Solar Millimeter Wave Bursts

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Abstract: Some observational results and statistical characteristics of solar millimeter wave bursts observed by employing the 35 GHz solar interferometer in Nagoya are briefly described.

1. Introduction

Continuous observations of radio events at 35 GHz have been carried out at the Department of Physics and Astrophysics, Nagoya University, by employing a full disk fanbeam interferometer from September 1970 through July 1974 and from May 1976 through July 1983. The longest baselines were 819 wavelengths from September 1970 through March 1971, 1911 wavelengths from April 1971 through July 1974, and 5849 wavelengths from May 1976 through July 1983, respectively. The performance of the interferometer has been described in Kawabata et al.(1974) and Kawabata et al.(1982a). In these periods, we have observed about four hundreds and fifty radio events. We summarize main features of solar millimeter wave bursts obtained by these observations.

2. Summary of Investigations on Individual events

As is well known, microwave bursts can be classified to non-thermal and thermal bursts. It has been well established that hard X-ray bursts in solar flares show close agreements in time profile with non-thermal centimeter wave bursts(Kundu,1961). Many authors have discussed the temporal and spectral behavior of microwave and X-rays to test a theory that both emissions are produced by the same electron population(eg. Wiehl et al.,1985). The agreements in time profile between γ-ray and non-thermal millimeter wave bursts have been also shown (Kawabata, et al., 1982b). These characteristics can be interpreted by the gyrosynchrotron theory of centimeter and millimeter wave bursts(eg. Bai and Ramaty,1979). Kawabata,Suzuki,and Ogawa(1983) have shown quantitative agreements between the time profiles of X- and γ-ray intensities and 35 GHz flux densities by using Hinotori observations of soft and hard X-ray images, highly ionized iron lines around 1.85A, hard X- and γ-ray counting rates, interferometric observations at 35 GHz, and magnetic fields in corona from magnetographs for the event on 13 May 1981. Kawabata et al.(1982b) have also showen that millimeter wave bursts are composed of a radio source at the top of arcade and a foot point near a sunspots. Wang et al. (1987) have obtained the similar results but the radio source near a sunspot is weak and is appeared only in the early phase of the flare for the flare on 30 March 1982. These investigations indicate that fully developed millimeter wave bursts are composed of a radio source at a sunspot and that at the top of an arcade. Our interferometric observations indicate that solar millimeter wave bursts are mostly single source within the 30 arcsecond resolutions. Double source events described above are rare exceptional cases. It has been also shown that even solar flares over the limb accompany millimeter wave

bursts and millimeter wave bursts near the limb show ascending motions (Kawabata et al. 1980b, Kato et al., 1982).
Thermal microwave bursts are associated with thermal X-ray flares (Kawabata, 1960,1963, and 1966). Interferometric observations (Kawabata et al., 1982a, and Wang et al. 1982) show post-burst increases also occur at the top of arcade. One of GRF associated with highly ionized iron lines around 1.85A observed by the satellite Tansei has been identified in location with an Hα flare kernel (Kawabata et al., 1980c).

3. Spectra of Microwave Bursts in Millimeter Wave Range

The ratio of the peak flux densities at 35 GHz F_{35} to those at 17 GHz F_{17} varies from 0.1 to close to unity. The typical value of the ratio F_{35}/F_{17} is about 0.3. The results indicate that the radio sources of non-thermal microwave bursts are optically thin in the frequency range above 35 GHz. Therefore, statistical investigations of microwave bursts in millimeter wave range gives direct information on the distributions of energetic electrons.
The peak flux density ratio F_{35}/F_{17} are 0.1-3 for GRF and 0.5-2 for post-burst increase, respectively.

4. Center-To-Limb Variations of Occurrence Frequencies

A statistical investigation shows that the distribution of occurrence frequency of non-thermal millimeter wave bursts in longitude reckoned from the central meridian is flat from the central meridian to the limb. On the other hand, the occurrence frequency of millimeter wave GRF has flat distribution up to 80° from the central meridian but decreases rapidly towards the limb.None of GRF are observed beyond 85° from the central meridian. Such a decrease of occurrence frequency of GRF can be interpreted by absorptions of radio emissions by spicules. Interferometric observations of the quiet sun at 35GHz (Kawabata et al. 1980b) indicate that the radio limb at the frequency is located at 1.015 solar optical radii. The radio emission of the quiet sun outside the optical limb can be interpreted by emissions from spicules. The observation indicates that spicules are opaque up to the height of 10,000 km above the photosphere. These investigations show that GRF are emitted from radio sources located below 10,000 km above the photosphere. The flat distribution up to the limb and association with flares over the limb of non-thermal bursts indicate that these bursts are emitted from radio sources at the height more than 10,000km above the photosphere. These investigations suggest that most of non-thermal millimeter wave bursts are emitted from top of arcade.

5. Recurrence Tendencies

Recurrence tendency of millimeter wave bursts are also investigated by the Chree's superposing epoch method. In this analysis, we have used the date of the central meridian passage of the location of flares. We can find an indication of the recurrence of millimeter wave bursts at the same heliographic longitude after 4 to 5 rotations, as is shown in Figure 1. It is remarkable that the probability of occurrence of non-thermal millimeter wave bursts 4 solar rotation periods after the epoch is higher than the one 27 days after the epoch. The similar periodicity

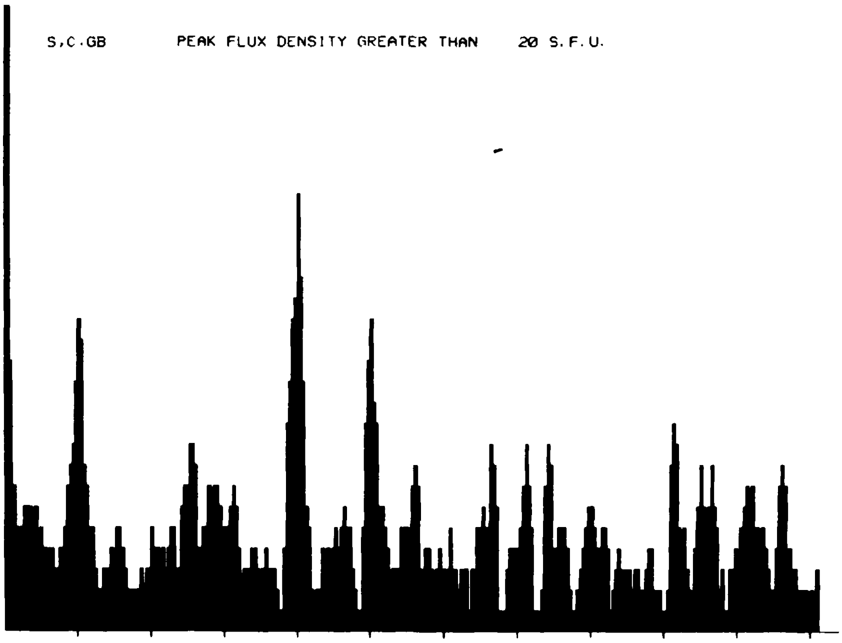

Figure 1. Chree's superposing epoch diagram for non-thermal millimeter wave bursts. The abscissa is the number of days after epoch. Intervals between marks are 27 days. Epoch are the date of central meridian passage of associated flares.

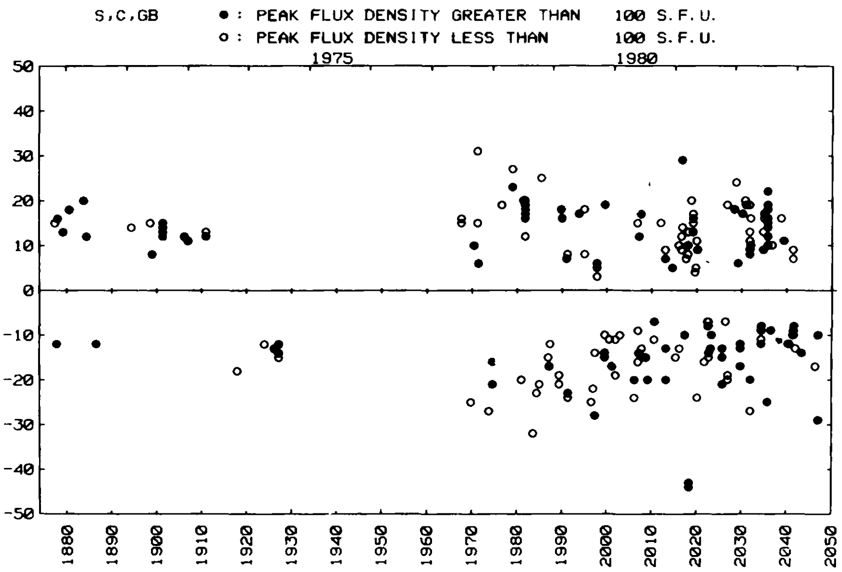

Figure 2. 11 year variations of latitude of millimeter wave bursts. The abscissa are years. Numerals at the bottom mean the Bartels rotation numbers. The ordinates are the latitude of millimeter wave bursts in degrees.

has been already reported by Rieger for γ-ray bursts, but with a different period.

6. 11 Year Latitude Variation

A diagram, showing the 11 year variation of the latitude of solar flare producing 35 GHz bursts similar to the butterfly diagram for sunspots, indicates that the most of solar flares producing 35 GHz bursts are located at the latitude below 20° , as is seen in Figure 2. Exceptions are only two events in April, 1981. Even millimeter wave bursts occured in the early phase of a solar cycle are associated with sunspot groups at the low latitude. The feature is more pronounced for intense bursts. Since millimeter wave bursts are produced only by relativistic electrons, we can expect that relativistic electrons can be accelerated only in sunspot group at low latitude. We can not find any evidence of migration of flares toward equatorial zone in a sunspot cycle similar to the butterfly diagram for sunspots. The characteristics appears to be connected with the delay of the maximum of the number of millimeter wave bursts per year after the sunspot maximum.

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