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Old Metal-rich Systems and the Mid-ultraviolet

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Abstract
As part of our Hubble Treasury program, we are using stellar spectra calculated from first principles for the mid-UV and optical regions to better understand the age and metallicity of old stellar systems such as globular clusters. We have compared combinations of spectra calculated for six individual stellar models to archival Faint Object Spectrograph mid-UV and optical spectra of the globular cluster G1 in Andromeda, finding an excellent match once spectra of hot horizontal branch stars are included. Both cool BHB stars and the very hot EHB stars are required. We show how the mid-UV can characterize their presence.

1.1 Introduction

Our Hubble Treasury program GO-9455 aims to provide tools to the community to better understand the age, metallicity, and population of old stellar systems such as globular clusters and elliptical galaxies from their spatially-unresolved composite spectra. These tools will include observational templates – the mid-UV and optical observed spectra of standard field stars, stars in old open clusters, and globular clusters in M31 (the Andromeda galaxy); and theoretical templates – mid-UV spectra calculated for a range of abundance mixtures and overall abundances for a variety of individual stars, and coadded to represent mono-age, mono-metallicity old stellar populations.

We calculate stellar theoretical spectra following Peterson, Dorman, & Rood (2001). We use the Kurucz program SYNTHE to generate spectral fluxes, from a modified and augmented Kurucz line list of atomic and molecular parameters and the stellar photospheric models of Castelli, Gratton, & Kurucz (1991) in which convective overshoot has been turned off. To produce theoretical composite spectra, we will coadd these theoretical stellar spectra, using weights to be found from stellar isochrones generated from stellar evolutionary sequences of the same range of abundances and abundance mixtures.

1.2 Comparing Calculations to Observations: M31 G1

To test the utility of our spectral calculations, we have run a simple trial comparison. We generated various combinations of spectra calculated for six individual stellar models at a given metallicity, and compared them to archival Hubble Space Telescope mid-UV and optical spectra of the M31 globular G1. Here we summarize the results and reproduce a pair of figures from this work (Peterson et al. 2003: copyright 2003. The American Astronomical Society. All rights reserved. Printed in U.S.A.)

Each panel shows five comparisons of observed spectra of M31 G1 (heavy line) and calculated spectra (light line). At the bottom of each panel is a comparison for a single star, HD 106516, and its model (Peterson et al. 2001). The G1 observed spectra was discussed by Ponder et al. (1998), and is dereddened by E(B-V) = 0.06.

Each composite spectrum is the sum of four to six stellar model spectra of the same metallicity [Fe/H] and the same relative abundance enhancement of the light elements, either +0.2 or 0.0 (solar). Every composite spectrum includes spectra representing main-sequence turnoff (MSTO) stars, main-sequence (MS) stars, red giants, and red horizontal branch (RHB) stars, whose weighting factors were simply estimated from star counts in the color-magnitude diagram of the Galactic globular cluster 47 Tucanae. Four of the composite spectra also include hot stars, either the evolved blue horizontal branch (BHB) and extreme horizontal branch (EHB) stars, or the blue straggler stars (BSS) above the MSTO.

In fitting theoretical spectra to the observations, a single normalization constant adjusted only for reddening was adopted for both the optical and the mid-UV. The continuum slope was matched by choosing the turnoff temperature. Metallicity was chosen to fit the optical lines.

1.3 Results

In the optical, all the theoretical composite spectra match the G1 observations about as well as the stellar calculation matches HD 106516 – except for CH and CN. CH appears weaker in G1 than in the calculations, and CN is seen to be much stronger. Except for this, from the optical alone we can achieve a reasonable fit with no hot stars, at [Fe/H] = –0.8 and a turnoff temperature of 6250K. Adding blue stragglers improves the Balmer-line fit, but raises the metallicity to [Fe/H] = –0.5.

In the ultraviolet, the composite spectrum without hot stars fails dramatically to reproduce the level of mid-UV flux below 2600A, and generates line cores that are too deep for the Mg II doublet at 2800A and the iron blend at 2730A. When hot BSS or a cool BHB star is added, these discrepancies are reduced but not eliminated.

The best fit includes both BHB and EHB stars. The turnoff temperature becomes 200K lower compared to the composite spectrum with no hot stars. The metallicity [Fe/H] = –0.8 agrees very well with that inferred by Rich et al. (1996) from the slope of the giant branch in the V,V-I color-magnitude diagram. Cool BHB stars are also seen in that diagram (hotter ones are largely too faint for detection there). The turnoff temperature of 6000K for the composite BHB + EHB spectrum agrees well with that of turnoff field metal-poor stars. This suggests that G1 is as old as the Galactic halo.

Despite the old age and moderate metallicity of G1, it harbors both cool and extremely hot stars on the blue horizontal branch. These stars make their presence known strongly in the mid-UV, but are barely detectable in the optical except for the Balmer lines. If not included in the spectral analysis, younger ages and/or lower metallicities would be inferred.

References

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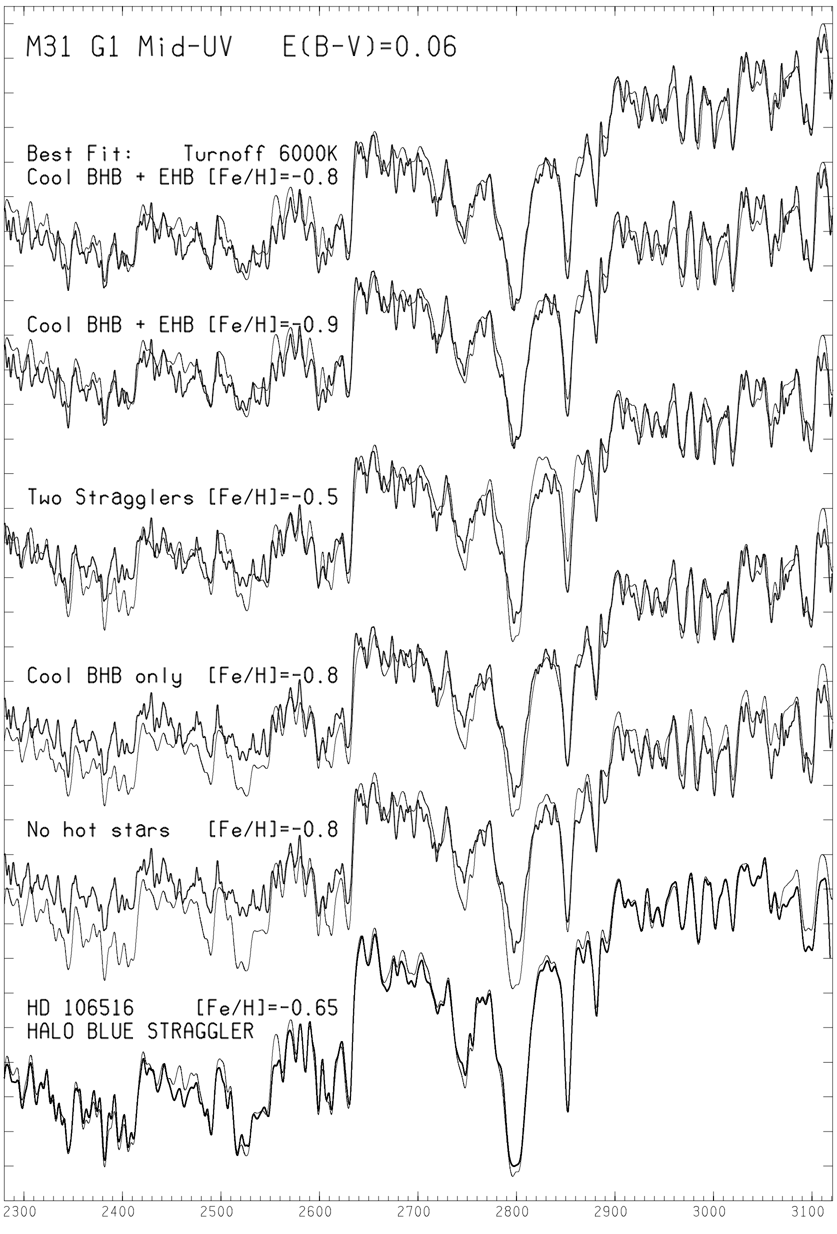

Fig. 1.1. Calculated spectra (light lines) are overplotted on observed spectra (heavy lines) of the M31 globular cluster G1 and the standard star HD 106516 at the bottom. Wavelengths in air appear beneath. Along the Y axis, tick marks show 10% of the maximum flux. The topmost plot shows the best fit of a composite spectrum to G1. As described in the text, this good fit requires that both cool BHB stars and hot EHB stars be included in the composite spectrum.

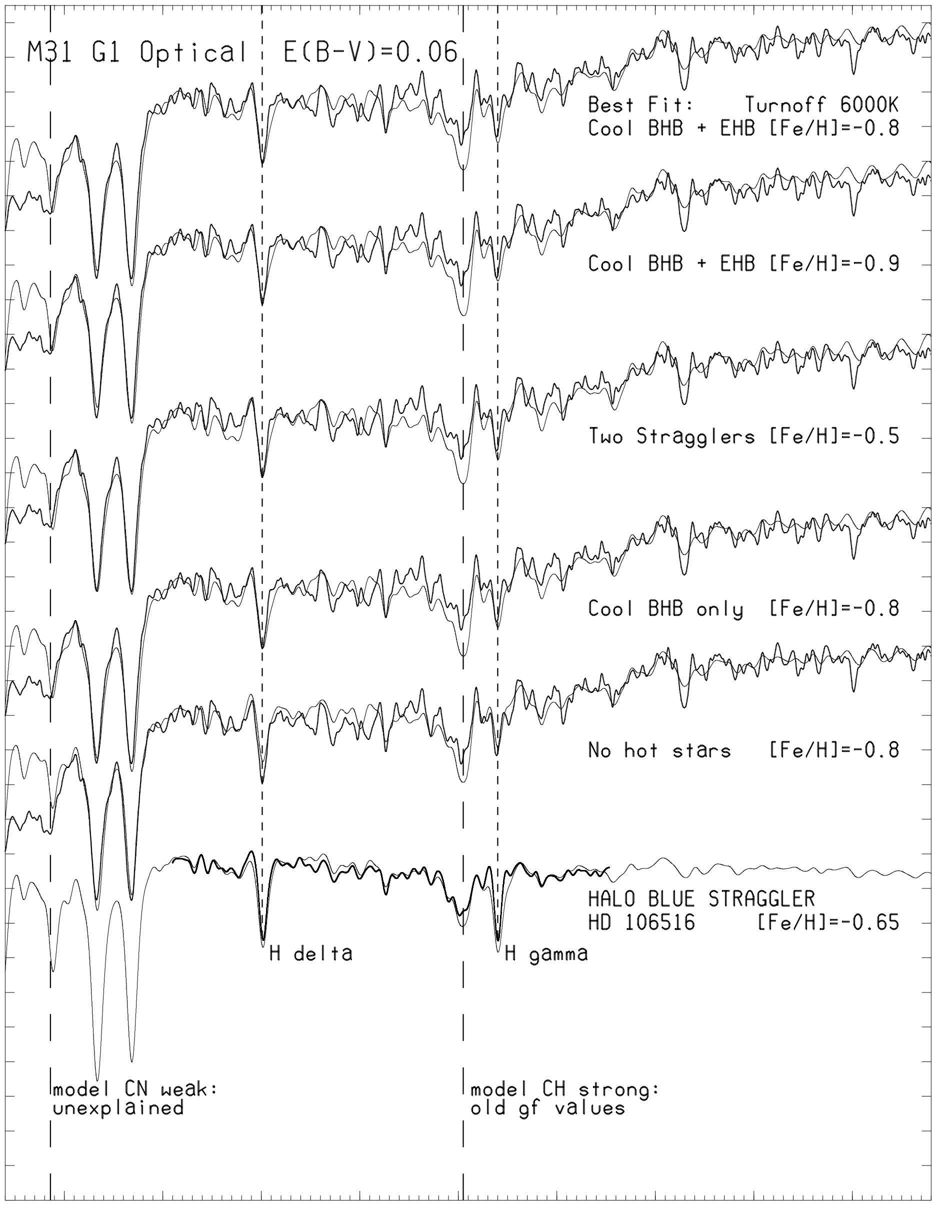

Fig. 1.2. The same comparisons as in the previous figure are shown in the optical rather than the mid-UV. In this spectral region, all composite spectra provide a respectable if not perfect fit. The Balmer lines Hδ and Hγ are somewhat underrepresented in the calculated composite spectrum which lacks hot stars, but otherwise the fit is very much like the fits for which hot stars have been included.

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