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
  \( E_{\text{max}} \sim 15 \text{ keV} \)
  – 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; \( E_{\text{NT}} << E_{\text{Th}} \)
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 $T_{\text{max}} = 4.7$) to
  - Fe XXIV (Log $T_{\text{max}} = 7.2$)

**GOES X-ray Flux**

TRACE 171 Å Response:
Log $T \approx 5.8 - 6.2$ or $0.7 - 1.6$ MK
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
EIS Spectroscopic Observations

10MK source above Ca XVII loop

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

- Source has enhanced nonthermal velocity component estimated from the broadened line as \( \xi = 60-130 \text{ km/s} \)

- Location of enhanced nonthermal velocity region is identified
Cooling Processes

- Radiative cooling

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

- Spitzer conductive cooling

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

- Non-local conductive cooling

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

where \(\lambda\) is the mean free path for thermal electrons.
Cooling Rates – 19 May

• RHESSI source has higher \( T_e \) value (\( \approx 20 \text{ MK} \)) than EIS source and \( \approx x10 \) lower emission measure

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

• Decay rate converges toward the non-local conduction rate
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 $\sim 1 \sim 3\times10^{30}$ 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 $T \approx 1$ 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.
Flows Observed with EIS

- EIS velocity measurements show:
  - upflows near the flare ribbons
  - downflows in many of the loops
- Velocities increase with increasing $T_{\text{ion}}$

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.
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