Coronal Seismology

ASTR 598

Laurel Farris

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Coronal seismology

Technique and motivation

Motivation:

- Mystery of coronal heating
- Space weather prediction

Properties of the solar corona that are difficult to measure: [why? And why do we need them?]

- magnetic field strength, $\vec{B}$
- density
- Alfvén velocity

Solution: coronal seismology

1. Observe disturbances (triggered by flares, footpoint motions, etc.) [insert eye candy here?]
2. Measure, e.g. period, velocities, timescales
3. Identify the type of wave or mode (MHD theory; stay tuned)
4. Extract coronal parameters from equations

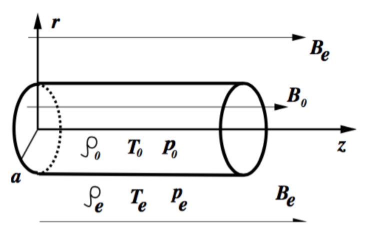
Other questions:

- How are these disturbances initiated?
- How are they damped, and what determines the timescales?

Magnetohydrodynamics (MHD)

Theory

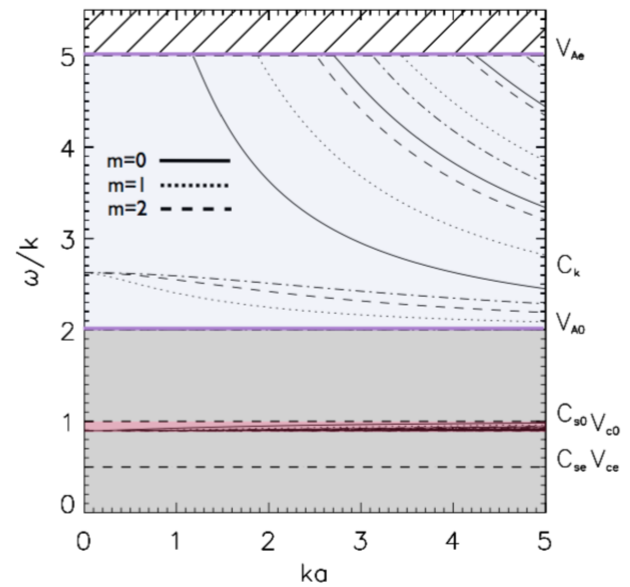
[Something about Asc, TRACE, etc.]



- Corona should support MHD oscillations
- Loop modeled by straight flux tube in uniform magnetic field.
- Characteristic speeds are determined by the environment
- Density, temperature inside loop different from outside loop
- Non-ideal effects: gravitational stratification, loop curvature, inhomogeneity in magnetic field strength (considered negligible).

Dispersion diagram

Solutions to dispersion relation



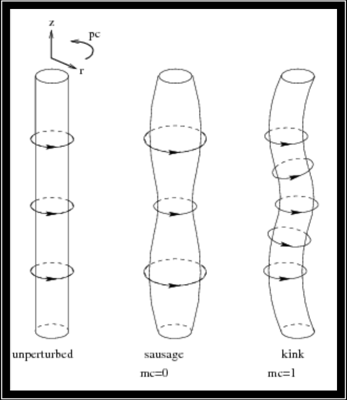
Magnetohydrodynamics (MHD)

Two mode categories

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

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
- $\lambda \sim \sigma$
- long-wavelength limit

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.
- Derive magnetic field!
- Not just a single, global mode.
- Plasma motions around footpoints of coronal loops
- 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).

Standing acoustic oscillations

[Insert movie here?] Characteristics:

- Pressure forces in opposition
- Period $=$ 7–31 minutes (20 minutes from another source)
- Decay times $=$ 5.7–36.8 minutes
- Peak velocity $=$ 200 km/sec

Standing oscillations vs. propagating waves

- In loops, propagating waves damp before reaching opposite footpoint.
- Velocity and intensity are 90° out of phase for standing oscillations, and are in phase for propagating acoustic waves.
- Frequencies less than the cutoff are standing oscillations, waves with frequency greater than the cutoff propagate into the chromosphere.
- no loop shape change or displacement
- near footpoints.

Propagating acoustic waves

Slow

- $v_{ph} < 150$ km s^{-1} $\rightarrow$ slow
- longitudinal, compressive, anisotropic
- Parallel to $\vec{B}$, perturbation of $\vec{B}$ is negligible.
- Generated impulsively at one end of a footpoint.
- Only penetrate $\sim$ 10% into loop before damped by thermal conduction
- weak dispersion in coronal conditions ($V_A \gg c_s$)
- 3 phases: periodic, QP, decay
- period = 3, 5, 10 minutes? Or 2–22 seconds? (see kink_1),
- 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 than c_s
- "large" amplitude, max in top of chromosphere
- Observed using spectroscopy (intensity variations in EUV emission and Doppler shifts)

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

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: $v_A = \frac{B}{\mu_o \rho}$; ~ 1000 km s^{-1} in the corona

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

Important Properties

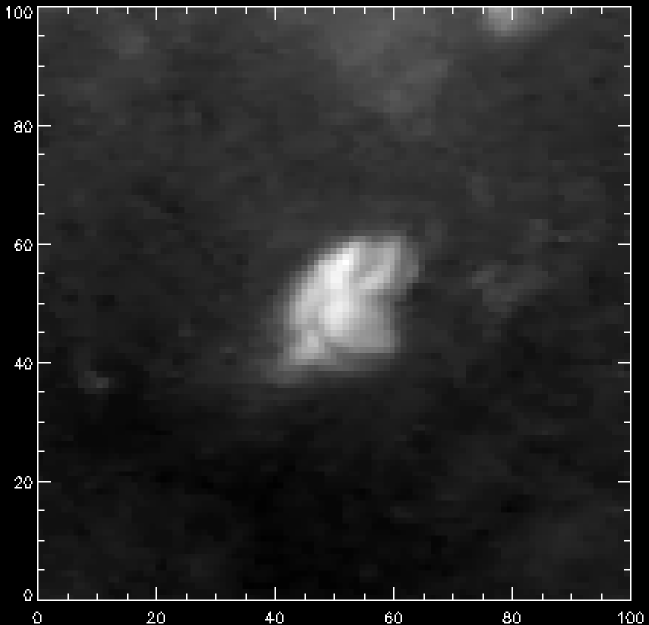
	period	**wavelength**	**velocity**
kink osc	value	value	value
sausage osc	value	value	value
acoustic osc	value	value	value
acoustic waves	value	value	value
fast waves	value	value	value
torsional modes	10 m	value	1000 km s^{-1}

Research

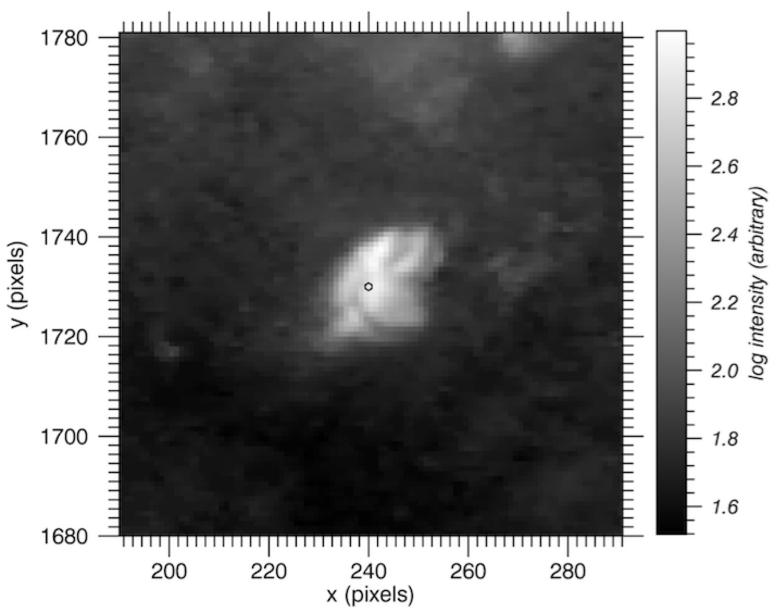
AIA/SDO

Research

[Looks nicer than white background]



Research



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x (pixels)
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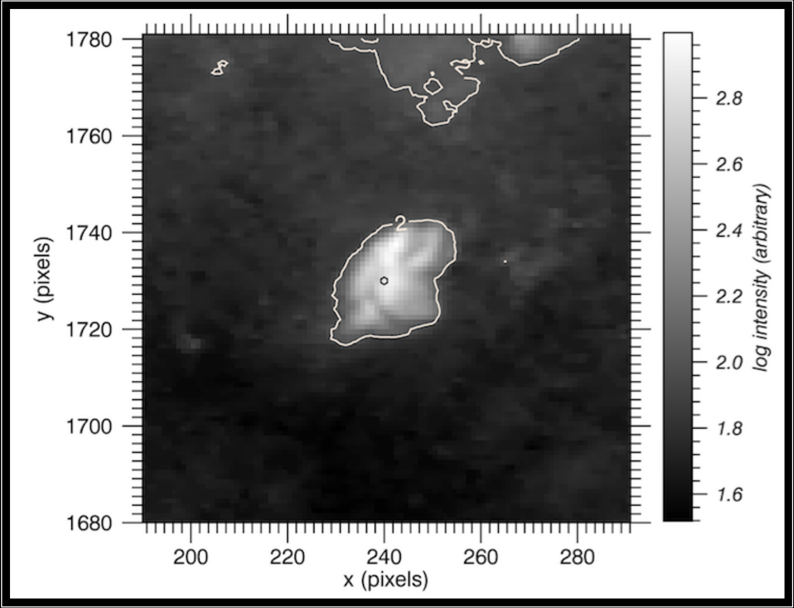
1.6
log intensity (arbitrary)

Research



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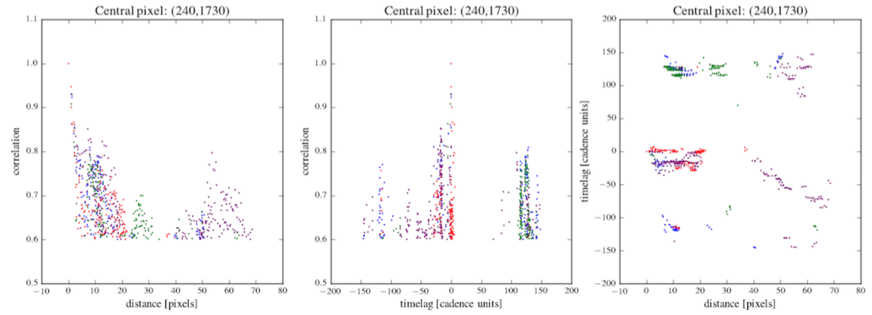
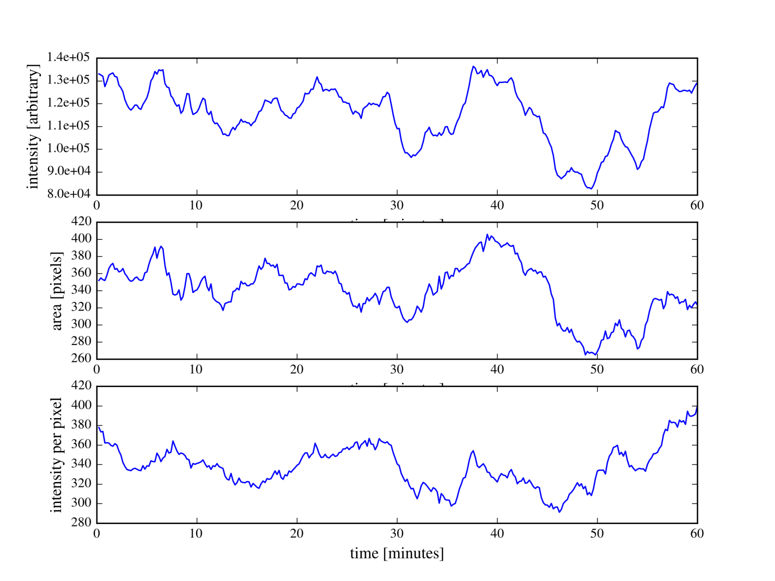
log intensity (arbitrary)

Research



Central pixel: (240,1730)
correlation
distance [pixels]
Central pixel: (240,1730)
correlation
timelag [cadence units]
Central pixel: (240,1730)
timelag [cadence units]
distance [pixels]

Research



intensity [arbitrary]
1.4e+05
1.3e+05
1.2e+05
1.1e+05
1.0e+05
9.0e+04
8.0e+04
0 10 20 30 40 50 60
area [pixels]
420 400 380 360 340 320 300 280 260
0 10 20 30 40 50 60
intensity per pixel
420 400 380 360 340 320 300 280
0 10 20 30 40 50 60
time [minutes]

Acknowledgements