Penumbra formation: An observational study of the photosphere and chromosphere in three dimensions.

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The formation of sunspots is generally well understood, with the exception of penumbra formation. Two main mechanisms have been proposed to explain its onset: Flux emergence triggering the development of penumbral filaments, and a reconfiguration of the chromospheric magnetic field to a more horizontal orientation. During our observation campaign at the Swedish Solar Telescope (SST) in May 2022, we obtained high-resolution spectropolarimetric observations of a forming penumbral sector, covering both the photosphere and the chromosphere. To compute the magnetic field, we applied Milne-Eddington and weak field approximation techniques, as well as the multi-atom non-LTE inversion code STiC, to fit full Stokes profiles of FeI 6302 Å and CaII 8542 Å. We found that strong horizontal magnetic fields in the chromosphere, exceeding 500 G, are a key prerequisite for penumbra formation. At the site of initial filament development, we observed localized flux emergence accompanied by strong redshifts (2–3 km/s) throughout the atmospheric layers. We interpret these redshifts as field-aligned horizontal flows, possibly indicating a siphon flow evolving into the Evershed flow. The forming penumbral filaments were temporarily disrupted but reformed shortly after, with no significant change in the chromospheric horizontal magnetic field component. We conclude that a strong horizontal magnetic field in the chromosphere is a necessary boundary condition, while flux emergence initiates the growth of penumbral filaments. The interaction between the chromosphere and photosphere during penumbra formation remains not fully understood. We aim to address this with further observations during upcoming campaigns at SST to study this interplay in more detail.