# Helioseismology at different wavelengths using HMI and AIA

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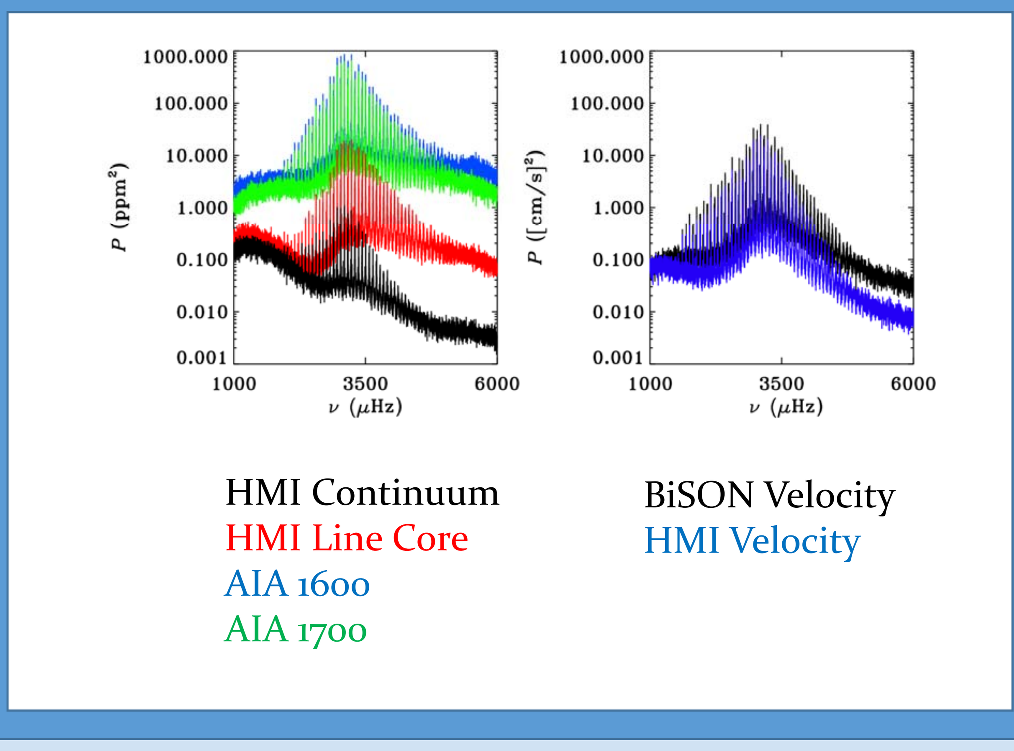
## Introduction

The high-cadence UV observations from the Atmospheric Imaging Assembly onboard the Solar Dynamics Observatory, along with the multiple observables available from the Helioseismic and Magnetic Imager, offer the possibility of helioseismology at multiple heights in the atmosphere. Here we show some results from analysis using integrated-light time series derived from the observations.

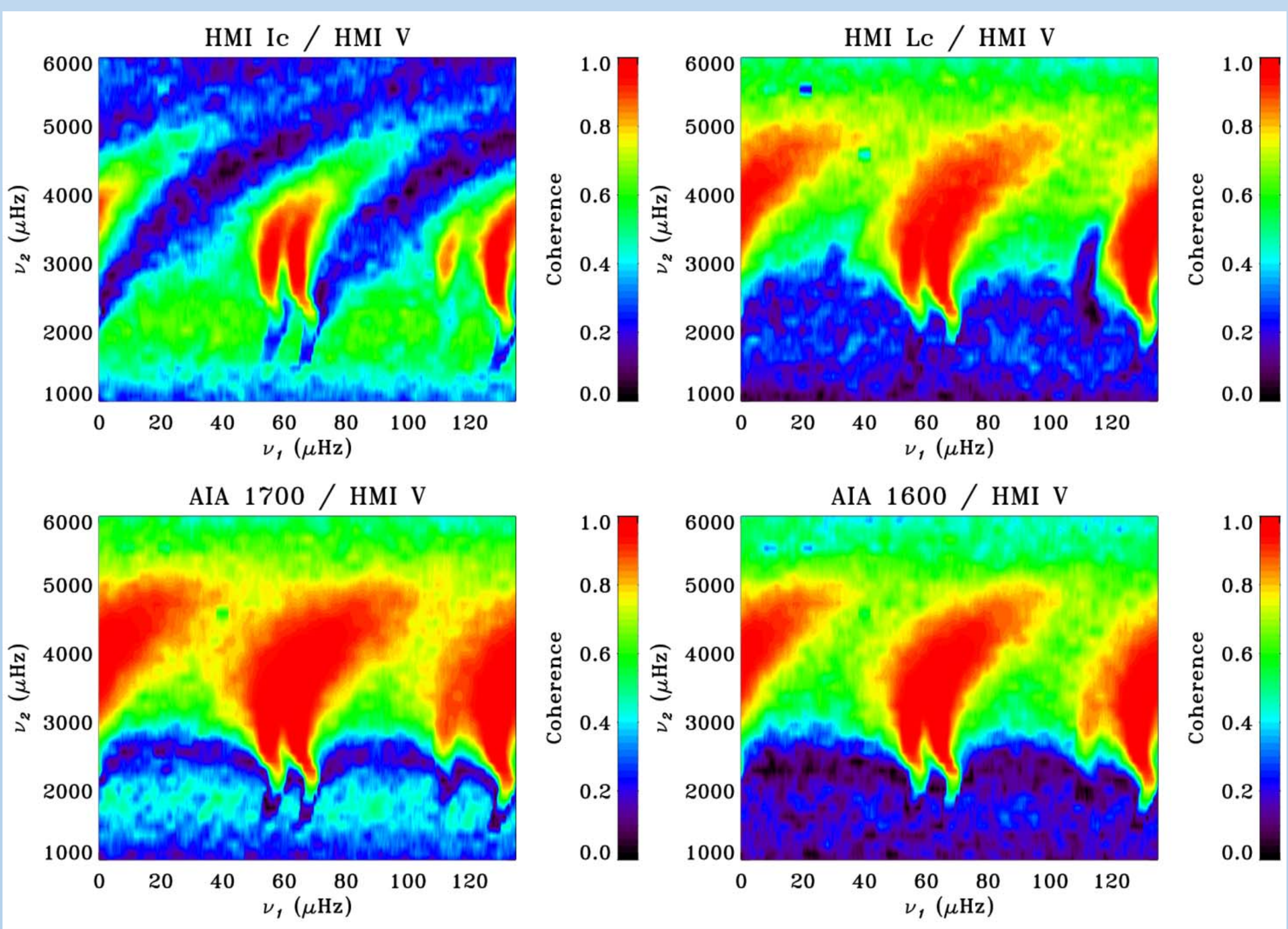
## Data

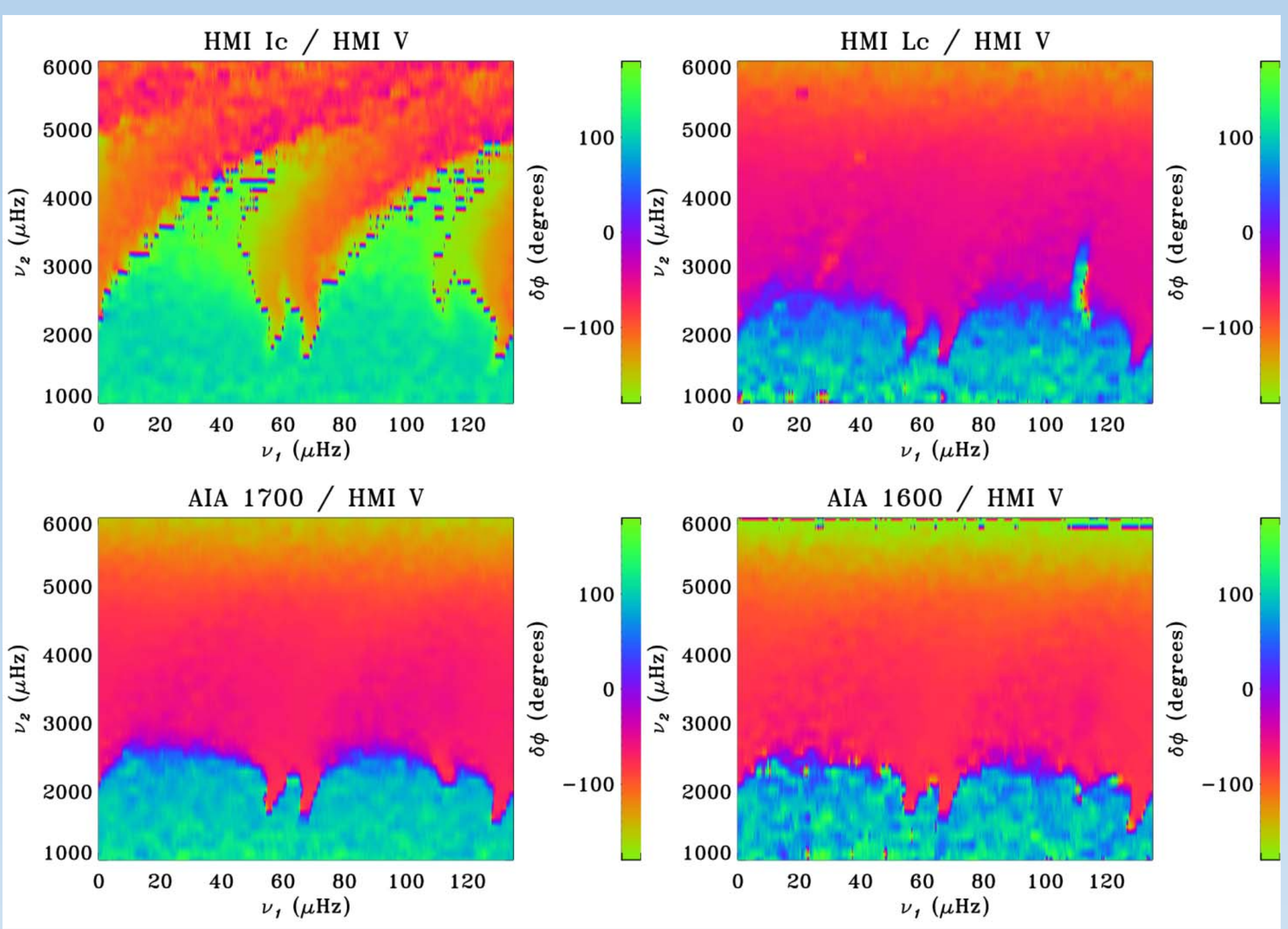
We consider the HMI Doppler velocity (formed approximately 100 km above the solar surface), the HMI Continuum intensity (20 km), the HMI Line Core intensity (270 km), and the AIA 1700 (360 km) and 1600 Å (480 km) UV bands. Each time series is formed from the DATAMEAN keyword attached to each image, detrended to remove daily variations and interpolated to a uniform 45s cadence. All show a clear five-minute spectrum.




## Phase and Coherence

Below we show the coherence (a frequency-dependent correlation measure) and phase difference for each of the other observables relative to the Doppler velocity in échelle format, where each row is a 135-microHz section of the spectrum corresponding roughly to one radial order. The spectra are strongly correlated in the five-minute band, especially in the modes but also between them for the higher-formed observables, while the lower coherence at low frequencies corresponds to granulation noise. The V/Ic phase difference shows the familiar modulation across the modes, but there is little phase modulation in the five-minute band for the higher observables, where the main feature is a sharp phase change at the upper boundary of the granulation regime.



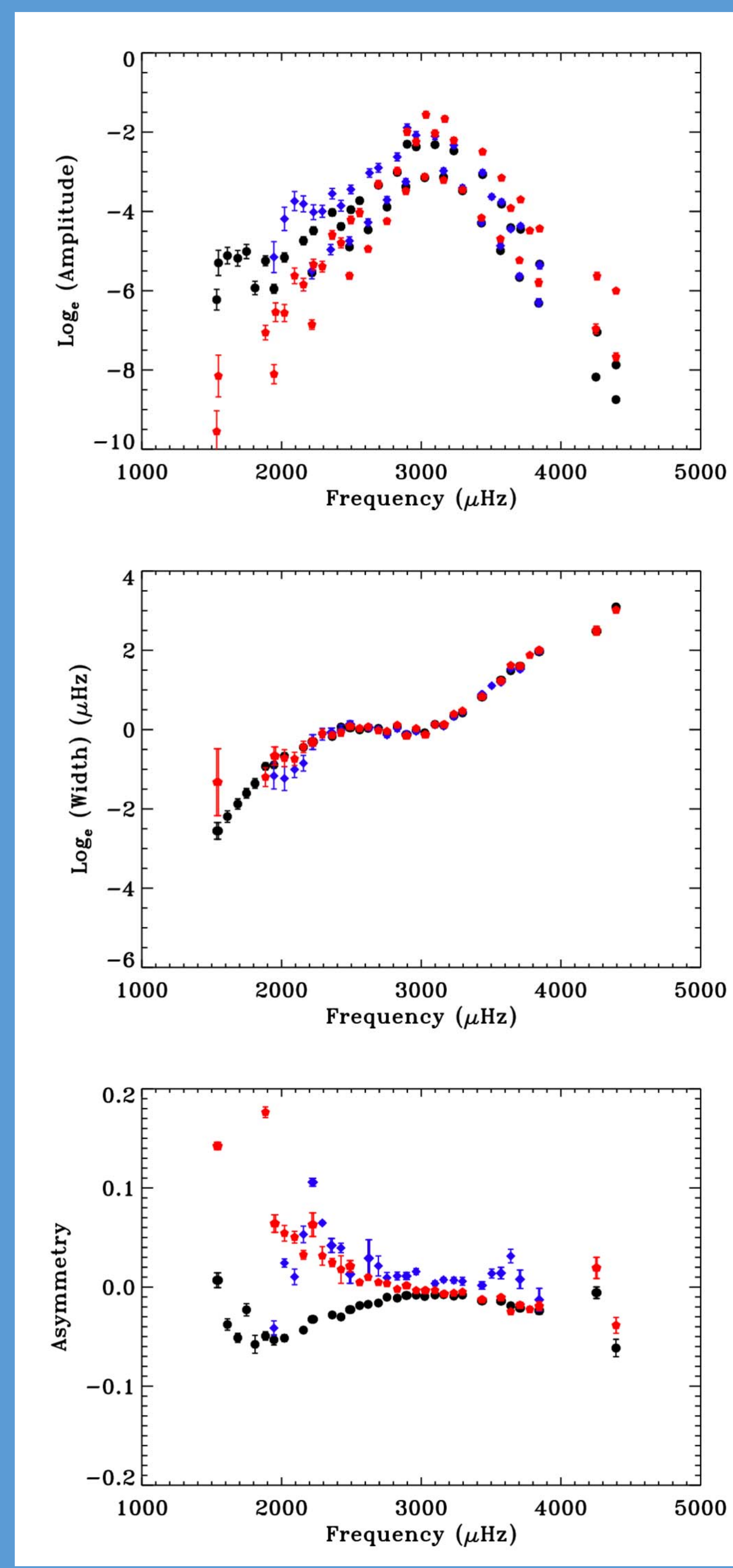

## Mode Fitting

We fit the four-year Sun-as-a-star spectrum using a simple MLE code that fits modes as asymmetric peaks in *l*=0,2 and *l*=1,3 pairs. On the right we show the amplitude (top, in arbitrary units normalized to the same scale for all observables), line width, and line asymmetry parameter as a function of frequency, for HMI V (black), HMI Ic (blue), and AIA 1700 (red).

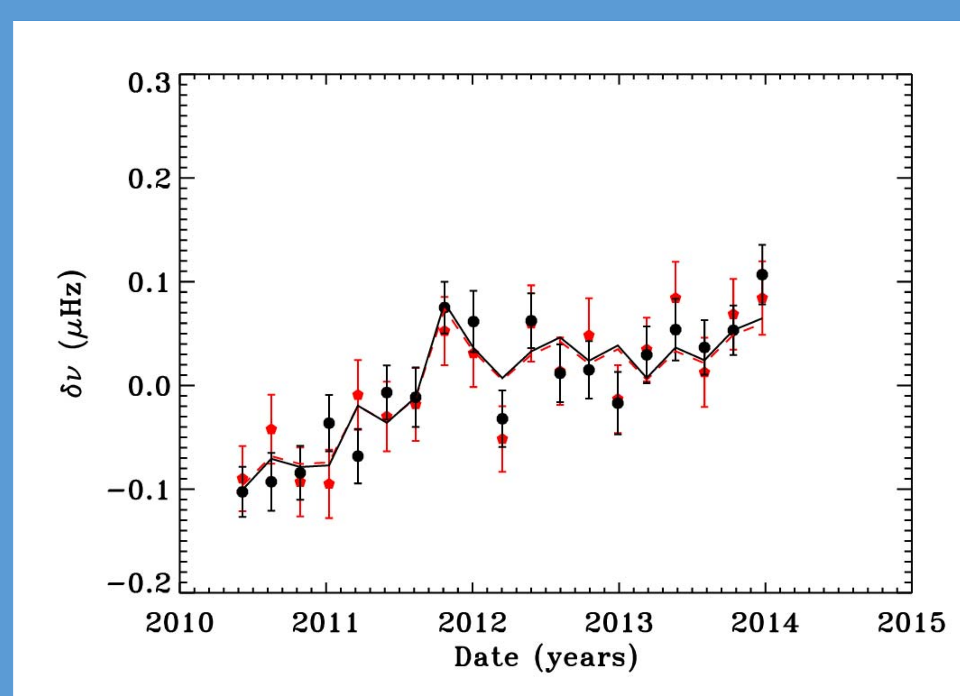
Most of the `scatter' in the amplitude measurements comes from the different sensitivities of the different observables to the modes with *l*>0. The fits at the lower-frequency end of spectrum are less reliable for HMI Ic due to the granulation noise.

With the exception of a few lower-frequency modes in Ic, the agreement in the width determinations is very good.

As expected, below the frequency of maximum power the asymmetry parameter is negative for velocity and positive for the intensity observables. Interestingly, the high-frequency asymmetry for the UV measurement follows that for the velocity in trending negative, perhaps because the line is formed high enough in the atmosphere to avoid granulation effects that would influence the peak asymmetry.

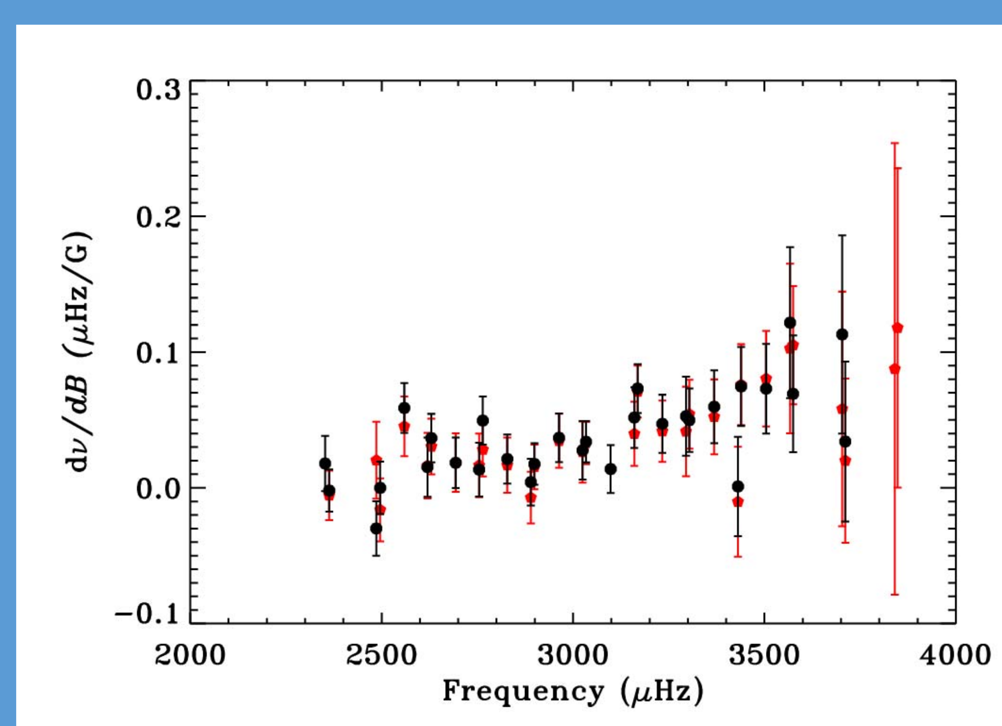



## Solar-Cycle Frequency Changes




The time series were divided into 19 72-day segments and mode parameters were determined for each segment. We then considered the frequency shift for each mode relative to the mean frequency of that mode. The frequency shifts averaged over all *l*=0, 1, and 2 modes that are common to all the segments are plotted (left) as a function of time for HMI V (black) and AIA 1700 (red). The lines represent the global unsigned magnetic field, scaled for the best linear fit to the frequency shifts. The sensitivity of 0.028±0.004 μHz/G is consistent with other work; the relatively small overall shift compared to those seen in earlier cycles reflect the weaker magnetic activity in the current cycle.

Finally, we plot (right) the frequency change per Gauss of activity for each mode. We see the well-known upward trend with frequency, and there is good agreement between the Doppler and UV intensity results. This agreement strengthens the supposition that the mode shift are intrinsic to the modes and not an artefact of the interaction of surface fields with the spectral line used for the helioseismic observations.




## Acknowledgments

I thank the National Solar Observatory for computing support, and Yvonne Elsworth and Bill Chaplin for useful discussions. SDO data courtesy SDO (NASA) and the AIA and HMI consortia.

## Further Reading

For more on multi-awavelength helioseismology, see for example:

R. Howe et al., 2012 Solar Phys. 281, 533
S.C. Tripathy, et al.: 2013, Journal of Physics Conference Series 440, 012026.