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Analysis of complex **3D** motions in spicules

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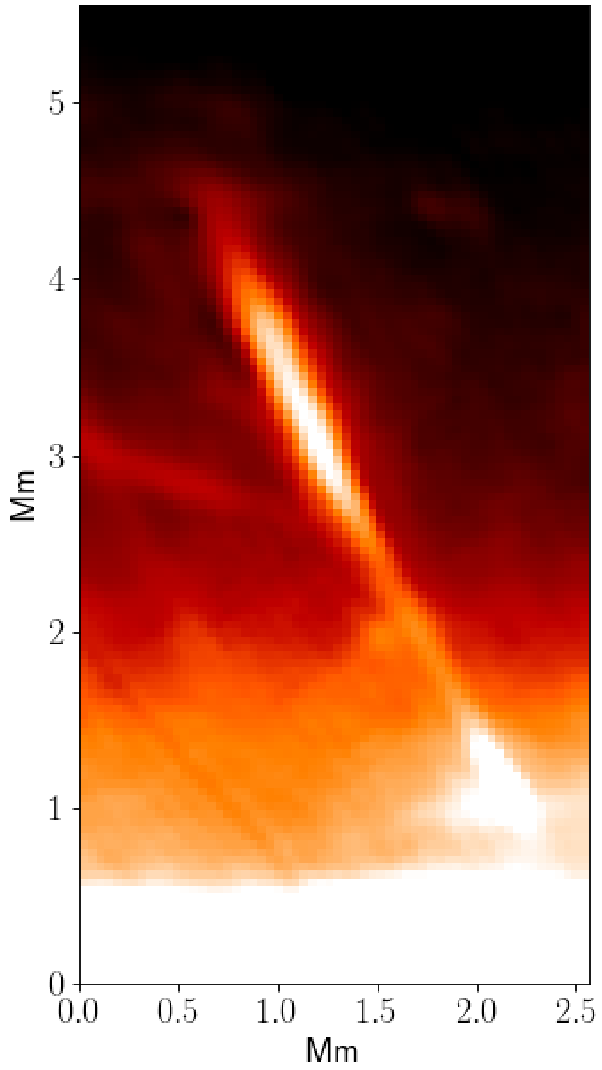
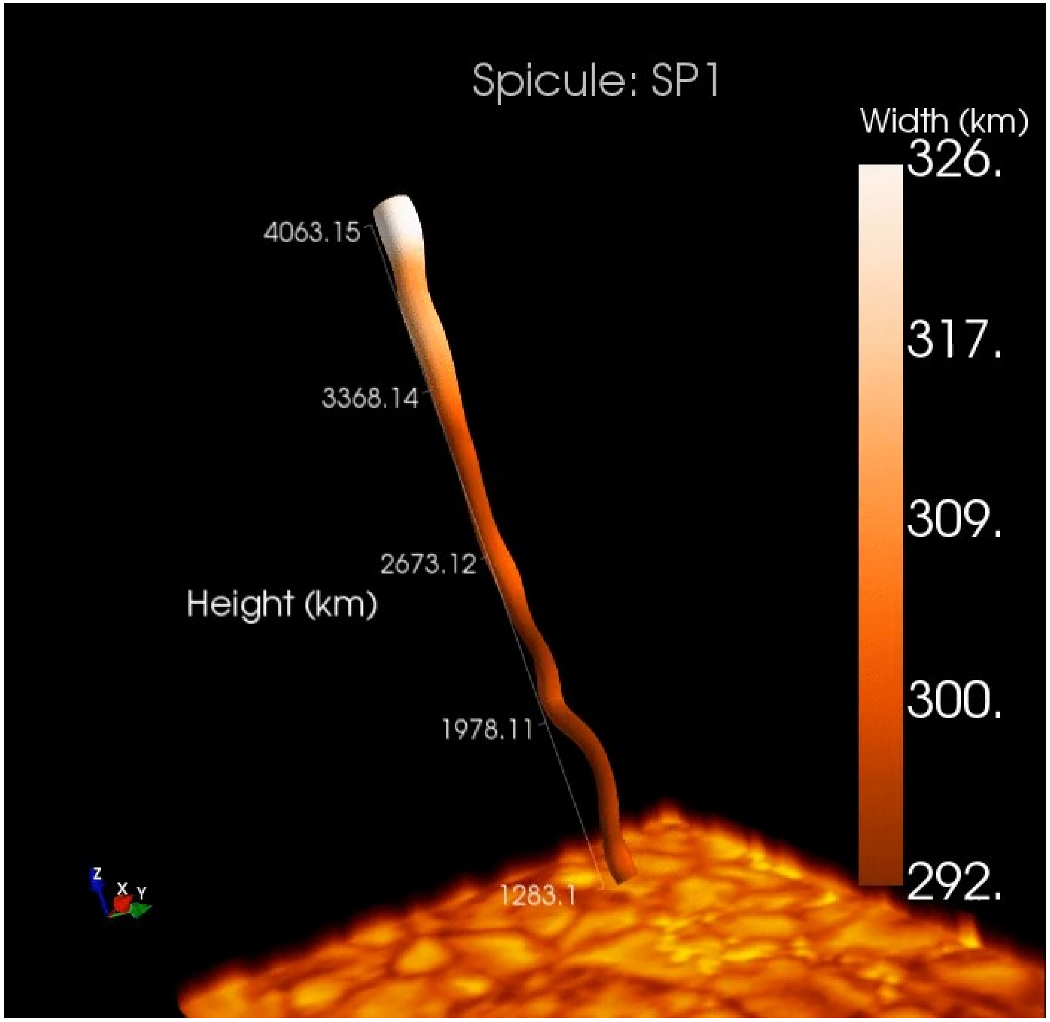
Imaging-spectroscopy data

SST/CRISP Hα data, 35 line-scan positions, cadence: 7.7 sec, pixel-size: 42.7 km

Sharma, Verth & Erdelyi, 2017

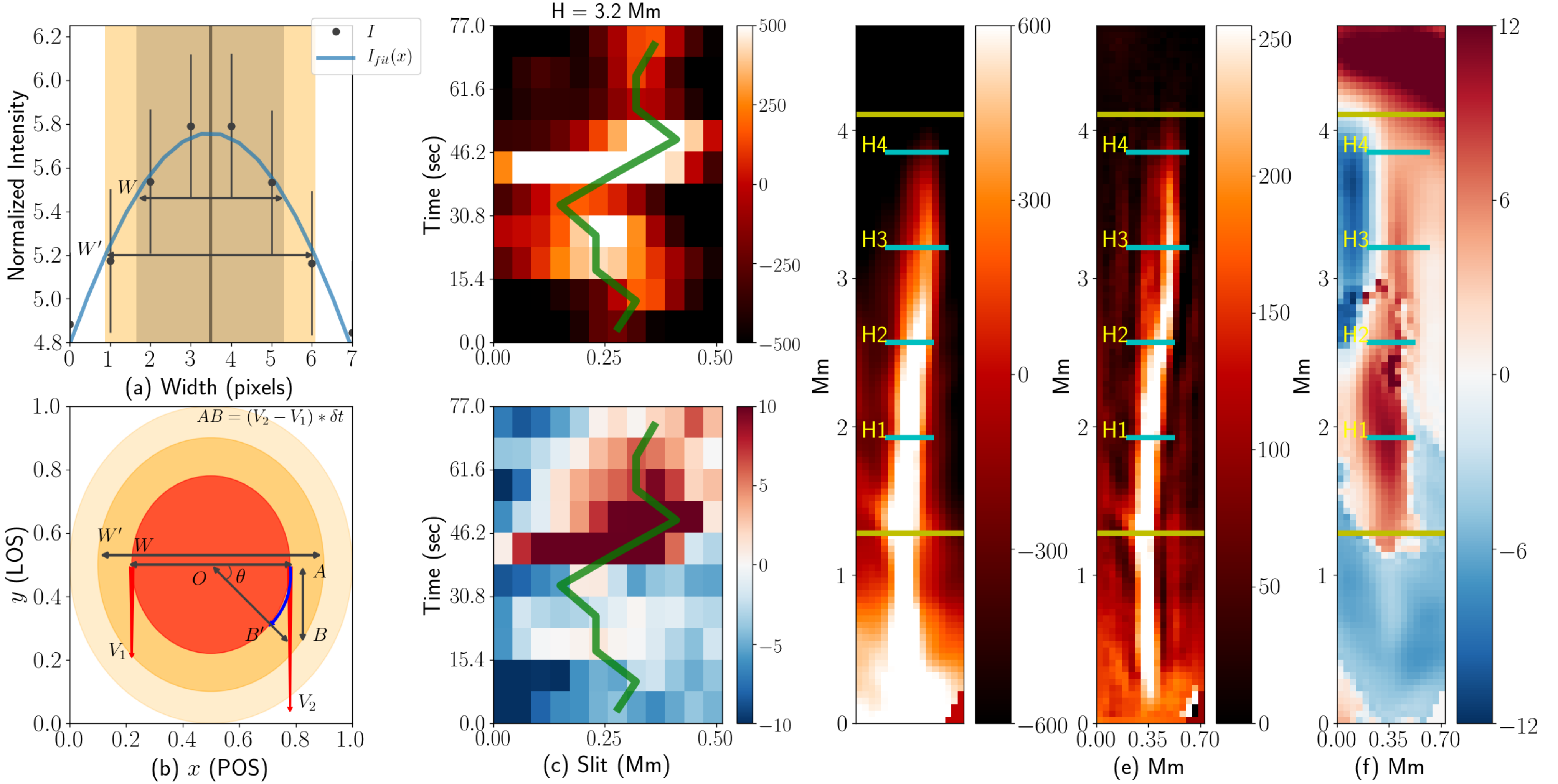




Base: Hinode G-band image

Spicule: SP1, Scan-pos = ±1.204 Ang, Length = 4.9 Mm, Height = 4.1 Mm, Inclination = 23°.6

Estimation of the dynamical components



$$I_{fit}(x) = a \exp\left\{\frac{(x-\mu)^2}{2\sigma^2}\right\} + b.$$

FWHM = $2\sigma(2\ln 2)^{1/2}$

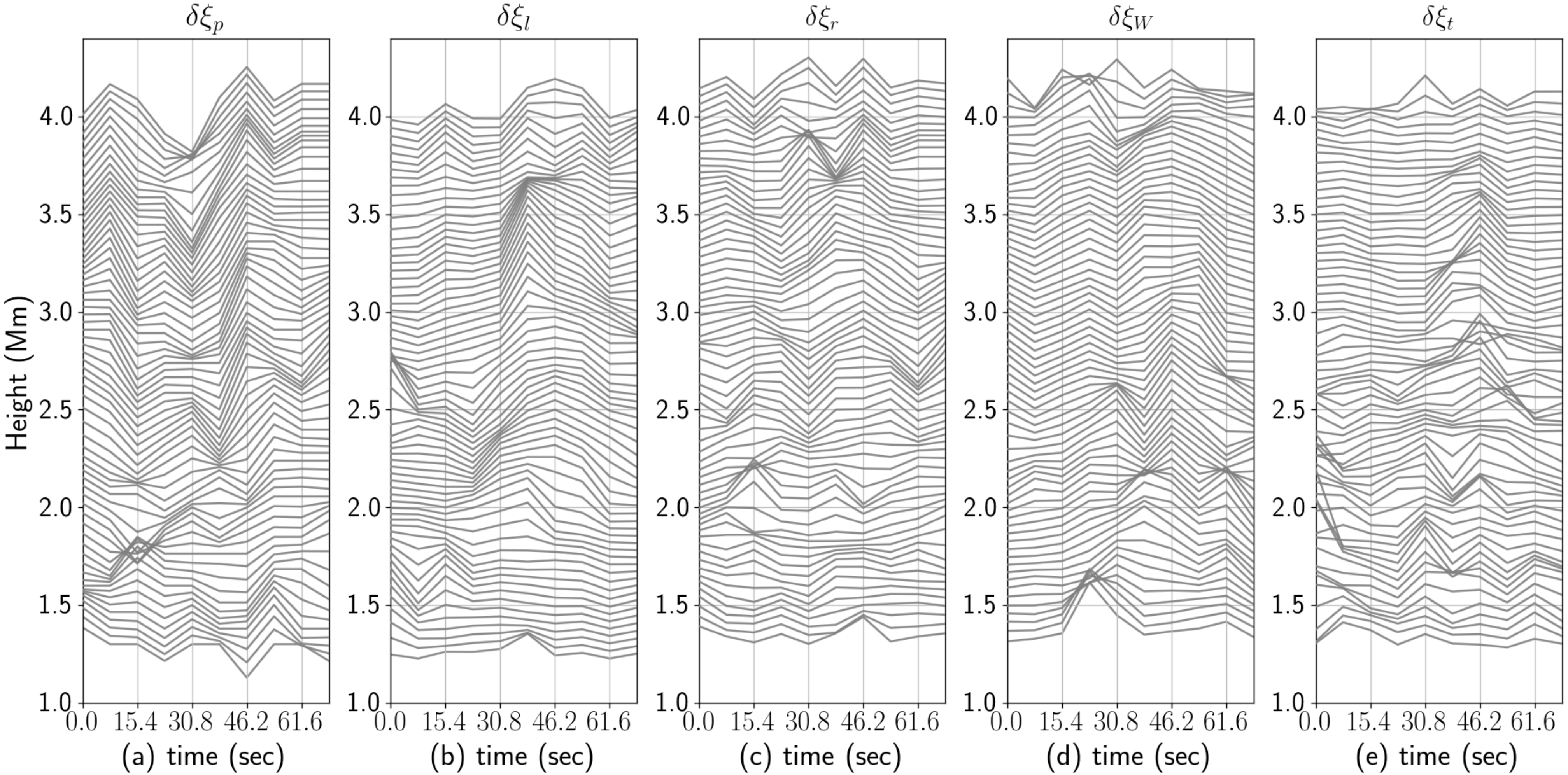
$$\theta = tan^{-1}\left(\frac{AB}{OA}\right)$$

$$AB' = \theta \cdot \breve{O}A$$

$$\xi_r = \sqrt{\xi_p^2 + \xi_l^2}$$

Pulse-like behavior

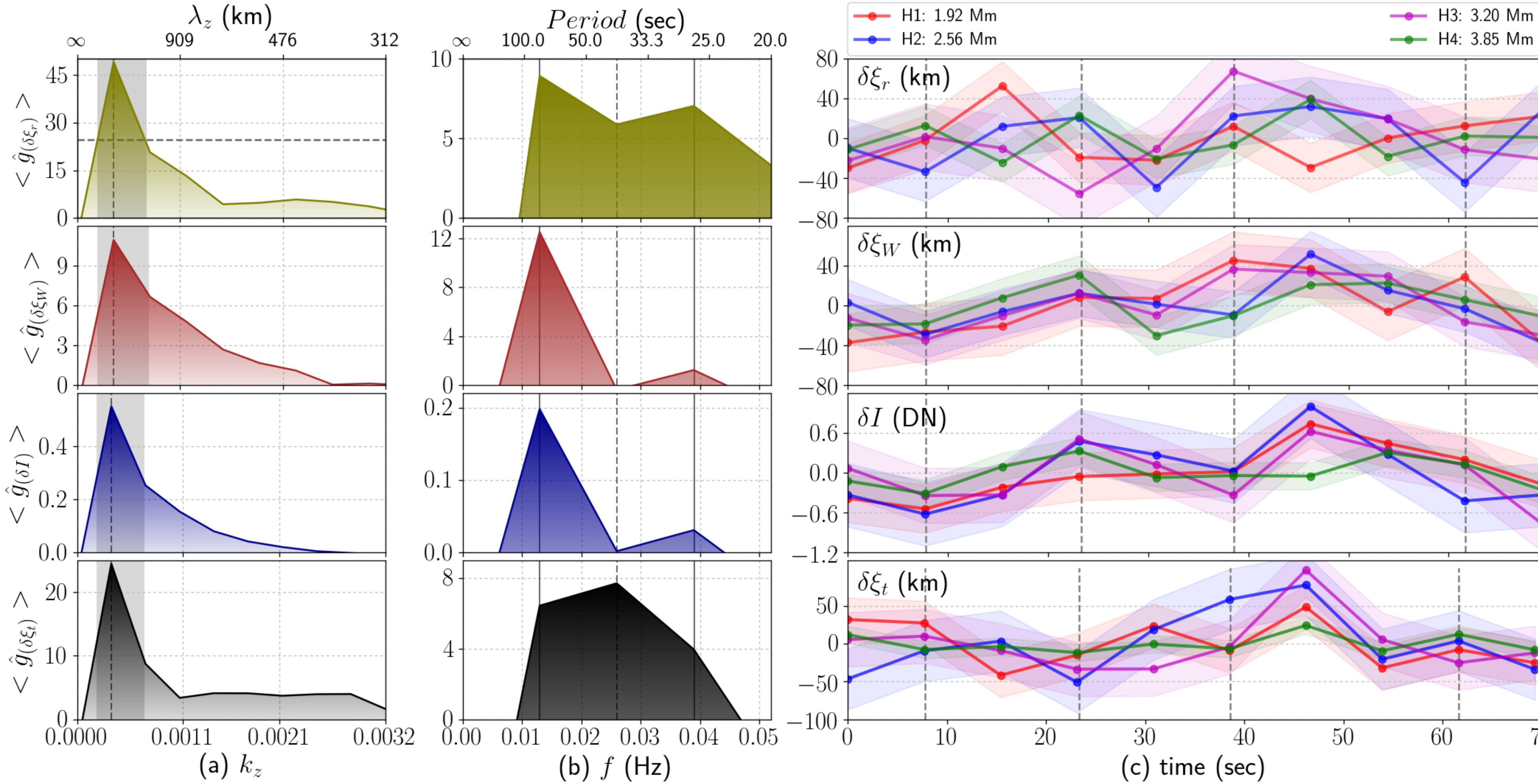
*Average magnitudes with Std. Dev. All units in ‘km’



288±94* | 30±17 | 180±70 | 156±24 | 44±39

Martinez-Sykora et al., Science, 2017 (Whiplash-effect)

Kuzma et al., A&A, 2017 (Velocity-pulse)



PSDs in wavenumber and frequency domains

λ = 2800 km

$$f_{\delta\xi_t} = 2 f_{\delta\xi_r}$$

$$< \hat{g}_{ii}(k_z) >= \frac{1}{T}\sum_{t=1}^{T} \left| \hat{g}_{ii}(k_z) - \bar{g}_{ii}(k_z) \right| ,$$

$$< \hat{g}_{jj}(f) >= \frac{1}{H}\sum_{H=1}^{H} \left| \hat{g}_{jj}(f) - \bar{g}_{jj}(f) \right| ,$$

Peak	fz (Hz)	time
P1	0.013	77.0 sec
P2	0.026	38.4 sec
P3	0.039	25.6 sec

Nonlinear period -doubling, -tripling?
Linsay., 1981, Jiang et al., 1998

Period-doubling associated with nonlinear kink:

Ziegler & Ulmschneider, 1997, Ruderman et al., 2010, Magyar & Van Doorsselaere, 2016

Transverse Tube Displacement

(Kukhiandze et al., 2006, De Pontieu et al., 2007, Sekse et al., 2013, Ebadi & Ghiassi, 2014)

Transverse Pressure Gradients

(Goossens et al., 2014, Sharma, Verth & Erdelyi, 2017)

Cross-sectional (non-/axisymmetric) Width variations

(Ziegler & Ulmschneider, 1997, Ruderman et al., 2010, Jess et al., 2012, Morton et al., 2012, Gafeira et al., 2017)

Longitudinal pressure changes

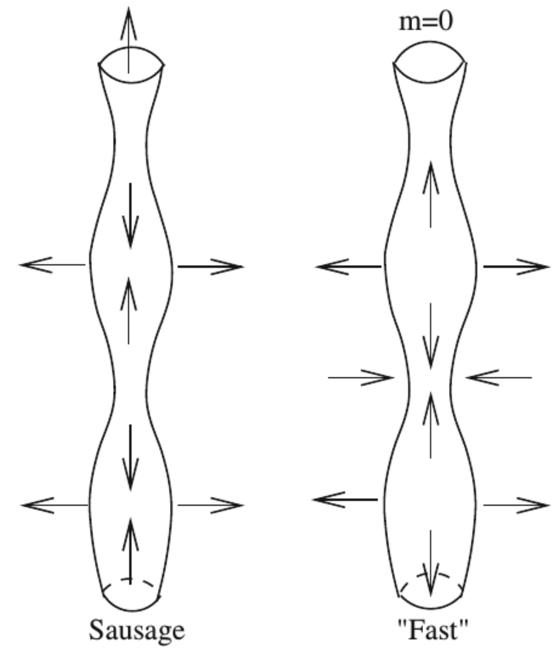
(Shibata, 1981, Ulmschneider et al., 1991, Ziegler & Ulmschneider, 1997)

Azimuthal shear/torsion

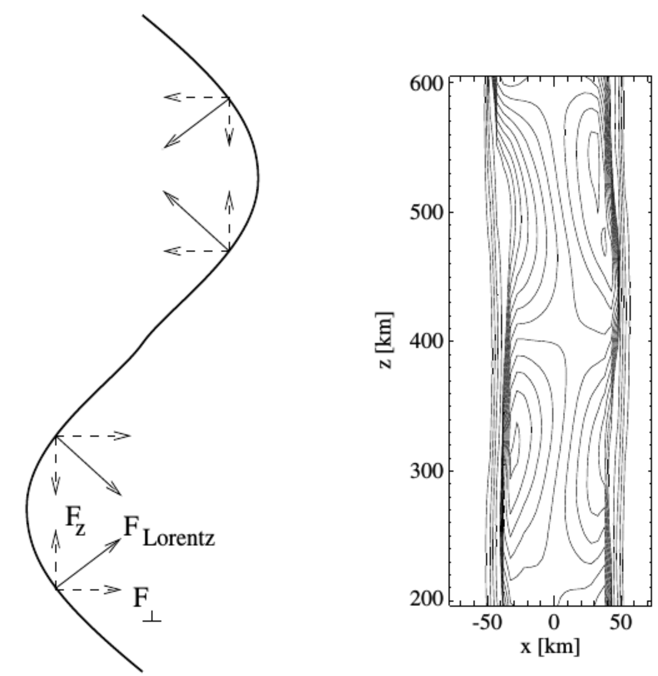
(De Pontieu et al., 2012, Kitiashvile et al., 2013)

Longitudinal oscillations

(Loughhead, 1974, De Pontieu et al., 2007, Pereira et al., 2012, Sekse et al., 2013)

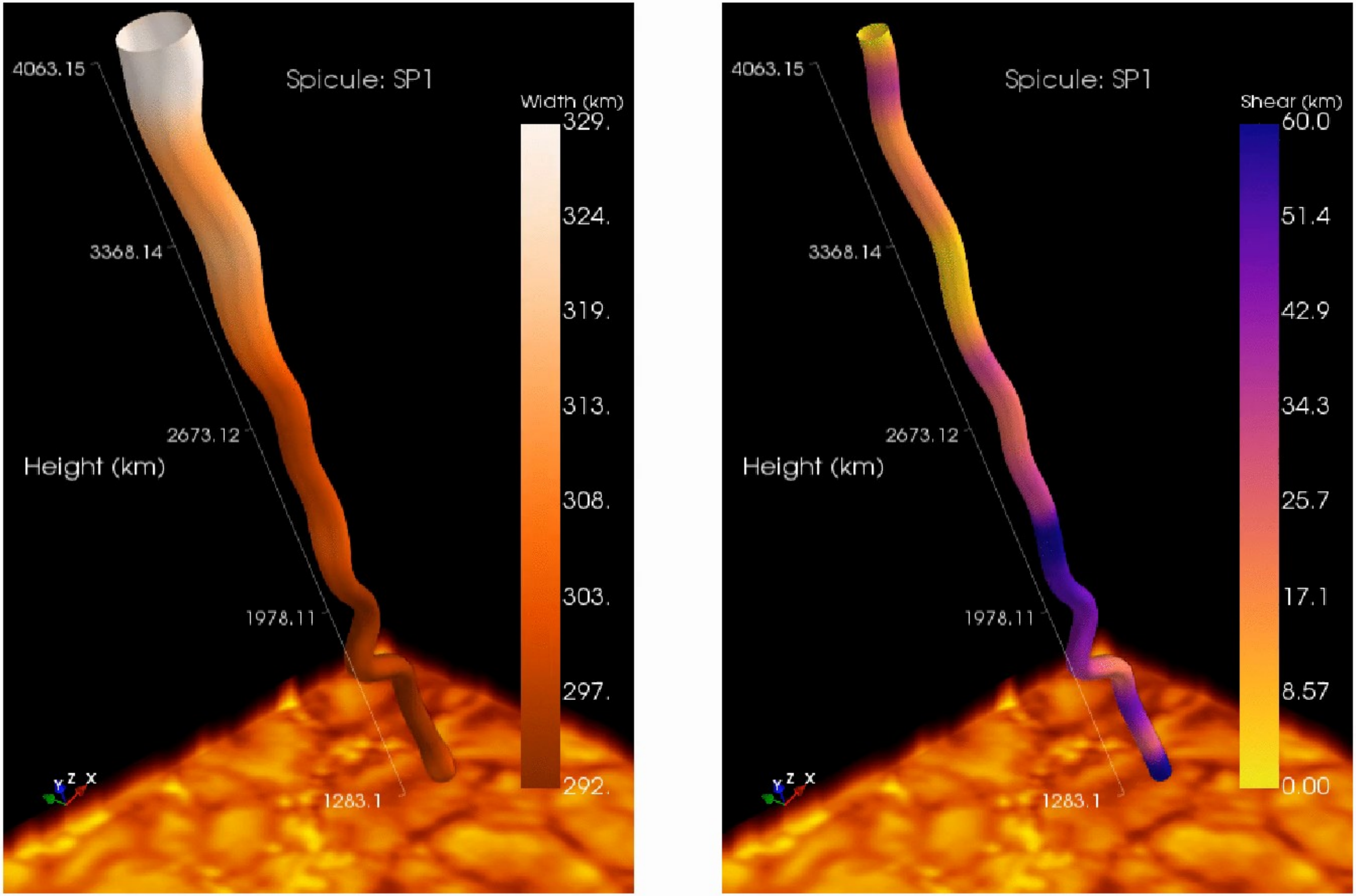


M. Ryutova (Physics of Magnetic Flux Tubes)



Ziegler & Ulmschneider, A&A, 1998

Transverse + Cross-sectional Width   Transverse + Azimuthal shear/torsion



Upward and downward motion of the Lorentz force associated with the vortex tube motions (Kitiashvile et al., 2013)

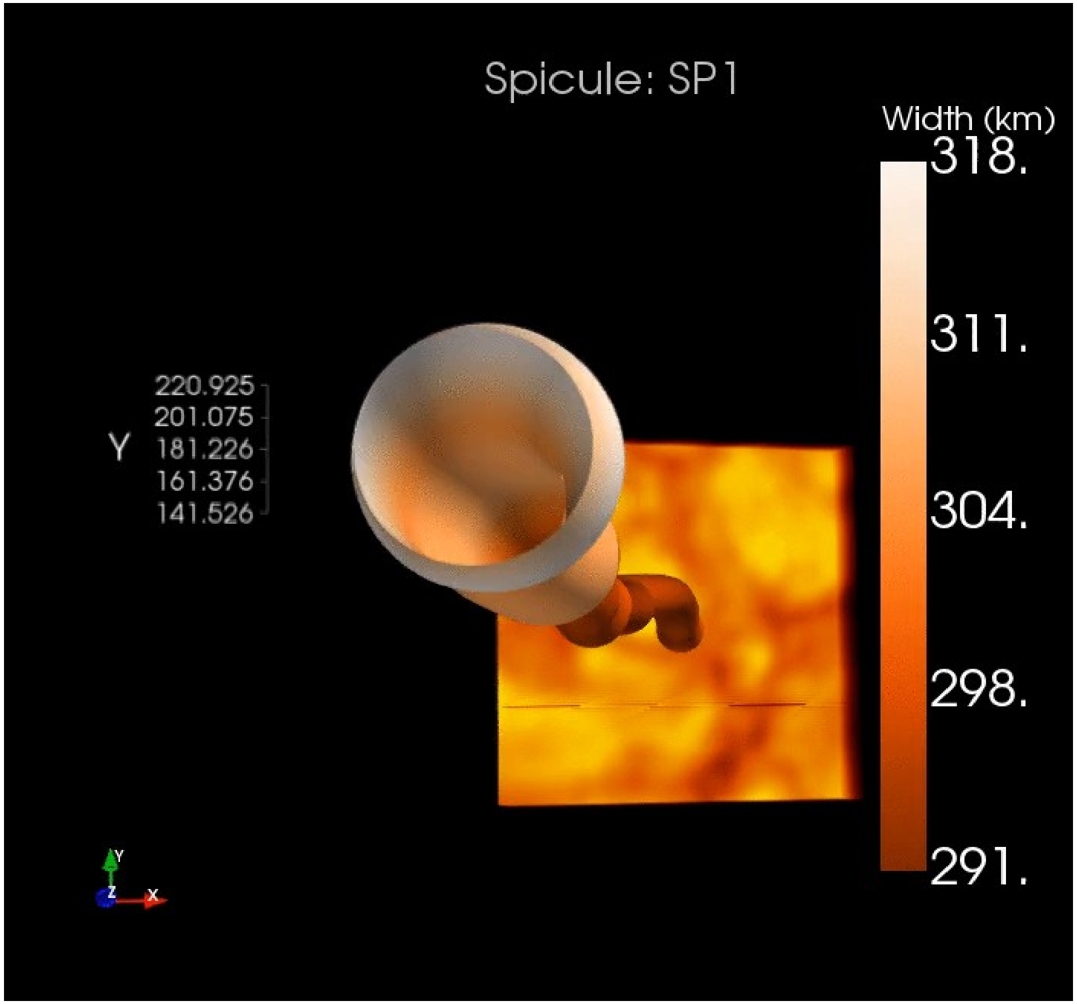
Evolution over height: Helical or non-helical?

Zaqarashvile & Skhirtladze, ApJ, 2008

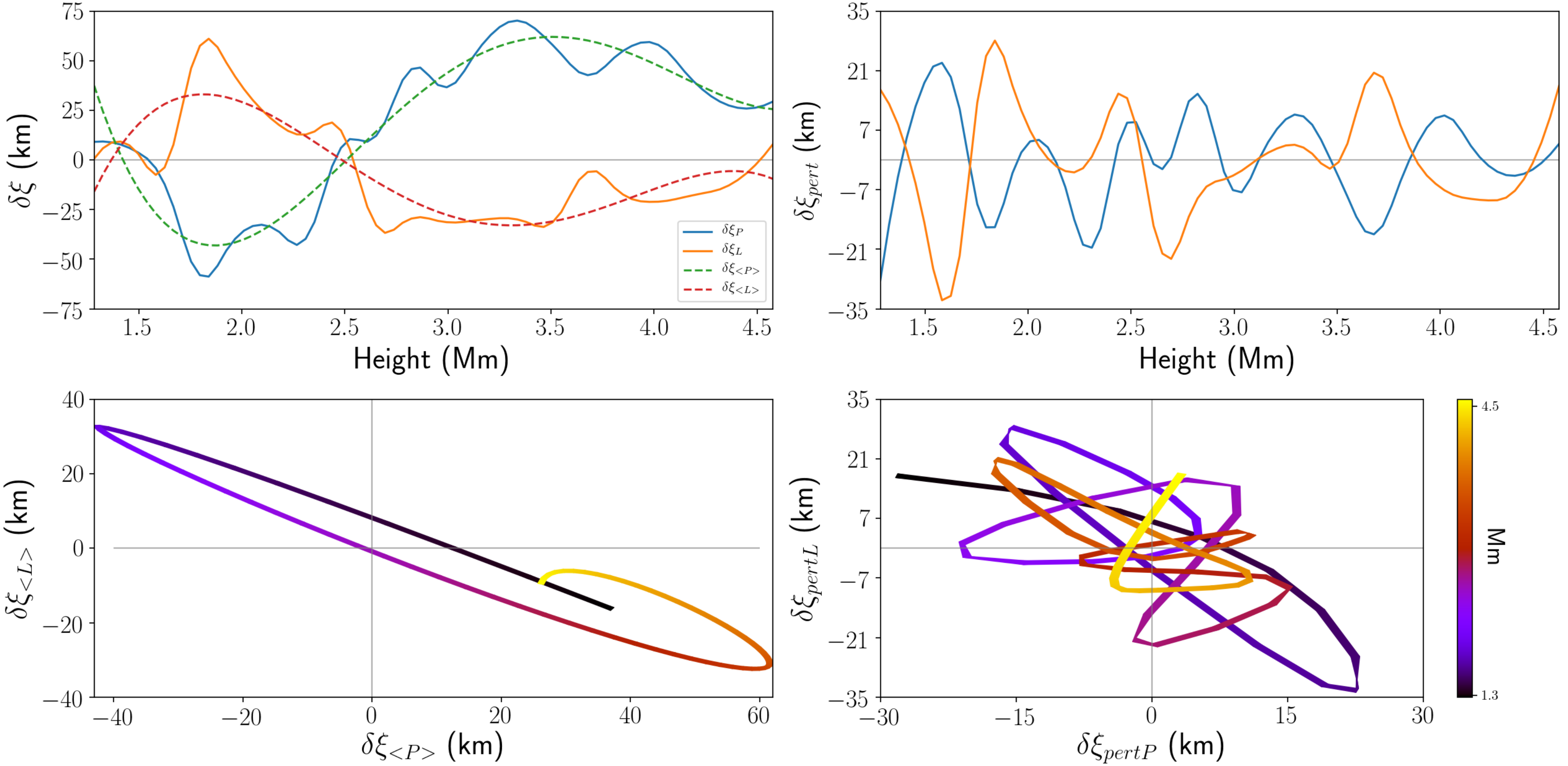
- Superposition of LOS and POS as two **linear** kink wave-modes.
- Helical motion with constant phase-difference

Stangalini et al., ApJ, 2017

- Small-scale magnetic element tracking.
- Footpoint motion
- Helical **linear** kink waves



Lissajous-like plot



- Coupled LOS-POS variations in opposite phase.
- Non-helical motion with height (more complex than suggested by Zaqarashvile & Skhirtladze, ApJ, 2008).
- Presence of other dynamical components (transverse + cross-sectional + azimuthal shear/torsion + longitudinal).
- Back-reaction to spicule motion?

Conclusion

- **Pulse-like behavior** (wave-period ~ observed lifetime).
- **Strong coupling** in between observed dynamical components (transverse, cross-sectional width, intensity, azimuthal shear) in **wavenumber (spatial) and frequency (temporal)** domains.
- **Nonlinear kink** (period -doubling, -tripling).
- **Linear theory** can explain coupling in independent wave-modes (kink, sausage, torsion) with **presence of twist** in flux tube (Terradas & Goossens, 2012) and/or **irregular cross-section shape**.
- In absence of twist, **fine-tuning of all drivers** would be essential.
- **Non-helical** behavior
- LOS – POS components in **opposite phase with lag**.

Analysis and visualizations powered by:
SunPy, MayaVi2, Matplotlib, Numpy & Scipy packages