# Coronal Seismology

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## ABSTRACT

Coronal seismology involves the investigation of magnetohydrodynamic (MHD) waves and oscillatory phenomenae that arise in the solar corona. Here some of the dominant waves, oscillations, and modes are intimately investigated in the literature. Analysis of data from the Atmospheric Imaging Assembly (AIA) instrument on the Solar Dynamics Observatory (SDO) is also presented, both as stand-alone research and in the broader context of coronal seismology.

*Subject headings:* Sun: corona Sun: oscillations Sun: seismology

## 1. Introduction

[Motivation: coronal heating, other questions...]

The heating of the corona by magnetohydrodynamic (MHD) waves is one of two prevalent theories on how it reaches such high temperatures, the other being magnetic reconnection (Roberts et al. (1984)).

The basic types of MHD waves and oscillations are discussed in §2. §3 discusses each of the research topics in detail, including including references to work that has been done and is currently being carried out to address each one. §5 and §6 include a description of the research project and its implications for the broader field of coronal seismology. Conclusions and future work are summed up in §7.

## 2. General MHD

### 2.1. Types of Waves

The categories of MHD waves and oscillations can be best understood by their speeds. Figure 1 shows the wave speeds relative to the internal and external Alfvén and sound speeds.

### 2.2. Equations and Models

MHD waves are often modeled with a cylindrical flux tube embedded in a magnetic field.

[cylindrical model, equations of ideal MHD, etc.]

$$\xi(x) = \xi(r)e^{i(kx+m\phi)}$$

For kink oscillations, m=1, and for sausage modes, m=0.

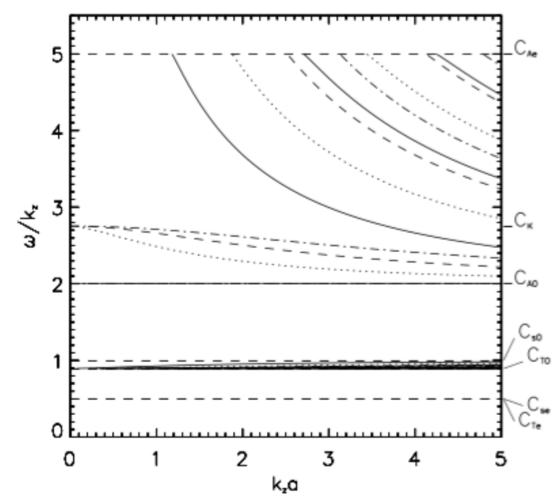


Fig. 1.— text (Image credit: Nakariakov & Verwichte (2005))

There are several equations for ideal MHD from which the dispersion relations are derived (I think).

### 2.3. Excitation and Damping Mechanisms

#### *2.3.1. Resonant Absorption*

#### *2.3.2. Phase Mixing*

### 2.4. Observation Techniques

Flux tubes (coronal loops), doppler shift and intensity variations, density variations, velocity and magnetic field values, etc.

## 3. Research Topics

### 3.1. Kink Oscillations

Kink oscillations are commonly associated with coronal loops, and characterize the spacial oscillations that occur over the surface of the loop (Nakariakov & Verwichte (2005)).

Some of the first observations of these spatial variations were carried out by Aschwanden et al. (1999), who utilized some of the first data released from the TRACE mission in order to investigate the oscillations present in coronal loops. Using data taken with the 171Å filter, they modeled five loops that were present with a solar flare in 1998. The resulting model had several qualities characteristic of fast kink modes, including asymmetry and displacements represented by sine curves. As the period of kink modes were already known to correlate with the magnetic field strength of the loop, pinpointing this type of mode as the driver in coronal loops provided a valuable constraint on coronal conditions. The absense of any phase shift along the length of the loops revealed that these were *standing waves*, with nodes located at the loop footpoints.

More recently, Pascoe et al. (2015) investigated the driving mechanism behind the production, and damping of kink oscillations. They compared two possible functional form of the damping profile of the driver: that of a Gaussian and an exponential form. While the noise level of the data was too high to distinguish between the two forms, the simulations followed the form of a Gaussian.

They also considered the effect of the spatial profile of the driver itself on the excitation and subsequent damping of the kink waves. Two different possiblilities were explored here: the effect of a "highly structured" driver, which they found to be unrealistic, and the effects of eddies and photospheric motions around the footpoints of the coronal loops.

### 3.2. Sausage Oscillations

Lopin & Nagorny (2015) plotted the changes in intensity and cross-sectional area for sausage oscillations in photospheric pores extending up through the solar atmosphere. They used the general cylinder model for the pores, though it is more likely that the cross-sectional area of the waveguide increases with height as the temperature increases and density drops. The relationship between pore size and intensity can indicate

### 3.3. Magnetoacoustic Waves

Magneto-acoustic waves can be divided into two categories: slow-mode and fast-mode (Aschwanden (2004)). The slow-mode waves have phase speeds roughly equal to the sound speed in the medium in which they reside, so these are general acoustic, or sound waves.

Fast-mode magnetoacoustic waves have phase speeds close to the Alfvén speed.

### 3.4. Acoustic Oscillations

The relatives periodicities of aacoustic oscillations were recognized as important characteristics, and modelled by Roberts et al. (1984). They recognized magnetoacoustic oscillations as a useful way to determine other properties of the solar atmosphere.

Srivastava & Dwivedi (2010) used intensity oscillations of a few different ionization species to pinpoint the orgin and progression of magnetoacoustic waves between bright points in the photosphere, through the transition regions, and up into the corona. The time series of intensity oscillations was converted into a power spectrum, and periodicities were extracted using wavelet analysis and periodograms (note here on what exactly these are?). The periods they derived ($\sim$ 263 +/- 80 s for the He II 256.32 Å emission line and ($\sim$ 241 +/- 60 s for the Fe XII 195.12 Å emission line) were close to the 5-minute global oscillations of the sun.

### 3.5. Propagating Acoustic Waves

While standing acoustic waves are primarily seen in closed coronal loops, propagating waves are seen in both closed and open structures. Their propagation speed is much lower than the local Alfvén speed, so they are categorized as slow, longitudinal waves (acoustic waves, essentially) that travel along magnetic field lines at speeds equal to the local sound speed. Since this speed is proportional to the square of the equilibrium temperature, which is unchanging along the length of a coronal loop, measurement of the propagation speed could potentially provide a method of constraining the temperature, though unfortunately this technique currently suffers from projection effects (Nakariakov & Verwichte (2005)).

### 3.6. Propagating Fast Waves

### 3.7. Torsional Modes

### 3.8. Mixed Modes

## 4. Discussion

The observational techniques and relevant properties of each of the different kinds of MHD waves are summarized in table 1.

## 5. Data

As part of the general topic of coronal seismology, a small research project was carried out as well, continuing over from several semesters previously. Several of the observational and analytical methods used in the literature were reproduced for this project.

## 6. Analysis

## 7. Conclusion

And we're finished.

## REFERENCES

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| Type of wave | Timescales | Sizescales | Observational techniques |
|---|---|---|---|
| Kink Oscillations | short | short | something |
| Sausage Oscillations | short | short | something |
| Acoustic Oscillations | x | x | x |
| Propagating | x | x | x |