Solar-stellar connection: the frequency of maximum oscillation power from solar data

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Abstract. Stellar oscillations provide powerful tools to derive stellar fundamental parameters such as the mass and radius. These global quantities are derived from scaling relations linking seismic quantities (\(\nu_{\text{max}}\) and \(\Delta \nu\)) to global stellar parameters. These relations use the Sun as a reference. In this work, we used VIRGO and GOLF data to study how the solar frequency at the maximum oscillation power (\(\nu_{\text{max}}\)) varies with time along the solar cycle. We show that these variations imply differences of about 4% in radius and 12% in mass. We showed also that the observational method based on intensity or velocity data has also an impact, implying differences in mass of about 22% and 7% in radius.

1. Introduction
Stellar oscillations provide powerful tools to derive stellar model independant estimates of the mass and the radius of a pulsating star. These global quantities are derived from scaling relations linking seismic quantities (\(\nu_{\text{max}}\) and \(\Delta \nu\)) to global stellar parameters (e.g. Kallinger et al. 2010; Belkacem et al. 2011, 2012). Two properties of the oscillation spectrum are used: the large separation, \(\Delta \nu\), the frequency separation between two consecutive radial orders and the frequency at the maximum power in the oscillation spectrum, \(\nu_{\text{max}}\).

The scaling relations are normalised to the solar values and therefore depend on some seismic parameters of the Sun, among them the frequency at maximum power, \(\nu_{\text{max},\odot}\). The level of precision of these scaling relations is such that the accuracy on the solar reference maximum frequency becomes non negligible.

In this work, we investigate the possible biases and the precision of the determination of the solar frequency of the maximum oscillation power. For this purpose, we used data from different instruments: VIRGO and GOLF onboard SOHO.

2. Data and method
We used GOLF and VIRGO data from 04/11/1996 to 09/15/2004 cut into 6 months long time series. \(\nu_{\text{max}}\) is derived by fitting the smoothed power spectrum by a gaussian-like model (figures 1 and 2). We can see clearly in VIRGO data the granulation background at low frequencies while it is less prevalent in GOLF data.
3. Results

The variation of $\nu_{\text{max}}$ with time shows a correlation with the number of sunspots for GOLF data but not for VIRGO data (figure 3). We see also on figure 3 that the $\nu_{\text{max}}$ obtained from GOLF data is systematically larger than the one obtained from VIRGO data. This still needs to be investigated and is certainly related to the different shape of the background spectrum and its possible variation along the cycle.

\[ \nu_{\text{max}} \text{ varies from 3135 to 3214 mHz for GOLF data along the solar cycle. If we compute the }\]
radius and the mass of a given star using these two values with Eq. (1) and (2) (e.g. Chaplin et al. 2011), this implies a difference in the stellar radius by 4 % and in the stellar mass by 12 %.

\[
\left( \frac{R}{R_\odot} \right) = \left( \frac{\nu_{\text{max}}}{\nu_{\text{max},\odot}} \right) \left( \frac{\Delta \nu}{\Delta \nu_\odot} \right)^{-2} \left( \frac{T_{\text{eff}}}{T_{\text{eff},\odot}} \right)^{0.5} 
\]

\[
\left( \frac{M}{M_\odot} \right) = \left( \frac{\nu_{\text{max}}}{\nu_{\text{max},\odot}} \right)^3 \left( \frac{\Delta \nu}{\Delta \nu_\odot} \right)^{-4} \left( \frac{T_{\text{eff}}}{T_{\text{eff},\odot}} \right)^{1.5} 
\]

For VIRGO data, \( \nu_{\text{max}} \) varies and from 3066 to 3110 mHz implying a difference in the stellar radius by 4.3 % and in the stellar mass by 13 %.

If we consider two different kind of solar data, intensity (VIRGO) and velocity (GOLF) data, the difference in the stellar radius is about 7% and about 22% in the stellar mass.

4. Conclusions

In this work, we have found different values of \( \nu_{\text{max}} \) depending on the way the oscillations are observed (intensity vs velocity observations) and on the period considered because of the effect of the solar activity. This kind of study is important to be able to estimate the accuracy of stellar parameters derived from scaling relations.

In a near future, we will investigate other methods to determine \( \nu_{\text{max}} \) (e.g. based on individual frequencies) as well as more sophisticated model to better reproduce the lower and higher frequency part of the excess power due to the oscillations in the power spectrum.

References

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