Spatial and Thermal Study of an Isolated Loop with XRT and EIS

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Abstract. We use multi-filter contemporaneous XRT and EIS observations of a small active region to study the spatial and thermal properties of an isolated quiescent loop. We study the loop as a whole, in segments, in transverse cuts, and point-by-point, always with some form of “background” subtraction. We find the loop DEM is not-isothermal, but is also not extremely broad, with $\approx 96\%$ of the EM between $6.2 \leq \log T \leq 6.7$, and an EM-weighted average temperature of $\langle \log T \rangle = 6.48 \pm 0.16$. There is some evidence for a gradual change in temperature along the loop, with $\langle \log T \rangle$ increasing by $\approx 0.1$ from the foot points to the peak. Including EIS data helps better constrain the EM at low $T$. Future work includes combining the analysis with contemporaneous RHESSI data and to explore XRT-EIS-RHESSI cross-calibration at AR temperatures.

1. Observations and Analysis

The XRT data consist of full-disk images of the Sun (2048×2048 FOV) taken in solar minimum conditions on 13 May 2007 during hours 16 and 18 in 9-10 filters/combinations. Long and short exposures in each filter pair were combined to maximize dynamic range. EIS raster scans of the AR were taken in hour 14, and of the quiet disk center in hour 16. We focus on a single isolated loop in a weak AR (Fig. 1), plus disk center bright points (BP) for calibration (Fig. 1). Total duration of the campaign was $<16.5$ mins (XRT). One small A class flare occurred during hour 18 observations, otherwise the regions were quiet.

Data were calibrated for instrumental/environmental effects using standard SSW software (xrt_prep, eis_prep). Contamination on the XRT CCD, but not the filters (analysis in progress Narukage et al. 2010), was included. The loop spine pixels were defined using a ridge fitting procedure (Fig. 1 right). We used xrt_dem_iterative2 (a forward fitting code) and a Markov Chain Monte Carlo (MCMC) code to compute DEMs from the data (see Schmelz et al. 2009, and references therein). Only Fe lines (excluding Fe vii) were used in the analysis. We assumed 5% (systematic) errors on the XRT data (except where photon noise was larger - typically only in the Be-thick filter), and 10% errors on EIS. Various analyses were tried: cuts across the loop, integrated loop, loop core/spine, loop segments, all with and without various definitions of the “background” (i.e., overlying and/or underlying, non-loop plasma). We also tried DEM solutions with XRT alone, EIS alone, and XRT+EIS combined (Fig. 2). In the latter case we have explored the XRT-EIS cross-calibration factor.
Figure 1. (Left) Ti-poly filter image taken 13 May 2007 showing quiet Sun and loop regions of interest (highlighted); the limb is at lower right. (Right) Average loop spine in Ti-poly (+). Background (x) was (typically) taken following an inflated version of the spine shape, offset $\Delta x \approx +8$, $\Delta y \approx -10$ pixels, with count rates significantly below loop minimum in all filters.

Figure 2. (Left) DEM for XRT + EIS for the loop spine with a cross-calibration factor of 1.0 (solid) and 300 MC simulations (dotted). The EM-weighted average temperature is $\langle \log T \rangle = 6.48 \pm 0.16$. The DEM is slightly changed from that derived from XRT alone, but is generally better defined at low $T$. Note however the family of divergent MC simulations at low $T$ (toothpaste tube effect) - this is likely due to a combination of small calibration problems (filter contamination; cross-calibration factor $> 1$; filter thickness and atomic physics uncertainties). (Right) Model/observed fluxes in XRT filters (positions 0-8) and EIS lines (9-16). Filters are arranged within each group in order of increasing thickness/$T$. Systematic offsets in the thinnest XRT channels are likely due to filter contamination (not included here).
2. Results and Discussion

We find that the DEM of the loop spine is not-isothermal, but is also not extremely broad, with \( \approx 96\% \) of the EM between \( 6.2 \leq \log T \leq 6.7 \) (Fig. 2). Including EIS data helps better constrain the DEM at low temperatures. DEMs of loop segments suggest there is a small increase in temperature of \( \Delta \log T \approx 0.1 \) from the loop footpoints to loop top (Fig. 3). Using data from X-ray bright points (which usefully have nearly iso-thermal DEMs; Saar, Farid, & DeLuca 2009), there is evidence that the cross-calibration factor between XRT and EIS is \( >1.0 \), but \( <3.0 \).

![Figure 3.](image)

**Figure 3.** (Left) Ti-poly image with loop spine segments as defined (highlighted). (Right) Average DEM weighted coronal temperature (using the high \( T \) MC fits only; see Fig. 2 left) for loop segments as numbered at left. There is a small systematic trend in \( T \) along the loop, with the loop top (log \( T \) \( \approx 0.1 \) higher than the footpoints. Symbol size is proportional to the fraction of MC models which converged. Error bars reflect spread of MC solutions only and do not include larger (and not fully characterized) systematic errors.

In the future we plan to revisit the analysis, including the recently identified filter contamination layer (Narukage et al. 2010). This should improve residuals in XRT filters at lower temperatures (Fig. 2). We will also further investigate and refine estimated of the XRT-EIS cross-calibration factor. Using data from hour 14 and 18 we will investigate time evolution of the loop. Finally, we would like to explore adding RHESSI data to the fits to further constrain the hottest plasma (e.g., Schmelz et al. 2009).

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**References**