Analysis of the GW170817 event using GWpy and PyCBC

Pedro J. S. Silva [1] Márcio E. S. Alves [2] Iara T. Melo [3,4]

[1]Faculdade de Engenharia e Ciências de Guaratinguetá – UNESP. [2]Instituto de Ciência e Tecnologia – UNESP, São José dos Campos, SP. [3]INFN Sezione Catania. [4]University of Catania.

Abstract

In 2017, the detection of the GW170817 marked the first observation of a gravitational wave generated by a binary neutron star system. This observation was followed by the detection of a short gamma-ray burst (sGRB) followed by a kilonovae. Such an event was the first of its kind which opened a new era for the GW multi-messenger astronomy. The GWpy and PyCBC libraries are essential tools for data analysis, enabling the identification of astrophysical events and the characterization of their properties. In this context, we present the analysis conducted for GW170817 with these libraries. GWpy was used to process and analyze the observational data. Finally, from the estimated parameters of GW170817 we have generated the corresponding GW waveform through the PyCBC library.

Introduction

In 2017, the detection of the GW170817 event marked a significant breakthrough in astronomy, representing the first direct observation of a gravitational wave (GW) originated from the merger of neutron stars in a binary system [3]. This milestone not only confirmed the predictions of Einstein's General Theory of Relativity [8] but also inaugurated a new era in multi-messenger astronomy [4], enabling the correlation between gravitational events and electromagnetic observations [2].

The detection of GW170817 was not limited to the GW; it was followed by the simultaneous observation of a short gamma-ray burst (sGRB) and a kilonova [1]. This unique combination of signals provided a deeper understanding of the astrophysical phenomena involved in the merger of neutron stars.

In this context, the GWpy [5] and PyCBC [6] libraries stand out as essential resources for data processing and analysis, enabling the precise identification of astrophysical events and the detailed characterization of their properties. This work presents a specific analysis of the GW170817 event, highlighting the contribution of these libraries to the investigation of this remarkable event in the era of multi-messenger astronomy.

Generating a GW

Using the *PyCBC* library [6], the GW is represented as a time series with the `get_td_waveform()` function. Essential parameters include the masses of the binary system in solar masses ($M_\odot$), the time interval in seconds, the initial frequency of the wave in Hertz, and the choice of the approximated waveform, such as `SEOBNRv4_opt`.

Modeling the gravitational wave GW170817

Using the estimated mass and minimum frequency parameters from the GW170817 event [3], we can simulate the GW strain using the *PyCBC* library. This procedure enables a detailed analysis of the behavior of the GW generated by this binary system.

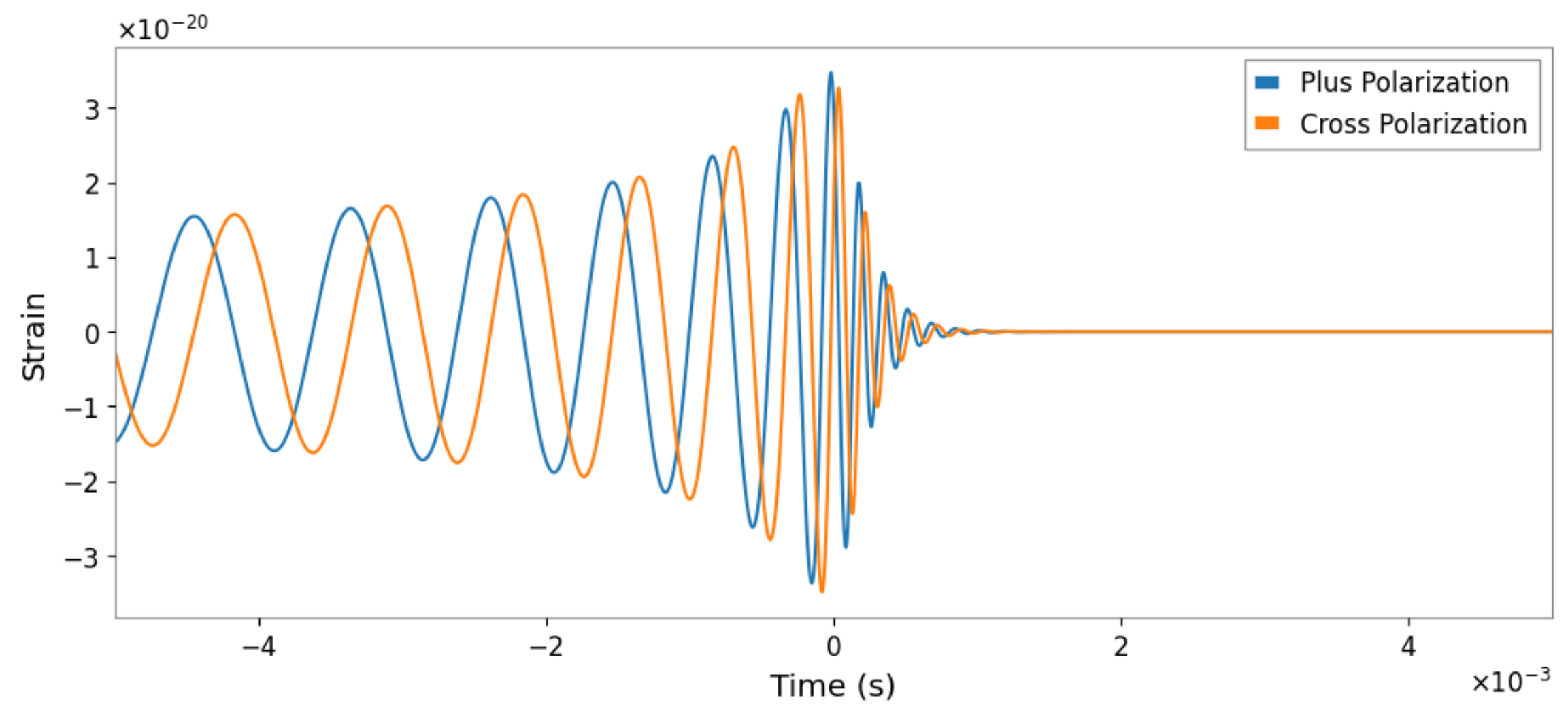

Figure 1. Representation of the strain over time, generated based on the mass, frequency, and time data from the GW170817 observation, with the scale adjusted to milliseconds.

It is also possible to obtain the GW strain as a function of the phase, expressed in radians. In order to distinctly highlight the difference between the integrators, the Figure 2 not only depicts the amplitude variation but also the behavior of each amplitude concerning each integrator.

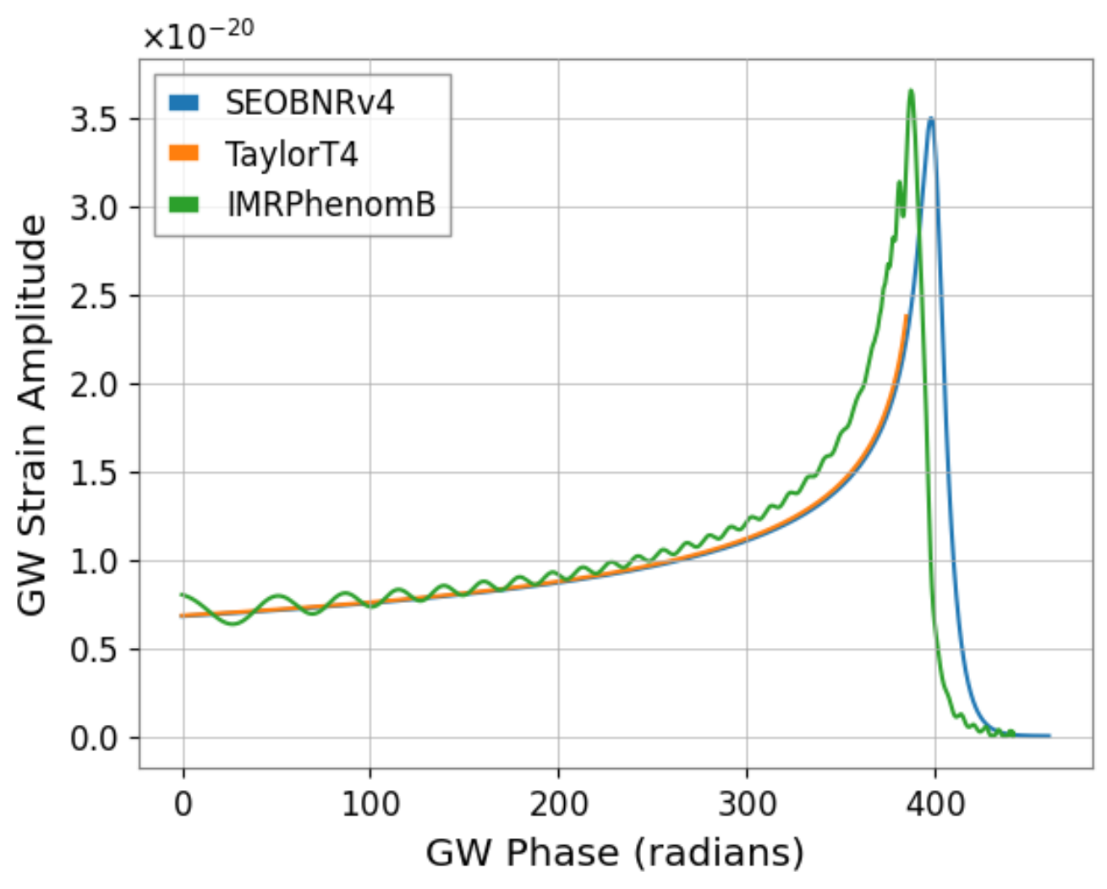

Figure 2. Observed amplitude as a function of the phase of the GW using the parameters from the GW170817 observation, also varying the integrators.

Accessing observational data

The *gwosc* library enables queries regarding data availability on *GWOSC* [5]. The `TimeSeries.fetch_open_data` method is employed to directly download data from `https://www.gw-openscience.org`, requiring knowledge of GPS times.

Practical implications

```
from gwosc.datasets import event_gps
gps = event_gps('GW170817')
print(gps)
```

For this example, we chose to retrieve data from the LIGO-Livingston interferometer ('L1'). We could have opted for G1 (GEO600), H1 (LIGO-Hanford), V1 (Virgo), or K1 (KAGRA).

From the acquired data, we generated the plot in Figure 3.

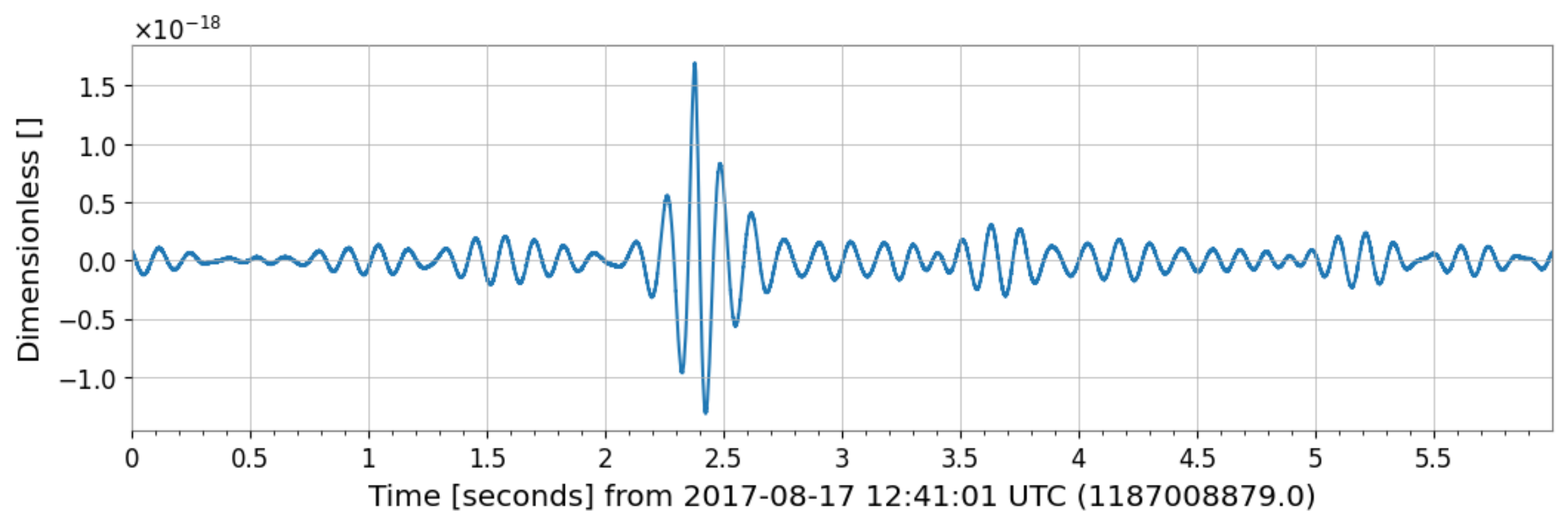

Figure 3. Observed segment generated by LIGO-Livingston for the gravitational wave GW170817.

Data processing

- Application of the Fourier transform (`fft()` and `abs()`) to identify frequencies in the signal.
- Handling discontinuities using `scipy.signal` and *GWpy*:
  - `asd()`: Computes the Amplitude Spectral Density (ASD).
  - `"median"`: Use of the median to mitigate fluctuations.
  - `Welch`: Combination of FFT Estimates from segments to attenuate discontinuities.

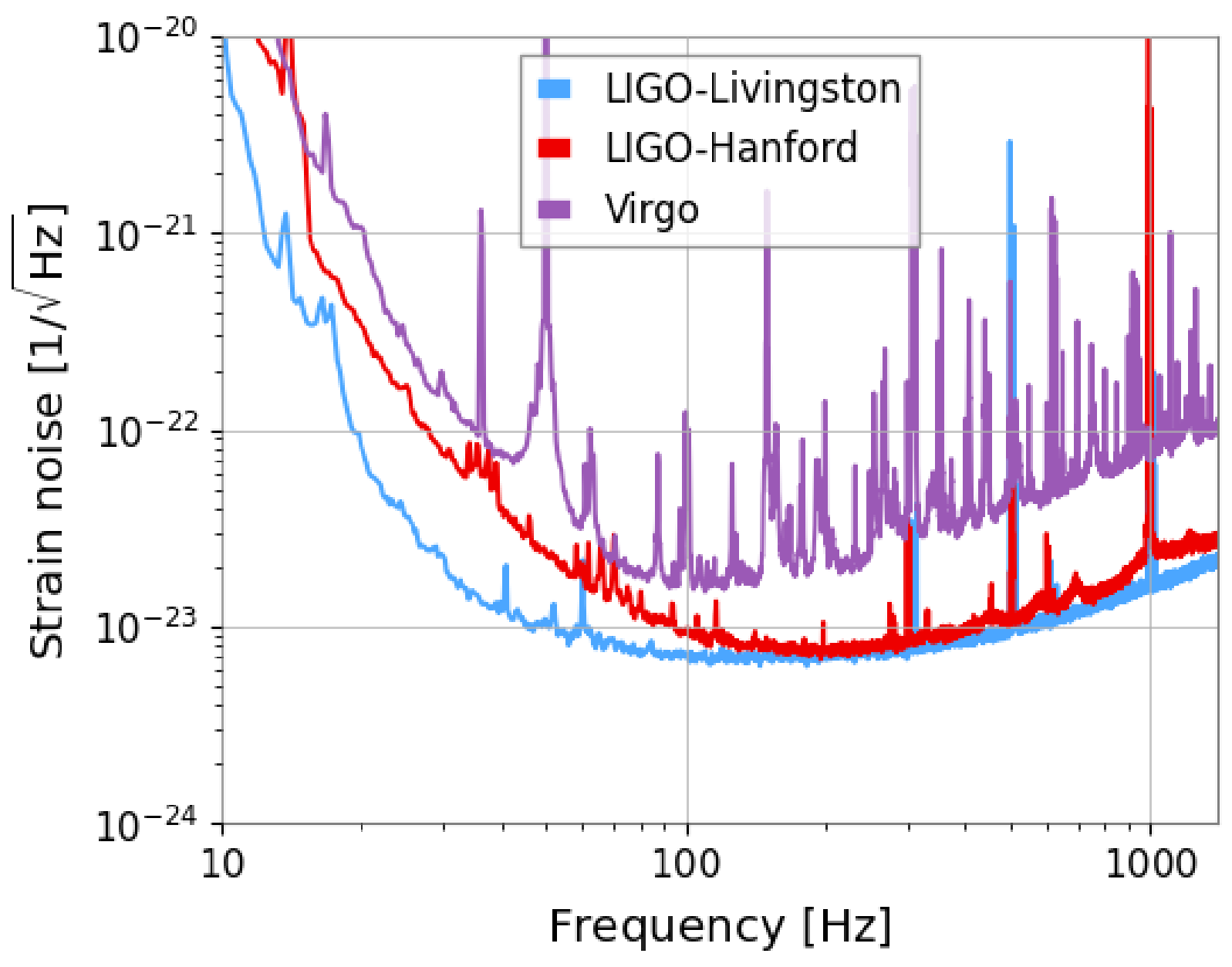

Figure 4. Comparison of the transients observed in GW observatories for GW170817.

The visualization highlights the relative sensitivity of each detector and reveals shared and unique characteristics, contributing to a comprehensive understanding of the signals captured by the systems.

Q-transform

- Using the Q-transform [7] to produce a time-frequency representation that characterizes the spectral nature of the observed data from the GW170817 transient.

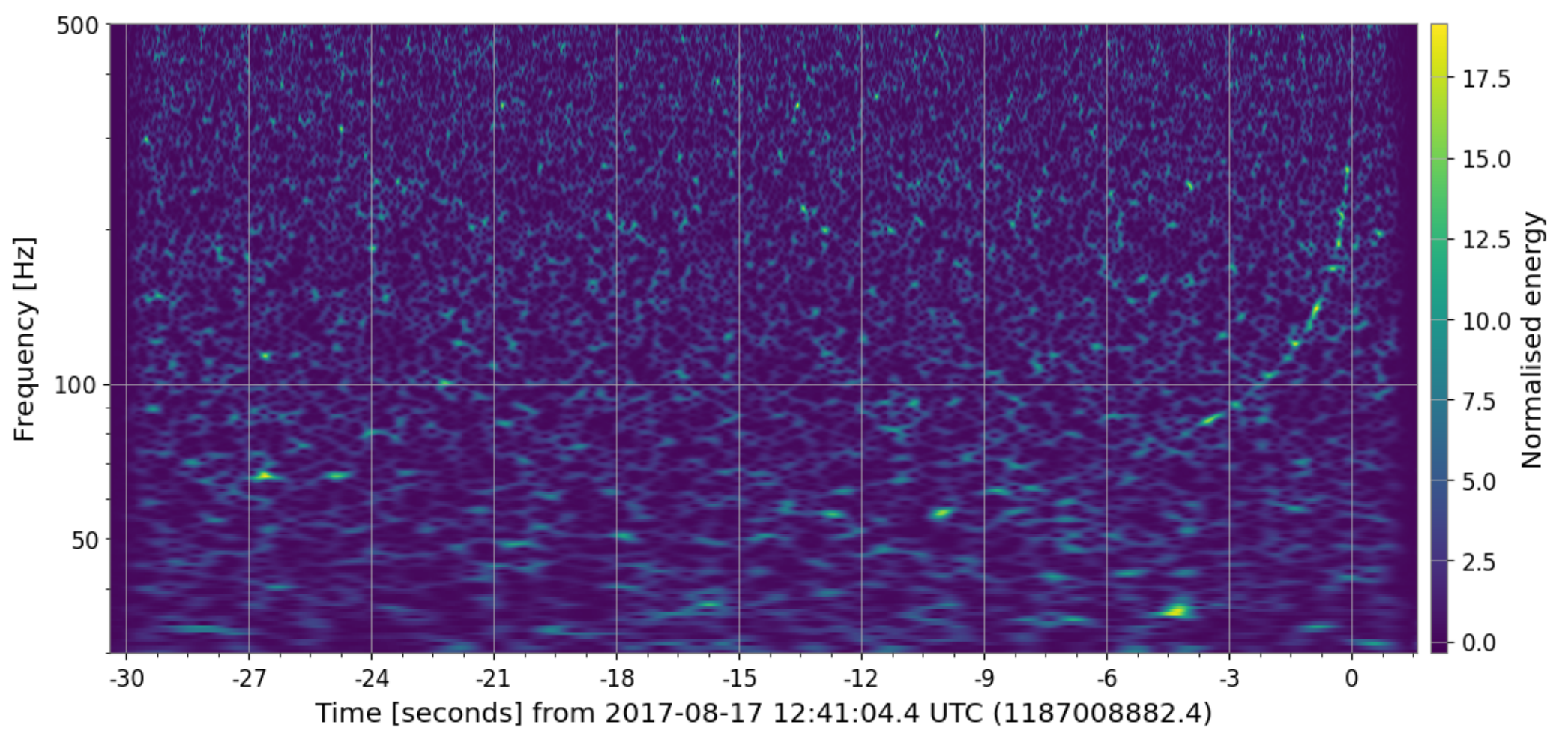

Figure 5. Spectrum obtained through the Q-transform of the GW170817 observation, emphasizing frequency, energy, and time properties.

References

[1] B. P. Abbott, R. Abbott, et al.
Estimating the contribution of dynamical ejecta in the kilonova associated with gw170817.
The Astrophysical Journal Letters, 850(2):L39, dec 2017.

[2] B. P. Abbott, R. Abbott, et al.
Gravitational waves and gamma-rays from a binary neutron star merger: Gw170817 and grb 170817a.
The Astrophysical Journal Letters, 848(2):L13, 2017.

[3] B. P. Abbott, R. Abbott, et al.
Gw170817: observation of gravitational waves from a binary neutron star inspiral.
Physical Review Letters, 119(16):161101, 2017.

[4] B. P. Abbott, R. Abbott, et al.
Multi-messenger Observations of a Binary Neutron Star Merger.
, 848(2):L12, October 2017.

[5] R. Abbott, T. D. Abbott, et al.
Open data from the first and second observing runs of Advanced LIGO and Advanced Virgo.
SoftwareX, 13:100658, January 2021.

[6] C. M. Biwer, Collin D. Capano, Soumi De, Miriam Cabero, Duncan A. Brown, Alexander H. Nitz, and V. Raymond.
PyCBC Inference: A Python-based Parameter Estimation Toolkit for Compact Binary Coalescence Signal.
, 131(996):024503, February 2019.

[7] Shourov Chatterji, Lindy Blackburn, Gregory Martin, and Erik Katsavounidis.
Multiresolution techniques for the detection of gravitational-wave bursts.
Classical and Quantum Gravity, 21(20):S1809, 2004.

[8] Albert Einstein.
Über gravitationswellen.
Sitzungsberichte der Königlich Preussischen Akademie der Wissenschaften, pages 154–167, 1918.

Acknowledgements

The present work was carried out with the support of the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior in Brazil (CAPES) - Funding Code 001.

pedro.jeronimo@unesp.br