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## On the sunspot penumbra formation with nonlinear force-free field extrapolations

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The mechanism behind the formation of the solar penumbra remains a topic of debate, with the magnetic field configuration above the photosphere not yet thoroughly explored. In this study, we examine the formation of sunspot penumbra through a novel approach using the analysis of magnetic fields derived from Non-Linear Force-Free Field (NLFFF) extrapolations. We perform NLFFF extrapolations on HMI/SDO data, capturing the evolution of active region NOAA 12757 before, during, and after penumbra formation. By tracking the magnetic field lines, we present unprecedented insights into the changes in topology and connectivity. Initially, prior to penumbra formation, we observe low-lying sea-serpent magnetic fields that gradually rise and become more vertical. The penumbra forms during this transition, and its extent stabilizes once the rise of the low-lying sea-serpent magnetic field lines ceases.

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