Analysis of multi-wavelength observations of persistent and spatially-extended quiet-Sun vortex flows

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A vortex is a rapidly spinning, circular or spiral flow of fluid (or air) around a central axis.

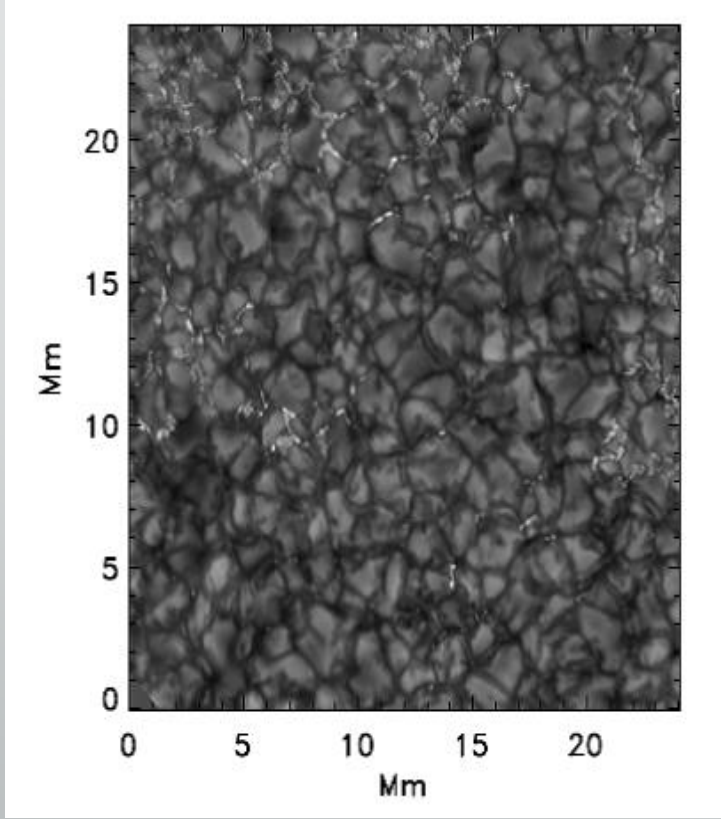
Vortex flows of different scales and intensities are ubiquitous in the Earth's atmosphere (as tornadoes and hurricanes) and ocean (water flowing down a drain)

"Bathtub effect"

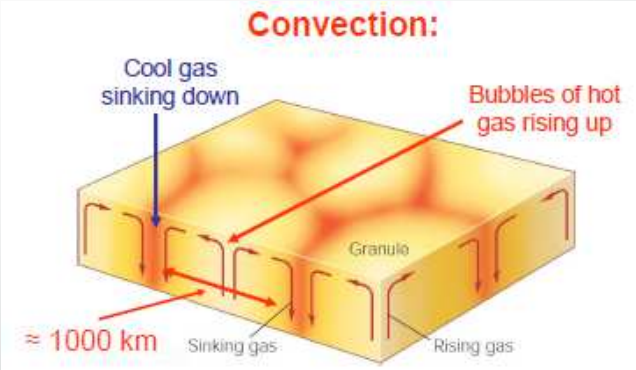
Large-scale tornadoes on the Sun

- A giant solar tornado - five times the Earth's diameter - swirling at incredible speed of some 82.7 km/s has been captured on video by NASA's Solar Dynamics Observatory.
- It is estimated that ~ 11 of them exist at any one time on the Sun with lifetimes from 1hr to several days.

Small-scale vortex flows

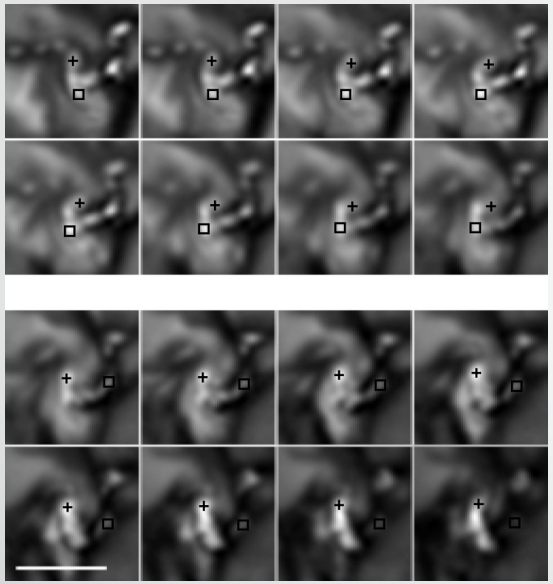


The solar granulation is a small-scale manifestation of ***overshoot of convection*** into the stable layers of the solar photosphere



Granules are upwellings of hotter gas in which the rising motion gets stopped through the departure of the EM radiation that we observe as sunshine. The dark lanes are the places where the cooled gas sinks back.

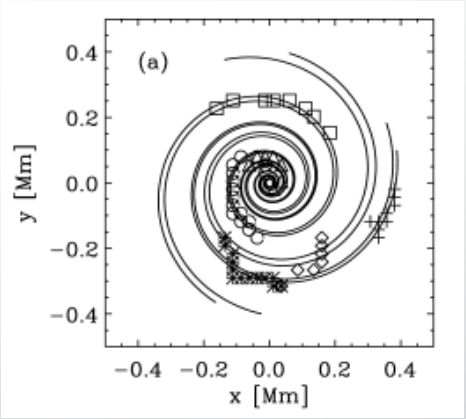
Convectively-driven vortex flows



SST/G-band. The bar corresponds to 1 Mm on the Sun. Marked with symbols two sets of two nearby BPs, so that it is easy to appreciate how the two BPs rotate with respect to each other.

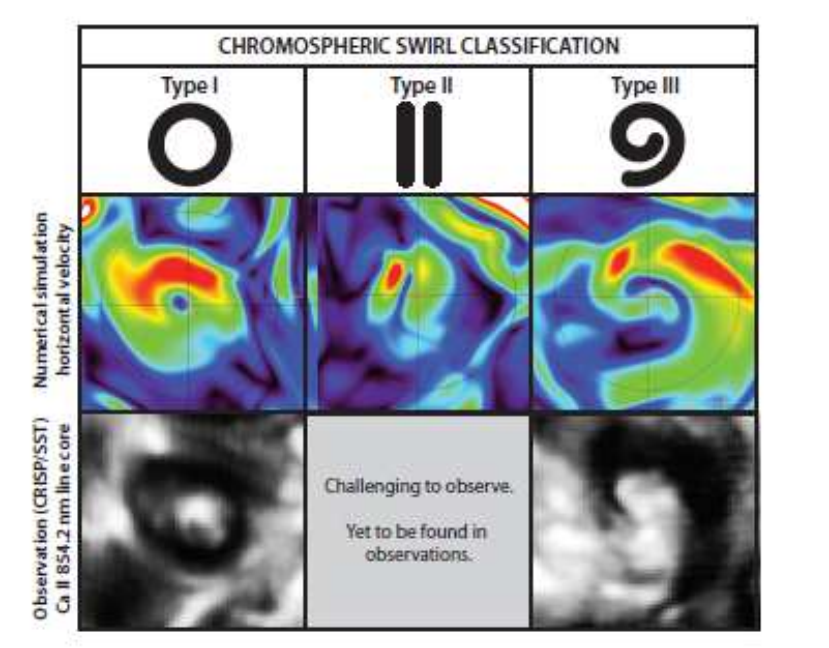
(Bonet et al. ApJ 687, L131, 2008).

The overturning flow at the edges of granules produces vortex tubes at the interface between the granule and the intergranular lane.



Logarithmic spiral (*solid lines*) that fits the trajectories of six observed BPs (*symbols*).

Chromospheric swirls as observable signature of tornadoes



- The three major types of chromospheric swirls: Type I (Ring), type II (Split), and type III (Spiral). The middle row shows the color-coded horizontal velocity in horizontal cross sections at z = 1000km for swirls in the numerical simulation. Observed examples of type I and III swirls are presented in the bottom row. The images are taken in the line core of the CaII infrared triplet line at 854.2nm .

  Wedemeyer et al. (2012)

Observations

1-m Swedish Solar Telescope (SST)

With the Crisp imaging Spectro-Polaripeter (CRISP)

Sampling of the Solar Chromosphere in:

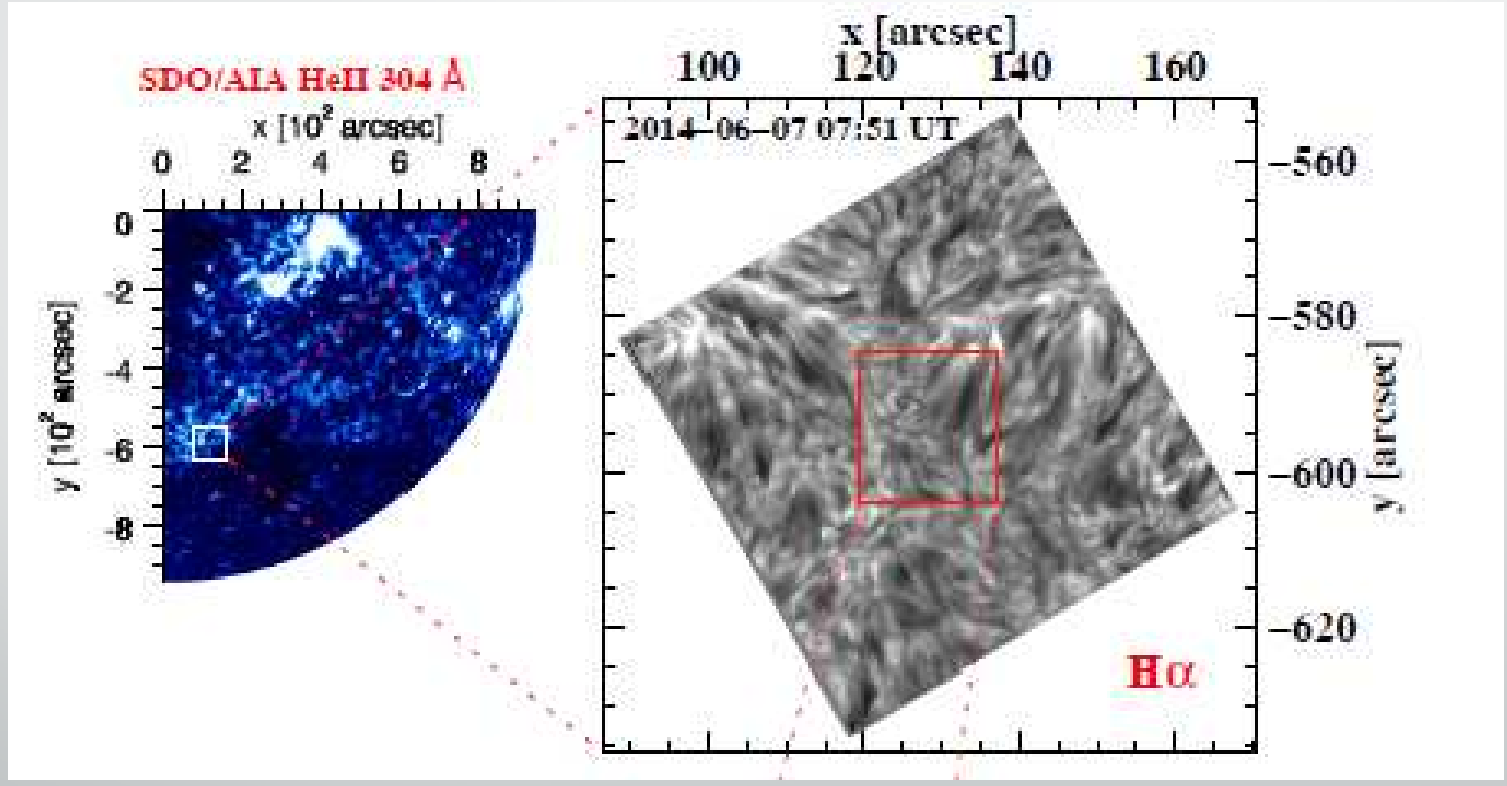
- **Ca II 8542 Å (Infra-red triplet) (line centre, ±0.055 Å, ±0.11 Å, ±0.495 Å)**
- **H-alpha 6563 Å (line centre, ±0.26 Å, ±0.77 Å, ±1.03 Å)**

60 x 60 arcsec^2 FOV

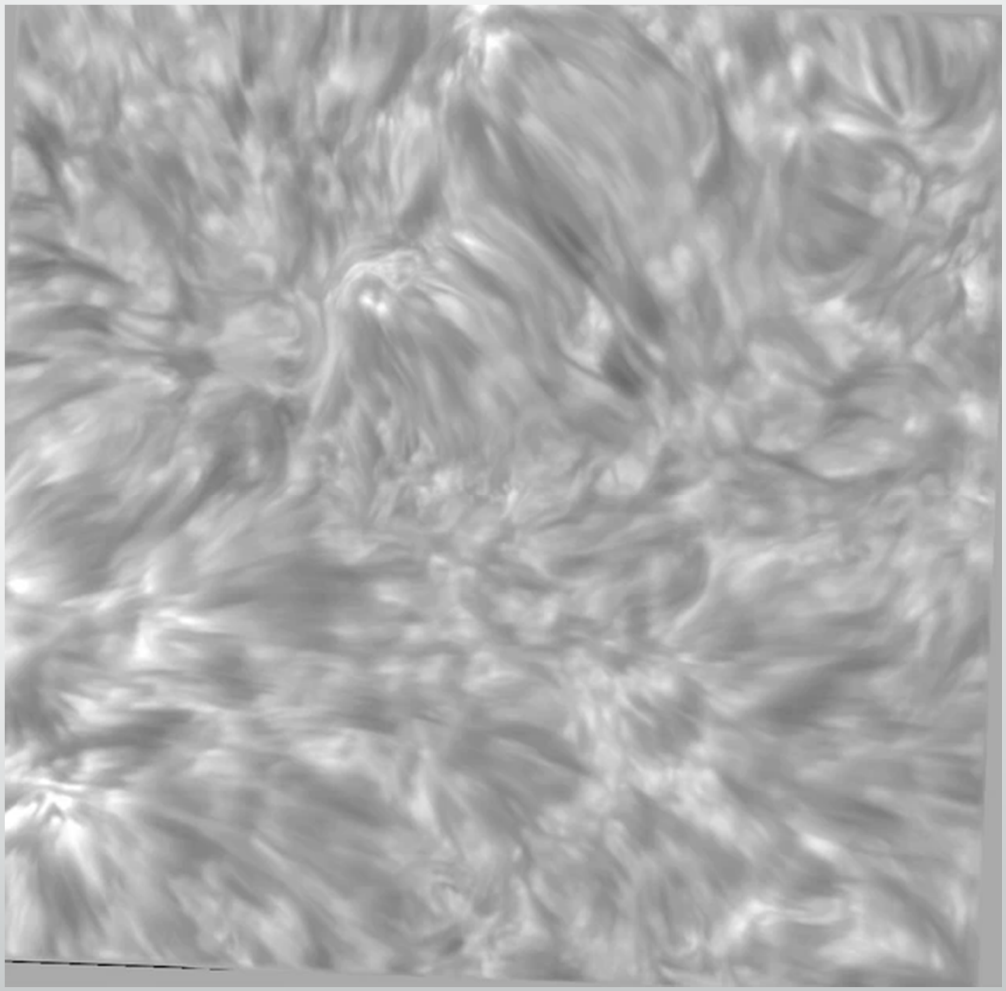
0.06 arcsec / pixel - after image restoration

4 sec Cadence

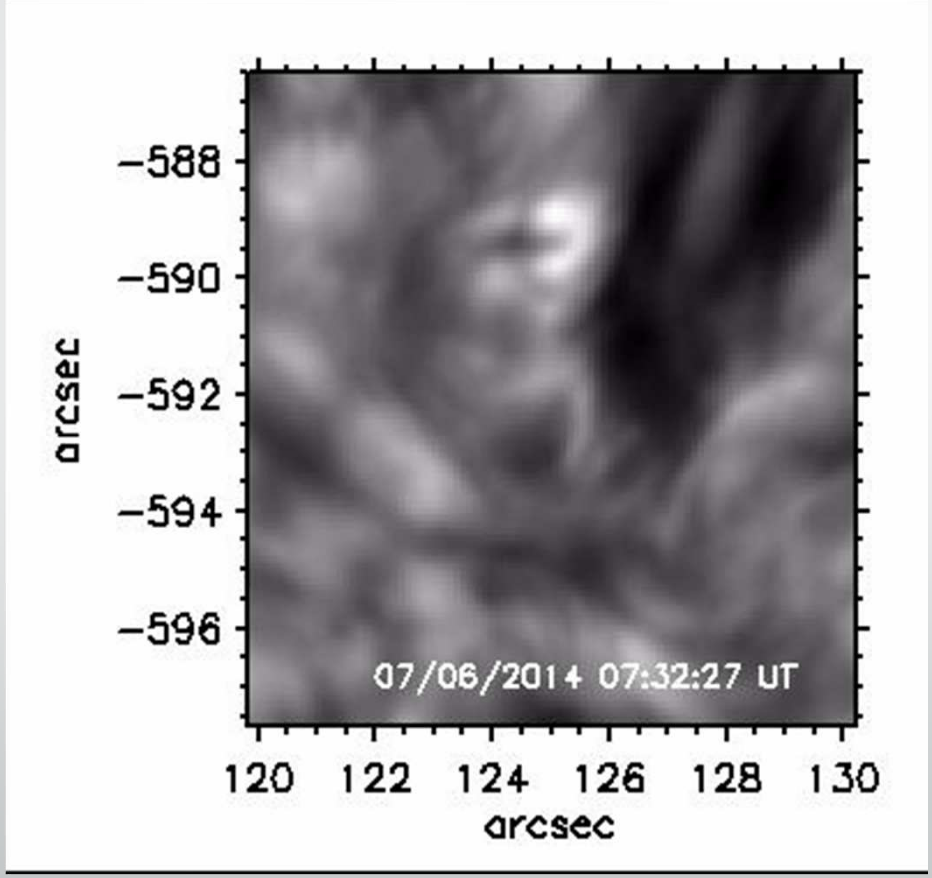
Almost 2 hours of observations - June 7, 2014


SDO/AIA HeII 304 Å
x [10² arcsec]
0
2
4
6
8
0
-2
-4
-6
-8
y [10² arcsec]
x [arcsec]
100
120
140
160
2014-06-07 07:51 UT
-560
-580
-600
-620
y [arcsec]
Hα

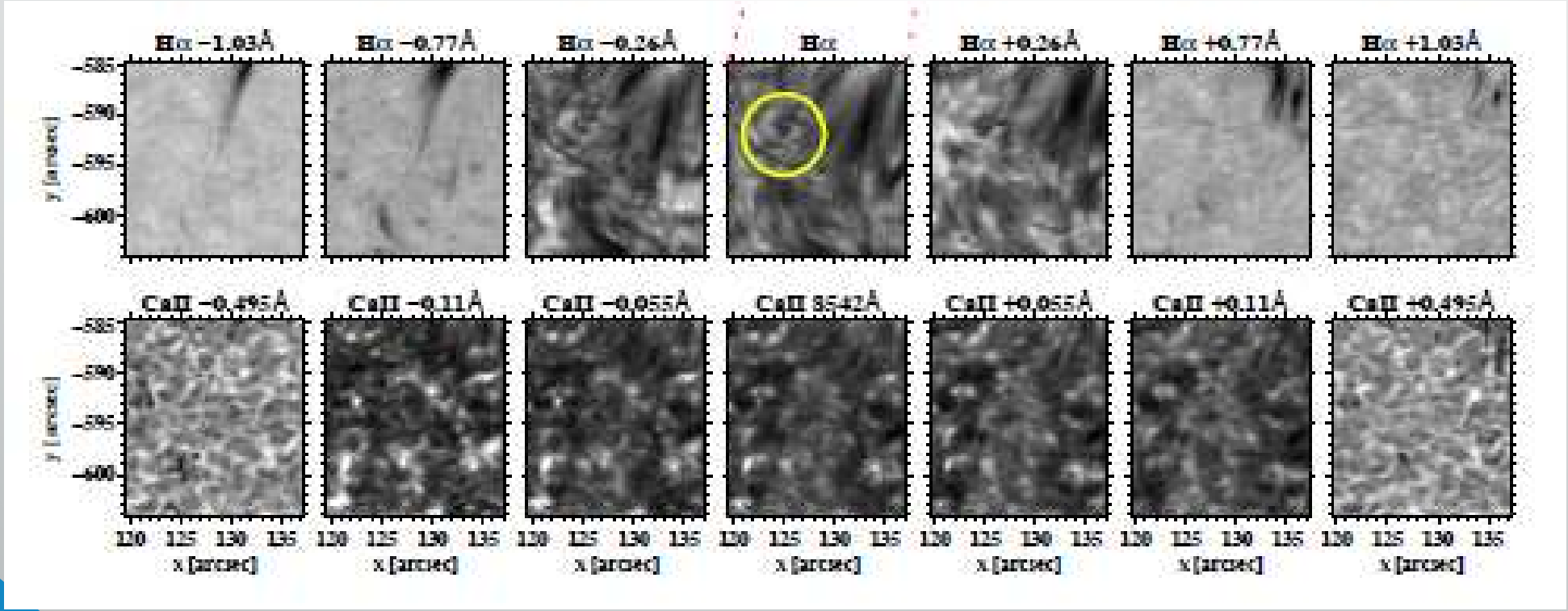
Hα line center



A closer inspection of the vortex flows- chromospheric swirls



The vortex region in 7 Hα and Ca II wavelengths



At least 4 different chromospheric swirls

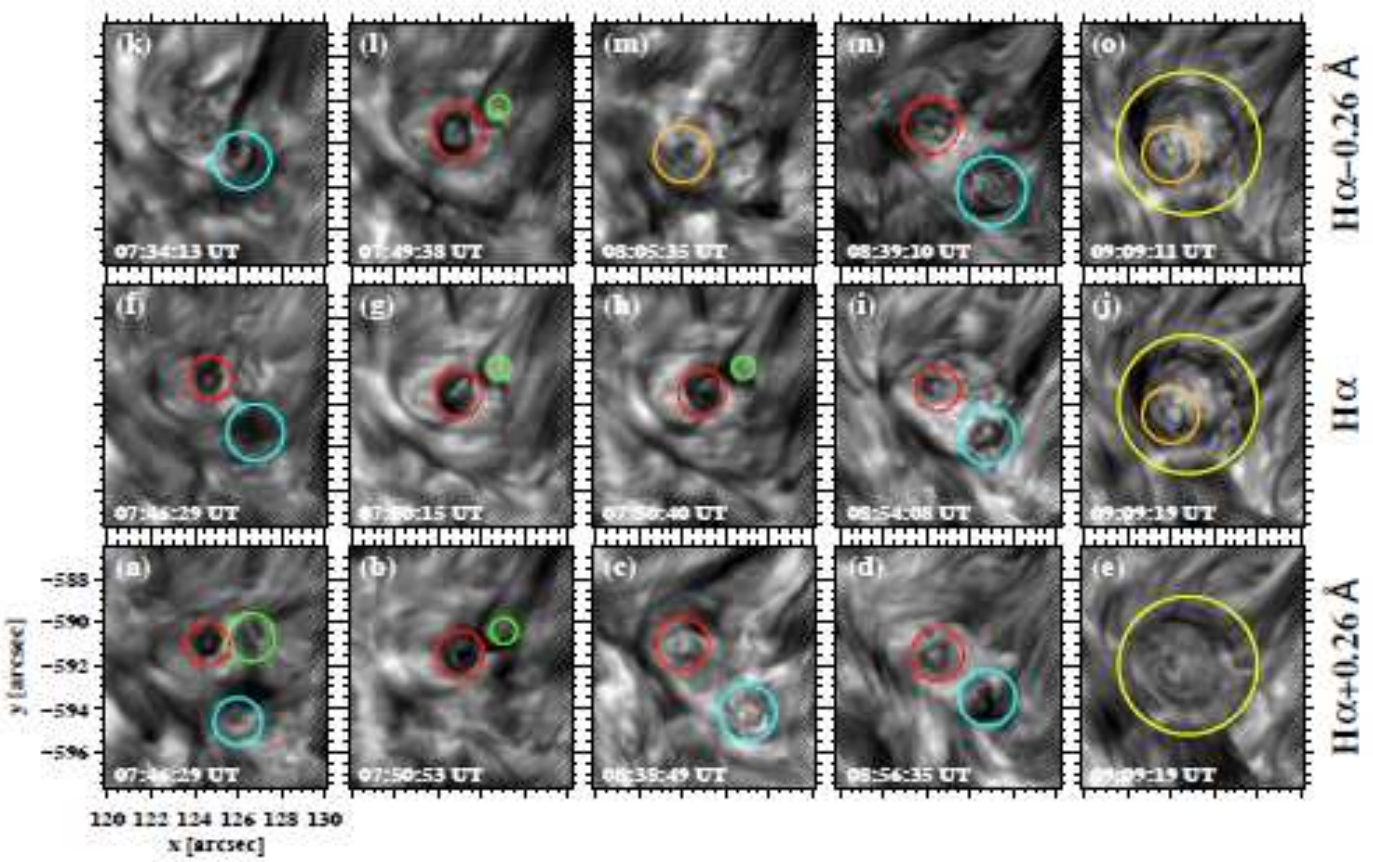
Yellow circle: vortex flows

Red swirl: most regular, at the center of the flow, rotates clockwise

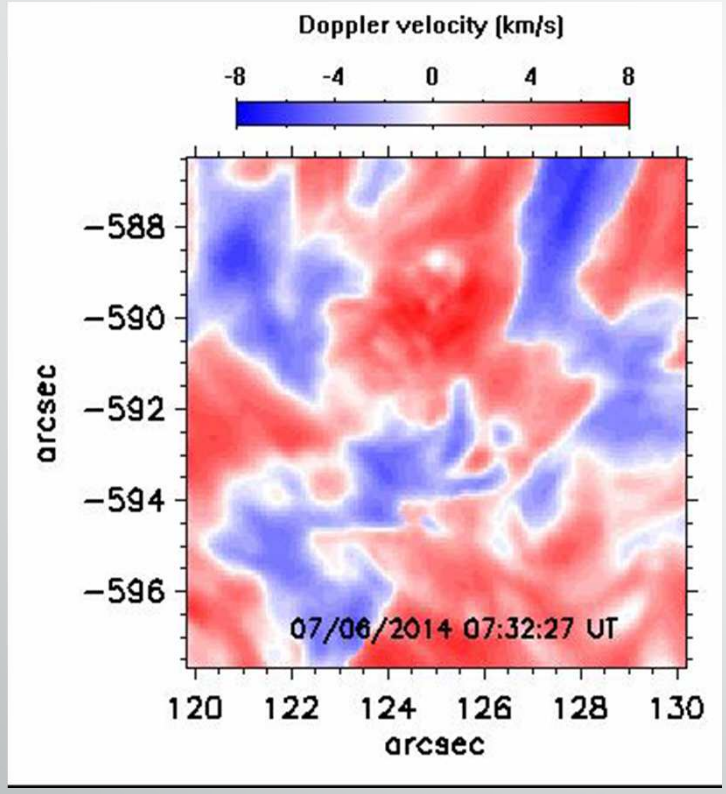
Green swirl: irregular, rotates mostly counter-clockwise

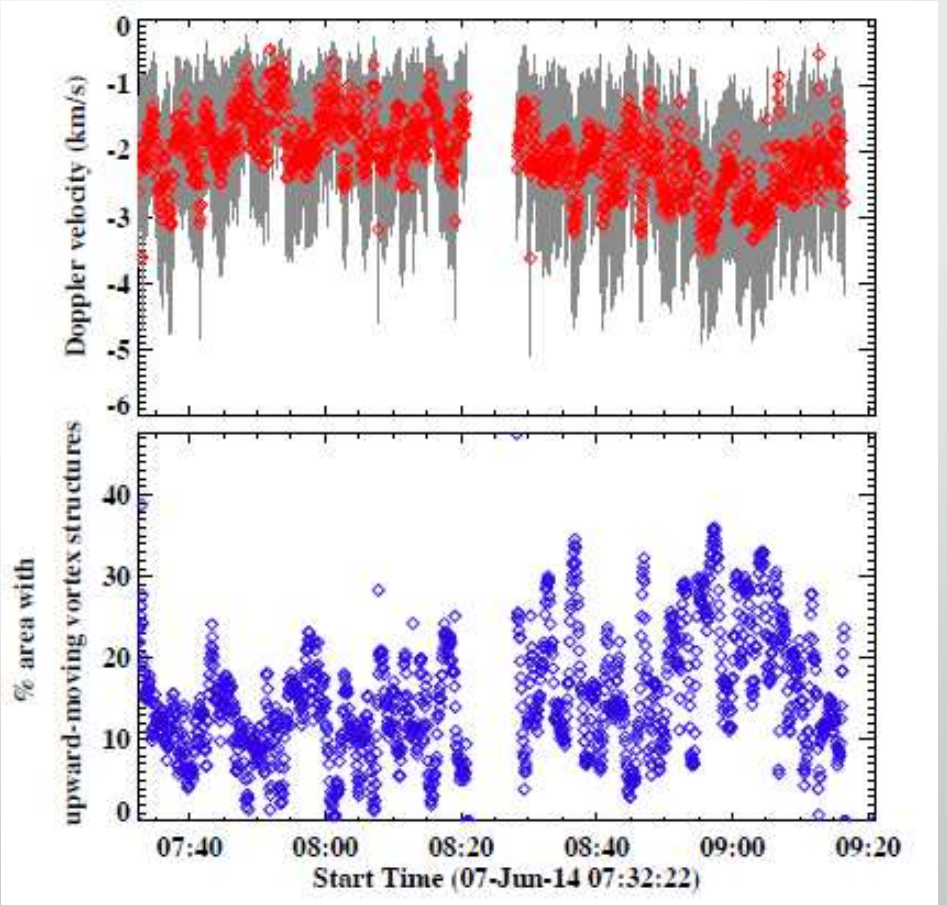
Cyan swirl: regular, but intermittent, rotates clockwise and at times counter-clockwise

Orange swirl: shortly visible



Doppler velocities

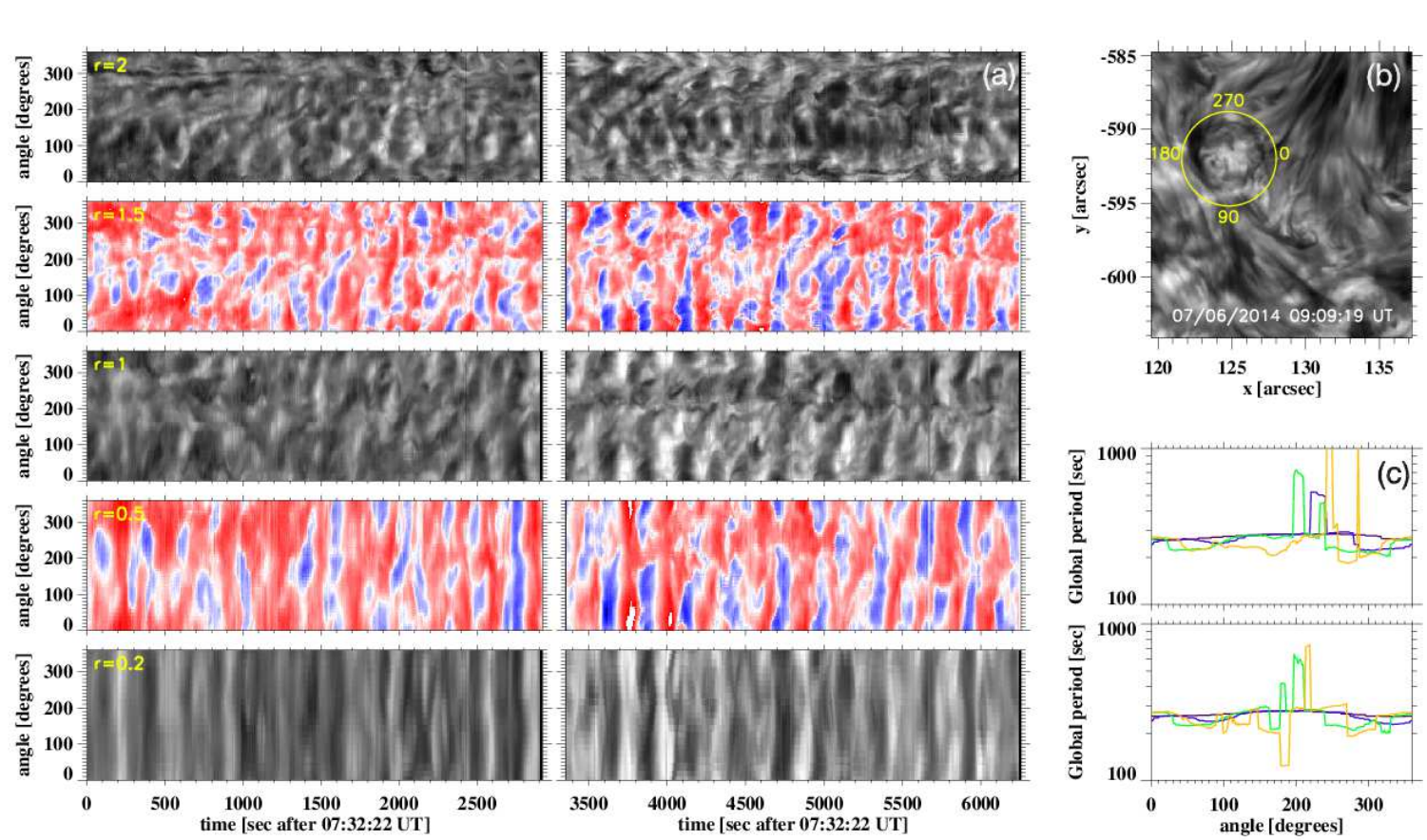




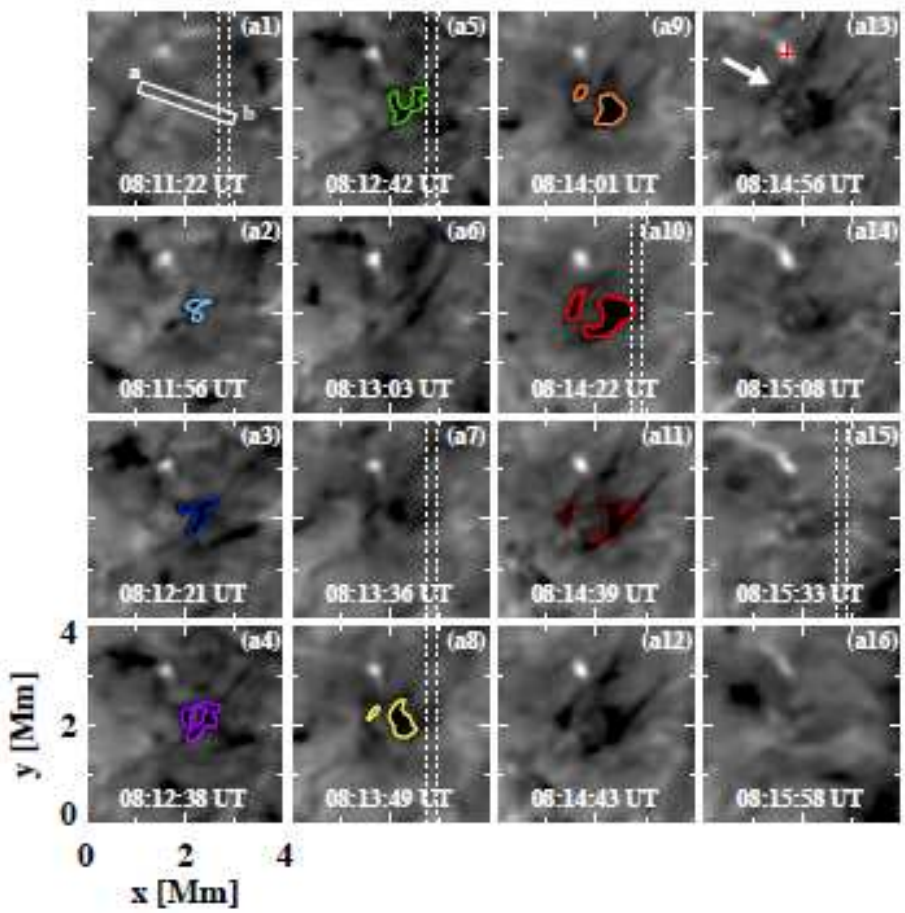
Time-angle slice images

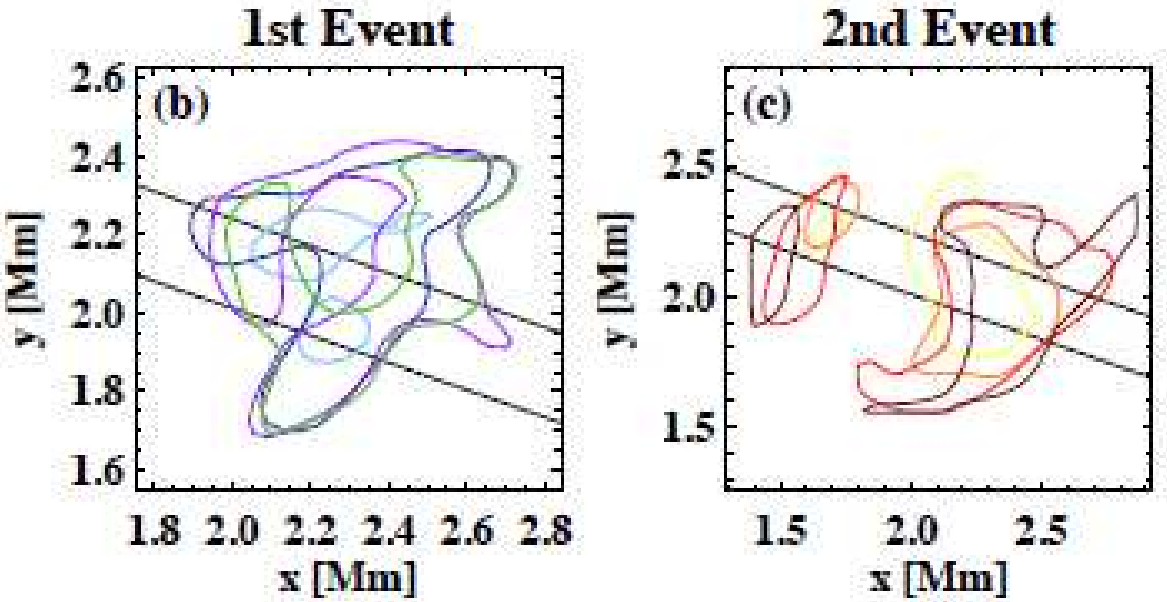
r=0.2″ vortex-related structures show a complete rotation

r> 1″ the rotation is obvious up to 200°. Then it is disrupted.

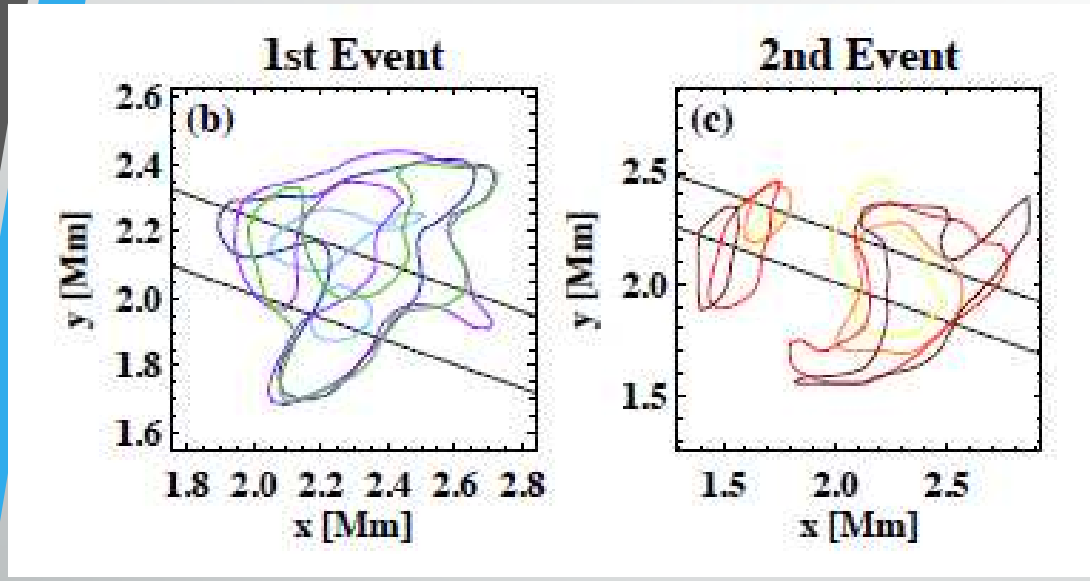


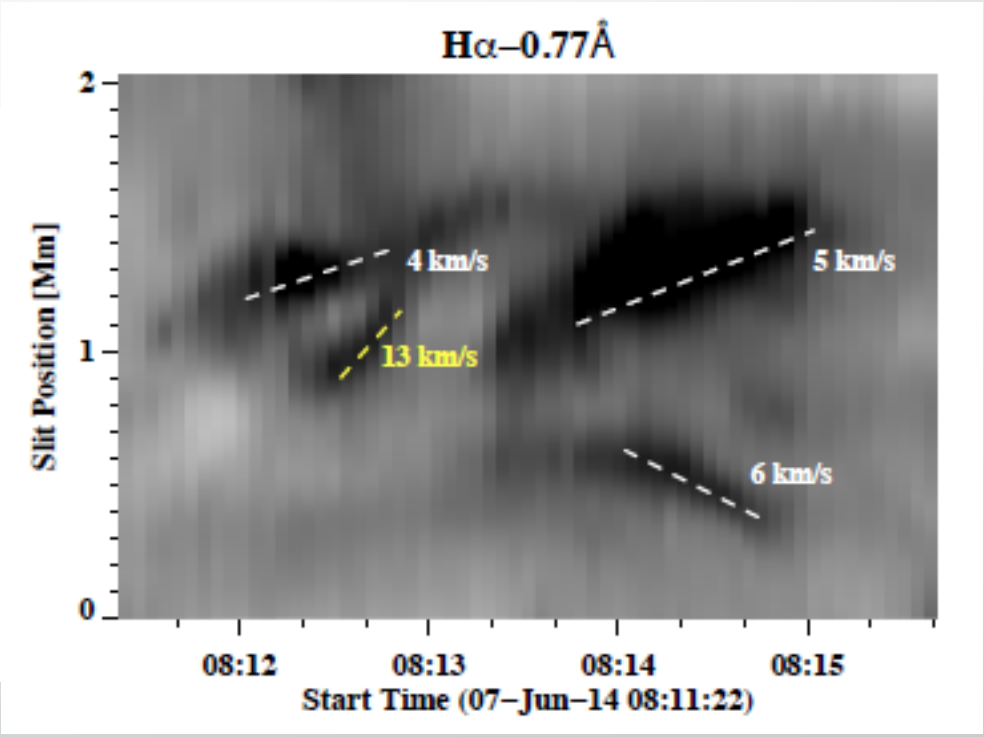
Individual swirls





Time evolution of individual swirls





CONCLUSIONS

The solar atmosphere is very complex and very dynamic

Study of vortex flows

Is very important because they are directly related to very important physical quantities:

vorticity, magnetic helicity and free energy

They also play a key role in various solar processes:

- the twisting of flux tubes by vortices has the potential to excite a wide variety of MHD waves (torsional Alfven and transverse kink waves)
- the twisting of magnetic field leads to the formation of current sheets allowing the possibility of magnetic reconnection

These processes are very important because they can provide an alternative mechanism for channeling mass and energy from the lower to the upper solar atmosphere

- Small-scale swirls may be the precursors of large scale tornadoes.

It is found that large scale tornadoes have a net positive Poynting flux of 400 W/m^{-2} more than the energy flux required to heat the corona (200W/m^{-2})