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NGC 5694: another extra-galactic globular cluster

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Abstract. We discuss the chemical composition of six giant stars of the outer Halo globular cluster NGC 5694, through the analysis of UVES@FLAMES high-resolution spectra. The cluster has an average iron content [Fe/H]=–1.83±0.01, solar-scaled [α/Fe] ratios and a very low Ba abundance ([Ba/Fe]=–0.71±0.06). These anomalous abundance patterns are different from those observed in other Halo globular clusters but similar to those of the metal-poor stars in typical dwarf spheroidal galaxies. These findings suggest an extra-galactic origin for NGC 5694, likely from a dwarf spheroidal galaxy.

Key words. Stars: abundances – Stars: atmospheres – Stars: Population II – Galaxy: globular clusters –

1. Introduction

NGC 5694 is an old, metal-poor globular cluster (GC) located in the outer Halo, at a galactocentric distance of 30 kpc (Lee et al. 2006). This cluster has not receveid a great deal of attention and only a few of works are devoted to the study of its chemical and kinematical properties, pointing out two peculiarities: *(i)* a large radial velocity, V_{rad}=–140.7 km/s, as estimated by Geisler et al. (1995), and *(ii)* a peculiar chemical composition in one giant star discussed by Lee et al. (2006).

The unusual abundance pattern of the only star studied so far (with solar-scaled abundance

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ratios for the α-elements and sub-solar abundance ratios for neutron-capture elements) is unique among the halo GC, suggesting a possible extra-galactic origin for this star cluster, as suggested for other (more metal-rich) GCs with anomalous abundance ratios, as Ruprecht 106 (Brown et al. 1997), Palomar 12 (Cohen 2004) and Terzan 7 (Sbordone et al. 2007).

2. Chemical analysis

In order to confirm the hypothesis of an extra-galactic origin for NGC 5694 proposed by Lee et al. (2006) and to provide a complete description of the chemical composition of this GC, we analysed high-resolution spectra acquired with the spectrograph UVES@FLAMES (VLT) of six giant stars located in the bright portion of the Red Giant Branch of the cluster. The targets have been selected among cluster members already confirmed by Geisler et al. (1995). Atmospheric parameters have been derived from the photometry by Correnti et al. (2011).

As a sanity check, we analysed UVES@FLAMES spectra retrieved from the ESO archive of 13 giant stars in the Galactic GC NGC 6397, taken as prototype of a genuine Halo cluster with the same metallicity of NGC 5694. The analysis of NGC 6397 has been performed by using the same linelist and the same methodology adopted for NGC 5694.

3. Chemical composition of NGC 5694

The main results concerning the chemical composition of NGC 5694 are summarysed as follows:

- the six stars studied do not show any detectable spread in the abundances of Fe, O, Mg, Si, Ca, Ti and Ba. For this reason we will refer to the average abundance of the six stars as to the cluster abundance;
- the cluster has an iron content of [Fe/H]= –1.83±0.01 from the analysis of single ionized lines. Neutral iron lines provide a lower abundance ([Fe/H]= –1.97±0.03) because of the occurence of NLTE effects. No evidences of intrinsic spread in the iron content of the cluster have been found. The derived metallicity well agrees with that provided by Lee et al. (2006);
- NGC 5694 is remarkably deficient in α-elements. [O/Fe], [Mg/Fe], [Ca/Fe] and [Ti/Fe] abundance ratios are solar-scaled, while only the [Si/Fe] ratio is enhanced with respect to the solar value. These values are lower than those usually observed in Galactic GCs of similar metallicity. Fig. 1 shows the position of NGC 5694 in the [α/Fe] vs [Fe/H] diagram, in comparison with Galatic GCs (green points), Halo field stars (grey points) and dwarf spheroidal galaxies stars (blue points); the position of NGC 6397 as derived by our differential analysis is shown as a star symbol. Also, the position of three anomalous

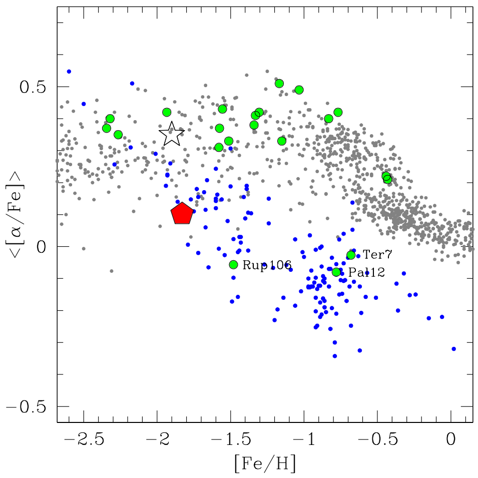

Fig. 1. <[α/Fe]> abundance ratios as a function of [Fe/H]: NGC 5694 is marked as a red pentagon. Grey points are Galactic field stars (Edvardsson et al. 1993; Reddy et al. 2003, 2006); green circles are Galactic GCs (Brown et al. 1997; Cohen 2004; Sbordone et al. 2007; Carretta et al. 2009b), blue points are stars of dwarf spheroidal galaxies (Shetrone, Coté & Sargent 2001; Shetrone et al. 2003; Sbordone et al. 2007; Letarte et al. 2010; Lemasle et al. 2012). NGC 6397 is shown as a empty star symbol.

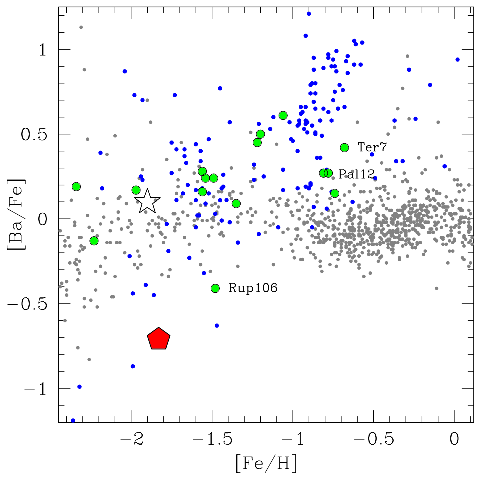

Fig. 2. [Ba/Fe] abundance ratios as a function of [Fe/H]. Same symbols of Fig. 1. Data for the Galactic GCs are from D'Orazi et al. (2010).

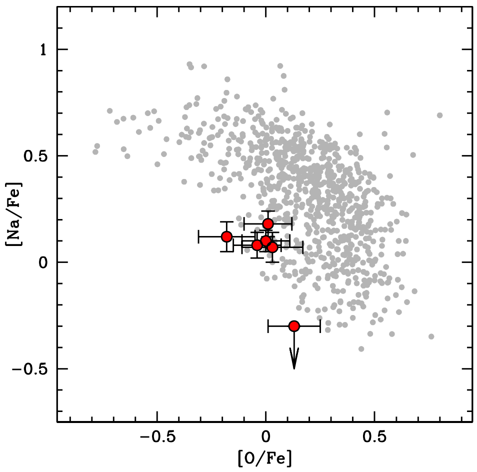

Fig. 3. [Na/Fe] abundance ratios as a function of [O/Fe]. Red circles are the six individual stars of NGC 5694. Grey points are individual stars of Galactic GCs by Carretta et al. (2009a).

GCs (namely, Ruprecht 106, Palomar 12 and Terzan 7) is explicitely shown;

- NGC 5694 exhibits a peculiar under-abundance of the [Ba/Fe] ratio, with an average value [Ba/Fe]=–0.70±0.06. As shown in Fig. 2, [Ba/Fe] of the cluster is ~0.5-0.7 dex lower than in the Milky Way stars; in particular, the Halo GCs with metallicities similar to that of NGC 5694 have solar-scaled [Ba/Fe] ratios (D'Orazi et al. 2010);
- Fig. 3 shows the position of the six individual stars of NGC 5694 in the [Na/Fe]–[O/Fe] plane, in comparison with the individual stars analysed in 19 Galactic GCs by Carretta et al. (2009a).
  One star of NGC 5694 out of six exhibit a lower [Na/Fe] abundance ratio with respect to all the others.
  Instead, O abundances do not show hints of intrinsic spread. The low Na abundance (coupled with a low Al abundance) in this star is compatible with the occurence of self-enrichment processes in the early stages of the cluster life.

4. Conclusions

The analysis of six giant stars of NGC 5694 confirms the first results provided by Lee et al. (2006) based on a single star. The cluster shows unusual low [α/Fe] abundance ratios, lower than those observed in Galactic (both field and GCs) stars of similar metallicity. Also, NGC 5604 is remarkably deficient of Ba abundance, with a [Ba/Fe] ratio lower then the Galactic stars by ~0.7 dex. In light of these findings, NGC 5694 formed from a gas already enriched by Type Ia Supernovae and likely in a galactic environment characterized by a star formation rate slower than that typical of the Galactic Halo. These anomalous chemical patterns are incompatible with those observed in other halo globular clusters, but they resemble the chemical patterns observed in the nearby dwarf spheroidal galaxies (see e.g. Tolstoy, Hill & Tosi 2009). These findings suggest an extra-galactic origin for NGC 5604, likely formed in a dwarf galaxies and then accreted by the Galactic halo.

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