PROCEEDINGS OF SCIENCE

High Resolution Integrated Light Spectroscopy of Galactic Globular Clusters

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Detailed chemical abundances of globular clusters can provide valuable information about nucleosynthesis, stellar evolution, and galaxy and cluster formation. High spectral resolution analyses enable abundance measurements of a larger number of elements with increased precision to study the relative contributions of different types of supernovae and AGB stars. In the Galaxy and its closest satellites, high resolution spectroscopy of individual stars has enabled the determination of chemical abundances in massive and low mass galaxies, with great success. Outside the Local Group of galaxies, however, integrated light spectra (ILS) of entire clusters must be used, as the individual stars cannot be resolved. A high resolution ILS analysis method, ILABUNDS, has been developed and tested on Galactic globular clusters by McWilliam & Bernstein (2008). This poster presents the analysis of the ILS of five Galactic globular clusters (47 Tuc, M3, M13, NGC 7006, and M15) with ILABUNDS. The latter four clusters were observed with the Hobby-Eberly Telescope at McDonald Observatory, while 47 Tuc was observed with the Las Campanas du Pont telescope (from McWilliam & Bernstein). Analyses of these clusters help to clarify the limits of the application of ILABUNDS to different stellar populations. In particular, the effects of different modeling assumptions are examined here, e.g. the effects of different horizontal branch morphologies.

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1. Introduction

An Integrated Light Spectrum (ILS) is a single spectrum comprised of light from an entire population of stars. An abundance analysis of an ILS requires models of the underlying stellar population, diagnostics to determine if the models sufficiently reproduce the true population, and calibrations on well-studied targets to ensure that the analysis methods produce reasonable results. Such techniques, and their validating tests, are necessary to obtain stellar abundances from distant, unresolved globular clusters (GCs).

In the past, ILS analyses of GCs have been done at low resolution; such studies are capable of determining iron and α-abundances (e.g. [7]). However, to obtain detailed chemical abundances (of, e.g., iron-peak or neutron capture elements), high-resolution ILS must be obtained. A new high resolution ILS method, ILABUNDS, has recently been developed, and has been tested on Galactic GCs [5], M31 GCs [1], and LMC GCs [2, 3]. These initial tests show that ILABUNDS does seem able to reproduce individual stellar abundances, though the effects of some observed GC traits have not yet been tested. In particular, the effects on ILS abundances from the horizontal branch (HB) morphology or star-to-star chemical variations within a GC, are not yet well understood. This work presents ILS analyses of five Galactic GCs, of varying metallicities and HB morphologies.

2. Observations and Methodology

High resolution ILS ($R = 30,000$) of the Galactic GCs M3, M13, NGC 7006, and M15 were obtained with the High Resolution Spectrograph (HRS) on the Hobby-Eberly Telescope (HET) at McDonald Observatory in 2011 and 2012. These spectra were supplemented with the ILS of 47 Tuc ($R = 34760$, from the du Pont telescope) from McWilliam & Bernstein (2008), hereafter MB08 [5]. The targets were selected to cover a range of metallicity (from $[\mathrm{Fe/H}] = -0.7$ to -2.37; [4]) and HB morphologies. In particular, M3, M13, and NGC 7006 form a second-parameter triad, i.e. the three clusters have similar metallicites and ages, yet very different HB morphologies.

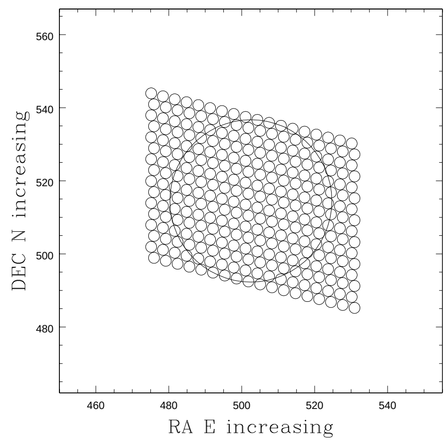

Figure 1: HET Pointings for M3. The large circle shows M3's core radius; the smaller circles show the fiber positions and sizes. The coordinates on the axes are arbitrary values.

The 3” fiber on HRS was used for the observations. HRS provides two sky fibers on either side of the object fiber; because of the large spatial extent of these GCs, the “sky” fibers were also on the target. The sky fibers were appropriately scaled (i.e. increased by about 20%) to account for their slightly lower throughput. The three fibers were scanned across the clusters, providing coverage of the clusters within their core radii; a sample pointing pattern is shown in Figure 1. No bright foreground stars were observed in any of the scans. Sky observations were taken separately. More details on the observations and data reduction will be given in a future paper (Sakari et al., *in prep.*). Sample sections of the final spectra are shown in Figure 2.

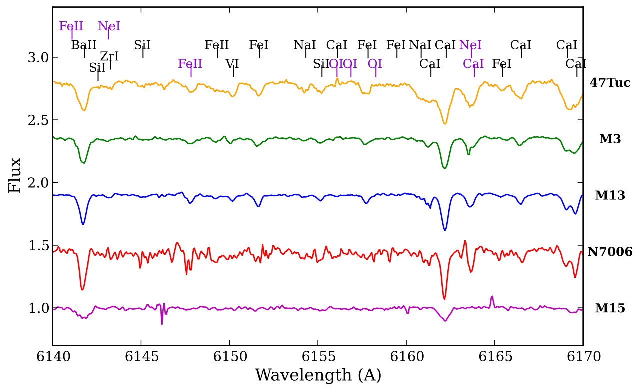

Figure 2: Spectra of the target GCs. Notable spectral features are labeled. The 47 Tuc spectrum is from MB08 [5]; the rest were observed with the HET.

The IL equivalent width analysis code ILABUNDS [5] was used to find the integrated chemical abundances of the target clusters. Resolved photometry from the ACS Globular Cluster Treasury [6] provided the atmospheric parameters of the stars. The V, $V-I$ color-magnitude diagrams were boxed, as shown in Figure 3; a suitable model atmosphere was then applied to each box, as described in MB08 [5]. In the analysis, each box was weighted by the number of stars. Changing the number or limits of the boxes has only a minor effect on the final abundances.

Equivalent widths of spectral lines were measured with the program DAOSPEC [8]. With measured equivalent widths and assigned model atmospheres, ILABUNDS then computed a total integrated abundance for the cluster. Solar abundances were also calculated, using the Solar spectrum from the Kurucz 2005 solar flux atlas;[1] the [X/Fe] ratios were then calculated for each line *relative to the Solar value for that line*, and were averaged together.

3. Results

The abundances (presented as [X/Fe] ratios) are shown in Table 1. The quoted errors are only the line-to-line scatter (as a result of, e.g., continuum uncertainties, blends, etc.), and do not take into account the errors in EW measurements or errors in the atmospheric parameters.

[1] http://kurucz.harvard.edu/sun.html

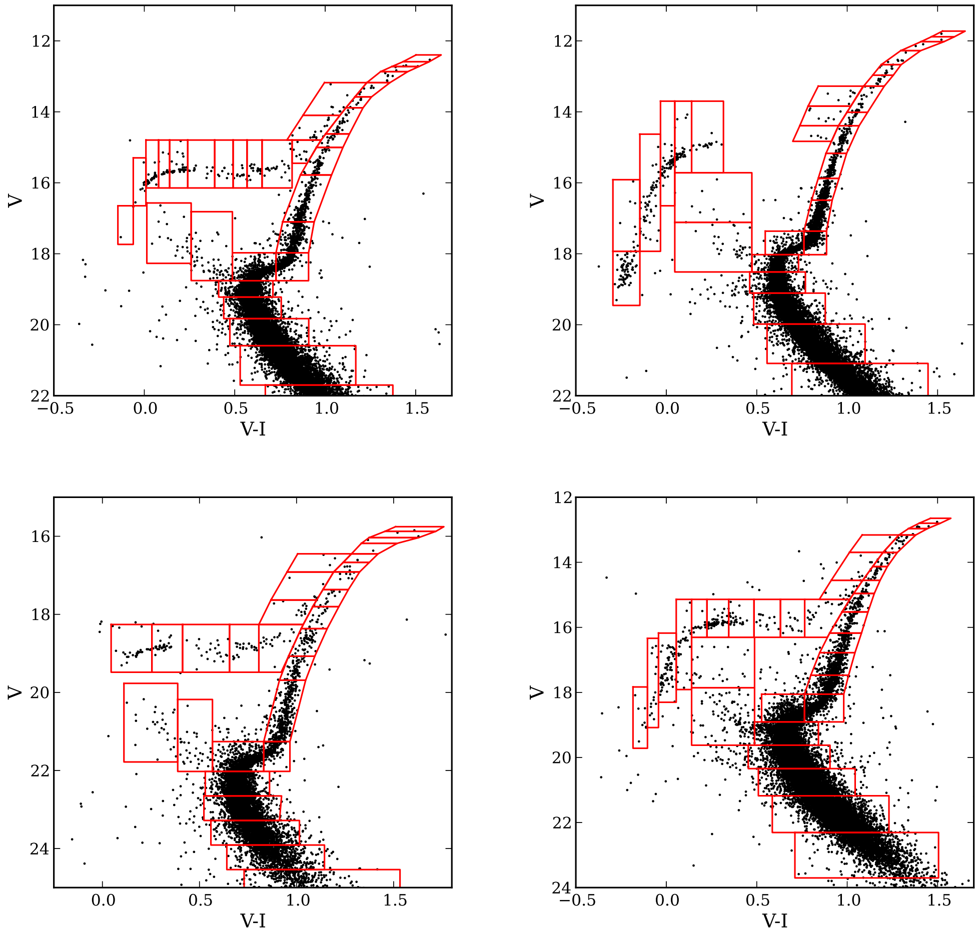

Figure 3: Boxed V, $V-I$ color-magnitude diagrams (from the ACS Globular Cluster Treasury [6]) of the target GCs M3 (top left), M13 (top right), NGC 7006 (bottom left), and M15 (bottom right).

	47 Tuc		M3		M13		NGC 7006		M15	
	[X/Fe]	σ	[X/Fe]	σ	[X/Fe]	σ	[X/Fe]	σ	[X/Fe]	σ
Fe I	-0.77	0.16	-1.47	0.13	-1.56	0.16	-1.54	0.18	-2.34	0.21
Fe II	-0.75	0.10	-1.45	0.08	-1.54	0.04	-1.56	0.07	-2.38	-
Ca I	+0.29	0.16	+0.34	0.11	+0.31	0.09	+0.41	0.19	+0.34	0.15
Ti I	+0.24	0.16	+0.26	0.05	+0.35	0.09	+0.34	0.20	-	-
Ti II	+0.32	0.07	+0.39	0.05	+0.44	0.07	+0.33	-	+0.30	0.15
Ni I	-0.15	0.08	-0.05	0.12	-0.07	0.06	-0.07	0.16	+0.08	-

Table 1: GC Abundances. The quoted errors are the line-to-line scatter, and are not the errors in the mean abundances.

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3.1 A Comparison with Literature Abundances

Figure 4 shows that our Fe abundances agree well with the literature values from the Harris catalogue [4]. In addition, the other elements generally agree well with literature values: Ca and Ti are enhanced (as α-elements tend to be) while Ni is approximately solar.

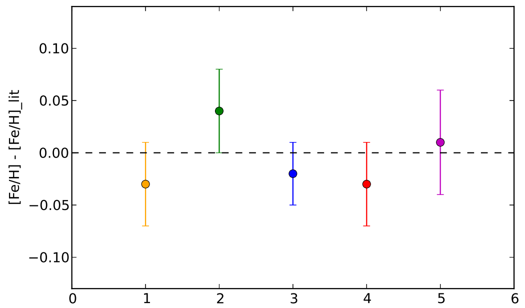

Figure 4: Differences in our [Fe/H] values from those quoted in Harris (1996, 2010 edition) for: 47 Tuc (orange), M3(green), M13(blue), NGC7006(red), and M15 (magenta).

3.2 Effects of HB morphology?

To test the effects of HB morphology, an analysis was also performed on M13's ILS and color-magnitude diagram, but with M3's HB photometry. A comparison between the regular M13 and red HB M13 abundances is shown in Figure 5. It is clear that for these elements in this wavelength range, it does not appear necessary to model the HB morphology perfectly, at least for the elements considered here and the wavelength ranges for the specific (atomic) lines.

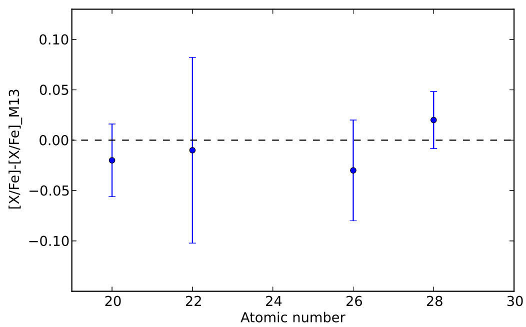

Figure 5: Differences between the correct M13 abundances and the red HB M13 abundances. The errors are the line-to-line scatter divided by the square root of the number of lines.

4. Conclusions

In these five Galactic GC ILS, the spectral variations from differing chemical compositions are obvious. With resolved photometry, ILABUNDS is capable of reproducing literature abundances of Fe, Ca, Ti, and Ni. Spectrum syntheses are needed to obtain abundances for most other elements; these will be presented in our forthcoming paper.

This analysis also shows that incorrect models of the HB do not have drastic effects on the output abundances of Fe, Ca, Ti, or Ni in this wavelength range. This is particularly encouraging for future high resolution observations of unresolved targets.

References

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