Mem. S.A.It. Vol. 84, 50

Memorie della

Extragalactic globular cluster populations from high resolution integrated light spectra

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Abstract. We present a comparison of high-resolution, integrated-light, detailed chemical abundances for Galactic and extragalactic globular clusters in both massive galaxies and dwarf galaxies. We include measurements of Fe, Ca, Si, Na, and Al for globular cluster samples in the Milky Way, M31, Large Magellanic Cloud, and NGC 5128. These and other recent results from our group on M31 and NGC 5128 are the first chemical abundances derived from discrete absorption features in old stars beyond the Milky Way and its nearest neighbors. These abundances can provide both galaxy enrichment histories and constraints on globular cluster formation and evolution.

Key words. Stars: abundances – Galaxies: star clusters – Galaxies: abundances – Galaxies: formation

1. Introduction

Unresolved globular clusters (GCs) are luminous and therefore observationally accessible to large distances, unlike individual red giant branch stars. This means that they are useful tools for learning about the chemical enrichment and formation history of other galaxies when it is not possible to use high resolution spectra of individual stars. Detailed abundances of key elements in old stars are in fact impossible to obtain in any other massive galaxy beyond the Milky Way (MW), even in our nearest neighbor galaxy, M31.

With the development of our original technique for abundance analysis of high resolution integrated light (IL) spectra of GCs, we can now make significant advances in chemical evolution studies of distant massive galaxies. Our technique has been developed and demonstrated on resolved GCs in the MW and Large Magellanic Cloud (LMC) in a series of papers (Bernstein & McWilliam 2002; McWilliam & Bernstein 2008; Colucci et al. 2009; Cameron 2009; Colucci et al. 2011, 2012). These works show that the IL analysis provides accurate Fe abundances and [X/Fe] ratios to ~0.1 dex for [Fe/H] of −2 to +0. This now makes it possible to use diagnostic abundance ratios in old stellar clusters to gain quantitative constraints on star formation histories in galaxies up to

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4 Mpc away. Here we compare abundance results for key elements in 4 galaxies: the Milky Way, M31, the LMC, and NGC 5128.

2. Data & analysis

The MW and LMC data presented here were obtained using the echelle spectrograph on the duPont telescope at Las Campanas. These data are described fully in McWilliam & Bernstein (2008), Cameron (2009), and Colucci et al. (2011). Our sample of 27 GCs in M31 were observed with HIRES on the Keck I telescope, and are described in Colucci et al. (2009) and Colucci et al. (2012). The first 4 GCs of our latest sample in NGC 5128 are also included here (Colucci et al. 2013, in prep) and were obtained with the MIKE spectrograph on the Magellan Clay Telescope in 2004-2005. Exposure times in NGC 5128 were between 9–15 hours per GC, and the signal-to-noise ratio at 6000 Å is ~60-80. Data were reduced with standard routines in the MIKE Redux pipeline.

The methods we use in our IL abundance analysis are described in detail in McWilliam & Bernstein (2008); Colucci et al. (2009); Cameron (2009); Colucci et al. (2012). To summarize briefly, we measure absorption line equivalent widths (EWs) using the semi-automated program GETJOB (McWilliam et al. 1995) and compare those with light-weighted, synthesized EWs that we calculate using an updated version of our ILABUNDS code (McWilliam & Bernstein 2008), which calls synthesis routines from MOOG (Sneden 1973). We also synthesize spectral regions for direct comparison to our spectra to assess blending and continuum placement.

3. Abundances across galaxy types

3.1. M31 and the MW (massive spirals)

We present abundances of Fe, Ca, and Si for 27 M31 GCs in the left panels of Figure 1. Our IL abundances for MW GCs and stellar MW abundances from the literature are also shown, for comparison. For the α-elements Ca and Si, we find a plateau value that is similar to the value in MW GCs and field stars from Venn et al. (2004) and Pritzl et al. (2005); this plateau is consistent with rapid early star formation in M31. There is also a clear knee visible in the M31 [Ca/Fe] values that closely matches the plateau shown by MW field stars.

In Figure 1, we also show abundances for Na and Al. Star-to-star variations in the light elements Na, O, Mg, and Al — specifically, depletion of Mg and O and enhancement of Na and Al — are a well known phenomenon in GCs (see Gratton et al. 2004). In the IL abundances, these trends manifest as [Mg/Fe] being lower than other [α/Fe], and [Na/Fe] and [Al/Fe] higher than expected compared to MW halo stars. We first published evidence of this effect in the IL of GCs in Colucci et al. (2009, 2012). Critically, this implies that Mg is a *bad* proxy for [α/Fe] in IL GC spectra. Preliminary results by Larsen et al. (2012) recently confirm our results. Figure 1 shows that the [Al/Fe] and [Na/Fe] values for M31 GCs are also elevated, particularly Na at high [Fe/H]. We can therefore infer that most of the M31 GCs host star-to-star abundance variations.

3.2. The LMC (dwarf irregular)

In the right panels of Figure 1, we show our LMC IL abundances from Colucci et al. (2012). The [Ca/Fe] and [Si/Fe] of the LMC decrease as a function of [Fe/H] more than is seen in M31 or the MW. This suggests a slower, more prolonged star formation history in the LMC than in more massive galaxies. In addition, the LMC sample contains clusters with much younger ages.

The oldest GCs in the LMC show [Na/Fe] and [Al/Fe] that are elevated to similar levels as seen in the MW and M31 GCs. However, the younger LMC GCs, which also happen to be the least massive GCs, show much lower values of [Na/Fe] and [Al/Fe]. This may provide insight into the formation scenario that results in abundance variations, however it is unclear if age or total GC mass is the dominant factor. Detailed abundances of young massive GCs will provide a crucial next test.

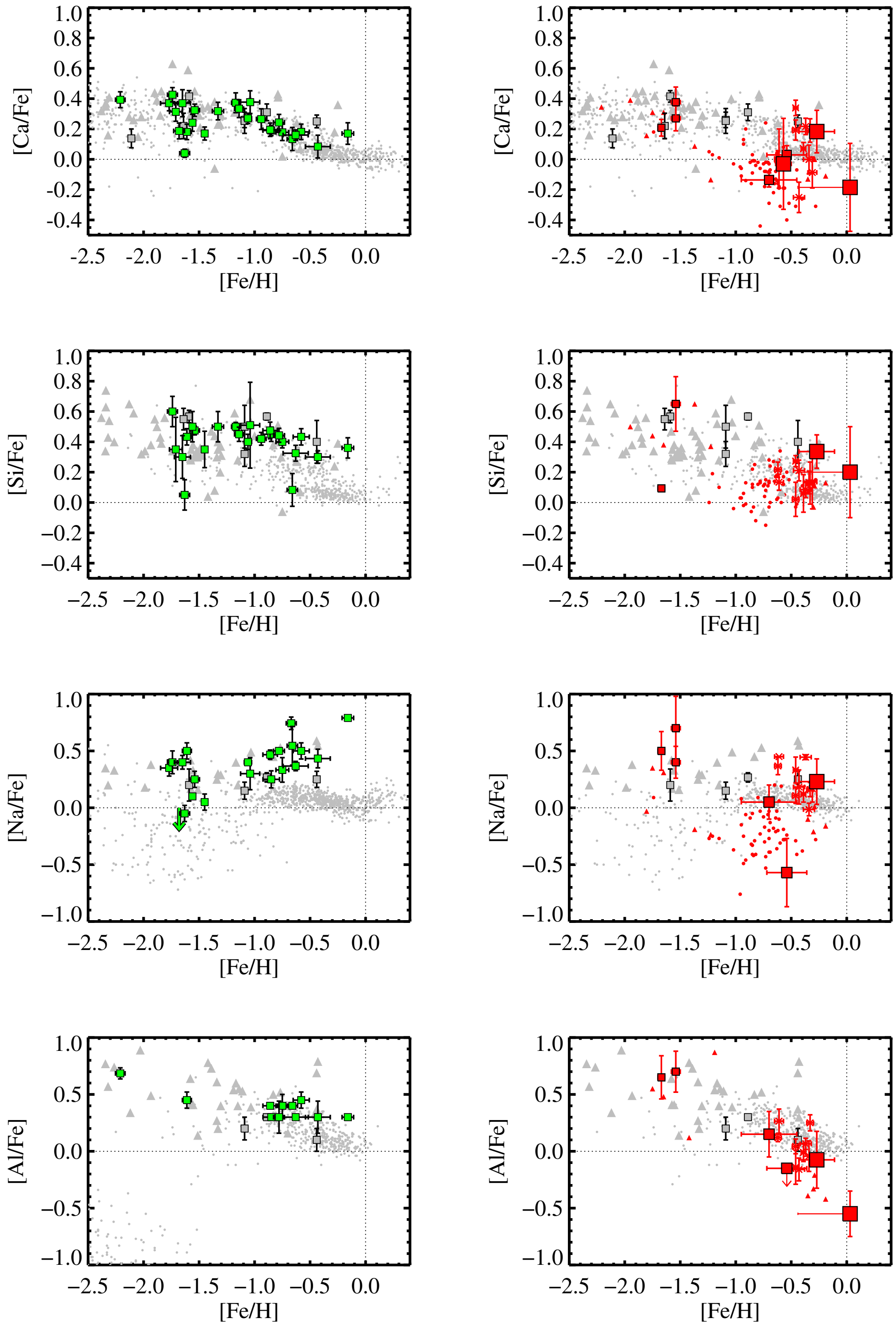

Fig. 1. Comparison of detailed abundances in the MW, M31, and the LMC. Stellar MW abundances from Venn et al. (2004) are shown as small gray circles, stellar GC abundances from Pritzl et al. (2005) are shown as gray triangles, and MW IL abundances from Cameron (2009) are shown as gray squares. In left panels, M31 GC IL abundances are shown as green squares. In right panels, LMC GC abundances are shown as red squares, with increasing symbol size denoting younger ages. The total range in age is 0.05−12 Gyr. LMC stellar abundances from Pompéia et al. (2008), Mucciarelli et al. (2008, 2009, 2010) and Johnson et al. (2006) are shown as small red symbols.

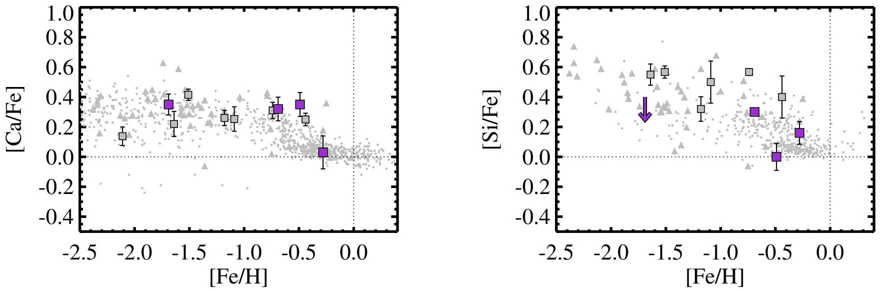

Fig. 2. Purple squares show preliminary Ca and Si abundances in NGC5128. Gray symbols are as in Fig 1.

3.3. NGC 5128 (massive E/S0)

In Figure 2, we show preliminary abundances of Fe, Ca, and Si for 4 GCs in NGC 5128. These are the first α-element abundances derived from individual Fe, Ca, and Si lines in a massive E/S0 type galaxy. This is a subset of the GCs currently in our sample from an ongoing program to study NGC 5128, the first 10 GCs of which will be presented in Colucci et al. (2013). Our preliminary results indicate that [α/Fe] in the more metal-poor GCs is comparable to that in the MW and M31 GCs, and that [α/Fe] may decrease at higher [Fe/H]. This suggests that the star formation rate in NGC 5128 at early times was was comparable to that of the MW and M31.

4. Summary

Detailed chemical abundances from high resolution IL spectra of GCs can be obtained in galaxies with a range of masses and Hubble types. This makes it possible for quantitative comparisons of detailed chemical enrichment histories and cluster formation scenarios in galaxies of all Hubble types and environments.

Acknowledgements. We thank the organizing committee and INAF for the opportunity to present this work and for hosting a very interesting conference.

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