Searching for Neutrinos from Gravitational Wave Events from LIGO-Virgo's O1, O2, and O3 Observing Runs

Raamis Hussain[1], Alex Pizzuto[1], and Justin Vandenbroucke[1]

for The IceCube Collaboration

[1]*University of Wisconsin – Madison*

Contact: rhussain@icecube.wisc.edu

Paper DOI: 10.3847/2041-8213/ab9d24

WIPAC Wisconsin IceCube Particle Astrophysics Center

IceCube

Overview: The discovery of high-energy astrophysical neutrinos by IceCube in 2013 and of gravitational waves by LIGO in 2015 have enabled a new era of multi-messenger astronomy. Gravitational waves (GWs) can identify the merging of compact objects such as neutron stars and black holes. These compact mergers are potential neutrino sources. The LIGO-Virgo Collaboration (LVC) has reported 67 GW candidates throughout its first three observing runs. We present an analysis searching for neutrinos from each of these GW candidates using an unbinned maximum likelihood approach.

Analysis Method

We test for spatially and temporally coincident neutrinos with a given GW event using a likelihood:

$$\mathcal{L} = \frac{e^{-(n_s+n_b)}(n_s+n_b)^N}{N!}\prod_{i=1}^{N}\frac{n_s\mathcal{S}_i + n_b\mathcal{B}_i}{n_s+n_b}$$

We create a test statistic using the log-likelihood ratio and a spatial weight derived from the GW skymap

$$\Lambda = 2\ln\left(\frac{\mathcal{L}\cdot w_{\mathrm{L}}}{\mathcal{L}(n_s=0)}\right)\ ;\ \ w_l = \frac{P(GW)}{A_{pix}}$$

We test a ±500 second time window centered around the GW merger time and scan the full sky for spatially coincident neutrinos

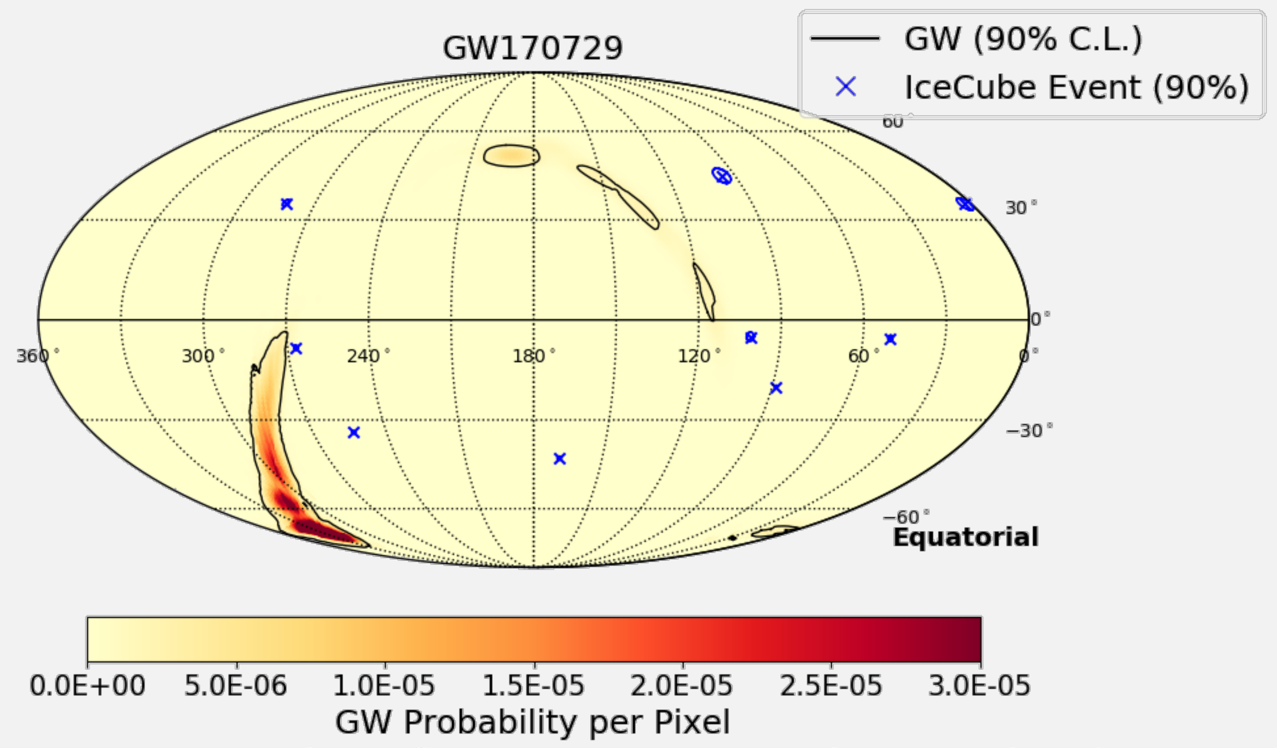

Figure 1: Example of GW event with overlaid neutrino events in blue crosses

Results

We tested 67 GW candidates reported by LVC and found no evidence of neutrino emission

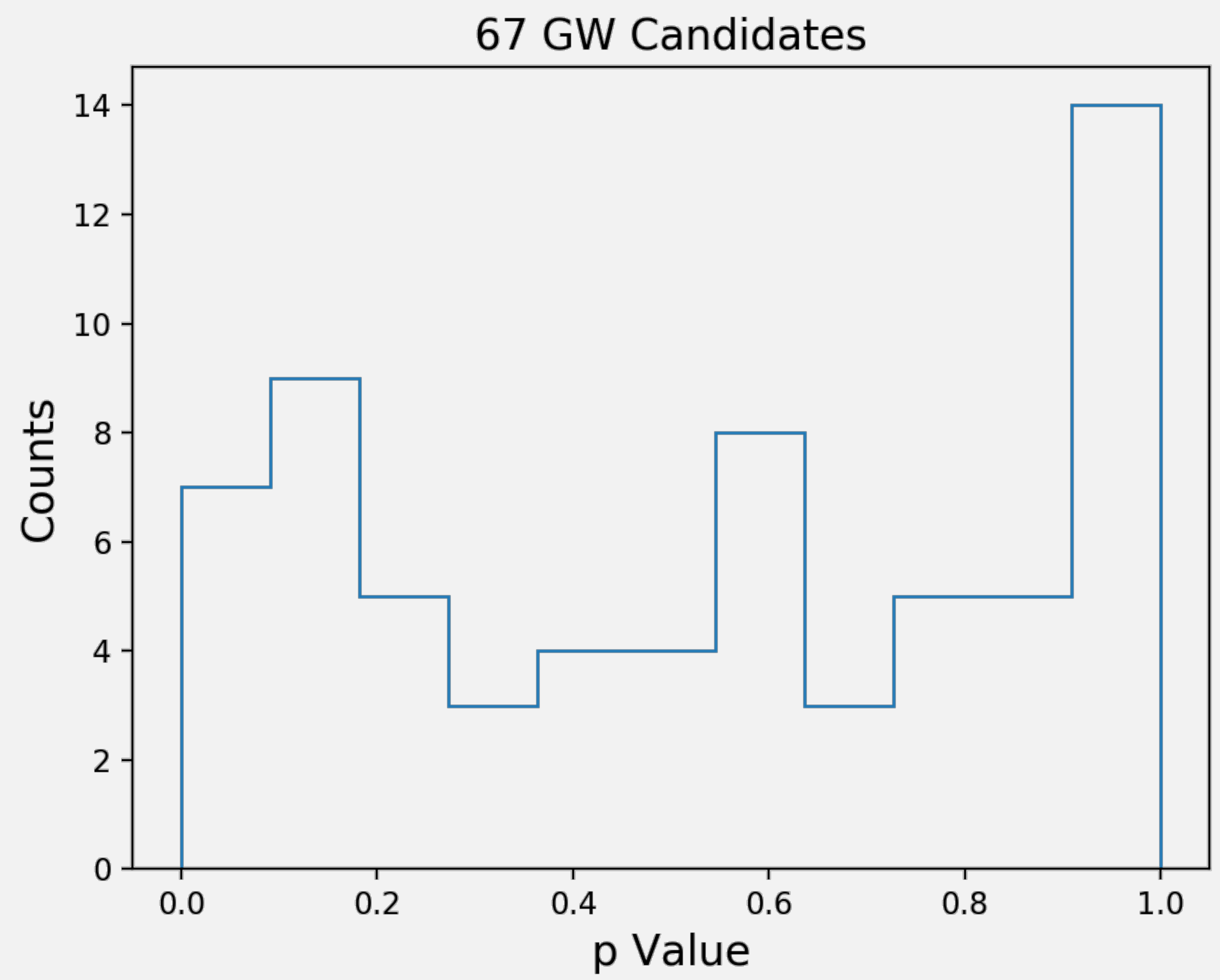

Figure 2: P value distribution for all reported GW candidates. Observed p values are consistent with a uniform distribution

We set time integrated flux upper limits as well as 90% upper limits on E_{iso}, which is the total isotropic equivalent energy emitted in high-energy neutrinos.

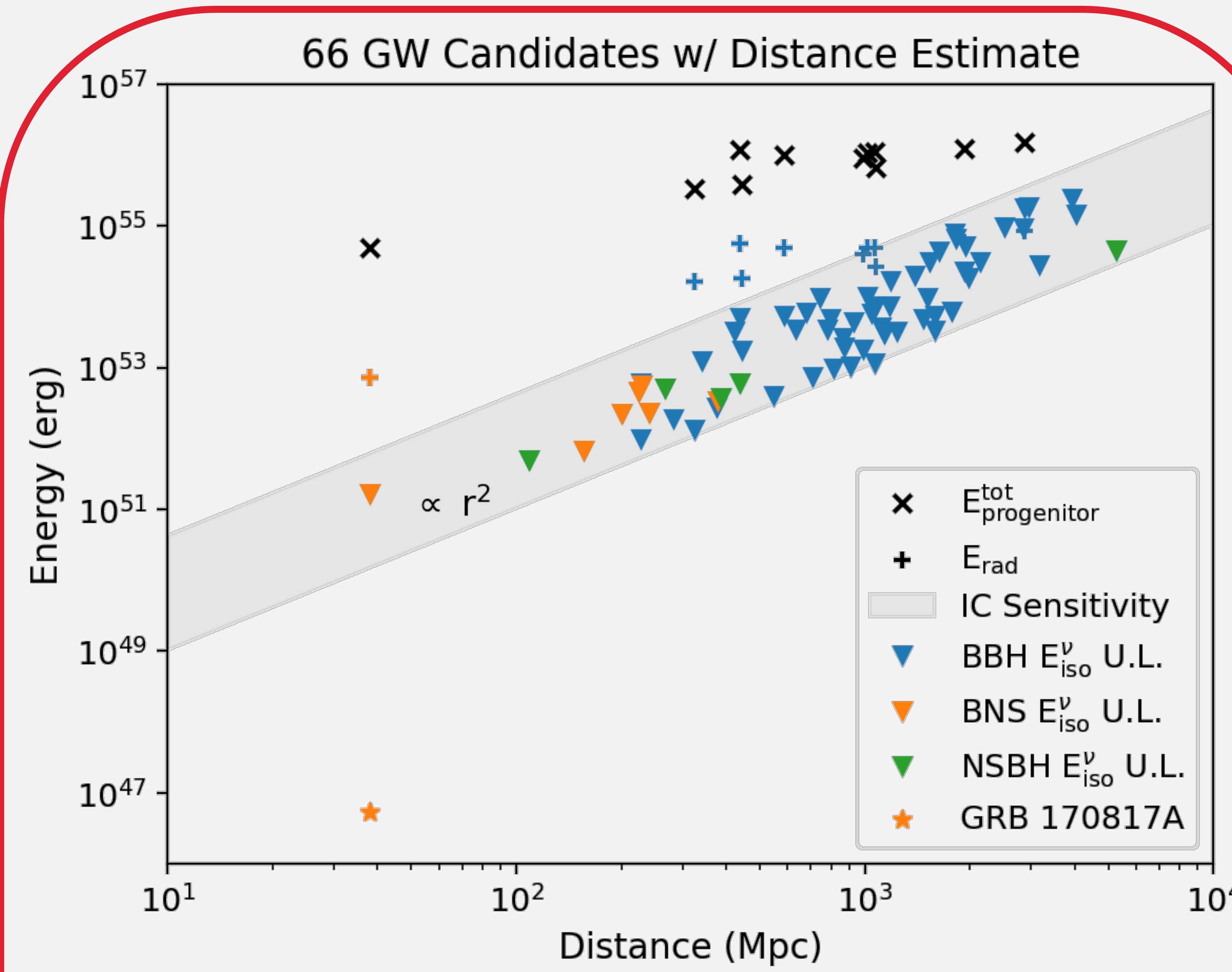

Figure 3: E_{iso} upper limits for 66 GW candidates with distance estimates. The gray band represents the best and worst median upper limit IceCube can set for a point source hypothesis. Also shown for reference are the total progenitor rest mass energies and the total radiated energy.

Conclusion

We performed a neutrino follow up search for each reported GW event and found no evidence of associated neutrino emission. Future analyses focusing on longer time scale emission and the use of cascade type events as an independent detection channel are in progress