

Carullo *et al.* Reply: Summary.—The Comment [1] discusses the impact on our analysis (“the Letter”) [2] of (i) a spurious shift in the discretized time axis within pyRing [3], and (ii) too short of an analysis segment ($T = 0.1$ s instead of $T \geq 0.2$ s).

In this Reply, we repeat the analysis including these two effects, alleviating some of the previous discrepancies observed with respect to Ref. [4]. However, even after accounting for the aforementioned effects, the Bayesian log evidence for an overtone remains negative, supporting the main findings of the Letter [2]. This overall conclusion is in agreement with two independent reanalyses, Refs. [5,6], and with Fig. 1 of Ref. [4], by the authors of the Comment [1]. The latter shows how at times consistent with the peak ($t \sim 2M$ in the units of that figure), the significance does not reach 2σ . The fact that the significance is much lower than the original 3.6σ estimate [7] in all of these works is a consequence of the uncertainty in t_{start} , not included in Ref. [7]. As we pointed out in the Letter [2] (following ideas introduced in Ref. [8]), accounting for this uncertainty is crucial to obtain unbiased results. This has proven to be important also in the recent analysis of Ref. [9].

Different choices of sampling rate (2048 Hz in Ref. [4], 16 384 Hz in the Letter [2]) and noise estimation methods (in the Letter [2] taken to be the same as in the original analysis of Ref. [7]) are behind the remaining differences. As shown in the Comment [1], the two codes give in fact indistinguishable output, if given identical inputs. The remaining technical differences give rise to appreciably different features in the parameters estimate, highlighting how at current detector sensitivity and when targeting short-lived components, such analyses can be significantly affected by technical details.

Results.—Figure 1 of this Reply updates Fig. 2 of the Letter [2]. Taking into account the remarks in the

Comment [1], we have increased the analysis duration from $T = 0.1$ s to $T = 0.2$ s and removed the time axis shift. The posteriors show a small shift in favor of an overtone at the t_{peak} value employed by Ref. [7], confirming an improved agreement with the latter analysis, but significant railing is still observed when the t_{peak} uncertainty is taken into account. The Bayesian log evidence for an overtone is negative throughout almost the entire time range. Comparing to Fig. 2 in the Comment [1], agreement is also observed in the injection set: noise (gray line there) frequently increases the overtone evidence, as expected given the current detection significance.

Although differing in the technical implementation and in certain analysis inputs, both our results and the ones of Ref. [4] agree with the reanalysis of Ref. [5]. Here, the authors employ frequency-domain methods and marginalize over the uncertainty in t_{peak} , reporting negative Bayesian evidence for an overtone and a significance of 1.8σ . Similar conclusions were found in Ref. [6].

Below, we address the specific technical points raised in the Comment [1].

Time axis shift.—In Refs. [2,4,7] the starting time of the analysis, t_{start} , is fixed and assumed to agree with t_{peak} , the time at which the gravitational-wave strain has a peak. The internal selection of t_{start} in pyRing conservatively selects the time-stamp immediately following the requested t_{start} . The time axis mislabeling pointed out in the Comment [1] implies a misidentification between the closest data time-stamp and t_{start} . At the sampling rate used in the Letter [2], this approximation leads to a shift of only ~ 0.06 ms. The statistical uncertainty in the value of t_{peak} determined from the data is ~ 2.5 ms, implying that the shift has a small impact on the analysis. This is confirmed by the bottom panel of Fig. 1 in the Comment [1]. The above

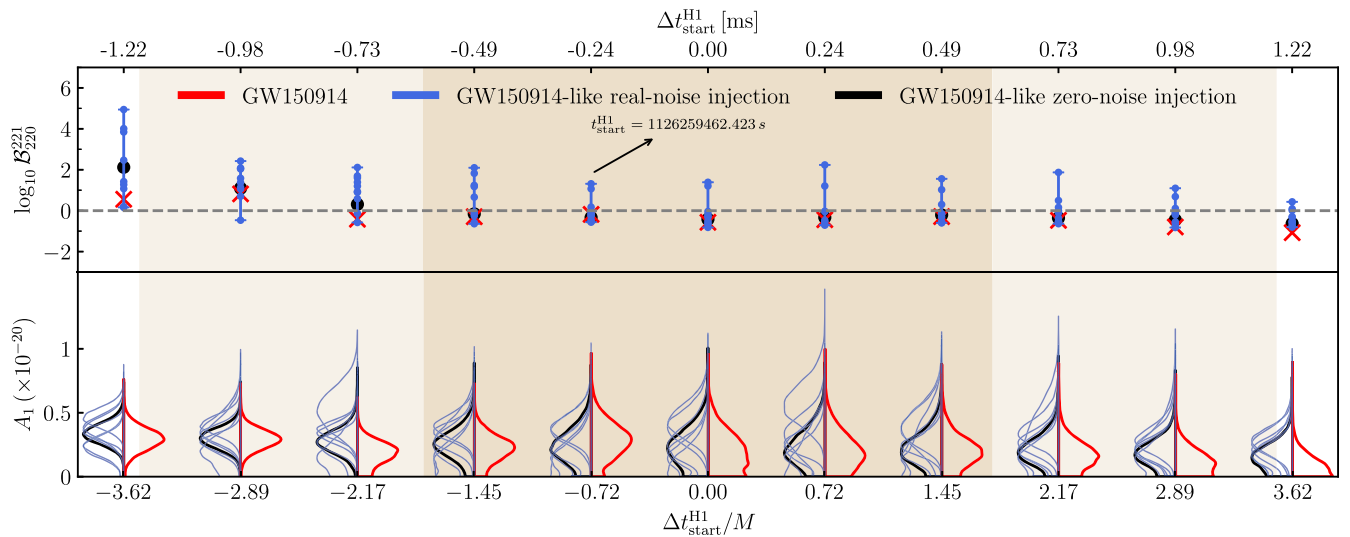


FIG. 1. Same as Fig. 2 in the Letter [2] but using the updated settings described above. The results were obtained with the pyRing commit 6d7d0e8d.

mislabeling has been removed since pyRing v2.1.0. Finally, the 0.24 ms shift in Fig. 2 of the Letter [2], mentioned in the Comment [1], was applied in post-processing for better comparison with Ref. [7] when using a lower sampling rate. This shift did not enter our analysis. To facilitate comparison with Ref. [4], we do not apply any time shift in Fig. 1 of this Reply.

Analysis duration.—While the signal power of the unfiltered GW150914 ringdown signal after 0.1 s is negligible, this may not be the case for the whitened signal entering the time-domain likelihood, which (depending on both the noise and model features) can be significantly stretched due to the overlap of the mode’s spectrum with the detector’s spectral lines. Increasing the analysis duration to $T = 0.2$ s produces a small increase in the inferred amplitude of the searched overtone, as shown in the bottom panel of Fig. 1 of the Comment [1], and in Fig. 1 of this Reply. However, while this increase is appreciable at t_{start} of Fig. 1 in [1] (corresponding to $-0.72M$ on our time axis), Fig. 1 above shows significant railing against zero when t_{start} is set to nearby values.

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Received 21 September 2023; accepted 26 September 2023; published 18 October 2023

DOI: [10.1103/PhysRevLett.131.169002](https://doi.org/10.1103/PhysRevLett.131.169002)

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