Coronal Seismology

ASTR 598

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Motivation/Main Scientific Question

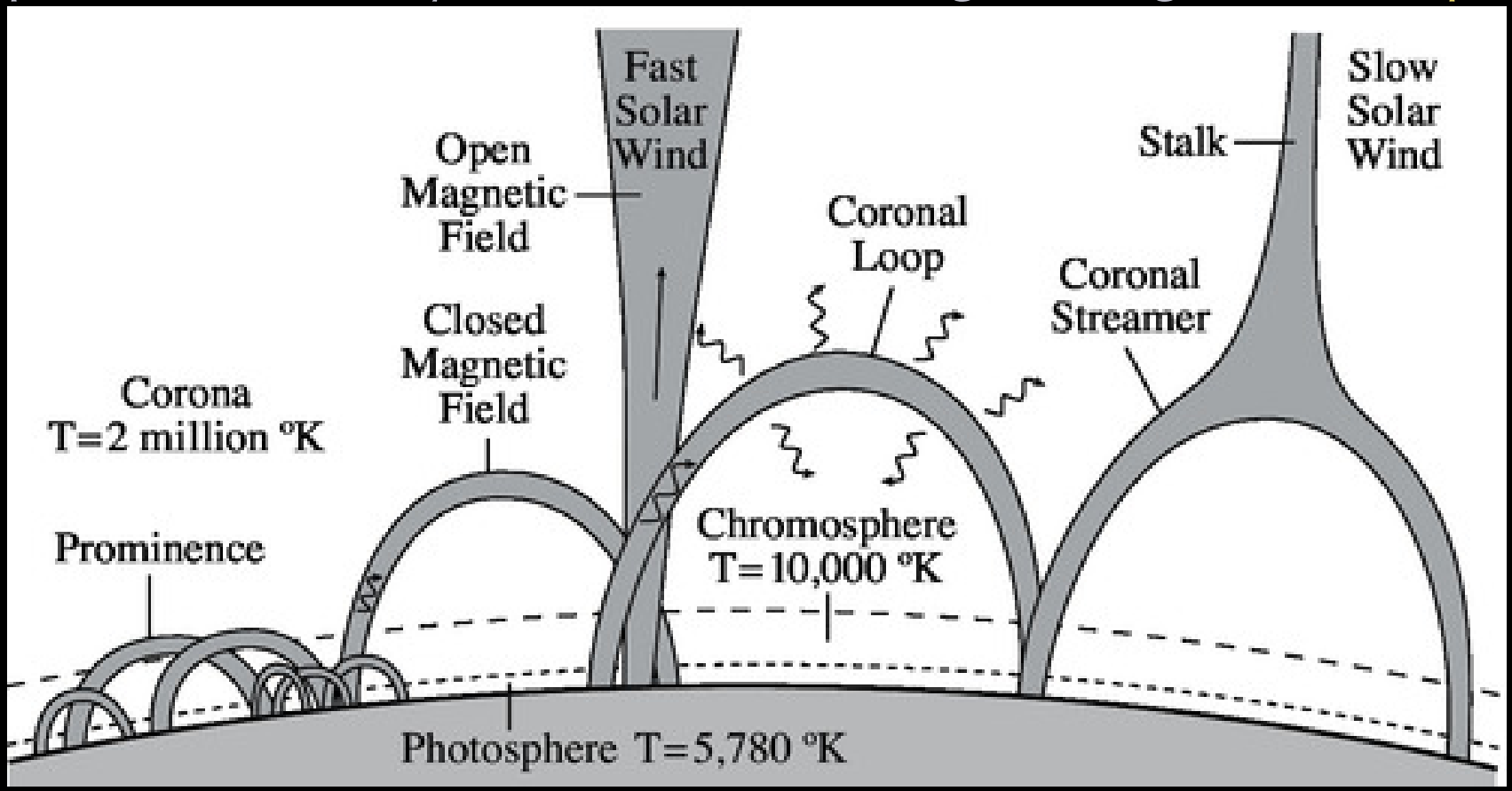
The coronal heating problem

- “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 properites that are otherwise inaccessible.

Coronal seismology

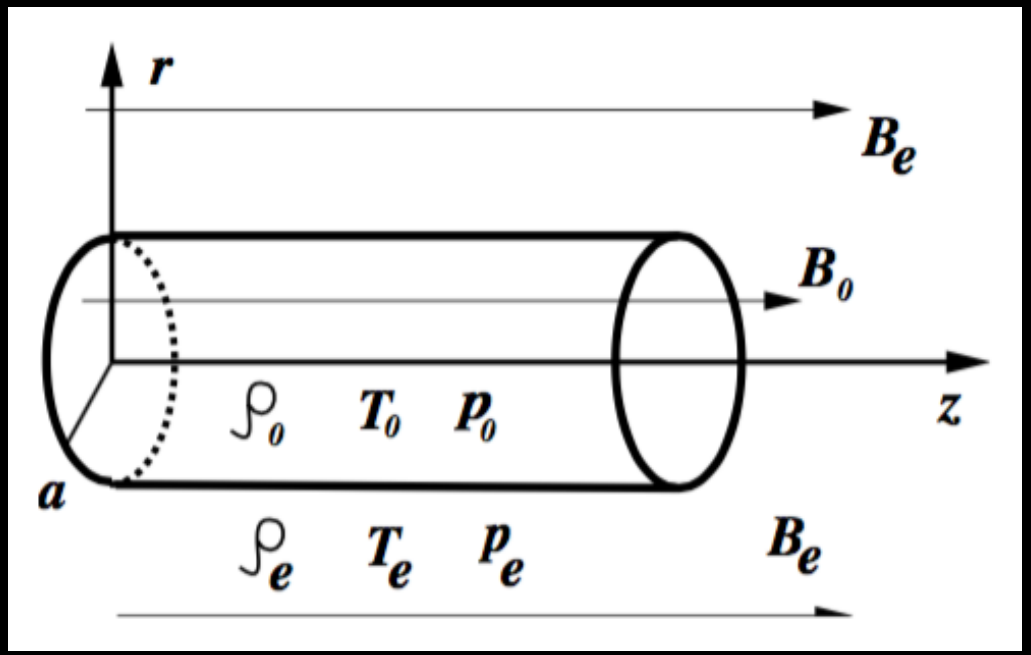
General idea

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

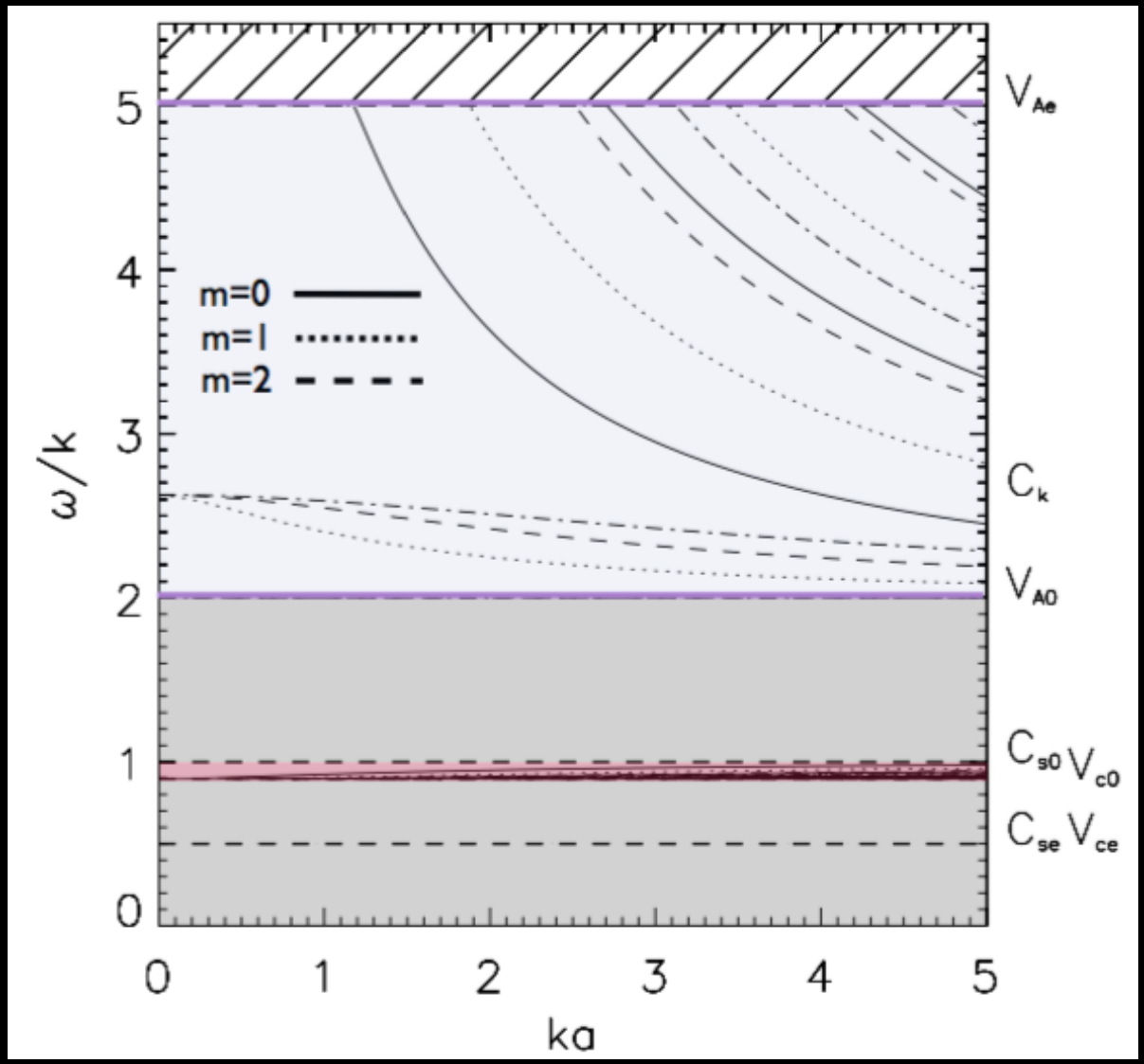
Basic MHD

What's the difference?

Characteristic speeds are determined by the environment (e.g. sounds 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)

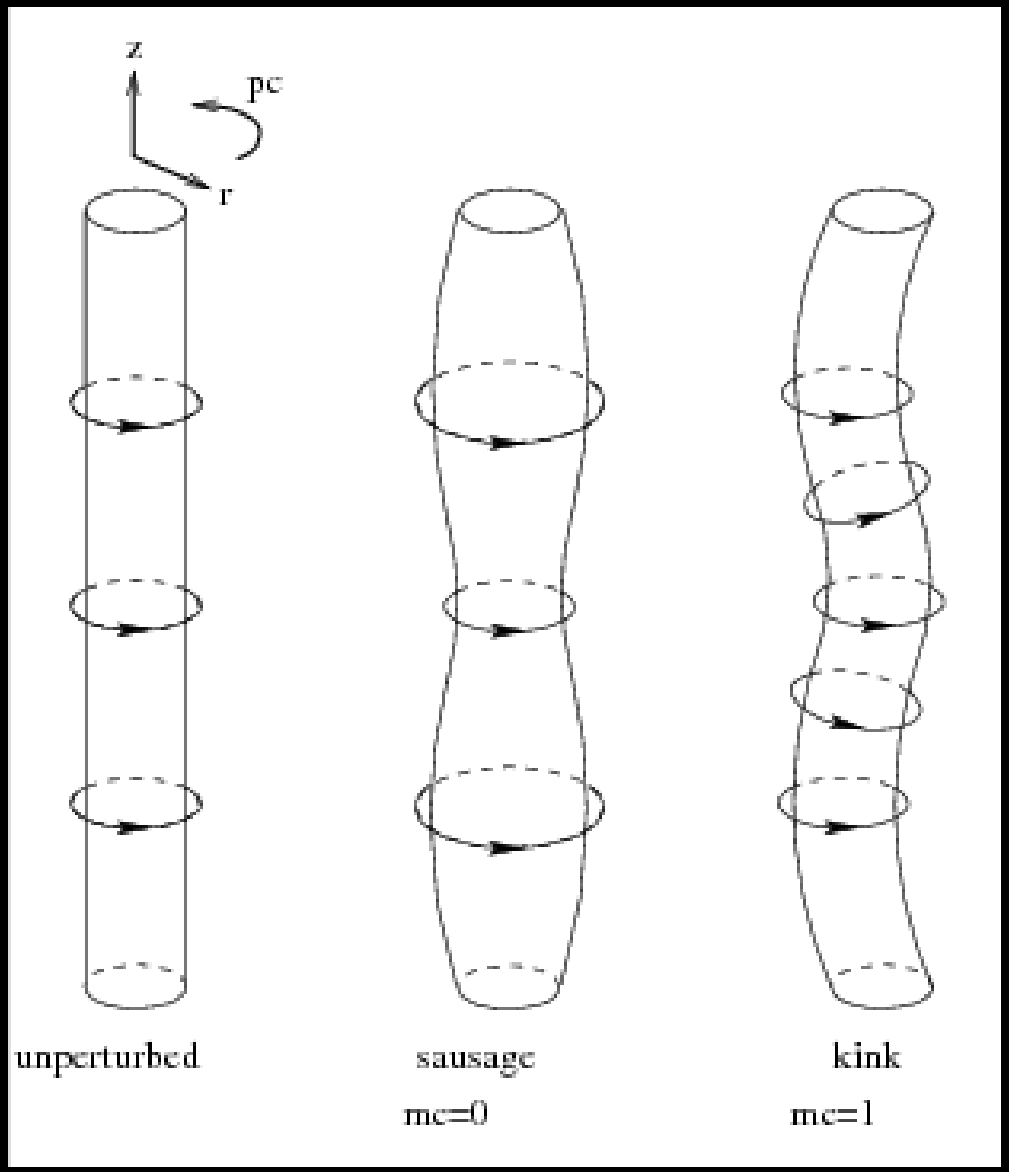
Observational Methods

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 $\rightarrow$ density change
- $\lambda \sim \sigma$

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-β 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"

Footpoint-driven, *propagating* kink waves (which are temporally and spatially ubiquitous in the corona). Both standing and propagating kink waves are rapidly damped.

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

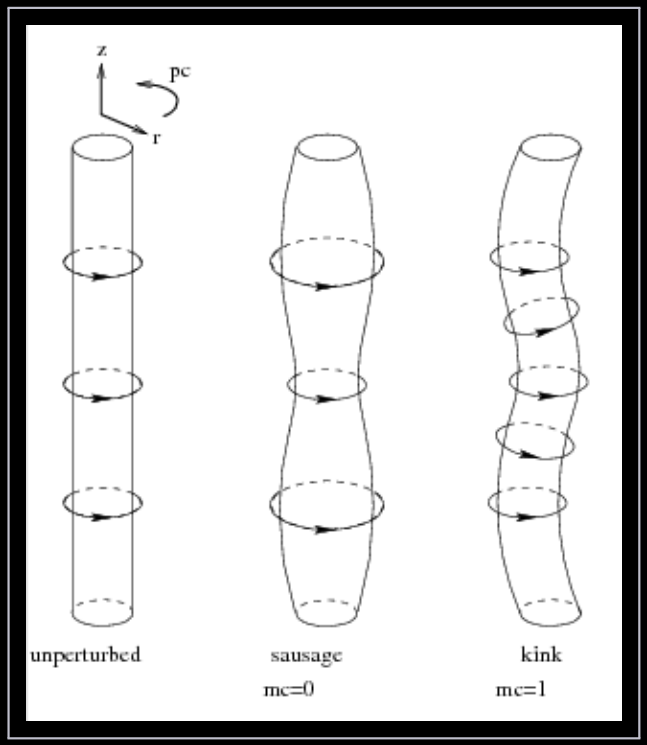
	timescale	**sizescale**	**obs. method**
kink osc	value	value	value
sausage osc	value	value	value
acoustic osc	value	value	value
acoustic waves	value	value	value
fast waves	value	value	value
torsional modes	value	value	value
mixed modes	value	value	value

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 TEX 2005
Practical TEX 2005
Practical TEX 2005



My Research