- SOLAR PORES -

A MAGNETIC EVOLUTION LABORATORY

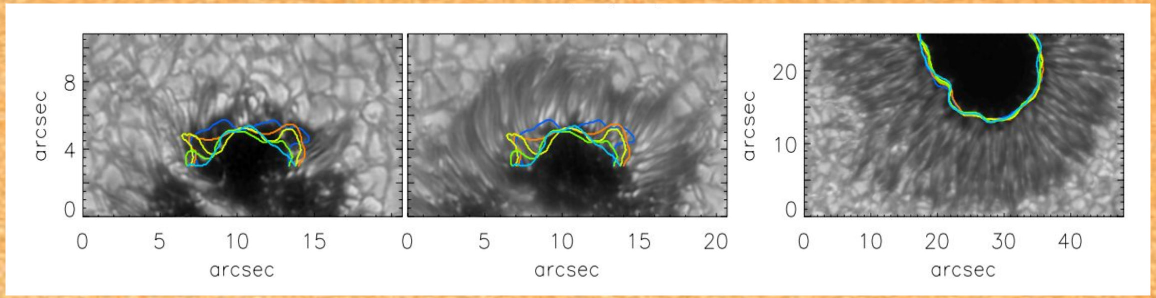
Marta García Rivas[1,2], Jan Jurčák[1], Nazaret Bello González[3]
[1]Astronomical Institute of the Czech Academy of Sciences, [2]Astronomical Institute of Charles University, [3]Leibniz-Institut für Sonnenphysik (KIS)

Abstract:
Analyses of the vector magnetic field on solar magnetic structures led to the Jurčák criterion, an empirical law that connects a critical value of the vertical component of the magnetic field to the umbral magnetoconvective mode in stable sunspots. We study the evolution of the vertical component of the magnetic field (B_{ver}) on evolving pores and the existence of an equivalent critical vertical magnetic value to provide steadiness. Indeed, we find that areas with weak B_{ver} are unstable and granulation takes over them. However, areas with strong B_{ver} show longer lifetimes.

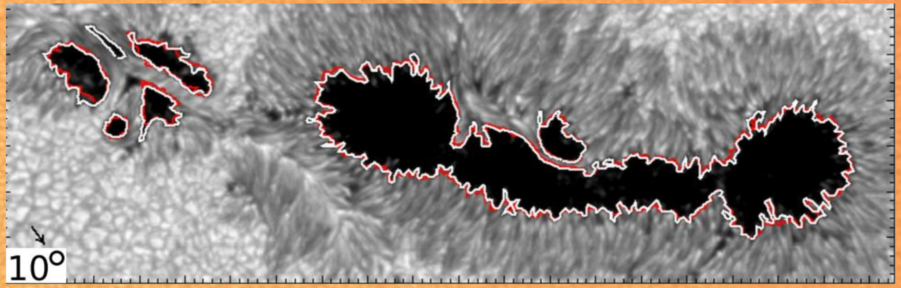
Context of the research

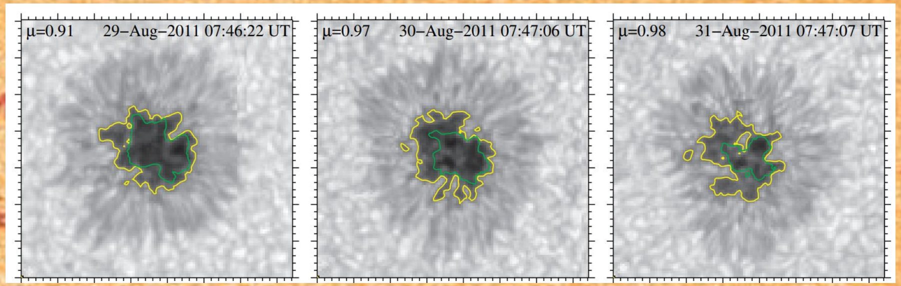
Jurčák criterion:
Empirical law that states that umbra-penumbra (U-P) boundaries of stable sunspots can be defined by a vertical magnetic field threshold, which matches the continuum intensity boundary. This criterion implies that in regions with $|B_{ver}| > B_{crit}$, umbral mode of convection prevails. On the other hand, regions with $|B_{ver}| < B_{crit}$ are unstable and prone to vanish against other modes of magneto-convection.

Formation of sunspots:
U-P boundary migrates towards the center of the umbra until it reaches a stable position. $|B_{ver}|$ on the boundary increases during the migration. until it stabilizes. I.e., penumbra invades umbral areas with weak $|B_{ver}|$.
E.g., Jurčák et al. (2015). *Fig:* Dark blue to light blue, variation of the UP boundary with time in forming (left and middle) and stable sunspots. .



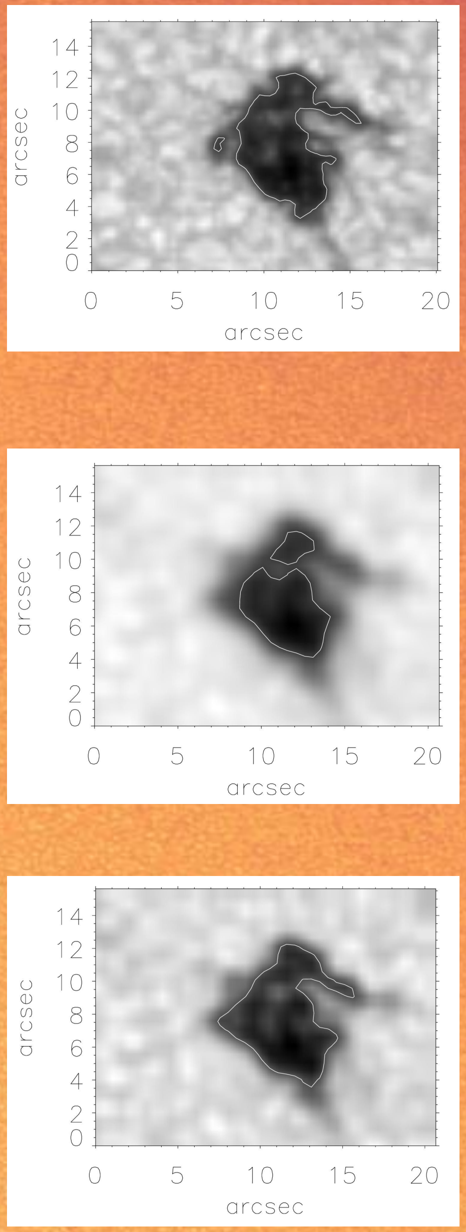
Stable sunspots:
U-P boundary fluctuates around a mean position due to the dynamical properties of penumbral filaments. $|B_{ver}|$, however, remains constant.
E.g., Jurčák (2011), Jurčák et al. (2018), Schmassmann et al. (2018), Lindner et al. (2020). *Fig:* Stable sunspot with intensity and magnetic contours. $I_c = 0.5\ I_{QS}$ in white. $B_{ver} = 1867$ G in red.





Decaying sunspots:
U-P boundary migrates towards the center of the umbra. In some cases $|B_{ver}|$ on the boundary decreases rapidly. In other cases, $|B_{ver}|$ varies slowly.
E.g., Benko et al. (2018), Löptien et al. (2020). *Fig:* Decaying sunspot with intensity and magnetic contours. $I_c = 0.5\ I_{QS}$ in yellow. $B_{ver} = 1867$ G in green.

Description of the work. Methodologies



Requirements:

- Infer vector magnetic field → Spectropolarimeter
- A homogeneous database → Space-based
- Study temporal evolutions → Temporal cadence smaller than lifetimes of pores
- Study boundary conditions → Medium to high spatial resolution

Selected data:

The Helioseismic and Magnetic Imager (HMI), onboard the Solar Dynamics Observatory (SDO) provides full disc Stokes parameters every 12 minutes. The regular spatial resolution of ~1" can be improved by correcting the data from scattered light, i.e., data are deconvolved using a HMI PSF model.

Therefore, we analyse **hmi.B_dconS** and **hmi.Ic_dconS** data series.

Methodology:

We retrieve photospheric vector field maps inferred using the Very Fast Inversion of Stokes Vector code (VFISV, Borrero et al. 2011) and disambiguate the azimuth with solutions computed by a minimum-energy method.

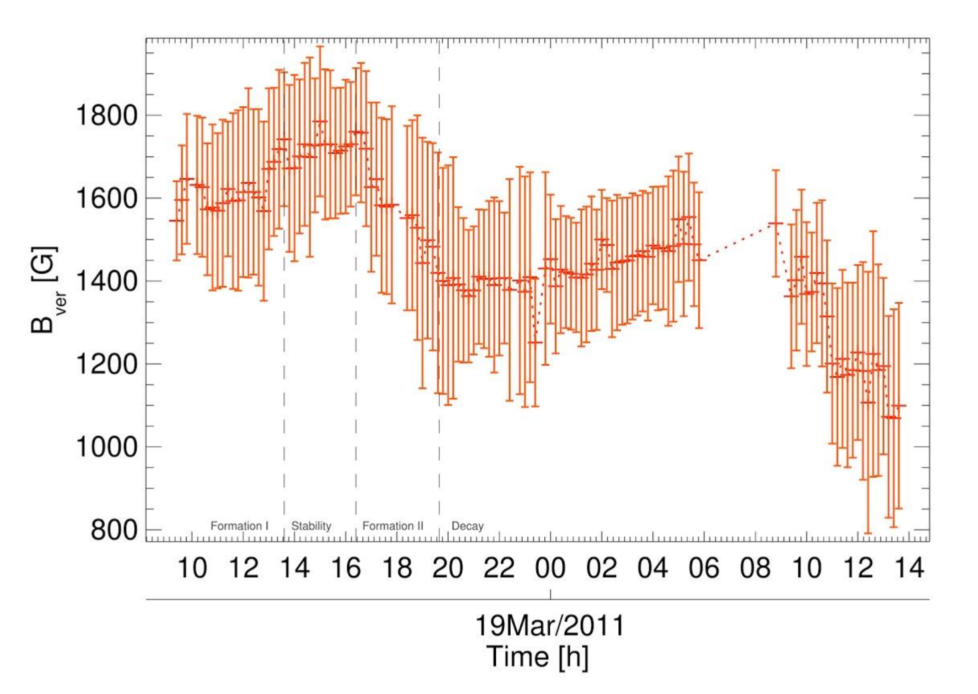
Vector field maps are analysed in a Local Reference Frame (LRF).

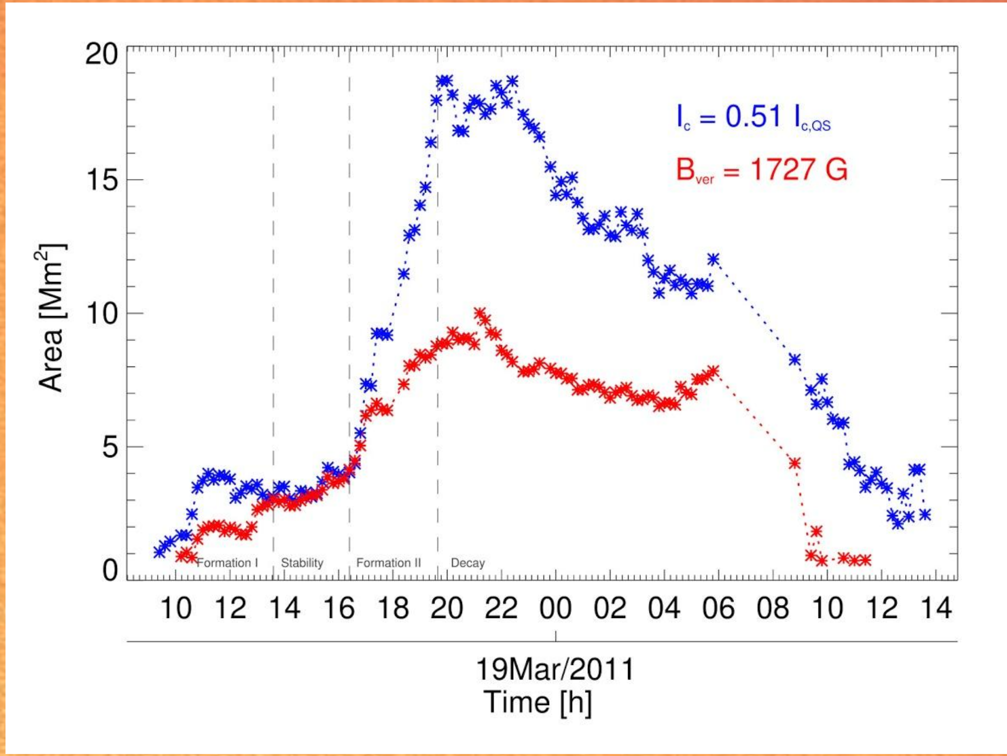
The boundary of a pore is defined by a continuum intensity threshold (0.51 I_{QS}) and magnetic properties are averaged along the isocontour.

Figure: Motivation to use HMI deconvolved data. Continuum intensity images of a pore that appeared on the solar surface the 18th March 2011. $I_C = 0.51\ I_{QS}$ contours in white. Top: Pore scanned at 19:48 UT with the spectropolarimeter onboard Hinode. Middle: Regular map of the pore observed with HMI at 19:45 UT. Bottom: Deconvolved map of the pore observed with HMI at 19:45 UT.

Results

The temporal evolution of the averaged vertical magnetic field (B_{ver}) along 0.51 I_{QS} contours during the lifetime of a pore shows the relationship between B_{ver} and the evolutionary stage. In the case study of the figure (pore in the active region NOAA 11175), the pore exhibits a **stable phase**. We consider the mean B_{ver} during the stability stage as a **pore's critical value** (B_{crit} = 1727 G in this case study).





The temporal evolution of the areas inside intensity and magnetic thresholds present different **stages** in this case study:

- *Formation I:* The pore grows and B_{ver} increases.
- *Stability*: The pore is shielded by a critical vertical magnetic field.
- *Formation II*: The pore grows steeply.
- *Decay*: The pore slowly decays, so does B_{ver}.

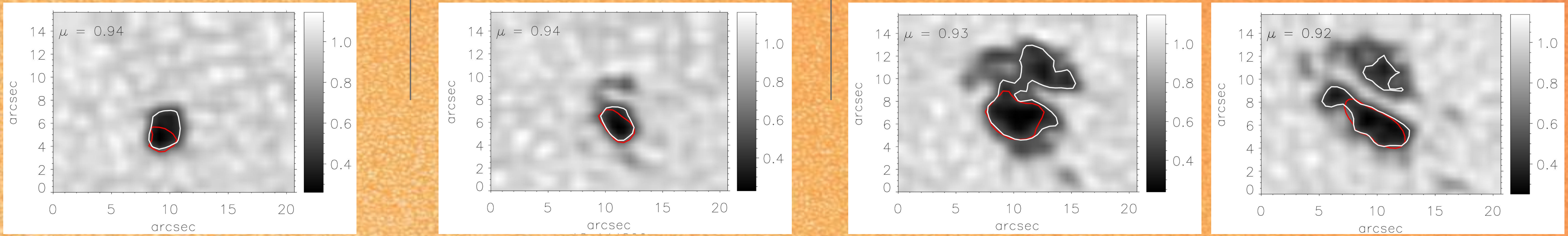
Results

The evolution of a pore depends on the strength of the magnetic field. We observe that pores with strong vertical magnetic fields are more stable and their lifetimes are longer.
The evolutionary stages of a pore can be described as follows:

Formation
The pore grows. B_{ver} on the boundary is weak but it tends to strengthen with time. Next stage depends on how strong B_{ver} gets, i.e., if it reaches a B_{crit}.

Stability
The boundary of a pore is defined by a critical vertical magnetic field. B_{crit} shields the pore against granulation.

Decay
Regions of a pore with weak B_{ver} disappear from the solar surface in a shorter time interval than regions with B_{ver} > B_{crit}.
Light bridges divide pores only in regions with B_{ver} < B_{crit}.



18-Mar-2011 11:12 UT — 18-Mar-2011 14:48 UT — 18-Mar-2011 23:12 UT — 19-Mar-2011 03:36 UT

Figure: Continuum intensity maps of an evolving pore in the active region NOAA 11175. In white, $I_c = 0.51\ I_{QS}$. In red, B_{ver}= 1727 G.

Impact and prospects for the future

- We are working on expanding the pores sample and creating a proper statistical analysis in order to:
    - Find whether it exists a critical vertical magnetic field that makes umbral magneto-convection to prevail in any type of pore against granulation.
    - Characterize the intrinsic properties of different types of pores (small pores, large pores, pores that develop a penumbra, sunspots that lose penumbra)
    - Find a possible relationship between the vertical magnetic field and the lifetime of the pores.
    - Study the influence of the magnetic properties on the different stages of the evolution of the pores.

- We aim to characterise the different evolutionary stages of pores (formation, stability and decay) to properly identify and catalogue them, and derive the fundamental physics operating in this mode of magneto-convection. Such magnetic structures are highly dynamic and they cannot be described by a one-time observation.