Hinode and the Flare/CME Connection: Events of 19th May, 2007

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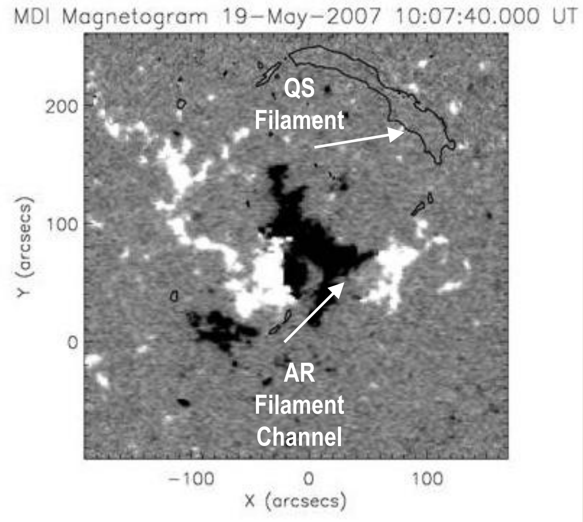
SUMMARY

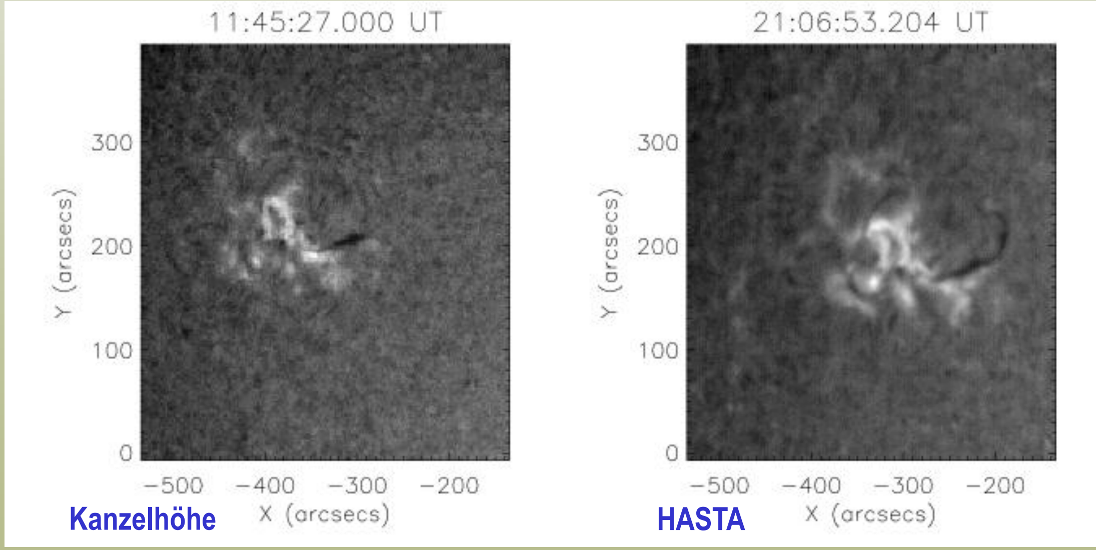
- Two independent filaments – Active Region and Quiescent, are observed in the days before the flare and CME eruption
- Observations of filament interactions and related heating are presented
- Heating cycles precede a final filament disappearance, heating and eruption
- Possible models for the merger topology and eruption instability are discussed
- Hinode EIS and other observations of an associated B 9.5 flare are also shown
- Evidence for prompt shock heating of coronal plasma near the reconnection site is presented

AR Magnetic Field and Filaments

- MDI magnetogram image shows field configuration for the AR and surrounding QS on 19 May
  - region is complex with leading +ve (non-Hale) polarity
  - AR filament lies between positive and negative flux belonging to two different bipoles
  - for the quiescent filament, weak field North of the extended filament channel is mainly positive polarity
  - flux cancellation occurs in both AR and QS sections between17 and 19 May

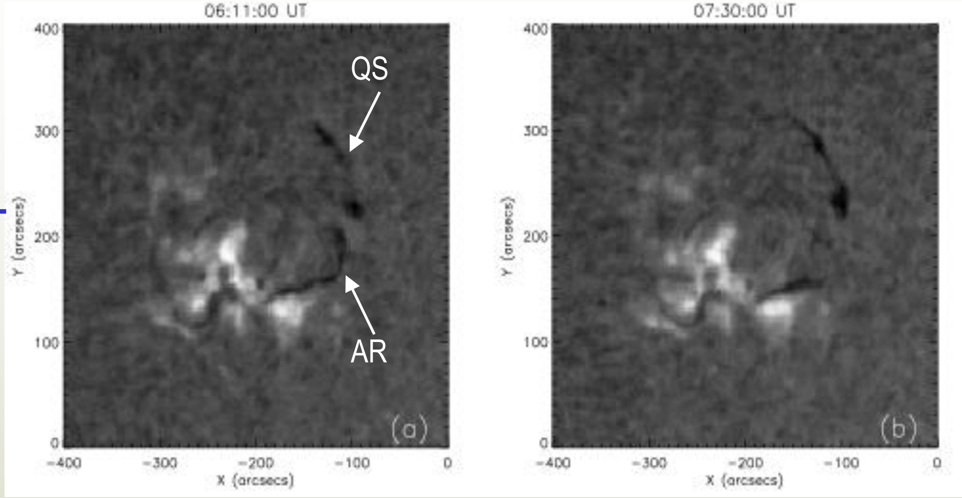


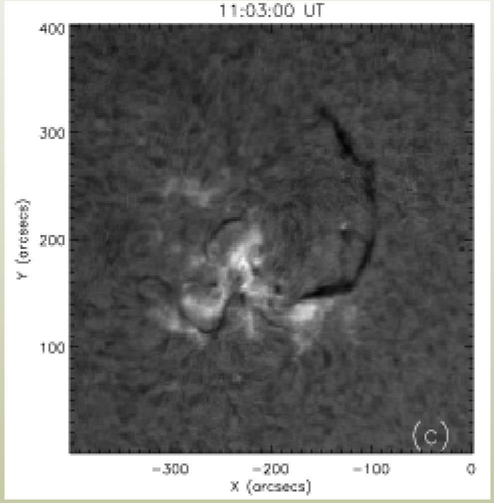
- Kanzelhöhe and HASTA Hα images on 17 May; 11:45 UT and 21:07 UT show
  - initial formation of AR filament
  - its extension to NW

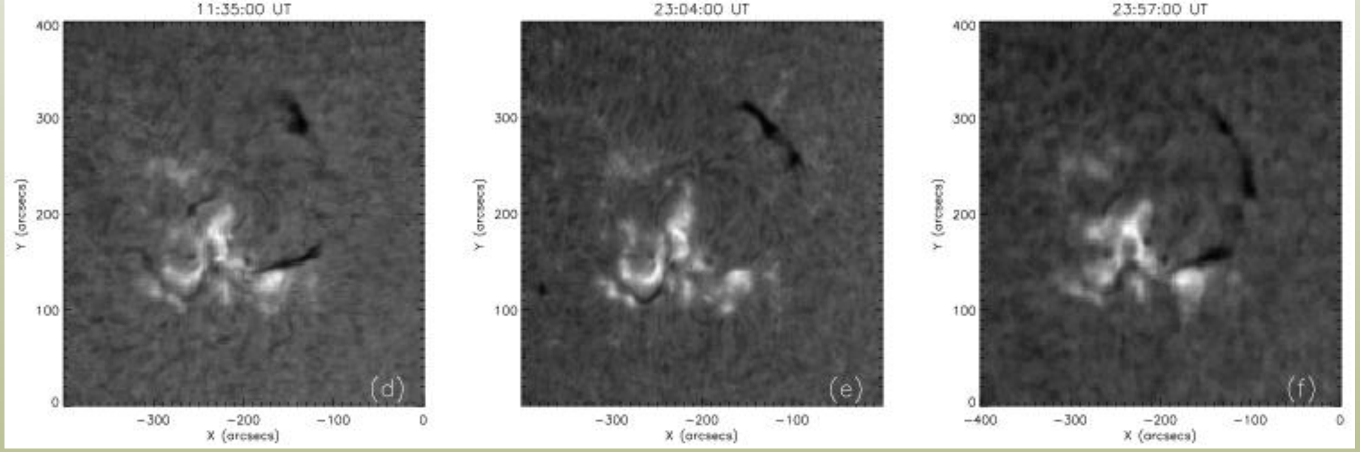


Quiescent Filament Appearance

- QS filament first seen in Kanzelhöhe Hα image on 18 May at 06:11 UT
  - maintain separate identities until 11:03 UT
  - filaments then appear joined







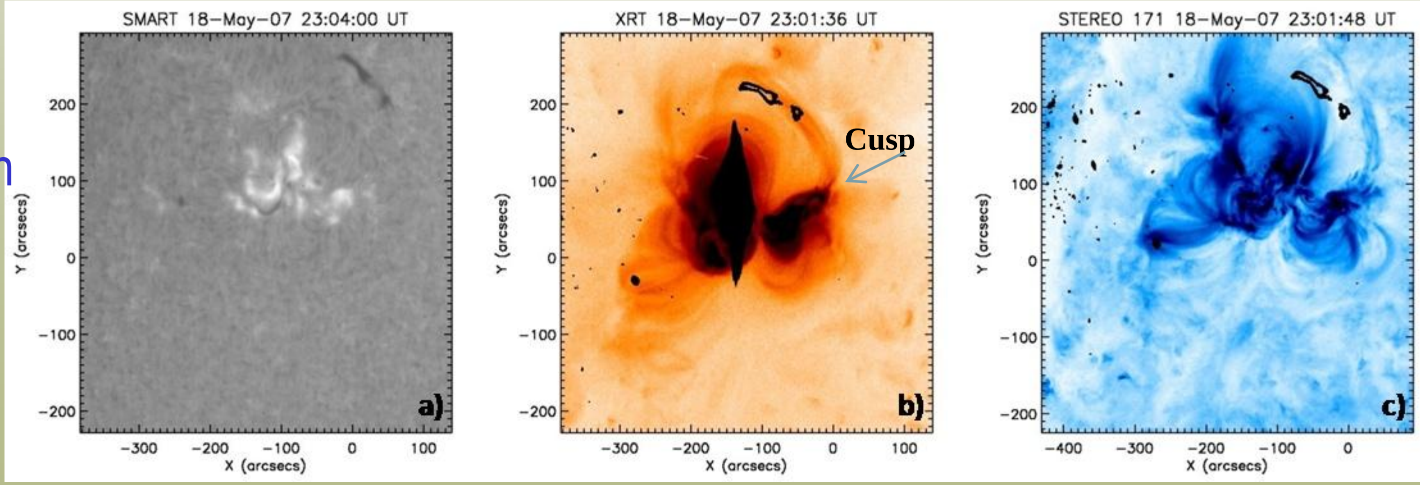
- AR section disappears and partially reappears between 11:35 UT and 23:57 UT
  - at this time no evidence of heating in Hinode XRT or STEREO EUVI images

Filament Heating Episodes

- Several heating episodes were seen before the final eruption on 19 May at ~ 12:30 UT
  - 18 May, 19:30 – 20:30 UT and 23:00 – 23:30 UT
  - 19 May, 01:30 – 02:00 UT and 04:30 – 06:00 UT
- These typically involved complete or partial disappearance of the Hα features and appearance of structures emitting soft X-rays (Hinode) and/or at e.g.171 Å (STEREO EUVI, TRACE)

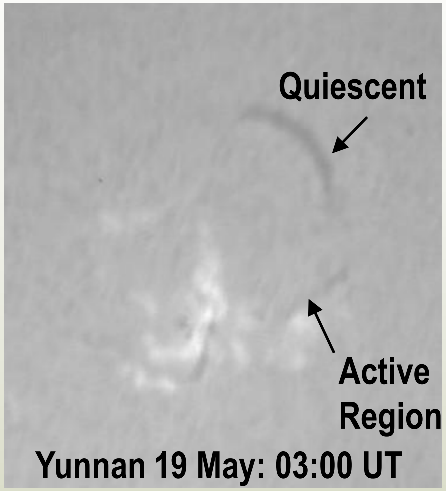
- On 18 May around 23:00 UT, Hida Hα images show absence of Hα from the active part of the filament (a) and there is an extended X-ray structure (XRT; T ~ 3 MK) which co-exists with a remaining part of the quiet filament (b)
- An extended structure is also observed in all four EUVI images - 171 Å is shown in (c)

- The EUV-emitting structures lie above the soft X-ray emission
- A small cusp structure is visible in the lower XRT loops close to the AR

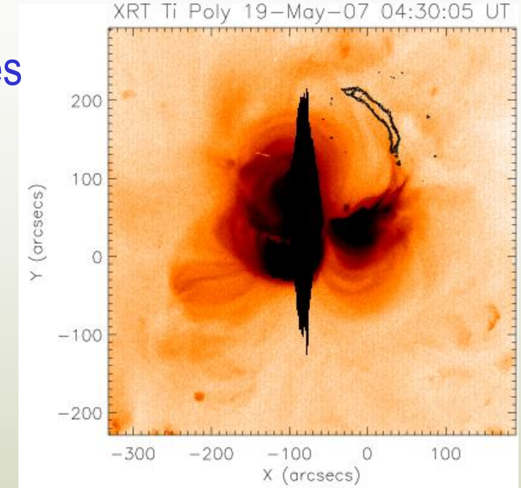


Filament Heating Episodes (continued)

- Two separate filaments exist on **19 May at 03:00** in a Yunnan Hα patrol image

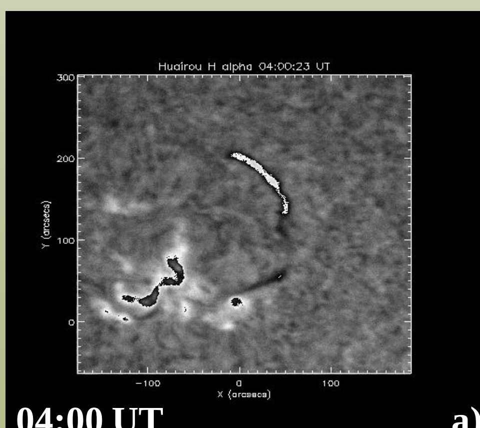


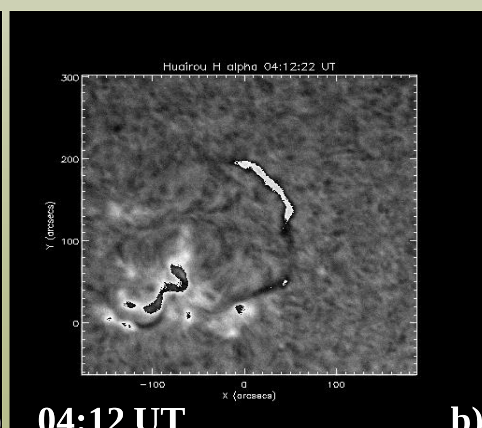
- Huairou Hα patrol images later on **19 May** show:
  a/b) merger of filaments
  c) partial disappearance of lower filament

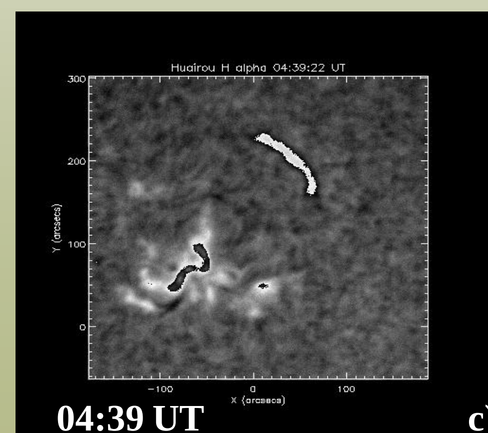


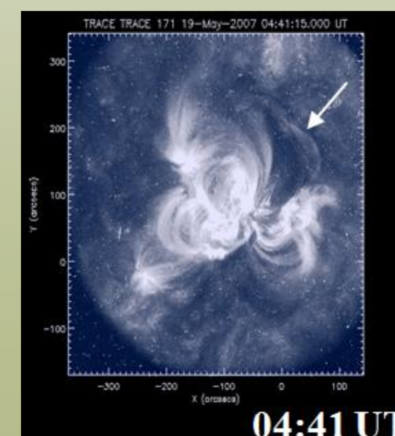
- X-ray emission is seen at 04:30 UT in place of the AR filament component
- Fainter X-rays co-exist with the quiescent Hα component
- Low level X-ray cusp is also visible

- Heated material also seen in TRACE 171 Å image



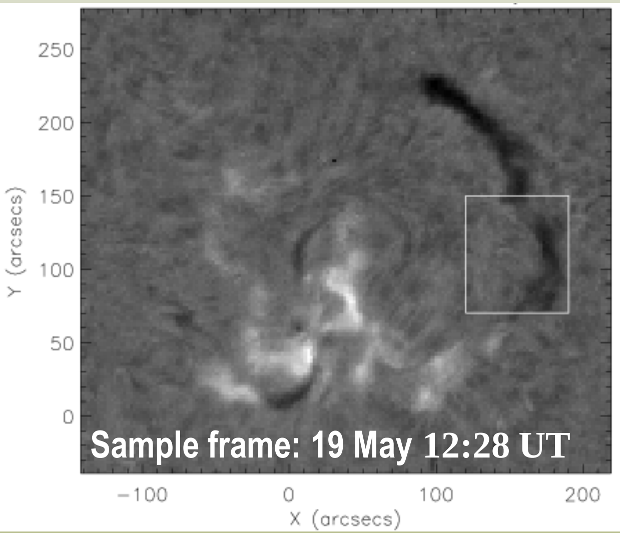


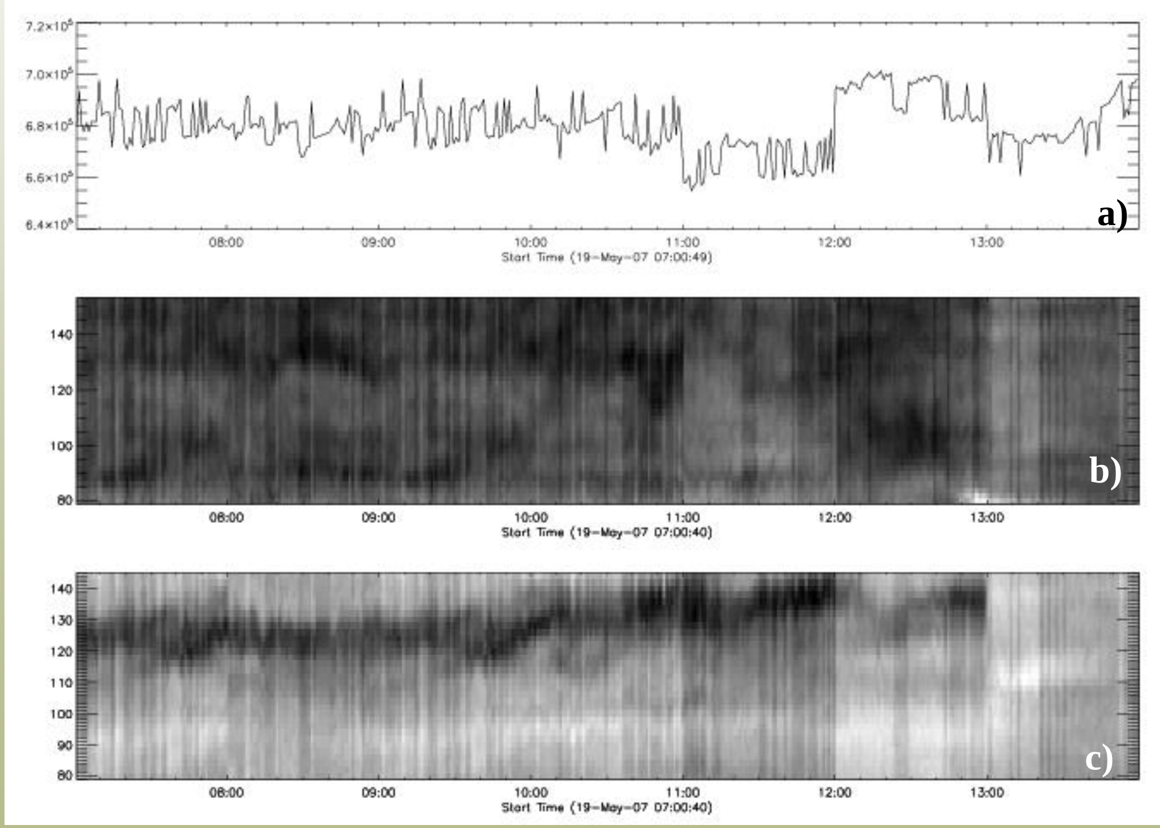




Filament Dynamic Behaviour

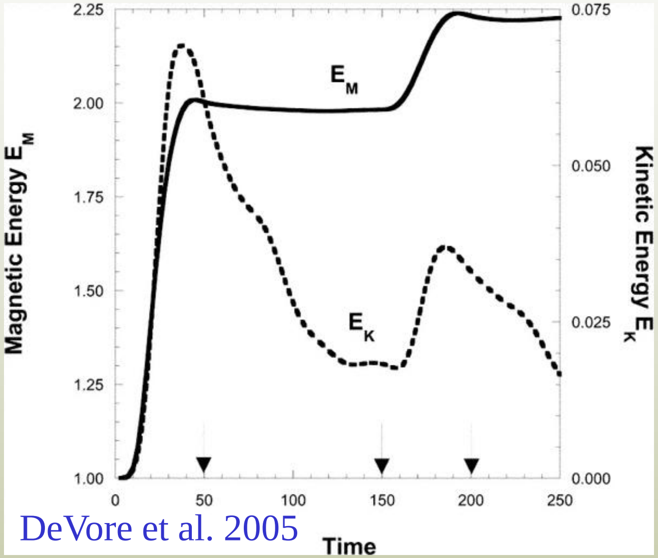
- Kanzelhöhe Ha images with ≈ 1 min cadence assessed for 19 May 06:00 UT to 13:50 UT
- Light curve (a) for a sample including the lower filament shows dynamic behaviour
- Stack plot for Σx (b) suggests heating and cooling episodes before final eruption
- Stack plot for Σy (c) shows modulation of filament width





Models for Filament Merger and Eruption

- Extensive simulations of filament/prominence merger were undertaken by DeVore, Antiochos and Aulanier (Ap.J. 2005) for different combinations of chirality and axial field alignment
  - no evidence for instability **but**
  - reconnection-driven merger gives new stable state of
    - → higher magnetic energy
    - → decaying kinetic energy



DeVore et al. 2005

- Following the energy release, heated prominence plasma could collect in magnetic field dips (Aulanier et al., 2006)

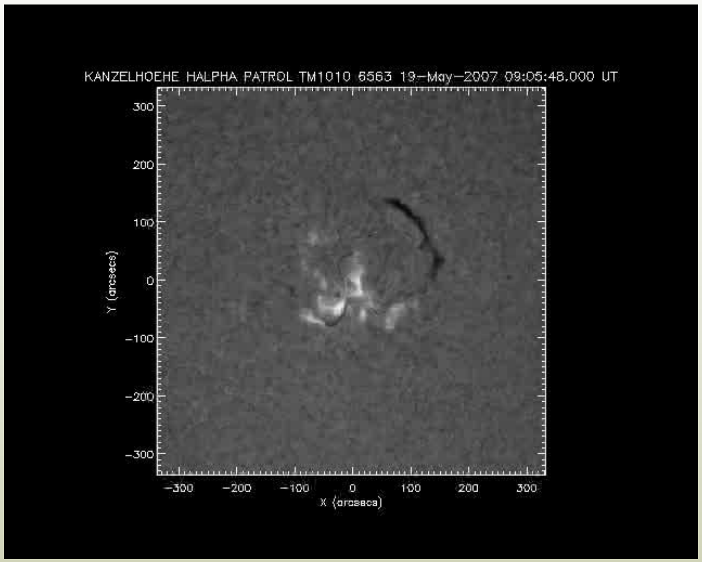
- Cause of the heating and cooling episodes seen in the two days before eruption?
  - repeated reconnections due to flux cancellations
  - these may also increase twist in the combined filament

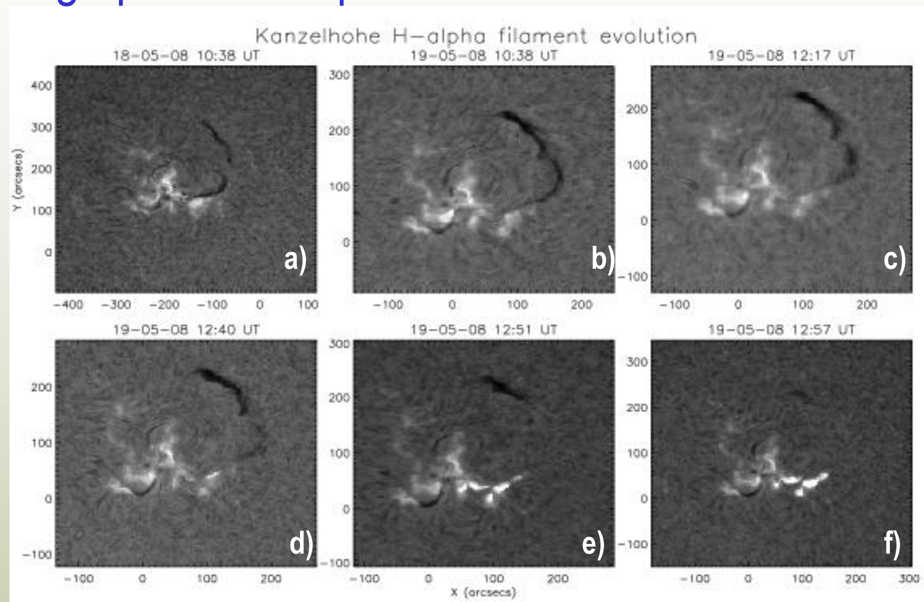
- Eruption when twist exceeds a critical value due to Kink instability (Török and Kliem 2005), **or**

- Torus instability (Kliem and Török, 2006) with less twist but overlying field decreasing rapidly

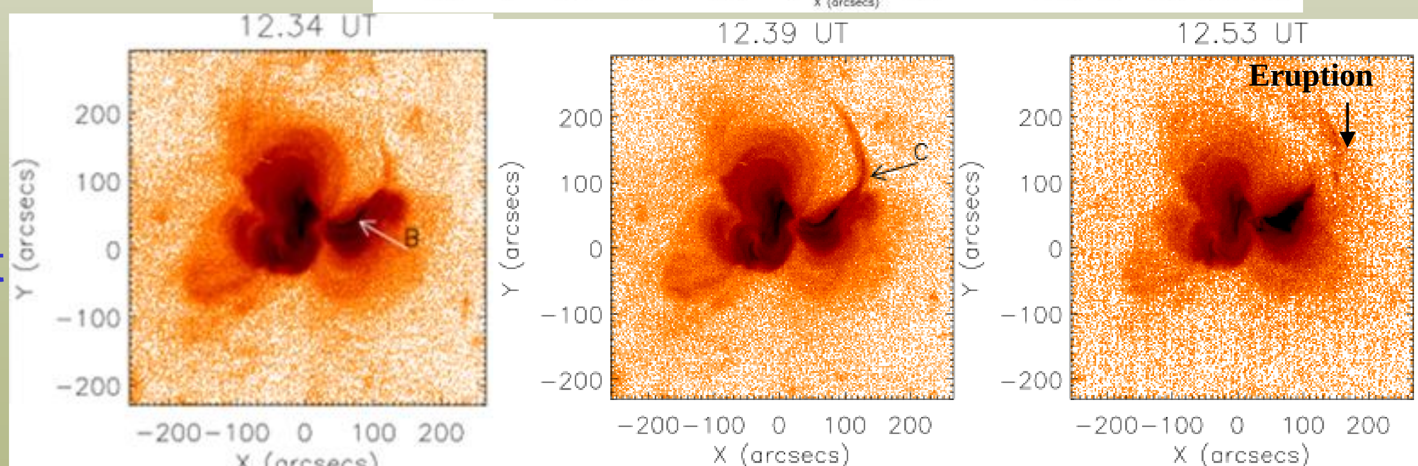
Final Filament Disappearance and Eruption

- Hα movie from Kanzelhöhe Observatory - 19 May: 09:06 UT - 13:57 UT
- Shows filament evolution and activity leading up to the eruption and associated flare





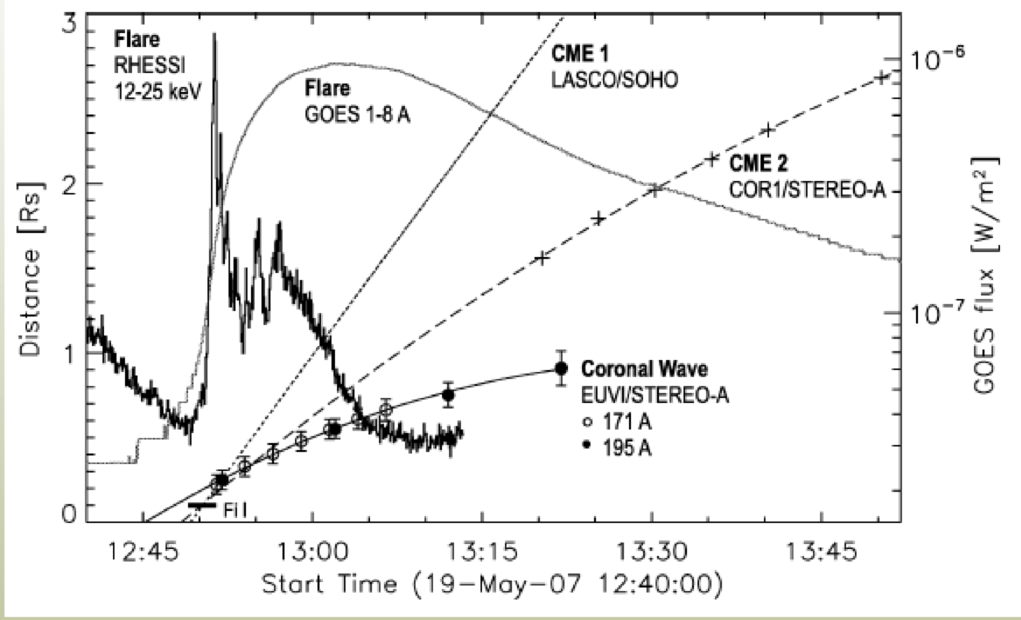
- XRT images show
  - brightening at the flare site (B)
  - progressive filament heating (C)
  - eruption of heated material



Summary of Events on May 19th (Veronig et al., 2008)

- In addition to early interaction of the filaments and the main eruption, other related events included:
  - GOES B9.5 flare
  - RHESSI 3 – 25 keV observation
  - two CMEs (960 km/s and 290 km/s)
  - global or EIT wave
  - twin dimming regions
  - magnetic cloud at Earth on 22 May

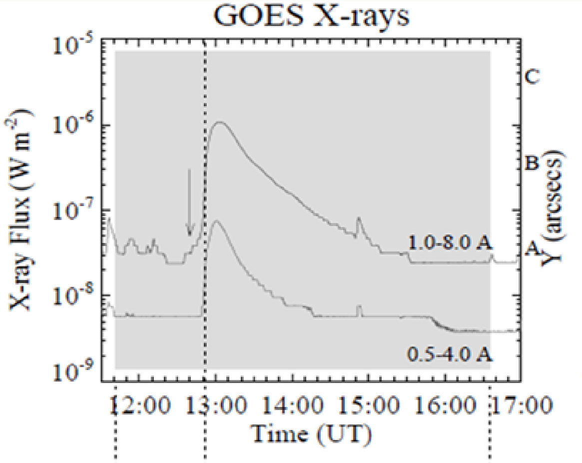
- Figure 6 from Veronig et al summarises the time development of some of these events

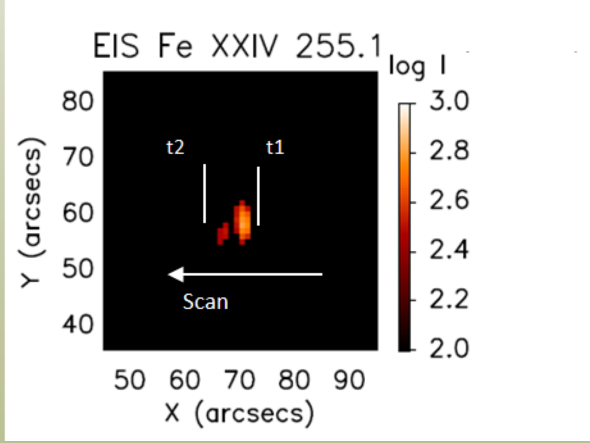


- Roles of the two CMEs launched on 19 May are being discussed
  - some evidence for complex structure in the 22 May STEREO-B/WIND magnetic cloud (Huttunen et al submitted, Solar Physics, 2008)
  - B9.5 flare probably forms below the faster CME

B9.5 LDE Flare Accompanying the Eruption

- GOES event started at 12:46 UT
  – hard X-ray impulse peaked at 12:52 UT (RHESSI)
- Recall that pre-eruption filament heating began at ~ 12:34 UT
- Hinode EIS scanned the flare site
  - 1" slit, 1" steps, 40 sec exposure
  - 20 spectral windows covered 0.05 MK < T < 15 MK
- Compact Fe XXIII (267.3 Å) and Fe XXIV (255.1 Å) emission registered between t_1 (12:51:20 UT) and t_2 (13:01:09 UT)
- Fe XXIII/Fe XXIV intensity gave T_e = 11 -12 MK, EM ~ 10^{47} cm^{-3}
- Fe XXIII / XXIV structure observed near peak of impulsive phase

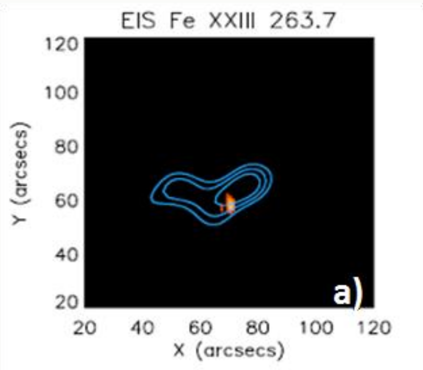


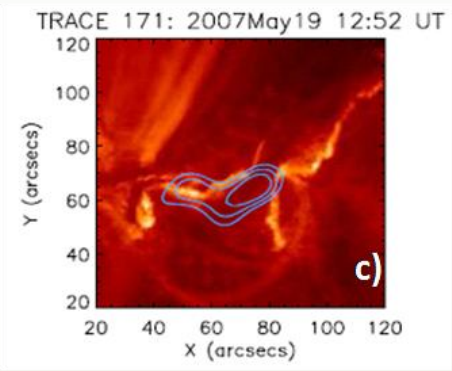


Flare Images

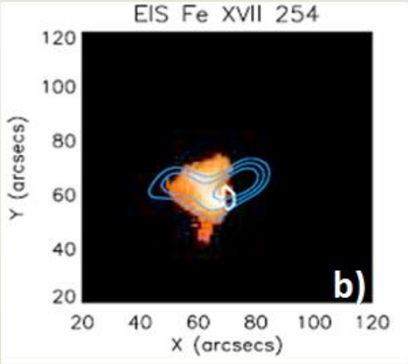
- Thermal RHESSI spectrum (T < 20 MK) with
  a weak impulsive phase

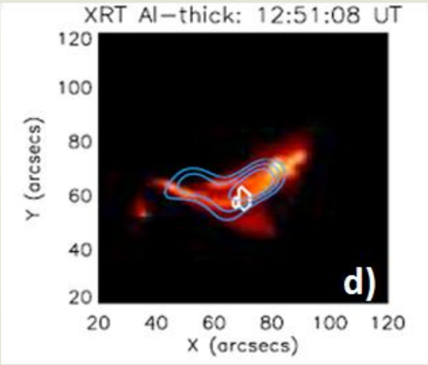
- Panel a): RHESSI 3 – 20 keV contours (blue)
  Fe XXIII / Fe XXIV countours (white)





- Panel b): Fe XVII (254 Å) contours (yellow)
  - other low T_e lines originate here below Fe XXIII
  - Ca XVII (192.8 Å) shows a hint of cusp structure





- Panel c): TRACE 171 Å image at 12:52 UT shows
  the flare ribbons
  - RHESSI and EIS emissions are located between the ribbons

- Panel d): shows XRT emission at 12:51 UT also located between ribbons

- Flare looks like standard model two ribbon LDE though with mainly thermal energy

Emission Light Curves and Derived Parameters

- Hinode EIS obtained Fe XXIII, Fe XXIV and Fe XVII spectra in addition to lines from other lower T_e ions e.g. Ca XVII

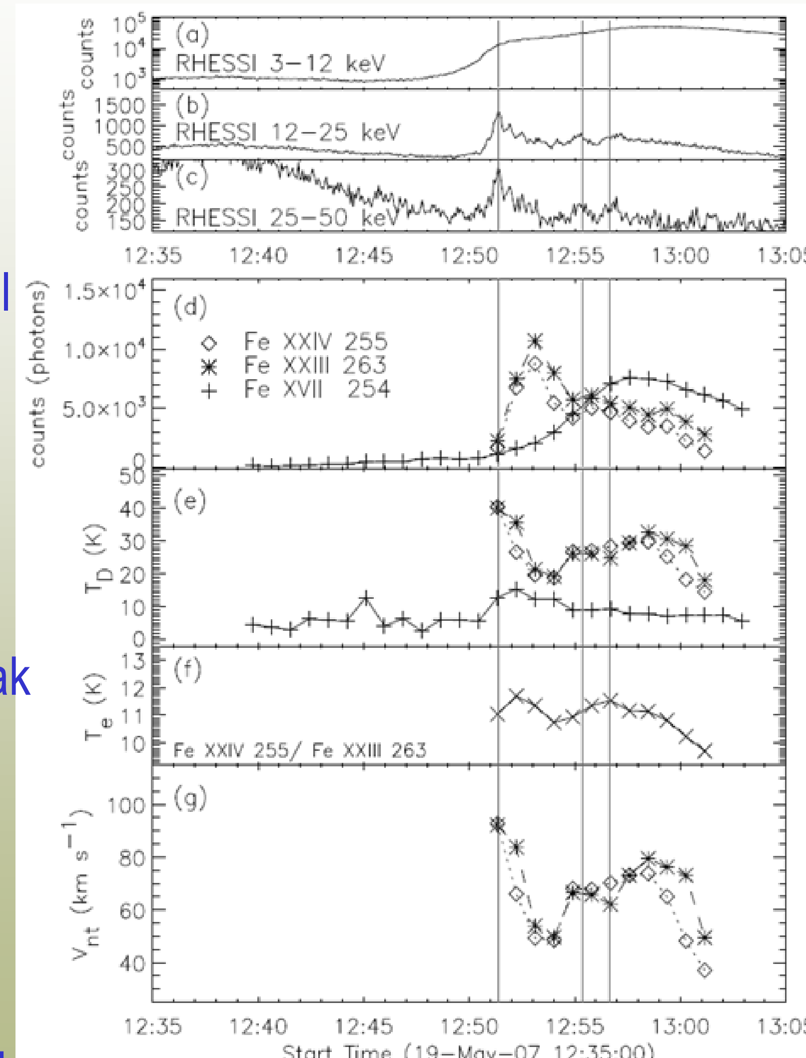
- Given EIS cadence, Fe XXIII and Fe XXIV intensities rise and fall along with RHESSI impulsive phase signal
  - Fe XVII shows a gradual GOES-like response

- Line widths and Fe XXIV/FeXXIII intensity ratio gives T_D and T_e values while $V_{nt} = \sqrt{2k (T_D – T_e)/m_i}$

- Peak V_{nt} ~ 100 km/s is at seen at impulsive phase peak and falls rapidly

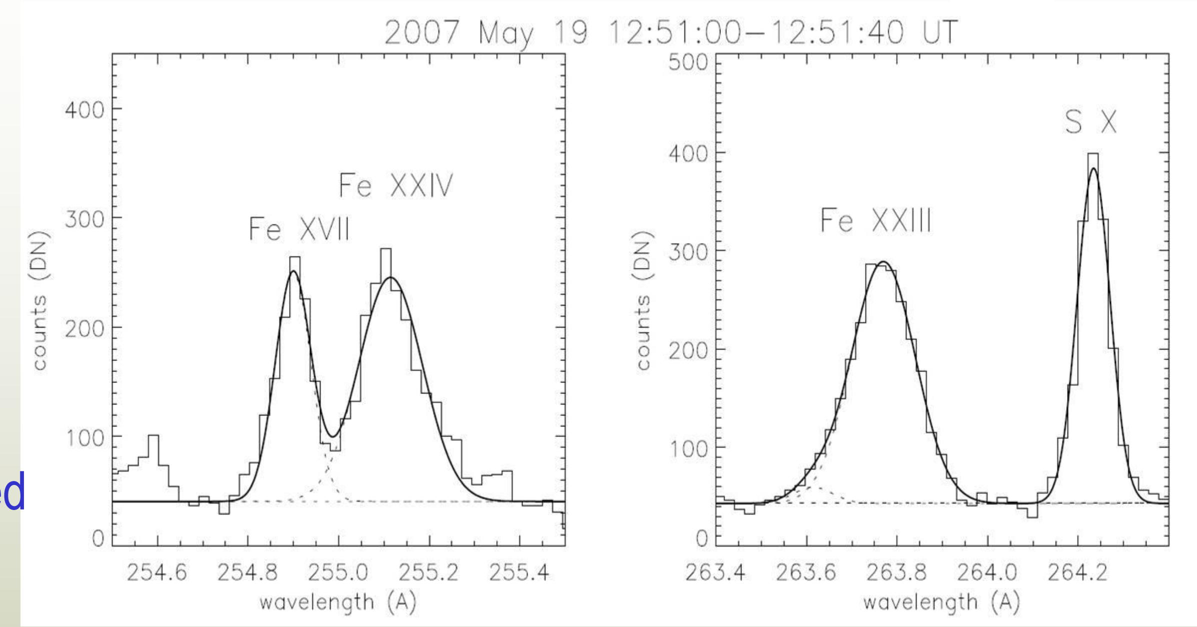
- Prompt high Fe ion stages suggest direct heating of swept-up plasma near the reconnection site

- Enhanced V_{nt} suggests turbulence from shock heating



EIS Spectra

- Sample spectra from just before the impulsive phase
  - Fe XXIII/Fe XXIV ratio gives T_e
  - S X 264.23 Å intensity value allows estimate of a weak S X blend contribution to Fe XXIV (255.11 Å) at < 10%
  - Fe XXIII and Fe XXIV broadened profiles give T_D and V_{nt} values



- Values in table below

Fe XVII, FE XXIII and Fe XXIV Parameter Values

	FWHM (*W*) (km/s)	T_D (K)	ξ or V_{nt} (km/s)
Fe XVII 254	82	8.3×10^{6}	31 (when T_i=5.0×10^{6} K)
Fe XXIII 263	178	3.9×10^{7}	106 (when T_i=1.0×10^{7}K)
Fe XXIV 255	142	2.4×10^{7}	82 (when T_i=1.0×10^{7} K)

Conclusions

- Two separate filaments (AR and QS) are observed before the eruption
- Several filament disappearances (Hα) are accompanied by plasma heating (Hinode/XRT, STEREO/EUVI, TRACE) during the 26 hours prior to the eruption and flare
- Dynamic behaviour of filament in the 6 – 7 hour interval before the eruption shows similar interaction and heating
- Merging episodes heat filament plasma and increase overall twist
- Eruption follows MHD instability – possibly a Kink instability enables aTorus-driven eruption
- GOES B9.5 flare associated with eruption agrees with standard LDE flare model interpretation
- Evidence for impulsive heating of coronal plasma – prompt Fe XXIII / Fe XXIV and turbulence, suggests role of shock originating at the flare reconnection site

END OF TALK