Coronal Seismology

ASTR 598

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Coronal seismology

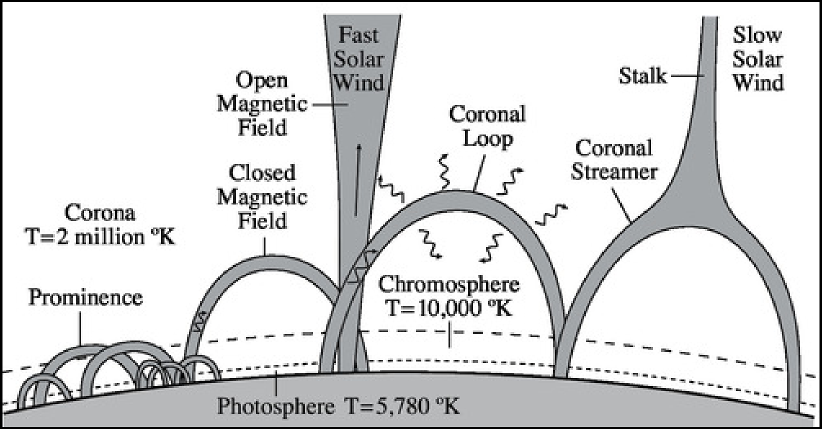
What it is: “Frozen-in” magnetic field creates density structures in the solar atmosphere, such as loops and prominences. These act as waveguides:

- Observe disturbances
- Identify the mode, or type of wave
- Insert observed properties into appropriate equations to derive coronal parameters, that are otherwise difficult or impossible to observe

Motivation:

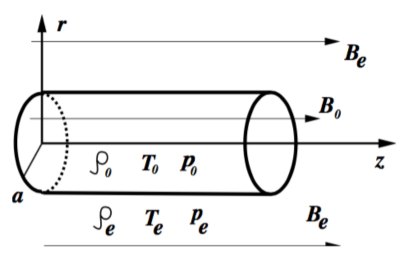
- Coronal heating problem

Coronal seismology



Magnetohydrodynamics (MHD)

Theory



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

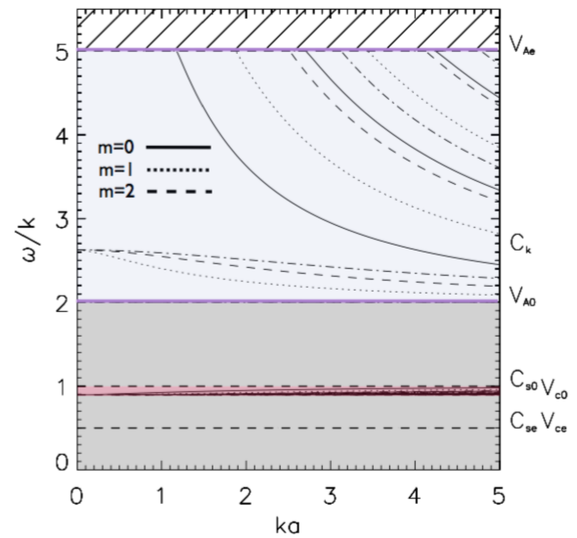
MHD

What's the difference?

[Relationship between size and decay time]. 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)

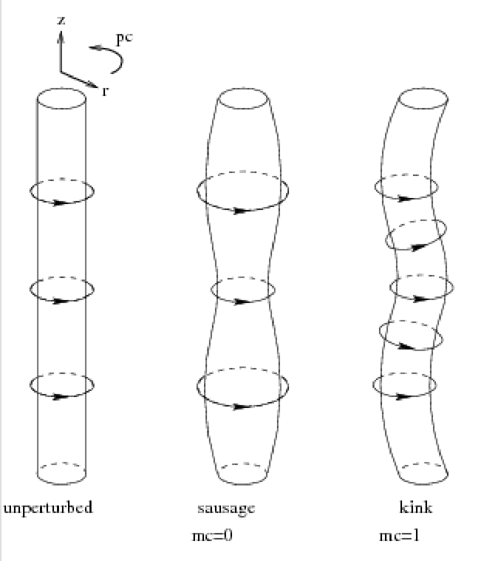
Observational Methods

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

The basics

Trapped fast modes supported by thick, dense loops because of the cutoff wavenumber (pfw_2). Observe spatially resolved radio (see sources in pfw_2).

Sausage modes

Observations of sausage modes in magnetic pores

Sausage modes

Sausage waves in transversely nonuniform monolithic coronal tubes

Standing acoustic oscillations

[Insert movie here?] Characteristics:

- Anisotropic (true in general for slow waves)
- Longitudinal/compressive
- Parallel to $\vec{B}$, perturbation of $\vec{B}$ is negligible.
- Pressure forces in opposition
- Impulsively excited
- Travel short distance (due to short decay time)
- Observed as variations in EUV emission intensity and Doppler shift (depending on orientation).
- Period = 7–31 minutes (20 minutes from another source)
- Decay times = 5.7–36.8 minutes
- Peak velocity = 200 km/sec
- Velocity and intensity are 90° out of phase.

Propagating acoustic waves

Slow

- $v_{ph} < 150$ km s^{-1} $\rightarrow$ slow
- Anisotropic
- longitudinal, compressive, acoustic
- “Essentially” parallel to $\vec{B}$
- Generated impulsively at one end of a footpoint; no time to reflect
- Travel short distance, penetrate $\sim$ 10% into loop before damped by thermal conduction
- weak dispersion in coronal conditions ($V_A \gg c_s$)
- period = 3, 5, 10 minutes? Or 2–22 seconds? (see kink_1), quasi-periodic
- 3 phases: periodic, QP, decay
- velocity: 50–200 km s^{-1}
- $c_T = \sqrt{\frac{c_s^2 v_A^2}{c_s^2 + v_A^2}}$ propagate sub-sonically at c_T, which is less that c_s
- “large” amplitude, max in top of chromosphere
- Observed using spectroscopy (intensity variations and Doppler

Propagating acoustic waves

Fast

- $v_{ph} > 150$ km s^{-1} $\rightarrow$ fast (*or* transverse standing waves).
- Quasi-isotropic
- Driven by magnetic forces + plasma pressure forces
- Compressive (magnetic sound wave)
- Speed: $c_F = \sqrt{c_s^2 + v_A^2}$
- Moreton waves in the chromosphere
- Fast EUV waves in the corona

pac_1

pac_2

pfw_1

pfw_2

Torsional modes

aka. Alfvén wave

Properties:

- m=0 (Axisymmetric, or azimuthally symmetric)
- transverse (shear) perturbations
- Parallel to $\vec{B}$
- Driving force: magnetic tensioin
- incompressible
- velocity: $v_A = \frac{B}{\mu_o \rho}$

How to observe:

- Only get Doppler shifts from *long*-period waves (> a few minutes).
- Measure additional (i.e. non-thermal) broadening of coronal emission lines; indirect way to observe short-period waves.
- Spatial variation in Doppler shift for long periods. Gyrosynchrotron emission in radio regime.

Effects of twisting:

- Coupling of various MHD modes

tor_1

tor_2

Mixed modes

Pulling individual modes out

Important Properties

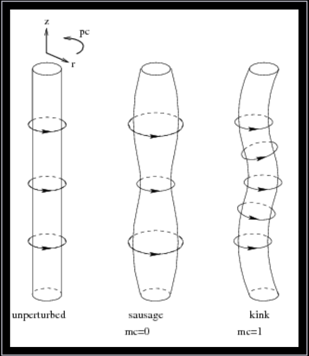
	timescale	sizescale	obs. method
kink osc	value	value	value
sausage osc	value	value	value
acoustic osc	value	value	value
acoustic waves	value	value	value
fast waves	value	value	value
torsional modes	value	value	value
mixed modes	value	value	value

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



Research