The Art of Modelling Stars in the 21st Century
Proceedings IAU Symposium No. 252, 2008
L. Deng & K.L. Chan, eds.

doi:10.1017/S174392130802334X

The Y^2 Isochrones Getting an Extra Dimension

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Abstract. The Yonsei-Yale Isochrones have been widely used since its birth in 2001. We announce a major upgrade mainly making varieties of helium values available. The recent works on the globular clusters with extreme helium abundances have called for such a need. The new version of the Y^2 Isochrones are available for $[\alpha/Fe] = 0$ through 0.6, $\Delta Y/\Delta Z = 1.5$ through 3.0, and extreme helium abundances ($Y =$ normal 0.05, 0.1, 0.15, 0.2), and for 11 metallicity grids, with full capability of interpolation. The database will be powerful for making population models. Besides, the accuracy of the models on the lower main sequence has been substantially improved. We illustrate the major upgrades and demonstrate the power of the new grids.

1. Introduction

Since Demarque and Larson (1964) used the concept of isochrone to derive the age of NGC 188, isochrones have been widely utilized in stellar population studies. This purely theoretical achievement helps setting one of the most important constraints on cosmology, because the age of the universe is a distinctive product of any cosmological model.

The Yonsei-Yale (Y^2) Isochrones (Yi *et al.* 2001) have been popular mainly for the following reasons. First, it reproduces the shapes of the observed color-magnitude diagrams (CMDs) of star clusters very well, which is important for cluster age estimation. Second, it covers a wide parameter space (11 metallicity grids, 3 alpha enhancement grids), which is particularly useful for population synthesis. Lastly, it is available for two options of the temperature-color transformation schemes. The Green *et al.* transformation appears superior in the metal-poor regime, but in the metal-rich regime Lejeune *et al.* calibration seems to work better (see Yi *et al.* 2001 for discussion).

2. Lower Main Sequence

The Y^2 isochrones, like most others, however had shortcomings. Most notable was the inaccuracy of its low-mass main sequence models. As (implicitly) demonstrated in Yi *et al.* (2001, see their Figure 10), their low-mass models are much redder than fainter than observation. This problem is particularly visible when the super-accurate photometry data have been obtained by space telescopes. Figure 1 shows the recent HST data of the globular cluster NGC 6387 (Richer *et al.* 2008). The data are for the proper-motioned confirmed member stars only. The incredible clearness of the main sequence down to the brown dwarf limit is unprecedented. Such a robust data provides a testbed for stellar evolution theory while posing a threat as well. We compare our updated isochrones to the observed HRD in Figure 1. The models are not yet the final, well-calibrated ones, but

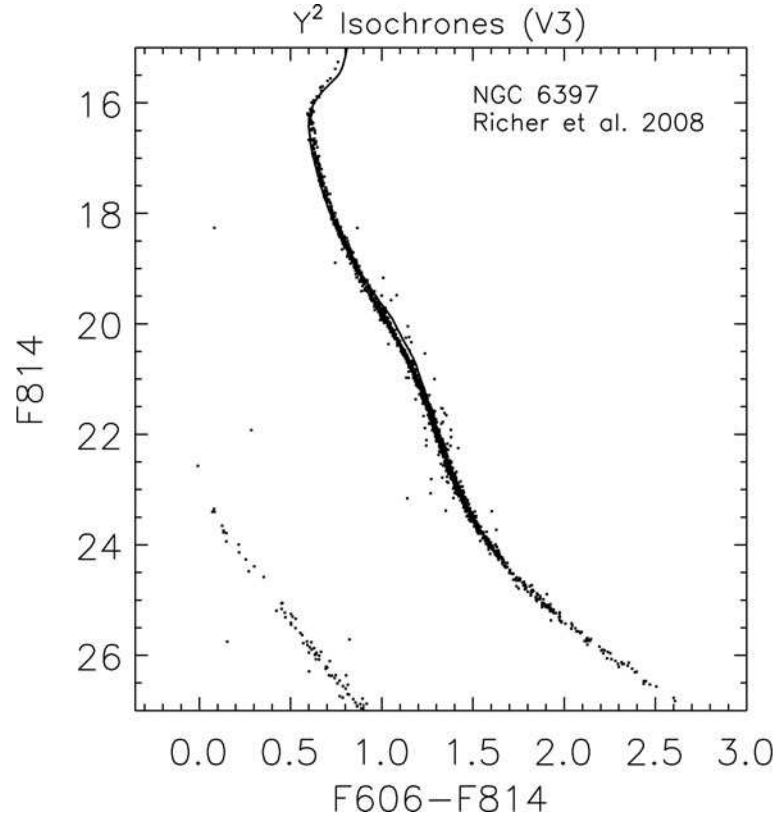

Figure 1. The HST observed HRD of NGC 6397 from Richer *et al.* (2008) compared with our new isochrone that has been improved for the accuracy on the lower main sequence.

simply based on the theoretical Kurucz spectral library. Yet, the match is surprisingly good. The delicate curvatures are reasonably reproduced. It should be noted that our models reach down to 0.2 solar mass, and so missing the lower end of the main sequence observed.

A very important remark to make is that such a good match is not possible when simple filter conversion formulae (from HST filters to Johnson VI) are used. In this sense, it is critical to use the isochrones specifically computed for the filter systems used for the observation.

3. Helium abundances

A remarkable new information has recently emerged on the chemical compositions of some stars. Observations for the colour-magnitude diagrams on globular clusters ω Cen and NGC 2808 revealed multiple populations. The most massive globular cluster ω Cen for example is now known to have up to five different metallicities both for the main sequence and the red giant branch (Bedin *et al.* 2004). Most shockingly, the bluest main sequence is found spectroscopically to be more metal-rich (Piotto *et al.* 2005) which implies an extremely high helium abundance of $Y \approx 0.4$. Interestingly, Lee *et al.* (2005b) noted that such extreme helium stellar populations would evolve into the extremely hot part of the HB explaining the hitherto mysterious origin for the EHB stars of ω Cen. Lee *et al.* claims that the same phenomenon is seen in NGC 2808 as well. Figure 2 shows a

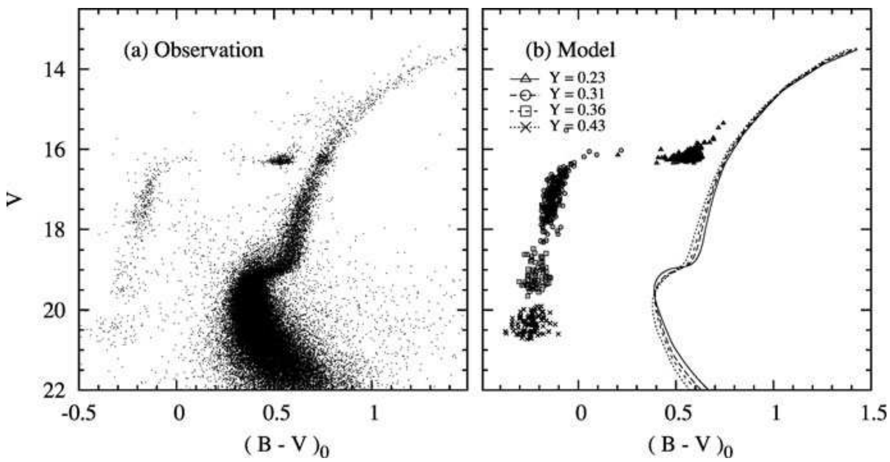

Figure 2. The observed and modeled colour-magnitude diagrams of the globular cluster NGC 2808. *left*: The cluster shows an exceptionally wide distribution of horizontal branch stars. *right*: It can be precisely reproduced by theory for example by assuming a large range of helium abundance. Original version from Lee *et al.* (2005b) and kindly provided by Chul Chung.

comparison between the observed HRD and our synthetic HRD using our latest stellar models. One can notice the wide scatter on the observed main sequence and an incredibly spread-out HB. NGC2808 has been a challenge to stellar evolution theory in this sense. Now with a new hypothesis of extreme helium abundances, we were able to reproduce both MS and HB spreads rather easily. Similar phenomena have been found amongst M87 globular clusters, too (Kaviraj *et al.* 2007).

Such a high helium abundance could in fact be more mysterious than the origin of the EHB stars itself, hence became a hot topic. The high value of helium abundance ($Y \approx 0.4$) seems particularly impossible when it is combined with its low metallicity empirically constrained ($Z \approx 0.002$–0.003). This leads to $\Delta Y/\Delta Z \approx 70$ which is extremely unlikely from the galactic chemical enrichment point of view unless some exotic situation is at work, such as the chemical inhomogeneity in the proto-galactic cloud enriched by first stars (Choi & Yi 2007; 2008). Inspired by this wave, we extend our models towards non-standard values of helium abundance.

4. Prospects

The sample fits we show in this paper demonstrate the power of the up-to-date stellar models in understanding (or at least reproducing) the details of stellar evolution. Whether such models are truly realistic will be answered only when we test the underlying hypotheses against more targets. Recent compilations of HST data on Galactic globular clusters by the Ata Sarajedini group and others are particularly exciting for providing such opportunities.

Our new isochrone database will likely be released in early 2008 in a published form. It will contains all the core hydrogen burning stages but core helium burning stages will be available soon after that. We expect it to be a powerful database to investigate various topics related with stellar populations with. Such examples include the origin of helium-rich populations, the UV upturn in massive spheroids, galactic halo formation, etc. Meanwhile, the availability of new hyper-accurate space photometry data will be critical to test and further elaborate stellar models beyond yesterday's imagination.

Acknowledgements

We thank Harvey Richer and Ivan King for sending us their new HST photometry data on NGC 6397. We are grateful to Chul Chung for regenerating the NGC2808 model HRD that suits the format of this paper. This research has been supported by Korea Research Foundation (SKY).

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Discussion

Z. Han: You used an extreme helium enrichment to explain the CMD of ω *Centauri*. I was wondering whether you have any other pieces of evidence for the enrichment?

S.K. Yi: The extreme helium abundance is derived indirectly from the CMD fitting and spectroscopic metal measurements. There is no other "direct" evidence as far as I know.

L. Deng: What is the main difference between your Y^2 isochrone and other isochrones e.g., Padova, Geneva?

S.K. Yi: Y^2 isochrones do not cover large-mass stars of $M > 5M_\odot$ but focus on making precision models for low-mass stars, compared to others. We also attempt to cover a wide parameter space so that they can be useful for the studies of unknown populations. There are other difference in the input physics as well.

G. Meynet: (1) Will you provide isochrons with the solar abundance given by Asplund *et al.* (2005)? (2) Can you say a few words about that He–rich stars in ω *Cen*?

S.K. Yi: (1) maybe in the future. (2) ω *Cen* is reported to have extreme–helium population of $Y \sim 0.4$, $\triangle Y/\triangle Z \sim 70$. Candidate origins include SNe, AGB stars, and rotating massive stars. We think (Choi & Yi 2007, 2008) AGB stars are very unlikely under the current theoretical assumptions. Rotating massive stars seem plausible, but it requires an explanation why only some globular clusters show this, and not galaxies.