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Analysis of Long Solar Oscillation Time Series

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The observations of global solar oscillations by the SOHO-MDI and the GONG instruments cover more than 10 years. Thus, long time series of observations are now available which should afford the investigation of physical processes in the solar interior, e.g. deep flows, that have small effects on solar oscillations. We analyze and discuss the sensitivity of modern approaches of time series analysis to detect such effects from long solar oscillation time series.

Investigation of Long Solar Oscillation Time Series

Analysis of instantaneous amplitude and frequency

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Introduction

Long solar oscillation time series contain information on various time scales. Over long observation periods characteristic changes of amplitude and frequency content are expected [1]. We investigated the properties of the envelope and the instantaneous frequency to analyze the time behaviour of global solar oscillations.

Methods

The envelope and instanteneous frequency of a time series x(t) can be obtained by its complex expansion

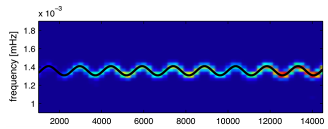
$$z(t) = x(t) + \mathrm{i}y(t) = a(t)e^{\mathrm{i}\phi(t)}$$

by means of the Hilbert Transformation from $a(t)$, and $\omega(t) = \dot{\phi}(t)$.

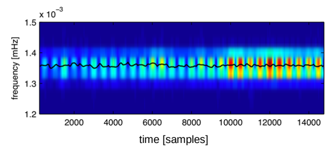
For non-bandpass signals we define a Mean Instantaneous Frequency (MIF)

$$\overline{\omega}(\tau) = \frac{\sum_\omega \omega S_x(\tau,\omega)}{\sum_\omega S_x(\tau,\omega)}$$

weighted with the energy distribution $S_x(\tau,\omega)$ over time and frequency of x(t). For $S_x(\tau,\omega)$ we used the Fourier spectrogram.



Example 1: The spectrogram and estimated MIF (black line) of a stochastically driven damped oscillator with periodically varying eigenfrequency. The modulation of the eigenfrequency is well presented by the MIF estimate.



Example 2: The spectrogram and estimated MIF (black line) of a stochastically driven damped oscillator with periodically modulated amplitude. The amplitude modulation also cause slight modulations of the estimated MIF.

Application to global solar oscillations

We investigated data from SOHO/MDI with an observation period of one year.

The Fourier Spectrogram was estimated from global solar oscillations with *l*=80, *m*=0. For each radial order *n* present in the spectrogram, the MIF (Fig. 1, black lines) and the spectrum of the MIF was computed (Fig. 2).

Figure 1 Spectrogram and MIFs for each radial order *n*

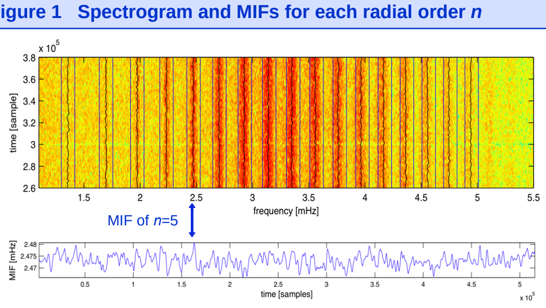
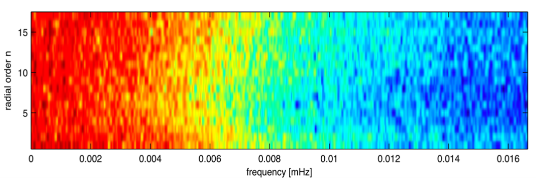


Figure 2 Spectra of the MIFs in dependence on radial order *n*



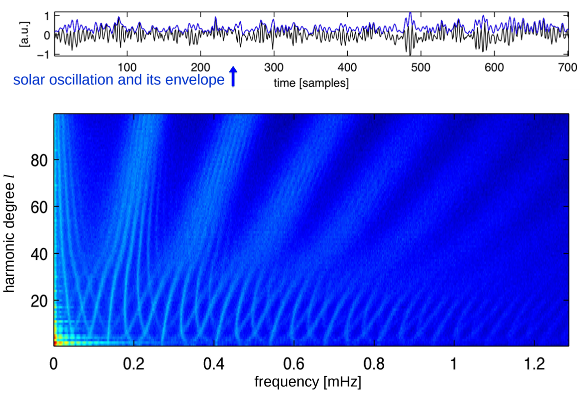
> The spectra have a large contribution in the low frequency range. This is due to the usage of overlapping sliding windows for the computation of the Fourier Spectrogram, which has a low pass filtering effect.
A characteristic slow modulation of the instantaneous frequencies is not observerable for the analyzed data.

The envelope of a signal containing several oscillating components is affected by

- > changes of the excitation power of the driving sources
- > couplings between oscillation modes (energy transfer)
- > beating

For each mode *l*=0,…,99 with *m*=0, the envelope and spectrum of the envelope was estimated (Fig. 3).

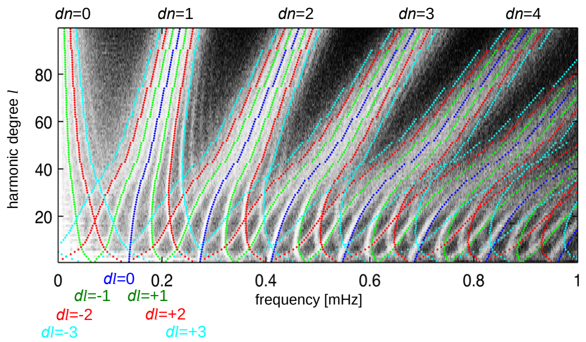
Figure 3 Envelope of a solar oscillation and spectra of envelope



> The *l*-*v* envelope spectrum show characteristic features depending on frequency and harmonic degree *l*.

Figure 4 Identification of beat frequencies

Based on the eigenfrequencies of solar model S [2] , beat frequencies between different combinations of modes *l, n, m*=0 can be assigned to these features.



> The main ridges can be assigned to beats between modes of adjacent radial order *dn*=0, 1, 2,… .
> The side lobes of each ridge are identified by beats between modes of adjacent harmonic degree *dl*=0, ±1, ±2, … .

Conclusions

We investigated the envelope and mean instantaneous frequency for the aim to quantify temporal changes of the solar eigenfrequencies and oscillation amplitudes. We observed that the envelope is strongly affected by beats between modes of different radial order and harmonic degree. The MIF is a promising measure for the analysis of frequency modulations, however amplitude modulations can also cause modulations of the instantaneous frequency.

In future investigations we aim to discriminate between different mechanisms that affect the envelope and the MIF estimate and we will apply these methods to longer observation periods.

References:
[1] S. C. Tripathy et al., Solar Physics, 2007
[2] J. Christensen-Daalsgard et al., Science, 1996

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