Study of the Fermi-LAT sensitivity to Gamma-Ray Bursts in the GW follow-up pipeline

Lorenzo Scotton

Rocca di Sant'Apollinare, 16 May 2019

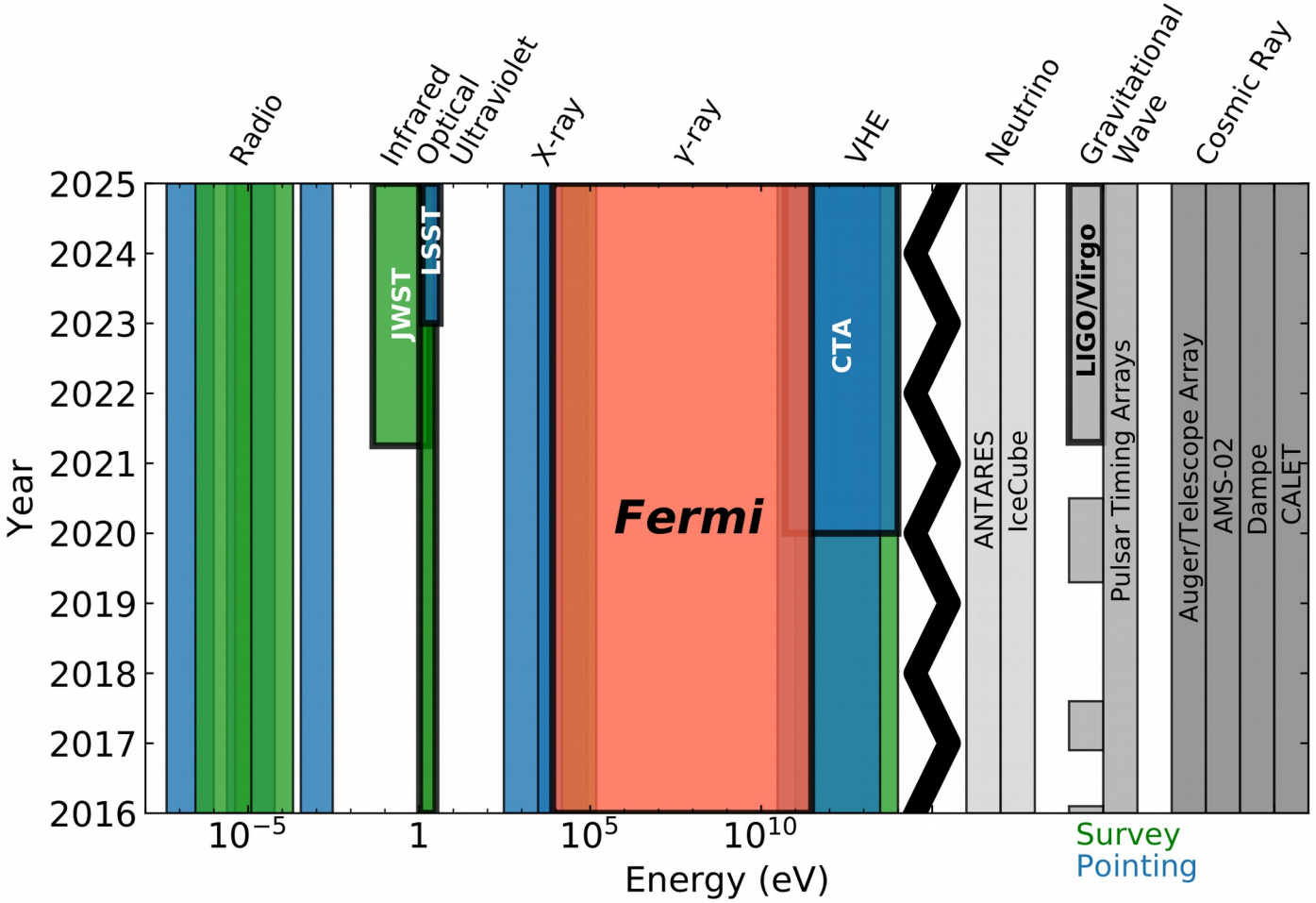
UNIVERSITÀ DEGLI STUDI DI TORINO

INFN Istituto Nazionale di Fisica Nucleare SEZIONE DI TORINO

Multimessenger astronomy

Studying the Universe via **different messengers**:

- **Photons** (*Fermi, Swift, Zwicky transient facility, ...*)
- **Neutrinos** (*Ice-cube, Antares*);
- **Gravitational Waves** (*LIGO/Virgo*)
- **Cosmic rays** (*Auger, ...*).



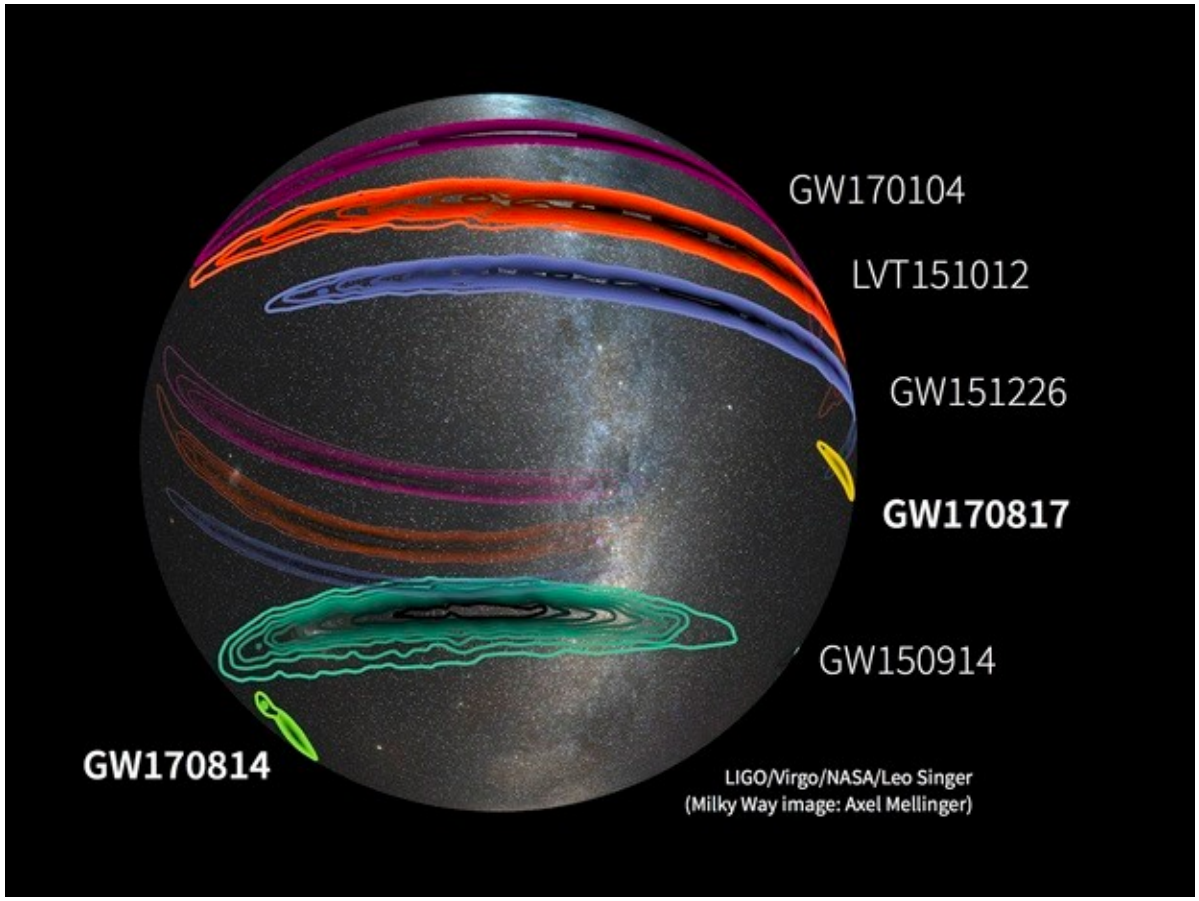
Energy range covered by *Fermi* in comparison with other present and future experiments

Gravitational Waves

11 GW events - *LIGO/VIRGO Collaboration* - first two observing runs (O1, O2):

- **10 BH - BH**: e.g. GW150914 (2017 Nobel prize);
- **1 NS -NS**: GW170817;

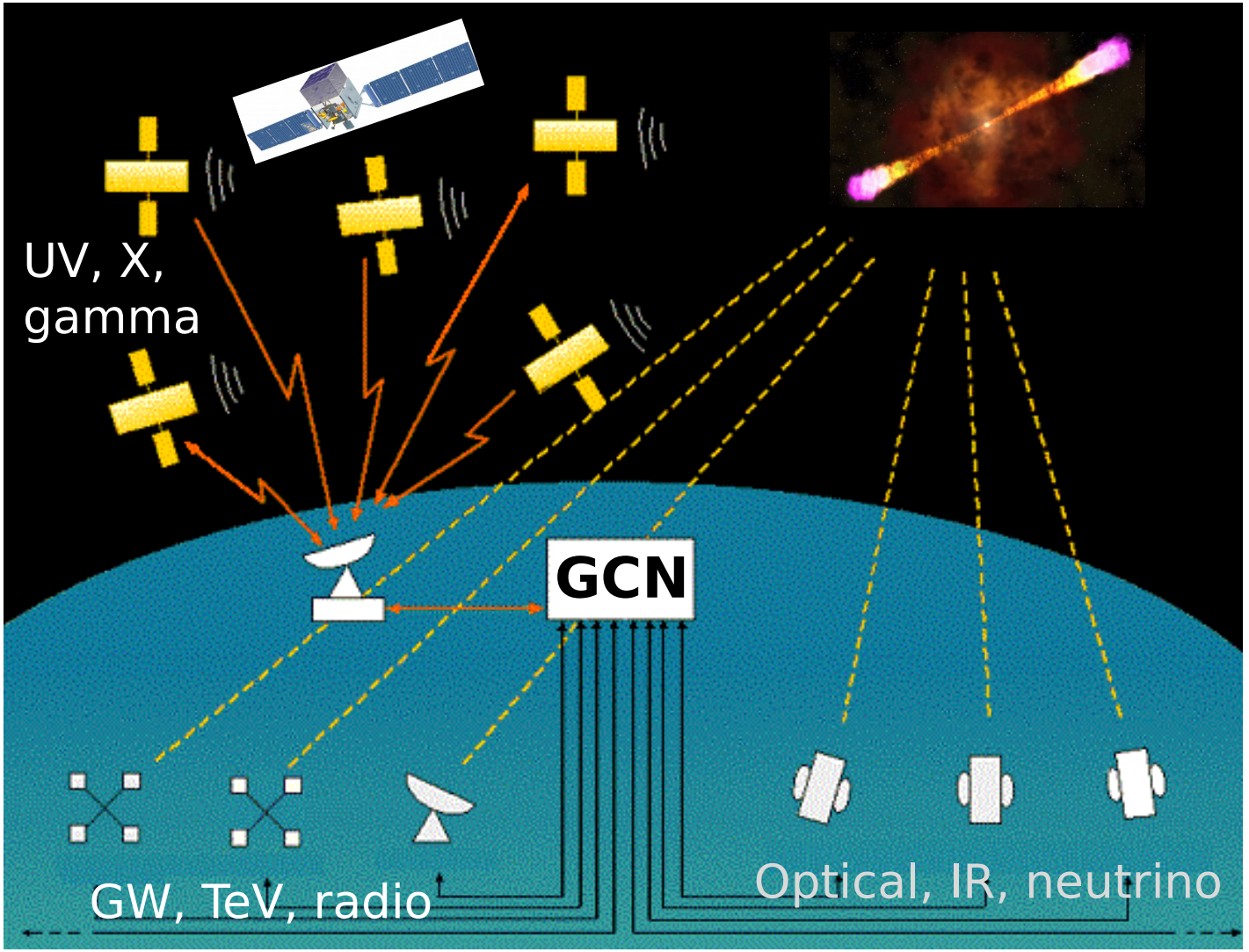
O3 (from 1 April 2019, for 1 year) – so far **8 candidates**:
5 BH-BH, **1 NS-NS**, **1 NS-BH**, **1 Terrestrial**
→ analysis is ongoing!



The GCN Network

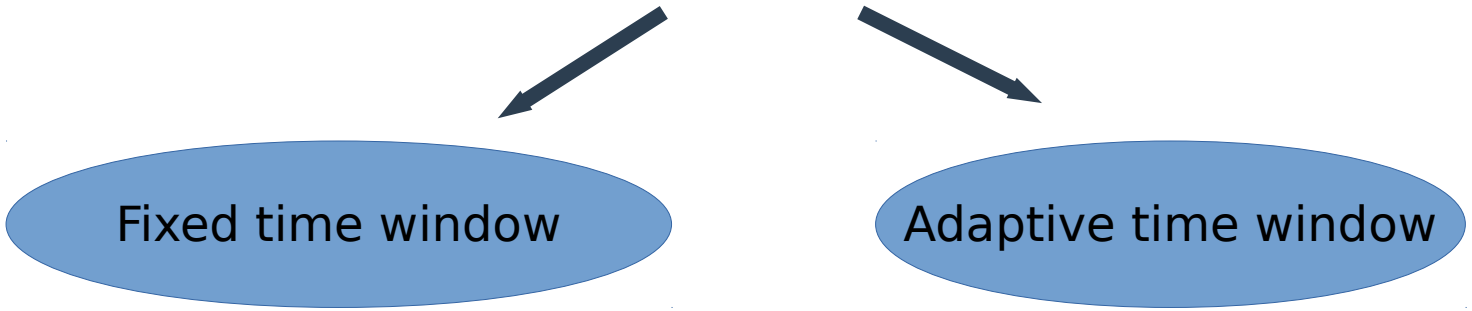
GRB Coordinates Network:

- **the real-time distribution** of GRB locations, images, spectra, lightcurves;
- the **distribution of follow-up observations.**



Fermi-LAT pipeline

The pipeline searches for high-energy gamma emission:



Starts at the time of the LIGO trigger

Maximes the time window for each pixel to get the highest possible exposure

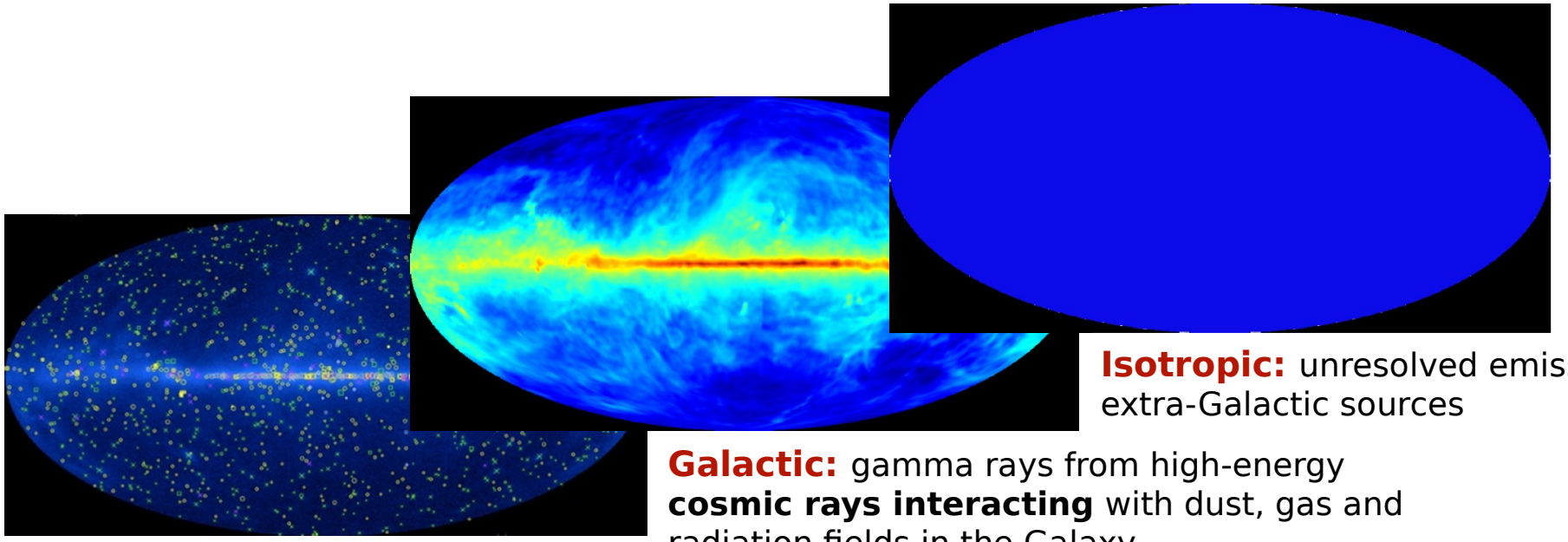
→ the analyses quantify whether the existence of a new source is statistically warranted (maximum likelihood);

→ In case of non-detection the flux of the source is constrained (**upper-limit**).

Fermi-LAT data analysis

Maximum likelihood technique, with a baseline likelihood model including:

- **all sources** (point-like and extended) from the LAT source catalog;
- the **Galactic and isotropic diffuse templates** provided by the Fermi-LAT Collaboration.



Isotropic: unresolved emission from extra-Galactic sources

Galactic: gamma rays from high-energy **cosmic rays interacting** with dust, gas and radiation fields in the Galaxy

5000+ γ-ray sources: several source classes, including AGN, PSRs, SNR

Fermi-LAT data analysis

The significance of the null-hypothesis (no GRB in the model) is estimated with the Test Statistic (TS):

$$TS = -2 \log (L_0/L_1)$$

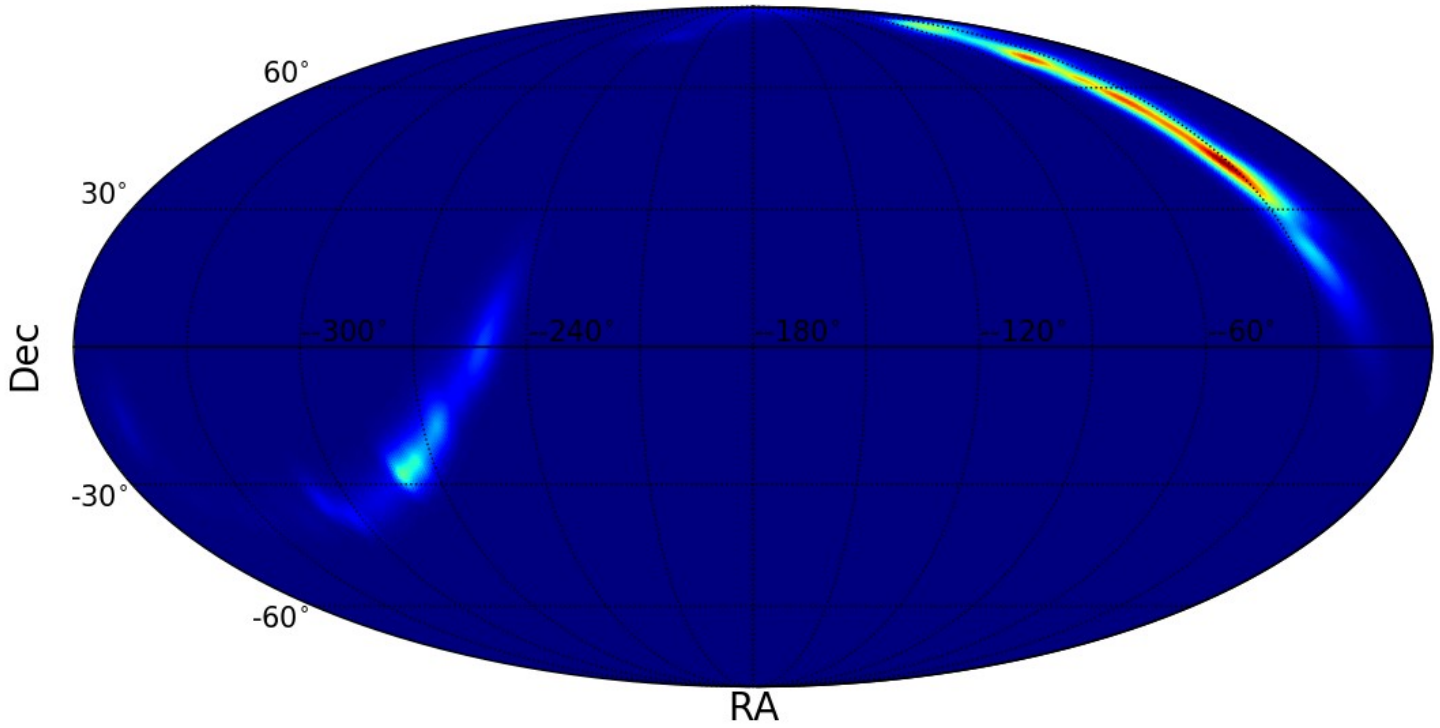
Likelihood of the data given the **model without GRB**

Likelihood of the data given the **model with the GRB**

TS = 25 ↔ 5σ (probability of 3×10^{-7} of rejecting erroneously the null hypothesis)

Fermi-LAT sensitivity to GRBs

Estimate the minimum detected flux needed for a GRB detection in a given sky area.



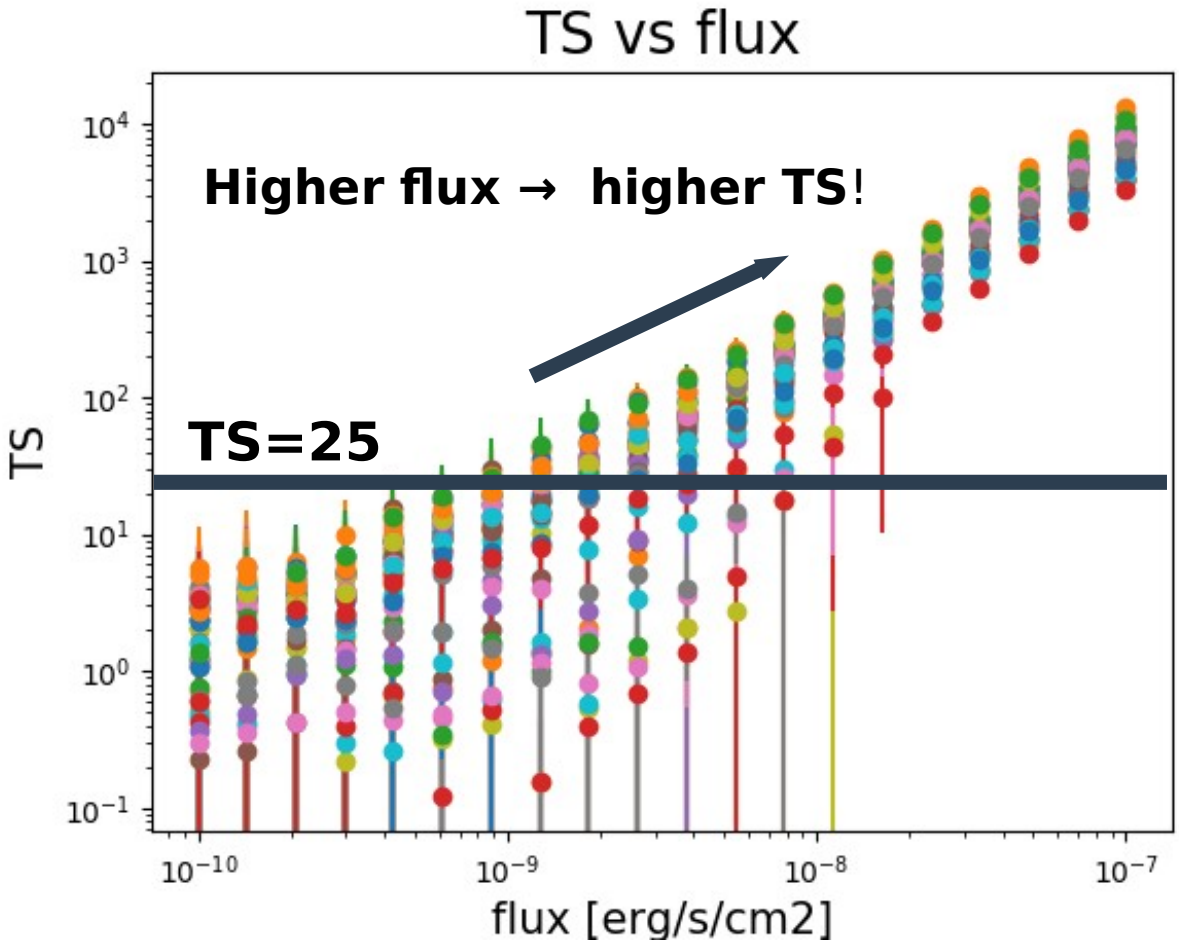
LIGO candidate G299232 (celestial coordinates)

Estimate of the LAT sensitivity

- **Fermi-LAT data** corresponding to:
  - the sky area of the LIGO event;
  - 10ks from the LIGO trigger;
- **Monte-Carlo simulations**, with the following model:
  - diffuse galactic template (gll_iem_v06.fits);
  - the isotropic template (P8R2_SOURCE_V6);
  - point and extended sources from 3FGL;
  - GRB : power-law, index -2;
- The **simulations**:
  - GRB in 44 different positions;
  - 20 different values of the GRB flux ($10^{-10} \div 10^{-7}$ erg/cm^2/s);

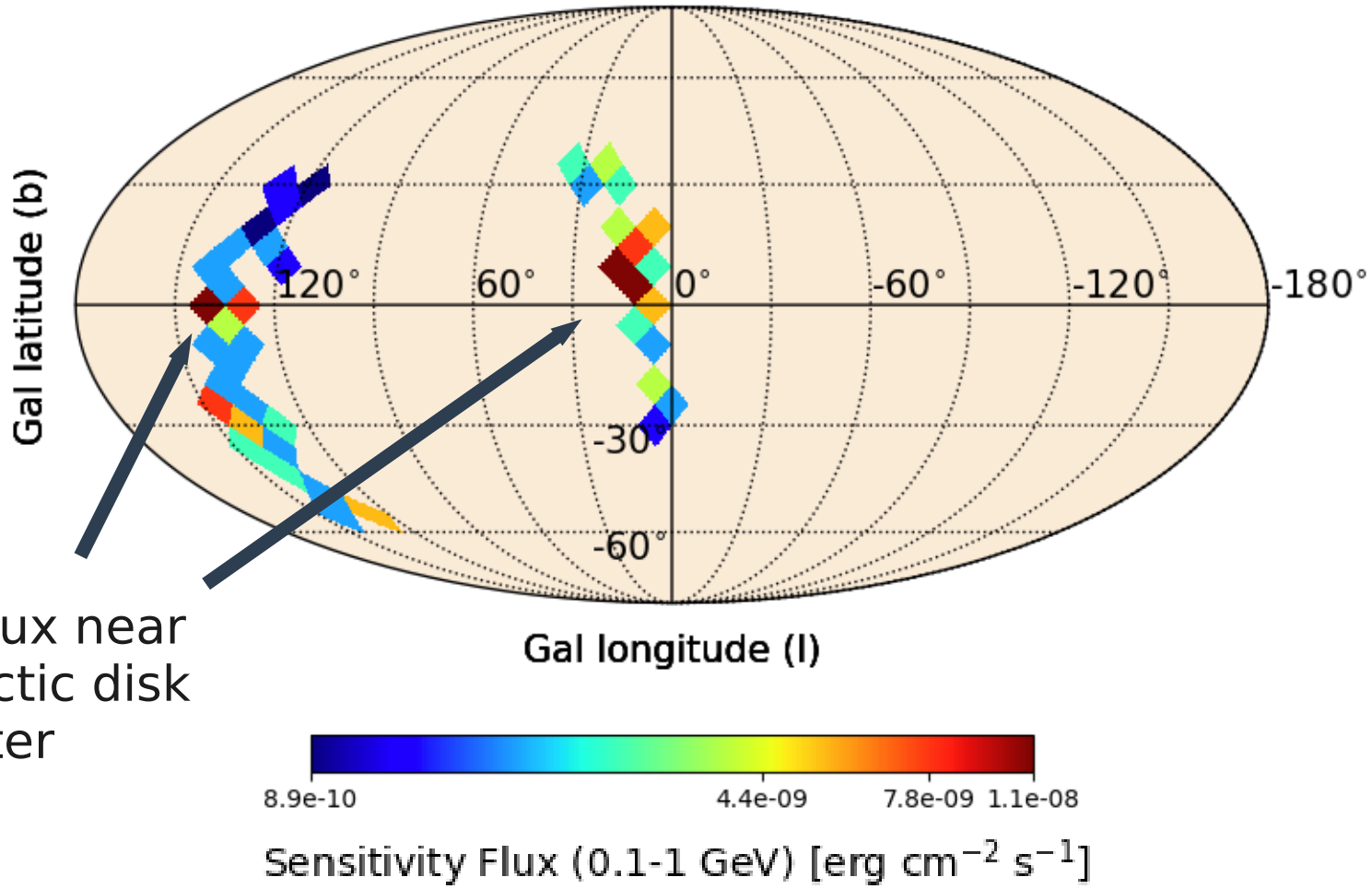
Estimate of the LAT sensitivity

- **Likelihood analysis**, to estimate the significance of the simulated photons excesses.
- Each color → one of the 44 positions within the sky area;



Estimate of the LAT sensitivity

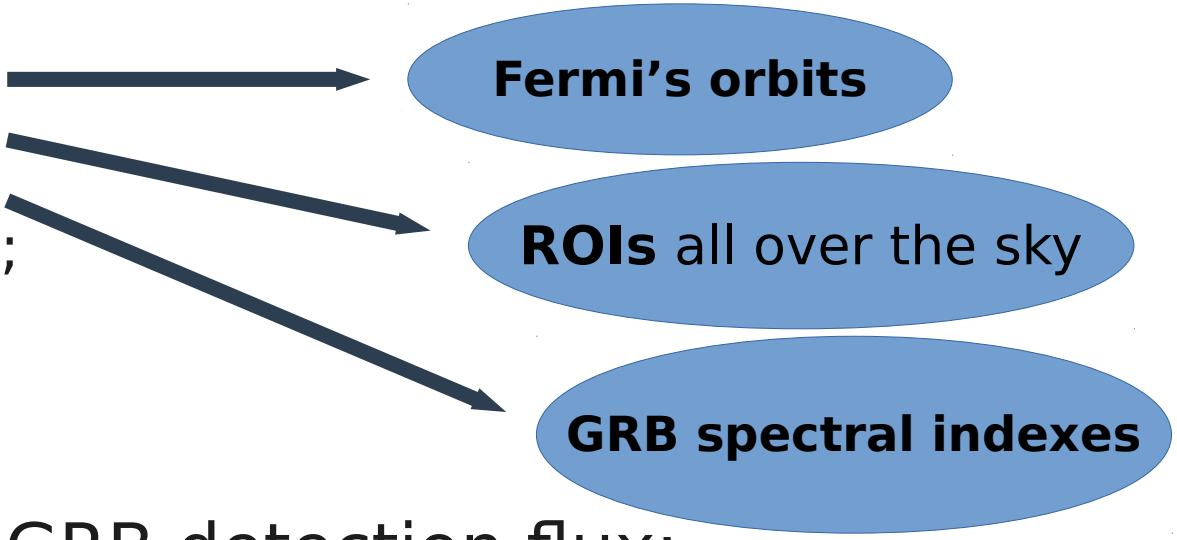
Flux threshold corresponding to the GRB detection (galactic coordinates)



Higher flux near the galactic disk and center

Future activities

- Set of **parameters**:
  - → Monte Carlo simulation;
  - → likelihood analysis;
  - → GRB detection flux;



- LAT sensitivity maps → GRB detection flux:
  - in the different sky regions;
  - for different GRB's spectral parameters;
  - as a function of the time (number of LAT orbits).

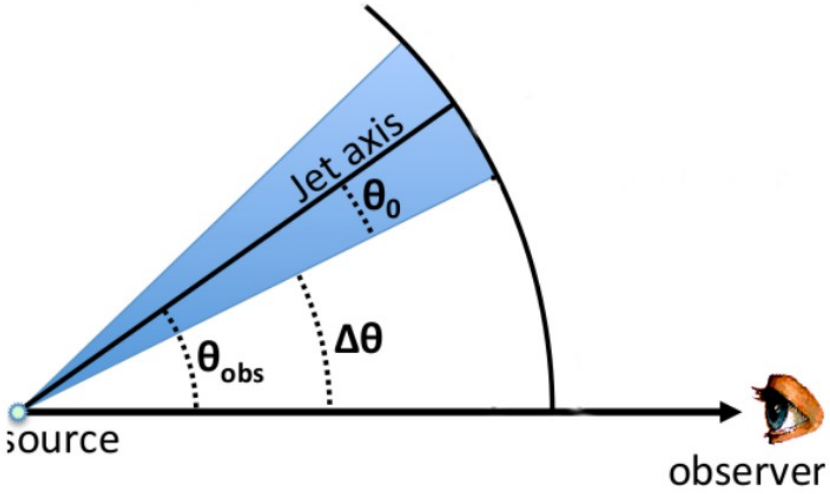
GW follow-up

S190426c : BNS (49%) → **No LAT detection** of electromagnetic counterpart.

Flux upper-limits > sensitivity

GRB is seen off-axis

Constraints on the off-axis emission!



Off-axis angle

Lazzati 2017
Song 2019