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Authors	SANNA, Nicoletta; FRANCIOSINI, Elena; PANCINO, ELENA; Mucciarelli, A.
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Lithium abundances in globular clusters

N. Sanna[1], E. Franciosini[1], E. Pancino[1,2], and A. Mucciarelli[3]

[1] Istituto Nazionale di Astrofisica – Osservatorio Astrofisico di Arcetri, Largo E. Fermi 5, 50125 Firenze, Italy, e-mail: `nicoletta.sanna@inaf.it`
[2] Space Science Data Center, ASI, Via del Politecnico snc, 00133 Roma, Italy
[3] Dipartimento di Fisica e Astronomia, Università degli Studi di Bologna, Via Gobetti 93/2, 40129 Bologna, Italy

Abstract. Lithium is created during the Big Bang nucleosynthesis and it is destroyed in stellar interiors at relatively low temperatures. However, it should be preserved in the stellar envelopes of unevolved stars and progressively diluted during mixing processes. In particular, after the first dredge-up along the RGB, lithium should be completely destroyed, but this is not what we observe today in globular clusters. This element allows to test stellar evolutionary models, as well as different types of polluters for second population stars in the multiple population scenarios. Due to the difficulty in the measurement of the small available lithium line, few GCs have been studied in details so far. Literature results are not homogeneous for what concerns type of stars, sample sizes, and chemical analysis methods. The Gaia-ESO survey allows us to study the largest sample of GCs stars (about 2000, both dwarfs and giants) for which the lithium has been analysed homogeneously.

Key words. Stars: abundances – Galaxy: globular clusters

1. Introduction

Lithium (Li) is one of the elements created during the Big Bang nucleosynthesis and it is destroyed in the stellar interiors at relatively low temperatures ($\sim 2.5\text{x}10^6 K$). However, it should be preserved in the stellar envelopes of unevolved stars and diluted by diffusion and mixing processes.

The study of Li abundance in globular clusters (hereafter GCs), among the oldest objects in the Galaxy, allows investigating the cosmic lithium problem and provides important information on stellar evolution and mixing processes and on the formation of multiple populations. Few GCs have been investigated so far in detail, and different evolutionary phases have been considered, but the emeriging scenario is complex. In general, the dwarf stars share the same lithium abundance, $A(Li) \sim 2.2$ dex as found by Spite & Spite (1982a); Spite & Spite (1982b), forming the so called Spite plateau. During the sub-giant branch phase diffusion processes dilute Li, as well as mixing during the first dredge-up process in the red giant branch (hereafter RGB). However, Mucciarelli et al. (2012) found that stars above the first dredge-up and below the RGB bump form another plateau at about $A(Li) \simeq 1.0$ dex, while after the bump Li is diluted again.

The above framework is further complicated by the phenomenon of multiple populations in globular clusters. In fact, in some clusters (e. g., NGC 362) first and second population stars have the same Li abundance, while

Table 1. GCs included in GES, with the main evolutionary phases covered by the members sample.

Cluster	Phase	Cluster	Phase	Cluster	Phase
M12	RGB, AGB	M15	RGB, AGB	M2	RGB, AGB
NGC104	MS, RGB, AGB	NGC362	RGB, AGB	NGC1261	RGB, AGB
NGC1851	RGB, AGB	NGC1904	RGB, AGB	NGC2808	RGB, AGB
NGC4372	RGB, AGB	NGC4590	RGB, AGB	NGC4833	RGB, AGB
NGC5927	RGB, AGB	NGC6553	RGB, AGB	NGC6752	MS, RGB, AGB

in others (e. g., NGC 6752) they do not, and in the case of ω Cen, both behaviors are observed at the same time (see Mucciarelli et al. 2018, and reference therein, for details).

Moreover, 14 Li-rich stars have been discovered so far in 12 different GCs, (Mucciarelli et al. 2019). The majority are RGB stars, with only two main sequence (hereafter MS) stars and two that belong to the asymptotic giant branch (hereafter AGB). Different enrichment scenarios have been proposed to explain their existance, such as engulfment of sub-stellar systems, self-enrichment based on the Cameron-Fowler mechanism (Cameron & Fowler 1971) and mass-transfer, but a consensus has not been reached yet.

The existence of stars enhanced in lithium has also important implications in terms of the formation of multiple populations in GCs. Being so fragile, Li is a powerful tracer of the physical conditions of the polluting source, and poses strict limits to the temperatures involved in the process.

2. Data sets and analysis

This work is based on spectra gathered by the Gaia-ESO survey, (Gilmore et al. 2012; Randich et al. 2013, hereafter GES) and on its recommended parameters and abundances. The spectra have been acquired using FLAMES-GIRAFFE (Pasquini et al. 2000) and FLAMES-UVES (Dekker et al. 2000), combining new observations and ESO archival data obtained with the GES instrumental setups. The reduction of the GIRAFFE and UVES spectra was performed as described in (Jackson et al. 2015) and (Smiljanic et al. 2014), respectively. The atmospheric parameters and abundances were determined with the GES multiple-pipeline strategy (Recio-Blanco et al. 2014; Smiljanic et al. 2014; Pancino et al. 2017a). The lithium abundance has been derived using the Li 6707 Å doublet, taking into account the blend with the neighboring Fe line. Within GES, 15 GCs were observed as part of the survey calibration strategy (Pancino et al. 2017a,b), covering a range of metallicities and global properties. We list them in Table 1 together with the evolutionary stages sampled by the member stars. In particular, RGB stars have been observed in all GCs, while for two GCs MS stars from the archive sample have been analyzed as well: this represents the largest sample homogeneously analyzed ever used to spectroscopically investigate Lithium in GCs. Of the about 2500 stars analyzed in GES, we selected almost 2000 bona-fide members using the GES [Fe/H] and radial velocity determinations, following Pancino et al. (2017b).

3. Discussion

Our knowledge about Li in GCs is based on inhomogeneous studies, focused on a few clusters, investigated with varying sample sizes, and analyzed with different methods. For example, in the case of NGC 6752 only 9 MS stars have been investigated (Pasquini et al. 2005), while $\simeq$ 350 stars (from below the MS turnoff up to the bright end of the RGB) have been studied in the case of NGC 6397 (Lind et al. 2009).

GES provides an unprecedented data set, that allows us to effectively attack the lithium problem in GCs, thanks to the very high quality

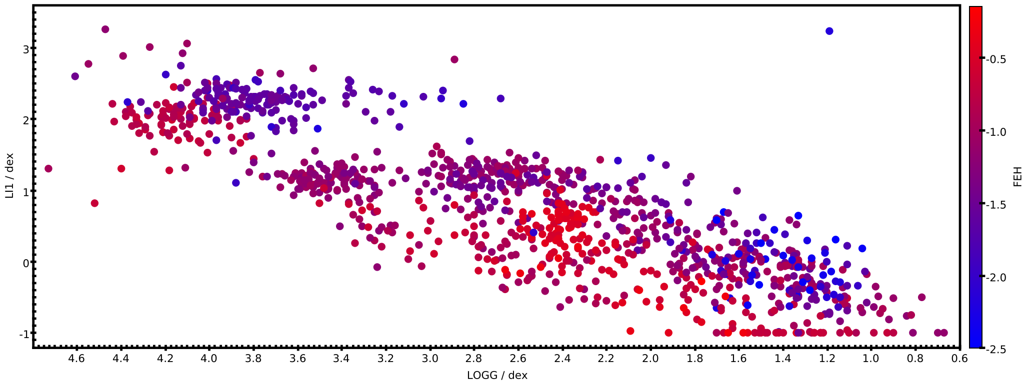

Fig. 1. Li abundance as a function of surface gravity for the member stars of the 15 GCs included in GES, color-coded by metallicity. The Spite plateau is well defined, at A(Li) ≃ 2.2 dex, as well as the plateau defined by stars above the first dredge-up and below the bump along the RGB, at A(Li) ≃ 1.1 dex. The evolutionary phases of the stars included in the sample are clearly identified.

of the spectra and the strategy used to homogenize the abundances. Typical uncertainties in the abundances of metal-poor stars amount to about 0.1 dex or less (Pancino et al. 2017b). In this respect, we can also take advantage of the relatively high number of GCs included in the survey and on their different properties, covering a range of global GC parameters like metallicity, total mass, concentration, and so on.

Figure 1 shows the Li abundances of the ≃2000 selected member stars in the 15 GCs, determined by GES, as a function of surface gravity (log*g*). The Spite plateau defined by dwarf stars appears well defined at A(Li) ≃ 2.2 dex, as well as the plateau defined by stars above the first dedge-up and below the RGB bump, at A(Li) ≃ 1.1 dex. The RGB stars brighter than the RGB bump show the expected behaviour, whit Lithium progressively diluted due to mixing processes. The stars in Figure 1 are color-coded by metallicity showing several effects that are worth further investigation.

3.1. Li-rich stars

As already mentioned above, 14 Li-rich stars in GCs are known in the literature, and their origin mechanism is still not well understood. Two of them are included in the GES sample presented here: the RGB bump star discovered in NGC 362 by D'Orazi et al. (2015) and the bright RGB or AGB star discovered in NGC 4590 by Ruchti et al. (2011) and Kirby et al. (2016).

Here we take the occasion and use these stars to demonstrate the exquisite quality of the GES spectra. Figure 2 shows the comparison between the spectra of the two Li-rich stars in NGC 362 and NGC 4590 observed by GES, compared with Li-normal member stars of the two GCs, having similar atmospheric parameters. The typical Li enhancement with respect to similar cluster stars is of at least one order of magnitude. The two Li-rich stars are well visible also in Figure 1, where they display A(Li)≃2.7 dex in the case of NGC 362 and A(Li)≃3.3 dex in the case of NGC 4590. These preliminary abundance estimates are not yet corrected for NLTE effects.

4. Conclusions

Using preliminary abundances from the Gaia-ESO Survey, we have demonstrated the power of the GES dataset for a global understanding of lithium in GCs. Almost 2000 member stars at different evolutionary stages were analyzed homogeneously, belonging to 15 GCs with different metallicity, mass, concentration, orbit, and selected to cover well the space of GC global properties as calibrators for GES. This sample offers the possibility to investigate stars

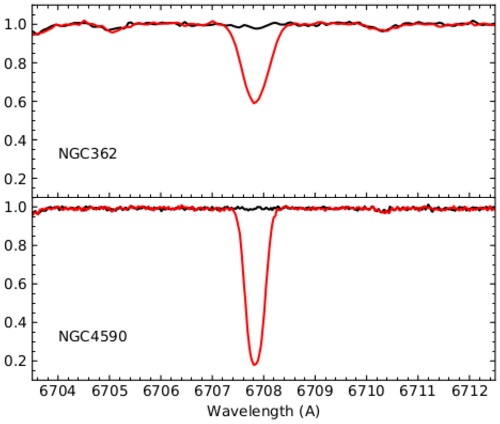

Fig. 2. Top panel: comparison between the spectrum of the Li-rich star in NGC 362 (red line) and a reference member star with similar atmospheric parameters. Bottom panel: a similar comparison in the case of the Li-rich star in NGC 4590.

with different properties, such as temperature, gravity and metallicity, in the largest sample homogeneously analyzed so far. The exquisite quality of the spectra allows us to well determine the Li abundance and identify rare Li-rich stars in this kind of systems. The GES dataset will enable a full statistical investigation of the Li behaviour in GCs, and it will undoubtedly provide an invaluable reference for further theoretical studies, allowing for a deeper understanding of stellar evolution and providing hopefully new insights on the multiple stellar population problem in GCs.

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