Strömgren photometry of the Bulge: the Baade’s Window and the globular cluster NGC 6522

A. Calamida\textsuperscript{1}, G. Bono\textsuperscript{2}, C. E. Corsi\textsuperscript{1}, G. Iannicola\textsuperscript{1}, V. Ripepi\textsuperscript{3}, B. Anthony-Twarog\textsuperscript{4}, B. Twarog\textsuperscript{4}, M. Zoccali\textsuperscript{5}, R. Buonanno\textsuperscript{2}, S. Cassisi\textsuperscript{6}, I. Ferraro\textsuperscript{1}, F. Grundahl\textsuperscript{7}, A. Pietrinferni\textsuperscript{6}, and L. Pulone\textsuperscript{1}

\textsuperscript{1} Osservatorio Astronomico di Roma/INAF
\textsuperscript{2} Università di Roma Tor Vergata
\textsuperscript{3} Osservatorio Astronomico di Capodimonte/INAF
\textsuperscript{4} University of Kansas
\textsuperscript{5} Pontificia Universidad Católica de Chile
\textsuperscript{6} Osservatorio Astronomico di Collurania/INAF
\textsuperscript{7} Department of Physics and Astronomy, Aarhus University

Abstract

We present $Ca-uvby$ Strömgren photometry of the Baade’s Window, including the Galactic globular cluster NGC 6522. We separate field and cluster stars by adopting color–color planes and proper motions. We then estimate the global metallicity of red-giants (RGs) in NGC 6522 by using a new theoretical metallicity calibration of the Strömgren index $hk$ presented in (Calamida et al. 2011). We find that metallicities estimated by adopting the $hk$ index and the $Ca-y$ color are systematically more metal-rich than metallicities estimated with $hk$ and the $u-y$, $v-y$ and $b-y$ colors. Current evidence indicate that the $hk$ metallicity index is affected not only by the $Ca$ abundance, but also by another source of opacity.

1 Introduction and data reduction

The study of the Milky Way bulge is fundamental to understand the star formation history of the Galactic spheroid. The Milky Way bulge is indeed dominated by metal-rich old stars ($t > 10$ Gyr, Zoccali et al. 2003). Their metallicity distribution is centered on solar metallicity and span a range from $[Fe/H] \sim -1.5$ to 0.5 dex, based on the high-resolution spectroscopy of $\sim 800$ stars (Zoccali et al. 2008, hereafter ZO08). These evidence would support a scenario in which the bulge formed very quickly ($t < 1$ Gyr) at the early stages of the Galaxy formation, and then accreted material from the disk (Zoccali et al. 2006, ZO08).
Figure 1: $y$, $v-y$ and $y$, Ca–$y$ CMDs for stars in the Baade's Window. Stars are selected in position and in photometric accuracy (see text for more details). Error bars display intrinsic errors in color and in magnitude, while the arrows show the reddening directions. The red solid line shows an isochrones for $t = 0.45$ Gyr and $Z = 0.04$, $Y = 0.303$, while the green and blue solid lines show two isochrones for the same chemical composition, $Z = 0.02$, $Y = 0.273$, and $t = 2$ and $t = 10$ Gyr, respectively. Red and blue dots mark red-giant and red-clump stars observed spectroscopically by Zoccali et al. (2008).

Furthermore, the Baade’s window, where the extinction is lower ($E(B-V) < 0.6$ mag), includes NGC 6522, which is classified as a bulge metal-intermediate Galactic globular cluster (GGC, $[\text{Fe/H}] \sim -1.3/-1.2$ dex). For this region ZO08 collected high-resolution spectroscopy for $\sim 200$ red-giants (RGs) and $\sim 200$ red clump stars. The two samples show the same metallicity distribution centered on solar metallicity and with most of the stars in the range $-1.0 < [\text{Fe/H}] < 0.7$ dex (see Fig. 8 in ZO08).

We collected a set of Ca-$uvby$ Strömgren images centered on the Baade’s and the Blanco’s windows and we plan to provide metallicity distributions based on the $hk$ Strömgren index for a significant sample of bulge RGs. The advantage of applying a Strömgren metallicity calibration to this data set is the possibility to estimate the metallicity of thousands of RGs in this region at the same time. With this study we would be able to eventually confirm the presence of a metallicity gradient in the bulge, as suggested by ZO08. The drawback is that our new theoretical metallicity calibration of the $hk$ index (Calamida et al. 2011, hereafter CA11) is only valid in the range $-2.7 < [\text{Fe/H}] < -0.6$ dex. We then apply the calibration to a significant sample of NGC 6522 candidate RGs, to constrain the metal content of this GGC.

Ca-$uvby$ Strömgren images were collected with the 1.54m Danish Telescope (ESO, La Silla) and the DFOSC camera in July 2000. The pointing was centered on the Baade’s
Window ($\alpha = 18:03:34$, $\delta = -30:04:10$), including NGC 6522. We secured a total of 16 images ($4y, 4b, 2v, 2Ca, 2u$), with exposure times ranging from 60s ($y$) to 1000s ($Ca$), and seeing between $\sim 1.2''$ and $\sim 1.6''$. The reader interested in the details of data reduction and calibration is referred to CA11. The final photometric catalog includes $\sim 80,000$ stars with an accuracy of $\sigma_y < 0.1$, $\sigma_{v-y} < 0.2$ mag at $y \approx 20$ mag. The accuracy of the calibration is $\sim 0.02$ mag for the $y, b, v$ bands and $\sim 0.05$ mag for the $Ca, u$ bands.

Fig. 1 shows the $y, v-y$ (left panel) and $y, Ca-y$ (right) Color-Magnitude Diagrams (CMDs) of the Baade’s Window. We exclude most of the stars belonging to NGC 6522 by selecting only objects with distances from the cluster center ($\alpha = 18:03:34$, $\delta = -30:02:02$) larger than 6 arcminutes. Stars are then selected in photometric accuracy according to the "separation index"$^1$.

In order to validate the absolute calibration we compare our photometry with theoretical predictions. We assume a mean distance of $\sim 5$ Kpc for the foreground thin disk stars according to the simulations by Schultheis and using the Besancon Galaxy model (Robin et al. 2003; see ZO08 for more details), and a distance modulus of $\mu_0 = 13.91$ and a mean reddening of $E(B-V) = 0.55$ for bulge stars (Barbuy et al. 1998). The extinction coefficients for the Strömgren colors are estimated by applying the Cardelli et al. (1989) reddening relation and $R_V = A_V/E(B-V) = 3.13$ (Barbuy et al. 1998). We find: $E(b - y) = 0.69 \times E(B - V)$, $E(v - y) = 1.31 \times E(B - V)$, $E(u - y) = 1.82 \times E(B - V)$ and $E(Ca-y) = 1.46 \times E(B - V)$.

The red solid line shows an isochrone for $t = 0.45$ Gyr and $Z = 0.04, Y = 0.303$, while the green and blue solid lines show two isochrones for the same chemical composition, $Z = 0.02, Y = 0.273$, and different ages, $t = 2$ Gyr and $t = 10$ Gyr, respectively. Red and blue dots show RG and red-clump stars observed spectroscopically by ZO08. Isochrones are from the BASTI data base and are based on $\alpha$-enhanced ([\alpha/Fe] = 0.4) evolutionary models (Pietrinferni et al. 2006). Evolutionary prescriptions were transformed into the observational plane using atmosphere models computed assuming $\alpha$-enhanced mixtures. Data plotted in Fig. 1 indicate that theory and observations, within the errors, agree quite well both with the thin disk main sequence ($1.0 \lesssim (v-y) \lesssim 2.5$ mag, $14 \lesssim y \lesssim 20$ mag, red solid line) and the bulge and thick disk sequences ($2.0 \lesssim (v-y) \lesssim 3.5$ mag, $14 \lesssim y \lesssim 18$ mag, green and blue solid lines). The spread of the sequences is mostly due to photometric errors and to the presence of differential reddening, but also to depth differences of the stars.

Fig. 2 shows the same CMDs but for NGC 6522: only stars with distances from the cluster center in the range 0.65 - 1.65 arcminutes are plotted. The cluster center is excluded due to crowding, but stars up to about 1.5 the half-light radius ($r_h = 1.0'$, Harris 2003) are selected (CA11). The green solid lines show an isochrone for $t = 13$ Gyr and $Z = 0.002, Y = 0.248$ and the predicted Zero Age Horizontal Branch (ZAHB) for $Z = 0.002$. The eight green stars are RGs with high-resolution spectra collected with FLAMES/GIRAFFE at the VLT (ESO, Barbuy et al. 2009, hereafter BA09). Note that theory and observations agree quite well and give $[\text{Fe/H}] \sim -1.3$ dex for NGC 6522, in agreement with the spectroscopic estimate $[\text{Fe/H}] \sim -1.2$ dex by BA09, converted to the Zinn & West (1984) metallicity scale (CA11).

$^1$The "separation index" quantifies the degree of crowding (Stetson et al. 2003).
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Figure 2: Same as Fig. 1 but for NGC 6522. The green solid lines show an isochrone for $t = 13$ Gyr and $Z = 0.002, Y = 0.248$ and the predicted ZAHB for $Z = 0.002$, while the green stars mark the eight cluster red-giants observed spectroscopically by Barbuy et al. (2009).

2 Metallicity distribution

We select NGC 6522 RGs by star position as in Section 1, in magnitude ($y < 18.0$ mag), in photometric accuracy ($\sigma(v, b, y) < 0.03$ and $\sigma(Ca) < 0.02$ mag), and in surface gravity ($[c] = (u−v)−(v−b)−0.2×(b−y) < 0.35$ mag), ending up with 51 RGs. A further selection is performed by using the proper motions by Sumi et al. (2003) and imposing $−2 < \text{pm(α)} < 6$ and $−2 < \text{pm(δ)} < 2$ mas/yr (CA11). The final sample includes 28 candidate cluster RGs.

Photometric metallicities are estimated by adopting the new theoretical calibration by CA11 based on the Strömgren $hk$ index. To unredden the $hk$ index we adopt $E(hk) = −0.155 E(b−y)$ (Anthony-Twarog et al. 1991).

The panels of Fig. 3 show the photometric metallicities of the 28 candidate RGs estimated adopting the Metallicity–Index–Color relations based on $hk_0$ and the $b−y$, $Ca−y$, $u−y$ unreddened colors plotted versus metallicities estimated with the $hk_0$, $v−y$ relation. The eight RGs in common with BA09 are marked with a red star. Metallicity estimates based on the $hk_0$, $b−y$ and on the $hk_0$, $u−y$ relations agree quite well with those based on the $hk_0$, $v−y$ relation ($<\Delta(M/H)_{by, uy} − [M/H]_{vy}> \approx 0.0 ± 0.02$ and $\approx −0.01 ± 0.02$ with $\sigma = 0.26$ and 0.19 dex, respectively.) On the other hand, the metallicity estimates based on the $hk_0$, $Ca−y$ relation are on average ≈0.3 dex more metal-rich than those based on the $hk_0$, $v−y$ relation. The difference might be due to the fact that the $hk_0$, $Ca−y$ relation is more sensitive to the $Ca$ abundance and, in turn, to the $\alpha$-element abundance, than the other relations.
Figure 3: Photometric metallicities of 28 candidate RGs of NGC 6522 estimated adopting the Metallicity–Index–Color relations $hk_0$, $b-y_0$, $Ca-y_0$, $u-y_0$ ([M/H]$_{by}$, [M/H]$_{cay}$, [M/H]$_{uy}$) versus metallicities estimated with the $hk_0$, $v-y_0$ relation ([M/H]$_{vy}$). The eight RGs with spectroscopic measurements from BA09 are marked as red stars.
3 Conclusions and future perspectives

We presented $Ca – uvby$ Strömgren photometry of the Baade’s Window, including the GGC NGC 6522. We separated field and cluster stars and estimated the global metallicity of candidate RGs in NGC 6522 by using a new theoretical metallicity calibration of the $hk$ index. We find that metallicities estimated by adopting the $hk$ index and the $Ca–y$ color are systematically more metal-rich than metallicities estimated with the $hk$ index and the $b–y$, $v–y$ and $b–y$ colors. The $hk$ index is then affected not only by the $Ca$ abundance, but also by another source of opacity.

We now plan to perform a new $\alpha$-enhanced theoretical calibration of the Strömgren index $m_1$ up to solar metallicities, to constrain the metallicity distribution of bulge RGs and red clump stars. We then plan to match Strömgren data with $z, y, J, H, K$-band photometry of the bulge from the VVV public survey project (VISTA, ESO, http://vvvsurvey.org/). The optical-NIR color-color planes will allow us to better disentangle the different components present in the observed field of view (thin/thick disk, bulge stars). We will then test the adoption of different intermediate- and broad-band color-color planes in order to study the metallicity and the age distribution of these stars.

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