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Non-magnetic bright points as a manifestation of vortex flows

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\textsuperscript{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).
1. Non-magnetic bright points (cont.)

Bolometric intensity maps

With magnetic fields:
Magnetohydrodynamic simulation.

Without magnetic fields:
Hydrodynamic simulation

Courtesy, F. Calvo.

Computations: Centro Svizzero di Calcolo Scientifico
1. Non-magnetic bright points (cont.)

Slices across a non-magnetic bright point (nMBP0868)

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

Courtesy, F. Calvo, IRSOL.
1. Non-magnetic bright points (cont.)

Slices across a non-magnetic bright point (nMBP0868)

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

Courtesy, F. Calvo, IRSOL.
1. Non-magnetic bright points (cont.)

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

- 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

From F. Calvo et al. 2016.
1. Non-magnetic bright points (cont.)

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

- **swirling motion** (but approximately 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.*
1. Non-magnetic bright points (cont.)

Statistical properties from 256 non-magnetic bright points:

<table>
<thead>
<tr>
<th>diameter [km] (intensity FWHM)</th>
<th>intensity contrast</th>
<th>mass density contrast [%]</th>
<th>Wilson depression [km]</th>
</tr>
</thead>
<tbody>
<tr>
<td>40 ± 10</td>
<td>20 ± 10</td>
<td>58 ± 10</td>
<td>103 ± 32</td>
</tr>
</tbody>
</table>

Adapted from F. Calvo et al. 2016.

in comparison with properties of magnetic bright points:

<table>
<thead>
<tr>
<th>diameter [km] (intensity FWHM)</th>
<th>intensity contrast</th>
<th>mass density contrast [%]</th>
<th>Wilson depression [km]</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 ± 300</td>
<td>≈ 37</td>
<td>—</td>
<td>≈ 150</td>
</tr>
</tbody>
</table>

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

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

From Calvo et al. (2016).
2. Reduction to an analytical toy model

Starting from the momentum equation

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

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.
The advection term is then given by

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

where the directional derivative is

\[\mathbf{v} \cdot \nabla = v_r \partial_r + \frac{v_\theta}{r} \partial_\theta + v_z \partial_z.\]

The simplest field satisfying the conditions 1–4 is \(\mathbf{v} = v_\theta (r) \hat{\theta}\). 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.
2. Reduction to an analytical toy model (cont.)

One can then estimate the magnitude of $v_\theta$. With

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

$$\frac{P_{\text{ext}}}{\rho_{\text{ext}}} \approx R_s T_{\text{ext}}, \quad T_{\text{ext}} \approx T_{\text{eff}},$$

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

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

while the maximum azimuthal velocities in the simulation are $v_{\theta \text{ max}} \approx 6 \text{ km s}^{-1}$. 
Table of content

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2. Reduction to an analytical toy model

References
References

Calvo, F., Steiner, O., & Freytag, B.: 2016, Non-magnetic photospheric bright points in 3D simulations of the solar atmosphere, A&A 596, A43


Salhab, R.G., Steiner, O., Berdyugina, S.V.: 2017, Simulation of the small-scale magnetism in main sequence stellar atmospheres, A&A 614, A78