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Nobeyama Radioheliograph Data on Dynamics of Microwave Counterparts of Giant Post-Eruptive Soft X-Ray Arches

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Abstract

The dynamics of a number of giant post-eruptive arches in several near-the-limb events is studied using the Nobeyama Radioheliograph data at 17 GHz in comparison with observations of the Yohkoh Soft X-ray Telescope. It is found that the leading front and the brightest part of some microwave arches rise in the corona with a characteristic speed of 1–4 km/s, coinciding with that of soft X-ray arches, and lift to altitudes of at least about of 140,000 of km.

Key words: Sun: activity — Sun: radio emission — Sun: soft X-ray emission

1. Introduction

Based on Yohkoh/SXT images (Tsuneta et al., 1991), Švestka et al. (1995) and Švestka (1996) described a number of giant post-flare arches rising sometimes with a constant speed of 1.1–2.4 km/s during more than 24 hours up to altitudes of 250–300 thousands of km above the solar limb. Events of such kind were studied also by Hiei, Hundhausen, and Burkepile (1996). As a rule, these arches are associated with gradual long-duration soft X-ray events (LDE) being a signature of coronal mass ejections (CME) which are closely associated with each other (see, e.g. Chertok, 1997). An analysis of the Nobeyama Radioheliograph (Nakajima et al., 1994) images at 17 GHz reveals the microwave counterparts of such soft X-ray arches (Hanaoka, 1994). The so-called coronal millimeter wavelength sources appear to belong to the same phenomenon (e.g., Moiseev and Nesterov, 1986; Urpo, Pohjolainen, and Krüger, 1994). In the present work, the high-spatial-resolution ($\approx 10''$) Nobeyama Radioheliograph data are used to study the dynamics of several such radio arches.

2. Method of Analysis

One can judge on coincidence of the location, general structure, and characteristic sizes of the soft X-ray and microwave arches by Figure 1a, where they are shown for one east-limb event on the background of the corresponding heliograms (see also Hanaoka, 1994). The evolution and rise of of the microwave arch system of the same event are illustrated by Figure 1b. As the analysis shows, the evolution of the radio arches is rather complicated reflecting in particular a nonstationary character of the post-CME energy release and a three-dimensionality of these structures. In the course of their development, the microwave arches are extended also along the solar limb. They can change their internal structure and location of individual components, and their brightness temperature decreases with time.

Therefore, the rise speed in the corona was measured by movement of the brightest source and the leading front of an arch separately. The radial scan going through the top of the microwave arch was taken and was normalized then by the corresponding peak of the radio brightness. The position of the leading front at the given time moment was determined on the half-peak level of this scan.

3. Results of the Speed Measurements

Data on the arch dynamics in three events are presented in Fig. 2 and 3. During the initial stage of the 4 November 1993 event (Fig. 2a; see also Fig. 1) during the time interval of 03–05 UT, the leading front and the brightest part of

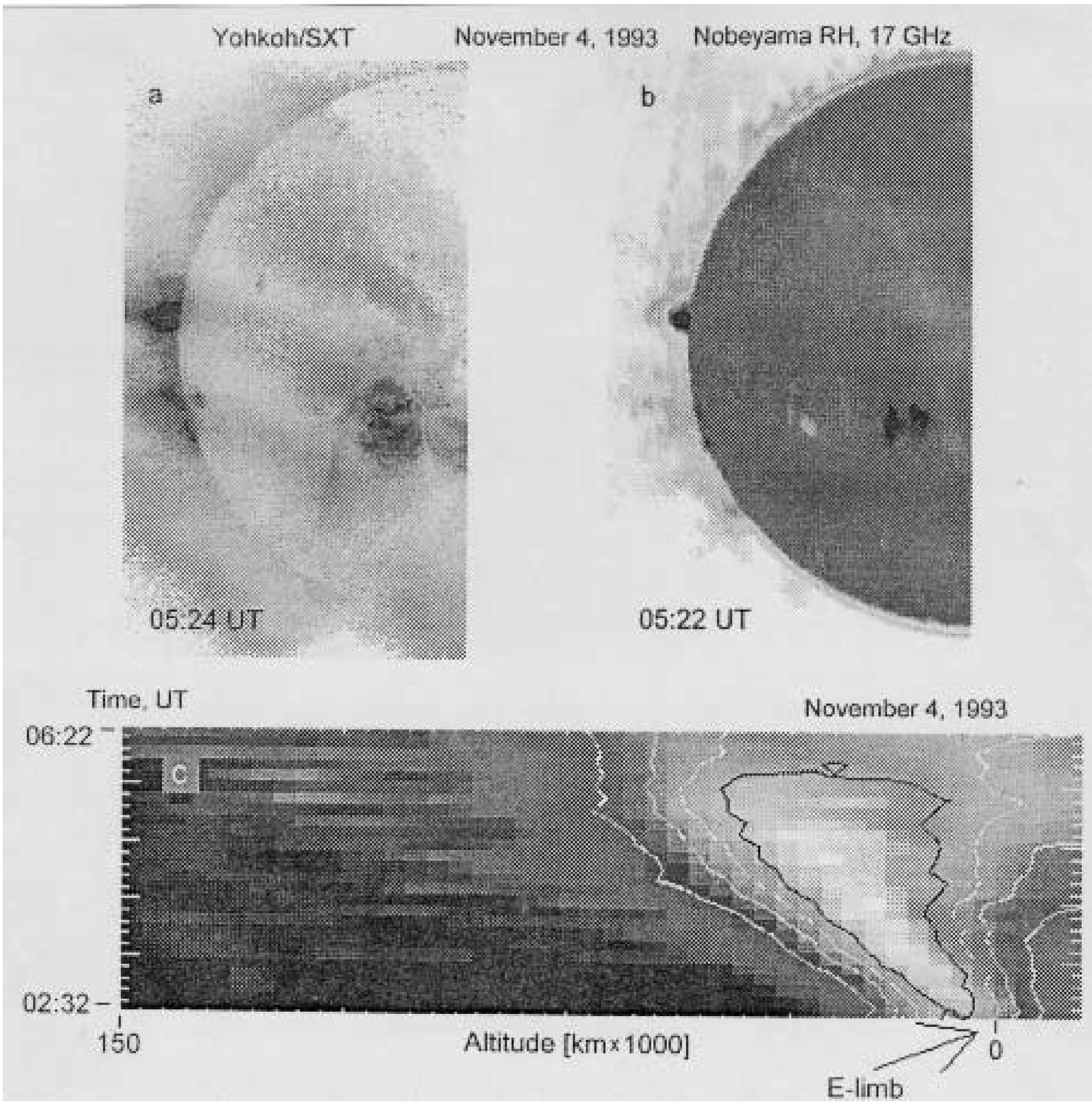

Fig. 1.. The dynamic of the giant arch system of November 4, 1993. The upper row – a typical view of the near-the-limb post-eruptive arches on the negative Yohkoh/SXT (a) and Nobeyama Radioheliograph (b) images. The low panel (c) – a time succession of the normalized radial scans through the top of the microwave arch. The horizontal strips correspond to individual scans made with a time interval of 10 min. The size of individual columns is equal to one pixel on the Nobeyama radio heliograms (4.91″ or 3810 km). A rise of the radio arch above the eastern limb is evident.

the microwave arch rise in the corona with practically constant speeds of 4.2 and 2.8 km/s, respectively. Then, after $\sim$ 05 UT, the leading front and somewhat later the brightest part seem to stop at projected altitudes of about 57 and 37 thousands of km. In this case, the altitude and speed of the leading front of the radio arch is approximately the same as those of the soft X-ray arches by measurements of Švestka et al. (1995).

A similar coincidence takes place also in the 16 March 1993 event (Fig. 2b). Here at the interval of 01–06 UT, the microwave arch, as well as the soft X-ray arch, lifts in the altitude range of 80–120 thousands of km with an average speed of about 1.7 km/s. At the same time, the brightest part of the microwave arch does not show a significant rise and keeps its position at relatively low altitudes of about 20 thousands of km.

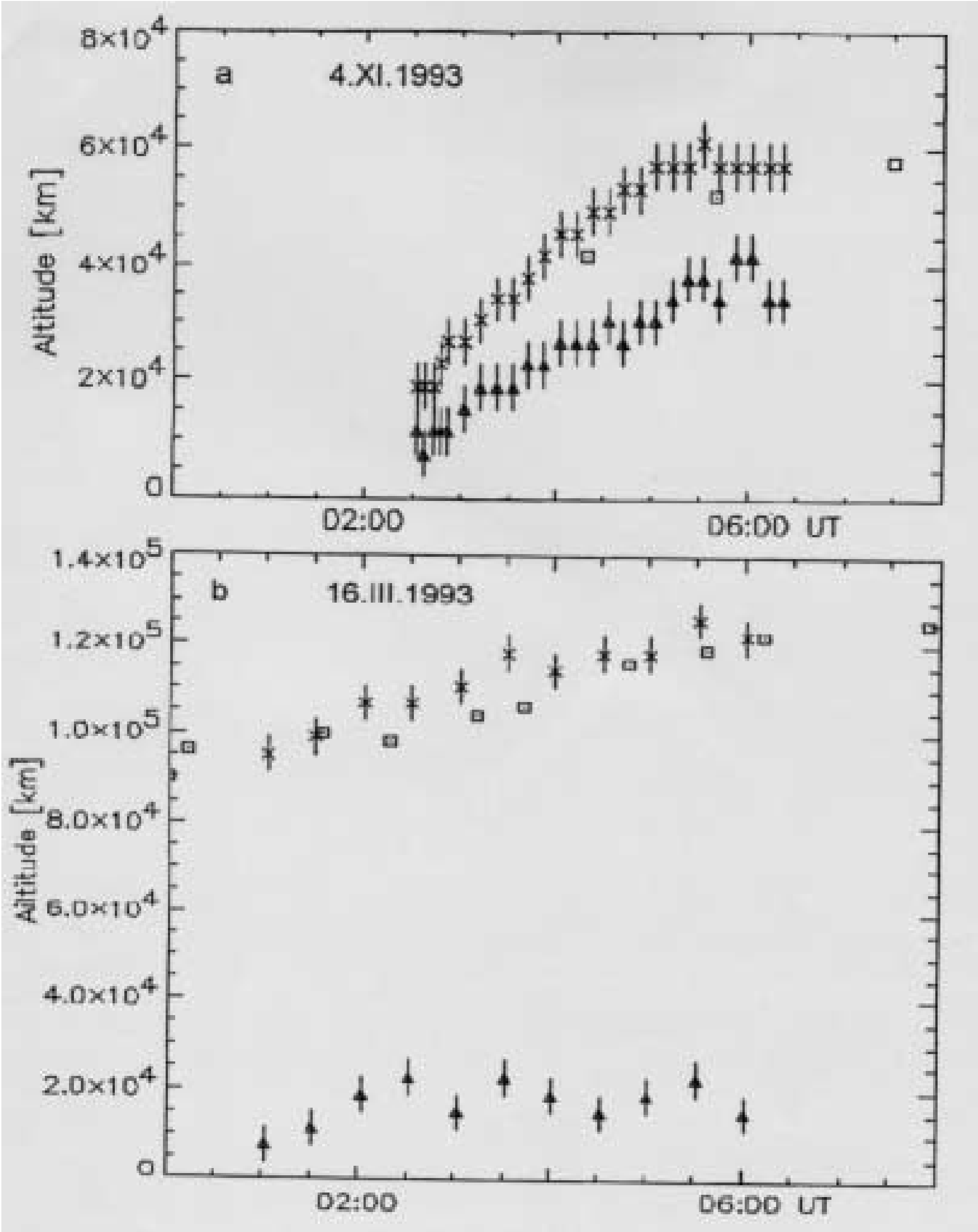

Fig. 2.. The time–altitude plots showing the lifting of both the leading front (crosses) and the brightest part (triangles) of the November 4, 1993 and March 16, 1993 microwave arches. Vertical bars denote ±1 pixel on the Nobeyama radio heliograms. Squares mark altitudes of peaks of the soft X-ray arches by measurements of Švestka et al. (1995).

Finally, the 29 June 1992 event (Fig. 3) displays a rise of the leading front of the microwave arch during 6 hours from altitudes of 55 to 115 thousands of km with an average speed of ~ 3.0 km/s. The brightest part reveals a more complex rise from 40 to 90 thousands of km with a sharp change of its position at 04:30 UT.

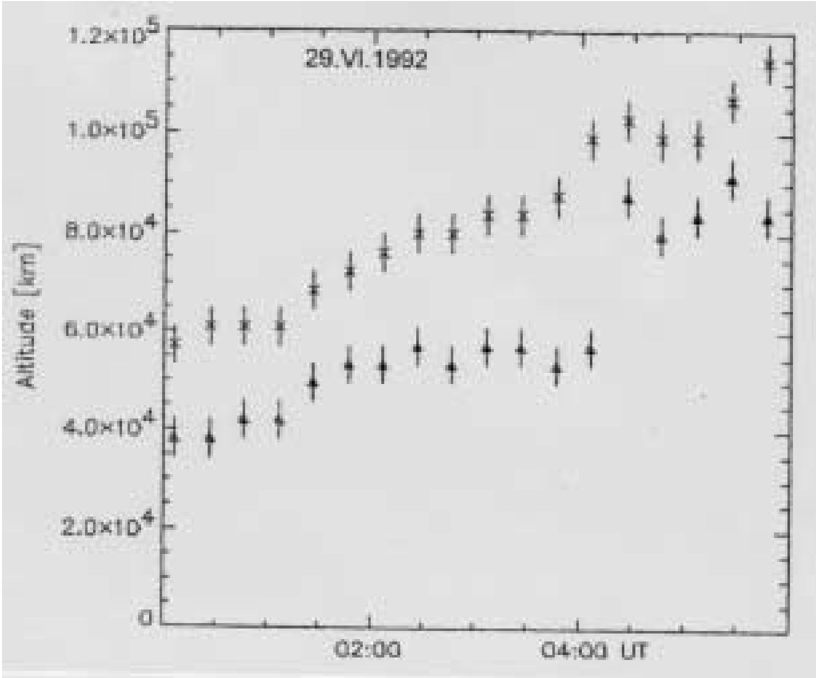

Fig. 3.. The time–altitude plots of the June 29, 1992 microwave arch. See caption to Figure 2.

4. Conclusion

The presented data allow us to conclude that the microwave post-eruptive radio arches and, in particular, their leading front, similar to the soft X-ray arches, rise in the corona for many hours with an average speed of a few km/s. The nature of the arch lifting appears to be associated either with a successive formation of new higher loops at the stage of the post-eruptive relaxation of the magnetic fields disturbed by a CME (e.g., Kopp and Pneuman, 1976) or with a continuous expansion of hot loops into the rarefied coronal plasma which arises also behind a CME (Švestka, 1996).

It should be added, that according to the modeling of Hanaoka (1994), the observed microwave emission and spatial structure of the arches correspond as a whole to thermal free-free radiation of optically thin plasma at 17 GHz with the temperature and emission measure derived from the Yohkoh/SXT images, although some differences take place due to the multi-temperature plasma in the arches and different emission conditions in the microwave and soft X-ray ranges.

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