Real-time analysis detection methods for the Cherenkov Telescope Array

Ambra Di Piano

with A. Bulgarelli, V. Fioretti, N. Parmiggiani, L. Baroncelli, G. Stratta, G. De Cesare

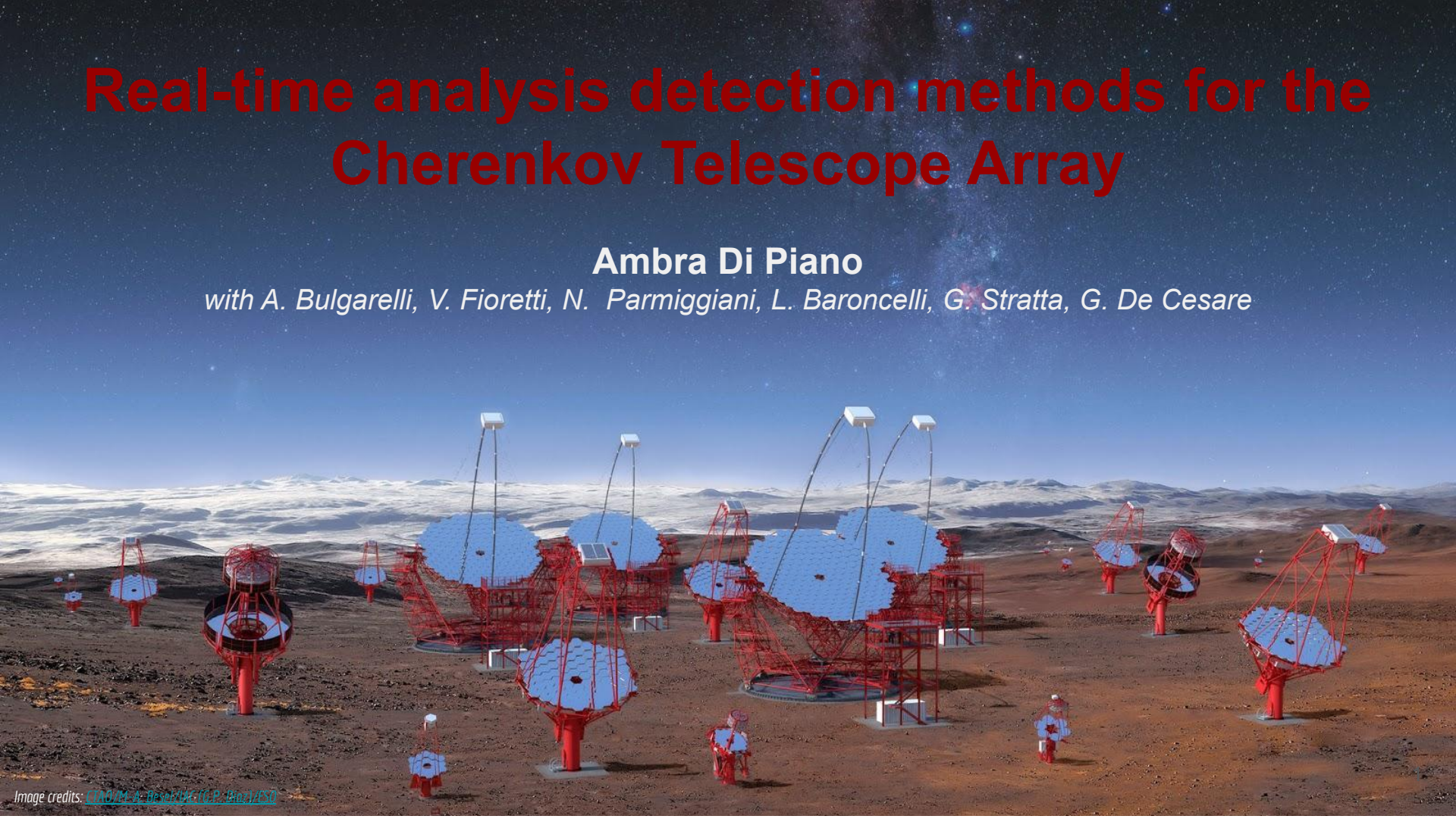


Image credits: CTAO/M.-A. Besel/M. Gil/P. Bar/ESO

The Cherenkov Telescope Array

MAGIC

CTA North
La Palma, Spain

CTA South
Paranal, Chile

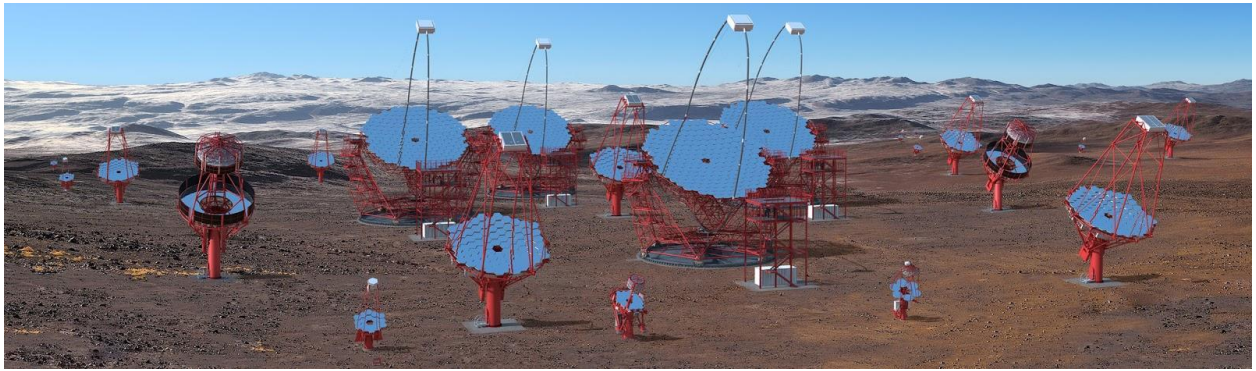
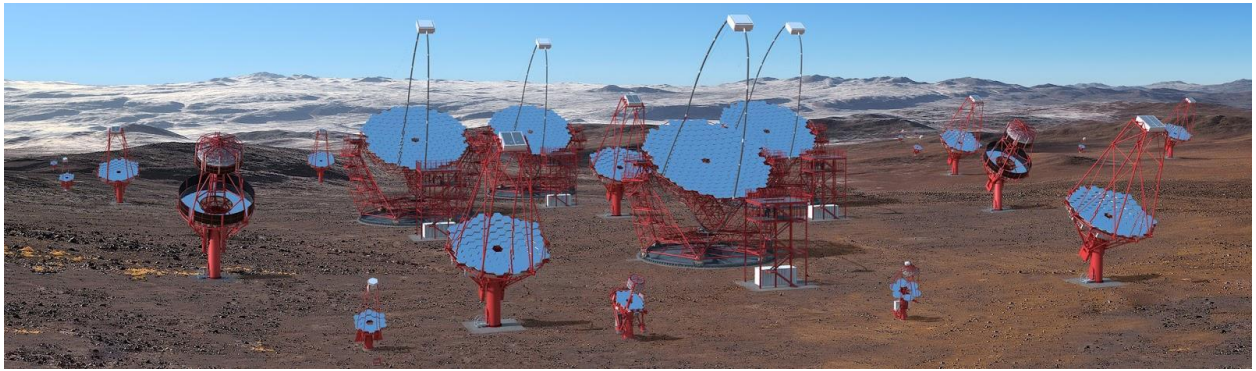


Image credits: Gabriel Pérez Diaz (top), Gabriel Pérez Dia and Marc-André Besez (bottom)

The Cherenkov Telescope Array

LST-1

CTA North
La Palma, Spain



CTA South
Paranal, Chile

Image credits: Gabriel Pérez Diaz (top), Gabriel Pérez Dia and Marc-André Besez (bottom)

The Cherenkov Telescope Array

CTA will pair superior **sensitivity** with better performances in terms of **angular and energy resolution** with respect to existing IACTs. It will also have a wider **energy range** and a far larger **field of view (FoV)**.

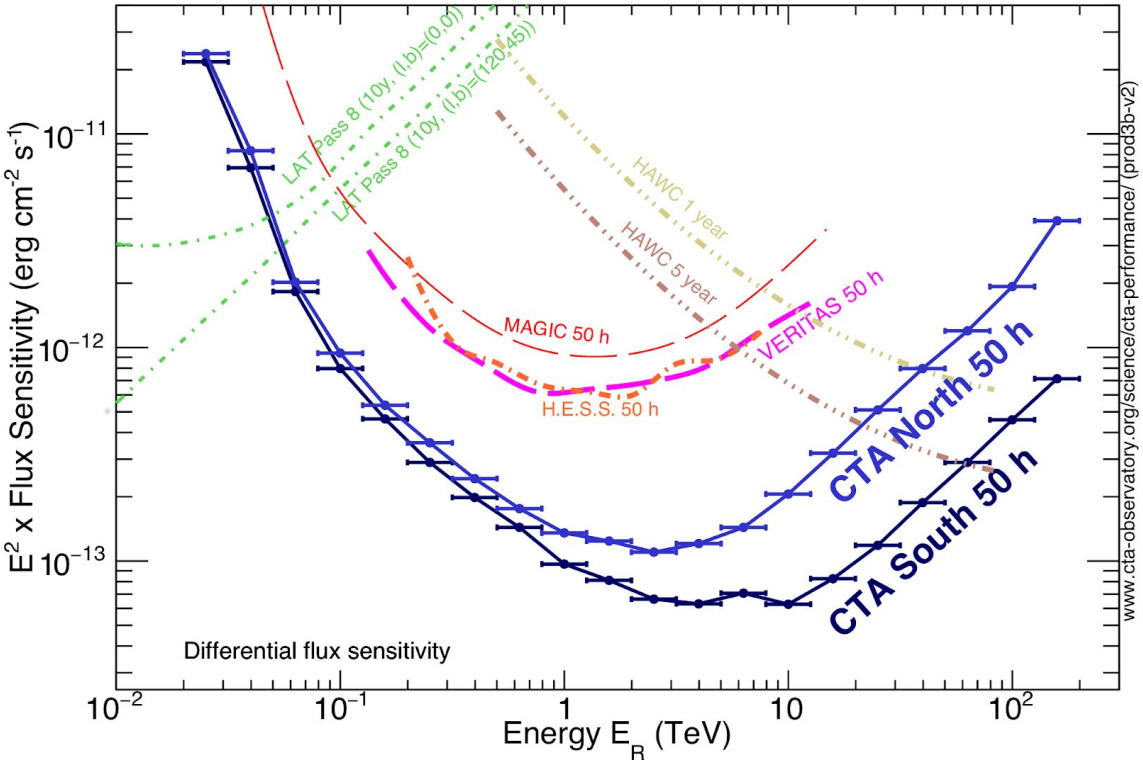


Image credits: CTA Collaboration

The Real-Time Analysis

SAG: Science Alert Generation → an **on-site automated software system** that analyses data during observations.

Provided by the SAG

- **RECO:** Low-Level Cherenkov data reconstruction;
- **DQ:** Online Data Quality of reconstructed Cherenkov data, to produce data quality summaries, data quality warnings and alarms;
- **DVR:** Data Volume reduction additional selection.

- **SCI: High-Level Analysis**
  - Science Monitoring → science quick looks (i.e. skymaps, lightcurves) for the Support Astronomer;
  - Science Alert Generation → issuing of science alert.

The Real-Time Analysis

We must

- Search for **transient** phenomena on timescales **from 10 seconds to 30 minutes**
- Issuing of candidate science alerts **within 20s of latency** since data becomes available to the system (5 of which are allocated to the SAG-SCI module)
- Perform first high-level analysis with sensitivity **not worse than half** of the CTA nominal sensitivity

The CTA-SAG is a key system in the context of **multi-messenger** and **multi-wavelength** astronomy.

SAG-SCI ‣ High-level data analysis

Workflow

- Simulated incoming stream of DL3
- If required we run a **blind search**
- We evaluate **flux** and **significance** of the detection
  - which technique?
  - which tool?

Techniques:
- full-fov max. likelihood
- on/off reflection
- on/off wobble

Science tools:
- ctools
- gammapy
- rta photometry tool by S. Tampieri

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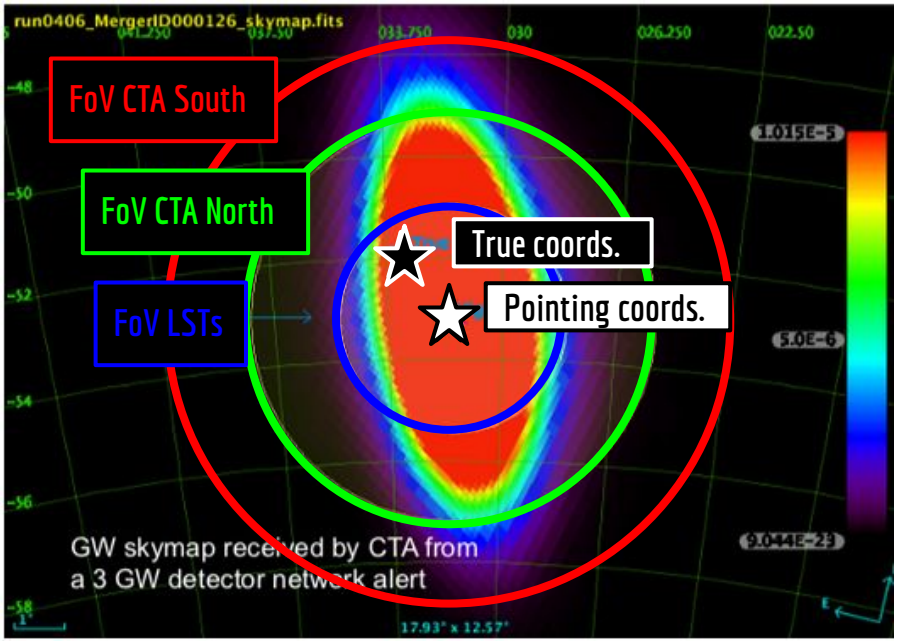
Follow-up from an external alert

Simulations (trials = 10^4):

- BNS merger → from **GW COSMoS** database by B. Patricelli
- GRB afterglow → by L. Nava for the **POSyTIVE** project
- EBL absorption → Gilmore et al. 2012

The **Extragalactic Background Light (EBL) absorption** is due to the interaction of VHE photons with the diluted and redshifted (as well as reprocessed) light of resolved, unresolved and diffuse sources in the universe.



GRB190114C lightcurve credits: Acciari et al. (2019)

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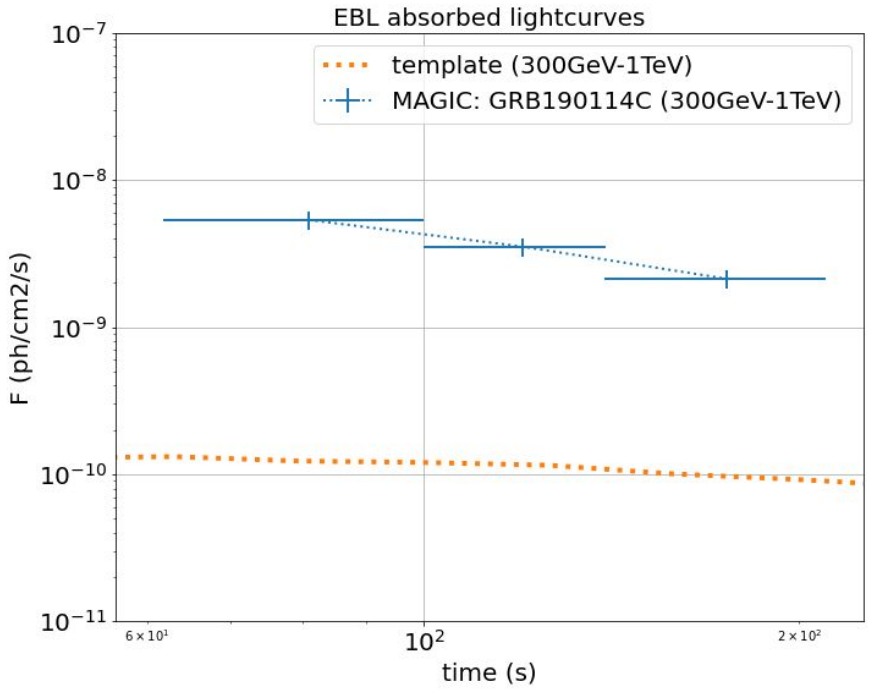


GRB190114C lightcurve credits: Acciari et al. (2019)

Follow-up from an external alert

Initial assumptions

- Pointing:
  - max. localisation probability
  - localisation uncertainty ~ FoV
- CTA South full-array
  - 30 GeV - 150 TeV
- External alert
  - $t_{delay} = t_{alert} + t_{slew} = 50$ s
- RTA sensitivity
  - Degradation of the Instrument Response Functions (IRFs)

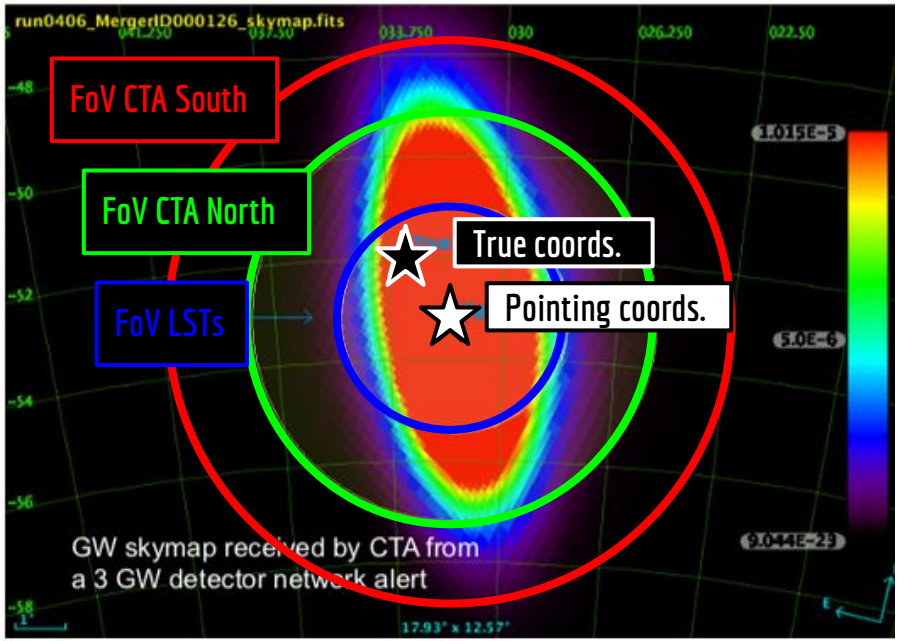
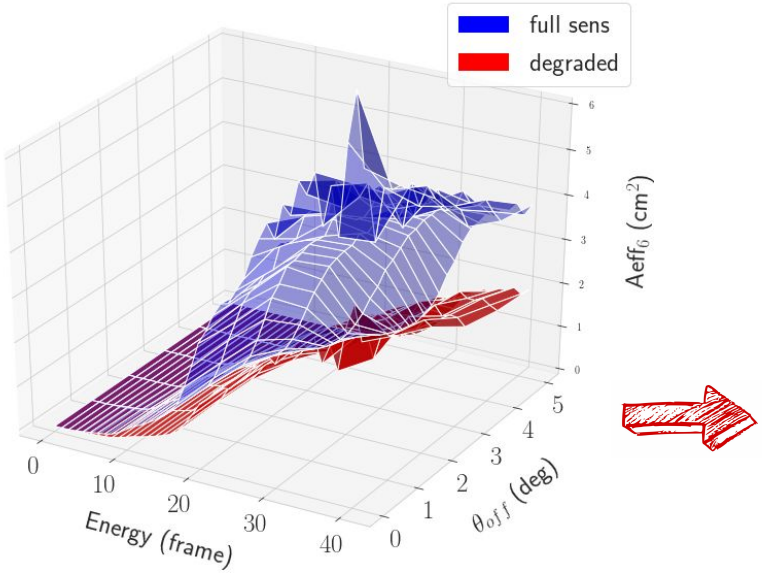
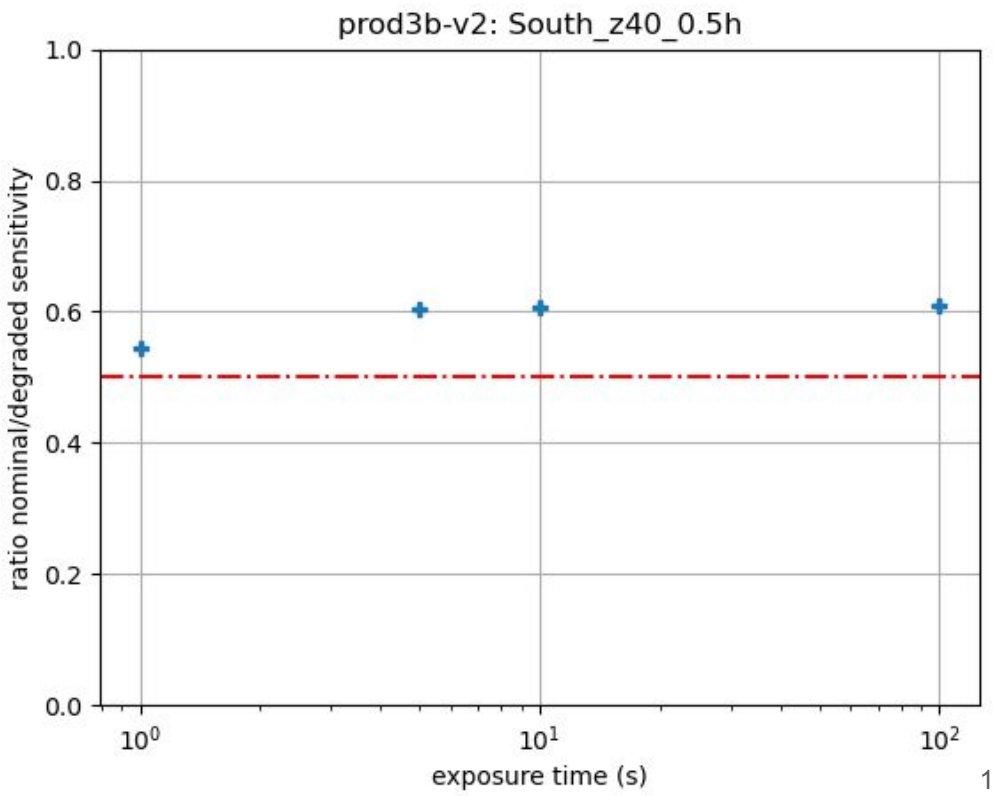


Image credits: poster by Stratta et al. (2019) presented at the first CTA Symposium

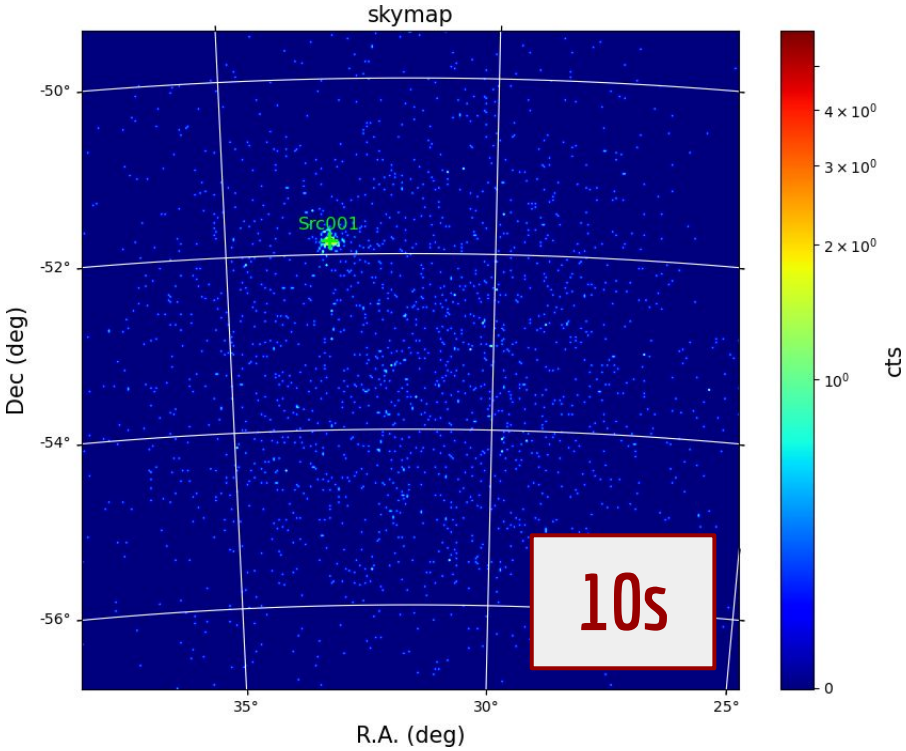
Sensitivity degradation

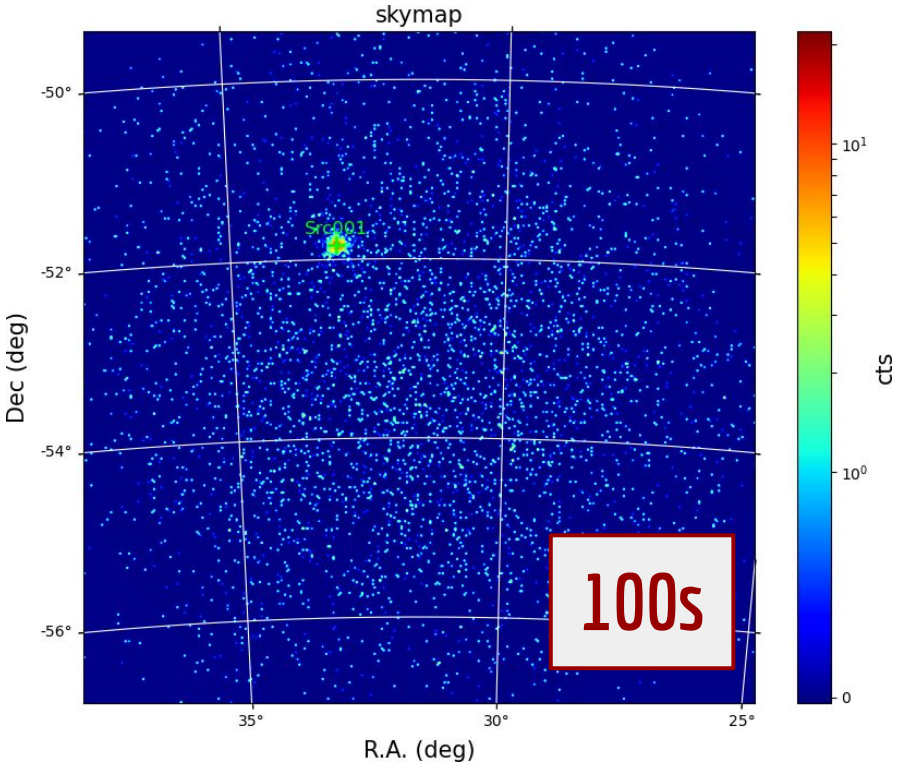




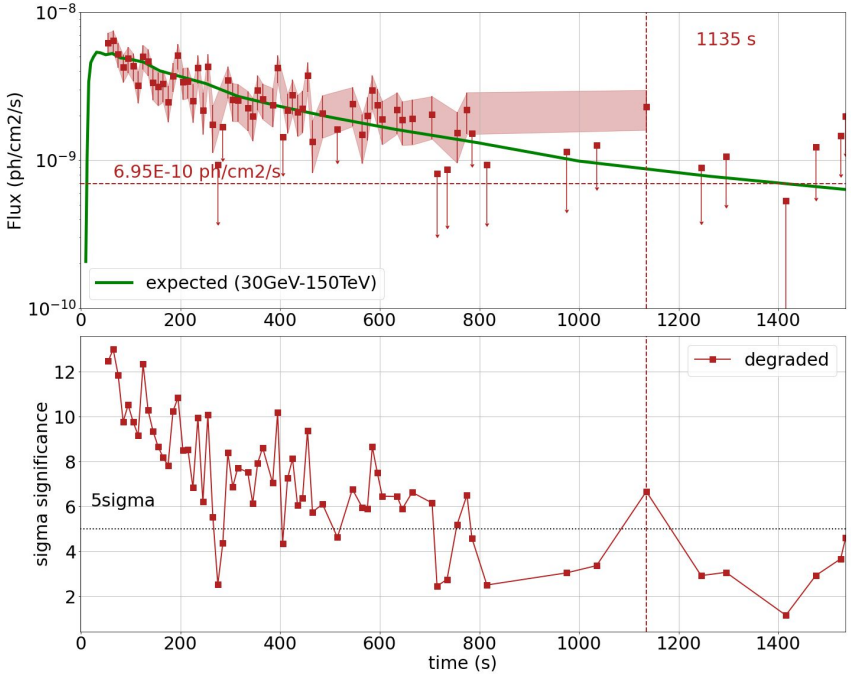
Example: CTA-South full array configuration; integral sensitivity within 30 GeV - 150 TeV energy range

Skymaps (example seed=1)

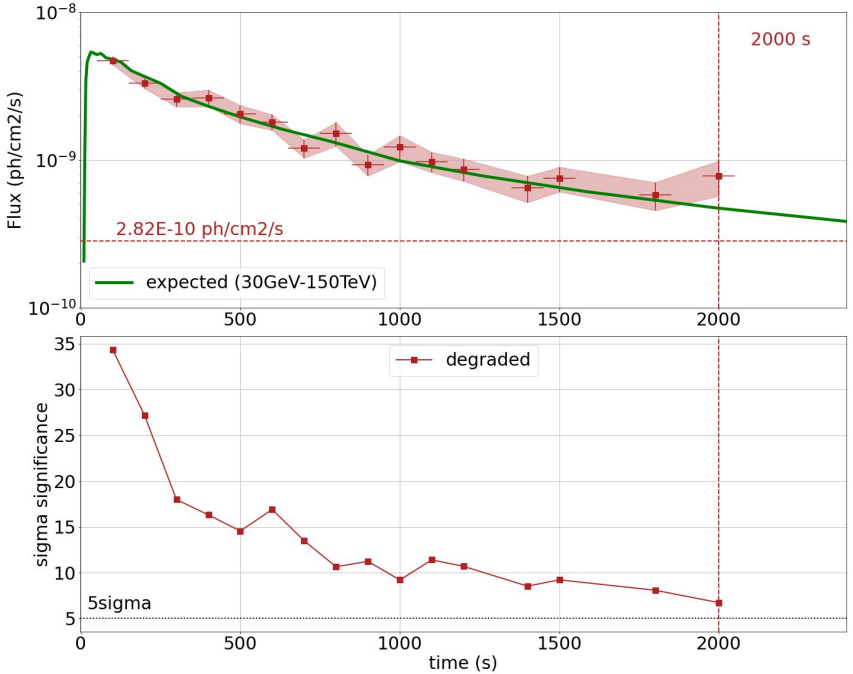




Lightcurves (example seed=1)



10s

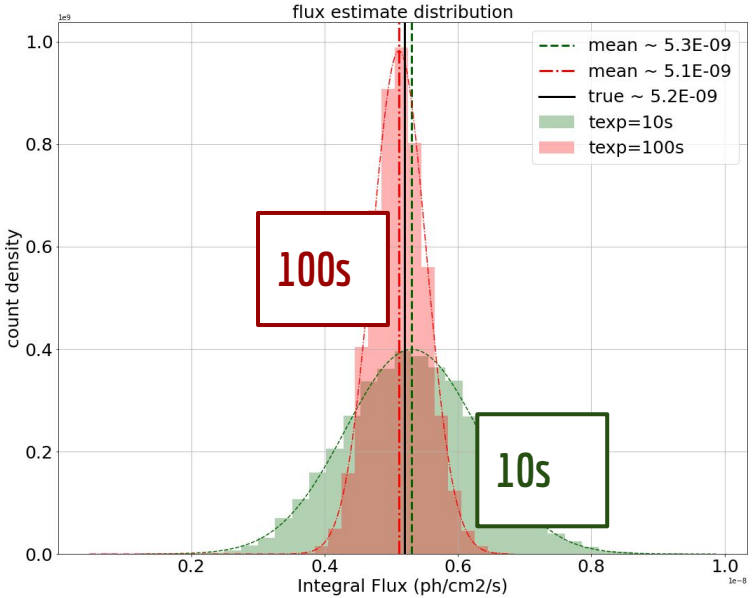


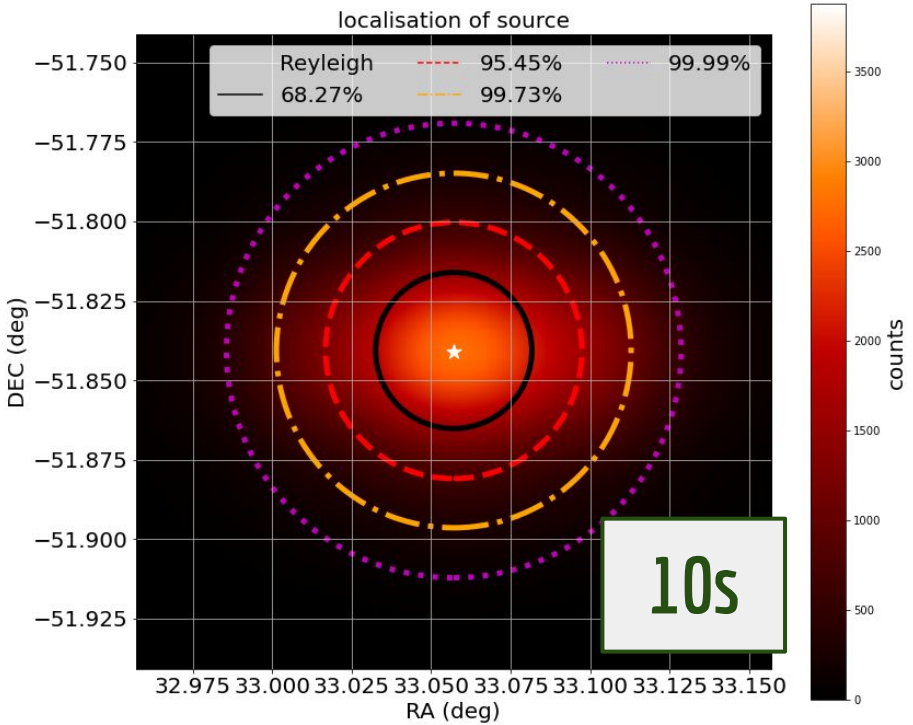
100s

Performance evaluation at very-short exposure times

- **Localisation accuracy**
  - distance between the detected candidate coordinates and the true coordinates of the source
- **Detection efficiency**
  - percentage of trials that result in positive detection
- **Detection significance**
  - we verified that $\sigma = \sqrt{TS}$ for d.o.f. = 1
- **Integrated flux**

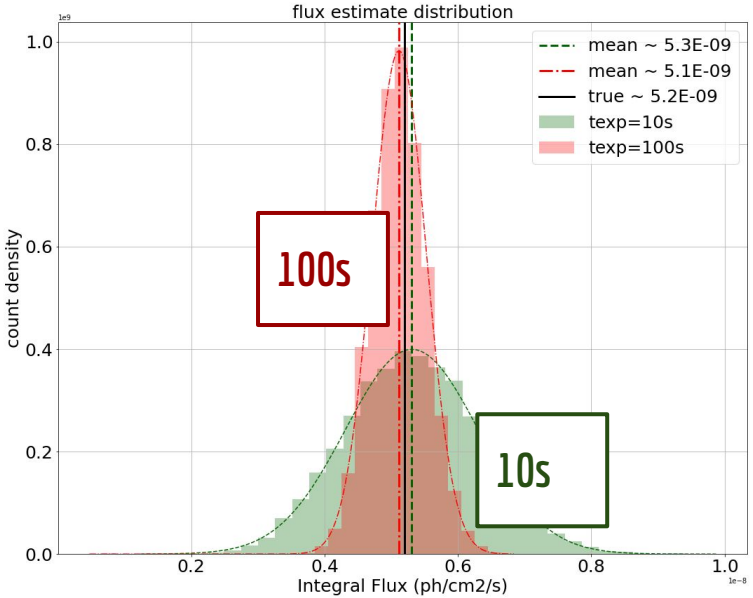
At given integrated flux - 10000 trials

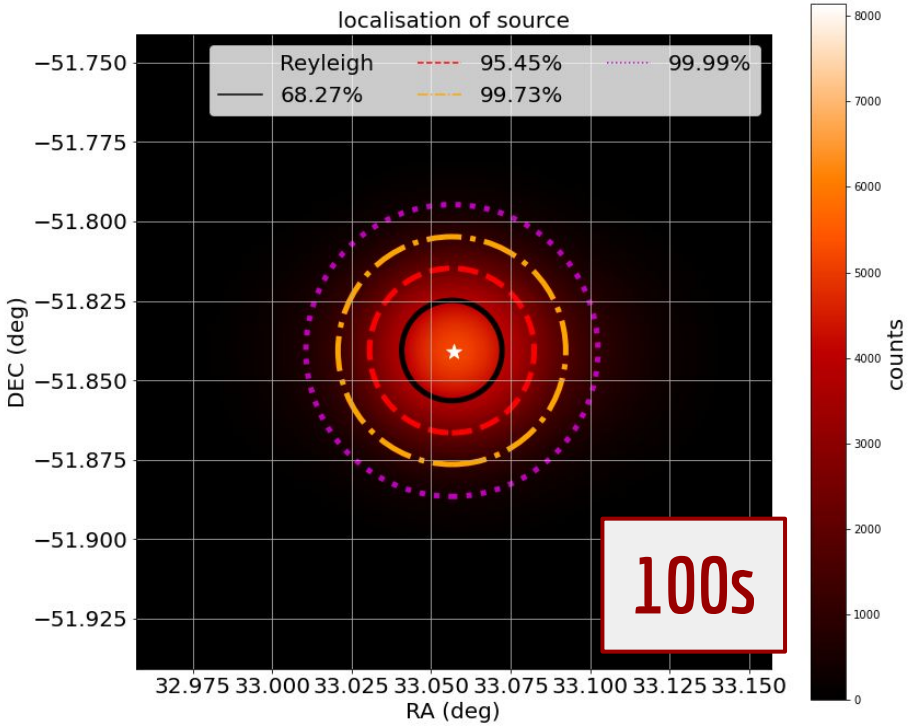




Confidence regions are drawn from a Rayleigh distribution for 1, 2, 3 and 5 Gaussian sigmas equivalent probability. 2d histogram bin size is 0.02 deg (equal to the pixel size of the skymap).

At given integrated flux - 10000 trials





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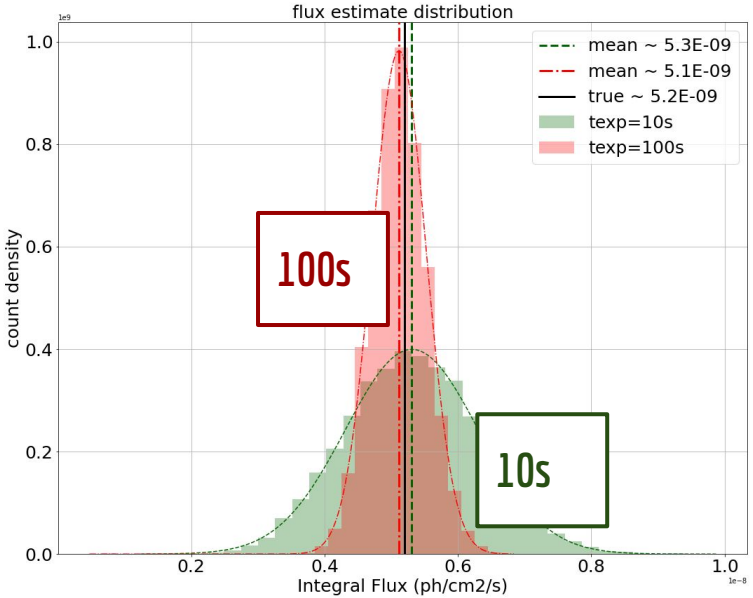
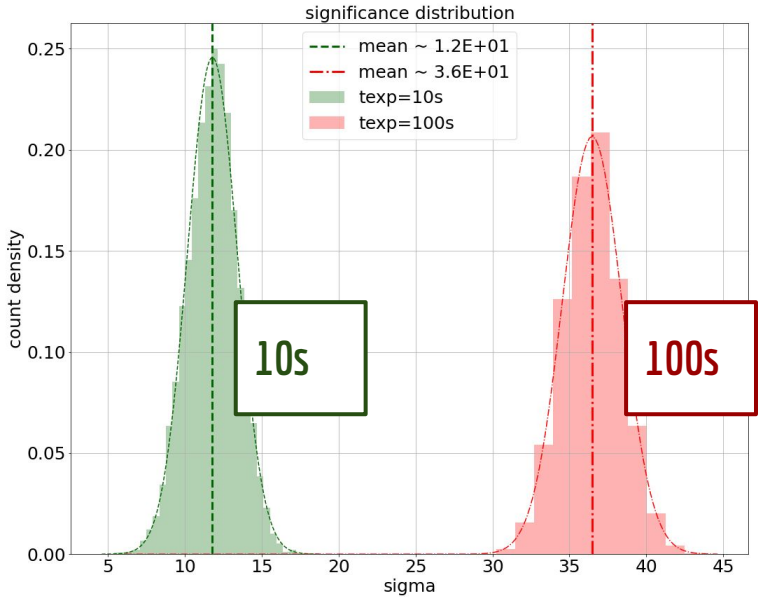
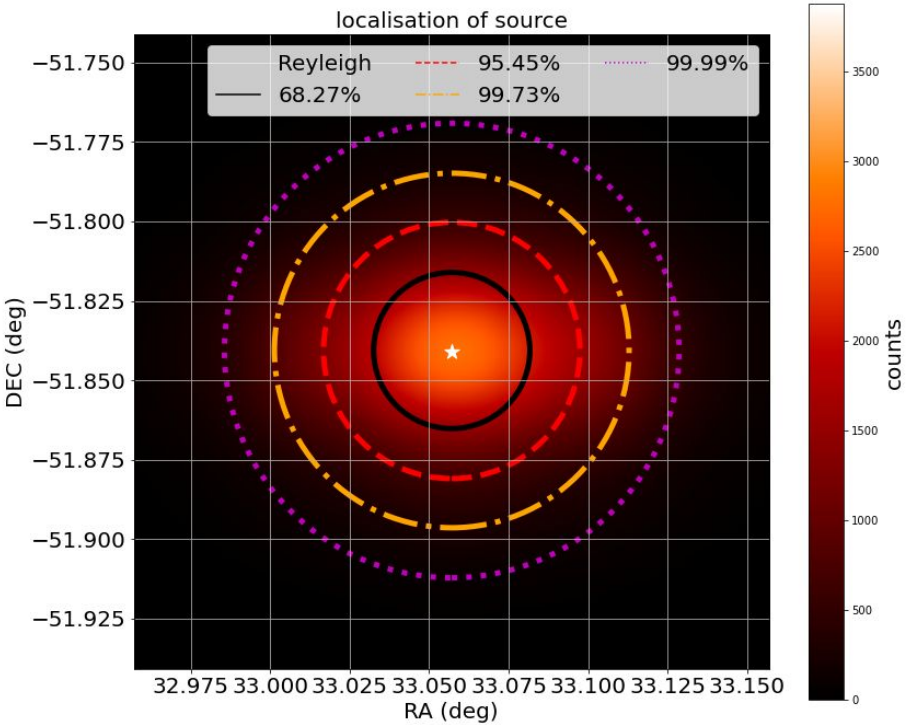
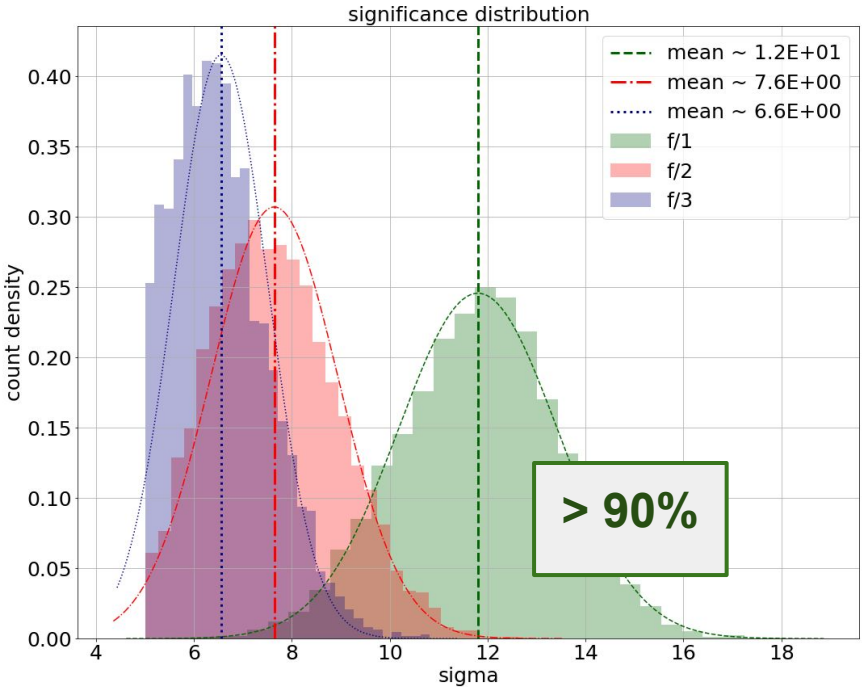




At given exposure time (10s) - 10000 trials





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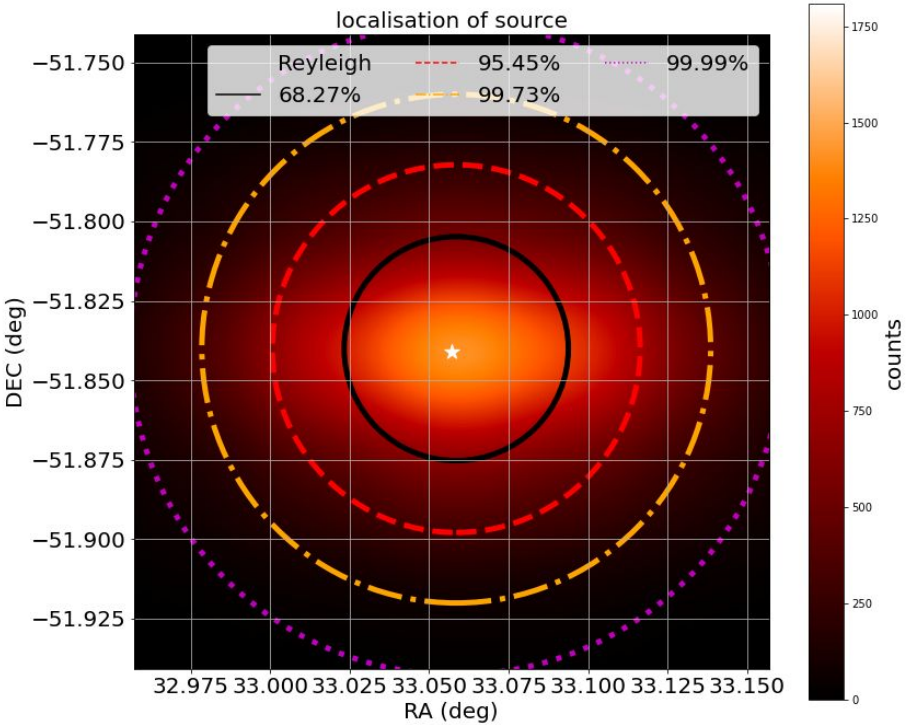

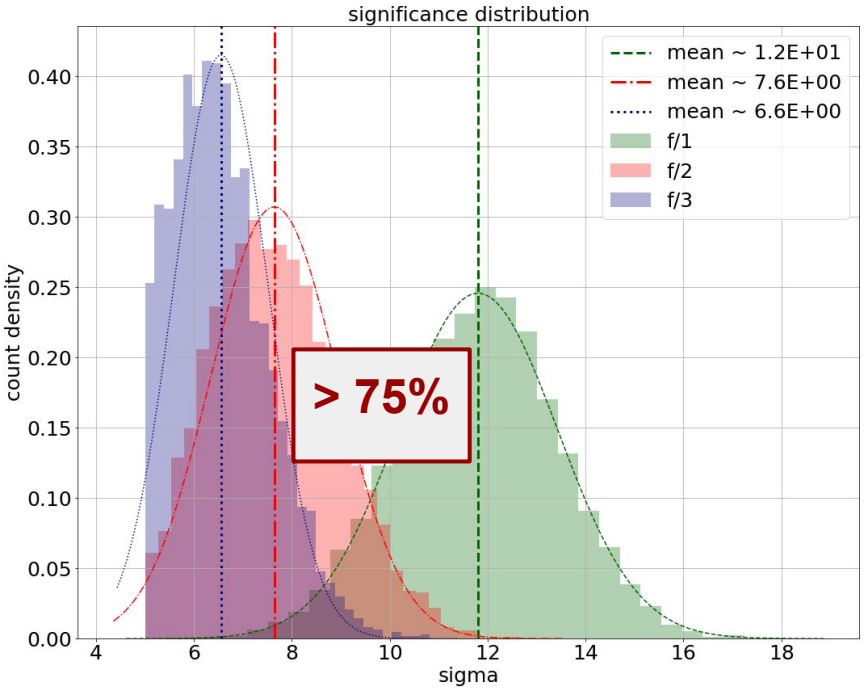

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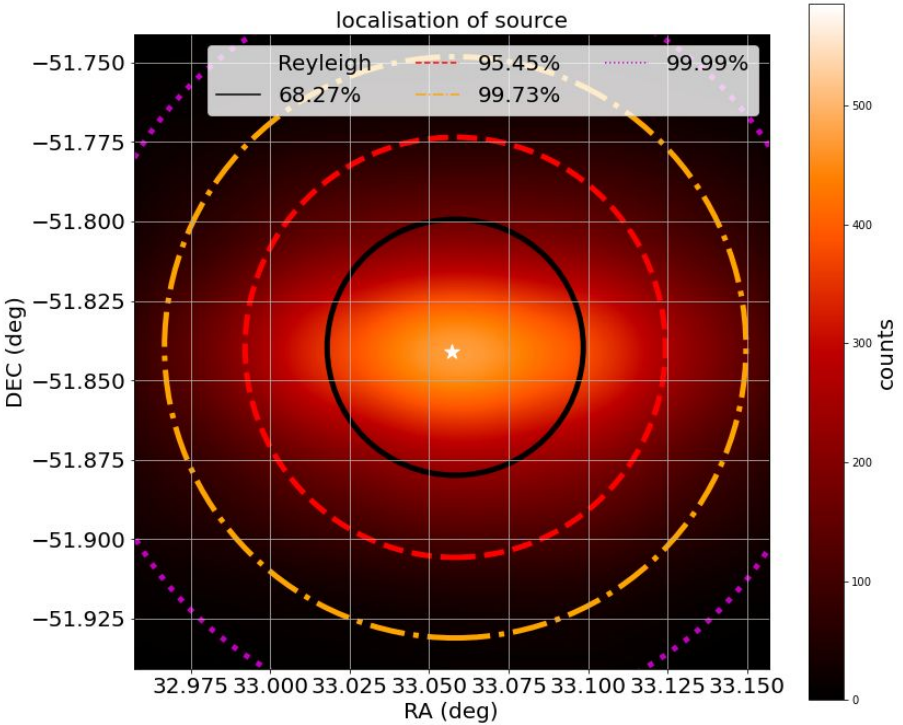

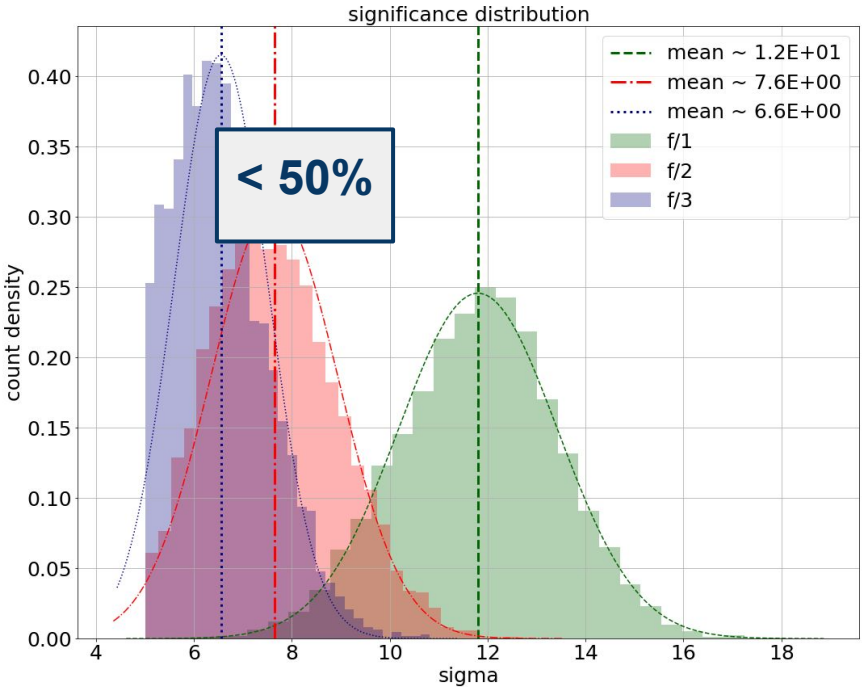

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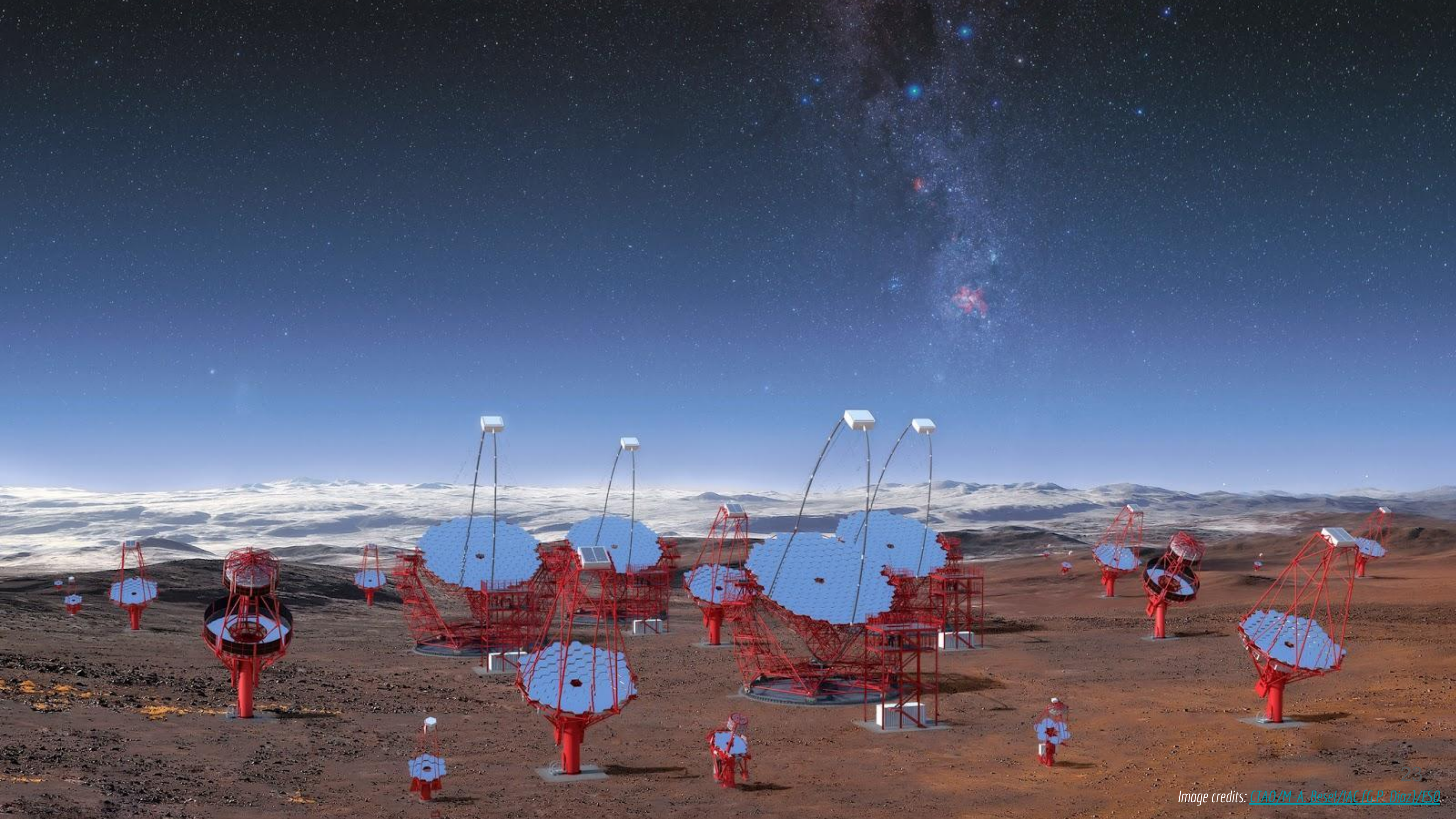
Further studies

- **Ongoing exploration of the parameter space**
  - delay of 50, 100, 150 seconds
  - integrated flux scaled 1/1, 1/2, 1/3
  - off-axis angle of 2, 3, 4 deg from pointing
- **Other parameters**
  - skymap pixel size and smoothing
  - blind-search acceptance threshold
  - different degradation of IRFs
  - different array configuration and energy range
- **Other studies**
  - techniques: full-fov max. likelihood, on/off reflection and wobble
  - tools: ctools, gammapy, rta photometry tool
- **Future?**
  - exposure times from 10 s to 30 min
  - different source models
  - different source classes



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