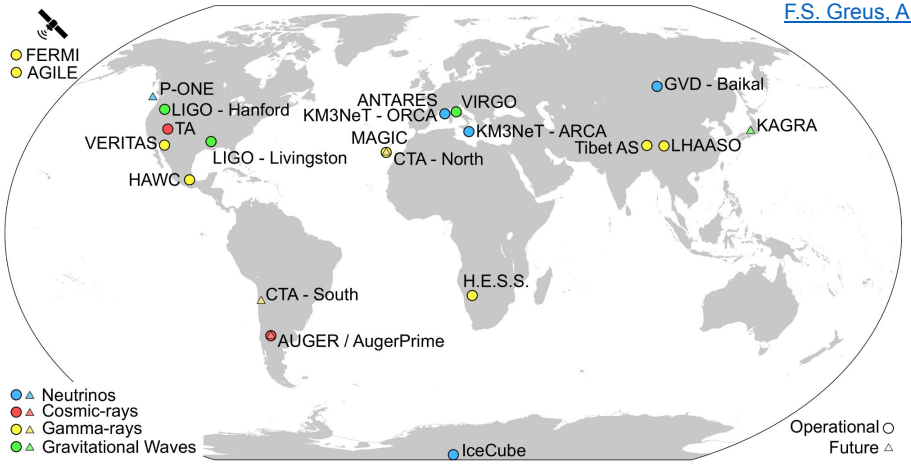
Neutrino ToO follow-ups with H.E.S.S.

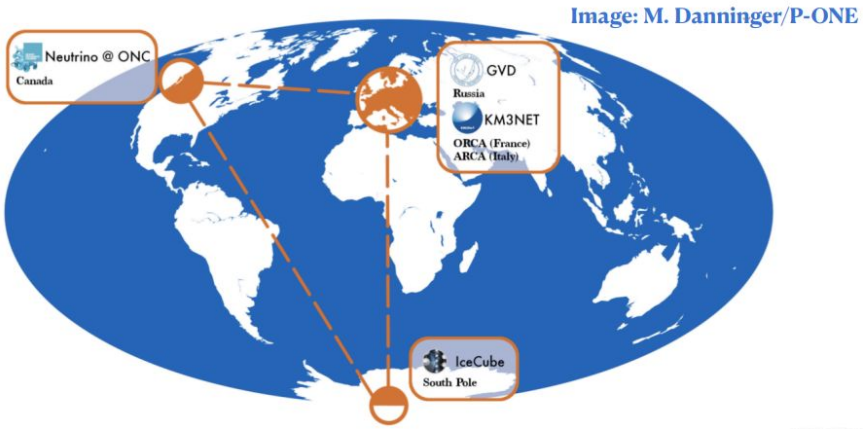
Ankur Sharma
On behalf of **H.E.S.S. Collaboration**

Cosmic Rays & Neutrinos in the Multi-Messenger Era
December 2024, Paris

Real-time Alerts Follow-Up

F.S. Greus, A.S. Losa (2021)

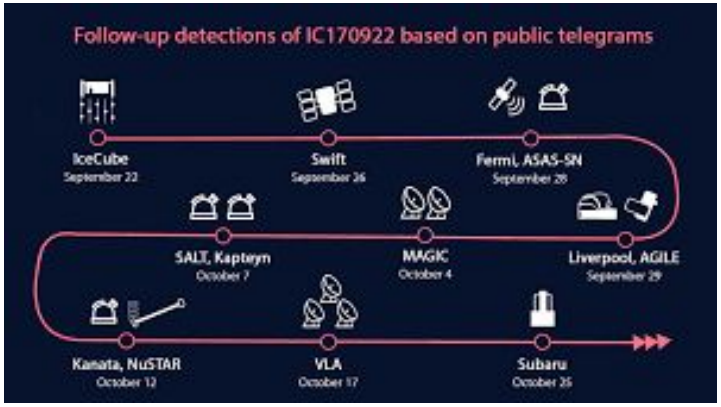


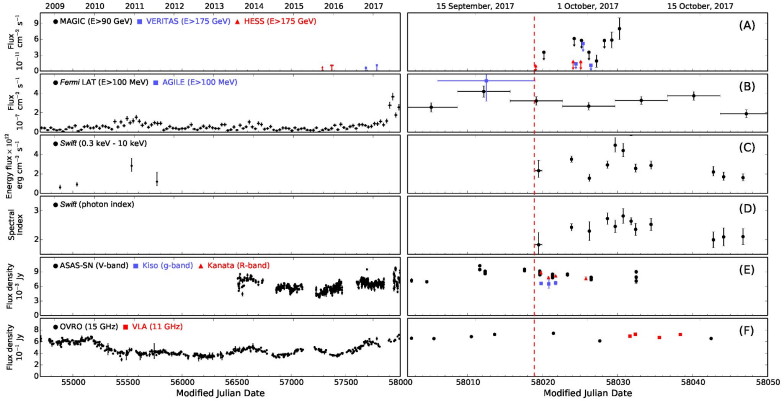


A multi-messenger effort: GW, Neutrino and EM follow-up in realtime

Follow-up of IceCube neutrino alert in 2017 provided evidence for the first extra-galactic source (**blazar**) of high-energy neutrinos: **TXS 0506+056**

IceCube Coll.

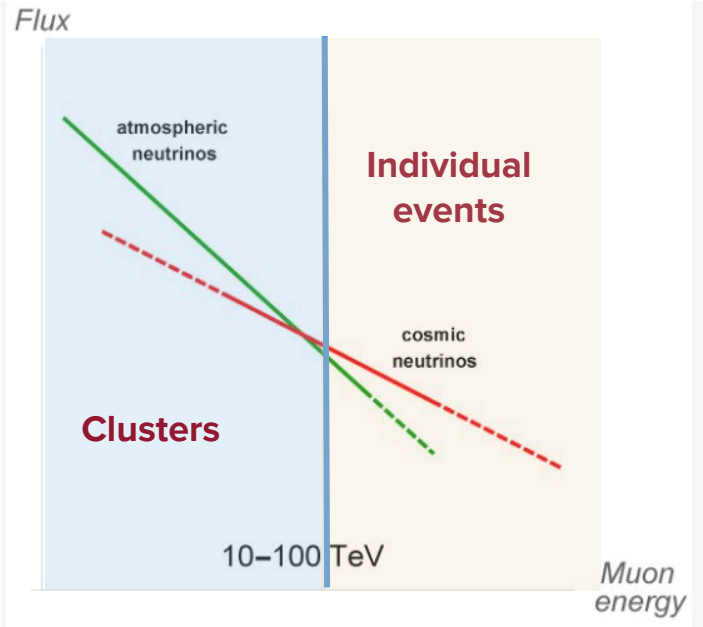




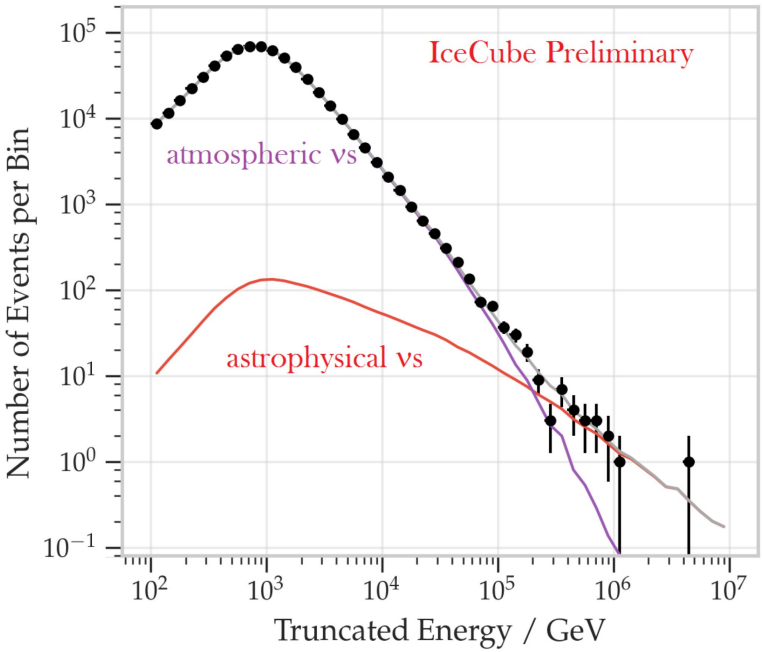
IceCube++ (2018)

Atmospheric vs. Astrophysical *ν*

Palladino, Spurio, Vissani (2020)



PoS(ICRC2019), 2019, pp. 1017.

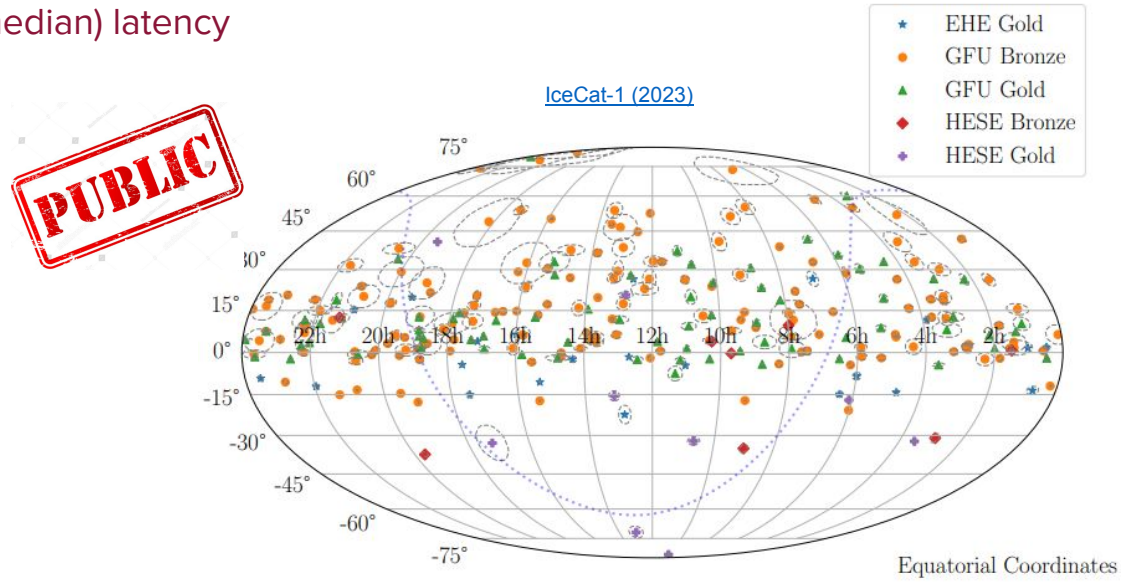


- Cosmic ν have **harder spectrum**; start to show excess at ~ **O(200) TeV**. Individual high energy events can point back to source
- For E < 100 TeV; signal statistically suppressed; can be identified by time-dependent searches (**clustering**)

➔ **Blanket strategy:**
Send out alerts for **(i)** isolated high-energy ν events and **(ii)** cluster of events associated with pre-defined directions in sky

★ Gold and Bronze alerts:

- Single track alerts with high likelihood of astrophysical origin
- Distributed through the **GCN/AMON*** network to the wider astronomy community
- Established in **2016**; archival alert-like events also available (IceCat-1)
- **50%** astrophysical probability for Gold and **30%** for Bronze events (average)
- In real-time with; ~ 30s (median) latency



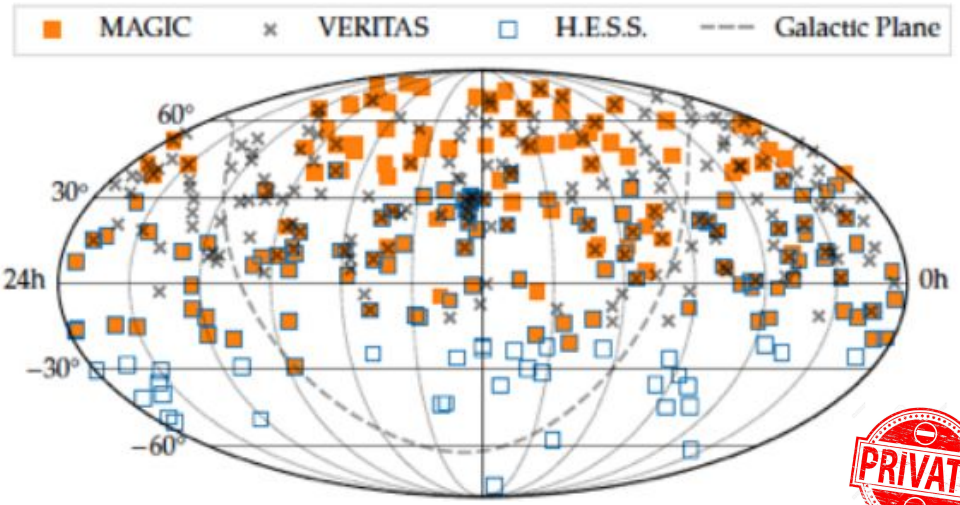
GCN: Gamma-ray Coordination Network
AMON: Astrophysical Multi-messenger Observatory Network

Objective: Identify/follow-up potential gamma-ray counterpart to the neutrino event

★ **Gamma-Ray Follow-Up (GFU) Alerts:**

- *'Neutrino flares'* (multiplets) from the direction of a source
- Target list pre-defined: ~ **140** sources from **TeVCat** and **Fermi 3LAC/3FHL**
- Time-scale of flare: from ~ seconds to 180 days

HESS under MoU with **IceCube** since 2018 to receive GFU alerts



PRIVATE

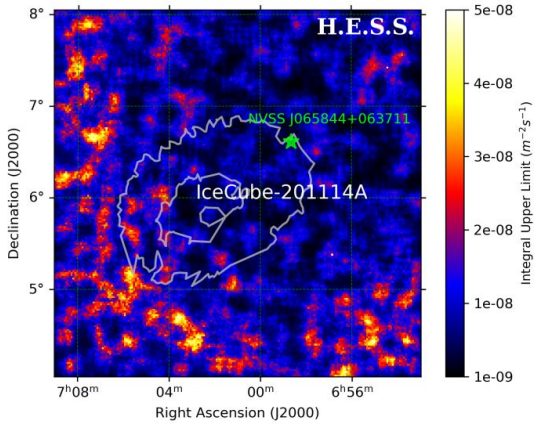
T. Kintscher, PhD thesis (2020)

Objective: Monitor the flux levels and spectral behavior of triggered source

- Array of 4(+1) IACTs operational since 2004 (2012); Energy sensitivity: **~ 30 GeV - 100 TeV**
- Neutrino ToO program est. in 2012 with ANTARES; from 2015 with IceCube. MoU for GFU alerts with IceCube since Dec. 2018
- **~20 hrs/yr** of dedicated observations, with an aim towards VHE behavior characterization
- Automated alert system; rapid response time (**upto 32 sec.**). Observation window of up to a few days for interesting events
- **20** ν ToO observations since 2016; 2 ANTARES alerts, 13 singlet alerts and 5 GFUs followed up

IC-201114A

Gold alert (E = 214 TeV, P_{astro} = 56%) with a blazar in RoI

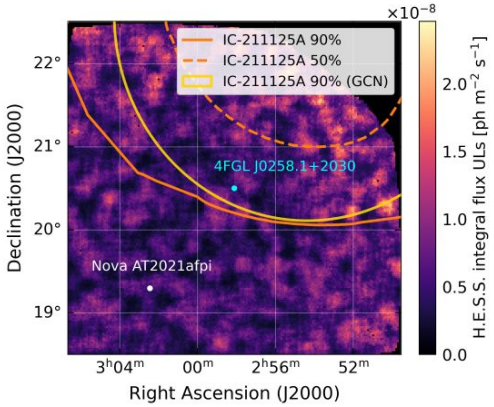


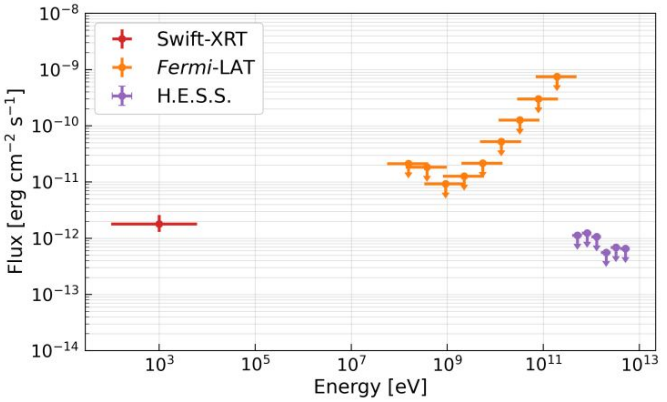
No signif. excess (14.3 hrs) in H.E.S.S. observations

PoS(ICRC2023), 2023, pp. 1501

IC-211125A

Bronze alert (Pastro= 39%) with 2 potential associations



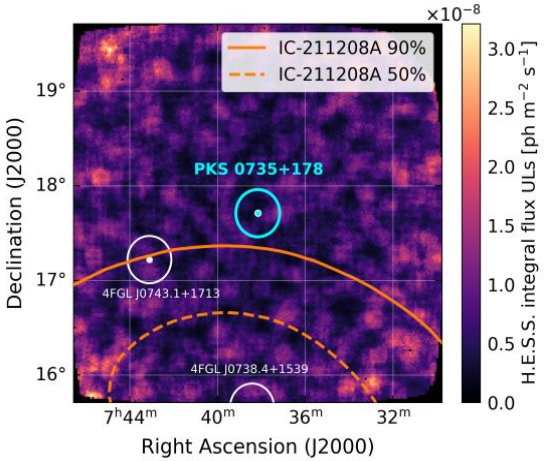


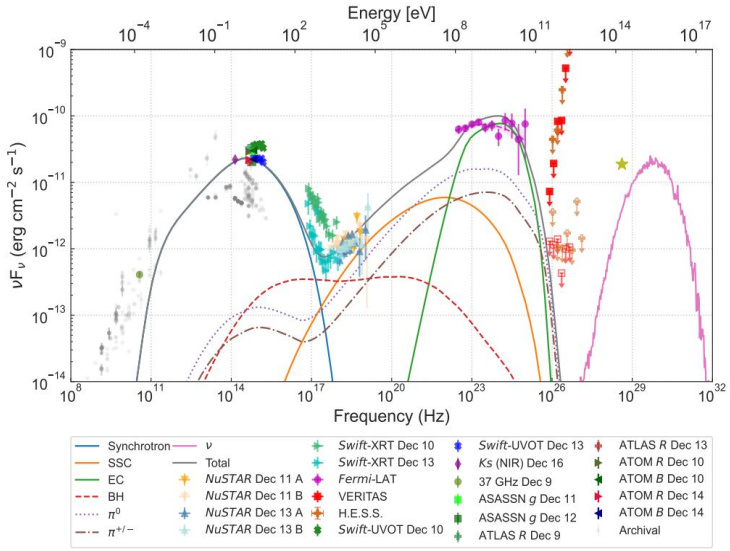
No signif. excess (5 hrs) in the FoV on both sources

PoS(ICRC2023), 2023, pp. 1546

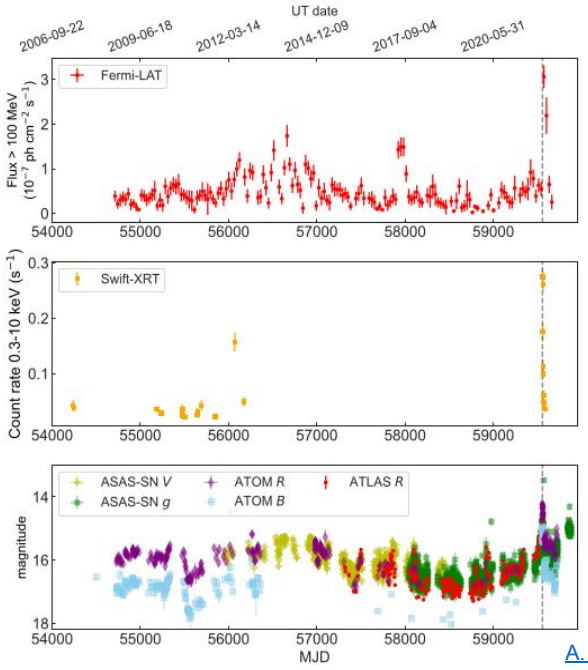
IC-211208A

PoS(ICRC2023), 2023, pp. 1546





Bronze alert (Pastro= 50.2%); blazar **PKS 0735+178** flaring in radio, X-ray, optical and γ-ray at ~2.0° from ν best-fit

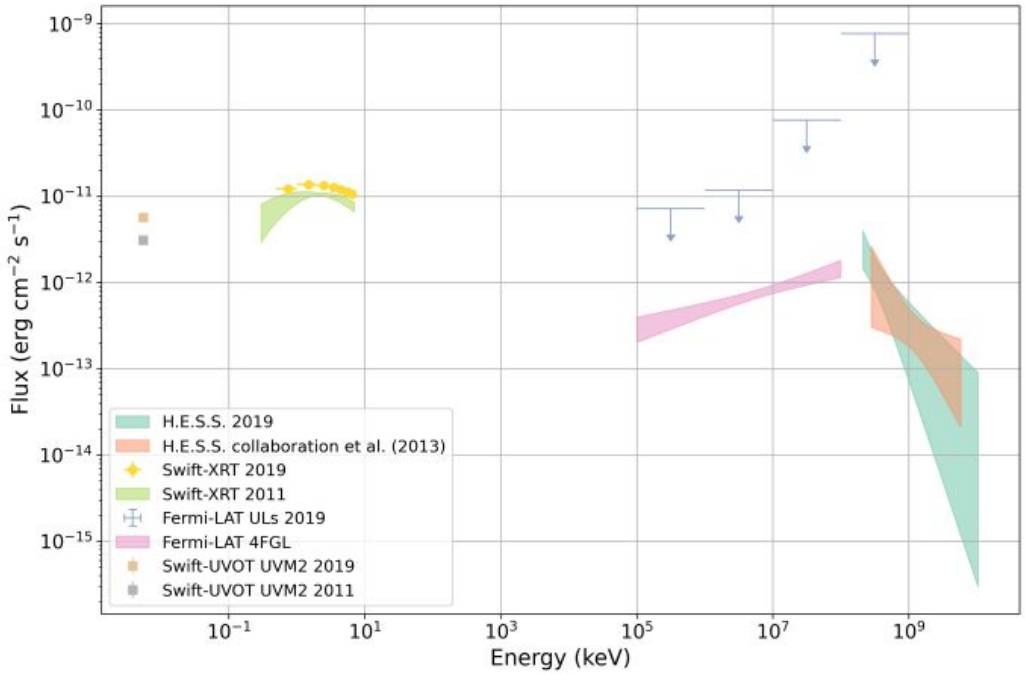


A. Acharyya et al., 2023 ApJ 954 70

No sig. excess (~ 8 hrs) on the source position in H.E.S.S. data

GFU 1ES 1312-423

Short flare of 0.26 days on 2019-03-12; also observed by SWIFT and ATOM

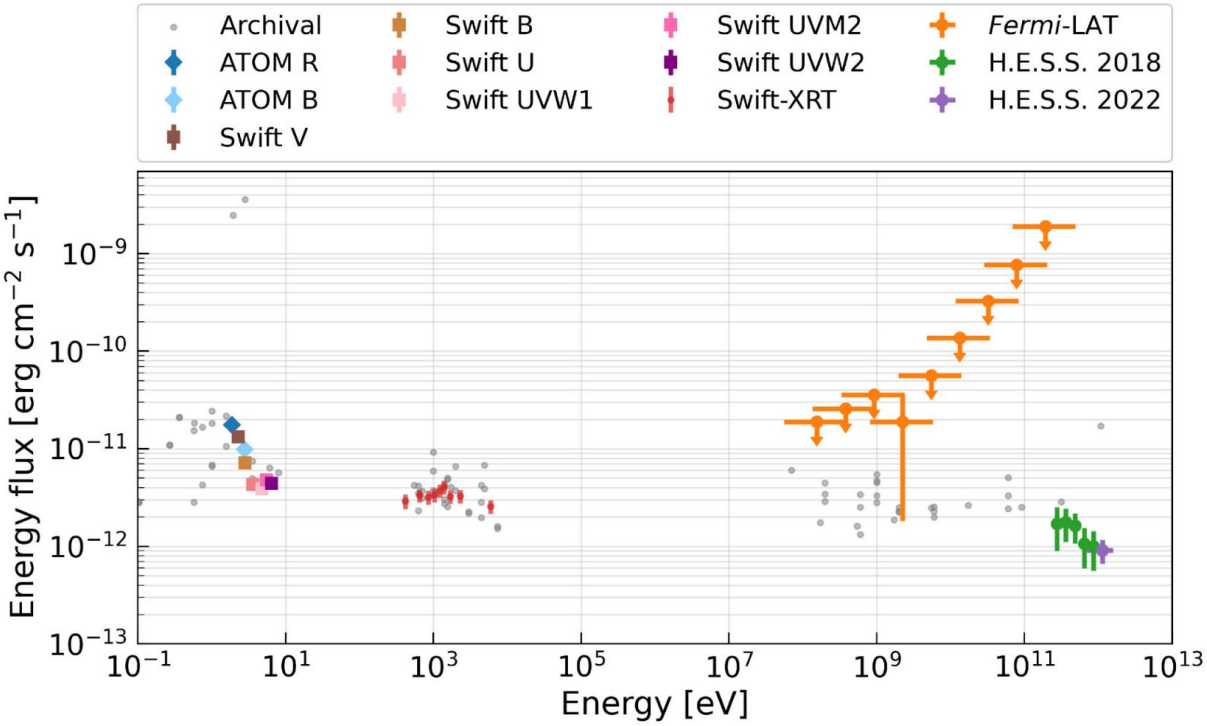


4σ detection with 2.6 hrs (E_{min} = 140 GeV)
No change in state during ν ToO follow-ups

PoS(ICRC2023), 2023, pp. 1501

GFU PKS 0625-35

Flare of 3 vs with E_{max} = 302 TeV for 3 days (3.56σ pre-trial) on 2022-04-19



3.5σ detection with 3 hrs of observation (E_{min} = 350 GeV)

PoS(ICRC2023), 2023, pp. 1546

What's next for Neutrino ToO ??

- Real-time neutrino event follow-ups promising; but identifying high energy neutrino sources remains a challenge
  - ➔ Many alerts not visible to H.E.S.S.; and most observations don't reveal any excess!
  - ➔ TeV gamma-ray emission may be suppressed for several of the alerts

- IceCube's directional reconstruction for alerts recently revised:
  - ➔ **Earlier**: between initial AMON alert and refined offline scan (~ hrs after alert), best-fit neutrino position shifted and uncertainty radius increased; more potential sources entered FoV
  - ➔ Mitigated by HESS's relatively large FoV
  - ➔ Improved error reconstruction will reduce source confusion

- Revision of GFU alerts under process
  - ➔ Unified source catalog for monitoring and public distribution of alerts

- Apart from **IceCube**, **KM3NeT** alerts coming online soon
  - ➔ More alerts imply more telescope time!

- Revision of follow-up strategy within H.E.S.S.
  - ➔ Currently on event-by-event basis (observability, high purity, known GeV counterpart etc.)
  - ➔ **Proposal**: Focus on highE - low FAR alerts. Cover broader region around each event with observations; compile list of sources in repeated associations with alerts!

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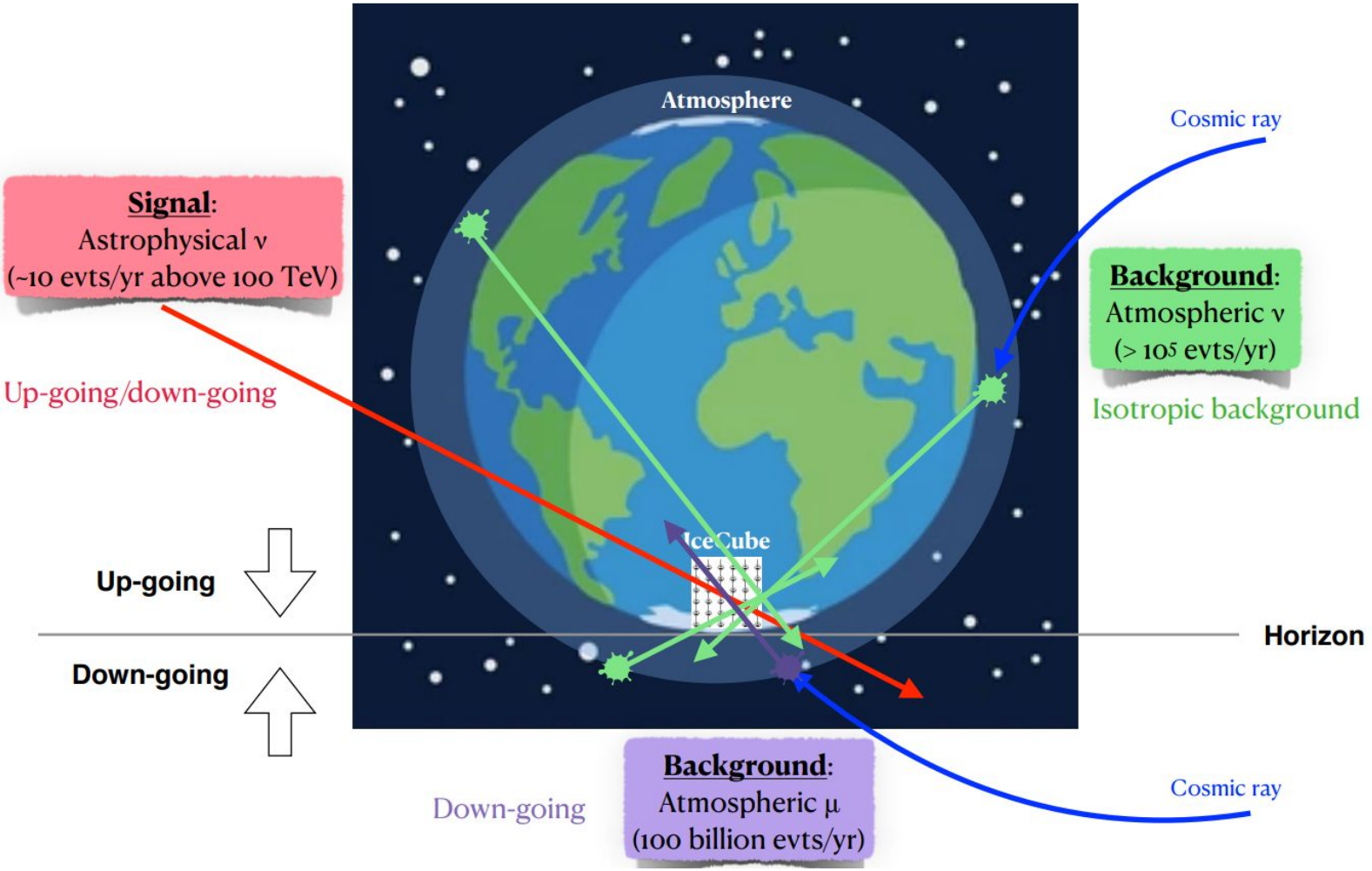
Backup

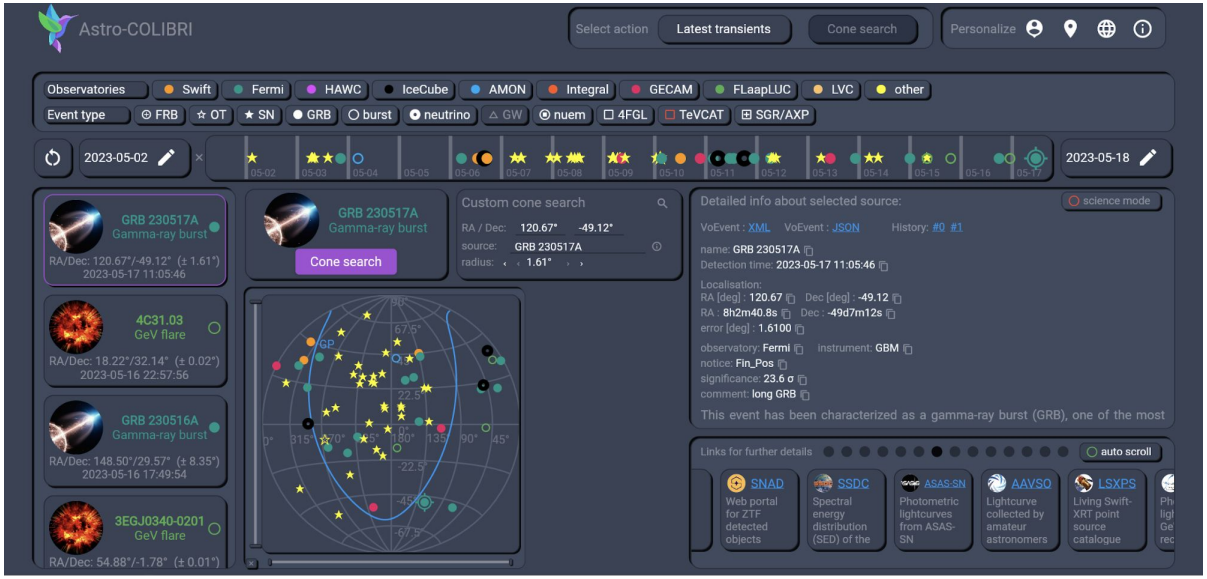
H.E.S.S.

Atmospheric neutrinos are an irreducible background for neutrino telescopes



Broker for astronomical alerts across different wavelength and different messenger observatories

- ➔ Alerts from a large variety of transient phenomena (smartphone notifications)
- ➔ Modern interfaces allowing for efficient and informed decision making
- ➔ Direct links to a many dedicated services



https://astro-colibri.com/