

On the magnetic connectivity of developing sunspots

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While stable sunspots have been extensively studied and their global surface properties are well understood, their formation process and connectivity with its surroundings continue to elude definitive explanation. Here, we present further advancements on the mechanism(s) responsible for sunspot development through a comprehensive analysis spanning from observations of the photosphere and chromosphere, to magnetic field extrapolations, and state-of-the-art realistic 3D magneto-hydrodynamic simulations. Our findings provide clear evidence that penumbra formation begins with the emergence of sunspot magnetic flux through the solar surface, giving rise to transient penumbral filaments. As this magnetic flux continues to ascend through the solar atmosphere, a stable, low-lying magnetic canopy eventually forms. Once a sufficient amount of flux has emerged, its further rise is inhibited at the photospheric level, leading to the formation of stable penumbrae. This process is also accompanied by the formation of an enhanced magnetic network surrounding the spot, the nature of which will be further discussed.