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
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
\( \triangle \) 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’ \((\propto \mathbf{J}_z/B_z)\)

**Result:**

- No single parameter (or even small number thereof) is an adequate predictor
- Best prediction from different 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?

![Chromospheric and Coronal Magnetism, Lindau, Sept 1st 2005](image)
Main flare phase
Estimates made by Emslie et al. (2004) confirm a significant fraction of total flare energy appears in form of fast particles.
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)

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-orient field line in corona, ‘tugs’ at photospheric anchor point?
Impulsive Phase Footpoints

- Epoch of strong chromospheric emissions – $\gamma$-rays through to infrared

- 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)

Xu et al. (2004)
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 \( \perp \) 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)

\[ E \sim 1 - 10 \text{ V/cm during flare impulsive phase} \]
HXR bursts – fragmentation in space & time

Impulsive phase energy release proceeds in a bursty manner

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

Flux and photon spectral hardness (RHESSI)  Grigis & Benz 2005
Challenges for coronal acceleration models

- From HXRs, electron flux is in excess of $2 \times 10^{36}$ e/s for $\sim 150$s

- $\Rightarrow$ large flare ‘volume’ of $l \times w \times h = 100'' \times 50'' \times 50''$ at $n_e = 10^9$cm$^{-3}$ is emptied of electrons in $\sim 50$s.
  (nb HXR sources suggest $\ll$ 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 $\sim 2.5 \times 10^{18}$ cm$^{-2}$ s$^{-2}$. This implies a beam density $\geq 0.1$ of background density

- $\Rightarrow$ high speed return current $\Rightarrow$ stability problems
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 $n_e \sim 10^{11}\text{cm}^{-3}$ (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)

Footpoints: 70-100 keV
Coronal source: 20-25 keV
Time evolution: blue → white

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

Veronig et al. (2003)

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

Chromospheric and Coronal Magnetism, Lindau, Sept 1st 2005
Summary

- Flare prediction cannot yet be made from preflare conditions ⇒ trigger is a subtle perturbation, photospheric or coronal
- Weak particle acceleration before main phase of instability ⇒ 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?