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A Special Flare-CME Event on April 21, 2002

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Abstract. The time and location of magnetic reconnection are indicated by radio (Nobeyama Radio Heliograph and Polarimeters, Hiraiso and Chinese radio spectrographs) and multi-wavelength (SOHO and TRACE satellites) data in a selected flare-CME event on April 21, 2002. Two hour radio burst started at high frequencies (maximum around 10 GHz). After that, a radio ejection at 17 GHz from one foot point was coincident with the expanded flare and post-flare loops. The reversal of polarization sense at the radio loop-top is associated with the strong coherent emissions around 2 GHz, which should be located above the loop-top at 17/34 GHz. The radio ejection and coherent emissions are also associated with a pair of moving type *IV* bursts at 0.2-2 GHz from high to low frequencies and 2.6-3.8 GHz from low to high frequencies, respectively. High time resolution (8 ms) data show three components of the frequency drifts at 2.6-3.8 GHz: very slow (5 MHz/s) of moving type *IV*, slow (50 MHz/s) of zebra strips, and fast (several GHz/s) of type *III*, which may represent respectively the speeds of flare loop or current sheet, outflows, and energetic electrons from the reconnection site.

Keywords. Sun: flares, CMEs, magnetic fields

1. Introduction

A special event on April 21, 2002 with X1.5 flare and very high-speed CME in AR9906 (S14W84) has attracted wide attention. The height, velocity and acceleration of CME are carefully fitted by Gallagher et al. (2003). Very rapid disruption of pre-CME streamer, very high Doppler shifts, and high temperature plasma in SOHO/UVCS are shown by Raymond et al. (2003). The spatial and temporal evolution of radio, X-ray and EUV data are carefully studied by Kundu et al. (2004).

One key problem to compare the observations with the models of flares-CMEs is how to get the location and time of magnetic reconnection (Forbs, 2004). The authors tried to give some evidences in this event as follow.

2. Radio ejection at 17/34 GHz with expanded flare and post-flare loops

Fig.1 shows the time evolution of TRACE images overlaid by 17 GHz contours of Nobeyama Radio Heliograph (NoRH). The main radio burst started at higher frequencies as shown in the first panel with a double source at two foot-points, which is confirmed by SOHO/MDI magnetograph in Fig.2a as well as 34 GHz contours of NoRH. After that, a radio ejection was detected from one foot point source (another one disappeared) at

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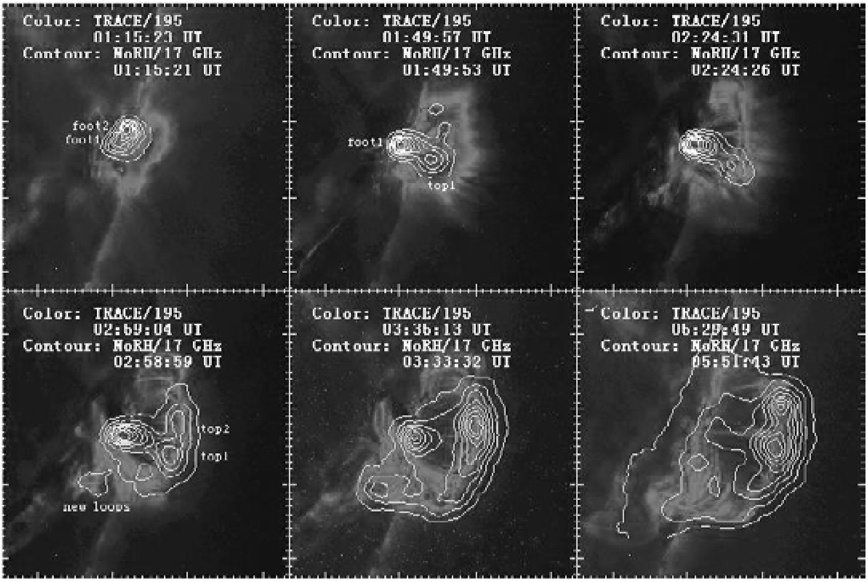

Figure 1. The TRACE images overlaid by 17 GHz contours of NoRH at different phase of the event

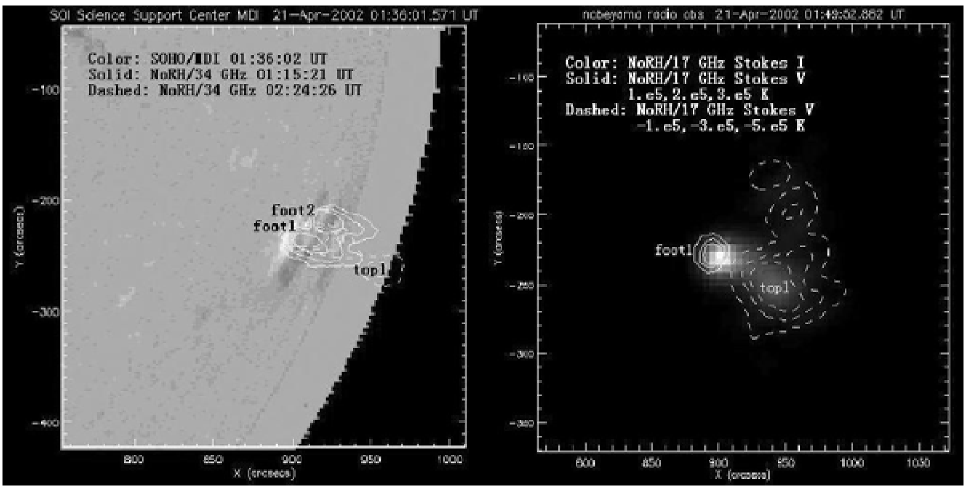

Figure 2. a. The SOHO/MDI magnetograph overlaid by 34 GHz contours at 01:15:21 (solid) and 02:24:26 (dashed) UT. b. The contours of Stokes V at 17 GHz are overlaid on Stokes I image at 17 GHz of NoRH (01:49:53 UT)

01:49 UT associated with the expanded flare and post-flare loops (Figs.1-2). The ejection was extended along the solar surface to form a mushroom shape well coincident with the EUV loops. The velocity of radio ejection and expanded loops keeps about 10 km/s until the post-flare phase. It is emphasized that the polarization sense of the radio ejection in loop-top source (LCP) is opposite to that at foot-point source (RCP) as in Fig.2b.

3. Associated with strong coherent emissions at 1-2 GHz

Fig.3 shows the Stokes I and V profiles at 1, 2, 3.75, 9.75, 17 and 35 GHz of Nobeyama Radio Polarimeters (NoRP) in this event. The maximum time is around 01:25 UT with

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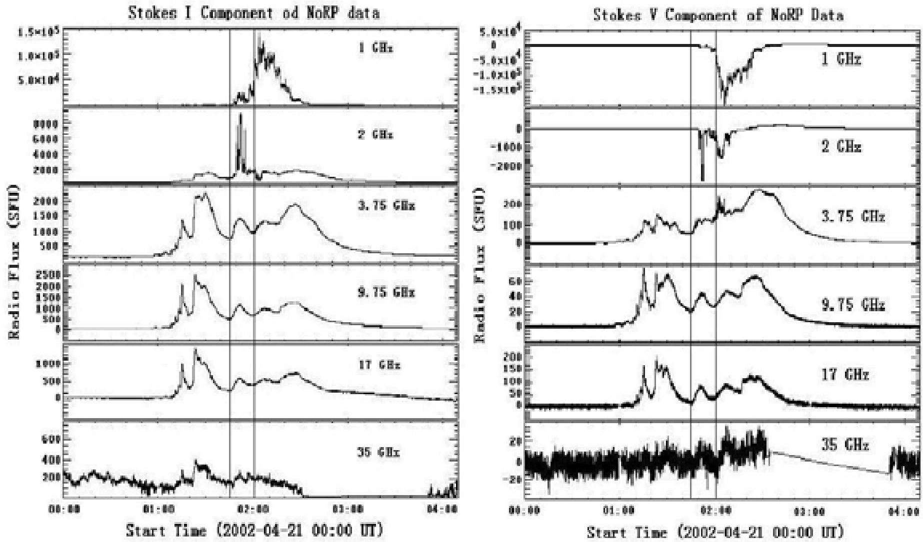

Figure 3. The Stokes I and V profiles at 1, 2, 3.75, 9.75, 17 and 35 GHz of NoRP in the event

turnover frequency of about 10 GHz corresponding to 17 GHz source at foot 2 in Fig.1. Almost during the same time as the radio ejection started (01:50 UT), a very strong emission at low frequencies (1-2 GHz) appeared with reversal polarization sense from RCP to LCP, which predicted as the coherent emissions by Kundu et al. (2004). Note that the polarization sense at 17 GHz of NoRP was not reversed as in NoRH image (Fig.2b), which may be explained by the high sensitivity and spatial resolution of NoRH.

4. A pair of moving type *IV* bursts at 0.2-2.0 and 2.6-3.8 GHz with fine structures

The coherent emissions are further analyzed with dynamic spectra of Hiraiso and Chinese Radio Spectrographs. There are a pair of moving type *IV* bursts respectively at 0.2-2 GHz from high to low frequencies and 2.6-3.8 GHz from low to high frequencies, respectively (Fig.4).

The fine structures with fast frequency drifts evidently exist in the type *IV* continuums in Fig.4. With high time resolution of 8 ms, the dynamic spectra at 2.6-3.8 GHz are selected in four time intervals as marked in Fig.4. The strong fluctuations at 2 GHz (Fig.3) mean that the type *IV* bursts are not real continuums. A group of quasi-periodic emission clusters are shown in the top panel of Fig.5. There are very slow frequency drift of moving type *IV* (5 MHz/s) and the fast drift of type *III* (several GHz/s) respectively in second and third panels. The 4th panel shows the multiple zebra strips with middle frequency drift (50 MHz/s). It is evident that the three components of frequency drifts commonly coexist in Fig.5.

5. Discussions

The fitting curve (Fig.6) of the velocity of the CME leading edge in this event (Gallagher et al., 2003) is well comparable with the typical falre-CME models, such as Lin & Forbes (2000). When the calculated velocity of the CME with average magnetic field

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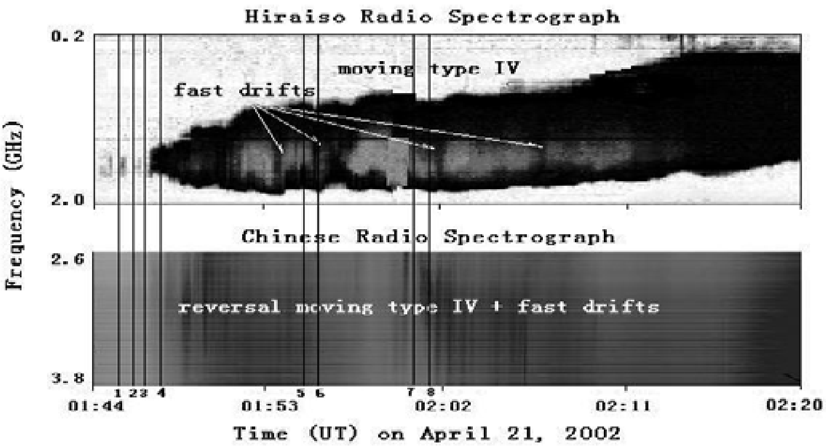

Figure 4. A pair of moving type *IV* bursts at 0.2-2.0 GHz and 2.6-3.8 GHz

of 100 Gauss in the active region is larger than the calculated local Alfvén velocity, the shock waves will be formed with radio type *II* bursts, which are reported in SGD by several spectrographs at meter bands around 01:20-01:30 UT, that consistent with the prediction in Fig.6.

On the other hand, the velocity of the radio ejection (top 1 in Figs.1-2) together with expanded flare and post-flare loops is comparable with the initial velocity of the CME. The reconnection site may be located in the 2 GHz source between two reversed type *IV* bursts (Fig.4), which should be above the loop-top of 17/34 GHz with the same velocity as the radio ejection and the velocity of moving type *IV* bursts. The different frequency drifts may correspond respectively to the speeds of current sheets, outflows, and accelerated electrons from the reconnection site.

Moreover, the coherent emissions as the radio signature of magnetic reconnection took place after the started time of the CME and the main flare phase, hence, it may refer to the second reconnection. The first reconnection may start in the pre flare- CME phase, such as the very rapid disruption of streamers, very high Doppler shifts, and high temperature plasma (Raymound, 2003), and the EIT ejection (Kundu et al., 2004). The fluctuations of coherent emissions with period of 10 seconds (typical Alfvén time) may be an intrinsic property of magnetic reconnection (Huang, 1990).

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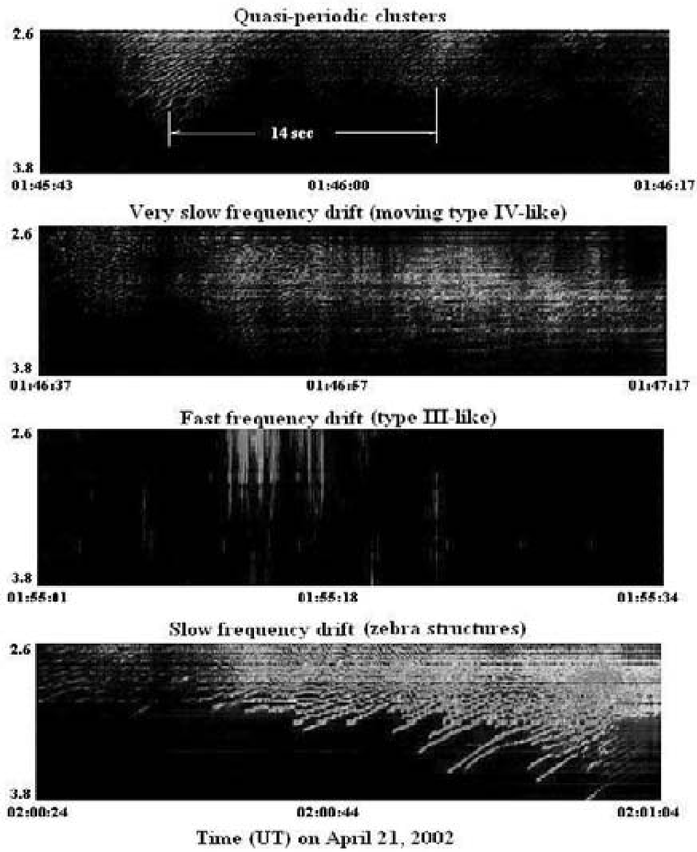

Figure 5. The quasi-periodic emission clusters and three components of frequency drifts from top to bottom in the dynamic spectra at 2.6-3.8 GHz

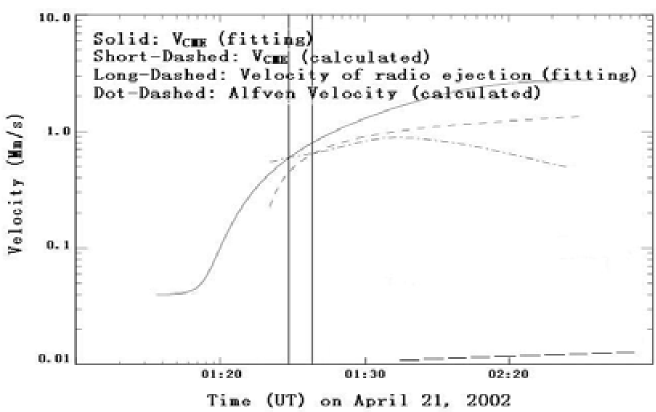

Figure 6. The fitting velocity of the CME and radio ejection in comparison with the calculated CME and Alfvén velocity

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Discussion

SCHMIEDER: Some of the drifts that you show look like type III bursts. Are they associated with the jet features?

HUANG: The drifts of opposite directions are associated and mixed in these observations.

JUN LIN : The jet-like structure observed should correspond to the reconnection outflow along the current sheet.

HUANG: Yes, I agree with your comment.

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