Searching for GRB Counterparts to GW Events from the Third Gravitational Wave Observing Run with Fermi-GBM and Swift-BAT

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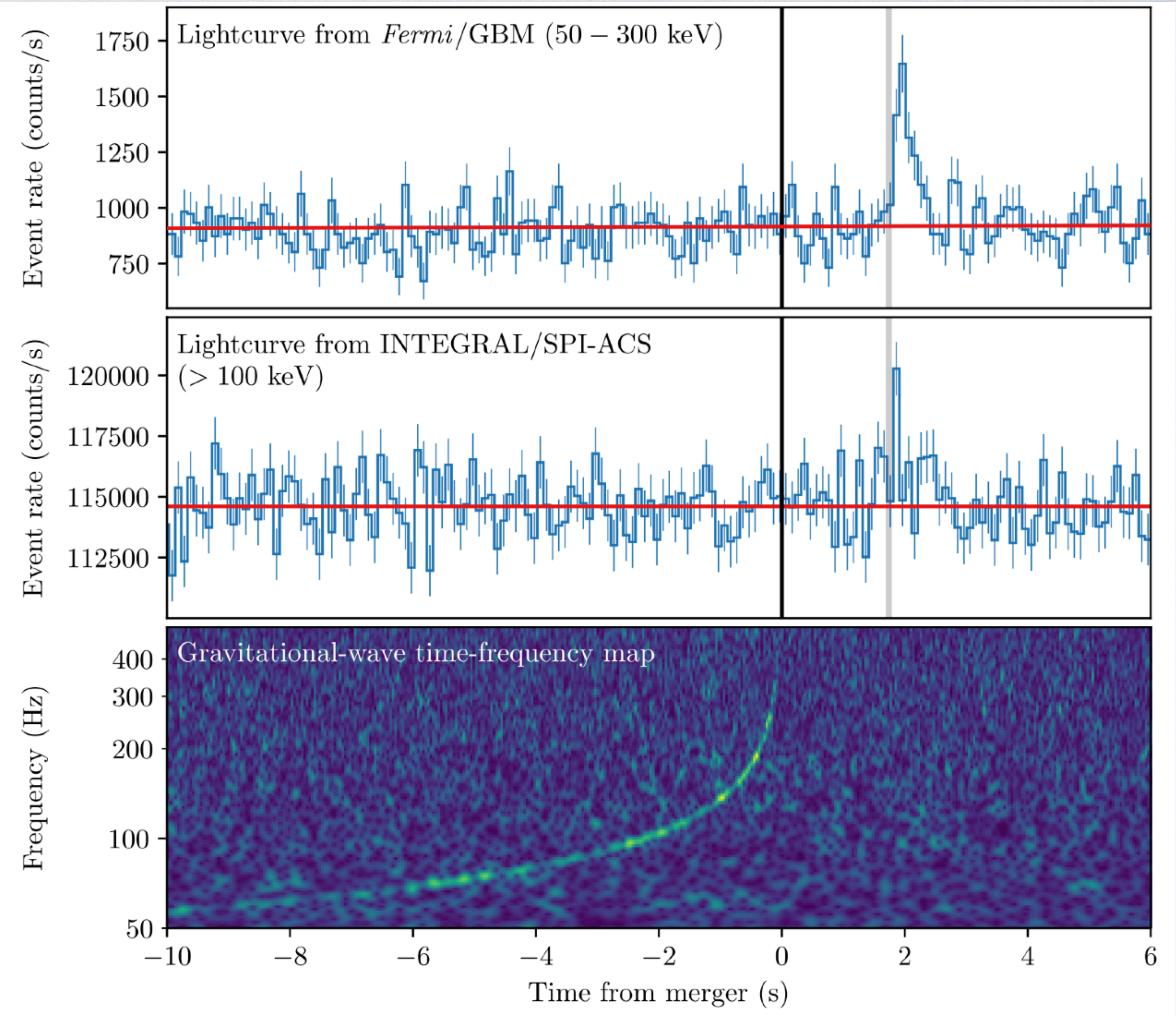
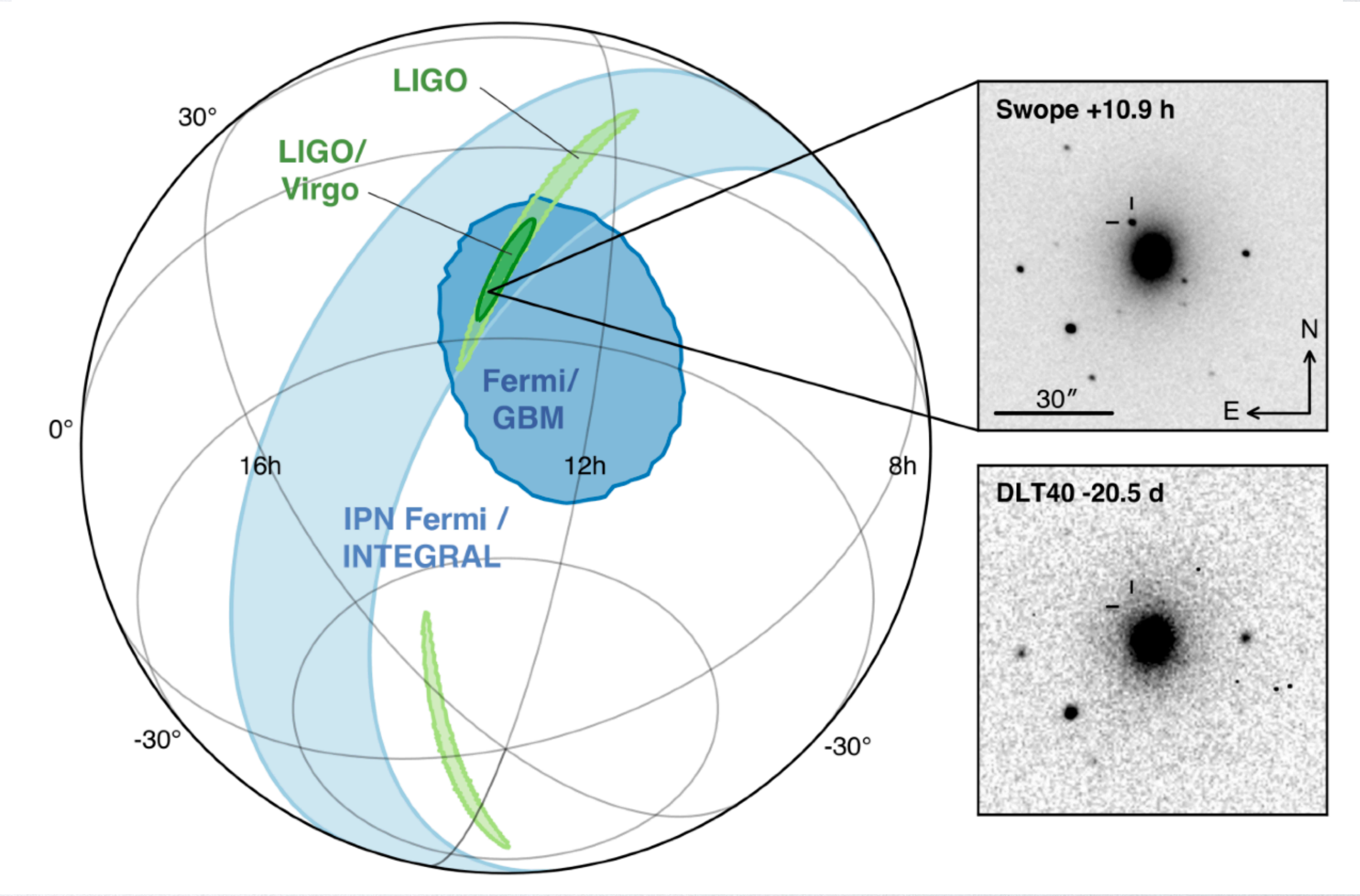
Motivation

B. P. Abbott *et al* 2017 *ApJL* **848** L13

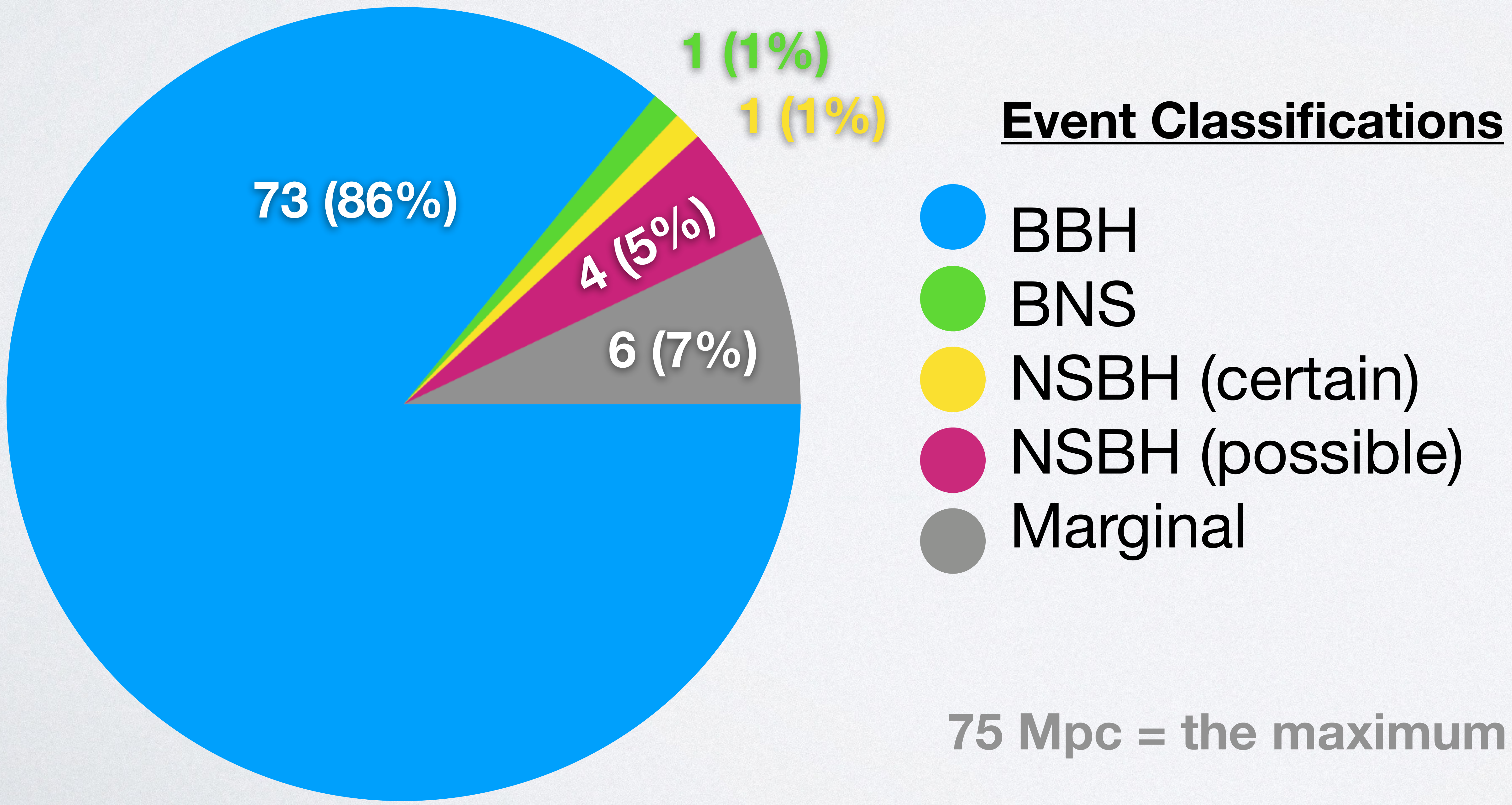
- **The joint detection of GRB 170817A / GW170817** provided incredible insight into a number of topics:
  - binary neutron star (BNS) mergers are progenitors to short GRBs
  - constraints on gamma-ray emitting region in the GRB
  - constraints on speed of gravity, Lorentz invariance, Shapiro delay
  - origins of heavy elements via subsequent kilonova
- **But plenty of questions remain to be answered**
  - rate of short GRB / kilanova production via BNS merger
  - structure of off-axis emission in GRBs
  - expected time delay between GW and GRB, which in turn informs measurements of fundamental physics parameters like speed of gravity
- **We need more joint detections of BNS events!**

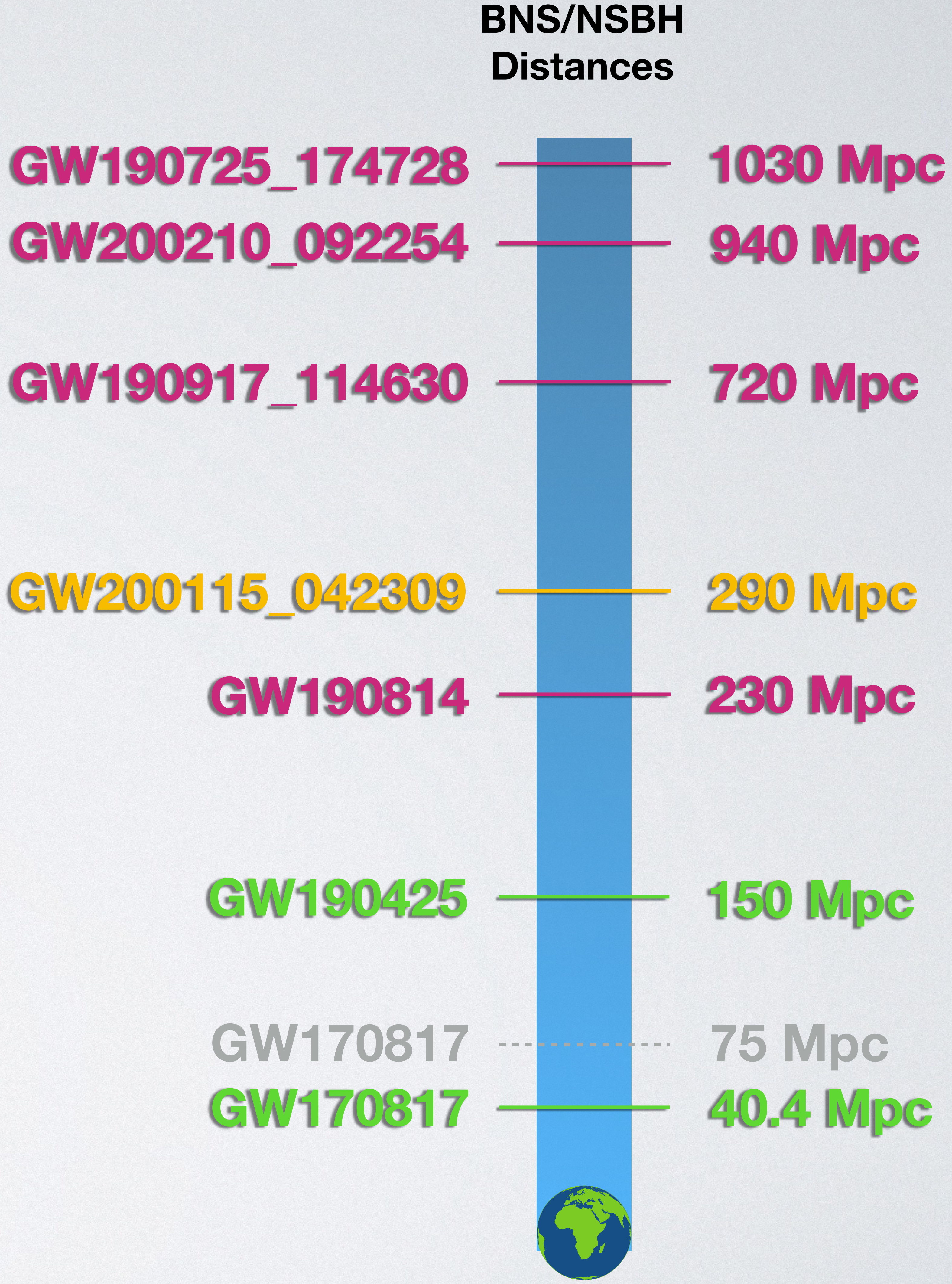




Third Gravitational Wave Observing Run (O3)

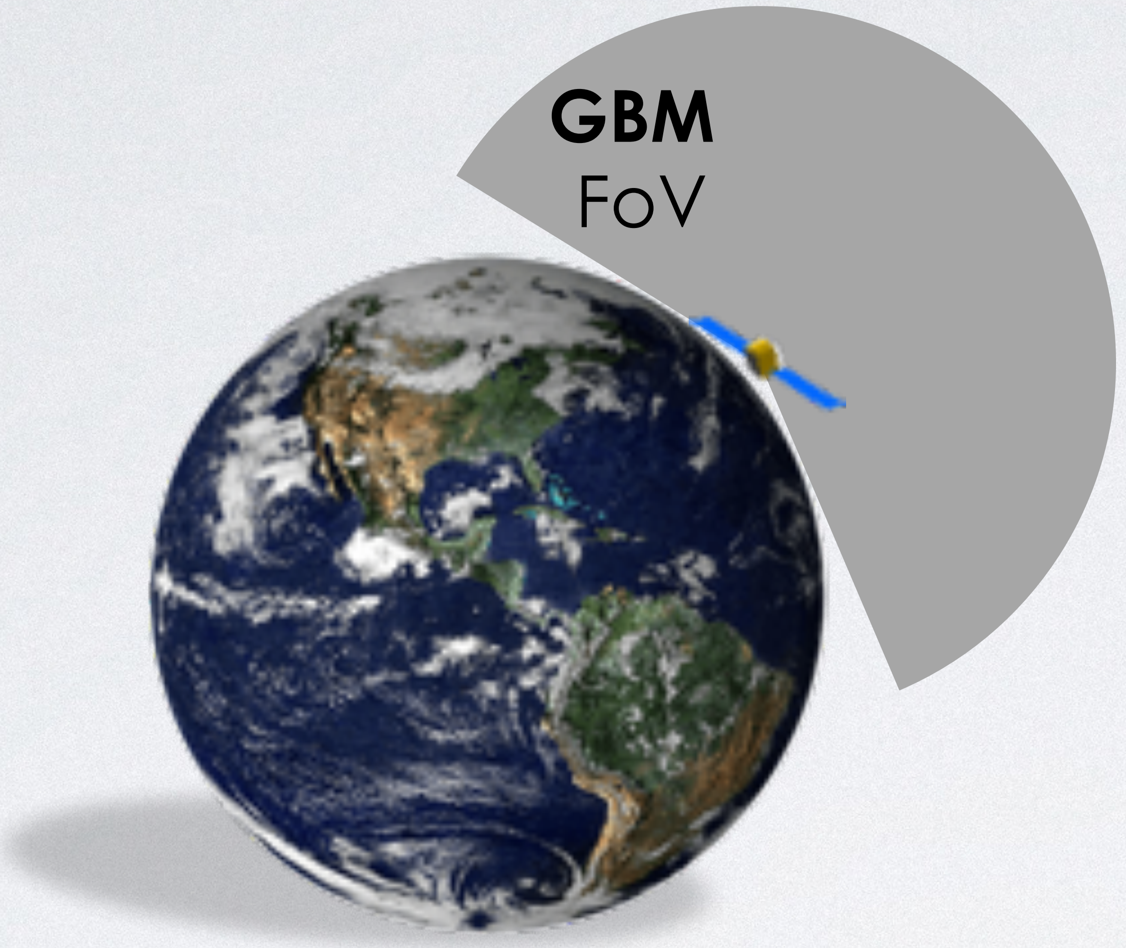
- Following sensitivity upgrades, LVK conducted its **third observing run from April 2019 to March 2020**
- Subsequent catalog publications GWTC-2, 2.1, and 3 containing a **8-fold increase in GW events** that are likely to be astrophysical (79 new events with $p_{astro} > 0.5$), 6 marginal events with FAR < 2 per year, $p_{astro} < 0.5$

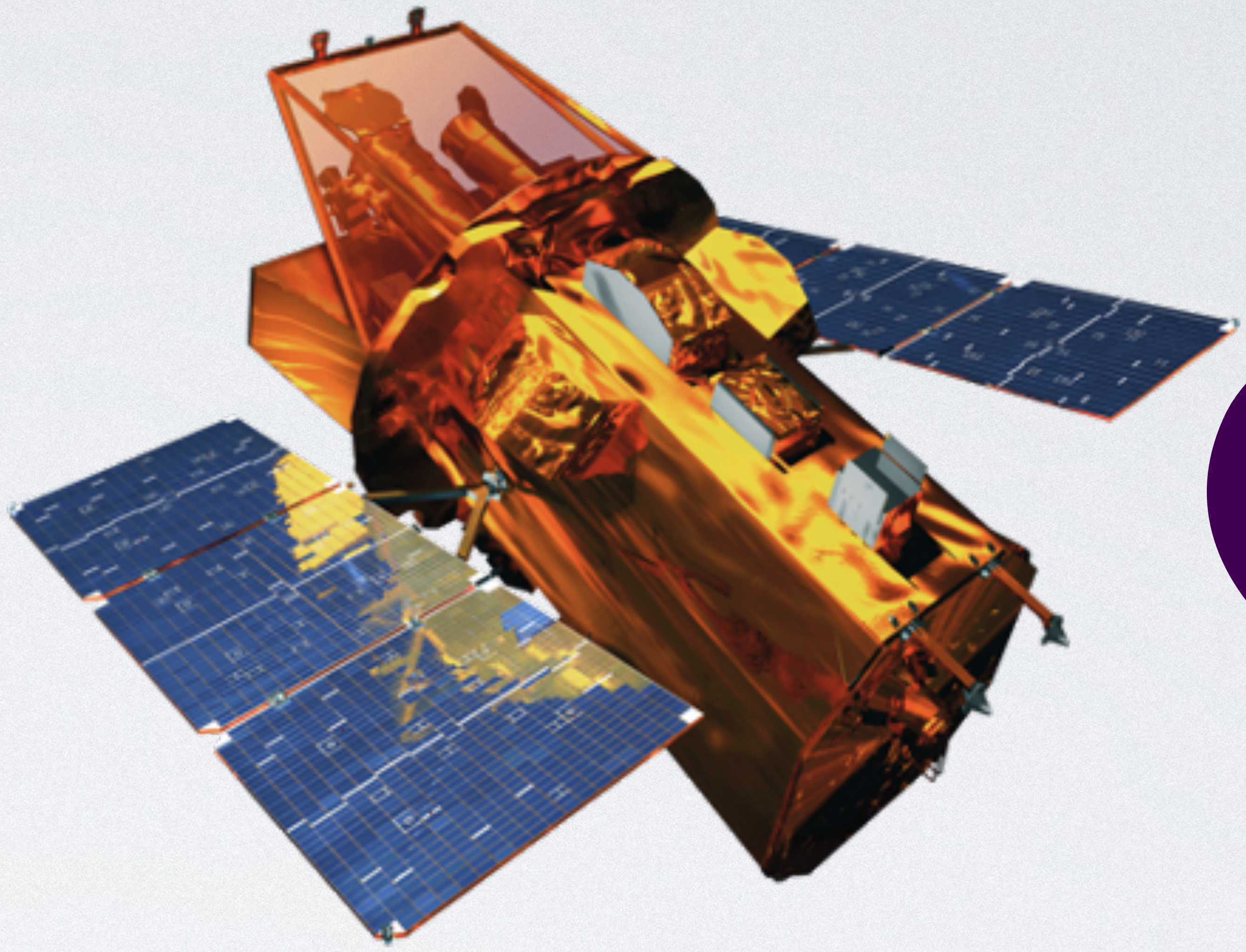


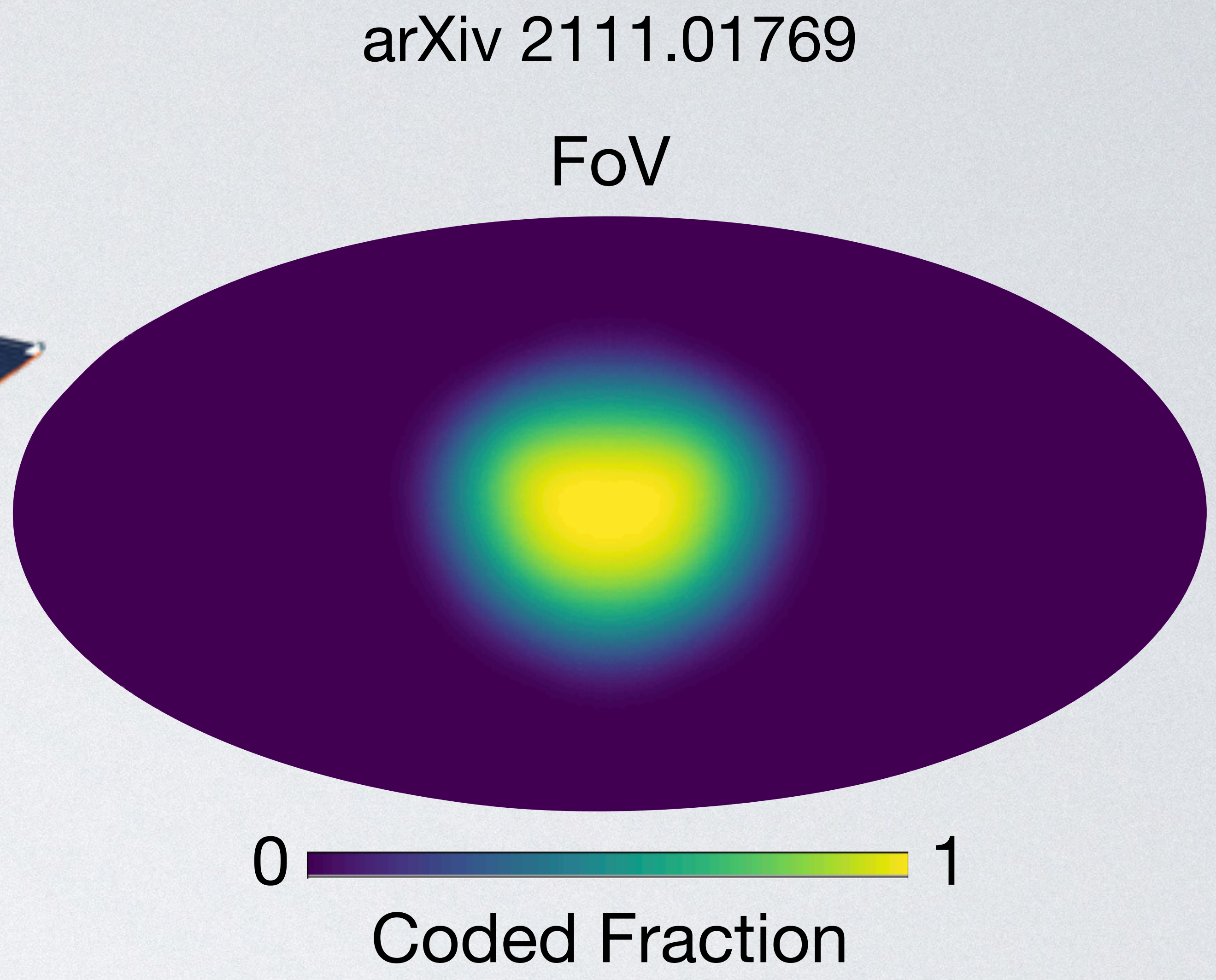


75 Mpc = the maximum distance where Fermi-GBM could detect GW170817

Complementary Instruments







Gamma-ray **B**urst **M**onitor (GBM)

- >8 sr field-of-view (FoV)
- Covers entire sky every ~90 min
- Localizations ~few deg
- Energy range: 8 keV - 40 MeV

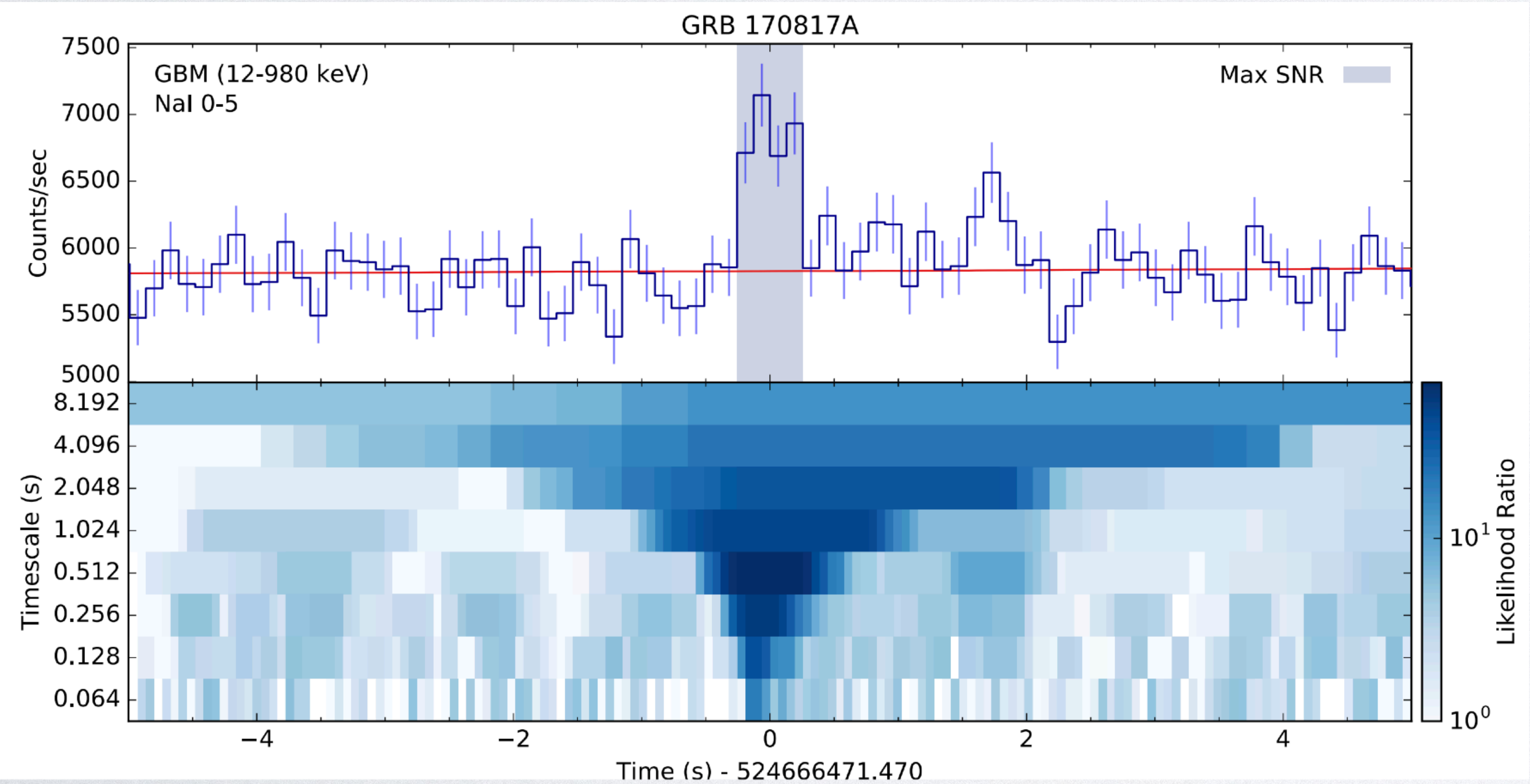
Burst **Al**ert **T**elescope (**BAT**)

- 2.2 sr FoV
- Sensitive to lower fluxes than GBM
- Localizations ~few arcmin
- Energy range: 15 keV - 150 keV (imaging)

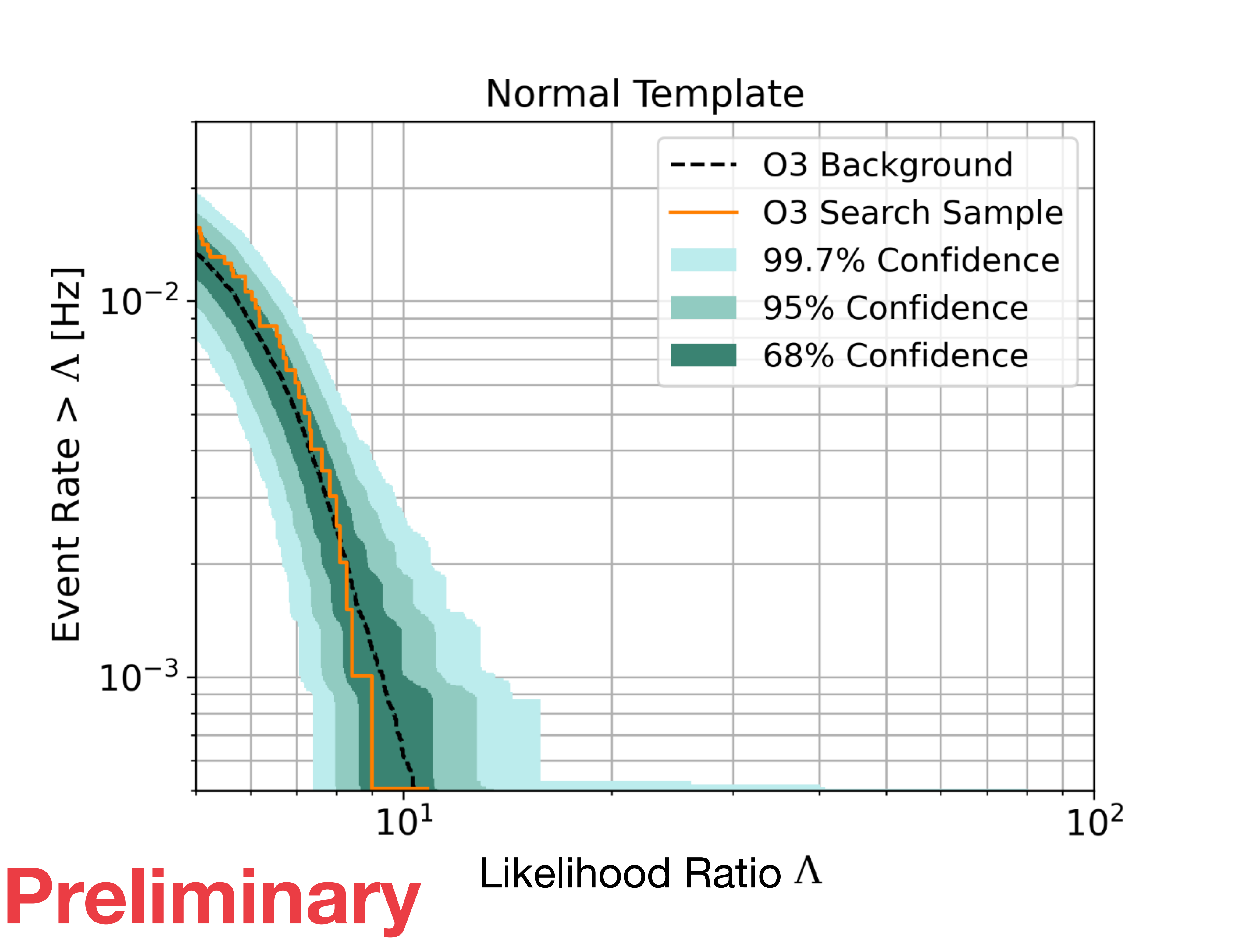
Fermi-GBM Searches

- **No on-board GRB triggers** within 10 minutes of GW events with $p_{astro} > 0.5$
- Most sensitive method, the **Targeted Search**, scanned continuous time tagged event (CTTE) data [-1 s, +30 s] around each GW event. Uses a likelihood ratio test identify GRB-like transients with 3 characteristic spectral templates (soft, normal, hard). **Found no significant GRB counterparts**.

Example Targeted Search for GRB 170817A

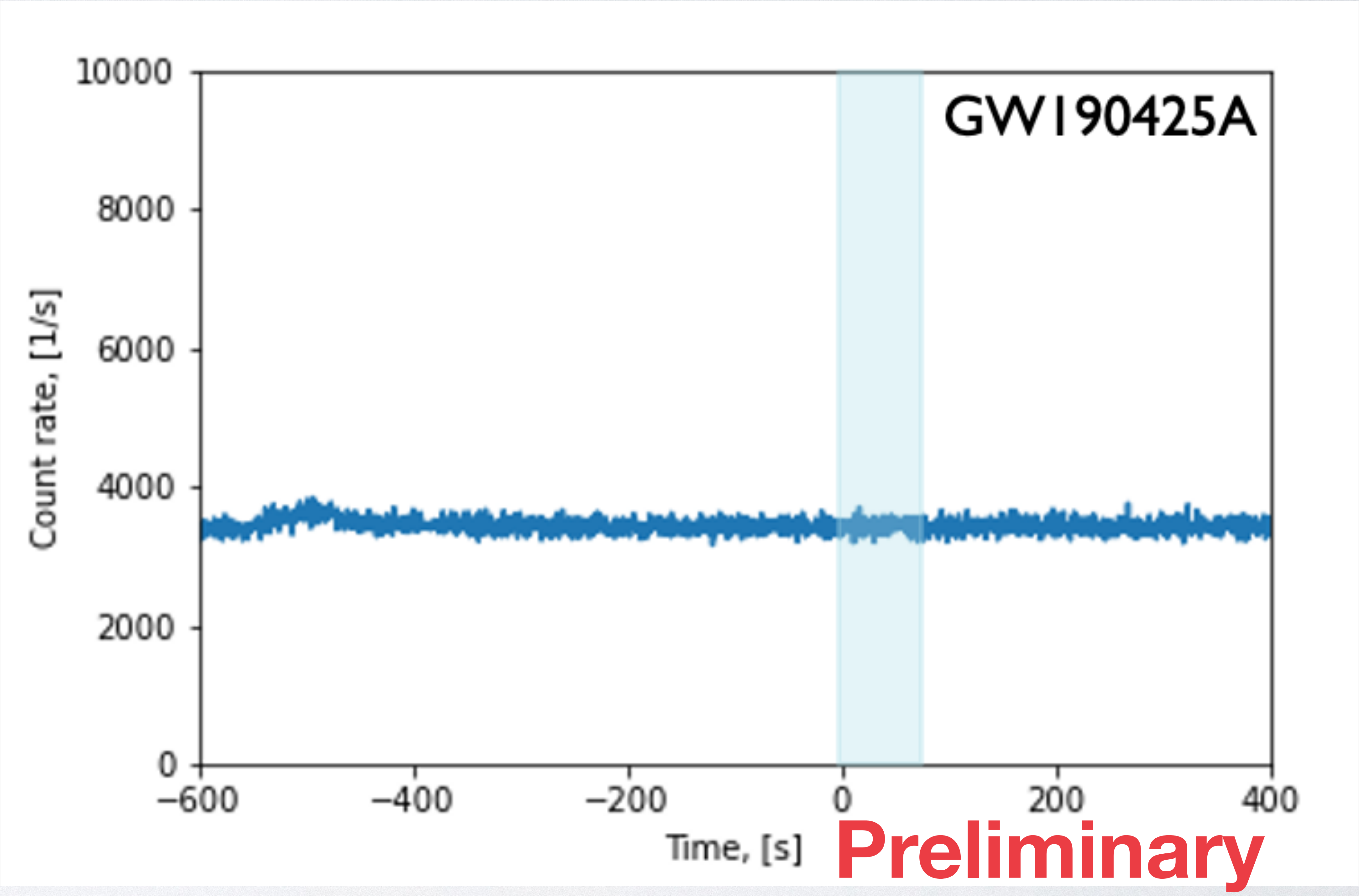


Kocevski et al. *ApJ.* (2018)



Swift-BAT Searches

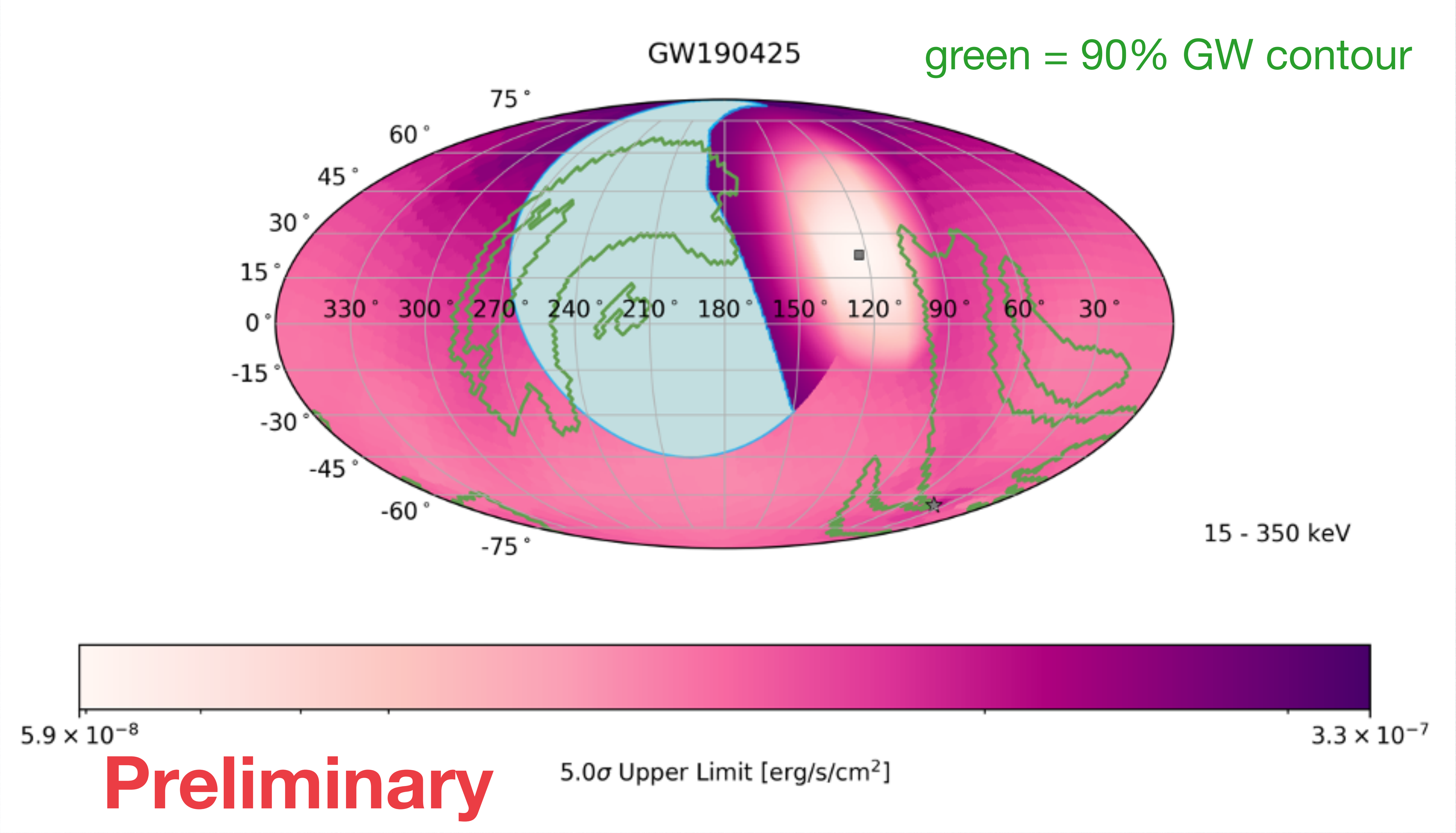
- **No on-board GRB triggers** associated with GW events with $p_{astro} > 0.5$
- Also applied a rates based search to scan for 1-second long transients [-1 s, +30 s] around each GW event. **No significant counterparts found, defined as ≥5σ above background.**



- **Note:** newer GUANO technique enables downlink of full Swift dataset near GW triggers. Implemented in the middle of O3, will be fully applied to next observing run.

Interpreting Non-detections

- Using the GBM Targeted Search and the BAT 1-s rates search we can set flux upper limits as a function of sky position
- **For the only BNS event GW190425 the marginalized flux U.L.** + estimated luminosity distance of 150 Mpc yields L_{iso} ~ 8.4x10^{47} erg/s >> GRB 170817A which **is not constraining**
- **Other reasons for the non-detection of GW190425:**
  - 60% sky coverage
  - viewing angle could too far off the jet axis



Upper limits assuming a Band spectrum (E_{peak} 230 keV, α = -1, β = -2.3)

Interpreting Non-detections

- Sheer volume of BBH events provides a few nearby, very massive systems that would have yielded a strong EM signal under a neutrino anti-neutrino ($\nu\bar{\nu}$) annihilation driven wind scenario

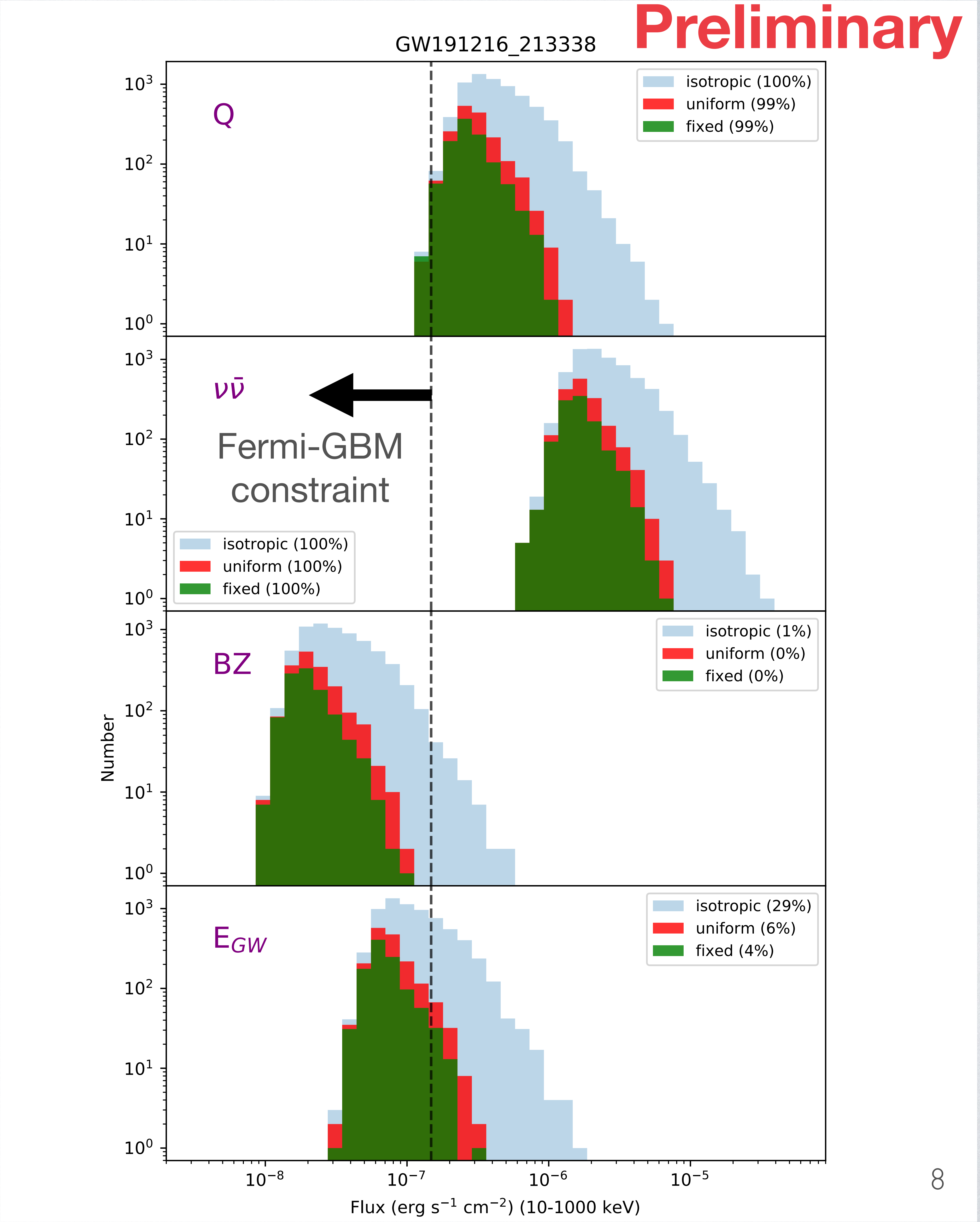
GW191216_213338

D_L 340 Mpc → closest BBH in O3

m1 12.1 Msun

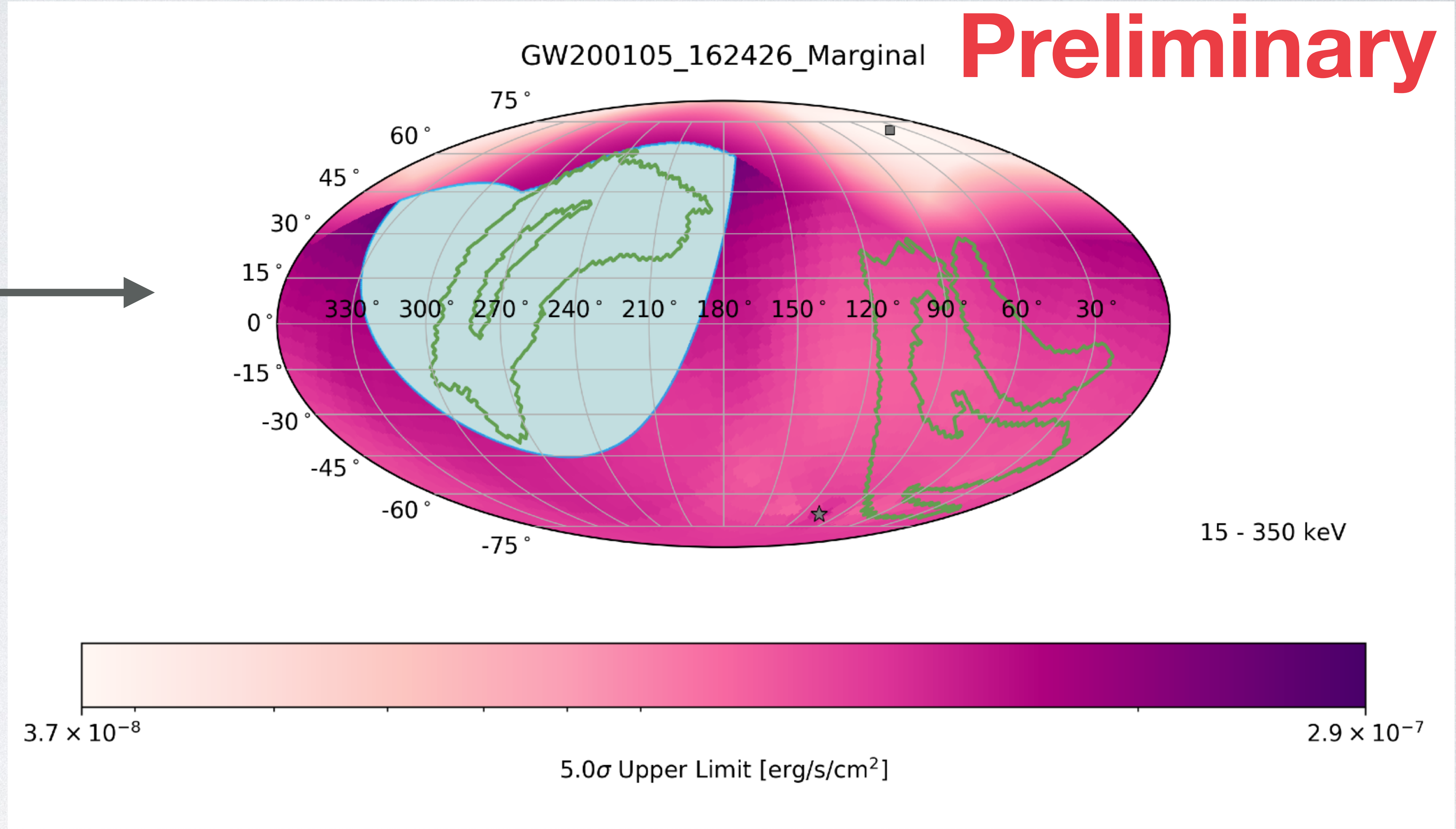
m2 7.7 Msun

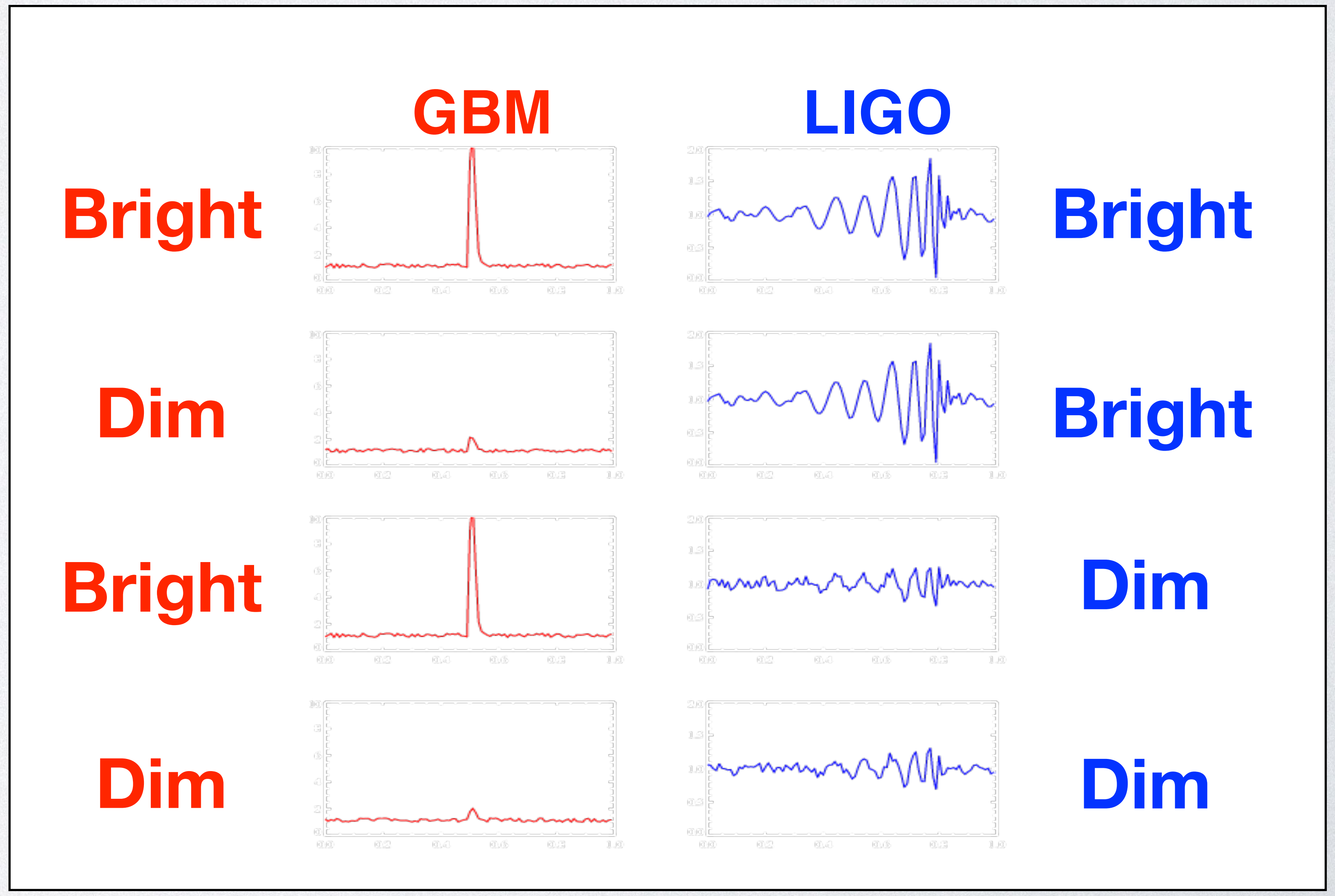
- **Details**: Simulate a population of EM emission scenarios, check which fraction are ruled out by gamma-ray flux upper limits. BBH parameters (final mass, distance, inclination, etc) sampled from posterior distributions, GRB opening angles sampled from isotropic (90˚), uniform 10-40˚, fixed 20˚ cases



What about the marginal GW events?

- Set of marginal GW events (FAR < 2 per year, p_{astro} < 0.5) from O3 contain several low-mass systems which could be BNS or **NSBH** →
- Applied the same Fermi-GBM and Swift-BAT searches to see if we could confirm any systems as astrophysical with a GRB counterpart. **No significant detections**.
- **Note:** Fermi-GBM, Swift-BAT, and many others are working on digging even deeper into the joint sub-threshold regime. See C. Stachie at al 2022 ApJ **930** 45, Aaron Tohuvavohu *et al* 2020 *ApJ* **900** 35, etc for more details





Summary

- LIGO, Fermi-GBM, and Swift-BAT are working together to enhance the number of joint GRB-GW detections, as best we can.
- No significant detection of a GRB counterpart to GW events with $p_{astro} > 0.5$ during O3
- **BNS/NSBH upper limits are not constraining**, for sure due to increased event distances compared to GW170817 but also partial coverage in some cases, potentially unfavorable viewing angles
- **BBH upper limits are constraining for some systems & models** ($\nu\bar{\nu}$)
- Rapidly approaching O4 will provide additional opportunities for joint detection of a BNS event, lots more BBH events to further constraint BBH models