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Small-scale to global structure of sunspots: recent advances

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The high-resolution observations reveal that the sunspots consist of small-scale dynamically evolving structures e.g. umbral dots, light-bridges, spines, penumbral filaments, strong downflows at periphery etc. Major portion of a sunspot is covered by its penumbra. The sunspot penumbra is composed of copious thin, radially elongated filaments, which are responsible for heat transport in the penumbra but whose structure is not clear. To explore internal structure of these penumbral filaments, we used the inversion code SPINOR, in its spatially coupled mode, to obtain the height stratification of thermal, magnetic and velocity parameters of a sunspot observed nearly at solar disk center by Solar Optical Telescope/Spectropolarimeter onboard the Hinode. Filaments of different sizes show similar thermal, magnetic, and velocity patterns in all parts of the sunspot penumbra. To reveal the common physical properties to all of them and reduce the fluctuations in the surroundings, we averaged all the selected filaments. The averaged filament displays upflows with upward directed field at the heads, downflows with downward directed field at the tails, and upflows continuing along the filament axis for more than half of its length with lateral downflows along its sides. We present a unified observational picture of a sunspot penumbral filament. Our illustration is consistent with the penumbral filaments being magneto-convective cells, in line with recent MHD simulations. The complex and inhomogeneous structure of penumbral filaments provide a natural explanation to a number of long-running controversies in the literature, e.g. whether more horizontal (inter-spines) or vertical (spines) fields are brighter, the Evershed flow takes place in dark or bright part of penumbra etc. We then investigated global properties of the sunspot. The sunspot umbra and the spines of the penumbra show striking similarity in their physical properties albeit with some quantitative differences. The scatter of the physical parameters over the full sunspot shows a qualitative similarity to that of the standard penumbral filament and its surrounding spines. Our results suggest that the spines in the penumbra are basically the outward extension of the umbra. The spines and the penumbral filaments are together the basic elements forming a sunspot penumbra.

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