High-resolution modeling of the solar photosphere with the ANARES RHD-code

Investigation of rotating intergranular plasma jets

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Abstract

Small granules that do not originate from the fragmentation process of regular sized granular cells and evolve on a considerably shorter timescale populate the intergranular lanes. They are found in high-resolution observational and hydrodynamic simulations data of the quiet sun's photosphere. We study their topography and dynamics based on a segmentation algorithm. The flow field suggests that they represent high-vertical jet-like structures that are found to differentially rotate about their center axis. Their associated high horizontal kinetic energy flux exceeds that of regular granules and may excite significant Poynting flux through MHD kink waves and torsional Alfvén waves that would be high enough to effectively heat the chromosphere and corona if only 10% of the wave energy is assumed to be dissipated into heat.

Introduction

We study the structure and dynamics of the solar photosphere from radiation hydrodynamics (RHD) modeling. The high-resolution of our photopheric model allows us to examine small-scale convective structures that do not originate from the fragmentation of larger granular cells but form and dissolve in the intergranular lanes on timescales well below the lifetime of typical granulation cells. Many such intergranular structures are associated with strong vortex motions as have been detected in numerous observations e.g. [8, 1, 9] and simulations alike e.g. [12, 7]. 3-D radiative MHD simulations showed that convective overturning and Kelvin-Helmholtz instabilities give rise to such small-scale vortices [2], which themselves can trigger acoustic wave excitation or the spontaneous formation of magnetic pore structures.

Numerical Model & Methods

The study is based on a simulation of the solar near-surface convection using the code ANARES (A Numerical Tool for Astrophysical REsearch) [4]. It considers full radiative transfer and realistic microphysics as well as realistic opacities based on the opacity distribution functions of the ATLAS-9 package to determine bin-averaged opacities and source functions.

- The radiative transfer equation is solved in the upper region of $\Delta z$ km extent using non-gray opacities with 4 bins.
- The temporal integration is performed with a second or third order Runge-Kutta scheme with 4 bins.
- Initial conditions: Temperature values are set to 4350 K and 20 000 K at the top and bottom of the grid.
- The applied high resolution finite-volume scheme is capable of treating turbulence by adopting local mesh refinement.
- Boundary conditions: Originally closed boundary conditions prone to non-physical reflections of waves and shocks are now replaced by open boundary conditions at the top and bottom, thereby allowing for convective mass and energy in- and outflows. In horizontal direction periodic boundary conditions are applied.

For the study of the structure and dynamics of intergranular jets, the 3-D segmentation algorithm developed by Lemmerer et al. 2014 [3] has been applied. Starting at the highest vertical position of a granule the maximum horizontal kinetic energy flux as compared to regular granules has been found below the surface. Above the surface these fluxes are of comparable magnitude and decrease fast with height.

Conclusions

- The findings indicate a jet-like character rather than being an exclusively convective phenomenon. They are believed to be triggered by turbulent convection and thus can be studied from RHD modeling of the quiet sun.
- The jets may generate MHD waves in magnetic flux tubes which are anchored in the photosphere. The horizontal motions may excite MHD kink waves [6, 11] or torsional Alfvén waves [5, 10], which transport photospheric energy into upper layers.
- If only 1% of the horizontal kinetic energy flux associated with the intergranular jets is transferred into MHD waves, the wave energy flux is sufficiently high to compensate energy losses from the quiet sun chromosphere and to heat the corona.

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