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Overall properties of open clusters projected towards the galactic anticenter direction: Washington photometry of NGC 1817 and NGC 2251

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Abstract. We present Washington photometry for red giant candidates in the open clusters NGC 1817 and NGC 2251. Published radial velocities are used to separate field stars from cluster giants. Effective temperatures and metal abundances are derived for each star. From new UBV and DDO photometric data, we also derive reddening and metal content for NGC 2251. The resulting mean metallicities are [Fe/H] = -0.33 ± 0.08 and -0.20 ± 0.05 for NGC 1817 and NGC 2251, respectively. We reexamine the overall properties of a sample of 30 clusters in the Galactic anticenter direction with distances, ages and metallicities available. This cluster sample presents no evidence of an abundance gradient perpendicular to the Galactic plane, nor is an age-metallicity relation found. However, a radial abundance gradient of -0.093 dex kpc^{-1} is derived over a Galactocentric distance of 14 kpc. This value practically does not change when all clusters with basic parameters known up to this date are considered.

Resumen. Presentamos fotometría de Washington de candidatas a gigantes rojas de los cúmulos abiertos NGC 1817 y NGC 2251. Estrellas del campo y gigantes del cúmulo se separan en base a velocidades radiales publicadas. Determinamos temperaturas efectivas y metalicidades para cada estrella en ambos cúmulos. A partir de nuevos datos fotométricos UBV y DDO, determinamos también enrojecimiento y metalicidad de NGC 2251. Las abundancias medias resultantes son [Fe/H] = -0.33 ± 0.08 y -0.20 ± 0.05 para NGC 1817 y NGC 2251, respectivamente. Al examinar las propiedades globales de 30 cúmulos proyectados hacia el anticentro galáctico con distancias, edades y metalicidades conocidas, no encontramos evidencia sobre un gradiente perpendicular al plano ni sobre una relación entre la edad y la metalicidad, aunque derivamos un gradiente radial de -0.093 kpc^{-1} dentro de 14 kpc de distancia galactocéntrica. Este valor prácticamente no cambia cuando se consideran todos los cúmulos con parámetros conocidos a la fecha.

1. Introduction

The present paper is devoted to NGC 1817 and NGC 2251, two open clusters located in the Galactic anticenter direction, for which we measure accurate abundances on a uniform scale, using high-quality photoelectric photometry in the Washington system. This study is part of a survey of some poorly studied open clusters, located at different Galactic radii, which has been carried out at Cerro Tololo Inter-American Observatory (CTIO) since 1992.
The fact that NGC 1817 and NGC 2251 lie at more than 1 kpc from the Sun in the Galactic anticenter direction makes them interesting objects in terms of the structure and chemical evolution of the outer disk. The determination of their metal abundances will allow us to compare the results with those known about other open clusters located approximately in the same direction and extend our knowledge of the Galactic disk. In addition, NGC 1817 and NGC 2251 are in themselves worth a detailed study because no previous *DDO* and/or Washington photometry of their stars has been published.

2. Photometric observations

21 and 3 stars in the fields of NGC 1817 and NGC 2251, respectively, were selected as red giant candidates and observed with the CMT_1T_2 filters of the Washington system using the CTIO 0.9 m telescope. The three stars of NGC 2251 were also observed in the UBV and DDO systems with the CTIO 0.6 m and 1.0 m telescopes. Single-channel pulse-counting photometers were used in conjunction with different dry-ice cooled phototubes. The resulting magnitudes and colours are available upon request to the first author.

3. Cluster membership and reddening

19 of the 21 stars in NGC 1817 and the three stars observed in NGC 2251 were found to be cluster giants from Coravel radial velocities (Mermilliod et al. 2003, Mermilliod 2005). Cluster membership for the NGC 2251 stars was also confirmed from two photometric criteria described by Clariá & Lapasset (1983). Even though the published E(B-V) values for NGC 1817 vary from 0.23 (Harris & Harris 1977, HH77) up to 0.33 (Dutra & Bica 2000), depending on the method and stars used to derive them, we adopted HH77's reddening as the most representative value for the red cluster giants. Regarding NGC 2251, we derived $\langle E(B-V) \rangle = 0.21 \pm 0.03$ from the UBV-DDO data, by applying the iterative method described by Janes (1977).

4. Metal content and effective temperatures

Geisler et al. (1991, hereafter GCM91) have calibrated 5 Washington metallicity sensitive indices in terms of high dispersion [Fe/H] values and proposed an iterative procedure to estimate metal abundance of late-type giants. We applied this procedure to the stars observed in NGC 1817 and NGC 2251. In both clusters, all the cluster giants are comparatively hot so that their individual Δ_i' indices, as defined by GCM91, coincide with their corresponding Δ_i indices. The resulting mean Δ_i' values for the NGC 1817 stars imply $[Fe/H]_1$ = -0.36 ± 0.04, $[Fe/H]_2$ = -0.19 ± 0.04, $[Fe/H]_3$ = -0.33 ± 0.03, $[Fe/H]_4$ = -0.39 ± 0.04 and $[Fe/H]_5$ = -0.36 ± 0.04, if the calibrations of GCM91 are used. The unweighted average of the five abundance estimates is $< [Fe/H]_W >$ = -0.33 ± 0.08, which will be adopted. For NGC 2251 we obtained $[Fe/H]_1$ = -0.25 ± 0.06, $[Fe/H]_2$ = -0.30 ± 0.11, $[Fe/H]_3$ = -0.27 ± 0.08, $[Fe/H]_4$ = -0.20 ± 0.03 and $[Fe/H]_5$ = -0.22 ± 0.03, the resulting mean value being $< [Fe/H]_W >$ = -0.25 ± 0.04. The present metallicity of NGC 1817, determined from confirmed red giants, is in excellent agreement with the value derived by Balaguer-Nuñez et al. (2004) from uvby-Hβ photometry of F and G main sequence stars. Note, however, that if instead of using $E(B-V) = 0.23$ (HH77), we had adopted the reddening value obtained by Twarog, Ashman & Anthony-Twarog (1997) for the cluster giants, i.e., $E(B-V) = 0.26$, the resulting metallicity would have been $\sim$ 0.1 dex larger.

An independent metallicity determination for the NGC 2251 giants may be performed from the observed DDO indices. We first corrected the observed DDO indices by reddening using the colour excess ratios given by McClure (1973) and then we applied the iterative method proposed by Piatti et al. (1993, hereafter PCM93). The resulting mean cyanogen anomaly is $< \Delta CN >$ = -0.14, which implies $[Fe/H]_{DDO}$ = -0.14 ± 0.05, if equation (8) of PCM93 is used. Considering the two independent metallicity determinations, we finally adopted [Fe/H] = -0.20 ± 0.05 for NGC 2251.

Effective temperatures were determined for the red giants from the calibration of Geisler et al. (1992). We assumed $\log g = 1.5$ and interpolated the effective temperatures between grids to the appropriate mean cluster metallicity. The resulting values are available upon request to the first author. These effective temperatures could be used as input temperatures for model atmosphere analysis of high dispersion spectroscopy. Additionally, they could contribute to the construction of CM diagrams for comparison with theoretical giant branch models.

5. Discussion

NGC 1817 and NGC 2251 have proved to be moderately metal-poor open clusters located in the outer disk towards the Galactic anticenter direction. Their derived abundances are compatible with the existence of a radial metallicity gradient along the Galactic disk (see, e.g., Chen, et al. 2003, and references therein).

We searched through the Webda database and in the available literature for clusters within a region defined by 155° $<$ l $<$ 205°, with known distances, ages and metallicities (30 in total). We computed the Galactocentric distances R_{GC}

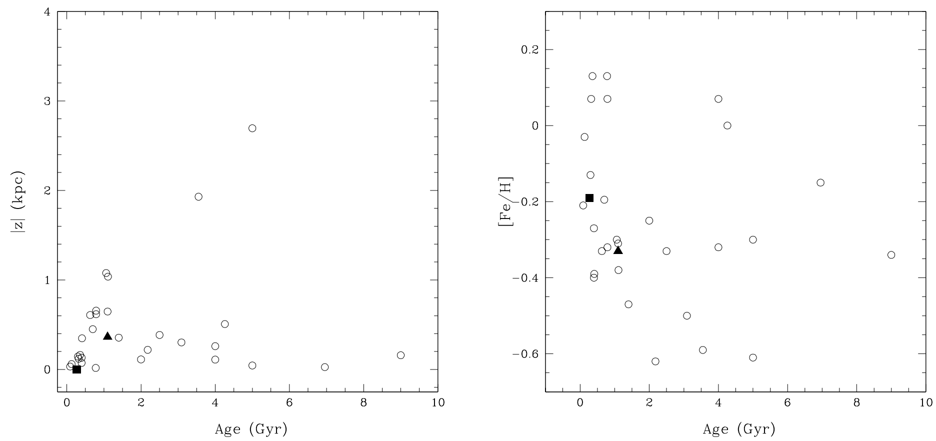

Figure 1. Relation between the distance from the Galactic plane, the age and metallicity of open clusters with known basic parameters (open circles) in the anticenter direction. NGC 1817 (triangle) and NGC 2251 (square) are shown.

from all these clusters, assuming the Sun′s distance from the Galactic center to be 8.5 kpc. The left panel of Figure 1 shows how the absolute distances away from the Galactic plane vary as a function of cluster ages. Even though the |Z| values do not seem to exhibit any tendency to decrease or increase with age, it is seen that the clusters younger than $\sim$ 0.5 Gyr tend to be located practically in the Galactic plane, while those which are older and are located in the same direction display a greater dispersion in |Z|. It would be quite reasonable to assume that the latter might have moved through the Galactic disk several times (Carraro & Chiosi 1994; Piatti et al. 1995), being currently observed at different Z values. These objects were probably formed at |Z| values higher than the ones corresponding to the younger clusters, considering the fact that if they had been formed close to the Galactic plane, they would have done it with initial perpendicular velocities too high for them to be located at high |Z| values at present. The second alternative seems quite unlikely to happen for objects formed close to the Galactic plane.

The selected clusters do not show any trend between their metallicities and ages (Figure 1, right panel), a result confirmed by several authors who considered clusters in other directions. Figure 2 (left panel) shows the behaviour of the cluster metallicities with respect to R_{GC} in the anticenter direction. Filled circles with error bars represent the average of [Fe/H] values within R_{GC} intervals of 1.0 kpc. If Berkeley 29, situated at $\sim$ 22 kpc from the Galactic center is not considered, then we estimate a radial abundance gradient of -0.052 dex kpc^{-1} (full line) within the first 16 or 17 kpc. However, if only the clusters within the first 14 kpc are considered, then this gradient turns out to be -0.093 dex kpc^{-1} (dashed line). Beyond this distance, the gradient becomes uncertain mainly

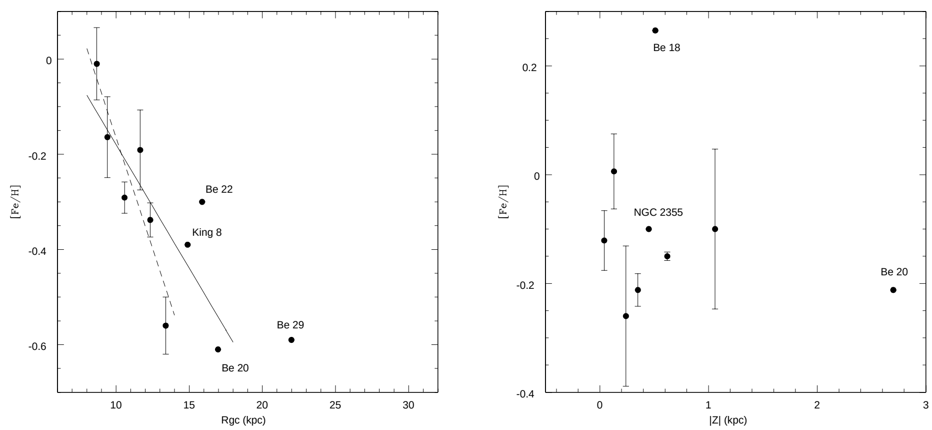

Figure 2. *Left:* Relationship between metallicity and Galactocentric distance of open clusters in the anticenter direction. *Right:* Relationship between metallicity and absolute distance away from the Galactic plane.

because of the lack of objects at great distances from the Galactic center. Note that there is no evidence of a sharp discontinuity at 10 kpc of Galactocentric distance, as claimed by Twarog et al. (1997). The right panel of Figure 2 was obtained by means of a similar procedure as in the left panel, although filled circles represent now mean [Fe/H] values within |Z| intervals of 0.1 kpc. To build this diagram, the data were previously corrected for the R_{GC} dependence on metallicity.

What happens if we consider all the open clusters with known [Fe/H] values in the Webda database or in the recent literature? In this case, the abundance gradient defined by 134 clusters is shown in Figure 3, wherein filled circles represent the average of [Fe/H] values in R_{GC} intervals of 0.5 kpc. According to this figure, there exists a radial abundance gradient within the first 14 kpc of Galactocentric distance, the value of which is -0.094 dex kpc^{-1}, no other gradient being clearly observed beyond this distance. For the few open clusters beyond 14 kpc, it is clear that this gradient does not continue but appears to approximately level off. Note that the flattening of the gradient was previously found by Yong et al. (2005).

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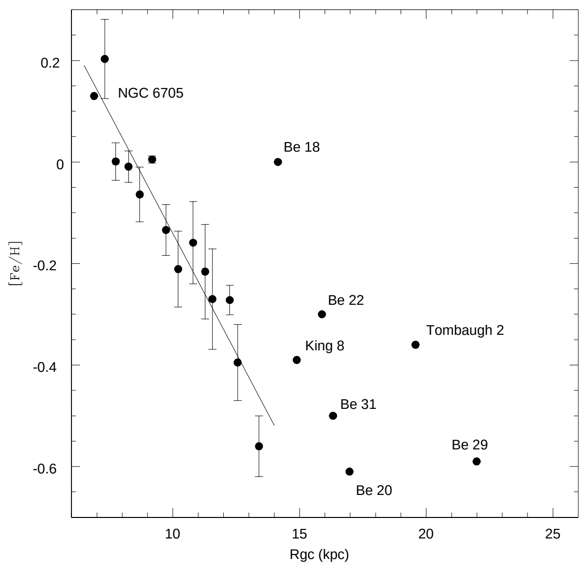

Figure 3. The radial abundance gradient defined by 134 open clusters with distances and metallicities known up to date.

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