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Globular clusters in the near–infrared

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The study of Globular Cluster (GC) stellar populations (SPs) addresses fundamental astrophysical questions ranging from stellar structure, evolution and dynamics, to Galaxy formation. Indeed, they represent: *i) fossils* from the remote and violent epoch of Galaxy formation, *ii)* test particles for studying Galaxy dynamics and stellar dynamical model, and *iii)* fiducial templates for studying integrated light from distant stellar systems. In particular, *high resolution spectroscopy* of GC SPs provides abundance patterns which are crucial for understanding the formation and chemical enrichment time-scale of the host galaxy. Here the major results on Galactic GCs based on high-resolution near-infrared (near-IR) spectroscopy are briefly reviewed. Optical and IR spectroscopy are complementary tools to investigate SPs in different environments, the latter being more suitable in the case of moderately-high extinction regions ($A_V \geqslant 2$) and high metallicity.

Since the Galactic halo GCs are mainly a low-to-intermediate metallicity population located in low-extinction regions, they have been extensively studied with high-resolution optical spectrographs, to derive accurate information about their chemistry, kinematics and dynamics. However, the few available IR spectroscopic studies of Halo GCs demonstrated how this spectral region can be exploited to derive unique chemical properties, which are not easily observable in the optical (i.e. C isotopes and ^{19}F). By using high resolution (R=10,000) K-band spectra of giants in ω Cen, Smith, Terndrup & Suntzeff (2002) derived C isotope ratios from the first overtone CO bandhead at 2.3 μm. Because ω Cen is the only GC showing star-to-star iron abundance variations, they could investigate the behavior of the ^{12}C/^{13}C ratio over the metallicity ([Fe/H]), finding no correlation. Smith *et al.* (2005) derived, for the first time, fluorine abundances in the Halo GC M4 from high-resolution (R=50,000) K-band spectra. The authors found that ^{19}F, only measurable in the IR, shows: *i)* star-to-star abundance variations, *ii)* a correlation with O, and *iii)* an anti-correlation with Na and Al, hence suggesting pollution from stars with M$> 3.5 M_\odot$. Finally, Yong *et al.* (2008) used H and K-band spectra (R=50,000) of giants to perform a detailed chemical analysis of the Halo cluster NGC 6712. They found star-to-star abundance variations of C, N, O, F and Na.

Because of the high level of extinction and metal content, M giants in Bulge GCs are suitable targets for high-resolution IR spectroscopy. In this framework, with the final goal being to trace the formation and chemical enrichment time-scales of the Bulge, our group collected high-resolution (25,000$\leqslant$R$\leqslant$100,000) H and K-band spectra of giant stars (near the Red Giant Branch Tip) for a number of GCs and fields. H band spectra of cool giants shows many absorption features due to both metals (Fe I, Ca I, Si i, Mg I, Ti I, Al I, etc.) and molecules (CO, OH), which allow accurate abundance analysis over a wide range of metallicities, up to the super-solar regime (see left panel of Fig. 1). Moreover, the IR CO bandheads and OH roto-vibrational lines provide the most robust estimates of oxygen and carbon abundances and their isotopic ratios in cool stars (Melendez, Barbuy & Spite (2001)). From the data analyzed so far (seven GCs) we found low C isotopic ratios ($<^{12}$C/^{13}C$> \leqslant 8$), which suggests that mixing mechanisms due to cool-bottom processing are at work during the evolution along the Red Giant Branch, and as summarized in the right panel of Fig. 1, an overall [α/Fe] enhancement up to solar metallicity, which points towards an early and rapid Bulge formation scenario.

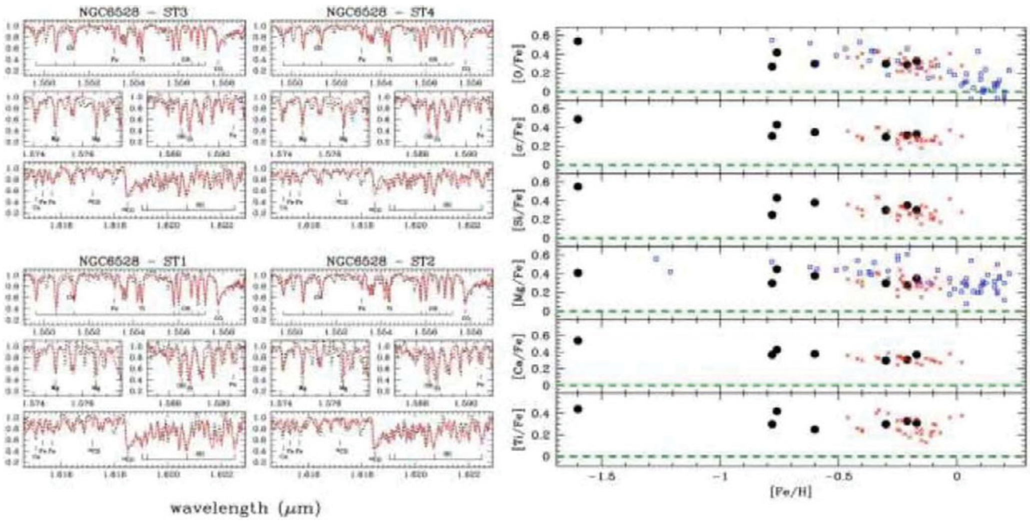

Figure 1. *Left Panel:* Selected portions of the observed NIRSPEC echelle spectra (*dotted lines*) of four giants in NGC 6528 with the best-fitting synthetic spectrum (*solid lines*) superimposed. A few important molecular and atomic lines of slight interest are marked (from Origlia, Valenti & Rich (2005)). *Right Panel:* Plot of α-element to iron abundance ratios as a function of [Fe/H] for observed giants in Bulge clusters (*filled circles* - from Origlia, Rich & Castro (2002), Origlia & Rich (2004), Origlia, Valenti & Rich (2005), Origlia *et al.* (2005), Origlia, Valenti & Rich (2008)) and fields (*squares* - from Zoccali *et al.* (2006), Lecureur *et al.* (2007), *x-crosses* - from Rich & Origlia(2005), Rich, Origlia & Valenti (2007)). *Green dashed lines* mark the solar reference value.

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