Excitation, damping and heating by transverse waves in loops

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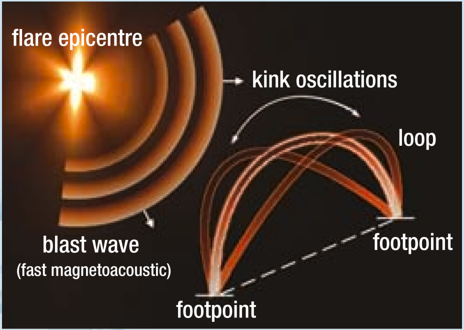
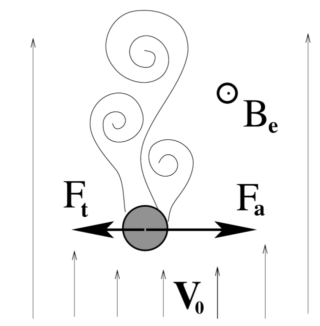
Excitation of transverse loop oscillations

Previously two ideas for exciting standing transverse waves in coronal loops:

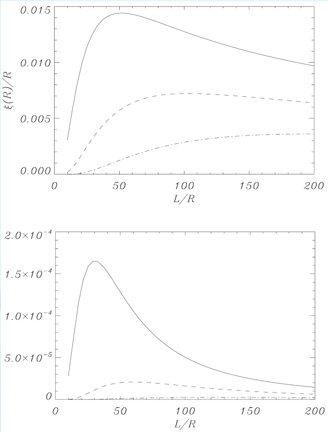
- Excitation by blast wave (Nakariakov & Verwichte 2004)
- Excitation by vortex shedding (Nakariakov et al. 2009)





Excitation of tranverse loop oscillations

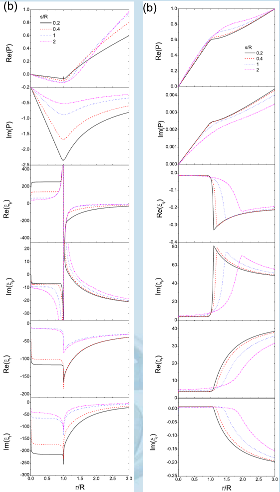
Numerical test of excitation by blast wave: energy absorption is very weak (Terradas et al. 2007)



On the other hand:
observational evidence of Zimovets & Nakariakov (2015, see previous workshop)
→ low coronal disturbance excites waves

Excitation of transverse loop oscillations

Yu & Van Doorsselaere (2016): use Invariant Imbedding Method to estimate excitation of transverse waves as a driven problem

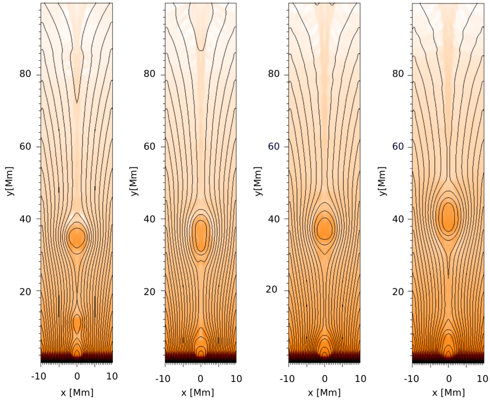


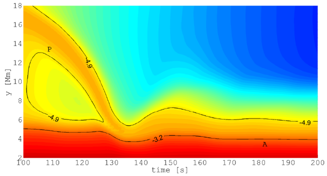
Left: driving with kink frequency,
Right: driving with $1.1\omega_{A,i}$

- For few % pressure driver, reasonable displacements (for kink).
- For high frequency driver, no loop response.
- High shear at loop edge → leads to vortex shedding?
- Combination of two mechanisms: pulse → shear → vortex shedding → transverse wave

Excitation of transverse loop oscillations

Jelinek et al. (2017, submitted): reconnection in Harris sheet
Flare blobs impact post-flare loops and excite (vertical) oscillations



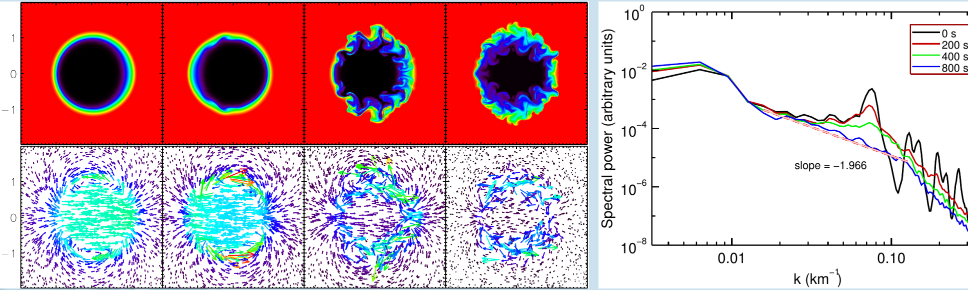


Not for cases of Zimovets & Nakariakov (2015), not for Aschwanden & Schrijver (2011). Relevant for QPPs in flares?

Damping of transverse loop oscillations

Previously: resonant absorption leads to exponential (e.g. Goossens et al. 1992) or Gaussian damping (Pascoe et al. 2012)

Terradas et al. (2008), Antolin et al. (2014): non-linear Transverse Wave Induced Kelvin-Helmholtz (TWIKH) rolls.



Magyar & Van Doorsselaere (2016a): TWIKH rolls result in "turbulence" → cascade to small scales → easy damping/dissipation!

Damping of transverse loop oscillations

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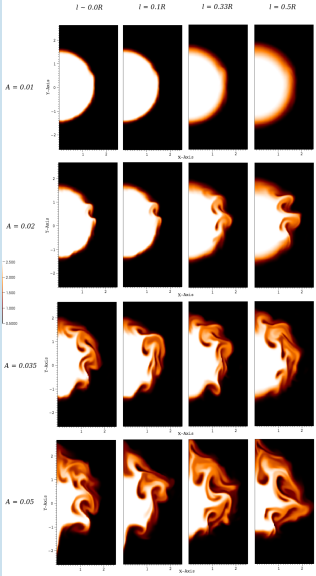
Magyar & Van Doorsselaere (2016b): Parameter study of damping of kink waves (w.r.t. initial amplitude and layer width)

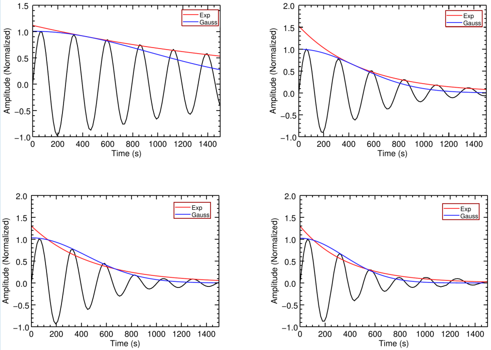
Use cylinder (radius $R = 1.5 Mm$, length $L = 120 Mm$, density contrast 5) with inhomogeneous layer (thickness l).

Excite by $v_y = A V_{A,i} \cos \pi z / L$, with $V_{A,i} = .7 Mm/s$.



Damping of transverse loop oscillations

Magyar & Van Doorsselaere (2016b): Parameter study of damping of kink waves

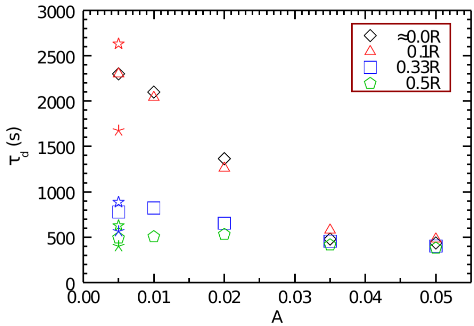


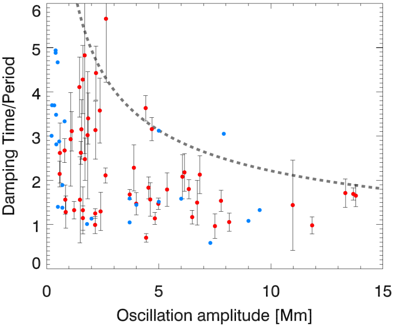
Top: $A = .01$, bottom: $A = .05$, left: $l/R = .1$, right: $l/R = .5$.

Top: Classic picture holds for linear oscillations. Bottom: Damping determined by turbulence of TWIKH rolls.

Damping of transverse loop oscillations

Magyar & Van Doorsselaere (2016b): Parameter study of damping of kink waves

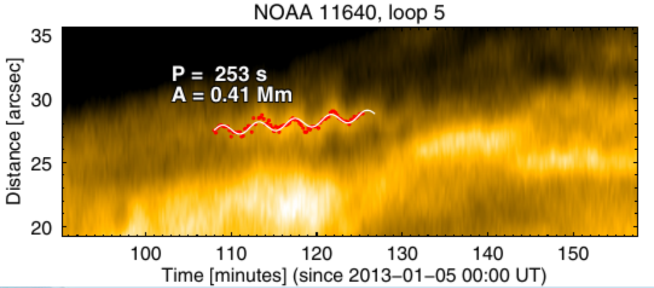




Compare to results of Goddard & Nakariakov (2016, right): numerical results do not cover enough parameters, but encouraging!

Damping of transverse loop oscillations

(apparently) Decayless transverse waves in many layers of solar atmosphere with many instruments (e.g. De Pontieu et al. 2007, Okamoto et al. 2007, McIntosh et al. 2011, Antolin & Verwichte 2011, Wang et al. 2012, Morton et al. 2012, Nisticò et al. 2013, Thurgood et al. 2014)

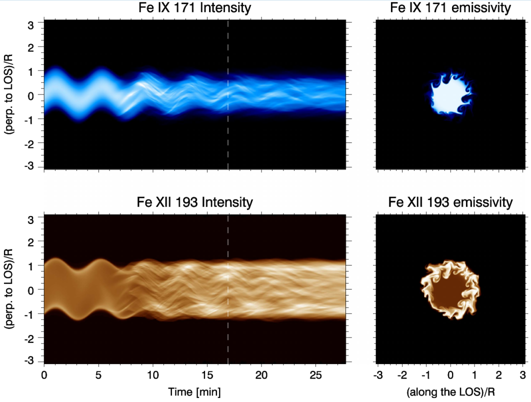


Decayless transverse waves (Anfinogentov et al. 2015)

Damping of transverse loop oscillations

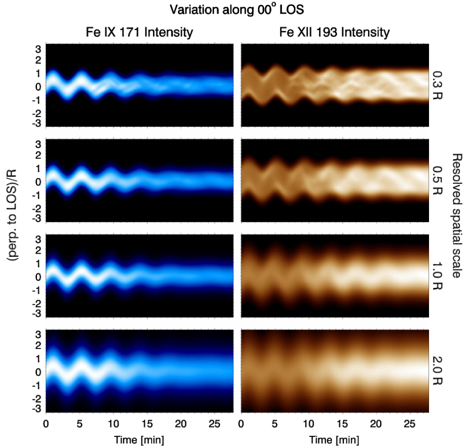
Antolin et al. (2016): Standing transverse waves with TWIKH rolls may lead to decayless oscillations

Excite waves with transverse kick, forward model with FoMo in 171Å (core) and 193Å (boundary).



Damping of transverse loop oscillations

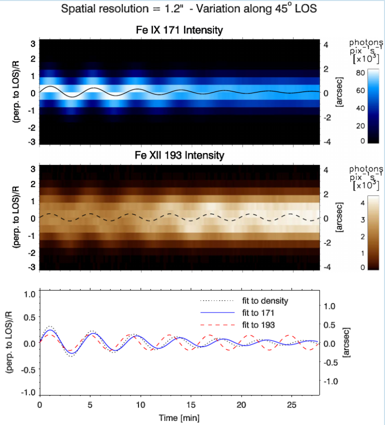
Antolin et al. (2016): Standing transverse waves with TWIKH rolls may lead to decayless oscillations



At lower resolution, "boundary line" seems decayless.

Damping of transverse loop oscillations

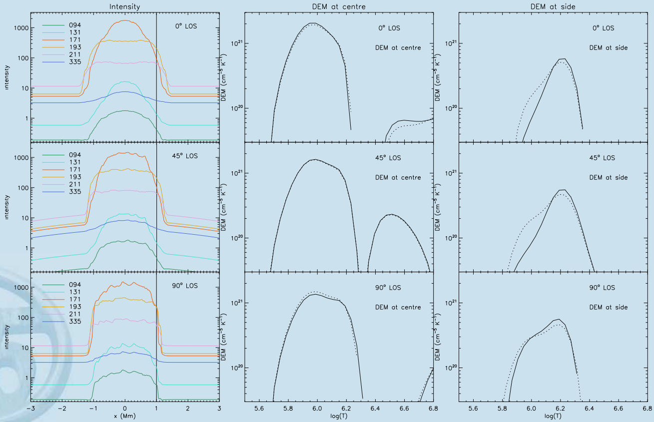
Antolin et al. (2016): Standing transverse waves with TWIKH rolls may lead to decayless oscillations



Different period for core, boundary, density. Great potential for seismology.

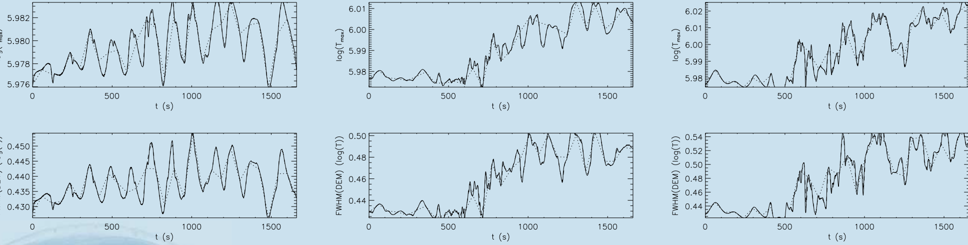
Heating by transverse loop oscillations

Van Doorsselaere & Antolin (2017, submitted): Forward modelling of 3D simulations (FoMo, Van Doorsselaere et al. 2016) + DEM inversions (Hannah & Kontar 2012)



Heating by transverse loop oscillations

Van Doorsselaere & Antolin (2017, submitted): Occurrence of TWIKH rolls leads to apparent increase in DEM temperature



Broad DEMs can be explained with turbulent loop models (TWIKH rolls).

Heating by transverse loop oscillations

Kostas Karampelas: driving loop at footpoint by transverse wave, quantify heating.
Last Friday: “A term was missing in the energy balance, I will have to look at it.”

Conclusions

- Excitation of waves by high frequencies in pressure pulses? (Yu et al. 2016)
- Excitation of transverse waves by impacting flare blobs. (Jelinek et al. 2017)
- Damping by non-linear effects in simulations compatible with observations. (Magyar & Van Doorsselaere 2016)
- Apparently decayless waves in “boundary” spectral line. (Antolin et al. 2016)
- Apparent heating by mixing of plasma due to turbulence. (Van Doorsselaere & Antolin 2017)
- Transverse waves and turbulence leads to heating. Quantification on its way!