Searching for multimessenger sources with the IceCube Neutrino Observatory

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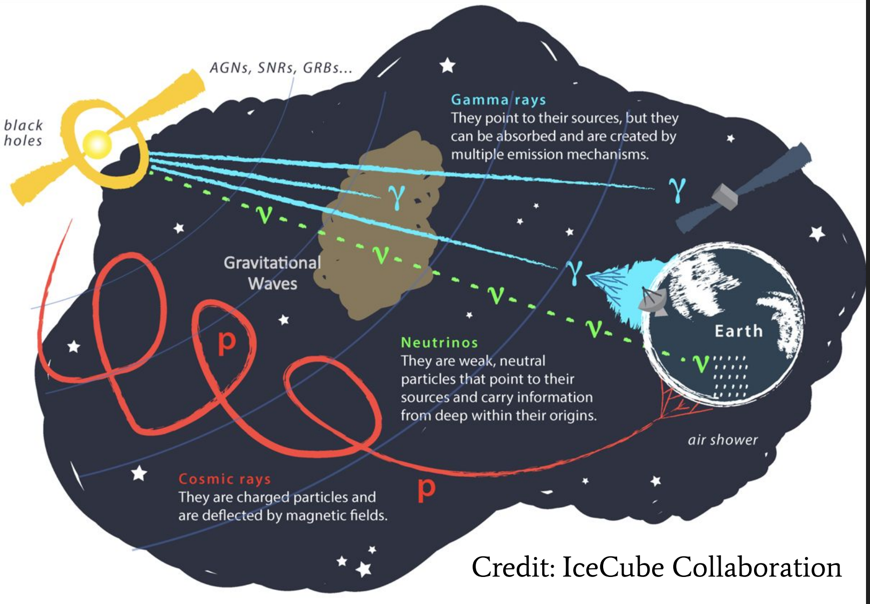
Photo credit:
Yuya Makino, IceCube/NSF

Multimessenger Astrophysics

Studying high energy sources through multiple lenses (messengers)

- Photons
- Neutrinos
- Cosmic rays
- Gravitational waves



Credit: IceCube Collaboration

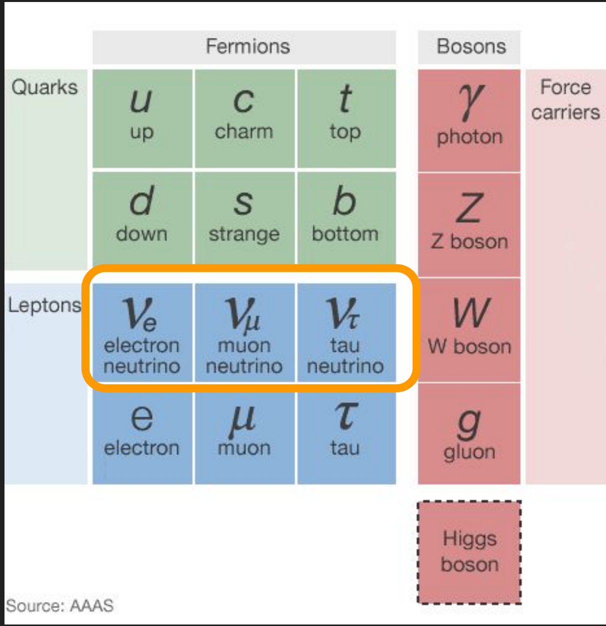
Neutrino astrophysics

Neutrinos have neutral charge and interact weakly

- \+ Travel long distances without interacting
- \- Difficult to detect

Detectable through their interactions

Astrophysical neutrinos are evidence of hadronic acceleration

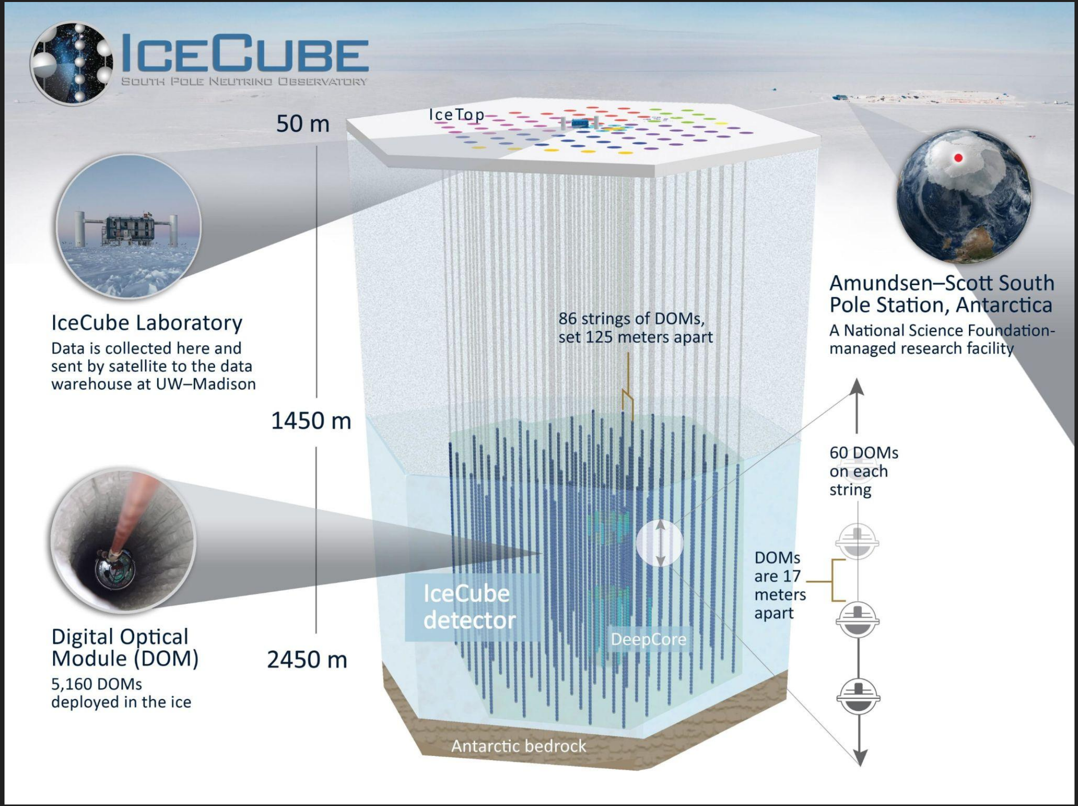


$$\pi^{\pm} \longrightarrow \mu^{\pm} + \overset{(-)}{\nu}_{\mu}$$

$$\mu^{\pm} \searrow e^{\pm} + \overset{(-)}{\nu}_{e} + \overset{(-)}{\nu}_{\mu}$$

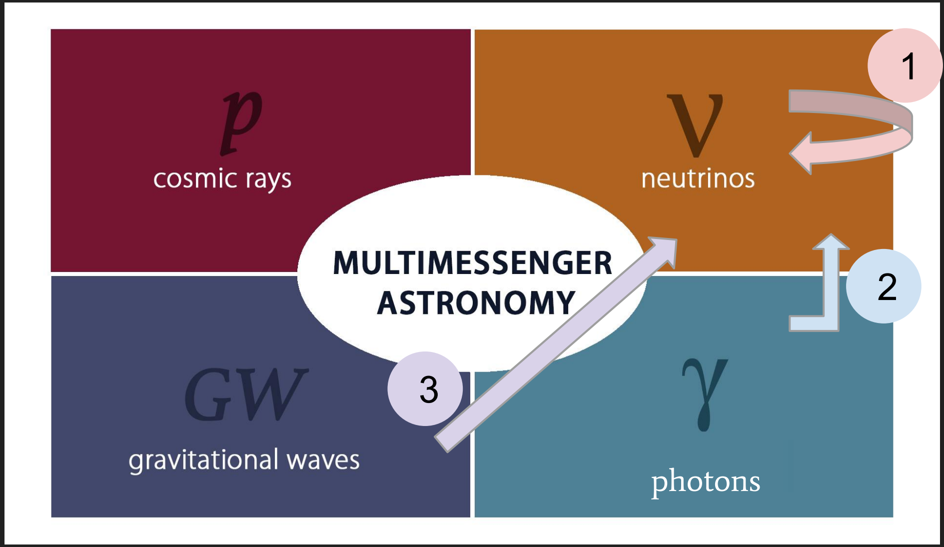
The IceCube Neutrino Observatory

- Cubic kilometer detector instrumented in the ice at the South Pole
- Detects Cherenkov light from interaction of neutrinos in the ice
- 86 strings, with 60 Digital Optical Modules (DOMs) on each string drilled in ice
- Spacing optimized for sensitivity to TeV-PeV neutrinos



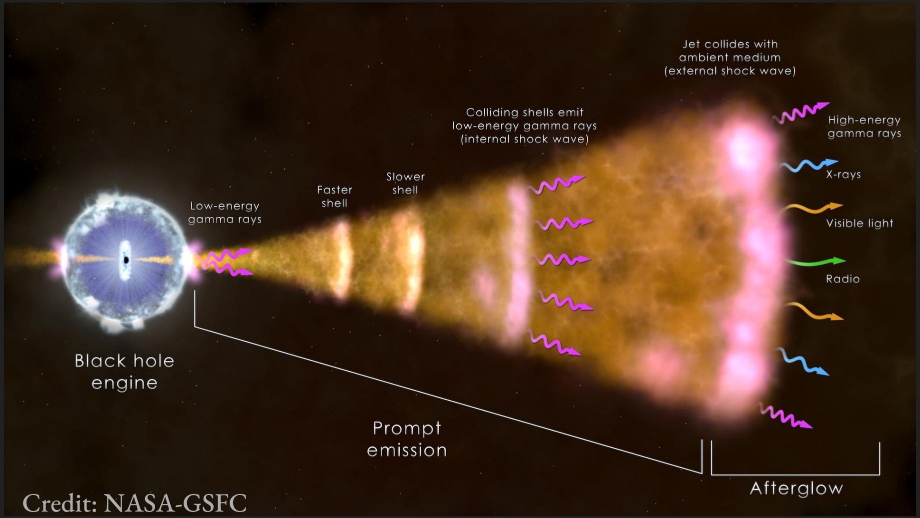
Realtime transient searches

- High background from cosmic rays interacting in the atmosphere
- Use likelihood analysis to identify signal from background
- Events which change brightness rapidly - “transients”
- Two analyses with IceCube:
  - GRB 221009A (the Brightest of All Time)
  - Compact object mergers



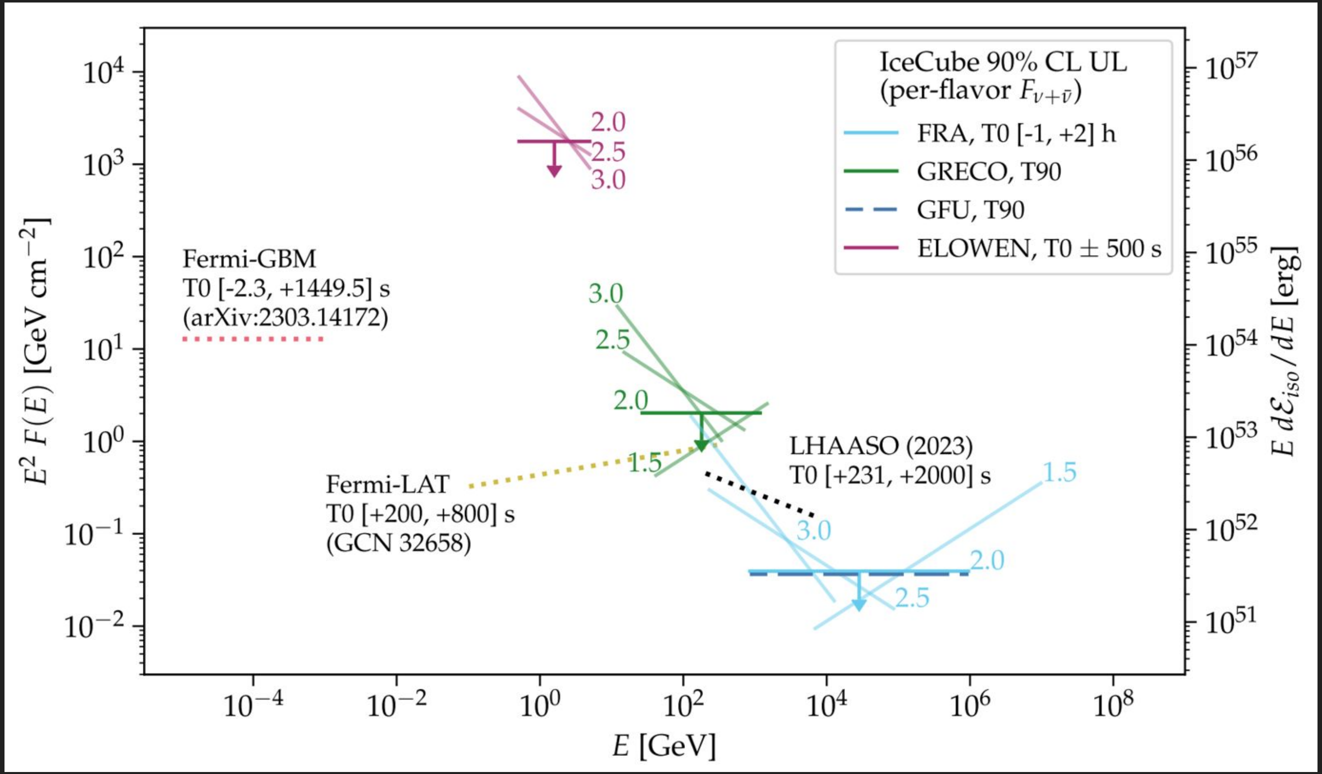
GRB 221009A: an extraordinary GRB

- On October 9th, 2022, Fermi-GBM detected an extremely bright burst
- Long GRB: from a supernova
- Highest energy gamma-rays ever observed from a GRB by LHAASO
- Expect neutrinos over a wide range of energies, from supernova and jet



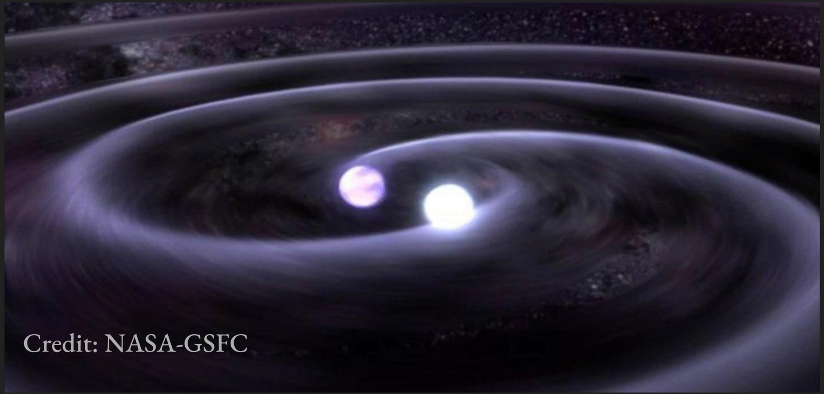
Upper limits on neutrino emission

- MeV analysis not shown here
- Non-detection in all time windows/energy range
- **Most constraining** limits from this burst than the population of GRBs due to its high flux



R. Abbasi *et al* 2023 *ApJL* **946** L26
Kruswijk et al, PoS-ICRC2023-1511

Mergers of compact objects


Credit: NASA-GSFC

- Merging objects can accelerate particles → produce neutrinos

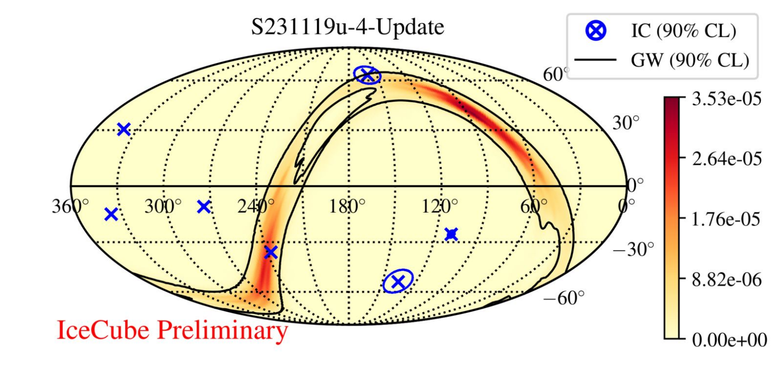
- Mergers are difficult to localize with GW information alone
  - Need good localization to identify electromagnetic counterparts
  - Neutrinos much better localized - inform other searches

- Currently in the middle of an observing run for the ground-based GW detector network (LIGO-Virgo-KAGRA Observing run 4, aka O4). Mostly BBH and a few NSBH events, no BNS yet

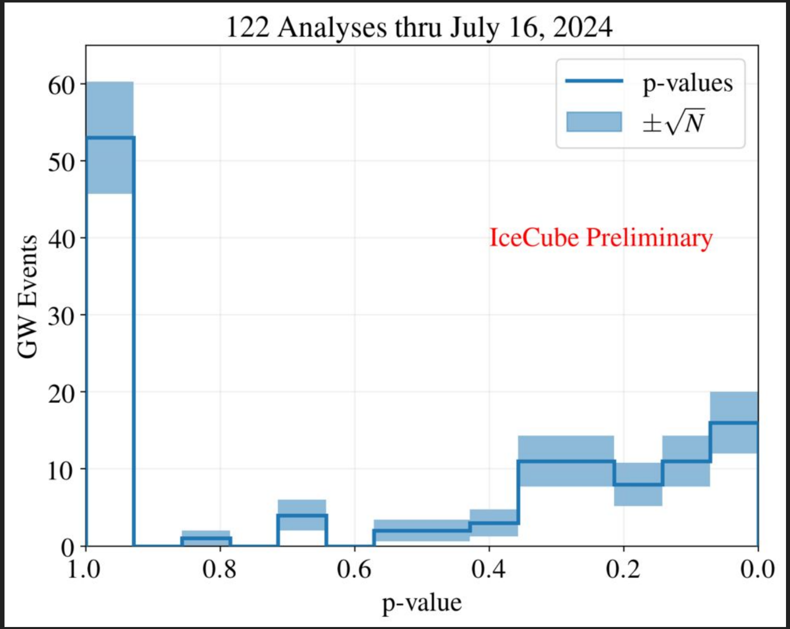
- Send IceCube results quickly (low-latency) to the community

IceCube searches in O4

- Two searches are run: (1) log-likelihood method, (2) Bayesian search including astrophysical priors
- No significant events yet, but still many months left! (Run until June 2025)



P-value distribution for search (1)



Summary

- Neutrinos are an exciting window on our universe, that allow us to understand processes happening near extreme astrophysical objects

- Searching for neutrinos in real time helps to inform other observatories' follow-ups

- More sources: supernovae, Active Galactic Nucleus flares, novae (incl. T Coronae Borealis), many others

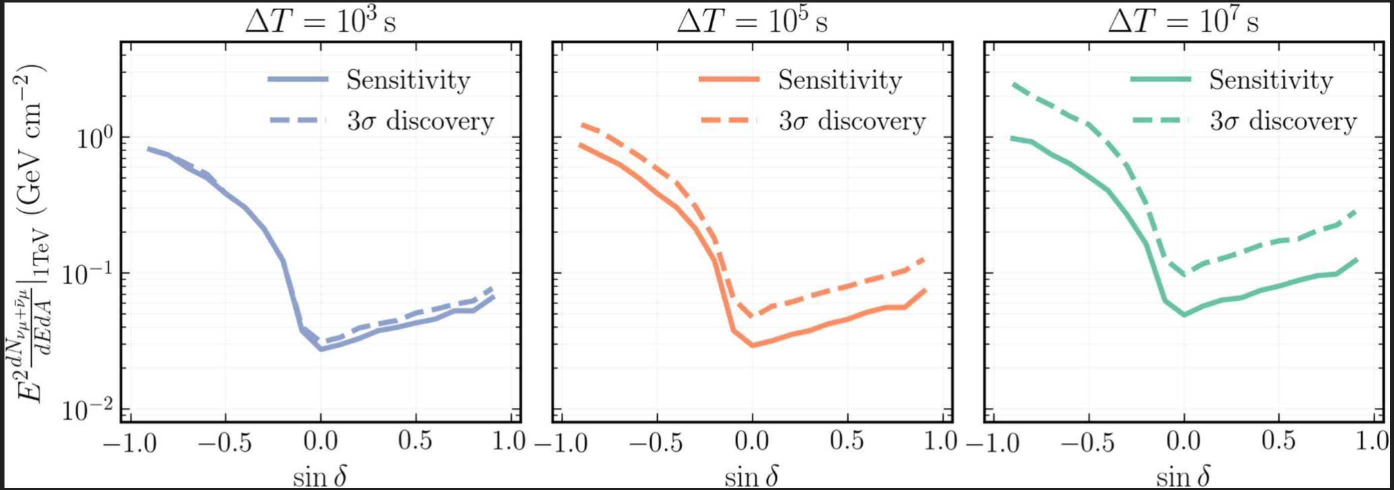
Thank you!
Questions?

Photo credit: Yuya Makino, IceCube/NSF

Backup

IceCube dataset

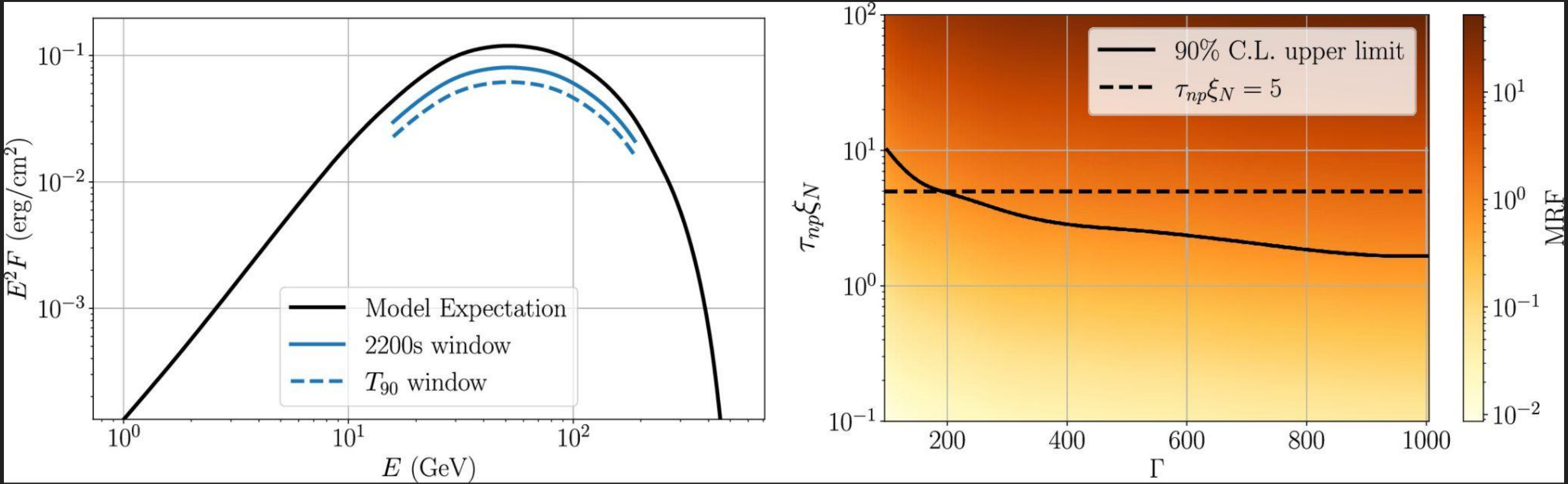
- Use a dataset of high-energy tracks
  - Good angular resolution (~1 deg)
  - Available in ~60s from the South Pole
- Better sensitivity in the Northern sky (atm. muons attenuated by Earth)



R. Abbasi *et al* 2021 *ApJ* **910** 4

GRB 221009A: GeV model limits

R. Abbasi *et al* 2024 *ApJ* **964** 126



Model: collision-decoupling model (Kohta Murase et al 2022 ApJL 941 L10)

Limits on Baryon loading (times opacity) versus jet Lorentz factor for 2200 seconds

More constraining limits from this burst than the population of GRBs due to high flux

Follow-up of LVK compact object mergers in realtime

- Neutrinos are ~500+ times better localized than GW events: inform follow-up in realtime
- Follow up all significant events sent by LVK
  - All mergers with +/- 500 second time window (centered on merger time)
  - Mergers with NS - additional 2 week follow-up (merger time [-0.1,+14] days)