Detecting Solar Modes in the D-Region using a Relative Ionospheric Opacity Meter

François Marshall
Dr. David J. Thomson (supervisor)
Queen's University
Kingston, Ontario, Canada
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Queen's UNIVERSITY

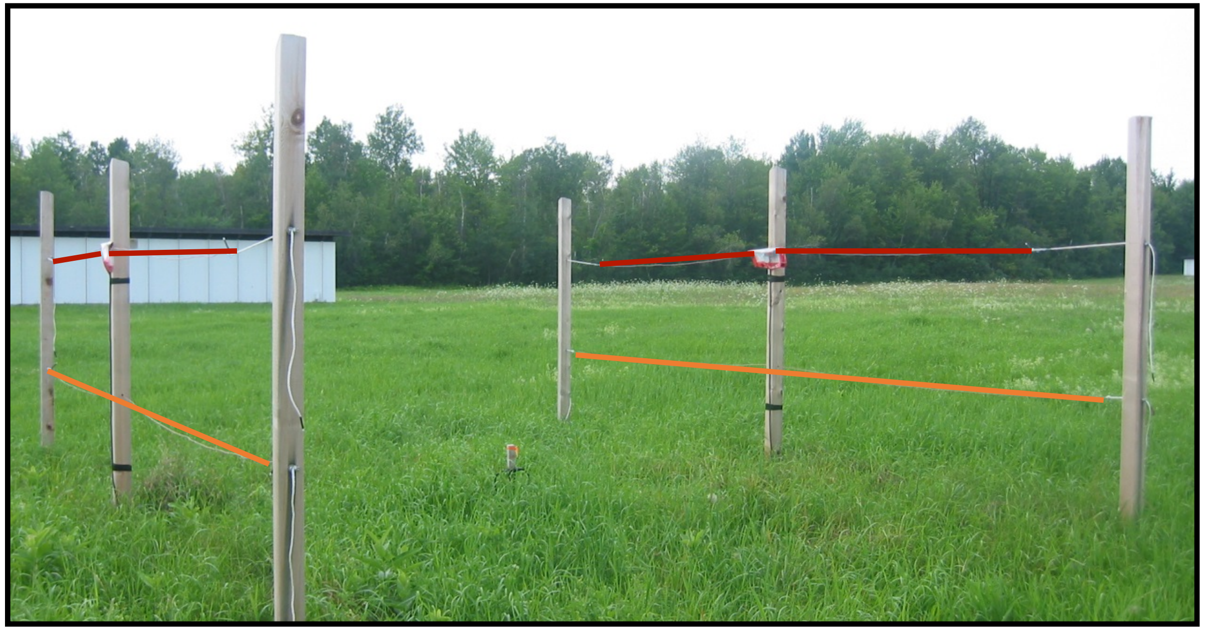
Introduction

- Relative ionospheric opacity meters (riometers).
- Normal modes in space-physics data.
- Statistical test for normal modes in a process.
- Validation of mode detections.

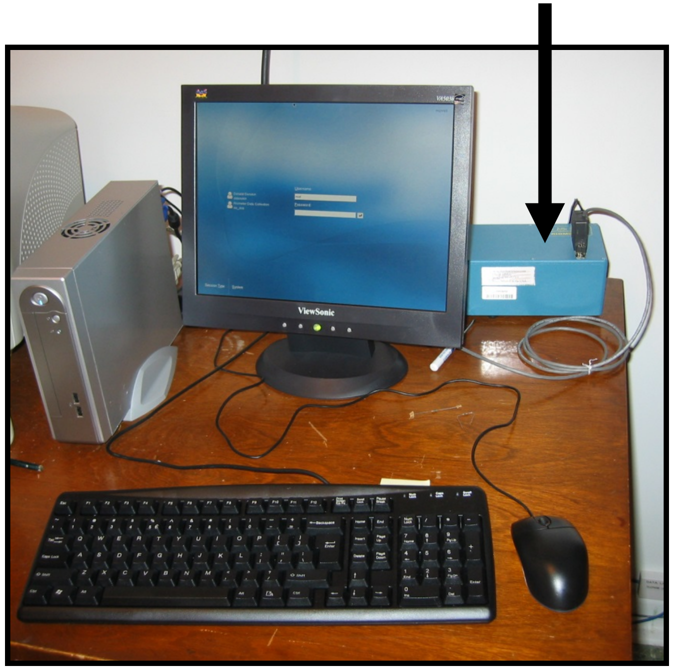
The Ottawa Riometer

- Radio-wave opacity of the D-region.
- Accepts 30.0 ± 0.1 MHz frequencies, and reads at 60 sps.

Antenna



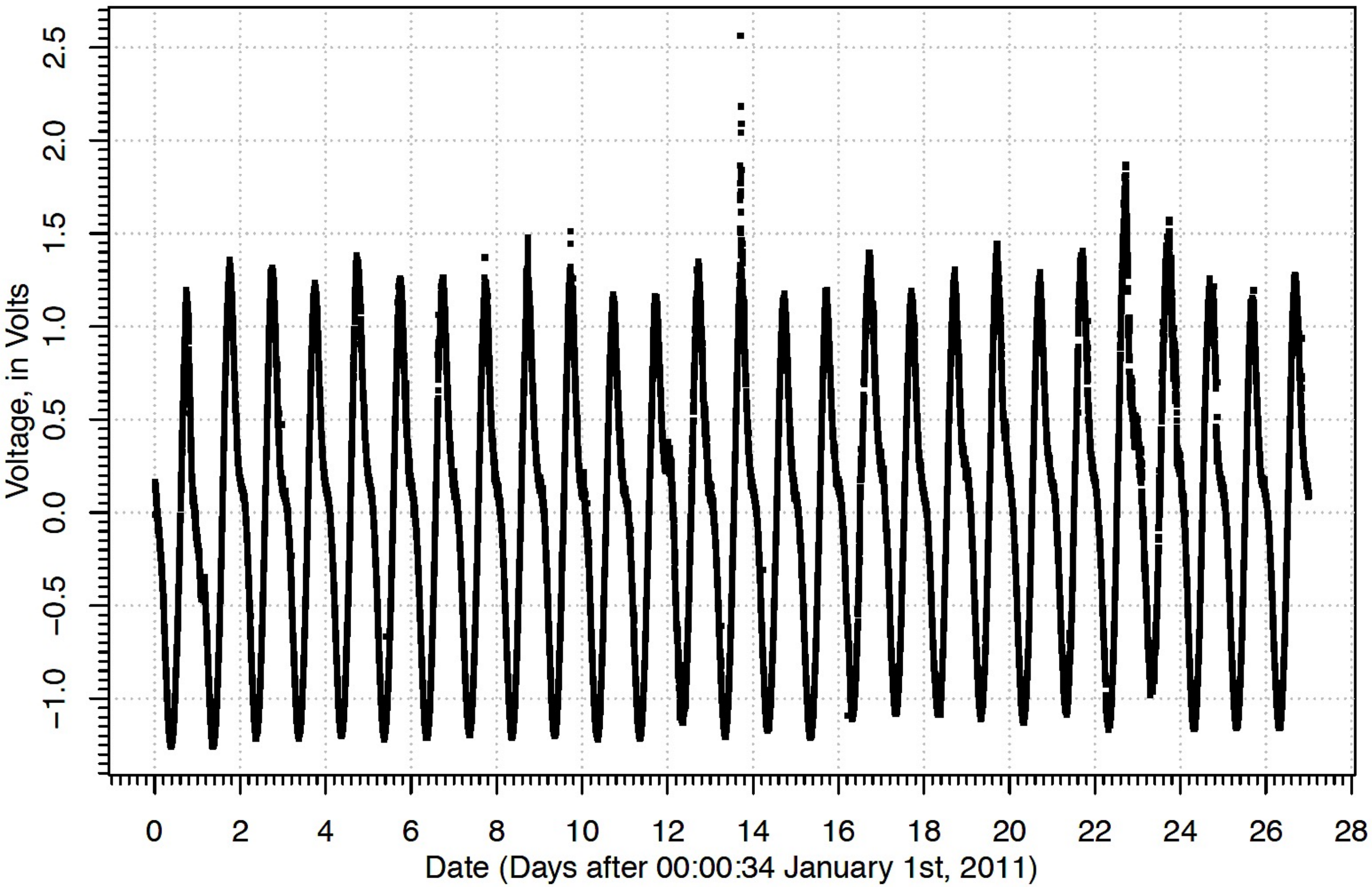
Riometer



Danskin, Canadian Solar Workshop presentation, 2014

The Voltage Response

- 27-day record.
- Daily variation from Earth's rotation.



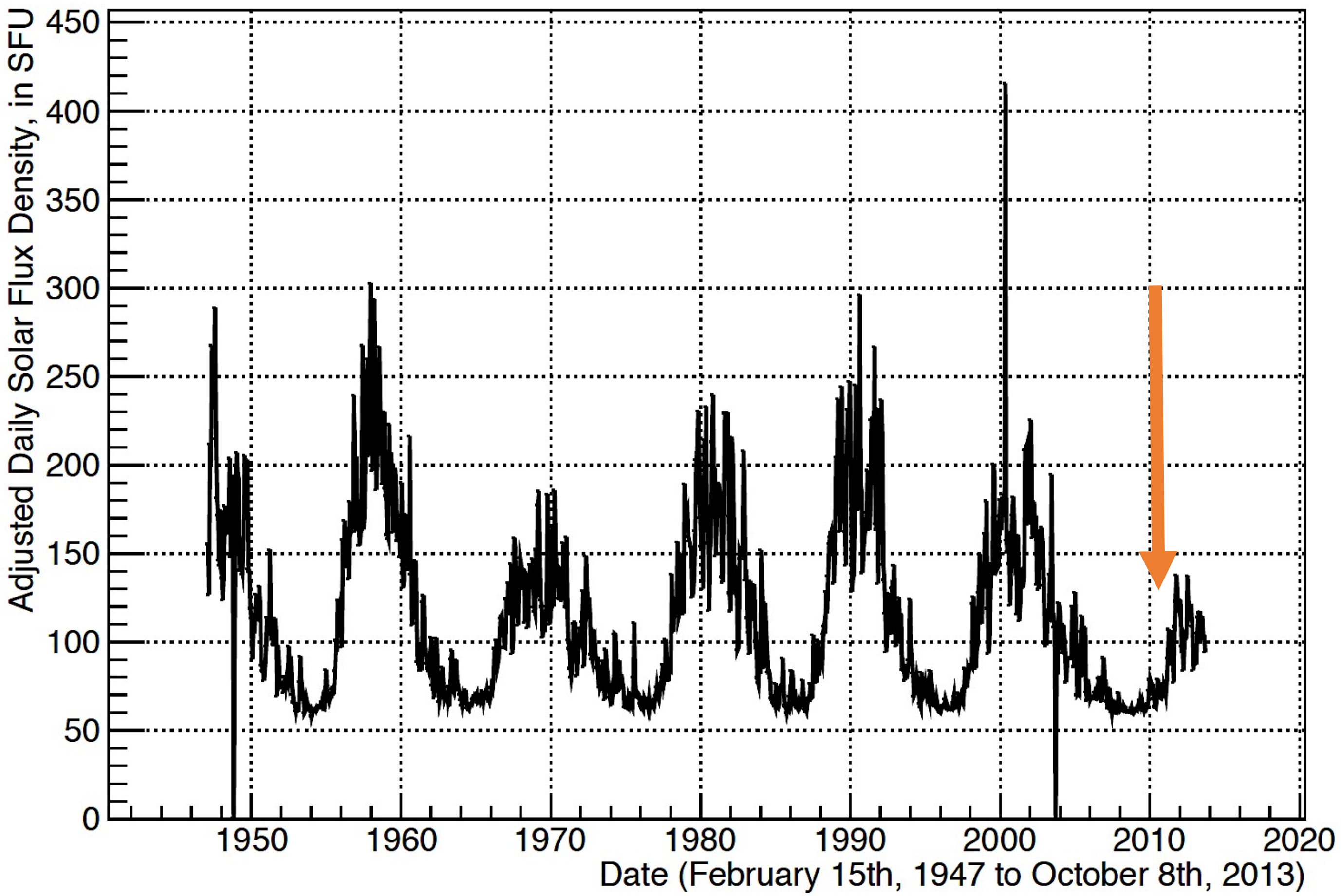
Data provided by Dr. Donald Danskin. NRCan Geomagnetic Laboratory.

Solar Oscillations in Space Physics

- Doppler helioseismology.
- Thomson et. al 1995 – Normal modes of the Sun propagate through the interplanetary medium.
- Thomson & Vernon 2015 – Normal modes are present on the ground on Earth.
- Question: What happens at the interface? – Ionospheric waves.

Mode Detection: Physical Considerations

- Mode frequencies shift with solar activity.
- In 2011, solar activity is on the rise.

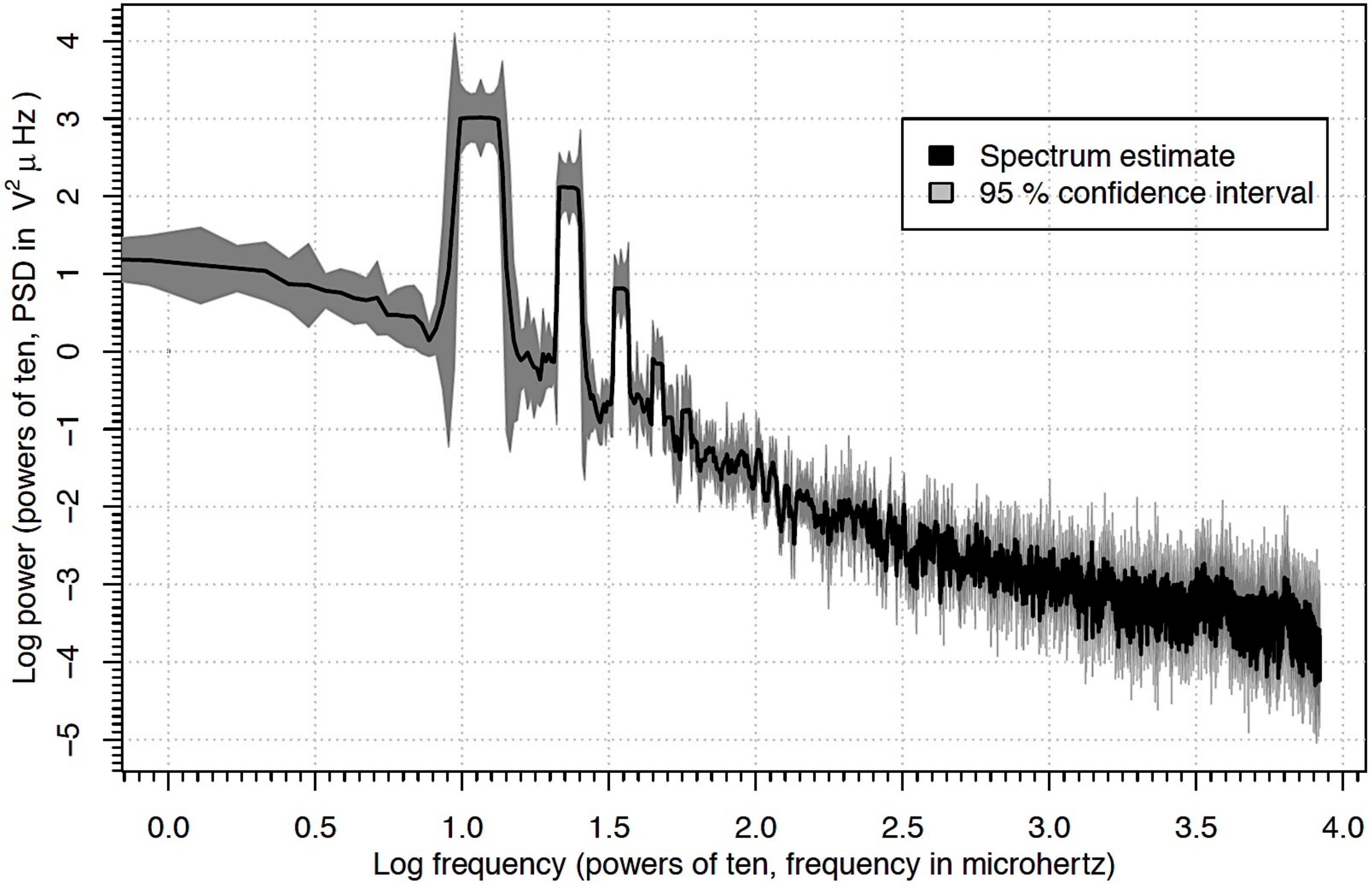


Data provided by Dr. Ken Tapping. NRC observatory in Penticton, BC.

Spectrum of the Voltage Series

- 0.7 < f < 1.7:
  - Fourier harmonics of Earth'
    rotation.

- 3.0 < f < 3.5:
  - Normal modes.



A Statistical Test for Normal Modes

Time domain

$$X(t) = \zeta(t) + \sum_{j=1}^{J} X_{M,j}(t)$$

$\zeta(t)$ is the noise process at time, t.

$X_{M,j}(t)$ is the j'th modulated Fourier series.

Frequency domain

$$S(f) = H(f)\, S_\zeta(f)$$

$S(f)$ is the spectrum of $X(t)$.

$S_\zeta(f)$ is the spectrum of $\zeta(t)$.

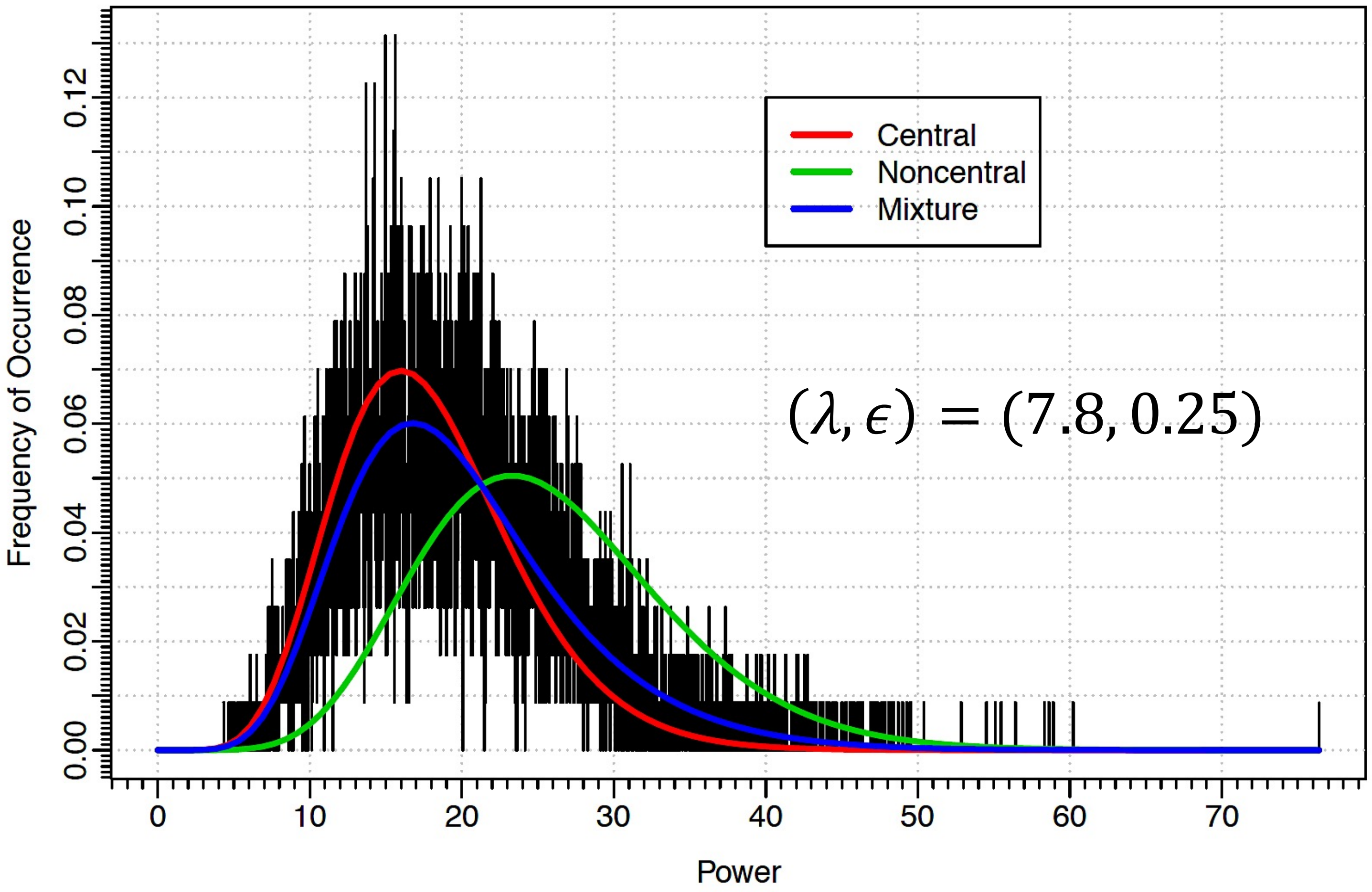
$$H(f) \overset{d}{=} \begin{cases} \chi^2(\nu;\ \lambda), & f \text{ a mode frequency} \\ \chi^2(\nu), & \text{otherwise} \end{cases}$$

Thomson et. al, "Interplanetary magnetic field: Statistical properties and discrete modes", 2001

Evidence of Normal Modes

$$F_H(h;\, \nu,\, \lambda,\, \epsilon) = \epsilon\, F_{nc}(h;\, \nu,\, \lambda) + (1-\epsilon)\, F_c(h;\, \nu)$$

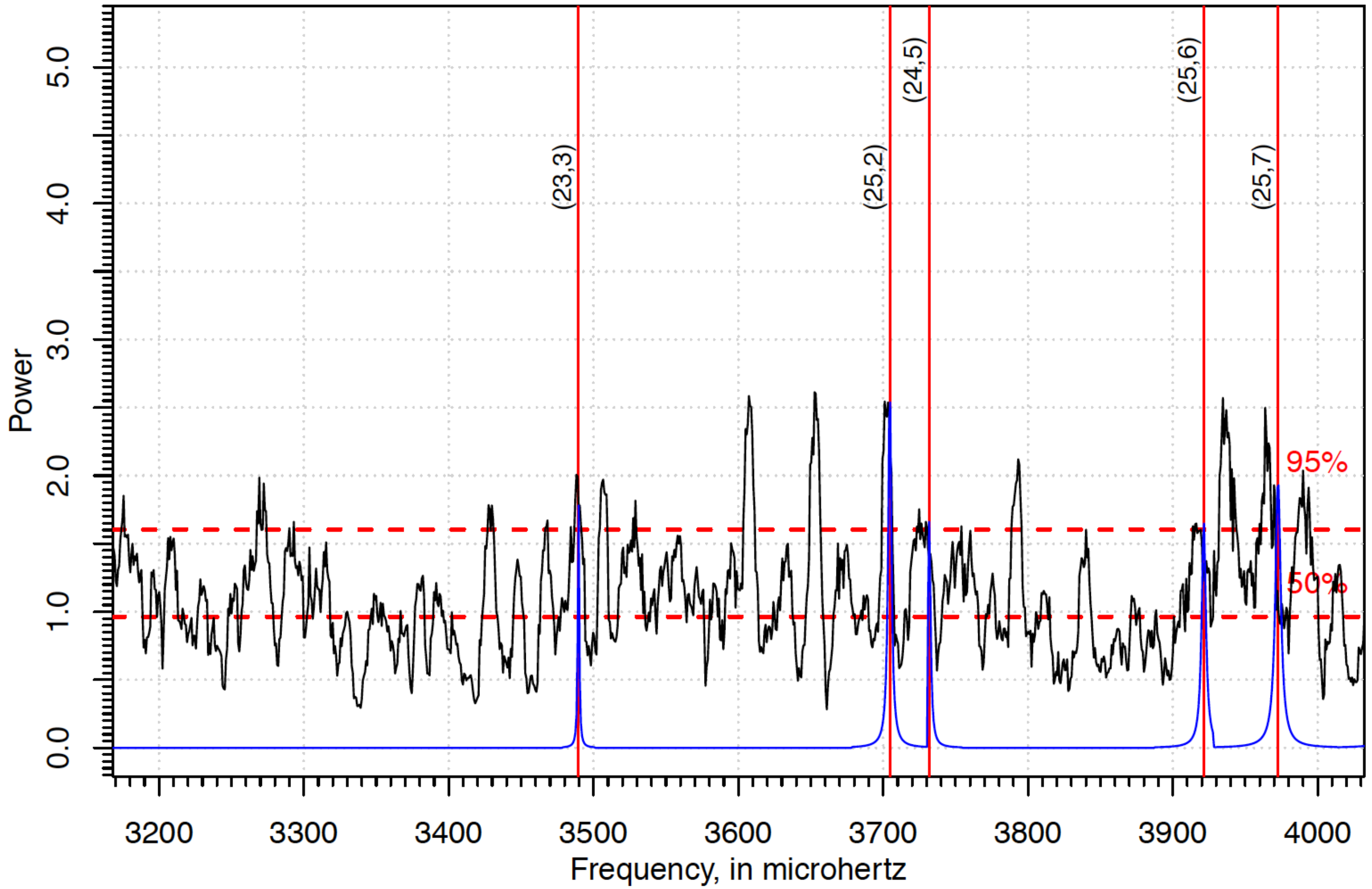
- >93% confidence for the Kolmogorov-Smirnov test.
- $\nu = 18$
- $7.2 \leq \lambda \leq 8.7$
- $0.24 \leq \epsilon \leq 0.29$



Thomson et. al, "Interplanetary magnetic field: Statistical properties and discrete modes", 2001

Validation: Optical Detections

- Michelson Doppler Imager (onboard SOHO).
- $l \leq 10$
- Cross-correlations are high (~0.6-0.9) for the matched peaks.



Korzennik, “Tables of Mode Parameters”, Harvard Smithsonian Institute for Astrophysics, updated October 2016

Conclusion

- The quiet-day curve is defined by a Fourier series with five high-SNR Fourier harmonics of the sidereal day.
- Kolmogorov turbulence is manifest as a linear trend in the spectrum of the voltage series.
- At >93% confidence of the Kolmogorov-Smirnov test, around one quarter of the background noise is caused by modal phenomena.
- Some of this modal behaviour is likely due to transportation of solar-oscillation energy via the solar wind.

References & Acknowledgements

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