NOAO Observing Proposal *Longterm proposal* **Panel:** *For office use.*
Date: March 21, 2011 **Category:** Low Mass Stars

Activity Cycles of Southern Asteroseismic Targets

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Abstract of Scientific Justification *(will be made publicly available for accepted proposals)***:**
The Mount Wilson Ca HK survey revealed magnetic activity variations in a large sample of solar-type stars with timescales ranging from 2.5 to 25 years. This broad range of cycle periods is thought to reflect differences in the rotational properties and the depths of the surface convection zones for stars with various masses and ages. Asteroseismic data will soon provide direct measurements of these quantities for individual stars, but many of the most promising targets are in the southern sky, while long-term magnetic activity cycle surveys have been confined to the north. We propose to continue a long-term monitoring campaign of Ca II H and K emission for a sample of 58 southern solar-type stars to measure their magnetic activity cycles, and their rotational properties when possible. This sample includes the most likely southern asteroseismic targets to be observed by the Stellar Observations Network Group (SONG), currently scheduled to begin operations in 2012. Our survey has already led to the discovery of the shortest known (1.6 year) activity cycle in a solar-type star, and several additional targets in our sample show promising short-term variations in the first three years of data.

Summary of observing runs requested for this project

Run	Telescope	Instrument	No. Nights	Moon	Optimal months	Accept. months
1	CT-1.5m-SVC	CSPEC + L1K	5	bright	Aug - Jan	Aug - Jan
2						
3						
4						
5						
6						

Scheduling constraints and non-usable dates *(up to four lines).*

Scientific Justification *Be sure to include overall significance to astronomy. For standard proposals limit text to one page with figures, captions and references on no more than two additional pages.*

Astronomers have been making telescopic observations of sunspots since the time of Galileo, gradually building a historical record showing a periodic rise and fall in the number of sunspots every 11 years. We now know that sunspots are regions with a sufficiently strong magnetic field to alter the local thermal structure, so this 11-year sunspot cycle actually traces a variation in surface magnetism. Attempts to understand this behavior theoretically often invoke a combination of differential rotation, convection, and meridional flow to modulate the global field through a magnetic dynamo (e.g., see Rempel 2006). Although we cannot observe spots on other solar-type stars directly, these areas of concentrated magnetic field produce strong emission in the Ca II H (396.8 nm) and K (393.4 nm) spectral lines. The intensity of the emission scales with the amount of non-thermal heating in the chromosphere, making these lines a useful spectroscopic proxy for the strength of, and fractional area covered by, magnetic fields (Leighton 1959). Wilson (1978) was the first to demonstrate that many solar-type stars exhibit long-term cyclic variations in their Ca II H and K (hereafter Ca HK) emission, analogous to the solar variations.

Significant progress in dynamo modeling emerged after helioseismology provided meaningful constraints on the Sun's interior structure and dynamics (Brown et al. 1989; Schou et al. 1998). Variations in the mean strength of the solar magnetic field lead to significant shifts ($\sim$0.5 μHz) in the frequencies of even the lowest-degree p-modes (Libbrecht & Woodard 1990; Salabert et al. 2004). Space-based asteroseismology missions, such as MOST (Walker et al. 2003), CoRoT (Baglin et al. 2006), and Kepler (Borucki et al. 2010) will soon allow additional tests of dynamo models using other solar-type stars (see Chaplin et al. 2007; Metcalfe et al. 2007).

High precision time-series photometry from MOST has already revealed latitudinal differential rotation in two solar-type stars (Croll et al. 2006; Walker et al. 2007), and the long-term monitoring from the Kepler satellite and future ground-based networks like the Stellar Observations Network Group (SONG; Grundahl et al. 2008) are expected to yield the precision necessary for asteroseismic measurements of stellar convection zone depths (Verner, Chaplin & Elsworth 2006). By combining such observations with the stellar magnetic activity cycles documented from long-term monitoring of the Ca HK lines, we can extend the calibration of dynamo models from the solar case to a broad range of F, G, and K stars.

The Mount Wilson Ca HK survey revealed magnetic activity variations in northern solar-type stars with cycle periods ranging from 2.5 to more than 25 years (Baliunas et al. 1995). In August 2007 we began a southern Ca HK survey of bright asteroseismic targets, which recently revealed the shortest known (1.6 year) activity cycle in a solar-type star (Metcalfe et al. 2010, see Figure 1). Our measurements also yield an estimate of the rotation period $P_{\rm rot} = 8.5 \pm 0.1$ days with a secondary peak near 7.9 days (see Figure 2), consistent with an independent estimate by Boisse et al. (2010) from the asteroseismic radial velocity data set of Vauclair et al. (2008). Several additional targets in our sample show promising short-term variations in the first three years of data.

We propose continued long-term monitoring of Ca II H and K emission for 58 southern asteroseismic targets. The requested allocation of 5 nights per semester will support NCAR's share of time, supplemented by time from other SMARTS partners. From the observations over the next two years, we expect to directly measure or provide firm lower limits on the cycle period for several stars with short-term activity variations. By comparing our observations to those from an earlier single-epoch survey (Henry et al. 1996), we will also establish limits on the cycle period for stars with the slowest variations in activity.

References

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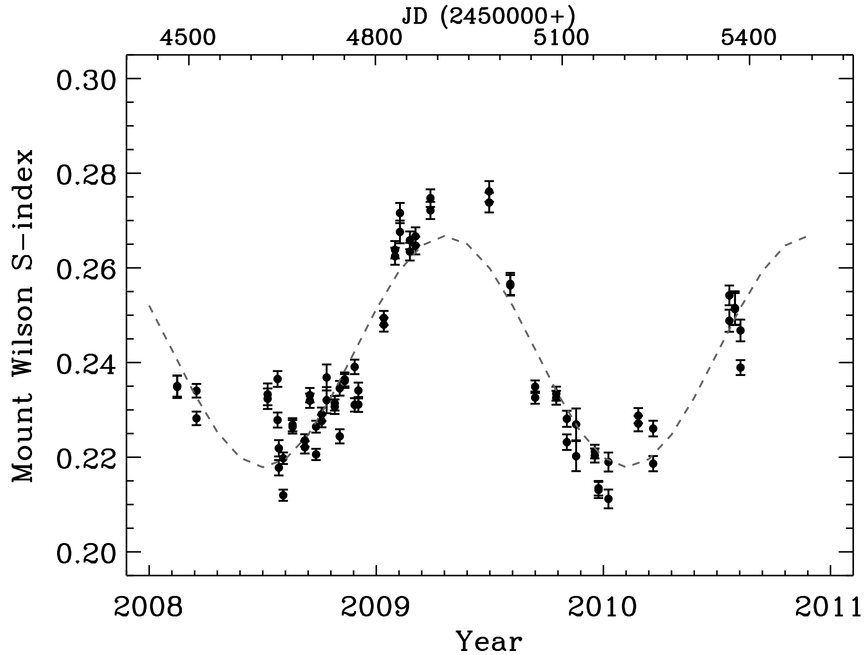

Figure 1: Chromospheric activity measurements of the F8V star ι Hor from the southern HK survey, showing a clear variation with a cycle period of 1.6 years, the shortest cycle measured for a solar-type star.

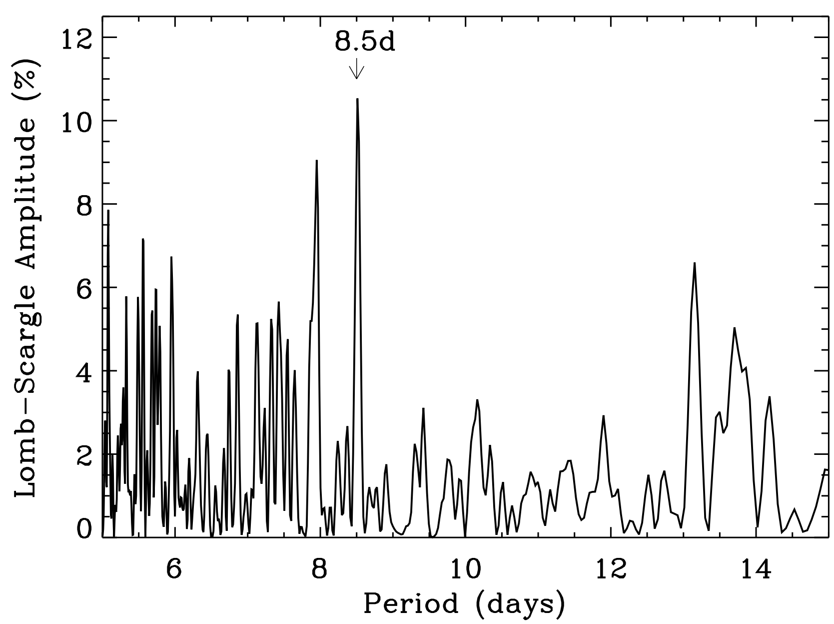

Figure 2: Lomb-Scargle periodogram of our Ca HK measurements after removing the 1.6 year sinusoid, suggesting a rotation period that is consistent with the estimate of Boisse et al. (2010).

Experimental Design *Describe your overall observational program. How will these observations contribute toward the accomplishment of the goals outlined in the science justification? If you've requested long-term status, justify why this is necessary for successful completion of the science. (limit text to one page)*

The single-epoch survey of Henry et al. (1996) contained a total of 1016 observations of 815 individual stars with visual magnitudes between 0.0 and about 9.0, which were observed using the *RC Spec* instrument on the CTIO 1.5m telescope. Several sub-samples were defined, including the "Best & Brightest" (B) and "Nearby" (N) samples, which together contain 92 individual stars with visual magnitudes between 0.0 and 7.9, and B−V colors that are approximately solar. We further limit our sample to the 58 stars in the combined (B+N) sample that are brighter than V=6, the limiting magnitude of future ground-based asteroseismic observations by SONG. All of the most promising southern asteroseismic targets are included in this B+N sub-sample.

The CTIO 1.5m telescope is now operated by a consortium of about a dozen partners, known as SMARTS (Small and Moderate Aperture Research Telescope System). This consortium runs the telescope in queue mode, with observations collected by a trained observer and made available for download by the principal investigator. The observer cycles between the available instruments based on the demand for each during the semester. It is important to note that SMARTS operates the *only* southern telescope run in queue mode with an aperture and instrument that are appropriate for this project. Aside from a dedicated survey telescope like the one at Mount Wilson, SMARTS is the only option that makes such time-domain monitoring feasible.

We have estimated the exposure times required to yield a S/N ∼100 for each of our 58 target stars based on their magnitudes and colors, generally rounded up to the nearest 30-60 seconds. We are requesting a total of 5 nights per semester (40 hours per semester assuming standard 8 hour nights for SMARTS). An observation for each of our target stars includes twice the exposure time plus 8 minutes of observing overhead (2 minutes of readout time, 1 minute for a wavelength calibration spectrum, and the 5 minutes of pointing overhead specified by SMARTS). The time required to cover our entire sample is 12 hours equivalent of observing time. Thus, the 40 hours per semester that we are requesting, when combined with time from other SMARTS institutions, will allow 13 observations per target per year, or roughly 1 observation per target every 2 weeks, whenever the target is available. This rate is sufficient to sample rotational modulation, and in some cases may allow us to determine the rotation period.

The results of our survey, including raw and calibrated time-series measurements of the Ca HK emission for the entire sample of 58 solar-type stars, are made available without restriction through the project web-site (`solar-stellar.org`). Updates are made monthly, after each epoch of observation through the SMARTS queue scheduling system. The data are processed through an IRAF-based pipeline, and archived as gzipped FITS files.

Proprietary Period: None

Use of Other Facilities or Resources *(1) Describe how the proposed observations complement data from non-NOAO facilities. For each of these other facilities, indicate the nature of the observations (yours or those of others), and describe the importance of the observations proposed here in the context of the entire program. (2) Do you currently have a grant that would provide resources to support the data processing, analysis, and publication of the observations proposed here?"*

(1) The Stellar Observations Network Group (SONG) is a concept for a global network of small telescopes dedicated to asteroseismology, and is currently being organized through the Danish Asteroseismology Center at the University of Aarhus. The prototype node of this network is expected to begin operating in 2012, with the full network coming online shortly afterward. SONG will perform asteroseismic observations to a limiting magnitude of V=6. Magnetic activity cycles are known to cause systematic shifts ($\sim$0.5 μHz) in the oscillation frequencies of solar-type stars, which must be considered for a proper asteroseismic analysis. The data obtained through this proposal can be combined with SONG and other asteroseismic data to predict these frequency shifts, and ultimately to help determine the physical nature of their source.

(2) Resources to support data processing, analysis, and publication of the observations proposed here will be provided by High Altitude Observatory, which is part of a federally funded research and development center sponsored directly by the National Science Foundation.

Long-term Details *If you are requesting long term status, list the observing runs (telescope, instrument, number of nights) requested in subsequent semesters to complete the project.*

We request long term status on the CTIO 1.5m using *RC Spec* with an allocation of 5 nights each semester for 3 additional semesters.

Previous Use of NOAO Facilities *List allocations of telescope time on facilities available through NOAO to the PI during the last 2 years for regular proposals, and at any time in the past for survey proposals (including participation of the PI as a Co-I on previous NOAO surveys), together with the current status of the data (cite publications where appropriate). Mark with an asterisk those allocations of time related to the current proposal. Please include original proposal semesters and ID numbers when available.*

We initiated this time-domain survey in 2007B-2008A with SMARTS time purchased by NCAR through Georgia State University, and continued it for two more years as NOAO long-term program 2008B-0039. The survey operated in 2010B with purchased SMARTS time, and in 2011A with CTIO Director's discretionary time because no new proposals were accepted for the CTIO 1.5m in 2011A.

We published results from the first two years of the survey in the proceedings of the Solar Analogs II workshop (Metcalfe et al. 2009; arXiv:0909.5464), where we detected significant long-term trends in 85% of the sample. At the end of the third year we discovered the shortest known (1.6 year) activity cycle in a solar-type star (Metcalfe et al. 2010; arXiv:1009.5399), including a demonstration that our cadence was sufficient to estimate the rotation period.

Observing Run Details for Run 1: CT-1.5m-SVC/CSPEC + L1K

Technical Description *Describe the observations to be made during this observing run. Justify the specific telescope, the number of nights, the instrument, and the lunar phase. List objects, coordinates, and magnitudes (or surface brightness, if appropriate) in the Target Tables section below (required for queue and Gemini runs).*

This proposal is for queue-scheduled all sky time-domain monitoring of bright stars. We are requesting the same telescope (CTIO 1.5m) and instrument (*RC Spec*) that was used in the single-epoch stellar activity survey of Henry et al. (1996). Since all targets are brighter than V=6, there are no lunar constraints (bright time is fine). We are requesting 5 nights equivalent each semester. When combined with allocations from other SMARTS institutions, this will be sufficient to observe each target 13 times annually on average, spread as evenly across the target's observing season as is feasible. Each observation consists of 2 target spectra and 1 calibration spectrum, and requires twice the target exposure time plus 8 minutes of observing overhead (2 minutes of readout time, 1 minute for the wavelength calibration spectrum, and the 5 minutes of pointing overhead specified by SMARTS). No target will be observed more than once in a two week period.

Instrument Configuration

Filters: BG39	Slit: 3.0	Fiber cable:
Grating/grism: 47	Multislit:	Corrector:
Order: II	λ_{start}: 3720	Collimator:
Cross disperser:	λ_{end}: 4180	Atmos. disp. corr.:

R.A. range of principal targets (hours): 0 to 23

Dec. range of principal targets (degrees): -77 to +24

Special Instrument Requirements *Describe briefly any special or non-standard usage of instrumentation.*

Target Table for Run 1: CT-1.5m-SVC/CSPEC + L1K

Obj ID	Object	α	δ	Epoch	Mag.	Filter	Exp. time	# of exp.	Lunar days	Sky	Seeing	Comment
001	HD1581	00:20:04.3	−64:52:29	J2000	4.226	BG39		2	14	spec	> 2.0	B-V=0.576
002	HD2151	00:25:45.1	−77:15:15	J2000	2.820	BG39		2	14	spec	> 2.0	B-V=0.618
003	HD3443	00:37:20.7	−24:46:02	J2000	5.572	BG39		2	14	spec	> 2.0	B-V=0.715
004	HD4628	00:48:23.0	+05:16:50	J2000	5.742	BG39		2	14	spec	> 2.0	B-V=0.890
005	HD7570	01:15:11.1	−45:31:54	J2000	4.959	BG39		2	14	spec	> 2.0	B-V=0.571
006	HD10361	01:39:47.2	−56:11:44	J2000	5.800	BG39		2	14	spec	> 2.0	B-V=0.860
007	HD10360	01:39:47.7	−56:11:34	J2000	5.900	BG39		2	14	spec	> 2.0	B-V=0.800
008	HD10476	01:42:29.8	+20:16:07	J2000	5.242	BG39		2	14	spec	> 2.0	B-V=0.836
009	HD10700	01:44:04.1	−15:56:15	J2000	3.495	BG39		2	14	spec	> 2.0	B-V=0.727
010	HD16160	02:36:04.9	+06:53:13	J2000	5.791	BG39		2	14	spec	> 2.0	B-V=0.918
011	HD17051	02:42:33.5	−50:48:01	J2000	5.400	BG39		2	14	spec	> 2.0	B-V=0.561
012	HD20766	03:17:46.2	−62:34:31	J2000	5.529	BG39		2	14	spec	> 2.0	B-V=0.641
013	HD20807	03:18:12.8	−62:30:23	J2000	5.239	BG39		2	14	spec	> 2.0	B-V=0.600
014	HD20794	03:19:55.7	−43:04:11	J2000	4.260	BG39		2	14	spec	> 2.0	B-V=0.711
015	HD22049	03:32:55.8	−09:27:30	J2000	3.726	BG39		2	14	spec	> 2.0	B-V=0.881
016	HD26965	04:15:16.3	−07:39:10	J2000	4.426	BG39		2	14	spec	> 2.0	B-V=0.820
017	HD30495	04:47:36.3	−16:56:04	J2000	5.491	BG39		2	14	spec	> 2.0	B-V=0.632
018	HD43834	06:10:14.5	−74:45:11	J2000	5.080	BG39		2	14	spec	> 2.0	B-V=0.714
019	HD49933	06:50:49.8	−00:32:27	J2000	5.783	BG39		2	14	spec	> 2.0	B-V=0.352
020	HD53705	07:03:57.3	−43:36:29	J2000	5.559	BG39		2	14	spec	> 2.0	B-V=0.624
021	HD63077	07:45:35.0	−34:10:21	J2000	5.363	BG39		2	14	spec	> 2.0	B-V=0.589
022	HD65907	07:57:46.9	−60:18:11	J2000	5.595	BG39		2	14	spec	> 2.0	B-V=0.573
023	HD76151	08:54:17.9	−05:26:04	J2000	6.000	BG39		2	14	spec	> 2.0	B-V=0.661
024	HD102365	11:46:31.1	−40:30:01	J2000	4.892	BG39		2	14	spec	> 2.0	B-V=0.664

Target Table for Run 1: CT-1.5m-SVC/CSPEC + L1K

Obj ID	Object	α	δ	Epoch	Mag.	Filter	Exp. time	# of exp.	Lunar days	Sky	Seeing	Comment
025	HD114613	13:12:03.2	−37:48:11	J2000	4.849	BG39		2	14	spec	> 2.0	B-V=0.693
026	HD115383	13:16:46.5	+09:25:27	J2000	5.209	BG39		2	14	spec	> 2.0	B-V=0.585
027	HD115617	13:18:24.3	−18:18:40	J2000	4.739	BG39		2	14	spec	> 2.0	B-V=0.709
028	HD128621	14:39:35.1	−60:50:14	J2000	1.350	BG39		2	14	spec	> 2.0	B-V=0.900
029	HD128620	14:39:36.5	−60:50:02	J2000	0.010	BG39		2	14	spec	> 2.0	B-V=0.710
030	HD130948	14:50:15.8	+23:54:43	J2000	5.863	BG39		2	14	spec	> 2.0	B-V=0.576
031	HD131156	14:51:23.4	+19:06:02	J2000	4.700	BG39		2	14	spec	> 2.0	B-V=0.730
032	HD131977	14:57:28.0	−21:24:56	J2000	5.723	BG39		2	14	spec	> 2.0	B-V=1.024
033	HD136352	15:21:48.1	−48:19:03	J2000	5.652	BG39		2	14	spec	> 2.0	B-V=0.639
034	HD140538	15:44:01.8	+02:30:55	J2000	5.865	BG39		2	14	spec	> 2.0	B-V=0.684
035	HD141004	15:46:26.6	+07:21:11	J2000	4.422	BG39		2	14	spec	> 2.0	B-V=0.604
036	HD147513	16:24:01.3	−39:11:35	J2000	5.385	BG39		2	14	spec	> 2.0	B-V=0.625
037	HD147584	16:28:28.1	−70:05:04	J2000	4.900	BG39		2	14	spec	> 2.0	B-V=0.555
038	HD155886	17:15:20.8	−26:36:09	J2000	5.290	BG39		2	14	spec	1.0	B-V=0.860
039	HD155885	17:15:21.0	−26:36:10	J2000	5.330	BG39		2	14	spec	1.0	B-V=0.850
040	HD156384	17:18:57.2	−34:59:23	J2000	5.910	BG39		2	14	spec	> 2.0	B-V=1.082
041	HD156274	17:19:03.8	−46:38:10	J2000	5.330	BG39		2	14	spec	> 2.0	B-V=0.770
042	HD158614	17:30:23.8	−01:03:47	J2000	5.314	BG39		2	14	spec	> 2.0	B-V=0.715
043	HD160691	17:44:08.7	−51:50:03	J2000	5.127	BG39		2	14	spec	> 2.0	B-V=0.694
044	HD165341	18:05:27.3	+02:30:00	J2000	4.026	BG39		2	14	spec	> 2.0	B-V=0.860
045	HD165185	18:06:23.7	−36:01:11	J2000	5.900	BG39		2	14	spec	> 2.0	B-V=0.615
046	HD165499	18:10:26.2	−62:00:08	J2000	5.473	BG39		2	14	spec	> 2.0	B-V=0.592
047	HD172051	18:38:53.4	−21:03:07	J2000	5.858	BG39		2	14	spec	> 2.0	B-V=0.673
048	HD190406	20:04:06.2	+17:04:13	J2000	5.788	BG39		2	14	spec	> 2.0	B-V=0.600
049	HD190248	20:08:43.6	−66:10:55	J2000	3.554	BG39		2	14	spec	> 2.0	B-V=0.751
050	HD191408	20:11:11.9	−36:06:04	J2000	5.315	BG39		2	14	spec	> 2.0	B-V=0.868
051	HD206860	21:44:31.3	+14:46:19	J2000	5.945	BG39		2	14	spec	> 2.0	B-V=0.587
052	HD207129	21:48:15.8	−47:18:13	J2000	5.579	BG39		2	14	spec	> 2.0	B-V=0.601
053	HD209100	22:03:21.7	−56:47:10	J2000	4.688	BG39		2	14	spec	> 2.0	B-V=1.056
054	HD211415	22:18:15.6	−53:37:37	J2000	5.363	BG39		2	14	spec	> 2.0	B-V=0.614
055	HD211998	22:24:36.9	−72:15:19	J2000	5.290	BG39		2	14	spec	> 2.0	B-V=0.650
056	HD212330	22:24:56.4	−57:47:51	J2000	5.310	BG39		2	14	spec	> 2.0	B-V=0.665
057	HD214953	22:42:36.9	−47:12:39	J2000	5.988	BG39		2	14	spec	> 2.0	B-V=0.584
058	HD217014	22:57:28.0	+20:46:08	J2000	5.469	BG39		2	14	spec	> 2.0	B-V=0.666