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Chemical composition of globular clusters in dwarf galaxies

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Abstract. This contribution gives an update on on-going efforts to characterise the detailed chemical abundances of Local Group globular clusters (GCs) from integrated-light spectroscopy. Observations of a sample of 20 GCs so far, located primarily within dwarf galaxies, show that at low metallicities the [α/Fe] ratios are generally indistinguishable from those in Milky Way GCs. However, the "knee" above which [α/Fe] decreases towards Solar-scaled values occurs at lower metallicities in the dwarfs, implying that GCs follow the same trends seen in field stars. Efforts are underway to establish NLTE corrections for integrated-light abundance measurements, and preliminary results for Mn are discussed.

Keywords. galaxies: star clusters: general – galaxies: abundances – techniques: spectroscopic

1. Introduction

It is well established that dwarf galaxies can have very high globular cluster (GC) specific frequencies (e.g. Miller & Lotz 2008; Georgiev *et al.* 2010; Harris *et al.* 2013). It is not the aim here to dwell on the possible reasons for this, but from a practical point of view it makes the GCs very useful tracers of stellar populations in their host galaxies. In particular, they can provide insight into the detailed chemical composition of old, metal-poor stellar populations for a larger and more diverse set of galaxies than those for which individual stars can be studied in detail.

GCs fill a gap between detailed studies of individual stars in the Milky Way (and its closest neighbours) and integrated-light (IL) studies of more distant galaxies. Historically, IL spectroscopic studies of GCs have typically been approached from "above" the gap, using techniques developed primarily for studies of galaxy light (e.g. Brodie & Huchra 1990; Worthey *et al.* 1994). However, GCs generally have much lower velocity dispersions than (giant) galaxies, and can therefore benefit from observations at higher spectral resolution. This makes it attractive to approach the analysis from "below" the gap and adapt techniques developed for stellar abundance analysis to the IL spectra.

2. Detailed abundance analysis from integrated-light spectroscopy

Over the past decade, several groups have been developing techniques for measuring detailed chemical abundances from integrated-light spectra of GCs (e.g. McWilliam & Bernstein 2008; Sakari *et al.* 2013; Colucci *et al.* 2017). The velocity broadening of GC spectra is typically 5–10 km/s, which is enough to make line blending an issue for many features of interest. As an example, Figure 1 shows a UVES integrated-light spectrum (with a nominal resolving power of $R \simeq 40\,000$) of the globular cluster 47 Tuc (Larsen *et al.* 2017) and the spectrum of Arcturus (Hinkle & Wallace 2005) for the region around the Na I 5683/5688 Å doublet. While the Na I lines are clearly detectable in both spectra,

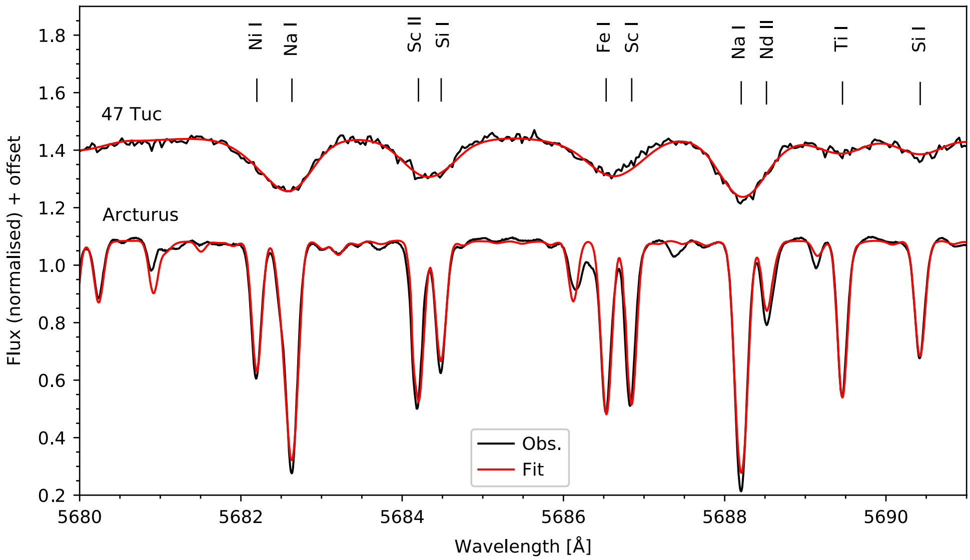

Figure 1. Spectra of 47 Tuc and Arcturus, shown together with the best-fitting model spectra.

they are blended with Ni I and Nd II lines in the 47 Tuc spectrum. Hence, spectral synthesis is required in order to properly account for line blending.

To synthesise model spectra, we mostly rely on the `SYNTHE` code in combination with model atmospheres computed with the `ATLAS9` code (Sbordone *et al.* 2004; Kurucz 2005). For the coolest, low surface gravity giants we use `TurboSpectrum` (Plez 2012) for the spectral synthesis and `MARCS` model atmospheres (Gustafsson *et al.* 2008), which allows for spherical (rather than plane-parallel) symmetry. To model the integrated-light spectra, we define ~ 100 points ($\log g$, $T_{\rm eff}$) at which the H-R diagram of the cluster is sampled, and the model spectra for each sampling point are then co-added with appropriate weights, according to an assumed distribution of stellar masses. The abundances used in the spectral synthesis are adjusted until the best fit (lowest χ^2) to the observed spectrum is obtained. Information about the H-R diagram (HRD) may come from an observed colour-magnitude diagram, from theoretical isochrones, or some combination – for extragalactic GCs, we typically use theoretical isochrones from the Dartmouth group in combination with empirical horizontal branch data for Galactic GCs of appropriate metallicities.

3. Abundances of GCs in Local Group galaxies

In the *AGILE* project (Abundances of Globular clusters In the Local group Environment), we are building up a sample of GCs in the Local Group with detailed and homogeneous abundance measurements from integrated-light spectra, using the methods described above. The aim is to provide a comprehensive picture of the chemical composition of metal-poor populations in the Local Group, and establish a reference sample for future observations with Extremely Large Telescopes that will be able to reach well beyond the Local Group. Results for 15 GCs obtained so far were published in Larsen *et al.* (2018a), covering the Fornax dwarf spheroidal galaxy, the Wolf-Lundmark-Melotte galaxy, NGC 147, NGC 6822, and M33. Measurements for 20 GCs in Cen A, using VLT/X-Shooter, have been presented in Hernandez *et al.* (2018).

In Fig. 2 we present updated data for the α-elements ([Ca/Fe], [Ti/Fe]), with additional observations of 3 GCs in NGC 185, two in NGC 205, and one GC in M31 (Larsen *et al.* (2018b)). Symbols are coloured according to the host galaxies of the clusters: red

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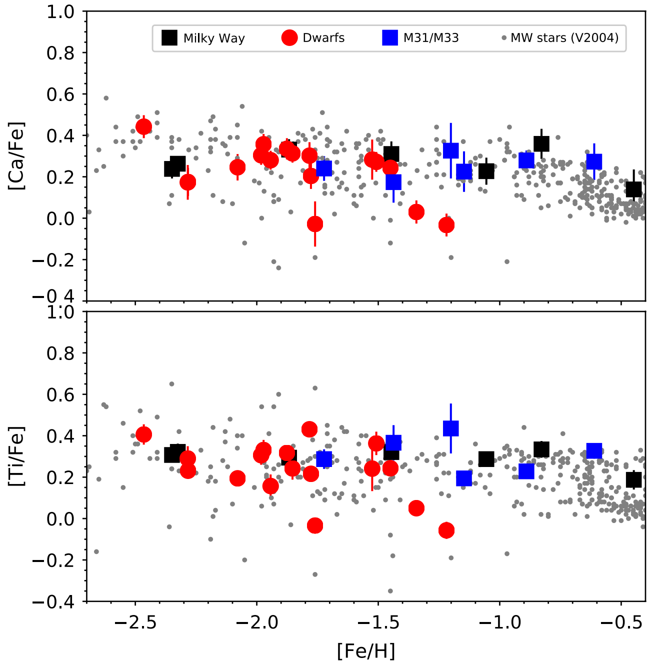

Figure 2. Integrated-light measurements of [Ca/Fe] and [Ti/Fe] for GCs in Local Group galaxies.

circles mark GCs in dwarf galaxies, blue squares GCs in M33/M31, and black squares our integrated-light observations of Milky Way GCs (Larsen *et al.* 2017). The overall impression is that there is only a very small scatter in both the [Ca/Fe] and [Ti/Fe] ratios, with GCs in dwarf galaxies as well as the spirals having very similar abundance ratios for these elements. The GC abundances are also very similar to those of Galactic field stars, shown with grey dots (Venn *et al.* 2004). However, it is worth noting that some of the more metal-rich GCs in the dwarf galaxies have lower [Ca/Fe] and [Ti/Fe] ratios; the GCs thus follow a similar trend of α-element abundances as a function of metallicity as that seen in field stars in dwarfs (Tolstoy *et al.* 2009).

4. Refining the analysis: NLTE effects

Based on tests on Milky Way GCs, where integrated-light measurements have been compared with data for individual stars, it appears that metallicities and abundance ratios are typically reproduced with an accuracy of $\sim$0.1 dex (Larsen *et al.* 2017). As in stellar abundance analysis, pushing the accuracy to significantly better levels requires consideration of a wide variety of effects beyond those included in our standard (1-D, LTE, etc) analysis.

Corrections for non-LTE effects are now included fairly commonly in abundance work on individual stars. For integrated-light spectra, a complication arises from the fact that these corrections depend on the physical parameters of the model atmospheres, and must therefore be computed for each HRD sampling point individually and then suitably averaged to give the corrections for abundances measured from integrated light.

As a pilot study, IL non-LTE corrections have been calculated for a few select elements (Mg I, Mn I, Ba II) for a metallicity of [Fe/H]=−2 and an age of 11 Gyr (Eitner *et al.* 2019). For Mg I and Ba II the corrections were found to be relatively modest, less than 0.10-0.15 dex for most lines of interest. However, for Mn I the corrections were larger,

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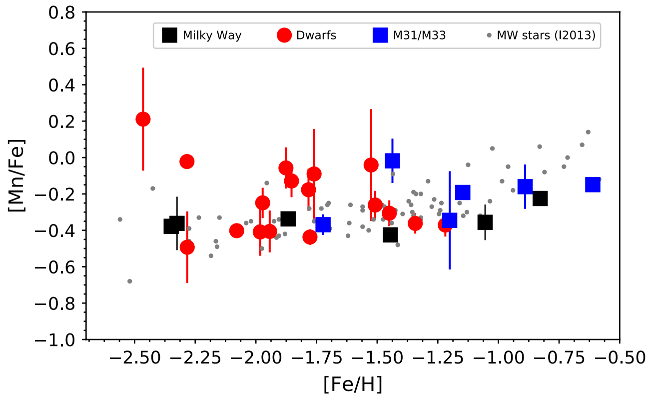

Figure 3. Integrated-light measurements of [Mn/Fe] for GCs in Local Group galaxies.

with an average correction of about 0.3 dex in the sense that Mn abundances estimated under the LTE assumption are too low. Similar results have been found for individual stars (Bergemann & Gehren 2008).

Figure 3 shows the LTE [Mn/Fe] ratios for the integrated-light measurements. The figure shows the trend of decreasing [Mn/Fe] with decreasing [Fe/H] that is also seen in LTE measurements of individual stars (e.g. Nissen *et al.* 2000; Ishigaki *et al.* 2013). However, once a correction of +0.3 dex is added, the [Mn/Fe] ratios become close to Solar even at the metal-poor end. For individual stars, the NLTE corrections become smaller at higher metallicities, thus removing much of the apparent trend of [Mn/Fe] with [Fe/H]; it is likely that the same will be true for the IL measurements.

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