Diagnosing the Alfvén speed in asymmetric fibrils using solar magneto-seismology

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Key takeaways

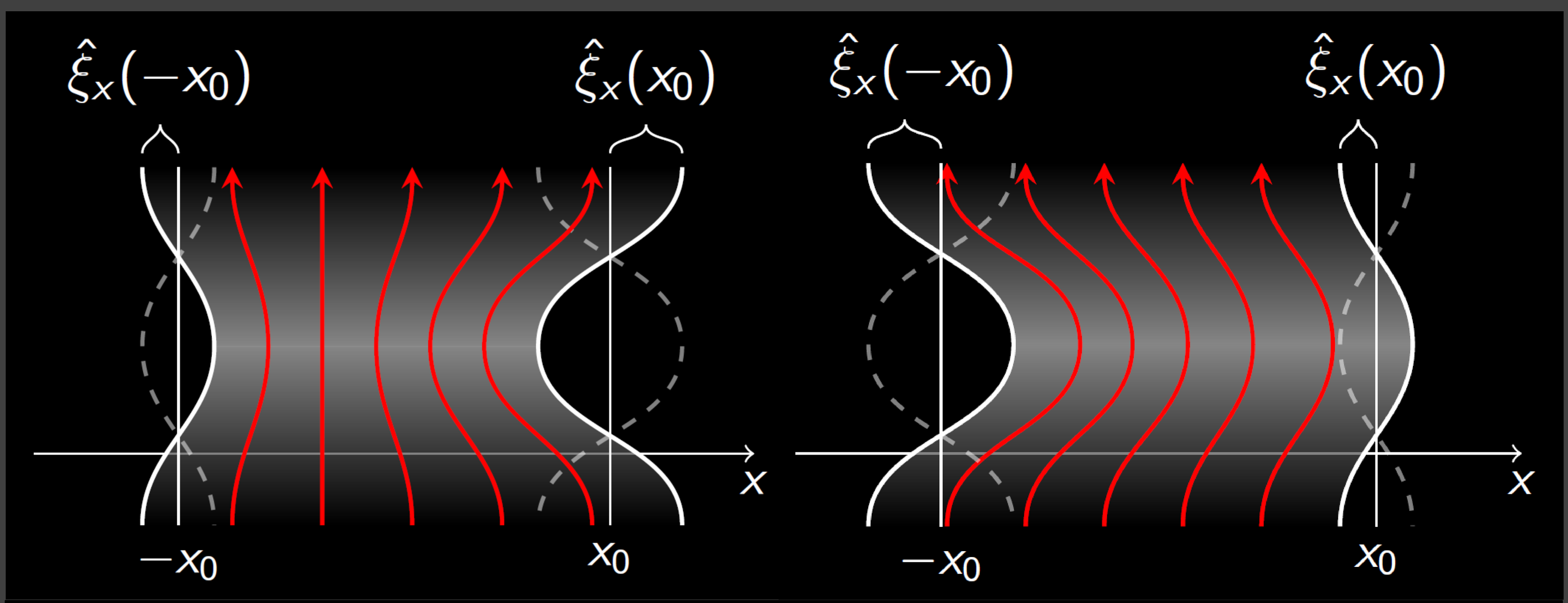
1. **Asymmetry** of solar MHD waves encodes background plasma parameters.
2. These parameters can be estimated using the **Amplitude Ratio Method**.
3. We estimate the Alfvén speed in several chromospheric fibrils as a proof-of-concept of this new technique.
4. Values range between 30 and 90 km s^{-1} which agree with estimates using other techniques.
5. We encourage observational solar physicists to use this technique to diagnose the magnetic field in further coronal and chromospheric structures.

Introduction

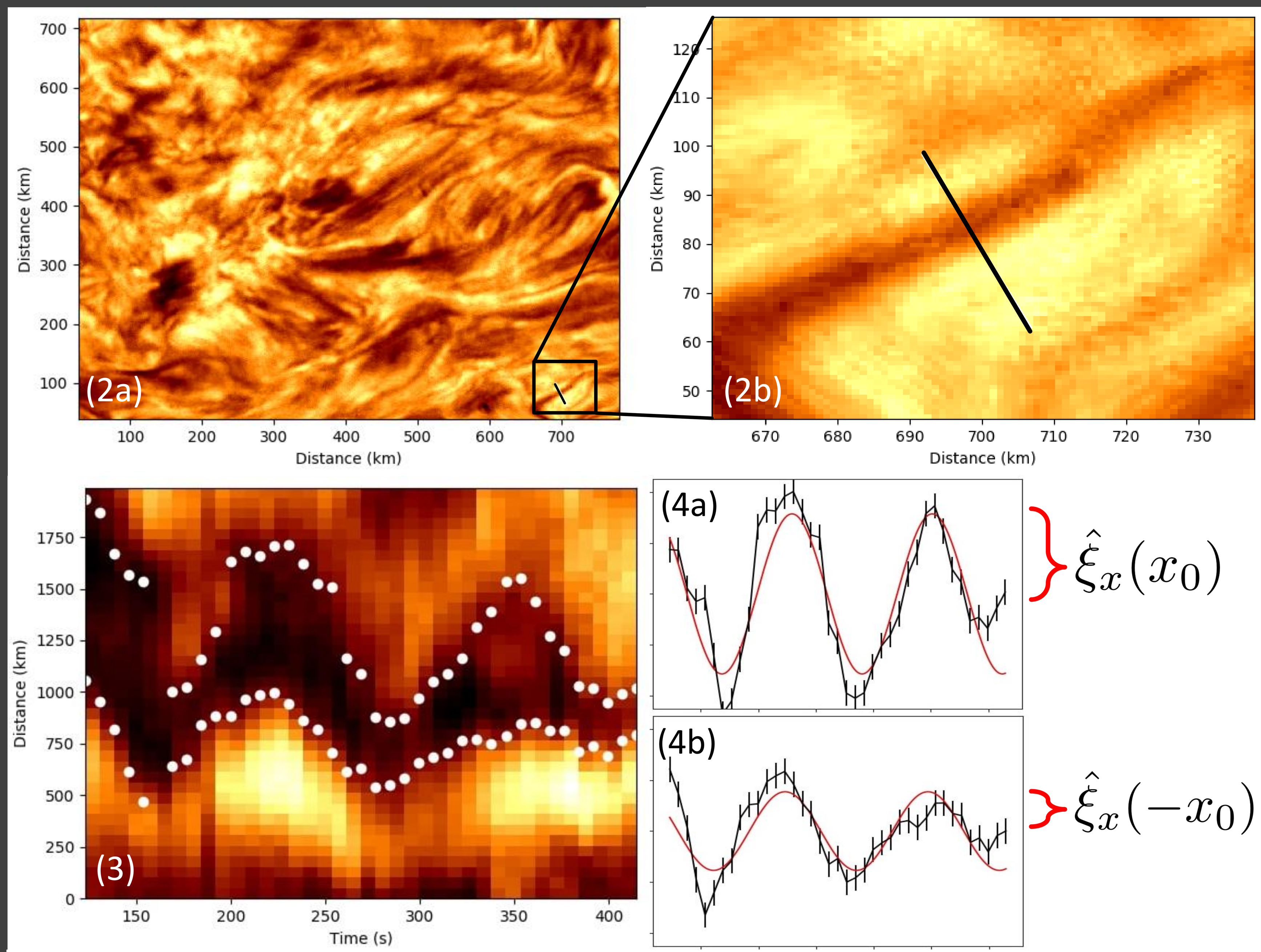
MHD waves behave differently depending on the parameters of the medium through which they propagate. Using solar magneto-seismology, observations of MHD waves in the solar atmosphere can be used to estimate these background parameters that are otherwise impossible to measure.

Many MHD waveguides in the solar atmosphere are **asymmetric** - *i.e.* the plasma on one side of the waveguide is different from the other. This asymmetry can be exploited to estimate background plasma parameters through solar magneto-seismology.

The **Amplitude Ratio Method** is a new technique that takes observations of asymmetric MHD waves and estimates background parameters using a simple inversion procedure. Here, we use it to estimate the Alfvén speed in a series of chromospheric fibrils.



(1a) Quasi-sausage mode (1b) Quasi-kink mode



(2) Observation window with a slit across a fibril. (3) Fibril boundaries located using Gaussian fitting. (4) Waveguide boundary data fit with sinusoids.

Background: Asymmetric MHD waves

The inhomogeneous solar atmosphere ensures that MHD waveguides deviate from the simple symmetric magnetic flux tubes and slabs we have grown familiar with. Waves which propagate along asymmetric waveguides therefore deviate from the traditional sausage and kink modes. We model this as a simple asymmetric slab waveguide (Figure 1), where the magnetic field lines are shown as red arrows.

Eigenmode analysis demonstrates that an asymmetric magnetic slab oscillates in the **quasi-kink** or **quasi-sausage** modes, where oscillations on each boundary are in phase or anti-phase, respectively (Reference 1). The asymmetry is seen in the different amplitudes on each side of the waveguide.

Scan the QR code for eigenmode animations.

Amplitude Ratio Method (ARM)

The asymmetry of MHD waves can be quantified by the signed ratio of the amplitudes at each side of the waveguide. Considering the simplest asymmetric MHD waveguide - an asymmetric magnetic slab (Figure 1) - the amplitude ratio, R_A, can be written as a function of the other parameters of the waveguide:

$$R_A := \frac{\hat{\xi}_x(x_0)}{\hat{\xi}_x(-x_0)} = f(\rho_{0,1,2}, T_{0,1,2}, x_0, \omega, k, v_A), \qquad (1)$$

where $\hat{\xi}_x$ is the transverse displacement (see Figures 1, 4), $\pm x_0$ are the positions of the boundaries of the waveguide, f is a transcendental function, given in full in Reference 2, ρ and T are the density and temperature (subscripts 0,1,2 correspond to the plasma region inside, on the left, and on the right, respectively), ω is the angular frequency, k is the wavenumber, and v_A is the Alfvén speed that is to be determined. The ARM works as follows:

Measure input parameters: R_A, x_0, $\rho_{0,1,2}$, $T_{0,1,2}$, k, ω → Solve Equation (1) for v_A → Estimate Alfven speed

Observations

Telescope: Dunn Solar Telescope, New Mexico,
Instrument: ROSA (Rapid Oscillations in the Solar Atmosphere) imager,
Spectral line: Hα,
Spatial resolution: 158 km (**pixel size:** 50 km),
Cadence: 7.68 s.

The data show a sea of dark dynamic strands, known as **fibrils**, which approximately align with the largely horizontal chromospheric magnetic field (Figure 2). The fibrils oscillate in a manner consistent with the fast magneto-acoustic modes of asymmetric waveguides.

Results

Fibril	Amplitude ratio	Eigenmode	Estimated Alfvén speed, km s^{-1}
1	1.29	Quasi-kink	**30.5**
2	-0.407	Quasi-sausage	**91.7**
3	-3.42	Quasi-sausage	**75.5**
4	-3.13	Quasi-sausage	**49.4**
5	2.04	Quasi-kink	**63.1**

The table above gives the estimated Alfvén speeds of a range of isolated chromospheric fibrils found using the ARM. They agree in order of magnitude with previous estimations made using different techniques. The errors in these estimates are significant. The error arises from (1) uncertainty in the input parameters and (2) the simplified model on which the ARM is based. For this reason, we present the above results as a proof-of-concept of this new technique which we hope to see built upon in future observations.

Contact

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References

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