Propagation of Alfvénic pulses in coronal arcades

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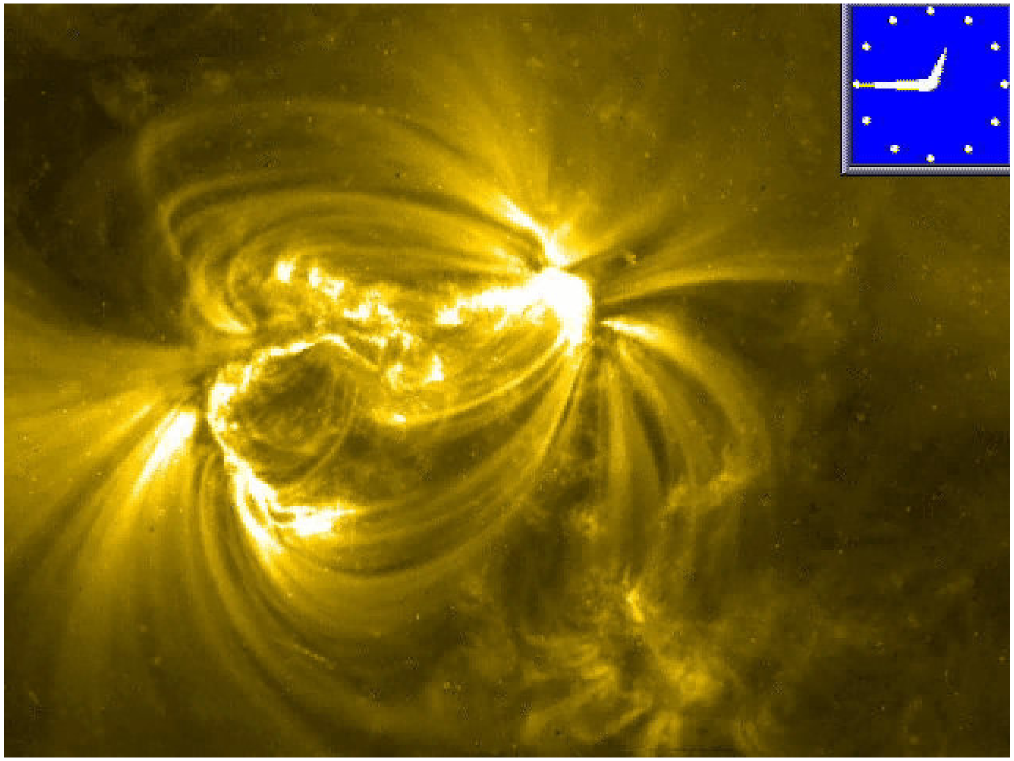
Loop oscillations and coronal seismology



- TRACE movies often show significant flare-induced transverse oscillations in coronal loops
- These oscillations are damped very efficiently
- Measured periods and damping times combined with MHD modeling provide viscosity coefficients and B (Nakariakov et al. 1999; Nakariakov & Ofman 2001)

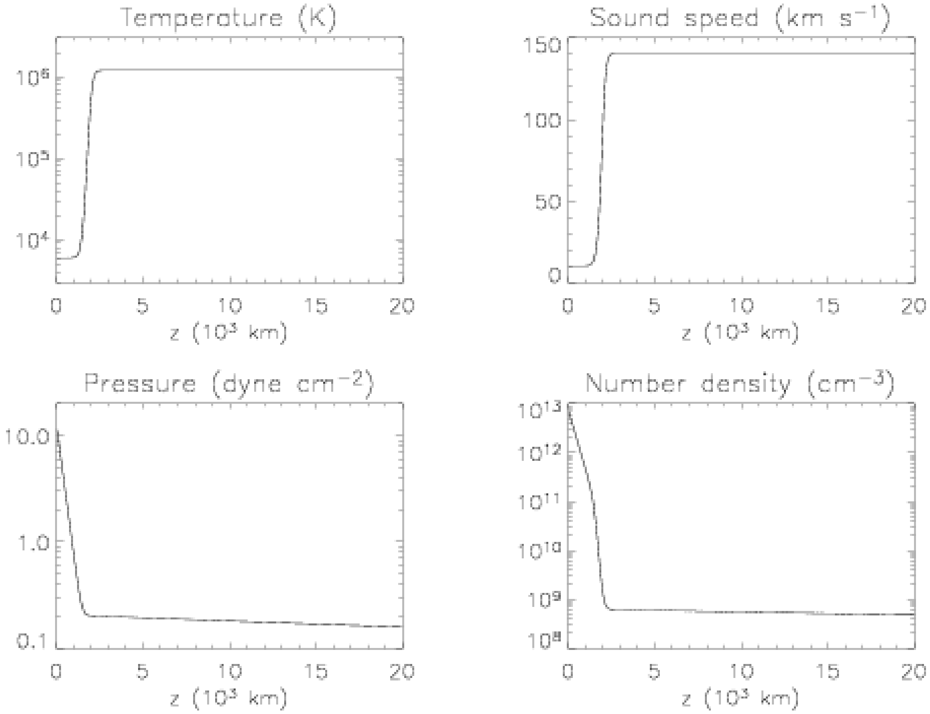
Brief review of observations and models

- Unfortunately only a few cases show global standing modes and a clear damped sinusoidal transverse displacement
- In the majority of cases the oscillations seem to be induced by propagating pulses moving back and forth along the loop and decaying in 1-3 crossing times (Aschwanden et al. 2002)
- The first class is generally modeled by applying the theory of MHD waves in (cylindrical) dense flux tubes (e.g. Roberts 2000): observed standing modes are trapped kink fast modes damped by shear viscosity (Nakariakov et al. 1999, R=10^6!)
- Other damping mechanisms: photospheric leakage, phase mixing, resonant absorption, motions near null points

Our model

- Here we investigate 2-D effects on the propagation of initially localized Alfvénic pulses in a magnetic arcade
- Thus we do not consider a loop with uniform density and B but a 2-D potential field in a vertically stratified atmosphere
- All quantities vary also along the loop (Va depends on z)
- Both transverse waves and compressive modes are studied
- Symmetric (A) and asymmetric (B) cases are investigated
- The nonlinear compressible MHD equations are solved with a conservative code (Londrillo & Del Zanna 2000, 2004)
- The 2.5-D simulations are performed in a square box of size L, with 400x400 points, outflow conditions in z, reflecting in x

Initial conditions: vertical stratification



- Vertically stratified atmosphere

$$\frac{dp}{dz}+\rho g=0\Rightarrow p(z)=p(z_0)\exp\left[-\frac{m_p g}{2k_B}\int_{z_0}^{z}\frac{dz'}{T(z')}\right.$$

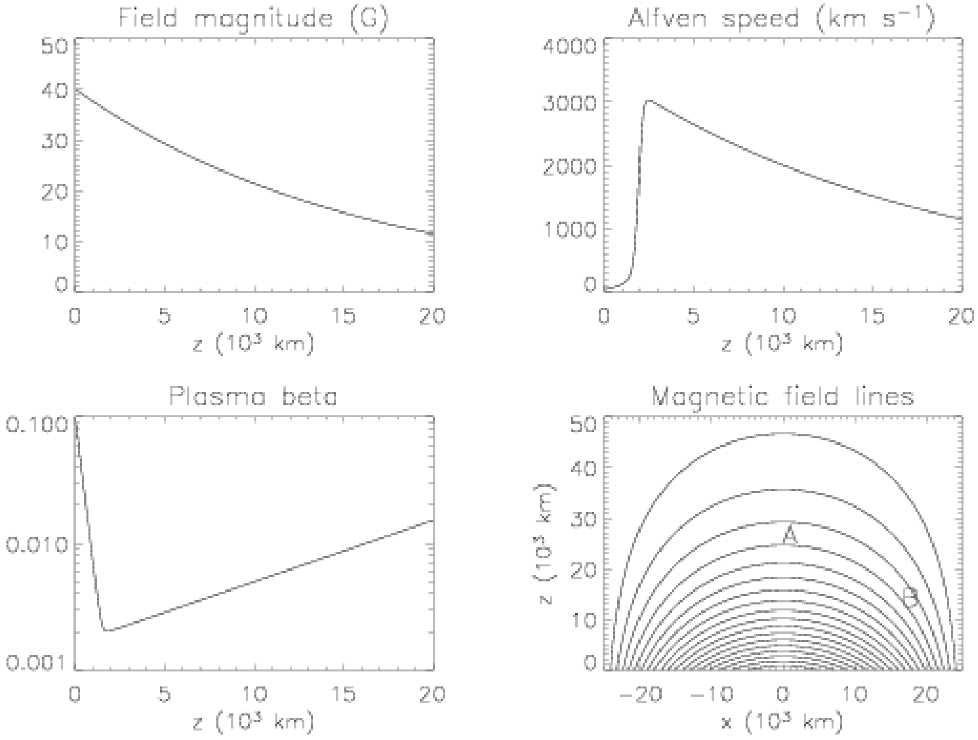
- Given temperature profile

$$T(z)=\frac{1}{2}(T_{cor}+T_{phot})+\frac{1}{2}(T_{cor}-T_{phot})\tanh\left(\frac{z-z_t}{z_w}\right.$$

- Typical lengths

$$L=50{,}000\ km,\ H_{cor}=72{,}000\ km,\ H_{phot}=360\ km$$

Initial conditions: magnetic field



- 2-D potential arcade

$$B_x = B_0 \cos(kx)\exp(-kz)$$
$$B_z = -B_0 \sin(kx)\exp(-kz)$$

- The Alfvén speed depends on z

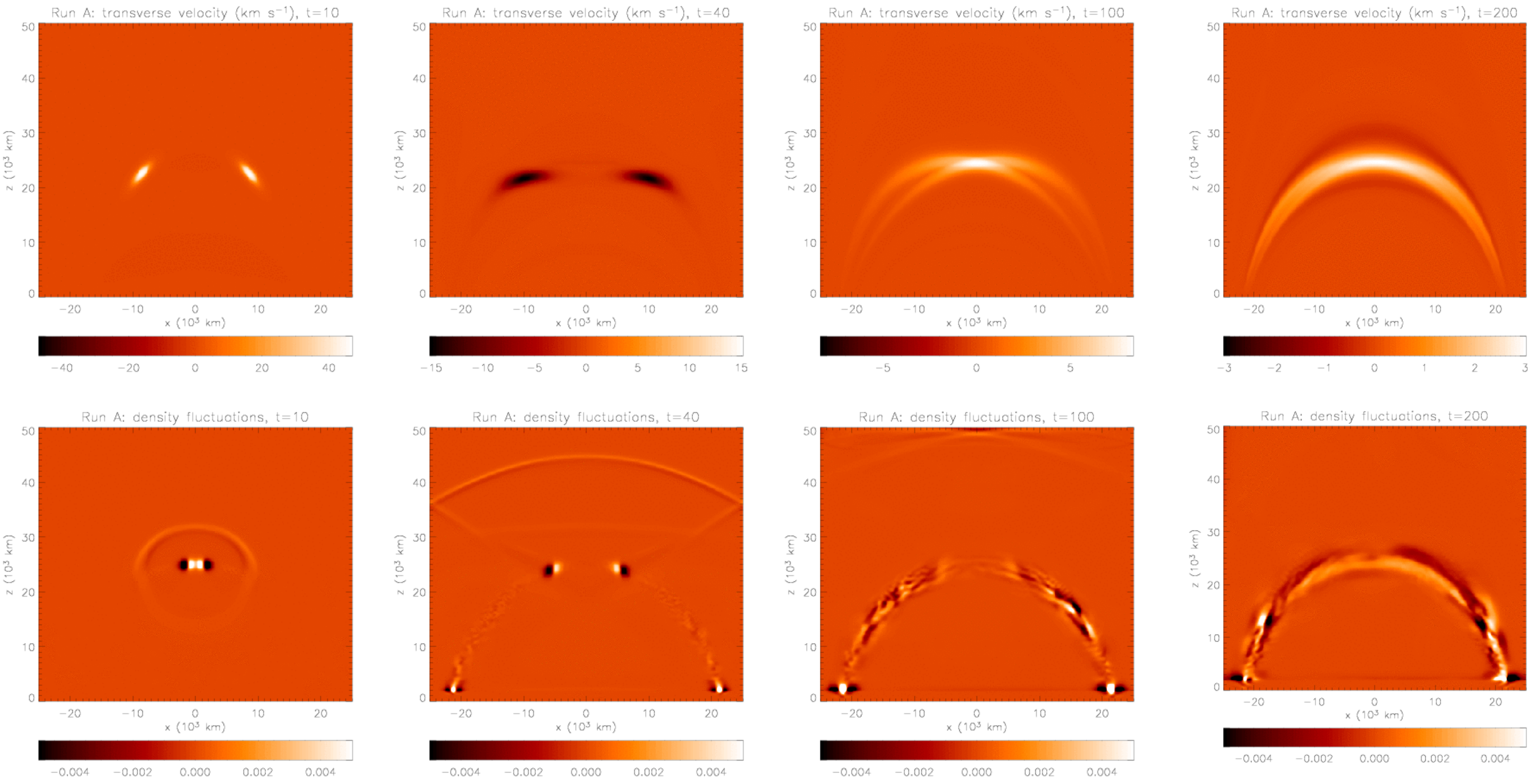
$$v_A = \frac{B}{\sqrt{4\pi\rho}} \propto \exp\left[-(1-\delta/2)kz\right]$$

$$\delta = (kH_{cor})^{-1} = \frac{L/\pi}{H_{cor}} \approx 0.22$$

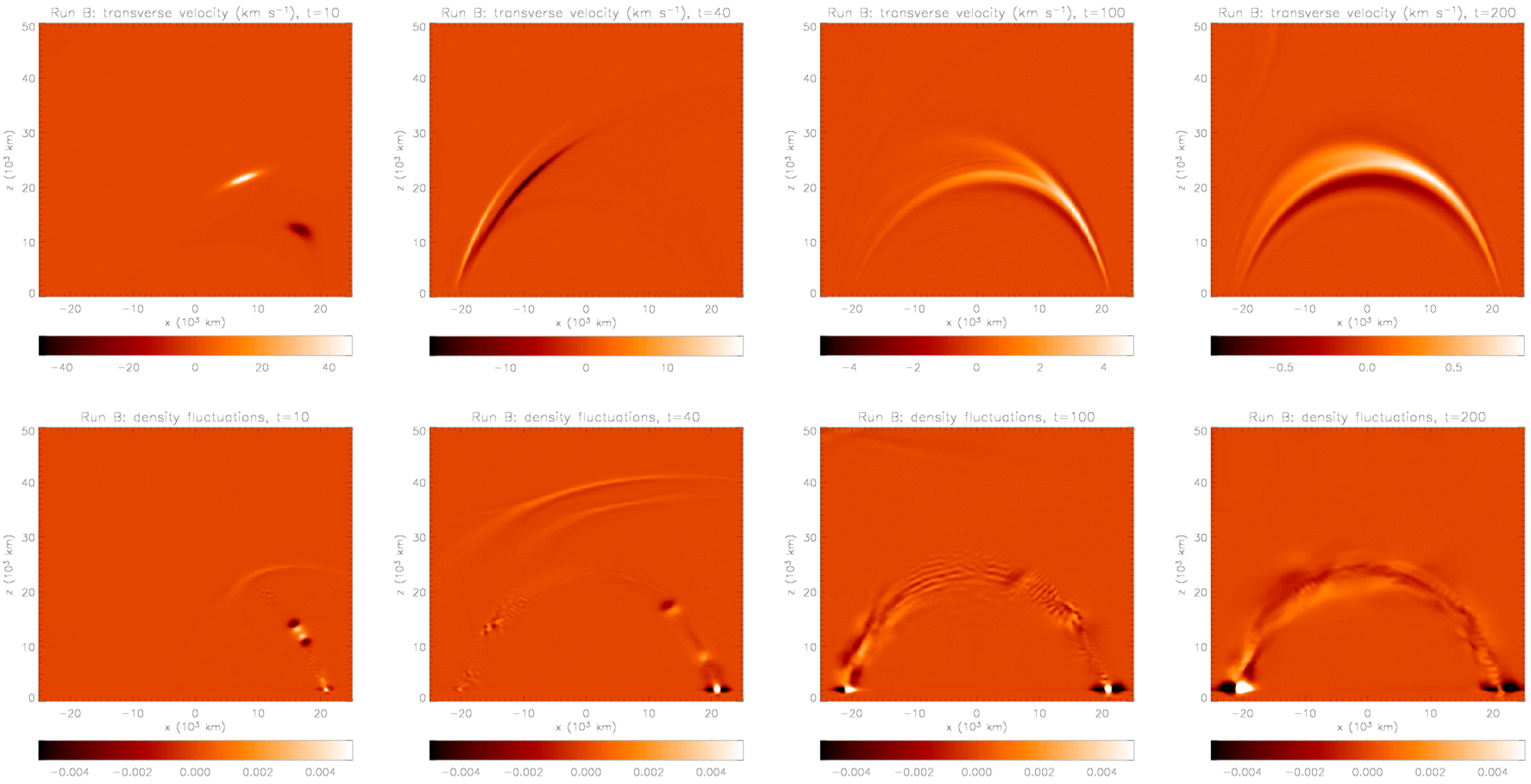
- Initial perturbation (case A or B)

$$v_y = \frac{\eta v_0}{1+(r/r_0)^4}, \quad \eta = 0.1$$

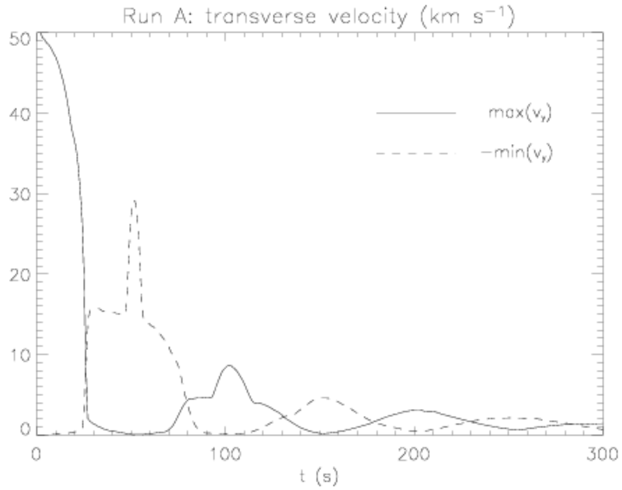
Symmetric case A

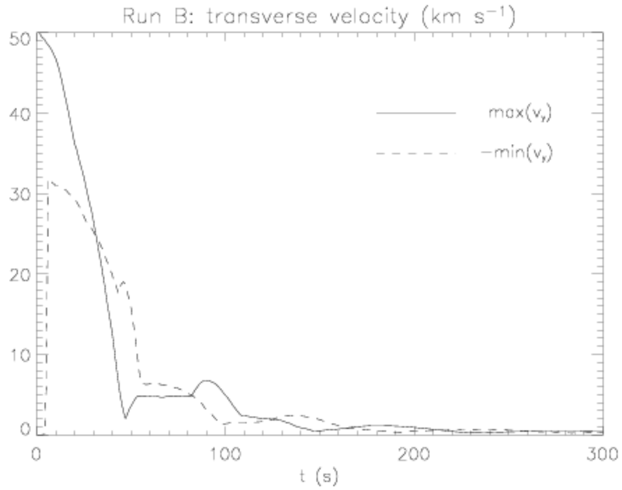


Asymmetric case B



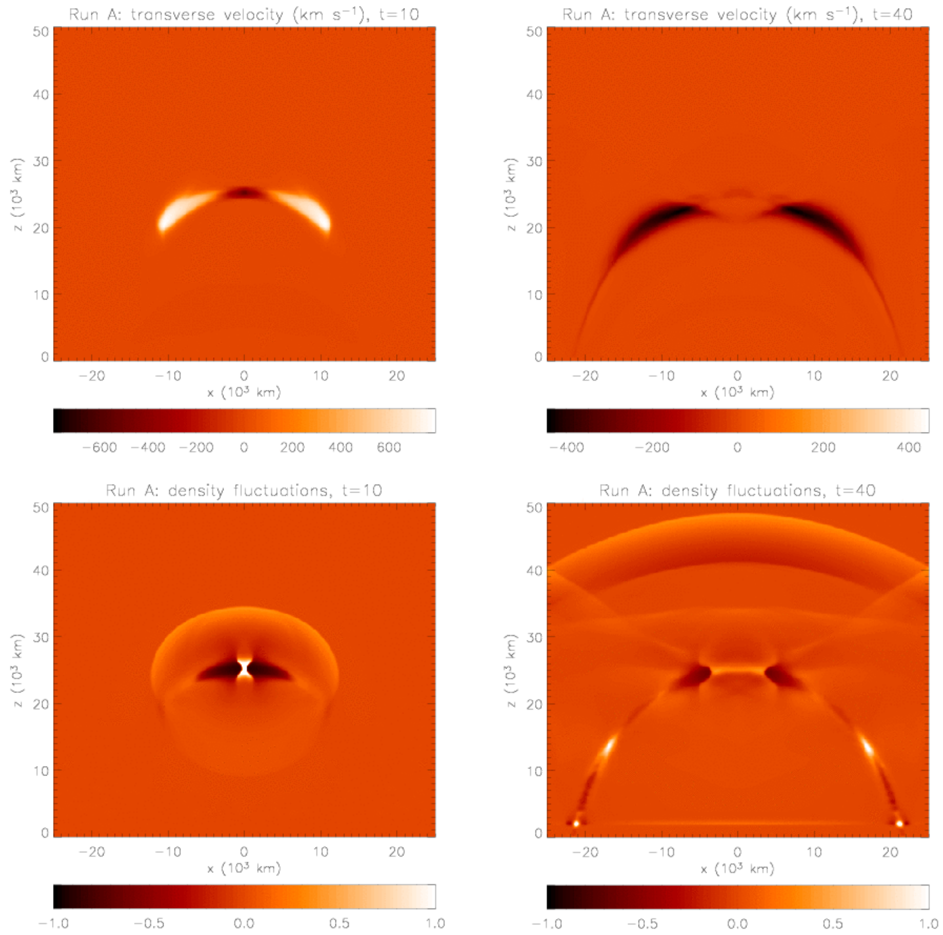
Comments on the numerical results





- Alfvénic pulses move back and forth along the loop bouncing at the TR
- Fast and slow magnetosonic waves are triggered by the ponderomotive force
- In both cases the transverse oscillations are quickly damped due to:
  - Spreading of the initial pulse induced by the varying background Alfvén speed
  - Leakage to the photosphere
  - Coupling to compressive modes
- The damping in case B is stronger
- The final state is always a superposition of quasi-global modes

A highly nonlinear case

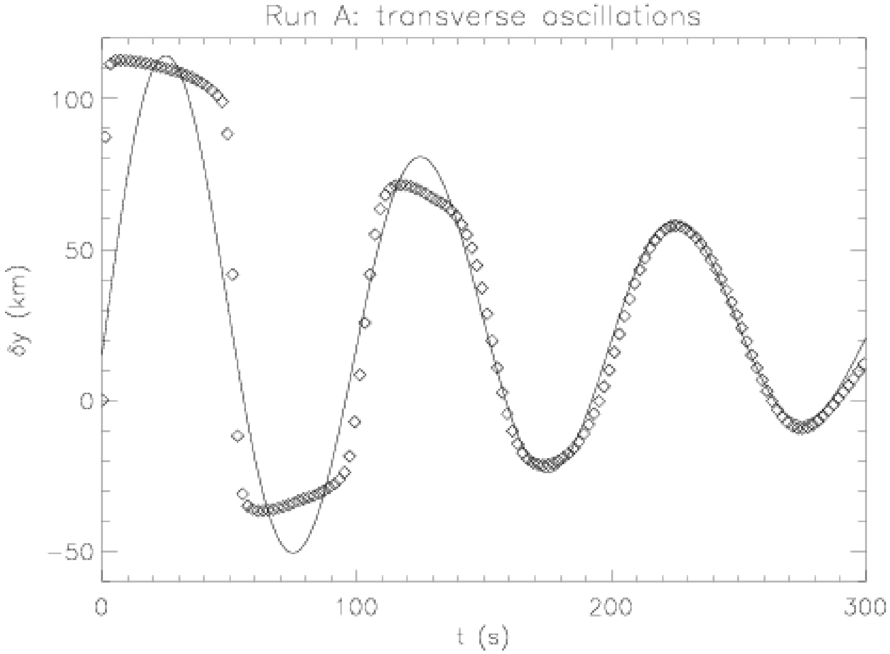


- Consider now case A with:

$$\eta = 5 \Rightarrow v_y^{\max}\left(t = 0\right) = 5{,}000\ km / s$$

- Pulses are highly distorted
- Compressive fluctuations are now of order one

Estimation of period and decay time



- The simulations show the propagation and spreading of the initially localized pulses
- A wave period and damping time are not easily identified in our model
- An estimation may be provided by fitting the transverse displacement (measured by integrating the transverse velocity in time) with:

$$\delta y(t) = s_0 + \int_0^t A\cos(2\pi t'/P)\exp(-t'/\tau_d)dt$$

- For our small loop (L=50,000 km):

$$A = 6.5\ km/s,\ P = 100\ s,\ \tau_d = 220\ s$$

Conclusions

- The observed strong decay of transverse oscillations may be easily explained if the Alfvén speed varies along the loop, especially the cases described in Aschwanden et al. (2002)
- Further details of the present model in Del Zanna et al. (2004

- References:

  - Aschwanden, De Pontieu, Schrijver, Title, 2002, Sol. Phys. 206, 99
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  - Londrillo, Del Zanna, 2000, ApJ 530, 558
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