

Degree dependence of the p-mode damping in Sun-as-a-star data

D. Salabert^{1,2}, W. J. Chaplin³, Y. Elsworth³ and R. New⁴

¹ National Solar Observatory, 950 N. Cherry Avenue, Tucson AZ 85719, USA

² High Altitude Observatory, National Center for Atmospheric Research, P.O. Box 3000, Boulder, CO 80307-3000, USA

³ School of Physics and Astronomy, University of Birmingham, Edgbaston, Birmingham B15 2TT, UK

⁴ School of Science and Mathematics, Sheffield Hallam University, Sheffield, S1 1WB, UK



UNIVERSITY OF BIRMINGHAM

1 Introduction

We report here on evidence for a degree dependence of the variations observed over the solar cycle of the widths of the low-degree p modes. The data came from the analysis of a ≈ 10 -yr dataset of Sun-as-a-star observations made by the BiSON network. Monte-Carlo simulations with artificially generated datasets were performed to validate our results, and to correct the fitted mode parameters from the effects arising from the temporal window functions. We confirm earlier results obtained by [2].

2 Data and Analysis

The following analysis made use of 3456 d of low-angular-degree solar p-mode full-disk observations collected by the six-station, ground-based Birmingham Solar-Oscillations Network (BiSON) data. Starting 1992 July 26, this ≈ 10 -yr period spans the falling phase of solar cycle 22 and the rising phase and the maximum of solar cycle 23. In order to derive solar-cycle trends, the 3456-d principal series was divided in 32 pieces of 108 d of data, covering a range of duty cycles between 63% and 87%.

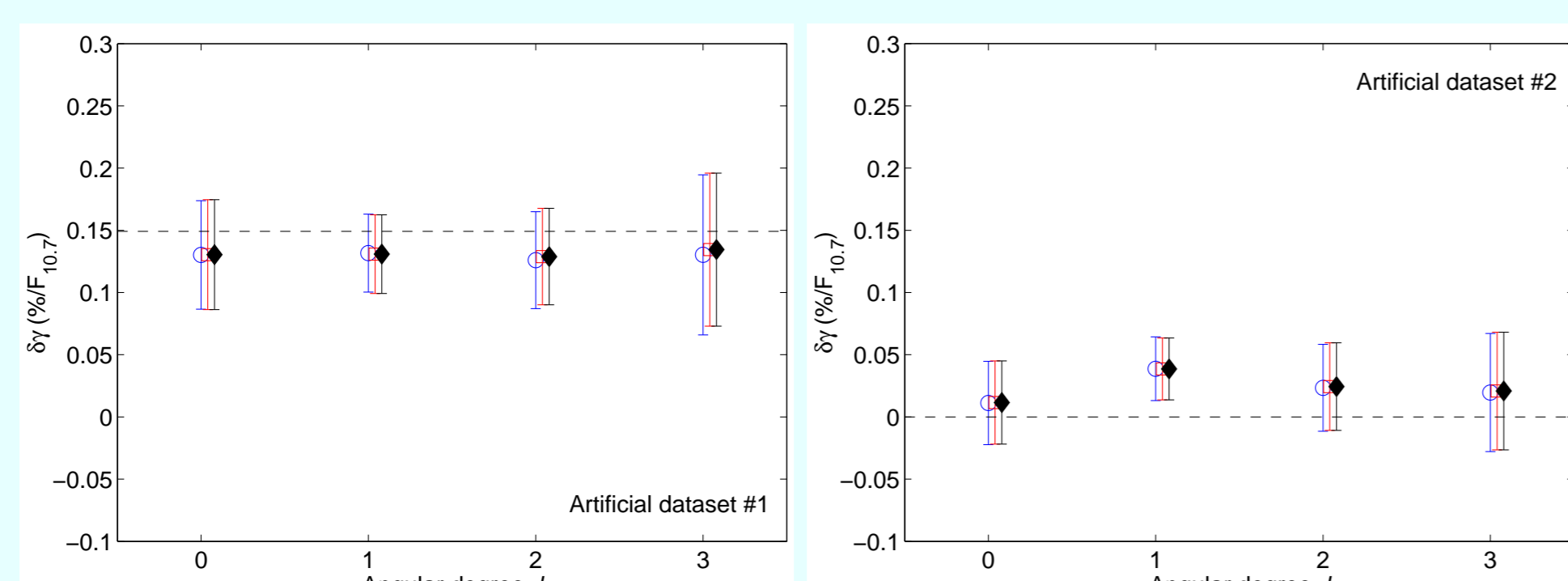
The fractional variations of the mode widths with solar activity were obtained by performing a linear regression against the 10.7-cm solar radio flux, used as a proxy of the global level of solar activity. The resulting gradients, $\delta\gamma$, correspond to the sensitivity to solar activity of the mode widths, γ , per unit of change in solar radio flux. They were averaged over 2600 and 3600 μHz , by 3 different ways to determine their means and uncertainties (different symbols on the plots). In the analogy for the p modes as a forced and damped oscillator, the mode width is related to its damping rate. Then, any change in the mode widths corresponds to variations in the mode damping.

3 Simulations with artificial data

In order to better understand any bias present in the estimated shifts arising from the observational window functions, the gaps in the data leading to overestimate the mode widths during the peak-finding process, two different sets of 20 time series of 3456-d artificial data were constructed: set #1 simulated activity-related variations in the mode parameters identical for each mode degree, while in set #2, the mode parameters remained constant with time.

For both sets, the time series were divided in 32 pieces of 108 d each, modulated by the corresponding BiSON window functions. The mode parameters and their fractional variations were determined as in Sec. 2.

Artificial datasets - Fractional variations (% per unit of change in $F_{10.7}$) in mode width, $\delta\gamma$, as a function of ℓ and averaged over 2600 and 3600 μHz , obtained from the analysis of the 3456-d artificial datasets #1 (left panel) and #2 (right panel). The dashed lines on each panel represent the modeled input variations.



The uncovered changes in the mode widths are slightly underestimated (set #1) and overestimated (set #2) by only an amount smaller than 0.03% per unit of change in the 10.7-cm radio flux. Moreover, the observed differences are degree independent as it was simulated during the construction of the artificial datasets.

By use of Monte-Carlo simulations with artificially generated datasets, we can conclude that the peak-finding routines return values close to their real values without any bias for one (or more) particular degree(s).

4 Results with BiSON data

From the results of the analysis of the artificial datasets #1 and #2, corrections from the impact of the window functions on the mode width estimates were computed for each (n, ℓ) and applied on the fitted widths from the 32 108-d BiSON time series. The temporal fractional variations were then determined as in Sec. 2.

The variations in mode damping, $\delta\gamma$, show a degree dependence between $\ell = 0$ and $\ell = 3$ along the solar cycle. The modes $\ell = 0$ presents variations twice smaller than for $\ell = 1, 2$, and 3.

BiSON data - Fractional variations (% per unit of change in $F_{10.7}$) in mode damping, $\delta\gamma$, as a function of ℓ and averaged over 2600 and 3600 μHz , obtained from the analysis of 3456-d BiSON data, once corrected from the window function effects with artificial sets #1 (left) and #2 (right). The solid lines represent a zero change.

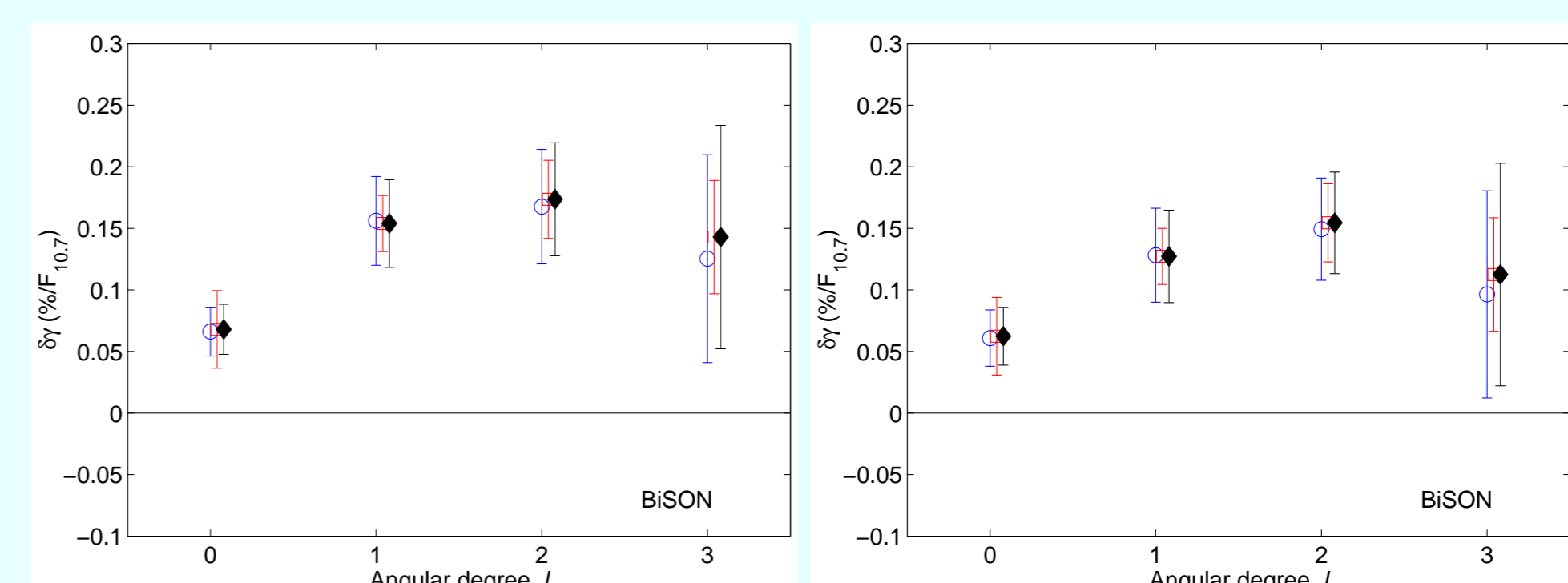


Table 1. Fractional variations (%) of the low- ℓ p-mode damping from solar minimum to solar maximum, averaged over 2600 and 3600 μHz . Corrections of the impact from the window functions were applied with artificial sets #1 and #2.

BiSON	$\ell = 0$	$\ell = 1$	$\ell = 2$	$\ell = 3$	$\langle \ell = 0, 1, 2 \rangle$
$\delta\gamma_{\#1} \dots$	$9.9 \pm 3.0\%$	$22.5 \pm 5.2\%$	$25.4 \pm 6.7\%$	$20.9 \pm 13.3\%$	$14.7 \pm 2.4\%$
$\delta\gamma_{\#2} \dots$	$9.1 \pm 3.4\%$	$18.6 \pm 5.5\%$	$22.6 \pm 6.0\%$	$16.4 \pm 13.2\%$	$13.8 \pm 2.6\%$

The averaged values over $\ell = 0, 1$, and 2 (last column in Table 1) are in good agreement with previous ℓ -averaged measurements of the variation in the mode damping made with full-disk data [1, 4, 3].

5 Conclusion

We have analyzed 3456 d of full-disk BiSON observations, divided into 32 contiguous 108-d time series to search for a degree dependence in the variations with solar activity of the low- ℓ p-mode damping. The fractional variations of the mode damping were obtained by performing linear regressions at each (n, ℓ) against the integrated solar radio flux and averaged over the frequency range from 2600 and 3600 μHz . We performed Monte-Carlo simulations with artificial 3456-d full-disk datasets to determine the impact of the window functions on the fitted mode widths and to define sets of corrective factors for each (n, ℓ) mode.

The variations in the mode damping, $\delta\gamma$, show strong indications of a degree dependence for modes between $\ell = 0$ and 3. The modes with $\ell = 0$ have significantly lower changes along the solar cycle than the other low- ℓ modes, and present an increase of about 10% from solar minimum to solar maximum. The modes with $\ell = 1, 2$, and 3 have comparable amounts of change, of about 20% from solar minimum to solar maximum.

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