The Solar-Stellar Spectrograph: A 25-Year Retrospective

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The detectors and everything downstream of the cameras have been replaced once, in 2008. The two spectrograph systems are present and labeled in the photo above, with the "blue" HK spectrograph on the right side and the "red" echelle spectrograph on the left side. From 1992 through 2012, the project was funded by NSF grants. Lowell has supported the project since then.

The 200 micron solar "telescope," mounted on the south side of the 1.1m John Hall Telescope dome, observes the Sun as an unresolved disk, with its fiber cable feeding into the spectrograph room on the second story. Usually, we average 16 1-second exposures (three or so days a week) to obtain a low-noise solar spectrum for the day.

Instrument:

The Solar-Stellar Spectrograph (SSS) has a dual fiber feed that allows for observations of the Sun and other solar analog stars with the same telescope/dual spectrograph combination. The dual spectrograph has roughly 70% coverage, with a spectral range of λλ3860-4010 in the blue and λλ5100-7600 in the red. The "blue spectrograph" covers a single order for Ca II H&K. The "red" echelle has coverage over a variety of proxies including, but not limited to, Na D, Mg b, and Hα. The spectrograph is contained within a triangular enclosure (which we affectionately call the "coffin"), which is about 5 feet on a side. Further, the optics reside on a separate platform to reduce noise due to vibrations. To top it off, the "coffin" is sealed by a heavy lid.

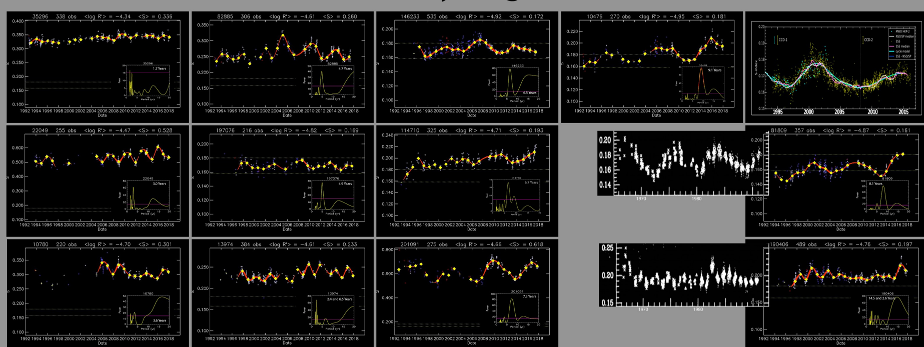
Data Reduction:

To reduce the copious amount of data, we use IDL (Interactive Data Language). Our IDL reductions encompass all the usual steps from debiasing data to scattered light removal, wavelength calibration, and continuum normalization. The results of the reductions can be expressed as raw HK indices or can be converted to the MWO S index or the fractional chromospheric emission log R' (HK). Other purposes we utilized for IDL consisted of producing the histogram of flat activity stars versus cycling stars (displayed below), time series, and the quantitative period analysis of the stellar sample.

Typically, we observe at the 1.1m John Hall Telescope 7-10 nights per month, with 20-50 stars observed per night at exposure times of 5-30 minutes. The facility is not robotic, so an observer must be present to operate it. Target observations are accompanied by flat-field exposures, darks, biases, and Thorium-Argon calibration spectra.

Representative Time Series

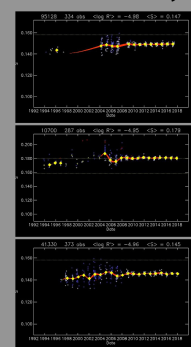
Cycling



Cycling Stars

The periodograms (in the bottom, right-hand corner of each of the time series) depict the amount of power in the frequency spectrum of a star (y-axis) at a given period in years (x-axis). Of particular interest, stars HD 13974 and HD 190406 appear to exhibit multi-periodic cycles. The first, HD 13974, has a primary period of 6.5 years and a secondary period of 2.4 years. The second, HD 190406, has a primary period of 14.5 years and a secondary period of 2.6 years. For HD 81809 and HD 190406, we display the MWO time series on the same scale, to illustrate the advantage of 50-year time series. Ricky Egeland (HAO) is presently leading an effort to combine the SSS and MWO data sets.

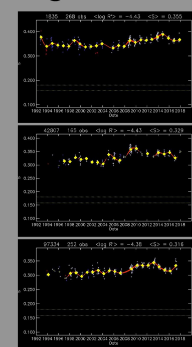
Flat Activity



Flat Activity Stars

Although it appears that the flat stars exhibit some activity pre-2008, there is an explanation. During the 2008 season, the SSS received an upgrade after its old cameras failed in a power surge. The new CCDs have much higher quantum efficiency and lower read noise, which is evident in the reduced scatter in the data from 2008 and beyond.

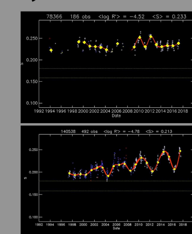
Irregular Activity



Irregular Stars

As we did for the cycling stars, we used a Lomb-Scargle periodogram to determine whether or not the irregular stars were true irregulars or had detectable cycles. The three depicted above are true irregulars, showing considerable variability but no peaks in the power spectrum at a statistically significant level.

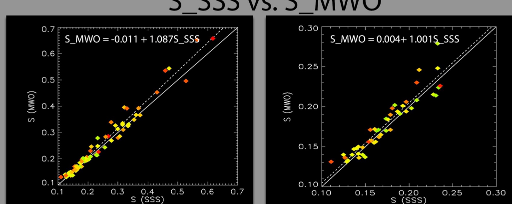
Hybrid Activity



Hybrid Stars

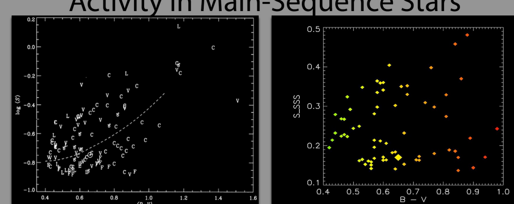
We use the term "hybrid" to indicate stars that may show a transition between a cycling and a flat activity state - perhaps the elusive examples of stellar Maunder Minimum transitions. HD 140538 enters into an abrupt state of ~4-year cycles from a seemingly dormant state. And, for now, the cycle strength of HD 140538 appears to be increasing, as did the solar cycle after its emergence from the Maunder Minimum. HD 78366 is another of our best examples of a hybrid. From apparent flat behavior, it rapidly enters into a short cycling period, and then recedes into its prior flat state. Interestingly, both HD 78366 and HD 140538 have higher activity levels than the usual flat activity stars, which tend to have activity levels around that of the Sun.

S_SSS vs. S_MWO



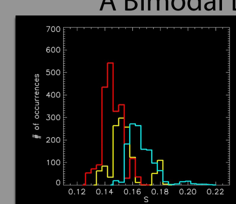
The plot on the left shows the S_SSS grand means (x-axis) versus the S_MWO grand means (on the y-axis) for all stars - F, G, and K stars. . The plot on the right displays the same axes but a reduced sample of stars with near-solar activity levels (S < 0.250). On this plot, only few G and K stars stray far from the expected value (white line). We are now comparing these results, derived using stellar fluxes based on the b-y color index, with the results obtained using B-V colors.

Activity in Main-Sequence Stars



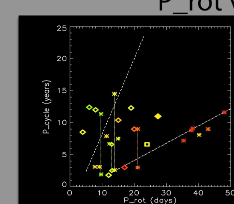
On the left, Baliunas et al. (1995, ApJ 438 265) plotted the overall activity behavior of their target set (111 stars in total), with the dotted line representing the Vaughan-Preston gap (1980) between the active, high-S stars and the inactive, low-S stars (our Sun being the ⊙). On the right, the sample of 77 stars from the SSS project can be seen depicting a near identical Vaughan-Preston gap. Stars with multiple periods tend to appear near the Vaughan-Preston gap, possibly indicative of a transition between activity states and driving dynamo mechanisms.

A Bimodal Distribution?



The cyan distribution contains nine cycling stars. The yellow contains eleven flat stars. Both the cyan and yellow distributions employed stars with chromospheric ages between 4.0-5.5 gigayears, with 0.60 > B-V > 0.76, replicating the range used by Baliunas & Jastrow (1990, Nature 348 520). The red histogram represents nine "old" flat stars with chromospheric ages > 5.5 gigayears (Wright 2004, ApJS 152 261). Although the histogram exhibits a bimodal distribution, the difference is weak for solar-age stars, and the very low-activity stars appear to be not true solar analogs, but significantly older than the Sun.

P_rot vs. P_cyc



Here we replicate Figure 1 from Böhm-Vitense (2007, ApJ 657 486) using SSS stars included in her sample (taken from the MWO sample) for which we were able to determine cycle periods. In general, our derived periods for inactive branch (lower dotted-line) stars agree well with those in Böhm-Vitense's paper, which used the MWO periods. We see more variability in the active branch stars (upper dotted-line), possibly due to short-term (20-30 year) changes in cycle periods. The solar twin 18 Sco (yellow square) appears to be transitioning away from the inactive branch.