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Neutral-MHD simulations of penumbral micro-jets

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Abstract. The successful launch of the Hinode satellite has resulted in a wealth of new discoveries. Amongst these was the detection of micro-jets in the penumbrae of sunspots (Katsukawa et al. 2007). Further observations found these micro-jets could be separated in to two distinct types: (1) bow-shock transients propagating perpendicular to their long-axis, and (2) micro-jet transients propagating parallel to their long-axis (Ryutova et al. 2008).
In this work, Neutral-MHD simulations are presented which show the development of penumbral micro-jets and bow-shocks, in the chromospheric atmosphere above sunspots. The inclusion of neutral particles is essential for obtaining the correct dynamics in the chromosphere, where the ion fraction can become extremely small, $\xi_i \geq 10^{-6}$. The penumbral chromosphere is simulated using the VAL-IIIC semi-empirical model, to obtain a realistic hydrostatic atmosphere. Both the micro-jet and bow-shock transients are shown to be generated by the same process; the interaction of small-scale chromospheric loops. Magnetic reconnection is seen to change the topology of the interacting loops, which then recoil due to magnetic tension. This recoiling of the loops, in combination with the sharp change in plasma density with height, is shown to accelerate the micro-jet transients to $v \approx 50$ km s^{-1}, and the bow-shock transients to $v \approx 10$ km s^{-1}; in agreement with the observed velocities. It is found that the type of transient is determined solely by the initial geometry of the interacting loops; loops with parallel axial magnetic fields form bow shocks, while loops with anti-parallel magnetic fields form micro-jets. It is concluded that the observed penumbral transients can be explained by the interaction of small-scale chromospheric loops above sunspots.