PREDICTED INTENSITY/VELOCITY AMPLITUDE AND PHASE LAG OF GRAVITY MODES

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ABSTRACT

The visibilities of g-modes for full disc intensity and Doppler velocity measurements are computed. The opacity perturbations of the photosphere induced by g-modes are taken into account but the interaction of g-modes with convection is neglected. The calculations are carried out in the adiabatic and nonadiabatic case in the range of frequency from 40 to 300 μHz. As expected, l=1,2 modes have for both measurements the highest amplitudes because of spatial filtering. Moreover assuming a mode energy of 10^{34} ergs the very low-degree g-mode amplitudes are estimated to be several tenths of ppm in full disc intensity and several cm/s in full disc Doppler velocity. The ratios of full disc intensity to Doppler velocity amplitudes and the phase differences between the two signals are also presented.

Keywords: g-modes visibility.

1. INTRODUCTION

The internal solar g-modes are trapped below the bottom of the convective zone. Their frequencies are therefore sensitive to the dynamics and to the structure of the inner layers of the Sun, especially the solar core. The identification of a few low-degree g-modes and the determination of their frequencies could provide us with more informations about the solar core than already provided by low-degree p-modes. In order to help the detection and the identification of g-modes, which are the primary goal of the VIRGO and GOLF experiments aboard SOHO, we estimate in the first and second sections the amplitudes of low degree g-modes (l=1-5) in full disc intensity and Doppler velocity measurements assuming that the g-modes have the same energy of 10^{34} ergs. This energy corresponds to the upper limit of the energy of a g-mode in the model of excitation of gravity waves described by Andersen [1]. These amplitudes are computed in the adiabatic and nonadiabatic case, using the Eddington approximation to describe the exchange of radiative energy in the photosphere. In the third section we predict the full disc intensity to Doppler velocity ratios and the corresponding phase differences of the two signals.

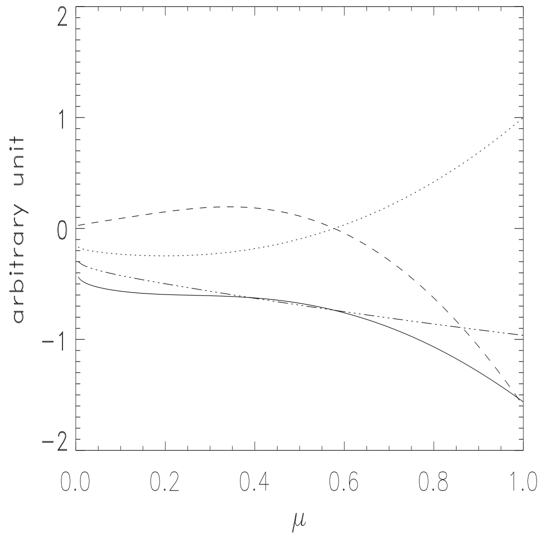

Figure 1: Contributions to the perturbation of intensity (solid line) as a function of μ (cosine of the angle between the normal at the surface and the line of sight) for a g-mode l=2 n=12 in the adiabatic case : temperature change (dotted line), opacity change (dashed line) and surface distortion (dotted-dashed line).

2. VISIBILITY OF G-MODES FOR FULL DISC INTENSITY MEASUREMENTS

P-and g-modes perturb the equilibrium of the photosphere. Locally they change the temperature as well as the opacity. Moreover they distort the layers. Therefore temperature change, opacity change, surface distortion are the three effects which contribute to the visibility of a mode for full disc intensity measurements. We define the visibility of a mode by the relative perturbation of integrated emergent intensity. As shown by several authors (Provost and Berthomieu [2],Toutain and Gouttebroze [3], Staude et al. [4]) the opacity change due to oscillations in the photosphere is not negligible as regards to p-mode visibility in the visible continuum. We show in this work that this is also the case for g-mode visibility. We compute g-mode visibility at λ=500 nm taking into account this opacity change using a method described in Toutain and Gouttebroze [3]. As shown in figure 1 for a mode l=2, n=12, the contribution to the total perturbation of intensity (solid line) of

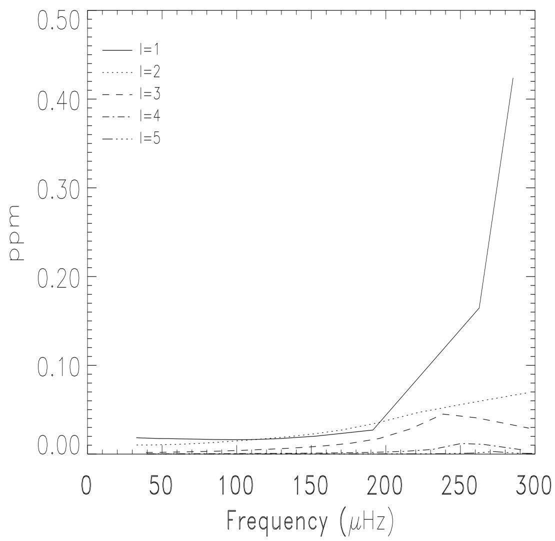

Figure 2: Amplitudes in the adiabatic case of low-degree g-modes for full disc intensity measurements at 500 nm. Equipartition of energy is assumed with a mode energy of 10^{34} ergs.

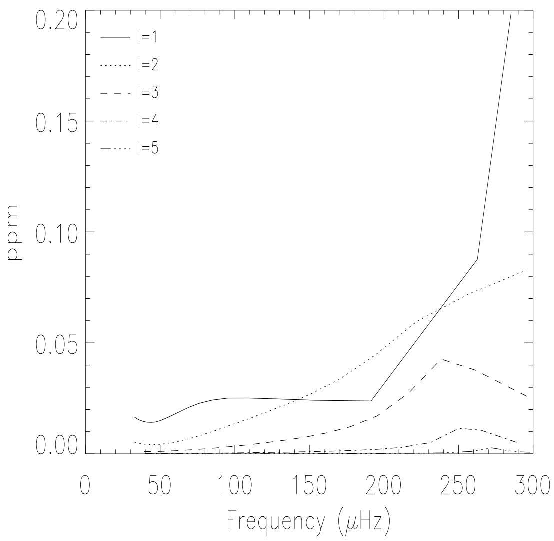

Figure 3: Amplitudes in the nonadiabatic case of low-degree g-modes for full disc intensity measurements at 500 nm. Equipartition of energy is assumed with a mode energy of 10^{34} ergs.

opacity change (dashed line) is rather large everywhere on the disc.

Moreover these changes act almost in the opposite way of the temperature perturbation (dotted line). Therefore the effect of surface deformation (dotted-dashed line) which is usually assumed small becomes important when it is integrated over the whole disc. In some cases it becomes even the leading term. Integrating intensity, as shown in figure 1 over the disc, and assuming equipartition of energy with a mode energy of 10^{34} ergs, we get the amplitudes (in ppm) of the integrated intensity perturbation due to g-modes. These quantities are plotted in figure 2 as a function of mode frequency.

Obviously l=1 modes dominate all over the g-mode frequency range except between 150-200 μHz where l=2 modes are a bit higher. The higher degree modes (l=3-5) are much smaller especially above 200 μHz where l=1 amplitudes increase very rapidly with frequency. Because the solar noise decreases rapidly with frequency, modes above 200 μHz: the g-mode (l=1, n=1) and the f-mode (l=1, n=0) are more likely detectable. In the nonadiabatic case (Eddington approximation) the amplitudes are two times smaller but their l-dependence is almost the same. See figure 3.

We would like to point out that these amplitudes are only predicted relative amplitudes because their absolute values depend of the mode energy which is unknown and in our calculations is put arbitrarily to 10^{34} ergs. Nevertheless, assuming 3 years of observations we have plotted on figure 4 the power spectrum amplitudes corresponding to the amplitudes shown in figure 3 for g-modes having lifetimes greater than 3 years. Moreover, we have superimposed in the frequency range of interest (from 40 to 300 μHz) the noise level (thick solid line) observed with the ACRIM radiometer (Woodard [5]). This level is an upper limit to the solar noise in this frequency range. We see clearly that if the noise measured with ACRIM is really solar noise and if the energy of g-modes is less than 10^{34} ergs only very few g-modes will be detected.

3. VISIBILITY OF G-MODES FOR FULL DISC DOPPLER VELOCITY MEASUREMENTS

We compute amplitudes of g-modes in Doppler velocity at τ_{5000}=1 assuming the same energy of 10^{34} ergs for each mode. The method used is described by Berthomieu and Provost [6]. The results are plotted in figures 5 and 6 for the adiabatic and nonadiabatic case, respectively. As expected the nonadiabatic effects in the photosphere have almost no influence on amplitudes of velocity perturbations. As for flux perturbations, the l=1 modes have the highest amplitudes all over the inspected frequency range. These amplitudes are also increasing rapidly above 200 μHz.

Once again these amplitudes are only predicted relative amplitudes. As in the previous section we have plotted (see figure 7) the power spectrum amplitudes of low-degree g-modes assuming 3 years of observations. The estimation of the solar noise level(solid thick line) in full disc Doppler velocity measurements is taken from the paper of Pallé et al. [7]. We see that with velocity measurements thanks to the smaller solar noise several g-modes should be detected if the energy of g-modes is about 10^{34}.

4. PREDICTED INTENSITY/VELOCITY AMPLITUDES AND PHASE DIFFERENCES

Because the intensity to velocity ratios are independent of mode energy, we can calculate predicted values. These ratios are plotted in figures 8 and 9 for the

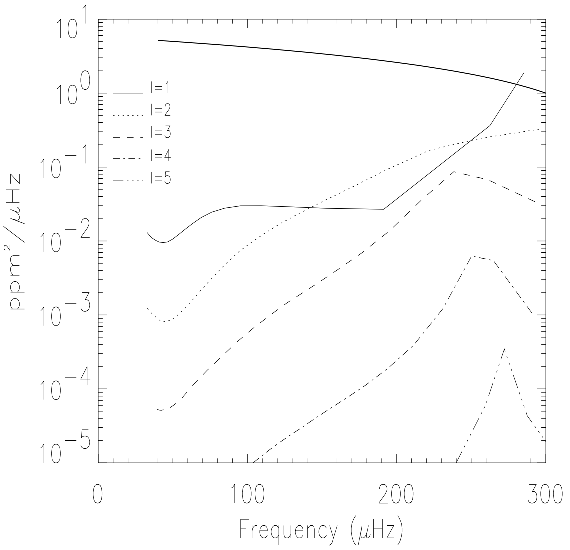

Figure 4: Power spectrum amplitudes of low-degree g-modes in the nonadiabatic case for 3 years of full disc intensity measurements at 500 nm. Equipartition of energy is assumed with a mode energy of 10^{34} ergs. The thick solid line is the noise measured with ACRIM

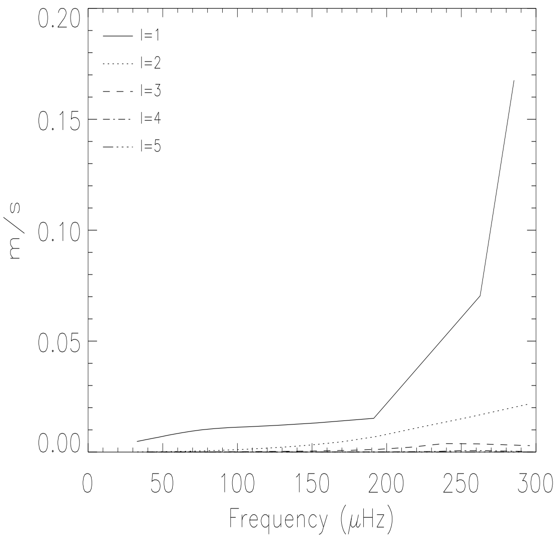

Figure 5: Amplitudes in the adiabatic case of low-degree g-modes for full disc velocity measurements at τ_{5000}=1. Equipartition of energy is assumed with a mode energy of 10^{34} ergs.

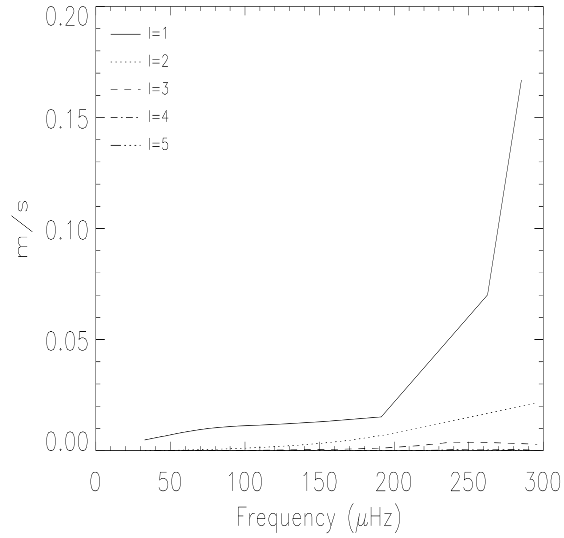

Figure 6: Amplitudes in the nonadiabatic case of low-degree g-modes for full disc velocity measurements at τ_{5000}=1. Equipartition of energy is assumed with a mode energy of 10^{34} ergs.

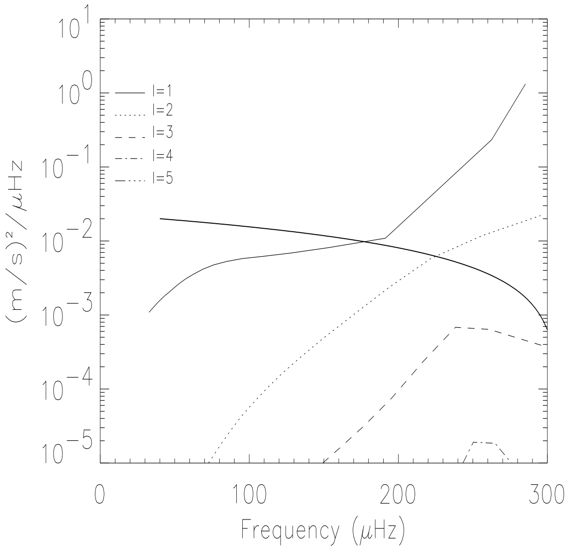

Figure 7: Power spectrum amplitudes of low-degree g-modes in the nonadiabatic case for 3 years of full disc velocity measurements at τ_{5000}=1. Equipartition of energy is assumed with a mode energy of 10^{34} ergs. The thick solid line is the noise measured by Pallé et al. [7].

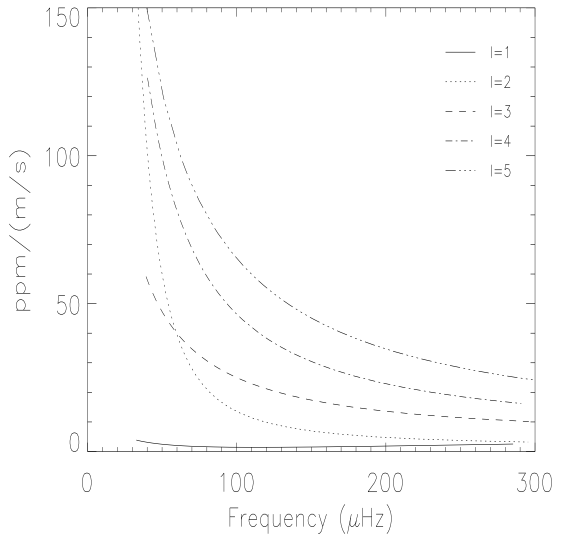

Figure 8: Intensity/velocity amplitudes in the adiabatic case of low-degree g-modes for full disc measurements.

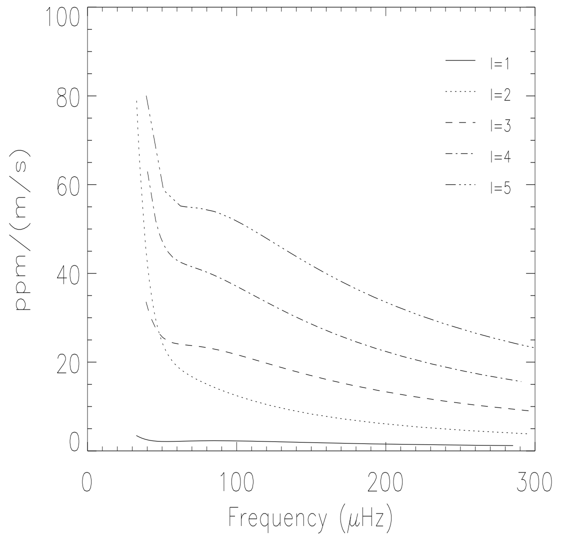

Figure 9: Intensity/velocity amplitudes in the nonadiabatic case of low- degree g-modes for full disc measurements.

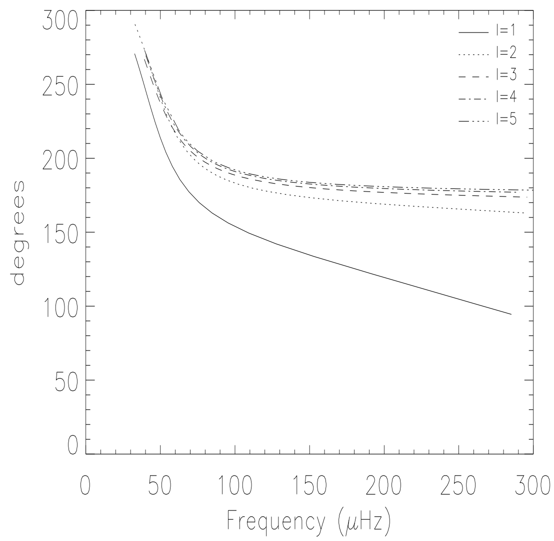

Figure 10: Phase difference between full disc intensity perturbation at 500 nm and full disc Doppler velocity perturbation at τ_{5000}=1.

adiabatic and nonadiabatic case, respectively. Following the previous sections we are especially interested in l=1 and l=2 modes because these modes are the most likely detectable. The curve of ratios for l=1 modes are very flat compared to the curve of ratios for l=2 modes which increase strongly at low frequencies. This indicates that intensity experiments could be more sensitive than velocity experiments to g-modes below 100 μHz. This kind of curves can be compared directly to observational ones in order to test the significance of potential g-modes in the power spectrum. Similarly we can also use the phase difference informations between intensity and velocity signals. These quantities using the Eddington approximation are plotted in figure 10.

5. CONCLUSIONS

Assuming that low-degree g-modes have the same energy, we have shown that l=1,2 g-modes with frequencies above 100 μHz are likely the most visible both with VIRGO and GOLF experiments. This is a crude estimation of what will be visible g-modes because we have neglected the coupling with the convection. Also the mechanisms which excite g-modes are not known. Nevertheless, combining these estimations with the fact that the solar noise increases at low frequencies for both intensity and velocity observations, it seems more sensible, in a first step, to search for g-modes at the highest frequencies of the g-mode frequency range.

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