Invisibility of Solar Active Region Umbra-to-Umbra Coronal Loops: New Evidence that Magnetoconvection Drives Solar-Stellar Coronal Heating

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Abstract

Coronal heating generally increases with increasing magnetic field strength: the EUV/X-ray corona in active regions is 10--100 times more luminous and 2--4 times hotter than that in quiet regions and coronal holes, which are heated to only about 1.5 MK, and have fields that are 10--100 times weaker than that in active regions. From a comparison of a nonlinear force-free model of the three-dimensional active region coronal field to observed extreme-ultraviolet loops, we find that (1) umbra-to-umbra coronal loops, despite being rooted in the strongest magnetic flux, are invisible, and (2) the brightest loops have one foot in an umbra or penumbra and the other foot in another sunspot's penumbra or in unipolar or mixed-polarity plage. The invisibility of umbra-to-umbra loops is new evidence that magnetoconvection drives solar-stellar coronal heating: evidently, the strong umbral field at both ends quenches the magnetoconvection and hence the heating. Our results from EUV observations and nonlinear force-free modeling of coronal magnetic field imply that, for any coronal loop on the Sun or on any other convective star, as long as the field can be braided by convection in at least one loop foot, the stronger the field in the loop, the stronger the coronal heating.

AR coronal loops are the brightest loops in the solar corona

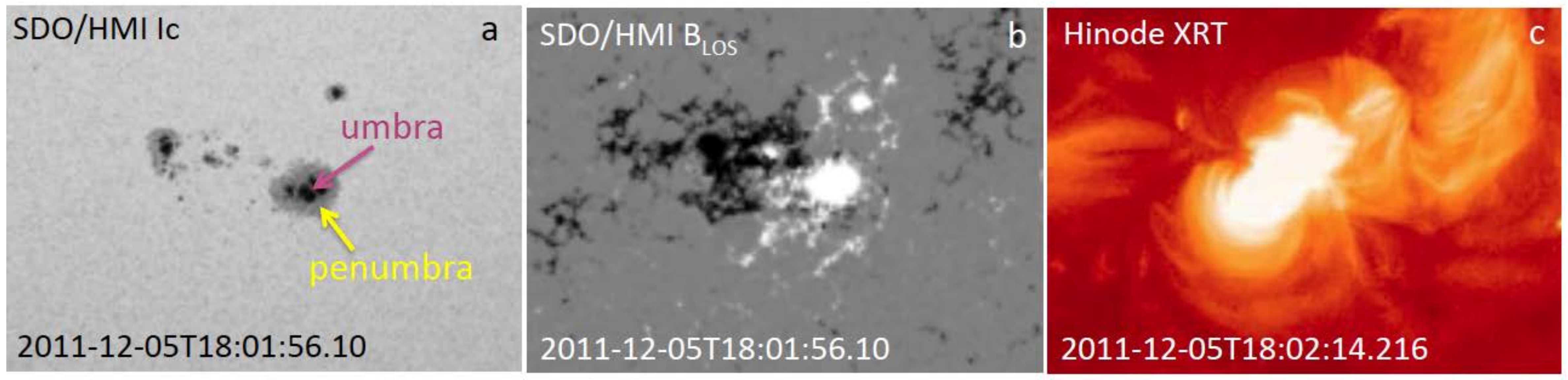

Fig. 1. An example bipolar active region (AR) with sunspots. (a). HMI continuum intensity image. The umbra and penumbra of the largest sunspot are indicated by two arrows. (b) HMI line-of-sight magnetogram of the AR at the same time. White/black areas have positive/negative magnetic polarity. (c) Hinode X-Ray Telescope image displaying hot coronal loops.

Umbra-to-umbra loops are never visible in any of the AIA channels

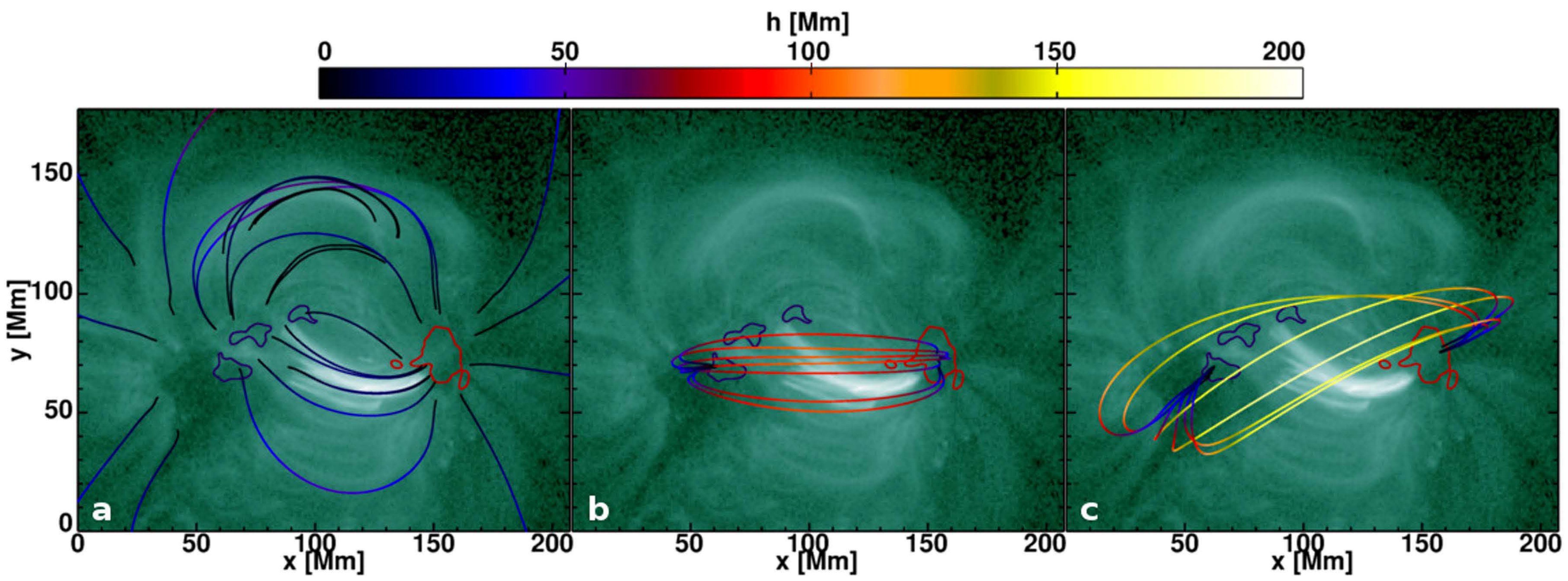

Fig. 2. An AIA 94 Å image of AR 12110 (on July 07, 2014 at 23:36 UT), with NLFF model field lines over-plotted on it. In panel (a) we show the example model field lines that match well with the observed loops in AIA 94 and 193 Å images. Panels (b) and (c) show a lower set and a (about twice) higher set of model field lines, respectively, that are rooted in umbra at each of their feet. Field-line color gives field-line height in Mm, according to the color bar on the top of the image.

Photospheric magnetic setting of coronal loops

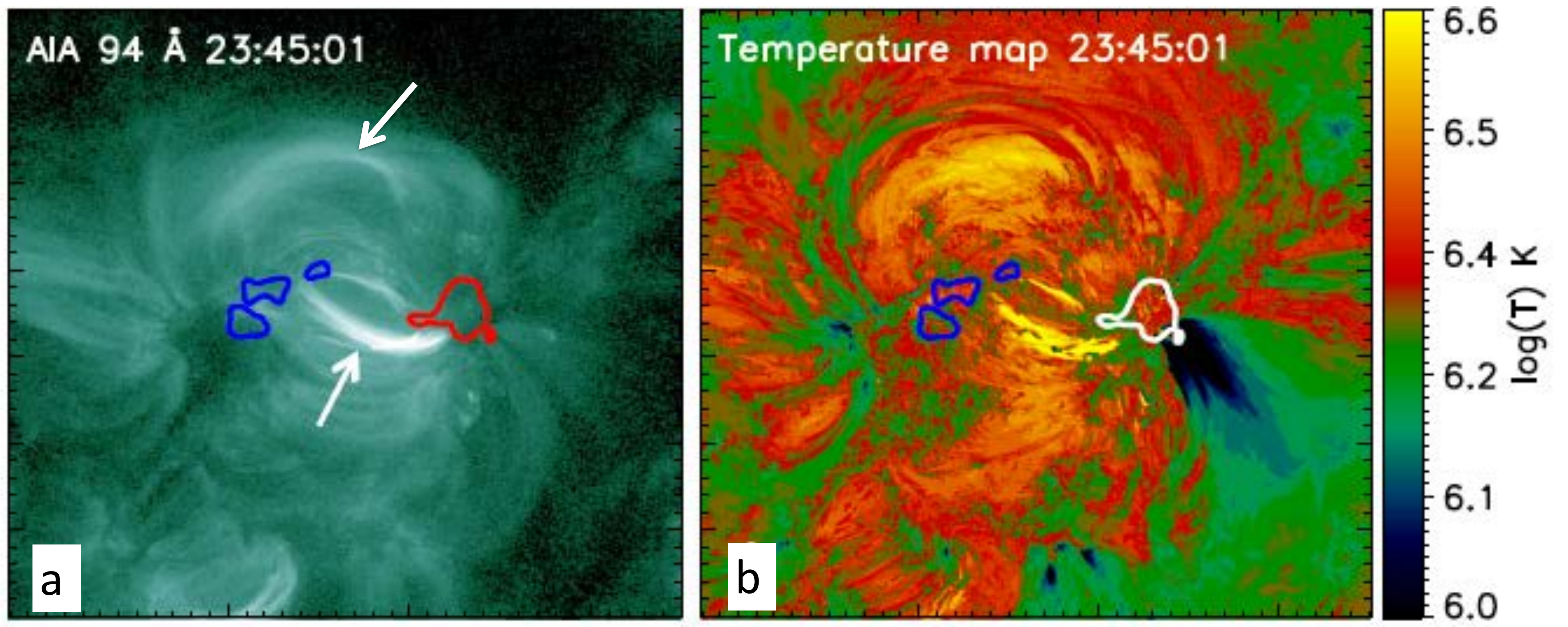

Fig. 3. Examples of bright loops. (a). AIA 94 Å image of a non-flaring active region. (b). Temperature map of the AR at the same time, produced by DEM analysis of six AIA channel images. Arrows in 94 Å image point to two bright loops, the brightest one connects umbra/penumbra to plage/penumbra, the dimmer one connects plage to plage. Plage-to-plage loops are never as bright as the brightest loops. Umbra-to-umbra loops are invisible.

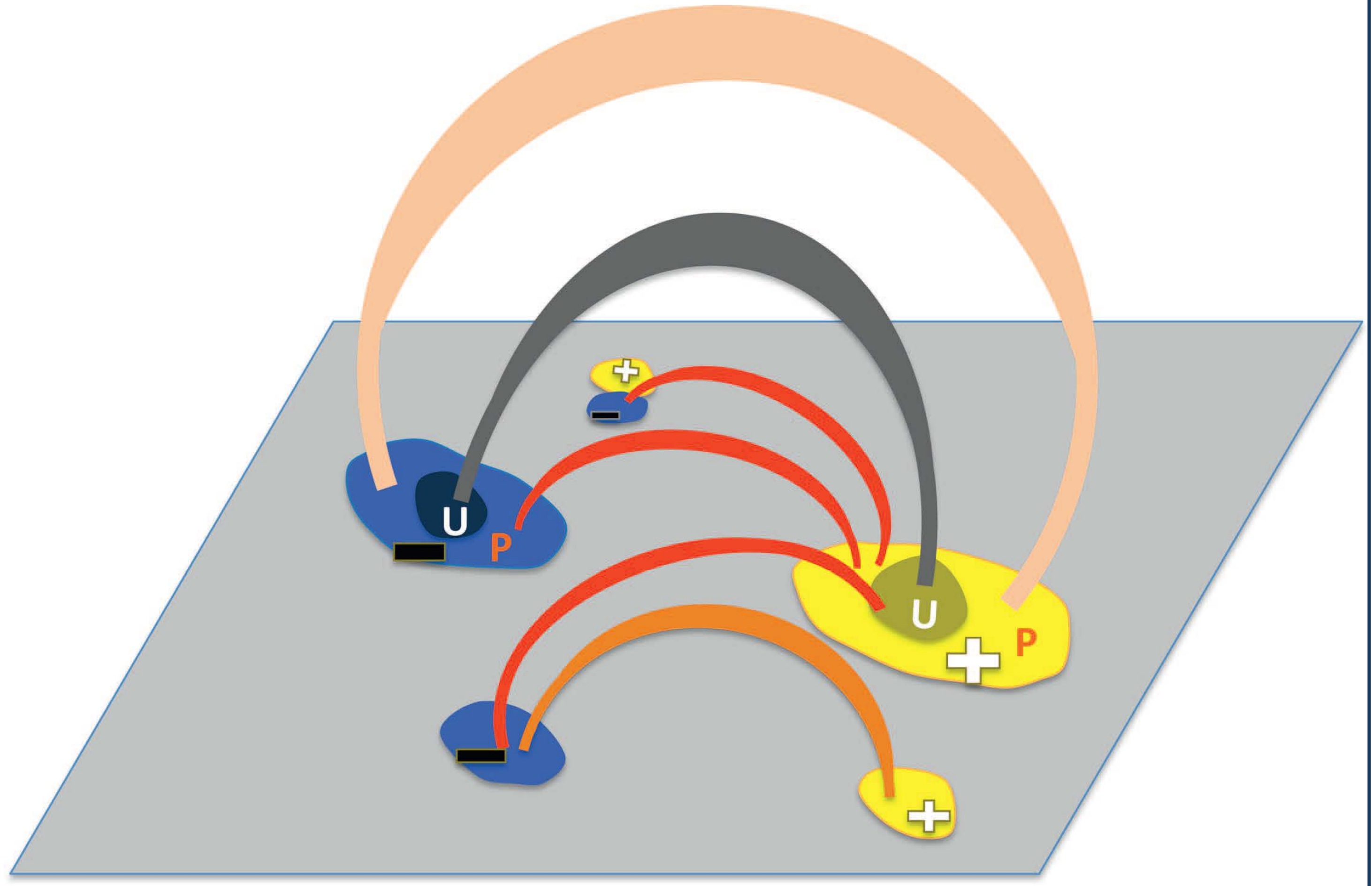

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Fig. 4. A schematic drawing depicting the dependence of the coronal EUV brightness of AR loops on their photospheric magnetic setting. Yellow/blue colors depict positive/negative polarity. "U" & "P" stand for umbra & penumbra. Different loop colors indicate different brightnesses, with red/dark-gray being the brightest /dimmest. Each of the two foreground positive & negative magnetic areas is a unipolar plage. A mixed-polarity plage is present on the top-left. The taller of the two penumbra-to-penumbra loops is the dimmer, because it is longer.

Summary and Outlook: We find that the convective freedom at the feet of a coronal loop, together with the strength of the field, determines the extent of the coronal heating in the loop. The hottest coronal loops have one foot in an umbra and the other foot in opposite-polarity penumbra or plage (coronal moss), the areas of strong field in which convection is not as strongly suppressed as in umbrae. The loops rooted in mixed-polarity flux at one or both of their feet are also among the brightest. We plan to extend this work quantitatively, and by using many non-flaring ARs with fully developed sunspots of opposite-polarity field.

SKT gratefully acknowledges support by NASA contract NNG09FA40C (IRIS). NKP is supported by an appointment to the NASA Postdoctoral Program at the NASA MSFC, administered by USRA through a contract with NASA. RLM and ARW are supported by funding from the LWS TRT Program of the Heliophysics Division of NASA's Science Mission Directorate. JKT acknowledges support from Austrian Science Fund (FWF): P25383-N27. Use of data from AIA+HMI (SDO), XRT (Hinode) is acknowledged.