# ASTROPHYSICAL TIME SERIES ANALYSIS

**İlter Onat Korkmaz**

**Ali Erinç Ayaz**

## 1 Introduction

X-Ray signals from neutron star, companion star binaries during a superburst had been analyzed by Strohmayer et al. (Strohmayer & Markwardt, 1999). In the mentioned paper, it was found that the spin frequency of the neutron star decreased with time. There, this phenomenon was explained by a hypothesis. According to this hypothesis, the initial explosion due to the thermonuclear reactions expanded the shell of materials accredited from the companion-star. Hence, due to the conservation of angular momentum, the spin frequency was said to decrease, only to be increased later on, because of the cooling and shrinking of the shell. The signals from the neutron-star companion-star binary system studied in this paper had also been studied (Strohmayer & Markwardt, 2002, p. 342). In the aforementioned paper, a periodicity of $\approx 582$ Hz was detected and it was argued to be the same as the spin frequency of the neutron star. In this paper, the same signals were analyzed by using various time analysis tools such as separate FFT power spectrum analysis on different time intervals.

## 2 Analysis on the Frequency of X-Ray Signals from Thermonuclear Bursts on 4U 1636-53

The periodicity of X-Ray signals originating from a neutron star-companion star binary system during a superburst was investigated. A superburst occurs when enough material from the companion star gets attracted to the neutron star's surface. Neutron stars' surface has an extremely high temperature, enough to initiate a thermonuclear reaction. Finally, the mentioned thermonuclear reaction produces X-Ray signals that are then captured by satellites (Figure 1).

More specifically, such signals from 4U 1636-53 were analysed (Figure 2). The superburst occurred at 17:00:45 UTC on 2001 February 22 and had a duration span of $\approx$2354 seconds. The time series analysis tools mentioned in previous sections (FFT with Leahy Normalization) were applied to the data in Figure 2. The results exhibited in Figure 4 and 3 suggest that the neutron star in the binary system had a spin frequency of ≈581.2 Hz. This was found by applying FTT to the raw data as a whole. This frequency is a bit lower than what was found in the previous works of Strohmayer and Markwardt (Strohmayer & Markwardt, 2002, p. 342).

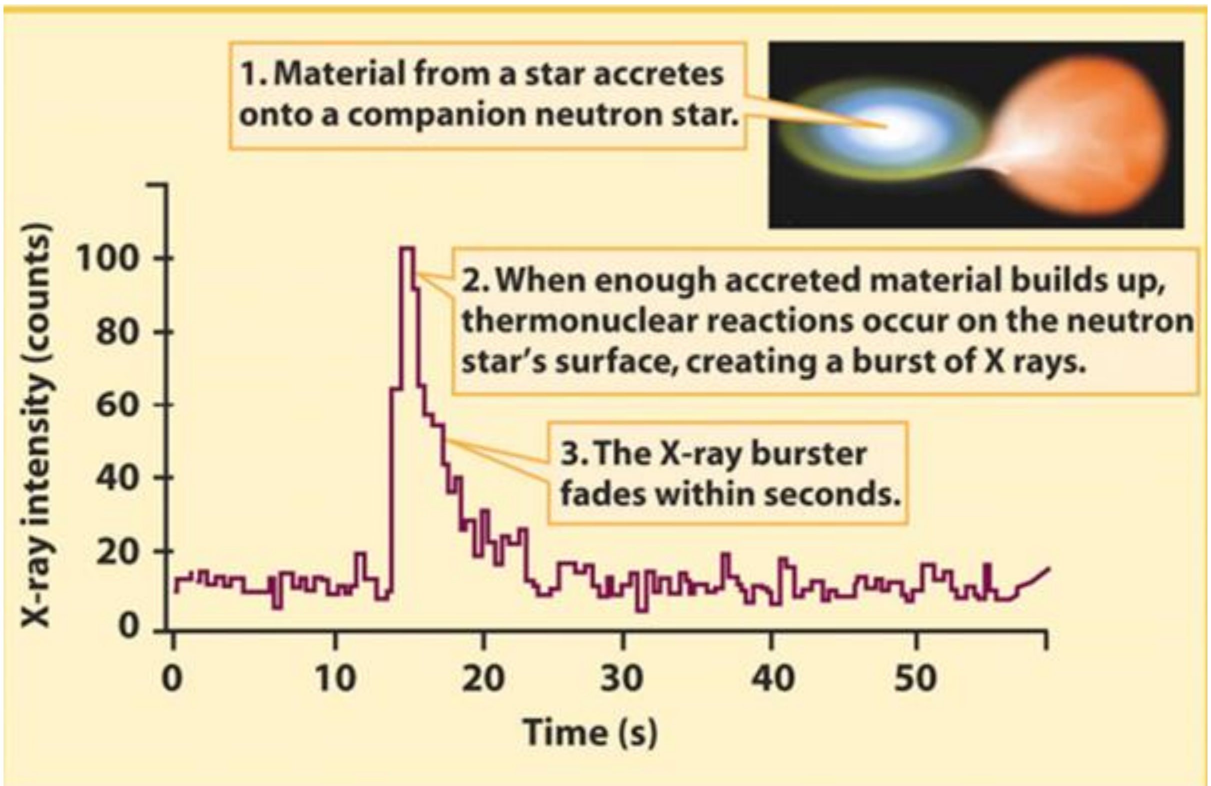


*Figure 1: An example of X-Ray superburst signal with explanation*

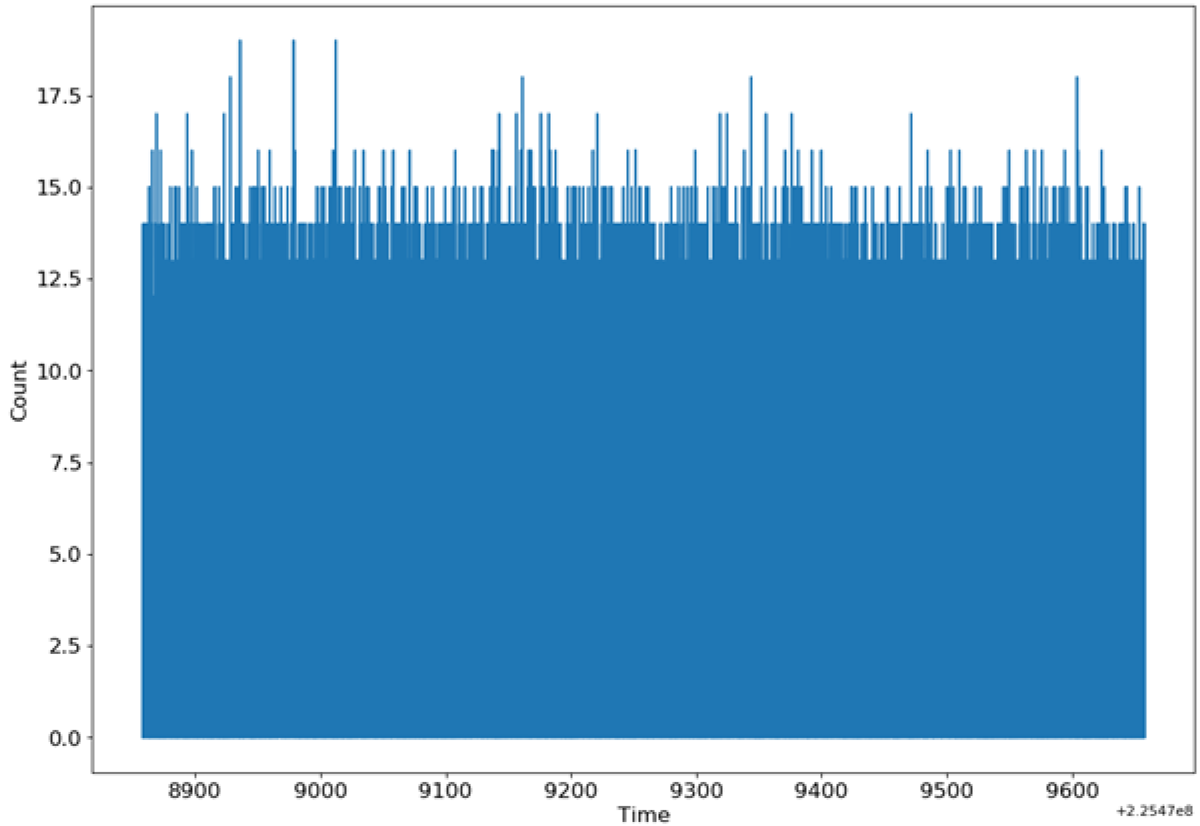


*Figure 2: Count of X-Ray signals versus time graph.*

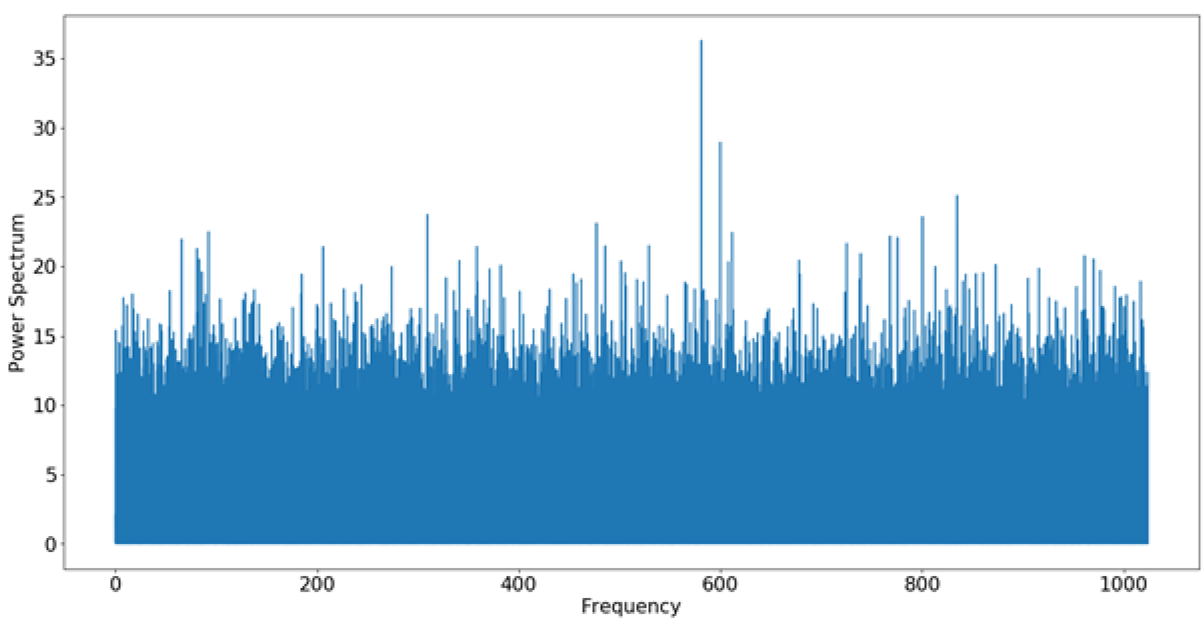


*Figure 3: Power spectrum of the FFT applied to the raw data*

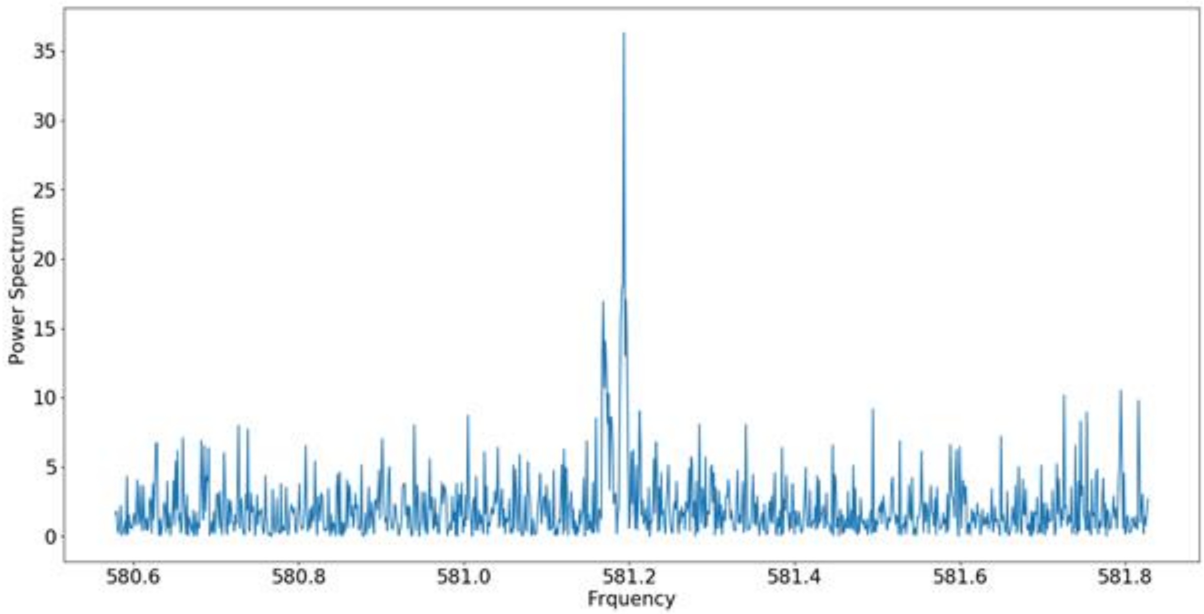


*Figure 4: The power spectrum of the FFT applied to the whole data, zoomed into the frequency neighbourhood of 581.2 Hz*

In order to analyse the frequency of the periodic behaviour of the data with respect to time, mentioned data was processed (FFT and Leahy Normalization) in 8 separate segments (Figure 5). While evaluating the significance of the spikes on the power spectrum, the confidence level formula for the Leahy Normalization was used to determine the detection threshold (Formula 1). In the power spectrum versus frequency graphs shown in Figure 5, only two segments had spikes with higher values than 95% confidence level, namely 7th and 8th segments.

However, the second segment had its spike frequency as ≈576 Hz. Since a periodicity close to 576 Hz is evidently present in the signal (≈582 Hz), the second segment can also be considered to exhibit a periodicity of 576 Hz. The low frequency at the beginning may be the result of expansion of the neutron star due to thermonuclear reactions on the surface which resulted in a decline of the neutron star's spin frequency. But when time passes, the neutron star starts to shrink which results in an increase of spin frequency (581.92 Hz).

$$\frac{\varepsilon}{N_{trials}} = e^{\frac{P_{threshold}}{2}} \qquad P_{threshold} = 2\ x \ln\left(\frac{N_{trials}}{\varepsilon}\right)$$

*Formula 1: Detection Threshold Formula*

At the fifth graph in Figure 5, there exists a spike around 24.88 Hz, with a power spectrum value that corresponds to a 93.4% confidence level. Though it's lower than the 95%, it's high enough to be considered significant at some level. This low frequency periodicity of the signal could be explained by the beat frequency due to the companion star's rotation around the neutron star. In the perspective in which the neutron star is stationary, the companion star could be partially blocking the neutron star, causing a minor but periodic effect on the signal.

Additionally, the results shown in Figure 5 confirmed that there is a spike around 582 Hz in the power spectrum that suggests the spin frequency of the neutron star. As it can be seen that in the last two graphs, there are spikes around 582 Hz, more accurately 581.925 and 581.926 Hz, which are in line with the results of Strohmayer and Markwardt's paper (Strohmayer & Markwardt, 2002, p. 342).

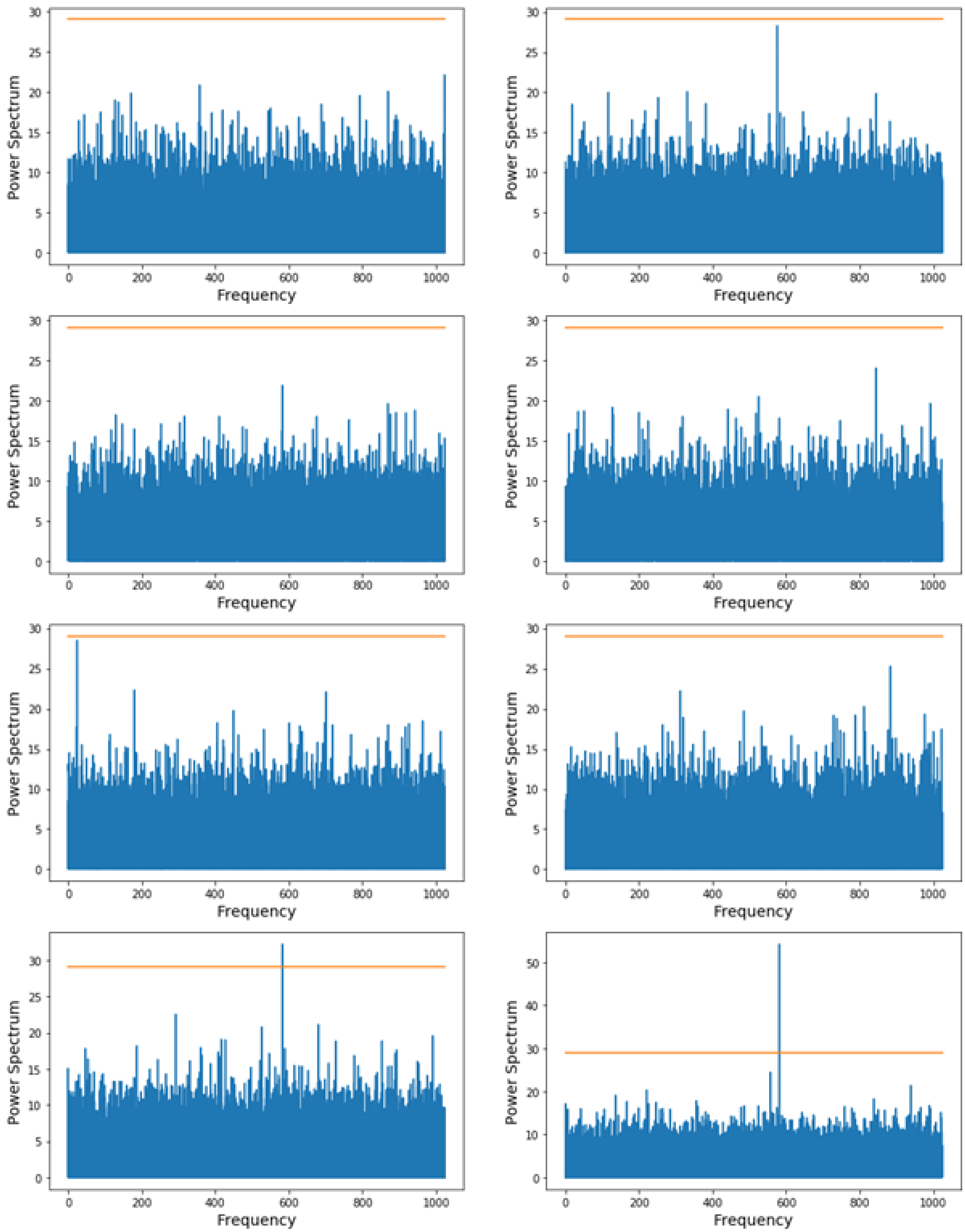


*Figure 5: The power spectrum of FFT amplitudes from separate sections of X-Ray data and 95% confidence level.*

## 3 References


Strohmayer, T. E., & Markwardt, C. B. (2002). *Evidence for a Millisecond Pulsar in 4U 1636–53 during a Superburst*. The Astrophysical Journal. Retrieved from https://iopscience.iop.org/article/10.1086/342152

Strohmayer, T. E., & Markwardt, C. B. (1999). On the Frequency Evolution of X-Ray Brightness Oscillations during Thermonuclear X-Ray Bursts: Evidence of Coherent Oscillations. *The Astrophysical Journal*, *516*(2), L81–L85. Retrieved from https://doi.org/10.1086/312009