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Enhanced He I Absorption at the Feet of Solar X-Ray Loops

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Abstract

A comparison of He I spectroheliograms and Yohkoh soft X-ray images of active regions indicates that He I absorption is enhanced at the feet of hot X-ray loops. It is suggested that the conduction of heat from the loops into the transition region at their feet would produce enhanced transition-region emission around 50 eV that would in turn cause enhanced excitation of He I leading to the excess He I absorption that is observed.

Key words: Sun: chromosphere — Sun: corona — Sun: spectra — Sun: transition region — Sun: X-rays

1. Introduction

He I absorption at 1083 nm is known to be related to the intensity of X-ray emission. For example, active regions that strongly emit in soft X-rays are also regions of strong He I absorption. Likewise, coronal holes that weakly emit soft X-rays show weaker He I absorption (Pneuman, Orall 1986). On the basis of this behavior, He I absorption is now being used as a ground-based technique to map coronal activity [see also Harvey et al. (1974) for earlier observations based on the He I D_3 587.6 nm line]. Before one can completely rely on this line, we need to understand the physical basis for the relationship. We have therefore used co-temporal full-disk pictures in soft X-rays from Yohkoh and He I spectroheliograms from the Norikura Solar Observatory to establish the morphological relationship between soft X-ray emission and He I absorption. Our analysis indicates that He I absorption is enhanced at the feet of the soft X-ray loops.

2. The Data

The soft X-ray telescope of Yohkoh has been described by Tsuneta et al. (1991). For this study, we used the pictures obtained on 1992 August 14 through a 0.1 μm aluminum filter. The Norikura data were obtained from spectra taken with a CCD camera (512 × 480 pixels) mounted on one of the exits of a Littrow-type spectrograph. The solar image was scanned so as to give a full-disk spectroheliogram; it comprises four scans in the east–west direction. One pixel corresponds to 1.″08 in spatial resolution and 9.7 pm in the dispersion direction. For spectroheliography, two wavelength bands are usually recorded: one in the band of 0.175 nm width centered at 1083.03 nm and the other in the band of 0.068 nm width at its nearby continuum of 1083.4 nm. The He I and X-ray images were reduced to equal size and then aligned with each other.

3. Results

Figure 1a shows the Yohkoh image and figure 1b shows the He I spectroheliogram. The general locations of enhanced He I absorption seem to coincide with the positions of the X-ray loops. However, the detailed shapes of the two pictures do not match. To examine these further we superpose the negatives of the X-ray loop images with contours of He I absorption in figures 2a through 2c. These figures show that there is generally less He I absorption associated with the body of the loops. There is a preference for enhanced He I absorption near to the extremities of the loops.

4. Discussion and Conclusions

The lower level of the ^{3}S–^{3}P transition corresponding to the 1083 nm absorption line is 19 eV above the ^{1}S ground level. The narrow width of the He I line locates its formation in the chromosphere (Hirayama 1971). Thus, collisional excitation to the ^{3}S state, which requires higher temperatures and larger line widths, is ruled out. Photoionization followed by recombination to the required energy level is a plausible mode of excitation (Goldberg 1939; Zirin 1989). The photoioniza-

(a) (b)

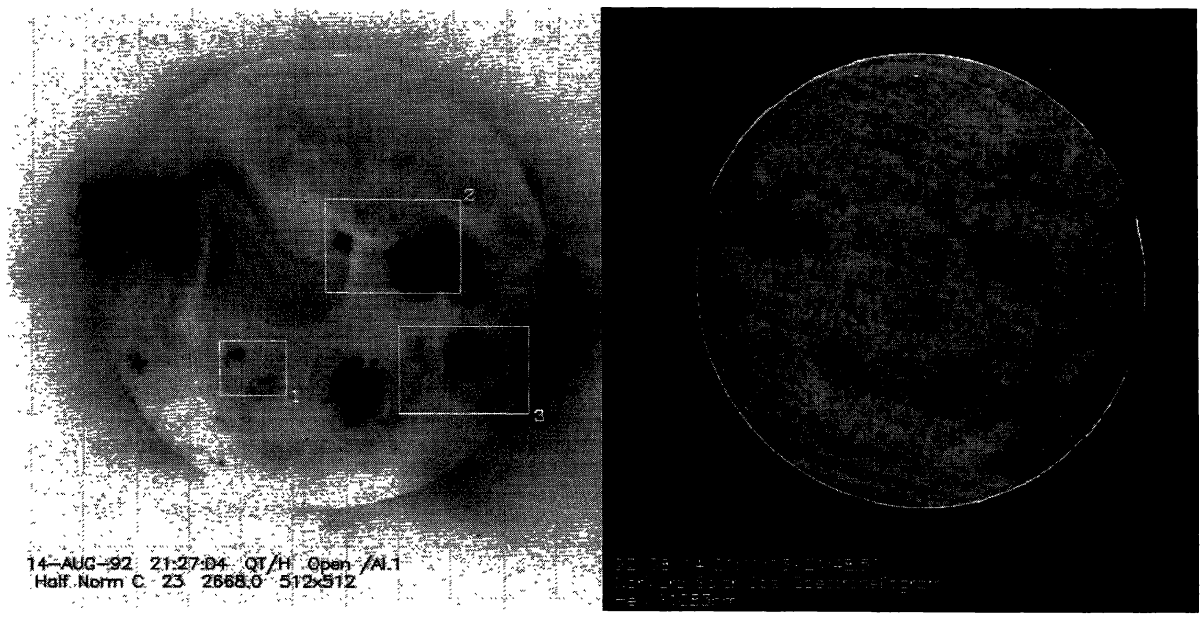

Fig. 1. (a) Yohkoh soft X-ray image (negative) through a thin Al filter, and (b) He I 1083 nm spectroheliogram divided by a continuum taken at the Norikura Solar Observatory. Enlarged images of the regions indicated by boxes 1–3 are given in figures 2a–c.

tion requires photon energies greater than 25 eV. Since the photoionization rate decreases as the −3-rd power of the photon energy, the transition-region radiation around 50 eV (wavelengths around 20 nm) would have the maximum cross-section to ionize the He atoms. Heat conducted back along the magnetic field lines of the X-ray loops can produce enhanced transition-region emission at the feet of the loops. This process could well produce enhanced He I absorption at the feet of the loops via excitation of He atoms by the transition-region emission. By this means, He I absorption near to the active regions could provide a measure of the conduction losses of the active-region loops, while soft X-ray emission from the loops would serve as a measure of the coronal radiative losses. The relationship between these two losses can then exist in a natural way on account of the geometry of the loops and the physical properties of the hot plasma in the loops.

A relationship between the coronal X-ray emission and the transition-region EUV emission is already known for stars (Ayres 1994). Furthermore, an inspection of Skylab images [e.g., figure 5.3 in Withbroe (1981)] shows a morphological relationship between the transition-region pictures and the X-ray pictures that is very similar to the relationship we see between the He I images and the soft X-ray images. Since the transition-region emission is confined to the feet of the hot loops, the texture of the transition-region images is more granular compared to the smoother texture in the X-ray images, where the emission emanates from the larger scale body of the loops.

An important difference between the transition-region images and the He I images is the excess darkening in He I filaments. This indicates a high level of excitation, even in the cool filaments. Detailed monitoring of the evolution of the H and He absorption in the filaments would provide interesting clues about the energy balance in the filaments.

In summary, a comparison of the He I spectroheliograms and the Yohkoh soft X-ray images of active regions indicates enhanced He I absorption at the feet of the hot X-ray loops. We suggest that the conduction of heat from the loops into the transition region at their feet would produce enhanced transition-region EUV emission that would in turn cause enhanced excitation of He I, leading to the observed excess absorption.

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(a)

(b)

(c)

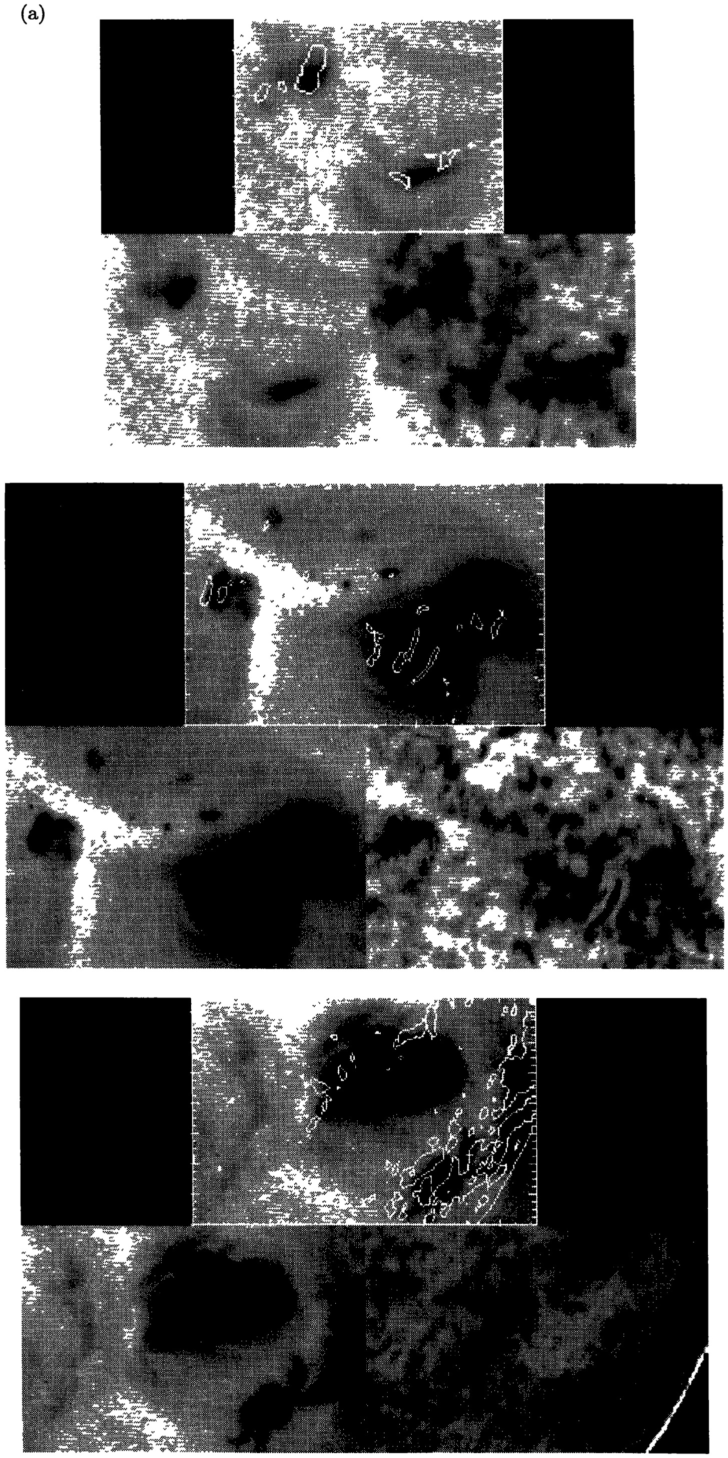

Fig. 2. (a) Enlarged images of box-region 1 shown in figure 1. (lower left) Negative soft X-ray image. (lower right) He I 1083 nm spectroheliogram. (top) The soft X-ray image with the iso-contour (5.5% depression level) of He I 1083 nm. (b) Same as figure 2a, but for box-region 2. (c) Same as figure 2a, but for box-region 3.

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