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Photometric observations and Coravel radial velocities of red giant candidates in open clusters

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Abstract. We present high precision multicolour photoelectric photometry together with Coravel radial-velocity data for a sample of red giant (RG) candidates in nine Galactic open clusters. Nearly 82% of the analized stars are found to be cluster RGs from photometric criteria, in excellent agreement with the Coravel membership probabilities. $E(B-V)$ colour excesses, effective temperatures and metallicities are derived for the cluster giants. A new spectroscopic binary was discovered among the RGs of NGC 2482.

Resumen. Presentamos fotometría fotoeléctrica multicolor de alta precisión y velocidades radiales (VRs) Coravel para una muestra de candidatas a gigantes rojas (GRs) en nueve cúmulos abiertos galácticos. Encontramos que aproximadamente el 82 % de las estrellas analizadas son GRs de los cúmulos, de acuerdo a criterios fotométricos, en excelente acuerdo con los resultados inferidos a partir de las VRs Coravel. Se determinan excesos de color $E(B-V)$, temperaturas efectivas y metalicidades para las gigantes de los cúmulos. Una nueva binaria espectroscópica fue descubierta entre las GRs de NGC 2482.

1. The observational material

The *DDO* system is a powerful tool to derive metallicities of population I and II red giants (RGs) (Piatti et al. 1993; Clariá et al. 1994a), to provide $E(B-V)$ colour excesses (Janes 1977), to predict MK spectral types and to estimate effective temperatures (Clariá et al. 1994b). When combined with BV data, *DDO* measurements allow us to separate fairly accurately cluster members from red field stars (Clariá & Lapasset 1983). We present here photoelectric *DDO* photometry of 33 RG candidates located in the field of nine selected open clusters (OCs). Photoelectric UBV measurements have also been obtained for 24 of these stars. These data are supplemented with Washington photometry of six G and K stars of Ruprecht 97. The observations were performed during several observing runs at Cerro Tololo Inter-American (CTIO) and La Silla (ESO) ob-

servatories. Single channel photometers, pulse-counting electronics and dry-ice cooled photomultipliers were used. Radial velocities (RVs) for 13 RG candidates in NGC 2437, NGC 2482, NGC 2546 and NGC 6425 were also obtained with the Coravel instrument at La Silla.

2. Reddening and cluster membership

$E(B-V)$ colour excesses were estimated using the observed $(B-V)$, $C(42-45)$ and $C(45-48)$ colours by applying the iterative method described by Janes (1977). To correct for reddening the CMT_1T_2 observations in Ruprecht 97, we adopted $E(B-V) = 0.21$ (van den Bergh et al. 1976). The unreddened Washington indices were derived using the reddening ratios given by Geisler et al. (1991). To separate red field stars from the physical members of the clusters, we applied two independent photometric criteria - denoted A and B - based on combined $(B-V)$ and DDO colours (Clariá & Lapasset 1983). We assigned membership status for 51 late-type stars and found that 42 stars (82%) are very likely cluster members, 2 stars (4%) are probable members, while the remaining 7 ones (14%) should be considered red field stars. A comparison between the photometric and kinematic (Coravel) membership results shows excellent agreement.

Table 1. Mean cluster abundances

Cluster	ΔCN	σ	[Fe/H]	σ	N	I
NGC 2360	0.01	0.01	-0.12	0.03	13	2.2
NGC 2433	0.05	0.01	0.03	0.03	8	2.4
NGC 2437	0.00	0.04	-0.16	0.11	2	2.5
NGC 2482	0.08	0.01	0.14	0.04	3	3.0
NGC 2546	0.07	0.02	0.11	0.09	2	3.0
Ruprecht 97	-	-	-0.03	0.03	2	-
Lodén 807	-0.01	0.02	-0.19	0.06	2	3.0
NGC 6425	0.11	0.01	0.25	0.04	2	2.5
NGC 6633	0.04	0.01	-0.01	0.03	5	2.0

3. Effective temperatures and metallicites

Clariá et al. (1994b, hereafter CPL) established an empirical DDO effective temperature calibration for G and K stars, which satisfactorily reproduces temperatures derived from near-IR colours. Using this calibration, we derived effective temperatures for all cluster giants and we even made rough estimates for some non-members. These temperatures should prove useful for future studies, for example as input temperatures for model atmosphere analysis of high dispersion spectroscopy or for the construction of colour-magnitude diagrams (CMDs) for comparison with theoretical giant branch models.

The DDO system has also proved very useful to determine metallicities of G and K giants. For the RGs confirmed as cluster members, we derived the DDO cyanogen anomaly index ΔCN and the corresponding [Fe/H] value by applying the method described by Piatti et al. (1993, PCM). Once the "normal" DDO colours were obtained, the corresponding MK spectral types and effective temperatures were determined from the calibration of CPL. The resulting mean cluster abundances are shown in Table 1,

whose columns give in succession the cluster designation, the mean value of ΔCN and its standard deviation of the mean, the derived cluster abundance and its formal uncertainty, the number N of RGs used to derive metallicity, and finally, the average number I of iterations performed until the [Fe/H] converged within 0.01 dex. To derive the metallicity of Ruprecht 97 using the Washington data, we applied the iterative method described by Geisler et al. (1991).

4. Discussion on individual clusters

NGC 2360: Coravel RVs measured by Mermilliod & Mayor (1990) for 24 RG candidates yielded 20 cluster members. These results are in excellent agreement with those derived here from the photometric criteria A and B. The only discrepancy is star 44 (Becker et al. 1976), a Coravel member which is found to be a photometric non-member. The mean reddening derived from the confirmed RGs is $<E(B-V)> = 0.11 \pm 0.02$. The average value of the cyanogen strength index from 14 RG members is $<\Delta$CN$> = 0.00 \pm 0.01$, which implies [Fe/H] = -0.16 $\pm$ 0.04, if equation (2) of PCM is used.

NGC 2437: Stars 29 and 242 (Cuffey 1941) were found to be cluster members according to the photometric criteria, in excellent agreement with the Coravel data. The suspected variable star 174 (Cuffey 1941), a Coravel cluster member, is here considered to be a probable member. The mean reddening from stars 29, 174 and 242 shows good agreement with previous reddening determinations. Unfortunately, the spectroscopic binary 242 lies outside the range of PCM's calibration. The mean *DDO* metal abundance from stars 29 and 174, i.e., [Fe/H] = -0.16 $\pm$ 0.03, has been adopted for the cluster.

NGC 2482: Star 7 (Moffat & Vogt 1975) has been discovered to be a new spectroscopic binary (SB) from the Coravel RV observations, while star 23 has been previously reported as a SB by Mermilliod et al. (2007). The average reddening value of three cluster members is ΔCN = 0.08 $\pm$ 0.01, equivalent to [Fe/H] = 0.14 $\pm$ 0.04 (PCM). This value places NGC 2482 in the metal-rich side of the metallicity distribution of the Galactic OCs.

NGC 2546: This cluster contains two bright red stars: Nos. 99 and 356 from Lindoff (1968). Although the photometric membership of both stars is confirmed here, their individual metallicities are quite discordant. If these two stars were indeed cluster members, their average value for the cyanogen anomaly would be ΔCN = 0.04 $\pm$ 0.06, which would lead to [Fe/H] = 0.0 $\pm$ 0.2, if equation (8) of PCM is used. Our mean reddening from these two stars is $E(B-V) = 0.11 \pm 0.03$, in good agreement with Lindoff's value.

Ruprecht 97: Six late-type stars in the cluster field were observed in the Washington system. To derive the cluster metal content, we applied the method proposed by Geisler et al. (1991, GCM). The resulting mean metallicities and their corresponding standard deviations from three assumed cluster giant members are: $[Fe/H]_1$ = -0.16 $\pm$ 0.11, $[Fe/H]_2$ = -0.28 $\pm$ 0.22, $[Fe/H]_3$ = -0.20 $\pm$ 0.15, $[Fe/H]_4$ = -0.05 $\pm$ 0.02 and $[Fe/H]_5$ = -0.11 $\pm$ 0.03, if the calibrations of GCM are used. The unweigthed mean of the five abundance estimates is [Fe/H] = -0.16 $\pm$ 0.08 and has been adopted for the cluster. Thus, Ruprecht 97 lies in the metal-poor side of the metal abundance distribution of Galactic OCs.

Lodén 807: This cluster contains three relatively bright RG candidates. Their $E(B-V)$ colour excesses and MK(DDO) spectral types are compatible with cluster membership for two of them. The average ΔCN value from these two stars implies [Fe/H] = -0.20 $\pm$ 0.07. Therefore, the current *DDO* data tend to support the metal-poor character of

Lodén 807.

NGC 6259: From Washington photometry of 8 Coravel RG members, Mermilliod et al. (2001) derived [Fe/H] = 0.06 ± 0.08. Only two RG candidates have been observed here in the *DDO* system. Unfortunately, none of them were found to be definite Coravel cluster members.

NGC 6425: The CMD published by The & Stokes (1970) reveals that only five late-type stars could be giant members. One of them - star 2 from The & Stokes (1970) - falls outside the range of the *DDO* calibrations, while other two stars - 14 and 22 - should be considered red field stars according to the photometric criteria. The remaining two observed stars (46 and 61) were found to be a probable member and a cluster member, respectively. Both stars have Coravel RVs nearly identical so thay they should be regarded as very likely cluster members. Their mean reddening is $<E(B-V)> = 0.34 \pm 0.01$. The *DDO* abundances of these two stars show good agreement, the mean value being [Fe/H] = 0.25 ± 0.04. Thus, the current *DDO* data rank NGC 6425 in the metal-rich side of the metallicity distribution of the Galactic OCs.

NGC 6633: From the photometric study of Hiltner et al. (1958), we selected 6 stars for observation in the *DDO* system: four of them forming the clump at $V = 8.5$ and $B-V = 1.10$, the brightest RG star 67 from Hiltner et al. (1958), and the somewhat hotter star 56 located in the Hertzsprung gap. Unfortunately, the latter falls outside the range of the *DDO* calibrations. Accurate Coravel RVs obtained by Mermilliod & Mayor (1989) for the remaining five stars indicate that all five of them are cluster members, in excellent agreement with the present photometric membership results. Their mean cyanogen anomaly is $<\Delta CN> = 0.04 \pm 0.01$, which implies [Fe/H] = -0.01 ± 0.03. This result tends to confirm that NGC 6633 is a slightly lower metallicity analogue of the Hyades and Praesepe clusters at a similar age.

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