Slow-Mode MHD Wave Penetration into a Coronal Null Point due to the Mode Transmission

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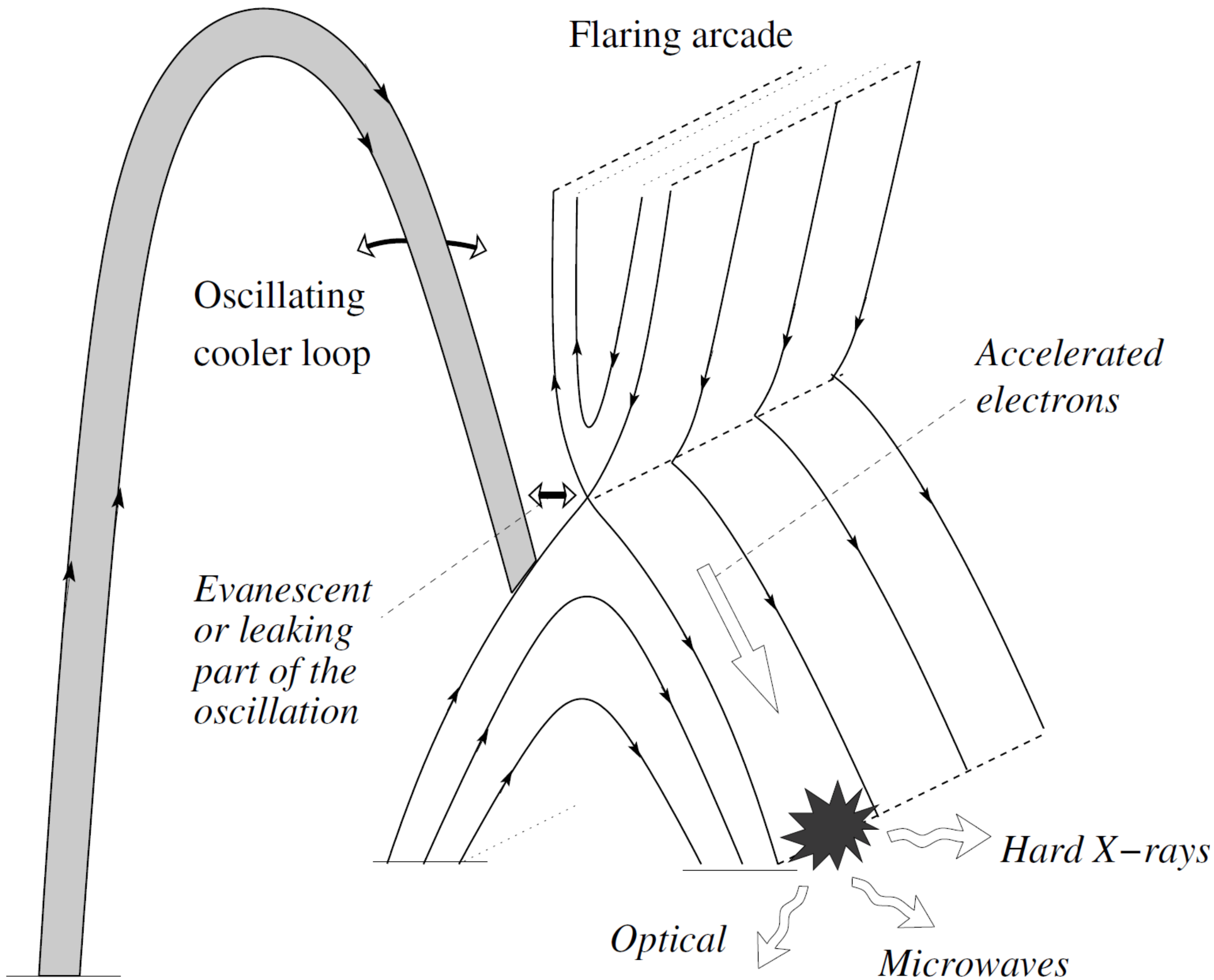
Outline

- Introduction and Motivation
- Aim of study
- Modelling
- Discussion of results
- Conclusions

MHD wave paradigm for long QPPs

- Long QPPs are interpreted in terms of MHD waves
- Transverse (kink-mode) oscillations of a remote dense loop -->
- Link between longitudinal waves and QPPs (Sych et al., 2009, A&A 505, 791; Sych, 2015, STP 1, 3)
- Curve loop geometry and centrifugal force cause the transverse oscillations of loops -->



from Nakariakov et al. (2006, A&A 452, 343)

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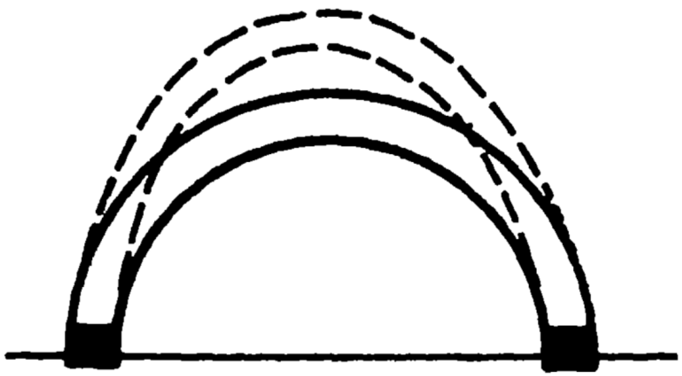


from Zaitsev & Stepanov
(1989, Sov. Astron. Lett. 15, 66)

FIG. 2. A model for the motion of eruptive plasma to engender oscillations of a flare loop with a period $\tau \sim L/c_A$, where L is the length of the loop. The hard x rays would be emitted at the loop footpoints.

Slow magnetoacoustic waves

- Waves responsible for QPPs are believed to be of the tube (longitudinal) mode
- Wave-guiding conditions may not be met throughout the solar corona
- Propagation outside plasma wave-guides, e.g. in inter-plume regions (Banerjee et al., 2011, Space Sci Rev)
- Propagation in an effectively smooth (averaged) medium if the scale of the wave front is much larger than the characteristic size of small-scale plasma structures

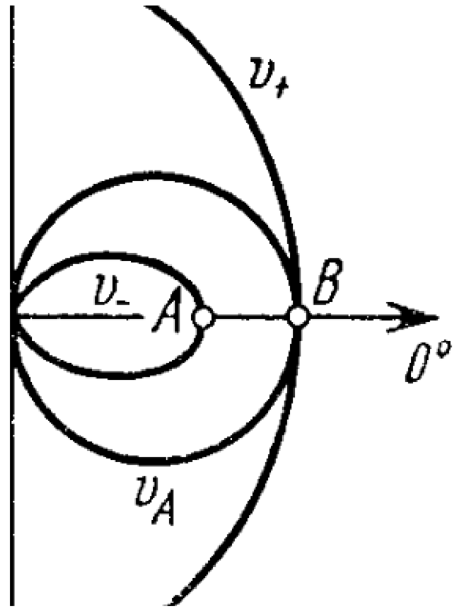
Aim of study

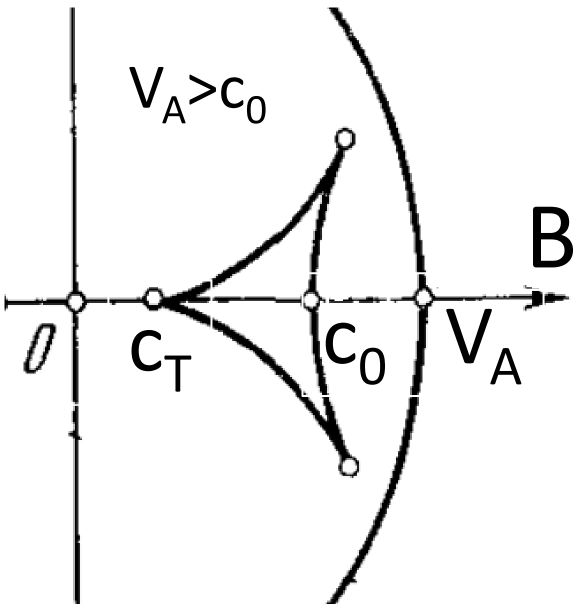
- To understand the observed link between the 3-min oscillations in sunspots and QPPs in flaring light curves
- To study the propagation of slow magnetoacoustic waves in a solar active region, taking into account the magnetoacoustic mode transmission and wave refraction

Geometrical acoustics

- Geometrical acoustics
- Phase Speed Diagram for slow magnetoacoustic waves
- Group Speed Diagram for slow magnetoacoustic waves

$$\frac{d\boldsymbol{r}}{dt} = a\frac{\boldsymbol{k}}{k} + k\frac{\partial a}{\partial \boldsymbol{k}},$$
$$\frac{d\boldsymbol{k}}{dt} = -k\nabla a,$$





Model

- 2D quadrupolar magnetic configuration

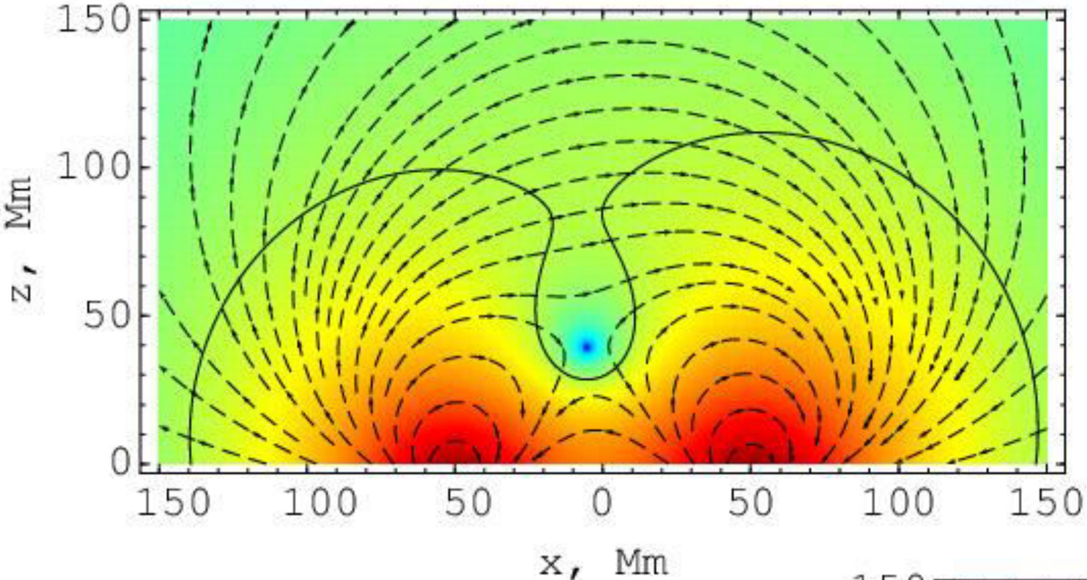
$$B_x = \frac{4m_1\left((z-h_1)^2-(x-d_1)^2\right)}{\left((z-h_1)^2+(x-d_1)^2\right)^2} + \frac{4m_2\left((z-h_2)^2-(x-d_2)^2\right)}{\left((z-h_2)^2+(x-d_2)^2\right)^2},$$

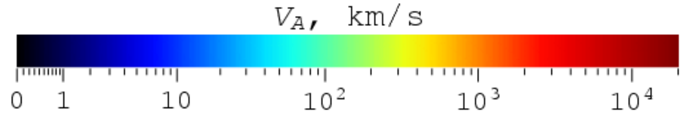
$$B_z = -\frac{8m_1(x-d_1)(z-h_1)}{\left((z-h_1)^2+(x-d_1)^2\right)^2} - \frac{8m_2(x-d_2)(z-h_2)}{\left((z-h_2)^2+(x-d_2)^2\right)^2}.$$

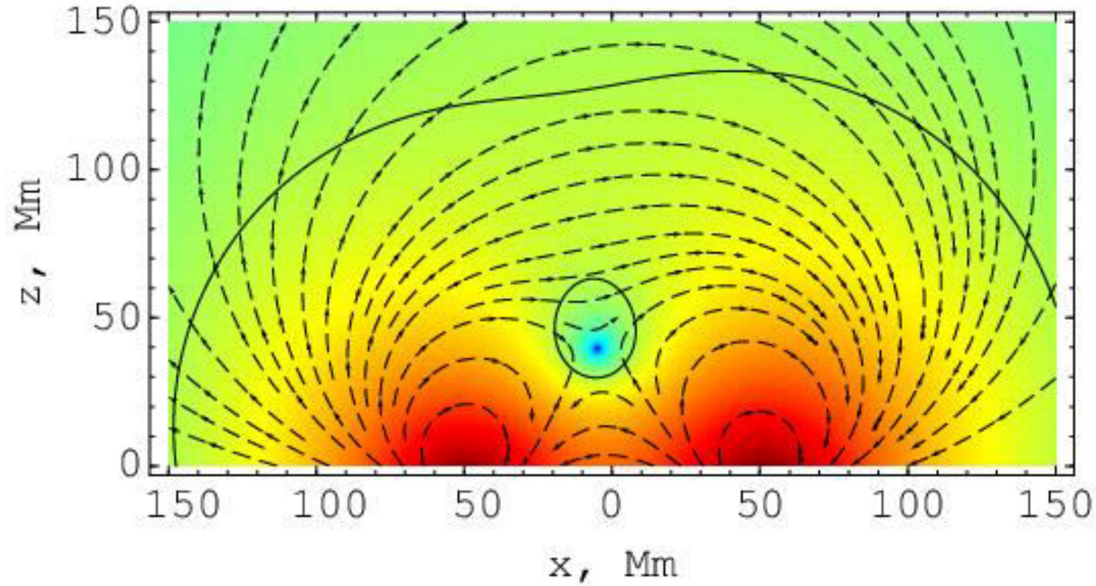
- "Island" and "Droplet" models
- Temperature = 2 MK, C_sound = 215 km/s
- Barometric density with H = 120 Mm

$$n = n_0 \exp\left(-\frac{z}{H}\right),$$

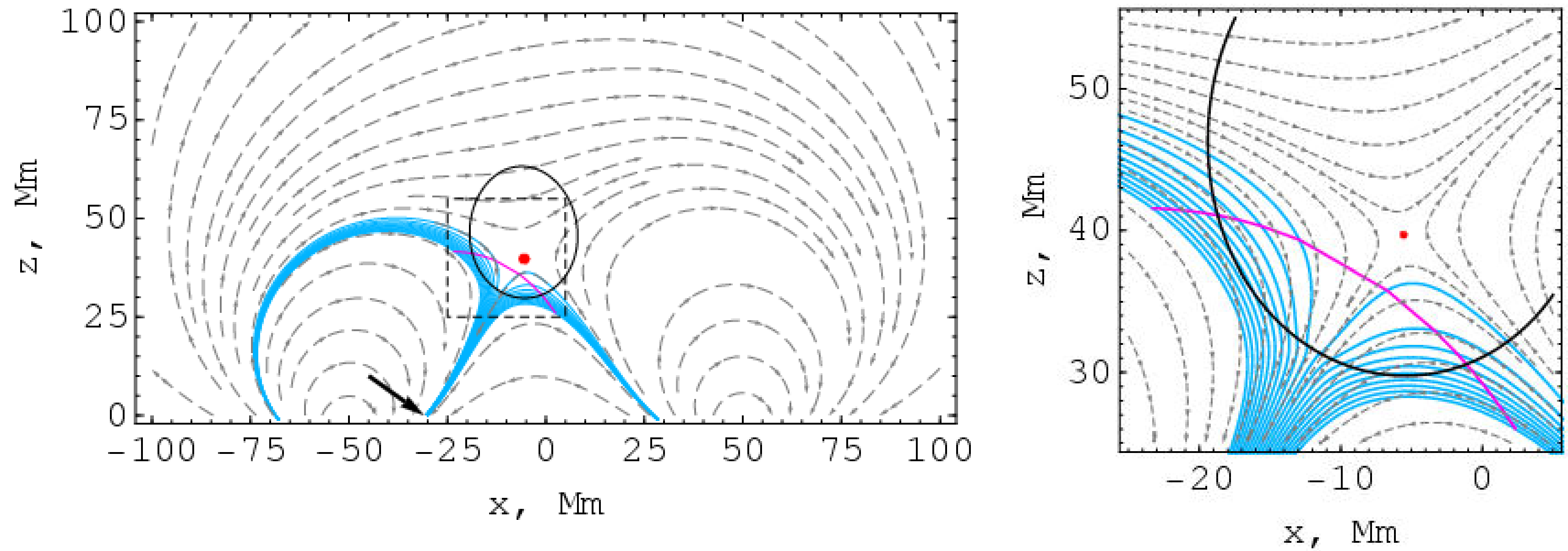
Alfven speed maps







Slow-mode wave propagation

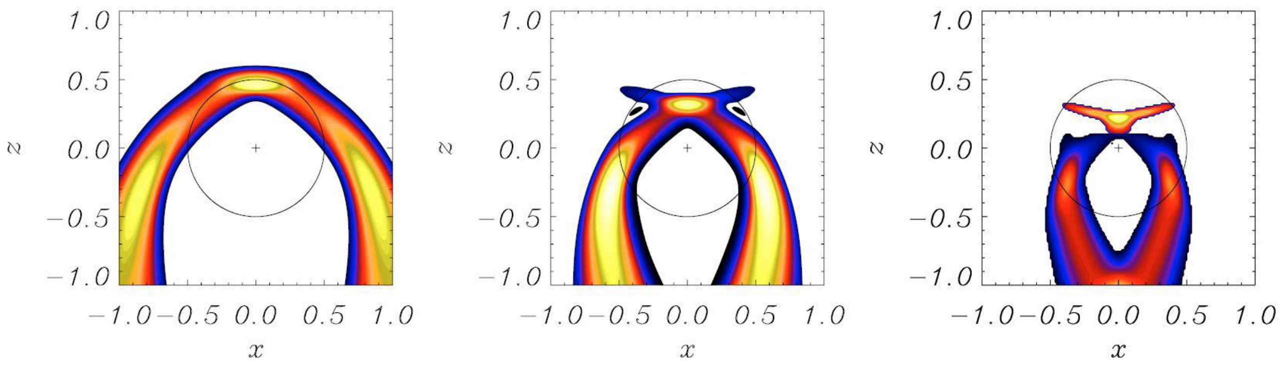


Physics of transmission

- **Slow magnetoacoustic** wave with the wave vector directed nearly along the magnetic field in the plasma with $c<V_A$ (outside the null point vicinity) has mainly the **sound** nature and contains the **longitudinal compressive** plasma motions
- Having passed through the equipartition level, the wave remains to be of the **same nature**. However, in the plasma with $c>V_A$ (inside the null point vicinity) it is a wave of the **fast magnetoacoustic** branch
- Fast magnetoacoustic waves can freely propagate across magnetic field lines and affect the null point

Mode Transmission

- P. Cally, Y. Zhugzhda, Y. Kravtsov, N. Erokhin, S. Moiseev
- Terminology: transmission and conversion
- Conditions for transmission: $c=V_A$
- Numerical simulations of wave propagation show the fast-to-slow mode transmission

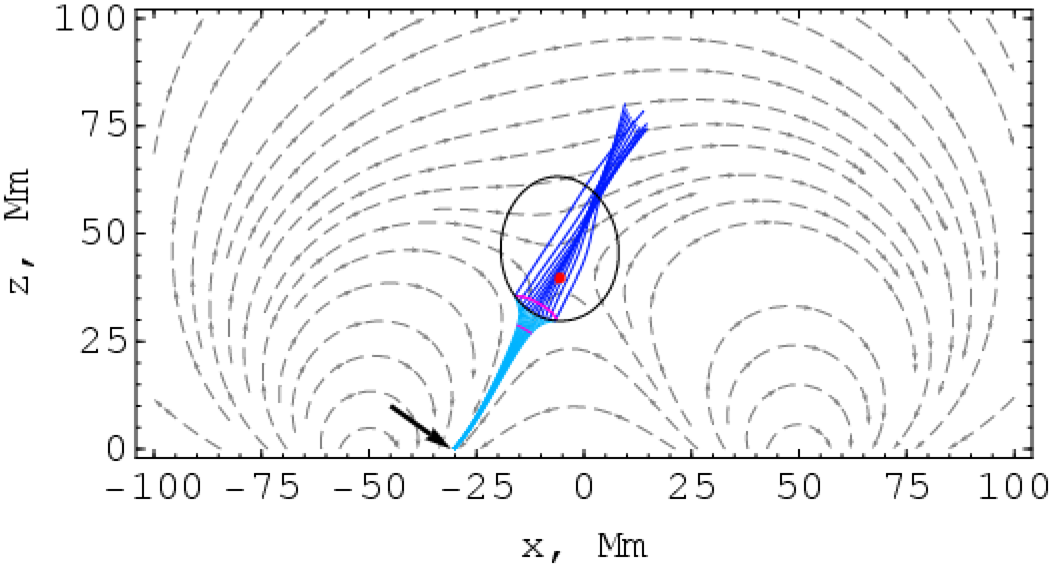


(from McLaughlin&Hood, 2006, A&A 459, 641)

- Slow-to-fast transmission coefficient (e.g., Cally, 2007, Astron. Nachr. 328, 286)

$$T = \exp\left(-\pi k h_s \sin^2\alpha\right)\Big|_{c=V_\mathrm{A}}, \quad h_s = \left|d\left(V_\mathrm{A}^2/c^2\right)/ds\right|^{-1}$$

- Refraction due to the AR plasma non-uniformity



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z, Mm
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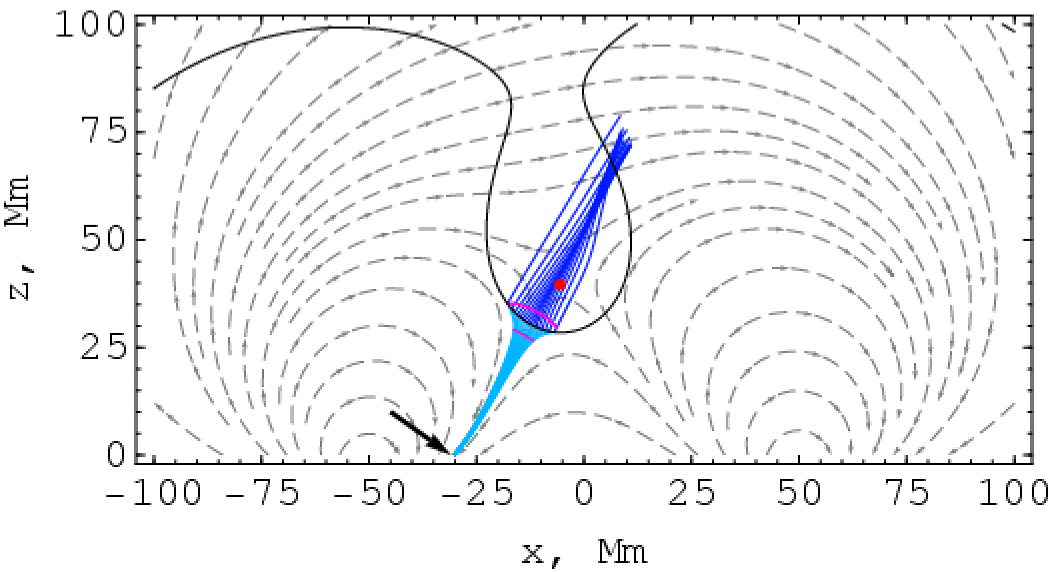

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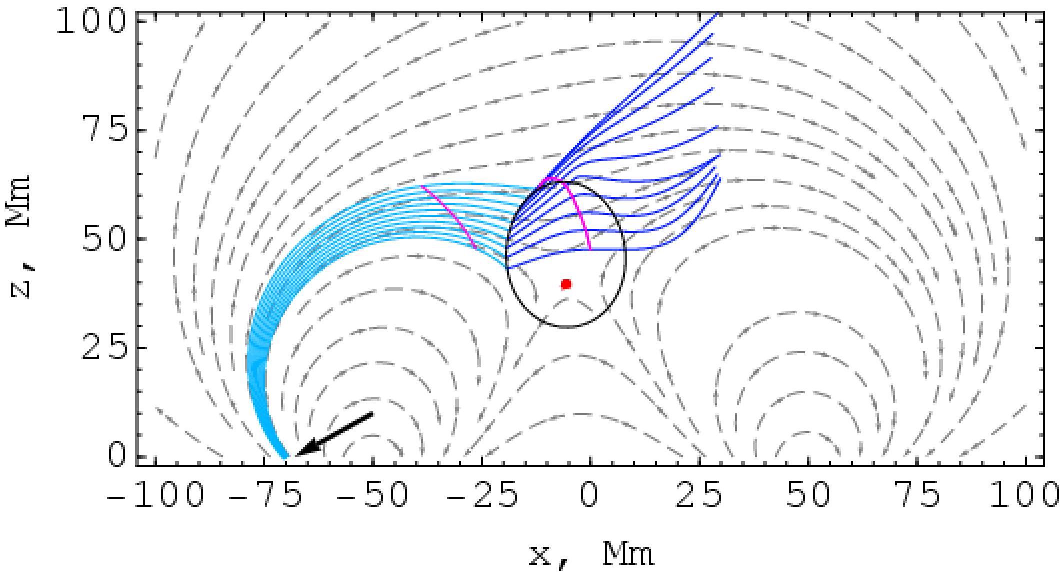

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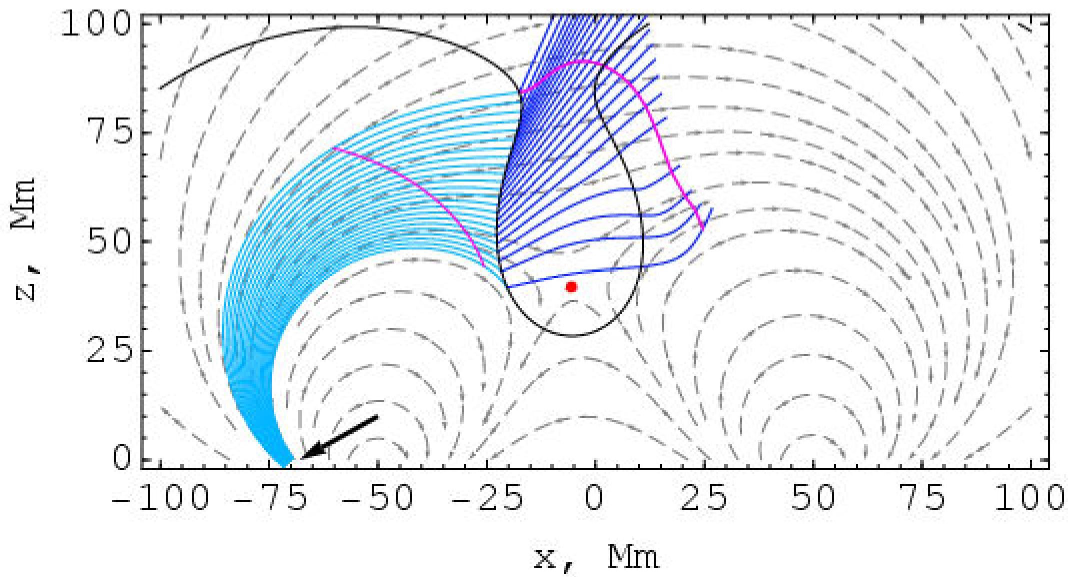

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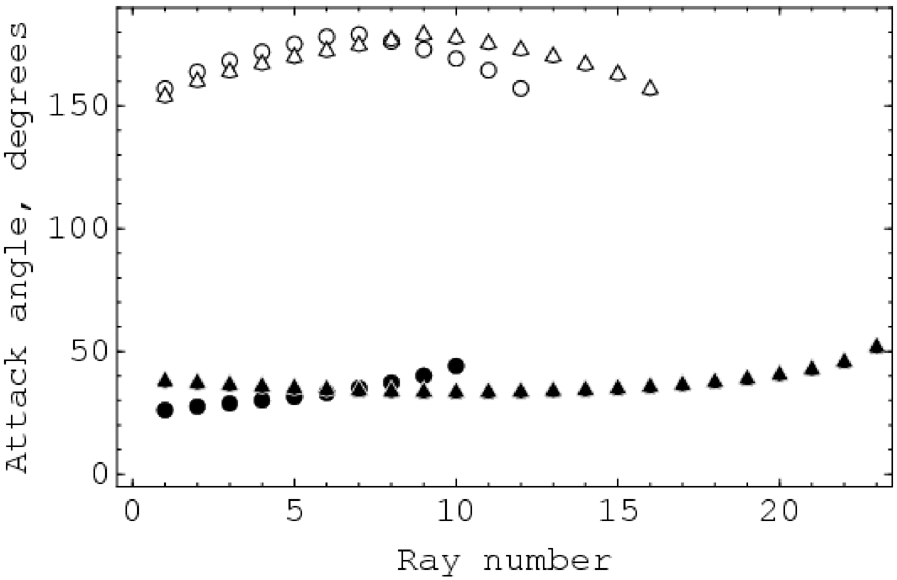
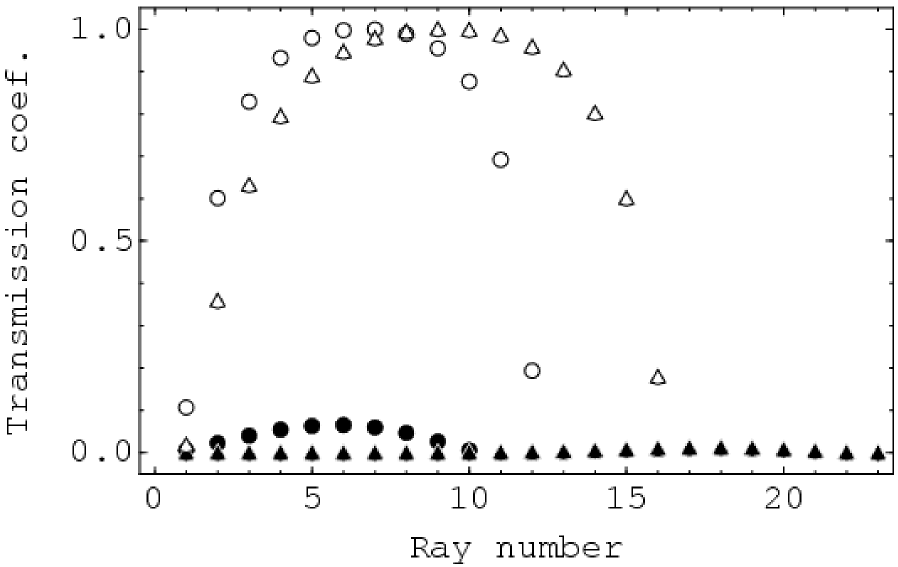
x, Mm

Efficiency of transmission





Summary

- We have performed analytical modelling of magnetoacoustic wave propagation, taking into account wave refraction and transmission of the slow magnetoacoustic mode into the fast mode
- The modelling has shown that pure slow magnetoacoustic waves driven at the base of the solar corona do not reach the magnetic null point in an active region. Hence, they cannot cause directly the triggering or modulation of the magnetic reconnection as it could be expected from observations
- The interaction of magnetoacoustic waves with the reconnection site is possible due to the mode transmission at the equipartition level subject to an appropriate attack angle distribution
- We have analysed the efficiency of magnetoacoustic mode transmission with account of wave refraction. The transmission mechanism can indeed be responsible for the penetration of slow magnetoacoustic waves into the flare reconnection site
- In particular, such penetration can explain the observed link between the 3 min oscillations in sunspots and QPPs in flaring light curves.

Thank you!

- Afanasyev A.N. and Uralov A.M., Slow-Mode MHD Wave Penetration into a Coronal Null Point due to the Mode Transmission, Solar Physics 2016, 291, 3185 http://adsabs.harvard.edu/abs/2016SoPh..291.3185A

- Observations of quasi-periodic pulsations (QPPs) in flaring light curves reveal their close link to magnetohydrodynamic (MHD) oscillations and waves in solar active regions. The nature of that link has not yet been understood in detail. QPPs detected in radio, extreme-ultraviolet and X-ray spectral bands are often interpreted as a result of the interaction of periodic MHD waves with a magnetic reconnection site (e.g. Nakariakov et al., 2006; Sych et al., 2009). In particular, it is often inferred from solar observations that QPPs are associated with longitudinal waves of slow magnetoacoustic nature (e.g. Sych et al., 2009). However, according to the polar diagram for the slow mode group velocities, slow magnetoacoustic waves propagate roughly along magnetic field lines, deviating slightly from them. So, the question arises: how can slow waves affect the flare reconnection site? One of the possible mechanisms is the generation of a fast-mode wave by a slow-mode one via MHD mode transmission. The transmission occurs mainly where the Alfvén speed becomes equal to the sound speed. However, the transmission scenario is considerably complicated by the wave refraction due to the large-scale non-uniformity of the coronal plasma.