Empirical mode decomposition and Coloured Noise Analysis on inttime har Data

Archishman

Abstract

Here we present a method to analyse the spectral modes present in an oscillatory solar time series data, using Empirical mode decomposition technique and subsequent Coloured noise analysis for successful detection of Quasi periodic oscillation.

Keywords : EMD, White and Coloured noise, Power Law fits, Confidence intervals

1. INTRODUCTION

We investigate the localisation of QPO in the IMFs obtained from Empirical mode decomposition. The IMFs obtained through the sifting process are generally orthonormal to a precise extent. The main oscillatory component of the signal is found to be contained in a single IMF for most non-stationary processes. Our challenge is to determine the mode containing the major oscillation using Random process analysis (2016 Kolotkov).

2. METHODOLOGY

The original signal is decomposed into many intrinsic mode functions IMFs where each IMF contains a narrow band oscillating component. The IMFs have a decreasing content of frequencies. With the first IMF-1 having the greatest frequency and the last IMF having the least.

Once we obtain the IMFs, we label them as; imf-i, where i denotes the i[th] IMF.

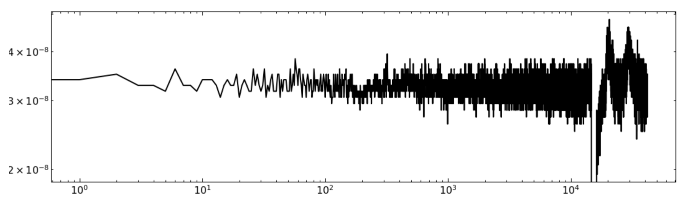

Fig 1: The original signal with uniform cadence.

After running a Masked EMD on the given signal, we obtain the IMFs

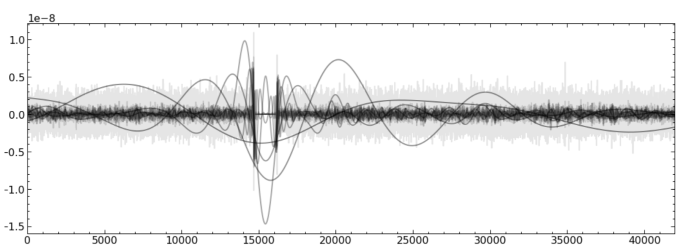

Fig 2: IMFs obtained after running through Masked IMF.

The original signal was of length 41969 samples, which was decomposed into 14 IMFs. Each imf is composed of a particular frequency range that defines the oscillations.

Below we have performed and computed the Fourier Power spectrum of each individual imf and the entire signal as shown.

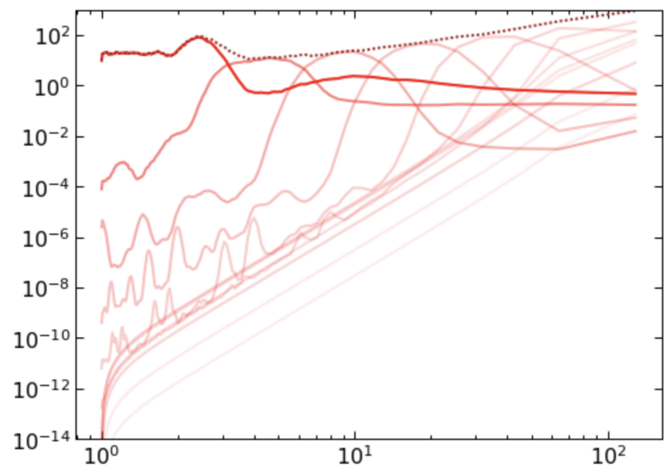

Fig 3 : Fourier spectrums of all the imfs (in red, with decreasing opacity) and the entire signal (in brown dotted lines)

Observe that the imfs till the 5[th] contain significant information regarding the QPP process in the solar atmosphere, however the 6[th] imf onwards we see that spectral density resembles a perfectly linear background noise process. And thus can be classified as a Random process.

Plotting the EMD Spectrum

The EMD spectrum is the Modal Energy of each IMF plotted against its Modal Period. The resulting plot is a set of points $(E_{m,i}, P_{m,i})$. We calculate modal energy and period of the i[th] imf in the following method :

$$E_{m,i} = \frac{1}{N}\sum_{k=1}^{N} imf^{2}_{i}(k) \quad ; \quad P_{m,i} = \frac{2N}{bm}$$

where b_m is the number of extrema in the IMF.

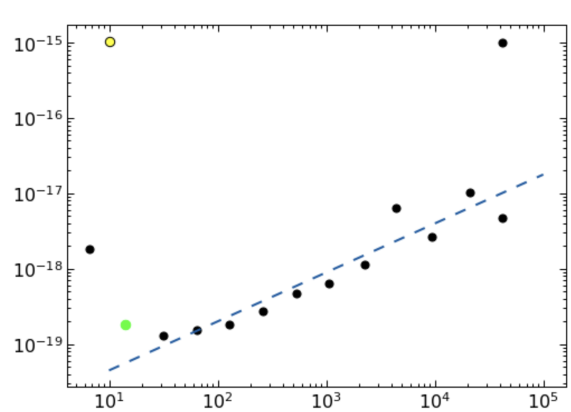

Fig 4: The blue dashed line denotes the least square fitting. IMFs that fall within 95% of the confidence levels are considered to be a part of the random processes. The green dot represents the second IMF that does not follow the coloured noise power law and is considered **Significant**. The yellow dot is the entire signal.

Now we further look in to the second imf and its frequency distribution

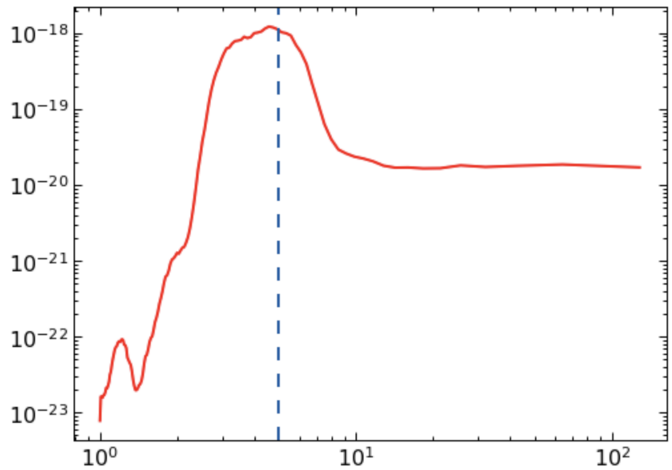

Fig 5: The IMF-2 has a clear peak at 5s period and then follows Pinkish (flicker) noise power law

3. RESULTS

The inttime_har data sets were analysed using the technique explained above. The results are compiled as follows:

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IMFs were obtained through Empirical Mode decomposition and the Modal Energy and Period were plotted as shown in Fig1.

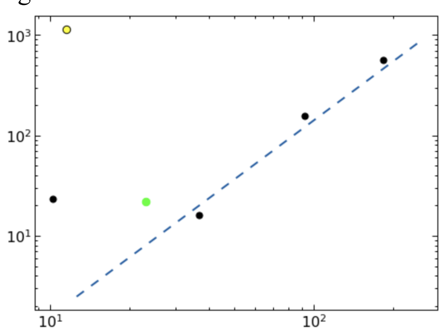

Fig 5 : E_m vs P_m Plot

The Fourier spectrums of each IMF has been plotted in a log-log scale to show their power densities and power law dependence.

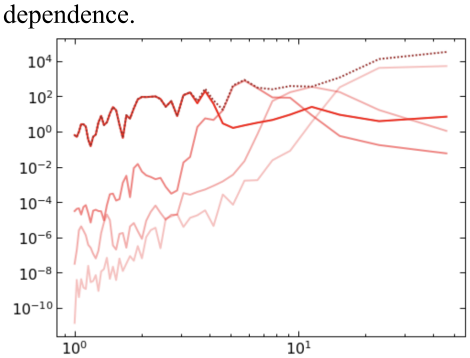

Fig 6 : Fourier spectrums of IMFs

From the EMD spectrum it is clear that the 2nd IMF contains the dominant oscillatory modes

Hence we further investigate the Fourier spectrum of the second IMF. Fig 3.

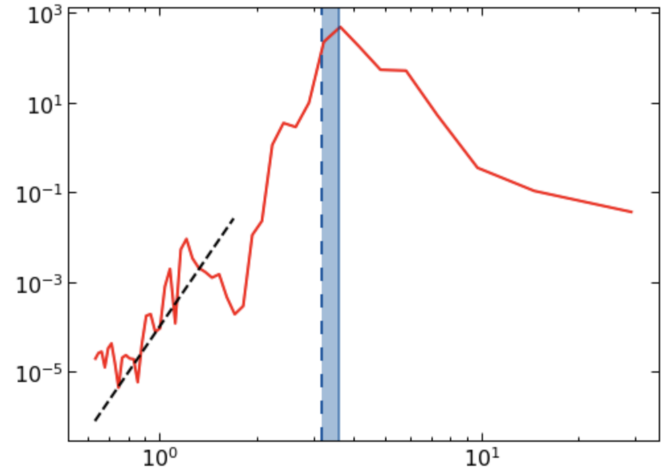

Fig 7. The peak of the spectrum occurs in the 3.2 - 3.6 min interval

Also, note that at the beginning, the Power Spectrum is partly random and follows a power-law like growth.

Thus the period of the signal can be estimated to be around **$3.4^{\mp.2}$** mins.

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IMFs were obtained through Empirical Mode decomposition and the Modal Energy and Period were plotted as shown in Fig 8.

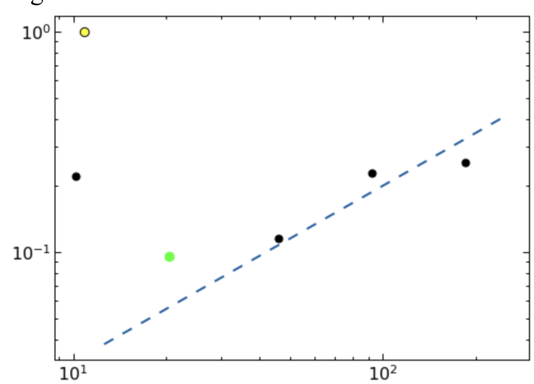

Fig 9. EMD Spectrum

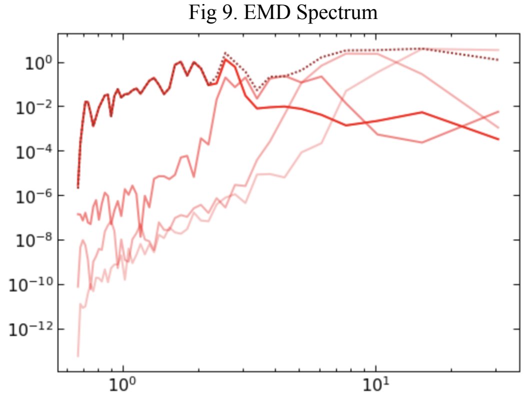

Fig 10. Fourier spectrum of the IMFs

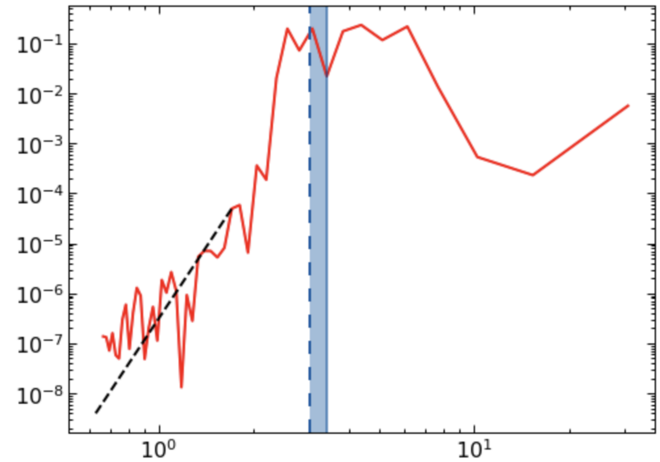

Fig 11. The blue region denotes the 3- 3.4 mins period range

Even, in this case, the period can be approximated to be around **$3.0^{\mp.2}$** mins.

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Clearly, the second IMF is considerably above the confidence level of the Background random noise, by power-law fit.

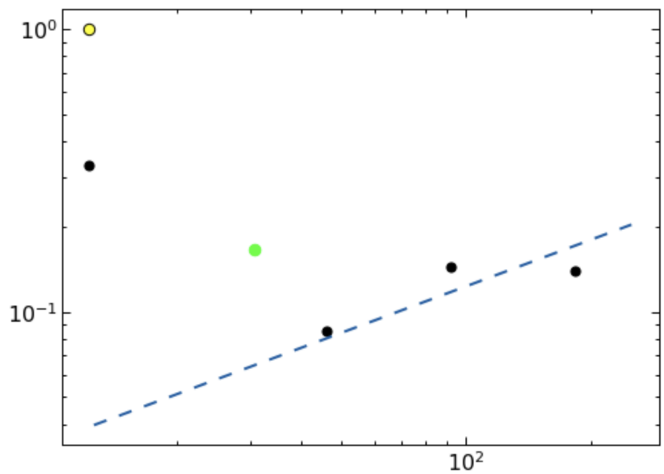

Fig 12. EMD Spectrum (blue dashed line denotes the least squares power law fit). The green dot represents the significant IMF and the yellow dot is the entire signal.

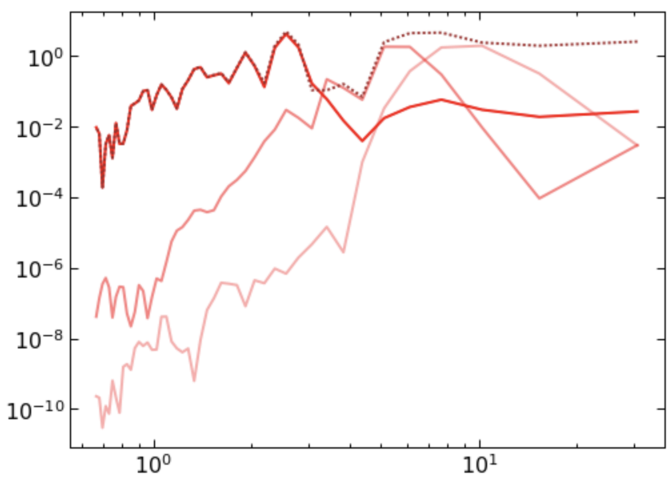

Fig 13. The brown dotted line represents the entire signal which follows the distribution of the second IMF at its peak, indicating mode mixing.

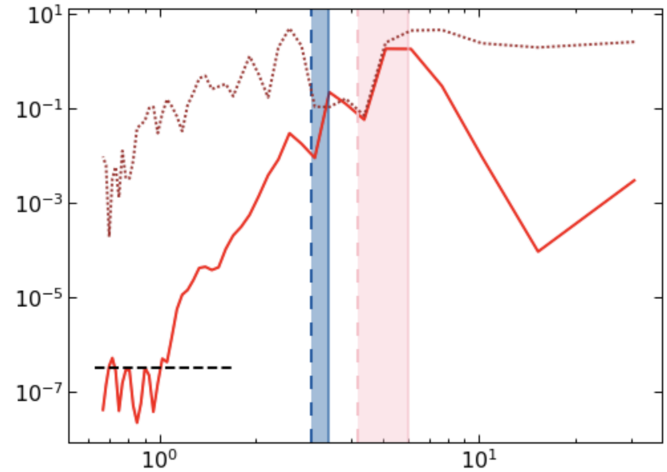

Fig 14. The pink region indicates frequency leakage between the IMFs leading to a greater dominant period. Whereas the blue region around the first peak is the true peak of the IMF-2.

Mode Leakage

Due to the process of EMD calculation depending on the signal extrema, there is influence of the signal extrema on the EMD decomposition as well as from the relation between signal amplitude and frequency variation.

We can conclude the major oscillation in IMF 2 to be **$3.2^{\mp.2}$** mins.

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Due to extremely low samples of data (92), 4 or fewer IMFs were generated as a result of which the noise or random process trend is hard to guess.

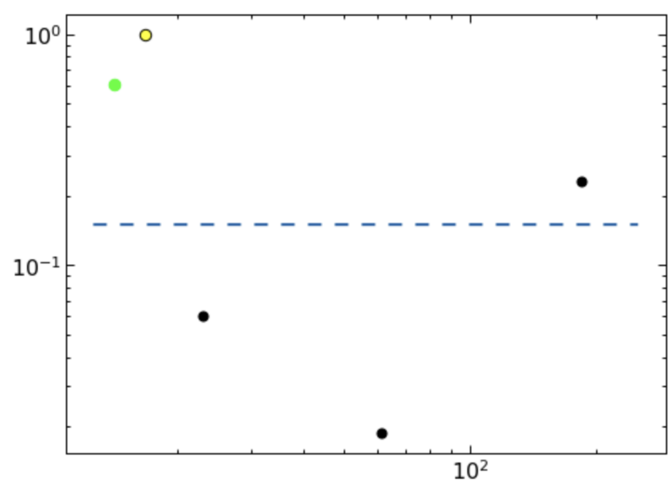

Fig 15. Clear distinction of significant QPO cannot be done

For practical purposes, we take it to be the first IMF.

However, from observing the fourier spectrums, we can observe that there is significant mode mixing between the first and second IMF which result in an increased period of the second IMF.

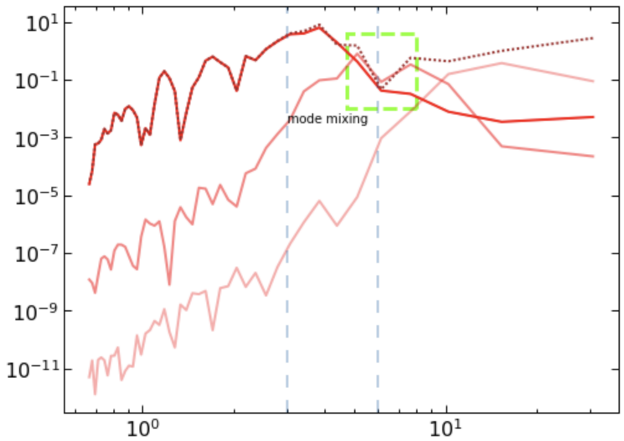

Fig 16. Fourier spectrums of the IMFs. (The green box denotes a region of mode leakage).

Since, the frequencies are distributed over the IMFs and localisation is not very strong, we employ advanced methods to find the dominant period.
First we detrend the assumed dominant IMF with a noise-like IMF (imf 4) to get a denoised spectrum.**
Here, we fit a least squares and gaussian fit to the spectrums to obtain the major period

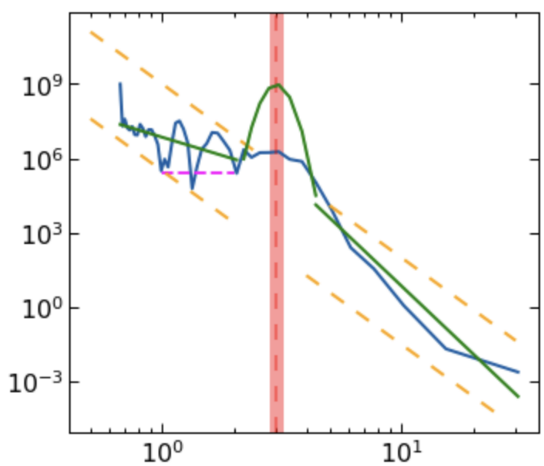

Fig 17. Power spectrum of IMF-1. Green lines denote the best fit, blue line is the spectral density of IMF-1. Orange boundaries represent the overall general trend.

Major period is **$3.0^{\mp.2}$** mins.

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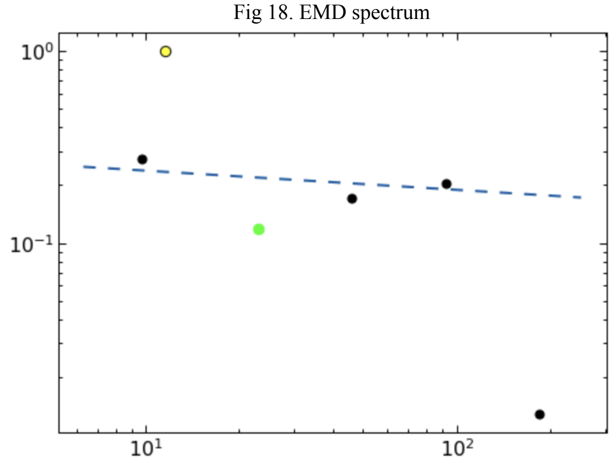
Fig 18. EMD spectrum



Similarly, here also clear distinction of significant IMF cannot be done. If we assume to take IMF-2 as dominant we get the following results.

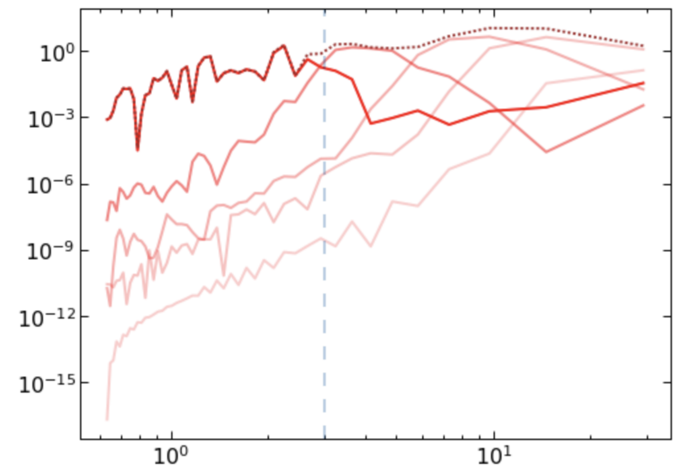


Fig 19. Fourier Spectrums of the IMFs

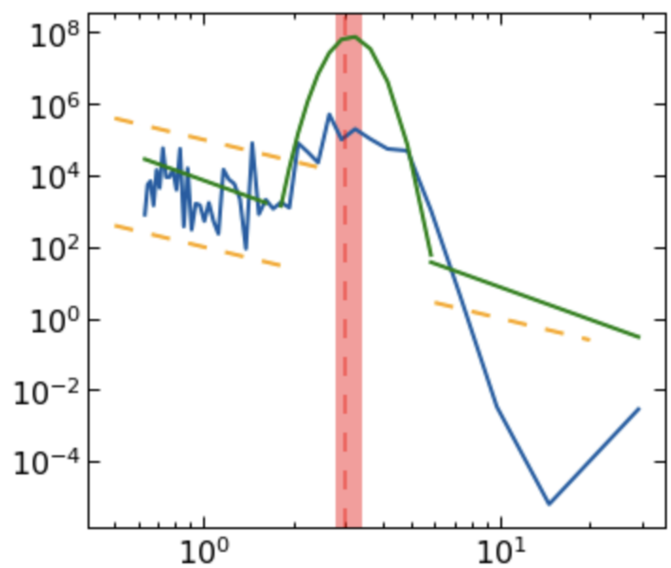


Fig 20. Refer Fig 18. Power spectrum of IMF-2. The peak of the gaussian fit coincides well with the 3 min period.

Clearly, from the fitting it's evident that major period is **$3.0^{\mp.2}$** mins

The Gaussian fit really behaves well in the above plot. It approximates the Major oscillatory component with a distinct peak above the noise levels.

Also, the orange borders are well defined for the random processes and provide a strong linear relationship.

** Denoising is done for better spectral clarity and precision

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Here we have very clear distinctions between the significant IMF and background Random process.

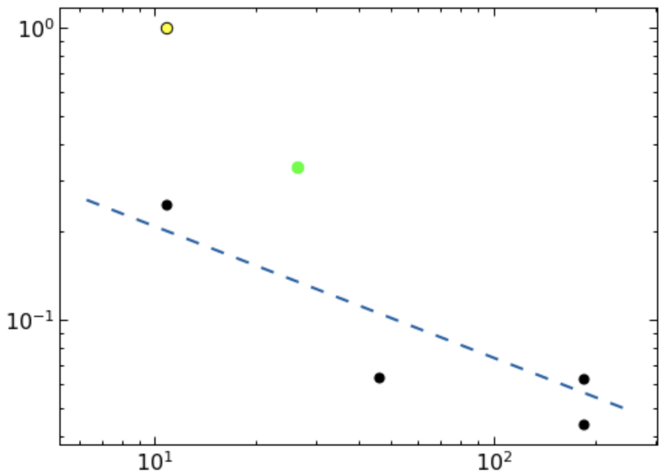

Fig 21. Emd spectrum

Observe that the second IMF-2, is the dominant oscillatory process in the entire signal. Thus the QPO must be localised within the IMF2

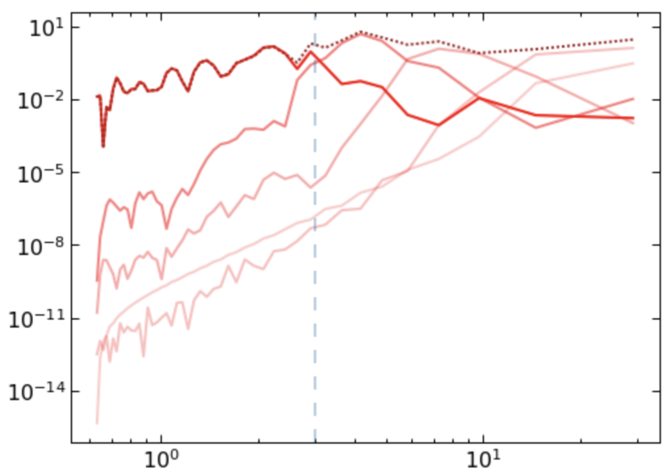

Fig 22. Fourier spectrums of all IMFs

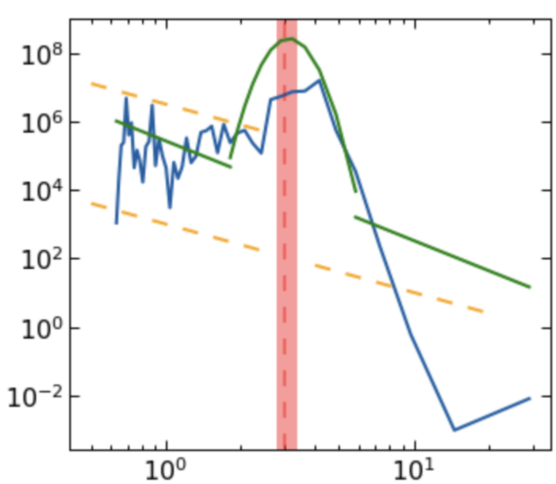

Fig 23. Power spectrum of noise detrended IMF 2

The major period clearly is in the range **$3.2^{\mp.2}$** mins.

References

Novel Data Analysis techniques in Coronal Seismology https://arxiv.org/abs/2112.13577;
2020 Murphy et al https://doi.org/10.1029/2020JA027887;
1998 Huang et al https://www.doi.org/10.21105/joss.02977;
1998 Huang et al https://www.doi.org/10.21105/joss.02977

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