SEARCH FOR SOLAR G-MODES FROM 1981 TO 1985

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ABSTRACT. Analysis of solar velocity data obtained at Izaña (Tenerife) over the years 1981 - 1985, has shown the existence of significant signals in the frequency range 25 - 125 μHz. Several ways of analyzing the data have been used in order to interpret these as solar internal gravity modes of degree $\ell \leq 3$.

1. INTRODUCTION

Detection and identification of solar g modes is one of the main goals in helioseismology; these modes yield new information on the structure of the Sun's core. Up to now, no convincing evidence of their existence has been available (1),(2).

2. ANALYSIS

The measured solar line of sight velocity by means of optical resonant scattering spectrometry (3) is used in order to study the low frequency signals (T >30m); it is expected that they contain information on the g modes. The cumulative amount of data collected during 1981, 82, 84 and 85 observing seasons is shown in Table I. Using an improved detrending model, the daily residual velocities are obtained; these residuals contain all the information on solar oscillations. Because the spectral region we are going to analyze is of very low frequencies, temporal integration over 14^m was performed in order to accelerate the computing without loosing any information on long period signals.

With the daily residuals four annual series were obtained,one for each year. The power spectrum was computed, in the frequency range 25 to 125 μHz, using a sine wave fitting procedure. As shown in Figure 1.a), the daily harmonics are the dominant feature in this region; therefore a proper algorithm was developed in order to remove them without altering other information, Figure 1.b).

From the power distribution in different frequency intervals of a power spectra, the noise level can be deduced. The presence of signal well above noise level is established and the variation of the noise amplitude with frequency seems to be compatible with a $1/\nu$ law (4).

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TABLE I

YEAR	DATES OF OBSERVATION	DATE SPAN (days)	SELECTED DAYS	DAILY MEAN DURATION (h.)
1981	29/5-21/8	85	75	9.24
1982	11/5- 5/9	118	95	9.52
1984	17/4-10/10	168	113	9.59
1985	4/4-30/9	179	105	9.46

Summary of the observation used in the analysis of the detection of solar g modes.

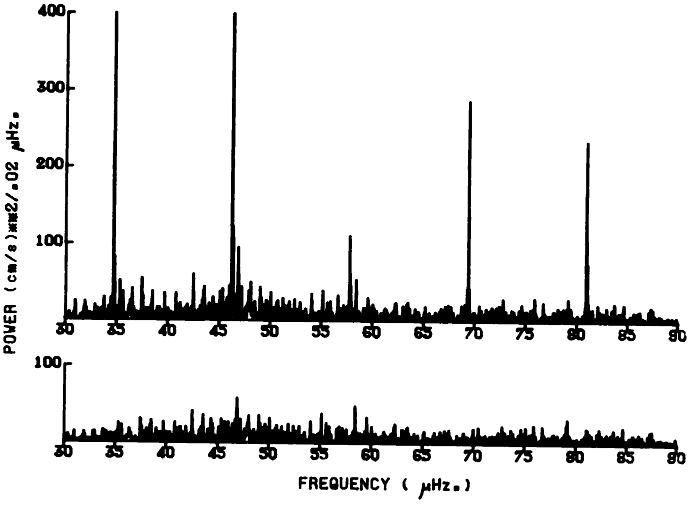

Figure 1. In a) the original power spectrum for the 1985 data in the frequency range 30 to 90 μHz. The daily harmonics 1/3, 1/4, 1/5, 1/6 and 1/7 are the dominant signals. In b) power spectrum of the same data where daily harmonics have been removed; as can be seen the information outside the regions where they are present has not been altered.

3. RESULTS

Asymptotic theory predicts the distribution of solar g modes with $\ell < 5$ and $15 \leqslant n \leqslant 50$ to be equally spaced in period for a given degree, when ignoring rotational splitting. Unfortunately, the density of g modes and its associated side bands are such that to resolve them a long data span, where rotational splitting appears, is needed. Therefore, interference phenomena will occur and the methods to search for solar g modes must take care of this effect. Using an improved asymptotic law (5), one can predict the position of solar g modes assuming the parameters P_o (related with the Brunt-Vaisala frequency) and ν_r (related with the rotational splitting). This is used to generate for each series, the power spectrum of synthesized g modes with $\ell<4$ with any given parameters P_o and ν_r. In the present analysis, the regions 35 to 45 minutes for P_o and 0 to 3.0 μHz. for ν_r were scanned. The product of any one of the synthesized spectrum with the observed one integrated over a certain frequency range, give us a number related to the degree of agreement between both spectra. Figure 2 shows, as an example, the P_o - ν_r diagram for 1981. The best values for both parameters deduced for each yearly series are shown in Table II.

Because 1984 and 1985 series are long enough to resolve individual peaks, they can be used to look for time-coherent signals. Taking a first subset from day number 1 to day number 80 the power spectrum in the range 25 to 125 μHz was computed. The procedure is repeated from day 5 to 85, 10 to 90, etc until the complete data set is scanned. In such a way we have obtained 17 and 20 displaced series of 80 days for 1984 and 1985. Analyzing their power spectrum we can study how power and phase of any particular frequency changes with time. Knowing in each spectral region the noise level and using some criteria (4), we select peaks (Table III) that have been coherent in time and well above noise. This behaviour is only possible if these frequencies correspond to solar g modes.

TABLE II

YEAR	Po(min.)	ν_r(μHz.)	Δn,1 (μHz.)
1981	41.4	2.0	1.0
1982	42.6	2.2	1.1
1984	35.0	2.2	1.1
	42.4	2.4	1.2
1985	37.4	2.6	1.3

Most probable values of P_o and ν_r for each observing season. In the last column the rotational splitting for ℓ=1 modes deduced from ν_r values. Two alternative P_o determinations are found for 1984, which correspond to similar rotational splitting values.

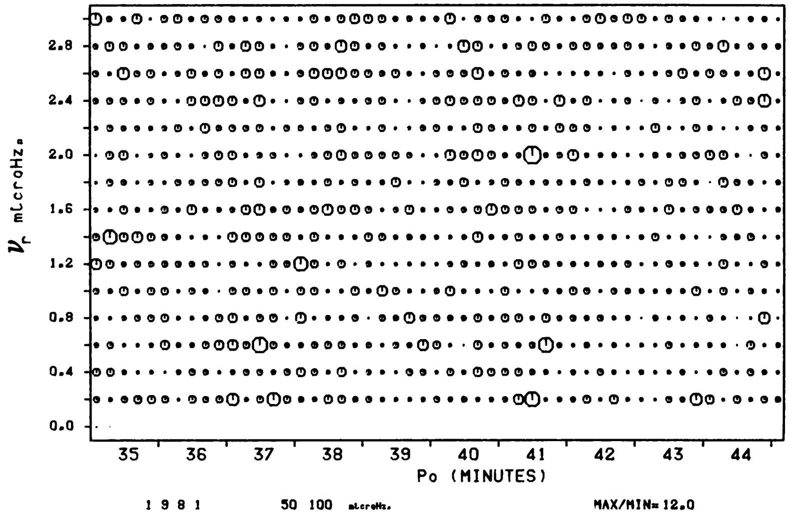

Figure 2. P_o - ν_r diagram for the 1981. Each symbol in the diagram has a size proportional to the product of the generated power spectrum and the observed one, integrated over the range 50 to 100 μHz. The scaling was made with respect to the minimum of the obtained values; the quantity MAX/MIN is indicative of the meaning of any particular value P_o, ν_r with respect to others.

4. CONCLUSIONS

The presence of signal in the frequency range 25 to 125 μHz above noise, shows the signature of solar g modes. The rotational splitting found for the g modes, 1 to 1.3 μHz, indicates that the solar core rotates $\simeq$3 times faster than the surface. Helium deficient solar models and/or models with a moderate degree of mixing in the interior seem adecuate to fit with the present results. In spite of interference phenomena in the spectral region studied, individual g modes have been detected with a coherent time longer than 200 days. Continous and much longer observations are needed to establish well the frequencies and properties of solar g modes.

TABLE III

1984		1985	
FREQUENCY (μHz.)	MEAN AMPLITUDE (cm/s)/.05 μHz.	FREQUENCY (μHz.)	MEAN AMPLITUDE (cm/s)/.05 μHz.
33.15	6.3	33.45	6.3
35.35	8.0	34.25	7.9
39.75	6.5		
40.40	5.9		
41.95	6.8		
47.90	9.2		
50.40	5.8		
55.20	6.8		
58.50	8.9	58.90	7.9
66.30	6.2		
67.20	6.3	76.60	7.4
70.55	5.6	77.30	6.4
81.15	5.8	79.70	6.6
92.00	5.5	93.20	6.2
108.45	5.3		
111.40	4.9		
115.45	4.6		

Peaks identified as g modes from the analysis of the displaced series of 80 consecutive days. This selection is based on the criteria of stable phase($\pm\pi$/10 rad.) and amplitude.

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