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Gravitational Waves

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Multifractal signatures of gravitational waves detected by aLIGO

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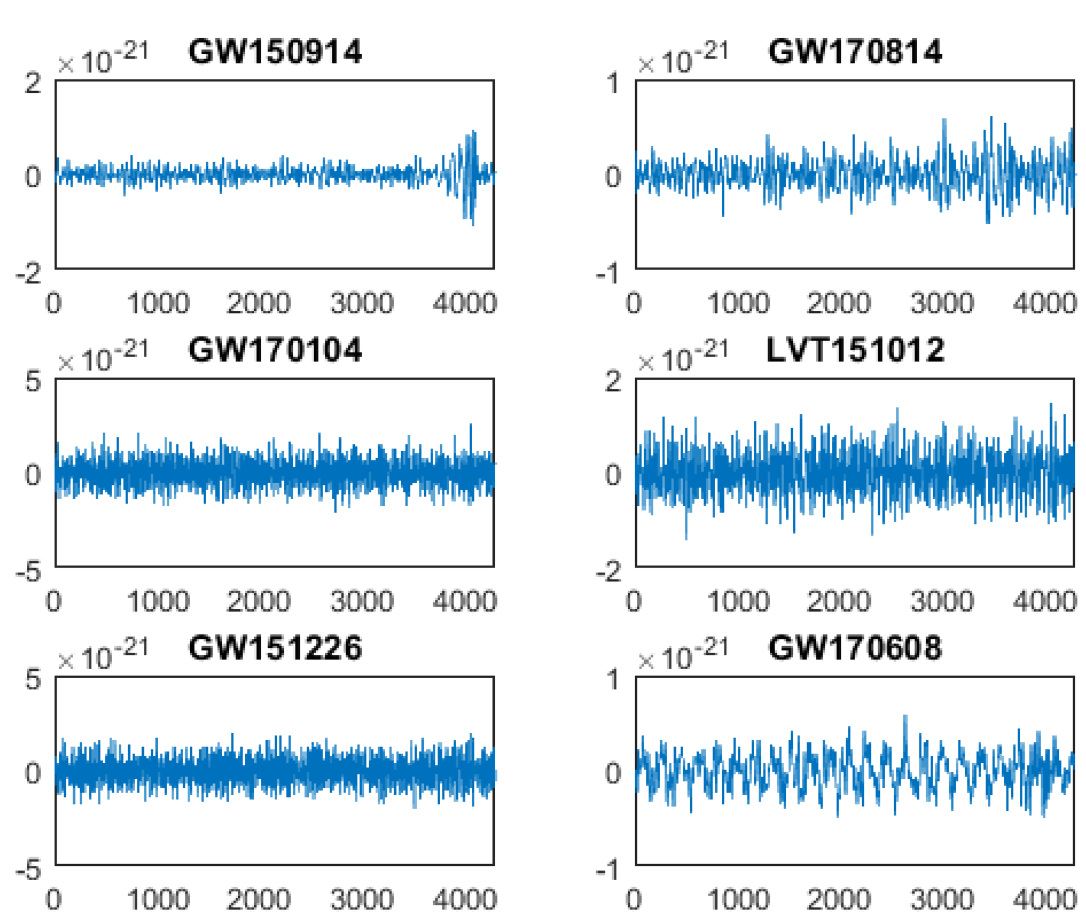
Introduction

In February 11, 2017, data on the First direct observation of gravitational waves (hereafter, GWs) from a binary black hole merger was published, opening up new avenues for studying the universe beyond the analysis of electromagnetic waves [1-3]. The GW150914 GW was generated from the merger of two black holes and the event was observed by the two advanced LIGO [2] detectors with a statistical significance of 5.1σ. The GW150914 analysis, as a time series, will be presented throughout this work.

Several works, including [4-8], have applied multifractal analyses to time series. One of the most recent and effective methods in time series analysis is the MFDMA (Detrended Moving Average for Multifractals), proposed by Gu and Zhou in 2010 [9], as a generalization of the DMA method proposed by Alesio in 2002 [10].

Since the first detection, five more signals have been confirmed as gravitational waves: GW151226 [11], GW170104 [12], GW170608 [13], GW170814 [14] and one signal remains as a suspected GW (LVT151012 [11]). The gravitational wave data used here are within the range of 32 seconds around the event and have a measurement frequency of 4096Hz..

MFDMA in Gravitational waves



Event	Chirp Mass (Msun)
GW150914	30
GW170804	24.1
GW170104	21.1
LVT151012	15.1
GW151226	8.9
GW170608	7.9

Results

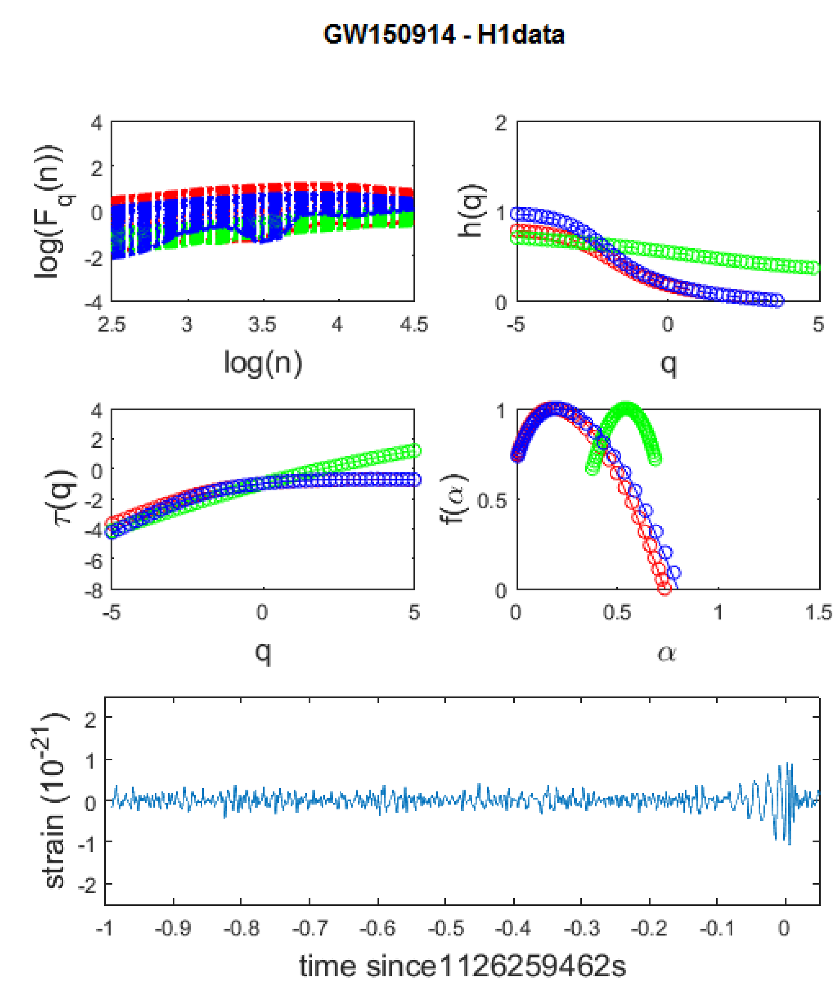


Fig. 1: Relation between parameters derived from multifractal analysis in the GW150914 time series.

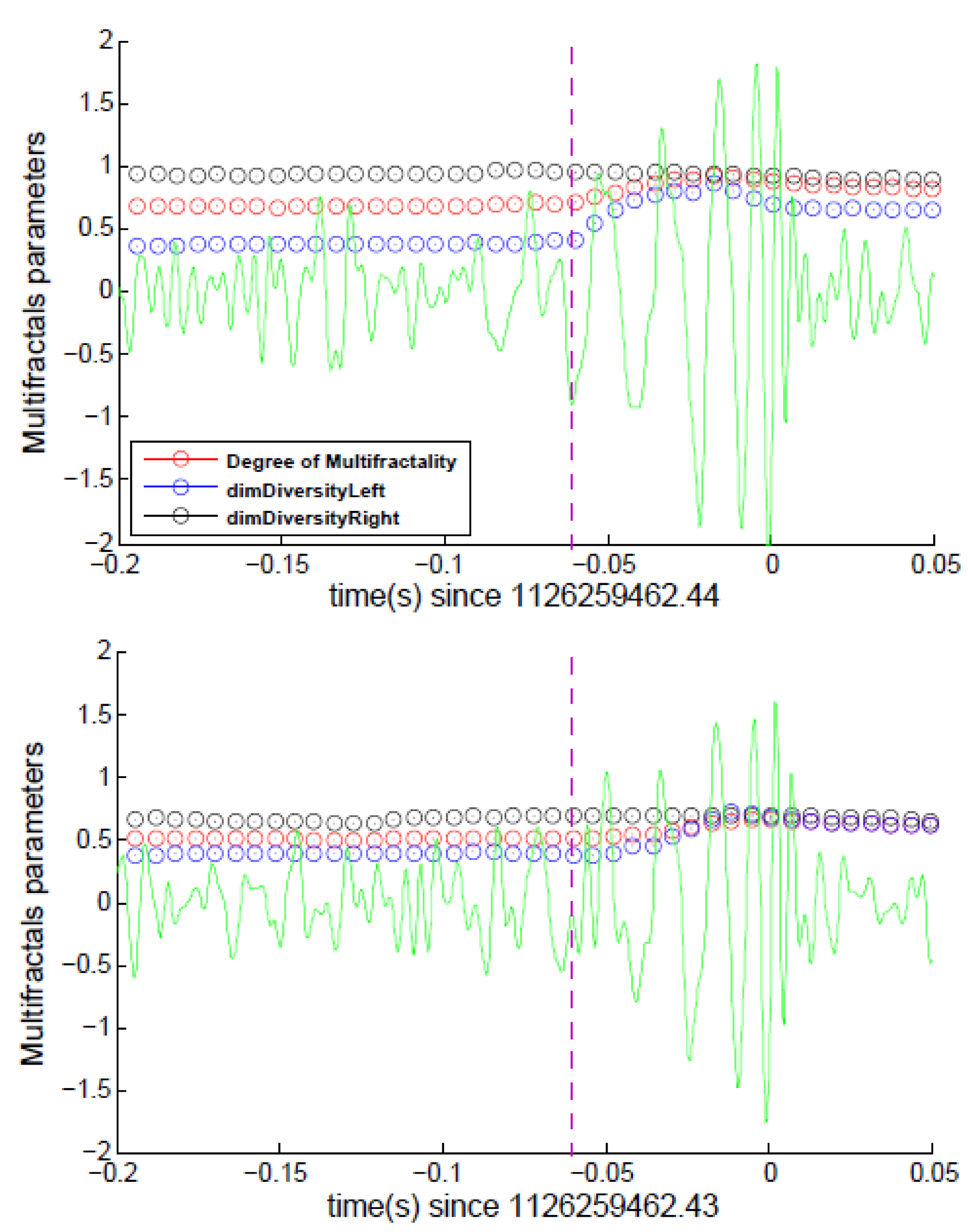


Fig. 2: Point-to-point multifractal analysis in the GW150914 time series from Hanford (top panel) and Livingston (bottom panel), illustrated in green. The vertical lines represent t = 0.06s, the time point at which the time series are divided.

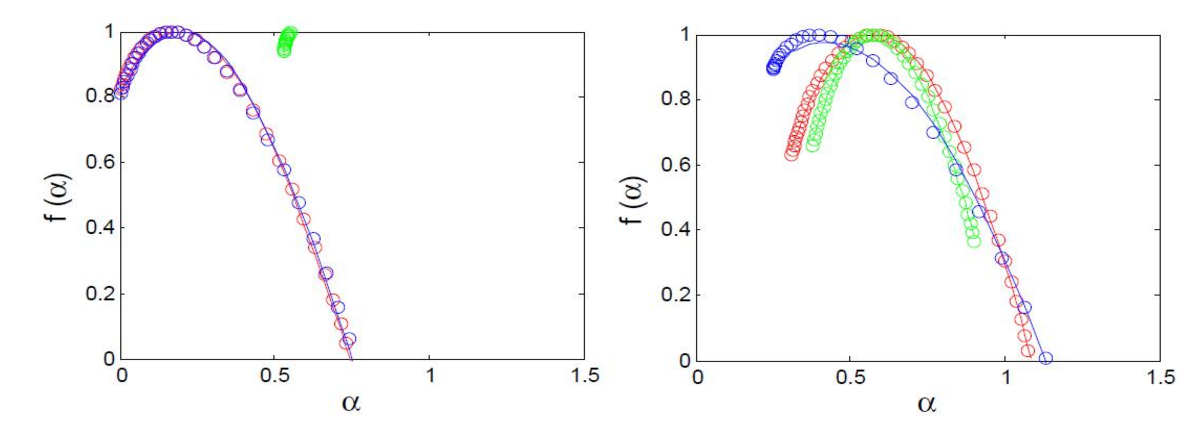


Fig. 3: The multifractal singularity spectrum of the first (left panel) and second (right panel) parts of the GW150914 time series are in red. In green and blue the results of the application of the shuffled and surrogate methods, respectively.

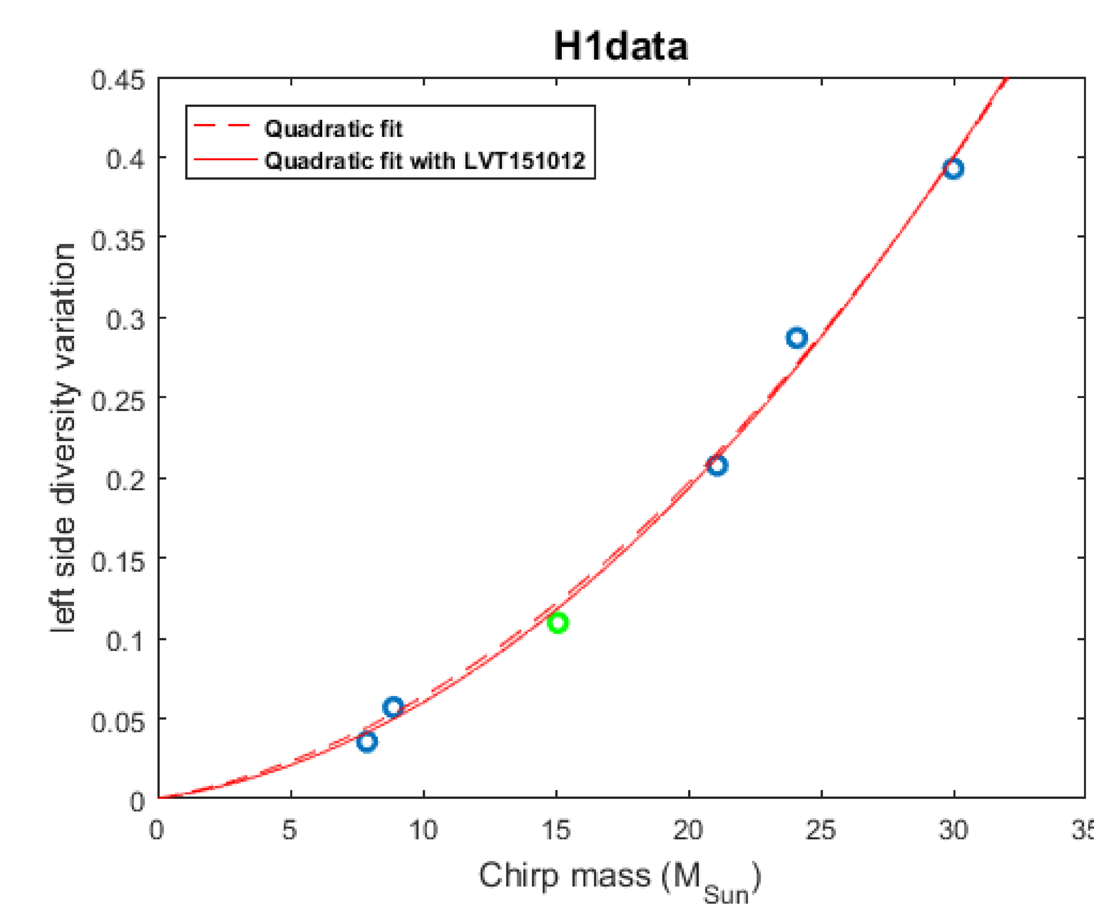


Fig. 4: The correlation between left side diversity variation and Chirp mass for each one GW (circles in blue) and LVT151012 (circle in green). The dashed line indicates a quadratic adjustment without the LVT signal and solid line is the same, but considering this signal.

Conclusions

We identified two types of multifractality in the strain measure of the time series by examining long memory and the presence of nonlinearities. The second type of multifractality are presents only in the seconds portions of the data. This phenomenon was associated with the increase in the amplitude of the gravitational wave caused by the collision of the two black holes. Thus, the moment used to divide the series into two parts separates these two regimes and can be interpreted as the moment of collision between the black holes. An empirical relationship between the left lateral diversity variation and the chirp mass of each event was also determined.

References

[1] B. P. Abbott et al. (LIGO Scientific Collaboration and Virgo Collaboration), Phys. Rev. Lett. 116, 061102 (2016).

[2] J. Aasi et al., Class. Quantum Gravity 32, 074001 (2015).

[3] B.P. Abbott et al. (LIGO Scientific Collaboration and Virgo Collaboration), Phys. Rev. Lett. 116, 131103 (2016).

[4] D. B. de Freitas, M. M. F. Nepomuceno, P. R. V. de Moraes Junior, C. E. F. Lopes, M. L. Das Chagas, J. P. Bravo, A. D. Costa, B. L. Canto Martins, J. R. De Medeiros, and I. C. Leao, Astrophys. J. 831, 87 (2016).

[5] D. B. de Freitas, M. M. F. Nepomuceno, M. Gomes de Souza, I. C. Le~ao, M. L. Das Chagas, A. D. Costa, B. L. Canto Martins, and J. R. De Medeiros, Astrophys. J. 843, 103 (2017).

[6] P. Mali, J. Stat. Mech. Theory Exp. 2016, 013201 (2016).

[7] P. Norouzzadeh, W. Dullaert, and B. Rahmani, Physica A, 380, 333 (2007).

[8] H. J. Tanna and K. N. Pathak, Astrophys. Space Sci. 350, 47 (2014).

[9] G.-F. Gu and W. X. Zhou, Phys. Rev. E 82 011136 (2010).

[10] E. Alessio, A. Carbone, G. Castelli, and V. Frappietro, Eur. Phys. J. B 27, 197 (2002).

[11] Abbott, B. P., et al. Physical Review Letters 116.24 (2016): 241103.

[12] Scientific, L. I. G. O., et al. Physical Review Letters 118.22 (2017): 221101.

[13] Abbott, B. P., et al. The Astrophysical Journal Letters 851.2 (2017): L35.

[14] Abbott, Benjamin P., et al. Physical review letters 119.14 (2017): 141101.