Magnetoacoustic waves propagating along a dense slab and Harris current sheet in the solar atmosphere

H. Mészárosová[1], M. Karlický[1] P. Jelínek[2,1], and J. Rybák[3]

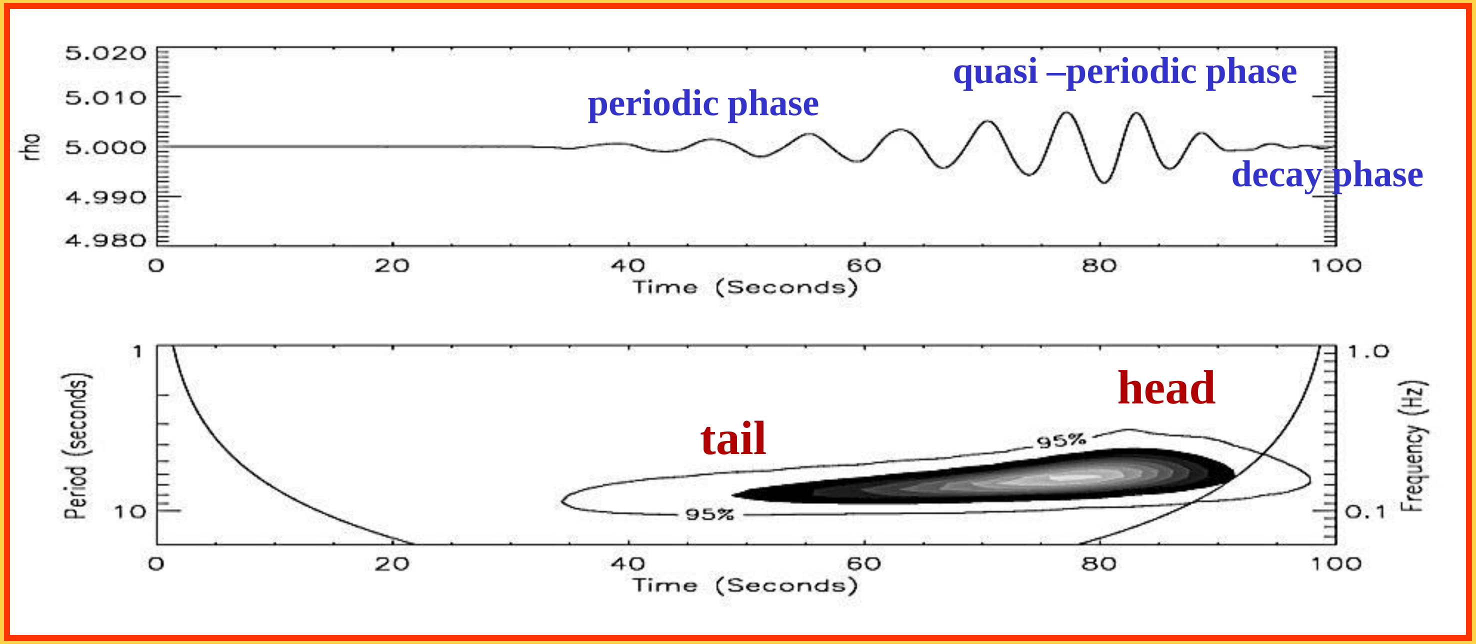
[1]Astronomical Institute, Academy of Sciences, Ondřejov, Czech Republic
[2]University of South Bohemia, Faculty of Science, České Budějovice, Czech Republic
[3]Astronomical Institute, SAS, Tatranská Lomnica, Slovak Republic

ISTP, Irkutsk, Russia June 9, 2015

O U T L I N E

- **Introduction:**
  - * basic magnetoacoustic waves features
  - * basic features of the dense slab & Harris current sheet
- **2D MHD numerical simulations:**
  - * parameters of the simulations
  - * spatial and temporal analysis of waves
  - * example of observed magnetoacoustic waves
  - * mutual interactions between two waves
- **Results and Conclusions**

Impulsively Generated Propagating Magnetoacoustic Waves



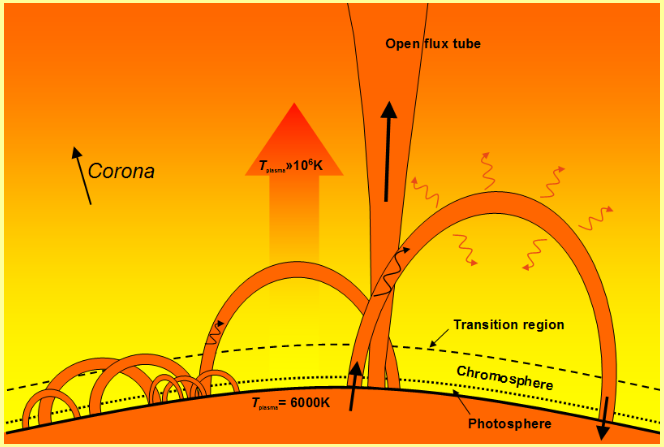
characteristic WAVELET TADPOLE signature where narrow spectrum tail precedes the broadband head

from Nakariakov et al., 2004, MNRAS

Impulsively Generated Magnetoacoustic Waves

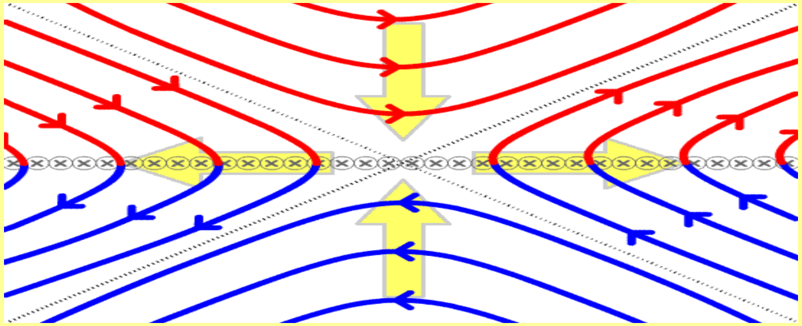
DENSE SLAB

≈ simulation of a coronal loop



waves propagate along a loop

HARRIS CURRENT SHEET



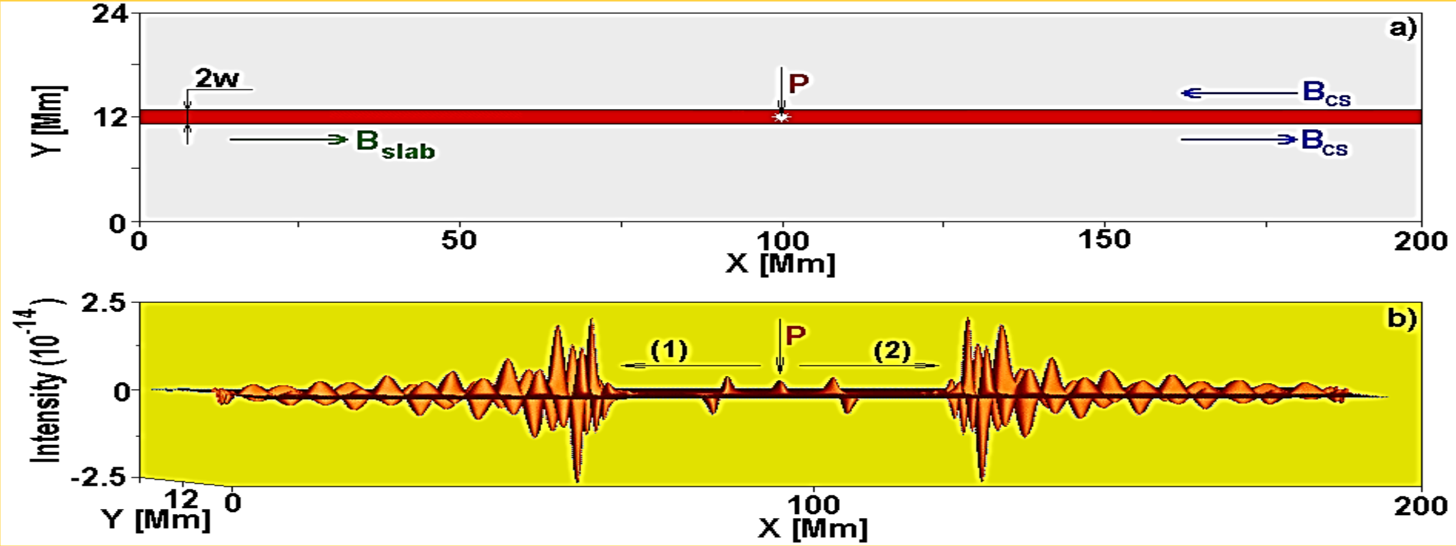
magnetic reconnection:

- **4 magnetic domains at the figure center,**
- **field lines with plasma flow inward from above and below the separator, reconnect, and spring outward horizontally,**
- **CS perpendicular to the field lines at the figure center,**
- **Harris: magnetic field profile is given by**

$$\mathbf{B} = B_0 tanh(x/L) e_z$$

waves propagate along the CS

Impulsively Generated Waves: 2D MHD numerical simulations



numerical box: length = 200 Mm, width = 24 Mm

uniform cell size: dx = dy = 80 km

red strip = waveguide (slab/current sheet), w = half-width of waveguide,

P = perturbation point,

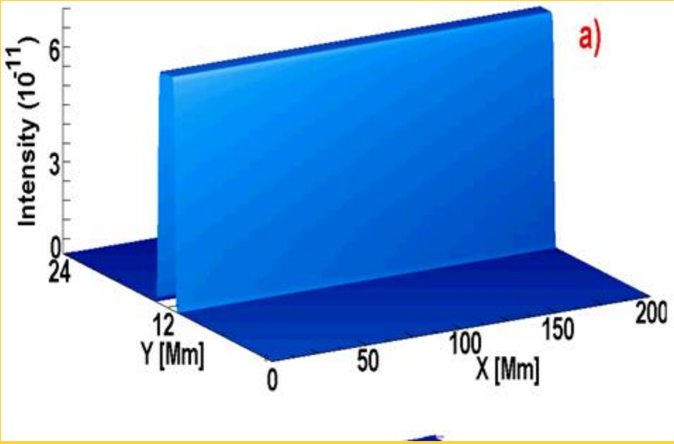
magnetic field configuration: green arrow = B_{slab}

blue arrows = B_{CS} (current sheet)

plasma dynamics described by full set of ideal time-dependent MHD equations

time step Δt = 0.044 s

example of waveguide: DENSITY SLAB (e.g. coronal loops)



mass density ρ profile

$$\varrho(X,Y) = \varrho_0 + (\varrho_{\rm slab} - \varrho_0)\cdot \mathrm{sech}^2 \left\{ \left[\frac{(Y - Y_P)}{w} \right]^{\alpha} \right\}$$

power index α = 8 determines the steepness of the profile

(Nakariakov & Roberts, SolPhys. 1995)

magnetic field B_{slab} is parallel to the X-axis and constant in the whole simulation region (B_{slab} = 3.5 ×10−3 T)

electron density $n_e = 10^{16}$ m^{-3}

selected the parameters in/out of slab:

mass density ρ_{in} = 6.69×10^{-11} kg m^{-3}

mass density ρ_{out} = 6.08×10^{-12} kg m^{-3}

temperature T_{in} = 0.45 MK,

T_{out} = 5 MK

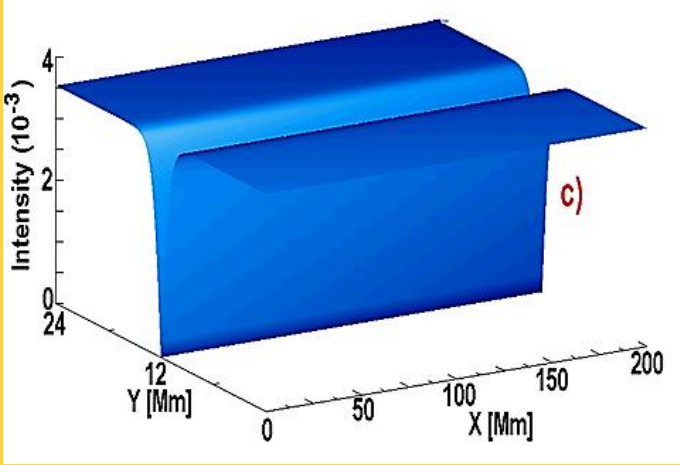
Alfvén velocity v_{A-in} = 0.39 Mm s^{-1}

v_{A-out} = 1.28 Mm s^{-1}

sound velocity c_{s-in} = 0.11 Mm s^{-1}

c_{s-out} = 0.37 Mm s^{-1}

example of waveguide: C U R R E N T S H E E T



magnetic field *B* profile

$$\mathrm{B} = B_{\mathrm{out}} \tanh\left[\frac{(Y - Y_P)}{w}\right] \hat{\mathrm{e}}_X$$

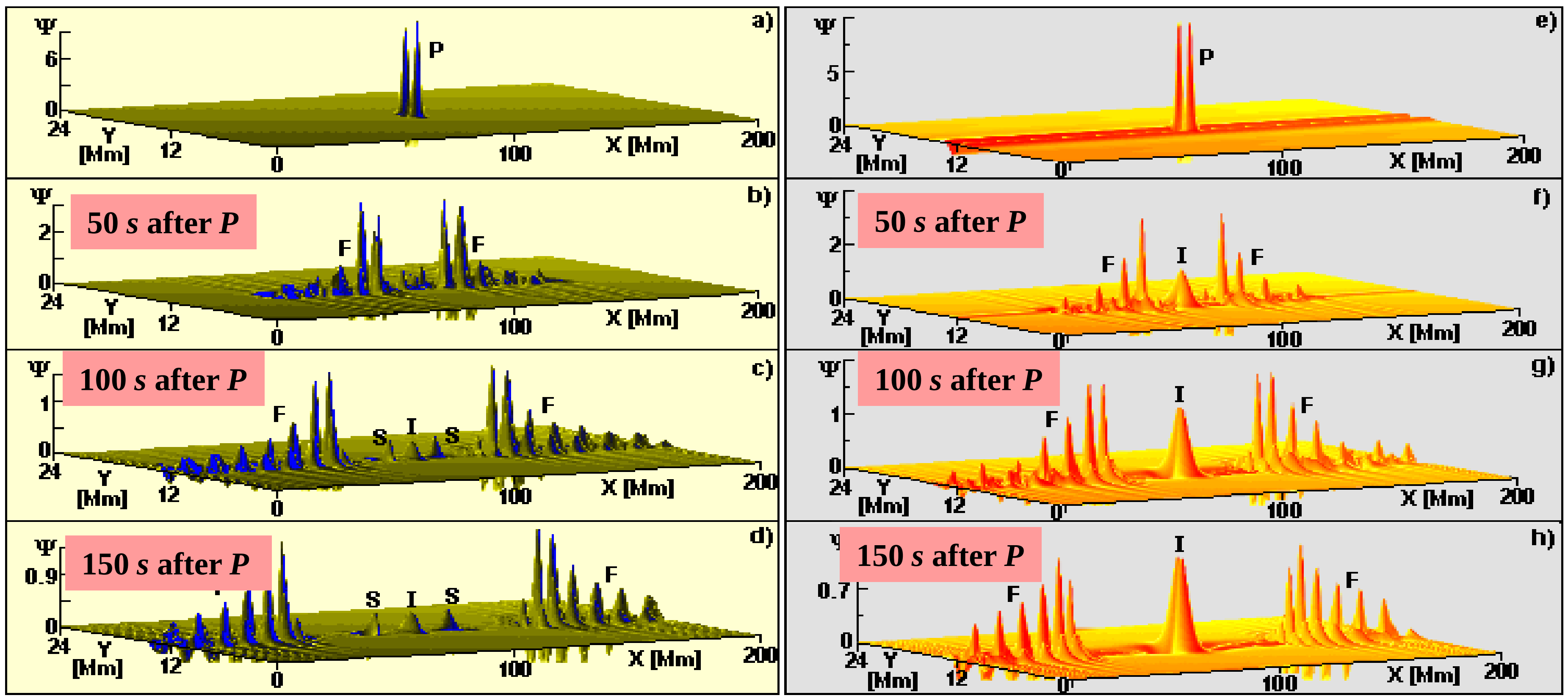
selected parameters in the center c,
at Y = w and in/out of the current sheet:

magnetic field $B_{out} = 3.5 \times 10^{-3}$ T
mass density $\rho_c = 6.69\times10^{-11}$ kg m^{-3}
$\rho_w = 3.32\times10^{-11}$ kg m^{-3}
$\rho_{out} = 6.08\times10^{-12}$ kg m^{-3}
temperature = T = 5 MK

sound speed c_s = 0.37 Mm s^{-1}
Alfven velocity v_{A-c} = 0
v_{A-w} = 0.40 Mm s^{-1}
v_{A-out} = 1.28 Mm s^{-1}

Time evolution of the magnetoacoustic waves (mass density):

density slab — Harris current sheet



P = initial perturbation
F = fast wave train
S = slow wave
I = nonpropagating peak of entropy mode in situ of perturbation

Mészárosová et al., 2014, ApJ

Role of the waveguide half-width *w* [Mm] & distance from perturbation *P* [Mm]

w = 0.5 Mm | *w* = 1.0 Mm | *w* = 2.0 Mm

distance

density slab

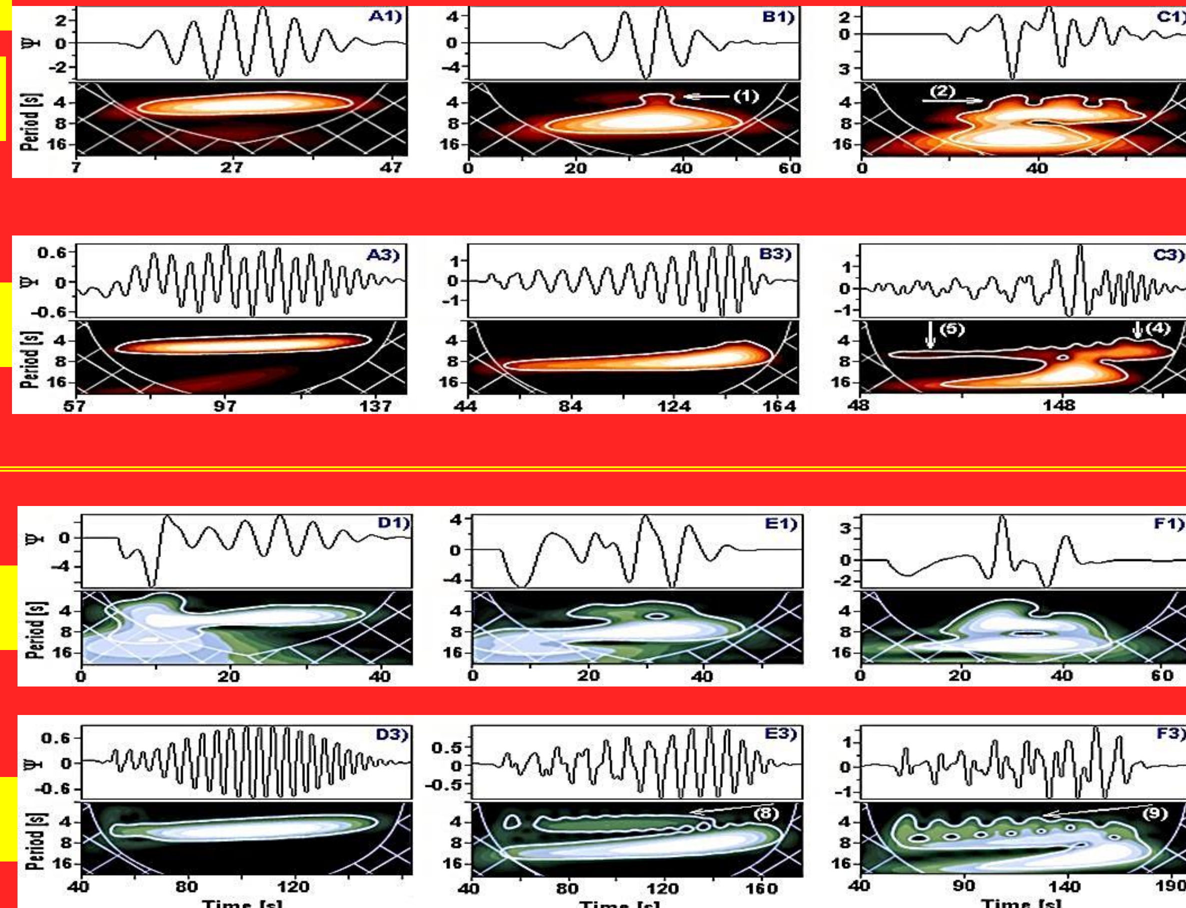
10 Mm

50 Mm

current sheet

10 Mm

50 Mm



Mészárosová et al., 2014, ApJ

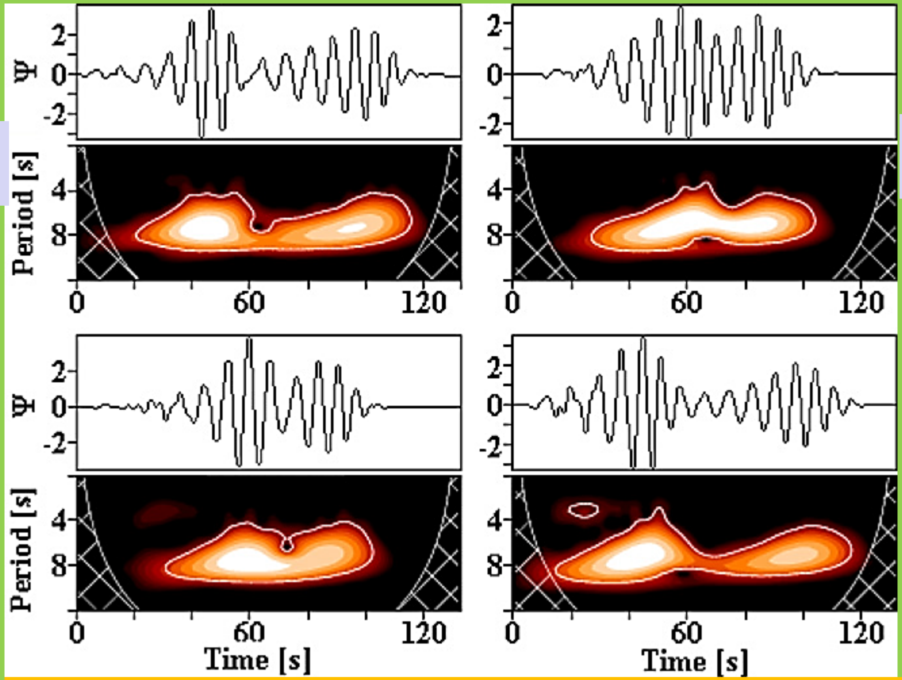
Time series and their wavelet spectra corresponding to a mutual interaction between two fast waves in the dense slab → superposition (temporary merger) of both waves

d = 90 Mm

d = 105 Mm

d = 95 Mm

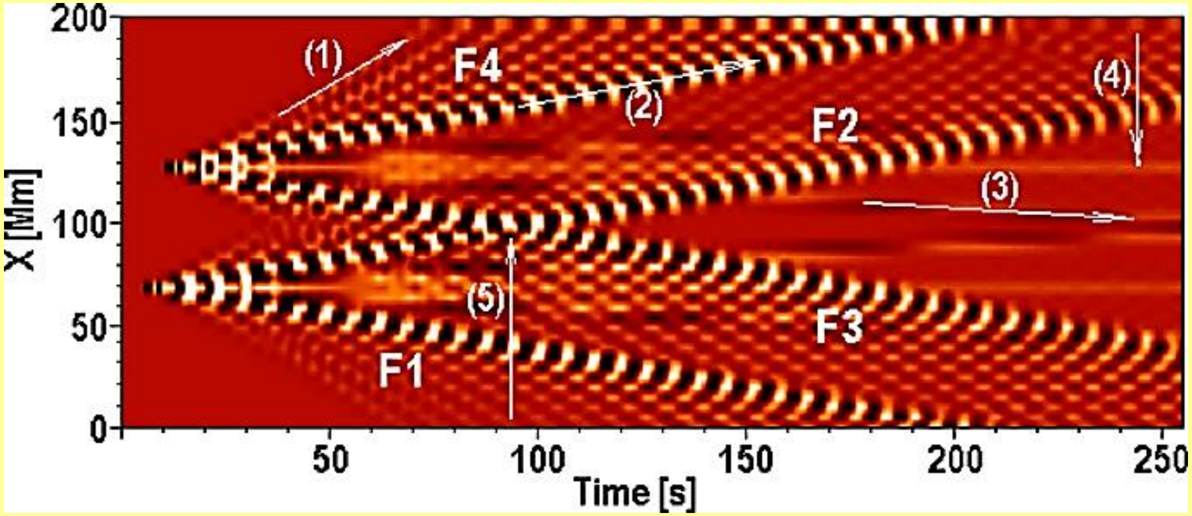
d = 110 Mm



d = distance from a perturbation place

Mészárosová et al., 2014, ApJ

Magnetoacoustic Waves: 2D MHD numerical simulations



Dynamic spectrum
of time series collected at selected points *X* = 0 – 200 Mm along the density slab (spatial step = 5 Mm)

1st perturbation generated 5 s after starting time at point X = 70 Mm
→ fast waves F1 and F2

2nd perturbation generated 10 s after starting time at point X = 130 Mm
→ fast waves F3 and F4

Arrow 1: fastest spectral components of the fast wave F4 (velocity = 1.0 Mm/s)
Arrow 2: slowest spectral components of the fast wave F4 (velocity = 0.35 Mm/s)
Arrow 3: one of slow waves (velocity = 0.1 Mm/s)
Arrow 4: nonpropagating peak of the entropy mode
Arrow 5: waves F2 and F3 propagate toward the waveguide center (X = 100 Mm) and they interact at a time of 93 s

Mészárosová et al., 2014, ApJ

Magnetoacoustic Waves: 2D MHD numerical simulations

Our computed velocities agree with those theoretically predicted by Roberts et al. (1984) – for the initial values of the MHD simulation:

Alfvén velocity out of the dense slab v_{A-out} = 1.28 Mm/s should correspond to the fastest components of the fast wave train

Alfvén velocity in the dense slab v_{A-in} = 0.39 Mm/s should correspond to the slowest components of the fast wave train

sound velocity in the dense slab c_{s-in} = 0.11 Mm/s should correspond to the slow magnetoacoustic wave

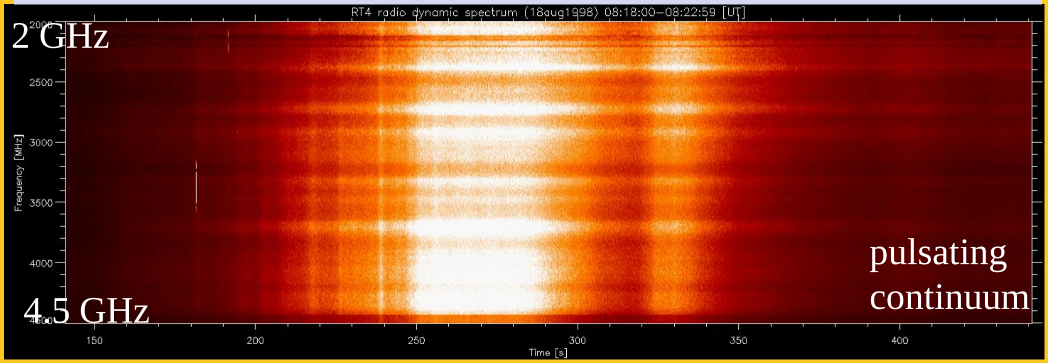
---

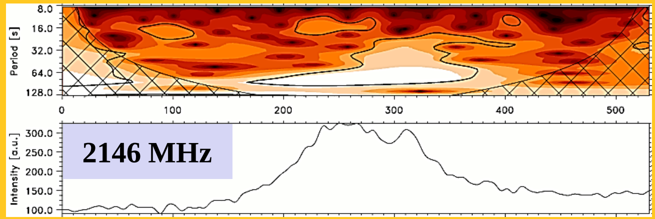
results of the MHD simulations for a dense slab:
fastest spectral components of the fast wave F4 (velocity = 1.0 Mm/s)
slowest spectral components of the fast wave F4 (velocity = 0.35 Mm/s)
slow waves (velocity = 0.1 Mm/s)

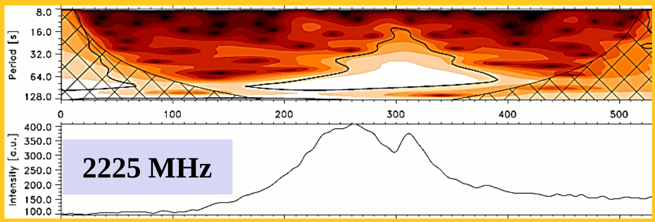
Mészárosová et al., 2014, ApJ

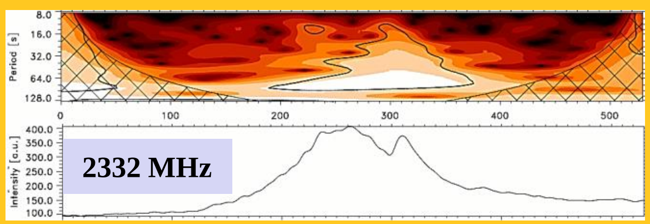
Magnetoacoustic Waves: Observations

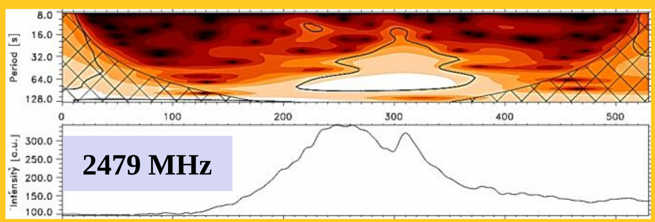
radio dynamic spectrum, Ondřejov observatory
18 Aug 1998, 2.0 – 4.5 GHz, 8:18 – 8:23 UT

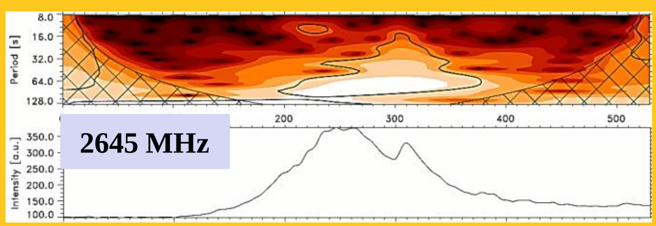




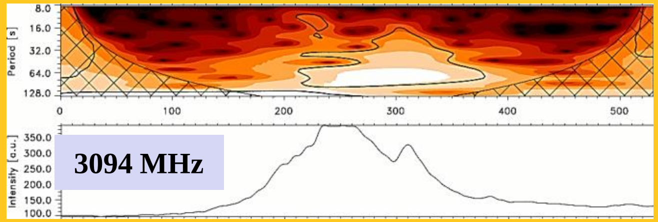


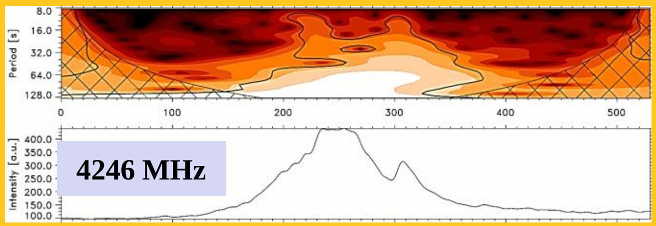






at all frequencies: wave period *P* = 94 s
additional head structures → waveguide ≈ loop





about 4 GHz:
shorter tadpole tail
closer to perturbation

Conclusions:

- **The dense slab and current sheet guide the fast waves in a similar way. They differ in guiding of the slow waves. The difference comes from the different magnetic fields and temperature structures of these waveguides.**

- **Each fast wave forms a wave train. The slow wave propagates as a single peak. We found a nonpropagating wave at the site of the initial perturbation in both types of the waveguide.**

- **For cases with the narrow waveguide (w = 0.5 Mm) the tadpole heads were suppressed. For waveguide half-width > 1 Mm there are additional structures of tadpole heads. In the dense slab case these additional structures were always delayed after the tadpole head maximum. The current sheet case is the opposite.**

- **mutual interactions of waves generated by two perturbations: Wavelet spectra of the fast waves depends on the evolution states of the wave trains of both waves at the time of their interaction.**

Thank you
for your attention!