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ScienceDirect
Advances in Space Research 38 (2006) 1529–1533
ADVANCES IN SPACE RESEARCH (a COSPAR publication)
www.elsevier.com/locate/asr

The Cinderella loop project

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Received 11 August 2004; received in revised form 11 April 2005; accepted 19 September 2006

Abstract

The solar loop that formed off the northeast limb of the Sun on 1999 November 6 (a.k.a. the Cinderella loop) is one of the few examples of a loop on the limb observed with all three of the following imaging instruments: the *Transition Region and Coronal Explorer (TRACE)*, the *SOHO* Extreme-ultraviolet Imaging Telescope (EIT), and the *Yohkoh* Soft X-ray Telescope (SXT). In this project we investigate the temperature differences that result when examining the Cinderella loop with one instrument compared with another. For example, what temperature differences result from the increased spatial resolution between the two EUV imagers? More specifically, given that *TRACE* and EIT have almost identical temperature response to coronal plasma, does the different spatial resolution of TRACE (with 0.5″ pixels) and EIT (with 2.6″ pixels) produce statistically different results? We find that the answer is no, and that our results do not change after background subtraction. In addition, the spatial resolution of EIT and SXT is similar, but the temperature responses of the two instruments are quite different. The two instruments do not seem to be viewing the same loop strands, and the plasma temperature differences are significant.

Keywords: Sun; Corona; Loops; Temperature

1. Introduction

Coronal loops dominate the X-ray and EUV emissions from the Sun near the peak of the 11-year solar cycle. The *Yohkoh* Soft X-ray Telescope (SXT) images showed loops that were both dynamic and flaring as well as those that were longer-lived and stable. The temperatures that resulted from ratios of the SXT broadband data show that the loop temperatures increased from the footpoints to the loop top (e.g., Kano and Tsuneta, 1996; Priest et al., 1998). The EUV imagers like the *Transition Region and Coronal Explorer (TRACE)* and the *SOHO* Extreme-ultraviolet Imaging Telescope (EIT), on the other hand, seem to see loops that require a continuous energy input. Ratios of the narrow passband data seem to show that these loops have a uniform temperature (Lenz et al., 1999; Aschwanden et al., 1999), but see Schmelz (2002) and Martens et al. (2002) for critiques of these results. The analysis of Nagata et al. (2003) seems to indicate that these hotter SXT loops can alternate with the cooler EUV loops throughout an active region, and that the loops viewed with the different instruments show different components of the region.

Recent results from spectrometers also show differences. The *SOHO* Coronal Diagnostic Spectrometer (CDS) observations of a loop on the limb observed on 1998 April 20 seem to indicate that the loop is stable and under approximately constant pressure. The analysis of these data by Schmelz et al. (2001) indicated that the loop was multi-thermal both along the line of sight as well as along its length, reminiscent of the stable SXT-type loops mentioned above. Observations of other CDS loops, including those described by Brkovic et al. (2002); Del Zanna and Mason (2003); Di Giorgio et al., 2003, and Landi and Landini (2004) seem to show more isothermal loops. These

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doi:10.1016/j.asr.2006.09.018

authors have stressed the importance of background subtraction as a precursor to temperature analysis.

Schmelz et al. (2003) analyzed the effect of background subtraction on EIT coronal loop data. The temperature analysis was done four different ways: (1) standard EIT analysis on the five loop pixels with no background subtraction; (2) constant background subtraction for each EIT image; (3) pixel pair background subtraction; and (4) radial background array subtraction (this method works only for loops observed above the limb). Each method produced two estimates of temperature for each loop pixel, one from the 171-to-195 ratio and the second for the 195-to-284 ratio. Both ratios produced loops with a uniform temperature, but each ratio resulted in a statistically different temperature value, perhaps indicating that the plasma along the line of sight was not isothermal. Background subtraction did not affect the EIT temperature analysis, i.e., the results were the same with and without background subtraction. Schmelz et al. (2003) also did a similar temperature analysis with randomly selected pixels for each data set. The results were the same as those for the loop pixels: two statistically different, uniform temperature "structures." These results may indicate that EIT ratio analysis does not generate a physically meaningful value of the electron temperature. Results from *TRACE* data can also be ambiguous (Chae et al., 2002;Testa et al., 2002), and a similar detailed analysis of the effects of background subtraction on loop temperature is in progress (see Schmelz, Roames, and Nasraoui in these proceedings). The exact reason for these results is a subject of on-going investigation, but the evidence seems to be strong that background subtractions does not significantly affect the temperatures of EIT and *TRACE* active region loops.

In this paper we look in detail at the solar loop observed off the northeast limb of the Sun on 1999 November 6 (a.k.a. the Cinderella loop). This is one of the few examples of a loop on the limb observed with all three imaging instruments: *TRACE*, EIT, and SXT.

2. Observations

TRACE was launched aboard a Pegasus XL launch vehicle in April of 1998. This instrument was designed to take images of the Sun's photosphere, the transition region, and the corona. *TRACE* operates by taking nearly simultaneous images in different passbands with as little delay as 1 s between images. The high spatial resolution of the subsequent images allows solar physicists to learn about the Sun's magnetic field and resulting solar structures. The Sun-synchronous orbit of *TRACE* permits continuous viewing of the Sun for eight-month periods. The instrument consists of a 30-cm aperture with four normal-incidence coatings for the EUV and UV quadrants. *TRACE* has a 1024×1024 CCD detector that takes images over a $8.5 \times 8.5'$ field of view with $0.5''$ pixels ($1''$ spatial resolution) and $0.1''$ image stabilization. A series of shutters and passbands selects the appropriate wavelength, from 171 to 5000 Å. An onboard computer processes the 1024×1024 data array and compresses the data. *TRACE* has 230 Mb of onboard storage. The data archives are free to the public after processing and are stored in databases across the world. The *TRACE* data used here were from 1999 November 6 at 02:21:13 UT for 171, 02:20:45 UT for 195, and 02:20:59 UT for 284. For details of the instrument, see Handy et al. (1999) and the *TRACE* website at http://vestige.lmsal.com/TRACE/.

EIT is one of 12 solar and heliospheric instruments on the *SOHO* spacecraft. For the past six years, EIT has been imaging the Sun and monitoring its activity in four EUV wavelength passbands: 171, 195, 284, and 304 Å, which primarily image the emission lines of Fe IX, Fe XII, Fe XV and He II, respectively. A rotating cover permits only one single multi-layer coated quadrant to image the Sun at any given time. Capable of taking either full-disk or sub-field images, the telescope has a 1024×1024 CCD detector, a $45'$ square field of view, and $2.6''$ pixels. EIT has two filters that block long wavelength solar rays and two opaque sheets that block the upper and lower halves of a reflected solar image. The EIT data used here were from 1999 November 6 at 02:57:56 UT for 171, 03:10:46 UT for 195, and 03:03:41 UT for 284. Please see the original instrument paper by Delaboudinière et al. (1996), the first results paper by Moses et al. (1997), and the EIT website (http://umbra.nascom.nasa.gov/eit/) for details of the EIT hardware and data analysis.

Developed jointly by the Lockheed-Martin Palo Alto Research Laboratory and the National Astronomical Observatory of Japan, the Soft X-ray Telescope (SXT) allowed solar physicists to observe full-disk images of the Sun over long periods of time with both high temporal and spatial resolution. SXT was one of four high-energy solar instruments aboard the Japanese spacecraft *Yohkoh*. This grazing incidence reflecting telescope had a 1.54-m focal length forming images in the 0.25 to 4.0 keV range on a 1024×1024 virtual phase CCD detector. SXT operated in the 3 to 60 Å wavelength range with $2.4''$ pixels. The telescope had a field of view that could cover the entire Sun, but it could also obtain small-scale, high-resolution images of solar flares with high time cadence. A series of thin metallic filters near the focal plane allowed SXT to differentiate between X-ray energies for plasma temperature diagnostics. A coaxially mounted visible-light telescope complimented the X-ray imager and provided information on the location of the high-energy images in comparison to those in visible light. The SXT data used here were from 1999 November 5 at 23:18:54 UT for Al.1, and 23:15:30 UT for AlMg. Details of the instrument can be obtained from the paper by Tsuneta et al. (1991). The *Yohkoh* Analysis Guide documents much of the available software for data reduction and analysis. See http://umbra.nascom.nasa.gov/yohkoh_archive.html#YAG.