THE NEW GLOBAL HIGH–RESOLUTION Hα NETWORK: FIRST OBSERVATIONS AND FIRST RESULTS

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. We will implement automatic detection routines for flare and filament eruptions. These routines can automatically trigger even higher cadence observations. Having high–cadence data from three observing stations will enable us to accurately track solar rotation rates as determined by local correlation and feature tracking techniques. This includes, e.g., tracking over several days the proper motion of active regions. High–cadence Hα data with high spatial resolution allow us to study in detail the correlations between coronal mass ejections and the solar surface activity. The new network also represents an important tool for correlative studies between ground–based and space observations, as well as for improving the reliability of current space weather predictions.

Key words: solar activity; space weather; full–disk observations; flare monitoring.

1. INTRODUCTION

While full–disk observations in the spectral line of Hα ($\lambda\,656.3$ 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 flares or filament eruptions, occur during the night so that they are missed and lost at a single observing station. 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 every flare and filament eruption occuring on the visible solar hemisphere. Observing the sun continuously in Hα is not only important for solar physics, but also for space weather research. As triggers of space weather variations, chromospheric features such as flares and filament eruptions and the associated coronal mass ejections, have a direct impact on the solar terrestrial environment. Uninterrupted high cadence Hα observations are therefore important for monitoring and forecasting both solar activity and space weather.

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) in the U.S.A., Kanzelhöhe Solar Observatory (KSO) in Austria, and Yunnan Astronomical Observatory (YNAO) in China.

2. NETWORK 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 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.

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 camerae, 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	9×9 μm^2	9×9 μm^2	9×9 μm^2
DR	14 bit	14 bit	8 bit

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 although occacionally a flare can be missed in winter time, we are still able to record the pre– and post–flare evolution with high temporal resolution. Moreover, we do not intend to use the network data for FFT analysis, as it is the case with the GONG network and therefore such short data gaps are negligible. Based on long–term weather records of the three stations, we anticipate a 70% duty cycle in summers and 60% in winters.

3. 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). Figure 1 shows one such high–resolution full–disk Hα image obtained by the network. This particular image was observed at BBSO on June 6, 2000, at 15:42 UT with the 15 cm Singer full–disk telescope. Please note the uniform contrast throughout the whole disk, which facilitates the detection of chromospheric features like plages, filaments, and prominences. 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 2 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 all network data are included into the recently 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.

4. 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. We believe that large format CCD cameras and advanced image processing techniques provide a unique opportunity for studies with full–disk Hα data. Among the scientific objectives of the new network are the following:

Feature Identification and Feature Tracking: Local correlation and feature tracking is used to determine global (differential rotation) and local flow fields (flows in active regions and filaments) from full–disk data. Discontinuities in currently available time sequences severely inhibits the accurate measurement of these flow fields.

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 and 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. Figure 1 is an excellent example of how ground based observations and space observations can supplement each other for studying correlations between the various activity phenomena.

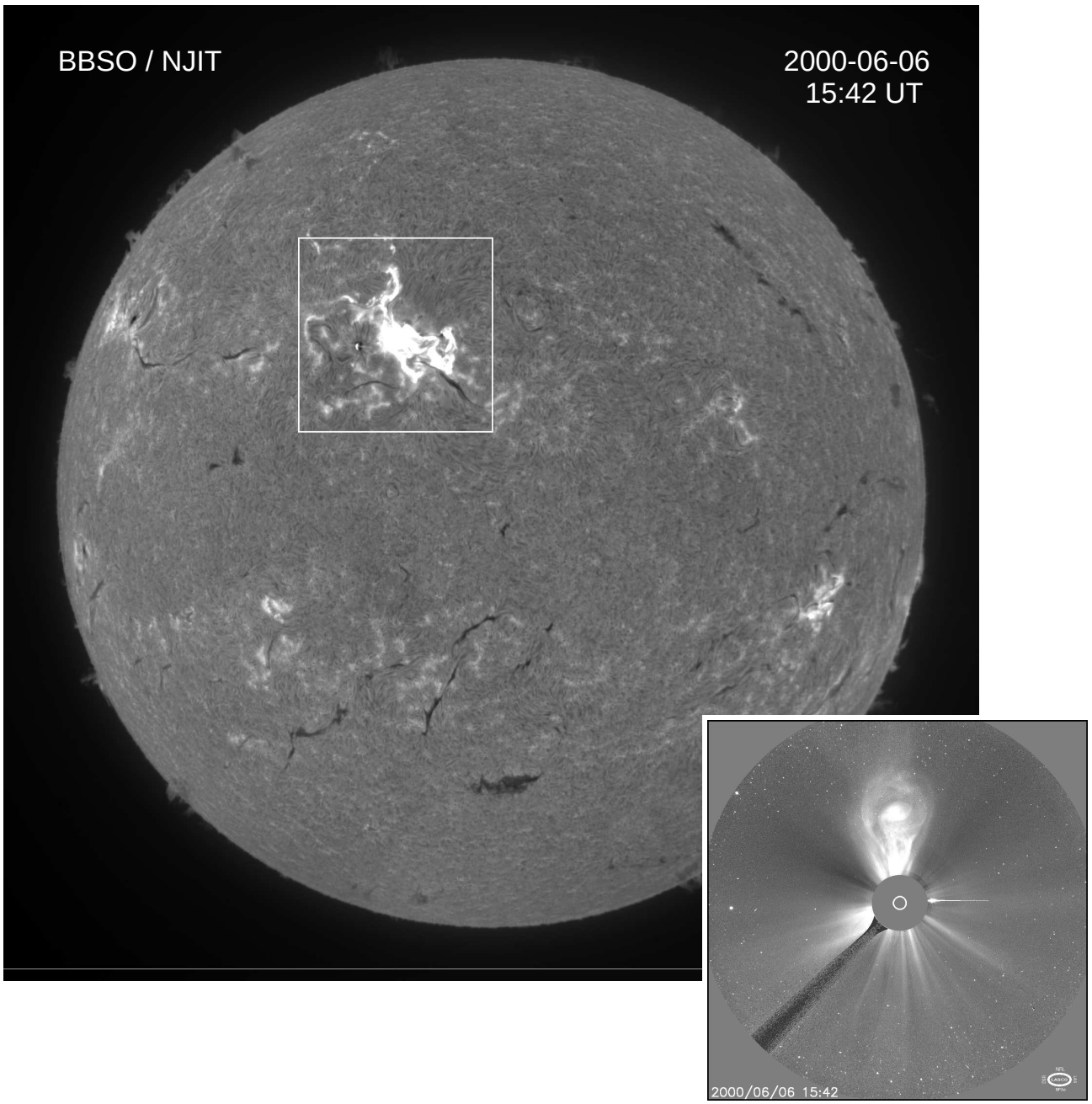

Figure 1. Contrast–enhanced full–disk Hα image (2K $\times$ 2K pixel) obtained after correcting for dark current and flat–field, and after subtracting the average center–to–limb variation of the quiet sun. This image was recorded with Big Bear Solar Observatory's 15 cm Singer full–disk telescope on June 6, 2000, at 15:42 UT during the eruption of an X2.3 flare in NOAA 9026. This flare, whose position is marked by the white box (400 $\times$ 400 pixel), started at 14:48 UT and was associated with a halo CME and a severe magnetic storm. The inset in the lower right corner shows this magnificent CME on a SOHO/LASCO C3 image recorded at the same time, although the contrast of the halo is quite weak.

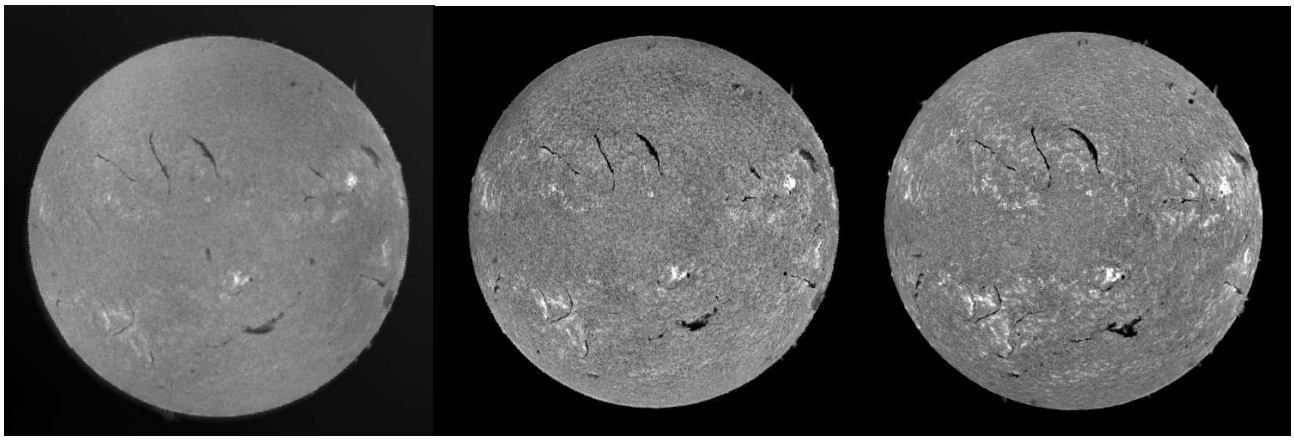

Figure 2. This series of contrast–enhanced Hα images was obtained on August 23, 2000, at Yunnan Astronomical Observatory (03:11 UT, left), Kanzelhöhe Solar Observatory (06:37 UT, center), and Big Bear Solar Observatory (15:46 UT, right). Note the evolution of the filament in the southern hemisphere within only a few hours.

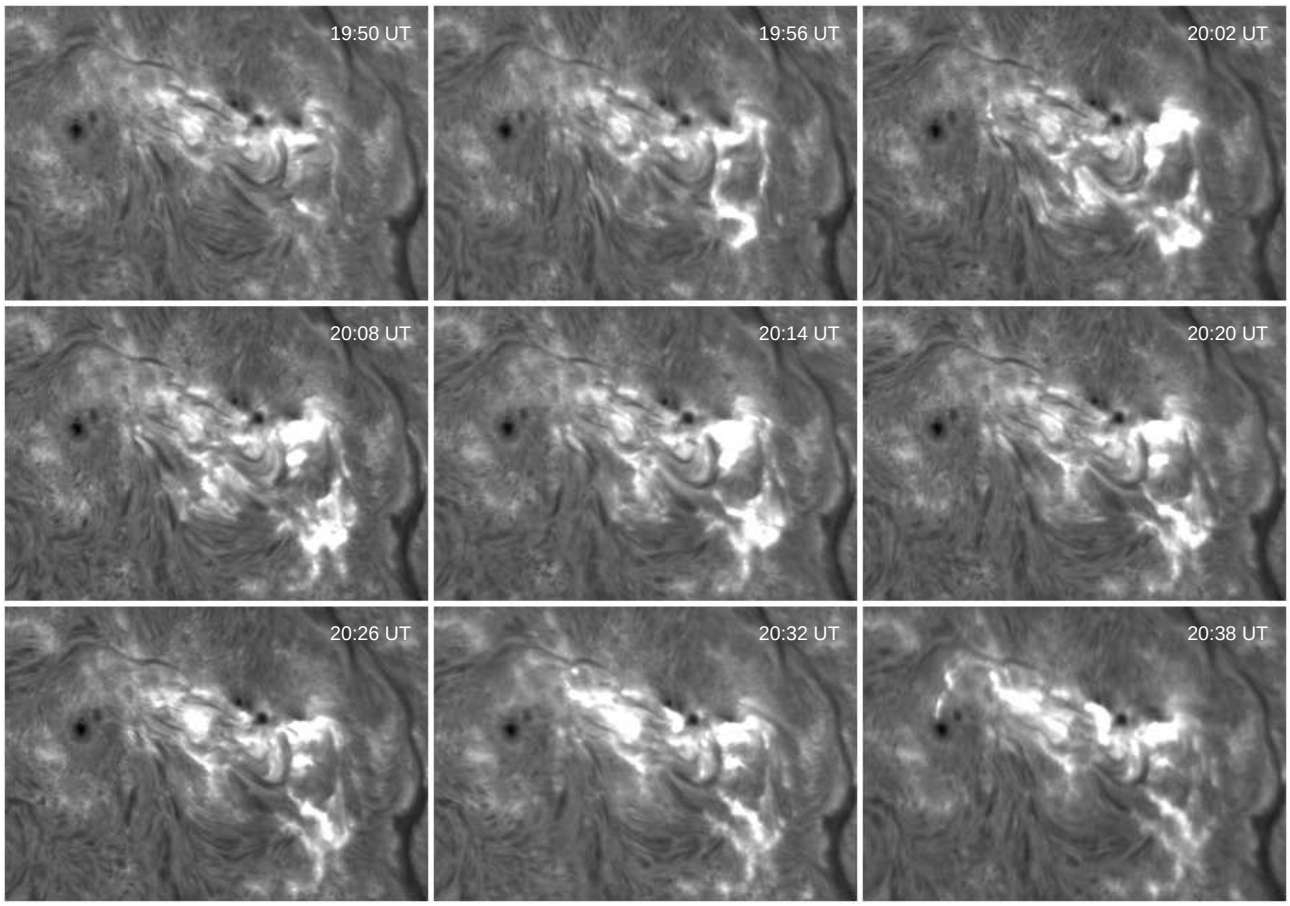

Figure 3. Temporal evolution of the M1.9 flare which erupted on July 10, 2000, at 20:05 UT (time of maximum X-ray flux measured by GOES) in the active region NOAA 9070. The frames are 300×210 *pixel subframes of* $2K \times 2K$ *high–resolution full–disk Hα images. The flare is located in the lower right corner of the active region. Only every sixth image of the actual observed 1 minute cadence data is shown.*

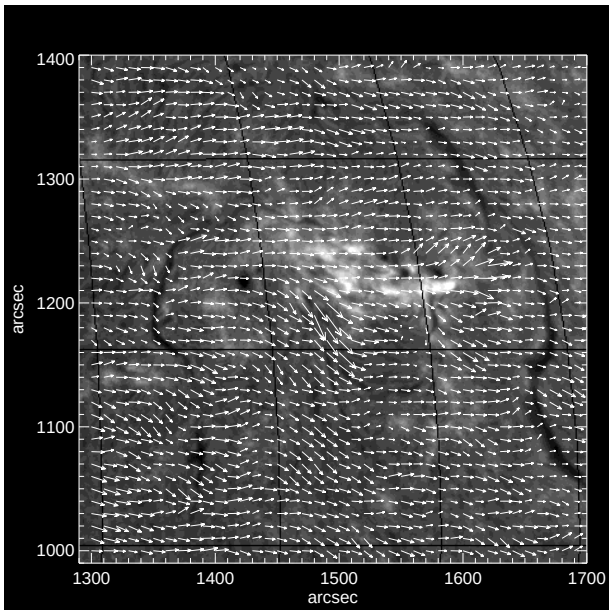

Figure 4. Average flow field around the M1.9 flare shown in Figure 3 derived by local correlation tracking (LCT) from 110 Hα images obtained before the flare started to erupt (18:00 – 19:50 UT). Solar north is on the top and east on the left of the image.

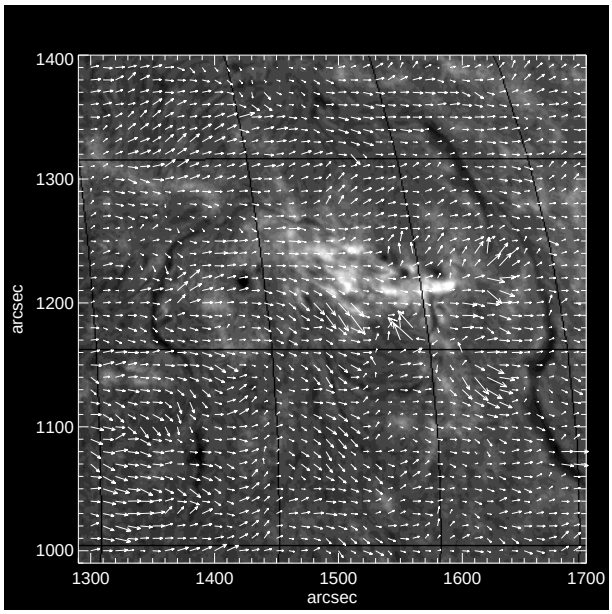

Figure 5. Flow field obtained by LCT from 75 frames observed during the flaring phase (19:50 – 21:15 UT).

Mini–Filaments: The energy release and mass ejections of erupting mini–filaments are of particular importance, since both can contribute to coronal heating and solar 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: The SOHO (Domingo et al., 1995) and TRACE (Schrijver et al., 1996) space missions are 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. Additionally, our data analysis and forecasting tools can be adopted by ISOON. The Max Millennium Program (Canfield, 1999) and its coordinated observing campaigns will also profit from the availability of high–cadence and high–resolution network observations.

Solar Activity and Space Weather Forecasting: Based on the detailed structure of the active regions monitored with high–cadence, 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.

5. PRELIMINARY RESULTS: FLOW FIELDS AROUND A FLARE

Although the network is in operation for only a few months and considering the fact that the first weeks after its installation have been mainly devoted to extensive testing and improving of the imaging and data archiving systems, we have already compiled a large amount of high quality contrast–enhanced full–disk data. One of the first questions which we try to answer with this material is, how the dynamics of the chromosphere is changing before and during a flare event. It is a well known fact that the proper motion of bipolar sunspot groups lead to shearing of the associated magnetic field lines, which in turn can trigger flares (see, e.g., Li et al., 1999; Raman et al., 1998; Wang et al., 1991). Additionally, the various components of a flare exhibit a pronounced dynamic behaviour during the flaring phase (for an overview see Martin, 1989). If there is a typical pattern in the motions around an active region observed in Hα, it can be used as a precursor for flaring activity. There have been only a few attempts to address this problem, but with data of lower quality and resolution (e.g., Gutermuth, 1999).

For a first preliminary analysis we selected a flare which erupted in active region NOAA 9070 on July 10, 2000.

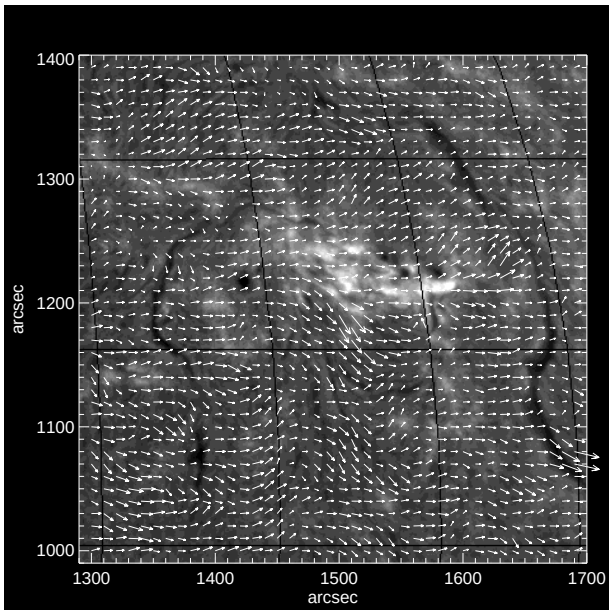

Figure 6. Flow field obtained by LCT from 80 frames observed after the flaring phase (21:15 – 22:35 UT).

In Figure 3 the temporal evolution of this M1.9 flare is shown, which reached the maximum of its X–ray emission at 20:05 UT as measured by the GOES satellite. A $600'' \times 600''$ subframe around NOAA 9070 is used to derive the average flow field by local correlation tracking from a 4.5 hour time series of calibrated high–cadence full–disk data. In each subframe the displacement between subsequent exposures is calculated for a grid of 60×60 evenly spaced points. The resulting displacement maps are converted into velocities and the average flow fields for the pre–flare, flaring, and post–flare phases are computed.

The first qualitative results of this analysis are shown in Figures 4 to 6. The displayed flow fields ($400'' \times 400''$ around the active region) are represented by white arrows superimposed on the images and the lengths of the arrows denote the magnitude of the motions in arbitrary units. A comparison of these figures yields the following results: (a) The flow field is clearly changing between the different flare phases. (b) Before the flare erupts (Figure 4), there exists a strong southwest–ward flow at the southern edge of NOAA 9070. From the western edge of the active region, flows are moving outwards. No motions of the nearby filament can be detected. (c) In Figure 5 the dynamics of the flare eruption leads to an increased radial motion away from the western edge, whereas the flow around the southern part has weakened. Additionally, the lower part of the filament starts moving to the west. (d) During the post–flare phase (Figure 6), the flows around NOAA 9070 have slowed down noticeably, whereas the motion of the lower portion of the filament has clearly increased.

These preliminary findings are a promising hint for using the changes in the flow fields around active regions as a precursor for flaring activity, in addition to other parameters like, e.g., area, intensity, and complexity. In continuation of this work we will perform a detailed statistical analysis of a representative sample of flares of different structure, size, and evolution.

6. CONCLUSIONS

The new global Hα network enables us to monitor the chromosphere of the sun continuously 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 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.

ACKNOWLEDGMENTS

This work is supported by NSF under grants ATM–0076602, ATM–9714796, and ATM–9903515, by NASA under grants NAG5–4919, NAG5–7350, and NAG5–7085, and by ONR under grant N00014–97–1–1037. The SOHO/LASCO image used in this paper is produced by a consortium of the Naval Research Laboratory (USA), Max–Planck–Institut für Aeronomie (Germany), Laboratoire d'Astronomie (France), and the University of Birmingham (UK). SOHO is a project of international cooperation between ESA and NASA.

REFERENCES

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

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

Gutermuth R. A., 1999, AAS 195, 10706

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

Li W., Lee C. Y., Chae J., Wang J., Goode P. R., Wang H., and Ai G., 1999, in Proceedings of the Ninth European Meeting on Solar Physics, ESA SP–448, 169

Martin S. F., 1989, Solar Physics 121, 215

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

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

Raman K. S., Selvendran R., and Thiagarajan R., 1998, Solar Physics 180, 331

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

Wang H., Tang F., Zirin H., and Guoxiang A., 1991, Astrophysical Journal 380, 282

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