Hinode and RHESSI Observations of the GOES B9.5 Flare of 19th May, 2007

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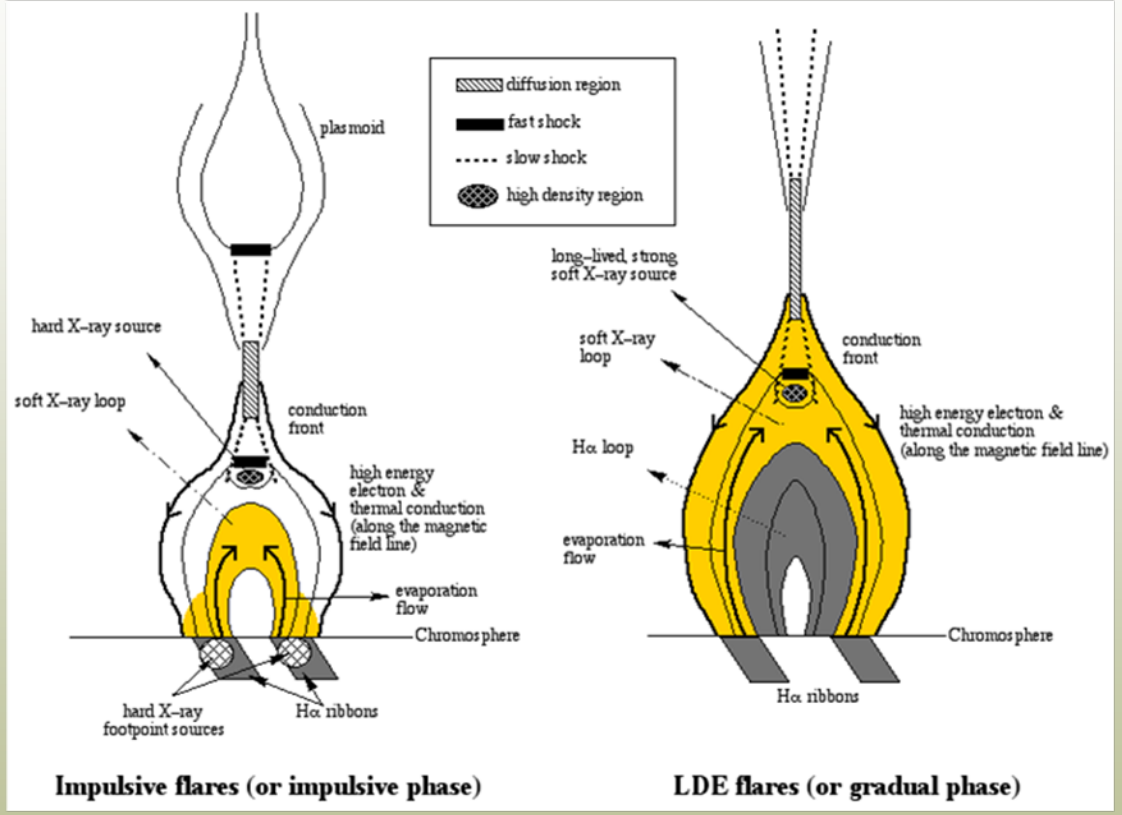
Introduction

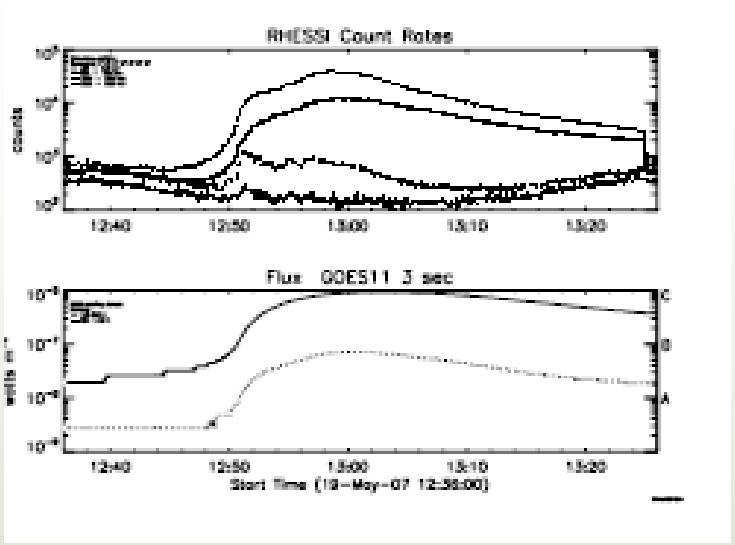
- Flares that have long lifetimes and cusp apexes have been observed extensively with *Yohkoh*
- Cusp structure is taken to be a signature of CSHKP model
- For long duration events soft X-ray emission persists well after initial phase and decays slowly

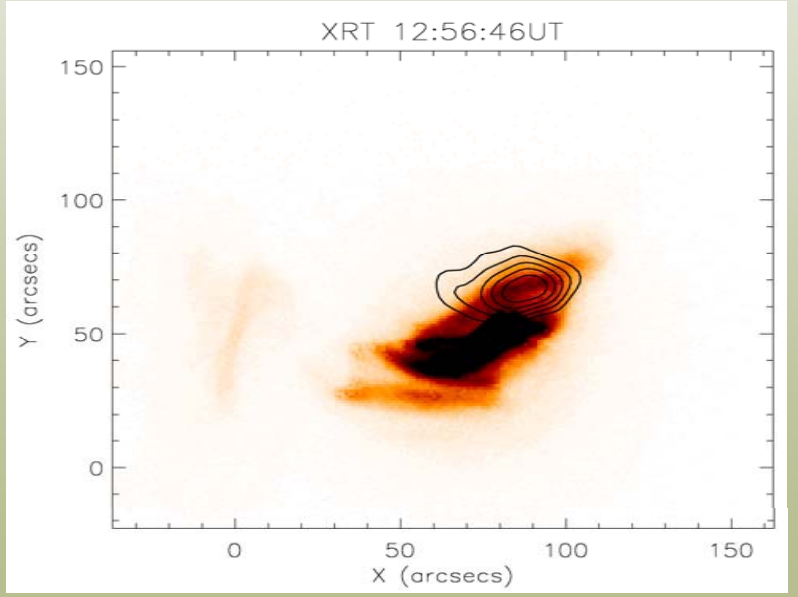


From Grand Archive of Flare and CME Cartoons (Hudson)

Flare - 19 May 2007

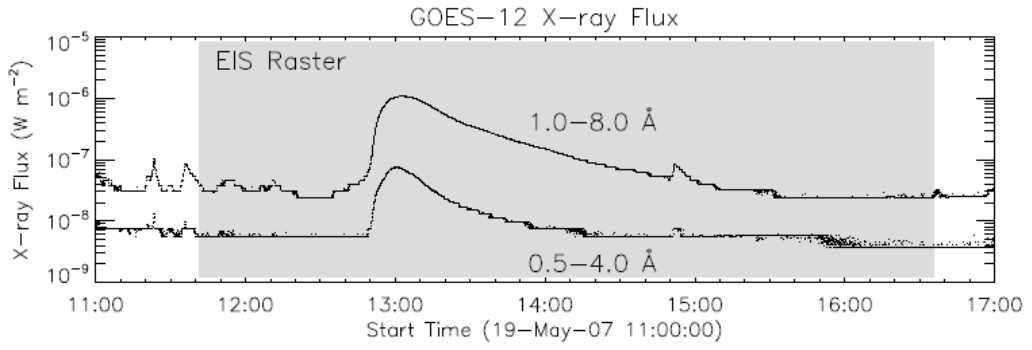
- GOES class B9.5
  - 12:48 UT start; 13:02 UT peak
- RHESSI observations to E_{max} ~ 15 keV
  - visible for ~ 60 minutes
- RHESSI temperature initially 22 MK
  - decays to ~ 15 MK in ~ 40 minutes
- Emission measure ~ 10^{46} cm^{-3} and volume ~ 3.10^{27} cm^3
- Little or no impulsive behaviour
  - very small spike at 12:51 UT; $E_{NT} << E_{Th}$





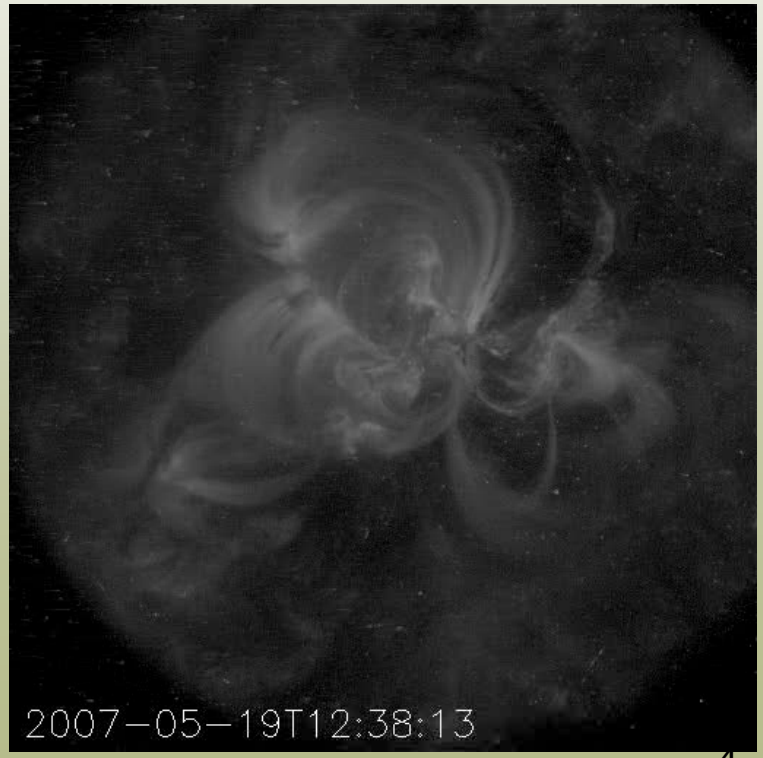
Flare - 19 May 2007

- Long duration flare with steep thermal hard X-ray spectrum
- Hinode/EIS was rastering the loop-top region for the rise and peak of the flare
- EIS study used 21 emission lines ranging from:
  - He II (Log T_{max} = 4.7) to
  - Fe XXIV (Log T_{max} = 7.2)



GOES X-ray Flux

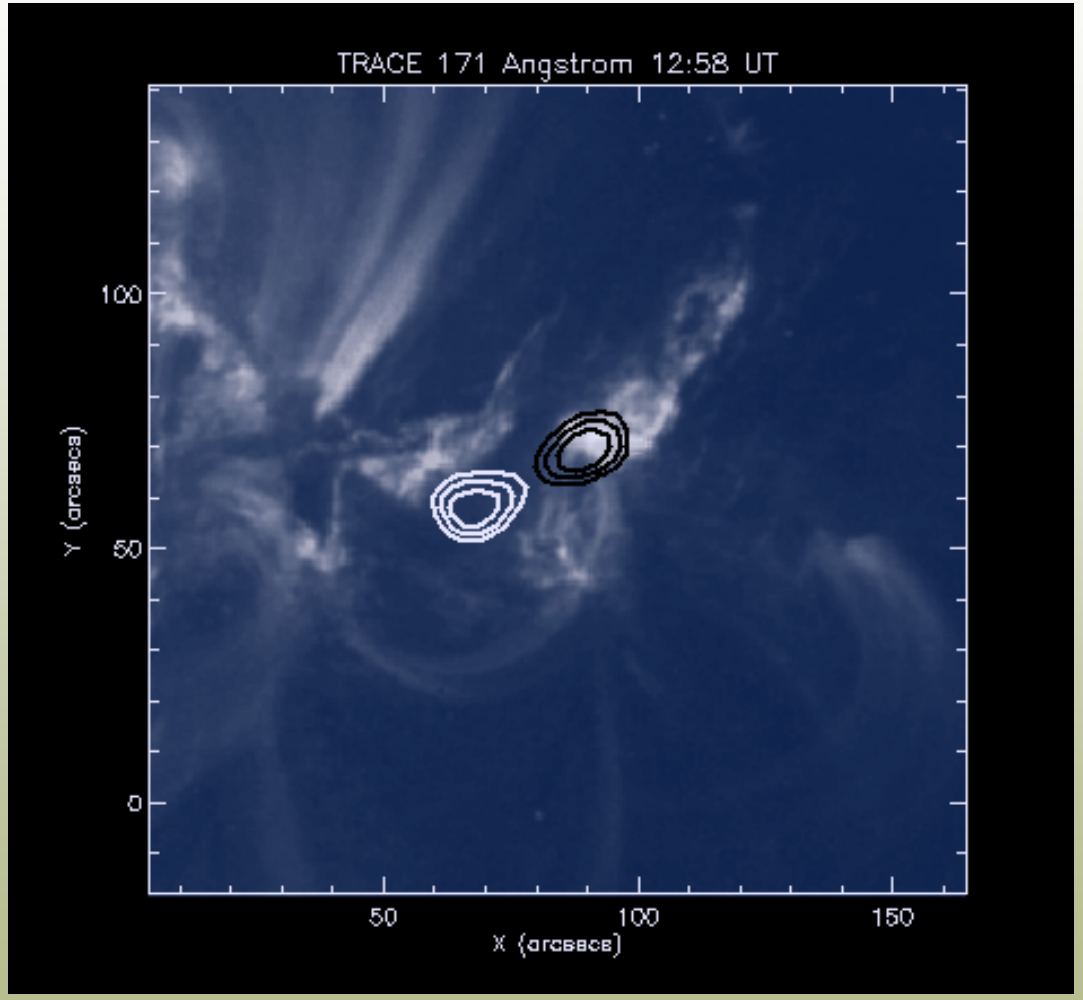
TRACE 171 Å Response:
Log T ≈ 5.8 - 6.2 or 0.7 – 1.6 MK



TRACE 171Å Fe VIII/IX band

TRACE Image and RHESSI Source Evolution

- TRACE 171 Å image at 12:58 UT
- RHESSI 6 – 12 KeV images are shown as contours
  - white at 12:51 UT
  - black at 13:01 UT
- XRT and TRACE images show a short arcade of loops across the filament channel
- RHESSI source location moves along the arcade

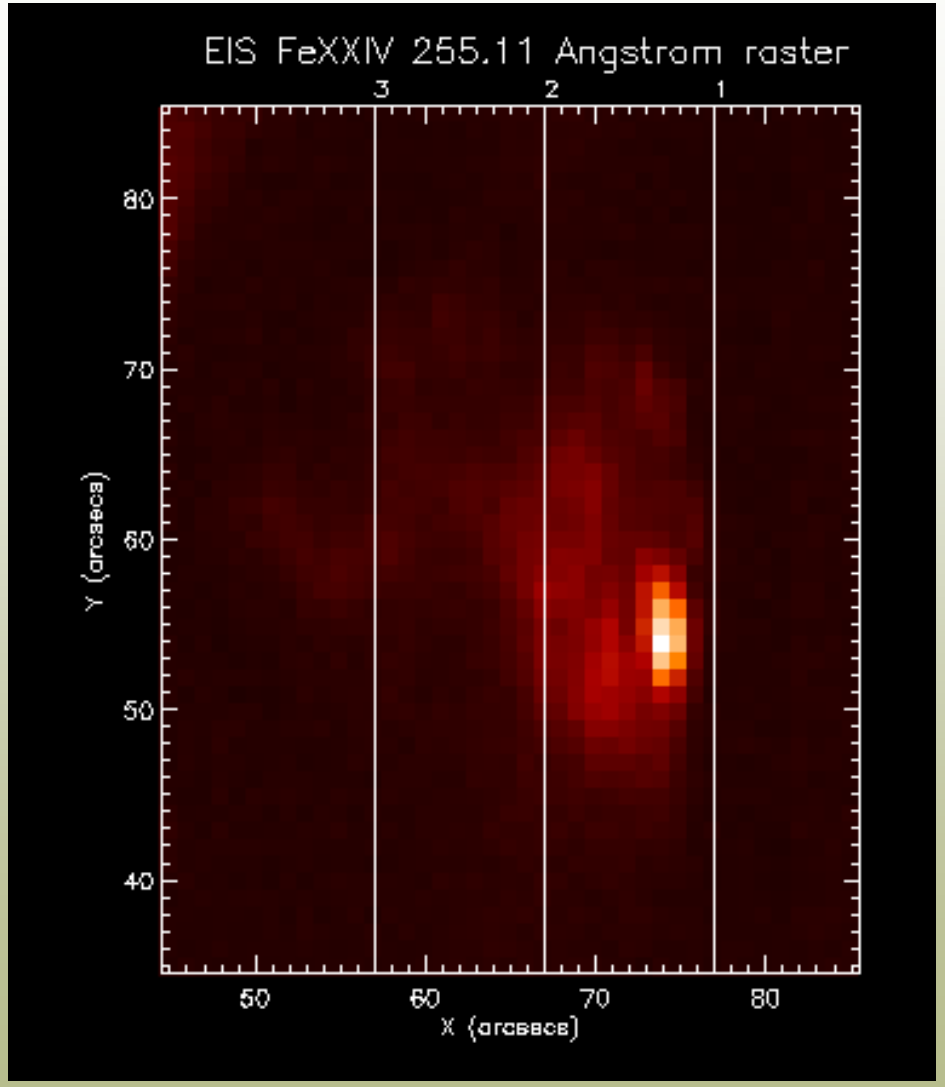


EIS Flare Region Raster Image in Fe XXIV 255 Å

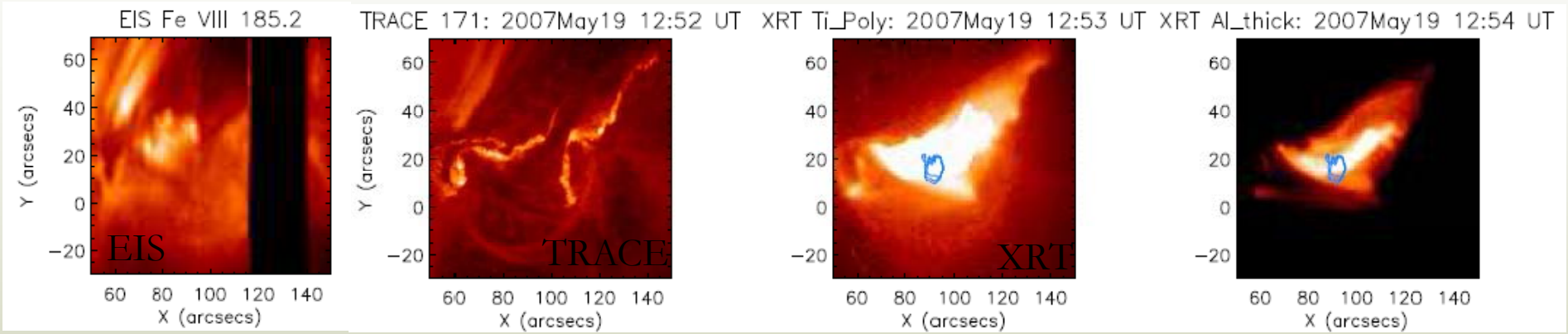
- EIS raster used: 1” slit
  330 exposures
  40s exposure time
  1” step size

- Times for indicated raster positions are:
  1 → 12:45:38 UT
  2 → 12:54:34 UT
  3 → 13:03:29 UT
  - flare start time 12:48 UT

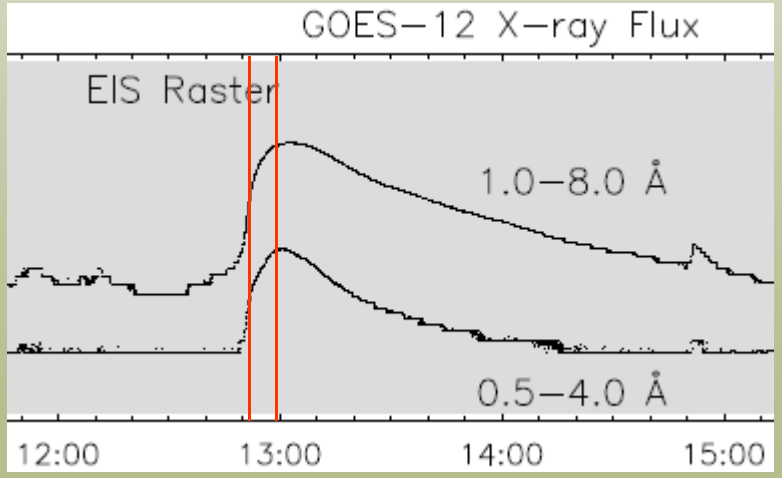
- Fe XXIV emission is from a compact region above the cooler flare plasma loops

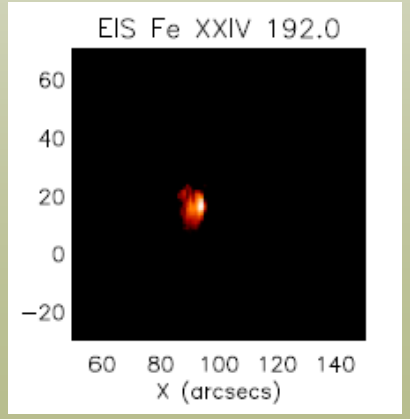


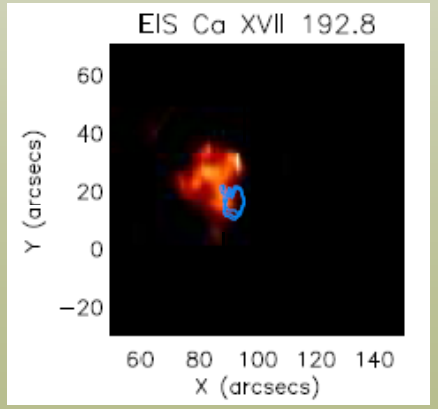
EIS Spectroscopic Observations



- 10 MK source found above the flare loop top



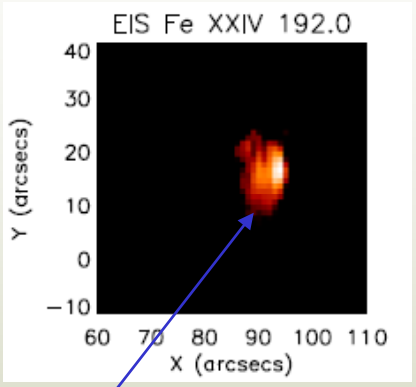


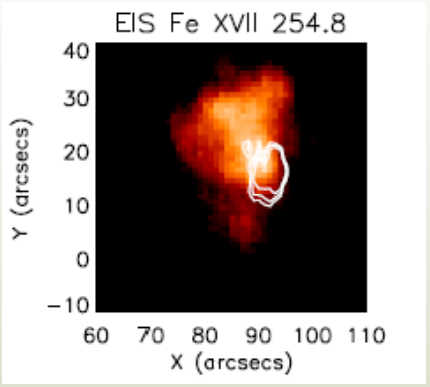


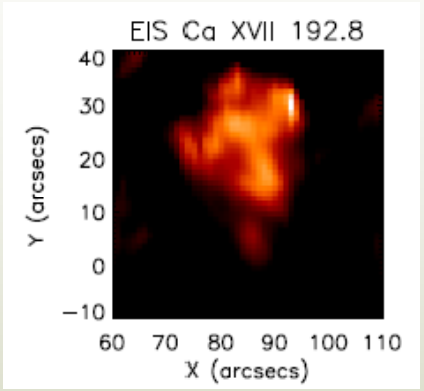
Scanning direction (= time)

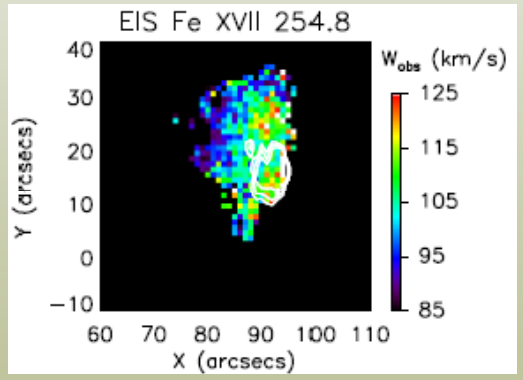
EIS Spectroscopic Observations

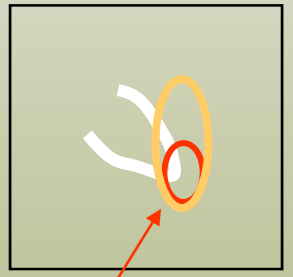
10MK source above Ca XVII loop











- Isolated hot source:
  T = 10 MK
  EM = 8×10^{46} cm^{-3}
  from I(Fe XXIV 255)/I(Fe XXIII 263)

- Source has enhanced nonthermal velocity component estimated from the broadened line as ξ = 60-130 km/s

- Location of enhanced nonthermal velocity region is identified

Cooling Processes

- Radiative cooling

$$E_{rad} = \kappa_r n_e^2 T^{-\frac{1}{2}} \qquad \kappa = 1.42 \times 10^{-19} \text{ ergs cm}^3 \text{ sec}^{-1} K^{-\frac{1}{2}}$$

- Spitzer conductive cooling

$$E_{spit} = \frac{\kappa_s T^{\frac{7}{2}}}{L} \qquad \kappa = 1.0 \times 10^{-6} \text{ ergs cm}^3 \text{ sec}^{-1} K^{-\frac{7}{2}}$$

- Non-local conductive cooling

$$\tau_{nl}^{-1} = 0.11 \frac{\lambda}{L} \tau_{spit}^{-1}$$

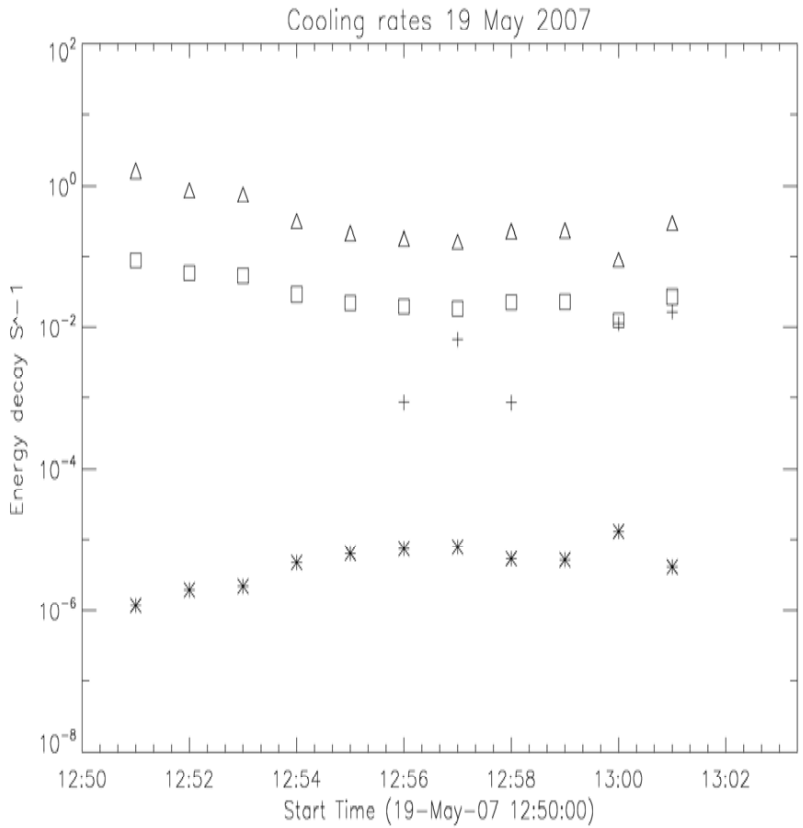
where λ is the mean free path for thermal electrons

Cooling Rates – 19 May

- RHESSI source has higher T_e value (≈ 20 MK) than EIS source and ≈ x10 lower emission measure

- RHESSI shows an initial energy increase then the thermal energy decays

- Decay rate converges toward the non-local conduction rate

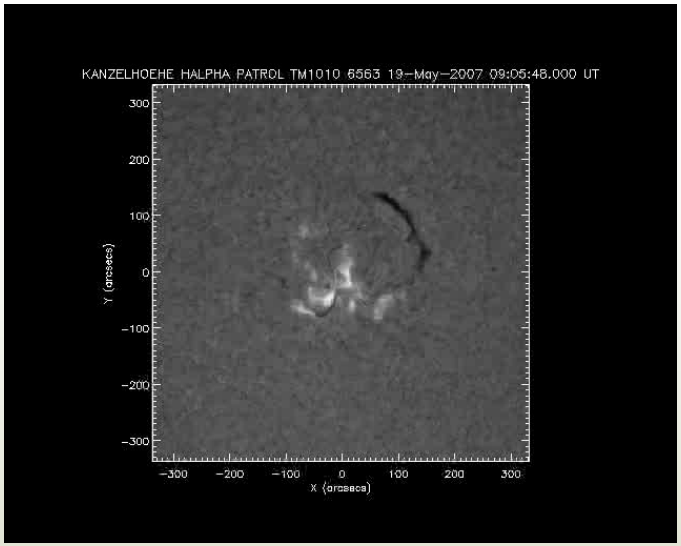


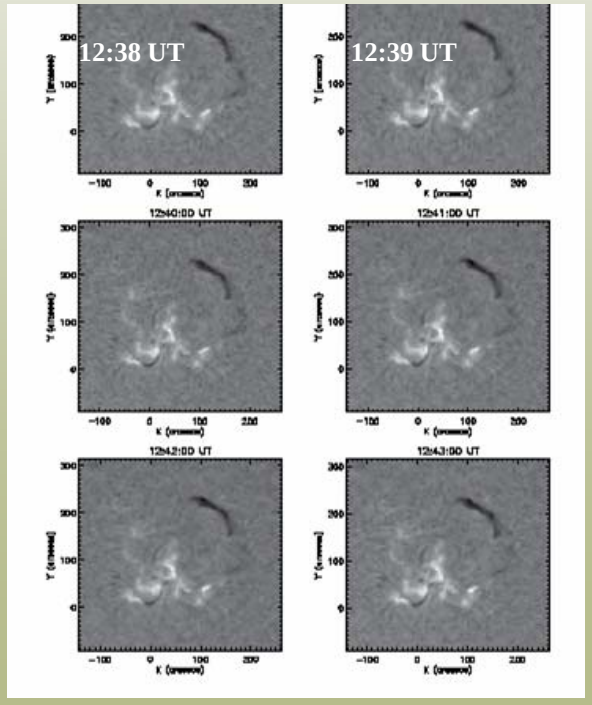
Observed: + Radiative: * Spitzer: Δ Non-local:□

Flare Plasma Heating

- Little or no impulsive non-thermal component
- In thick target model, non-thermal electrons heat and ablate the plasma
- Here flare plasma not heated by electron beam energy
- Dissipation of magnetic energy in slow shocks near reconnection site would dump around 10^{31} ergs into corona (Cargill and Priest, 1982)
  - sufficient to heat the RHESSI sources; total energy ~ 1 – 3 x 10^{30} erg
- V_{NT} component observed by EIS due to shock turbulence

Evolution of Filament Eruption





Southern filament extension: Modulated →12:05 UT
to 12:16 UT
Splitting of filament: Begins →12:20 UT

Lower filament disappearance: Starts →12:30 UT
Ends →12:45 UT
Upper filament disappearance: Starts →12:43 UT
Ends →12:57 UT

First Hα brightening at flare core → 12:46 UT

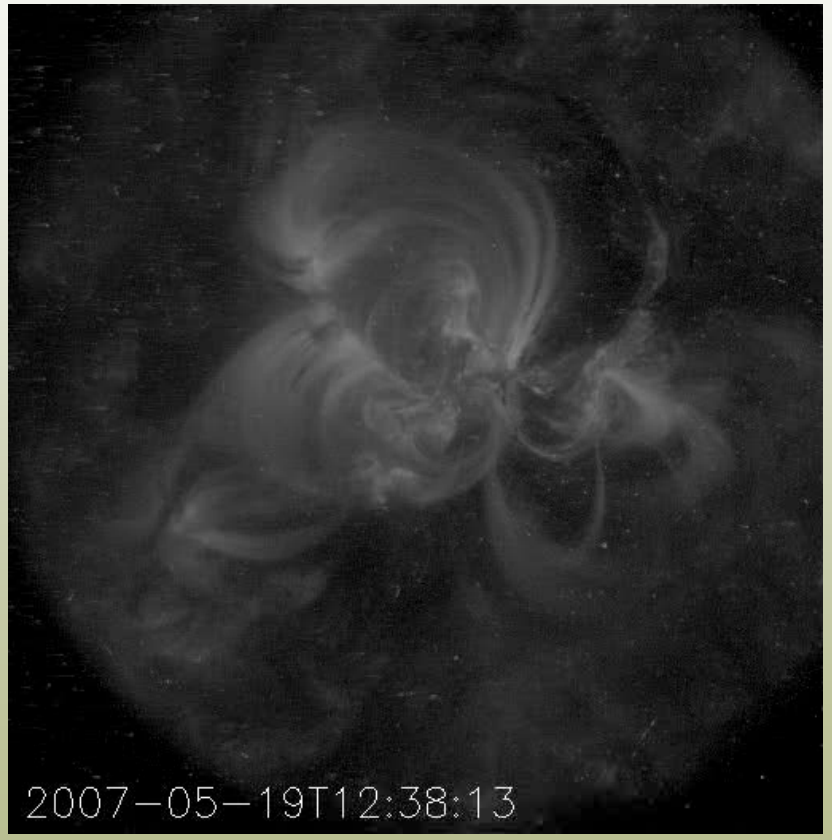
Both Ha ribbons start → 12:49 UT

Main RHESSI/Goes flare start → 12:51 UT

CME seen in SOHO C2 → 13:24 UT
Launch at ≈12:44 UT with v = 958 km/s

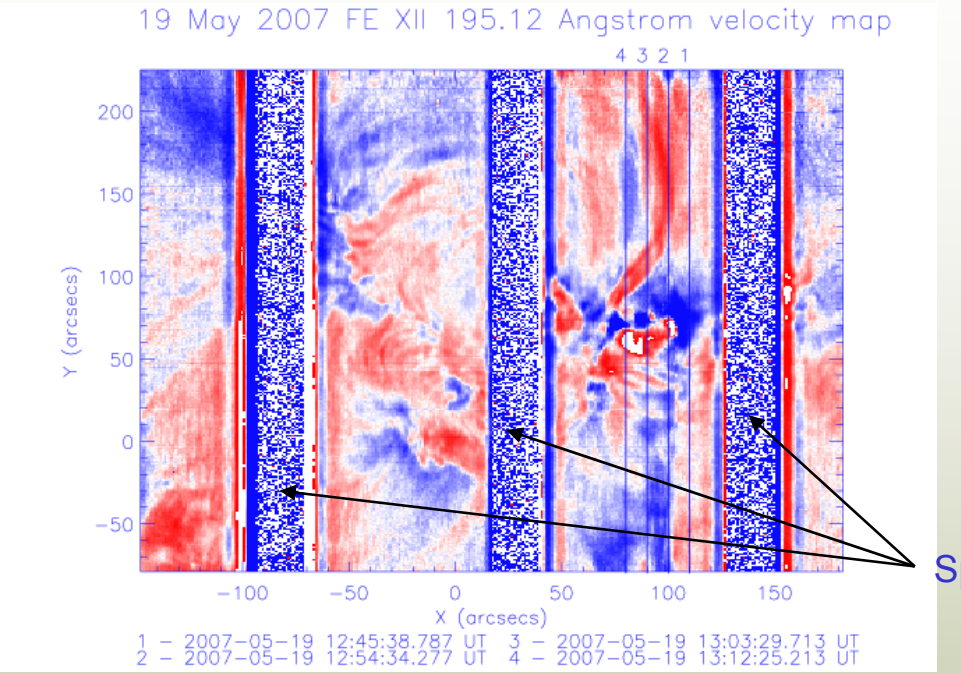
Trace and Kanzelhoehe Hα Observations

- TRACE 171 Å movie shows the Hα filament material being heated in the process of eruption
- Start of movie at 12:38 UT is part-way through the lower filament disappearance
- Lower filament heats to T ≈ 1 MK during eruption from 12:30 UT to 12:45 UT
- Heating of upper filament likewise seen from 12:43 UT to 12:57 UT

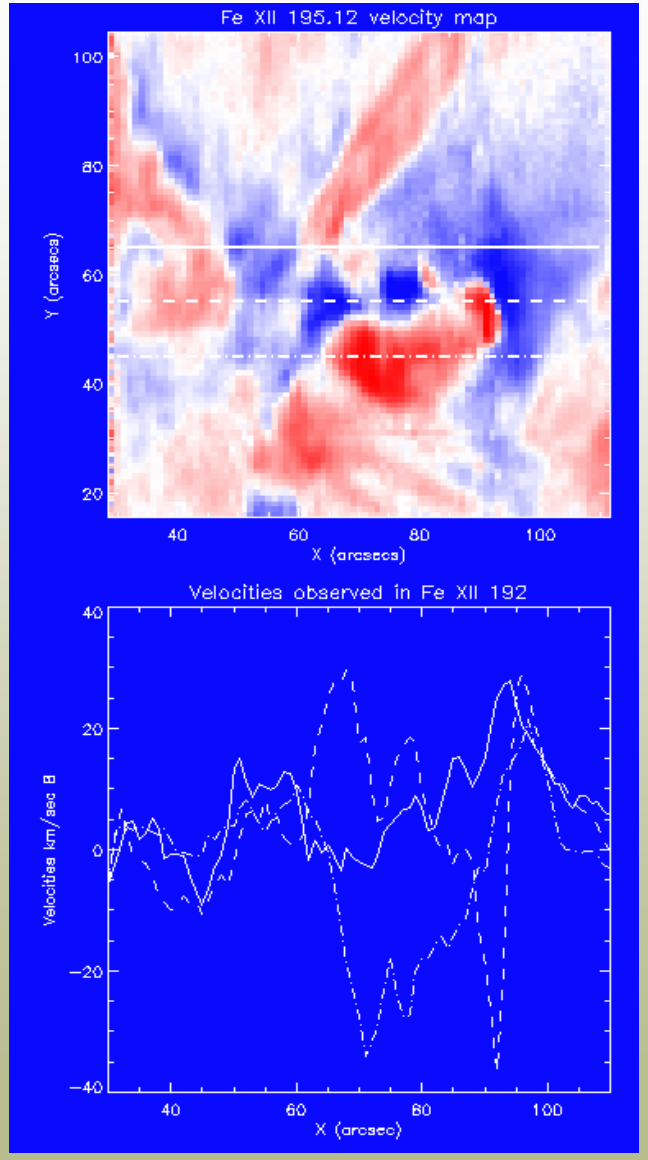


TRACE 171Å Fe VIII/IX band

Flows Observed with EIS



Spacecraft Eclipses



- EIS velocity map was made during the flare raster
  1 → 12:45:38 UT; 2 → 12:54:34 UT; 3 → 13:03:29 UT; 4 → 13:12:25 UT.
- EIS velocity measurements show:
  - upflows near the flare ribbons
  - downflows in many of the loops
- Velocities increase with increasing T_{ion}

Conclusions

- Long duration flare observed with RHESSI and Hinode and also with STEREO, TRACE and SOHO on 19 May, 2007
  - conductive cooling converges to non-local conduction rate

- Flare shows no evidence for non-thermal particles
  - no footpoint emission or Hard X-Rays
  - need to find other ways to heat source e.g. shocks

- Turbulent broadening ($v_{nt} \approx$ 60 – 130 km/s) seen in Fe XXIV line at top of cusp; RHESSI source located higher up?
  - broadened lines emitted by the slow shock region?
  - slow shock heating possible for flares in weak magnetic field

- Filament material heated before/during eruption

END OF TALK