First O3 Fermi-LAT follow-up results

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on behalf the
Fermi-LAT Collaboration

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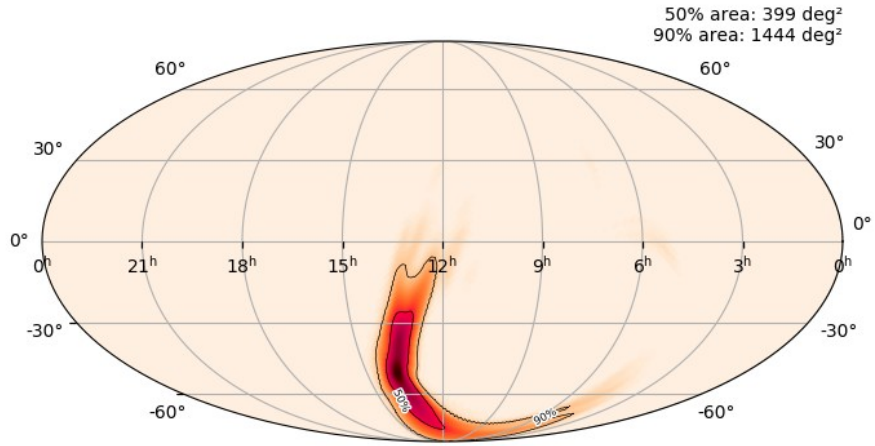
Follow-up analysis pipelines

- Two independent follow-up pipelines running automatically on ground after the trigger.
- Two analysis methods implemented (Vianello et al., *The Astrophysical Journal Letters* (841) 2017):
  - Fixed Time Interval (FTI)
  - Adaptive Time Interval (ATI)
- Standard unbinned maximum likelihood technique used for LAT data analysis and based on Poisson statistic.
- We include all sources (point-like and extended) from the latest LAT source catalog, as well as the Galactic and isotropic diffuse templates.
- Results are available typically few hours after the trigger.

Fixed Time Interval

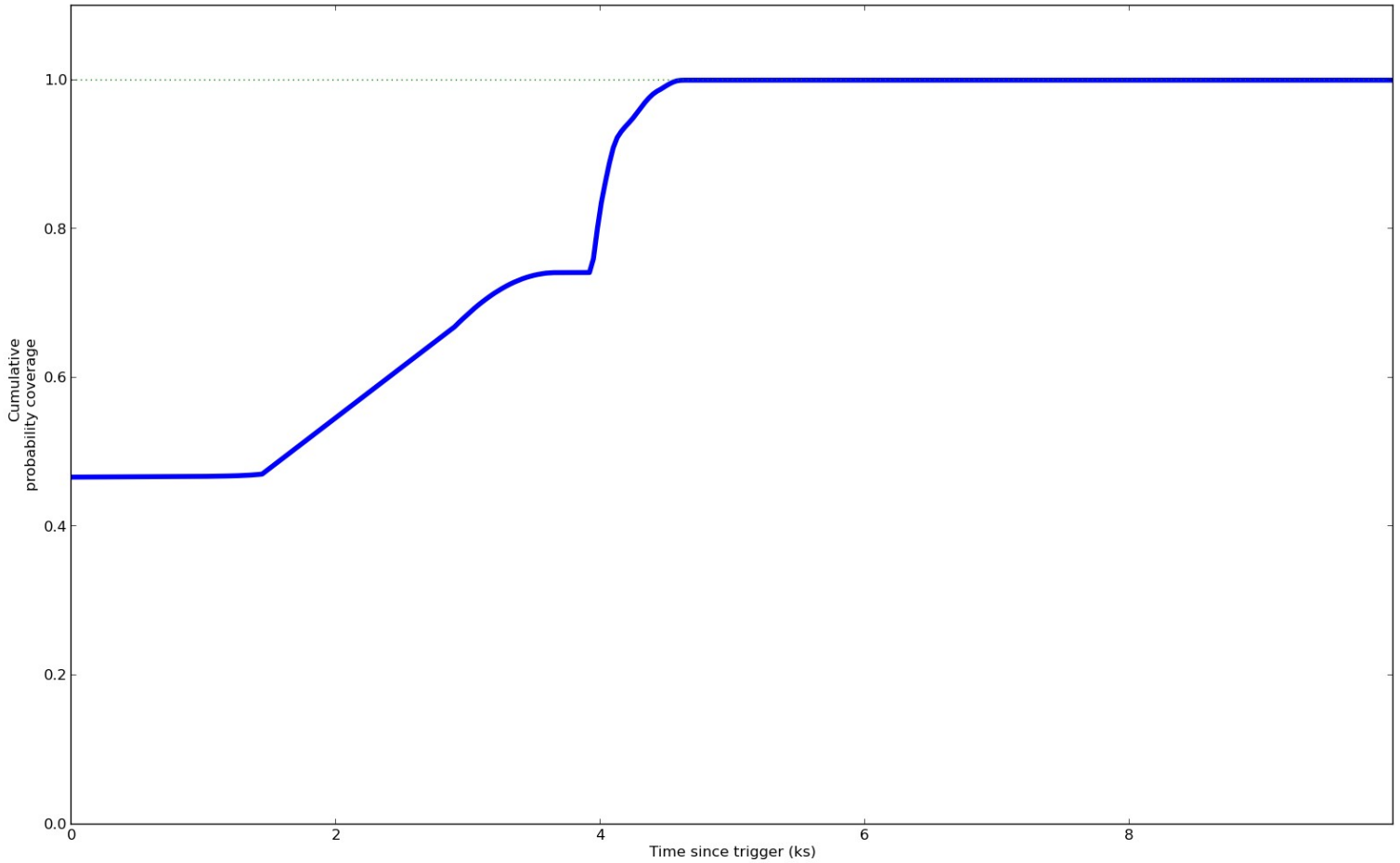
- Compute the cumulative probability coverage:

$$C(t) = \sum_{h=0}^{H} p_h w_h(t)$$

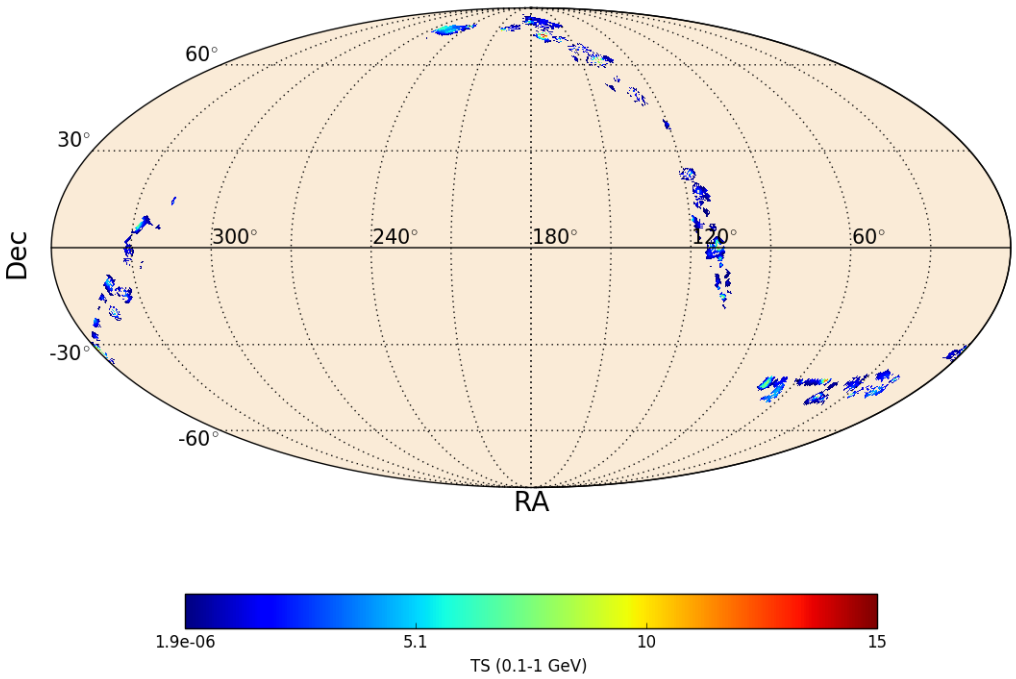


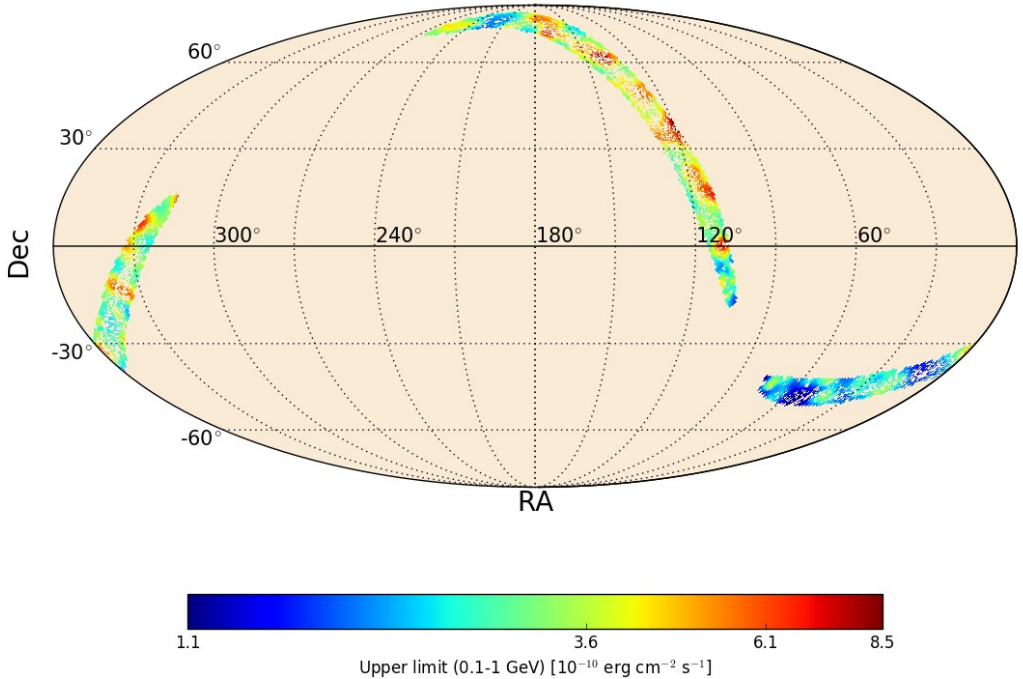
- Choose the time window and select all pixels within the 90% containment of the LIGO/Virgo localization maps.
- Run an independent likelihood analysis for each pixel, testing for the presence of a new source at the center of the pixel.
- In case of non-detection, compute also a global Bayesian upper bound for the flux.

Cumulative coverage



FTI TS and UL map



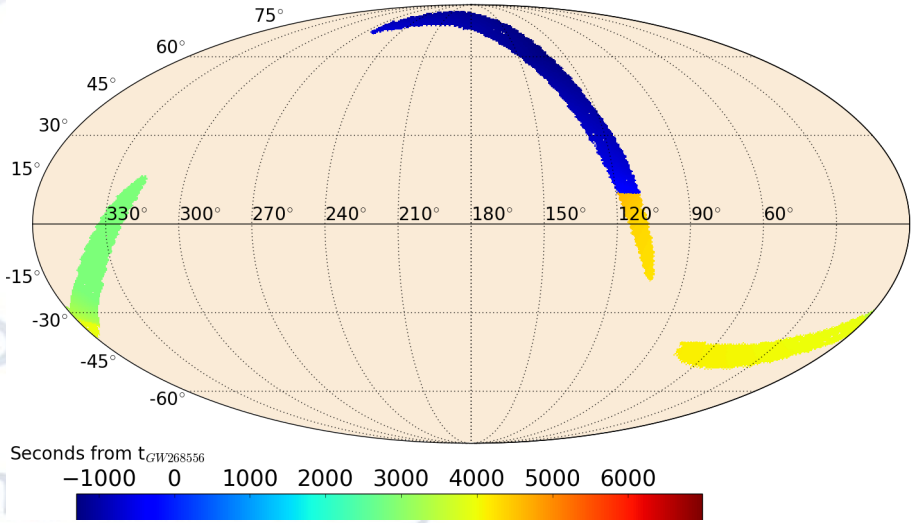


Adaptive Time Interval

- Maximize the time window for each point in the sky separately in order to get the largest possible exposure close to the trigger time.

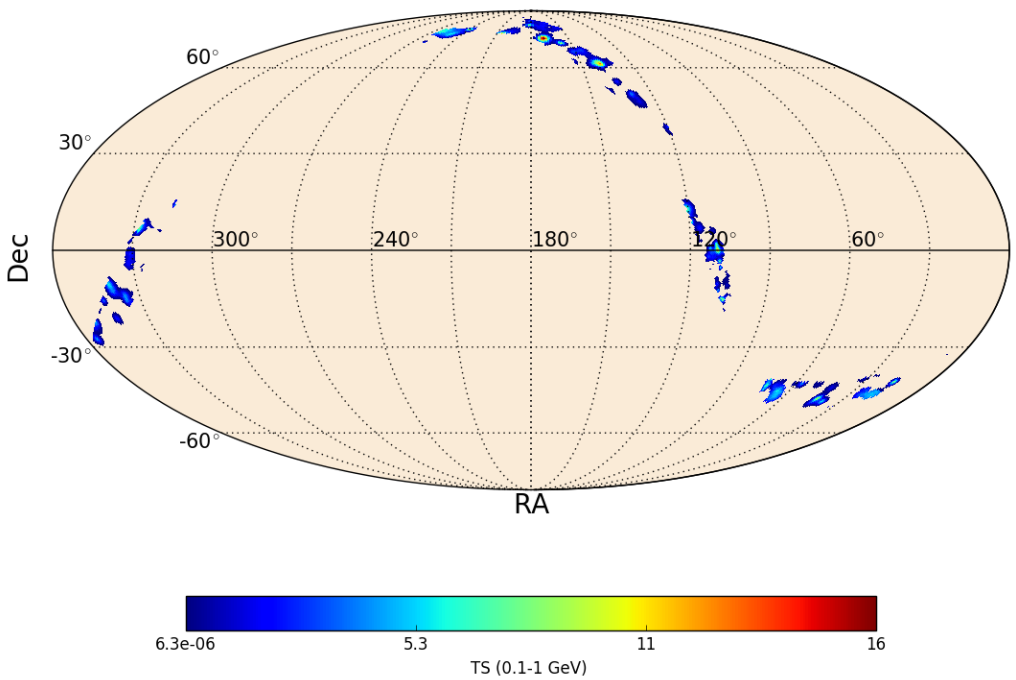
For each pixel the time interval:

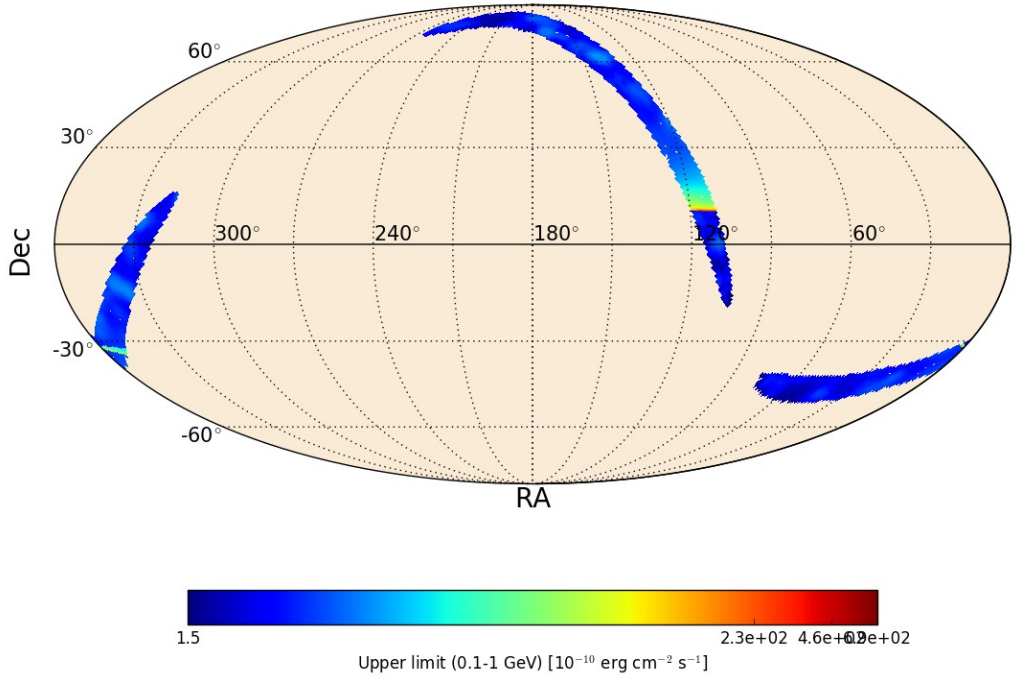
- starts when the center of the ROI becomes observable by the LAT
- ends when is no longer observable



- Run an independent likelihood analysis for each pixel as for FTI.
- In case of non-detection, compute a flux upper bound for each pixel separately.

ATI TS and UL map

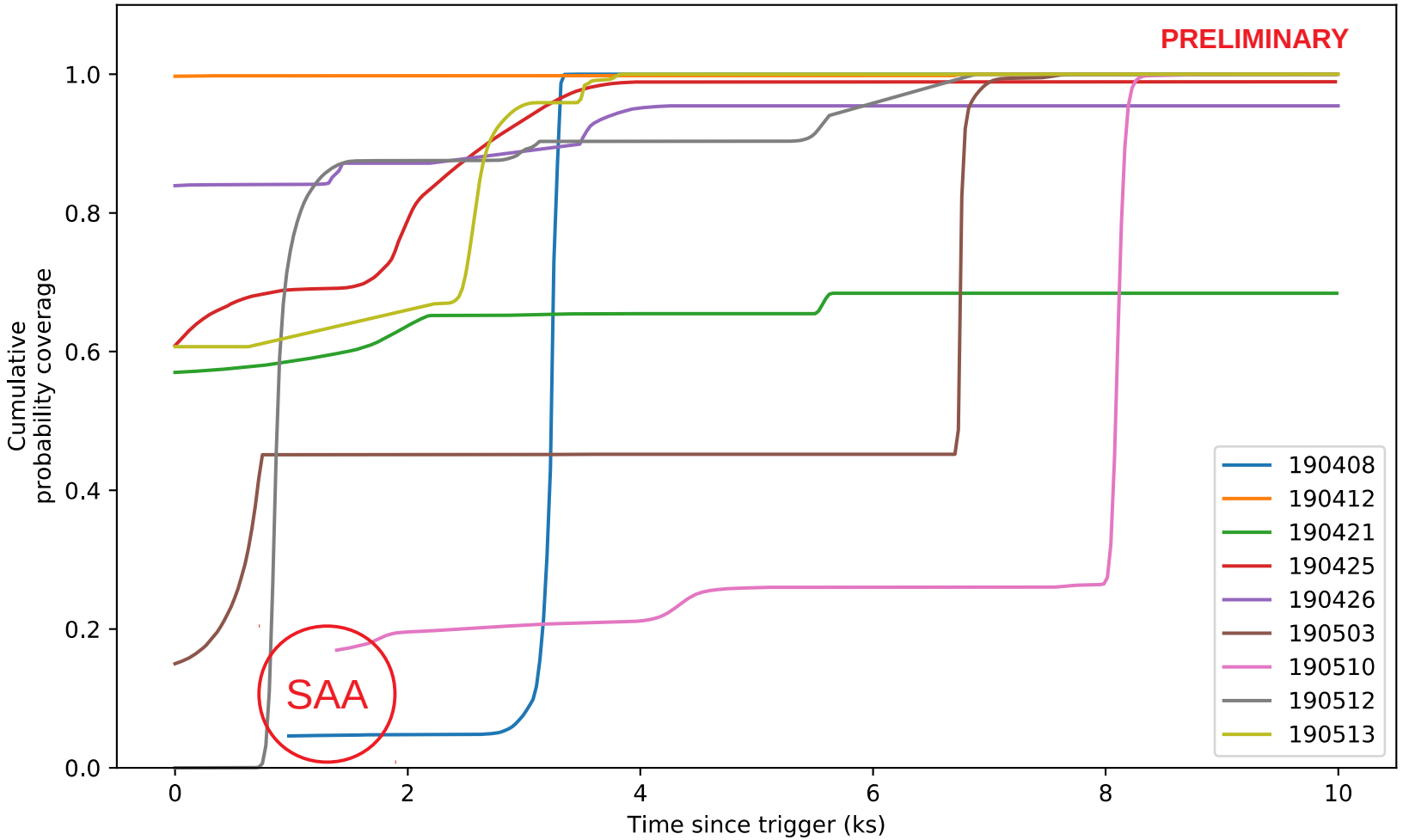




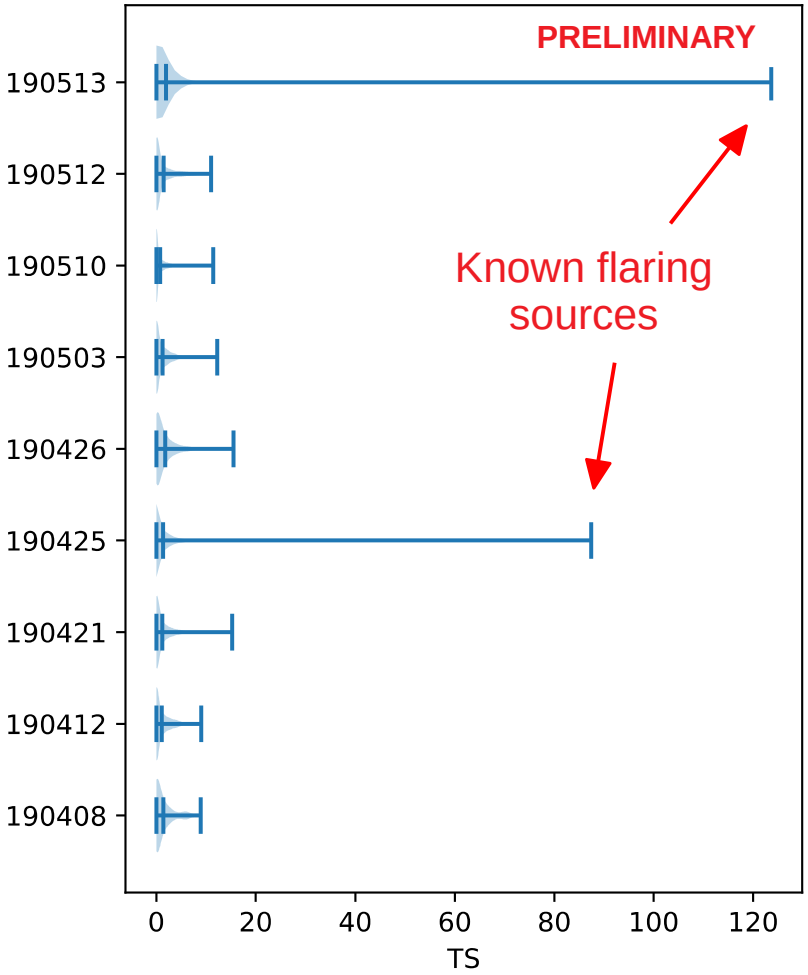
Observing run O3

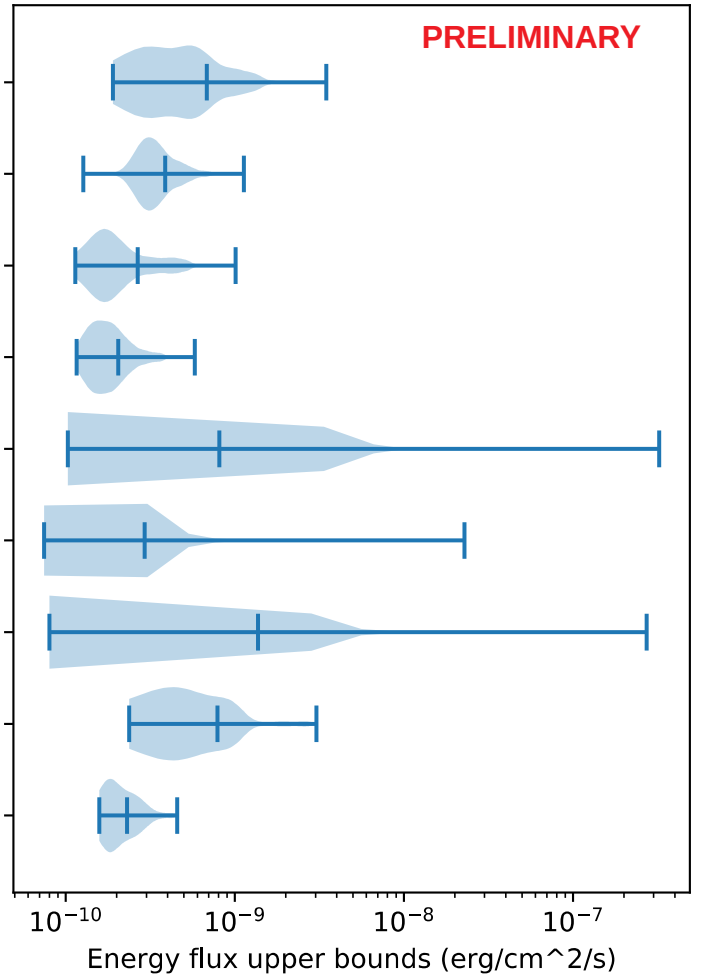
Event ID	Ligo/Virgo GCN	Event type	FAR (yr-1)	Fermi-LAT GCN
S190408an	24069	BBH (>99%)	1 / 1.1 e+10	24082
S190412m	24098	BBH (>99%)	1 / 1.9 e+19	24115
S190421ar	24141	BBH (97%)	1 / 2.1	24174
S190425z	24168	BNS (>99%)	1 / 69834	24266
S190426c	24237	BHNS (60%)	1 / 1.6	24342
S190503bf	24377	BBH (96%)	1 / 19.4	24390
S190510g	24342	Terrestrial (58%)	1 / 3.6	24460
S190512at	24503	BBH (99%)	1 / 16.7	24515
S190513bm	24522	BBH (94%)	1 / 84864	24532

Coverage plots

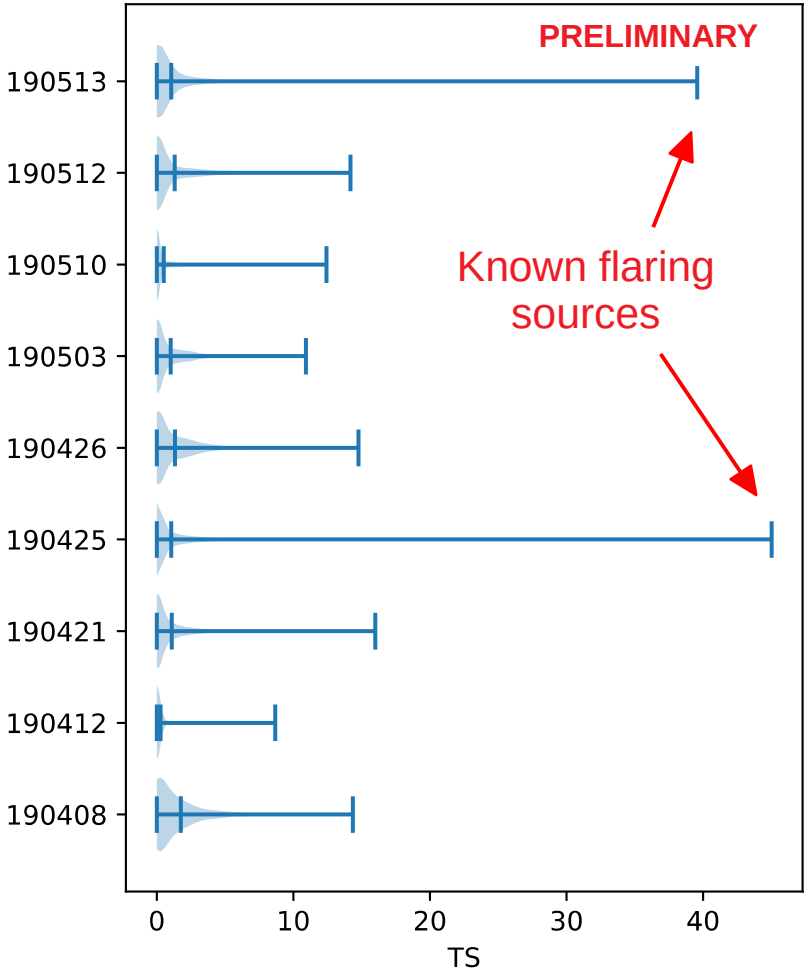


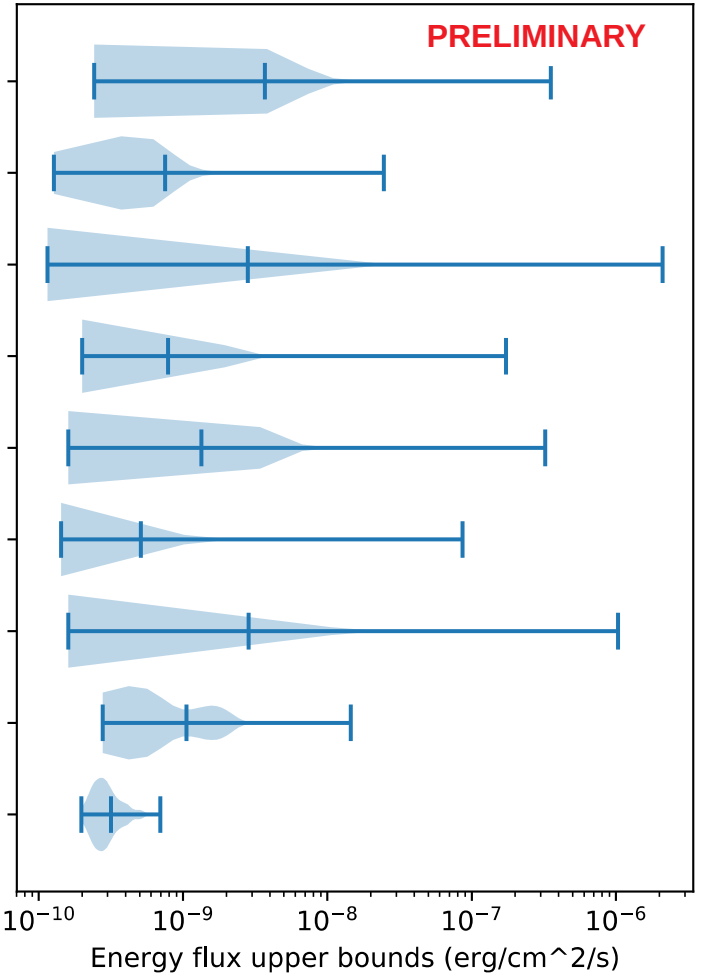
FTI results


PRELIMINARY
190513
190512
190510
190503
190426
190425
190421
190412
190408
Known flaring sources
0
20
40
60
80
100
120
TS


PRELIMINARY
10^{-10}
10^{-9}
10^{-8}
10^{-7}
Energy flux upper bounds (erg/cm^2/s)

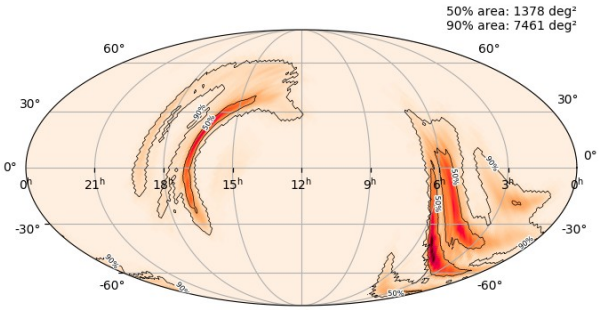
ATI results


PRELIMINARY
190513
190512
190510
190503
190426
190425
190421
190412
190408
Known flaring sources
0
10
20
30
40
TS


PRELIMINARY
10^{-10}
10^{-9}
10^{-8}
10^{-7}
10^{-6}
Energy flux upper bounds (erg/cm^2/s)

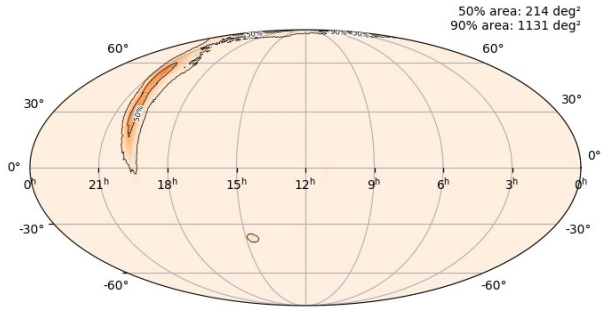
NS events

S190425



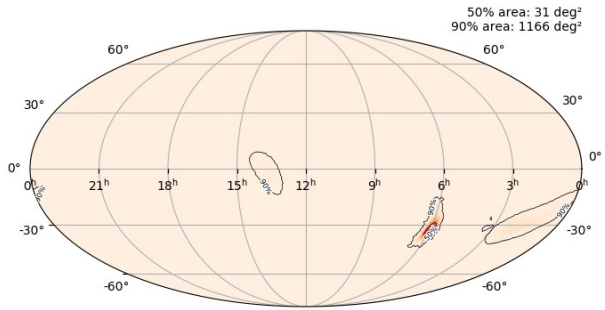
- BNS (>99%)
- Good coverage at the trigger time (> 60%)
- No EM emission detected
  - Large localization area
  - Large distance
  - Beamed emission not aligned with our line of sight?

S190426



- BHNS (60%), MassGap (25%), BNS (15%)
- Excellent coverage at the trigger time (> 80%)
- No EM emission detected (expected?)

S190510



- Terrestrial (58%) BNS (42%)
- Fermi was in the SAA at the trigger time and resumed data taking after ~ 1300 s with a low coverage (< 20%)
- No EM emission detected

https://gracedb.ligo.org/latest/

Conclusions

- During O3 LIGO/Virgo interferometers detected so far 9 GW event candidates:
  - 6 BBH / 1 (+1) BNS / 1 BHNS.
- Using the automatic follow-up pipelines we searched for EM counterparts in the LAT data:
  - No significant candidate counterpart was found performing either the FTI or ATI analysis methods.
- We put energy flux upper bounds of the order of 10^{-10} erg/cm^2/s.
- Fermi after 10 years of mission will continue to monitor the high-energy sky and play a primary role in the new era of multi-messenger astronomy!