Polarized Kink Waves in Magnetic Elements

Evidence for Chromospheric Helical Waves

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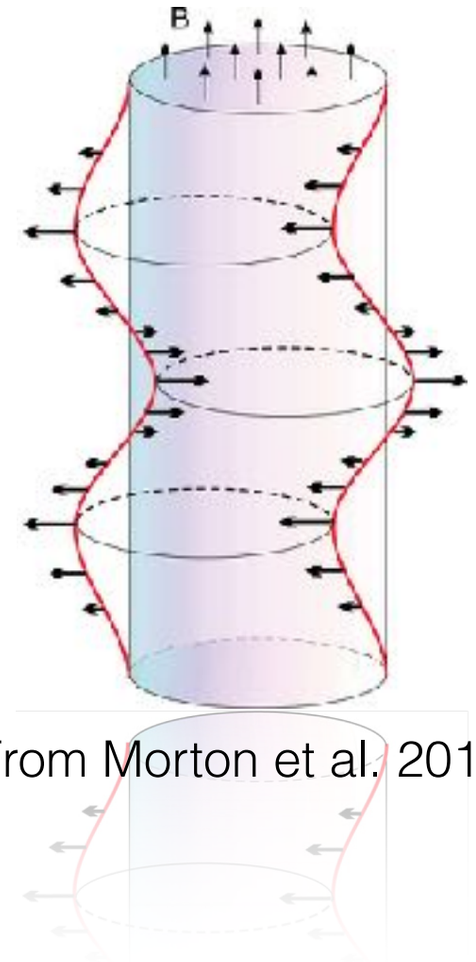
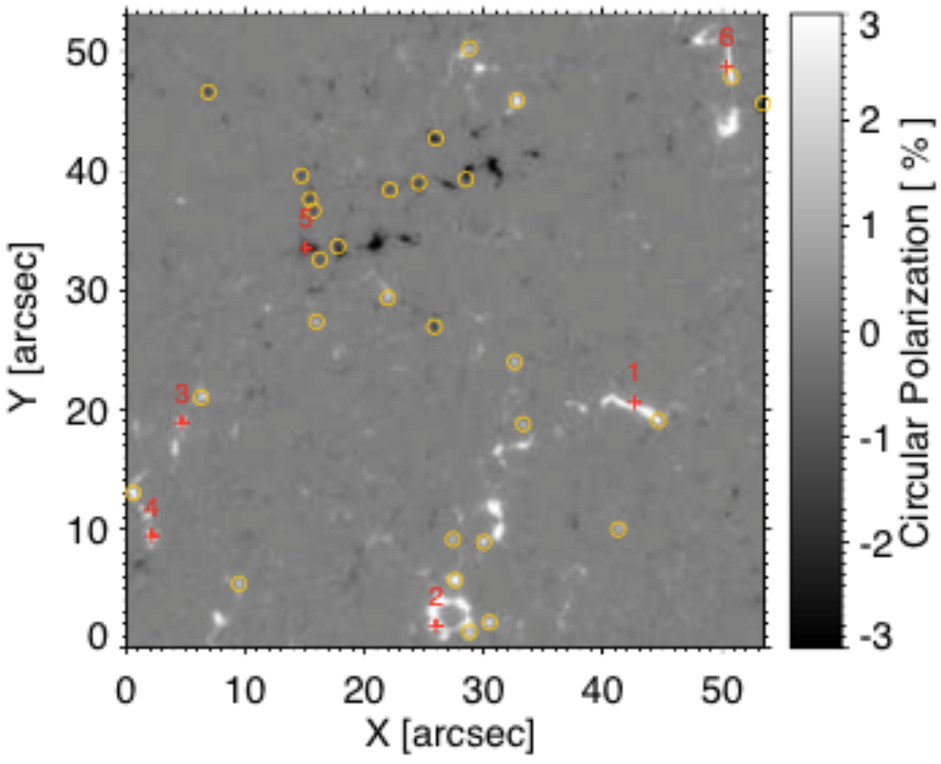
Kink waves in the lower atmosphere

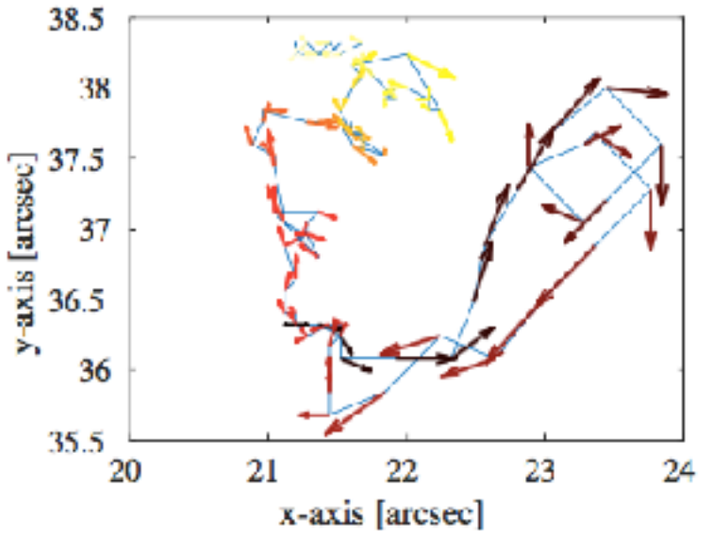
- They have been detected at different heights from the photosphere to the corona
  (e.g. Jess et al. 2012, Morton et al. 2014, Jafarzadeh+ 2017)

- In the lower atmosphere they can be detected by tracking magnetic elements



From Morton et al. 2012

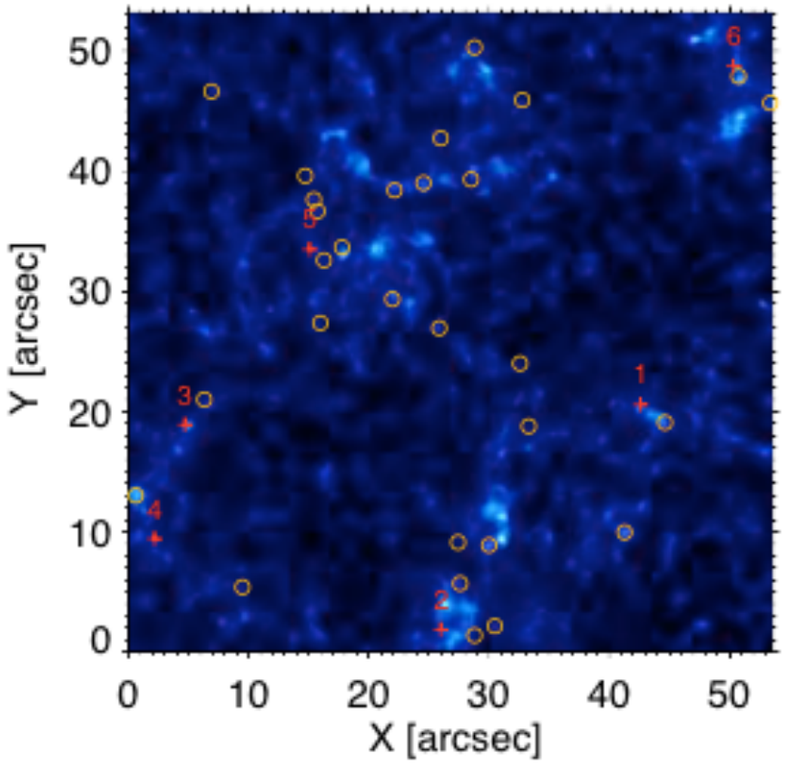




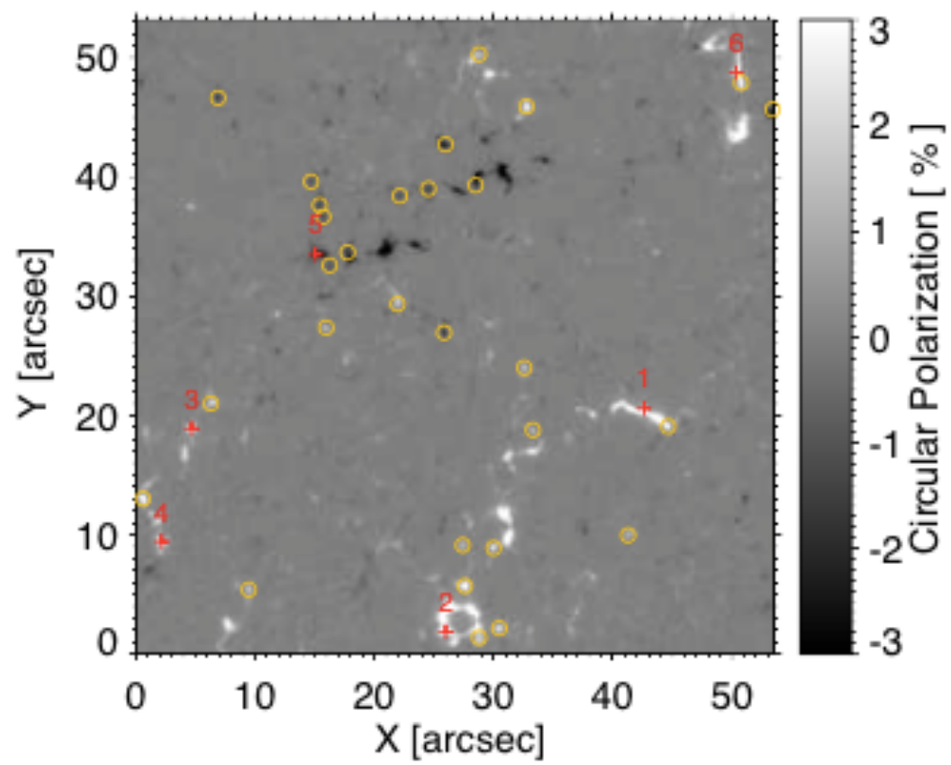
From Stangalini+ 2017

Multi-height observations from CRISP@SST

450 km



200-230 km



Simultaneous data of the **photosphere** (Fe I 630.1 and 630.2 nm full Stokes)

+

chromosphere

Ca II H 396.9 nm core

Acquired at disk center on 6/8/2011

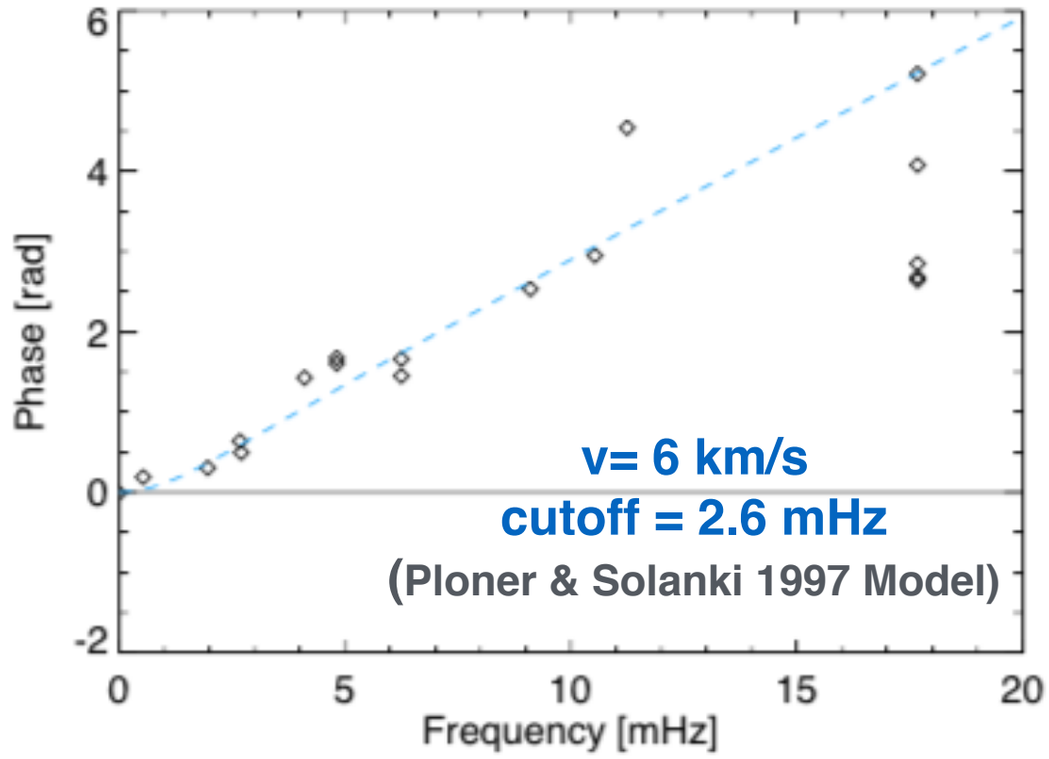
0.16 arcsec resolution

Cadence 28 s

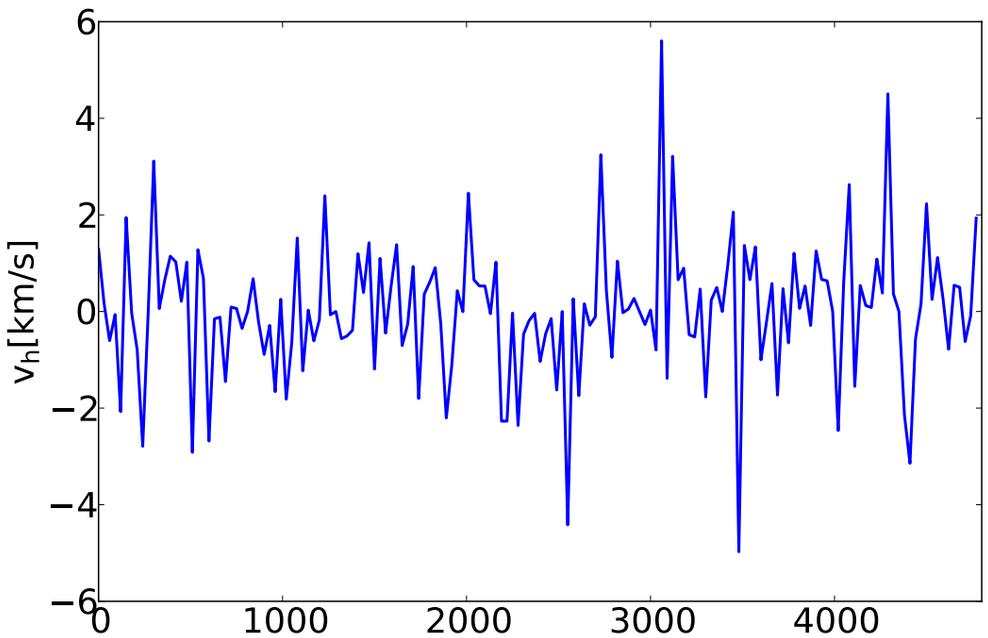
Duration 47 min

Phase lag: upward propagation

- Photosphere-chromosphere phase lag
- Only elements with coherence > **0.9** are considered



Analysis methods: beyond FFT and wavelet



non-stationary and (probably) non-linear processes

We need a method that overcomes the limitations of FFT and wavelet analysis

Empirical Mode Decomposition (Huang 1998)

EMD moves from the assumption that most of the physical systems are the

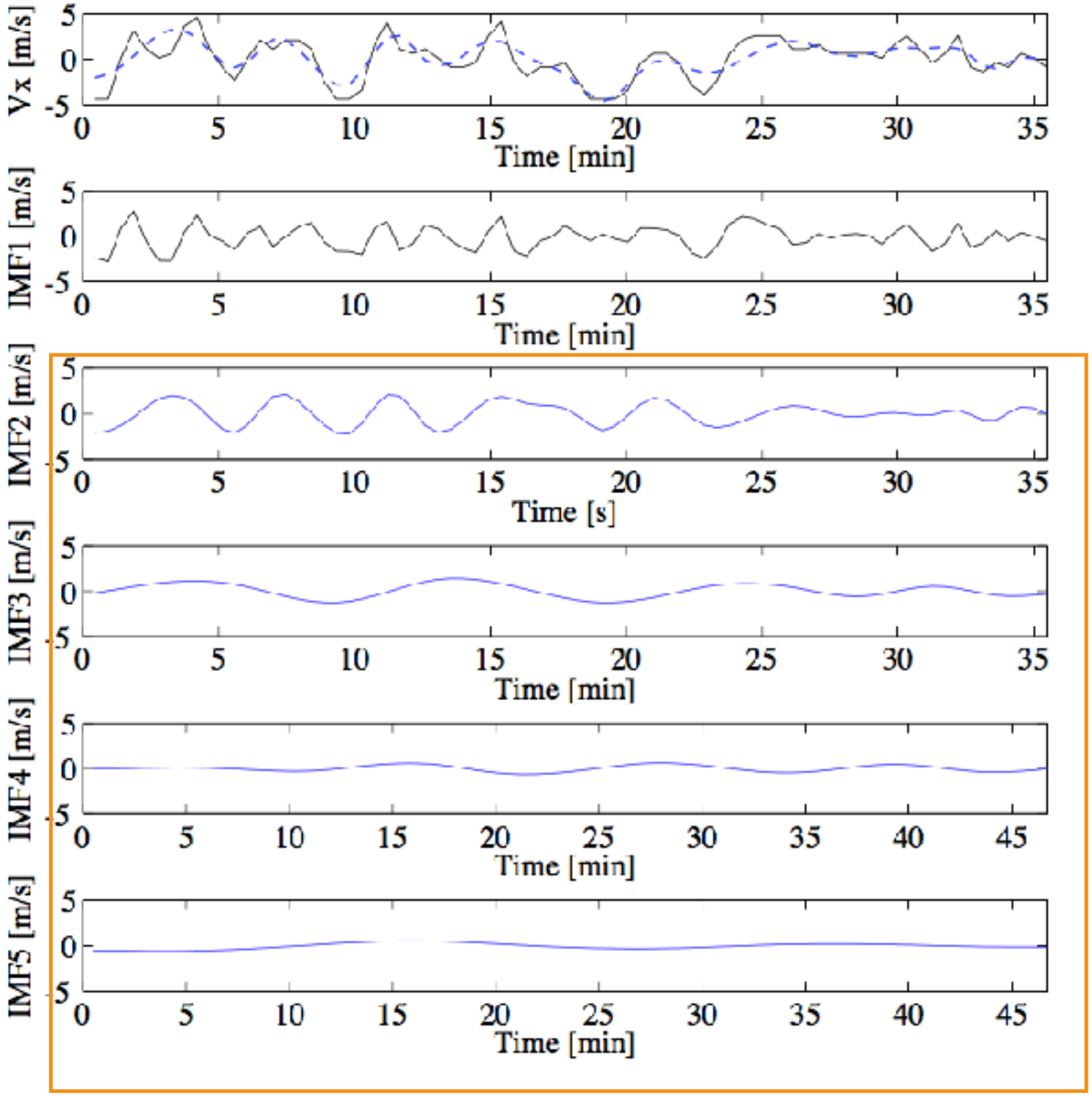
superposition of many different time scales

simultaneously active

Intrinsic mode functions built on top of the signal itself and representing oscillations at a local level

$$v(t) = \sum_{i=1}^{n} IMF_i(t)$$

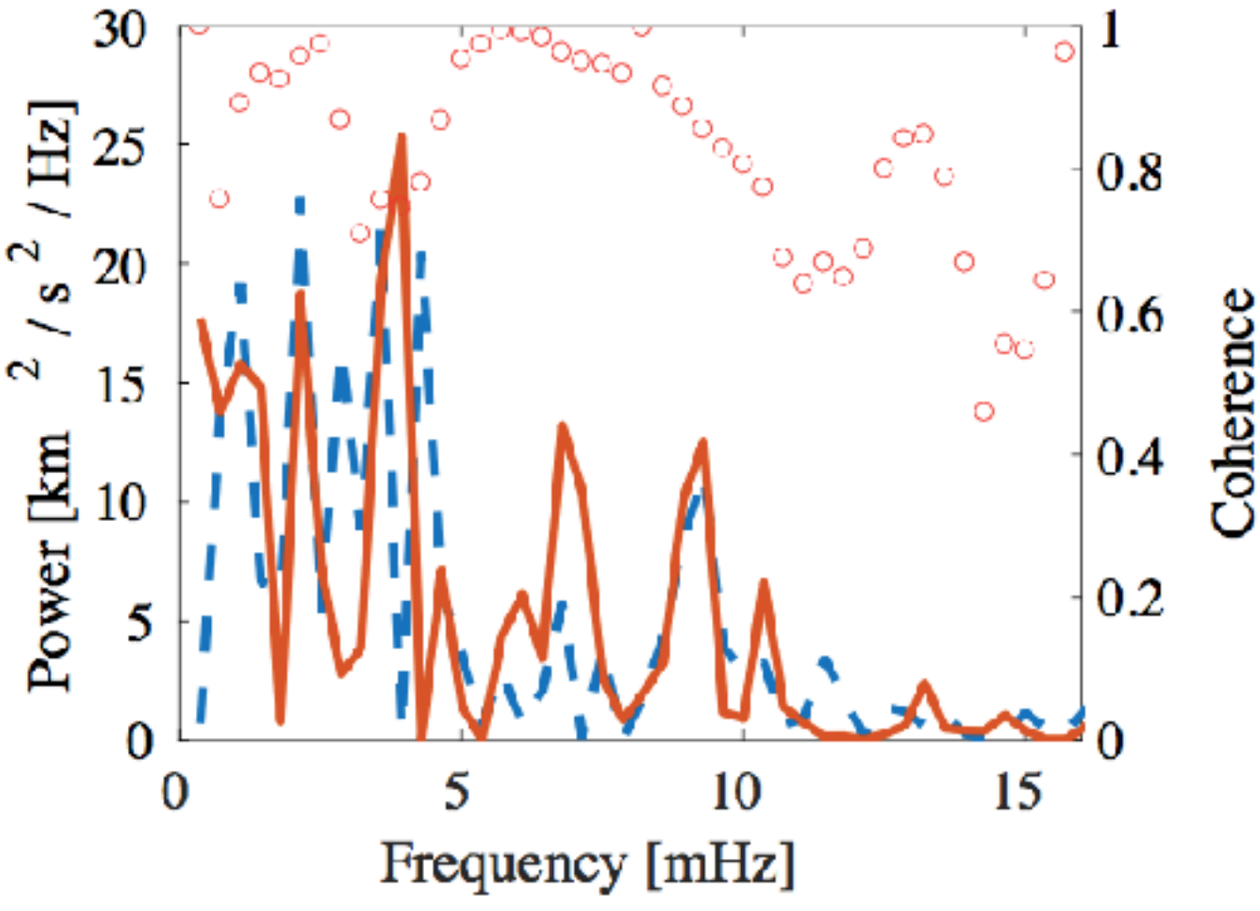
Rilling (2003) stopping criterium



V_x-V_y Coherence Spectrum

- When studying kink like oscillations, one generally focuses on the horizontal perturbations along one axis

- What if we study both components?

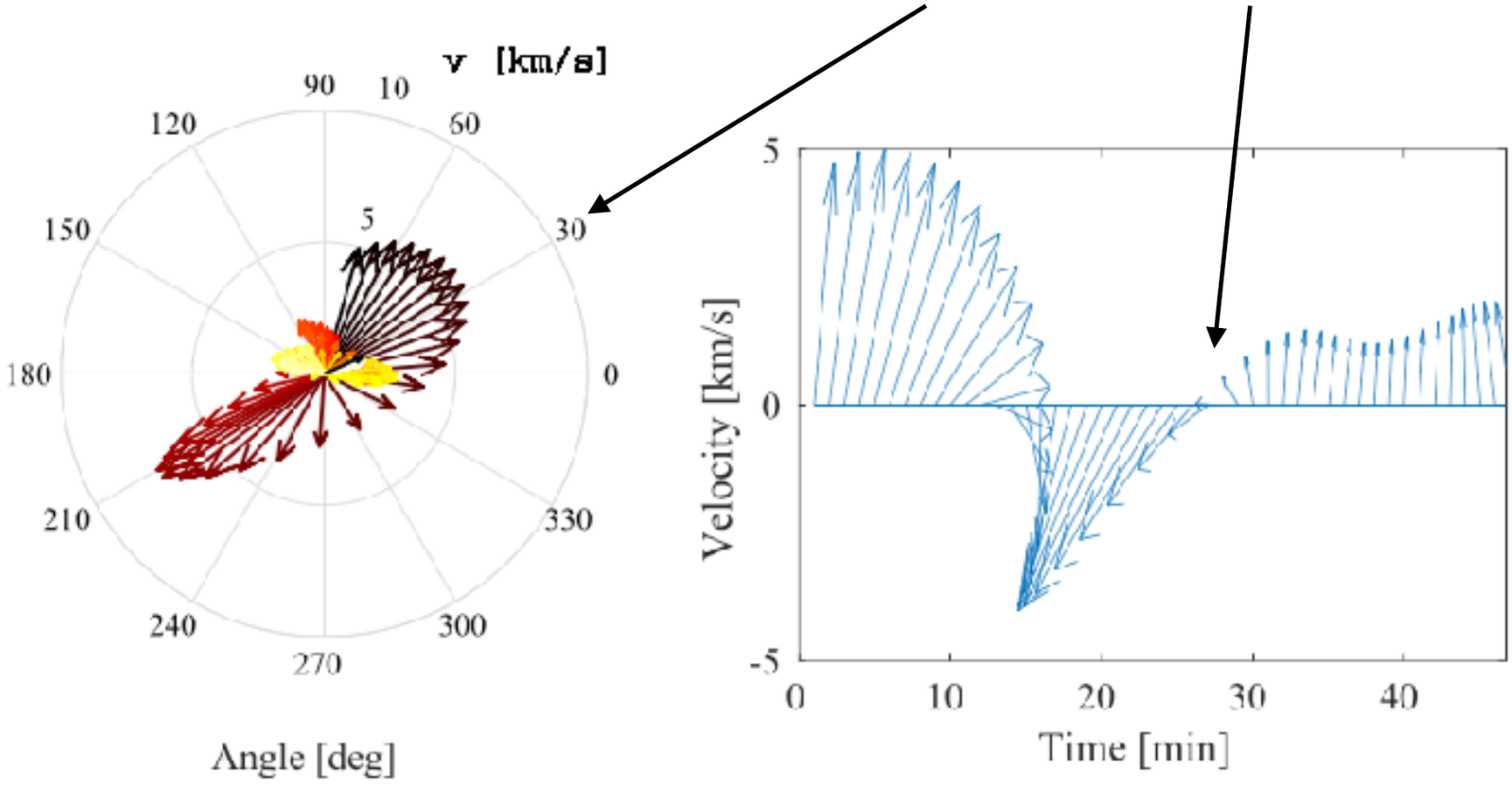


Evolution of the velocity vector

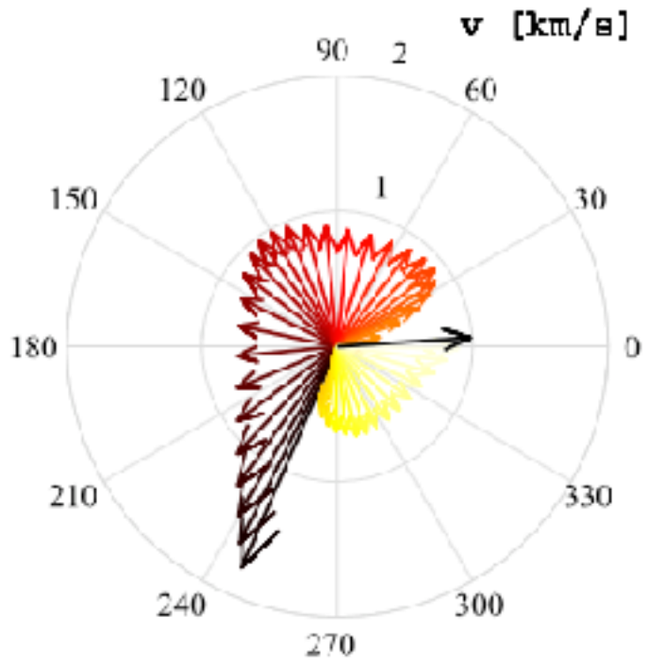
We study the evolution of the velocity vector of EMD filtered time series (sum of the low frequency IMFs) in the chromosphere

Helical waves

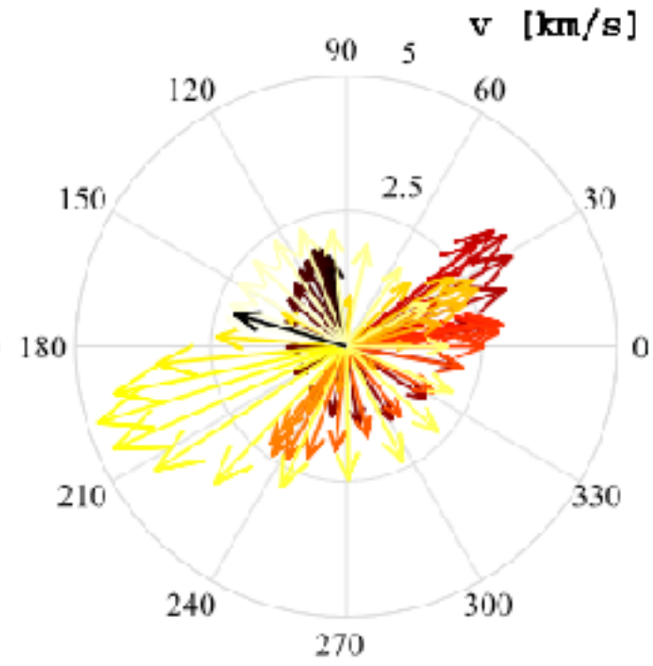
Rotation of the velocity vector



Stangalini+ 2017



Angle [deg]



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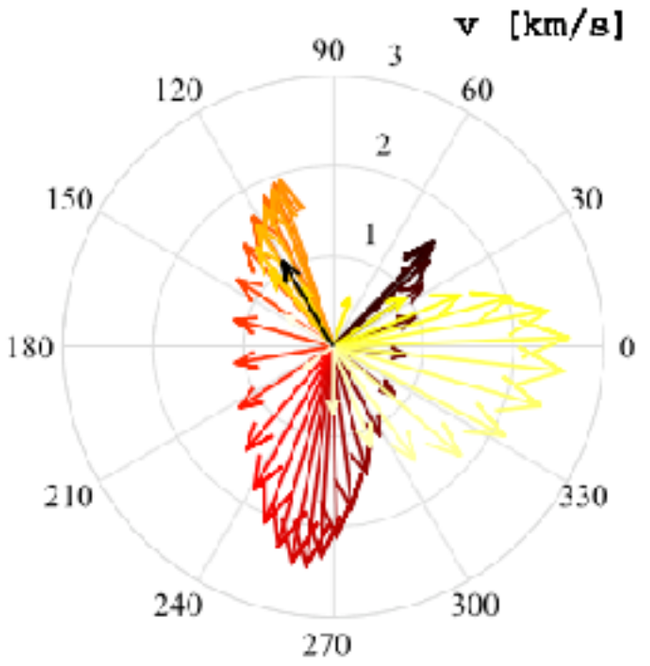

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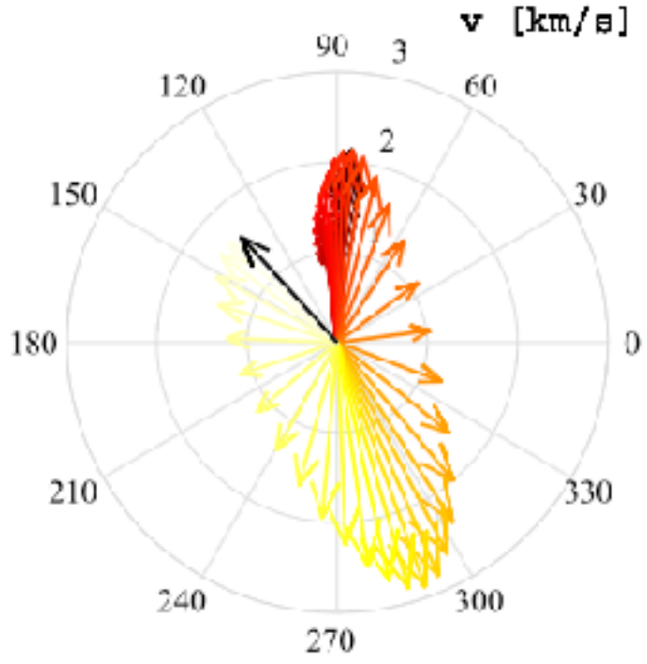
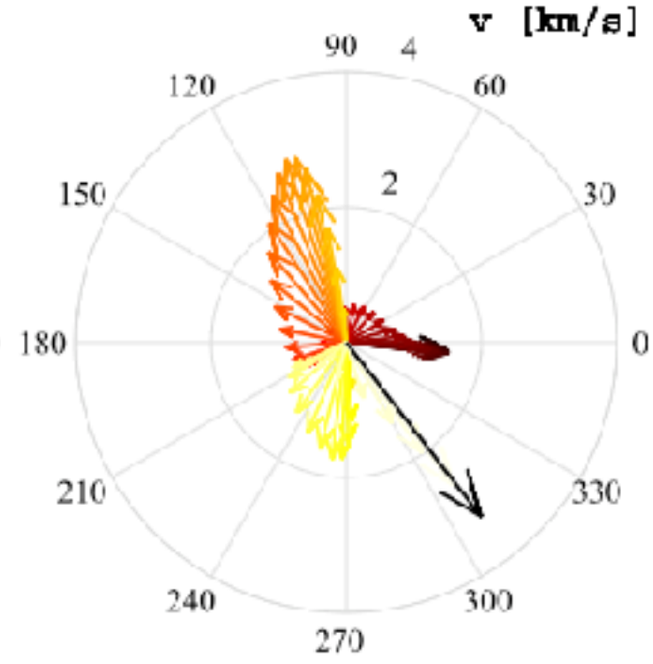


Angle [deg]



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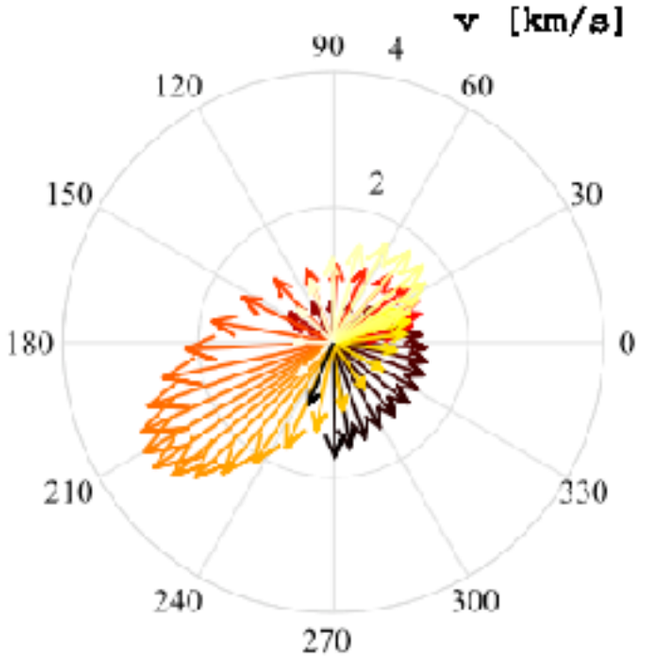
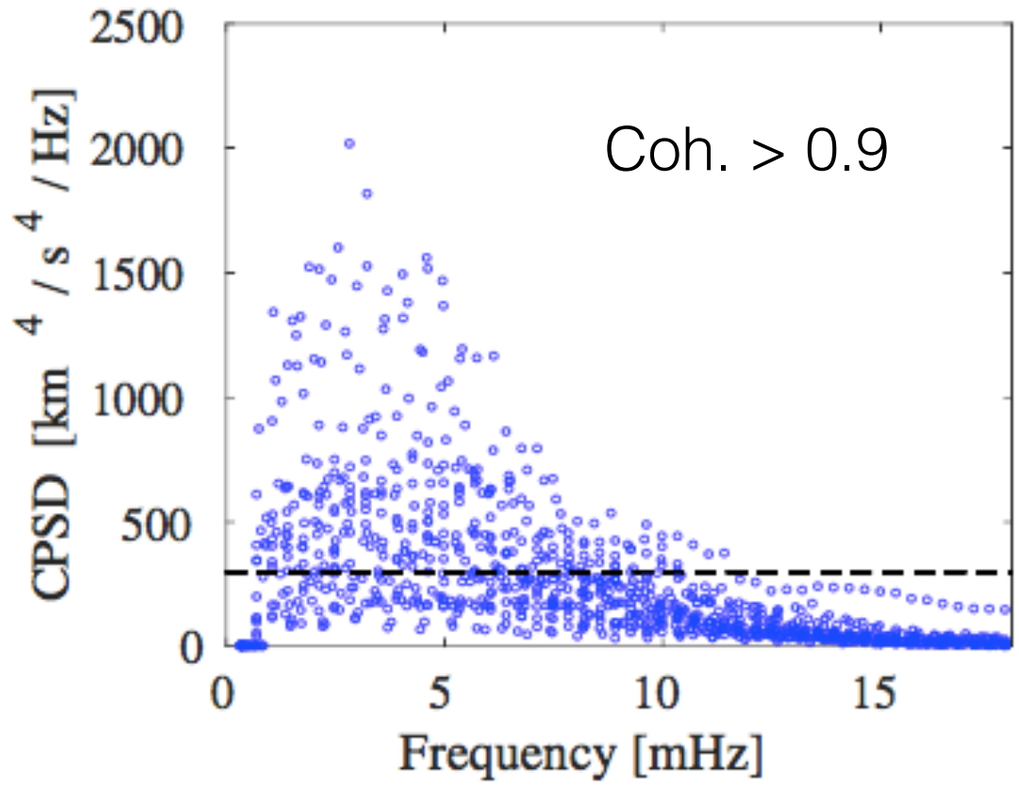


Angle [deg]

“Statistics” of an incomplete sample

- Cross-correlation at low frequencies (<10 mHz)

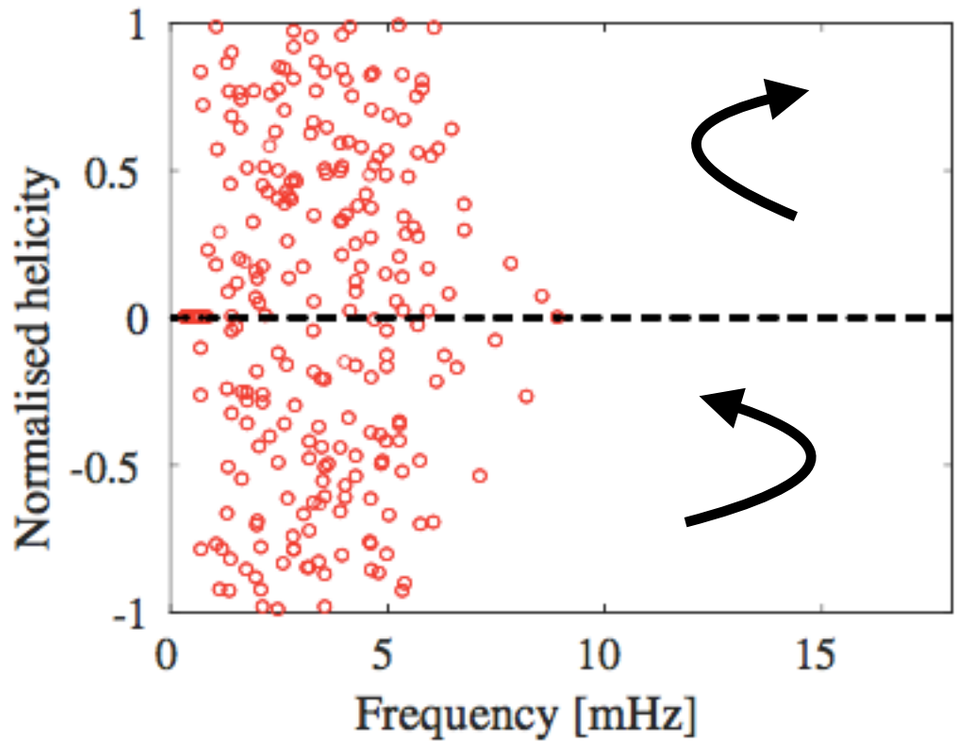


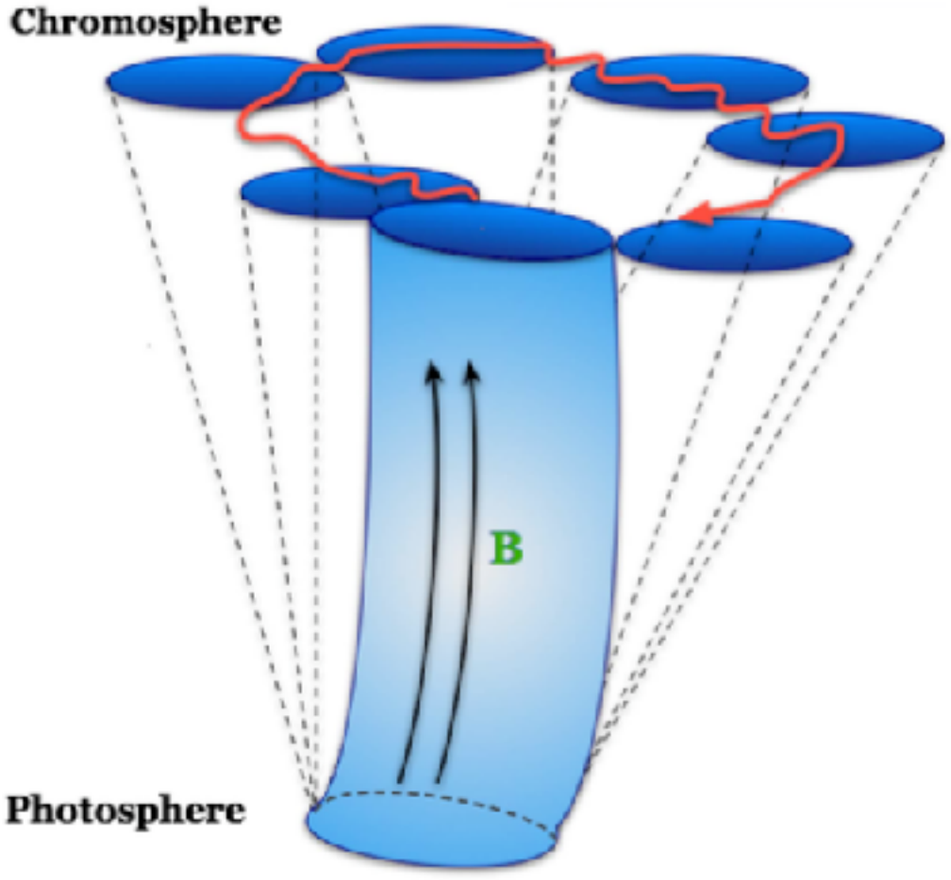
- Normalized helicity of velocity perts as defined by Carbone & Bruno (1997):

$$\sigma(\omega) = \frac{\omega H(\omega)}{|a_x|^2 + |a_y|^2}$$

$$H(\omega) = \frac{2\, Im[a_x^*\, a_y^*]}{\omega}$$

where a_i are the FFT transforms of V_i





High frequency

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Low frequency helical oscillation

A polarized motion was also found in solar spicules De Pontieu+ (2007)

Zaqarashvili & Skhirtladze (2008) have shown that the superposition of random photospheric pulses with different orientations may easily explain the observed polarised motion.

Summary

- Vx and Vy spectra are coherent (> 0.8-0.9)
- Photospheric pulses in different directions and different amplitudes are effective in generating helical waves
- Despite the expansion of the flux tubes, in the chromosphere they still maintain their kink-like helical oscillatory behavior