INSTITUTE OF SOLAR-TERRESTRIAL PHYSICS
OF SIBERIAN BRANCH OF THE RUSSIAN ACADEMY OF SCIENCES

Radial structure of magnetospheric Alfven waves and phase difference between transverse magnetic components: two case studies

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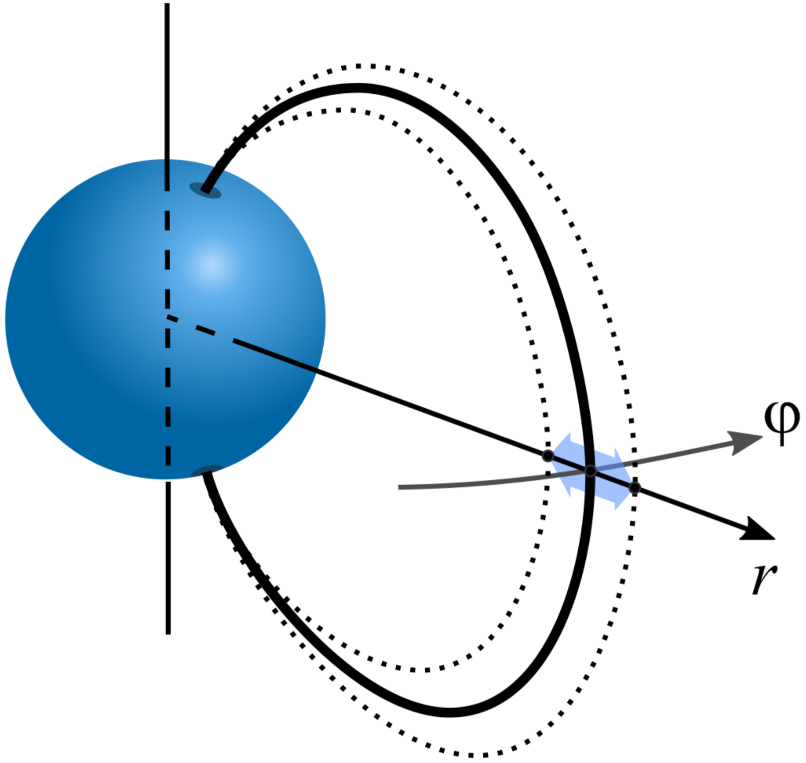
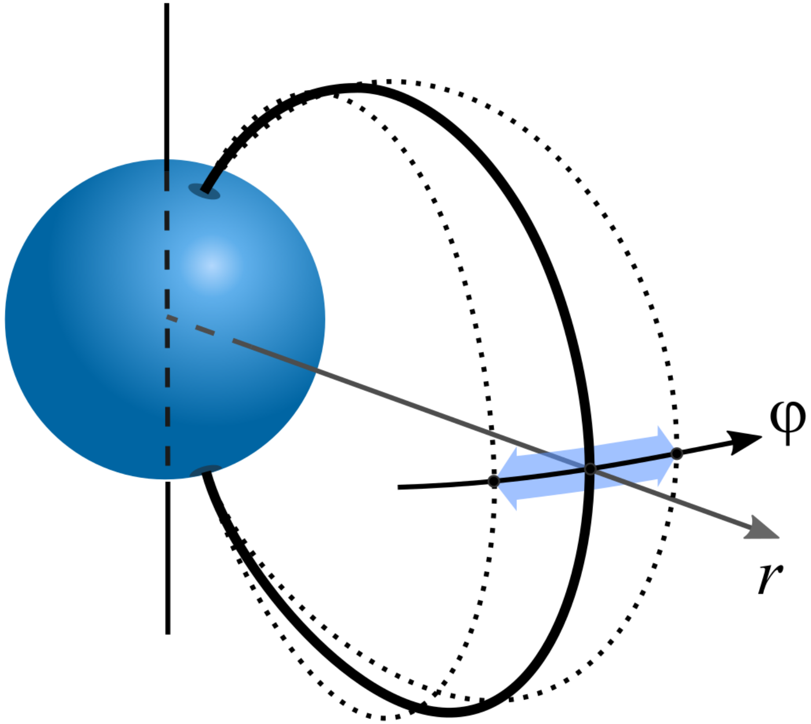
Introduction. Alfven waves

MHD oscillations can be classified into three main types, but the present study focuses on Alfvén waves. The spatial structure of Alfvén waves varies significantly depending on their polarization, source, or region of generation.



Poloidal oscillations (radial component of magnetic field dominates)
m >>1



Toroidal oscillations (azimuthal component of the magnetic field dominates)
m ~ 1

Phase shift/difference between transverse components

There are several ways to determine the type of observed geomagnetic oscillations, among which we can distinguish: 1) presence/absence of a certain component of the electromagnetic field. 2) the ratio between the transverse and longitudinal component of the magnetic field. 3) presence/absence of a pressure perturbation, etc. However, the same Alfvén waves have a very diverse small-scale structure in the direction across the magnetic shells. The method of ‘phase portraits’ is proposed to determine this structure.*

$$\varphi(a,l,k_2,\omega) = U(a,\omega)H(a,l,\omega)e^{ik_2\varphi - i\omega t}$$

$$\Delta\Phi(a,\omega) = -\arctan\frac{\mathrm{Re}\left[\nabla_a U(a,\omega)/U(a,\omega)\right]}{\mathrm{Im}\left[\nabla_a U(a,\omega)/U(a,\omega)\right]}$$

*Leonovich, A. S., Zong, Q.-G., Kozlov, D. A., & Vlasov, A. A. (2022). “Phase portraits” of Alfven waves in magnetospheric plasma. Journal of Geophysical Research: Space Physics, 127, e2022JA030432

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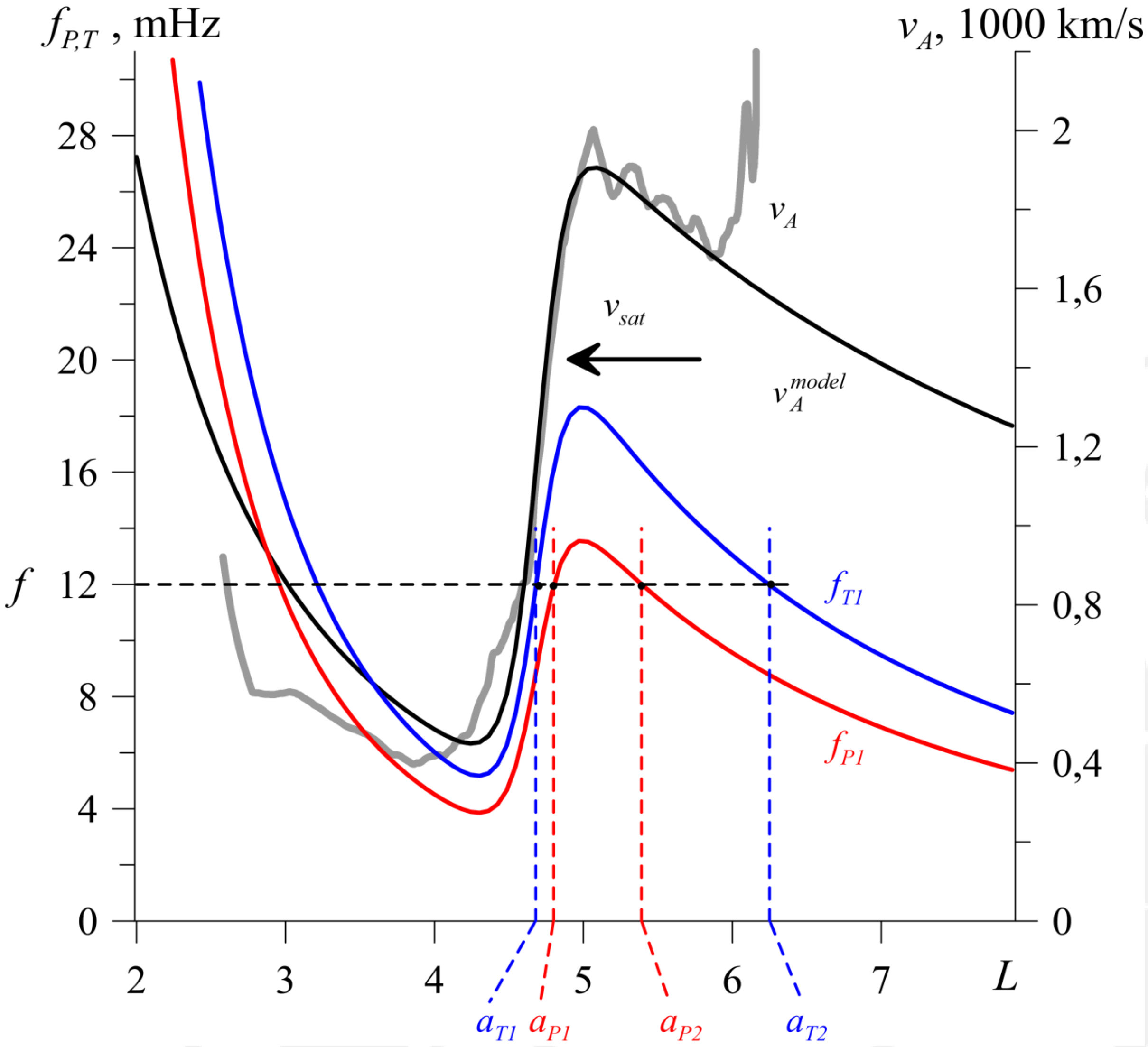
First case*

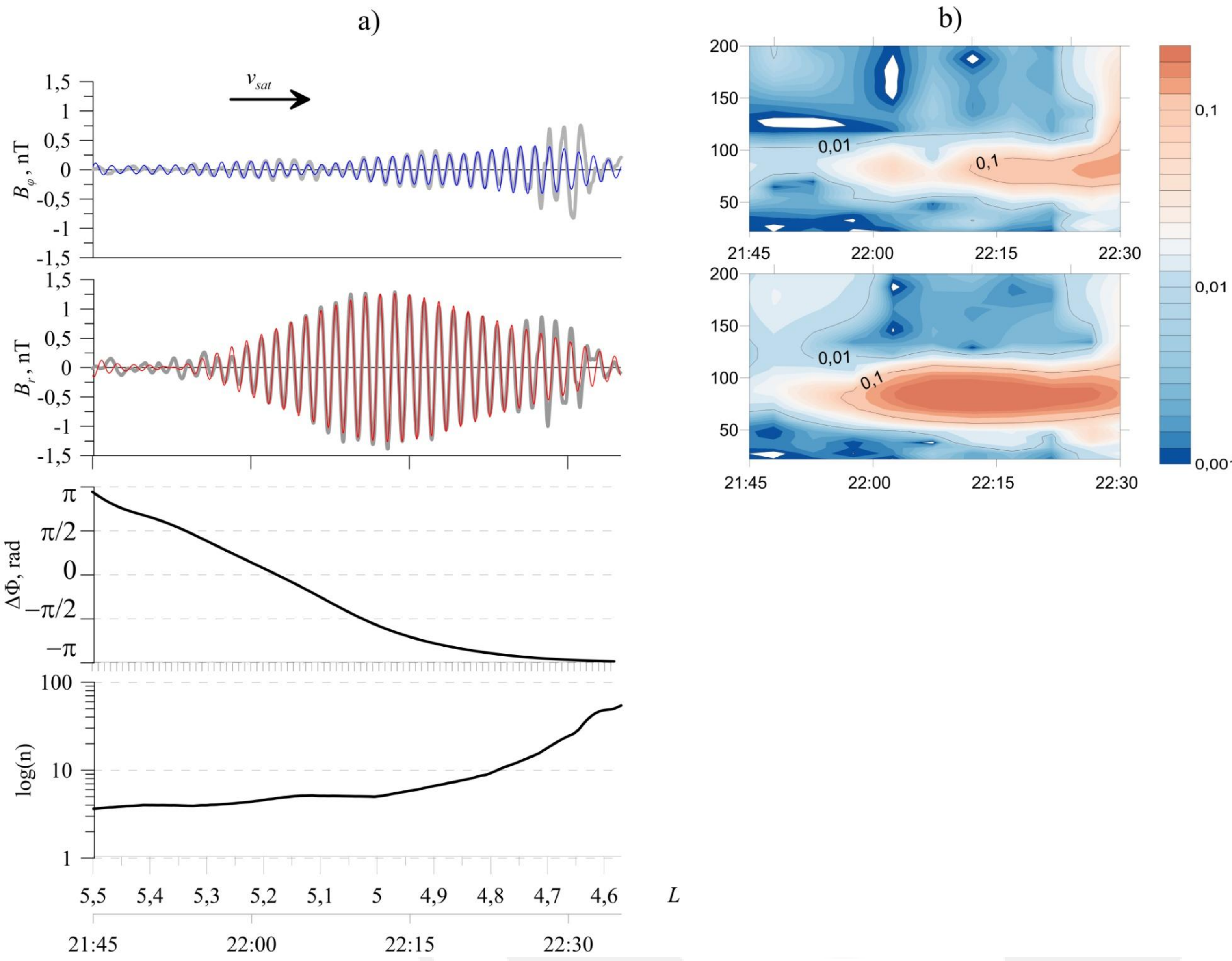
This event is dated 23 October 2012. The satellite recorded a very unique event in which the Alfvén wave changed its polarisation from poloidal to toroidal. This was the original interpretation of the event. The theoretical model and phase portrait method allowed us to extract more information from this event.



*Daniil A. Kozlov, Anatoly S. Leonovich, Alexander A. Vlasov, Determining the radial structure of high-m Alfvén wave by means of the "phase portrait" method, Advances in Space Research, Volume 73, Issue 1, 2024

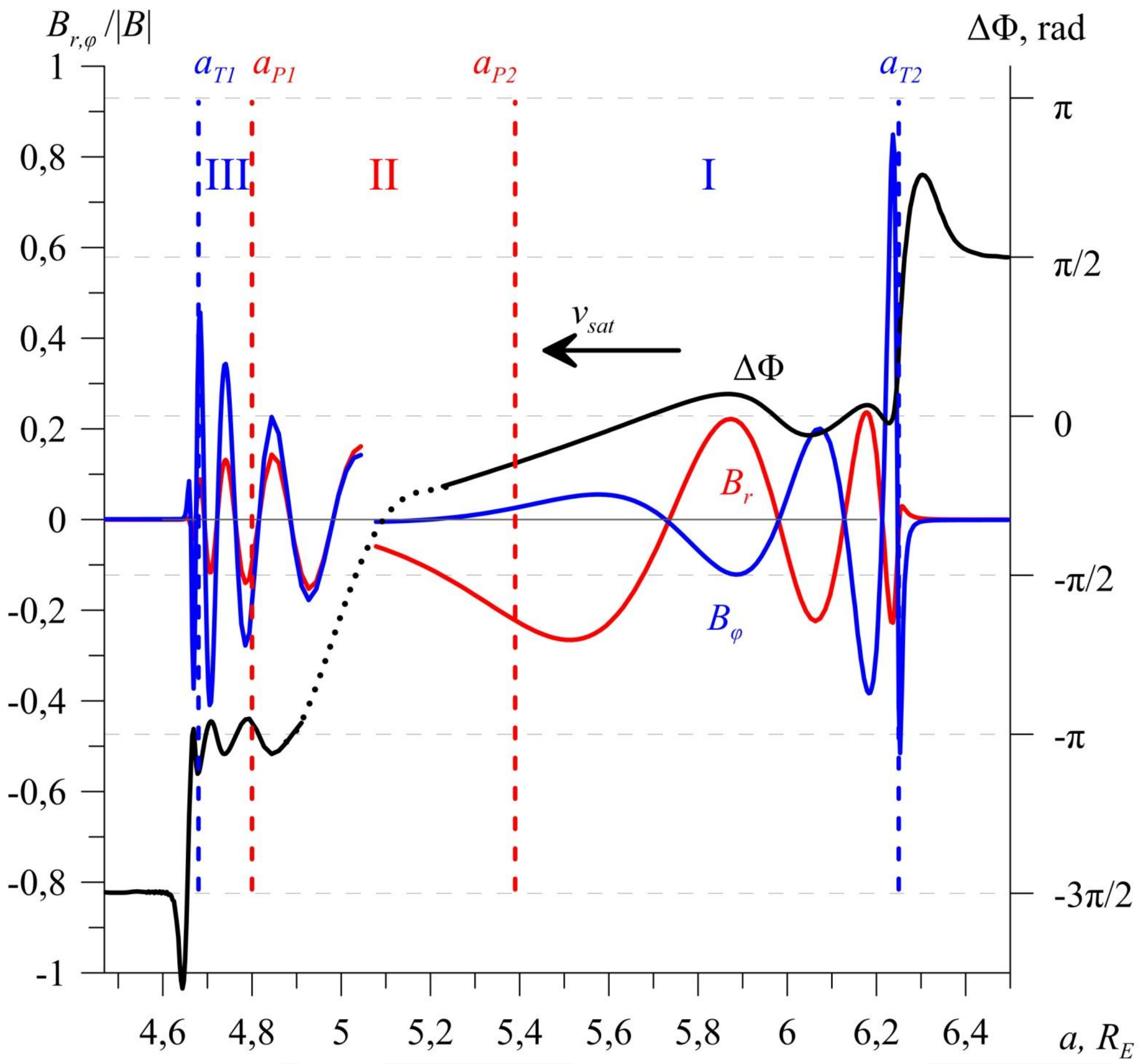
Further interpretation

The graph shows the change of polarisation from poloidal to toroidal. The phase difference decreases monotonically. Semi-integer values of pi correspond to regions of opacity, and integer values correspond to regions of transparency.



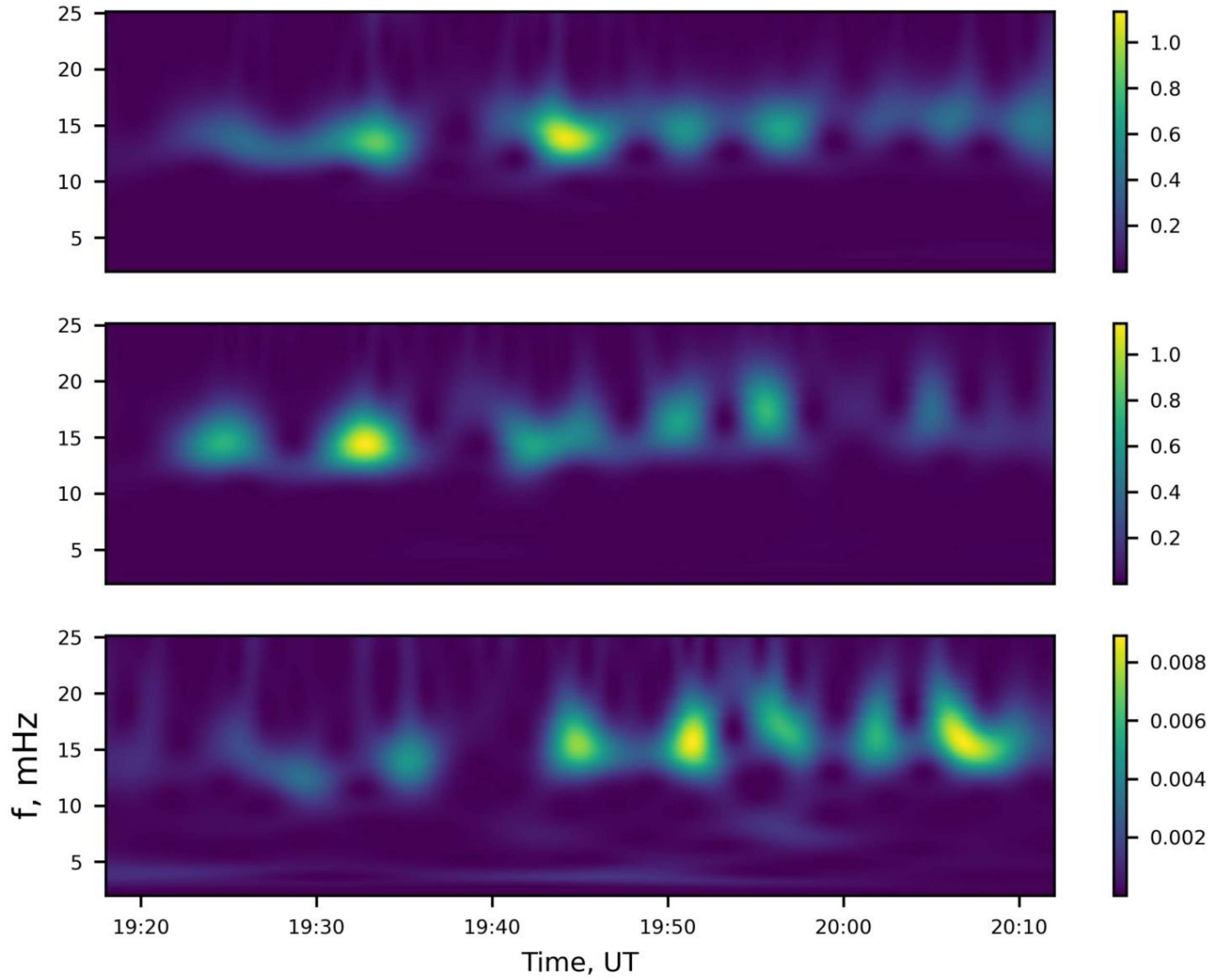
Model

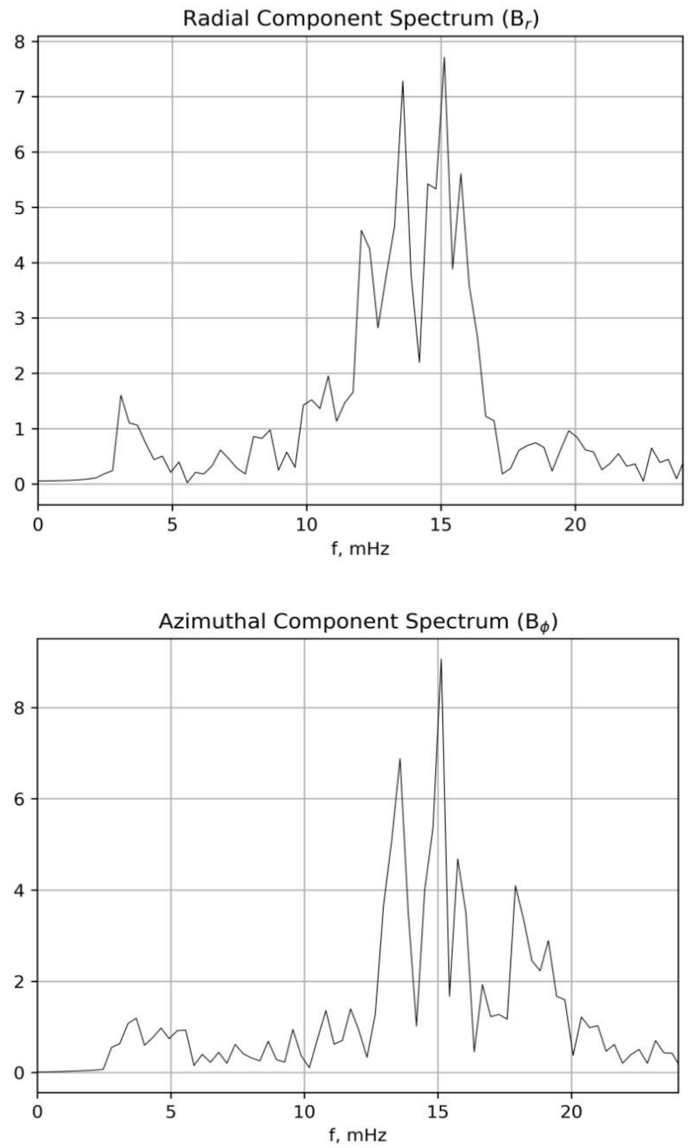
The graph shows numerical calculations based on the event parameters. The same phase difference transition is observed when there are two poloidal and two toroidal resonant surfaces in the event region. Probably, the wave was generated on the poloidal surfaces and then ran away to the toroidal surfaces and was absorbed.



The **second** case on the same day, a little earlier…

In [Mager et al., 2018]* this event was classified as the first case of an Alfvén resonator observation.

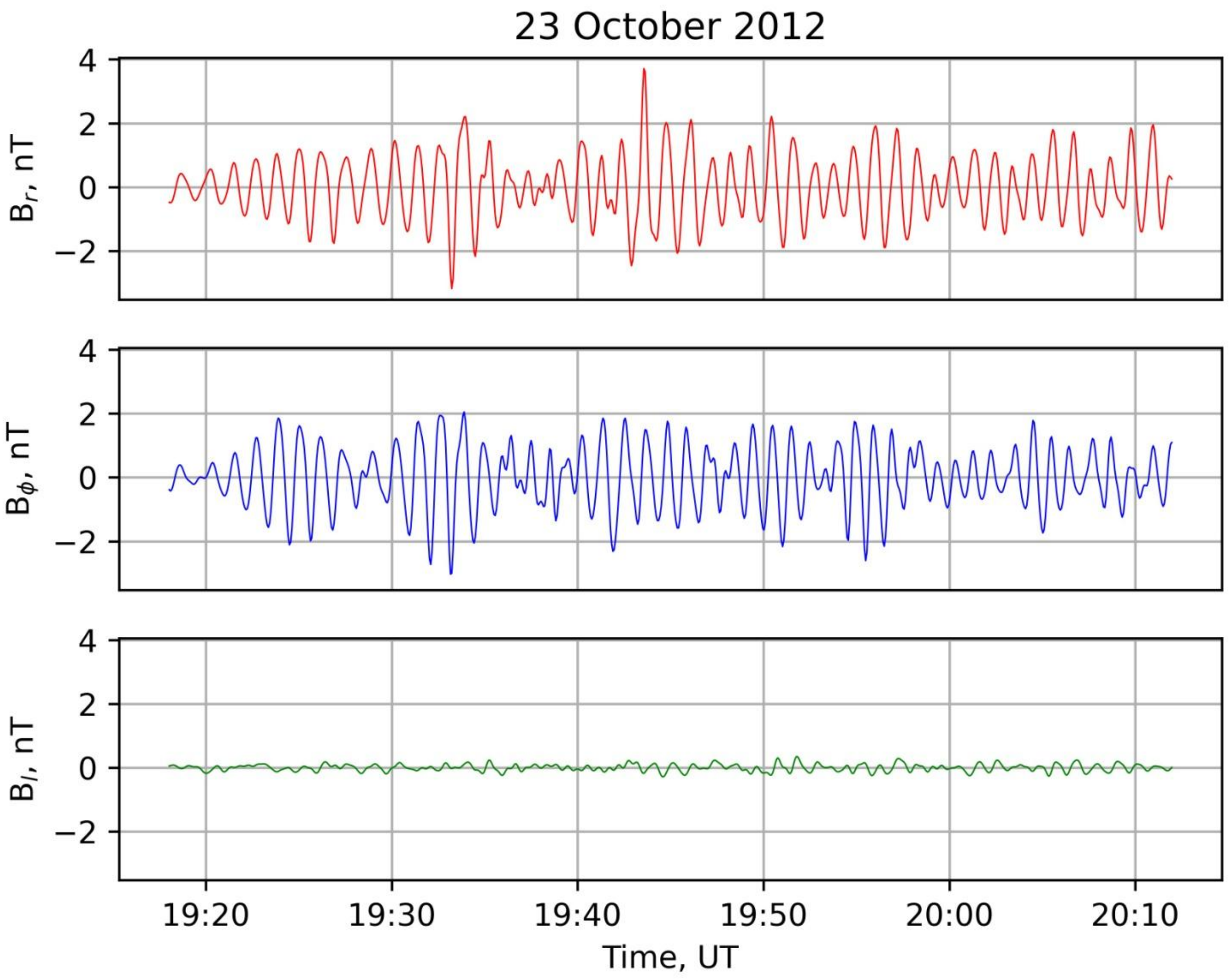




*Mager, P. N., Mikhailova, O. S.,Mager, O. V., & Klimushkin, D. Y. (2018). Eigenmodes of the transverse Alfvénic resonator at the plasmapause: A Van Allen Probes case study. Geophysical Research Letters, 45, 10,796–10,804.

Satellite data

Beats are observed in the graph, resulting from the presence of multiple harmonics in the resonator. The dominance of the transverse components of the magnetic field once again confirms that these are Alfvén oscillations.



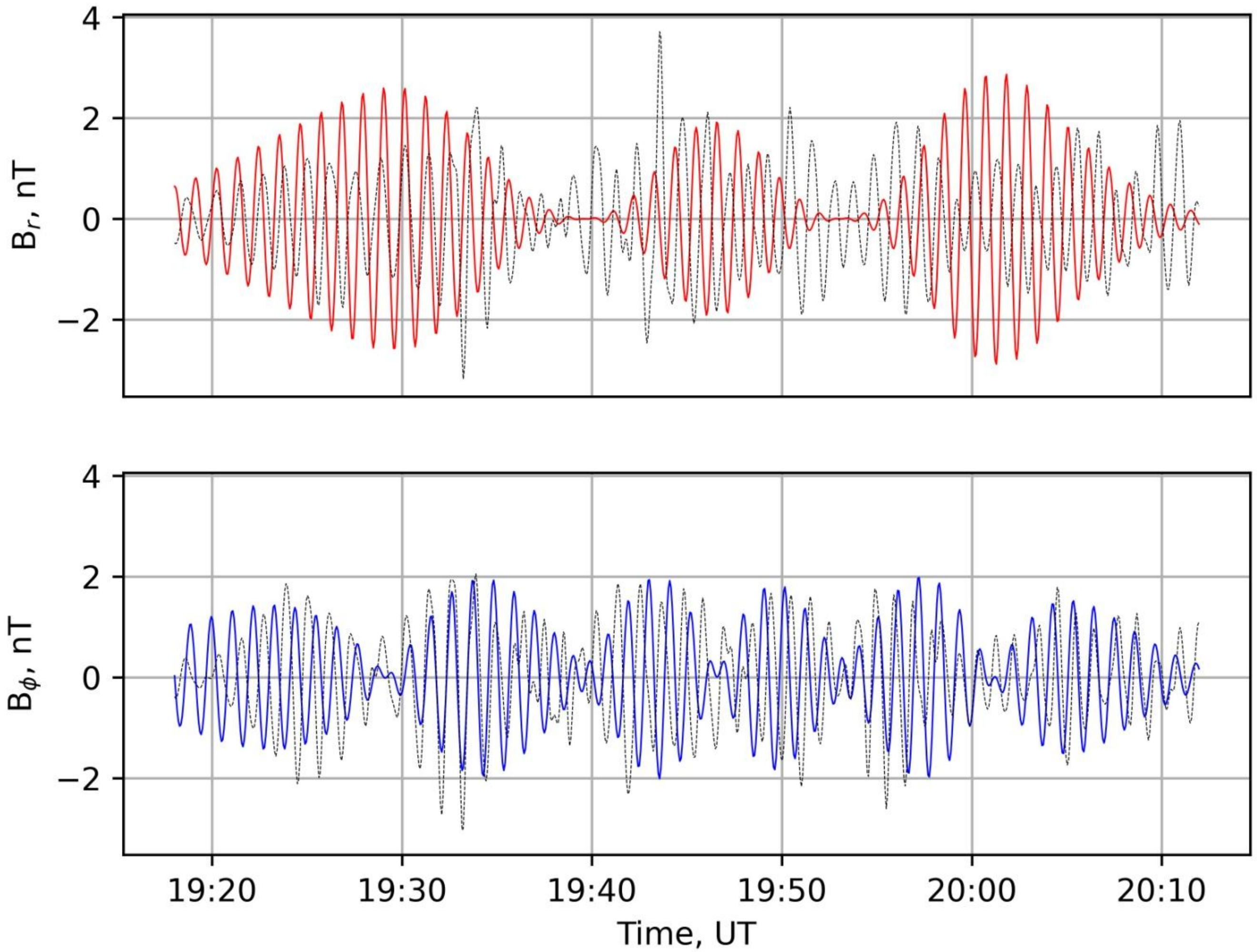
Resonator model

According to this paper [Mager et al., 2018], transverse harmonics with n = 0 and n = 2 were most likely excited in the event. Then the solution for the wave structure in such an Alfvén resonator has the form:

$$\Phi = A_0 y_0(a) P_N e^{-i\omega_0 t} + A_2 y_2(a) P_N e^{-i\omega_2 t},$$

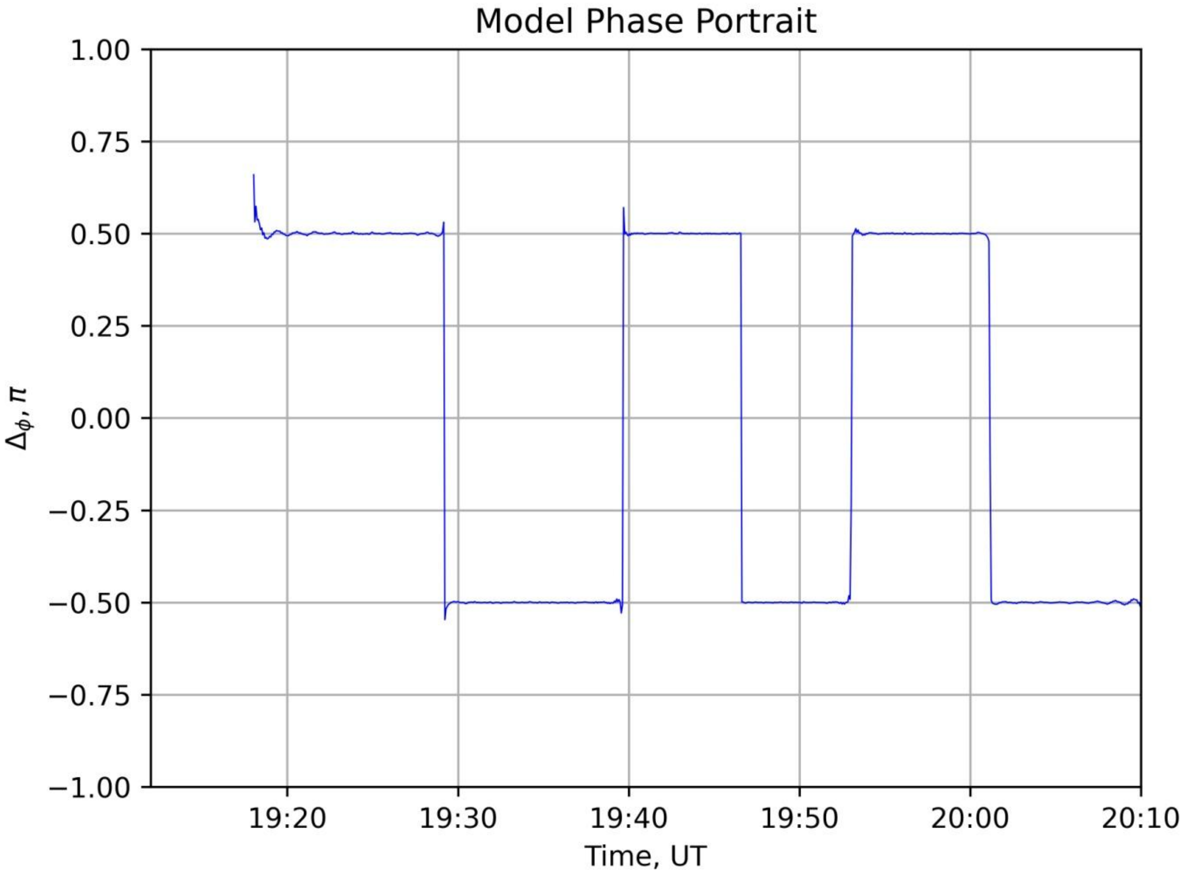
$$y_n = \frac{1}{\pi^{1/4}} \frac{2}{2^{n/2}} \frac{1}{n!} H_n(\zeta) e^{-\zeta^2/2},$$

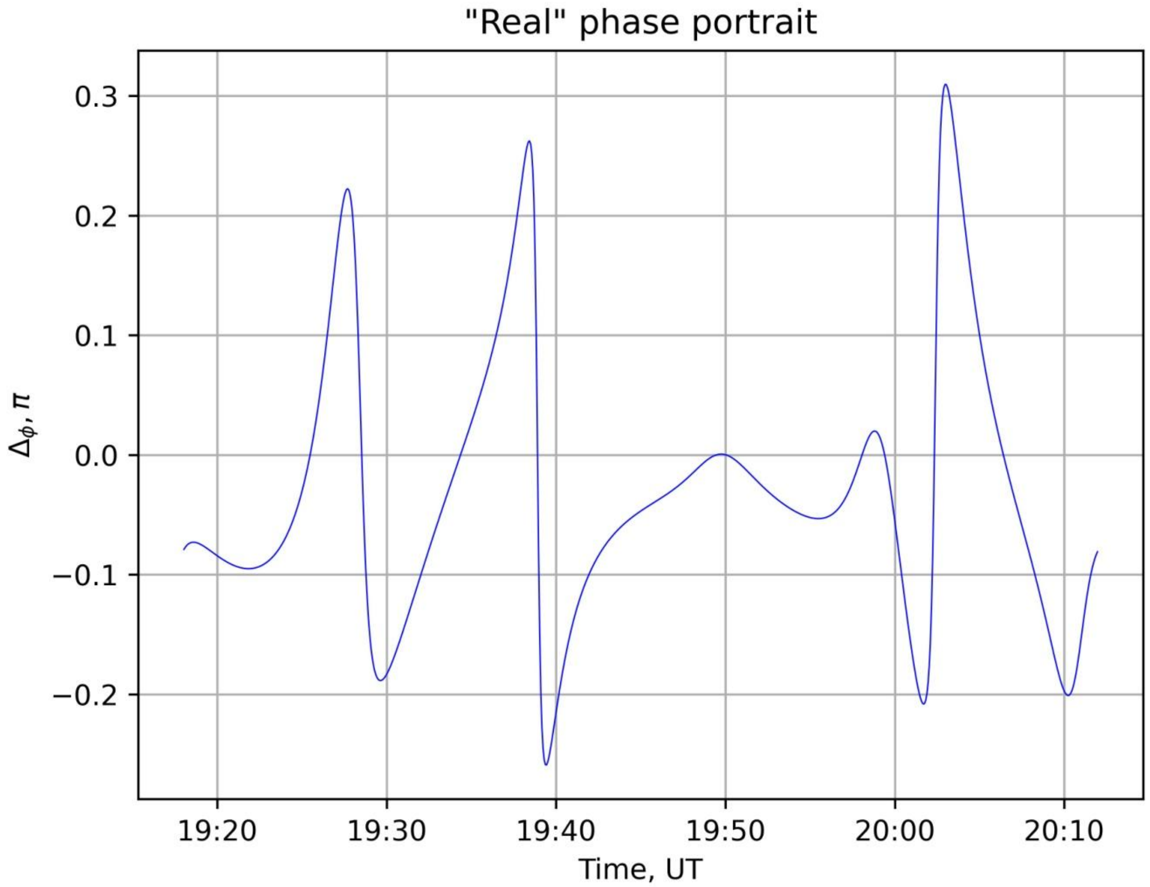
$$\zeta = \frac{a - a_{PN}}{\bar{\lambda}_{PN}}.$$



Phase portrait comparison

According to [Leonovich et al., 2022], the phase difference of Alfven resonators has the form of a periodic function making transitions between **0.5π** and **-0.5π.**





Conclusion

- The theoretical model of the Alfvén resonator shows good agreement with satellite data, including phase portraits.
- Using the “phase portrait” method with data from only **one** instrument (in our case, a magnetometer), we were able to:

1. Determine the spatial structure of Alfvén oscillations.
2. Determine the type of the observed Alfvén wave.
3. Estimate the approximate locations of regions of transparency and opacity, as well as the boundaries between them.

Thank you for your attention!

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