Karlsruher Institut für Technologie

Multi-messenger Studies with GW and Neutrinos

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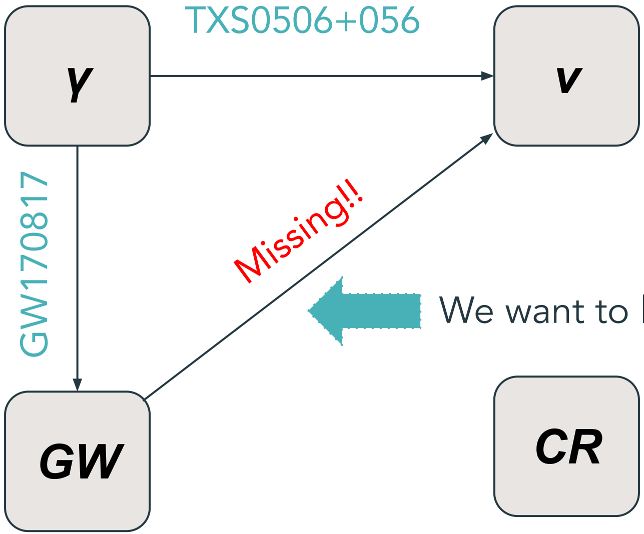
ET Seminar (Part-II@KIT)
13.05.2022

Motivation

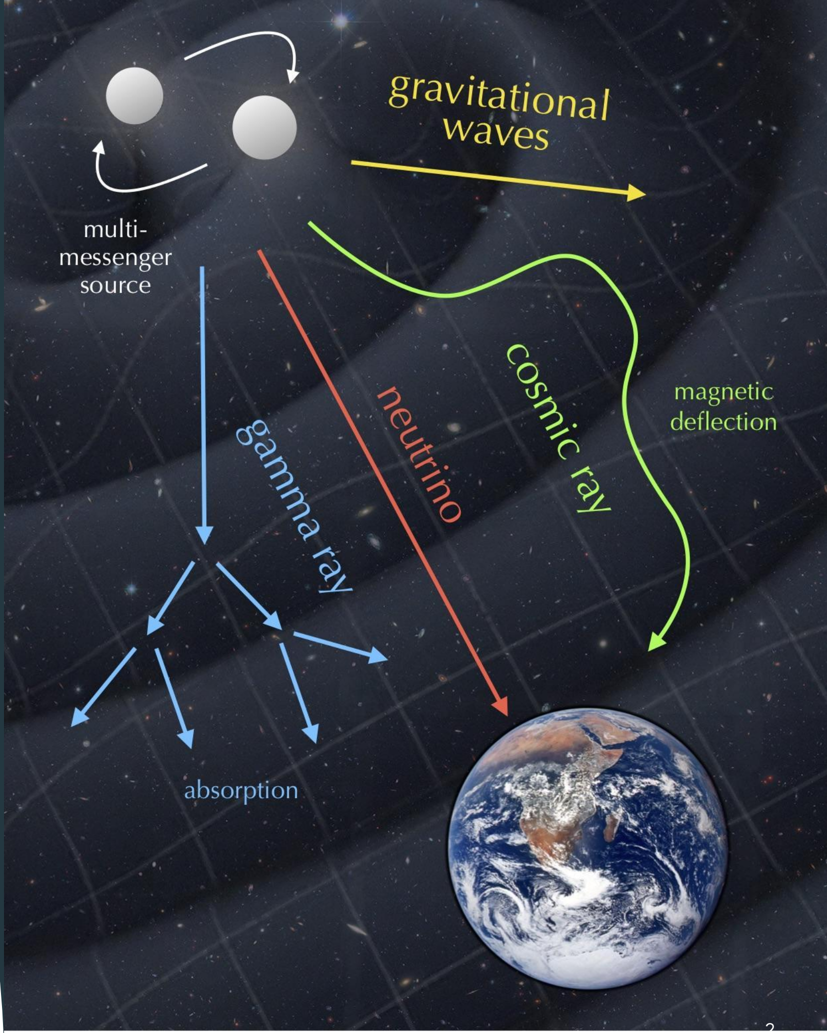
With multi-messenger studies, we access maximum information that we get from nature to unveil the unknowns of the Universe.

Ref: Aartsen et al., Science 361 (2018)



We want to look into this!

Ref: Abbot et al. 2017b, PhRvL 119, 161101



Our Aim @KIT

- Primary

❖ Neutrino counterparts of GW events
❖ Real-time alert and follow-up

- Why?

❖ Better GW source localisation
❖ Identify potential UHECR sources
❖ Probe EM obscured sources
❖ Understand the fundamental processes ongoing in astrophysical sources

Current Status

D.Veske et al., arXiv: 2107.09663 (ICRC2021)

Search for high-energy neutrino counterparts
❖ GW datasets: GWTC 1+2+3
❖ Neutrino dataset: High-energy (≥ TeV) dataset, GFU
❖ Methodology: Maximum likelihood (offline) Low-latency algorithm (online)
❖ Time window: ±250/±500 s around merger

Results: No significant coincidence found so far

Current Status

A. Balagopal V. et al., arXiv: 2107.11285 (ICRC2021)

Search for low-energy neutrino counterparts	
❖	GW datasets: GWTC 1+2+3
❖	Neutrino dataset: Low-energy (< TeV) dataset, GRECO
❖	Methodology: Maximum likelihood (offline)
❖	Time window: ±500 s around merger

Results: No significant coincidence found so far

Ray of hope?

Ref: D.Veske et al., arXiv: 2107.09663 (ICRC2021)

- ❖ A ~600 GeV neutrino was found to be slightly correlated with GW190728, emitted 360 s before the BBH merger. However, search is ongoing for more convincing coincidence.
- ❖ Developing second/third generation neutrino and gravitational wave detectors would increase the detection probability many times.

Workplan @KIT

Search for neutrino counterparts of GW events

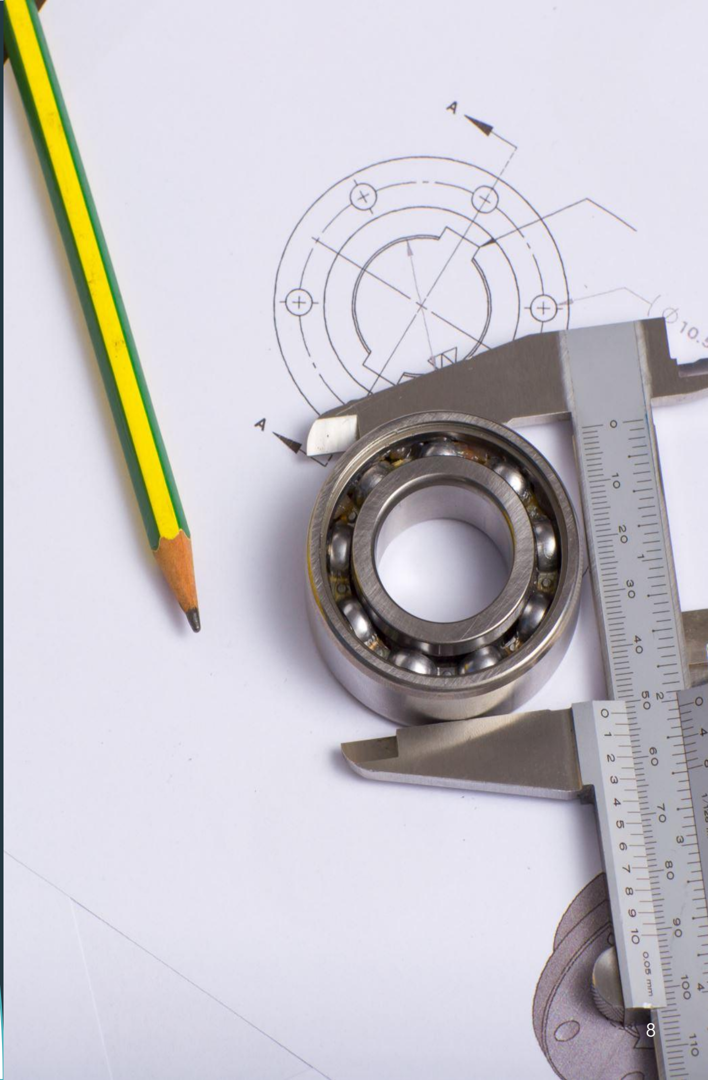
- ❖ Prospects of low-energy seems promising
- ❖ We combine every information, including sub-threshold GW events
- ❖ No particular preference for any GW source category
- ❖ The datasets: GWTC 1+2+2.1+3 and GRECO
- ❖ Analysis method: Maximum Likelihood

Workplan @KIT

Add GRECO and GWTCs with sub-threshold events

↓

Define a likelihood to maximise its value



Workplan @KIT

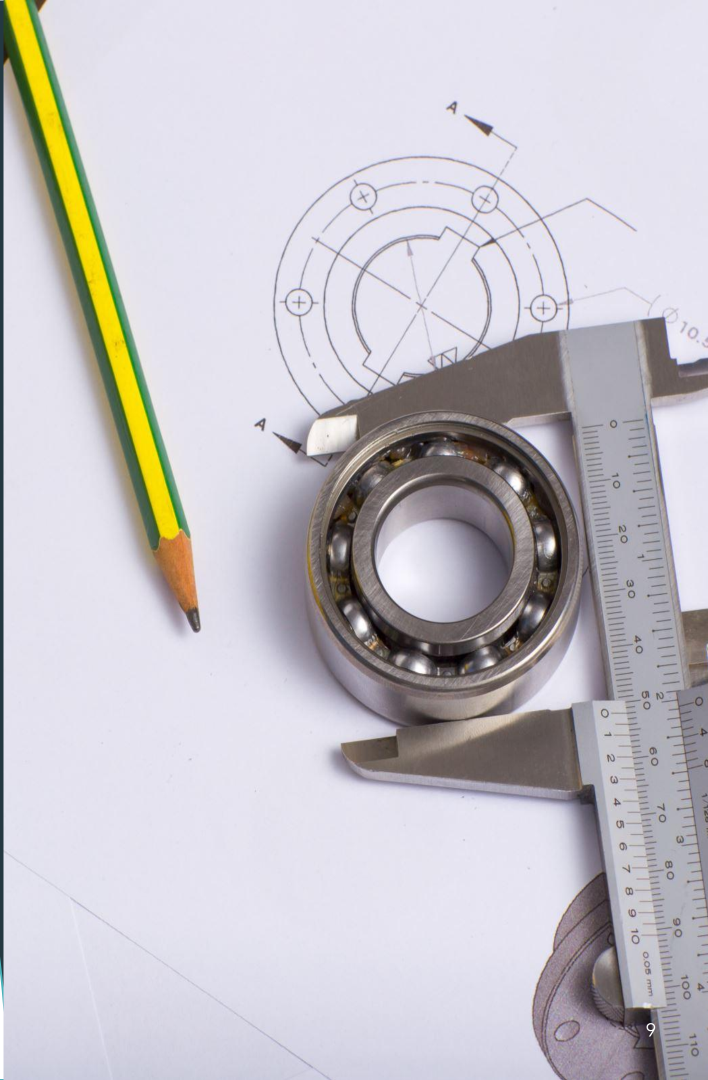
Add GRECO and GWTCs with sub-threshold events

Define a likelihood to maximise its value

$$\frac{(n_s+n_b)^N}{N!} exp^{-N} \prod_{i=1}^{N} \left(\frac{n_s S_i}{N} + \frac{n_b B_i}{N} \right)$$

Poisson probability of observing N events in which
n_s = signal events
n_b = background events

For all N events, total probability of containing n_s signal events where for i^{th} event
S_i = signal probability
B_i = background probability



Workplan @KIT

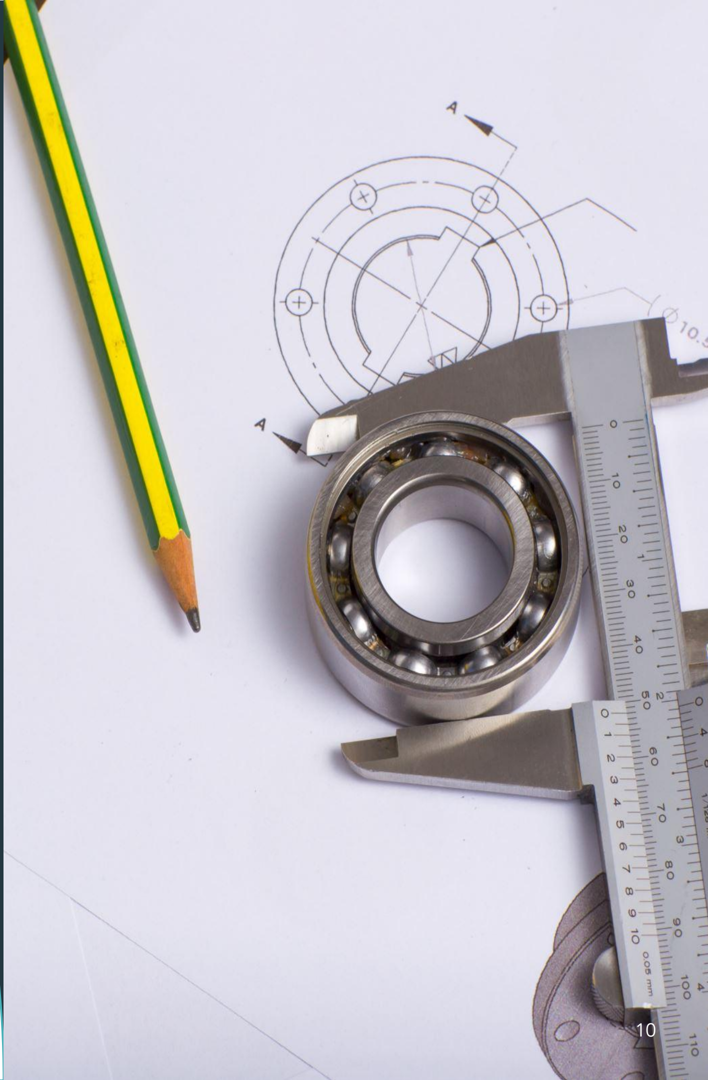
Add GRECO and GWTCs with sub-threshold events

Define a likelihood to maximise its value

$$\frac{(n_s+n_b)^N}{N!} exp^{-N} \prod_{i=1}^{N} \left(\frac{n_s S_i}{N} + \frac{n_b B_i}{N}\right)$$

We can find the maximum likelihood by maximizing the Test Statistic.

Maximum TS value = Maximum likelihood



Workplan @KIT

Add GRECO and GWTCs with sub-threshold events

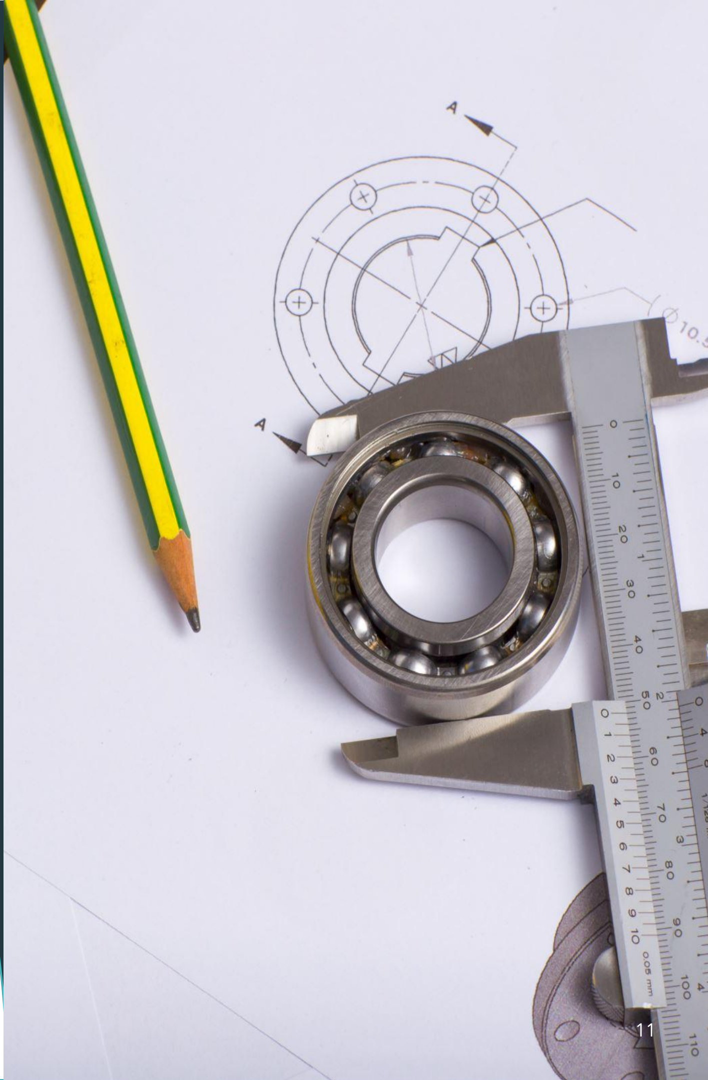
Define a likelihood to maximise value

$$\frac{(n_s+n_b)^N}{N!} exp^{-N} \prod_{i=1}^{N} \left(\frac{n_s S_i}{N} + \frac{n_b B_i}{N} \right)$$

We can find the maximum likelihood by maximizing the Test Statistics.

Maximum TS value = Maximum likelihood

$$TS \equiv 2 \ln \left[\frac{L(n_s)}{L(n_s=0)} \right]$$



Workplan @KIT

Add GRECO and GWTCs with sub-threshold events

↓

Define a likelihood to maximise its value

↓

Define TS from likelihood

↓

$$2\sum_{i=1}^{N} ln\left[\frac{n_s S_i}{N B_i} + \left(1-\frac{n_s}{N}\right)\right]$$

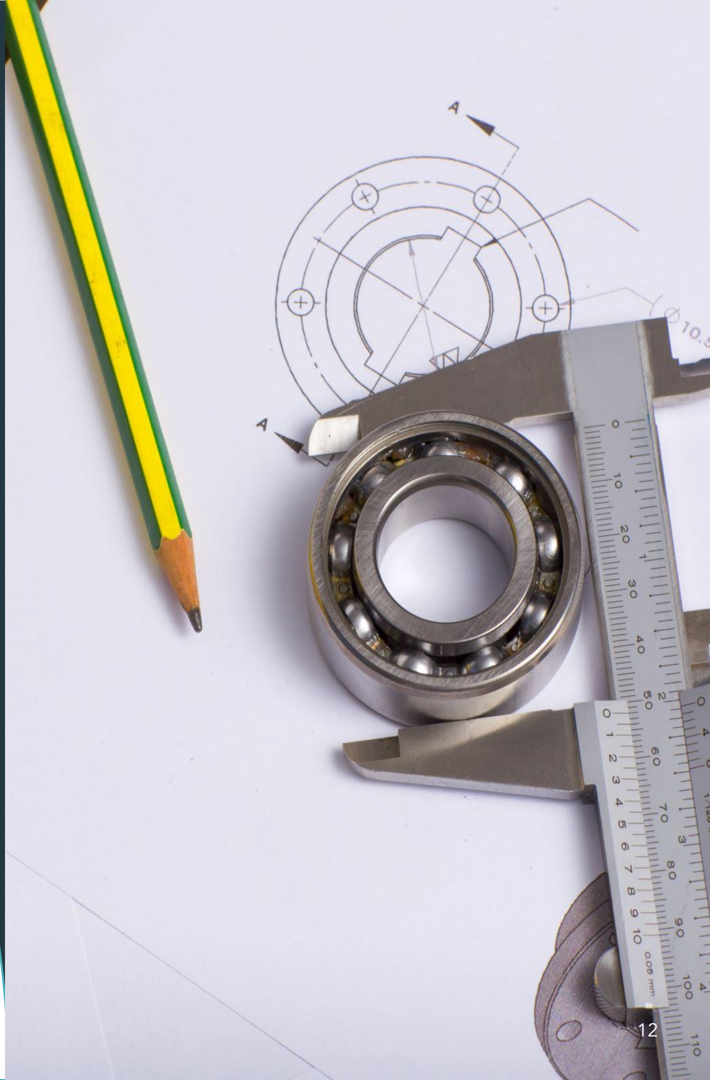
←

Calculate for all neutrinos around 1000s of each GW events

↑

Find the maximum TS

A. Balagopal V. et al., arXiv: 2107.11285 (ICRC2021)



https://ampelproject.github.io/

Work on AMPEL

AMPEL: Alert Management, Photometry and Evaluation of Lightcurves

Motivation:

- Contribute in real-time astronomy
- Data provenance and reproducibility
- Analysis flexibility

Using AMPEL, we can select, analyze, update, combine, enrich and react to data.

https://ampelproject.github.io/

Upcoming plans

- Implement our analysis for real-time alerts by extending the current AMPEL framework.
  Ref: J. Nordin, J., et al., Astronomy & Astrophysics 631 (2019): A147.

- Improve our search methods with improving detectors.

- Be a part of the Virgo collaboration to understand the GW data better.


Exciting times are coming!!