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Coronal Condensation as the Origin of Supersonic Downflows above a Sunspot

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Downflows at supersonic speeds towards sunspots were first discovered as strongly redshifted secondary emission peaks in the transition region (TR) spectra in the 1980s.[1,2] Such sunspot supersonic downflows (SSDs) eventually can impart their energy into the lower atmosphere as their speeds decrease from the supersonic to a sub-sonic state, and likely also play an important role in the mass cycle of the sunspot atmosphere. Early observations both revealed that SSDs can be persistent within sunspots over multiple days,[3,4,5] meaning that a substantial mass supply is required to sustain these persistent SSDs.[6,7] However, the origin of such quasi-steady SSDs still remains a mystery.

Here, we have conducted a case study on the origin of SSDs in active region (AR) 12740 based on joint spectroscopic and imaging observations from the Interface Region Imaging Spectrograph (IRIS), the Atmospheric Imaging Assembly (AIA) onboard the Solar Dynamics Observatory, and the EUV Imager (EUVI) onboard the Solar Terrestrial Relations Observatory.

In our observations, almost all the identified SSDs appear at the footpoints of sunspot plumes and are temporally associated with episodes of coronal rain. These fast downflows can be simultaneously detected as secondary emission peaks in several transition region and chromospheric lines. The average density, Doppler velocity and mass flux of these SSDs are of the order of $10^{10.4}$ cm^{-3}, 100 km s^{-1} and 5×10^{-7} g cm^{-2} s^{-1}, respectively. EUV imaging observations from two different viewpoints suggest that these SSDs originate from coronal condensation repeatedly occurring in magnetic dips of high-lying magnetic field lines, which is facilitated by magnetic reconnection. One episode of condensation clearly indicates that reconnection near an X-shaped structure leads to the formation of a magnetic dip, which can also be reconstructed through a potential field extrapolation. Subsequently, as the coronal plasma converges into the newly-formed dip, the loss of thermal equilibrium is triggered. As a result, the hot coronal plasma catastrophically cools from ~2 MK down to ~ 0.01 MK, forming a transient prominence. Due to the gravity, the cool prominence materials mostly slide into the sunspot along inclined field lines of the plumes, resulting in a nearly steady SSD event. This drainage process lasts for ~2 hrs, suggesting a considerable mass flux. In the dip region, the total mass of condensation (1.3×10^{14} g) and condensation rate (1.5×10^{10} g s^{-1}) were found to be large enough to sustain this long-lived SSD event, which has a mass transport rate of 0.7–1.2×10^{10} g s^{-1} at the endpoint of one stream of strong SSDs, enhanced localized chromospheric heating was detected in the sunspot umbra as a long-lived (≥ 2 hrs) bright dot in Hα images. Our results demonstrate that the reconnection-facilitated coronal condensation[8] repeatedly occurring in high-lying magnetic structures results in the quasi-steady SSDs.

References

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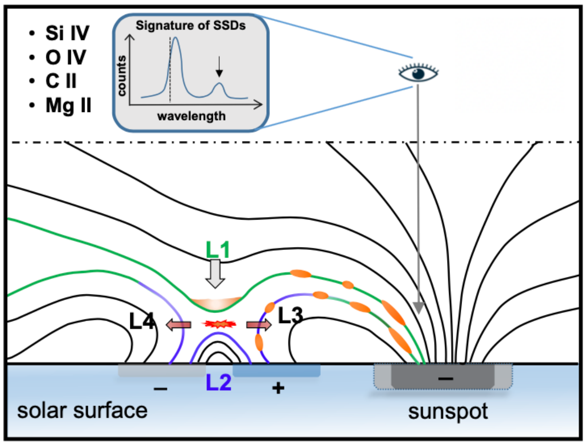

Figure 1. the schematic diagram for the origin of quasi-steady SSDs in our observations. The "+" and "-" signs denote the positive- and negative- polarity magnetic fields on the solar surface, and the solid lines represent magnetic field lines. Near the reconnection site (red explosive feature), four groups of field lines, "L1", "L2", "L3" and "L4", are highlighted by green and blue solid lines. The red arrows in (a) mark the diverging motion of newly formed loops from the reconnection site. The brown shadowed regions represent coronal rain clumps.