Equipartition field strength on outer sunspot boundary

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The outer boundary of sunspots, specifically the penumbra-quiet Sun transition, has not been studied in detail. Prior observations hinted at specific magnetic field strengths but did not derive a definitive conclusion on its nature. Our studies investigate the magnetic properties of this outer boundary by analyzing SDO/HMI data of a long-lived sunspot and statistically large sample of sunspots observed by SDO/HMI where the intensity maps and inversion results are deconvolved by neural network trained on Hinode SP data. Observational analysis revealed a strong correlation between the continuum intensity boundaries of sunspots (defined as 0.9 of the quiet-Sun continuum intensity) and iso-contours of magnetic field strength. The mean absolute magnetic field strength at this outer boundary was found to be approximately 650 G. This value match the typical value of equipartition field strength in the solar photosphere, but this key physical parameter cannot be reliably determined through inversions of observables. This observational finding is strongly supported by the sunspot simulations. Simulations clearly demonstrate that the total magnetic field strength is approximately equal to the equipartition field strength at the outer penumbral boundary, thereby defining the sunspot's border. Vertical cuts through simulated sunspots show that the magnetopause – the boundary between the sunspot and the surrounding plasma – precisely coincides with the transition from super-equipartition to sub-equipartition field strength. Based on the convergence of observational evidence and simulation results, we conclude that the outer boundary of sunspots is fundamentally defined by the equipartition field strength.