Astron. Astrophys. 364, 793–798 (2000)

ASTRONOMY
AND
ASTROPHYSICS

Microwave M burst on May 3 1999

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Received 29 February 2000 / Accepted 11 August 2000

Abstract. We present a remarkable fine structure of "decimetric pulsation" event (DCIM), observed with the 2.60–3.80 GHz spectrometer in Beijing Astronomical Observatory on 3 May 1999; a "M" dynamic spectrum has been detected, thanks to the high time and frequency resolutions. We call this fine structure a microwave M burst and propose a plausible model which treats the observed M burst as an emission produced by the same electron beam travelling along magnetic lines and mirrored; this beam might be originally formed from the plasmoid of a type IV-DCIM burst. The M burst could be another radio evidence of the mirror effect on electron beam after the N-burst. It is the first time that such a feature has been detected in type IV-DCIM bursts.

Key words: Sun: activity – Sun: radio radiation

1. Introduction

Solar type III bursts are probably better studied and elucidated than other forms of radio emission in all of astrophysics. They are attributed to electron beams propagating out through the corona along magnetic field lines at a speed of about c/3 (Wild 1950); on its passage the beam sets up Langmuir waves (plasma oscillations) which then are converted into electromagnetic waves near the local plasma frequency. Other theory of type III bursts, however, has also been proposed very recently (Wu et al. 2000). On the dynamic spectrum, ordinary type III bursts observationally appear as an emission rapidly drifting toward lower frequencies (higher altitudes). In some cases, bursts start just like ordinary type III bursts, but their frequency drift rates gradually change from negative through zero to positive; if the emission stops here, the bursts are called inverted-U bursts (simple U bursts) because of their appearance in the dynamic spectrum (sometimes they are called J-burst due to a shorter descending branch). Certain observations made before revealed a third ascending branch following the type U-event, which is called "N-burst" (Caroubalos et al. 1987; Hillaris et al. 1988). It is possible, however, that a fourth descending branch following the type N-event, thus suggesting the capital letter M in the dynamic spectrum. We call the bursts "M-burst" . A microwave M burst, which is a fine structure of type IV-DCIM bursts detected on May 3 1999 by Beijing Asronomical Observatory (BAO) spectrometer over the band 2.6-3.8 GHz is studied in this paper.

Observational and theoretical aspects of type IV bursts have been less studied than those of type III bursts, but type IV bursts are better known around meter wavelength than above 1 GHz. Boischot (1957) was the first to identify that type IV burst was meter-wavelength continuum emitted by a solar flare or by an eruptive prominence. Weiss (1963) used the name "moving type IV" (IVM) to distinguish it from the stationary component of type IV bursts. The type IV burst is also called "decimetric pulsation" (DCIM) in the decimetric and microwave bands, because DCIM is characterized by long duration (tens of minutes), broad bandwidth (more than 2.0 GHz as present event), no obvious frequency drift and association with or following a solar flare. Wiehl et al. (1985) reported a comprehensive study on a number of DCIM bursts and classified them into 4 main subtypes: short and long lasting bursts, narrowband and wideband bursts.

We will put the emphasis on the fine structure, of a kind that has never been recorded before in such high frequency range, around 3.0 GHz. In Sect. 2, we will describe the instrument and give an overview of the event on May 3 1999. In Sect. 3, we will analyse the properties of the fine structure and the event. In Sect. 4, we will discuss a plausible model of this fine structure and draw a conclusion in Sect. 5.

2. Observation

For a detailed study of the fine structures in the high-frequency part of decimetric and microwave bursts, new spectral observations (intensity and polarization) with high resolution in time and in frequency over a wide frequency range are needed. For this purpose, a broad band radio spectrometer is being developed by the solar radio astronomical community of China (Fu et al. 1995). It consists of 5 separate spectrometers covering the respective frequency range: 0.70-1.40 GHz, 1.00-2.00 GHz, 2.60-3.80 GHz, 4.00-5.20 GHz and 5.20-7.60 GHz. The 2.60-3.80 GHz component spectrometer started working in October 1996 at BAO. It has 120 frequency channels of 10 MHz bandwidth each, a time resolution of 8ms, high sensitivity and high accuracy measurement of circular polarization (Ji et al. 2000).

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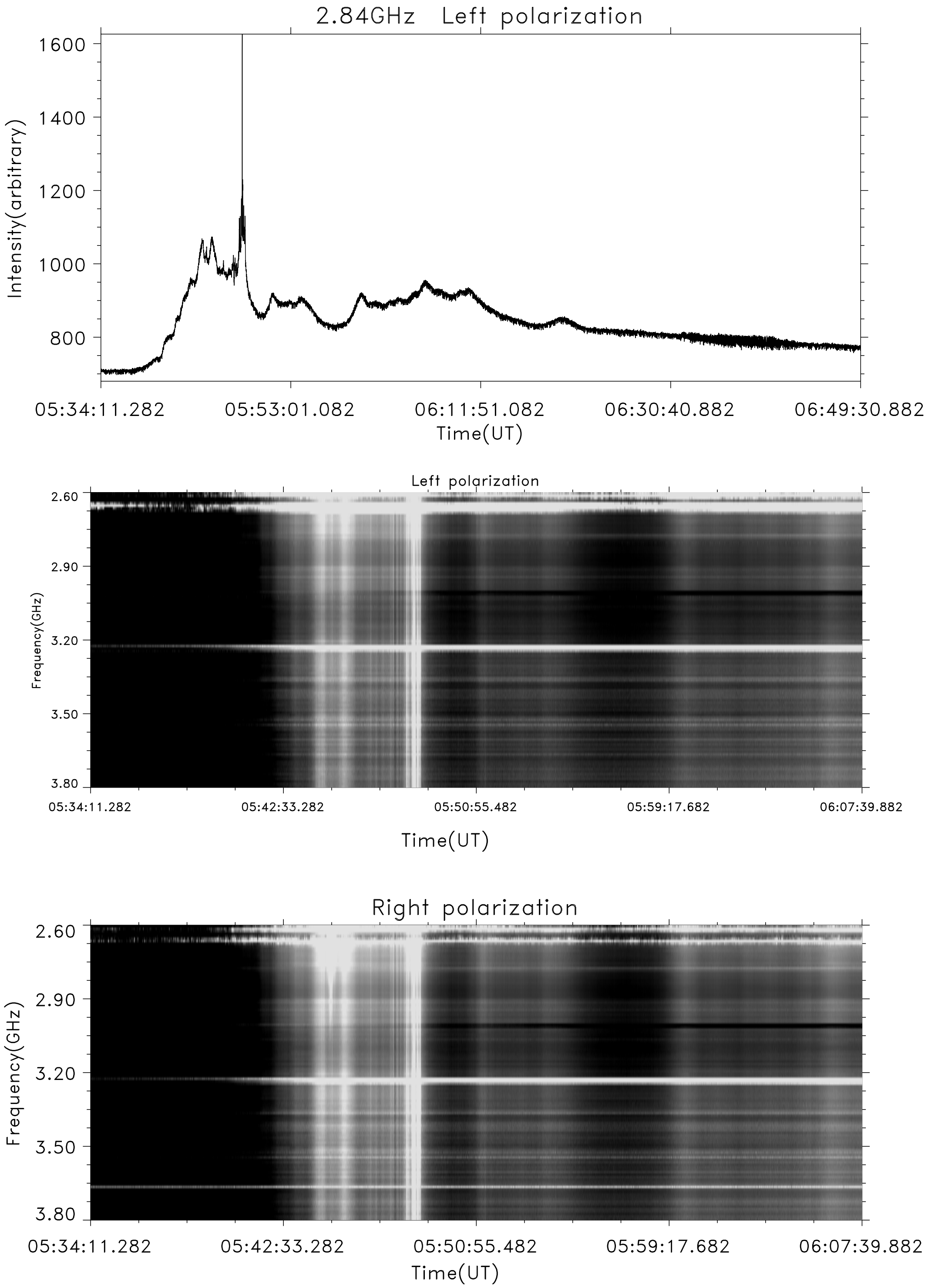

Fig. 1. An overview of DCIM on May 3 1999 observed by BAO, top to bottom: a single frequency time profile, left- and right-handed dynamic spectra respectively. (the period between two triangle markers is given in the top panel in Fig. 2).

An overview of type IV-DCIM on May 3 1999 is given in Fig. 1, including a single frequency time profile, left- and right-handed circular dynamic spectra respectively. Fig. 2 shows a fine structure, which has a ‘M’ appearance.

This type IV-DCIM event lasted from 05:42 UT to about 06:49 UT. According to Solar-Geophysical Data (SGD), it was also recorded by the spectrometer over the range of 800–2000 MHz from 05:42 UT to 06:41 UT in Ondrejov Observatory. Moreover, a type 48C burst was detected by LEAR and SVTO at fixed frequency 2695 MHz and 4995 MHz, etc. On the other hand, a M4.4/2N flare was recorded by GOES and LEAR in the active region NOAA 8525 located at N15E32. This flare lasted

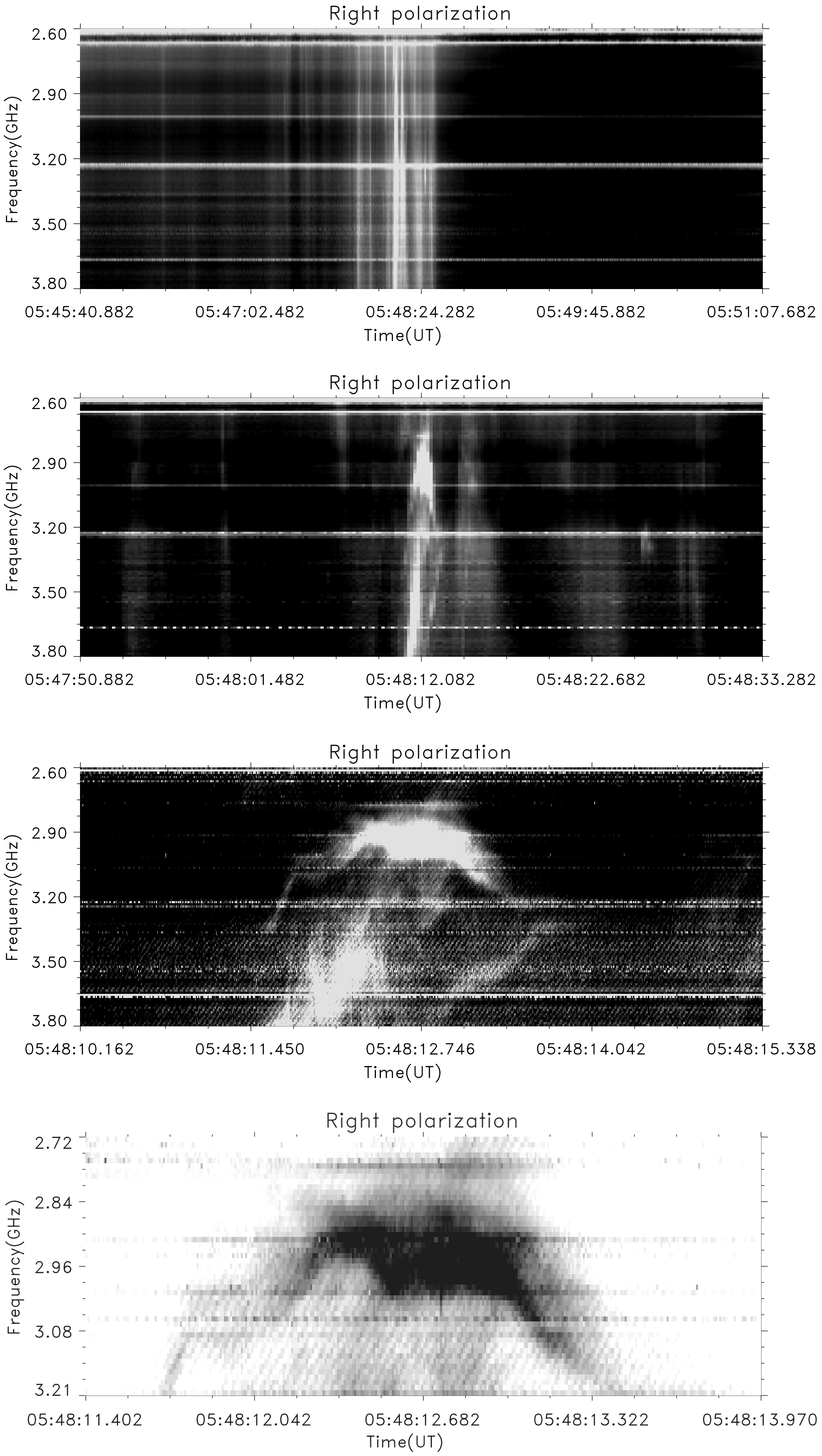

Fig. 2. Dynamic spectra of the M burst, which is a fine structure of DCIM; top and second panel: data integrated into 200ms; third and bottom: data recoded with a resolution of 8ms.

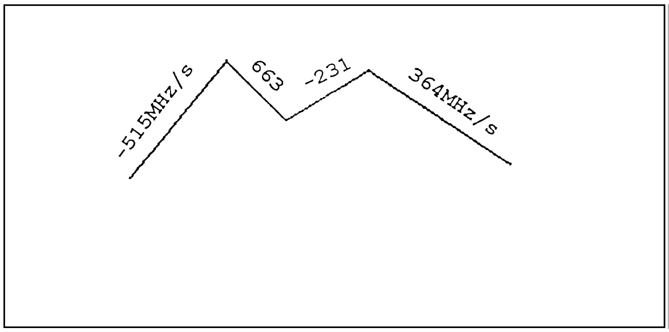

Fig. 3. Simplified dynamic spectrum of M-burst; the numbers on each branch represent the average magnitudes of drift rates.

from 05:36 UT to 06:32 UT in GOES X-ray at 1-8 Å(or from 05:34 UT to 07:45 UT in H_α), reaching its maximum around 06:02 UT (or 05:51 UT in H_α). In addition, there were some sudden ionospheric disturbances between 05:43 UT and 06:01 UT (maximum at 05:50 UT).

3. Data analysis

3.1. Bandwidth and duration

As mentioned above, this type IV-DCIM was also recorded over the range of 800–2000 MHz, which means that it had a bandwidth of more than 2.0 GHz, since it was beyond 3.80 GHz high frequency limit of the BAO spectrometer. It lasted for more than one hour (67 minutes), and had a long decay phase (about 60 minutes); near the intensity peak (around 05:48:12 UT) a peculiar fine structure was detected. This fine structure with a negative picture (Fig. 2 bottom panel) had a bandwidth about 430 MHz between 2.74 GHz and 3.17 GHz, and a total duration over 1.3 seconds.

3.2. Frequency drift and polarization

Fig. 3 shows the average drifting rates of the four branches. The branches of the first U have bigger rates than those of the second one. In addition, as given in Fig. 1, the type IV-DCIM and the fine structure were almost unpolarized all time.

4. Discussion

4.1. Evolution of the fine structure

Simple U bursts are generally interpreted as being produced by electron streams travelling once along the closed magnetic lines from the first foot to the second foot; in the event the tube is pinched at the second foot, the electrons with not too small a pitch angle are mirrored near the second foot. The electrons might then generate a second U emission on their way from the second foot back to the first; the combination of the first and second U burst creates a M burst. We interpret this fine structure as a microwave M burst.

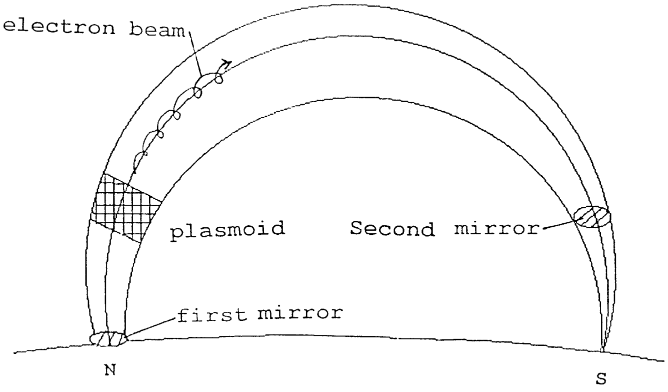

Fig. 4. A possible arch model for the flare on May 3 1999; the shaded zone represents the radio source (a plasmoid) of the type IV-DCIM, from which an electron beam is formed during the burst; the dashed areas are the two magnetic mirrors near the feet of the arch.

As shown in Fig. 4, an asymmetrical magnetic arch (the two mirrors are not located at a same plasma level) is expected in this flare; a plasmoid trapped near the top of magnetic arch moves together with this expanding arch. It is the radio source of type IV-DCIM: the plasmoid sets up Langmuir oscillations on its passage, which then are converted into electromagnetic waves at the local plasma frequency. Meanwhile, the electrons in the plasmoid are also propagating along the field lines in both directions. A electron beam could be formed from the plasmoid during the burst and then move along magnetic lines and mirrored by the second pinched tube (the higher mirror) near the top of arch. At the same time, the plasmoid is just propagating through the same plasma layer, emitting the type IV-DCIM bursts, while the beam emission is the microwave M burst which in Fig. 2 overlaps on the continuum (DCIM).

Therefore, the M burst is another radio evidence for a magnetic mirror effect on beam of electrons in the solar corona after the N-burst (Caroubalos et al. 1987; Hillaris et al. 1988). As in case of simple U emission, the M burst is a new sub-class of type III bursts because it is produced by a same electron beam; however, it is a fine structure detected in type IV-DCIM bursts.

4.2. Mirror evidence

We interpreted the four consecutive branches, which are numbered 1 (first branch, descreasing frequency f along time), 2 (second branch, increasing f), 3 (third branch, descreasing f) and 4 (fourth branch, increasing f), as an emission produced by a same electron beam, so we have to prove it and rule out any possible coincidence whereby a U-burst could have been followed by another, unrelated U-burst. If the four branches of fine structure are emitted by a same electron beam, we expect that the duration of the time profile at fixed frequency to increase regularly along each of the four branches and continuously from one to next. This is because of the dispersion Δv of the beam velocity. As a matter of fact, it is difficult to measure the duration

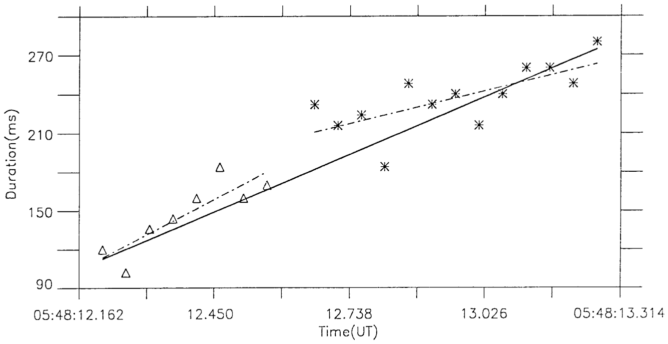

Fig. 5. Measurements of the duration (D) along the branches 1 (Δ) and 4 ($*$); the slopes of the regression line are all positive, dD/dt>0.

because a continuum, which results from the velocity dispersion of electron beam 1 and 2, is encountered between the branches 2 and 3. However, we measured the durations at fixed frequency of branches 1 and 4, as given in Fig. 5. The duration of time profiles increases regularly along branches 1 and 4 and also increases from branch 1 and 4 (dD(t)/dt > 0); despite the absence of 2 and 3 branches, this fact is enough to support the conclusion that these branches all are produced by a same electron beam.

The intensity at given frequency of branch 4 decreases with increasing frequencies, and finally fades away into the DCIM. This is because the Coulomb collisions with the ambient plasma are stronger at the lower altitudes than at higher altitudes; and it is also because, due to these collisions, the electrons of the beam decelerate and change their distribution, finally part of them is lost, so they cannot gradually propagate their emissions out at the beginning of the branch 4 (the intensities decrease). The branch 4 has a longer average duration than branch 1, which is due to the velocity dispersion. The extent of the electron beam increases with the elapsed time, because

$$L_{beam} \simeq L' + \Delta v \times \Delta t$$

where Δv: speed dispersion of beam, Δt: elapsed time after beam left the acceleration region, (when $\Delta t = 0$, $L_{beam} = L'$, L' is the original length of electron beam). In addition, if the magnetic mirror is not located high enough, the reflection process cannot occur because the injected beam (branch 2) would be absorbed due to the collisions along its way before it approaches the mirror; if the second mirror were located at a lower altitude, the electron beam 4 would have been damped by collisions before being reflected.

4.3. Magnetic arch

We have interpreted that this M burst is emitted by a same electron beam, which has to propagate through a relatively dense medium (corresponding to the plasma frequency of 3 GHz). As noted earlier, the beam can be quickly isotropized by Coulomb collisions in this high density medium unless certain conditions are met. The collision time is given by

$$\tau_D = 3.1 \times 10^{-20} \left(\frac{v^3}{n_e} \right) (\mathrm{s})$$

where $n_e(\mathrm{cm}^{-3})$ is the electron density and v(cm/s) is the beam speed (Benz et al. 1992). The plasma frequency corresponds closely to the observed frequency for plasma mechanism, from which we deduce the electron density around the radio sources, $n_e = 1.12 \times 10^{11}\mathrm{cm}^{-3}$ at the plasma frequency of 3 GHz. To achieve an average lifetime τ_D=170 ms (which is average duration of the branch 1 from Fig. 5) as required by the present observation, we require a speed of beam roughly $v \simeq 0.28$c (c is the light speed in vacuum) corresponding to 1 branch. The beam decelerates its speed from branch 1 to 4 due to the collisions, ultimately the second U-emission has a longer duration of about 0.8s than the first one (about 0.5s). So we can also roughly deduce the length of this arch

$$L_{arch} = 0.28c \times 0.5 = 1.4 \times 10^9\mathrm{cm}$$

where we have used the duration of the first U-burst and the speed of the beam in branch 1.

In order for the coronal plasma to be magnetically confined, the plasma parameter β, which expresses the ratio of thermal to magnetic pressures, has to be less than 1,

$$\beta = 3.47 \times 10^{-15} n_e T / B^2 < 1$$

we find that in order to confine the plasma contained in the coronal arch the magnetic field has to exceed 20 Gauss if we assume the temperature $T = 10^6$K.

5. Conclusion

Type IV solar radio bursts exhibit a wealth of well documented fine structures between 100 MHz and 1 GHz. The BAO radio spectrograph aims at carrying observations with high time and frequency resolutions at the higher frequencies where fine structures are still poorly known. In this paper we have described an observation by this instrument of a type IV-DCIM burst lasting more than one hour, between 3 and 4 GHz.

This event exhibits a remarkable fine structure which has a M appearance in dynamic spectra, we call it M-burst after we interpret it as an emission produced by a same electron beam, which is originally formed from the plasmoid–the source of this type IV-DCIM, moving along closed magnetic arch lines and mirrored. So the M burst is a new sub-class of type III bursts, however it is a fine structure of a type IV-DCIM burst.

In 1959, within a year of Boischot's classification of type IV bursts on the basis of their long durations, wide spectra and moving sources, Wild et al. (1959) classified type V bursts on the basis of their wide spectra, moderately long durations and association with type III bursts. On dynamic spectrograms they appear as diffuse continua following certain type III bursts or bursts groups. Since type V bursts are characterised by continuum emissions sometimes following type III bursts; Weiss

& Stewart (1965) suggested that type V bursts could be interpreted by several consecutive reflections on magnetic mirrors near the footpoints of magnetic arches. Hence it is natural that such a structure as a M emission would have been detected in a type V burst. Hovever, as mentioned above, this M burst is a fine structure of a type IV-DCIM burst. The type IV bursts are generally thought to be different from type V bursts in meter wavelengths. A major question that has to be clarified in the future is whether the type IV and type V bursts have some similar aspects. It would be important and interesting if this kind of structure is also detected in a type V burst.

Acknowledgements. We thank Debang Lao and Guo Yang for data processing; we also thank Dr. Yuying Liu, Huirong Ji, Leping Zheng, Congling Cheng, Zhijun Cheng, Wujing Lu and other staff of the BAO for operating the spectrometers properly. This work is supported by National Nature Science Foundation Projects 19773016, 19833050 and 19973008. We also acknowledge the referee, Dr. C.E. Alissandrakis for helpful comments to improve this paper.

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