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INTERACTIONS AMONG CONVECTION, MAGNETIC FIELDS AND P-MODE OSCILLATIONS IN THE SUN

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Research Progress

Two papers on different aspects of the excitation and damping of solar oscillations by Goldreich and senior research fellow Murray have been accepted for publication in the Astrophysical Journal.

The first paper, which also includes ex-graduate student Kumar as coauthor, evaluates the rate at which turbulent convection feeds energy into individual p-modes. It is shown that stochastic excitation by turbulent convection provides a satisfactory fit to the product of the mode energies and linewidths. A somewhat surprising conclusion is that entropy fluctuations are about an order of magnitude more significant than are fluctuations of the Reynolds stress in exciting p-modes. However, entropy fluctuations cannot excite f-modes. This may account for the relatively low energies of the f-modes compared to those of the p-modes.

The second paper explores the role of scattering of acoustic modes by turbulent velocity fluctuations. Scattering of a mode is concentrated near the top of its acoustic cavity. Because the turbulence has low Mach number, scattering couples modes having similar frequencies. Its net effects are to increase the linewidths of all modes and to transfer energy from p-modes to f-modes. Scattering is likely to be the dominant source for the linewidths of p-modes. In particular, it may account for the unexpectedly large linewidths measured for low frequency modes.

Copies of preprints of the two papers referred to above are attached to this report. Consequently, we shall curtail our discussion of this work. The remainder of the report is devoted to a description of unpublished results soon to be submitted as a thesis by Gregory Willette.

Description of Gregory Willette's Thesis

The topic of Willette's thesis is the stochastic excitation of the solar p-modes by turbulent convection, and the work consists of three parts: two theoretical sections and one observational.

The first section deals with the role of convective structures in a wide number of problems, including the creation of acoustic disturbances, the transport of magnetic fields, the penetration of flows into stable layers of the atmosphere (overshoot), and the connection between convection and differential rotation. A model of plume convection is developed to discuss these issues. It is argued that the scaleheight-sized flows (the only energetically significant ones) are properly characterized as coherent, entropy-preserving plumes, in contradistinction to the picture of amorphous parcels of fluid suggested by the Mixing Length Theory (and the theory of Homogeneous Isotropic Turbulence), and in spite of the large Reynolds numbers typical in astrophysical convection. The entrainment of mass and lower entropy material, which is important for plumes arising from a small source, may be neglected to an adequate approximation for the larger plumes. The braking of the flow is due to a pressure perturbation which is usually neglected in models of plumes. It is found that simultaneous conservation of mass, energy, momentum and entropy leads to a mathematical singularity in the model equations. This singularity forces the flow to diverge at some specific depth in the atmosphere which may be interpreted as a 'mixing length,' and this penetration scale is not very sensitive to the conditions at the source boundary. In addition, the model suggests a striking asymmetry between upward and downward directed plumes, as is commonly noted in numerical simulations of turbulent compressible convection. This work was done in collaboration with Dr. Stirling Colgate of Los Alamos National Laboratory.

In the second section of the thesis, an explicit calculation of the acoustic radiation of a buoyant oscillating bubble is presented as a model for the excitation of the solar p-modes. The central scientific issue addressed in this paper is the cancellation of monopole and dipole radiation fields in an anisotropic medium, first pointed out by Goldreich and Kumar (1990). The acoustic Green's function for a plane parallel polytrope (a model for the solar convective envelope) is computed and used to calculate the excited amplitudes of the p and f modes. The convective element is modelled as a bubble expanding and contracting as it bobs up and down in the atmosphere. Changes in fluid volume generate monopole radiation, while the resulting buoyancy oscillation creates a dipole field. When the bubble oscillation frequency is small compared to the acoustic cutoff, the monopole and dipole disturbances cancel to the quadrupole order in the far field. This cancellation effect limits the p-mode amplitudes, while it is found that the f-mode cannot be excited by the combined monopole and dipole mechanisms due to its near incompressibility. The technical developments from this work may be useful for similar problems, since the polytropic approximation is appropriate in many systems. In particular, the Green's function can be used to calculate the evolution of the sound wave excited by the expected cometary impact with Jupiter in July 1994 (work in progress).

The final section of the thesis is an analysis of surface velocity data taken with the magneto-optical filter on the 26 inch telescope at Big Bear Solar Observatory (BBSO). The data set consists of a time series of high resolution Doppler images obtained at the center of the solar disk. Analysis of the data lead to several interesting results, including a state-of-the-art estimate of the frequencies and amplitudes of the solar oscillations of high spherical harmonic degree ($l \lesssim 2000$). The 'ridge' structure of the dispersion relation is seen clearly in the data up to the highest observed wavenumbers, and the mode amplitudes agree with the theory of Goldreich et. al. (1993) (in order of magnitude and qualitative behavior). Moreover, the mode energies follow a Boltzmann distribution ($P(E) \propto \exp\{-E/\overline{E}\}$) as was predicted in the stochastic excitation model of Goldreich and Kumar (1989).

REFERENCES

1. Goldreich, P., Murray, N., and Kumar, P. 1994, Excitation of Solar P-Modes, accepted for publication in the ApJ

2. Goldreich, P., and Murray, N. 1994, The Effects of Scattering on Acoustic Modes