Characterizing the Intermittency of the 4 Hz Quasi-periodic Oscillation in XTE J1550-564 via Hilbert-Huang Transform

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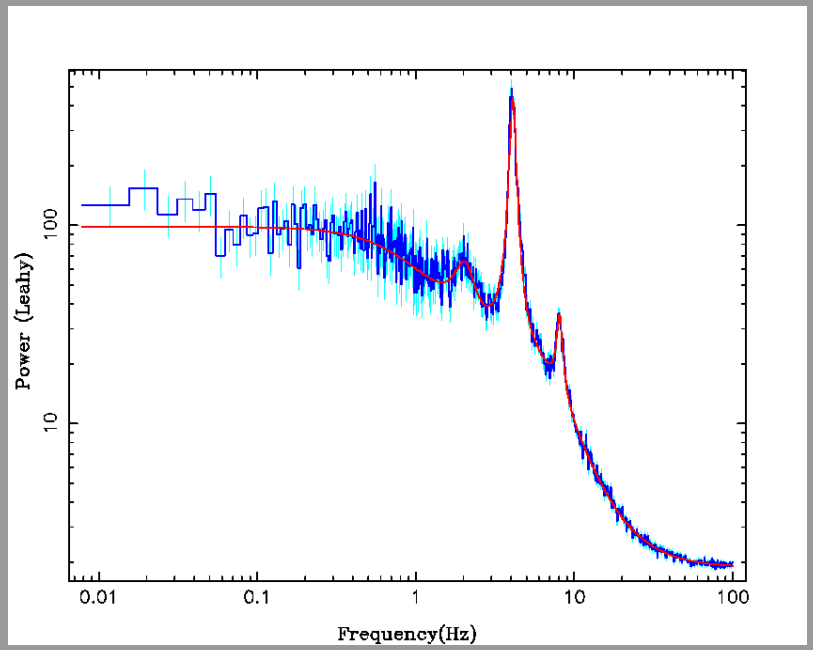
February 10, 2015

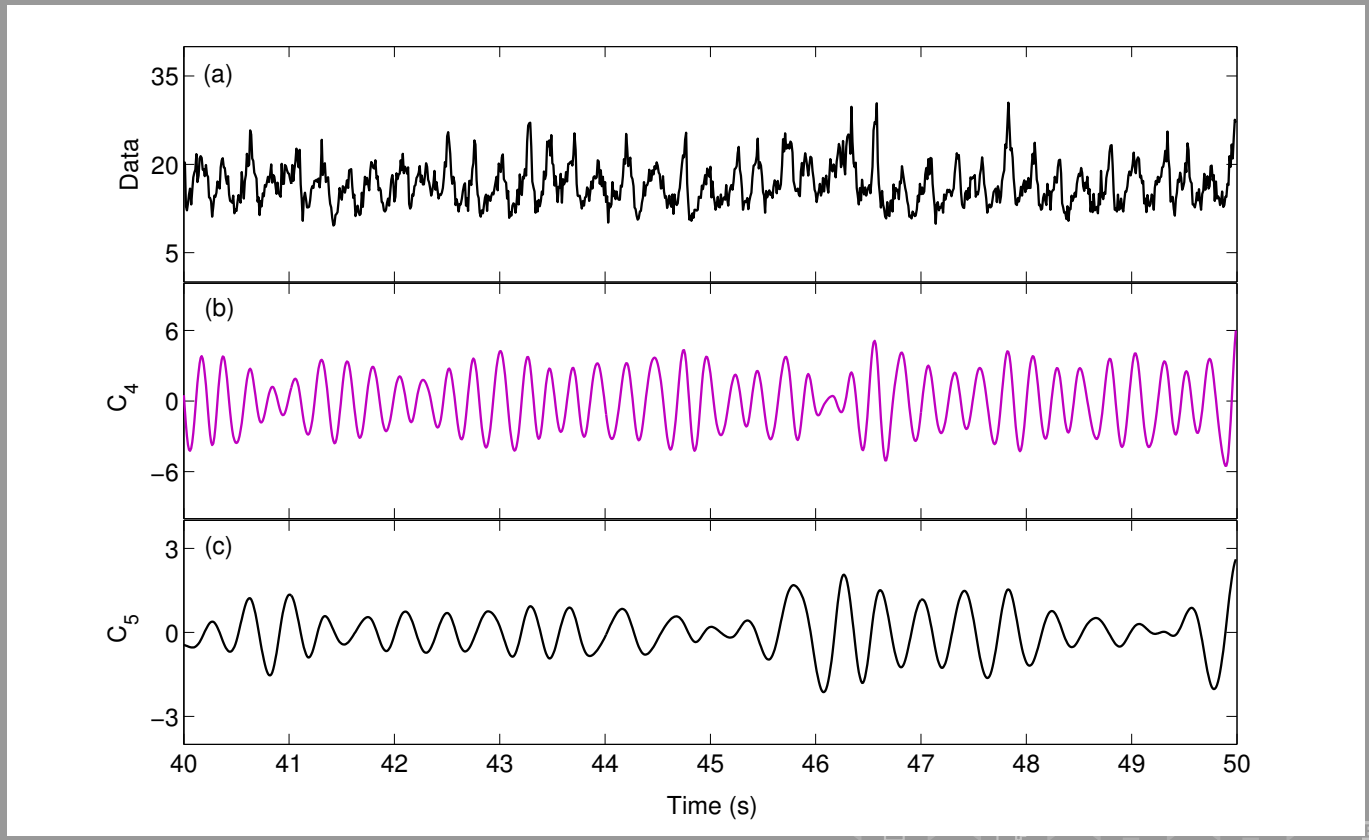
Quasi-periodic Oscillation (QPO)

- Broad peak
- Non-stationary period
- A strong power, 4 Hz QPO in XTE J1550-564 (Remillard et al. 2002)



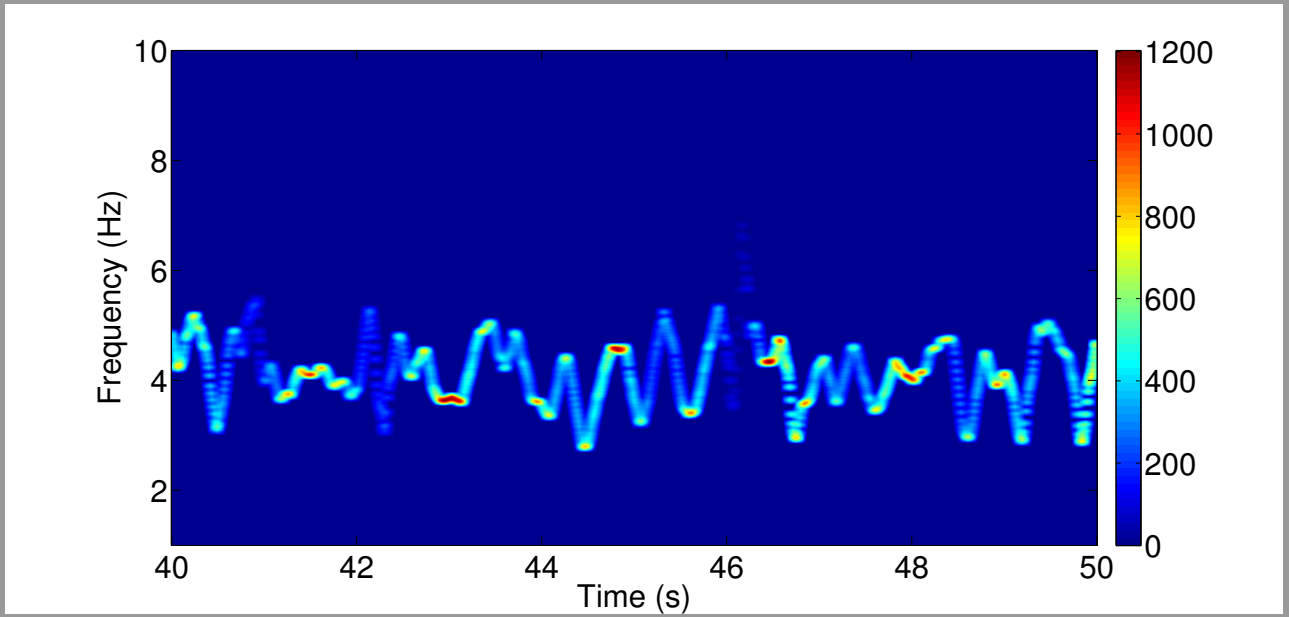
First Step of Hilbert-Huang Transform (HHT)

- Huang et al. (1998)
- Non-stationary and non-linear time series
- First step of HHT: Empirical mode decomposition (EMD)
- Intrinsic mode functions (IMFs)

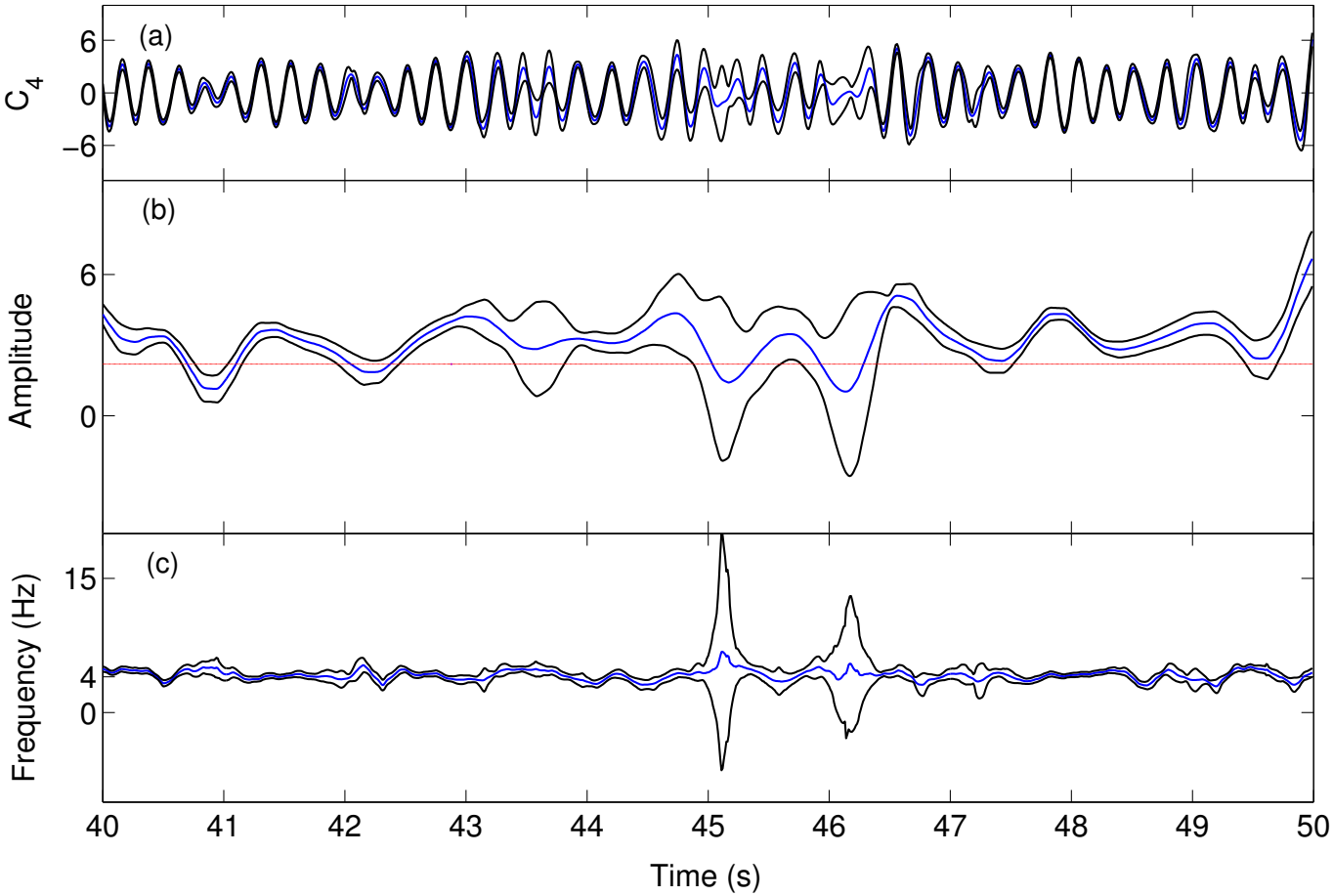


Second Step of Hilbert-Huang Transform (HHT)

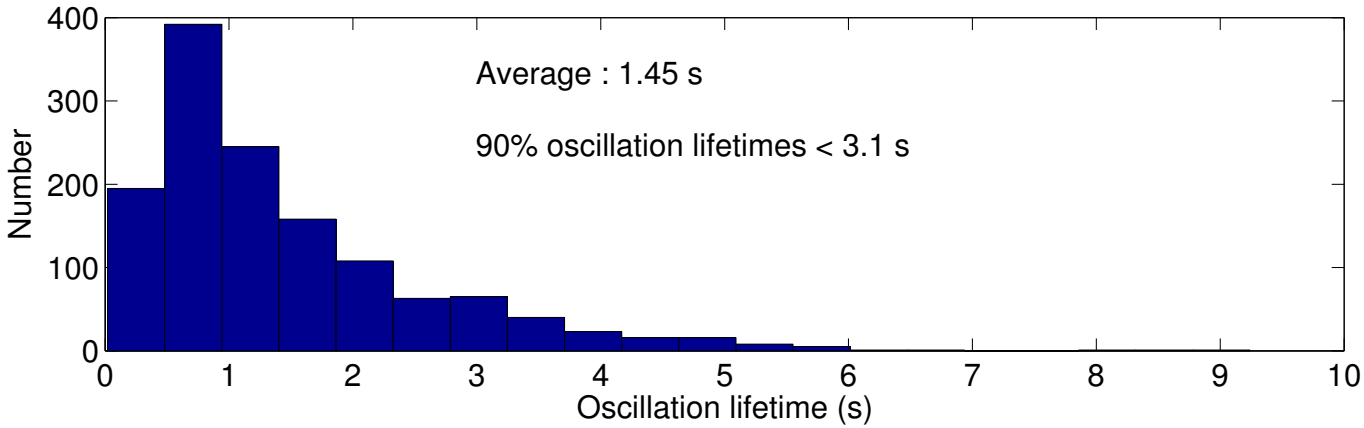
- $Y_4(t) = \frac{1}{\pi} P \int_{-\infty}^{\infty} \frac{X_4(t')}{t-t'} dt' \leftarrow$ Hilbert transform
- $X_4(t) + iY_4(t) = a_4(t) e^{i\theta_4(t)} \leftarrow$ Instantaneous amplitude
- $f_4(t) = \frac{1}{2\pi} \frac{d\theta_4(t)}{dt} \leftarrow$ Instantaneous frequency

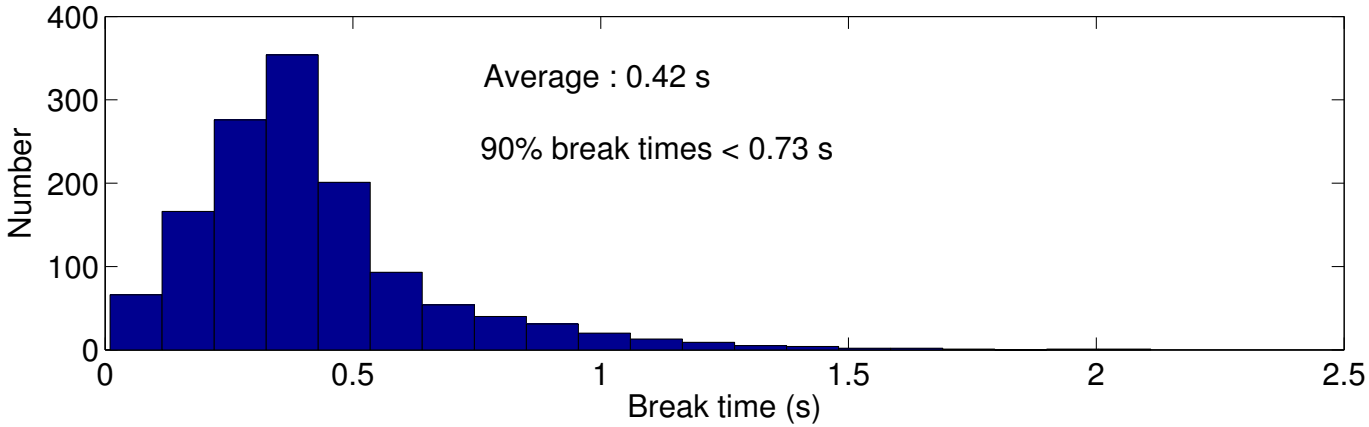


Confidence Limits



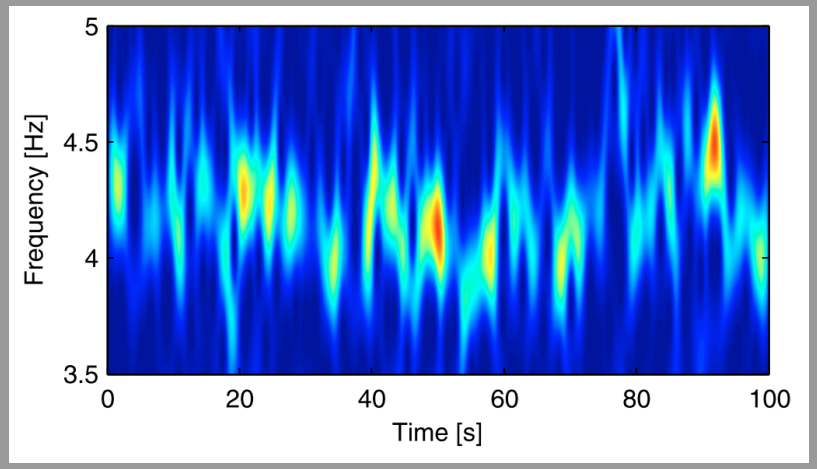
Lifetimes


Average : 1.45 s
90% oscillation lifetimes < 3.1 s
Number
Oscillation lifetime (s)
0
100
200
300
400
0
1
2
3
4
5
6
7
8
9
10


Average : 0.42 s
90% break times < 0.73 s
Number
Break time (s)
0
100
200
300
400
0
0.5
1
1.5
2
2.5

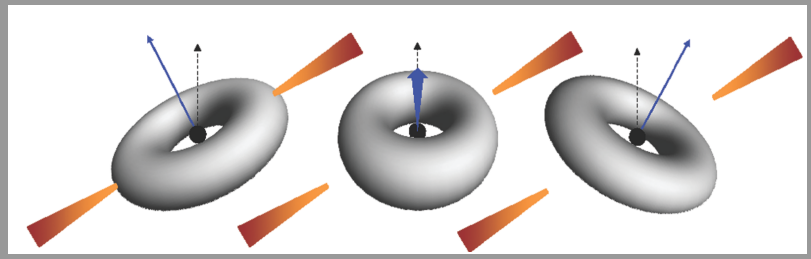
Contributions of Our Research

Wavelet analysis



(Lachowicz & Done 2010)

Lense-Thirring precession



(Ingram & Done 2009)

Summary

Method

We employed HHT to study the detailed time-frequency variation of the 4 Hz QPO in XTE J1550-564.

Result

We have demonstrated that the ~ 4 Hz peak is broadened by a series of intermittent, frequency-changing oscillations with lifetime of a few seconds.

Contributions

Our results are significantly improve the time-frequency resolution for tracking the evolution of the 4 Hz QPO.

Our findings not only consistent with previous research but also fit nicely into the Lense-Thirring precession QPO model.

Future Works

Main project

Extend this work to the remain QPOs in XTE J1550-564

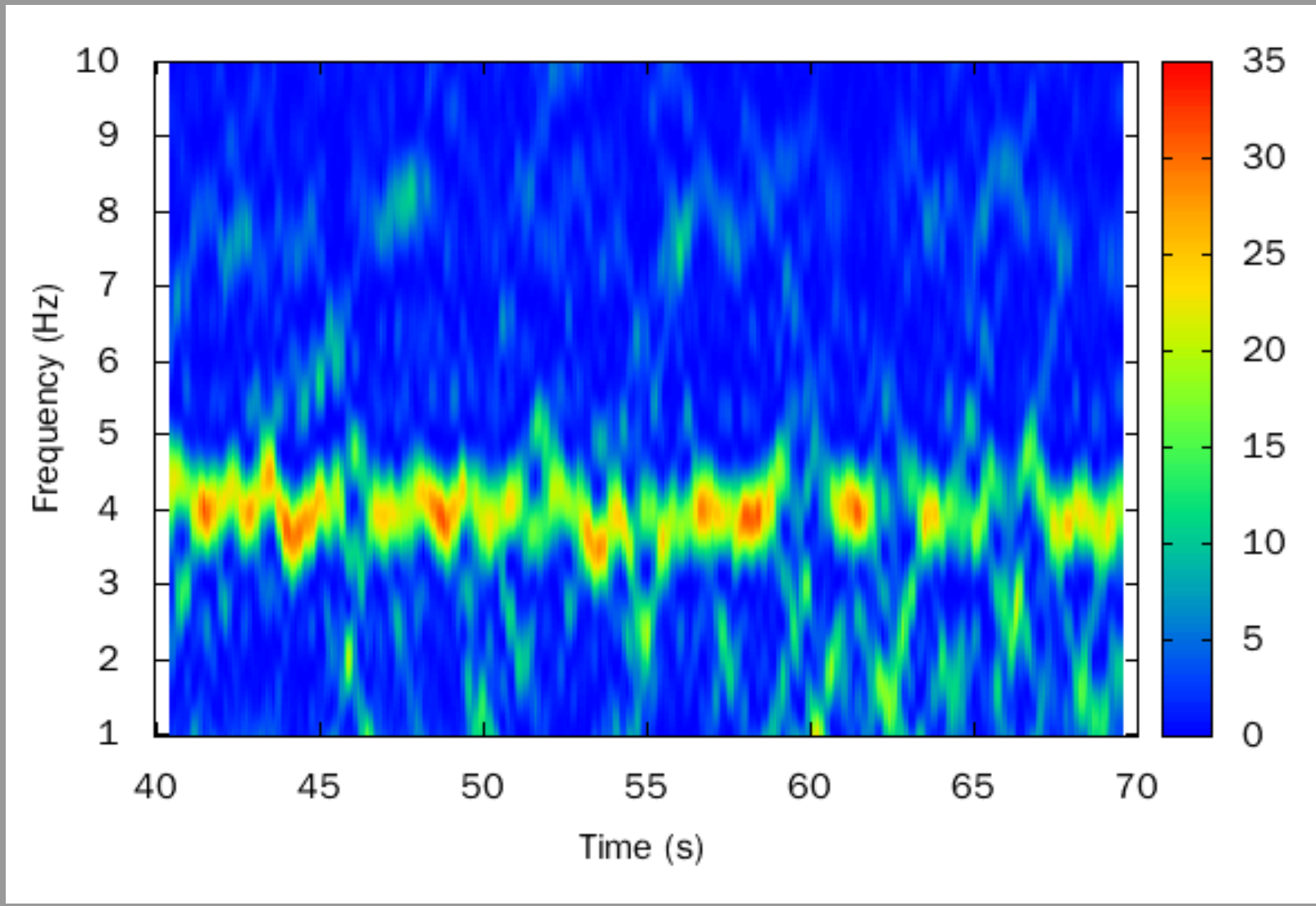
Side project/Collaboration

Non-stationary, evenly spaced time series

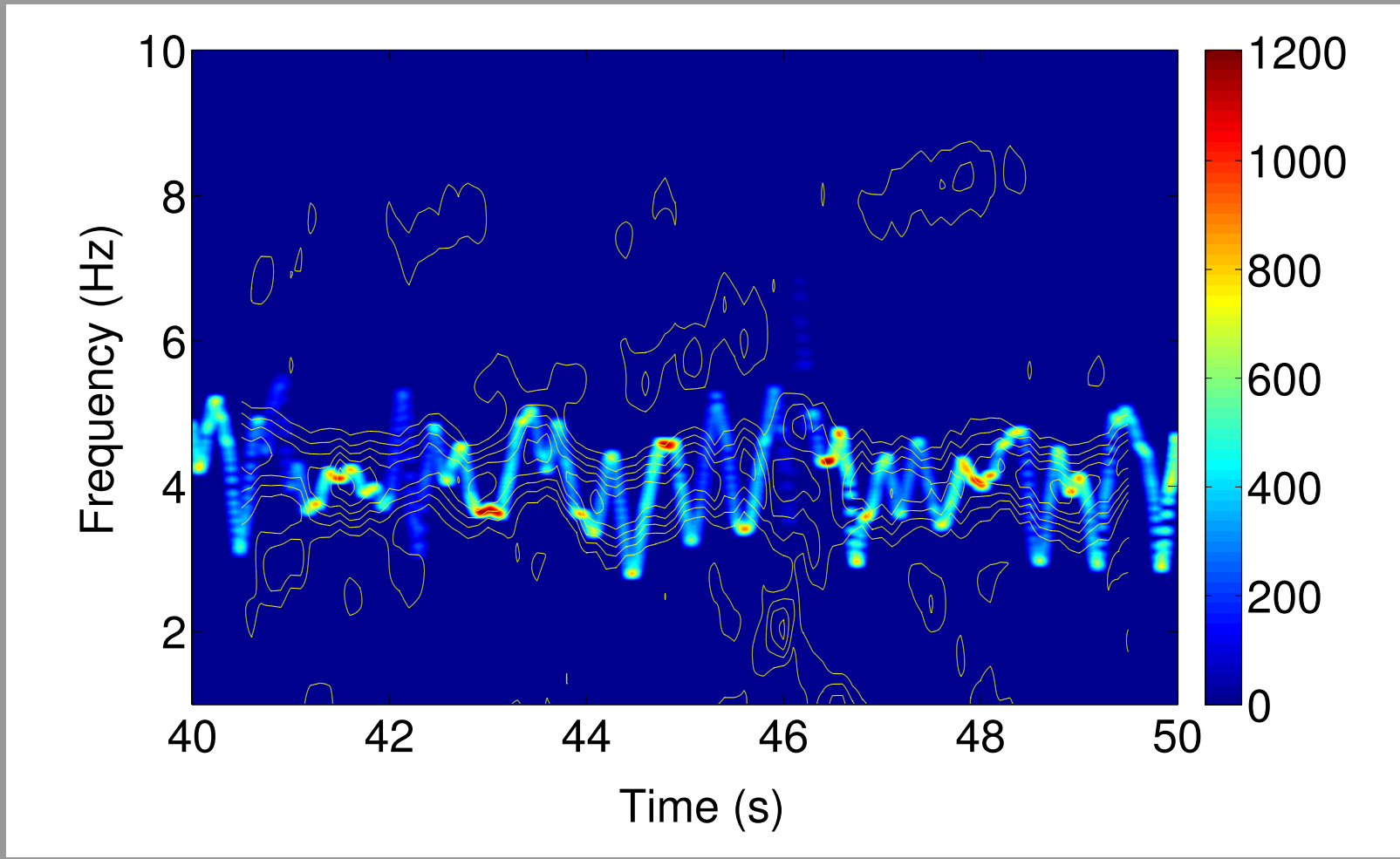
Observation Number	Date	MJD[a]	Type	QPO ν[b] (Hz)
29	1998 Sep 29	51085.27	C	4.13
	...	...	...	8.3
	...	...	...	2.1
30	1998 Sep 29	51085.92	C	2.89
	...	...	...	5.8
	...	...	...	1.4
31	1998 Sep 29	51085.99	C	3.09
	...	...	...	6.1
	...	...	...	1.5
32	1998 Sep 30	51086.89	C	3.51
	...	...	...	7.0
	...	...	...	1.8
33	1998 Oct 01	51087.72	C	3.44
	...	...	...	6.9
	...	...	...	1.7
34	1998 Oct 02	51088.01	C	3.21

(Remillard et al. 2002)

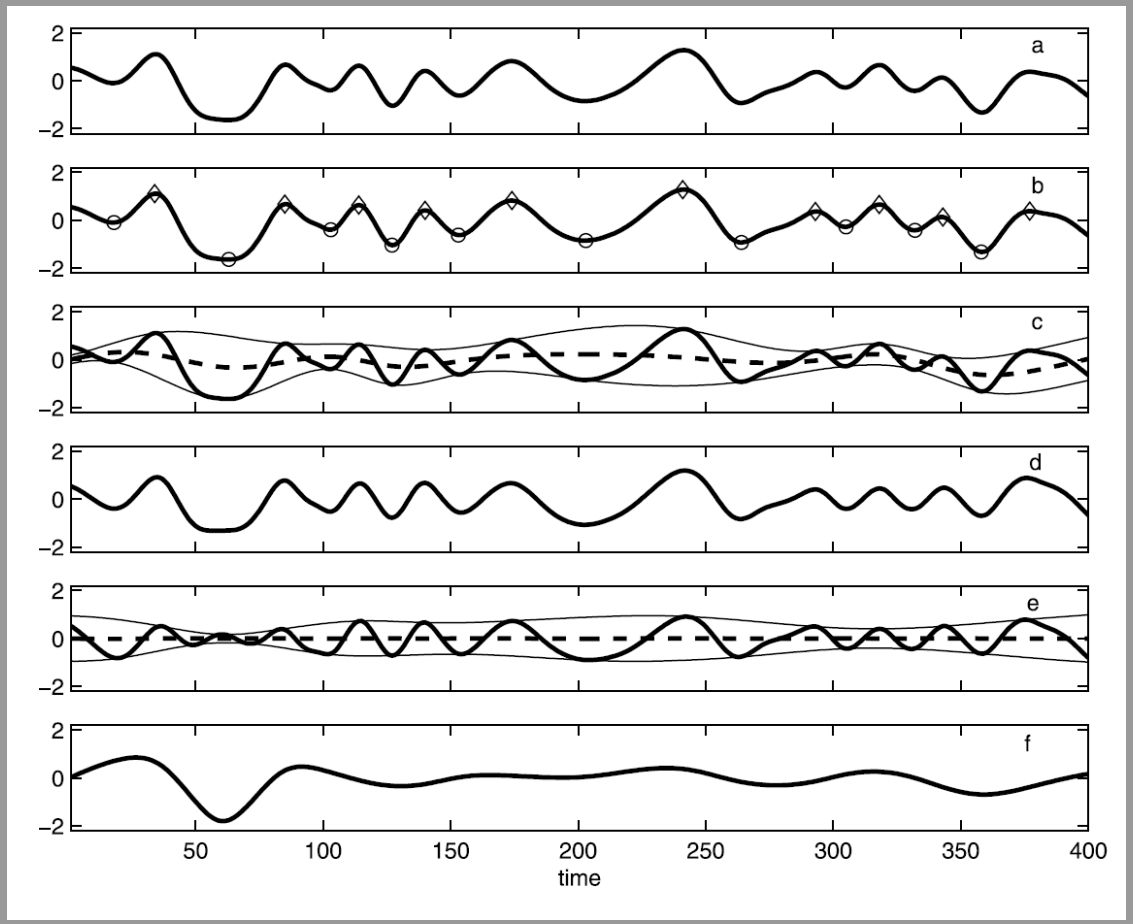
Dynamic Power Spectrum



Hilbert Spectrum & Dynamic Power Spectrum



Sifting Process of Empirical Mode Decomposition



(Huang & Wu 2008)

Comparison between Analysis Methods

TABLE 1. Comparison Between Fourier, Wavelet, and HHT Analysis

	Fourier	Wavelet	HHT
Basis	a priori	a priori	a posteriori adaptive
Frequency	convolution over global domain, uncertainty	convolution over global domain, uncertainty	differentiation over local domain, certainty
Presentation	energy in frequency space	energy in time-frequency space	energy in time-frequency space
Nonlinearity	no	no	yes
Nonstationarity	no	yes	yes
Feature extraction	no	discrete, no; continuous, yes	yes
Theoretical base	complete mathematical theory	complete mathematical theory	empirical

(Huang & Wu 2008)