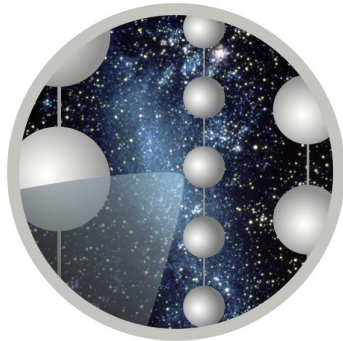


IceCube responses to O4 LVK alerts



ICECUBE

Erik Blaufuss - U Maryland for the IceCube Collaboration
(with input from Jessie Thwaites (UW Madison) and Albert Zhang (Columbia))
LVK Town Hall - July 6, 2023

Neutrino signal counterparts to GW alerts

- Particle acceleration in mergers a natural neutrino production source
- Realtime selection of neutrino events available for real-time searches
 - Track-like events from ν_μ interactions in or near the IceCube instrumented volume
 - Better direction localizations for neutrino events
 - 99%+ livetime coverage, all-sky sensitivity - backgrounds stronger in Southern hemisphere
- Pipelined, automated searches running after each LVK alert
 - Search for correlated neutrino signal in a +/- 500s window about merger time
 - Automated posting of results via GCN-Kafka for all alerts
 - Highlight more interesting p-values via human-written GCN circulars.

Additional background, details and motivation [shown in at a February town hall.](#)

IceCube follow up - broad overview

IceCube follows up with 2 analyses. Both use neutrinos from the realtime neutrino stream in a ± 500 s time window around the GW merger time.

- Low-Latency Algorithm for Multi-messenger Astrophysics (LLAMA) (also called “Bayesian search”)
 - Uses a Bayesian odds ratio, based on [Bartos et al, 2018](#): uses SNR, p_{astro} ($p_{\text{terrestrial}}$), source distance as priors
 - Run on **significant** and **low significance*** alerts.
- Unbinned Maximum Likelihood (UML, also called “generic” transient search):
 - Uses a spatial prior method in usual transient LLH point source search method
 - Run on **significant** alerts
 - After 2 weeks: -0.1 -14 day neutrino search performed on significant or interesting BNS or NSBH events → GCN circular

* currently only for CBC alert pipelines

For more details see [R. Abbasi et al 2023 ApJ 944 80](#)

IceCube follow up - details

IceCube responds to all LVK alerts (high and low significance) via the [General Coordinates Network \(GCN\)](#) as Notices (machine generated) and, for some, as Circulars (human written).

For O4, we are sending GCN Notices for every alert (and at each update). These are currently sent only to the new GCN Kafka system.

- GCN Notice Topic: **gcn.notices.icecube.lvk_nu_track_search**

The contents and escalation of response is determined by the lowest p-value* obtained from either the UML or LLAMA analyses:

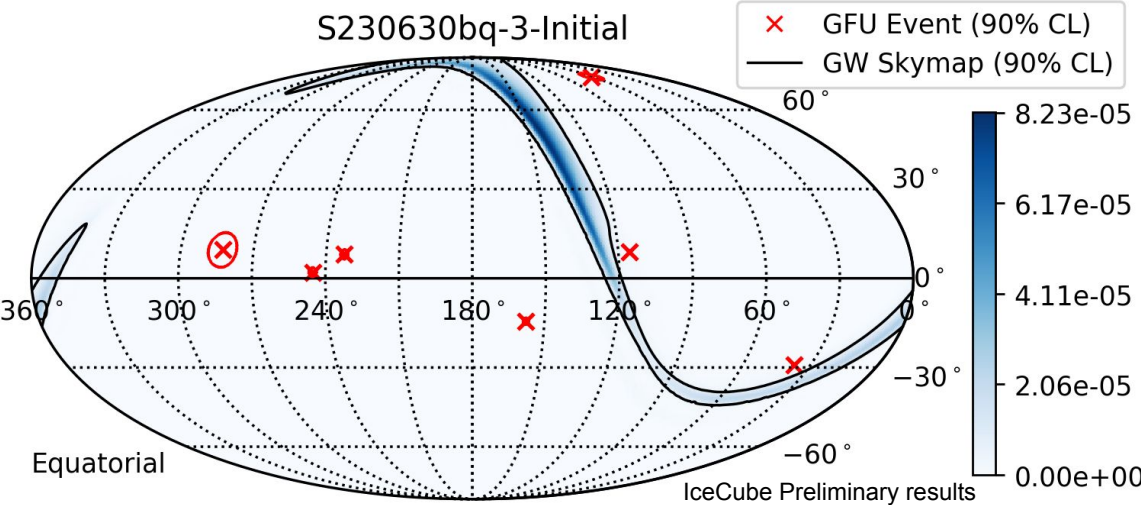
- $p\text{-value} > 0.1$: automated GCN notice - listing only p-values, time integrated flux upper limits
- $0.01 < p\text{-value} < 0.1$: automated GCN notice - listing p-values, time integrated flux upper limits, and coincident neutrino information direction information
- $p\text{-value} < 0.01$: automated GCN notice AND GCN circular (human generated) including coincident neutrino alert information

More information can be found on the [IceCube GCN mission page](#), as well as [Notice schema](#)

* Note- p-values reported do not correct for trials

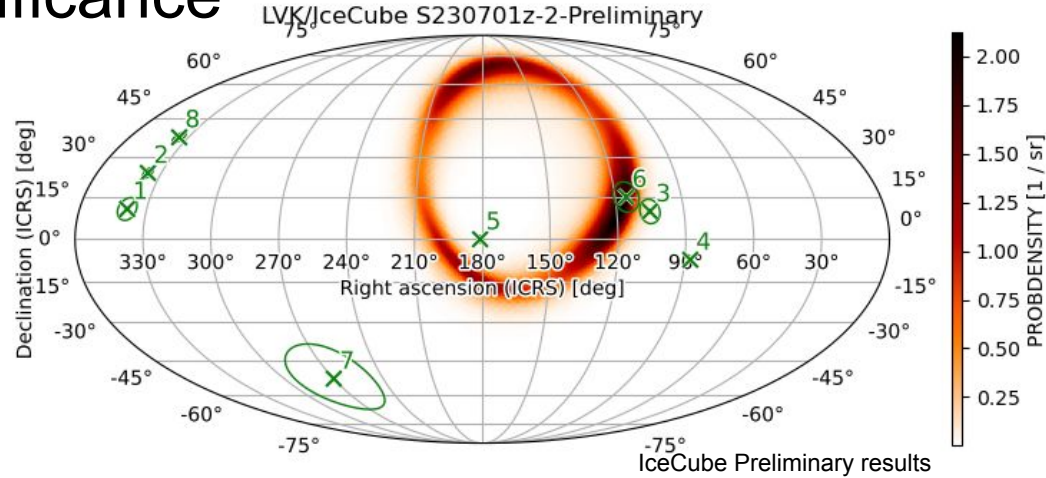
Recent alerts...at high significance

```
{  
  "$schema": "https://gcn.nasa.gov/schema/gcn/notices/icecube/LvkNuTrackSearch.schema.json",  
  "type": "IceCube LVK Alert Nu Track Search",  
  "ref_id": "S230630bq-3-Initial",  
  "alert_datetime": "2023-07-01T00:47:38.487Z",  
  "trigger_time": "2023-06-30T23:45:32Z",  
  "observation_start": "2023-06-30T23:37:12.000Z",  
  "observation_stop": "2023-06-30T23:53:52.000Z",  
  "observation_livetime": 1000,  
  "pval_generic": 0.1622,  
  "pval_bayesian": 0.1857,  
  "n_events_coincident": 0,  
  "neutrino_flux_sensitivity_range": {  
    "flux_sensitivity": [  
      0.0277,  
      0.6181  
    ],  
    "sensitive_energy_range": [  
      542,  
      23100000  
    ]  
  }  
}
```



Recent alerts...at low significance

```
{
  ...
  "pval_generic": "null",
  "pval_bayesian": 0.0018,
  "n_events_coincident": 1,
  "coincident_events": [
    {
      "event_dt": 172.17,
      "localization": {
        "ra": 114.94,
        "dec": 15.16,
        "uncertainty_shape": "circle",
        "ra_uncertainty": 5.534,
        "containment_probability": 0.9,
        "systematic_included": false
      },
      "event_pval_bayesian": 0.0018,
      "event_pval_generic": "null"
    }
  ],
}
```



LVK alert
FAR: 1.62 E-5
P(Terrestrial): 0.856

Additionally, a [GCN Notice](#) was also sent.

Summary

- IceCube is following LVK alerts in 04 with automated pipelines are now online.
- Interesting/significant neutrino-GW correlations are quickly shared with follow-up observers, with hope of neutrinos “pointing the way” to a common source.
- Results shared automatically via GCN-Kafka
 - Sharing via SCiMMA is an option if there’s community interest
- Future:
 - Public webpage cataloging all historical results in preparation
 - Investigating searches in other neutrino event types (starting events, cascades, etc)

Questions? Requests? We’d love to hear them!

Contact: roc@icecube.wisc.edu

Backup - Using GCN Kafka for IceCube alerts

New to the GCN Kafka alerts?

Good documentation is available on the [GCN website](#)

An example listening script for IceCube lvk_nu_track_search stream [is available](#)

(need to use your GCN credentials)