Observations of Flare (and CME) onset

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Talk topics

Overview of some features appearing in the minutes before the flare impulsive phase (where this means strong HXRs, chromospheric footpoints)

- Coronal X-ray sources
- Early chromospheric ribbons
- Photospheric magnetic disturbances
- EUV/UV line broadening
- Pulsations/oscillations

Note – most observations presented here are M/X flares, most are eruptive, and we know that the CME acceleration correlates in time with HXR burst (Temmer+10)

Caveat – Though I’ve tried to avoid phenomena reported for only one events, it’s likely that none of the onset signatures reported here is universal.
Battaglia+09 - 4 RHESSI events with pre-flare emission:

- Initially thermal coronal sources ($T \sim 20$ MK)
- Coronal $n_e \sim$ few x $10^9$ cm$^{-3}$, increasing over $\sim 60$s (interpreted as conduction-driven evaporation)
- Coronal non-thermal tail appears after $\sim 60-100$s
- Footpoints after another $\sim 200$s

Early-phase coronal heating precedes impulsive phase by minutes

Also e.g. Siarkowski+09, Awasthi+14, Battaglia+19

See also Simões talk & Hudson poster “hot onsets”,
Non-thermal preflare coronal sources

Non-thermal sources can accompany thermal sources during the rise phase. Rare - possibly since pre-flare corona is not very dense

e.g. Lin+03, Veronig+06, Caspi & Lin 10

SOL2002-07-23 coronal source:
• Occurs prior to main impulsive phase
• No HXR footpoints evident
• Non-thermal component, varies on ~10s timescales
• $n_e \sim 10^{10} \text{ cm}^{-3}$
• Microwaves imply $B_{\text{cor}} \sim 200\text{G}$ (Asai+06)

SOL2003-11-03: Veronig+06 observe pre-flare thermal to non-thermal evolution, and downwards source motion

Krucker+08
Early appearance of flare ribbons - UV

- 9 events seen with TRACE 1600, Yohkoh HXT, BATSE (Warren & Warshall 01)
- All show UV ribbons preceding HXR by minutes.
- Eventual HXR sources appear at slightly different locations from UV ribbons

See also:
Fárnik & Savy 96, 98 - no clear spatial relationship between pre-flare & flare SXR sources (Yohkoh SXT)
Early appearance of flare ribbons - EUV

SOL2010-08-07 (Fletcher+13)

- EUV pre-flare ribbons appearing minutes before impulsive phase
- Heated to ~10MK
- Basically stationary, at essentially same locations as later HXR sources
- Showed insufficient energy in non-thermals electrons to heat pre-flare ribbons
- Also not clear that conduction can heat pre-flare ribbons.

See also Simões+15 – early hot footpoints
Flare-related non-reversing changes in the photospheric field are well known (e.g. Wang+94, Kosovichev+Zharkova01, Sudol+Harvey 05, Petrie+Sudol 10)

Timing of changes with respect to other flare signatures is less well studied

Timing of field changes and HXRs in 5 X flares (Burtseva+15)
GONG field changes fitted with

\[ B(t) = a + b(t) + c \left( 1 + \frac{2}{\pi} \tan^{-1}(n(t - t_0)) \right) \]

3 biggest flares: flux change peaks 1-4 mins before main RHESSI HXRs (GONG uncertainty ± 0.3 min)
Strong field re-organisation precedes acceleration
Photospheric field changes - position

Map of ‘c’ parameter (strength of field change) with RHESSI source centroids superposed

In all flares studied, good correspondence of early HXR sources and strongest field changes

Liu+18 – SOL20150622
Goode Solar Telescope: field changes sweep across photosphere with the flare ribbons (as identified in Hα red wing)
IRIS line broadening in the Si IV line 80,000K (Jeffrey+2018) 1.7s cadence => very detailed pre-flare evolution

\[ \Delta \lambda^2_{tot} = \Delta \lambda^2_{inst} + 4 \ln 2 \left( \frac{\lambda}{c} \right)^2 \left( v^2_{th} + v^2_{nth} \right) \]

- \( v_{nth} \) varies on a timescale of 10s
- \( v_{nth} \) increases before the flare, and decreases as the flare heats.
- ‘non-thermal’ KE before flare ~ thermal energy of the 80,000K flare plasma

=> Energy transferred from turbulence to plasma on 10s timescale
Pre-flare coronal line broadening

Hinode/EIS coronal line broadening SOL2013-05-15, with HXRs (Kontar+17)

Ratio of turbulent KE to non-thermal electron power is \(~ 1 - 10s\)

\(\rightarrow\) electron acceleration with turbulence loading/dissipation timescale \(~ 1-10s\)
Harra+13: EIS increase in non-thermal Fe XII 195Å observations of line width preceding 4 M/X flares by 10s of minutes

Non-thermal width enhancements at base of active region loops (A,B) and also corona (C) in eruptive events

Also Harra+09 – broadening increasing for some hours prior to major eruption, associated with helicity injection (Magara & Tsuneta 08)
SOL2014-09-10 – alternating red/blueshifts, brightening and broadening in pre-flare sigmoid (interpreted as flux rope)  Zhou+16

Period $T \sim 280s$, from about 20 mins before flare main onset and flux rope eruption. Destabilising flux rope?

See also Tan+16: $\sim 30\%$ of (412) flares studied show long period pulsations in SXR light curves, $T=8\text{-}30$ minutes, from 1-2h before flare
Conclusions

• Clear evidence that the solar atmosphere is ‘gearing up’ for a flare, some minutes (or even longer) in advance of the impulsive phase

• Includes thermal and non-thermal coronal sources, strong changes in the magnetic field orientation, presence of turbulent broadening, heating of lower atmosphere, oscillatory behaviour

• Field changes preceding HXR footpoint emission (electron acceleration) by 10s of seconds are particularly intriguing

• Interesting suggestions that turbulence leads to heating and acceleration in both corona and lower atmosphere

• Are these phenomena rare or common? Unclear - requires studies with large samples