Canonical $B_{\rm ver}$ value on umbra/penumbra boundaries

Jan Jurčák[1], Nazaret Bello González[2], Rolf Schlichenmaier[2], Reza Rezaei[3,4]

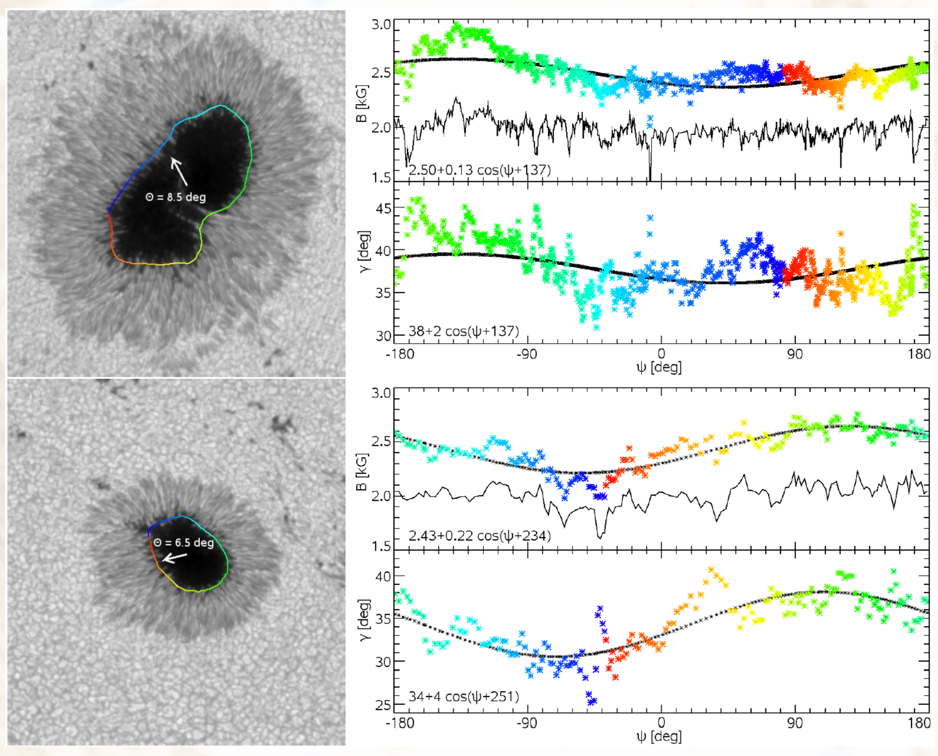
[1]Astronomical Institute of the Academy of Sciences, Fričova 298, 251 65 Ondřejov, Czech Republic
[2]Kiepenheuer-Institut für Sonnenphysik, Schöneckstr. 6, 79104, Freiburg, Germany
[3]Instituto de AstrofÃsica de Canarias, 38205 La Laguna, Tenerife, Spain
[4]Departamento de AstrofÃsica, Universidad de La Laguna, 38205 La Laguna, Tenerife, Spain

We review past and upcoming studies related to the canonical value of the vertical component of the magnetic field on stable umbra/penumbra boundaries of sunspots, $B_{\rm ver}^{\rm stable}$.

Discovery of $B_{\rm ver}^{\rm stable}$ and motivation for further analyses

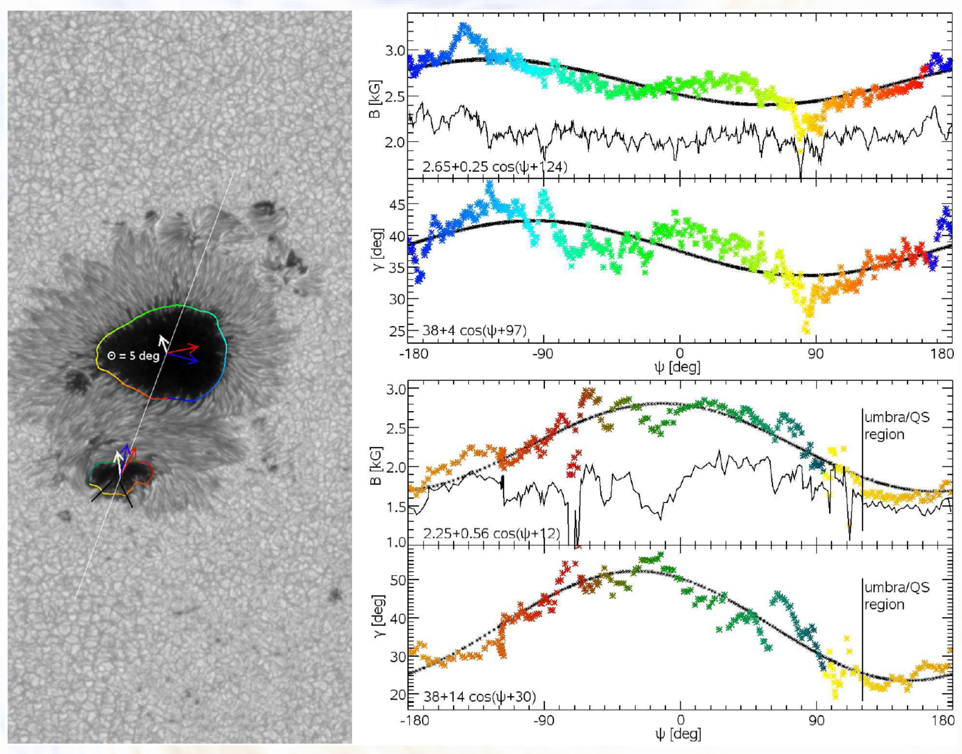
Jurčák 2011, A&A 531, 118

An analysis of magnetic properties of nine stable sunspots show that the magnetic field strength and inclination vary on the umbra/penumbra boundaries. However, the vertical component of the magnetic field strength is constant there. Based on the limited sample, we estimated $B_{\rm ver}^{\rm stable} \sim 1.8$ kG.



Magnetic field strength and inclination are marked by coloured symbols. The vertical component of the magnetic field strength is marked by the thin solid line.

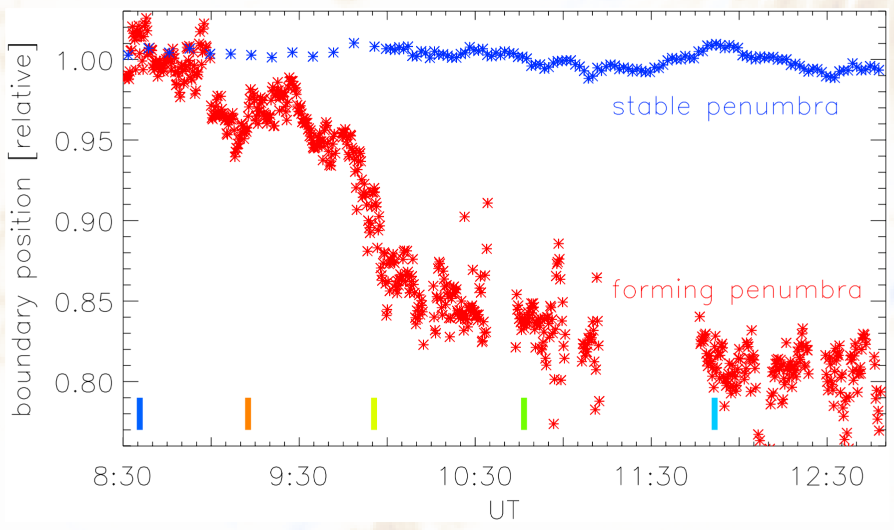
On the boundary of an umbra with only partially developed penumbra, the values of $B_{\rm ver}$ vary more than on the boundaries of stable sunspots. It is the weakest on the section, where the penumbra is not developed. We speculated that once the penumbral filaments develop, they protrude deeper into the umbra until they reach the value of $B_{\rm ver}^{\rm stable}$.



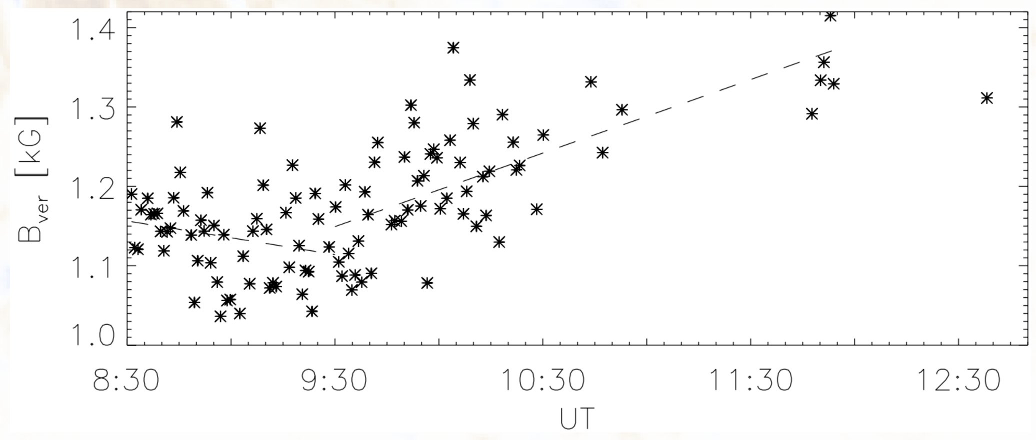
Formation of a stable umbra/penumbra boundary

Jurčák, Bello González, Schlichenmaier, Rezaei 2015, A&A 580, L1

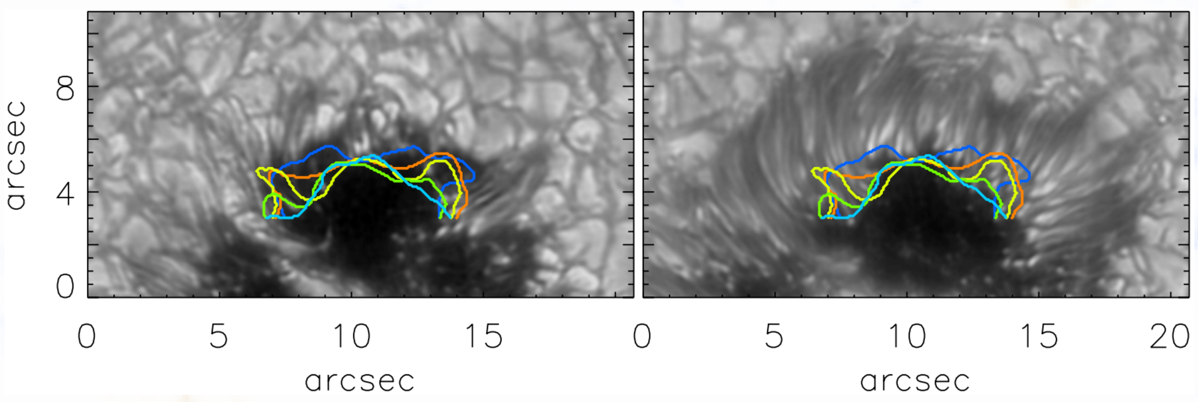
We studied the changing value of $B_{\rm ver}$ on the forming umbra/penumbra boundary. The $B_{\rm ver}$ increases during penumbra formation owing to the incursion of the penumbra into umbral areas. Eventually, the inner penumbra boundary settles at $B_{\rm ver}^{\rm stable}$ of 1.8 kG, which hints toward the role of $B_{\rm ver}^{\rm stable}$ as inhibitor of the penumbral mode of magneto-convection.



The red symbols mark the evolution of the mean distance between the UP boundary (examples marked in the previous figure) and the sunspot centre. The blue symbols show for comparison the case of stable UP boundary.



Temporal evolution of Bver. Symbols correspond to the mean values of $B_{\rm ver}$ along the UP boundary for each GFPI scan. As the boundary position stabilises around 12:00 UT (previous image), the $B_{\rm ver}$ saturates around 1.3 kG. At 12:30 UT and 15:45 UT, Hinode observations of the same active region show at the studied boundary an unvarying $B_{\rm ver}$ value of 1.8 kG.

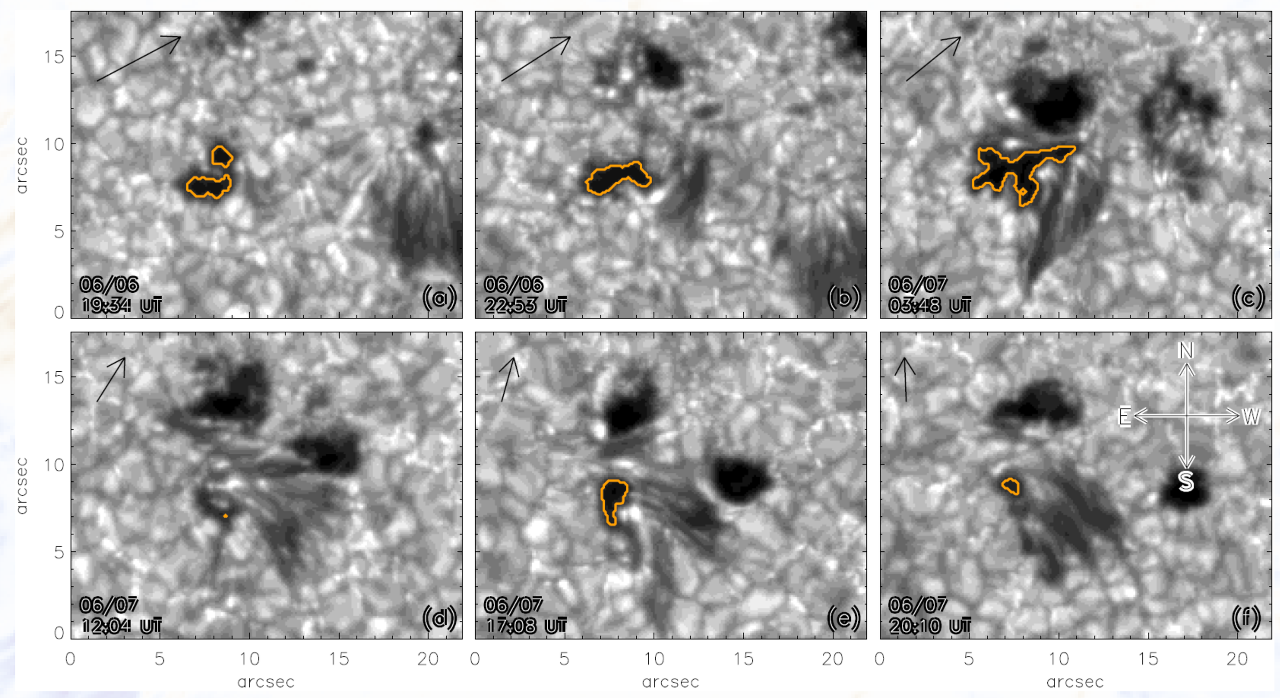


The formation of a penumbra around a segment of an umbra between 8:30 UT (left) and 12:50 UT (right). The G-band images were used to define the position of the umbra/QS and umbra/penumbra boundary. The colour contours mark the position of the UP boundary at different times.

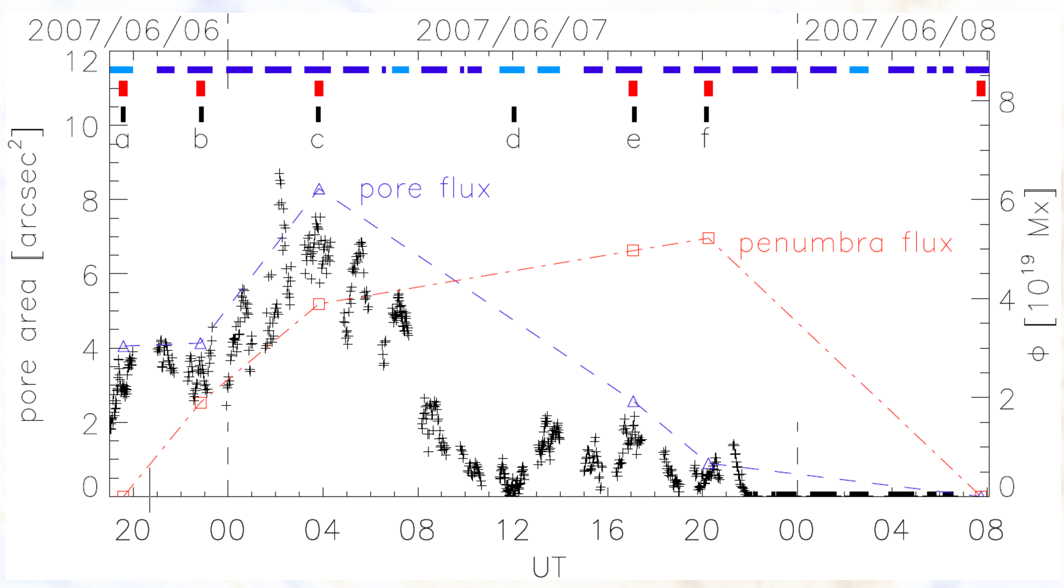
Formation of a penumbra at the expense of a pore

Jurčák, Bello González, Schlichenmaier, Rezaei 2017, A&A 597, A60

We report on a formation of a penumbra segment at a boundary of a pore with $B_{\rm ver} < B_{\rm ver}^{\rm stable}$. While $B_{\rm ver}$ in the pore is smaller than $B_{\rm ver}^{\rm stable}$, the protrusion of penumbral grains into the pore area is not blocked, a stable boundary does not establish, and the pore is fully overtaken by the penumbral mode of magneto-convection.



G-band images showing selected stages of pore and penumbra evolution. The orange contours mark pore areas with $I_c < 0.5 \times I_c^{\rm QS}$.



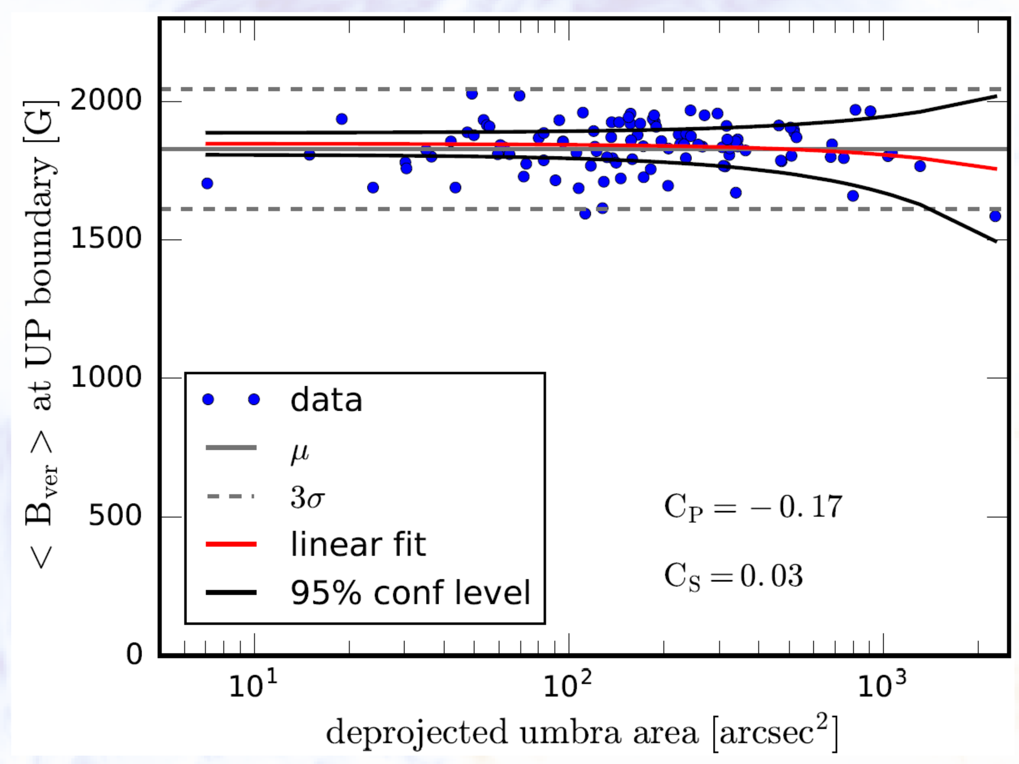
Evolution of the pore area with $I_c < 0.5 \times I_c^{\rm QS}$ (black + symbols). The sparse SP scans allow us to show that the forming penumbra flux (red □ symbols) grows at the expense of the pore magnetic flux (blue △ symbols).

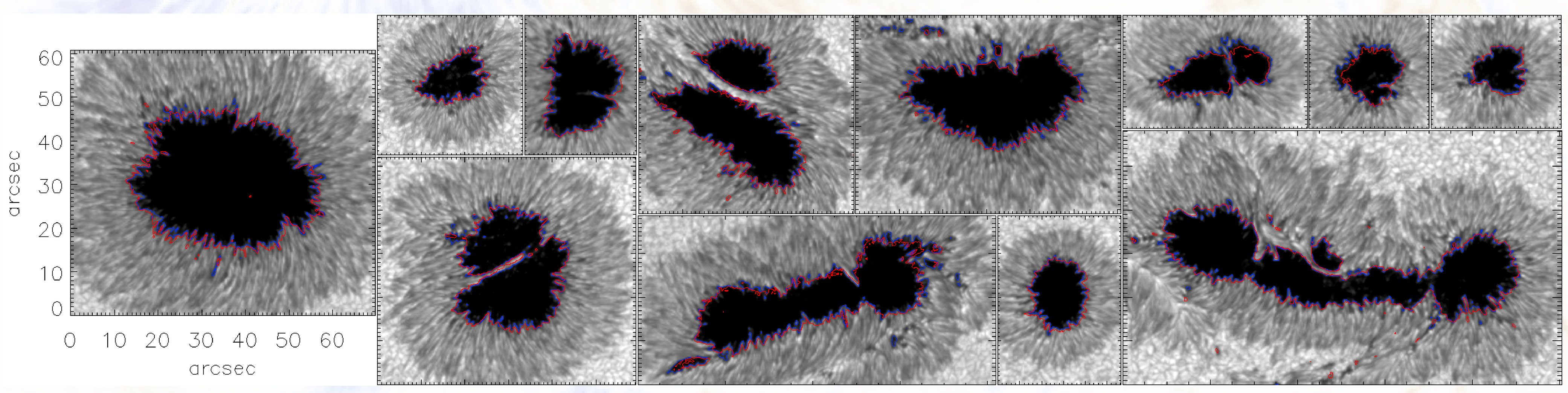
Statistical study of $B_{\rm ver}$ on UP boundaries

Rezaei, Jurčák, Bello González, Schlichenmaier 2017, in preparation

We study a sample of 106 sunspots observed with Hinode SP between 2006 and 2015 to investigate the $B_{\rm ver}$ value on umbra/penumbra boundaries. Our sample of $B_{\rm ver}$ show a Gaussian distribution with mean value of 1830 G and 1σ value of 70 G. This canonical value of $B_{\rm ver}$ shows no dependence on umbral area, umbral area fraction, or phase of the solar cycle.

Variation of $B_{\rm ver}$ as a function of umbra area. The solid and dashed gray lines denote the avergae and 3σ range of the PDF. The black lines mark the 95% confidence limit of the linear fit marked in red. C_p and C_s stand for Pearson and Spearman correlation coefficients, respectively.





Sample of studied sunspots of various sizes displayed in the same scale. The blue contours mark the UP boundaries based on continuum intensity ($0.5 \times I_c^{\rm QS}$) and the red contours are based on $B_{\rm ver} = 1.83$ kG.