THE NEW GLOBAL HIGH–RESOLUTION Hα NETWORK: PRELIMINARY RESULTS ON THE CHROMOSPHERIC DIFFERENTIAL ROTATION

M. Steinegger[1], C. Denker[1], P. R. Goode[1], W. H. Marquette[1], J. Varsik[1], H. Wang[1], W. Otruba[2], H. Freislich[2], A. Hanslmeier[3], G. Luo[4], D. Chen[4], and Q. Zhang[4]

[1]Big Bear Solar Observatory, NJIT, 40386 North Shore Lane, Big Bear City, CA 92314, U. S. A.
[2]Kanzelhöhe Solar Observatory, A–9521 Treffen, Austria
[3]Institute of Geophysics, Astrophysics, and Meteorology, Universitätsplatz 5, A–8010 Graz, Austria
[4]Yunnan Astronomical Observatory, P. O. Box 110, Kunming 650011, P. R. China

ABSTRACT

A new global network for high–resolution Hα full–disk observations of the sun has been established at the Big Bear Solar Observatory (U.S.A.), the Kanzelhöhe Solar Observatory (Austria), and the Yunnan Astronomical Observatory (China). Each of the three stations have a $2K \times 2K$ pixel CCD detector available to monitor the sun with a spatial resolution of 1 arcsec per pixel and a cadence of at least 1 image per minute. Having high–cadence data from three observing stations available enables us to accurately track solar rotation rates and meridional motions by local correlation (LCT) and feature tracking techniques. This includes, e.g., tracking over several days the motions around active regions. After an overview of the new Hα network and its scientific objectives, we present and discuss the first preliminary results of the determination of the chromospheric differential rotation by LCT from a high–cadencence time–series of $H\alpha$ full–disk images. The obtained equatorial rotation rate of 13.3044 deg/day (2.6876 μrad/s) agrees well with the values obtained by other authors. Finally, we briefly outline our future plans for the continuation of this work.

Key words: solar rotation; solar activity; full–disk observations .

1. INTRODUCTION

While full–disk observations in the spectral line of Hα (λ 656.3 nm) obtained at a single observing site can contribute to important solar research, for several reasons it is necessary to monitor the sun round–the–clock. The most severe problem for single station observations is the inevitable night–time gap. Many interesting and important chromospheric phenomena, such as e.g. flares or filament eruptions, occur during the night so that they are missed and lost at single observing stations. Round–the–clock full–disk observations with high spatial resolution and high cadence performed by a dedicated network of Hα telescopes distributed around the globe can continuously follow the evolution of active regions and monitor in detail the continuous changes in the chromosphere. To overcome the limitations of single observing sites and to enable the continuous monitoring of the solar chromosphere with fast and large format CCD cameras, the new global high–resolution Hα network has been established between Big Bear Solar Observatory (BBSO), Kanzelhöhe Solar Observatory (KSO), and Yunnan Astronomical Observatory (YNAO). Full–disk $H\alpha$ data with a spatial resolution of 1 arcsec per pixel and a cadence of at least 1 image per minute are obtained by this network. Among the many different aspects of solar activity, which can be studied with data of such temporal and spatial resolution, the accurate measurement of the chromospheric differential rotation and its possible variation with time is one of the most important and interesting topics. The solar differential rotation has been measured with a variety of different techniques (for a recent review see Beck, 1999). However, the vast majority of these measurements deals with the photospheric rotation. Although there are several papers on the chromospheric rotation (e.g., Vrsnak et al., 1998; Donahue and Keil, 1995; Brajsa et al., 1991), none of them has used local correlation tracking of high–cadence and high–resolution full–disk Hα data. We present the first results obtained by applying local correlation tracking to data from the new global Hα network.

2. THE NEW GLOBAL Hα NETWORK

2.1. Sites and Instruments

BBSO has a long tradition in obtaining synoptic full–disk observations of the sun in Hα (Denker et al., 1999). The same applies to KSO, where high-cadence full–disk

Table 1. Characteristics of the full–disk Hα imaging systems at Big Bear Solar Observatory (BBSO), Kanzelhöhe Solar Observatory (KSO), and Yunnan Astronomical Observatory (YNAO). Both BBSO and KSO use an Apogee KX4 CCD camera, whereas YNAO operates a Kodak Megaplus CCD camera. All cameras use a Kodak KAF–4200 sensor. The meanings of the symbols and abbreviations are the following: geographical longitude (ϕ) and latitude (β), elevation (h), telescope aperture ($\oslash$), filter bandpass ($\Delta\lambda$), tunable filter range (FR), number of pixels (PN), pixel size (PS), and dynamic range (DR).

	BBSO	KSO	YNAO
ϕ	$+116°54.9'$	$-13°54.4'$	$-102°47.4'$
β	$+34°15.2'$	$+46°40.7'$	$+25°01.5'$
h	2067 m	1526 m	1940 m
$\oslash$	15 cm	10 cm	18 cm
$\Delta\lambda$	0.05 nm	0.07 nm	0.05 nm
FR	±0.10 nm	±0.30 nm	±0.06 nm
PN	2k × 2k	2k × 2k	2k × 2k
PS	$9 \times 9\ \mu\mathrm{m}^2$	$9 \times 9\ \mu\mathrm{m}^2$	$9 \times 9\ \mu\mathrm{m}^2$
DR	14 bit	14 bit	8 bit

Hα data are obtained since more than 25 years (Otruba, 1999). The characteristics of the Hα imaging systems operated at each of the network's sites are summarized in Table 1. At each observatory a $2K \times 2K$ pixel CCD camera is in operation, allowing to obtain full–disk Hα images with a resolution of 1 arcsec per pixel and a cadence of at least 1 image per minute. In case of a rapid solar activity change, this cadence can be increased to a rate of several images per minute. All cameras use the same Kodak KAF–4200 sensor, which is essential for obtaining a homogeneous and consistent data set.

The largest time difference between the network sites is about 9.4 hours between BBSO and YNAO. The difference between BBSO and KSO is about 8.7 hours and that between YNAO and KSO about 5.9 hours. During the summer, each station can observe 12 hours on clear days. Therefore, during the summer months and good weather, there is no night–time gap. In winter, when each station is expected to operate 8 hours, the BBSO/YNAO gap will be about 1.4 hours and the BBSO/KSO gap about 0.7 hours. However, these short gaps are no real limitation because we do not intend to use the network data for FFT analysis, as it is the case, e.g., for the GONG network and therefore such short data gaps are negligible. Moreover, the error of measurements made by local correlation tracking increases only slightly ($\sim 1/\sqrt{n}$ for n images), if there are short gaps in the data.

Based on long–term weather records of the three stations, we anticipate a 70% duty cycle in summers and 60% in winters.

2.2. Data Products

All data obtained by the network are processed in exactly the same way in order to produce a homogeneous data set. After correcting for dark current and flat–field, the average quiet sun limb darkening function is subtracted to obtain contrast–enhanced Hα images. A detailed description of this data calibration can be found in Denker et al. (1999). The first network observations have been obtained in March 2000 at BBSO, KSO, and YNAO. Since then we have been able to constantly improve the quality of the data. In Figure 1 we present a recent set of network data observed on August 23, 2000.

The central data archive of the network resides at BBSO, where the most recent network observations can be accessed through the World Wide Web (http://www.bbso.njit.edu/Research/Halpha/). Since the amount of high–cadence data (about 5 GB per day and per site on an average observing day) does not allow an instantaneous transfer by internet, the data from KSO and YNAO are sent on a regular basis to BBSO on exabyte and DLT tapes. At BBSO some of the network data are included into the currently upgraded archiving system (ftp://ftp.bbso.njit.edu/Archive/).

Besides high–cadence contrast–enhanced Hα images of unique quality and resolution, we are going to provide lists with the positions and characteristics of all flares and filament disappearances, as well as lists with all new flux emergences observed on the sun.

2.3. Scientific Objectives

In combination with space and ground–based observations, Hα full–disk observations of high temporal and spatial resolution have been proven to be a key diagnostic for determining the magnetic field topology between the photosphere, chromosphere, transition region, and corona. Besides the determination of global (differential rotation) and local flow fields (flows in active regions and filaments), the scientific objectives of the new network are the following:

Flare Monitoring: High–resolution Hα images with 24 hours high–cadence coverage are essential to identify all the flares on the visible hemisphere of the sun. High spatial resolution and cadence will allow to derive a detailed picture of flare evolution and the underlying physical processes.

Filament Eruptions and Coronal Mass Ejections: Round–the–clock high–resolution full–disk Hα data are extremely important for studying the correlation between filament disappearances and CMEs and for understanding their possible driving mechanisms.

Mini–Filaments: The energy release and mass ejections of erupting mini–filaments are of particular importance, since both can contribute to coronal heating and so-

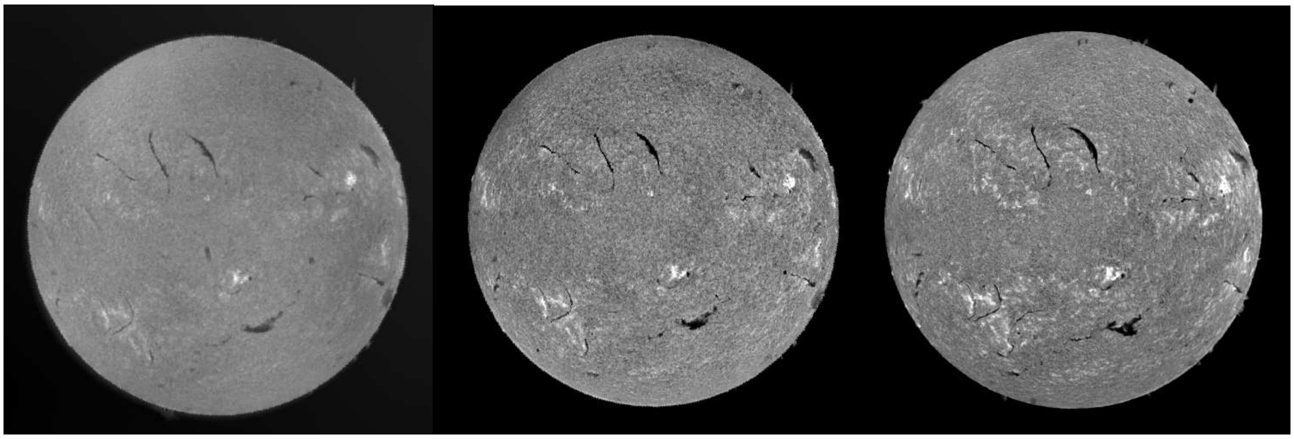

Figure 1. This series of contrast–enhanced Hα images was obtained on August 23, 2000, at Yunnan Astronomical Observatory (03:11 UT, left), Kanzelhöhe Solar Observatory (06:37 UT, center), and Big Bear Solar Observatory (15:46 UT, right).

lar wind acceleration (Wang et al., 2000). With high–cadence and high–contrast Hα data, the spatial distribution of mini–filaments is easy to measure and their detailed evolution can be studied.

Support of Space–Based Observations: During several occasions in the past, the SOHO (Domingo et al., 1995) and TRACE (Schrijver et al., 1996) space missions have been supported by supplying Hα data from BBSO and KSO. By having available high cadence round–the–clock observations from three different sites, we are able to offer even more complete and homogeneous data sets for correlative studies with data obtained in space. Of special interest in this respect is the upcoming HESSI (Holman et al., 1997) mission which will be devoted to solar flare research. High quality Hα data obtained simultaneously with the X– and γ–ray data from HESSI will be an essential tool to reveal the physics behind solar flare eruptions. Since HESSI will provide full–disk observations, continuous solar full–disk data obtained from the ground are vitally important.

Support of Ground–Based Observations: The data and aims of the new Hα network are similar to those of the ISOON project (Neidig et al., 1997), which however is still not fully operational. Data from our network will be available to ISOON for closing data gaps and supplementing their observations. The Max Millennium Program (Canfield, 1999) and its coordinated observing campaigns will also profit from the availability of high–cadence and high–resolution Hα observations supplied by the new network.

Solar Activity and Space Weather Forecasting: Based on the detailed structure of the active regions monitored with high–cadence by the new network, we will predict the probability of flaring and filament eruptions. The automatic detection of filament and flare eruptions will extend the forecast times for space weather predictions. By analyzing statistical properties of and relationships between the various phenomena, we will derive a reliable flare precursor. This will certainly increase the significance and reliability of solar activity and space weather forecasts.

3. PRELIMINARY RESULTS ON THE CHROMOSPHERIC DIFFERENTIAL ROTATION

As pointed out by Beck (1999), determining the solar rotation by cross–correlation methods, i.e., measuring the displacement of features distributed over the whole solar disk, is more objective than the tracing of single structures. We apply the method of local correlation tracking (LCT) to a set of in total 1025 full–disk Hα images obtained on July 12 to 14, 2000, with 1 minute cadence by our new network.

For this purpose an evenly spaced cartesian grid of 64×64 points was overlayed on each of the the $2K \times 2K$ pixel images. By cross–correlating subsequent images, the relative displacements of the grid points have been derived. After eliminating all grid points lying outside the solar disk, the relative displacements have been remapped into heliographical coordinates. In Figure 2, we show the rotation of the chromosphere derived from a subset of 479 high–cadence full–disk Hα network data obtained on July 12, 2000, between 14:42 UT and 23:14 UT. The arrows superimposed on the solar image represent the average flow of the chromospheric plasma during this period in arbitrary units. This figure demonstrates that the general velocity pattern of the chromospheric plasma is disturbed by irregular motions around active regions.

For each grid point the helographic displacement can easily be converted into a value of the synoptic rotation rate corresponding to its latitude and longitude. Projection of these values onto the central meridian and plotting them as function of the heliographic latitude Φ, yields the run of the synoptic differential rotation rate $\Omega(\Phi)$. In Figure 3 we display $\Omega(\Phi)$ for each of the grid points in each of the 479 images used to derive the average rotation pattern of Figure 2. The solid line represents a least–square fit of the common form of $\Omega(\Phi) = A + B \cdot \sin^2 \Phi + C \cdot \sin^4 \Phi$.

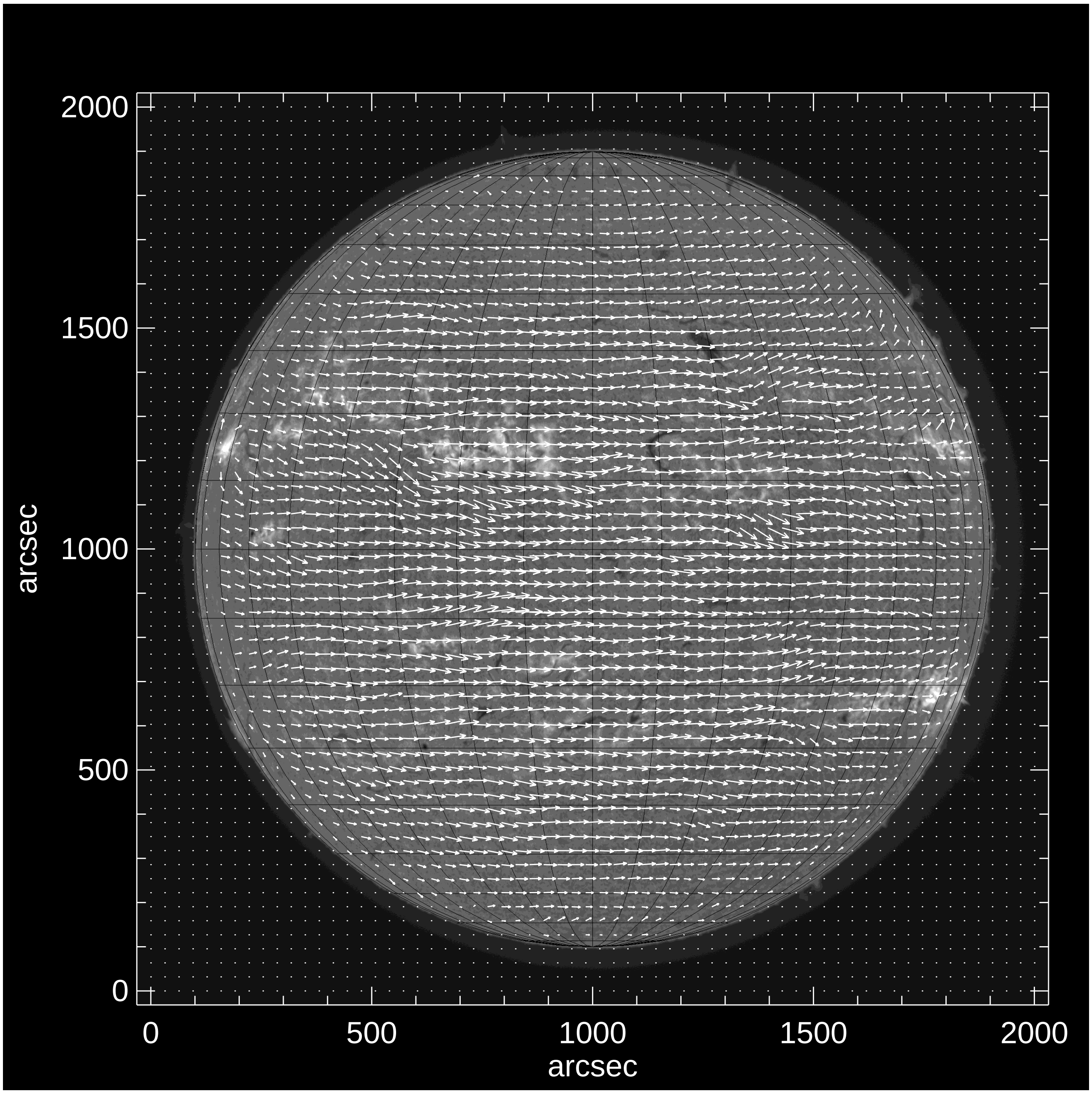

Figure 2. *Solar differential rotation derived from an 8.5 hour time series of 1 minute cadence full–disk Hα data obtained on July 12, 2000, by local correlation tracking (LCT).*

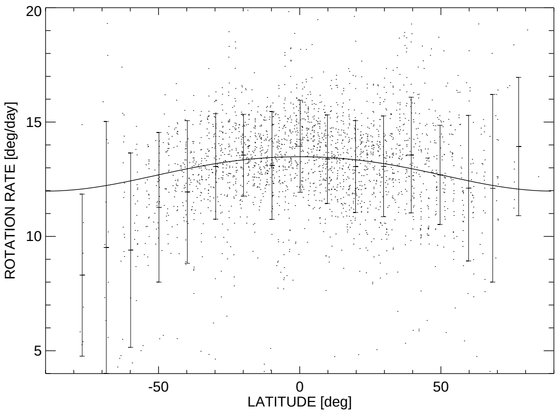

Figure 3. Rotation rate Ω as function of heliographic latitude Φ derived from a set of 479 high–cadence $2K \times 2K$ full–disk pixel Hα images obtained on July 12, 2000, by means of LCT. The error bars denote the standard deviations of the mean values for 10^o–bins of latitude. The solid curve represents a least–square fit of the form $\Omega(\Phi) = A + B \cdot \sin^2 \Phi + C \cdot \sin^4 \Phi$.

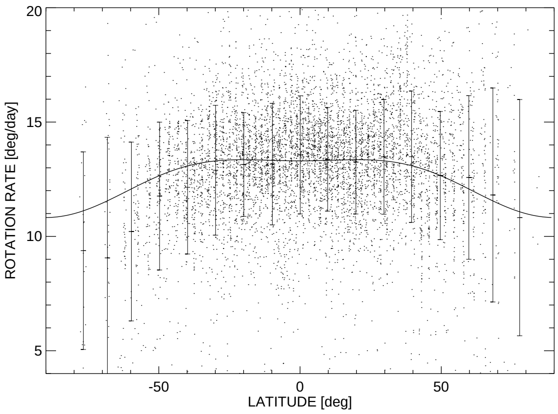

Figure 4. Same as Figure 3, but derived from a series of 1025 high–cadence full–disk Hα data obtained on July, 12–14, 2000.

Table 2. Coefficients of a least–square fit of the form $A + B \cdot \sin^2 \Phi + C \cdot \sin^4 \Phi$ to the rotation rate values plotted in Figures 3 and 4, corresponding to the average motion derived from 479 and 1025 full–disk Hα images, respectively. The coefficients of the fit and their standard deviations are given in units of degrees per day.

	A	B	C
Figure 3	13.4843	−1.1346	−0.3689
	±0.0011	±0.0075	±0.0096
Figure 4	13.3044	0.8039	−3.2832
	±0.0003	±0.0025	±0.0033

To reduce the influence of outliers, only rotation values in the interval of 0 to 20 deg/day have been considered in the fit. The coefficients and their errors are summarized in the first row of Table 2. The vertical bars represent the standard deviation of the mean values calculated for latitude bins of 10^o width. Because of the noise and scattering towards the solar limb, these errors increase for latitudes greater than about 60^o.

If we extend the data set to 1025 frames, observed on three consecutive days from July 12 to 14, 2000, the errors of the coefficients of the fit are reduced by a factor of $\approx$ 3 (second row of Table 2). However, as is demonstrated by Figure 4, in this case the maximum of the rotation curve is not located at the solar equator. The difference between the rotation at the equator of 13.3044 deg/day (2.6876 μrad/s), and the maximum rate of 13.3536 deg/day at $\Phi \approx 20^o$ might reflect the influence of the motions around the active regions, which are located at this latitude range. This equatorial dip was also found by Snodgrass (1983), who derived the magnetic rotation of the photosphere by cross–correlating magnetograms, and it is also present in Doppler measurements (Howard et al., 1980).

The synodic rotation rate of 13.3044 deg/day obtained for the solar equator corresponds to a siderial rate of 13.1181 deg/day (for a discussion of the relationship between synodic and siderial rotation periods see Rosa et al., 1995), about 1.0 deg/day lower than similar measurements derived either by spectroscopic methods or by tracing sunspots (see Beck, 1999, and his Figures 1 and 3). However, our result agrees well with that obtained by Vrsnak et al. (1998), who have derived the synodic rotation rate by tracing large filaments in full–disk Hα images. They derived an average value of 13.5 ± 0.7 deg/day. Similar values have been found by Brajsa et al. (1991) tracing polar crown filaments. Donahue and Keil (1995) have measured the chromospheric rotation from disk–integrated chromospheric Ca II K fluxes as function of the solar cycle. Their siderial period of 26 days obtained for the period of maximum solar activity in 1989 corresponds to a synodic rotation rate of $\approx$ 13.6 deg/days. This is also in accordance with our result, which reflects the chromospheric rotation during solar activity maximum conditions. The findings of Hathaway and Wilson (1990), that the sun rotates faster during the activity minimum, needs to be confirmed for the chromosphere by analyzing Hα data obtained during minimum conditions.

4. CONCLUSIONS

Due to the successfull installation of the new global Hα network, which is a co–operation between BBSO, KSO, and YNAO, the sun can be monitored continuously in Hα with high spatial resolution (1 arcsec per pixel) and high cadence (1 exposure per minute). The calibrated full–disk images available from the network are to date unique in quality and resolution. The availability of these data is essential for a variety of important scientific research projects, relevant for both solar physics and space weather.

Analyzing a first set of high–cadence network data, we have been able to derive the chromospheric differential rotation by means of local correlation tracking, confirming previous results by other works. In continuation of the study presented here, we plan to address the following topics concerning the rotational and meridional motions of the solar chromosphere:

- further increasing the accuracy of our differential rotation measurements by extending the data set to several weeks;
- studying the long–term variations of the chromospheric differential rotation on solar cycle time–scales;
- analyzing a possible north–south asymmetry in the chromospheric rotation;
- using an adaptive grid for measuring the polar rotation with higher accuracy;
- determining how the differential rotation is disturbed by the presence of meridional motions and flow fields around active regions;
- analyzing how the changes in the motions around active regions can be used for predicting solar flares.

At the time of this writing, two other solar observatories have already expressed their interest in joining the network: the Baikal Astrophysical Observatory of the Institute of Solar–Terrestrial Physics in Russia, and the Huairou Solar Observing Station of the Beijing Astronomical Observatory in China. Both observatories are equipped with $2K \times 2K$ pixel CCD cameras and capable of operating them in 1 minute high–cadence mode. The extension of the network by these two stations will further increase its duty cycle and data coverage.

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REFERENCES

Beck J. G., 1999, Solar Physics 191, 47

Brajsa R., Vrsnak B., Ruzdjak V., Schroll A., Pohjolainen S., Urpo S., and Teräsranta H., 1991, Solar Physics 133, 195

Canfield R. C., 1999, AAS, 194, 8006

Denker C., Johannesson A., Marquette W. H., Goode P. R., Wang H., Zirin H., 1999, Solar Physics 184, 87

Domingo V., Fleck B., and Poland A.I., 1995, Solar Physics 162, 1

Donahue R. A., and Keil S. L., 1995, Solar Physics 159, 53

Goode P. R., Wang H., Marquette W. H., and Denker C., 2000, Solar Physics, in press

Hathaway D. H., and Wilson R. M., 1990, Astrophysical Journal 357, 271

Holman G. D., and 18 co–authors, 1997, AAS 191, 7416

Howard R., Boyden J. E., and LaBonte B. J., 1980, Solar Physics 66, 167

Neidig D., and 10 co–authors, 1997, SPD 29, 0224

Otruba W., 1999, ASP Conference Series 184, 314

Rosa D., Brajsa R., Vrsnak B., and Wöhl H., 1995, Solar Physics 159, 393

Schrijver C., and 13 co–authors, 1996, AAS, 188, 6704

Snodgrass H. B., 1980, Astrophysical Journal 270, 288

Vrsnak B., Rosa D., Bozic H., Brajsa R., Ruzdjak V., Schroll A., and Wöhl H., 1998, Solar Physics 185, 207

Wang, H., and 7 co–authors, 2000, Astrophysical Journal 530, 1071