NUMERICAL SIMULATIONS OF CORONAL LOOP KINK OSCILLATIONS EXCITED BY DIFFERENT DRIVER FREQUENCIES

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Outline

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- Motivation
- Simulation setup
- Results
- Summary

Introduction

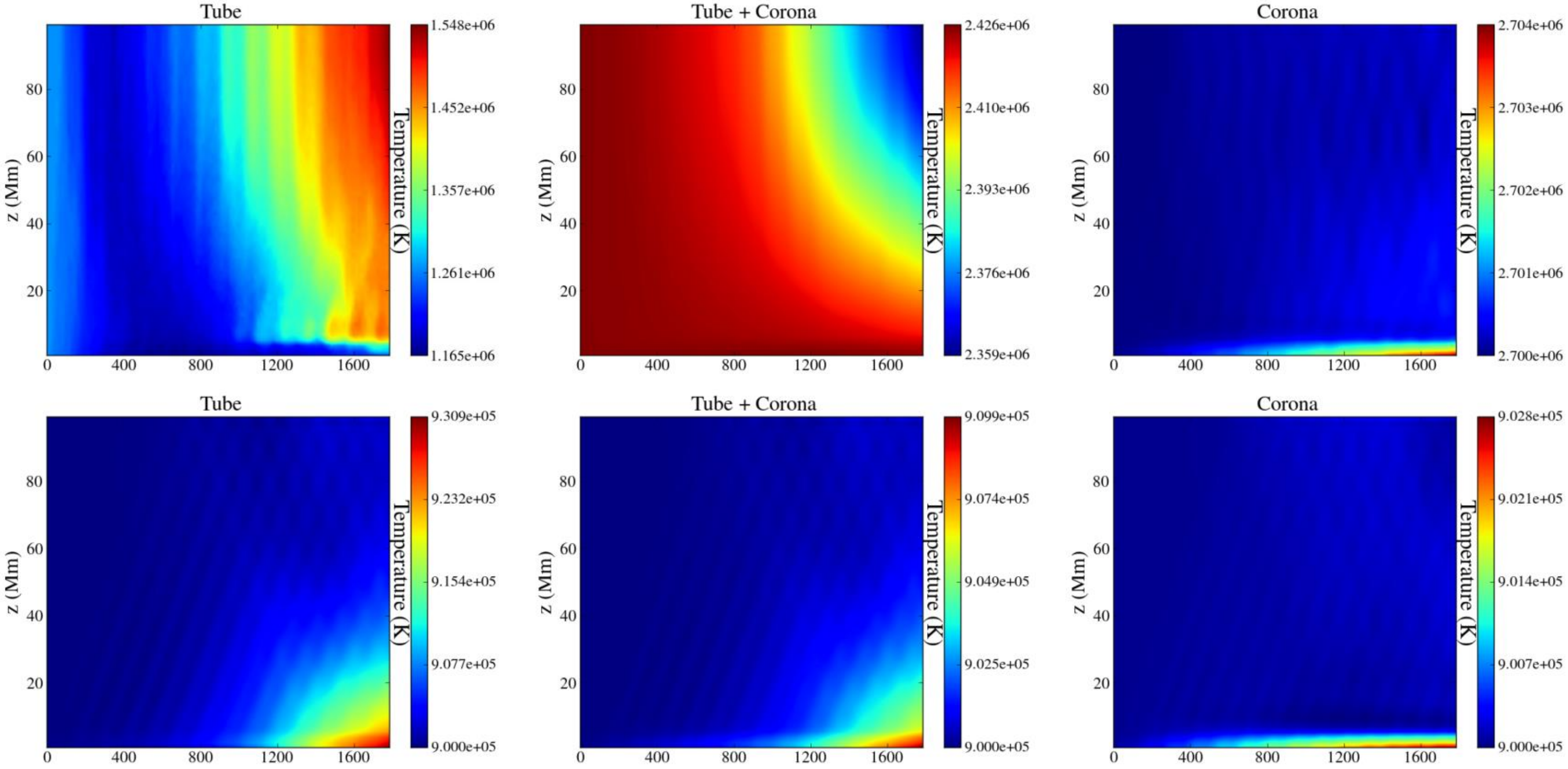
- Plasma of the solar corona is an elastic medium that can support propagation of waves
- Observations show that MHD waves are omnipresent in the solar atmosphere
- Two regimes for transverse waves in the solar corona: rapidly-decaying large-amplitude kink waves (e.g. Nakariakov et al. 1999) and decayless low-amplitude kink waves (Wang et al. 2012; Nisticò et al. 2013, Anfinogentov et al. 2015)
- The interest in kink oscillations is mainly associated with the coronal heating problem and with coronal plasma diagnostics
- Numerical simulations of kink oscillations of loops: resonant absorption, Kelvin-Helmholtz instability, phase mixing of Alfven waves (e.g., Terradas et al. 2008; Pascoe et al. 2010; Antolin et al. 2014; Magyar & Van Doorsselaere 2016)

Motivation

- Heating due to viscosity (near loop apex) is dominated by resistive heating (near footpoints), however, both can become insignificant in comparison to effects of mixing of plasmas of different temperatures due to KHI (Karampelas & Van Doorsselaere, 2017)

Different temperatures inside and outside the loop

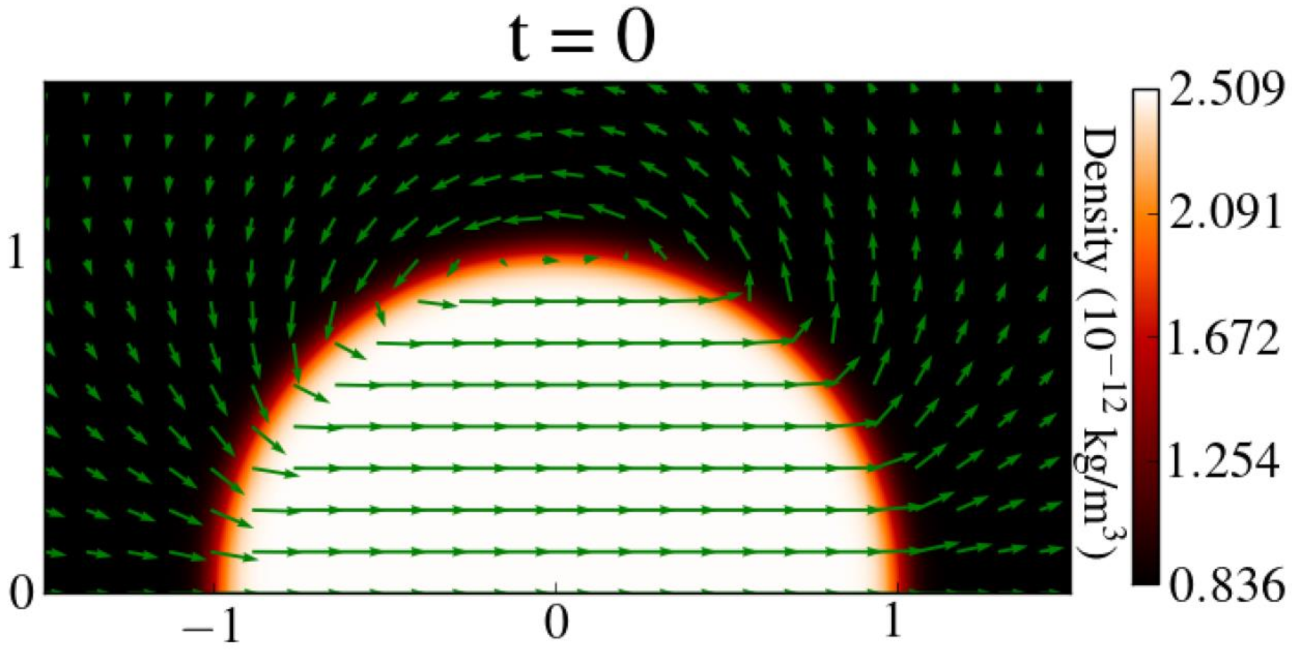
Equal temperatures inside and outside the loop



Motivation

- Mixing of plasmas of different temperatures at the loop boundary can hide effects of plasma heating due to energy dissipation in small scales
- Gravitational stratification of the plasma
- Sophisticated model for wave driver
- Eigenspectrum of a coronal loop
- Longitudinal distribution of heating in a loop

Setup



- MPI-AMRVAC code
- Hotter and denser loop in straight magn
  - ✓ Hyperbolic tangent function for plasma de
- Gravitational stratification of the plasma
  - ✓ $g(z) = g_0\,\mathrm{Cos}(\pi z/L)$
- Equilibrium with slightly reduced magnetic field strength inside the loop
  - ✓ Slow waves of several km/s amplitude propagate inside the box
- Boundary conditions
  - ✓ Open side boundaries (continuous boundary conditions), except for x=0 boundary, which takes into account the setup symmetry
  - ✓ Reflection of waves at one footpoint (*asymm* for *vel*, *cont* for *mag* , *strat_gh* for *p* and *rho*)
  - ✓ Continuous monoperiodic wave driver at the other loop footpoint with velocity amplitude of 5 km/s

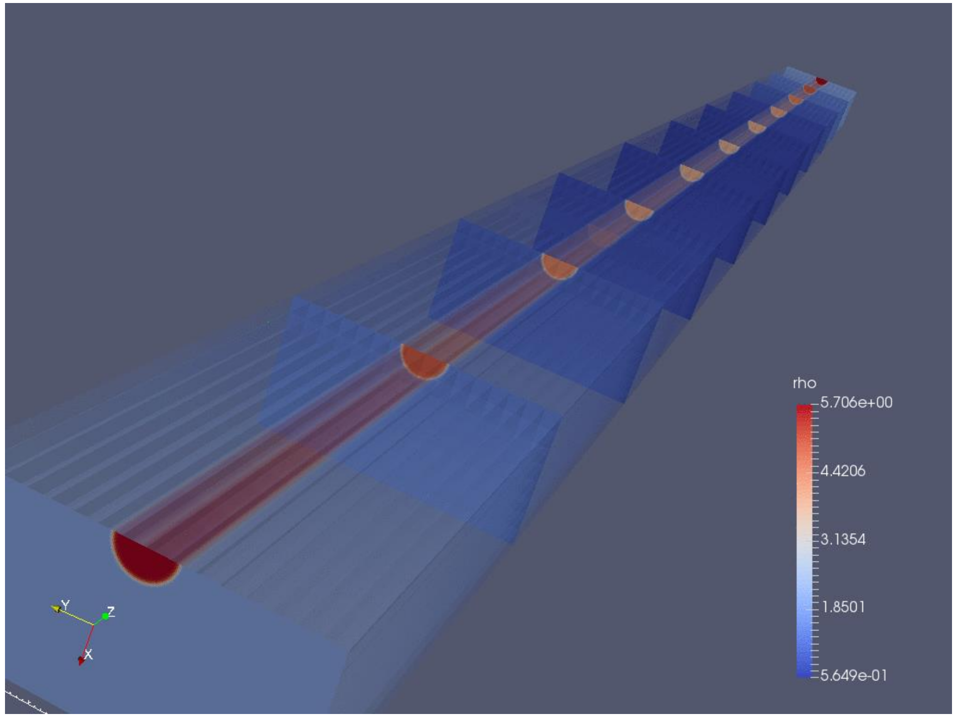
Setup

Parameter	Value
Loop length	200 Mm
Loop radius	1 Mm
Loop radius/thickness of the tube boundary*	16
Loop number density*	$3\text{x}10^9$ cm^{-3}
Density ratio*	3
Loop temperature*	3 MK
Temperature ratio*	3
Magnetic field strength*	22.8 G

* initial values

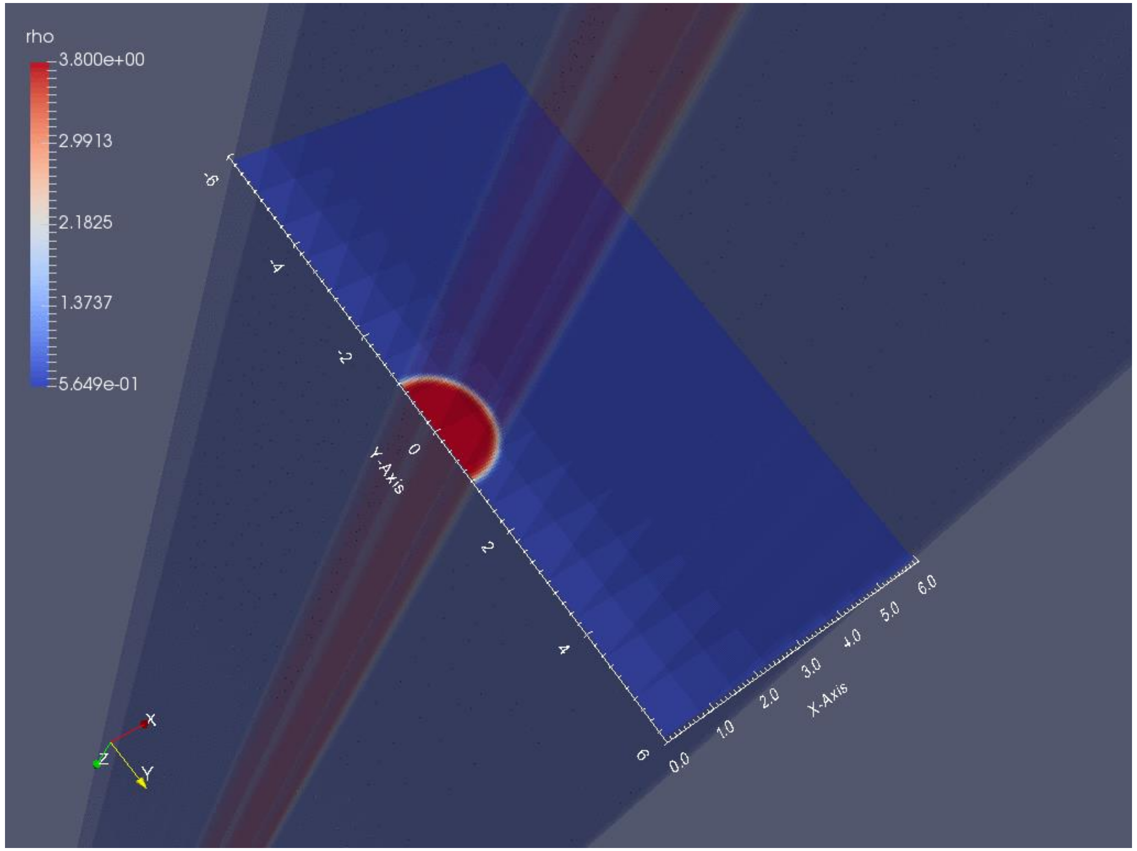
Setup

- Uniform grid: 128x256x64 cells
- Box sizes: X: 0÷6 Mm, Y: -6÷6 Mm Z: 0÷200 Mm
- Resolution: 47 km/pix in xy-plane, 3.1 Mm/pix in z-direction
- Driver excites transverse motions in one footpoint only
- Period of driver: 92 – 421 s, fundamental mode (FM): 328 s
- Runtime: 2000 s; more than 6 FM periods
- Method: one-step TVD scheme + Woodward limiter

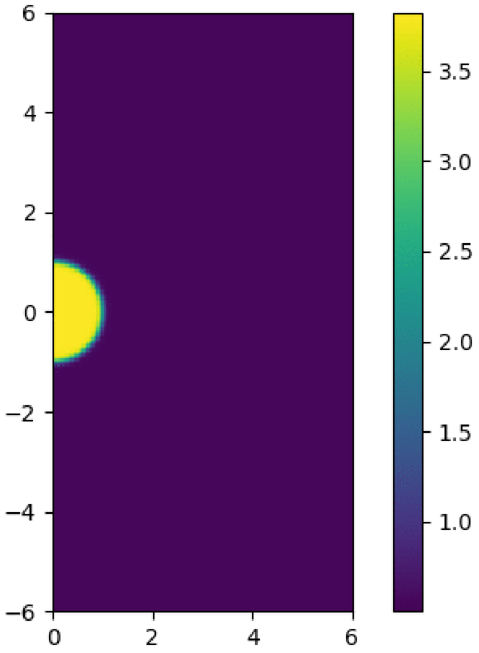


Driven standing kink oscillations

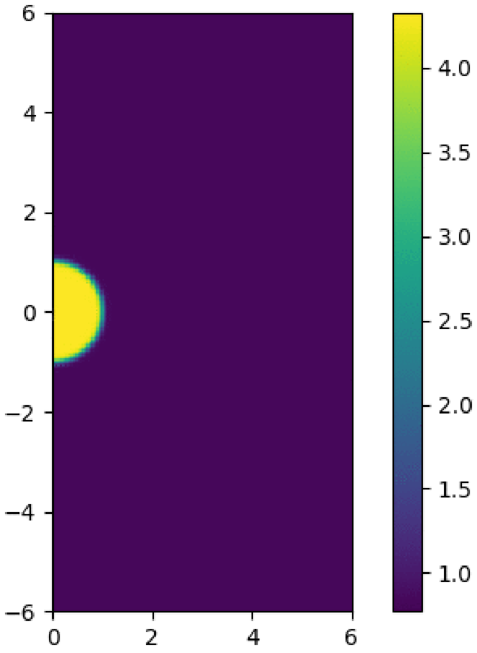
Fundamental mode



Kelvin-Helmholtz instability



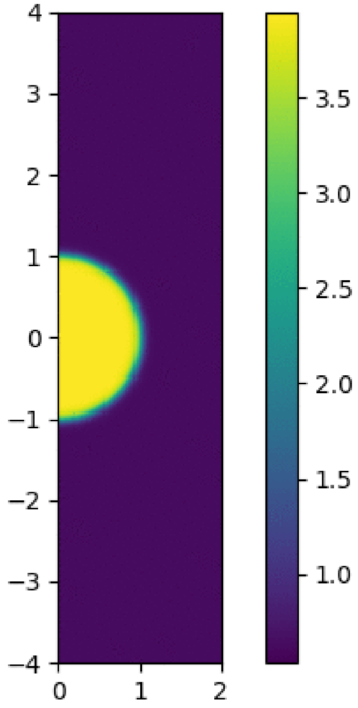
First harmonics;
anti-node is at 100 Mm



Second harmonics;
anti-nodes are at 50 and 150 Mm

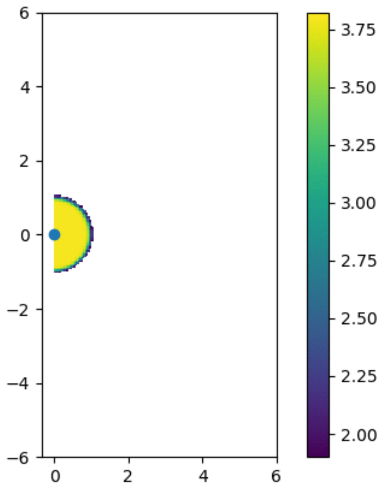
Driven kink oscillations of a loop

Not an eigenfrequency

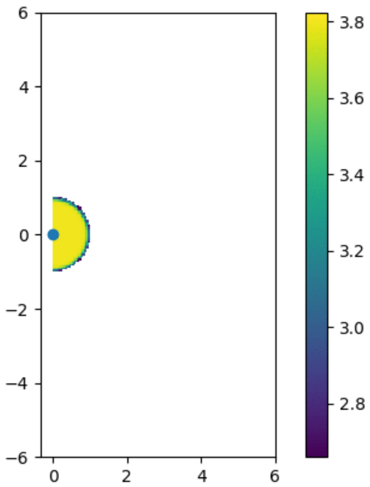


Double resolution in xy-plane:
23 km/pix
(0÷2Mm, -4÷4Mm)

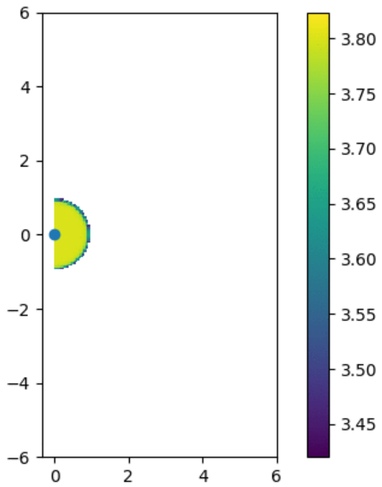
Density threshold values



Thr = 0.5

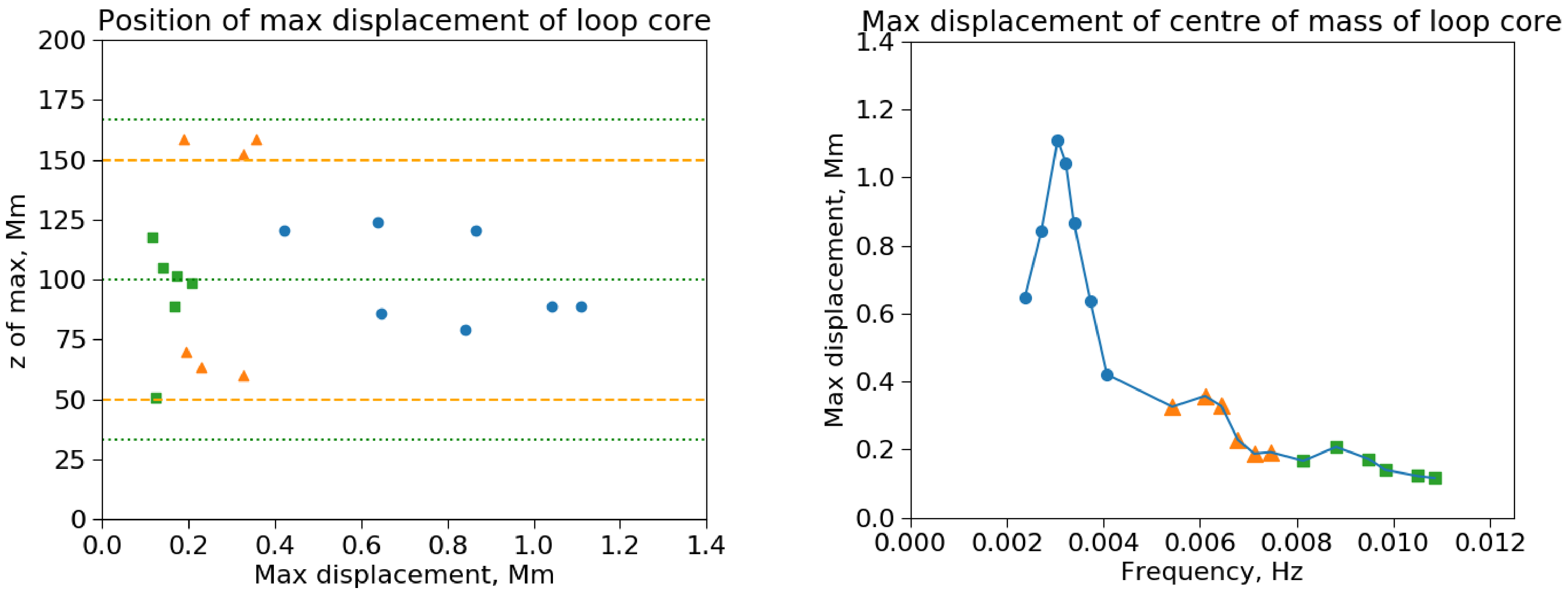


Thr = 0.7

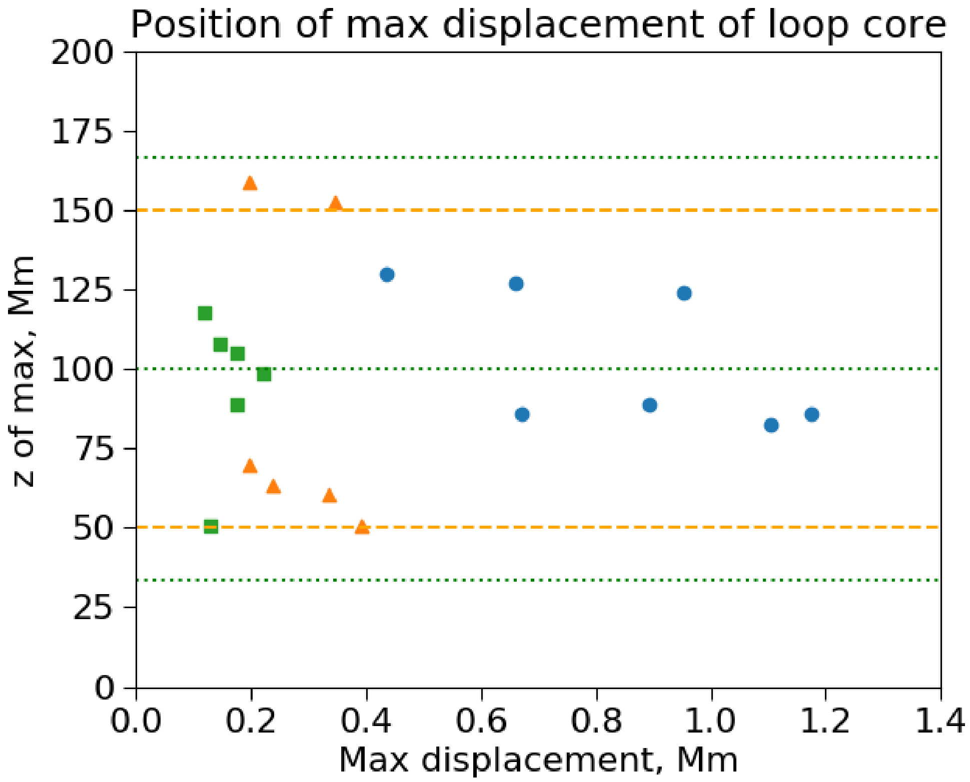


Thr = 0.9

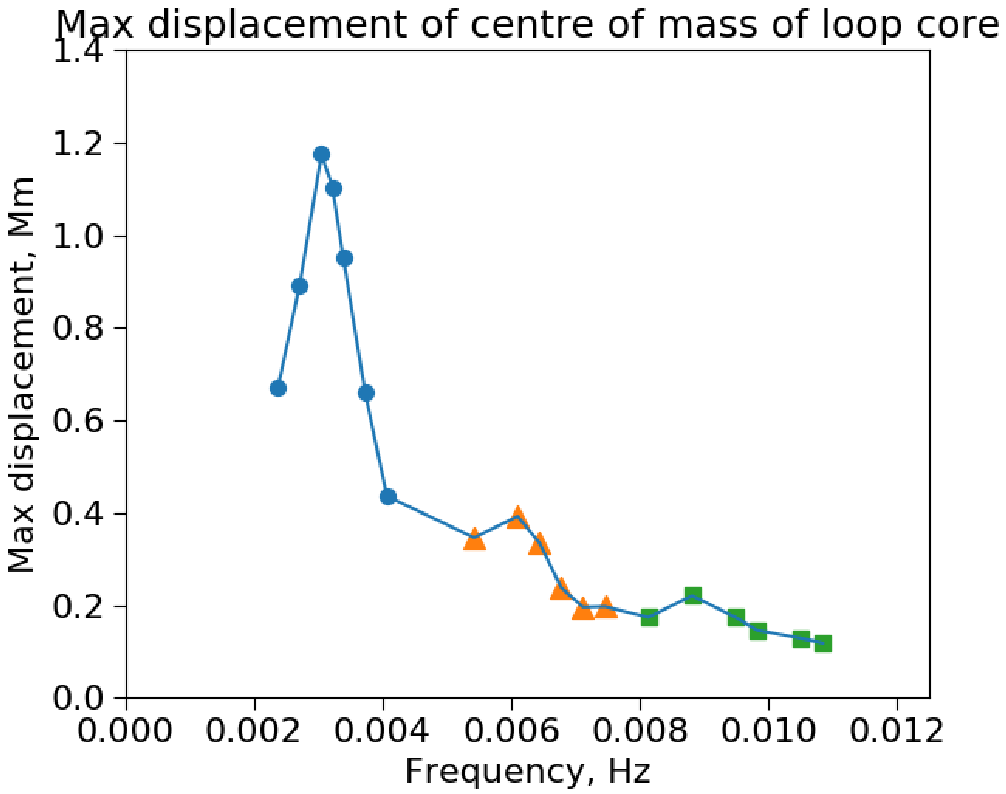
Loop displacement (thr = 0.5)



Loop displacement (thr = 0.7)

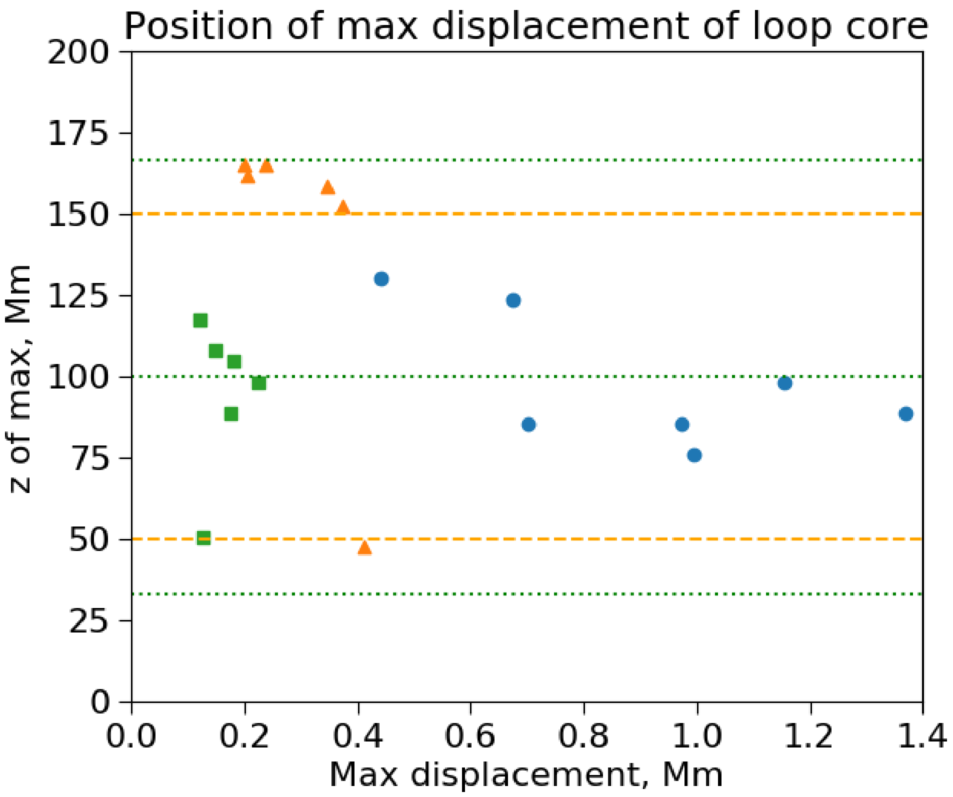


Position of max displacement of loop core

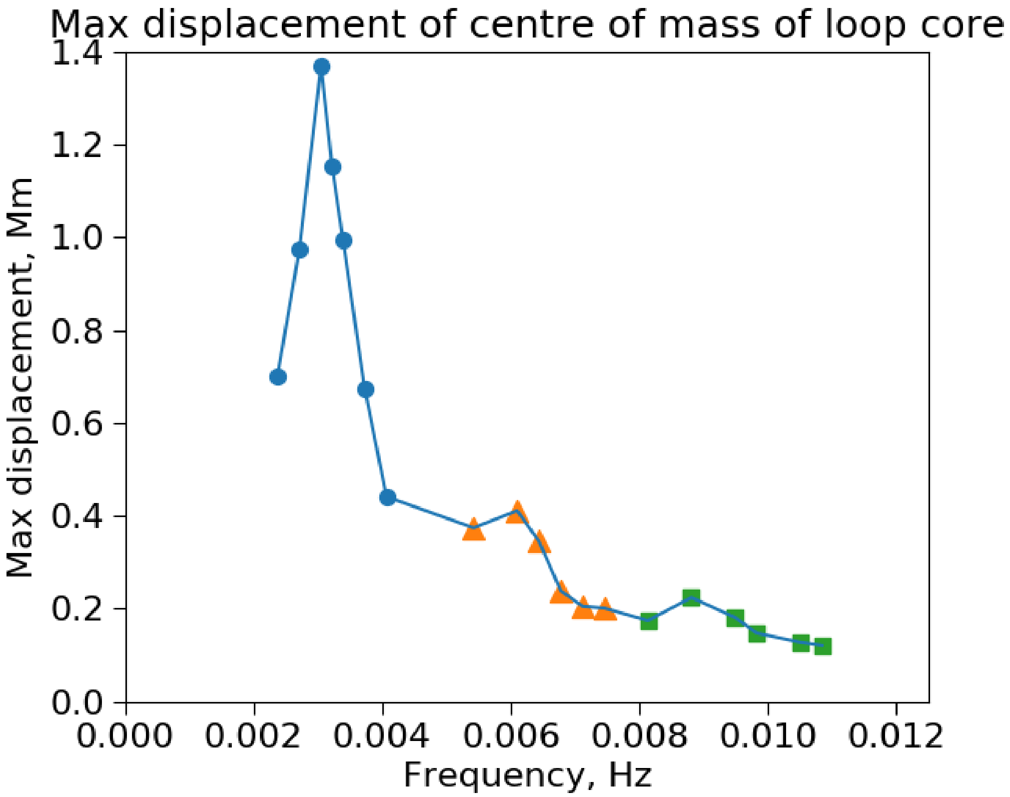


Max displacement of centre of mass of loop core

Loop displacement (thr = 0.9)

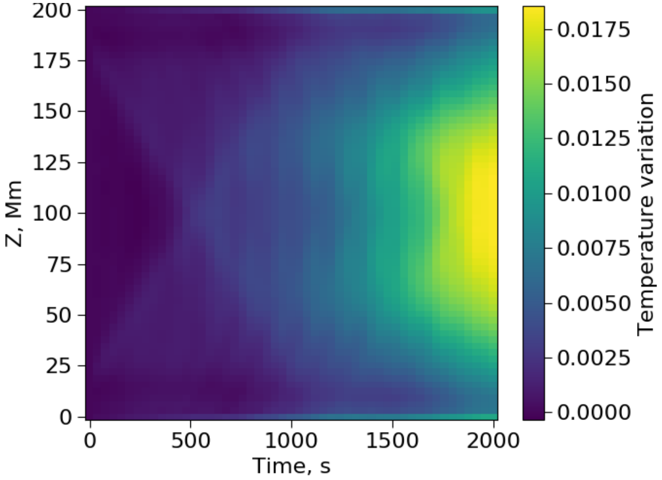


Position of max displacement of loop core

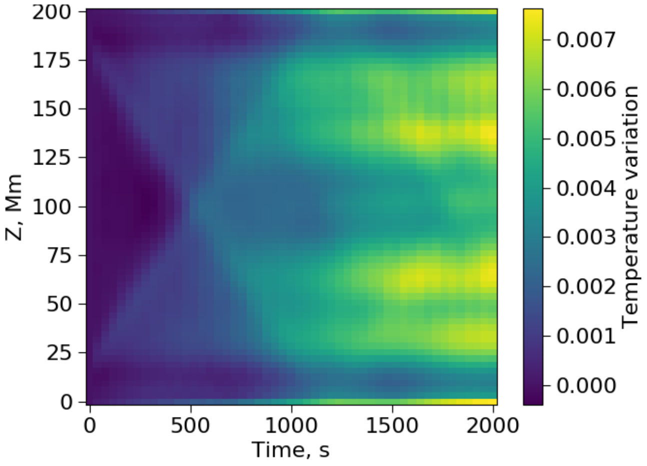


Max displacement of centre of mass of loop core

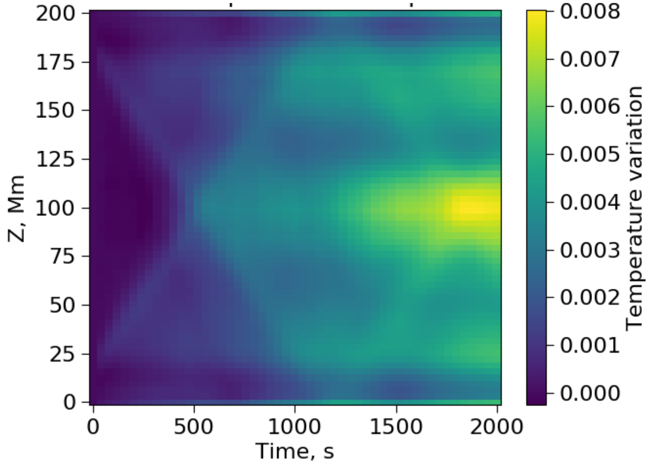
Volume averaged temperature variation



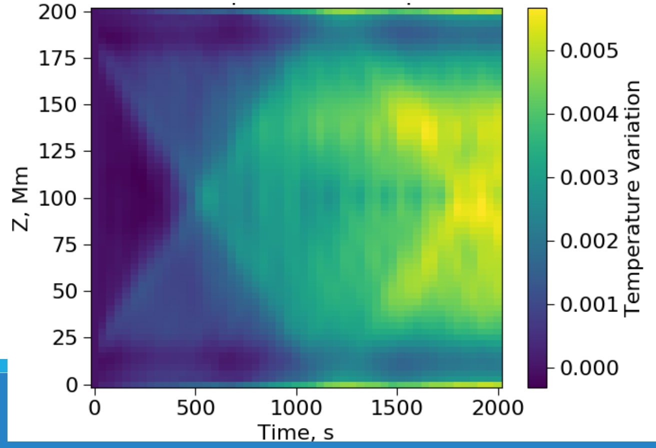
1st harmonics

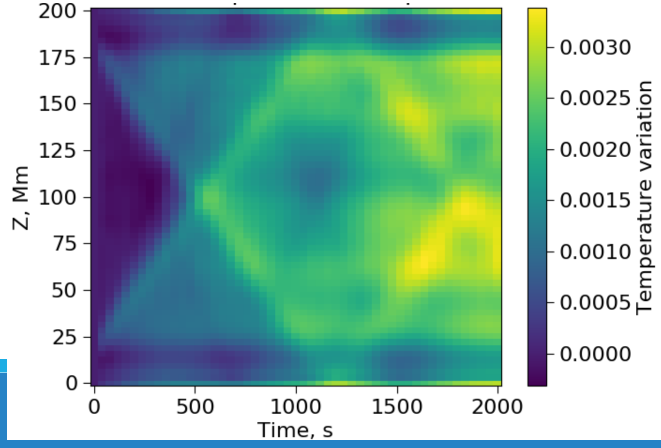


2nd harmonics



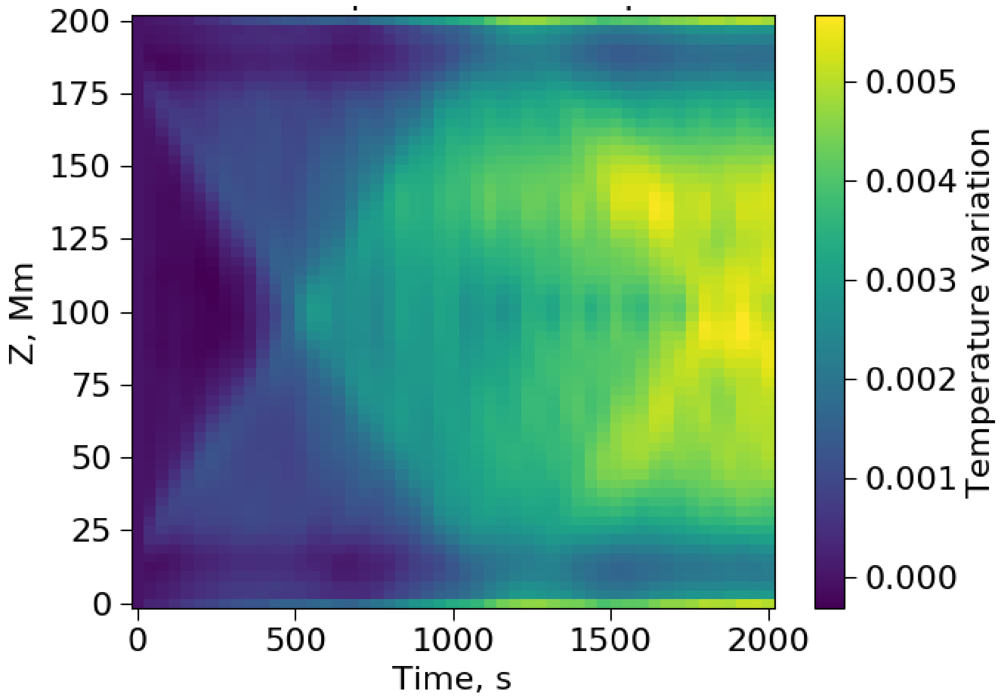
3rd harmonics



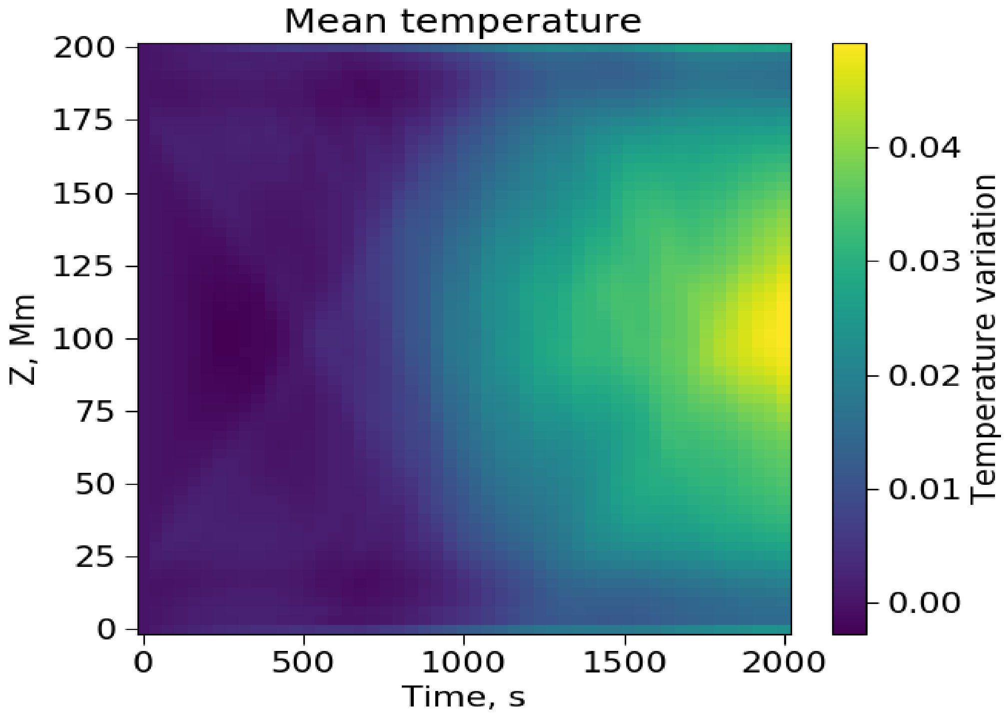


Convergence test for intermediate case

47 km/pix



23 km/pix (0÷2Mm, -4÷4Mm)



Summary

- We studied the excitation of a coronal loop by transverse motions and performed 3D numerical simulations of footpoint driven kink oscillations of a magnetic tube filled in with the denser, hotter, and gravitationally stratified plasma.
- We showed the response of a coronal loop to different monoperiodic external excitations. The maximum loop displacement is lower for higher frequencies because the energy of a driver is distributed to anti-nodes.
- In the cases of intermediate driver frequencies, KHI develops as well, which could explain the saturation in the kinetic energy density in those cases.
- For a hotter and denser stratified loop, the formation of hotter (than background plasma) KH turbulent layer at the loop boundary due to the coronal plasma mixing gives the enhancement in the volume averaged temperature at the positions of oscillation anti-nodes, or at those of the maximum loop displacement for non-eigenfrequency cases.

Concluding remarks

- Comparison with results of previous studies allows us to conclude that the **initial temperature configuration appears to play the significant role in the coronal loop heating by transverse footpoint motions**. In particular, transverse oscillations in **hotter** loops result in plasma heating.
- This **plasma heating** associated with mixing due to KHI **occurs** at some heights **both for resonance kink excitation** of loops **and for non-resonance one**.

Thank you!