# Peeking beneath the precision floor - I. Metallicity spreads and multiple elemental dispersions in the globular clusters NGC 288 and NGC 362 

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#### Abstract

The view of globular clusters (GCs) as simple systems continues to unravel, revealing complex objects hosting multiple chemical peculiarities. Using differential abundance analysis, we probe the chemistry of the Type I GC, NGC 288 and the Type II GC, NGC 362 at the 2 per cent level for the rst time. We measure 20 elements and nd differential measurement uncertainties of the order of 0.010 .02 dex in both clusters. The smallest uncertainties are measured for Fe I in both clusters, with an average uncertainty of $\sim 0.013$ dex. Dispersion in the abundances of $\mathrm{Na}, \mathrm{Al}, \mathrm{Ti} \mathrm{I}, \mathrm{Ni}, \mathrm{Fe} \mathrm{I}, \mathrm{Y}, \mathrm{Zr}, \mathrm{Ba}$, and Nd are recovered in NGC 288, none of which can be explained by a spread in He. This is the rst time, to our knowledge, a statistically signi cant spread in $s$-process elements and a potential spread in metallicity has been detected in NGC 288 . In NGC 362, we nd signi cant dispersion in the same elements as NGC 288, with the addition of $\mathrm{Co}, \mathrm{Cu}, \mathrm{Zn}, \mathrm{Sr}, \mathrm{La}, \mathrm{Ce}$, and Eu. Two distinct groups are recovered in NGC 362, separated by 0.3 dex in average differential $s$-process abundances. Given strong correlations between Al and several $s$-process elements, and a signi cant correlation between Mg and Si , we propose that the $s$-process rich group is younger. This agrees with asymptotic giant branch star (AGB) enrichment between generations, if there is overlap between low- and intermediate-mass AGBs. In our scenario, the older population is dominated by the $r$-process with a $\Delta^{\mathrm{La}} \Delta^{\mathrm{Eu}}$ ratio of $-0.16 \pm 0.06$. We propose that the $r$-process dominance and dispersion found in NGC 362 are primordial.


Key words: techniques: spectroscopic stars: abundances stars: Population II globular clusters: general globular clusters: individual: NGC 288 globular clusters: individual: NGC 362.

## 1 INTRODUCTION

Globular clusters (GCs) are among the most well-studied enigmas in modern astrophysics. Once prized as theoretical test beds for stellar evolution, nucleosynthesis, and stellar dynamics, the assumption of their simplicity has continued to unravel in recent years (a selection of reviews on the subject include; Gratton, Carretta \& Bragaglia 2012a; Bastian \& Lardo 2018; Gratton et al. 2019; Milone \& Marino 2022). Chemically, GCs are anything but simple, with many showing star-to-star abundance variations involving light elements (e.g. O and Na; Yong et al. 2009; Carretta et al. 2014; Carretta 2015; Yong, Grundahl \& Norris 2015) as well as spreads in iron (Gratton et al. 2012b; Yong et al. 2014; Yong, Da Costa \& Norris 2016; Marino et al. 2018) and other heavy elements (Gratton et al. 2012b; Yong et al. 2014).

Early detection of the chemical complexity of GCs, like a large spread in strength of the cyanogen molecule (CN; Freeman \&

[^0]Rodgers 1975; Norris \& Bessell 1975; Bessell \& Norris 1976; Cottrell \& Da Costa 1981), has since been shown to be indicative of multiple stellar populations (MSPs) formed through distinct episodes of star formation. The chemical differences between generations are attributed to high temperature hydrogen burning involving the elements $\mathrm{C}, \mathrm{N}, \mathrm{O}, \mathrm{F}, \mathrm{Na}, \mathrm{Mg}$, and Al in sites including asymptotic giant branch stars (AGBs), fast rotating massive stars, binaries and supermassive stars (see Gratton, Sneden \& Carretta 2004, for a review). The use of narrow-band lters aboard the Hubble Space Telescope (HST) in the last decade has been groundbreaking in revealing the seemingly ubiquitous appearance of MSPs in Milky Way GCs (Marino et al. 2008; Piotto et al. 2015; Milone et al. 2017).

Despite the discovery that almost all GCs are not simple stellar systems, some GCs remain outliers even in this increasingly complex space. Cataloguing the characteristics of MW GCs has revealed two populations, termed Type I and Type II. Grouping GCs into these two types was done using pioneering high resolution photometry and chemical abundance analysis by Milone et al. (2017) and Marino et al. (2019a). The majority ( $\sim 80$ per cent) of GCs are of Type I and display two distinct populations in chemical and colour magnitude
space due to differences in $\mathrm{O}, \mathrm{Na}, \mathrm{N}$, and He abundances (the result of H-burning, as mentioned). Type I GCs are also characterized by homogeneous abundances in elements heavier than Si. Type II GCs account for the other $\sim 20$ per cent of MW GCs and are characterized by additional complexity in their HST pseudo twocolour diagrams ( chromosome maps ) (Milone et al. 2017). Many Type II GCs demonstrate multiple populations beyond just the two found in Type I GCs, often displaying spreads in metallicity and/or slow neutron capture elements (Marino et al. 2011a, 2015, 2021).

One of the most famous Type II GCs is $\omega$ Centauri ( $\omega$-Cen), the most most massive and chemically complex GC (Marino et al. 2011b, 2012). Owing to both of these characteristics, it has been proposed to be the nucleus of an accreted dwarf galaxy (dGal; Majewski et al. 2000; Bekki \& Freeman 2003). Another Type II GC, M 54, is known to be the nucleus of the presently disrupting Sagittarius dGal (Ibata, Gilmore \& Irwin 1994, 1995). To explain the anomalous chemistry of Type II GCs, an extragalactic origin has been proposed for these GCs, be-it as the nuclei of accreted dGals or as a member of a GC system of an accreted dGal (Bekki 2012; Marino et al. 2015; Da Costa 2016; Marino et al. 2019a). To investigate this further, Milone et al. (2020) included information on the GCs dynamics and found that seven out of 13 (7/13) Type II GCs likely share a common origin (accreted as part of one event). One of the more famous Type II GCs that is not classi ed as accreted, is the massive GC M 22. Chemically, M 22 has often been compared to $\omega$-Cen given its large dispersion in metallicity (recently con rmed using differential abundance analysis, McKenzie et al. 2022) and heavy elements (Marino et al. 2011a) and yet it is rmly connected to the MW disc making accretion unlikely.

Among the least massive Type II GCs is NGC 362, which displays both a spread in metallicity ( $\sim 0.12$ dex) , detectable with low resolution spectroscopy (Husser et al. 2020), and a Ba-enhanced population of stars occupying a second red giant branch (RGB; Carretta et al. 2013). While a spread in slow neutron capture elements is likely, thus far no obvious spread in rapid neutron capture elements (namely Eu) has been detected (Worley \& Cottrell 2010). NGC 362 is also known to harbour at least two stellar populations and is unique among MSP-hosting GCs given that the older generation of stars is located in the central regions of the cluster (Lim et al. 2016). Despite its classi cation as a Type II, and unlike its more massive counterparts, NGC 362 is not considered a likely candidate to be the nucleus of an accreted dGal (Pfeffer et al. 2021). Although, an extragalactic origin for this GC could still be likely. We investigate this possibility in an upcoming companion paper.

The common companion to NGC 362 in the literature is the Type I GC NGC 288, which together with NGC 362, forms the canonical second parameter problem pair. The second parameter problem manifests as the appearance of distinctly different horizontal giant branch morphologies in the colour magnitude diagrams (CMDs) of nearly identical metallicity GCs. This is highlighted using the purple bounding boxes in Fig. 1 for NGC 288 (left) and NGC 362 (right). Chemically, in the study of Shetrone \& Keane (2000) NGC 288 was found to be slightly more metal-poor than NGC $362([\mathrm{Fe} / \mathrm{H}]=-1.39$ versus $[\mathrm{Fe} / \mathrm{H}]=-1.33$ ) and slightly more enhanced in $\mathrm{Al}, \mathrm{Na}$, and Ba. Like most GCs, NGC 288 is also known to host two populations of stars but without any clear difference in metallicity between the two (at $R \sim 18000$ ), as is expected for a Type I GC (Hsyu et al. 2014).

The primary aim of this study is to re-examine the chemical abundances within the two GCs, NGC 288 and NGC 362, at the 0.01 dex ( 2 percent) precision level. To do this we use the technique of differential abundance analysis to remove as many systematic sources of error as possible. Such measurements should thereby, (i)


Figure 1. Colour magnitude diagrams for the clusters, NGC 288 (left) and NGC 362 (right) created using cleaned catalogues from Stetson et al. (2019). The different horizontal giant branch morphology of the two clusters (characteristic of the second parameter problem) is highlighted by the purple bounding box in both clusters. The stars chosen for this study are highlighted in orange in both clusters.
provide new insight into the chemical homogeneity of each cluster and, (ii) reveal any unexpected elemental correlations which could be indicative of the cluster formation environment and/or internal evolution.

The paper is organized as follows. Section 2 describes the observational data set and analysis technique. Section 3 presents the recovered dispersion in each element, in the context of the element individually and as a member of a nucleosynthetic group. Correlations within each group are also explored in this section. Section 4 explores the unexpected correlations between elements not found in the same nucleosynthetic group. The unexpected correlations are then discussed in the context of cluster formation and evolution. Finally, Section 5 provides a summary of the major results and the conclusions of the paper.

## 2 OBSERVATIONS AND ANALYSIS

### 2.1 Target selection

We select a total of 14 stars from the original work of Shetrone \& Keane (2000) to reanalyse, six in NGC 288 and eight in NGC 362. These stars are shown in orange in Fig. 1 highlighting their locations near the tip of the RGB. ${ }^{1}$ As differential abundance analysis requires both high signal-to-noise ( $\mathrm{S} / \mathrm{N}$ ) and high resolution spectra, we select our sample from amongst the brightest stars in the original study and re-observe them using VLT/UVES ( $R \sim 110000$; Dekker et al. 2000). Example spectra for two of the program stars, NGC 288-344 and NGC 362-1401 are shown in Fig. 2 highlighting the Mgb lines at $\sim 5100^{-}$in the top panel and two Tii lines at $\sim 6554$ and $\sim 6556^{-}$ in the bottom panel, alongside $\mathrm{H} \alpha$ at $\sim 6562^{-}$.

The choice of stars in our study is also governed by the requirement that they act as approximate stellar siblings, meaning they span a

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Figure 2. Example spectra showing two regions of the VLT/UVES spectra for a sample star from each cluster and the reference star mg9. In the top panel, the Mgb lines are shown at 5167.3, 5172.7, and $5183.6^{-}$via the vertical dashed lines. The bottom panel highlights two Ti i lines at $\sim 6554$ and $\sim 6556^{-}$, alongside $\mathrm{H} \alpha$ at $\sim 6562^{-}$. The best- tting stellar parameters recovered via the method described in Section 2.3 are listed for the program stars. The stellar parameters for mg 9 are taken from Yong et al. (2013).
very small range in stellar parameters. The original stellar parameters derived by Shetrone \& Keane (2000) were used in the initial selection to ensure this. Note that we will refer to the effective temperature ( $T_{\text {eff }}$ ), surface gravity $(\log g)$, and metallicity (expressed as $[\mathrm{Fe} / \mathrm{H}]$ ) as the fundamental stellar parameters in this work. Observational information and characteristics of the stellar spectra are presented in Table 1, alongside the Gaia DR2/DR3 (Gaia Collaboration 2018, 2021) IDs and the membership probability as determined by Vasiliev \& Baumgardt (2021) using proper motions from Gaia EDR3 (Gaia Collaboration 2021).

### 2.2 Line list and equivalent width measurements

The line list to measure abundances was created by combining the line lists from the studies of Yong et al. (2013), Battaglia et al. (2017), and Ji et al. (2020) (and references therein). In the case of overlapping lines, priority was given to the more recent publication. Two additional species were added to the nal line list, Zr II (Roederer et al. 2018) and Sr I from NIST (Meggers, Corliss \& Scribner 1975). Hyper ne structure (HFS) corrections were applied to the $5853.67^{-}$, $6141.71^{-}$, and $6496.9^{-}$lines of Ba II, the 5303.53 ${ }^{-}$line of La II and the $6645.10^{-}$line of Eu II using linemake ${ }^{2}$ (Lawler, Bonvallet \& Sneden 2001a; Lawler et al. 2001b; Placco et al. 2021). To apply the HFS corrections, the additional transitions output from linemake were added to the input linelist.

Initial equivalent width (EW) measurements were made using the automated EW measurement software, DAOSpec (Stetson \& Pancino 2008). Secondary measurements were also made using REvIEW ${ }^{3}$ a PYTHON-based automated tool for EW measurements described in McKenzie et al. (2022). Initial cuts were made to only include lines with EW measurements in the range $[5,100] \mathrm{m}^{-}$as measured by DAOSpec. The two overlapping measurement sets were then compared for every line in common. To identify poor measurements in either method, lines were initially agged if the

[^2]standard deviation of the two measurements was greater than $5 \mathrm{~m}^{-}$. This proved a more conservative method than culling by using an arbitrary value of sigma.

Following initial ag assignments, the agged lines were then examined by hand using the splot routine within IRAF. ${ }^{4}$ The hand-measured value most often lay between the two automated measurement values and thus the mean value of the two was assigned as the nal EW. In the case that the values differed greatly from the hand-measured value, the hand-measured value was adopted. Finally, additional lines were added for elements with exclusively larger than $100 \mathrm{~m}^{-}$measurements (e.g. Ba II, Mn I, and V I).

A sample of EWs for several stars in the study, including the reference star (mg9, or B3169; Buonanno et al. 1986; Yong et al. 2013) discussed in the upcoming section, are given in Table C1. The full version of Table C1 is included with the online supplementary material.

### 2.3 Stellar parameter determination

Stellar parameters and abundances were determined using the PYTHON tool q2 (Ram•rez et al. 2014) in a two-step process. Using q2 to communicate to the 1D local thermodynamic equilibrium (LTE) radiative transfer code MOOG (Sneden 1973) and a set of $\alpha$-enhanced MARCS model atmospheres (Gustafsson et al. 2008), initial stellar parameters were found using the classical spectroscopic approach in a differential sense with respect to the reference star (Melendez et al. 2009). We do not consider departures from LTE in this study as the range of stellar parameters spanned by our program stars is small (a result of our choice of stellar siblings ). We select the same reference star as Yong et al. (2013) to perform our differential analysis, namely the star mg9 found near the tip of the RGB in NGC 6752. This choice was motivated by the similarities in stellar parameters between mg 9 and our program stars ( $T_{\text {eff }}=4288 \mathrm{~K}, \log g=0.91, \xi=1.72 \mathrm{~km} \mathrm{~s}^{-1}$, $[\mathrm{Fe} / \mathrm{H}]=-1.66)$, and to place the abundances on the same scale as the study of Yong et al. (2013).

The initial values of effective temperature ( $T_{\text {eff }}$ ) and microturbulence ( $\xi$ ) were found via minimizing the slopes of $\Delta^{\mathrm{FeI}}$ versus excitation potential and $\Delta^{\mathrm{FeI}}$ versus $\log$ (EW/wavelength), respectively. The differential abundance of $\mathrm{Fe}\left(\Delta^{\mathrm{Fel}}\right)$ is determined line by line as $\delta A_{\text {line }}=A_{\text {line }}^{\text {program star }}-A_{\text {line }}^{\mathrm{mg} 9}$ where $A$ is the abundance measurement associated with each line. An initial value of surface gravity $(\log g)$ was found via imposing ionization equilibrium between the $\Delta^{\mathrm{FeI}}$ and $\Delta^{\text {FeII }}$ abundances. Note that $\Delta^{\mathrm{X}}$ refers to the differential elemental abundance relative to the references star mg9 (here and throughout), and hence all excitation balances and ionization equilibria were achieved in a differential sense. Determining stellar parameters in this manner has been shown to provide accurate results (Nissen \& Gustafsson 2018).

As a starting point for the minimization process, the stellar parameters from Shetrone \& Keane (2000) were fed to q2. Preliminary step sizes of $\pm 200 \mathrm{~K}, \pm 0.5 \mathrm{~cm} \mathrm{~s}^{-2}$ and $\pm 0.5 \mathrm{~km} \mathrm{~s}^{-1}$ in $T_{\text {eff }}, \log g$, and micro-turbulence, respectively, were then selected for the initial exploration. q2 uses an iterative process to converge on the besttting stellar parameters by nding an initial minimum, re-sampling the atmospheric grid with a smaller step size surrounding the initial solution and then re-determining the best- tting stellar parameters.

[^3]Table 1. Target information for the fteen stars selected for re-analysis with VLT/UVES. Gaia IDs (Gaia Collaboration 2018, 2021) and membership probability as taken from Vasiliev \& Baumgardt (2021) are listed in the rst two columns. The total exposure time resulting from summing $N$ exposures is listed prior to the date the observation was collected, which is then followed by the total number of exposures. $V$-band magnitudes are taken from Shetrone \& Keane (2000; table 1, references listed therein).

| Star | Gaia ID | Mem. Prob. | $\begin{gathered} \text { RA } \\ {[\mathrm{J} 2000]} \end{gathered}$ | $\begin{gathered} \text { Dec. } \\ {[\mathrm{J} 2000]} \end{gathered}$ | V | Exp. Time [s] | Obs. Date | $N$ Im. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| NGC 288-20c | 2342903118077555840 | 1.0 | 00:52:43.30 | -26:36:57.09 | 12.96 | 6000.0 | July 15, 2005 | 2 |
| ... | ... | ... | ... |  | ... | ... | July 21, 2005 | $\ldots$ |
| NGC 288-281 | 2342904488170510592 | 0.99 | 00:52:58.46 | -26:36:06.12 | 13.27 | 9000.0 | Aug. 18, 2005 | 3 |
| NGC 288-287 | 2342907584843612416 | 1.0 | 00:52:46.67 | -26:35:08.10 | 14.72 | 15000.0 | Aug. 24, 2005 | 5 |
| ... | ... | $\ldots$ | ... | ... | ... | ... | Aug. 25, 2005 | ... |
| $\ldots$ | ... | ... | ... | ... | ... | $\ldots$ | Sept. 11, 2005 | ... |
| NGC 288-338 | 2342904763048460416 | 1.0 | 00:52:52.80 | -26:34:38.73 | 13.63 | 6000.0 | Sept. 15, 2005 | 2 |
| NGC 288-344 | 2342904732985400704 | 1.0 | 00:52:52.88 | -26:35:20.09 | 13.27 | 9000.0 | Aug. 18, 2005 | 3 |
| $\ldots$ | ... | $\ldots$ | $\ldots$ | ... | ... | $\ldots$ | Sept. 11, 2005 | $\ldots$ |
| NGC 288-351 | 2342904659969201024 | 1.0 | 00:52:52.51 | -26:36:04.03 | 13.54 | 9000.0 | Aug. 14, 2005 | 3 |
| NGC 362-1137 | 4690886864638749312 | 1.0 | 01:02:59.23 | -70:49:43.8 | 13.02 | 9000.0 | July 21, 2005 | 3 |
| $\ldots$ | ... | ... | ... | ... | ... | ... | Aug. 5, 2005 | ... |
| $\ldots$ | ... | ... | ... | ... | ... | ... | Aug. 20, 2005 | $\ldots$ |
| NGC 362-1334 | 4690839448199896704 | 1.0 | 01:03:38.19 | -70:52:00.6 | 12.77 | 9000.0 | Aug. 24, 2005 | 3 |
| ... | ... | ... | ... | ... | ... | ... | Aug. 26, 2005 | ... |
| $\cdots$ | $\ldots$ | $\ldots$ | $\ldots$ | ... | ... | ... | Sept. 11, 2005 | $\cdots$ |
| NGC 362-2127 | 4690839448199896704 | 1.0 | 01:02:37.12 | -70:50:33.0 | 12.95 | 9000.0 | July 20, 2005 | 3 |
| NGC 362-1401 | 4690839723077800320 | 0.99 | 01:03:36.08 | -70:50:50.9 | 12.63 | 6000.0 | Aug. 23, 2005 | 2 |
| NGC 362-1423 | 4690839791797273216 | 1.0 | 01:03:33.48 | -70:49:35.0 | 12.77 | 6000.0 | Aug. 23, 2005 | 2 |
| NGC 362-1441 | 4690886795919334912 | 1.0 | 01:03:22.52 | -70:48:38.7 | 12.72 | 6000.0 | Aug. 22, 2005 | 2 |
| NGC 362-77 | 4690886727199867904 | 1.0 | 01:03:25.04 | -70:49:56.2 | 12.72 | 9000.0 | Aug. 23, 2005 | 3 |
| ... | ... | ... | ... | ... | ... | ... | Aug. 24, 2005 | ... |
| NGC 362-MB2 | 4690886658480344320 | 1.0 | 01:03:07.53 | -70:49:43.7 | 12.94 | 6000.0 | Aug. 22, 2005 | 2 |

This process is continued until an absolute minimum is found, yielding the nal stellar parameters.

Using the initial stellar parameters determined via the process described above, preliminary $\mathrm{Fe}_{\mathrm{I}}$ and $\mathrm{Fe}_{\text {II }}$ abundances were found in both the absolute and differential sense. In the case of the reference star mg9, abundances were only determined in the absolute sense. This is described in more detail in the next section. The initial Fe I and Fe II abundances were then plotted as a function of wavelength to examine outliers. Initially, a $1.5 \sigma$ cull was performed to remove the bulk of the outliers. These lines were then visually examined to identify blended lines, poor continuum placement and/or inaccurate measurement of EW. Based on this they were remeasured, or removed from the line list for that star entirely.

Following the culling procedure, the second step in the process was performed by re-determining the stellar parameters via running the $1.5 \sigma$-culled linelist through q2. The initial stellar parameters determined during the rst round of minimization were used as the starting point for $q 2$ and the step sizes were reduced to $\pm 30 \mathrm{~K}$, $\pm 0.1 \mathrm{~cm} \mathrm{~s}^{-2}$ and $\pm 0.1 \mathrm{~km} \mathrm{~s}^{-1}$ in $T_{\text {eff }}, \log g$, and micro-turbulence, respectively. Formal error analysis was performed by q2 in a purely differential sense taking into account co-variances and following the approach of Epstein et al. (2010). The nal stellar parameters adopted for the remainder of the study are listed in Table 2, alongside the stellar parameters of the reference star.

Comparing our nal parameters to Shetrone \& Keane (2000), we
nd average absolute differences of $\Delta T_{\text {eff }}=30 \pm 21 \mathrm{~K}$ (NGC 288) and $\Delta T_{\text {eff }}=46 \pm 28 \mathrm{~K}(\mathrm{NGC} 362)$ in effective temperature, $\Delta \log g=$ $0.16 \pm 0.10 \mathrm{dex}$ (NGC 288) and $\Delta \log g=0.19 \pm 0.10 \mathrm{dex}$ (NGC 362) in surface gravity, $\Delta \xi=0.12 \pm 0.0 .10 \mathrm{~km} \mathrm{~s}^{-1}$ (NGC 288) and $\Delta \xi=0.21 \pm 0.16 \mathrm{~km} \mathrm{~s}^{-1}(\mathrm{NGC} 362)$ in microturbulence and nally,

Table 2. Final stellar parameters for the program stars in NGC 288 and NGC 362, respectively, (separated by the third horizontal line) derived using the process outlined in Section 2.3 and adopted for the remainder of the study. The differential uncertainties on the stellar parameters are also listed. The stellar parameters for the NGC 6752 reference star, mg9, taken from Yong et al. (2013) are also listed.

| Star | $T_{\text {eff }}$ <br> $(\mathrm{K})$ | $\log g$ <br> $\left(\mathrm{~cm} \mathrm{~s}^{-2}\right)$ | $\xi$ <br> $\left(\mathrm{km} \mathrm{s}^{-1}\right)$ | $[\mathrm{Fe} / \mathrm{H}]$ |
| :--- | :--- | :---: | :--- | :---: |
| 20 c | $4109 \pm 9$ | $0.76 \pm 0.05$ | $1.78 \pm 0.03$ | $-1.376 \pm 0.01$ |
| 281 | $4144 \pm 7$ | $0.86 \pm 0.06$ | $1.61 \pm 0.02$ | $-1.362 \pm 0.01$ |
| 287 | $4335 \pm 12$ | $1.18 \pm 0.05$ | $1.65 \pm 0.02$ | $-1.438 \pm 0.01$ |
| 338 | $4314 \pm 14$ | $1.28 \pm 0.06$ | $1.60 \pm 0.03$ | $-1.390 \pm 0.01$ |
| 344 | $4168 \pm 5$ | $0.95 \pm 0.06$ | $1.67 \pm 0.03$ | $-1.393 \pm 0.01$ |
| 351 | $4264 \pm 16$ | $1.13 \pm 0.05$ | $1.69 \pm 0.03$ | $-1.422 \pm 0.02$ |
| 403 | $3977 \pm 20$ | $0.55 \pm 0.05$ | $1.62 \pm 0.03$ | $-1.326 \pm 0.02$ |
| 1137 | $4071 \pm 20$ | $0.62 \pm 0.07$ | $1.76 \pm 0.05$ | $-1.243 \pm 0.02$ |
| 1334 | $4043 \pm 23$ | $0.62 \pm 0.07$ | $1.83 \pm 0.06$ | $-1.175 \pm 0.03$ |
| 2127 | $4124 \pm 14$ | $0.59 \pm 0.05$ | $1.85 \pm 0.04$ | $-1.271 \pm 0.02$ |
| 1401 | $3853 \pm 17$ | $0.32 \pm 0.14$ | $2.00 \pm 0.10$ | $-1.278 \pm 0.04$ |
| 1423 | $4046 \pm 15$ | $0.27 \pm 0.09$ | $2.14 \pm 0.07$ | $-1.301 \pm 0.02$ |
| 1441 | $3942 \pm 11$ | $0.41 \pm 0.10$ | $1.91 \pm 0.07$ | $-1.179 \pm 0.02$ |
| 77 | $4127 \pm 17$ | $0.50 \pm 0.07$ | $1.97 \pm 0.06$ | $-1.297 \pm 0.02$ |
| MB2 | $4085 \pm 12$ | $0.40 \pm 0.10$ | $2.59 \pm 0.12$ | $-1.328 \pm 0.02$ |
| mg9 | 4288 | 0.91 | 1.72 | -1.66 |

comparing the metallicity of our adopted atmospheric models to those of Shetrone \& Keane (2000), yields average differences of $\Delta[\mathrm{Fe} / \mathrm{H}]_{\text {model }}=0.05 \pm 0.03$ dex (NGC 288) and $\Delta[\mathrm{Fe} / \mathrm{H}]_{\text {model }}=$ $0.07 \pm 0.05$ dex (NGC 362).

Table 3. Average (differential) cluster abundances in the elements discussed in Section 3.1 ( $\Delta_{\text {ave }}^{X}$ ), along with the average measurement error in each element ( $\sigma_{\text {meas, ave }}$, the contribution from He is not included), the dispersion in the element within the cluster ( $\sigma \Delta^{\mathrm{X}}$ ) and the uncertainty on the dispersion ( $\sigma \Delta_{\text {error }}^{\mathrm{X}}$ ) as de ned in Section 3.1.1. Two measurements sets are given for NGC 362, the rst is without including the $s$-process enhanced star 1441 (no $s$-rich) and second, including 1441 ( $s$-rich).

and the scale of the dispersions in NGC 288 appearing more similar to NGC 6752. This is also apparent in Ti I, although to a lesser extent, where both cluster dispersions are considered genuine. Note that the larger uncertainty associated with the Ti measurements is likely due to the larger number of measured lines leading to increased scatter in this case. The lack of any signi cant spread in Ca in NGC 288 is in agreement with previous observations of narrow-band Ca photometry of the cluster (Lim et al. 2015).

When only considering $\mathrm{Ca}, \mathrm{Si}, \mathrm{Ti}$ I, and Ti II, the weighted average alpha element dispersion values ( $\Delta^{\alpha}-\Delta^{\mathrm{Fe}}$, analogous to $[\alpha / \mathrm{Fe}]$ ) in the two clusters are $\sigma_{\Delta^{\alpha / \mathrm{Fe}}}=0.02 \pm 0.006$ for NGC 288 and $\sigma_{\Delta^{\alpha / \mathrm{Fe}}}=$ $0.05 \pm 0.02$ for NGC 362. The uncertainties on the dispersion values are determined as described in Section 3.1.1. The average value of $\sigma_{\mathrm{ave}+\mathrm{He}}$ for the four $\alpha$-elements is 0.03 dex in NGC 288 and 0.04 dex in NGC 362. In the case of NGC 362, the average $\alpha$-element dispersion value is slightly larger than the uncertainty introduced by $\sigma_{\text {ave }+\mathrm{He}}(\sim 1.25 \times$ larger $)$. In the case of NGC 288, the spread can be explained by measurement errors and a He-spread alone. If the dispersion in NGC 362 is genuine, this is likely the rst detection of a spread which has been predicted (Marino et al. 2018) but previously undetected (Kovalev et al. 2019).

To evaluate the scale of our $\alpha$-element dispersion values, we can compare our values to the two lightest Type II GCs (both more massive than NGC 288), NGC $1261\left(M=1.82 \times 10^{5} \mathrm{M}_{\odot}\right)$ and NGC $6934\left(M=1.36 \times 10^{5} \mathrm{M}_{\odot}\right)($ Baumgardt \& Hilker 2018). Note that both are similar in metallicity to our two GCs [NGC $1261[\mathrm{Fe} / \mathrm{H}]$ $\sim-1.3$, NGC $6934[\mathrm{Fe} / \mathrm{H}] \sim-1.6$ Marino et al. (2021)]. Using the most recent abundance measurements from Marino et al. (2021) and the same $\alpha$-elements, we nd a dispersion of $\sigma_{[\alpha / \mathrm{Fe}]}=0.03 \pm 0.004$ in NGC 1261 and $\sigma_{[\alpha / \mathrm{Fe}]}=0.04 \pm 0.003$ in NGC 6934. Although the
average measurement errors are $\sim 0.10$ dex in both clusters, making it dif cult to conclude that the dispersion is real.

If the $\alpha$-dispersion is to be believed in the two clusters (which may not be the case for NGC 288), our values place NGC 362 well within the low-mass range of Type II GCs and NGC 288 not far outside the range despite being a Type I GC. In total we nd ve out of six (5/6, in $\mathrm{Na}, \mathrm{Al}, \mathrm{Si}, \mathrm{Ca}$, and Ti ) genuine dispersion measurements in the light and $\alpha$-elements in NGC 362 and three out of size ( $3 / 6$, in $\mathrm{Na}, \mathrm{Al}$, and Ti) in NGC 288. Of these dispersion measurements, the largest and smallest dispersions are $\sigma_{\Delta^{\mathrm{Na}}} \sim 0.25 \pm 0.08$ and $\sigma_{\Delta^{\mathrm{Si}}} \sim 0.01 \pm$ 004 in NGC 288 and $\sigma_{\Delta^{\mathrm{Na}}} \sim 0.21 \pm 0.06$ and $\sigma_{\Delta^{\mathrm{Mg}}} \sim 0.04 \pm 0.11$ in NGC 362, respectively.

Another interesting thing to note is the opposite direction of the trend in $\alpha$-element dispersion found within GCs versus dGals. Massive GCs display larger spreads in both light elements and $\alpha$ elements (e.g. $\omega$-Cen with a spread of 0.2 dex in Si , Johnson \& Pilachowski 2010), while massive dGals show small spreads in $\alpha$ elements compared to their less massive counterparts. For example, in the LMC (total mass, $M_{\mathrm{T}}=1.4 \times 10^{11} \mathrm{M}_{\odot}$, Erkal et al. 2019) $\sigma_{[\mathrm{S} / \mathrm{Fe]}} \sim 0.10$ over $\Delta[\mathrm{Fe} / \mathrm{H}]=0.2$ dex (Pompeia et al. 2008; Berg et al. 2015), while in the less massive dGal, Sculptor (total mass, $M_{\mathrm{T}}=3.4 \times 10^{8} \mathrm{M}_{\odot}$, Battaglia et al. 2008), $\sigma_{[\mathrm{Si} / \mathrm{Fe}]} \sim 0.3$ over $\Delta[\mathrm{Fe} / \mathrm{H}]=0.3$ dex (Hill et al. 2019). Note that the studies of Pompeia et al. (2008) and Hill et al. (2019) were both completed using the VLT/FLAMES spectrograph with comparable resolutions and $\mathrm{S} / \mathrm{N}(\sim 80)$. This trend in dGals has been proposed to be due to inhomogeneous mixing in low gas-mass environments and has been supported by simulations (Revaz \& Jablonka 2012). Beyond the light element variations, perhaps the heavy $\alpha$-element dispersion in GCs may also be distinct from dGals.
(viii) We nd at least two distinct $s$-process groups in NGC 362, separated by 0.3 dex in $\Delta^{\mathrm{Y}, \mathrm{Ba}, \mathrm{La}}$ and aided by the presence of an extremely $s$-process enhanced star.
(ix) Given both the presence of strong correlations between Al and several $s$-process elements, and a signi cant positive correlation between Mg Si in the $s$-process rich group, we hypothesize that the $s$-rich group is younger than the $s$-weak group. This is in agreement with enrichment scenarios from AGB stars, if there is overlap between low- and intermediate-mass AGB star enrichment.
(x) In NGC 288 a $3 \sigma$ or greater correlation is found between the $s$-process elements $\mathrm{Ba}, \mathrm{Nd}$, and Fe -peak elements Ni and Fe . This trend is also observed in the $s$-weak population in NGC 362.
(xi) The $s$-weak population is dominated by the $r$-process, displaying a $\Delta^{\mathrm{La}} \Delta^{\mathrm{Eu}}$ (analogous to [La/Eu]) ratio of $-0.16 \pm 0.06$. If the $s$-weak population truly represents an earlier epoch of star formation in NGC 362, this suggests a primordial origin for the $r$-process enrichment.

These results have signi cant implications for our understanding of globular cluster formation in the early Milky Way. In particular, our analysis provides evidence that NGC 288 and NGC 362 are chemically inhomogeneous in elements from all four nucleosythentic groups ( $\alpha$-elements, Fe-peak, $s$-, and $r$-process). By extension, we speculate that perhaps all GCs could be chemically inhomogeneous at the 0.02 dex level. Whether these inhomogeneities are primordial or the result of internal evolution remains to be seen. Regardless, these results act as a high-precision reproducible for theories of both Type I and II GC formation and place constraints on the level of (in)homogeneity in the ISM in the earliest dGal environments.

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## DATA AVAILABILITY

The data underlying this article are available in the article and online through provided links and supplementary material.

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## SUPPORTING INFORMATION

Supplementary data are available at MNRAS online.

## TableC1Complete.dat <br> TableC2Complete.dat TableC3Complete.dat

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## APPENDIX A: VERIFYING REFERENCE STAR CONSISTENCY

To perform our differential abundance analysis, we re-analysed the reference star mg9 from the study of Yong et al. (2013) following the procedure described in Section 2. A comparison of the recovered elemental abundances between studies (the difference between the two) is shown in Fig. A1. The large difference in Ba II abundances between the two studies can be partially explained by the lack of HFS corrections applied to the element in Yong et al. (2013). To investigate this we re-determined the Ba II abundance without applying HFS corrections and re-calculated the difference. Without HFS corrections, the difference between studies is shown as the red point, signi cantly reducing the tension between the two.


Figure A1. Absolute abundance differences measured in the reference star mg 9 for the elements in common between this study and Yong et al. (2013). Almost all elements show agreement within $1 \sigma$ with the exception of BaII, La II, and Eu II. This is likely due to the use of spectral synthesis in the original study for the elements La II and Eu II. In the case of Ba II, HFS corrections were applied in this study and not in Yong2013. The red marker shows the difference if HFS corrections are not applied. Note that the same stellar parameters were assumed for the reference star in both studies.

## APPENDIX B: ADDITIONAL CHEMICAL CORRELATIONS

Element correlations for each nucleosynthetic group as discussed in Section 3.2 are shown for the $\alpha$-elements (both clusters: Fig. B1), the Fe-peak elements (NGC 288: Fig. B2, NGC 362: Fig. B3) and heavy elements (NGC 288: Fig. B4, NGC 362: Fig. B5). Chemical correlations for all possible element correlations in the two $s$-process groups in NGC 362 are shown in Fig. B6. the $s$-rich group is shown in the topmost panel and $s$-weak group below. Interpretations of the interesting and unexpected correlations are discussed in Section 4.1 and subsequent sections.


Figure B1. $\alpha$-element correlations coloured by statistical signi cance for NGC 288 (left) and NGC 362 (right).


Figure B2. Fe-peak element correlations coloured by statistical signi cance for NGC 288.


Figure B3. Fe-peak element correlations coloured by statistical signi cance for NGC 362.


Figure B4. $s$ - and $r$-process element correlations coloured by statistical signi cance for NGC 288.


Figure B5. $s$ - and $r$-process element correlations coloured by statistical signi cance for NGC 362.


Figure B6. Same as Fig. 10 for the two $s$-process groups in NGC 362. The $s$-process rich group is shown on the top and the $s$-process weak group on the bottom. Note that only in the $s$-process rich group are the $s$-process elements $\mathrm{Ce}, \mathrm{Ba}$, and Y found to correlate with the light element Al indicating enrichment via AGB stars as a natural consequence of GC evolution. The lack of correlation between the $s$-process weak group and the light element Al supports primordial enrichment in $s$-process elements within the protocluster environment.

## APPENDIX C: EQUIVALENT WIDTHS AND STELLAR ABUNDANCES

Table C1 lists a sample of EW measurements for all stars in this study, including the reference star mg9. A description of how the lines are measured and which lines are included for the nal analysis
is given in Section 2.2. A sample of abundances measurements for select stars in NGC 288 and NGC 362 are given in Tables C2 and C3, respectively. Full tables are included in the online material.

Table C1. Sample of the equivalent widths measured for the stars in this study and used in the determination of differential abundances. Lines for the reference star, mg 9 are also included. A description of the measurement methodology and choice of lines to include is given in Section 2.2.

| Wavelength ( ${ }^{-}$) | Element | $\begin{gathered} \chi \\ (\mathrm{eV}) \end{gathered}$ | $\log g f$ | $\begin{aligned} & \mathrm{mg} 9 \\ & \left(\mathrm{~m}^{-}\right) \end{aligned}$ | $\begin{gathered} \text { NGC } 288-281 \\ \left(\mathrm{~m}^{-}\right) \end{gathered}$ | $\begin{gathered} \text { NGC } 288-287 \\ \left(\mathrm{~m}^{-}\right) \end{gathered}$ | $\begin{gathered} \text { NGC } 288-338 \\ \left(\mathrm{~m}^{-}\right) \end{gathered}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 6363.78 | 8.0 | 0.02 | $-10.3$ | 11.1 | 26.6 | 10.3 | 19.3 |
| 5682.63 | 11.0 | 2.1 | -0.71 | 56.6 | 64.9 | 80.9 | 56.1 |
| 5688.2 | 11.0 | 2.1 | -0.41 | ... | 90.7 | ... | $\ldots$ |
| 6154.226 | 11.0 | 2.1 | - 1.547 | 13.7 | 16.3 | 27.1 | 13.5 |
| 6160.747 | 11.0 | 2.1 | - 1.246 | 25.6 | 32.4 | 43.0 | 24.1 |
| 5528.4 | 12.0 | 4.35 | -0.5 | 170.6 | 197.3 | 170.1 | 195.3 |
| 5711.09 | 12.0 | 4.34 | - 1.72 | 84.2 | 113.5 | 98.9 | 98.3 |
| 6698.673 | 13.0 | 3.14 | - 1.647 | 17.2 | 19.6 | 20.2 | 14.3 |
| 5645.613 | 14.0 | 4.93 | -2.14 | 14.8 | ... | 23.1 | 22.0 |
| 5665.55 | 14.0 | 4.92 | -2.04 | 16.6 | 27.0 | ... | 25.6 |
| 5684.48 | 14.0 | 4.95 | - 1.42 | ... | ... | 32.1 | ... |
| 5690.43 | 14.0 | 4.93 | - 1.87 | 22.3 | 34.3 | 32.5 | 36.4 |
| 5701.1 | 14.0 | 4.93 | $-2.05$ | 16.9 | 26.9 | 24.9 | 26.6 |
| 5948.55 | 14.0 | 5.08 | -1.23 | 47.5 | 60.9 | 65.8 | 61.5 |
| 6142.49 | 14.0 | 5.62 | - 1.48 | 9.6 | ... | 14.9 | ... |
| 6155.14 | 14.0 | 5.62 | -0.86 | 29.7 | 40.0 | 42.0 | 43.7 |
| 6237.33 | 14.0 | 5.62 | - 1.08 | 20.3 | 29.6 | 31.2 | 29.1 |
| 6243.814 | 14.0 | 5.62 | - 1.244 | 13.1 | ... | 20.7 | 22.8 |
| 6244.465 | 14.0 | 5.62 | - 1.091 | $\ldots$ | ... | 21.1 | ... |
| 6721.84 | 14.0 | 5.86 | -0.94 | 14.2 | ... | 20.8 | 18.8 |
| ... | ... | ... | $\ldots$ | ... | $\ldots$ | ... | ... |

Table C2. Sample of the stellar abundances for the GC NGC 288 determined following the methodology described in Section 2.4. All abundances listed are quoted in a differential sense relative to the reference star mg 9 . The abundances listed for mg 9 are absolute abundances.

| Element | $N$ | mg9 | $\sigma$ | $N$ | NGC 288-281 | $\sigma$ | $N$ | NGC 288-287 | $\sigma$ | $N$ | NGC 288-338 | $\sigma$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| NaI | 3 | 4.895 | 0.025 | 4 | $-0.034$ | 0.015 | 3 | 0.358 | 0.018 | 3 | $-0.036$ | 0.016 |
| Mg I | 2 | 6.351 | 0.014 | 2 | 0.279 | 0.142 | 2 | 0.134 | 0.139 | 2 | 0.225 | 0.036 |
| Al I | 1 | 5.303 | ... | 1 | $-0.068$ | 0.007 | 1 | 0.097 | 0.011 | 1 | $-0.105$ | 0.013 |
| Si I | 10 | 6.230 | 0.036 | 6 | 0.335 | 0.009 | 11 | 0.298 | 0.013 | 9 | 0.318 | 0.019 |
| CaI | 12 | 5.037 | 0.036 | 3 | 0.248 | 0.013 | 7 | 0.226 | 0.021 | 6 | 0.269 | 0.027 |
| Sc II | 1 | 1.408 | ... | 1 | 0.440 | 0.019 | 1 | 0.446 | 0.021 | 1 | 0.413 | 0.026 |
| Til | 39 | 3.550 | 0.068 | 18 | 0.309 | 0.017 | 33 | 0.198 | 0.026 | 23 | 0.286 | 0.028 |
| Ti II | 10 | 3.574 | 0.051 | 5 | 0.261 | 0.016 | 10 | 0.179 | 0.027 | 7 | 0.233 | 0.026 |
| V I | 1 | 2.339 | ... | 0 | ... | ... | 1 | 0.279 | 0.030 | 1 | 0.403 | 0.038 |
| Cri | 4 | 3.915 | 0.054 | 3 | 0.221 | 0.035 | 4 | 0.200 | 0.028 | 3 | 0.239 | 0.031 |
| CriI | 2 | 4.127 | 0.003 | 2 | 0.301 | 0.132 | 2 | 0.155 | 0.030 | 2 | 0.211 | 0.080 |
| MnI | 3 | 3.503 | 0.029 | 0 | ... | ... | 2 | 0.374 | 0.131 | 2 | 0.445 | 0.234 |
| Fel | 130 | 5.849 | 0.093 | 97 | 0.250 | 0.008 | 105 | 0.191 | 0.013 | 105 | 0.231 | 0.015 |
| Fe II | 15 | 5.770 | 0.032 | 16 | 0.263 | 0.026 | 14 | 0.213 | 0.027 | 13 | 0.251 | 0.033 |
| CoI | 2 | 3.504 | 0.236 | 1 | 0.279 | 0.009 | 2 | 0.194 | 0.018 | 1 | 0.285 | 0.015 |
| Ni I | 43 | 4.524 | 0.107 | 23 | 0.298 | 0.011 | 38 | 0.237 | 0.018 | 31 | 0.291 | 0.014 |
| CuI | 1 | 2.416 | ... | 1 | 0.844 | 0.025 | 1 | 0.383 | 0.027 | 1 | 0.653 | 0.035 |
| ZnI | 1 | 2.951 | ... | 1 | $-0.051$ | 0.010 | 1 | 0.179 | 0.016 | 1 | 0.144 | 0.019 |
| Sr I | 1 | 3.548 | ... | 1 | 0.111 | 0.012 | 1 | 0.102 | 0.016 | 1 | 0.184 | 0.020 |
| Y II | 8 | 0.582 | 0.096 | 5 | 0.467 | 0.047 | 7 | 0.296 | 0.030 | 7 | 0.402 | 0.031 |
| Zr II | 1 | 1.446 | $\ldots$ | 1 | 0.325 | 0.018 | 1 | 0.355 | 0.018 | 1 | 0.420 | 0.023 |
| BaII | 3 | $-0.175$ | 0.049 | 3 | 0.343 | 0.042 | 3 | 0.194 | 0.039 | 3 | 0.386 | 0.035 |
| La II | 3 | $-0.627$ | 0.074 | 2 | 0.357 | 0.058 | 2 | 0.303 | 0.035 | 2 | 0.395 | 0.029 |
| Ce II | 3 | -0.080 | 0.057 | 3 | 0.376 | 0.040 | 2 | 0.340 | 0.018 | 3 | 0.444 | 0.043 |
| Nd II | 11 | $-0.025$ | 0.044 | 4 | 0.400 | 0.020 | 11 | 0.277 | 0.023 | 8 | 0.395 | 0.030 |
| Sm II | 1 | -0.438 | ... | 1 | 0.523 | 0.016 | 1 | 0.358 | 0.017 | 0 | ... | $\ldots$ |
| Eu II | 1 | - 1.240 | ... | 1 | 0.401 | 0.020 | 1 | 0.370 | 0.020 | 1 | 0.433 | 0.025 |

Table C3. Same as Table C2, for the GC NGC 362.

| Element | $N$ | mg9 | $\sigma$ | $N$ | $\begin{gathered} \text { NGC } \\ 362-1137 \end{gathered}$ | $\sigma$ | $N$ | NGC 362-1334 | $\sigma$ | $N$ | $\begin{gathered} \text { NGC } \\ 362-2127 \end{gathered}$ | $\sigma$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| NaI | 3 | 4.895 | 0.025 | 4 | $-0.074$ | 0.033 | 3 | $-0.022$ | 0.035 | 3 | 0.361 | 0.028 |
| Mg I | 2 | 6.351 | 0.014 | 2 | 0.270 | 0.088 | 2 | 0.241 | 0.144 | 2 | 0.275 | 0.050 |
| Al I | 1 | 5.303 | ... | 1 | $-0.329$ | 0.018 | 1 | $-0.181$ | 0.021 | 1 | 0.200 | 0.013 |
| Si I | 10 | 6.230 | 0.036 | 7 | 0.286 | 0.023 | 7 | 0.324 | 0.027 | 8 | 0.255 | 0.018 |
| CaI | 12 | 5.037 | 0.036 | 4 | 0.295 | 0.030 | 3 | 0.319 | 0.032 | 5 | 0.216 | 0.024 |
| Sc II | 1 | 1.408 | .. | 1 | 0.508 | 0.037 | 1 | 0.546 | 0.038 | 1 | 0.401 | 0.029 |
| Til | 39 | 3.550 | 0.068 | 18 | 0.368 | 0.039 | 14 | 0.377 | 0.046 | 23 | 0.218 | 0.029 |
| Ti II | 10 | 3.574 | 0.051 | 4 | 0.297 | 0.035 | 4 | 0.363 | 0.037 | 5 | 0.175 | 0.026 |
| V I | 1 | 2.339 | $\ldots$ | 1 | 0.822 | 0.066 | 1 | 0.946 | 0.085 | 1 | 0.453 | 0.040 |
| Cri | 4 | 3.915 | 0.054 | 2 | 0.305 | 0.042 | 2 | 0.348 | 0.043 | 3 | 0.209 | 0.052 |
| Cr II | 2 | 4.127 | 0.003 | 2 | 0.472 | 0.097 | 1 | 0.392 | 0.038 | 1 | 0.457 | 0.029 |
| MnI | 3 | 3.503 | 0.029 | 3 | 1.314 | 0.249 | 3 | 1.367 | 0.185 | 3 | 0.884 | 0.124 |
| Fei | 130 | 5.849 | 0.093 | 77 | 0.371 | 0.017 | 74 | 0.421 | 0.020 | 72 | 0.359 | 0.012 |
| Fe II | 15 | 5.770 | 0.032 | 14 | 0.366 | 0.055 | 13 | 0.421 | 0.059 | 15 | 0.341 | 0.042 |
| CoI | 2 | 3.504 | 0.236 | 1 | 0.363 | 0.017 | 1 | 0.404 | 0.019 | 1 | 0.310 | 0.013 |
| Ni I | 43 | 4.524 | 0.107 | 24 | 0.325 | 0.020 | 24 | 0.384 | 0.024 | 27 | 0.307 | 0.017 |
| CuI | 1 | 2.416 | ... | 1 | 0.796 | 0.065 | 1 | 0.299 | 0.066 | 1 | 0.576 | 0.048 |
| ZnI | 1 | 2.951 | ... | 0 | ... | ... | 1 | 0.252 | 0.038 | 1 | 0.124 | 0.025 |
| Sri | 1 | 3.548 | ... | 1 | 0.051 | 0.030 | 1 | 0.073 | 0.034 | 0 | ... | ... |
| Y II | 8 | 0.582 | 0.096 | 3 | 0.309 | 0.030 | 2 | 0.501 | 0.031 | 3 | 0.247 | 0.053 |
| Zr II | 1 | 1.446 | ... | 1 | 0.269 | 0.028 | 1 | 0.388 | 0.029 | 1 | 0.281 | 0.022 |
| Ba II | 3 | 0.099 | 0.396 | 2 | 0.440 | 0.041 | 2 | 0.573 | 0.048 | 2 | 0.479 | 0.074 |
| La II | 3 | $-0.627$ | 0.074 | 3 | 0.426 | 0.032 | 3 | 0.530 | 0.045 | 3 | 0.404 | 0.042 |
| Ce II | 3 | $-0.080$ | 0.057 | 2 | 0.376 | 0.033 | 2 | 0.339 | 0.080 | 2 | 0.338 | 0.031 |
| Nd II | 11 | $-0.025$ | 0.044 | 5 | 0.538 | 0.039 | 5 | 0.688 | 0.065 | 6 | 0.463 | 0.038 |
| Sm II | 1 | $-0.438$ | ... | 0 | ... | ... | 0 | ... | ... | 0 | ... | ... |
| Eu II | 1 | $-1.240$ | ... | 1 | 0.563 | 0.032 | 1 | 0.725 | 0.035 | 1 | 0.592 | 0.027 |

This paper has been typeset from a $\mathrm{T}_{\mathrm{E}} \mathrm{X} / \mathrm{EA} \mathrm{T}_{\mathrm{E}} \mathrm{X}$ le prepared by the author.


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[^1]:    ${ }^{1}$ Although a fascinating subject, we want to avoid investigating the phenomena of MSPs in our clusters. Cross-matching with the catalogues of Piotto et al. (2015), resulted in HST UV photometry for only two of our NGC 362 stars and three of our NGC 288 stars. Stars in both clusters appeared to occupy the same region of each cluster s chromosome map.

[^2]:    ${ }^{2}$ https://github.com/vmplacco/linemake
    ${ }^{3}$ https://github.com/madeleine-mckenzie/REvIEW

[^3]:    ${ }^{4}$ IRAF is distributed by the National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy (AURA) under cooperative agreement with the National Science Foundation.

