Non-magnetic bright points in 3D simulations of the solar atmosphere

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and the CO^{5}BOLD group

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One Sun, two approaches

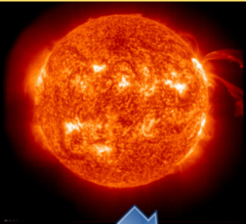
$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{v}) = 0,$$

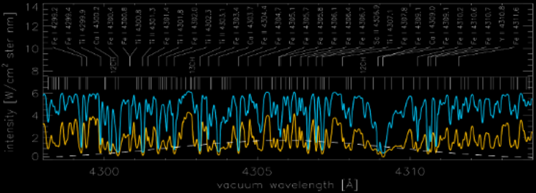
$$\frac{\partial (\rho \mathbf{v})}{\partial t} + \nabla \cdot \left(\rho \mathbf{v}\mathbf{v} + \left(P + \frac{\mathbf{B}\cdot\mathbf{B}}{2} \right) \mathbf{I} - \mathbf{B}\mathbf{B} \right) = \rho \mathbf{g},$$

$$\frac{\partial \mathbf{B}}{\partial t} + \nabla \cdot (\mathbf{v}\mathbf{B} - \mathbf{B}\mathbf{v}) = 0,$$

$$\frac{\partial (\rho e_{\mathrm{tot}})}{\partial t} + \nabla \cdot \left(\left(\rho e_{\mathrm{tot}} + P + \frac{\mathbf{B}\mathbf{B}}{2} \right) \mathbf{v} - (\mathbf{v}\cdot\mathbf{B})\,\mathbf{B} + \mathbf{F}_{\mathrm{rad}} \right) = 0,$$

$$+ \text{ radiative transfer : } \frac{\mathrm{d}}{\mathrm{d}s}\mathbf{I}(s) = -\mathbf{K}(s)\mathbf{I}(s) + \varepsilon(s).$$





Ideal MHD and RT equations

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

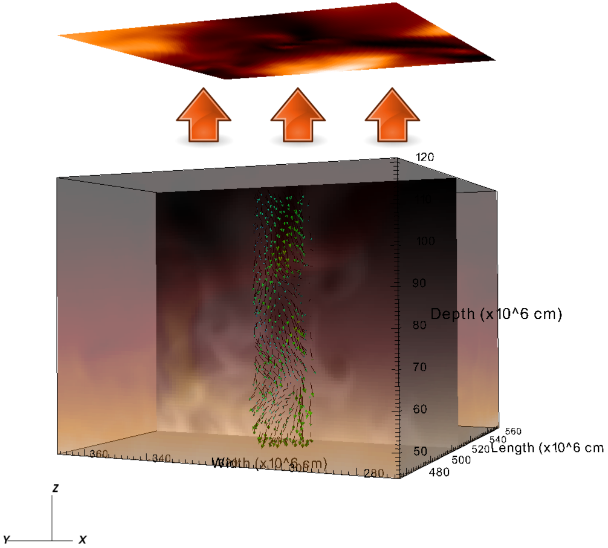
$$\frac{\partial (\rho \mathbf{v})}{\partial t} + \nabla \cdot \left(\rho \mathbf{v}\mathbf{v} + \left(P + \frac{\mathbf{B} \cdot \mathbf{B}}{2} \right) \mathbf{I} - \mathbf{B}\mathbf{B} \right) = \rho \mathbf{g},$$

$$\frac{\partial \mathbf{B}}{\partial t} + \nabla \cdot (\mathbf{v}\mathbf{B} - \mathbf{B}\mathbf{v}) = 0,$$

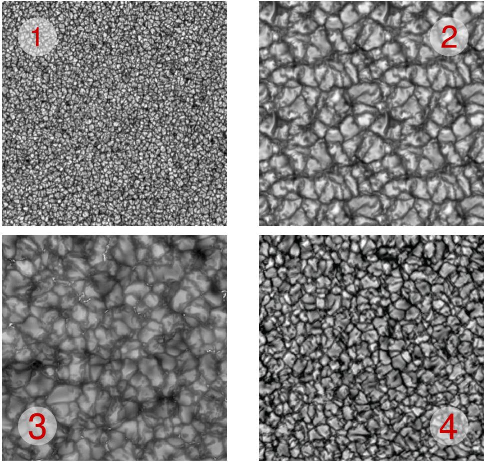
$$\frac{\partial (\rho e_{\mathrm{tot}})}{\partial t} + \nabla \cdot \left(\left(\rho e_{\mathrm{tot}} + P + \frac{\mathbf{B} \cdot \mathbf{B}}{2} \right) \mathbf{v} - (\mathbf{v} \cdot \mathbf{B})\,\mathbf{B} + \mathbf{F}_{\mathrm{rad}} \right) = 0$$

$$+ \text{ radiative transfer : } \tfrac{\mathrm{d}}{\mathrm{d}s}\mathbf{I}(s) = -\mathbf{K}(s)\mathbf{I}(s) + \varepsilon(s)$$

Radiative transfer: back to 2D images from 3D boxes (post-processing)



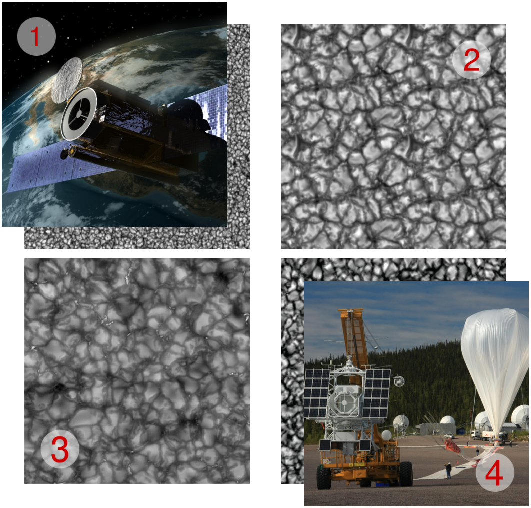
Models and reality : spot the odd one out!



One of these images is a simulation from CSCS. . . which one?

Models and reality : spot the odd one out!

Hinode

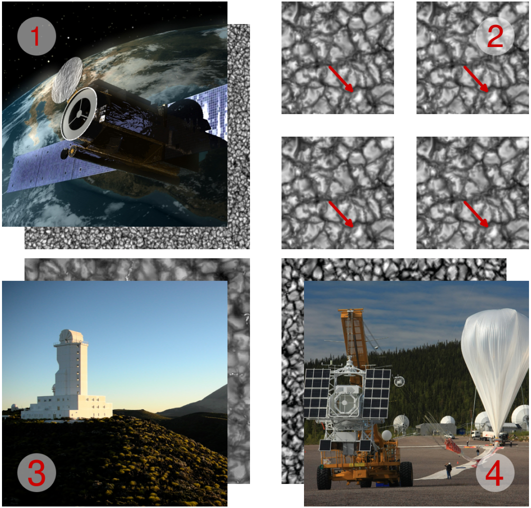


Sunrise

One of these images is a simulation from CSCS. . . which one?

Models and reality : spot the odd one out!

Hinode



Rothorn (CSCS)

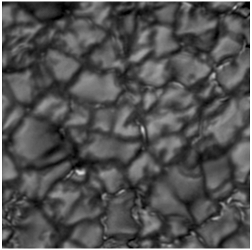
VTT

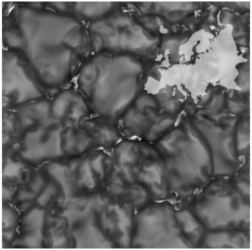
Sunrise

Look carefully at the second image: it cannot possibly be real. Why?

Models and reality at the same scale

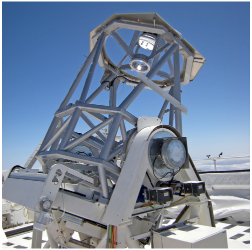
Real image





Simulation

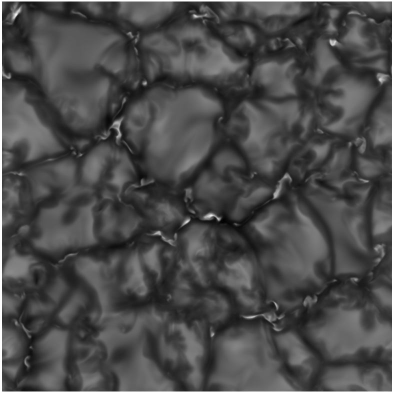
GREGOR@
Tenerife



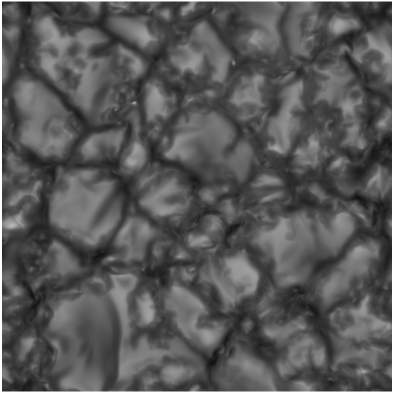
Rothorn@
CSCS

Magnetic and non-magnetic models

White spots emerge from magnetic field concentrations in inter-granular lanes.



Magnetic model

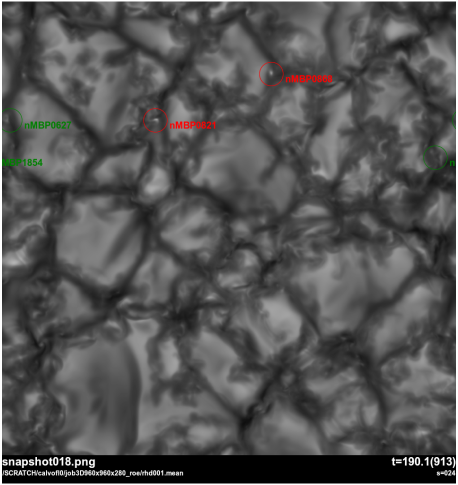


Non-magnetic model

Similar *smaller* white dots have drawn our attention in *non-magnetic* models. Where are they coming from?

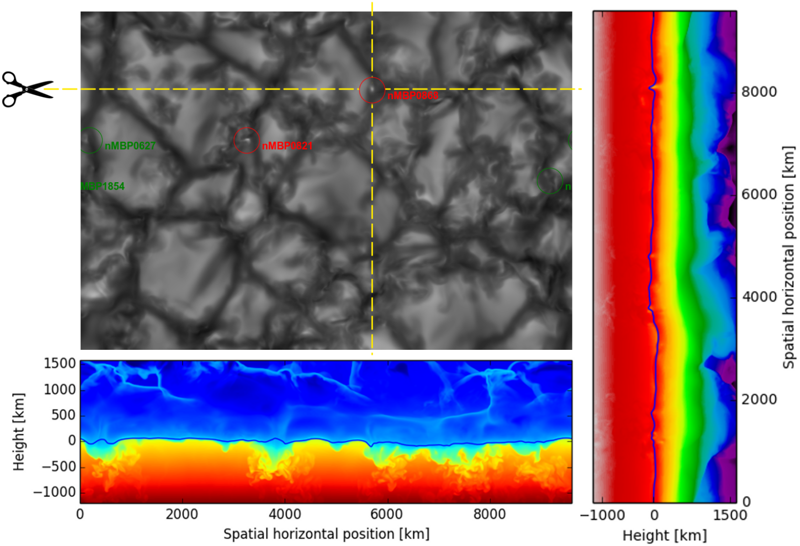
Non-magnetic bright points

Let's have a look at nMBP0868.



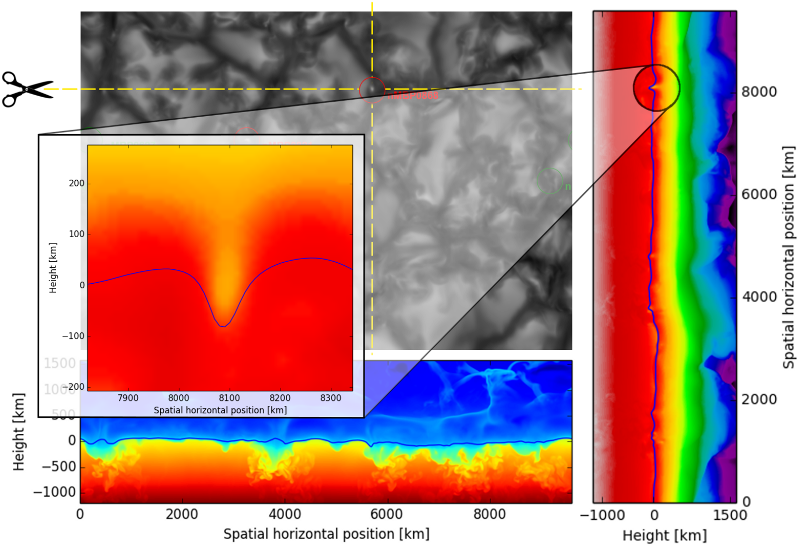
Why is it brighter than its neighbourhood?

Slice across nMBP0868



Emergent intensity (top left), temperature (bottom), log(rho) (right)

Slice across nMBP0868

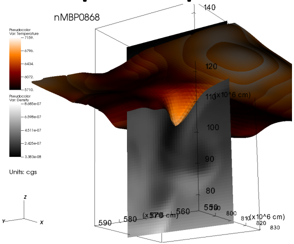


Emergent intensity (top left), temperature (bottom), log(rho) (right)

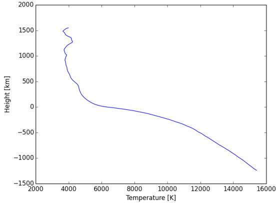
Bolometric emerging intensity

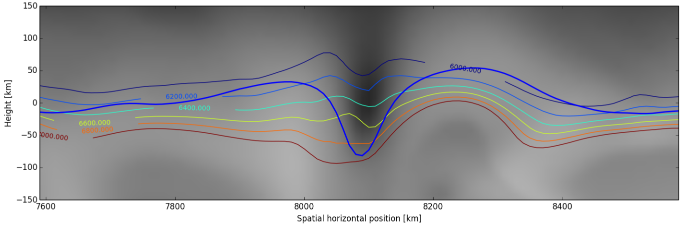
To understand all these contrasts, we have two ingredients:

Optical depth



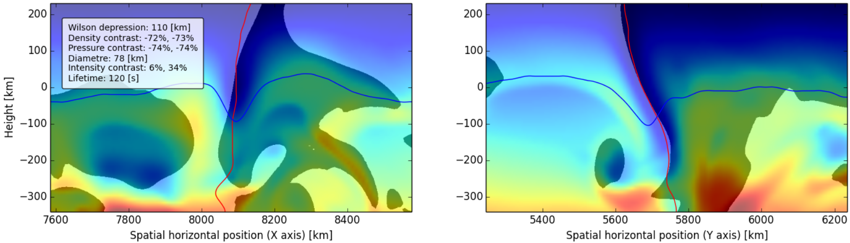
Temperature





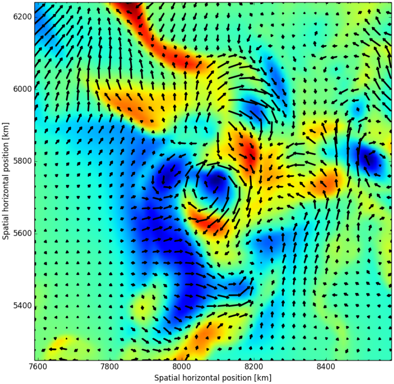
Thick blue: isosurface at $\tau = 1$. Contours: temperature in [K].

Slice across nMBP0868



- Constant optical depth $\tau = 1$: *blue line*
- Minimum density: *red line*
- Density: background color, low (blue) to high (red)
- Velocity: shadows, light is out of the screen, dark is in the screen

nMBP's ontology

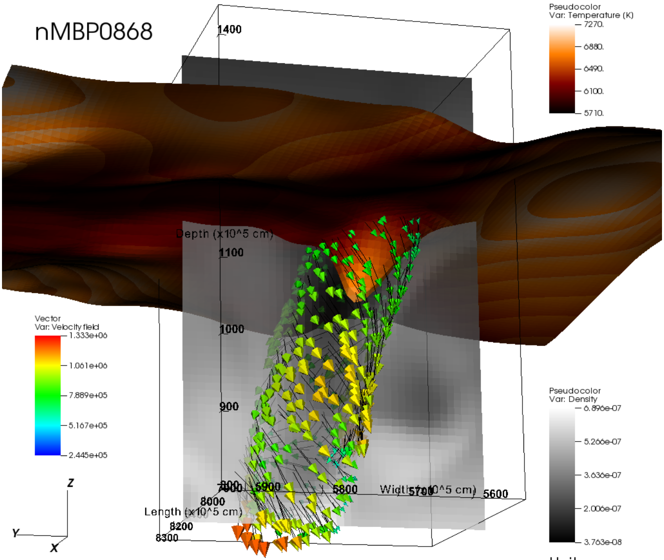


Density (blue: low, red: high) and velocity field in an horizontal plane, 150 [km] below $\langle \tau \rangle = 1$

nMBP's are regions with:

- swirls, but about 150 [km] below $\tau = 1$ there are many swirls that do not produce nMBP's
- low density, but there are also many of those regions which do not produce nMBP's
- high contrast in emergent intensity, but again, not all structures with high contrast and similar size are nMBP's!

Slice across nMBP0868



Units: cgs

Conclusions

- Non-magnetic bright points appear spontaneously in inter-granular lanes
- Cool plasma falling inside inter-granular lanes starts swirling faster and faster just as a skater brings his arms along his body

Stéphane Lambiel (Source : http://www.zimbio.com/photos/Stephane+Lambiel/**)**

Water swirl (Source : http://www.neatologie.com/water-sculptures/**)**

- This is similar to the bathtub effect: water swirls and in the "eye" of the swirl pressure and density are lower

A simple model

The Navier-Stokes equation is the non-conservative form is given by:

$$\underbrace{\frac{\partial \mathbf{v}}{\partial t}}_{\text{Field dynamics}} + \underbrace{(\mathbf{v}\cdot\nabla)\mathbf{v}}_{\text{Advection}} + \underbrace{\frac{1}{\rho}\nabla P}_{\text{Gradient pressure}} + \underbrace{\mathbf{g}}_{\text{Gravity}} = 0.$$

In cylindrical coordinates, the advection term reads:

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

Assume a stationary field $\mathbf{v} = v_\theta\hat{\theta}$ and $\nabla P = (\partial_r P)\hat{\mathbf{r}} + (\partial_z P)\hat{\mathbf{z}}$:

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

Opened questions

- Are there really such bright points in the Sun? The new generation of telecopes will tell us...
- Can one have both magnetic and non-magnetic bright points?
- What if a huge concentration of magnetic field lines was trapped in a tornado?