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An Estimation of Global p-mode Frequencies and Splittings from the IRIS Network Data: 1989–1996

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Abstract. The IRIS network has accumulated low-l p-modes data since July, 1989, i.e. one complete solar cycle. Since the last publication of a frequency table (Gelly et al. 1997) the IRIS data bank was not only filled with new data, but also has been supplemented with data from other helioseismology instruments, through cooperative programs. The results of a new estimations of frequencies and splitting obtained from $IRIS^{++}$ data (Gelly et al. 1998) for period 1989-1996, as well as their variation along the solar magnetic activity cycle are presented.

1. Introduction

The IRIS network has been operating since July 1,1989 when first instrument was installed on the mountaintop site of Kumbel in Uzbekistan. However, results of the precise frequency determinations were published only for 1989-1992 covering the period of solar activity (Gelly et al. 1997). Furthermore it is well established now that p-modes parameters are changed during solar activity cycle. In the present paper the results of the frequency measurements as well as rotational splitting and frequency shift extracted from IRIS data for period 1989-1996 are presented.

2. Data

The p-modes parameters were extracted from power spectra derived from 8 one-year time series.

Table 1. Day durations and duty cycle of IRIS data string

Years	1989	1990	1991	1992	1993	1994	1995	1996
Duration(days)	183.4	364.4	364.3	365.6	360.2	362.3	363.2	365.0
Duty cycle (%)	34.3	34.2	41.2	40.0	34.0	43.0	48.0	41.4

Duty cycle of these time series presented in Table 1. One can see that duty cycle of that data are low, so the method of direct Fourier transform (without deconvolution) was applied for the analysis. The method of deconvolution was used early for analysis of IRIS data for shorter data string covering summer period of 1989-1992 (Gelly et al. 1997).

3. Extraction of p-mode parameters

To obtain parameters of p-modes we have performed fitting of profiles in power spectra with Maximum Likelyhood Method minimization of log-likelyhood function with χ_2^2 p.d.f. that can be written as

$$S = \sum_{i \in peak} \left(\ln(M(\nu_i, \vec{p})) + \frac{O(\nu_i)}{M(\nu_i, \vec{p})} \right) \tag{1}$$

where $M(\nu_i, p)$ - power in i^{th} bin of the model , $O(\nu_i)$ - observed power in i^{th} bin in the fitting range. The first temporal sidebands were taken into account in the model as well. $M(\nu_i, \vec{p})$ for each azimuthal mode component has been modeled according to (Nigam&Kosovichev 1998):

$$M(\nu_i, \vec{p}) = \left(\frac{A}{1 + X^2} \right) * [(1 + \xi)^2 + \xi^2] \tag{2}$$

where $\vec{p} = (A, \nu_0, \Gamma, \xi)$ - vector of parameters, $X = 2(\nu - \nu_0)/\Gamma$, ν_0 -central frequency for Lorentzian component, Γ its width, A- height and parameter ξ - 'fractional' asymmetry of the mode. To reduce of free parameters we have fixed frequency separation and ratio between first sidebands and main peek at values that were determined from analysis of window function for each power spectra. Because of strong overlap between modes in pairs $l = 2$ & 0 and $l = 3$ & 1 they were fitted together.

4. Frequency shift

Frequency shift via solar activity cycle was determined by direct substruction of frequencies obtained in 1989-1995 and 1996 (minimum of solar activity). Because of strong dependens of shift on radial order of the modes we have made analysis in three frequency ranges, namely for $\nu < 2500\mu Hz$, $2500\mu Hz < \nu < 3700\mu Hz$ and for $\nu > 3700\mu Hz$. We found that for $\nu < 2500\mu Hz$ the frequency shift is very small. For $2500\mu Hz < \nu < 3700\mu Hz$ frequency shift is clearly seen and about $0.48 \pm 0.02\mu Hz$. For high-frequency modes ($\nu > 3700\mu Hz$) frequency shift not well determined because accuracy for frequency determination for these modes is very low. By taking into acount the shift average frequencies were determined and presented in table 3.

5. Estimation of rotational splitting

The rotational splitting presented in this paper was obtained by different methods (Lazrek et al. 1996): 1) auto-correlation method of averaged profiles for individual modes and 2) cross-correlation method of individual profile with close value of radial order for every year and 3)fitting of profiles in power spectra. For methods 1 and 2 we had chose modes with radial order $11 < n < 18$ where splitting was clearly visible and S/N ratio was high. Average values for these two methods are $430.5 \pm 17.8nHz$, $450.5 \pm 17.7nHz$ and $415.0 \pm 11.7nHz$ for $l = 1, l = 2$ and $l = 3$ respectively. For rotational splitting obtained directly by fitting of modes in power spectra we have: $440.9 \pm 26.2nHz$, $423.5 \pm 22.4nHz$ and $424.8 \pm 26.8nHz$ for the same modes. Averaged value for all method are shown in Table 2.

Table 2. Sideral splitting obtained from 8 one-year duration IRIS power spectra

l	$\Delta\nu(nHz)$
1	435.7 ± 22.0
2	437.0 ± 20.0
3	419.9 ± 26.2

6. Conclusions

The quality of IRIS data available now for period 1989-1996 allows us to make the precise determination of frequency of p-modes, rotational splitting and frequency for period of 1989-1996, i.e. fall phase of 22 solar activity cycle. Our results for rotational splitting are in a good agreement with BiSON results and demand a slow rotational core (Chaplin et al. 1999). The frequency shift of modes with $2500\mu Hz < \nu < 3700\mu Hz$ for period 1989-1992 confirm early published results (Gelly et al. 1997). Unfortunately precision of frequency and, consequently frequency shift for modes with $\nu > 3700\mu Hz$ in low, because of overlap between profiles and sidelobes of neighbour peak. We hope that duty cycle of IRIS series will be increased soon by adding data from other helioseismological programs and consequently precision of p-modes parameters determination will be significantly increased.

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References

Chaplin W.J. et al. 1999, MNRAS,308, 405-414

Gelly B. et al, 1997, A&A, 317, L71-L74

Gelly B. et al., 1998, SOHO-6/GONG-98 Workshop Proceedings, 51-55

Lazrek M. et al., 1996, Solar Phys., 166, 1

Nigam R., Kosovichev A.G., 1998, AJ, 505, L51

Table 3. Frequencies for low-l p-modes obtained from fitting of 8 one-year duration $IRIS^{++}$ power spectra. Frequencies were averaged over all spectra and corrected for shift via solar cycle

n	$l=0$	$l=1$	$l=2$	$l=3$
9	...	...	[1536.07 ± 0.62]	...
10	[1548.59 ± 0.70]	[1612.79 ± 0.85]	[1673.55 ± 0.65]	...
11	[1685.78 ± 0.63]	[1749.41 ± 0.35]	[1811.88 ± 0.44]	...
12	[1821.72 ± 0.50]	[1885.57 ± 0.72]	[1945.82 ± 0.44]	...
13	1957.33 ± 0.25	2020.83 ± 0.22	2082.26 ± 0.38	2138.24 ± 0.50
14	2093.67 ± 0.24	2156.79 ± 0.37	2217.73 ± 0.34	2273.57 ± 0.89
15	2228.76 ± 0.11	2292.07 ± 0.30	2352.22 ± 0.30	2407.61 ± 0.35
16	2362.82 ± 0.14	2425.73 ± 0.25	2485.90 ± 0.50	2541.78 ± 0.37
17	2496.25 ± 0.15	2559.28 ± 0.26	2619.69 ± 0.28	2676.10 ± 0.33
18	2629.56 ± 0.22	2693.56 ± 0.34	2754.65 ± 0.32	2811.63 ± 0.45
19	2764.07 ± 0.06	2828.26 ± 0.31	2898.66 ± 0.43	2947.28 ± 0.46
20	2898.96 ± 0.11	2963.49 ± 0.32	3024.90 ± 0.36	3038.70 ± 0.55
21	3033.77 ± 0.10	3098.48 ± 0.34	3160.04 ± 0.30	3219.79 ± 0.95
22	3168.64 ± 0.08	3233.47 ± 0.34	3295.17 ± 0.46	3354.41 ± 0.75
23	3303.65 ± 0.24	3368.81 ± 0.35	3431.02 ± 0.38	3491.25 ± 0.83
24	3439.18 ± 0.21	3504.39 ± 0.48	3567.46 ± 0.65	3628.00 ± 1.11
25	3575.34 ± 0.46	3640.64 ± 0.47	3703.37 ± 0.98	3765.26 ± 1.10
26	3711.78 ± 0.58	3776.89 ± 0.50	3840.34 ± 1.44	3901.96 ± 2.03
27	3848.04 ± 0.77	3913.46 ± 0.85	3975.96 ± 2.18	4039.88 ± 0.37
28	3984.36 ± 1.33	4050.87 ± 2.54	4114.45 ± 1.93	4180.49 ± 2.62
29	4121.55 ± 2.66	4188.36 ± 1.21	4252.50 ± 1.40	4317.39 ± 1.62
30	4260.50 ± 2.18	4326.67 ± 2.35	4390.97 ± 2.08	4458.34 ± 2.31
31	4394.81 ± 4.10	4460.78 ± 3.39	4527.99 ± 2.43	4592.24 ± 4.26
32	4536.30 ± 2.47	4602.76 ± 3.84	4661.17 ± 2.31	4729.36 ± 4.03
33	4674.82 ± 1.91	4739.29 ± 3.10	4800.13 ± 5.02	4863.95 ± 4.19
34	4808.27 ± 4.58	4880.61 ± 5.03	4941.56 ± 2.99	5003.65 ± 3.95
35	4950.53 ± 4.71	5021.63 ± 4.74	...	...