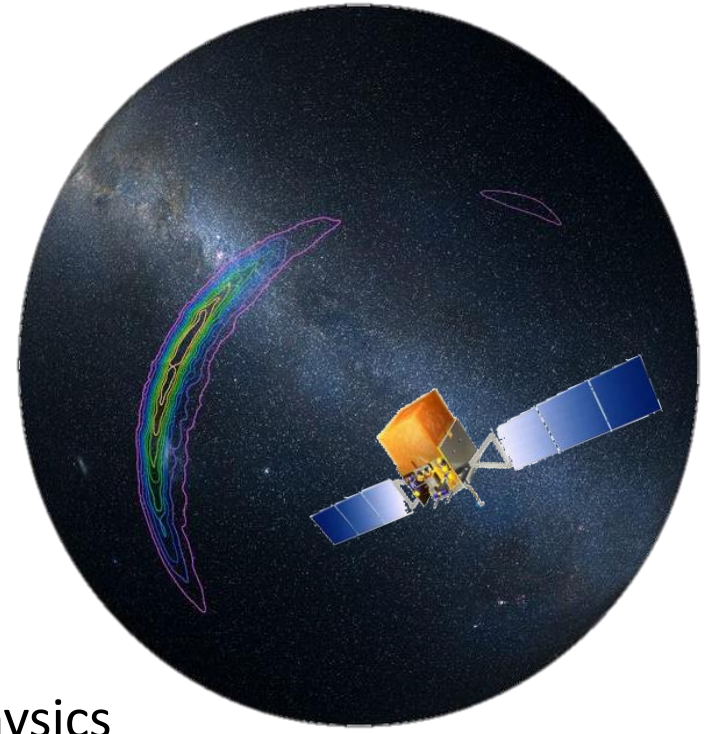
The Threshold for Fermi-LAT GRB Detection in Gravitational Wave Localization Area

First Perugia Gravi Gamma Workshop, 16-18 May, 2019

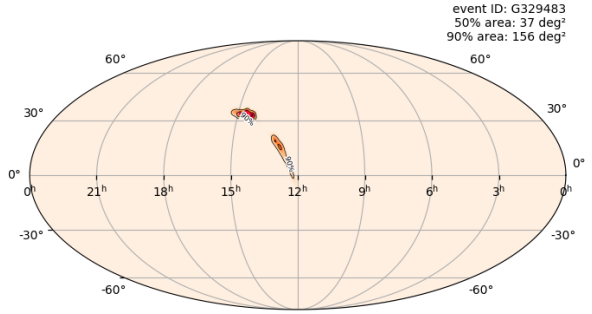


Miloš Kovačević
Institute for nuclear physics
Perugia
presentation

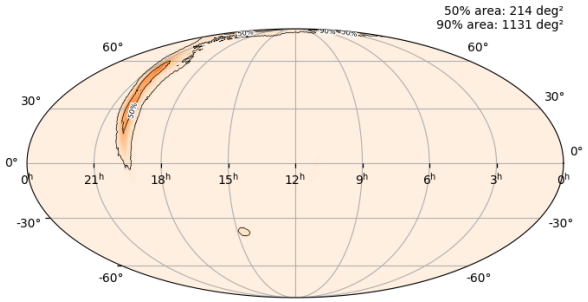
Giacomo Vianello
Lorenzo Scotton
Nicola Omodei
Rupal Basak
et al.
the topic

GW localization sky area (90%): 100 – 10.000 deg²

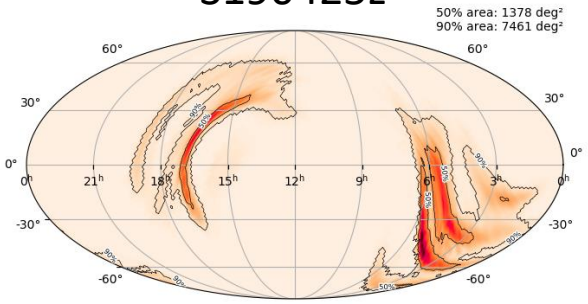
S190412m



S190426c

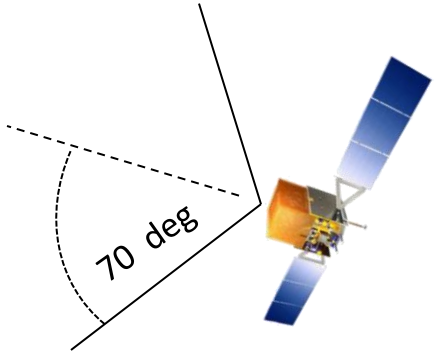


S190425z



https://gracedb.ligo.org

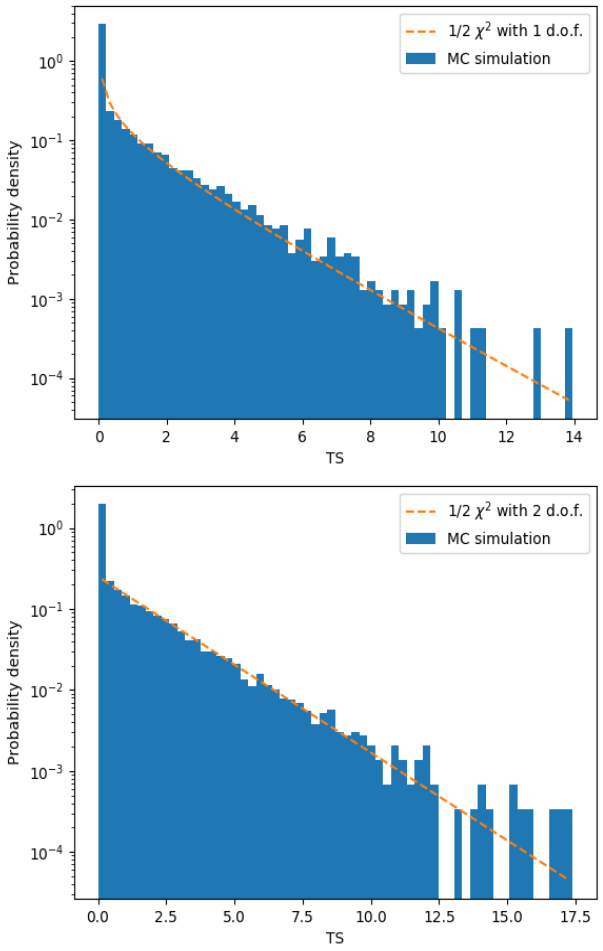
Fermi-LAT:
field of view 70 deg & rocking back and forth &
1.5 hour for one orbit (switches to other half of the sky)
→ observes the whole sky in 3 hours (about 10k seconds) at E > 100 MeV



GWs connected to GRBs:
Emission of GRBs at E > 100 MeV after prompt phase can contain substantial energy
→ Makes sense to look for high energy emission even after typical prompt (few 10s), in case GW area not in LAT field of view during trigger time

Distribution of TS values with simulated background for single position/pixel

preliminary



- Test Statistics (TS) based on maximum likelihood method:

TS = -2 log (L_0/L_1)

L_1: max. likelihood (background & GRB)

L_0: max. likelihood (background)

- Distribution of TS values can be approximated closely like: ½ χ^2 with degree of freedom equal to number of additional free parameters when adding GRB to the background model

- Probability to obtain certain TS_0 value (or higher) in one analysis due to background fluctuation, should be equal to surface of the area under the ½ χ^2 function from TS_0 to infinity.

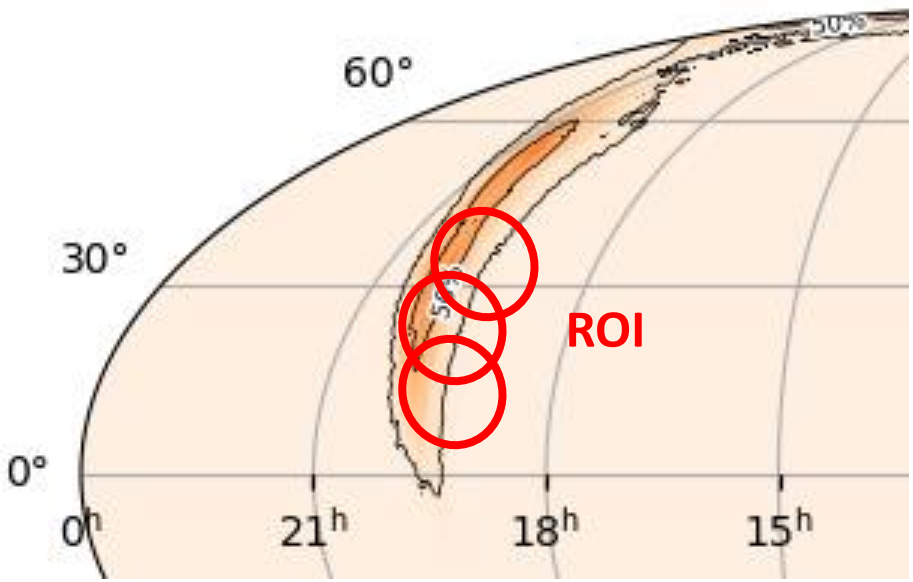
- Upper plot: GRB in the model has a fixed position with flux left to vary, so the 10k TSs follow pretty well ½ χ^2 with 1 d.o.f. (TS=25.00 ↔ 5σ)

- Lower plot: GRB in the model has position and flux left to vary, so the 10k TSs follow pretty well ½ χ^2 with 2 d.o.f. (TS=28.75 ↔ 5σ)

Mattox et al. 1996; G. Vianello et al., 2017

Analyzing larger area with Fermi-LAT

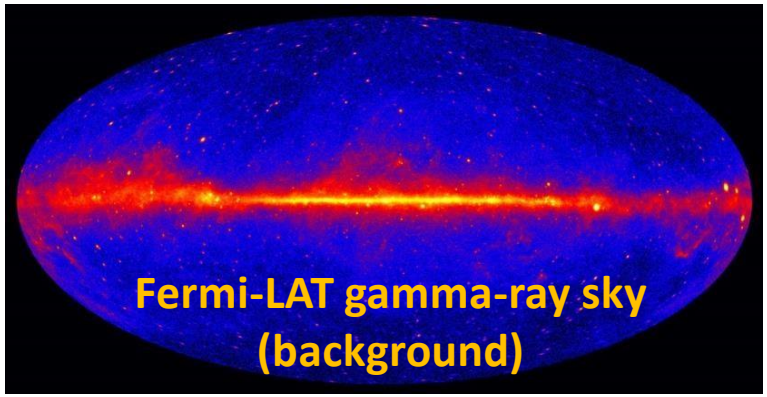
- Divide GW area (90% prob.) into pixels (with HEALPix) and perform analysis at each pixel
- Taking into account for multi-trial in determining the TS threshold (for 5σ for example)
- 1000 or more pixels/positions
- Not (theoretically) difficult if trials are independent



- LAT point spread function @100 MeV is about 10 deg
- Analysis at single position takes into account photons from Region Of Interest (ROI) of about 10 deg
- Same photons are used in analysis for many different pixels

→ Results from analysis of different pixels are not independent

Approach for time fixed window (10.000 seconds after the trigger)
single TS threshold (5σ) for 90% GW prob. area



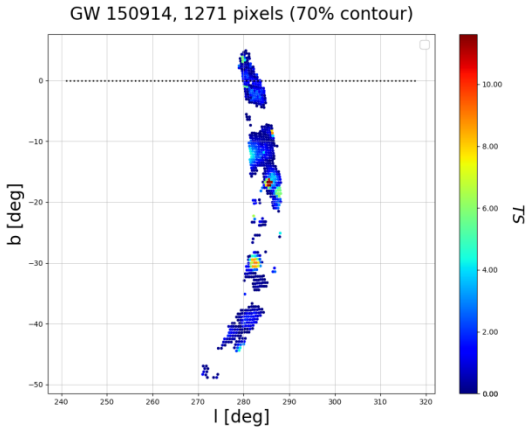
- **1) Simulating the background (whole sky)**
- 10.000 times
- For 10.000 seconds
- Background is composed of all components:
  - point & extended sources
  - diffuse galactic emission
  - isotropic background
- Convolve with Fermi-LAT response and real pointing history to produce photons

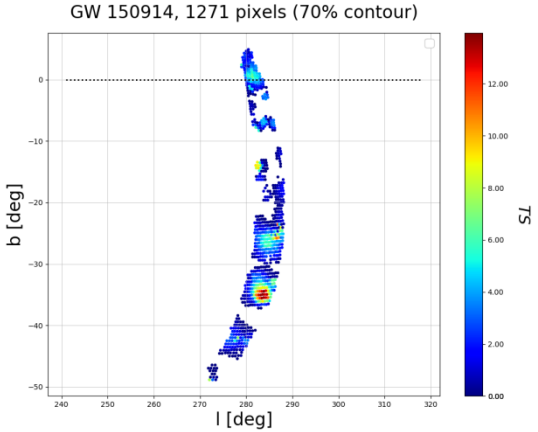
- **2) Performing LAT analysis**
- standard unbinned likelihood analysis
- at each point (HEALPix pixel) in GW loc. area (90% containment for example)
- for each of 10.000 backg. simulations
- (N_{pix} x 10.000 total analysis)
- with real Fermi pointing history during the time window

- **3) Calculating TS value**
- after each analysis as $TS = -2 \log (L_0/L_1)$
- L_1: max. likelihood (for model: background & GRB)
- L_0: max. likelihood (for model: just background)

Then…

preliminary

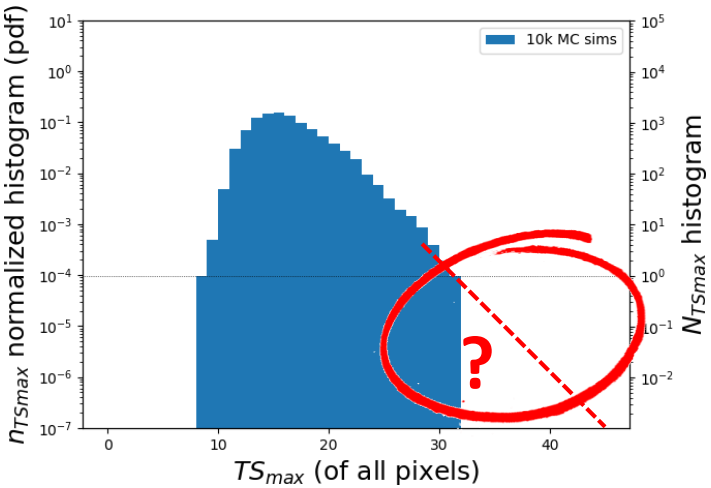




(missing pixels have TS<0)

- Take the max. TS out of each map/simulation and see how they are distributed
- 10k simulations is not enough to have good resolution at TS>30; >> 10k is needed (not feasible)
- Semi-analytical, semi-numerical approach is required

preliminary



Conclusions

- Working on TS distribution taking into account multi-trial of non-independent pixels
- Examining how possible deviation from ½ Chi^2 (in 10k s time window) and different background components might affects the analysis
- Since there is 1 GW per week on average, seems too computationally intensive to perform 10k analysis for each 1k-10k pixels in 90% GW loc. area, each week
  Probably new method is needed