A unified construction of stellar evolution and chemical evolution models for the multiple populations in globular clusters

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Abstract. Recent investigations of multiple stellar populations in globular clusters (GCs) suggest that the horizontal-branch (HB) morphology and mean period of type ab RR Lyrae variables are mostly sensitive to helium abundance, while the star formation timescale has the greatest effect on our chemical evolution model constructed to reproduce the Na-O anti-correlation of GCs. Therefore, by combining the results from synthetic HB model with those from chemical evolution model, we could put better constraints on star formation history and chemical evolution in GCs with multiple populations. From such efforts made for four GCs, M4, M5, M15, and M80, we find that consistent results can be obtained from these two independent models.

Keywords. globular clusters, multiple populations, horizontal-branch

Synthetic HB models constructed to reproduce the observed HB morphology and mean period of type ab RR Lyrae stars ($\langle P_{ab} \rangle$) are mostly sensitive to He & CNO abundances and relative ages for subpopulations (Lee *et al.* 1994; Jang *et al.* 2014; Jang & Lee 2015; Joo *et al.* 2013). These parameters are also provided by chemical evolution models reproducing the Na-O anti-correlation (Kim & Lee 2018). For the first time, by combining the results from synthetic HB model and chemical evolution model, we are able to place a better constraint on star formation history and chemical evolution in GCs with multiple populations. Our procedure for combining these two models is as follow:

1. A synthetic HB model first provides initial estimates of He & CNO abundances and a minimum number of subpopulations/generations (G1,G2, & G3...) within the fitting error of $\Delta Y = \pm 0.01$ and $\Delta [CNO/Fe] = \pm 0.2$ dex.

2. Then, the chemical evolution model reproducing the Na-O anti-correlation and the He and CNO abundances can provide Δt's between subpopulations and the number of required generations to within the fitting error of ± 0.04 Gyr.

3. The synthetic HB models are constructed again with these Δt's and the number of subpopulations.

4. These processes are repeated until the two models agree to within $\Delta Y \approx 0.01$, $\Delta t \approx 0.04$ Gyr, and $\Delta [CNO/Fe] \approx 0.03$ dex.

As a result, we can reproduce the Na-O anti-correlation, HB morphology and, $\langle P_{ab} \rangle$ simultaneously with relatively low uncertainties ($\Delta[Na/Fe] = \pm 0.08$, $\Delta[O/Fe] = \pm 0.06$, ΔHB type $= \pm 0.03$, $\Delta\langle P_{ab} \rangle = \pm 0.015$ days). Figure 1 shows our best-fit models for the four GCs (M4, M5, M15, and M80) compared with the observations (adopted from Figure 1 of Jang *et al.* 2019).
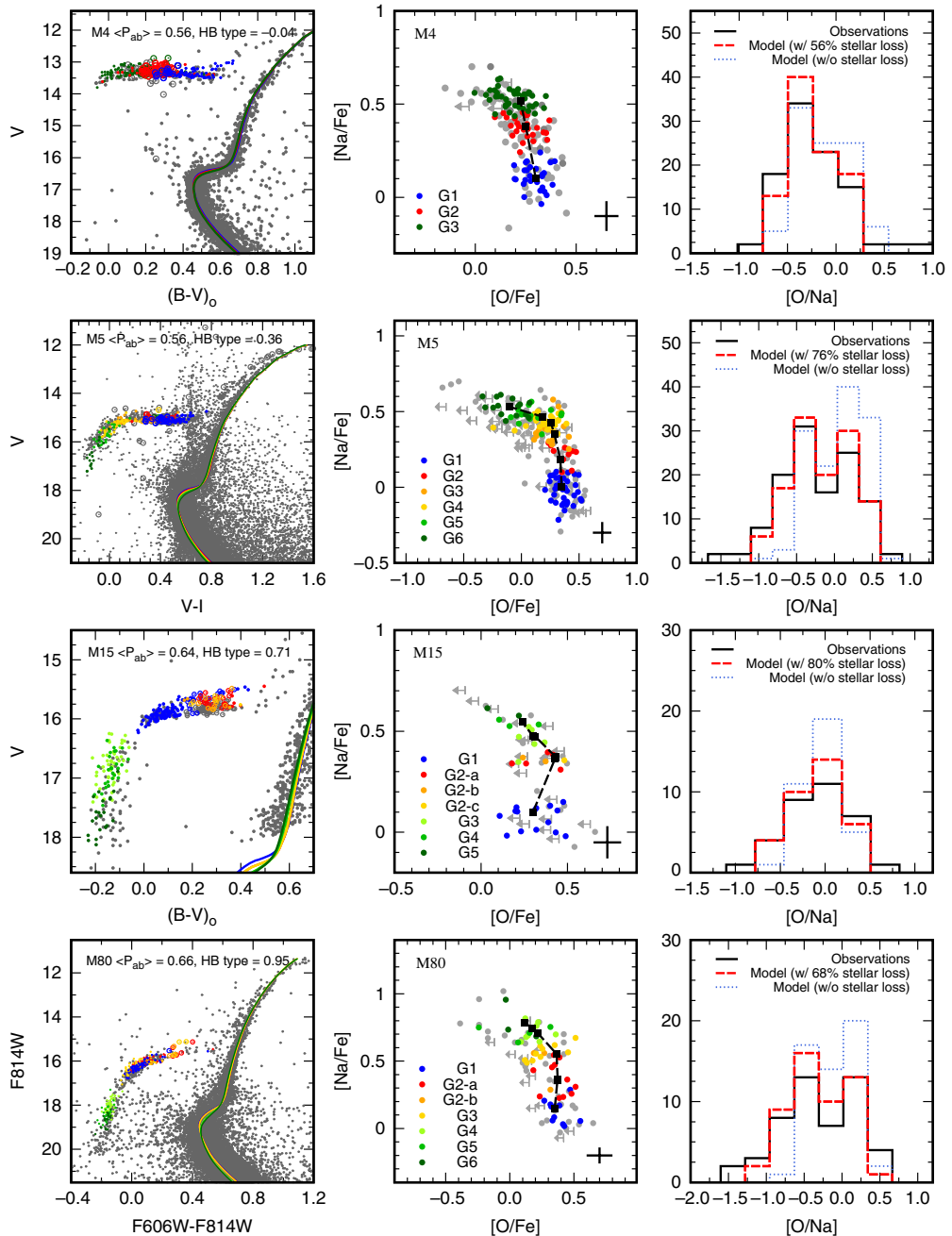
Figure 1. Our synthetic HB and chemical evolution models compared with photometric and spectroscopic observations for M4, M5, M15, and M80 (adopted from Figure 1 of Jang *et al.* 2019; data in gray color from Mochejska *et al.* 2002; Stetson *et al.* 2014; Viaux *et al.* 2013; Arellano Ferro *et al.* 2016; Buonanno *et al.* 1985, 1994; Bingham *et al.* 1984; Anderson *et al.* 2008; Carretta *et al.* 2009a,b, 2015). The left panels compare the synthetic HB models and isochrones (colored circles and lines) with the observed CMDs. The middle and right panels are our chemical evolution models compared with the observed Na-O anti-correlations and [O/Na] histograms (see the text for the details). In the middle panels, our model predictions with/without observational errors are depicted by colored circles and filled black squares.

References

Anderson, J., Sarajedini, A., Bedin, L. R., *et al.* 2008, *AJ*, 135, 2055
Arellano Ferro, A., Ahumada, J. A., Kains, N., *et al.* 2016, *MNRAS*, 461, 1032
Bingham, E. A., Cacciari, C., Dickens, R. J., & Pecci, F. F., 1984, *MNRAS*, 209, 765
Buonanno, R., Corsi, C. E., Buzzoni, A., *et al.* 1994, *A&A*, 290, 69
Buonanno, R., Corsi, C. E., & Fusi Pecci, F., 1985, *A&A*, 145, 97
Carretta, E., Bragaglia, A., Gratton, R., & Lucatello, S. 2009a, *A&A*, 505, 139
Carretta, E., Bragaglia, A., Gratton, R. G., *et al.* 2009b, *A&A*, 505, 117
Carretta, E., Bragaglia, A., Gratton, R. G., *et al.* 2015, *A&A*, 578, A116
Jang, S., Kim, J. J., & Lee, Y.-W. 2019, submitted
Jang, S. & Lee, Y.-W. 2015, *ApJS*, 218, 31
Jang, S., Lee, Y.-W., Joo, S.-J., & Na, C. 2014, *MNRAS*, 443, L15
Joo, S.-J. & Lee, Y.-W. 2013, *ApJ*, 762, 36
Kim, J. J. & Lee, Y.-W. 2018, *ApJ*, 869, 35
Lee, Y.-W., Demarque, P., & Zinn, R. 1994, *ApJ*, 423, 248
Mochejska, B. J., Kaluzny, J., Thompson, I., *et al.* 2002, *AJ*, 124, 1486
Stetson, P. B., Braga, V. F., Dall'Ora, M., *et al.* 2014, *PASP*, 126, 521
Viaux, N., Catelan, M., Stetson, P. B., *et al.* 2013, *A&A*, 558, 12