

# Observations of Flare (and CME) onset

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Overview of some features appearing in the minutes before the flare impulsive phase (where this means strong HXR, 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 event, it's likely that none of the onset signatures reported here is universal.

# Thermal preflare coronal sources

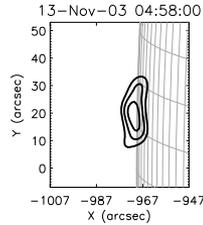
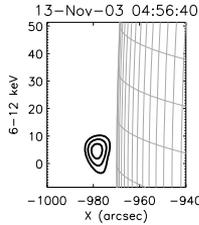
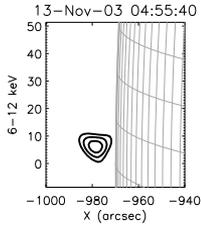
$t_1$ :  
thermal

$t_2$ : non-  
thermal

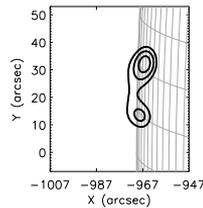
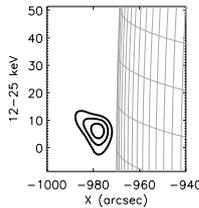
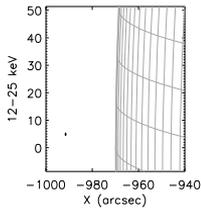
$t_3$ : first  
footpoints

Battaglia+09 - 4 RHESSI events with pre-flare emission:

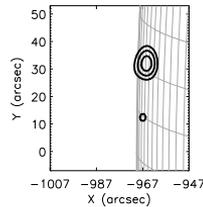
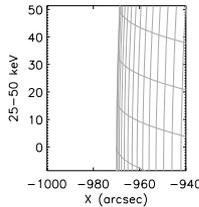
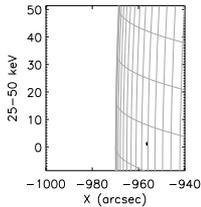
6-12 keV



12-25 keV



25-50 keV



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

Early-phase coronal heating precedes impulsive phase by minutes

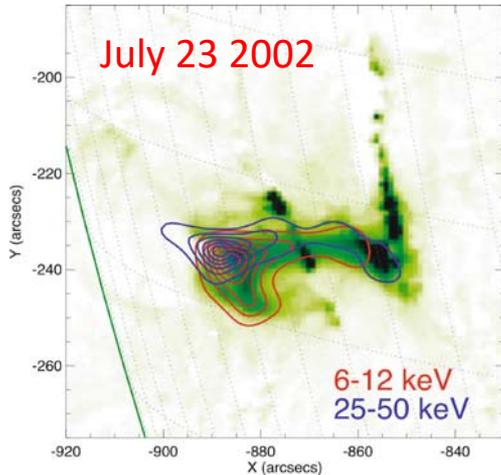
Also e.g. Siarkowski+09, Awasthi+14, Battaglia+19

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



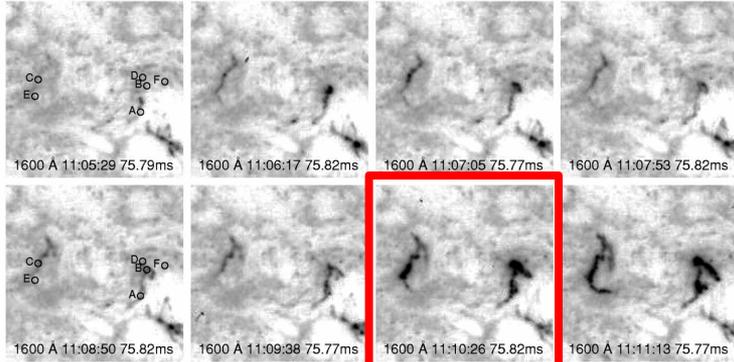
Krucker+08

SOL2002-07-23 coronal source:

- Occurs prior to main impulsive phase
- No HXR footpoints evident
- Non-thermal component, varies on  $\sim 10$ s 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

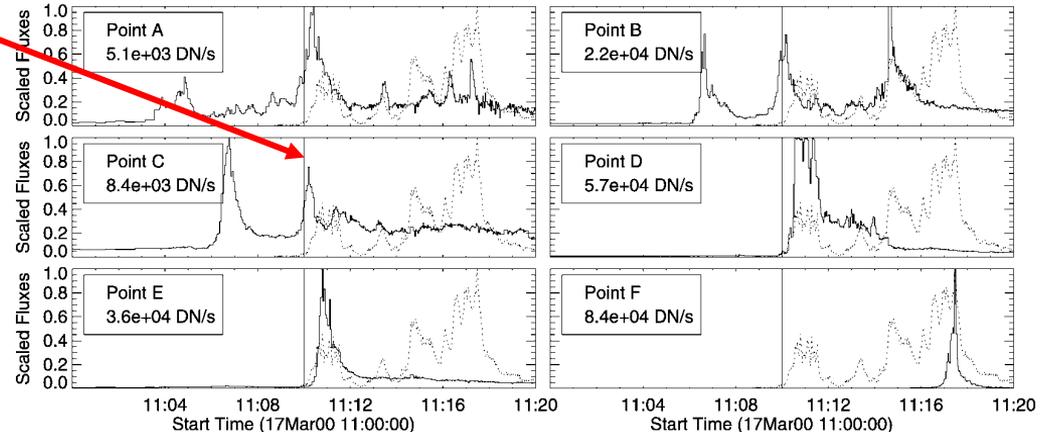
# Early appearance of flare ribbons - UV



HXR onset

- 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

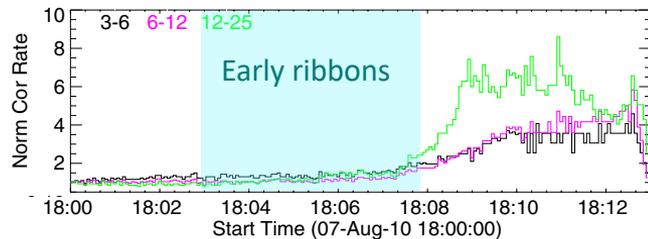
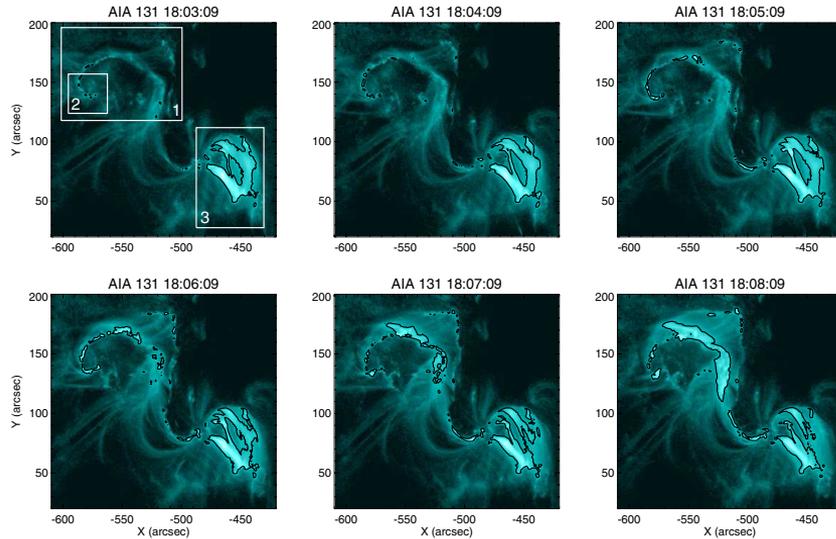
TRACE 1600 (solid) & BATSE 25-100keV (dotted)



See also:

Fárník & 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)

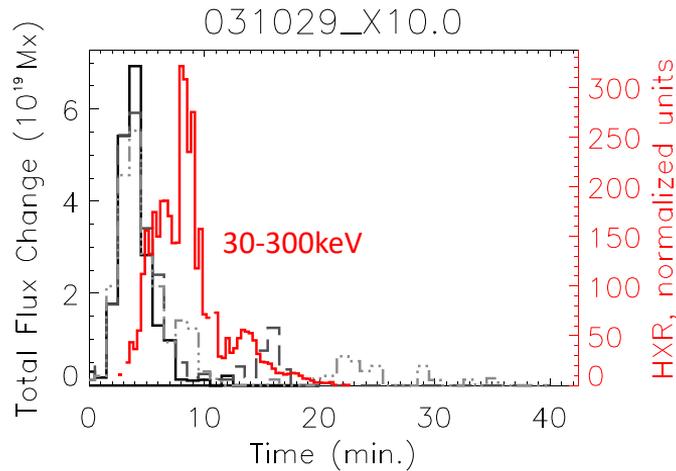
- EUV pre-flare ribbons appearing minutes before impulsive phase
- Heated to  $\sim 10\text{MK}$
- Basically stationary, at essentially same locations as later HXR sources
- Showed insufficient energy in non-thermals electrons to heat pre-flare ribbons
- Also not clear that conduction can heat pre-flare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

See also Simões+15 – early hot footpoints

# Photospheric field changes - timing

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



Solid, dash, dot-dash correspond to histograms against start, mid, endpoint of change

$$t_s = t_o - \frac{\pi}{2n}; t_o; t_e = t_o + \frac{\pi}{2n}$$

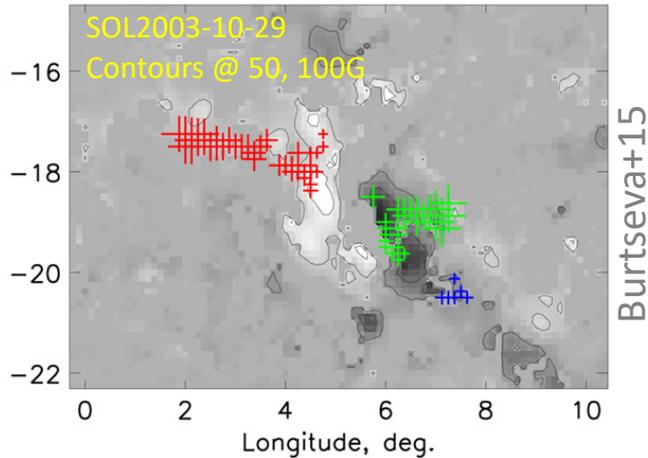
Timing of field changes and HXRs in 5 X flares (Burtseva+15)

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  $\pm 0.3$  min)  
Strong field re-organisation precedes acceleration

# Photospheric field changes - position



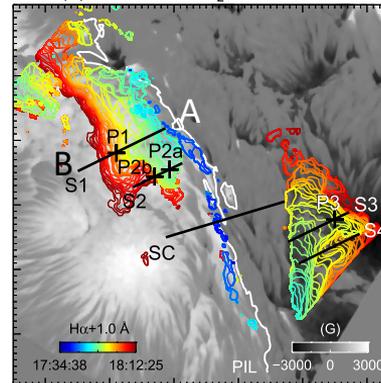
Map of 'c' parameter (strength of field change) with RHESSI source centroids superposed

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

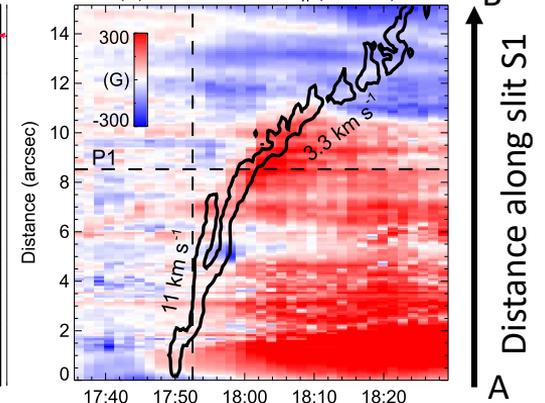
Liu+18 – SOL20150622

Goode Solar Telescope: field changes sweep across photosphere with the flare ribbons (as identified in H $\alpha$  red wing)

Flare ribbon locations on magnetogram  
(b) GST/NIRIS B<sub>z</sub> 17:34:03 UT



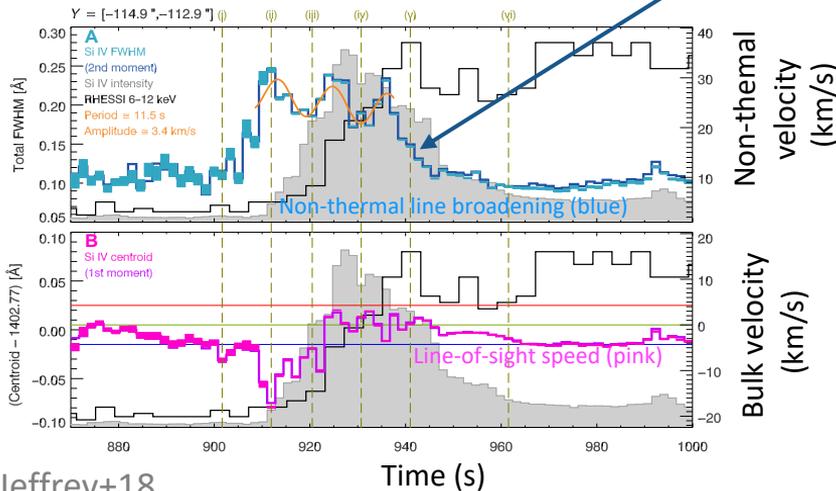
Change in horizontal field with time  
(a) GST/NIRIS  $\Delta B_x$  (Slit S1)



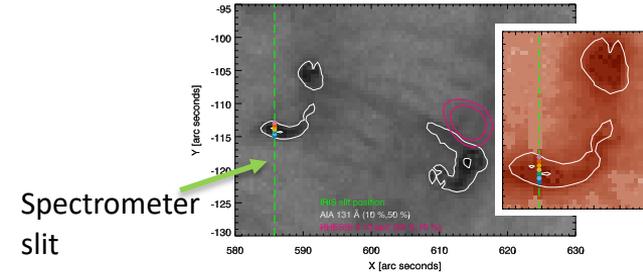
# Pre-flare line broadening -TR/upper chromosphere

IRIS line broadening in the Si IV line 80,000K (Jeffrey+2018)  
 1.7s cadence => very detailed pre-flare evolution

$$\Delta\lambda_{tot}^2 = \Delta\lambda_{inst}^2 + 4 \ln 2 \left(\frac{\lambda}{c}\right)^2 (v_{th}^2 + v_{nth}^2)$$



Jeffrey+18

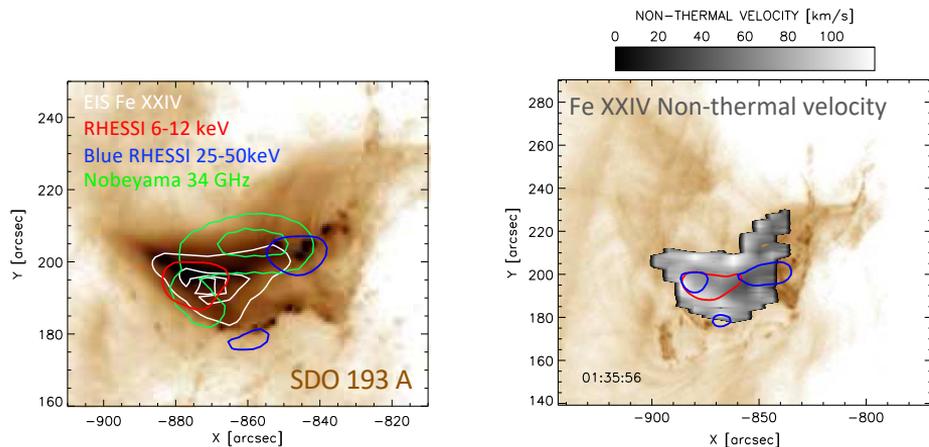


- $v_{nth}$  varies on a timescale of 10s
- $v_{nth}$  increases *before* the flare, and decreases as the flare heats.
- ‘non-thermal’ KE before flare  $\sim$  thermal energy of the 80,000K flare plasma

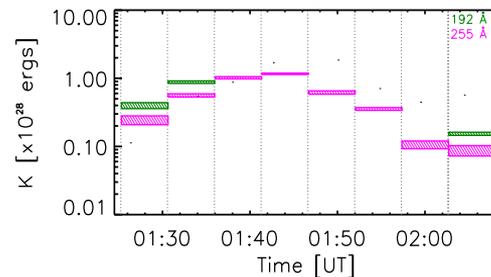
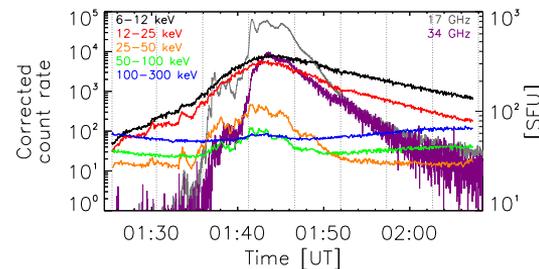
=> Energy transferred from turbulence to plasma on 10s timescale

# Pre-flare coronal line broadening

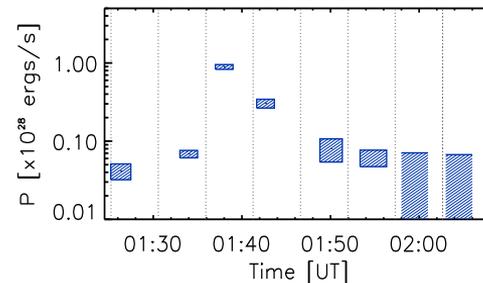
Hinode/EIS coronal line broadening SOL2013-05-15, with HXRs (Kontar+17)



Kontar+17



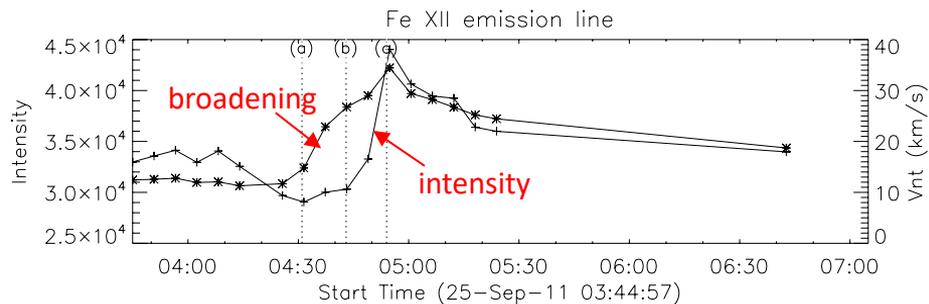
Turbulent KE  
(from EUV  
line  
broadening)



Non-thermal  
electron  
power (from  
HXRs)

Ratio of turbulent KE to non-thermal electron power is  $\sim 1 - 10$ s  
 $\Rightarrow$  electron acceleration with turbulence loading/dissipation timescale  $\sim 1-10$ s

# Long-duration pre-flare coronal line broadening

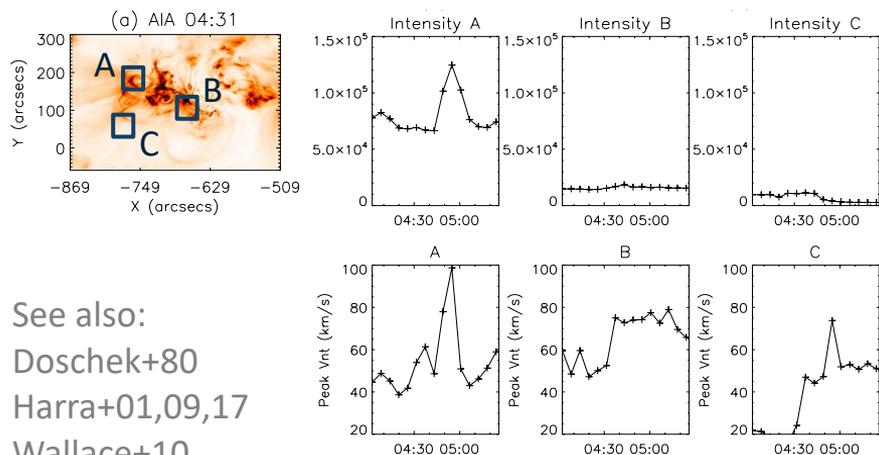


Harra+13: EIS increase in non-thermal Fe XII 195Å observations of line width preceding 4 M/X flares by 10s of minutes

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

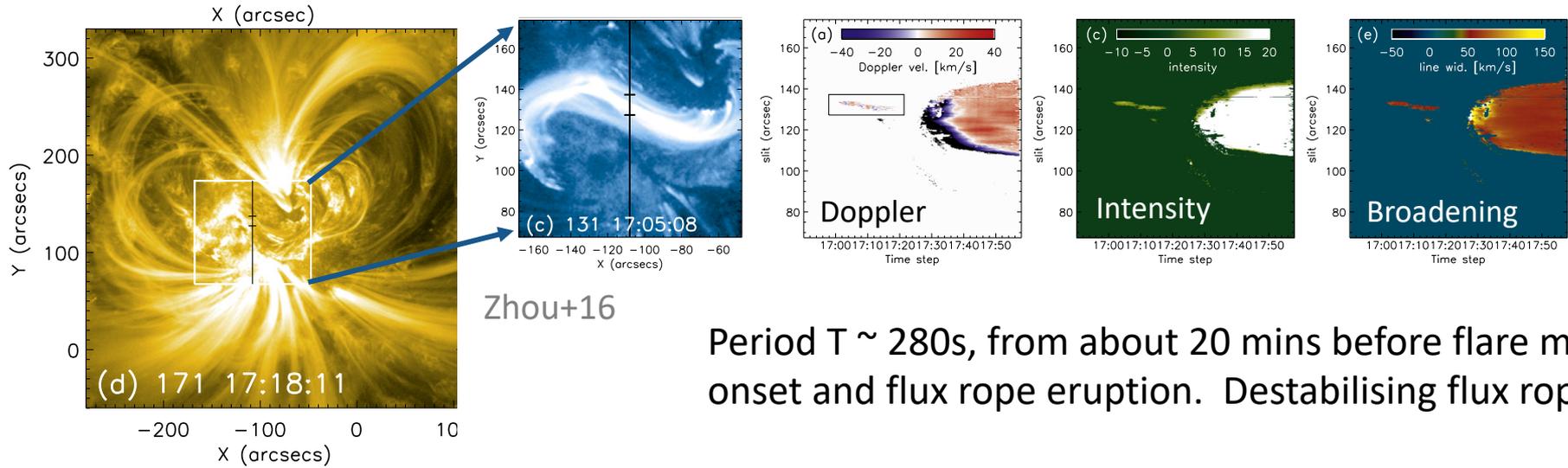
Also Harra+09 – broadening increasing for some hours prior to major eruption, associated with helicity injection (Magara & Tsuneta 08)

See also:  
Doschek+80  
Harra+01,09,17  
Wallace+10



# Preflare oscillations

SOL2014-09-10 – alternating red/blueshifts, brightening and broadening in pre-flare sigmoid (interpreted as flux rope) Zhou+16



Period  $T \sim 280$ s, 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,  $T=8-30$  minutes, from 1-2h before flare

- 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