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The Gaia-ESO Survey: Detailed Abundances in the Globular Cluster NGC 4372

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Abstract

We present the abundance analysis for a sample of 7 red giant branch stars in the metal-poor globular cluster NGC 4372 based on UVES spectra acquired as part of the Gaia-ESO Survey. We derive abundances of O, Na, Mg, Al, Si, Ca, Sc, Ti, Fe, Cr, Ni Y, Ba, La. We find a metallicity of [Fe/H] = -2.19 $\pm$ 0.03 and find no evidence for a metallicity spread. This metallicity makes NGC 4372 one of the most metal-poor galactic globular clusters. We also find an α-enhancement typical of halo globular clusters at this metallicity. Significant spreads are observed in the abundances of light elements. We confirm the presence of the Na-O anti correlation. Abundances of Na and O follow the general GCs trend, although at the high [O/Fe] and [Na/Fe] end with one star with very high Na content. This could indicate that NGC 4372 was formed in an environment with high Na and O for its metallicity. More unusual is the Mg-Al anti correlation which spans a range of more than 0.5 dex in Al abundances. Mg is also anti-correlated with Na and Si abundances at a lower significance level. This pattern suggests the action of nuclear processing at unusually high temperatures. This behavior can also be seen in giant stars of other massive, metal-poor clusters.

1 Introduction

Spectroscopy (starting several decades ago) and more recently photometry have shown that globular clusters are much more complex than previously imagined, in particular with the almost ubiquitous discovery of multiple populations. None of the scenarios proposed to date can fully account for the abundance trends observed in Galactic Globular Clusters (GGCs). Detailed chemical studies of large samples of GGCs are required to uncover the evolution of these objects. Providing high quality data on more GCs is clearly needed to strengthen any conclusion. We present here, the first ever high-resolution spectroscopic analysis of the globular cluster NGC 4372 based on observations from the Gaia-ESO survey (GES).

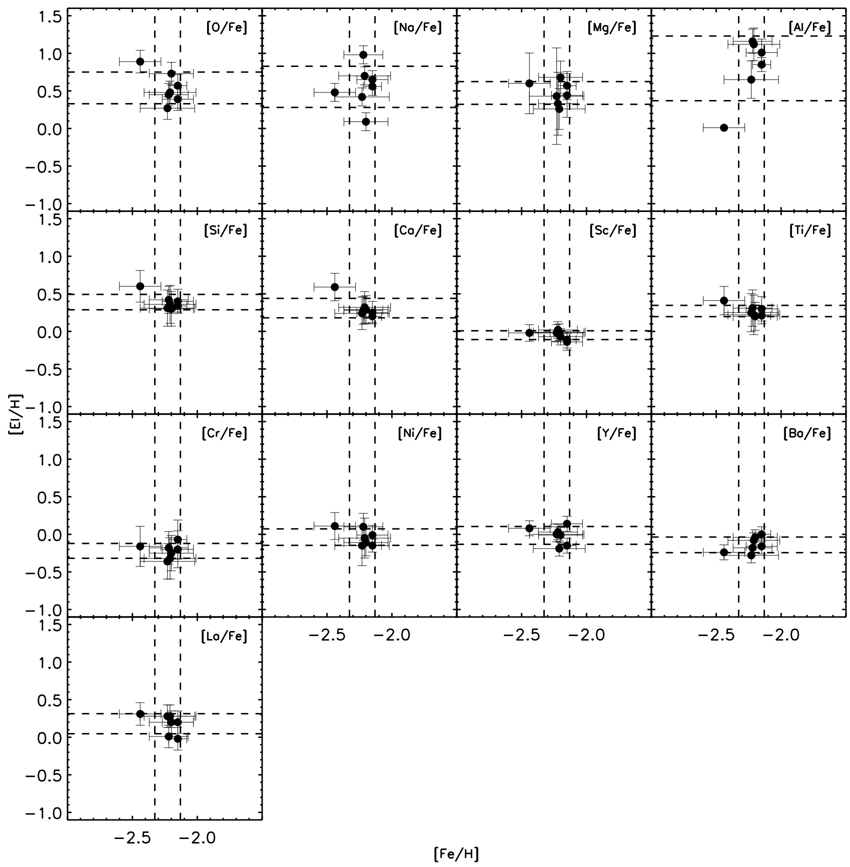

Figure 1: Abundance ratios versus [Fe/H] for individual members of the cluster. The dashed lines indicate the 1σ area around the average value.

The GES is a public spectroscopic survey using the high-resolution multi-object spectrograph FLAMES on the Very Large Telescope [5]. Targeting more than 10^5 stars, GES will provide the first homogeneous overview of the distribution of kinematics and elemental abundances. The survey also maps a significant sample of more than 80 open clusters, covering all the accessible cluster ages and stellar masses. The GES includes GGCs as calibrators, adding some relatively unstudied clusters to the ones already present in the ESO archive. Within this context, this study is focused on the chemical abundances of NGC 4372. With limited spectroscopic data, little is known about any possible abundance variations of this metal-poor halo cluster. We present here an abundance analysis of a large number of elements (eg. light elements, alpha-elements, iron peak elements and neutron capture elements), analyze its stellar population and study the chemical evolution of the cluster.

2 Observational Data

GES consortium is structured in several working groups, WGs, having specific duties from target selection and data reduction to delivery of science data. A detailed description of the data reduction method can be found in [13]. Chemical abundances were computed by 13 different Nodes within the WG11. The abundances were performed using different methodologies. This strategy has two main advantages: 1) quantification and qualification of all sources of errors, including any method-dependent effects, 2) proper analysis of all types of objects, including special treatment if required. The final recommended values distributed by GES are used in this study. We refer the reader to [16] for a detailed description of the abundance analysis. GES provides chemical abundances for Na, Mg, Al, Si, Ca, Ti, Fe, Cr, and Ni for the seven stars in our sample. To complete the analysis and include key elements we have also obtained the abundances of O, Sc, Y, Ba, and La. For this set of elements whose lines are affected by blending, we have used the spectrum-synthesis method. We calculated 5 synthetic spectra having different abundances for each line, and estimated the best-fitting value as the one that minimizes the RMS scatter. Only lines not contaminated by telluric lines were used. All the spectrum-synthesis values were obtained using the astrophysical parameters recommended by GES. In addition, the Na abundance was recomputed and a non-LTE correction was applied based on [10].

3 Abundance Analysis

A large body of evidence now shows that the stars in a globular clusters do not share the same initial chemical composition [6]. As a general rule we can define a globular cluster as an object homogeneous in its Fe content and most other heavy elements, but the light elements Li, C, N, O, Na, Mg and Al can show substantial intracluster variations.

Figure 1 shows the abundance ratios versus [Fe/H] for individual member stars in the cluster. One star stands out as slightly metal poorer than the main body of cluster members. The radial velocity and stellar parameters for this object are in agreement with those of the rest of observed stars but the distinct chemical pattern of this star suggests wither that it has some kind of anomaly or it may not be a member. However, given its spatial location, velocity, position in the CMD and low metallicity, its seems very unlikely that this is a field star. [8] show that according to the prediction of the Besancon Galactic model, only a few field stars with that velocity are expected in the direction of NGC 4372 where none of them is more metal-poor than -1.8 dex. To be cautious and conservative, we exclude this star from the analysis. One can consider inhomogeneity when the intrinsic scatter is significantly higher than the expected dispersion given by the average errors. A clear spread can be identified only in Na and Al. A smaller scatter is shown by Mg.

Figure 1 shows no evidence for an intrinsic Fe abundance spread with the exception of our peculiar star. The issue of intrinsic metallicity spreads in GGCs is of great current interest. Such spreads are found generally only in the most luminous GGCs, with $M_V \leq$ -8.5. NGC 4372 has M_V = -7.8 so it is unlikely to host an intrinsic Fe abundance spread. However, we do note that [4] did find one of their sample of 11 stars to be significantly (about

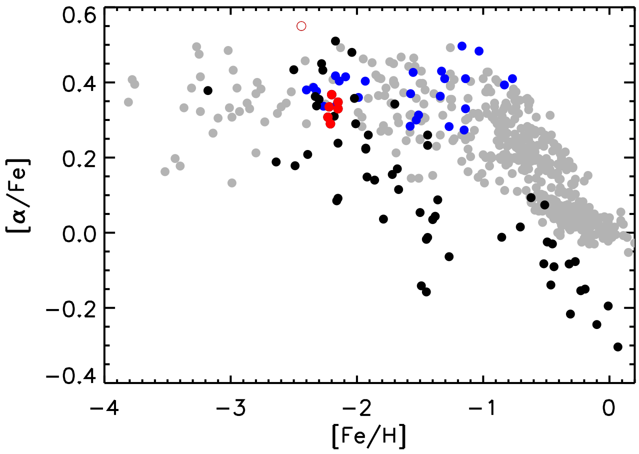

Figure 2: Mean α-element abundance versus [Fe/H]. Red symbols correspond to values from NGC 4372 from the present study where the open red symbol corresponds to the peculiar star. Blue symbols are GGCs [1]. Gray symbols are halo and disk stars [3, 11, 12] while black symbols correspond to extragalactic objects [14, 15, 7, 9].

0.5 dex) more metal-poor than the rest. This star, like our peculiar star, also had a velocity compatible with membership. Excluding the peculiar star, we found a mean [Fe/H] value of:

$$[\mathrm{Fe/H}] = -2.19 \pm 0.03$$

Our observed scatter is consistent with that expected from errors and thus we conclude that there is no clear metallicity spread in NGC 4372.

All the α elements analyzed (Mg, Si, Ca, Ti) are overabundant relative to the Sun. This is a common feature among almost every GC as well as among similarly metal-poor halo field stars in the Galaxy. Figure 2 represents the [α/Fe] versus [Fe/H] relation. The peculiar star stands out from the cluster behavior, suggesting once again the singularity of this star. Excluding this star, we derive for NGC 4372 a mean α element abundance of:

$$[\alpha/Fe] = 0.33 \pm 0.03$$

NGC 4372 falls in a region where both Galactic and extraGalactic objects overlap in their α element content so it is not possible to draw conclusions regarding its origin from this diagram.

4 Na-O and Mg-Al anticorrelation

The Na-O anti correlation is the classical signature of the process of proton-capture reactions in H-burning at high temperature in a previous generation of stars. Almost all GGCs studied

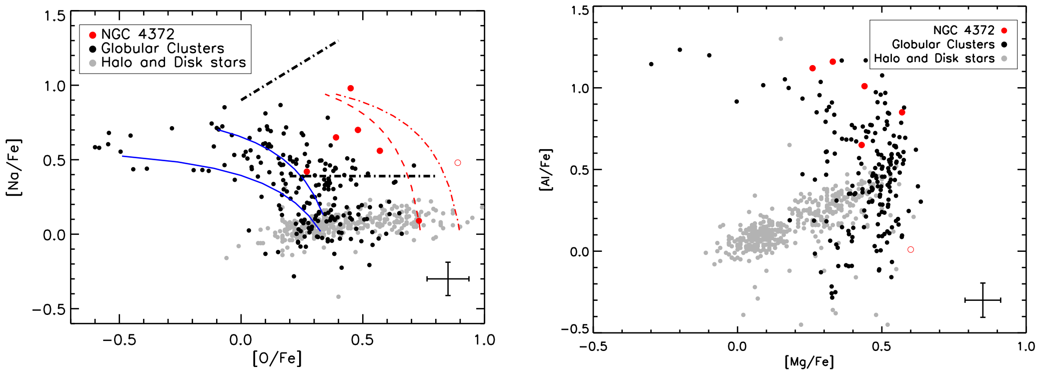

Figure 3: *Left-Panel*: [O/Fe] vs [Na/Fe]. Red symbols correspond to values from the present study while the red open symbol corresponds with the peculiar star. Black symbols are GGCs while gray symbols are halo and disk stars. The blue solid lines represent the dilution models determined by [2] from the stars in NGC 6121 and NGC 2808. The dash-dotted red line represents the dilution model for all the stars in our sample while the dashed red line excludes the peculiar star. The dash-dotted black lines are the empirical separations into P, I and, E populations according to [2]. *Right-Panel*: [Mg/Fe] vs [Al/Fe]. Symbols are as in previous figure.

in detail to date shown this feature. Figure 3 (left panel) shows the Na-O abundances in the stars of our sample. In addition, two distinct Na-O anticorrelations have been over plotted as red solid lines, which correspond with the dilution models determined by [2]. One is O richer and is represented by the trend of the stars in NGC 6121 while the other is O poorer and is represented by the trend of the stars in NGC 2808. NGC 4372 stars have a clear intrinsic dispersion and anti-correlation. Its stars inhabit an area in the figure that follow the general GCs trend, although our sample lies at the high [O/Fe] and [Na/Fe] end with one star with very high Na content. Although the small number of stars does not allow us to perform a proper statistical analysis, some different characteristics can be identified among our sample. One star of Na-poor/O-rich, which corresponds to the putative primordial stellar component, while a group of Na-rich/O-poor stars would be associated with a second generation of stars. Our sample does not seem to show any star with very large O-depletion, resembling the behavior of other metal-poor clusters as NGC 7078 (M15), NGC 7099 or NGC 4590 [2].

An apparent anti correlation can also be identified between [Mg/Fe] and [Al/Fe] in NGC 4372 (Figure 3, right panel). The Mg-Al relation presents similar features to the ones found in previous studies [1]. The star-to-star variations in the Al abundances is limited to a range of ~ 0.5 dex (excluding the peculiar star). On the other hand, star-to-star variations in the Mg abundances are smaller. The correlation detected among stars of NGC 4372 follows the behavior displayed by GGC stars with a clear distinction from disk and halo field stars. [1] show that Al-rich and Mg-depleted stars are present only in massive clusters (NGC 2808, NGC 6388, NGC 6441), metal-poor clusters (NGC 6752) or both (NGC 7078 = M15).

5 Summary and Conclusion

We present detailed chemical abundances of 14 elements in 7 red giant members of NGC 4372 using high resolution, high S/N spectroscopy. Chemical abundances have been computed by different techniques and methods within the GES collaboration. For 6 elements not provided by GES, we have used the spectrum-synthesis method. We found a metallicity of [Fe/H]= -2.19 $\pm$ 0.02 with a σ_{obs} = 0.03 dex, in good agreement with the most updated studies. We rule out an intrinsic metallicity spread. We confirm the Na-O anti correlation although not very extended, probably due to our small sample. The abundances of Na and O are slightly higher compared with other globular clusters which could indicate that NGC 4372 was formed in an environment with high Na and O for its metallicity. Intrinsic spreads are also seen in other light elements, in particular an apparent anti correlation can also be identified between [Mg/Fe] and [Al/Fe]. The alpha elements show an enhancement of [α/Fe]= 0.33 $\pm$ 0.03 typical of other GCs indicating similar fast star formation time scales.

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