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Investigation of Slow Rising LDE Flares and Associated CMEs

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It was shown by other authors that acceleration phase of CME lasts as long as the rising phase of associated flare. Thus, slow evolution of slow rising flares allows to study earliest stages of CME evolution in details.

Using LASCO data we examined statistical properties of these CME while SXT, EIT and TRACE data were utilized to analyse structure and evolution of associated slowLDE flares. The SXT, EIT and TRACE data allow us to identify CME-related structures visible in EUV and SXR.

Investigation of slow rising LDE flares and associated CMEs

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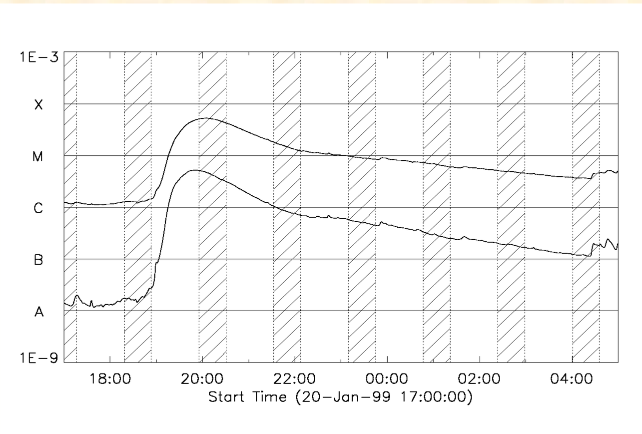


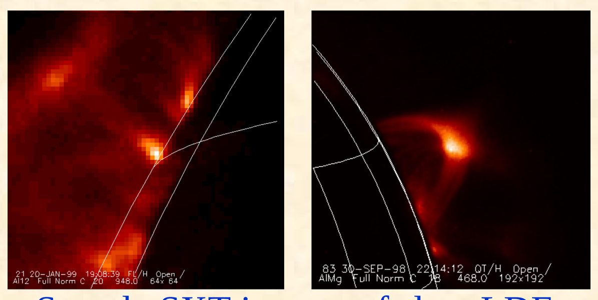
GOES X-ray flux for January 20th, 1999 (upper curve: 1-8 Å, lower curve: 0.5-4 Å).

Slow LDEs

- Slow LDEs are flares in which the SXR emission increases slowly and the X-ray rise phase lasts longer than usually, i.e. more than 20 minutes.
- During such flares impulsive phase is weak or is not present.
- „Supra-arcade downflows" are observed.

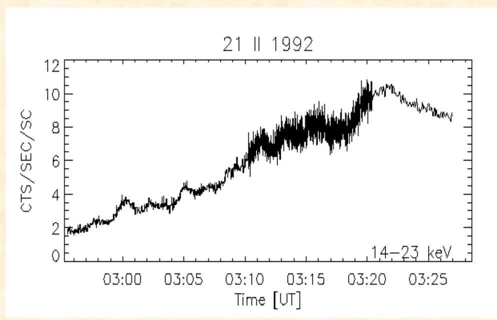
Characteristics of slow LDEs from *Yohkoh* investigation

- Most of the slow LDEs have kernels at altitude of h ~ 20-50 Mm.
- They have low temperatures (T<10 MK), low densities ($N \sim 10^{10}$ cm $^{-3}$) and large sizes ($r > 7 \times 10^{8}$ cm).
- The heating function is small, typically $E_H < 1$ erg cm^{-3}s^{-1}.



Sample SXT images of slow LDEs.

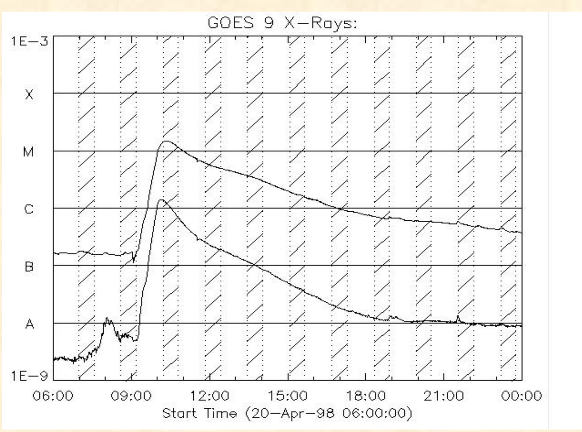
- Slow LDEs confirm relation between heating function E_H and the flaring loop semi-length L which was found in the paper of Jakimiec et al. (2002).
- Heating function E_H decreases very slowly with characteristic time τ > 800 s after reaching its maximum value.
- During the rise phase long lasting HXR emission was observed (in most cases without short lasting pulses).
- Sources of HXR emission in low energy channel were spatially correlated with tops of the loops seen in SXR images.
- High energy emission sources near the footpoints of the loops were observed rarely.



Example of HXR light curve for a typical slow LDE.

Bąk-Stęślicka, U., Jakimiec. J., *Solar Phys.*, 231, 95, 2007
Hudson, H., McKenzie, D., High Energy Solar Physics: Anticipating HESSI ASP Conference Series, 2000
Hudson, H., McKenzie, D., *Earth Planets Space*, 53, 581, 2001
Jakimiec, J., Falewicz, R., Tomczak, M., *Adv.in Space Res*, 30, 665, 2002

Examples of slow LDE flares associated with CMEs

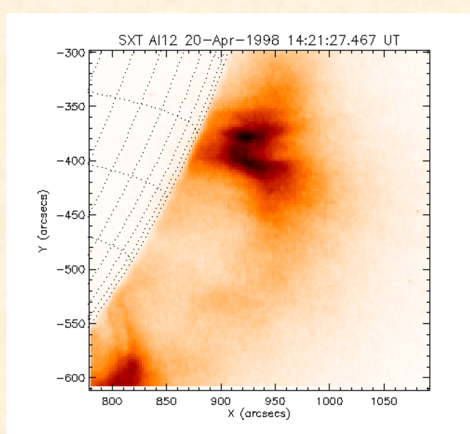


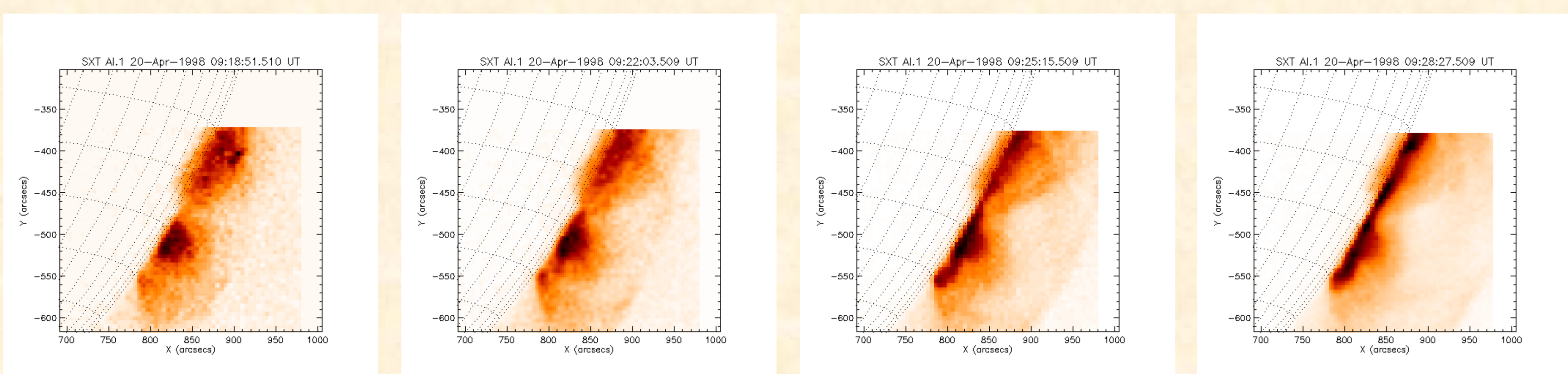
GOES X-ray flux for April 20th, 1998 (upper curve: 1-8 Å, lower curve: 0.5-4 Å).

April 20th, 1998

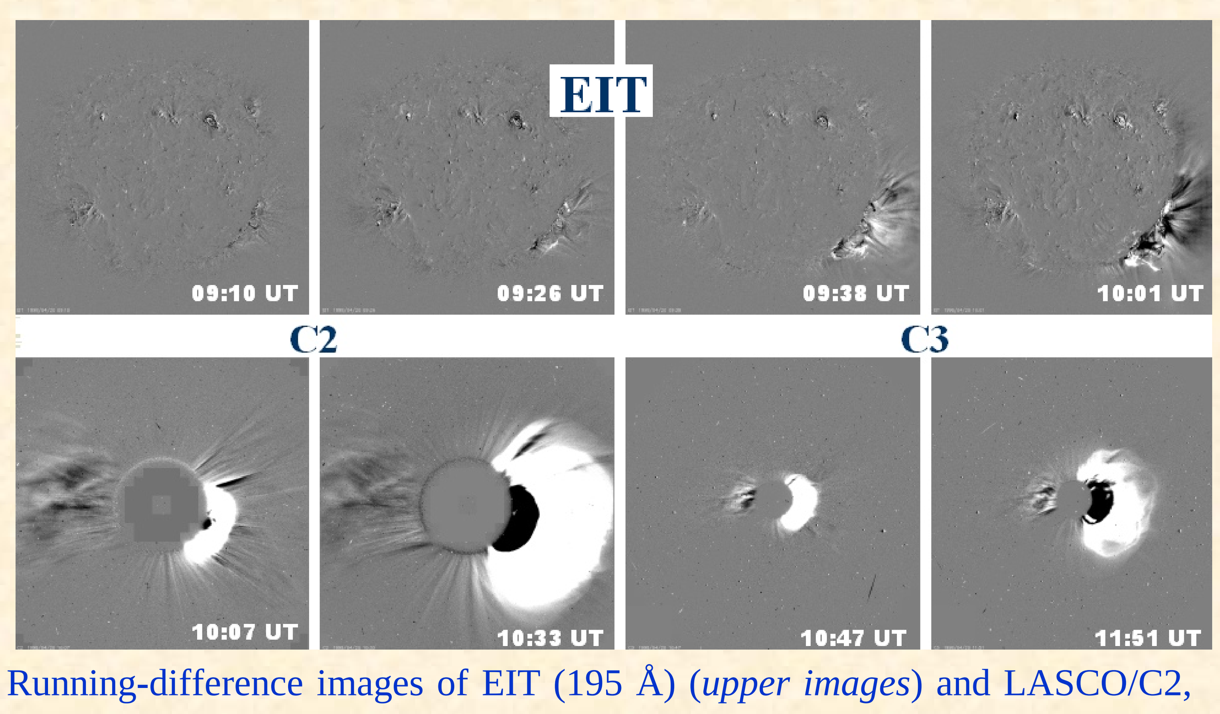
Basic information

Onset: 09:38 UT
Peak: 10:21 UT
Class: M1.4
AR: 8194

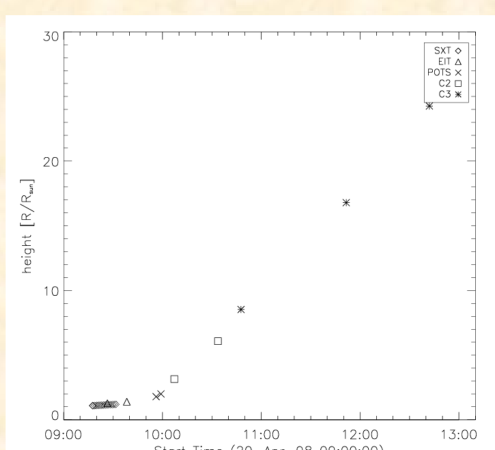




A sequence of SXT images illustrating the evolution of the X-ray ejections. First ejection was observed between 09:18-09:30 UT. Loop-like structure reached the altitude h>130000 km.

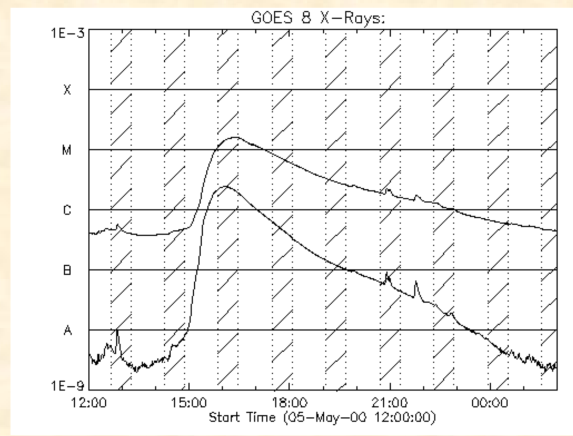


Running-difference images of EIT (195 Å) (*upper images*) and LASCO/C2, LASCO/C3 (*lower images*) illustrating the evolution of the CME.



High-time profile of the CME front, leading edge of the X-ray ejection and type II burst source. Relationship between X-ray ejection, type II burst source and CME suggest, that hot plasma seen on SXT images may be considered as the early stage of CME.

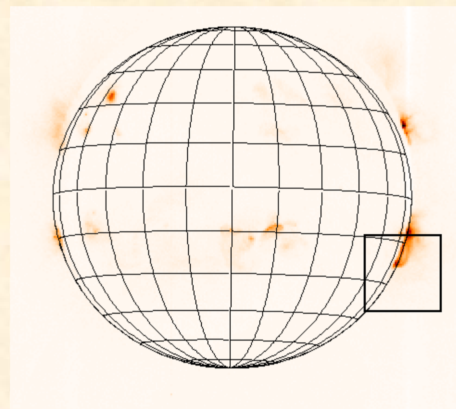
May 5th, 2000

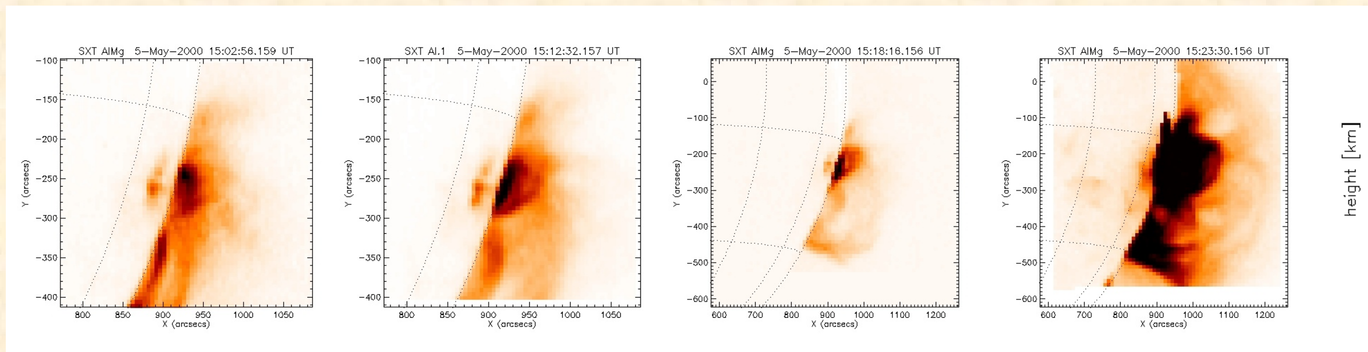


GOES X-ray flux for May 5th, 2000 (upper curve: 1-8 Å, lower curve: 0.5-4 Å).

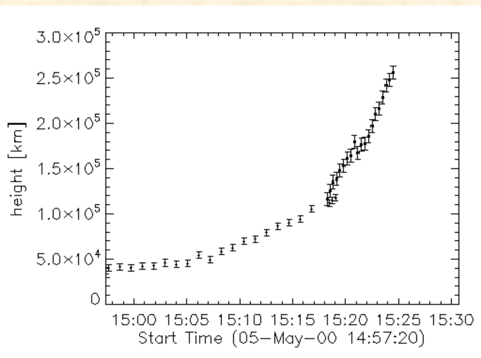
Basic information

Onset: 15:19 UT
Peak: 16:21 UT
Class: M1.5
AR: 8976

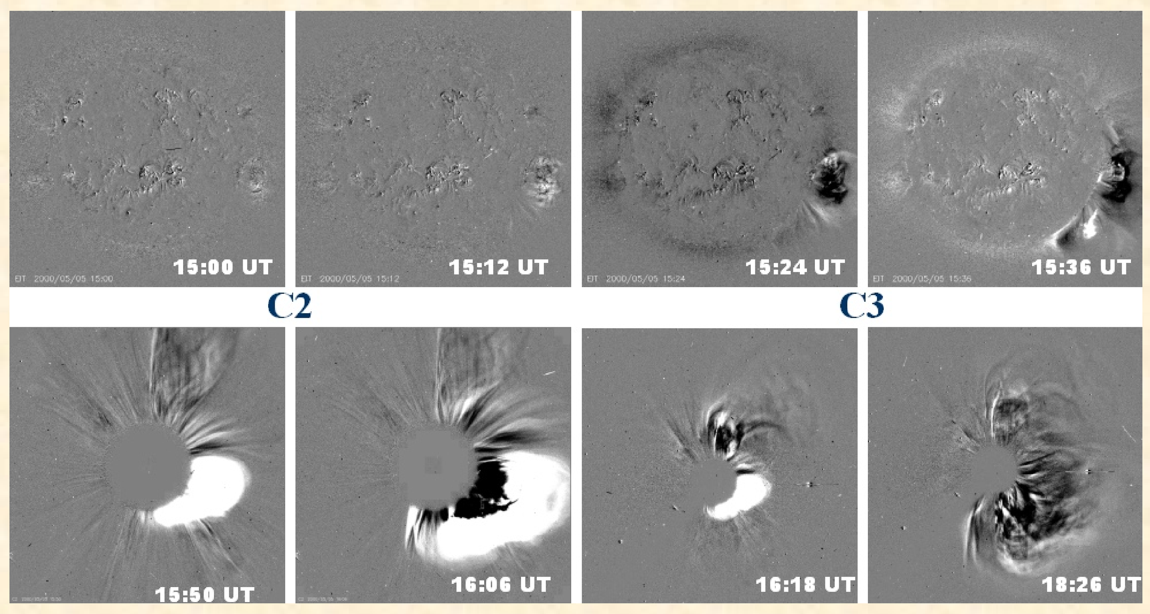




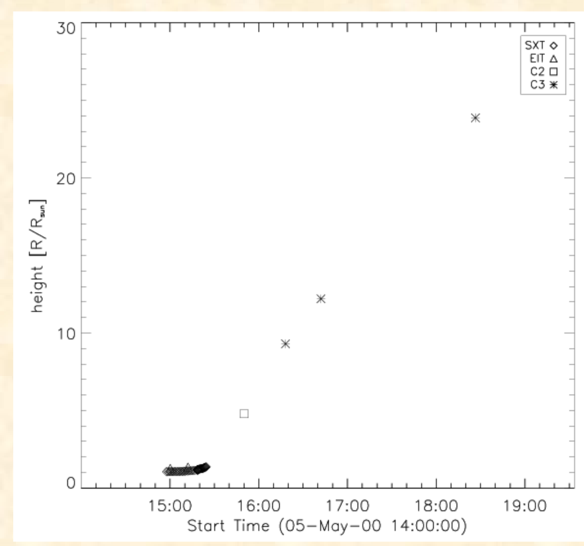
A sequence of SXT images illustrating the evolution of the X-ray ejections. First ejection was observed between 14:57-15:25 UT. Loop-like structure reached the altitude h>250000 km. Figure on the right shows high-time profile of the first X-ray ejection.



High-time profile of the leading edge of the first X-ray ejection.



Running-difference images of EIT (195 Å) (*upper images*) and LASCO/ C2, LASCO/C3 (*lower images*) illustrating the evolution of the CME.



High-time profile of the CME front and the front of the X-ray ejection. Observed altitudes of the X-ray ejection suggest, that this hot plasma could be an internal part of the CME

Results

Results for the six selected slow LDEs connected with CMEs

Date	Flare Onset [UT]	Flare Peak [UT]	GOES class	CME velocity [a] [km/s]	CME acceleration [b] [m/s²]
20-Apr-1998	09:38	10:21	M1.4	1606	396
05-May-00	15:19	16:21	M1.5	1382	262
16-Oct-00	06:40	07:28	M2.5	1312	240
05-Apr-01	08:37	09:22	M8.4	1752	599
21-May-02	23:14	00:30	C9.7	1248	277
13-Jul-05	14:01	14:49	M5.0	1423	407

a - mean velocity during the propagation phase,
b - mean acceleration during the main acceleration phase,

Conclusions

- In most cases acceleration of the CME during the main acceleration phase is lower than 400 m/s^2.
- Despite of lower value of acceleration, velocities of these CMEs are higher than typical velocity of a CME connected with a flare. This fact is due to duration of the CME acceleration phase which last as long as the slow LDE rising phase i.e. at least 20 min.
- In many cases, X-ray ejections were observed. High-time profile of the CME front and the leading edge of the X-ray ejection indicates that hot plasma seen on SXT images may be considered as the early stage of CME.