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Study of star clusters in the Small Magellanic Cloud from Ca II triplet spectroscopy

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Resumen / Presentamos resultados obtenidos a partir de espectros en el infrarrojo cercano de estrellas gigantes rojas de dos cúmulos estelares de edad intermedia pertenecientes a la Nube Menor de Magallanes (NmM): NGC 411 y NGC 419. Los espectros, obtenidos utilizando el instrumento FORS2 del VLT (Paranal, Chile), están centrados en la región del triplete del Ca II ($\sim$ 8600 Å). Usando estas líneas de absorción, medimos las velocidades radiales medias de los cúmulos con un error de $\sim$3 km s^{-1}. También medimos anchos equivalentes, a partir de los cuales derivamos las metalicidades medias de los cúmulos con un error de 0.05 dex. Por otro lado, con el objetivo de examinar las propiedades químicas globales de la NmM en la región interna de la galaxia, analizamos los resultados derivados para estos dos cúmulos estelares conjuntamente con los obtenidos para otros veinte cúmulos, previamente estudiados por nuestro grupo, también observados con el VLT y analizados con las mismas técnicas que en el presente trabajo.

Abstract / We present results obtained from near-infrared spectra of red giant stars of two intermediate-age star clusters belonging to the Small Magellanic Cloud (SMC): NGC 411 and NGC 419. The spectra, obtained using the FORS2 instrument on the VLT (Paranal, Chile), are centered in the Ca II triplet region ($\sim$8600 Å). Using these absorption lines, we measure cluster mean radial velocities with an error of $\sim$3 km s^{-1}. We also measure equivalent widths from which we derive cluster mean metallicities with an error of 0.05 dex. In addition, with the aim of examining the global chemical properties of the SMC in the inner part of the galaxy, we analyze the results derived for these two star clusters together with those obtained for another twenty clusters previously observed by our group with the VLT and studied by applying the same technique.

Keywords / galaxies: star clusters — Magellanic Clouds — stars: abundances

1. Introduction

A significant aspect to analyze in the context of the chemical evolution of the Small Magellanic Cloud (SMC) is the possible existence of a metallicity gradient. A metallicity variation with distance from the center of the SMC has been investigated not only for clusters (Parisi et al. 2009, 2015, hereafter P09, P15; Dias et al. 2014, 2016) but also for field stars (Parisi et al. 2010, 2016, hereafter P10, P16; Dobbie et al. 2014; Choudhury et al. 2018). There is agreement among the different authors about the clear existence of a field star metallicity gradient in the internal region of the SMC. However, the existence of a cluster metallicity gradient cannot be ensured and substantial differences have been found between the chemical behavior of the clusters and field stars (P15, P16). In particular, in a series of papers (P09, P10, P15, P16), a sample of 29 SMC clusters (20 of them in the internal SMC region) and their surrounding fields were analyzed.

The radial velocities (RVs) and metallicities of the observed stars allow us to discriminate possible physical cluster members from field stars (see Section 4. for more details).

In the present work, we performed similar spectroscopic analyses for two SMC stellar clusters, namely: NGC 411 (α = 1^h 7^m 56^s and δ = -71° 65′ 5″) and NGC 419 (α = 1^h 8^m 18^s and δ = -72° 53′ 3″). These clusters are aged 1.2 $\pm$ 0.2 Gyr and between 1.2 and 1.6 Gyr, respectively (Alves & Sarajedini, 1999; Glatt et al., 2008). We show in Fig. 1 their positions in the galaxy, as well as the location of an additional sample of SMC clusters also studied with the Ca II triplet (CaT) technique.

2. Spectroscopic observations

Using the FORS2 instrument on the Very Large Telescope (VLT, Chile), we obtained spectra for 61 red giant stars of these two clusters and of their surrounding fields. Color-magnitude diagrams were built from aperture photometry of the pre-images in the V and I bands. Spectra have a dispersion of 0.85 Å px^{-1} and cover a range of $\sim$1600 Å centered in $\sim$8600 Å, the region of the CaT lines. We used the pipeline (v. 3.9.5) provided by the VLT to perform the reduction of the spectra.

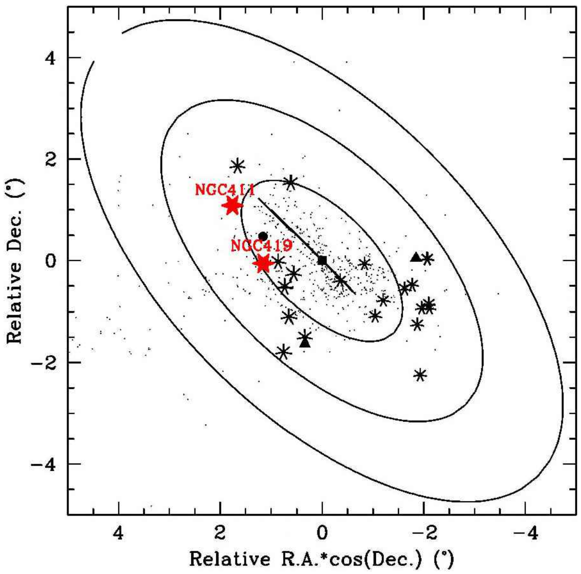

Figure 1: Spatial distribution of SMC clusters having CaT metallicites, located in the inner part of the galaxy ($a < 4°$). Clusters studied by P09 and P15 are plotted with asterisks, while those examined by G18 are identified with triangles. The black circle represents cluster NGC 416 taken from Da Costa & Hatzidimitriou (1998). The two clusters here studied are shown with red stars. The center and the bar of the galaxy are represented by a square and a solid line, respectively. The ellipses have semi-major axes a of $2°$, $4°$ and $6°$, respectively. Clusters from the catalog of Bica et al. (2008) are plotted in black dots.

3. Radial velocities and metallicities

We performed cross-correlations between the observed spectra and those of 30 template spectra obtained by Cole et al. (2004), in order to measure RVs of our program stars. For that purpose, we used the IRAF task FXCOR (Tonry & Davis, 1979), which also calculates heliocentric velocities from the observed ones. For each target, we adopted as the heliocentric RV the average of each cross-correlation result, which has a typical error of $\sim$7.5 km s^{-1}. This error is the sum in quadrature between the standard deviation of the cross-correlations (6 km s^{-1}) and the error introduced by the correction for the star centering in the slit (4.5 km s^{-1}). Metallicities were determined according to the procedure described by Grocholski et al. (2006), P09 and P15, using the sum of the equivalent widths of the three CaT lines and the calibration of Cole et al. (2004).

4. Membership selection

To discriminate cluster members from field stars, we followed a procedure based on the combination of the apparent cluster radius with the RVs and metallicities of the observed stars (P09, P15). We built the corresponding radial stellar density profiles (P09) from which we estimated the cluster radii. The behavior of the RVs and the metallicities as a function of the distance to the center of NGC 411 are shown in Figs. 2 and 3,

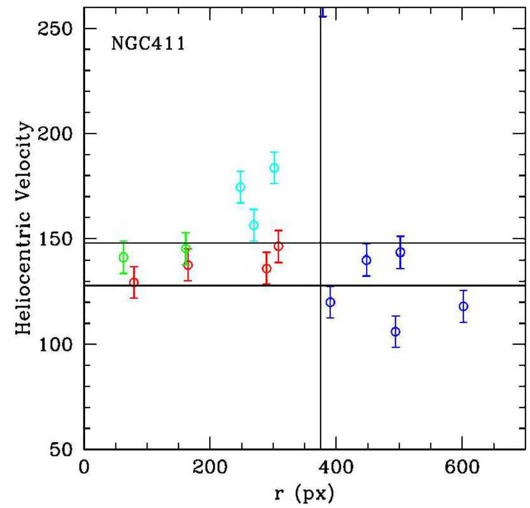

Figure 2: RV vs. distance from the center (r) of NGC 411. The vertical line indicates the adopted cluster radius. The horizontal lines represent our velocity cuts ($\pm$10 km s^{-1}). Color code: nonmembers outside the cluster radius (blue circles), nonmembers eliminated because of discrepant RV or metallicity (teal and green circles, respectively), and final cluster members (red circles).

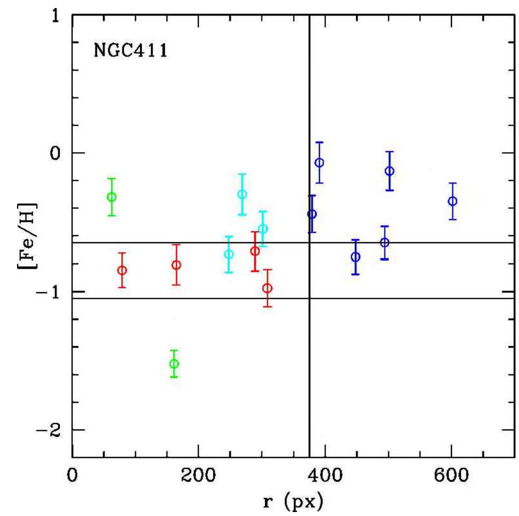

Figure 3: Metallicity vs. distance from the center (r) of NGC 411. The vertical line indicates the adopted cluster radius. The horizontal lines represent the metallicity cuts ($\pm$ 0.20 dex). The color code is the same as in Fig. 2.

respectively. We discarded as cluster members stars with distances to the cluster center larger than the cluster's radius (marked with a vertical line in both figures) and having RVs and metallicities outside of the adopted cuts. Color code of symbols in Figs. 2 and 3 are explained in the captions. The RV cuts ($\pm$ 10 km s^{-1}, horizontal lines in Fig. 2) were calculated considering the sum in quadrature between the intrinsic cluster velocity dispersion (5 km s^{-1}, Pryor & Meylan, 1993) and our final adopted error in the RV measurements (7.5 km s^{-1}). The metallicity cuts ($\pm$0.2 dex, horizontal lines in Fig. 3) are the rounded up values of our typical metallicity error (0.14 dex). Finally, we calculated cluster mean RVs and metallicites from stars that turned out to be cluster members. We followed the same procedure for the cluster NGC 419. We obtained mean RVs of 137.4±3.1 km s^{-1} and 172.9±3.0 km s^{-1} for NGC 411 and NGC 419, respectively. The mean metallicity values found are [Fe/H] = −0.83±0.05 and [Fe/H] = −0.65±0.05 for NGC 411 and NGC 419, respectively. The quoted RVs and metallicity errors correspond to the standard error of the mean. On the other hand, the metallicities of the stars discarded as cluster members allowed us to estimate the mean metallicity of the surrounding stellar fields: [Fe/H] = -0.68 ± 0.10 and [Fe/H] = -0.82 ± 0.04 for NGC 411 and NGC 419, respectively. Our cluster metallicities exhibit an excellent agreement with the values obtained by previous authors: NGC 411: -0.84 ± 0.03 (Da Costa & Hatzidimitriou, 1998) and ~ -0.8 (Kayser et al., 2009); NGC 419: −0.7-−0.6 (Kayser et al., 2009).

5. Inner metallicity gradient: preliminary results

Fig. 4 shows the metallicities as a function of the semi-major axis a for clusters and field stars, represented with black symbols. In the mentioned papers, an elliptical system was adopted in which the corresponding semi-major axis a is used instead of the projected distance to the Galactic center (see P09 for more details). In Fig. 4 we also plot with triangles the CaT metallicity of the clusters L11 and NGC 339, and their surrounding fields, which we studied in Gramajo et al. (2018, G18). We also include the cluster NGC 416 (black circle). Among the many interesting conclusions that can be drawn from this figure, we highlight the fact that in the inner region, field stars present a small metallicity dispersion, in contrast with the large dispersion found for the star clusters. Such a difference is not observed in the outer part of the SMC ($a > 4°$), where both populations present similar metallicity behavior (P16). On the other hand, while field stars exhibit a negative metallicity gradient in the inner regions of the SMC, in excellent agreement with the results found by Dobbie et al. (2014) and Choudhury et al. (2018), clusters do not clearly show a statistically significant metallicity gradient due to their extremely large metallicity dispersion. In fact, it is interesting to note that clusters appear to be distributed in two groups, above and below the sequence followed by the field stars. This result could be reflecting a possible difference in the chemical evolution of clusters and field stars (P16). The positions of NGC 411 and NGC 419 and of their surrounding fields are represented in Fig. 4 by red stars, respectively. As can be seen, they reinforce what was raised by P16. Dias et al. (2016, D16) suggest splitting the star cluster samples according to their positions in the SMC: main body, wing/bridge, counter-bridge, and west halo. Each of these groups would follow a tidal characteristic which is a consequence of the interaction of the SMC with the Large Magellanic Cloud and of both galaxies with the Milky Way. D16 argued in favor of the existence of a metallicity gradient in the west halo. However, their photometric metallicities do not have the precision required in order to be conclusive. Our sample is not large enough to significantly test the split proposed by D16. Nevertheless, it represents an interesting idea to explore. To do that, a larger spectroscopically studied cluster and field samples are needed. We have created a trinational project involving Chile (PI: B. Dias), Brazil (PI: L. Kerber) and Argentina (PI: C. Parisi) to obtain spectroscopic data of the SMC, with the aim of analyzing the chemical properties of the SMC with a larger cluster sample with very precise CaT metallicities.

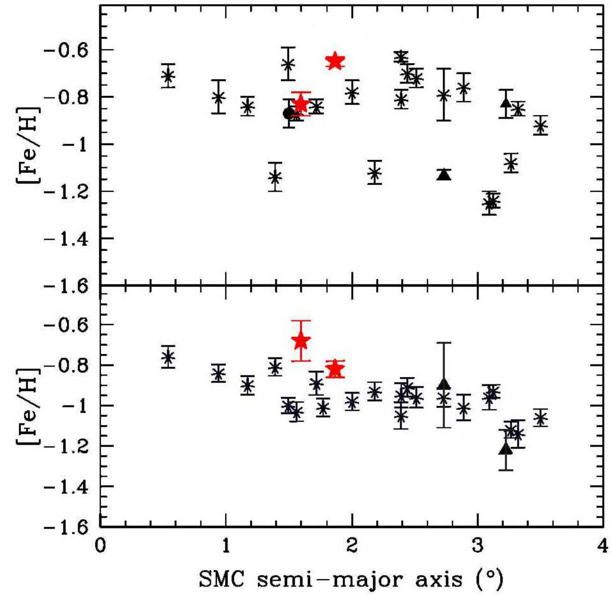

Figure 4: *Upper panel:* Mean metalllicity vs. semi-major axis a for the SMC clusters. Symbols are the same as in Figure 1. *Bottom panel:* Mean metalllicity vs. semi-major axis a for field stars from P10 and P16 (asterisks), G18 (triangles) and the present study (stars).

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