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MICROWAVE BURSTS AND CORONAL MASS EJECTIONS

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The general relationship of coronal mass ejections (CMEs) with flare activity is of great interest. Up to now the association of CMEs with soft X-ray bursts has been mainly analyzed (see Kahler et al. (1989) and references therein). In the present report the relationships of CMEs and microwave bursts will be discussed. I shall outline some results of our recent investigations (Chertok et al., 1990). Then short comments will be given on the possible use of the micrоwave high-resolution radioheliograph observations for study of the CMEs and related phenomena.

An important point of our analysis is that the combination of the absolute peak flux density (S) and the effective duration (d) at the half peak flux level is taken as a main characteristic of radio bursts. We used the data on about 60 P78-1 SOLWIND CMEs which according to Sheeley et al. (1984, 1985), Kahler et al. (1984), Cane et al, (1987), and so on are identified with flares on near-limb helilongitudes $|l| \geq 45^\circ$ as well as the data on about 20 flares those are not accompanied by CMEs.

The analysis reveals that the location of events on the S-d-plot allows not only to separate flares with CMEs and ones without CMEs but to determine the relations between characteristics of microwave bursts and such parameters of CMEs as angular sizes, speed, mass, shape. As an illustration the S-d-plot is shown in Figure 1 where the events with large, average, and small angular sizes as well as the events without CMEs are marked by different signs. One can see that microwave events of two qualitatively different types are associated with CMEs: (1) large non-impulsive bursts with $S \simeq 10^2$-$4\ 10^4$ s.f.u. and $d \simeq 2$-20 min; (2) prolonged "gradual rise and fall" (GRF) bursts with $S \simeq 6$-100 s.f.u. and $d \geq 20$ min.

Moreover, the definite zones may be distinguished on the S-d-plot in which CMEs with different angular sizes ($\Delta\Theta$) are concentrated. The majority ($\simeq 80\%$) of large CMEs with $\Delta\Theta \geq 60^\circ$ are observed in combination with the most intensive ($S \geq 4\ 10^2$-$5\ 10^3$ s.f.u.) and long-duration ($d \geq 2$-4 min) radio bursts. In the intermediate burst zone ($S \simeq 10^2$-$5\ 10^3$ s.f.u. for $d \simeq 2$-4 min and $S \simeq 10^2$-$4\ 10^2$ s.f.u. for $d > 4$ min) and GRF-zone the CMEs of average sizes ($\Delta\Theta \simeq 30$-60°) predominate. The impulsive burst zone ($d \lesssim 2$ min) may be characterized as one of events either without CMEs or with CMEs of small sizes ($\Delta\theta \lesssim 30$-40°).

Besides angular sizes, the analogous separation takes place also for other parameters of CMEs on the S-d-plot (Figure 2). In the zone of the intensive non-impulsive bursts, the CMEs of complex shapes (filled loops, curved front, remnants), high speed ($v \geq 1000$ km/s) and big mass ($m \geq (8$-$12)\ 10^{15}$ g) are mainly observed. For the intermediate burst and GRF zones the CMEs of simpler shapes (spikes, fan), average speed ($V \sim 400$-1000 km/s) and moderate mass ($m \sim (1$-$10)\ 10^{15}$ g) are typical. As for as several CMEs associated with sufficiently intensive impulsive bursts are concerned they have

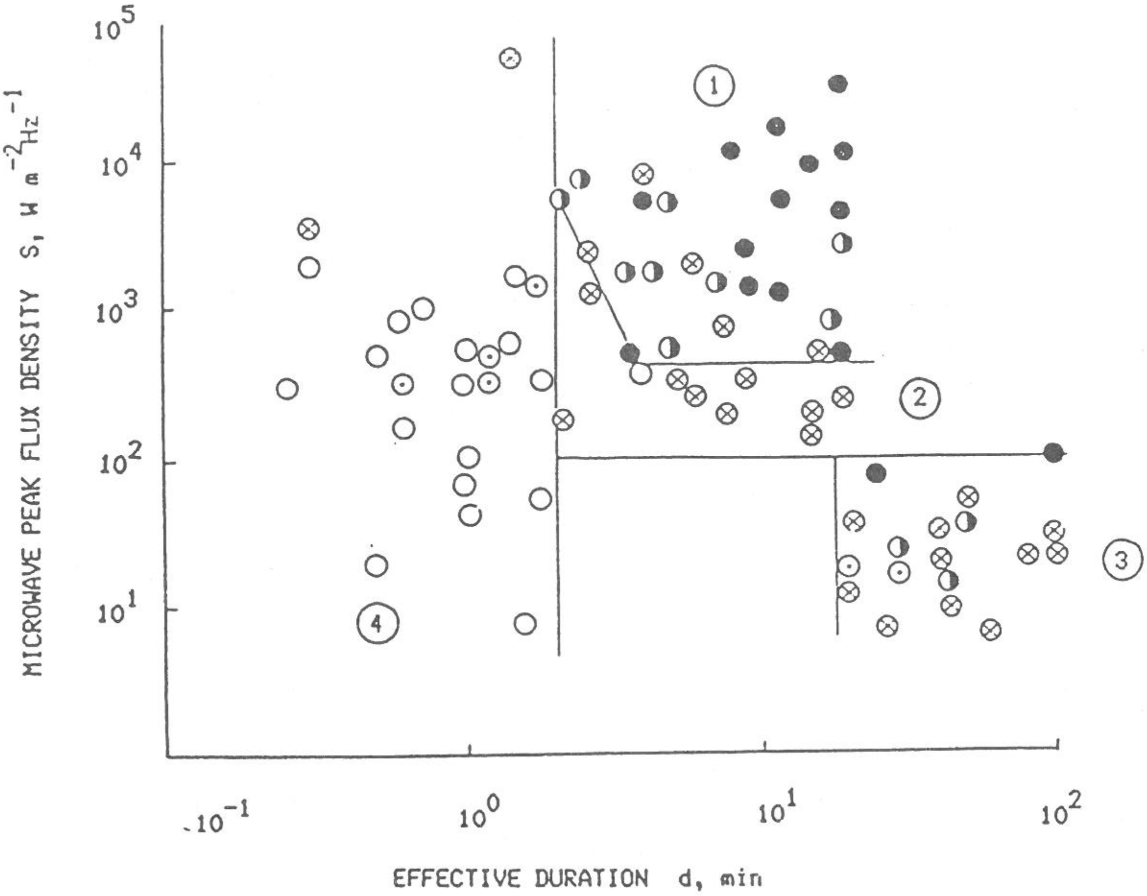

Fig 1. - Scattered S-d-plot showing the relation between microwave burst properties and angular width of corresponding CMEs: ● - very large (≥90°), ◑ - large (60-90°), ⊗ - average (30-60°), ⊙ - small (≤30°) CMEs; O -events without CMEs. Lines mark the conditional zones of intensive (1), moderate (2), GRF (3), and impulsive (4) radio bursts.

as a rule the simple shape, moderate speed (V ≃ 400-900 km/s) and mass ($m < 8\ 10^{15}$ g).

The similar regularities are obtained when the combination of the intensity and whole duration of soft X-ray bursts is used instead of the radio parameters S and d (Figure 3).

Thus, the results described above mean that there is a wide spectrum of events with the different correlation between the eruption of CMEs and flare or flare-like energy release, but this correlation discovers a definite reflection in characteristics of microwave and soft X-emission. Such reflection is possible both when the ascending CME initiates a flare and when on the contrary the eruption of CME is stimulated by the flare energy release. In the majority of confined (impulsive) flares the energy release happens without visible CME in general. The magnetic field reconnection may be initiated by other phenomena such as the emergence of a new magnetic flux, the interaction of magnetic loops and so on.

On the other hand, the CME eruption may be a consequence of a disappearance of the equilibrium of existing coronal structures (Wolfson and Gould, 1985; Low, 1986). According to Harrison et al. (1990), the eruption of CME starts often before the impulsive phase

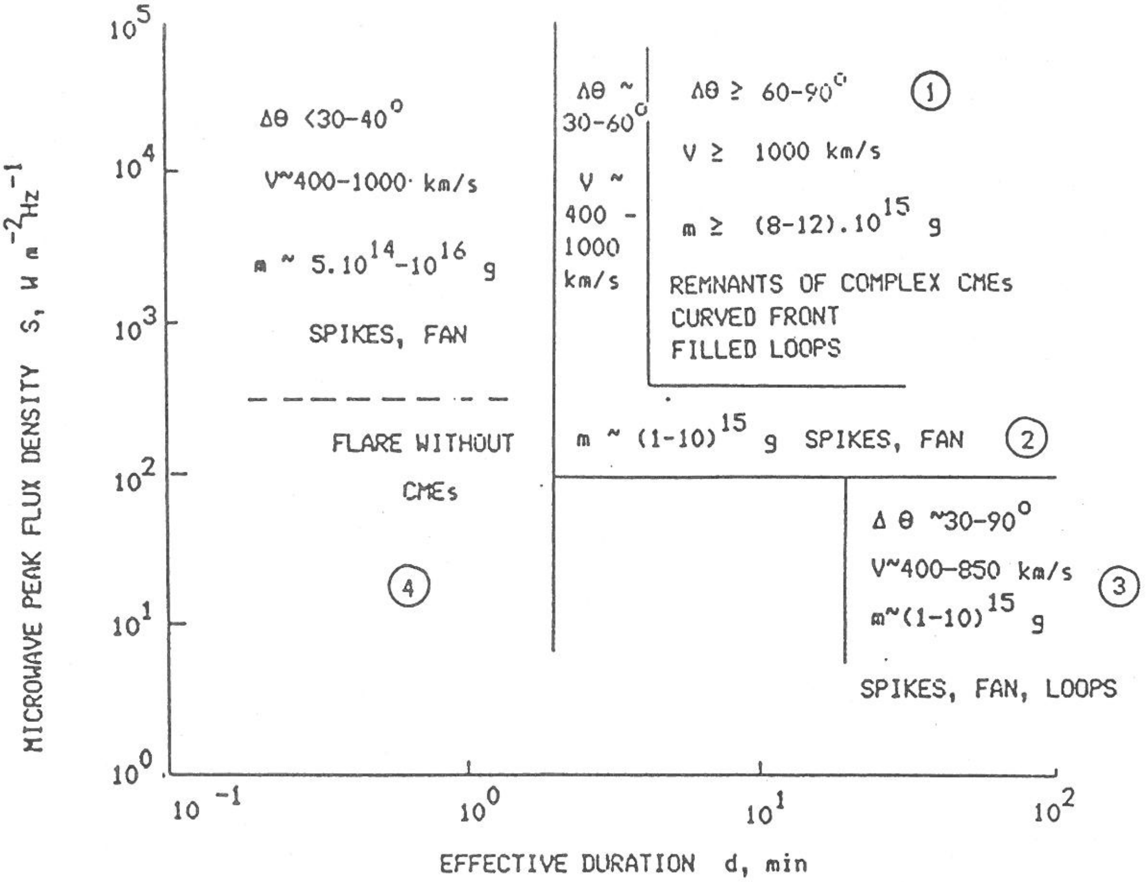

Fig. 2. - Summary of the correlation between the microwave bursts and the characteristics of CMEs. The zones of intensive (1), intermediate (2), GRF (3), and impulsive (4) radio bursts are indicated.

of the flare which takes place then near one of legs of the transient loop. However such a situation seems to be typical for relatively small flares. In large flares with the developed spatial-time structure the more complicated relationship between CME and flare takes place accompanied by the multiple energy release in different parts of the magnetosphere above active region. In such cases the observed dependence between parameters of microwave bursts and CMEs reflects the fact that the eruption of large, massive and fast CME combines with the powerful, long energy release including the numerous particle acceleration. In different eruptive events, the prolonged energy release at the stage of the postflare loop formation, when the magnetic field disturbed by the CME recovers to its initial state, can give an additional contribution to the relation under consideration (see Anzer and Pneumann (1982), Kahler (1984), Cliver et al (1986), Kai et all. (1986)).

However, the eruption of CMEs including average or even large ones not always results in the explosive energy release. When there are not suitable conditions in the active region, the eruption of prominence and ascent of CME lead rather to the prolonged heating of a large plasma volume in the low corona and generation of GRF radio emission than to the particle acceleration.

The data indicated above reveal also that the various shapes of CMEs observed with the white-light coronagraphs reflect the real physical differences of events but are not consequence of geometrical or other analogous factors.

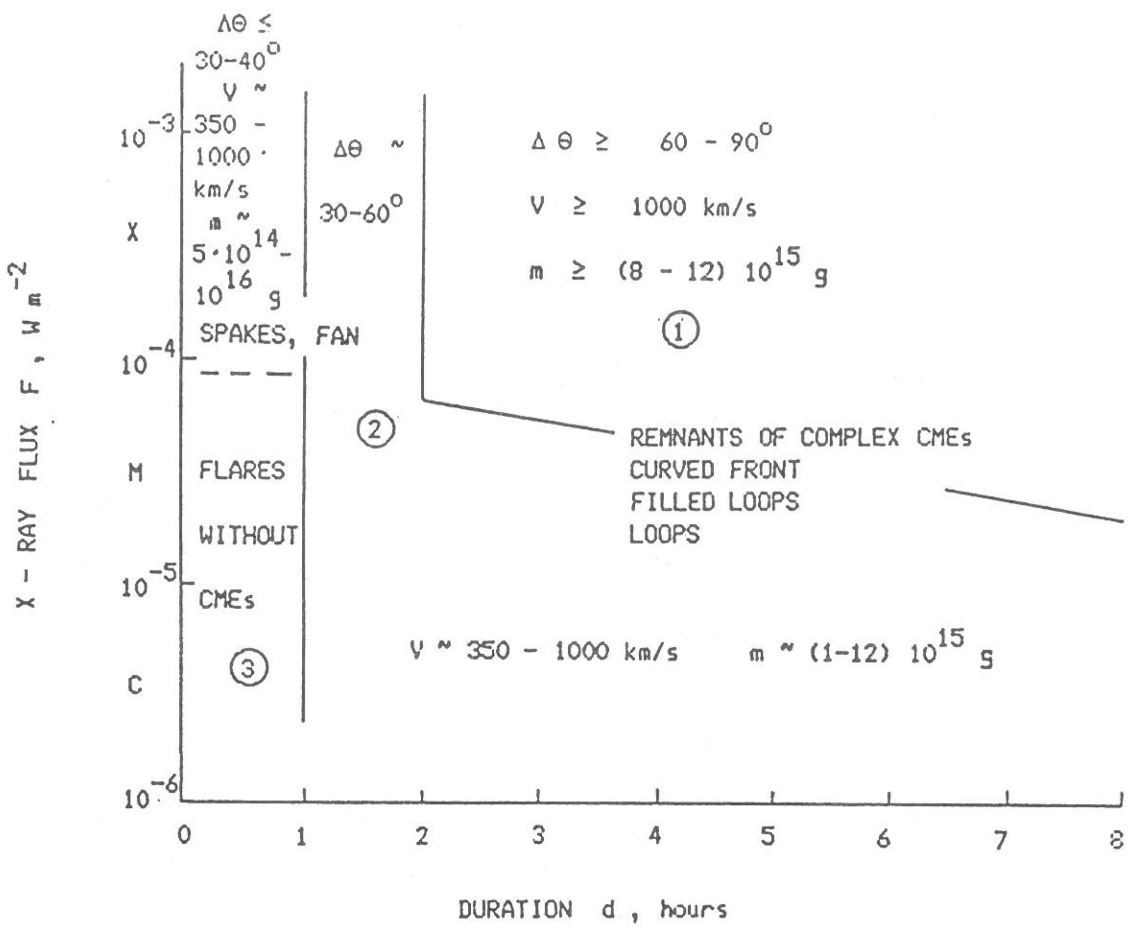

Fig. 3. - Summary of the correlation between the soft X-ray burst parameters and characteristics of CMEs. The zones of intensive and long-duration (1), moderate (2) and impulsive (3) soft X-ray bursts are indicated.

The close dependence which according to the present analysis exists between parameters of microwave (soft X-ray) bursts and CMEs should be taken into account in models ofthe CME eruption. Simultaneously it can be used for the electromagnetic diagnostics of flares causing interplanetary disturbances and geomagnetic storms.

It is obvious that the high-resolution microwave observations, in particular with new Nobeyama radioheliograph, in combination with other ground-based and space measurements, can give very important data for detailed investigations of the flare processes and related events taking place during the different stages of the CME eruption. In particular the following topics may be mentioned:

a) Evolution of the magnetic field and corresponding radio emission accompanying the disappearance of filaments both inside and outside active regions.

b) Overall study of the flare precursors, their relationships with the CME eruption and explosive energy release.

c) Location, dynamics, relation to primary energy release, and other features of the radio sources in quasi-impulsive and prolonged flares connected with different CMEs.

d) General characteristics and peculiarities of the radio emission during the ascension of CME, reconstruction of the coronal magnetic field and its restoration to the initial state.

c) Detailed investigations of the "gradual rise and fall" radio emission which is an indicator of the origin of many CMEs.

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Harrison, R.A., Hildner E., Hundhausen A.J., Sime D.G., and Simnett G.M.: 1990, J. Geophys. Res., 95, 917.
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Howard et al. (1985)

SOLWIND coronagraph

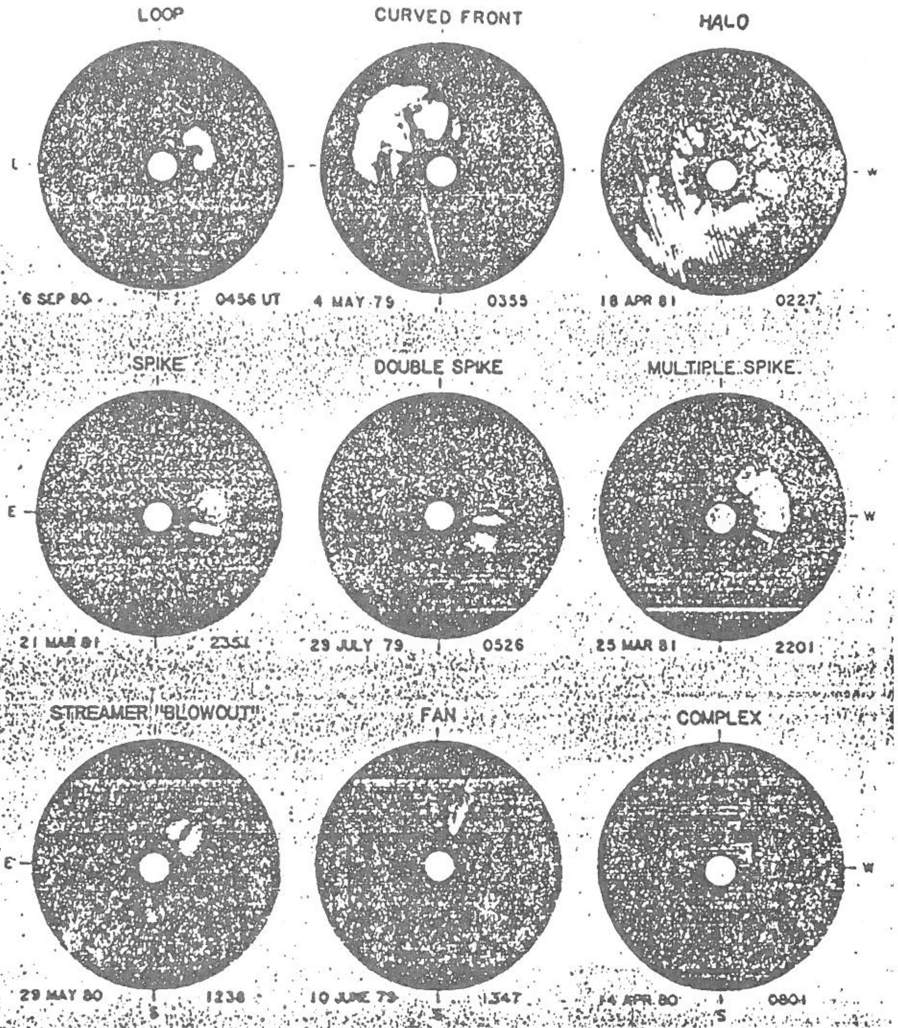
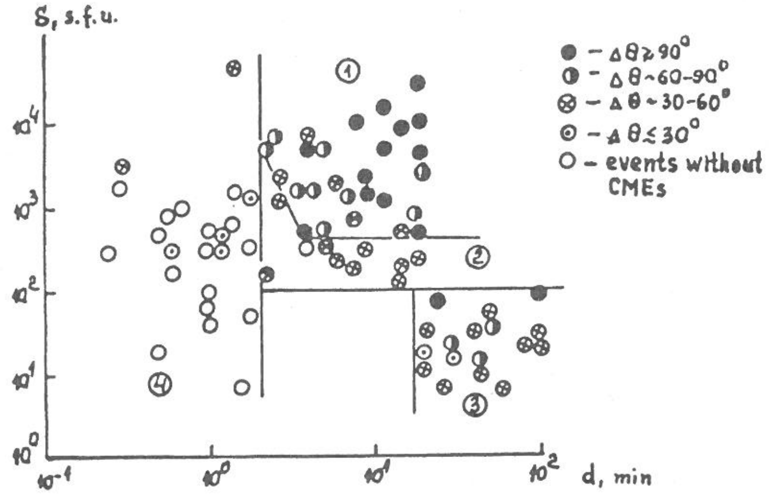


Fig. 1. Coronal difference images illustrating nine of the 10 structural classes of coronal mass ejections discussed in the text. The difference images are constructed by subtracting a preevent coronal image from the image taken at the date and time indicated below each image. The field of view extends from 2.5 to 8 $R_{\odot}$.

CMEs and soft X-ray bursts

X-ray burst duratin – decisive parameter Sheeley et al. (1983) Kahler et al. (1989)

S-d-plot of microwave bursts and angular sizes of CMEs (Δ



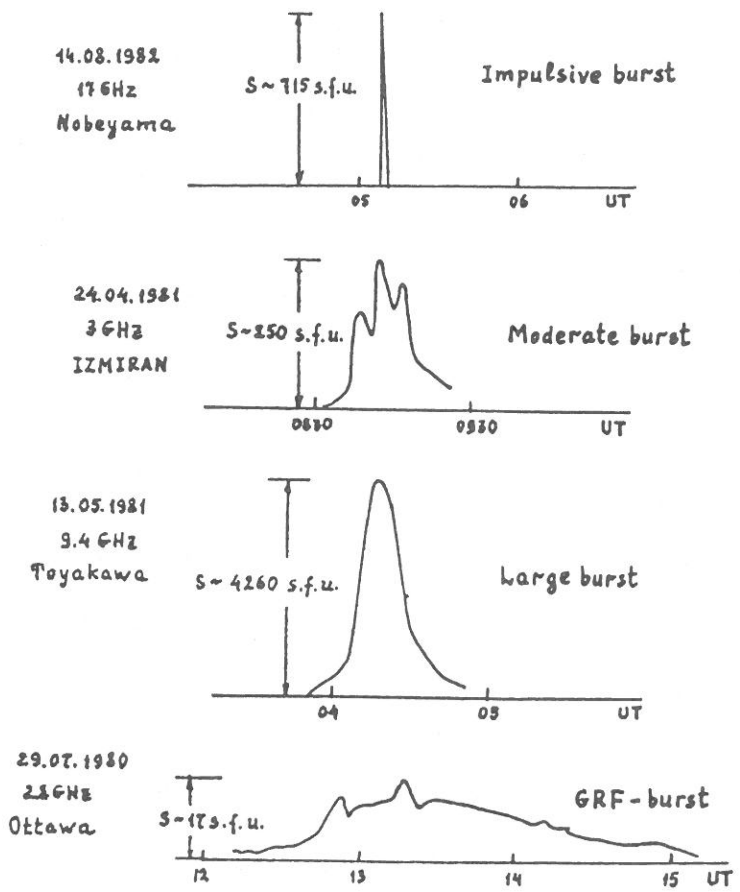
Events with CMEs: – large ($S>10^2$ s.f.u.) non-impulsive ($d>2$ min) radio bursts;
– "gradual rise and fall" (GRF) bursts.

① – Large, long-duration bursts $S>4\cdot10^2-5\cdot10^3$ s.f.u., $d>2-4$ min — ~80% CMEs with $\Delta\theta\gtrsim60-90°$ (~50% CMEs with $\Delta\theta\gtrsim90°$)

② – Intermediate burst zone S to 10^2 s.f.u. — CMEs with $\Delta\theta$~30-60°

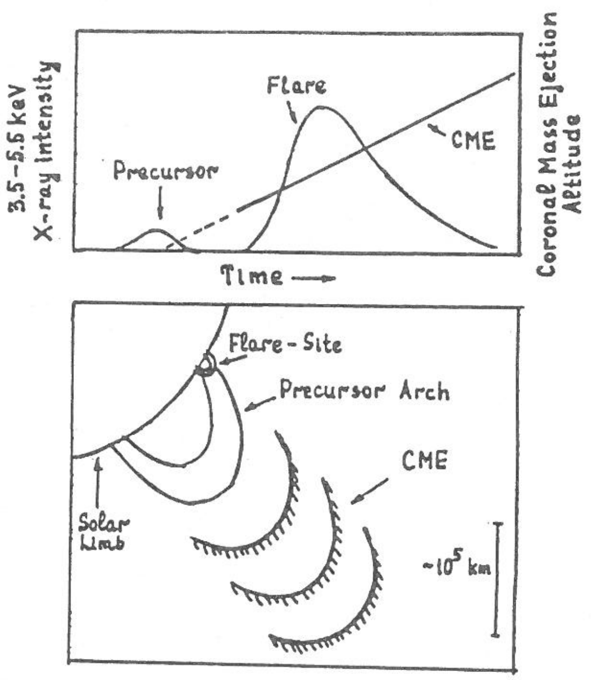
③ – GRF-burst zone $S<10^2$ s.f.u., $d\gtrsim20$ min — CMEs with $\Delta\theta$~30-90°

④ – Impulsive zone ($d<2$ min) — Flares without CMEs
Most intensive $S>250$ s.f.u. — CMEs with $\Delta\theta<30-40°$



CME, Precursor, Flare

Harrison et al. (1985, 1990)



X-ray precursors: Charikov and Pharaphonov (1984); Tappin (1990)

Microwave radio precursors: Kai et al. (1983); Tikhomirov et al. (1987)

CMEs and microwave bursts

Chertok, Gnezdilov, Zaborova (1990)

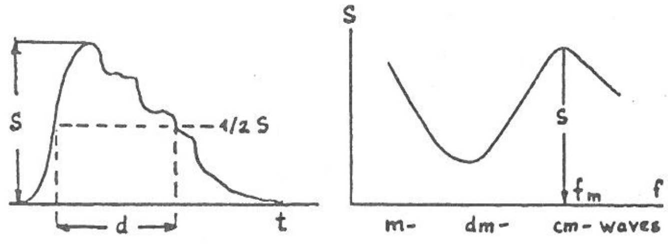
CMEs: P78-1 satellite-coronagraph SOLWIND, 1979-1982

- CMEs from near-limb flares $|\ell| \gtrsim 45°$
- flares without CMEs

Sheeley et al. (1984, 1985)
Kahler et al. (1984)
Cane et al. (1987)

Microwave bursts:

combination "intensity S – effective duration d"



Time-intensity profile

Frequency spectrum of the burst

S – absolute peak flux density at $f \gtrsim 3$ GHz
d – effective duration at the level 1/2 S

On the S-d-plot: —— zones of CMEs with different parameters (angular sizes, speed, mass, shapes)
—— flares without CMEs

POSSIBLE TOPICS FOR STUDY OF DIFFERENT STAGES
OF THE CME ERUPTION AND RELATED PHENOMENA
BY THE HIGH-RESOLUTION MICROWAVE RADIOHELIOGRAPH
(in combination with other ground-based and space measurements)

— Instability and disappearance of filaments (prominences) both inside and outside active regions;

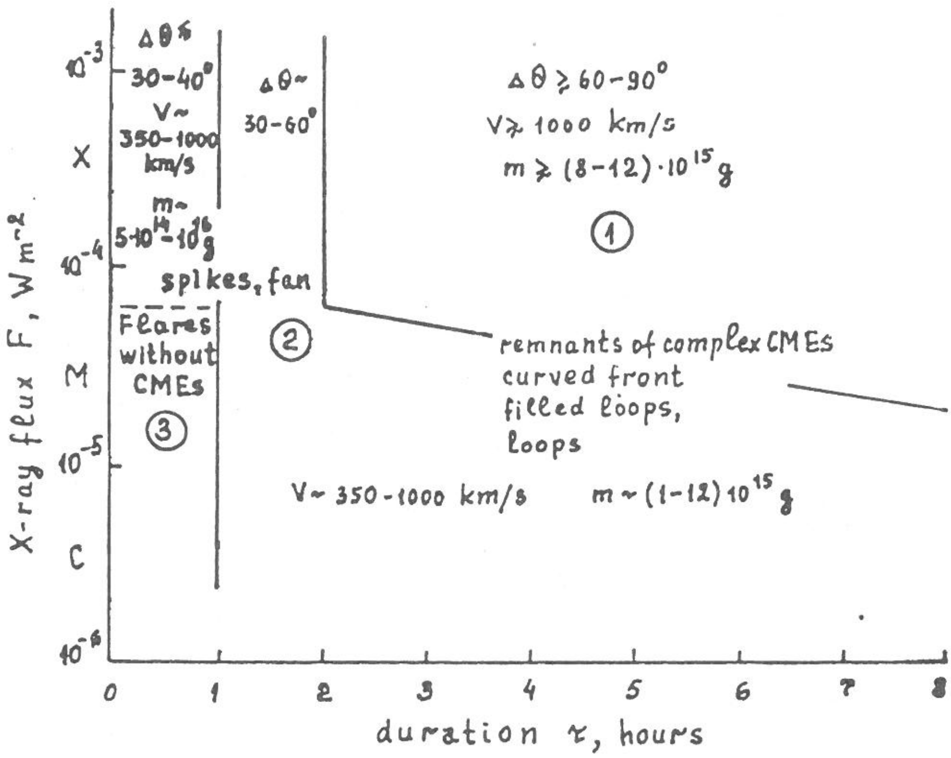
— Flare precursors;

— Quasi-impulsive and prolonged flares with different CMEs;

— Radio emission during the ascension of CME, reconstruction of the coronal magnetic field and its recovery to the initial state;

— "Gradual Rise and Fall" emission as an indicator of many CME eruptions

Soft X-ray bursts — parameters of CMEs
1-8 Å

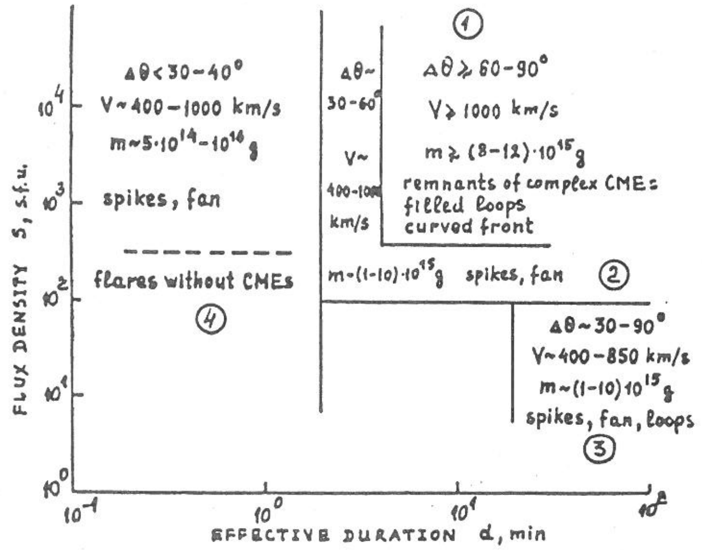


① - zone of large, long-duration bursts (LDE)

② - intermediate burst zone
LDE - bursts of moderate intensity

③ - impulsive zone

Microwave bursts — parameters of CMEs



① - zone of large, non-impulsive bursts
② - intermediate burst zone
③ - GRF-zone
④ - impulsive burst zone

Wide spectrum of events with different relationships between the CME eruption and flare energy release —— Definite reflection in characteristics of microwave (soft X-ray) bursts

Eruption of CME ⇄ impulsive energy release

Confined impulsive flares without CMEs —— impulsive bursts

Low (1986): disappearance of the equilibrium of the coronal structures ⟶ eruption of CME

Harrison et al. (1990): - eruption of CME before the impulsive phase;
- flare occurs then near one leg of the transient loop

Relatively small flares?

Moderate and large flares: complicated relation between the CME and flare

Large CME —— multiple powerful energy release, numerous particle acceleration —— intensive, long-duration microwave bursts

Eruption of CME without explosive energy release —— Prolonged heating of the coronal plasma (small acceleration) —— gradual rise and fall burst (GRF)

Additional contribution: long-duration energy release on the stage of the restoration of the coronal magnetic field after propagation of the CME

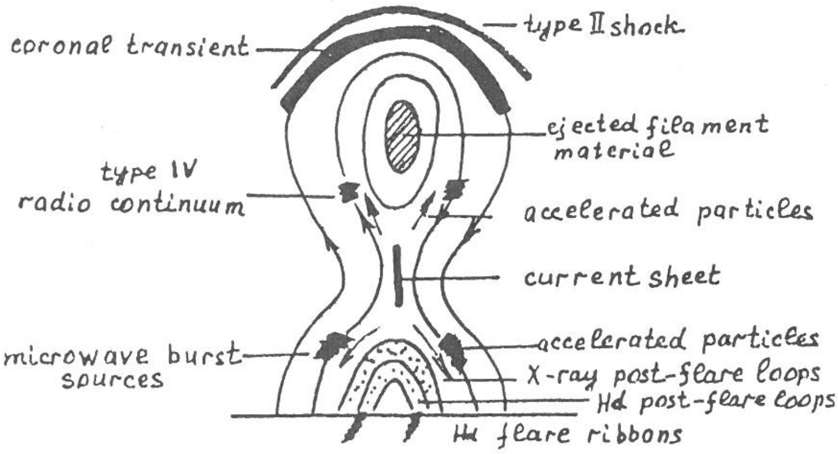
CMEs of various shapes —— real physical differences of events

Base for electromagnetic diagnostics of flares causing the interplanetary disturbances and geomagnetic storms

— CME eruption;
— reconstruction of the coronal magnetic field;
— restoration of the magnetic structure to its initial state;
— magnetic reconnection in the vertical current sheet;
— prolonged energy release and long-duration particle acceleration;
— formation of post-flare loops;
— elevated coronal sources of gradual and extended microwave and millimeter radio bursts, long-duration X-ray events (LDE)

Tsuneta et al. (1982)
Takakura et al. (1982)
Kahler (1984)
Cliver et al. (1986)
Kai et al. (1986)
Tanaka (1986)
Moiseev, Nesterov (1986)
Urpo (1988)
Kruger et al. (1989)

Koop, Pneuman (1976); Anzer, Pneuman (1982); Martens, Kuin (1989)



— Surplus and delayed >10 MeV proton fluxes in the interplanetary space from extended flares with soft radio spectrum ($f_m \approx 3$-5 GHz)

Chertok, Fomichev (1989)
Bazilevskaya et al. (1990)