Seismological insights into solar and stellar magnetic activity cycles

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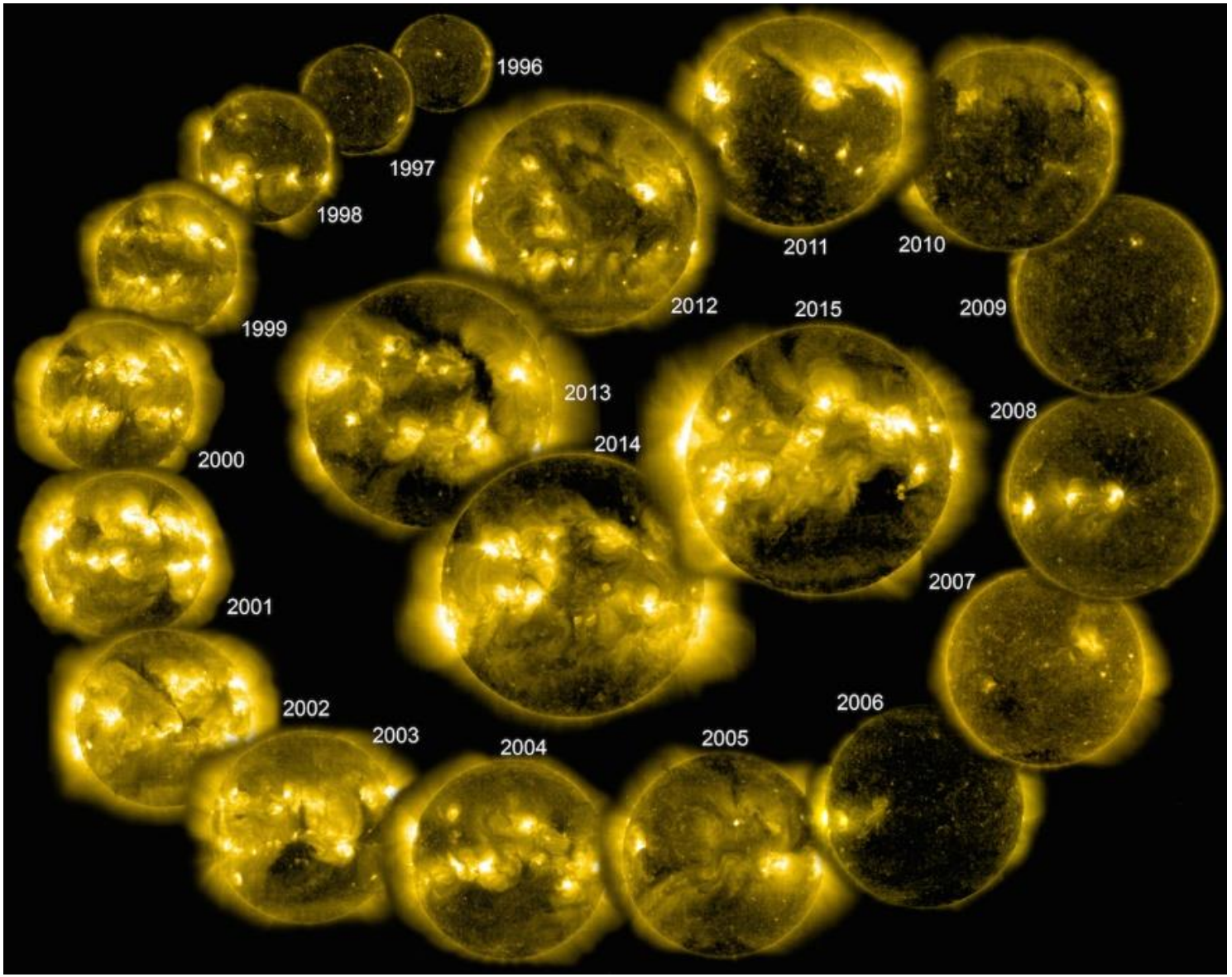
Outline

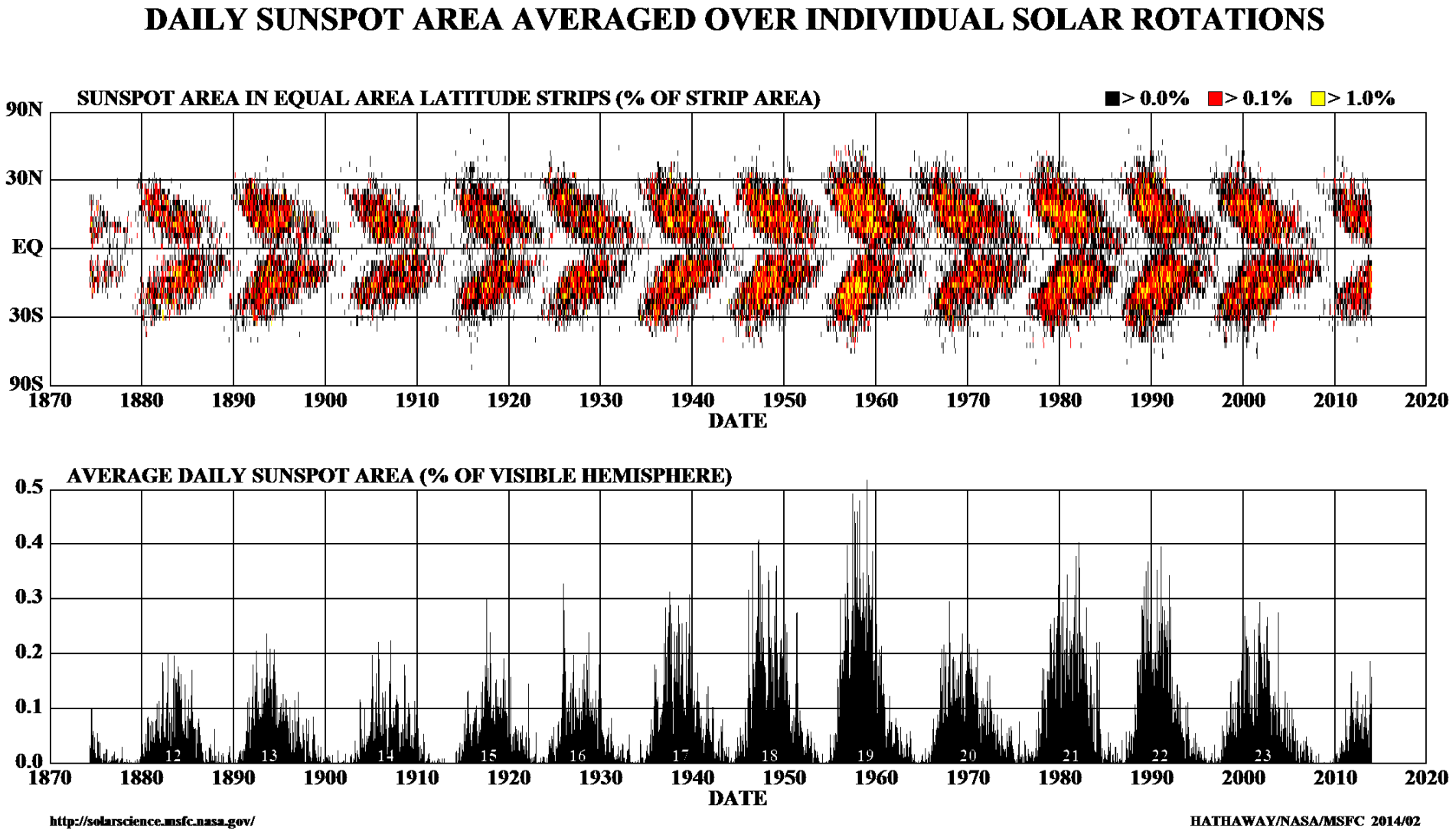
- Introduction to the solar cycle.
- Helioseismic insights into the solar cycle.
- Stellar activity cycles.
- Asteroseismic observations.
- Is the solar cycle unusual?
- Something a little different…

The solar cycle



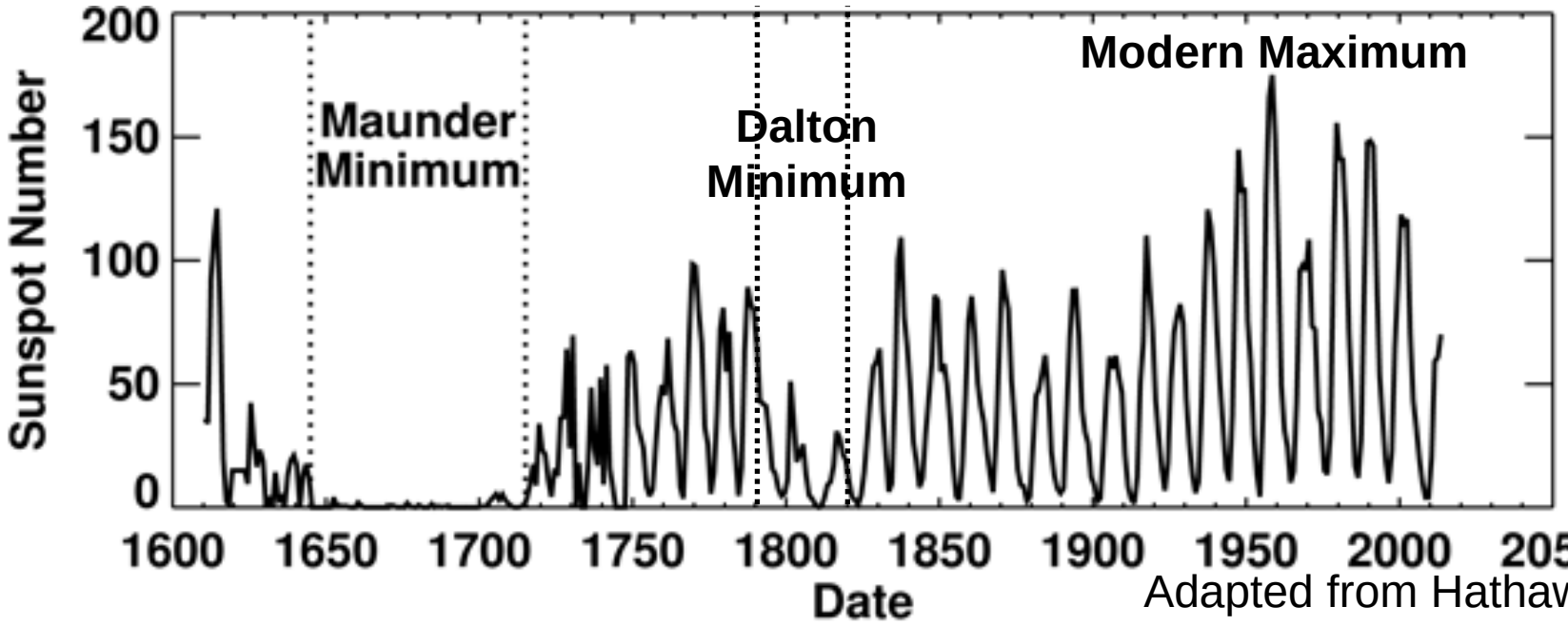
Courtesy of SOHO, ESA/NASA

The sunspot cycle



Long term trends in solar activity

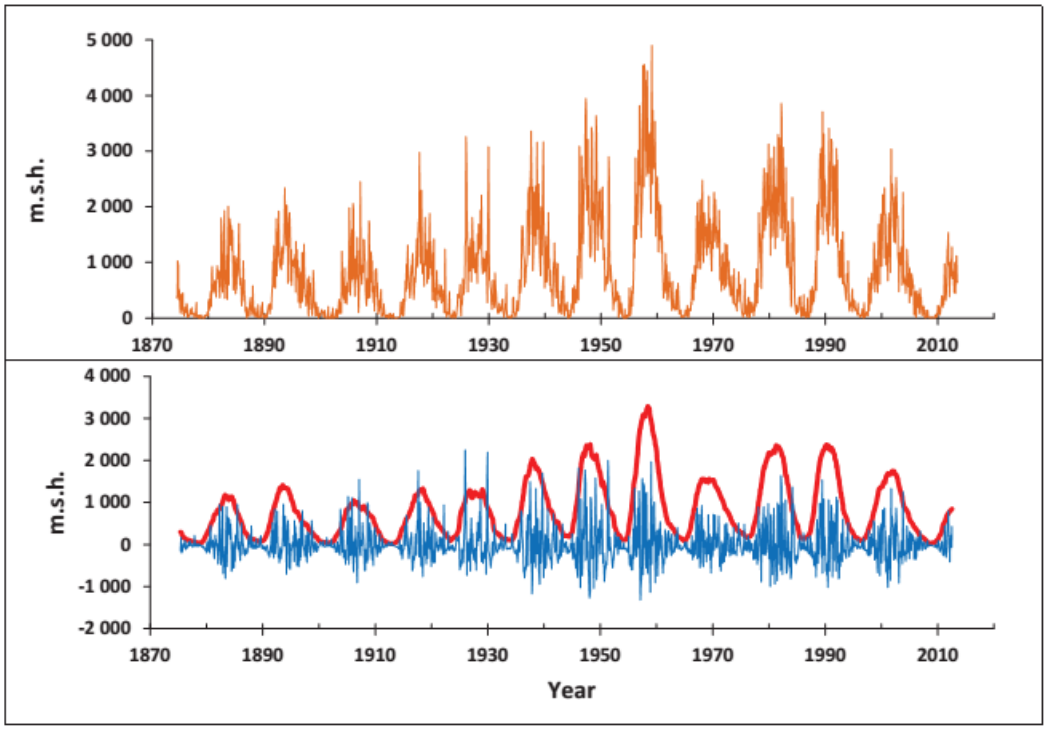
- Gleissburg cycle: 70-100yr modulation of cycle amplitude.
- Grand minima and maxima
- de Vries/Seuss cycle: 210yr cycle

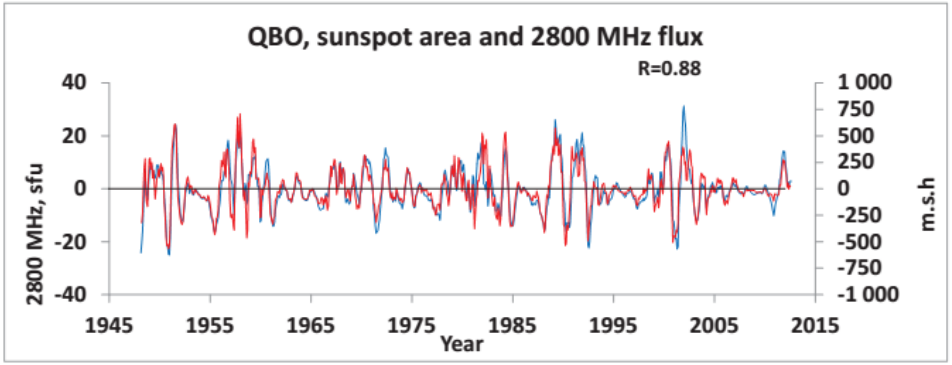


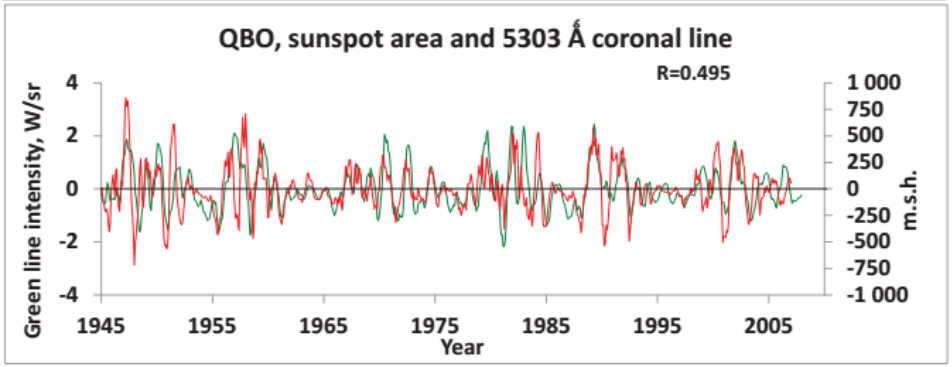
Adapted from Hathaway (LRSP)

Variability on timescales <11yr

- Reiger periodicities: numerous <1yr e.g. 154d
- Quasi-biennial: 1-4yr

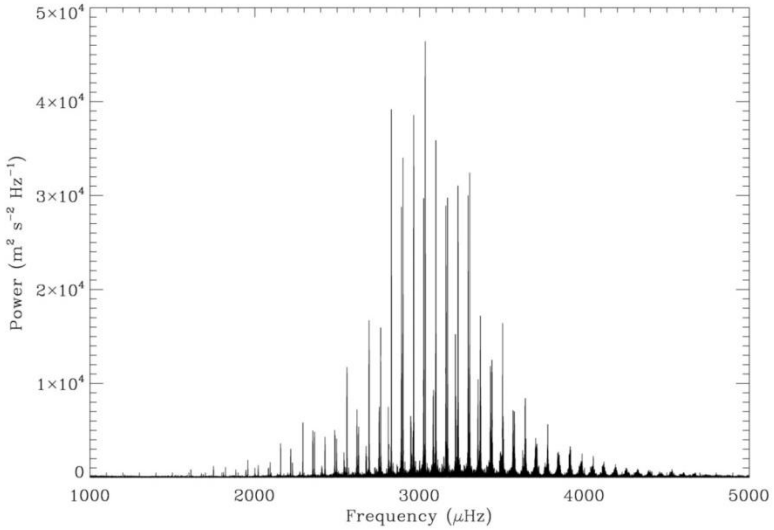


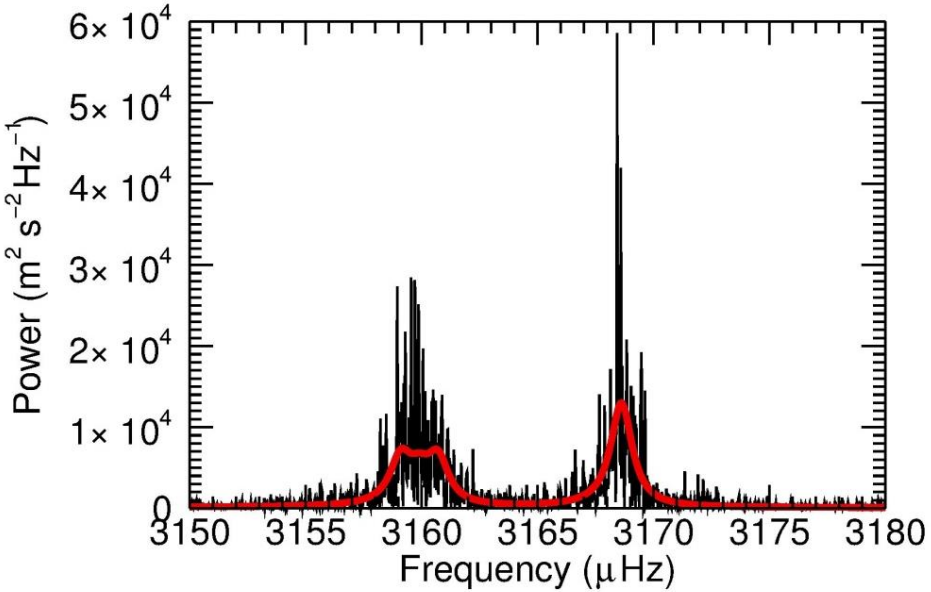


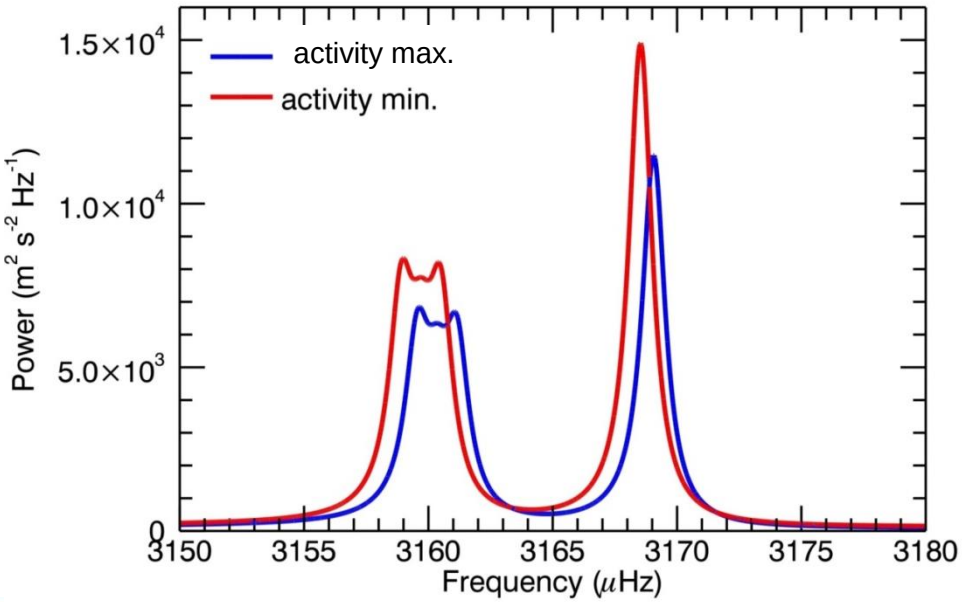


Solar cycle variations in p modes

Unresolved BiSON data





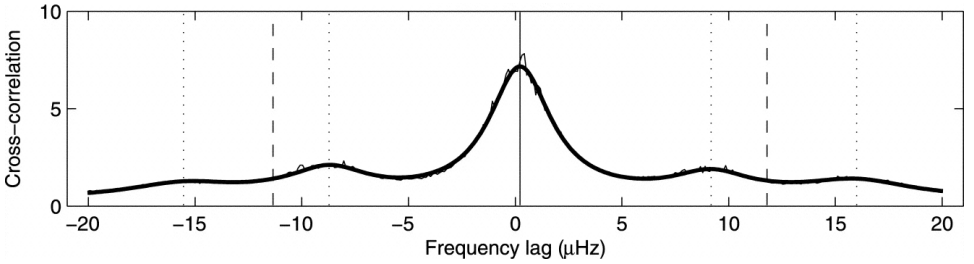


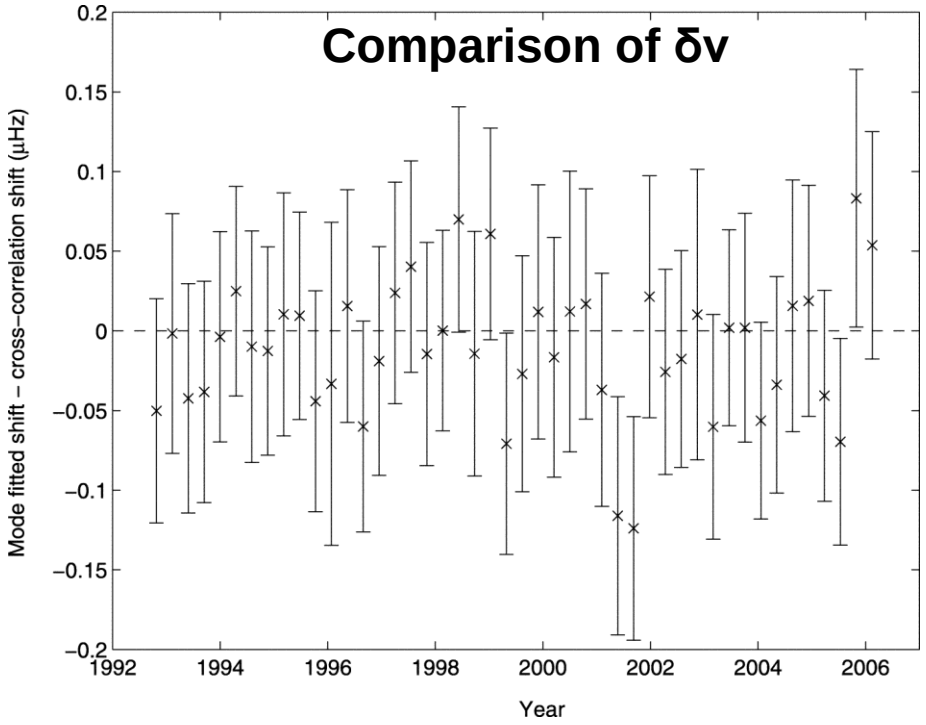
Determining the frequency shift

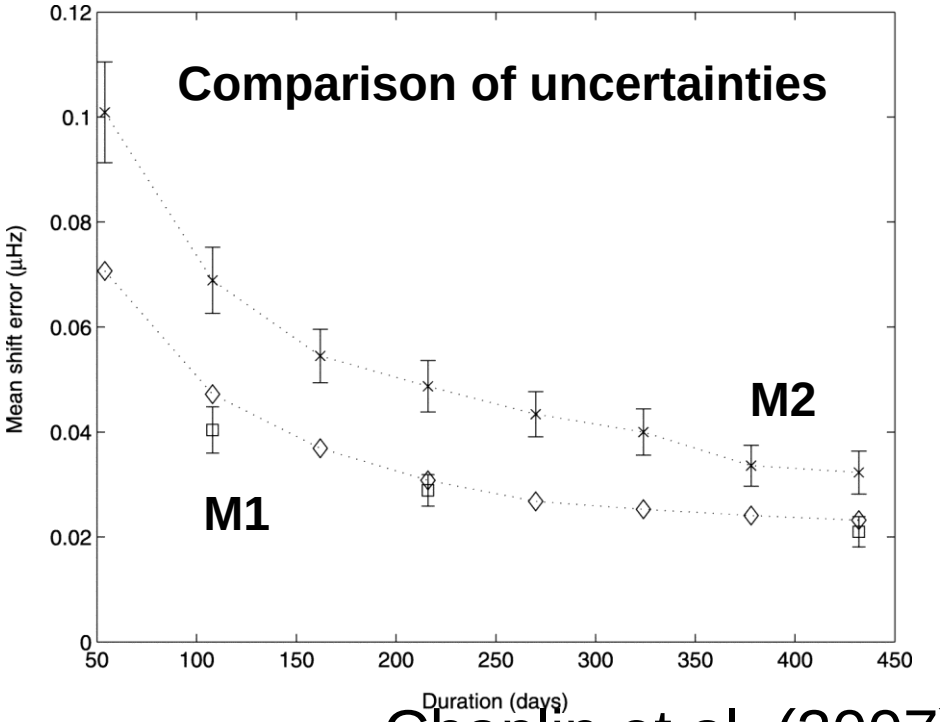
Method 1: Directly from fitted frequencies

$$\delta\nu_t = \overline{\nu_{\ell,n,t} - \overline{\nu_{\ell,n}}}$$

Method 2: Cross-correlations







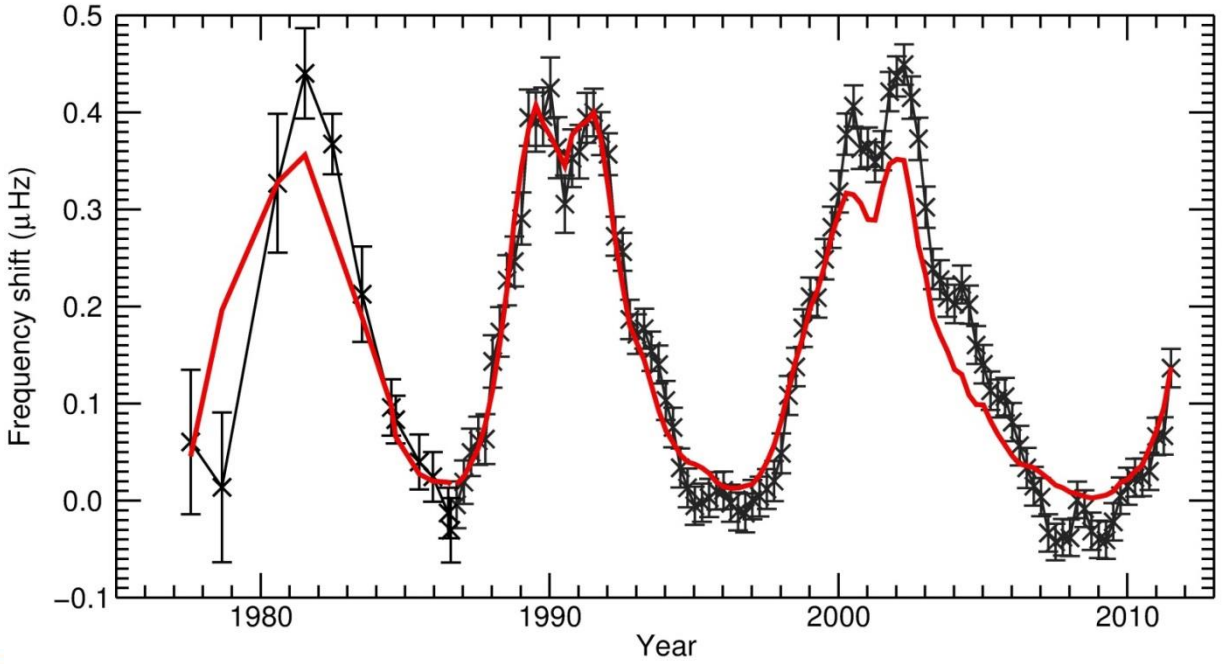
Chaplin et al. (2007)

Seismic frequencies and the solar cycle

- Seismic frequencies respond to changes in the surface activity (Woodard & Noyes ,1985).
- Causes (see also A. Santos poster):
  - Direct – Lorentz force.
  - Indirect – change in cavity properties.

Shifts from BiSON

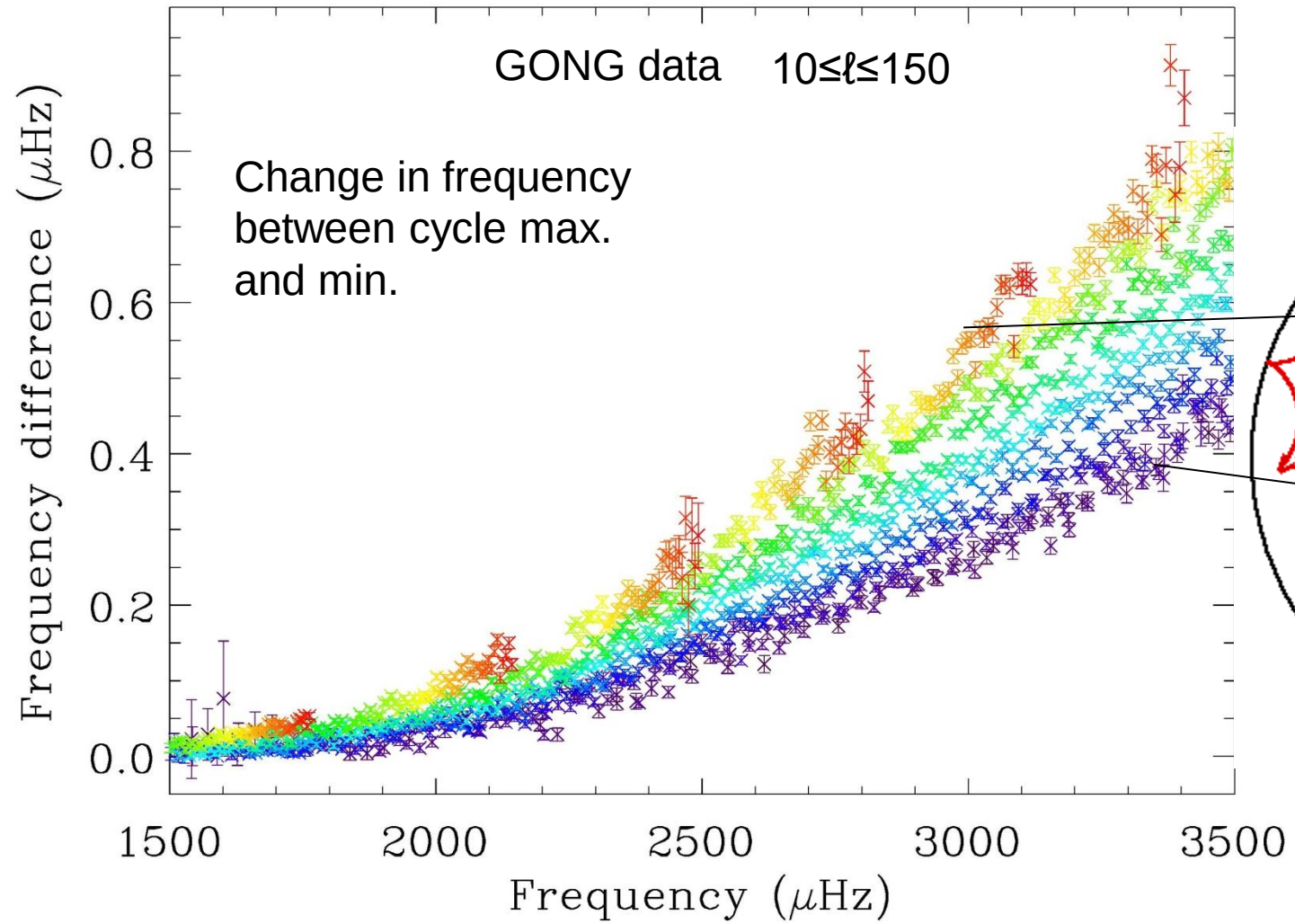
Scaled 10.7cm flux

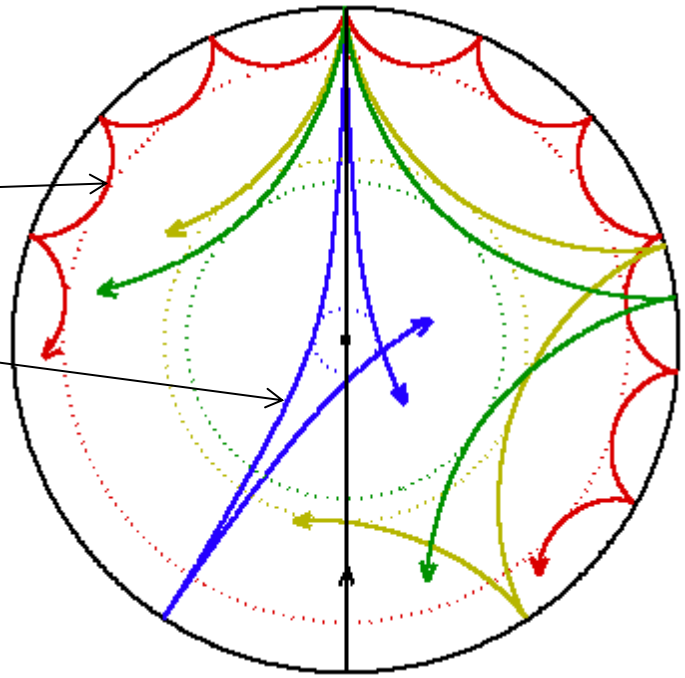


shift ≈ 0.01% of mode frequency

Shift of ≈ 0.03μHz G^{-1}

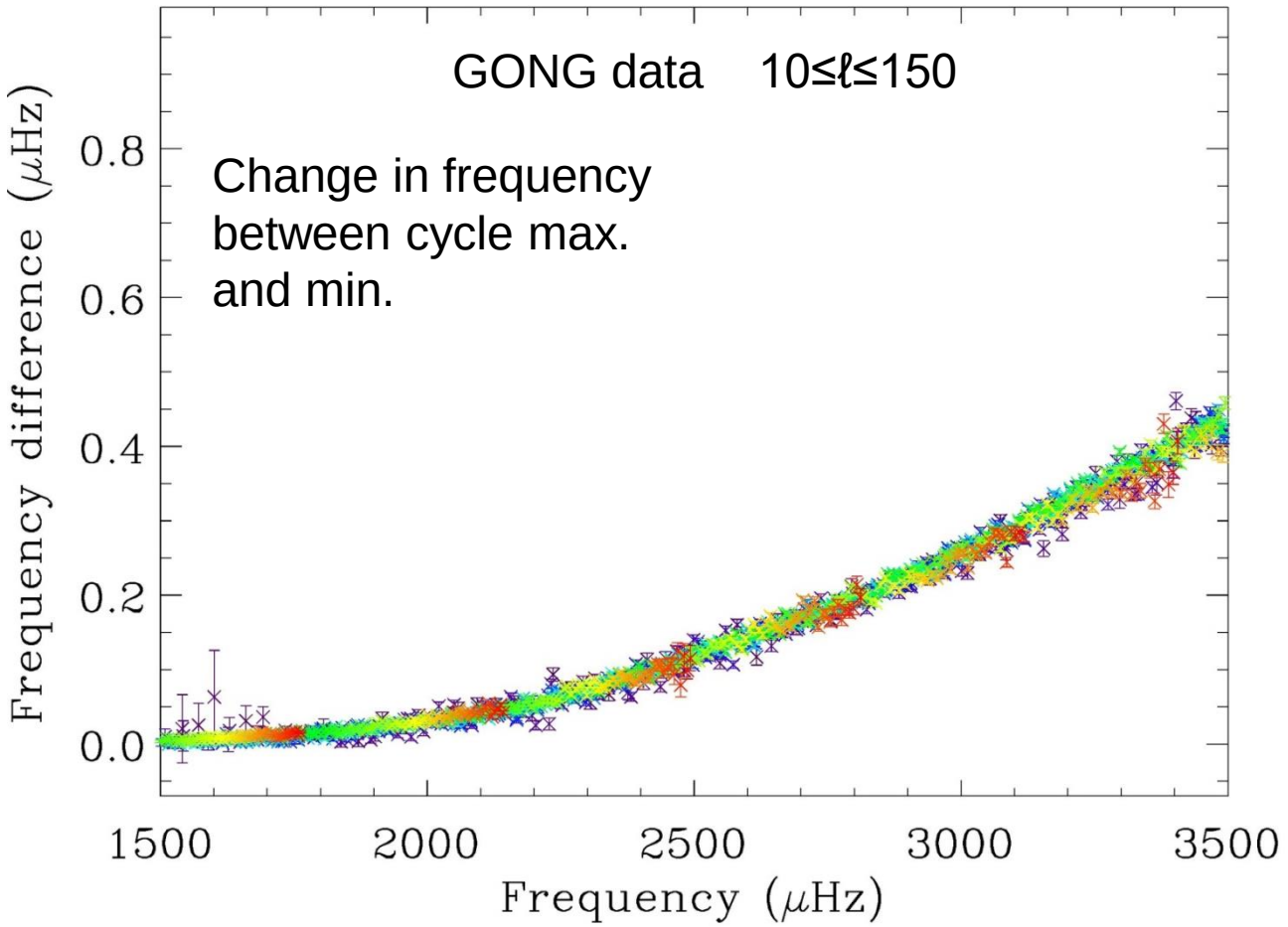
Max-min frequency shift





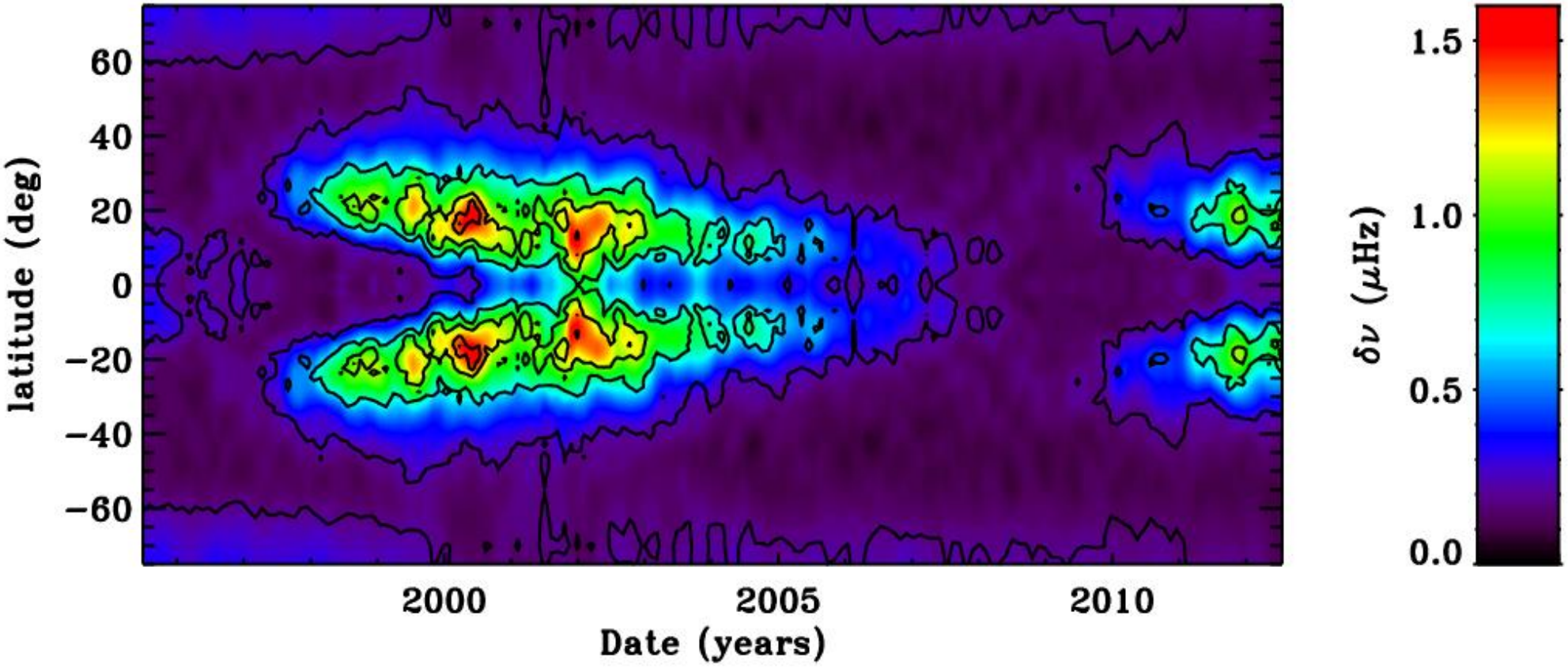
Max-min frequency shift

- Mode inertia given by $M_{n,l}/M_{sun}$



Frequency shift inversions

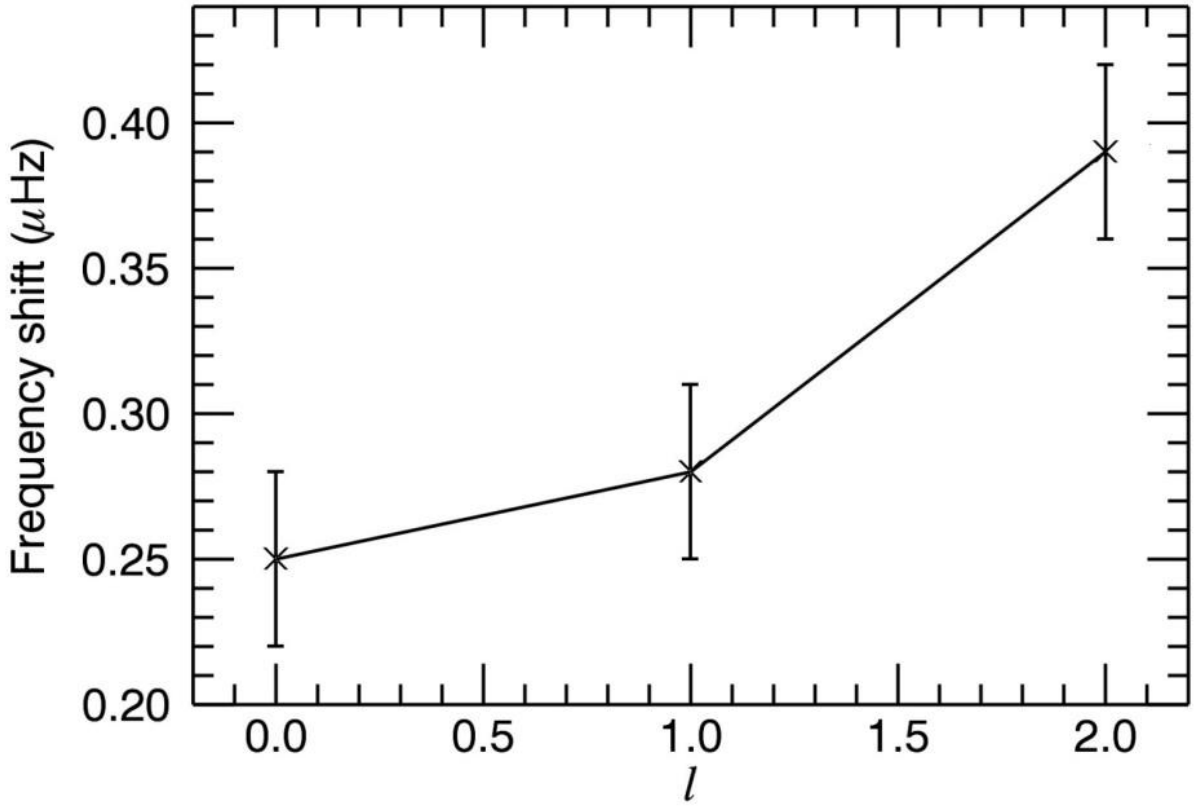
- Howe et al. (2002) localized the frequency shifts in latitude.

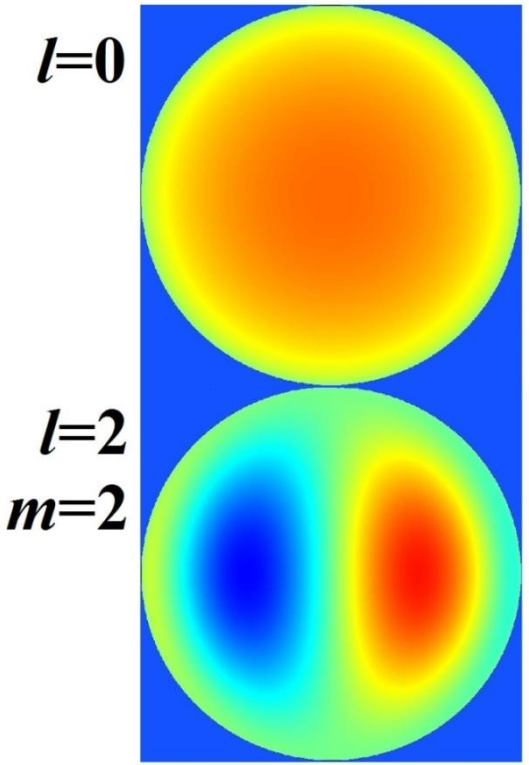


Courtesy of Rachel Howe

Degree dependence of frequency shifts

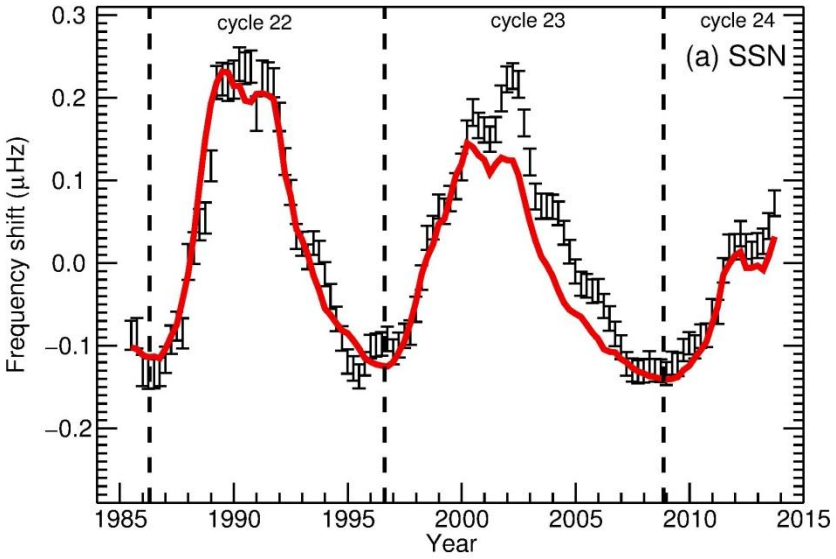
- Size of the shift is related to the latitudinal distribution of the surface magnetic field.



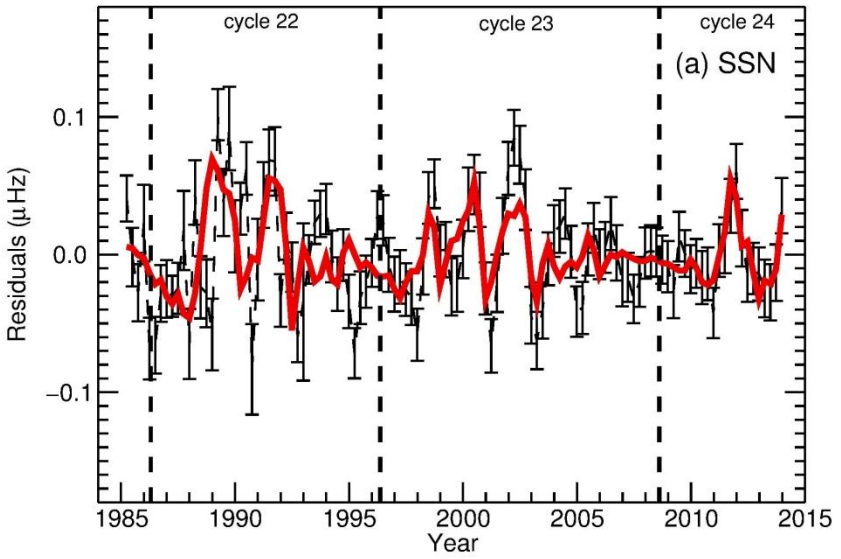


Quasi-biennial (2.5yr) oscillation

- Two dynamos at BCZ & near-surface shear layer (e.g. Benevolenskaya 1998)
- Beating between different dynamo configurations (e.g. Simoniello et al. 2013)

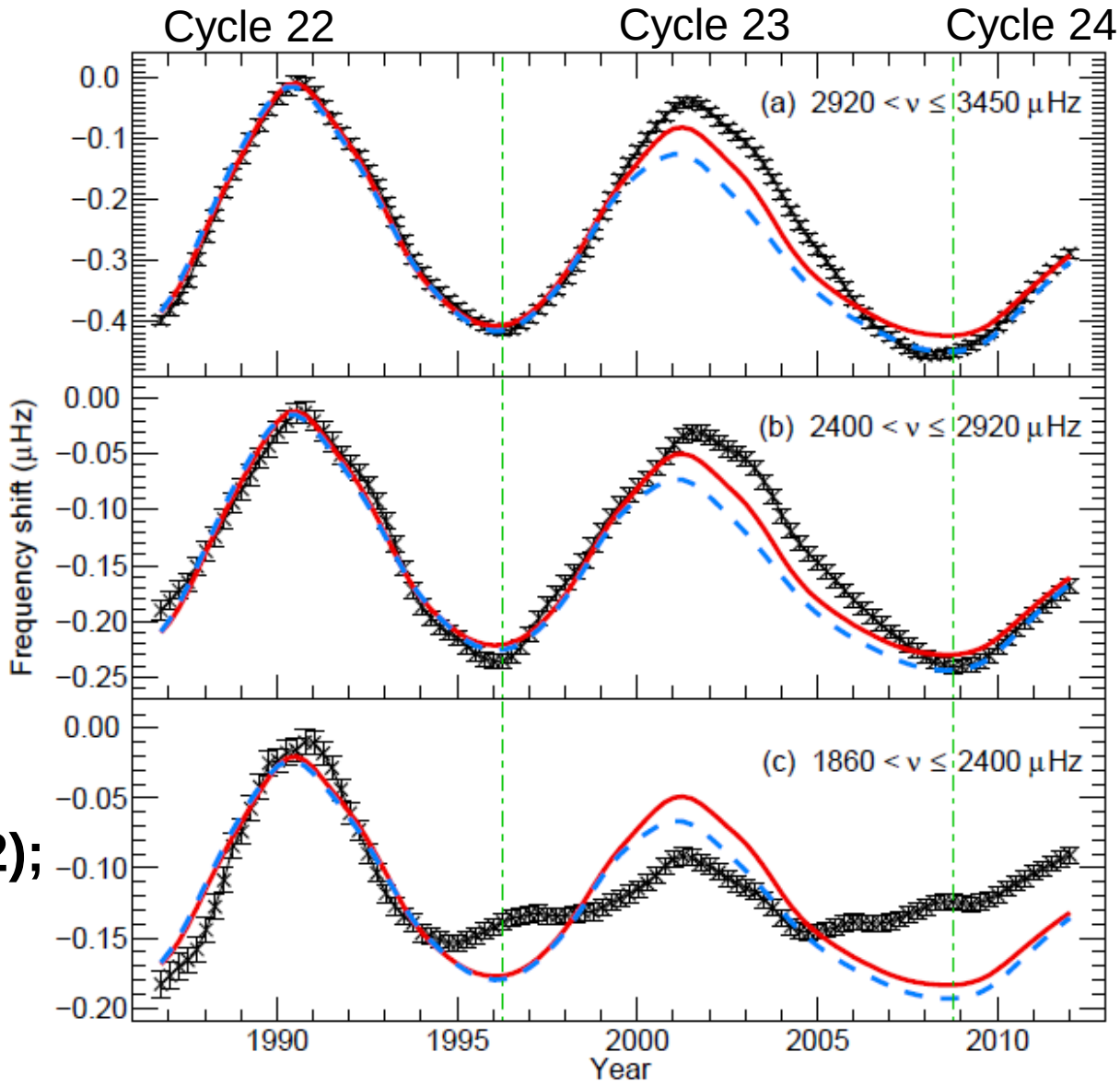


Remove
11yr signal



Broomhall & Nakariakov, 2015

The unusual solar cycle – smoothed



Black=average frequency shift

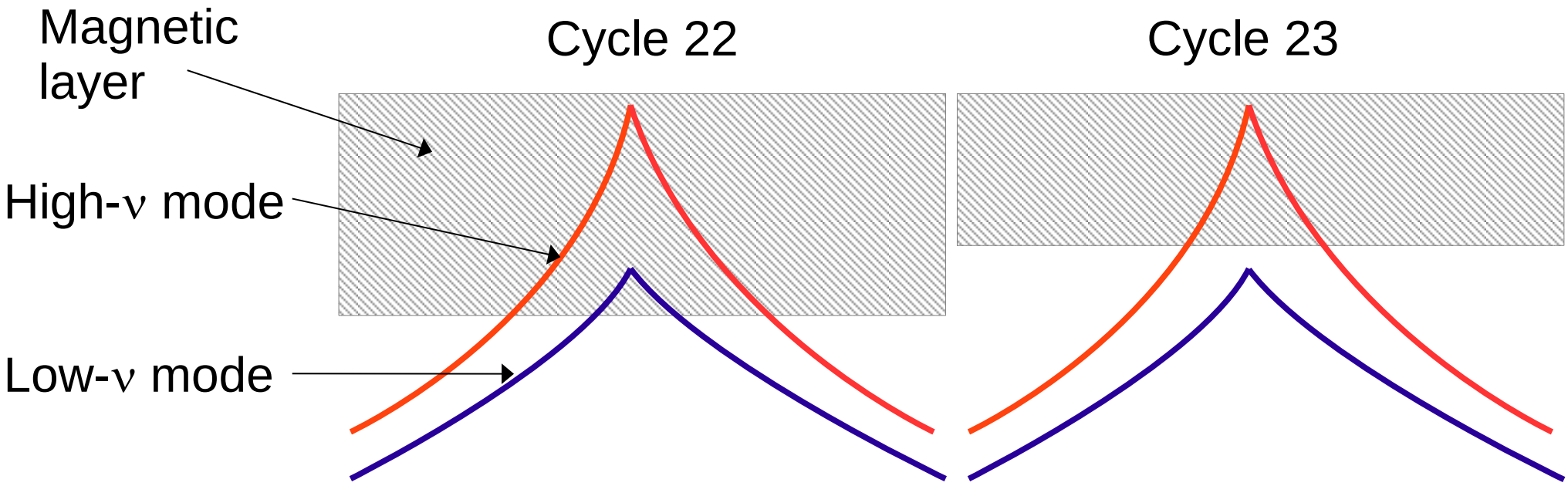
Red=10.7cm flux

Blue=ISN

Basu et al. (2012); Salabert et al., (2015)

Changes in the magnetic layer

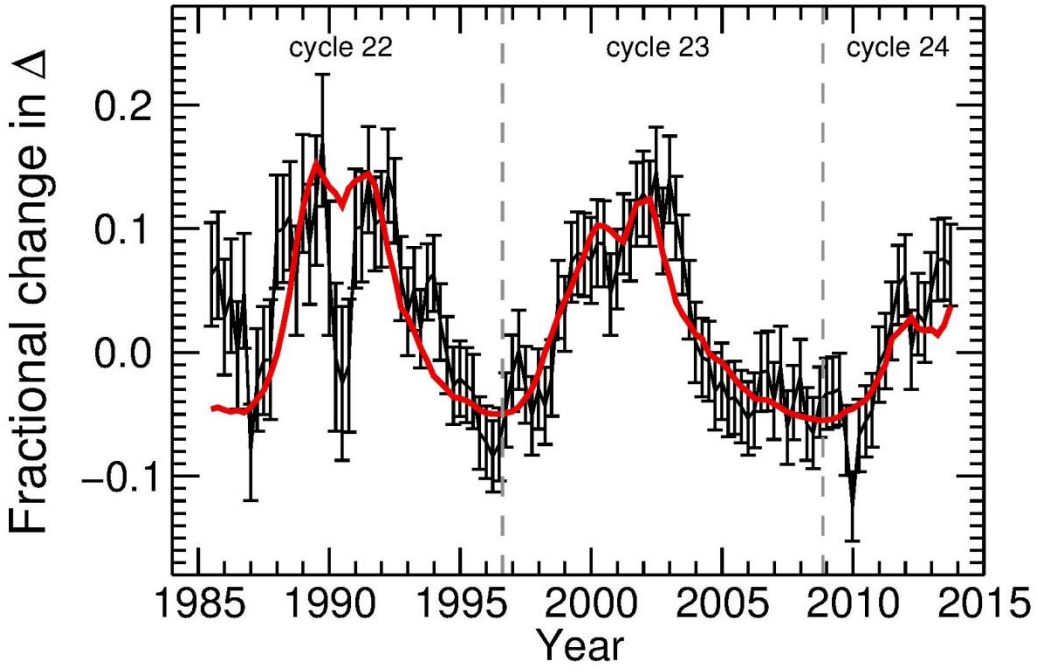
- The upper turning point of the low-ν modes are beneath the magnetic layer in cycle 23
- The changes must occur above $0.9965R_{\odot}$.

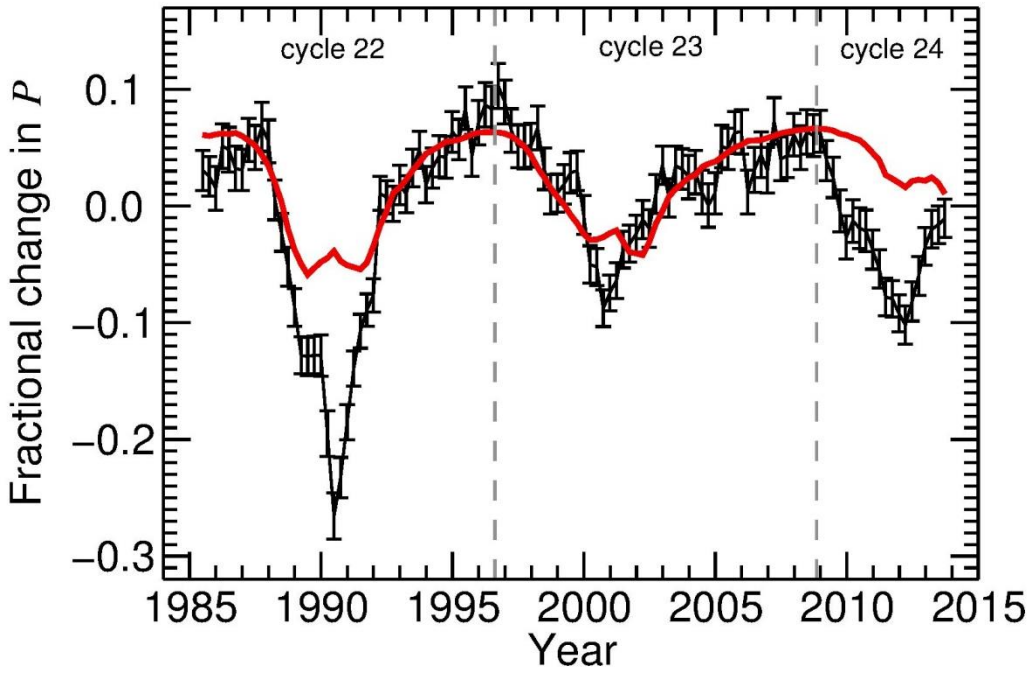


Mode damping rates and powers

- From cycle minimum to maximum
  - Damping rates (Δ) increase.
  - Mode powers (P) decrease.

Scaled 10.7cm flux

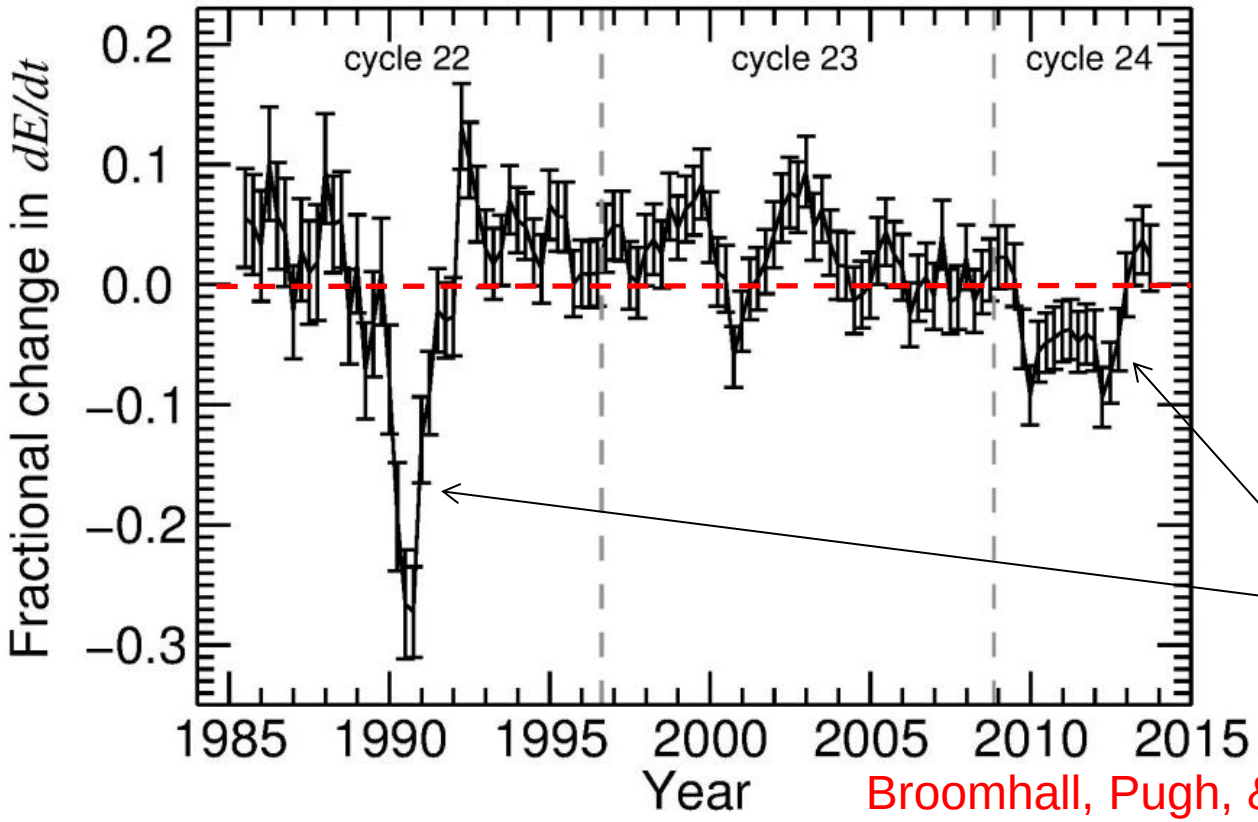




Broomhall, Pugh, & Nakariakov, 2015

Energy supply rate

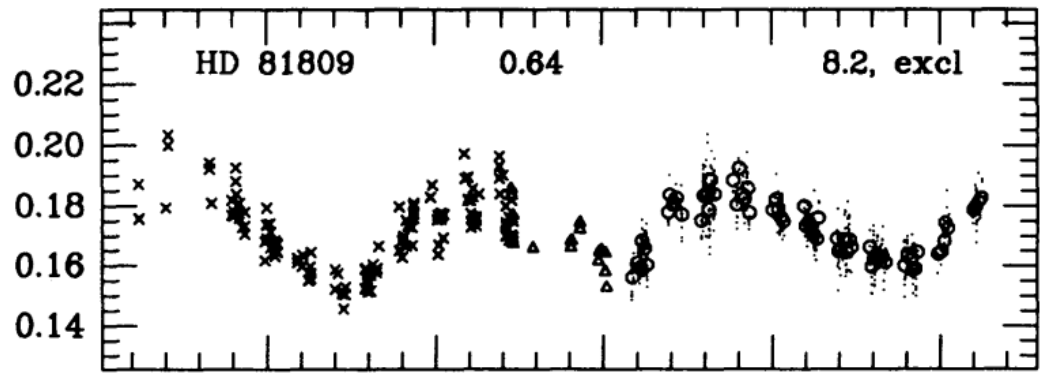
- Mode energy=power × mode mass.
- Energy supply rate ∝ energy × damping rate.

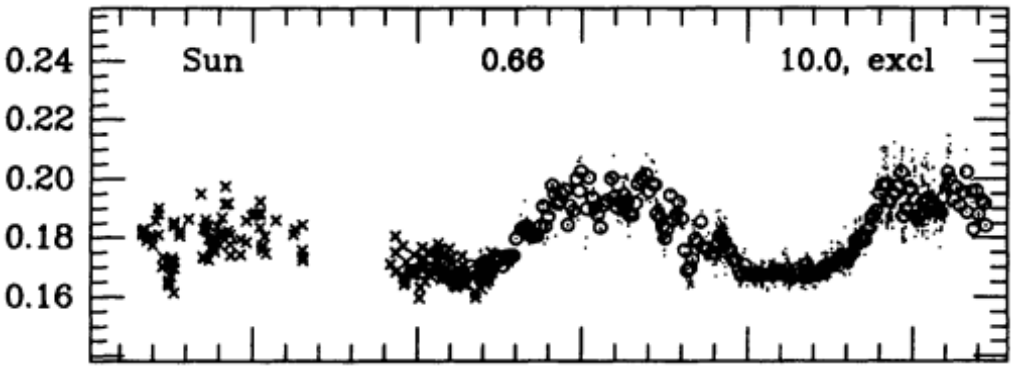


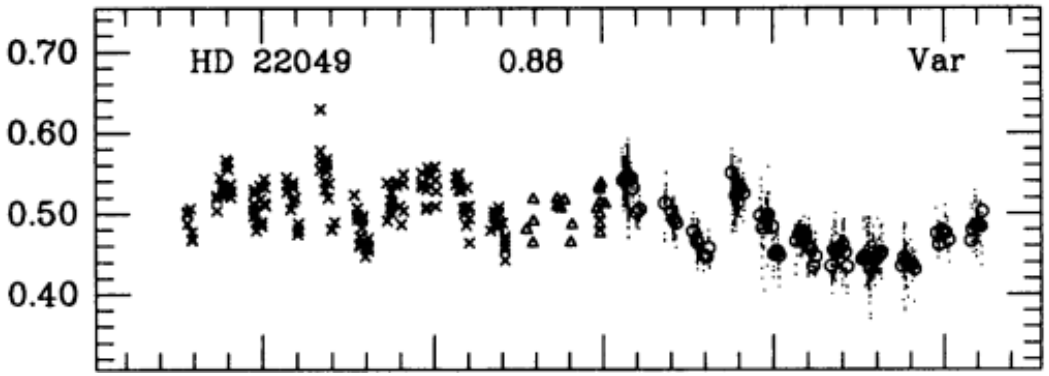
Broomhall, Pugh, & Nakariakov, 2015

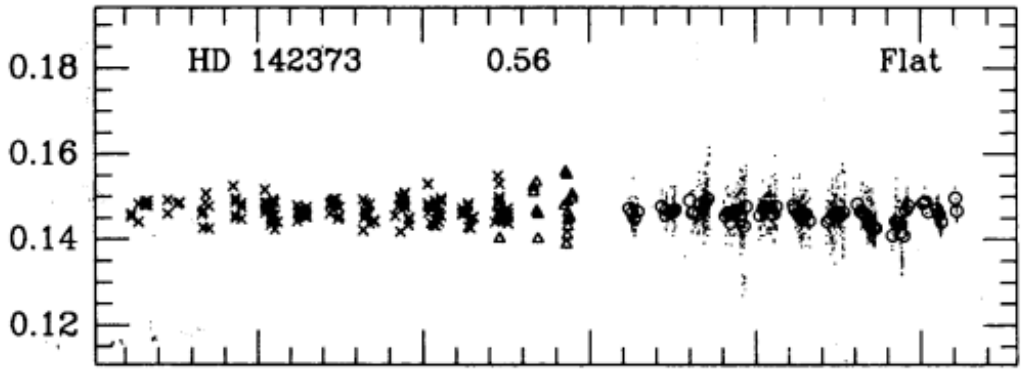
Long-term surveys

- Mount Wilson HK survey, Solar-Stellar Spectrograph at Lowell, photometric surveys…





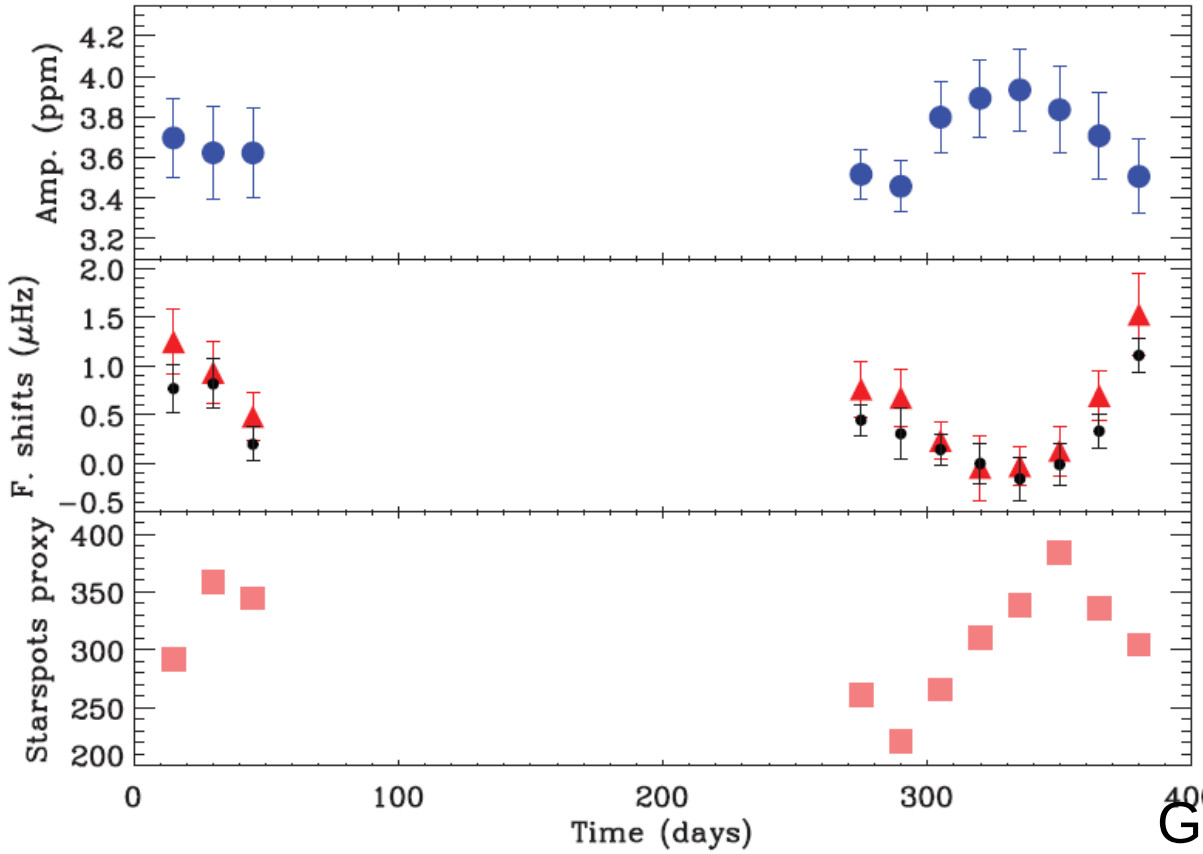




Baliunas et al. 1995

HD49933

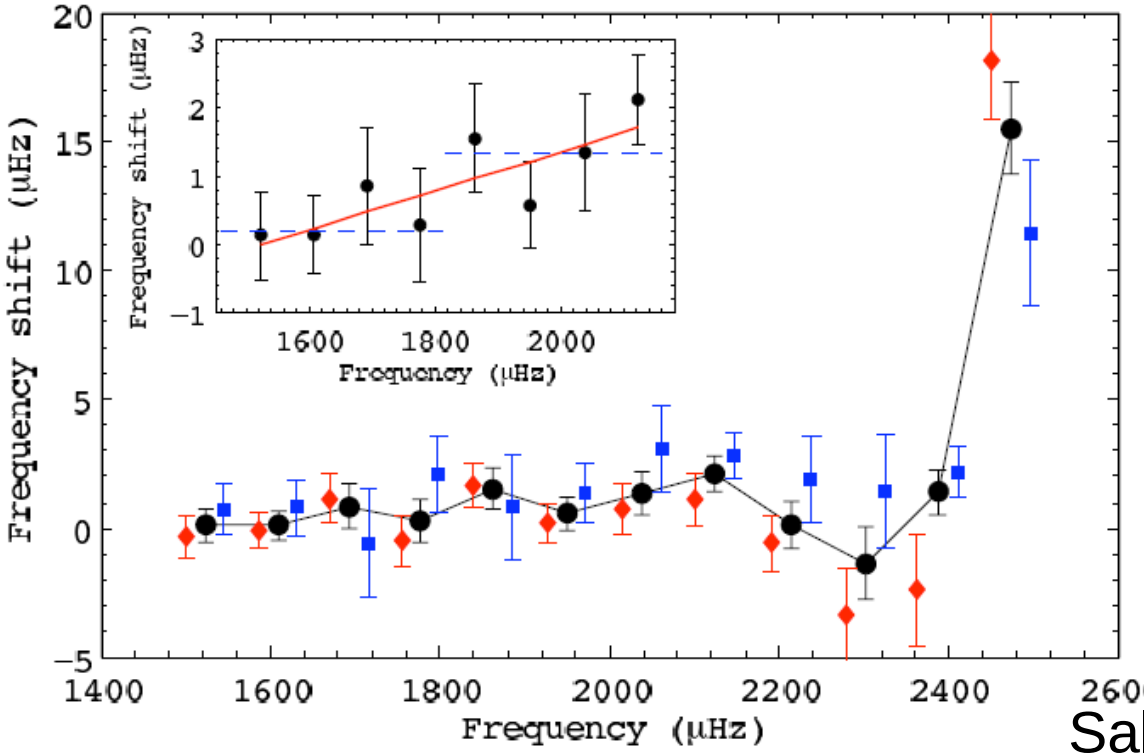
- F5V star, 1.2$M_{\odot}$, 1.34$R_{\odot}$, 0.1$P_{o,\,rot}$.
- More than 50 individual modes observed in CoRoT data.



Garcia et al., 2010

Frequency dependence of shifts

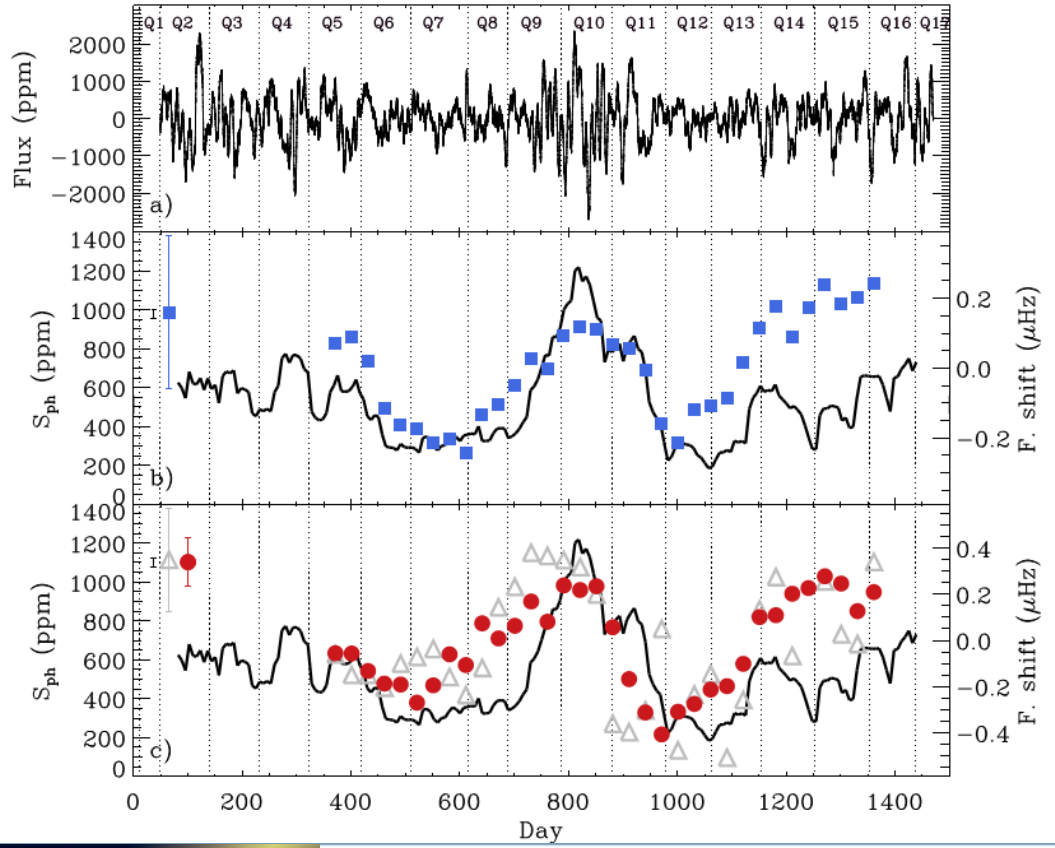
- Shows similar frequency dependence to Sun.
- Larger shift expected since hotter and more evolved (Metcalfe et al., 2007).



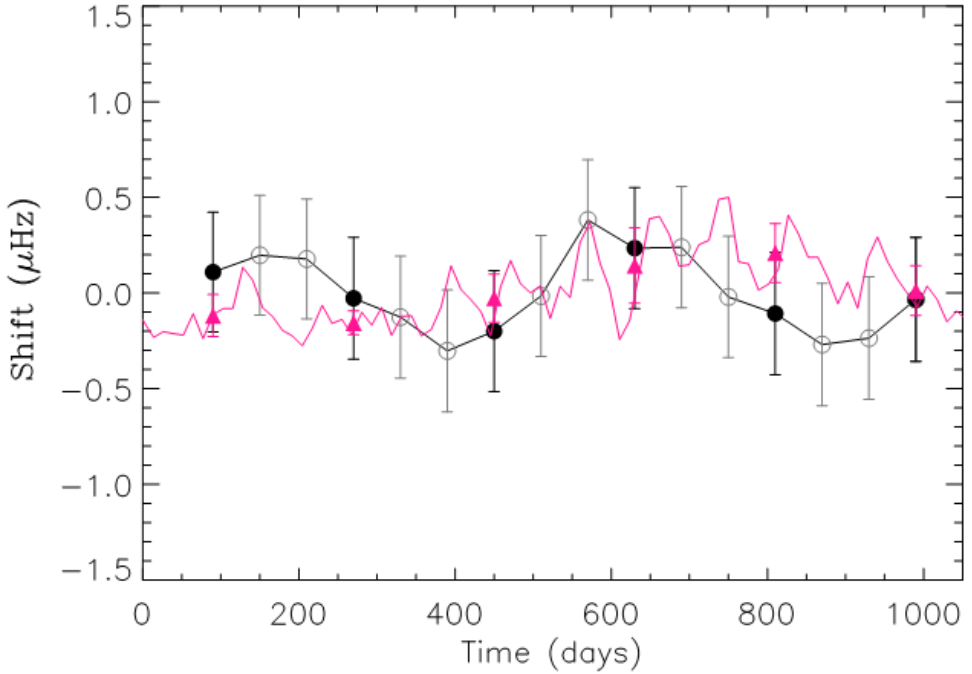
Salabert et al., 2011

Other examples?

KIC10644254 – Salabert et al. (2016)



KIC3733735 – Régulo et al. (2016)



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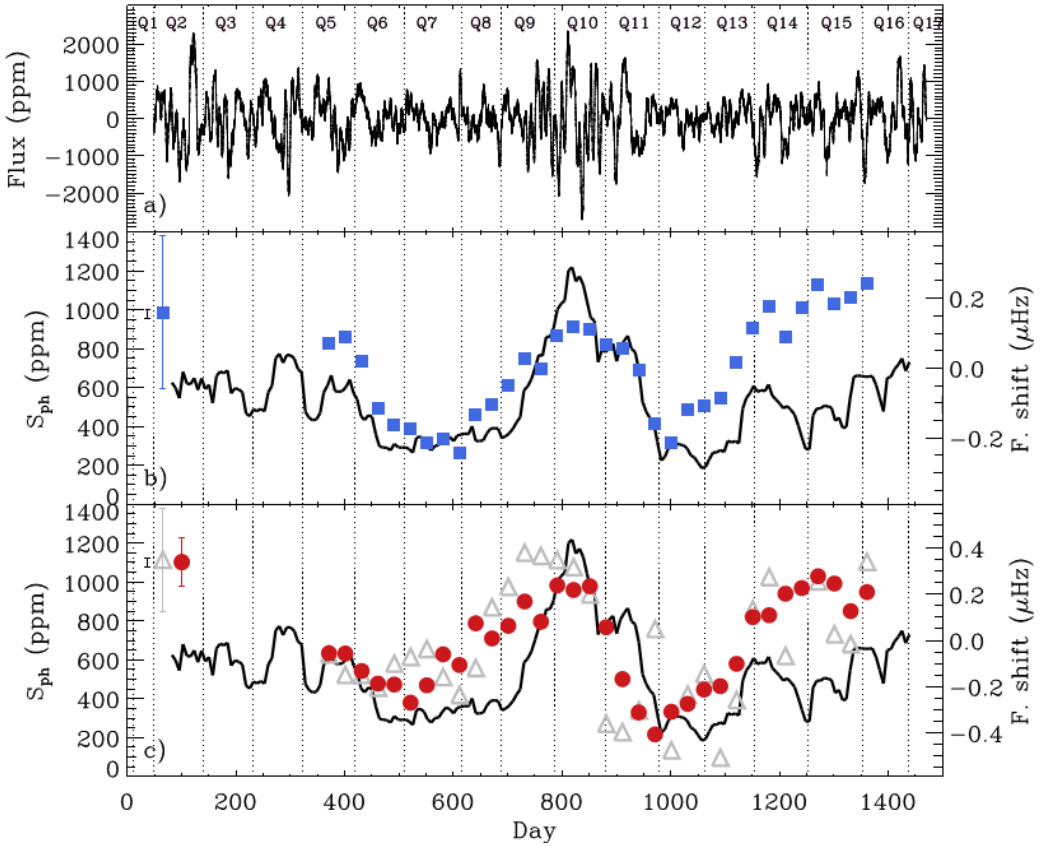

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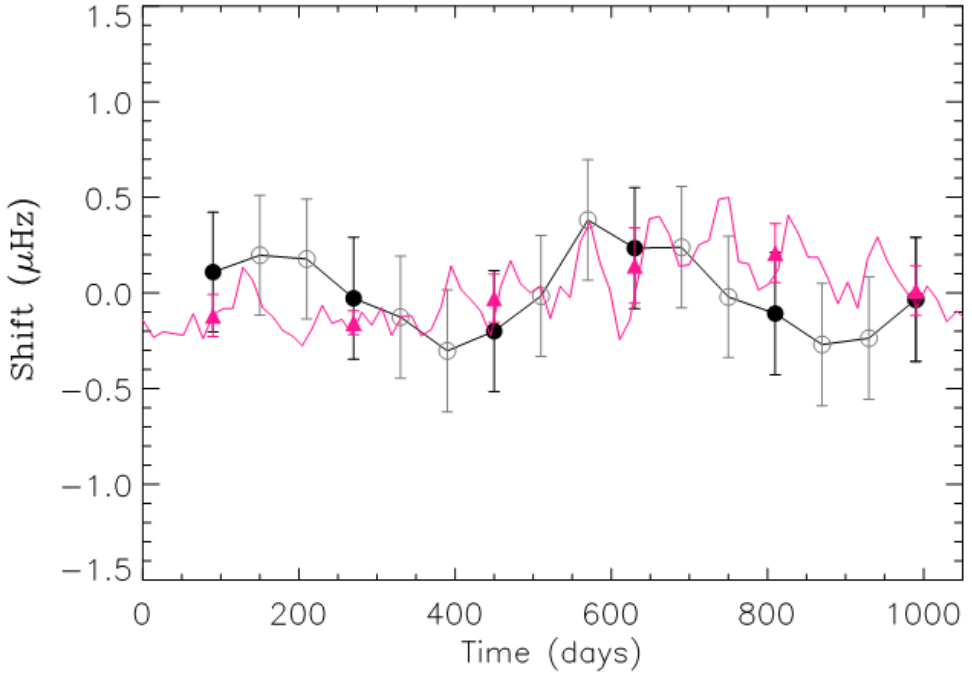
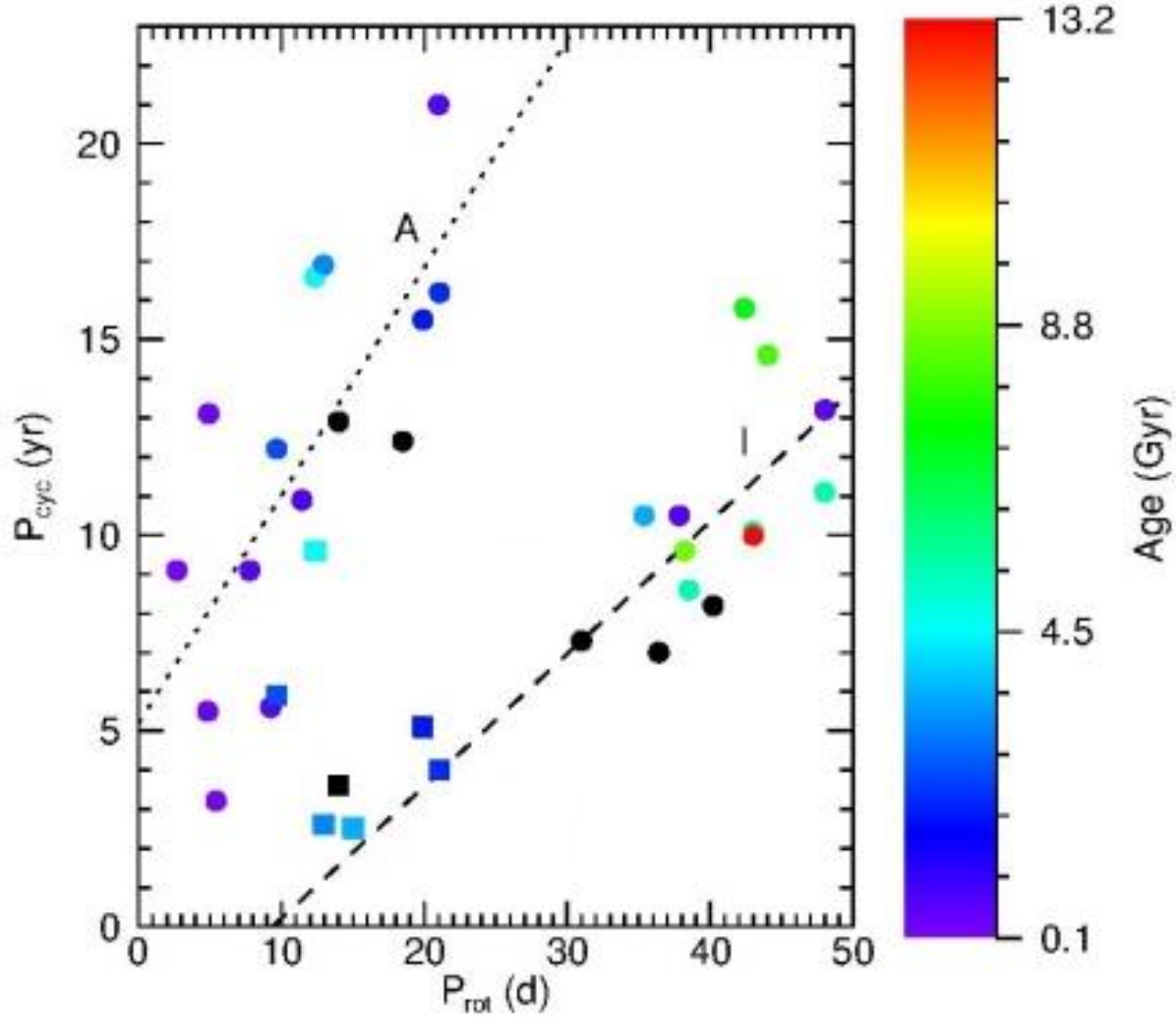


Talk by René Kiefer in this session

Where to look: length of cycle

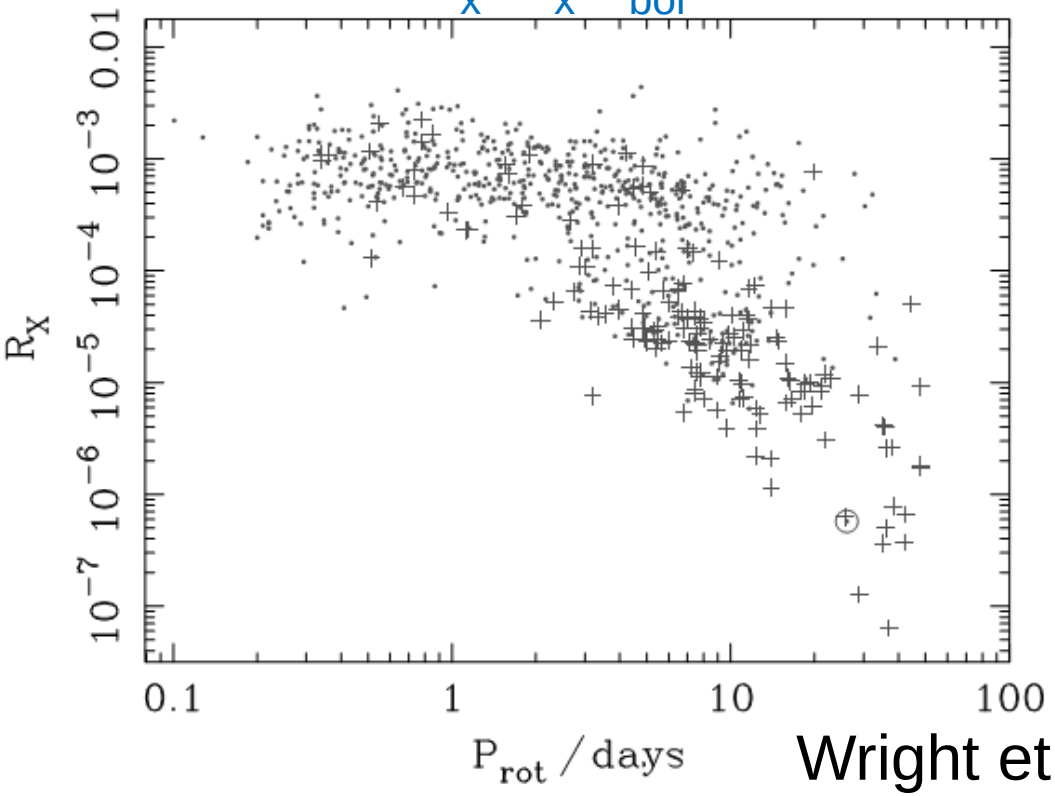
- Cycle length decreases with rotation rate



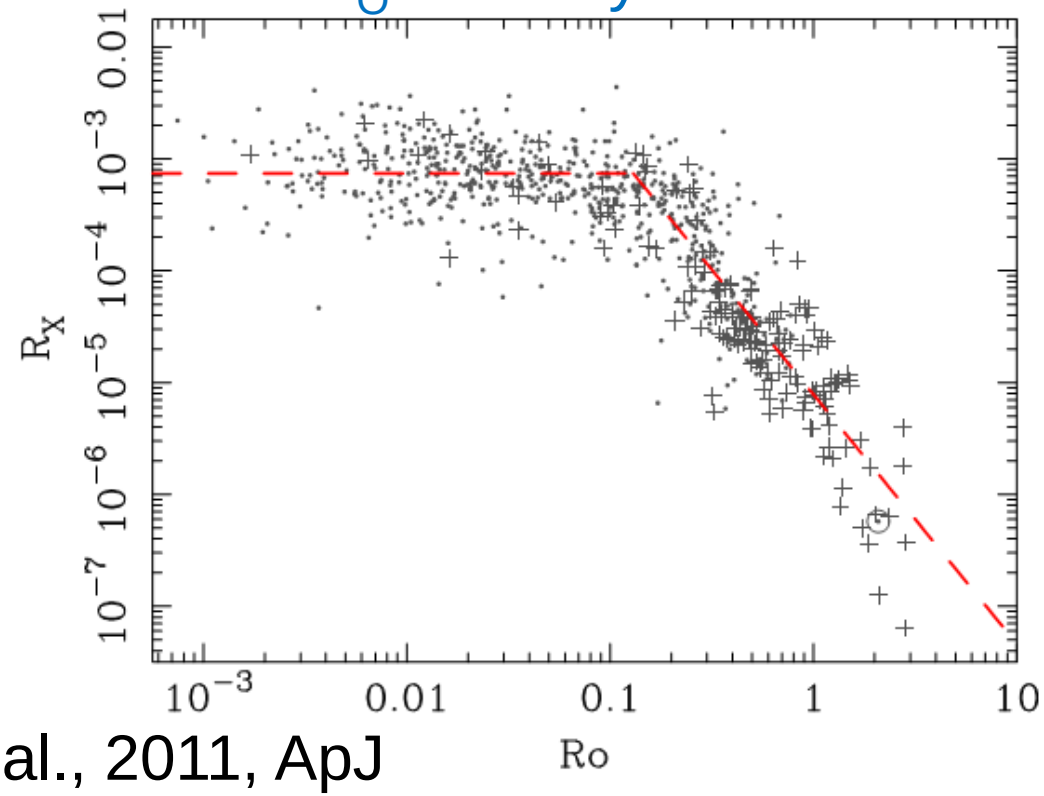
Where to look: Activity-rotation

- Activity increases with rotation rate until saturation.

$R_x = L_x / L_{bol}$



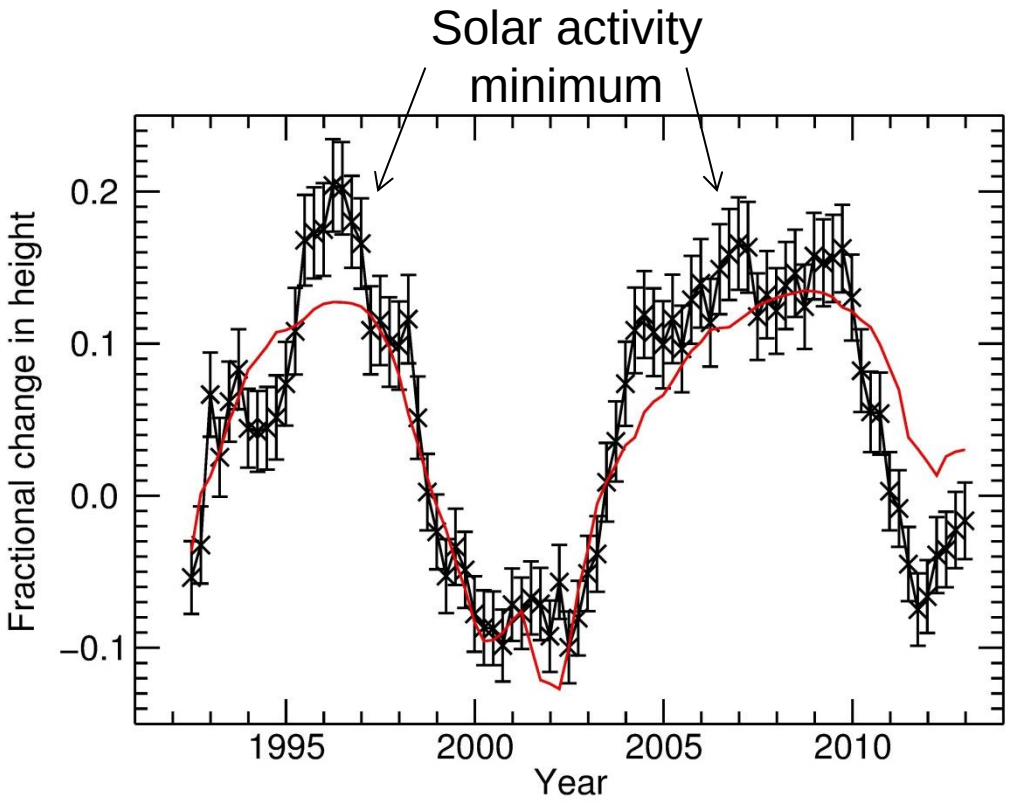
R_O=Rossby number



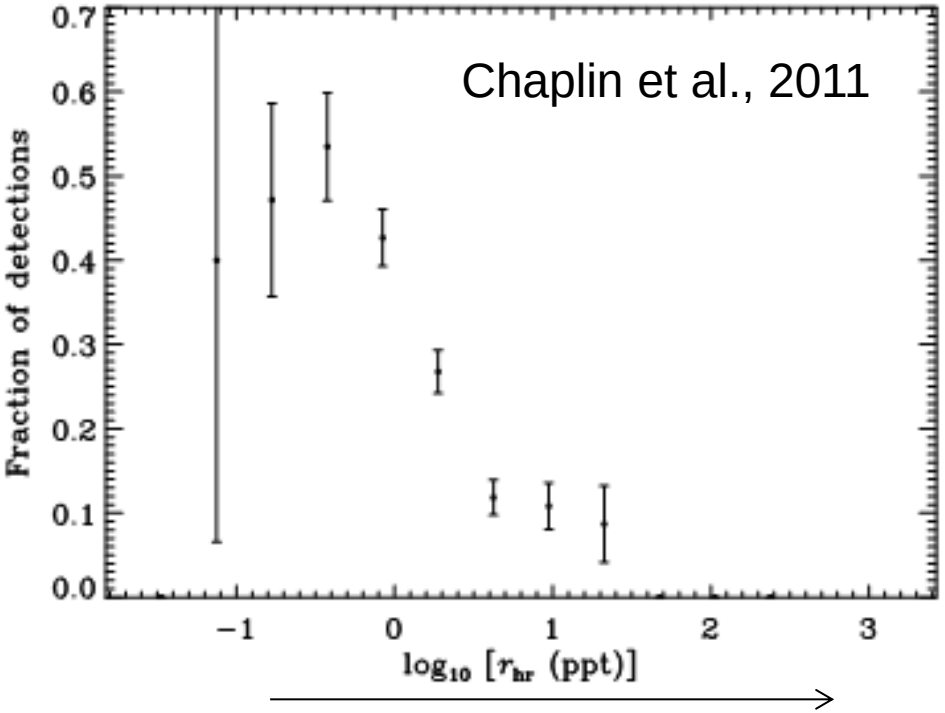
Wright et al., 2011, ApJ

But here's the catch…

- Magnetic field suppresses the oscillations.



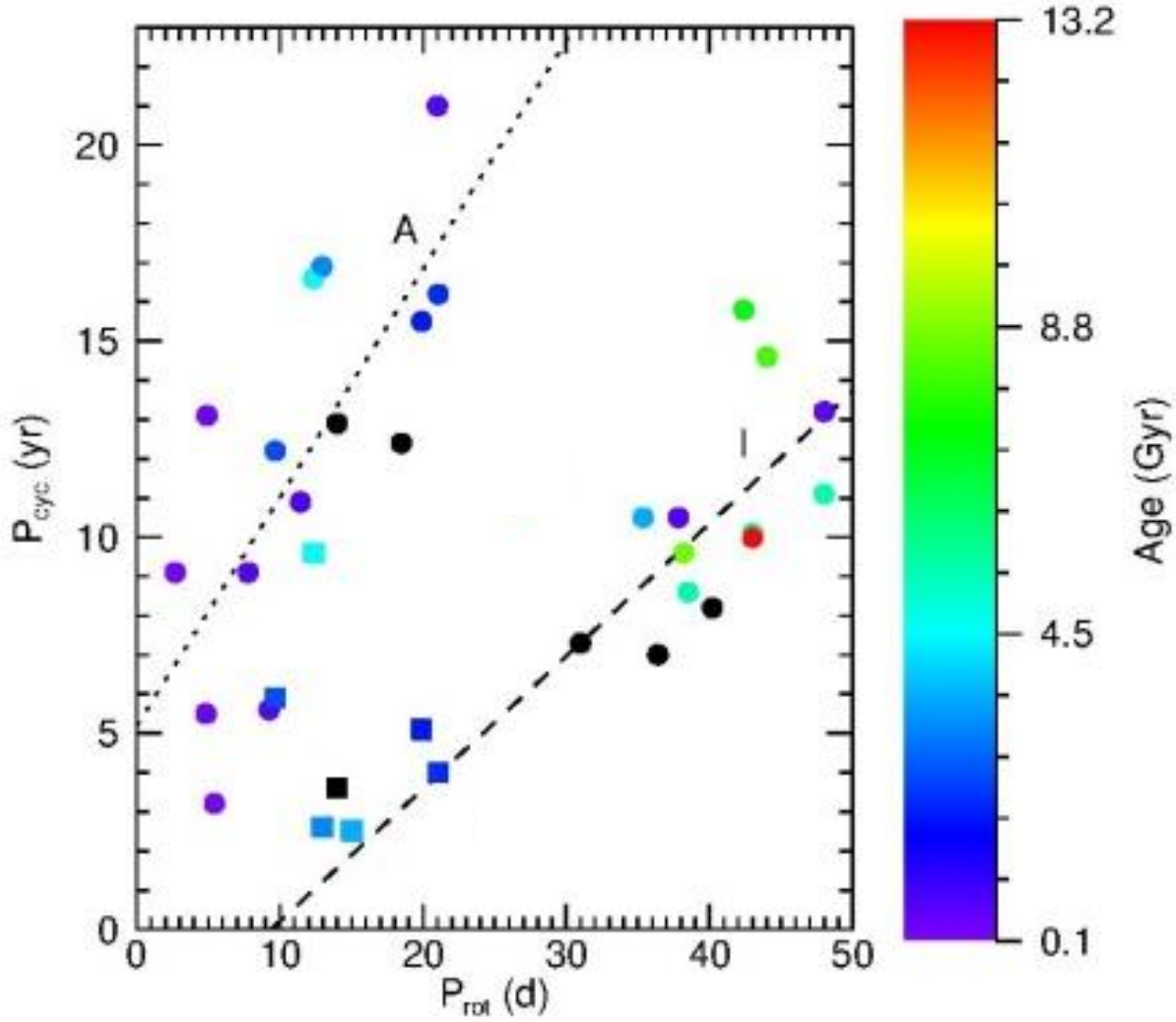
Solar cycle variations in amplitude



Increasing activity

Stellar activity cycles

- Cycle length decreases with rotation rate
- Bohm-Vitense (2007) active and inactive branches.
  - Fed by different dynamos.



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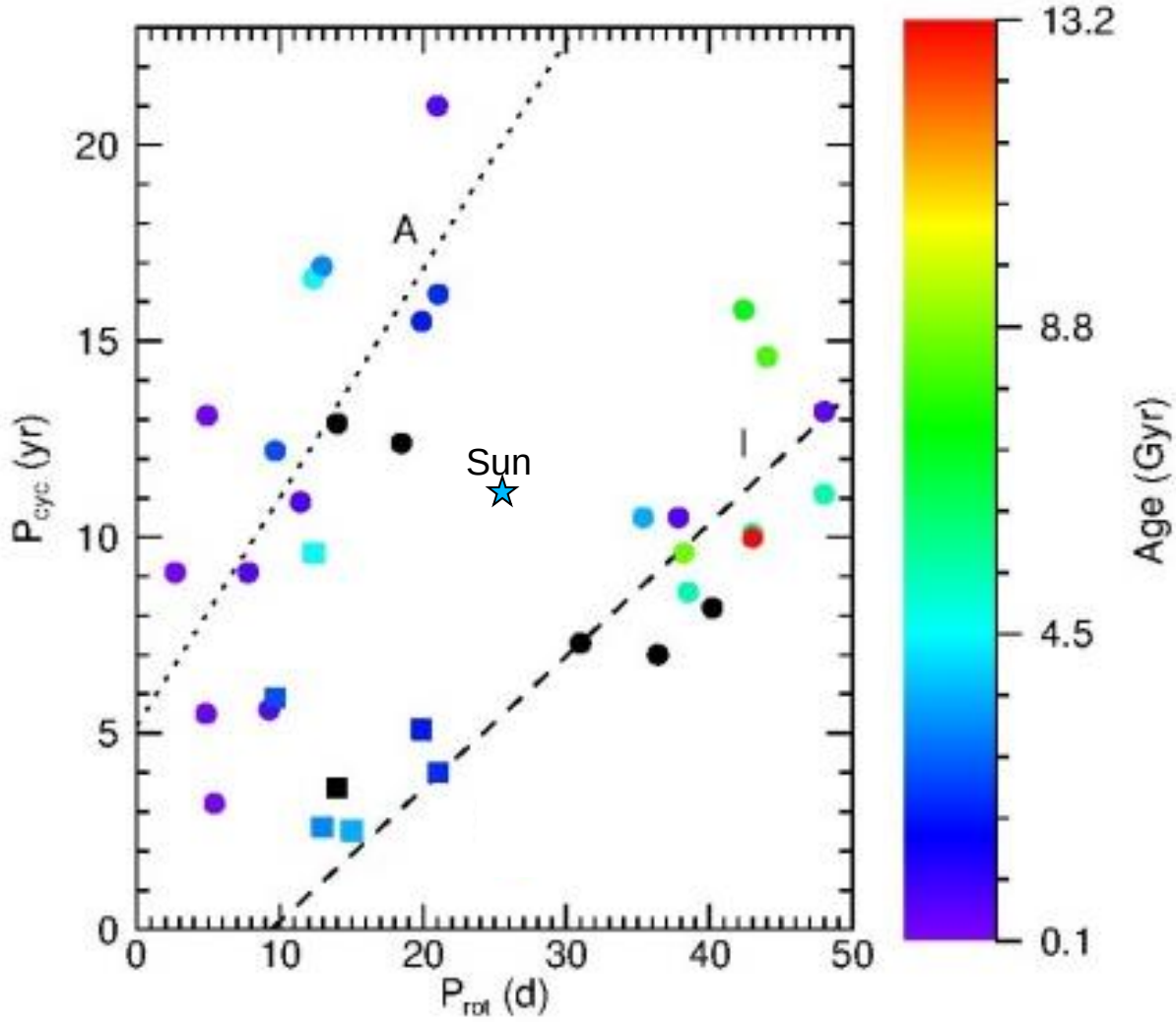

Stellar activity cycles

- Cycle length decreases with rotation rate
- Bohm-Vitense (2007) active and inactive branches.
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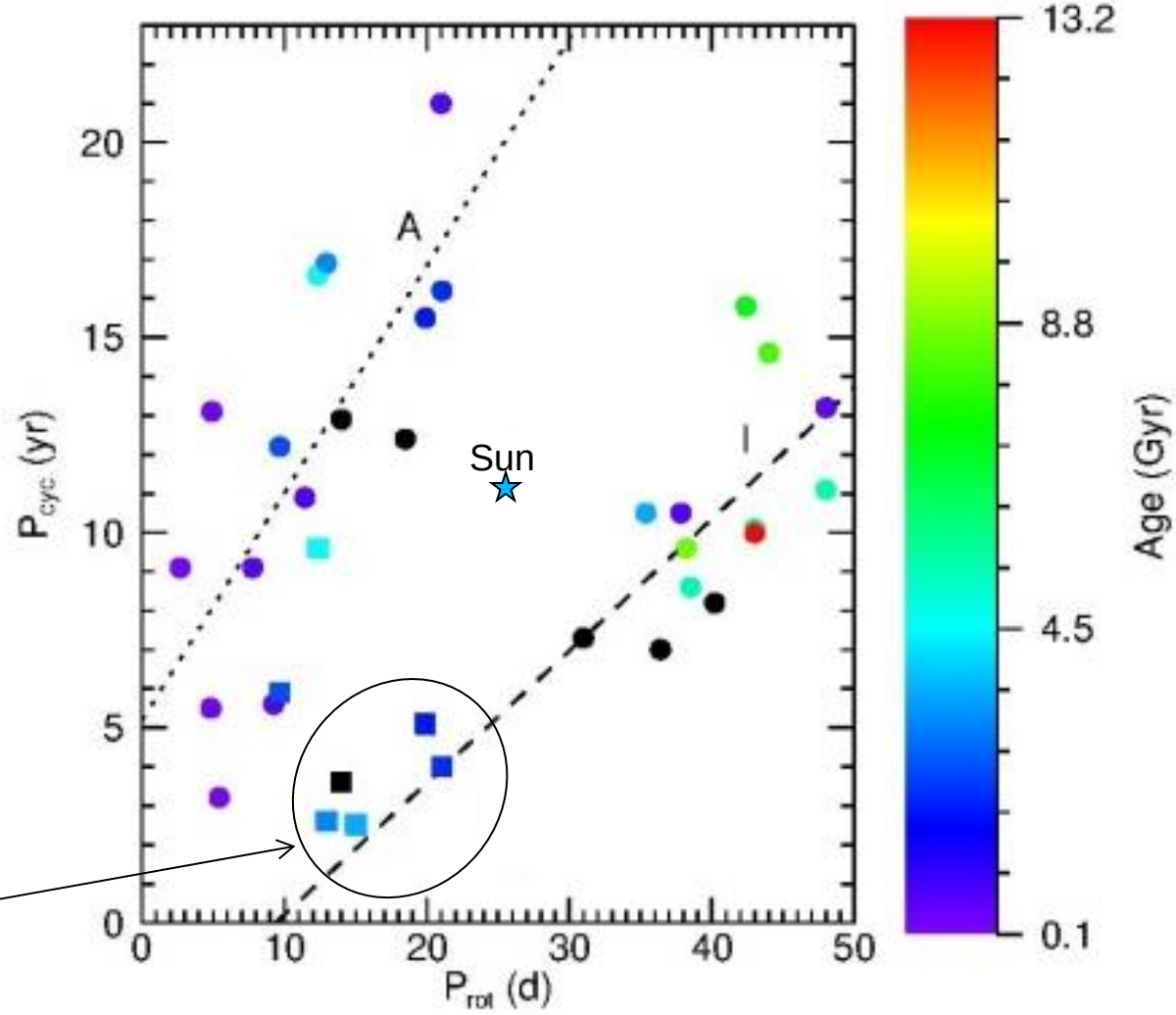
Secondary activity cycles



Stellar activity cycles

- Cycle length decreases with rotation rate
- Bohm-Vitense (2007) active and inactive branches.
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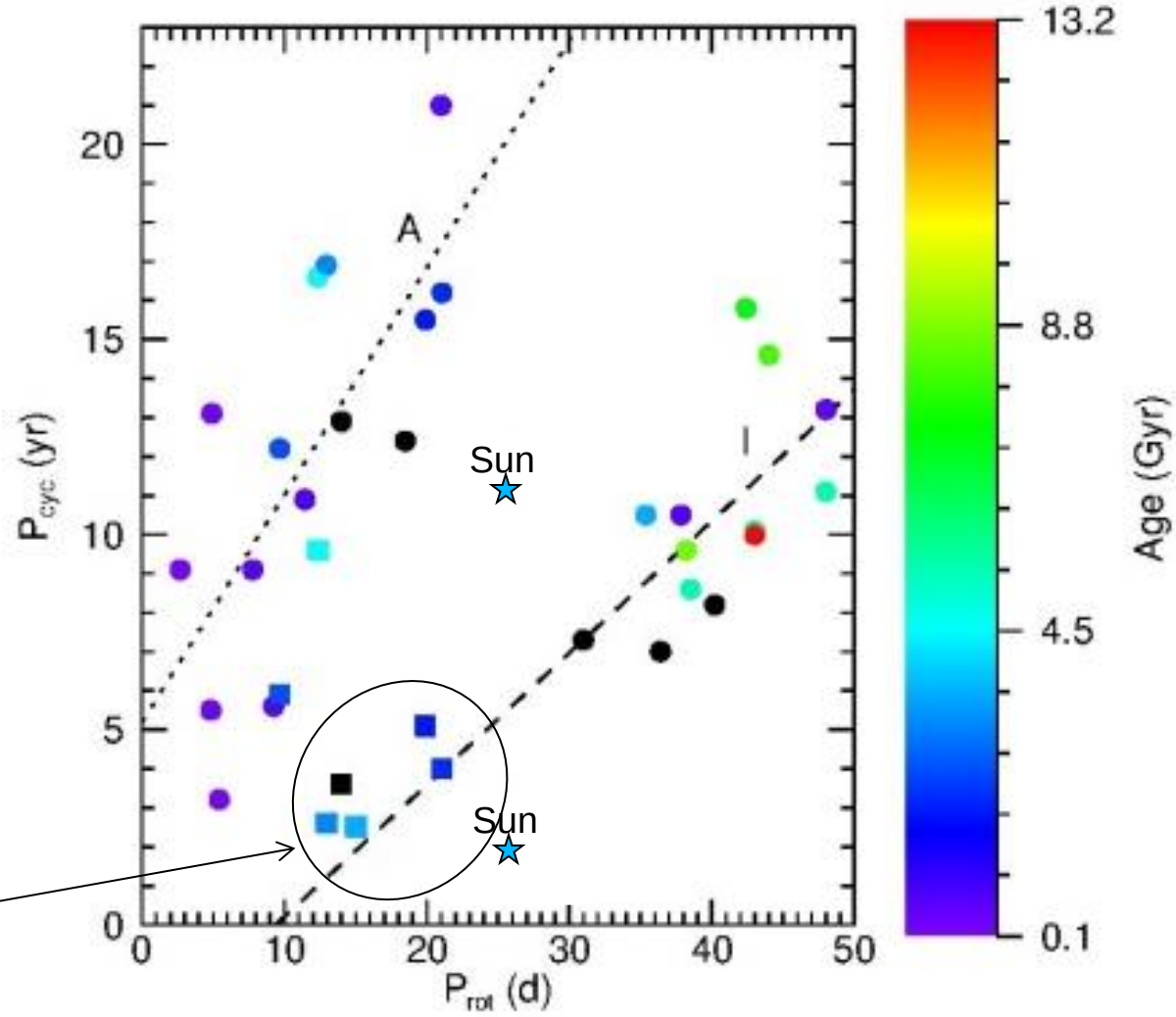
Secondary activity cycles



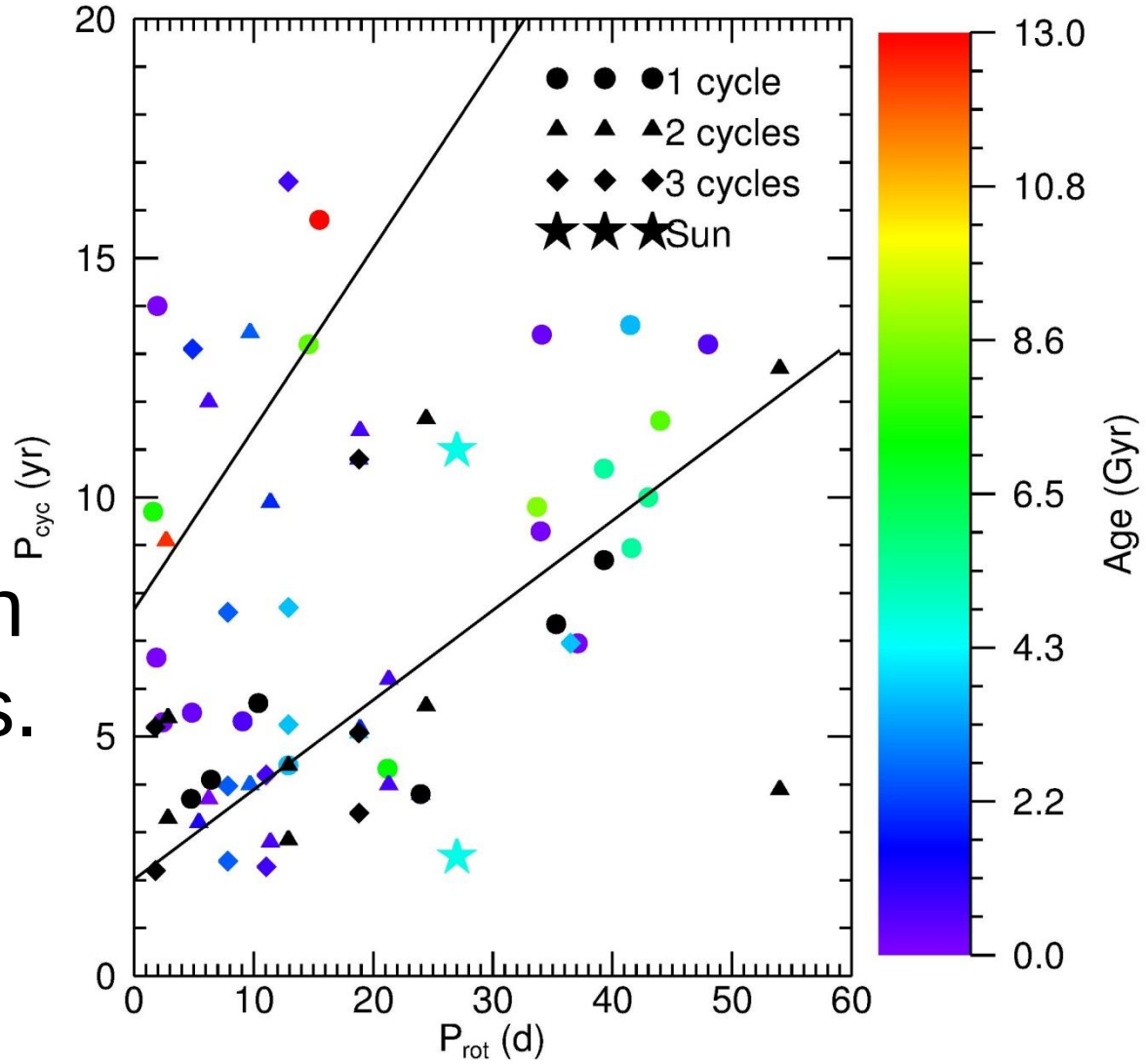
How reliable are cycle lengths?

- Even dominant solar cycle length varies between ~9-14yrs (Hathaway, LRSP)
- From Oláh et al., 2016.

Star	Sp. type	P_{rot} (days)	$P_{cyc,(range)}$ (years)	lt[c]	P_{cyc}, Baliunas et al. (1995) (years)
			simple cycles		
HD 3651	K0V[a]	44[b]	11.6(9.57–13.7)-lt	yes	13.8 ± 0.4
HD 4628	K2.5V[a]	41.6	8.94(8.30–9.5)	no	8.37 ± 0.08
HD 10476	K1V[a]	33.7	9.8(9.01–9.85)	no	9.6 ± 0.1
HD 16160	K3V[a]	57	12.1	no	13.2 ± 0.2
HD 26965	K1V[a]	43[b]	10.0(9.57–10.5)	no	10.1 ± 0.1
HD 32147	K3+V[a]	39.3	10.6(9.85–11.3), lt	yes	11.1 ± 0.2
HD 81809	G5V[a]	39.3	8.69(8.10–9.28)	no	8.17 ± 0.08
HD 103095	K1V[a]	36.5	6.95(6.9–7.0), lt	yes	7.30 ± 0.08
HD 160346	K2.5V[a]	35.3	7.35(7.2–7.5), lt	yes	7.00 ± 0.08
HD 166620	K2V[c]	41.5	13.6(9.6–17.6)	no	15.8 ± 0.3
HD 201091	K5V	37.1	6.95(6.7–7.2), lt	yes	7.3 ± 0.1
HD 219834B	K2V	34.0	9.29(9.01–9.57)	no	10.0 ± 0.2
Sun	G2V	27.275	11(9–14), 3.65(3.3–4.0)[d]	yes	

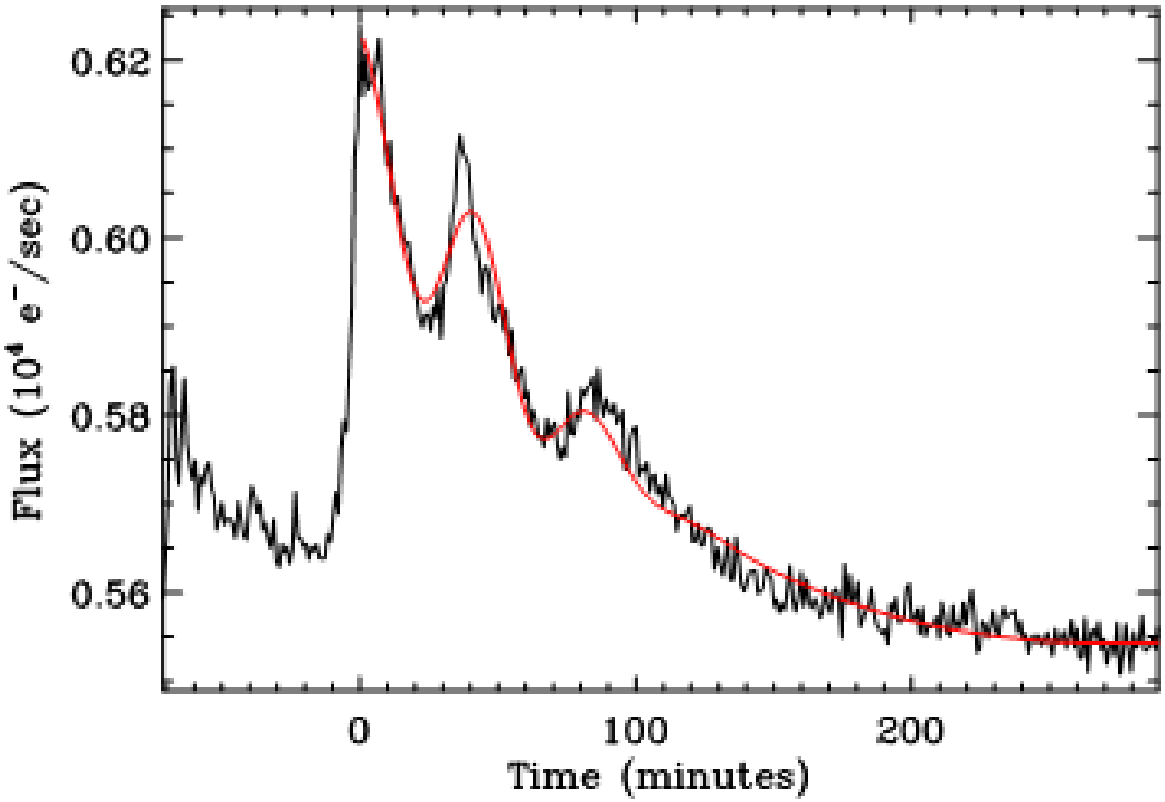
Meta-data cycle analysis

- Using new results from Oláh et al., (2016) for MW HK project and others from literature.
- No clear separation of I and A branches.



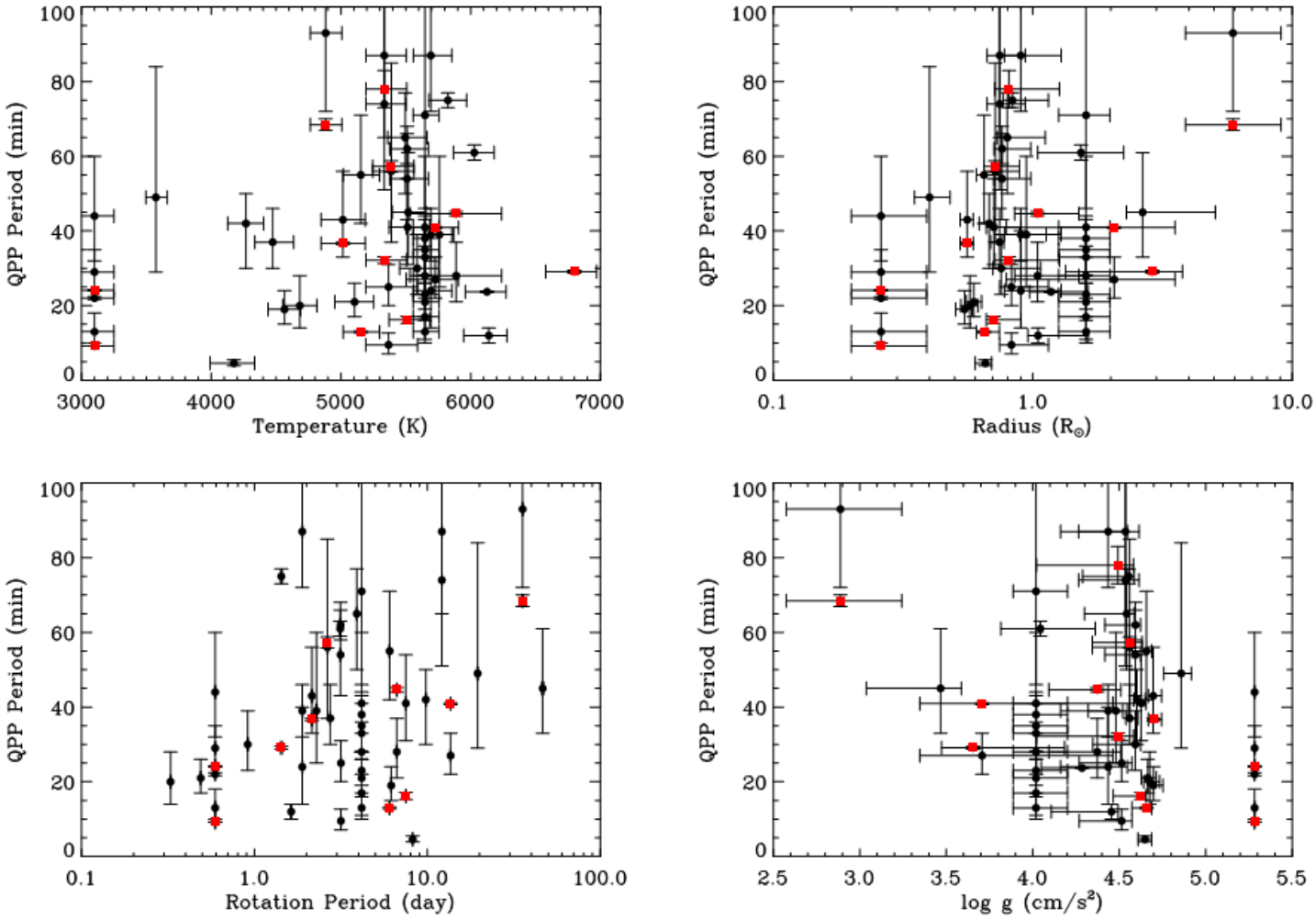
Stellar quasi-periodic pulsations

- QPPs often observed in solar flares but rarely in stellar flares



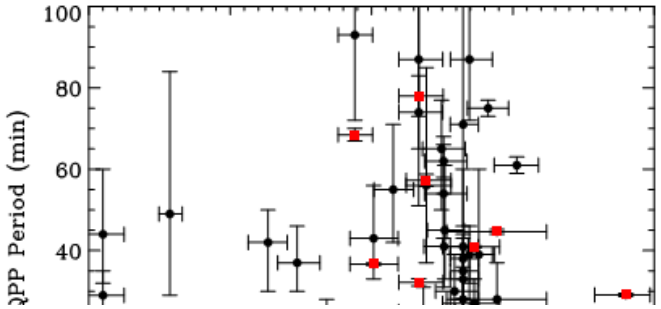
Pugh et al. 2016

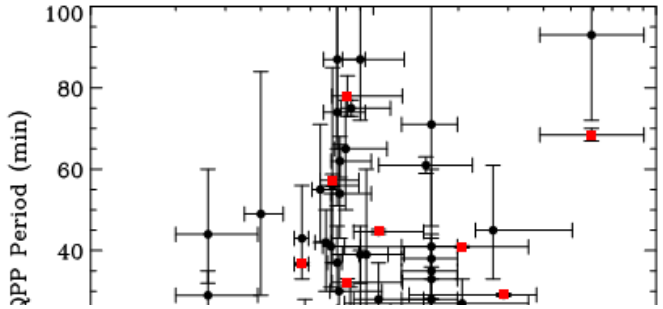
Period vs stellar parameter



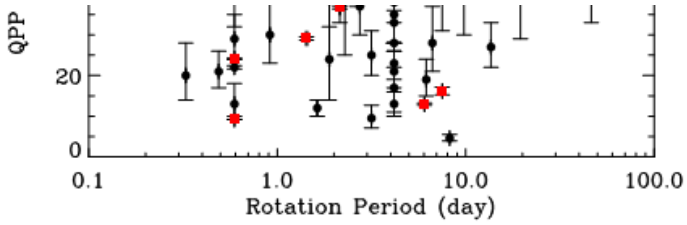
Pugh et al. 2016

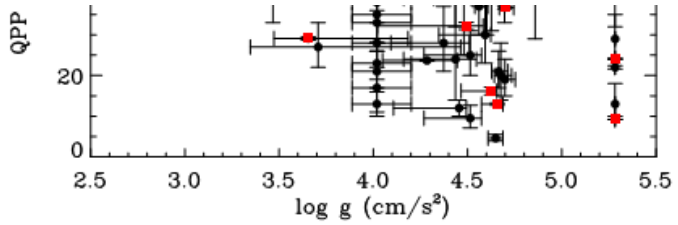
Period vs stellar parameter





Conclusion: period dependent on LOCAL active region and NOT GLOBAL stellar parameter





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Summary

- The Sun’s activity cycle is complex.
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Thank you for listening!