a very low value, as expected for a cluster located at high Galactic latitude. At this point, since we do not have any other information, we have to rely on a detailed comparison between the CMD morphology and theoretical isochrones. In the following analysis, we adopt the Padova isochrones (Girardi et al. 2000).

In Figures 5 and 6, we play with age and metallicity, trying to encounter the best overall fit of the CMD. In detail, in Figure 5 we keep the metallicity fixed at $Z = 0.001$ and change the age from 3.8 to 5.6 Gyr. In both CMDs, the best fit is provided by the age of 4.8 Gyr (*dash-dotted line*), which implies a reddening $E(B - V) = 0.04$ and $E(V - I) = 0.05$. The older isochrone (5.6 Gyr) implies an untenable $E(B - V) = 0.00$, or slightly negative, while the youngest one (3.8 Gyr) implies a reddening $E(B - V) = 0.12$, which is still acceptable, but the overall fit of the red part of the CMD looks very poor.

On the other hand, in Figure 6 we keep the age of 4.8 Gyr fixed and play with metallicity. In this case, the best fit is provided by $Z = 0.001$. The fit with a lower metal abundance

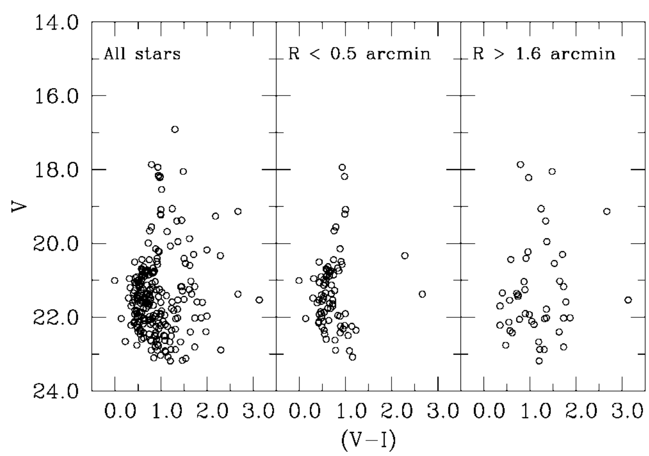

FIG. 4.—V vs. $(V - I)$ CMDs of Whiting 1 as a function of the distance from the cluster nominal center.

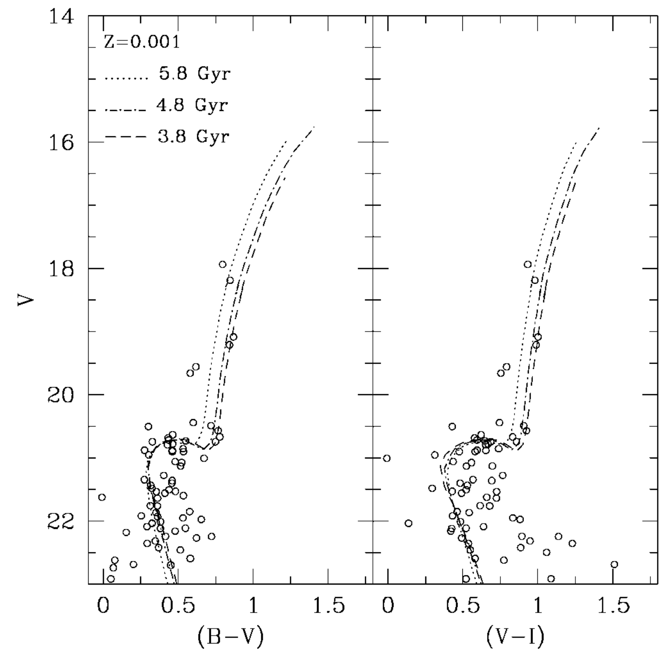

FIG. 5.—Looking for the cluster age. Isochrone fitting for the $Z = 0.01$ metallicity. Dotted, dash-dotted, and dashed isochrones are for the ages of 5.8, 4.8, and 3.8 Gyr, respectively. See text for details.

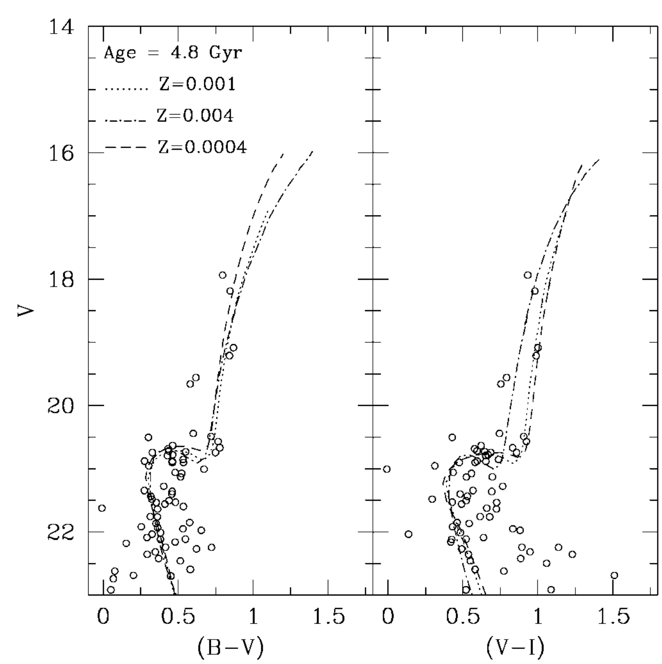

FIG. 6.—Looking for the cluster metallicity. Isochrone fitting for the age of 4.8 Gyr. Dotted, dashed, and dash-dotted isochrones are for the metallicity $Z = 0.001$, 0.0004, and 0.004, respectively. See text for details.

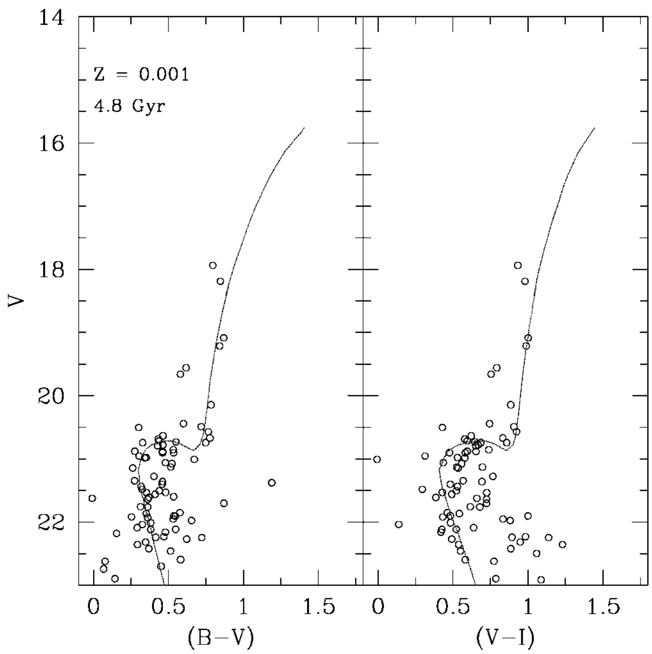

FIG. 7.—Final isochrone solution for the Whiting 1 CMD obtained for the age of 4.8 Gyr, the reddening $E(B-V) = 0.04$, and the distance modulus $(m-M)_V = 18.4$. The isochrone is for a metallicity $Z = 0.001$.

is not so bad as well, while the larger metallicity isochrone poorly fits the CMD and implies a negative reddening.

From this exercise, we infer that the cluster metal abundance is around $Z = 0.001$ and the age around 5 Gyr. The best fit is therefore outlined in Figure 7, and from this we derive a distance modulus $(m-M)_V = 18.4$ and a reddening $E(B-V) = 0.04$. As a consequence, we obtain a heliocentric distance of about 45 kpc. The results we achieved are listed in detail in Table 3.

6. CONCLUSIONS

We have presented the first CCD *BVI* photometric study of the star cluster Whiting 1. The CMDs we derive allow us to infer estimates of the cluster basic parameters, which are summarized in Table 3.

TABLE 3
FUNDAMENTAL PARAMETERS OF WHITING 1

Parameter	Value
Radius (arcmin)	0.5
$E(B-V)$	0.04
$E(V-I)$	0.05
$(m-M)_0$	18.4
X (kpc)	28.9
Y (kpc)	6.9
Z (kpc)	−39.0
Age (Gyr)	5.0
Metallicity	0.001

In detail, we find that:

1. Whiting 1 is a compact star cluster with a radius of 0′.5.
2. We propose that it is a 5 Gyr old cluster with a low metal content, $Z = 0.001$ ([Fe/H] ≈ -1.20).
3. Its position high onto the Galactic plane and its distance from the Sun (≈45 kpc) can hardly be reconciled with Whiting 1 being a disk old open cluster.

The combination of age, position, and metallicity makes Whiting 1 a very puzzling object. We can rule out the hypothesis of an old open cluster, because of the low metal content, and mostly because of its positions. The cluster bears some similarities with Palomar 1 (Rosenberg et al. 1998), an 8 Gyr old globular cluster, and other transitional clusters like Terzan 7, Ruprech 106, and others mentioned in Rosenberg et al. (1998). Following the kind of discussion by Rosenberg et al. (1998), we here tentatively propose that Whiting 1 is the Milky Way's youngest globular cluster insofar known, although a clear explanation for its formation and evolution remains very challenging.

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