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HRTS OBSERVATIONS OF EXPLOSIVE EVENTS IN A FLARING ACTIVE REGION

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Abstract

Explosive events are a highly dynamic, small-scale phenomena that are commonly observed on the Sun with the NRL High Resolution Telescope and Spectrograph (HRTS). There is now considerable evidence which suggests that they are signatures of magnetic reconnection during flux emergence and cancellation. Data from the Big Bear Solar Observatory and the HRTS instrument are used to demonstrate the direct correspondence between explosive events and evolving magnetic structures.

1. Introduction

The first rocket flight of the Naval Research Laboratory's High Resolution Telescope and Spectrograph (HRTS-1) revealed the widespread occurrence of explosive events in the solar atmosphere. These events are characterized by small spatial scales (2"), short time scales (60s), and high velocities (100 km s^{-1}) and are most prominent in spectral lines formed at transition zone temperatures (10^5 K) (Bartoe and Brueckner 1983, Dere *et al.*, 1989). It has generally been assumed that the explosive events consist of plasma accelerated by the action of magnetic forces, but, until recently, the relevant magnetic field data has not been available to test this hypothesis. The first clues came from the slitless EUV spectroheliograms recorded by the NRL experiment on Skylab/ATM which provided evidence of broadened emission line profiles in an emerging flux region (Brueckner, 1976). The broadening was evident in lines of ions such as Ne VII (5 x 10^5 K) and Mg IX (9 x 10^5 K) formed in the upper transition zone but was not seen in coronal lines such as Fe XVI (2 x 10^6 K).

HRTS spectra obtained during the Spacelab-2 mission provided the first direct evidence that C IV explosive events are the result of emerging magnetic flux (Brueckner *et al.*, 1988). The C IV profiles in this explosive event were some of the most spectacular. Both bulk and random motions at velocities up to 300 km s^{-1} were seen in a 15" by 30" area on the perimeter of a sunspot with a classic arch filament system in Hα indicating the presence of newly emerging magnetic flux.

Further examples of the association of explosive events with emerging magnetic flux are seen in the HRTS-6 raster images reported by Dere *et al.* (1991). The primary goal of this rocket flight was to map the velocity field of a coronal hole situated on the solar disk. The 1 $R_\odot$ HRTS slit viewed regions considerably beyond the coronal hole boundaries. At one end of the slit, a small emerging active region was seen with an extraordinarily large concentration of explosive events situated on its edges. The number of instances where demonstrable flux emergence could be associated with explosive events indicates a very clear connection. The underlying physical mechanism that produces the explosive events must certainly be magnetic reconnection, much as in the Heyvaerts *et al.* (1977) flare model. The red and blueshifted material would correspond to reconnection jets.

Many more explosive events are created in the quiet sun than can attributed to emerging active region flux. Nevertheless, Dere *et al.*(1991) suggested that magnetic reconnection was responsible for the production of all of the explosive events. In the quiet sun, the explosive events often appear on the edges of the magnetic network (Porter and Dere, 1991). The appearance of the explosive events on the edges of the network suggested a relationship to the intranetwork fields which emerge in the network cell centers and migrate to the network boundaries where they cancel (Martin 1984, Livi *et al.* 1985). Dere *et al.* 1991 suggested that the existence of the explosive events indicated that reconnection was involved in the cancellation process as previously surmised by Martin. It was clear that the characteristics of the explosive events and the cancellation phenomena observed in the photosphere were considerably different. The explosive events had lifetimes on the order of 60s compared to the 4-6 hour period required to complete the cancellation of magnetic elements. The size of explosive events is 1500 km compared to typical boundary between canceling magnetic elements of 6000 km. These disparities led Dere *et al.* (1991) to conclude that reconnection took place in a bursty manner, both spatially and temporally.

2. The HRTS-7 Rocket Flight

The evidence for associating explosive events with the process of magnetic reconnection driven by the eruption of new magnetic flux appears to be quite strong. The case for interpreting explosive events as evidence for reconnection during magnetic flux cancellation in the quiet sun is largely circumstantial. For the HRTS-7 rocket flight, the observing sequence was designed to perform a small raster sequence in a large flare-producing active region near the peak of the sunspot cycle. One goal was to provide a clear cut demonstration of the association of explosive events with magnetic flux cancellation. To achieve this, the rocket launch would be supported by the Big Bear Solar Observatory (BBSO) which would record video magnetograms of the active region and other areas covered by the HRTS slit throughout the day. In addition, magnetograms were also obtained by Kitt Peak (NSO-Tucson) and the San Fernando Observatory.

The HRTS telescope is a 30 cm cassegrain that focuses an image of the sun onto the slit jaws of the tandem-Wadsworth spectrograph (Bartoe and Brueckner, 1975). The spectrograph records the solar spectrum from 1170-1700 Å along a 1 $R_\odot$ radius equivalent slit with a spatial resolution of 1" and a spectral resolution of 0.07 Å. In this spectral region there are a number of strong resonance lines formed at temperatures representative of the solar chromosphere and transition region. The slit jaw is also viewed by the broadband ultraviolet spectroheliograph and the Hα system. The UV spectroheliograph images the continuum near 1600 Å which is formed in the temperature minimum region. It provides an excellent medium for registering the ultraviolet spectra to the photospheric magnetograms with very little error. The Hα slit jaw image is both recorded on photographic film and downlinked to the ground as a video signal to provide real-time pointing information.

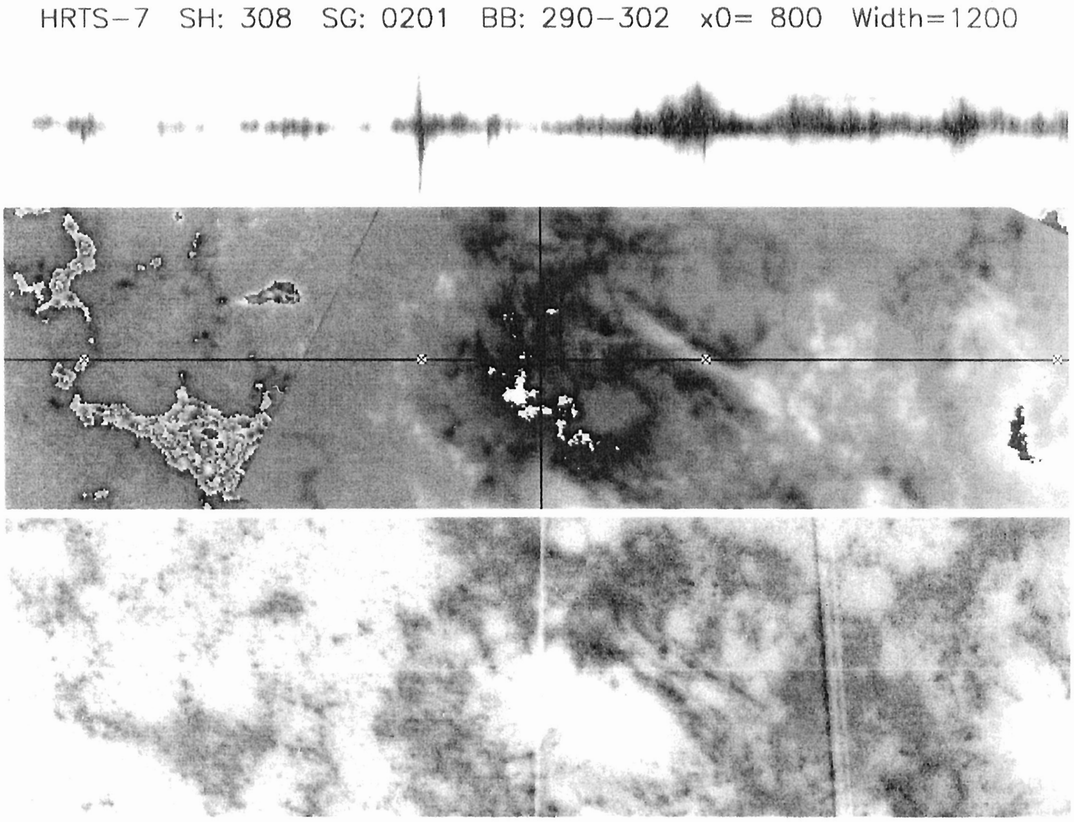

Fig. 1. C IV spectra (top), magnetogram (middle), and UV spectroheliogram (bottom).

NOAA active region 6368 appeared on the disk with a delta sunspot configuration and sufficient flare activity to be deemed a suitable target. Of particular interest was a tongue of magnetic polarity that protruded into fields of opposite polarity. Throughout the day of the rocket launch, flares and subflares were seen along this magnetic tongue. The HRTS-7 rocket was launched on November 20, 1990 at 1840 UT.

Figure 1 shows portions of the data in the vicinity of the active region. At the top is the C IV spectrum, with blueshifts down and redshifts up. In the center is the BBSO magnetogram with the position of the HRTS slit indicated and the positions of explosive events marked with an 'X'. The magnetogram is a composite of several adjoining fields of view. The subfield at the left was obtained with a longer integration time than the two on the right. At the bottom is the UV spectroheliogram with a large sunspot (low emission) at the center of the field.

One explosive event is located on the right edge of the intruding polarity, just to the right of center. Another spectrum at a slightly different raster position shows another explosive event on the opposite side of the intruding polarity. One would expect that a differential flow field would lead to cancellation and reconnection along the border of this region which could result in flaring, explosive events and other dynamic activity, as are seen. However the largest explosive event, just to the left of center in Figure 1, occurs in an area where the fields are considerably weaker. The sequence of BBSO magnetograms in Figure 2 show that this explosive event (observed at 1840 UT) occurred near a small magnetic dipole that is seen to emerge during the period 1707-1728 UT. By 1842, one of the polarities moves to the east (left) to merge with a pre-existing patch of magnetic flux. We interpret the explosive event to be due to the interaction of this flux with other magnetic flux in the region, in bursts of

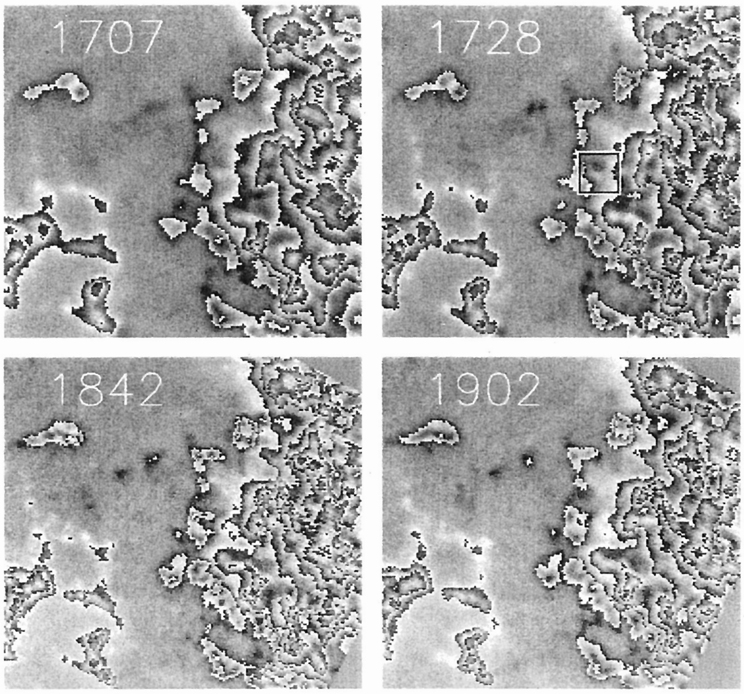

Fig. 2. A time sequence of BBSO video magnetograms in the region of an explosive event

magnetic reconnection. Nevertheless, a considerable number of explosive events are seen in the quiet sun for which opposite polarity magnetic patches are not visible in relatively deep BBSO magnetograms (1024 integrations). Since magnetic flux of both polarities must be involved, magnetic flux bundles below the detection limit of the BBSO magnetograph are apparently present.

References

1. Bartoe, J.-D. F., Brueckner G. E., 1975, *J. Opt. Soc. Am.* **65**, 13.
2. Brueckner, G. E., 1975, in *Solar Gamma- X- and EUV Radiation*, S.R. Kane (ed.), I.A.U. Symp. 68, 105-107.
3. Brueckner, G. E. and Bartoe, J.-D. F., 1983, *Astrophys. J.* **272**, 329.
4. Brueckner, G. E., Bartoe, J.-D. F., Cook, J. W., Dere, K. P., Socker, D. G., Kurokawa, H., and McCabe, M., 1988, *Astrophys. J.* **335**, 986-995.
5. Dere, K.P., J.-D. F.Bartoe, and G.E. Brueckner, 1989, *Solar Phys.* **123**, 41.
6. Dere, K. P., Bartoe, J.-D. F., Brueckner, G. E. and Recely, F., 1989, *Astrophys. J. Lett.* **310**, L95.
7. Dere, K. P., Bartoe, J.-D. F., Brueckner, G. E., Ewing, J. and Lund, P., 1991, *J. Geophys. Res.* **96**, 9399.
8. Heyvaerts, J., Priest, E. R., and Rust, D. M.: 1977, *Astrophys. J.* **216**, 123.
9. Livi, S. H. B., J. Wang, S.F. Martin: 1985, *Australian J. Phys.* **38**, 855.
10. Martin, S. F.: 1984, in *Small-Scale Dynamical Processes in Quiet Stellar Atmospheres*, S. L. Keil, (ed.), National Solar Observatory, Sunspot, 30.
11. Porter, J. G., and Dere, K. P., 1991, *Astrophys. J.*, **370** 775.