Physical parameters of evolved stars in clusters and in the field from line-depth ratios

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Summary. We present a high-resolution spectroscopic analysis of two samples of evolved stars selected in the field and in the intermediate-age open cluster IC 4651, for which detailed measurements of chemical composition were made in the last few years. Applying the Gray’s method based on ratios of line depths, we determine the effective temperature and compare our results with previous ones obtained by means of the curves of growth of iron lines. The knowledge of the temperature enables us to estimate other fundamental stellar parameters, such as color excess, age, and mass.

1 Introduction

The study of stellar populations in our Galaxy and in its neighborhoods has received in the last years a big impulse, especially thanks to the use of large telescopes and to the detailed spectroscopic analysis performed on high-resolution spectra. In this context, open clusters, that are homogeneous samples of stars having the same age and chemical composition, are very suitable to investigate the stellar and Galactic formation and evolution. In spite of this, the data on stars belonging to open clusters are often insufficient to adequately constrain age, distance, metallicity, mass, color excess, and temperature. This is due to the fact that the main classical tool to study cluster properties is the color-magnitude diagram, which suffers of several uncertainties and intrinsic biases due to, for example, the uncertain knowledge of the chemical composition and the reddening of the stars. As a consequence, spectroscopic methods, being independent of the reddening, are very efficient to evaluate temperatures of stars in clusters.

Spectroscopic effective temperatures are usually determined imposing that the abundance of one chemical element with many lines in the spectrum (typically iron) does not depend on the excitation potential of the lines. Another method for determining effective temperature is based on line-depth ratios (LDRs). It has been widely demonstrated that the ratio of the depths
of two lines having different sensitivity to temperature is an excellent measure of stellar temperatures with a sensitivity as small as a few Kelvin degrees in the most favorable cases ([14, 13, 12]).

In the present paper, we apply the LDR method to high-resolution UVES and FEROS spectra for deriving effective temperatures in nearby evolved field stars with very good Hipparcos distances and in giants of the intermediate-age open cluster IC 4651. For both the star samples, the temperature was already derived spectroscopically, together with the element abundances, with the curves of growth of absorption lines spread throughout the optical spectrum ([17, 18]). In addition, for the stars belonging to the open cluster IC 4651, we make the first robust determination of the average color excess, based on spectroscopic measurements.

2 Star samples

We have analysed seventy-one evolved field stars and six giant stars belonging to the open cluster IC 4651. The sample of field stars was already analysed by [18] for the determination of radii, temperatures, masses and chemical composition. The stars in the intermediate-age cluster IC 4651 have been selected from the sample studied by [17] for abundance estimates.

The field stars data were acquired with the FEROS spectrograph \( R = 48000 \) at the ESO 1.5m-telescope in La Silla (Chile), while the IC 4651 spectra were acquired with UVES \( R = 100000 \) at the ESO VLT Kueyen 8.2m-telescope in Cerro Paranal (Chile). In both cases, the signal-to-noise ratio \( (S/N) \) was greater than 150 for all the spectra, which make them very suitable for the temperature determination described in Sec. 3.

3 Effective temperature determination

The wavelength range covered by FEROS and UVES spectrographs contain a series of weak metal lines which can be used for temperature determination with the LDR method. Lines from similar elements such as iron, vanadium, titanium, but with different excitation potentials \( (\chi) \) have indeed different sensitivity to temperature. This is due to the fact that the line strength, depending on excitation and ionization processes, is a function of temperature and, to a lesser extent, of the electron pressure. For this reason, the better line couples are those with the largest \( \chi \)-difference. In the range \( 6150 \leq \lambda \leq 6300 \) there are several lines of this type whose ratios of their depths have been exploited for temperature calibrations ([14, 13, 7, 5]), and for studies of the rotational modulation of the average effective temperature of magnetically active stars ([10, 4]) or for investigating the pulsational variations during the phases of a Cepheid star ([15, 3]). In particular, we choose 15 line pairs for which [5] already made suitable calibrations.
Field giant stars

The comparison between the temperatures obtained by us ($T_{\text{eff}}^{\text{LDR}}$) and those obtained by [18] ($T_{\text{eff}}^{\text{SPEC}}$) is plotted in Fig. 1. We find a very good agreement between $T_{\text{eff}}^{\text{SPEC}}$ and $T_{\text{eff}}^{\text{LDR}}$ in all the temperature range 4000–6000 K.

![Fig. 1. Comparison between the temperatures obtained from LDR and curve-of-growth analyses for the field stars (left) and the giants belonging to IC 4651 (right).](image)

Giant stars in IC 4651

$T_{\text{eff}}^{\text{LDR}}$ is systematically lower than $T_{\text{eff}}^{\text{SPEC}}$ by an amount typically between 70 and 90 K. The only exception is the star E95 for which the difference amounts to about 320 K. [17] already found for this star the largest difference between photometric and spectroscopic temperature among their giant star sample. However, the position on the HR diagram of this star corresponds to a subgiant and this could be the reason for the disagreement.

4 Color excess of IC 4651

We can evaluate for each star the intrinsic color index ($B - V$)$_0$ by inverting for example the ($B - V$)–$T_{\text{eff}}$ calibrations of [12] and [1, 2] with the aim to compute the color excess $E(B - V)$ of the cluster IC 4651. Thus, for the two temperature sets, $T_{\text{eff}}^{\text{LDR}}$ and $T_{\text{eff}}^{\text{SPEC}}$, we obtain $E(B - V) \approx 0.12$ and 0.16 for the Gray’s calibration, and $E(B - V) = 0.13$ and 0.17 for the Alonso’s calibration. It is worth noticing that there is not a large difference between color excesses obtained with the two calibrations. From a preliminary analysis, we find an improving of the agreement if we properly take into account the metallicity effects ([6]). Moreover, our color excess values are in good agreement with the results of $E(B - V) = 0.13$ and $E(b - y) = 0.091$ obtained by [9] and [17], respectively ($E(b - y) = 0.72E(B - V)$, [8]). The
present determination of \( E(B - V) \) is a strong argument in favor of such a low reddening notwithstanding the distance of \( \approx 900 \text{ pc} \) estimated by [16] and the low galactic latitude of IC 4651 (\( \simeq 9^\circ \)).

5 Conclusion

In this paper we have derived accurate atmospheric parameters for field evolved stars and giant stars in the open cluster IC 4651 by means of high-resolution spectra acquired with the ESO spectrographs FEROS and UVES.

For the field giant stars, we find a good agreement between temperatures computed by [18] with the curves-of-growth method and by ourselves with the LDR technique. For the giants in the intermediate-age open cluster IC 4651, we have determined the effective temperatures by means of the LDR method, that allowed us to compute the reddening. We find a rather low reddening towards the cluster, \( E(B - V) \approx 0.13 \), that needs to be explained, given the high distance (\( \simeq 900 \text{ pc} \)) and the low galactic latitude of IC 4651.

We conclude that our technique is well suited to derive accurate effective temperatures and reddening of clusters with a nearly-solar metallicity. The determination of very precise temperatures is of great importance to derive stellar age and mass distributions ([11]), representing a powerful tool for stellar population studies in addition to those based on photometric data.

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