Precision Asteroseismology
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On the information content of stellar spectra

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Abstract. With the increasing quality of asteroseismic observations it is important to minimize the random and systematic errors in mode parameter estimates. To this end it is important to understand how the oscillations relate to the directly observed quantities, such as intensities and spectra, and to derived quantities, such as Doppler velocity. Here I list some of the effects we need to take into account and show an example of the impact of some of them.

Keywords. stars: oscillations

1. Calculation of mode sensitivities

To do precision asteroseismology, we need precise and accurate observations, preferably for a large number of modes. We thus need to understand how the oscillations of a star relate to the observed quantities, such as spectra and broad-band intensity measurements.

Often the intensity perturbation caused by a mode is calculated by multiplying a spherical harmonic with the limb darkening and integrating over the disk. For a velocity observation, a velocity projection factor is also included. This neglects many physical, instrumental and data analysis effects and can cause systematic errors, loss of S/N and failure to make the best use of the observations. It is thus planned to systematically attack these problems, noting that significant work has been done in other contexts (e.g. Zima 2006). This is becoming increasingly important in view of the increased quantity and quality of data soon to be available from the SONG project (Grundahl *et al.* 2009).

For intensity observations some effects to consider include accurate limb darkening, that the intensity perturbation is not necessarily given by the limb darkening times the spherical harmonic (due to such effects as the observing height change with incidence angle), that there are nonadiabatic effects, that the mode phases depend on height (Baldner & Schou 2012), causing center-to-limb phase shifts, the interaction of the oscillations with convection causing spatially variable perturbations and so forth. For spectrally-resolved observations (e.g. Doppler velocity) the situation is further complicated by the nonradial motion near the surface, change of height of formation as a function of spectral line, position in the spectral line, line broadening, convective blueshift etc.

To illustrate the importance of some of these effects, Fig. 1 shows the relative mode visibilities for different values of the degree l, and angular order m, as a function of inclination i. To calculate these results, a snapshot of a solar MHD calculation (courtesy of Bob Stein, using the Stagger code (Beeck *et al.* 2012) and the EOS and opacities from Nordlund (1982)) was used to synthesize the Fe I 617.3 nm line as a function of viewing angle. These profiles were then shifted according to a solid-body rotation law and averaged over the disk to create a reference line profile. The velocity pattern from several low-degree spherical harmonics was then added to the velocity profile, integrated and cross-correlated with the reference profile to determine the mode sensitivity.

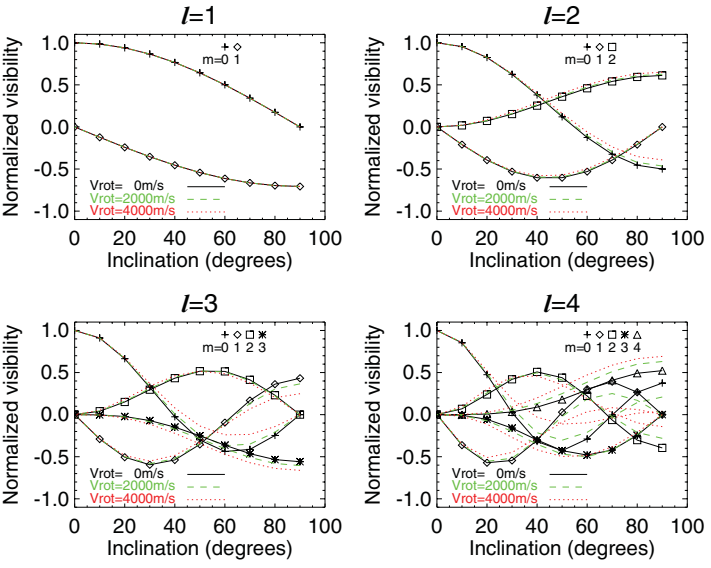

Figure 1. Visibilities as a function of inclination angle, divided by the total visibility (summed in quadrature over m). The results are labeled by the equatorial velocity.

Figure 1 shows that even a modest solar-like rotation causes a significant change in the mode visibilities, especially at $l = 3$ and $l = 4$, which could cause a significant mis-estimation of the inclination. For unresolved modes it may also lead to mis-estimation of the rotational splittings. The zero-velocity cases follow the results of Gizon & Solanki (2003), as expected. On the other hand many potentially significant effects were not taken into account. The oscillations were assumed to be radial at the surface, constant as a function of height and unaffected by the granulation. Also, no account was taken of differential rotation or the possible variation of the phase or amplitude with height described by Baldner & Schou (2012).

2. Conclusion

It is clear that there are many effects we need to take into account if we wish to accurately model stellar spectra and extract the maximum information. Figure 1 only shows one example and the plan is to systematically investigate all the relevant effects.

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