A New Technique for Estimating the Sun's Magnetic Field Strength using Asymmetric Waves

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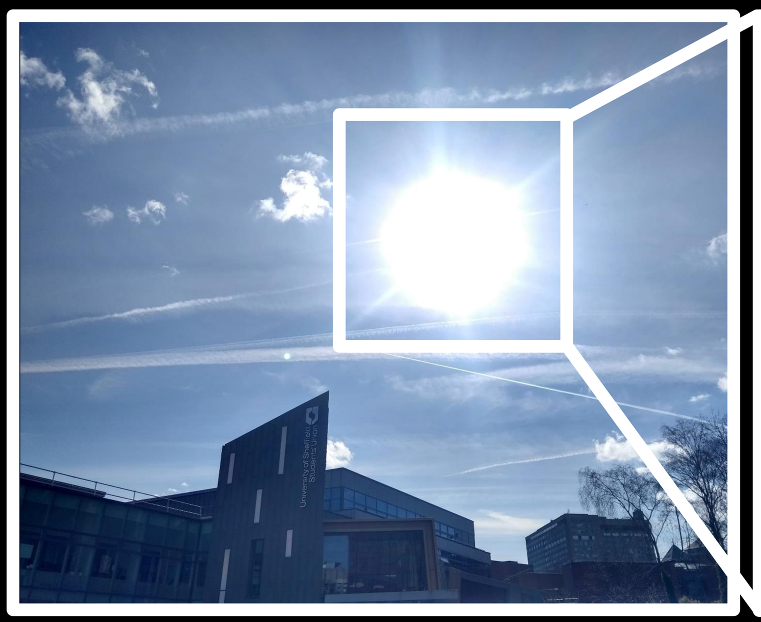
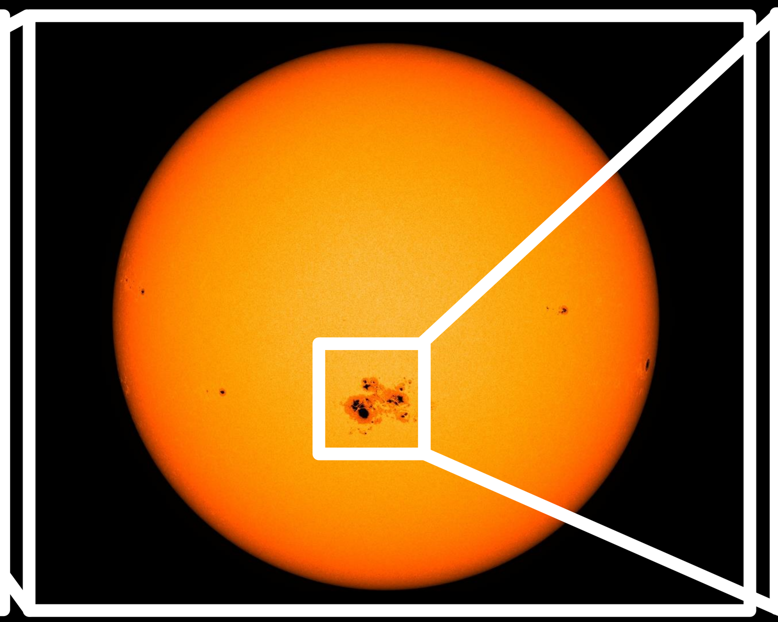
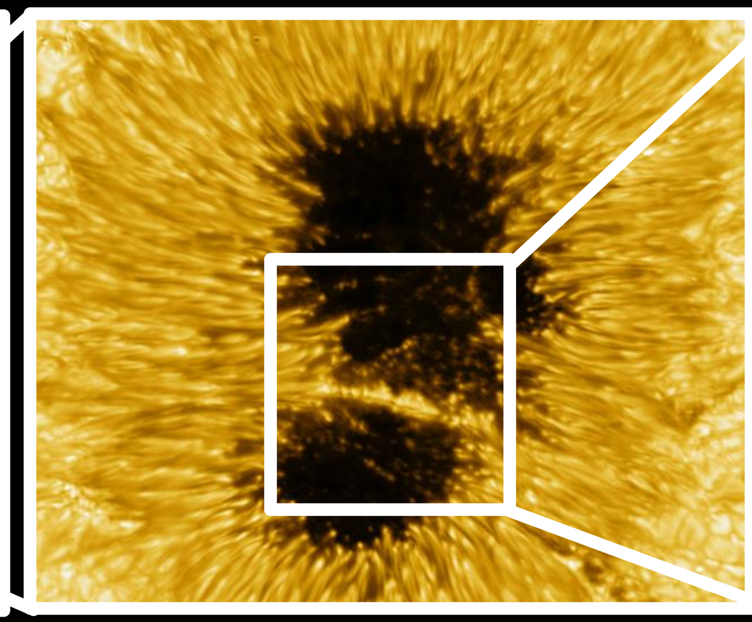


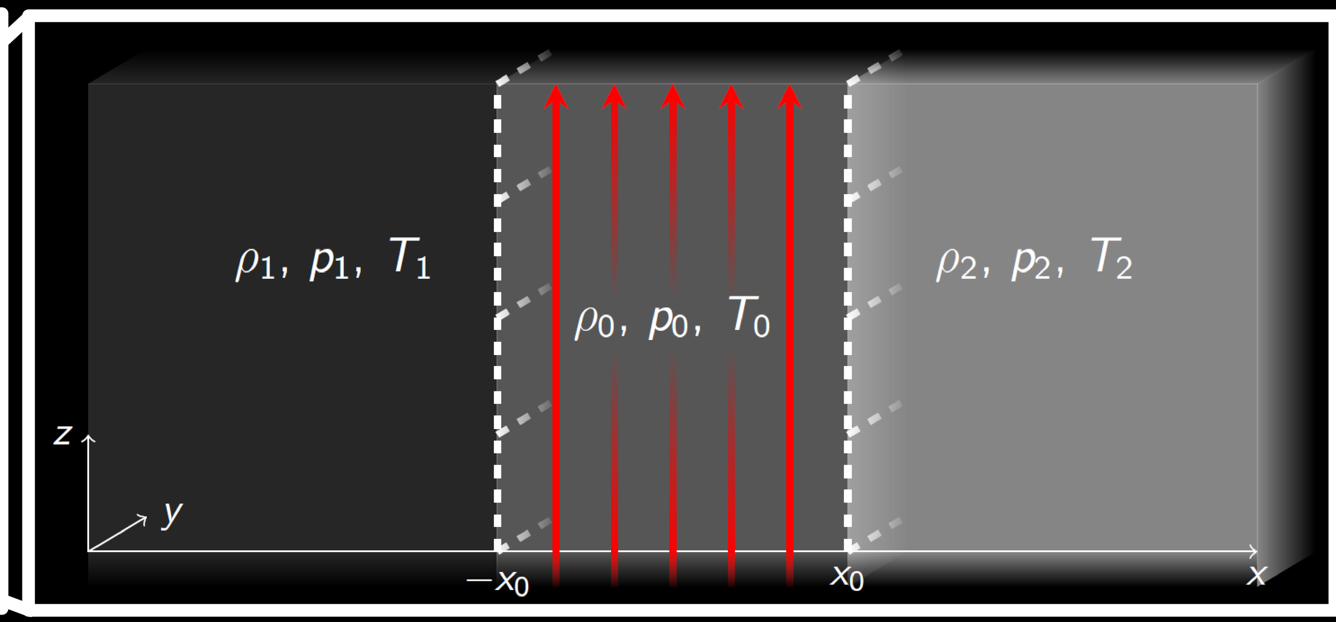
(a) Sheffield's rarely seen Sun



(b) The Sun's visible surface



(C) Sunspot formed by a strong magnetic field



(d) Model of an asymmetric waveguide; magnetic field in red.

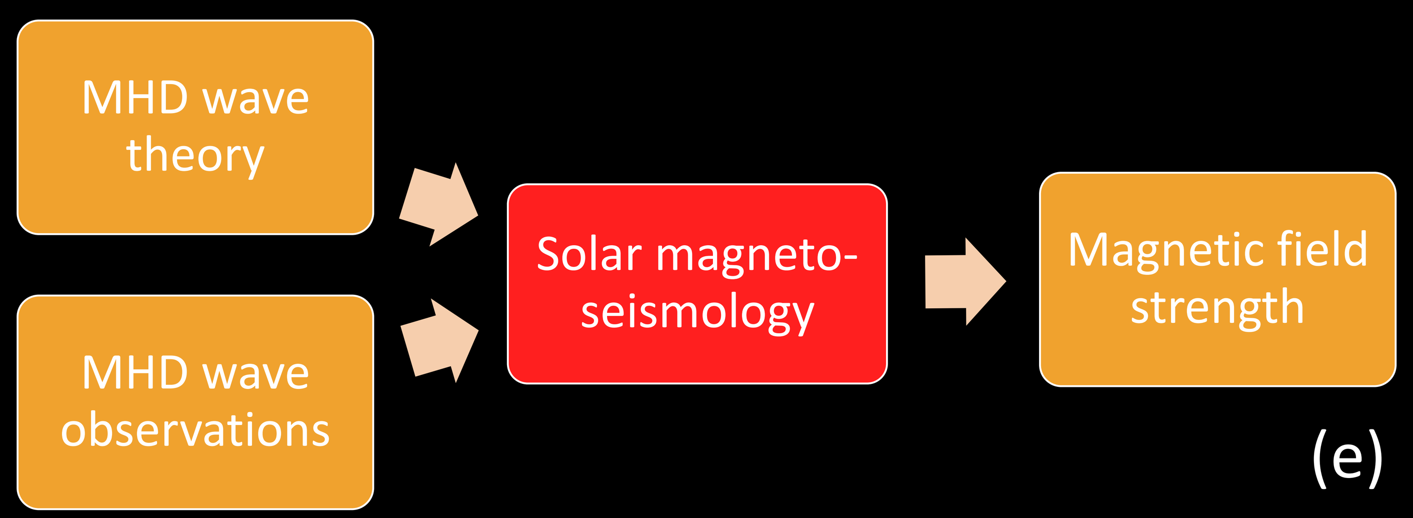
Introduction

It is hard to believe, but sometimes the Sun shines in Sheffield (Figure a). The star producing this radiation has an atmosphere dominated by complex magnetic fields, which have eluded our understanding for decades (Figure b).

Magnetic structures in the Sun's atmosphere (*e.g.* the *light wall* above the sunspot in Figure c) sway and dance in unison, choreographed by the bubbling motion from plasma upwelling from beneath the surface and from disturbances by nearby flares. They dance with oscillations known as *magnetohydrodynamic (MHD) waves.*

Unfortunately, we cannot measure the strength of the magnetic field in the upper solar atmosphere, known as the *corona*, directly, so we must use indirect methods. One such indirect method is known as *solar magneto-seismology,* which involves comparing observations of MHD waves with the waves that propagate in simplified models, and inverting an approximation for the magnetic field strength (Figure e).

OBJECTIVE:
We present the first development of an SMS technique that uses observations of asymmetric MHD waves to estimate the magnetic field strength in coronal structures.



(e)

Asymmetric Waveguide Model

The solar atmosphere is highly inhomogeneous and it is likely that many solar structures such as sunspot light walls, magnetic bright points, and prominences, are asymmetric. By this, we mean a magnetic structure that can guide waves in the Sun's atmosphere that has different temperature, density, or magnetic field on each side.

We model these asymmetric structures using a simplified mathematical model of an asymmetric plasma, of half-width x_0, magnetic field B_0, density ρ, temperature T, and pressure p (Figure d). We can then derive a technique that uses the asymmetric waves that propagate in this model to estimate the magnetic field strength.

Asymmetric Eigenmodes

A linear (*i.e.* small amplitude) wave analysis of the asymmetric model (Figure d) can be completed using an eigenmode analysis.

We find that the types of waves that propagate along this structure are either *asymmetric sausage* or *asymmetric kink waves* (Figures f, g), depending on whether the oscillations on each side of the structure are in phase or in anti-phase.

For animations, see the flipbooks or scan the QR code here →

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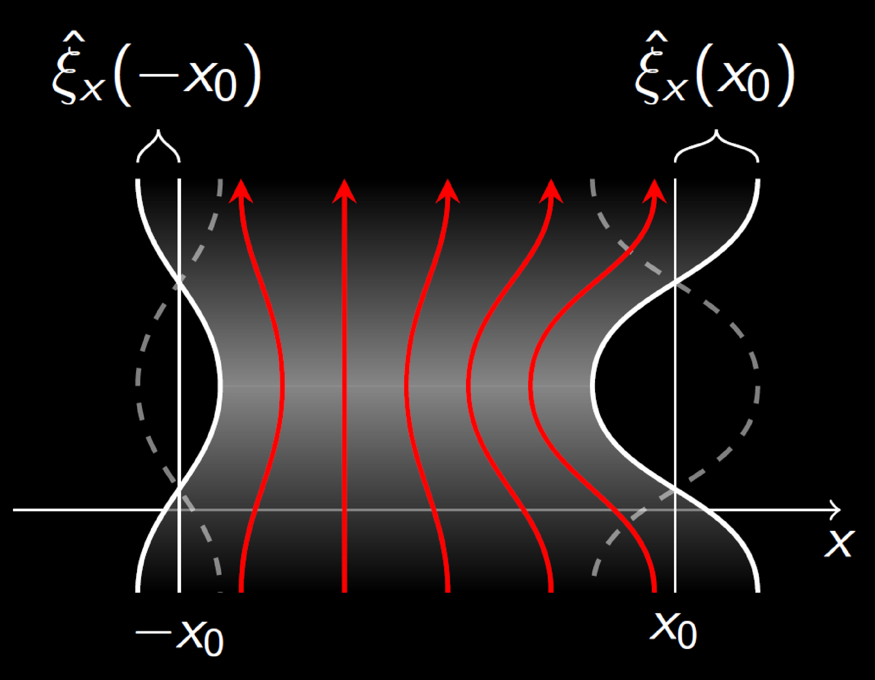
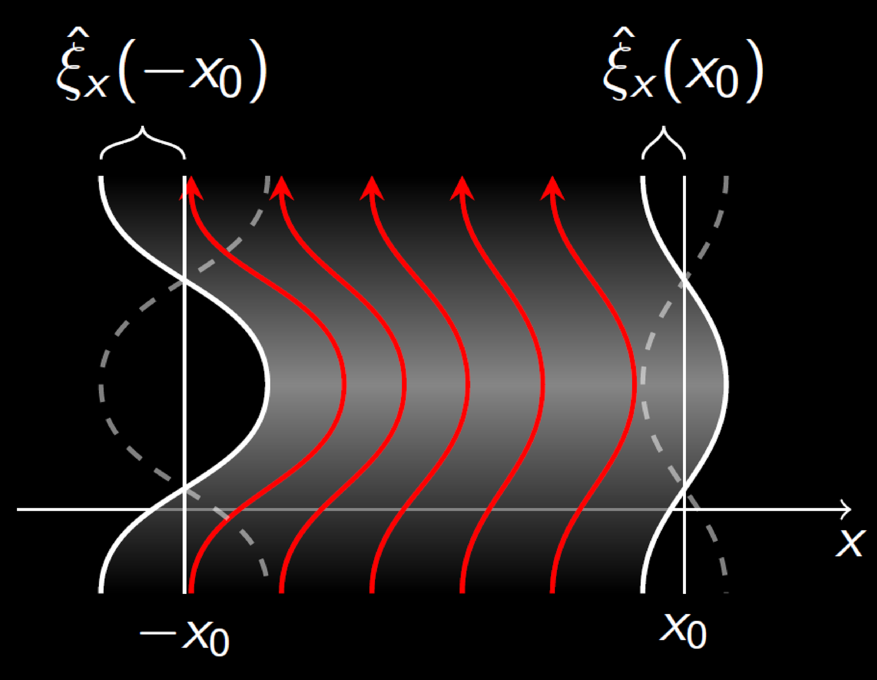


(f) Asymmetric sausage mode



(g) Asymmetric kink mode

A Novel SMS Technique – *Amplitude Ratio*

To quantify the asymmetry of these waves, we define the *amplitude ratio,* R_A, to be the ratio of the amplitude of oscillation on each side of the structure, which we have derived to be

$$R_A := \frac{\hat{\xi}_x(x_0)}{\hat{\xi}_x(-x_0)} = f(\rho_{0,1,2}, T_{0,1,2}, x_0, \omega, k, B_0), \tag{1}$$

where *f* is a transcendental function, given in full in Reference [1], B_0 is the magnetic field strength, ω is the angular frequency, *k* is the wavenumber. We can use this equation to estimate the magnetic field strength.
The procedure is as follows:

1. Observe the background parameters: ρ, T, x_0,
2. Observe the wave parameters: ω, k,
3. Invert the *amplitude ratio* Equation (1) for the magnetic field strength: B_0.

The inversion procedure can be accomplished either:

1. *Analytically:* using the thin slab approximation, valid for wavelengths much shorter than the width of the structure, such that the magnetic field strength is estimated using

$$B_0 \approx \frac{\omega}{k}\sqrt{\mu_0\rho_0\left[1 + \frac{1}{x_0}\left(\frac{R_A\frac{\rho_2}{\rho_0 m_2} + \frac{\rho_1}{\rho_0 m_1}}{R_A + 1}\right)\right]}.$$

2. *Numerically:* using a one- or two-dimensional root finding algorithm. By using a two-dimensional root finding algorithm, we can make an approximation for the slab density as well as the magnetic field, adding to the value of this technique for parameter diagnosis.

Conclusions

The strength of the complex magnetic field in the solar corona is often impossible to measure using traditional techniques, so we must use inventive indirect techniques.

For the first time, a technique for estimating the magnetic field strength of structures in the solar corona using asymmetric wave observations has been developed. The *Amplitude Ratio technique* opens up a new possibility of understanding the strength of the magnetic field that is key for future forecasting of the largest explosions in the solar system: *coronal mass ejections*.

Full details of the *Amplitude Ratio technique* are published in Reference [2].

Contact

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References

[1] Allcock and Erdélyi, 2017, *Solar Physics, 292:35,*
[2] Allcock and Erdélyi, 2018, *The Astrophysical Journal*, 855(2):90.