Comment on “Tests of general relativity with GW170817”

Anatoly A. Svidzinsky¹ and Robert C. Hilborn²

¹Department of Physics & Astronomy, Texas A&M University, College Station, TX 77843
²American Association of Physics Teachers, One Physics Ellipse, College Park, MD 20740

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In a recent paper “Tests of general relativity with GW170817” (arXiv:1811.00364 [gr-qc]) the authors claimed overwhelming evidence in favor of tensor gravitational wave (GW) polarization over vector by analyzing GW signals measured by the LIGO-Virgo network. Here we show that the measured LIGO-Livingston signal is substantially reduced at certain frequency intervals which can be attributed to noise filtering. We found that if these regions are excluded from the analysis then data are consistent with vector GW polarization and not with tensor. We show that if the signal accumulation method is applied over the entire detector bandwidth, including the regions in which the signal is depleted by noise subtraction, the result underestimates the LIGO-Livingston signal amplitude. That smaller amplitude then leads to an erroneous conclusion that favors tensor polarization over vector polarization for the GW.

In a recent preprint [1] the authors reported results of the gravitational wave (GW) polarization test with GW170817 performed using a Bayesian analysis of the signal properties with the three LIGO-Virgo interferometer outputs. The authors found overwhelming evidence in favor of pure tensor polarization over pure vector with an exponentially large Bayes factor. This result is opposite to the conclusion of our analysis based on a direct comparison of the GW signals measured by the three detectors [2]. Namely, we found that the measured signal ratios are inconsistent with the predictions of general relativity, but consistent with the recently proposed vector theory of gravity [3, 4]. Here we explain why we came to the opposite conclusion and argue that the results reported in [1] must be reconsidered by removing “corrupted” frequency intervals from the LIGO-Livingston strain time series.

For the GW170817 event involving low mass neutron stars the gravitational waveform is known analytically for almost the entire time interval when the signal passes through the detector’s sensitivity band (apart from the last second before merger). This is the case because the energy loss by the binary system is accurately described by the quadrupole formula up to the last second. Both in general relativity and vector gravity [3] the waveform is given by

\[ s(t) \propto \frac{1}{(c_t - t)^{1/4}} \cos[2\phi(t)], \quad (1) \]

where

\[ \phi(t) = -\left( \frac{c^3}{5GM_c} \right)^{5/8} (c_t - t)^{5/8} + \phi_0, \quad (2) \]

\( c_t \) is the coalescence time and \( M_c \) is the chirp mass of the binary system.

We used published strain time series for the three detectors [2] which are not normalized to the detector’s noise. The best fit to the LIGO-Livingston and LIGO-Hanford data yields \( M_c = 1.188 \ M_\odot \) and \( t_c = 0.296 \) s (here we made an adjustment for different arrival times of the signal at the detector locations).

Next we introduce an integrated complex interferometer response

\[ I(t_0, \Delta t) = \int_{t_0}^{t_0 + \Delta t} (c_t - t)^{1/4} e^{-2i\phi(t)} h(t) dt, \quad (3) \]

where \( \Delta t \) is the signal collection time and \( h(t) \) is the strain measured by the interferometer that contains both signal and noise. According to Eqs. (1), (2) and (3), the signal contribution to \( I \) is proportional to \( \Delta t \) provided we disregard a small correction produced by the fast oscillating term. Thus, the signal accumulates with an increase of the collection time \( \Delta t \). In contrast, noise does not accumulate with \( \Delta t \) and for large enough \( \Delta t \) the noise contribution to \( I \) can be disregarded.

Thus, the theory predicts that the ratio

\[ u = \frac{I(t_0, \Delta t)}{\Delta t} \]

should be independent of the signal collection time interval \([t_0, t_0 + \Delta t]\). This ratio can be interpreted as a signal per unit time. It depends, in particular, on GW polarization which allows us to distinguish between pure tensor and pure vector polarizations using the three interferometer network [2]. In addition, \( u \) should be used to determine how much signal is present in the interferometer data stream at different times. If noise filtering has not altered the signal at certain frequencies then \( u \) must have the same (complex) value for any collection time interval.

In Fig. [4] we plot \(|u|\) for LIGO-Hanford detector for different collection time intervals. The result is shown as a set of rectangular bars. The length of a bar is equal to the collection time \( \Delta t \), while the height corresponds to the uncertainty produced by the detector noise. Namely, the half-height is equal to one standard deviation. We calculated the error by injecting a test signal into the measured strain time series. The average value of \(|u|\) for each interval \( \Delta t \) is indicated by a dashed line. The figure shows that \(|u|\) for the LIGO-Hanford detector is consistent with a constant for the entire time when the...
Fig. 1 shows that signal in these regions is substantially smaller than the signal content in other intervals.

The signal reduction can be attributed to noise filtering. For example, a glitch which occurred in LIGO-Livingston detector about 1.1 s before coalescence can explain why there is less signal in the data stream during the glitch duration. Namely, the glitch removal from the data stream led to some of the GW signal being subtracted off unintentionally, as one can see from Fig. 2. Signal reduction in other frequency regions of the LIGO-Livingston detector can be attributed to filtering fan noise (see Fig. 3 in [7]).

The GW170817 event allows us to determine the amount by which GW signal is suppressed by the noise filtering. Perhaps noise filtering yields substantial signal reduction at certain frequencies for GW events for which signal per unit time is very weak, which is the case for GW170817. Thus, for such events one should perform a consistency check of Figs. 1 and 2 and remove “corrupted” frequency intervals from the data analysis. This must be taken into account in the analysis of future GW events produced by inspiral of low-mass objects.

Contrary to the amplitude situation, we found that signal phase was not altered in both detectors, namely the phase of $u$ is consistent with a constant. This explains why sky location of the source is predicted correctly from the measured strain time series. The sky localization is constrained primarily by the differences in arrival times of the signal in various detectors [8]. For the GW170817 event the time delays are obtained with a high accuracy by fitting the signal phase $\phi(t)$ for hundreds GW cycles. More importantly, the GW source location is known to high accuracy thanks to the observation of concomitant electromagnetic emission.

As we showed in [2], the ratio of LIGO-Hanford and LIGO-Livingston signal amplitudes $|H/L|$ is crucial for distinguishing between tensor and vector GW polarizations. In Ref. [2] we obtained this ratio by accumulating the LIGO-Livingston signal only from the regions shown by the solid bars in Fig. 2. In these regions the signal is not corrupted. We found $0.6 < |H/L| < 0.8$. This estimate, combined with other constraints, is compatible with vector theory of gravity [3, 4] but rules out general relativity [2].

However, signal accumulation from the entire frequency band erroneously underestimates the LIGO-Livingston signal amplitude yielding $1 < |H/L| < 1.2$ [9]. This incorrect estimate results in the opposite conclusion about GW polarization. Namely, it rules out vector polarization, but is consistent with tensor polarization (see Fig. 17 in [2]). This is what the authors of Ref. [1] have found. We believe that if the LIGO-Virgo analysis were done taking into account the Livingston signal amplitude reduction in certain frequency regions, they would obtain the opposite result for the GW polarization, which would agree with our findings [2].
[1] B. P. Abbott et al. (LIGO Scientific Collaboration and Virgo Collaboration), *Tests of General Relativity with GW170817*, arXiv:1811.00364 [gr-qc] (2018).

[2] A. A. Svidzinsky and R. C. Hilborn, *GW170817 event rules out general relativity in favor of vector gravity*, arXiv:1804.03520v2 [physics.gen-ph] (2018).

[3] A. A. Svidzinsky, *Vector theory of gravity: Universe without black holes and solution of dark energy problem*, Physica Scripta 92, 125001 (2017).

[4] A. A. Svidzinsky, *Simplified equations for gravitational field in the vector theory of gravity and new insights into dark energy*, arXiv:1810.07541 [physics.gen-ph] (2018).

[5] LIGO-Virgo Collaboration, *Data release for event GW170817*, Gravitational-wave strain data 16384 Hz sampling rate, https://losc.ligo.org/events/GW170817

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[7] C. F. Da Silva Costa, C. Billman, A. Effler, S. Klimenko and H. P. Cheng, *Regression of non-linear coupling of noise in LIGO detectors*, Class. Quantum Grav. 35, 055008 (2018).

[8] S. Fairhurst, *Localization of transient gravitational wave sources: beyond triangulation*, Class. Quantum Grav. 35, 105002 (2018).

[9] To obtain this estimate we applied data whitening procedure which assigns larger weight to frequency regions with better detector strain sensitivity.