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Hard X-Ray, Soft X-Ray, and EUV Studies of Solar Eruptions

Annual Report
Option Year 1
December 17, 2003

Contract NASW-02006

Prepared for
National Aeronautics and Space Administration
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Overview

This contract is funded to study the hard X-ray (HXR), soft X-ray (SXR), EUV, and magnetic nature of solar eruptions, with the objective of elucidating the physics of the eruption process. In particular, our aim is to examine the viability of two specific eruption mechanisms, detailed in our proposal. These mechanisms are the "breakout model" (Antiochos 1998, ApJ, 502, L181), and the "tether cutting model" (e.g., Moore et al. 2001, ApJ, 552, 833).

During the second year, we have continued to make significant progress in our goals to study solar eruption data, and interpret these data in the context of the breakout and the tether cutting models.

Data Sets Utilized. In our publications during this second year of the grant period, we primarily used data from the EUV Imaging Telescope (EIT) and the Michelson Doppler Imager (MDI) instruments on SOHO, and from the Soft X-ray Telescope (SXT), Hard X-ray Telescope (HXT), and the Bragg Crystal Spectrometer (BCS) on Yohkoh.

1. Summary of Work Performed

During the second year we have continued to focus on slowly-evolving eruptions, in order to be able to study the early-evolution dynamics with the 12-minute time cadence of EIT. We have studied in detail four events during this one-year period.

Event 1. This was an eruption on 1999 April 18. We did a preliminary study of this event in year 1, where we presented the results in Sterling et al. (2001, ApJ 561, L219). During the second year we extended that earlier work. This is a slow filament eruption, and detailed examinations in SXRs and EUV indicate pre-eruption intensity "dimmings" which are consistent with (but not proof of) the breakout model. Data from MDI show that the eruption occurs in a quadrupolar magnetic configuration, which is also consistent with breakout. Meanwhile, the detailed SXT data show that tether-cutting reconnection occurs early in the eruption, but it is not possible to conclude whether tether cutting is the ultimate cause of the eruption. Our conclusions are summarized in Sterling & Moore (2004a).

Event 2. This was a prominence eruption of 1999 February 8-9, which was very slowly-evolving and occurred in a very quiet region of the Sun. In this case the prominence eruption begins well before we see brightenings in EUV or SXR data, and initially we thought that this might be clear evidence that tether cutting was not the cause of the eruption; i.e., that tether-cutting reconnection occurred only well after the fast filament eruption. By examining the energetics of the erupting system, however, we concluded that this eruption was of such low energy that tether cutting could have been occurring at very early times, but accompanied by heating too low to show up in SXT images until much later. Thus, we had to conclude that we could not rule out tether cutting as the cause of the eruption for this case. This work provides important limits to the application of timing analysis in the study of the cause of eruption onset. This work is summarized in Sterling & Moore (2004b).

Events 3 and 4. These two filament eruptions, one of 2000 February 26 and the other of 2002 January 4, are qualitatively similar in EUV. Both show indications of a more-extended "coronal cavity" taking part in the respective eruptions, rather than the filaments alone, and they may also show pre-existing coronal loops overlying the cavities. An important question for breakout is the timing between the opening of the overlying loops relative to the time of flare onset. Also, timings of the acceleration of the upward-moving filament and the flare onset (with the cautions of the Sterling & Moore 2004b results in mind) can tell up about tether cutting. We present our observations of these timings, using EIT and SXT data to follow the loop geometry, and EIT, SXT, HXT, and BCS (Bragg Crystal Spectrometer on Yohkoh) data for the flare-onset time; the Yohkoh data were available for Event 3 only. Our preliminary results are that tether cutting has a hard time explaining the evolution of Event 3, where we do not have enough data to address tether cutting for Event 4. Both events give new constraints on the breakout model, regarding the amount of opening of the overlying fields at the times of filament acceleration and flare onset, but detailed comparisons with the breakout model are needed to say whether our finding are or are not consistent with that model. This work is still in progress, and more details of these eruptions will be given under our report for NASA grant 589.

2. Future Plans

We believe that our findings are giving new insights into the question of whether breakout or tether cutting may be the source of solar eruptions. We plan to continue our work by examining more events in detail. We also expect to extend our data set to include events from TRACE and the Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI) satellite.

3. Presentations and Publications

Presentations.

3-5 February 2003, Sagamihara, Kanagawa, Japan. Fourth Solar-B Science Meeting. "Solar Eruption Onset: Where Does the Action Begin?" by A. C. Sterling.

7 - 11 April 2003, Dublin, Ireland. UK Solar Physics meeting. "Evidence for Gradual External Reconnection Leading to Explosive
Eruption of a Solar Filament," A. Sterling and R. Moore.

19 June 2003, Laurel, MD. Solar Physics Division (SPD) of the American Astronomical Society (AAS) oral presentation. "Evidence for Gradual External Reconnection Leading to Explosive Eruption of a Solar Filament," A. C. Sterling & R. L. Moore.

26 June 2003, Tatranska Lomnica, Slovakia. International Solar Cycle Studies (ISCS) 2003 Symposium. A Near-Solar-Cycle's Worth of CME Studies with Yohkoh," by A. C. Sterling. (Invited oral presentation.)

Publications.

Sterling A. C., & Moore, R. L. 2004a. "Evidence for Gradual External Reconnection Before Explosive Eruption of a Solar Filament." ApJ, in press.

Sterling, A. C., & Moore, R. L. 2004b. "Tether-Cutting Energetics of a Solar Quiet Region Prominence Eruption." ApJ, in press.

Sterling, A. C. 2003. In Proc. ISCS 2003 Symposium, "Solar Variability as an Input to the Earth's Environment," Tatranska Lomnica, Slovakia, 23---28 June 2003 (ESA SP-535, Sep.~2003). "A Near-Solar-Cycle's Worth of CME Studies with Yohkoh."

Harra, L. K., & Sterling, A. C. 2003. In "Stars as Suns: Activity, Evolution and Planets," p. 65. International Astronomical Union, Symposium no. 219, held 21-25 July, 2003 in Sydney, Australia. "Solar Coronal Waves - what are They?"

Sterling, A. C., Moore, R. L., & Thompson, B. J. 2002. In "Multi-Wavelength Observations of Coronal Structure and Dynamics," P. C. H. Martens and D. P.

Cauffaman (eds.), COSPAR Colloquia Series, vol. 13, Pergamon. "SXT and EIT Observations of Quite Region Large-Scale Eruptions: Implications for Eruption Theories."

Moore, R. L., Falconer, D. A., & Sterling, A. C. 2002. In "Multi-Wavelength Observations of Coronal Structure and Dynamics," P. C. H. Martens and D. P. Cauffaman (eds.), COSPAR Colloquia Series, vol. 13, Pergamon. "Contagious Coronal Heating from Recurring Emergence of Magnetic Flux."

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13. ABSTRACT *(Maximum 200 words)*

This three-year program will use hard X-ray (HXR), soft X-ray (SXR), EUV, and magnetic-field data to explore the nature of solar eruptions that result in solar flares and Coronal Mass Ejections (CMEs). HXR and SXR data, respectively, will be from the Hard X-ray telescope (HXT) and the Soft X-ray Telescope (SXT) on Yohkoh; EUV data will be from the EUV Imaging Telescope (EIT) on SOHO or from TRACE; and magnetic field data will primarily be from the Michelson Doppler Imager (MDI) on SOHO. The primary analysis tool will be intercomparison of these various data sets. Two theories for the eruption mechanism of CMEs will work as a guide for the studies: the "tether-cutting" model, which assumes that reconnections near the center of the preflare bipole structure leads to its eruption; and the "breakout" model, which assumes eruption occurs after overlying restraining fields are eroded away by reconnection in a multi-polarity magnetic environment. Expected observational signatures of each model will be used to check these ideas.

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