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Diagnoses on magnetic loops in the solar transition region

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Loops are fundamental structures in the solar transition region. We found that transition region loops are dynamic. Some relatively stable loops, with 382-626 km cross-sections, show obvious evidence of siphon flows in the Dopplergrams with speeds 10 to 20 km s^{-1}. We found that the siphon flows are associated with magnetic cancellation with a rate of 10^{15} Mx s^{-1}. These physical properties suggest that these loops are impulsively heated by magnetic reconnection, and the siphon flows play an important role in the energy redistribution. Interactions between transition region loops are observed, which indicate impulsive release of energy and reconfiguration of loops.

The physical properties of transition region loops are crucial for understanding the nature of the solar atmosphere. With spectral data of the line pair of O IV 1399.8 Å and 1401.2 Å ($T_{max}=1.4\times10^5$ K) of 23 transition region loops obtained by IRIS, we carry out the first systematic analyses to their loop lengths (L), electron densities (n_e), and effective temperatures. We found electron densities, loop lengths, and effective temperatures of these loops are in the ranges of 8.9×10^9–3.5×10^{11} cm^{-3}, 8–30 Mm, and 1.9×10^5–1.3×10^6 K, respectively. At a significant level of 90%, regression analyses show that the relationship between electron densities and loop lengths is $n_e[cm\text{-}3] \propto (L[Mm])^{-0.78\pm0.42}$, while the dependences of electron densities on effective temperatures and that on the line intensities are not obvious. These observations demonstrate that transition region loops are significantly different than their coronal counterparts.

Above a region with late-phase flux emergence, we observe a loop system consists of many transition-region loop threads that are 5 to 12 arcsec in length and about 0.5 arcsec in width and coronal loops with similar length and about 2 arcsec in width. Although the loop system consists of threads with different temperatures, most individual loop threads have temperatures in a narrow range. In the middle of the loop system, there is a clear systematic blueshift of about 10 km s^{-1} in the transition region that is consistent with a flux-emerging picture, while a redshift of about 10 km s^{-1} in the corona is observed. The nonthermal velocity of the loop system is smaller than that of the surrounding region in the transition region but is comparable that in the corona. The electron densities of the coronal counterpart of the loop system range from 1×10^9 cm^{-3} to 4×10^9 cm^{-3}. The electron density of a transition-region loop is also measured and found to be about 5×10^{10} cm^{-3}, a magnitude larger than that in the coronal loops. In agreement with imaging data, the temperature profiles derived from the differential emission measurement technique confirm that some of the loops have been heated to corona level. Our observations indicate that the flux emergence in its late phase is much different from that at the early stage. While the observed transition region is dominated by emerging flux, these emerging loops could be heated to corona level, and the heating (if via nonthermal processes) most likely takes place only after they reach the transition region or lower corona.

At even later phase of flux emergence, we find the transition-region loops are still expanding and moving upward with a velocity of a few kilometers per second ($\lesssim$10 km s^{-1}). The expansion of the loops leads to interactions between the loops themselves and with the ambient field, which can drive magnetic reconnection evidenced by multiple intense brightenings, including transition-region explosive events and IRIS bombs in the footpoint region associated with the moving polarity. A set of quasi-periodic brightenings with a period of about 130 s is found at the loop apex, from which the Si IV 1394 Å profiles are significantly non-Gaussian with enhancements at both blue and red wings at Doppler velocities of about 50 km s^{-1}. We suggest that the transition-region loops in the very late phase of flux emergence can be powered by heating events generated by the interactions between the expanding loops and the ambient fields and also by (quasi-)periodic processes, such as oscillation-modulated braiding reconnection.

Our studies indicate that transition region loops are significantly different from their coronal counterparts, and they are one of the critical aspects of the complex solar atmosphere. Further studies on the theoretical aspect based on the physical parameters obtained here are of significance for understanding the nature of transition region loops.

References
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