PRELIMINARY RESULTS FROM OBSERVATIONS WITH THE LOWL INSTRUMENT

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ABSTRACT The so-called LOWL instrument (described elsewhere in this volume) is designed to make spatially resolved observations of low degree solar oscillations. Here we present results from an analysis of the first 83 days of data taken with this instrument, and estimate the improvement in the estimates of the rotation of the solar core which should become possible. The plan is to run the instrument continuously for as long as possible which should lead to a substantial improvement in our knowledge of the conditions in the solar core.

INTRODUCTION

The rotation of the solar core is of considerable theoretical interest. It has been speculated that the core could be rotating considerably faster than the outer parts of the Sun or even around another axis than the envelope.

Unfortunately it is difficult to measure the rotation rate of the solar core for a number of reasons. First of all only modes with very low degree (of which there are few) penetrate to the solar core, secondly the splittings for these modes are dominated by the contributions from the solar envelope, and thirdly these modes are difficult to observe due to atmospheric transparency variations and instrumental stability problems.

Until now the instrumental problems have been solved by observing using integrated sunlight. This approach unfortunately has several problems. It is only possible to observe the very lowest \(l\)'s, it is not possible to separate out the individual \(l\)'s and \(m\)'s except in the power spectra and modes with even \((l + m)\) can for all practical purposes not be observed. Further complications arise because \(\Delta l = 2, \Delta n = -1\) have a frequency splitting very close to 1 day\(^{-1}\), causing problems if the duty cycle is low. Also since different \(m\)'s overlap for a given \((n, l)\), splittings can be obtained only by carefully modeling the spectrum.

The LOWL instrument is designed to eliminate most of the instrumental and atmospheric problems (such as scintillation) by observing the red and blue
wings of a solar line simultaneously. Making spatially resolved observations makes it possible to separate different modes by applying different spatial masks.

A drawback of the LOWL instrument is that it is only a single instrument and therefore unlikely to give much more than a 30% duty cycle. The resulting sidelobes in the power spectra will have to be taken into account in the analysis and will reduce somewhat the number of modes for which it is possible to estimate mode parameters and the accuracy of the estimated mode parameters.

RESULTS/DISCUSSION

The data was taken between February 26 and May 19, 1994. The length of the original time series were 118307 minutes, these time-series were gap-filled and Fourier transformed on a length of 120000 minutes, giving a frequency resolution of $0.139\muHz$ and an effective duty-cycle of about 22%. This is less than expected due to instrument downtime. Given the status of the analysis we can not show the final results, but only some results indicating the quality of the data.

![Power Spectra Examples](image)

**Figure 1:** Examples of power spectra for selected modes. The different $m$'s have been displaced vertically to show the splitting. The power spectra were binned in frequency to make them cleaner.

Figure 1 shows power spectra for a few low degree modes. As can be seen the signal to noise ratio is quite high. The frequency splitting is obvious for $l \geq 2$ and marginally visible for $l = 1$.

We have analyzed the data with two different programs developed by each of us. An $l - \nu$ diagram of the modes fitted by one of us (JS) is shown in Fig. 2. Only modes with $l \leq 50$ and $\nu \leq 4\muHz$ are shown, but we intend to continue the analysis to at least $l = 80$. It should be noted that since this is only a preliminary
analysis some of the modes, especially at low $l$, may be spurious and that some of the holes in the $l - \nu$ diagram will probably be filled. In particular the results shown in Fig. 2 were for a fit using several $a$ coefficients, possibly causing some of the failures for $l = 0$ and $l = 1$.

\[ \begin{align*}
\nu & \quad (\muHz) \\
0 & \quad 10 \quad 20 \quad 30 \quad 40 \quad 50 \\
\end{align*} \]

\begin{figure}
\centering
\includegraphics[width=\textwidth]{figure2.png}
\caption{$l - \nu$ diagram showing the modes fitted.}
\end{figure}

Figure 3 shows other parameters for the fitted modes. Some of the scatter in the amplitudes is likely due to the smearing resulting from the limited instrumental resolution. If the smearing is not corrected properly there will be a spurious $l$ dependence of the mode power that appears like scatter.

Given the high signal to noise ratio, it should be possible to obtain realization noise limited frequencies and splittings. The expected results were discussed in Veitzer et al. (1993). Among the expected results are $a_1$ with a standard error of $\approx 100nHz$ per mode, $l = 2$ with errors of $\approx 50nHz$ and $l = 3$ with errors of $\approx 30nHz$, all for 90 day time-series. For a one year time-series these numbers should be reduced by a factor of 2.

Unfortunately it appears that the temporal sidelobes will degrade the obtainable errors somewhat. Veitzer et al. (1993) discussed this problem for an assumed duty cycle of 35%. The results obtained here have slightly higher errors than they obtained, possibly due to the lower duty cycle. We are currently looking into this problem.

To estimate the constraints we will eventually be able to put on the rotation rate in the solar core, we have made up a somewhat optimistic artificial dataset. This set contains all modes with $l \leq 60$ and $1mHz \leq \nu \leq 4mHz$ with errors estimated by assuming 1 year of observations and realization noise limited errors. Using an optimally localized averaging kernels method we were, as an example, able to construct an averaging kernel at $r = 0.2R$ with a full width at half maximum of 0.08$R$ and a corresponding error of 32nHz!

Of course the assumptions used for this estimate are somewhat optimistic, particularly the assumptions of noise free data and being able to fit modes down to 1mHz. A pessimistic estimate would be to multiply the errors by 2. On the other hand the estimates do indicate that it should eventually become possible to constrain the rotation rate in the solar core.
CONCLUSION

We have shown that the LOWL instrument produces data with a very good signal to noise ratio for low degree modes. We do not yet know how the data will compare to that of GONG or SOI, but if the problems caused by the time-gaps can be handled, the quality should be comparable for low degree modes. For high degree modes, the instrument is not competitive due to the low resolution.

We have also estimated that the radial resolution of the inversions using this data should be quite good even close to the solar core and that the corresponding errors should be quite acceptable.

REFERENCES