Relationships between flares and CMEs

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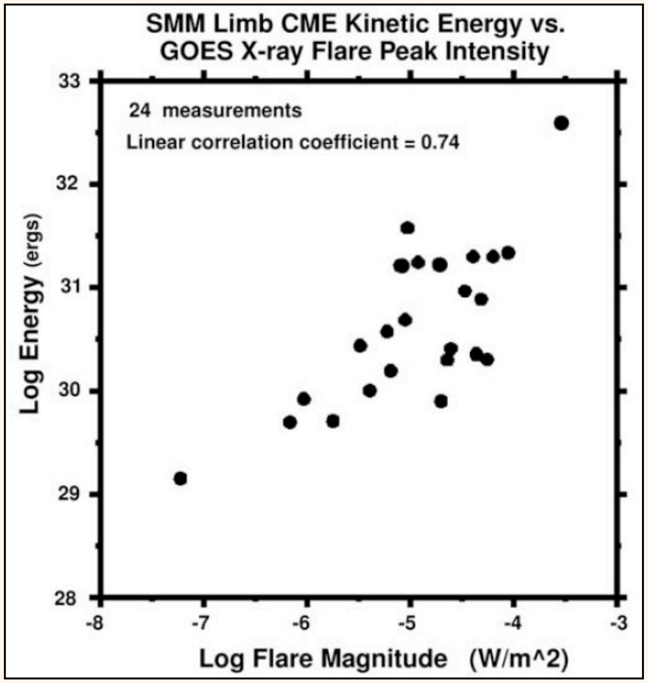
Contents

- Historical stuff
- Energy and field
- RHESSI coronal hard X-ray sources
- Conclusions

Historical high points

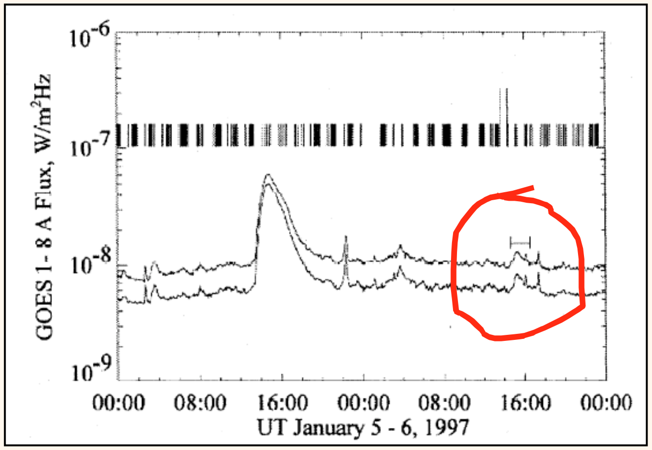
- Recognition of CME phenomenon as distinct and geoeffective
- Clear evidence from the January 1997 event (Webb et al., 1998) that yes, CMEs can happen without “flares” **A**
- Clear association of CME dynamics with compact, low-lying structures (X-ray dimming; Dere et al. 1997)
- The ill-considered controversy on causality arising from the “myth” debate **B**

B

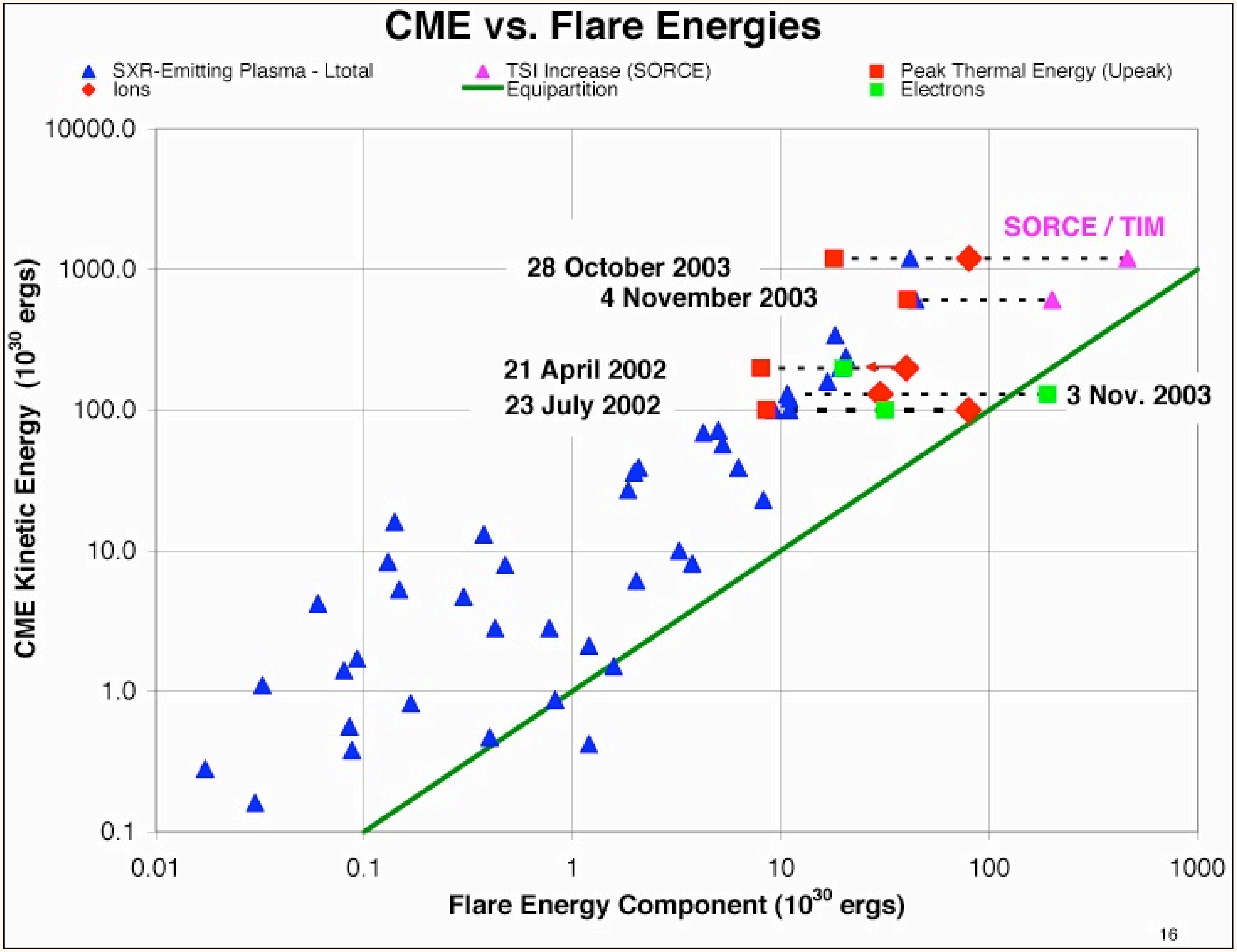


CME and flare energies are well-correlated after all!
- Burkepile et al. 2004

A



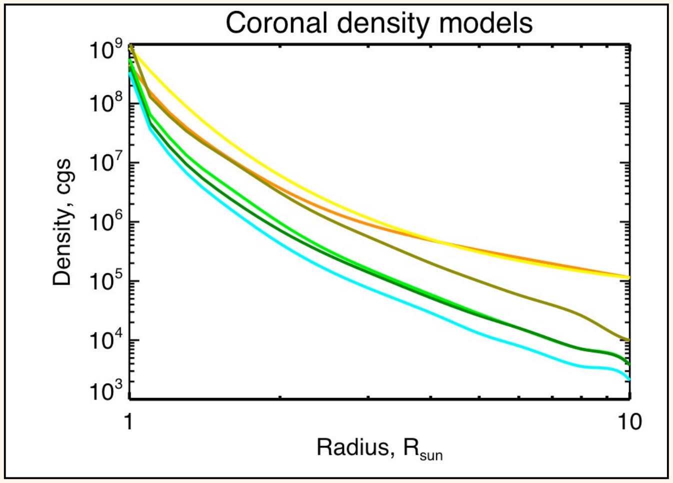
"…remarkably weak and unimpressive…"
- Webb et al. 1998

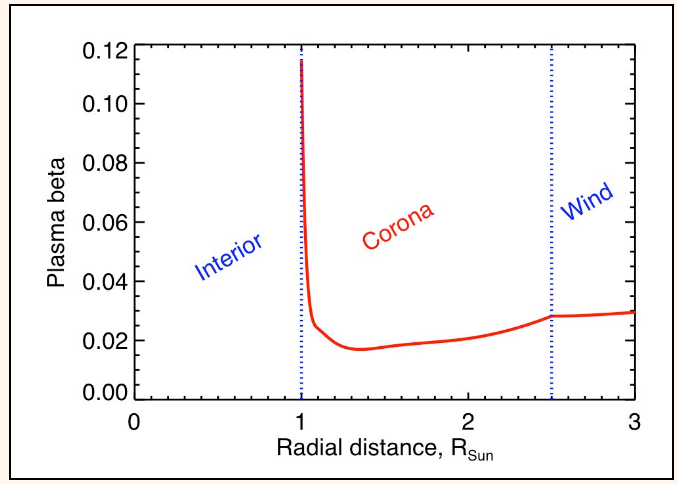


From Brian Dennis (2005)
http://sprg.ssl.berkeley.edu/~tohban/nuggets/?page=article&article_id=10

Density, field, energy

QS





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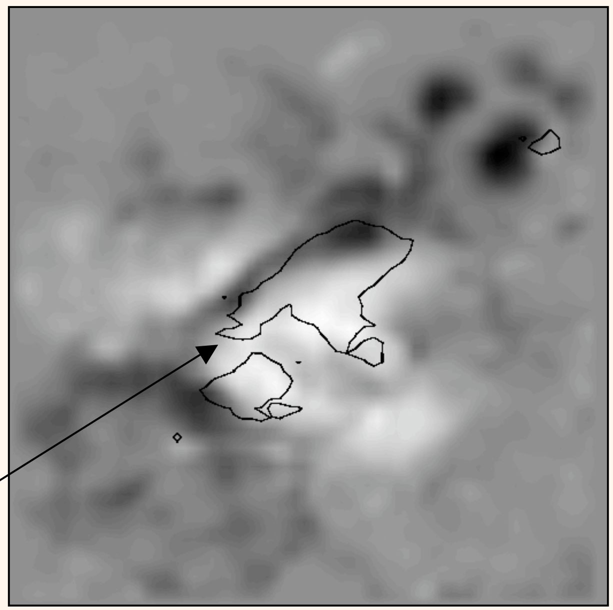
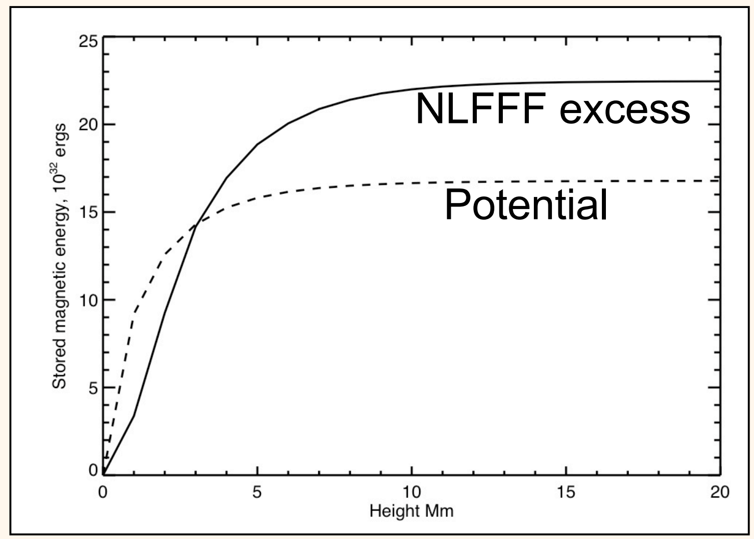


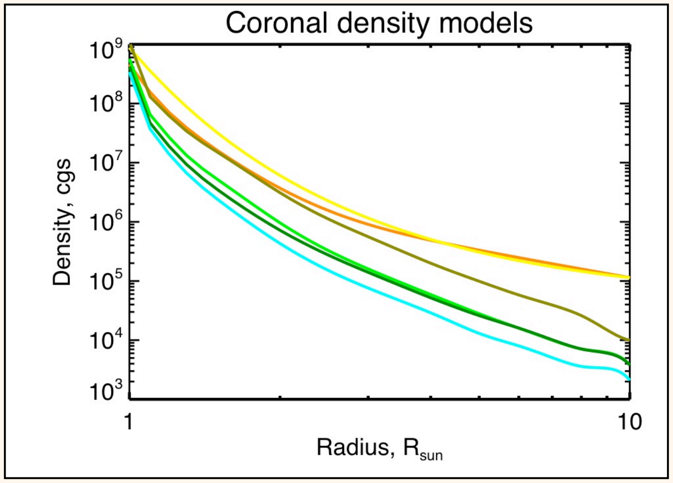
NLFFF excess
50% contour

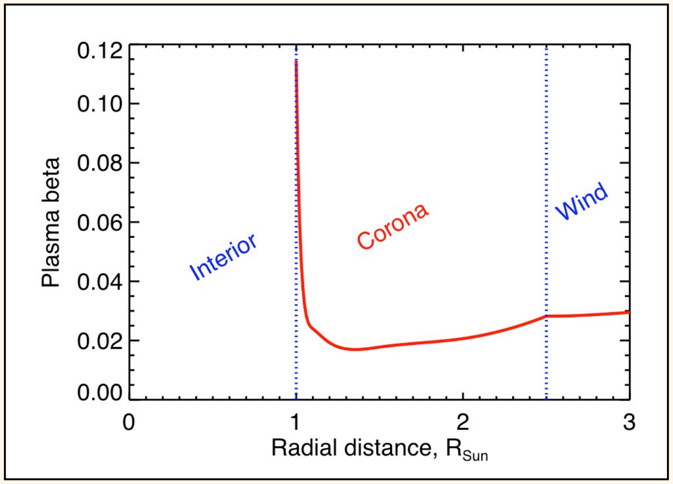


Wheatland et al. method,
NLFFF by J. McTiernan

Density, field, energy WG 2!

QS





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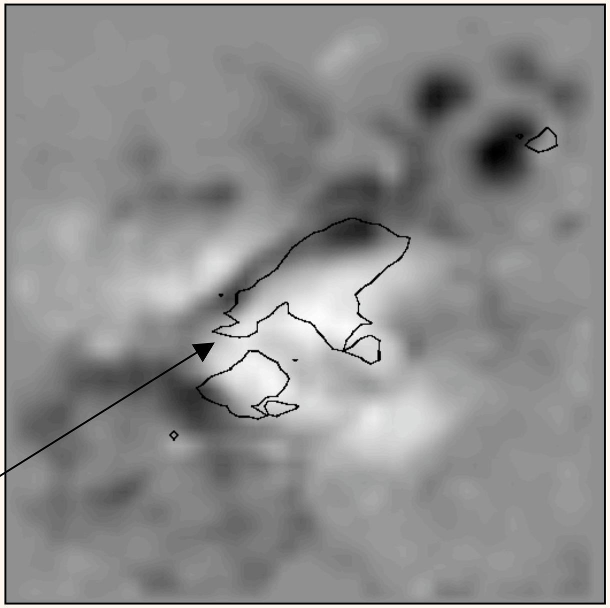

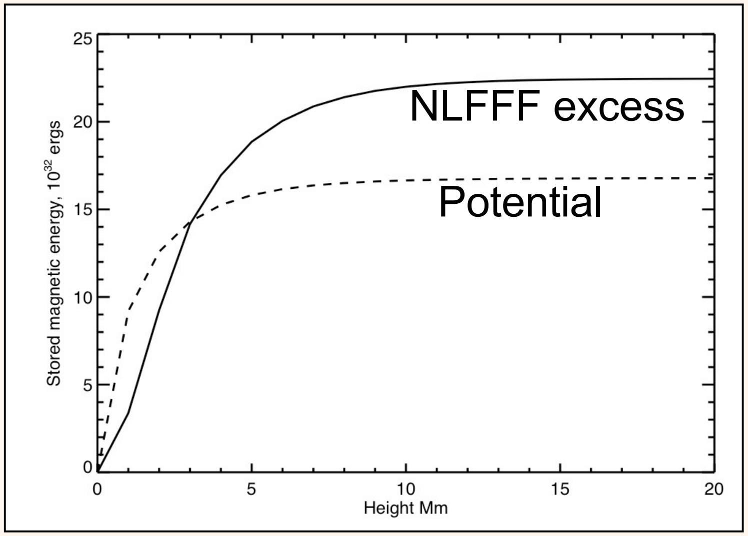

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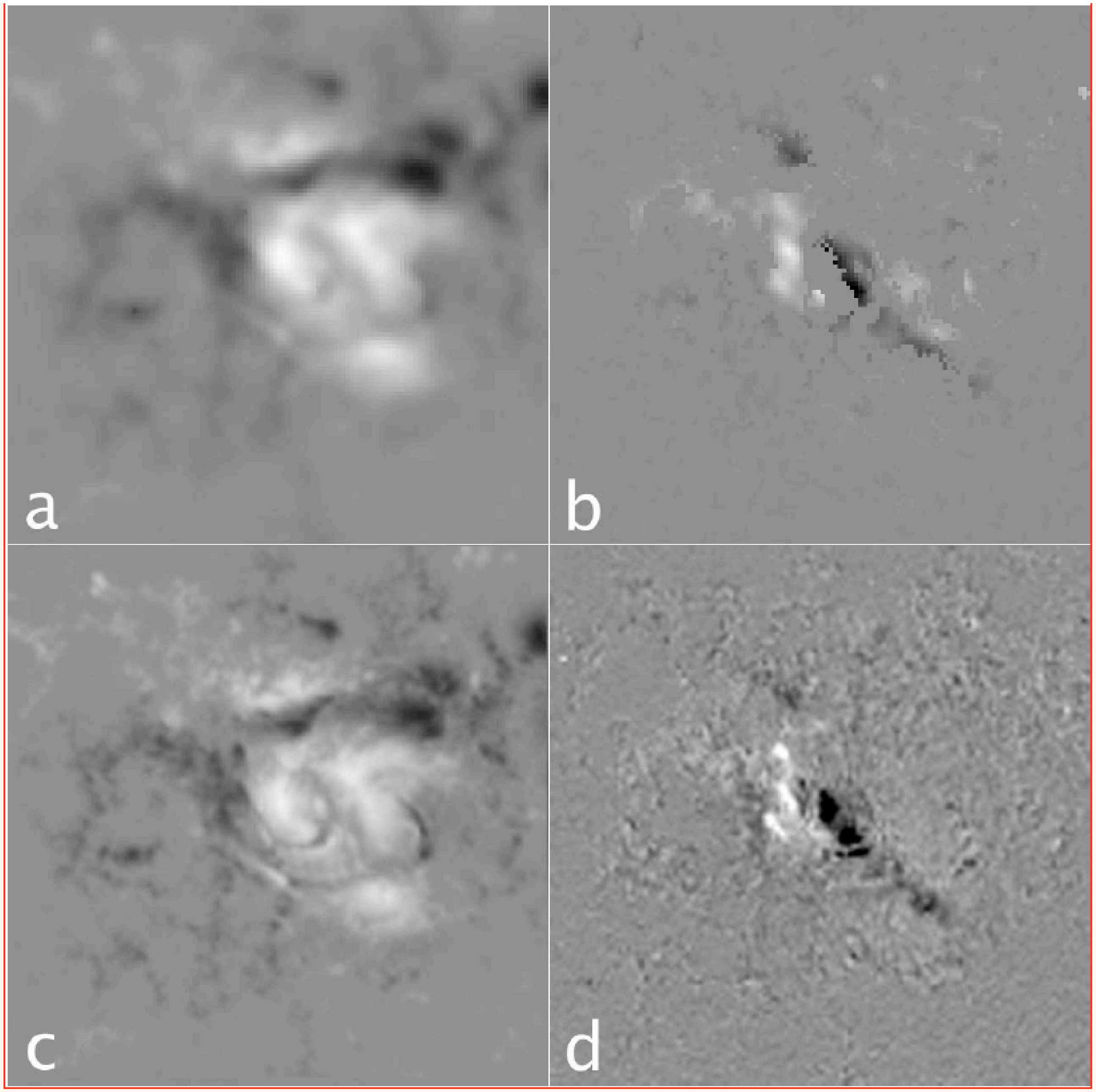
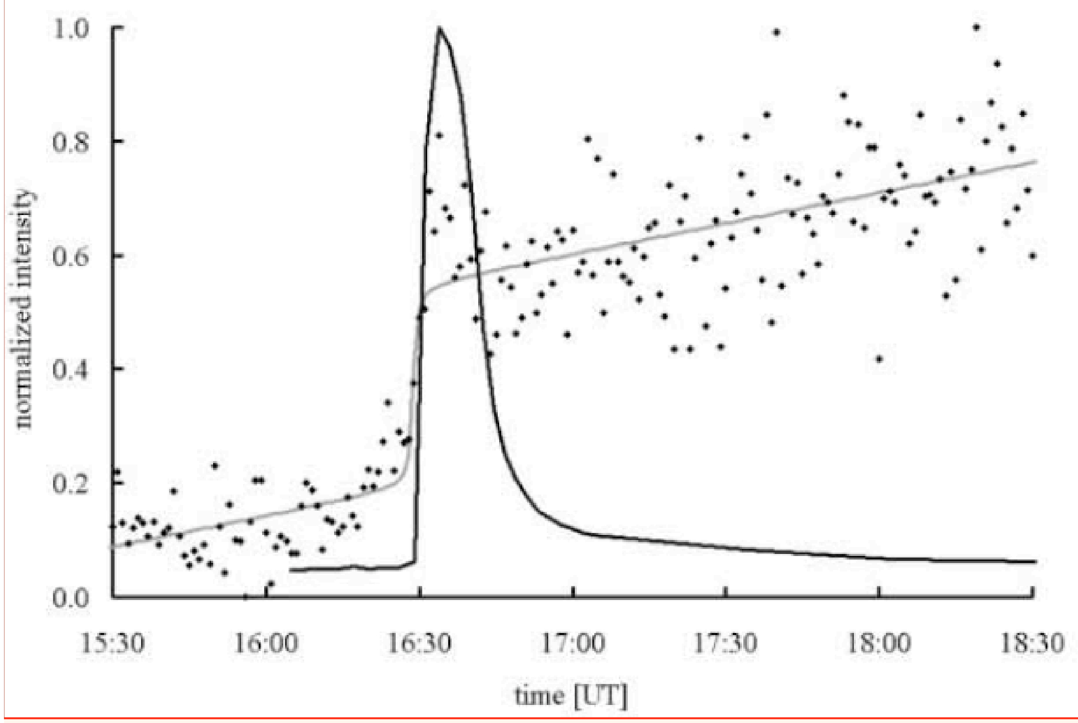


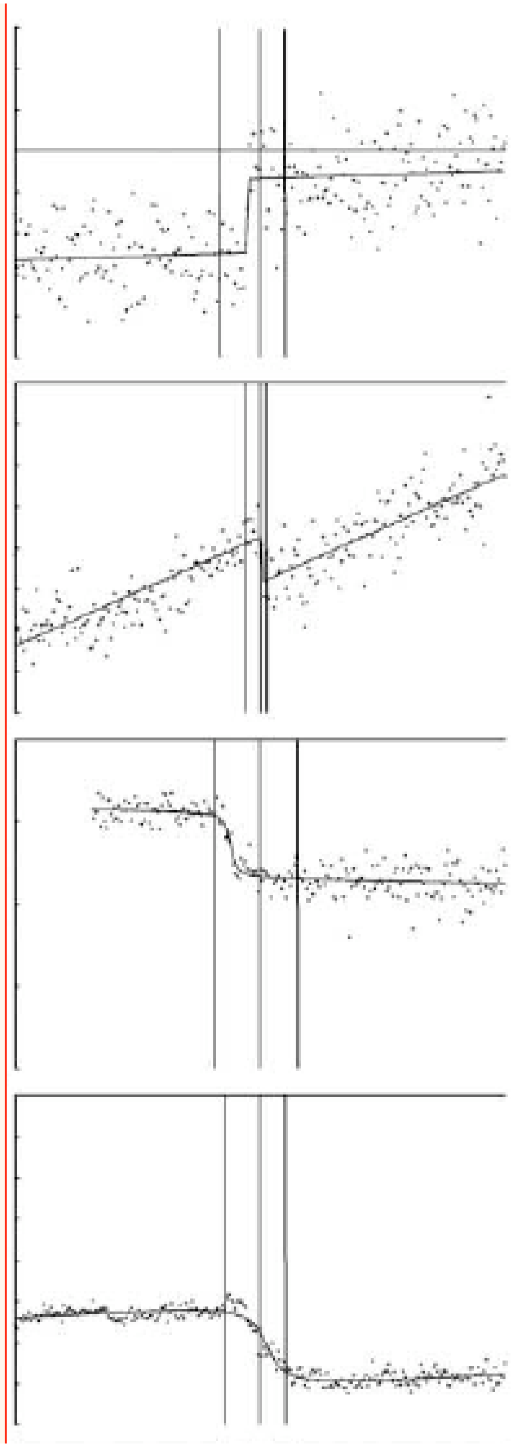
Sudol & Harvey (2005), flare of 2003 Oct. 29,
line-of-sight field differences



Flare of 2001 Aug. 25:
GONG + GOES

The changes are stepwise, of order 10% of the line-of-sight field, and primarily occur at the impulsive phase of the flare

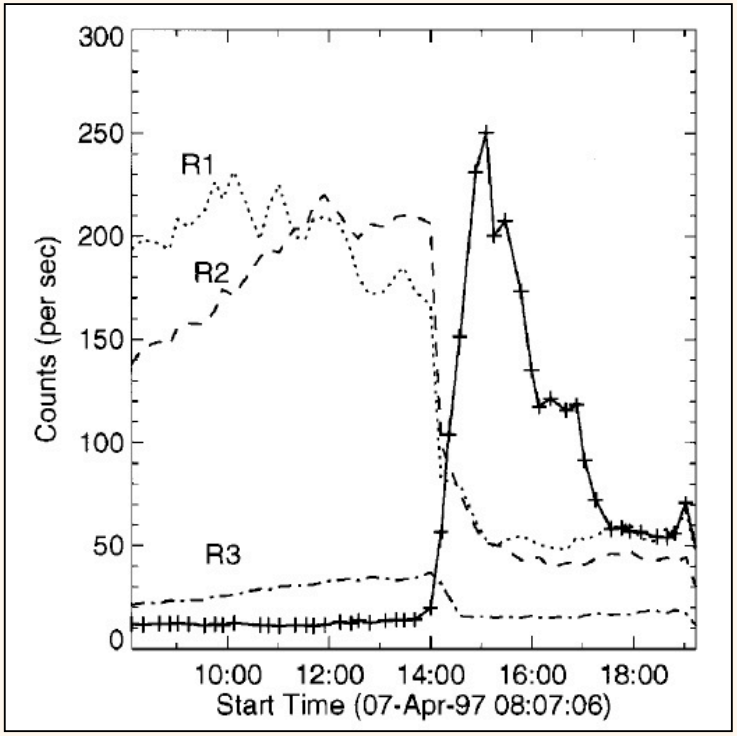
Other examples with GOES times



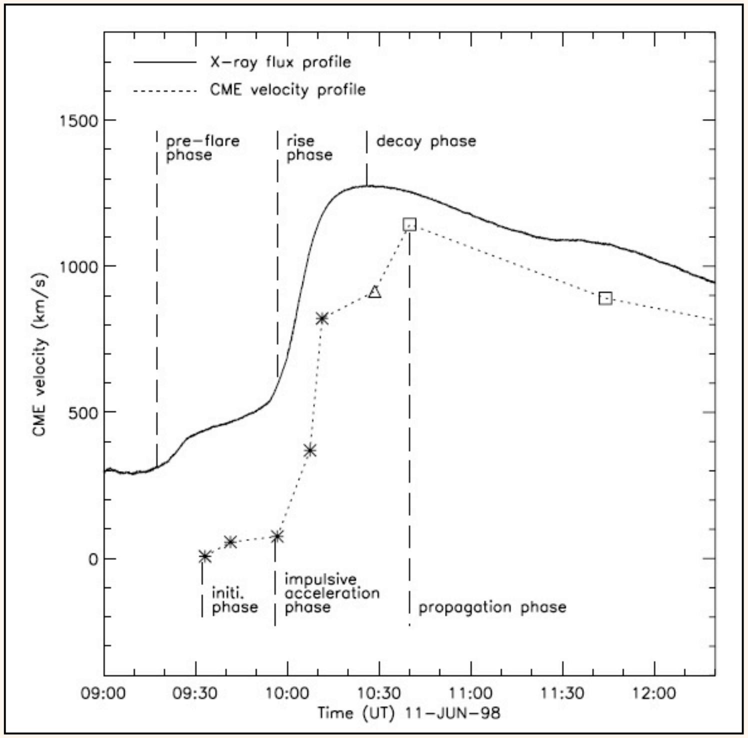
Questions about magnetic energy

- Is there enough stored energy?
- Are we losing energy by lack of sufficient angular resolution in the observations?
- Can direct coronal observations (polarization, FASR) solve our problems?
- Is there energy on large scales that NLFFF approaches cannot properly deal with?
- What about the solar wind?

Timing of acceleration phase and dimming

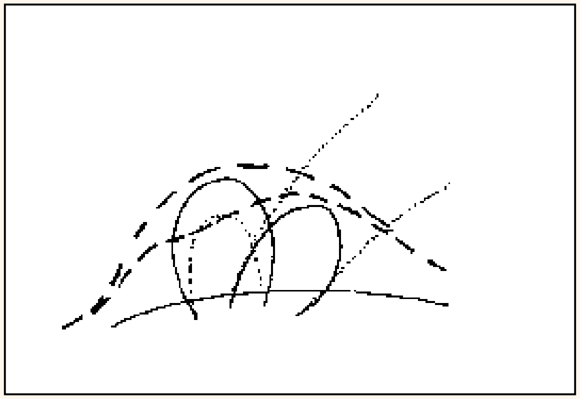


Zarro et al. 1999

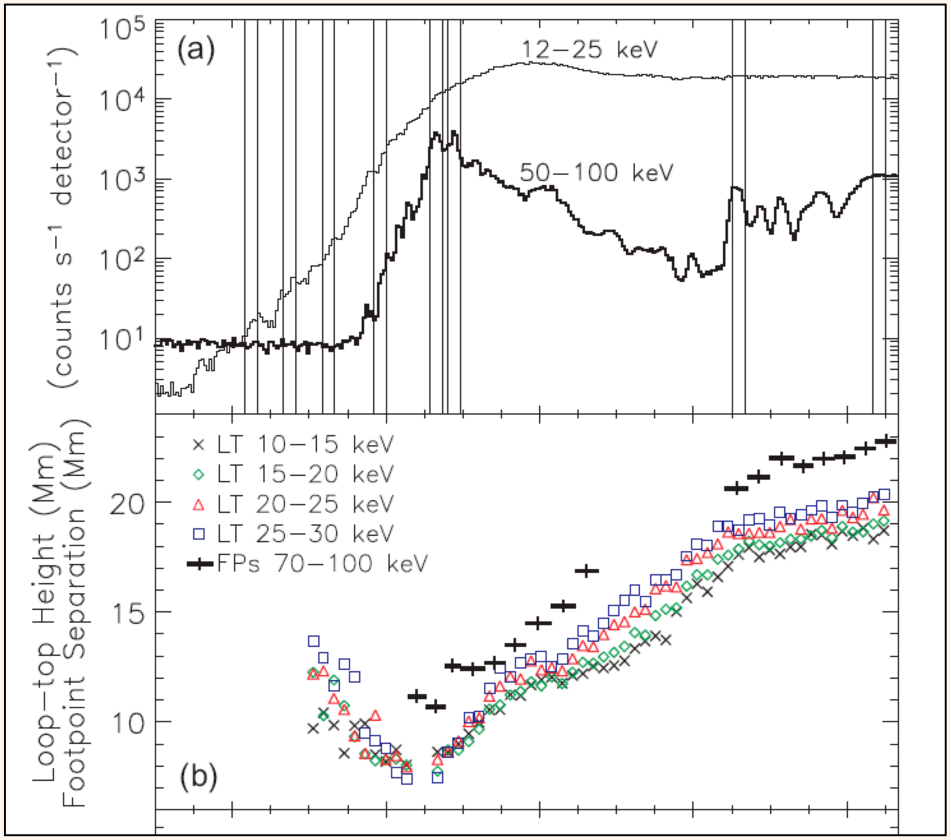


Zhang et al. 2001

Implosive motion

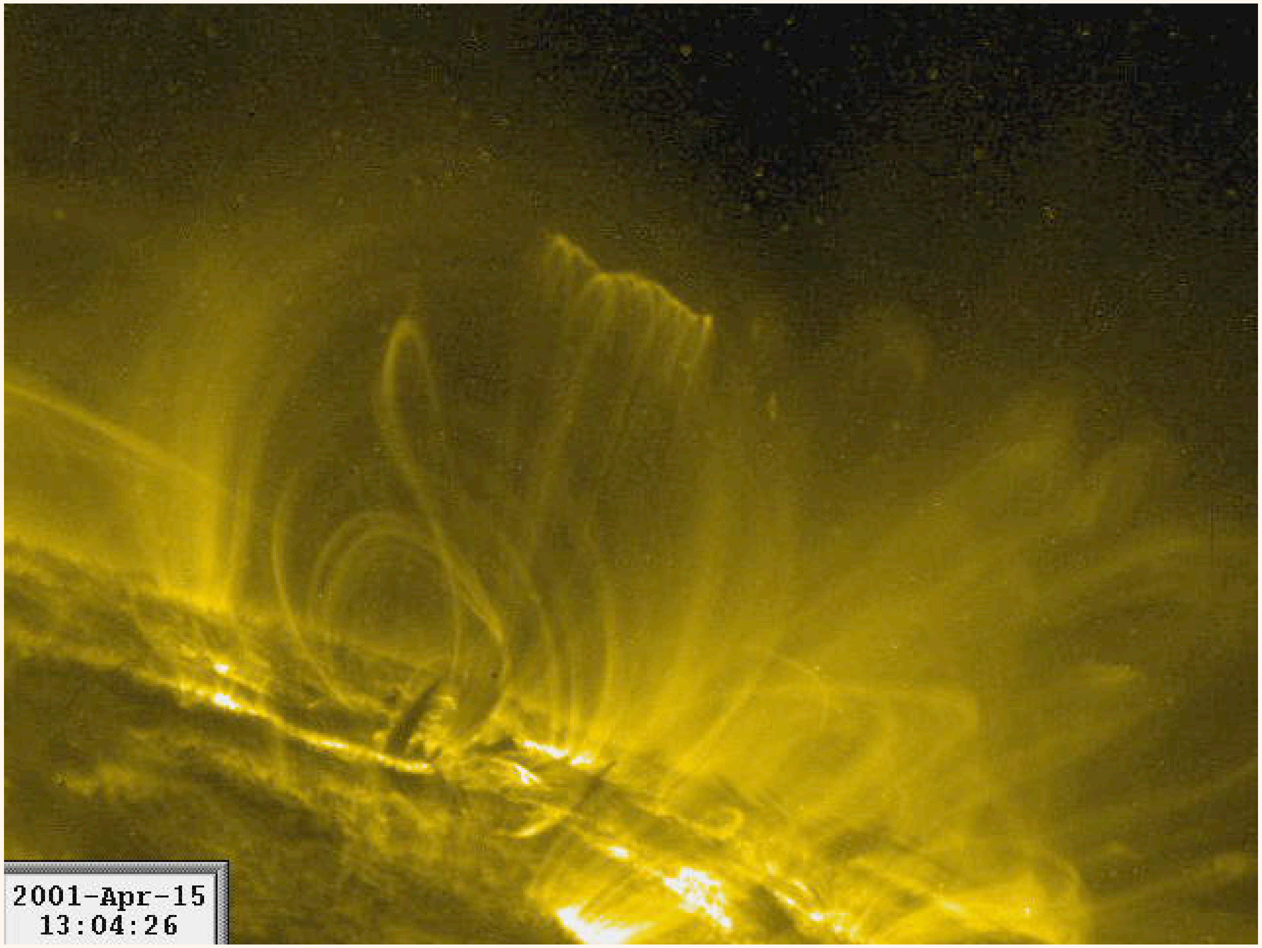


Hudson 2000



Veronig et al. 2005

TRACE movie: dimming and implosion

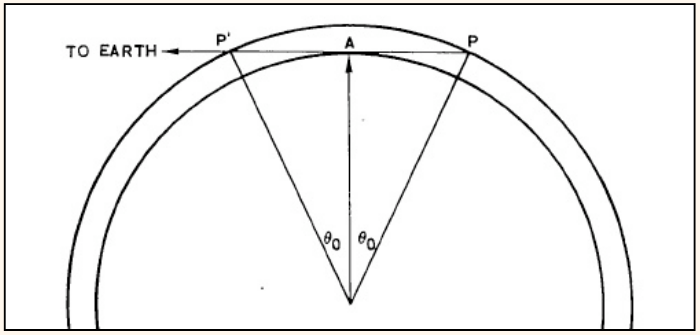


Global waves

- Metric type II bursts
- Moreton waves (a.k.a. *tsunami*)
- Heliospheric type II bursts
- EIT waves
- Seismic wave

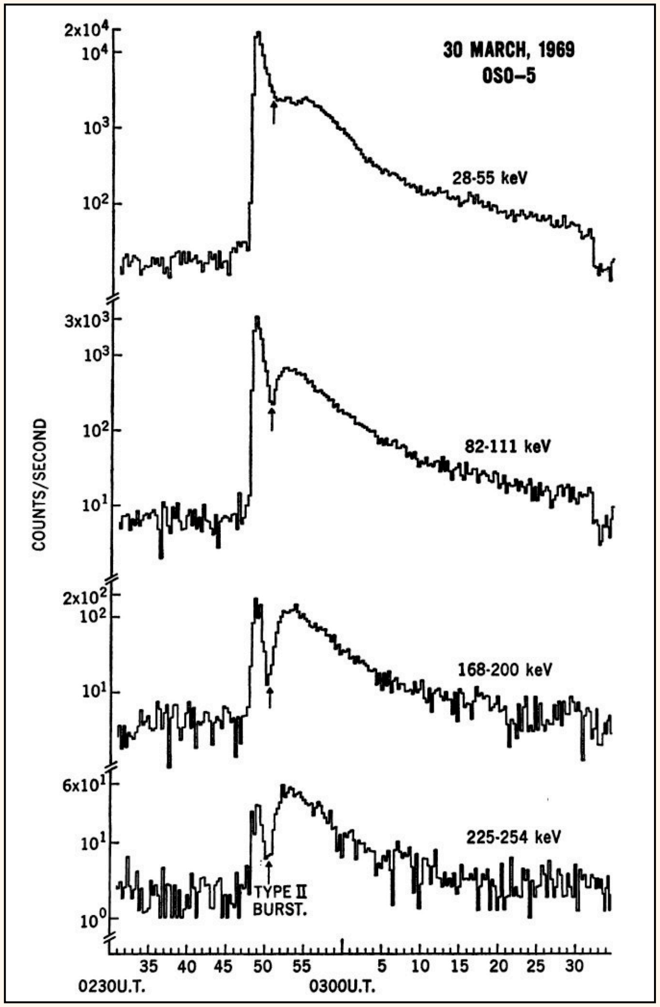
Except for the CME bow shocks, all of these waves point rather directly to the flare restructuring. What can we learn about this from how they are excited?

Disk occultation

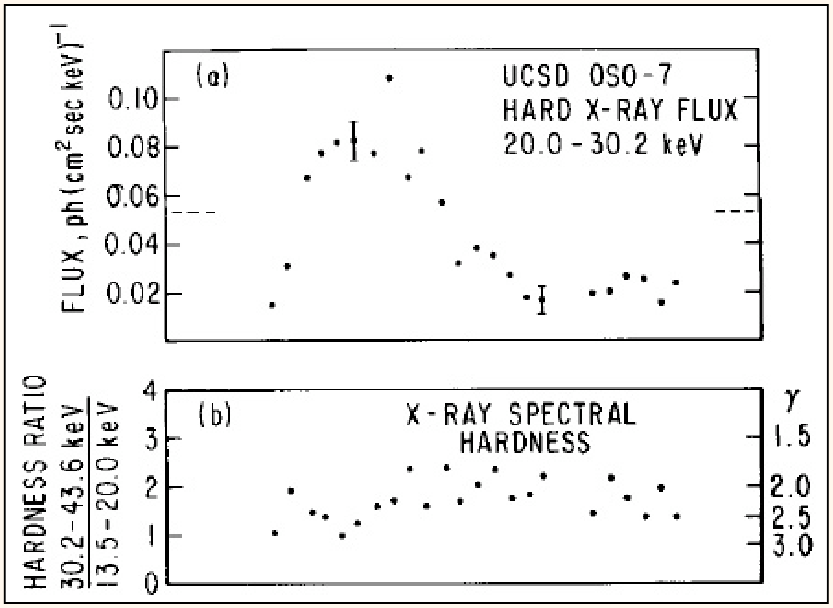


$$\cos\theta = \left[\left(\frac{R}{R+h}\right)^2 \times \sec^2\psi - \tan^2\psi\right]^{1/2}$$

McKenzie 1975



Frost & Dennis 1971



Hudson 1978

Coronal hard X-ray sources

Table 1 Coronal hard X-ray sources: representative parameters

Type[a]	Phase[b]	Archetype event (d/m/y)	Number studied	Height Mm	E_{obs} keV	F_{30}[c]	γ[d]	Density cm^{-3}	Δt Min	Scale Mm	Velocity[e] $km\ s^{-1}$
Early	(1)	23/07/2002 [1]	3	20	<100	10	5	$\sim 10^{10}$	5	5	small
Masuda	(2)	13/01/1992 [2]	<10	20	25-50	0.2	3-4.5	$<10^9$	2	5	small
Coronal thick	(2)	14/04/2002 [3]	~5	20	<50	1	6-7	$\sim 10^{11}$	15	10	small
Fast ejecta	(2)	18/04/2001 [4]	10	>100	<100	0.1	4	$\sim 4 \cdot 10^9$	5	>20	$\sim 10^3$
High coronal	(2-3)	16/02/1984 [5]	10	>100	<100	0.1	3-5	$<10^9$	5	>20	$\sim 10^3$
Superhot	(3)	27/06/1980 [6]	many	20	<40	100	Th	–	5-30	–	–
Double	(2)	15/04/2002 [7]	3	30	15-25	–	Th	$\sim 10^{10}$	~3	10	complex
Occulted	(2-3)	2/12/1967 [8]	many	20	10-50	0.5	4-7	$\sim 10^{10}$	1-30	10	small
Late phase	(3)	30/03/1969 [9]	10	40	30-250	2	2	–	10-100	–	–
MeV	(3)	20/01/2005 [10]	3	20	200-10^3	2^f	2	$\sim 10^{10}$	10	<20	–
Footpoints	(1-3)	21/05/1980 [11]	many	–	5-10^3	100	2-5	$>10^{12}$	0.1-30	<3	–

[a] Not intended as a classification scheme
[b] Event phase: (1) pre-impulsive; (2) impulsive; (3) late
[c] Maximum reported, in ph/(cm^2 sec keV) at 30 keV
[d] Th = Thermal
[e] Apparent radial velocity
[f] Extrapolation

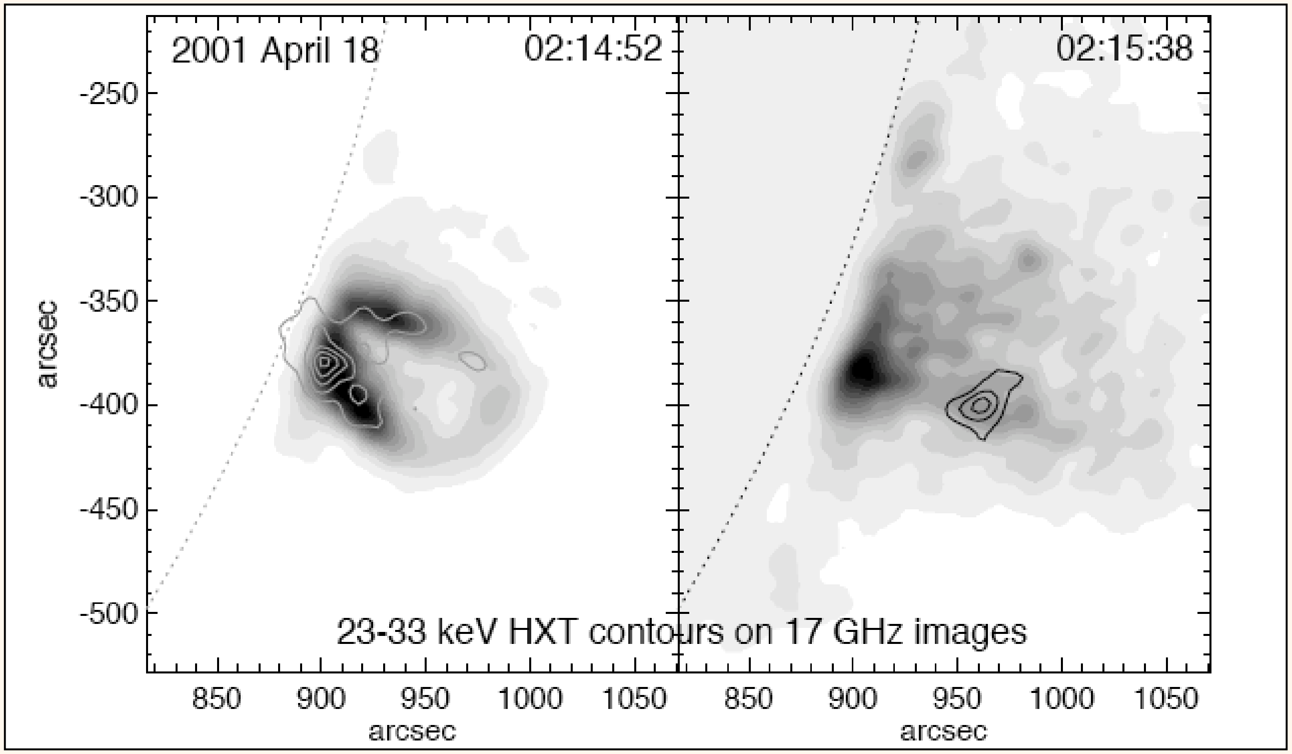
[1] Lin et al (2003)
[2] Masuda et al (1994)
[3] Veronig and Brown (2004)
[4] Hudson et al (2001)
[5] Kane et al (1992)
[6] Lin et al (1981)
[7] Sui and Holman (2003)
[8] Zirin et al (1969)
[9] Frost and Dennis (1971)
[10] Krucker et al (2008b)
[11] Hoyng et al (1981)

Krucker et al. 2008

What are the coronal sources?

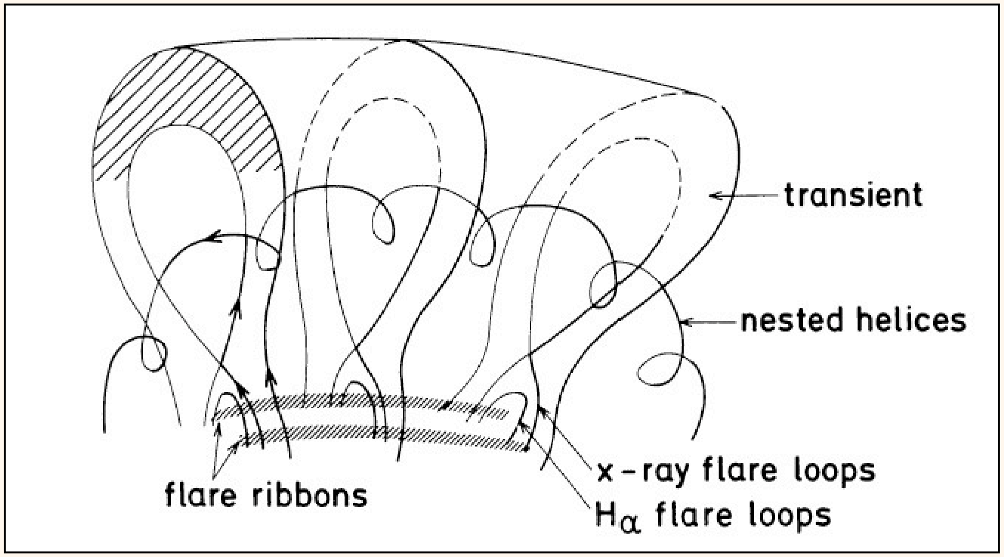
- Large numbers of fast electrons trapped stably in coronal mirror geometries
- Early-phase sources (cf. Masuda event) are mysterious and probably really important
- Possibility that the tail of the electron distribution is the dominant pressure
- Moving sources may wind up being identified with the filament region of the CME

Prototype moving source

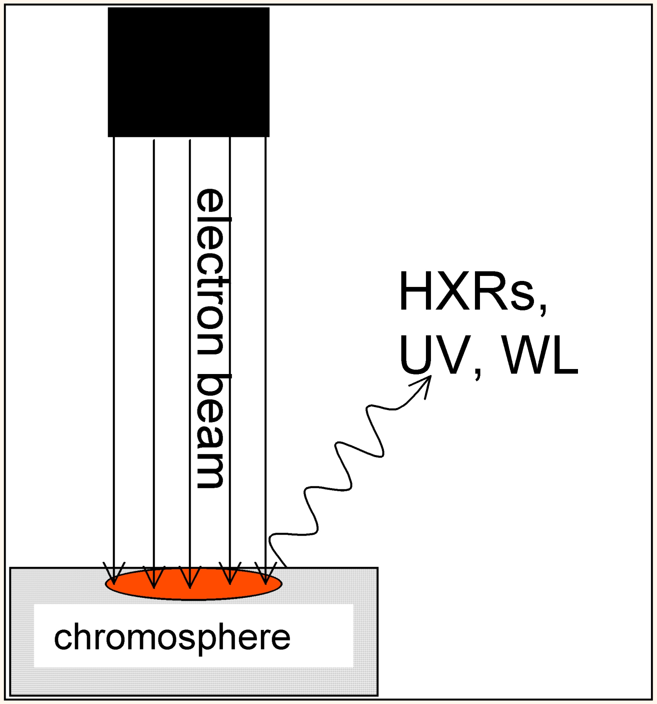


Hudson et al. 2001

Background information (flare models)

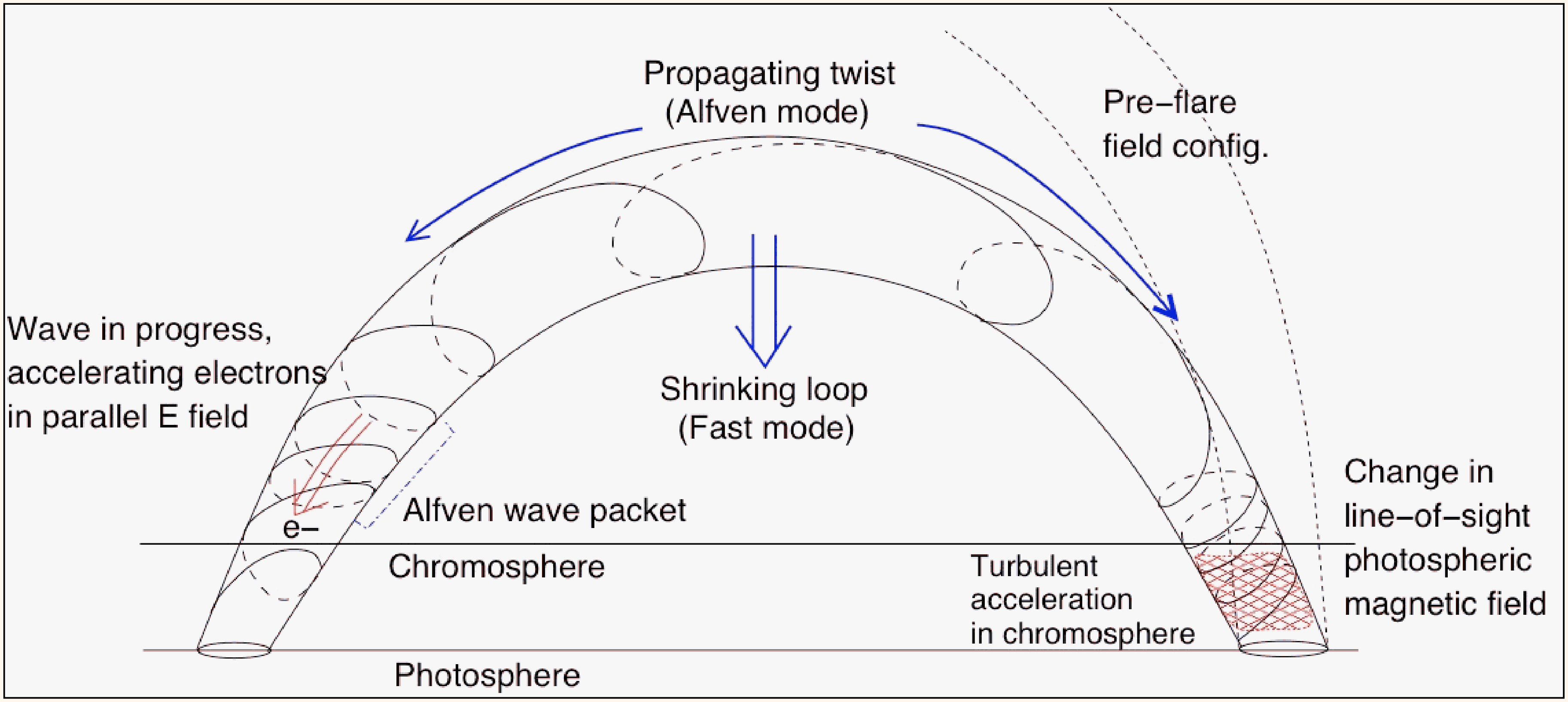


The "CSHKP" model
(Anzer & Pneuman 1982)



The thick-target model
(L. Fletcher)

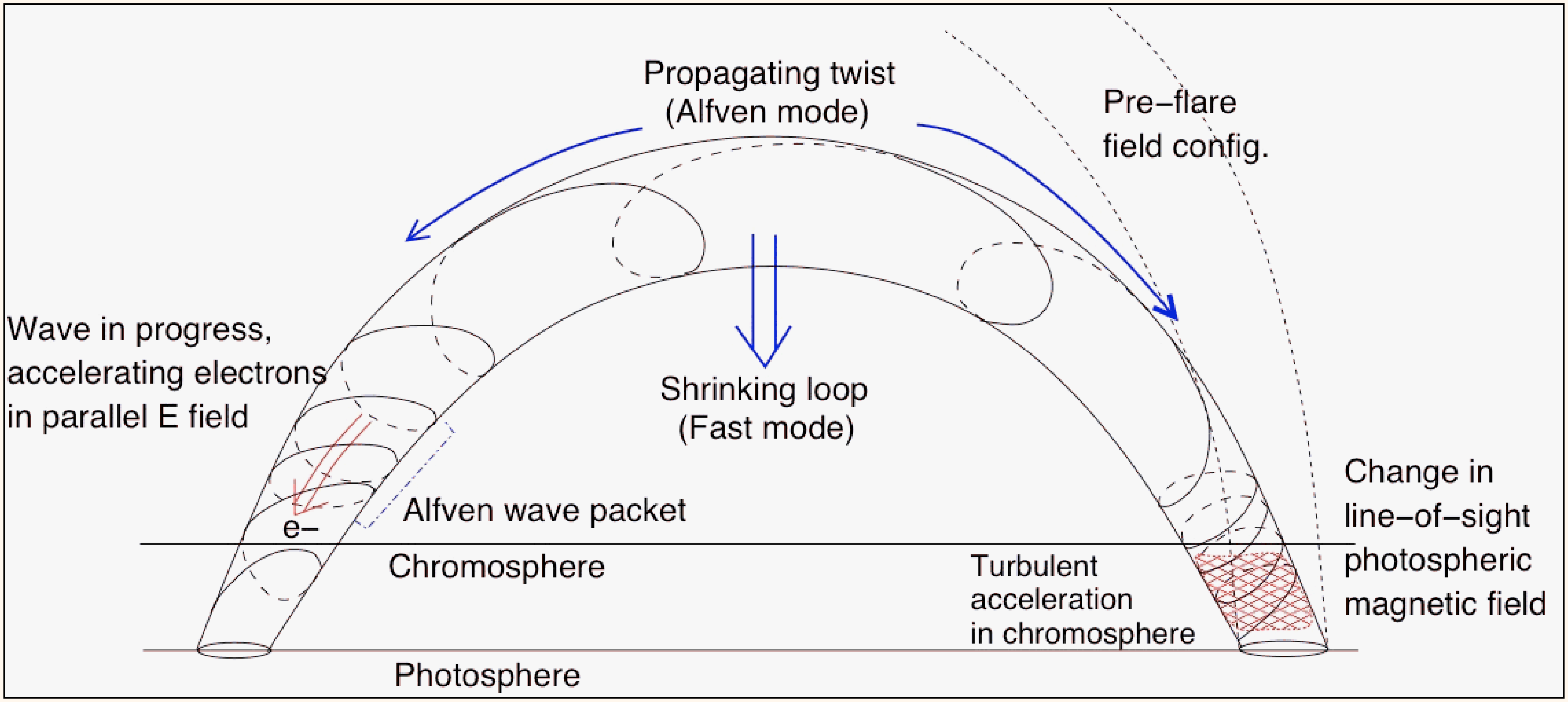
New description of the impulsive phase



Fletcher & Hudson 2008

http://solarmuri.ssl.berkeley.edu/~hhudson/cartoons/

New description of the impulsive phase



Fletcher & Hudson 2008

Importance of Poynting flux!

http://solarmuri.ssl.berkeley.edu/~hhudson/cartoons/

Observational problem areas

- What are the physical conditions within a filament channel?
- What is the nature of the flow field in the dimming regions?

Note that both of these problems involve studying faint things in an optically thin medium. What is there between the bright things?

Observational problem areas

- What are the physical conditions within a filament channel?
- What is the nature of the flow field in the dimming regions?
- Non-local effects - both particles and waves

Note that both of these problems involve studying faint things in an optically thin medium. What is there between the bright things?

Importance of Poynting flux!

Conclusions

- Flares and CMEs are normally closely related
- We need to study the low corona -chromosphere -transition region to understand powerful CMEs
- We have coronal nonthermal signatures in hard X-rays from the new RHESSI observations