3-D radiation magnetohydrodynamics simulations of the near surface layers of the Sun

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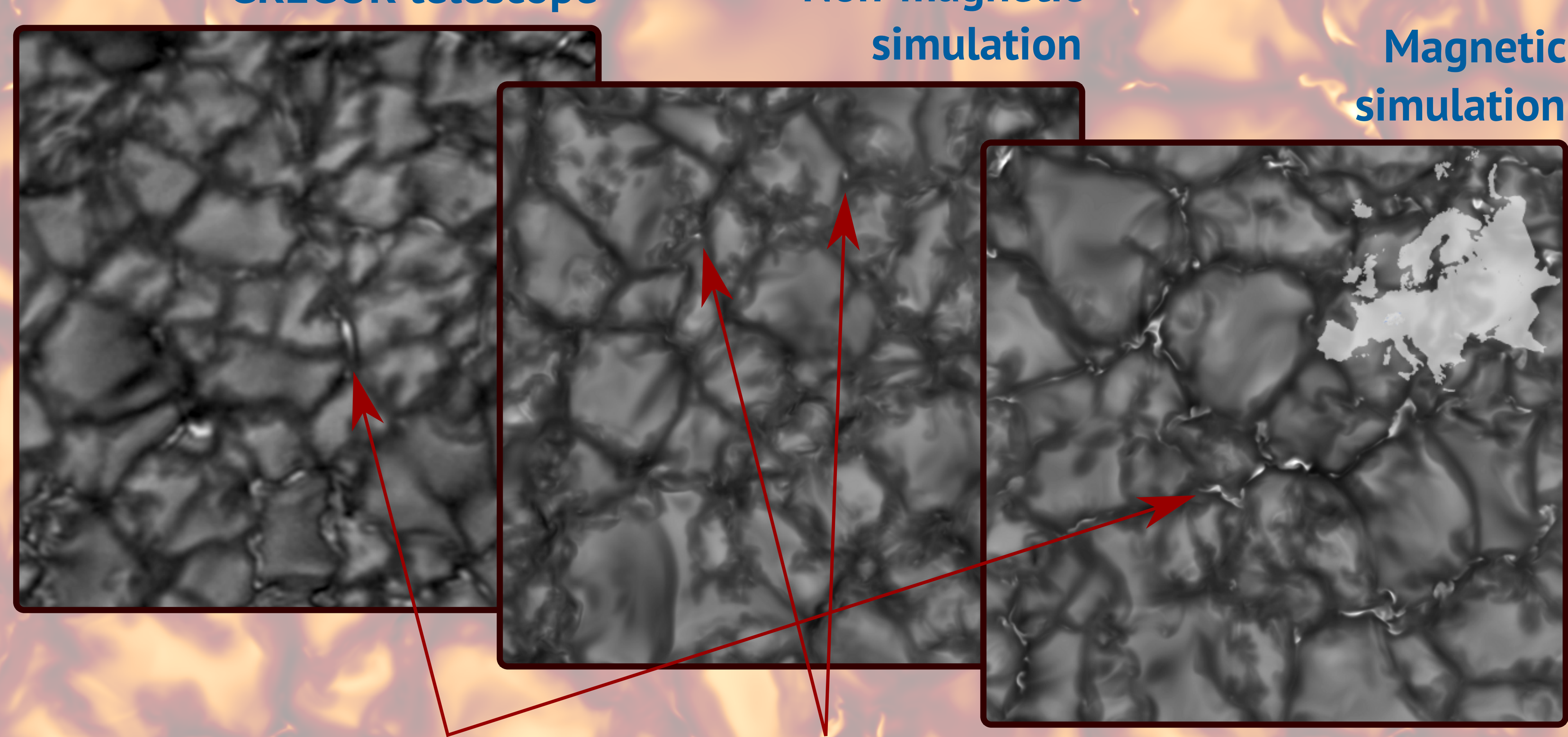
We carry out numerical radiation magnetohydrodynamics simulations of the near surface layers of the Sun using the facilities at CSCS. The simulations reproduce the well known granular structure of the solar surface with excellent fidelity. Simulations with magnetic fields also reproduce magnetic bright points in the intergranular space as is observed on the Sun. Simulations without magnetic fields show tinier non-magnetic bright points, which have not been observationally detected so far but our simulations predict their existence and basic physical properties of them. The simulated model atmospheres also serve for the computation of synthetic polarimetric and intensity maps.

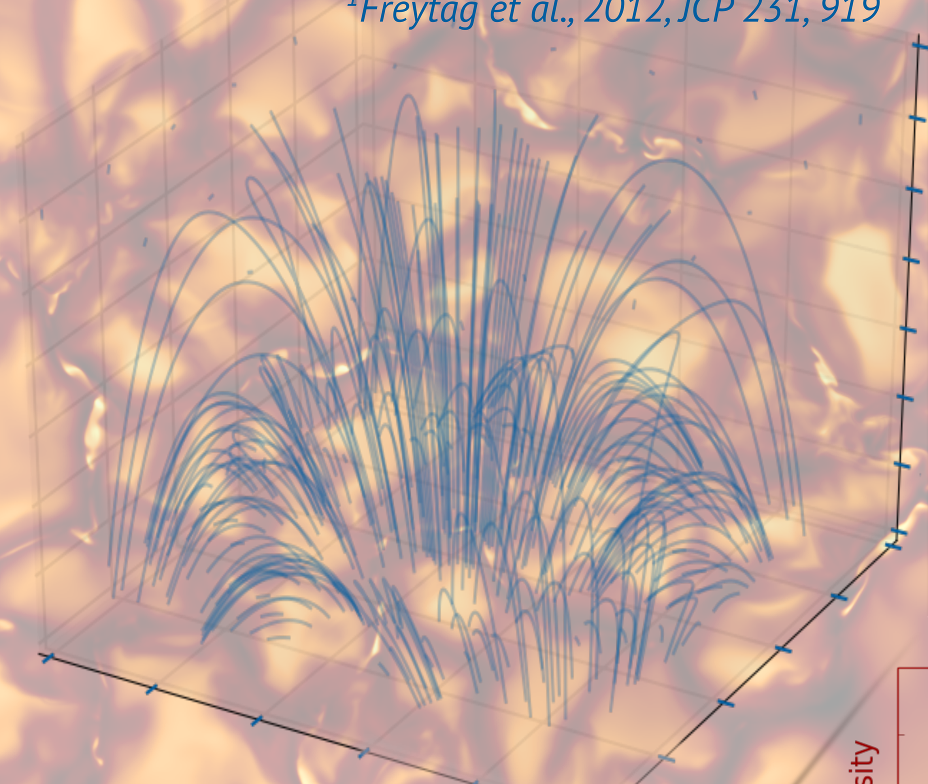
Radiation Magnetohydrodynamics (MHD)



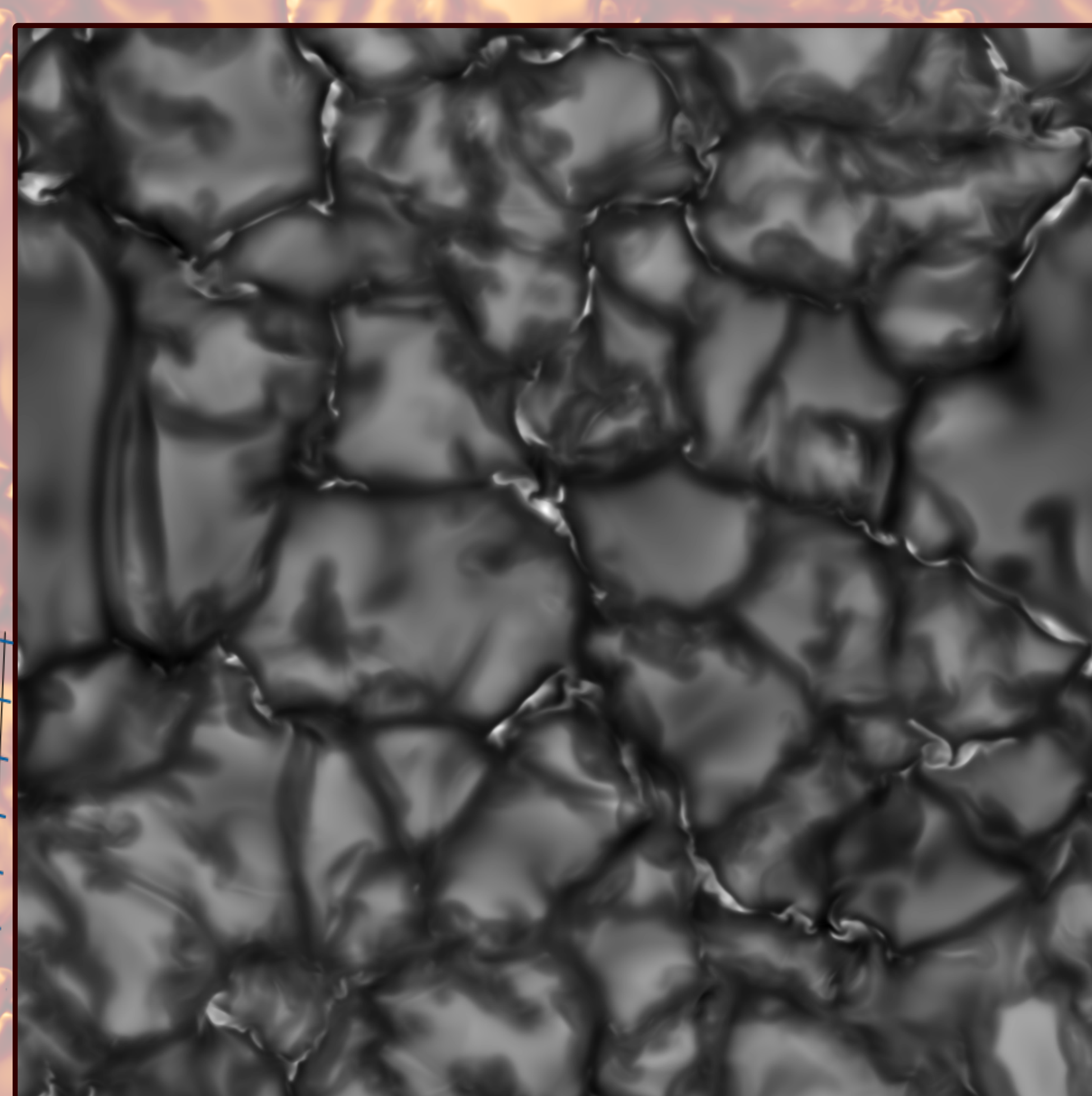
What comprise those simulations?

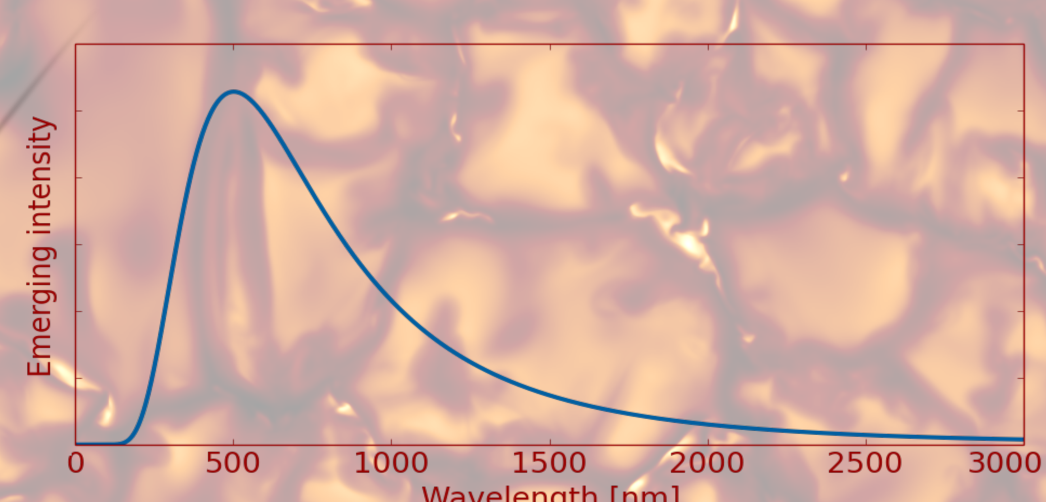
(Magneto-)hydrodynamics equations are solved with an explicit method based on Roe and HLL Riemann solvers. The (M)HD step is alternated with a radiative transfer step (operator splitting). We use the CO[5]BOLD code of Freytag et al. (2012)[1].

[1]Freytag et al., 2012, JCP 231, 919



▲ Top panel: *force-free magnetic field solution that we have recently developed for replacing the conventional homogeneous vertical fields for the initial model.*





What light can tell us

The plot above shows emergent **intensity** as a function of wavelength, providing a first approximation of the continuum. To get extra information on the Sun atmosphere, one can look closer (i.e. increase spectral resolution, see plot on the right) and analyse lines produced by chemical elements present in the solar atmosphere.

The further analysis of **polarization** of the radiation emerging from different locations of the solar disc provides *all* additional information that can be retrieved from light (e.g. magnetic fields, velocity gradients,...).

Magnetic and non-magnetic bright points

Magnetic field concentrates within inter-granular lanes producing magnetic bright points (MBPs), visible both in observations and in synthetic intensity maps from simulations.

Interestingly, smaller non-magnetic bright points (nMBPs) also appear in simulations not including magnetic fields. Why?

Matter swirls down in nMBPs producing a funnel of smaller density (bathtub effect). This low density allows one to see deeper, thus into hotter, bright regions!

Radiative Transfer

In this context, radiative transfer (RT) describes how light propagates and interacts with the solar plasma.

RT was used for producing the intensity maps shown on this poster from our 3-D models of the solar atmosphere. These "virtual observations" can be directly compared with real observations.

Transport of polarized light

Currently, we are interested in the linear polarization of the continuum radiation across the solar disk, which we plan to synthesize from our 3-D models.

Solving the RT equations for polarized light requires additional post-processing.

◀ Left panel: *total radiative intensity (integrated over the entire spectrum) emerging from an instant of the 3-D magnetic simulation.*

A parallelization challenge

Solving MHD equations requires the computation of RT in a simplified way (no polarization, only total intensity required).

3-D RT is however a non-linear, non-local process and cannot parallelize as easily as a traditional stencil algorithm. Without specific assumptions, full and accurate 3-D RT also becomes a huge numerical problem.