The vertical Na-O relation in the bulge globular cluster NGC 6553

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ABSTRACT
In this article, we present a detailed chemical analysis of seven red giant members of NGC 6553 using high-resolution spectroscopy from VLT FLAMES. We obtained the stellar parameters (Teff, Log(g), vt, [Fe/H]) of these stars from the spectra, and we measured the chemical abundance for 20 elements, including light elements, iron-peak elements, α-elements and neutron-capture elements. The metallicities in our sample stars are consistent with a homogeneous distribution. We found a mean of [Fe/H]=−0.14±0.07 dex, in agreement with other studies. Using the alpha-elements Mg, Si, Ca and Ti we obtain the mean of [α/Fe]=0.11±0.05. We found a vertical relation between Na and O, characterized by a significant spread in Na and an almost non-existent spread in O. In fact, Na and Al are the only two light elements with a large intrinsic spread, which demonstrates the presence of Multiple Populations (MPs). An intrinsic spread in Mg is not detected in this study. The α, iron-peak and neutron capture elements show good agreement with the trend of the bulge field stars, indicating similar origin and evolution, in concordance with our previous studies for two other bulge GCs (NGC 6440 and NGC 6528).

Key words: globular clusters: individual (NGC 6553) - nucleosynthesis, abundances - stars: abundances

1 INTRODUCTION
Having a complete picture of different components of our Galaxy will allow us to understand with more detail their formation, evolution and the different astrophysical processes which have been involved during their lifetime. In fact, nowadays, our knowledge regarding the Milky Way has been greatly improved, thanks to a large number researchers and new surveys which use the latest generation of facilities such as the VLT FLAMES, VVV/VVVX survey (Minniti et al. 2010), the Gaia-ESO survey (Gilmore et al. 2012), SDSS-IV (Blanton et al. 2017), and the Gaia mission.

In this picture, undoubtedly the bulge of the Milky Way occupies an essential place. For this reason, there are more and more researchers studying distinct components or astrophysical processes in the bulge, such as dynamics (Portail et al. 2017; Beaulieu et al. 2000), chemistry (Nandakumar et al. 2018; Grieco et al. 2012), and even exoplanets (Cortés et al. 2019; Sahu et al. 2006), among others. Since the bulge is likely the oldest component of our Galaxy, it can give us relevant information on its formation and subsequent evolution. One of the fundamental constituents of the bulge are globular clusters (GCs), less studied than their halo counterparts due to difficulties including high and often variable extinction, even across the small angular extent of a typical GC, as well as crowding and the difficulty in separating true bulge stars from intervening thin and thick disk stars.

Many studies have analyzed in detail the GCs of

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2 Observations and Data Reduction

We observed seven red giants stars in NGC 6553 with the fiber-fed multiobject FLAMES spectrograph mounted at the ESO VLT/UT2 telescope in Cerro Paranal (Chile) in period 93A (ESO program ID 093.D-0286, PI S. Villanova). The analyses of the stars observed with FLAMES were conducted using the blue and red arms of the high-resolution spectrograph UVES. We obtained a single spectra for each star with a exposure time of 2774 seconds.

The seven targets observed with FLAMES-UVES come from the membership list of NGC 6553 previously published in Saviane et al. (2012) and Mauro et al. (2014) using FORS2 Ca triplet spectroscopy and VVV photometry, whose spatial distribution is shown in Figure 1. All the stars of our sample belong to the upper Red Giant Branch (RGB), with a color-magnitude diagram (CMD) of the cluster (Figure 2). FLAMES-UVES data have a spectral resolution of about $R = 47000$. The data was taken with central wavelength 580 nm, which covers the wavelength range 476-684 nm. Our S/N is about 25 at 560 nm (lower chip) and about 30 at 650 nm (upper chip).

The reduction process includes includes bias and flat-field corrections, wavelength calibration, spectral rectification, and sky subtraction. We apply the same procedure described in our previous articles (Muñoz et al. 2017, 2018).

The mean radial velocity for NGC 6553 in our sample is $-3.86 \pm 2.12$ km $s^{-1}$, the velocity dispersion is 5.62 km $s^{-1}$. This radial velocity is compatible with the values in the literature: Saviane et al. (2012) with four stars found a value of $-9.0 \pm 4.0$ km $s^{-1}$ (Harris 1996, 2010 edition) quotes a value of $-3.2 \pm 1.5$ km $s^{-1}$ and Tang et al. (2017) found a value of $-0.14 \pm 5.46$ km $s^{-1}$.

Table 1 lists the stellar parameters of our sample: ID, J2000 coordinates (Ra and Dec), J, H, K$_s$ magnitudes from VVV PSF photometry, calibrated on the system of 2MASS (Mauro et al. 2014; Cohen et al. 2017), heliocentric radial velocity, $v_t$, log(g), micro-turbulent velocity ($v_t$) and metallicity. Moreover, Table 2 shows the metallicity values from Saviane et al. (2012), Mauro et al. (2014) and Tang et al. (2017). The procedure for the determination of the atmospheric parameters is discussed in the next section.

3 Atmospheric Parameters and Abundances

We have analyzed our sample of NGC 6553 stars using the local thermodynamic equilibrium (LTE) program MOOG (Sneden 1973). Atmospheric models were performed using ATLAS9 (Kurucz 1970) and the line list for the chemical analysis is the same described in Villanova & Geisler (2011) and widely used in several studies (Rain et al. 2019; Villanova et al. 2013; Muñoz et al. 2017, 2018; Mura-Guzmán et al. 2017). The stellar parameters $v_t$, $v_t$, and log(g) were adjusted iteratively and new stellar models were calculated in an effort to remove trends in excitation potential and equivalent width vs. abundance for $v_t$ and $v_t$ respectively.
Table 1. Parameters of the observed stars for NGC 6553.

| ID  | Ra (h:m:s) | DEC (°:′:″) | J (mag) | H (mag) | Ks (mag) | RV_H (km s⁻¹) | T_eff [K] | log(g) | [Fe/H] | v_t [km/s] | v_t FeI/FeII |
|-----|------------|-------------|---------|---------|---------|--------------|-----------|--------|--------|-----------|-------------|
| 1   | 18:09:15.66 | -25:56:00.77 | 10.86   | 9.90   | 9.63   | 6.12±0.21    | 4172±15 | 1.21±0.12 | -0.17±0.07 | 1.24±0.04 | 85/10       |
| 2   | 18:09:15.71 | -25:52:58.70 | 12.17   | 11.276 | 11.035 | -8.07±0.19   | 3998±16 | 1.19±0.13 | -0.06±0.07 | 0.98±0.07 | 82/9        |
| 3   | 18:09:17.51 | -25:55:42.30 | 12.05   | 11.17  | 10.94  | -7.49±0.41   | 4216±19 | 1.34±0.20 | -0.19±0.07 | 1.35±0.05 | 90/10       |
| 4   | 18:09:22.39 | -25:54:37.94 | 12.20   | 11.33  | 11.10  | -10.95±0.27  | 4051±16 | 1.06±0.17 | -0.07±0.07 | 0.89±0.10 | 88/11       |
| 5   | 18:09:22.43 | -25:57:59.32 | 11.76   | 10.80  | 10.52  | -1.81±0.42   | 4055±22 | 1.40±0.16 | -0.16±0.07 | 1.05±0.12 | 101/13      |
| 6   | 18:09:23.98 | -25:52:01.20 | 12.07   | 11.22  | 10.95  | -2.76±0.26   | 4399±16 | 1.94±0.14 | -0.08±0.07 | 0.97±0.10 | 92/11       |
| 7   | 18:09:24.67 | -25:51:11.10 | 11.92   | 11.03  | 10.71  | 2.04±0.31    | 4340±20 | 1.74±0.19 | -0.22±0.07 | 1.47±0.06 | 81/8        |

Column 12: Numbers of line measured for FeI and FeII.

Table 2. Iron abundances from different authors for NGC 6553.

| ID  | [Fe/H]_{this work} | [Fe/H]_{S12} | [Fe/H]_{M14} | [Fe/H]_{D16} | [Fe/H]_{T17} |
|-----|-------------------|--------------|--------------|--------------|--------------|
| 1   | -0.17±0.07        | -0.44        | -0.27±0.14   | -0.15        | -            |
| 2   | -0.06±0.07        | 0.10         | -0.02±0.14   | -0.13        | -0.17        |
| 3   | -0.19±0.07        | 0.29         | 0.30±0.14    | -0.22        | -            |
| 4   | -0.07±0.07        | 0.12         | -0.13±0.14   | -0.09        | -0.16        |
| 5   | -0.16±0.07        | 0.24         | 0.12±0.14    | -0.13        | -            |
| 6   | -0.08±0.07        | -0.06        | 0.09±0.14    | -0.10        | -0.08        |
| 7   | -0.22±0.07        | 0.00         | 0.04±0.14    | -0.14        | -            |

References. S12: Saviane et al. (2012); M14: Mauro et al. (2014); D16: Dias et al. (2016); T17: Tang et al. (2017).

Figure 1. Distribution of the stars observed in NGC 6553 (green filled circles). The blue dashed line show the extent of the tidal radius (Harris 1996, 2010 edition).

Figure 2. CMD of NGC 6553 from the VVV survey corrected by the VVV reddening maps (Gonzalez et al. 2012). The red filled circles represent our observed UVES sample.
tainties for $T_{\text{eff}}$ were determined from the uncertainty of the least-squares fit of abundance vs. excitation potential, in addition to the uncertainty in the slope due to the uncertainties in $v_t$. Finally to calculate the uncertainty in $\log g$, we include the contribution from the uncertainty in $T_{\text{eff}}$ in addition to the scatter in the Fe II line abundances.

In Figure 4 we found good agreement among the stellar parameters derived in this study and from three different model isochrones with similar metallicity and with an age of 13 Gyr. The models used in this comparison are: PARSEC (Bressan et al. 2012), MESA (Choi et al. 2018; Dotter 2016) and the Dartmouth (Dotter et al. 2008) models. In Figure 4 these models are plotted in green, blue and black respectively. Although we note a small offset among the data and the isochrone, it is important to account that an offset of ~100 K between photometric and spectroscopic $T_{\text{eff}}$ can arise because of uncertainties in the mixing length parameter and/or surface boundary condition (Choi et al. 2018). Also other studies find a similar mismatch especially associated with metal rich stars (Ness et al. 2013).

The reddening is high for most of the bulge GCs, and NGC 6553 is no exception. NGC 6553 has a color excess of $E(B-V)=0.70$ quoted by Harris (1996, 2010 edition) and Guarnieri et al. (1998) found a value of $E(B-V)=0.63$. The potentially high differential reddening and high crowding make it difficult to obtain the stellar parameters. In order to avoid the effect of the extinction and the differential reddening in the measurement of the stellar parameters, we decided to calculate the stellar parameters directly from the spectra.

We used equivalent widths (EWs) of the spectral lines and the spectrum-synthesis method to obtain abundances of a large number of elements, which are listed in Table 3. We used the spectrum-synthesis method for lines affected by blending. In this case, we generated five synthetic spectra with different abundances for each line, and we estimated the best-fitting value as the one that minimises the rms scatter. Figure 3 shows an example of this method for two different lines. We carefully excluded the telluric contaminated lines in our analysis. The adopted solar abundances we use are produced by Marino et al. (2008). The error introduced by the uncertainty on the EW ($\sigma_{\text{EW}}/N$) was calculated by dividing the rms scatter by the square root of the number of the lines used for a given element and a given star. For el-

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**Figure 3.** Spectrum synthesis fits for Europium (upper panel) and Aluminum (lower panel) lines for the star #5 and #4 respectively. The dashed line is the observed spectrum, and the solid color lines show the synthesized spectra corresponding to different abundances.

**Figure 4.** $\log g$ vs $T_{\text{eff}}$ for NGC 6553. The black points display an isochrone with a metallicity of -0.16 dex, $[\alpha/\text{Fe}]=+0.20$ dex and age of 13 Gyr (Dotter et al. 2008, Dartmouth isochrone). The green points is a isochrone with a metallicity of -0.16 dex and age of 13 Gyr (Bressan et al. 2012, PARSEC isochrone). The blue points is a isochrone with a metallicity of -0.16 dex and age of 13 Gyr (Choi et al. 2016; Dotter 2016, MESA isochrone).
elements whose abundance was obtained by spectrum synthesis, the error is given in the output of the fitting procedure. The error for each [X/Fe] ratio as a result of uncertainties in atmospheric parameters and $\sigma_{S/N}$ are showed in Table 4. The total internal error ($\sigma_{tot}$) is given by:

$$\sigma_{tot} = \sqrt{\sigma_{Teff}^2 + \sigma_{\log(g)}^2 + \sigma_{v_t}^2 + \sigma_{[Fe/H]}^2 + \sigma_{S/N}^2}$$  \hspace{1cm} (1)$$

In Table 4 we compare the total internal error for all the elements measured with the observed error (standard deviation of the sample).

4 RESULTS

In this section, we will discuss and examine in detail our results. Furthermore, we compare them with the literature, focusing on our previous articles (Muñoz et al. 2017, 2018), which present an identical analysis of two bulge GCs (NGC 6440 and NGC 6528).

4.1 Iron

We found a mean [Fe/H] value for the cluster of [Fe/H] = -0.14 ± 0.07 dex. The scatter observed in this cluster is $\sigma_{obs}$ = 0.06, which is consistent with the total expected observational error of $\sigma_{tot}$ = 0.07, indicating a homogeneous iron content. Saviane et al. (2012) using CaII triplet found a mean in iron of [Fe/H] = -0.16 ± 0.06 in their sample. We present in Table 2 the targets which we have in common. Mauro et al. (2014) found a mean value in iron of [Fe/H] = 0.02 using the CaII triplet equivalent widths from Saviane et al. (2012) but using near IR instead of optical photometry for the analysis (see Table 2). These studies are compatible with our results taking into account the uncertainties. It is interesting to note that Saviane et al. (2012) found a scatter of $\sigma$ = 0.06, compatible with no spread in iron in agreement with our finding of homogeneity in iron. Mauro et al. (2014) found a larger scatter of $\sigma$ = 0.17. However, this value is similar to their errors, indicating homogeneity in metallicity, in agreement with our results.

Tang et al. (2017) using high-resolution spectra in a sample of ten members of NGC 6553 from APOGEE found a mean of [Fe/H] = -0.15 ± 0.05 with a spread in iron of $\sigma$ = 0.05, in excellent agreement with our sample. We have three stars in common with Tang (Table 2) - their results for these stars are compatible with our results taking into account the errors.

Dias et al. (2016) studied the low-resolution optical spectra of the same stars from Saviane et al. (2012). They used a full-spectrum fitting technique to derive the abundance. They found an average metallicity for NGC 6553 of [Fe/H] = -0.13 ± 0.01 in agree with our finding. Also, we found good accordance star by star (see Table 2).

Finally, Ernandes et al. (2018) study the iron peak-elements in four stars member of NGC 6553 using high-resolution spectroscopy. They found a metallicity of [Fe/H] = -0.20 dex with a scatter of $\sigma$ = 0.02, in good agreement with our results.

4.2 Iron-peak elements

We have measured the abundance of seven iron-peak elements: Sc, V, Cr, Mn, Ni, Cu/Fe (see Table 3 and Figure 5). We have analyzed the iron in detail in the previous section.

In Figure 5 we plotted iron-peak elements versus [Fe/H]. Filled dark green triangles are our data for NGC 6553 (this study), Filled yellow triangles are our data for NGC 6528 (Muñoz et al. 2018), filled blue triangles: NGC 6440 (Muñoz et al. 2017), filled orange squares: Bulge field stars (Barbuy et al. 2013; Johnson et al. 2014), filled gray squares: halo and disk stars (Fulbright 2000; François et al. 2007; Reddy et al. 2003, 2006).
Vanadium shows a very high super-solar abundance; how-

Comparison with our previous studies for NGC 6440 (Muñoz et al. 2017) and NGC 6528 (Muñoz et al. 2018). We found good agreement with NGC 6528 for the case of Cr, Ni, and Cu. All of these elements are super-solar except for Mn. Vanadium shows a very high super-solar abundance; however, the observational error is quite large for this element.

Three of the iron-peak elements (Cr, Mn, Ni) were analysed in APOGEE DR13. The mean values of the ten stars presented in Tang et al. (2017) are: [Cr/Fe]=0.00, [Mn/Fe]=0.04, [Ni/Fe]=0.06. Cr shows the same mean value found in this study as in Tang et al. (2017). V and Cu given by APOGEE DR13 are subject to large uncertainties (Tang et al. 2017), therefore, we made no comparison for V and Cu.

Ernandes et al. (2018) studied some iron-peak elements (Sc, V, Mn, Cu, and Zn) in NGC 6553. Their results are compatible with our results for Sc and Cu, taking into account the uncertainties. The more substantial difference is for Vanadium, although our error for this element is large.

Similar to the case of NGC 6528 and NGC 6440, the super-solar abundance for most of the iron-peak elements is evidence of early pollution by SN explosion(s).

| El.  | 1    | 2    | 3    | 4    | 5    | 6    | 7    | Cluster\(^1\) |
|------|------|------|------|------|------|------|------|-------------|
| O/Fe | -0.17| -0.14| -0.05| -0.16| -0.06| 0.06 | 0.03 | -0.07±0.03   |
| Na/Fe\(_{NLT}\) | ±0.03| ±0.03| ±0.05| ±0.04| ±0.05| ±0.05| ±0.04| +0.23±0.09   |
| Mg/Fe | ±0.27| ±0.23| ±0.22| ±0.17| ±0.07| 0.14 | 0.29 | +0.20±0.03   |
| Al/Fe | ±0.04| ±0.05| ±0.06| ±0.05| ±0.04| ±0.04| ±0.04| +0.32±0.05   |
| Si/Fe | ±0.03| ±0.04| ±0.04| ±0.04| ±0.04| ±0.04| ±0.04| ±0.04       |
| Ca/Fe | ±0.06| ±0.06| ±0.06| ±0.05| ±0.06| ±0.05| ±0.06| ±0.06       |
| Sc/Fe | ±0.03| ±0.05| ±0.06| ±0.05| ±0.06| ±0.05| ±0.06| ±0.06       |
| Ti/Fe | ±0.06| ±0.15| ±0.05| ±0.04| ±0.15| ±0.04| ±0.04| ±0.04       |
| V/Fe  | ±0.05| ±0.07| ±0.05| ±0.07| ±0.06| ±0.05| ±0.06| ±0.06       |
| Cr/Fe | ±0.02| ±0.10| ±0.09| ±0.03| ±0.18| ±0.02| ±0.03| ±0.03       |
| Mn/Fe | ±0.09| ±0.06| ±0.09| ±0.10| ±0.09| ±0.09| ±0.09| ±0.09       |
| Fe/H  | ±0.01| ±0.19| ±0.01| ±0.07| ±0.16| ±0.08| ±0.02| -0.14±0.06  |
| Ni/Fe | ±0.02| ±0.02| ±0.02| ±0.02| ±0.03| ±0.03| ±0.02| ±0.02       |
| Cu/Fe | ±0.32| ±0.07| ±0.07| ±0.08| ±0.07| ±0.08| ±0.07| ±0.07       |
| Zr/Fe | ±0.07| ±0.06| ±0.08| ±0.08| ±0.09| ±0.08| ±0.08| ±0.08       |
| Y/Fe  | ±0.03| ±0.07| ±0.06| ±0.07| ±0.06| ±0.06| ±0.07| ±0.07       |
| Ba/Fe | ±0.04| ±0.05| ±0.04| ±0.05| ±0.05| ±0.04| ±0.05| ±0.04       |
| Ce/Fe | ±0.01| ±0.29| ±0.13| ±0.10| ±0.40| 0.18  | 0.04±0.08  |
| Nd/Fe | ±0.24| ±0.07| ±0.12| ±0.03| ±0.31| ±0.08| ±0.13±0.04 |
| Eu/Fe | ±0.06| ±0.06| ±0.08| ±0.03| ±0.01| ±0.23| ±0.02| ±0.02±0.04  |

Columns 2-8: abundances of the observed stars. Column 9: mean abundance for the cluster. Column 10: abundances adopted for the Sun in this paper. Abundances for the Sun are indicated as log(El). The errors presented for each abundance was calculated by dividing the rms scatter by the square root of the number of the lines used for a given element and a given star. For elements whose abundance was obtained by spectrum-synthesis, the error is the output of the fitting procedure.

\(^1\) The errors are the statistical errors obtained of the mean.
4.3 α elements

Alpha elements are suggested to come from SN II explosions at an early epoch. We managed to measure five α elements (O, Mg, Si, Ca, and Ti). NGC 6553 shows very similar behavior to NGC 6528 for the case of the alpha-elements, with a very strong overabundance relative to the solar scale for (O, Mg, Si, Ca and Ti). NGC 6553 shows very similar behavior to NGC 6553, this one shows some compatibility with the bulge trend as well with the disk trend (see Figure 7).

We did not find a clear Si spread in NGC 6553 (σtot=0.15, σobs=0.25), similar to the case of Tang et al. (2018). It is interesting to note that in NGC 6528 (Muñoz et al. 2018) we found a similar behavior (σtot=0.11, σobs=0.14). An intrinsic spread in Silicon is mainly found in metal-poor GCs or massive GCs (Tang et al. 2018; Ventura et al. 2012; D’Antona et al. 2016). Therefore, we did not expect to find a spread in Silicon in NGC 6553 or NGC 6528. However, the elements for which we did expect to find a significant spread, viz. O and Mg or both, in fact show little or no scatter, basically equal to the total error (Table 4). We will discuss O and Mg in the next sections.

4.4 Na-O anticorrelation

Without a doubt, the Na-O anticorrelation has given us a powerful tool to study the MPs in GCs. Currently, virtually all old massive globular clusters clearly show this remarkable anticorrelation with at least one clear exception - Ruprecht 106 (Villanova et al. 2013; Dotter et al. 2018).

However, it has been established that the extension of this anticorrelation is mainly connected with the mass and metallicity of the GC (Carretta et al. 2009, 2015, 2011, 2010b).

In our previous articles (Muñoz et al. 2017, 2018), we have found in NGC 6528 and NGC 6440 a peculiar O-Na anti-correlation, basically vertical and with a very short, if any, horizontal extension, implying a Na but no significant O spread. NGC 6553 follows this pattern, with a very low scatter in O of σobs=0.09 (compared to a total expected error of 0.07) and a more significant spread in Na of σobs=0.24 (compared to an expected error of 0.11). A similar pattern was shown in Tang et al. (2017): a small scatter in Oxygen (σobs=0.05), and a spread much greater in Na (σobs=0.15) in comparison with their expected error. Their scatter values are very close to our results (see Figure 8).

Our results are in agreement with previous findings about the mentioned in various articles about the extension of the anti-correlation Na-O and its dependence on cluster mass. The GCs from our previous studies (i.e., NGC 6440 and NGC 6528) including the one presented here - NGC 6553, have masses between (2.35±0.19)x10^5 and (8.96±1.85)x10^5 M⊙ (Baumgardt & Hilker 2018). Basically, these are intermediate mass GCs in comparison with other Galactic GCs. We find definite evidence that such intermediate mass bulge GCs have at most a short, almost vertical Na-O anticorrelation, extension, without a significant spread in Oxygen. On the other hand, contrasting its results with NGC 6441 (Gratton et al. 2006, 2007), a massive Bulge GCs of (1.23±0.01)x10^6 M⊙ (Baumgardt & Hilker 2018), we noticed a broader extension of the correlation. Finally, comparing with the GC HP 1 with a low mass of (1.11±0.38)x10^5 M⊙ (Baumgardt & Hilker 2018), which have an unclear O-Na anti-correlation (Barbuy et al. 2016), although HP 1 is the most metal poor among the GCs compared in this research, with a metallicity of [Fe/H]=−1.06±0.10 dex (Barbuy et al. 2016). Therefore, apparently there is a relationship between the mass and metallicity of

Table 4. Estimated errors on abundances for NGC 6553, due to errors on atmospherics parameters and to spectral noise, compared with the observed errors.

| ID       | ∆(O/Fe) | ∆Log(g) | ∆[O/H] | ∆[Fe/H] | ∆σ_S/N | ∆σ_tot | ∆σ_obs |
|----------|---------|---------|--------|---------|--------|--------|--------|
|          |         | 0.01    | 0.13   | 0.09    | 0.03   | 0.07   | 0.09   |
|          |         | −0.04   | 0.00   | −0.06   | 0.03   | 0.11   | 0.24   |
|          |         | −0.07   | 0.00   | −0.01   | 0.04   | 0.09   | 0.08   |
|          |         | −0.01   | 0.05   | 0.03    | 0.03   | 0.07   | 0.13   |
|          |         | 0.07    | −0.08  | 0.06    | 0.05   | 0.15   | 0.25   |
|          |         | −0.07   | 0.03   | −0.02   | 0.05   | 0.09   | 0.09   |
|          |         | 0.04    | −0.01  | 0.00    | 0.03   | 0.06   | 0.17   |
|          |         | −0.06   | 0.00   | −0.01   | 0.06   | 0.11   | 0.14   |
|          |         | −0.06   | 0.00   | −0.10   | 0.07   | 0.14   | 0.18   |
|          |         | −0.09   | −0.01  | −0.04   | 0.09   | 0.15   | 0.09   |
|          |         | 0.10    | 0.10   | 0.04    | 0.05   | 0.19   | 0.16   |
|          |         | 0.01    | −0.06  | 0.00    | 0.02   | 0.07   | 0.06   |
|          |         | 0.12    | 0.15   | 0.13    | 0.06   | 0.26   | 0.08   |
|          |         | 0.06    | 0.09   | 0.12    | 0.07   | 0.20   | 0.20   |
|          |         | 0.12    | 0.16   | 0.16    | 0.06   | 0.29   | 0.30   |
|          |         | 0.05    | 0.11   | 0.07    | 0.04   | 0.16   | 0.33   |
|          |         | 0.11    | 0.15   | 0.11    | 0.05   | 0.23   | 0.22   |
|          |         | 0.13    | 0.13   | 0.10    | 0.08   | 0.15   | 0.23   |
|          |         | 0.06    | 0.10   | 0.08    | 0.06   | 0.15   | 0.23   |
|          |         | −0.01   | 0.09   | −0.03   | 0.04   | 0.10   | 0.10   |
the bulge GCs with their Na-O extension, in agreement with the literature.

4.5 Mg-Al and Na-Al

The study of the relationship between Mg and Al is another useful tool when studying MPs in GCs. Many authors have found an anti-correlation between these two elements (Carreta et al. 2009; Mészáros et al. 2015), but unlike the Na-O anticorrelation, this is present in fewer GCs studied so far. Nevertheless, similar to the case of Na-O, the extension of this anti-correlation strongly depends on mass and metallic-ity (Pancino et al. 2017).

Similar to the case of NGC 6528 from our previous study, we have not found a Mg-Al anti-correlation in this cluster (see Figure 9). The spread of Mg is basically the same as the total error ($\sigma_{\text{tot}}=0.09$; $\sigma_{\text{obs}}=0.08$) and the spread of Al is somewhat greater than the total error ($\sigma_{\text{tot}}=0.07$; $\sigma_{\text{obs}}=0.13$). These results are in agreement with the result presented by Tang et al. (2017). They found a mean of Mg of $[\text{Mg/Al}]=0.15$ with a scatter of $\sigma=0.02$, while in the case of Al they found a mean of $[\text{Al/Fe}]=0.20$ with a scatter of $\sigma=0.14$.

We build a plot using Na and Al (see Figure 9), the light elements showing the most significant spread in our sample. We found a good agreement with bulge field star trend with an important extension. The spread in these elements allows us to verify the presence of MPs in this GC. Also, again we found a good concordance with the bulge GC NGC 6528. Finally, there are regions in this diagram where it is possible to disentangle bulge and disk stars regardless if they are in clusters or the field (see figure 9).

4.6 Neutron-Capture elements

We measured the abundances for five neutron-capture elements: Zr, Ba, Ce, Nd, and Eu.

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Figure 6. [O/Fe],[Mg/Fe], [Si/Fe], [Ca/Fe], [Ti/Fe] vs [Fe/H]. Filled yellow triangles are our data for NGC 6553 (this study), filled cyan circles : NGC6441 (Gratton et al. 2006, 2007), filled gray circles: NGC 5927(Mura-Guzmán et al. 2017), filled magenta triangles: HP1 (Barbuy et al. 2016), filled orange squares: bulge field stars(Gonzalez et al. 2012), filled grey squares : Halo and Disk fields stars (Venn et al. 2004).

Figure 7. [alpha/Fe] vs [Fe/H]. Filled dark green triangles are our data for NGC 6553 (this study). Filled yellow triangles: NGC 6528, filled blue triangles: NGC 6440 (Muñoz et al. 2017), filled cyan circles : NGC6441 (Gratton et al. 2006, 2007), filled gray circles: NGC 5927(Mura-Guzmán et al. 2017), filled magenta triangles: HP1 (Barbuy et al. 2016), filled orange squares: bulge field stars(Gonzalez et al. 2012), filled grey squares : Halo and Disk fields stars (Venn et al. 2004).
As seen in Figure 10, these elements show a gradual decrease with increasing metallicity. This effect is due to the enrichment of iron from SN Ia (Van der Swaelmen et al. 2016).

The five elements show good agreement with the bulge field star trend, basically solar abundance for the case of Ba and Eu, and sub-solar for the case of Nd and Zr with a value around -0.3 dex (see Figure 10).

Comparing our results from NGC 6553 with NGC 6528 (Muñoz et al. 2018), we observe a good agreement for Zr and Ba. But, we find a significant difference in Eu of 0.23 dex.

The ratio of [Ba/Eu] shown in Figure 11, is a good indicator of the contribution of the s-process vs. r-process during the evolution of our Galaxy. In this plot we notice an increase of the [Ba/Eu] vs. [Fe/H] for the bulge field stars, suggesting some contribution from the AGB stars around the solar metallicity (Van der Swaelmen et al. 2016).

We noticed that the results for our studies with NGC 6440 (Muñoz et al. 2017), NGC 6528 (Muñoz et al. 2018) and NGC 6553 (this study) are compatible with the bulge field stars trend. Specifically, regarding NGC 6553, we notice a nucleosynthetic history dominated by s-process, indicating an area of formation mainly enriched by AGB stars at the early epoch (Van der Swaelmen et al. 2016).

5 CONCLUSIONS

In this article, we have derived detailed chemical abundances for the GC NGC 6553 from seven RGB star members. Using FLAMES-UVES data, we measured the chemical abundances of 20 elements, together with an accurate measurement of the errors. We have performed a detailed comparison with other bulge GCs studied homogeneously as part of our previous studies (Muñoz et al. 2017, 2018) and also compared to results in the literature for other bulge GCs (NGC 6441 and HP 1), as well as for field stars from the Halo, Disk and the Bulge.

Summarizing the most import results, NGC 6553 is one of the most metal-rich among Galactic GCs; the mean in metallicity found in our sample is [Fe/H]=-0.14±0.07 dex, and is homogeneous in iron content.

Using the alpha-elements Mg, Si, Ca and Ti we obtain the mean of [α/Fe]=0.11±0.05. Overall, the s-elements, iron peak elements and heavy elements measured for NGC 6553, show a good agreement with the bulge field stars trend as we can see in Figures 5, 7, 6 and 10. Although, it is possible to observe in this GC some compatibility with the disk trend (see Figure 7), in agreement with the finding by Zoccali et al. (2001). However, we found very good accordance with NGC 6528, another bulge GCs, and with the general chemical patterns of the bulge.

Our most important finding is of a vertical Na-O relation, with a significant intrinsic spread in Na, but almost nonexistent in the case of Oxygen. This is compatible with the other bulge GCs NGC 6528 and NGC 6440 from our previous studies (Muñoz et al. 2017, 2018). This short extension in the Na-O anticorrelation found in these clusters (NGC 6553, NGC 6528 and NGC 6440) is in agreement with that found by Carretta in his previous studies (Carretta et al. 2015, 2011, 2010a) regarding the mass of the GCs.
Nonetheless, Carretta mentions other factors that may play a role in this regard. Metallicity is another important factor, considering that these three GCs are metal-rich among galactic GCs, with a metallicity between [Fe/H]=-0.50 to -0.14 dex, this would be in agreement with what was mentioned by Carretta et al. (2009) and Gratton et al. (2010, 2011) about the extension of the Na-O and the metallicity. Other factors must come into play, such as the environment of formation and evolution of these GCs, taking into account that these three metal rich GCs are members of the bulge of our galaxy. It is also important to note that our samples are small, only seven stars in each bulge GCs, therefore we need to increase it to be conclusive about our finding.

Likewise, we have found no Mg-Al anti-correlation, similar to the case of NGC 6528 (Tang et al. 2017). Finally, we detect the presence of MPs in this bulge GCs mainly via the spread in Na and Al (see Figure 9).

We measured five neutron capture elements, which follow the trend of the bulge field stars and the bulge GCs from our previous studies (NGC 6440 and NGC 6528). [Ba/Eu] versus [Fe/H] is dominated by s-process material, indicating a formation mainly enriched by AGB stars at an early epoch.

Finally, we have presented in this research a new chemical tagging for the GC NGC 6553. Together with the other two bulge GCs we have studied, these provide a homogeneous dataset for more than a single bulge GC. Clearly the bulge deserves much more dedicated studies to uncover the many hidden secrets it must contain about the nature of the formation and evolution of this primary Galactic component. Such a study recently begun is the CAPOS (bulge Cluster APOgee Survey) project designed to observe the bulk of the bulge GCs using the high resolution, near IR multiplexing capabilities of the APOGEE spectrograph.

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Figure 10. [Eu, Ba/Fe] vs [Fe/H]. Filled dark green triangles are our data for NGC 6553, filled yellow triangles: NGC 6528 (Muñoz et al. 2018), filled blue triangles: NGC 6440 (Muñoz et al. 2017), filled orange squares: bulge field stars (Van der Swaelmen et al. 2016), filled grey squares: Halo and disk stars (Fulbright 2000; François et al. 2007; Reddy et al. 2006; Barklem et al. 2005; Venn et al. 2004).

Figure 11. [Ba/Eu] vs [Fe/H]. Filled dark green triangles are our data for NGC 6553, filled yellow triangles: NGC 6528 (Muñoz et al. 2018), filled blue triangles: NGC 6440 (Muñoz et al. 2017), filled orange squares: bulge field stars (Van der Swaelmen et al. 2016), filled grey squares: Halo and disk stars (Fulbright 2000; François et al. 2007; Reddy et al. 2006; Barklem et al. 2005; Venn et al. 2004).
