Dynamics of Small-scale Vortices in the Solar Atmosphere

N. Yadav[1] , R. H. Cameron[1] & S. K. Solanki[1,2]

[1] Max-Planck-Institut für Sonnensystemforschung, Justus-von-Liebig-Weg-3, 37077, Göttingen

[2] School of Space Research, Kyung Hee University, Yongin, Gyeonggi 446-701, Republic of Korea

MAX-PLANCK-GESELLSCHAFT

Max-Planck-Institut für Sonnensystemforschung

Motivation

Small-scale magnetic structures are known to play an important role in the heating of solar atmosphere. In this work, we investigate the internal structure of magnetic flux tubes, study the dynamics of small-scale vortices, explore their physical properties, and calculate their quantitative contribution in the Poynting flux transport to upper solar atmospheric layers for an active plage region.

Methodology

Using 3D MHD simulation code 'MURaM', we have performed numerical simulation of a solar plage region ranging from 1.5 Mm below the mean solar surface and 2.5 Mm above the surface. For detecting and isolating vortices, the 'Swirling Strength' criteria is used which tells about the revolution frequency of the flow and selects the locations which are rotating faster than the threshold frequency.

Results

Magnetic flux tubes emerging through the photosphere have complex filamentary substructure, are abundant of vortices of an average diameter of ~50 km. These small-scale vortices have higher temperature, higher mass density than the average values and carry ~30-40% of the total energy flux transporting into the atmosphere indicating their importance in mass and energy transport.

Simulation Set-up

- Dimension: 12Mm x 12Mm x 4 Mm
- Resolution: 1200 x 1200 x 400 (grid points)
- 2 hrs. HD run till quasi-stationary state
- Vertical magnetic field of 200 Gauss
- 1.2 hrs. MHD run
- 6 minutes data at 10 sec cadence
- **10 km resolution**
- **Improved diffusive scheme**

Figure 1: 3D visualization of vortex features (green) emerging from strong magnetic regions

Vortex Detection

- The 'Swirling strength' criteria
- Velocity gradient tensor $L_{ij} = \frac{\partial v_i}{\partial x_j}$
- On vortex locations, L_{ij} has complex conjugate eigenvalues
- The imaginary part of complex eigenvalues gives the swirling strength ($\boldsymbol{\lambda_{ci}}$) i.e. the frequency of swirling motion around the core of vortex.

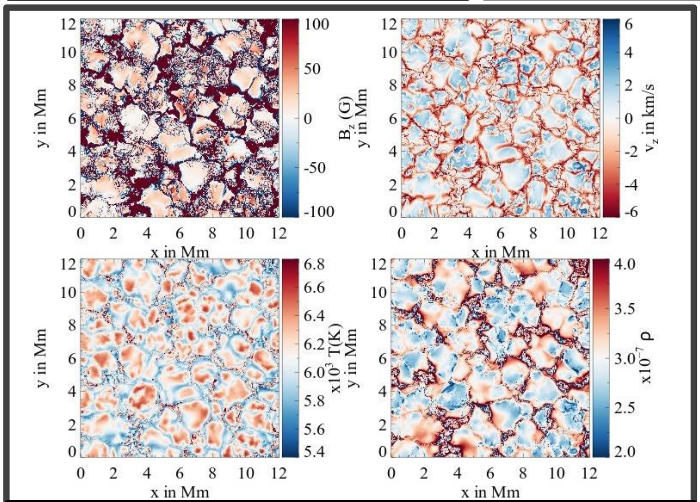

Figure 2: Top left: vertical component of magnetic field (B_z); top right: v_z ;bottom left: T; bottom right: mass density (ρ) at the τ = 1 layer

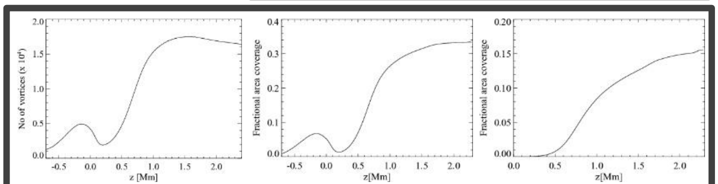

Figure 3: Left: total number of vortices; Area coverage ratio of vortices for two values of swirling time threshold: 100 s (middle) and 50 s (right)

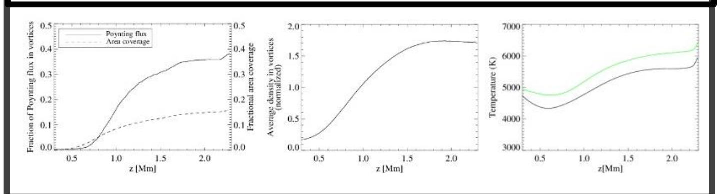

Figure 4: Left: fraction of Poynting flux over the vortex sites (solid) and fraction of area coverage (dashed); middle: average density (normalized) over the vortex sites; right: average temperature over the vortex sites(green) and horizontally averaged temperature (black)

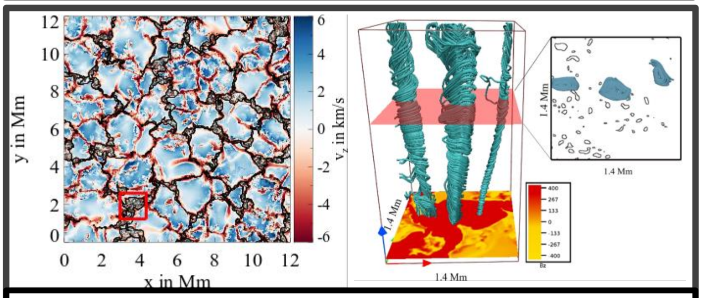

Figure 5: Left: vertical component of flow velocity (v_z) at τ = 1 layer with black contours of B_z (red square displays a magnetic element that is zoomed-in in the right figure)

Right: velocity streamlines on the vortex locations in magnetic element displayed by red square, a perpendicular cut at 1.3 Mm above surface is also displayed with over plotted contours of swirling strength.

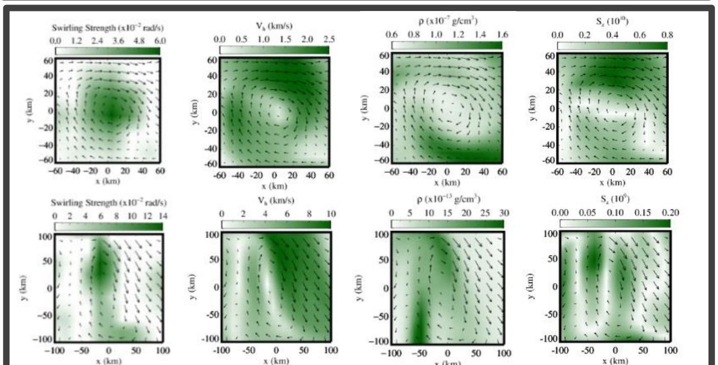

Figure 6: Left to right: profiles of swirling strength, horizontal velocity, mass density and vertical component of Poynting flux on solar surface (top row) and at 1.3 Mm above surface (bottom row) in a vortex.

Conclusions

From these results, we conclude that magnetic flux tubes have filamentary internal structure comprising of small-scale vortices that are denser, hotter structures providing an important path for energy and mass transport from the photosphere to upper atmospheric layers.

References

- Moll et al. (2011), *Astronomy & Astrophysics* **533**.
- Vögler et al. (2005), *Astronomy & Astrophysics* **429**.
- Rempel M. (2016), *The Astrophysical Journal* **834**.
- Verth G. & Jess D. B. (2016), *John Wiley & Sons Inc, Hoboken*, NJ, 25.

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Poster

3. Magnetic coupling and mass flux through the atmosphere

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[2] *School of Space Research, Kyung Hee University, Yongin, Gyeonggi 446-701, Republic of Korea*

Recent advances in both observational and simulation techniques have allowed us to detect small-scale structures in the solar atmosphere. These structures are believed to be play an important role in the heating of solar atmosphere. The aim of present work is to investigate the dynamics of small-scale vortices in a plage region in detail, to explore their physical properties, and to calculate their quantitative contribution in the Poynting flux transport to upper solar atmospheric layers.Using three-dimensional (3D) magnetohydrodynamic (MHD) simulation code 'MURaM', we have performed numerical simulation of a solar plage region. For detecting and isolating the vortices, the 'Swirling Strength' criteria is used. After extraction of vortices, we have investigated the response of vortices to the 3D atmosphere i.e. how the different physical quantities e.g. density, temperature etc. varies with height on vortex locations and compared it to the average values on the same geometrical height. We found the photospheric magnetic elements are abundant of small-scale vortices, having average diameter of ∼60 km. These small-scale vortices have higher temperature, higher mass density than the average values and are found to carry more than 50% of the total energy flux passing through the chromosphere. A subset of vortices is also found, which is loop-like, low lying, and is more inclined. From these results, we conclude that these vortices are denser, hotter small-scale magnetic structures ubiquitous in the plage region, and provide an important path for energy and mass transport from the photosphere into the chromosphere.