Solar-cycle variation of oscillation frequencies and surface magnetic field

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Pulsating Stars

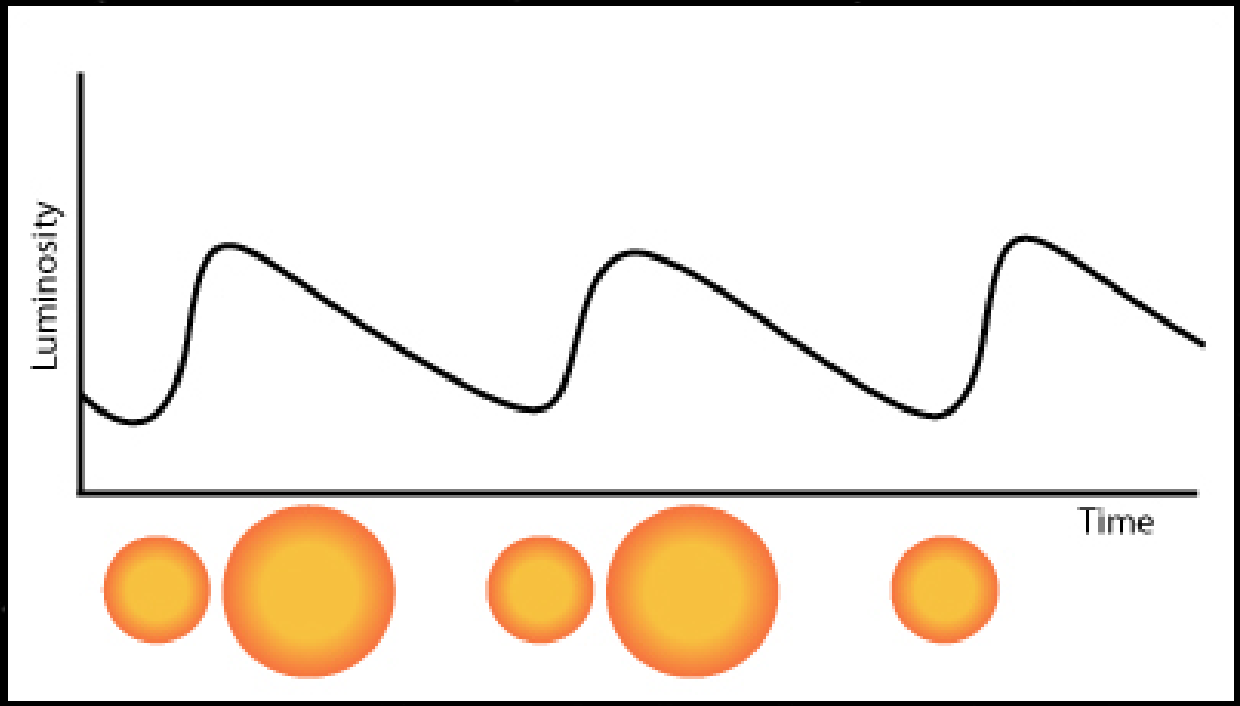


Image credit: European Science Agency, http://sci.esa.int/science-e-media/img/20/cepheid-variables.jpg

- Cepheid variables
- Standard candle

Closer to Home…

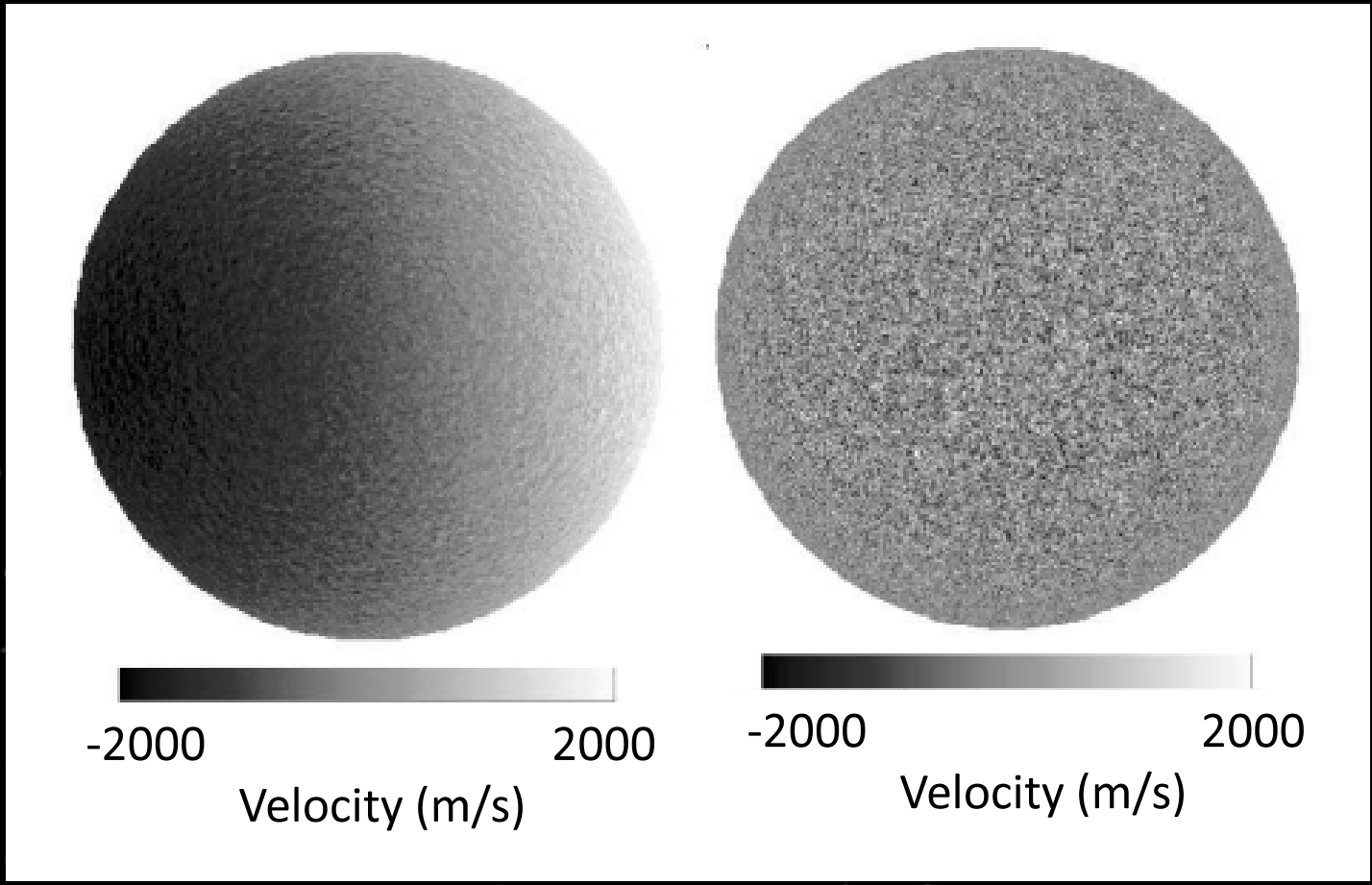


Image credit: Christensen-Dalsgaard, 2002 [1]

Instruments

- Michelson Doppler Interferometer (MDI) on SOHO spacecraft
- Global Oscillation Network Group (GONG)

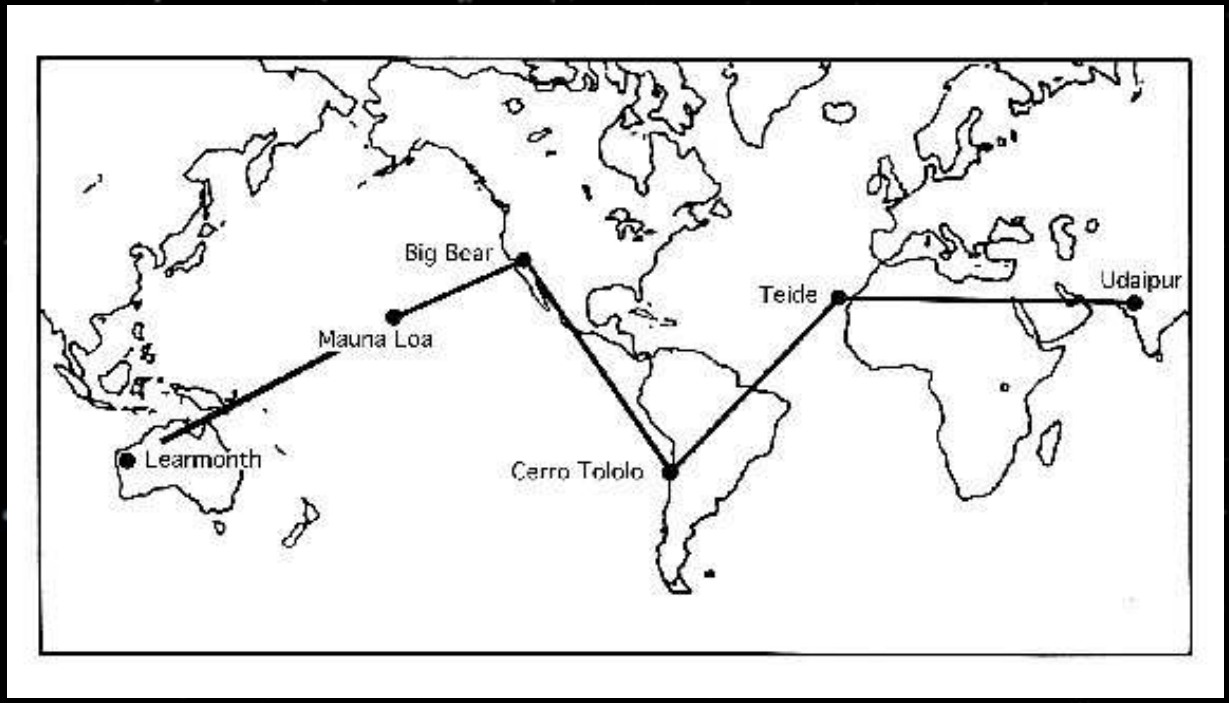


Image credit: GONG, http://gong.nso.edu/

Solar Oscillations

- Oscillation period ~ 5 minutes
- Data averaged over 72 days (SOHO) or 36 days (GONG) to find frequencies
- p-modes and g-modes

Motivation

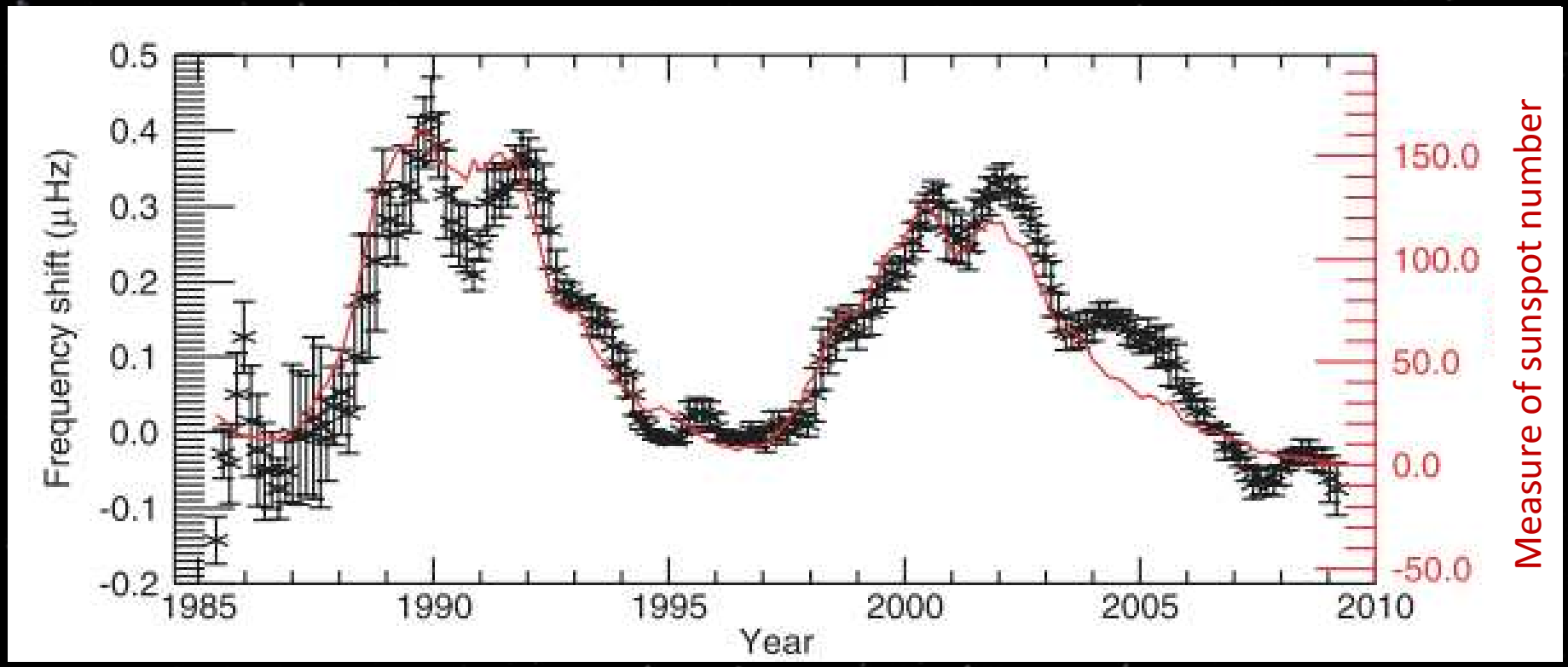


Image credit: Broomhall et al., 2009 [2]

Oscillation Modes

Radial direction:

- Radial order, n

Surface:

- Degree, l
- Azimuthal order, m
- $-l \leq m \leq l$

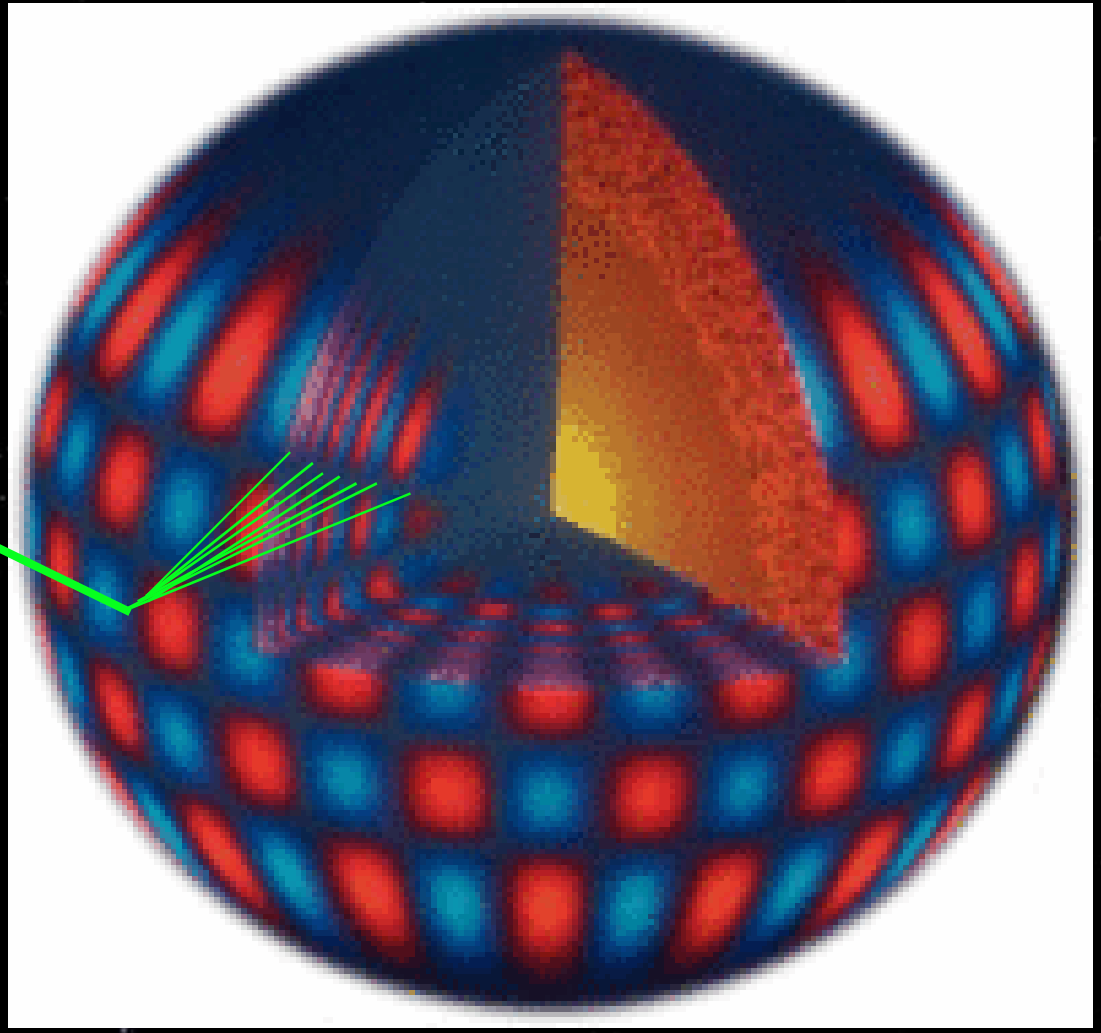


Image credit: GONG, http://gong.nso.edu/

Spherical Harmonics

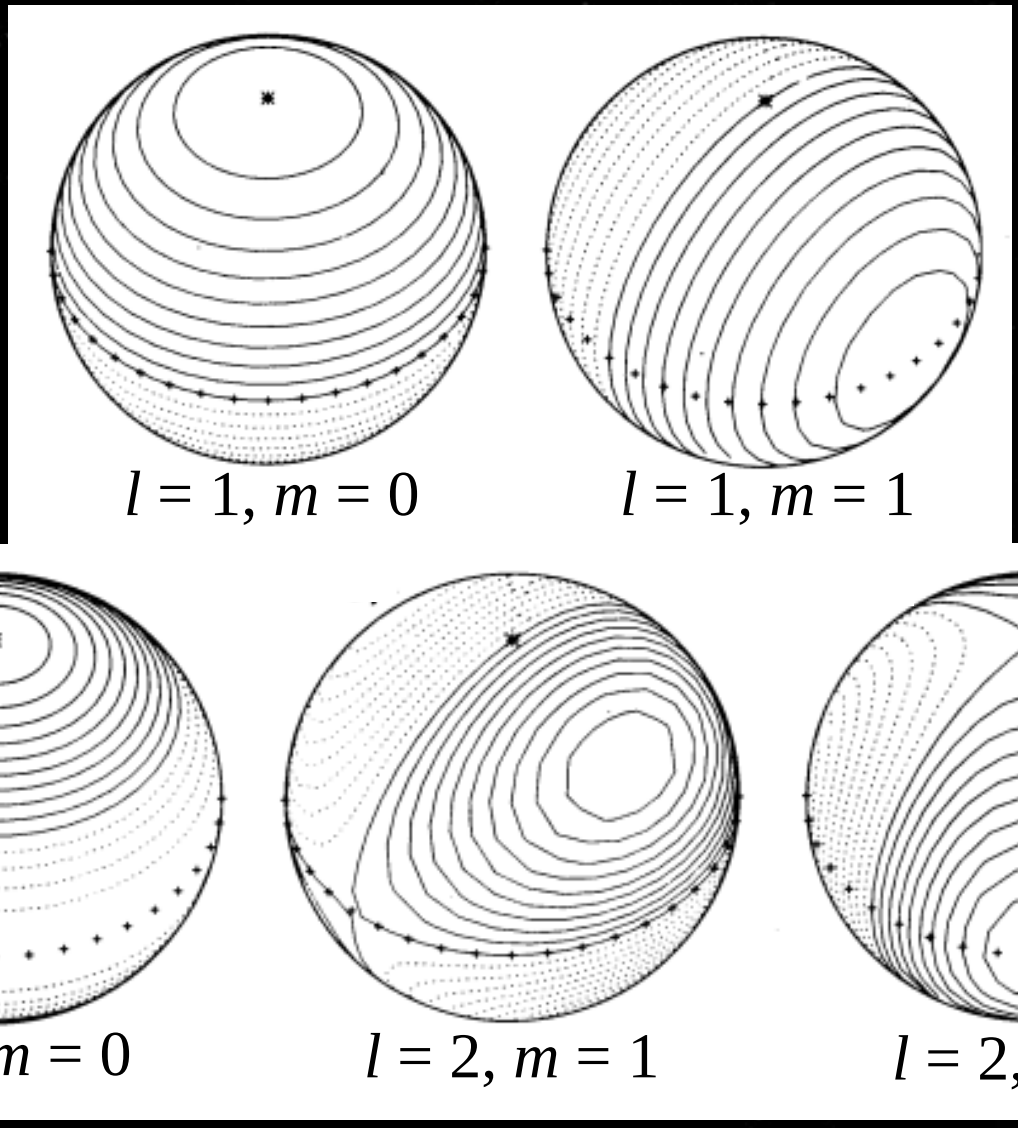


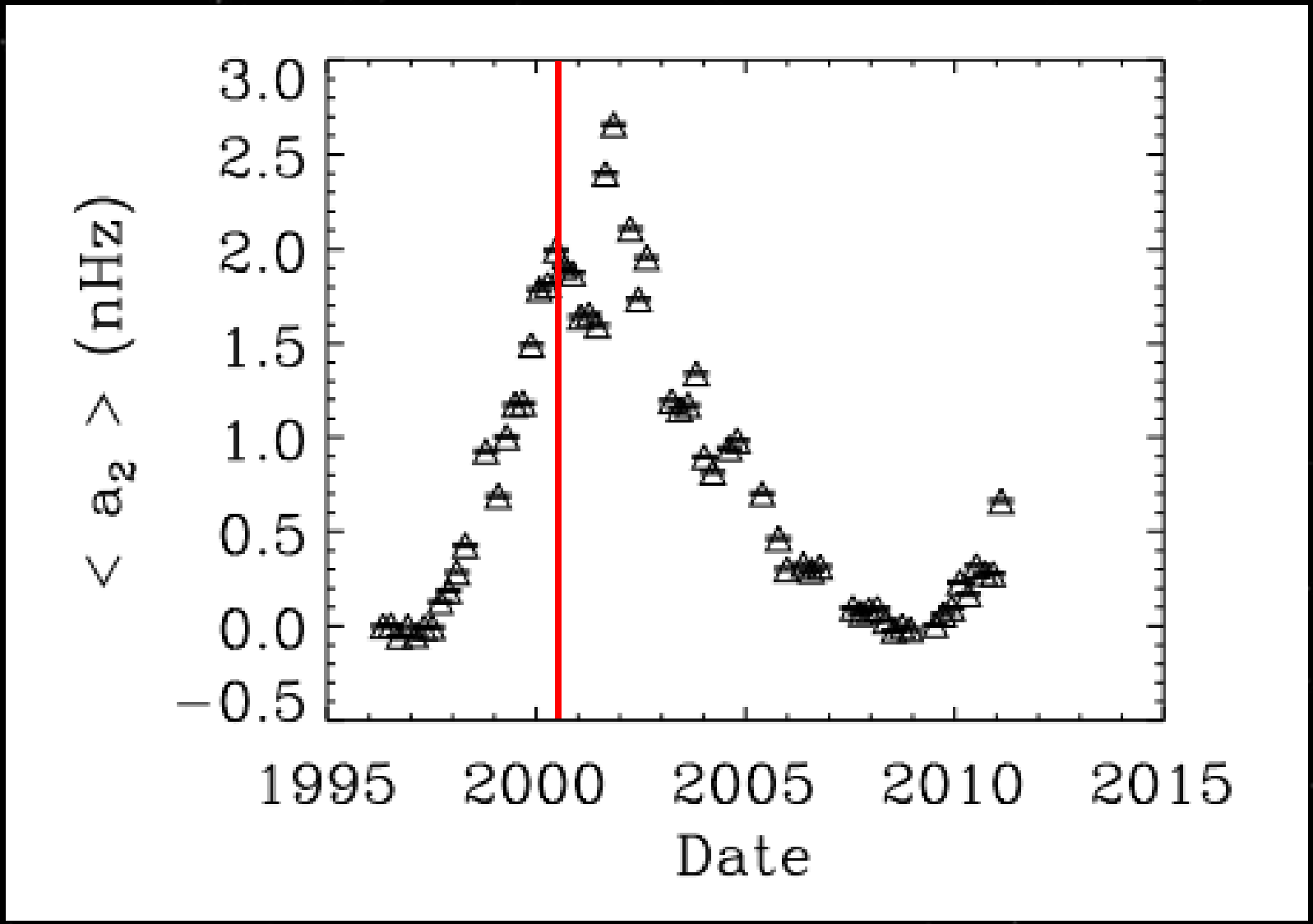
Image credit: Christensen-Dalsgaard, 2003 [3]

Frequency Splitting

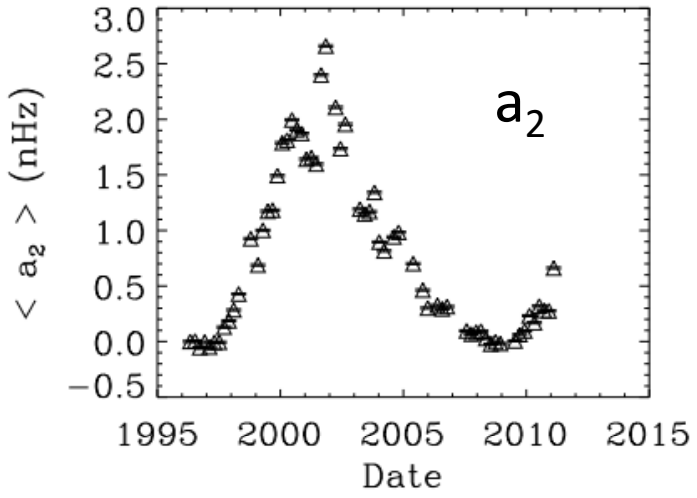
- Fourier analysis
- Legendre decomposition

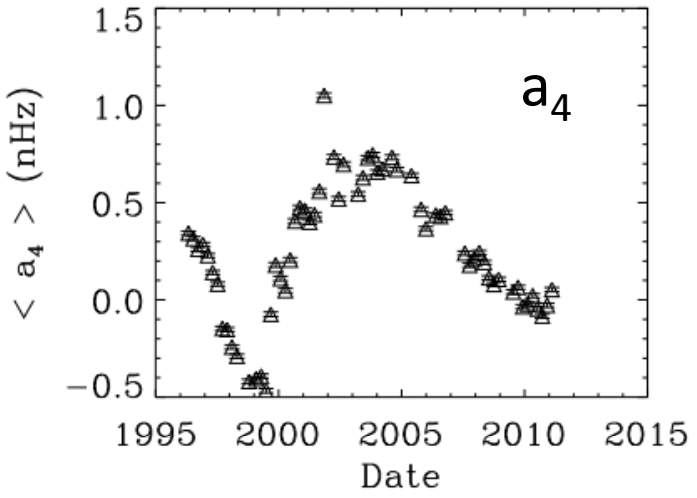
$$\nu_{nlm} = \nu_{nl0} + \sum_{k=1}^{k_{max}} a_k(n,l) P_k^{(l)}(m)$$

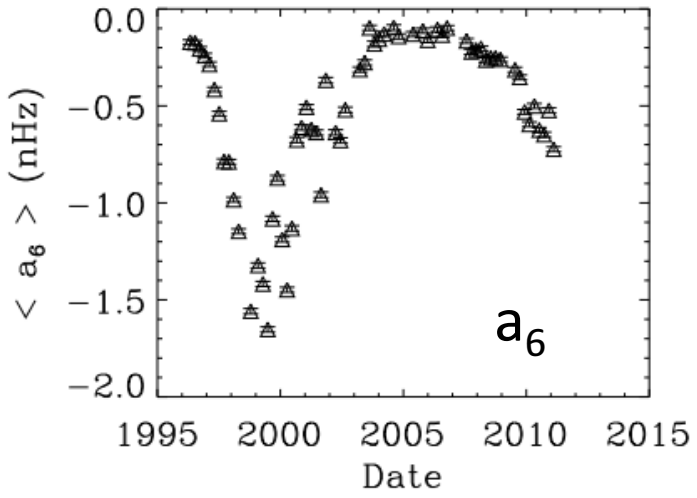
a_k Coefficients over the Solar Cycle

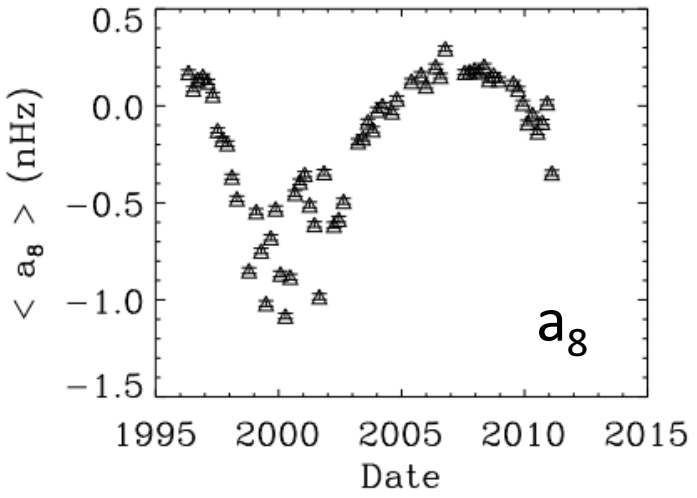


a_k Coefficients over the Solar Cycle









Surface Magnetic Field

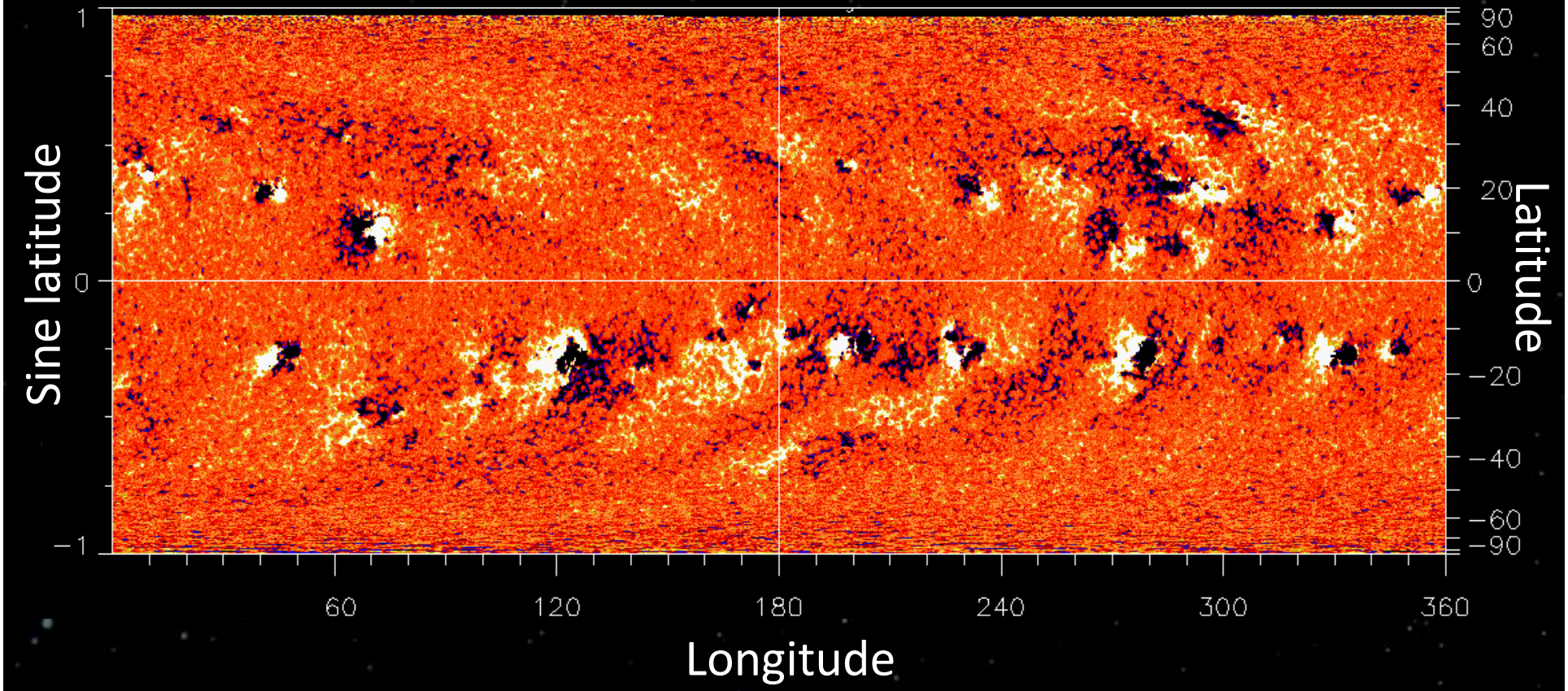
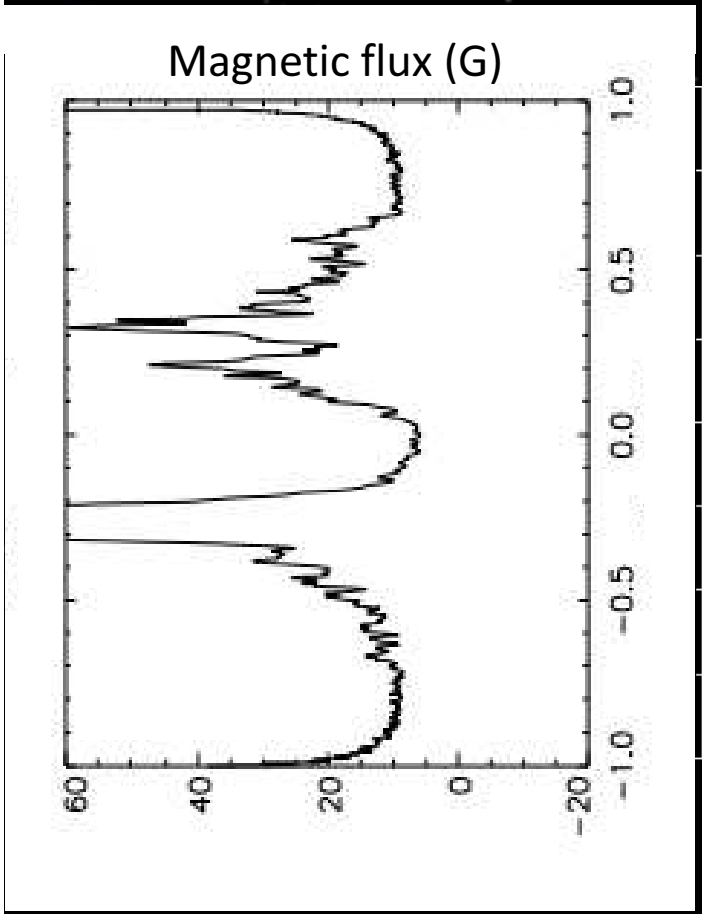
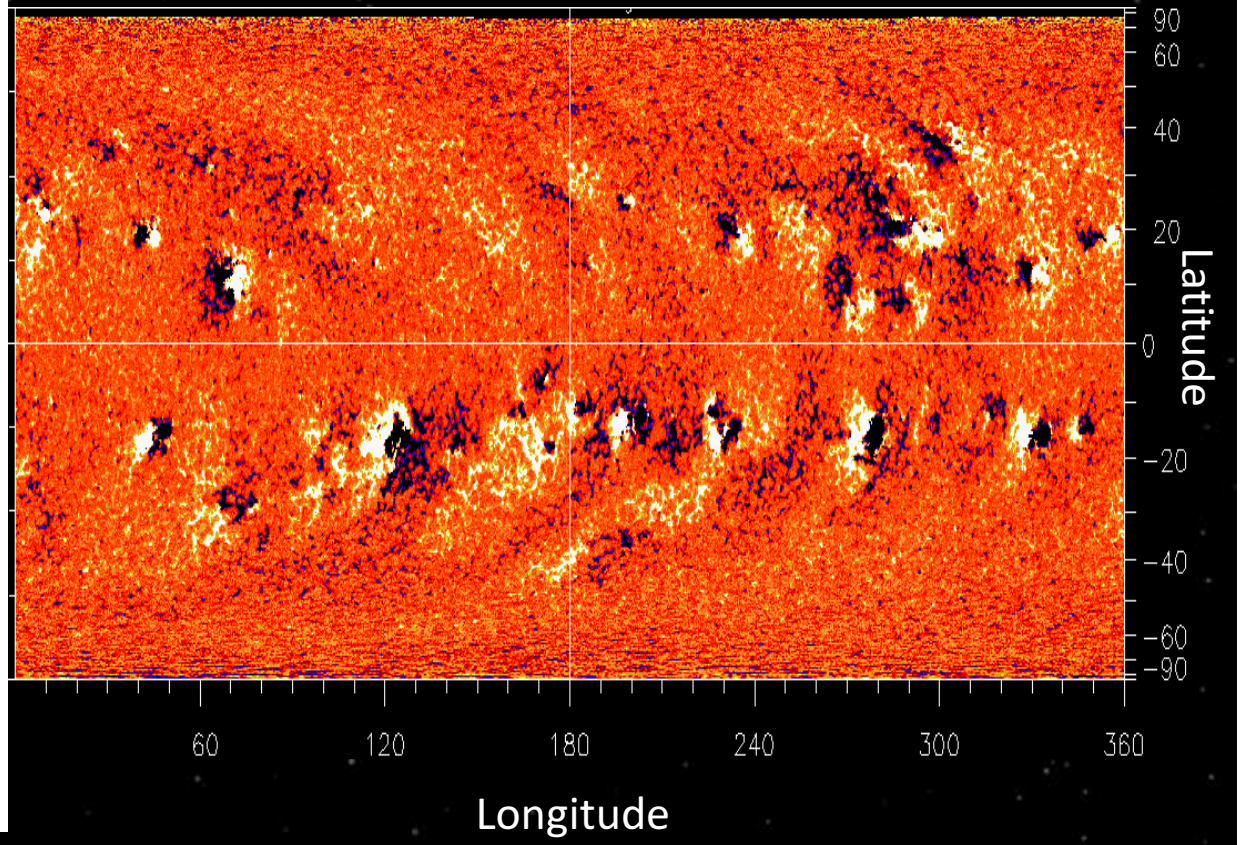


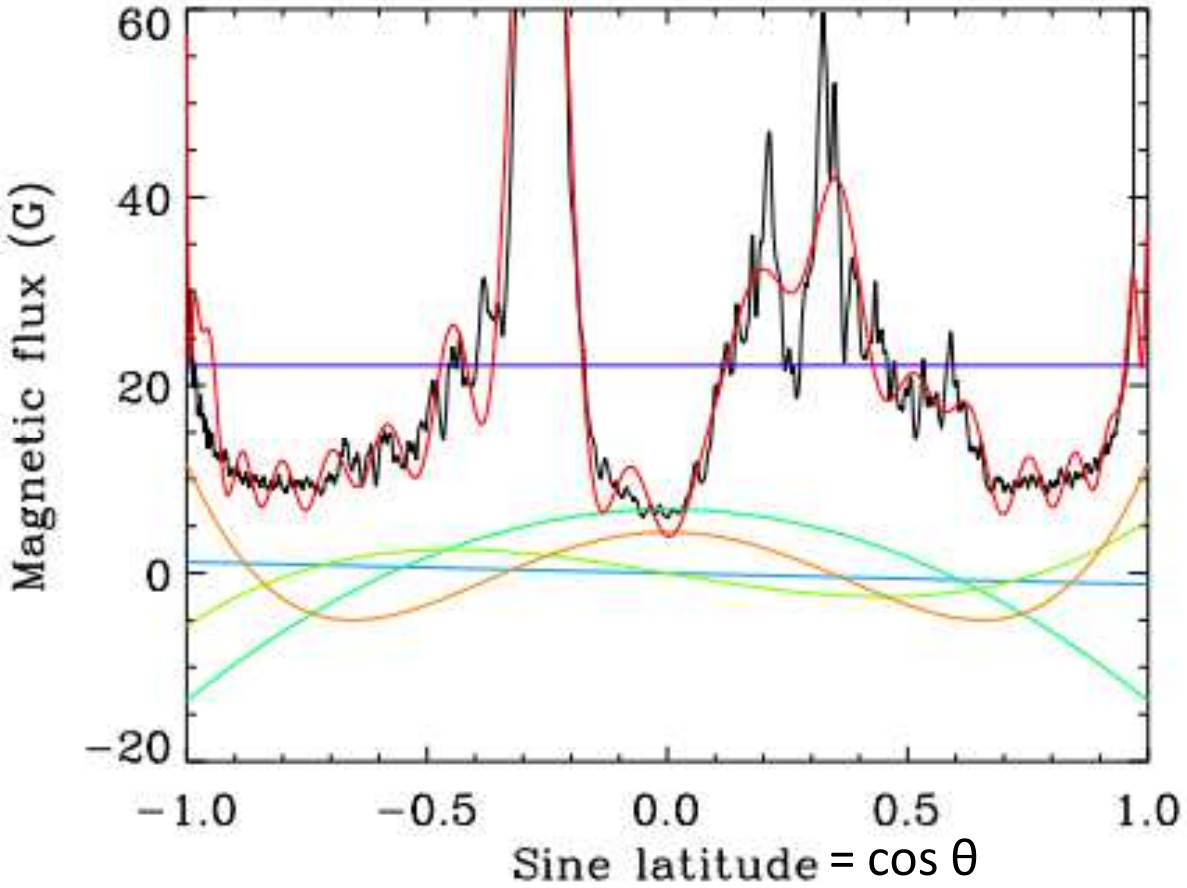
Image credit: Solar Oscillations Investigation,
http://soi.stanford.edu/magnetic/index6.html

Surface Magnetic Field





Legendre Decomposition of B-field



Scaled P_k for:

k = 0

k = 1

k = 2

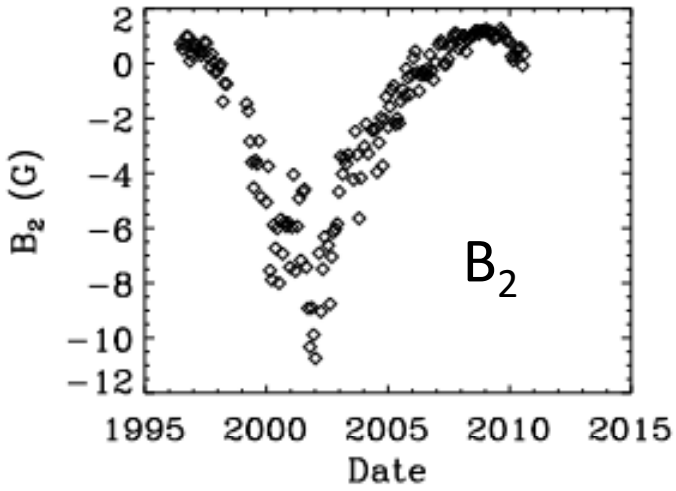
k = 3

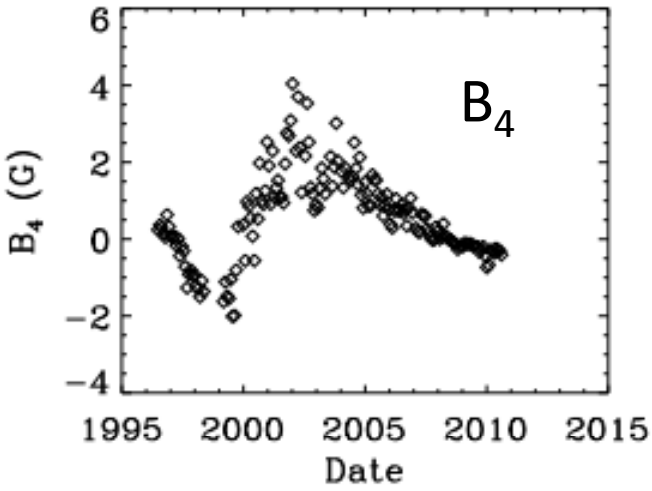
k = 4

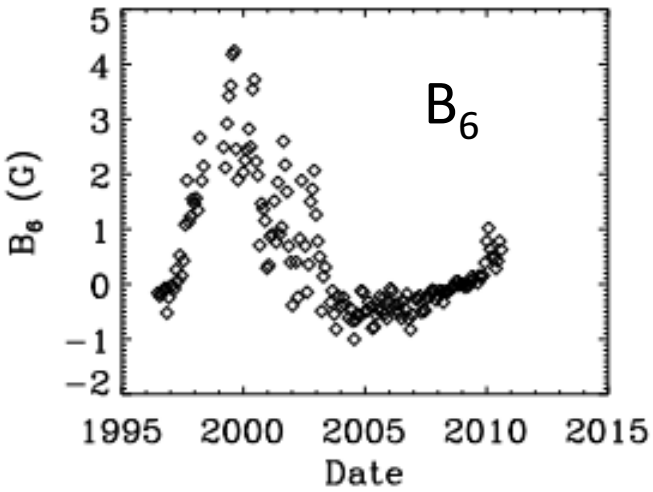
Sum (40 components)

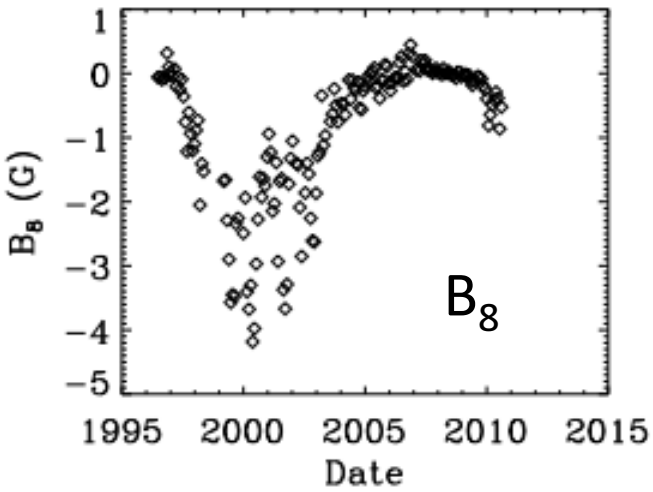
$$B(t,\cos\theta) = \sum_k B_k(t) P_k(\cos\theta)$$

B_k Coefficients over the Solar Cycle

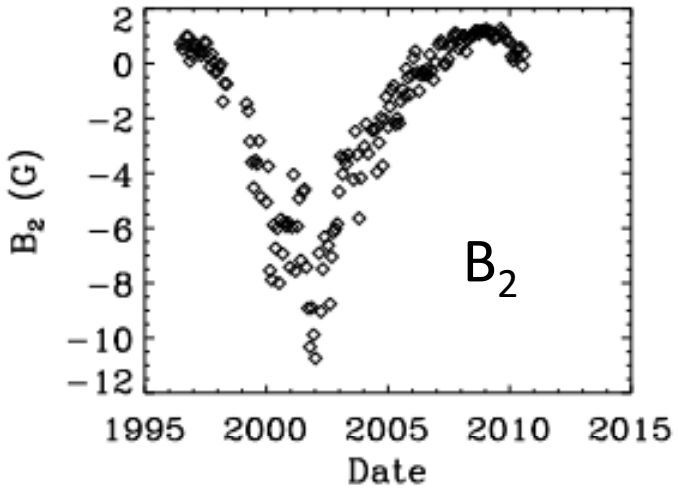


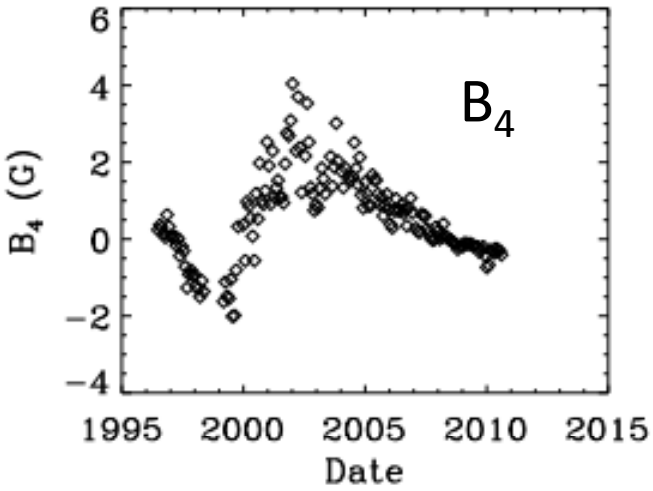






B_k Coefficients over the Solar Cycle





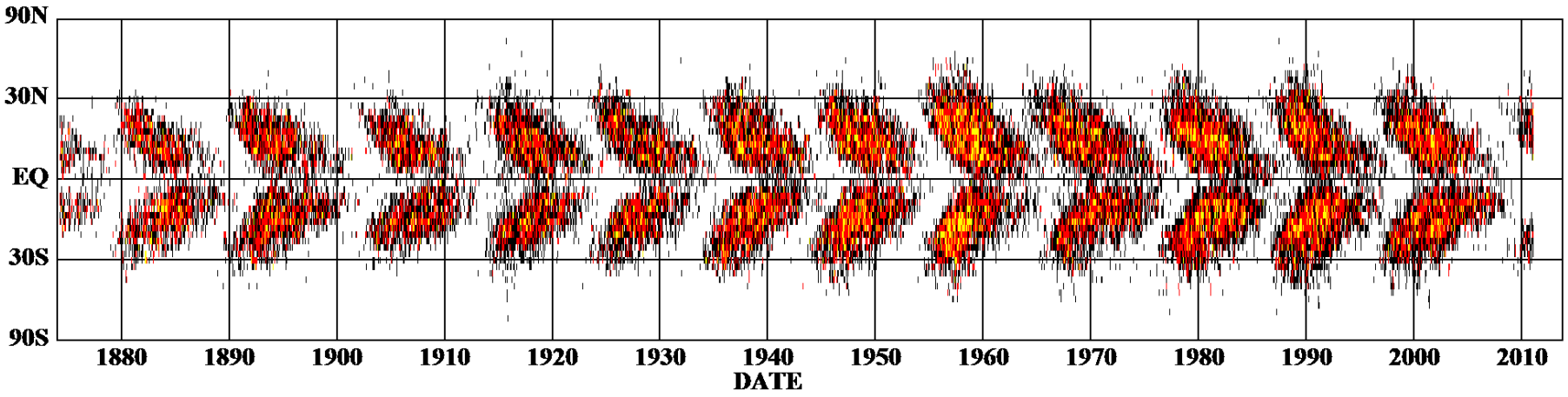
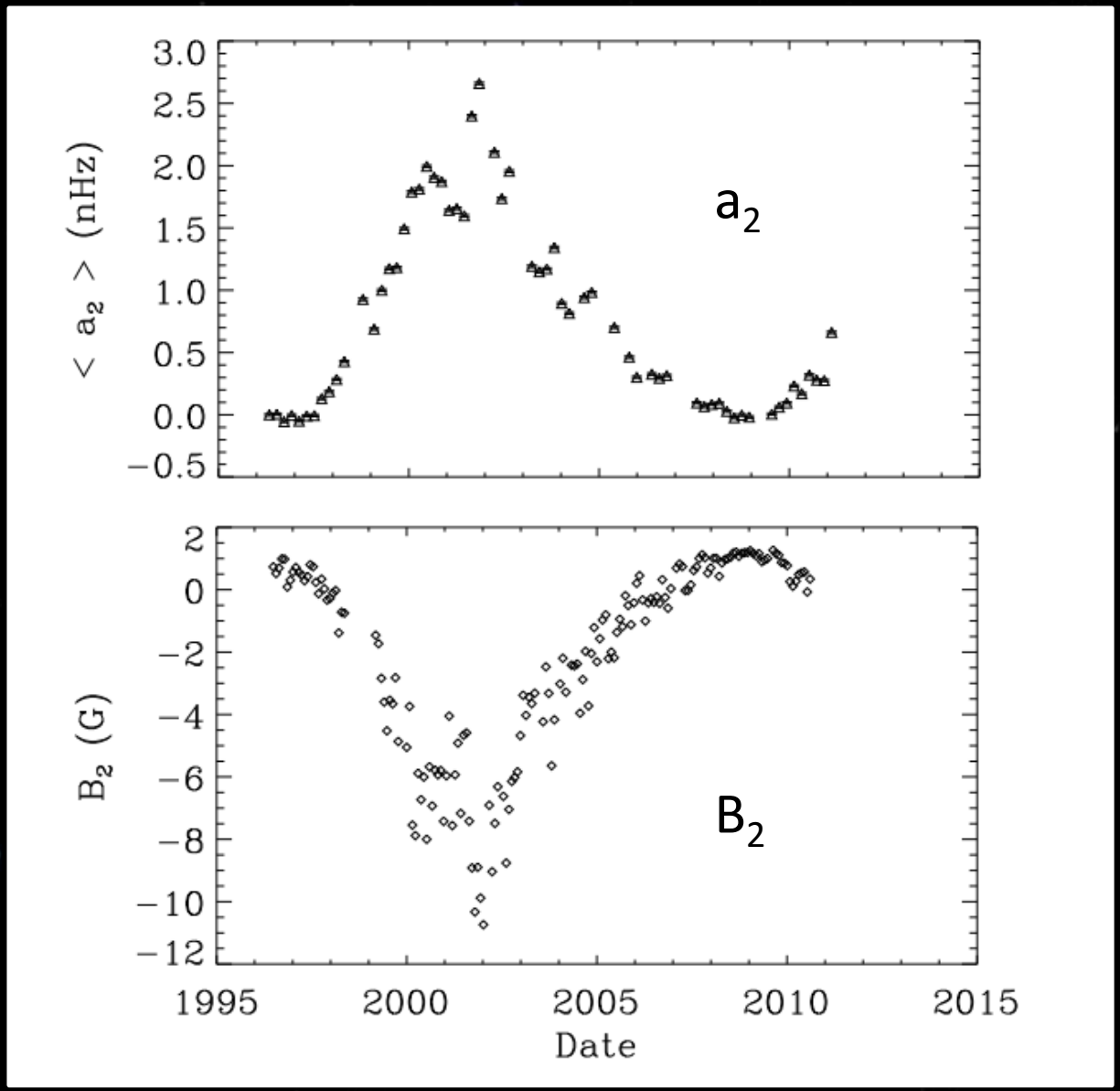
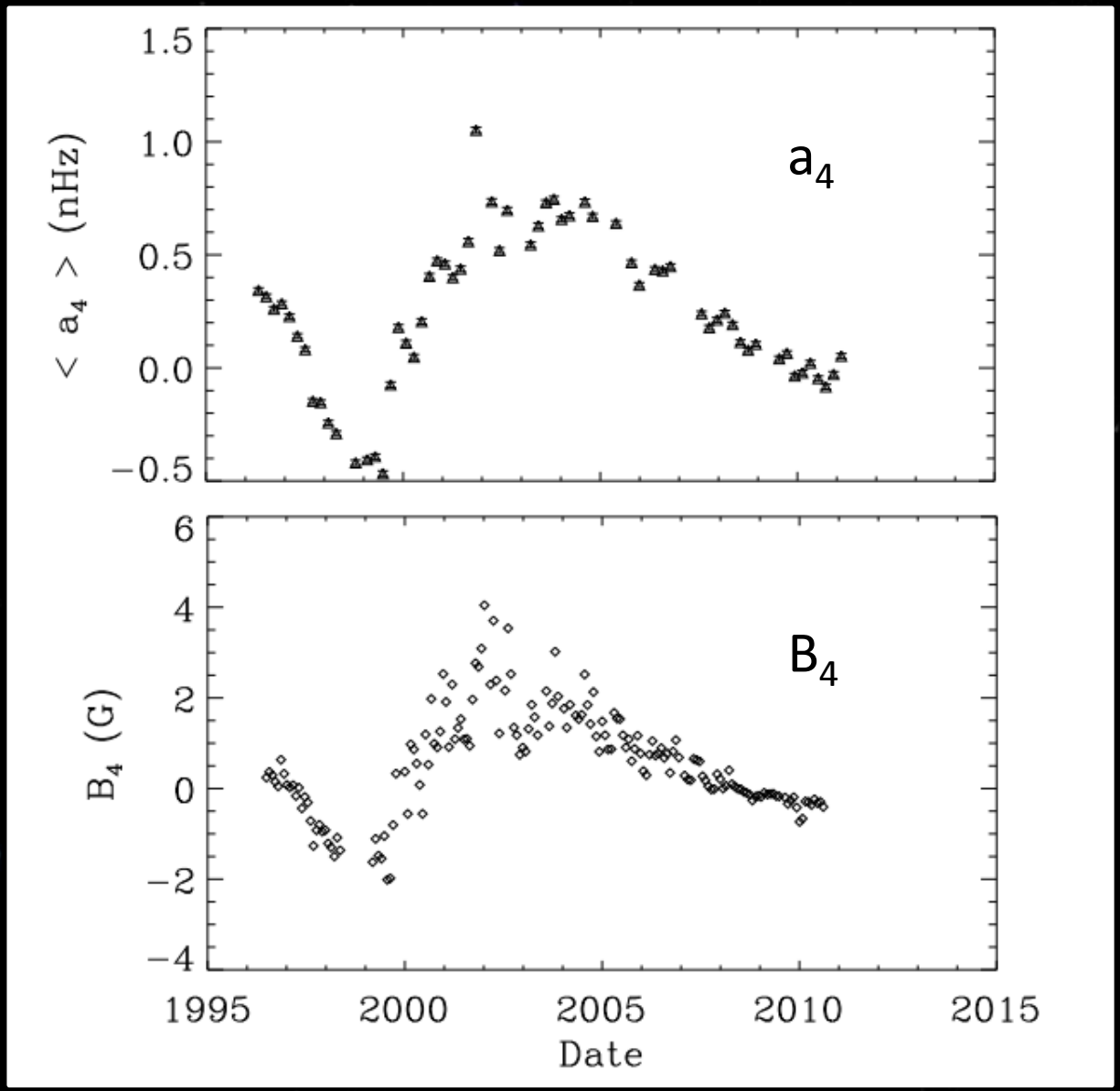


Image credit: David Hathaway, http://solarscience.msfc.nasa.gov

a_k vs. B_k

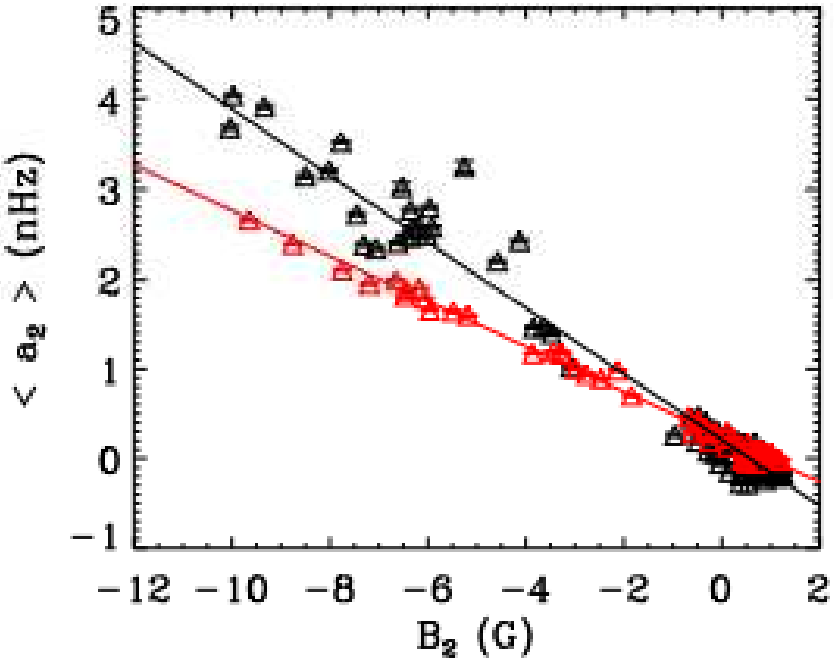

3.0
2.5
2.0
1.5
1.0
0.5
0.0
−0.5
< a2 > (nHz)
a2
2
0
−2
−4
−6
−8
−10
−12
B2 (G)
B2
1995
2000
2005
2010
2015
Date

a_k vs. B_k

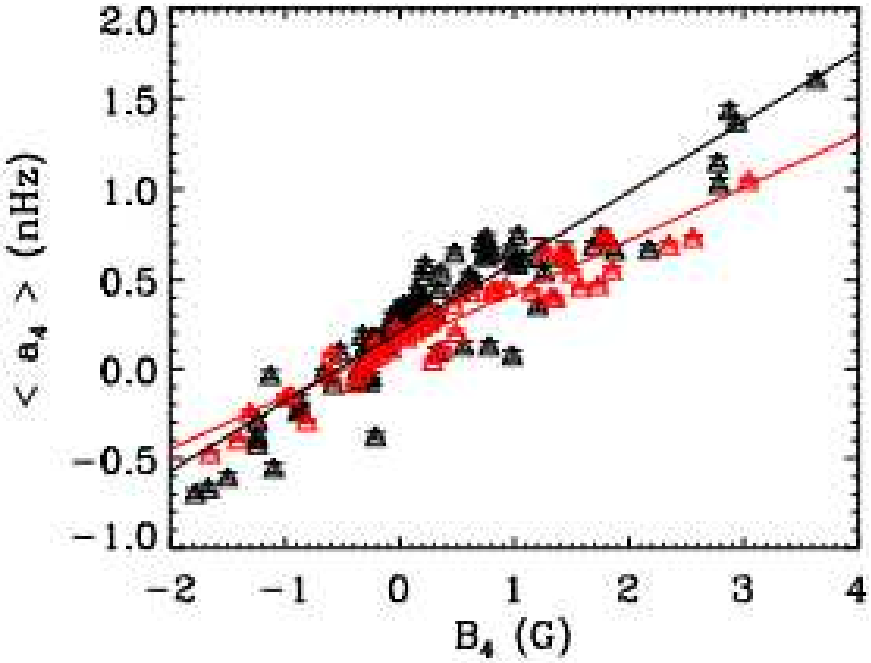

1.5
1.0
0.5
0.0
−0.5
< a4 > (nHz)
a4
6
4
2
0
−2
−4
B4 (G)
B4
1995
2000
2005
2010
2015
Date

a_k vs. B_k – Linear Correlation

a_2 vs. B_2



a_4 vs. B_4



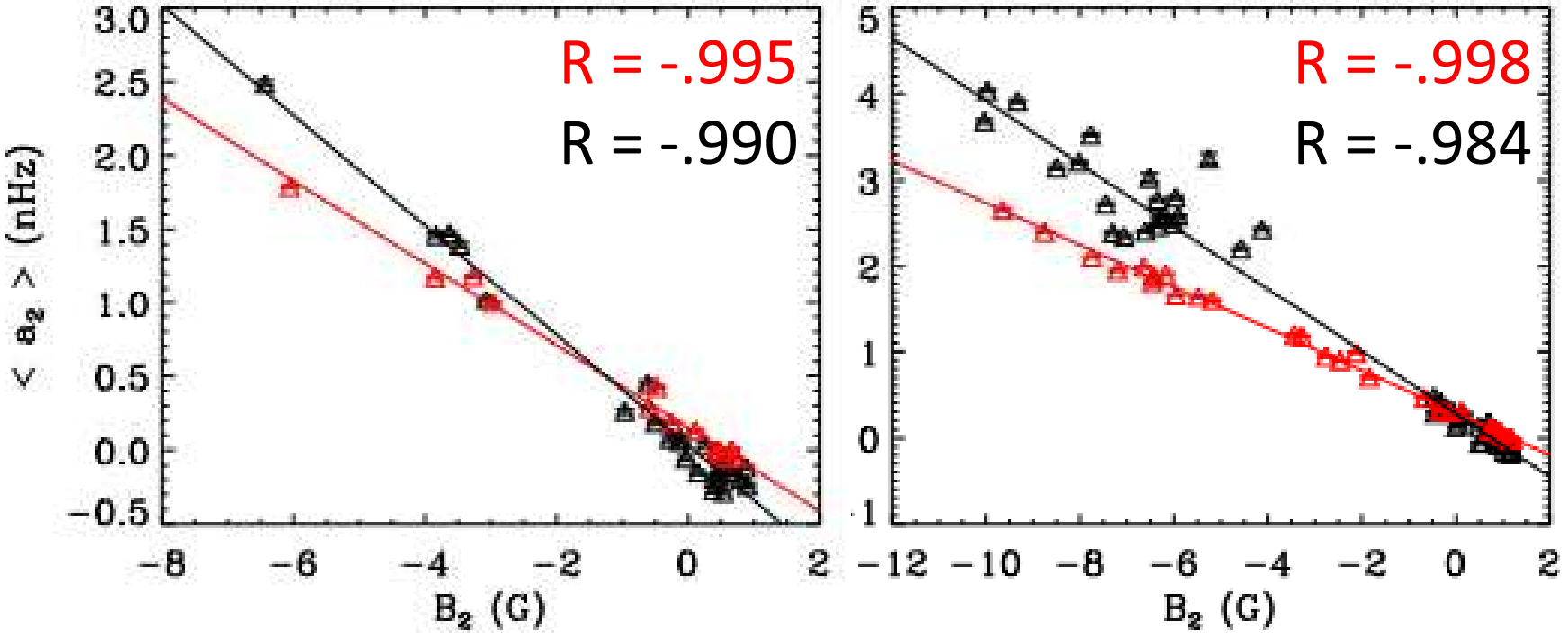
SOHO

GONG

a_k vs. B_k over the Solar Cycle

Rising phase

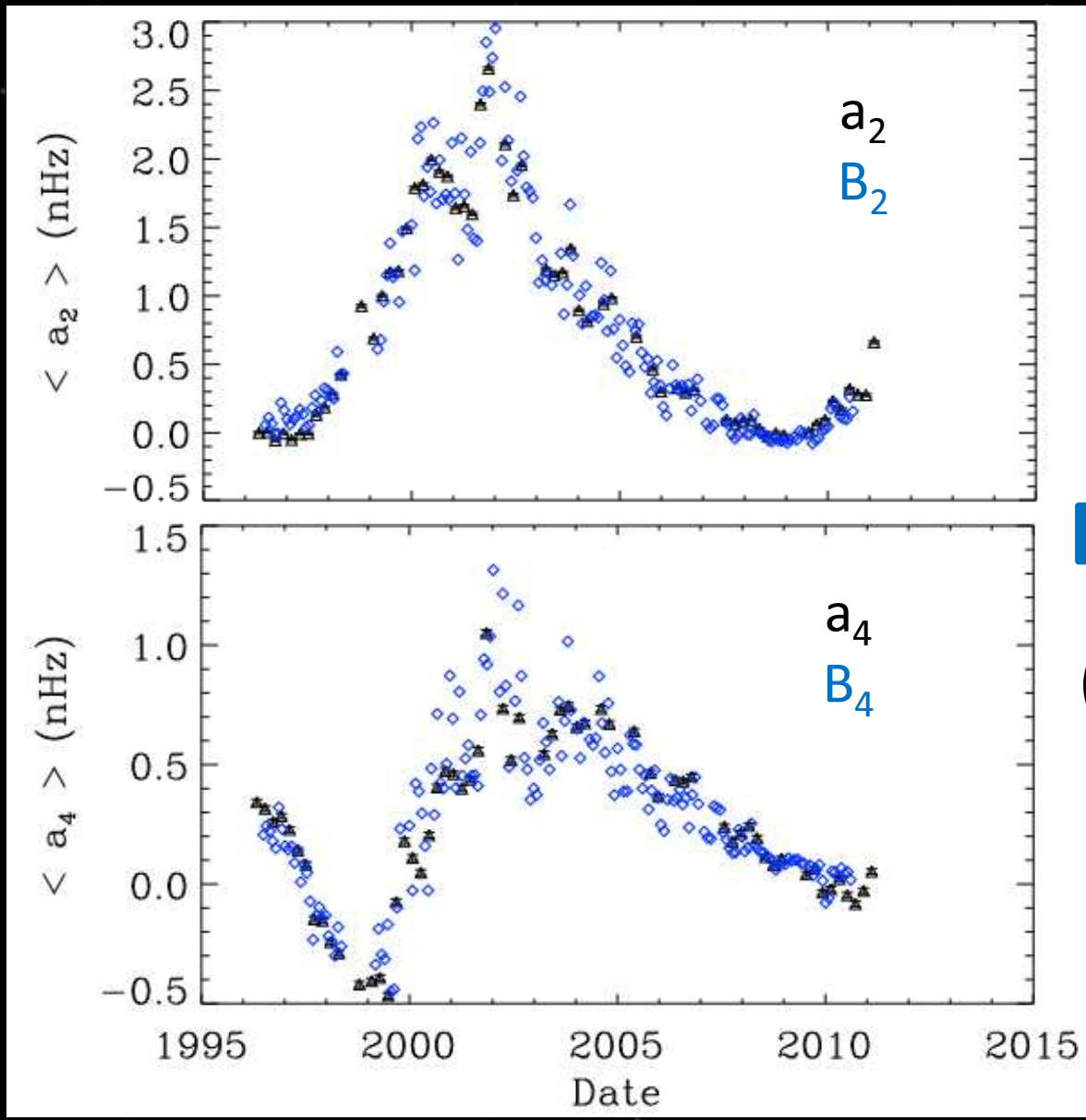
Declining phase



SOHO

GONG

a_k vs. B_k

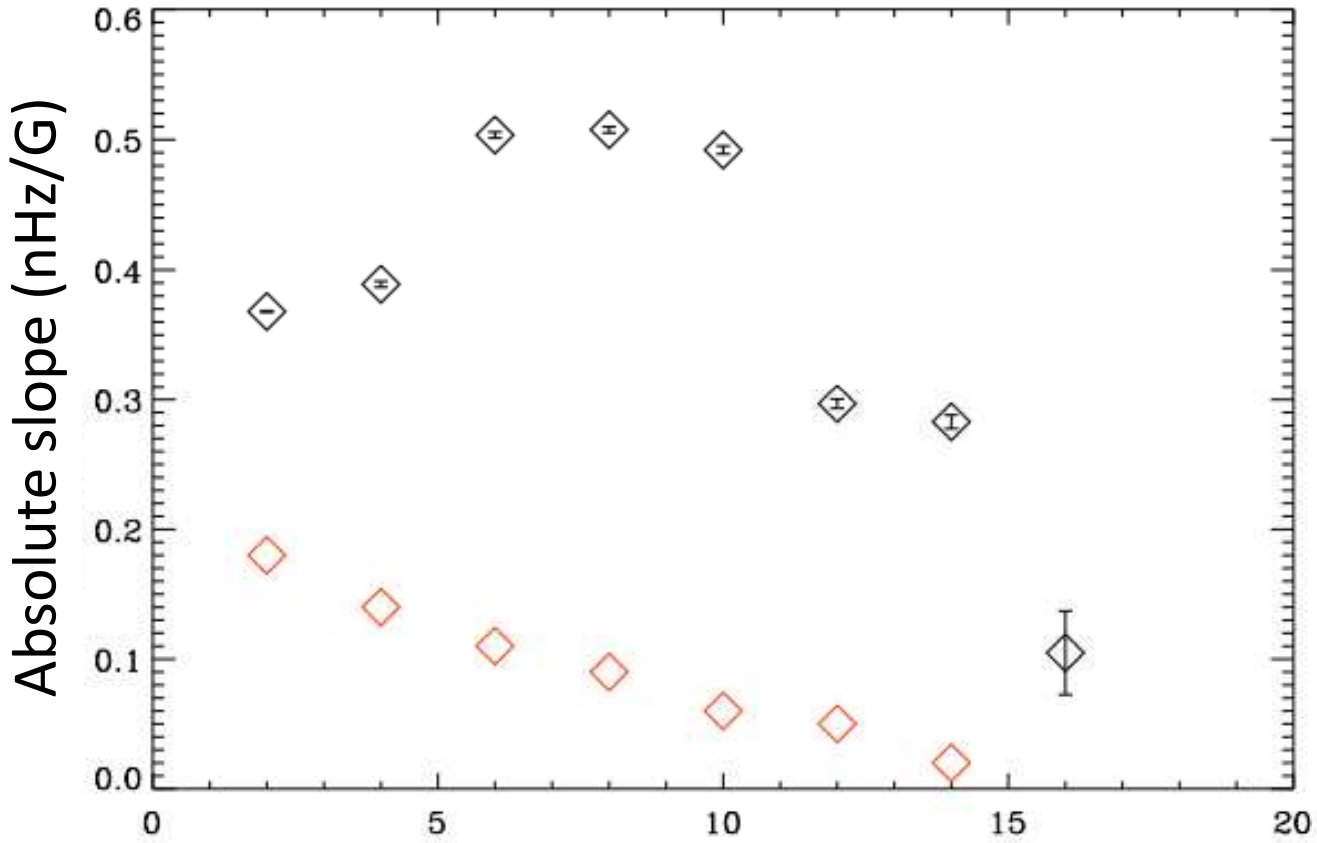


a_k

B_k (scaled)

(SOHO data)

Absolute slope of the linear fit

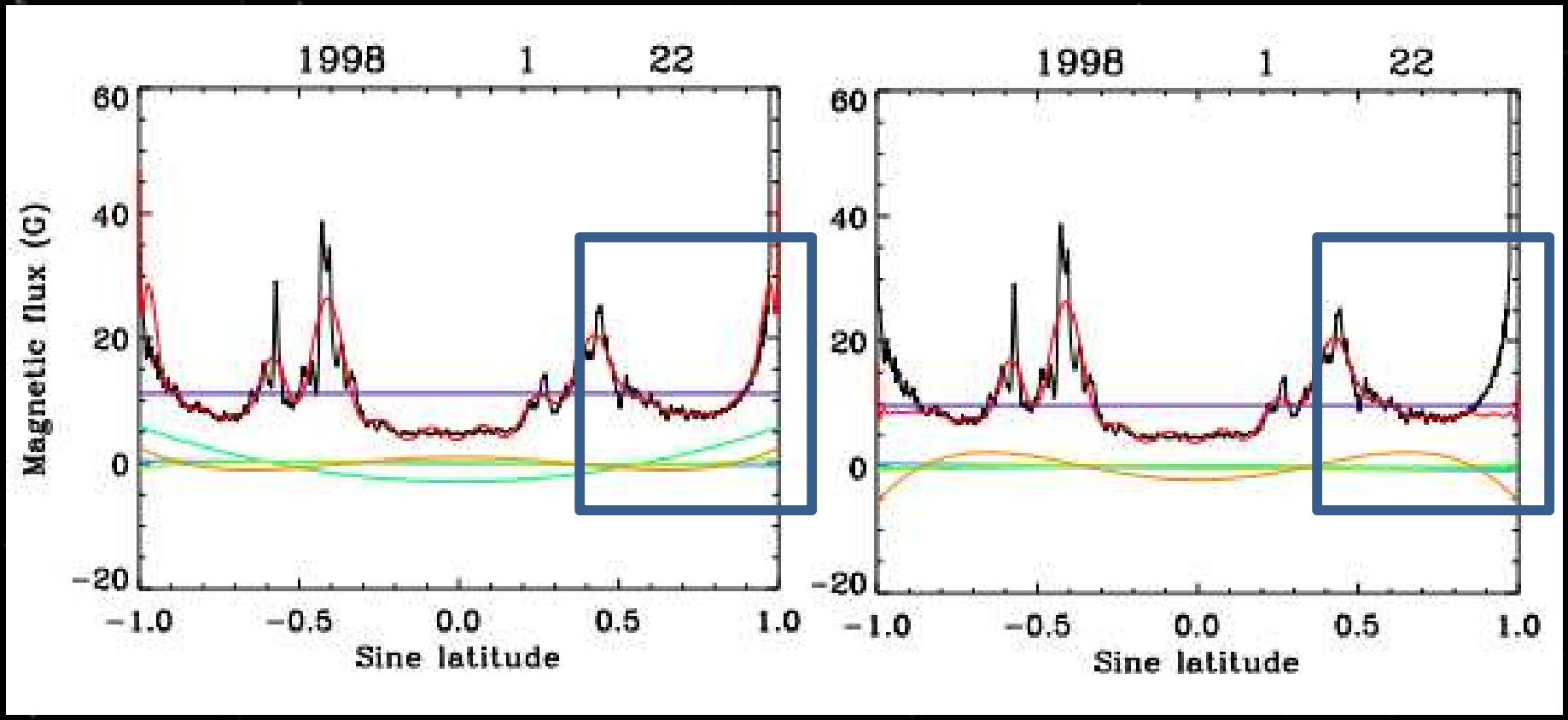


◇ My data

◇ Antia et al. (2001) [4]

GONG data

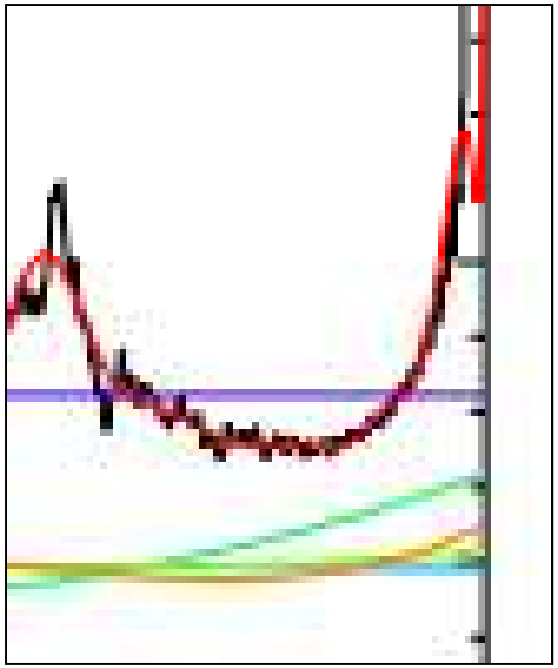
Legendre decomposition at the poles



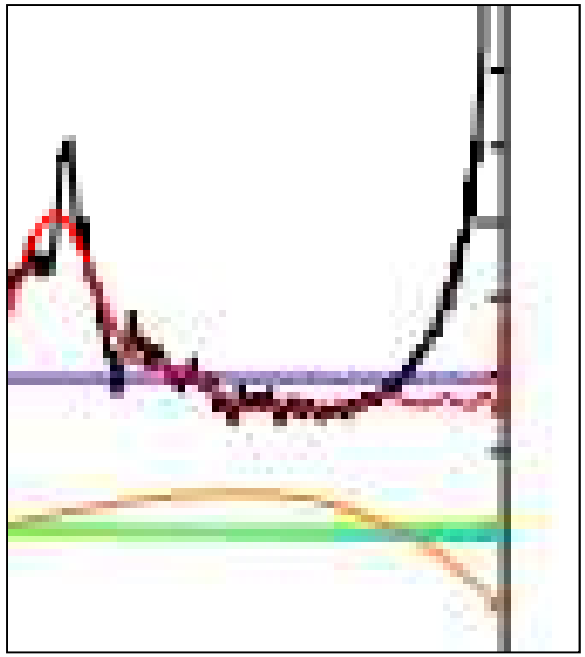
Rising edges (similar to Antia et al.)

Flattened edges

Legendre decomposition at the poles

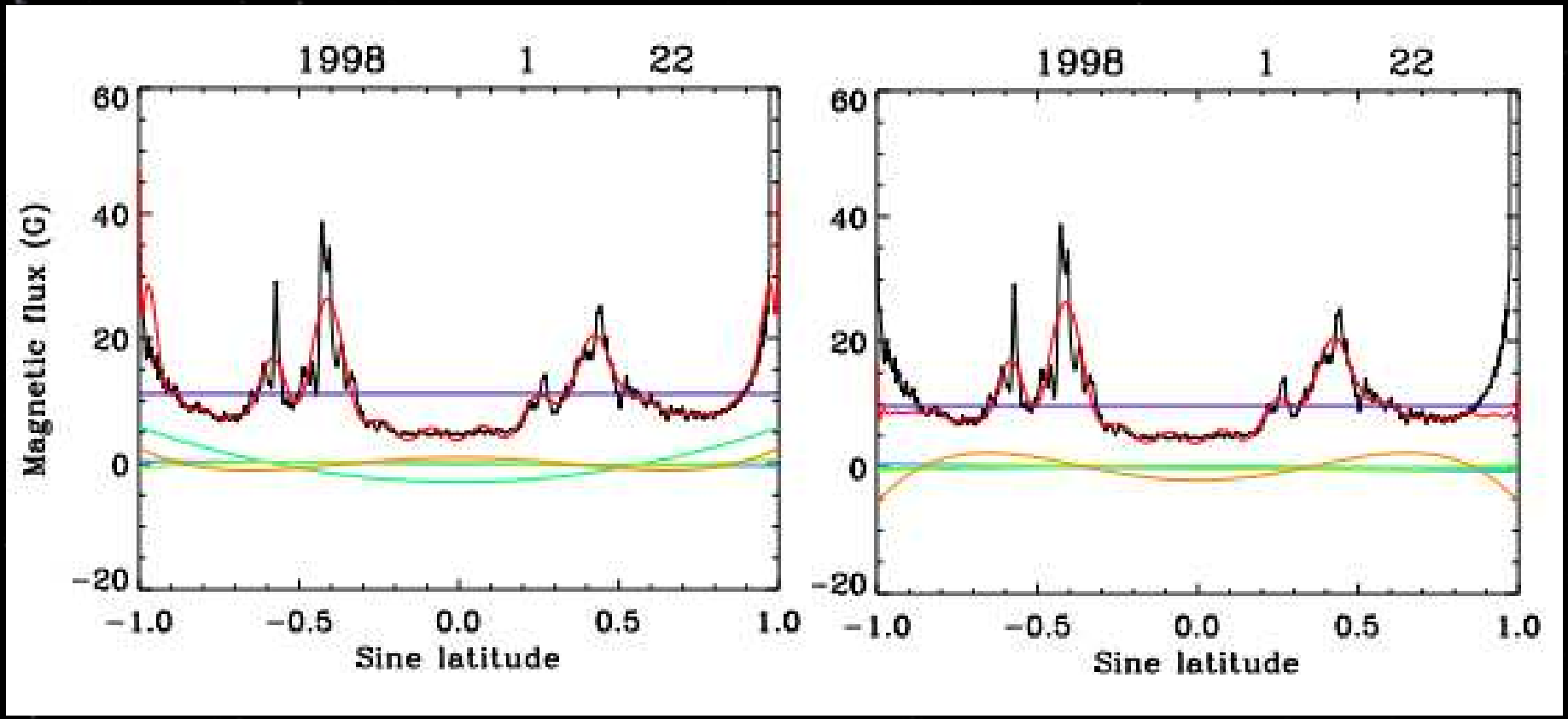


Rising edges (similar to Antia et al.)



Flattened edges

Legendre decomposition at the poles

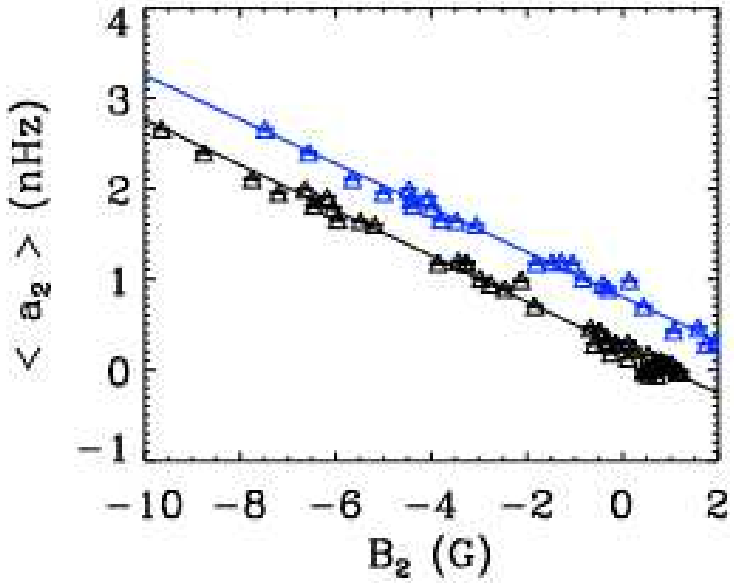


Rising edges (similar to Antia et al.)

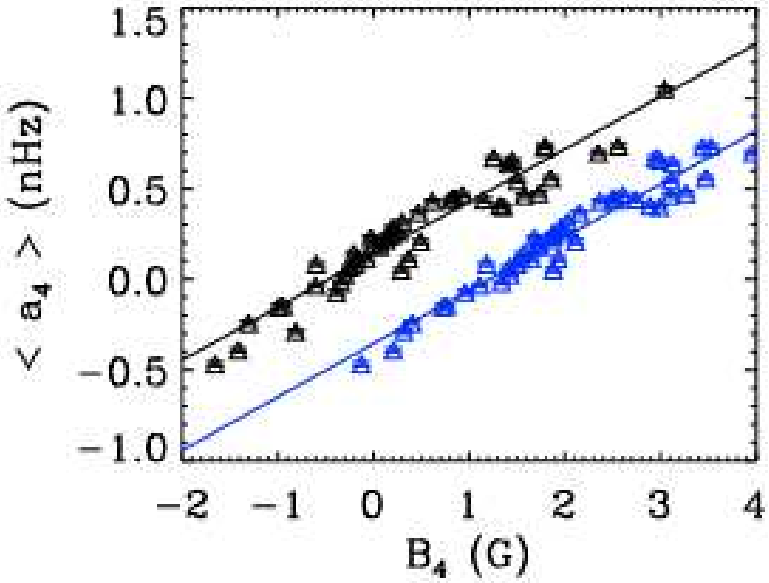
Flattened edges

Legendre decomposition at the poles

a_2 vs. B_2



a_4 vs. B_4



Flattened edges

Rising edges

Conclusion

- Linear correlation between a_k and B_k – corroboration of Antia's result
- Correlation strength is similar for rising and declining phases of solar cycle – what does this mean for subsurface effects?
  - Further work: separating modes with different penetration depths
- Slope varies nonmonotonically with k, regardless of handling of decomposition at poles

References

[1] J. Christensen-Dalsgaard, *Helioseismology*, Reviews of Modern Physics **74** (2003), pp. 1073–1129

[2] A. M. Broomhall, W. J. Chaplin, Y. Elsworth, S. T. Fletcher and R. New, *Is the current lack of solar activity only skin deep?*, The Astrophysical Journal **700** (2009), pp. L162 – L165

[3] J. Christensen-Dalsgaard, *Lecture notes on stellar oscillations, fifth edition* (2003)

[4] H. M. Antia, S. Basu, F. Hill, R. Howe, R. W. Komm and J. Schou, *Solar-cycle variation of the sound-speed asphericity from GONG and MDI data 1995-2000*, Monthly Notices of the Royal Astronomical Society **327** (2001), pp. 1029 – 1040