Observations of Large Scale Instabilities

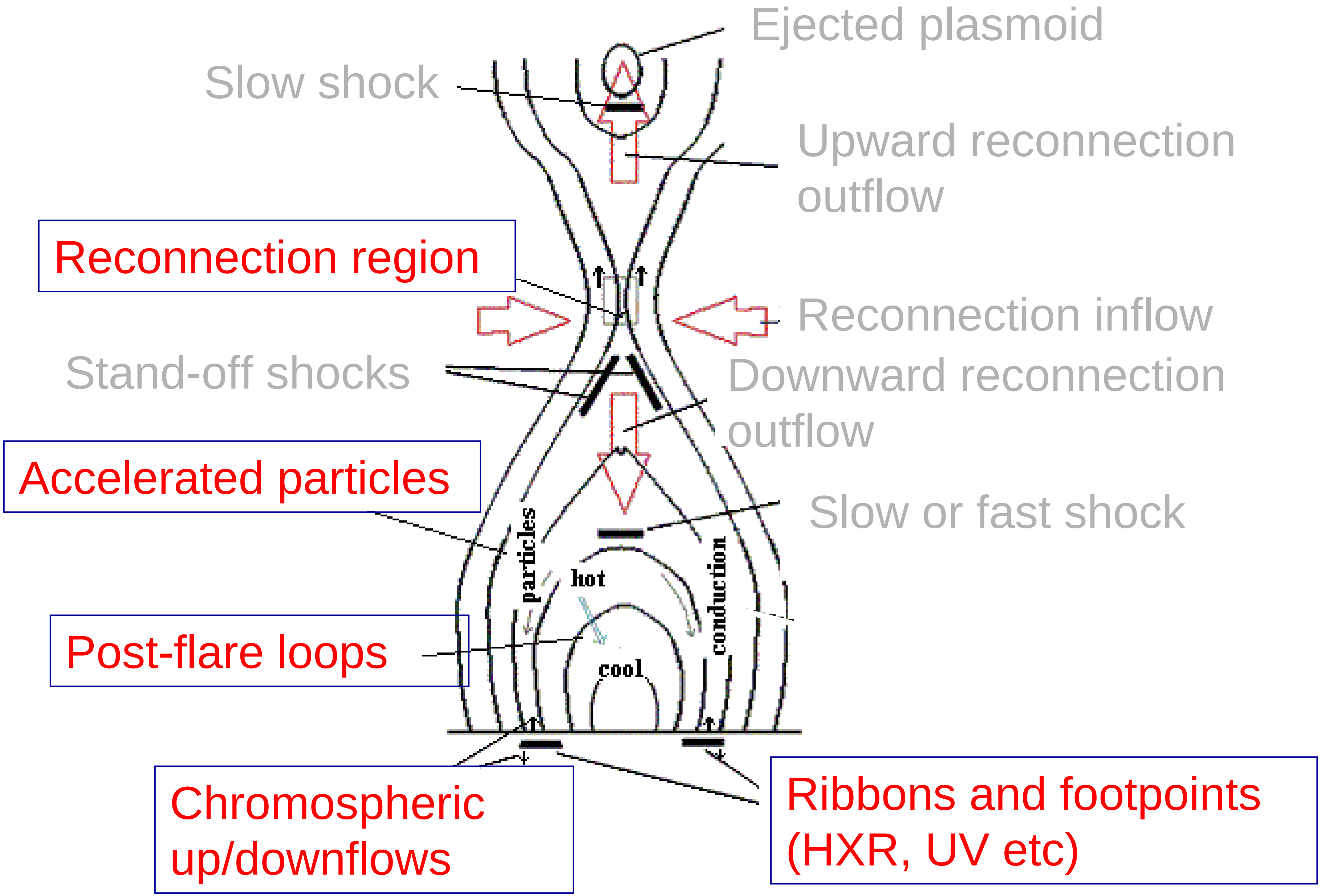
Lyndsay Fletcher

University of Glasgow

An overview of (selected) recent results pertaining to large-scale active region instabilities (i.e. flares), and questions arising from these.

- Preflare
- Impulsive phase sources and characteristics
- Coronal sources

For Orientation….



Flare Precursors

Preflare Changes

What are the signs that an instability is about to take place?

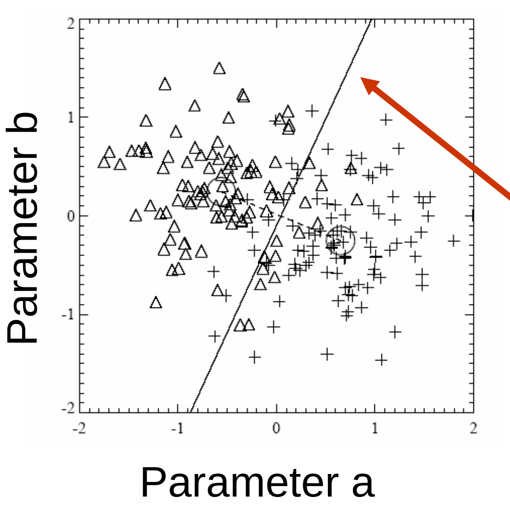
Still the best - The rise/darkening/expansion of an AR Hα filament minutes to hours before flare (Svestka 1976, Martin 1980)

Other pre-flare phenomena include:

- *Magnetic complexity, flux emergence, rapid evolution*
- Small-scale UV/EUV 'twinkles' (Moore & Sterling, Warren & Warshall)
- Small-scale GOES events and preheating
- Large-scale magnetic configuration – "sigmoids" (Hudson & Sterling)
- moving blueshift Hα events (Des Jardins & Canfield 2003)

Magnetic properties and flare productivity

Leka & Barnes (2003a,b) seek parameter(s) of photospheric vector field that, in combination, predict flare activity



\+ Flaring regions

△ Non-flaring regions

b = *f*(a) discriminates flaring/non-flaring

\- Extend to multiple dimensions

75 statistical parameters studied in discriminant analysis:

- Distribution of fields, field gradients + their moments
- Helicity, current density, free energy + related
- Shear angle, inclination angle + related

For example:

Standard deviation of inclination angle, and kurtosis of 'twist parameter' ($\propto J_z/B_z$)

truth table

TABLE 6

CLASSIFICATION TABLE FOR $[d\sigma(\gamma)/dt,\ d\kappa(\alpha)/dt]$

	Predicted	
Observed	Flare	No Flare
Flare	8	2
No flare........................	4	10

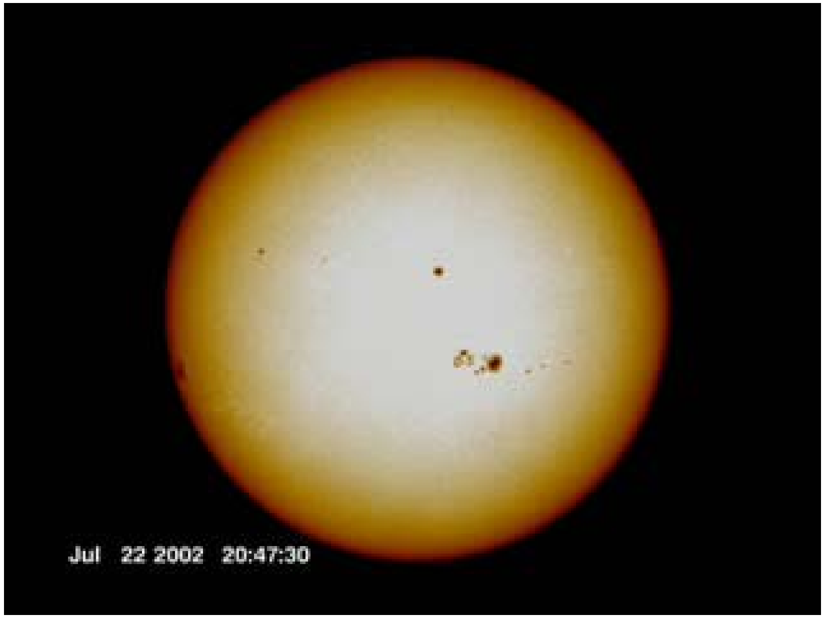
<u>Result:</u>

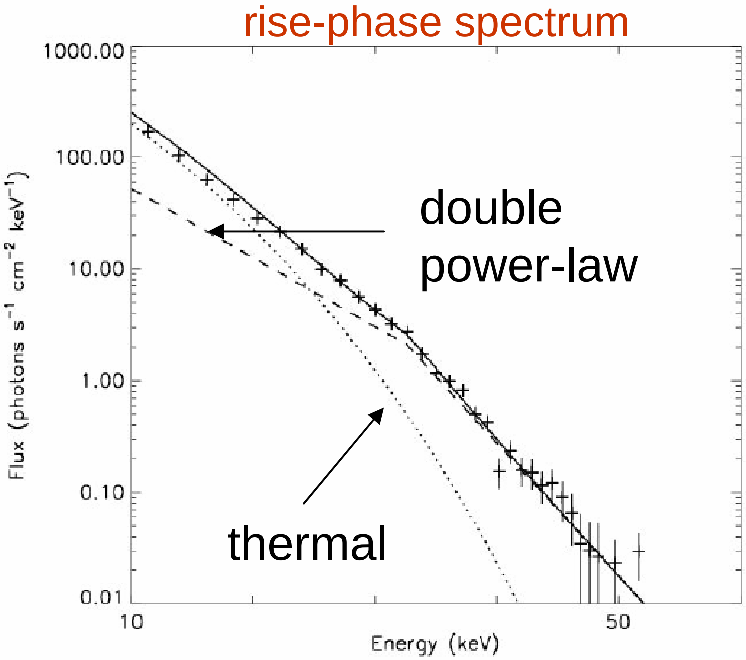
- No single parameter (or even small number thereof) is an adequate predictor
- Best prediction from diff[t] combinations of ~ 6 parameters
- Most frequently occurring parameters are standard deviation of B(x,y), & time rate of change of shear vector

No unique photospheric magnetic identifier. Is this a surprise?

Pre-impulsive phase coronal sources

- RHESSI discovery (Lin et al. 2003, Schmahl et al. 2005)
- Source appears 10 minutes *before* impulsive phase
- Negligible chromospheric emission
- *Significance*: confined coronal acceleration precedes full-blown non-linear phase of instability…modest reconnection?





Main flare phase

Flare Energy Budget

Estimates made by Emslie et al. (2004) confirm a significant fraction of total flare energy appears in form of fast particles

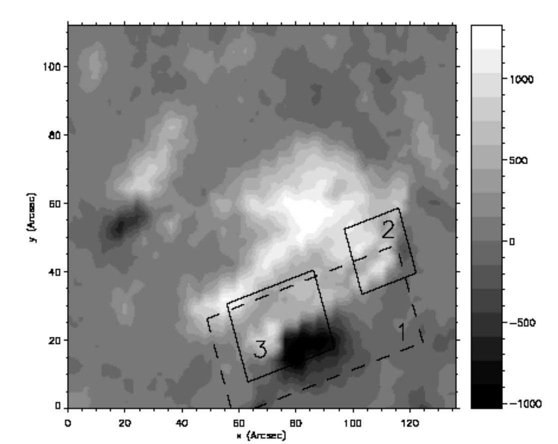
Table 3. CME/Flare Energy Budgets for the 21 April 2002 and 23 July 2002 Events

Mode	Symbol	$\log_{10}$ (Energy, erg) 21 April 2002	$\log_{10}$ (Energy, erg) 23 July 2002
Magnetic	U_B	32.3 ± 0.3	32.3 ± 0.3
Flare			
Thermal plasma, $T > 10$ MK	U_{th}	$31.3^{+0.4}_{-1}$	$31.1^{+0.4}_{-1}$
Nonthermal electrons	U_e	$31.3^{+?}_{-0.5}$	$31.5^{+?}_{-0.5}$
Nonthermal ions, >1 MeV nucleon^{-1}	U_i	<31.6	31.9 ± 0.5
CME			
Kinetic	U_K	32.3 ± 0.3	32.0 ± 0.3
Gravitational potential	U_Φ	30.7 ± 0.3	31.1 ± 0.3
Energetic particles at 1 AU	U_p	31.5 ± 0.6	<30

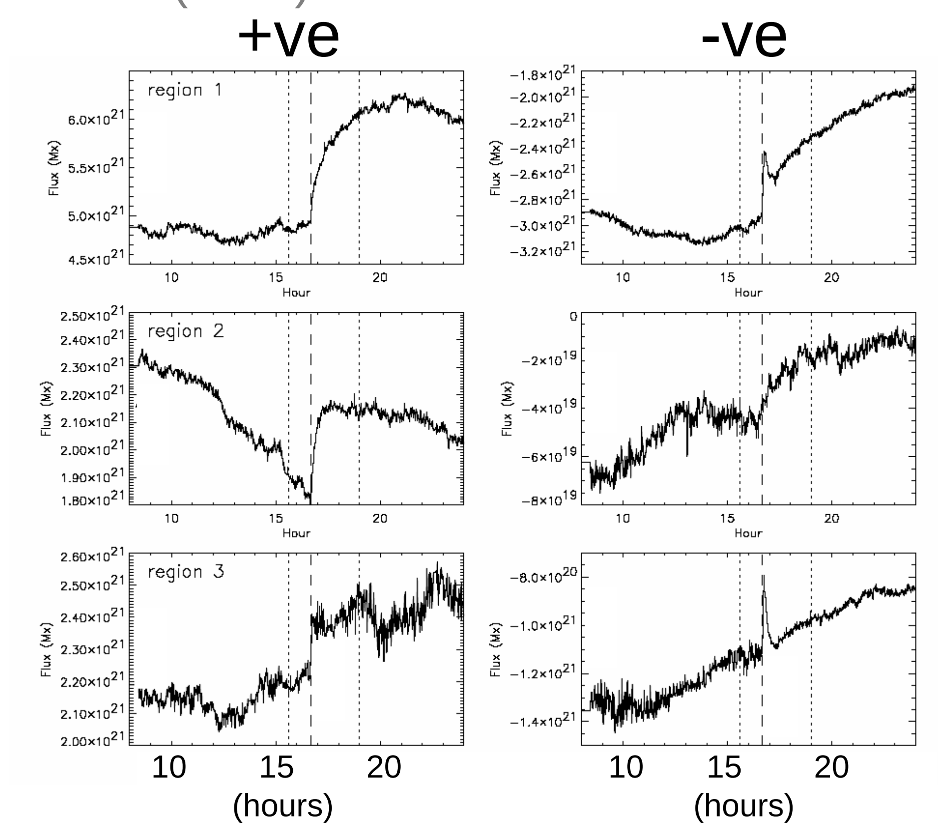
Non-Reversible Magnetic Changes

- Several reports of *non-reversible* changes in both LOS and vector field:

  e.g. Cameron & Sammis (1999), Zharkova & Kosovichev (2002), Wang et al. (2002), Sudol & Harvey (2004), Liu et al. (2005)



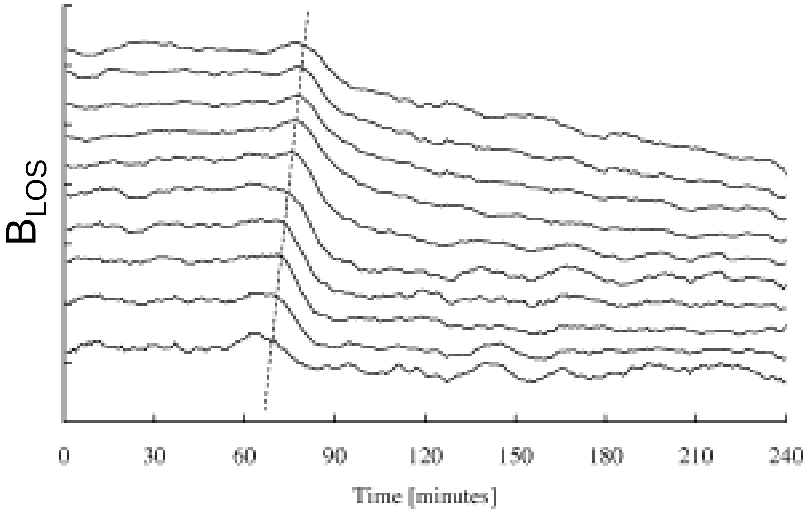
Meunier & Kosovichev 2003



Changes on timescales of minutes, *coincident with impulsive phase*

Propagating Magnetic Changes

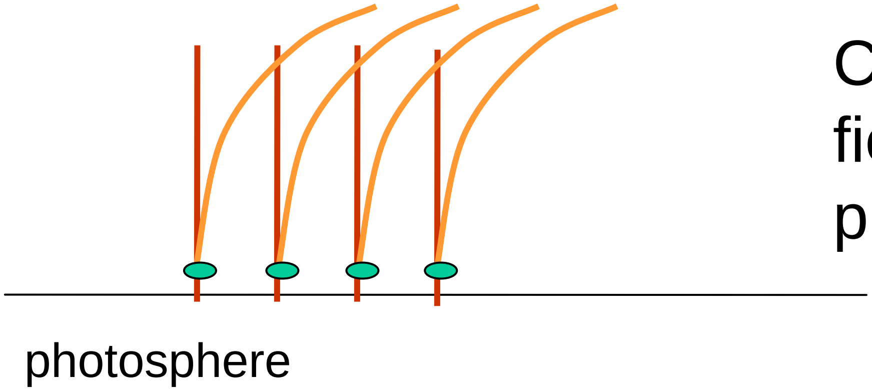
- Sudol & Harvey (2004) detect the magnetic change propagating across photosphere (GONG data)



Stackplot of LOS magnetic changes at 10" intervals across AR

Rate of propagation ~ 30km/s

= typical flare ribbon speed

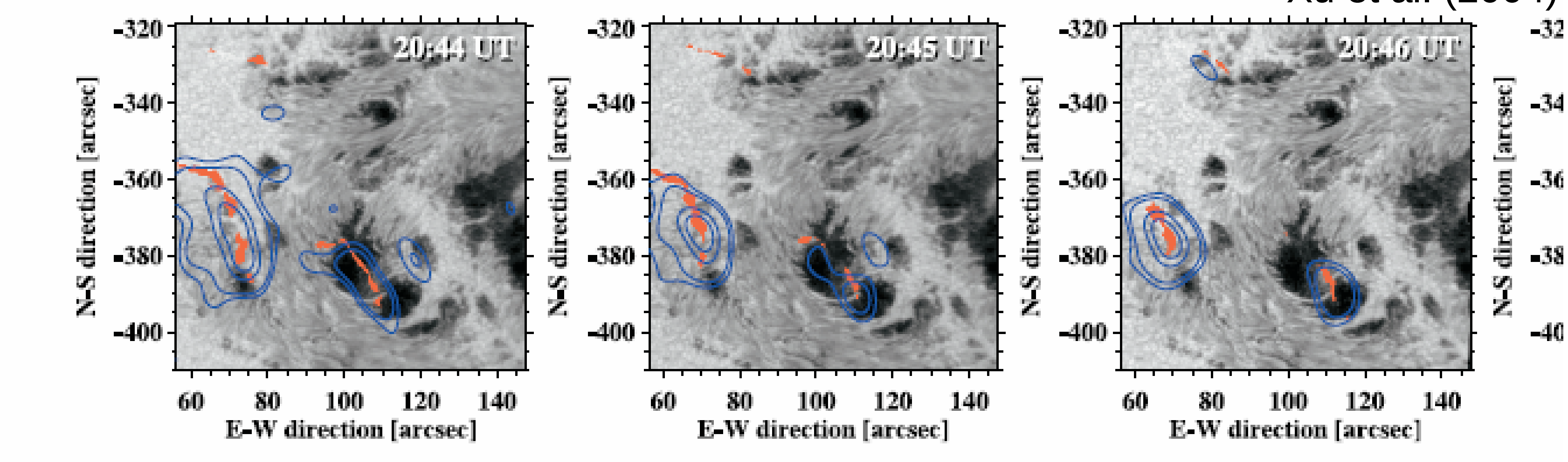


Connectivity change re-orients field line in corona, 'tugs' at photospheric anchor point?

Impulsive Phase Footpoints

- Epoch of strong chromospheric emissions – γ-rays through to infrared

Xu et al. (2004)



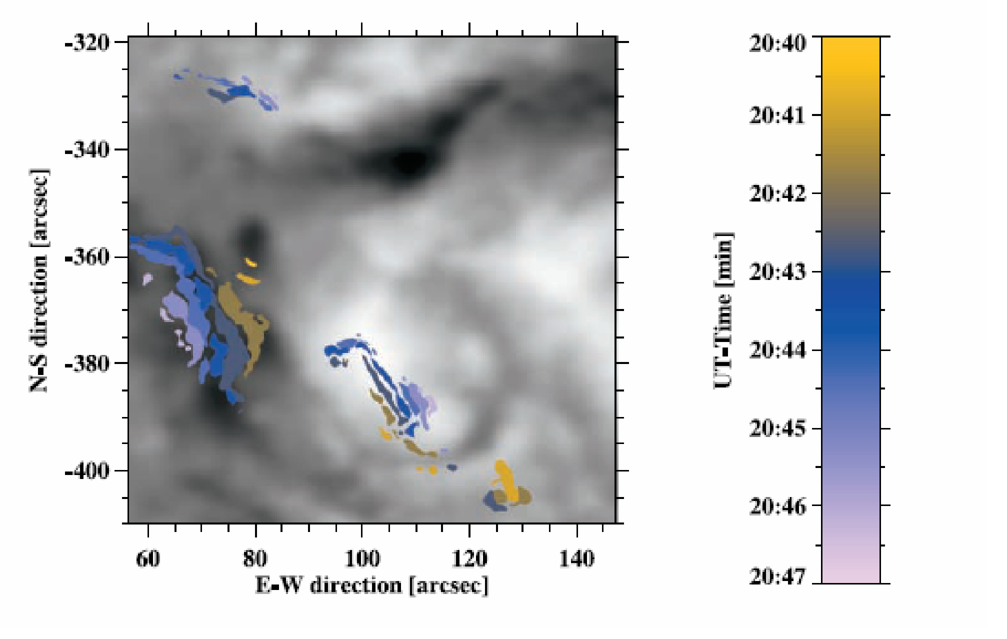
- Very compact sources – comparable to instrument limits
- Due to particle bombardment of lower atmosphere
- Related to chromospheric intersections of coronal separatrices/quasi-separatrix layers (e.g. Demoulin et al. 1997, Metcalf et al. 2003)

Footpoint Motion

Footpoint/ribbon motion maps evolution of (quasi-) separatrices, i.e. transfer of magnetic flux between domains

e.g. IR ribbon evolution (Xu et al. 2004)

Expansion not $\perp_r$ neutral line – also seen in HXRs and UV

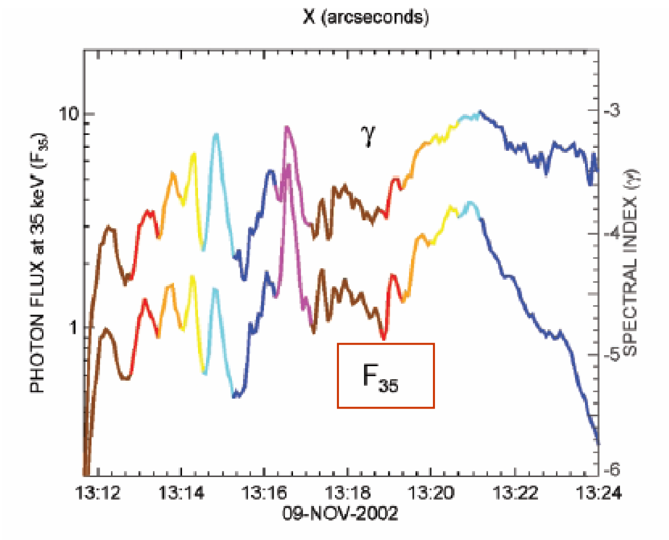


Footpoint speed & field strength used to calculate coronal reconnection rate: (e.g. Poletto & Kopp 1986, Asai et al 2004)

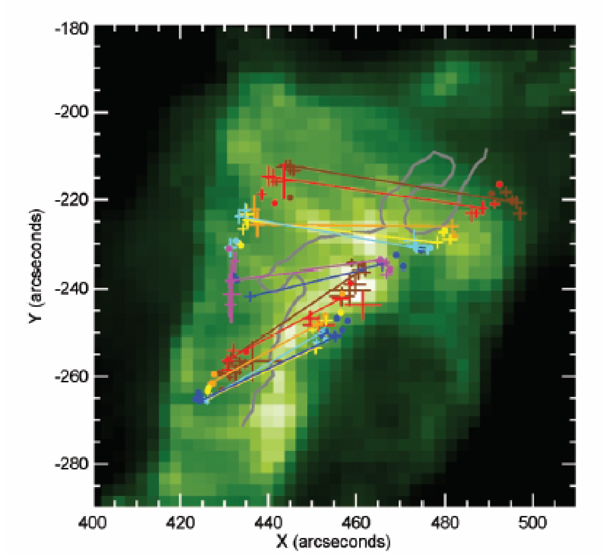
E ~ 1 – 10 V/cm during flare impulsive phase

HXR bursts – fragmentation in space & time

Impulsive phase energy release proceeds in a bursty manner



Flux and photon spectral hardness (RHESSI) Grigis & Benz 2005



- Each burst corresponds to illumination of a new footpoint pair.
- Location of footpoints (& reconnection site) *may* propagate systematically.
- In this case, v_{prop} ~ 50-100km/s

Challenges for coronal acceleration models

- From HXRs, electron flux is in excess of 2×10^{36} e/s for ~150s

- $\Rightarrow$ large flare 'volume' of $l \times w \times h$ =100" × 50" × 50" at $n_e = 10^9 cm^{-3}$ is emptied of electrons in ~50s.
  (nb HXR sources suggest << whole volume involved. If n_e increased too much, electrons are stopped in corona)

- Narrow ribbons imply high electron flux / unit area – conservative lower limit ~ 2.5×10^{18} cm^{-2} s^{-2}. This implies a beam density $\geq$ 0.1 of background density

- $\Rightarrow$ high speed return current $\Rightarrow$ stability problems

Coronal Sources

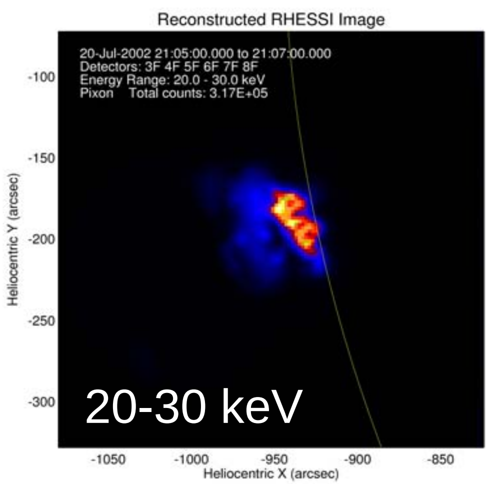
Impulsive Phase Coronal Hard X-ray Sources

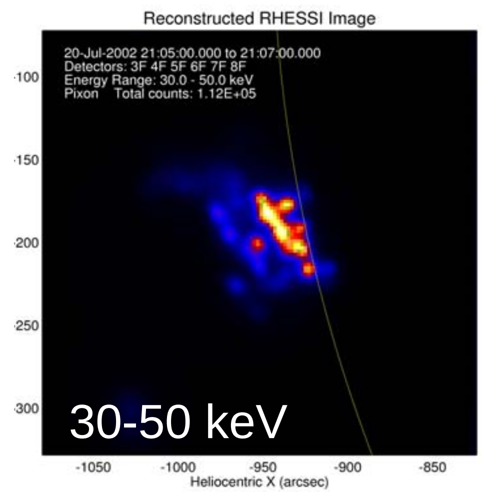
- First observed by SMM/HXIS, then at better resolution by Yohkoh/HXT. Now in many RHESSI flares (inc. occulted)

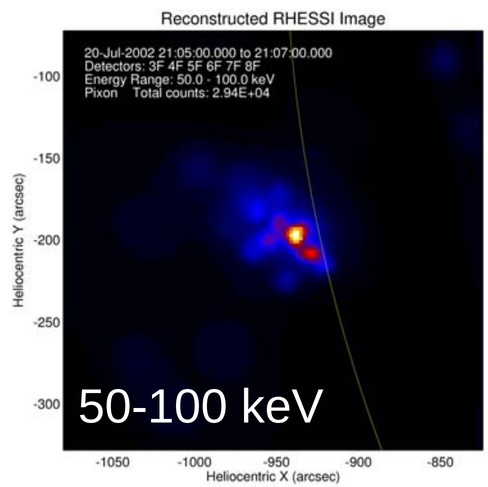
- Flares without HXR footpoints up to 50keV – only coronal HXR loops. Requires $n_e \sim 10^{11} cm^{-3}$ (Veronig & Brown 2004)

Occulted sources present up to at least 50 keV (Bone et al.)

Show impulsive behaviour on ~ 10s timescale (Balciunaite et al.)

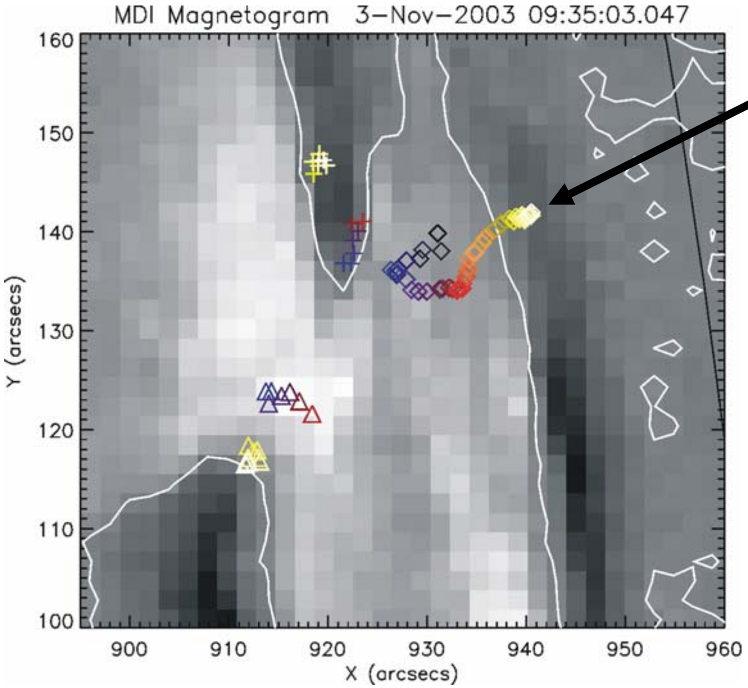






Coronal source motion

Several RHESSI observations of coronal sources show first a (projected) dip, followed by rise (Veronig et al. 2003, Sui et al. 2004, Ji et al. 2005)



Veronig et al. (2003)

Footpoints: 70-100 keV
Coronal source: 20-25 keV

Time evolution:
blue $\rightarrow$ white

Decrease in source height occurs at same time as a hardening of the spectrum

Ji et al. (2005) find instances of coronal sources descending as footpoints approach.

Summary

- Flare prediction cannot yet be made from preflare conditions
  $\Rightarrow$ trigger is a subtle perturbation, photospheric or coronal
- Weak particle acceleration before main phase of instability
  $\Rightarrow$ role for reconnection in permitting destabilisation
- Magnetic response at photospheric level to coronal changes
  Q. what happens in chromosphere?
- Coronal electron acceleration hypothesis has problems with numbers/fluxes required
  Q. Are we looking in the right place for the electrons?
- Occasionally flares happen in an already dense corona
  Q. How does that material get & stay there?