New insights on small-scale vortical motion dynamics

Kostas Tziotziou

IAASARS, National Observatory of Athens, Greece

In collaboration with

Elena Khomenko[1] **Georgia Tsiropoula[2]** **Ioannis Dakanalis[2,3]** **Ioannis Kontogiannis[4]**

[1] Instituto de Astrofisica de Canarias, Spain

[2] IAASARS, National Observatory of Athens, Greece

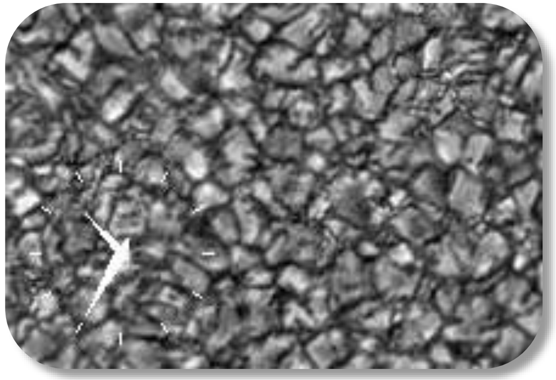
[3] National Kapodistrian University of Athens, Greece

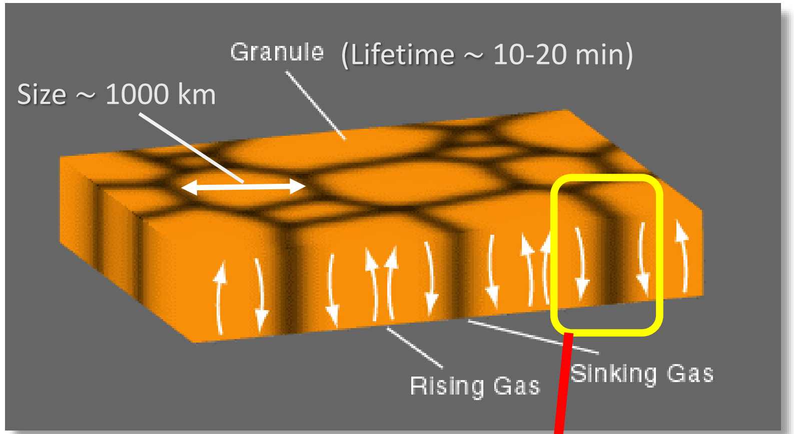
[4] Leibniz-Institut für Astrophysik Potsdam (AIP), Germany

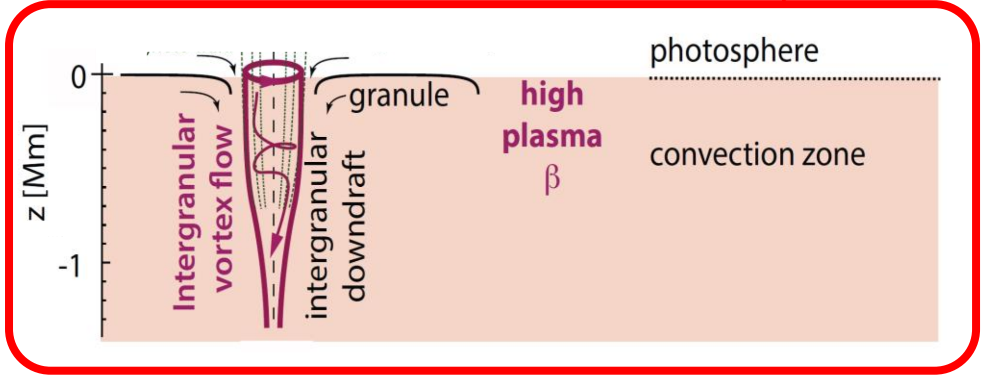
IAASARS

Solar convection, intergranular vortex flows and magnetic tornados

Formation of intergranular vortex flows

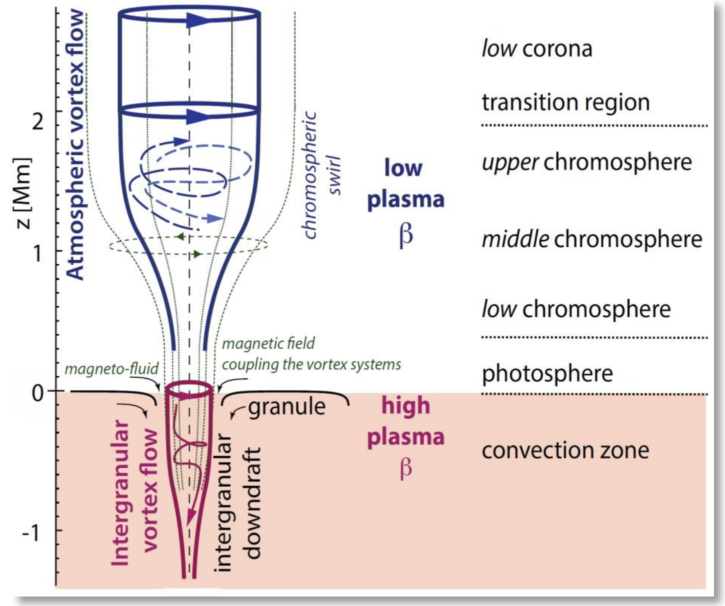


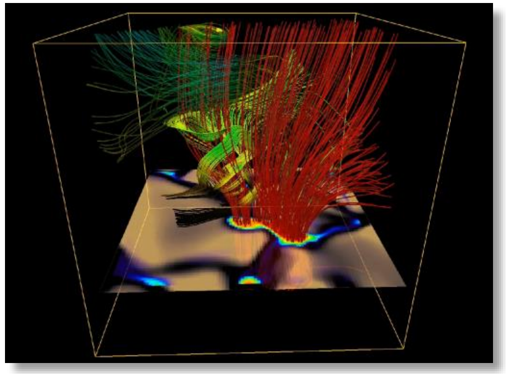




"Bathtub effect" → Intergranular vortex flow

Formation of magnetic tornadoes



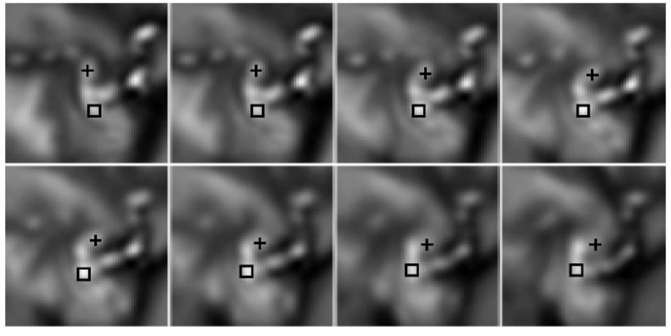


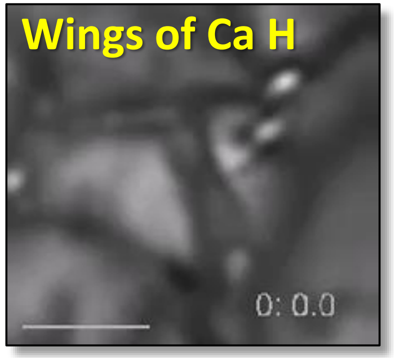
Wedemeyer & Steiner 2014, PASJ, 66, 10

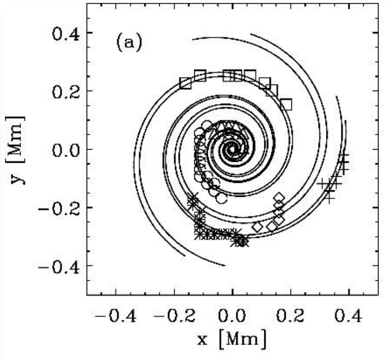
Vortex motions on the solar surface and the solar atmosphere

Photospheric signatures

SST



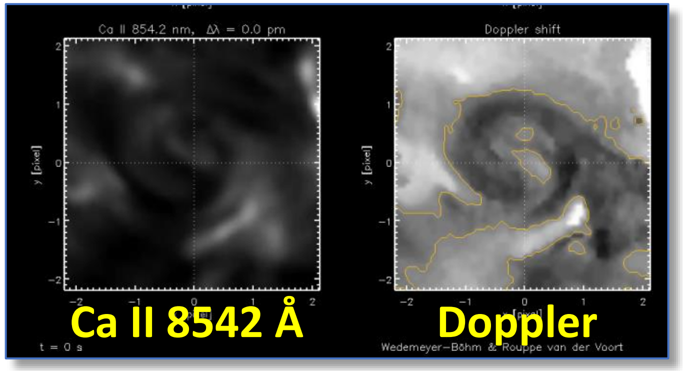




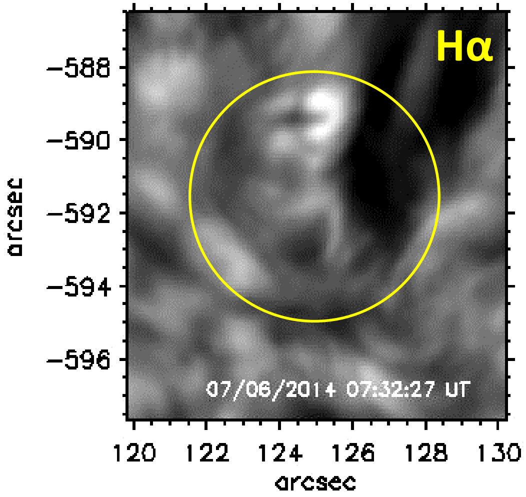
Bonet et al. 2008, ApJ, 687, 131

Chromospheric signatures

SST

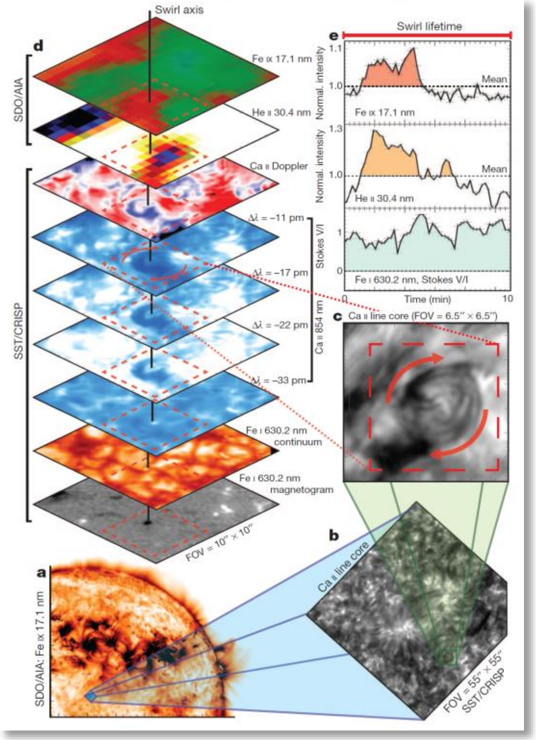


Wedemeyer & Rouppe van der Voort 2009, A&A, 507, L9

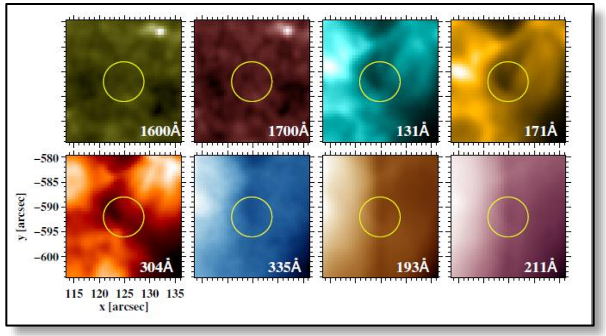


Tziotziou et al. 2018, A&A, 618, 51

Higher up



Wedemeyer-Bohm et al. 2012, Nature, 486, 505

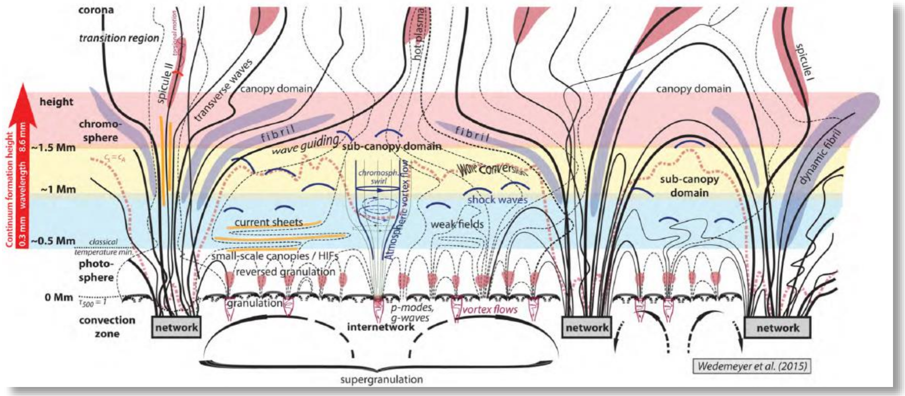


Tziotziou et al. 2018, A&A, 618, 51

Proper chromospheric swirl population estimation

Estimations suffer from:

- ❑ **observational limitations**



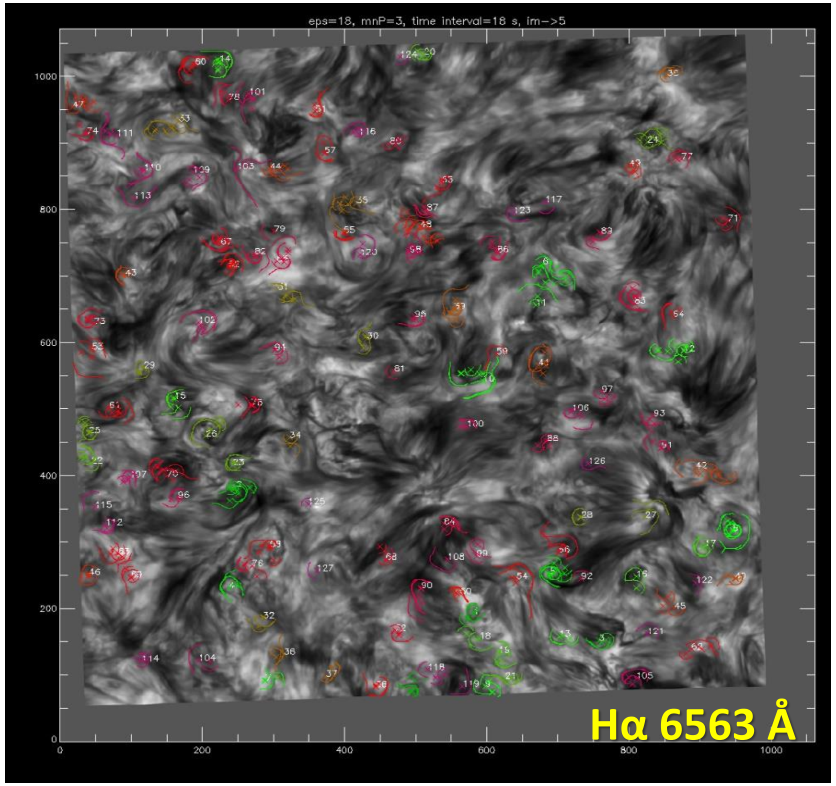
- ❑ **Detection difficulties - Methods based on velocity fields derived with Local Correlation Tracking (LCT)**

- Vorticity $\boldsymbol{\omega} = \nabla \times \boldsymbol{v}$
- Maximum vorticity method (*Strawn et al. 1999*)
- Γ-functions method (*Graftieaux et al. 2001*)
- Lagrangian-averaged vorticity deviation (*Haller et al. 2016*)
- Δ-criterion (Chong et al. 1990), Q-criterion (Hunt et al. 1988), λ_2-criterion (*Jeong and Hussain 1995*)
- Swirling strength or λ_{ci} –criterion (*Zhou et al. 1999*)
- Enhanced swirling strength (*Chakraborty et al. 2005*)

- ❑ **Past studies: 3.8 chromospheric swirls per 1´× 1´ FOV**
  (Wedemeyer-Bohm et al. 2012, Nature, 486, 505, visual inspection)

- ❑ **New Hα and Ca II 8542 Å observations : ~80 swirls within same FOV**

SST



Tziotziou et al. 2021, to be submitted

Novel automated morphological detection method (no LCT)

Dakanalis et al. 2021, Solar Phys., 296, 17

See also poster 312 in poster session 4.2

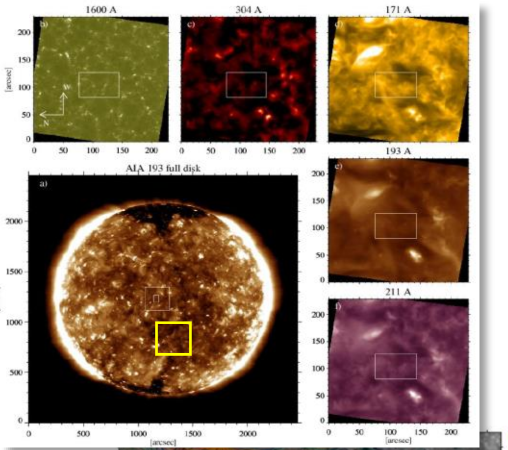
What determines their population?

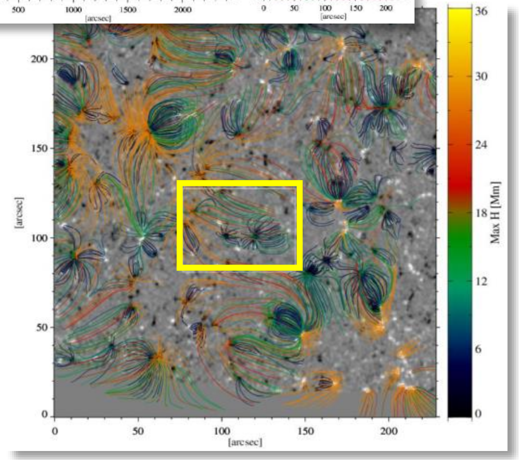
- **Simulations & observations suggest:** ***numbers of vortex motions@photosphere >> numbers@chromosphere***

  Formation of intergranular vortex flows (IVFs) prerequisite for formation of magnetic swirls
  BUT all IVFs result to magnetic swirls

- **Formation of magnetic swirls:**

✓ **depends on local magnetic field environment: open field topologies (e.g. coronal holes) facilitate their unimpeded rotation**



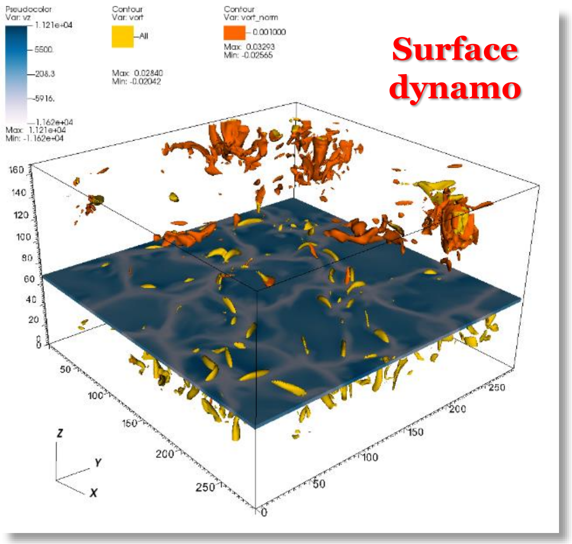


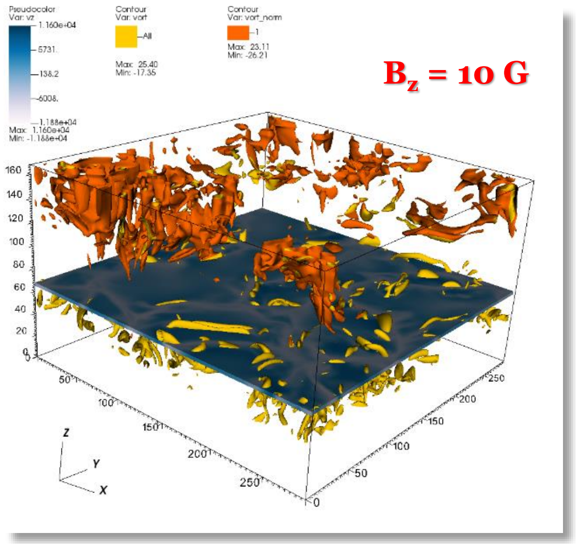
✓ **requires significant magnetic flux concentrations@quiet-sun photosphere + absence of high field strengths & filling factors@chromospheric heights that may hinder their rotation**

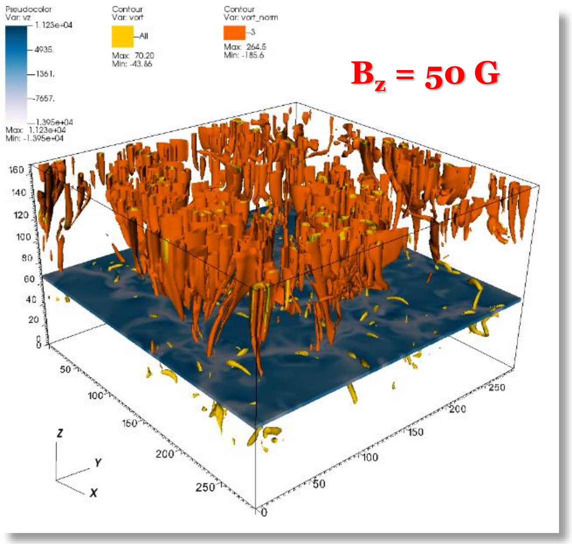
$$Q = \frac{1}{2}\left(\|\Omega\|^2 - \|S\|^2\right)$$

S and Ω are the symmetric and anti-symmetric versions of the velocity gradient tensor

Q / β







Tziotziou et al. 2021, to be submitted

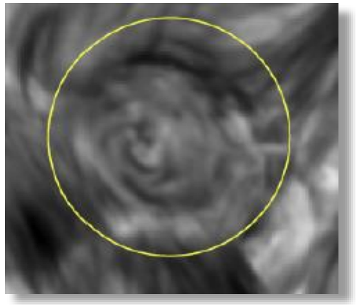
Excitation and propagation of waves

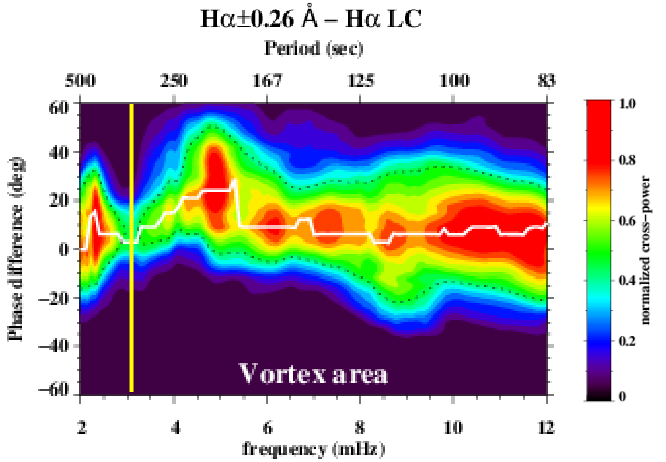
- **Simulations suggest the excitation and often coexistence of different MHD wave modes (such as kink waves and torsional Alfvén waves) in vortex tubes (Fedun etal. 2011, Annales Geophysicae, 29, 1029)**
- **An oscillatory (Tziotziou et al. 2019, A&A, 623 and cross-wavelet phase difference analysis (Tziotziou et al. 2020, A&A, 643, 166) reveals:**

  ✓ Lowered cut-off frequencies (below which phase differences are zero) ~2.5-3 mHz within a vortex area. **Natural interpretation when combined with observed swaying motions: kink waves**

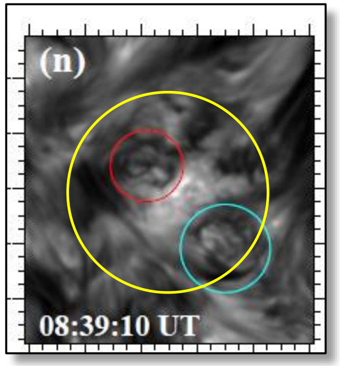
  ✓ Positive phase differences indicate upwards propagating waves with speeds of 20–30 km/s (compatible with Alfvénic type wave speeds)

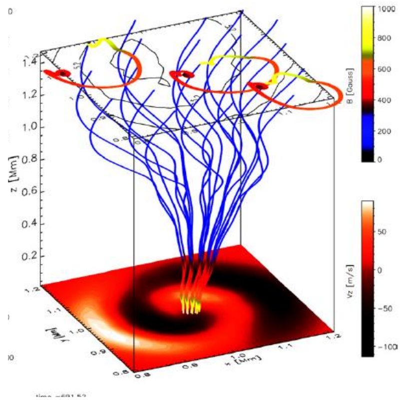
  ✓ Co-existence of localized torsional Alfvén waves related to the substructure of vortex flows



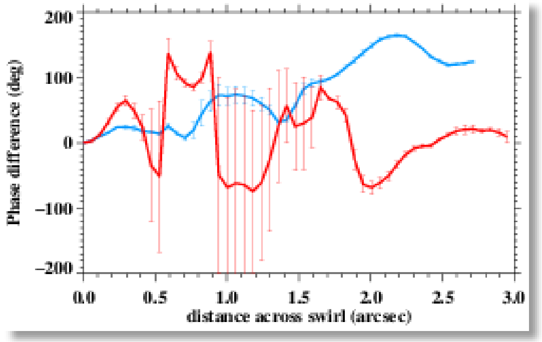


Substructure: manifestation of torsional Alfvén waves (Fedun *et al*. 2011, ApJ, 740, L46)



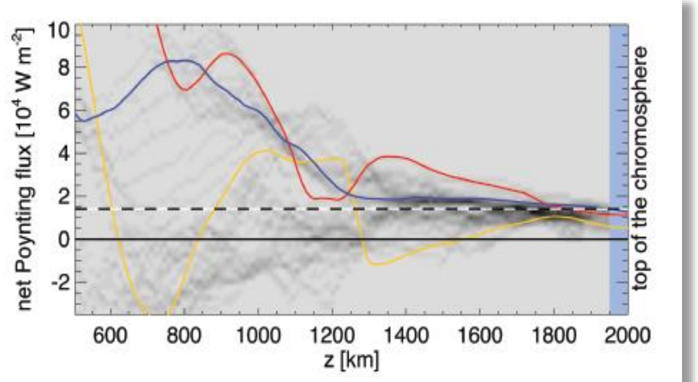


Torsional Alfvén waves (Jess et al. 2009) → 180° phase delay expected at FWHM oscillations at opposite swirl boundaries



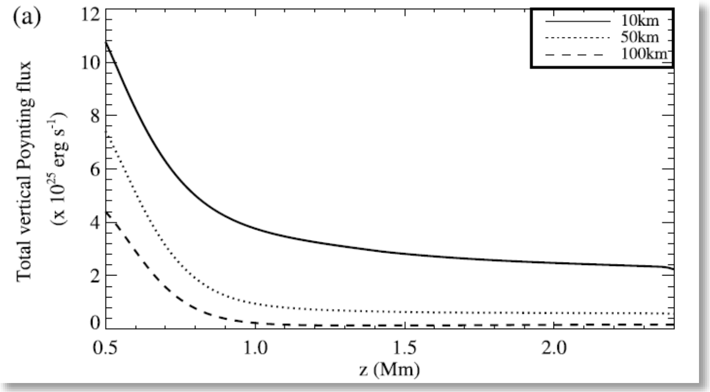
Transfer of energy

- **Magnetic tornadoes transport energy from the Sun's surface up to the corona, contributing to the heating of the Sun's outer atmosphere**



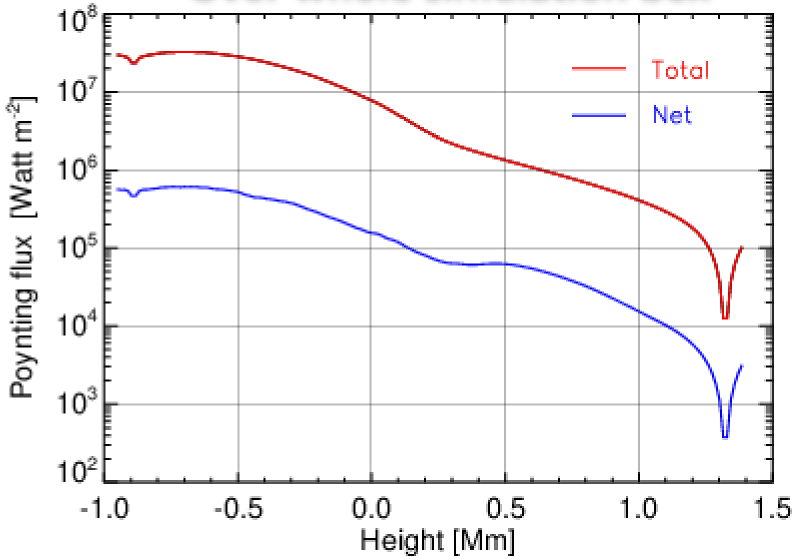
Wedemeyer-Bohm et al. 2012, Nature, 486, 505

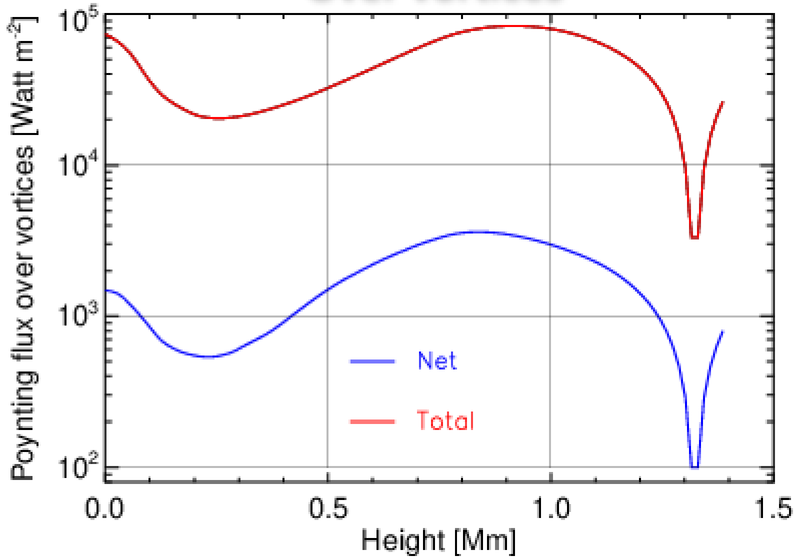
✓ net positive Poynting flux of
  - 440 W m^{-2} (Wedemeyer-Bohm et al. 2012, Nature, 486, 505)
  - 12.5 and 7.5 kW m^{-2} at heights 1000 and 1500 km, respectively (Yadav et al. 2020, ApJL, 894, L17)



Yadav et al. 2020, ApJL, 894, L17

✓ Our simulations suggest:
  - total Poynting flux of >10 kW m^{-2} @ chromosphere
  - net Poynting flux of ~1 kW m^{-2} @ chromosphere





Tziotziou et al. 2021, to be submitted

SUMMARY

- *Vorticity on the solar surface, resulting from solar convection, is an omnipresent process*
- *Magnetic vortex flows in the solar atmosphere are favoured in areas with open magnetic field topologies; vorticity maybe extremely important towards high solar latitudes and polar regions*
- *There seem to be a higher number of magnetic vortices in the solar atmosphere than previously though*
- *Such structures, as both simulations and observations indicate, foster a wide variety of Alfvénic type modes*
- *There is a considerable transfer of energy to higher atmospheric layers associated to vortices; given the higher population estimates, they may play a significant role to the heating of the Sun's outer atmosphere*
- *Their significance in solar wind driving at polar regions has to be further investigated*

Thank you!