Hα Synoptic Observations of Flare-Filament Eruption Complex 1997 April 6 – 7

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Abstract. The active region complex NOAA 8027 has invoked considerable interest because of simultaneous observations from a variety of ground and space observatories, particularly highlighted by observations from SOHO. We present results from ground-based synoptic Hα observations from the National Solar Observatory/Sacramento Peak. These Hα images were taken with a two-minute cadence. The active region complex shows the following phenomena: (a) three Flares (1997 April 6, 18:46 UT, X-ray class B2.6; 1997 April 6, 24:34 UT, X-ray class B3.7 and 1997 April 7, 14:03 UT X-ray class C6.8), (b) a horizontal surge or spray on 1997 April 6 between 23:34 UT and 23:56 UT with mean velocities of 60 km s⁻¹, (c) a filament disappearance and its reformation between 1997 April 6 23:36 and April 7, 00:36 UT, (d) a filament disappearance on 1997 April 7, 13:52, and (e) a darkening in the region is seen before the commencement of the larger two-ribbon flare of 1997 April 7.

Surface flows as seen in Hα (derived from tracking the horizontal shift of intensity patterns using image registration and destretch techniques) are suppressed before and after the larger flare of 1997 April 7. The flare ribbon expands at a mean rate of 2 km s⁻¹. Using a simple vertical model of the magnetic field around the flare, we estimate the Poynting flux (the work the kinetic energy has to perform to overcome the magnetic field) is approximately 5 × 10³⁰ ergs. The surface flow vorticities determined from the destretch algorithm show that they are opposite in each of the flare kernels, representing a relaxation of the twist in the magnetic field.

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1. Introduction

High cadence synoptic observations of the Sun are a useful diagnostic tool to monitor and forecast the onset and progress of eruptive solar activity (see e.g. Neidig et al. in these proceedings). Solar flares and filament eruptions as seen in Hα provide useful inputs to monitor space weather. Filament (or prominence) eruptions have been linked with mass ejections. While they both occur independently, filament eruptions and solar flares sometimes appear coupled. A detailed review of solar flares and coronal mass ejections has been presented by Kahler (1992).

On 1997 April 6–7 the active region NOAA 8027 evoked considerable interest because of eruptive activity including flares and Earth-ward bound mass-ejections, which were detected by simultaneous observations from a variety of ground and space observatories, particularly highlighted by observations from SOHO. A similar event on 1997 January 6–7 (Webb et al. 1997; Gopalswamy et al. 1997; and Thompson 1997) has been extensively analyzed.

In this paper we analyze data high cadence chromospheric (Hα) images using local correlation tracking to characterize the evolution of the active region during the two-day activity of 1997 April 6–7.

2. Observations

The observations were automatically carried out at the National Solar Observatory/Sacramento Peak Hilltop Hα Patrol Telescope. This telescope uses a 7.62 cm stopped down objective and a Halle filter to observe in the core of Hα. The full-disk image is 16.5 mm in diameter and is recorded on 2415 Technical Pan 35-mm format film. An automatic film camera takes one full disk image every 1 or 2 minutes, as preset.

The data consists of full-disk images taken at a 2-minute cadence, on 1997 April 6–7. On April 6, the patrol obtained 280 images (clouds interrupted a significant fraction of the day; see Fig. 1) and on April 7, 407 407 images covering the entire observing day.

3. Data Reduction

The entire data set of 687 images for 1997 April 6–7 were digitized with a sampling of 2.3 arcseconds in two orthogonal directions, x and y, using the NSO/Sacramento Peak Fast Microphotometer. Successive images were aligned to maximize their spatial correlation functions. Data spikes due to dust and scratches on the film were removed using temporal and spatial continuity criteria.

Active region NOAA 8027 was located at coordinates S30E27 on April 6, at 1725 UT. We investigated a 577 × 577 arcseconds square area (251 × 251 pixels) covering the active region and its surroundings. The brightness in each image was normalized to a region of the quiet-Sun background. Each image (577 square arcseconds) was further subdivided into 9.2×9.2 arcseconds sub-boxes for local correlation (destretch and tracking) analysis. The local cross-correlation algorithm tracks by shifting sub-images from the current scene with reference to the previous scene (reference) to maximize its correlation. (see November 1988;
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Figure 1. Hα brightness variation of the 577 square arc-seconds FOV containing the active region NOAA 8027. The time of the three flares during the two days are marked by an arrow. The brightness is normalized to the quiet-Sun background in the same FOV. Gaps in the data on April 6 are due to cloudy conditions.

Keil et al (1995; Keil, Balasubramaniam & Smaldone 1997). After removing high frequency components due to seeing, the local-correlation technique tracks the apparent surface motions of intensity features as seen in Hα, over time.

4. Phenomena Observed

The significant phenomena observed during the two days were as follows.

The active region AR 8027 displayed three flares, whose x-ray maximum times are given, namely: 1997 April 6, 18:46 UT, X-ray class B2.6; 1997 April 6, 24:34 UT, X-ray class B3.7 and 1 1997 April 7, 14:03 UT X-ray class C6.8 (see Fig. 1–2).

Using the normalized quiet-Sun background as reference, we derived the changes in the light level of the entire active region during the observed times on April 6 and 7, over the 577 square arcseconds FOV. Fig. 1 shows the normalized brightness variations. As an illustration, Fig. 2 shows the evolution of filament eruption and the two-ribbon flare on April 7.

A horizontal surge (or spray) occurred on 1997 April 6 between 23:34 UT and 23:26 UT with a mean velocity of the order of 60 km s⁻¹ (Fig. 3). A filament disappeared and reformed between April 6, 23:36 UT and April 7, 00:36 UT. A filament disappeared on April 7, 13:52 UT, before the two-ribbon flare onset at 13:54 UT. The filament eruption appears to be associated with the mass-ejection as tracked by SOHO (Maia et al. 1997; Thompson 1997) and various other instruments.

A darkening occurred in the region before the commencement of the larger two-ribbon flare of April 7 (see the brightness plot in Fig. 1), before the com-
Figure 2. $\text{H}\alpha$ time-series images of the 577 square arc-seconds FOV containing the erupting filament and two-ribbon flare of active region NOAA 8027. The positions of the filament before the eruption on April 7 is marked by an arrow. The contrast in the earlier panels has been enhanced to show the filament.
Figure 3. Velocities of a surge determined from physically tracking the blob that appeared as a part of the filament eruption of April 6.

mencement of the flare on April 7. The magnetic field under each flare ribbon is of opposite sign, as seen in NSO/Kitt Peak Magnetograms.

5. Results

The following results were derived using image registration and local correlation techniques that track the apparent surface motion of intensity features seen in Hα. These apparent motions could be produced by (a) real motions due to material flow, (b) waves, (c) sequential darkening and brightening of the solar surface, or (d) a combination of the above processes.

- Surface flows as seen in Hα in a region surrounding the flare kernels were conspicuously of a lower value (suppressed) immediately before and immediately after the larger flare of 1997 April 7, while the flare kernels were apparently moving away from each other.

- The center of mass of kinetic energy distribution due to the expanding two-ribbon flare system of 1997 April 7 moves with a velocity \( u(r) \) of the order of 50 km s\(^{-1}\). We define the kinetic energy distribution as: 
  \[ E_u(r) = \frac{1}{2\pi} \int_0^{2\pi} u(r, \phi) \, d\phi, \]
  where \((r, \phi)\) are the polar coordinates from the center of the active region. The center of mass of the kinetic energy distribution is 
  \[ R(t) = \frac{1}{\int E_u(r) \, dr} \int \int E_u(r) \, dr. \]
  We find that \( dR/dt \approx 40 \) km s\(^{-1}\) from 14:10 UT through 15:20 UT.

- The flare ribbons expand at a mean rate of of 2 km s\(^{-1}\). Using a simple vertical model of the magnetic field around the flare (namely, the DC
solutions discussed in Milano, Gomez and Martens 1997), we estimate the Poynting flux (the work the kinetic energy has to perform to overcome the magnetic field) is of the order of $5 \times 10^{30}$ ergs.

- Artificial tracers ("corks"), allowed to move with trajectories determined by the local surface velocities derived from image destretching, settle down at what appear to be super-granular boundaries with sizes of about $5 \times 10^4$ km.

- The curl of the chromospheric surface velocity ($\nabla \times \mathbf{u}(x, y)$), herein referred to as the surface vorticity, has opposite signs in each of the flare-ribbons.

6. Discussion and Conclusions

The surface motions are significantly suppressed around the region of the flare kernel, before and after the flare of April 7, possibly due to the bipolar magnetic field.

For the flare of April 7, the significant increase in the curl of the chromospheric surface velocity about the flare kernels, 18 – 20 minutes before the onset of the x-ray flare and about 30 minutes before the Hα/x-ray maximum could provide a significant lead-time for predicting this flare. Further studies are required to show the statistical significance of these advance signatures, for active regions that produce both filaments eruptions and flares. If so, they would be a useful forecasting tool!

The flow vorticities determined from the destretch algorithm show that they are opposite in each of the flare kernels, which could represent a relaxation of the twist in the magnetic field. The vorticities in the flare kernels begin to develop about 12 minutes before the onset of the flare in x-rays. This is perhaps an indicator of the onset of the flare instability, which could also provide a significant lead time for flare prediction. Since we see the vorticities continuously before and during the flare, they could be either a cause and/or a consequence of the relaxation of the magnetic field in the chromosphere.

Careful tracking of the surge of April 6 reveals that it is probably a result of a sudden eruption of a segment of the filamentary structure near the flare kernel. From this we may conclude that the surge observed in the present case is a part of the filament eruption process due to geometric effects seen close to the disk.

While the filament is frequently disrupted during the eruptive activity of April 6 and 7; it also appears to continuously reform. Whether the filament reforms because of support by newly restructured magnetic fields or from a redistribution of the existing mass and magnetic flux cannot be determined.

From the measurements of the divergence and the curl of the surface velocity field in the chromosphere, the flow appears to be nearly incompressible:

$$\frac{< |\nabla \cdot \mathbf{u}| >}{< |\nabla \times \mathbf{u}| >} \approx .3$$

The kinetic energy power spectra obey a power-law distribution with slopes of about 1.5, indicating a fully developed turbulence.
The April 7 two-ribbon flare is not symmetric: the velocities of expansion of the two ribbons are quite different. This could be due to (a) geometric effects because the active region was not located at solar disk center, (b) physical asymmetry of the structure of flare ribbons, or (c) a combination of the two effects.

From these simple synoptic observations of chromospheric Hα, with high cadence, we have shown the wealth of information that can be extracted for dynamic solar activity. We plan to analyze many similar data sets to establish the statistical significance of these flows as precursors to solar activity. We will incorporate the results from these studies into algorithms that ingest data from the USAF Improved Solar Observing Optical Network (ISOON) and aid in issuing real-time forecasts and alerts of solar activity.

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