The Strömgren System:

A Problem with the c_1 Index

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The photometric analysis of 96 stars with *Hipparcos* parallaxes (Perryman et al. 1997) confirmed a discrepancy between the absolute magnitude, M_V, and the Stromgren c_1 index. The problem with the c_1 index is related to a strong metallicity correlation for late-type stars, spectral class G2-K8, at (b-y) greater than 0.40. The c_1 index is inflated above ~0.35 for 19 out of the 96 observations implying that these stars are giants when their absolute magnitudes verify that they are dwarfs. The source of this problem is discussed.

Introduction

The Strömgren photometric system has been widely used to define the parameters of a star independent of distance. The intermediate band pass filters were chosen to identify characteristics of a spectrum that the Johnson system could not. The b and y filters are centered on regions of the spectrum that have very few spectral features so that the (b-y) temperature index can be transformed to the (B-V) temperature index with very little scatter. The m_1 index, (v-b)-(b-y), is designed to measure the line-blanketing effects mostly on the v filter which is directly correlated with metallicity. The c_1 index, (u-v)-(v-b), is designed to measure the height of the Balmer discontinuity which should reflect the star's intrinsic luminosity [Crawford & Barnes (1970)].

Recently a problem has been identified with the metallicity calibration for late-type G and K stars by Twarog et al. (2002). The source, the c_1 index, emerged when comparing the Hyades cluster stars to stars that lie above Hyades in the color-magnitude diagram.

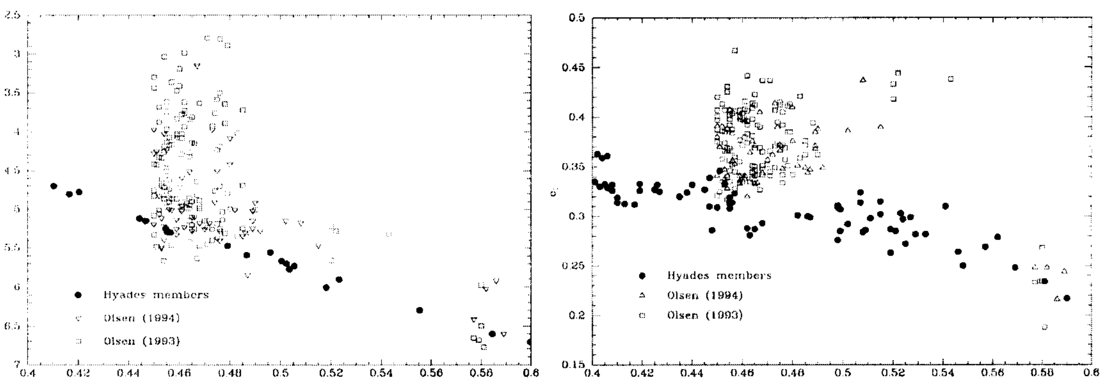

Fig. 1. The Hyades cluster members (filled circles) against stars from the Olsen catalogs (open triangles and squares). The plot on the left is color-mag diagram and the plot on the right is a color-color diagram of c_1 (Twarog et al. 2002).

In Figure 1 stars that are located between (b-y) of 0.47 and 0.57 on the CMD sit above the main sequence either because they are metal-rich or binaries. They are only 0.2-0.7 magnitudes brighter than the Hyades main sequence implying that they are not bright enough to be giants. However in the color-color plot in Figure 1, the c_1 index places them 0.08 - 0.15 magnitudes above the Hyades main sequence classifying them as giants. This error in the c_1 index is too large to be compensated by photometric scatter; therefore, these stars are affected either by an atmospheric anomaly or they are very metal-rich (Twarog et al. 2002).

There is a dearth of stars within this temperature range with reliable Strömgren photometry to conclude anything significant about the c_1 index, but this raises enough interest to investigate the problem. The *Hipparcos* catalog provides reliable absolute magnitudes for 118,000 stars within ~500 pc and can be used to provide a good comparison to the c_1 index.

The purpose of this research is to supply Strömgren photometry for a good amount of late-type G and K stars in order to further investigate the problem with the c_1 index. Using *Hipparcos* records, 284 stars were pre-selected with absolute magnitudes between 4.5 and 6.5. These stars were picked because their absolute magnitudes verify that they are dwarfs yet they are located above the Hyades defined main sequence. Observations of the program stars and the reduction process will be discussed in the next section.

Observations and Reduction

There were two observing runs, both at Mount Laguna Observatory, the first on the 24" photometer and the second on the 40" photometer. The 24" run on July 17-21, 2005 was somewhat photometric with one overcast night. Throughout the four nights of observing we encountered many problems with the telescope including: an offset in declination axis, dome tracking, a rusted discriminator cable, and problems with the telescope's guidance system. We observed a total 35 program stars with only about 5 standard observations each night.

On the 40" run July 27-30, 2005 we had four photometric nights and very few problems with the telescope. There were some problems with filter motion during exposures because the v filter was placed in the filter slot 7, the last slot, and the others were in 1, 3, and 4. Since the filter box was moving from the last slot to the first slot, there were some instances when the exposure was taken before filter motion stopped. Any problems with the filter motion would be apparent in raw counts and were omitted during data reduction. We observed at total of 96 program stars with around 10 standard observations each night.

The data reduction was done using FOTOM 3.0 which was developed at San Diego State University in 1989. The program corrects the data for extinction and transforms it to a standard system giving y, b-y, m_1, c_1 and their respective standard errors. Each set of data was reduced separately to compare the transformations for each night and each run.

When reducing the data from the 24" run we encountered problems with FOTOM regarding the calculated airmass and the transformations. FOTOM calculates the airmass from the coordinates of the star and the universal time and reported airmasses of 8 and 9 for some of the standard observations. In addition, the transformation solutions for nights 1 and 2 were aborted by FOTOM due to lack of standard observations. We reduced all four nights of data together in order to create a universal transformation solution, but since the weather conditions varied each night the transformed magnitudes were not usable. Because of these problems in the 24" data we decided to focus this research on our observations at the 40".

The 40" data was considerably more photometric and was reduced easily. We observed many standard stars on the second run producing a good transformation each night. There were a handful of stars affected either by filter motion or changes in sky brightness which were not included in the final set of data. Furthermore the standard errors estimated by FOTOM were unexplainably large, around 1.0-1.2 mag in the c_1. The method of error calculation FOTOM uses is ambiguous so we compared our (b-y) colors to the *Hipparcos* standard data for (B-V) to determine the reliability of the color calibration. It should be noted that due to time constraints the uncertainties were not evaluated completely so this data does not include them. The colors and magnitudes that were found for the program stars will be discussed in the next section.

Analysis

The research done this summer of 96 stars on the 40" at Mount Laguna Observatory produced results that verified a problem with the c_1 index. The stars chosen are brighter than the Hyades defined main sequence because either they are metal-rich or binaries. *Hipparcos* records confirm that the stars are not in the giant or sub-giant luminosity class. Figure 2 displays the position of the stars on a color-magnitude diagram.

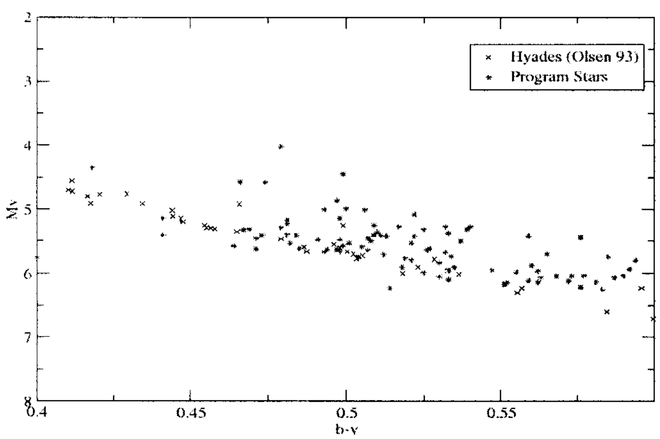

Fig. 2. Color-Magnitude diagram showing the program stars (red stars) and the Hyades main sequence (black X's)(Olsen 1993). Most of the program stars are located 0.1-0.7 mag above Hyades.

The program stars (red stars) range from 0.1 to 0.7 magnitudes above the Hyades main sequence (black X's) with a few exceptions of two bright stars at 4.0 and 4.3 mag and dim star at an unusually low (b-y) of 0.4. It should be noted that the scatter in the (b-y) should have a minimal effect on the position of the star in the CMD. These magnitudes are consistent with a binary system or metal abundant stars, given that evolved stars in the giant and sub-giant phase would be located 2-5 magnitudes above the main sequence.

The location on the CMD should correlate directly with each star's c_1 index when plotted against color because c_1 is a distance-independent measure of luminosity. This implies that interstellar reddening should not have an effect on the color index.

In Figure 3 a two-color plot of c_1 shows the comparison of the program stars to the Hyades main sequence. Although it should be noted that there is more scatter in the two-color plot over the same range in (b-y), many of the program stars are located far above the Hyades relation. Stars that are located above 0.35 mag would be classified as giants, assuming nothing else about the star, and stars between 0.20 and 0.25 mag would be classified as dwarfs. Since the absolute magnitude of these stars is not in the giant and sub-giant range, a large portion of these stars would be misclassified as giants. This implies a problem with the c_1 index in this temperature range.

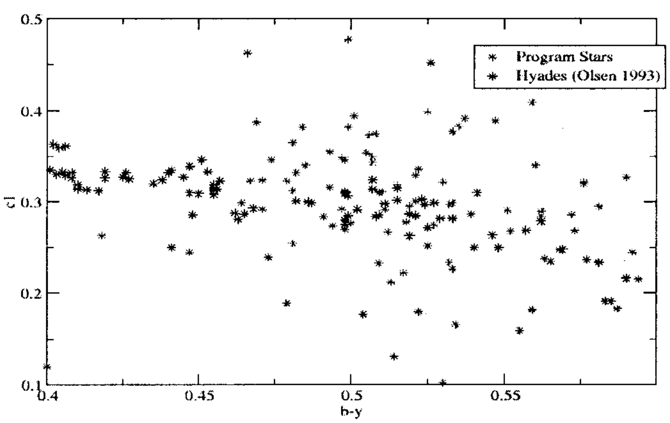

Fig. 3. Two-color plot of the c_1 index for the 96 program stars (green stars) with the Hyades main sequence (black stars).

Conclusions

The Strömgren color indices are defined by certain properties of light in the atmosphere of stars. Since stars radiate essentially as blackbodies we can obtain their temperature from the (b-y) color using the shapes of their spectra. For the same reason, the m_1 index reflects the amount of metals due to a line-blanketing affect and the c_1 index indicates the luminosity of a star due to the Balmer jump. The c_1 index should increase with increasing luminosity as the Balmer jump decreases with increasing luminosity. These effects which define the characteristics of a star's spectrum are not absolute for all temperature ranges. Innovative technology is increasing the power of telescopes allowing astronomy research to delve into very cool stars, which make up most of the galaxy's star population.

We observed 96 stars with Strömgren uvby photometry and found 19 stars that have c_1 indices above 0.35 mag (indicated by the red stars in Figure 4). The greens stars would be correctly identified as dwarfs with a c_1 index between 0.20 and 0.25 mag and the purple are between dwarf and giant classification. Theoretically the c_1 index should be below 0.25 mag for all of the stars in Figure 4, but since there is some influence on the c_1 at this temperature range the values are exaggerated misclassifying them as giants.

The source of this problem is metallicity. These stars are all presumed to be either metal-rich or binary and somehow the metallicity of the stars is affecting the c_1 index somewhat linearly with color - the redder the color the more c_1 diverges with metallicity (Twarog et al. 2002). Somehow the ultraviolet light is being dimmed and the violet light is being brightened in the atmosphere of late-type G and K stars. The culprit could be line-blanketing, a continuum shift towards the violet, or some unknown physical process that we have not yet identified. The way [Fe/H] is being determined photometrically needs to be overhauled in this temperature range.

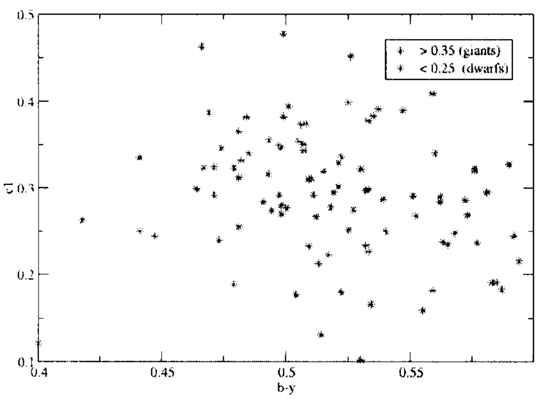

Fig. 4. A two-color plot of c_1 for the program stars.

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