On the Frequency Discrepancy Problem of Helioseismology

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The theory of global adiabatic p-modes is developed, taking into account the influence of the solar atmosphere on the formation of the eigenoscillations. It is shown that waves of the whole frequency range $\nu \approx 2 \div 10\,\mathrm{mHz}$ may reach the chromosphere-corona transition region (CCTR) by means of a tunneling of acoustic waves through the atmospheric barriers. The main acoustic cavity inside the Sun becomes considerably extended in this way, leading to a change of frequencies: low frequencies are increased, while high frequencies are decreased in comparison with an absence of wave tunneling. The transition from low p-mode frequencies to high peak frequencies ($\nu \geq 6$ mHz) is smooth. This mechanism may solve the frequency discrepancy problem of helioseismology without changing the usual standard model of the Sun.

The locations of the turning points are determined from the wave equation for $div\mathbf{v}$. It is shown that the internal turning point of the acoustic cavity is strongly shifted toward the center of the Sun, while the upper turning point is shifted from the surface to the CCTR. That means, the turning points cannot be located in the convective zone. This is also a significant difference to the usual, generally accepted picture. This result means that the role of turbulent convection is evidently limited by the generation of acoustic noise. The influence of convection on the formation of the observed power spectrum, especially on the frequency shifts as shown by some authors, is probably of minor importance.

The asymptotic solutions of the wave equation are obtained, on the base of which the boundary value problem is solved. A new complex integral dispersion relation for the eigenfrequencies is derived. The imaginary parts of the frequencies indicate a decay of the amplitudes, resulting from considerable energy losses by tunneling from the main cavity. The formulae for the complex eigenfunctions are also derived.

The calculated imaginary parts of eigenfrequencies are not small for the whole range of the p-mode spectrum. Hence the mechanism considered here together with radiative losses should explain the linewidths of the p-mode spectrum. When the wave trapping is considered in the cavities–barriers system the real parts of discrete frequencies are determined by the lengths and the physical model parameters of the cavities. In the same manner the imaginary parts of the frequencies are determined by the lengths and the physical situation of the tunnels.

We deduce that large values of imaginary parts of the frequencies indicate a considerable transmission of waves through the photospheric barrier to both sides, especially for $\nu \approx 4 \div 6\,\mathrm{mHz}$. This means, a trapping of modes in a chromospheric local cavity is perhaps problematical. In our frequency calculations the chromospheric modes are absent. We suppose, the reason for the non-existense of these modes is the presence of the fine structures in the chromospheric and the CCTR.

It is shown that waves with a decaying amplitude (complex frequency) may exist in a limited area only. That means, a penetration of linear p-modes to the corona is impossible. Concerning the waves the behavior of the CCTR is that of a free surface. We conclude that the p-modes may drive forced surface gravity waves of this free surface.