PHOTOSPHERIC LINE ASYMMETRY AND GRANULAR VELOCITY MODELS

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Abstract. We analyze spectral line profiles obtained from regions of the solar surface exhibiting either an upflow or a downflow on a spatial and temporal scale corresponding to the white-light granulation. The differences between their line bisectors are measured to quantify changes in the asymmetry of the profile resulting from granular motion. The observed bisector differences are compared with differences predicted using conflicting granular models. Models, in which the motion of large, long-lived granules decreases rapidly with increasing height in the photosphere, are compatible with the observed line profile asymmetries.

1. Introduction

Conflicting observational descriptions of the granular velocity field have been reported. Canfield and Mehltretter (1973) and Keil and Canfield (1978) find that the vertical flow associated with the white-light granulation decreases rapidly with increasing height above $\tau_{5000\,\text{Å}} = 1$. They report scale heights of approximately 100 km, and their observations are compatible with models in which the granular flow is negligible in layers higher than 300 km above $\tau_5 = 1$. Durrant *et al.* (1979), on the other hand, found that the granular flow decreases much more slowly with height, an appropriate scale height being ~1700 km.

The studies mentioned above lacked temporal resolution (i.e., consisted of a single spectrogram). Separation of line shifts due to granular motions from line shifts due to other motions (e.g. the 5-min oscillations) had to be effected solely in the spatial domain. This presents a number of problems that have been thoroughly discussed by Keil (1980a, Paper I). In Paper I a temporal sequence of spectrograms was used to effect the separation between granular and other line shifts, using both the spatial and temporal properties of the data. Keil (1980b, Paper II) found that the observed granular line shifts of Paper I were best reproduced with a velocity model in which the amplitude decreased with increasing height, an appropriate scale height being approximately 80 km.

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All of the studies discussed above used wavelength shifts of the line center to infer velocity models. Throughout most of its lifetime, the radiation escape time is short compared to the evolution of a granule. Therefore, a model of the granular flow and the associated temperature and pressure fluctuations will yield definite predictions for the shape of lines emerging from a given place and time within the granulation pattern. If the model contains steep vertical velocity gradients, the emergent lines will have characteristic asymmetries. If the velocity gradients are small, the lines will be shifted, but will exhibit little asymmetry due to granular velocities. With sufficiently good spatial resolution (better than 1″) this asymmetry or lack of asymmetry should be detectable, providing independent information.

The asymmetry of individual profiles is distinct from the asymmetry of spatially unresolved solar profiles. The latter results from both the individual asymmetries and from the fact that hot, upflowing material contributes more to the average profile than does cool downflowing material (cf. Beckers and Nelson, 1978; Dravins *et al.*, 1980).

Using the observations of Paper I, differences between average line profile shapes emergent from upflowing regions and downflowing regions of the granulation are measured. By observing bisector differences, many of the problems caused by blends and seeing effects are reduced. The results are compared with predictions using granular models respectively with a large and a small velocity gradient.

2. The Data

The observations consist of a temporal sequence of spectrograms made using Sacramento Peak Observatory's Vacuum Tower Telescope and Echelle Spectrograph and are described fully in Paper I. In Paper I the temporal and spatial locations of line shifts associated with the white light granulation were determined by two-dimensional Fourier analysis. In all, 136 upflows and 147 downflows were located. Using the space-time coordinates of the extremes of these flows, the corresponding line profiles for the Fe I 5166, 5165, 5164, and 5162 Å lines were extracted from the original microphotometer tracings together with the local continuum intensity and the magnitude of the line center shift for each line. Table I lists some of the properties of these four lines.

To suppress effects due to motions other than the granulation and effects due to random noise, profiles whose line center shifts fell within 100 m s^{-1} intervals were averaged. A mean upflow and a mean downflow profile were also generated by averaging all upflow and all downflow profiles. Before averaging, each profile was normalized so that the local continuum intensity was equal to unity and the lines were shifted so that their central intensities were at the same wavelength. The velocity intervals cover the range from +0.5 km s^{-1} to −0.5 km s^{-1}. Of the other motions, the 5-min oscillations simply shift the entire profile while adding little additional asymmetry, because its scale height is about 1100 km (Canfield and Musman, 1973). The vertical motions of the supergranulation are small (Worden, 1975).