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Erratum: "A Search for IceCube Sub-TeV Neutrinos Correlated with Gravitational-wave Events Detected By LIGO/Virgo" (2023, ApJ, 959, 96)

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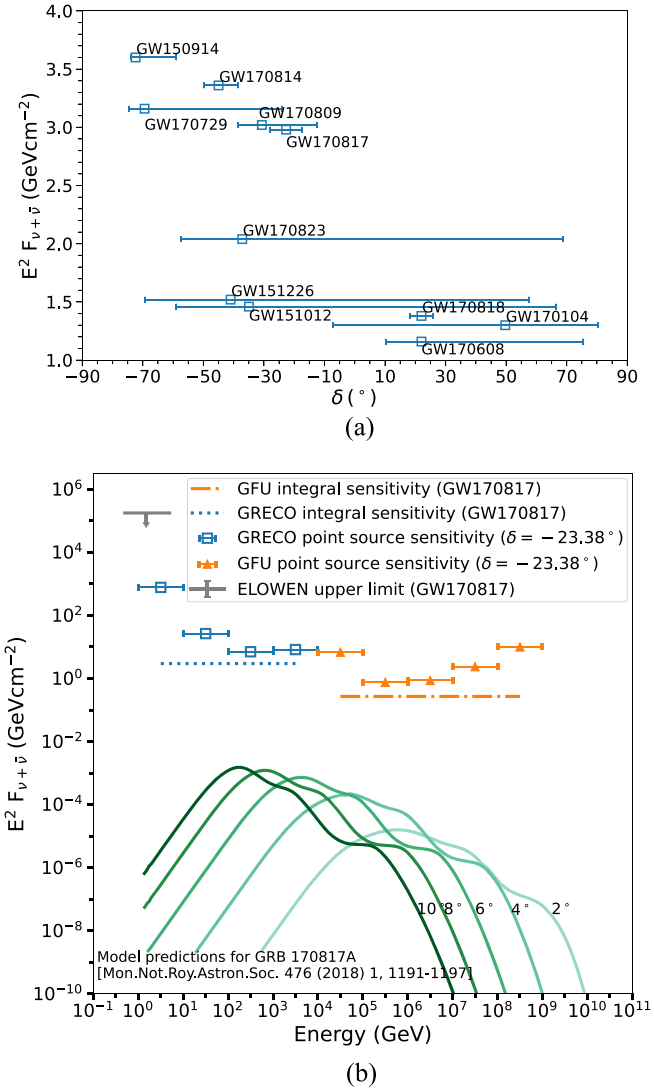

Figure 1. (a) Sensitivities of the GRECO Astronomy data set to the 11 GW events in the GWTC-1 catalog. The x-axis represents the declinations of the corresponding GW events (decl. with maximum probability shown by the squares and the declinations covering the 68% probability region shown as error bars). $F_{\nu+\bar{\nu}}$ represents the time-integrated flux as defined in Equation (3). The sensitivities for events in the Northern and Southern Hemispheres are within an order of magnitude. (b) The differential sensitivities of the GRECO Astronomy data set (in blue squares) compared to the differential sensitivities of the high-energy data set (GFU). The differential sensitivity curves are constructed by dividing the entire energy range into decadal bins. The GRECO Astronomy data set contains neutrinos of all flavors while GFU contains only muon neutrinos. Also shown are the integral sensitivities to a decl. corresponding to that of the host galaxy of GW170817, NGC4993 (Coulter et al. 2017). The gray marker shows the flux upper limit on GW170817 obtained with the follow-up analysis using extremely low-energy neutrinos detected with IceCube (Abbasi et al. 2021). The green curves represent model predictions showing low-energy neutrino emission from a GRB like 170817A (Biehl et al. 2018). All sensitivities shown in (a) and (b) assume a spectral index of 2 for the flux.

The flux upper limits and the $E_{\rm iso}$ upper limits calculated using the GRECO Astronomy data set initially reported in this publication are underestimated by a factor of 2. Event weights, calculated from simulated neutrino signal, are used to convert the best-fit number of signal events, $\hat{n}_s$, to the time-integrated flux for the combination of neutrinos and antineutrinos, $F_{\nu+\bar{\nu}}$, assuming equal flux of ν and $\bar{\nu}$. Initially, the event weights incorrectly assumed the summed flux of ν and $\bar{\nu}$ instead of the average flux. Using event weights for the summed flux of ν and $\bar{\nu}$ double counts the factor of 2, which is already included in the conversion from $\hat{n}_s$ to $F_{\nu+\bar{\nu}}$. Revised Figures 1, 2, and 5 and Table 1 are provided here, where $F_{\nu+\bar{\nu}}$ represents the combined neutrino and antineutrino fluxes.

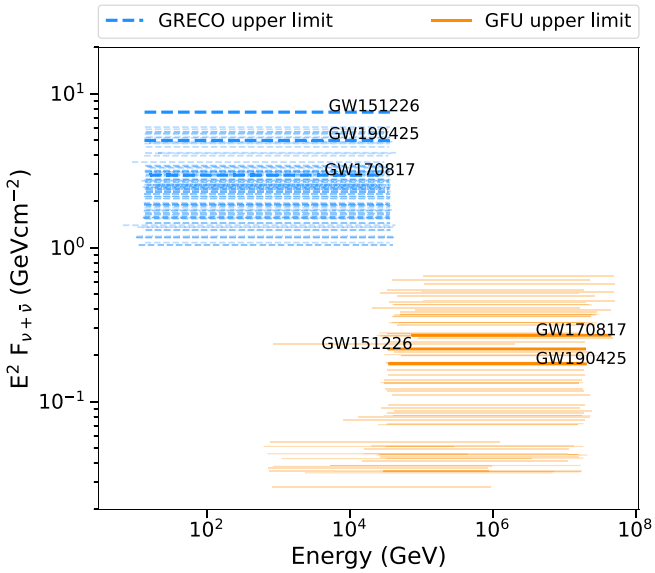

Figure 2. Flux upper limits obtained for the 90 GW events obtained in this analysis (blue dashed). The corresponding flux upper limits obtained with the high-energy muon neutrino follow-up analysis are also shown (orange solid; Aartsen et al. 2020; Abbasi et al. 2023). These limits are for a flux with a spectral index of 2. The energy ranges shown here are the central 90% energies contributing to the flux limits at the declinations spanning the 90% probability regions of the GW skymap. These energy ranges are computed for each decl. bin by calculating the upper and lower energy limits of the data set at which the sensitivity degrades by 90%. Three GW events are highlighted here. These are GW151226 (the event with the lowest pretrial p-value in this analysis), GW190425 (the only BNS event with a pretrial p-value < 0.1), and GW170817 (first and only BNS event for which the electromagnetic counterpart has been observed).

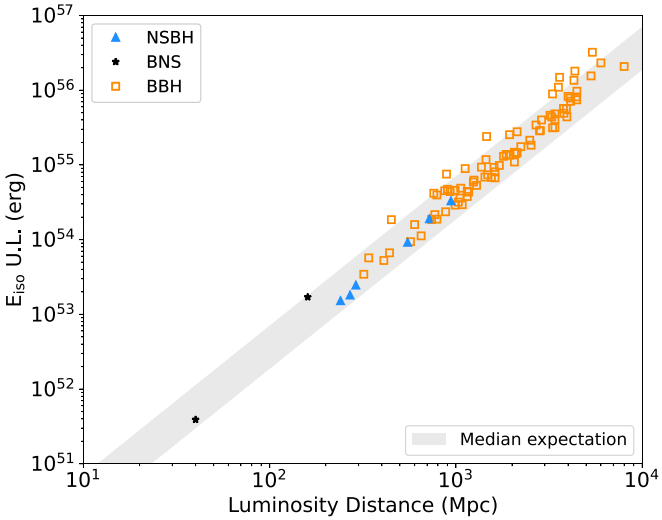

Figure 5. Upper limits to the isotropic-equivalent energy emitted in low-energy neutrinos of all flavors. The orange squares show the BBH events, the blue triangles the NSBH events and the black stars the BNS events. Also shown is the median expectation of the E_{iso} upper limits, derived from the background sensitivities of the GRECO Astronomy data set (gray band). The events that lie above the band are those with p-values <0.1 seen in this analysis. Also note that the observed isotropic energy in gamma rays from GRB170817A is 1.36×10^{46} erg, which is several orders of magnitude below the scale of this figure. The corresponding event GW170817 is the bottom-left star in this figure.

Table 1
The Obtained Results for the 90 GW Events Followed Up in This Analysis

GW	Type	Area (deg^2)	Distance (Mpc)	p-value	Upper Limit ($E^2 F_{\nu+\bar{\nu}}$) (GeV cm^{-2})	E_{iso} U. L. (erg)
GW151226	BBH	1039.0	450	7.83×10^{-3}	7.60	6.20×10^{54}
GW190910_112807	BBH	10880.3	1460	3.07×10^{-2}	6.08	7.48×10^{55}
GW200316_215756	BBH	410.4	1120	3.79×10^{-2}	3.42	8.94×10^{54}

Table 1
(Continued)

GW	Type	Area (deg^2)	Distance (Mpc)	p-value	Upper Limit ($E^2 F_{\nu+\bar{\nu}}$) (GeV cm^{-2})	E_{iso} U. L. (erg)
GW190630_185205	BBH	1216.9	890	4.12×10^{-2}	5.66	2.42×10^{55}
GW190426_190642	BBH	8214.5	4350	4.13×10^{-2}	5.60	6.06×10^{56}
GW190413_052954	BBH	1484.5	3550	4.23×10^{-2}	4.10	3.24×10^{56}
GW170823	BBH	1650.0	1940	5.07×10^{-2}	5.18	7.14×10^{55}
GW191230_180458	BBH	1012.2	4300	5.47×10^{-2}	5.88	13.58×10^{55}
GW190930_133541	BBH	1679.6	760	5.48×10^{-2}	2.72	12.1×10^{54}
GW190728_064510	BBH	395.5	870	6.72×10^{-2}	3.96	13.66×10^{54}
GW191216_213338	BBH	480.1	340	6.93×10^{-2}	5.24	5.7×10^{53}
GW190425	BNS	9958.2	160	9.08×10^{-2}	4.98	5.64×10^{53}
GW200129_065458	BBH	81.8	900	9.25×10^{-2}	3.12	4.72×10^{54}
GW200220_061928	BBH	3484.7	6000	1.03×10^{-1}	4.52	2.32×10^{56}
GW190731_140936	BBH	3387.3	3300	1.05×10^{-1}	5.46	2.80×10^{56}
GW170818	BBH	40.3	1060	1.23×10^{-1}	1.76	15.12×10^{54}
GW190503_185404	BBH	94.4	1450	1.24×10^{-1}	4.88	4.52×10^{55}
GW190421_213856	BBH	1211.5	2880	1.26×10^{-1}	4.80	16.64×10^{55}
GW200308_173609	BBH	18705.7	5400	1.49×10^{-1}	4.76	3.22×10^{56}
GW191103_012549	BBH	2519.6	990	1.58×10^{-1}	2.48	4.58×10^{54}
GW170814	BBH	88.1	600	1.83×10^{-1}	4.14	4.82×10^{54}
GW190925_232845	BBH	1233.5	930	1.84×10^{-1}	3.34	13.28×10^{54}
GW190412	BBH	20.9	740	1.91×10^{-1}	1.40	5.78×10^{54}
GW190521_074359	BBH	546.5	1240	2.17×10^{-1}	1.92	17.9×10^{54}
GW190805_211137	BBH	3949.1	5310	2.53×10^{-1}	3.18	5.56×10^{56}
GW190517_055101	BBH	473.3	1860	2.72×10^{-1}	3.40	5.26×10^{55}
GW200220_124850	BBH	3168.9	4000	2.77×10^{-1}	2.92	8.26×10^{55}

Table 1
(Continued)

GW	Type	Area (deg^2)	Distance (Mpc)	p-value	Upper Limit ($E^2 F_{\nu+\bar{\nu}}$) (GeV cm^{-2})	E_{iso} U. L. (erg)
GW190514_065416	BBH	3009.7	4130	2.78×10^{-1}	1.88	2.08×10^{56}
GW190915_235702	BBH	396.9	1620	3.05×10^{-1}	1.18	2.6×10^{55}
GW190916_200658	BBH	4499.2	4460	3.15×10^{-1}	2.66	3.74×10^{56}
GW200112_155838	BBH	4250.4	1250	3.50×10^{-1}	3.12	6.26×10^{54}
GW190828_063405	BBH	520.1	2130	3.59×10^{-1}	2.56	5.16×10^{55}
GW190803_022701	BBH	1519.5	3270	3.71×10^{-1}	1.58	13.24×10^{55}
GW190917_114630	NSBH	2050.6	720	3.84×10^{-1}	2.24	8.12×10^{54}
GW190707_093326	BBH	1346.0	770	3.88×10^{-1}	2.42	6.9×10^{54}
GW190403_051519	BBH	5589.4	8000	4.13×10^{-1}	1.96	4.80×10^{56}
GW191126_115259	BBH	1514.5	1620	4.61×10^{-1}	1.88	6.72×10^{54}
GW200322_091133	BBH	31571.1	3600	5.15×10^{-1}	1.90	14.88×10^{55}
GW191113_071753	BBH	2993.3	1370	8.15×10^{-1}	2.76	9.14×10^{54}
GW191215_223052	BBH	595.8	1930	8.48×10^{-1}	2.74	13.46×10^{54}
GW190602_175927	BBH	694.5	2690	8.52×10^{-1}	3.30	10.56×10^{55}
GW200105_162426	NSBH	7881.8	270	8.55×10^{-1}	1.44	18.1×10^{52}
GW200225_060421	BBH	509.0	1150	8.55×10^{-1}	1.36	4.42×10^{54}
GW190521	BBH	1008.2	3920	8.65×10^{-1}	2.96	14.54×10^{54}
GW200306_093714	BBH	4371.2	2100	8.66×10^{-1}	1.36	14.16×10^{54}
GW191127_050227	BBH	1499.2	3200	8.69×10^{-1}	1.72	4.62×10^{55}
GW190620_030421	BBH	7202.1	2810	8.71×10^{-1}	1.82	12.32×10^{55}
GW200209_085452	BBH	924.5	3400	8.73×10^{-1}	1.56	4.06×10^{55}
GW200210_092254	BBH	1830.7	940	8.74×10^{-1}	2.42	3.3×10^{54}
GW190706_222641	BBH	653.8	4420	8.78×10^{-1}	1.44	2.54×10^{56}
GW190519_153544	BBH	857.1	2530	8.78×10^{-1}	1.76	6.78×10^{55}

Table 1
(Continued)

GW	Type	Area (deg^2)	Distance (Mpc)	p-value	Upper Limit ($E^2 F_{\nu+\bar{\nu}}$) (GeV cm^{-2})	E_{iso} U. L. (erg)
GW150914	BBH	184.6	440	8.79×10^{-1}	3.60	4.52×10^{54}
GW190814	BBH	19.3	240	8.87×10^{-1}	2.8	4.98×10^{53}
GW190719_215514	BBH	2890.1	3940	8.88×10^{-1}	1.62	13.96×10^{55}
GW190408_181802	BBH	148.8	1550	8.91×10^{-1}	1.18	2.20×10^{55}
GW200115_042309	NSBH	511.9	290	8.92×10^{-1}	2.56	2.46×10^{53}
GW200219_094415	BBH	702.1	3400	8.97×10^{-1}	2.76	4.82×10^{55}
GW190727_060333	BBH	833.8	3300	8.98×10^{-1}	2.66	11.92×10^{55}
GW190720_000836	BBH	463.4	790	9.02×10^{-1}	2.30	13.16×10^{54}
GW190708_232457	BBH	13675.4	880	9.04×10^{-1}	2.44	7.9×10^{54}
GW170817	BNS	31.9	40	9.07×10^{-1}	2.96	14.14×10^{51}
GW170729	BBH	1032.3	2840	9.08×10^{-1}	3.26	10.30×10^{55}
GW200208_130117	BBH	38.0	2230	9.10×10^{-1}	3.10	17.56×10^{54}
GW190513_205428	BBH	518.4	2060	9.10×10^{-1}	1.08	3.12×10^{55}
GW190701_203306	BBH	46.1	2060	9.11×10^{-1}	2.40	4.10×10^{55}
GW190725_174728	BBH	2292.5	1050	9.13×10^{-1}	2.14	13.30×10^{54}
GW190828_065509	BBH	664.0	1600	9.15×10^{-1}	3.00	3.00×10^{55}
GW200128_022011	BBH	2677.5	3400	9.17×10^{-1}	2.12	3.16×10^{55}
GW151012	BBH	1554.3	1080	9.17×10^{-1}	1.20	8.60×10^{54}
GW200224_222234	BBH	49.9	1710	9.19×10^{-1}	2.58	9.84×10^{54}
GW170809	BBH	340.7	1030	9.26×10^{-1}	3.02	9.56×10^{54}
GW191204_171526	BBH	344.9	650	9.28×10^{-1}	2.48	11.24×10^{53}
GW190924_021846	BBH	357.9	570	9.29×10^{-1}	1.60	2.86×10^{54}
GW170104	BBH	935.8	990	9.34×10^{-1}	1.30	8.62×10^{54}
GW190527_092055	BBH	3662.4	2490	9.34×10^{-1}	4.32	6.66×10^{55}

Table 1
(Continued)

GW	Type	Area (deg^2)	Distance (Mpc)	p-value	Upper Limit ($E^2 F_{\nu+\bar{\nu}}$) (GeV cm^{-2})	E_{iso} U. L. (erg)
GW191129_134029	BBH	848.3	790	9.36×10^{-1}	2.32	18.8×10^{53}
GW191105_143521	BBH	728.7	1150	9.38×10^{-1}	2.32	3.78×10^{54}
GW200202_154313	BBH	159.3	410	9.38×10^{-1}	0.50	5.26×10^{53}
GW200208_222617	BBH	1889.2	4100	9.43×10^{-1}	1.56	7.86×10^{55}
GW200311_115853	BBH	35.6	1170	9.44×10^{-1}	2.50	4.34×10^{54}
GW190926_050336	BBH	2505.9	3780	9.44×10^{-1}	2.24	2.54×10^{56}
GW191219_163120	NSBH	2232.1	550	9.53×10^{-1}	1.82	9.20×10^{53}
GW190413_134308	BBH	730.6	4450	9.54×10^{-1}	2.42	2.46×10^{56}
GW190512_180714	BBH	218.0	1430	9.56×10^{-1}	2.34	2.80×10^{55}
GW200302_015811	BBH	7010.8	1480	9.58×10^{-1}	2.08	7.38×10^{54}
GW191109_010717	BBH	1784.3	1290	9.63×10^{-1}	2.36	5.32×10^{54}
GW190929_012149	BBH	2219.3	2130	9.66×10^{-1}	1.66	17.32×10^{55}
GW191204_110529	BBH	4747.7	1800	9.85×10^{-1}	1.68	13.04×10^{54}
GW200216_220804	BBH	3009.5	3800	9.86×10^{-1}	1.04	4.92×10^{55}
GW170608	BBH	538.8	320	1.0	1.16	10.16×10^{53}

Note. The obtained p-values and flux upper limits assuming a spectral index $\gamma = 2$ are shown. The events are ordered with respect to their obtained p-values. The table also shows the upper limits on the total isotropic-equivalent energy emitted in neutrinos with energies between 3 GeV and 50 TeV in this analysis. The distances reported in this table are the mean distances to the GW source marginalized across the whole sky, and is also used in Figure 5. The areas of the GW events are obtained from the sky localizations of the 90% probability regions of the GW skymaps.

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