Fermi-LAT Observation of GW events

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Search of LAT counterpart to GW events

- Thanks to its large field of view Fermi (GBM and LAT) is the perfect instrument to follow up transient events in the sky
  - In few minutes we cover more sky than any X-ray/optical telescope can do in days!
- sGRB are thought to be related to NS-NS mergers, which is one of the primary candidate for Gravity Wave (GW) emission
  - The GBM is the most proficient detector of sGRB (>200 so far)
  - LAT can also detect gamma-ray afterglow minutes after the prompt emission
    - LAT can detect gamma-rays even for events that are not in the field of view at the time of the trigger
    - If gamma-ray radiation comes from afterglow radiation, as we think, less beaming is expected, making plausible the detection of orphan gamma-ray afterglows

Following up LIGO events

- 3 GW events announced by the LIGO/VIRGO Collaboration
  - GW150914, LVT151012, GW151224, all associated to BH-BH mergers
- BH-BH mergers are not expected to produce EM radiation. Keeping that in mind, and acknowledging that surprises and serendipitous discoveries are not new in astrophysics, **we search our data performing different analysis**:
  - Automated Searches: (ASP, LAT BA, LAT Transient Factory, and FAVA).
    - These 4 tools **continuously monitor the sky** and played an important rule in major LAT discoveries.

Specific searches in the LIGO contours

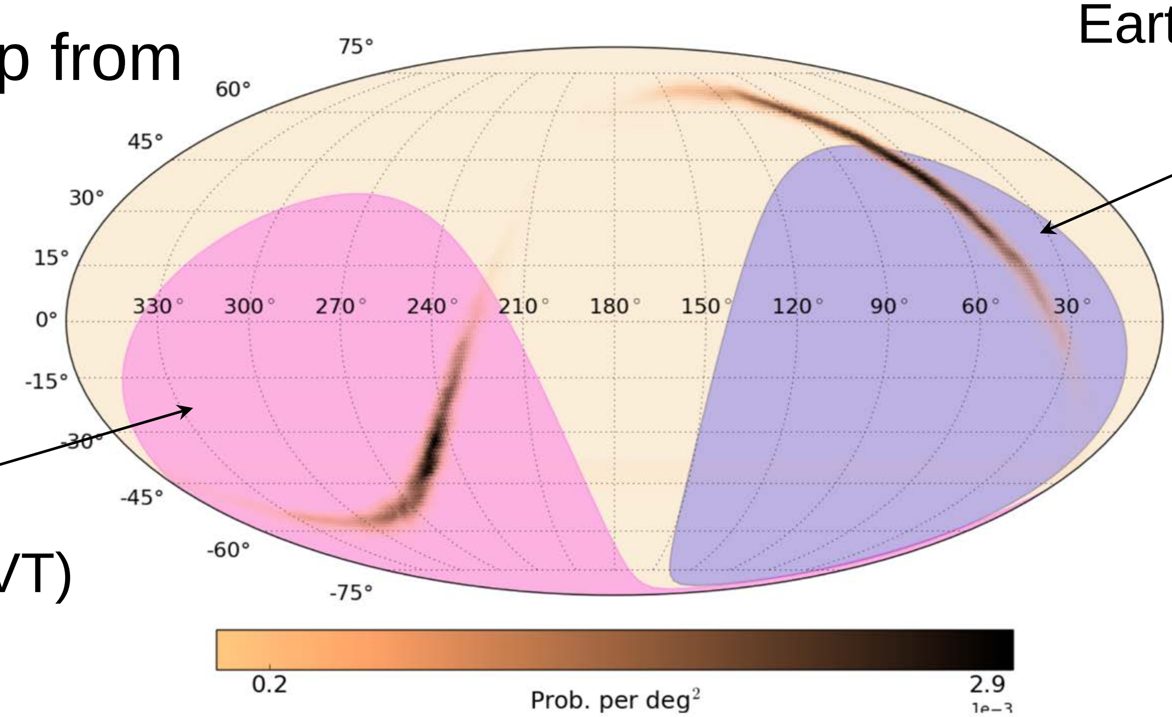
- **Short-baseline search**
- **Long-baseline search**
- **Adaptive time windows**

From LVC probability maps to LAT analysis

- We developed a novel technique (Vianello, et al. in preparation) to search for EM counterpart in LAT data starting from LIGO probability maps
  - LVC releases probability maps (in HELPix).
  - We **downscale the maps** to match the Fermi LAT PSF (~4 degrees at 100 MeV)
  - We center a ROI in each pixel, and we run **standard likelihood analysis (Unbinned)**
  - We adopt **<u>several timescales</u>** to be sensitive to transients of different duration

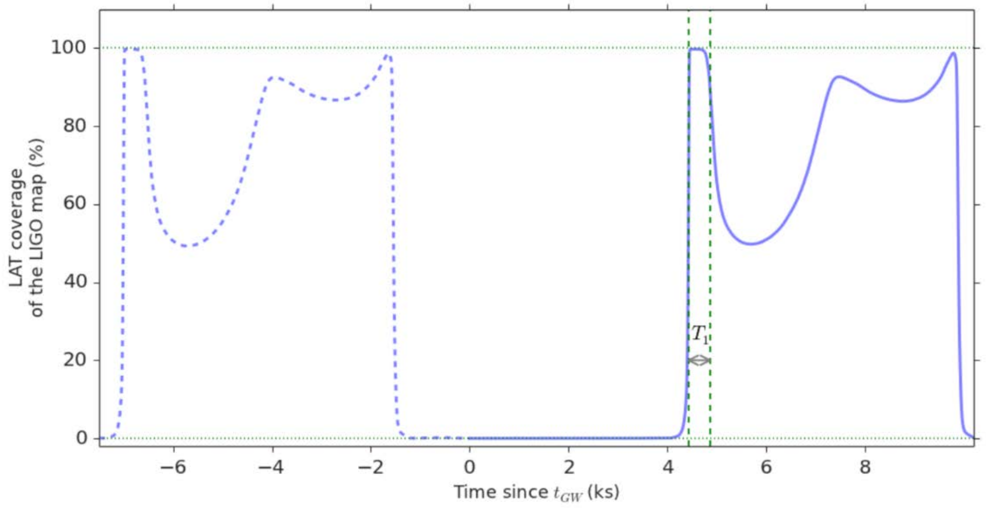
Probability map from LVT151012.

Earth (at the time of the LVT)

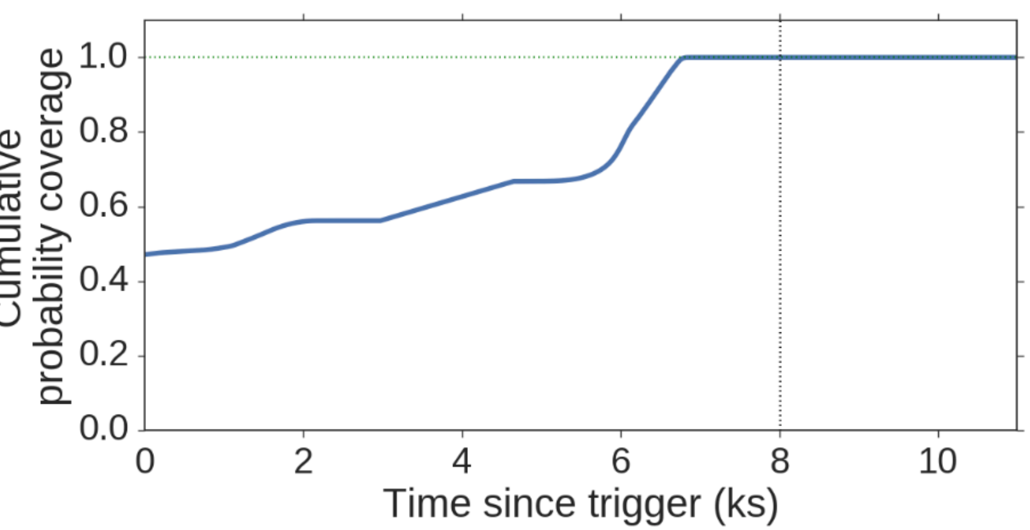


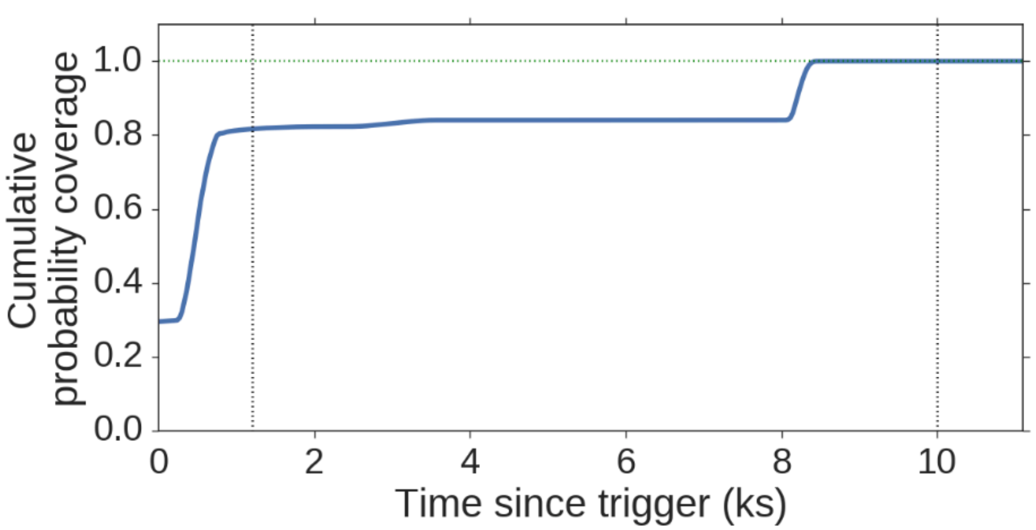
LAT FoV (at the time of the LVT)

Coverage



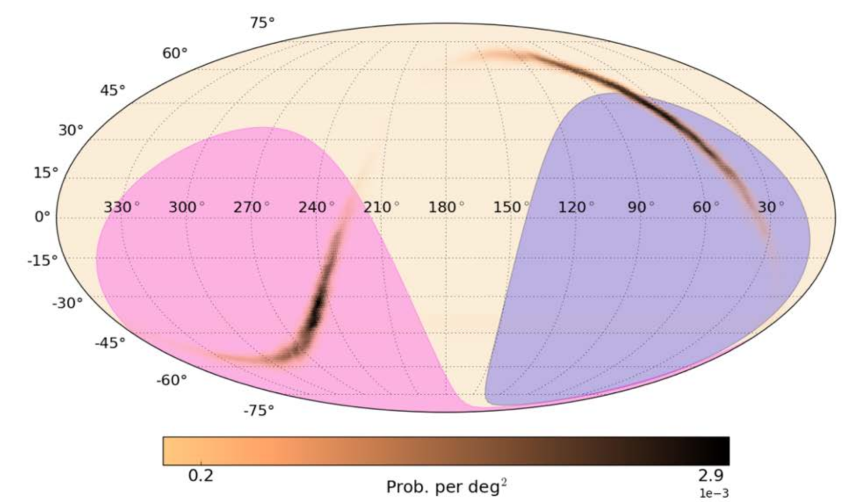
For GW150914 the coverage was **very bad**, in fact we start observing the region of the GW event only 4ks after the trigger.

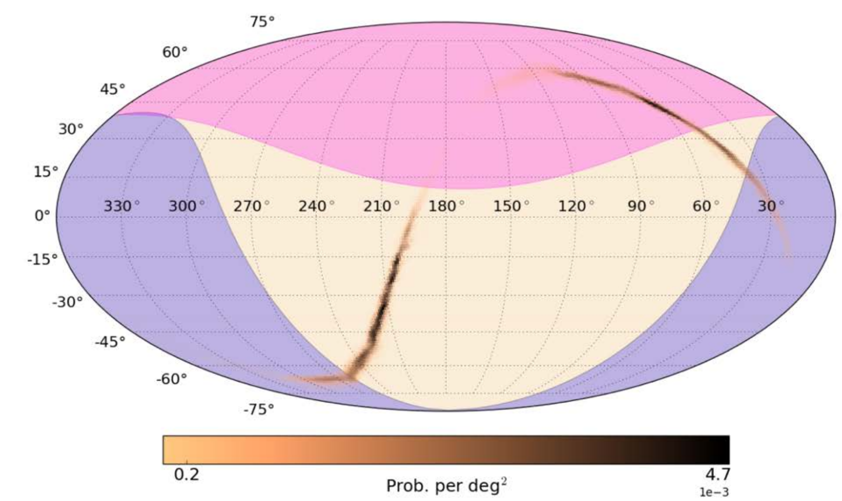




For LVT151012 and GW151226, the coverage was much better: **50% and 30% of the GW region was covered at the time of the trigger.**

In 8ks and 10ks after the GW trigger the entire probability map is covered





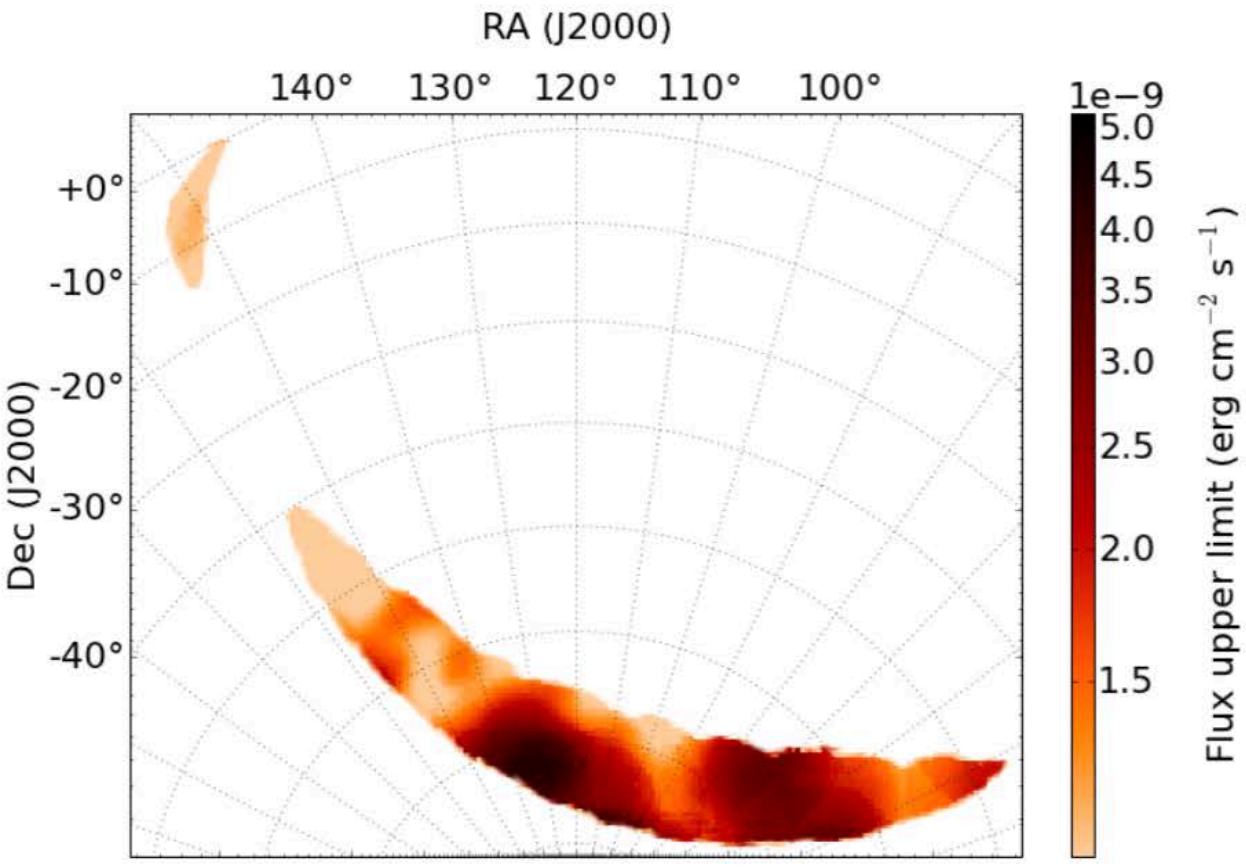
Different time windows for the LAT Analysis

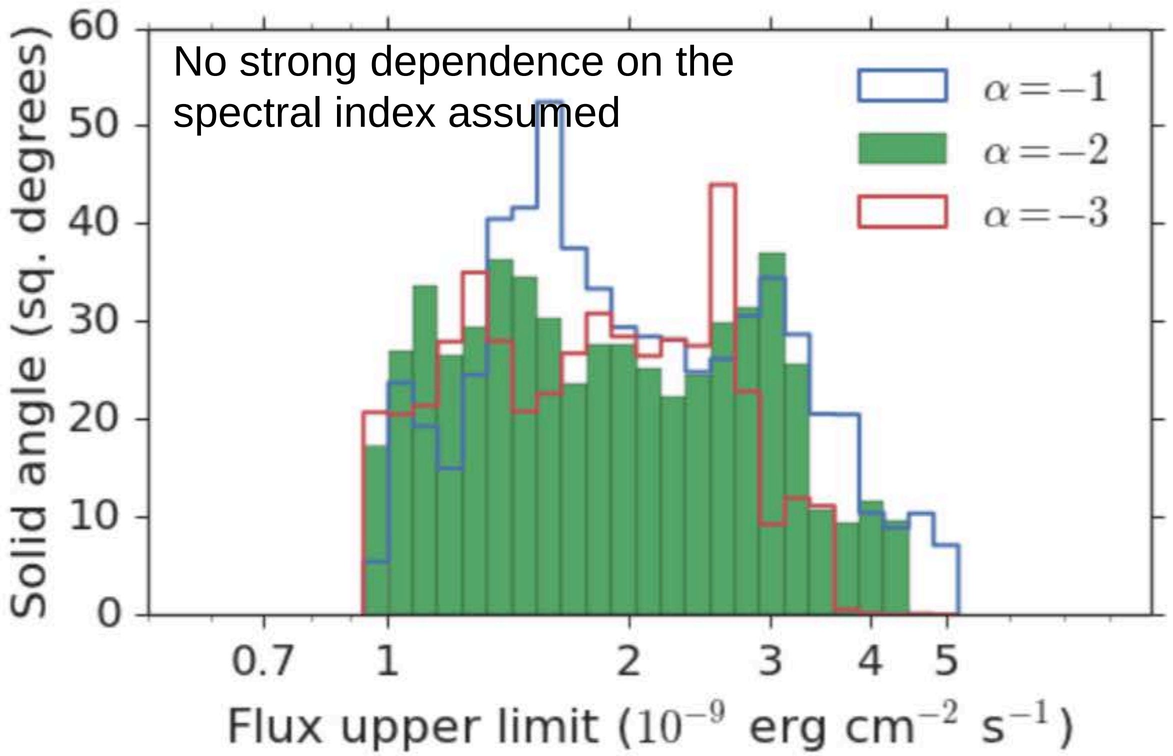
- GW150914:
  - We searched in the time interval having more than 90% coverage (from T0+4400, T0+4500)
  - Fixed window of 10ks
  - “Adaptive” time window (entry-exit for each pixel in the sky), over an interval of 10 days (before and after the trigger).
- LVT151012 & GW151226
  - Fixed (short) time windows of T0-10s, T0+10s
  - Fixed (long) time windows (8ks for GW151012 and 1.2 ks and 10ks for GW151226)
  - “Adaptive” time windows, as defined above
- Long baseline search
  - ASP: integration time of 6 hours, 1 day
  - FAVA: integration time of 1 week

No significant excess was detected in any of our searches (therefore, we compute a series of **Upper Limits**)

Results - GW150914 - fixed time window

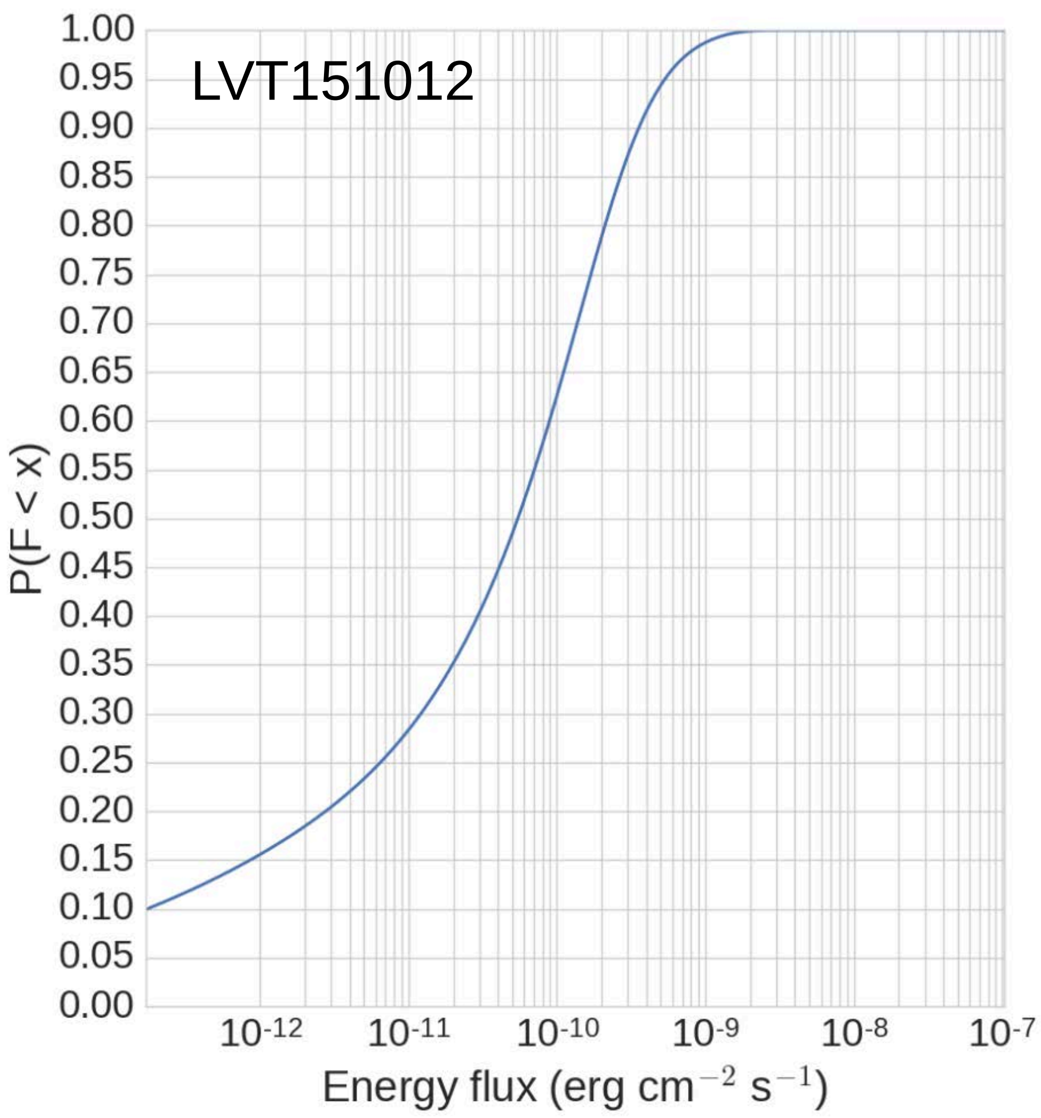
- For GW150914 we calculate **UL map** for the fixed time window search (from T0+4400, T0+4500).

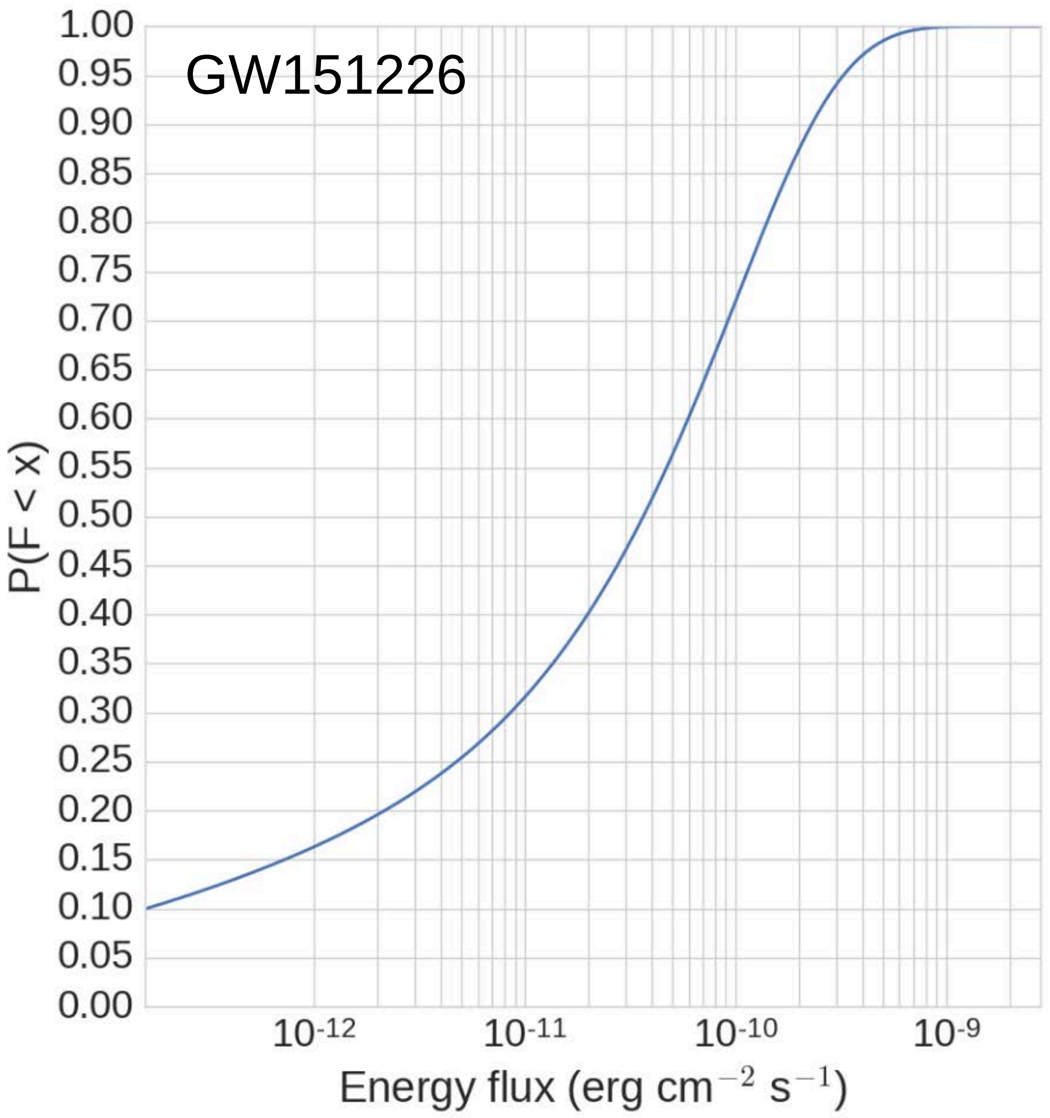




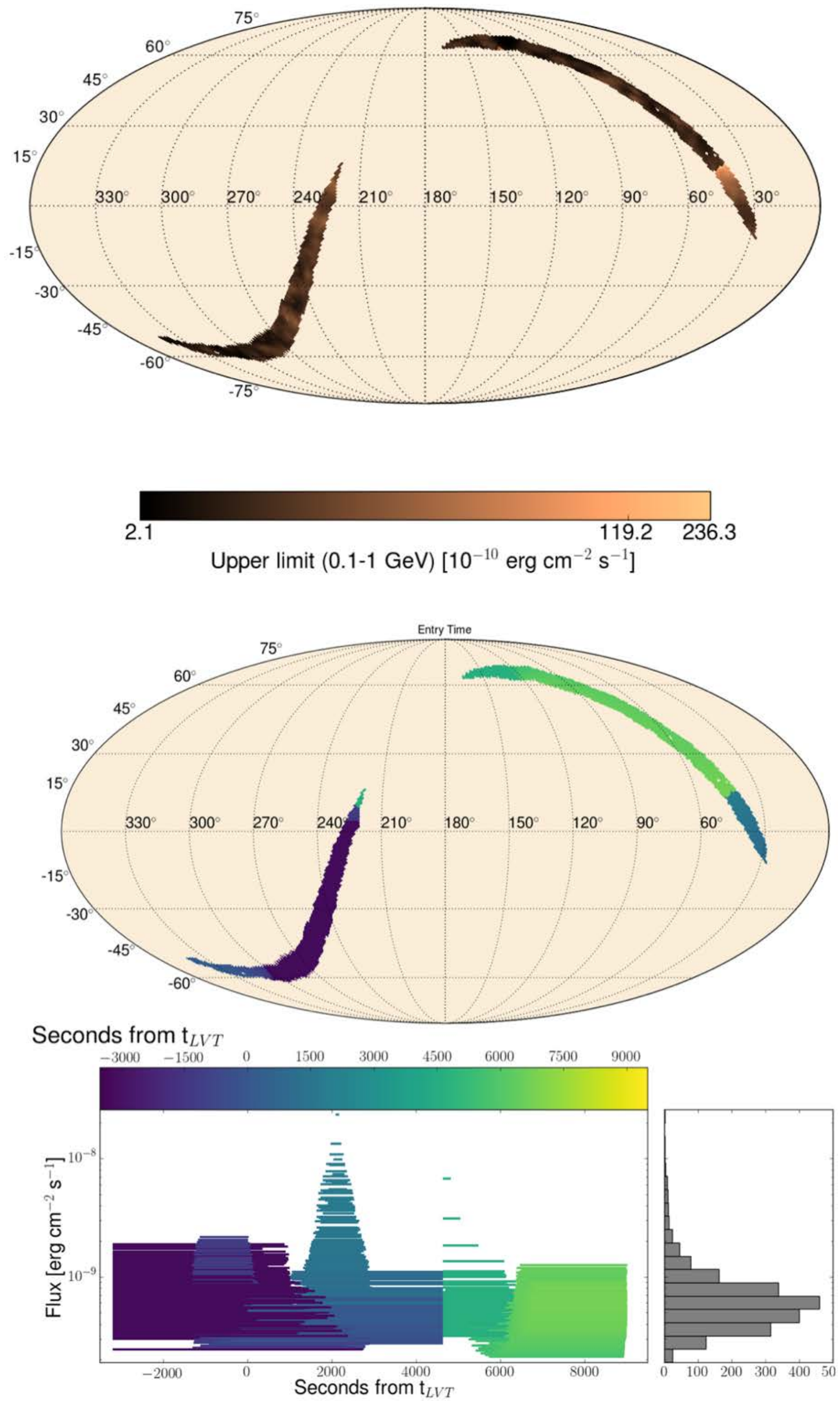
LVT151012 - GW151226 - fixed time window

- For LVT151012 and GW151226 we developed a **fully bayesian method** to calculate a “global” UL, using the probability map as prior (and using Markov-Chain Monte Carlo to marginalize the posterior probability). These UL can be used to constrain models <u>if the location of the GW event is unknown!</u>

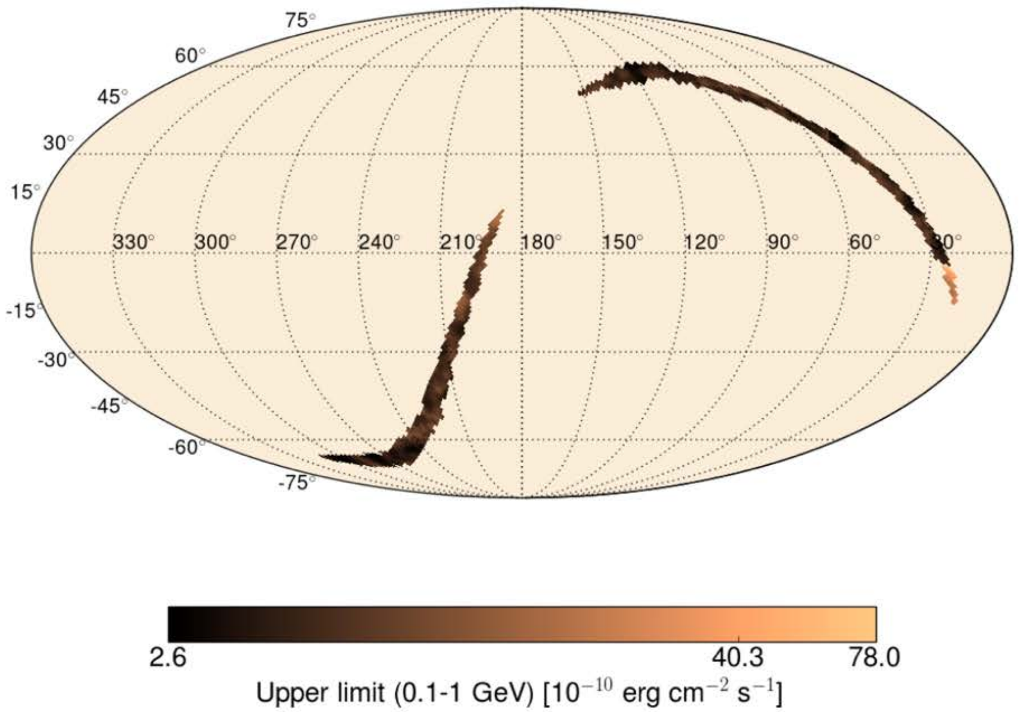


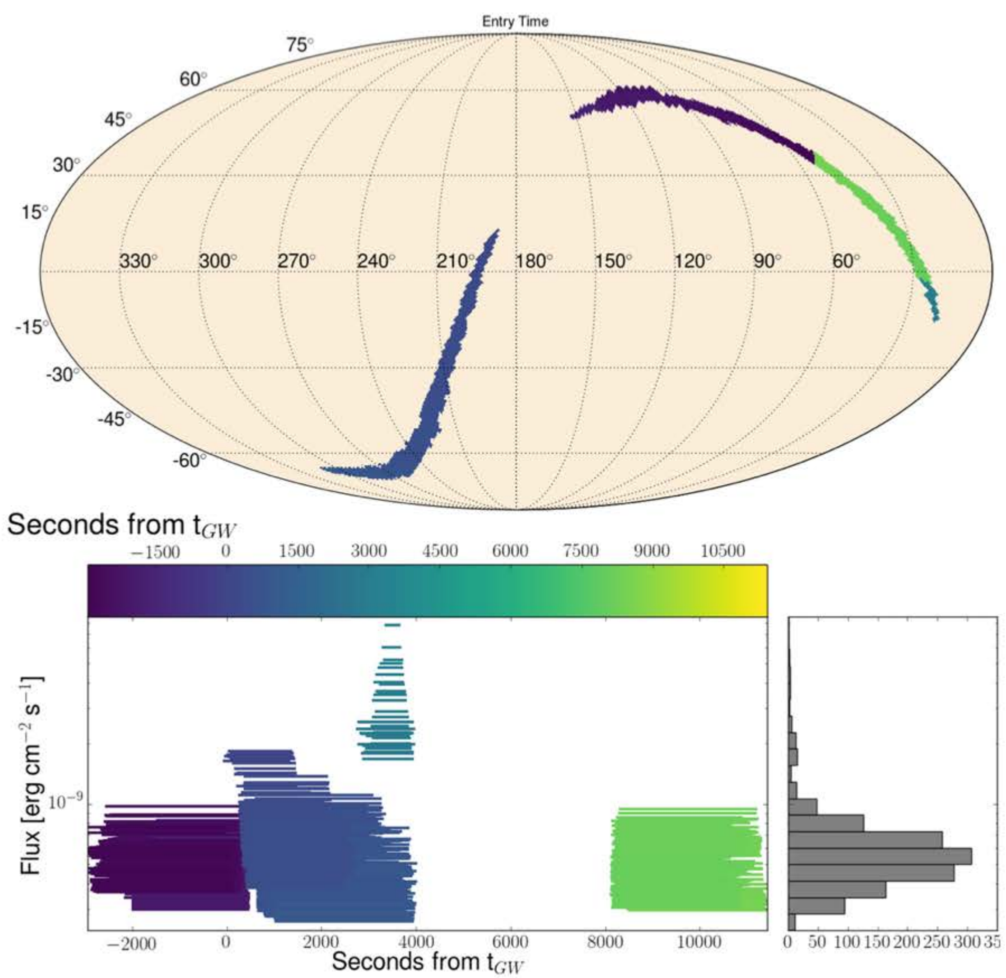


LVT151012 - GW151226 - Adaptive intervals



- We compute Flux LAT Upper Limit maps
- These Upper limits depend on the location of the pixel in the sky, which also determines the interval of time we used in our analysis
  - The colors of the horizontal lines in the last panel matches the colors of the pixels in the second panel.
- These UL can be used to constrain models <u>if the location of the GW event is known</u> (for example from its detection by some other facility)





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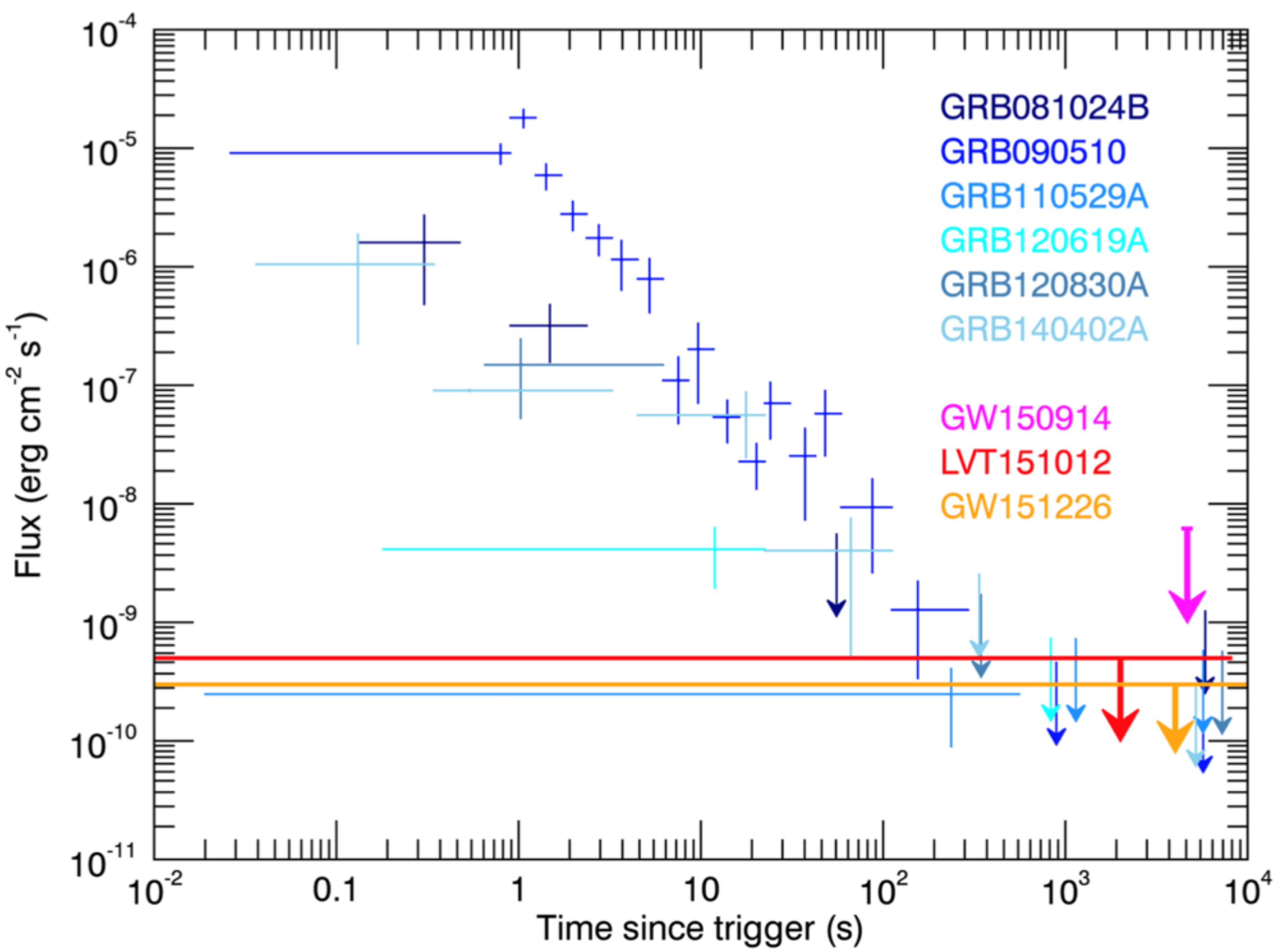
Putting in the context...



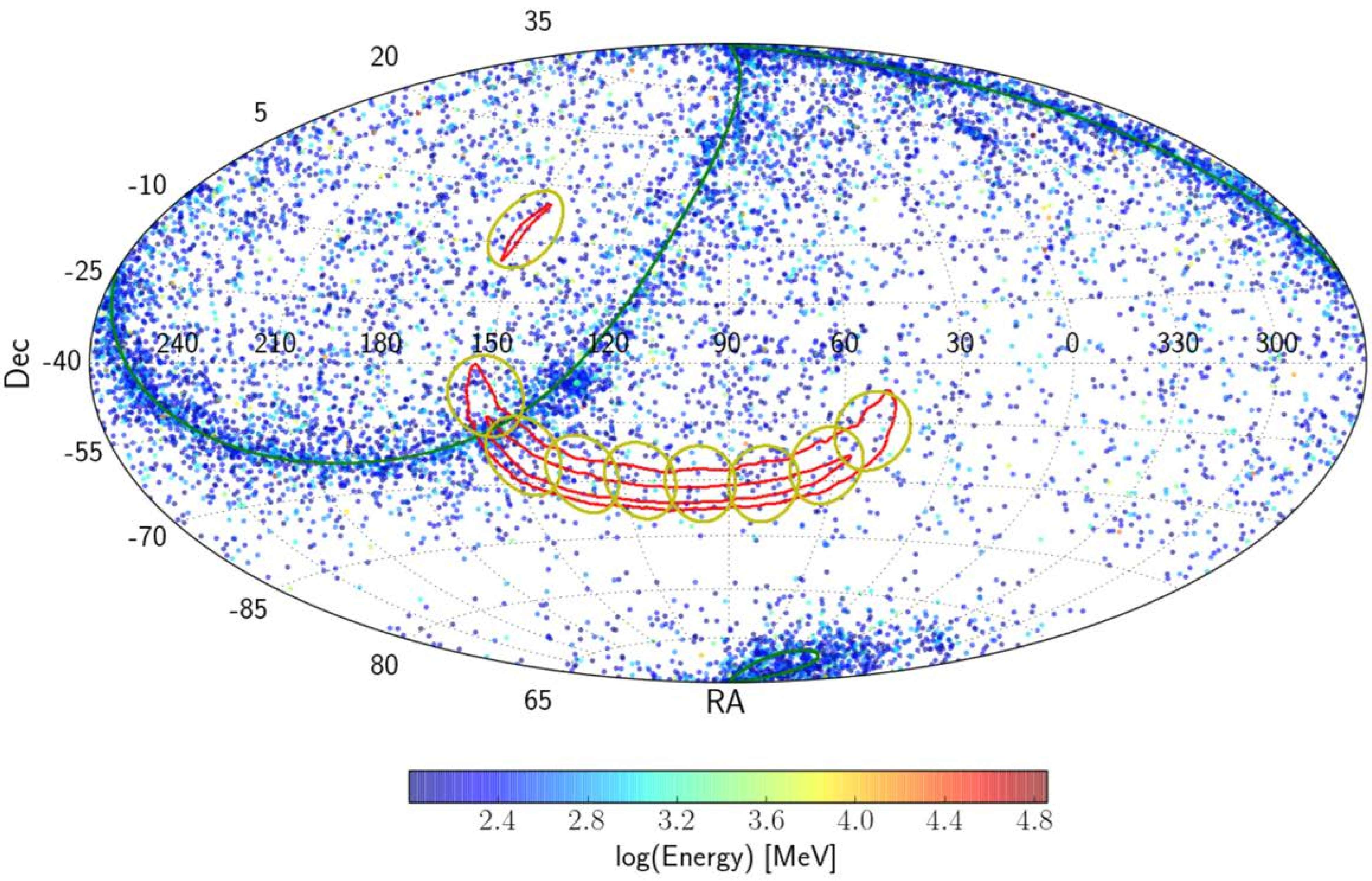
- We do not suggest GW150914, LVT151012, or GW151226 necessarily produced EM counterparts similar to the population sGRBs!
- However, we can put our Upper Limits in the context of the more familiar sGRBs:
  - If GW events have similar behaviors of sGRB detected by the LAT, they would have been detected within tens to hundreds of seconds.
- After the LIGO discovery numerous merger models with EM emission components proposed:
  - BH-BH systems with “cirumbinary” disks or common envelopes (see Woosley, 2016 or Janiuk et al. 2016, Perna et al. 2016, Murase 2016) or single star progenitor forming a BBH merger (Loeb et al 2016).
  - EM counterpart: extraction of energy and angular momentum of the merging BHs via the Blandford-Znajek mechanism (Blandford & Znajek 1977).
    - But: (Lyutikov 2016 and Murase et al. 2016) not really working with stellar-mass BH with GW150914-GBM luminosity

Conclusions

- We have set up a series of tools to monitor and followup with Fermi-LAT GW events triggered by LIGO/VIRGO
- Successfully applied to Observing Run “O1”:
  - Fermi-LAT Observations of the LIGO Event GW150914 (Ackermann et al. 2016, astro-ph:1602.04488)
  - Searching the Gamma-ray Sky for Counterparts to Gravitational Wave Sources: Fermi GBM and LAT Observations of LVT151012 and GW151226 (Racusin et al. 2016, astro-ph:1606.04901)
  - Paper describing the methodology coming up (Vianello, Omodei & Chiang)
- No LAT counterpart detected so far: flux Upper Limit derived to be used to constrain models
- Excitement for the new LIGO Observing Run “O2” (later this year)!

Back up

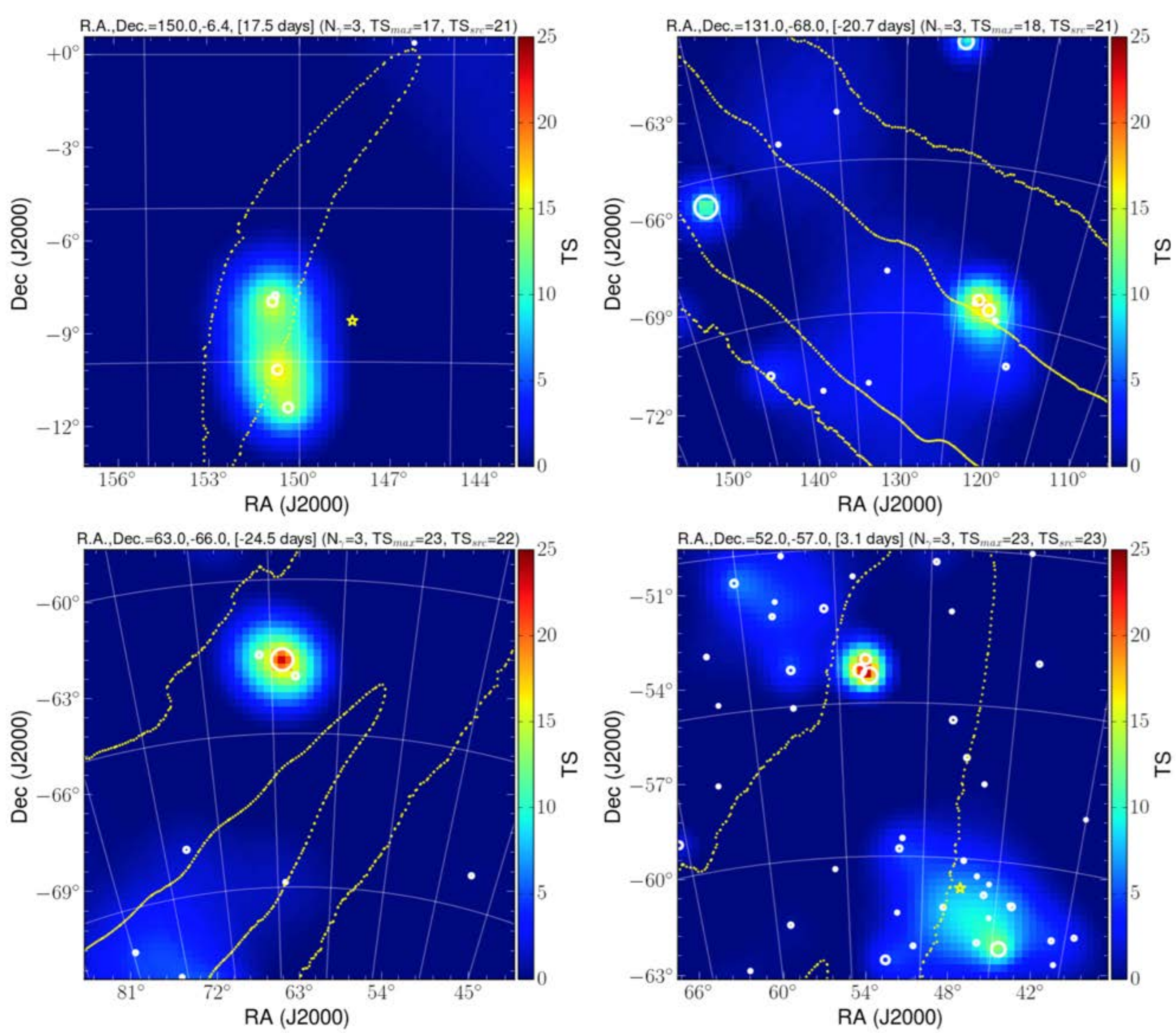
Adaptive interval over long time widow

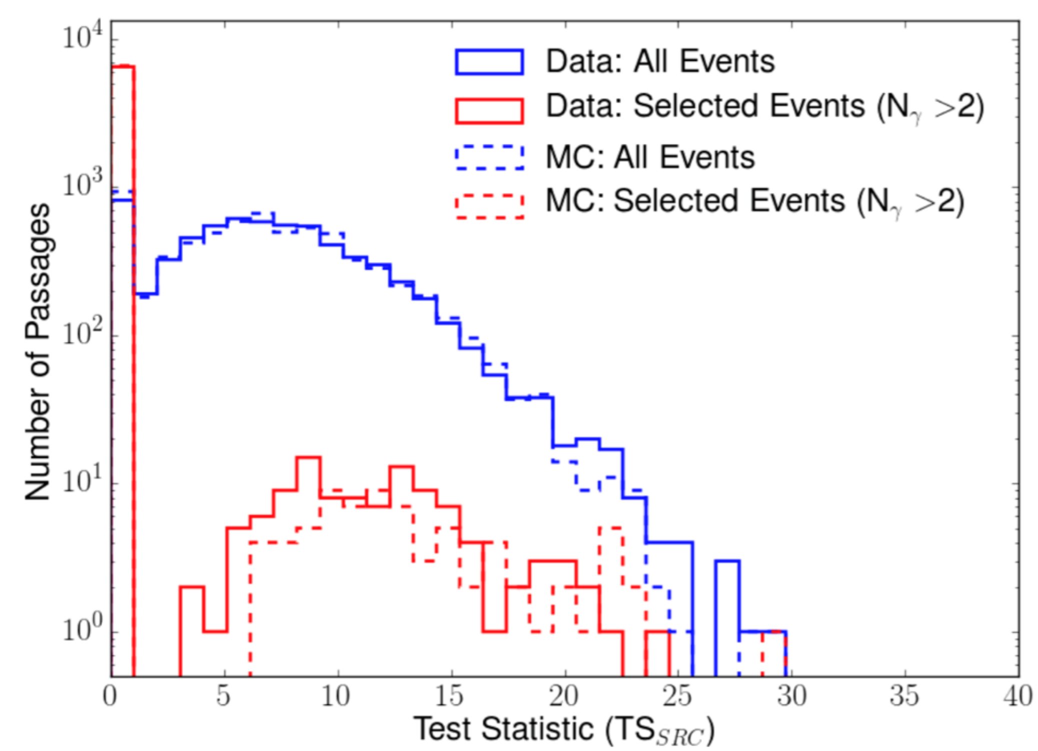


- For 150914 we calculate TS maps in 9 partially overlapping regions orbit-by-orbit (adaptive interval) over ling period of time (+/- 30 days)
  - Large number of trials!

Comparison with MC simulations

- Due to the large number of trials, high values of TS can be obtained by random coincidence of LAT events
  - Monte Carlo simulation are essential to study the significance of these excess
  - Our study shows that the distribution of TS obtained from MC data matches perfectly the observed ones: no statistically significant excess is found!





Left: most significant excesses found on searches over +/- 30 days.
Top: Data-MC comparison