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Alfvén waves in the solar photosphere

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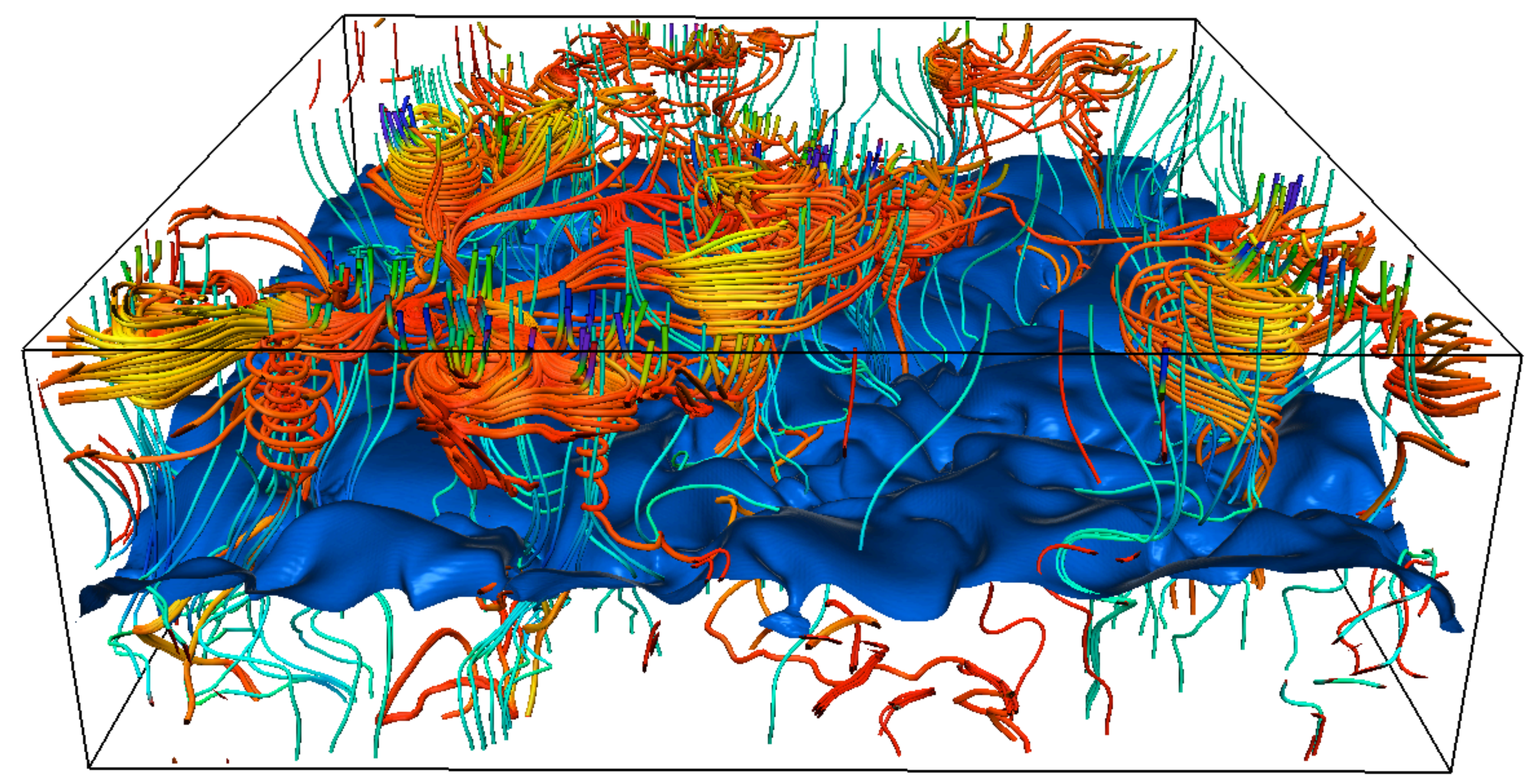
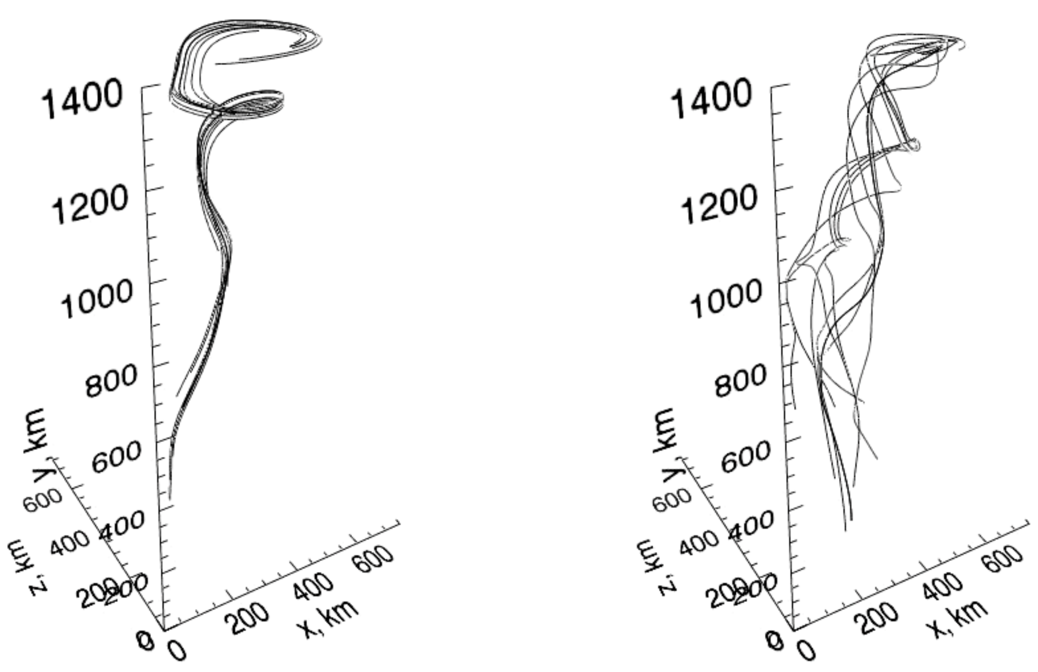
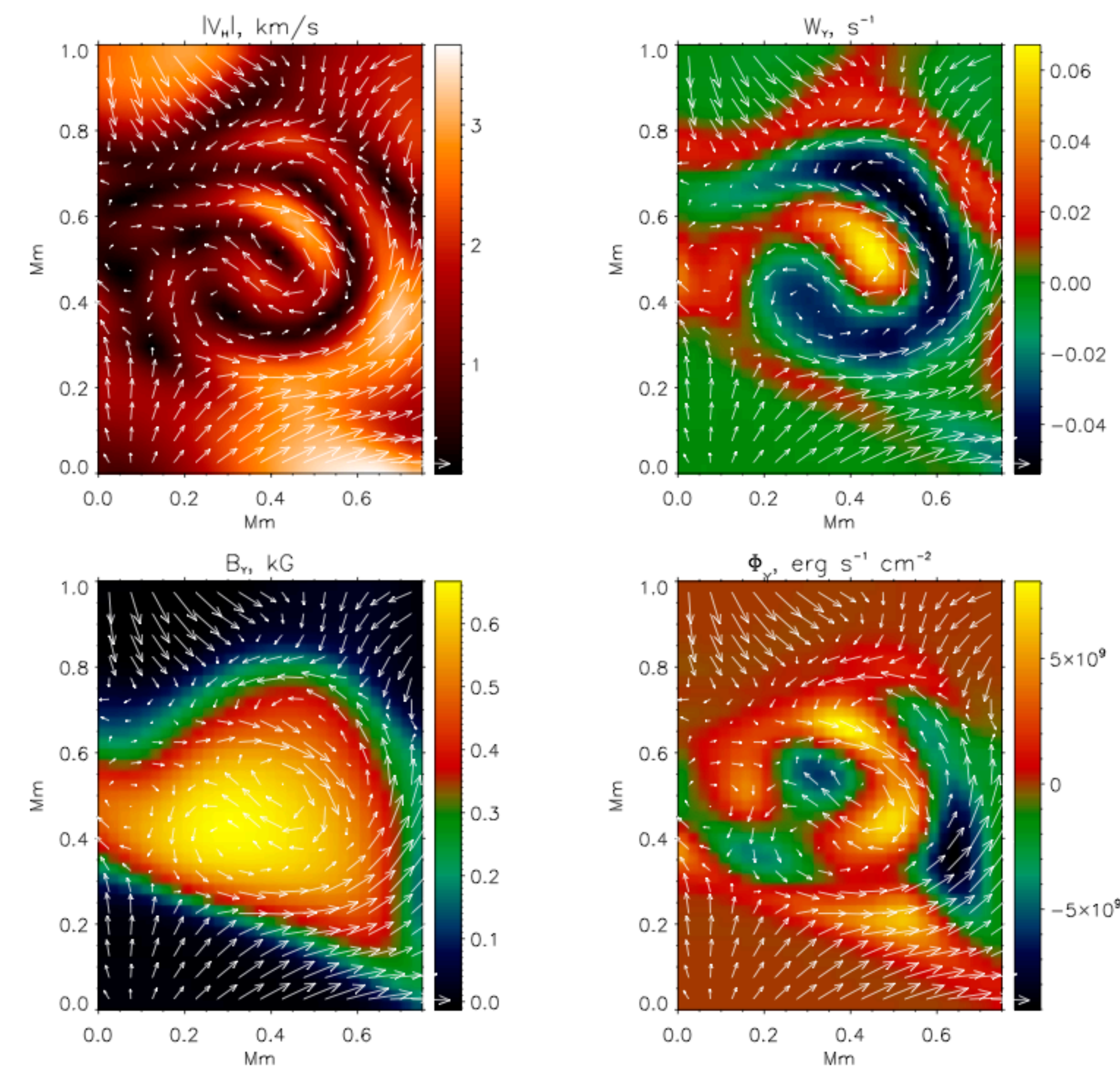
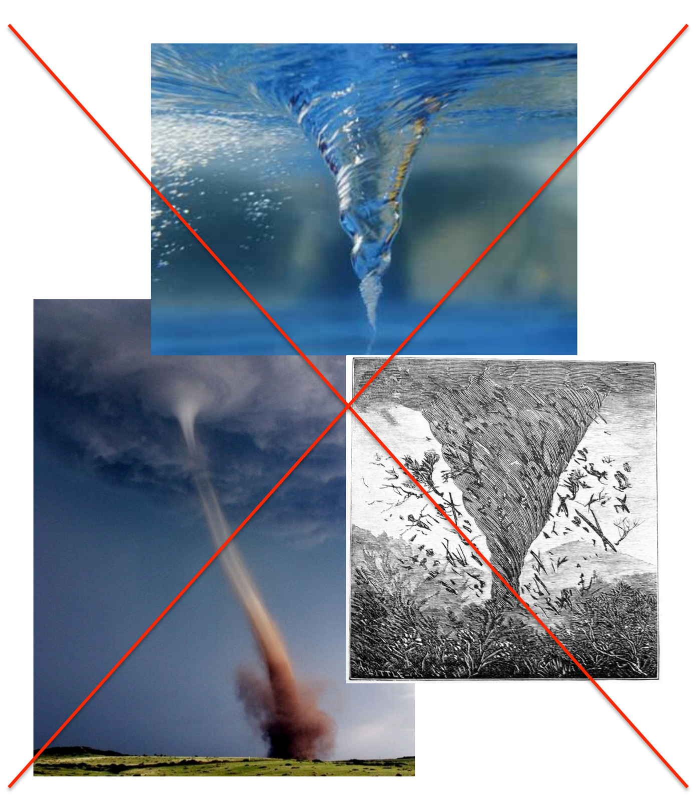
Three-dimensional magneto-hydrodynamic simulations of the magnetised solar photosphere show presence of vortex-like structures in the intergranular magnetic field concentrations [1]. They were called "magnetic tornadoes" due to their apparent similarity to Earth's tornadoes. However, in the 3D rendering of the simulated photosphere (right), the velocity field lines (red-yellow) show strong twisting, while the magnetic field lines (blue-green) do not. Taking into account the frozen-in condition for magnetic field in MHD, how is it possible they have so different shapes? To find it out, we performed a high, 2 second cadence simulation of photospheric magneto-convection with the MuRAM code. Figure below shows a visualisation of 3D time-independent (left) and time-dependent (right) velocity fields in a single "vortex". As can be seen, apparent "vortex" disappears, if time dependence of the velocity field is taken into account in the visualisation.

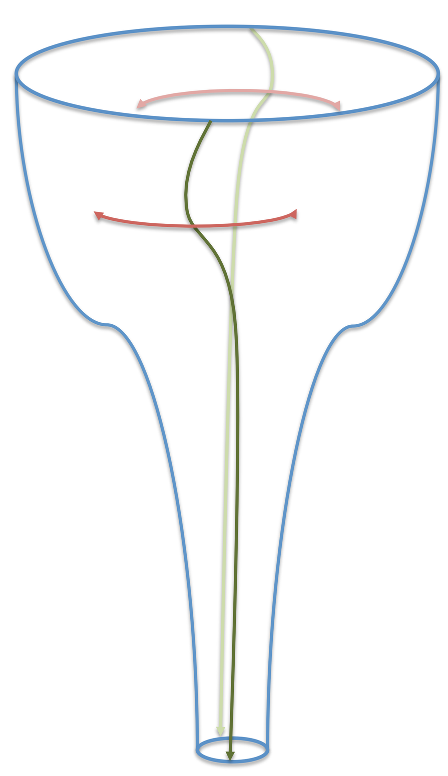




Closer look at one of the magnetic "vortex" structures in the photosphere reveals a complex velocity pattern in the magnetic field concentration [2]. In the image to the right are shown: the modulus of horizontal velocity with arrows showing horizontal velocity field direction; the vertical components of the vorticity, of the magnetic field, and of Poynting flux vectors. Layers of oppositely rotating plasma can be seen within the same structure which is embedded into the magnetic field concentration. Horizontal plasma motions generate Poynting flux.

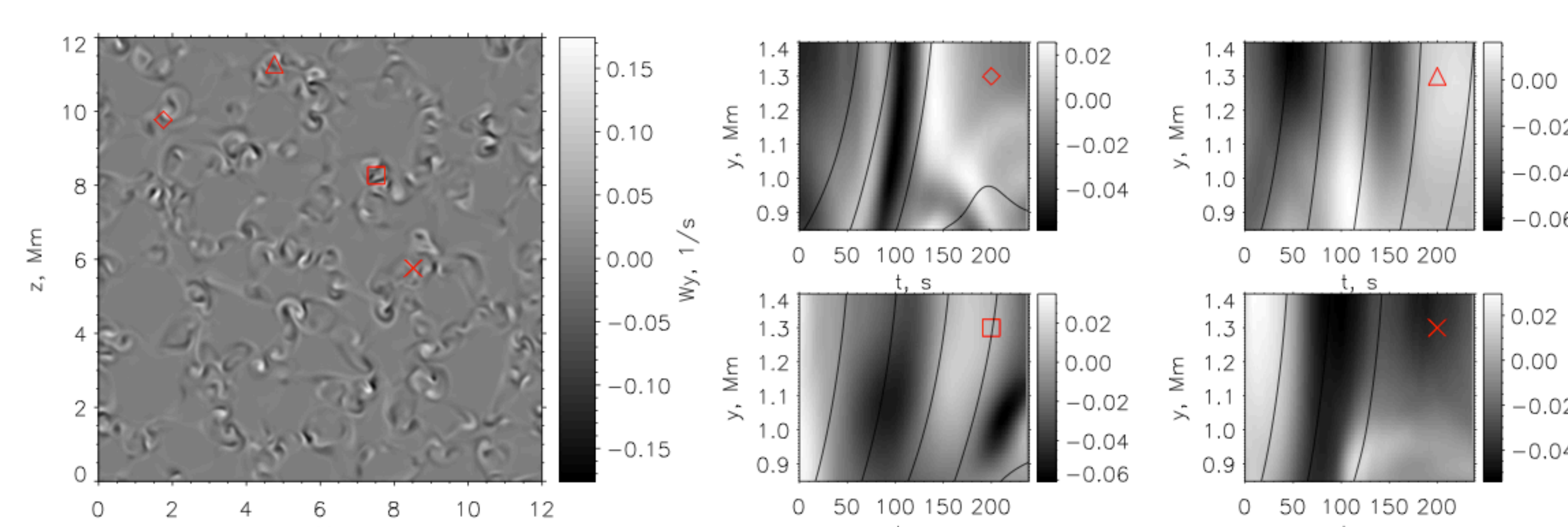


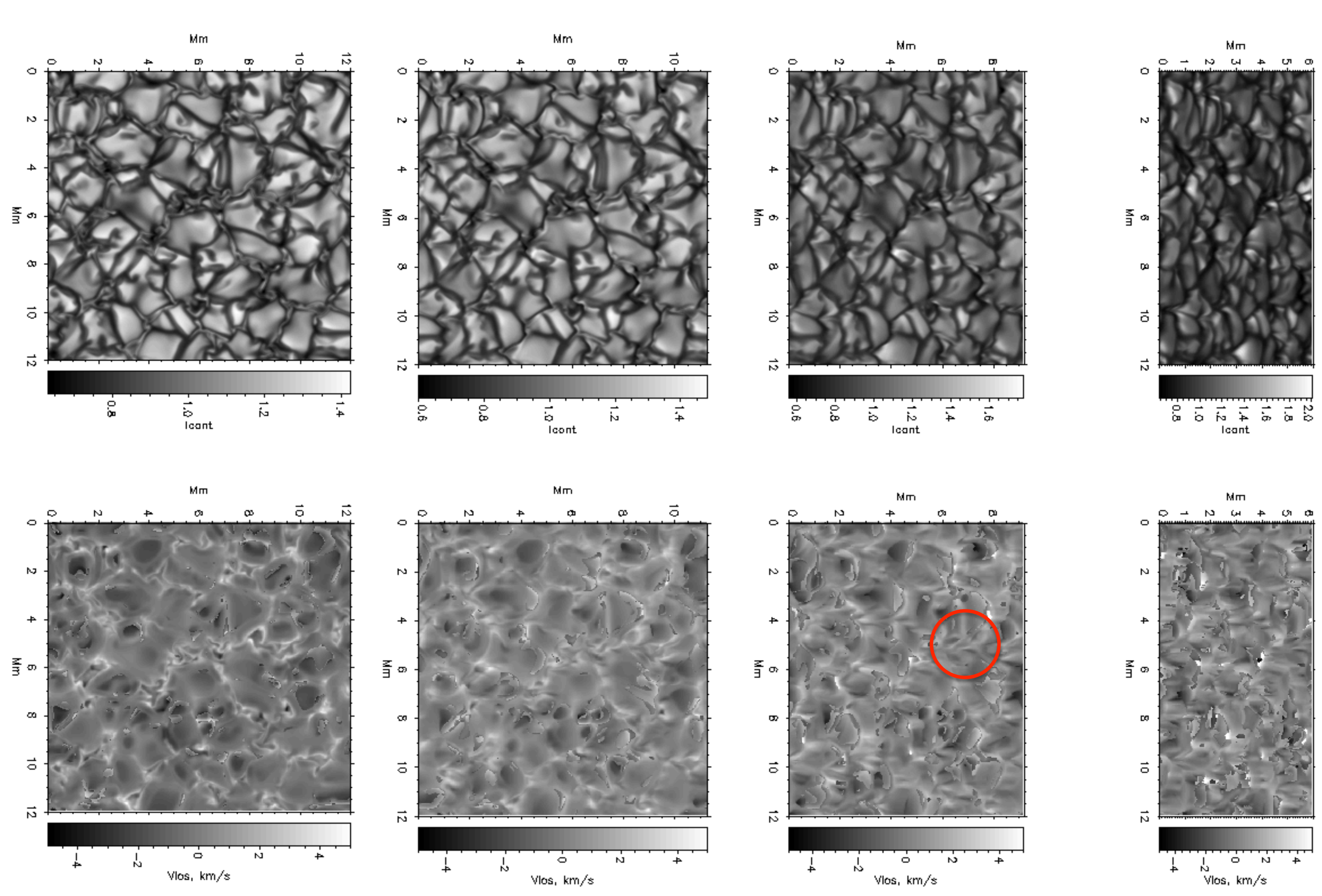




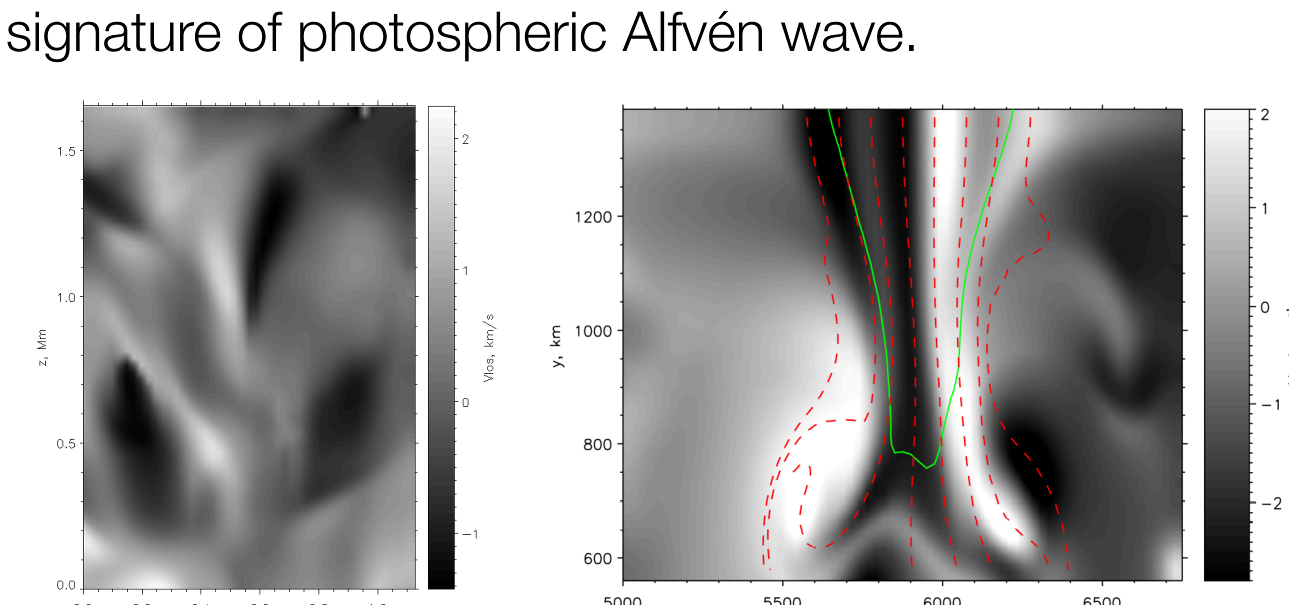
As we have found, the horizontal motions in the magnetic field concentrations are not swirling motions and have no physical relationship to tornadoes. They are fast-changing, torsional oscillations in the plane almost perpendicular to the magnetic field [3]. We performed time-distance analysis of propagation of the vertical vorticity perturbations and identified wave type. In the figure below, few examples of torsional wave propagation are shown. The curves, overplotted in the right part of the figure, correspond to the tracks of test particles moving with the local time-dependent Alfvén speed. Torsional waves propagate with Alfvén speed along vertical field lines, thus they are Alfvén waves.

How to detect these waves? They are horizontal, but found in higher layers of the photosphere, and photospheric features such as magnetic bright points will not be subject to such motions. Also, they do not produce temperature or pressure perturbations. An option would be to use spectro-polarimetric observations off solar disk centre to get signatures of horizontal torsional motions in the line-of-sight Doppler shifts. Figure below shows a simulation of FeI 630.25 nm line (top row – continuum intensity, bottom row – zero-crossing wavelength for Stokes V) at four different inclinations (0, 20, 40, 60 degrees).





The images below are a blow-up of a feature marked by a circle in the Stokes V ZCWL taken at 40° inclination (left), and horizontal velocity taken at the vertical cut through an intergranular lane in the simulation (right). Layered structures are visible in both figures, thus ZCWL shift in 630.25 nm FeI Stokes V is a possible signature of photospheric Alfvén wave.



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[2] Shelyag, S., Fedun, V., Keenan, F.P., Erdélyi, R., Mathioudakis, M. Photospheric magnetic vortex structures. 2011, AnnGeo, 29, 883.
[3] Shelyag, S., Cally, P.S., Reid, A., Mathioudakis, M. Alfvén waves in sumulations of solar photospheric vortices. 2013, ApJL, 776, 4

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