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U-shaped type II solar radio bursts associated with the 1980 March 28 flare

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Abstract. The observations of the 1980 March 28, 2B flare in optical, radio microwave and metric and x-ray wavelengths are presented. In the dynamic radio spectrum, unusual and rare U-shaped type II radio bursts associated with this flare have been observed. The normal type II bursts display negative frequency drift, due to the flare-triggered shock wave travelling outwards in the solar corona. But in this case the type II emission first showed the usual negative frequency drift, and then after reaching a plateau level, showed a positive drift, thus giving the shape of an inverted 'U'. We propose a model for this type II emission. We suggest that the shock wave generated by the flare or the flare spray propagates through ducting and repeated reflections, which takes place within a large scale coronal loop or an arcade of loops, thus resulting in reversed frequency drift in type II emission.

Key words : solar flare—spray—surge—U-shaped type II burst—dynamic radio spectrum

1. Introduction

An impulsive solar flare of importance 2B, with an explosive flash phase and associated flare spray and surge activity, was observed at the Udaipur Solar Observatory on 1980 March 28 at 0954 UT, in Hale region 16740 (N25, E56). Associated with this flare, unusual and rarely observed "U-shaped type-II" solar radio bursts were recorded at the Solar Radio Laboratory, IZMIRAN in the frequency range of 30 to 90 MHz. This event was also observed in the 30–1000

MHz frequency band at the Weissenau Radio Observatory. In this paper a detailed description of the optical flare, spray and surge activities and the associated dynamic radio spectrum, observed at Udaipur and IZMIRAN is given. The micro-wave and x-ray observations are also presented. A schematic model of the observed U-shaped type II radio bursts is proposed.

2. Optical observations

The 1980 March 28 flare occurred in the north-east corner of the Hale region 16740 of $\beta\gamma$ character. In this very active region, on the next day, March 29, a gamma-ray flare was observed by the gamma ray monitor on the Solar Maximum Mission satellite. The flare of March 28 occurred at the location marked 'F' in the magnetic field map (obtained from the Mt Wilson observatory) shown in figure 1, in predominantly negative (following) polarity region and between the preceding positive and the following "inverted" positive polarity regions. The time lapse H-alpha observations were made at 10s intervals from the Udaipur Solar Observatory, using the 150 mm aperture telescope, in conjunction with a 0.5 Å passband Halle filter.

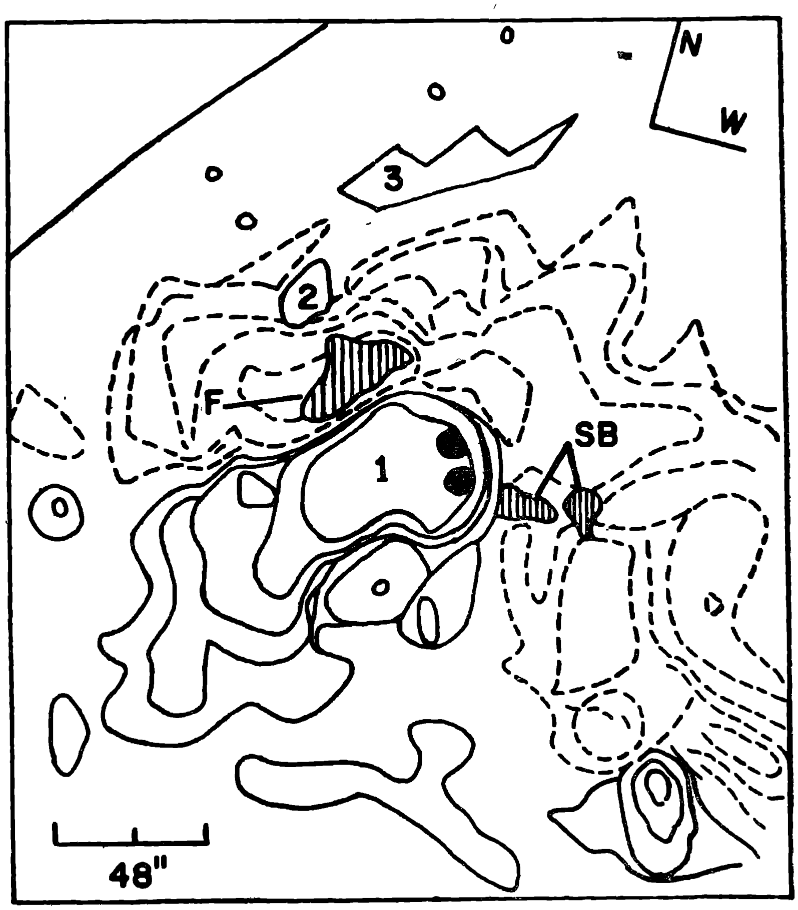

Figure 1. Longitudinal magnetic field map taken from Mt Wilson observatory on 1980 March 28, at 17.30 UT of Hale region 16740. Continuous lines show positive polarity while dotted lines negative polarity. A flare is indicated by hatched portion F, and dark dots refer to the location of the sunspots.

During the observations, the solar "seeing" remained between 3–5 arcsec. Just before this 2B flare, a subflare was also observed at 0951 UT, in the SW portion of this active region.

In figure 2 is shown the development sequence of this impulsive flare in H_α. This flare started as two bright kernels of about 4 arcsec diameter at 09.54.25 UT. Initially, the two small kernels brightened up slowly, but after about 2 min suddenly the kernels flared up and joined together in an explosive flash phase, to reach the maximum intensity at 09.56.40. A bright flare spray indicated as A in figure 2 ejected out around the time of the flash phase, towards the eastern limb and with a velocity of more than 700 km s^{-1} (measured along the trajectory) from the flaring region. This feature A attained the maximum brightness at 09.56.47 and was visible only for 35s, through the 0.5 Å passband filter. At 09.56 a bright flare surge, feature B (figure 2), ejected from the north-east corner of the flaring region. In the beginning this feature B appeared to move at a relatively slow velocity of 80 km s^{-1}. but within 2 min accelerated to nearly 200 km s^{-1}. At 09.57.35 another bright mass indicated as C in figure 2, ejected out from the tip of feature B, with a speed of more than the chromospheric escape velocity of 650 km s^{-1}. During the declining phase of the flare, bright and dark surges ejected out near the north-east corner of the flare, as seen in the H-alpha flare sequence shown in figure 2.

In figure 3 are shown the area of the flare in millionth of the solar disc, the 3000 MHz radio emission recorded at IZMIRAN, and the hard x-ray data obtained from ISEE-3, on the same time baseline axis. The time of commencement and duration of type II and type III radio burst emissions and sudden ionospheric disturbances are also indicated by horizontal bars. The flare growth curve indicates that after the initial slow rise beginning at 09.54, the area of the flare increased rapidly to reach the flare maximum at 09.56. Krivsky *et al.* (1982) have reported observing an extensive faint diffuse H_α-aurora beyond the limb, associated with this flare. Our observations do not show this diffuse aurora. Perhaps the exposures made on our film were not long enough to record the faint aurora. Dr N. R. Sheeley (1982, personal communication) has reported observing a streamer-like coronal transient on the east limb, from the P78–1 space coronagraph data, taken between 0540 and 1419 UT on March 28. This coronal transient seems to be associated with this flare and the accompanying mass ejection.

3. X-ray and microwave emissions

At 3000 MHz and 2800 MHz frequencies, observations of this event were made at IZMIRAN and the Physical Research Laboratory, Ahmedabad. The 3000 MHz record is shown in figure 3. The x-ray data from ISEE–3, supplied by Dr S.R. Kane, in the energy bands of 26–43 KeV, 43–78 KeV, 78–154 KeV and 154–398 KeV are also shown in the top portion of figure 3. The time-intensity profiles of the microwave and hard x-ray bursts show a short decay time as compared to the rise time. Although this flare was classified as 2B in H-alpha, it gave rise to intense hard x-rays even in the 154–398 KeV energy band. The intensity time profiles of 26–43 and 43–78 KeV channels clearly show a "premaximum" peak at 09.55, corresponding to a minor hump in the 3000 MHz record. The H-alpha observations also indicate slight premaximum brightening of the two H_α-kernels. Both soft x-ray and microwave emissions attained maximum around 09.56.30 and the H_α emission also seems to have peaked at this time or within 10–15 seconds. From the analysis of these observations, it is clear that the "premaximum" peak observed in H_α, microwave and soft x-rays, indicates "preheating" of the flare plasma, before the onset of the impulsive major flare.

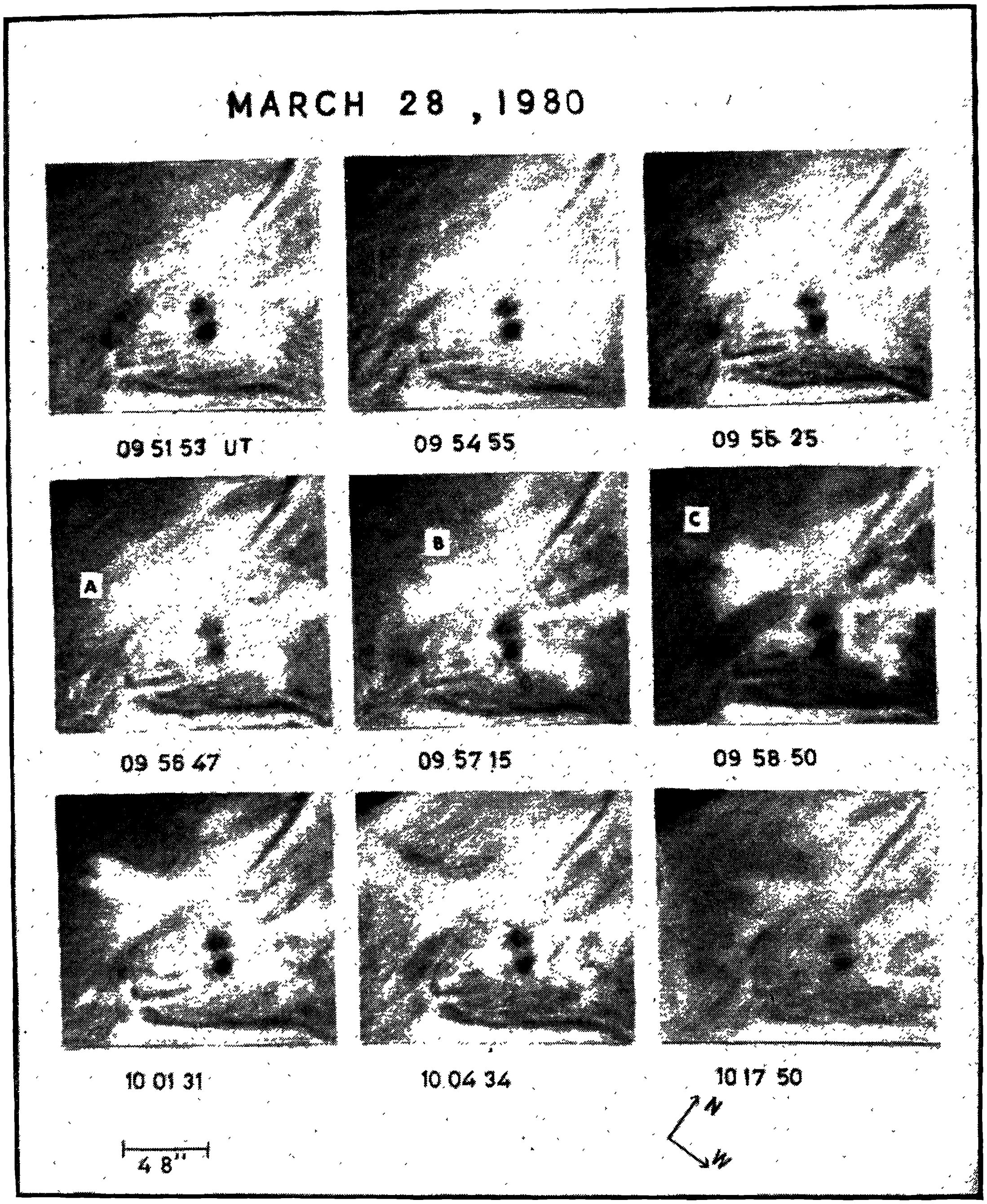

Figure 2. Flare development sequence in H_α showing flare spray A and surges B and C. Time lapse observations were made at interval of 10s from Udaipur Solar Observatory.

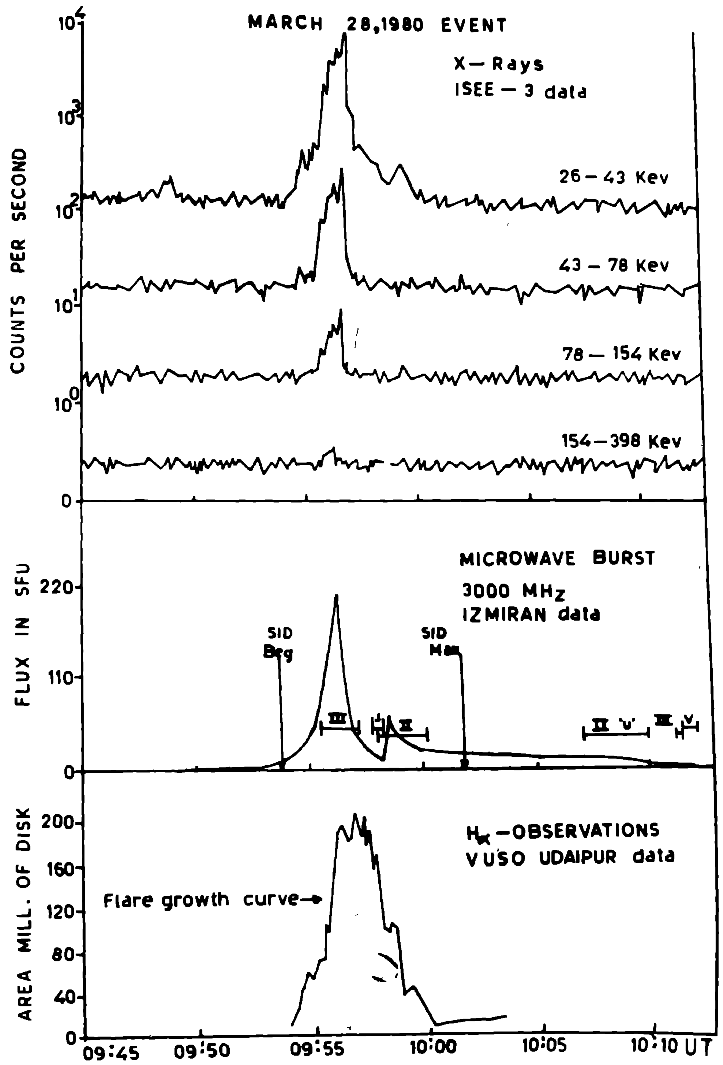

Figure 3. Top : X-ray data from ISEE-3. Middle: Microwave burst at 3000 MHz observed at IZMIRAN and associated dynamic bursts and SID's indicated by horizontal lines. Bottom: The H_α flare growth curve observed at Udaipur.

4. Unusual U-shaped type II and type III radio emissions

This event was recorded on 1980 March 28 (0955–1010 UT) with IZMIRAN radio spectrograph in the frequency range of 45–90 MHz and at the Weissenau observatory in the frequency range of 30–1000 MHz. The dynamic radio spectrum made at IZMIRAN is shown in figure 4. The two spectra complementing each other have enabled us to construct a rough schematic diagram shown in figure 5, which clearly shows the main features of this event. The radio emission began with type III and V bursts at 09.55.48–09.57.24 UT. Thereafter the two type II emission bands appeared at 46–86 MHz between the time interval of 09.57.30–09.58.12 UT. These were followed by additional type II-like bands and overlapping flare continuum with numerous blobs and diffuse structures at high frequencies between 09.57.30–10.00.30 UT. Another long lasting type II burst took place between 10.00.30–10.14 UT. Analysis of the dynamic radio spectra reveals that this burst has clear harmonic structure, and

Figure 4. The dynamic radio spectrum obtained at IZMIRAN. U-shaped type II burst is seen clearly at 1008-1010.2 UT.

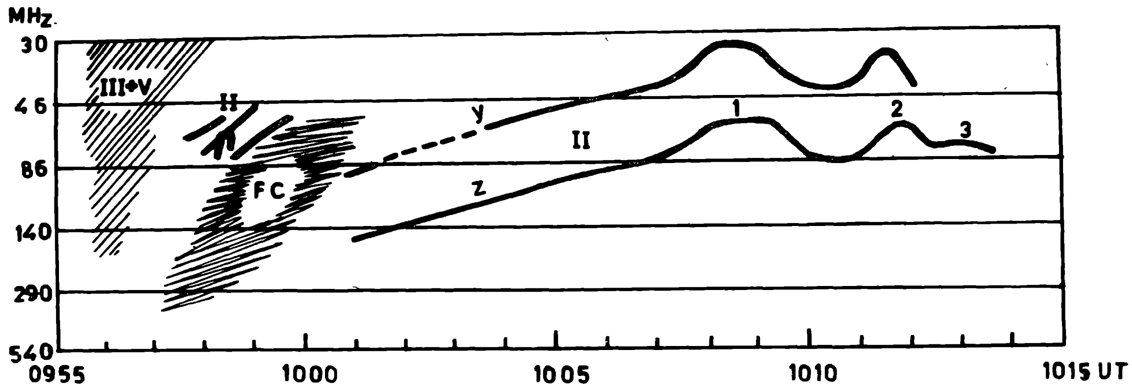

Figure 5. A schematic diagram of combined dynamic spectra obtained from IZMIRAN and Weissenau Observatory in frequency range of 30–540 MHz, showing three (1, 2, 3) U-shape structure in the type II emission. 'Y' indicates the fundamental and 'Z' the harmonic.

the splitting of the fundamental and harmonic is evident. The main peculiarity of this type II burst is the appearance of two or three U-shaped structures at the final stage of the burst, between 10.07–10.14 UT. A detailed examination of the dynamic spectra shows that both the first and the second U-shaped structures consist of two emission bands. The general structure of the type II burst as a whole and the similarity between the pattern of low and high frequency bands, appear to provide very strong evidence that the two emission bands are split from one and are not independent bands. The U-structure, with bands splitting, is perhaps the continuation of the eorresponding split emission bands, observed during the preceding type II burst. According to Weissenau spectrum, the third U-shaped structure is rather faint and consists of a number of blobs and type III-like fragments forming an emission band. One can see that the third U-structure has higher turning frequency compared to the first two.

5. Discussion

This solar flare of class 2B displayed extremely interesting and rarely observed U-shaped type II radio emission. In the optical, microwave and x-ray emissions, this flare displayed the usual normal characteristics of a moderate flare, except for emitting fast mass ejections and the H_α emission aurora observed by Krivsky *et al.* (1982). The type II solar radio bursts associated with this flare are of great interest here and are discussed below in some detail.

The type II solar radio bursts are known to be initiated by shock waves arising because of solar flares and mass ejections. In the classical type II bursts, the emission bands drift from high to low frequencies in some tenths of MHz s^{-1}, This corresponds to the propagation of shock waves outwards in the solar corona from high to low electron density. The typical velocity of the shock ranges from 500 to 2500 km s^{-1}. Some observations made from Culgoora radio heliograph and Clark lake array show that in few events the shock may undergo refraction and propagate along a curved path, guided by magnetic fields (Kai 1969; Smerd 1970; Dulk *et al.* 1971; Palmer 1972; Nelson & McLean 1977; Gergely & Kundu 1981).

In this paper, unusual and rarely reported type II bursts with clear indication of reversal of freqency drift have been discussed. The main peculiarity of this unusual type II burst was recorded about 7 min (from 10. 07.18 to 10.14 UT) after the long lasting type II burst had started at 10.00.30. According to the frequency drift three stages can be distinguished in this type II burst. In the first stage the two emission bands, separated by 40–45 MHz, were definitely split bands and showed the normal negative type II frequency drift for about 80s with an average drift of 0.37 MHz s^{-1}. In the second stage the low frequency band reached nearly the 60 MHz level, and the freqency drift stopped rather sharply and during the next 47s the emission bands were almost horizontally disposed. In the third stage, the burst which began sharply, showed a clear reversal (i.e. drift from low to high frequencies) with an average drift of about 0.73 MHz s^{-1}. Since the bursts displayed the shape of inverted "U", we call these peculiar type II bursts "U-shaped" type II bursts. Towards the final stage of this burst, two or three U-shaped structures could be identified. Roberts (1959) and Nelson & McLean (1977) have also reported indication of positive frequency drift in some type II bursts.

According to the time-lapse H_α observations made at Udaipur, this flare occurred in a complex magnetic region with inverted polarity. An intense spray 'A' ejected out with a velocity of more than 700 km s^{-1} around the time of flash phase and was followed by relatively slow moving surges. It is most likely that around the H_α flash phase, a shock wave was generated by the flare which was responsible for the first set of normal type II emission at 09.57.30-09.58.12.

The other long lasting type II burst which started at 10.00.30 until 10.14 UT might have been generated by the shock produced by the spray emission A. It is suggested that the observed U-structures of the type II bursts may be due to ducting propagation and repeated reflections of the shock wave, between large scale loop like region with comparatively high value of the Alfvén velocity. Depending on the spatial distribution of the magnetic field strength and the electron density, the Alfvén velocity may be minimum either within one large coronal loop or between an arcade of loops. Figure 6 shows the proposed scenario to explain the U-shaped type II emission. From the H_α optical observations, it is difficult to precisely say whether there were

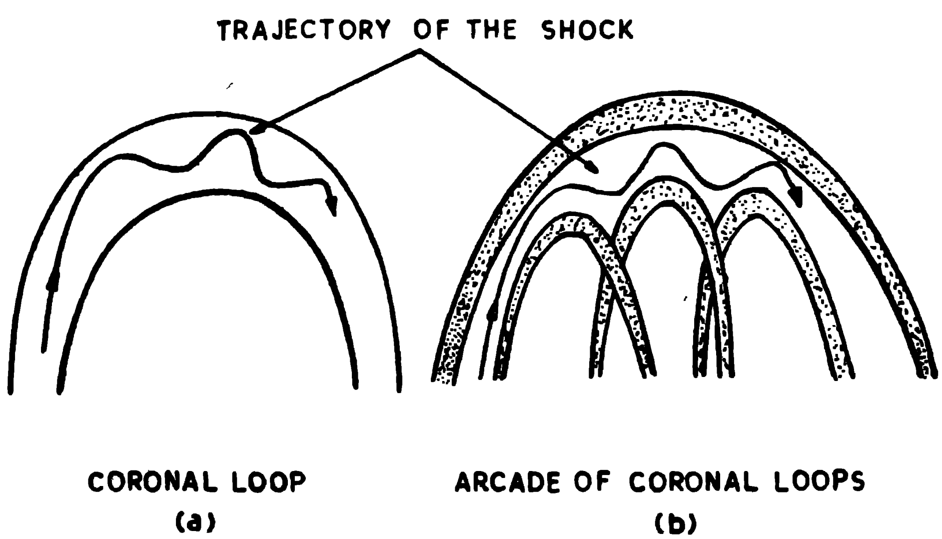

Figure 6. A scenario of the proposed model for U-shaped type II emission for trajectory of the shock (a) within a single coronal loop, (b) within an arcade of loops.

two independent shocks responsible for the two sets of type II bursts or whether it was only one initial shock which was trapped during the final stages, within the coronal loop structure, which displayed the unusal U-shaped type II bursts.

It is difficult to see why only this active region gave rise to the U-shaped type II bursts. It appears that the strength of the shock, the magnetic field structure, the electron density over the active regions, and the location of the shock generating spray are important parameters in creating the appropriate conditions for the shock to travel along the coronal loop and to generate the unusual U-shape type II emission. In order to settle this question, as to why only a few flares give rise to such type II bursts while others do not, we would require a detailed knowledge of the spatial magnetic field configuration and the electron density in active region and in the corona.

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