

# Analyzing the Ca II H line of Giant Stars through Comparison with the Ca II K line

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## 1. Introduction

The Ca II K line, which originates in the chromospheric regions of stellar atmospheres, has been studied extensively in the optical spectra of giant stars. The Ca II H line has not been used as often to probe the stellar atmosphere, though both lines exhibit double-peaked emission in their cores, which is considered an indicator of the onset of mass outflows from the chromosphere. It is possible that the Ca II H line probes a different depth of the stellar chromosphere than the K line. In this project we analyze the Ca II H line in the spectra of giant stars in relation to the Ca II K line to determine if there are significant differences between the lines, and whether these differences are correlated with characteristics of the sample stars.

Both the Ca II H and K lines exhibit emission and absorption features. In the H line, the wide and deep absorption feature produced in the photosphere is designated  $H_1$ . The reemission in the core of the line produced at the base of the chromosphere is designated  $H_2$ , with the blue-ward peak labeled  $H_{2V}$  and the red-ward peak labeled  $H_{2R}$ .  $H_3$  is the re-absorption feature that forms the peaks in  $H_2$  and is produced higher in the chromosphere. The  $H_{2V}$  and  $H_{2R}$  peaks often do not have equal strength, as seen in Figure 1. To quantify this asymmetry, the parameter  $V/R$  is used, which is simply the ratio of the  $H_{2V}$  emission to the  $H_{2R}$  emission.  $V/R$  values of  $< 1$  are often considered to indicate outflows in the chromospheric region because the  $H_3$  absorption feature is redshifted in these cases.

## 2. Observations and Data Reduction

High resolution spectra of the Ca II H and K lines were obtained at McDonald Observatory for a sample of 94 field giants. The spectra were acquired during several observing runs from November 1998 through June 2008 using both the Sandiford Cassegrain Echelle (CE) spectrometer on the 82-in telescope and the 2d-coudé spectrometer on the 107-in telescope at McDonald Observatory. This paper examines the Ca II H line found in a

different order of the same spectra that were obtained for Smith & Shetrone (2000),(2004) and Shetrone et al. (2008), as well as the spectra obtained during an observing run in June 2008.

The observing procedure and data reduction process for the spectra acquired during observing runs from November 1998 through August 2007 are described in Smith & Shetrone (2000),(2004) and Shetrone et al. (2008). The most recent data was taken during a two night observing run from 2008 June 22 to June 23 using the 2d-coudé spectrometer on the 107-in telescope. For this most recent run, the observing procedure was to take at least three exposures of each object with the maximum exposure time being 1200s. Bias frames, flat field frames, and ThAr lamps were taken at the end of each night. The spectra were bias corrected, flat-field corrected, and wavelength calibrated using routines within the IRAF **echelle** package. The individual spectra for each object taken on a given night were combined to remove cosmic rays. During the data reduction process, the number of observed electrons was preserved to keep the Poisson statistics valid for each spectra.

Using the IRAF **fxcor** and **dopcor** packages, the spectra were shifted to the velocity frame of the Hinkle spectral Atlas of Arcturus (Hinkle et al. 2000). The spectra were then divided by the Arcturus Atlas to obtain a continuum curve, which was fit by a spline function. This continuum fit was normalized by a low order Legendre polynomial, excluding the core of the Ca II H line in the fitting sample. The combined spectra were divided by the normalized continuum fit to obtain normalized, Poisson-accurate spectra. This normalization procedure matches the procedures found in Smith & Shetrone (2004) and Shetrone et al. (2008).

### 3. Results and Discussion

Our sample is comprised of 94 giants that show the double-peaked Ca II H and K emission features. They range in  $B - V$  color from 0.68 to 1.68 and have absolute magnitudes ranging from -4.29 to 2.51. Most of the stars observed are G and K giants, while a few are F and M giants. Many of the stars were observed on multiple epochs, and the  $V/R$  parameter for the H line was calculated for each observation. The error (denoted  $\epsilon_H$ ) on each  $V/R$  value was calculated with the derived error  $\epsilon_H^2 = \sigma_V^2/I_{H2R}^2 + I_{H2V}^2\sigma_R^2/I_{H2R}^4$  as described in Shetrone et al. (2008). In the above equation, the flux counted in the  $H_{2V}$  and  $H_{2R}$  peaks in the unnormalized spectra are represented by  $I_{H2V}$  and  $I_{H2R}$ , respectively. Taking the square root of  $I_{H2V}$  and  $I_{H2R}$  gives the errors on these values, denoted  $\sigma_V$  and  $\sigma_R$ , respectively. In order to compare the H and K lines, the  $V/R$  values of the Ca II K line were taken from Smith & Shetrone (2004) and Shetrone et al. (2008), with the exception of

the June 2008 values. Several  $V/R$  values for the Ca II K emission feature were taken from Smith & Shetrone (2000) and adjusted with the zero point offset of +0.026 to correct for differences between normalization procedures, as described in Shetrone et al. (2008).

The difference between the Ca II H line and K line  $V/R$  values was calculated for each observation of each star in the sample, then plotted versus the H line  $V/R$  values in Figure 3. The expected relationship between the variables is plotted as a solid line of zero slope centered at zero on the vertical axis. The best fit to the data is plotted as a dashed line of zero slope centered at +0.0471 on the vertical axis. Therefore, Figure 1 illustrates that the Ca II H line  $V/R$  value is larger than the Ca II K line  $V/R$  value for our sample by a +0.0471 offset, on average. This small positive offset is statistically significant.

Once it was found that the H line  $V/R$  values are larger on average than the K line  $V/R$  values, the  $B - V$  colors were plotted (Figure 3) versus the difference between the Ca II H line and K line  $V/R$  values to see if there was any correlation between these variables. The best fit to the data is plotted as a dashed line with a slope of 0.168 and y-intercept of -0.164. This positive slope indicates that cooler stars, with large  $B - V$  colors, are more likely to have H-K values greater than zero. These cooler stars most likely have opposite asymmetries between the emission peaks in the H and K lines, with the H line  $V/R > 1$  and the K line  $V/R < 1$ . In this case, the  $V/R$  values could indicate that the chromospheric layer from which the H $\beta$  absorption feature is formed is falling in towards the star, and the layer from which the K $\beta$  absorption feature is formed is flowing outwards.

A color magnitude diagram for our sample is plotted in Figure 4. The data points are color coded to designate distance in terms of error bar, or  $\sigma$ , from the H-K = 0 line in Figure 3. The red circles indicate the H-K value for the given data point is  $> 1\sigma$  away in the positive direction. The green boxes indicate the H-K value for the given data point is  $> 1\sigma$  away in the negative direction. The blue triangles indicate the H-K value for the given data point is within  $1\sigma$ . The red circles appear to congregate where  $B - V > 1.2$ , and the green boxes seem to gather where  $B - V < 1.2$ . The blue triangles are evenly spread across the  $B - V$  range of the data points. Therefore, it seems that as they become cooler, many stars undergo some change in their atmospheres that causes different chromospheric layers to exhibit opposite motions.

#### 4. Summary

In this project we measured  $V/R$  values for the double-peaked emission features in the Ca II H line in 94 giant star spectra, and compared these values to  $V/R$  values of the Ca II

K line. We found the difference between the H line  $V/R$  ratio and the K line  $V/R$  to be on average  $+0.0471$ . We also found that this difference between the H and K line  $V/R$  ratios is correlated with  $B - V$  color, with cooler giants tending to display  $H-K > 0$ , whereas hotter giants tend to cluster around  $H-K = 0$ . This could indicate that the chromospheric layer that produces the  $H_3$  absorption in these cooler giants is flowing in towards the star and the layer that produces the  $K_3$  absorption is outflowing from the star. For hotter giants, the data indicate that the opposite, or that both chromospheric layers are flowing in towards the star, is more often the case. Therefore, it appears that as giant stars age and cool, their atmospheres may undergo some change that causes the layers that create the double-peaked nature of the emission lines in the cores of the Ca II H and K lines to display motions in opposite directions.

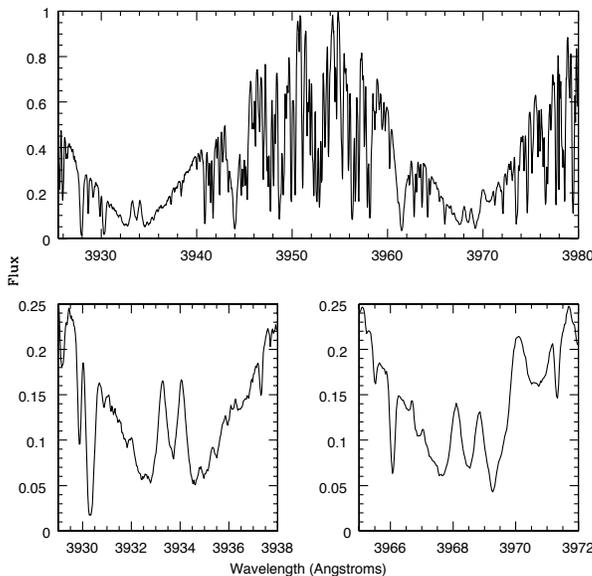


Fig. 1.— One spectrum of the star HD211073, obtained on 2001-10-03. In the upper window, the Ca II K line is visible on the left, and the Ca II H line is on the right. In the lower left window, a zoomed-up version of the double-peaked core of the K line is given, and in the lower right window, a zoomed-up version of the core of the H line is given. The asymmetry between the  $H_{2V}$  and  $H_{2R}$  peaks is noticeable.

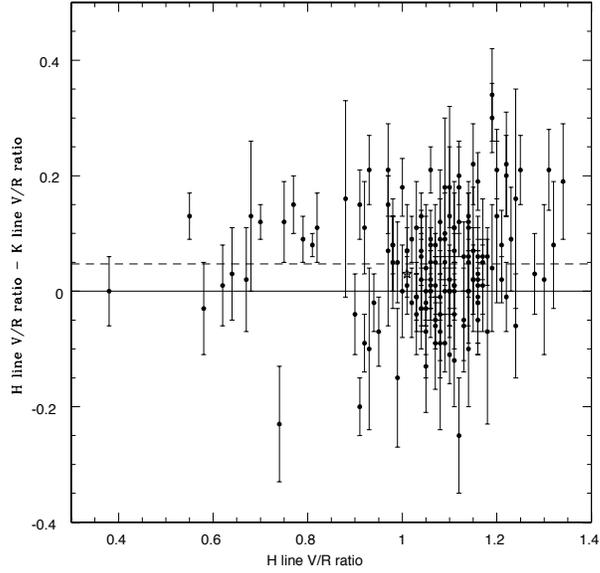


Fig. 2.— The Ca II H line  $V/R$  values are plotted versus the difference between the Ca II H line and K line  $V/R$  values. The solid line represents the expected relationship between the two variables, and the dashed line represents the actual best fit to the data.

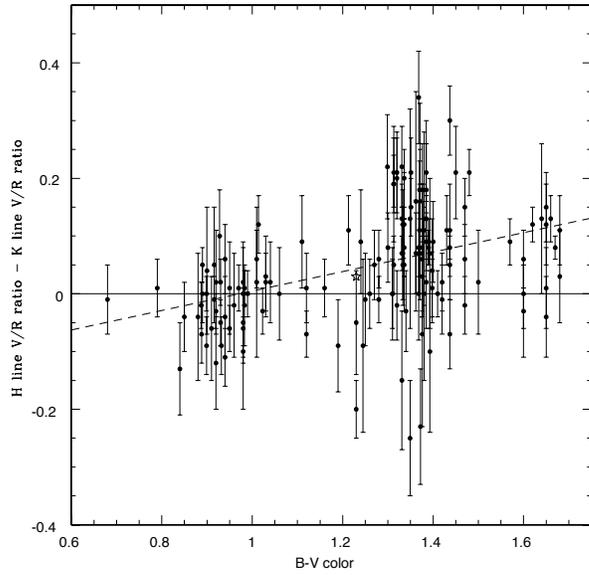


Fig. 3.— The  $B - V$  color of each star is plotted versus the the difference between the Ca II H line and K line  $V/R$  values.

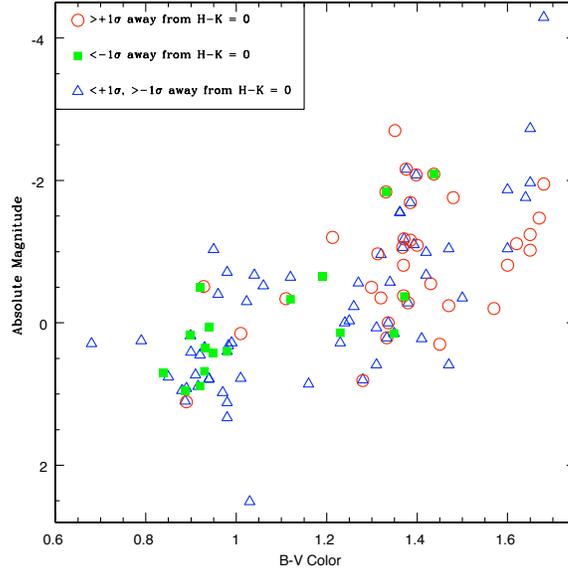


Fig. 4.— Color magnitude diagram for our sample. The red circles represent stars more than one error bar away from  $H-K = 0$  in the positive direction. The green boxes represent stars more than one error bar away from  $H-K = 0$  in the negative direction. The blue triangles represent stars that lie within one error bar of  $H-K = 0$ .