

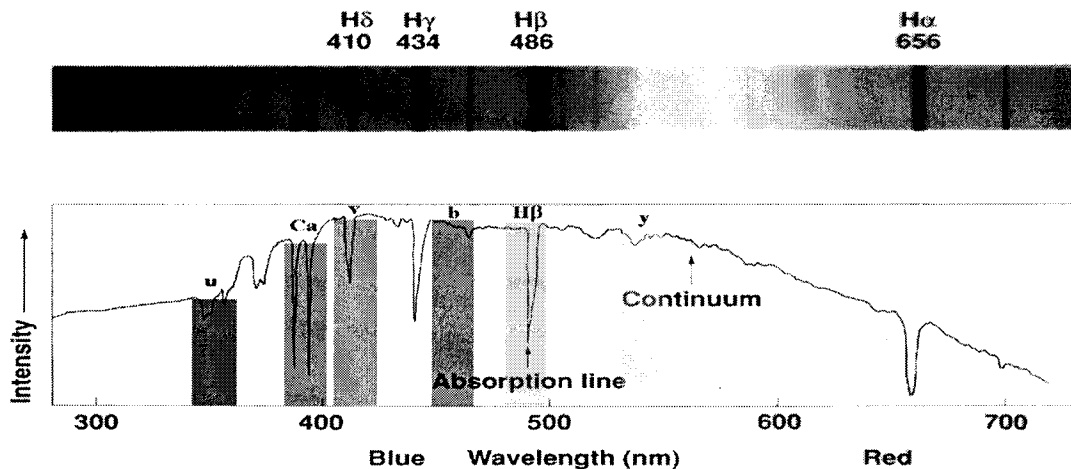
# H $\beta$ and Ca Extensions Expose Metal-Rich Dwarfs

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The photometric analysis of a selection of Hipparcos stars determined that a fraction of the selected stars are metal-rich G through K type dwarfs. The findings discussed below show a large spread in the b-y temperature index vs. the H $\beta$  temperature index which is proven to be caused by a difference in metal content compared to the average solar type star.

## Introduction

The Strömgen photometric system has been widely used to measure the effective temperature, luminosity, and metal content of stars. It includes four intermediate-band filters: ultraviolet (u), violet (v), blue (b), and yellow (y). This intermediate-bandpass system is filter-defined, requiring no second-order terms in the extinction corrections or transformation equations.



Visual portion of stellar spectrogram

Hartmann/Impey: The Cosmic Journey, 5th ed., Fig. 16-6, Hartmann: The Cosmic Voyage, 1992 ed., Fig. 16-3

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Figure 1. The band passes of the key filters from the Strömgen system including the H $\beta$  and Ca extensions.

However, all the filters are affected by the fundamental stellar parameters so combinations of the filters are used to create color indices that can disentangle the parameters, such as

$$\begin{aligned} & b-y \text{ for temperature} \\ m_1 &= (v-b)-(b-y) \text{ for metallicity} \\ c_1 &= (u-v)-(v-b) \text{ for luminosity.} \end{aligned}$$

Color-color plots of the indices can then be used to enhance the isolation of the parameters.

Figure 1 exhibits the band passes of the Strömgen system with its H $\beta$  and Calcium extensions. The H $\beta$  extension uses a narrow filter and a broader filter that measure on the same central wavelength, the H $\beta$  line of the Balmer series. The narrow filter is 25 Angstroms wide and measures how much light passes at the line wavelength, i.e., it measures the line strength. The broader filter is 250 Angstroms wide and measures how much energy is emitted in the absence of the line, i.e., it measures the continuum of the spectrum near the Balmer line. The Ca filter measures the H and K lines of Ca II and, when combined with the traditional uvb filters, can be used to construct the

metallicity index  $hk$ . The  $hk$  index works much like  $m_1$  above, but replaces the  $v$  filter with  $Ca$ :  $hk = (Ca-b) - (b-y)$ .

The need for the  $H\beta$  (NOT Calcium) extension is that metallicity may cause the  $uvbyCa$  indices to shift because both temperature and metal content can affect the color of a star - higher metallicity makes stars appear redder. This could cause stars to be misclassified by spectral type or luminosity class.

According to the work done by Twarog et al. (2002, 2007), late G through K type stars in the subgiant class are easily confused with exceptionally metal-rich dwarfs because the  $m_1$  and  $c_1$  indices for exceptionally metal-rich dwarfs are anomalous. Using the extended Strömrgren system with  $H\beta$  may be a way to isolate the very metal-rich dwarfs from the subgiants.

## Observations and Reduction

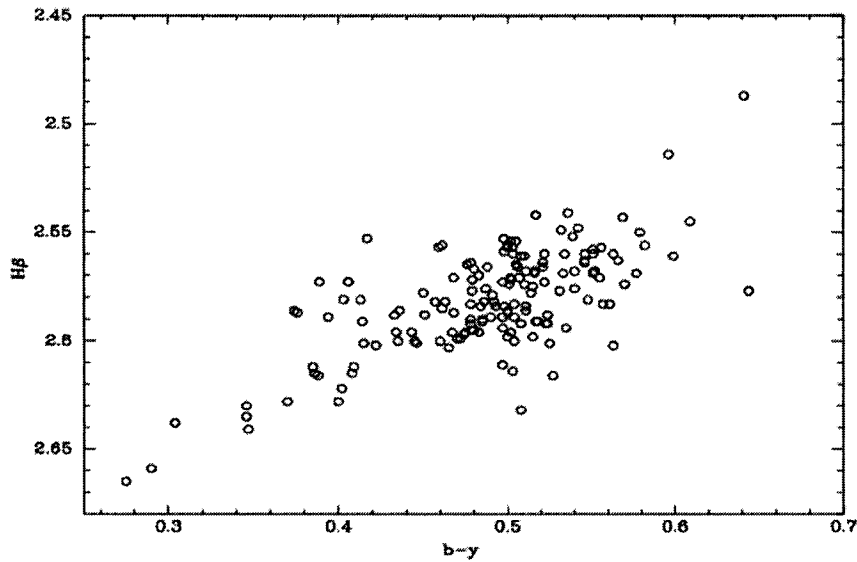
Strömrgren photometric data was obtained with the 24" and 40" telescopes at Mt. Laguna Observatory during Lindsay Mayer and Luis Vargas run in July 2005 (hereafter referred to as MV). Additional Strömrgren data with the  $H\beta$  and  $Ca$  extensions were obtained with the photomultiplier photometer on the 24" telescope at Mt. Laguna Observatory during July 2007. Data used in the current analysis were only taken under photometric conditions. The general sequence was to observe each star in the filter sequence:  $\beta_n$ ,  $\beta_w$ ,  $Ca$ ,  $y$ ,  $b$ ,  $b$ ,  $y$ ,  $Ca$ ,  $\beta_w$ ,  $\beta_n$ , followed by observations of blank sky through each filter. Integration times for each filter were set to provide a total of  $\sim 10,000$  counts above sky for summed integrations in each filter, with a minimum to integration time of 10 seconds. In some cases, individual filter integrations were repeated to bring the total count level closer to the desired 10,000 counts.

We observed stars previously observed by MV these were program stars selected from the Hipparcos catalog and standard stars selected from Olsen (1993). The program stars were selected based on their temperature range as defined by the  $b-y$  index ( $0.4 < b-y < 0.6$ ), and their absolute magnitude if indicative of the star being a dwarf (Vargas 2005).

Data reduction was done using Microsoft Office Excel 2003 to convert the counts to instrumental magnitudes and indices, as well as determine the extinction coefficients from the nightly observations and the transformation coefficients from the instrumental to the standard system from the standard stars. Each star's counts were reduced to the instrumental magnitudes, and then the extinction coefficients for each night were found using the extinction stars from each night to adjust each star for extinction. Next, the zero points from all the stars in common were used to merge all the nights into one instrumental system and the standard stars were again used to find the transformation coefficients to convert the instrumental values for the program stars to the standard system for  $b-y$ ,  $hk$ , and  $H\beta$ . The final indices for the program stars were then used to make the color-color comparisons of  $(b-y)-H\beta$ ,  $hk-(b-y)$ , and  $hk-H\beta$ .

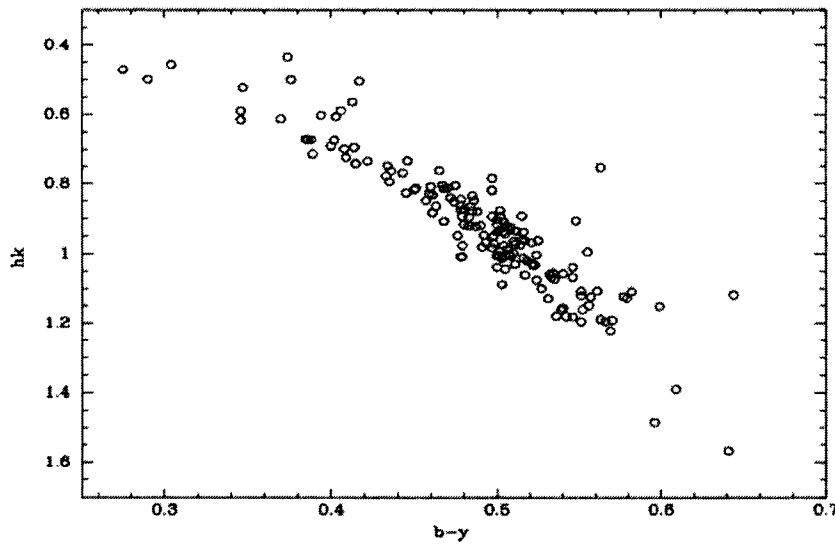
## Analysis

Figure 2 shows the  $b-y$  vs.  $H\beta$  for the program and standard stars. If all the stars had the same metallicity they would form a straight line with  $H\beta$  decreasing as  $b-y$  increases. In Figure 2, there is a trend of that sort, but it scatters around  $b-y = 0.37$  to  $0.6$ . This scatter shows a band of stars that are at different positions because of how red the stars are. The band lies across the mean relation between  $H\beta$  and  $b-y$ . Stars toward the left in the band should be metal-poor, i.e.,  $b-y$  looks bluer, and stars toward the right should be metal-rich, i.e.,  $b-y$  looks redder. If what is claimed about the metallicity in the band is true, then the small group of stars that lie around  $H\beta = 2.58$  and  $b-y = 0.4$  are metal-poor stars and the fairly larger group of stars that lie to the opposite side of the mean relation are metal-rich stars. The redder stars possibly could be caused by interstellar reddening, but since these are nearby stars it is unlikely.



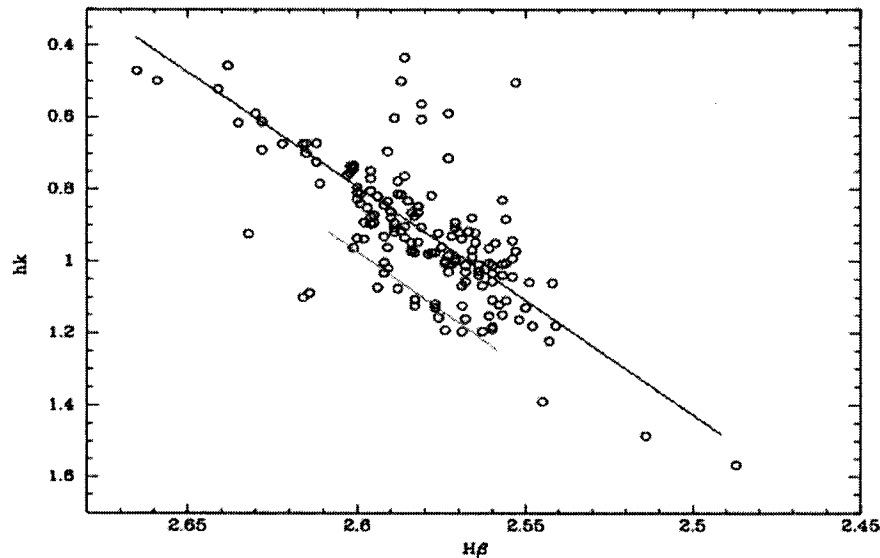
**Figure 2.** The relationship between the two temperature indices,  $H\beta$  and  $b-y$ , for the program and standard stars.

Figure 3 shows a well-defined trend from the top left to lower right. Metallicity in this figure decreases vertically up and increases vertically down. If the claimed metal-poor stars from Figure 2 around  $b-y=0.4$  are looked at in Figure 3, it is shown that they are undeniably metal-poor (they have smaller  $hk$  indices at their  $b-y$ ) and this figure also confirms the claim about the mean relation and metallicity scale of the band.



**Figure 3.** The relationship between the metallicity,  $hk$ , and the color temperature,  $b-y$ , indices for the program and standard stars.

Figure 4 shows the majority of the stars located between  $H\beta = 2.55$  to  $2.6$  and the stars where  $hk \approx 0.5$  are the confirmed metal-poor stars from Figures 2 and 3, but now they have the same  $H\beta$  as those with larger  $b-y$  values. This again supports the claim that the band in Figure 2 is caused by metal abundance and not temperature. It's also expected that the stars that parallel the main trend line are high metallicity stars, but exactly how high will be determined when the data can be combined with the  $uvby$  data from MV.



**Figure 4.** The relationship between the metallicity,  $hk$ , and the temperature,  $H\beta$ , indices for the program and standard stars. The top line shows the approximate main trend line and the bottom line shows the parallel stars that are expected to be metal-rich.

## Conclusions

Stars observed by MV were observed a second time, but with the  $H\beta$  and Ca extensions, as well as the b and y filters from the Strömgren, because it appeared that the cause of the possible misclassification found by MV was due to the temperature index b-y. Strömgren color indices are readily affected by temperature and luminosity, but they can also be affected by metal abundance in that exceptionally metal-rich dwarfs may be confused with normal subgiants. To prove that the temperature index b-y was significantly affected by the high metal content of some of the stars, another temperature measurement was made with  $H\beta$ , which should be both reddening and metallicity independent. Figure 2 shows the b-y indices for a large portion of the program stars appear to scatter off the main relation for normal field stars with  $H\beta = 2.55$  to 2.6. The difficulty of determining if this scatter is the product of metallicity effects using the traditional  $hk$ -(b-y) diagram is illustrated in Fig. 3, while Fig. 4 demonstrates that using  $H\beta$  as the primary temperature index successfully overcomes this problem. When combined with the earlier data of MV, it will be possible to determine the definitive metallicity of these stars, as well as identify any super-metal-rich stars that may incorrectly appear to resemble subgiants from the traditional uvby indices. This essentially supports the claim that b-y was at least part of the cause of the misclassification of G through K type metal-rich dwarfs as subgiants.

## Acknowledgments

I would like to thank the program for giving me the chance to learn about and experience real astronomical research. I'd also like to thank Dr. Etzel and my advisor Dr. Twarog for showing me how things are in the real world of astronomy up at MLO. This program had to have been one of the coolest experiences I've ever had and I'm excited for the ULTRA project to be up and running!

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