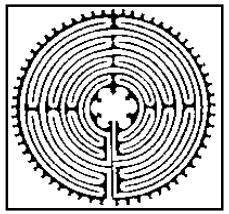
SOLI INVICTO

GLOBAL CORONAL MASS EJECTIONS

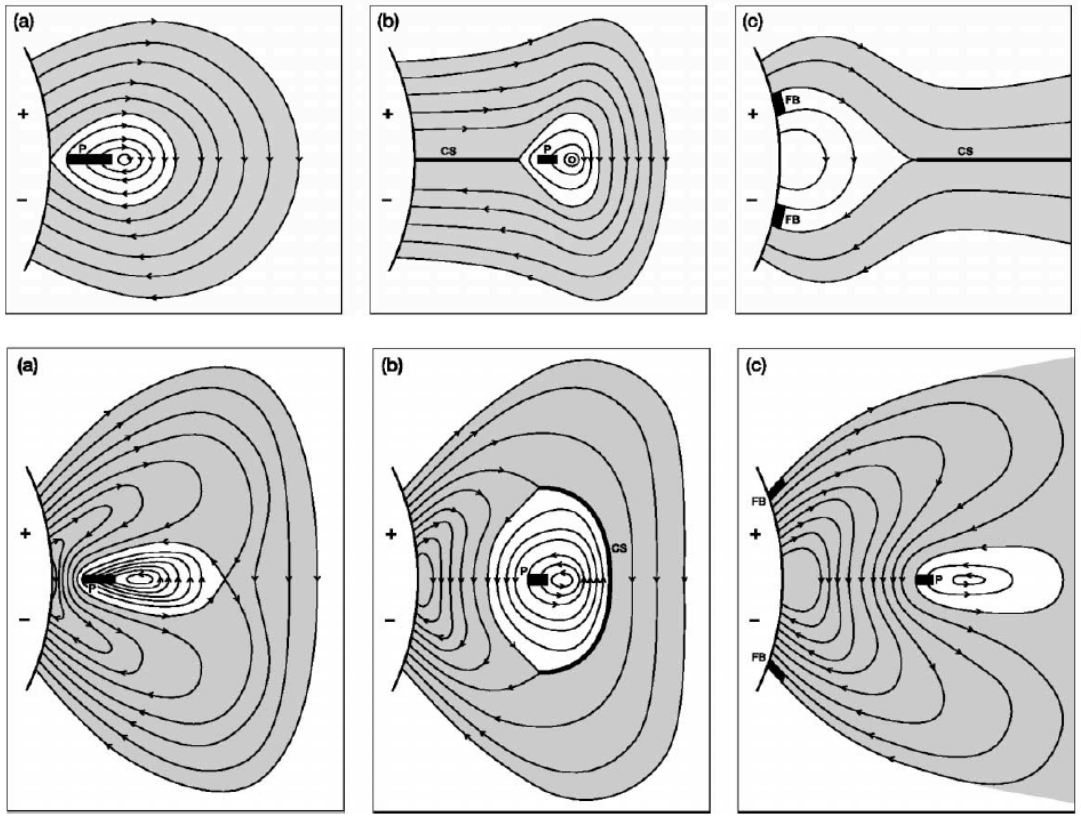
Andrei N. Zhukov



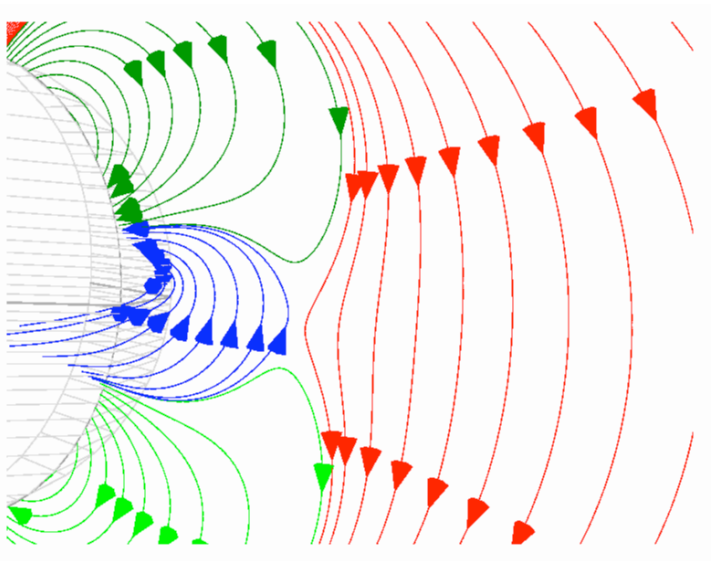

Solar-Terrestrial Center of Excellence – SIDC,
Royal Observatory of Belgium

Skobeltsyn Institute of Nuclear Physics,
Moscow State University, Russia

CME models: eruption of a bipolar region of the magnetic field!



(Low and Zhang 2002)



(Antiochos et al. 1999)

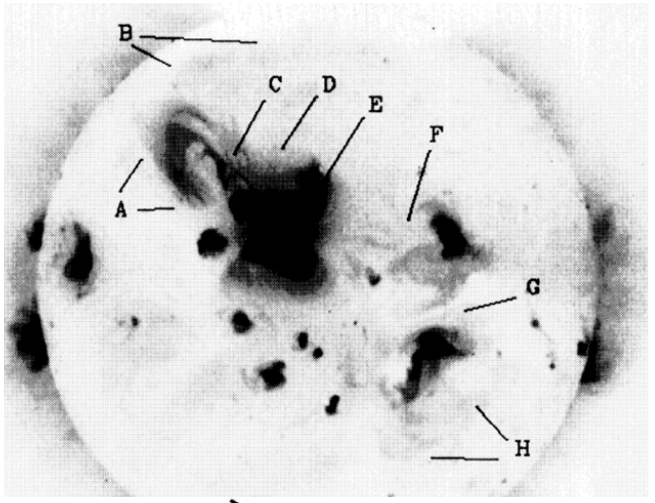
Eruption of multipolar magnetic flux systems during a CME

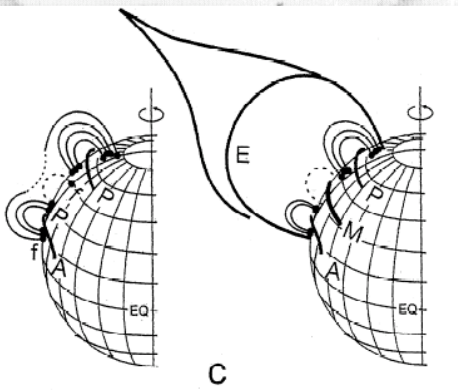
- Hudson et al. (1996): very large scale of coronal disturbances during the CME initiation observed by Yohkoh/SXT, with large regions of the X-ray corona appear to become empty.

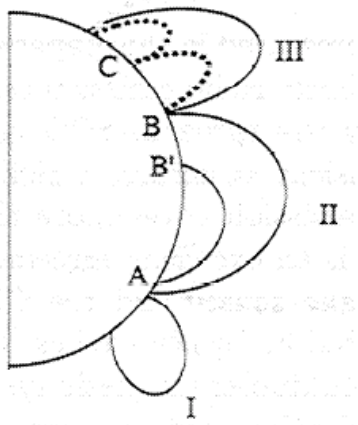
- Webb et al. (1997): multiple erupting neutral lines associated with CME initiation as seen by Yohkoh/SXT.

- Maia et al. (1999): sites of radio emission spread over large volumes of the corona – eruption of a large-scale multipolar structure seen by SOHO/LASCO C1.

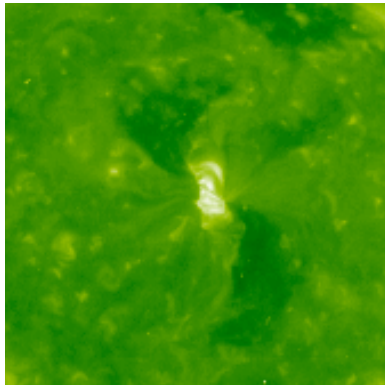
- New quality from high-cadence (around 12 minutes) continuous observations of the corona by SOHO/EIT: possibility to observe the evolution of large-scale source regions of many CMEs in unprecedented detail.



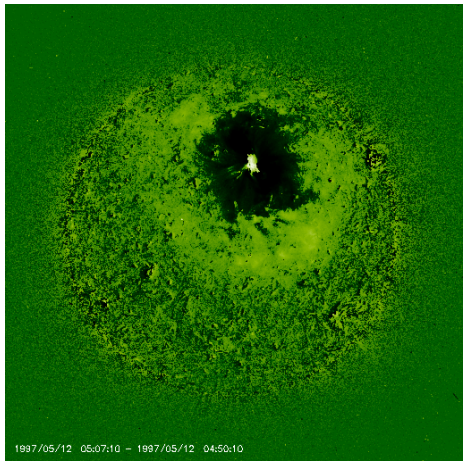




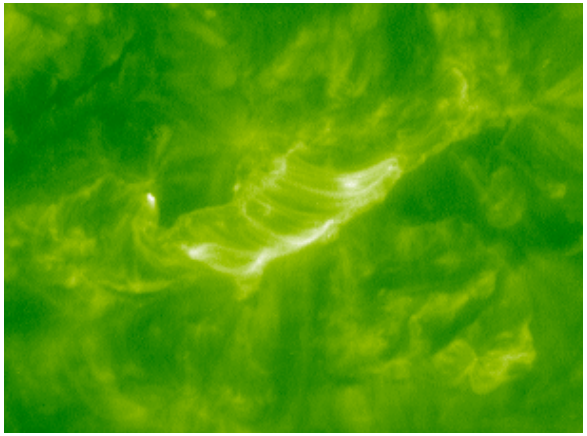
CME SIGNATURES IN EUV



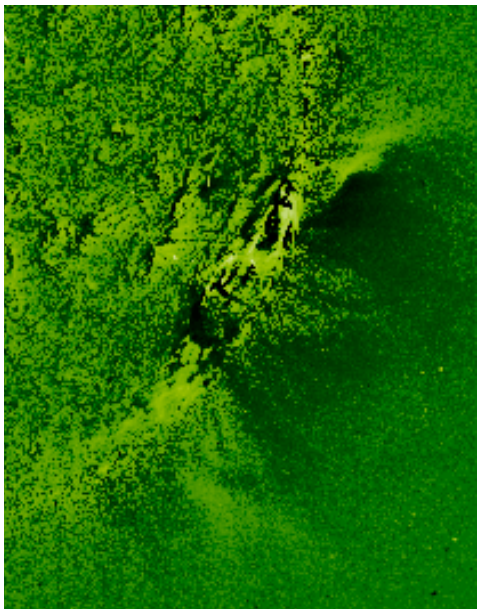
Dimmings
(including TCHs)



EIT wave

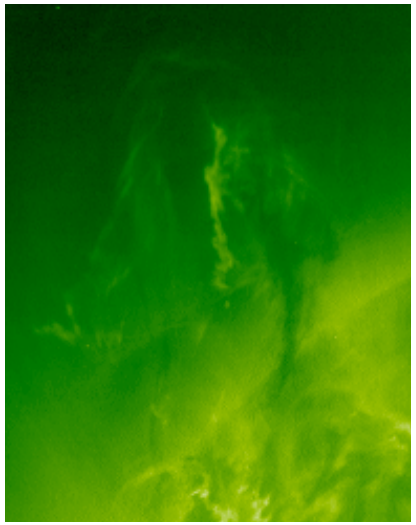


Post-eruption
arcade



Limb signatures:
opening of loops,
plasmoid lifting
etc.

SOHO/EIT
195 Å



Erupting
prominence
(filament)

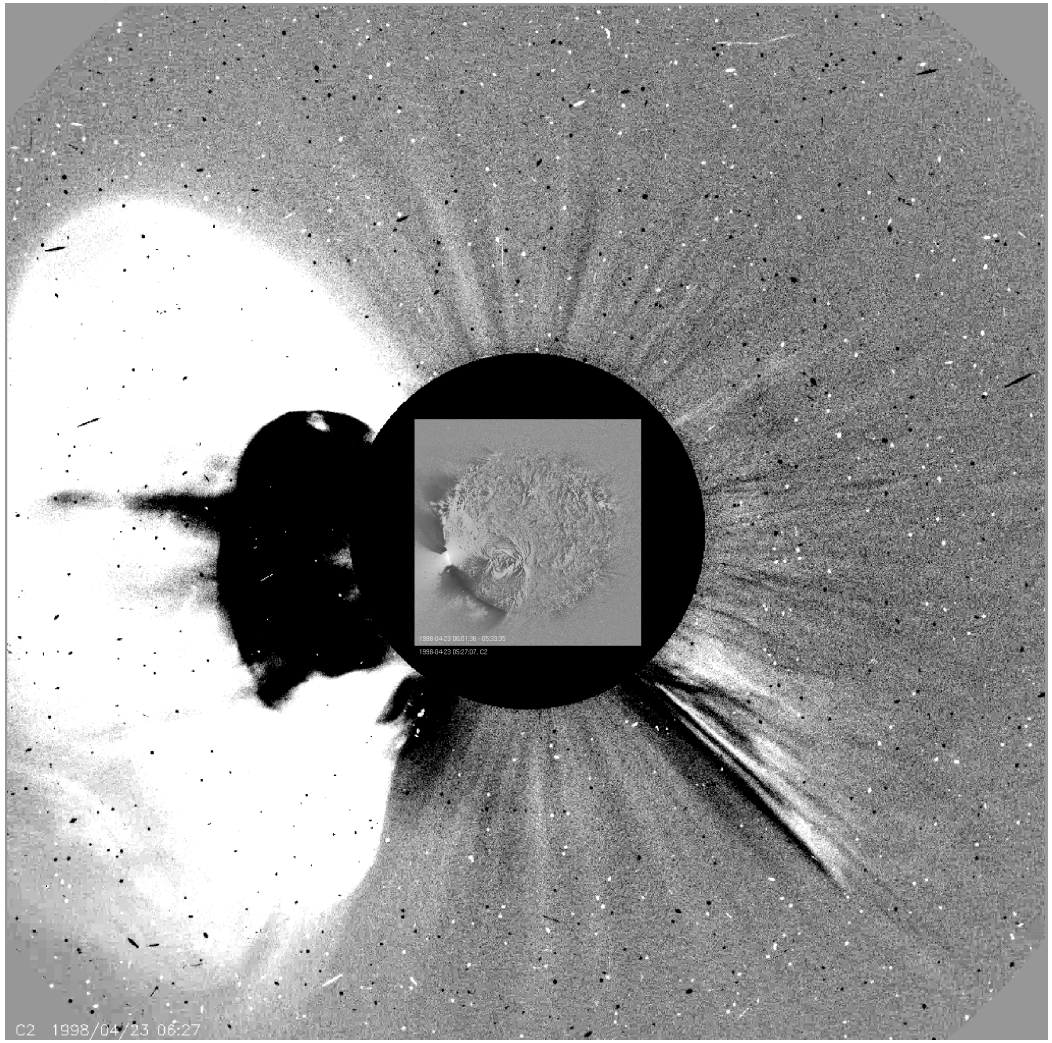
(Zhukov 2004)

CORONAL DIMMINGS AND CMES

$$I(\lambda_{ij}) = \int_h Ab(Z)C(N_e, T, \lambda_{ij})N_e N_H dh$$

- Coronal dimmings correspond to the places of mass evacuation during CMEs *(Sterling & Hudson 1997, Harrison et al. 2003, Zhukov & Auchère 2004)*.

- Thompson et al. (2000): extended dimming areas map out well the apparent "footprint" of CMEs observed by a coronagraph



A CME ON OCTOBER 28, 2003

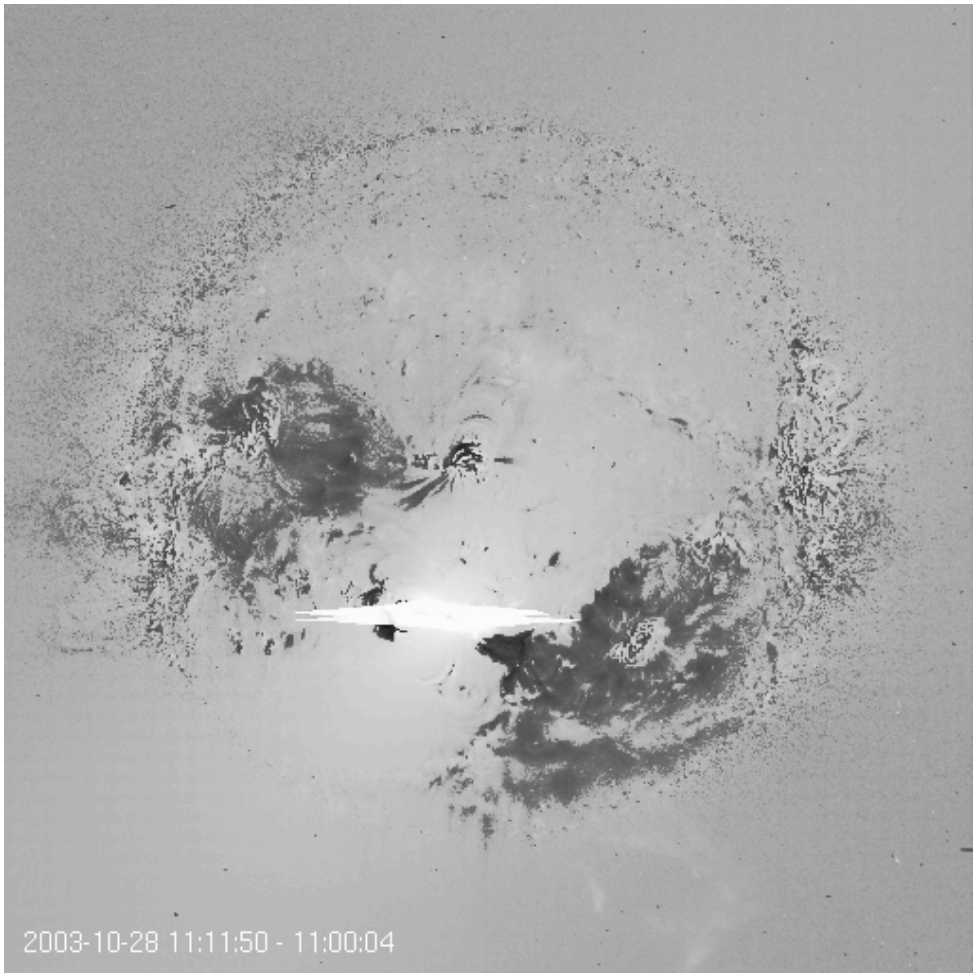
Evolution of the low corona

SOHO/EIT
Fe XII bandpass
(195 Å)
~1.5 MK plasma

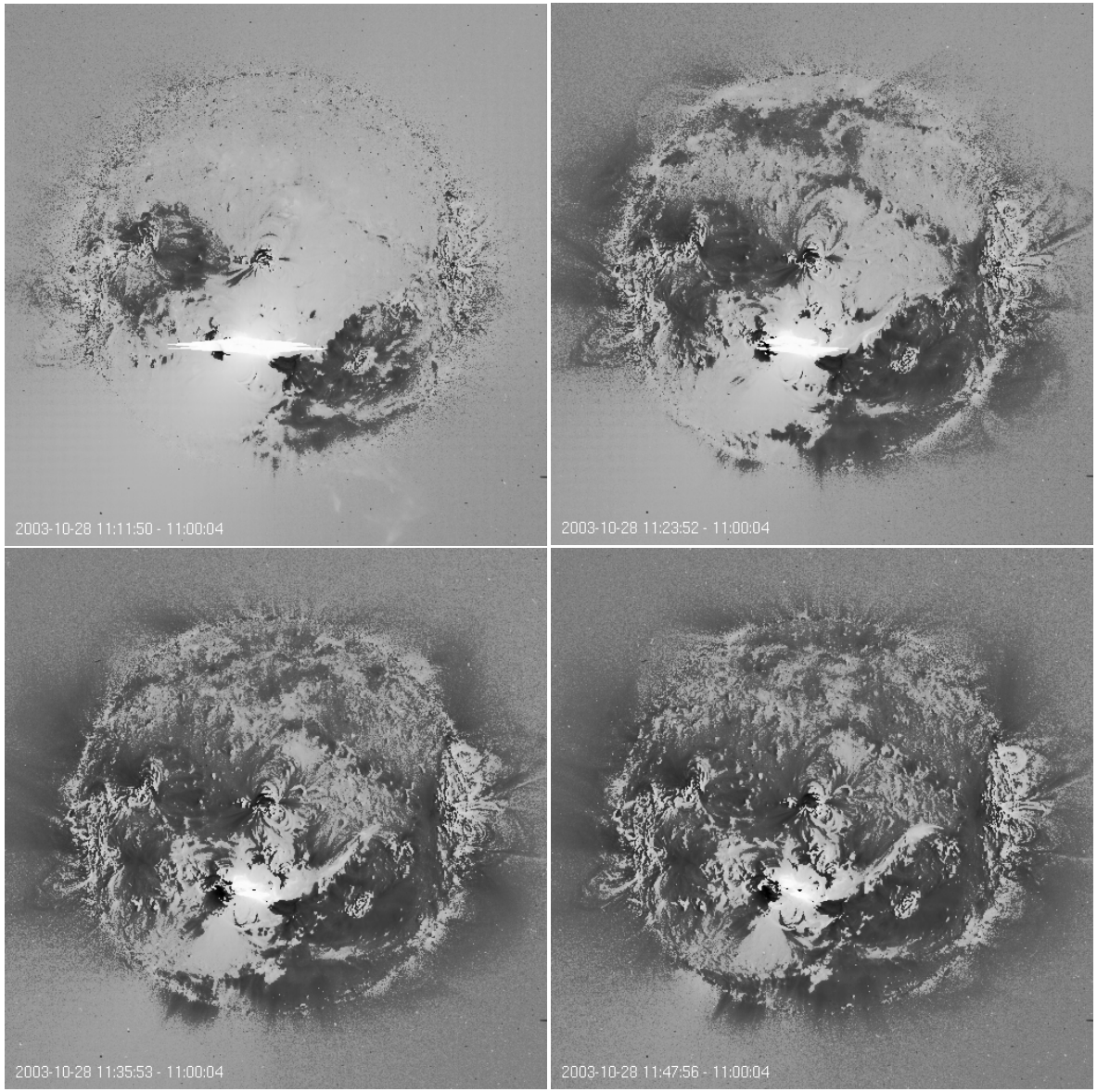
BASE DIFFERENCE MOVIE

(last pre-event image subtracted)

SOHO/EIT
Fe XII bandpass
(195 Å)
~1.5 MK plasma



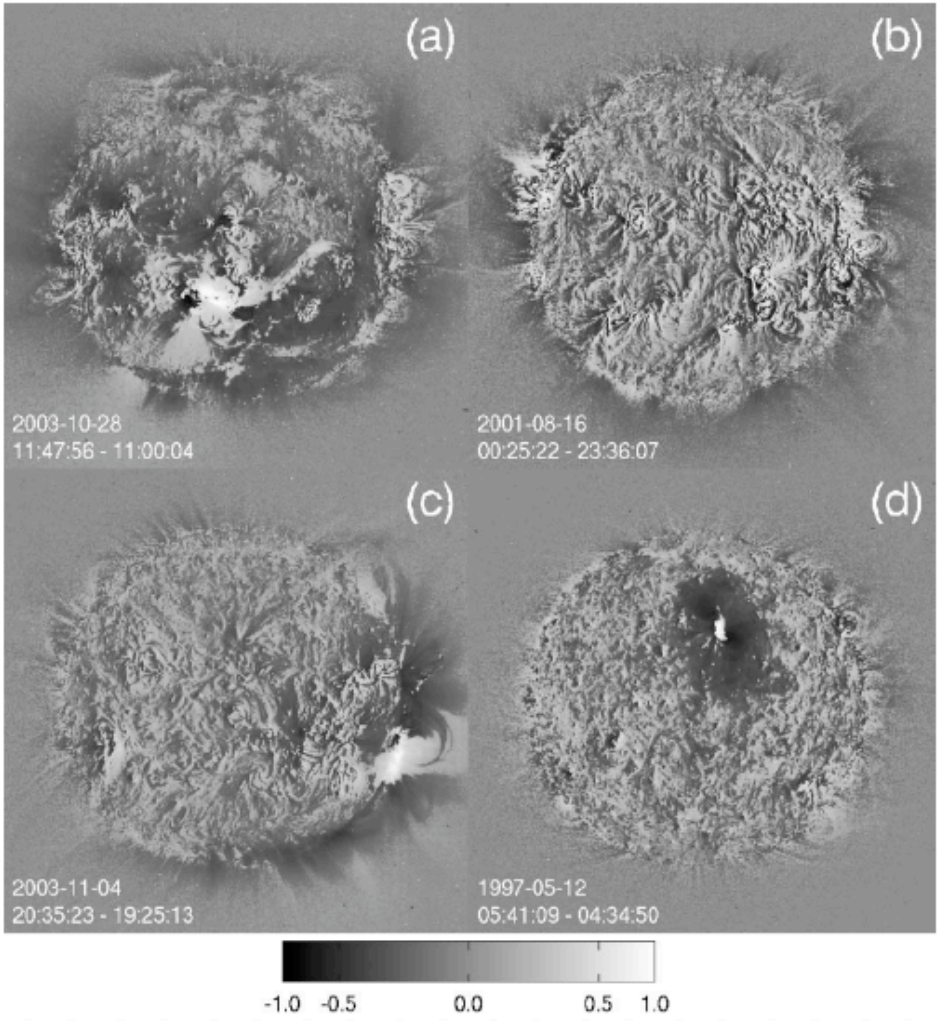
DYNAMICS OF A GLOBAL DIMMING



Definition: a global CME is a CME that has associated dimmings above the limb extending to more than 180° in apparent position angle around the solar disk *(Zhukov & Veselovsky 2007).*

Angular width of limb dimming:

~ 350° – global!



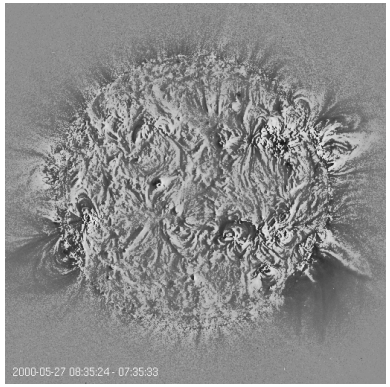
~ 270° – global!

~ 190° – global!

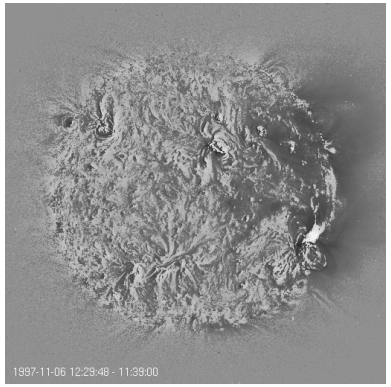
~ 0° – NOT global!

True angular widths of dimmings

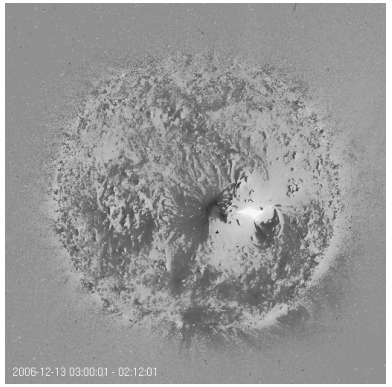
~30º

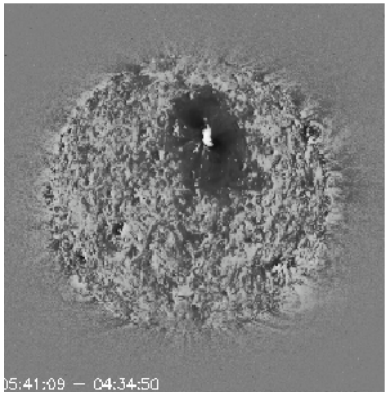


~90º

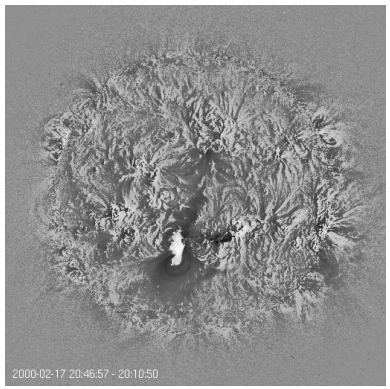


~140º

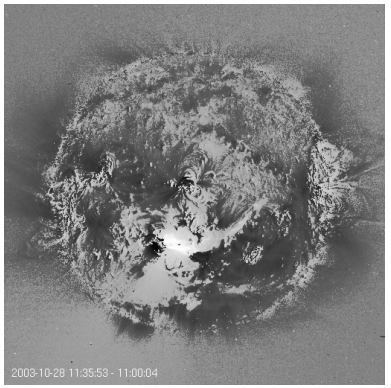




~70º – a typical CME width



~100º



~180º – global CME

There seems to exist a continuous distribution of dimming true angular widths!

Global CMEs: statistics

(Zhukov & Veselovsky 2007)

TABLE 1

EXAMPLES OF GLOBAL CMEs IN 2000–2005

CME Start Time[a]	CME Speed (km s^{-1})	CME E_{kin}[b] (erg)	CME AW[c] (deg)	Dimming Time[d]	Extent[e] (deg)	Flare[f]	Active Region[g]
2000 Jul 14, 10:54 ...	1674	1.9×10^{32}	360	10:58	210	X5.7, 10:24	9077; N22°, W07°
2001 Apr 6, 19:30	1270	6.8×10^{31}	360	19:59	190	X5.6, 19:21	9415; S21°, E31°
2001 Aug 15, 23:54 ..	1575	1.3×10^{32}	360	00:25	270	None	Back side
2002 Jul 16, 16:02 ...	1636	...	360	16:35	280	None	Back side
2003 Oct 28, 11:30 ...	2459	1.2×10^{33}	360	11:47	350	X17.2, 11:10	0486; S16°, E08°
2003 Oct 29, 20:54 ...	2029	3.4×10^{32}	360	21:24	280	X10.0, 20:49	0486; S15°, W02°
2003 Nov 2, 17:30 ...	2598	1.6×10^{32}	360	17:59	190	X8.3, 17:25	0486; S14°, W56°
2003 Nov 4, 19:54 ...	2657	6.1×10^{32}	360	20:35	190	X28.0, 19:50	0486; S19°, W83°
2005 Jan 15, 23:06 ...	2861	...	360	23:11	200	X2.6, 23:02	0720; N15°, W05°
2005 Jan 19, 08:29 ...	2020	...	360	08:46	210	X1.3, 08:22	0720; N15°, W51°

10 global CMEs 2000 – 2005

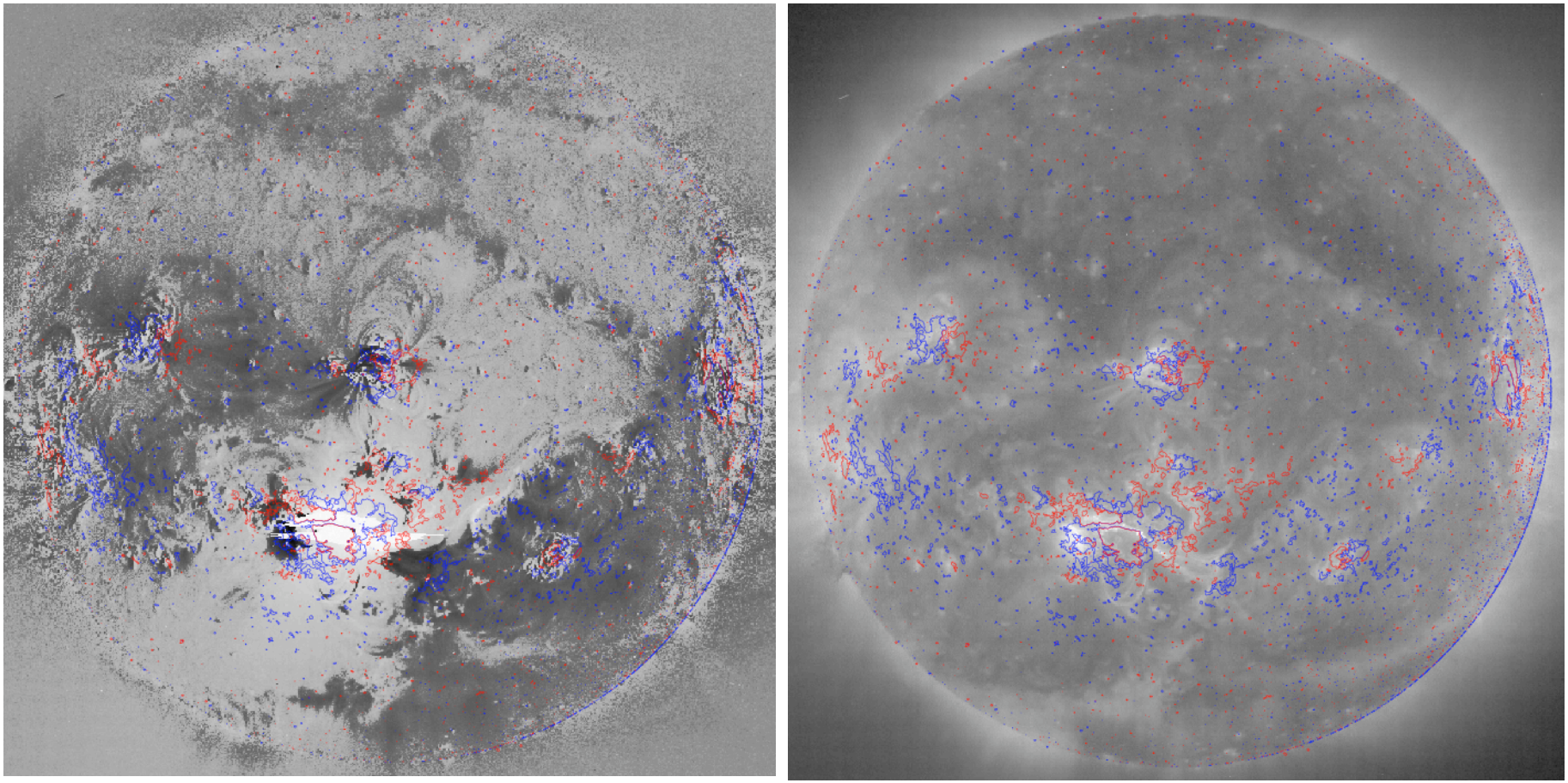
Very high speed (more than 1250 km/s) and kinetic energy!

All global CMEs are full halos!

Associated with strong flares: X1.3 and higher!

However, of 13 flares stronger than X5 observed by EIT in 1997–2006, only 6 were associated with global CMEs.

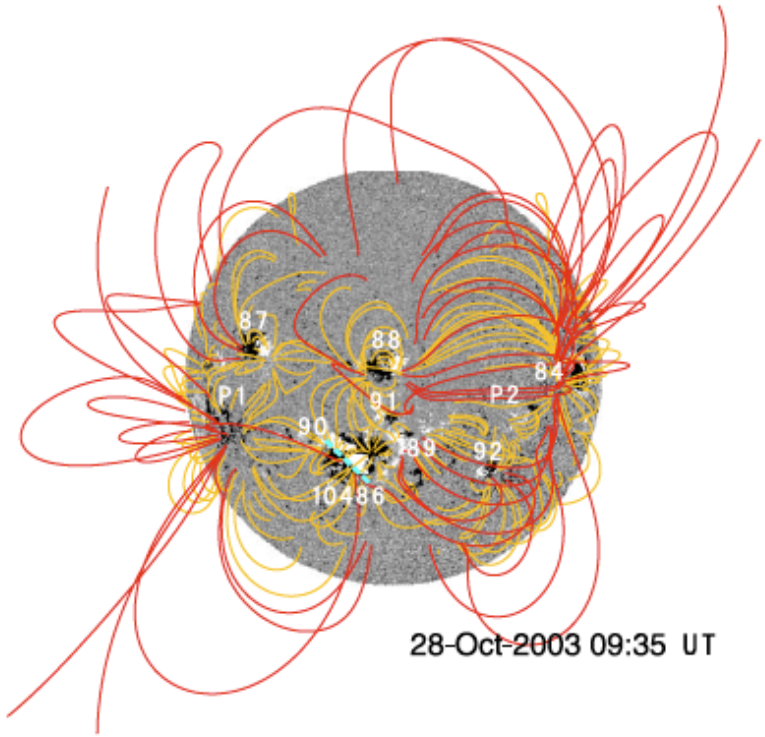
GLOBAL CMES: ERUPTION OF MULTIPOLAR MAGNETIC FIELDS!

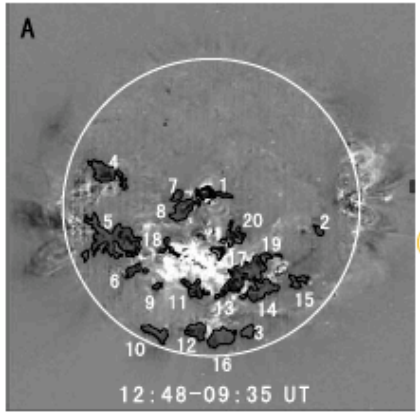


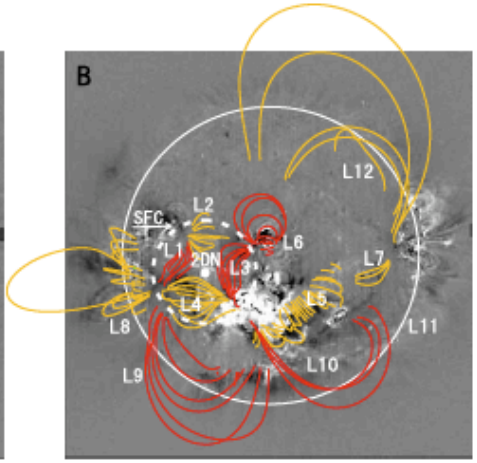
SOHO/EIT and SOHO/MDI

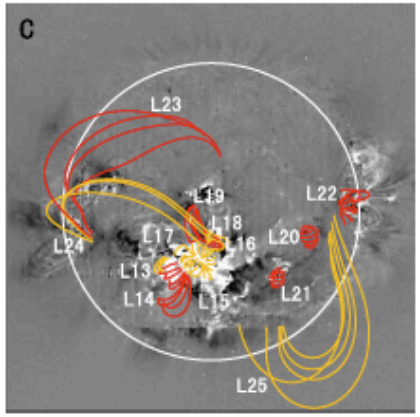
(Zhukov & Veselovsky 2007)

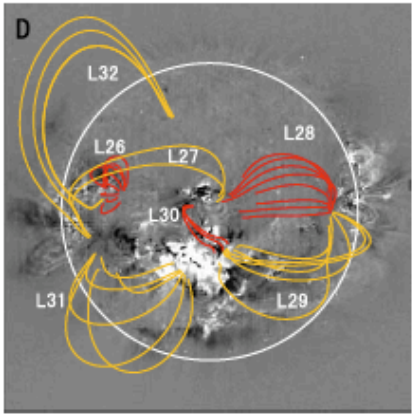
GLOBAL CMES: ERUPTION OF MULTIPOLAR MAGNETIC FIELDS!





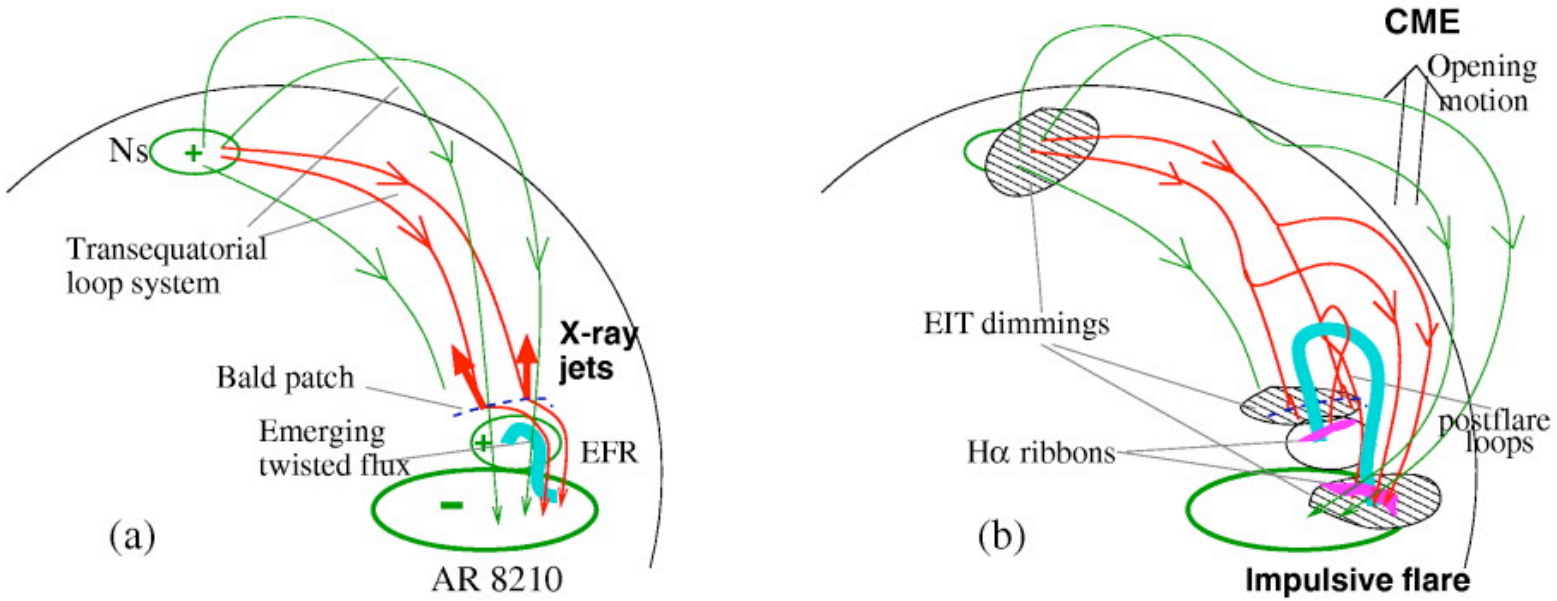






(Zhang et al. 2007)

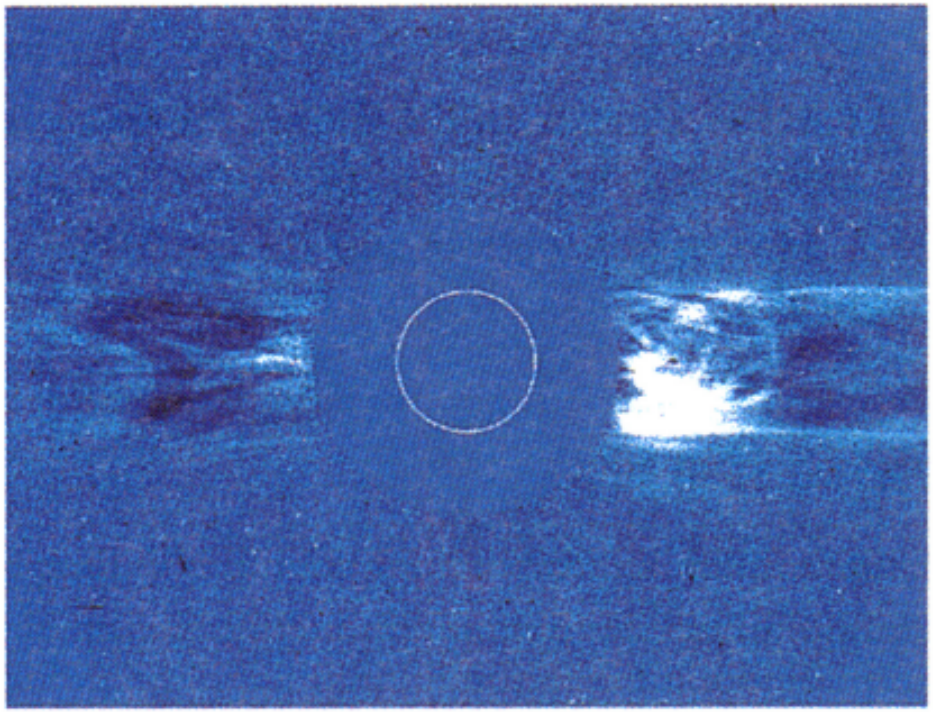
Eruption of multiple magnetic flux systems: radial imbalance of the magnetic force



(T. Wang et al. 2002)

Pushing the overlying (often transequatorial) magnetic flux by the main erupting flux of the active region *(Delannée & Aulanier 1999; T. Wang et al. 2002; Liu et al. 2006)*, leading to the opening of large-scale overlying loops.

Global CMEs are NOT toroidal CMEs *(Brueckner et al. 1998)*

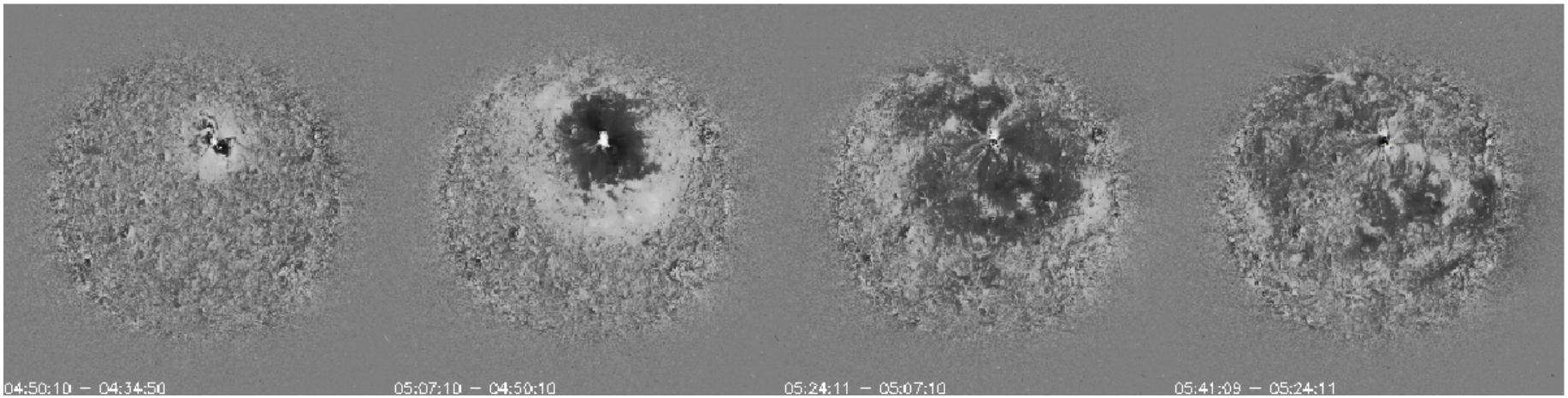


(4) 1997/05/21 22:00 UT

Global CMEs are NOT global EIT waves

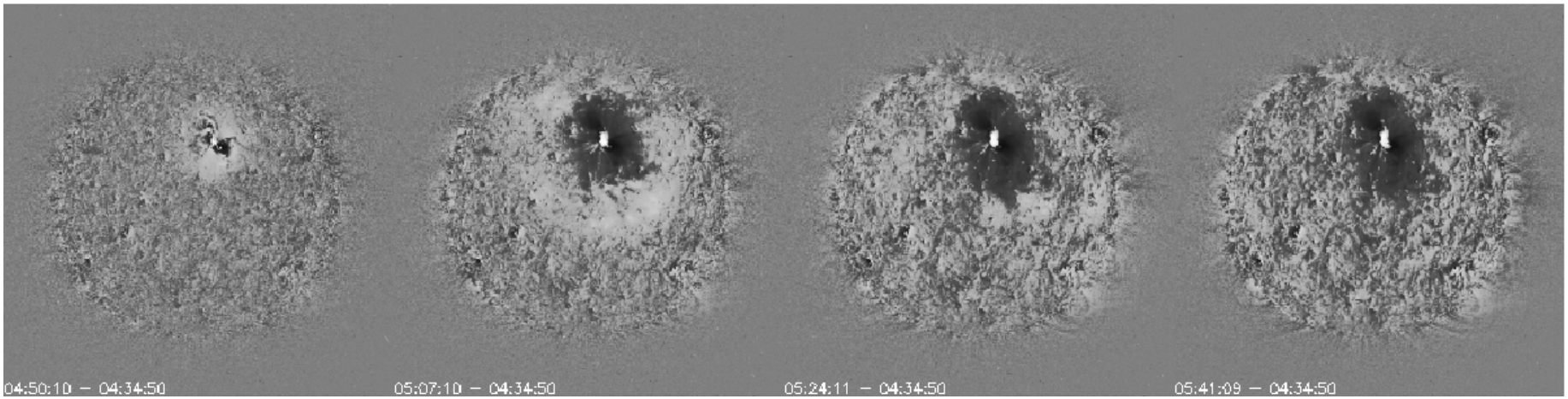
Running difference images

EIT wave is global!



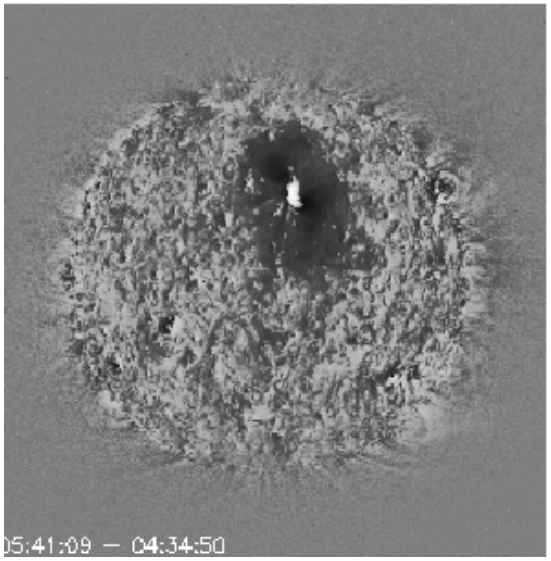
Base difference images

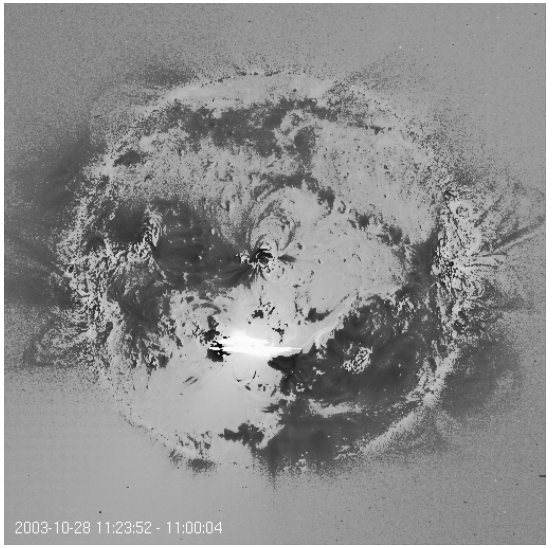
Coronal dimming is local!



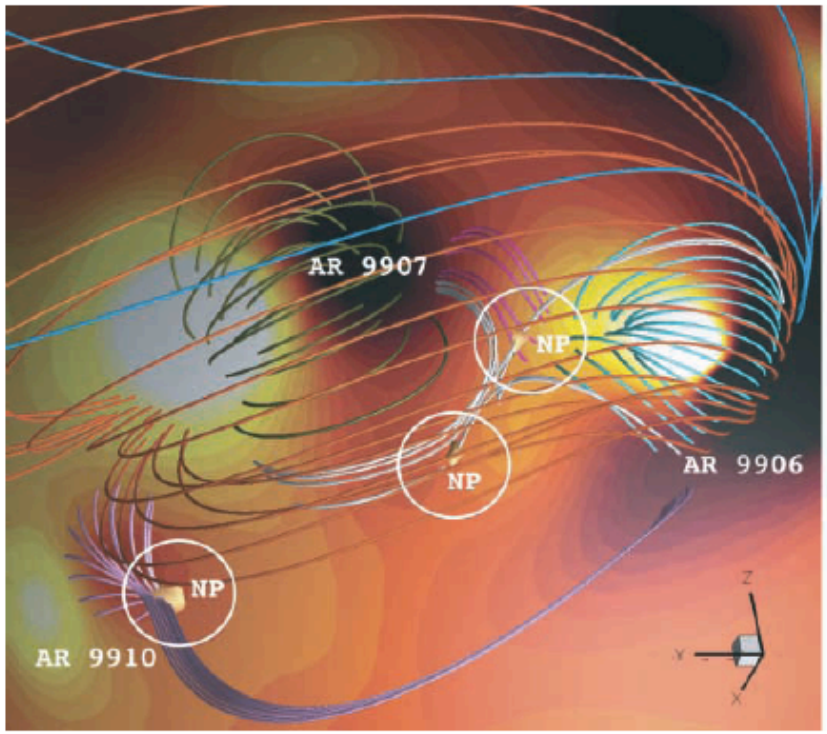
Global CMEs are NOT global EIT waves

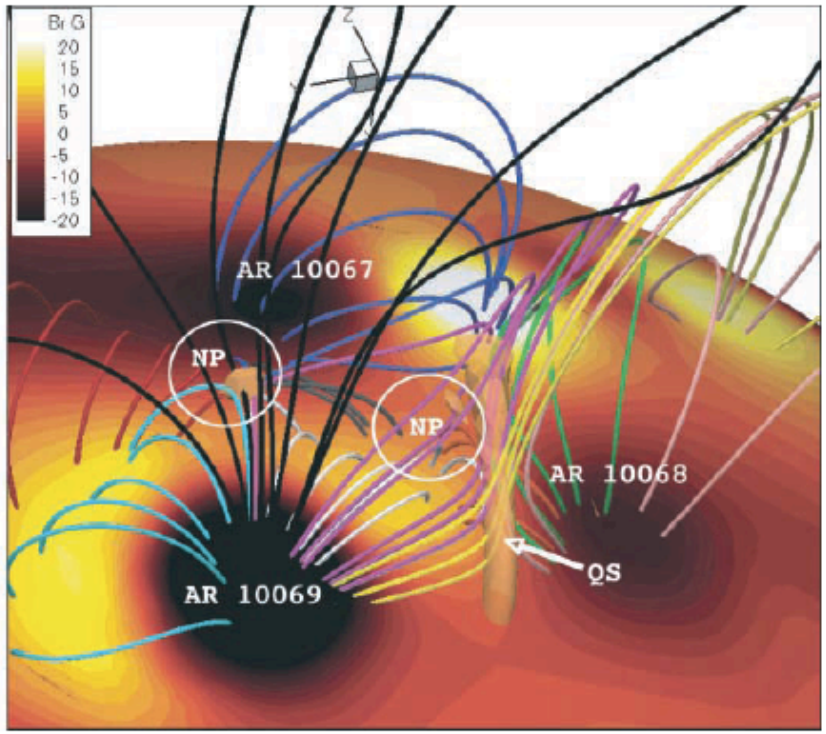
- However, in common cases of local CMEs the EIT wave speed is around 300 km/s
- In the October 28, 2003 global CME event a Moreton wave was observed, propagating at a speed of 1300–2100 km/s
- As the speed of the incident shock wave should be higher than the local Alfvén speed, then $\rho\, v^2/2 > B^2/8\pi$ Eruption possible?





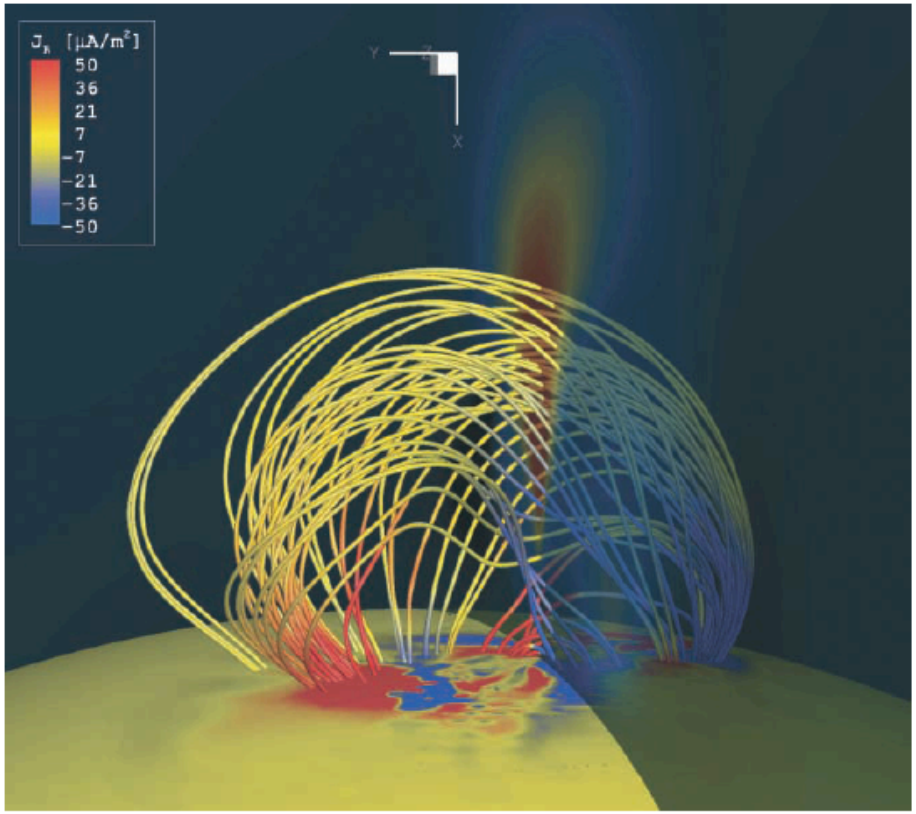
Numerical models of CMEs in realistic multipolar magnetic topologies





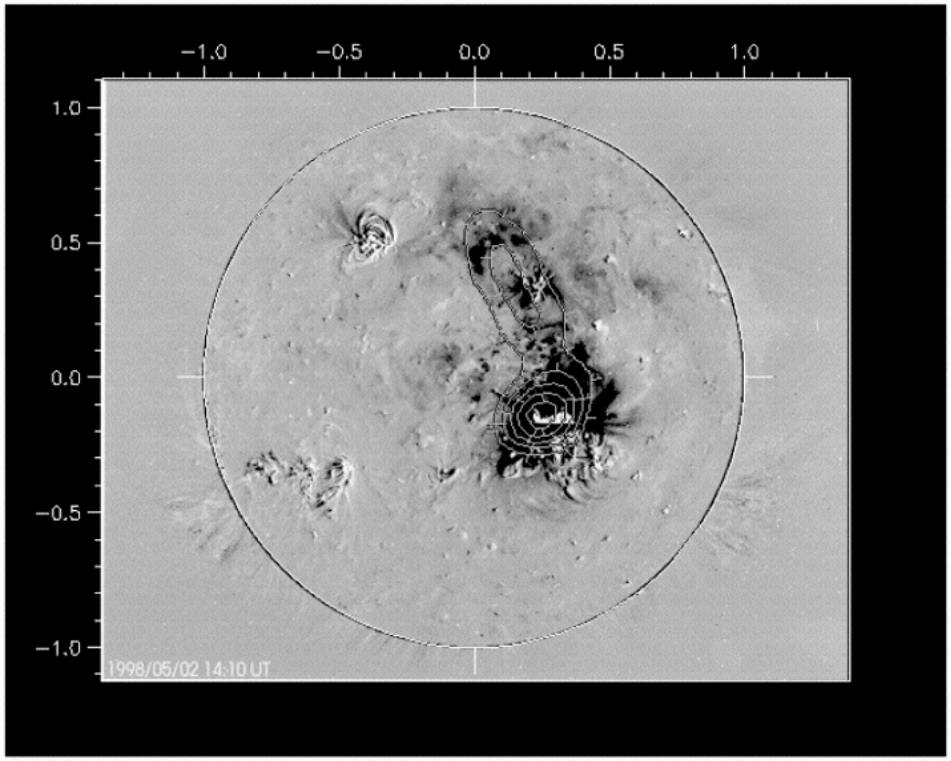
The erupting field is found to be a mixture of magnetic elements from various flux systems. This is a consequence of reconnection between neighboring flux systems through pre-existing null points and quasi-separators *(Roussev et al. 2007)*.

Numerical models of CMEs in realistic multipolar magnetic topologies



The erupting field is found to be a mixture of magnetic elements from various flux systems. This is a consequence of reconnection between neighboring flux systems through pre-existing null points and quasi-separators *(Roussev et al. 2007)*.

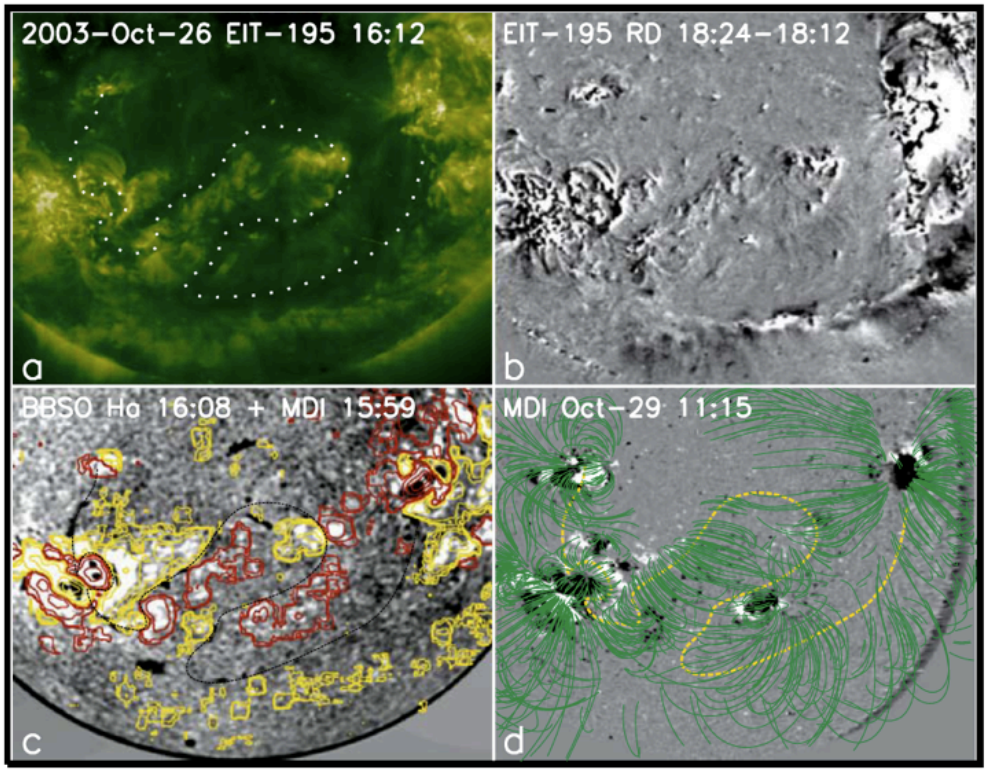
Flare-accelerated electrons may provoke departure from the state of the ionization equilibrium *(an idea by E. Marsch)*



(Pohjolainen et al. 2001)

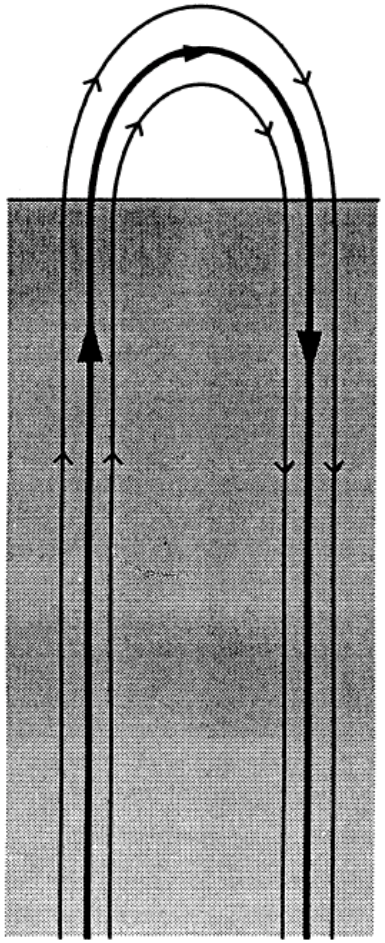
Dimmings often coincide with locations of intense radio continuum emission. The radio emission appears shortly (around 20 minutes) before the dimming *(Pohjolainen et al. 2001, Wen et al. 2006)*.

Non-local coupling of distant magnetic flux systems



(Zhou et al. 2007)

Alfvén speed in filament/prominence cavities ($B \sim 10$ G, $n \sim 10^7$ cm^{-3}) may well reach 7000 km/s!



Non-local electric current circuit closed deep in the convection zone *(Melrose 1995)*.

CONCLUSIONS

- Global CMEs are rare events characterized by a very large extent of coronal dimmings. They belong to the tail of the continuous distribution of dimming true angular widths.

- During such extreme events a huge amount of the free energy is released in the form of both kinetic (CME) and radiative (flare) energy.

- Global CMEs correspond to the ejection of plasma from multiple interconnected large-scale coronal magnetic flux systems.

- Dimmings may be considered an important nonlocal manifestation of the CME initiation process and need to be described in a realistic CME model.

- A major observational limitation is a low cadence (12 minutes) of SOHO/EIT – we need high-cadence EUV imaging from KuaFu!