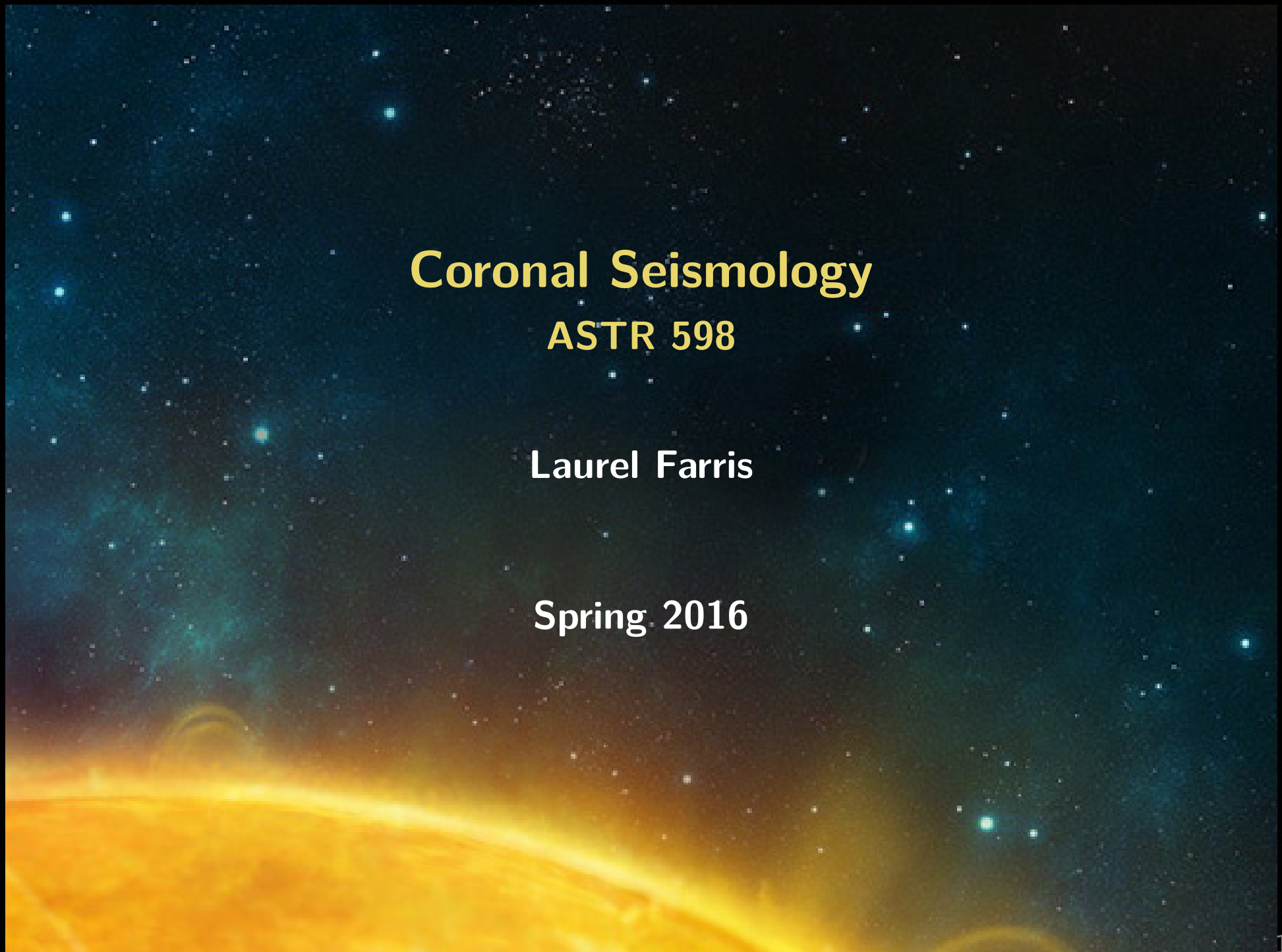
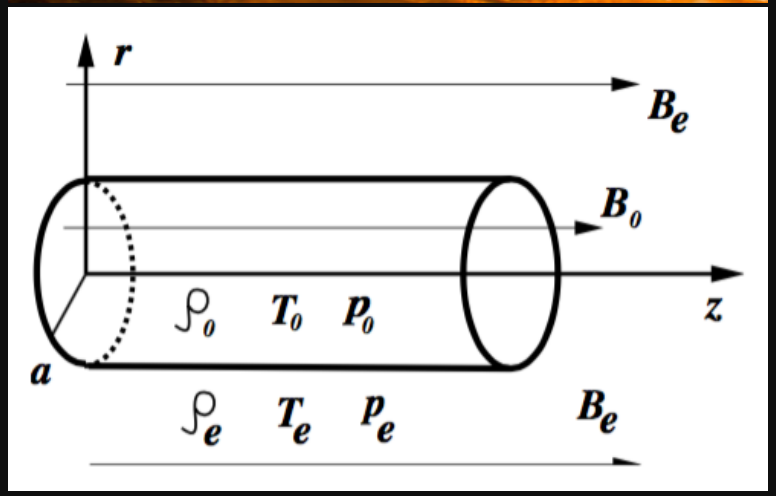

Coronal Seismology
ASTR 598
Laurel Farris
Spring 2016

Magnetohydrodynamics (MHD)

Theory



Model

- Straight cylindrical flux tube in uniform magnetic field.
- Equations of "ideal" MHD
- Characteristic wave speeds are determined by ρ, T, P, and $\vec{B}$

Sound speed

- $C_s \propto \sqrt{\frac{P}{\rho}}$
  $\propto \sqrt{T}$

Alfvén speed

- $V_A \propto \frac{B}{\sqrt{\rho}}$

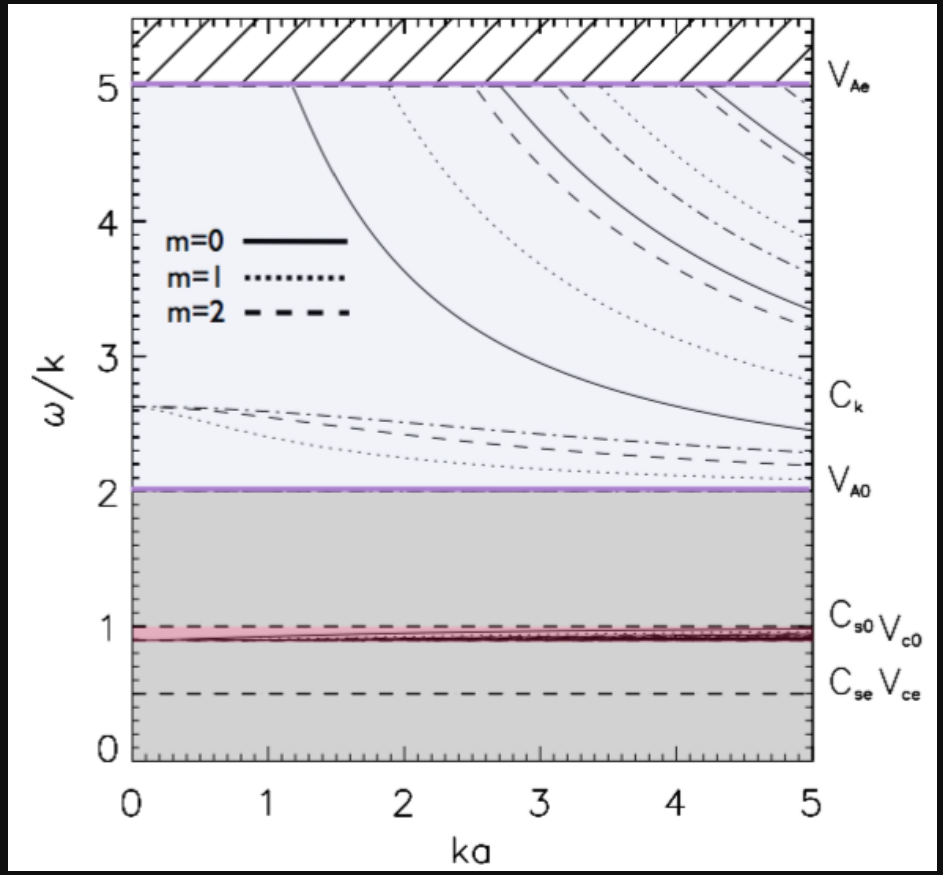
MHD modes in the solar corona

Main categories

- Magnetoacoustic
  - Fast
  - Slow
- Alfvén

Research Topics

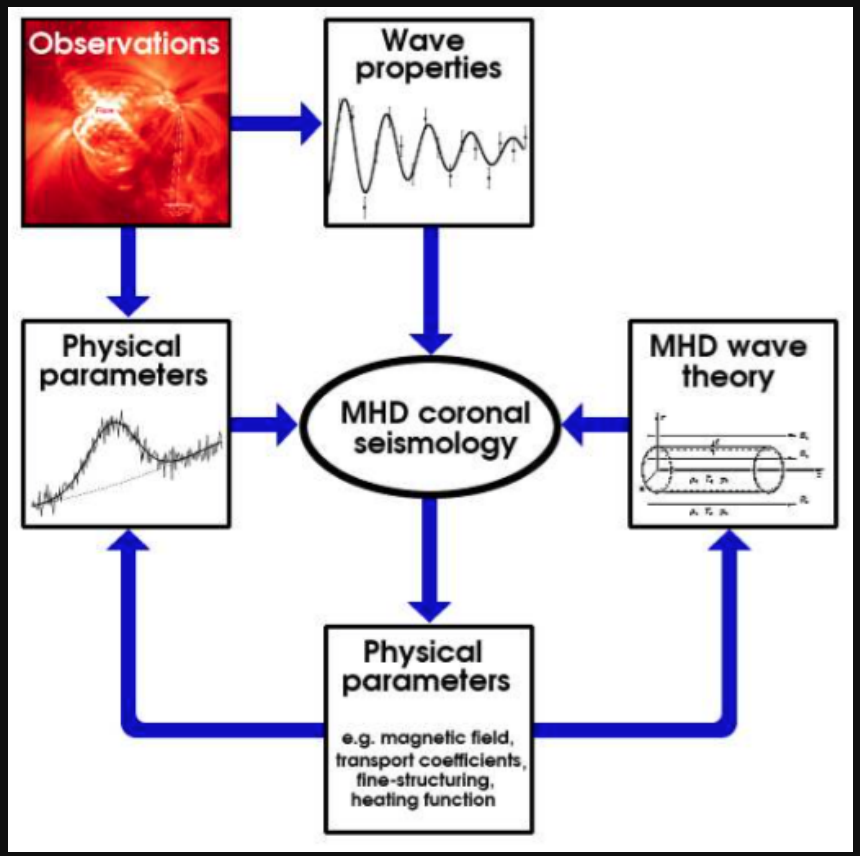
1. Kink oscillations
2. Sausage oscillations
3. Acoustic oscillations
4. Propagating acoustic waves
5. Propagating fast waves
6. Torsional (Alfvén) modes



- $C_k = V_A \sqrt{\frac{2}{1+\rho_e/\rho_o}}$
- $\xi(x) = \xi(r) e^{i(kz+m\phi)}$

Coronal seismology

Technique and motivation



Elusive coronal properties

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

Motivation

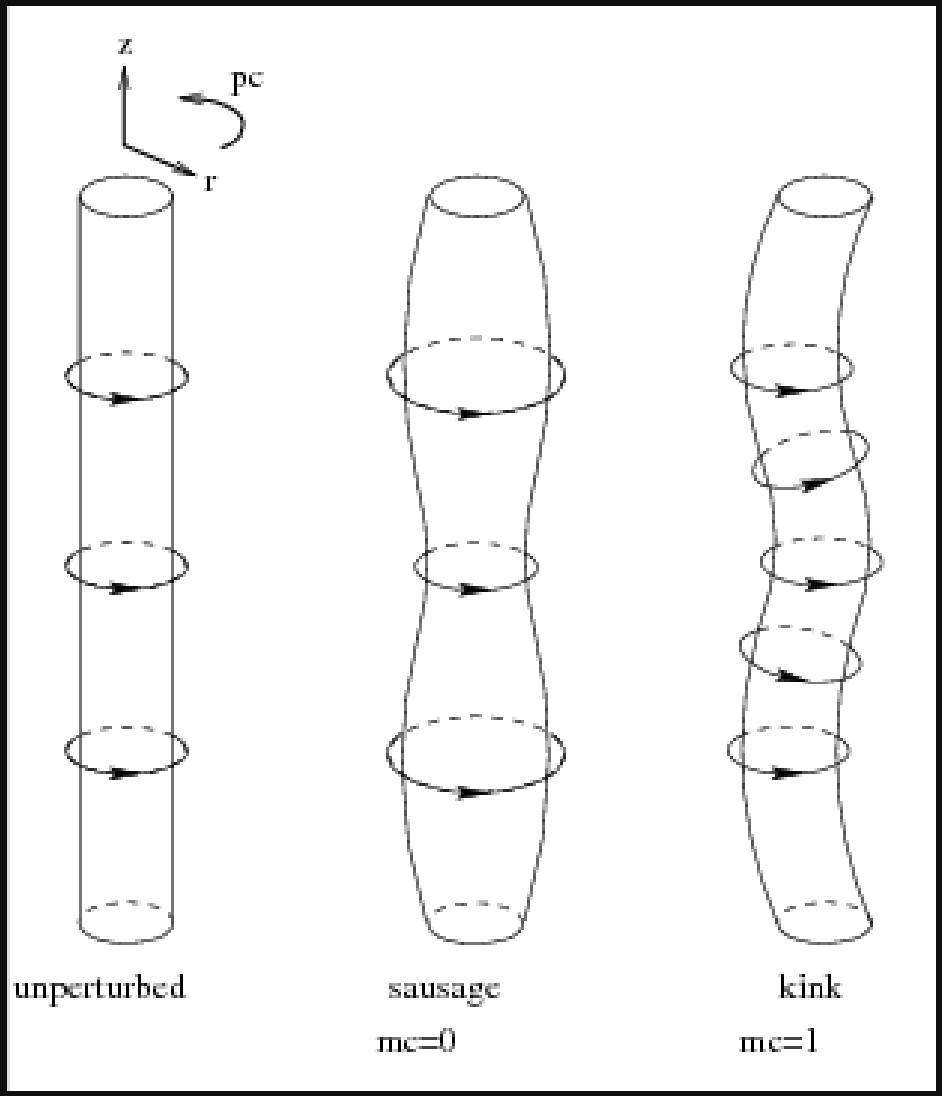
- Coronal heating
- Space weather prediction

Coronal seismology

1. Observe disturbances
2. Measure physical parameters
3. Identify wave properties
4. Extract physical parameters

Fast standing oscillations

Kinks vs. Sausages



Period

- $P = \frac{2\ell}{V_{ph}}$ $(\lambda = 2\ell)$

Sausage

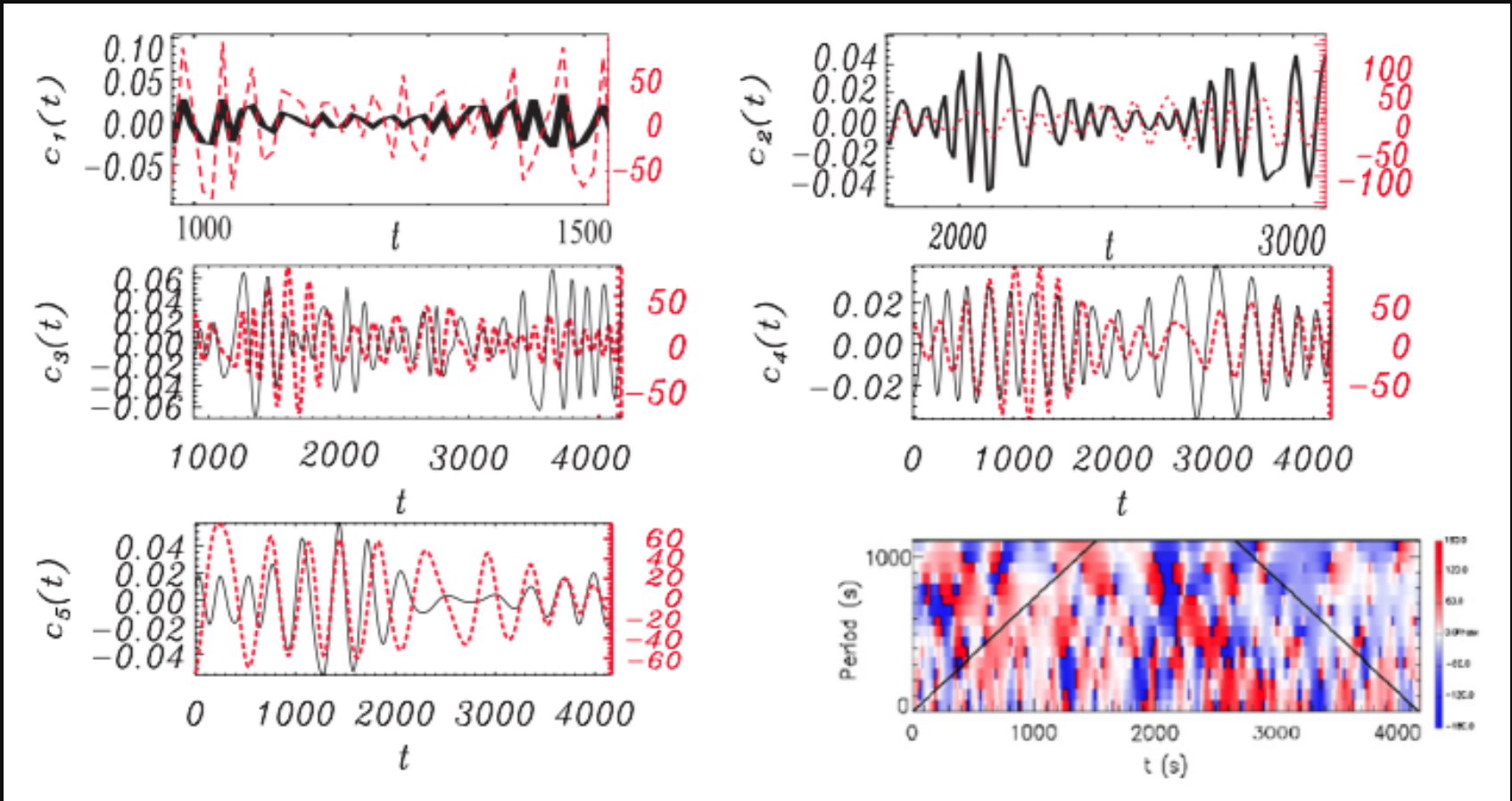
- No loop spatial displacement
- Symmetric
- Intensity change
  $\rightarrow$ density change

Kink

- loop spatial displacement
- Asymmetric
- No intensity change

“Observations of sausage modes in magnetic pores”

Morton et al. 2011



- Periods $\sim$ 30-450 seconds (0.5-7.5 minutes)
- Possibly driven by 5-minute acoustic oscillations

Acoustic waves

A. K. Srivastava and B. N. Dwivedi

Observed

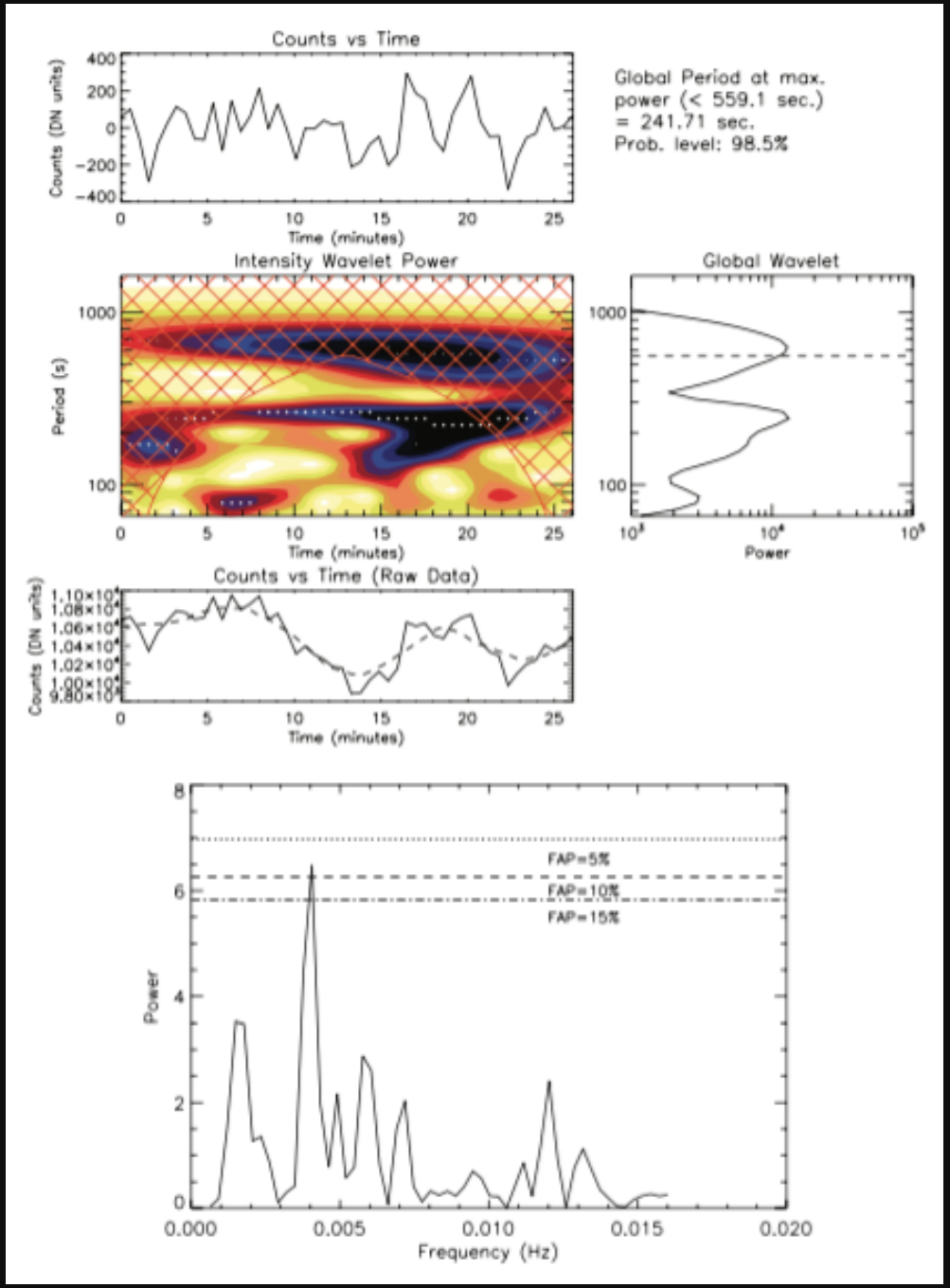
- Time series of a bright point (BP) in solar atmosphere

Measured Periods

- He II 256 Å; P$\sim$ 263 s
- Fe XII 195 Å
- Fe XV 284 Å; P$\sim$ 241 s

Identified

- Acoustic oscillations leaking into the inner corona



Alfvén waves

General properties

Properties

- transverse (shear) perturbations
- Parallel to $\vec{B}$
- Driving force: magnetic tension
- incompressible (no twisting)
- $V_A = \dfrac{B}{\sqrt{\mu_o \rho}} \approx 1000 \text{ km s}^{-1}$

How to observe

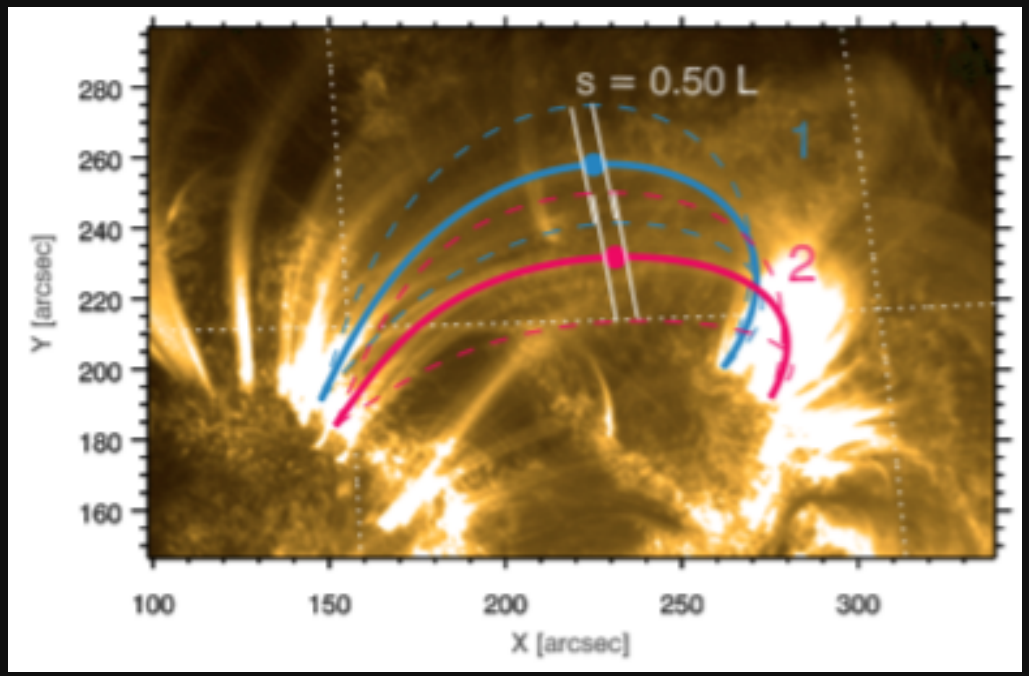
- Doppler shifts from *long*-period waves ($>$ a few minutes) reveal spatial variation; Gyrosynchrotron emission in radio regime.
- non-thermal broadening of coronal emission lines; indirect way to observe short-period waves.

Effects of twisting

- Coupling of various MHD modes

Alfvén waves

Verwichte et al.



Objective

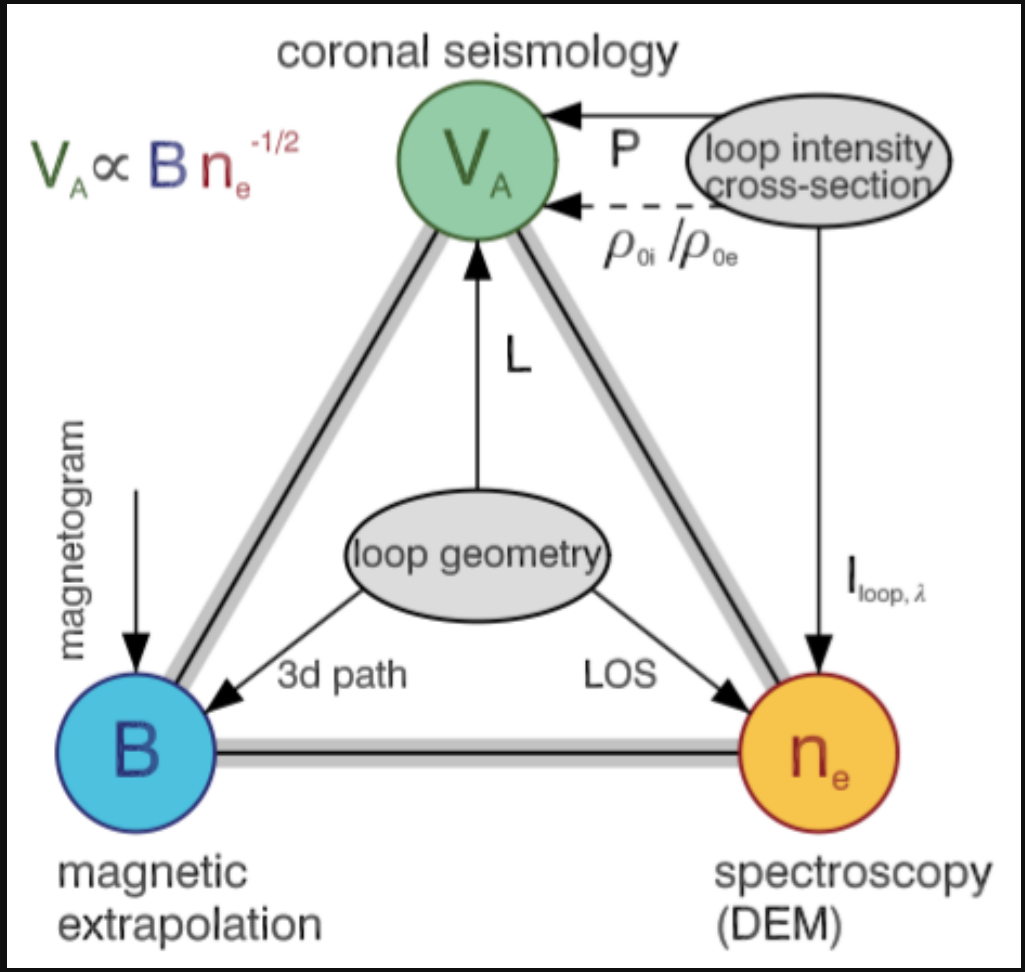
- Determine Alfvén speed in two ways:
  1. Coronal seismology
  2. Magnetic extrapolation and spectral methods

Observed

- Two transversely oscillating loops triggered by flare
- AIA/SDO 171 Å

Alfvén waves

Verwichte et al.



"The determination of the Alfvén speed from the observed phase speed lies at the heart of the seismological method. . . "

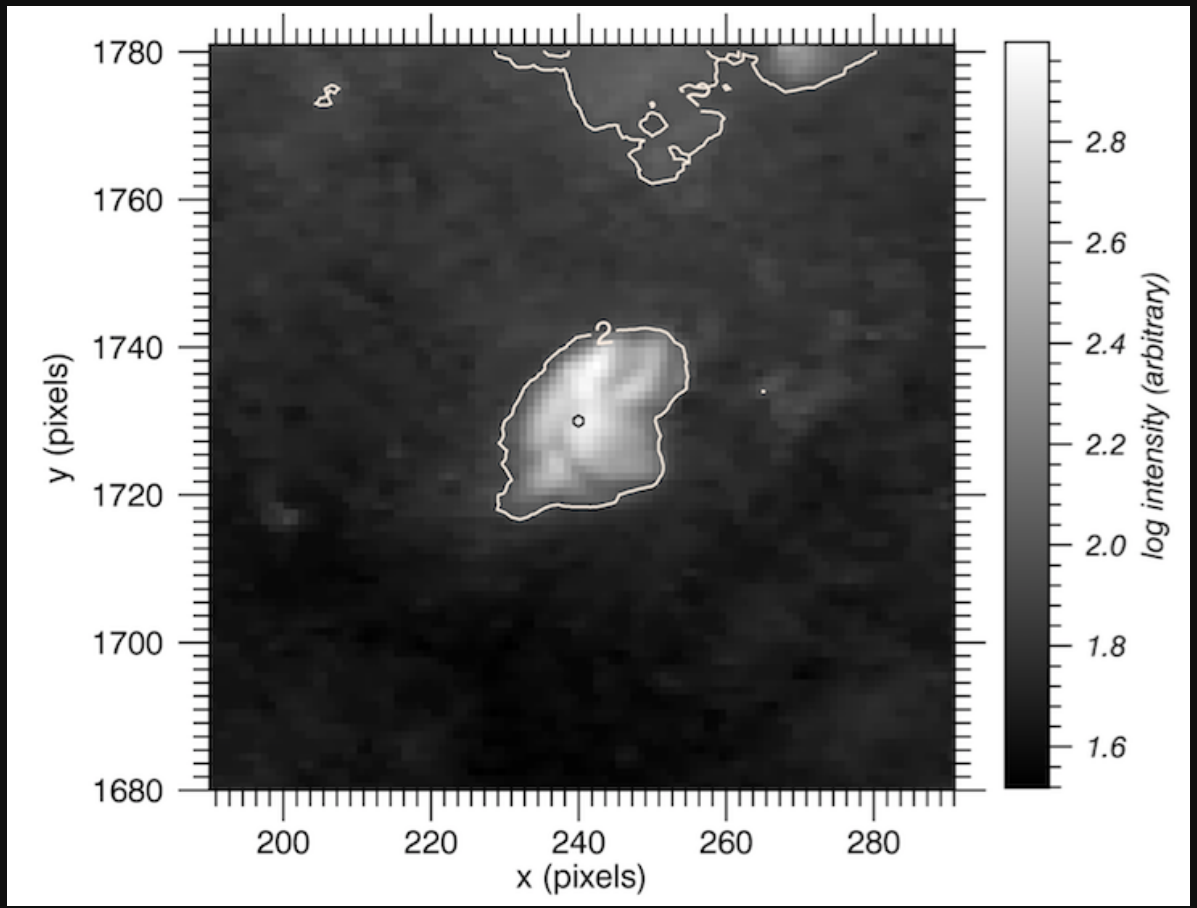
Research

AIA/*SDO*

Fe XII, XXIV
193 Å

Research

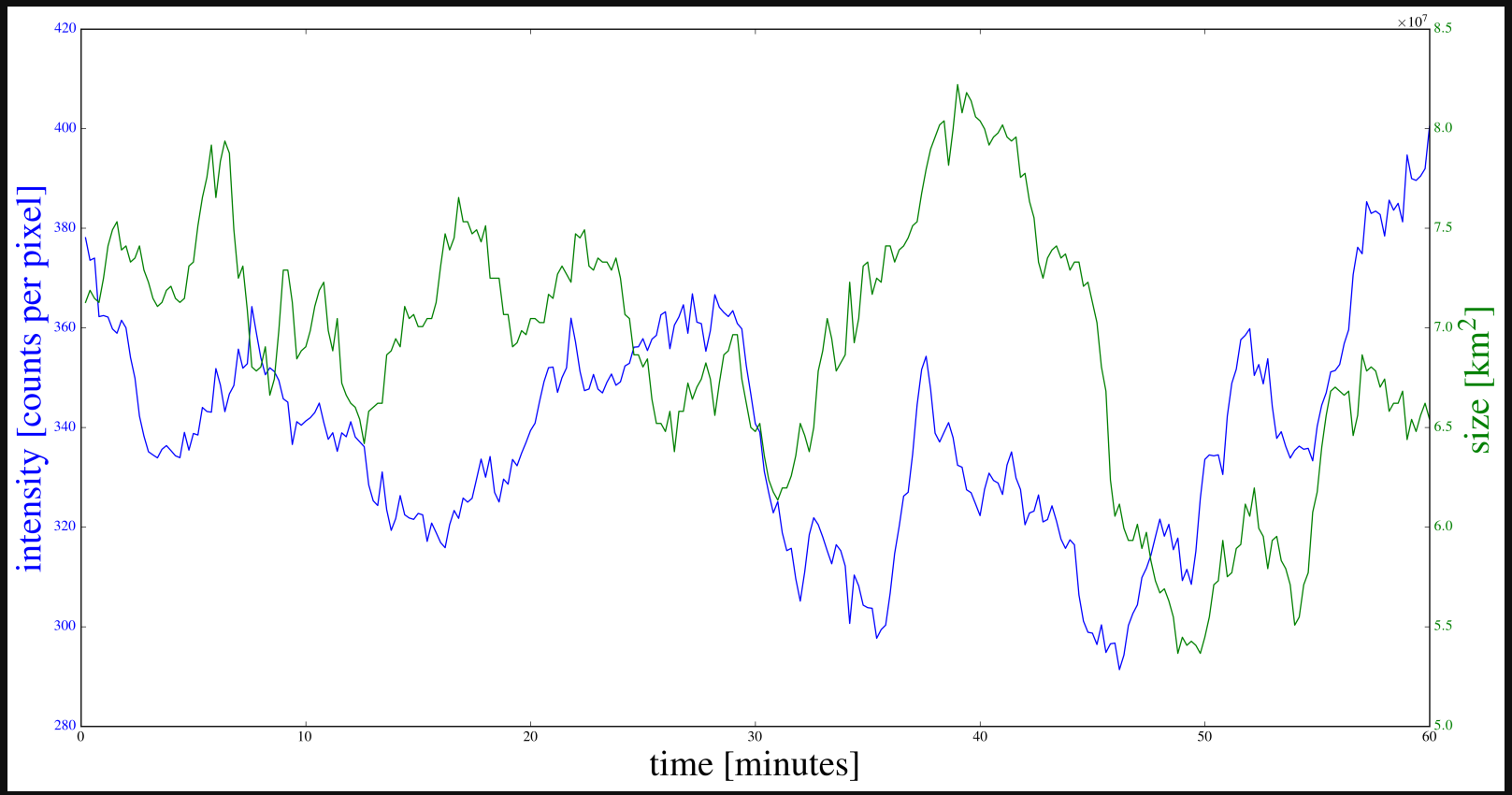
Bright point (BP)



- Image:
  $\sim$ 45000 km across
- Bright point:
  $\sim$ 9000 km across

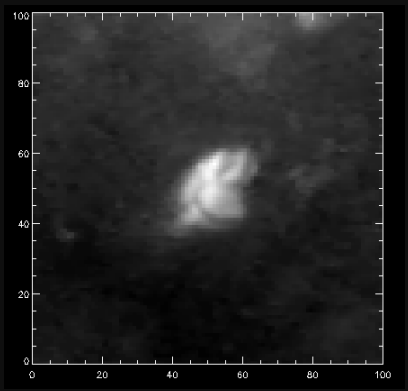
Research

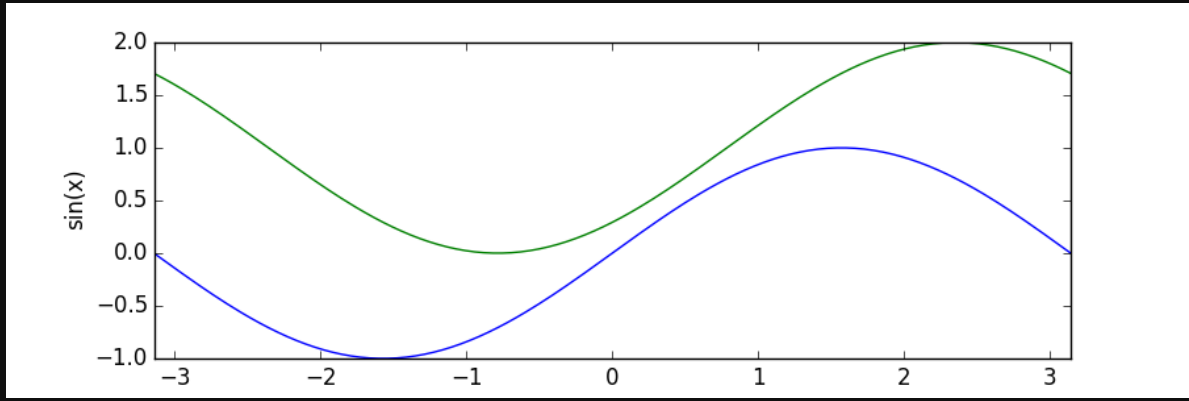
Plots

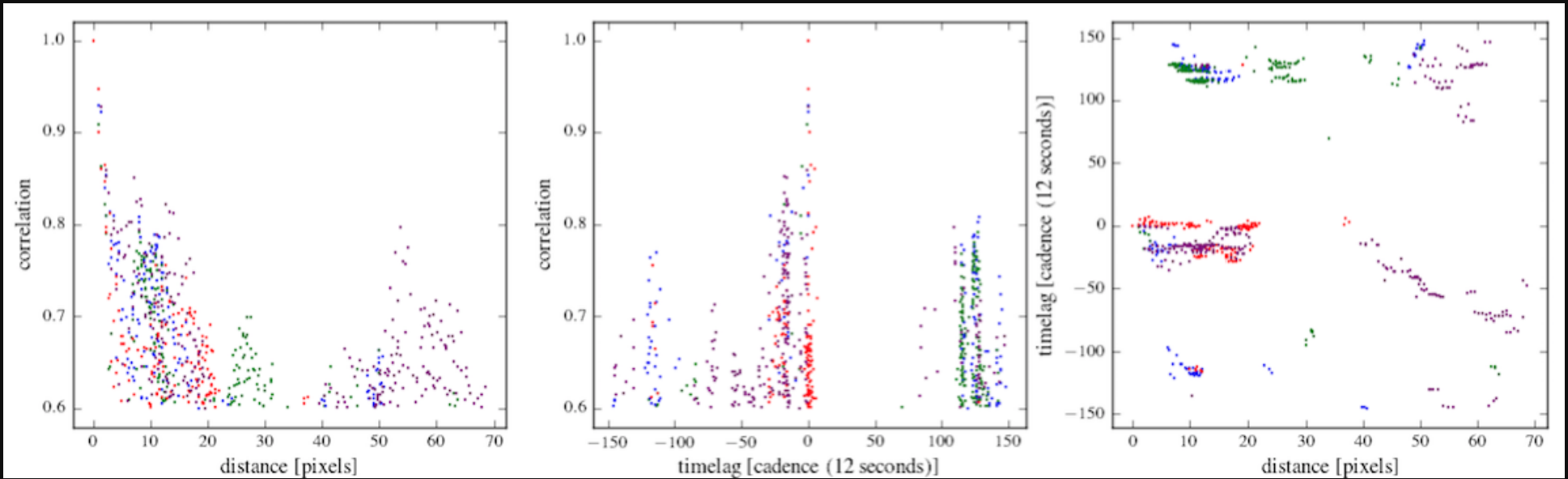


Research

Cross-correlations



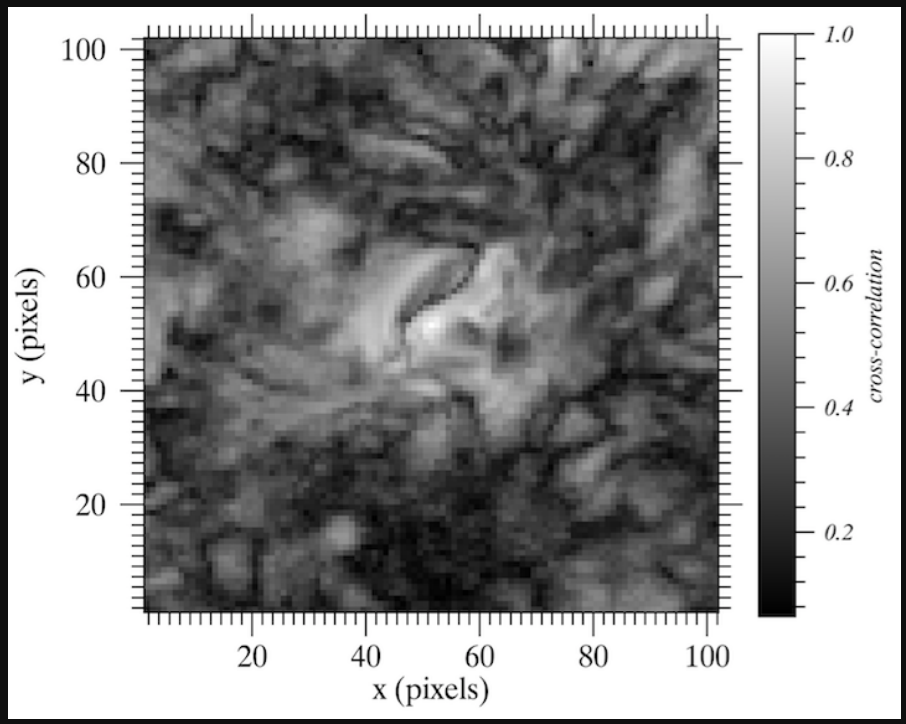




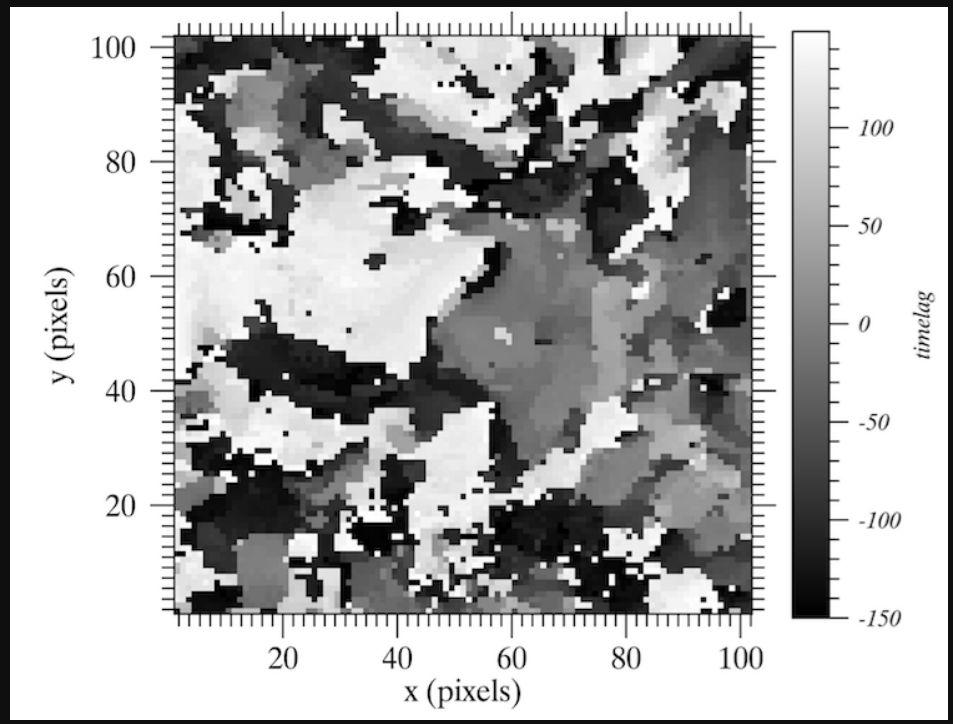
Research

Cross-correlation & timelag images

Cross-correlation



Timelag



2 pixels $\sim$ 1 arcsec $\sim$ 700 km

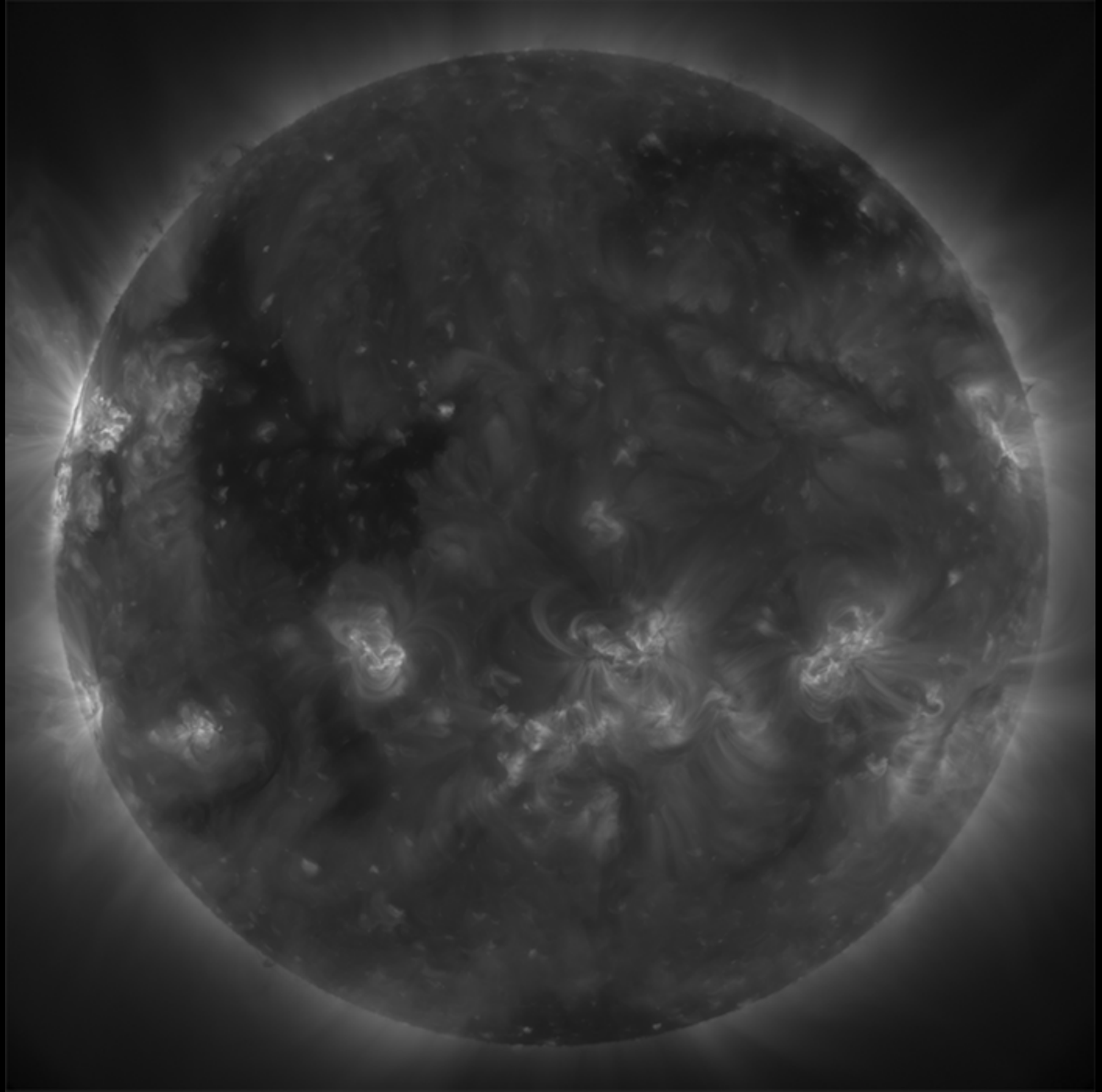
Other questions and future work

Other questions

- What is the excitation mechanism for the observed disturbances?
- How are they damped, and what determines the timescales?

My future work

- Download data in other wavelengths (i.e. coronal heights).
- Download data from other instruments, e.g. the Extreme Ultraviolet Variability Experiment (EVE) on SDO.
- Characterize other bright points in coronal hole, quiet sun, and active regions.



Acknowledgements

Advisor: James McAteer

Extra slides here