Persistency of long period oscillations in sunspots

N. Chorley, B. Hnat, V. M. Nakariakov & K. Shibasaki*

Centre for Fusion, Space and Astrophysics,
University of Warwick, Coventry CV4 7AL, UK

* Nobeyama Radio Observatory: Solar Group,
Nagano, Japan

n.d.y.chorley@warwick.ac.uk

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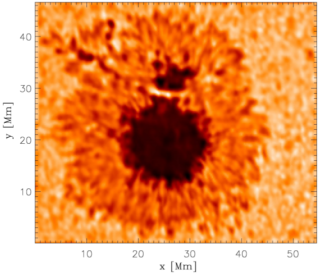
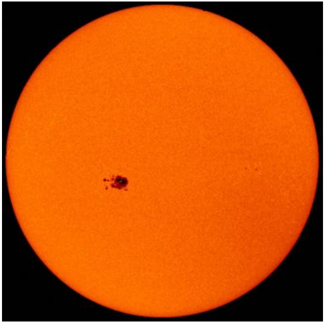
Introduction - Sunspots

- 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)

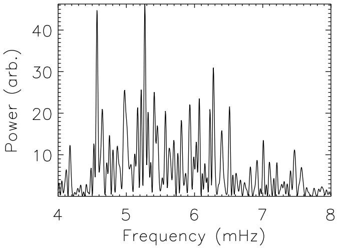




Introduction - Oscillations in sunspots

- 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).

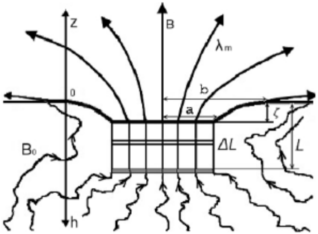


Introduction - Longer period oscillations

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

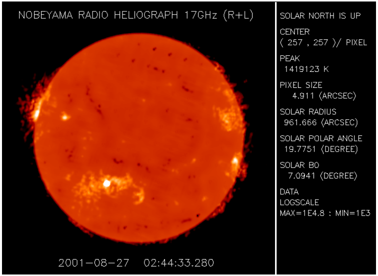
- $P \geq 60$ minutes.
- What is their nature?
- Can we learn about the solar interior and dynamo?
- Shallow sunspot model (Solov'ev & Kirichek 2008)?
- Coronal origin? Excitation by other processes in the corona, e.g. prominence oscillations (e.g. Wiehr et al. 1989; Foullon et al. 2004, 2009).



Solov'ev & Kirichek 2008

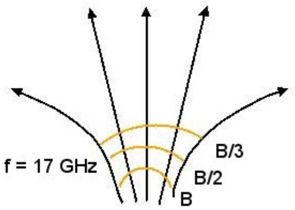
Microwave emission from sunspots

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



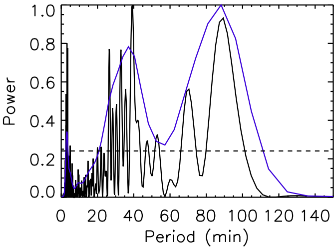
Microwave emission from sunspots (2)

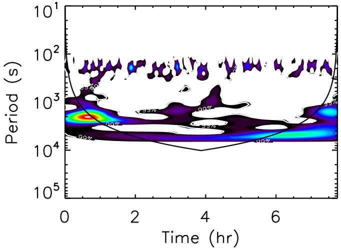
- Modulation of emission in two ways:
  - Fast mode-like: field compresses and emitting layer oscillates vertically.
  - Slow mode-like: density in emitting layer varies.

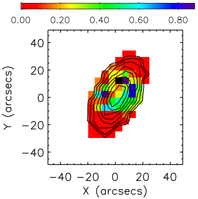


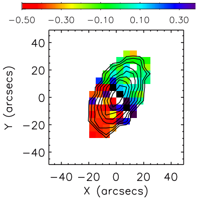
- Gyroresonant emission from each narrow layer at different harmonic of cyclotron frequency $n\omega_{ce}$, $n = 1, 2, 3$.

Long period oscillations in sunspots with NoRH





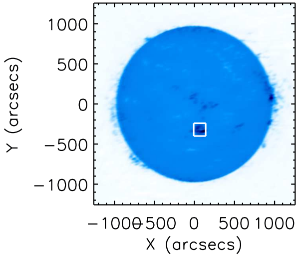


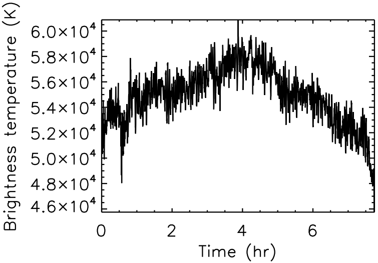


- Chorley et al. 2010, *Astron. Astrophys.*, **513**, A27.
- What happens to these oscillations over longer periods of observation?

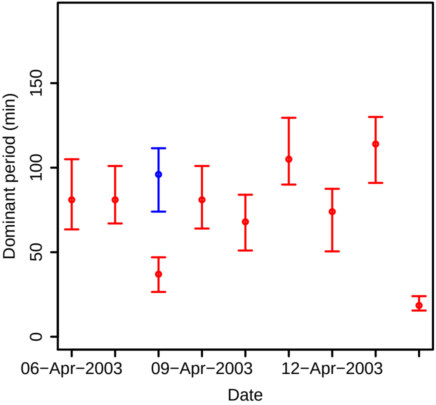
Data preprocessing

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





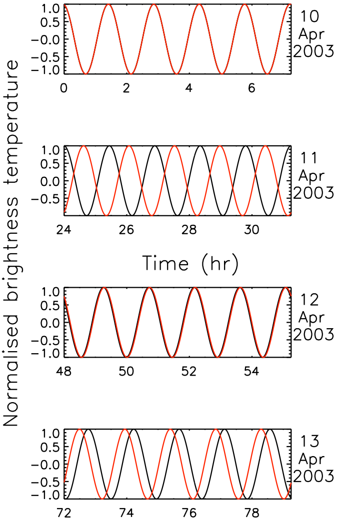
Results 1 - Persistency of the long period oscillations

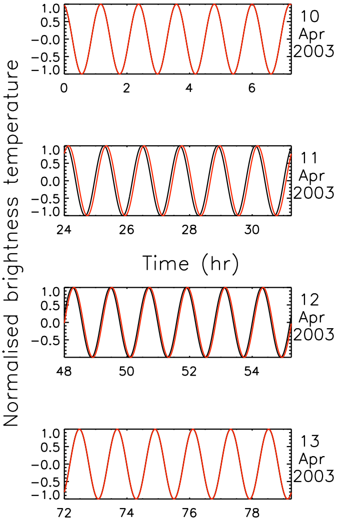


- Mean period, $\langle P \rangle = 79.83$ min.

Results 2 - Coherency of the long period oscillations

- Left: $P = 87$ min, right: $P = 73$ min.





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 dominate power spectra over ≈ 8 days.
- $P = 73$ min component does not undergo significant phase shift during 4 observation intervals.
- This is not the same for nearby components.
- This is still a work in progress.