The 16th Cambridge Workshop on Cool Stars, Stellar Systems and the Sun
ASP Conference Series, Vol. 448, Electronic Edition
Christopher M. Johns-Krull, Matthew K. Browning, and Andrew A. West, eds.

Results of the First Observations with the Hamburg Robotic Telescope

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Abstract. The results of the first scientific observations with the Hamburg Robotic Telescope (HRT) are presented. These observations were performed between October 2008 and August 2009. The goals of this program were a test of the observational performance of the telescope and the creation of a transformation equation from the HRT S-index to the Mount Wilson S-index. The mean of the deviations between the transformed HRT S-Indices and the corresponding Mount Wilson S-Indices is ≈4%. These deviations can be -at least partially- explained by stellar variability and the non-simultaneity of the observations. Furthermore, the first monitoring of several stars was performed.

1. Introduction

The HRT[1] was built by Halfmann Teleskoptechnik GmbH (Germany) and installed at Hamburger Sternwarte in 2005. This Cassegrain-Nasmyth F/8 type telescope has a 1.2 m aperture, an Alt/Az mounting and final direct drives with high-precision absolute encoders. The only instrumentation of the HRT is the Échelle Spectrograph HEROS (Heidelberg Extended Range Optical Spectrograph). It is connected with the telescope via a Polymicro FVP 50/70 μ fused silica fiber, which is equipped with microlenses at both ends in order to adapt the HRT-HEROS focal ratios.
The telescope is designed for long-term spectroscopic monitoring of active stars. The first scientific observations were performed at the Hamburger Sternwarte between October 2008 and August 2009. In this time only the blue channel of HEROS (380-570 nm) was operating with a spectral resolution of R≈20 000. The final location of the HRT will be Guanajuato in Mexico.

2. Mount Wilson S-index

The Mount Wilson S-index (hereafter S_{MWO}) is the most important standard activity index in the optical spectral range, since O. Wilson began a long-term monitoring program of main sequence stars ”Mount Wilson HK-Project” at the Mount Wilson Obser-

[1]http://www.hs.uni-hamburg.de/DE/Ins/Per/Hempelmann/HRT/index.html

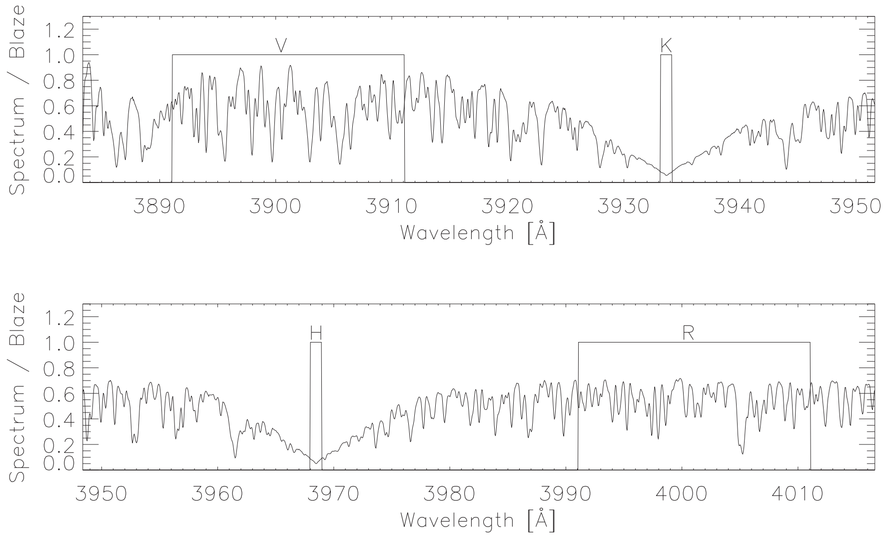

Figure 1. The Ca ɪɪ K+H spectral range with the four bandpasses to calculate the HRT S-index. (Spectrum of the Sun observed at Mar. 8. 2009

vatory (MWO) in 1966 (Wilson 1978). This long-term program searched for chromospheric variations in main-sequence stars like the 11 years solar cycle (Wilson 1978; Vaughan et al. 1981; Duncan et al. 1991; Baliunas et al. 1995).
The S_{MWO} is calculated form the number of counts obtained in four channels and is defined as (Vaughan et al. 1978; Duncan et al. 1991):

$$S_{\mathrm{MWO}} = \alpha\left(\frac{N_{\mathrm{H}} + N_{\mathrm{K}}}{N_{\mathrm{R}} + N_{\mathrm{V}}}\right). \tag{1}$$

This index is the ratio of the number of counts N_{H} and N_{K} in the triangular bandpasses H and K with a FWHM of 1.09 Å centered in the Ca ɪɪ H+K line cores and the number of counts N_{R} and N_{V} in the 20 Å continuum bandpasses V and R centered at 3901.07 Å and 4001.07 Å.
The reason why the triangular bandpass was used is the instrumental profile of the scanning detector slit of the H and K channel. The factor α is a calibration factor to be able to compare the values between the first and second instrument of the Mount Wilson HK-Project. Duncan et al. (1991) adopted the factor α as a constant (α=2.4), because the night to night variations of α were less than the precision of the S-index. The S-index is thus a dimensionless quantity, which allows to estimate the activity level of a star, which in turn depends on the color index of the object.

3. HRT S-index

Before calculating S_{HRT} the radial velocity shift has to be estimated for the object in the Ca ɪɪ H+K region (3900 Å to 4000 Å). Here the Ca ɪɪ H+K region of the observed

spectrum is compared to a synthetic spectrum calculated with the multi-purpose stellar atmosphere code PHOENIX (Hauschildt et al. 1999). Then the radial velocity shift is estimated by a cross correlation. The synthetic spectrum is selected from a grid of synthetic spectra with average stellar parameters corresponding to an average color index B-V and luminosity class (Gray 2005). The wavelength of the selected synthetic spectrum is converted from vacuum wavelength into air wavelength and thereafter the spectral lines are broadened by the rotation velocity (vsini) and the instrumental broadening (R). Finally, the wavelength of the observed spectrum is corrected by the estimated radial velocity shift.
The S-index is determined from the blaze-normalized and merged spectrum, for which a 1 Å bandpass is used and not the classical triangular bandpass with a FWHM of 1.09 Å for the cores of the Ca II H+K lines. The reason for using the 1 Å bandpass is that there is no triangular instrumental profile. Fig. 1 shows an example of a spectrum where the four bandpasses are marked. Finally, the ratio of these four areas is calculated with Eq. 1. The factor α is set to 1, because α is only a multiplication factor and has no influence of the precision of the transformation equation.
The error of the HRT S-index is estimated with the error propagation of the standard deviation of the variations of the integral over each area in the four bandpasses. A Monte-Carlo simulation was carried out in order to determine these variations.

4. S-index Transformation from the HRT S-index into the Mount Wilson S-index

The S-index from different instruments has to be converted to the Mount Wilson S-index in order to be comparable. Therefore, it is necessary to create a transformation equation from S_{HRT} to S_{MWO}. For the creation of this transformation equation, we selected mainly constant as well as non-periodic variable active stars. Therefore, we used data from two activity surveys. For 15 objects of the sample, S_{MWO} was taken from the Mount Wilson survey (Baliunas et al. 1995). For the other 14 objects of the sample, S_{MWO} was taken from Hall's observations at the Lowell observatory (see Hall et al. 2007, 2009). From 13 objects of the Lowell data, the measurements of 2008 were used or in the case that the object was not observed in 2008, the average S_{MWO} of this

Table 1. Stars that are used to derive the transformation equation from the HRT S-index into the Mount Wilson S-index.

Objects and references:
(1) Hall, (2) Baliunas et al. (1995), (3) Hall et al. (2009)

HD6920	(1)	HD39587	(1)	HD79028	(1)	HD131156A	(2)
HD10307	(1)	HD41330	(1)	HD89744	(2)	HD137107	(2)
HD10476	(1)	HD42807	(1)	HD101501	(3)	HD142373	(2)
HD13421	(2)	HD43587	(2)	HD114378	(2)	HD201091	(2)
HD19373	(1)	HD61421	(2)	HD115383	(2)	HD217014	(2)
HD22072	(2)	HD72905	(2)	HD120136	(1)		
HD32923	(1)	HD75332	(2)	HD121370	(1)		
HD35296	(1)	HD75528	(1)	HD124570	(2)		

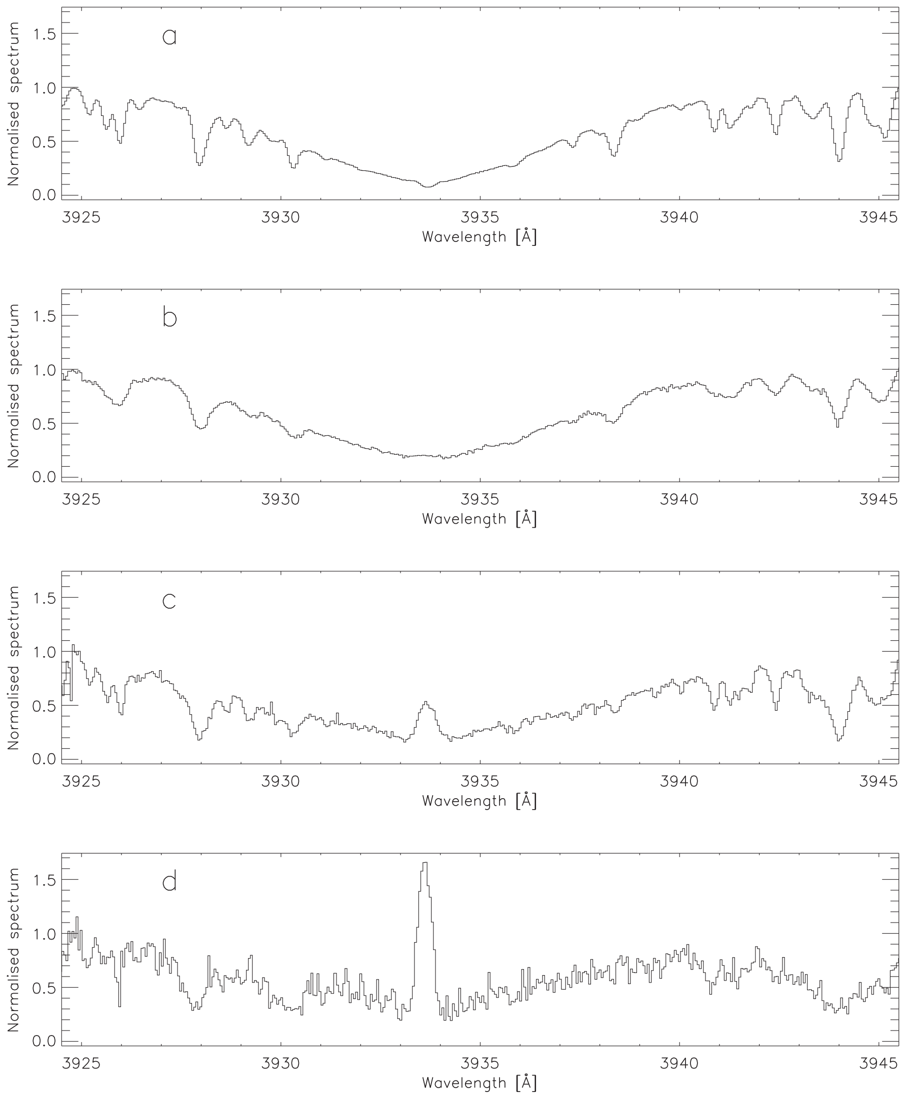

Figure 2. Examples of Ca II K lines from objects, which were used to create the transformation equation. These objects show different activity level; a: HD61421, b: HD114378, c: HD101501, d: HD201091

object was used.
For HD101501, the $S_{\rm MWO}$ was taken from Hall et al. (2009) and for HD201091, the $S_{\rm MWO}$ was extrapolated from the period derived by Baliunas et al. (1995).
The objects which are used to derive the transformation equation from the HRT S-index into the Mount Wilson S-index are collected in Table 1. The spectra of the Ca II K line of four of the sample stars are shown in Fig. 2. The spectra are sorted by increasing activity from top to down.
Fig. 3 shows the $S_{\rm MWO}$ vs. $S_{\rm HRT}$. We obtained a linear relation between the $S_{\rm HRT}$ and $S_{\rm MWO}$ and the solid line in Fig. 3 represents the fit. The transformation equation from

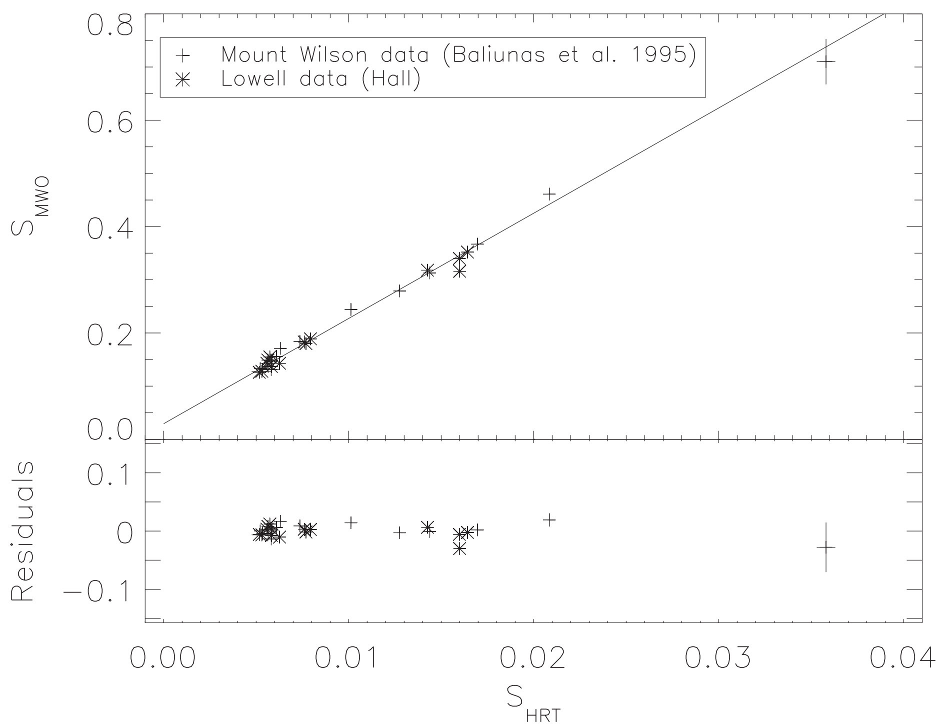

Figure 3. S_{MWO} vs. S_{HRT}. The solid line in the upper part represents the linear fit to convert the HRT S-index into the Mount Wilson S-index. In the lower plot, the residuals of the fit are shown.

the HRT S-index into the Mount Wilson S-index is:

$$S_{\text{MWO}} = (0.029 \pm 0.004) + (19.8 \pm 0.6) S_{\text{HRT}}. \tag{2}$$

This fit has a reduced χ^2 of 1.2 and the residuals have a standard deviation of 0.011. The mean of the deviations between the transformed HRT S-Indices and the corresponding Mount Wilson S-Indices is 3.8%. These deviations are certainly caused, at least partially, by the non-simultaneity of the observations.

5. Results for two stars of the first monitoring period

The first monitoring of several stars was performed during this observation period. The goal of these observations was to measure the rotation period of the star. To find a periodic variation, a Fourier analysis was performed with the Lomb-Scargle method (Scargle 1982; Horne & Baliunas 1986). As examples, the results of the monitoring of the Sun and HD120136 are presented.

5.1. The Sun

The Sun was observed on 73 occasions (spectra of the blue sky) and two times at night (Moon spectra) during October 2008 and July 2009 (Mittag 2010). The Sun was spotless in 54 observations and had only few and quite faint spots at 21 observations.

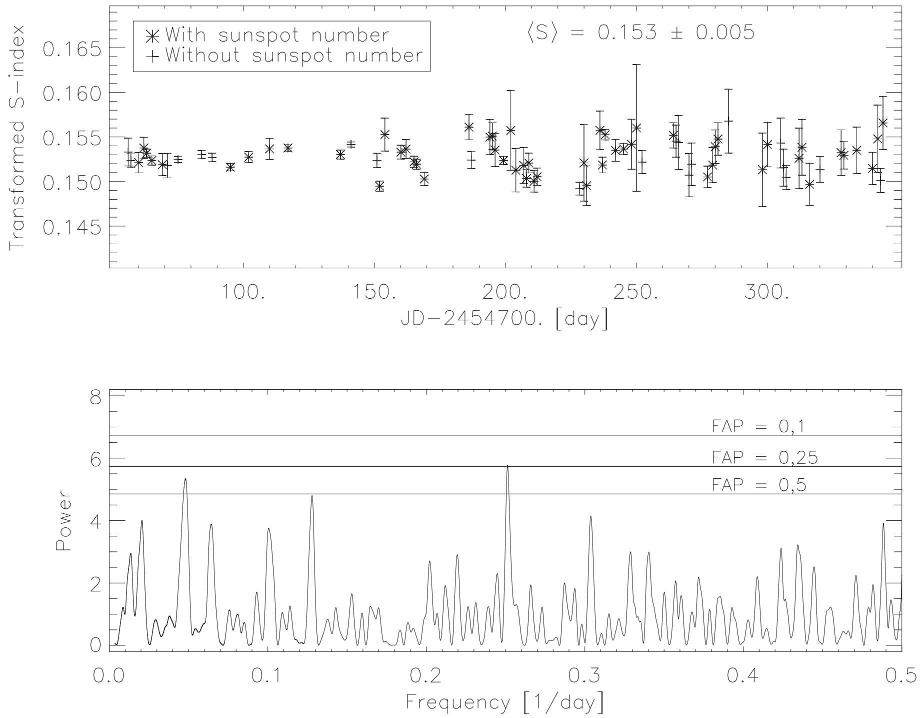

Figure 4. In the upper plot, the time series of S-index of the Sun is shown. The lower plot shows the periodogram of the Fourier analysis.

In Fig. 4 (top) the S-index vs. time is displayed and we obtained an average S-index of $S_{\rm MWO}$=0.153±0.005. One can see that the activity level is constant over this time. To check whether the rotation period of the Sun is seen in the data, a Fourier analysis was performed. The periodogram is presented in Fig. 4 (bottom), which obviously does not contain any significant peak. This result is not unexpected because the Sun was relatively inactive at this time .

5.2. HD120136

HD120136 or τ Boo is a bright star with B-V=0.508 mag and a visual magnitude of V=4.5 mag (Hipparcos Main catalogue). Furthermore, the rotation period of τ Boo is known (P=3.3±0.5 day, Baliunas et al. 1997). Therefore, this star is a good object to test whether the rotation period is measurable in the S-index.
Fig. 5 (top) shows the time series of the S-index. We obtained an average S-index of $S_{\rm MWO}$=0.182±0.006. Some variability of the S-index is visible. A Fourier analysis was performed and the corresponding periodogram is presented in the bottom panel of Fig. 5. A peak is clearly visible at the frequency of ν = 0.313, which corresponds to a period of 3.19±0.02 day. The error of the period is calculated using Eq. 3 of Baliunas et al. (1995). The significance of this peak is only 87%. For a clear detection, this is too low. However, this period corresponds to the known value. The possible reason for this low significance is the poor data sampling, which is due to the poor observing

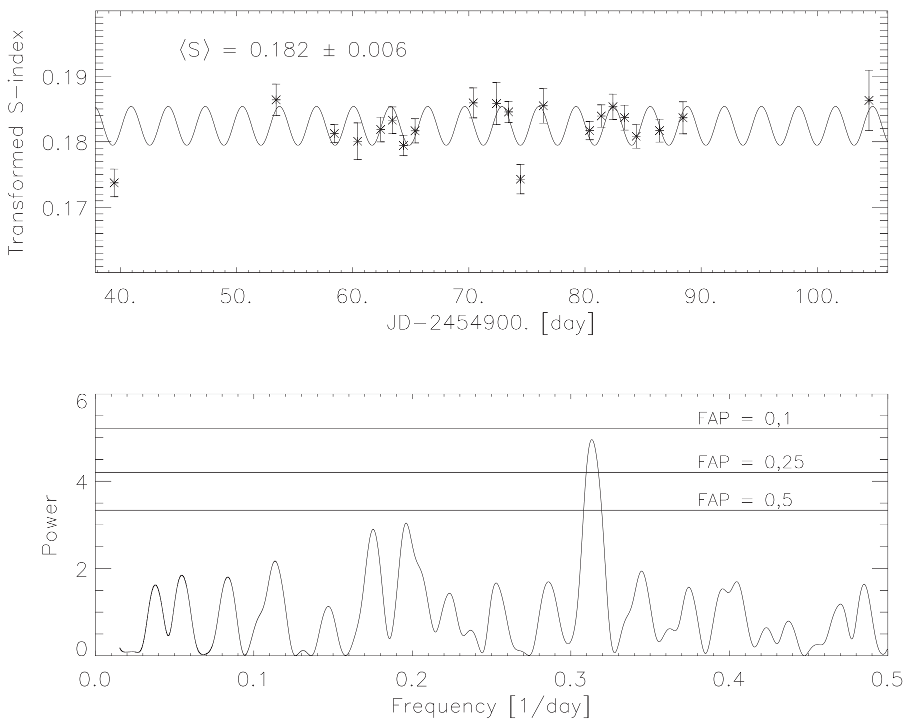

Figure 5. In the upper plot, the time series of S-index of HD120136 is shown. The solid line represents the sine-cosine fit. The Fourier spectrum is shown in the lower panel.

conditions in Hamburg. The solid line in Fig. 5 (top) represents a sine-cosine fit. The reduced χ^2 of this fit is 1.4. For the amplitude of the variation in the S-index, we obtained a value of 0.0030±0.0006, i.e. ≈1.6% of the average S-index.

6. Conclusion

The observational performance of the telescope and spectrograph were tested and optimized during October 2008 and August 2009. It was possible to observe fully automatically at the end of this period.
We create a transformation equation in order to convert the HRT S-index into the Mount Wilson S-index with the results of these observations. Furthermore, we could measure the known rotation period of τ Boo. However, the significance of the peak in the periodogram is only 87%, which is certainly caused by the poor data sampling.
The accuracy of those observations is hampered by the high level of dark noise of the used CCD-camera. The camera was replaced by an Andor Ikon-L camera with negligible dark current after this observational campaign. Thus, observations of the S-index will be more accurate in the future.
We can summarize that the results of the first scientific observations show the potential of the HRT for a future monitoring program and single observations. Only the blue

channel of HEROS was in operation in the period between October 2008 and August 2009. The potential applications will increase with the present commissioning of the red channel of HEROS.

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