# Bridging Gravitational Waves and High-Energy Gamma Rays: Searching for sGRB Afterglows from Compact Binary Coalescences with CTAO

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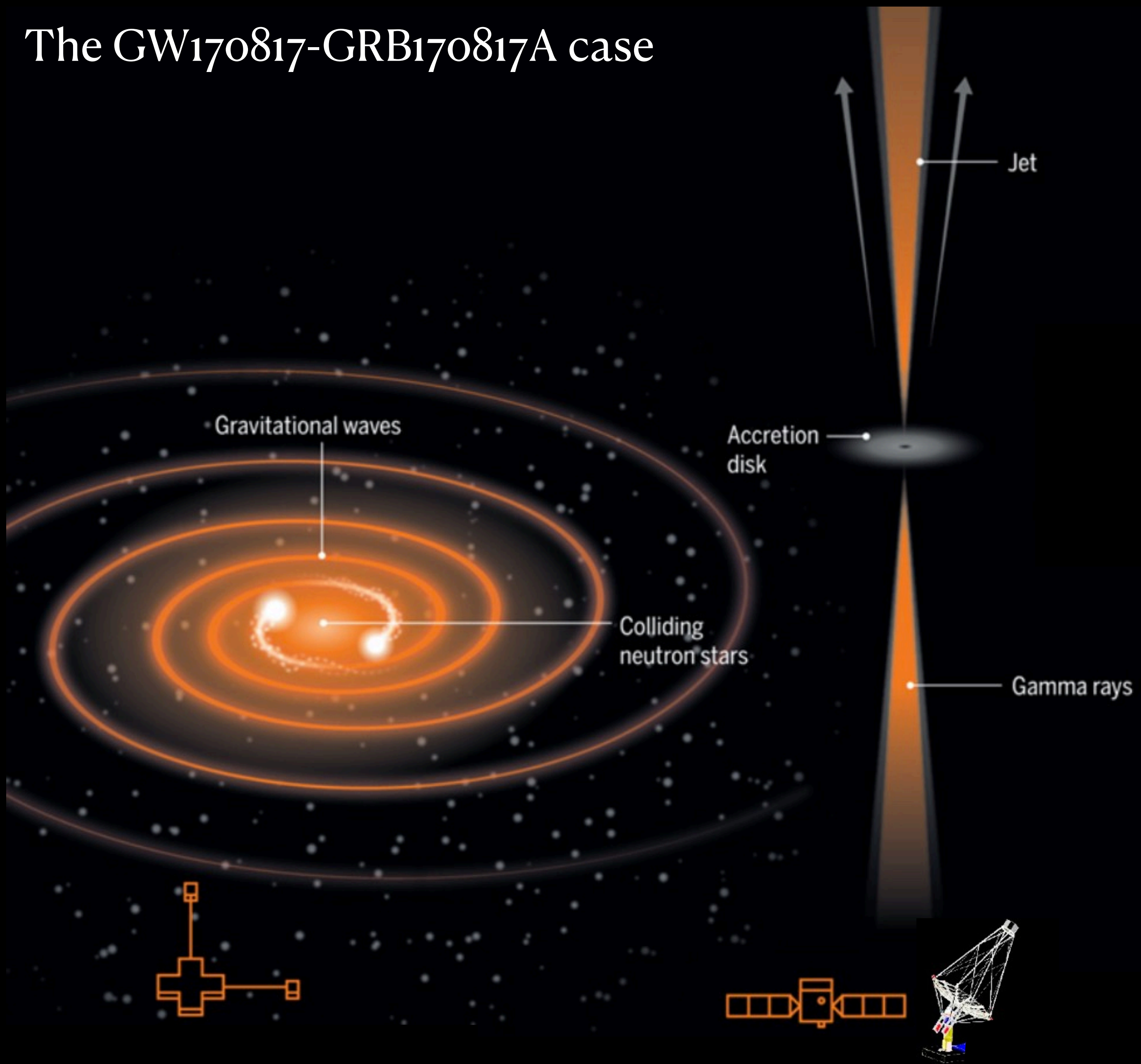
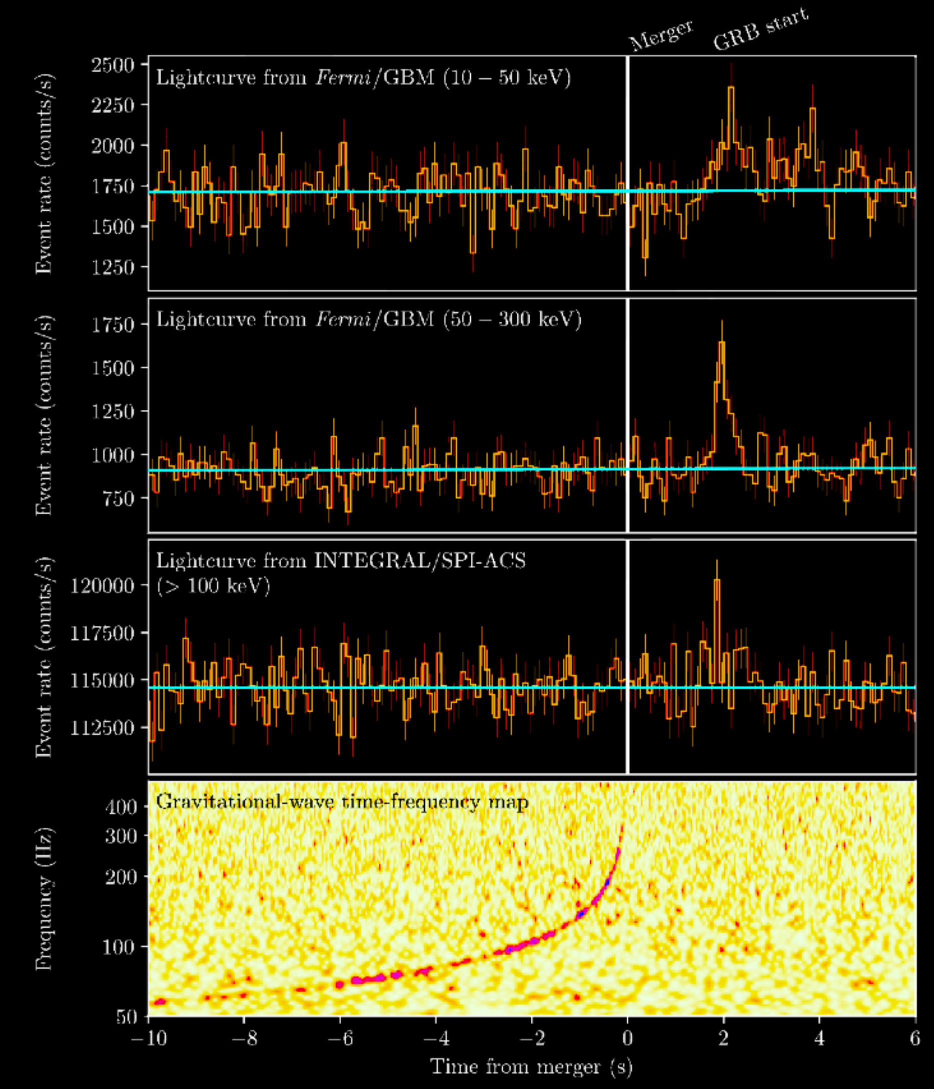
Image credit: NASA SVS

Abbott et al., *ApJL* 848.2 (2017): L13

# The GW170817-GRB170817A case



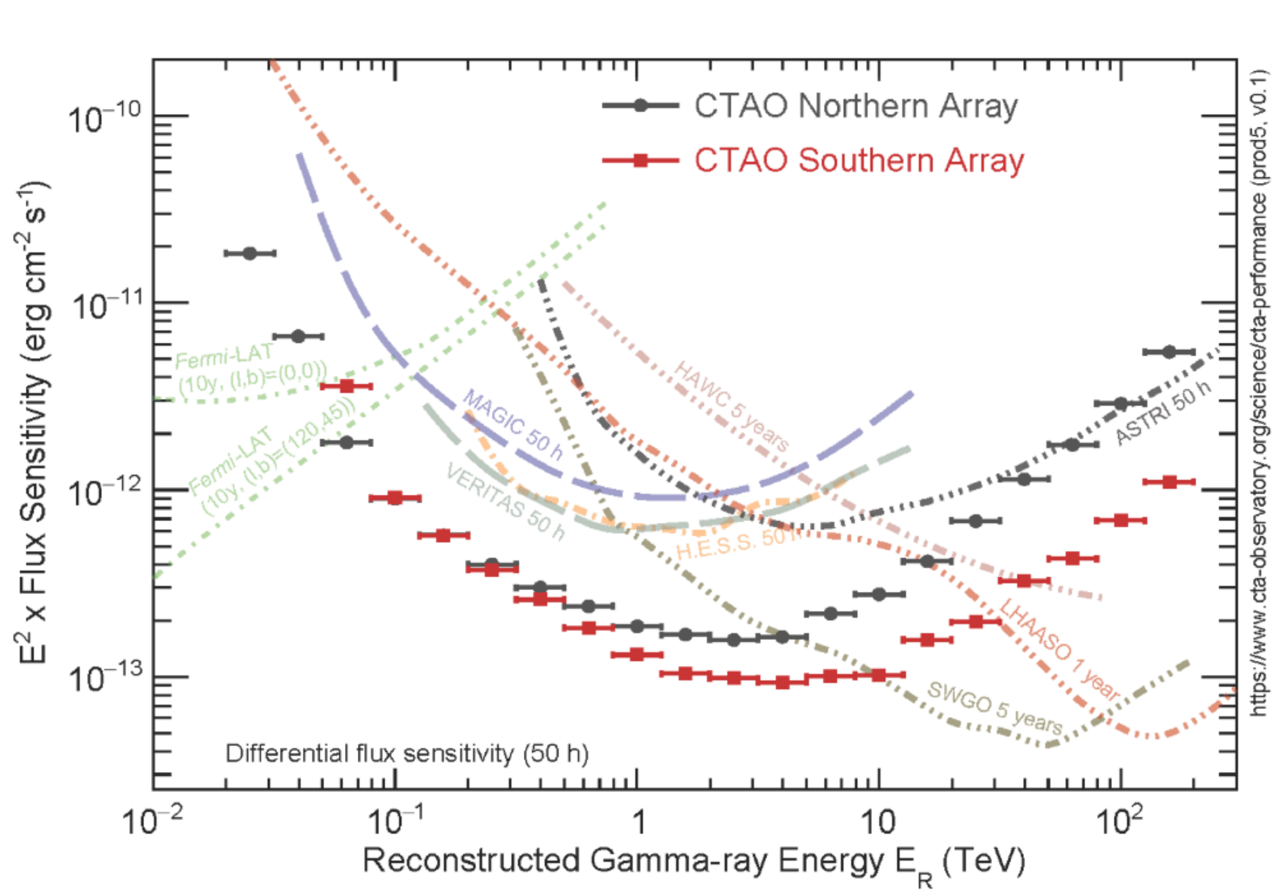




Implications:

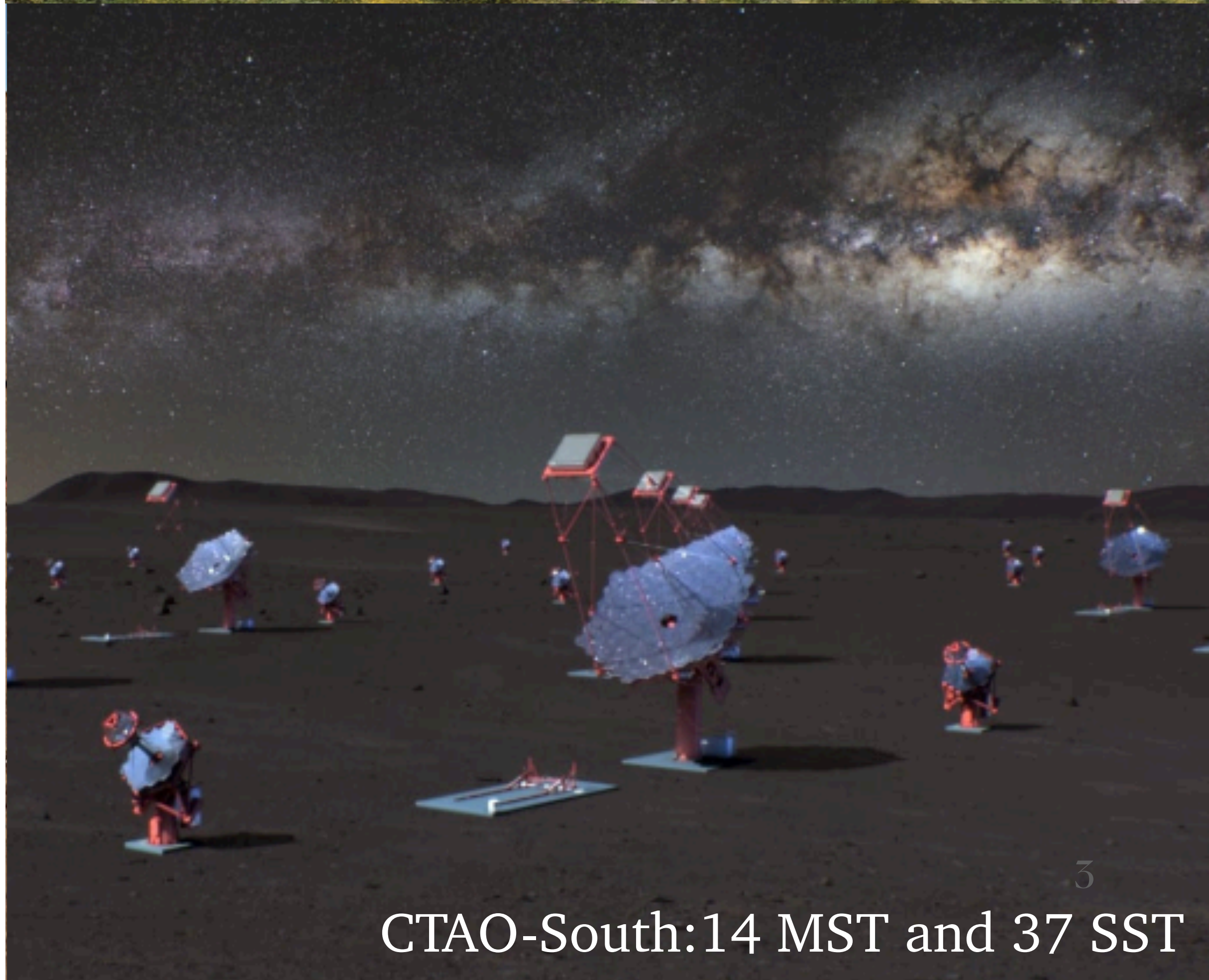
- Astrophysical, fundamental, cosmological, nuclear…
- Beyond GeVs: ULs > 270 GeV by H.E.S.S. 5h after BNS merger ApJL 850 (2017) L22

# Cherenkov Telescope Array Observatory

- CTAO design: 2 arrays with 3 types of telescopes!
- Key for **transient physics**:
    - High sensitivity in short scale exposures at ~GeV energies: large effective area (~$10^5$ m$^2$) compared to satellites as Fermi-LAT (~1 m$^2$)
    - ~mCrab sensitivities, reach of z~2-4 for GRBs
    - Real time analysis assured by the SAG system
    - Relatively large FoVs !







# Prospects on CTAO detectability of sGRBs from BNS mergers during O5

**What?**

- **Prospects for sGRBs detections from BNS mergers in Observing run O5**
  - ➡ Ingredients : GRB **evolution**, IACTs are **pointing telescopes**
  - ➡ Approach: GRB injections to obtain **detectability plots**: identify rates and sweet spot in latency/exposure.

**How?**

- **Best strategies for the (generally) poorly localised GW sources**
  - ➡ Ingredients: GW **location posterior**, **evolving accesible sky**, GRB **evolution**
  - ➡ Approach:

1. **Observation strategy for the follow-up campaign**
   - **Fixed window**: Comparison of 1', 5', 20': Fast campaigns covering large regions versus usual IACT exposures
   - **Average window** (1): Average LC among all the GRBs: is useful to use the average expected evolution?
   - **Variable window** (2): Tailored exposure per each GRB, so that the exposure is the one required for 5sigma detection
2. **Evaluate the role of the Real Time Analysis**
   - Realistic scenario: 'a hotspot is found, let's accumulate signal'

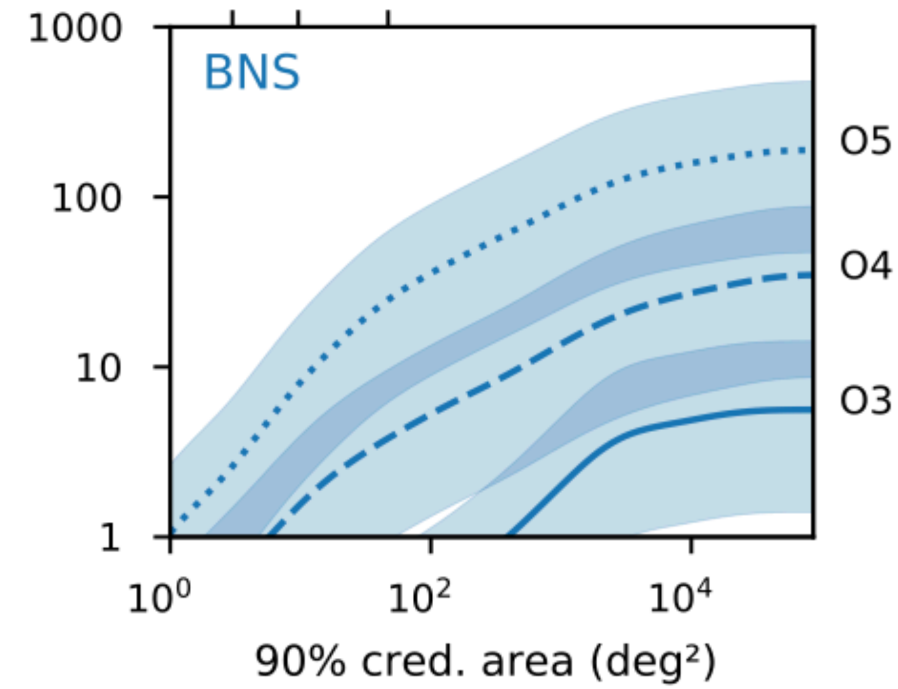
# GW-GRB simulation in a nutshell

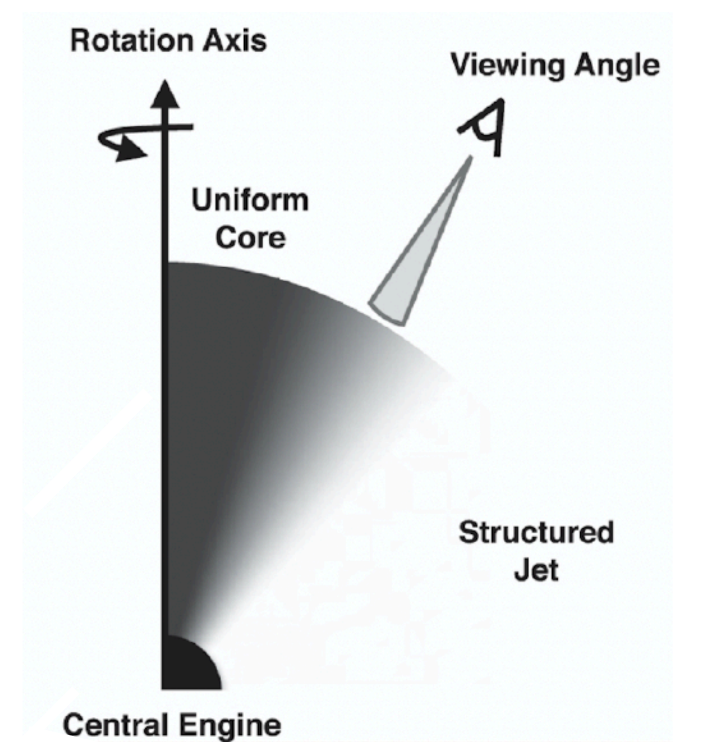
- **GW: 2307 BNS mergers** (Petrov, P et al., *Astrophys.J.* 924 (2022) 2, 54)
  - 4 interferometers in O5 (LHVK): 2 aLIGO 330Mpc, AdV 150–260Mpc. KAGRA~130Mpc
  - Homogeneous and isotropic distribution
  - 3D BAYESTAR localization, Singer&Price, 2016.

- **GRBs:** Phenomenological set of short GRB simulations
  - Assume that **all launch** a jet: gaussian structure in energy and Lorentz factor.
  - Afterglow emission for jet-medium interaction

- Link via **distance**, **viewing angle** and the **mass of the BNS**
  - **Viewing angle** given by the orbital inclination of the binary
  - **Jet core angle :** from sGRB distribution, ~14deg (A&A , 52:43–105, 2014.)

- **$E_{iso}$** from short GRB distribution in Ghirlanda et al. A&A, 594:A84, Oct 2016
- **Lightcurve**: temporal decay and luminosity at TeV similar to that in soft X-rays.
- **Spectrum**: EBL- absorbed GRB spectrum, power-law with photon index of -2.2. External medium ~0.1cm$^{-3}$



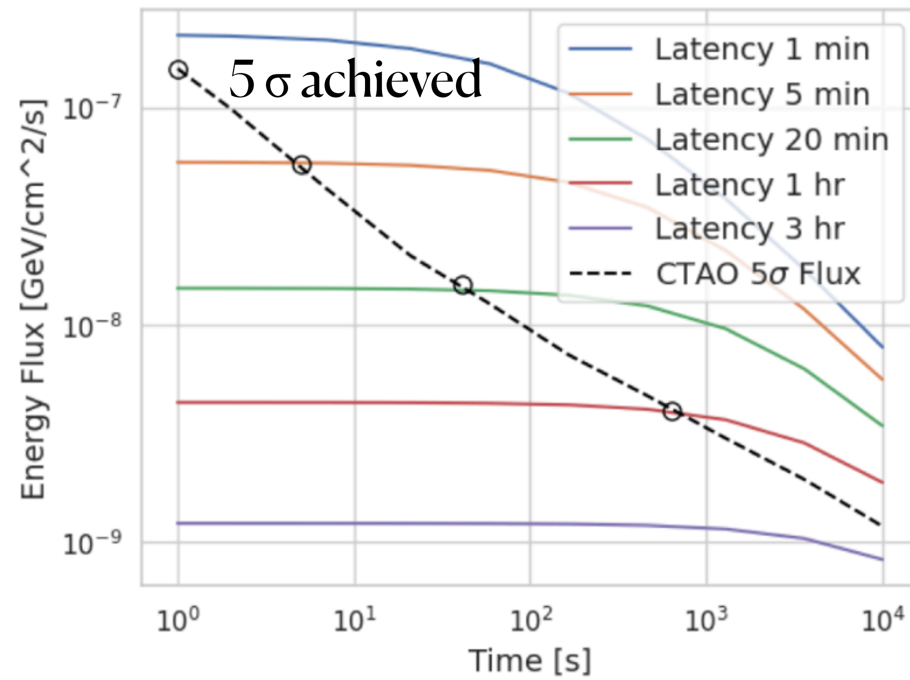




From Abbot et al, 848:L13 (27pp), 2017

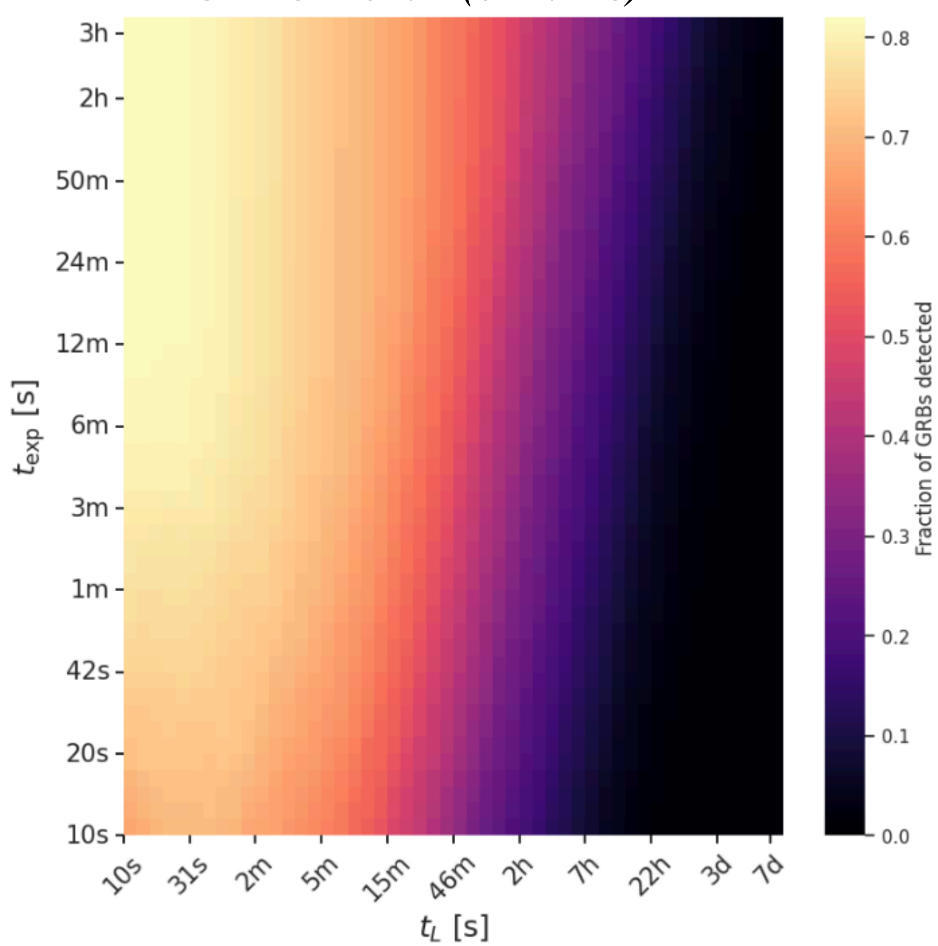
# GRB detectability parameter space

- Assessing detectability from CTAO alpha IRFs
- Main conclusions on-axis:
  - 10s exposures **are enough** for detection
  - Turning point at 15', detectability goes to zero after a day

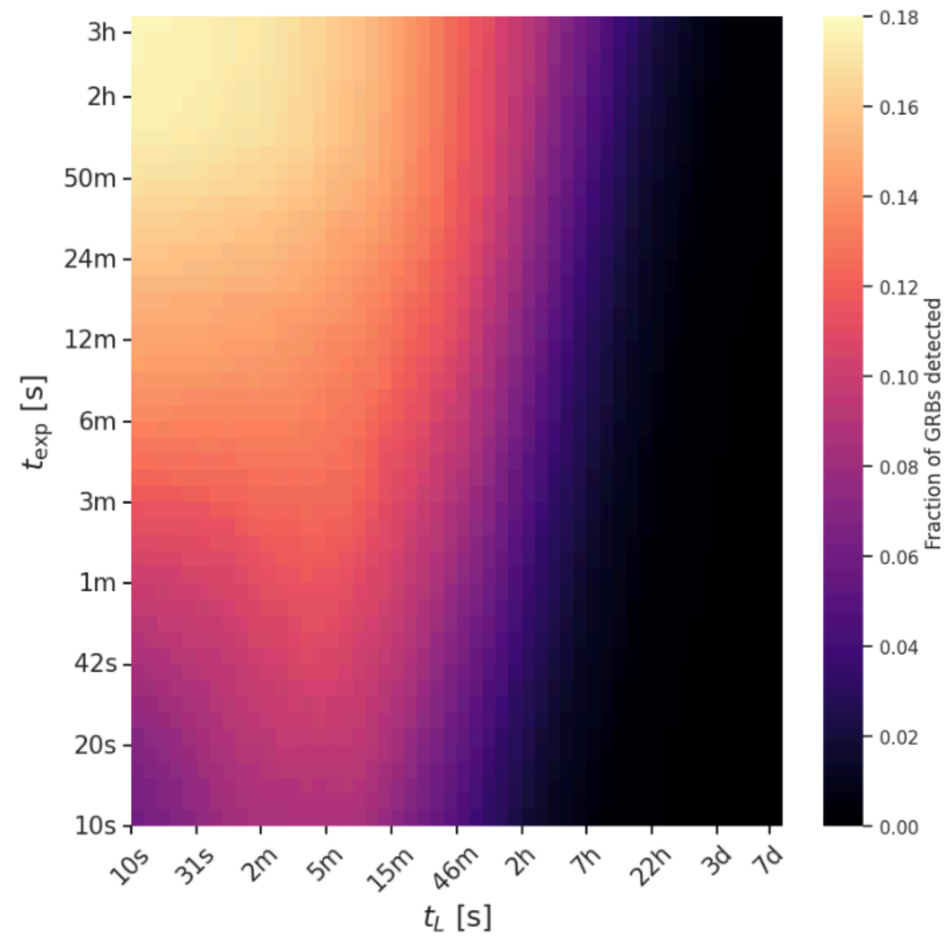
- Main conclusions off-axis:
  - Detectability **notably** decreases
  - Detection not directly at ~seconds of delays
  - Minimum exposures of ~3 min in best case scenario




*CTAO North (on-axis)*



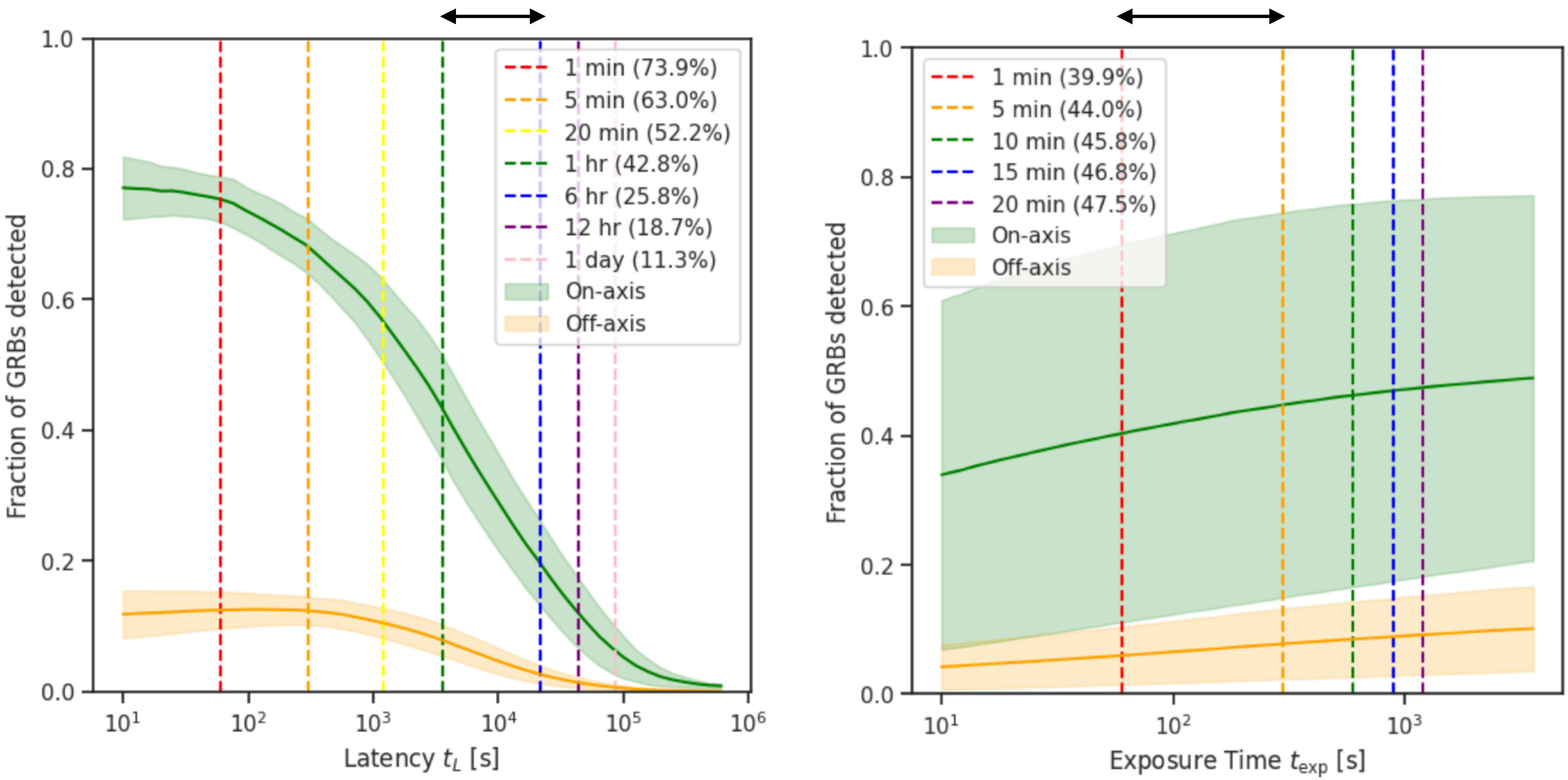

*CTAO North (off-axis)*



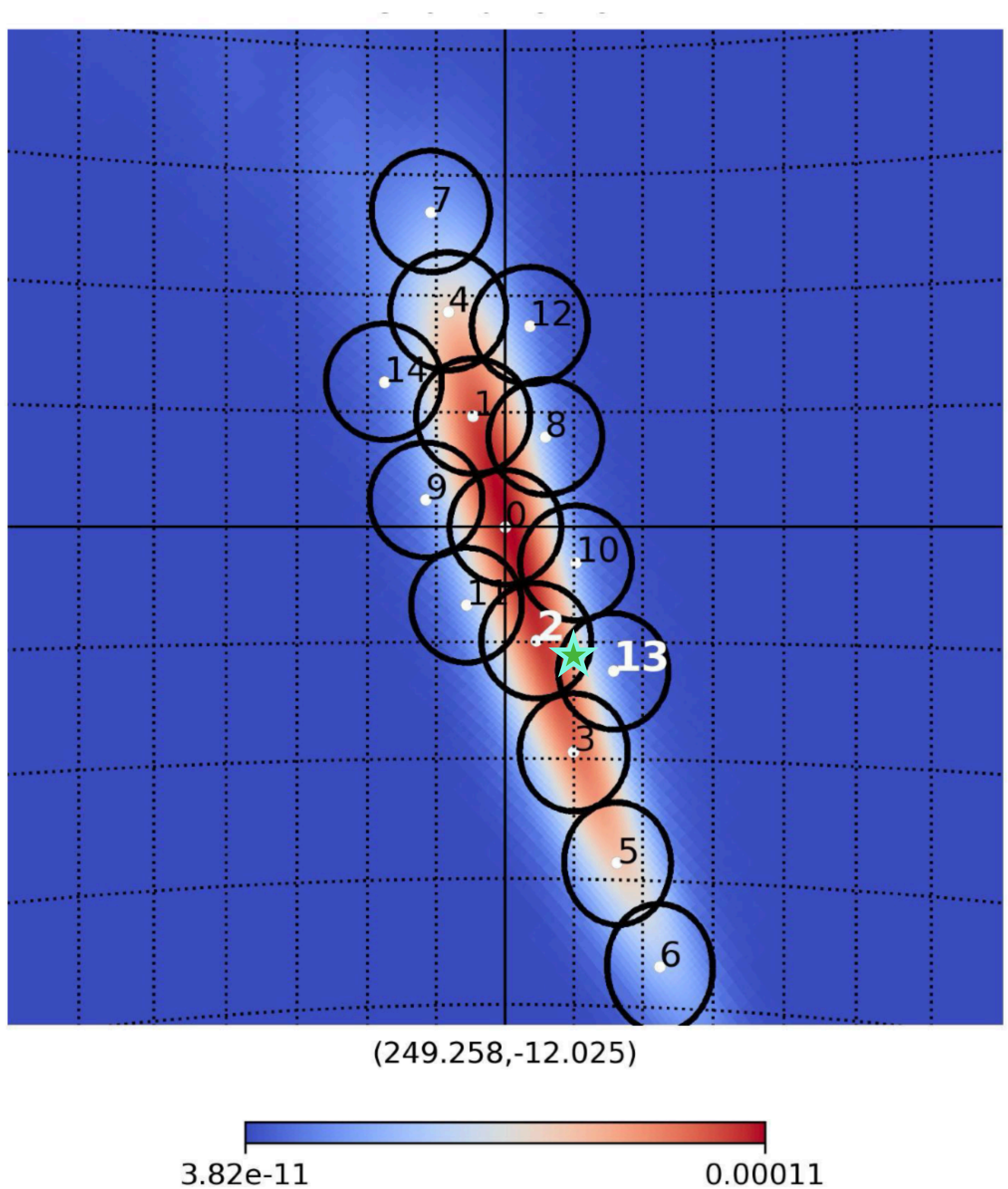
GW TOY

# Deeper look into the delay-exposure results

- Projected the previous plots over **latency** and **exposure** parameters to identify marginal gains
- Identifying turning points of the GRB detectability



# tilepy used as as observation orchestrator



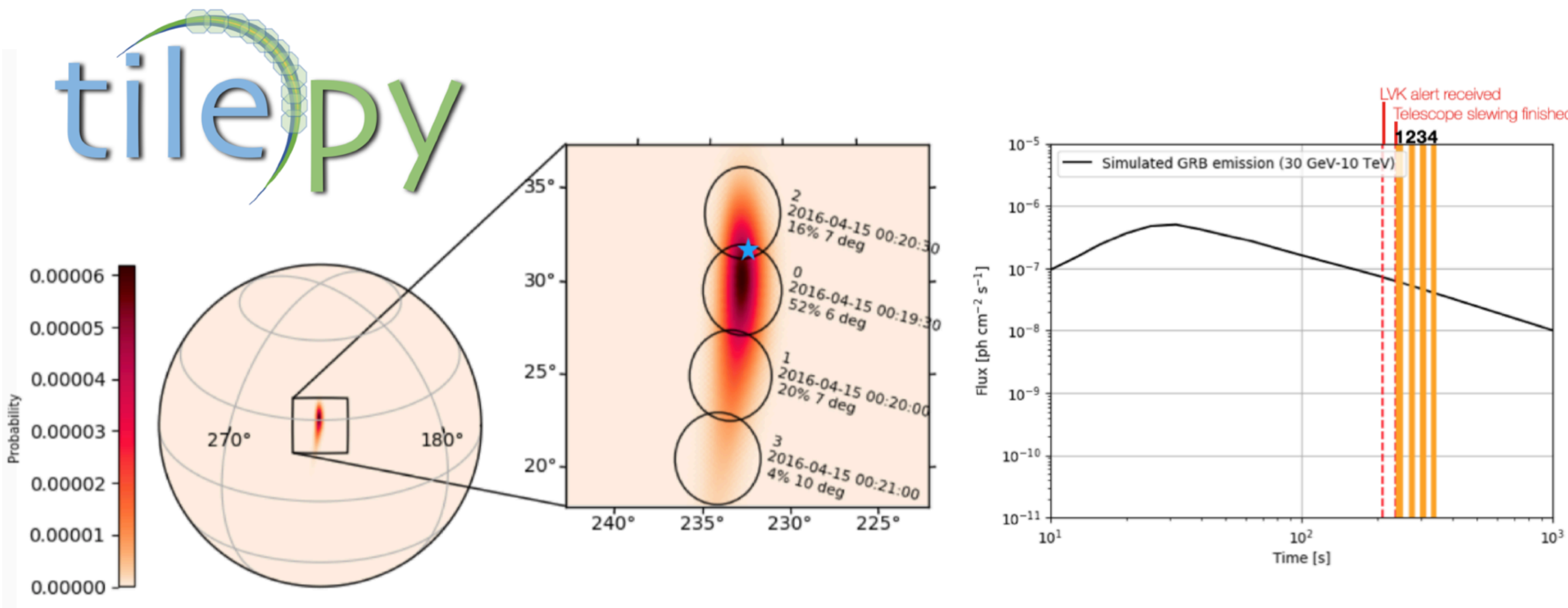

github.com/astro-transients/tilepy

# Study of the observation strategy

- Observation scheduling is handled by open source code **tilepy (LGPLv3 license)**
- Cases to study:
  - several **fixed** time windows: standard scheduling approach, using 1-min, 5-min and 20-min exposures
  - **fixed average** GRB case.
  - **variable: time is an extra variable to determine on the fly!** Code is customised to check previous look-up tables per zenith angle following CTAO alpha IRFS

$$\int_{t_0}^{t_0+T_{\rm exp}} F(t)dt \geq F^{s}_{5\sigma}(T_{\rm exp}),$$

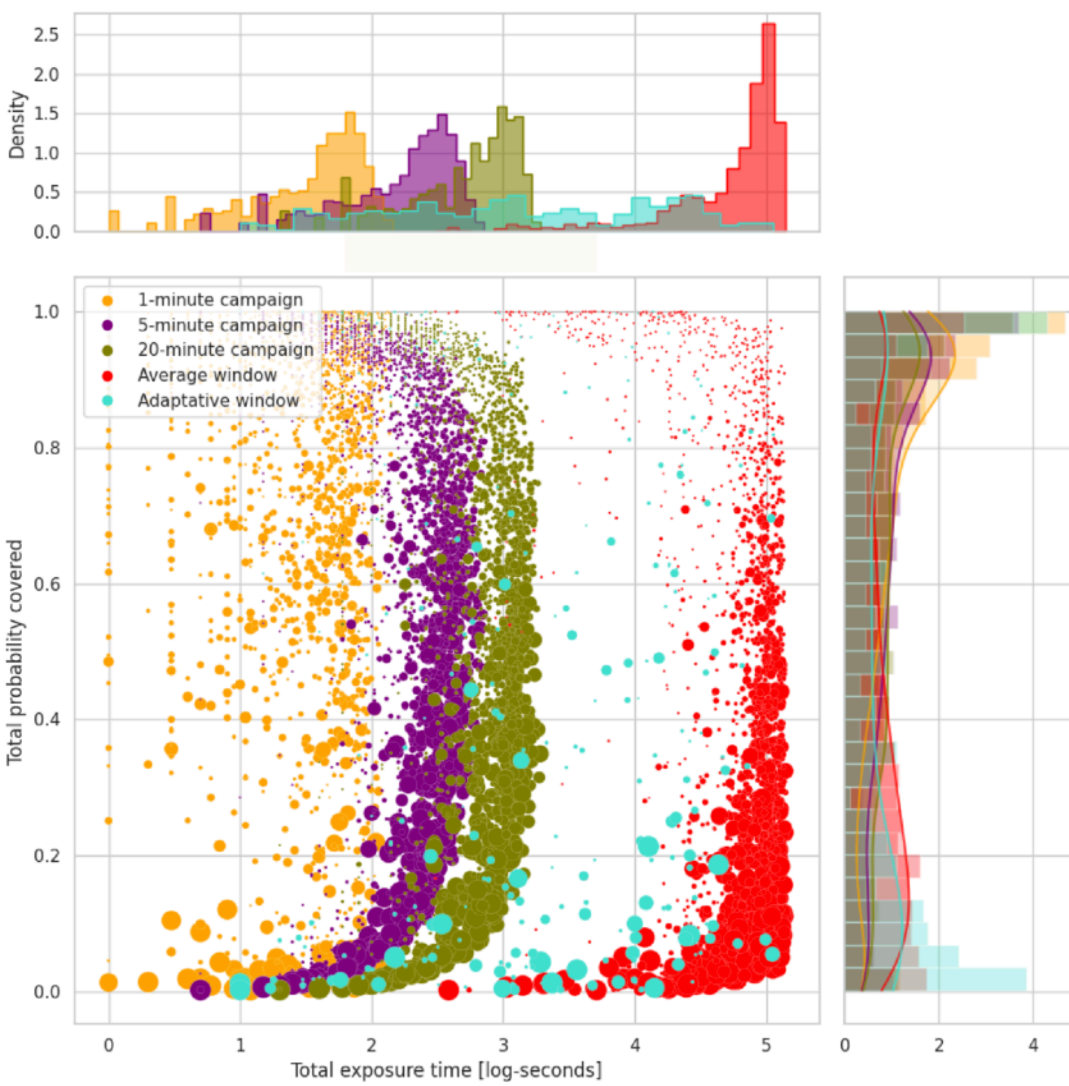
- Example of realistic variable case, embedded in tilepy, considering CTAO IRFs, and night evolution.

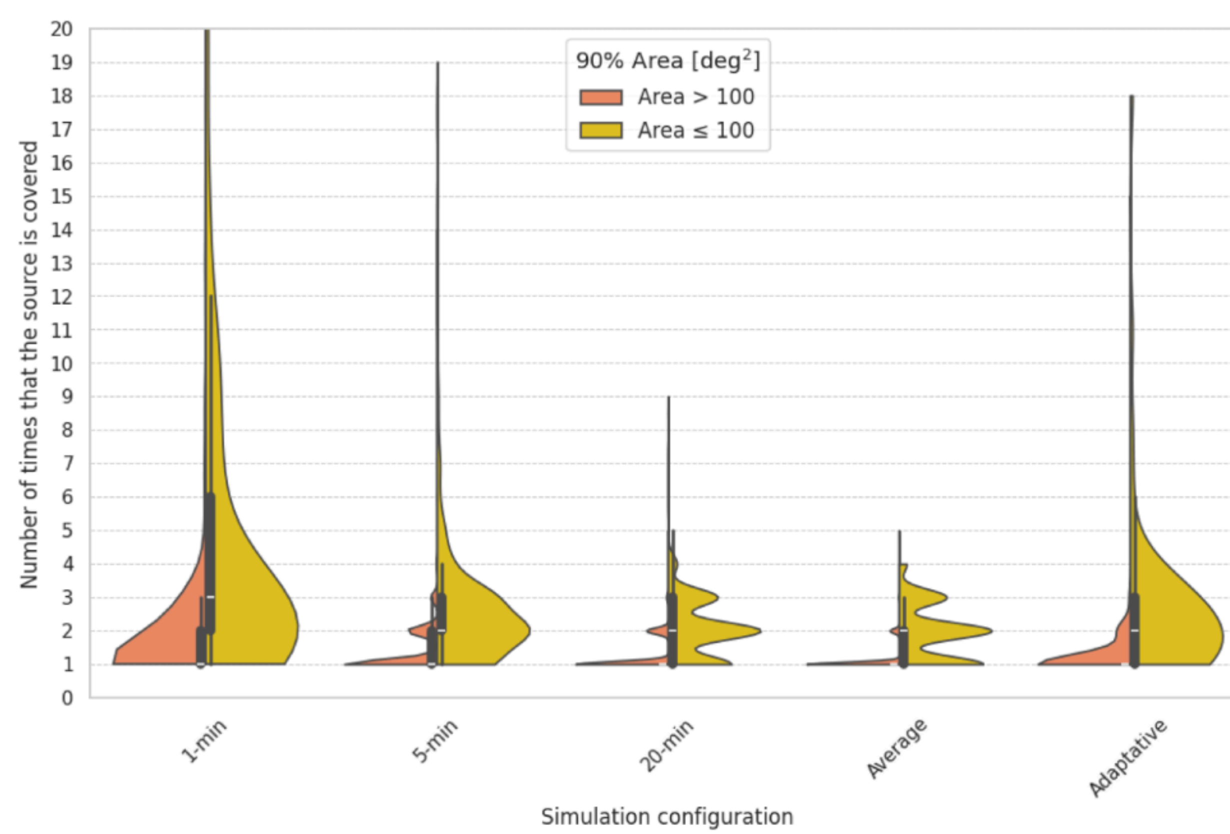


# Detectability results including tiling

- Source is covered in a large number of cases, but not always detected!
- **Statistically, the source is detectable in 4% of the cases** pre 4h
- Yet, source is revisited several times, specially when 90% C.R. <100 deg => role of RTA

| | 1-minute | 5-minute | 20-minute | Variable | Average |
|---|---|---|---|---|---|
| *Percent (%)* | | | | | |
| Percent Covered | 70.0 | 65.9 | 62.9 | 6.7 | 44.7 |
| Percent Detected [4hr campaign] | 4.7 | 5.1 | 4.8 | 4.9 | 4.5 |

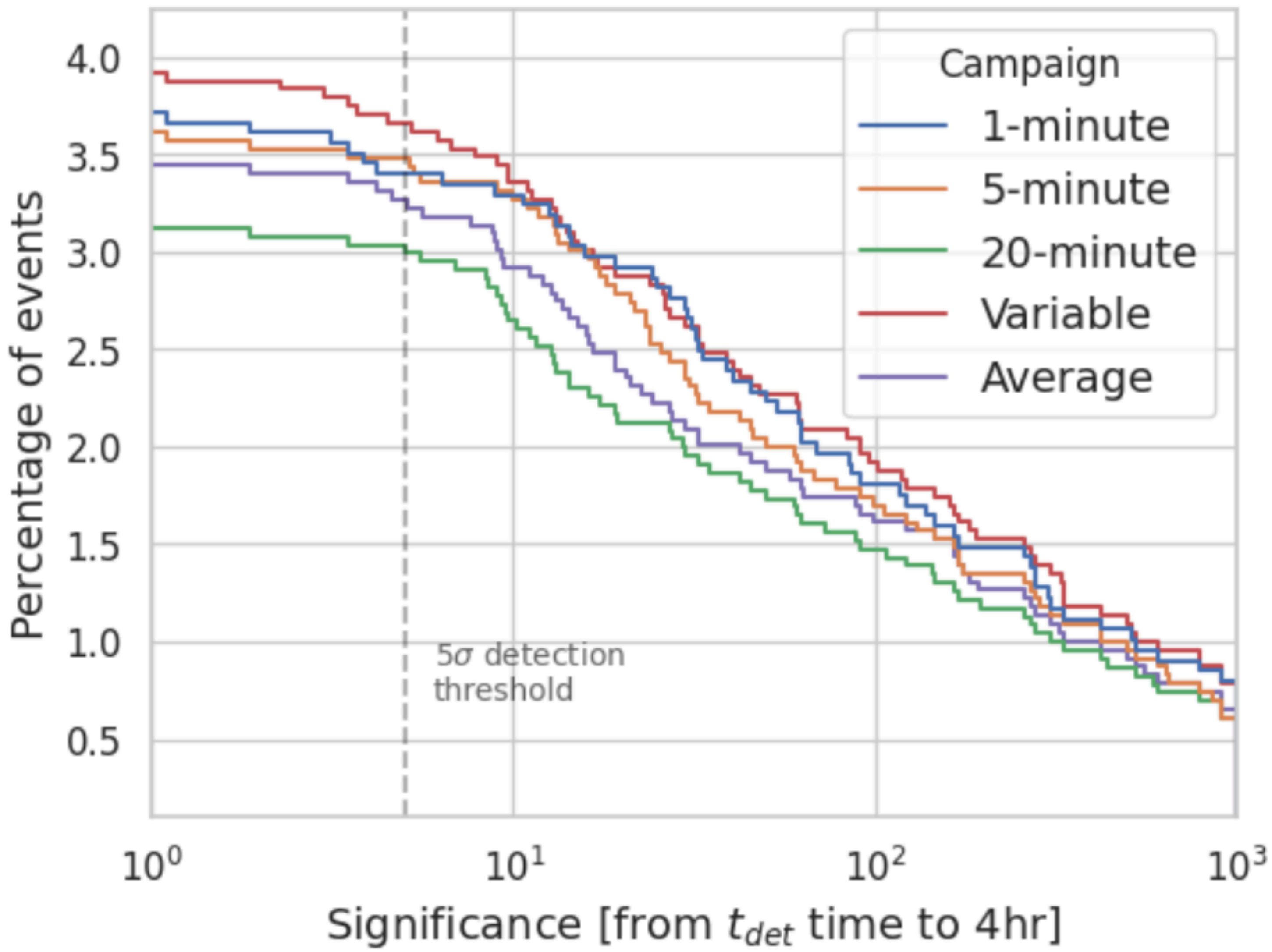


# Accumulated significance when RTA is involved

- We explore the significance distribution reached in **a realistic scenario**:
  - During the observations, data is accumulated and analysed in real time by the RTA.
  - **Self-triggering via RTA happens when 5 sigma is achieved:** observation scheduled are stopped and source is monitored until the end of the campaign.

- **Boost of significance** obtained, which will enable to have better scientific outcome of the observing campaign!



# Outlook

- Take-home message:
  - Detection prospects are **strongly powered** by an adapted set-up, i.e. strategy and RTA
  - In the little numbers regime, major dependence on the considerations of the simulated GW-GRBs
  - **Pipeline stablished** by combining **GW-toy, tilepy and realistic RTA behaviour**

- More results in **Green, Patricelli, Nava, Schüssler, Seglar-Arroyo, Stamerra et al. (CTAO Consortium paper)**, ***expected end Nov 2025***

- **CTAO/LST-1 observing transients**!
  - **BOAT GRB221009A**: see Abe, K., et al., *ApJL* 988.2 (2025): L42.
  - **BBH observations during Observing Run O4**: later in this session!

- Zooming out:
  - GW170817 was a **lucky one**! **BUT** the field is just at a **starting stage**!
  - Observing Run O4c finishing in **November 18, 2025**.
  - Latest announcement: **extra <u>6 months of O4 starting late summer/early fall 2026!</u>**
  - LVK Observing Run O5 expected to start >2028


Thanks for your attention!

# Back-up

# The sGRB emission at VHE energies

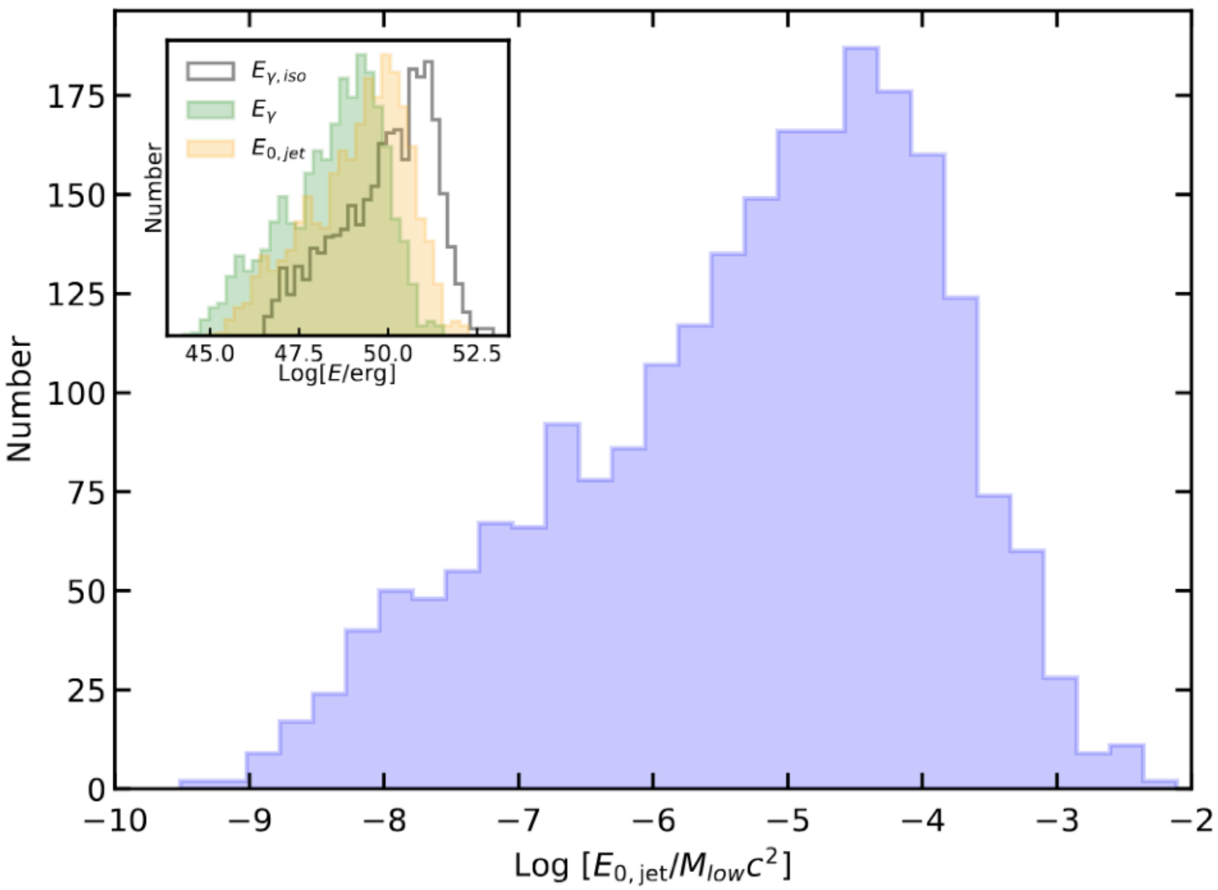



Figure 1: Ratio between the energy of the jet launched following the merger of the BNS and the mass of the lightest NS. The inset shows the distributions of the jet energy $E_{0,\mathrm{jet}}$ (orange filled histogram), the radiated energy $E_\gamma$ (green filled histogram), and the isotropic equivalent radiated energy $E_{\gamma,\mathrm{iso}}$ (black empty histogram).

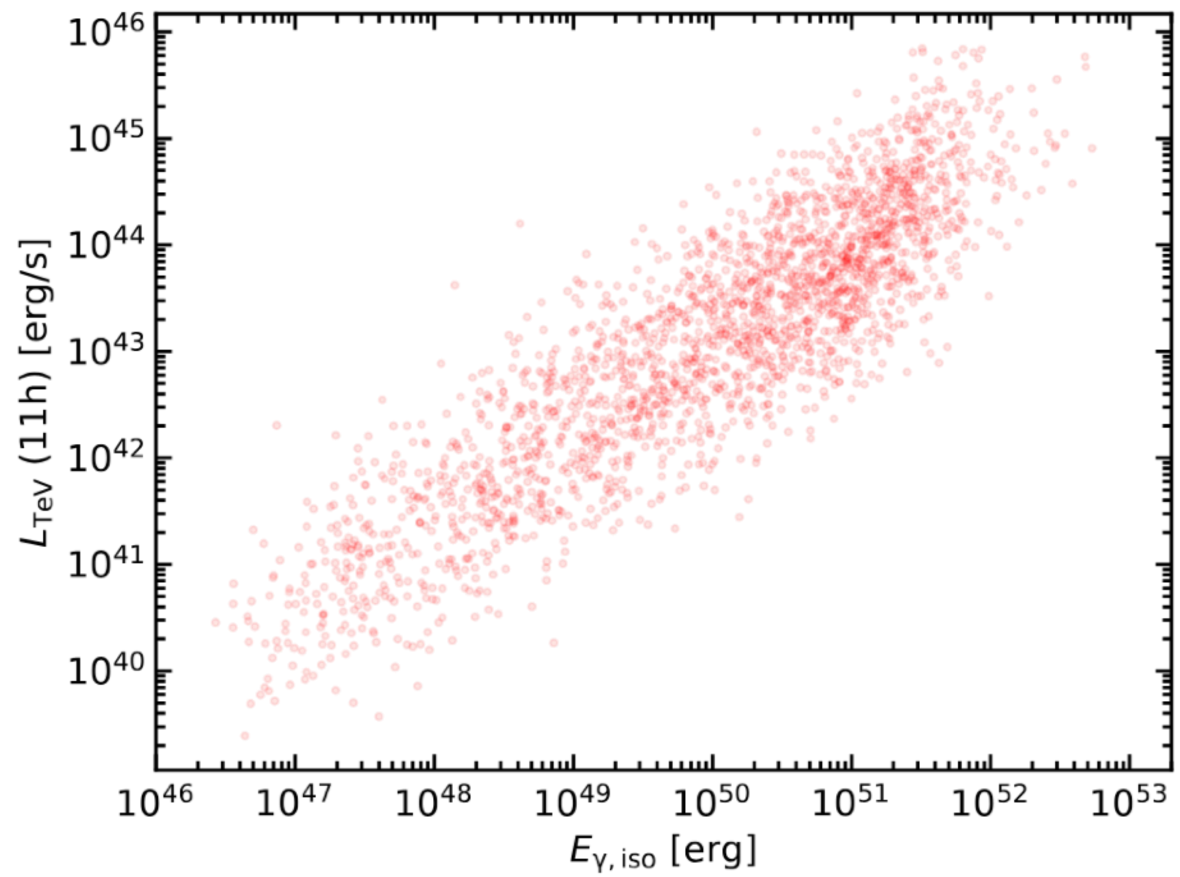
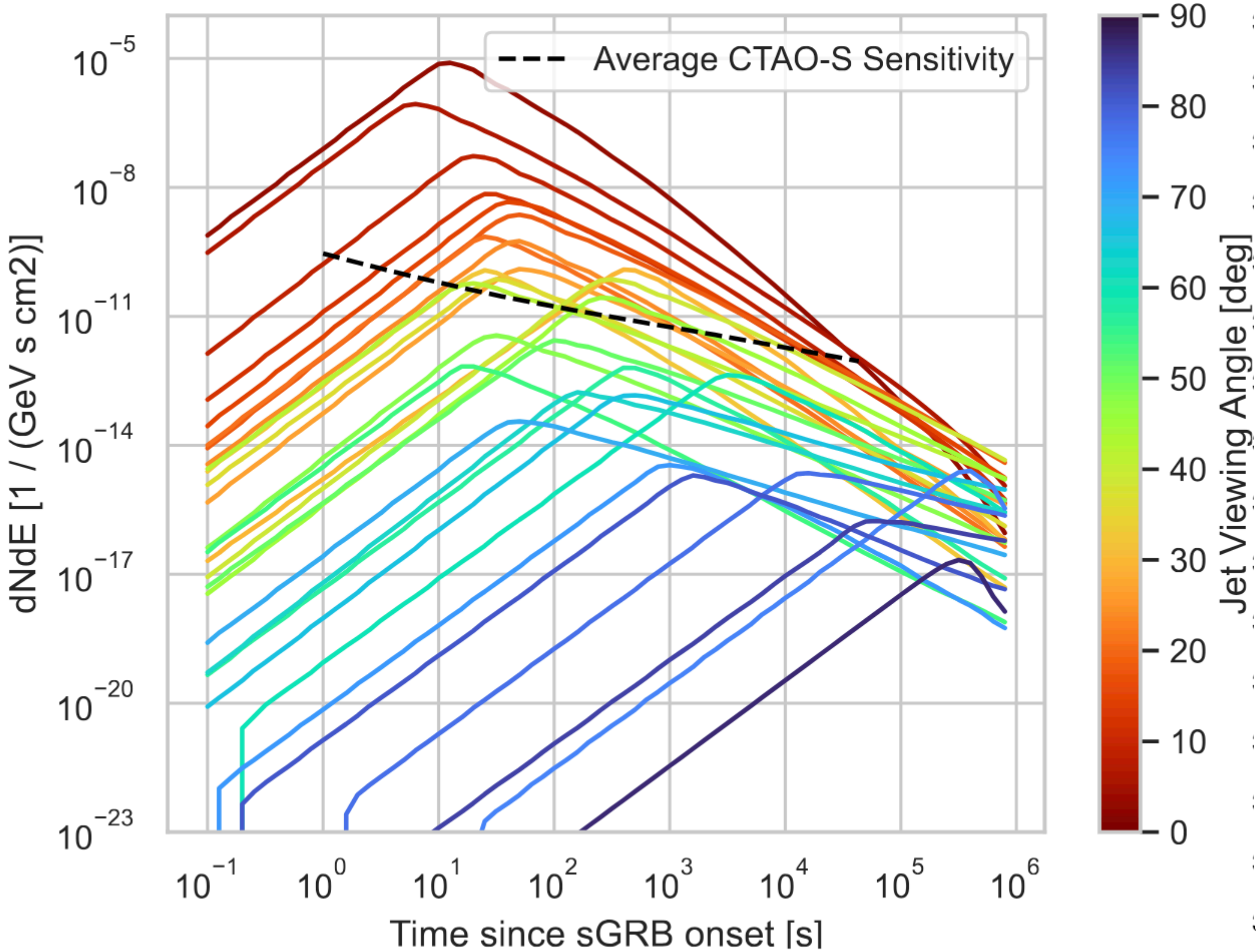



Figure 2: TeV luminosity at 11 h versus $E_{\gamma,\mathrm{iso}}$ for the sample of short GRBs simulated in this work.



Green, Patricelli, Nava, Schussler, Seglar-Arroyo, Stamerra (CTA Consortium paper), *expected Nov 2025*

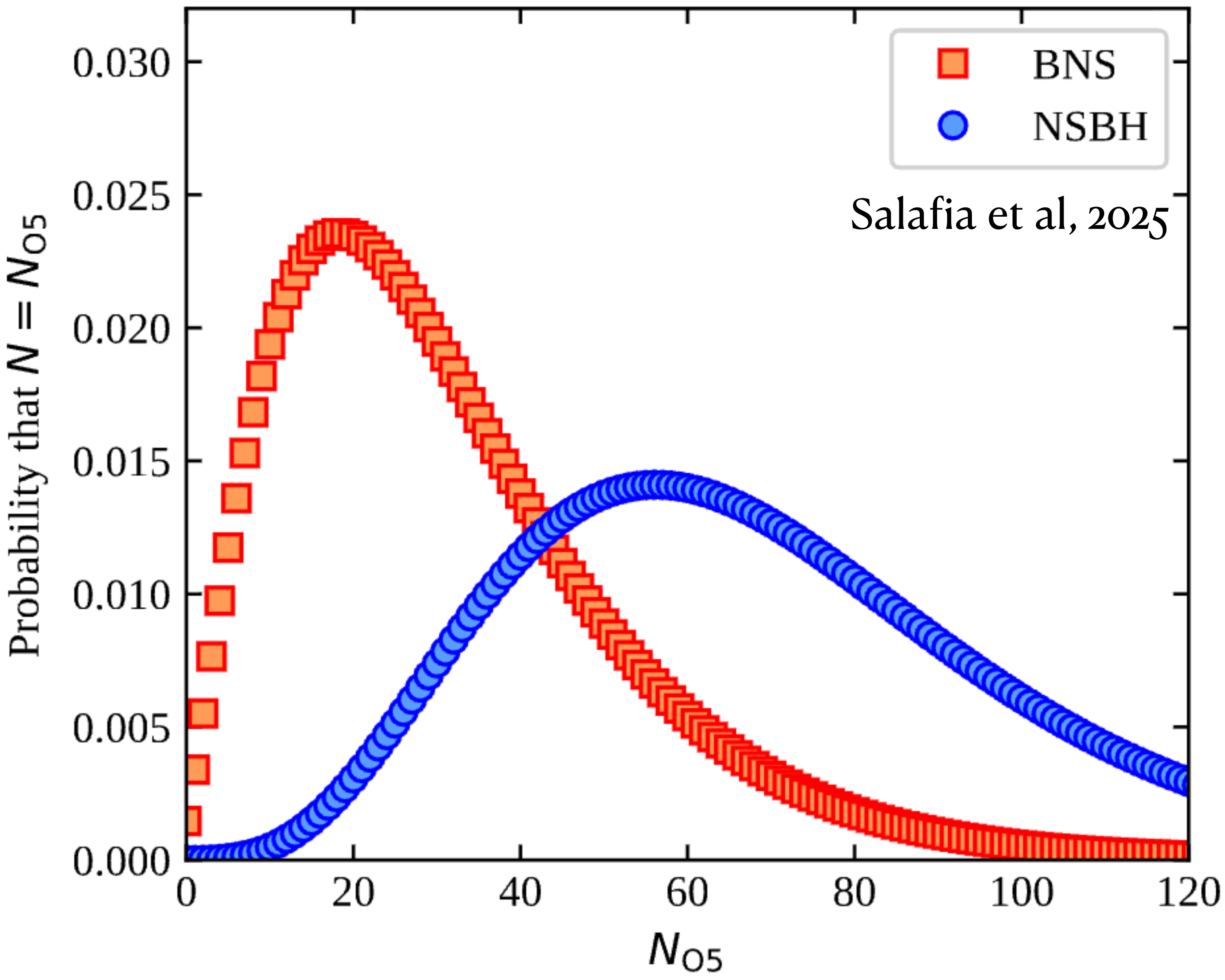
# Viewing angle to LC connection




**Green, Patricelli, Nava, Schussler, Seglar-Arroyo, Stamerra (CTA Consortium paper),** ***expected Nov 2025***

# Updated O5 BNS/BBH prospects

New estimates using O4 results so far point to $N_{\mathrm{BNS,O5}} = 28^{+44}_{-21}$ $N_{\mathrm{NSBH,O5}} = 65^{+61}_{-38}$



# Latest LVK observing run planning