PHYSICAL REVIEW D **113,** 082004 (2026)

All-sky search for long-duration gravitational-wave transients in the first part of the fourth LIGO-Virgo-KAGRA observing run

A. G. Abac *et al.*[*]

(LIGO Scientific Collaboration, Virgo Collaboration, and KAGRA Collaboration)

(Received 24 July 2025; accepted 9 December 2025; published 27 April 2026)

We present an all-sky search for long-duration gravitational waves (GWs) from the first part of the LIGO-Virgo-KAGRA fourth observing run (O4), called O4a and comprising data taken between May 24, 2023, and January 16, 2024. The GW signals targeted by this search are the so-called "long-duration" ($\gtrsim 1$ s) transients expected from a variety of astrophysical processes, including nonaxisymmetric deformations in magnetars or eccentric binary coalescences. We make minimal assumptions on the emitted GW waveforms in terms of morphologies and durations. Overall, our search targets signals with durations of ~1–1000 s and frequency content in the range 16–2048 Hz. In the absence of significant detections, we report the sensitivity limits of our search in terms of root-sum-square signal amplitude ($h_{\rm rss}$) of reference waveforms. These limits improve upon the results from the third LIGO-Virgo-KAGRA observing run (O3) by about 30% on average. Moreover, this analysis demonstrates substantial progress in our ability to search for long-duration GW signals owing to enhancements in pipeline detection efficiencies. As detector sensitivities continue to advance and observational runs grow longer, unmodeled long-duration searches will increasingly be able to explore a range of compelling astrophysical scenarios involving neutron stars and black holes.

DOI: 10.1103/83j3-pgk1

I. INTRODUCTION

The direct detection of gravitational waves (GWs) from a pair of black holes (BHs) during the first observing run (O1) [1] of the Laser Interferometer Gravitational-wave Observatory (LIGO) [2] marked a major milestone in GW astrophysics. The detection of GWs from the binary neutron star (NS) merger GW170817 during the second LIGO and Virgo [3] observing run (O2) [4] initiated the era of multimessenger astrophysics, via the identification of an electromagnetic counterpart in practically all bands of the spectrum by a suite of electromagnetic observatories from the ground and space [5,6].

During the third observing run (O3) of Advanced LIGO, Virgo, and KAGRA [7,8], several other interesting compact binary systems were detected. These include a likely NS-NS merger with total mass significantly larger than that of known galactic binary NS systems [9]; BH-NS candidates [10]; pairs of compact objects with one of the two belonging to the so-called lower mass gap (the dividing line between the heaviest NSs and the lightest BHs) [11]; and a BH-BH coalescence whose compact remnant falls in the intermediate BH mass range [12]. In total, about 90 transient GW signals have been confidently detected in the O1–O3 runs, all of them confidently associated with compact binary coalescences (CBC) [13–15]. The O4 run is the longest LIGO-Virgo-KAGRA observing run to date. Similarly to the O1–O3 runs, the first eight months of O4 (called O4a) have brought new CBC detections, including the notable GW230529—a merger of a NS with a lower mass-gap BH [16].

While all of the above mentioned O1–O4 detections are exciting, we are yet to probe the large variety of astrophysical scenarios that predict GWs from systems other than CBCs. This motivates continued searches for other classes of GW signals (e.g., Refs. [17–23]). Here, we present a search for unmodeled, long-lived (~1–1000 s) GW transients in O4a data [24], updating previous results [17–19].

This analysis includes the first application of the XGBoost [25] postprocessing classifier of coherent waveburst (cWB) to long-duration GW searches (Sec. III), and results from the first PySTAMPAS [26] all-sky search for long-duration GWs (Sec. III). The use of diverse methods in the search for long-duration GW signals is motivated by the wide range of potential signal morphologies—including variations in duration, temporal evolution, and frequency content—expected from different astrophysical scenarios. Many of these scenarios remain unexplored and constraining them

---

[*] Full author list given at the end of the article.

via GW observations holds the promise of significantly advancing our understanding of the physics and astrophysics of compact objects. Hence, this analysis targets a variety of GW signals, including those produced by nonaxisymmetric deformations in newly born NSs or magnetars formed in massive star core collapses or binary NS mergers [27–30], fallback accretion onto newly born NSs or BHs [31–34], or instabilities and fragmentation in the accretion disks around BHs [35]. Low-mass CBCs can also generate GW signals that are relatively long-lived ($\gtrsim 1$ s) in the frequency band of ground-based GW detectors. Generally, these CBC signals are well-modeled and therefore are better searched for with matched filtering techniques [36]. However, here we also target low-mass (total mass $\leq 5 M_\odot$) CBCs with high eccentricity ($0.2 \leq e \leq 0.6$), as these do not fall within the parameter space covered by matched filter-based searches. Hereafter, we refer to these systems as eccentric compact binary coalescences (ECBCs). Our results complement other dedicated waveform-independent searches for high mass (source total mass $M \geq 70 M_\odot$) eccentric CBC signals with eccentricity $e \leq 0.3$ (e.g., Ref. [37]).

This paper is organized as follows. In Sec. II, we describe our dataset. Sections III and IV present our data analysis methods and the reference waveforms used to quantify our sensitivity, respectively. In Secs. V and VI, we report our results and conclude.

II. DATA

The LIGO-Virgo-KAGRA fourth observing run (O4) started on May 24, 2023, at 15∶00 UTC. The first part of the O4 observing run, O4a, ended on January 16, 2024, at 16:00 UTC. During O4a, the LIGO Hanford (LHO) and Livingston (LLO) detectors operated at improved sensitivity compared to their O3 run. A conventional measure of sensitivity is the binary neutron star (BNS) inspiral range, which quantifies the average distance at which a fiducial 1.4–1.4$M_\odot$ BNS could be detected with a signal-to-noise ratio (SNR) of 8 (see e.g., Ref. [38] and references therein). During O4a, the LHO and LLO detectors reached a BNS range of about 160 Mpc, corresponding to approximately 30% and 15% improvements, respectively, compared to O3 [39]. The Virgo detector did not join O4a.

The search algorithms employed in this work require coincident data from at least two detectors. Because the BNS range for the KAGRA detector was substantially smaller than that of the LIGO detectors in O4a, we do not include KAGRA data in our search, and we consider only data where both LIGO detectors are simultaneously available. A total of 126.6 days of coincident LHO-LLO data were collected during O4a. This corresponds to a duty cycle of about 53% for joint observations collecting so-called “ANALYSIS_READY” data. The last are data collected with the interferometers operating under observing conditions that are considered suitable for searching for GW signals. Removal of coincident data with significant data quality issues (by applying so-called “category 1” vetoes, as defined in [40]) left us with about 125 days of coincident LHO-LLO data [41]. Next, a small fraction (about 1%–2%) of this coincident data is discarded because their duration is shorter than the time window used by each pipeline (see Sec. III for details). Finally, as we describe in the next section, strategies to reduce the impact of glitches (transient noise events that have a variety of origins) resulted in a small ($\lesssim 1\%$) amount of data being removed from the analysis.

During O4a, the calibration uncertainty in the amplitude below 2 kHz was less than 10%, and it improved in the second half of O4a to be less than 2% below 2 kHz. Calibration uncertainty is not taken into account in the results presented in this paper, as these calibration errors are much smaller than the astrophysical uncertainties that affect the class of signals we target here.

III. SEARCH METHODS

Given the large uncertainties in potential postmerger GW signal characteristics (Fig. 3; [27–35]), hereafter we use two independent unmodeled search methods (and corresponding background estimations) that are based on different data-processing and clustering techniques: cWB [25,42] and PySTAMPAS [26]. In this section, we discuss briefly their basic workings. More details are provided in Secs. III A and III B.

Unmodeled searches for long-duration GW transients typically look for patterns of excess power in some time-frequency representation of the data and rely on the cross-correlation between the data streams of noncolocated detectors to distinguish actual astrophysical GWs from background events generated by instrumental or environmental noise in the detectors [43–52].

To estimate the distribution of background events, the data from one detector are time-shifted with respect to the other by an amount of time large enough to remove any coherent GW signal from the cross-correlated data. The process of time sliding the data is repeated multiple times for different values of the time shift to estimate the inverse false-alarm rate (iFAR) of potential candidate events accurately.

A. Coherent wave burst

cWB is an unmodeled transient search pipeline [42]. It is based on a multiresolution time-frequency wavelet transform known as Wilson-Daubechies-Meyer (WDM) [53]. Time-frequency pixels that contain excess energy (as estimated from the wavelet coefficients) across the detector network are selected and nearby pixels are clustered (Fig. 1, left panel). In the pixel selection process, periods where a known physical factor is affecting the detector’s data

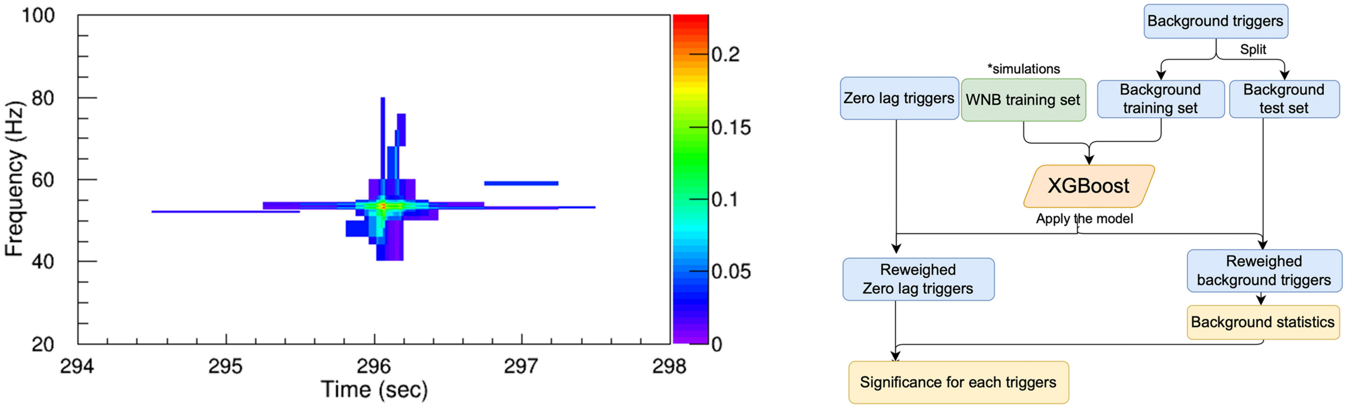

FIG. 1. Left: time-frequency representation of the loudest trigger found by cWB in O4a; the color bar represents the amplitude of the likelihood. Right: schematic workflow of cWB including trigger production step and XGBoost machine learning method used to evaluate ranking statistic of each trigger.

quality are removed (so-called “category 2” vetoes, defined as in [40,41]).

After the clustering step, cWB performs an all-sky search for each cluster of pixels by utilizing a likelihood algorithm computed over an equal area pixelated grid of sky positions obtained using the hierarchical equal area isolatitude pixelization (HEALPix[1]) scheme [54,55]. Triggers are reconstructed from the sky position where the likelihood reaches a maximum.

In the postprocessing, cWB (version 6.4.5.0) uses a supervised boosted decision tree classifier, XGBoost [25], to reweight the network coherent signal-to-noise ratio (SNR) of triggers (Fig. 1, right panel). The reweighted values are used as ranking statistics [56]. We note that this XGBoost reweighting procedure entirely replaces the waveform duration cut (and all other thresholds in postprocessing) used for cWB long-duration searches in O2 [17] and O3 [19]. Eliminating the duration cut enables long-duration searches on a larger parameter space, while enhancing sensitivity. Consequently, some CBC triggers with high SNR identified by cWB during the search retain high ranking statistics after the reweighting process. Hence, similar to the approach employed for short-duration signals [57], CBC signals are excised *a posteriori* from the analysis (see Sec. V and Fig. 4 for more details).

In the O4a long-duration analysis, the data are divided into four chunks of approximately equal duration across the approximately 122 days of observing time analyzed. The chunks are further split into 1200 s-long data segments, which are then transformed with the WDM wavelet into seven time-frequency resolutions (frequency bins ranging from 0.5 Hz to 16 Hz; time bins ranging from $1/64$ to 1 s) covering the frequency range 16–2048 Hz. To estimate the background distribution of noise triggers, time slides are performed by sliding the data between detectors 600 times in 2-second steps within each 1200 s-long data segment. A 2-second time step is longer than the longest time bin utilized for the cWB search and is sufficient to break any coherence in the time-frequency pixels. This process is further extended by performing shifts across different data segments of each chunk, resulting in a total of 2400 independent time shifts per chunk. This yields a background of about 772 years in total for the four chunks (half of which is used for training, as described below).

The XGBoost models for each chunk are trained independently with dedicated training sets. These training sets are created by randomly selecting 50% of the background data from the corresponding chunk, and injecting a series of white noise burst signals to cover the analysis frequency range. The produced XGBoost model is then applied to the remaining 50% background to produce the background statistical distribution. To evaluate the efficiency of the XGBoost model, a set of simulations with a selection of waveform models, as described in Sec. IV, is analyzed with the XGBoost models.

We note that in O4a, excessive noise fluctuations around the known 60 Hz and 180 Hz power lines and harmonics are observed in the background. Thus, in the postproduction, noise fluctuations at these frequencies are excised (from both the background and the foreground).

B. PySTAMPAS

PySTAMPAS [26] is an enhanced version of the stochastic transient analysis multidetector pipeline (STAMP) [58] that was used in previous analyses [18,19]. It is designed to perform unmodeled all-sky searches for long-duration GW transients at a reduced computational cost compared to STAMP [26]. The data are split into 512 s-long windows which overlap by 50%. For each window and each detector, spectrograms of the auto-power SNR are built using the short-time fourier transform (STFT) over short segments with duration 0.5, 1, 2, and 4 s that are Hann-windowed and

---

[1] http://healpix.sf.net

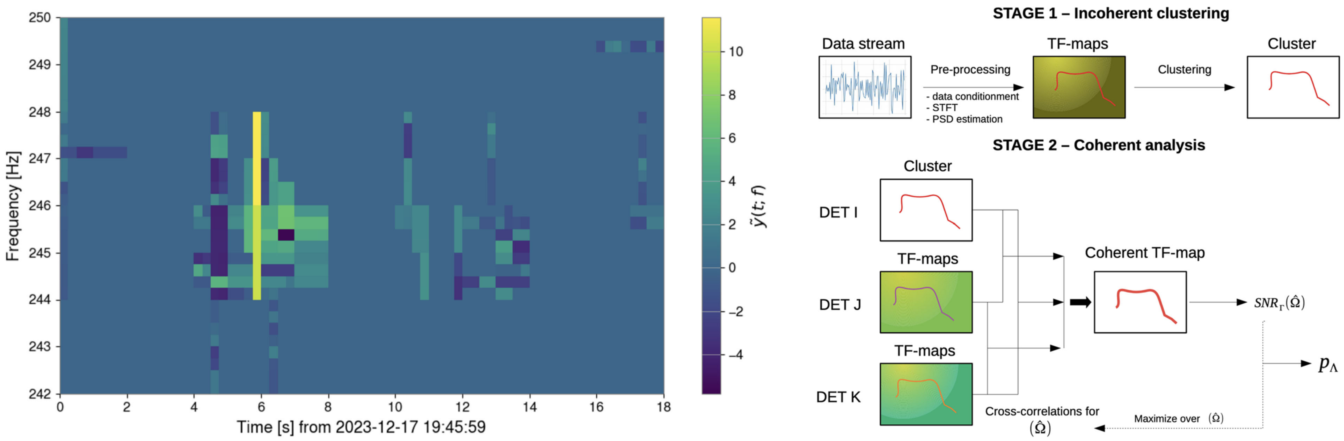

FIG. 2. Left: time-frequency representation of the loudest trigger found by PySTAMPAS in O4a. The color bar represents the coherent SNR in each pixel. Right: schematic workflow of PySTAMPAS for a generic three-detector network (in this work, only two detectors were used).

overlap by 50%. The four spectrograms are then combined into a single multiresolution spectrogram that covers the frequency band 22–2000 Hz. For each frequency bin, the power spectral density (PSD) is estimated by taking the median of the squared modulus of the STFT over the window duration. A seed-based clustering algorithm is applied on each multiresolution spectrogram to extract clusters of pixels that form candidate GW triggers. Pixels forming each cluster are then cross-correlated with the spectrogram from the other detector to compute a coherent SNR of the GW energy for each pixel. Finally, a detection statistic is built for the whole trigger [19], which is the sum of the coherent SNR of each pixel normalized by the square root of the number of pixels in the trigger [59]. The PySTAMPAS workflow is illustrated schematically in Fig. 2.

To estimate the background distribution of noise triggers, the spectrogram from the other detector is time-shifted by an amount of time greater than 1000 s. This is a conservative choice that allows us to break any coherence in time over the duration of the longest signals targeted by this search, regardless of signal frequency content. This operation is repeated 320 times with different values of the time shift, allowing to simulate 108 years of background. To deal with non-Gaussian noise artifacts, frequency bins that correspond to known spectral lines in the detectors and that generate an excess of noise triggers are masked. In total, 9% of the total frequency band is masked in this analysis. As was done in previous searches with STAMP [19], triggers for which the maximal fraction of SNR in a single time bin exceeds 0.3, or for which the ratio of auto-power SNR between the two detectors exceeds 5, or that have a duration lower than 10 s, are vetoed in postprocessing. Because of the high rate of noise fluctuations at low frequency, triggers whose central frequency is below 50 Hz are also dismissed. Finally, spectrograms for which the fraction of pixels above the threshold considered for clustering is above 0.5% are removed from the analysis. These correspond to unusually noisy stretches of data that the clustering algorithm is unable to handle. About 0.03% of the O4 data considered for this search (see Sec. II) are removed by this cut.

IV. WAVEFORM MODELS

The analysis presented here is an unmodeled search for GW signals, and as such it does not rely on the use of template waveforms to make detection statements. In the absence of a detection, to put our results in context, we quantify the sensitivity of our search by setting upper limits on the GW strain amplitude of a set of simulated waveforms added coherently into the detector data. We note that because of the limited distance reach of our analysis, we do not consider redshift effects on the model waveforms.

The waveform models used in this analysis include those from a similar search performed on O3 data [19]. These waveforms are representative of some compelling astrophysical scenarios, such as postmerger magnetars (magnetar) with ellipticity in the range 0.005–0.08 [30], accretion disk instabilities (ADI) [35], newly formed magnetars powering gamma-ray burst plateaus (GRBplateau) [27,31,60], inspiral-merger-ringdown ECBC waveforms [61] with an eccentricity between 0.2 and 0.6 and a total mass between 2.8 and $10M_\odot$, and broadband chirps from innermost stable circular orbit waves around rotating BHs with a mass between 5 and $20M_\odot$ (ISCOchirp) [34].

In addition to the above, we include in our analysis GW signals modeled for binary NS mergers (inspiralB), millisecond magnetars (msmagnetar-A), and fallback accretion onto NSs (PT-A; PT-B) with their time frequency representation shown in Fig. 3. The inspiral model employs the IMRPhenomPv2NRTidalv2 approximant for equal-mass binaries ($1.4M_\odot$) [62]. The millisecond magnetar model is an analytical model derived from the dynamics of spinning down nascent NSs proposed by Sarin *et al.*

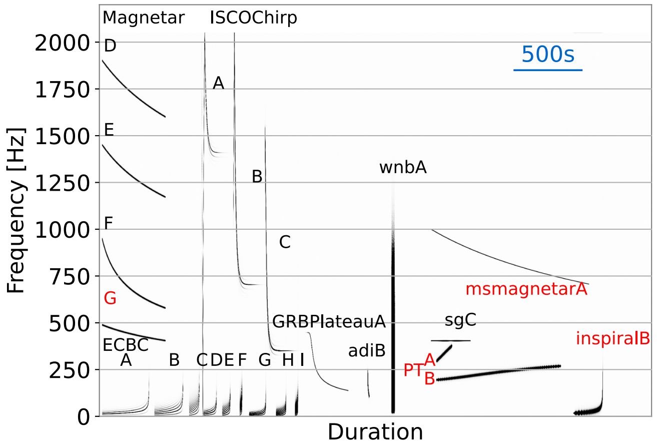

FIG. 3. Time-frequency representation of the waveforms used to test the sensitivity of this search. The x-axis represents a linear time axis with the various signal types off-set horizontally for clarity. Waveforms that are new in this analysis (compared to O2 [18,63] and O3 [19] long-duration burst searches) are marked in red.

[29] and Lasky *et al.* [28], with frequency evolution modeled with an arbitrary but fixed braking index. The PT models (A and B) were proposed by Piro and Thrane [33] for stars of intermediate mass that end their lives forming NSs, which eventually collapse to BHs via fall-back accretion. When the incoming material has sufficient angular momentum to form a disk, the accretion spins up the NS sufficiently to produce nonaxisymmetric instabilities and gravitational radiation with frequencies in the range 700–2400 Hz for about 30–3000 s until collapse to a BH occurs.

Finally, to fill out the parameter space, we perform sensitivity estimates also for "*ad-hoc*" waveforms: band-limited white noise burst (WNB) and sine-Gaussian bursts (SG).

V. RESULTS

Similarly to what was done in the O2 and O3 long-duration GW searches [18,19], for both the PySTAMPAS and cWB analyses we set a detection threshold corresponding to an iFAR higher than 50 years.

In the cWB analysis, we find 25 CBC triggers (11 of which with iFAR above the 50 years detection threshold) that were confidently detected by low-latency searches and subsequently reported as public alerts [64–88]. After excluding triggers associated with these known, quasicircular CBC events, the cWB search remains sensitive to ECBC signals. As shown in Fig. 4, the resulting distribution of cWB triggers is consistent with the background within 2σ. The most significant trigger has a SNR of 11, centered at 54 Hz, with an iFAR of 0.70 years and a false alarm probability (FAP) of 0.38. This trigger happened during a period of elevated glitch rate. This, combined with the estimated FAP of 0.38, suggests that the trigger is likely due to noise.

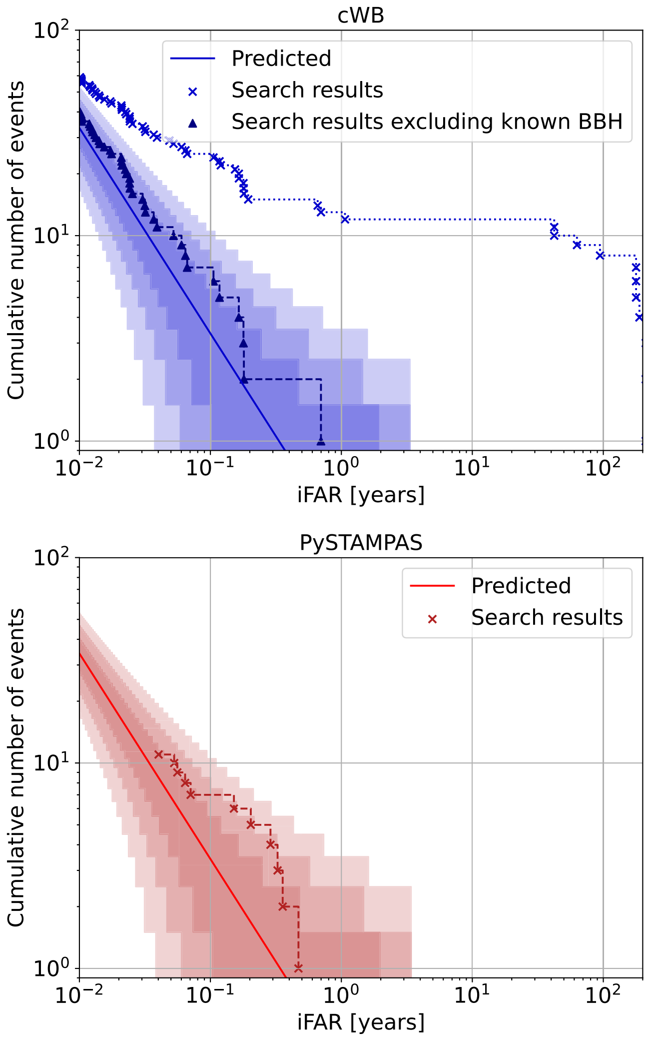

FIG. 4. Cumulative number of events as a function of the iFAR found by cWB (top) and PySTAMPAS (bottom). Cross markers represent all events found in the search, while triangle ones exclude known BBH events found in low latency. Assuming a Poisson distribution for noise events, the expected value for the background (i.e., T/iFAR, where T is the observing time) is shown by the solid line, while the shaded regions represents the $1-2-3\sigma$ uncertainties. We note that, because of its cumulative nature, the $\approx 2\sigma$ excess in the PySTAMPAS distribution over several iFAR bins is dominated by the contribution of the three loudest background events with the FAP being approximately 0.52, 0.62, and 0.65, respectively.

The distribution of triggers found by PySTAMPAS is also consistent with the background within 2σ, as shown in the bottom panel of Fig. 4. The most significant trigger has an iFAR of 0.49 years (FAP ≈ 0.52) and is consistent with a noise fluctuation in LLO between 242 Hz and 250 Hz. Given the cumulative nature of the distribution shown in Fig. 4, the $\approx 2\sigma$ excess that can be seen over several iFAR bins for PySTAMPAS is dominated by the contribution of the

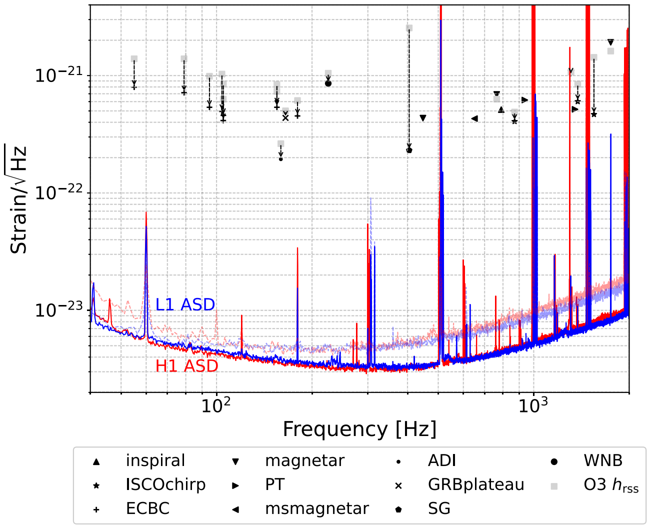

FIG. 5. Root-sum-square amplitude at 50% detection efficiency as a function of the central frequency of each tested waveform with iFAR > 50 years (black markers). The O3 results [19] are represented by light-gray square markers, showing the improvement in sensitivity (vertical arrows). For each waveform, the most constraining result from either of the two pipelines is shown. For reference, the mean amplitude spectral densities of the Livingston (blue) and Hanford (red) detectors during O4a are plotted, along with those from the O3b (faded dashed curves).

three loudest background events, with the FAP being approximately 0.52, 0.62, and 0.65, respectively. The loudest of these triggers is shown in the left panel of Fig. 2. PySTAMPAS did not recover any of the CBC triggers identified by cWB because these had durations shorter than 10 s and are therefore removed in post-processing.

In the absence of a significant GW candidate in either analysis, we derive sensitivity estimates on the GW amplitude of the various waveform models described in Sec. IV. To this end, simulated waveforms are injected coherently into the detectors' data at different amplitudes, and the detection efficiency (fraction of the total number of injections that are recovered) is measured as a function of waveform amplitude. The spanned range of amplitudes is chosen so that the detection efficiency is sampled across the whole range of its possible values—from 0% to 100%. For each injected signal of a given amplitude, the starting time, sky position (right ascension and cosine of the declination), polarization angle, and cosine of the inclination angle are randomly drawn following a uniform distribution. We note that for estimating the detection efficiency, a signal is considered to be recovered by a given pipeline if it produces a trigger within the time and frequency boundaries of the injected waveform, with an iFAR higher than 50 years.

The results are presented in Fig. 5 as root-sum-square amplitudes ($h_{\rm rss}$) at 50% detection efficiency, where

$$h_{\rm rss} = \sqrt{\int_{-\infty}^{\infty} (h_+^2(t) + h_\times^2(t))dt}. \tag{1}$$

In the above equation, h_+ and $h_\times$ are the GW amplitudes for the + and × polarizations. For each waveform, the lowest value from either of the two pipelines is reported. We discuss these results in Sec. VI.

TABLE I. Rate upper limits per unit volume at 90% confidence level on eccentric CBC with various component masses and eccentricity e, computed with Eq. (2). In the last column, we show updated results from the O3 run, which we have recomputed as discussed in Sec. VI. We find that uncertainties on these values are dominated by systematic errors associated to the method used to fit the efficiency curves, estimated to be of order 15% (see text for discussion).

				$\mathcal{R}_{90\%}$ [Gpc^{-3} yr^{-1}]	
Waveform	$M_1\,[M_\odot]$	$M_2\,[M_\odot]$	e	O4a	O3
ECBC_A	1.4	1.4	0.2	9.1×10^3	2.0×10^4
ECBC_B	1.4	1.4	0.4	1.1×10^4	2.4×10^4
ECBC_C	1.4	1.4	0.6	1.8×10^4	4.4×10^4
ECBC_D	3.0	3.0	0.2	1.3×10^3	4.6×10^3
ECBC_E	3.0	3.0	0.4	1.4×10^3	5.5×10^3
ECBC_F	3.0	3.0	0.6	3.7×10^3	8.9×10^3
ECBC_G	5.0	5.0	0.2	4.2×10^2	3.0×10^3
ECBC_H	5.0	5.0	0.4	5.2×10^2	4.0×10^3
ECBC_I	5.0	5.0	0.6	8.0×10^2	4.7×10^3

We also derive upper limits on the rate of eccentric CBC events (ECBCs), updating previous results from O2 [18] and O3 [19]. In the absence of a detection, assuming that these events are uniformly distributed in the observed volume and follow a Poisson distribution, the 90% confidence upper limit on their rates is given by [89]

$$\mathcal{R}_{90\%} = \frac{2.3}{4\pi T \int_0^{r_{\rm max}} dr\, r^2\, \epsilon(r)}, \tag{2}$$

where $\epsilon(r)$ is the detection efficiency as a function of distance r, $r_{\rm max}$ is the maximal detectable distance, and T is the observing time [90]. In Table I, we report our best results, derived using the cWB pipeline (which has the best sensitivity for this family of waveforms). We discuss these results in Sec. VI.

VI. DISCUSSION

The $h_{\rm rss}$ at 50% efficiency of this O4a search has decreased by 30% (on average across the detector bandwidth) compared to O3 (Fig. 5). This improvement is primarily driven by the sensitivity increase of the LIGO detectors between O3 and O4a. However, the pipelines used for this search are also different from the ones used in O3. This improves the O4a sensitivity (compared to O3) for most waveforms. Specifically, the ECBCs are better recovered than in O3 (up to a factor about 2 lower in h_{rss} at 50% efficiency), because the new version of cWB, enhanced with XGBoost, better discriminates these signals from noise transients [25]. The sensitivity to monochromatic SGs has also improved by a factor of about 10 thanks to a more robust PSD estimation in PySTAMPAS (which is now based on the median PSD over a time window longer than twice the duration of the signal). The sensitivity to magnetar waveforms has not improved compared to O3, as these signals are best recovered using the seedless clustering strategy used in O3 [45]. The seedless clustering strategy is being developed in the PySTAMPAS package at the time of writing. Hence, this strategy has not been used for the O4a results presented here.

To put the above results in the context of previous analyses, we note that the O3 long-duration search broadly constrained GW signals with energies of order $10^{-2}M_\odot$ (comparable to the maximum rotational energy of a $1.4M_\odot$ NS [91]), and morphologies similar to the ones considered here, to distances $\gtrsim$1–10 Mpc (see Fig. 2 in [19]). For a GW signal with an energy E_{GW} and central frequency f_0, the horizon distance d corresponding to a given h_{rss} is $d \simeq \sqrt{\frac{5GE_{\mathrm{GW}}}{2\pi^2 c^3 f_0^2 h_{\mathrm{rss}}^2}}$ [92]. The overall improvement of ≈30% in h_{rss} at 50% efficiency achieved via this analysis pushes the above lower limits on the distances to values about 30% larger.

We also derive rate upper limits on ECBC events (Table I). The upper limits range from 420 $\mathrm{Gpc}^{-3}\ \mathrm{yr}^{-1}$ to 18,000 $\mathrm{Gpc}^{-3}\ \mathrm{yr}^{-1}$ depending on the mass and eccentricity of the system. These ECBC rate constraints are compatible with expectations that, overall, only a small fraction of CBC systems have a significant eccentricity [93] given current estimates of CBC rates ($10-1700\ \mathrm{Gpc}^{-3}\ \mathrm{yr}^{-1}$ for NS-NS systems, $7.8-140\ \mathrm{Gpc}^{-3}\ \mathrm{yr}^{-1}$ for NS-BH, and $17.9-44\ \mathrm{Gpc}^{-3}\ \mathrm{yr}^{-1}$ for BH-BH [94]).

The above rate upper limits on ECBCs require a careful sampling and modeling of the tail of the detection efficiency curve at large distances. For this analysis (O4a column in Table I), we revisit and improve the efficiency estimation procedure that was employed in O3. First, we use a quadratic interpolation of the sampled efficiency values instead of the sigmoid fit used in O3 [19]. To assess the robustness of the quadratic interpolation, we compare our results with a log-normal distribution fit and a linear interpolation. Both these methods give results consistent with the quadratic interpolation within about 15% of the estimated rate upper limit. On the other hand, a sigmoid fit systematically overestimates the detection volume (the integral in the denominator of Eq. (2), resulting in an underestimate of the 90% rate upper limits by a factor of about 2–3 across different waveforms and detection pipelines. An example of this is presented in Fig. 6. As a second improvement to our detection efficiency estimates, we limit the r_{max} in Eq. (2) to the highest sampled distance so as to ensure that the 90% rate upper-limits are not affected by errors that may be introduced when extrapolating fits or interpolations to the efficiency curves at distances beyond the range that was actually sampled. In the O3 long duration search [19], the lack of the above constraint resulted in an underestimation of the rate upper limits by a factor of about 5 (on average across ECBC waveforms) for the cWB pipeline. This issue did not affect the O3 STAMP-AS Zebragard results [19].

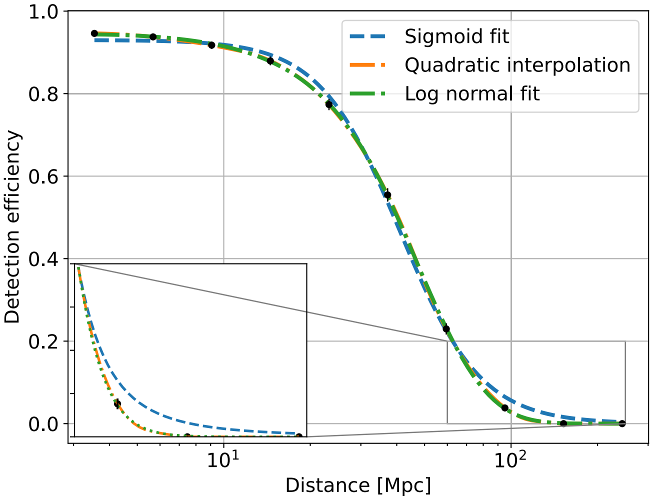

FIG. 6. Detection efficiency as a function of the distance recovered by cWB for the ECBC-A waveform model on O4a data. The black dots represent data points, the dashed, dashed-dotted, and dash-dot-dotted curves represent a sigmoid function fit, a quadratic interpolation, and a log-normal fit, respectively. This illustrates how a sigmoid fit overestimates the detection efficiency at large distances, leading to a detection volume overestimated by a factor ~2 in that case.

Given the above noted improvements in the detection volume estimates, in the rightmost column of Table I we compare our O4a results with the rate upper limits that we derive applying the same efficiency curve estimation of our O4a analysis to the (previously unpublished) O3 STAMP-AS Zebragard results for ECBCs. The O4a upper limits improve on the O3 results by factors of about 2–7, consistent with the improvement in sensitivity shown in Fig. 5 and the fact that the observing time of O4a is about half of O3. Indeed, for this waveform family, the improved O4a sensitivity implies a distance reach of about 1.4–2.4 times larger than in O3, hence a detection volume about 2.7–14 times larger and therefore rate upper limits that are 1.4–7 times smaller.

In conclusion, with this O4a analysis, we have made substantial progress in our ability to search for long-duration GW signals, thanks to the combination of the improved O4a sensitivity and enhancements in pipeline detection efficiencies. With further progress in GW detectors' sensitivity [95] and longer data taking runs, long-duration unmodeled searches have the potential to probe several interesting astrophysical scenarios involving NSs and BHs [27–35]. We note that the pipeline improvements introduced in this search extend beyond refining population-level constraints on long-duration GW sources. They also enhance the sensitivity of in-depth investigations of any candidate event that may be identified in all-sky searches like the one presented here, and they can strengthen triggered searches for long-duration postmerger signals [63,96]. These advances directly support efforts to address one of the major open questions highlighted by the multimessenger observations of GW170817: the nature of the postmerger remnant.

ACKNOWLEDGMENTS

This material is based upon work supported by NSF's LIGO Laboratory, which is a major facility fully funded by the National Science Foundation. The authors also gratefully acknowledge the support of the Science and Technology Facilities Council (STFC) of the United Kingdom, the Max-Planck-Society (MPS), and the State of Niedersachsen/Germany for support of the construction of Advanced LIGO and construction and operation of the GEO 600 detector. Additional support for Advanced LIGO was provided by the Australian Research Council. The authors gratefully acknowledge the Italian Istituto Nazionale di Fisica Nucleare (INFN), the French Centre National de la Recherche Scientifique (CNRS) and the Netherlands Organization for Scientific Research (NWO) for the construction and operation of the Virgo detector and the creation and support of the EGO consortium. The authors also gratefully acknowledge research support from these agencies as well as by the Council of Scientific and Industrial Research of India, the Department of Science and Technology, India, the Science & Engineering Research Board (SERB), India, the Ministry of Human Resource Development, India, the Spanish Agencia Estatal de Investigación (AEI), the Spanish Ministerio de Ciencia, Innovación y Universidades, the European Union NextGenerationEU/PRTR (PRTR-C17.I1), the ICSC—CentroNazionale di Ricerca in High Performance Computing, Big Data and Quantum Computing, funded by the European Union NextGenerationEU, the Comunitat Autonòma de les Illes Balears through the Conselleria d'Educació i Universitats, the Conselleria d'Innovació, Universitats, Ciència i Societat Digital de la Generalitat Valenciana and the CERCA Programme Generalitat de Catalunya, Spain, the Polish National Agency for Academic Exchange, the National Science Centre of Poland and the European Union - European Regional Development Fund; the Foundation for Polish Science (FNP), the Polish Ministry of Science and Higher Education, the Swiss National Science Foundation (SNSF), the Russian Science Foundation, the European Commission, the European Social Funds (ESF), the European Regional Development Funds (ERDF), the Royal Society, the Scottish Funding Council, the Scottish Universities Physics Alliance, the Hungarian Scientific Research Fund (OTKA), the French Lyon Institute of Origins (LIO), the Belgian Fonds de la Recherche Scientifique (FRS-FNRS), Actions de Recherche Concertées (ARC) and Fonds Wetenschappelijk Onderzoek - Vlaanderen (FWO), Belgium, the Paris Île-de-France Region, the National Research, Development and Innovation Office of Hungary (NKFIH), the National Research Foundation of Korea, the Natural Sciences and Engineering Research Council of Canada (NSERC), the Canadian Foundation for Innovation (CFI), the Brazilian Ministry of Science, Technology, and Innovations, the International Center for Theoretical Physics South American Institute for Fundamental Research (ICTP-SAIFR), the Research Grants Council of Hong Kong, the National Natural Science Foundation of China (NSFC), the Israel Science Foundation (ISF), the US-Israel Binational Science Fund (BSF), the Leverhulme Trust, the Research Corporation, the National Science and Technology Council (NSTC), Taiwan, the United States Department of Energy, and the Kavli Foundation. The authors gratefully acknowledge the support of the NSF, STFC, INFN and CNRS for provision of computational resources. This work was supported by MEXT, the JSPS Leading-edge Research Infrastructure Program, JSPS Grant-in-Aid for Specially Promoted Research 26000005, JSPS Grant-in-Aid for Scientific Research on Innovative Areas 2402: 24103006, 24103005, and 2905: JP17H06358, JP17H06361 and JP17H06364, JSPS Core-to-Core Program A. Advanced Research Networks, JSPS Grants-in-Aid for Scientific Research (S) 17H06133 and 20H05639, JSPS Grant-in-Aid for Transformative Research Areas (A) 20A203: JP20H05854, the joint research program of the Institute for Cosmic Ray Research, University of Tokyo, the National Research Foundation (NRF), the Computing Infrastructure Project of the Global Science experimental Data hub Center (GSDC) at KISTI, the Korea Astronomy and Space Science Institute (KASI), the Ministry of Science and ICT (MSIT) in Korea, Academia Sinica (AS), the AS Grid Center (ASGC) and the National Science and Technology Council (NSTC) in Taiwan under grants including the Science Vanguard Research Program, the Advanced Technology Center (ATC) of NAOJ, and the Mechanical Engineering Center of KEK.

DATA AVAILABILITY

The data that support the findings of this article are openly available [24]. All raw data corresponding to the findings in this manuscript can be found in [24] and [97].

[1] B. P. Abbott, R. Abbott, T. D. Abbott, M. R. Abernathy, F. Acernese *et al.*, Phys. Rev. Lett. **116**, 061102 (2016).

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

[3] F. Acernese *et al.*, Classical Quantum Gravity **32**, 024001 (2015).

[4] B. P. Abbott, R. Abbott, T. D. Abbott, F. Acernese, K. Ackley *et al.*, Phys. Rev. Lett. **119**, 161101 (2017).

[5] B. P. Abbott, R. Abbott, T. D. Abbott, F. Acernese, K. Ackley *et al.*, Astrophys. J. Lett. **848**, L13 (2017).

[6] B. P. Abbott, R. Abbott, T. D. Abbott, F. Acernese, K. Ackley *et al.*, Astrophys. J. Lett. **848**, L12 (2017).

[7] T. Akutsu *et al.*, Nat. Astron. **3**, 35 (2019).

[8] T. Akutsu *et al.*, Prog. Theor. Exp. Phys. **2021**, 05A102 (2021).

[9] B. P. Abbott, R. Abbott, T. D. Abbott, S. Abraham, F. Acernese *et al.*, Astrophys. J. Lett. **892**, L3 (2020).

[10] R. Abbott, T. D. Abbott, S. Abraham, F. Acernese, K. Ackley *et al.*, Astrophys. J. Lett. **915**, L5 (2021).

[11] R. Abbott, T. D. Abbott, S. Abraham, F. Acernese, K. Ackley *et al.*, Astrophys. J. Lett. **896**, L44 (2020).

[12] R. Abbott, T. D. Abbott, S. Abraham, F. Acernese, K. Ackley *et al.*, Phys. Rev. Lett. **125**, 101102 (2020).

[13] B. P. Abbott, R. Abbott, T. D. Abbott, S. Abraham *et al.*, Phys. Rev. X **9**, 031040 (2019).

[14] R. Abbott, T. D. Abbott, F. Acernese, K. Ackley, C. Adams *et al.*, Phys. Rev. D **109**, 022001 (2024).

[15] R. Abbott, T. D. Abbott, F. Acernese, K. Ackley, C. Adams *et al.*, Phys. Rev. X **13**, 041039 (2023).

[16] A. G. Abac, R. Abbott, I. Abouelfettouh, F. Acernese, K. Ackley *et al.*, Astrophys. J. Lett. **970**, L34 (2024).

[17] B. P. Abbott *et al.*, Classical Quantum Gravity **35**, 065009 (2018).

[18] B. P. Abbott, R. Abbott, T. D. Abbott, S. Abraham, F. Acernese *et al.*, Phys. Rev. D **99**, 104033 (2019).

[19] R. Abbott, T. D. Abbott, F. Acernese, K. Ackley, C. Adams *et al.*, Phys. Rev. D **104**, 102001 (2021).

[20] R. Abbott, H. Abe, F. Acernese, K. Ackley, N. Adhikari *et al.*, Phys. Rev. D **106**, 102008 (2022).

[21] R. Abbott, T. D. Abbott, F. Acernese, K. Ackley, C. Adams *et al.*, Astrophys. J. **955**, 155 (2023).

[22] R. Abbott, H. Abe, F. Acernese, K. Ackley, N. Adhikari *et al.*, Astrophys. J. **966**, 137 (2024).

[23] A. G. Abac, R. Abbott, I. Abouelfettouh, F. Acernese, K. Ackley *et al.*, Astrophys. J. **985**, 183 (2025).

[24] LIGO Scientific Collaboration, Virgo Collaboration, and KAGRA Collaboration, arXiv:2508.18079.

[25] T. Chen and C. Guestrin, arXiv:1603.02754.

[26] A. Macquet, M. A. Bizouard, N. Christensen, and M. Coughlin, companion paper, Phys. Rev. D **104**, 102005 (2021).

[27] A. Corsi and P. Mészáros, Astrophys. J. **702**, 1171 (2009).

[28] P. D. Lasky, C. Leris, A. Rowlinson, and K. Glampedakis, Astrophys. J. Lett. **843**, L1 (2017).

[29] N. Sarin, P. D. Lasky, L. Sammut, and G. Ashton, Phys. Rev. D **98**, 043011 (2018).

[30] S. Dall'Osso, B. Giacomazzo, R. Perna, and L. Stella, Astrophys. J. **798**, 25 (2015).

[31] D. Lai and S. L. Shapiro, Astrophys. J. **442**, 259 (1995).

[32] A. L. Piro and C. D. Ott, Astrophys. J. **736**, 108 (2011).

[33] A. L. Piro and E. Thrane, Astrophys. J. **761**, 63 (2012).

[34] M. H. P. M. van Putten, Astrophys. J. **819**, 169 (2016).

[35] M. H. P. M. van Putten, Phys. Rev. Lett. **87**, 091101 (2001).

[36] LVK Collaboration, Mon. Not. R. Astron. Soc. **524**, 5984 (2023).

[37] A. G. Abac, R. Abbott, H. Abe, F. Acernese, K. Ackley *et al.*, Astrophys. J. **973**, 132 (2024).

[38] H.-Y. Chen, D. E. Holz, J. Miller, M. Evans, S. Vitale, and J. Creighton, Classical Quantum Gravity **38**, 055010 (2021).

[39] E. Capote, W. Jia, N. Aritomi, M. Nakano, V. Xu *et al.*, Phys. Rev. D **111**, 062002 (2025).

[40] D. Davis, J. S. Areeda, B. K. Berger, R. Bruntz, A. Effler *et al.*, Classical Quantum Gravity **38**, 135014 (2021).

[41] S. Soni, B. K. Berger, D. Davis, F. Di Renzo, A. Effler *et al.*, Classical Quantum Gravity **42**, 085016 (2025).

[42] M. Drago, S. Klimenko, C. Lazzaro, E. Milotti, G. Mitselmakher, V. Necula, B. O'Brian, G. A. Prodi, F. Salemi, M. Szczepanczyk, S. Tiwari, V. Tiwari, V. Gayathri, G. Vedovato, and I. Yakushin, SoftwareX **14**, 100678 (2021).

[43] E. Thrane, S. Kandhasamy, C. D. Ott, W. G. Anderson, N. L. Christensen *et al.*, Phys. Rev. D **83**, 083004 (2011).

[44] E. Thrane and M. Coughlin, Phys. Rev. Lett. **115**, 181102 (2015).

[45] E. Thrane and M. Coughlin, Phys. Rev. D **88**, 083010 (2013).

[46] E. Thrane and M. Coughlin, Phys. Rev. D **89**, 063012 (2014).

[47] R. Khan and S. Chatterji, Classical Quantum Gravity **26**, 155009 (2009).

[48] A. Macquet, M. A. Bizouard, N. Christensen, and M. Coughlin, Phys. Rev. D **104**, 102005 (2021).

[49] V. Boudart and M. Fays, Phys. Rev. D **105**, 083007 (2022).

[50] V. Boudart, Phys. Rev. D **107**, 024007 (2023).

[51] S. Klimenko, G. Vedovato, M. Drago, F. Salemi, V. Tiwari, G. A. Prodi, C. Lazzaro, K. Ackley, S. Tiwari, C. F. Da Silva, and G. Mitselmakher, Phys. Rev. D **93**, 042004 (2016).

[52] R. Coyne, A. Corsi, and B. J. Owen, Phys. Rev. D **93**, 104059 (2016).

[53] V. Necula, S. Klimenko, and G. Mitselmakher, J. Phys. Conf. Ser. **363**, 012032 (2012).

[54] A. Zonca, L. Singer, D. Lenz, M. Reinecke, C. Rosset, E. Hivon, and K. Gorski, J. Open Source Software **4**, 1298 (2019).

[55] K. M. Górski, E. Hivon, A. J. Banday, B. D. Wandelt, F. K. Hansen, M. Reinecke, and M. Bartelmann, Astrophys. J. **622**, 759 (2005).

[56] M. J. Szczepańczyk, F. Salemi, S. Bini, T. Mishra, G. Vedovato, V. Gayathri, I. Bartos, S. Bhaumik, M. Drago, O. Halim, C. Lazzaro, A. Miani, E. Milotti, G. A. Prodi, S. Tiwari, and S. Klimenko, Phys. Rev. D **107**, 062002 (2023).

[57] LIGO Scientific Collaboration, Virgo Collaboration, and KAGRA Collaboration, Phys. Rev. D **112**, 102005 (2025).

[58] E. Thrane, S. Kandhasamy, C. D. Ott, W. G. Anderson, N. L. Christensen, M. W. Coughlin, S. Dorsher, S. Giampanis, V. Mandic, A. Mytidis, T. Prestegard, P. Raffai, and B. Whiting, Phys. Rev. D **83**, 083004 (2011).

[59] E. Thrane and M. Coughlin, Phys. Rev. Lett. **115**, 181102 (2015).

[60] R. Coyne, A. Corsi, and B. J. Owen, Phys. Rev. D **93**, 104059 (2016).

[61] E. A. Huerta, C. J. Moore, P. Kumar, D. George, A. J. K. Chua *et al.*, Phys. Rev. D **97**, 024031 (2018).

[62] T. Dietrich, A. Samajdar, S. Khan, N. K. Johnson-McDaniel, R. Dudi, and W. Tichy, Phys. Rev. D **100**, 044003 (2019).

[63] B. P. Abbott, R. Abbott, T. D. Abbott, F. Acernese, K. Ackley *et al.*, Astrophys. J. Lett. **851**, L16 (2017).

[64] LIGO Scientific Collaboration, Virgo Collaboration, and KAGRA Collaboration, GRB Coordinates Network **33917**, 1 (2023), https://ui.adsabs.harvard.edu/abs/2023GCN.33917....1L/abstract.

[65] LIGO Scientific Collaboration, Virgo Collaboration, and KAGRA Collaboration, GRB Coordinates Network **33914**, 1 (2023), https://ui.adsabs.harvard.edu/abs/2023GCN.33914....1L/abstract.

[66] LIGO Scientific Collaboration, Virgo Collaboration, and KAGRA Collaboration, GRB Coordinates Network **34075**, 1 (2023), https://ui.adsabs.harvard.edu/abs/2023GCN.34075....1L/abstract.

[67] LIGO Scientific Collaboration, Virgo Collaboration, and KAGRA Collaboration, GRB Coordinates Network **34086**, 1 (2023), https://ui.adsabs.harvard.edu/abs/2023GCN.34086....1L/abstract.

[68] LIGO Scientific Collaboration, Virgo Collaboration, and KAGRA Collaboration, GRB Coordinates Network **34113**, 1 (2023), https://ui.adsabs.harvard.edu/abs/2023GCN.34113....1L/abstract.

[69] LIGO Scientific Collaboration, Virgo Collaboration, and KAGRA Collaboration, GRB Coordinates Network **34161**, 1 (2023), https://ui.adsabs.harvard.edu/abs/2023GCN.34161....1L/abstract.

[70] LIGO Scientific Collaboration, Virgo Collaboration, and KAGRA Collaboration, GRB Coordinates Network **34380**, 1 (2023), https://ui.adsabs.harvard.edu/abs/2023GCN.34380....1L/abstract.

[71] LIGO Scientific Collaboration, Virgo Collaboration, and KAGRA Collaboration, GRB Coordinates Network **34411**, 1 (2023), https://ui.adsabs.harvard.edu/abs/2023GCN.34411....1L/abstract.

[72] LIGO Scientific Collaboration, Virgo Collaboration, and KAGRA Collaboration, GRB Coordinates Network **34504**, 1 (2023), https://ui.adsabs.harvard.edu/abs/2023GCN.34504....1L/abstract.

[73] LIGO Scientific Collaboration, Virgo Collaboration, and KAGRA Collaboration, GRB Coordinates Network **34692**, 1 (2023), https://ui.adsabs.harvard.edu/abs/2023GCN.34692....1L/abstract.

[74] LIGO Scientific Collaboration, Virgo Collaboration, and KAGRA Collaboration, GRB Coordinates Network **34741**, 1 (2023), https://ui.adsabs.harvard.edu/abs/2023GCN.34741....1L/abstract.

[75] LIGO Scientific Collaboration, Virgo Collaboration, and KAGRA Collaboration, GRB Coordinates Network **34775**, 1 (2023), https://ui.adsabs.harvard.edu/abs/2023GCN.34775....1L/abstract.

[76] LIGO Scientific Collaboration, Virgo Collaboration, and KAGRA Collaboration, GRB Coordinates Network **34739**, 1 (2023), https://ui.adsabs.harvard.edu/abs/2023GCN.34739....1L/abstract.

[77] LIGO Scientific Collaboration, Virgo Collaboration, and KAGRA Collaboration, GRB Coordinates Network **34756**, 1 (2023), https://ui.adsabs.harvard.edu/abs/2023GCN.34756....1L/abstract.

[78] LIGO Scientific Collaboration, Virgo Collaboration, and KAGRA Collaboration, GRB Coordinates Network **34760**, 1 (2023), https://ui.adsabs.harvard.edu/abs/2023GCN.34760....1L/abstract.

[79] LIGO Scientific Collaboration, Virgo Collaboration, and KAGRA Collaboration, GRB Coordinates Network **34799**, 1 (2023), https://ui.adsabs.harvard.edu/abs/2023GCN.34799....1L/abstract.

[80] LIGO Scientific Collaboration, Virgo Collaboration, and KAGRA Collaboration, GRB Coordinates Network **34895**, 1 (2023), https://ui.adsabs.harvard.edu/abs/2023GCN.34895....1L/abstract.

[81] LIGO Scientific Collaboration, Virgo Collaboration, and KAGRA Collaboration, GRB Coordinates Network **34927**, 1 (2023), https://ui.adsabs.harvard.edu/abs/2023GCN.34927....1L/abstract.

[82] LIGO Scientific Collaboration, Virgo Collaboration, and KAGRA Collaboration, GRB Coordinates Network **34967**, 1 (2023), https://ui.adsabs.harvard.edu/abs/2023GCN.34967....1L/abstract.

[83] LIGO Scientific Collaboration, Virgo Collaboration, and KAGRA Collaboration, GRB Coordinates Network **35168**, 1 (2023), https://ui.adsabs.harvard.edu/abs/2023GCN.35168....1L/abstract.

[84] LIGO Scientific Collaboration, Virgo Collaboration, and KAGRA Collaboration, GRB Coordinates Network **35297**, 1 (2023), https://ui.adsabs.harvard.edu/abs/2023GCN.35297....1L/abstract.

[85] LIGO Scientific Collaboration, Virgo Collaboration, and KAGRA Collaboration, GRB Coordinates Network **35298**, 1 (2023), https://ui.adsabs.harvard.edu/abs/2023GCN.35298....1L/abstract.

[86] LIGO Scientific Collaboration, Virgo Collaboration, and KAGRA Collaboration, GRB Coordinates Network **35420**, 1 (2023), https://ui.adsabs.harvard.edu/abs/2023GCN.35420....1L/abstract.

[87] D. Belardinelli, GRB Coordinates Network **35428**, 1 (2023), https://ui.adsabs.harvard.edu/abs/2023GCN.35428....1B/abstract.

[88] LIGO Scientific Collaboration, Virgo Collaboration, and KAGRA Collaboration, GRB Coordinates Network **35493**, 1 (2024), https://ui.adsabs.harvard.edu/abs/2024GCN.35493....1L/abstract.

[89] P. R. Brady, J. D. E. Creighton, and A. G. Wiseman, Classical Quantum Gravity **21**, S1775 (2004).

[90] J. Abadie *et al.*, Phys. Rev. D **85**, 122007 (2012).

[91] P. Beniamini, D. Giannios, and B. D. Metzger, Mon. Not. R. Astron. Soc. **472**, 3058 (2017).

[92] P. J. Sutton, arXiv:1304.0210.
[93] P. C. Peters, Phys. Rev. **136**, B1224 (1964).
[94] R. Abbott, T. D. Abbott, F. Acernese, K. Ackley, C. Adams *et al.*, Phys. Rev. X **13**, 011048 (2023).
[95] B. P. Abbott, R. Abbott, T. D. Abbott, M. R. Abernathy, F. Acernese *et al.*, Living Rev. Relativity **21**, 3 (2018).
[96] B. Margalit and B. D. Metzger, Astrophys. J. Lett. **880**, L15 (2019).
[97] https://gwosc.org/O4/O4a/.

A. G. Abac,[1] I. Abouelfettouh,[2] F. Acernese,[3,4] K. Ackley,[5] C. Adamcewicz,[6] S. Adhicary,[7] D. Adhikari,[8,9]
N. Adhikari,[10] R. X. Adhikari,[11] V. K. Adkins,[12] S. Afroz,[13] A. Agapito,[14] D. Agarwal,[15] M. Agathos,[16]
N. Aggarwal,[17] S. Aggarwal,[18] O. D. Aguiar,[19] I.-L. Ahrend,[20] L. Aiello,[21,22] A. Ain,[23] P. Ajith,[24] T. Akutsu,[25,26]
S. Albanesi,[27,28] W. Ali,[29,30] S. Al-Kershi,[8,9] C. Alléné,[31] A. Allocca,[32,4] S. Al-Shammari,[33] P. A. Altin,[34]
S. Alvarez-Lopez,[35] W. Amar,[31] O. Amarasinghe,[33] A. Amato,[36,37] F. Amicucci,[38,39] C. Amra,[40] A. Ananyeva,[11]
S. B. Anderson,[11] W. G. Anderson,[41] M. Andia,[42] M. Ando,[43] M. Andrés-Carcasona,[44] T. Andrić,[45,46,8,9]
J. Anglin,[47] S. Ansoldi,[48,49] J. M. Antelis,[50] S. Antier,[42] M. Aoumi,[51] E. Z. Appavuravther,[52,53] S. Appert,[41]
S. K. Apple,[54] K. Arai,[41] A. Araya,[43] M. C. Araya,[41] M. Arca Sedda,[45,46] J. S. Areeda,[55] N. Aritomi,[2]
F. Armato,[29,30] S. Armstrong,[56] N. Arnaud,[57] M. Arogeti,[58] S. M. Aronson,[12] K. G. Arun,[59] G. Ashton,[60]
Y. Aso,[25,61] L. Asprea,[28] M. Assiduo,[62,63] S. Assis de Souza Melo,[64] S. M. Aston,[65] P. Astone,[38] F. Attadio,[39,38]
F. Aubin,[66] K. AultONeal,[67] G. Avallone,[68] E. A. Avila,[50] S. Babak,[20] C. Badger,[69] S. Bae,[70] S. Bagnasco,[28]
L. Baiotti,[71] R. Bajpai,[72] T. Baka,[73,37] A. M. Baker,[6] K. A. Baker,[74] T. Baker,[75] G. Baldi,[76,77] N. Baldicchi,[78,52]
M. Ball,[79] G. Ballardin,[64] S. W. Ballmer,[80] S. Banagiri,[6] B. Banerjee,[45] D. Bankar,[81] T. M. Baptiste,[82] P. Baral,[83]
M. Baratti,[84,85] J. C. Barayoga,[41] B. C. Barish,[41] D. Barker,[86] N. Barman,[81] P. Barneo,[87,88,89] F. Barone,[90,4] B. Barr,[91]
L. Barsotti,[92] M. Barsuglia,[20] D. Barta,[93] A. M. Bartoletti,[94] M. A. Barton,[91] I. Bartos,[95] A. Basalaev,[8,9]
R. Bassiri,[96] A. Basti,[85,84] M. Bawaj,[78,52] P. Baxi,[97] J. C. Bayley,[91] A. C. Baylor,[83] P. A. Baynard II,[98]
M. Bazzan,[99,100] V. M. Bedakihale,[101] F. Beirnaert,[102] M. Bejger,[103] D. Belardinelli,[22] A. S. Bell,[91] D. S. Bellie,[104]
L. Bellizzi,[84,85] W. Benoit,[105] I. Bentara,[57] J. D. Bentley,[106] M. Ben Yaala,[56] S. Bera,[107,108] F. Bergamin,[33]
B. K. Berger,[96] S. Bernuzzi,[27] M. Beroiz,[41] D. Bersanetti,[29] T. Bertheas,[109] A. Bertolini,[37,36] J. Betzwieser,[110]
D. Beveridge,[74] G. Bevilacqua,[111] N. Bevins,[112] R. Bhandare,[113] R. Bhatt,[41] D. Bhattacharjee,[114,115]
S. Bhattacharyya,[116] S. Bhaumik,[95] V. Biancalana,[111] A. Bianchi,[37,117] I. A. Bilenko,[118] G. Billingsley,[41]
A. Binetti,[119] S. Bini,[41,76,77] C. Binu,[120] S. Biot,[121] O. Birnholtz,[122] S. Biscoveanu,[104] A. Bisht,[9] M. Bitossi,[64,84]
M.-A. Bizouard,[123] S. Blaber,[124] J. K. Blackburn,[41] L. A. Blagg,[125] C. D. Blair,[74,110] D. G. Blair,[74] N. Bode,[8,9]
N. Boettner,[106] G. Boileau,[123] M. Boldrini,[38] G. N. Bolingbroke,[126] A. Bolliand,[127,40] L. D. Bonavena,[95]
R. Bondarescu,[87] F. Bondu,[128] E. Bonilla,[96] M. S. Bonilla,[129] A. Bonino,[130] R. Bonnand,[31,127] A. Borchers,[8,9]
S. Borhanian,[131] V. Boschi,[84] S. Bose,[132] V. Bossilkov,[110] Y. Bothra,[37,117] A. Boudon,[57] L. Bourg,[98] M. Boyle,[133]
A. Bozzi,[64] C. Bradaschia,[84] P. R. Brady,[83] A. Branch,[110] M. Branchesi,[45,46] I. Braun,[114] T. Briant,[134] A. Brillet,[123]
M. Brinkmann,[8,9] P. Brockill,[83] E. Brockmueller,[8,9] A. F. Brooks,[41] B. C. Brown,[95] D. D. Brown,[126]
M. L. Brozzetti,[78,52] S. Brunett,[41] G. Bruno,[15] R. Bruntz,[135] J. Bryant,[130] Y. Bu,[136] F. Bucci,[63] J. Buchanan,[135]
O. Bulashenko,[87,88] T. Bulik,[137] H. J. Bulten,[37] A. Buonanno,[138,1] K. Burtnyk,[86] R. Buscicchio,[139,140] D. Buskulic,[31]
C. Buy,[109] R. L. Byer,[96] G. S. Cabourn Davies,[75] R. Cabrita,[15] V. Cáceres-Barbosa,[131] L. Cadonati,[98] G. Cagnoli,[141]
C. Cahillane,[142] A. Calafat,[107] T. A. Callister,[143] E. Calloni,[32,4] S. R. Callos,[125] G. Caneva Santoro,[44] K. C. Cannon,[43]
H. Cao,[92] L. A. Capistran,[144] E. Capocasa,[20] E. Capote,[86,41] G. Capurri,[85,84] G. Carapella,[68,145] F. Carbognani,[64]
M. Carlassara,[8,9] J. B. Carlin,[136] T. K. Carlson,[146] M. F. Carney,[114] M. Carpinelli,[139,64] G. Carrillo,[125] J. J. Carter,[8,9]
G. Carullo,[130,147] A. Casallas-Lagos,[148] J. Casanueva Diaz,[64] C. Casentini,[149,22] S. Y. Castro-Lucas,[150] S. Caudill,[146]
M. Cavaglià,[115] R. Cavalieri,[64] A. Ceja,[129] G. Cella,[84] P. Cerdá-Durán,[151,152] E. Cesarini,[22] N. Chabbra,[34]
W. Chaibi,[123] A. Chakraborty,[13] P. Chakraborty,[8,9] S. Chakraborty,[113] S. Chalathadka Subrahmanya,[106]
J. C. L. Chan,[153] M. Chan,[124] K. Chang,[154] S. Chao,[155,154] P. Charlton,[156] E. Chassande-Mottin,[20] C. Chatterjee,[157]
Debarati Chatterjee,[81] Deep Chatterjee,[92] M. Chaturvedi,[113] S. Chaty,[20] A. Chen,[158] A. H.-Y. Chen,[159] D. Chen,[160]
H. Chen,[155] H. Y. Chen,[161] S. Chen,[157] Yanbei Chen,[162] Yitian Chen,[133] H. P. Cheng,[163] P. Chessa,[78,52]
H. T. Cheung,[97] S. Y. Cheung,[6] F. Chiadini,[164,145] G. Chiarini,[8,9,100] A. Chiba,[165] A. Chincarini,[29] M. L. Chiofalo,[85,84]
A. Chiummo,[4,64] C. Chou,[159] S. Choudhary,[74] N. Christensen,[123,166] S. S. Y. Chua,[34] G. Ciani,[76,77] P. Ciecielag,[103]

M. Cieślar,[137] M. Cifaldi,[22] B. Cirok,[167] F. Clara,[86] J. A. Clark,[41,98] T. A. Clarke,[6] P. Clearwater,[168] S. Clesse,[121]
F. Cleva,[123,127] E. Coccia,[45,46,44] E. Codazzo,[169,170] P.-F. Cohadon,[134] S. Colace,[30] E. Colangeli,[75] M. Colleoni,[107]
C. G. Collette,[171] J. Collins,[110] S. Colloms,[91] A. Colombo,[172,140] C. M. Compton,[86] G. Connolly,[125] L. Conti,[100]
T. R. Corbitt,[82] I. Cordero-Carrión,[173] S. Corezzi,[78,52] N. J. Cornish,[174] I. Coronado,[175] A. Corsi,[176]
R. Cottingham,[110] M. W. Coughlin,[105] A. Couineaux,[38] P. Couvares,[41,98] D. M. Coward,[74] R. Coyne,[177]
A. Cozzumbo,[45] J. D. E. Creighton,[83] T. D. Creighton,[178] P. Cremonese,[107] S. Crook,[110] R. Crouch,[86] J. Csizmazia,[86]
J. R. Cudell,[179] T. J. Cullen,[41] A. Cumming,[91] E. Cuoco,[180,181] M. Cusinato,[151] L. V. Da Conceição,[182]
T. Dal Canton,[42] S. Dal Pra,[183] G. Dálya,[109] B. D'Angelo,[29] S. Danilishin,[36,37] S. D'Antonio,[38] K. Danzmann,[9,8,9]
K. E. Darroch,[135] L. P. Dartez,[110] R. Das,[116] A. Dasgupta,[101] V. Dattilo,[64] A. Daumas,[20] N. Davari,[184,185] I. Dave,[113]
A. Davenport,[150] M. Davier,[42] T. F. Davies,[74] D. Davis,[41] L. Davis,[74] M. C. Davis,[105] P. Davis,[186,187] E. J. Daw,[188]
M. Dax,[1] J. De Bolle,[102] M. Deenadayalan,[81] J. Degallaix,[189] M. De Laurentis,[32,4] F. De Lillo,[23] S. Della Torre,[140]
W. Del Pozzo,[85,84] A. Demagny,[31] F. De Marco,[39,38] G. Demasi,[190,63] F. De Matteis,[21,22] N. Demos,[92] T. Dent,[191]
A. Depasse,[15] N. DePergola,[112] R. De Pietri,[192,193] R. De Rosa,[32,4] C. De Rossi,[64] M. Desai,[92] R. DeSalvo,[194]
A. DeSimone,[195] R. De Simone,[164,145] A. Dhani,[1] R. Diab,[95] M. C. Díaz,[178] M. Di Cesare,[32,4] G. Dideron,[196]
T. Dietrich,[1] L. Di Fiore,[4] C. Di Fronzo,[74] M. Di Giovanni,[39,38] T. Di Girolamo,[32,4] D. Diksha,[37,36] J. Ding,[20,197]
S. Di Pace,[39,38] I. Di Palma,[39,38] D. Di Piero,[198,49] F. Di Renzo,[57] Divyajyoti,[33] A. Dmitriev,[130] J. P. Docherty,[91]
Z. Doctor,[104] N. Doerksen,[182] E. Dohmen,[86] A. Doke,[146] A. Domiciano De Souza,[199] L. D'Onofrio,[38] F. Donovan,[92]
K. L. Dooley,[33] T. Dooney,[73] S. Doravari,[81] O. Dorosh,[200] W. J. D. Doyle,[135] M. Drago,[39,38] J. C. Driggers,[86]
L. Dunn,[136] U. Dupletsa,[45] P.-A. Duverne,[20] D. D'Urso,[184,169] P. Dutta Roy,[95] H. Duval,[201] S. E. Dwyer,[86] C. Eassa,[86]
M. Ebersold,[202,31] T. Eckhardt,[106] G. Eddolls,[142] A. Effler,[110] J. Eichholz,[34] H. Einsle,[123] M. Eisenmann,[25]
M. Emma,[60] K. Endo,[165] R. Enficiaud,[1] L. Errico,[32,4] R. Espinosa,[178] M. Esposito,[4,32] R. C. Essick,[203]
H. Estellés,[1] T. Etzel,[41] M. Evans,[92] T. Evstafyeva,[196] B. E. Ewing,[131] J. M. Ezquiaga,[153] F. Fabrizi,[204,63]
V. Fafone,[21,22] S. Fairhurst,[33] A. M. Farah,[143] B. Farr,[125] W. M. Farr,[205,206] G. Favaro,[99] M. Favata,[207]
M. Fays,[179] M. Fazio,[56] J. Feicht,[41] M. M. Fejer,[96] R. Felicetti,[198,49] E. Fenyvesi,[93,208] J. Fernandes,[209]
T. Fernandes,[210,151] D. Fernando,[120] S. Ferraiuolo,[211,39,38] T. A. Ferreira,[82] F. Fidecaro,[85,84] P. Figura,[103]
A. Fiori,[84,85] I. Fiori,[64] M. Fishbach,[203] R. P. Fisher,[135] R. Fittipaldi,[212,145] V. Fiumara,[213,145] R. Flaminio,[31]
S. M. Fleischer,[214] L. S. Fleming,[215] E. Floden,[105] H. Fong,[124] J. A. Font,[151,152] F. Fontinele-Nunes,[105] C. Foo,[1]
B. Fornal,[216] K. Franceschetti,[192] F. Frappez,[31] S. Frasca,[39,38] F. Frasconi,[84] J. P. Freed,[217] Z. Frei,[218] A. Freise,[37,117]
O. Freitas,[210,151] R. Frey,[125] W. Frischhertz,[110] P. Fritschel,[92] V. V. Frolov,[110] G. G. Fronzé,[28] M. Fuentes-Garcia,[41]
S. Fujii,[219] T. Fujimori,[220] P. Fulda,[95] M. Fyffe,[110] B. Gadre,[73] J. R. Gair,[1] S. Galaudage,[199] V. Galdi,[221] R. Gamba,[131]
A. Gamboa,[1] S. Gamoji,[194] D. Ganapathy,[222] A. Ganguly,[81] B. Garaventa,[29] J. García-Bellido,[223]
C. García-Quirós,[202] J. W. Gardner,[34] K. A. Gardner,[124] S. Garg,[43] J. Gargiulo,[64] X. Garrido,[42] A. Garron,[107]
F. Garufi,[32,4] P. A. Garver,[96] C. Gasbarra,[21,22] B. Gateley,[86] F. Gautier,[224] V. Gayathri,[83] T. Gayer,[142] G. Gemme,[29]
A. Gennai,[84] V. Gennari,[109] J. George,[113] R. George,[161] O. Gerberding,[106] L. Gergely,[167] Archisman Ghosh,[102]
Sayantan Ghosh,[209] Shaon Ghosh,[207] Shrobana Ghosh,[8,9] Suprovo Ghosh,[225] Tathagata Ghosh,[81] J. A. Giaime,[82,110]
K. D. Giardina,[110] D. R. Gibson,[215] C. Gier,[56] S. Gkaitatzis,[85,84] J. Glanzer,[41] F. Glotin,[42] J. Godfrey,[125]
R. V. Godley,[8,9] P. Godwin,[41] A. S. Goettel,[33] E. Goetz,[124] J. Golomb,[41] S. Gomez Lopez,[39,38] B. Goncharov,[45]
G. González,[82] P. Goodarzi,[226] S. Goode,[6] A. W. Goodwin-Jones,[15] M. Gosselin,[64] R. Gouaty,[31] D. W. Gould,[34]
K. Govorkova,[92] A. Grado,[78,52] V. Graham,[91] A. E. Granados,[105] M. Granata,[189] V. Granata,[227,145] S. Gras,[92]
P. Grassia,[41] J. Graves,[98] C. Gray,[86] R. Gray,[91] G. Greco,[52] A. C. Green,[37,117] L. Green,[228] S. M. Green,[75]
S. R. Green,[229] C. Greenberg,[146] A. M. Gretarsson,[217] H. K. Griffin,[105] D. Griffith,[41] H. L. Griggs,[98] G. Grignani,[78,52]
C. Grimaud,[31] H. Grote,[33] S. Grunewald,[1] D. Guerra,[151] D. Guetta,[230] G. M. Guidi,[204,63] A. R. Guimaraes,[82]
H. K. Gulati,[101] F. Gulminelli,[186,187] H. Guo,[158] W. Guo,[74] Y. Guo,[37,36] Anuradha Gupta,[231] I. Gupta,[131]
N. C. Gupta,[101] S. K. Gupta,[95] V. Gupta,[105] N. Gupte,[1] J. Gurs,[106] N. Gutierrez,[189] N. Guttman,[6] F. Guzman,[144]
D. Haba,[232] M. Haberland,[1] S. Haino,[233] E. D. Hall,[92] E. Z. Hamilton,[107] G. Hammond,[91] M. Haney,[37] J. Hanks,[86]
C. Hanna,[131] M. D. Hannam,[33] O. A. Hannuksela,[234] A. G. Hanselman,[143] H. Hansen,[86] J. Hanson,[110]
S. Hanumasagar,[98] R. Harada,[43] A. R. Hardison,[195] S. Harikumar,[200] K. Haris,[37,73] I. Harley-Trochimczyk,[144]
T. Harmark,[147] J. Harms,[45,46] G. M. Harry,[235] I. W. Harry,[75] J. Hart,[114] B. Haskell,[103,236,237] C. J. Haster,[228]
K. Haughian,[91] H. Hayakawa,[51] K. Hayama,[238] M. C. Heintze,[110] J. Heinze,[130] J. Heinzel,[92] H. Heitmann,[123]

F. Hellman,[222] A. F. Helmling-Cornell,[125] G. Hemming,[64] O. Henderson-Sapir,[126] M. Hendry,[91] I. S. Heng,[91] M. H. Hennig,[91] C. Henshaw,[98] M. Heurs,[8,9] A. L. Hewitt,[239,240] J. Heynen,[15] J. Heyns,[92] S. Higginbotham,[33] S. Hild,[36,37] S. Hill,[91] Y. Himemoto,[241] N. Hirata,[25] C. Hirose,[242] D. Hofman,[189] B. E. Hogan,[217] N. A. Holland,[37,117] I. J. Hollows,[188] D. E. Holz,[143] L. Honet,[121] D. J. Horton-Bailey,[222] J. Hough,[91] S. Hourihane,[41] N. T. Howard,[157] E. J. Howell,[74] C. G. Hoy,[75] C. A. Hrishikesh,[21] P. Hsi,[92] H.-F. Hsieh,[155] H.-Y. Hsieh,[155] C. Hsiung,[243] S.-H. Hsu,[159] W.-F. Hsu,[119] Q. Hu,[91] H. Y. Huang,[154] Y. Huang,[131] Y. T. Huang,[142] A. D. Huddart,[244] B. Hughey,[217] V. Hui,[31] S. Husa,[107] R. Huxford,[131] L. Iampieri,[39,38] G. A. Iandolo,[36] M. Ianni,[22,21] G. Iannone,[145] J. Iascau,[125] K. Ide,[245] R. Iden,[232] A. Ierardi,[45,46] S. Ikeda,[160] H. Imafuku,[43] Y. Inoue,[154] G. Iorio,[99] P. Iosif,[198,49] M. H. Iqbal,[34] J. Irwin,[91] R. Ishikawa,[245] M. Isi,[205,206] K. S. Isleif,[246] Y. Itoh,[220,247] M. Iwaya,[219] B. R. Iyer,[24] C. Jacquet,[109] P.-E. Jacquet,[134] T. Jacquot,[42] S. J. Jadhav,[248] S. P. Jadhav,[168] M. Jain,[146] T. Jain,[239] A. L. James,[41] K. Jani,[157] J. Janquart,[15] N. N. Janthalur,[248] S. Jaraba,[249] P. Jaranowski,[250] R. Jaume,[107] W. Javed,[33] A. Jennings,[86] M. Jensen,[86] W. Jia,[92] J. Jiang,[163] H.-B. Jin,[251,252] G. R. Johns,[135] N. A. Johnson,[95] M. C. Johnston,[228] R. Johnston,[91] N. Johny,[8,9] D. H. Jones,[34] D. I. Jones,[225] R. Jones,[91] H. E. Jose,[125] P. Joshi,[131] S. K. Joshi,[81] G. Joubert,[57] J. Ju,[253] L. Ju,[74] K. Jung,[254] J. Junker,[34] V. Juste,[121] H. B. Kabagoz,[110,92] T. Kajita,[255] I. Kaku,[220] V. Kalogera,[104] M. Kalomenopoulos,[228] M. Kamiizumi,[51] N. Kanda,[247,220] S. Kandhasamy,[81] G. Kang,[256] N. C. Kannachel,[6] J. B. Kanner,[41] S. A. KantiMahanty,[105] S. J. Kapadia,[81] D. P. Kapasi,[129] M. Karthikeyan,[146] M. Kasprzack,[41] H. Kato,[165] T. Kato,[219] E. Katsavounidis,[92] W. Katzman,[110] R. Kaushik,[113] K. Kawabe,[86] R. Kawamoto,[220] D. Keitel,[107] L. J. Kemperman,[126] J. Kennington,[131] F. A. Kerkow,[105] R. Kesharwani,[81] J. S. Key,[257] R. Khadela,[8,9] S. Khadka,[96] S. S. Khadkikar,[131] F. Y. Khalili,[118] F. Khan,[8,9] T. Khanam,[176] M. Khursheed,[113] N. M. Khusid,[205,206] W. Kiendrebeogo,[123,258] N. Kijbunchoo,[126] C. Kim,[259] J. C. Kim,[260] K. Kim,[261] M. H. Kim,[253] S. Kim,[262] Y.-M. Kim,[261] C. Kimball,[104] K. Kimes,[129] M. Kinnear,[33] J. S. Kissel,[86] S. Klimenko,[95] A. M. Knee,[124] E. J. Knox,[125] N. Knust,[8,9] K. Kobayashi,[219] S. M. Koehlenbeck,[96] G. Koekoek,[37,36] K. Kohri,[263,264] K. Kokeyama,[33,265] S. Koley,[45,179] P. Kolitsidou,[130] A. E. Koloniari,[266] K. Komori,[43] A. K. H. Kong,[155] A. Kontos,[267] L. M. Koponen,[130] M. Korobko,[106] X. Kou,[105] A. Koushik,[23] N. Kouvatsos,[69] M. Kovalam,[74] T. Koyama,[165] D. B. Kozak,[41] S. L. Kranzhoff,[36,37] V. Kringel,[8,9] N. V. Krishnendu,[130] S. Kroker,[268] A. Królak,[269,200] K. Kruska,[8,9] J. Kubisz,[270] G. Kuehn,[8,9] S. Kulkarni,[231] A. Kulur Ramamohan,[34] Achal Kumar,[95] Anil Kumar,[248] Praveen Kumar,[191] Prayush Kumar,[24] Rahul Kumar,[86] Rakesh Kumar,[101] J. Kume,[271,272,43] K. Kuns,[92] N. Kuntimaddi,[33] S. Kuroyanagi,[223,273] S. Kuwahara,[43] K. Kwak,[254] K. Kwan,[34] S. Kwon,[43] G. Lacaille,[91] D. Laghi,[202,109] A. H. Laity,[177] E. Lalande,[274] M. Lalleman,[23] P. C. Lalremruati,[275] M. Landry,[86] B. B. Lane,[92] R. N. Lang,[92] J. Lange,[161] R. Langgin,[228] B. Lantz,[96] I. La Rosa,[107] J. Larsen,[214] A. Lartaux-Vollard,[42] P. D. Lasky,[6] J. Lawrence,[178] M. Laxen,[110] C. Lazarte,[151] A. Lazzarini,[41] C. Lazzaro,[170,169] P. Leaci,[39,38] L. Leali,[105] Y. K. Lecoeuche,[124] H. M. Lee,[276] H. W. Lee,[277] J. Lee,[142] K. Lee,[253] R.-K. Lee,[155] R. Lee,[92] Sungho Lee,[261] Sunjae Lee,[253] Y. Lee,[154] I. N. Legred,[41] J. Lehmann,[8,9] L. Lehner,[196] M. Le Jean,[189,127] A. Lemaître,[278] M. Lenti,[63,190] M. Leonardi,[76,77,279] M. Lequime,[40] N. Leroy,[42] M. Lesovsky,[41] N. Letendre,[31] M. Lethuillier,[57] Y. Levin,[6] K. Leyde,[75] A. K. Y. Li,[41] K. L. Li,[280] T. G. F. Li,[119] X. Li,[162] Y. Li,[104] Z. Li,[91] A. Lihos,[135] E. T. Lin,[155] F. Lin,[154] L. C.-C. Lin,[280] Y.-C. Lin,[155] C. Lindsay,[215] S. D. Linker,[194] A. Liu,[234] G. C. Liu,[243] Jian Liu,[74] F. Llamas Villarreal,[178] J. Llobera-Querol,[107] R. K. L. Lo,[153] J.-P. Locquet,[119] S. C. G. Loggins,[281] M. R. Loizou,[146] L. T. London,[69] A. Longo,[204,63] D. Lopez,[179] M. Lopez Portilla,[73] M. Lorenzini,[21,22] A. Lorenzo-Medina,[191] V. Loriette,[42] M. Lormand,[110] G. Losurdo,[282,84] E. Lotti,[146] T. P. Lott IV,[98] J. D. Lough,[8,9] H. A. Loughlin,[92] C. O. Lousto,[120] N. Low,[136] N. Lu,[34] L. Lucchesi,[84] H. Lück,[9,8,9] D. Lumaca,[22] A. P. Lundgren,[283,284] A. W. Lussier,[274] R. Macas,[75] M. MacInnis,[92] D. M. Macleod,[33] I. A. O. MacMillan,[41] A. Macquet,[42] K. Maeda,[165] S. Maenaut,[119] S. S. Magare,[81] R. M. Magee,[41] E. Maggio,[1] R. Maggiore,[37,117] M. Magnozzi,[29,30] M. Mahesh,[106] M. Maini,[177] S. Majhi,[81] E. Majorana,[39,38] C. N. Makarem,[41] D. Malakar,[115] J. A. Malaquias-Reis,[19] U. Mali,[203] S. Maliakal,[41] A. Malik,[113] L. Mallick,[182,203] A.-K. Malz,[60] N. Man,[123] M. Mancarella,[108] V. Mandic,[105] V. Mangano,[184,169] B. Mannix,[125] G. L. Mansell,[142] M. Manske,[83] M. Mantovani,[64] M. Mapelli,[99,100,285] C. Marinelli,[111] F. Marion,[31] A. S. Markosyan,[96] A. Markowitz,[41] E. Maros,[41] S. Marsat,[109] F. Martelli,[204,63] I. W. Martin,[91] R. M. Martin,[207] B. B. Martinez,[144] D. A. Martinez,[129] M. Martinez,[44,286] V. Martinez,[141] A. Martini,[76,77] J. C. Martins,[19] D. V. Martynov,[130] E. J. Marx,[92] L. Massaro,[36,37] A. Masserot,[31] M. Masso-Reid,[91] S. Mastrogiovanni,[38] T. Matcovich,[52] M. Matiushechkina,[8,9] L. Maurin,[224] N. Mavalvala,[92] N. Maxwell,[86] G. McCarrol,[110] R. McCarthy,[86] D. E. McClelland,[34] S. McCormick,[110] L. McCuller,[41]

S. McEachin,[135] C. McElhenny,[135] G. I. McGhee,[91] J. McGinn,[91] K. B. M. McGowan,[157] J. McIver,[124] A. McLeod,[74] I. McMahon,[202] T. McRae,[34] R. McTeague,[91] D. Meacher,[83] B. N. Meagher,[142] R. Mechum,[120] Q. Meijer,[73] A. Melatos,[136] C. S. Menoni,[150] F. Mera,[86] R. A. Mercer,[83] L. Mereni,[189] K. Merfeld,[176] E. L. Merilh,[110] J. R. Mérou,[107] J. D. Merritt,[125] M. Merzougui,[123] C. Messick,[83] B. Mestichelli,[45] M. Meyer-Conde,[287] F. Meylahn,[8,9] A. Mhaske,[81] A. Miani,[76,77] H. Miao,[288] C. Michel,[189] Y. Michimura,[43] H. Middleton,[130] D. P. Mihaylov,[114,73] S. J. Miller,[41] M. Millhouse,[98] E. Milotti,[198,49] V. Milotti,[99] Y. Minenkov,[22] E. M. Minihan,[217] Ll. M. Mir,[44] L. Mirasola,[169,170] M. Miravet-Tenés,[151] C.-A. Miritescu,[44] A. Mishra,[24] C. Mishra,[116] T. Mishra,[95] A. L. Mitchell,[37,117] J. G. Mitchell,[217] S. Mitra,[81] V. P. Mitrofanov,[118] K. Mitsuhashi,[25] R. Mittleman,[92] O. Miyakawa,[51] S. Miyoki,[51] A. Miyoko,[217] G. Mo,[92] L. Mobilia,[204,63] S. R. P. Mohapatra,[41] S. R. Mohite,[131] M. Molina-Ruiz,[222] M. Mondin,[194] M. Montani,[204,63] C. J. Moore,[239] D. Moraru,[86] A. More,[81] S. More,[81] C. Moreno,[148] E. A. Moreno,[92] G. Moreno,[86] A. Moreso Serra,[87] S. Morisaki,[43,219] Y. Moriwaki,[165] G. Morras,[223] A. Moscatello,[99] M. Mould,[92] B. Mours,[66] C. M. Mow-Lowry,[37,117] L. Muccillo,[190,63] F. Muciaccia,[39,38] D. Mukherjee,[130] Samanwaya Mukherjee,[24] Soma Mukherjee,[178] Subroto Mukherjee,[101] Suvodip Mukherjee,[13] N. Mukund,[92] A. Mullavey,[110] H. Mullock,[124] J. Mundi,[235] C. L. Mungioli,[74] M. Murakoshi,[245] P. G. Murray,[91] D. Nabari,[76,77] S. L. Nadji,[8,9] A. Nagar,[28,289] N. Nagarajan,[91] K. Nakagaki,[51] K. Nakamura,[25] H. Nakano,[290] M. Nakano,[41] D. Nanadoumgar-Lacroze,[44] D. Nandi,[82] V. Napolano,[64] P. Narayan,[231] I. Nardecchia,[22] T. Narikawa,[219] H. Narola,[73] L. Naticchioni,[38] R. K. Nayak,[275] L. Negri,[73] A. Nela,[91] C. Nelle,[125] A. Nelson,[144] T. J. N. Nelson,[110] M. Nery,[8,9] A. Neunzert,[86] S. Ng,[129] L. Nguyen Quynh,[291] S. A. Nichols,[82] A. B. Nielsen,[292] Y. Nishino,[25,43] A. Nishizawa,[293] S. Nissanke,[294,37] W. Niu,[131] F. Nocera,[64] J. Noller,[295] M. Norman,[33] C. North,[33] J. Novak,[127,249,296] R. Nowicki,[157] J. F. Nuño Siles,[223] L. K. Nuttall,[75] K. Obayashi,[245] J. Oberling,[86] J. O'Dell,[244] E. Oelker,[92] M. Oertel,[249,127,297,296] G. Oganesyan,[45,46] T. O'Hanlon,[110] M. Ohashi,[51] F. Ohme,[8,9] R. Oliveri,[127,297,296] R. Omer,[105] B. O'Neal,[135] M. Onishi,[165] K. Oohara,[298] B. O'Reilly,[110] M. Orselli,[52,78] R. O'Shaughnessy,[120] S. O'Shea,[91] S. Oshino,[51] C. Osthelder,[41] I. Ota,[82] D. J. Ottaway,[126] A. Ouzriat,[57] H. Overmier,[110] B. J. Owen,[299] R. Ozaki,[245] A. E. Pace,[131] R. Pagano,[82] M. A. Page,[25] A. Pai,[209] L. Paiella,[45] A. Pal,[300] S. Pal,[275] M. A. Palaia,[84,85] M. Pálfi,[218] P. P. Palma,[39,21,22] C. Palomba,[38] P. Palud,[20] H. Pan,[155] J. Pan,[74] K. C. Pan,[155] P. K. Panda,[248] Shiksha Pandey,[131] Swadha Pandey,[92] P. T. H. Pang,[37,73] F. Pannarale,[39,38] K. A. Pannone,[129] B. C. Pant,[113] F. H. Panther,[74] M. Panzeri,[204,63] F. Paoletti,[84] A. Paolone,[38,301] A. Papadopoulos,[91] E. E. Papalexakis,[226] L. Papalini,[84,85] G. Papigkiotis,[266] A. Paquis,[42] A. Parisi,[78,52] B.-J. Park,[261] J. Park,[302] W. Parker,[110] G. Pascale,[8,9] D. Pascucci,[102] A. Pasqualetti,[64] R. Passaquieti,[85,84] L. Passenger,[6] D. Passuello,[84] O. Patane,[86] A. V. Patel,[154] D. Pathak,[81] A. Patra,[33] B. Patricelli,[85,84] B. G. Patterson,[33] K. Paul,[116] S. Paul,[125] E. Payne,[41] T. Pearce,[33] M. Pedraza,[41] A. Pele,[41] F. E. Peña Arellano,[303] X. Peng,[130] Y. Peng,[98] S. Penn,[304] M. D. Penuliar,[129] A. Perego,[76,77] Z. Pereira,[146] C. Périgois,[305,100,99] G. Perna,[99] A. Perreca,[76,77,45] J. Perret,[20] S. Perriès,[57] J. W. Perry,[37,117] D. Pesios,[266] S. Peters,[179] S. Petracca,[221] C. Petrillo,[78] H. P. Pfeiffer,[1] H. Pham,[110] K. A. Pham,[105] K. S. Phukon,[130] H. Phurailatpam,[234] M. Piarulli,[109] L. Piccari,[39,38] O. J. Piccinni,[34] M. Pichot,[123] M. Piendibene,[85,84] F. Piergiovanni,[204,63] L. Pierini,[38] G. Pierra,[38] V. Pierro,[306,145] M. Pietrzak,[103] M. Pillas,[179] F. Pilo,[84] L. Pinard,[189] I. M. Pinto,[306,145,307,32] M. Pinto,[64] B. J. Piotrzkowski,[83] M. Pirello,[86] M. D. Pitkin,[239,91] A. Placidi,[52] E. Placidi,[39,38] M. L. Planas,[107] W. Plastino,[227,22] C. Plunkett,[92] R. Poggiani,[85,84] E. Polini,[92] J. Pomper,[84,85] L. Pompili,[1] J. Poon,[234] E. Porcelli,[37] E. K. Porter,[20] C. Posnansky,[131] R. Poulton,[64] J. Powell,[168] G. S. Prabhu,[81] M. Pracchia,[179] B. K. Pradhan,[81] T. Pradier,[66] A. K. Prajapati,[101] K. Prasai,[308] R. Prasanna,[248] P. Prasia,[81] G. Pratten,[130] G. Principe,[198,49] G. A. Prodi,[76,77] P. Prosperi,[84] P. Prosposito,[21,22] A. C. Providence,[217] A. Puecher,[1] J. Pullin,[82] P. Puppo,[38] M. Pürrer,[177] H. Qi,[16] J. Qin,[34] G. Quéméner,[187,127] V. Quetschke,[178] P. J. Quinonez,[217] N. Qutob,[98] R. Rading,[246] I. Rainho,[151] S. Raja,[113] C. Rajan,[113] B. Rajbhandari,[120] K. E. Ramirez,[110] F. A. Ramis Vidal,[107] M. Ramos Arevalo,[178] A. Ramos-Buades,[107,37] S. Ranjan,[98] K. Ransom,[110] P. Rapagnani,[39,38] B. Ratto,[217] A. Ravichandran,[146] A. Ray,[104] V. Raymond,[33] M. Razzano,[85,84] J. Read,[129] T. Regimbau,[31] S. Reid,[56] C. Reissel,[92] D. H. Reitze,[41] A. I. Renzini,[139,41] B. Revenu,[309,42] A. Revilla Peña,[87] R. Reyes,[194] L. Ricca,[15] F. Ricci,[39,38] M. Ricci,[38,39] A. Ricciardone,[85,84] J. Rice,[142] J. W. Richardson,[226] M. L. Richardson,[126] A. Rijal,[217] K. Riles,[97] H. K. Riley,[33] S. Rinaldi,[285] J. Rittmeyer,[106] C. Robertson,[244] F. Robinet,[42] M. Robinson,[86] A. Rocchi,[22] L. Rolland,[31] J. G. Rollins,[41] A. E. Romano,[310] R. Romano,[3,4] A. Romero,[31] I. M. Romero-Shaw,[239] J. H. Romie,[110] S. Ronchini,[131] T. J. Roocke,[126] L. Rosa,[4,32] T. J. Rosauer,[226] C. A. Rose,[98] D. Rosińska,[137] M. P. Ross,[311] M. Rossello-Sastre,[107]

S. Rowan,[91] S. K. Roy,[205,206] S. Roy,[15] D. Rozza,[139,140] P. Ruggi,[64] N. Ruhama,[254] E. Ruiz Morales,[312,223]
K. Ruiz-Rocha,[157] S. Sachdev,[98] T. Sadecki,[86] P. Saffarieh,[37,117] S. Safi-Harb,[182] M. R. Sah,[13] S. Saha,[155]
T. Sainrat,[66] S. Sajith Menon,[230,39,38] K. Sakai,[313] Y. Sakai,[287] M. Sakellariadou,[69] S. Sakon,[131]
O. S. Salafia,[172,140,139] F. Salces-Carcoba,[41] L. Salconi,[64] M. Saleem,[161] F. Salemi,[39,38] M. Sallé,[37] S. U. Salunkhe,[81]
S. Salvador,[187,186] A. Salvarese,[161] A. Samajdar,[73,37] A. Sanchez,[86] E. J. Sanchez,[41] L. E. Sanchez,[41]
N. Sanchis-Gual,[151] J. R. Sanders,[195] E. M. Sänger,[1] F. Santoliquido,[45,46] F. Sarandrea,[28] T. R. Saravanan,[81] N. Sarin,[6]
P. Sarkar,[8,9] A. Sasli,[266] P. Sassi,[52,78] B. Sassolas,[189] B. S. Sathyaprakash,[131,33] R. Sato,[242] S. Sato,[165] Yukino Sato,[165]
Yu Sato,[165] O. Sauter,[95] R. L. Savage,[86] T. Sawada,[51] H. L. Sawant,[81] S. Sayah,[189] V. Scacco,[21,22] D. Schaetzl,[41]
M. Scheel,[162] A. Schiebelbein,[203] M. G. Schiworski,[142] P. Schmidt,[130] S. Schmidt,[73] R. Schnabel,[106]
M. Schneewind,[8,9] R. M. S. Schofield,[125] K. Schouteden,[119] B. W. Schulte,[8,9] B. F. Schutz,[33,8,9] E. Schwartz,[314]
M. Scialpi,[315] J. Scott,[91] S. M. Scott,[34] R. M. Sedas,[110] T. C. Seetharamu,[91] M. Seglar-Arroyo,[44] Y. Sekiguchi,[316]
D. Sellers,[110] N. Sembo,[220] A. S. Sengupta,[317] E. G. Seo,[91] J. W. Seo,[119] V. Sequino,[32,4] M. Serra,[38] A. Sevrin,[201]
T. Shaffer,[86] U. S. Shah,[98] M. A. Shaikh,[276] L. Shao,[318] A. K. Sharma,[107] Preeti Sharma,[82] Prianka Sharma,[113]
Ritwik Sharma,[105] S. Sharma Chaudhary,[115] P. Shawhan,[138] N. S. Shcheblanov,[319,278] E. Sheridan,[157] Z.-H. Shi,[155]
M. Shikauchi,[43] R. Shimomura,[320] H. Shinkai,[320] S. Shirke,[81] D. H. Shoemaker,[92] D. M. Shoemaker,[161] R. W. Short,[86]
S. ShyamSundar,[113] A. Sider,[171] H. Siegel,[205,206] D. Sigg,[86] L. Silenzi,[36,37] L. Silvestri,[39,183] M. Simmonds,[126]
L. P. Singer,[321] Amitesh Singh,[231] Anika Singh,[41] D. Singh,[222] N. Singh,[107] S. Singh,[232,61] A. M. Sintes,[107]
V. Sipala,[184,169] V. Skliris,[33] B. J. J. Slagmolen,[34] D. A. Slater,[214] T. J. Slaven-Blair,[74] J. Smetana,[130] J. R. Smith,[129]
L. Smith,[91,198,49] R. J. E. Smith,[6] W. J. Smith,[157] S. Soares de Albuquerque Filho,[204] M. Soares-Santos,[202]
K. Somiya,[232] I. Song,[155] S. Soni,[92] V. Sordini,[57] F. Sorrentino,[29] H. Sotani,[322] F. Spada,[84] V. Spagnuolo,[37]
A. P. Spencer,[91] P. Spinicelli,[64] A. K. Srivastava,[101] F. Stachurski,[91] C. J. Stark,[135] D. A. Steer,[323] N. Steinle,[182]
J. Steinlechner,[36,37] S. Steinlechner,[36,37] N. Stergioulas,[266] P. Stevens,[42] M. StPierre,[177] M. D. Strong,[82] A. Strunk,[86]
A. L. Stuver,[112,†] M. Suchenek,[103] S. Sudhagar,[103] Y. Sudo,[245] N. Sueltmann,[106] L. Suleiman,[129] K. D. Sullivan,[82]
J. Sun,[256] L. Sun,[34] S. Sunil,[101] J. Suresh,[123] B. J. Sutton,[69] P. J. Sutton,[33] K. Suzuki,[232] M. Suzuki,[219]
B. L. Swinkels,[37] A. Syx,[127] M. J. Szczepańczyk,[324] P. Szewczyk,[137] M. Tacca,[37] H. Tagoshi,[219] K. Takada,[219]
H. Takahashi,[287] R. Takahashi,[25] A. Takamori,[43] S. Takano,[325] H. Takeda,[326,327] K. Takeshita,[232]
I. Takimoto Schmiegelow,[45,46] M. Takou-Ayaoh,[142] C. Talbot,[143] M. Tamaki,[219] N. Tamanini,[109] D. Tanabe,[154]
K. Tanaka,[51] S. J. Tanaka,[245] S. Tanioka,[33] D. B. Tanner,[95] W. Tanner,[8,9] L. Tao,[226] R. D. Tapia,[131]
E. N. Tapia San Martín,[37] C. Taranto,[21,22] A. Taruya,[328] J. D. Tasson,[166] J. G. Tau,[120] D. Tellez,[129] R. Tenorio,[107]
H. Themann,[194] A. Theodoropoulos,[151] M. P. Thirugnanasambandam,[81] L. M. Thomas,[41] M. Thomas,[110] P. Thomas,[86]
J. E. Thompson,[225] S. R. Thondapu,[113] K. A. Thorne,[110] E. Thrane,[6] J. Tissino,[45,46] A. Tiwari,[81] Pawan Tiwari,[45]
Praveer Tiwari,[209] S. Tiwari,[202] V. Tiwari,[130] M. R. Todd,[142] M. Toffano,[99] A. M. Toivonen,[105] K. Toland,[91]
A. E. Tolley,[75] T. Tomaru,[25] V. Tommasini,[41] T. Tomura,[51] H. Tong,[6] C. Tong-Yu,[154] A. Torres-Forné,[151,152]
C. I. Torrie,[41] I. Tosta e Melo,[329] E. Tournefier,[31] M. Trad Nery,[123] K. Tran,[135] A. Trapananti,[53,52] R. Travaglini,[181]
F. Travasso,[53,52] G. Traylor,[110] M. Trevor,[138] M. C. Tringali,[64] A. Tripathee,[97] G. Troian,[198,49] A. Trovato,[198,49]
L. Trozzo,[4] R. J. Trudeau,[41] T. Tsang,[33] S. Tsuchida,[330] L. Tsukada,[228] K. Turbang,[201,23] M. Turconi,[123]
C. Turski,[102] H. Ubach,[87,88] N. Uchikata,[219] T. Uchiyama,[51] R. P. Udall,[41] T. Uehara,[331] K. Ueno,[43]
V. Undheim,[292] L. E. Uronen,[234] T. Ushiba,[51] M. Vacatello,[84,85] H. Vahlbruch,[8,9] N. Vaidya,[41] G. Vajente,[41]
A. Vajpeyi,[6] J. Valencia,[107] M. Valentini,[117,37] S. A. Vallejo-Peña,[310] S. Vallero,[28] V. Valsan,[83] M. van Dael,[37,332]
E. Van den Bossche,[201] J. F. J. van den Brand,[36,117,37] C. Van Den Broeck,[73,37] M. van der Sluys,[37,73] A. Van de Walle,[42]
J. van Dongen,[37,117] K. Vandra,[112] M. VanDyke,[132] H. van Haevermaet,[23] J. V. van Heijningen,[37,117] P. Van Hove,[66]
J. Vanier,[274] M. VanKeuren,[114] J. Vanosky,[86] N. van Remortel,[23] M. Vardaro,[36,37] A. F. Vargas,[136] V. Varma,[146]
A. N. Vazquez,[96] A. Vecchio,[130] G. Vedovato,[100] J. Veitch,[91] P. J. Veitch,[126] S. Venikoudis,[15] R. C. Venterea,[105]
P. Verdier,[57] M. Vereecken,[15] D. Verkindt,[31] B. Verma,[146] Y. Verma,[113] S. M. Vermeulen,[41] F. Vetrano,[204]
A. Veutro,[38,39] A. Viceré,[204,63] S. Vidyant,[142] A. D. Viets,[333] A. Vijaykumar,[203] A. Vilkha,[120]
N. Villanueva Espinosa,[151] V. Villa-Ortega,[191] E. T. Vincent,[98] J.-Y. Vinet,[123] S. Viret,[57] S. Vitale,[92] H. Vocca,[78,52]
D. Voigt,[106] E. R. G. von Reis,[86] J. S. A. von Wrangel,[8,9] W. E. Vossius,[246] L. Vujeva,[153] S. P. Vyatchanin,[118] J. Wack,[41]
L. E. Wade,[114] M. Wade,[114] K. J. Wagner,[120] L. Wallace,[41] E. J. Wang,[96] H. Wang,[232] J. Z. Wang,[97] W. H. Wang,[178]
Y. F. Wang,[1] G. Waratkar,[209] J. Warner,[86] M. Was,[31] T. Washimi,[25] N. Y. Washington,[41] D. Watarai,[43] B. Weaver,[86]

S. A. Webster,[91] N. L. Weickhardt,[106] M. Weinert,[8,9] A. J. Weinstein,[41] R. Weiss,[92] L. Wen,[74] K. Wette,[34]
J. T. Whelan,[120] B. F. Whiting,[95] C. Whittle,[41] E. G. Wickens,[75] D. Wilken,[8,9,9] A. T. Wilkin,[226] B. M. Williams,[132]
D. Williams,[91] M. J. Williams,[75] N. S. Williams,[1] J. L. Willis,[41] B. Willke,[9,8,9] M. Wils,[119] L. Wilson,[114]
C. W. Winborn,[115] J. Winterflood,[74] C. C. Wipf,[41] G. Woan,[91] J. Woehler,[36,37] N. E. Wolfe,[92] H. T. Wong,[154]
I. C. F. Wong,[234,119] K. Wong,[203] T. Wouters,[73,37] J. L. Wright,[86] M. Wright,[91,73] B. Wu,[142] C. Wu,[155] D. S. Wu,[8,9]
H. Wu,[155] K. Wu,[132] Q. Wu,[311] Y. Wu,[104] Z. Wu,[109] E. Wuchner,[129] D. M. Wysocki,[83] V. A. Xu,[222] Y. Xu,[107]
N. Yadav,[28] H. Yamamoto,[41] K. Yamamoto,[165] T. S. Yamamoto,[43] T. Yamamoto,[51] R. Yamazaki,[245] T. Yan,[130]
K. Z. Yang,[105] Y. Yang,[159] Z. Yarbrough,[82] J. Yebana,[107] S.-W. Yeh,[155] A. B. Yelikar,[157] X. Yin,[92]
J. Yokoyama,[334,43] T. Yokozawa,[51] S. Yuan,[74] H. Yuzurihara,[51] M. Zanolin,[217] M. Zeeshan,[120] T. Zelenova,[64]
J.-P. Zendri,[100] M. Zeoli,[15] M. Zerrad,[40] M. Zevin,[104] L. Zhang,[41] N. Zhang,[98] R. Zhang,[163] T. Zhang,[130] C. Zhao,[74]
Yue Zhao,[175] Yuhang Zhao,[20] Z.-C. Zhao,[335] Y. Zheng,[115] H. Zhong,[105] H. Zhou,[142] H. O. Zhu,[74] Z.-H. Zhu,[335,336]
L. Zimmermann,[57] M. E. Zucker,[92,41] and J. Zweizig[41]

(LIGO Scientific Collaboration, Virgo Collaboration, and KAGRA Collaboration)

[1]*Max Planck Institute for Gravitational Physics (Albert Einstein Institute), D-14476 Potsdam, Germany*
[2]*LIGO Hanford Observatory, Richland, Washington 99352, USA*
[3]*Dipartimento di Farmacia, Università di Salerno, I-84084 Fisciano, Salerno, Italy*
[4]*INFN, Sezione di Napoli, I-80126 Napoli, Italy*
[5]*University of Warwick, Coventry CV4 7AL, United Kingdom*
[6]*OzGrav, School of Physics and Astronomy, Monash University, Clayton 3800, Victoria, Australia*
[7]*The Pennsylvania State University, University Park, Pennsylvania 16802, USA*
[8]*Max Planck Institute for Gravitational Physics (Albert Einstein Institute), D-30167 Hannover, Germany*
[9]*Leibniz Universität Hannover, D-30167 Hannover, Germany*
[10]*University of Wisconsin-Milwaukee, Milwaukee, Wisconsin 53201, USA*
[11]*LIGO Laboratory, California Institute of Technology, Pasadena, California 91125, USA*
[12]*Louisiana State University, Baton Rouge, Louisiana 70803, USA*
[13]*Tata Institute of Fundamental Research, Mumbai 400005, India*
[14]*Centre de Physique Théorique, Aix-Marseille Université, Campus de Luminy,*
163 Avenue de Luminy, 13009 Marseille, France
[15]*Université catholique de Louvain, B-1348 Louvain-la-Neuve, Belgium*
[16]*Queen Mary University of London, London E1 4NS, United Kingdom*
[17]*University of California, Davis, Davis, California 95616, USA*
[18]*University of Minnesota, Minneapolis, Minnesota 55455, USA*
[19]*Instituto Nacional de Pesquisas Espaciais, 12227-010 São José dos Campos, São Paulo, Brazil*
[20]*Université Paris Cité, CNRS, Astroparticule et Cosmologie, F-75013 Paris, France*
[21]*Università di Roma Tor Vergata, I-00133 Roma, Italy*
[22]*INFN, Sezione di Roma Tor Vergata, I-00133 Roma, Italy*
[23]*Universiteit Antwerpen, 2000 Antwerpen, Belgium*
[24]*International Centre for Theoretical Sciences, Tata Institute of Fundamental Research,*
Bengaluru 560089, India
[25]*Gravitational Wave Science Project, National Astronomical Observatory of Japan,*
2-21-1 Osawa, Mitaka City, Tokyo 181-8588, Japan
[26]*Advanced Technology Center, National Astronomical Observatory of Japan,*
2-21-1 Osawa, Mitaka City, Tokyo 181-8588, Japan
[27]*Theoretisch-Physikalisches Institut, Friedrich-Schiller-Universität Jena, D-07743 Jena, Germany*
[28]*INFN Sezione di Torino, I-10125 Torino, Italy*
[29]*INFN, Sezione di Genova, I-16146 Genova, Italy*
[30]*Dipartimento di Fisica, Università degli Studi di Genova, I-16146 Genova, Italy*
[31]*Univ. Savoie Mont Blanc, CNRS, Laboratoire d'Annecy de Physique des Particules—IN2P3,*
F-74000 Annecy, France
[32]*Università di Napoli "Federico II," I-80126 Napoli, Italy*
[33]*Cardiff University, Cardiff CF24 3AA, United Kingdom*
[34]*OzGrav, Australian National University, Canberra, Australian Capital Territory 0200, Australia*
[35]*LIGO Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA*
[36]*Maastricht University, 6200 MD Maastricht, Netherlands*
[37]*Nikhef, 1098 XG Amsterdam, Netherlands*

[38]*INFN, Sezione di Roma, I-00185 Roma, Italy*
[39]*Università di Roma "La Sapienza", I-00185 Roma, Italy*
[40]*Aix Marseille Univ, CNRS, Centrale Med, Institut Fresnel, F-13013 Marseille, France*
[41]*LIGO Laboratory, California Institute of Technology, Pasadena, California 91125, USA*
[42]*Université Paris-Saclay, CNRS/IN2P3, IJCLab, 91405 Orsay, France*
[43]*University of Tokyo, Tokyo, 113-0033, Japan*
[44]*Institut de Física d'Altes Energies (IFAE), The Barcelona Institute of Science and Technology,*
Campus UAB, E-08193 Bellaterra (Barcelona), Spain
[45]*Gran Sasso Science Institute (GSSI), I-67100 L'Aquila, Italy*
[46]*INFN, Laboratori Nazionali del Gran Sasso, I-67100 Assergi, Italy*
[47]*University of Florida, Gainesville, Florida 32611, USA*
[48]*Dipartimento di Scienze Matematiche, Informatiche e Fisiche, Università di Udine, I-33100 Udine, Italy*
[49]*INFN, Sezione di Trieste, I-34127 Trieste, Italy*
[50]*Tecnologico de Monterrey, Escuela de Ingeniería y Ciencias, 64849 Monterrey, Nuevo León, Mexico*
[51]*Institute for Cosmic Ray Research, KAGRA Observatory, The University of Tokyo, 238 Higashi-Mozumi,*
Kamioka-cho, Hida City, Gifu 506-1205, Japan
[52]*INFN, Sezione di Perugia, I-06123 Perugia, Italy*
[53]*Università di Camerino, I-62032 Camerino, Italy*
[54]*University of Washington, Seattle, Washington 98195, USA*
[55]*California State University Fullerton, Fullerton, California 92831, USA*
[56]*SUPA, University of Strathclyde, Glasgow G1 1XQ, United Kingdom*
[57]*Université Claude Bernard Lyon 1,*
CNRS, IP2I Lyon / IN2P3, UMR 5822, F-69622 Villeurbanne, France
[58]*Georgia Institute of Technology, Atlanta, Georgia 30332, USA*
[59]*Chennai Mathematical Institute, Chennai 603103, India*
[60]*Royal Holloway, University of London, London TW20 0EX, United Kingdom*
[61]*Astronomical course, The Graduate University for Advanced Studies (SOKENDAI),*
2-21-1 Osawa, Mitaka City, Tokyo 181-8588, Japan
[62]*Università degli Studi di Urbino "Carlo Bo," I-61029 Urbino, Italy*
[63]*INFN, Sezione di Firenze, I-50019 Sesto Fiorentino, Firenze, Italy*
[64]*European Gravitational Observatory (EGO), I-56021 Cascina, Pisa, Italy*
[65]*LIGO Livingston Observatory, Livingston, Louisiana 70754, USA*
[66]*Université de Strasbourg, CNRS, IPHC UMR 7178, F-67000 Strasbourg, France*
[67]*Embry-Riddle Aeronautical University, Prescott, Arizona 86301, USA*
[68]*Dipartimento di Fisica "E.R. Caianiello," Università di Salerno, I-84084 Fisciano, Salerno, Italy*
[69]*King's College London, University of London, London WC2R 2LS, United Kingdom*
[70]*Korea Institute of Science and Technology Information, Daejeon 34141, Republic of Korea*
[71]*International College, Osaka University,*
1-1 Machikaneyama-cho, Toyonaka City, Osaka 560-0043, Japan
[72]*Accelerator Laboratory, High Energy Accelerator Research Organization (KEK),*
1-1 Oho, Tsukuba City, Ibaraki 305-0801, Japan
[73]*Institute for Gravitational and Subatomic Physics (GRASP), Utrecht University,*
3584 CC Utrecht, Netherlands
[74]*OzGrav, University of Western Australia, Crawley, Western Australia 6009, Australia*
[75]*University of Portsmouth, Portsmouth, PO1 3FX, United Kingdom*
[76]*Università di Trento, Dipartimento di Fisica, I-38123 Povo, Trento, Italy*
[77]*INFN, Trento Institute for Fundamental Physics and Applications, I-38123 Povo, Trento, Italy*
[78]*Università di Perugia, I-06123 Perugia, Italy*
[79]*University of Oregon, Eugene, Oregon 97403, USA*
[80]*Syracuse University, Syracuse, New York 13244, USA*
[81]*Inter-University Centre for Astronomy and Astrophysics, Pune 411007, India*
[82]*Louisiana State University, Baton Rouge, LA 70803, USA*
[83]*University of Wisconsin-Milwaukee, Milwaukee, WI 53201, USA*
[84]*INFN, Sezione di Pisa, I-56127 Pisa, Italy*
[85]*Università di Pisa, I-56127 Pisa, Italy*
[86]*LIGO Hanford Observatory, Richland, WA 99352, USA*
[87]*Institut de Ciències del Cosmos (ICCUB), Universitat de Barcelona (UB),*
c. Martí i Franquès, 1, 08028 Barcelona, Spain
[88]*Departament de Física Quàntica i Astrofísica (FQA), Universitat de Barcelona (UB),*
c. Martí i Franqués, 1, 08028 Barcelona, Spain

[89]*Institut d'Estudis Espacials de Catalunya, c. Gran Capità, 2-4, 08034 Barcelona, Spain*
[90]*Dipartimento di Medicina, Chirurgia e Odontoiatria "Scuola Medica Salernitana," Università di Salerno, I-84081 Baronissi, Salerno, Italy*
[91]*IGR, University of Glasgow, Glasgow G12 8QQ, United Kingdom*
[92]*LIGO Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA*
[93]*HUN-REN Wigner Research Centre for Physics, H-1121 Budapest, Hungary*
[94]*Concordia University Wisconsin, Mequon, Wisconsin 53097, USA*
[95]*University of Florida, Gainesville, Florida 32611, USA*
[96]*Stanford University, Stanford, California 94305, USA*
[97]*University of Michigan, Ann Arbor, Michigan 48109, USA*
[98]*Georgia Institute of Technology, Atlanta, Georgia 30332, USA*
[99]*Università di Padova, Dipartimento di Fisica e Astronomia, I-35131 Padova, Italy*
[100]*INFN, Sezione di Padova, I-35131 Padova, Italy*
[101]*Institute for Plasma Research, Bhat, Gandhinagar 382428, India*
[102]*Universiteit Gent, B-9000 Gent, Belgium*
[103]*Nicolaus Copernicus Astronomical Center, Polish Academy of Sciences, 00-716, Warsaw, Poland*
[104]*Northwestern University, Evanston, Illinois 60208, USA*
[105]*University of Minnesota, Minneapolis, Minnesota 55455, USA*
[106]*Universität Hamburg, D-22761 Hamburg, Germany*
[107]*IAC3–IEEC, Universitat de les Illes Balears, E-07122 Palma de Mallorca, Spain*
[108]*Aix-Marseille Université, Université de Toulon, CNRS, CPT, Marseille, France*
[109]*Laboratoire des 2 Infinis—Toulouse (L2IT-IN2P3), F-31062 Toulouse Cedex 9, France*
[110]*LIGO Livingston Observatory, Livingston, Louisiana 70754, USA*
[111]*Università di Siena, Dipartimento di Scienze Fisiche, della Terra e dell'Ambiente, I-53100 Siena, Italy*
[112]*Villanova University, Villanova, Pennsylvania 19085, USA*
[113]*RRCAT, Indore, Madhya Pradesh 452013, India*
[114]*Kenyon College, Gambier, Ohio 43022, USA*
[115]*Missouri University of Science and Technology, Rolla, Missouri 65409, USA*
[116]*Indian Institute of Technology Madras, Chennai 600036, India*
[117]*Department of Physics and Astronomy, Vrije Universiteit Amsterdam, 1081 HV Amsterdam, Netherlands*
[118]*Lomonosov Moscow State University, Moscow 119991, Russia*
[119]*Katholieke Universiteit Leuven, Oude Markt 13, 3000 Leuven, Belgium*
[120]*Rochester Institute of Technology, Rochester, New York 14623, USA*
[121]*Université libre de Bruxelles, 1050 Bruxelles, Belgium*
[122]*Bar-Ilan University, Ramat Gan, 5290002, Israel*
[123]*Université Côte d'Azur, Observatoire de la Côte d'Azur, CNRS, Artemis, F-06304 Nice, France*
[124]*University of British Columbia, Vancouver, British Columbia V6T 1Z4, Canada*
[125]*University of Oregon, Eugene, Oregon 97403, USA*
[126]*OzGrav, University of Adelaide, Adelaide, South Australia 5005, Australia*
[127]*Centre national de la recherche scientifique, 75016 Paris, France*
[128]*Univ Rennes, CNRS, Institut FOTON—UMR 6082, F-35000 Rennes, France*
[129]*California State University Fullerton, Fullerton, California 92831, USA*
[130]*University of Birmingham, Birmingham B15 2TT, United Kingdom*
[131]*The Pennsylvania State University, University Park, Pennsylvania 16802, USA*
[132]*Washington State University, Pullman, Washington 99164, USA*
[133]*Cornell University, Ithaca, New York 14850, USA*
[134]*Laboratoire Kastler Brossel, Sorbonne Université, CNRS, ENS-Université PSL, Collège de France, F-75005 Paris, France*
[135]*Christopher Newport University, Newport News, Virginia 23606, USA*
[136]*OzGrav, University of Melbourne, Parkville, Victoria 3010, Australia*
[137]*Astronomical Observatory Warsaw University, 00-478 Warsaw, Poland*
[138]*University of Maryland, College Park, Maryland 20742, USA*
[139]*Università degli Studi di Milano-Bicocca, I-20126 Milano, Italy*
[140]*INFN, Sezione di Milano-Bicocca, I-20126 Milano, Italy*
[141]*Université de Lyon, Université Claude Bernard Lyon 1, CNRS, Institut Lumière Matière, F-69622 Villeurbanne, France*
[142]*Syracuse University, Syracuse, New York 13244, USA*
[143]*University of Chicago, Chicago, Illinois 60637, USA*
[144]*University of Arizona, Tucson, Arizona 85721, USA*

[145]*INFN, Sezione di Napoli, Gruppo Collegato di Salerno, I-80126 Napoli, Italy*
[146]*University of Massachusetts Dartmouth, North Dartmouth, Massachusetts 02747, USA*
[147]*Niels Bohr Institute, Copenhagen University, 2100 København, Denmark*
[148]*Universidad de Guadalajara, 44430 Guadalajara, Jalisco, Mexico*
[149]*Istituto di Astrofisica e Planetologia Spaziali di Roma, 00133 Roma, Italy*
[150]*Colorado State University, Fort Collins, Colorado 80523, USA*
[151]*Departamento de Astronomía y Astrofísica, Universitat de València, E-46100 Burjassot, València, Spain*
[152]*Observatori Astronòmic, Universitat de València, E-46980 Paterna, València, Spain*
[153]*Niels Bohr Institute, University of Copenhagen, 2100 Kóbenhavn, Denmark*
[154]*National Central University, Taoyuan City 320317, Taiwan*
[155]*National Tsing Hua University, Hsinchu City 30013, Taiwan*
[156]*OzGrav, Charles Sturt University, Wagga Wagga, New South Wales 2678, Australia*
[157]*Vanderbilt University, Nashville, Tennessee 37235, USA*
[158]*University of the Chinese Academy of Sciences/International Centre for Theoretical Physics Asia-Pacific, Bejing 100049, China*
[159]*Department of Electrophysics, National Yang Ming Chiao Tung University, 101 Univ. Street, Hsinchu, Taiwan*
[160]*Kamioka Branch, National Astronomical Observatory of Japan, 238 Higashi-Mozumi, Kamioka-cho, Hida City, Gifu 506-1205, Japan*
[161]*University of Texas, Austin, Texas 78712, USA*
[162]*CaRT, California Institute of Technology, Pasadena, California 91125, USA*
[163]*Northeastern University, Boston, Massachusetts 02115, USA*
[164]*Dipartimento di Ingegneria Industriale (DIIN), Università di Salerno, I-84084 Fisciano, Salerno, Italy*
[165]*Faculty of Science, University of Toyama, 3190 Gofuku, Toyama City, Toyama 930-8555, Japan*
[166]*Carleton College, Northfield, Minnesota 55057, USA*
[167]*University of Szeged, Dóm tér 9, Szeged 6720, Hungary*
[168]*OzGrav, Swinburne University of Technology, Hawthorn Victoria 3122, Australia*
[169]*INFN Cagliari, Physics Department, Università degli Studi di Cagliari, Cagliari 09042, Italy*
[170]*Università degli Studi di Cagliari, Via Università 40, 09124 Cagliari, Italy*
[171]*Université Libre de Bruxelles, Brussels 1050, Belgium*
[172]*INAF, Osservatorio Astronomico di Brera sede di Merate, I-23807 Merate, Lecco, Italy*
[173]*Departamento de Matemáticas, Universitat de València, E-46100 Burjassot, València, Spain*
[174]*Montana State University, Bozeman, Montana 59717, USA*
[175]*The University of Utah, Salt Lake City, Utah 84112, USA*
[176]*Johns Hopkins University, Baltimore, Maryland 21218, USA*
[177]*University of Rhode Island, Kingston, Rhode Island 02881, USA*
[178]*The University of Texas Rio Grande Valley, Brownsville, Texas 78520, USA*
[179]*Université de Liège, B-4000 Liège, Belgium*
[180]*DIFA- Alma Mater Studiorum Università di Bologna, Via Zamboni, 33–40126 Bologna, Italy*
[181]*Istituto Nazionale Di Fisica Nucleare—Sezione di Bologna, viale Carlo Berti Pichat 6/2–40127 Bologna, Italy*
[182]*University of Manitoba, Winnipeg, Manitoba R3T 2N2, Canada*
[183]*INFN-CNAF—Bologna, Viale Carlo Berti Pichat, 6/2, 40127 Bologna BO, Italy*
[184]*Università degli Studi di Sassari, I-07100 Sassari, Italy*
[185]*INFN, Laboratori Nazionali del Sud, I-95125 Catania, Italy*
[186]*Université de Normandie, ENSICAEN, UNICAEN, CNRS/IN2P3, LPC Caen, F-14000 Caen, France*
[187]*Laboratoire de Physique Corpusculaire Caen, 6 boulevard du maréchal Juin, F-14050 Caen, France*
[188]*The University of Sheffield, Sheffield S10 2TN, United Kingdom*
[189]*Université Claude Bernard Lyon 1, CNRS, Laboratoire des Matériaux Avancés (LMA), IP2I Lyon/IN2P3, UMR 5822, F-69622 Villeurbanne, France*
[190]*Università di Firenze, Sesto Fiorentino I-50019, Italy*
[191]*IGFAE, Universidade de Santiago de Compostela, E-15782 Santiago de Compostela, Spain*
[192]*Dipartimento di Scienze Matematiche, Fisiche e Informatiche, Università di Parma, I-43124 Parma, Italy*
[193]*INFN, Sezione di Milano Bicocca, Gruppo Collegato di Parma, I-43124 Parma, Italy*
[194]*California State University, Los Angeles, Los Angeles, California 90032, USA*
[195]*Marquette University, Milwaukee, Wisconsin 53233, USA*
[196]*Perimeter Institute, Waterloo, Ontario N2L 2Y5, Canada*
[197]*Corps des Mines, Mines Paris, Université PSL, 60 Bd Saint-Michel, 75272 Paris, France*

[198]*Dipartimento di Fisica, Università di Trieste, I-34127 Trieste, Italy*
[199]*Université Côte d'Azur, Observatoire de la Côte d'Azur, CNRS, Lagrange, F-06304 Nice, France*
[200]*National Center for Nuclear Research, 05-400 Świerk-Otwock, Poland*
[201]*Vrije Universiteit Brussel, 1050 Brussel, Belgium*
[202]*University of Zurich, Winterthurerstrasse 190, 8057 Zurich, Switzerland*
[203]*Canadian Institute for Theoretical Astrophysics, University of Toronto, Toronto, Ontario M5S 3H8, Canada*
[204]*Università degli Studi di Urbino "Carlo Bo," I-61029 Urbino, Italy*
[205]*Stony Brook University, Stony Brook, New York 11794, USA*
[206]*Center for Computational Astrophysics, Flatiron Institute, New York, New York 10010, USA*
[207]*Montclair State University, Montclair, New Jersey 07043, USA*
[208]*HUN-REN Institute for Nuclear Research, H-4026 Debrecen, Hungary*
[209]*Indian Institute of Technology Bombay, Powai, Mumbai 400 076, India*
[210]*Centro de Física das Universidades do Minho e do Porto, Universidade do Minho, PT-4710-057 Braga, Portugal*
[211]*Aix Marseille Univ, CNRS/IN2P3, CPPM, Marseille, France*
[212]*CNR-SPIN, I-84084 Fisciano, Salerno, Italy*
[213]*Scuola di Ingegneria, Università della Basilicata, I-85100 Potenza, Italy*
[214]*Western Washington University, Bellingham, Washington 98225, USA*
[215]*SUPA, University of the West of Scotland, Paisley PA1 2BE, United Kingdom*
[216]*Barry University, Miami Shores, Florida 33168, USA*
[217]*Embry-Riddle Aeronautical University, Prescott, Arizona 86301, USA*
[218]*Eötvös University, Budapest 1117, Hungary*
[219]*Institute for Cosmic Ray Research, KAGRA Observatory, The University of Tokyo, 5-1-5 Kashiwa-no-Ha, Kashiwa City, Chiba 277-8582, Japan*
[220]*Department of Physics, Graduate School of Science, Osaka Metropolitan University, 3-3-138 Sugimoto-cho, Sumiyoshi-ku, Osaka City, Osaka 558-8585, Japan*
[221]*University of Sannio at Benevento, I-82100 Benevento, Italy and INFN, Sezione di Napoli, I-80100 Napoli, Italy*
[222]*University of California, Berkeley, CA 94720, USA*
[223]*Instituto de Fisica Teorica UAM-CSIC, Universidad Autonoma de Madrid, 28049 Madrid, Spain*
[224]*Laboratoire d'Acoustique de l'Université du Mans, UMR CNRS 6613, F-72085 Le Mans, France*
[225]*University of Southampton, Southampton SO17 1BJ, United Kingdom*
[226]*University of California, Riverside, Riverside, California 92521, USA*
[227]*Dipartimento di Ingegneria Industriale, Elettronica e Meccanica, Università degli Studi Roma Tre, I-00146 Roma, Italy*
[228]*University of Nevada, Las Vegas, Las Vegas, Nevada 89154, USA*
[229]*University of Nottingham NG7 2RD, UK*
[230]*Ariel University, Ramat HaGolan St 65, Ari'el, Israel*
[231]*The University of Mississippi, University, Mississippi 38677, USA*
[232]*Graduate School of Science, Institute of Science Tokyo, 2-12-1 Ookayama, Meguro-ku, Tokyo 152-8551, Japan*
[233]*Institute of Physics, Academia Sinica, 128 Section II, Academia Road, Nankang, Taipei 11529, Taiwan*
[234]*The Chinese University of Hong Kong, Shatin, NT, Hong Kong*
[235]*American University, Washington, DC 20016, USA*
[236]*Dipartimento di Fisica, Università degli studi di Milano, Via Celoria 16, I-20133, Milano, Italy*
[237]*INFN, sezione di Milano, Via Celoria 16, I-20133, Milano, Italy*
[238]*Department of Applied Physics, Fukuoka University, 8-19-1 Nanakuma, Jonan, Fukuoka City, Fukuoka 814-0180, Japan*
[239]*University of Cambridge, Cambridge CB2 1TN, United Kingdom*
[240]*University of Lancaster, Lancaster LA1 4YW, United Kingdom*
[241]*College of Industrial Technology, Nihon University, 1-2-1 Izumi, Narashino City, Chiba 275-8575, Japan*
[242]*Faculty of Engineering, Niigata University, 8050 Ikarashi-2-no-cho, Nishi-ku, Niigata City, Niigata 950-2181, Japan*
[243]*Department of Physics, Tamkang University, No. 151, Yingzhuan Road, Danshui District, New Taipei City 25137, Taiwan*
[244]*Rutherford Appleton Laboratory, Didcot OX11 0DE, United Kingdom*
[245]*Department of Physical Sciences, Aoyama Gakuin University, 5-10-1 Fuchinobe, Sagamihara City, Kanagawa 252-5258, Japan*

[246]Helmut Schmidt University, D-22043 Hamburg, Germany
[247]Nambu Yoichiro Institute of Theoretical and Experimental Physics (NITEP), Osaka Metropolitan University, 3-3-138 Sugimoto-cho, Sumiyoshi-ku, Osaka City, Osaka 558-8585, Japan
[248]Directorate of Construction, Services and Estate Management, Mumbai 400094, India
[249]Observatoire Astronomique de Strasbourg, 11 Rue de l'Université, 67000 Strasbourg, France
[250]Faculty of Physics, University of Białystok, 15-245 Białystok, Poland
[251]National Astronomical Observatories, Chinese Academic of Sciences, 20A Datun Road, Chaoyang District, Beijing, China
[252]School of Astronomy and Space Science, University of Chinese Academy of Sciences, 20A Datun Road, Chaoyang District, Beijing, China
[253]Sungkyunkwan University, Seoul 03063, Republic of Korea
[254]Department of Physics, Ulsan National Institute of Science and Technology (UNIST), 50 UNIST-gil, Ulju-gun, Ulsan 44919, Republic of Korea
[255]Institute for Cosmic Ray Research, The University of Tokyo, 5-1-5 Kashiwa-no-Ha, Kashiwa City, Chiba 277-8582, Japan
[256]Chung-Ang University, Seoul 06974, Republic of Korea
[257]University of Washington Bothell, Bothell, Washington 98011, USA
[258]Laboratoire de Physique et de Chimie de l'Environnement, Université Joseph KI-ZERBO, 9GH2+3V5, Ouagadougou, Burkina Faso
[259]Ewha Womans University, Seoul 03760, Republic of Korea
[260]National Institute for Mathematical Sciences, Daejeon 34047, Republic of Korea
[261]Korea Astronomy and Space Science Institute, Daejeon 34055, Republic of Korea
[262]Department of Astronomy and Space Science, Chungnam National University, 9 Daehak-ro, Yuseong-gu, Daejeon 34134, Republic of Korea
[263]Institute of Particle and Nuclear Studies (IPNS), High Energy Accelerator Research Organization (KEK), 1-1 Oho, Tsukuba City, Ibaraki 305-0801, Japan
[264]Division of Science, National Astronomical Observatory of Japan, 2-21-1 Osawa, Mitaka City, Tokyo 181-8588, Japan
[265]Nagoya University, Nagoya, 464-8601, Japan
[266]Department of Physics, Aristotle University of Thessaloniki, 54124 Thessaloniki, Greece
[267]Bard College, Annandale-On-Hudson, New York 12504, USA
[268]Technical University of Braunschweig, D-38106 Braunschweig, Germany
[269]Institute of Mathematics, Polish Academy of Sciences, 00656 Warsaw, Poland
[270]Astronomical Observatory, Jagiellonian University, 31-007 Cracow, Poland
[271]Department of Physics and Astronomy, University of Padova, Via Marzolo, 8-35151 Padova, Italy
[272]Sezione di Padova, Istituto Nazionale di Fisica Nucleare (INFN), Via Marzolo, 8-35131 Padova, Italy
[273]Department of Physics, Nagoya University, ES building, Furocho, Chikusa-ku, Nagoya, Aichi 464-8602, Japan
[274]Université de Montréal/Polytechnique, Montreal, Quebec H3T 1J4, Canada
[275]Indian Institute of Science Education and Research, Kolkata, Mohanpur, West Bengal 741252, India
[276]Seoul National University, Seoul 08826, Republic of Korea
[277]Department of Computer Simulation, Inje University, 197 Inje-ro, Gimhae, Gyeongsangnam-do 50834, Republic of Korea
[278]NAVIER, École des Ponts, Univ Gustave Eiffel, CNRS, Marne-la-Vallée, France
[279]Gravitational Wave Science Project, National Astronomical Observatory of Japan (NAOJ), Mitaka City, Tokyo 181-8588, Japan
[280]Department of Physics, National Cheng Kung University, No. 1, University Road, Tainan City 701, Taiwan
[281]St. Thomas University, Miami Gardens, Florida 33054, USA
[282]Scuola Normale Superiore, I-56126 Pisa, Italy
[283]Institució Catalana de Recerca i Estudis Avançats, E-08010 Barcelona, Spain
[284]Institut de Física d'Altes Energies, E-08193 Barcelona, Spain
[285]Institut fuer Theoretische Astrophysik, Zentrum fuer Astronomie Heidelberg, Universitaet Heidelberg, Albert Ueberle Straße 2, 69120 Heidelberg, Germany
[286]Institucio Catalana de Recerca i Estudis Avançats (ICREA), Passeig de Lluís Companys, 23, 08010 Barcelona, Spain
[287]Research Center for Space Science, Advanced Research Laboratories, Tokyo City University, 3-3-1 Ushikubo-Nishi, Tsuzuki-Ku, Yokohama, Kanagawa 224-8551, Japan
[288]Tsinghua University, Beijing 100084, China
[289]Institut des Hautes Etudes Scientifiques, F-91440 Bures-sur-Yvette, France

[290]*Faculty of Law, Ryukoku University,*
67 Fukakusa Tsukamoto-cho, Fushimi-ku, Kyoto City, Kyoto 612-8577, Japan
[291]*Phenikaa Institute for Advanced Study (PIAS), Phenikaa University,*
Yen Nghia, Ha Dong, Hanoi, Vietnam
[292]*University of Stavanger, 4021 Stavanger, Norway*
[293]*Physics Program, Graduate School of Advanced Science and Engineering, Hiroshima University,*
1-3-1 Kagamiyama, Higashihiroshima City, Hiroshima 739-8526, Japan
[294]*GRAPPA, Anton Pannekoek Institute for Astronomy and Institute for High-Energy Physics,*
University of Amsterdam, 1098 XH Amsterdam, Netherlands
[295]*University College London, London WC1E 6BT, United Kingdom*
[296]*Observatoire de Paris, 75014 Paris, France*
[297]*Laboratoire Univers et Théories, Observatoire de Paris, 92190 Meudon, France*
[298]*Graduate School of Science and Technology, Niigata University,*
8050 Ikarashi-2-no-cho, Nishi-ku, Niigata City, Niigata 950-2181, Japan
[299]*University of Maryland, Baltimore County, Baltimore, Maryland 21250, USA*
[300]*CSIR-Central Glass and Ceramic Research Institute, Kolkata, West Bengal 700032, India*
[301]*Consiglio Nazionale delle Ricerche—Istituto dei Sistemi Complessi, I-00185 Roma, Italy*
[302]*Department of Astronomy, Yonsei University,*
50 Yonsei-Ro, Seodaemun-Gu, Seoul 03722, Republic of Korea
[303]*Department of Physics, University of Guadalajara, Avenida Revolucion 1500,*
Colonia Olimpica C.P. 44430, Guadalajara, Jalisco, Mexico
[304]*Hobart and William Smith Colleges, Geneva, New York 14456, USA*
[305]*INAF, Osservatorio Astronomico di Padova, I-35122 Padova, Italy*
[306]*Dipartimento di Ingegneria, Università del Sannio, I-82100 Benevento, Italy*
[307]*Museo Storico della Fisica e Centro Studi e Ricerche "Enrico Fermi," I-00184 Roma, Italy*
[308]*Kennesaw State University, Kennesaw, Georgia 30144, USA*
[309]*Subatech, CNRS/IN2P3—IMT Atlantique—Nantes Université,*
4 rue Alfred Kastler BP 20722 44307 Nantes CÉDEX 03, France
[310]*Universidad de Antioquia, Medellín, Colombia*
[311]*University of Washington, Seattle, Washington 98195, USA*
[312]*Departamento de Física—ETSIDI, Universidad Politécnica de Madrid, 28012 Madrid, Spain*
[313]*Department of Electronic Control Engineering, National Institute of Technology,*
Nagaoka College, 888 Nishikatakai, Nagaoka City, Niigata 940-8532, Japan
[314]*Trinity College, Hartford, Connecticut 06106, USA*
[315]*Dipartimento di Fisica e Scienze della Terra, Università Degli Studi di Ferrara,*
Via Saragat, 1, 44121 Ferrara FE, Italy
[316]*Faculty of Science, Toho University, 2-2-1 Miyama, Funabashi City, Chiba 274-8510, Japan*
[317]*Indian Institute of Technology, Palaj, Gandhinagar, Gujarat 382355, India*
[318]*Kavli Institute for Astronomy and Astrophysics, Peking University,*
Yiheyuan Road 5, Haidian District, Beijing 100871, China
[319]*Laboratoire MSME, Cité Descartes, 5 Boulevard Descartes,*
Champs-sur-Marne, 77454 Marne-la-Vallée Cedex 2, France
[320]*Faculty of Information Science and Technology, Osaka Institute of Technology,*
1-79-1 Kitayama, Hirakata City, Osaka 573-0196, Japan
[321]*NASA Goddard Space Flight Center, Greenbelt, Maryland 20771, USA*
[322]*Faculty of Science and Technology, Kochi University,*
2-5-1 Akebono-cho, Kochi-shi, Kochi 780-8520, Japan
[323]*Laboratoire de Physique de l'École Normale Supérieure, ENS,*
(CNRS, Université PSL, Sorbonne Université, Université Paris Cité),
F-75005 Paris, France
[324]*Faculty of Physics, University of Warsaw, Ludwika Pasteura 5, 02-093 Warszawa, Poland*
[325]*Laser Interferometry and Gravitational Wave Astronomy,*
Max Planck Institute for Gravitational Physics,
Callinstrasse 38, 30167 Hannover, Germany
[326]*The Hakubi Center for Advanced Research, Kyoto University,*
Yoshida-honmachi, Sakyou-ku, Kyoto City, Kyoto 606-8501, Japan
[327]*Department of Physics, Kyoto University,*
Kita-Shirakawa Oiwake-cho, Sakyou-ku, Kyoto City, Kyoto 606-8502, Japan
[328]*Yukawa Institute for Theoretical Physics (YITP), Kyoto University,*
Kita-Shirakawa Oiwake-cho, Sakyou-ku, Kyoto City, Kyoto 606-8502, Japan

[329]*University of Catania, Department of Physics and Astronomy, Via S. Sofia, 64, 95123 Catania CT, Italy*
[330]*National Institute of Technology, Fukui College, Geshi-cho, Sabae-shi, Fukui 916-8507, Japan*
[331]*Department of Communications Engineering, National Defense Academy of Japan,*
1-10-20 Hashirimizu, Yokosuka City, Kanagawa 239-8686, Japan
[332]*Eindhoven University of Technology, 5600 MB Eindhoven, Netherlands*
[333]*Concordia University Wisconsin, Mequon, Wisconsin 53097, USA*
[334]*Kavli Institute for the Physics and Mathematics of the Universe (Kavli IPMU), WPI,*
The University of Tokyo, 5-1-5 Kashiwa-no-Ha, Kashiwa City, Chiba 277-8583, Japan
[335]*Department of Astronomy, Beijing Normal University,*
Xinjiekouwai Street 19, Haidian District, Beijing 100875, China
[336]*School of Physics and Technology, Wuhan University,*
Bayi Road 299, Wuchang District, Wuhan, Hubei, 430072, China

[†]Deceased, September 2024.