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INTERSTELLAR POLARIZATION AND EXTINCTION TOWARDS THE OPEN CLUSTER NGC 457

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ABSTRACT

NGC 457 is a moderately reddened and relatively young open cluster, very rich in variable stars and in Be stars in particular, but not associated with any prominent star-forming field. We combine new multi-wavelength polarization measurements with existing UBV and $uvby$ photometries to obtain precise estimates of the total-to-selective extinction in the field of the cluster and reevaluate its distance and age. The polarization measurements show a tight alignment of the polarization vectors with the Galactic plane and yield an average value of the total-to-selective extinction of 3.05 ± 0.17 for the cluster's field. Using this value and the confirmed color excess $E(B-V) = 0.500 \pm 0.030$ mag, we obtain a distance modulus of 12.20 ± 0.39, corresponding to 2.75 ± 0.49 kpc and, assuming slightly sub-solar metallicity, an age of 15.8 Myr.

Keywords: stars: early-type, stars: fundamental parameters, stars: general, techniques: polarimetry, open clusters and associations: individual: NGC 457

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1. INTRODUCTION

NGC 457 is a young open cluster located at $l = 126.6348°$, b =-04.3826°, somehow below the star-forming fields associated with Cas OB1 and Cas OB8. It appears isolated from the Cassiopeia-Perseus complex of open clusters and not associated with any prominent nebulosities. The most extensive photoelectric UBV photometry of cluster's stars is obtained by Pesch (1959) (78 stars) and Hoag et al. (1961) (34 stars). CCD intermediate-band *uvby* photometry of nearly 60 stars in the direction of the cluster is provided by Fitzsimmons (1993). Hβ photometry is available only for several stars of the cluster (Eggen 1982). The yellow supergiant ϕ Cassiopeiae (F0 Ia) is projected within the boundaries of the cluster. As a part of their CCD variability survey, Moździerski et al. (2014) found that NGC 457 is very rich in Be stars and in variable stars in general.

High resolution spectroscopy of main-sequence B-type stars has been performed by Dufton et al. (1994) and yielded normal chemical composition. The works by Tadross (2003) ($[Fe/H] = -0.46$) and Fitzpatrick & Massa (2007) ($[M/H] = -0.43$) suggest, however, that the metallicity of the cluster might be lower than solar. The cluster is moderately reddened ($E(B-V) = 0.5$ mag) with distance estimates varying between 2.4 kpc and 3.3 kpc (see also Moździerski et al. (2014) for a recent review).

In order to reevaluate the existing estimates of the NGC 457 parameters, we present new multi-wavelength polarization measurements of 12 stars in this direction. We use the wavelength of maximum polarization to calculate the total-to-selective extinction ratio for the cluster and further combine this result with existing UBV and *uvby* photometric data to provide new estimates of the cluster's distance and age.

In general, a combination between multi-wavelength polarimetry and precise photometry provides more constraints on the derivation of the four free clusters' parameters: reddening, distance, metallicity and age. Often, especially when fitting isochrones to the cluster sequence, we introduce bias because of an assumed (average for the Galaxy) value of the total-to-selective extinction ratio, or assumed solar metallicity. These uncertainties affect various aspects of the analysis of the cluster populations in the Galaxy (see for example Paunzen et al. (2010) for a thorough discussion). A combination between polarization and intermediate-band $uvby\beta$ photometry should be especially useful because it can provide metallicity independent reddening and distance and mutually independent estimates of metallicity and age.

2. POLARIZATION OBSERVATIONS AND ANALYSIS

Polarimetric observations of NGC 457 were performed during the night of September 22, 2016 using the optical polarimeter on the 0.5-m f/13.5 Cassegrain telescope at the Virginia Military Institute (VMI) Observatory located at McKethan Park in Lexington, VA. The design, construction, and operation of the polarimeter are described by Topasna et al. (2013). The polarimeter uses a rotatable achromatic half-wave plate at positions of 0°, 22.5°, 45°, and 67.5° with respect to the fiducial setting at 0° along a line of constant right ascension. The star's light then passes through a Wollaston prism and filter wheel and is imaged on an Alta U6 CCD. The CCD records a dual image of each star, its ordinary I^o and extraordinary I^e rays. Due to vignetting by the optics, the usable field-of-view is approximately ten arcminutes in diameter.

Aperture photometry is used to measure the ordinary and extraordinary fluxes I^o and I^e. Following the method described by di Serego Alighieri (1997) we compute the ratios $R_q^2 \equiv I^o_{0^\circ} I^e_{45^\circ} / I^e_{0^\circ} I^o_{45^\circ}$ and $R_u^2 \equiv I^o_{22.5^\circ} I^e_{67.5^\circ} / I^e_{22.5^\circ} I^o_{67.5^\circ}$ and then normalized Stokes parameters $q = (R_q - 1)/(R_q + 1)$ and $u = (R_u - 1)/(R_u + 1)$. While this method removes the detector's polarization, the telescope's instrumental polarization is eliminated by imagining an unpolarized standard star, calculating its normalized Stokes parameters, and then vectorially subtracting these from the Stokes parameters of the program stars. Using the list of standard stars (both polarized and unpolarized) from Serkowski (1974), we imaged the unpolarized standard HD 185395 (θ Cyg) as well as the polarized standard HD 7927 (ϕ Cas).

The degree of polarization and position angle are computed from the Stokes parameters using $p_0 = \sqrt{q^2 + u^2}$ and $\theta = \frac{1}{2} \tan \frac{u}{q}$ with standard errors given by $[q^2\sigma_q^2 + u^2\sigma_u^2]^{1/2}/p$ and $[q^2\sigma_u^2 + u^2\sigma_q^2]^{1/2}/2p^2$. Finally, the inherent bias is removed using the Wardle & Kronberg (1974) estimator $p = \sqrt{p_0^2 - \sigma_p^2}$.

From our $UBVRI$ observations, we measured the wavelength dependence of the polarization. The observed polarization of starlight has been well studied and is described by the empirical relationship

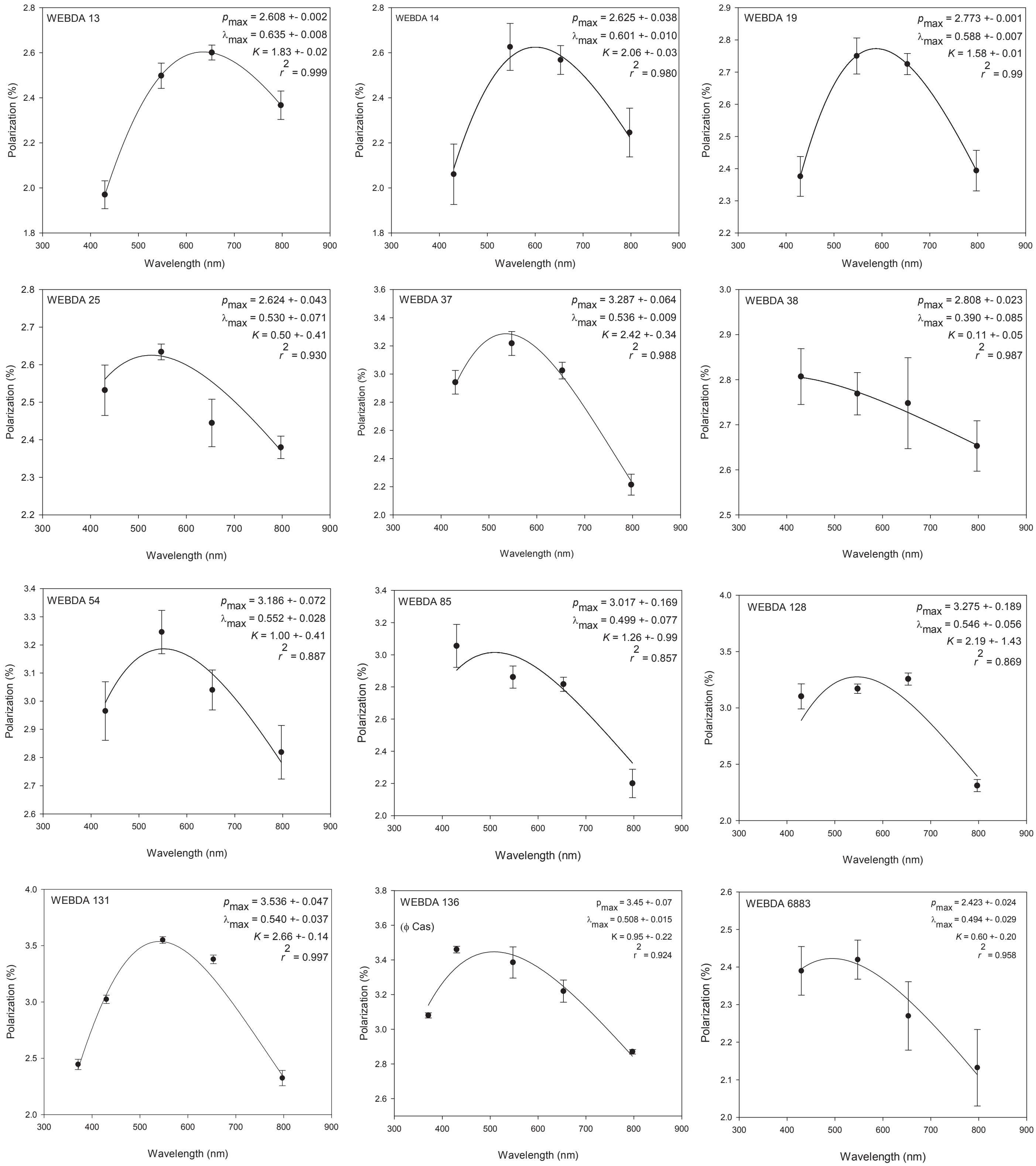

Figure 1. Serkowski's curves for the measured stars in the field of NGC 457.

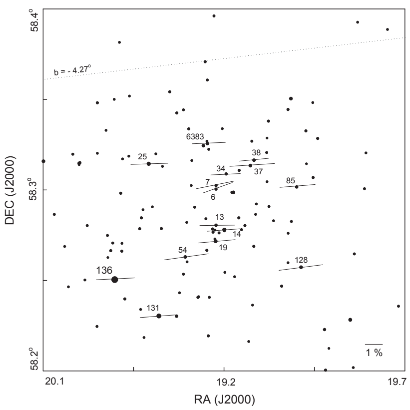

Figure 2. Polarization vectors map for the observed stars in the field of NGC 457.

$$p(\lambda)/p_{max} = \exp[-K\ln^2(\lambda_{\max}/\lambda)] \quad (1)$$

where p_{max} is the maximum degree of polarization at the wavelength λ_{max}. The parameter K was shown by Wilking et al. (1982) to be a function of λ_{max} as $K = (-0.10 \pm 0.05) + (1.86 \pm 0.09)\lambda_{max}$ that is related to grain sizes and distribution in the ISM. This correlation was however later critiqued by Clarke & Al-Roubaie (1983, 1984) as also depending on the signal-to-noise ratio, choice of bandpass, and presence of clouds along the line of sight. Further discussion of the Serkowski's equation, the linear dependence of K, and other issues can be found in Clarke (2010) and references therein. In our analysis, when fitting our observations to the Serkowski's equation above, we let K be a free-fit parameter.

The standard polarized star, HD 7927 (ϕ Cas) was also imaged during this night. For HD 7927, the degree of polarization and position angle listed by Serkowski (1974) are $p_{max} = 3.4 \pm 0.1$ and $\lambda_{max} = 0.51\ \mu m$ with the position angle $\theta_V = 94 \pm 1°$. A later analysis of the polarization standards by Hsu & Breger (1982) lists these parameters for HD 7927 as $p_{max} = 3.41 \pm 0.02$, $\lambda_{max} = 0.515 \pm 0.006\ \mu m$, and $\theta_V = 92.3 \pm 0.1°$. The degree of polarization and wavelength of the maximum polarization

Table 1. Polarization measurements of stars in the direction of NGC 457.

WEBDA	Filter	$p(\%)$	θ	WEBDA	Filter	$p(\%)$	θ
13	B	1.970 ± 0.199	95.07 ± 0.16	38	B	2.807 ± 0.062	95.20 ± 0.12
	V	2.498 ± 0.135	91.21 ± 0.08		V	2.769 ± 0.047	94.97 ± 0.08
	R	2.601 ± 0.076	95.41 ± 0.05		R	2.748 ± 0.101	94.16 ± 0.04
	I	2.367 ± 0.109	93.90 ± 0.07		I	2.653 ± 0.095	92.94 ± 0.03
14	B	2.061 ± 0.134	99.46 ± 0.10	54	B	2.965 ± 0.104	99.58 ± 0.06
	V	2.626 ± 0.104	94.72 ± 0.06		V	3.246 ± 0.077	99.44 ± 0.04
	R	2.568 ± 0.064	93.79 ± 0.04		R	3.040 ± 0.071	97.79 ± 0.04
	I	2.246 ± 0.108	92.70 ± 0.08		I	2.819 ± 0.095	98.00 ± 0.05
19	B	2.376 ± 0.062	99.30 ± 0.04	85	B	3.055 ± 0.134	97.86 ± 0.07
	V	2.750 ± 0.056	95.48 ± 0.03		V	2.843 ± 0.069	96.05 ± 0.04
	R	2.726 ± 0.033	97.76 ± 0.02		R	2.857 ± 0.049	96.62 ± 0.03
	I	2.394 ± 0.063	98.00 ± 0.04		I	2.217 ± 0.088	96.89 ± 0.06
25	B	2.530 ± 0.067	91.78 ± 0.04	128	B	3.208 ± 0.111	97.44 ± 0.05
	V	2.634 ± 0.021	92.90 ± 0.01		V	3.170 ± 0.042	97.17 ± 0.02
	R	2.433 ± 0.063	93.36 ± 0.04		R	3.256 ± 0.054	99.10 ± 0.03
	I	2.383 ± 0.023	92.62 ± 0.02		I	2.310 ± 0.054	96.41 ± 0.04
37	B	2.942 ± 0.084	99.04 ± 0.04	6383	B	2.390 ± 0.065	96.32 ± 0.04
	V	3.218 ± 0.085	95.06 ± 0.04		V	2.420 ± 0.052	95.41 ± 0.03
	R	3.025 ± 0.059	95.95 ± 0.03		R	2.270 ± 0.091	96.63 ± 0.06
	I	2.215 ± 0.074	96.55 ± 0.05		I	2.132 ± 0.102	93.93 ± 0.08
131	U	2.445 ± 0.046	93.55 ± 0.05	136	U	2.743 ± 0.014	94.47 ± 0.01
	B	3.023 ± 0.037	97.58 ± 0.04		B	3.484 ± 0.019	94.37 ± 0.20
	V	3.550 ± 0.030	94.56 ± 0.03		V	3.571 ± 0.090	93.86 ± 0.09
	R	2.871 ± 0.039	95.94 ± 0.05		R	2.562 ± 0.064	94.72 ± 0.06
	I	2.353 ± 0.068	92.50 ± 0.10		I	2.823 ± 0.026	90.87 ± 0.03

we measured are $p_{max} = 3.45 \pm 0.07$ and $\lambda_{max} = 0.51 \pm 0.02$ μm with $\theta_V = 93.9 \pm 0.1°$. Our results are consistent with the previously published values which brings confidence in our polarization measurements.

The broad-band wavelength-dependent polarisation measurements in the $BVRI$ filters for the twelve observed stars in the direction of the cluster are listed in Table 1. We find convenient to use the WEBDA (W hereafter) identification. For two of the brightest stars, W131 and W136 (ϕ

Table 2. Polarization parameters of stars in the direction of NGC 457.

WEBDA	m_V[a]	Sp Type[a]	Prob.[a]	$p_{max}(\%)$	σ_p	λ_{max}	σ_λ	K	σ_K	r^2	$R = 5.6\lambda_{max}$	Remarks
13	10.81	B5	0.07	2.604	0.004	0.635	0.001	1.84	0.46	0.999	3.556	
14	9.75	B3	0.73	2.625	0.038	0.601	0.014	2.06	0.31	0.980	3.363	
19	9.51	B1 IV	0.38	2.773	0.007	0.588	0.021	1.58	0.01	0.999	3.291	
25	8.59	K5III	0.18	2.624	0.043	0.530	0.071	0.50	0.41	0.912	2.967	HD 236697
37	9.83	B1V	0.69	3.287	0.064	0.536	0.009	2.42	0.34	0.989	2.999	
38	10.12	A0	0.56	2.808	0.023	0.390	0.085	0.11	0.05	0.987	2.186	
54	10.18	B3	0.81	3.186	0.072	0.552	0.028	1.00	0.41	0.887	3.091	
85	10.78	B5	0.74	3.015	0.193	0.510	0.087	1.20	1.20	0.788	2.855	
128	9.63	B6Ve	0.56	3.294	0.213	0.529	0.068	2.08	1.42	0.909	2.965	
131	7.01	B6Ib	0.80	3.530	0.047	0.540	0.037	2.66	0.14	0.997	3.024	HD 7902
136	4.95	F5Ia+F2Ia	0.59	3.570	0.150	0.534	0.017	1.66	0.47	0.867	2.990	HD 7927
6383	10.34	B3		2.423	0.024	0.494	0.029	0.60	0.20	0.958	2.767	BD+57° 253

[a] Adopted from the WEBDA database

Cas), measurements in the U filter are included as well. The corresponding Serkowski's fits are shown on Fig. 1. The derived polarization parameters p_{max}, λ_{max}, and K that have been determined via the Serkowski equation, along with their uncertainties and goodness of fit, are included in Table 2 (columns 5 to 11). Listed as well are the apparent magnitude, spectral type and the probability of membership (columns 2, 3 and 4), all adopted from the WEBDA database. Also shown (column 12) are the values of the total-to-selective extinction for each star, computed as $R = 5.6\lambda_{max}$. The average value for this region is R=3.0 $\pm$ 0.1, consistent with what is generally found for the local ISM. We should also note that the average measured value of λ_{max} is 0.54 $\pm$ 0.02 μm, which is also consistent with a value of 0.52 μm for this region along the Galactic plane as computed from the empirical relation $\lambda_{max} = 0.545 + 0.030\sin(l + 175°)$ derived by Whittet (1977) to describe the systematic modulation of λ_{max} as a function of Galactic longitude.

Figure 2 presents the V-band polarization vectors, which show a general alignment in the direction of the Galactic plane. The length of the vectors is proportional to the maximum degree of polarization (a scale bar is provided for reference). The dotted line corresponds to the Galactic plane at $b = -4.27°$. The polarization is fairly uniform across the field of the cluster.

3. CLUSTER PARAMETERS

In the following analysis we utilize the *uvby* (CCD) photometry by Fitzsimmons (1993) and the UBV (photoelectric) photometry by Pesch (1959). Figure 3, top panel, presents the c_1 vs. $b - y$ diagram based on the *uvby* data from Fitzsimmons (1993). We have plotted the original data together with the dereddened quantities. All stars with $[m_1] > 0.19$ are omitted on this diagram as apparent field stars of spectral types later than B9. Following Fitzsimmons (1993) we also removed two B stars that are less reddened than the rest of the sample and seem to be non-members (W38 and W109). We also removed from this *uvby* sample W12 because it seemed misidentified. The c_1 vs. $b - y$ diagram contains both the quantities that are individually dereddened and the quantities dereddened by an average color excess $E(b - y) = 0.74\ (B - V)$, adopting $E(B - V) = 0.5$. The individually corrected for reddening $(b - y)_0$ index was calculated as $(b - y)_0 = (c_1 - 0.2(b - y) - 1.14)/9.79$ and $c_0 = c_1 - 0.2 * E(b - y)$. This procedure of reddening correction (which is based on the calibration by Crawford (1978)) yields $(b - y)_0$ and c_0 located exactly on the reference line on the c_1 vs. $b - y$ diagram. Both the average-corrected and individually-corrected dereddened quantities tightly follow the intrinsic color line in $(b - y, c_1)$ coordinates. We consider this as a test that the $b - y$ and c_1 quantities are free of systematic errors, which brings confidence in the following analysis.

In addition, we performed extensive comparisons between corresponding *uvby* and UBV photometric quantities for the stars in common between the samples by Fitzsimmons (1993), Hoag et al. (1961) and Pesch (1959). These comparisons are useful to detect small systematic errors in the photometric data (Crawford 1994). We analyzed the comparisons between V, $b - y$, $B - V$, $u - b$, $U - B$ and the derived color excesses $E(b - y)$ and $E(B - V)$ and found no indications for systematic errors for both the UBV and *uvby* quantities.

Since the overlap between the samples of recognized member stars with *uvby* data and member stars with polarization data is not significant, we derived an average R value based on the polarization sample and then utilized it for the *uvby*-based analysis. Rosenzweig & Morrison (1986) studied the individual extinction curves of several B-type stars in NGC 457 and found the extinction toward the cluster to be uniform. Thus, using an average value of R is justified in this case. For the 9 B-type stars in the field (W 13, 14, 19, 37, 54, 85, 128, 131, 6383) the average λ_{max}-based total-to-selective extinction ratio is $R = 3.10(\pm 0.25\ s.d., \pm 0.08\ s.e.)$. (For all estimates in this section both the standard deviation and the error of the mean are provided). For the 6 stars that have probability membership greater than 50% (W 14, 37, 54, 85, 128, 131), $R = 3.05(\pm 0.17\ s.d., \pm 0.08\ s.e.)$. It should be noted that star W 38 has $\lambda_{max} = 0.390$ and calculated $R = 2.186$, both of them smaller than these values for the rest of the stars with measured polarization. This is what we expect for a foreground non-member.

Since Hβ photometry is available only for 3 stars of NGC 457, we calculated β indices for each star from the dereddened c_0 quantity and then used them to obtain the absolute magnitudes M_V via the calibration by Balona & Shobbrook (1984). The stars that we consider appear as main-sequence (MS hereafter) stars on all photometric diagrams and we thus felt that this procedure is justified as providing reliable magnitudes (see for example Balona (1994); Kaltcheva & Hilditch (2000)). Figure 3, middle panel, presents the color excess $E(b-y)$ vs. the distance modulus $DM = V_0 - M_V$ for the accepted here $R = 3.05$. Omitting the four stars that appear at smaller distances, we obtain $DM = 12.2(\pm 0.39\ s.d., \pm 0.06\ s.e.)$. This estimate is based on 44 stars between DM 11.4 and 13. We note that the average and median values are the same for this sample. Since we use calculated β indices, the somehow wider (for a cluster) range in DM is expected. The average color excess (based on the same 44 stars) is $E(b-y) = 0.376\ (\pm 0.022\ s.d., \pm 0.003\ s.e.)$. Figure 3, bottom panel, presents the V_0 vs. $(b-y)_0$ diagram with selected PARSEC isochrones (Bressan et al. 2012) for DM=12.2 mag overplotted. Considering the metallicity estimates by Tadross (2003) and Fitzpatrick & Massa (2007), we selected isochrones for slightly sub-solar composition of Z=0.005. This yields age for the cluster of no more than 15.8 Myr, which is within the range of the previous estimates (cf. Table 3) .

In addition we used the data from Pesch (1959) to reevaluate the cluster's parameters based on UBV photometry. This sample contains a total of 78 stars and the majority of them nicely follow the MS on the $U-B$ vs. $B-V$ diagram. We removed several stars later than A0 and also 4 late B-type stars with color excess less than the average for the cluster and thus deviating from the cluster sequence. We also removed stars that appear slightly evolved (W 46, 92, 128, 131, 215 and 153). This left in the sample 53 earlier than A0 stars that we assume to be main-sequence objects. Next we calculated $(U-B)_0$, $(B-V)_0$, $E(B-V)$ and M_V following Crawford (1994). The dereddened colors are shown on Fig. 4 and follow closely the intrinsic line. Based on this sample we obtain $E(B-V) = 0.500(\pm0.03\ s.d., \pm0.004\ s.e.)$, in excellent correspondence with the *uvby*-based estimate. Figure 4, bottom left, presents the color excess $E(B-V)$ vs. the distance modulus $DM = V_0 - M_V$ for the accepted $R = 3.05$. If we exclude 5 deviating stars (W 19, 37, 54, 198, 275), the median distance modulus is $11.99(\pm0.39\ s.d., \pm0.056\ s.e.)$ The maximum of the distribution of the distance modulus is, however, at 12.1, indicating a distance similar to the one based on the *uvby* data. Figure 4, bottom right, presents the histogram of the UBV-based distance moduli.

It should be noted that any distance modulus less than 12.2 would displace the isochrones toward the upper part of the V_0 vs. $(b-y)_0$ diagram and would not be a good fit for the isochrone set utilizing Z=0.005. A lower metallicity, however, would provide a better fit for a distance modulus less than 12.2. An additional metallicity estimate for NGC 457 is provided by Tadross (2001) ($[Fe/H] = -1.04$), but it could be somehow an underestimation, as discussed by Paunzen et al. (2010), and we did not consider it here.

Table 3 summarizes the previous results on color excess, distance and age for NGC 457. The first column contains a reference to the original papers, followed by the color excess, the apparent and true distance moduli and the value of R used in these studies. Where available, the errors of these determinations are included. For some of the references that are not providing the apparent distance modulus, we recalculated it based on the rest of the available data. It should be noted that the values of R used to calculate the distance to NGC 457 slightly vary (for example Becker & Fenkart (1971) adopt $R = 3$, while Phelps & Janes (1994) and Mermilliod (1981a) are using 3.1 and 3.2, respectively).

Table 3. Published Data for NGC 457.

Source	$E(B-V)$	App. DM	True DM	R	Distance (pc)	Age (Myr)	DM(R=3.05)
Pesch (1959)	0.50 ± 0.02	13.8	12.3 ± 0.45	3.00	2880 ± 580	-	12.275
Johnson et al. (1961)	0.47	13.71	12.3 ± 0.2	3.00	2880	-	12.277
Lindoff (1968)	-	-	-	-	-	11.2	-
Becker & Fenkart (1971)	0.49	13.67	12.2	3.00	2760	-	12.176
Moffat (1972)	0.45	-	12.5	-	3162	-	-
Mermilliod (1981b)	0.49	13.7	12.132	3.20	2670	-	12.206
Baade (1983)	0.45	13.95	-	-	3300	< 20	12.578
Meynet et al. (1993)	-	-	-	-	-	17.78	-
Fitzsimmons (1993)	0.50 ± 0.02	13.63	12 ± 0.2	3.20	2512	< 30	12.105
Phelps & Janes (1994)	0.49	13.919	12.4	3.10	3020	7 to 19	12.425
Loktin et al. (2001)	0.468 ± 0.012	-	12.109 ± 0.107	-	2641	21.09	-
Kharchenko et al. (2005)	0.47	13.38	-	3.10	2429	24	11.947
Maciejewski et al. (2008)	0.48 ± 0.05	13.55 ± 0.10	-	-	2600 ± 300	25.12	12.086

Column 6 lists the distances as obtained in the previous investigations. All of the references, listed in Table 3 provide estimates based on original data, except Loktin et al. (2001) which utilizes previous photometries. The available age estimates are shown in Column 7. The last column presents the true distance modulus calculated based on previously obtained color excesses and apparent distance moduli (columns 2 and 3) and the obtained here $R = 3.05$. This recalculation provides a median true distance modulus and distance based on 9 of sources in Table 3 of 12.20($\pm$0.06 *s.e.*) and 2754 pc ($\pm$76 *s.e.*), respectively. This is in complete agreement with the values obtained here.

4. CONCLUDING REMARKS

Based on new polarization data, we obtained an average $R = 3.05 \pm 0.17$ for the total-to-selective extinction ratio in the field of the open cluster NGC 457. Both the *uvby* and *UBV* photometries yield similar results for the average color excess $E(b-y) = 0.376 \pm 0.022$ ($E(B-V) = 0.500 \pm$

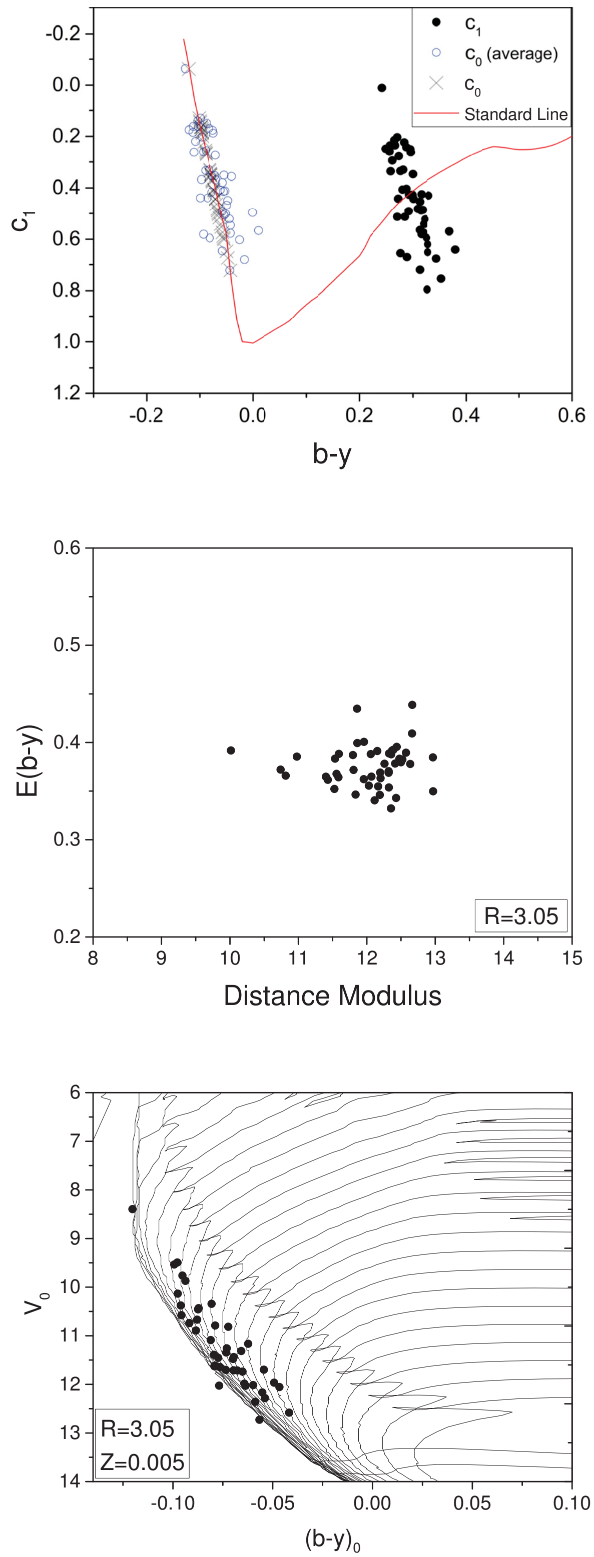

Figure 3. Top: Photometric c_1 vs. $b - y$ diagram for stars in the field of NGC 457. The intrinsic-color line is from Crawford (1975, 1978, 1975). Middle: Color excess $E(b - y)$ vs. Distance Modulus. Bottom: The V_0 vs. $(b - y)_0$ diagram with selected PARSEC isochrones (for Z=0.005) overplotted.

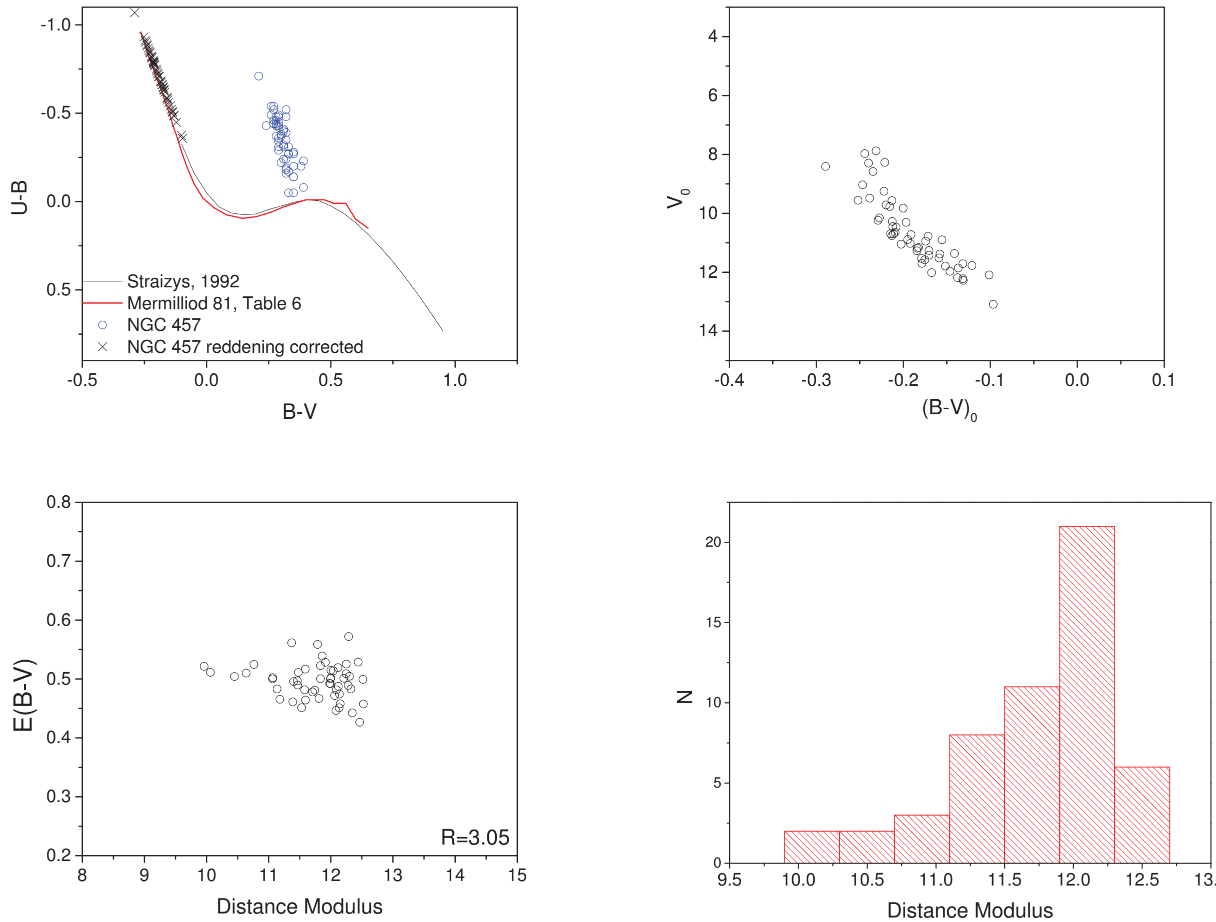

Figure 4. Top panels: Photometric $U - B$ vs. $B - V$ diagram and V_0 vs. $(B - V)_0$ diagram for stars in the field of NGC 457. Both the intrinsic-color lines from Mermilliod (1981a) and Straižys (1992) are shown. Bottom panels: Color excess $E(B - V)$ vs. Distance Modulus for $R = 3.05$ and the histogram of the Distance Moduli.

0.030). This is in agreement with earlier works (Pesch 1959; Fitzsimmons 1993) and a little bit larger than the accepted WEBDA value of $E(B - V) = 0.475$. The *uvby*-based distance modulus $DM = 12.2(\pm 0.39\ s.d.)$ is supported by the UBV analysis. This distance modulus corresponds to a distance of $2.75(\pm 0.49\ s.d.)$ kpc which is identical with the average value of the corrected previous determinations presented in Table 3. Based on this estimate, we obtain an age of 15.8 Myr, if we utilize a slightly sub-solar metallicity with Z=0.005.

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