The Nature and Physics of Vortex Flows in Solar Plasmas

ISSI International Team, K. Tziotziou and E. Scullion conveners

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Non-magnetic bright points as a manifestation of vortex flows

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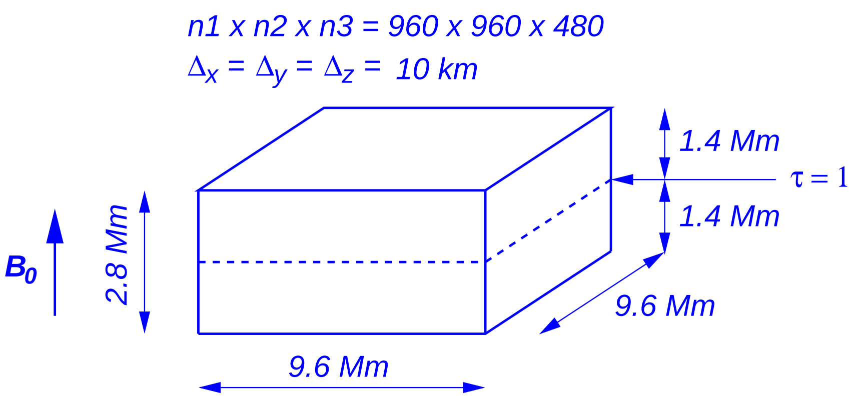
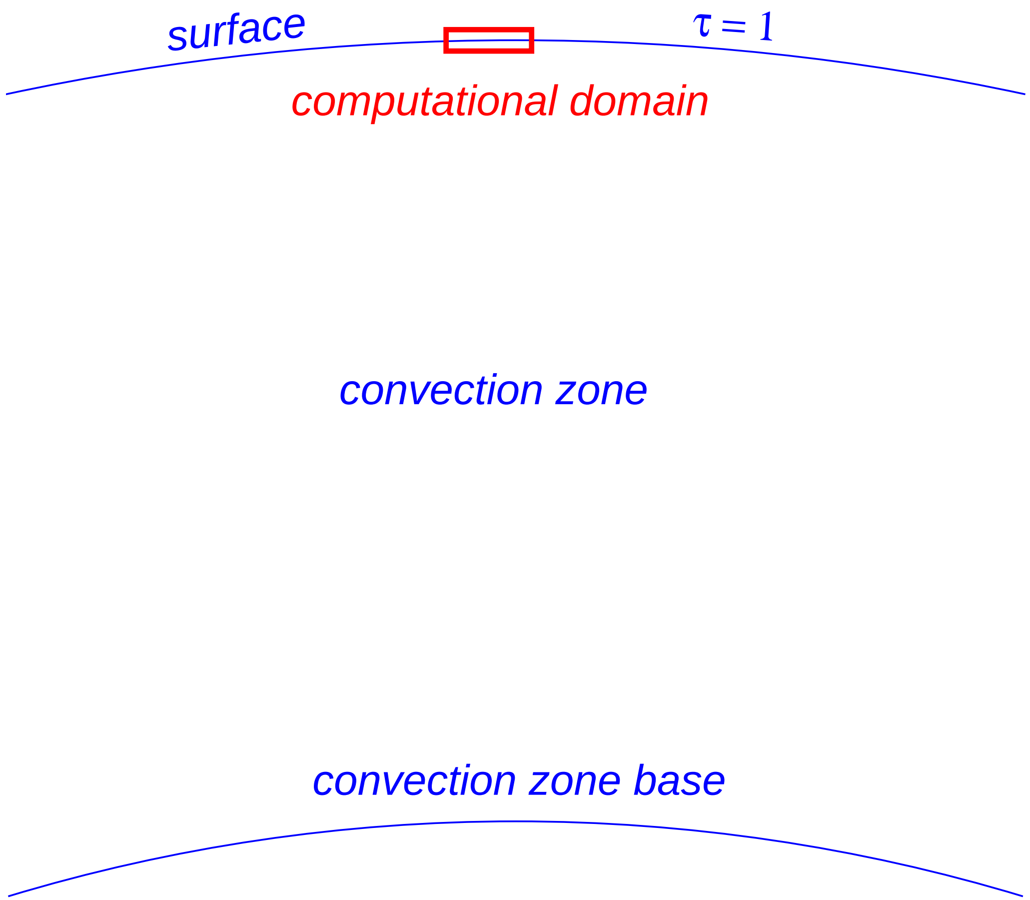
[a] via zoom teleconference

1. Non-magnetic bright points

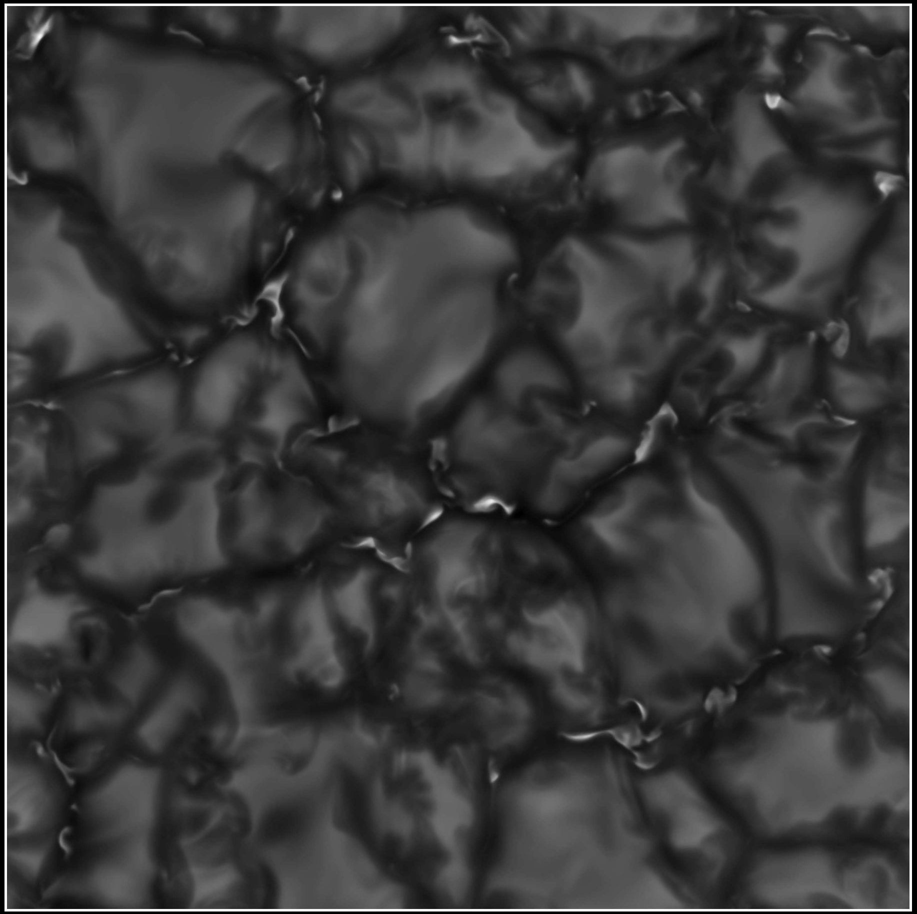


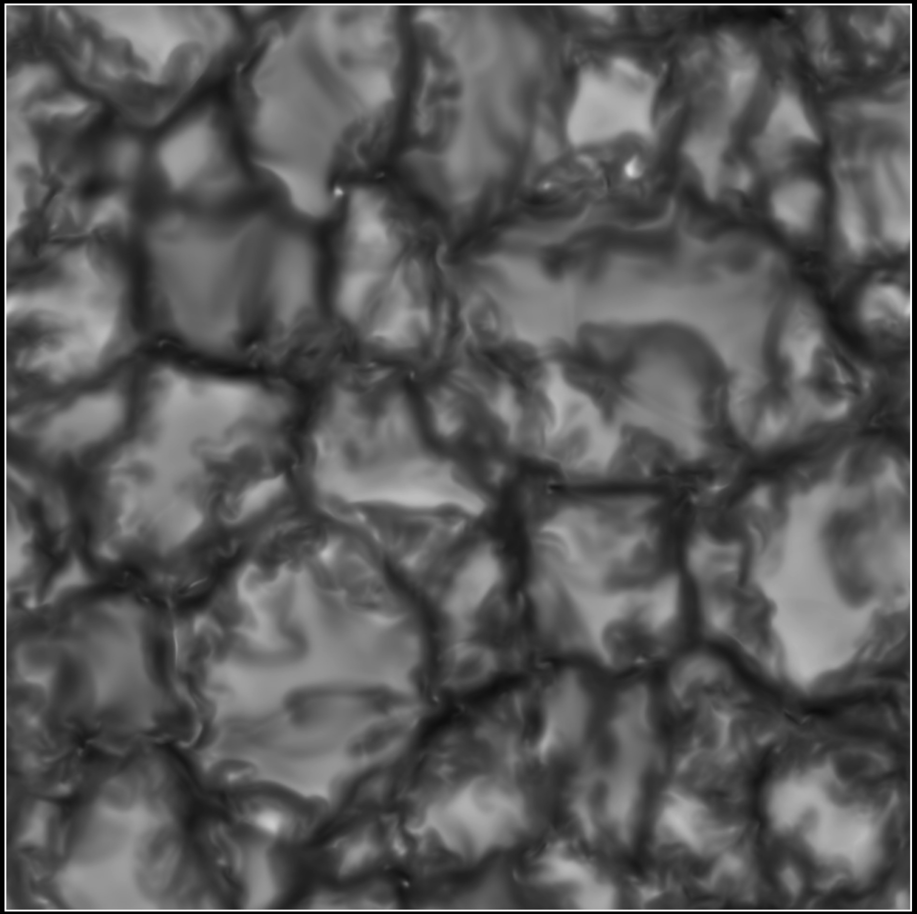


Size of a typical three-dimensional computational domain (left) in comparison with the size of the Sun (right).

magnetic vs. non-magnetic bright points

Bolometric intensity maps





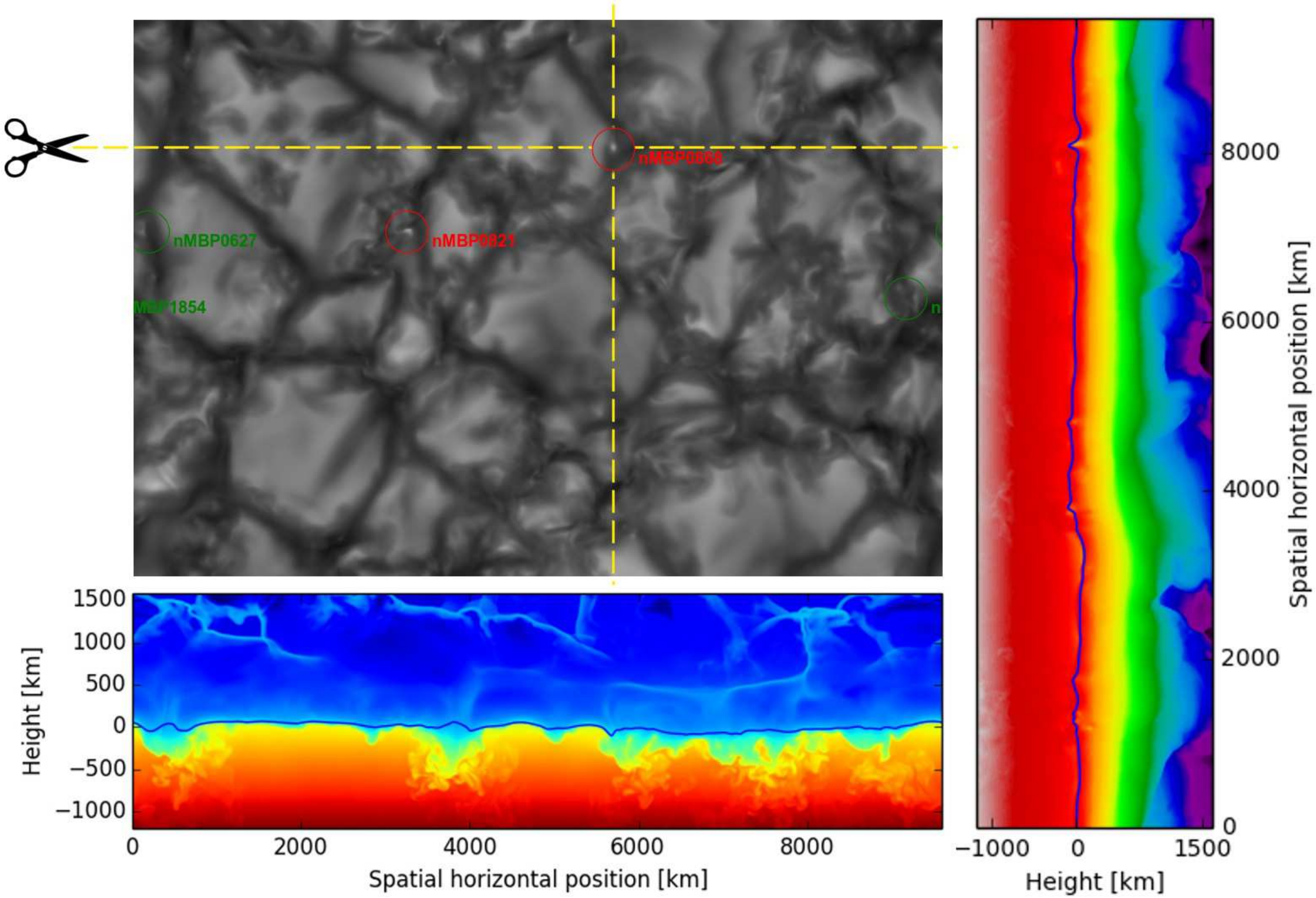
Computations: *Centro Svizzero di Calcolo Scientifico*

With magnetic fields:
Magnetohydrodynamic simulation.

Without magnetic fields:
Hydrodynamic simulation

Courtesy, *F. Calvo*.

Slices across a non-magnetic bright point (nMBP0868)

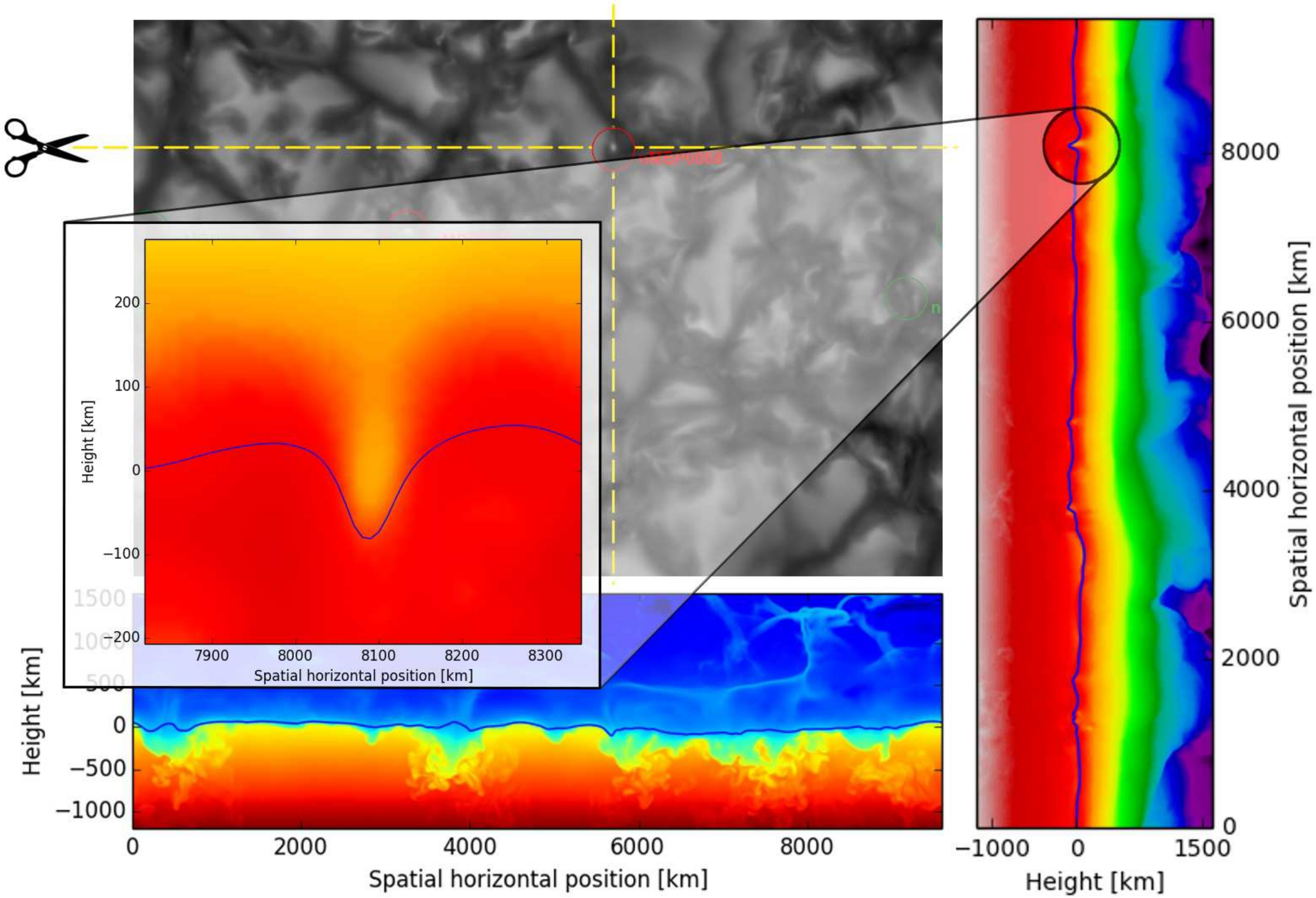


Courtesy, *F. Calvo, IRSOL.*

Emergent intensity I (*top left*), temperature T (*bottom*), density $\log(\rho)$ (*right*)

1. Non-magnetic bright points (cont.)

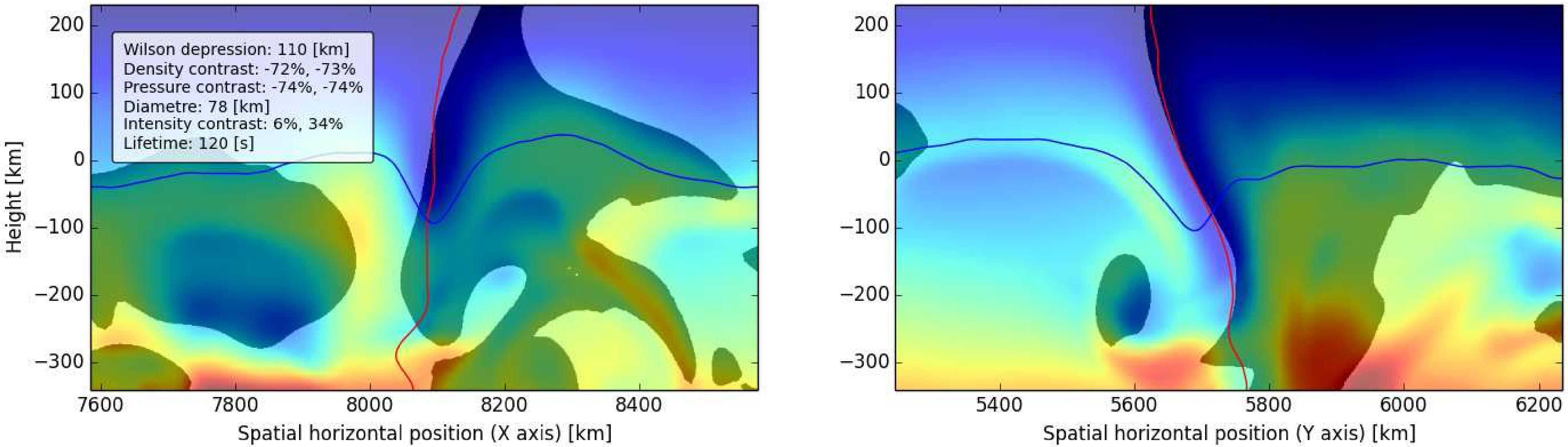
Slices across a non-magnetic bright point (nMBP0868)



Courtesy, *F. Calvo, IRSOL.*

Emergent intensity I (*top left*), temperature T (*bottom*), density $\log(\rho)$ (*right*)

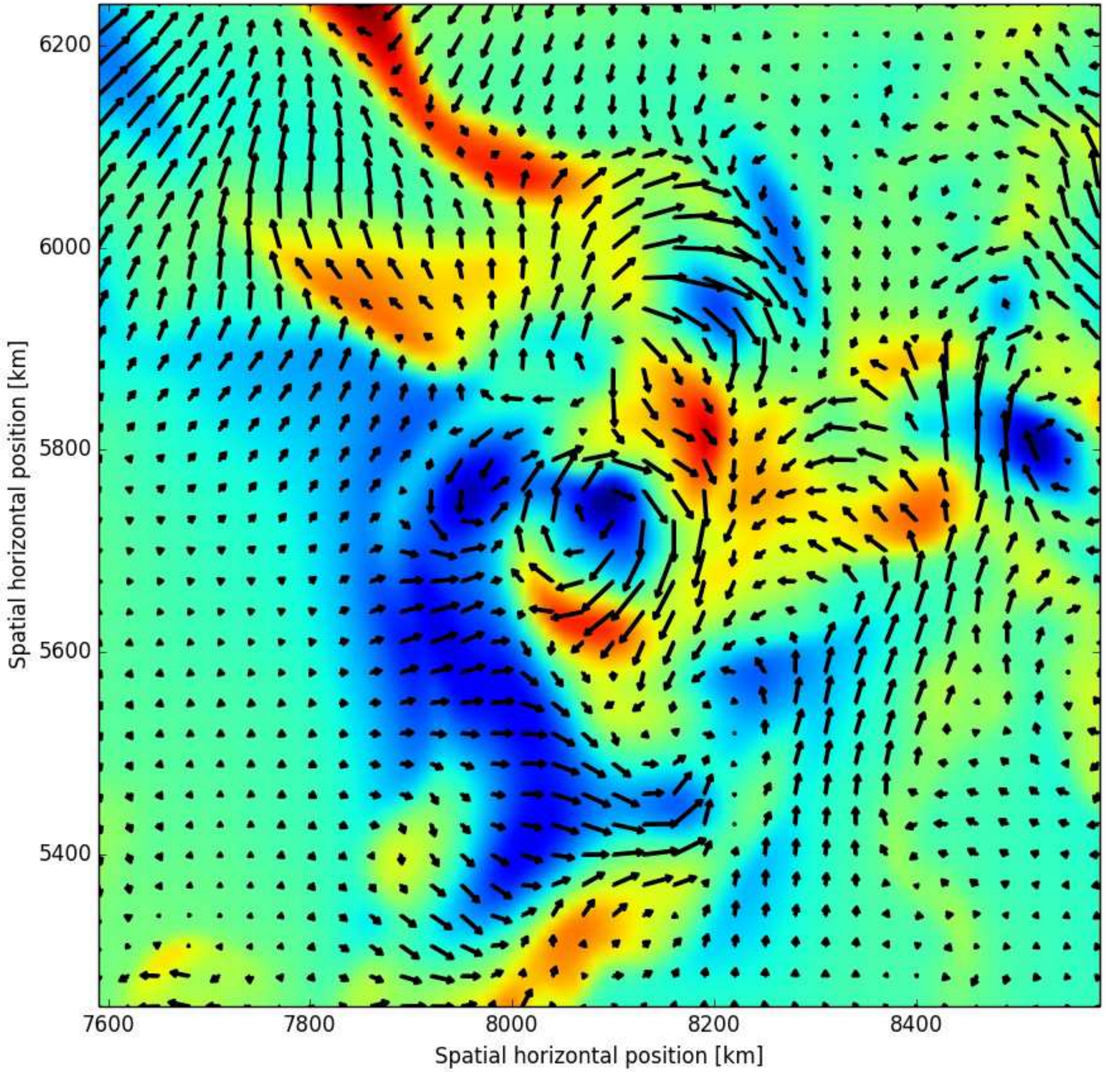
Slices across a non-magnetic bright point (nMBP0868).



From *F. Calvo et al. 2016*.

- Surface of optical depth $\tau = 1$: *blue contour*
- Local density minimum: *red curve*
- Density: background *colors*; low (blue) to high (red)
- Velocity: *shadows*; light is out of the sectional plane, dark is into it

1. Non-magnetic bright points (cont.)



non-magnetic bright points (nMBPs) are locations with:

- *swirling motion* (but ≈ 150 [km] below $\tau = 1$ there are often swirls that do not produce nMBPs);
- *low density* (but a density deficiency alone does not warrant nMBP's);
- *high intensity contrast* (but a local intensity peak does not need to be a nMBP).

Density (blue: low, red: high) and velocity field in an horizontal plane, 150 [km] below $\langle\tau\rangle = 1$

From *F. Calvo et al. 2016*.

Statistical properties from 256 non-magnetic bright points:

diameter [km] (intensity FWHM)	intensity contrast local [%]	global [%]	mass density contrast [%]	Wilson depression [km]
40 ± 10	20 ± 10	2.3 ± 9	58 ± 10	103 ± 32

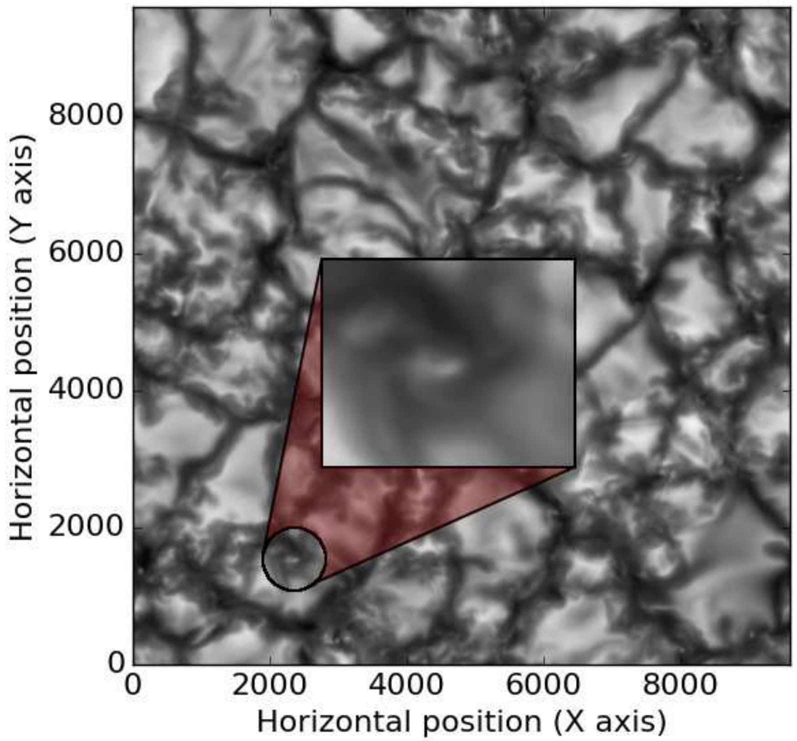
Adapted from *F. Calvo et al. 2016*.

in comparison with properties of magnetic bright points:

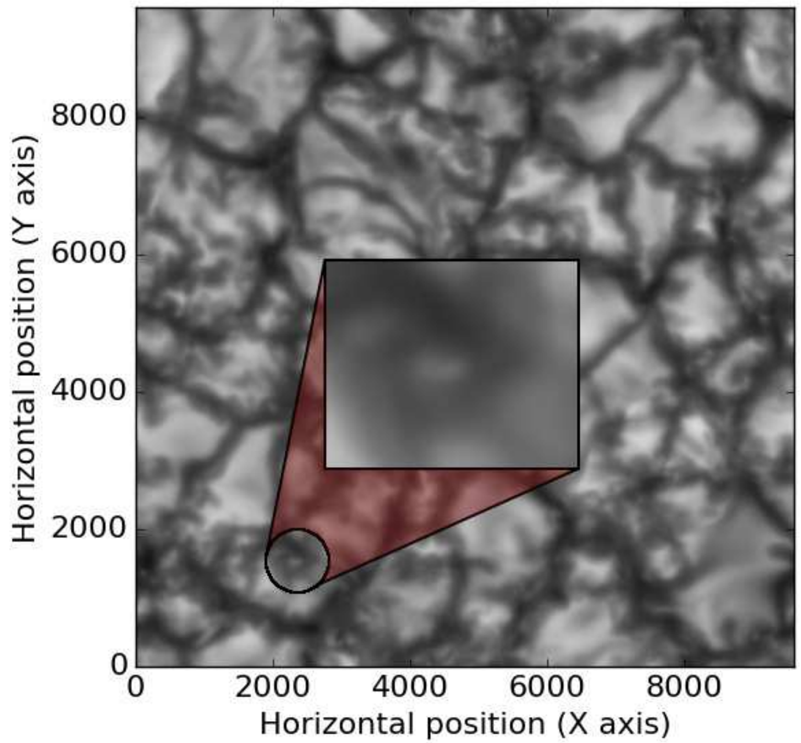
diameter [km] (intensity FWHM)	intensity contrast local [%]	global [%]	mass density contrast [%]	Wilson depression [km]
100 ± 300	≈ 37	≈ 11	—	≈ 150

Data from *Wiehr, E.: 2004, A&A 422,63; Rietmüller et al.: 2010, ApJ 723, L169, Salhab et al.: 2018, A&A 614, A78*.

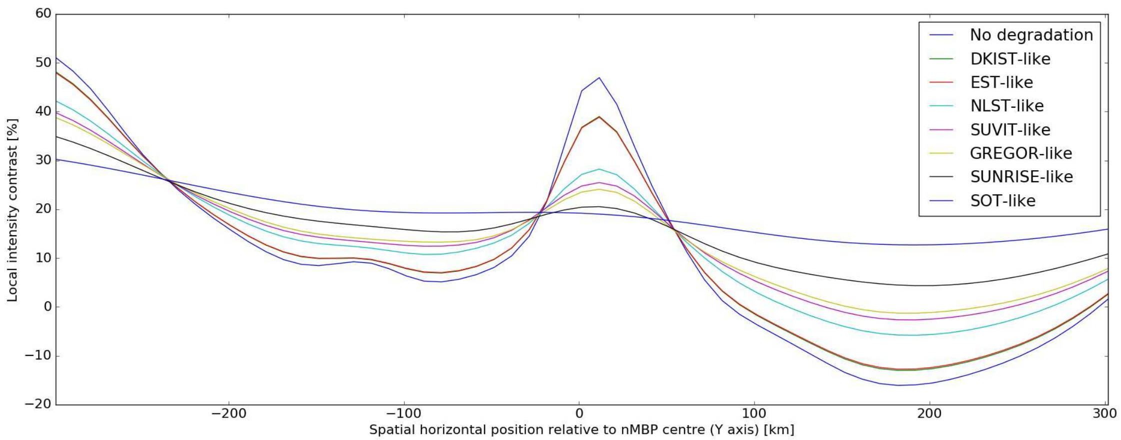
1. Non-magnetic bright points (cont.) Application of various PSFs



full resolution



Gregor resolution



Intensity contrast across a non-magnetig bright point as observed with different telescopes.

From *Calvo et al. (2016)*.

2. Reduction to an analytical toy model

Starting from the momentum equation

$$\frac{\partial \boldsymbol{v}}{\partial t} + (\boldsymbol{v} \cdot \boldsymbol{\nabla})\, \boldsymbol{v} + \frac{1}{\rho} \boldsymbol{\nabla} P + \boldsymbol{g} = 0\,,$$

we assume

1. nMBPs are long-lived and stable so that the velocity field can be considered stationary;
2. They have cylindrical symmetry;
3. Their velocity field has a non-vanishing azimuthal component;
4. They extend in the vertical direction and their shape does not depend on depth.

Because of 2., the Euler momentum equation can be written in cylindrical coordinates.

2. Reduction to an analytical toy model (cont.)

The advection term is then given by

$$(\boldsymbol{v}\cdot\boldsymbol{\nabla})\boldsymbol{v} = \left[(\boldsymbol{v}\cdot\boldsymbol{\nabla})v_r - \frac{v_\theta^2}{r}\right]\hat{\boldsymbol{r}} + \left[(\boldsymbol{v}\cdot\boldsymbol{\nabla})v_\theta + \frac{v_\theta v_r}{r}\right]\hat{\boldsymbol{\theta}} + (\boldsymbol{v}\cdot\boldsymbol{\nabla})v_z\hat{\boldsymbol{z}}\,,$$

where the directional derivative is

$$\boldsymbol{v}\cdot\boldsymbol{\nabla} = v_r\partial_r + \frac{v_\theta}{r}\partial_\theta + v_z\partial_z\,.$$

The simplest field satisfying the conditions 1–4 is $\boldsymbol{v} = v_\theta\,(r)\,\hat{\boldsymbol{\theta}}$. Inserting it into the Euler momentum equation and projecting it into the horizontal plane yields

$$\frac{1}{\rho}\frac{\partial P}{\partial r} = \frac{v_\theta^2}{r}\,.$$

The pressure gradient is provided by the centripetal force.

One can then estimate the magnitude of v_θ. With

$$\frac{P_\mathrm{ext} - P_\mathrm{int}}{\rho_\mathrm{ext}} \approx v_\theta^2 \, , \qquad \frac{\rho_\mathrm{int} - \rho_\mathrm{ext}}{\rho_\mathrm{ext}} \equiv C_\rho \, , \quad \frac{T_\mathrm{int} - T_\mathrm{ext}}{T_\mathrm{ext}} \equiv C_T \, ,$$

$$\frac{P_\mathrm{ext}}{\rho_\mathrm{ext}} \approx R_\mathrm{s} \, T_\mathrm{ext} \, , \qquad T_\mathrm{ext} \approx T_\mathrm{eff} \, ,$$

one obtains with $C_\rho \approx -0.5$ and $C_T \approx 0$

$$v_\theta = \sqrt{R_\mathrm{s} \, T_\mathrm{eff} \, [1 - (1 + C_\rho)(1 + C_T)]} \approx \sqrt{\frac{R_\mathrm{s} \, T_\mathrm{eff}}{2}} = 4.4 \, \mathrm{km\,s}^{-1} \, ,$$

while the maximum azimuthal velocities in the simulation are $v_\theta^\mathrm{max} \approx 6 \, \mathrm{kms}^{-1}$.

Table of content

References

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