RING DIAGRAM ANALYSIS OF MT. WILSON DATA

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INTRODUCTION

In a three-dimensional power spectra of high-degree solar oscillations, the ridges of the $k-\omega$ diagram become a surface with a shape reminiscent of trumpets (Hill 1988). A ring of power appears at a constant frequency, $\omega$, for every radial order $n$. If a velocity field, $U$, is present beneath the solar surface, the resulting advection of the wave front will produce an apparent Doppler shift $\Delta \omega$, given by

$$\Delta \omega = k \cdot U = k_x U_x + k_y U_y,$$

where $U_x$ and $U_y$ are the $x$ and $y$ components of $U$. The position of the rings depends on this Doppler shift, and can be used to estimate the values of $U_x$ and $U_y$.

Here, we present the status of applying a ring diagram analysis to a 9.2 hour run (60 s cadence) of full-disk 1024x1024 pixel Doppler images in the NaD lines. They were obtained at Mt. Wilson in July, 1988 using the Magneto-Optical Filter. The spatial resolution at the center of the disk is 2.2 arcsec. The observing system has been described by Rhodes, Cacciani, and Korzennik.

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(1988), and an earlier status report has been presented by Hill et al. (1991). Since then, we have attempted to develop a correction for the variable effective spatial resolution across the disk, and have improved the ring fitting algorithm. The process of fitting the rings at 25 heliographic positions is currently underway. When finished, these rings will be used to infer the subphotospheric horizontal flow field.

**FORESHORTENING CORRECTIONS**

As we move closer to the limb of the disk in our image, the effect of foreshortening increases. The result are rings that are incomplete in the direction of the foreshortening. We have simulated this effect and attempted to remove it by modeling it as a convolution of a point spread function and the real data. Here we assumed a spatially-invariant PSF across the disk to simplify the convolution. We found no improvement after deconvolving the PSF. This is not surprising since, in this case, we are incorrectly assuming that the spatially varying sampling can be modelled as a spatially-invariant PSF.

![Diagram](image)

**FIGURE I**  Fitted rings to the 3-D FFT of a $14.85^\circ \times 14.85^\circ$ region at the center of the disk.

**FITTING THE RINGS**

In order to estimate the horizontal flows, we need to know the positions and shapes of the rings. We have used an analytic approximation of ellipses for the ring shape. In the fitting process we choose a frequency and an $n$ value. Then, a radial cross-section of the two-dimensional distribution of power (around the
observed ring) gives us a curve with the approximate ring shape. Finally, a least-squares procedure fits an ellipse to this curve. The analytic relations between the ellipse parameters and the two components of the velocity field can be found in Hill (1988). The results of the fitting procedure for a region in the middle of the disk for $p$-modes with $n = 2, 3$ and $4$ ($p_2$, $p_3$ and $p_4$) are shown in Figure I. The final $U_x$ component obtained with this method for $p_2$ at three different positions in the disk appear in Figure II. These velocities are very high, which may be due to short comings in the ellipse approximations.

![Graph of $U_x$ vs. frequency for $p_2$ at different positions](image)

**FIGURE II** $U_x$ component of the velocity as a function of frequency for $p_2$ at three different positions in the disk.

**CONCLUSIONS AND FURTHER WORK**

To correct images for the foreshortening we must face the problem of a formal convolution with spatially variant point spread functions. This is currently an unsolved problem whose solution will have many applications in astronomy (ie. adaptive optics).

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1We say *formal* because in a true convolution the implicated functions cannot be spatially variant.
The ring fitting process should be based on a good underlying model and take into account the local distribution of power, not only in the $k_x - k_y$ plane but also in some interval of frequency. We are currently testing a maximum likelihood fitting procedure, with a model of the distribution of power in $\omega$ (Anderson et al., 1990). This model predicts a Lorentzian profile in frequency around the $\omega_0$ value predicted for a gived $n$ and $\ell$, or $k$ number. Preliminary tests are providing more reliable estimates of $U_x$ of $20-50$ m/s.

The last step is to invert the data and infer a horizontal flow map as a function of both position on the disk and depth (e.g., Hill 1990). Due to the small variations in the positions of the rings that we need to measure, more effort on improving geometrical and seeing corrections of our images should be made, such as described in Rhodes et al. (1991).

REFERENCES


