DETAILED CHEMICAL ABUNDANCE STUDIES OF EXTRA-GALACTIC GLOBULAR CLUSTERS

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1. ABSTRACT

The new technique of high resolution integrated-light abundance analysis of extra-galactic globular clusters (GCs) will enable Gemini to measure detailed chemical abundance ratios in GCs in other galaxies out to ∼4 Mpc, including the nearest giant elliptical galaxy, Cen A (NGC 5128). Diagnostic abundance ratios will be used to constrain the formation timescale, star formation rate (SFR), initial mass function (IMF), and the roles of accretion of low mass satellites, mass inflows and outflows, on the formation and evolution of galaxies.

In addition to understanding the chemical evolution history, ideas on the astrophysical sites of nucleosynthesis and stellar nucleosynthesis yields will be constrained by the abundance ratio trends with environment. Much of our understanding of chemical evolution and stellar nucleosynthesis yields relies upon studies of nearby Galactic stars. To make progress in our understanding of stellar yields and chemical evolution, and to understand the evolution of galaxies, it is vital to test this paradigm by studying the chemical composition, as a function of time, and environmental parameters, especially for environments different than the Galaxy. These abundance patters will constrain the rate of growth of Cen A and all other galaxies within ∼4Mpc. The formation evolution of these nearby systems can constrain theoretical predictions on the cosmological growth of structure.

Similar abundance studies, that rely on individual red giant branch stars as probes are limited to well within the Local Group, even for the next generation of 30m telescopes.

2. INTRODUCTION

Recent papers (McWilliam & Bernstein 2008; Colucci et al. 2009) have shown that detailed elemental abundances can be obtained from high resolution integrated-light (IL) spectra of globular clusters (GCs). Abundance errors are similar to that found for individual GC red giant stars, although more S/N is required (60:1 and higher) for the IL spectra due to the shallower lines.

High resolutoin GCIL abundance measurement is possible because the cluster velocity dispersions are small enough that line broadening is tolerable, and the same lines employed for individual RGB stars can be measured in the IL spectra. Analysis is made easier by the fact that GC light is dominated by the luminous red giant stars.

Use of this technique has only just begun. However, it holds promise for studying the detailed composition for GCs in many galaxies beyond the Local Group, because the GCs are intrinsically bright. GC ages can range from zero to the age of the Universe, so they probe the chemical history of a galaxy.

Sampling the chemical composition of all galactic environments is essential, in order to fully understand and constrain chemical evolution models. Environments dissimilar to the Milky Way Galaxy, are particularly important to study. Although abundances of luminous supergiant stars have been studied beyond the Local Group (e.g., Krudritzki refs, Bresolin etc), these are young, massive stars, that essentially trace the current galactic gas.

Currently, detailed abundances for 47 Tuc and five GCs in M31 have been published, while studies on a large sample of Galactic GCs, and very small samples of GCs in the LMC, M31 and M33 are underway. An obvious target is the nearest giant Elliptical galaxy, Cen A (NGC 5128), at a distance of $\sim$3.8 Mpc. At the distance of Cen A 47 Tuc would have an apparent magnitude of V=18.5; thus the interesting GC targets in Cen A have V 19, so the acquisition of spectra will be very slow (and require an efficient spectrograph). There are 1500 known GCs in Cen A alone, populating both red and blue sequences (e.g., Harris et al 2006; Peng et al 2004; Beasley et al 2008). Also accessible for Gemini South will be GCs in the galaxies of the Sculptor group.

Given the long exposure times required and the large number of GC targets available, the field is unlikely to be played-out before the new Gemini HROS is built.

Perhaps the most important task will be to accurately measure the [Fe/H] and [α/Fe] ratios of the Cen A GC system. Abundance ratios provide valuable diagnostics: The α/Fe ratio (where α is O, Mg, Si, S, Ca, Ti) probe the Type II/Type Ia SNe ratio, and $\sim$1 Gyr timescales. Low mass AGB stars, which have progenitor timescales of several Gyr, are traced by their production of s-process neutron-capture elements (e.g. Zr, Y, Ba, La). These element families can be used to trace the IMF and SFR history.

There has been much discussion of whether the IMF slope is everywhere constant (e.g. Kroupa & Weider 2003). However, evidence exists to the contrary: for example Ballero et al. (2007) require a top-heavy IMF to match the observed metallicity distribution function of the Galactic bulge and the measured [Mg/Fe] ratios. The [Mg/Fe] ratios in the Galactic bulge indicate rapid formation ($\leq$1Gyr), yet the mean metallicity is approximately solar. Thus, the bulge has reached a similar [Fe/H] as the solar neighborhood but without significant iron from Type Ia SNe. The required increase in bulge element yields can be obtained if the bulge had relatively fewer low-mass stars (i.e. a top-heavy IMF) than the disk. The same argument applies to giant elliptical galaxies: observed [Mg/Fe] ratios (e.g. Worthey et al. 1992) indicate rapid formation without much Type Ia SNe material, yet the metallicities are solar, or higher! But these measurements for giant elliptical galaxies were based on Lick indices, normally using template spectra of stars with solar [Mg/Fe] ratios. The GCIL abundance ratios will be superior. I note that the Lick indices of Henry & Worthey (1999) did not find enhanced [Ca/Fe] ratios in gaint elltipicals; this could be interpreted as evidence of a top-heavy IMF, since higher [Mg/Ca] ratios are expected for higher mass Type II SNe.

The reason is that the yields of hydrostatic alpha elements, like Mg and O, increase with stellar envelope (and total) mass (e.g. see Woosley & Weaver 1995 SN nucleosynthesis predictions), while the explosive alphas (e.g., Si, Ca, Ti) do not; indeed for very high mass core-collapse SNe the yield of iron and heavier alphas can decline, due to fall-back onto the remnant. In this way the [Mg/Ca] ratios are sensitive to the ratio of high-mass/low-mass Type II SN progenitors.

Thus, the [Mg/Ca] ratios will probe the slope of the IMF in Cen A which will add to the evidence for, or against, a variable IMF. The [C/O] ratios are also sensitive to the IMF slope. While a good oxygen abundance measurement can be obtained from the [O I] line at 6300Å the C measurement will prove difficult with the proposed MIKE spectra; however, future abundance studies with the near-IR CO bands at 1.6 and 2.3μ should provide very good carbon abundances.

Issues regarding the IMF are important for understanding the chemical history of a galaxy. In particular, the SFR and formation timescale inferred by the detailed chemical abundance ratios are sensitivite to the adopted IMF. Basically, if one only sees the ejecta from short-lived stars one might assume that the formation timescale was short, but if the IMF is very strongly weighted to massive stars the inferred formation timescale can be longer.

The scenario for the formation of elliptical galaxies is not universally accepted. For example, Larson (1974), Arimoto & Yoshii (1987), and Chiosi & Carraro (2002) favor a monolithic collapse model, where ellipticals are assumed to have formed at high redshift as a result of a rapid collapse of a gas cloud that is rapidly converted into stars. On the other hand, hierarchical semi-analytic models predict that ellipticals are formed by several merging episodes, which trigger star formation (e.g., White & Rees 1978). In this picture massive ellipticals form at relatively low redshifts though major mergers between spiral galaxies (e.g., Kauffmann & White 1993; Kauffmann & Charlot 1998).

While Cen A is a radio galaxy, its bimodal GC population is very similar to normal elliptical galaxies of the Virgo supercluster. Thus, Cen A may be used as a nearby laboratory for understanding the formation and evolution of early-type galaxies.

Lick index studies of Cen A GCs (e.g., Peng et al. 2004; Woodley et al. 2010; Beasley et al. 2008), have found a bimodal metallicity distribution and generally old ages. Intermediate-ages have been claimed for a number of the Cen A GCs by these studies, albeit with very large scatter and measurement uncertainties. These results supports a rapid, early, formation with subsequent major accretion and/or star formation events in more recent times. Major star bursts or mergers should result in a [α/Fe] ratio spikes (e.g. see Gilmore & Wyse 1991) for ∼Gyr timescales. Attempts at [α/Fe] ratio measurement for GCs in Cen A (e.g., Woodley et al. 2010; Beasley et al. 2008), also based on Lick indices, have been made, but with very large uncertainties; the plots of [α/Fe] with age and metallicity show enormous scatter, and are inadequate for chemical constraints on the formation timescale. It is clear, that progress on understanding the closest giant elliptical galaxy is hampered by the limitations of the Lick index method.

From the scatter in [Fe/H] derived from SSP models and from Washington colors, and from the scatter in [α/Fe], in Woodely et al. (2010), I estimate the typical abundance uncertainties between 0.15 to 0.20 dex for the Lick system; in contrast to quoted uncertainties as low as 0.01 dex. For GCIL abundance analysis of 47 Tuc McWilliam & Bernstein (2008) found the uncertainty in the mean [Fe/H] of $1\sigma=\pm0.03$ ±0.05 for random and systematic uncertainties, respectively, although that was for very good S/N spectra. The GCIL method of McWilliam & Bernstein (2008) employed two techniques for constraining GC ages, that are not included in the Lick system: a plot of excitation potential versus derived abundance for the Fe I lines, and the constraint demanding consistent age, metallicity and (B−V) color. When these more accurate [Fe/H] values and additional age constraints are added to the Lick system the age estimates will be superior to the Lick system alone.

Questions to be addressed with GCIL abundances of nearby galaxies include:

- What are the metallicities, [α/Fe] ratios, s-process and r-process abundances, and ages of Cen A GCs? Do these point to significant past major merger events? How do these abundance results impact the proposed formation scenarios for giant elliptical galaxies (i.e., monolithic collapse versus Hierarchical formation)?
- Is the implied Cen A formation timescale consistent with the mean metallicity, or is it necessary to increase the assumed element yields? And are the results consistent with the "outside-in" formation suggested by Pipino & Matteucci (2004)?
- Was the Cen A IMF, implied by [Mg/Ca] (and [C/O]) ratios, top-heavy?
- What constraints on nucleosynthesis can be obtained from the composition of Cen A GCs?
- What is fraction of late-time dwarf galaxy accretion for Cen A?
- Do detailed chemical abundances of Cen A resemble the Galactic bulge?
- What are the distributions of [Fe/H], [α/Fe] and ages for GCs in the spiral galaxies within ∼4 Mpc? Are there any correlations of these measured parameters with spiral type, luminosity, mass etc.? Do these measurements indicate past accretion events and how does the accretion history of the nearest large spirals compare with the Milky Way?

3. SPECTROGRAPH REQUIREMENTS FOR GCIL PROJECTS

- **Throughput.** The GC targets at ∼4 Mpc are V∼19, requires the best possible throughput for the instrument. The main point of a big telescope is to gather as much light as possible, thus it would be a waste not to demand the maximum possible throughput.
- **Resolution.** Velocity dispersions increase for more luminous GCs. Typical target GCs are expected to be M_v∼-9 to -10 (similar to 47 Tuc), for which the intrinsic line width are of order R∼11,000. Spectrograph resolving powers between R=20,000 and 30,000 would provide good resolution of the lines.
- **Wavelength coverage.** For normal metallicity GCs a wavelength coverage from 5000Åto 9000Å is desirable, while metal-poor GCs should include wavelengths at least from the Ca II K line at 3933Å to the Ca II triplet line near 8662Å.

- **Multiplexing.** Given that there are numerous GCs in the target galaxies, multi-object capability would be very powerful. However, if fibers are employed the light lost from the fiber and issues with sky subtraction may increase the noise significantly; we expect that one magnitude may be lost to this. Unfortunately, this would mean losing the faintest 1 magnitude of the GC luminosity function, and 1 magnitude of distance modulus from the range of the technique. A high-resolution multi-slit option is not practical for Gemini. Given these losses, and the added complexity of a multi-object system, I think that it is wiser to opt for a simple, but very efficient single-object slit spectrograph, and have an optional multi-fiber configuration available.

REFERENCES

Arimoto, N., & Yoshii, Y., 1987, A&A, 173, 23
Beasley, M.A., et al. 2008, MNRAS, 386, 1443
Chiosi, C., & Carraro, G., 2002, MNRAS, 335, 335
Gilmore, G., & Wyse, R.F.G. 1991, ApJ, 367, L55
Kauffman, G., & Charlot, S. 1998, MNRAS, 294, 705
Kauffman, G., & White, S.D.M. 1993, MNRAS, 261, 921
Larson, R.B. 1974, MNRAS, 166, 585
McWilliam, A., & Bernstein, R.A. 2008, ApJ, 684, 326
Peng, E.W., Ford, H.C., & Freeman, K.C. 2004, apj, 602, 705
White, S.D.M., Rees, M.J., 1978, MNRAS, 183, 341
Woodley, K.A., Harris, W.E., Puzia, T.H., Gomez, M., Harris, G.L., & Geisler, D. 2010, ApJ, 708, 1335