Solar Flares With and Without Large-Scale Processes

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Overview

- ★ What is a solar flare?
- ★ What happens when there is a solar flare?
  - ⊙ Restructuring
  - ⊙ Radiation
  - ⊙ Eruption
    - ❖ Parallel flows (ie, jets)
    - ❖ Perpendicular flows (ie, CMEs)

Flare Observations

Table 5.1. *Flare classifications*

GOES class	1-8Å peak W/m^2	Hα class	Hα Area *Millionths of hemisphere*	CME fract.[a] *percent*	Events/year *max/min*
A	$>10^{-8}$	-	-	-	-
B	$>10^{-7}$	S	<200	-	-
C	$>10^{-6}$	1	>200	20	>2000/300
M	$>10^{-5}$	2	>500	50	300/20
X	$>10^{-4}$	3	>1200	90	10/one?
-	$>10^{-3}$	4	>1200	100	few?/none?

[a]Yashiro et al. (2005) (approximate values)

From *Heliophysics II,* eds. Schriver & Siscoe

Definitions

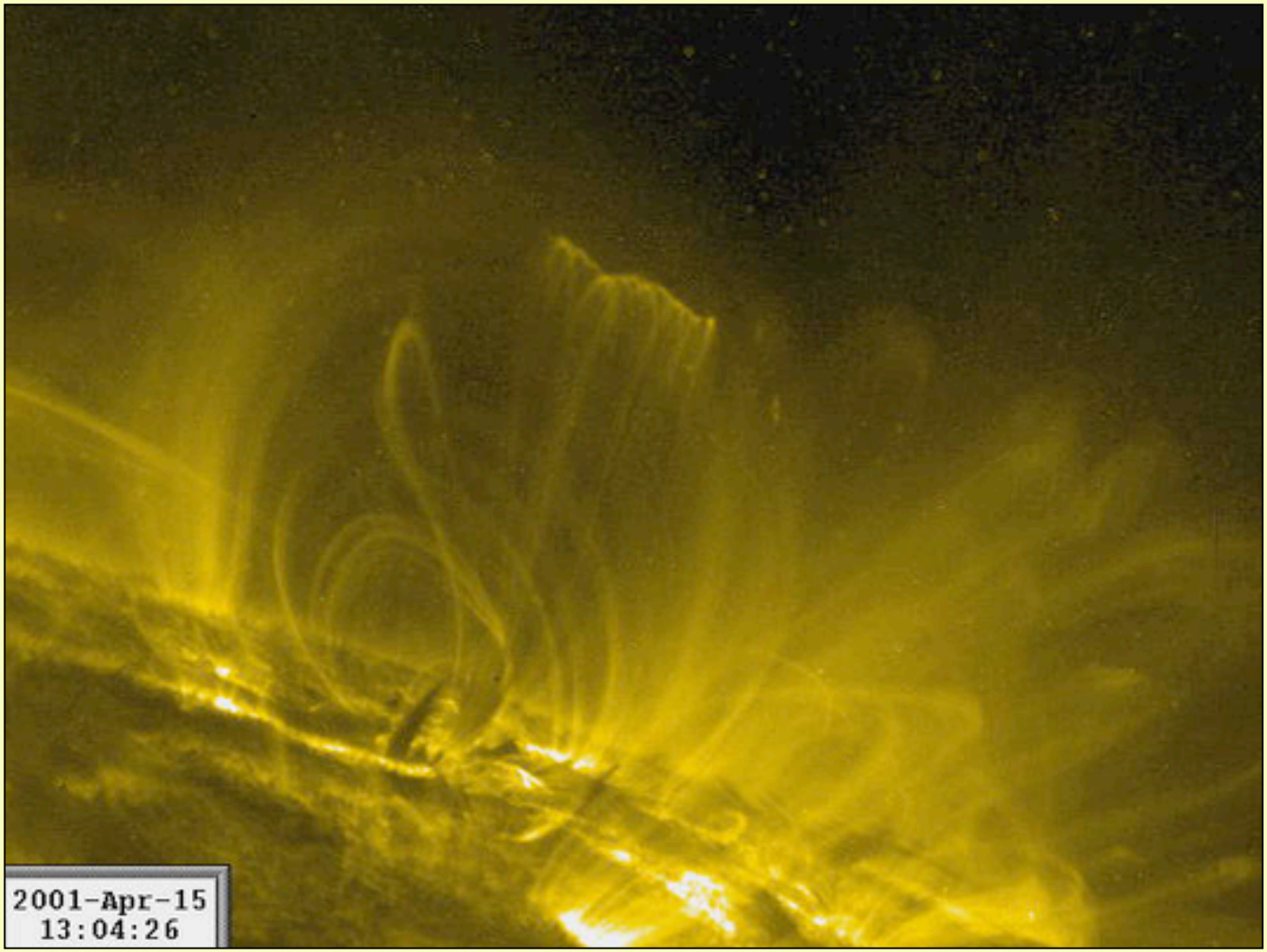
- A solar flare is, strictly speaking, the electromagnetic radiation from a coronal magnetic energy release
- A coronal mass ejection (CME) is a catastrophic expansion of a part of the coronal field
- Both flare and CME require a *magnetic implosion* to release the energy:

$$\langle B^2/8\pi \rangle|_{before} > \langle B^2/8\pi \rangle|_{after}$$

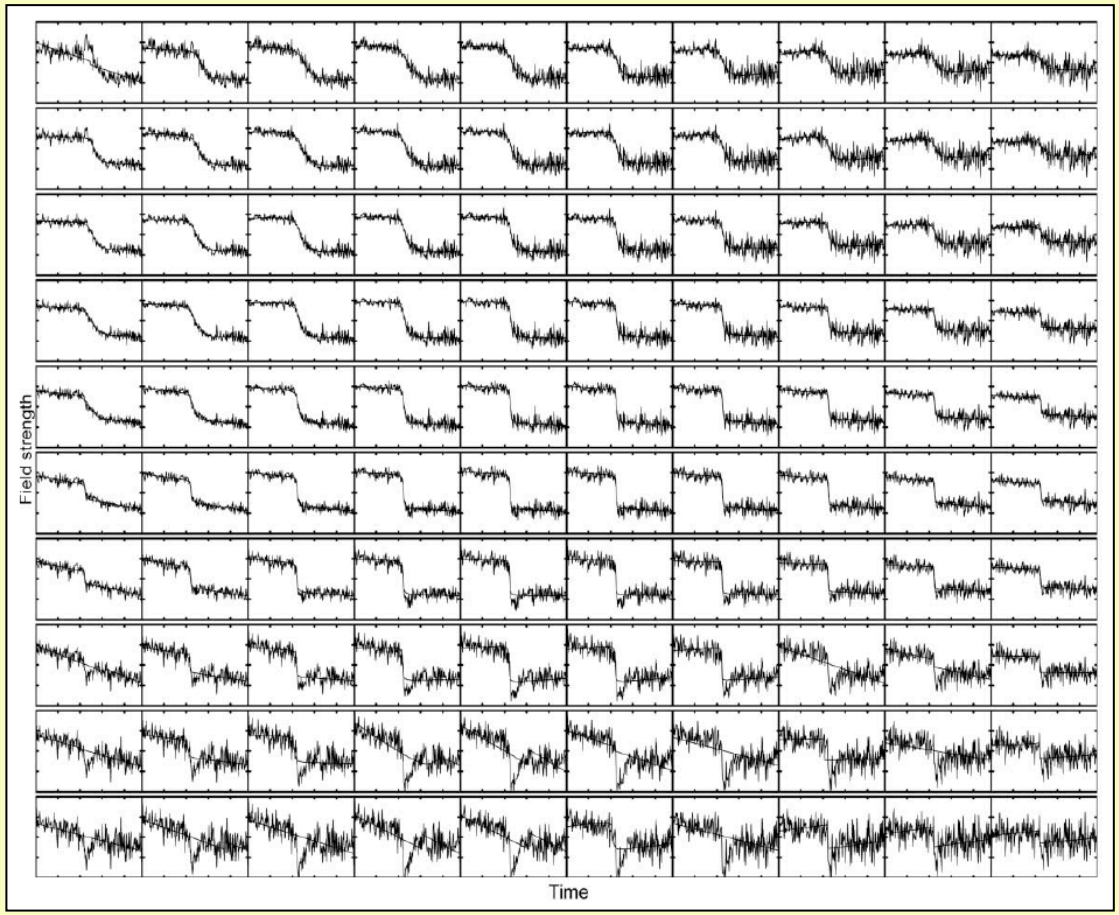
Large Scales

- The coronal magnetic energy release requires action on large scales:
  - Soft X-ray loops and arcades
  - Global waves (coronal, chromospheric, seismic)
  - Large-scale coronal phenomena (CMEs, radio and hard X-ray sources)
- But, we cannot neglect the microphysics:
  - Particle acceleration
  - Magnetic reconnection

TRACE: dimming, implosion, oscillations



Photospheric field changes (LOS only)

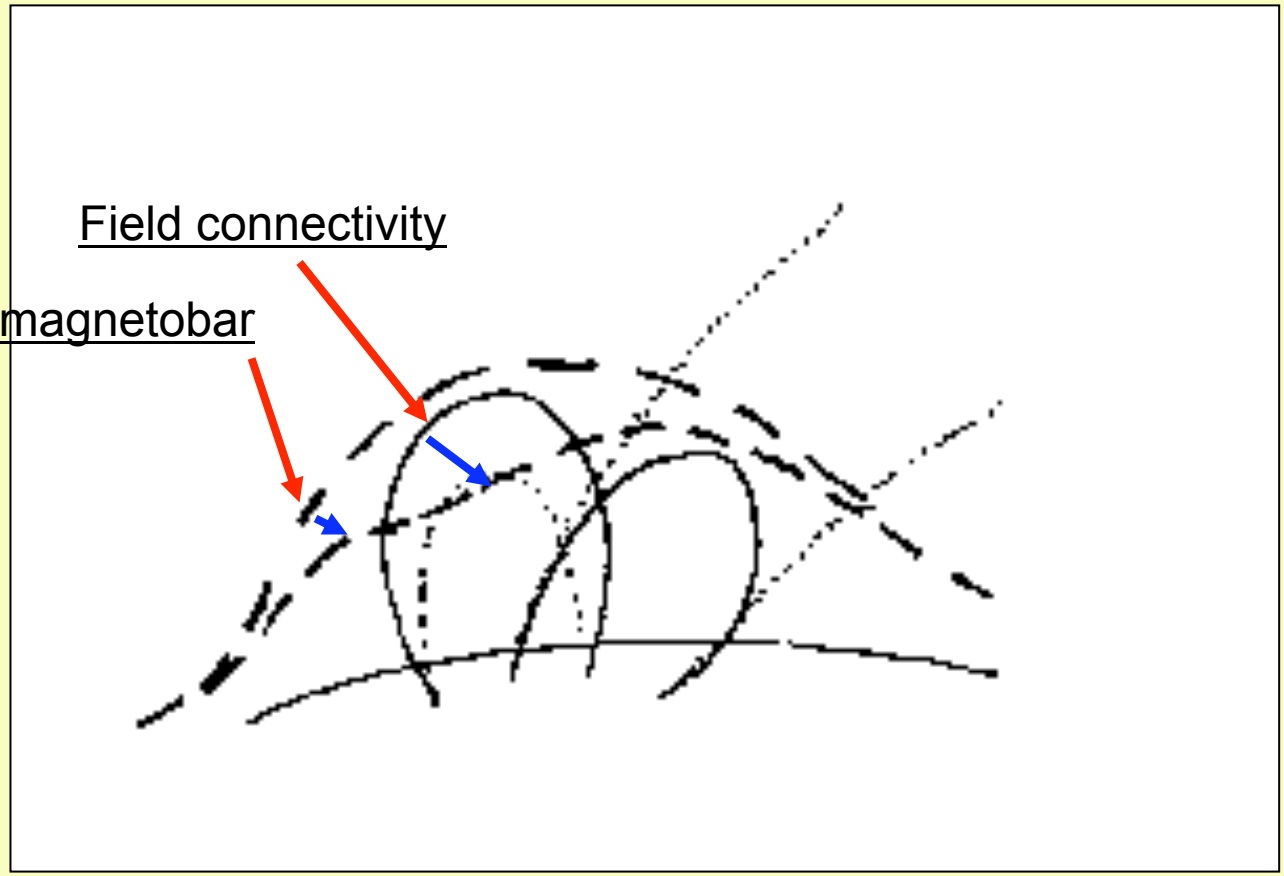


"Confusogram" values:
10x10 2.5" pixels
240 minutes time base
500 G magnetic range

Sudol-Harvey 2005
2 Nov. 2003 flare
cf Kosovichev & Zharkova 1999; Wang et al. 2002

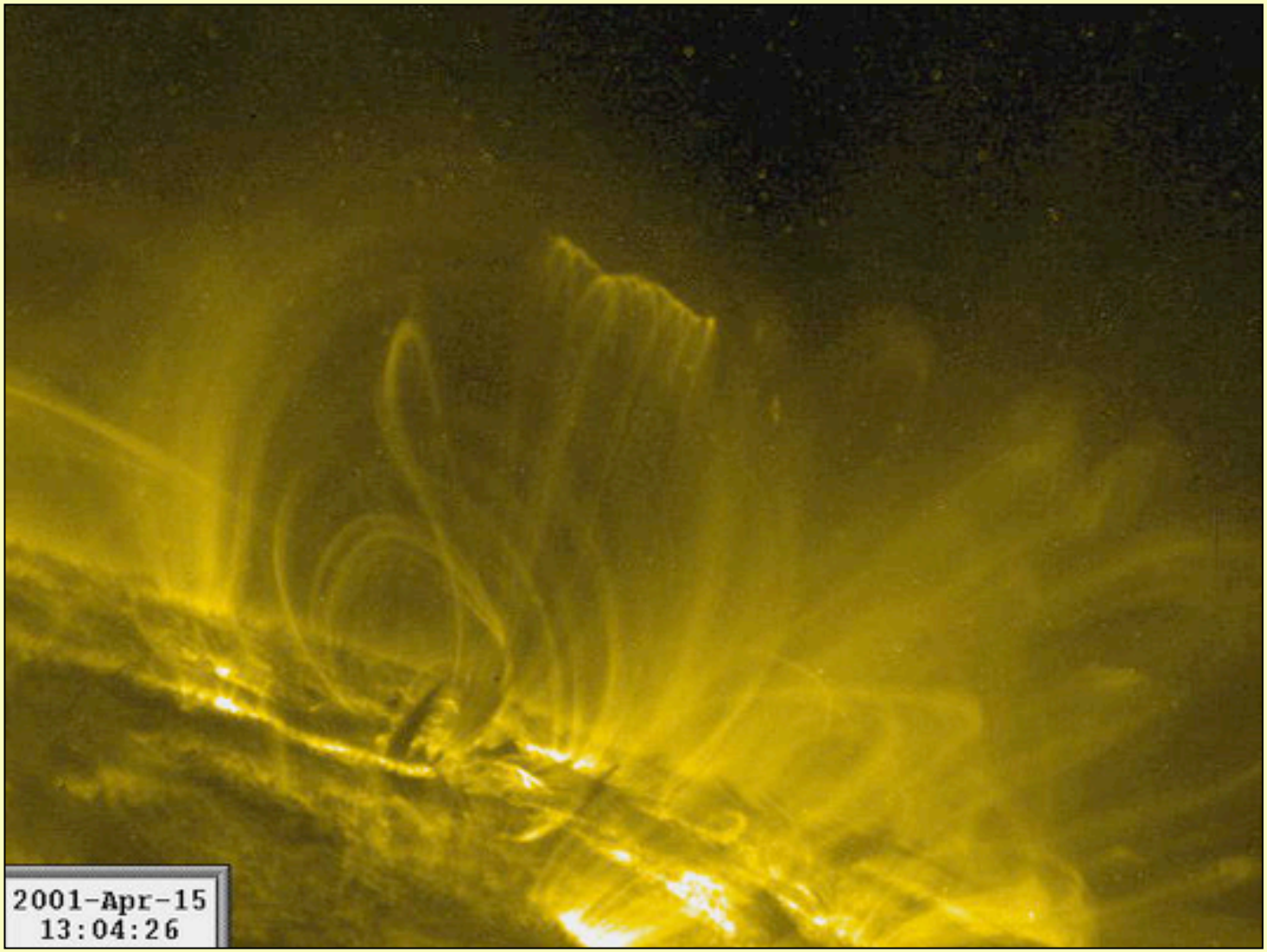
Magnetic Implosion

Fields



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

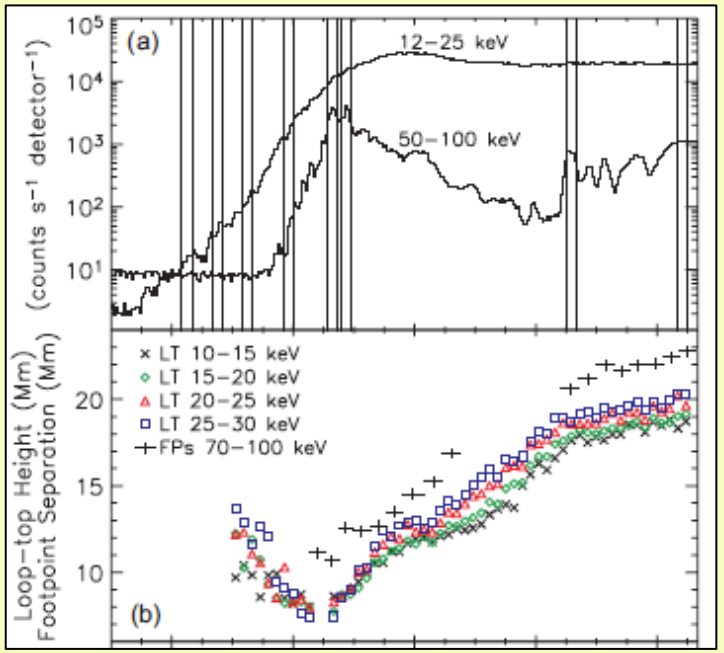
TRACE: dimming*, implosion, oscillations



*CME

RHESSI and downward motions

- Sui & Holman, ApJ 596, L251 (2003)
- Sui et al., ApJ 612, 546 (2004)
- Holman et al. Unpublished (2005)
- Veronig et al., A&A 446, 675 (2006)
- Ji et al., ApJ 660, 893 (2007)
- Ji et al., ApJ 680, 734 (2008)



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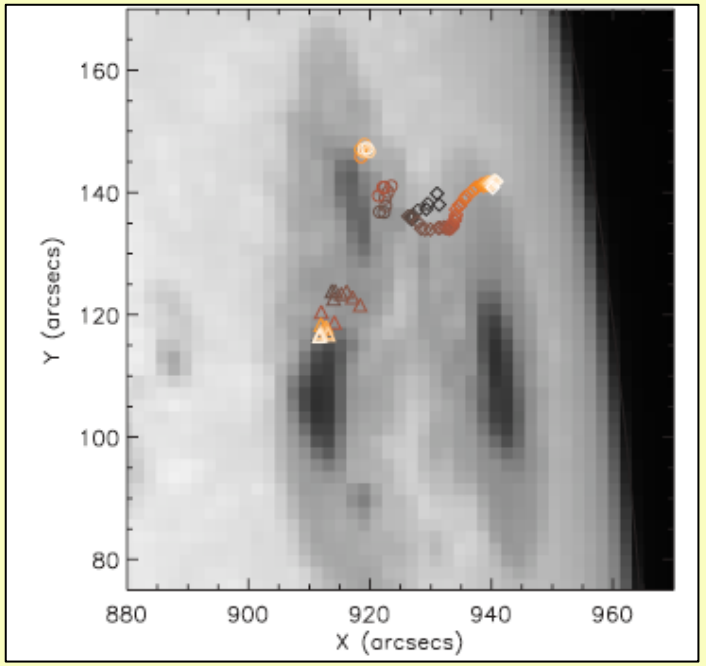
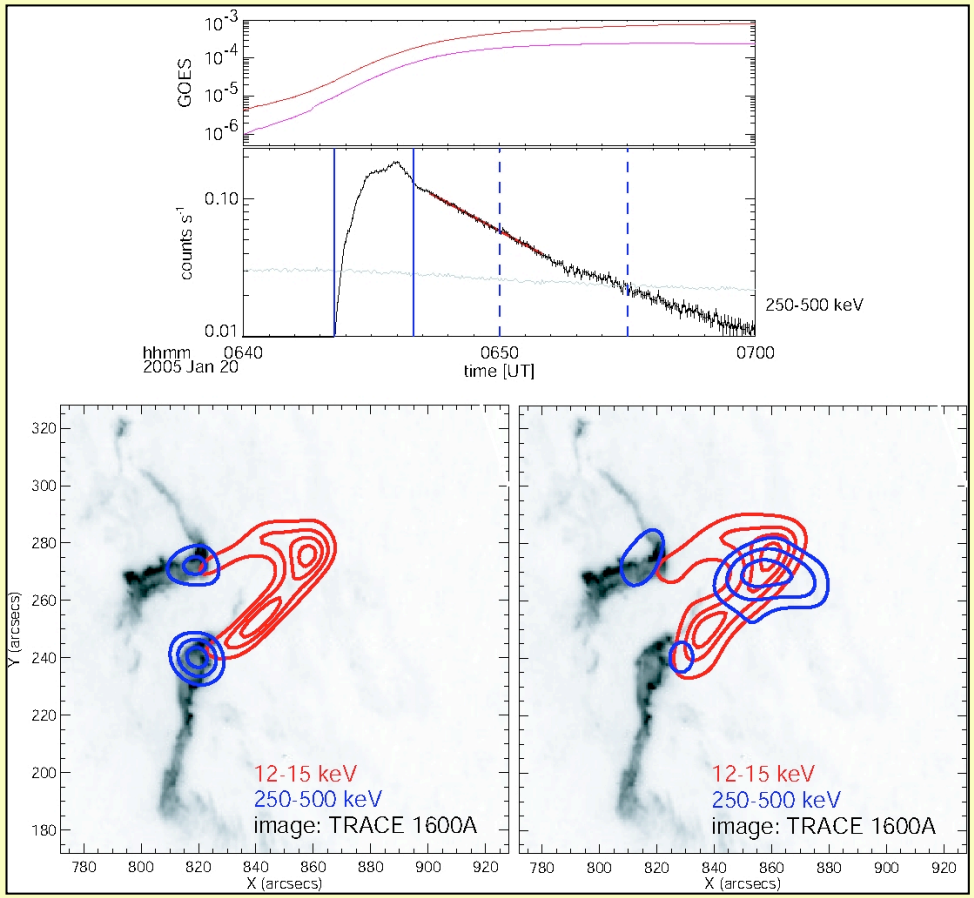


Coronal Hard X-ray Sources

- There are lots of meter-wave radio source types (I, II, III, IV, V, …), so why not hard X-rays?
- They exit: Frost & Dennis (1971); Hudson (1978); Krucker et al. (2008)
- The remarkable Masuda source (Masuda et al. 1994, 2000; Krucker et al. 2008) needs special discussion
- An identification with the CME process seems to be developing

Extended Coronal HXR

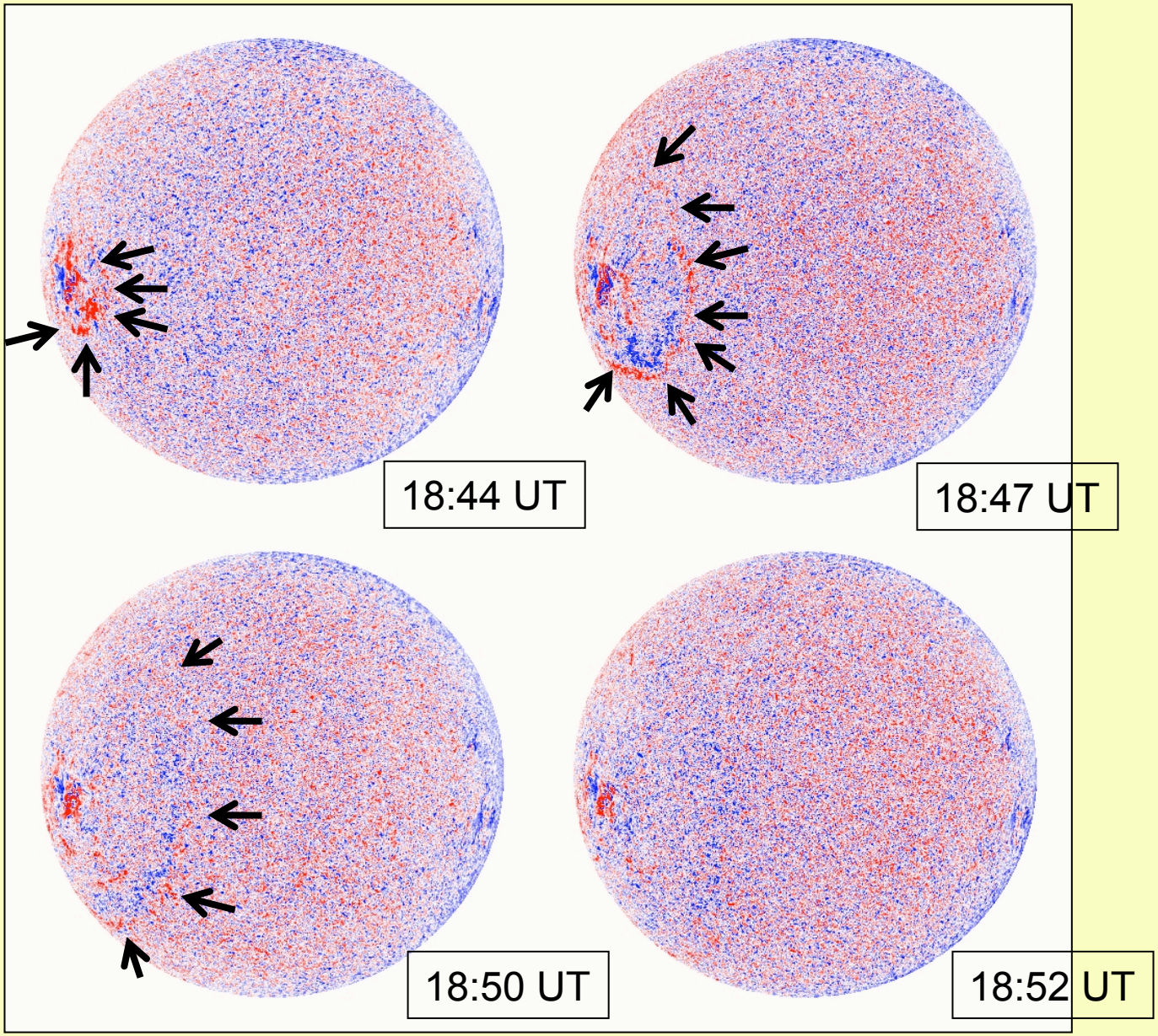
- Coronal hard X-ray sources are prevalent, but faint
- We are coming to believe that they are strongly associated with CMEs, rather than the flare process itself



Global Waves

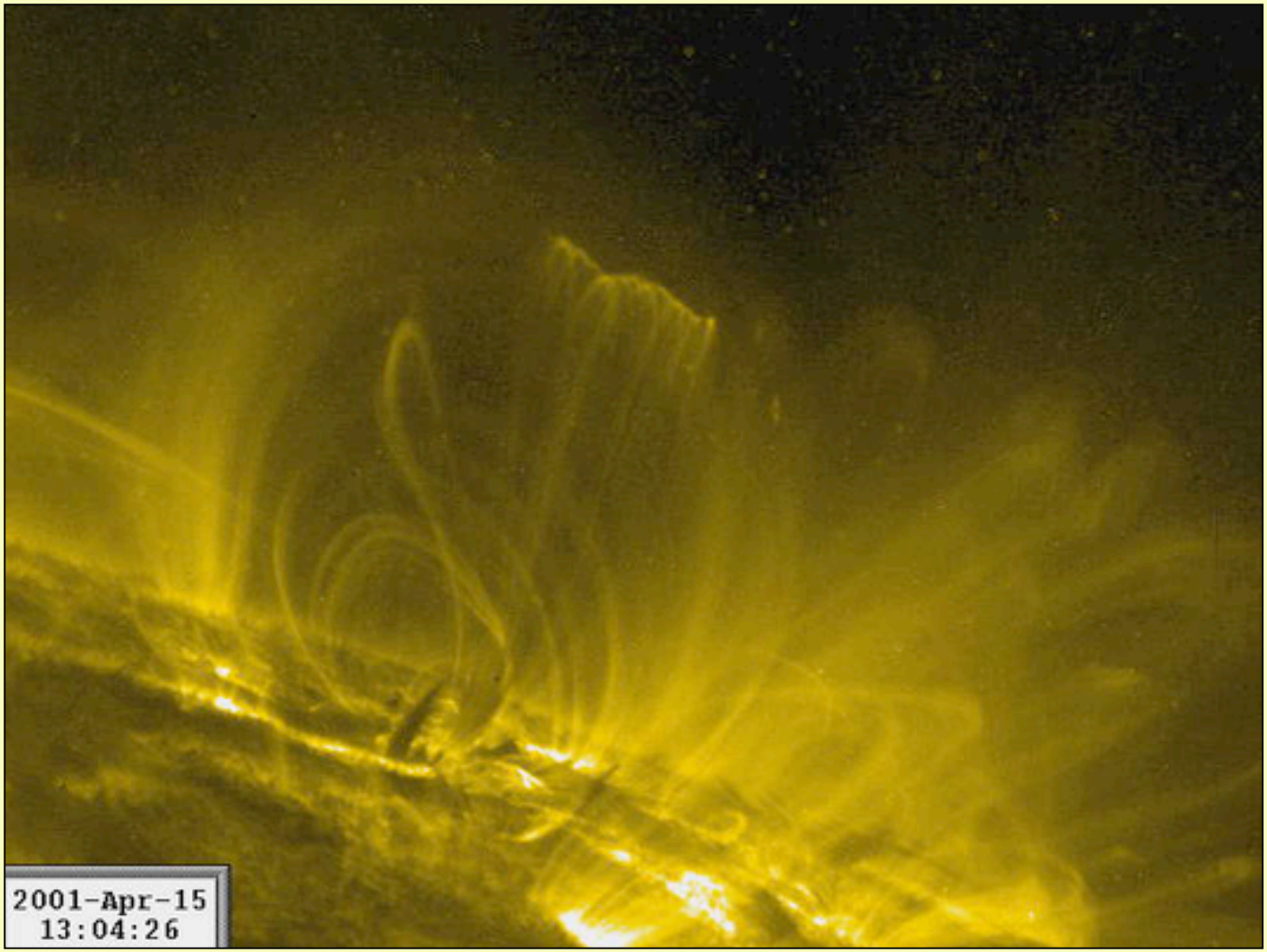
- SSC* shock; Type II burst; Moreton wave; EIT wave
- Major controversy on the interpretation of the metric type II and Moreton wave: is it a blast wave (Uchida)?
- Gopalswamy et al (2009) list of CMEless X-class flares (cf. de La Beaujardiere et al. 1994, Wang & Zhang 2007)

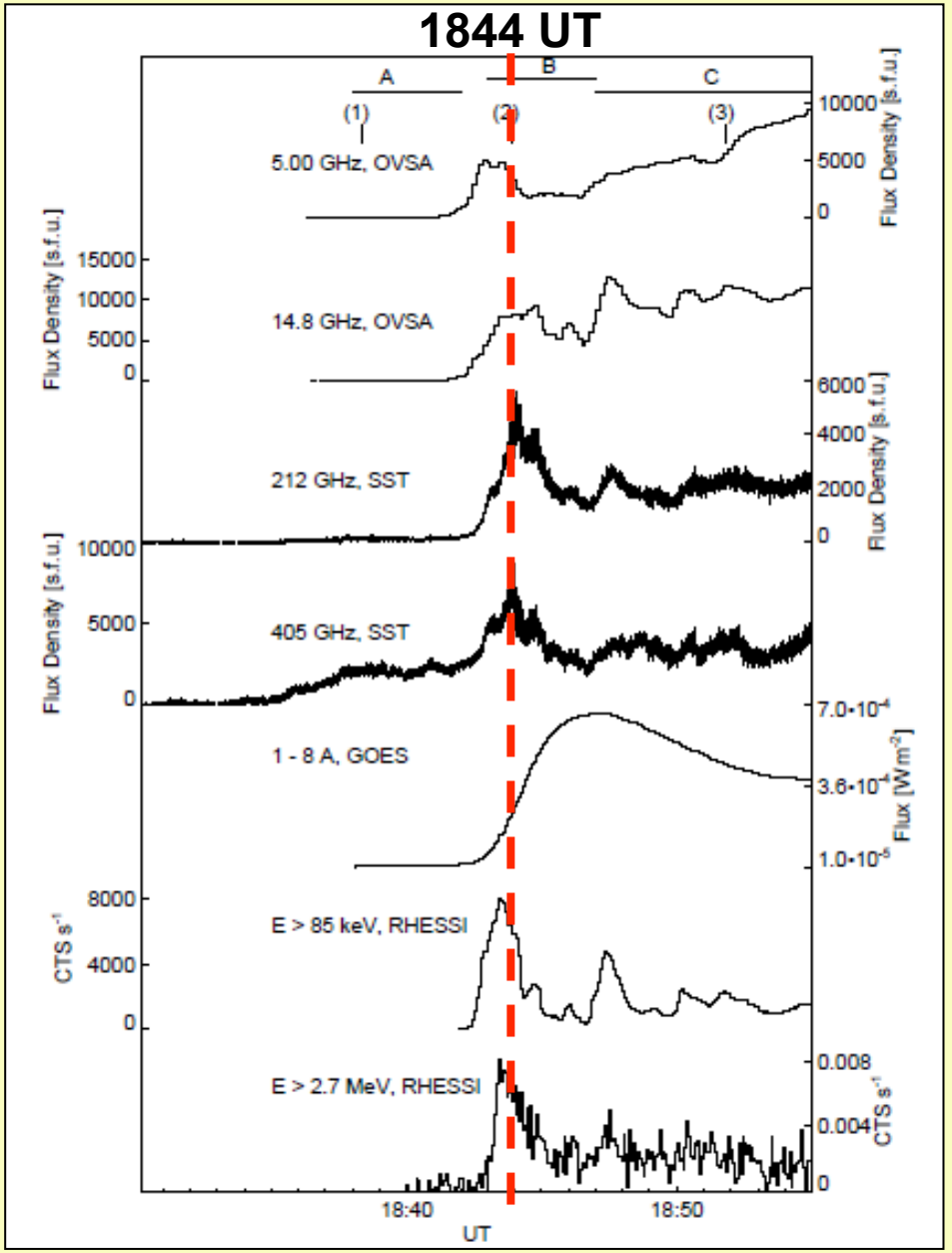
*Storm Sudden Commencement (geomagnetic term)



Subtracted Doppler Images (R-B Wing) Showing Down-Up Pattern

TRACE: dimming, implosion, oscillations





Kaufmann et al. (2008)

The wave appears near the peak of the impulsive phase of the high-energy flare …

CMEless X-class flares

Table 1. X-class flares without CMEs during solar cycle 23 and their properties

#	Flare Start	Peak	Dur	Imp	Location	AR #	Hα	III	μfpk/flux
1	2000/06/06 13:30	13:39	16	X1.1	N18E12	9026[d]	N	N	2.7/560
2	2000/09/30 23:13	23:21	8	X1.2[c]	N07W90	9169	N	N	15.4/2800
3	2001/04/02 10:04	10:14	16	X1.4	N17W60	9393	1B[e]	Y	15.4/1200
4	2001/06/23 04:02	04:08	9	X1.2[c]	N10E23	9511	1B	N	5/100
5[a]	2001/11/25 09:45	09:51	9	X1.1[c]	S16W69	9704[d]	N	N	15.4/130
6	2002/10/31 16:47	16:52	8	X1.2[c]	N29W90	0162	N	N	8.8/3300
7[b]	2004/02/26 01:50	02:03	20	X1.1[c]	N14W15	0564	2N[e]	N	15.4/830
8	2004/07/15 18:15	18:24	13	X1.6	S11E45	0649	N	N	8.8/530
9	2004/07/16 01:43	02:06	29	X1.3	S11E41	0649	N	N	15.4/1900
10	2004/07/16 10:32	10:41	14	X1.1	S10E36	0649	1F[e]	Y	15.4/1200
11	2004/07/17 07:51	07:57	8	X1.0	S11E24	0649	3B[e]	N	5/820
12	2005/01/15 00:22	00:43	40	X1.2	N14E08	0720	1F	N	15.4/3000
13[a]	2005/09/15 08:30	08:38	16	X1.1	S12W14	0808	2N	N	15.4/4100

Wang & Zhang 2007;
Gopalswamy et al. 2009

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9	2004/07/16 01:43	02:06	29	X1.3	S11E41	0649	N	N	15.4/1900
10	2004/07/16 10:32	10:41	14	X1.1	S10E36	0649	1F[e]	Y	15.4/1200
11	2004/07/17 07:51	07:57	8	X1.0	S11E24	0649	3B[e]	N	5/820
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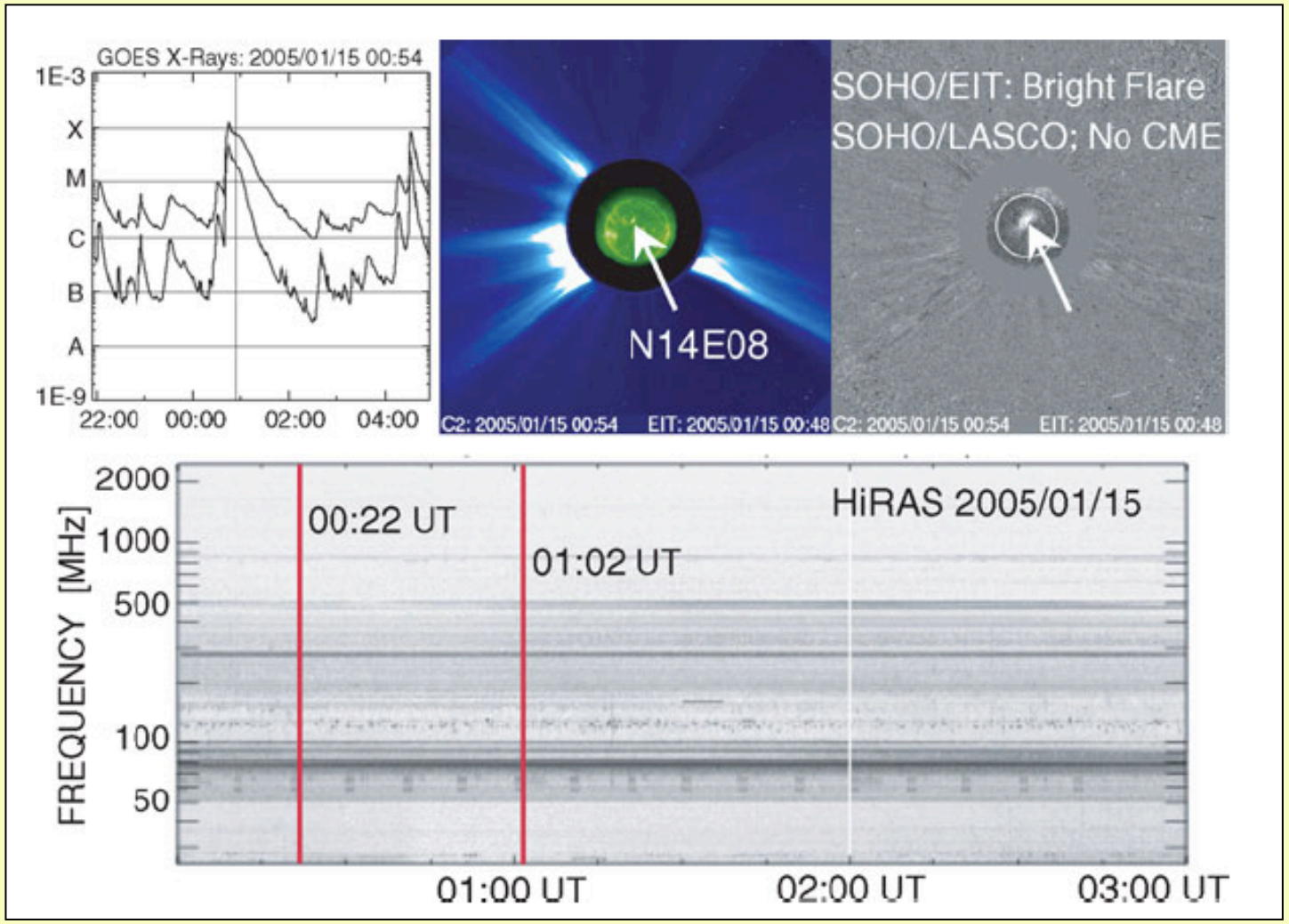
No events > X2

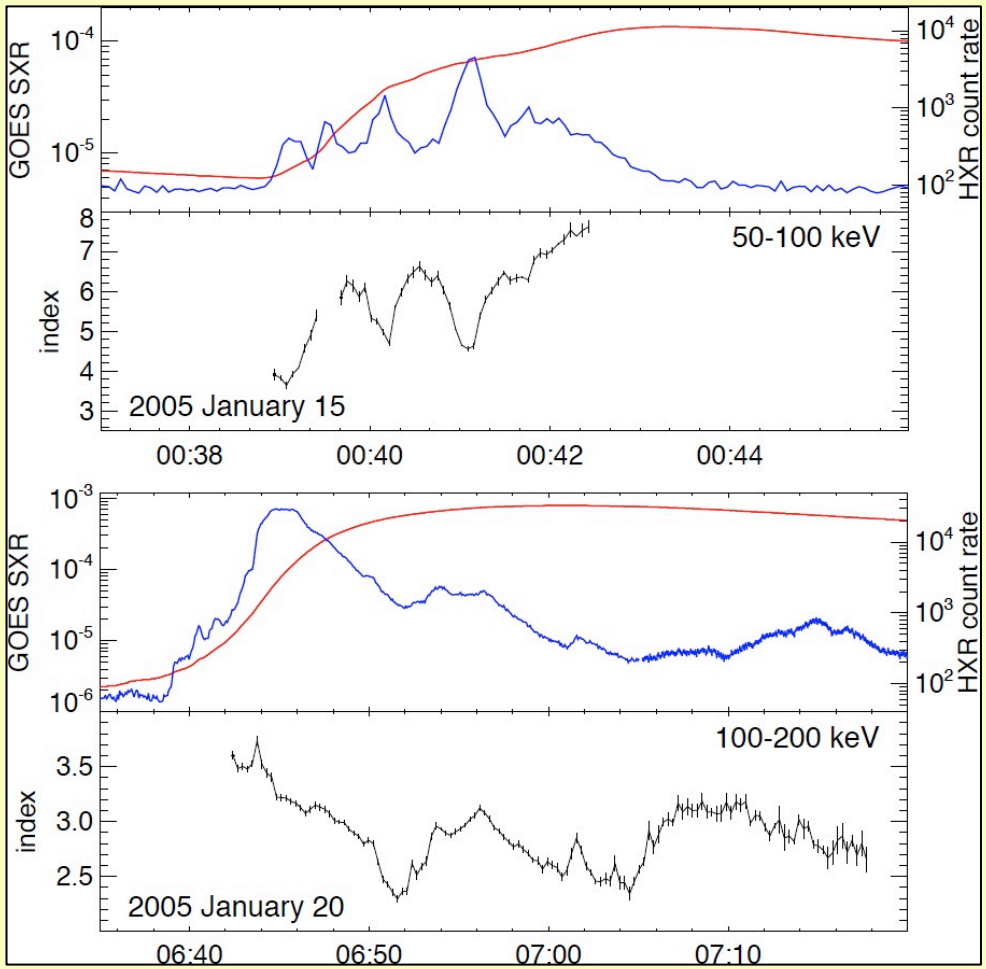
Wang & Zhang 2007;
Gopalswamy et al. 2009

CMEless X-class flares



Gopalswamy et al. 2009

The CMEless events do not show the SHH pattern (“soft-hard-harder”) of coronal HXR



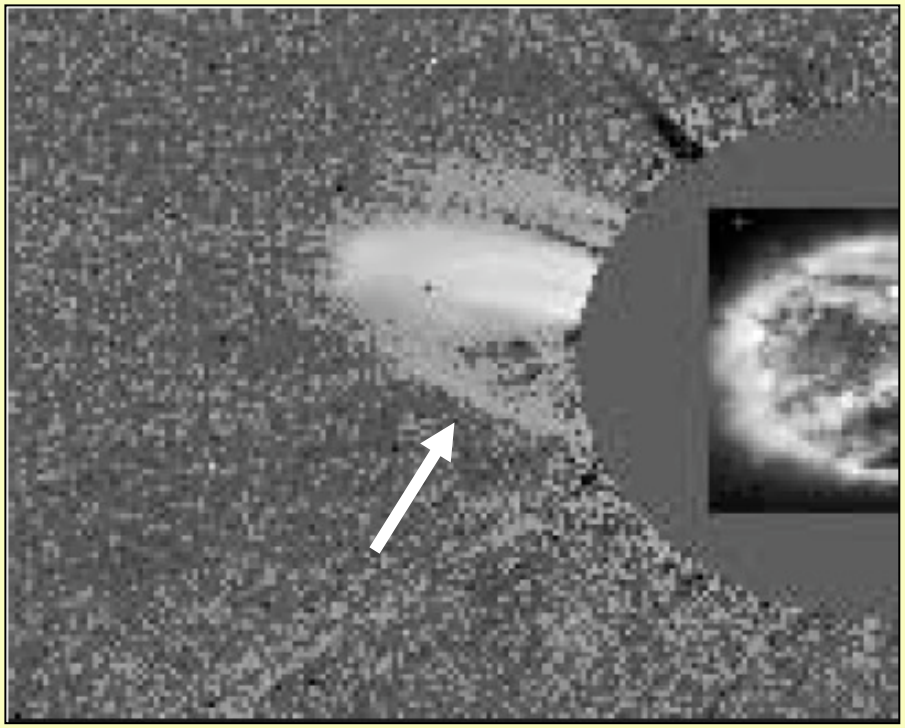
LASCO shock signatures

Table 1
All High-Speed CMEs ($V > 1500$ km s $^{-1}$) Between 1997 and 1999

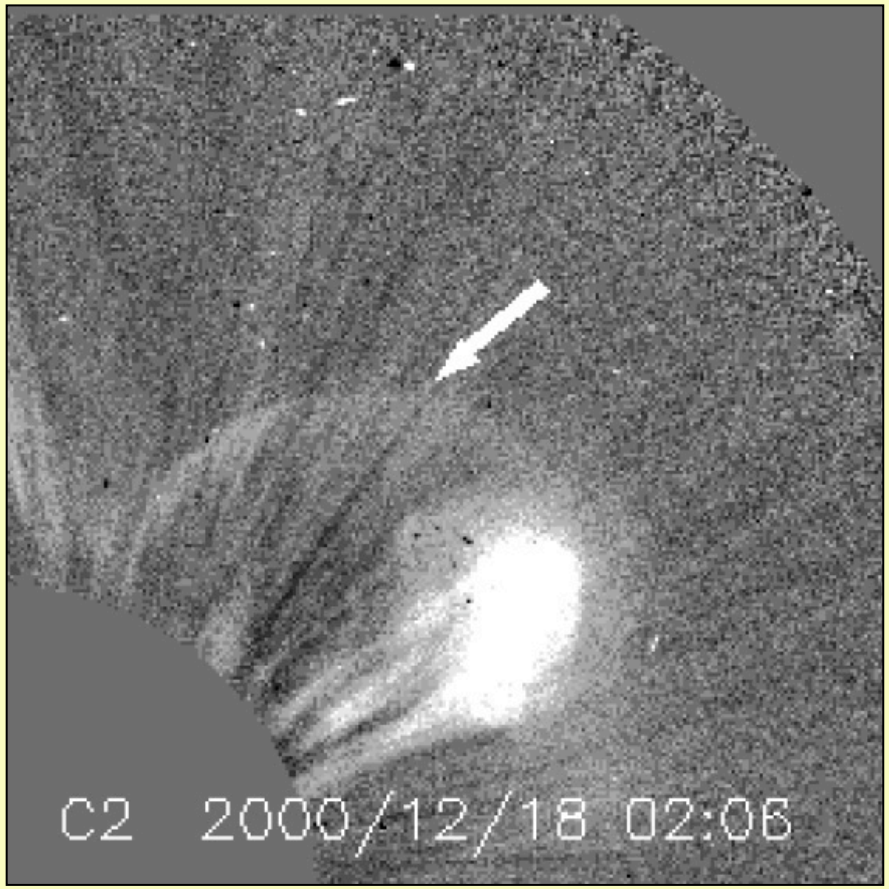
Event	CME Date	First Appearance (C2 UT)	Linear Speed (km s^{-1})	AW (deg)	P.A. (deg)	Type II (Dm)
1	1997 Nov 6	12:10:00	1556	360	262	Yes
2	1998 Mar 31	6:12:00	1992	360	177	No
3	1998 Apr 20	10:07:00	1863	165	278	Yes
4	1998 Apr 23	5:27:00	1618	360	116	Yes
5	1998 May 9	3:35:58	2331	178	262	Yes
6	1998 Jun 4	2:04:00	1802	360	314	No
7	1998 Nov 24	2:30:00	1798	360	226	No
8	1998 Nov 26	6:18:05	1505	360	198	No
9	1998 Dec 18	18:21:00	1749	360	36	Yes
10	1999 May 3	6:06:00	1584	360	88	Yes
11	1999 May 27	11:06:00	1691	360	341	Yes
12	1999 Jun 1	19:37:00	1772	360	359	Yes
13	1999 Jun 4	7:26:54	2230	150	289	Yes
14	1999 Jun 11	11:26:00	1569	181	38	Yes
15	1999 Sep 11	21:54:00	1680	120	13	No

Ontiveros & Vourlidas. 2009

Examples from Vourlidas et al. 2003



1999 April 2



Comments on coronal shocks

- The evidence for blast waves independent of CME occurrence is lacking
- CME-driven waves may start in the flare core
- Shock signatures in LASCO don’t look like the cartoons, ie are not bow waves of the observed CME

Conclusions

- The CME phenomenon is probably central to the large-scale coronal nonthermal effects
- CMEless flares have clearly distinguishable hard X-ray properties
- CMEless flares have an upper cutoff in energy

Something new has been learned

- The classical Uchida theory for type II / Moreton wave as a flare blast wave must be abandoned
- We can unify the flare/CME wave excitation mechanism
- CME waves (and other large-scale waves) offer an opportunity to study the restructuring that causes a flare