# Persistency of long period oscillations in sunspots

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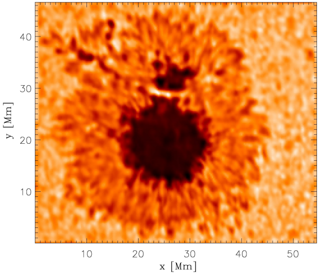
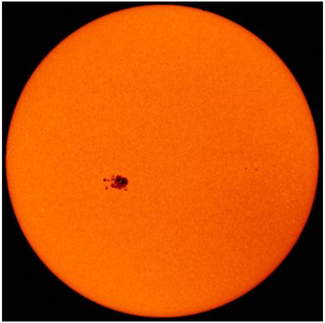
# Introduction - Sunspots

- Sunspots are MHD objects!
- Structures associated with solar magnetic field.
- Formed by emerging magnetic flux.
- Field strength (photosphere) $\approx 10^3$ G ($10^{-1}$ T)

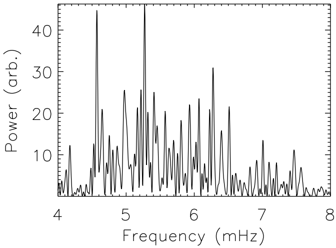


# Introduction - Oscillations in sunspots

- Sunspots are dynamic features.
- 3 minute oscillations (Beckers & Tallant 1969).
- Running penumbral waves (Zirin & Stein 1972).
- 5 minute oscillations (Thomas, Cram & Nye 1984).
- Solar p-modes absorbed by sunspots.

- Longer period oscillations - two kinds: compressible and incompressible (possibly torsional oscillations).

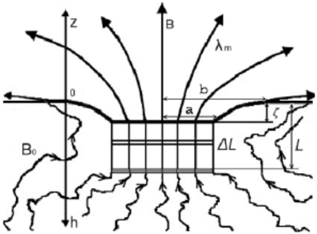


# Introduction - Longer period oscillations

| Reference | Period (min) |
|---|---|
| Demchenko et al. 1985 | 70 |
| Berton & Rayrole 1985 | 40-50 |
| Nagovitsyn & Vyal'shin 1990 | 45-120 |
| Druzhinin et al. 1993 | 20-60 |

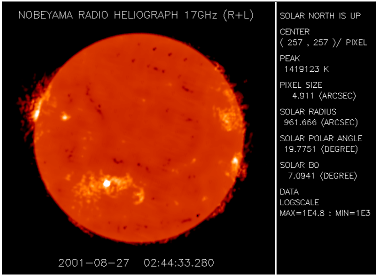
# Motivation - Longer period oscillations

- $P \geq 60$ minutes.
- What is their nature?
- Can we learn about the solar interior and dynamo?
- Shallow sunspot model (Solov'ev & Kirichek 2008)?
- Coronal origin? Excitation by other processes in the corona, e.g. prominence oscillations (e.g. Wiehr et al. 1989; Foullon et al. 2004, 2009).



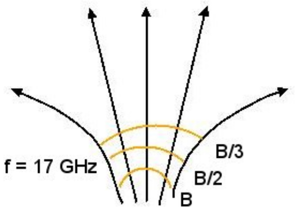
Solov'ev & Kirichek 2008

- Physical mechanism for radio emission: electron gyroresonance.
- Images from Nobeyama Radioheliograph @ 17 GHz.
- Emission generated at the second or third harmonic of electron cyclotron frequency.
- Spatial resolution: 10" per pixel, temporal resolution: 1 sec.



# Microwave emission from sunspots (2)

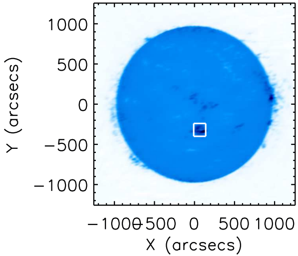
- Modulation of emission in two ways:
  - Fast mode-like: field compresses and emitting layer oscillates vertically.
  - Slow mode-like: density in emitting layer varies.

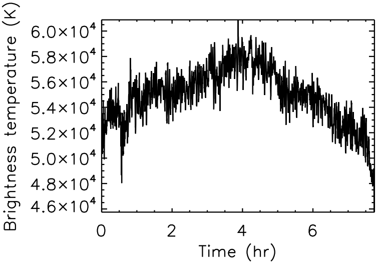



- Gyroresonant emission from each narrow layer at different harmonic of gyrofrequency $n\omega_{ce}$, $n = 1, 2, 3$.

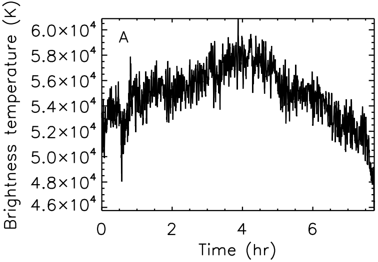
# Data preprocessing

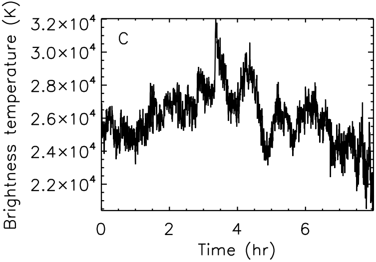
- Small field of view taken and microwave intensity signal integrated over this.
- Images derotated before integration.

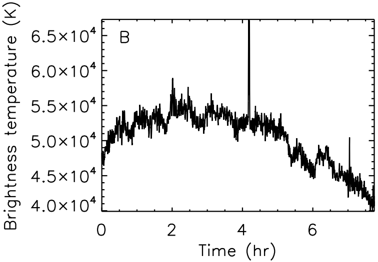


# Application - Sunspot time series from NoRH

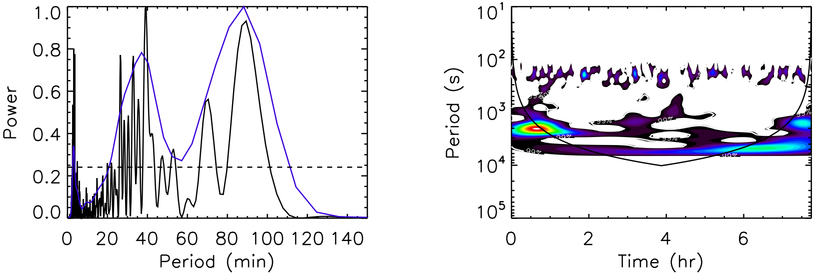



- A: AR0330, 08-Apr-2003 22:45 - 09-Apr-2003 06:29.
- B: AR108: 10-Sep-2002 22:45 - 11-Sep-2002 06:29.
- C: AR673: 21-Sep-2004 22:45 - 22-Sep-2004 06:45.

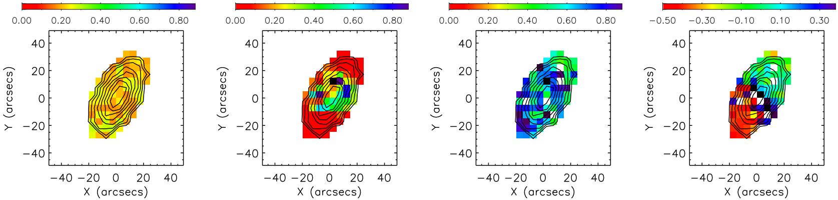
# Results 1 - Periodograms and Morlet wavelet power spectra

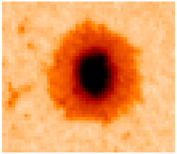



- High temporal resolution & long duration observations (8 hours) ⇒ low frequency oscillations well resolved.

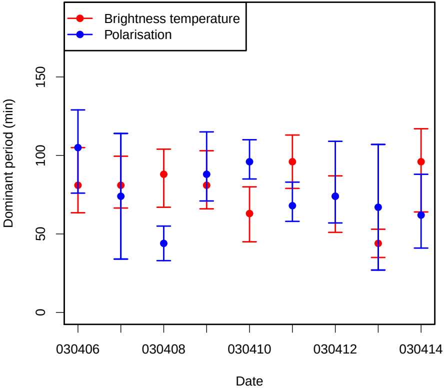
# Results 2 - Spatial structure of the oscillations

- Left to right: period, power, maximum correlation, lag for max correlation.

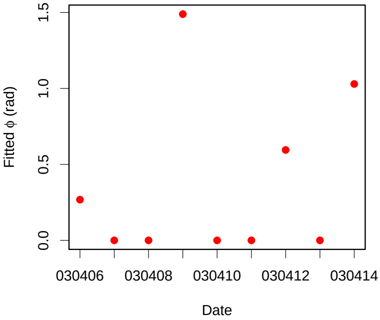


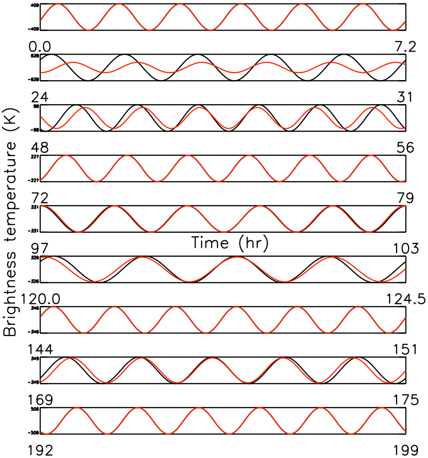



# Results 3 - Persistency of the long period oscillations




| Measurement | $\mu$ (min) | $\sigma$ (min) |
|---|---|---|
| Brightness temp. | 78.22 | 16.48 |
| Polarisation | 75.33 | 18.55 |


1.5
1.0
0.5
0.0
Fitted ϕ (rad)
030406
030408
030410
030412
030414
Date


0.0
7.2
24
31
48
56
72
79
97
103
120.0
124.5
144
151
169
175
192
199
Time (hr)
Brightness temperature (K)

# An oscillator with nonlinear driving

- Why are the oscillations not damped?
- What's generating them?

- An **empirical** model:

$$\frac{d^2x}{dt^2} + k\frac{dx}{dt} + \omega_0^2 x = \left[\sum_{i=1}^{n} A_i \cos(\omega_i t + \phi_i)\right]^2$$

- $\cos 2\omega_i t$ - frequency doubling (or period halving).
- $\cos(\omega_i + \omega_j)t, \cos(\omega_i - \omega_j)t$ - generation of higher and lower frequencies.

# Conclusions

- Long periods (several tens of minutes) persist throughout observation periods and remain stable over long times (9 days).
- 3 minute oscillations could generate long period oscillations through nonlinear driving.
- Solar g modes? Similar periods, but lacking theoretical foundation.
- Publication: Chorley et al. 2010, *Astron. Astrophys.*, **513**, A27.