The Young Solar Analogs Project - Observations & Analysis

Jon M. Saken[1], **Richard O. Gray**[2], **Christopher J. Corbally**[3], **Michael M. Briley**[2]

[1] *Department of Physics and Physical Science, Marshall University, Huntington, WV USA 25755*

[2] *Department of Physics and Astronomy, Appalachian State University, Boone, NC USA 28608*

[3] *Vatican Observatory Research Group, Steward Observatory, Tucson, AZ USA 85721-0065*

Abstract. The Young Solar Analogs project is a long term spectroscopic and photometric monitoring campaign designed to yield a better understanding of how a star's early activity affects a young solar system. This paper will describe our observational methods and reduction techniques, as well as strategies used to determine periodicities due to rotational modulation.

1. Introduction

Since 2007 we have conducted spectroscopic monitoring in Ca II H & K and the G-band of 31 Young Solar Analogs (YSAs). The targets cover the spectral range of stars most likely to contain Earth analogs, F8-K2, and a broad enough range of ages, 0.3 Gyr - 1.5 Gyr, to investigate how activity level changes with stellar age. The ultimate goal of this project is to develop an understanding of the stars' activity levels, their variations, and how this activity might affect the early conditions on potentially life-bearing planets.

Wilson (1978) and Baliunas et al. (1995) established the direct relationship between stellar activity and the strength of emission in the cores of the Ca II H & K lines. We are employing a similar technique in our current campaign. The chromospheric activity index S2 is calculated by taking the ratio of the average fluxes in two 2 Å-wide bands centered on the Ca II H & K lines to fluxes in nearby continuum bands.

In 2012 we began photometric monitoring in Strömgren-v, Johnson-Cousins B, V, and R, and narrow-band Hα. To complement these efforts we recently started high-cadence, high-S/N spectroscopy of our program stars with the Vatican Advanced Technology Telescope (VATT), along with high-cadence photometry in order to detect and characterize flare activity and stellar flickering.

Some initial results from the YSA project can be found in the papers Gray et al. (2014) and Corbally, Gray & Saken (2014) in these proceedings. A searchable database of both the reduced data and reduction parameters is being developed for eventual release to the astronomical community.

2. Spectroscopic Observations

Routine monitoring (∼8 nights per month) is carried out at Appalachian State University's Dark Sky Observatory (DSO) 0.8-m telescope. High-cadence observations, capable of detecting changes on time scales of about one minute, are carried out on the 1.8-m VATT at Mt. Graham (∼2 nights per month). In addition to the YSA targets, several chromospherically "stable" stars are included as a control for any systematic effects producing changes in the spectral indexes.

Table .1: Young Solar Analog Stars

Name	SpT	V	Age (Gyr)	Name	SpT	V	Age (Gyr)
HD 5996	G9 V (k)	7.67	0.5	HD 124694	F8 V	7.19	0.6
HD 9472	G2+ V	7.64	0.4	HD 130322	G8.5 V	8.04	1.2
HD 13531	G7 V	7.35	0.3	HD 131511	K0 V	6.01	0.3
HD 27685	G4 V	7.84	0.7	HD 138763	F9 V	6.53	0.3
HD 27808	F8 V	7.12	0.7	HD 149661	K0 V	5.76	1.4
HD 27836	G0 V (k)	7.60	0.7	HD 152391	G8.5 V (k)	6.64	0.7
HD 27859	G0 V (k)	7.80	0.7	HD 154417	F9 V	6.01	0.5
HD 28394	F8 V	7.02	0.7	HD 170778	G0- V (k)	7.50	0.3
HD 42807	G5 V	6.44	0.3	HD 189733	K2 V (k)	7.68	0.5
HD 76218	G9- V (k)	7.69	0.5	HD 190771	G2 V	6.17	0.7
HD 82885	G8+ V	5.41	1.6	HD 192263	K2 V (k)	7.79	1.0
HD 96064A	G8+ V (k)	7.64	0.3	HD 206860	G0 V	6.00	0.4
HD 101501	G8 V	5.32	1.4	HD 209393	G5 V (k)	7.96	0.5
HD 102195	G9.5 V (k)	8.06	1.1	HD 217813	G1 V	6.66	0.7
HD 113319	G4 V	7.52	1.5	HD 222143	G3 V (k)	6.58	0.8
HD 117378	F9.5 V	7.64	0.5				

Observations using the DSO GM spectrograph employ the 1200 g/mm grating in the first order. This grating gives a spectral range of 3800 - 4600 Å with a resolution of 1.8 Å / 2 pixels. This spectral range includes the Ca II K & H lines as well as the Ca I resonance line, the G-band, and the Hγ line. Since April 2009, we have used an Apogee camera with a 1024 $\times$ 256 pixel e2v technologies CCD30-11 chip with enhanced ultraviolet sensitivity. An Fe-Ar hollow-cathode comparison lamp is used for wavelength calibrations.

Observations using the VATT spectrograph also employ a 1200 g/mm grating, with a spectral coverage of 1000 Å and 1 Å resolution. The camera is a 2688 $\times$ 512 pixel, back illuminated STA0520A CCD. An Hg-Ar comparison lamp is used for wavelength calibrations.

3. Spectroscopic Reductions

Raw spectra are reduced using standard IRAF procedures. For the DSO spectra, several 5-minute exposures are stacked to provide a S/N of at least 100 in the continuum near the Ca II K & H lines.

Chromospheric activity is measured using an index similar to the Mt. Wilson "S" index. This is the ratio of the monochromatic flux in the cores of the Ca II K & H lines to the flux in nearby continuum regions, 3891.067 - 3911.067 Å and 3991.067 - 4011.067 Å (Fig. 1). S2 utilizes 2 Å rectangular passbands in the cores, while S4 utilizes 4 Å passbands. The variability analysis utilizes only S2. S2 and S4 are used together to transform to the Mount Wilson system without the need for a color term. However, period and variability determinations can be carried out in the instrumental system.

The G-band index traces concentrations of magnetic field closer to the photosphere. It is defined by comparing the monochromatic flux in G-band to the flux in two nearby continuum regions, c_1: 4263.0 - 4266.0 Å, and c_2: 4329.9 - 4334.0 Å. The G-band is normalized so that the index is 1 when the G-band is completely dark and 0 when there is no absorption (Fig. 2).

$$G = 1 - \frac{\frac{1}{11\text{Å}} \int_{4298\text{Å}}^{4309\text{Å}} I(\lambda) d\lambda}{c_1 + 0.5821(c_2 - c_1)}$$

4. Photometric Observations

In 2012 photometric observations commenced using a robotic 6-inch Ritchey-Chrétien astrograph and a KAF-8300 monochrome CCD. This instrument is truly robotic, capable of following a pre-determined list of targets and shutting down in case of cloudy weather with no human intervention, through the use of off-the-shelf commercial software. As a result, observations are obtained nearly every clear night, in Strömgren-v, Johnson-Cousins B, V, and R, and narrow-band Hα.

5. Photometric Reductions

Basic reductions are carried out using standard IRAF procedures. An electroluminescent panel is used to provide extremely consistent flat-field images. Since the target stars are

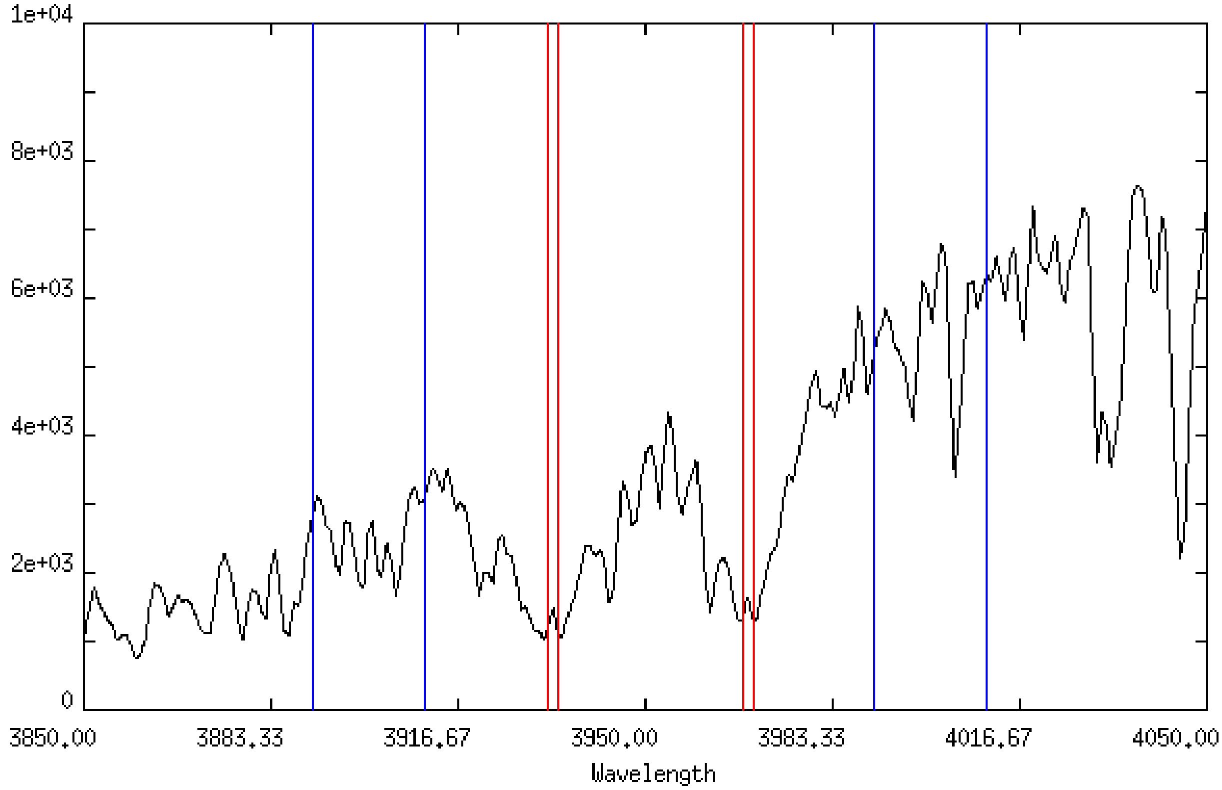

Figure .1: Continuum and spectral regions for S2 index. Continuum regions are in blue.

often much brighter than any of the other stars in the field, we have found that standard differential photometry usually yields unacceptably large photometric errors. To overcome this problem, the "Superstar" technique (SST) was developed. Instead of using just a few comparison stars, SST combines the flux of many stars in the field to create a comparison star with a flux comparable to the target. Stars exhibiting any variability are excluded. The SST method typically produces errors of only ∼0.005 - 0.007 mag. For the few targets with particularly sparse fields, a piggy-back wide-field imager is being deployed.

6. Rotational Modulations

In searching for periodicities due to rotational modulation we restrict our data to observations taken within a season. Starspots form and fade on short timescales and differential rotation will cause spots at different latitudes to exhibit different periods or even "drift". Therefore combining data across seasons would not necessarily yield a well-defined period.

The Lomb-Scargle periodogram has become a standard for searching for periodic signatures in unevenly sampled data. Although the periodogram in many cases will detect a significant period, due to the assumption of purely sinusoidal modulation, the variations in spot size, latitude and drift may cause other periods to be missed. Also, it is easily "thrown off" by episodic activity, such as flares.

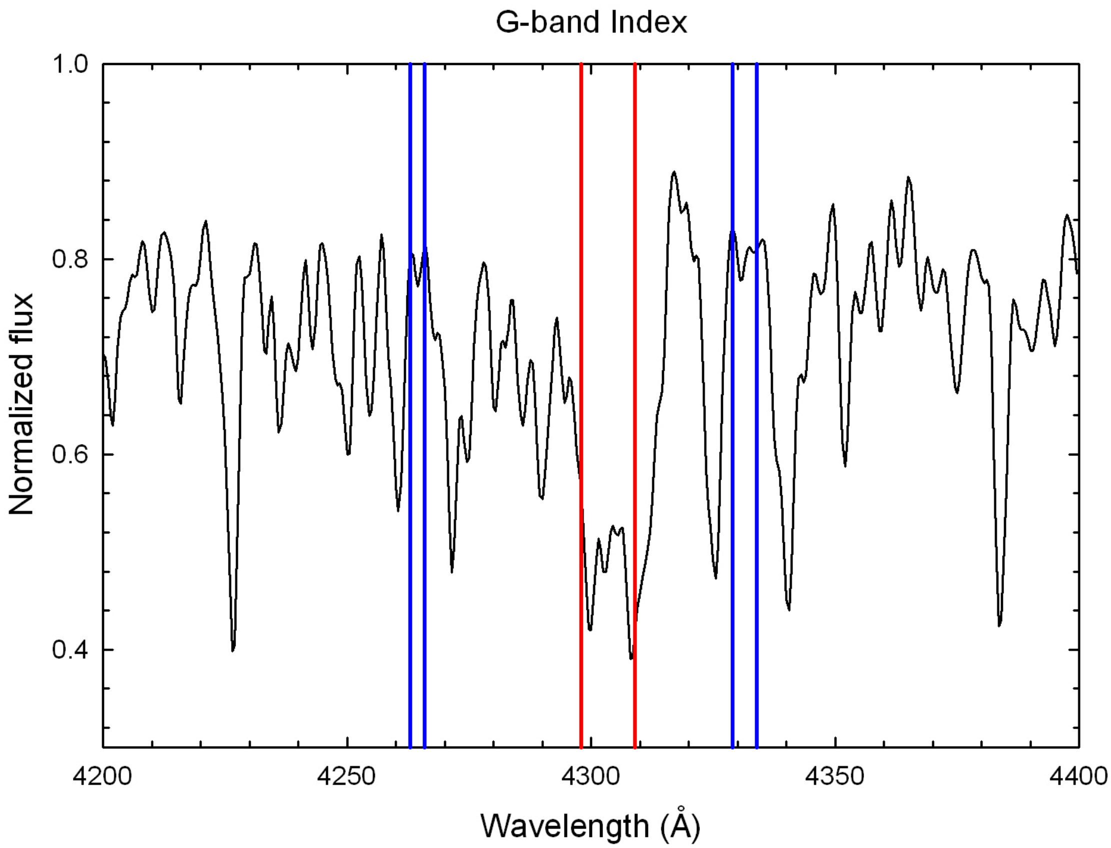

Figure .2: Continuum and spectral regions for G-band index. Continuum regions are in blue.

Therefore we also employ a Maximum Likelihood search using a fine grid of test periods and a "robust" estimator, the sum of absolute differences, to minimize the effect of transients. This technique is less susceptible to short-term variations in sparse data. In both cases we look for confirmation between seasons and/or correlations between photometry and spectral indexes to help verify the reality of a detected period.

The False Alarm Probability for both methods is estimated using Monte Carlo techniques. A run of ∼10,000 test cases is made in which the data is repeatedly scrambled amongst the observation times and checked for the most significant period. The fraction of these "random" data sets with a more significant period than the the test period gives an estimate of the False Alarm Probability. This technique preserves the noise characteristics of the data and any systematic effects introduced by the sequence of observation times.

Acknowledgements. We gratefully acknowledge support from NSF grant AST-1109158.

References

Baliunas, S. L. et al. 1995, ApJ, 438, 269

Corbally, C. J., Gray, R. O., Saken, J. M. 2014, Short-term Activity in Young Solar Analogs, in 18th Cambridge Workshop on Cool Stars, Stellar Systems, and the Sun, Proceedings of Lowell Observatory, eds. G. van Belle & H. Harris

Gray, R. O., Saken, J. M., Corbally, C. J., Briley, M. M., Fuller, V.A ., Lambert, R. A., Newsome, I. M., Childers, M. J. 2014, The Young Solar Analogs Project, in 18th Cambridge Workshop on Cool Stars, Stellar Systems, and the Sun, Proceedings of Lowell Observatory, eds G. van Belle & H. Harris

Wilson, O. C. 1978, ApJ, 226, 379