Vortices and Alfvénic pulses in the simulated solar atmosphere

José Roberto Canivete Cuissa[1,2],
Oskar Steiner[1,3]
Contact: *jose.canivete@irsol.usi.ch*

[1] Istituto ricerche solari Aldo e Cele Daccò (IRSOL), Faculty of Informatics, Università della Svizzera italiana, CH-6605 Locarno, Switzerland
[2] Center for Theoretical Astrophysics and Cosmology, University of Zurich, Winterthurerstrasse 190, 8057 Zurich, Switzerland
[3] Leibniz-Institut für Sonnenphysik (KIS), Schöneckstrasse 6, 79104 Freiburg i.Br., Germany

IRSOL
Un istituto
affiliato all'USI

Motivation

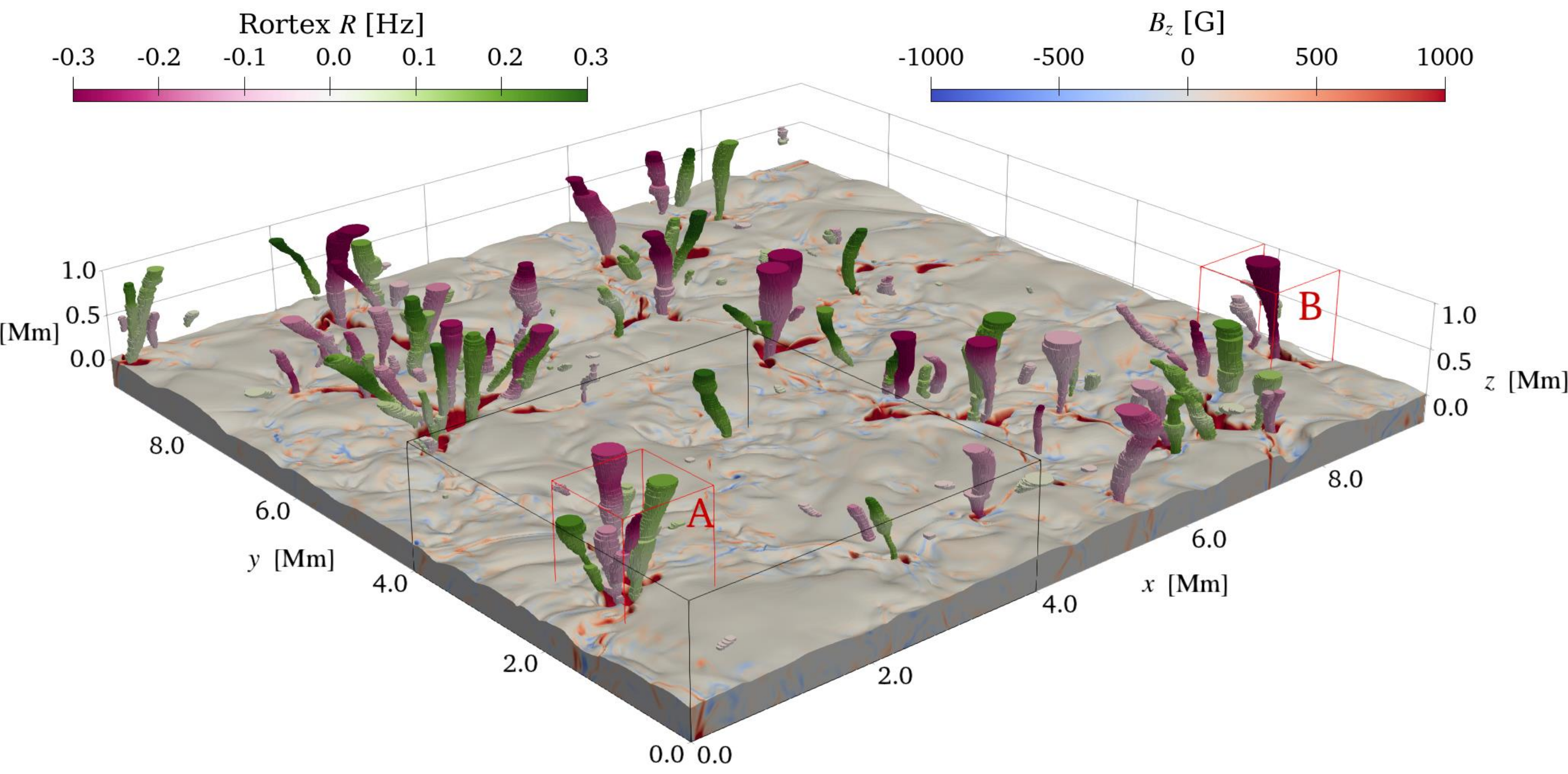
- Observations show the ubiquitous presence of small-scale swirling motions in the quiet solar atmosphere.
- The swirls are tightly coupled to the small-scale magnetic field of the Sun ("*magnetic tornadoes*") and connect the different layers of the solar atmosphere.

> Can swirls channel energy from the convection zone to the upper atmosphere?

- The origin, dynamics, and statistics (size, density, etc.) of these features are still not well understood. We use numerical simulations of the solar atmosphere to address these questions.

Numerical Simulations

- We analyzed radiative-MHD numerical simulations of the solar atmosphere carried out with the CO5BOLD code.
  - 9.6 x 9.6 x 2.8 Mm^3 (960 x 960 x 280 grid points)
  - Surface $\tau_{500} = 1$ at ~ 1.2 Mm from the bottom (shown in gray)
  - Initial homogenous B_z of 50 G.

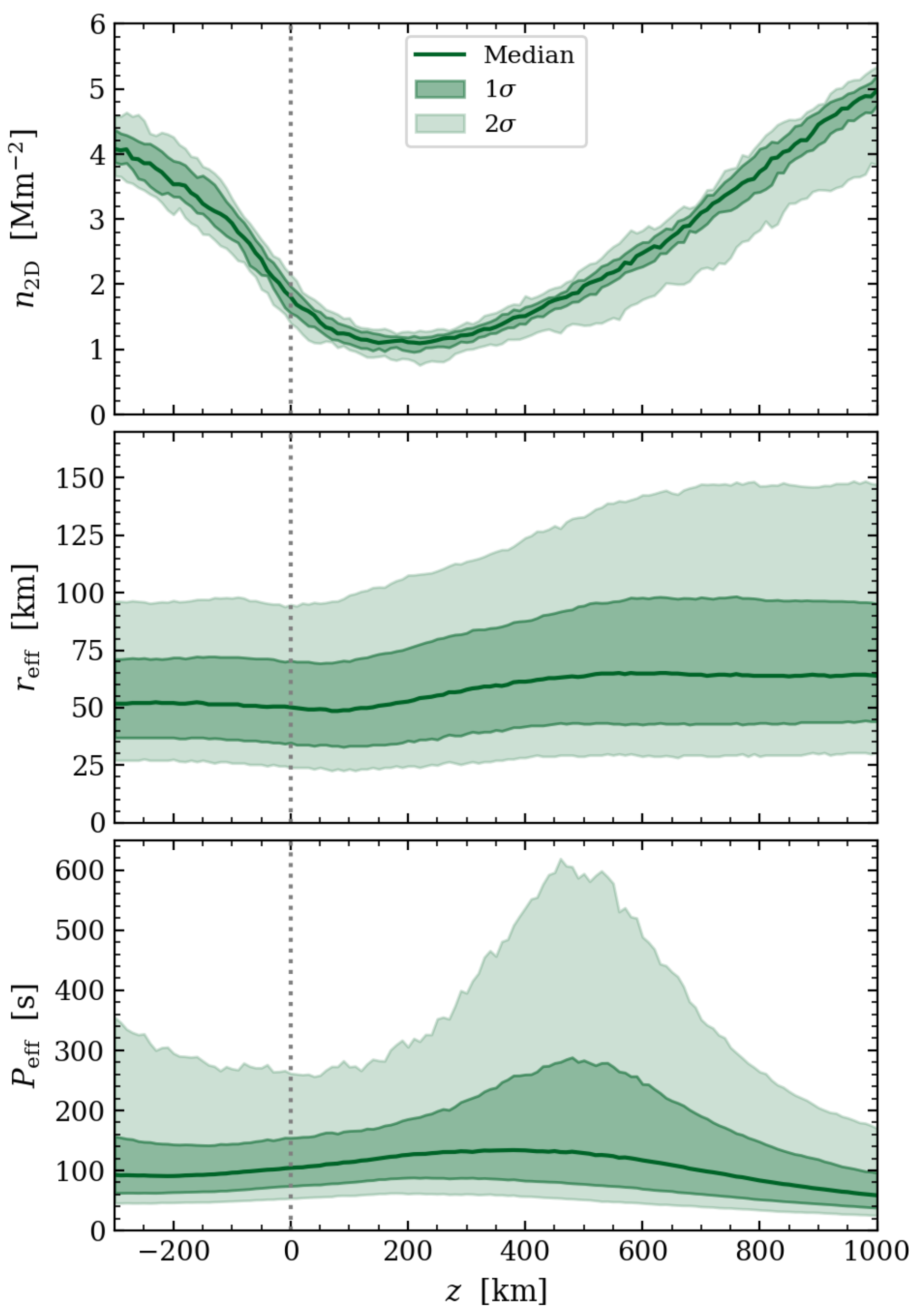


- We used the SWIRL algorithm[1] to identify swirls in the simulations. The Rortex criterion R is inversely proportional to the period of rotation of the swirl. Swirls appear to stem from magnetic flux concentrations shown on the $\tau_{500} = 1$ surface.

[1] *https://github.com/jcanivete/swirl*

Statistics

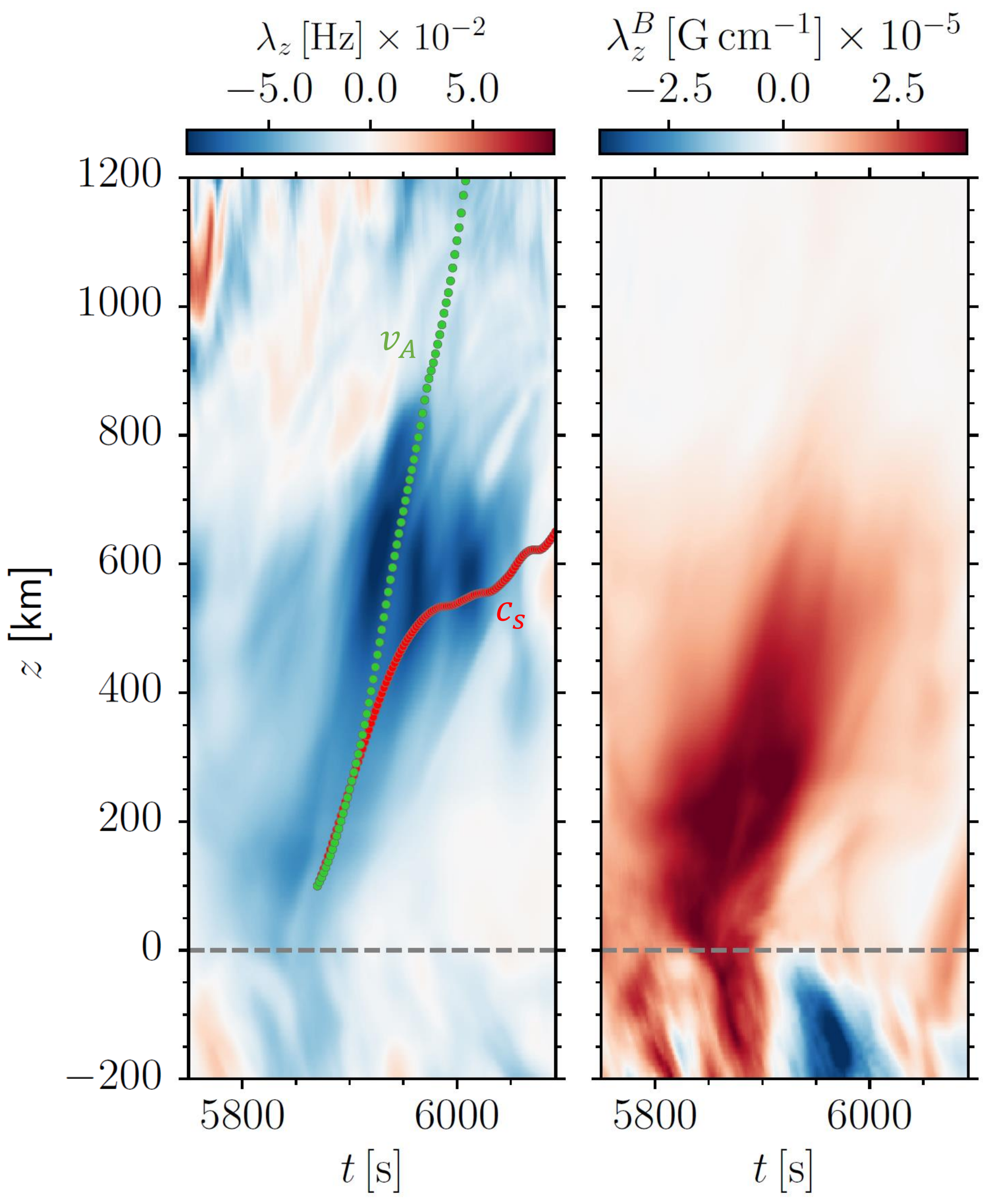
- We carried out a statistical analysis with the SWIRL algorithm over 30 simulation time instances.



- On average, the algorithm identified ~ 1 swirls/Mm^2 in the photosphere and ~ 3 swirls/Mm^2 at the basis of the chromosphere.
- The average radius of the identified swirls is ~ 50 − 60 km in the whole atmosphere. Larger swirls can be found in the chromosphere.
- Swirls show an average period of rotation of ~ 100 s. The slowest swirls are found in the middle photosphere because of the expansion of the plasma.

Alfvénic pulses

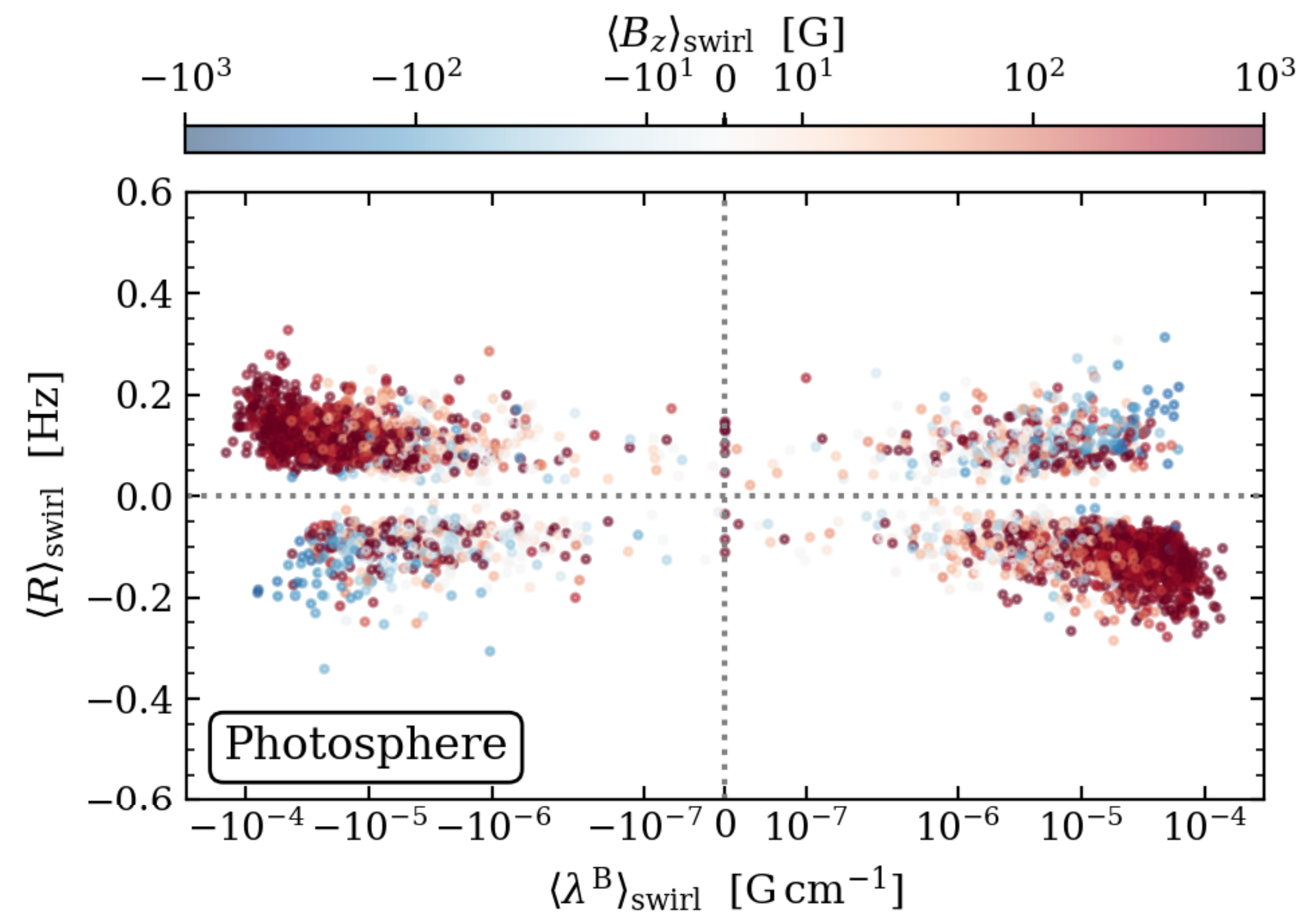
- We studied several swirl events in detail. We used the swirling strength (λ_z, detects curvature in the velocity field; similar to the Rortex) and the magnetic swirling strength (λ_z^B, detects twists in the magnetic field lines) to investigate the temporal evolution of these events. Moreover, we employed the swirling strength equation to study their dynamics. We found that:



  - The studied swirls propagate upwards at the local Alfvén speed v_A.
  - They are unidirectional, that is the rotational direction does not change with time.
  - They co-occur with twists in the upwardly directed magnetic fields. In this case, the magnetic field is twisted in the opposite direction of the plasma rotation.
  - The main driving force of the upward propagation is the magnetic tension.

> These are the characteristics of torsional Alfvénic pulses.

- This correlation is supported by our statistical analysis.



  - For a torsional Alfvén pulse associated with an atmospheric swirl,

$$\mathrm{sign}(\langle R \rangle \langle \lambda^B \rangle) = -\mathrm{sign}(\langle B_z \rangle)$$

    where $\langle R \rangle$, $\langle \lambda^B \rangle$, and $\langle B_z \rangle$ are averaged over the swirl's area.
  - This relation holds for ~ 80 % of the identified swirls in the photosphere.

- An average upwardly directed Poynting flux of 12.8 ± 6.5 kW m^{-2}, primarily generated by swirling motions, is found at the base of the chromosphere.
- Most of the energy flux is associated with large and complex magnetic structures where multiple swirls can coexist at the same time.

Conclusions

- We find a clear correlation between swirl events and torsional Alfvénic pulses in realistic numerical simulations of the solar atmosphere. Statistically, ~ 80 % of the identified swirls are compatible with torsional Alfvénic waves.
- Upwardly propagating torsional Alfvénic pulses carry energy in the form of Poynting flux. They may contribute to chromospheric heating.
- The statistical analysis carried with the SWIRL algorithm suggest that swirls could be more numerous, smaller, and rotate faster than previously thought.

References

- Battaglia et al., 2021, A&A, 649, A121
- Canivete Cuissa & Steiner, 2022, A&A, 668, A118
- Canivete Cuissa & Steiner, 2023, A&A, submitted