Multi-wavelength Analysis of an X2.7 Flare on 3 November 2003 from Active Region NOAA 10488

Bhuwan Joshi[1], P. K. Manoharan[2], A. M. Veronig[3], P. Pant[1], Kavita Pandey[4]

[1] Aryabhatta Research Institute of Observational Sciences (ARIES), Nainital 263 129 , India

e-mails: bhuwan@aries.ernet.in, ppant@aries.ernet.in

[2] Radio Astronomy Centre, TIFR, Udhagamandalam (Ooty) 643 001, India

e-mail: mano@ncra.tifr.res.in

[3] IGAM/Institute of Physics, University of Graz, Universitätsplatz 5, 8010 Graz, Austria

e-mail: asv@igam.uni-graz.at

[4] Department of Physics, Kumaun University, Nainital 263 002, India

e-mail: kavitaphysics@yahoo.co.uk

The evolution of an X2.7 solar flare, that occurred in a complex βγδ-type active region on 2003 November 3, is discussed utilizing multi-wavelength data set. The Hα images taken from solar tower telescope at ARIES, Nainital, India, reveal well-defined footpoint (FP) and looptop (LT) sources. As the flare evolves, LT source moves upward and the separation between the two FP sources increases which is consistent with the reconnection models of solar flares. The coalignment of Hα with hard X-ray (HXR) images obtained from RHESSI shows spatial correlation between Hα and HXR footpoints, while the upward moving HXR LT source is always located above Hα LT source. The EUV images of flaring region at 195 Å taken from SOHO/EIT reveal intense emission from low-lying loops near the active region during the impulsive phase. On the other hand, two bright loops are seen well outside the active region which undergo large scale reorganization during the flare. In radio wavelengths, type III radio bursts are observed few minutes prior to start of HXR LT emission indicating the pre-flare coronal activity. A type II radio burst followed the main phase of the event. The observations support the "break-out" model of solar eruptions proposed by S.Antiochos and coworkers.

Introduction

In the declining phase of the solar cycle 23, the Sun produced several historical eruptive events [1]. In particular, three complex super active regions, namely, NOAA 10484, 10486, and 10488, produced intense flare events during October 19 to November 4, 2003. Active region NOAA 10488 (or simply 0488) emerged at N09E09 on October 27, 2003, and grew rapidly to a large active region. Its maximum area was 1750 millionth of the solar hemisphere on 31 October. The group disappeared over the west limb of the Sun (N08W95) on 06 November. It was a fast emerging flux region [2]. The group showed βγδ magnetic configuration.

In this paper we present the multi-wavelength analysis of an X-class flare that occurred in active region NOAA 0488 on November 3, 2003, during 01:00 UT to 02:30 UT. This event also produced a fast coronal mass ejection.

Observations

The soft X-ray measurements by GOES satellite show a rapid increase in soft X-ray intensity in both channels, i.e., at wavelength ranges of 1 - 8 Å and 0.5 - 4 Å between 01:05 to 02:00 UT (cf. Fig.1). The maximum of X-ray intensity is observed around 01:30 UT. In Hα this flare was classified as 2B and observed at the location N10W83 on the solar disk (SGD). The Hα observations presented in this paper were made using a 15 cm f/15 Coudé refractor mounted on a tower at Aryabhatta Research Institute of Observational Sciences (ARIES), Nainital, India. The images were recorded with 385 x 576 pixel (pixel size 22 μm^2), 16 bit CCD camera. With the help of a Barlow lens the images have been magnified twice, so we get a spatial resolution of 1" per pixel. The temporal cadence of images is about 20 seconds.

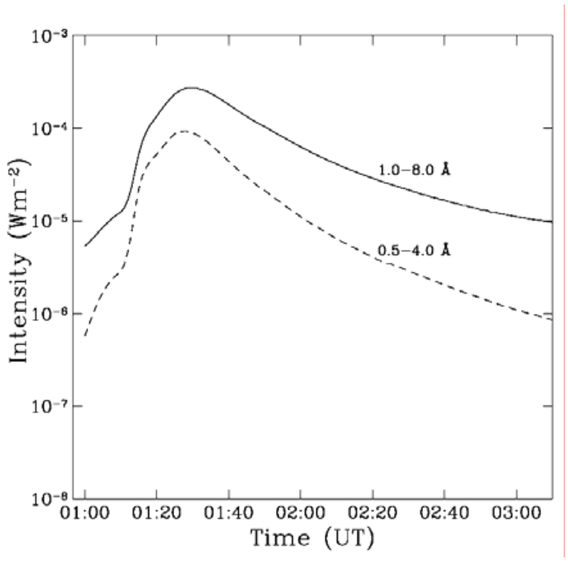

Fig.1. Soft X-ray light curve of the flare obtained from GOES measurements. Solid line is from 1-8 Å channel and dashed line is from 0.5-4 Å channel.

Flare evolution in hard X-ray has been analyzed using data from RHESSI [3] spacecraft. RHESSI covered whole event, although X-ray images above 30 keV are strongly affected by a particle event. The images at 195 Å obtained from EIT onboard SOHO [4] images chromospheric and coronal plasma at the peak temperature of 1.5 x 10^6 K. These images are valuable to infer the magnetic field morphology associated with the flare.

The above investigations have been compared with dynamic radio spectra observed from HiRAS, Japan and WAVES instrument on Wind spacecraft [5]. A fast coronal mass ejection, as imaged by LASCO on board SOHO [6], was also observed in association with this flare event.

Results and discussions

Fig. 2 shows some representative Hα images of the flare. A careful examination of these images reveal that during the rising phase of the flare intense emission comes from two locations, one from the northern and another from the southern side of the active region. These two bright emitting regions are observed till the declining phase of the event. The Hα filtergrams show the expansion of loops connecting these two bright regions (i.e. footpoints of the loop system) after the flare maxima at ~01:30 UT. The Hα light curve inferred from CCD count rate showed a fairly quick rise and gradual decline similar to soft X-ray profile with a peak around 01:31 UT. Starting from ~01:40 UT, the total intensity of the flaring region seems to be dominated by the emission originating from the top of the rising loops. On the other hand, the overall size and thickness of the loop system increase with time and provide a clear picture of the post-flare situation associated with the flare event.

Here it is relevant to mention that another flare of class X3.9 occurred in the same active region nine hours later (between 09:43 to 10:19 UT; maximum at 09:55 UT) which looks totally homologous to this event. Several aspects of this late X-class flare have been studied in detail ([7], [8], [9], [10]) and they show various common

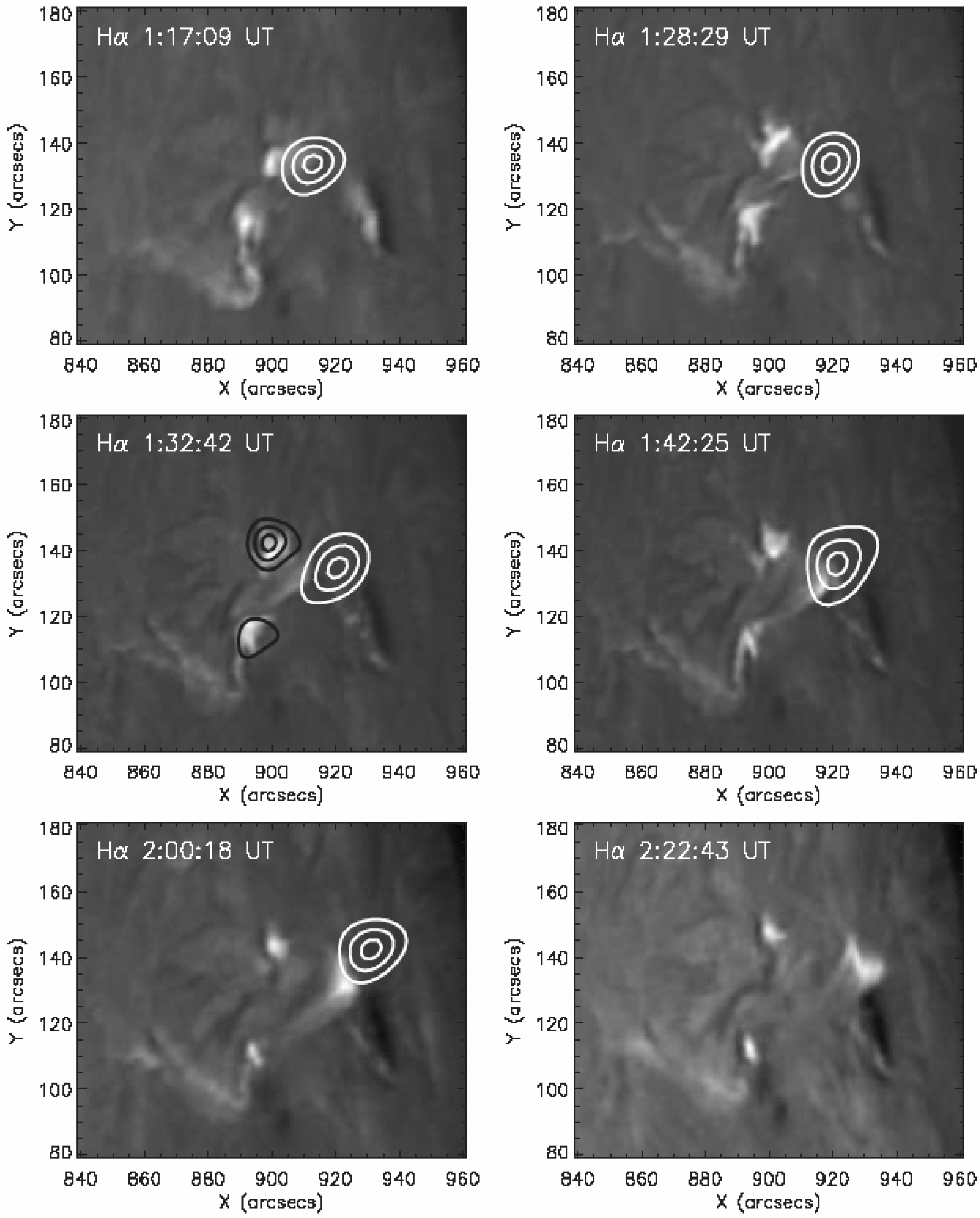

Fig.2. Sequence of Hα images overlayed by RHESSI X-rays images which are closest in time. White contours are 10-15 keV, black contours (only in the third panel) are 50-100 keV. The contours levels are 60, 80 and 95% of the peak flux of each image.

features between the two events in different wavelengths.

In Fig. 2, RHESSI X-ray images are also shown overlayed on Hα filtergrams. The RHESSI images have been reconstructed with the Clean algorithm with the natural weighting scheme using front detector segments 3 to 8 in the energy bands 10-15 keV and 50-100 keV [11]. At high energies we were able to reconstruct RHESSI images only at 01:33 UT. At this time, two footpoints are observed in hard X-rays which are roughly co-spatial with the two strong footpoints observed in Hα (see Fig. 2, third panel). Due to the strong contribution from the particle event, it was not possible to reconstruct RHESSI footpoint images at earlier times. The signal (solar) to "noise" (particle event) ratio is as low as 1:50 during these times (Gordon Hurford, private communication). However, in Hα two strong footpoints are observed during the whole impulsive phase which separate from each other in the course of time.

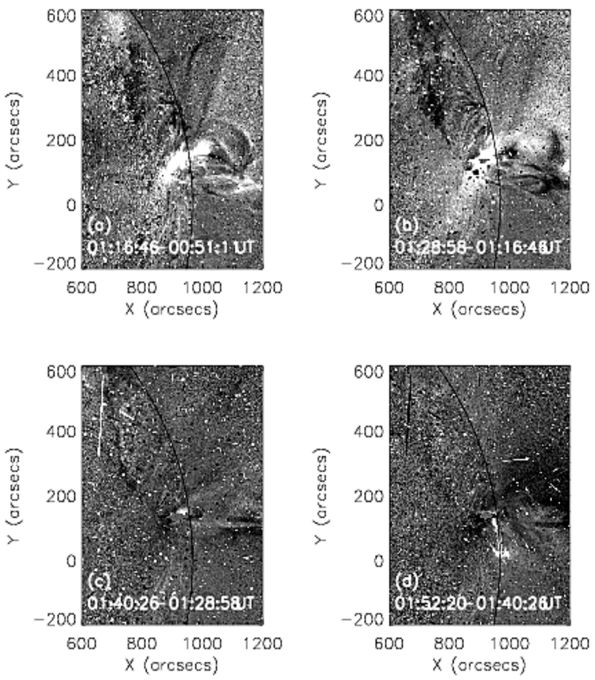

Fig.3. Difference images derived from the SOHO/EIT observations in 195 Å line showing the sequence of activities from pre-flare to peak of the event.

At low energies (≤ 30 keV) the X-ray emission is concentrated in a distinct looptop (LT) source located above the Hα LT source at each instant, as it is expected since the Hα LT source is the result of cooling (and also shrinking) of the hot X-ray emitting flare loops ([9] and references therein). The RHESSI LT source can be observed as early at 01:02:20 UT when the X-ray level is still very low until the end of RHESSI observations at about 02:01 UT when the spacecraft again entered the Earth's shadow.

Fig. 3 shows the EUV images of the flare and its environment taken at 195 Å with EIT on board SOHO spacecraft. These running difference images reveal the sequence of activities from the beginning to the declining phase of the flare. During the rising phase (cf. Fig. 3a) the eruption is evident where patchy pattern of high intensity is observed on the disk, close to active region. Moreover, two bright loop tops are seen well outside the limb towards the west side of the active region. Another interesting point is that the loop tops are seen as two bright triangles and the southern triangle is brighter than the one located just above, towards the north. These bright triangles indicate the possible reconnection sites at the top of the loops. Fig. 3b, which corresponds to the impulsive phase of the flare, shows eruption of plasma from the loop top. The intense emission observed close to flare site in the previous image continues here. Further, the emitting region at the top of the loop system shows complex structure, suggesting a crucial stage at the time of reconnection process, i.e., the restructuring of the magnetic field after the reconnection followed by the ejection of plasma and field. The images recorded at the later time intervals (Figs. 3c and 3d) show relaxation of field at the flare region and the intensity of the emission declines heavily.

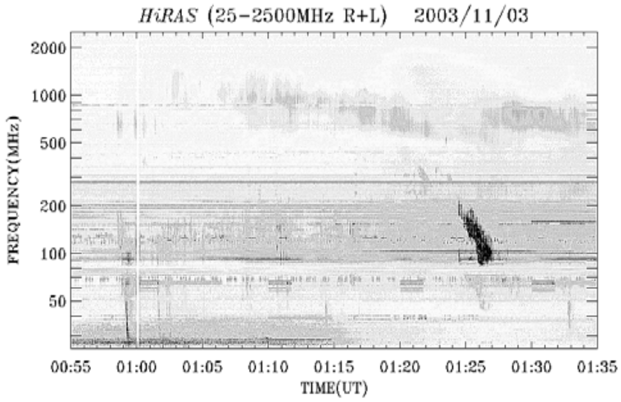

Fig.4. The dynamic radio spectrum of the event from 25 to 2500 MHz observed by HiRAS spectrograph.

HiRAS spectrograph operated by NICT, Japan, observed significant activities at a wide range of frequencies between 30 and 2000 MHz in association with this LDE flare event (see Fig. 4). The radio emission starts with a bunch of type III bursts from 1000 MHz to the low frequency at 00:59 UT which is continued in the whole frequency range of 1-14 MHz in WAVES/Wind spectrum. The type III burst observed in HiRAS spectrograph is followed by slow drifting continuum which moves from ~ 1500 MHz at around 01:02 UT to ~ 400 MHz at about 01:22 UT. This frequency drift suggests a possible increase in height of the arcade of loops and expansion in volume of the loops. Another important feature is the occurrence of type II burst between 01:24 UT to 01:28 UT in the frequency range of ~ 200-80 MHz. The speed of this type II ranges between 500 to 800 km/s. It is to be noted that just after the type II burst, another slow moving continuum starts at 1000 MHz and drifts to the low frequency. This burst in the time interval 01:26 to 01:35 is intense and on the whole it is brighter than the above mentioned slow drifting continuum. In the time interval 01:26 - 01:29 these two bands of continuum bursts lie one over the other on the frequency scale, suggesting the presence of two radio emitting loop systems of high-energy accelerated electrons.

A CME associated with the flare event, with fairly wide bright loop front with cavity and gusty outflow moving towards north-west side of the Sun, was observed at ~ 01:59 UT by LASCO C2 and with C3 at later times. The angular width and position angle of the CME were 65^0 and 304^0, respectively. At first, the CME appeared in C2 at a radial distance of ~ 4 R⊙ and it could be followed by C3 up to ~20 R⊙. The height-time plot derived from the white-light images shows that the propagation speed of the CME in the LASCO field of view is about 827 km/s. A second-order polynomial fit to the height-time data indicates a deceleration of ~ 28 m/s^2 in the CME propagation at heliocentric heights less than 30 R⊙.

Summary and conclusion

The flare 2B/X2.7 on 3rd November 2003 has uniquely been observed with the set of instruments, which cover a wide range of wavelengths and energy bands. The flare occurred in a very complex active region having βγδ magnetic configuration. The observations presented in the earlier sections provide a picture that an initial eruption of a low-lying short loops (field lines with strong twist) is caused by the reconnection process by the near by field lines. This process is followed by a sequence of larger heights magnetic reconnections. The reconnections at the flare site among short non-potential loops cause the outward expansion of the flux rope, initiation of the flare, and acceleration of particles to high energy. Earlier theoretical works suggested that in a complex magnetic geometry, the emerging magnetic flux is prevented by the overlying fields [12]. It results in building up of stress along the boundaries of the stressed field lines. Multiple currents can be formed. However, the localized reconnections tend to weaken the shielding of the overlying field lines. When sufficient enough weakening is achieved the built up stress break-out and rising field lines reconnect at the larger heights. In our present analysis, the break-out seems to cause acceleration of particles to high energies.

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