GONG p-Mode Parameters Through Two Solar Cycles

SOHO-29: 22 years of GOLF and VIRGO:
2 sunspot cycles seen by seismology

Nice, 27.-29. 11. 2018

René Kiefer[1,2,3], Rudi Komm[3], Frank Hill[3], Anne-Marie Broomhall[1], Markus Roth[2]

[1]University of Warwick, [2]Kiepenheuer-Institut für Sonnenphysik, [3]NSO

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Frequencies, Frequencies, Frequencies

Change of solar oscillation eigenfrequencies with the solar cycle

Martin F. Woodard* & Robert W. Noyes

VARIATIONS IN HIGH DEGREE ACOUSTIC MODE FREQUENCIES OF THE SUN DURING SOLAR CYCLE 23 AND 24

S. C. Tripathy, K. Jain and F. Hill

SOLAR *p*-MODE FREQUENCIES AND THEIR DEPENDENCE ON SOLAR ACTIVITY: RECENT RESULTS FROM THE BISON NETWORK

Y. Elsworth,[1] R. Howe,[1] G. R. Isaak,[1] C. P. McLeod,[1] B. A. Miller,[1] R. New,[2] C. C. Speake,[1] and S. J. Wheeler[1]

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Variation of low-order acoustic solar oscillations over the solar cycle

Y. Elsworth, R. Howe, G. R. Isaak, C. P. McLeod & R. New

Nature **345**, 322–324 (24 May 1990) | Download Citation

Fifty Years of Seismology of the Sun and Stars
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Mode Frequencies from GONG, MDI, and HMI Data

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High Degree Mode Parameters Through Time

THE ASTROPHYSICAL JOURNAL, 531:1094–1108, 2000 March 10

SOLAR-CYCLE CHANGES IN GONG *p*-MODE WIDTHS AND AMPLITUDES 1995–1998

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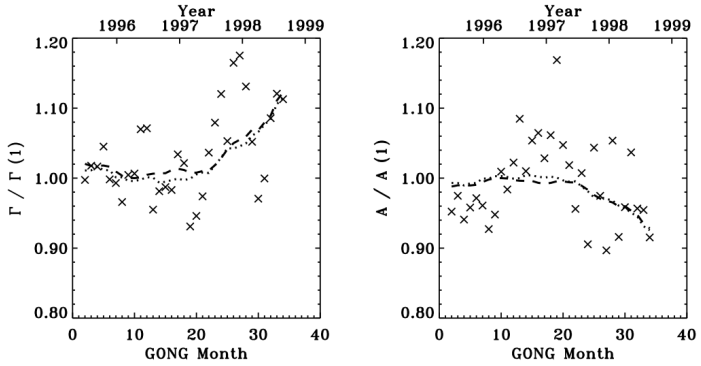
Received 1999 August 18; accepted 1999 November 27



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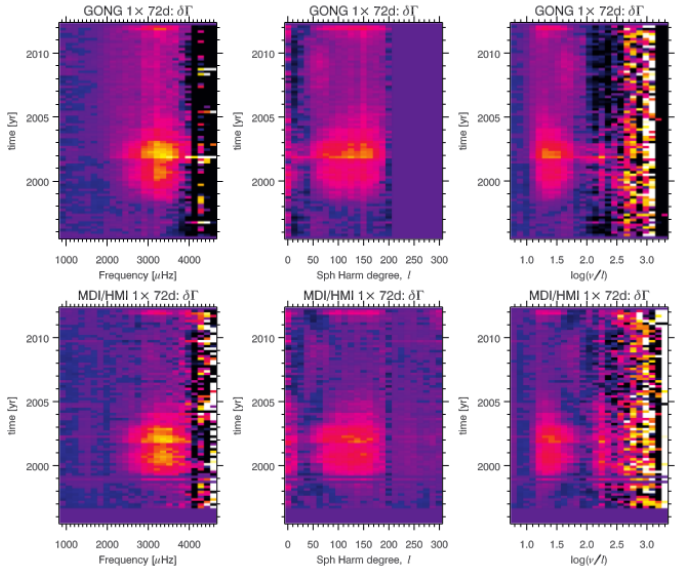

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THE ASTROPHYSICAL JOURNAL, 543:472–485, 2000 November 1

WIDTH AND ENERGY OF SOLAR *p*-MODES OBSERVED BY GLOBAL OSCILLATION NETWORK GROUP

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Received 2000 April 20; accepted 2000 June 15

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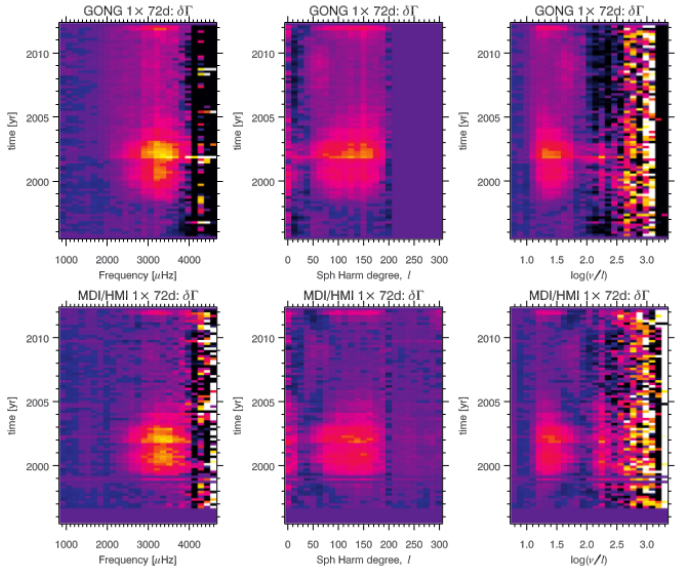
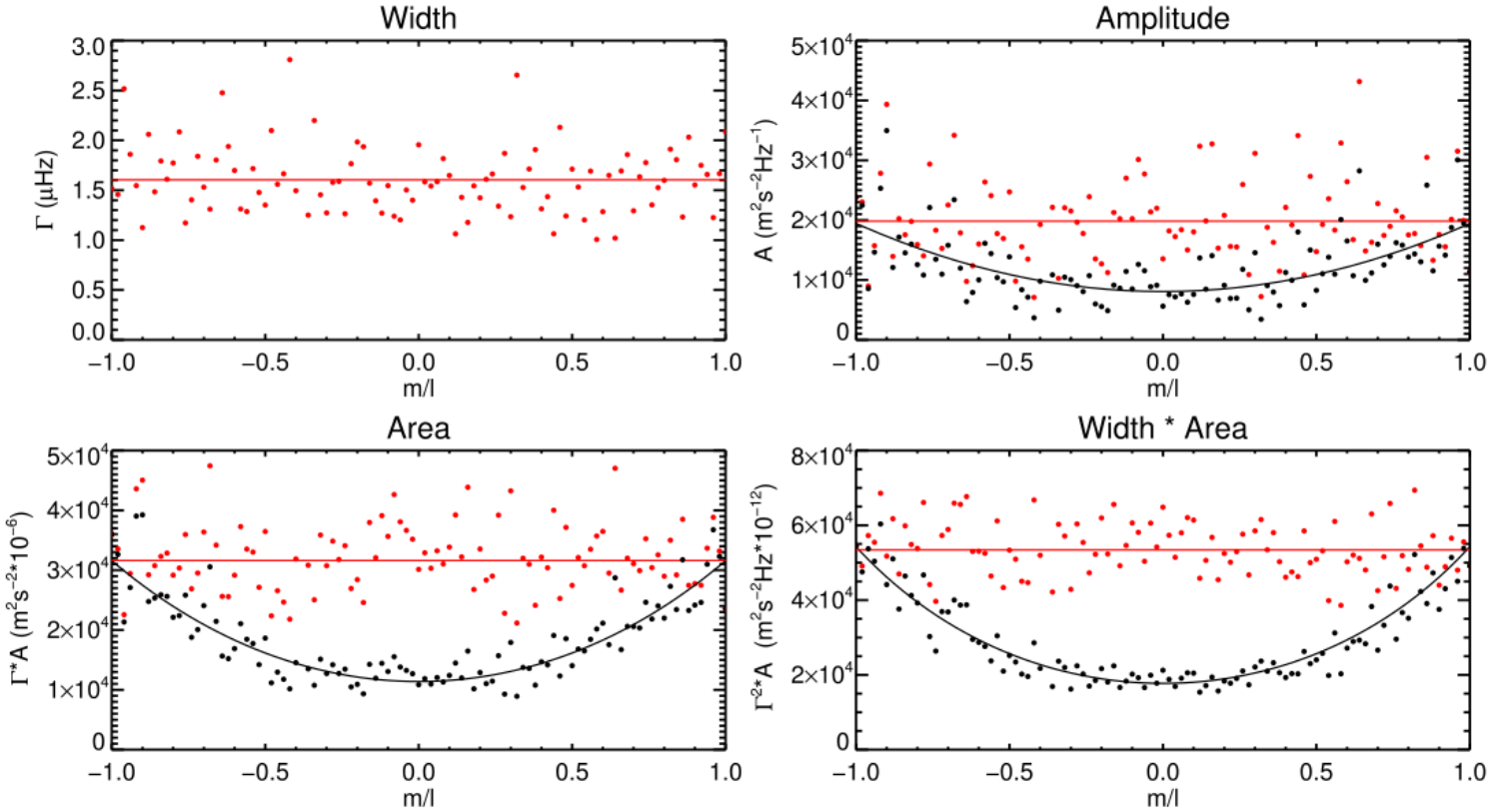


What Are We Looking at?

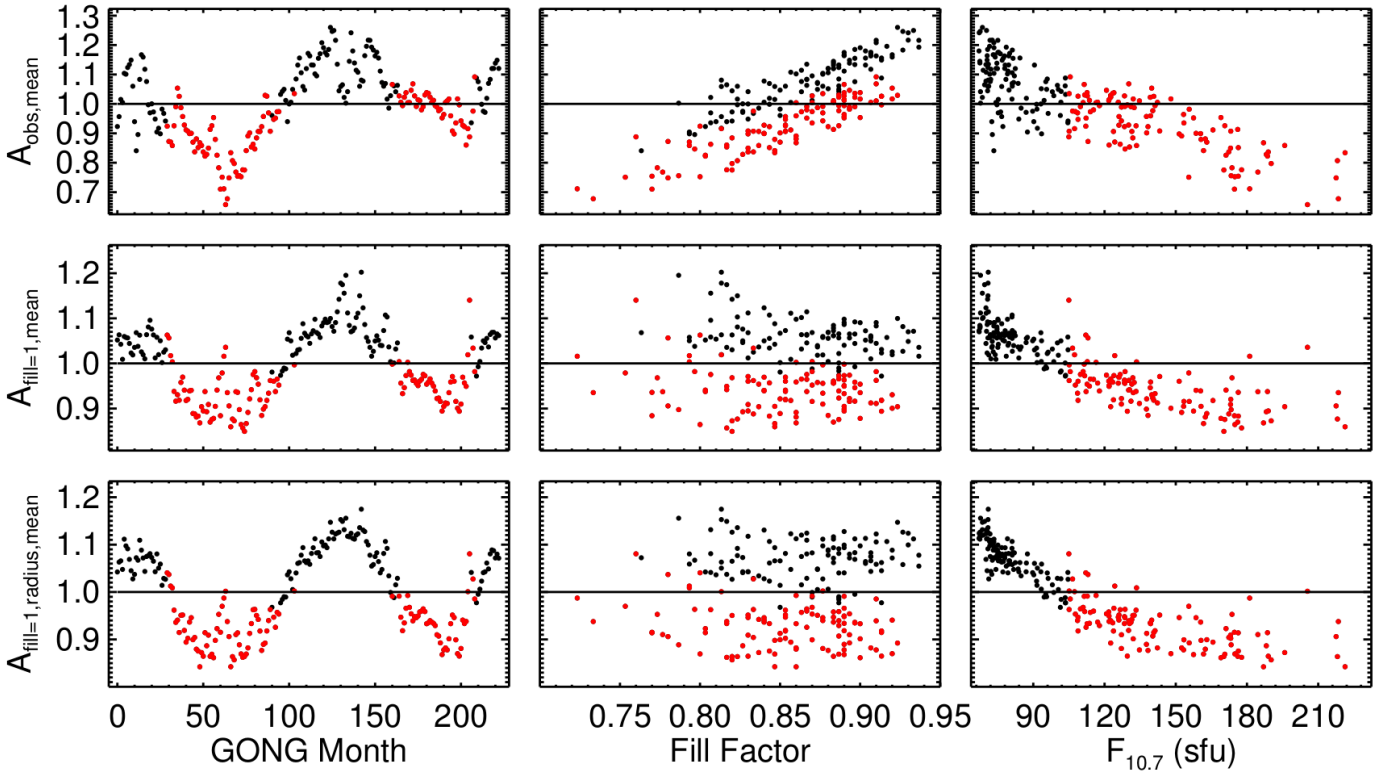
- 223 GONG 108 day-long time series, 3 GONG months, network merged
  - May 1995 – March 2017
- GONG pipeline output: mode widths and amplitudes
  - Products Width x Amplitude, Width^2 x Amplitude
- Harmonic degrees l=0-150
- Modes present in all time samples

Azimuthal Correction & Averaging

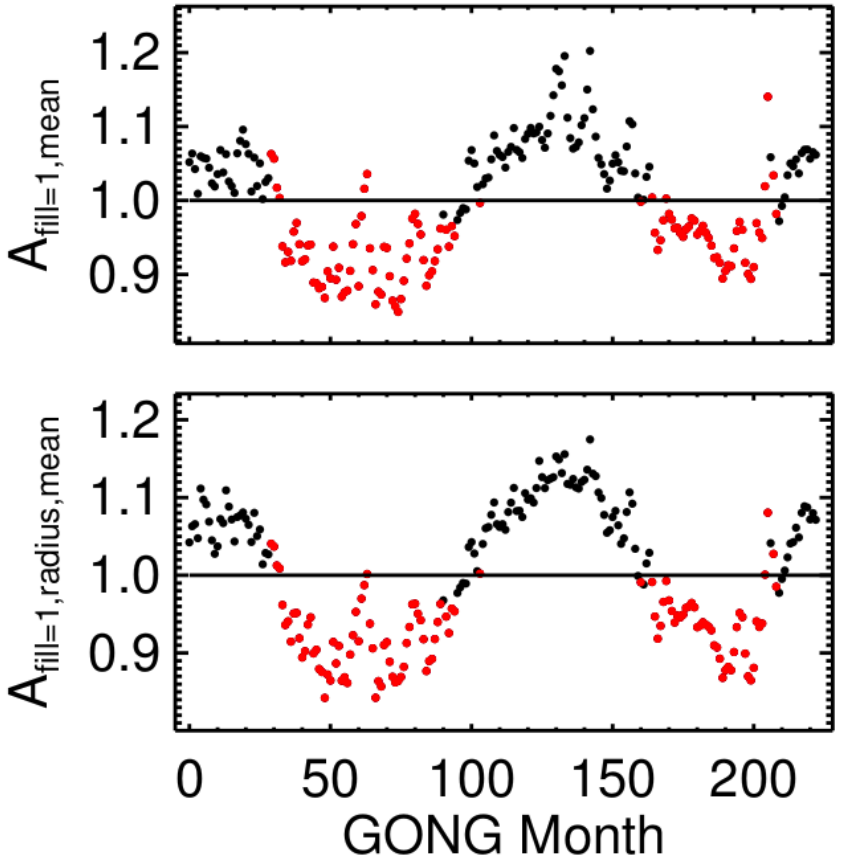


(n,l) = (10,50)

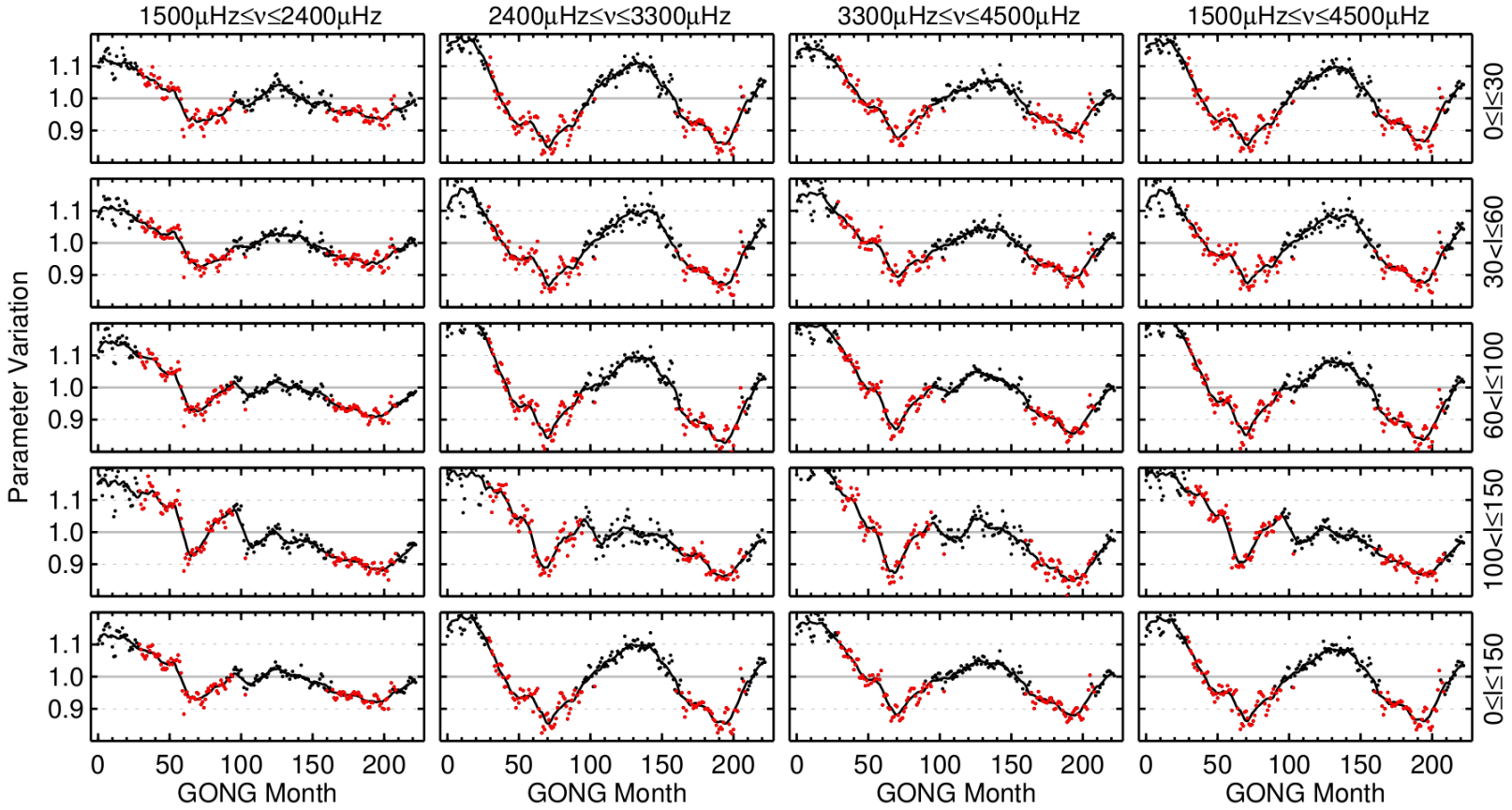
Correct for Fill and Solar Radius



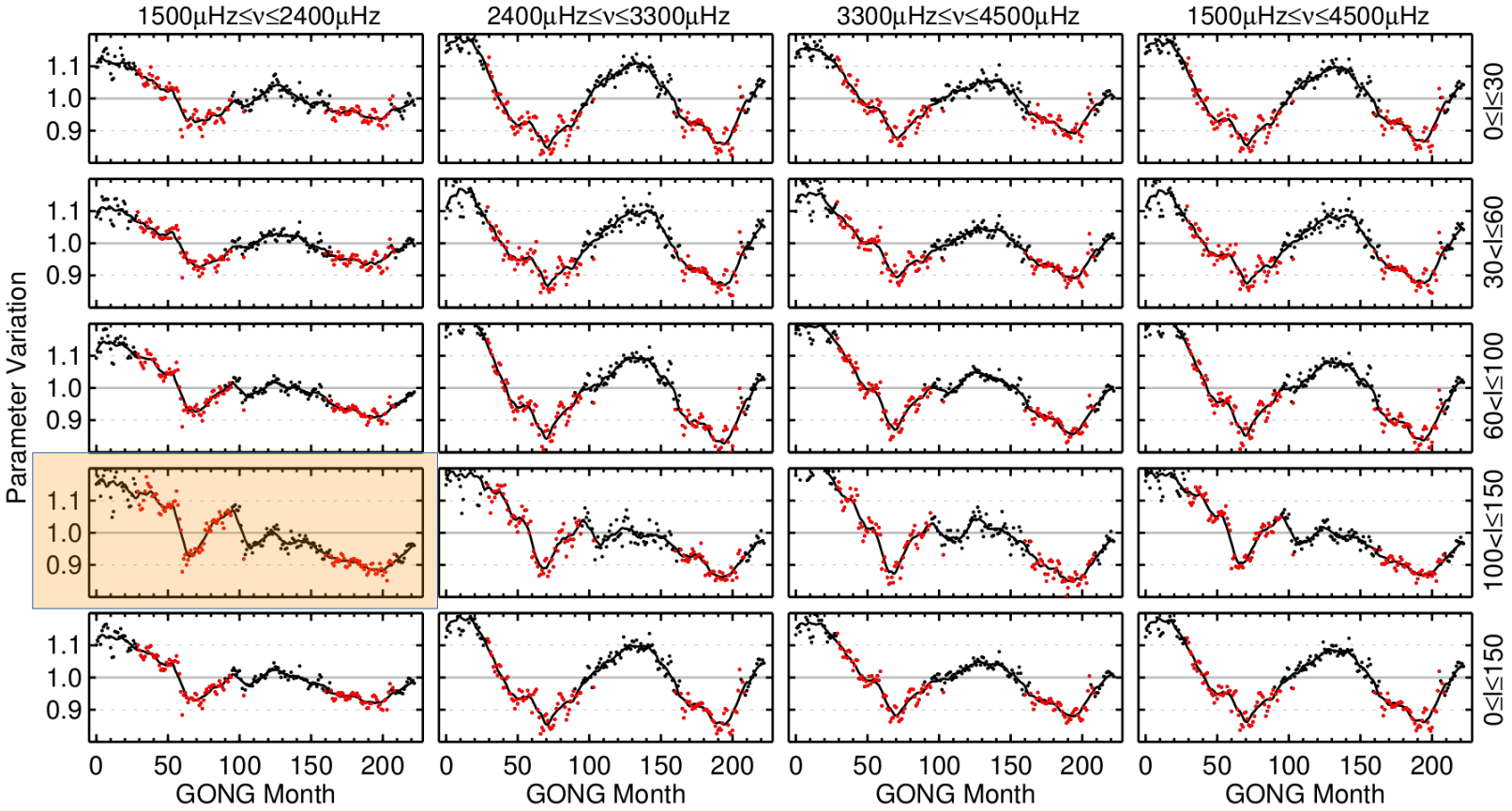
Correct for Fill and Solar Radius



Uncorrected Mode Amplitudes



Uncorrected Mode Amplitudes



Empirical Correction

$$C = 1 - \frac{0.03 \cdot l}{150} - \frac{0.06 \cdot \nu}{4500\ \mu\mathrm{Hz}} - 0.06 \qquad \text{(months 1 – 58)},$$

$$C = 1 - \frac{0.02 \cdot l}{150} - \frac{0.04 \cdot \nu}{4500\ \mu\mathrm{Hz}} - 0.04 \qquad \text{(month 59)},$$

$$C = 1 - \frac{0.01 \cdot l}{150} - \frac{0.02 \cdot \nu}{4500\ \mu\mathrm{Hz}} - 0.02 \qquad \text{(month 60)},$$

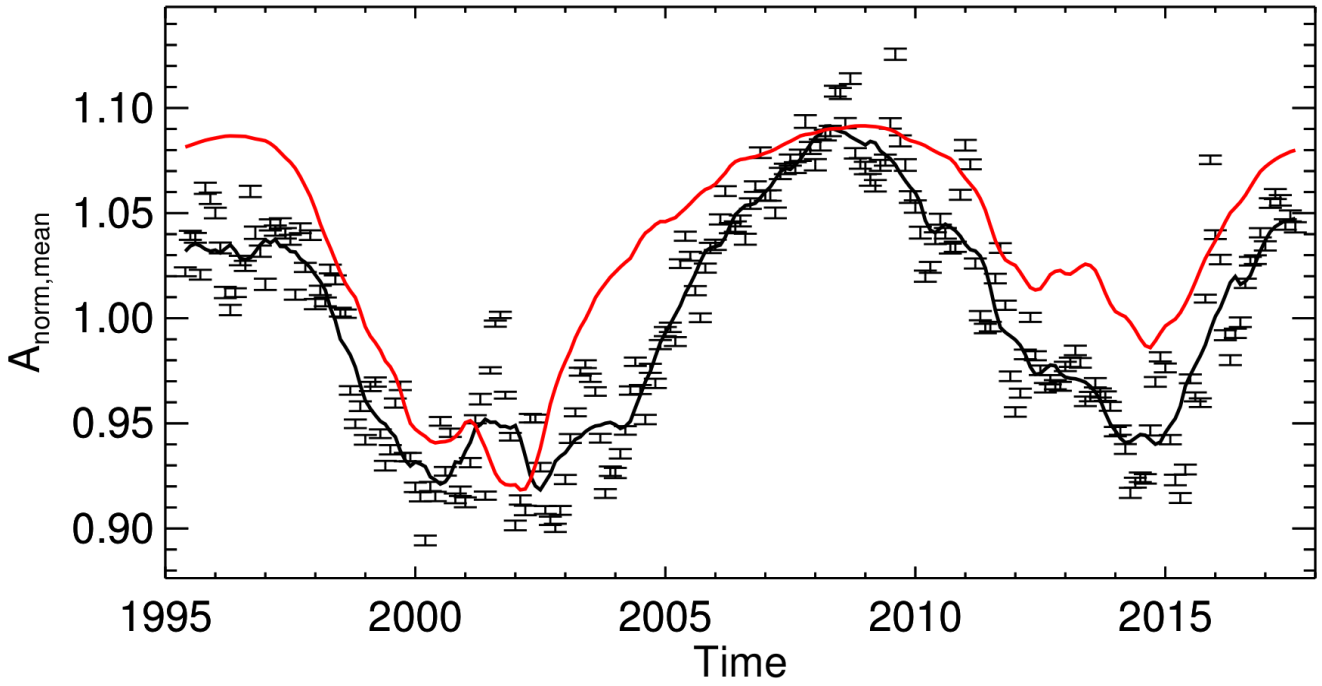
$$C = 1 \qquad \text{(months 61 – 98)},$$

$$C = 1 + \frac{0.0733 \cdot l}{150} \qquad \text{(month 100)},$$

$$C = 1 + \frac{0.1466 \cdot l}{150} \qquad \text{(month 101)},$$

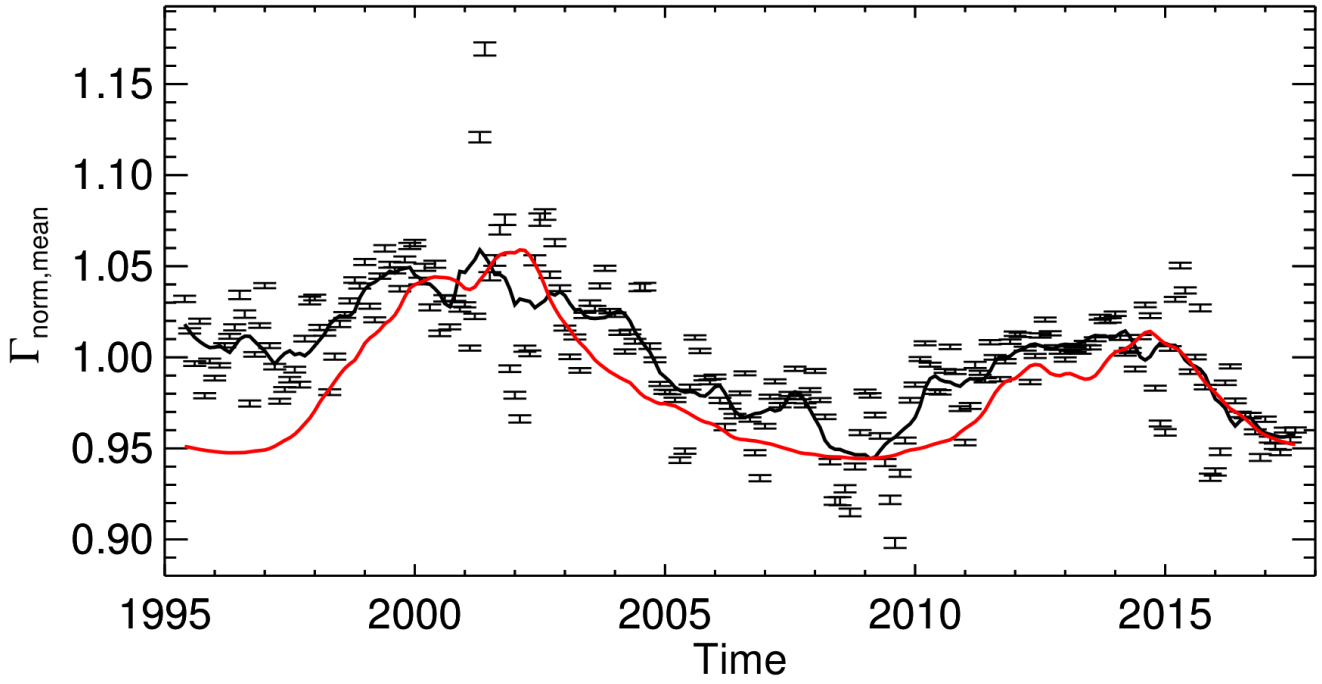
$$C = 1 + \frac{0.22 \cdot l}{150} \qquad \text{(months 102 – 223)},$$

Mode Amplitudes



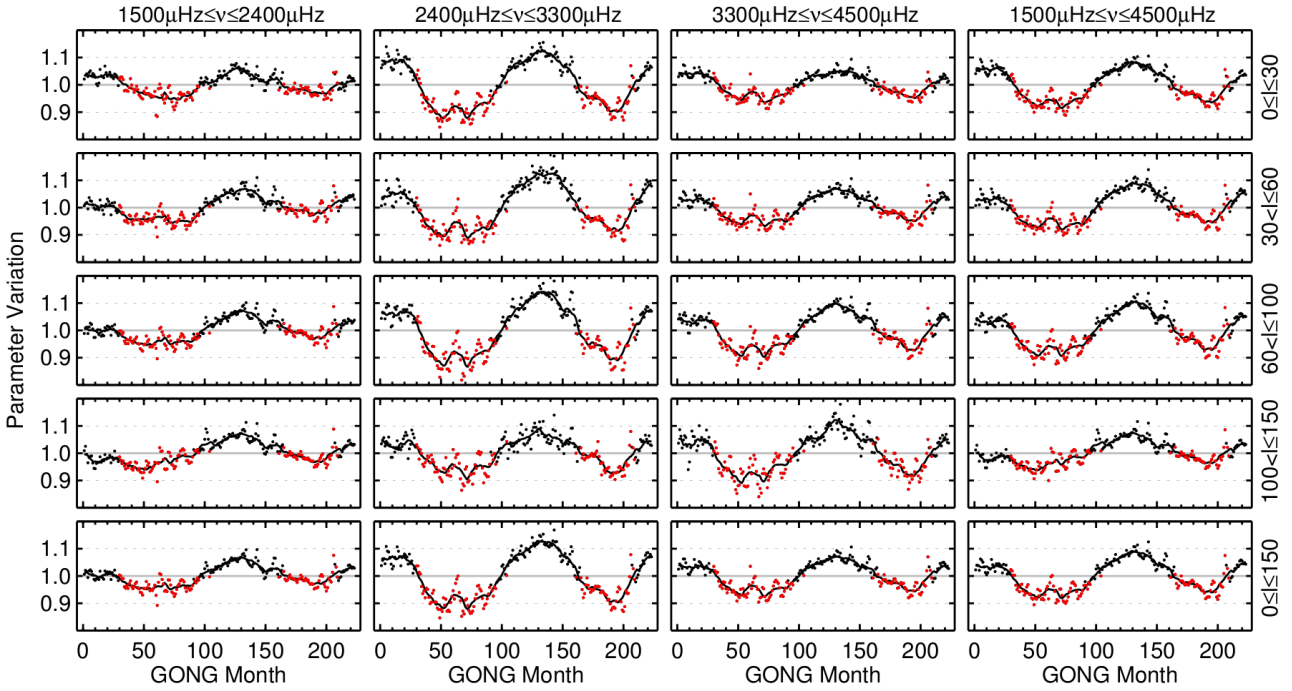
- Averaged over all n,l,m,nu, 1272 modes
- Black: 1-yr smoothed
- Red: scaled F10.7
- Spearman rho = -0.91
- Variation: 17.3%

Mode Widths



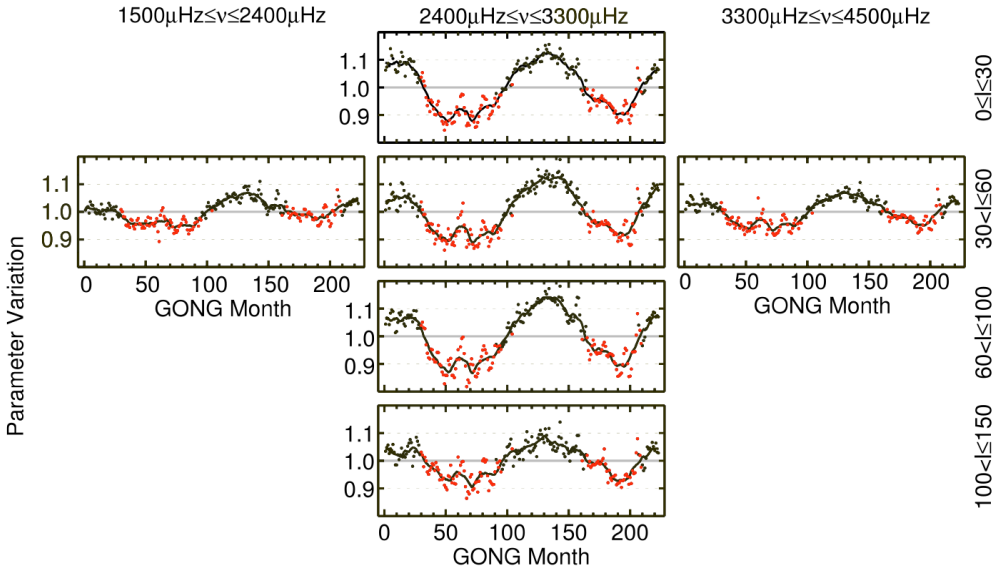
- Averaged over all n,l,m,nu, 1275 modes
- Black: 1-yr smoothed
- Red: scaled F10.7
- Spearman rho = 0.62
- Variation: 11.5%

Corrected Mode Amplitudes



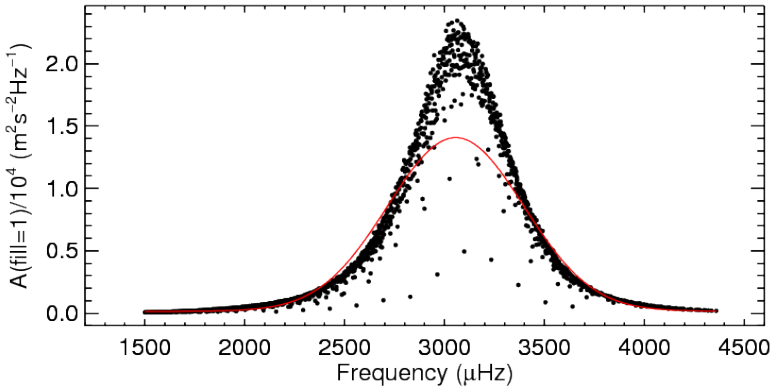
- Normalized to mean
- Columns:
  same frequency ranges
- Rows:
  same harmonic degrees
- Colour: high/low activity

Corrected Mode Amplitudes

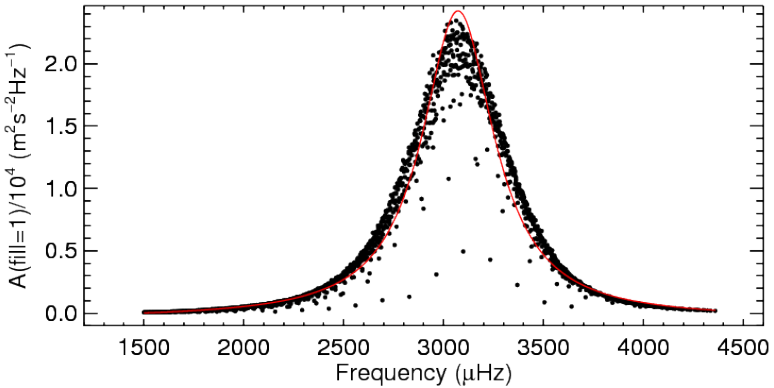


- Normalized
- Columns: same frequency ranges
- Rows: same harmonic degrees
- Colour: high/low activity

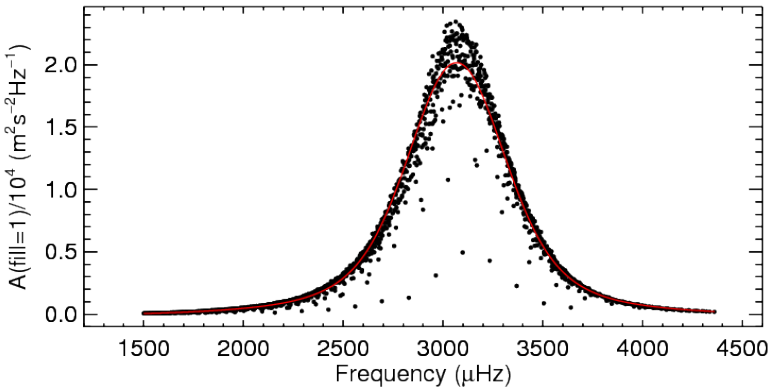
Gaussian vs Lorentzian vs Voigt



Gaussian

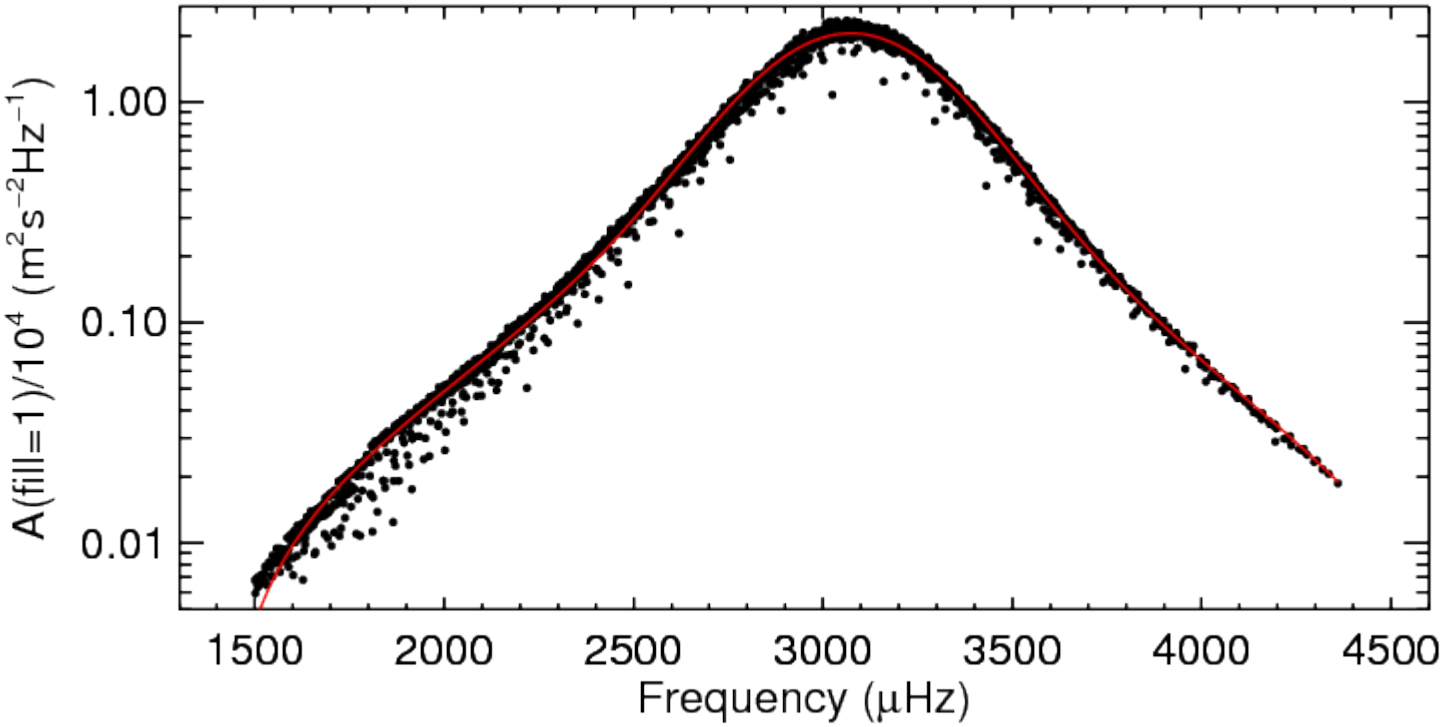


Lorentzian



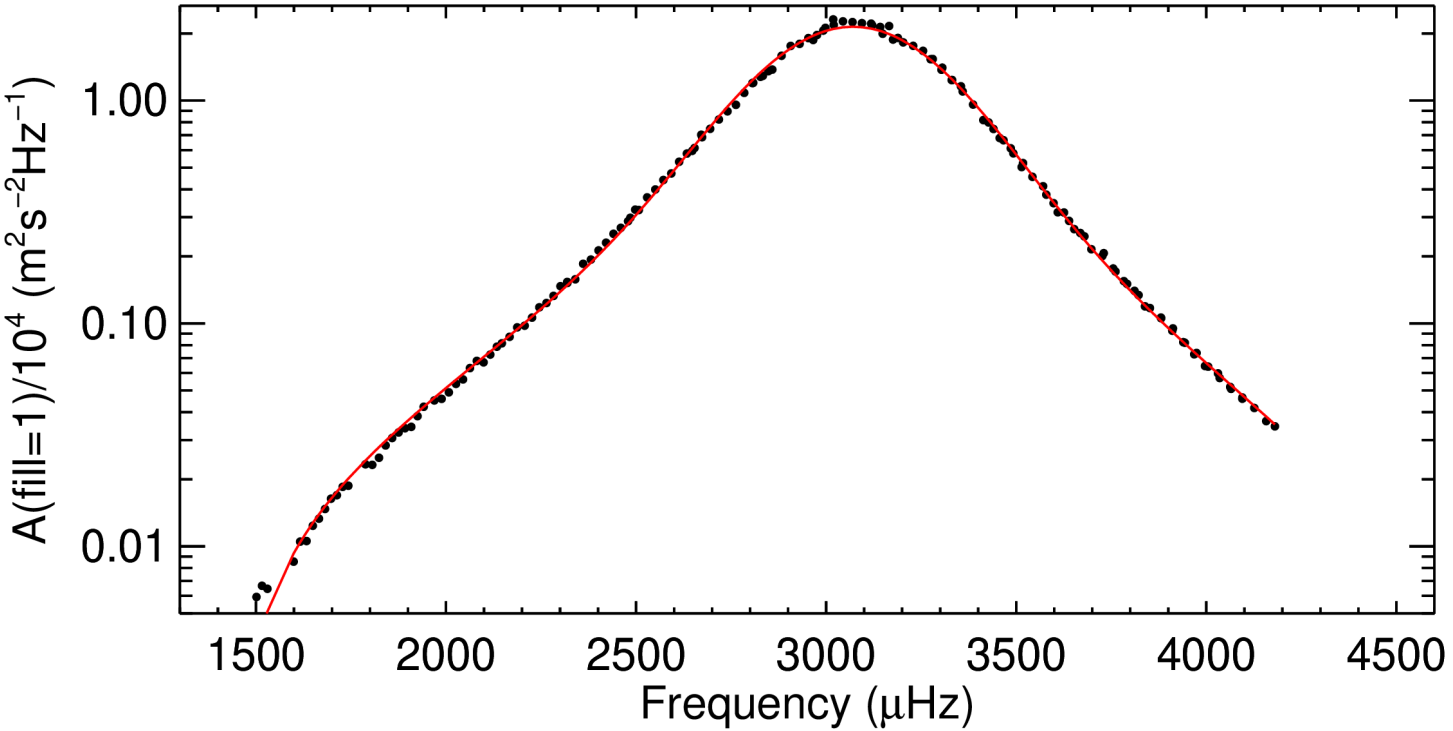
Asymmetric Voigt

Asymmetric Voigt Profile



l = 2 – 150, m averaged, time averaged

Asymmetric Voigt Profile



l = 31 - 40

Asymmetric Voigt Profile

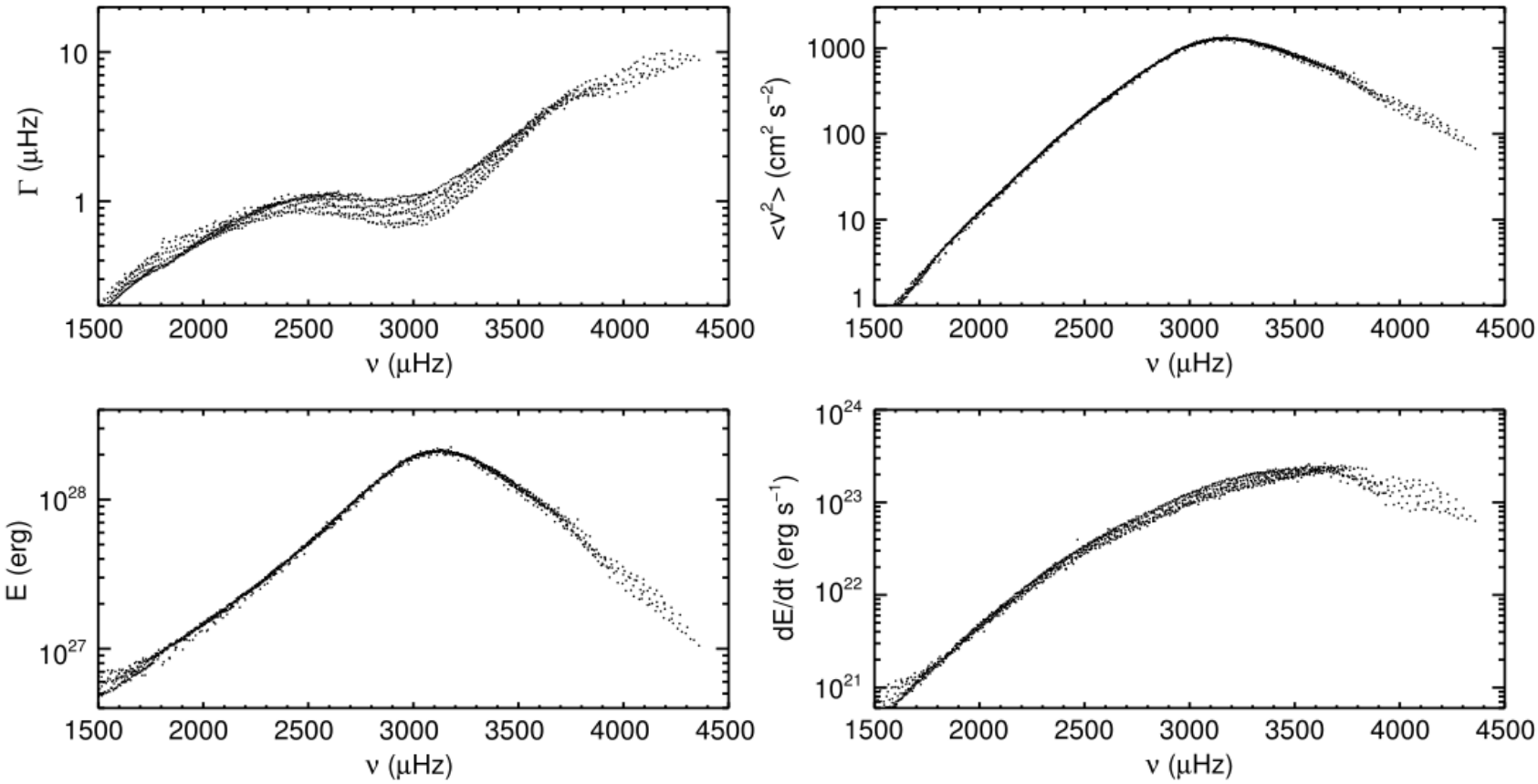
Table 1 Fit parameters of the frequency distribution of mode amplitudes for modes with $2 \leq l \leq 150$.

ν_{max} [μHz]	σ [μHz]	γ [μHz]	Σ [μHz]
3079.76 ± 0.17	181.8 ± 0.3	150.9 ± 0.2	611.8 ± 0.5
$a/10^4$ [$m^2\,s^{-2}\,Hz^{-1}$]	b [$m^2\,s^{-2}\,Hz^{-1}$]	S	χ^2_{red}
3299 ± 2	-581 ± 1	-0.100 ± 0.002	32.8

Physical Quantities

- Mean squared velocities $\langle v_{nl}^2 \rangle = \frac{\pi}{2} C_{\mathrm{vis}} \Gamma_{nl} A_{nl}$
- Mode energies $E_{nl} = M_{nl} \langle v_{nl}^2 \rangle$
- Mode energy supply rates $\frac{\mathrm{d}E_{nl}}{\mathrm{d}t} = 2\pi E_{nl} \Gamma_{nl} = \pi^2 C_{\mathrm{vis}} M_{nl} A_{nl} \Gamma_{nl}^2$

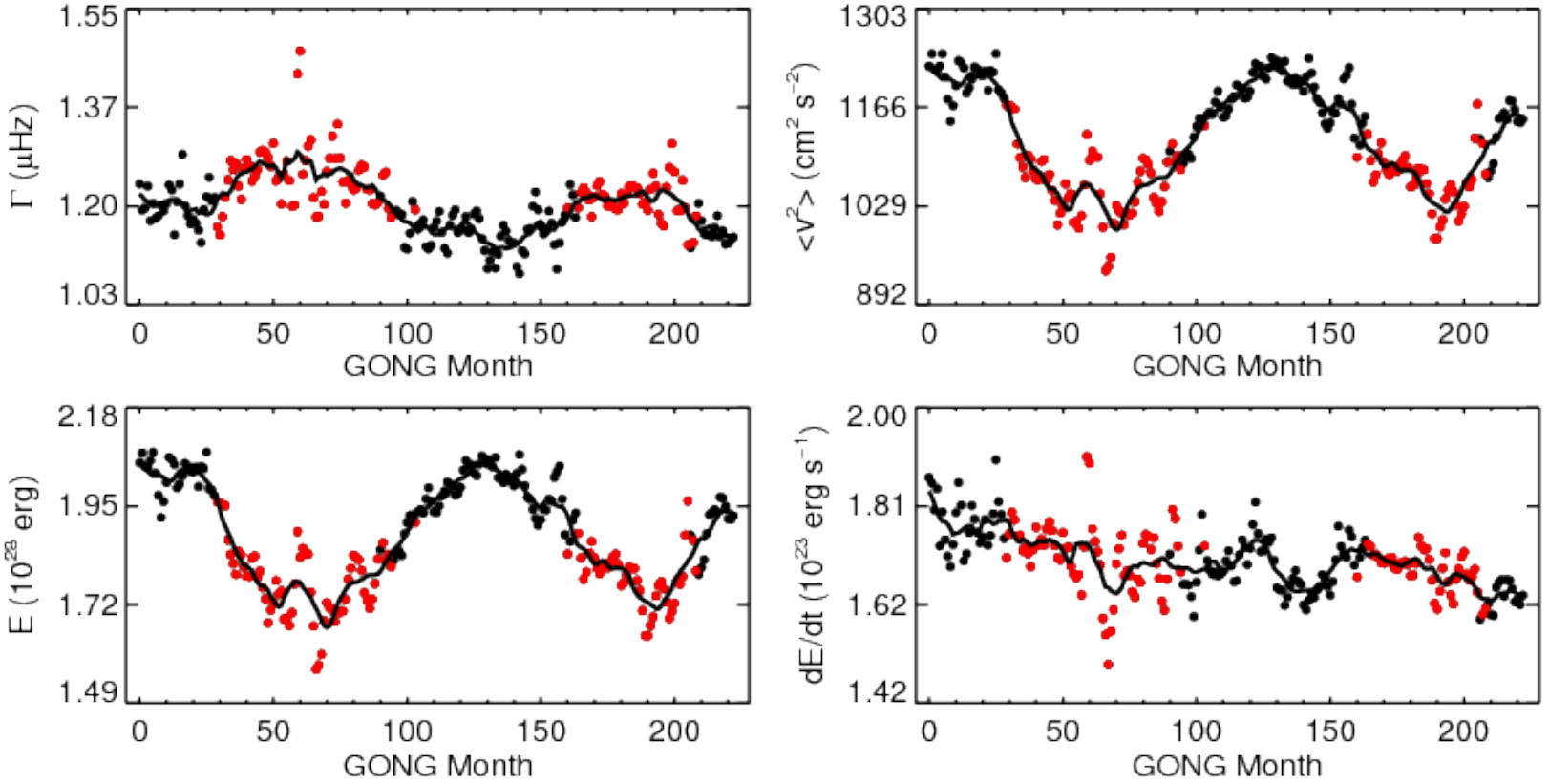
Physical Quantities



Physical Quantities

	Γ	$\langle v^2 \rangle$	E	$\mathrm{d}E/\mathrm{d}t$
Frequency range [μHz]	2400 – 3000	2900 – 3300	2900 – 3300	3000 – 3600
Number of modes	358	237	237	385
Correlation ρ	0.69	−0.88	−0.88	−0.01
p value	$< 10^{-10}$	$< 10^{-10}$	$< 10^{-10}$	0.88

Physical Quantities



Conclusions

- p mode parameters change along the solar cycle
  - Mode amplitudes are anti-correlated with the level of activity
  - Mode widths are correlated with the level of activity
  - Magnitude of fractional parameter changes depends on mode frequency and harmonic degree
- Mode amplitudes as a function of frequency follow an asymmetric Voigt profile
- Mode velocities, energies anti-correlated with activity

Thank You for Your Attention!

Solar Phys (2018) 293:151
https://doi.org/10.1007/s11207-018-1370-x

GONG p-Mode Parameters Through Two Solar Cycles

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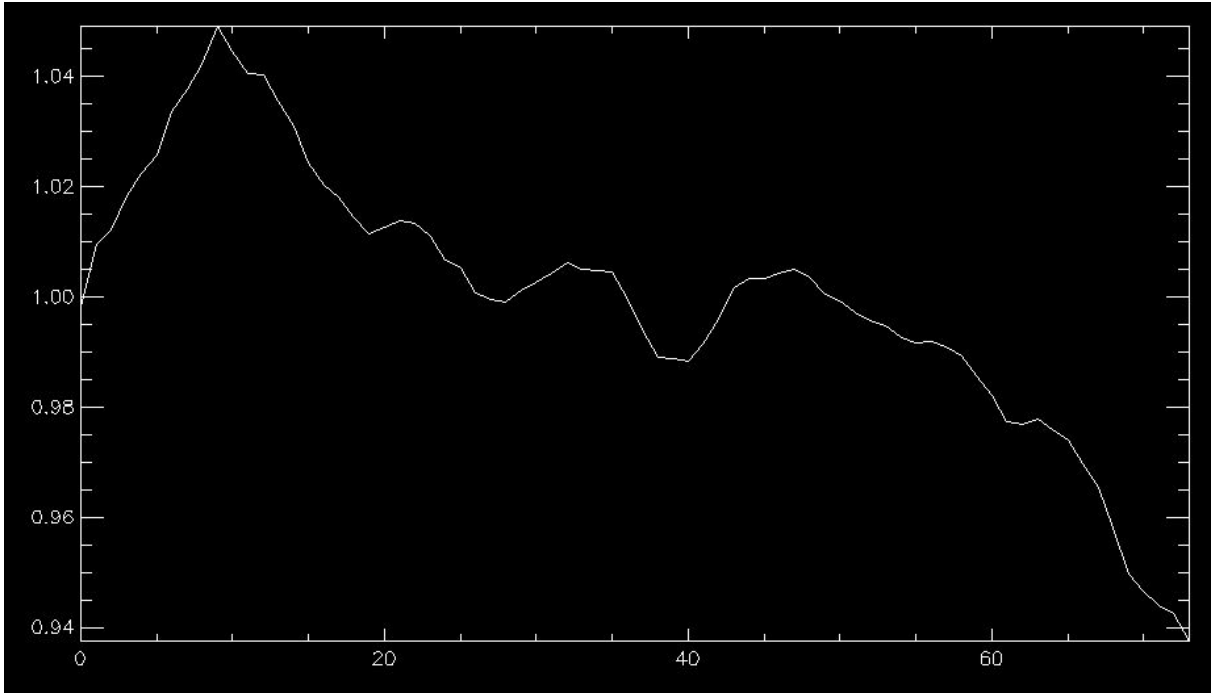
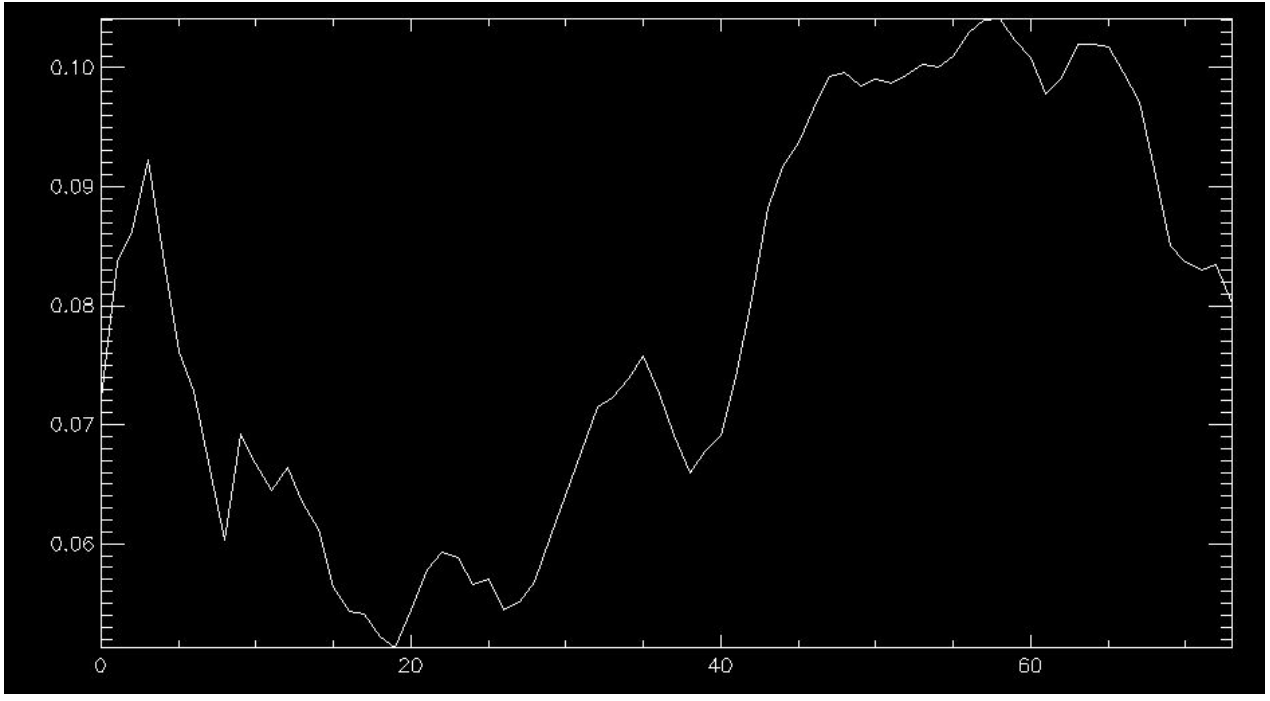
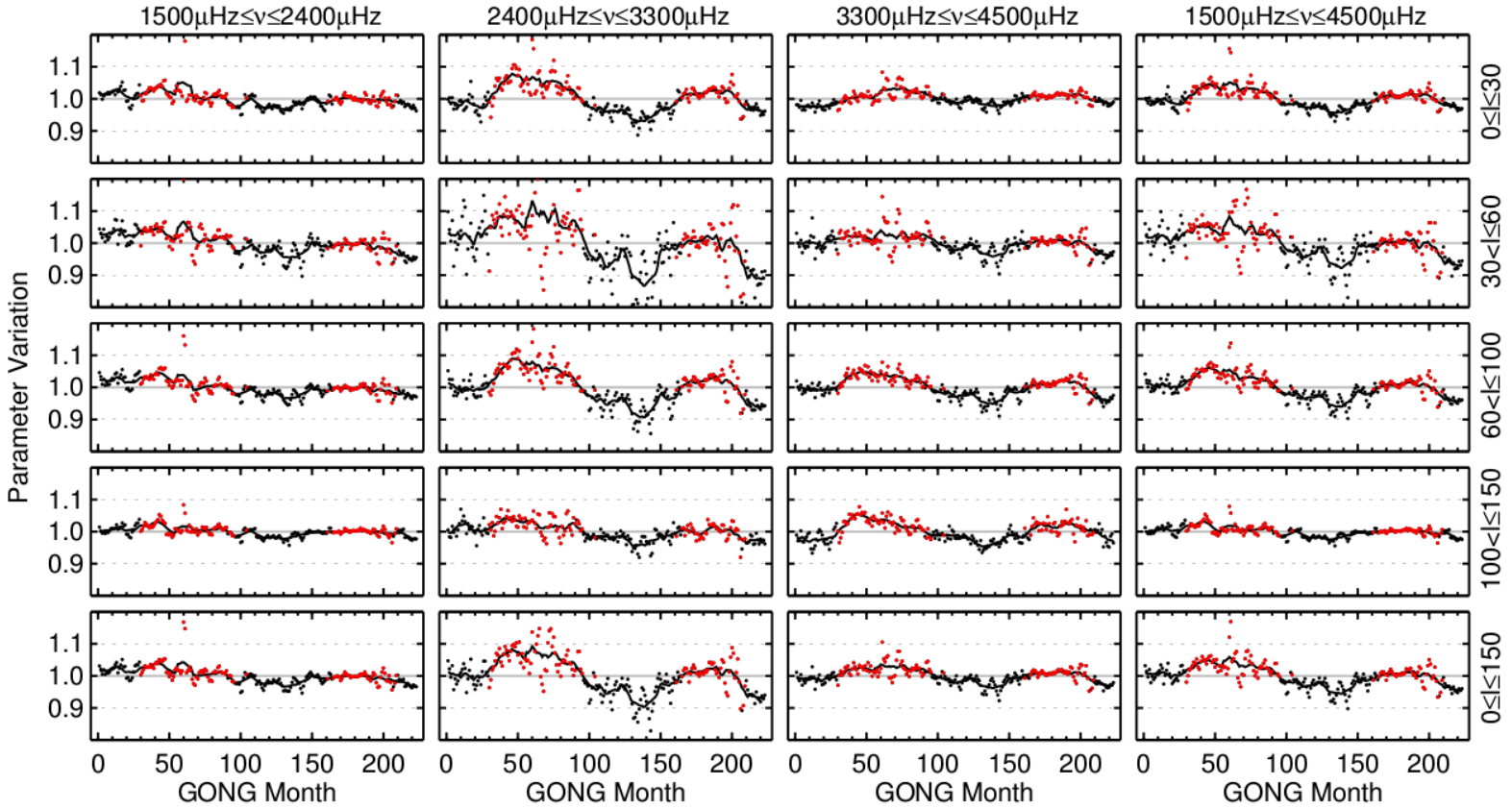
HMI Mode Amplitudes



Linear Trend Removed



GONG Widths


1500μHz≤ν≤2400μHz
2400μHz≤ν≤3300μHz
3300μHz≤ν≤4500μHz
1500μHz≤ν≤4500μHz
Parameter Variation
1.1
1.0
0.9
0≤l≤30
30<l≤60
60<l≤100
100<l≤150
0≤l≤150
0
50
100
150
200
GONG Month