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CME ACCELERATION IN SOLAR FLARES

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What secuence of processes on the Sun lead to positive feedback between heating of plasma and acceleration of electrons, heating and motion of plasma resulting in formation of CME and acceleration of protons?

(Cliver et al., 2019)

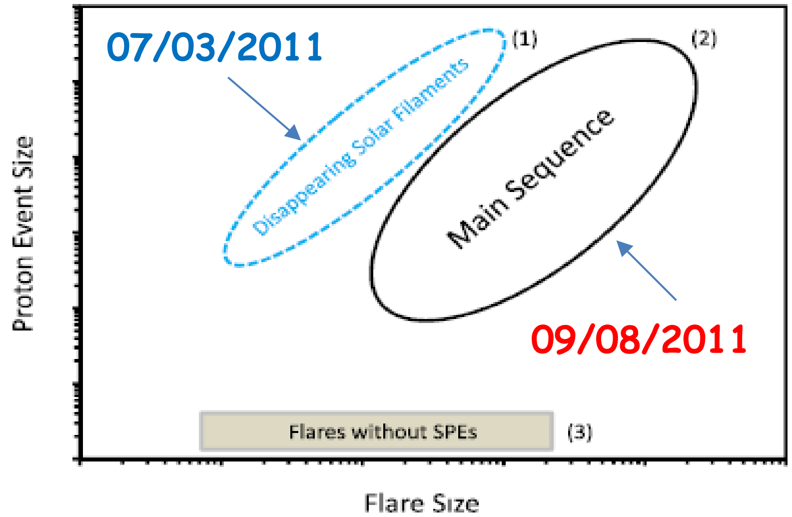
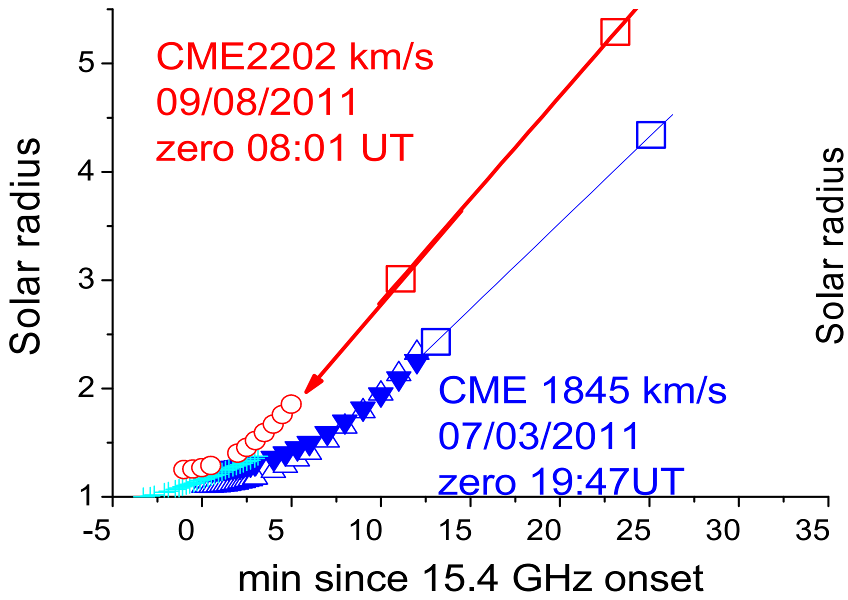


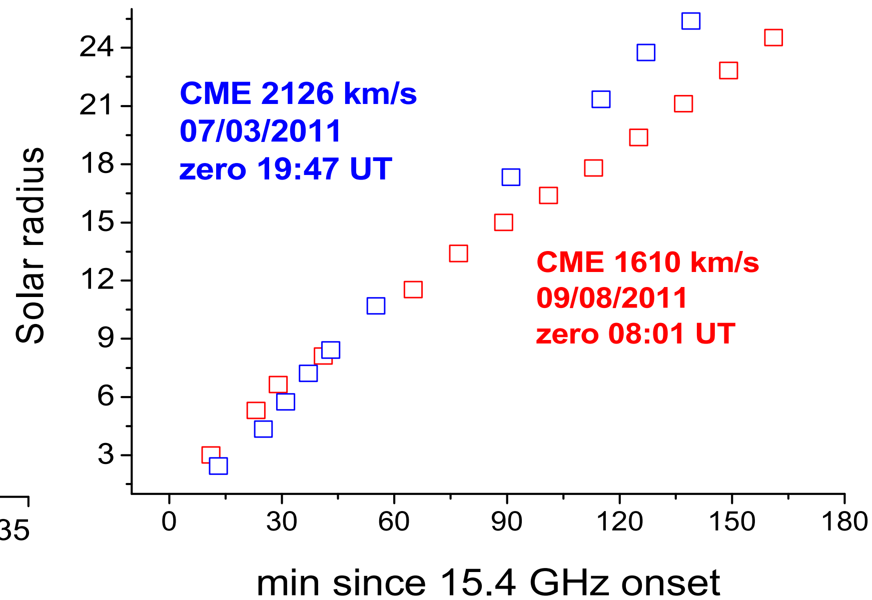
Figure 17. Schematic comparison of SPE vs. flare size parameters for large, well-connected SPEs showing three characteristic zones of events: (1) DSF-associated SPEs, (2) main sequence of SPEs associated with big flares and strong shocks, and (3) non-SPE events with either no or slow associated CMEs.

We answer this question for the gradual M3.7 flare on 07/03/2011 (Struminsky et al., 2021 in press) **and the impulsive X6.9 flare on 09/08/2011** (Sharykin et al., 2015; Struminsky et al., 2020) **using information on :**

- **plasma heating** - SXR (GOES) → T, EM → dT/dt;
- **plasma motion in flare region** - dEM/dt, AIA (SDO), drift of frequencies (1415-245 MHz, RSTN);
- **electron acceleration** - microwaves (15.4-2.695 GHz, RSTN), HXR > 150 keV (Anti-Coincidence Shield of Spectrometer on INTEGRAL — ACS SPI);
- **CME position** - LASCO/SOHO (C2-C3);
- **proton acceleration** - *γ*-rays > 100 MeV (FermiLAT, Ackermann et al., 2014; Share et al., 2018), solar proton events (protons > 100 MeV, ACS SPI)

CME – model acceleration and observations



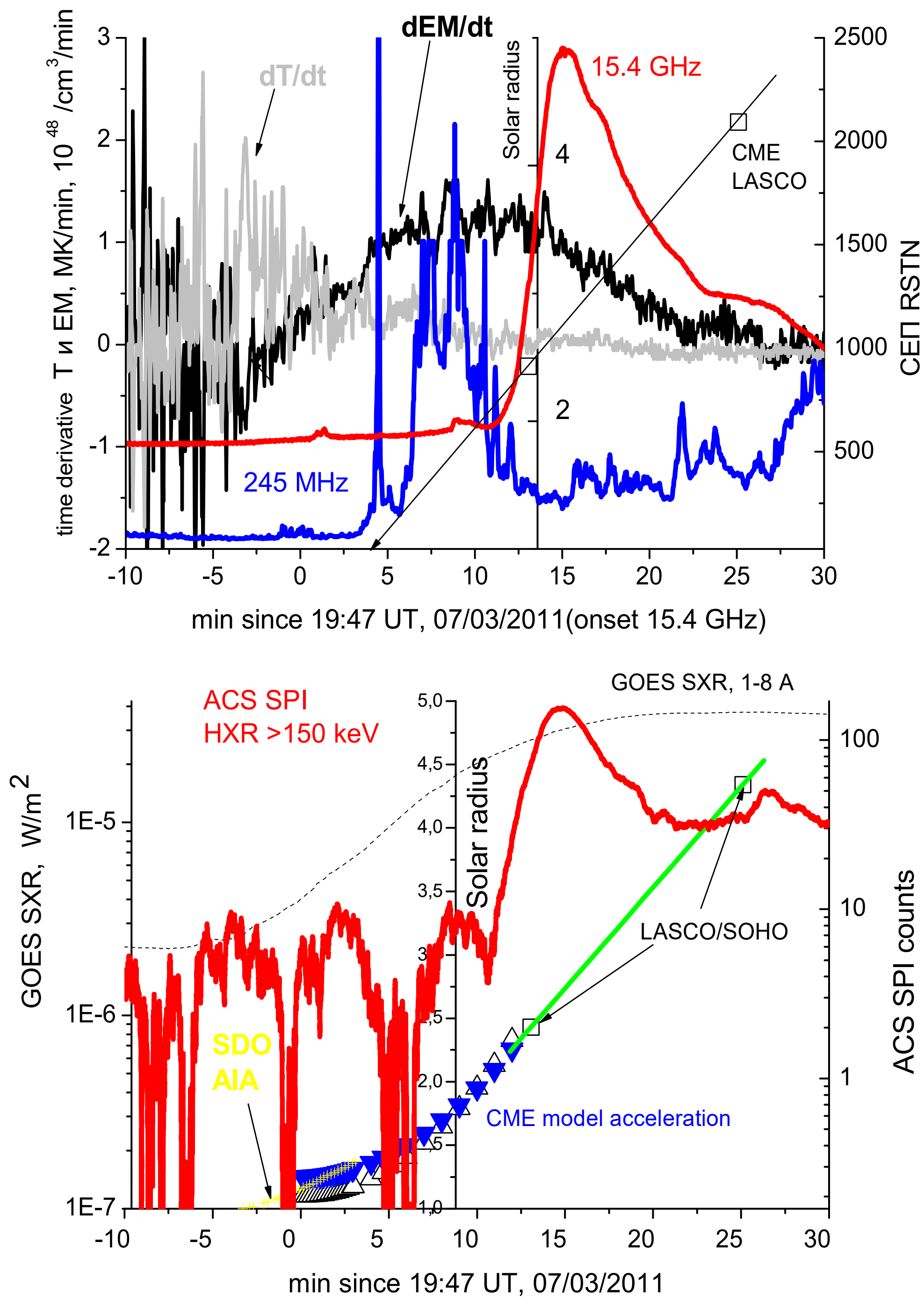


Let us assume that CME starts moving at t_0 with V_0=0 and a = const from R_0= 1.25R_S till t. After t CME moves with V=const, which is known from the LASCO observations, since R =A+Bt, V=B, a = B/(t-t_0). A stretching condition of accelerated and steady motion gives us t = (2R_0-2A-Bt_0)/B.

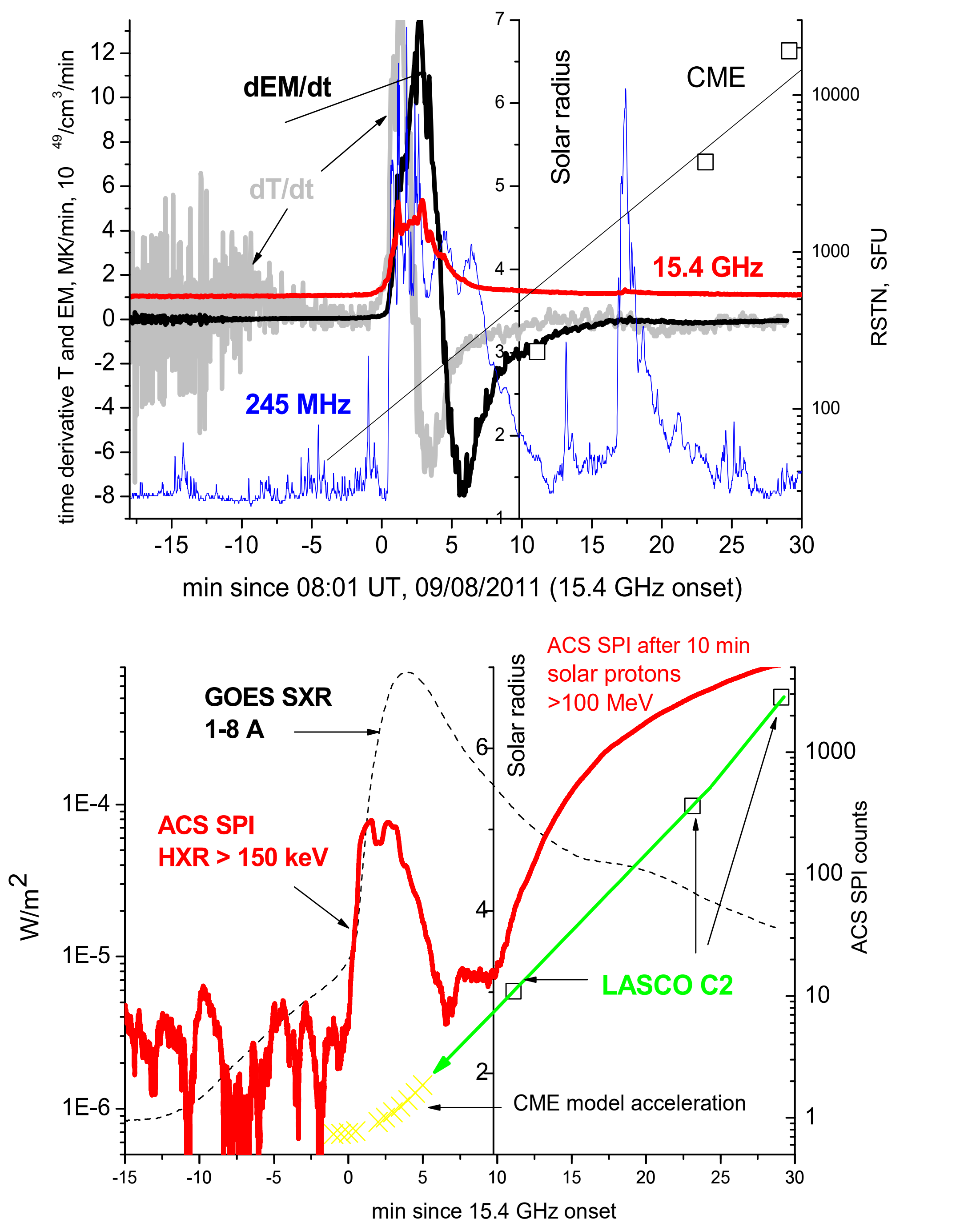
event	t_0[s]	*A* [km]	*B* [km/s]	*t* [s]	*A* [km/s]
07/03/2011 19:47 UT	0	244037	1845	676	2.7
09/08/2011 08:01 UT	-60	629439	2202	278	6.5

Since final average CME velocities from LASCO observations are 2226 km/s (07/03/2011) and 1610 km/s (09/08/2011) we need to assume additional acceleration in the 1st case and deceleration in the 2nd case.

Gradual (75 min) M3.7, 07/03/2011 19:47 UT



Impulsive (20 min) X6.9, 09/08/2011 08:01 UT



Left – Acceleration of non-thermal electrons with soft spectrum at heights ~10^5 km (f_p~245 MHz, $n_e < 7.4 \cdot 10^8$ cm^{-3}), electrons heat surrounding plasma, EM is practically constant, the magnetic flux rope is confined, the electron spectrum becomes harder.

Middle – The acceleration site moves from (1) to (2), a new acceleration site (3) may appear by chance, T is increasing. If the acceleration site (3) is close to the chromosphere then the chromospheric evaporation starts (the case of 09/08/2011).

Right – The acceleration of CME is going up to ~$3.5 \cdot 10^5$km due to plasma expansion. Further the CME (plasma above closed field lines of active region including the magnetic flux rope) moves with conctant velocity or with small acceleration/deceleration. Particles (electrons < 10 MeV, protons > 100 MeV) are accelerating below the CME in (4).