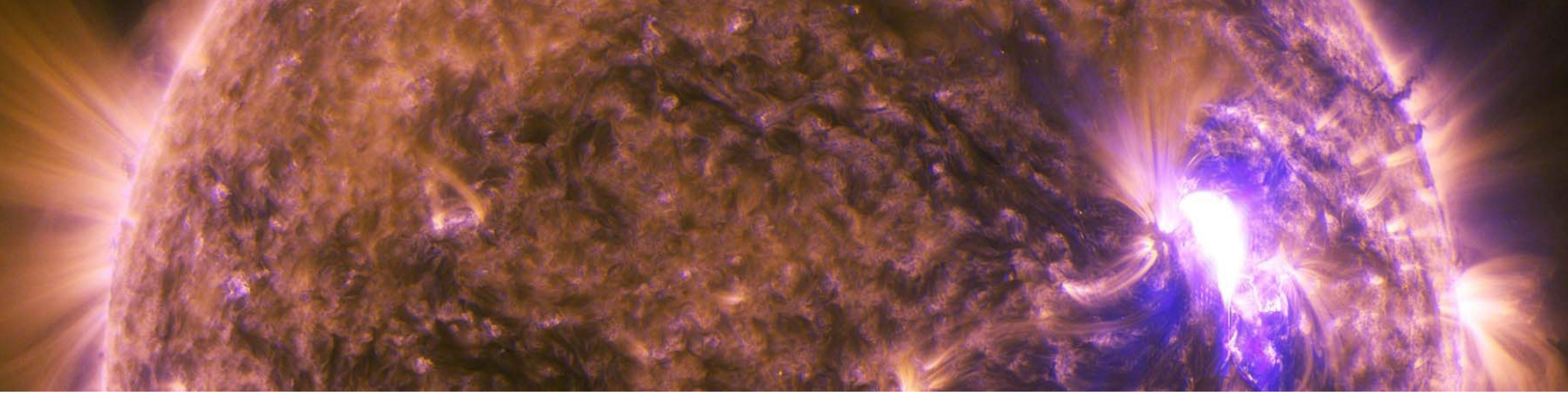

Properties of Quasi-Periodic Pulsations in Solar Flares From a Single Active Region

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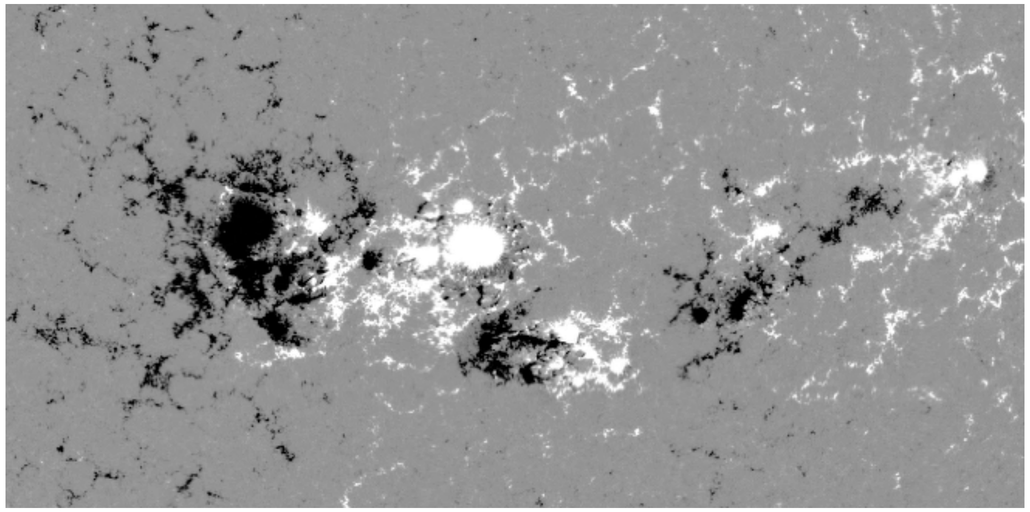
Overview

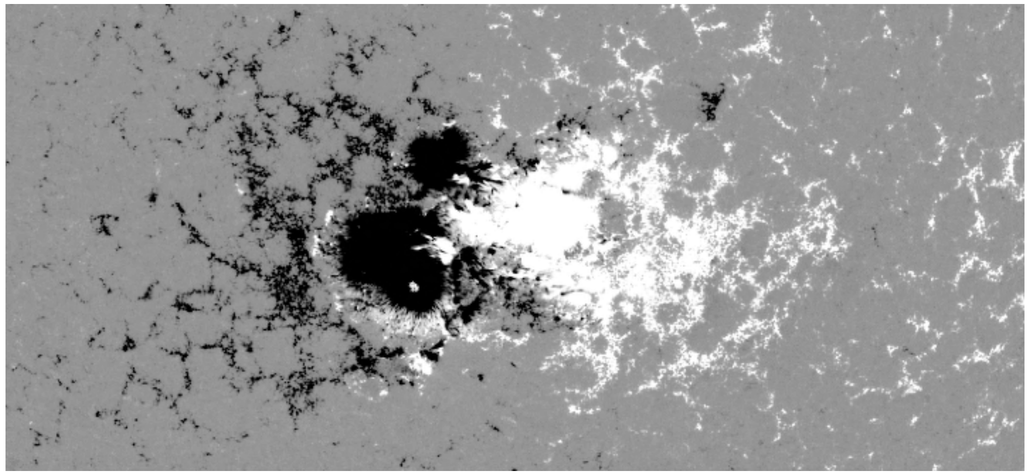
- Recap on study of QPPs in solar flares from a single long-lived active region
- How to deal with time derivative data
- Outline of sample of flares with significant QPPs
- Comparison with Inglis et al. 2016
- Checking for relationships between the QPP period and flare or active region properties

Recap: solar flare QPP study

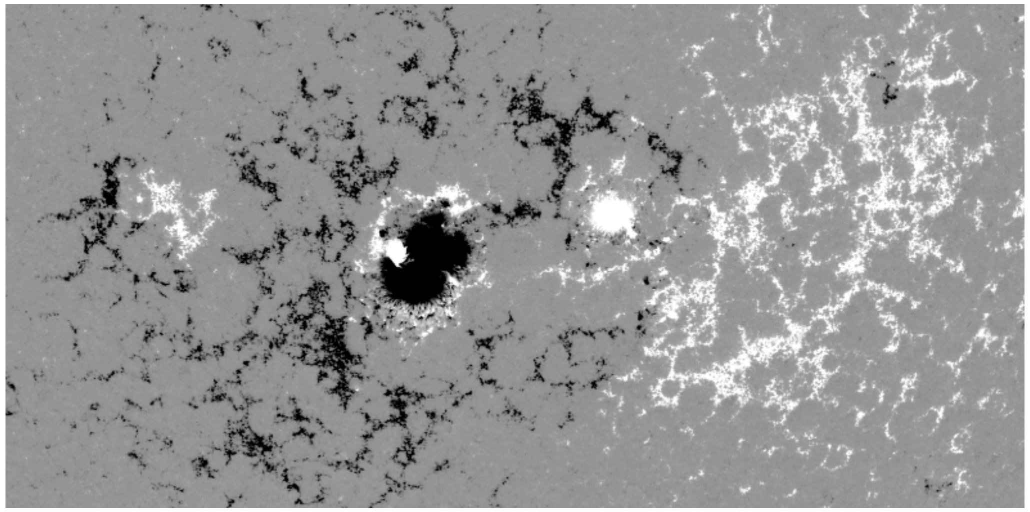
- 181 GOES class flares from a single (very) active region
- 137 C-class, 38 M-class, 6 X-class
- Observations from GOES, EVE, RHESSI, Fermi, Vernov, NoRH
- How many have QPPs?
- Do QPP properties relate to the evolution of the active region properties?



NOAA 12172, 12173, 12171



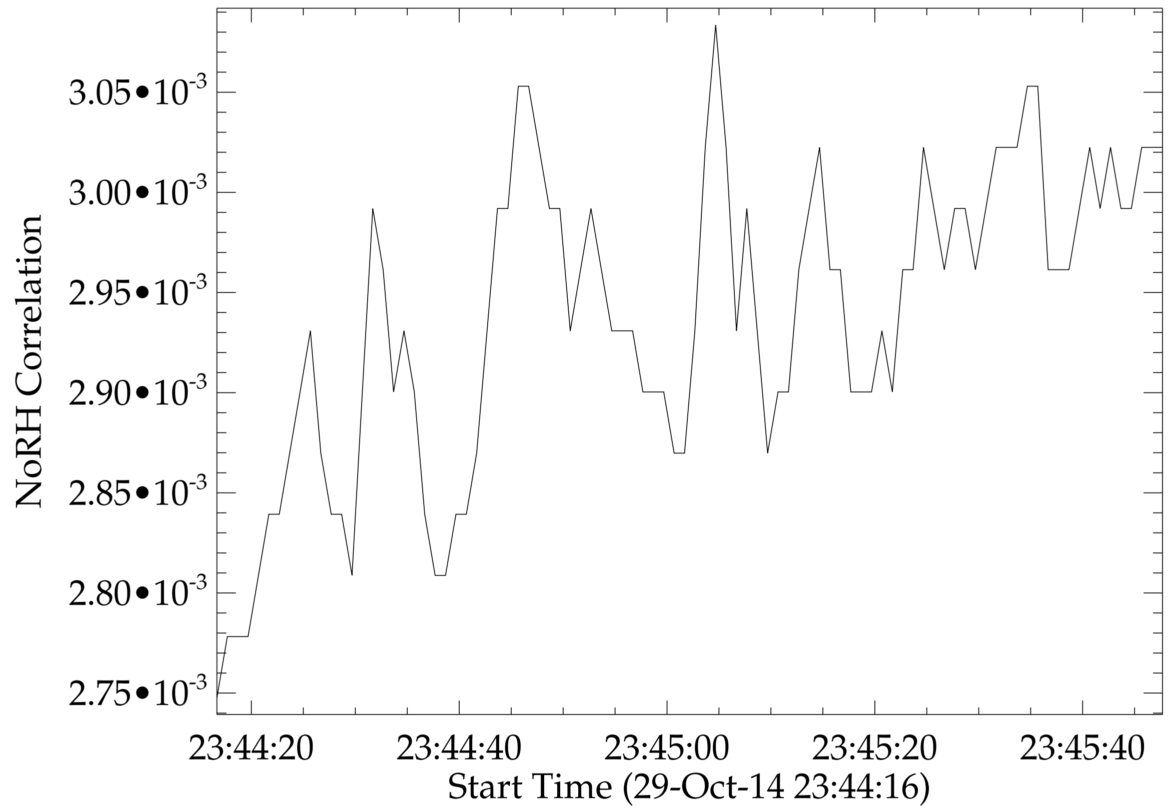
NOAA 12192

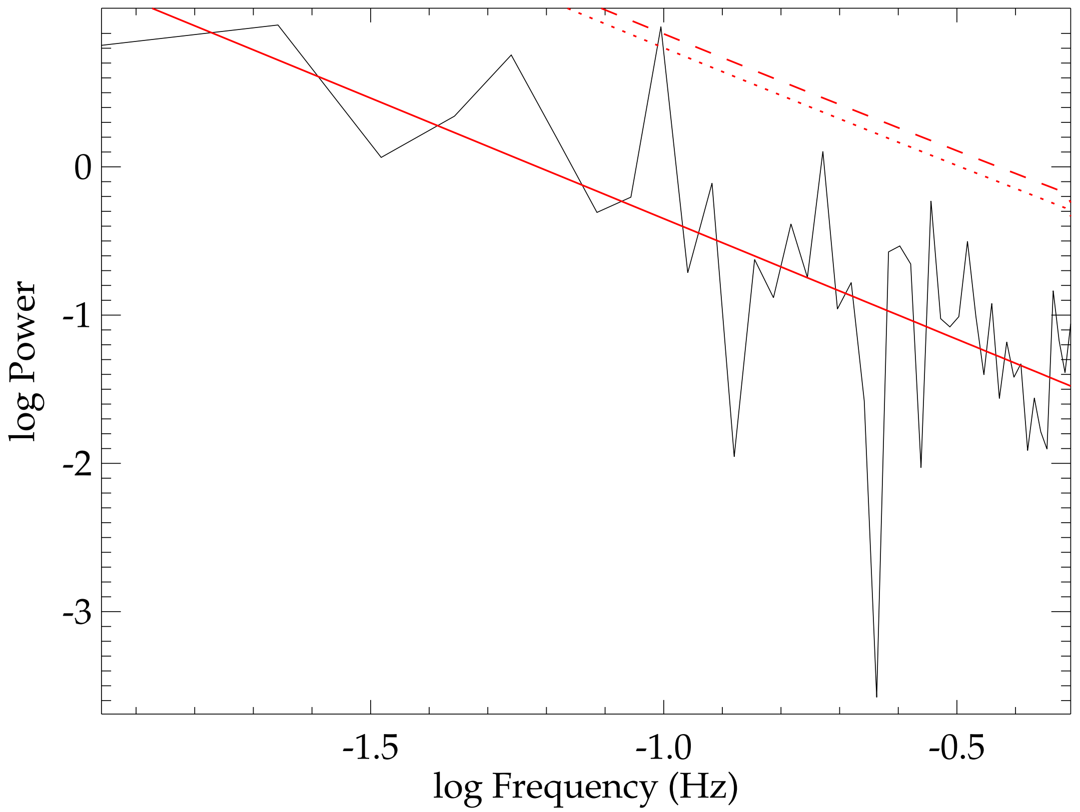


NOAA 12209

Recap: examples

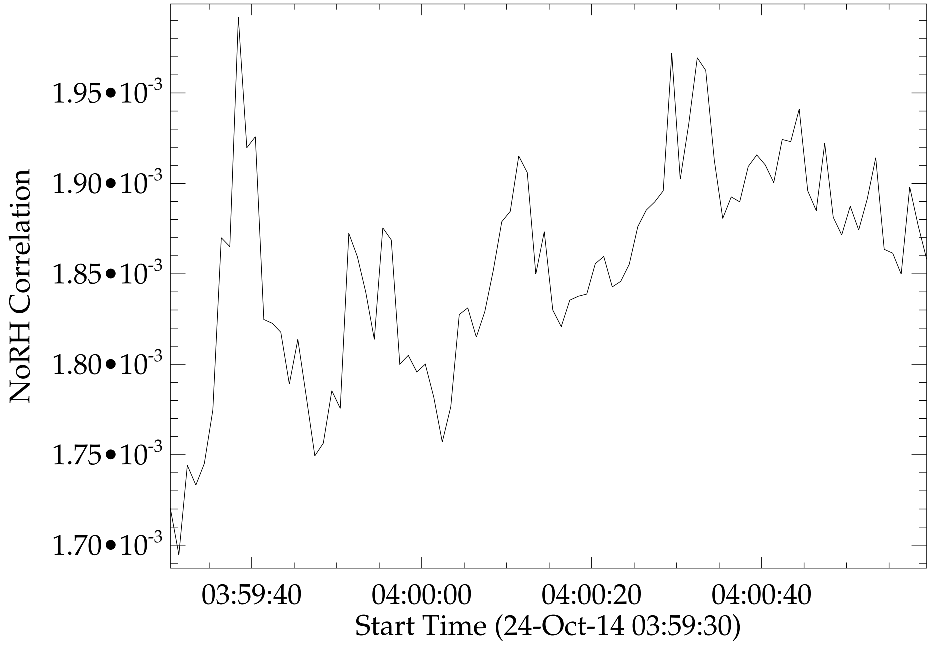
- Solar flare observed by Nobeyama Radioheliograph
- Power spectrum confidence levels calculated according to Pugh et al. 2017a/b
- *Left:* Correlation time series of part of a flare
- *Right:* Periodogram with a peak above 99% confidence level, at a period of ~10 seconds

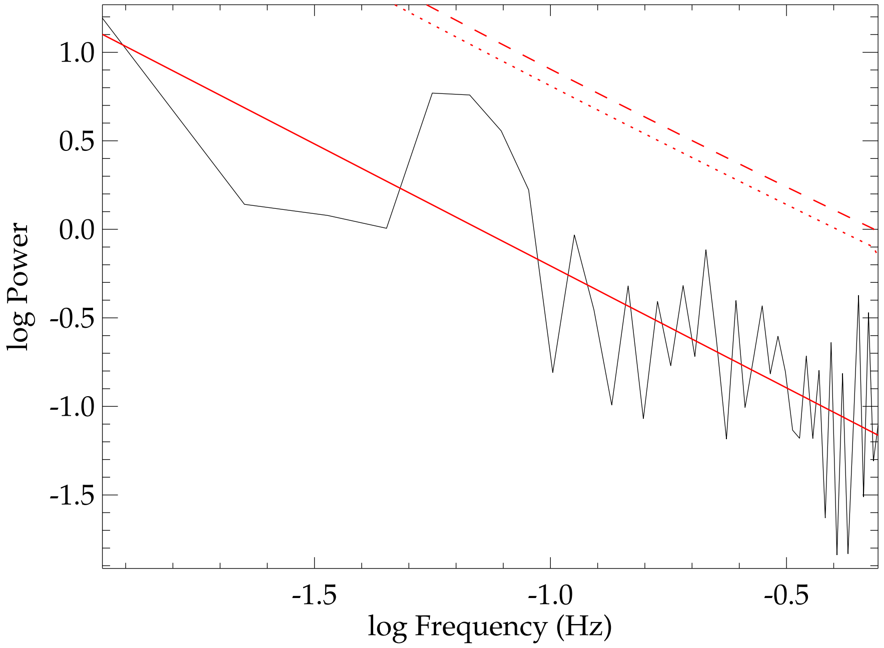


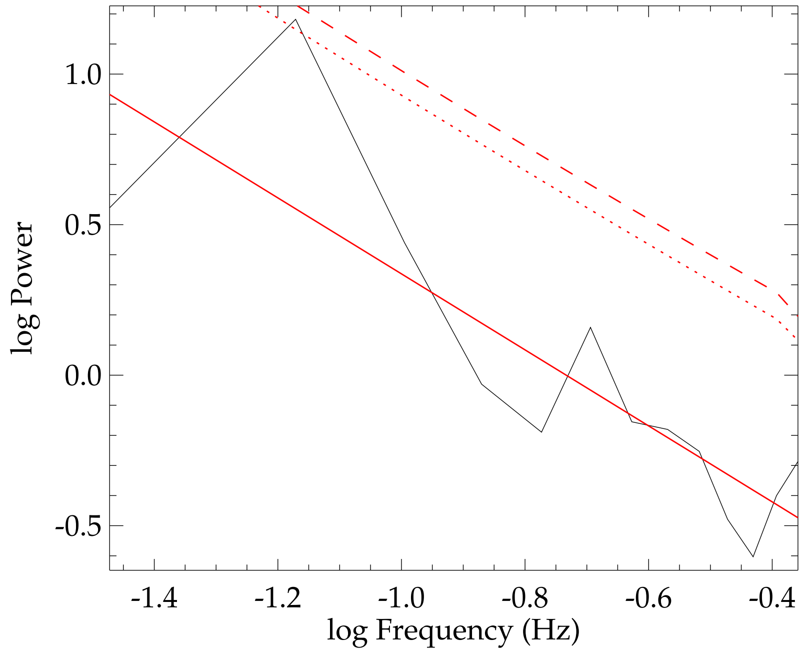


Recap: examples

- Solar flare observed by Nobeyama Radioheliograph
- Left: Correlation time series of part of the flare
- Middle: Periodogram with a broad peak below the 95% confidence level
- Right: Rebinned periodogram (with n=3), where the peak is now above the 95% confidence level, at a period of ~15 seconds



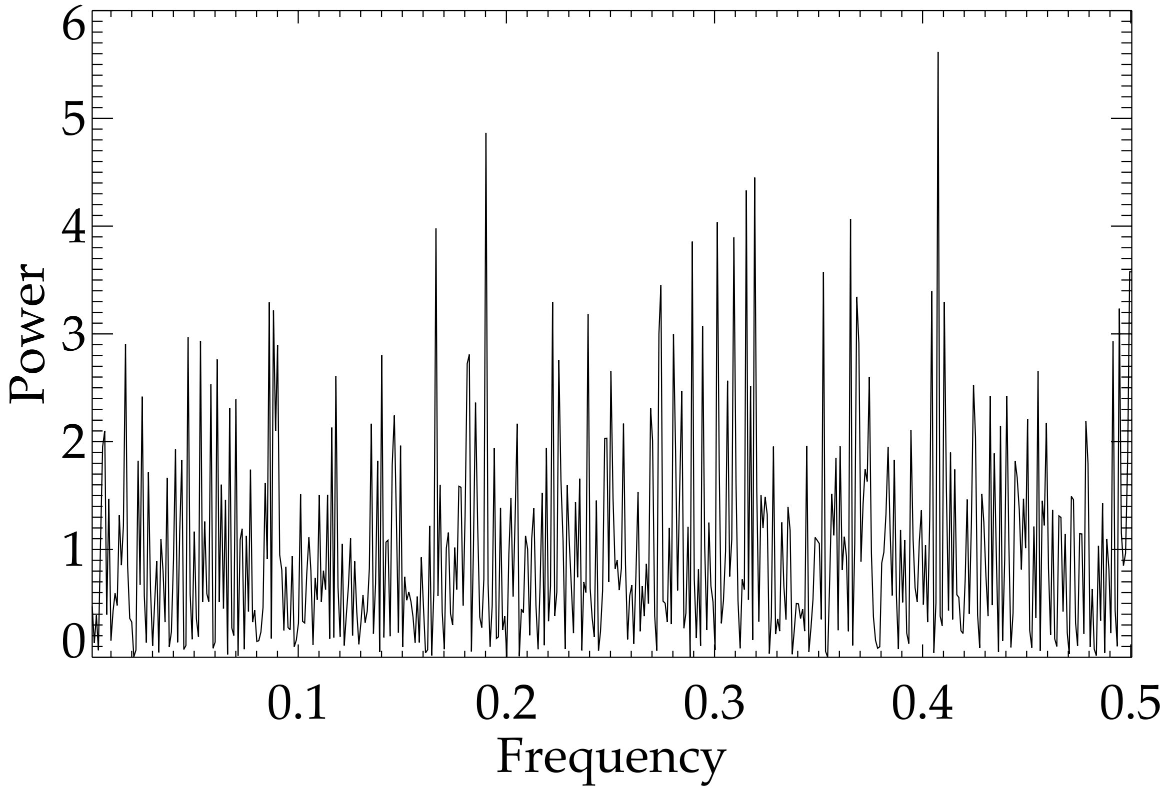




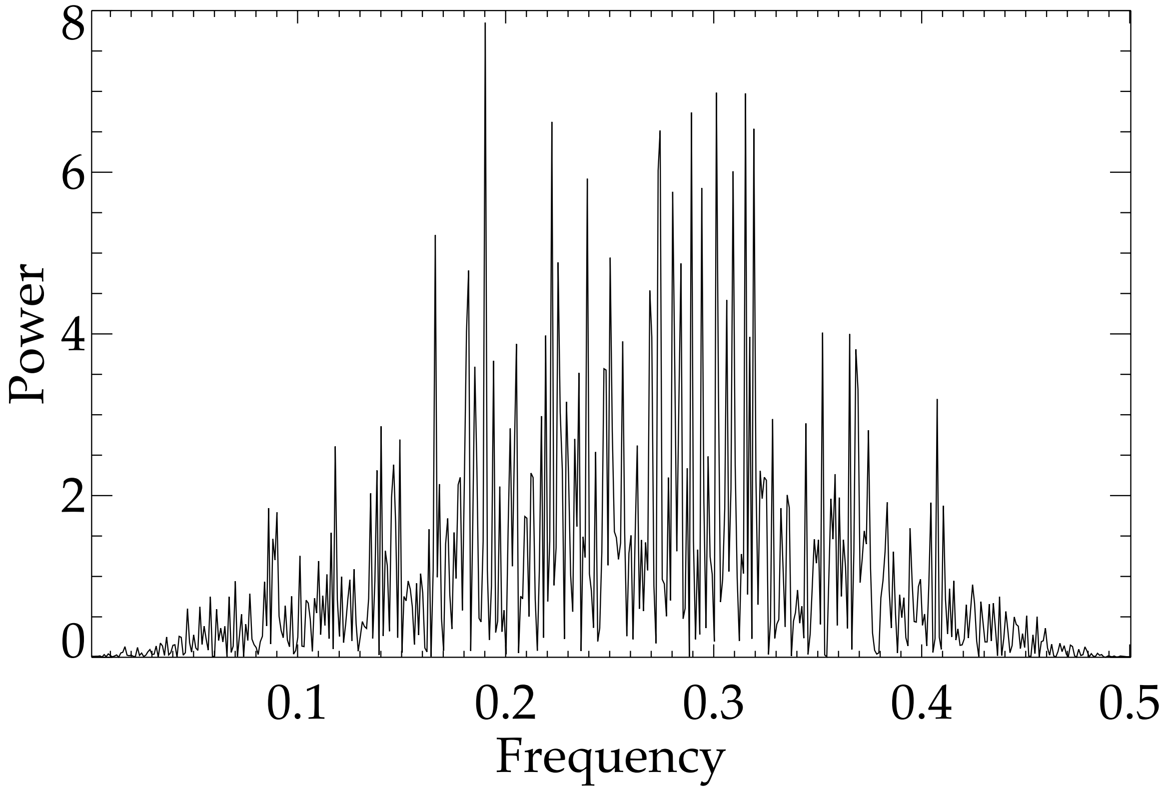
A note on time derivative data

- Fourier power spectrum of time derivative data look quite different to that of the regular data!

Power spectrum of white noise



Power spectrum of white noise derivative



- Discrete Fourier transform: $F_k(x) = \sum_{n=0}^{N-1} x_n \exp(-i\omega n)$

A note on time derivative data

- For a function *x(t)* that can be differentiated analytically:

$$F\left(\frac{dx(t)}{dt}\right) = i\omega F(x(t))$$

- So power spectrum would have an extra ω^2 term compared to non-differentiated function

- No analytical derivative for data with random noise, so use a numerical derivative. Typically a 3-point finite difference is used:

$$\dot{x}_n = \frac{x_{n+1} - x_{n-1}}{2h}$$

- Then the Fourier transform is (see Pugh et al. 2017b for derivation):

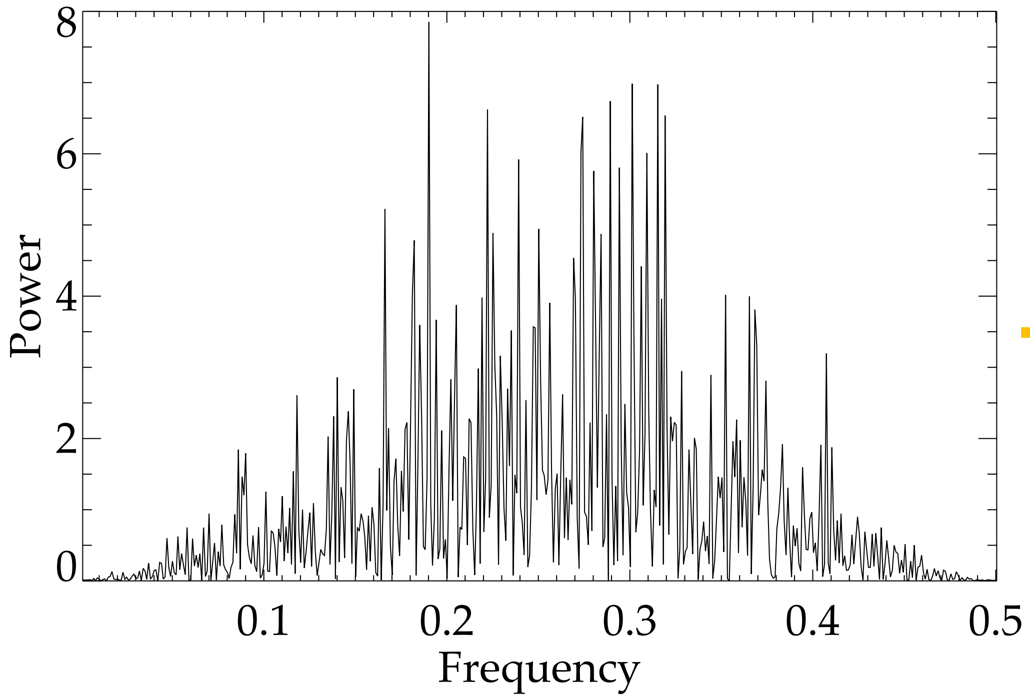
$$F(\dot{x}) = \frac{i}{h}\sin(\omega)F(x)$$

- Hence there is a $\sin^2\omega$ multiplying term for the power spectrum

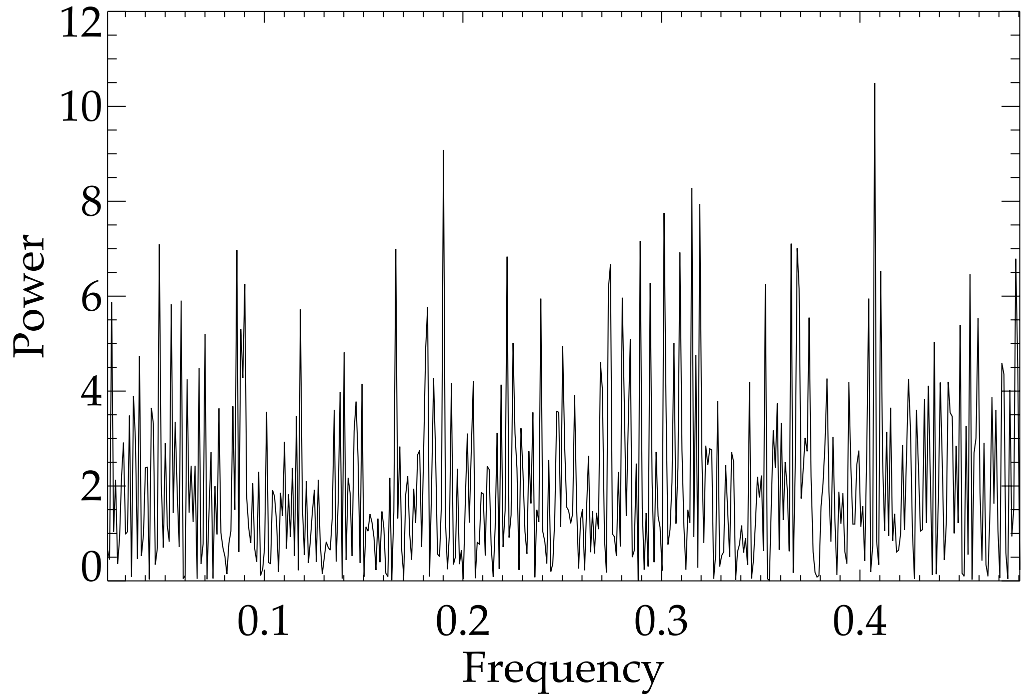
A note on time derivative data

- If the power spectrum is divided by the $\sin^2\omega$ multiplying term then confidence levels can be calculated as normal
- Slight problem: ω goes from 0 to π between the lowest and highest frequencies, so $\sin^2\omega \rightarrow 0$ towards the first and last points
- So remove first and last few points of the power spectrum before proceeding

Power spectrum of white noise derivative

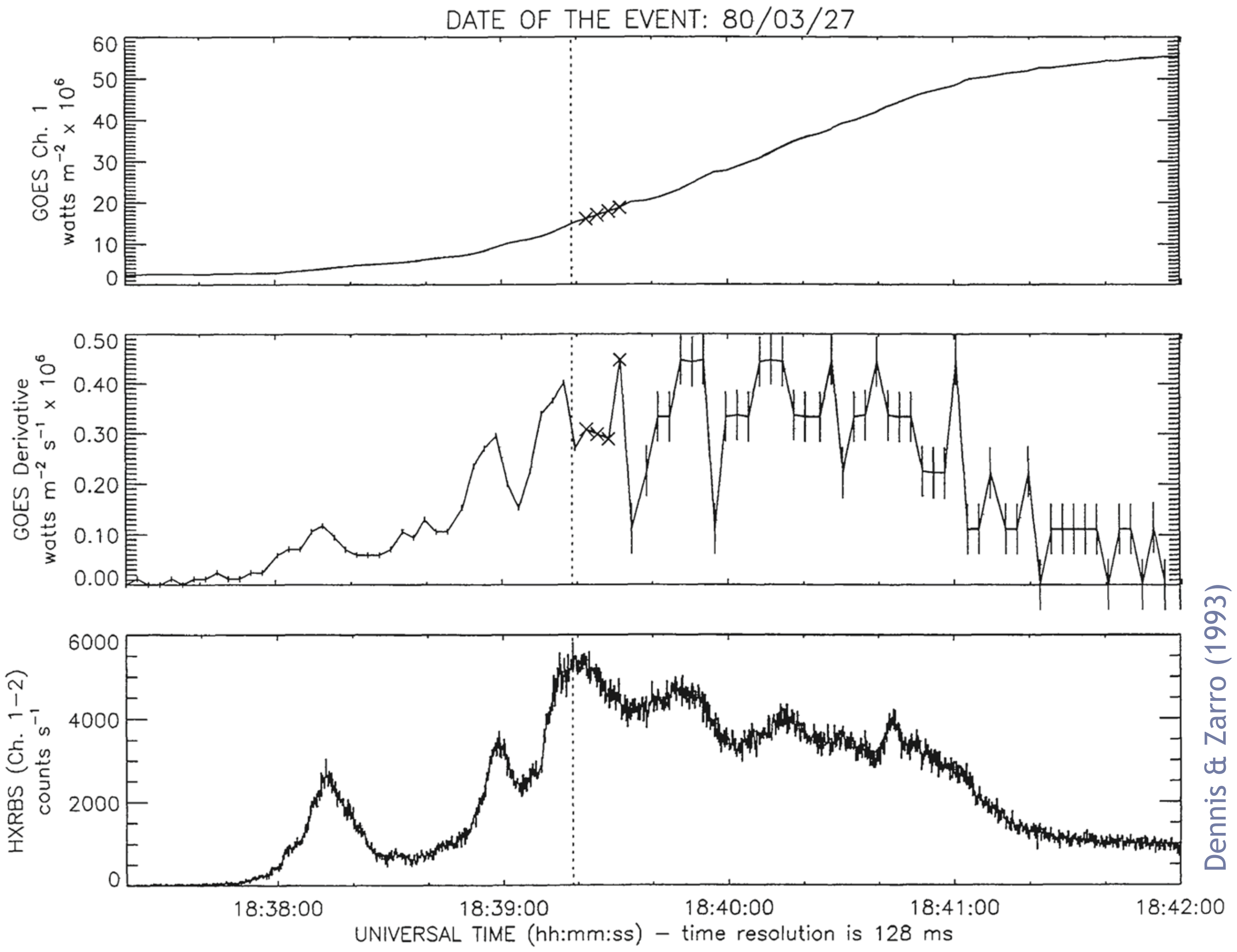


with the $\sin^2\omega$ term removed



A note on time derivative data

- Why bother?
- Neupert effect: flare SXR derivative strongly correlates with HXR/microwave emission, where QPPs tend to be seen well
- GOES provides near continuous SXR observations, with little noise and a suitable time cadence for QPPs

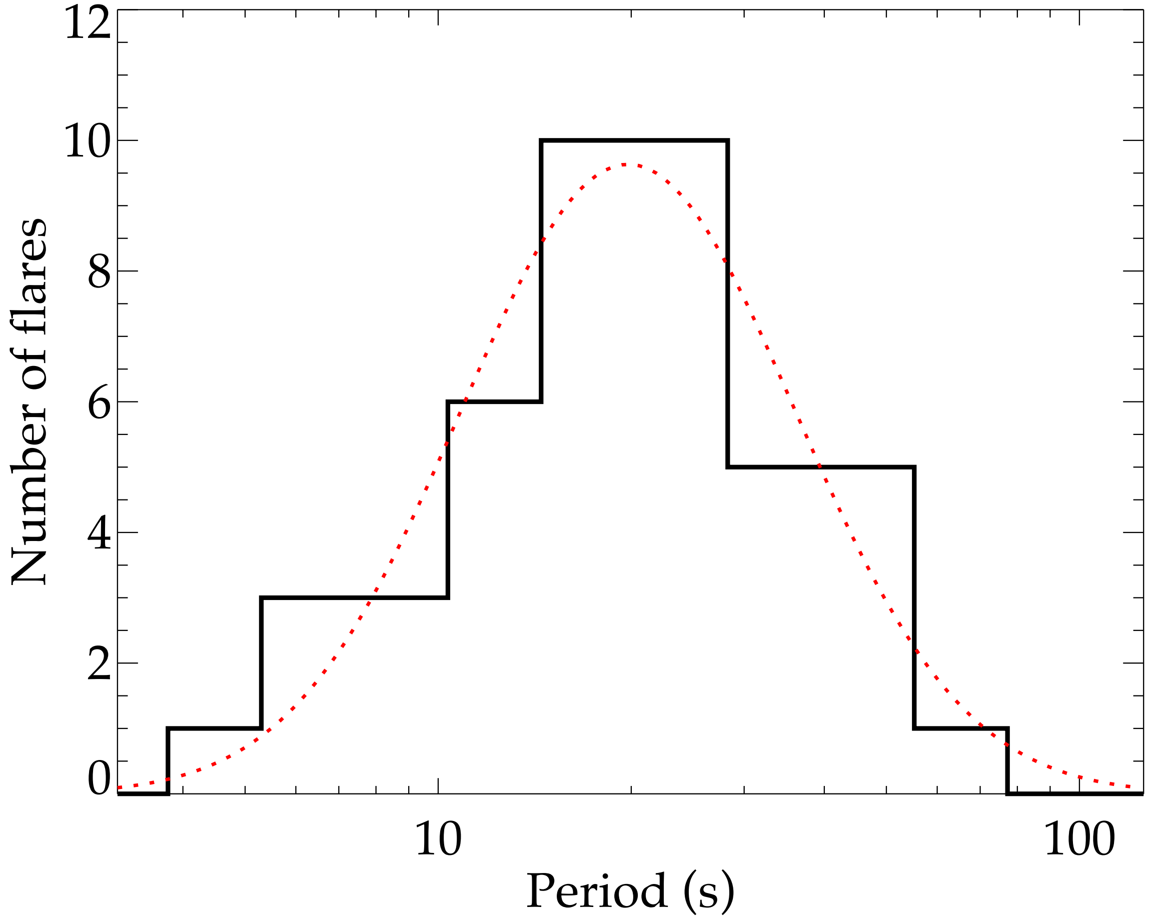


Dennis & Zarro (1993)

- Taking the derivative suppresses the approx linear rise of SXR flux in impulsive phase, in a non-subjective way

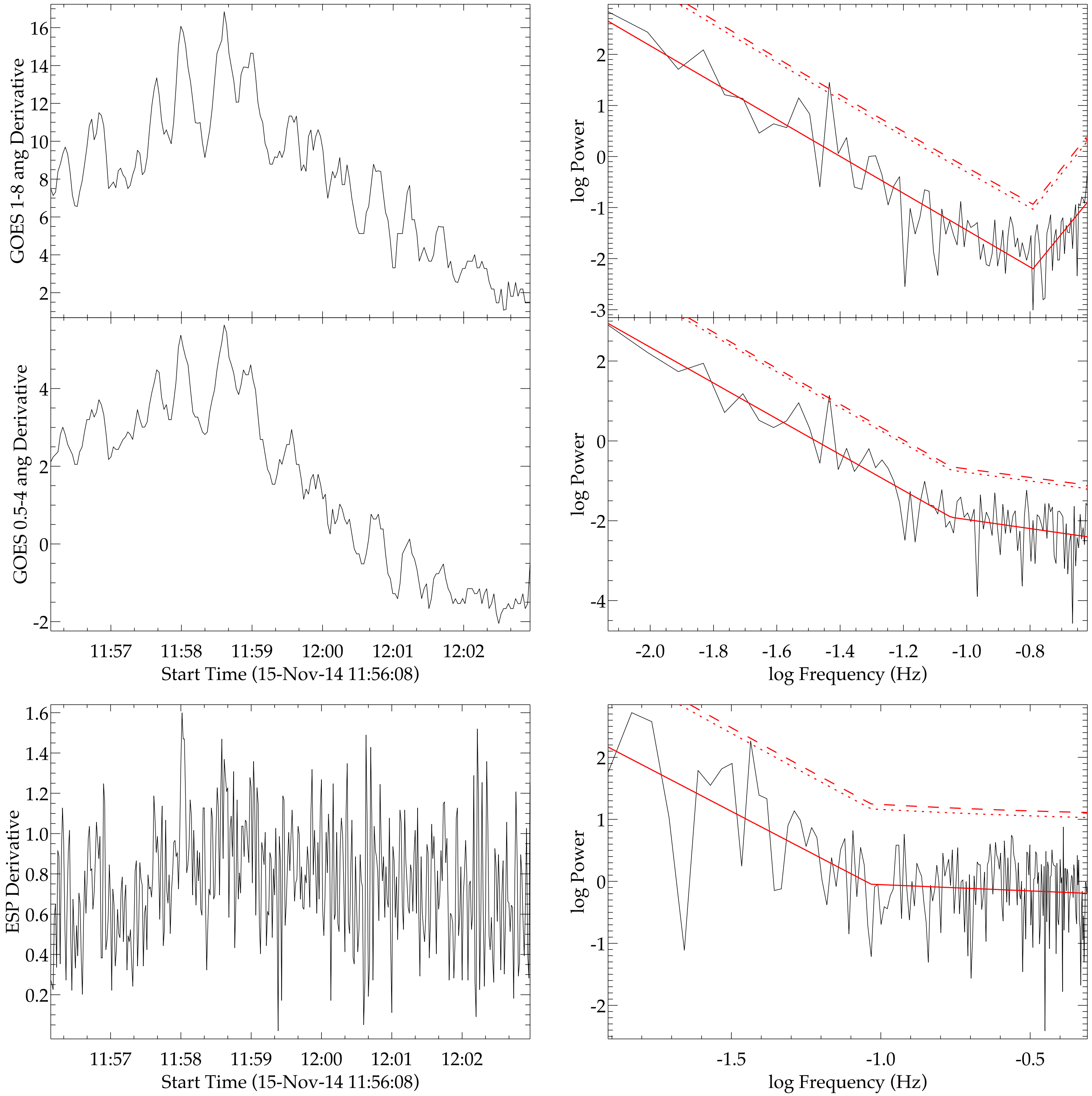
The set of flares with significant QPPs

- Out of 181 flares: 37 with periodic signal above 95% global confidence level (20% of sample)
- Right: histogram of periods, with mean period of 20^{+16}_{-9} seconds
- Pugh et al. 2017b



The set of flares with significant QPPs

- Seven of these flares have the same QPP signal detected above the 95% confidence level in data from two different instruments
- Right: 27 s period detected in both GOES/XRS and EVE/ESP light curves

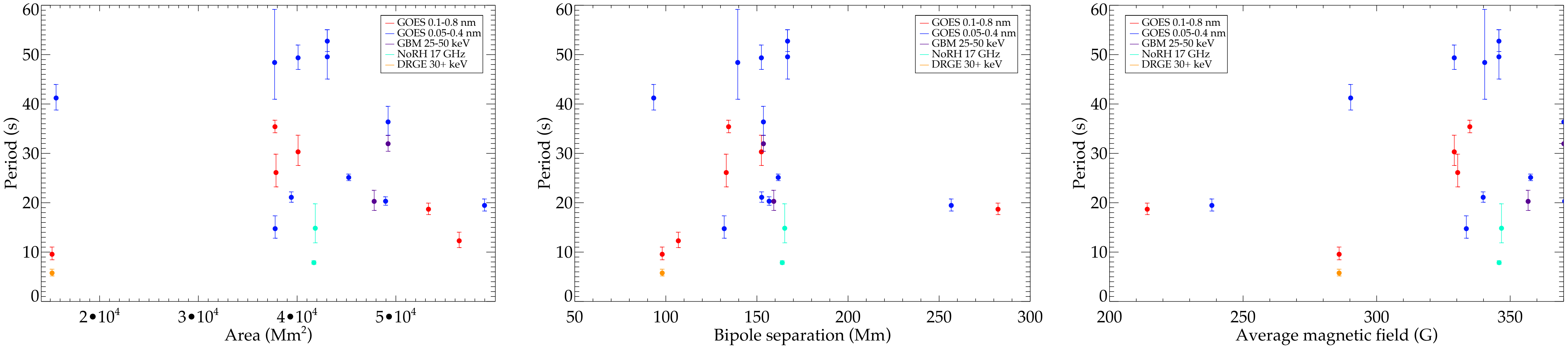


Comparison with Inglis et al. 2016

- Most results consistent with Inglis et al. 2016, who used a different method
- They find a significant peak in 30% of flare power spectra, compared to 20% in this study
- Similar log-normal distribution of the periods, but theirs peaks at around 12 s
- 44 flares included in both samples:
    - We find the same periods in 6 flares (13 if the selection criteria of Inglis et al. are relaxed)
    - Find no evidence of QPPs in 24 of the flares
    - We identify a different period in data from the same instrument for 1 flare, and from different instruments for 1 more flare
    - 3 flares where Inglis et al. identify a period and this study does not, and 2 flares for the opposite case

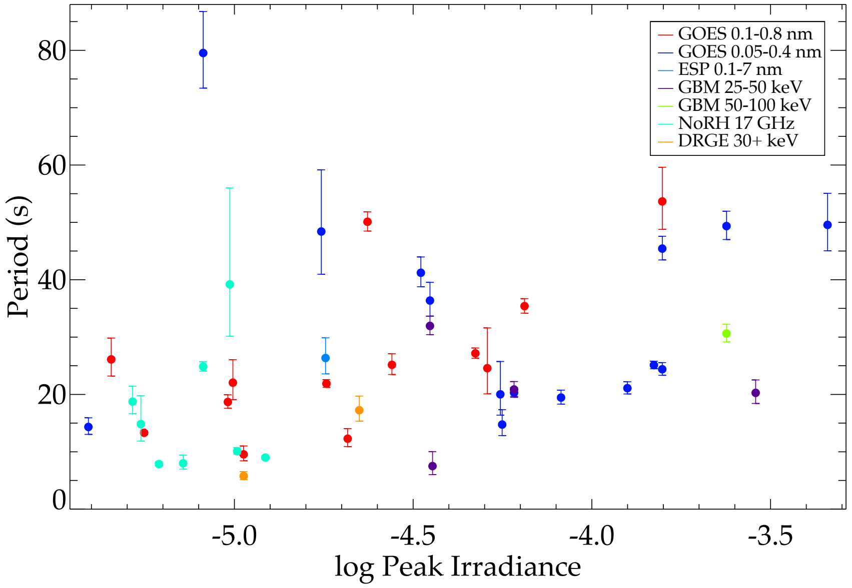
Relation to active region (AR) properties?

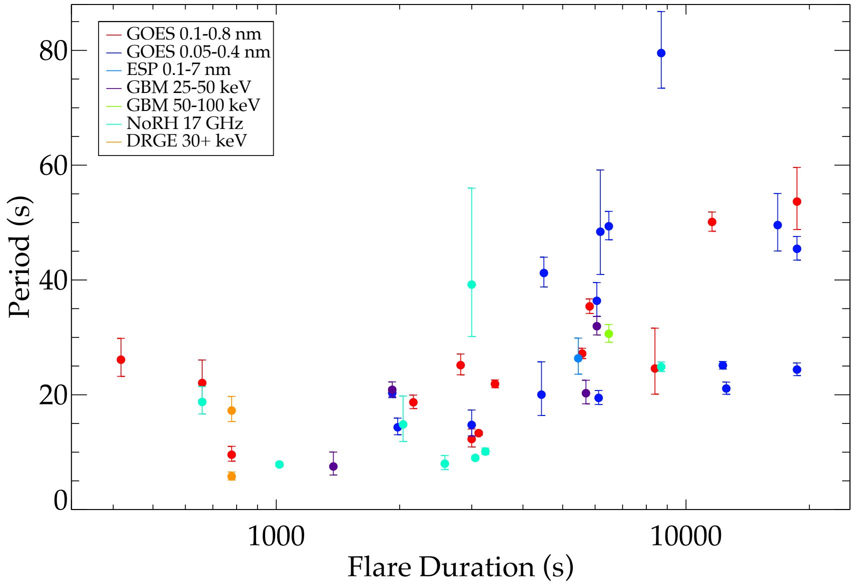
- AR properties as a function of time determined from SDO/HMI line-of-sight magnetograms (following similar method to Higgins et al. 2011, accounting for line-of-sight effects)
- No correlation between the QPP period and AR area *(left)*, bipole separation distance *(middle)*, or field strength *(right)*
- Probably because only part of the AR produces the flares!
- Next step: estimate size of flare sites from AIA, Hinode/XRT, RHESSI, etc data

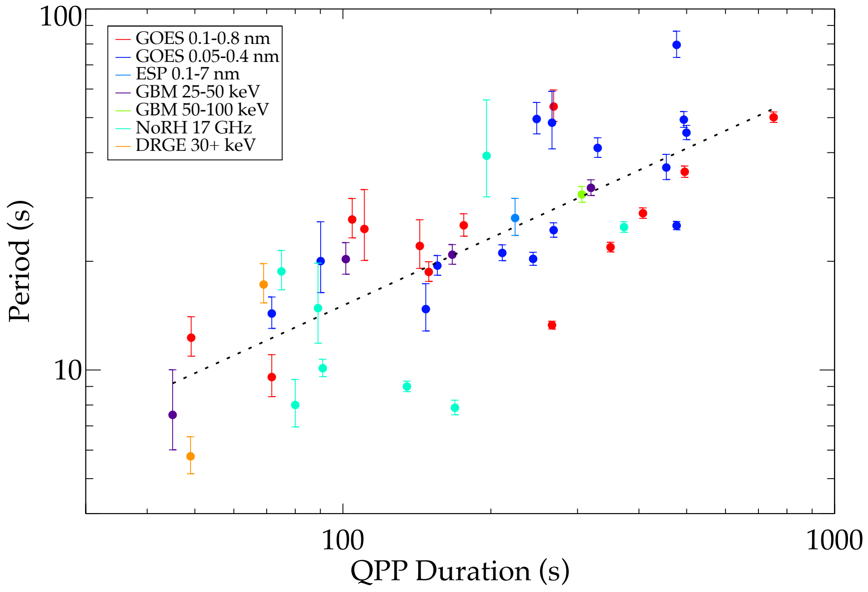


Relation to flare properties?

- QPP periods plotted against flare amplitude, flare duration, and the duration of the QPP signal
- Period vs flare duration correlation: observational bias?
- Period vs QPP signal duration: can’t detect long-period short-duration QPP signals, but should be able to detect short-period long-duration signals







Summary

- Adapted the method described by Vaughan 2005 to test for the presence of QPPs in flares, which accounts for data uncertainties and power-law power spectra, and avoids detrending
- Applied the method to a sample of solar flares from a single active region
- 20% of flares have a periodic signal above the 95% global confidence level in the power spectra
- No correlation of QPP periods with AR properties measured at the photosphere
- Need to try measuring sizes of flaring sites using spatially resolved X-ray/radio observations