The structure of the solar core: an observer's point of view

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Outline of the talk

- The rotation of the solar core:
  - Splitting determination techniques
  - The ‘Art of Fitting’: Fourier vs Power
  - Systematic errors
  - Recent results
- The structure of the solar core:
  - The Phoebus group
  - g-mode detection techniques
  - Nasty examples...
- The future

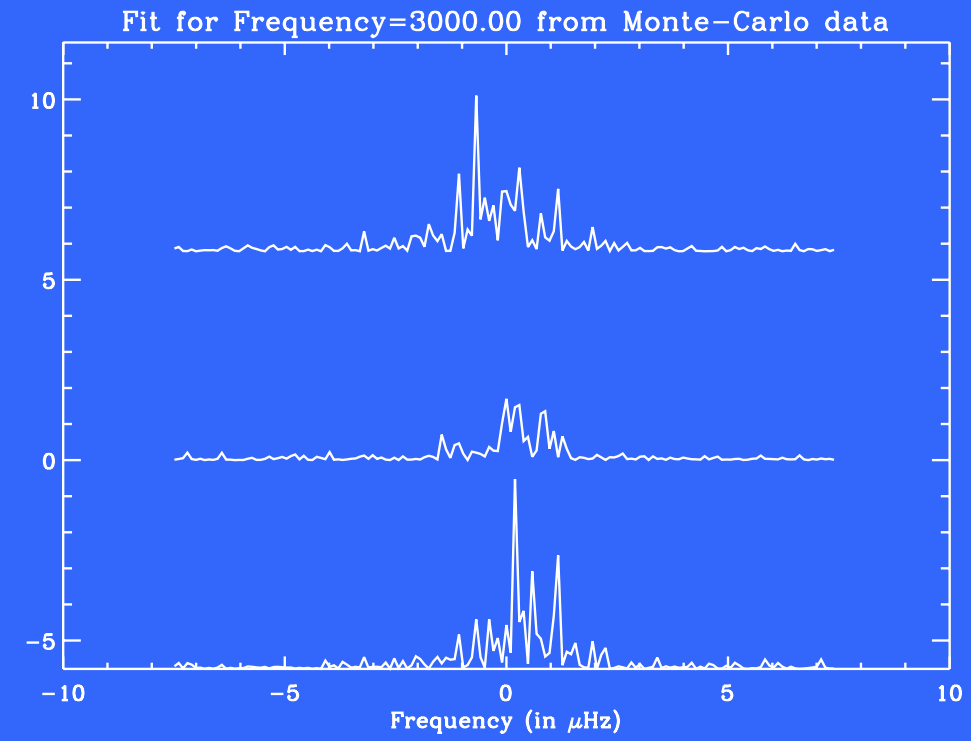
Splitting fitting techniques

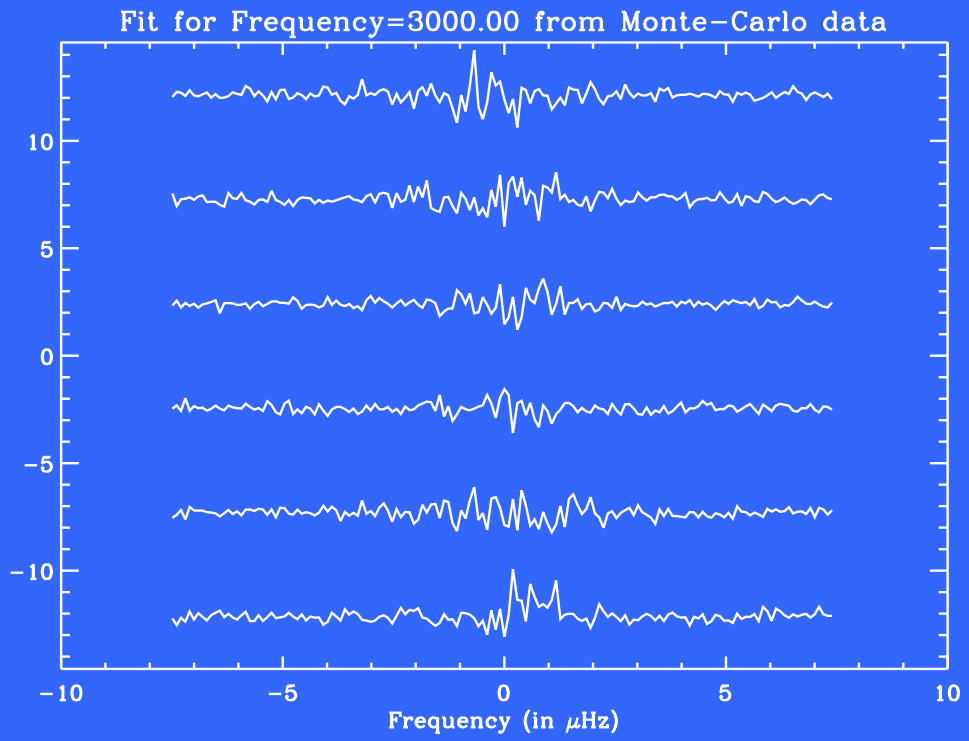
	Others	Mean profile	Auto-correlation	*m* averaged spectra	MLE: power spectra	MLE: Fourier spectra
BiSON					●	
GOLF		●	●		●	
GONG					●	●
IPHIR	●				●	
IRIS		●	●		●	
LOI					●	●
LOWL						●
Mt Wilson				●		
SOI/MDI						●

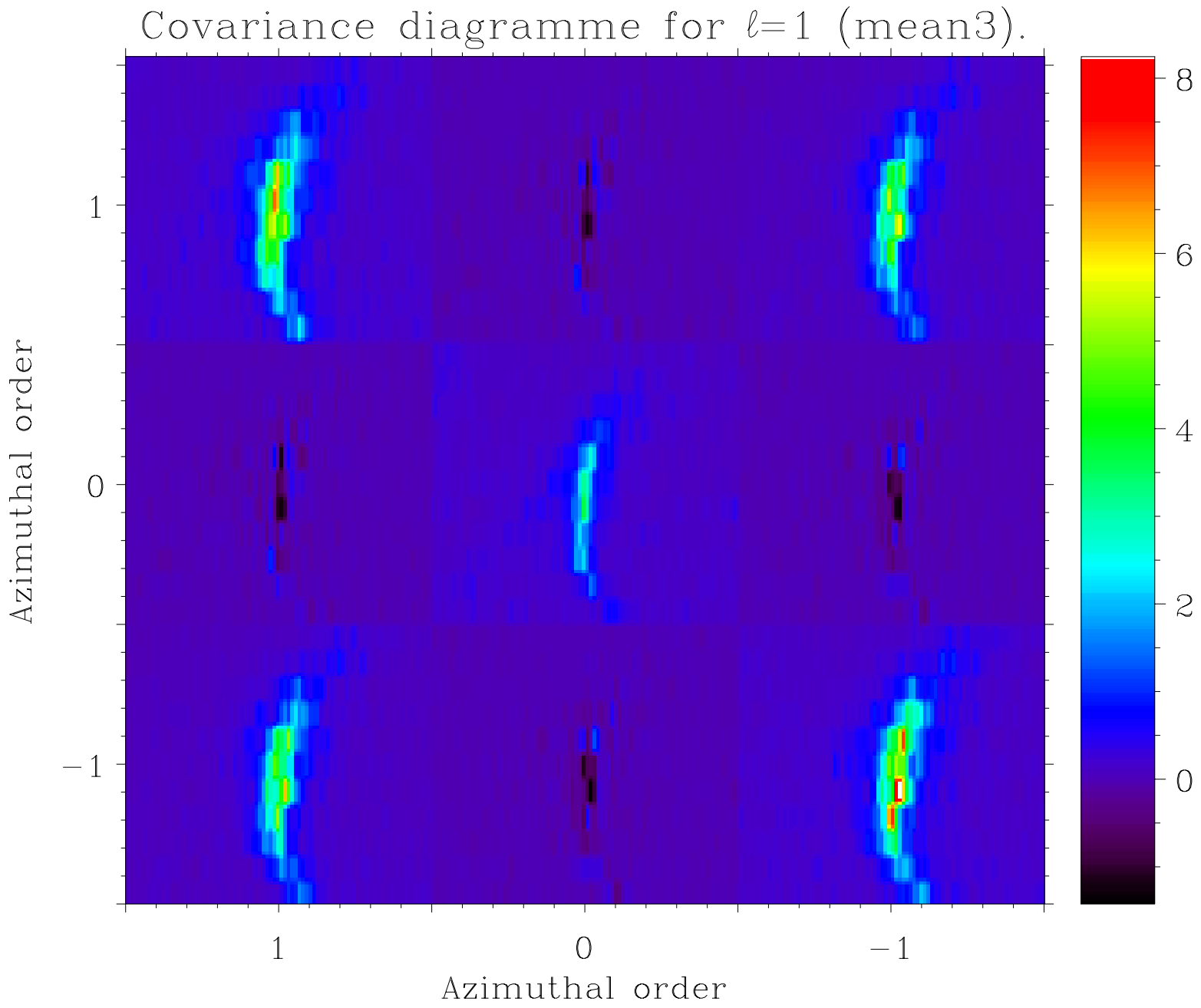
‘The Art of Fitting’: Fourier vs power

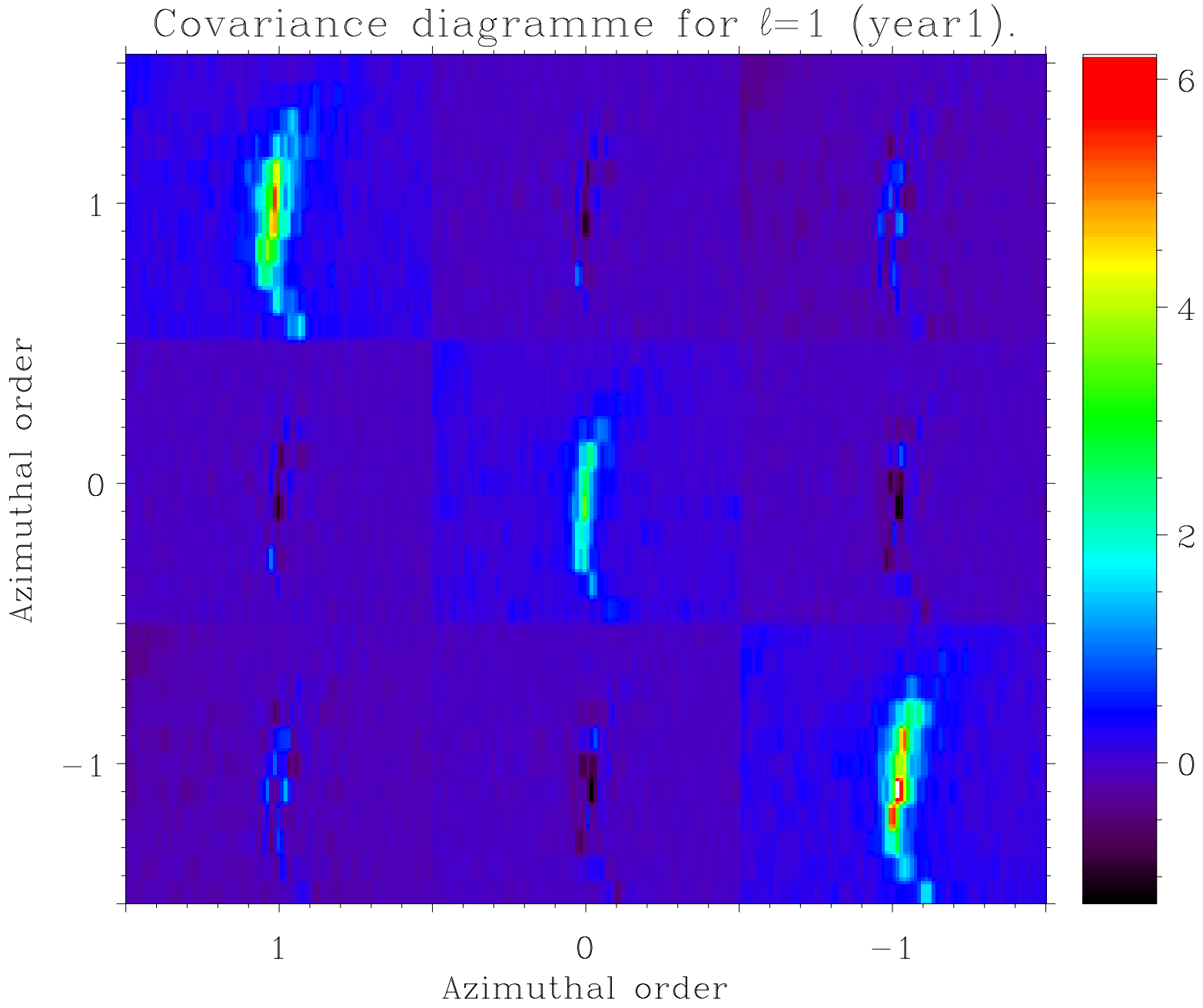
- Schou (1992) introduced the inclusion of the phase in ‘power spectra fitting’...
- ... it became ‘Fourier spectra fitting’
- For understanding what was fitted, Appourchaux et al (1998) devised colorful diagnostics...
- ... that is when it became an ‘Art’

Power spectra versus Fourier spectra





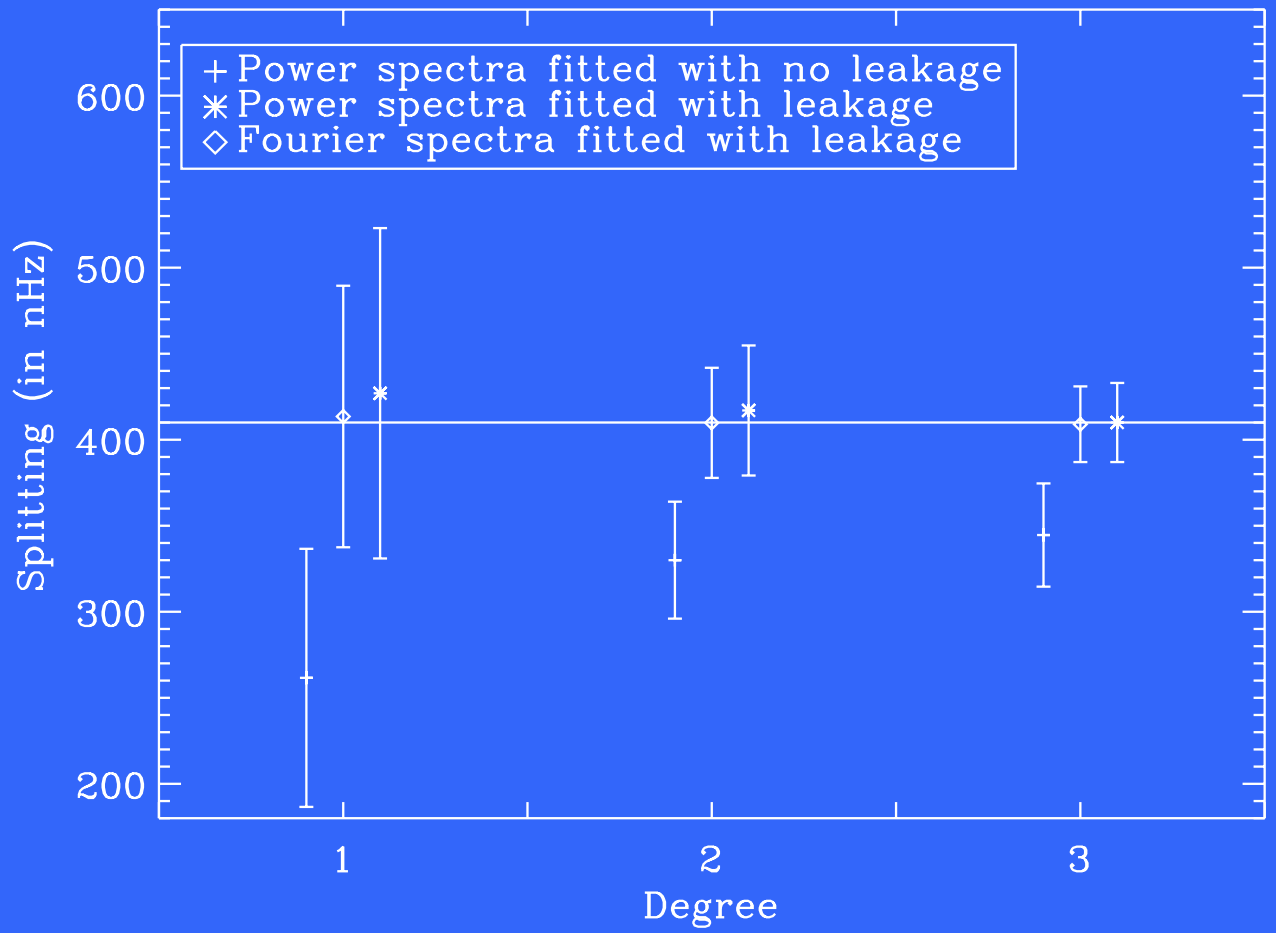

Covariance diagramme for ℓ=1 (mean3).
Azimuthal order
1
0
−1
Azimuthal order
1
0
−1
8
6
4
2
0


Covariance diagramme for ℓ=1 (year1).
Azimuthal order
1
0
−1
Azimuthal order
1
0
−1
6
4
2
0

Some source of systematic errors

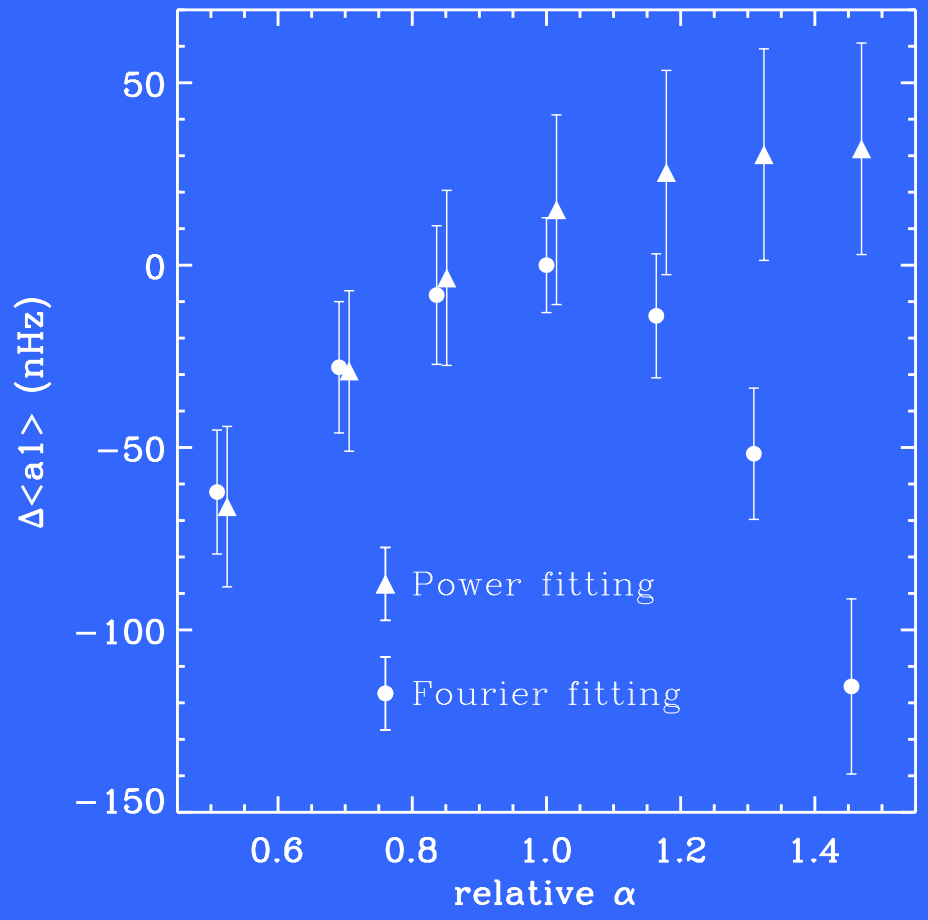
- Fitting techniques:
  - Power spectra: over- and under- estimation
  - Fourier spectra: smallest biased estimates
- Leakage matrix:
  - Power spectra: over- and under- estimation
  - Fourier spectra: quadratic underestimation
- Aliasing modes or l leaks:
  - Strong effects on any a_i for any fitting technique

Power spectra versus Fourier spectra (The return of...)



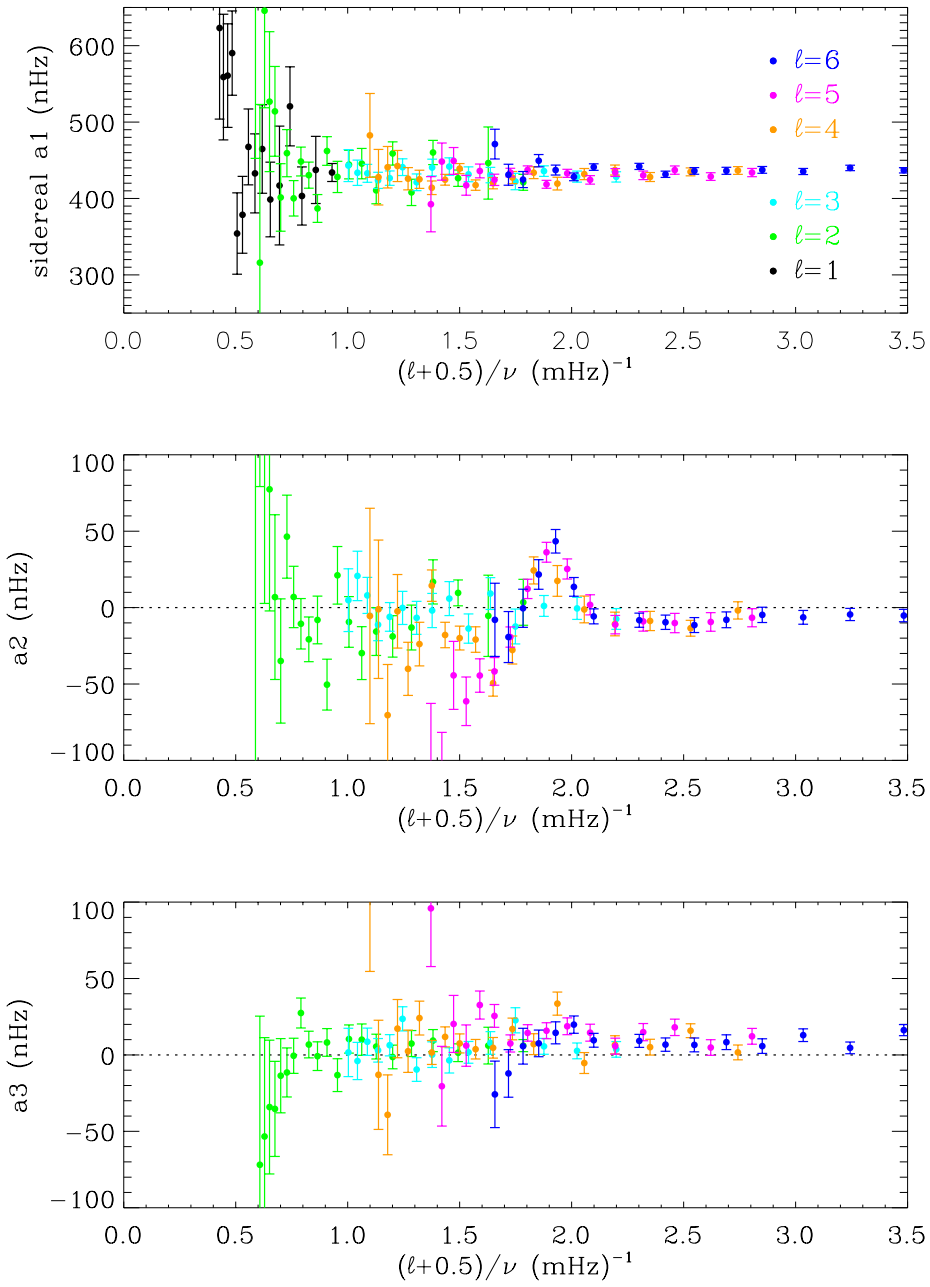
Appourchaux et al, 1998

Power spectra versus Fourier spectra (The sequel...)



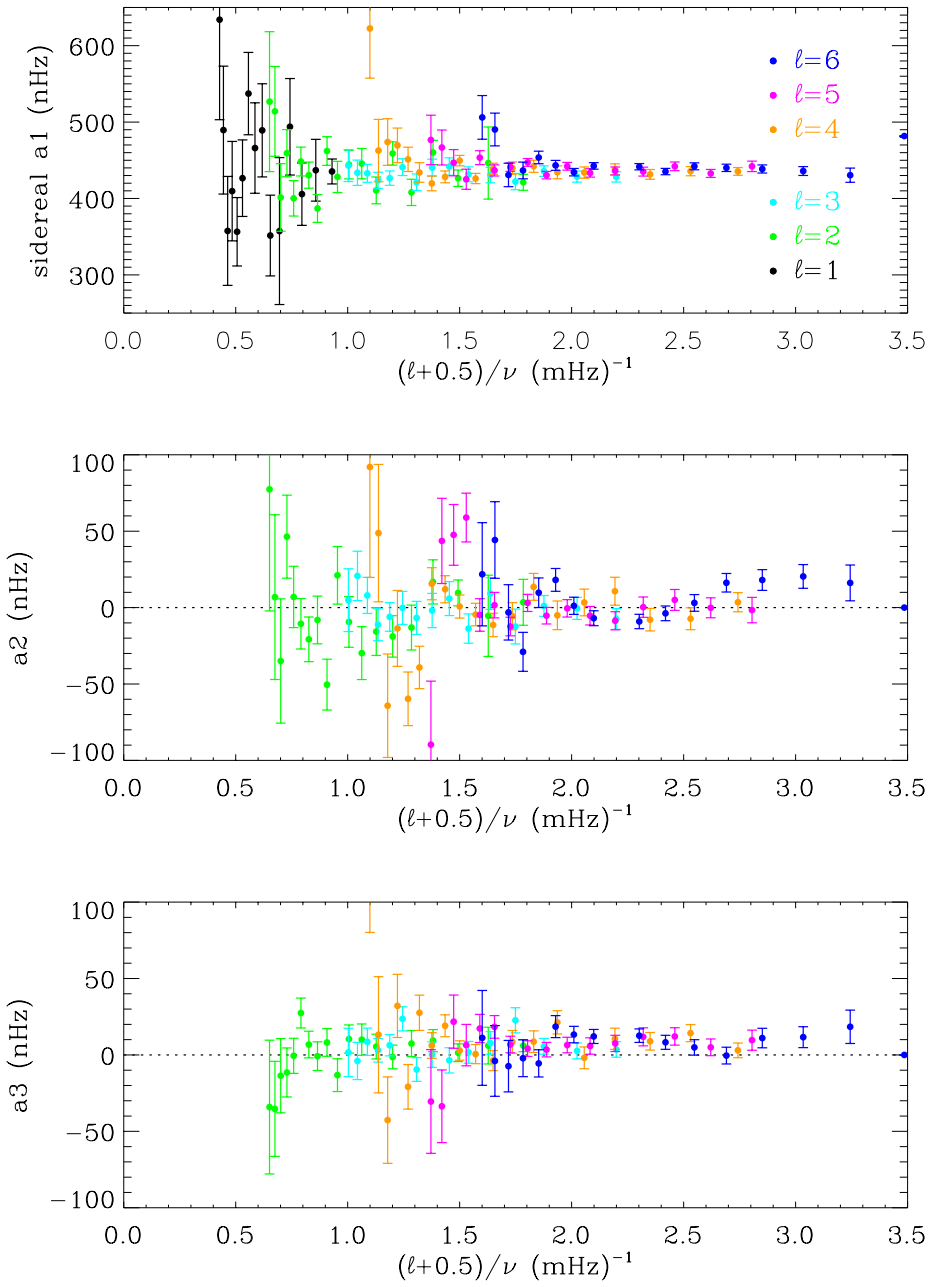
Rabello-Soares and Appourchaux, 1998

Effect of aliasing modes for GONG (uncleaned)

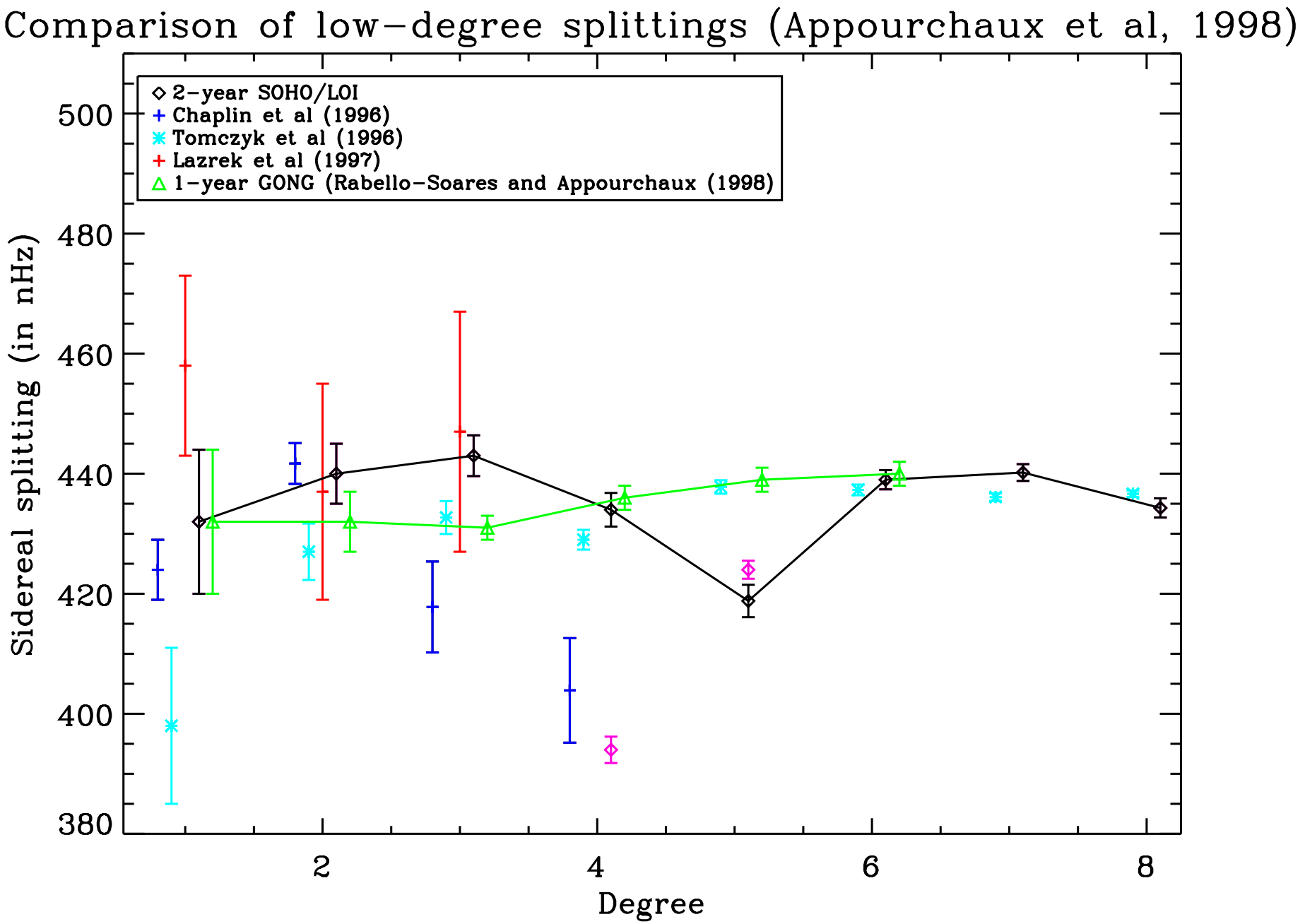


Rabello-Soares and Appourchaux, 1998

Effect of aliasing modes for GONG (cleaned)



Rabello-Soares and Appourchaux, 1998


Comparison of low−degree splittings (Appourchaux et al, 1998)
2−year SOHO/LOI
Chaplin et al (1996)
Tomczyk et al (1996)
Lazrek et al (1997)
1−year GONG (Rabello−Soares and Appourchaux (1998)
Sidereal splitting (in nHz)
500
480
460
440
420
400
380
2
4
6
8
Degree

Interim conclusion 1

- Helioseismic data are getting better every day
- The fitting techniques are very close to maturity
- Leakage model visualization is a must!
- The systematic errors for the splittings are now ‘well’ understood
- The rotation of the solar core is still under investigation...Ah! these g modes...

On trapping g modes...

The Phoebus group

SOI/MDI
- P.Scherrer
- T.Hoeksema
- A.Kosovichev

VIRGO
- C.Frohlich
- T.Appourchaux
- T.Toutain
- W.Finsterle
- B.Andersen

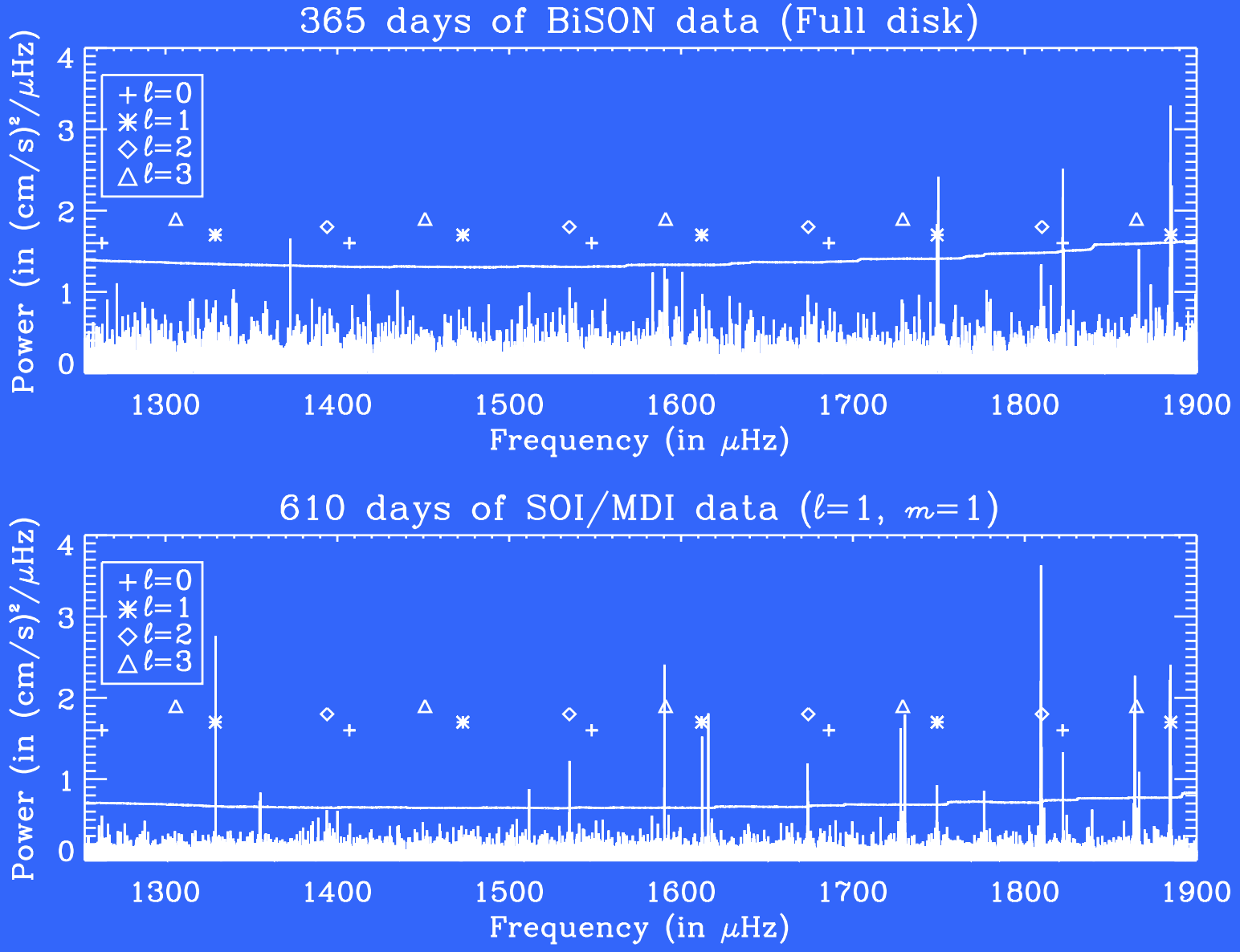
BiSON
- W.Chaplin
- Y.Elsworth
- G.Isaak

Theoreticians
- D.O.Gough
- J.Provost
- T.Sekii

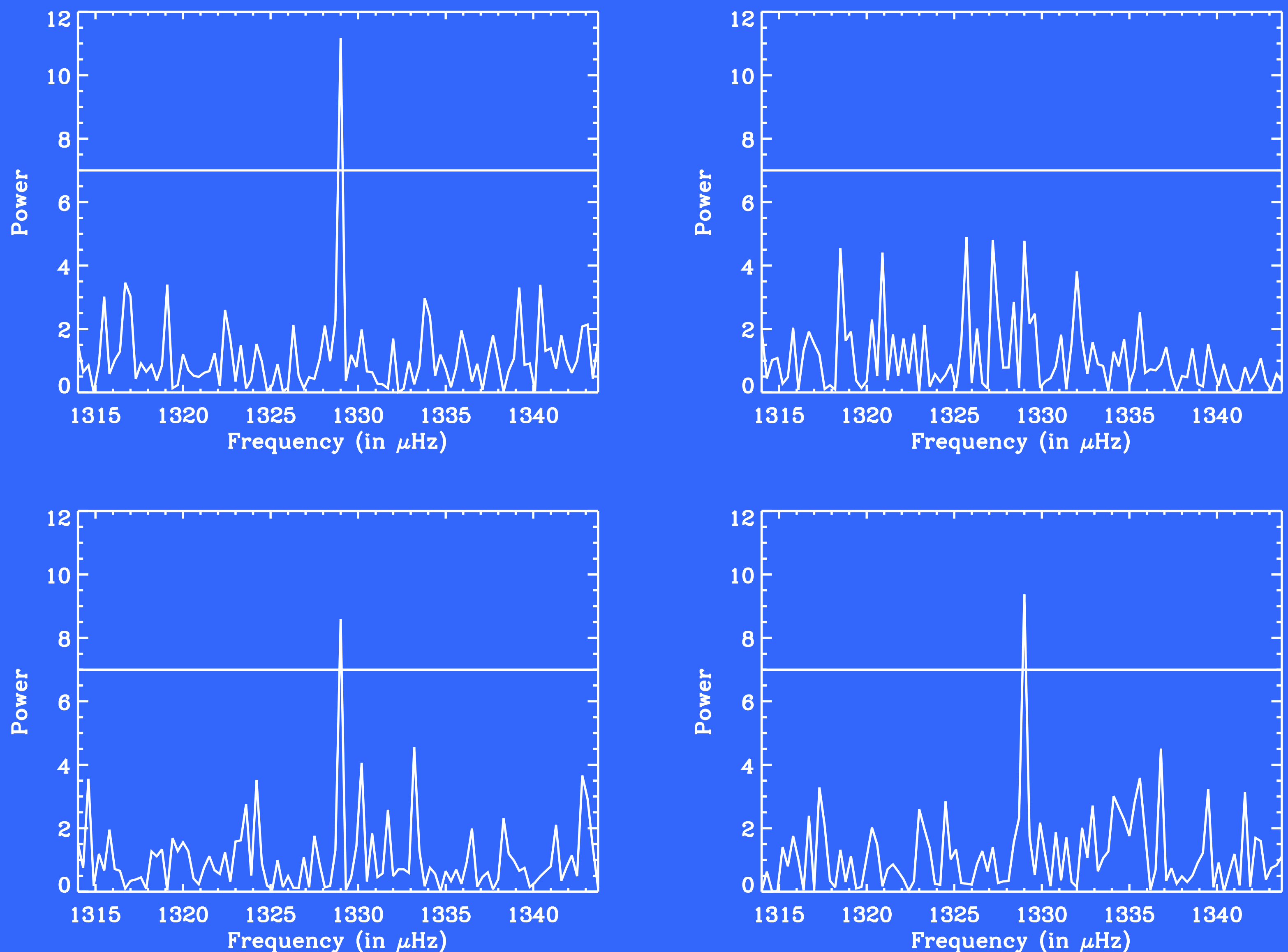
g-mode detection techniques

- Statistical methods
- Patterns:
  - Splitting (Collapsogramme)
  - Splitting + P_0
- Autocorrelation of spectra
- Data combination:
  - multivariate analysis
  - cross spectra

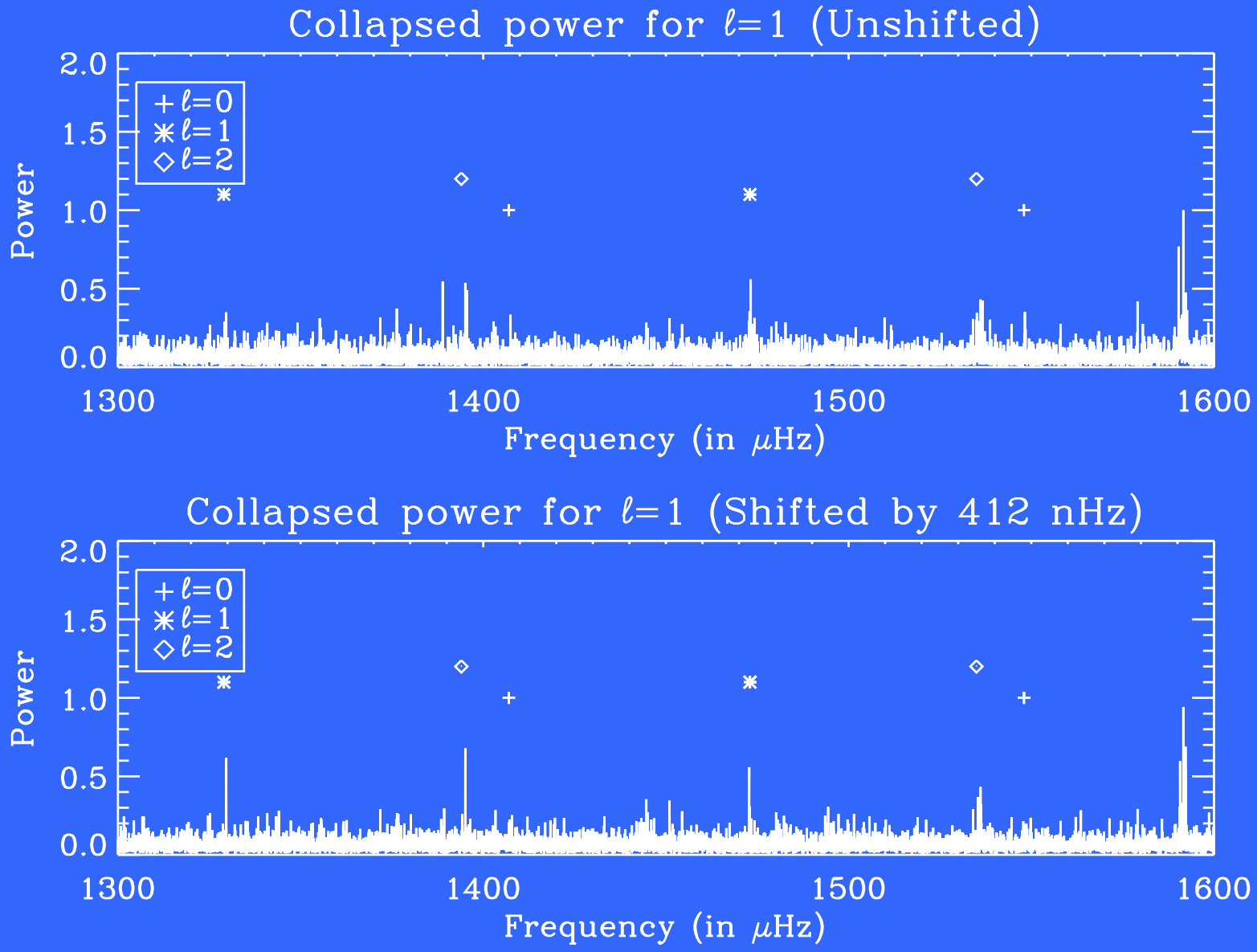
Statistical method: the 10-σ limit



Hide and seek: a low order p mode



Collapsogrammes for the SOI/MDI data



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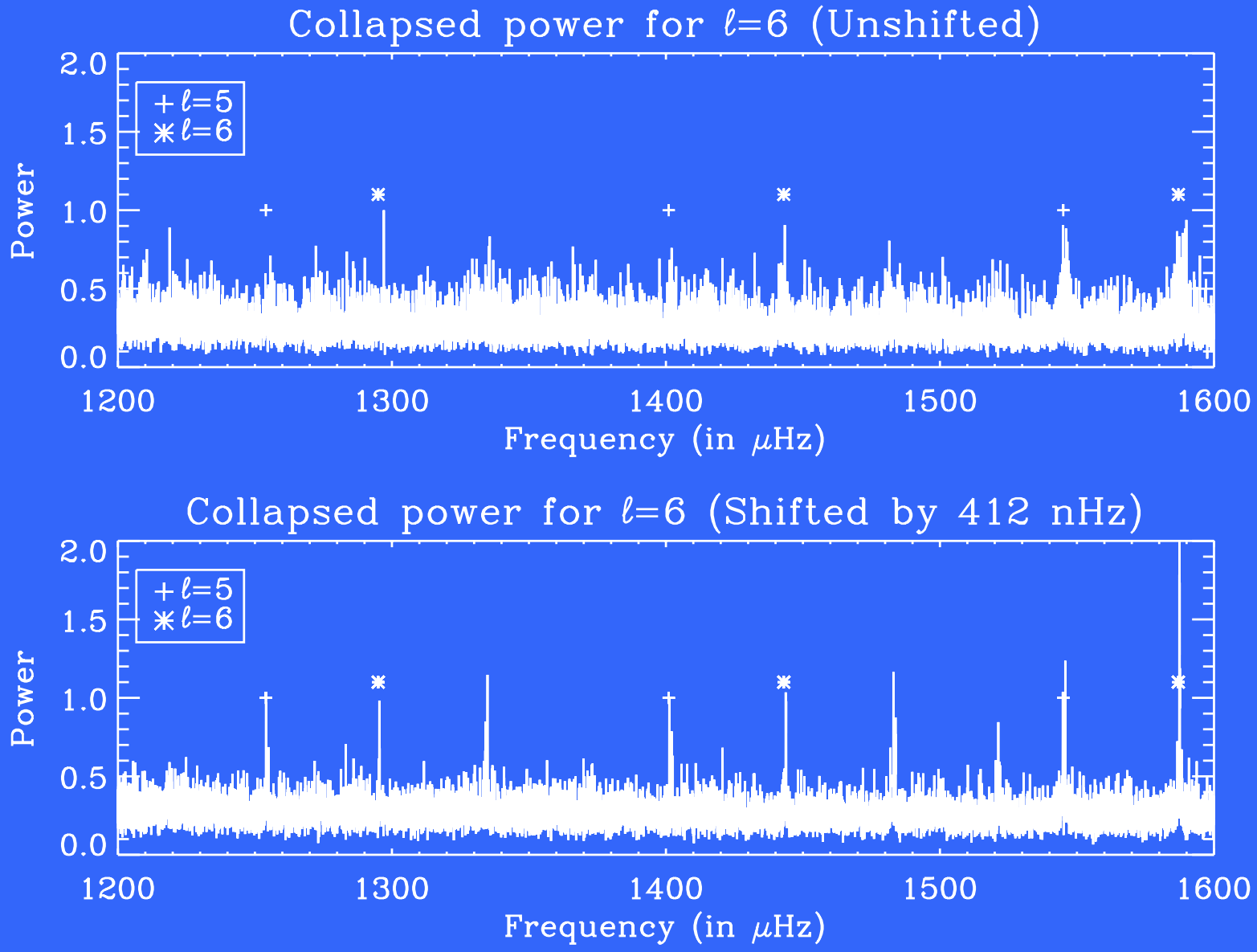

The future

- The rotation of the solar core:
  - Getting there...
  - Need more time
  - Unified splittings
- The structure of the solar core:
  - g modes too faint?
  - Low frequency p modes instead of g modes...
  - May need other instrumentation or data...

Leakage matrix: an example for l=1

$$y(\nu) = \boldsymbol{C}\, x(\nu)$$

- $x(\nu)$ are the modes desired
- $y(\nu)$ is what we observe
- C is the leakage matrix

$$C^{11} = \begin{pmatrix} 1 & 0 & \alpha_{11} \\ 0 & 1 & 0 \\ \alpha_{11} & 0 & 1 \end{pmatrix}$$

Correlation matrices

$$V_{11} = \begin{pmatrix} f_1(\nu) + \alpha_{11}^2 f_{-1}(\nu) & 0 & \alpha_{11} f_1(\nu) + \alpha_{11} f_{-1}(\nu) \\ 0 & f_0(\nu) & 0 \\ \alpha_{11} f_1(\nu) + \alpha_{11} f_{-1}(\nu) & 0 & f_{-1}(\nu) + \alpha_{11}^2 f_1^2(\nu) \end{pmatrix}$$