

MEASUREMENTS OF SOLAR INTERNAL ROTATION OBTAINED WITH THE
MT. WILSON 60-FOOT SOLAR TOWER

Edward J. Rhodes, Jr.
University of Southern California
Los Angeles, California 90089-1342

and

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California 91109

Alessandro Cacciani
University of Rome
Rome, Italy

Martin Woodard
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California 91109

Steven Tomczyk
Sylvain Korzennik
Roger K. Ulrich
University of California at Los Angeles
Los Angeles, California 90024

ABSTRACT. We have obtained estimates of the solar internal rotational velocity from measurements of the frequency splittings of p-mode oscillations. Specifically, we have analyzed a 10-day time series of full-disk Dopplergrams obtained during July and August 1984 at the 60-Foot Tower Telescope of the Mt. Wilson Observatory. The Dopplergrams were obtained with a Na magneto-optical filter and a 244 x 248-pixel CID camera. From the time series we computed power spectra for all of the prograde and retrograde sectoral p-modes from $\ell = 0$ to 200 and for all of the tessaral harmonics up to $\ell = 89$. We then applied a cross-correlation analysis to the resulting sectoral power spectra to obtain estimates of the frequency splittings. From $\ell = 4$ to $\ell = 30$ we obtained a mean value of the frequency splitting of roughly 450 nHz (sidereal) in close agreement with most previously published results, while from $\ell = 40$ to $\ell = 140$ we obtained a mean value of about 470 nHz. We believe that the latter value is slightly higher than the surface rotational splitting of 461 nHz because of possible confusion due to the

temporal sidelobes introduced by the day/night observing cycle. Confirmation of this possibility will have to await our computation of tesseral power spectra for degrees greater than our current limit of 89. Finally, for degrees between 140 and 200, the frequency splittings are indistinguishable from the surface rotation rate.

1. Introduction and Discussion

Several recent studies have obtained estimates of the solar internal equatorial rotation rate from measurements of the frequency splittings of oscillations¹⁻⁴. Each of these studies obtained estimates of the rotation rate which were either near or slightly below the surface rotation rate of magnetic features⁵. During the summer of 1984 we obtained solar full-disk Dopplergrams every 40 seconds for up to 11 hours per day on 90 different days. These Dopplergrams were obtained with a magneto-optical filter feeding a CID camera. We have analyzed a 9.5-day subset of these images in order to obtain our own estimates of the internal equatorial rotation rate. Spherical harmonic filtering yielded time series of sectoral harmonics which were Fourier transformed to yield the power spectrum of Figure 1. Figure 2 shows that this spectrum clearly contained frequency shifts induced by solar rotation. Figures 3 and 4 contain some of our results and those of Duvall and Harvey¹ and Libbrecht⁴ for comparison. Figure 5 shows all of our results from $\ell = 4$ to $\ell = 200$.

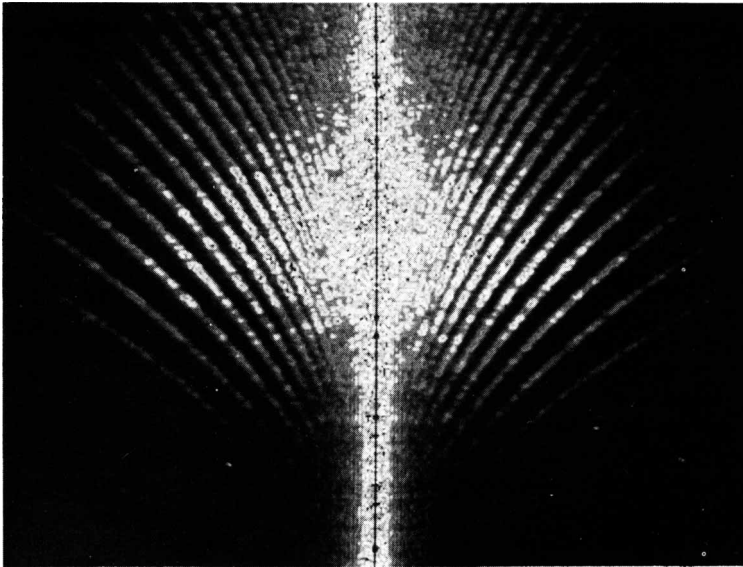


Figure 1. Two-dimensional, ℓ - ν , power spectrum computed from 9.5-day time series of Sectoral harmonic amplitudes. The vertical black line in the center is the temporal frequency axis, while the x-axis ranges from $\ell = -200$ at the left to $\ell = 200$ at the right. The sharp ridges of observed power are due to the solar p-modes. At least 23 ridges can be distinguished in each half of the spectrum.

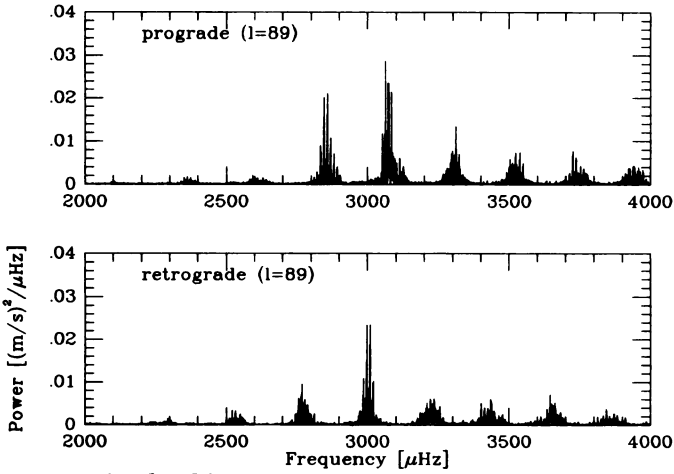


Figure 2. Two vertical slices through the power spectrum shown in Figure 1. Here the prograde and retrograde sectoral harmonic peaks corresponding to a degree of 89 are displayed as a function of the absolute temporal frequency, ν , in mHz. The prograde peaks can be clearly seen to have higher frequencies than do the corresponding retrograde peaks in the lower panel. Since the total prograde-minus retrograde frequency splitting is equal to $2 \times 89 \times \Delta\nu$, where $\Delta\nu$ is the rotational frequency, it is clear that $\Delta\nu$ can be computed easily by dividing the measured splitting by 188. The sidelobes present in each peak are due to both the temporal window function and to spatial leakage from adjacent degrees.

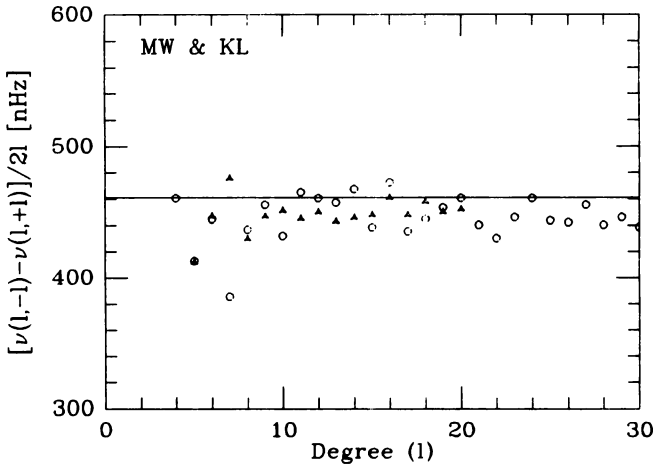


Figure 3. Comparison of our rotational frequency splittings obtained from a cross-correlation of the prograde and retrograde portions of Figure 1 (shown as the circles) with the corresponding measurements of Libbrecht⁴ (shown as the triangles). Both sets of splittings appear to lie systematically below the surface rotational rate of magnetic features of 461 mHz (sidereal)⁵ which is drawn as the solid line.

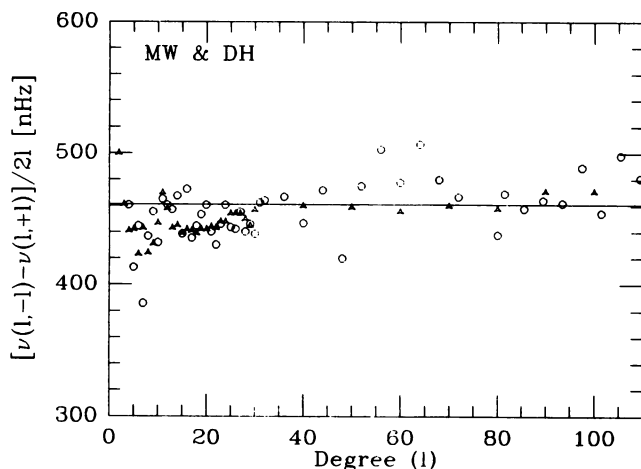


Figure 4. Comparison of our rotational frequency splittings (the circles) with those of Duvall and Harvey¹ (the triangles) for $\ell = 4$ to $\ell = 100$. Below $\ell = 40$ both sets of results lie systematically below the surface rotation rate (again shown as the solid line). The relatively large scatter of our values above $\ell = 44$ may be due to the shorter duration of our dataset (9.5 days versus 17 days for Duvall and Harvey) or it may be due to increased contamination from the spatial sidelobes from adjacent degrees.

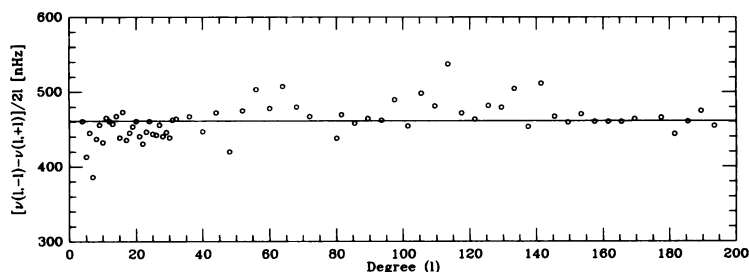


Figure 5. Our rotational splittings extending from $\ell = 4$ to $\ell = 200$. As shown in Figures 3 and 4, our values lie below the surface rotation rate of magnetic features for $\ell = 4$ to 42, while they average 470 nHz between $\ell = 42$ and $\ell = 140$. Above $\ell = 140$ our results are indistinguishable from the surface rate of 461 nHz.

1. Duvall, T. L., Jr. & Harvey, J. W., *Nature*, 310, 19-22(1984).
2. Brown, T. M., *Nature*, 317, 591-594 (1985).
3. Brown, T. M. in *Seismology of the Sun and the Distant Stars* (ed. Gough, D. O.) 199-214.
4. Libbrecht, K. G., *Nature*, 319, 753-755 (1986).
5. Snodgrass, H. B., *Astrophys. J.*, 270, 288-299 (1983).