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THE NON-LINEARITY EFFECT ON THE COLOR-TO-METALLICITY CONVERSION OF GLOBULAR CLUSTERS IN NGC 5128

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ABSTRACT

The metallicity distribution of globular clusters (GCs) provides a crucial clue for the star formation history of their host galaxy. With the assumption that GCs are generally old, GC colors have been used as a proxy for GC metallicities. Bimodal color distributions of GCs observed in most large galaxies have, for decades, been interpreted as bimodal metallicity distributions, indicating the presence of two populations within a galaxy. However, the conventional view has been challenged by a new theory that non-linear GC color-metallicity relations can cause a bimodal color distribution even from a single-peaked metallicity distribution. Using photometric and spectroscopic data of NGC 5128 GCs in combination with stellar population simulation models, we examine the effect of non-linearity in GC color-metallicity relations on transformation of the color distributions into the metallicity distributions. Although in some colors offsets are present between observations and models for the color-metallicity relations, their overall shape agrees well for various colors. After the offsets are corrected, the observed spectroscopic metallicity distribution is well reproduced via modeled color-metallicity relations from various color distributions having different morphologies. We discuss the implications of our results.

Key words: galaxies: individual: NGC 5128 — galaxies: star clusters: general

1. INTRODUCTION

The color distributions of globular clusters (GCs) in most large galaxies are bimodal. The bimodal color distribution has generally been interpreted as a bimodal metallicity distribution, which indicates the presence of two populations within a galaxy. Yoon et al. (2006) gives a plausible alternative explanation for the origin of GC color bimodality, in which the non-linear nature of GC color-metallicity relations (CMRs) can lead to a bimodal color distribution even from a single-peaked metallicity distribution. The issue is still debated, although many studies have attempted to examine the new explanation by various means (e.g. Blakeslee et al. (2012); Chies-Santos et al. (2012); Brodie et al. (2012)).

The essential point of the dispute is whether GC CMRs are indeed non-linear and whether non-linear relations could effectively work on the conversion of GC metallicities into colors. The GC system of NGC 5128, the central giant elliptical in the Centaurus group of galaxies, is the best target to study this problem due to its proximity (∼4 Mpc), richness of GCs, and low internal extinction. In this study, using archival photometric and spectroscopic data for NGC 5128 GCs, we demonstrate the non-linearity of GC CMRs and examine the effect of non-linearity on the conversion between GC colors and metallicities.

2. DATA AND THEORETICAL MODELS

We match the photometric data obtained by Peng et al. (2004) and spectroscopic data obtained by Beasley et al. (2008) and Woodley et al. (2010). Of 235 GCs with both photometric and spectroscopic data, we select 99 GCs older than 8 Gyr which have spectral S/N greater than 30 for subsequent analysis.

The theoretical models used in this study are constructed using the Yonsei Evolutionary Population Synthesis (YEPS) code (Chung et al., 2013). The YEPS model comprehensively handles the effect of horizontal branch stars of GCs, which is the main source of non-linearity in GC CMRs. Since we selected relatively old GCs for our sample, we adopt the YEPS model of 13.0 Gyr for the following analysis. We adopt an alpha enhancement of $[\alpha/Fe]$=0.14, which was suggested by Woodley et al. (2010) as a mean value for NGC 5128 GC $[\alpha/Fe]$ values.

3. COLOR-METALLICITY RELATIONS

In Figure 1, the top panels represent color histograms of selected GCs and the solid lines show kernel density estimators of GC colors. The second row shows theoretical CMRs (red lines) and linear least-squares fits to the observed data (blue lines). There are some offsets between

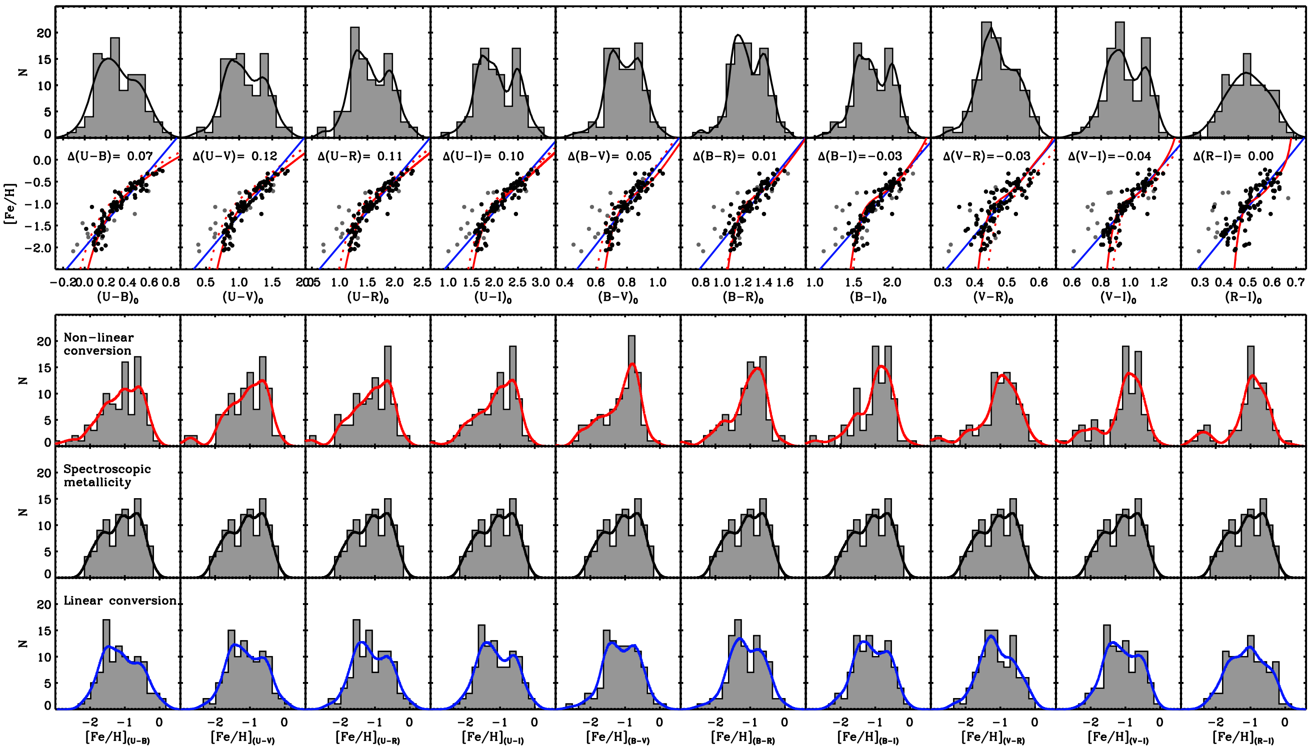

Figure 1. Color distributions, CMRs, and metallicity distributions of GCs in NGC 5128. See text for details.

observations and models in GC CMRs, which probably come from the incompleteness of the models and possible systematic uncertainties in observations, such as reddening corrections and standardizations. We determine the offsets in the direction of colors using total least squares fits with sigma-clipping after the normalization of colors and metallicities. The black dots are the final sample used in the total least square method and the grey dots are outliers removed by sigma clipping. The red dotted and solid lines represent the original 13.0 Gyr YEPS model and the model shifted by the offset value denoted on the top of each panel, respectively. We can verify that the non-linear model CMRs, after shifting by the offsets, match the observations in overall shape very well, though large scatter in the observations make the non-linearity vague.

4. CONVERSION OF GC COLORS TO METALLICITY

The third and the fifth rows in Figure 1 represent metallicity distributions converted from colors via YEPS model CMRs and linear fitted CMRs, respectively. The fourth row shows the observed spectroscopic metallicity distribution. The red, black, and blue lines in the lower panels show kernel density estimators of corresponding distributions. We find that the converted metallicity distributions via non-linear CMRs (3^{rd} row) from various color distributions having different morphologies reproduce the observed spectroscopic metallicity distribution features such as skewed distribution with a metal rich peak well, while the linear conversion (5^{th} row) fails to reproduce such features.

5. DISCUSSION

In this study, we demonstrate the non-linearity of GC CMRs and examine the effect of the non-linearity on the conversion of GC color distributions into metallicity distributions. We find that metallicity distributions converted through modeled non-linear CMRs show good agreement with each other, and the overall shape and the peak positions are quite similar to those of observed spectroscopic metallicity distributions. On the other hand, the shape of metallicity distributions converted from colors via linear CMRs significantly disagree with each other and have very different features from the observed distributions. Our results clearly show the non-linearity effect on the conversion between GC colors and metallicities, supporting the argument of Yoon et al. (2006). We also suggest a possible way of estimating true GC metallicity distributions, which is vital for exploring galaxy formation history.

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