The Young Solar Analogs Project

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Abstract.
The Young Solar Analogs Project has been monitoring a set of 31 young (0.3 - 1.5 Gyr) solar-type stars (F8 – K2) spectroscopically since 2007 and photometrically since 2012. The goal is to better understand the early sun and the challenges it presented to the development of life on Earth. This paper reviews the progress of the project, and discusses some of the early results, including the development and evaluation of a G-band index.

1. Introduction

The Young Solar Analogs project studies young (0.3 – 1.5 Gyr) solar-type stars (F8 – K2) in order to learn more about the magnetic activity of the sun and the space environment in the solar system during a critical period in the development of life on Earth. We have been monitoring a set of 31 young solar analogs (YSAs) spectroscopically since 2007 with the 32-inch telescope at the Dark Sky Observatory of Appalachian State University, and photometrically since 2012 with a small robotic telescope at that same observatory. The purpose of those observations is to characterize the behavior of YSAs on three timescales – long timescales (years to decades) to investigate the stellar activity cycles; medium timescales (days to weeks and months) to investigate rotational periods, active longitudes, flip-flop cycles, and convective overturn; and short timescales (minutes to hours) to learn about short-term behavior such as flares and "flickering". Spectroscopic observations with the

Vatican Advanced Technology Telescope on Mt. Graham began in early 2013, and those observations have concentrated on short timescale phenomena. See the paper by Corbally et al. in this volume for more details. See also the paper in this volume by Saken et al. for further information about our equipment and methods.

2. Spectroscopic Monitoring

2.1 Ca II K & H activity index

The spectroscopic data for this project consist of 1.8Å/2 pixel-resolution spectra from the Dark Sky Observatory (DSO) GM spectrograph with a spectral range from 3800 - 4600Å. This spectral range includes the Ca II K & H lines and the G-band, as well as other strong photospheric features. Stellar activity may be monitored by measuring the chromospheric emission in the cores of the K & H lines. Our instrumental S_2 and S_4 activity indices, which may be transformed to the Mount Wilson program S_{MW}-index (Baliunas et al. 1995), measure the chromospheric emission in the K & H cores with 2 and 4Å bands respectively. They constitute the basic measure of stellar activity on our program and allow detection of stellar activity cycles and rotation periods (see Figures .1 and 6). More recently, the Vatican Observatory Spectrograph has also been employed for this project, especially for high-cadence observations.

A number of our stars appear to show regular or quasi-regular cyclical activity, although we will need a longer baseline to fully evaluate the nature of this activity. By design, some of our programme stars are in common with the Mount Wilson program, and so we have much longer baselines for those stars. Two examples are HD 82885 (see Figure .1, top panel) and HD 206860 (Figure .1, bottom panel). HD 206860 was found by Baliunas et al. (1995) to have a 6.2 year period, although that period was given a "poor" false alarm probability (FAP). Our data indicate an activity minimum near MJD = JD−2450000 = 4700 and a maximum near MJD = 5800. The difference between these two extrema is about 3 years. In addition, our observed maximum occurred about 24 years after the last-reported maximum of Baliunas et al.. These two timings suggest that HD 206860 is continuing with a regular cycle of about 6 years.

On the other hand, HD 82885 was assigned a period of 7.9 years with a "fair" FAP by Baliunas et al. Our data suggest that the cycle time may have shortened to about 5 years. Observations by Hall et al. (2009) also support a shorter cycle period for this star.

Some of our stars show apparently novel stellar activity cycles. A case in point is HD 76218, which seems to vary mostly in terms of the *dispersion* of the S_{MW} activity measures in a given observing season. That dispersion arises primarily from rotational modulation but also from short-term "flickering" (see paper by Corbally et al. in this volume), although the relatively long exposure times used at DSO will tend to average out the variability due to flickering. Figure .2 shows that at the beginning of our project, HD 76218 exhibited very little activity dispersion, but that dispersion increased year-by-year until 2011, after which the dispersion began to decrease. If this star is truly undergoing a cycle, we expect that the dispersion will begin to increase again in the next few years. Another star in our sample, HD 170778, appears to be behaving in a similar way. One interpretation of this behavior is that the star shifts between a state dominated by a single large active region (which would give rise to a high-amplitude rotational modulation) and a state dominated by many small

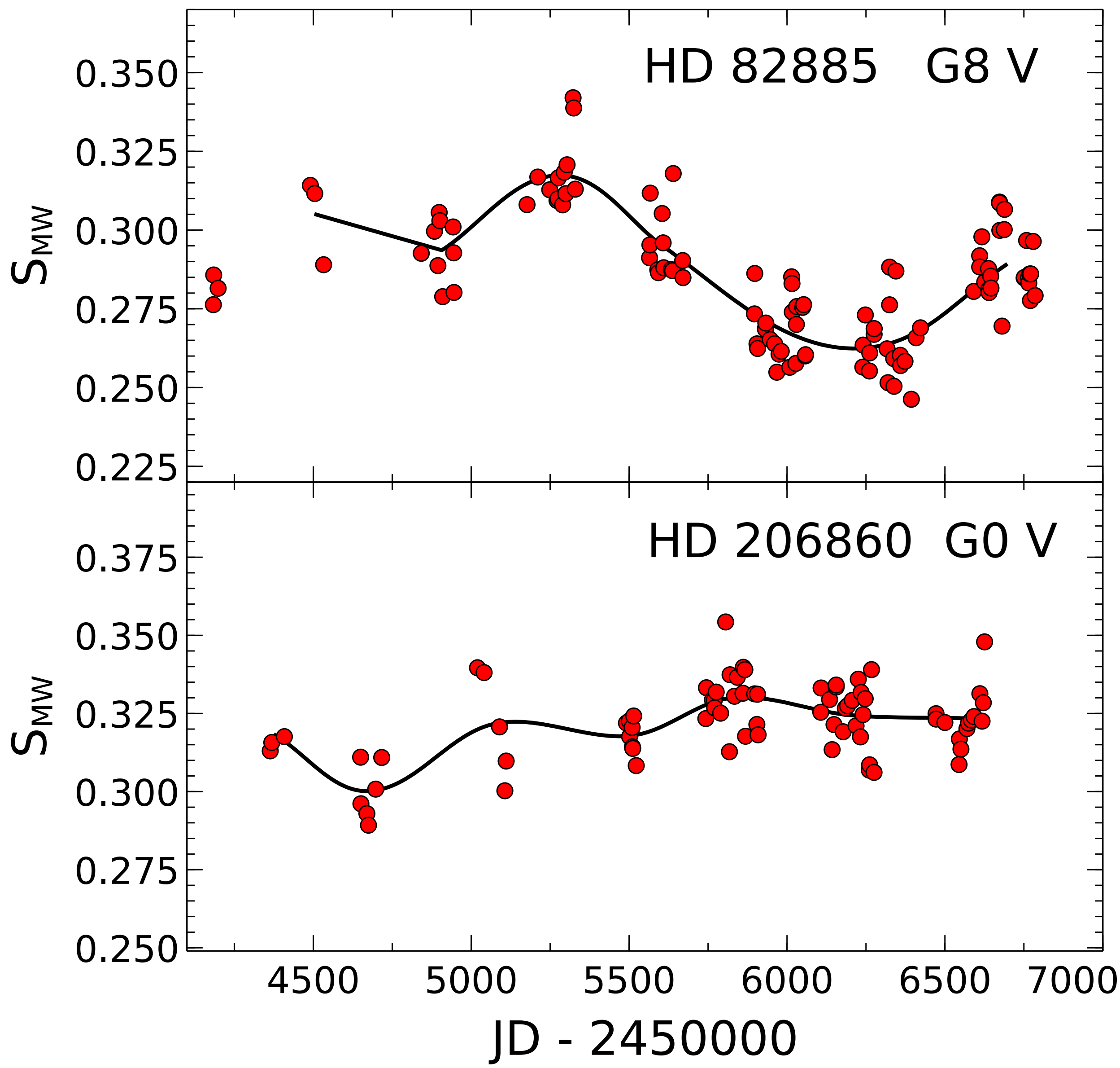

Figure .1: Top panel: activity behavior of HD 82885 over eight observing seasons based on observations at the Dark Sky Observatory. The ordinate is the Mount Wilson $S_{\rm MW}$ activity index, based on chromospheric emission in the cores of the Ca II K & H lines. The abscissa is the modified Julian date. The black line joins the seasonal means. Bottom panel: the same for HD 206860.

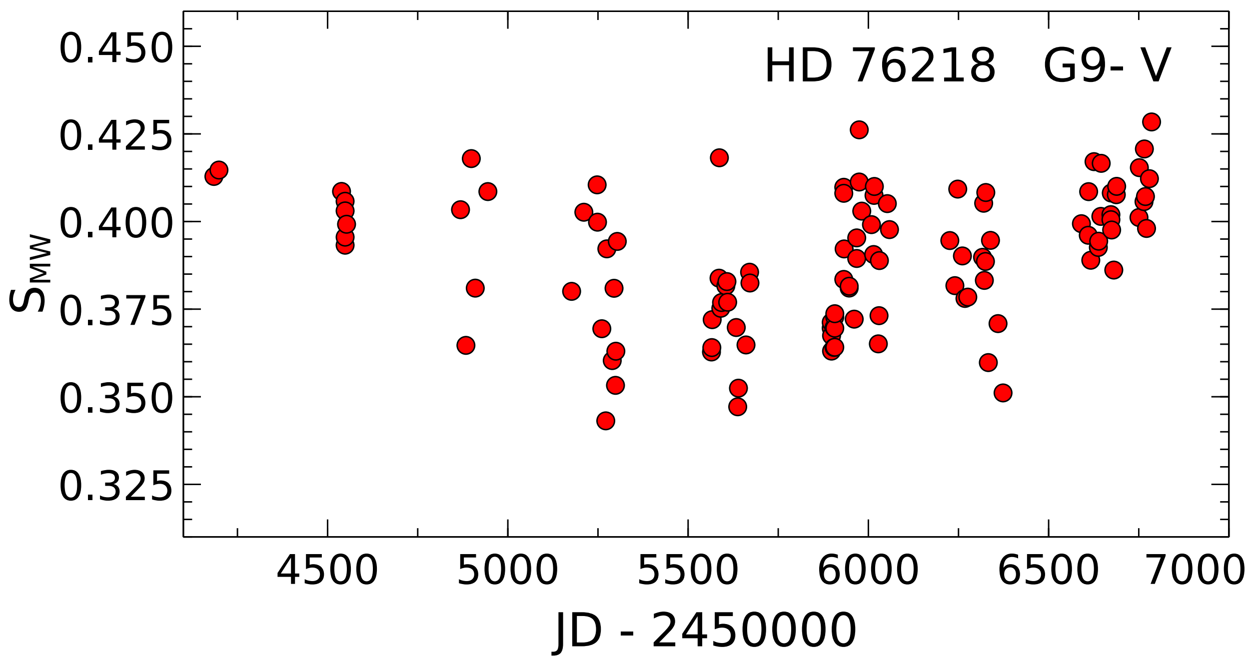

Figure .2: The Ca II K & H activity behavior of HD 76218 over eight observing seasons based on observations at the Dark Sky Observatory. HD 76218 may be exhibiting a novel form of cyclical behavior in which it is the *dispersion* in the activity measures that appears to be varying in a regular fashion.

activity regions spread more or less uniformly with longitude. Indeed, during the "high-dispersion" seasons, HD 76218 does show a strong rotational signal. This cyclical behavior may be an indication of an underlying flip-flop cycle. Other interpretations may be possible.

2.2 The G-band Index

The same spectra that we use to measure the chromospheric emission in the cores of Ca II K & H also contain a number of strong photospheric features. One of these is the G-band, a strong, wide absorption feature near 4300Å arising from the CH molecule. We measure this feature by numerically integrating over three bands, one centered on the G-band and two "continuum" bands flanking the G-band (see Figure .3). This G-band index is primarily sensitive to temperature (see Figure .4), but, as argued by Hall (2008), may also contain information on large-scale magnetic structures via G-band "bright points". G-band bright points form in tight magnetic-field knots where the gas is compressed and heated leading to the dissociation of the CH molecule and thus a decrease in the line opacity in the G-band, weakening the G-band and reducing the G-band index (G). When plotted against time, most of our programme stars show little variation in G, which is not unexpected, but some show an interesting anticorrelation between $S_{\rm MW}$ and G in the sense that the G-band is weakest at activity maximum. The most straightforward explanation for this behavior is that the G-band bright points are more prevalent at activity maximum, but more study is required.

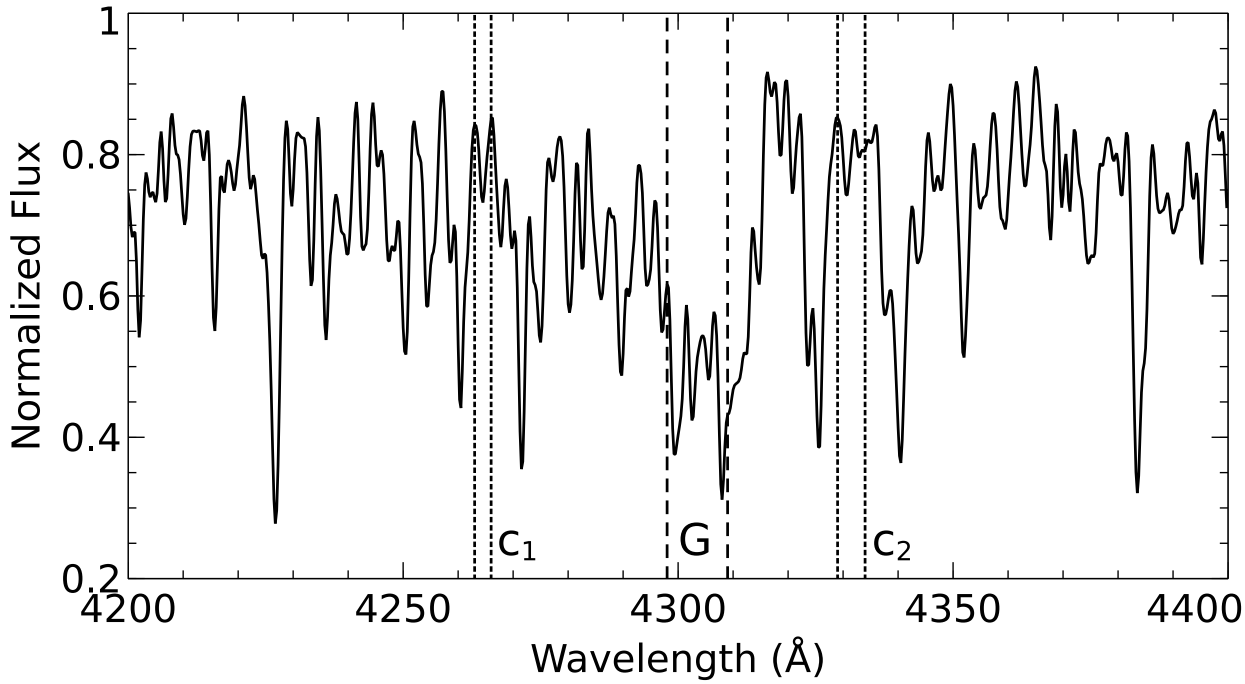

Figure .3: The passbands used in the definition of the G-band index.

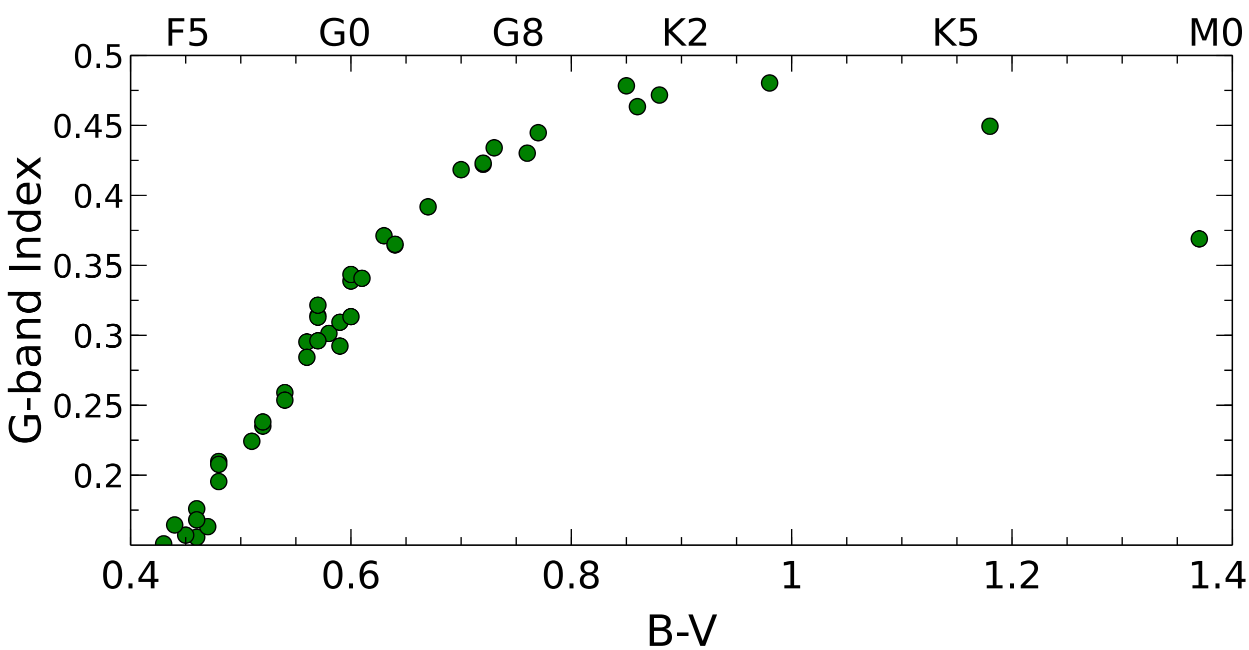

Figure .4: The dependence of the G-band index on the temperature and main-sequence spectral type.

In reality, however, our stars show a variety of behaviors in the G-band, and we are just at the beginning of trying to analyze and understand these variations.

A few examples: HD 138763 (F9 V) appears to show periodic or pseudo-periodic variations in the G-band (see Figure .5) which may or may not (future observations will tell) be of the same period as the Ca II K & H variations. A number of our stars, including HD 222143, appear to show an inflection point in the G-band variations at the time of minimum or maximum activity in the K & H measures. In other stars the G-band variations do not seem to be related to the S_{MW} variations, but again more observations are required.

3. Photometric Monitoring

A 6-inch robotic telescope at DSO provides 5-band photometric data for the program stars every clear night. We currently have two seasons of data for our stars – not yet enough to confirm the year-to-year inverse relationship (relative to the sun) between irradiance and activity (cf. Hall et al. 2009) except in the case of a few stars. However, both photometry and activity measurements show rotational modulation, and on the timescale of a rotational period, many of our stars are brightest at highest activity. This behavior is also opposite to that of the sun, as the sun dims when a large spot is on the visible hemisphere. Figure .6 shows this in the case of HD 13531. Both photometry and activity show a strong rotational signal at 7.67 days.

4. Conclusions

The Young Solar Analogs project is unique in the sense that it combines activity data from three different sources – chromospheric data via the measurement of emission in the cores of the Ca II K & H lines, photospheric data from measurement of the G-band, and 5-band multi-color photometric data. This unique dataset will give us new insight into the activity behavior of young solar-type stars that will be relevant to understanding our early sun and solar system, but also of value for the evaluation of habitable zones around other stars.

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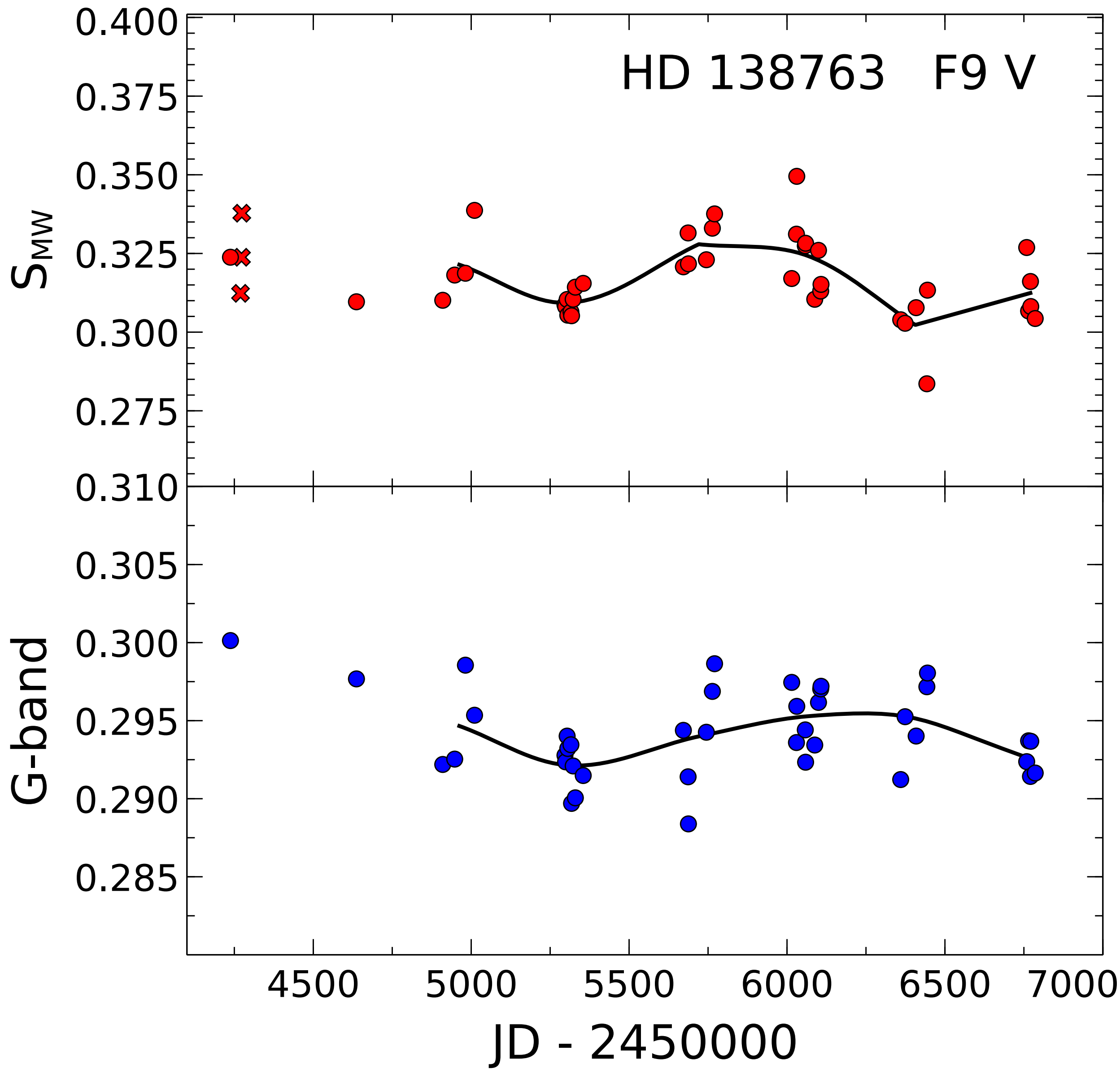

Figure .5: Top panel: the variation of S_{MW}, the Mount Wilson activity index for HD 138763 with time. Note the apparent presence of a fairly low amplitude cycle. Bottom panel: the variation in the G-band index for the same star. Is this star showing cyclical behavior in the G-band with a period different from that of S_{MW}? Further observations are required.

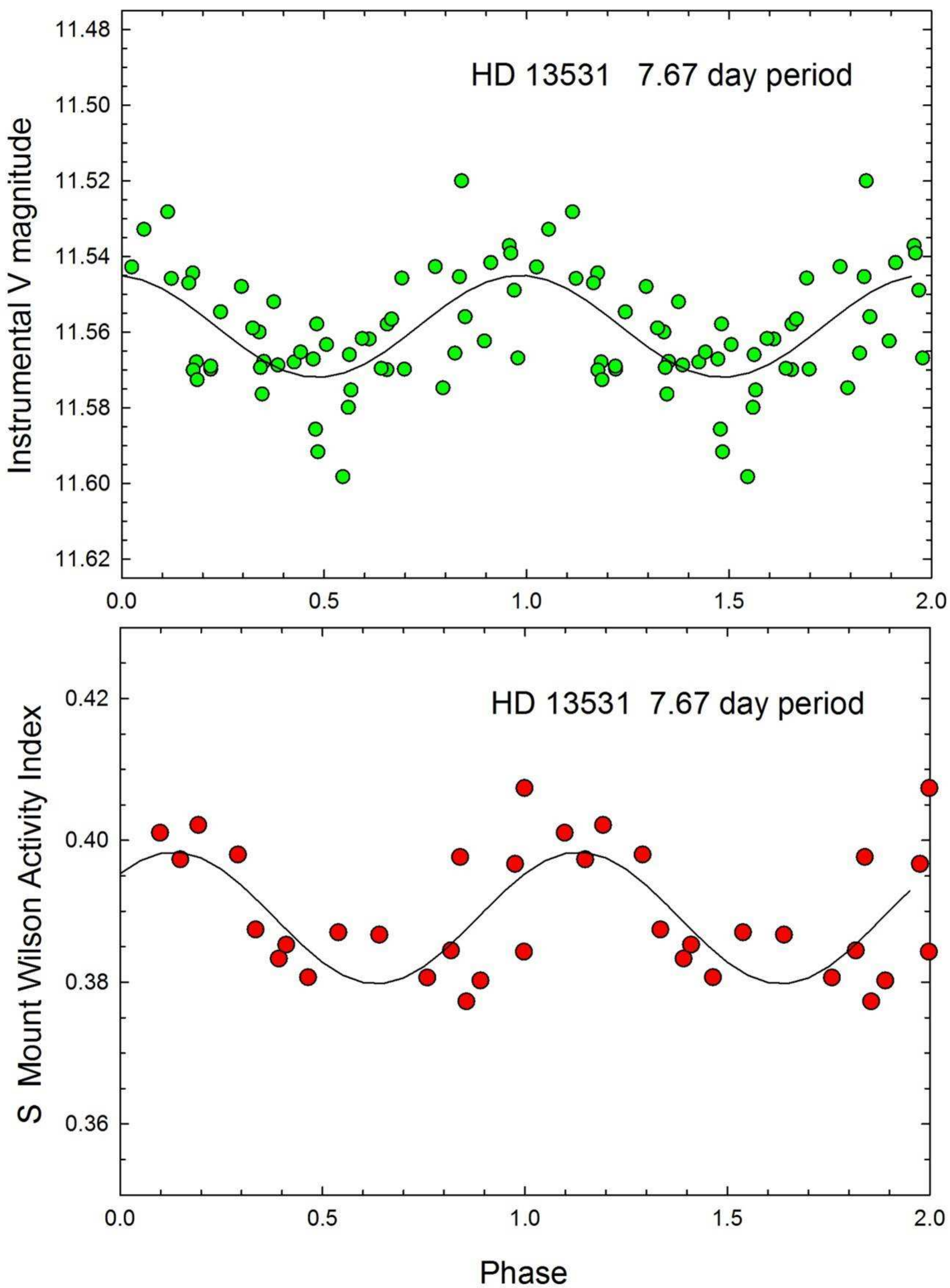

Figure .6: The upper panel shows DSO photometric data in the Johnson V-band phased to a rotational period of 7.67 days. The bottom panel shows DSO Ca II K & H activity data phased to the same period. Note that during a rotational period, the star is brightest when most active.

Ruth Angus managed to overcome an uncooperative airline connection to make it for her talk on gyrochronology.