

# Coronal Seismology

ASTR 598

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# Motivation/Main Scientific Question

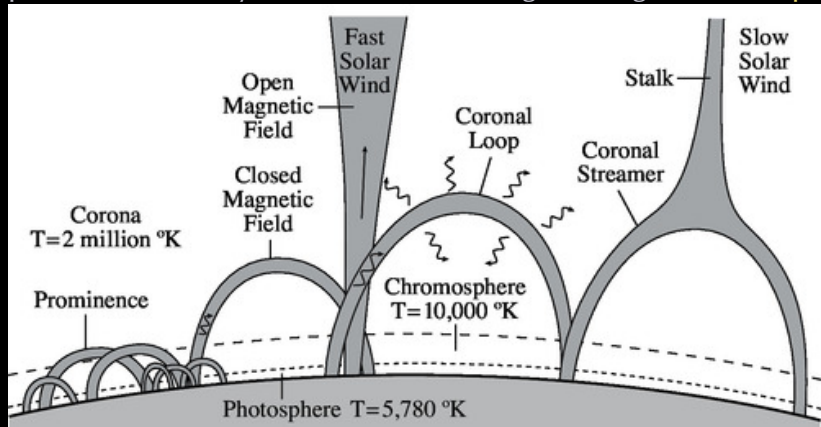
## The coronal heating problem

- “Frozen-in” magnetic field creates structure in the solar atmosphere, such as loops and prominences.
- Can observe oscillations and waves in the corona to extract properties about the solar photosphere and atmosphere. Phase speeds, amplitudes, dissipation, etc. can help determine physical properties that are otherwise inaccessible.

# Coronal seismology

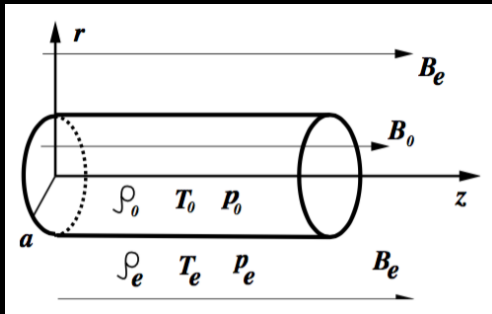
## General idea

Based on how the **phase** speed is determined by local plasma parameters. Density structures act as waveguides, e.g. **coronal loops**.



# Modeling

Theory before observations



- Straight flux tube in uniform magnetic field.
- $\xi(x) = \xi(r)e^{i(kz+m\phi)}$

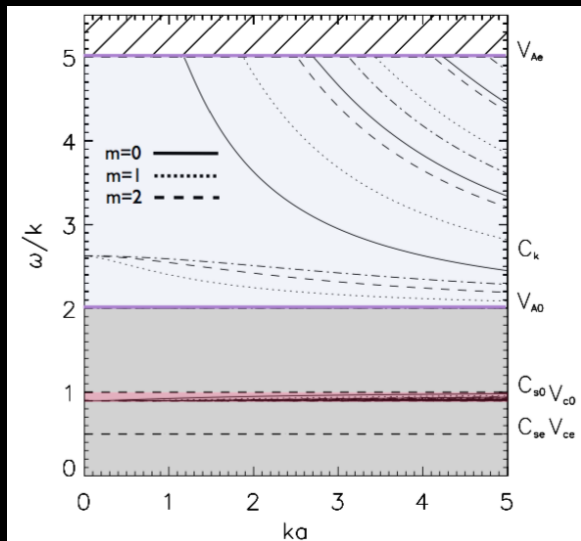
# Basic MHD

What's the difference?

Characteristic speeds are determined by the environment (e.g. sound waves traveling at  $c_s = \sqrt{\frac{\gamma P}{\rho}}$ ) Types of waves/oscillations:

- Alfvén:  $V_A = \frac{B}{\mu_0 \rho}$
- Magnetoacoustic:  $C_s = \sqrt{\frac{\gamma P}{\rho}}$ 
  - Fast  $C_{A_0} < C_{fast} < C_{A_e}$
  - Slow  $C_{T_0} < C_{slow} < C_{s_0}$

# Dispersion diagram



# Background

Nak, Asc, Roberts, all those common authors.

# MHD modes

## Oscillations vs. waves

Or magnetoacoustic vs. Alfvén. Or fast vs. slow.

- Fast standing oscillations
  - Kink
  - Sausage
- Slow standing oscillations
  - Acoustic
- Propagating slow waves
  - Acoustic
- Propagating fast waves
  - Moreton
  - EIT waves
- Torsional modes (aka. Alfvén waves)



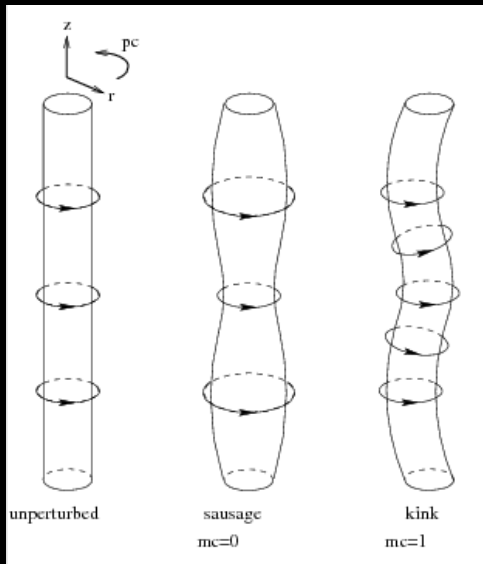
# Observational Methods

How do you know what kind of mode you're looking at, or how to find potential MHD modes in the first place?

McIntosh et al. algorithm

# Fast standing oscillations

## Kinks vs. Sausages



## Kink

- loop spatial displacement
- Asymmetric
- No intensity change
- $k\sigma \ll 1$ , or  $\sigma \ll \lambda$

## Sausage

- No loop spatial displacement
- Symmetric
- Intensity change  
→ density change

# Fast standing oscillations

## Kinks vs. Sausages

The long-wavelength limit

### Kink

- $k\sigma \ll 1$ , or  $\sigma \ll \lambda$

### Sausage

- $\lambda \sim \sigma$

# Kink modes

## general characteristics

- $c_k = \sqrt{\frac{\rho_o V_{Ao}^2 + \rho_c V_{Ac}^2}{\rho_o + \rho_c}} \approx V_A \sqrt{\frac{2}{1 + \frac{\rho_e}{\rho_o}}}$  in the low- $\beta$  plasma.
- $v_{ph} = \frac{\omega}{k} \approx C_k \gtrsim V_A$
- Period  $P = \frac{2l}{V_A} \sqrt{\frac{1 + \rho_e/\rho_o}{2}}$  where  $\lambda = 2l$  ( $l$  is the loop length).  
Typically,  $l \approx 60 - 600$  Mm in the corona.
- “current pinch” instability
- Important observation from which magnetic field strength can be derived.

# Kink modes

Coronal loop oscillations observed with the *Transition Region And Coronal Explorer (TRACE)*

- Not just a single, global mode.
- Gaussian vs. exponential
- Plasma motions around footpoints of coronal loops

# Kink modes

Excitation and damping of broadband kink waves in the solar corona

# Sausage modes

Observations of sausage modes in magnetic pores

# Sausage modes

Sausage waves in transversely nonuniform monolithic coronal tubes



# Standing acoustic oscillations

ac\_1

ac\_2

# Propagating acoustic waves

Nodes are in motion; *traveling waves* (Oscillations have fixed nodes).

pac\_1

pac\_2

# Propagating fast waves

- Moreton waves in the chromosphere
- Fast EUV waves in the corona

pfw\_1



pfw\_2

# Torsional modes

aka. Alfvén wave

tor\_1

tor\_2

# Mixed modes

Pulling individual modes out

# Important Properties

	<b>timescale</b>	<b>sizescale</b>	<b>obs. method</b>
kink osc	value	value	value
sausage osc	value	value	value
acoustic osc	value	value	value
acoustic waves	value	value	value
fast waves	value	value	value
torsional modes	value	value	value
mixed modes	value	value	value

# Example Table

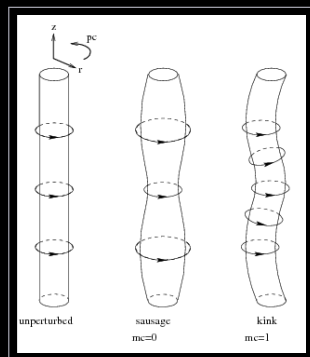
		Condition (Gold standard)	
		True	False
Test outcome	Positive	True Positive	False Positive
	Negative	False Negative	True Negative

# Example of Two Column Output

Practical T<sub>E</sub>X 2005

Practical T<sub>E</sub>X 2005

Practical T<sub>E</sub>X 2005





# My Research