Heating effects from driven kink and Alfvén waves in coronal loops

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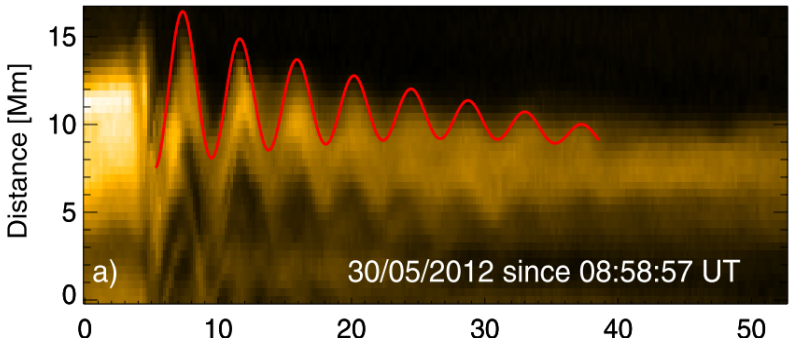
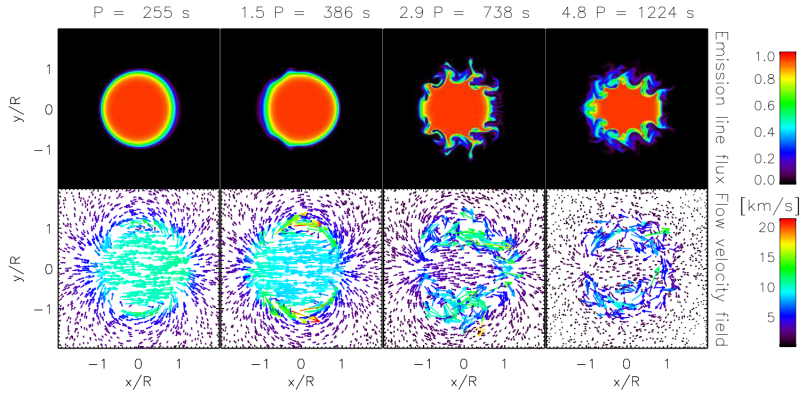
CONTENTS

KINK AND ALFVÉN WAVES

- Kink waves are ubiquitous in the solar atmosphere (De Moortel & Nakariakov 2012; Nakariakov et al. 2016).
  - Transverse Wave Induced K-H (TWIKH) rolls probably play an important role in coronal heating (Terradas et al. 2008; Antolin et al. 2014, 2017; Magyar et al. 2015; Karampelas et al. 2017; Howson et al. 2017)



Goddard et al. 2016

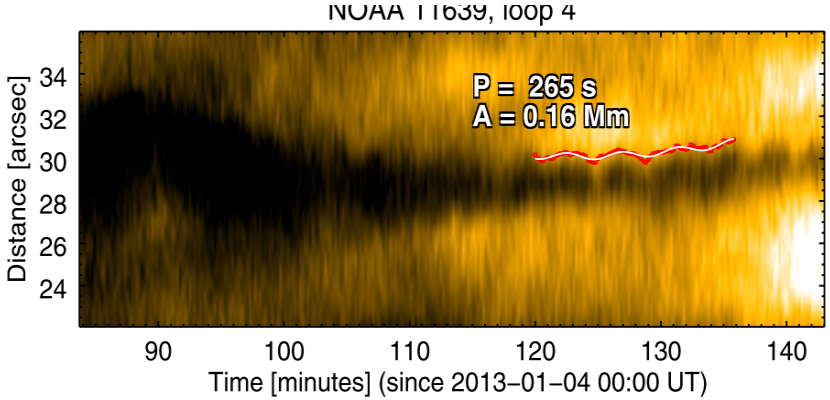


Antolin et al. 2014

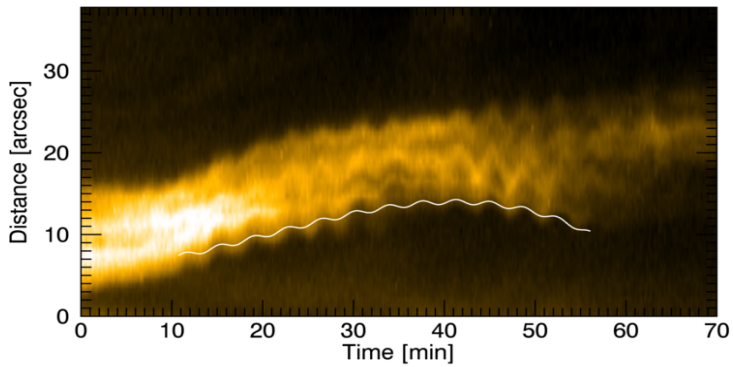
- Alfvén waves:
  - torsional motions $\Rightarrow$ could be detectable to spectrographs indirectly (Zaqarashvili 2003, Jess et al. 2009)
  - could carry a large amount of energy to the corona $\Rightarrow$ important for heating (Uchida & Kaburaki 1974, Muller et al. 1994, Beliën et al.1999)

DECAYLESS OSCILLATIONS

- Decayless transverse oscillations are observed.
  - A common phenomenon in corona (Anfinogentov et al. 2015)



Anfinogentov et al. 2015



Nakariakov et al. 2016

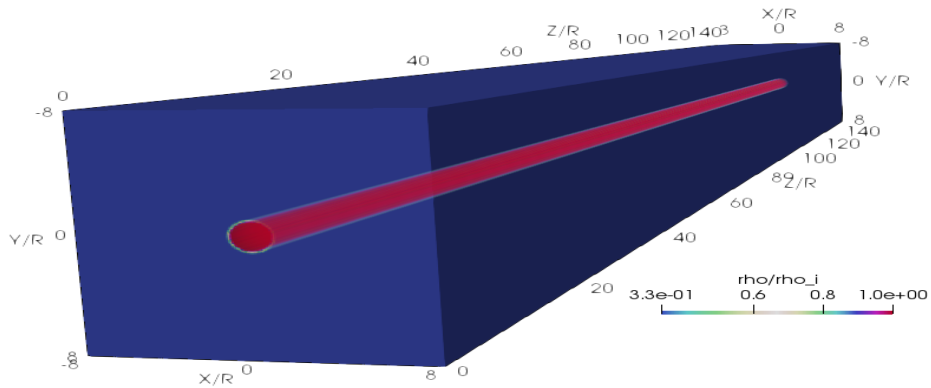
  - they can be explained as periodic brightening of TWIKH rolls (Antolin et al. 2016) or driven oscillations at footpoints (Nakariakov et al. 2016, Karampelas et al. 2017)
- We consider driven oscillations in loops and examine the heating effects.

NUMERICAL MODELS

- Equilibruim

Table 1. Parameters used in simulations

Parameters	Values
Loop length (L)	150 Mm
Loop radius (R)	1 Mm
External density (ρ_e)	2.5×10^{-15} g/cm^3
Density ratio (ρ_i/ρ_e)	3
Temperature (T)	1 MK
Magnetic field (B_i)	50 G

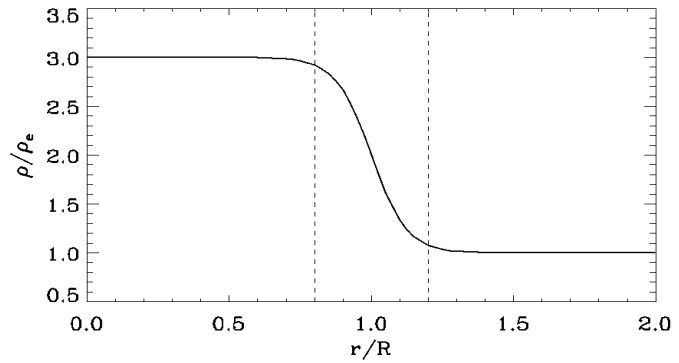


- density profile

$$\rho(x, y) = \rho_e + (\rho_i - \rho_e)\zeta(x, y),$$

where

$$\zeta(x, y) = \frac{1}{2}(1 - \tanh(b(r(x, y) - 1))).$$



NUMERICAL MODELS

- Footpoint drivers
  - kink driver (K-model)

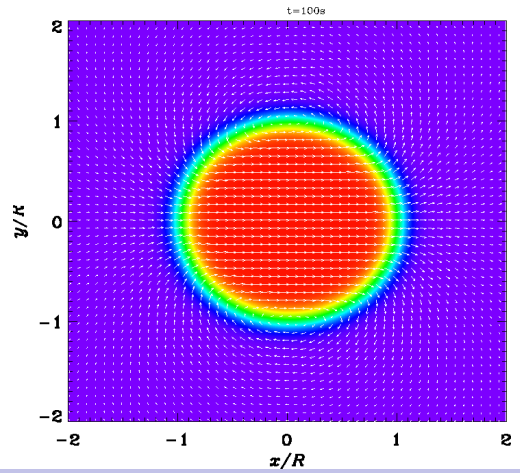
$$\mathbf{v}_{\mathrm{i}} = v_0 \left[\sin\left(\frac{2\pi t}{P_{\mathrm{k}}}\right), 0, 0 \right], \tag{1}$$

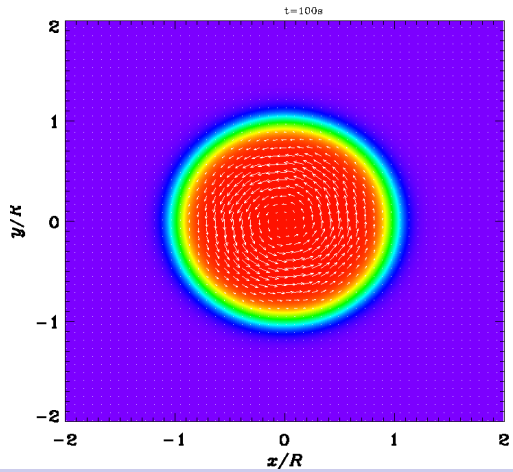
$$\mathbf{v}_{\mathrm{e}} = v_0 R^2 \sin\left(\frac{2\pi t}{P_{\mathrm{k}}}\right) \left[\frac{x^2 - y^2}{(x^2+y^2)^2}, \frac{2xy}{(x^2+y^2)^2}, 0 \right]. \tag{2}$$

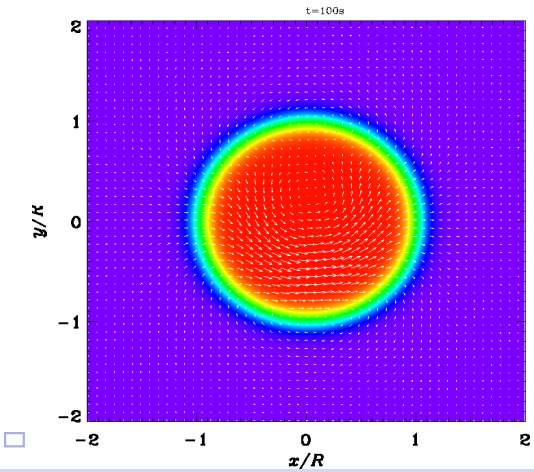
  - Alfvén driver (A-model)

$$v_\theta = v_0 \sin\left(\frac{2\pi t}{P_{\mathrm{A}}(r)}\right) \begin{cases} 2^4 \left(\frac{r}{R}\right)^2 \left(\frac{r}{R} - 1\right)^2, & r/R \le 1 \\ 0, & r/R > 1 \end{cases}$$

  - mixed driver = kink + Alfvén (M-model)

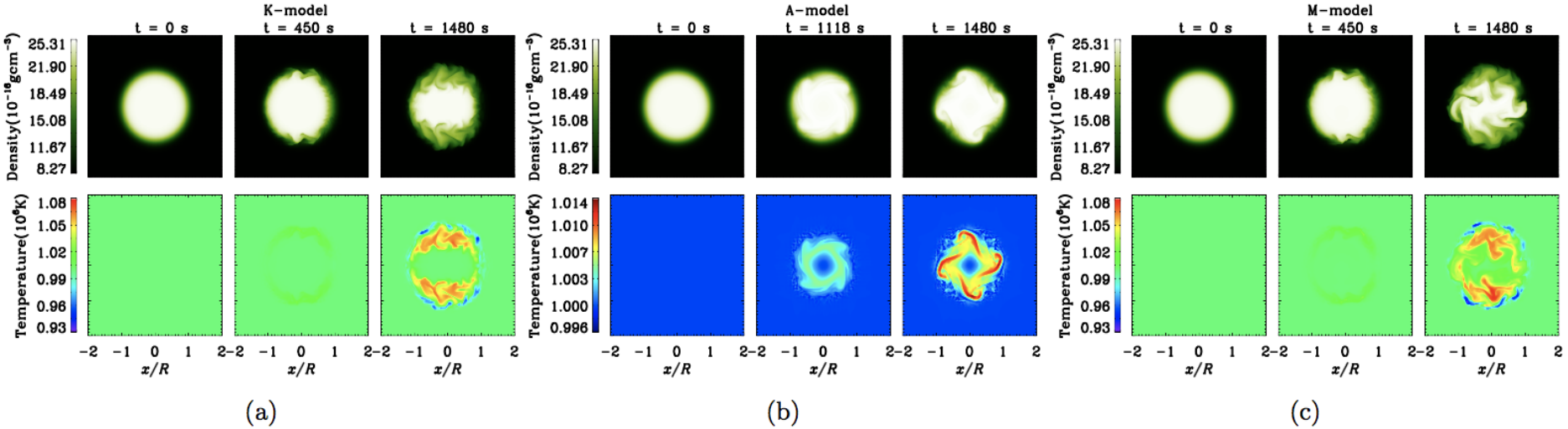






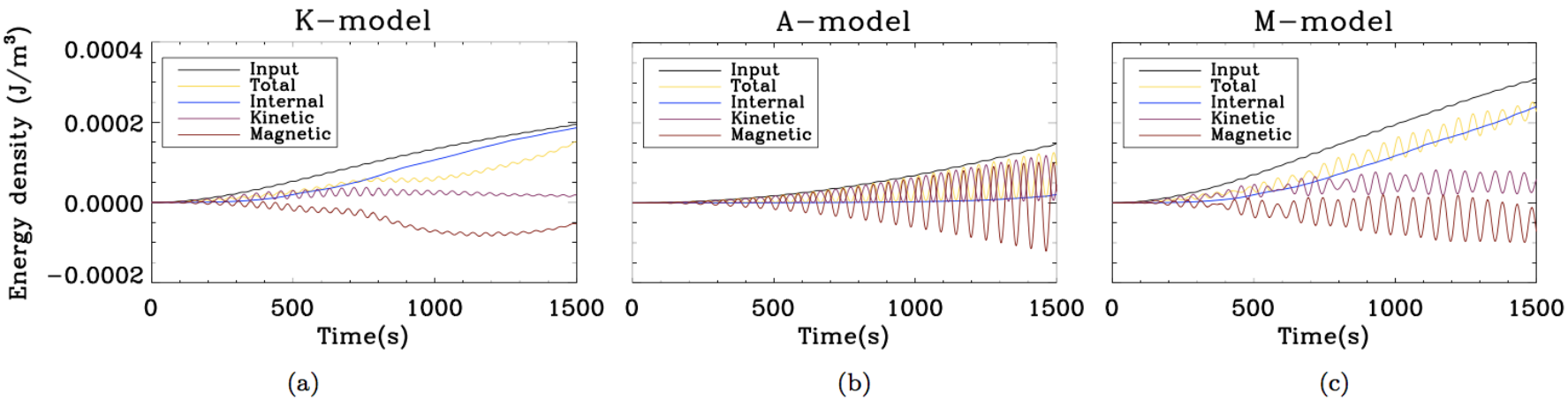
DYNAMICS

- TWIKH rolls can be observed in the K-model, similar to previous studies (Terradas et al. 2008; Antolin et al. 2014, 2016, 2017; Magyar et al. 2015; Karampelas et al. 2017; Howson et al. 2017)
- KHI eddies appear around the boundary in the A-model
- The loop is deformed and more eddies occur in the M-model
- Temperature perturbations appear: adiabatic heating (and cooling) processes



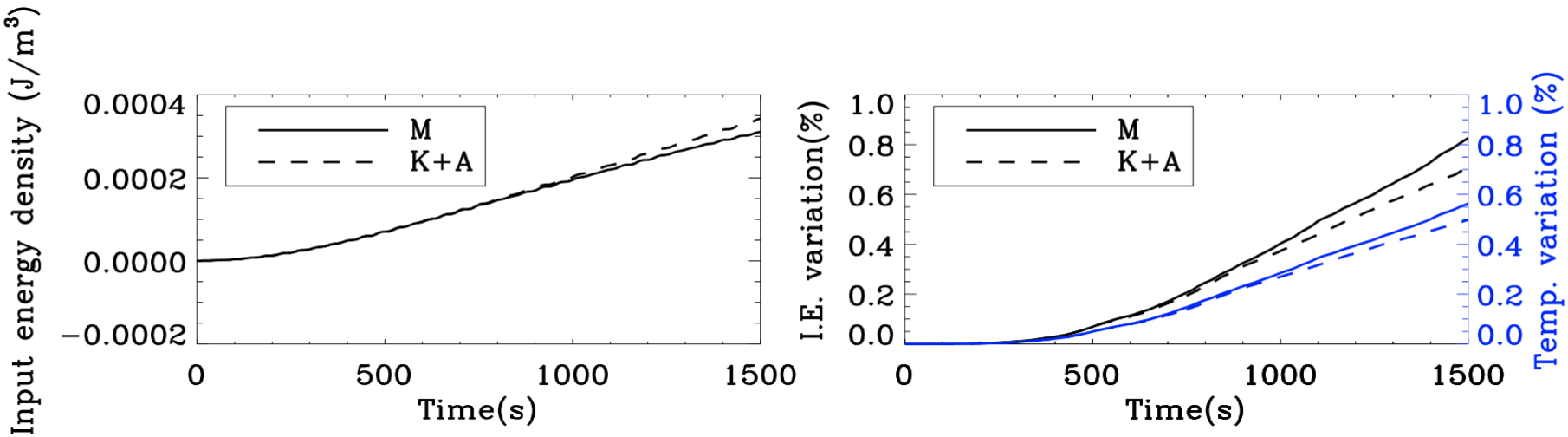
ENERGETICS

- Input energy $\approx$ internal + kinetic energy
- Magnetic energy decrease $\Rightarrow$ internal energy + energy flux through the boundary
- For the M-model, the energy flux $\sim 36.5 Wm^{-2}$, close to balance the radiative losses of quiet corona ($\sim 100 Wm^{-2}$).



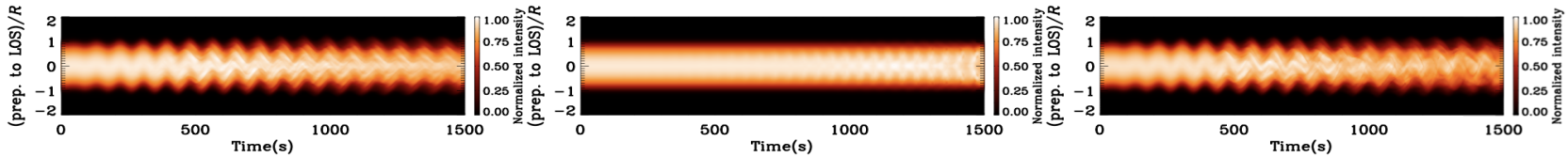
ENERGETICS

- Internal energy and temperature increase for all three models.
- The input energy in the M-model and the sum of the other two models are almost the same level, but the temperature and internal energy still get a larger increase.
- **Mixed modes can lead to a more efficient energy dissipation in the turbulent state of plasma**
- **It means the TWIKH rolls act as an agent to dissipate energy in other wave modes.**

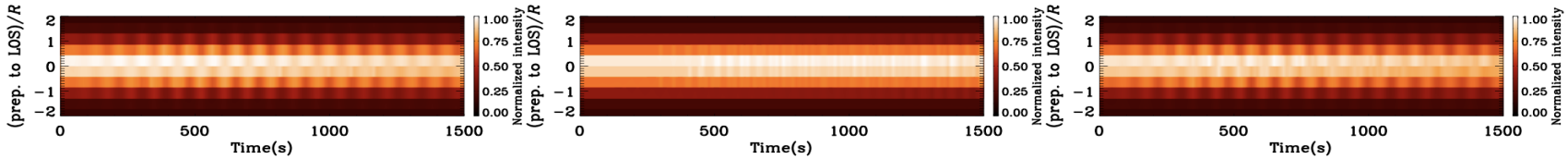


OBSERVABLE PROPERTIES: Imaging Models

- Original (numerical) resolution models
  - Transverse oscillations and small scales can be seen in the K-model and M-model.
  - Intensity perturbations appear in the A-model due to the KHI.



- Degraded resolution models (mimic SDO/AIA)
  - Transverse oscillations can be seen in the K-model and M-model, similar to the real observations (Nisticò et al. 2013; Anfinogentov et al. 2013, 2015).
  - Small scales disappear due to the coarse resolution.

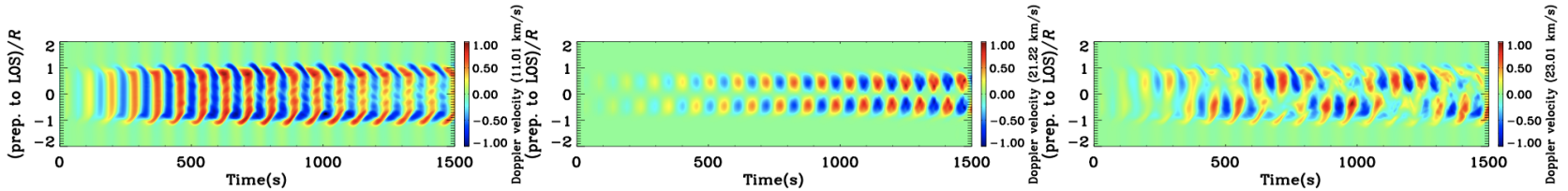


From left to right: the K-model, A-model and M-model

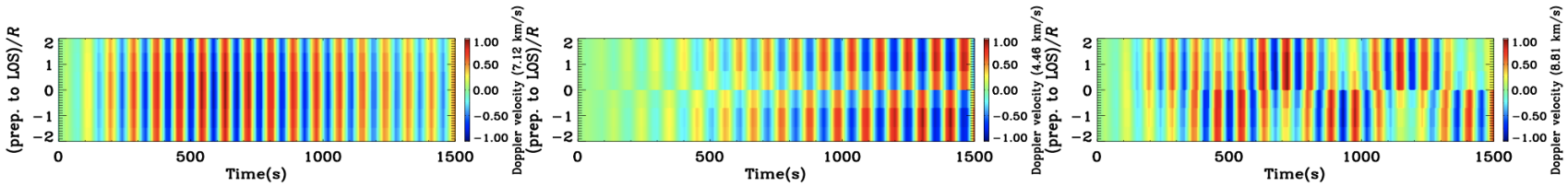
- **Alfvén modes can probably co-exit with kink modes, leading to enhanced heating.**

OBSERVABLE PROPERTIES: Spectral Models

- Original (numerical) resolution models
  - K-model: transverse oscillations and KHI $\Rightarrow$ staggered blue and red "bow-like" shapes
  - A-model: Alfvén oscillations $\Rightarrow$ staggered spot regions
  - M-model: mixed transverse and torsional motions $\Rightarrow$ "tadpole-like" pairs



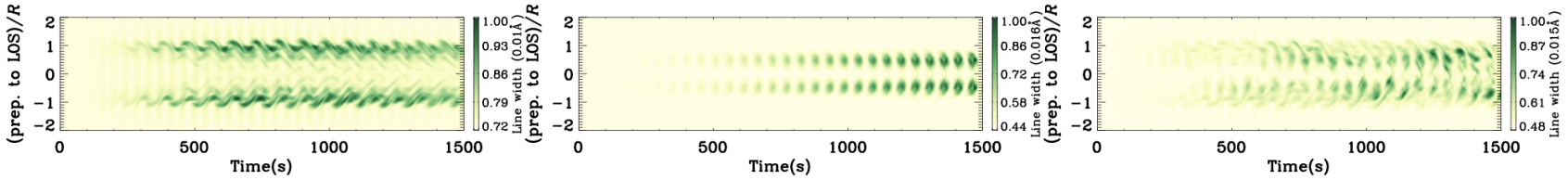
- Degraded resolution models (mimic Hinode/EIS)
  - Small scales disappear due to the coarse resolution.
  - Beating can be seen in the M-model due to the frequency mismatch between the two modes.



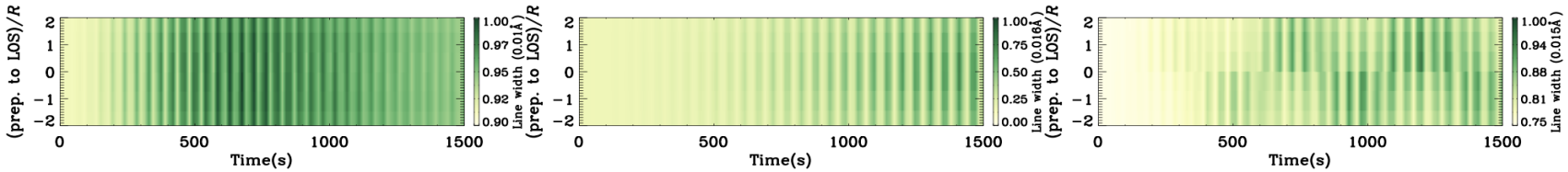
From left to right: the K-model, A-model and M-model

OBSERVABLE PROPERTIES: Spectral Models

- Original (numerical) resolution models
  - Line broadening can be observed due to the KHI and Alfvén oscillations.



- Degraded resolution models (mimic Hinode/EIS)
  - All the shapes become stripes without small scales.
  - We can also see the beating in the M-model



From left to right: the K-model, A-model and M-model

CONSLUSIONS

- We simulated different loops with different drivers and KHI is obtained in all models.
- Mixed modes can lead to a more efficient energy dissipation in the turbulent state of plasma and the KHI eddies can act as an agent to dissipate energy in other wave modes.
- Alfvén modes and small structures are not observable in real imaging observations, therefore, Alfvén modes can probably co-exist with kink modes, leading to enhanced heating.

Thank you!