# Exploring neutrino-GW correlation: Navigating challenges envisioning the ET era


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## Motivation:

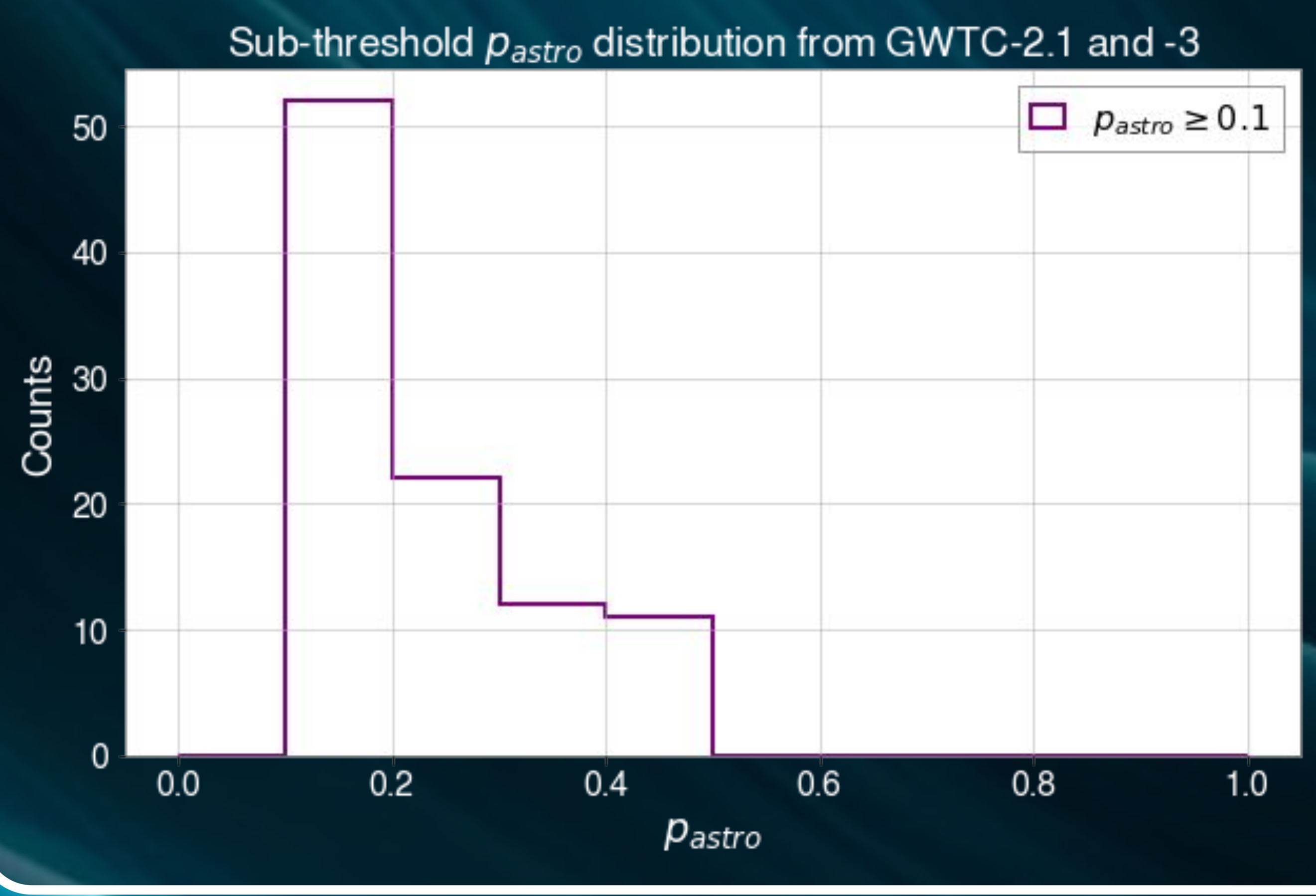
- ***Missing correlation*** between neutrino and GW sources.
- ***Improve GW source*** localisation with neutrinos.
- ***Better understanding*** of the sub-threshold GWs and their significance.

## Ongoing work:

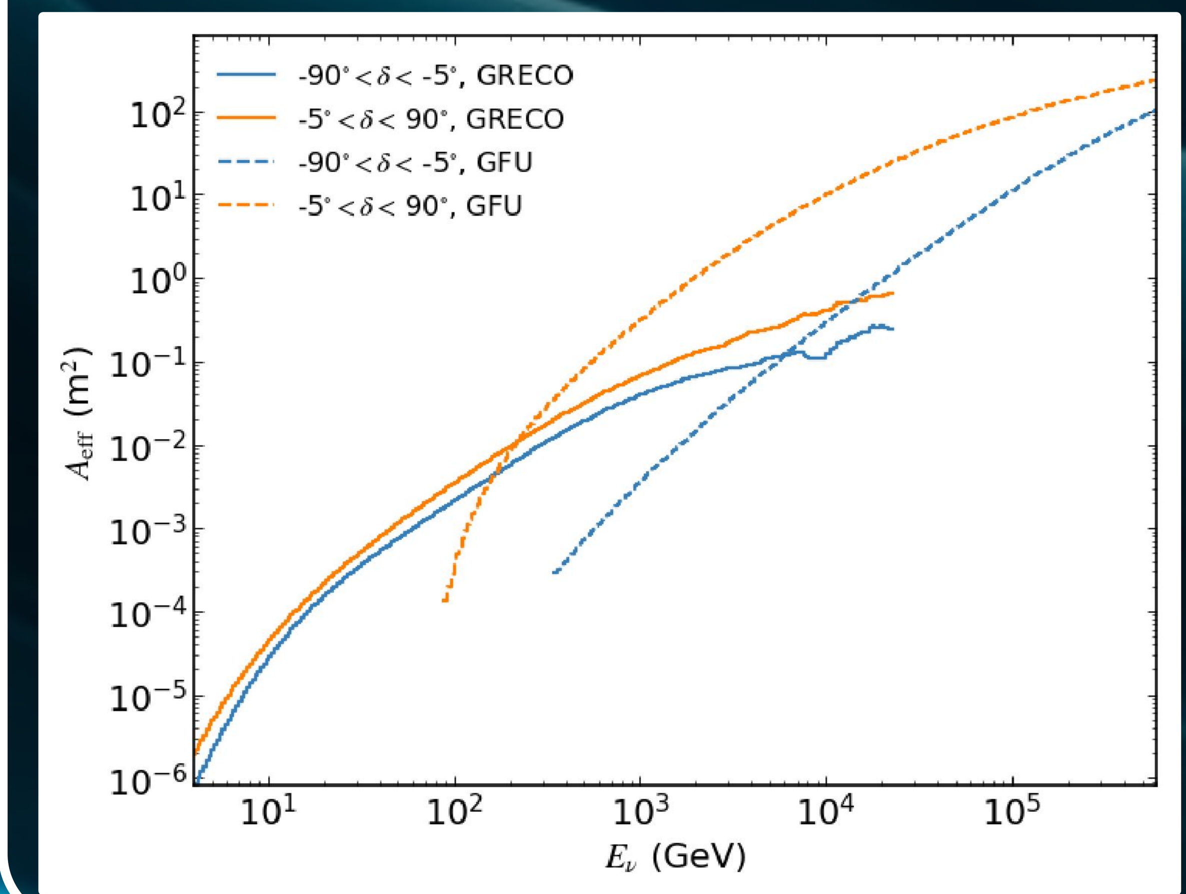
- Archival studies for sub-TeV neutrino counterparts to sub-threshold GW events
  - GW dataset: ***GWTC-2.1 & -3***[1,2]
  - Neutrino dataset: IceCube sub-TeV neutrinos ***'GRECO'***[3]
  - Time window: ***GW event-time ± 500 s***

## Gravitational Wave Transient Catalogues[1,2]:

- 2247 GW sub-threshold candidates with ***FAR < 2 day$^{-1}$***.
- 97 sub-threshold candidates identified with ***$p_{astro}$ > 0.1.***
  - ***90 CBCs and 7 cWBs***




## IceCube sub-TeV neutrinos[3]

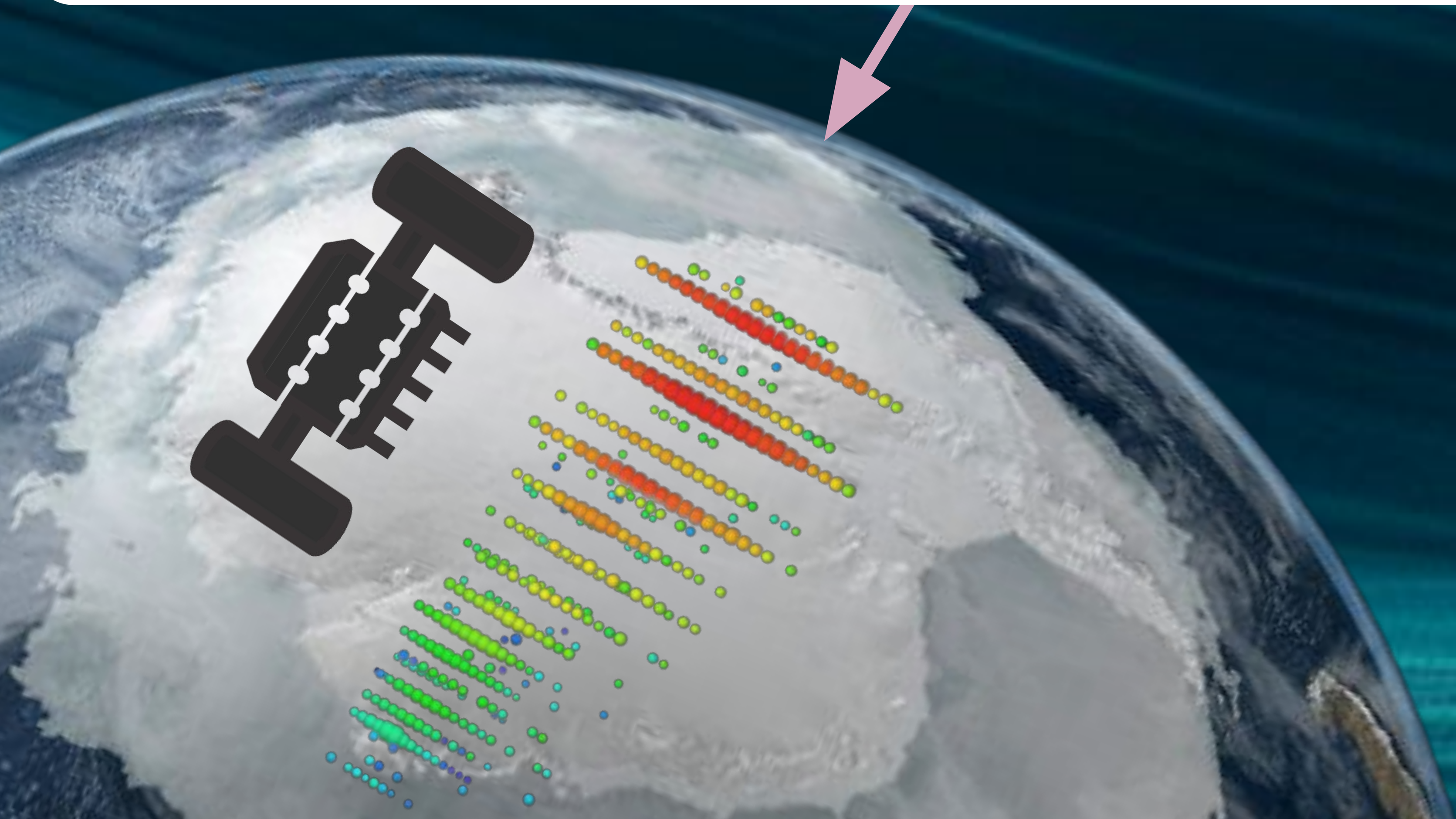



- ***All-flavour dataset*** with stable event rate.
- ***Good effective area*** coverage.
- Suitable for ***transient follow-ups***.

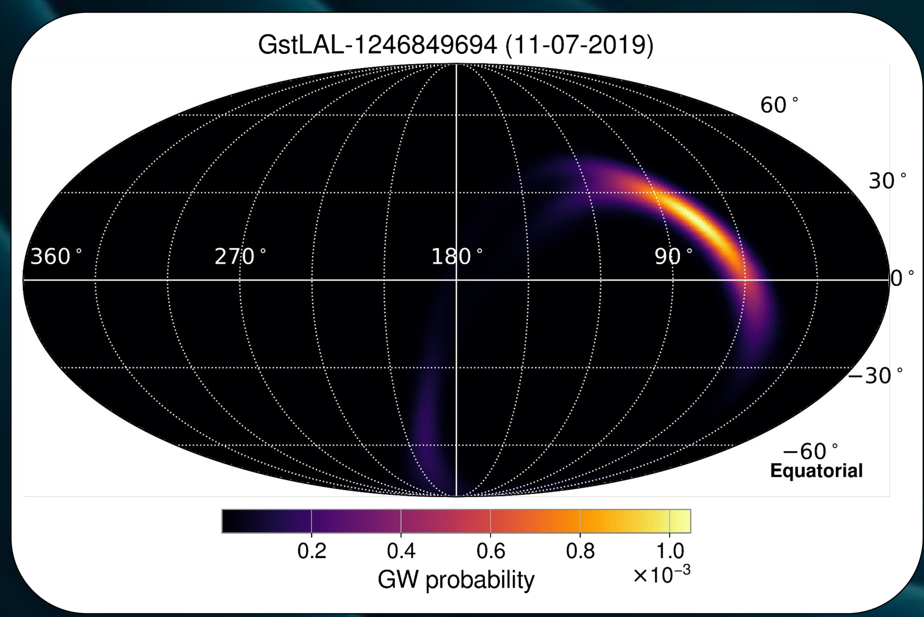
## Unbinned Maximum Likelihood Analysis[4]

$$\mathcal{L}(n_s(\gamma)) = \frac{(n_s + n_b)^N}{N!} e^{-(n_s+n_b)} \prod_{i=1}^{N} \left( \frac{n_s S_i}{n_s + n_b} + \frac{n_b B_i}{n_s + n_b} \right).$$

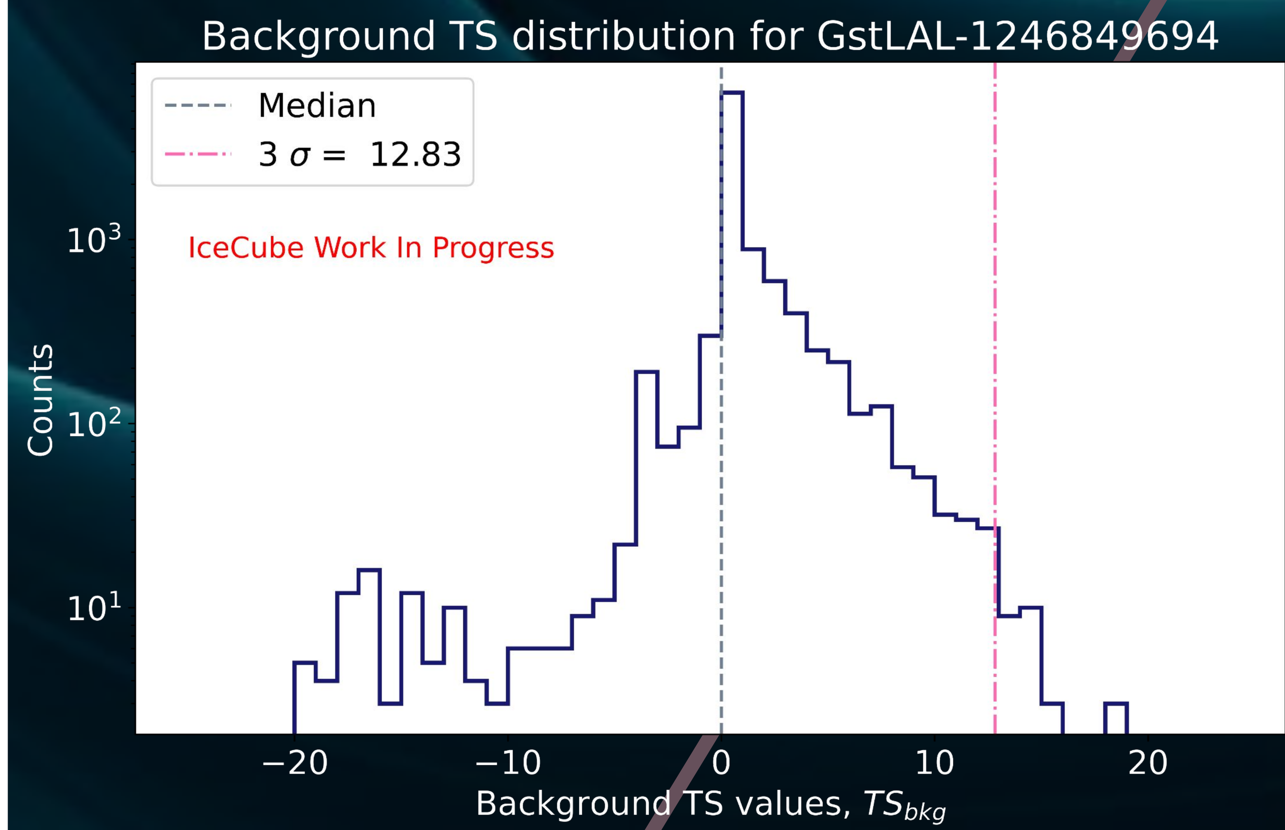
$$TS = \max \left[ 2 \ln \left( \frac{\mathcal{L}_k(n_s(\gamma)) \cdot \omega_k}{\mathcal{L}_k(n_s = 0)} \right) \right]$$



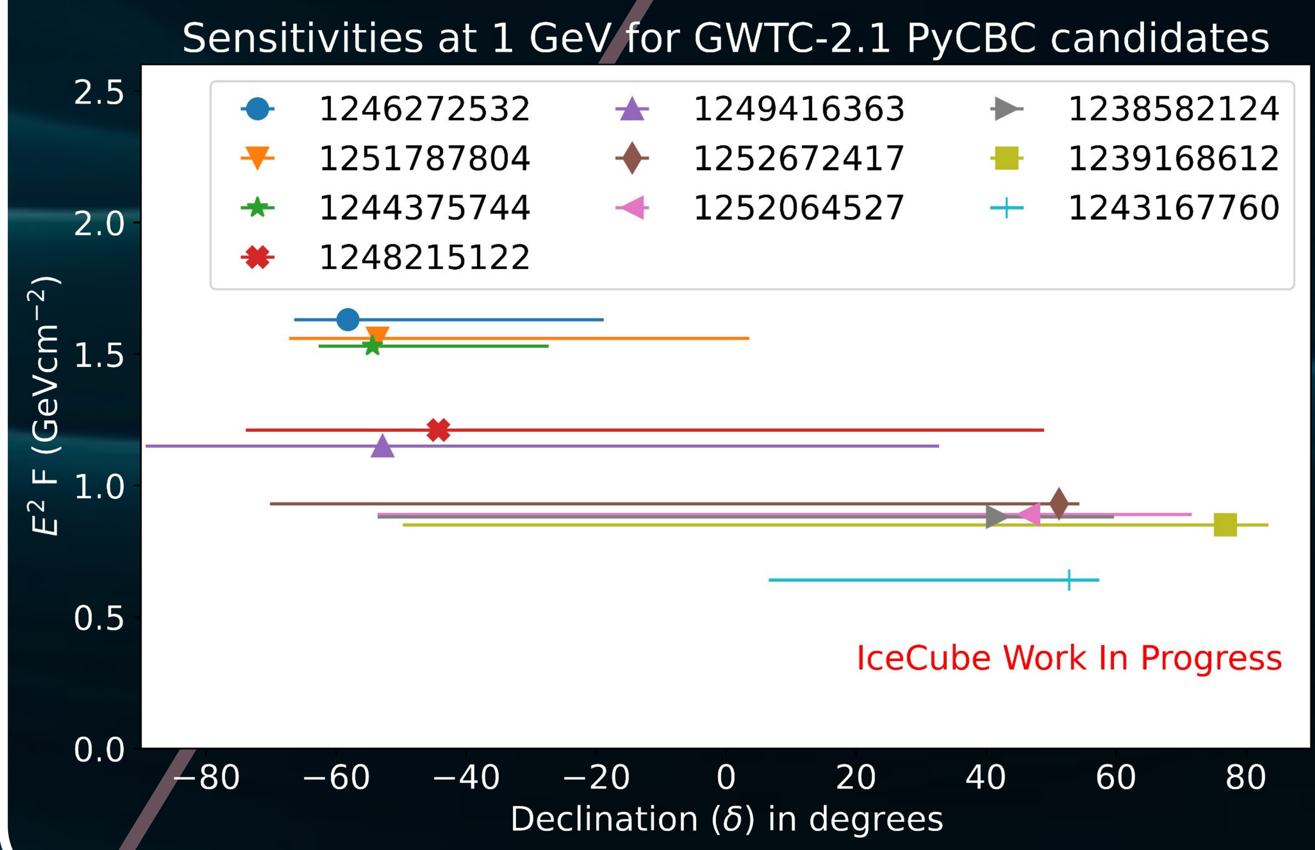
## Current Status[4]:




GW skymap for an event with ***$p_{astro}$ = 0.35***




Generating ***10,000 independent background events*** by time-scrambling the GRECO dataset




***Declination dependence of sensitivities*** for few of the sub-threshold GW candidates

## Future challenges:

- Big data handling in the era of Einstein Telescope
  - ***O(100) BNS candidates need to be followed up everyday*** to extract the maximum information.
  - ***Huge number of sub-threshold GW candidates*** of interests.
- Current approach of data handling will not be optimum
  - Need to identify ***suitable data brokers and analysis pipelines (eg. AMPEL[5])***
  - ***Prior selection*** of promising candidates needed.
  - ***Sustainable processing resources*** has to be identified.

## Outlook:

- With identifying neutrino counterparts, the ***significance*** of sub-threshold GW candidates will be ***significantly improved.***
- ***Sensitivity studies*** will be carried out considering future ET framework, e.g. calculating neutrino emissions of BNS events.
- Current multi-messenger follow-up techniques need to be ***adapted*** keeping in mind the ***next generation detectors.***
- ***Efficient data brokers and analysis techniques*** need to be identified.
- Our approach should be sustainable and compatible with the ***FAIR Data Management principles.***

## References:


[1] **The LIGO and the Virgo Collabs.**, R. Abbott et al, *Phys. Rev. X 11, 021053 (2021).*
[2] **The LIGO and the Virgo Collabs.**, R. Abbott et al, *Phys. Rev. X 13, 041039 (2023).*
[3] **IceCube Collaboration**, R. Abbasi et al, *APJ 953, 160 (2023).*
[4] **IceCube Collaboration**, T. Mukherjee et al, *PoS-ICRC 2023-1504 (2023).*
[5] **J. Nordin et al,** *A&A 631, A147 (2019).*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