Momentum Conservation in Flares

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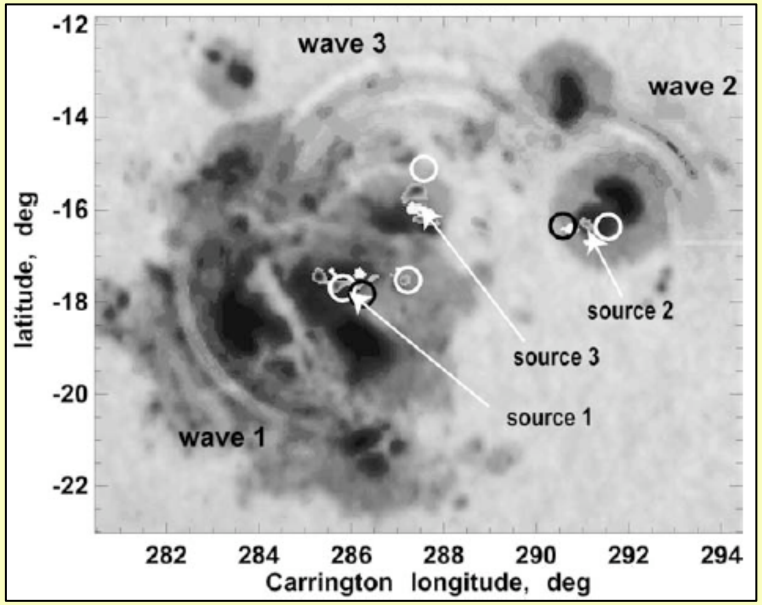
History of flare momentum studies

- “The importance of particle beam momentum in beam-heated models of solar flares,” Brown & Craig 1984 (14 citations)
- “The unimportance of beam momentum in electron-heated models of solar flares,” McClymont & Canfield, 1984 (12 citations)
- “Momentum balance in four solar flares,” Canfield et al., 1990 (49 citations)

Four Impulses

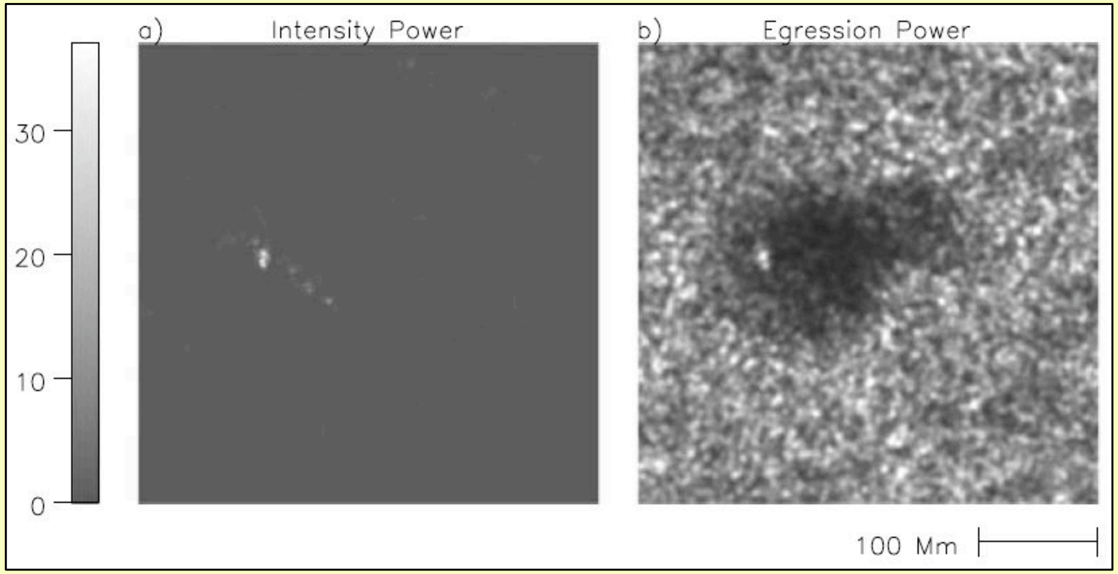
- Primary energy release in the corona (CME?)
- Chromospheric heating: evaporation and downward shock (Kostiuk & Pikel’ner 1974)
- Interruption of evaporative flow (new idea 1997)
- “Coronal rain” from cooling loops

Seismic Waves ("sunquakes")



Seismic wave:
- example of 28-Oct-03
- multiple radiant points
- HXR association
- now many examples

(Kosovichev 2007)



Acoustic source:
- holographic imaging
- WLF (left) matches source
- "egression power" (right) easier to see in umbra

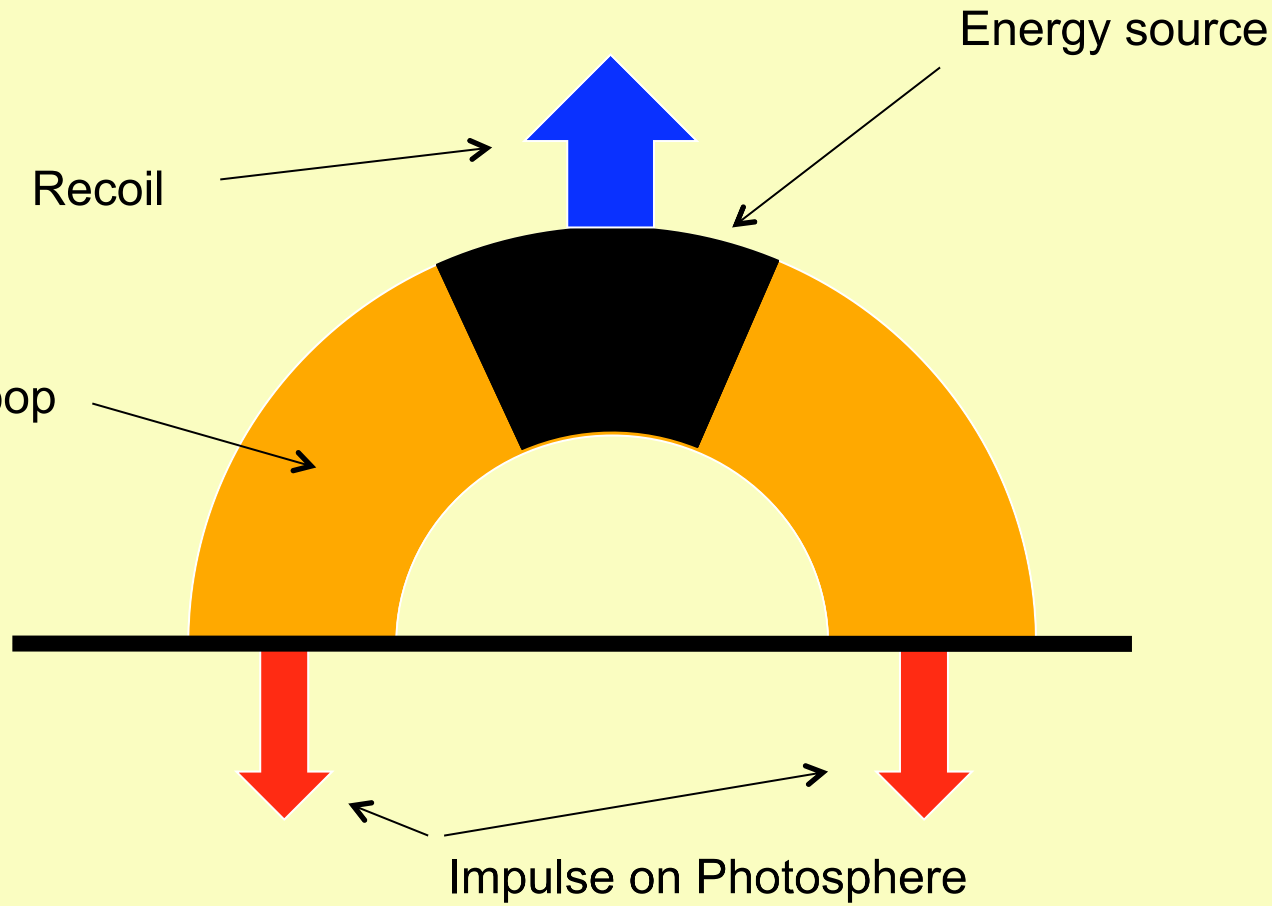
(Source Lindsey & Donea 2008)

Representative Parameters

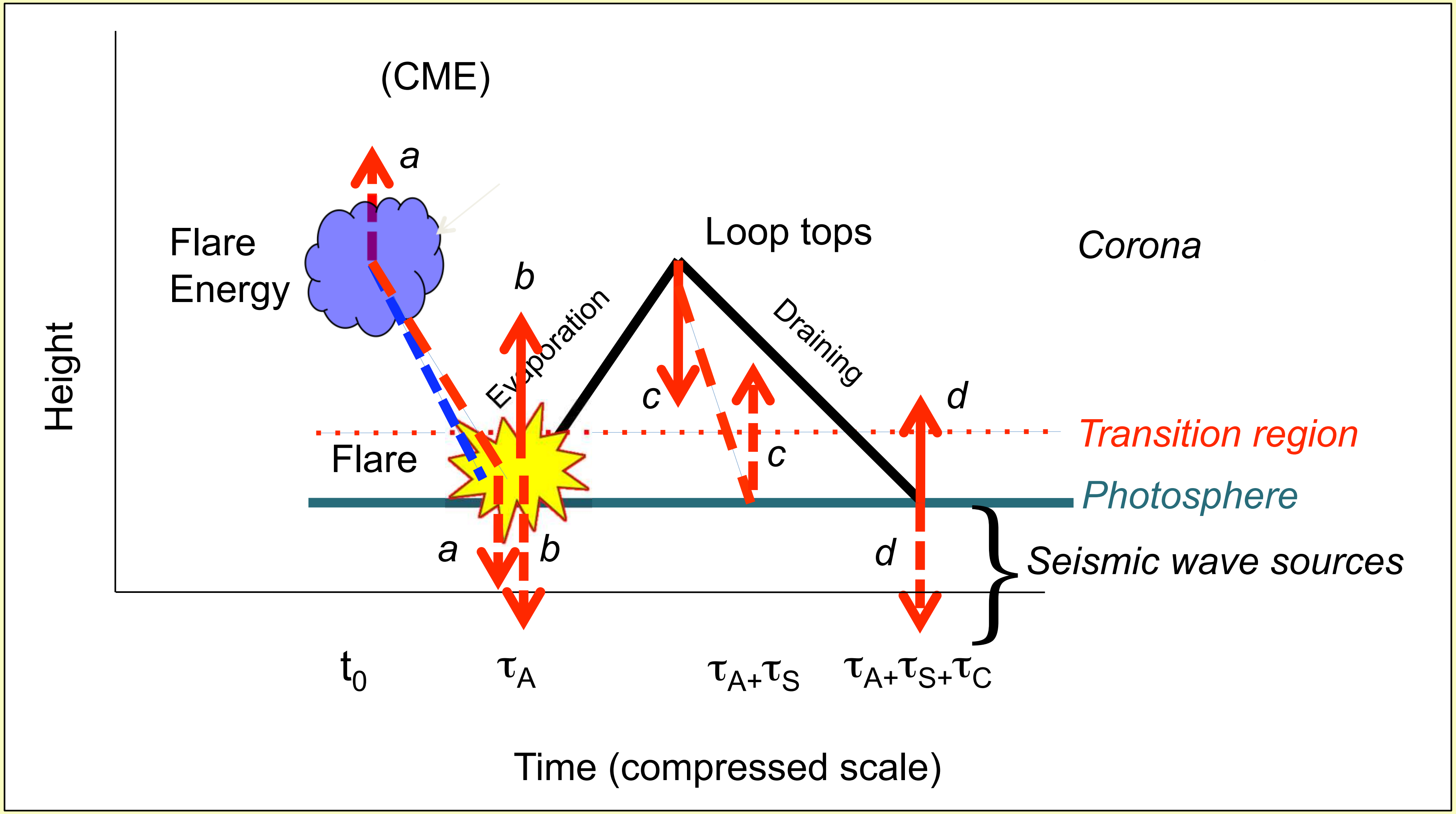
Table 1. Representative parameters for an X-class flare with CME and quake

Property	Value
Total energy of flare	10^{32} erg
Flare loop height	1×10^9 cm
Coronal density (preflare)	1×10^9 cm^3
Coronal field	1×10^3 G
Impulsive sub-burst duration	10 s
Impulsive phase duration	100 s
Number of sub-bursts	10
Impulsive sub-burst footpoint area	3×10^{17} cm^2
Evaporation speed	5×10^7 cm s^{-1}
Evaporated mass	1×10^{14} g
Draining time	1000 s
CME mass	1×10^{15} g
CME speed	2×10^8 cm s^{-1}
Seismic wave energy	4×10^{27} erg

Momentum conservation in primary energy release



Momentum cartoon[1]



[1]Simplified view of vertical component

Momentum estimates[1]

Table 2. Vertical momentum components, model X-class flare with CME

Label (Fig. 1)	Phenomenon	Mass g	Velocity km/s	Δt s	Momentum^i g cm s^{-1}	Δp dyne/cm^2
a	Primary $(e^-)^\alpha$	3×10^{11}	c/3	10	3×10^{21}	1×10^{3}
a	Primary (waves)	—	c/3	10	1×10^{20}	1×10^{2}
b	Evaporation flow	10^{14}	500	30	5×10^{21}	6×10^{2}
b′	Radiation$^\beta$	—	c	10	1×10^{19}	3
c	CME	10^{15}	2000	100	2×10^{23}	7×10^{2}
d	Draining	10^{15}	10	$\sim 10^4$	2×10^{21}	0.07
	Seismic wave		6	20-50	1×10^{21}	

$^\alpha$ 20 keV
$^\beta$ White-light flare

[1]Scaled to X1

Inferences about momentum

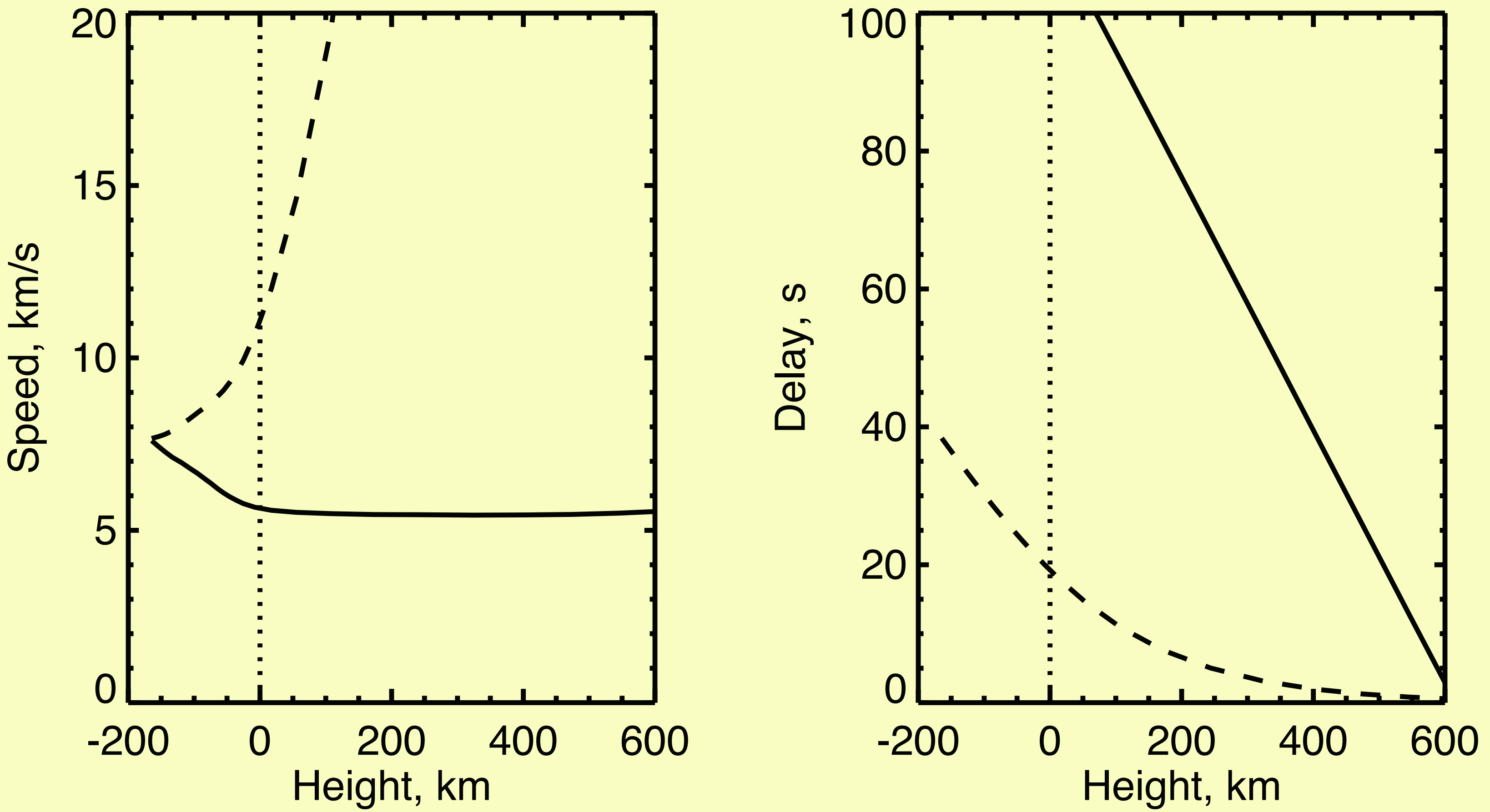
• There is sufficient momentum in the coronal energy flux to explain the seismic wave

• CME acceleration predicts one photospheric impulse; evaporation two of opposite signs

• We don’t know which particular mechanism couples best into the sunquake yet

Time scales

- Fontenla (2009) umbra model
- 3000 G
- Pulse at 600 km



Speculations

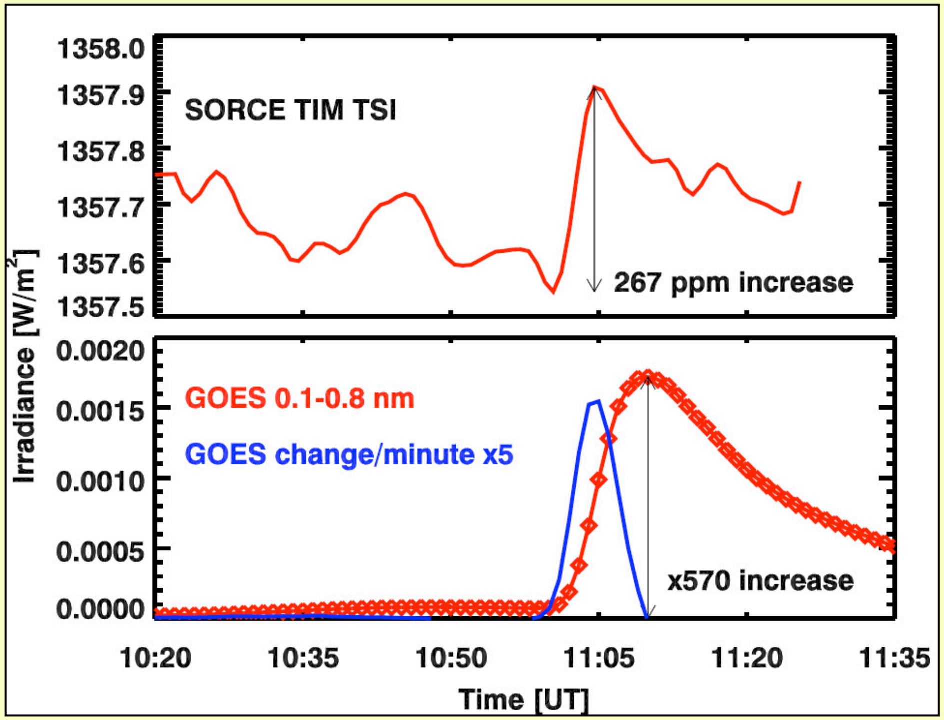
- Analysis of momentum transfer should help in understanding sunquakes (Shock? Backwarming? Lorentz force?)
- The initial flare energy release and coupling into CME flows, if any, require wave concepts (**ExB/v_A**)
- There are several immediate problems worth analysis (imho)

http://sprg.ssl.berkeley.edu/~hhudson/presentations/warwick.101119

Backup slides

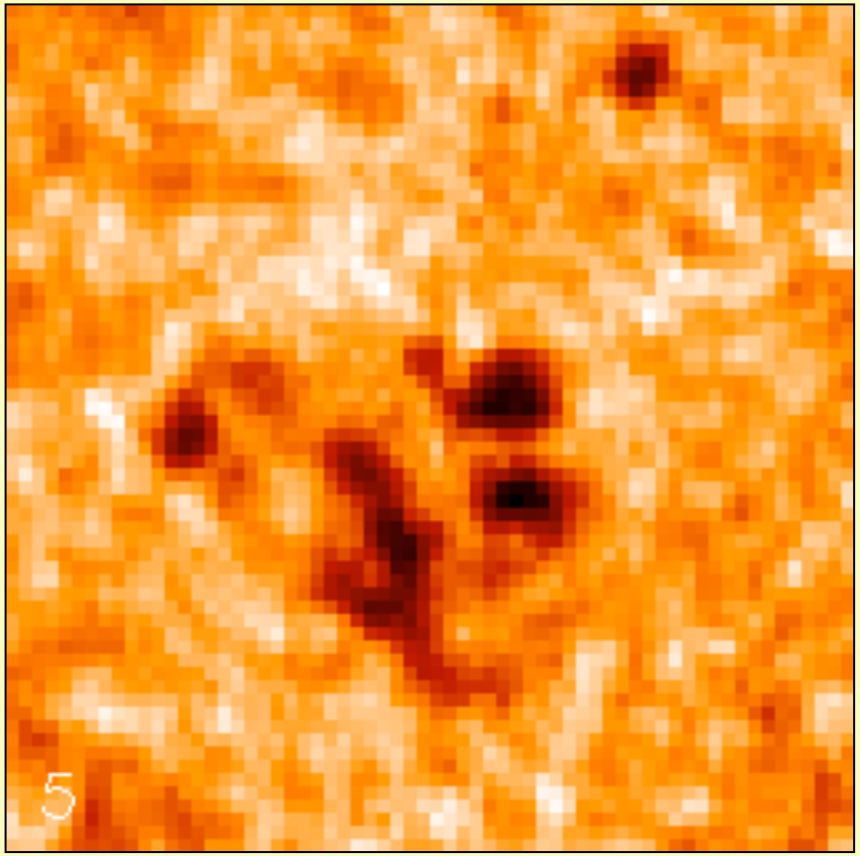
Flare energy

Short-lived



Woods et al 2004

Small-scale[1]



Hudson et al 2006

[1]TRACE 0.5" pixels

The Lorentz force in context

"…an enormous amount of magnetic energy…seems to be annihilated during the flare. This should cause a subsequent relaxation of the entire field structure…moving large masses…"

- Wolff 1972

"The magnetic force applied to the photosphere…1.2 x 10^{22} dyne…"

- Anwar et al. 1993 (McClymont)

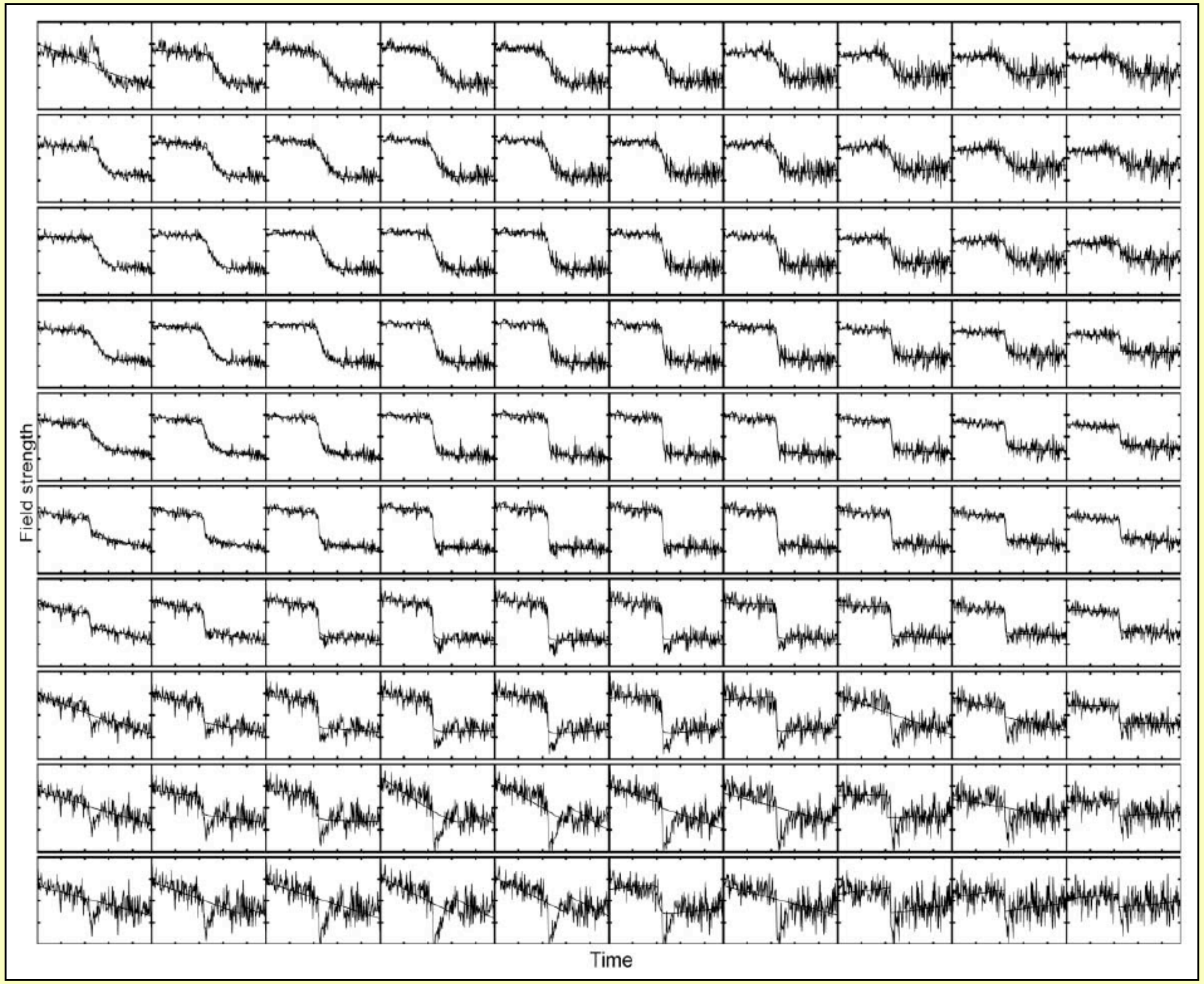
"Magnetic forces should be of particular significance… where the magnetic field is significantly inclined from vertical."

- Donea & Lindsey 2005

"Our estimates suggest that the work done by Lorentz forces in this back reaction could supply enough energy to explain observations of flare-driven seismic waves."

- Hudson et al. 2008 ("Jerk")

Magnetic changes during flares



“Confusogram” legend:
10x10 2.5” pixels
240 minutes time base
500 G magnetic range

(Sudol & Harvey 2005)

Significance of low β

• In the active-region corona, except possibly for small inclusions, β is low. Thus gas pressure is explicitly unimportant.

• At low β all visible structures are mere tracers and can't be dynamically important.

• This also applies to the sunspot regions where seismic waves are launched.