Helioseismology across solar cycles: results from the BISON network

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Introducing BiSON

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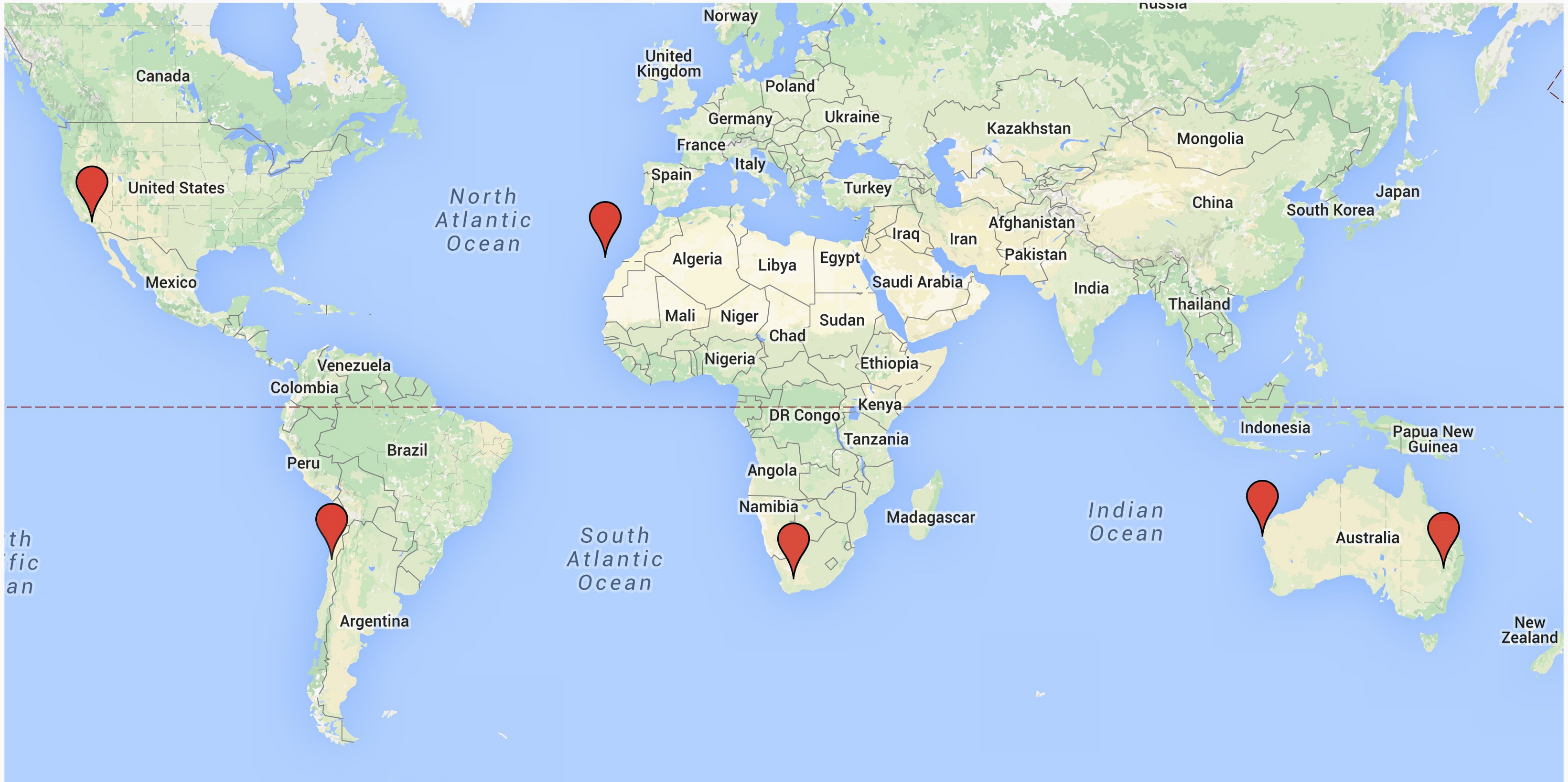
Birmingham Solar Oscillations Network: A global (semi-) automated network



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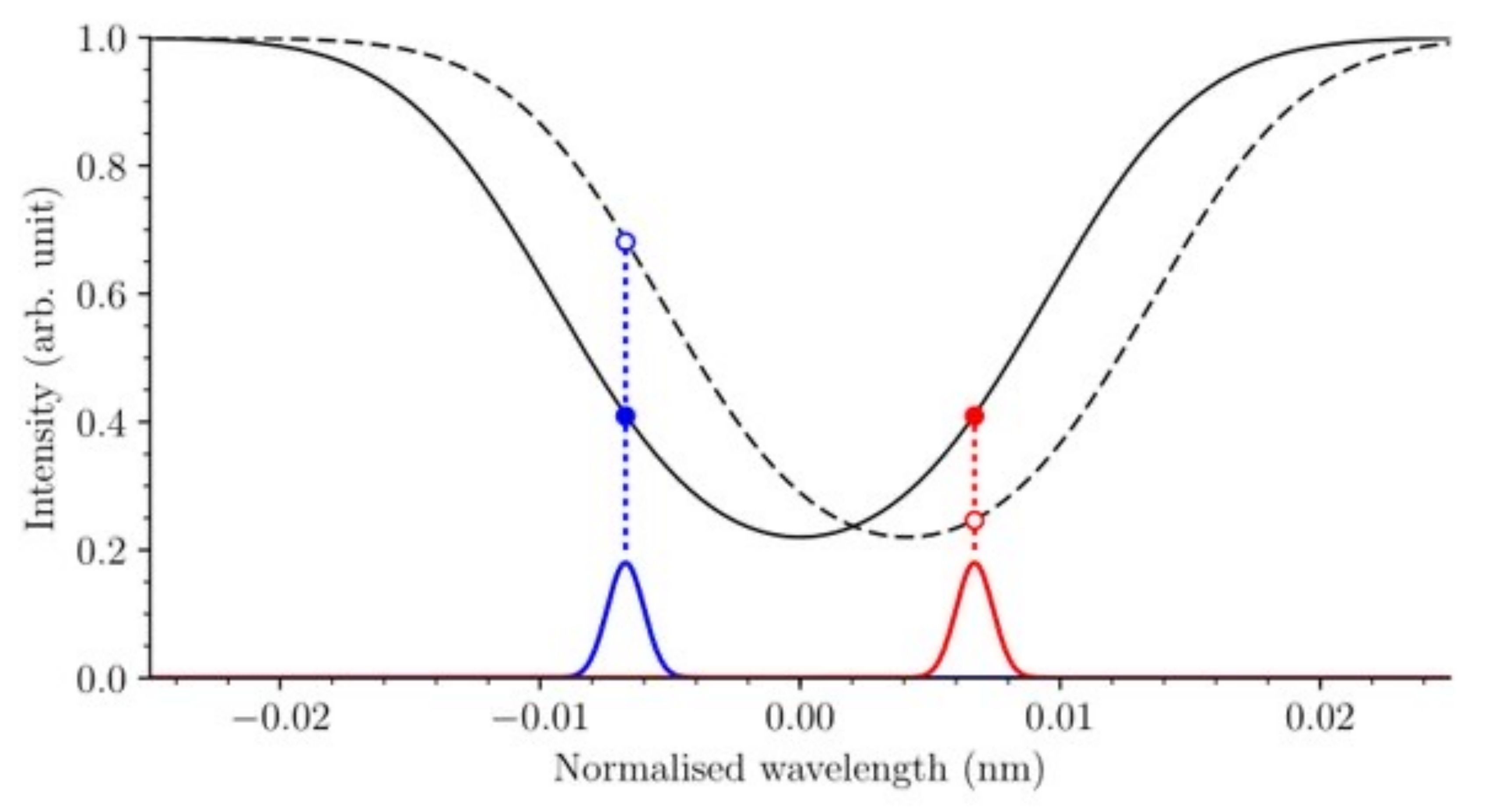
Measuring the Doppler shift of the Potassium D1 line



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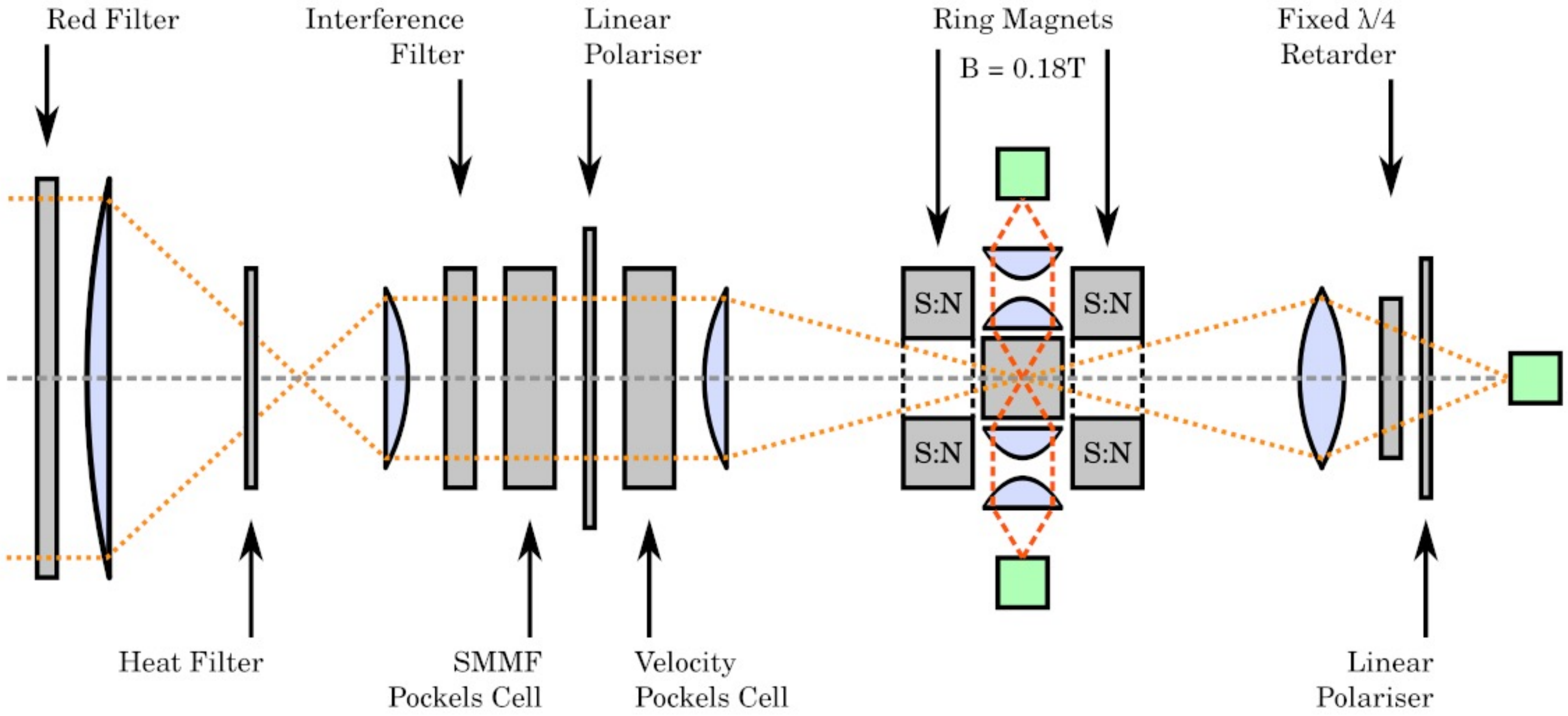
Schematic of the instrument



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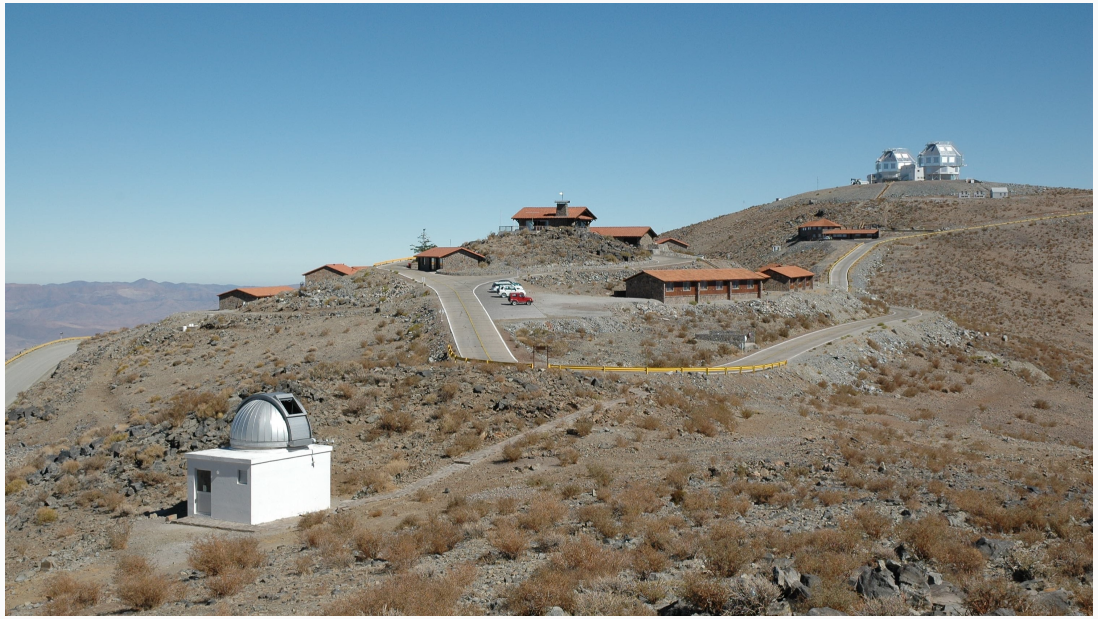
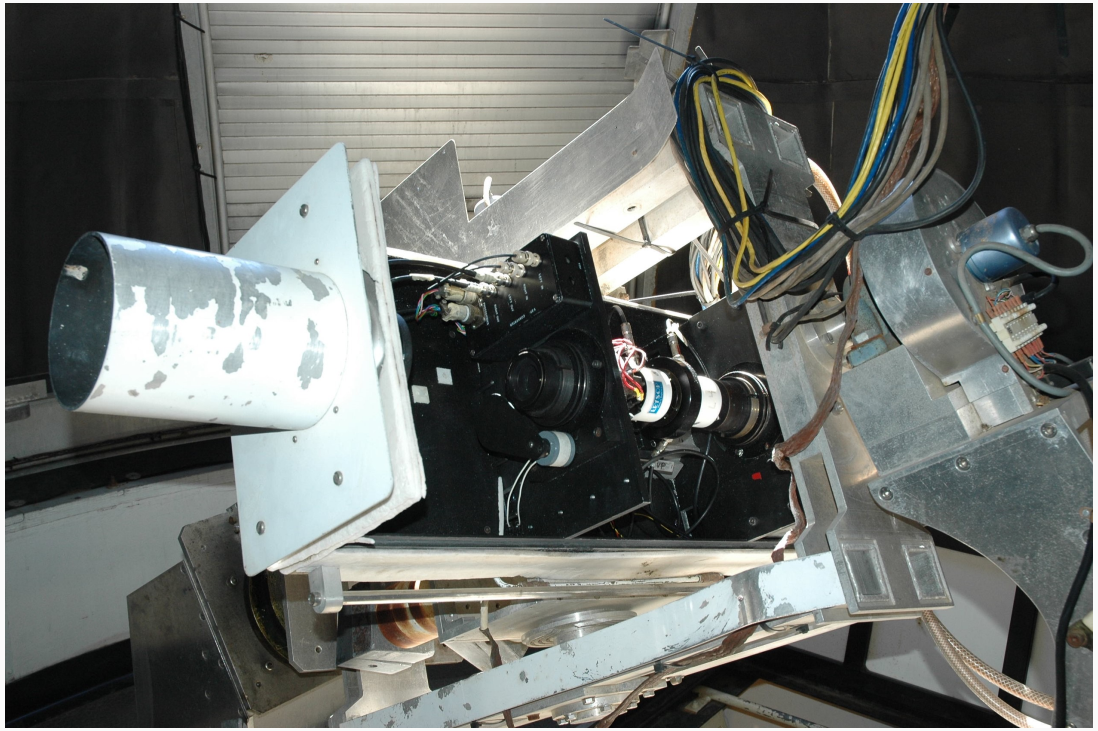
Example of a BiSON site and an instrument





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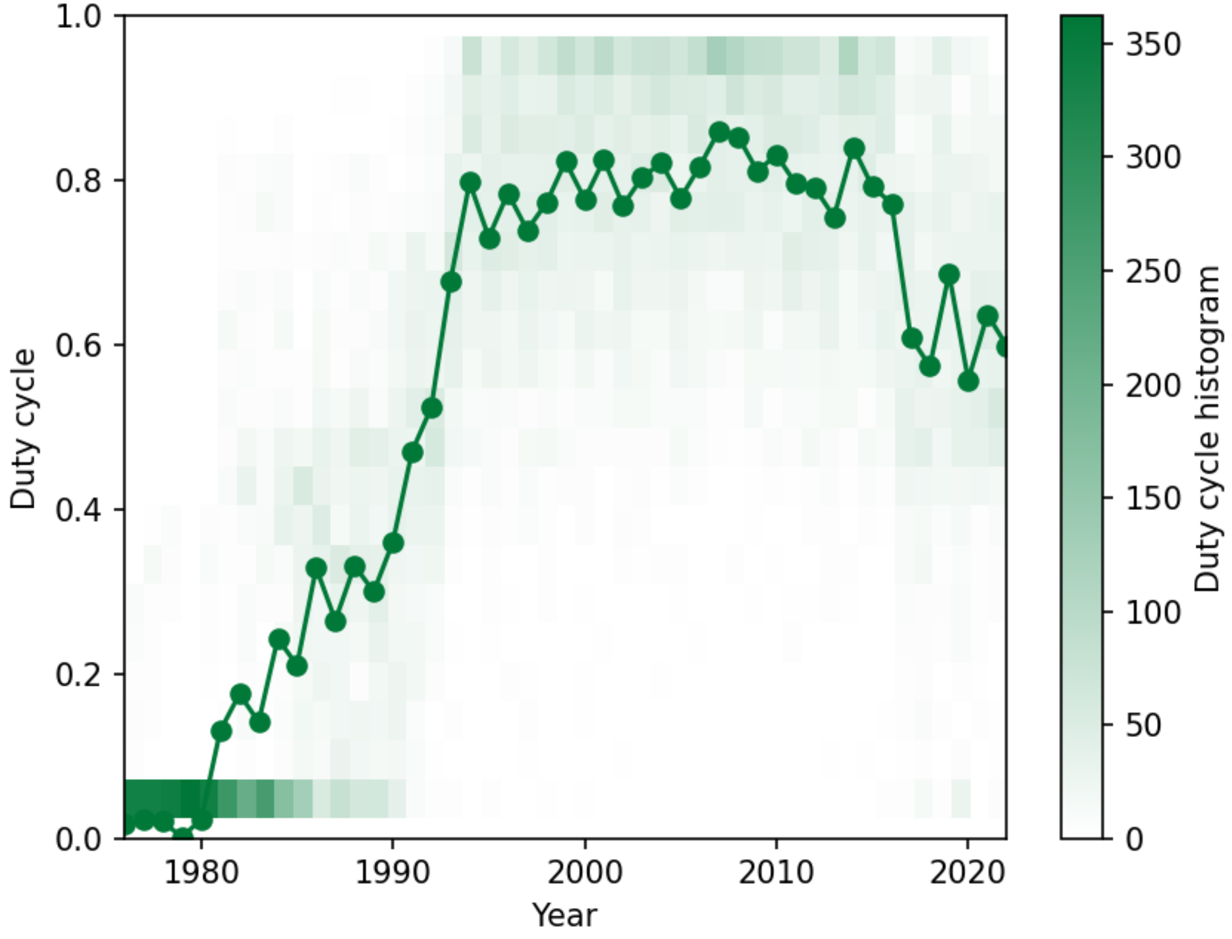
BiSON duty cycle



Early observations were mostly summer campaigns.

Full network deployed in early 1990s.

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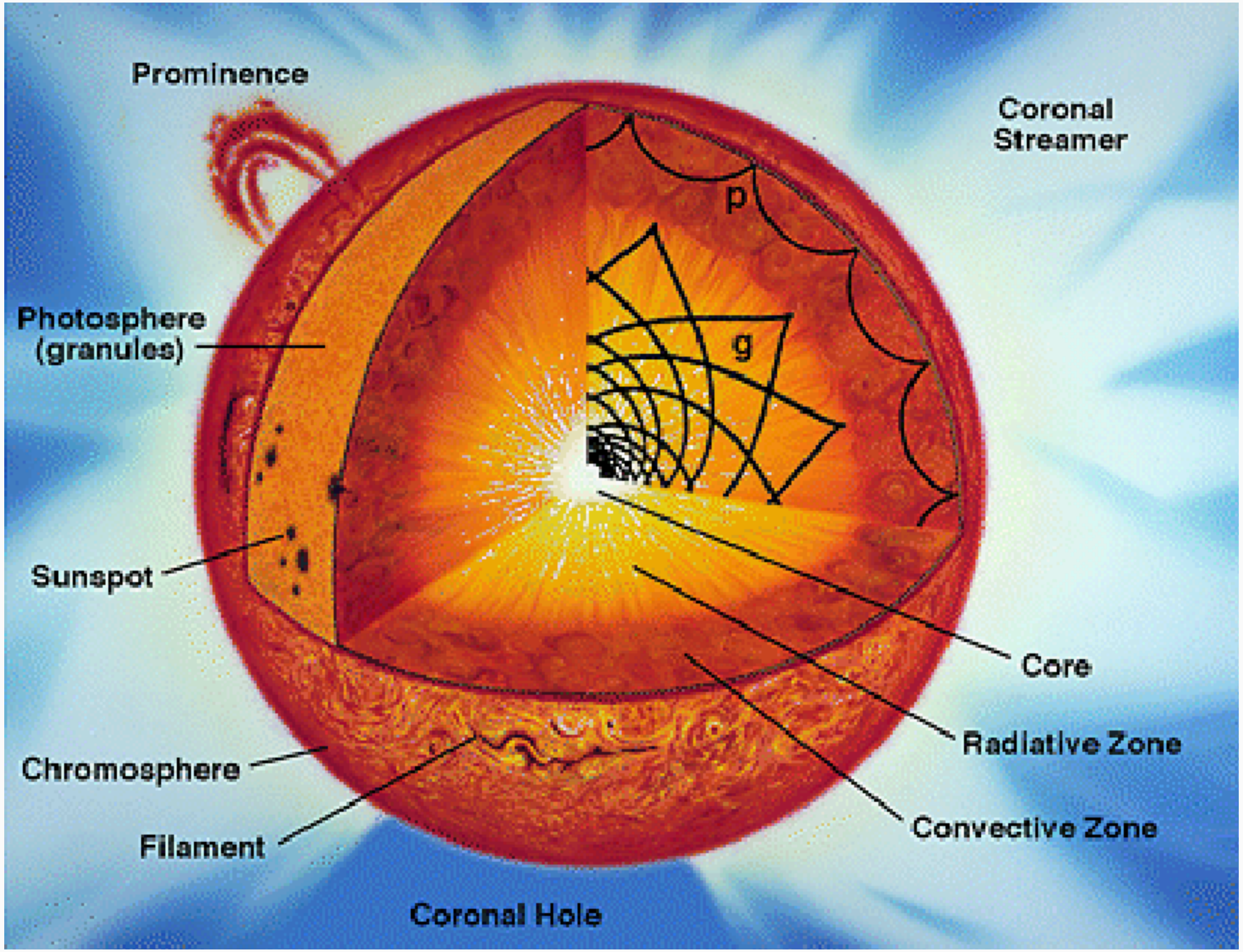
Inside the Sun



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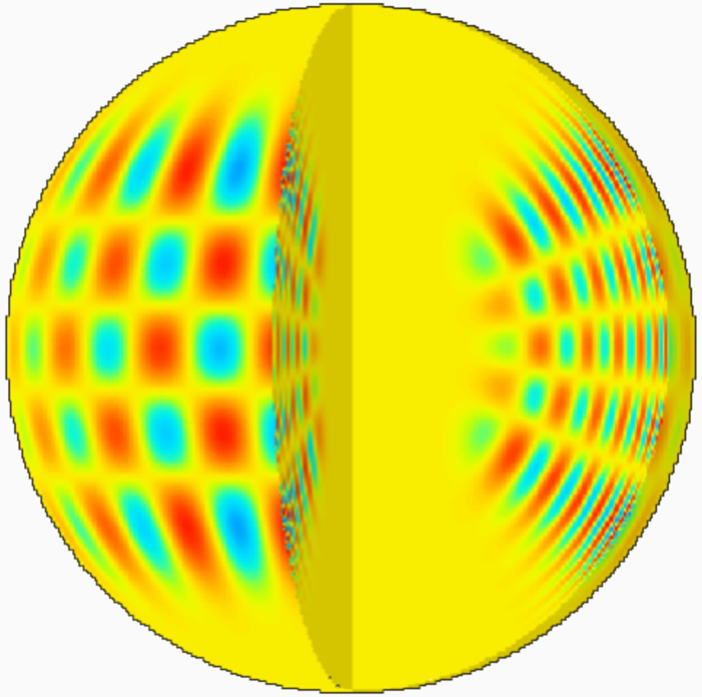
p-mode anatomy

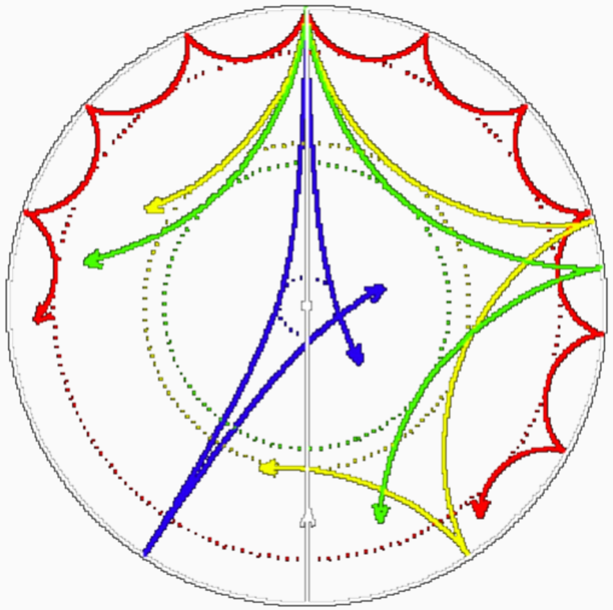


A p mode is a standing acoustic wave.

Each mode can be described by a spherical harmonic.

Quantum numbers *n* (radial order), *l* (degree), and *m* (azimuthal order) identify the mode.

Different modes sample different regions

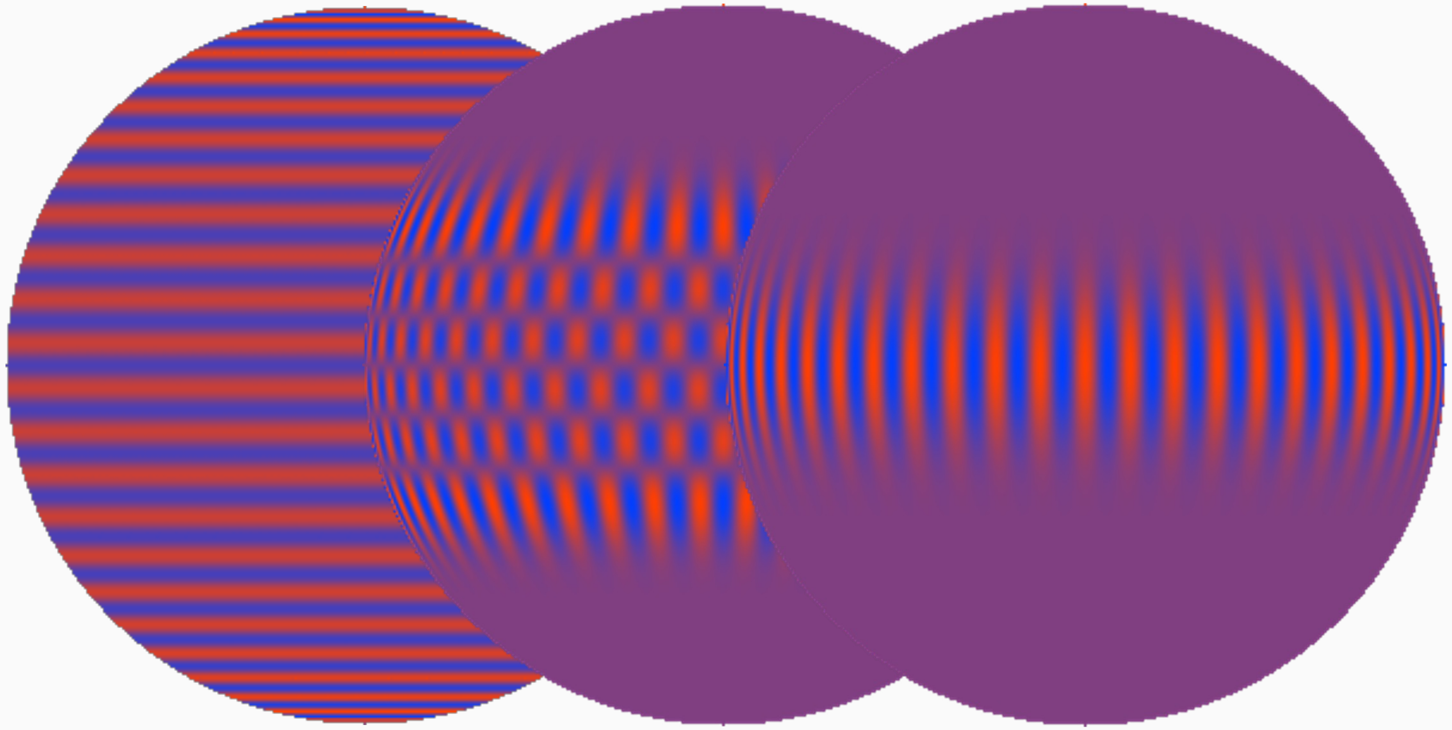


The lower the degree *l*, the fewer surface reflections, and the deeper the mode penetrates.

All modes are most sensitive to the near-surface region

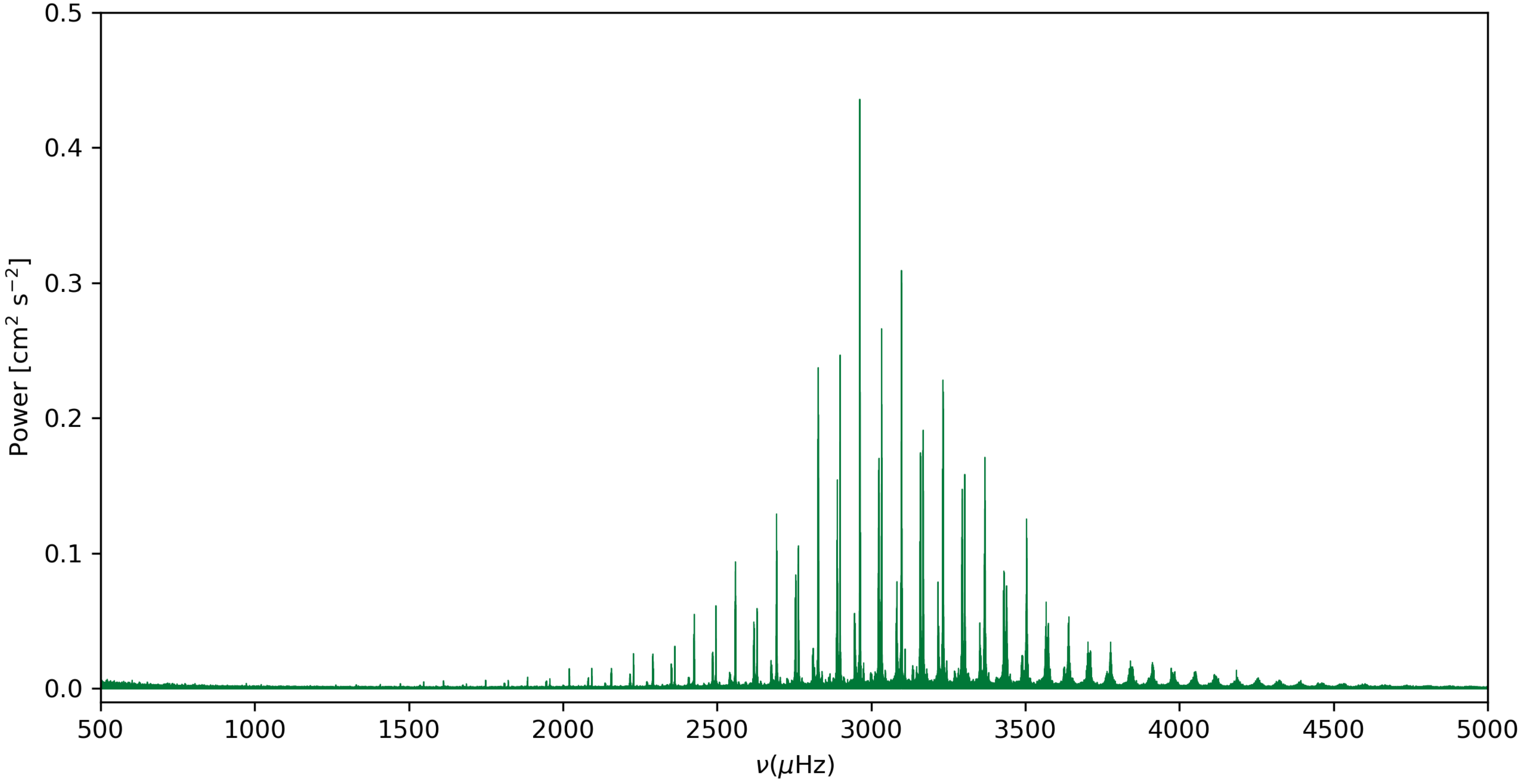
Rotation splits modes into multiplets

Different *m* values sample different latitude ranges



$l=50, m=0$ $m=45$ $m=50$

Acoustic Spectrum from 45 years of BiSON data



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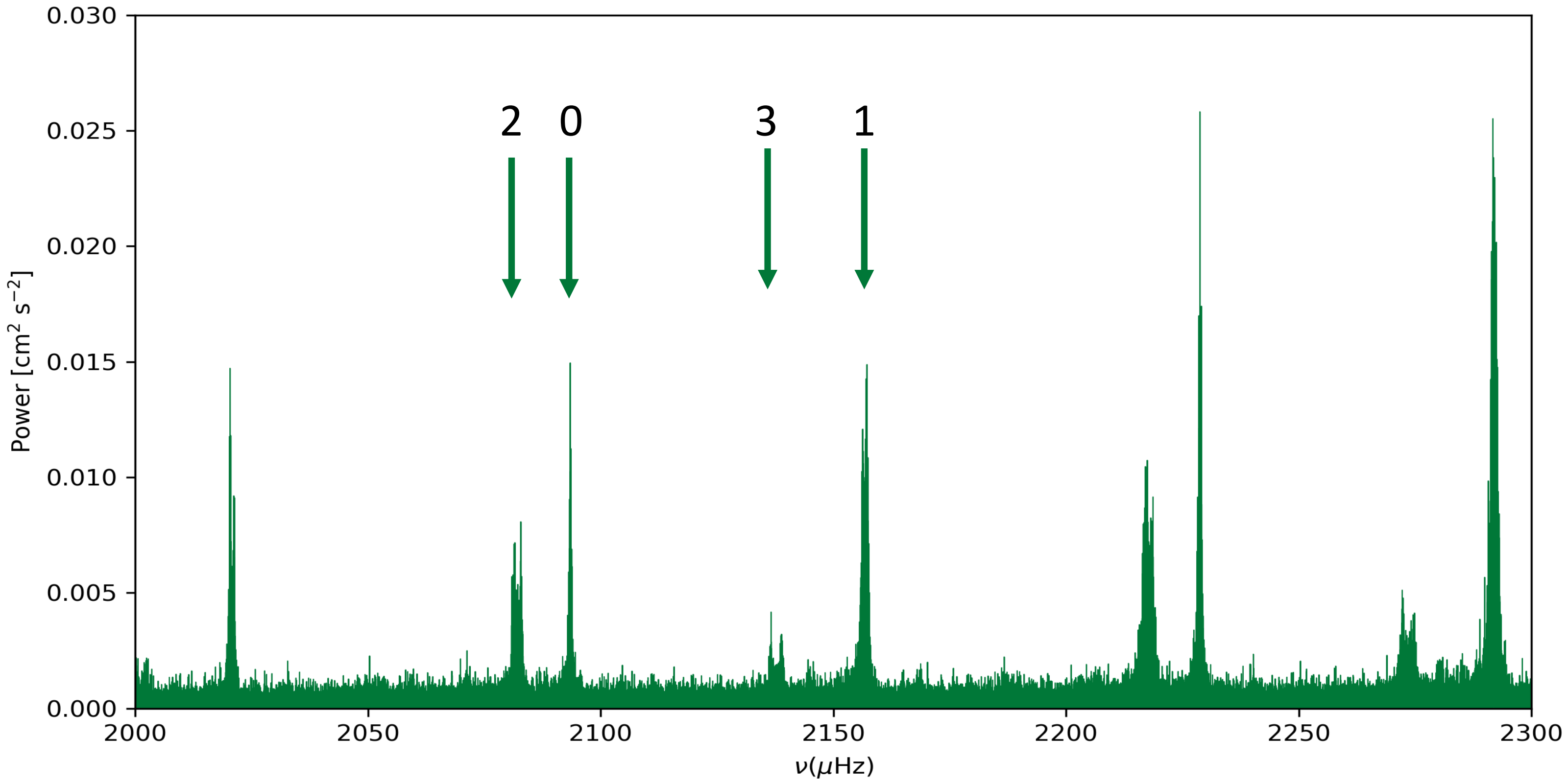
Acoustic Spectrum from 45 years of BiSON data



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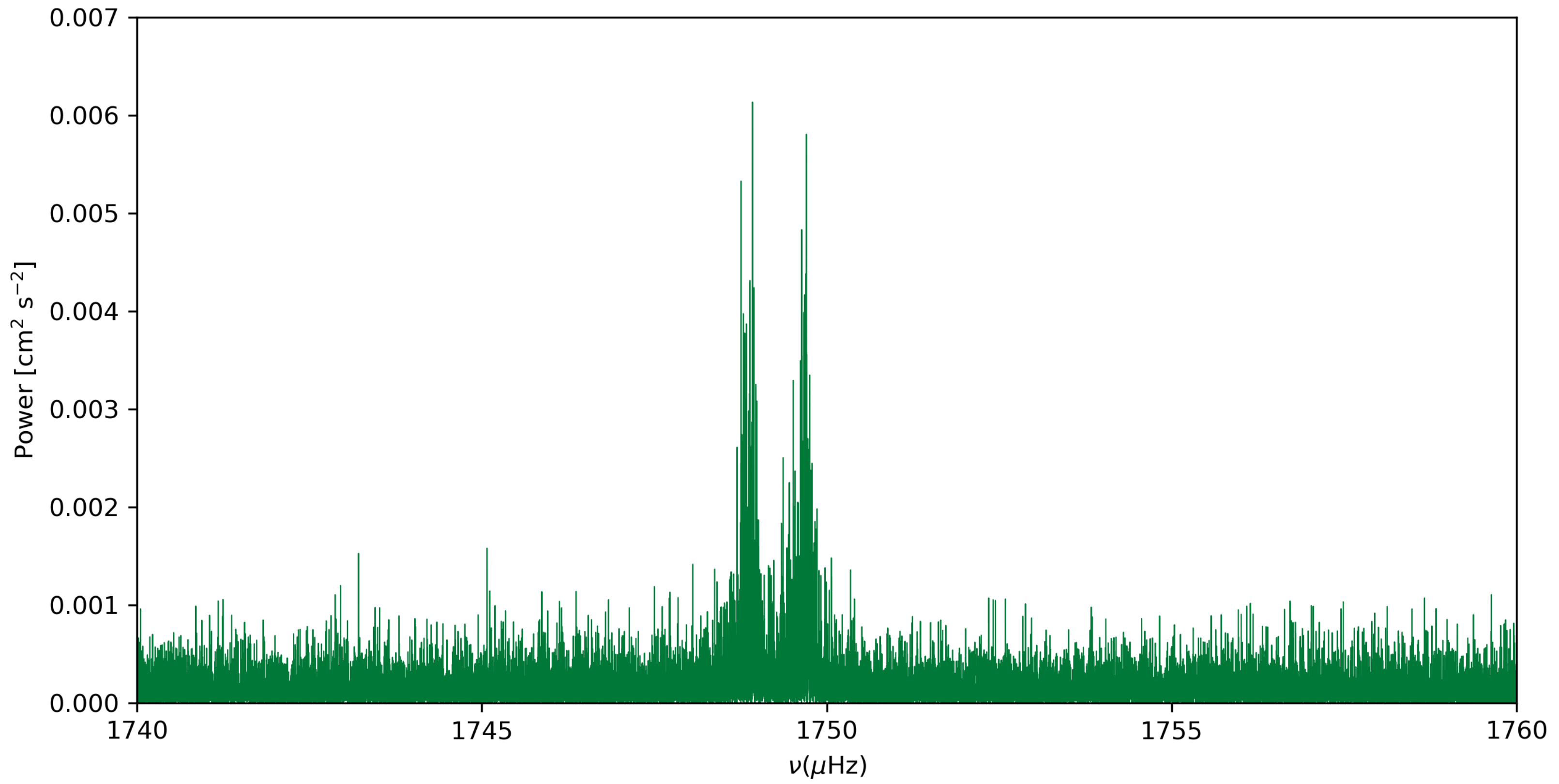
Acoustic Spectrum from 45 years of BiSON data



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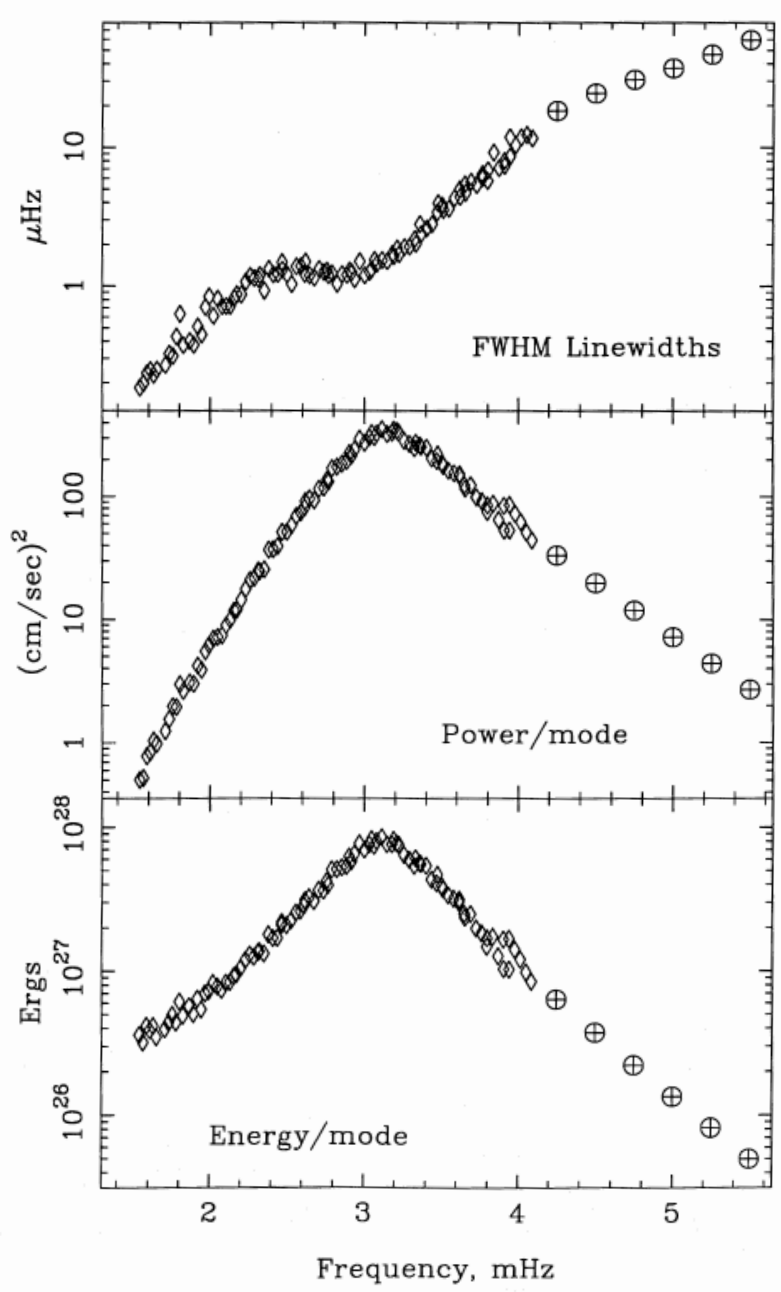

Medium-degree mode parameters

From Libbrecht, 1988.

Amplitude peaks, linewidth has plateau around 3mHz.

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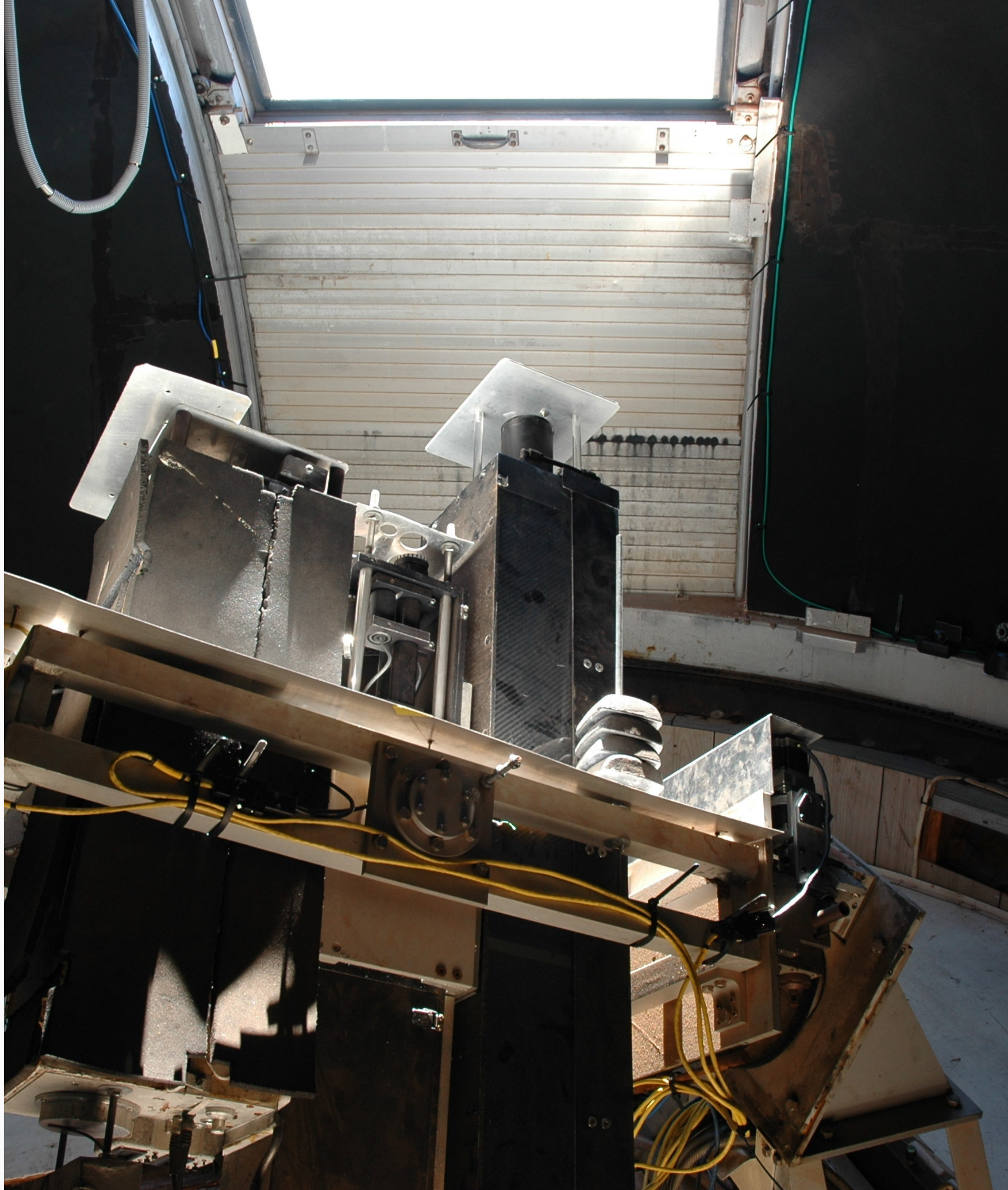
Frequency variations



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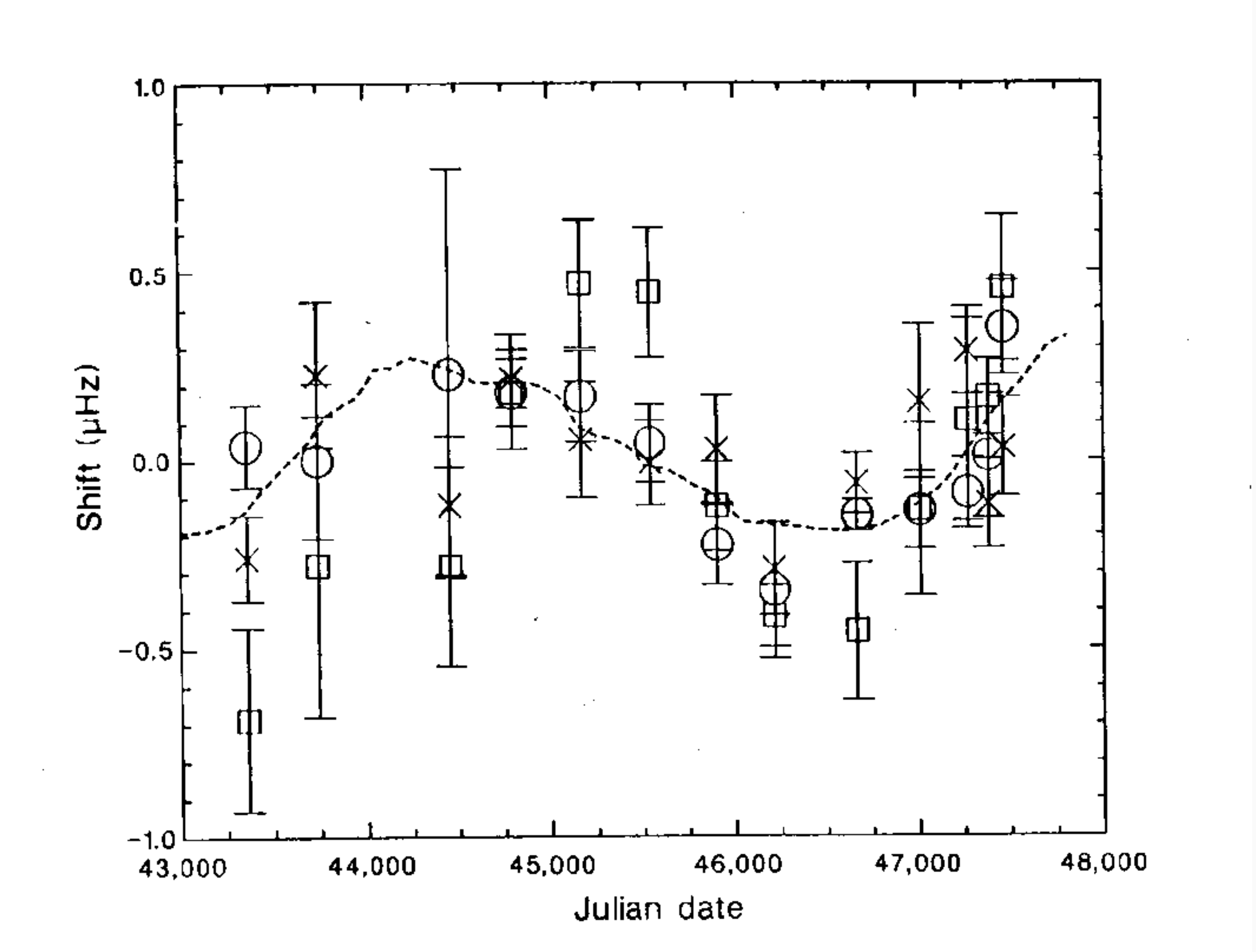
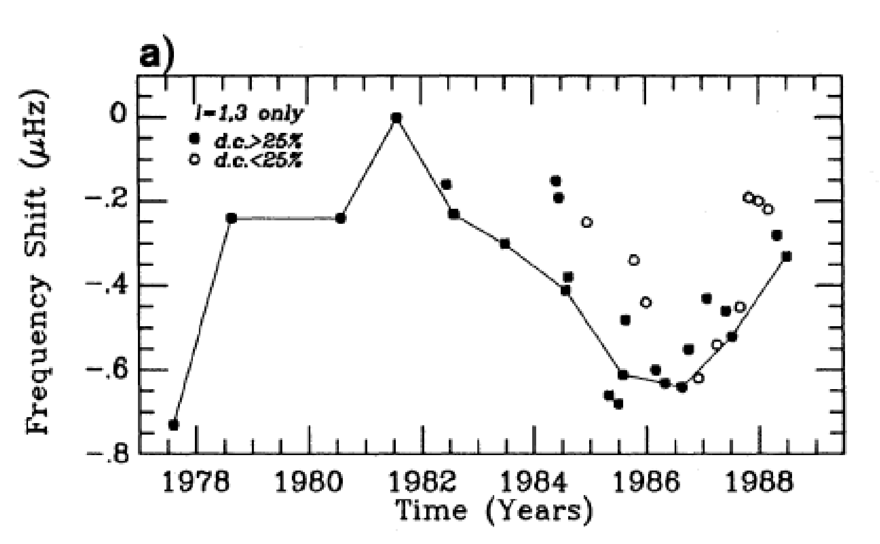
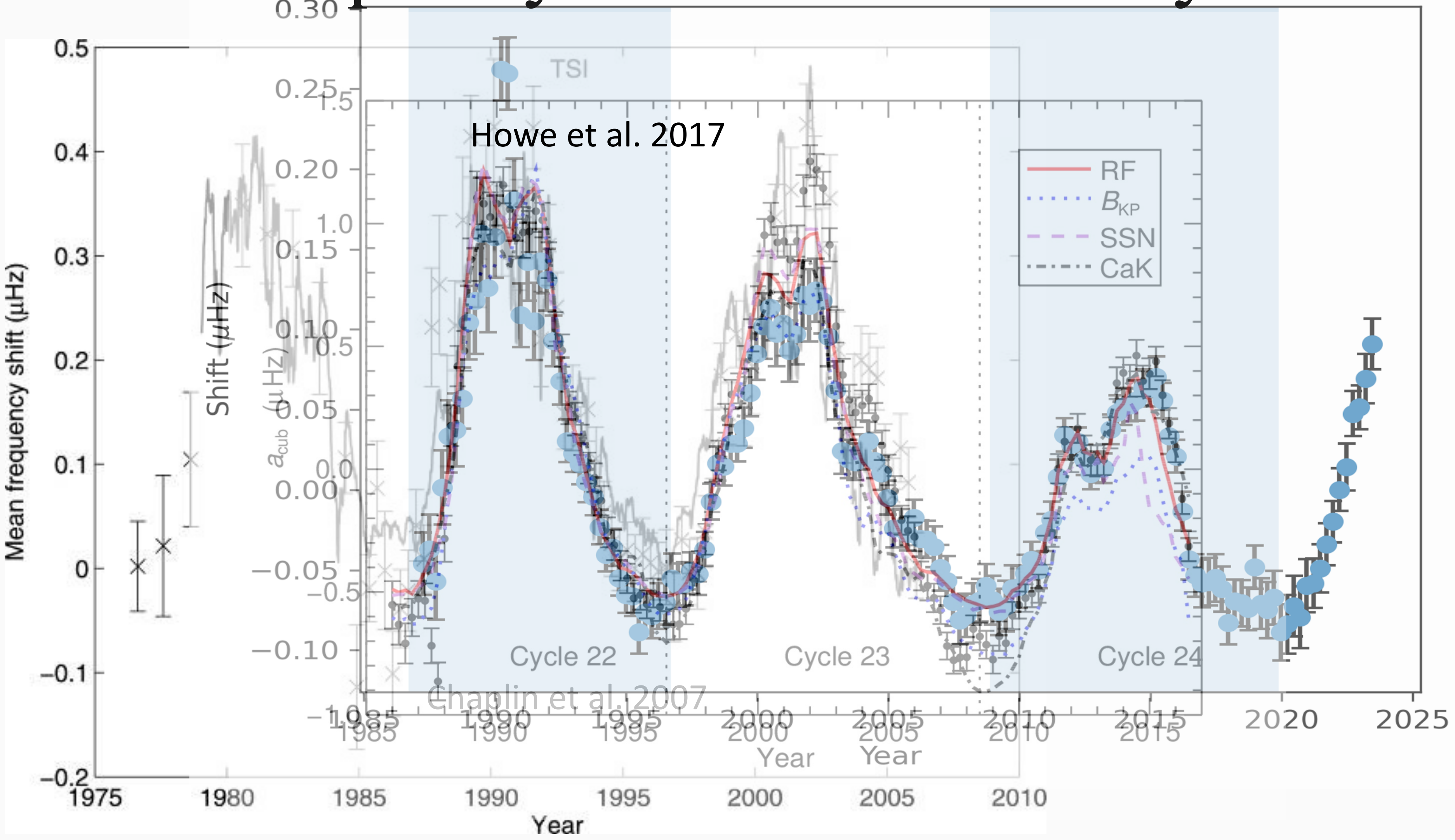
Frequency shifts with solar cycle



BiSON, Mark I (Palle et al. 1989, Elsworth et al. 1990)



Frequency shifts with solar cycle



modes, close together in frequency ($l = 0, 1, 2$, with two n-

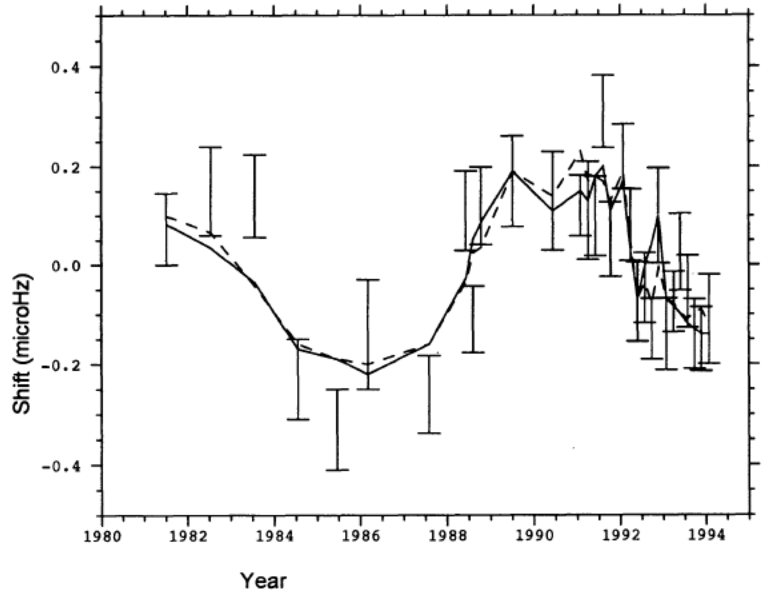


FIG. 3.—Mean frequency shifts, 1981–1994, averaged over 24 modes. The modes are $l = 0$, $n = 17$–24, $l = 1$, $n = 17$–24, $l = 2$, $n = 16$–23. The points are represented by $\pm 1\ \sigma$ error bars. *Solid curve*: linear fit to Sunspot number. *Dotted curve*: linear fit to 10.7 cm flux.

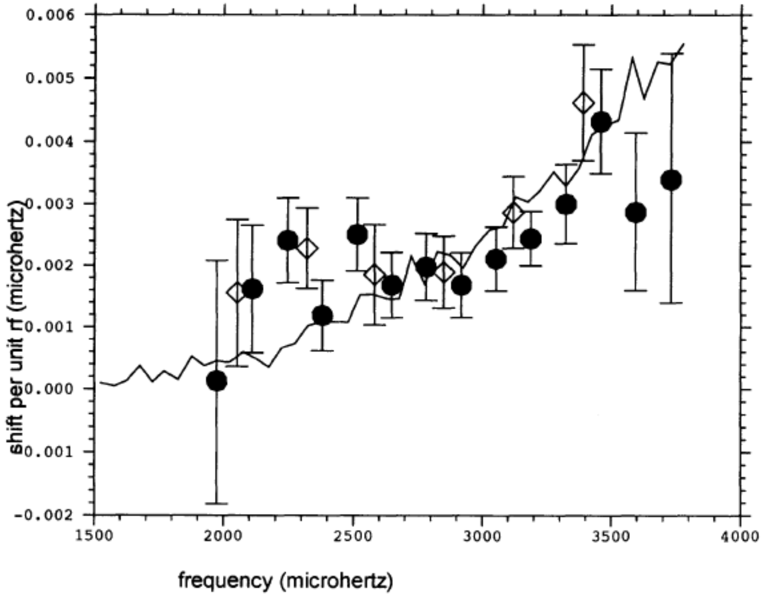


FIG. 4.—The frequency dependence of solar-cycle shifts in p-mode frequencies. Comparison of results obtained by different methods. *Filled circles*: BISON data: mean difference between high-activity and low-activity data sets, for groups of three modes. *Open diamonds*: BISON data: gradient of frequency-shift vs. 10.7 cm flux fit, for groups of six modes. *Solid curve*: Results of Libbrecht, Woodard, & Kaufman (1990), for higher degree modes.

Solar p-Mode Frequencies and Their Dependence on Solar Activity: Recent Results from the BISON Network

Elsworth, Y.; Howe, R.; Isaak, G. R.; McLeod, C. P.; Miller, B. A.; New, R.; Speake, C. C.; Wheeler, S. J. ApJ 434, 801 (1994)

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Frequency shifts with solar cycle (resolved-Sun)

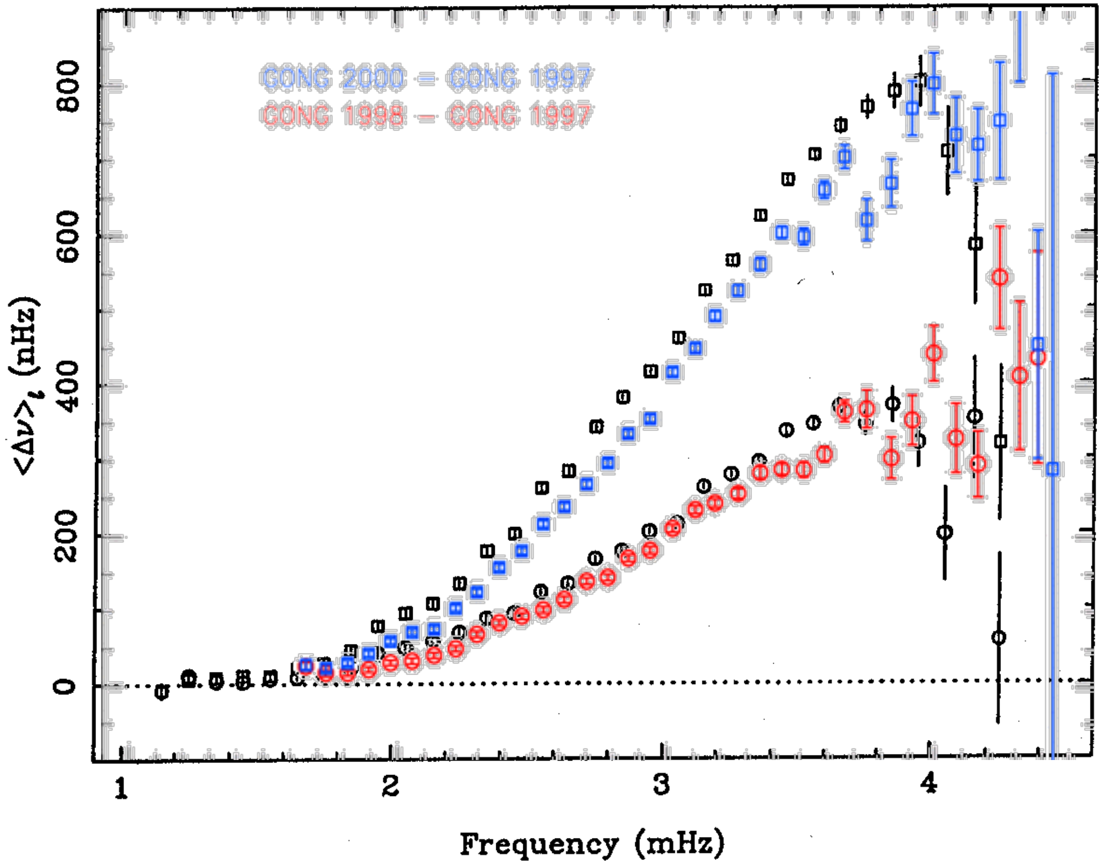
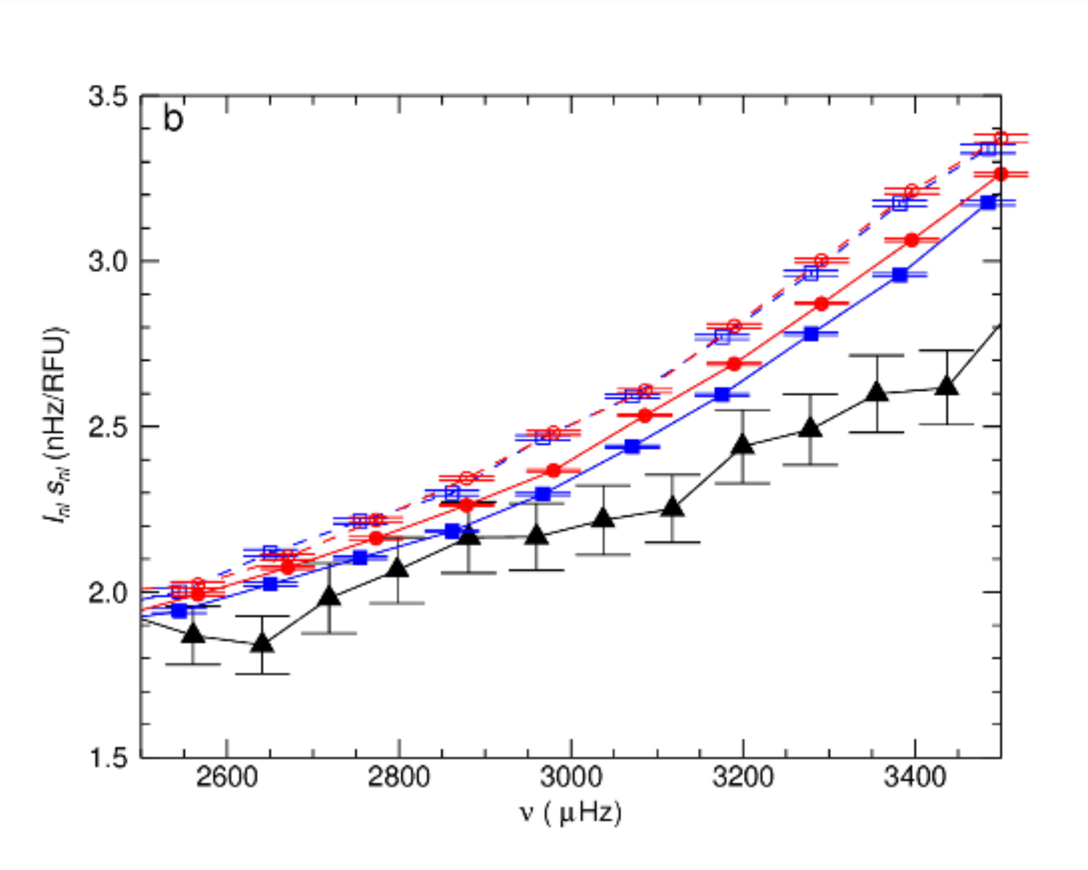
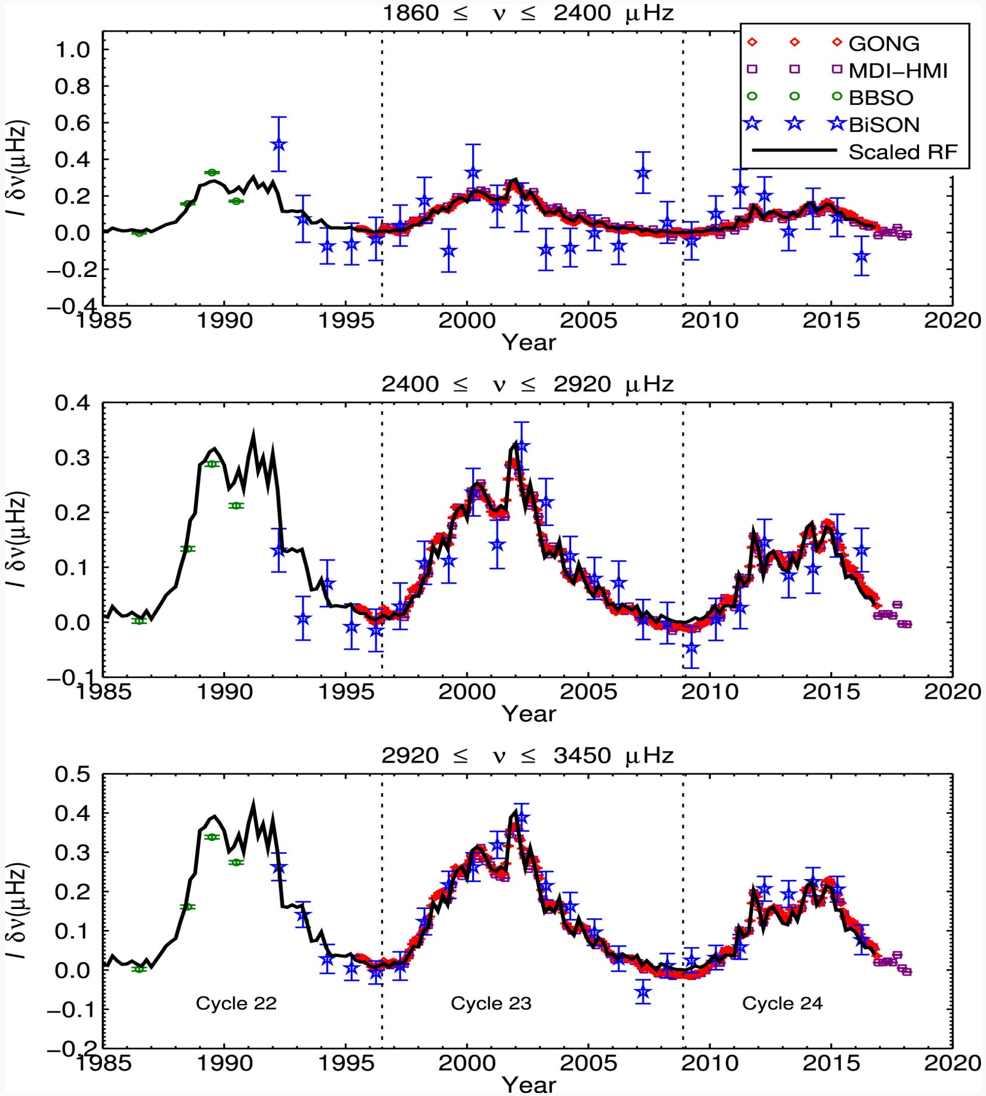


Figure 18. Frequency shift as a function of frequency, using frequencies from 1986 as a reference. The frequency dependence was obtained by averaging over modes in the range $4 \leq l \leq 140$ in degree. Data from 1988 are denoted by circles, data from 1989 by squares. From Woodard and Libbrecht (1991).

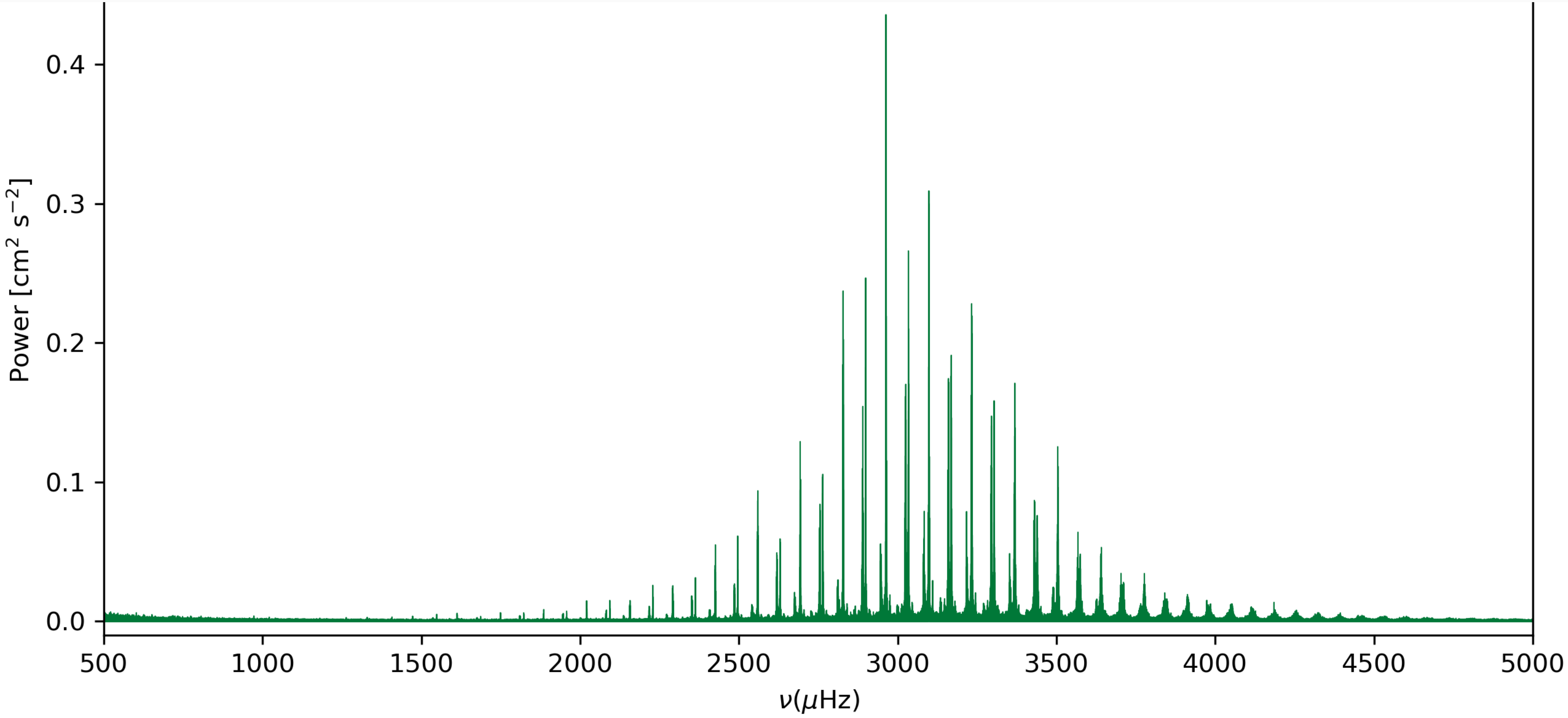
The frequency dependence of frequency changes tells us the changes are mostly happening close to the surface.

Comparing BiSON frequency shift results with resolved-Sun

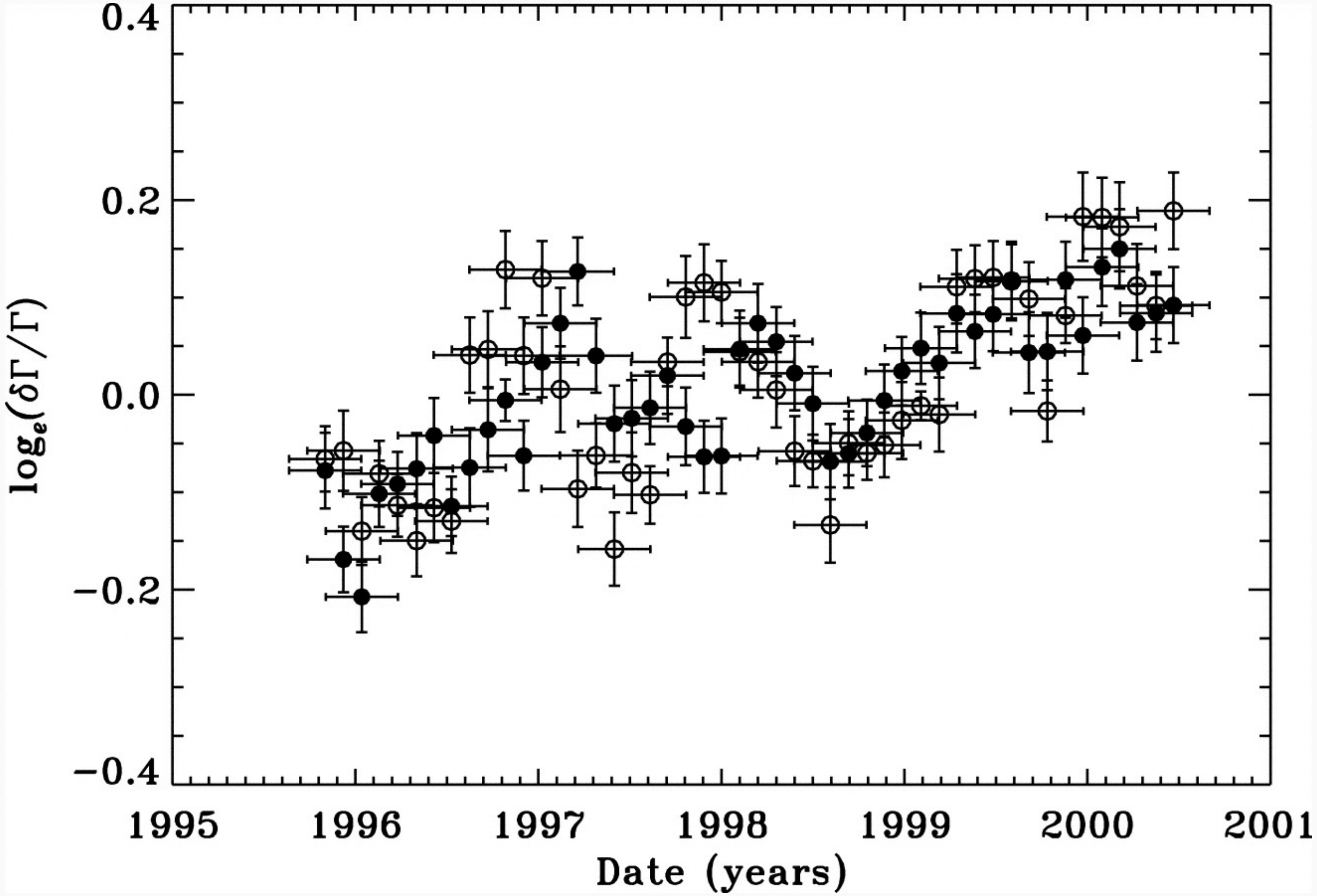




Other parameters



Low-degree mode linewidth increasing with solar activity (Howe et al. 2003)



Low-degree mode amplitude decreasing with solar activity

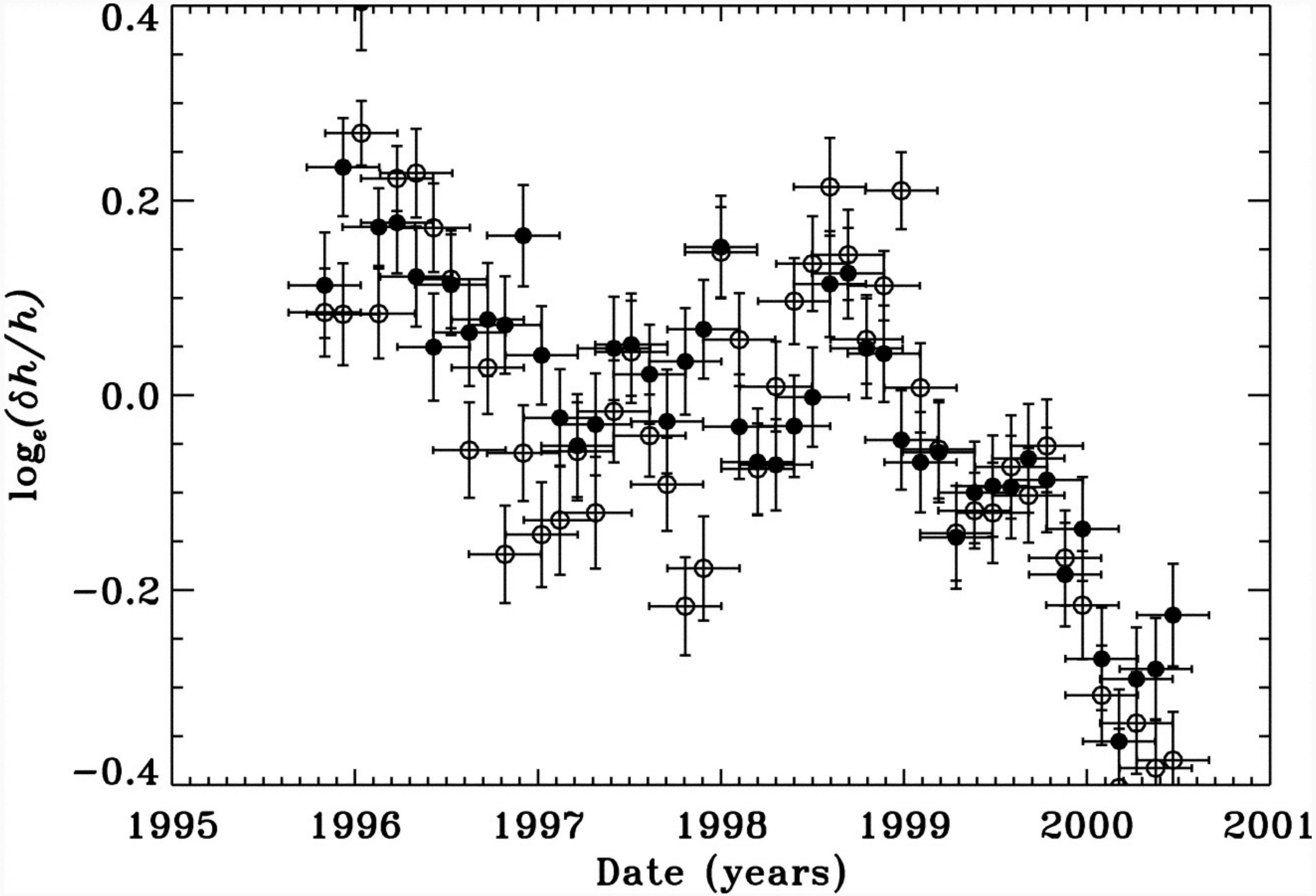


Table 1. Mean, corrected variations over the solar cycle (from activity minimum to maximum) of several p-mode parameters — averaged over modes in the range $2600 \leq \nu \leq 3600$ μHz — as inferred from the analysis of BiSON data

(Chaplin et al. 2000)

Parameter	*Mean, fractional change (per cent)*
Line width	24 ± 3
Peak height	-46 ± 5
Velocity power	-22 ± 3
Energy supply rate	0 ± 4

Results are consistent with change in damping, rather than excitation

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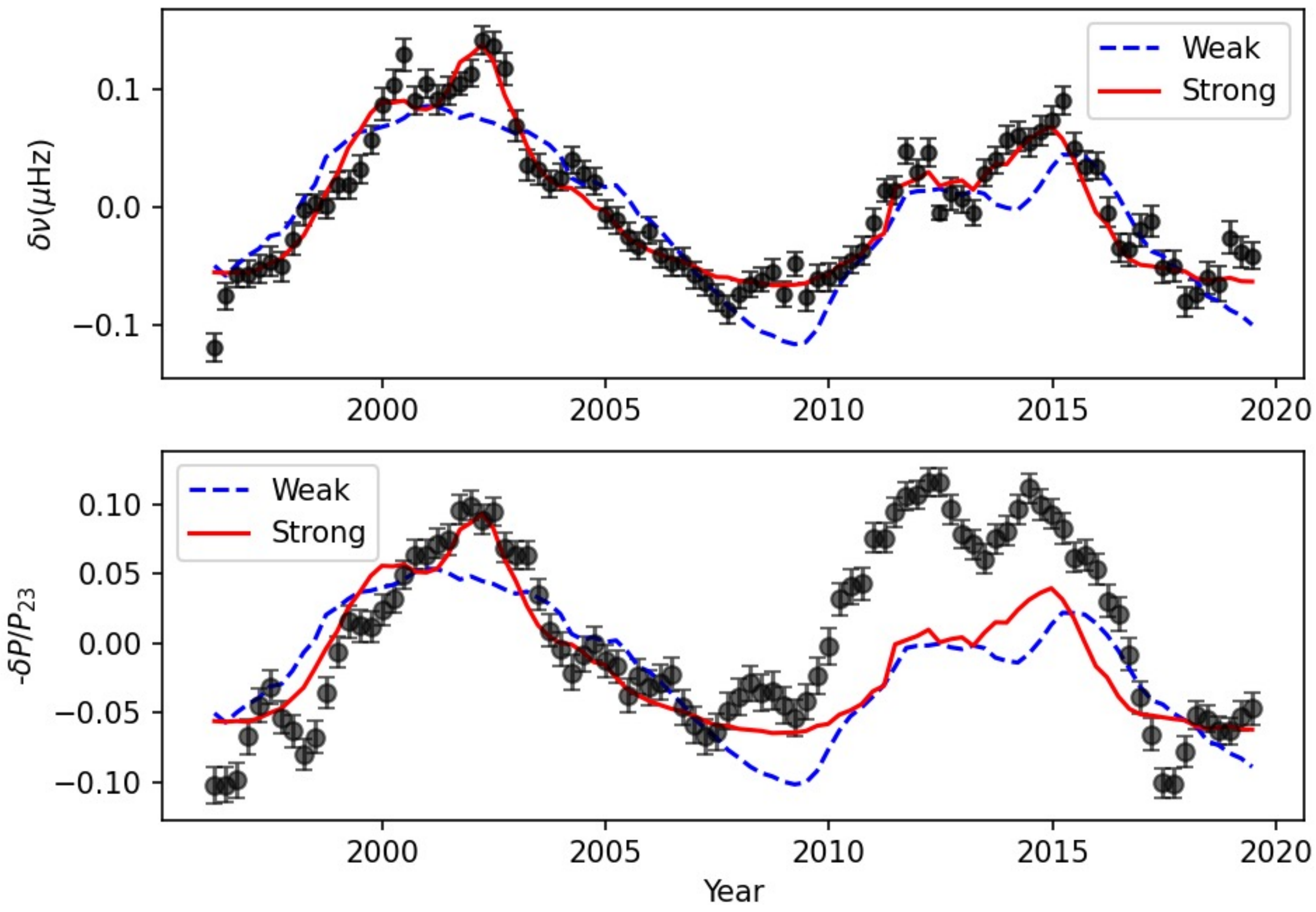
Amplitude shifts with solar cycle



Even though Cycle 24 was weaker, the change in the strength of the low-degree modes observed by BiSON was about the same!

(Howe et al. 2022, MNRAS 514, 3821)

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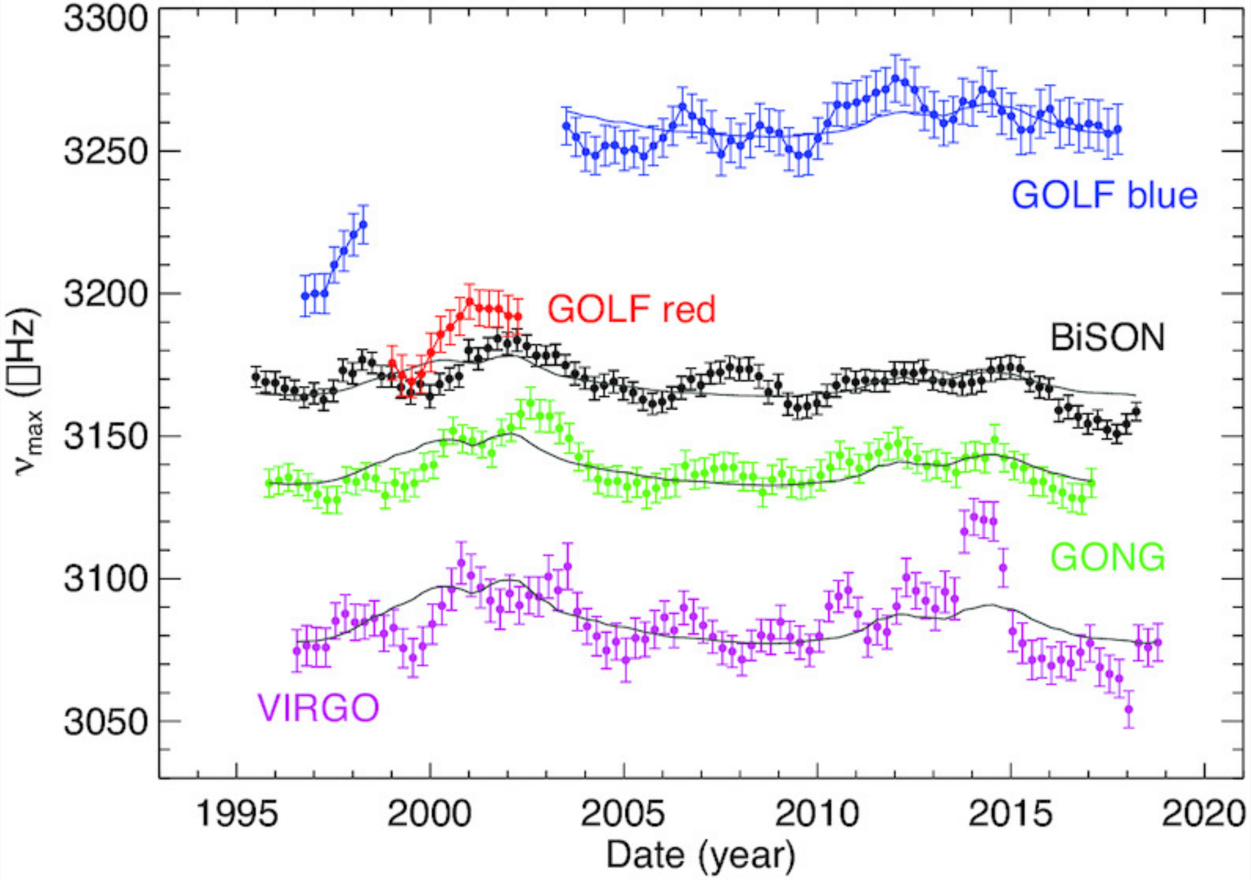
Figure 2. Best-fitting ν_{max} from each data set as a function of time (coloured points with associated error ...



The ν_{max} value is weakly correlated with activity

(Howe et al. 2020)

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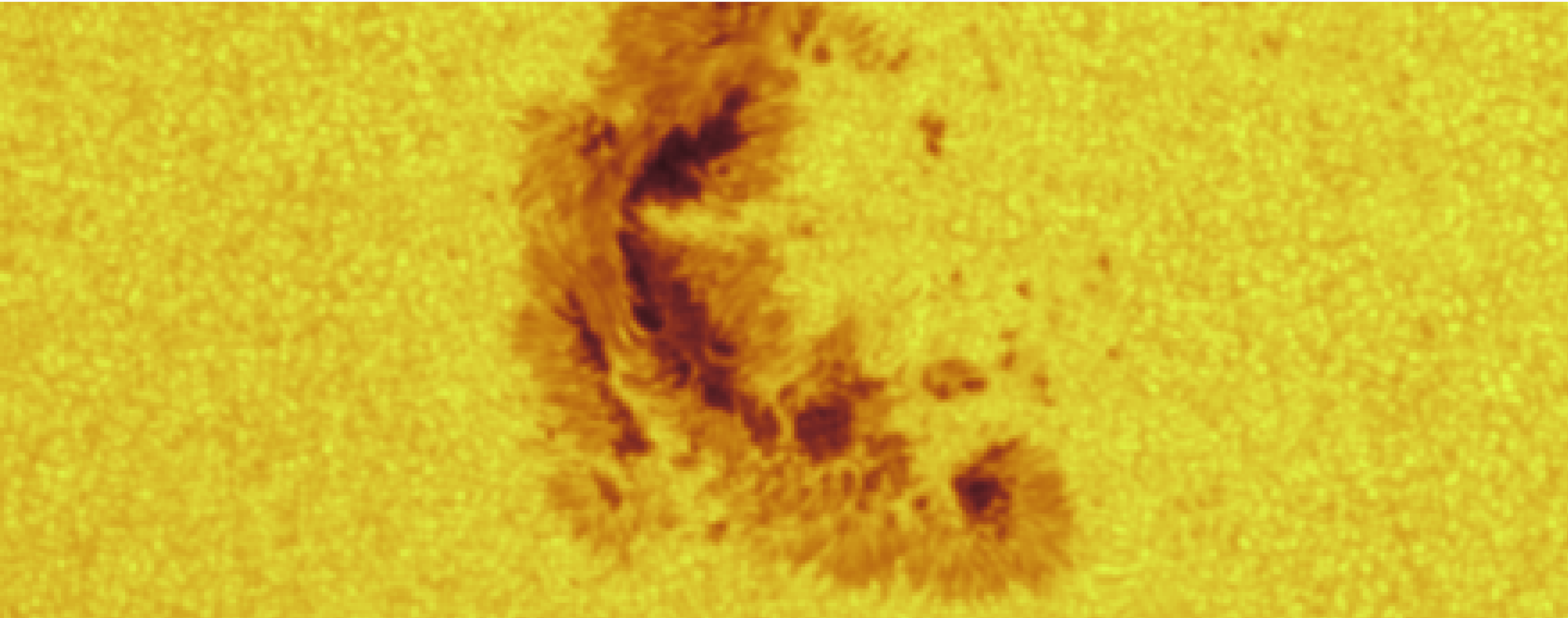
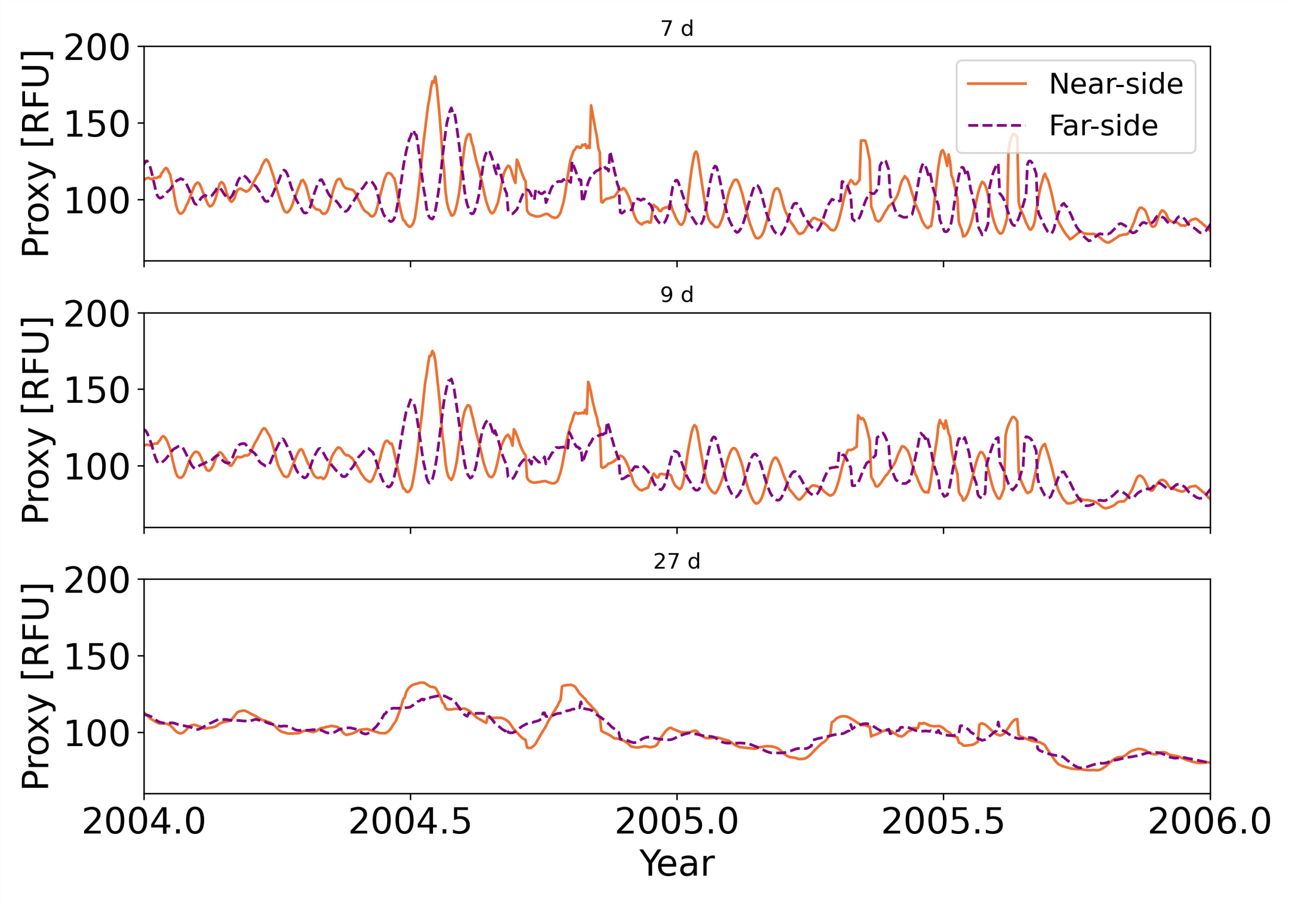
Far-side sensitivity



Near and far-side proxies



$P_{\mathrm{farside}}(t)=$
$[P_{\mathrm{nearside}}(t+13\mathrm{d})+P_{\mathrm{nearside}}(t-13\mathrm{d})]/2.$

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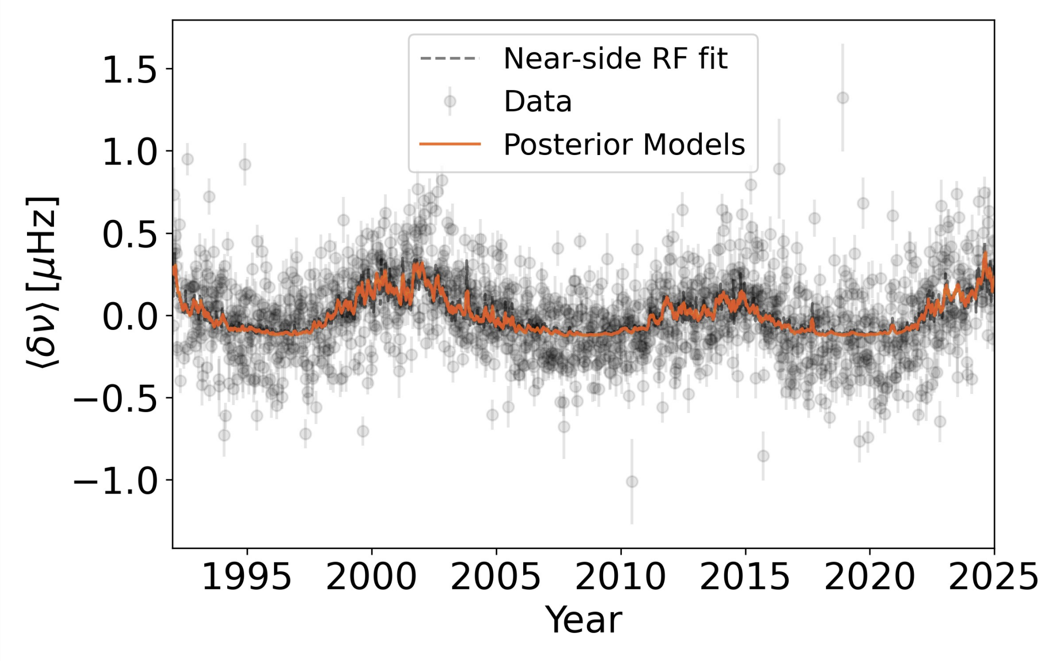
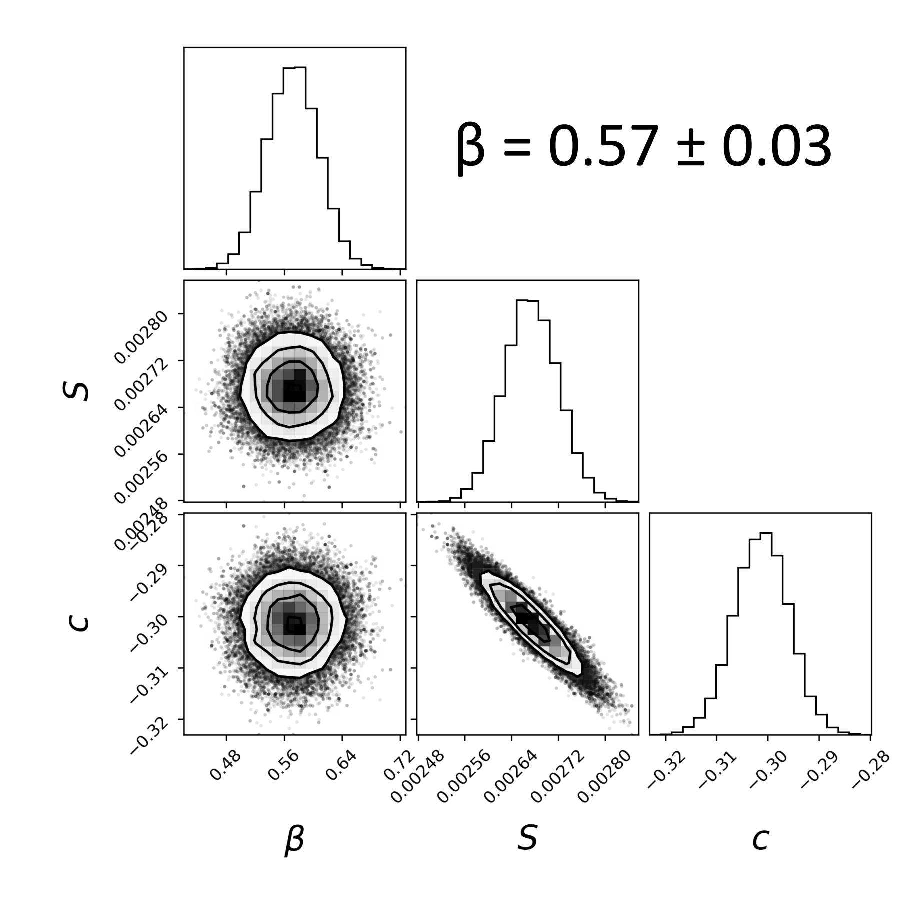
Try including the farside proxy in the model

$\delta\nu = S * [(1 - \beta) * P_{nearside} + \beta * P_{farside}] + c$

Use MCMC to fit the model (with 'chi-squared' likelihood).





Howe et al., 2025

Summary

Over multiple solar cycles, we can follow helioseismic mode parameter changes with activity.

Frequency shifts due to changes in the cavity properties near the surface

Small differences in sensitivity between cycles may reflect changes in the Sun’s outer, magnetic layers

Amplitude and lifetime changes are mainly due to damping, not excitation.

Global modes are sensitive to activity on the far side of the Sun as well