Do Alfvén wave nonlinearities increase or decrease heating?

Student: Mr A. P. K. Prokopyszyn

Supervisors: Prof A. W. Hood & Prof I. De Moortel

European Research Council

Established by the European Commission

European Commission

University of St Andrews

Solar & Magnetospheric Theory Group

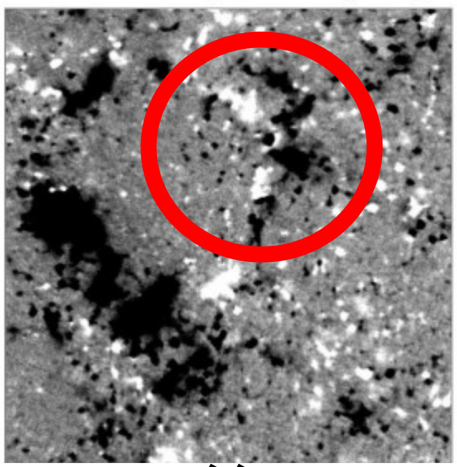
University of St Andrews

Science & Technology Facilities Council

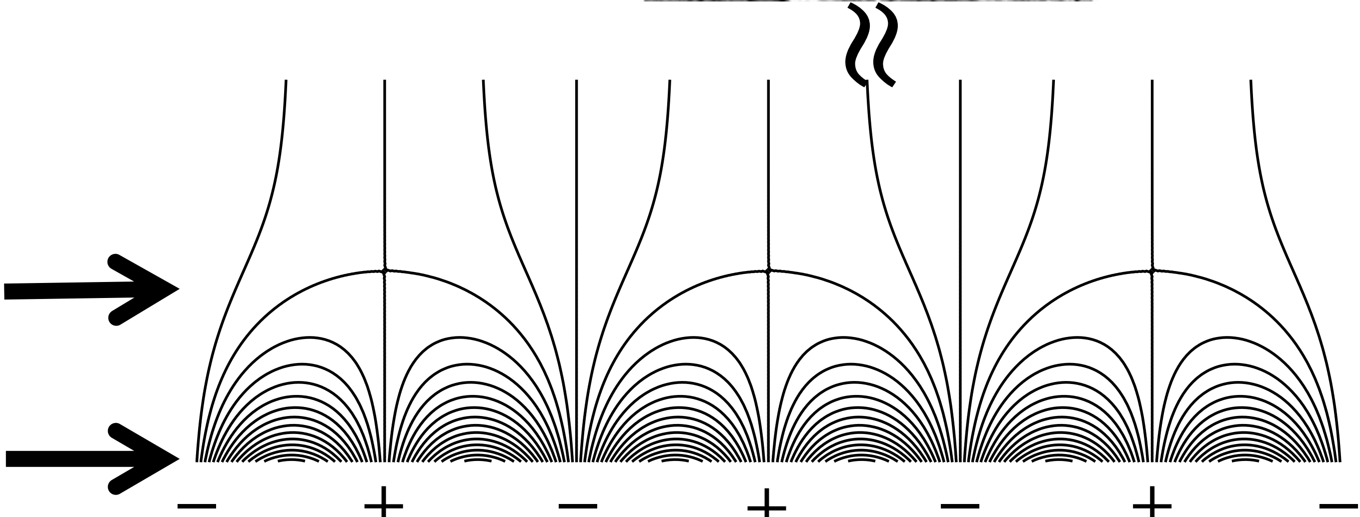
What is this talk about?

- Modelling waves in the solar atmosphere.
  - Approximated using a 2D model.
- Studying nonlinear effects.

Mixed Polarity Region

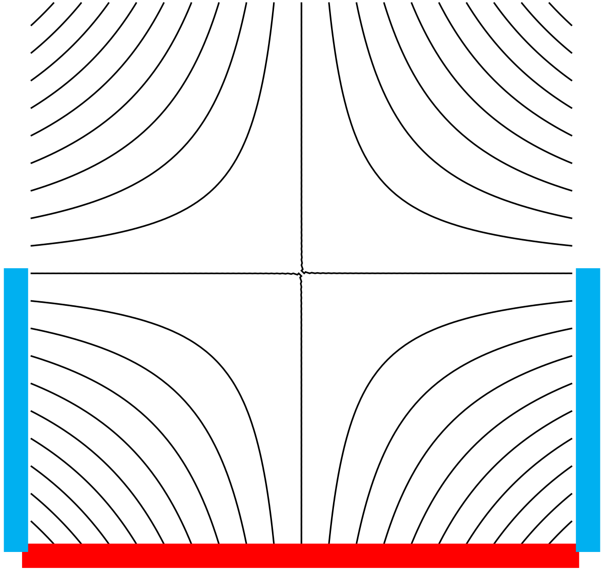


(HINODE Magnetogram)

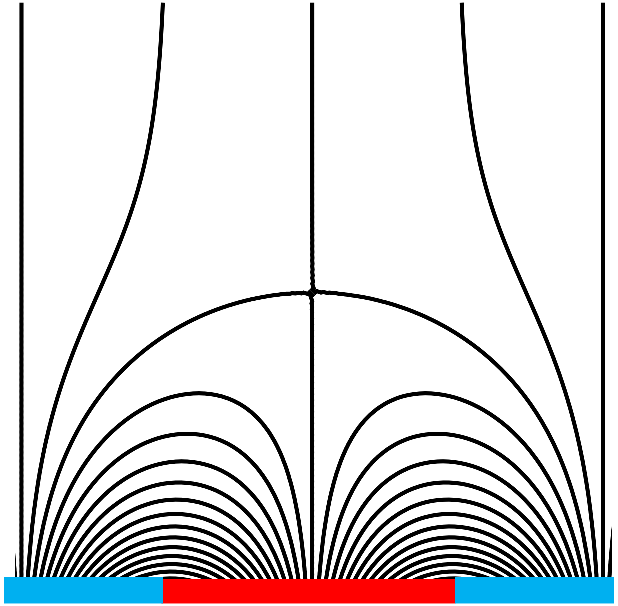


Why use an x-point field?

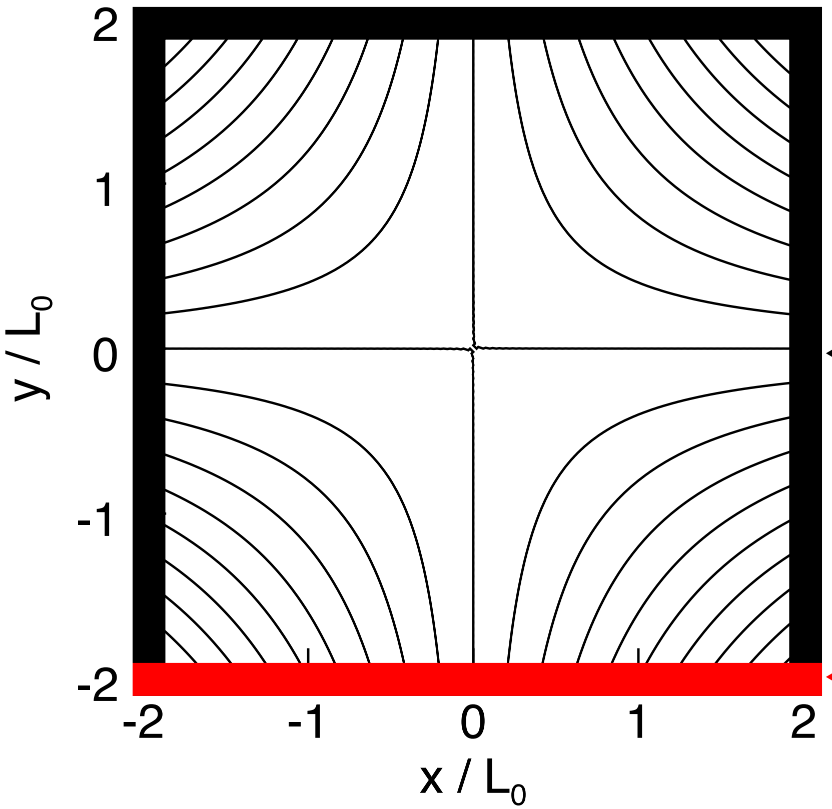
- There is balance between convenience and complexity.
- McLaughlin et. al. (2016, 2013, 2011) has researched the behaviour of waves near null points.



≈



What is this talk about?

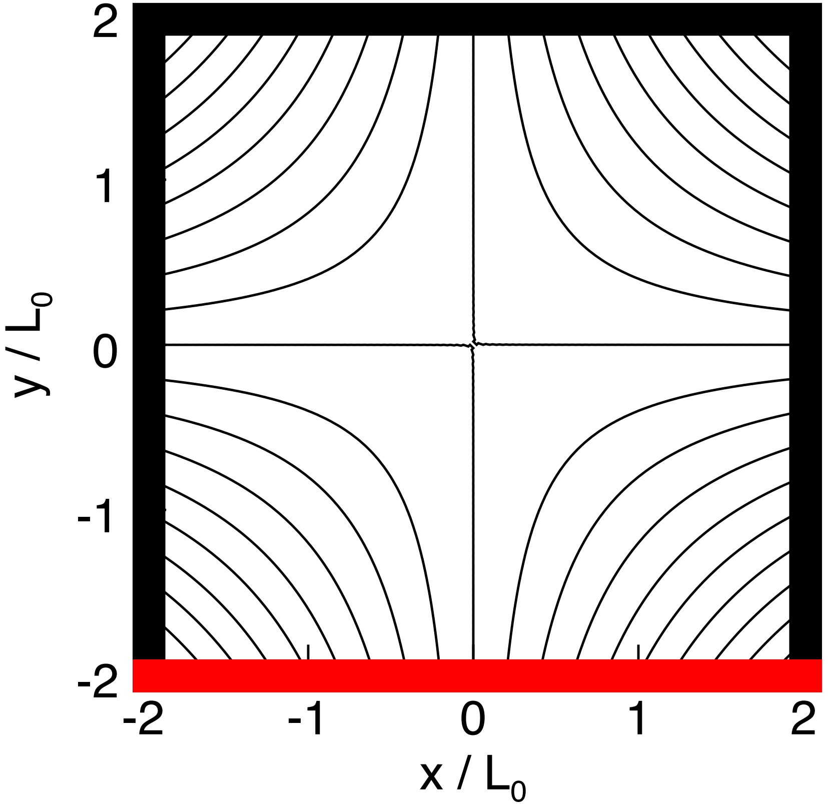


Looking at results from numerical experiments:

Line-tied boundary (v=0)

Nonlinear driver, sinusoidal, single frequency

What is this talk about?



Parameter study:

Compare nonlinear against linear experiments

$$\frac{v_{driv}}{v_A^{norm}} = [10^{-1}, 10^{-2}, 10^{-3}]$$

Nonlinear (10^{-1}) Linear (10^{-3})

v_{driv} = Driver Amplitude

$v_A^{norm} = v_A$, at $R/L_0 = 1$

Equations being solved:

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

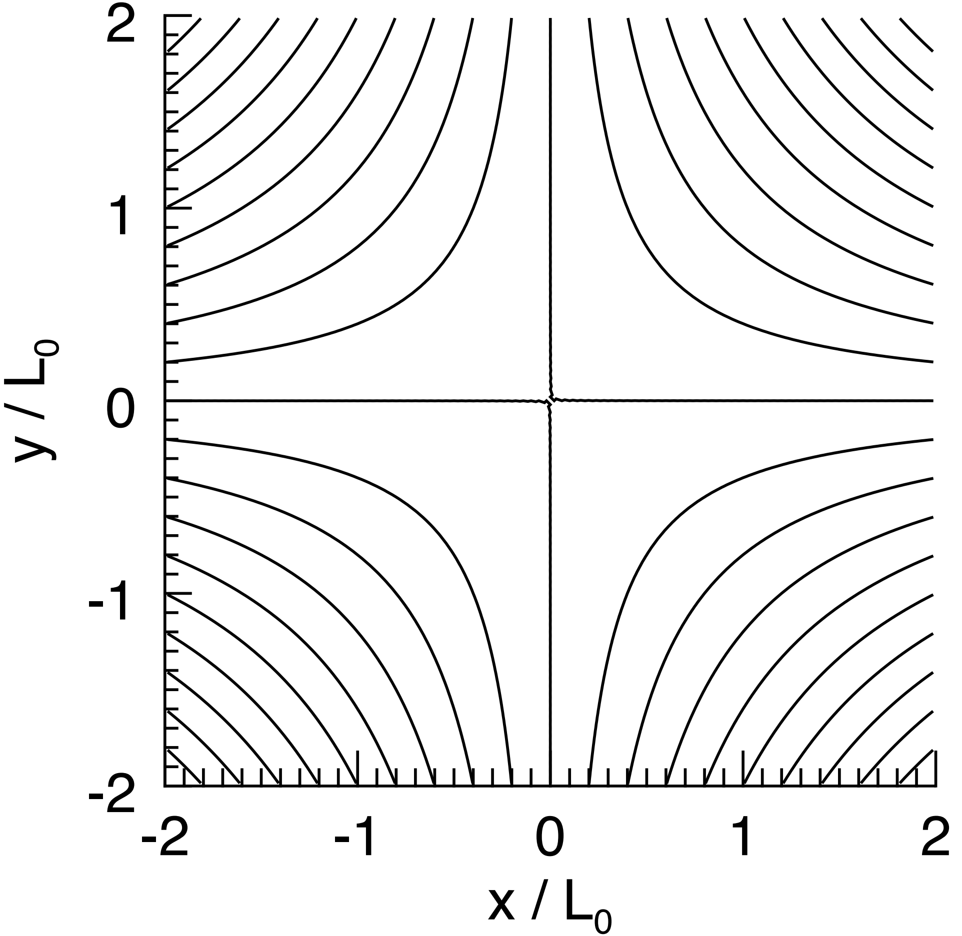
$$\rho \frac{D\boldsymbol{v}}{Dt} = \boldsymbol{j} \times \boldsymbol{B} - \boldsymbol{\nabla}\mathrm{p} + \mathbf{F}_{\nu}^{shock}$$

$$\frac{\partial \boldsymbol{B}}{\partial t} = \boldsymbol{\nabla} \times (\boldsymbol{v} \times \boldsymbol{B}) + \eta \nabla^2 \boldsymbol{B}$$

$$\frac{\rho^{\gamma}}{\gamma - 1} \frac{D}{Dt}\left(\frac{p}{\rho^{\gamma}}\right) = \frac{j^2}{\sigma} + H_{\nu}^{shock}$$

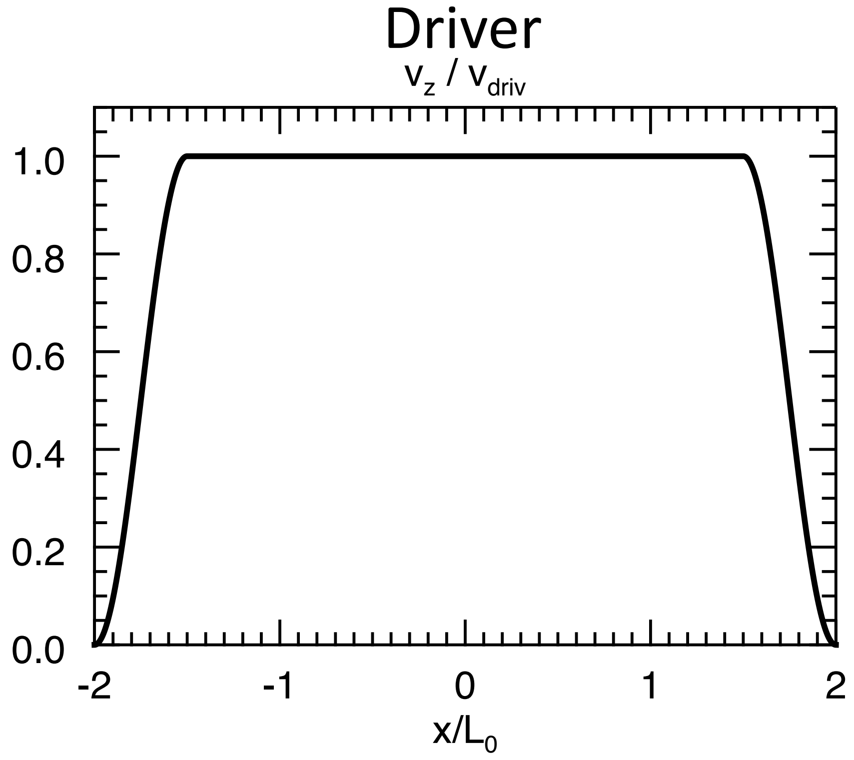
Setup

- Uniform ρ_0, p_0
- $\boldsymbol{B}_0 = \frac{B_{norm}}{L_0}\,(x, -y)$
- $\boldsymbol{v}_0 = 0$
- $\beta = 10^{-2}\,\frac{L_0^2}{R^2}$
- $\eta = 10^{-3}\eta_{norm}$

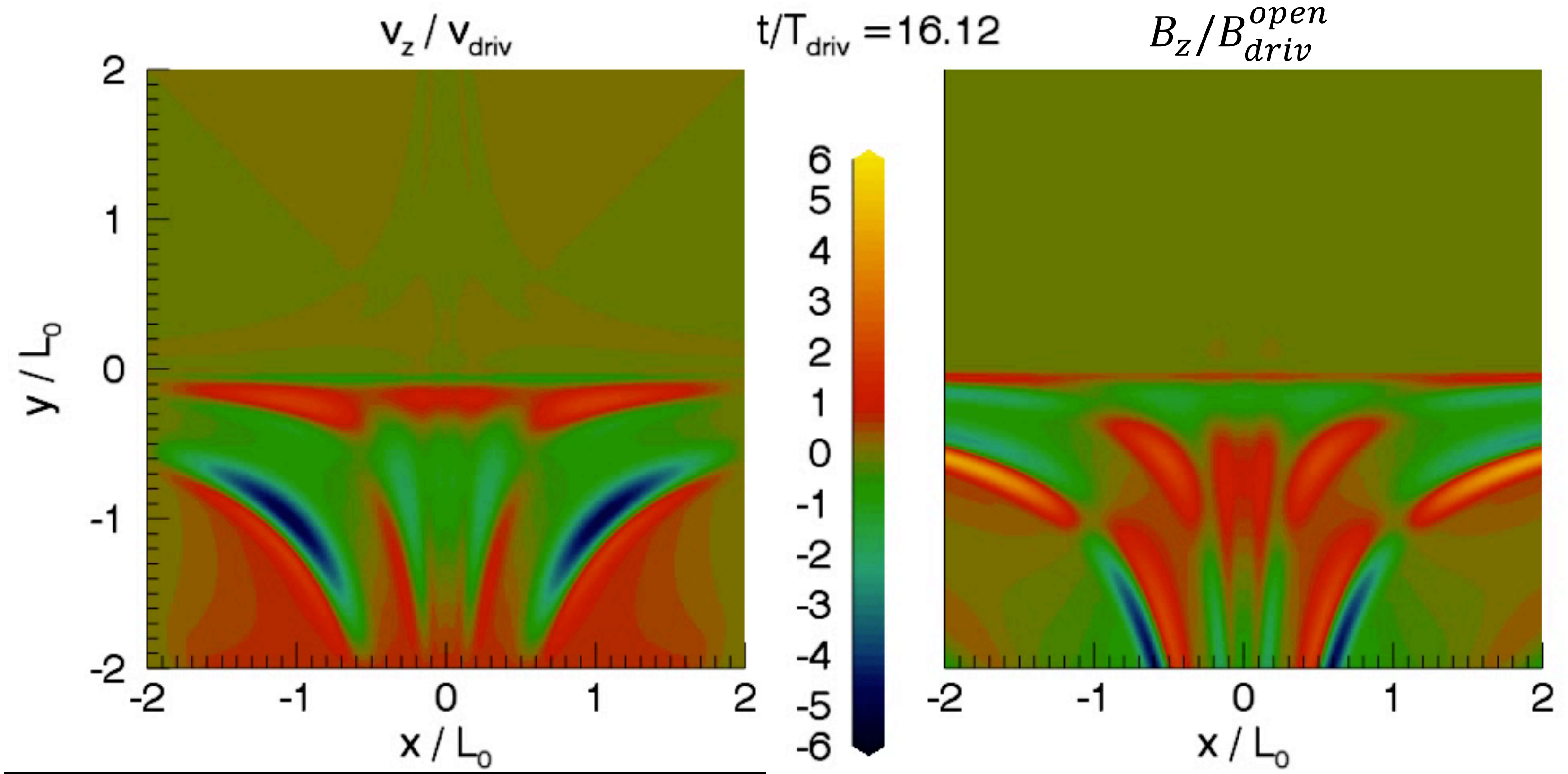


Boundary Conditions

- Driver at $y = y_{min}$
- Sinusoidal time profile
- Single frequency
- Line-tied $(v = 0)$ boundary conditions otherwise
- After 20 driving time periods the driver is switched off



Alfvén Waves

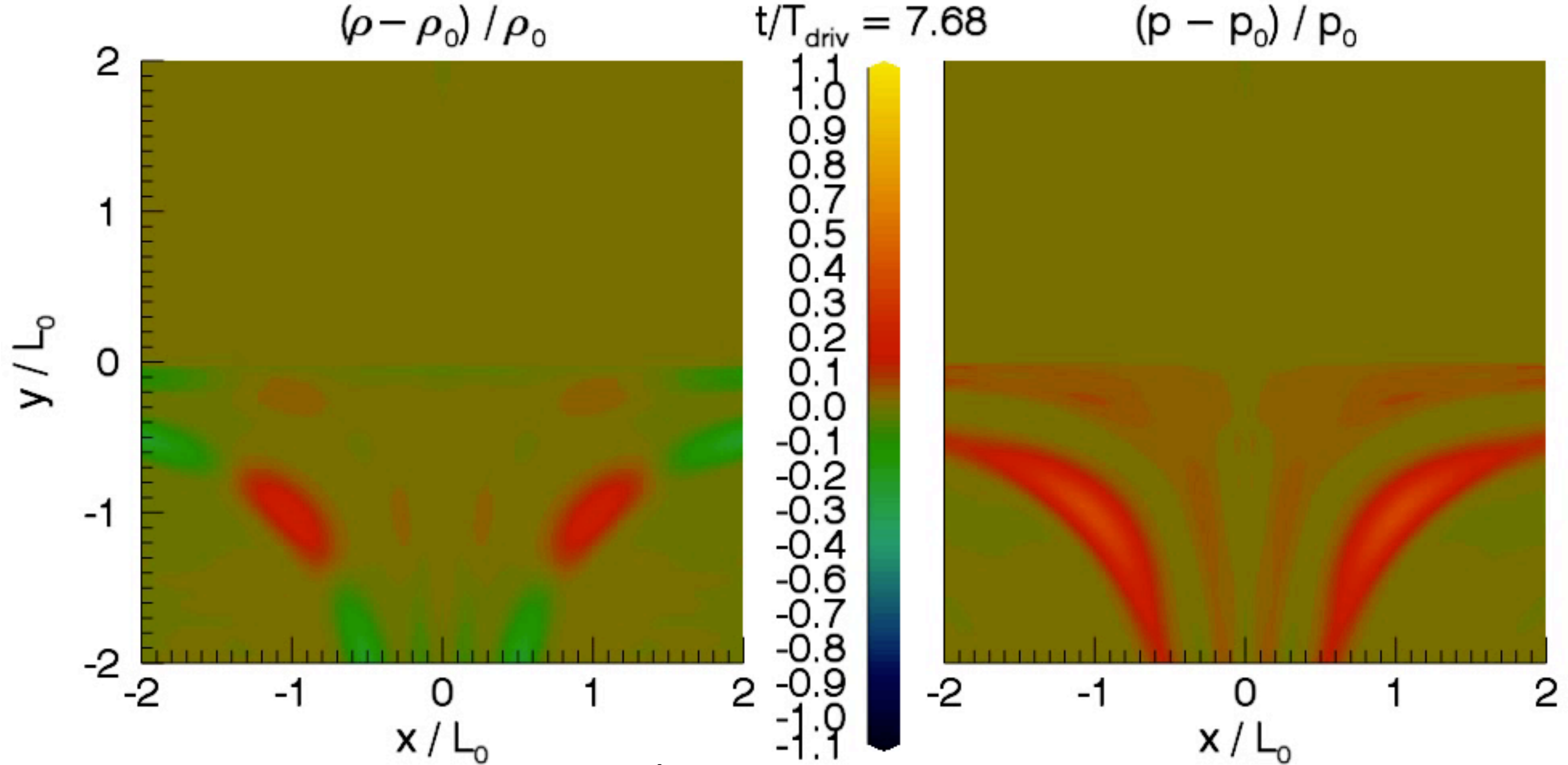


- Phase mixing due to varying field
- Resonance
- Magnetic pressure force

$$v_{driv} = 10^{-2} v_A^{norm}$$

Density Changes

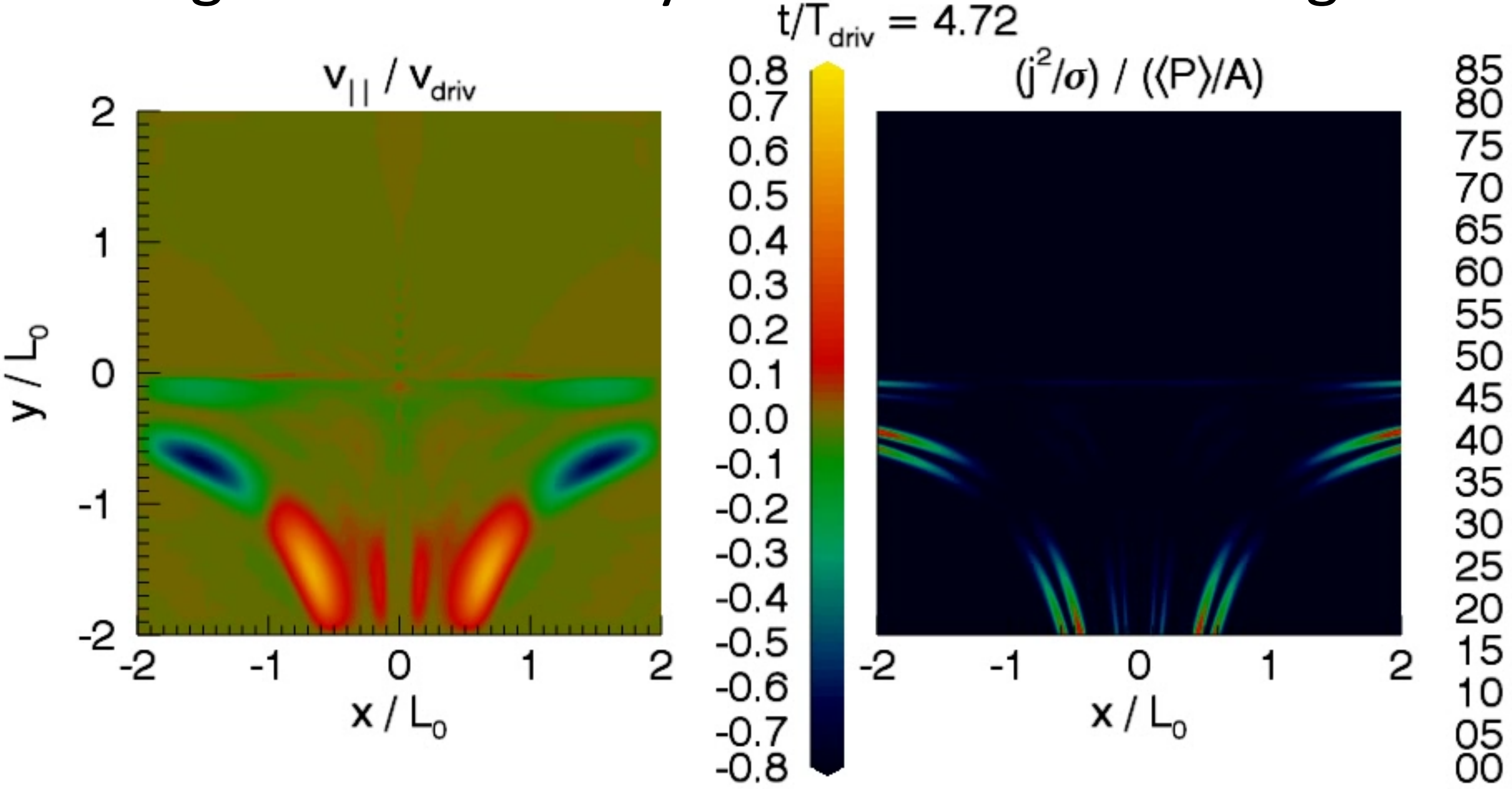
Pressure Changes



- Density structures generated
- Pressure force limits density amplitude
- Internal energy increases on resonant field lines

$$v_{driv} = 10^{-2} v_A^{norm}$$

Longitudinal Velocity   Ohmic heating

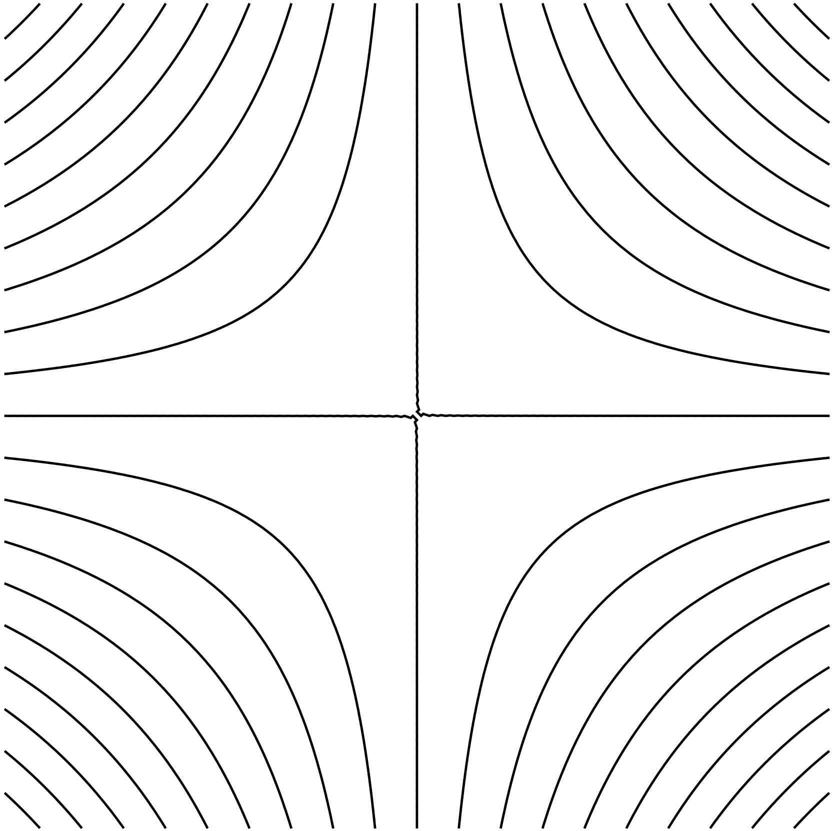


- Perpendicular gradients cause most of the heating
  - Phase mixing dominant heating mechanism
- Heating pushes plasma away from footpoints

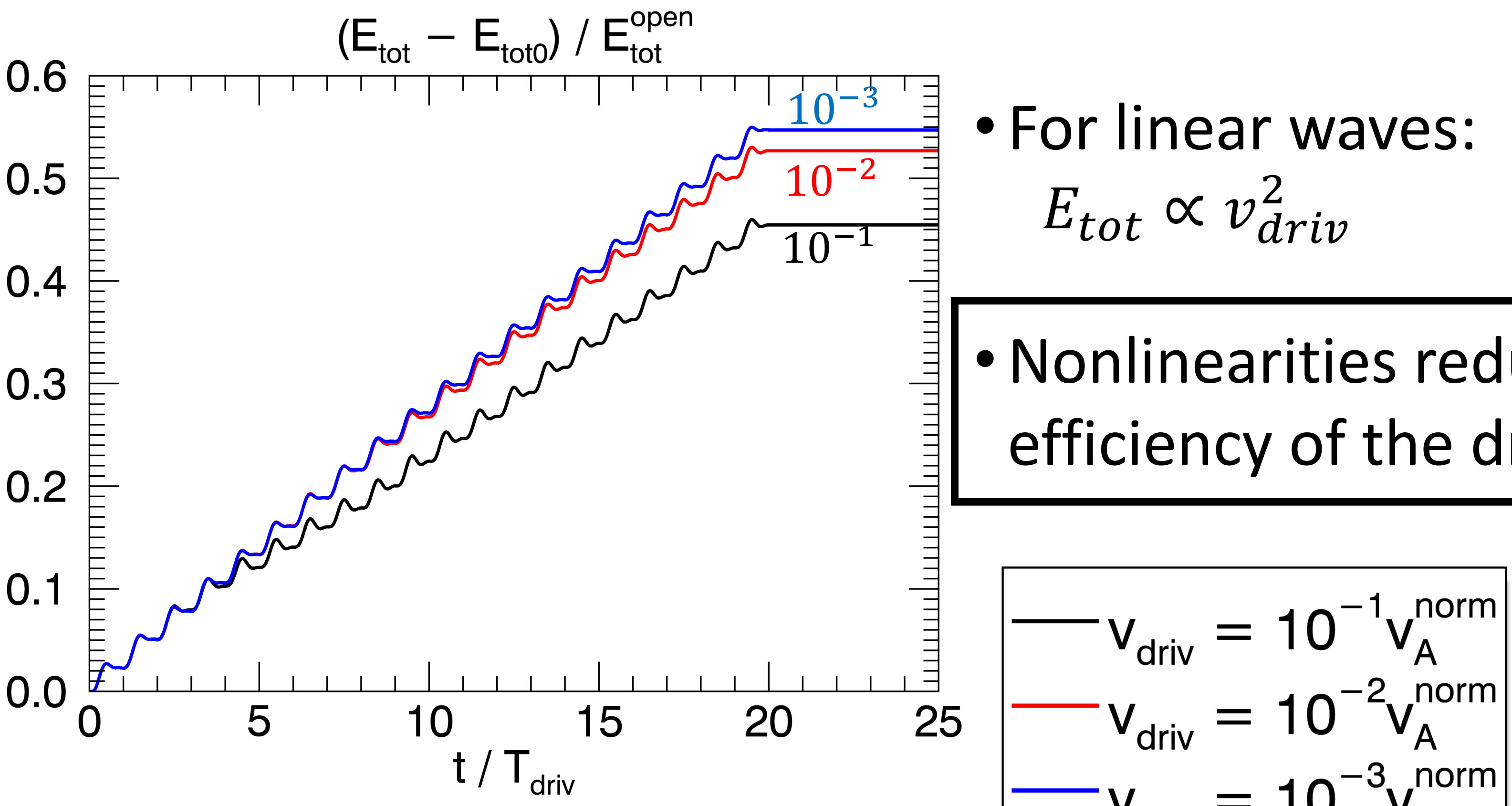
$$v_{driv} = 10^{-2} v_A^{norm}$$

How strong is the phase mixing?

- Phase mixing occurs due to:
  - Differences in magnetic field strength.
  - Differences in field line length.
- Driver amplitude of: $\sim 10^{-2}\ v_A^{norm} \approx 10km/s$ required to balance radiative losses in corona.



Total Energy

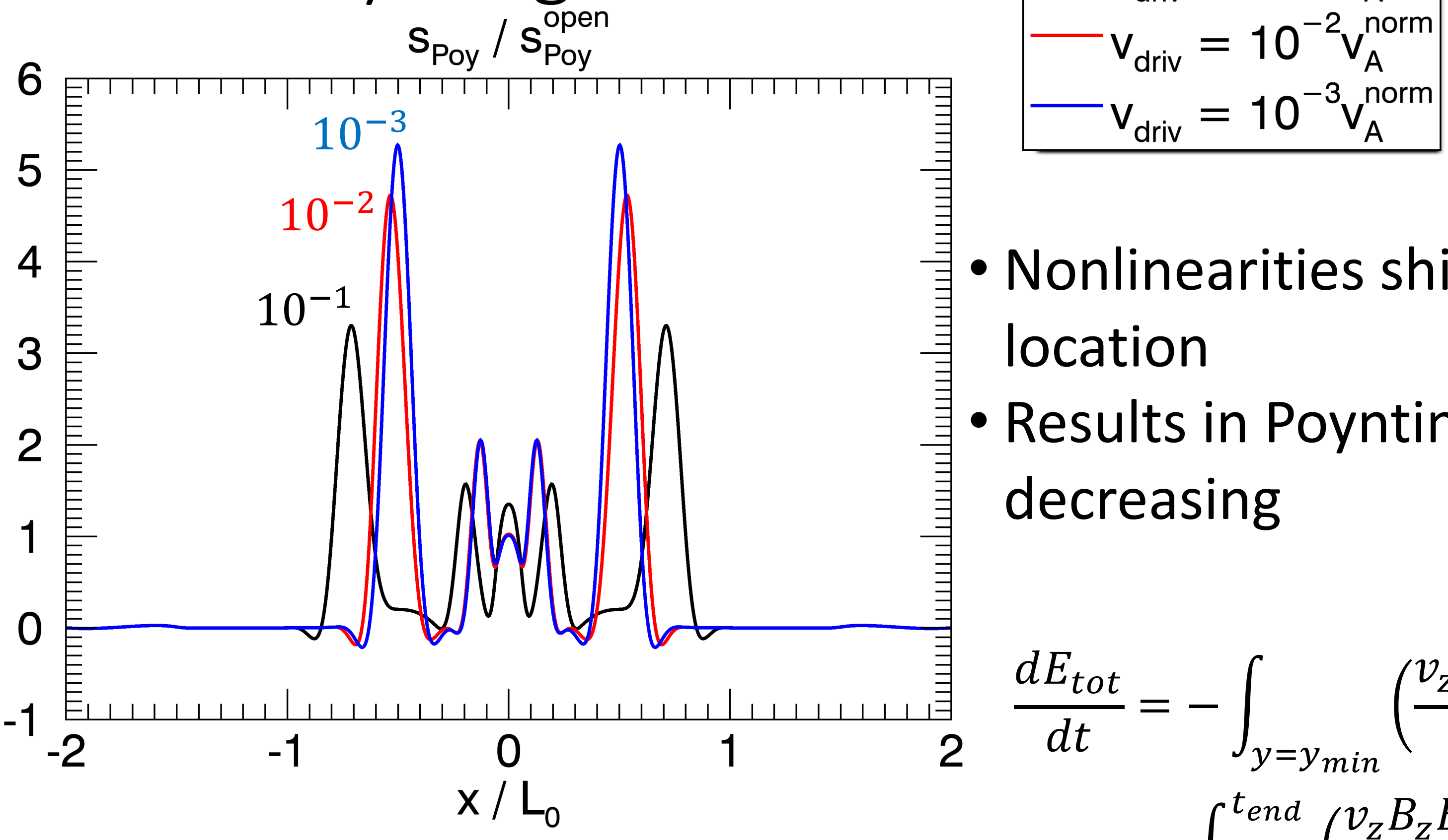


$(E_{tot}^{open} = constant \times v_{driv}^2)$

- For linear waves: $E_{tot} \propto v_{driv}^2$

- Nonlinearities reduce the efficiency of the driver.

Poynting Flux



$(s_{tot}^{open} = constant \times v_{driv}^2)$

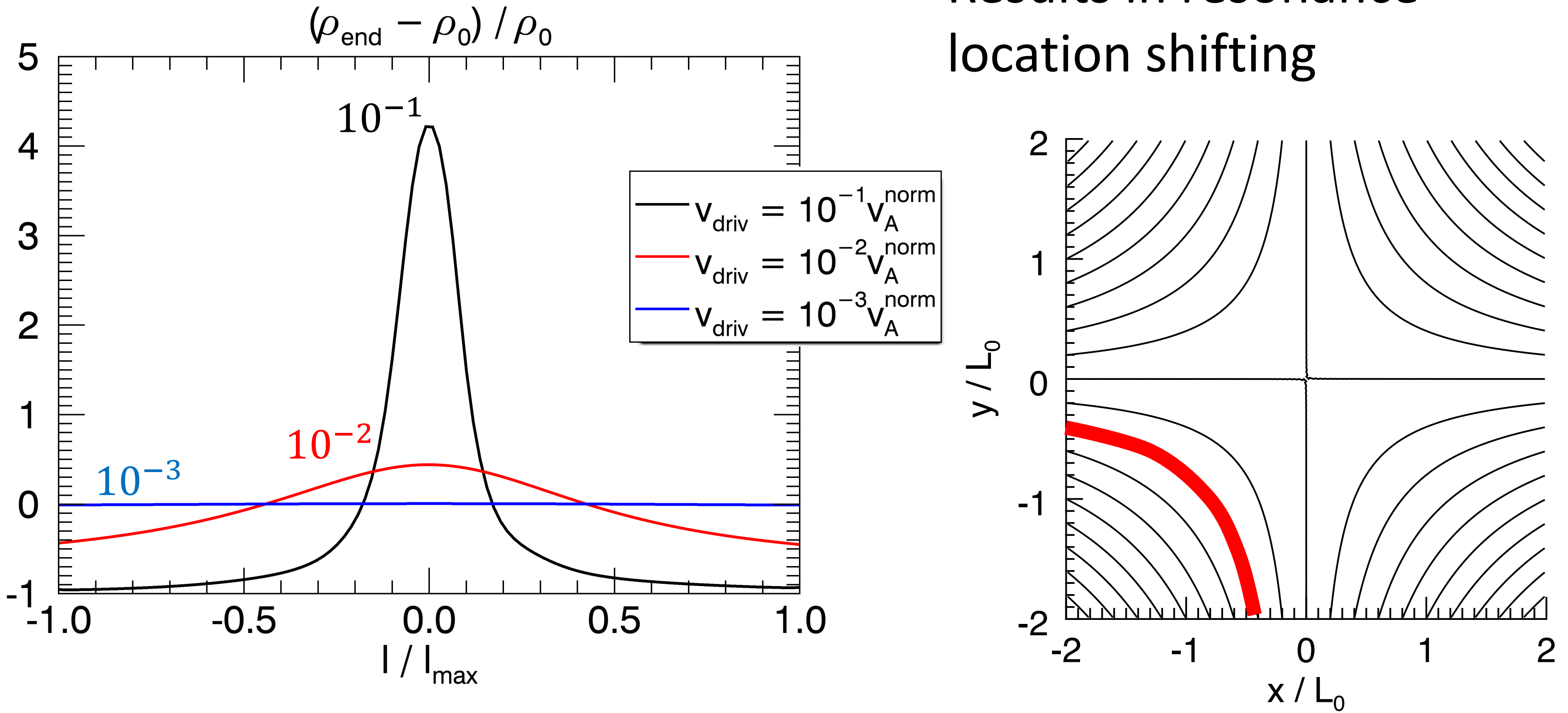
- Nonlinearities shift resonance location
- Results in Poynting flux decreasing

$$\frac{dE_{tot}}{dt} = -\int_{y=y_{min}} \left(\frac{v_z B_z B_y}{\mu}\right)(x, y_{min})dx$$

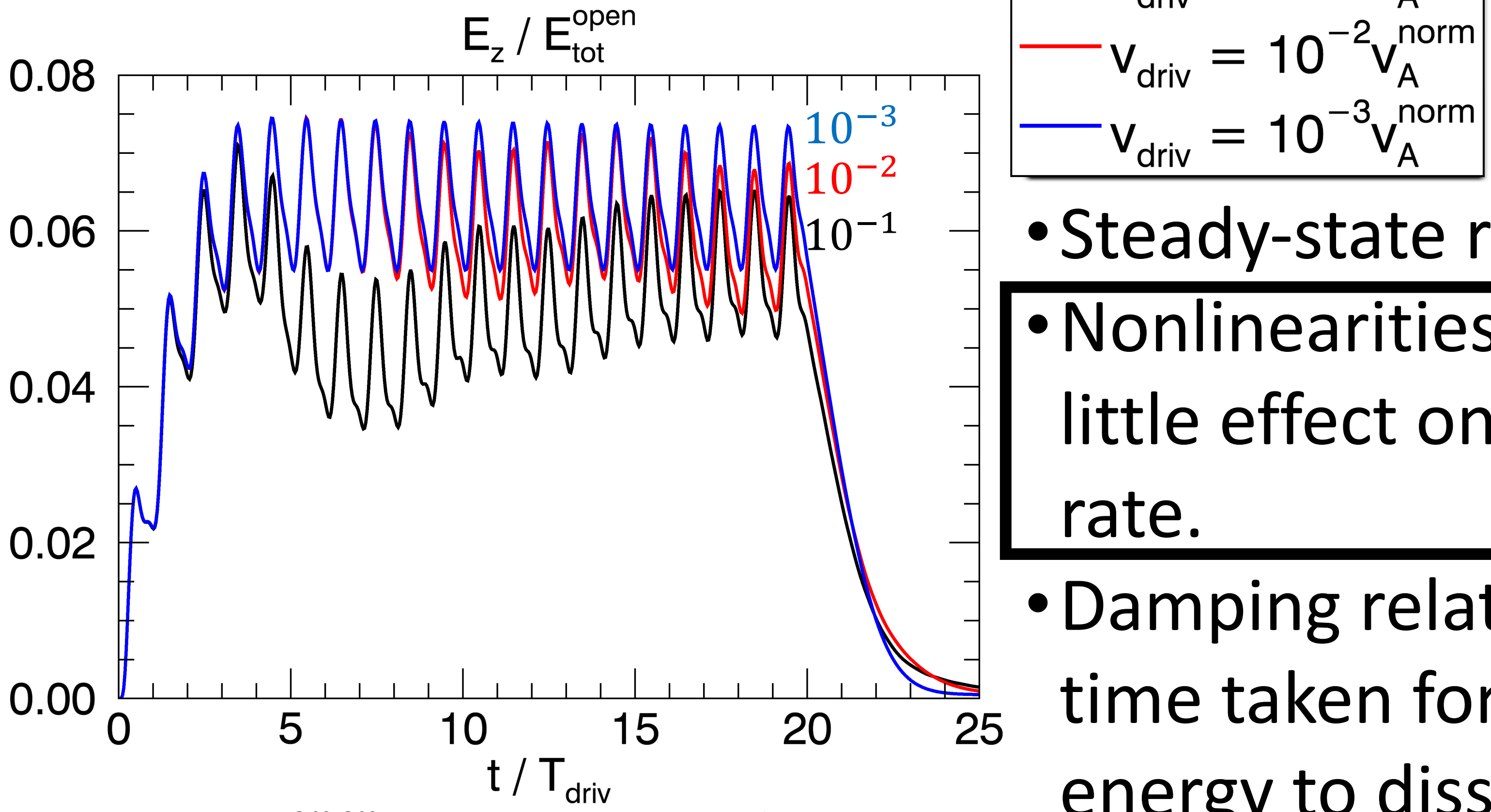
$$s_{poy} = \int_0^{t_{end}} \left(\frac{v_z B_z B_y}{\mu}\right)(x, y_{min})dt$$

Density Along Resonant Field Line

- Density structures reduce time period of field lines
- Results in resonance location shifting



Alfvén Wave Energy



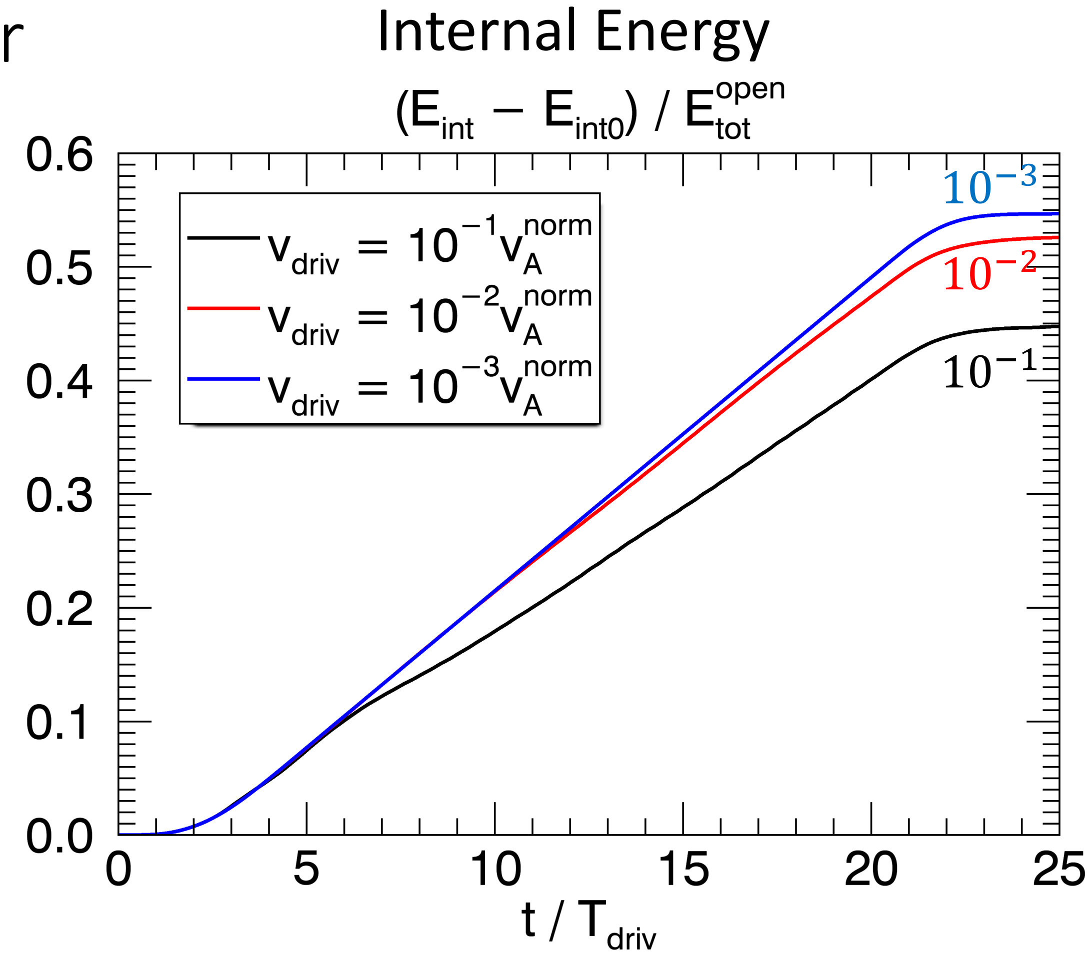
$(E_{tot}^{open} = constant \times v_{driv}^2)$

- Steady-state reached
- Nonlinearities have little effect on damping rate.
- Damping relates to time taken for wave energy to dissipate

Do Alfvén Wave nonlinearities increase or decrease heating?

Results suggest decrease, because:

- Nonlinearities decrease driver efficiency.
- Appear to have little effect on damping rate.



Summary

- Phase mixing occurs due to different field line lengths.
- Heating strong enough to balance radiative losses in corona.
- Creates density structures.
  - Which shift resonance location.
  - Results in total Poynting flux reducing.
- Despite large density structures there is little change to damping rate.

See Prokopyszyn et. al. 2018 for more information

This project has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement No 647214).

Thank you for listening.

Questions?