Plasma Heating During a Coronal Mass Ejection Observed by SOHO

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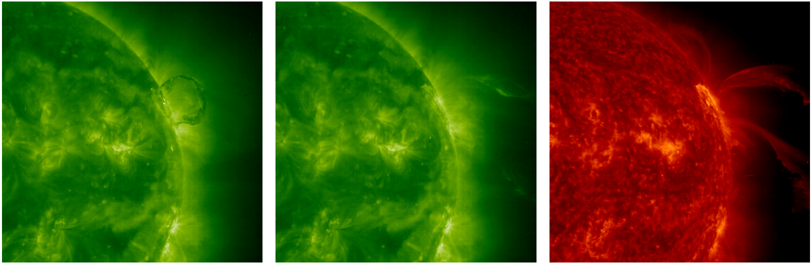
Outline

- Analyzing SOHO/UVCS observations with a time-dependent ionization code to constrain plasma heating during a CME
- Constraining candidate CME heating mechanisms

Introduction

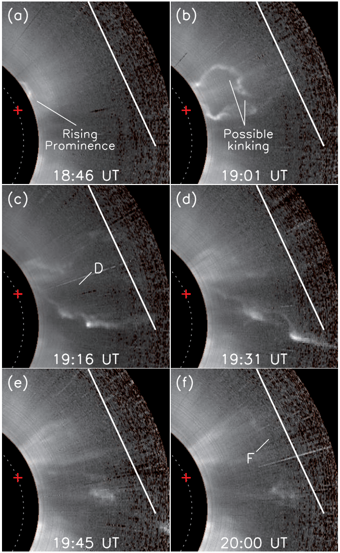
- The understanding of astrophysical phenomena usually begins with the energy budget
- White light coronagraph observations give CME kinetic and potential energies
- The magnetic energy is difficult to diagnose
- The Ultraviolet Coronagraph Spectrometer (UVCS) on SOHO lets us study the thermal energy content of CMEs
- Ionization/recombination timescales are comparable to the CME propagation timescale
- We perform a time-dependent ionization analysis to constrain plasma heating requirements during a CME observed by SOHO/UVCS on 2000 June 28

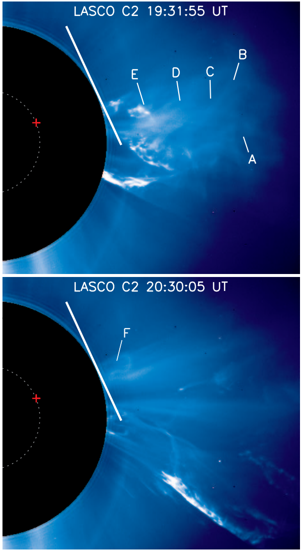
SOHO/EIT observations show a rising dark arcade at 195 Å followed by bright He II arches at 304 Å



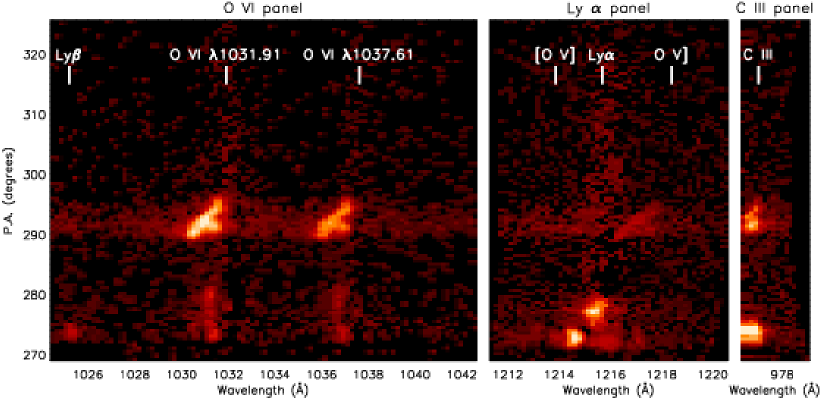
- *From left to right:* 195 Å at 18:48 UT and 19:13 UT, and 304 Å at 19:19 UT

We identify six features seen by UVCS in MLSO/MK4 polarization brightness and LASCO white light images





UVCS observed Ly α, Ly β, C III, O V, O VI, C II, and N III emission during this event

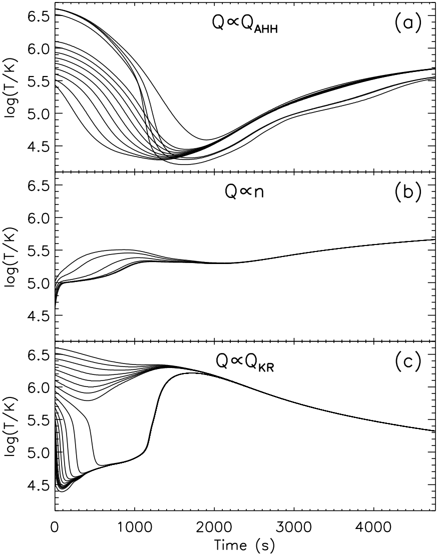


- Blob F appears as a diagonal shear flow feature in UVCS with weak Ly α and Ly β emission

We use a 1-D time-dependent ionization code to track ejecta between the flare site and UVCS slit

- We run a grid of models with different initial densities, initial temperatures, and heating rates (e.g, Akmal et al. 2001)
- The final density is derived from UVCS observations using:
  - The density sensitive [O V]/O V] line ratio
  - Radiative pumping of the O VI doublet (Raymond & Ciaravella 2004)
- Assume homologous expansion
- Multiple heating parameterizations
  - An exponential wave heating model by Allen et al. (1998)
  - The expanding flux rope model by Kumar & Rust (1996)
  - Heating proportional to n or n^2
- The models consistent with UVCS observations give the allowable range of heating rates
- Murphy, Raymond, & Korreck 2011, ApJ, 735, 17

Allowed temperature histories for blob F



Cumulative heating energy, kinetic energy, and potential energy in units of 10^{14} erg g^{-1}

Blob	Q_{AHH}	$Q \propto n$	$Q \propto n^2$	Q_{KR}	K.E.	P.E.
A	**6–35**	**7–46**	**22–42**	**7–127**	**136 (>29)**	**7.4**
B	0.3–37	1.4–86	18–117	7–379	164 (>27)	7.9
C	0.2–36	0.6–87	12–112	1–392	164 (>27)	7.7
D	0.2–61	0.4–163	13–112	1–422	136 (>19)	7.9
E	**1.6–13**	**3–13**	**17–109**	**6–30**	**164 (>11)**	**8.2**
F	6.5–8.2	16.9	—	56.6	8.6 (>5.5)	5.5

- For blobs A and E, the cumulative heating energy is less than or comparable to the kinetic energy

Cumulative heating energy, kinetic energy, and potential energy in units of 10^{14} erg g^{-1}

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F	6.5–8.2	16.9	—	56.6	8.6 (>5.5)	5.5

- For blobs B–D, the cumulative heating energy is constrained to be less than ∼2–3 times the kinetic energy

Cumulative heating energy, kinetic energy, and potential energy in units of 10^{14} erg g^{-1}

Blob	Q_{AHH}	$Q \propto n$	$Q \propto n^2$	Q_{KR}	K.E.	P.E.
A	6–35	7–46	22–42	7–127	136 ($>$29)	7.4
B	0.3–37	1.4–86	18–117	7–379	164 ($>$27)	7.9
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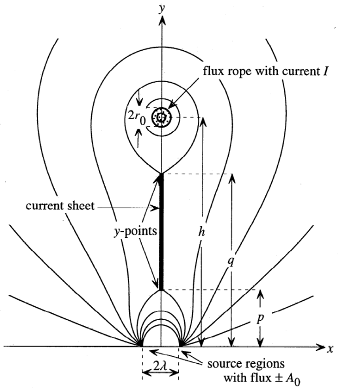
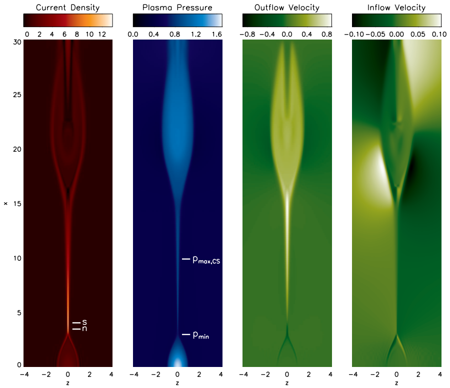
E	1.6–13	3–13	17–109	6–30	164 ($>$11)	8.2
F	**6.5–8.2**	**16.9**	—	**56.6**	**8.6 ($>$5.5)**	**5.5**

- For blob F, the cumulative heating energy is comparable to or greater to the kinetic energy

Upflow from the CME current sheet can contribute to the mass and energy budgets of CMEs



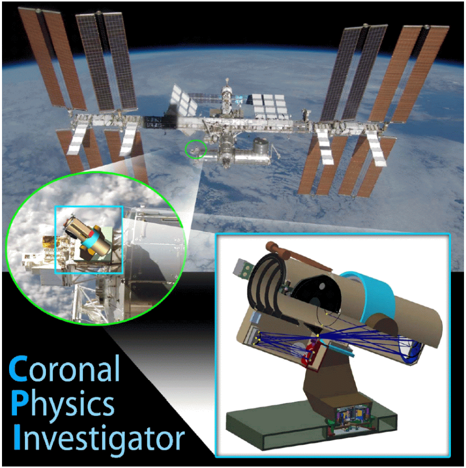


- Flux rope models predict a current sheet behind the rising plasmoid (e.g., Lin & Forbes 2000)
- Simulations of asymmetric outflow reconnection show that most of the outflow energy is directed towards the unobstructed exit (P23.14; Murphy 2010; Reeves et al. 2010)

Candidate CME heating mechanisms

- Small-scale reconnection or tearing within the expanding flux rope and ejecta
  - UVCS line widths provide constraints on turbulence
  - Flux rope kinking may drive this reconnection
- Flare heating through energetic particles or thermal conduction
  - Unlikely due to weak C class flare
    - However, the flare may have been partially occulted
    - Cf. yesterday's talk by L. Glesener
  - Energetic particles affect heating, ionization rates, and line strengths
- Wave heating by photospheric motions requires heating rates much larger than inferred for coronal holes
  - The eruption itself could drive waves that dissipate and heat the ejecta (lab experiments by Tripathi & Gekelman 2010)

Determining the thermal energy content of CMEs benefits greatly from UV spectroscopy of the corona



- CPI is an ultraviolet coronagraph spectrometer proposed for the International Space Station (see poster P24.06 by J. Raymond et al.; Kohl et al. 2011, arXiv:1104.3817)

Conclusions

- Heating is an important but not well understood term in the CME energy budget
- For some features the plasma heating is comparable to or greater than the kinetic energy
- Candidate heating mechanisms include the CME current sheet, small-scale reconnection, and dissipation of waves driven by the eruption
- Thermal conduction, energetic particle heating, and wave heating from photospheric motions are probably not significant for this event

Open questions and future work

- Open questions:
  - What is responsible for CME heating?
  - Do CME current sheets contribute substantially to the total CME energy budget?
- Future work:
  - Analyze a larger sample of UVCS events
  - Extend this analysis to AIA (need a density diagnostic)