Spatially Resolved Measurements of Turbulence in the Flare Reconnection Region

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Reconnection happens

- But needs small length scales, and locally enhanced resistivity, to achieve useful speeds/timescales
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2012/05/17 Event

- GOES M5.1
- Complex motions, with eruptions, oscillations, and inflows
- This study focuses on the plasma sheet above the post-eruption arcade in the south.

Movie file: http://solar.physics.montana.edu/mckenzie/SADmovies/Explosive_Flare_20120517.mp4
EIS and AIA
EIS rasters at range of temperature
EIS rasters at range of temperature

Fe XXIV 192 Angstroms

Fe XII 195 Angstroms
Non-thermal broadening velocities vary with height

**Box 1:**
Fe XXIV/Fe XXIII – 49 km/s; Temperature = 13.6 MK
Fe XII – 28 km/s

**Box 2:**
Fe XXIV/Fe XXIII – 34 km/s; Temperature = 12.7 MK
Fe XII – 33 km/s

**Box 3:**
Fe XXIV/Fe XXIII – 28 km/s; Temperature = 11.8 MK
Fe XII – 35 km/s

**Box 4:**
Fe XXIV/Fe XXIII – 28 km/s; Temperature = 11.4 MK
Fe XII – 41 km/s

**Box 5:**
Fe XXIV/Fe XXIII – 40 km/s; Temperature = 13 MK
Fe XII – 36 km/s
2012/01/27 Event

- GOES X1.7
- Similar orientation to the 17-May event
- EIS non-thermal speeds are 35-50 km/s, along the line of sight.
- Images reveal motions in the plane of the sky. LCT allows us to capture and measure the velocity fields.

Movie file: http://solar.physics.montana.edu/mckenzie/SADmovies/AIA_20120127_rawSADs.mp4
LCT Methodology

- Selected 645 images in 131 Å, from 19:00:21--23:29:58 UT. Cadence is 24s.
- Enhanced for contrast and to emphasize motions.
2012/01/27 Event

- Enhanced for contrast, to emphasize dynamics, and to reduce noise
- Local correlation tracking via FLCT on the 644 pairs of enhanced images (Fisher & Welsch 2008, ASPCS, vol. 383, p. 373)

Movie file:
http://solar.physics.montana.edu/mckenzie/SADmovies/AIA_20120127_SADs.mov
LCT Methodology

- Considering the whole field of view, median speed is 40 km/s.
- EIS nonthermal broadening speeds in this event are 35--50 km/s.
- Similarly, McKenzie (2013) found median speed of 38 km/s in the 2011/10/22 plasma sheet. Speeds for 2012/05/17 are slower.
LCT Velocity Fields

- The velocity fields include time-varying shears & vortices, on a range of length scales.
- These velocity field characteristics are consistent with turbulence, at the same locations & same times as the EIS measurements.
2012/01/27 Event

- In selected strips of reduced field of view:
  - Strip 1: median = 13 km/s
  - Strip 2: median = 23 km/s
  - Strip 3: median = 47 km/s
  - Strip 4: median = 67 km/s

- EIS non-thermal speeds are 35-50 km/s
  - EIS data are from southern parts of Strips 1-2 only.
Conclusions

- Temperatures in the plasma sheet are $11\sim15$ MK.
- EIS & AIA both suggest velocities of 20-60 km/s in the plasma sheet. EIS = line-of-sight $|v|$ for four flares. AIA = plane-of-sky $v$ for three flares.
- In both instruments, the velocities appear to increase with height.
- AIA directly observes the cascade from large length scales (CME-size) to sizes at the limit of resolution.
- Directly observed motions in AIA appear consistent with the non-thermal broadening in EIS. Supports interpretation as turbulence.
- With $\beta \geq 1$ (McKenzie 2013) this turbulence is important for generating small length scales and tangled magnetic fields needed for fast & prolonged reconnection.
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