# Flare global waves of three kinds

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### Abstract

Flares produce at least three kinds of global waves: coronal (metric type II; coronagraphic), chromospheric (Moreton) and interior ("sunquakes"). In addition, EIT waves, coronal dimmings, and CMES may also have wave-like properties. Each of the three types of global wave begins at the impulsive phase of a flare. This is also the time of sudden stepwise change in the photospheric line-of-sight field, and the time of the CME acceleration phase. We review the observational material, starting with the published seismic events, and ask whether or not a common origin is consistent with the physical parameters in the likely region of origin.

# **Morphology** I



#### Type II burst:

- slow drift ~10<sup>3</sup> km/s
- onset delayed
- radiant @ early impulsive phase (Culgoora file image)

#### Moreton wave:

- chromospheric signatures
- speed ~10<sup>3</sup> km/s
- radiant @ early impulsive phase (Balasubramaniam et al. 2010; from 2002 Dec. 6 "tsunami")

# **Morphology II**



Coronagraphic shock:

- flanks may be important
- consistent with RH
- common feature (now)
  (Vourlidas 2003; Ontiveros
  & Vourlidas 2009)

EIT "wave":

- heterogeneous sources
- speed usually <10<sup>3</sup> km/s
- clear magnetic deflections
- radiant @ impulsive phase (Thompson et al. 1999)

# Morphology III



Soft X-ray wave:

- speed ~10<sup>3</sup> km/s
- radiant @ impulsive phase
- suggests low Mach number
- ignore many artifacts! (Khan & Aurass 2002; Hudson et al. 2003)

Storm commencement (SI)

- geomagnetic signature
- global magnetospheric effect
- 1859 Carrington flare
- interplanetary shock wave
- ICME association (Source INGV)

# Morphology IV





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)

### **Energies of global waves**

- IP shock:

- CME

- ~ 0.1 (Mewaldt et al. 2008)
- Moreton wave:  $>10^{-6}$  (Gilbert et al. 2008)
- Seismic wave:  $\sim 10^{-4}$  (Lindsey & Donea)
  - ~1<sup>a</sup> (Emslie et al. 2005)

<sup>a</sup> (if present)

## Flare energy

#### **Short-lived**<sup>1</sup>

#### Small-scale<sup>2</sup>



<sup>2</sup>TSI impulsive phase, flare SOL20031028T11:05

Hudson et al 2006

<sup>2</sup>*TRACE 0.5" pixels, flare SOL20040722T00:30* 

# Magnetic changes during flares

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"Confusogram" legend: 10x10 2.5" pixels; 240 minutes time base; 500 G magnetic range; SOL20031102T17:03 (X8.3 flare)

(Sudol & Harvey 2005)

### **Energetic inferences**

• Flare energy scales are consistent with wave energies, except possibly that of the IP wave

• Flare energy sources are compact and brief, and can excite coronal waves via the Lorentz force

 Seismic wave excitation may require an intermediary atmospheric shock wave, or radiative coupling, or Alfvénic coupling

## 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  $\beta$  all visible structures are mere tracers and can't be dynamically important.

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

• In the solar wind,  $\beta$  increases and so these observations do not necessarily apply.

## **Momentum for seismic wave<sup>1</sup>**

Phenomenon	Mass g	Velocity km/s	$\Delta t s$	Momentum gm cm/s					
$\frac{\text{Surge/jet}^a}{\text{CME}^b}$	$2 \times 10^{15}$ $10^{16}$	500 1000	$\sim 300 \\ 100?$	$1.1 \times 10^{23}$ $10^{24}$					
$Evaporation^{c}$	$2 \times 10^{15}$	500	30	$1 \times 10^{23}$					
$\operatorname{Trapping}^{b}$	$2 imes 10^{15}$	500	30	$-1 \times 10^{23}$					
Draining	$2 \times 10^{15}$	10	$\sim 10^4$	$2 \times 10^{21}$					
Seismic wave <sup><math>d</math></sup>		40	20-50	$2.5 \times 10^{22}$					
$^a\mathrm{Bain}$ and Fletcher (2009); $^b\mathrm{rough}$ estimate; $^c\mathrm{Canfield}$ et al. (1987); $^d10^{29}~\mathrm{erg}$									

<sup>1</sup>Scaled to X1

# **Flare Momentum Conservation**



### **Momentous inferences**

- There is sufficient momentum in either CME or evaporative flows to explain the seismic wave
- The mismatch in detail probably reflects spectral selection (ie, different timescales)
- CME excitation predicts one pulse, evaporative excitation two of opposite sign
- These considerations suggest that flares without CMEs will have weaker seismic signatures

### 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<sup>22</sup> 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")

# Conclusions

- Several kinds of global wave are commonly excited during a major solar flare
- The radiant points of these global waves strongly tend to coincide with the impulsive phase, both spatially and temporally
- Heating, shock dynamics, or the Lorentz force may each play a role
- But ultimately it is the restructuring of the magnetic field that must supply the energy and momentum because plasma β is low



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