Solar origin of SEP events and dynamical behaviour of the corona

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We review what we learnt on the origin of energetic electron events from joint observations made with ACE, WIND, ULYSSES (ULS), imaging instruments on SOHO, radio spectrographs and the Nançay Radioheliograpgh (NRH). ULS and ACE provided for a very few events stereoscopic observations and showed the effects of particle propagation. The main limitations of these studies   were the low cadence of the imaging instruments on SOHO and the lack of stereoscopic observations.

The September-October 1999 period (Period of rather quiet activity. No significant solar X-ray flare)

Type III storms detected in the high corona and in the IP medium are long lived features associated with type I storms produced in the corona at metric wavelengths (Bougeret et al., 1994). Noise storms (NS) are due to electrons accelerated quasi continuously and are commonly observed by the Nançay Radioheliograph (NRH).

During this period, ULS was magnetically connected to the solar disk visible on Earth. ULS and ACE were not located on the same IMF line. Not all the anisotropic events were observed by the two spacecrafts. This is illustrated for the 5-9 September period. The origin of a persistent anisotropy seen by ULS (and not by ACE) is associated in space and time with coronal bursty activity detected by the NRH. The radio source is located at the foot of the IMF line connected to ULS.

Moreover, during the same period, the two spacecrafts ULS and ACE detected a long duration event characterized by comparable isotropic electron intensities. This is consistent with the concept of a reservoir of seed population (Roelof et al., 92) associated at the sun with the source of a noise storm lasting several days.

<u>November 28 1997, series of highly-collimated electron-events</u>

A close association is found between three successive energetic electron events, three interplanetary type III bursts packets, and three packets of metric type III bursts. For each of these three events, a first group of short bursts lasting from one to two minutes is followed by a second group 4-5 minutes later. The source on the sun is located at a longitude consistent with the foot of the IMF line connected with the electron events.

For the strongest electron event, the dispersion of the onset time versus energy shows that electrons with energies below 60 keV may be understood as released at the sun during the occurrence of the first type III group. Electrons with energies above 100 keV require a release time a few min later, compatible with the occurrence of the second type III burst group. These observations show that the origin of these higher energy electrons energies is in the LOW corona.

Events associated with large scale restructuring of the magnetic field. The July 14, 2000 flare/CME event

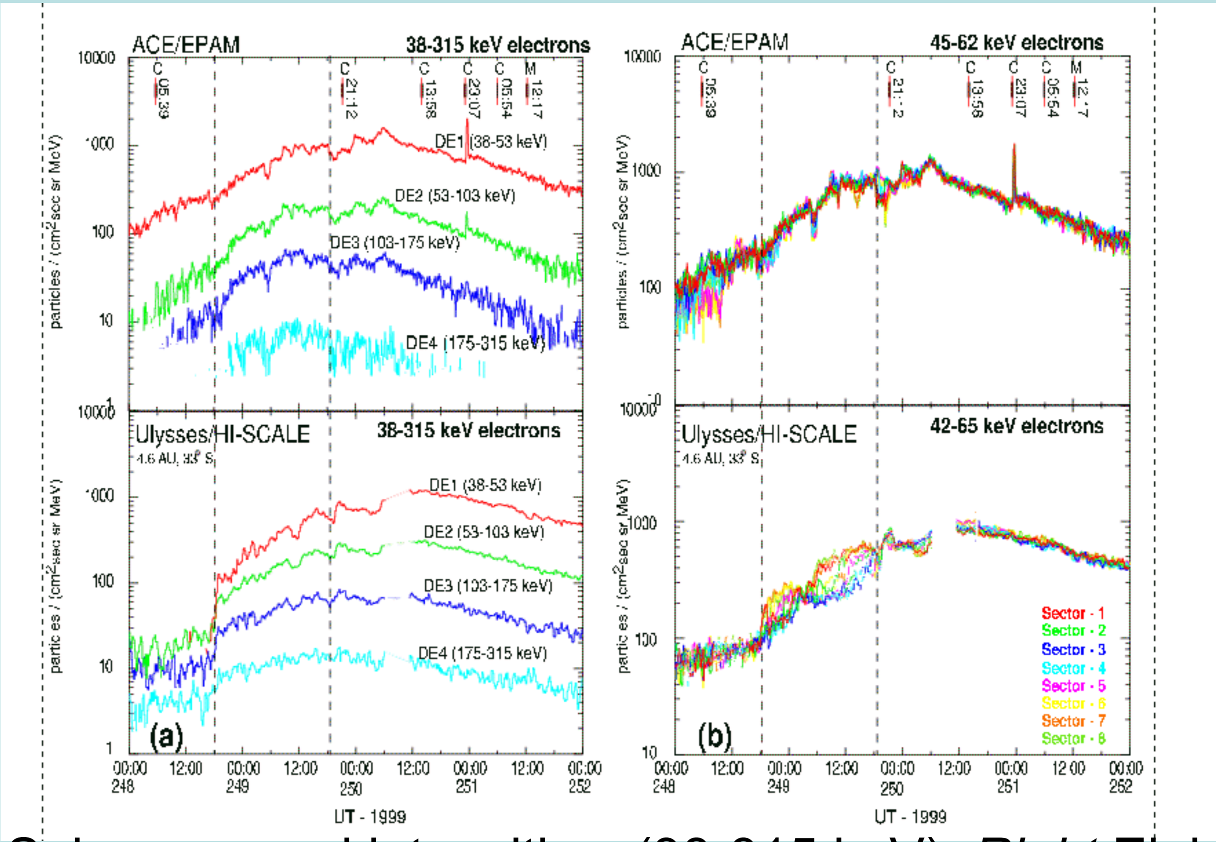
Fast CMEs originate from a small coronal region in the vicinity the flare site and expand, by successive loop interactions, at larger and larger distances from the flare site, which leads to the opening of the coronal magnetic field. Signatures of these interactions are detected in radio under the form of a non-thermal emission. These emissions (coronal type II like burst) follow quite closely in position and time the angular spread of the CMEs which reach their full extend in a few minutes. This implies that their lateral expansion is associated with a fast disturbance (Moreton wave) with a typical velocity in excess of 1000 km/sec (e.g. Pojholainen et al., 2001; Maia et al., 2001). During the Bastille flare event, the onset of the anisotropic electron event detected by ACE coincided in time with the appearance of several radio sources seen in the **western** hemisphere. The anisotropy persisted during many hours. After the first flare/CME event observed by LASCO, the NRH detected several similar sub-events and we interpret this global and recurrent coronal activity as responsible for populating the IP medium with energetic electrons released during successive phases.

Event associated with a flare located behind the limb. The April 20 1998 event

Strong intensity of radio sources can mask presence of other weaker sources. For CMEs associated with flares located behind the solar limb, the strongest emitting sources will be occulted. This was the case for the April 20, 1998 event. For this event signature of the CME driven shock was detected. In addition, for the first time, the **CME expanding loops was imaged directly at radio wavelengths by non thermal synchrotron emission from electrons with energies of ~O.5-5 MeV.** Origin of these energetic electrons is unknown: shocks or reconnection in the low corona?

These radio CME events could also explain why some electron events are released many minutes later than the flare or type III burst onset.

Joint ULS and ACE observations of electrons
September 05 (248) to 09 (252)

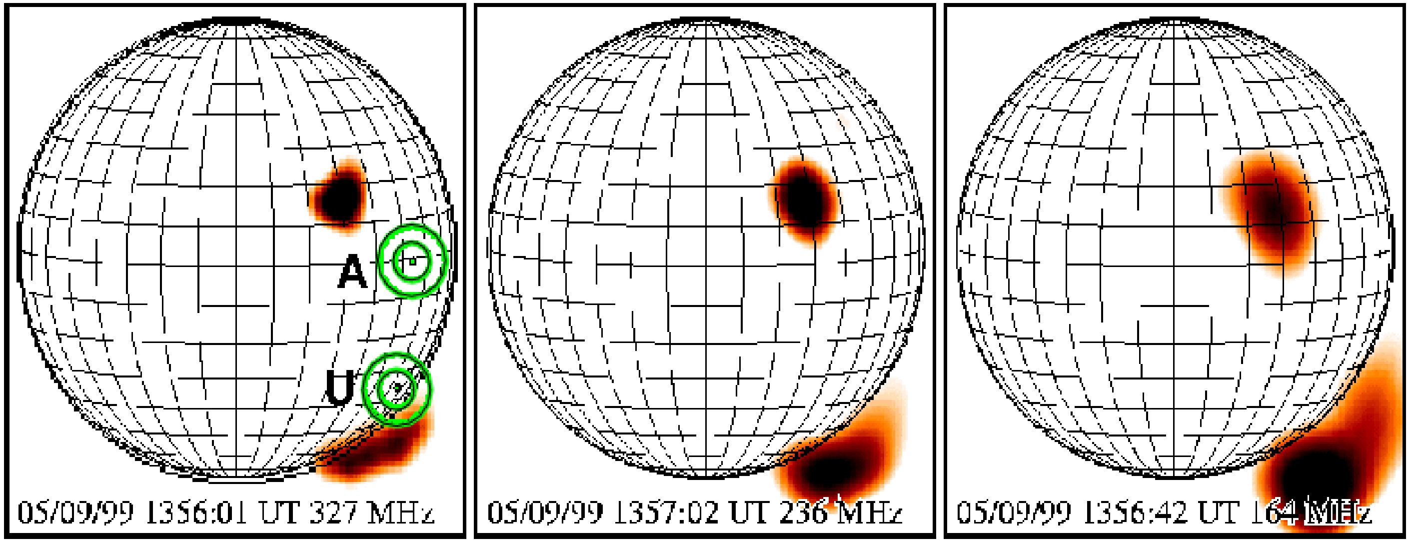


ACE/EPAM

ULS/HI-SCALE
B connection
65°S-35°W
4.6 AU

Left Spin-averaged intensities (38-315 keV). *Right* Eight sectors (53 keV)

ACE and ULS: Wide radial and latitudinal separation.
Vertical lines : Period of anisotropy seen by ULS, only.
Similar overall shape and intensities seen by ULS and ACE, reservoir of seed particles.



NRH
3 frequencies

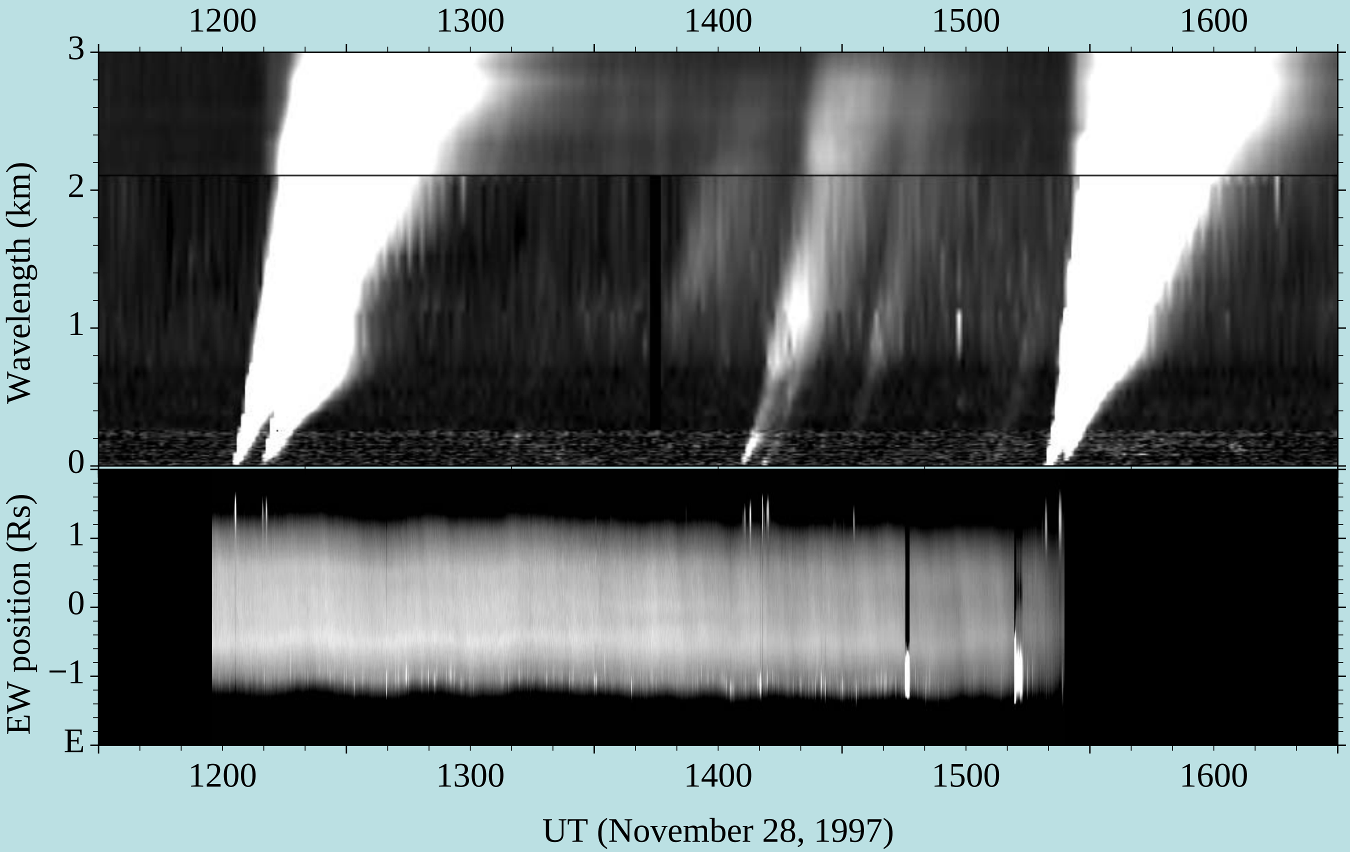
Foot points
(A) ACE
(U) ULS

Source at 15° N, 30° W: persistent noise storm enhancement which began at ~10:00 UT lasting beyond 15:30 UT.
Association with the slow increase seen by ACE.

Source at 40-60° S: bursty event which began at ~14:00 UT correlated with IP type III (WAVES);
Time association with ULS anisotropy period (transit ~4 hour);
ACE was not well connected.

Reservoir : persistent noise storm source (15°N,30°W)
M. Pick, D. Maia, S.E. Hawkins, III Space Science Reviews, 1-4, 2001.

Energetic electron beam events November 28 1997

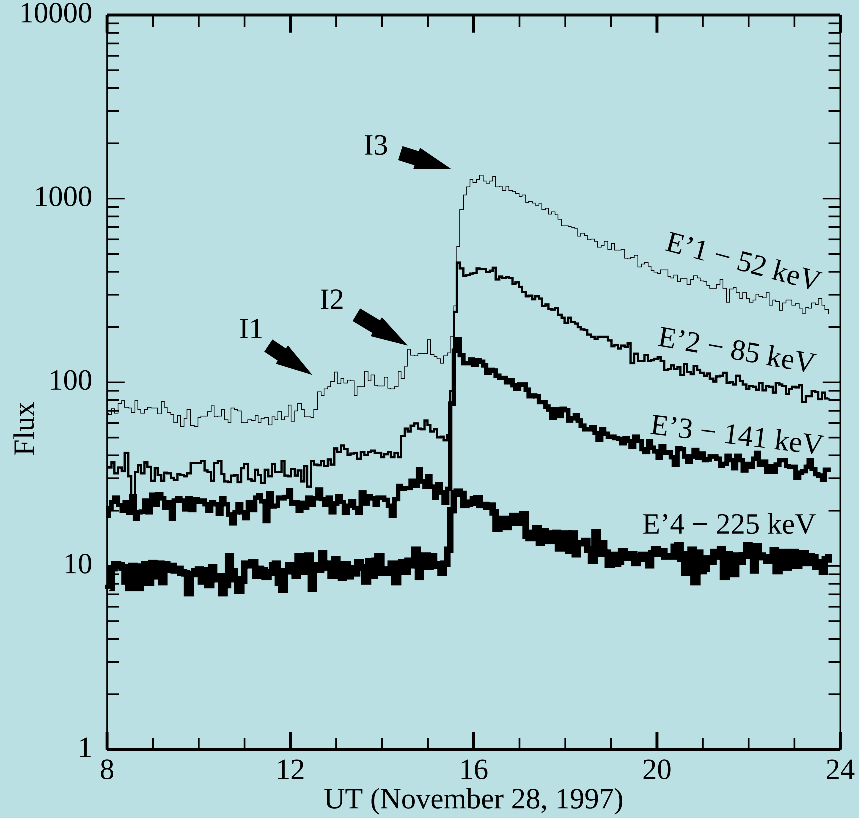


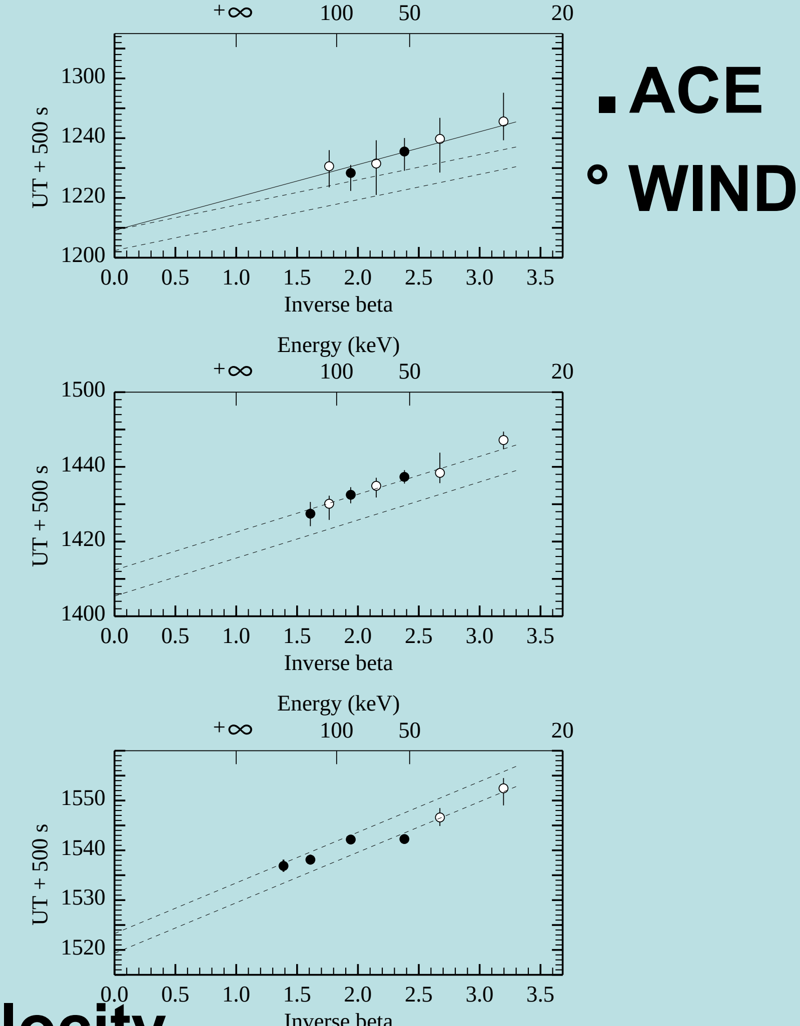
WIND/WAVES

NRH
E-W plot

Three similar radio events located on the western limb.
Each event includes two successive type III groups separated by 4 or 5 minutes

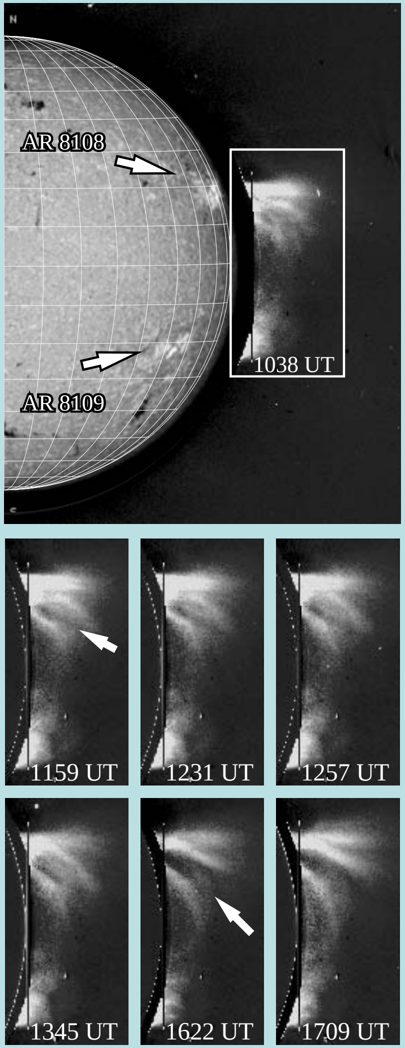
D. Maia, M. Pick, S. E. Hawkins, S. Krucker, The Astrophys., 500, 1058, 2001





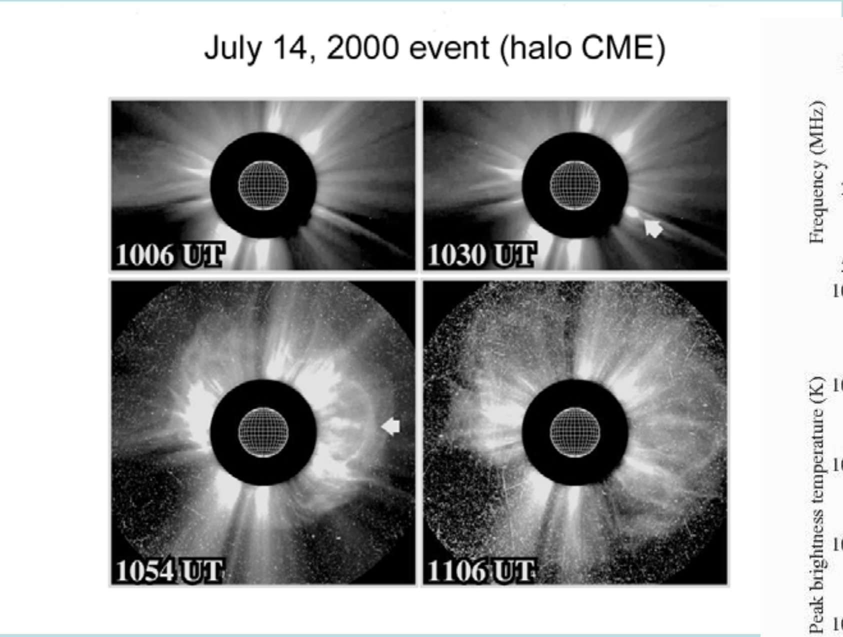
<u>Right</u> Onset time versus inverse velocity

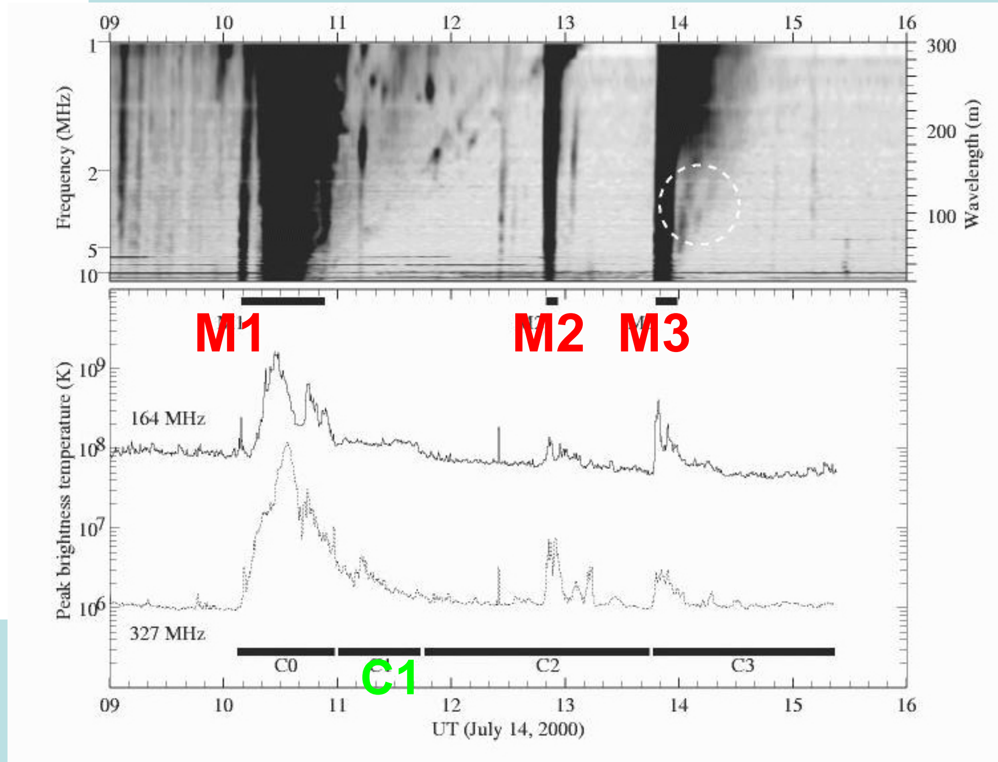
Dashed lines correspond to a release at the time of the two successive type III burst groups (PAD=0). I1 is a weak event. I2: release at the first solar injection. **I3 incompatible with one single injection.**



LASCO C1 (FeX) Coronal evolution at the vicinity of the release site. Opening of the B field occurs after the second event I2.

The July 14 2000 Halo CME event





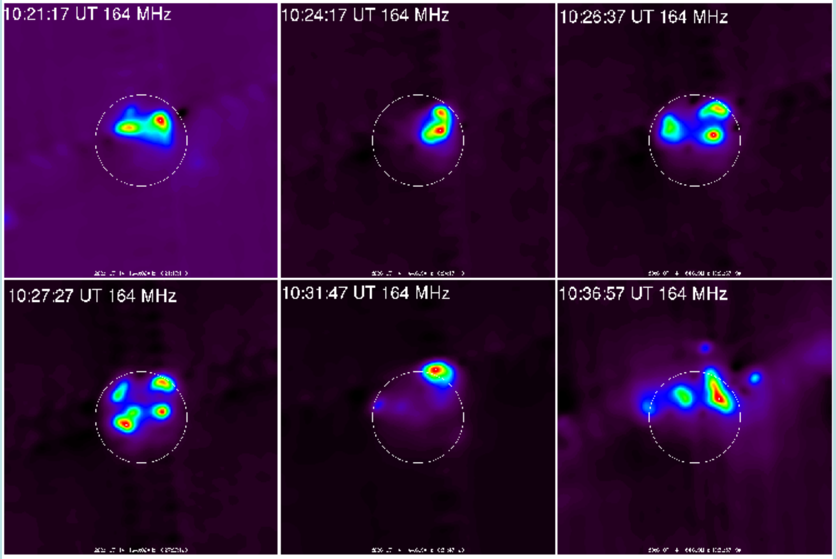
WIND

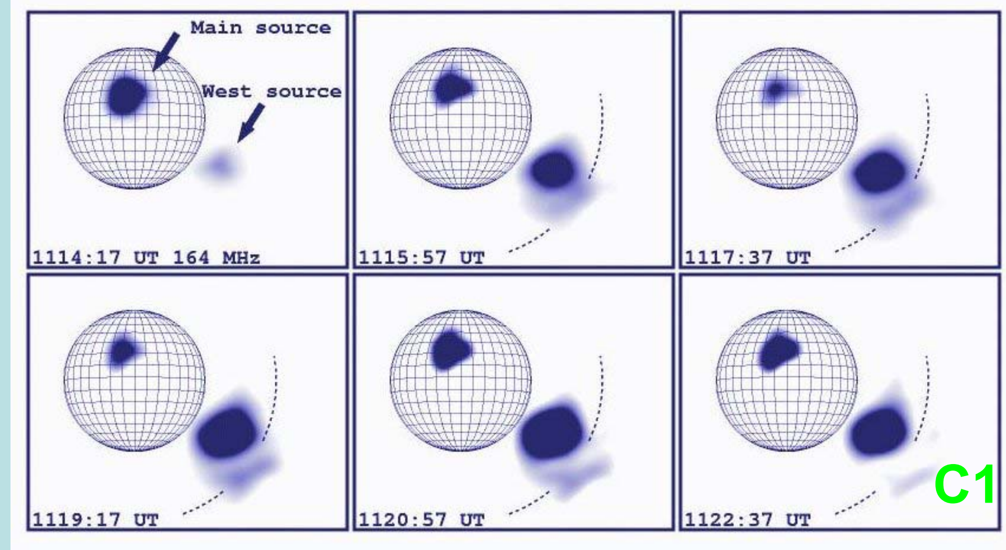
NRH

This event is recurrent: After the main phase at 10: 00 UT (M1), two other strong bursts (M2 and M3) are detected.

Two shocks associated with M1 and M3

D. Maia, M. Pick, S. E Hawkins III,V.V. Formichev, and K. Jiricka, Solar Phys., issue 1/2, 204, 197-212 2001.

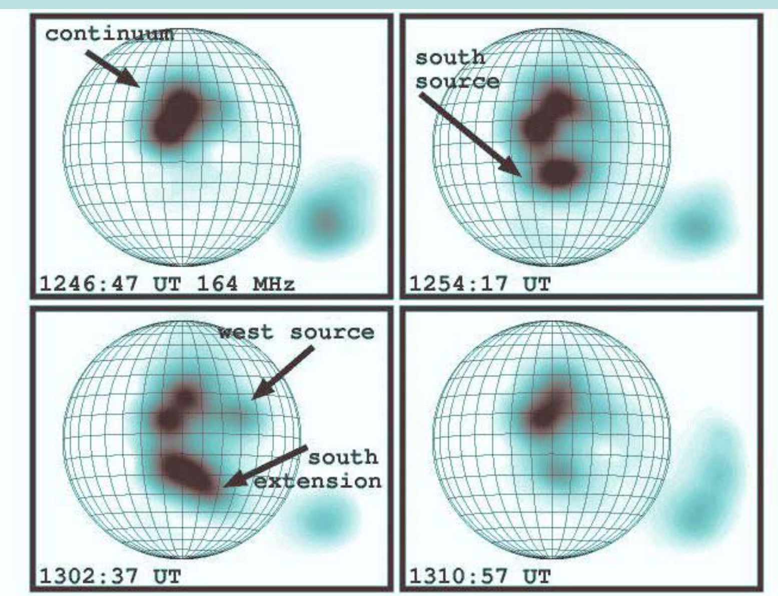




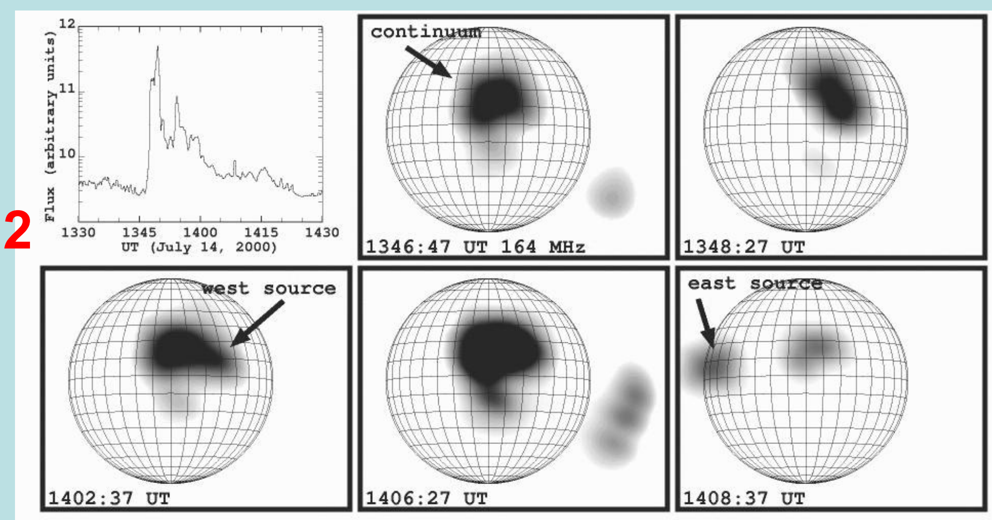
M1 Radio sources spread over a large angular extend in 15 min.

M1 Accelerated electrons illuminate outward moving features launched

Moving sources N-W (V>1500 km/sec) a few tens minutes after the CME onset



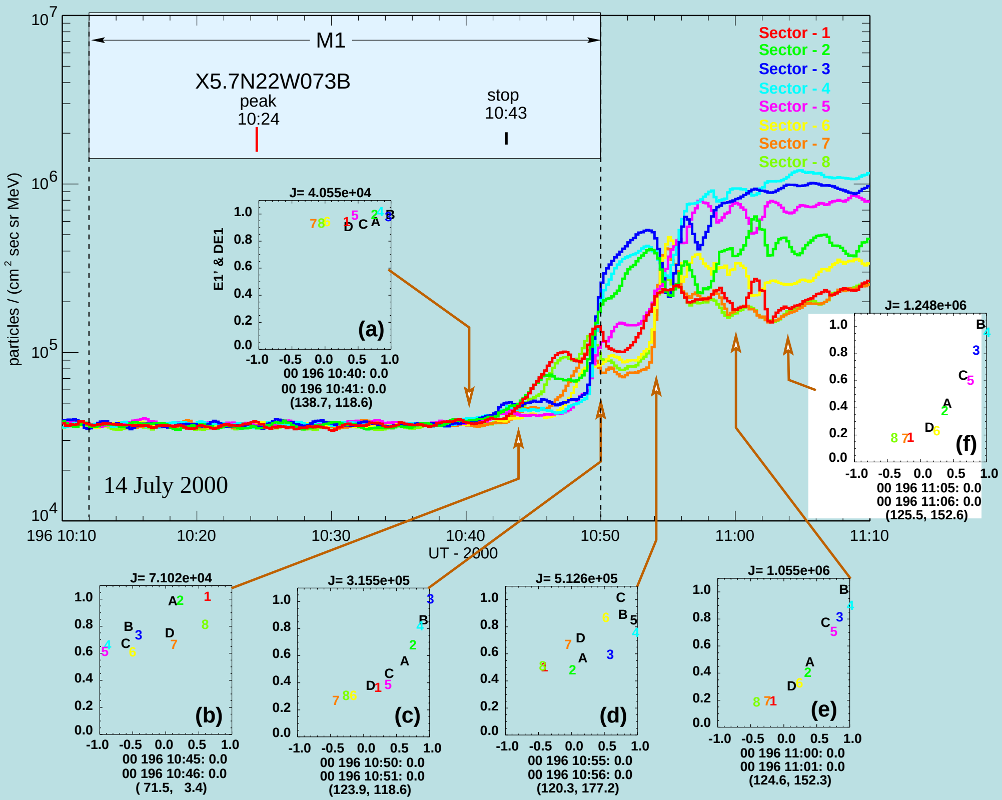
M2



M3

M2 and **M3** are not detectable by LASCO

ACE/EPAM energetic electrons



~40-300 keV electrons

4 energy channels, PAD

SW 600 km/s, foot 40 W

Spiral 1.07 AU

Transit time 24 min

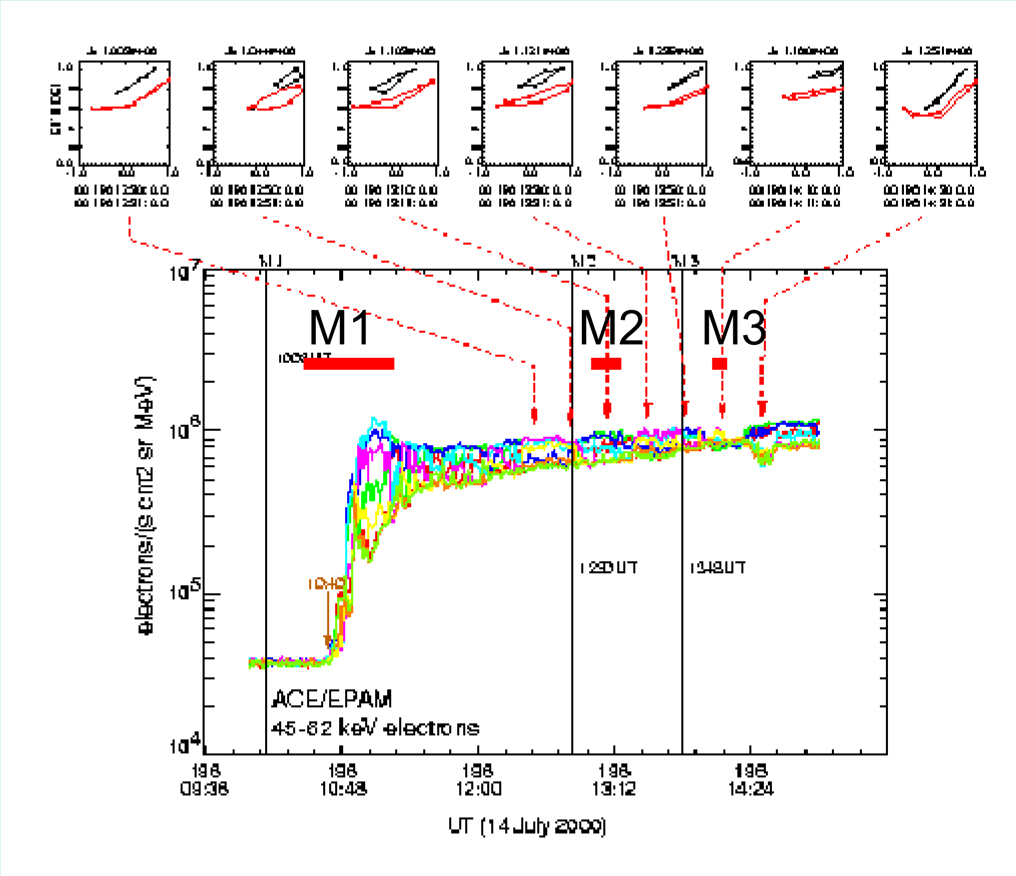
Onset ~1040 UT

Mapping back 1024 UT

(8 min substract)

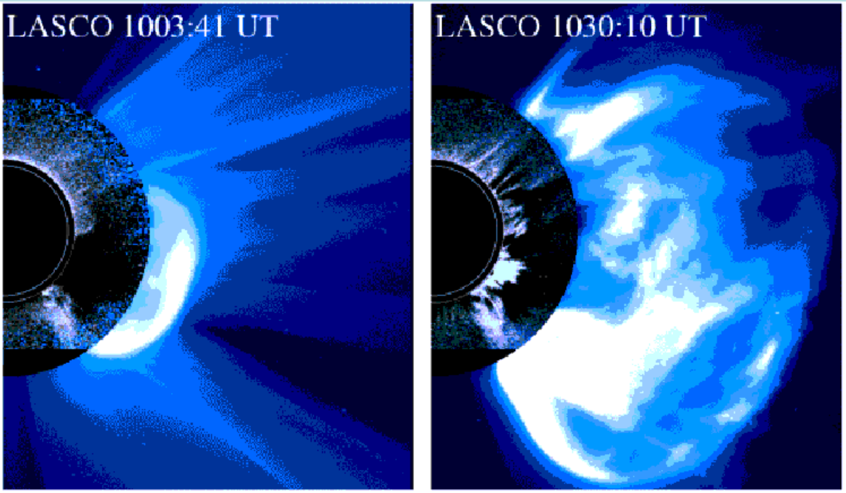
Time indicated in the figure for flare and M1 not corrected for transit.

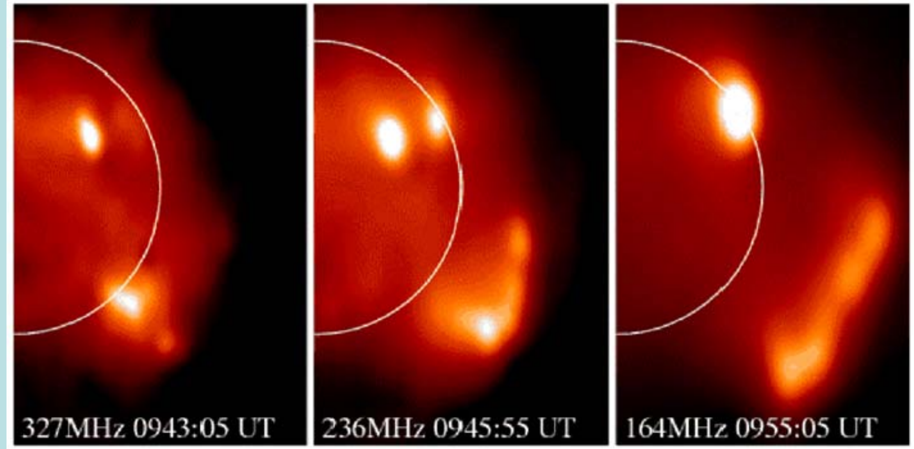
Anisotropy: coincides in time with radio sources seen in the western hemisphere. Strong modification observed at a longitude consistent with B foot point.



Anisotropy persists during many hours. **Global and recurrent coronal activity responsible for populating the IP medium with energetic electrons during many hours.**

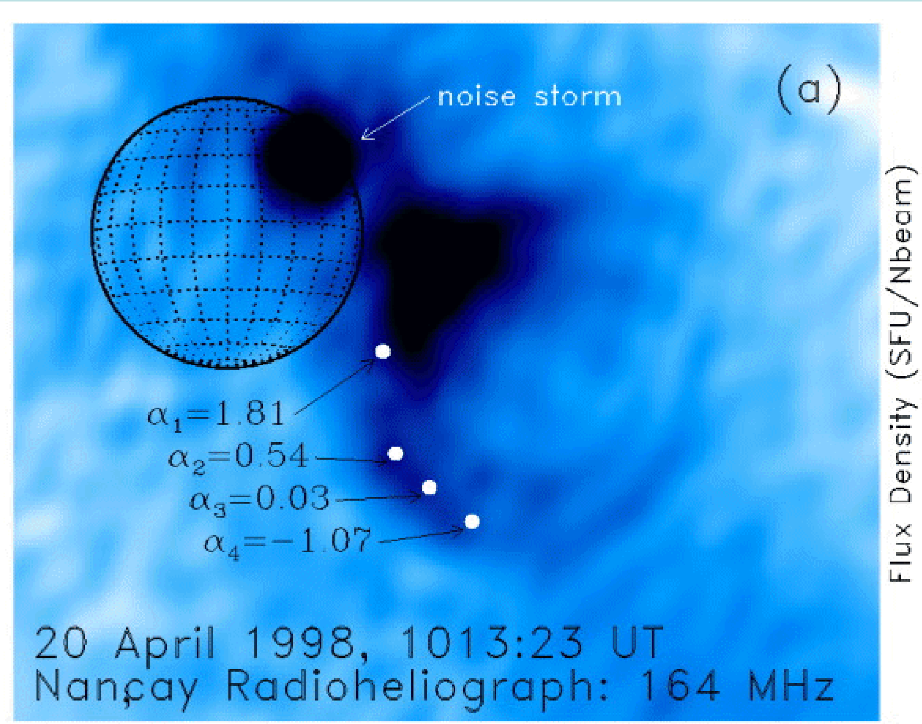
The April 20 1998 CME



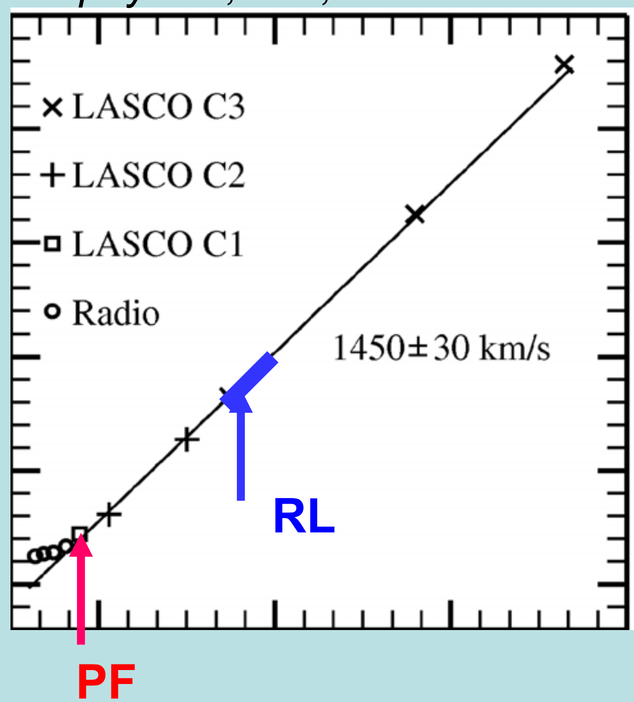


Plasma front (PF) detected in radio, coincides with the CME leading edge

D. Maia, M. Pick, A. Vourlidas and R. Howard
The Astrophys. J., 528, L49-51



Radio CME: emitting loops (RL)



The April 20 1998 CME
Direct imaging at radio wavelengths

- **The loops are illuminated by energetic electrons after ~10:06 UT**
- **Gyrosynchrotron radiation 0.5-5 MeV electrons**
- **B 0.1-few gauss**
- **Energy for electrons >100 keV >4 10^{29} ergs**

T. S. Bastian, M. Pick, A. Kerdraon, D. Maia and A. Vourlidas, the Astrophys. J., 558, L65-69, 2001.