Evolving views of solar flares, and targets for cycle 24

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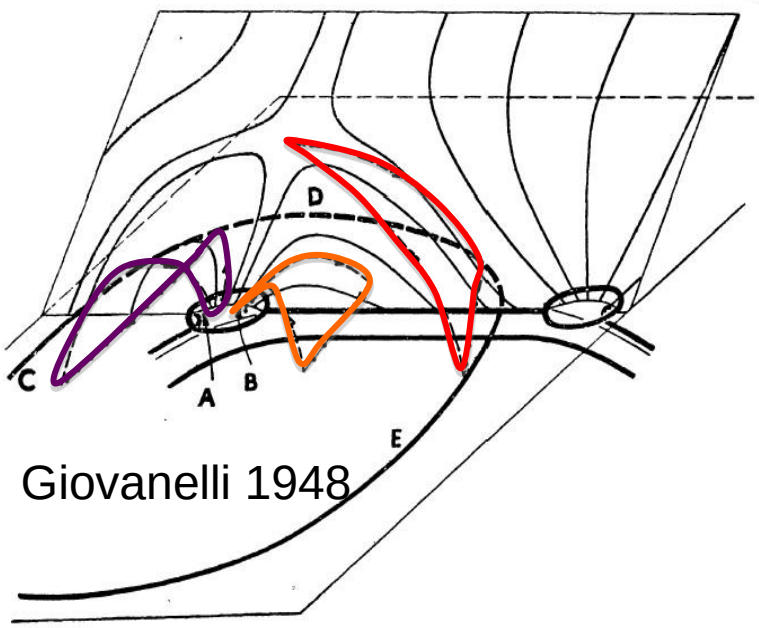
View of flares c. Cycle 18.



Giovanelli 1948

"It has been generally accepted that in the main flares are confined to the chromosphere…" (Giovanelli 1948)

Giovanelli cartoon also include magnetic topology, coronal current systems (coloured lines).

But no knowledge of non-thermal particles, CMEs,

- Energy storage is in the corona.
- Majority of flare radiation comes from chromosphere
- How are they linked?

Flares: what we have learned

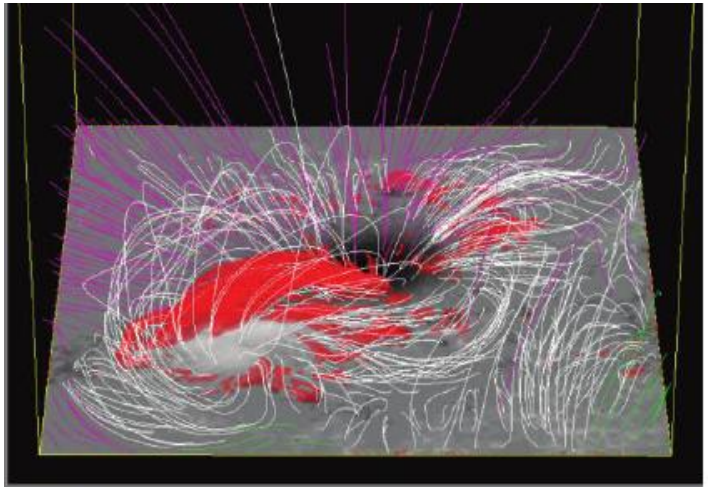
Energy is stored in stressed coronal fields.

Topology changes (via reconnection) allow field to reconfigure, liberating energy.

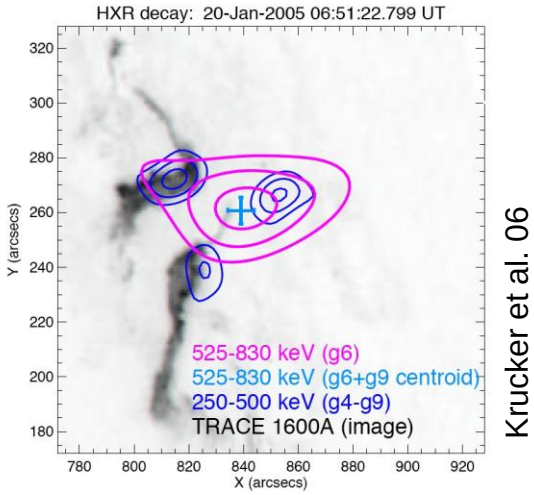
Up to 50% of magnetic energy released goes to K.E. of non-thermal particles

Accelerated particles are present in both corona and chromosphere

Chromosphere is heated, radiates strongly and expands



Schrijver et al. 06



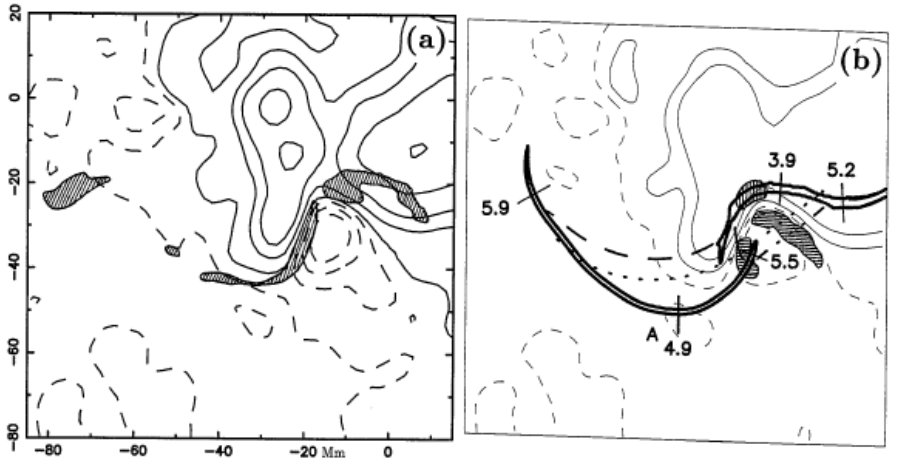
Krucker et al. 06

Coronal currents

Location: Hard to work out but seems strongest currents within ~ 15,000km of neutral line (eg Schrijver et al 08)

Topology: Topology is crucial. But how is it related to coronal current systems inferred from magnetic measurements?

Spatial relationship between quasi-separatrix layers (R) and Hα flare ribbons (L), from Demoulin et al (1997)



Variation: how do currents change and re-route in a flare?

Energy transport

Agent: in dominant model, particle beams transport energy from stressed coronal field to chromosphere.

Electrons: $10^{28} – 10^{29}$ erg s^{-1} goes into electrons (known from bremsstrahlung diagnostics), appearing mostly in chromosphere.

Ions: similar amount of energy overall

Accelerator: unknown, but most focus has been on

(1) DC field acceleration in reconnection electric field (e.g. Somov, Litvinenko)

(2) stochastic acceleration in coronal MHD turbulence - resulting from fast mode wave launched as field relaxes (eg Miller,Petrosian)

Non-thermal electrons

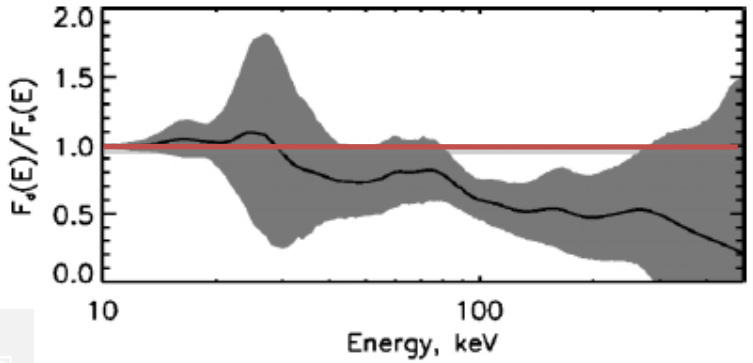
Number:

-Coronal HXRs: at any instant < 1-10% of coronal electrons accelerated

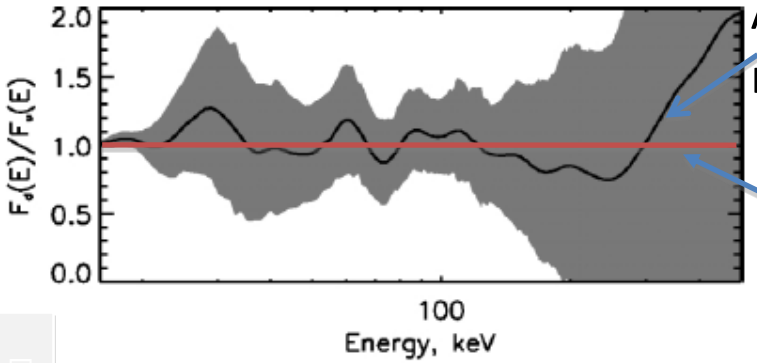
-Chromospheric HXRs: beam model ➔ > 10% of coronal electrons accelerated, and leave corona, each second. Also, n_{beam}/n_{corona} > 0.1.

Angular distribution: observations difficult but, so far, little evidence for beam dist^{ns} (Kontar & Brown 06, Kasparova et al 07)

Aug 20 2002



Jan 17 2005



Albedo measurements

isotropy

Coronal magnetic restructuring

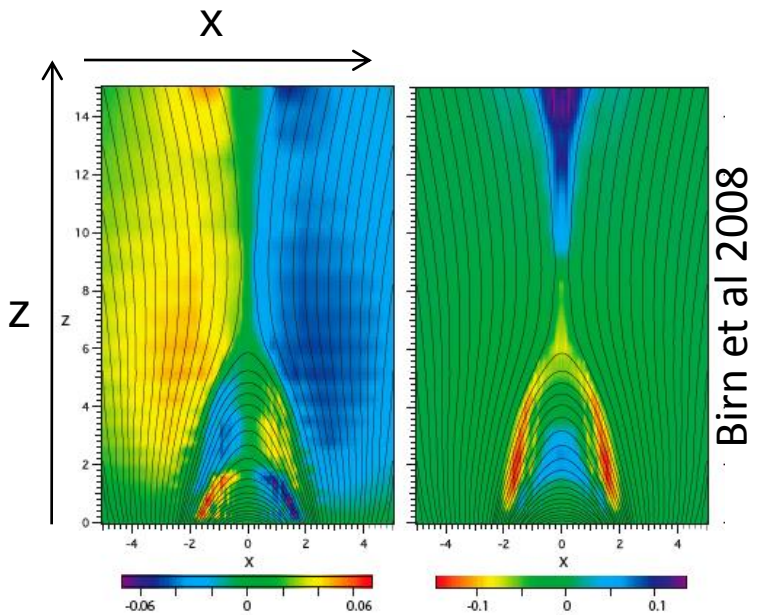
Ramifications of coronal magnetic restructuring in a flare:

- Reconnection electric field -> particle acceleration
- Coronal shocks/shock heating

Quite well - studied

- Launch of MHD waves: fast, slow, Alfven – as a mode of <u>energy transport</u> (e.g. Longcope & Priest, Fletcher & Hudson)

- Corona-chromosphere magnetic link i.e. does change in coronal B lead to perturbation of lower atmosphere (c.f. 'McClymont jerk', Anwar et al 1993)



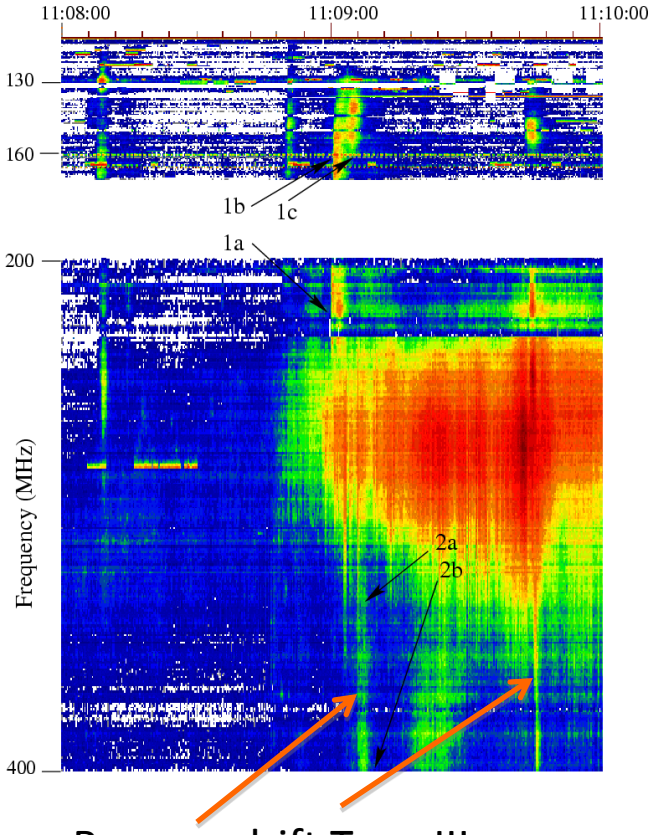
Electron transport

Need to do coronal electron transport going beyond collisional physics, e.g.

1. electron beam + coronal plasma = Langmuir waves, energy loss

2. observations imply a dense electron beam (n_{beam} ~ n_{corona}), strong return current, and energy loss / instability

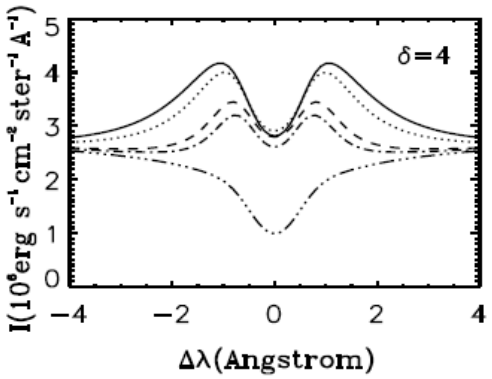
(cf work of Battaglia, Hannah, Kontar, Zharkova…)



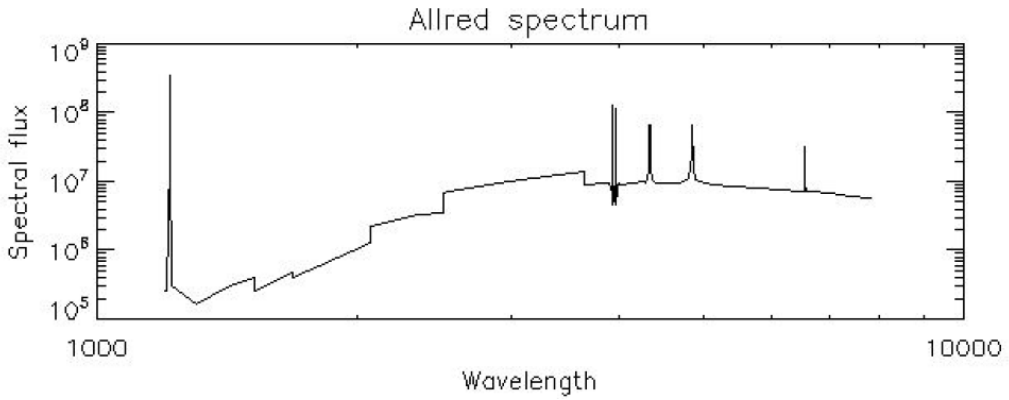
Reverse drift Type III bursts, linked to Langmuir waves from electron beams propagating downwards

Chromosphere

They're messy and difficult, but chromospheric diagnostics – line and continuum – constrain flare energy deposition as f^n of height.



Hα line profiles for different beam fluxes (Fang et al 03)



Spectrum arising from beam excitation of chromosphere - RMHD modelling by Allred et al 05

Chromosphere/ionosphere analogy. Can coronal currents close through the chromosphere?

Main messages

- Flares are magnetic. We need to think also about energy transport by magnetic perturbations when considering energy release.
- The corona is a plasma. We need to think again about plasma effects (waves, return currents) in our beam modeling, and support with radio/HXR observations.
- The flare energy is manifested primarily in chromospheric radiation. We need renewed focus on chromospheric diagnostics and modeling.