EVOLUTION OF CORONAL mm-WAVE SOURCES

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Abstract

Coronal mm-wave emission at source heights up to the order 100 000 km above the photosphere are sporadically observed as off-limb sources by radio telescopes of medium angular resolution. Previous work showed that coronal mm-wave sources (CMMS) fall into different categories, e.g., explosive burst emission, post- and interflare radiation, and radiation from prominences. The source heights can be checked in the case of behind-limb sources. Systematic knowledge on the evolution of CMMS is still lacking. The present report discusses some general properties of CMMS and considers new observations from the Metsähovi Radio Research Station at 37 GHz of the year 1992 with respect to the effect of temporal evolution.

1. Introduction

Usually solar mm-wave radiation originates at heights of less than a few thousand km above the photosphere. Occasionally, however, solar mm-wave maps show the existence of off-limb sources indicating source heights of a few ten thousand km and more. These coronal mm-wave sources (CMMS) were firstly described in detail by Urpo et al. (1986a). Several years before, mm-radiation at a source height up to 200 000 km related to an Hα prominence was already noted by Kundu (1972). Flare-related rising motion at the solar limb at 17 GHZ and 35 GHz has been detected by Nakajima (1982) and Kato et al. (1982), respectively. Single isolated observations of solar CMMS of different nature have been obtained at several stations, e.g. Haystack, Hiraiso, Itapetinga, La Posta, Metsähovi, and Katsiveli. More systematic studies of CMMS have been made by Urpo et al. (1986b, 1989) and Krüger et al. (1989,1992). The spectrum of a CMMS was studied by Borovik et al. (1989). The aim of the present contribution is to outline briefly the characteristics of CMMS and to study different forms of appearance and time scales characterizing their temporal evolution.

2. Observations

The largest amount of observations of CMMS hitherto available was obtained at the Metsähovi Radio Research Station of the Helsinki University of Technology (HUT),Finland. The station has performed solar mm-wave observations with a radome-shielded 14 m single dish for more than 15 years. However, solar observations are not daily operating but obtained during observing periods of one to three weeks once or several times per year. The observing frequencies most commonly used are either 22 GHz, 37 GHz, or about 80 GHz. The angular resolution obtained at these frequencies is 4.0, 2.4, and about 1.0 arc minutes, respectively. The calibration of the measurements refer to estimated quiet Sun levels of 9000, 7800, and about 7200 K, respectively. Maps of the Sun are obtained by scanning the beam of the telescope in right ascension and changing the declination in small steps between subsequent scans.

Results of observations are regularly published in the HUT Metsähovi Radio Research Station Report Series A and technical descriptions in Report Series B.

3. General characteristics of CMMS

Comparisons with optical solar flare reports show that the CMMS preferably originate in flare-rich active regions. They are related either to the main flare phase (and thus are the signature of a mm-wave burst maximum) or, as found more frequently in sporadic observations, they are related to the post-maximum burst phase which can last several hours (cf. Urpo et al., 1986a, 1989). Besides the association with flares, CMMS have been found to be related to filament eruptions (Zodi et al., 1988), coronal mass ejections (CME) and solar noise storms (Krüger et al., 1989, 1992), and (inter-flare) S-component sources (Urpo et al., 1993).

Statistics have been made concerning the relationship to microwave bursts in the cm-wave range (Urpo et al., 1989). According to this investigation almost all CMMS were associated with (especially gradual) microwave burst emission whereas only less than 20 per cent of cases were related to great bursts. The brightness temperatures T_b at 37 GHz typically range between 8500 and 20000 K and are consistent with an exponential decrease of T_b after the time of a flare or burst start. There was found a certain (but statistically not significant) tendency of the source heights to increase and decelerate with time up to a saturation level which for many events is of the order 100 000 km above the photosphere. There is a correlation with soft X-ray long enduring events (LED) and in single cases CMMS are related to hard X-ray arches.

Spectral information on CMMS is still rather poor. From a study of RATAN-600 observations (Borovik et al., 1989) the brightness temperature can be approximated by a ν^{-2} law favouring an interpretation of the bulk of radiation in the cm-mm-wave range by optically thin thermal bremsstrahlung where average values $T_e = 10^7 K$, $N_e = 8 \times 10^9 cm^{-3}$, a source size of $(50 \pm 10) arc\ sec$, and a ray path inside the source $\Delta s = 5 \times 10^9 cm$ could fit the observations. At higher frequencies a possible contribution of optically thick radiation at medium temperature (about $10^4 K$) cannot be excluded. Information about the occurrence of CMMS at short mm-waves is still very rare. Until now they have been observed up to 87 GHz.

4. Time characteristics of CMMS

Coronal processes of solar activity are known to have quite different time scales. There are slowly developing features with time scales of several hours until days like LDE of soft X-rays and noise storms on the one hand, and many features of shorter time scales which are in particular connected with bursts and flares on the other hand. Correspondingly, coronal mm-wave emisison is also related to different time scales depending on its (sub)type:

(i) CMMS observed during the main phase of a flare or microwave burst frequently disappear with a time scale of the order of minutes.

(ii) CMMS with a time scale of a few hours are special post-flare events typically related to soft X-ray LDE and sometimes hard X-ray post-flare arches. Coronal mm-wave emission associated with filaments is expected to have similar time scales.

(iii) Sometimes time scales of CMMS of several hours and perhaps days are also indicated. It is thought that this radiation forms a "super-gradual" background emission which may be superimposed by individual flare events.

An example of mm-wave off-limb activity covering four days June 25 - 28, 1992 connected with AR 7205 is shown in Figure 1. This demonstrates the presence of CMMS of the above third category. A type IV burst occurred on 25 June 1992 at about 06 UT preceded and followed by high flare activity.

5. Discussion and conclusions

In the following we will restrict to CMMs of the above category (ii) and (iii), i.e. we will exclude immediate burst emissions. As shown by Krüger et al. (1989, 1992) such sources are typically associated with X-rays and noise storms. Hard X-ray arches and CMMS have comparable source heights, while noise storms, depending on frequency, are extending into much greater coronal heights. Taking into account the relative positions of the X-ray arches and of the sources of type I noise storms at different frequencies as measured at Culgoora cf., e.g., Švestka et al. (1982), it can be concluded that the CMMS are located relatively deep near the foot points of giant magnetic loop systems forming the big area of noise storms or even coronal mass ejections .

In summary, CMMS indicate temporal enhancements of the electron density in the corona above flare-rich active regions. They coexist with post-flare arches in X-rays and form the base of noise storm regions. CMMS can be used for diagnostics of flare-active regions when appearing at the east limb of the Sun. As to be concluded from their lifetime, except for main-phase burst sources, CMMS indicate the presence of closed magnetic loop structures. Since CMMS are often related to CME events, they are likely to indicate the roots of dynamical processes taking place at higher coronal levels. There is a need for observing these structures with higher spatial resolution.

Acknowledgements: The present work was supported by a grant of Deutsche Agentur für Raumfahrtangelegenheiten (DARA) No. 50 QL 9208 5.

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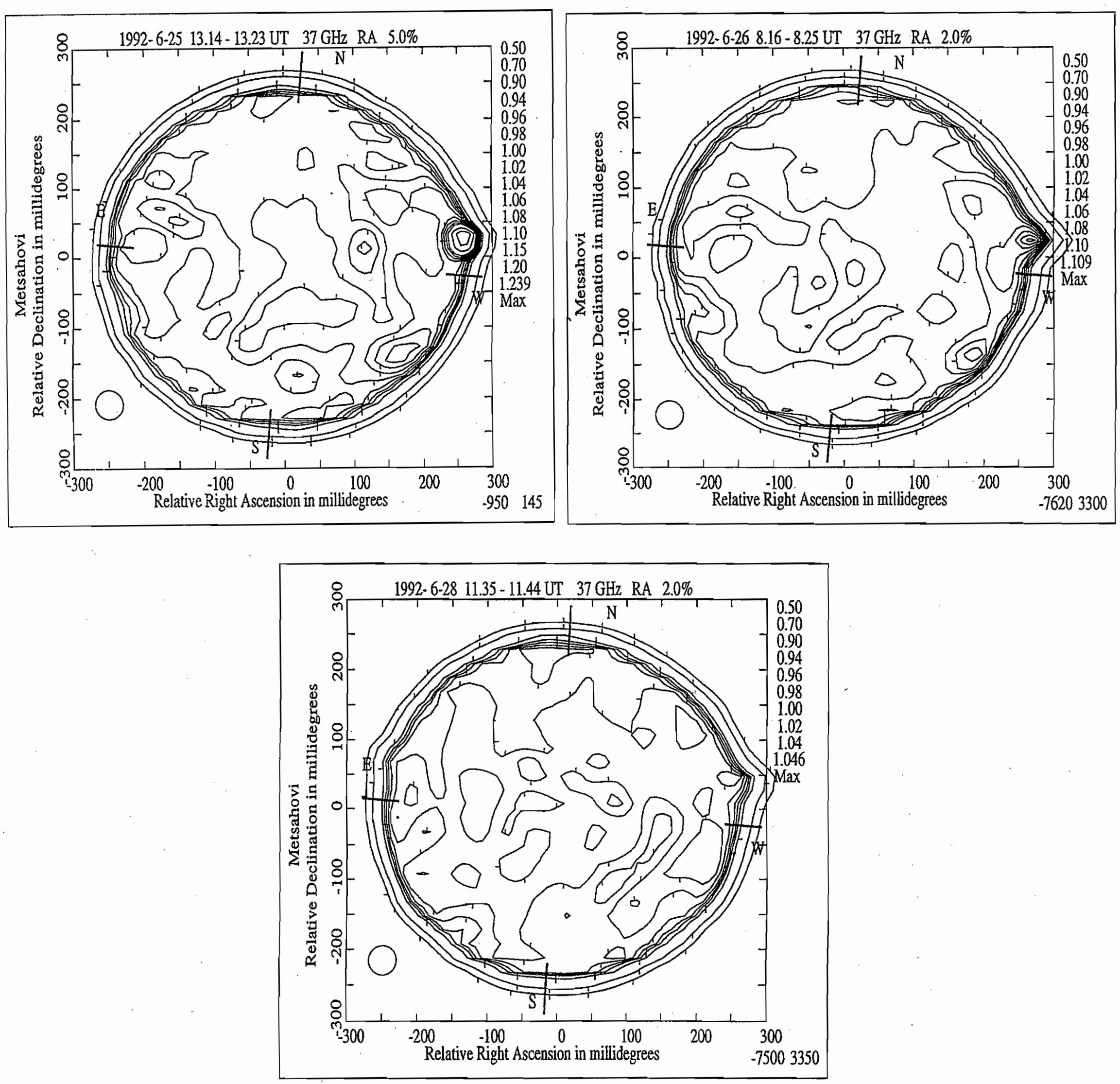

Fig. 1: Solar maps at 37 GHz on 1992 June 25, 26, and 28 showing the presence of off-limb CMMS over a period of four days.