How much can the damping of transverse waves contribute to coronal heating?

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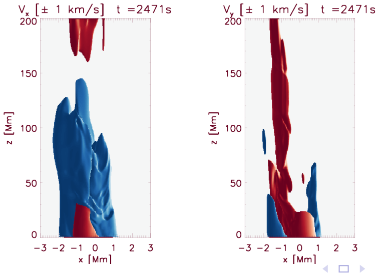
BUKS 2018
September 4th, 2018



Solar & Magnetospheric Theory Group
University of St Andrews

European Research Council
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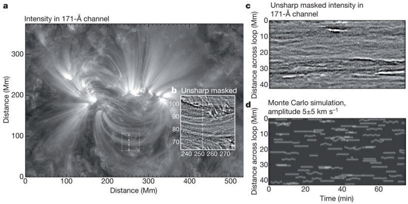
Can MHD waves heat the corona?

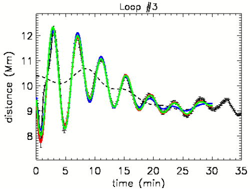
2. Transverse waves are damped.

1. Transverse waves carry energy

$$2 \times 10^5 erg\ cm^{-2} s^{-1}.$$



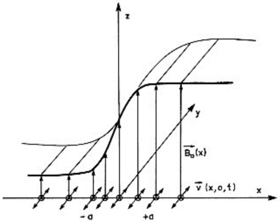
McIntosh+ 2011



Pascoe+ 2016

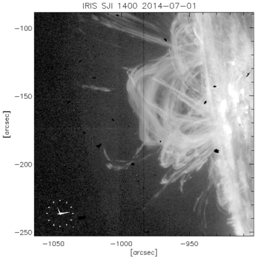
3. Energy conversion - Heating

Phase mixing occurs when the Alfén speed varies perpendicularly to the direction of propagation of the wave.
It generates electric currents



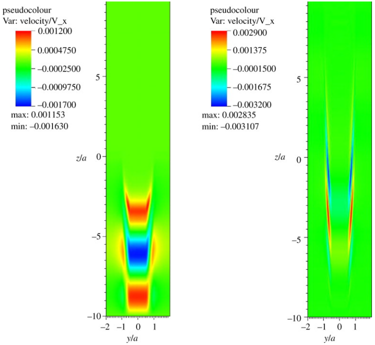
Has a chance?

- Structured corona: V_A not uniform in the corona
- Connection with other layers: Transverse MHD waves propagating upwards



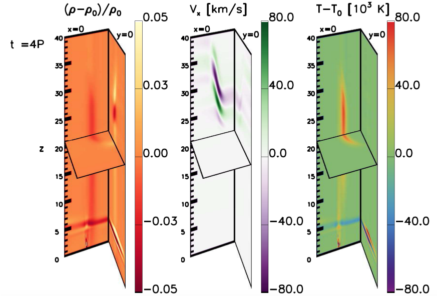
Antolin+ 2014

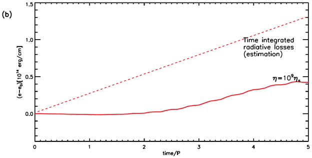
- Mode coupling has been proved to cause energy transfer to the boundary layer



Pascoe+ 2010

- ... and a modest heating.





Pagano&DeMoortel 2017

Observed spectrum

COMP Measured the observed spectrum of transverse oscillations

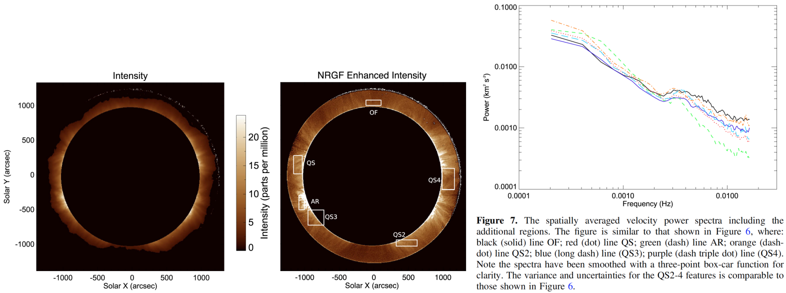
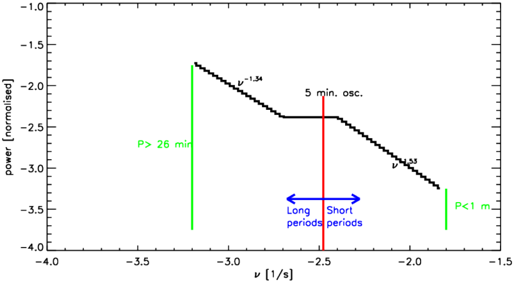


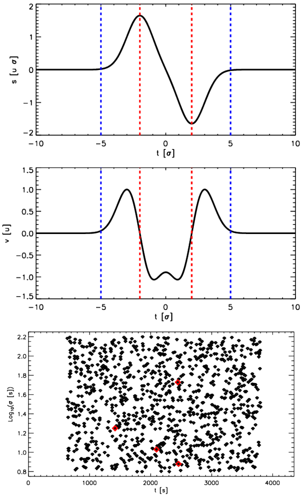
Figure 7. The spatially averaged velocity power spectra including the additional regions. The figure is similar to that shown in Figure 6, where: black (solid) line OF; red (dot) line QS; green (dash) line AR; orange (dash-dot) line QS2; blue (long dash) line (QS3); purple (dash triple dot) line (QS4). Note the spectra have been smoothed with a three-point box-car function for clarity. The variance and uncertainties for the QS2-4 features is comparable to those shown in Figure 6.

Morton+2016

- Hours long observation
- Steady state spectrum
- Observation in the low corona

Single oscillations and composed driver





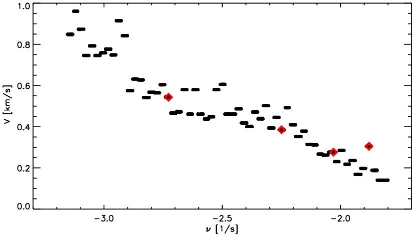
$$E_i = \int_{-\infty}^{+\infty} v_i^2\, dt \propto \int_{-\infty}^{+\infty} u_i^2 \frac{t^2}{\sigma_i^2} e^{-\frac{t^2}{\sigma_i^2}}\, dt = u_i^2 \frac{\sqrt{\pi}}{2}\sigma \qquad (1)$$

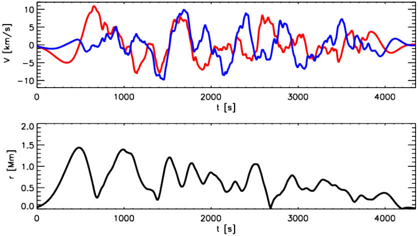
$$W_i = E/t \propto u_i^2$$

Observed spectrum, 2D

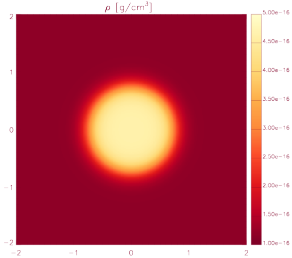
2D driver

- random θ
- max velocity 10 km/s.
- $P_i = 1/\nu_i = 10\sigma_i$





Initial condition, loop model



$$\rho = \rho_e + \frac{\rho_0 - \rho_e}{2}\left(1 - tanh\left(\frac{e}{a-b}\left(r - \frac{b+a}{2}\right)\right)\right)$$

$$p = const$$

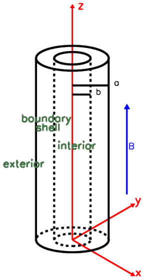
$$B_z = const$$

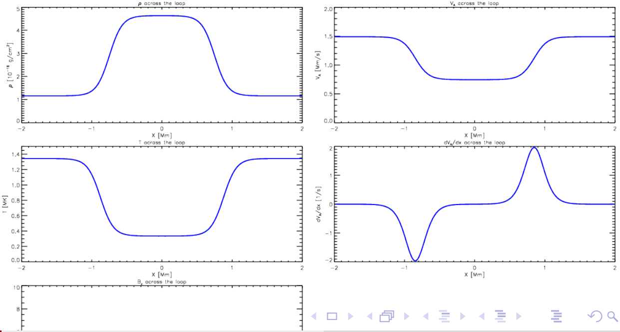
$$b = 0.5\ Mm$$

$$a = 1.0\ Mm$$

$$\rho_c = 4$$

$$\beta = 0.02$$





MHD Equations

AMRVAC

$$\frac{\partial \rho}{\partial t} + \vec{\nabla} \cdot (\rho \vec{v}) = 0,$$

$$\frac{\partial \rho \vec{v}}{\partial t} + \vec{\nabla} \cdot (\rho \vec{v} \vec{v}) + \nabla p - \frac{\vec{j} \times \vec{B}}{c} = 0,$$

$$\frac{\partial \vec{B}}{\partial t} - \vec{\nabla} \times (\vec{v} \times \vec{B}) = \eta \frac{c^2}{4\pi} \nabla^2 \vec{B},$$

$$\frac{\partial e}{\partial t} + \vec{\nabla} \cdot [(e + p)\vec{v}] = \eta j^2 - \nabla \cdot \vec{F}_c,$$

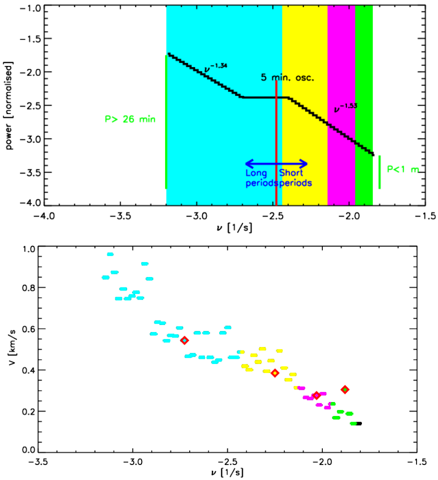
$$\nabla \cdot \vec{B} = 0$$

$$\vec{j} = \frac{c}{4\pi} \nabla \times \vec{B}$$

$$\frac{p}{\gamma - 1} = e - \frac{1}{2} \rho \vec{v}^2 - \frac{\vec{B}^2}{8\pi},$$

Observed spectrum and phasemixing

Having a 200 Mm loop and $V_A = 750\ km/s$



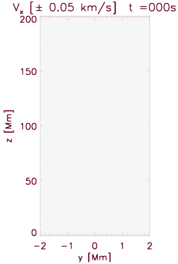
$\lambda = \frac{V_A}{\nu}$

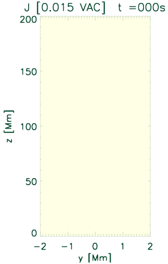
We pick 4 pulses

- $\lambda = 2L\ P = 533\ s$
- $\lambda = 2/3L\ P = 178\ s$
- $\lambda = 2/5L\ P = 107\ s$
- $\lambda = 2/7L\ P = 76\ s$

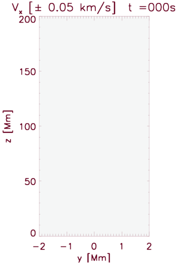
MHD ideal simulations

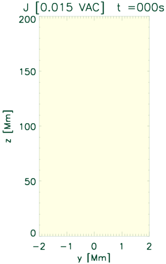
$\lambda = 2L \; P = 533 \; s$



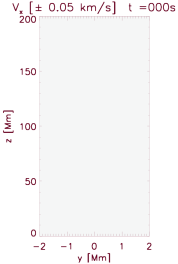


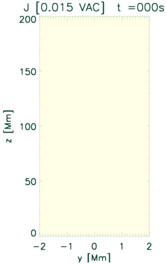
$\lambda = 2/3L \; P = 178 \; s$



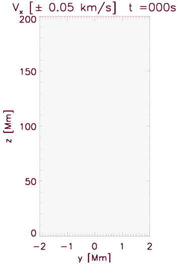


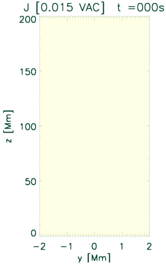
$\lambda = 2/5L \; P = 107 \; s$



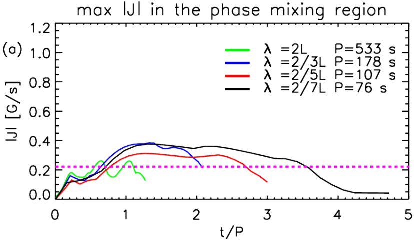


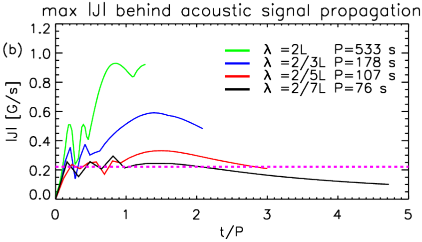
$\lambda = 2/7L \; P = 76 \; s$





Simulations - currents





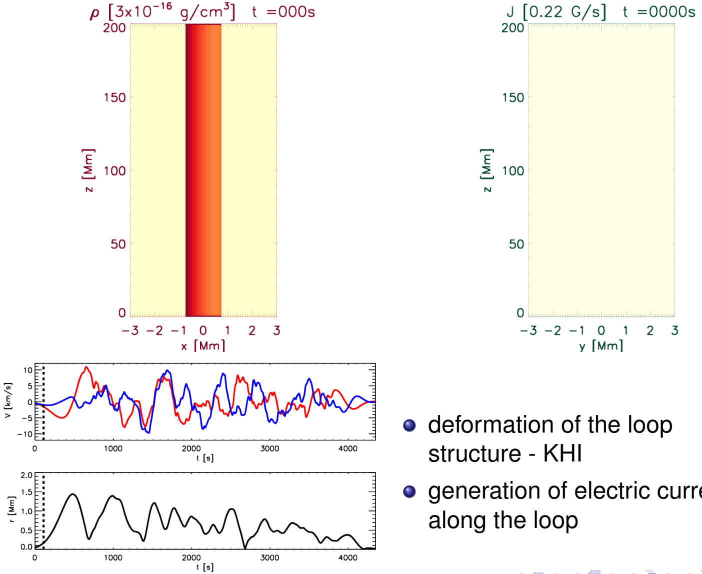
Phase-mixing currents

- develop along the loop
- stronger for higher frequencies
- due to phase mixing

Slow-modes currents

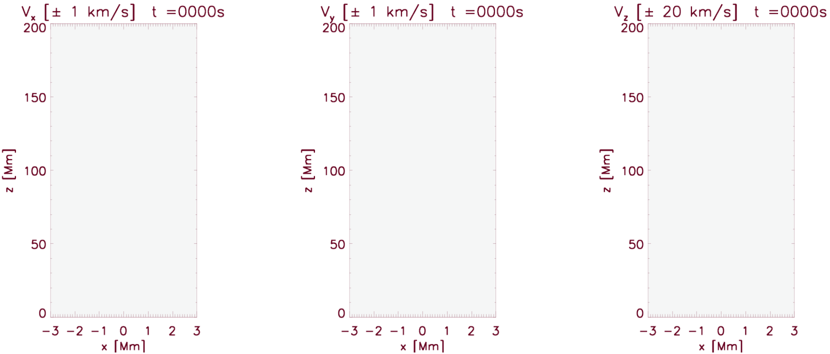
- develop near footpoints
- stronger for lower frequencies/larger amplitudes
- due to guide field compression after displacement

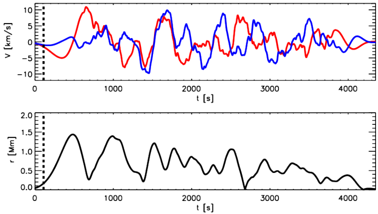
Observed spectrum simulation



- deformation of the loop structure - KHI
- generation of electric currents along the loop

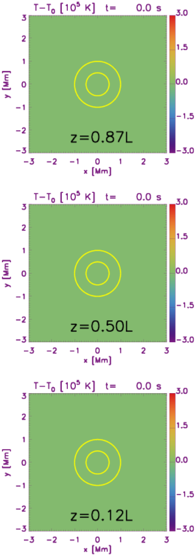
Observed spectrum simulation

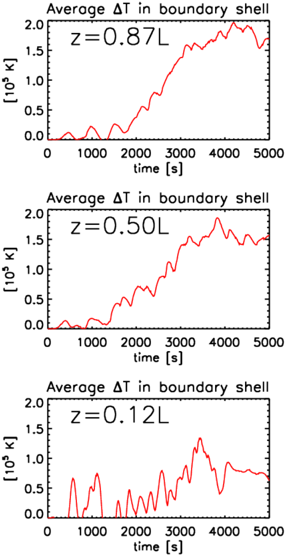




- transverse oscillations 1 km/s
- slow-mode parallel velocities 20 km/s

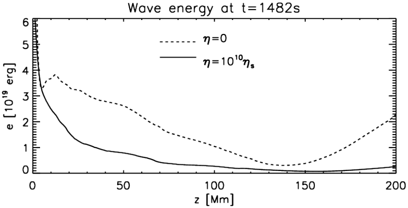
Wave associated heating

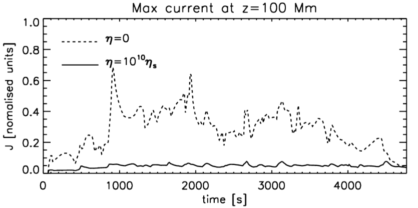


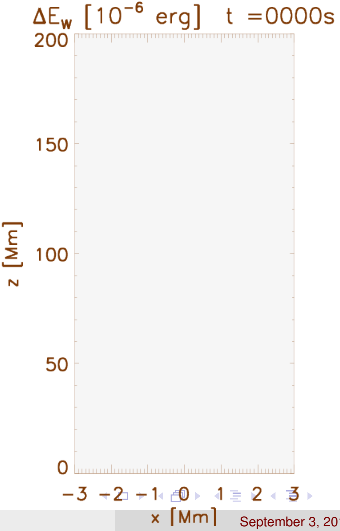


Wave associated heating

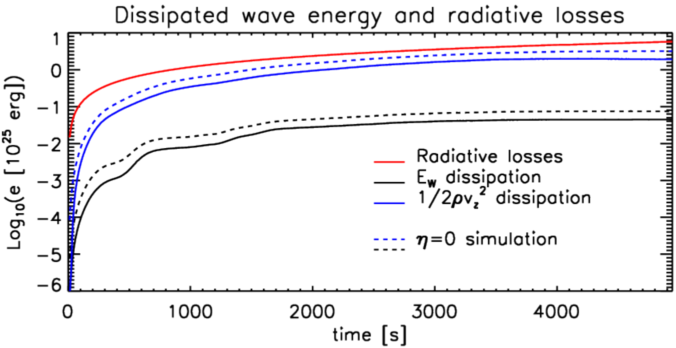
$$E_W = \frac{1}{2}\left(\rho v_x^2 + \rho v_y^2 + \frac{B_x^2}{8\pi} + + \frac{B_y^2}{8\pi}\right)$$





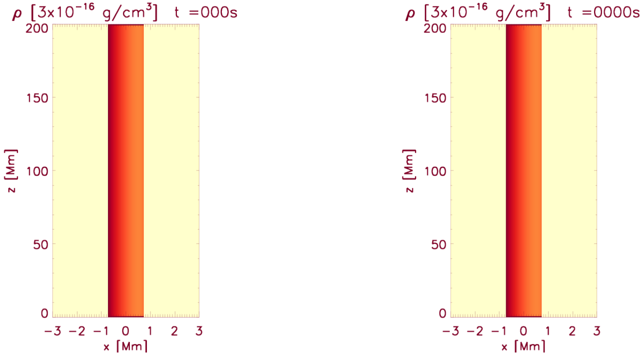


Wave associated heating



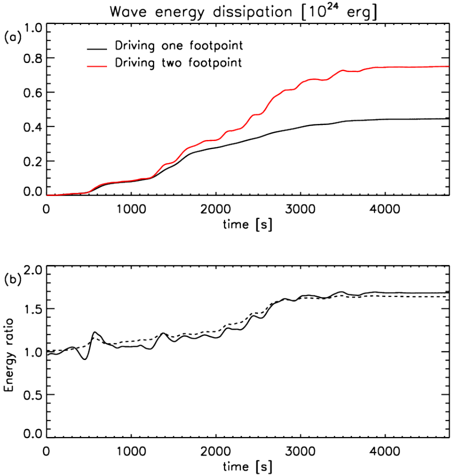
Two footpoints simulation

To investigate the dissipation of counter propagating Alfvén waves we modify the setup placing two distinct drivers at either footpoints.



Two footpoints simulation

$$\zeta(t) = \frac{\int_0^t u_1^2(t) + u_2^2(t)\, dt}{\int_0^t u_1^2(t)\, dt}$$



Conclusions

Can waves heat the corona? Probably not via phase-mixing

- Wave-based models do not match the radiative losses outputs
- Low frequency?
- High frequency?

Do waves play a role in coronal heating? Probably yes

- Contribute mildly to the energy input
- They can produce transients
- Trigger other processes - KHI?
- Trigger other processes - Turbulence?
- Are an essential component of the solar corona and contribute to the magnetic field evolution.

Acknowledgments

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European Research Council

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