Gamma-ray burst precursors observed by Fermi-GBM

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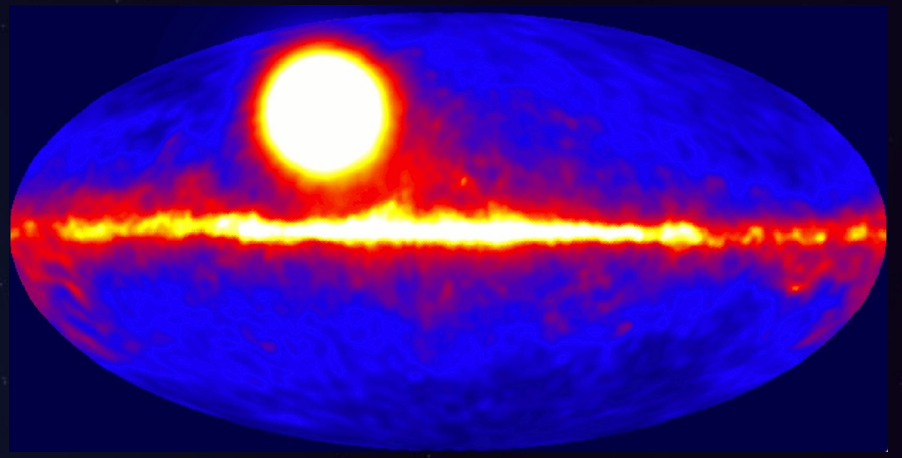
Gamma-ray bursts

- Discovered in 1967
- Two types:
  - Massive star collapse $(> 2s)$
  - Binary neutron star merger $(< 2s)$

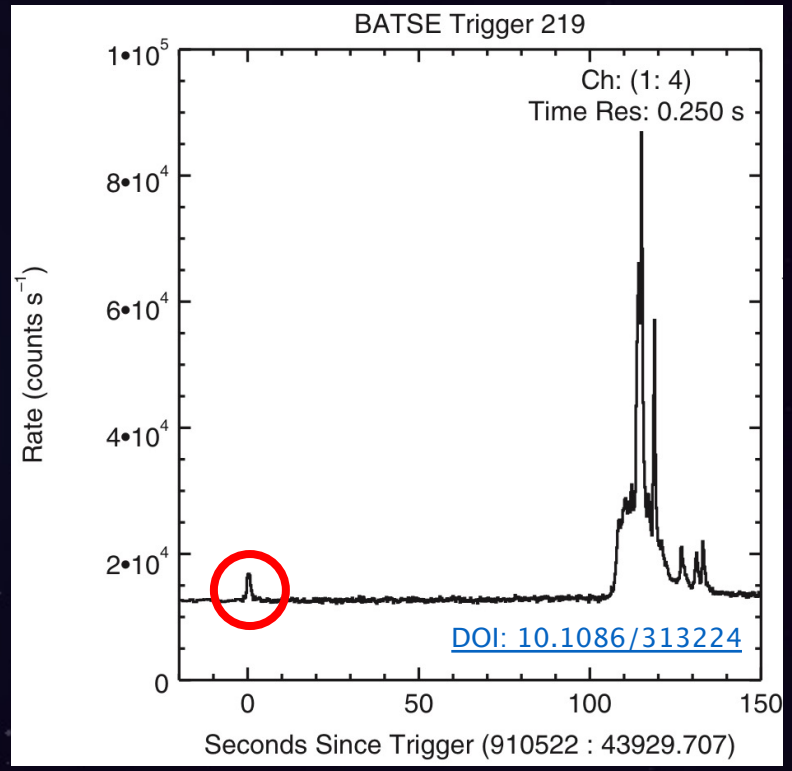


(Credit: NASA. Animation: Andrew Levin)

- Compact object launches erratic outflow → particle acceleration:
  - Electrons → gamma rays
  - Baryons → cosmic-rays and neutrinos?

Precursors

- Three phases
  - Prompt: Gamma rays
  - Afterglow: X-ray to radio
  - Precursor: Gamma-ray activity **before** prompt
- First reported in 1991
- Mostly in long GRBs
- Several studies:
  → Between 3% and 20% of GRBs have a precursor



Precursors

- Theoretical candidates:

  Photospheric emission, cocoon/shock breakout, NS magnetic interactions, crust cracking, central engine turning on & off, …

  → Origin still uncertain

- Goal of this analysis:
  - Construct precursor catalog:
    - Examine precursor properties
    - Allow multi-messenger follow-up studies

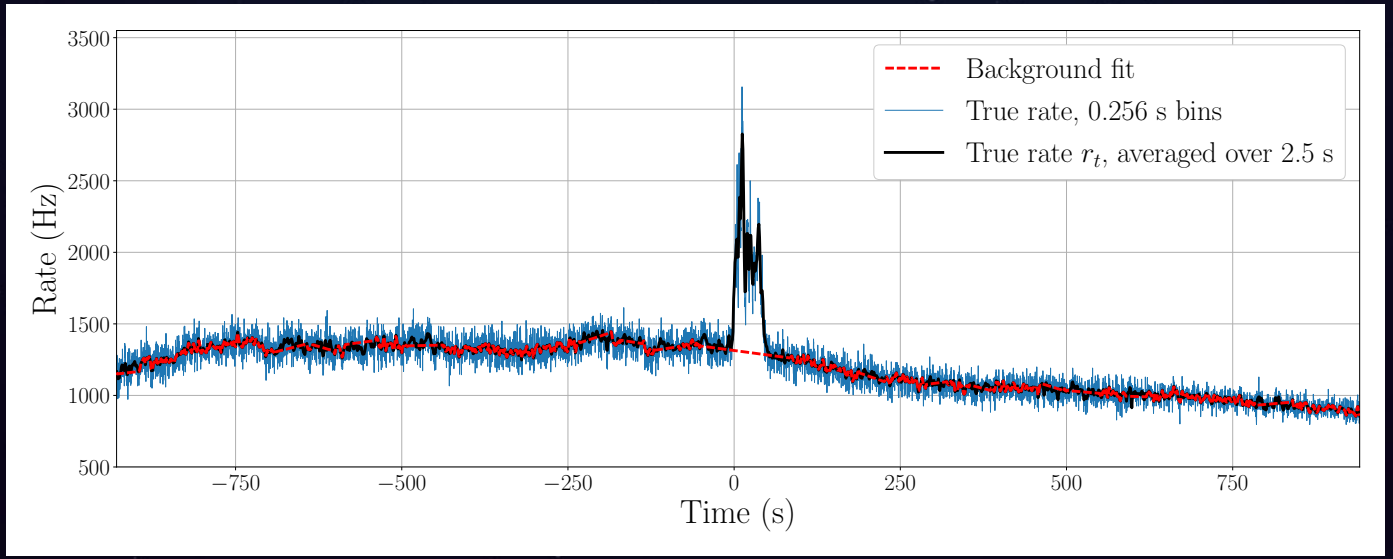
Analysis: data

- Fermi-GBM:
  - Active since 2008
  - Has been detecting ~1 GRB per day
- Format:
  - Time window: [-1000 s, 1000 s] around trigger
  - 12 identical NaI detectors
    (pointing in different directions)
    → Select 2-3 relevant subdetectors

- Available online: https://heasarc.gsfc.nasa.gov/FTP/fermi/data/gbm/bursts/

Analysis: background characterization

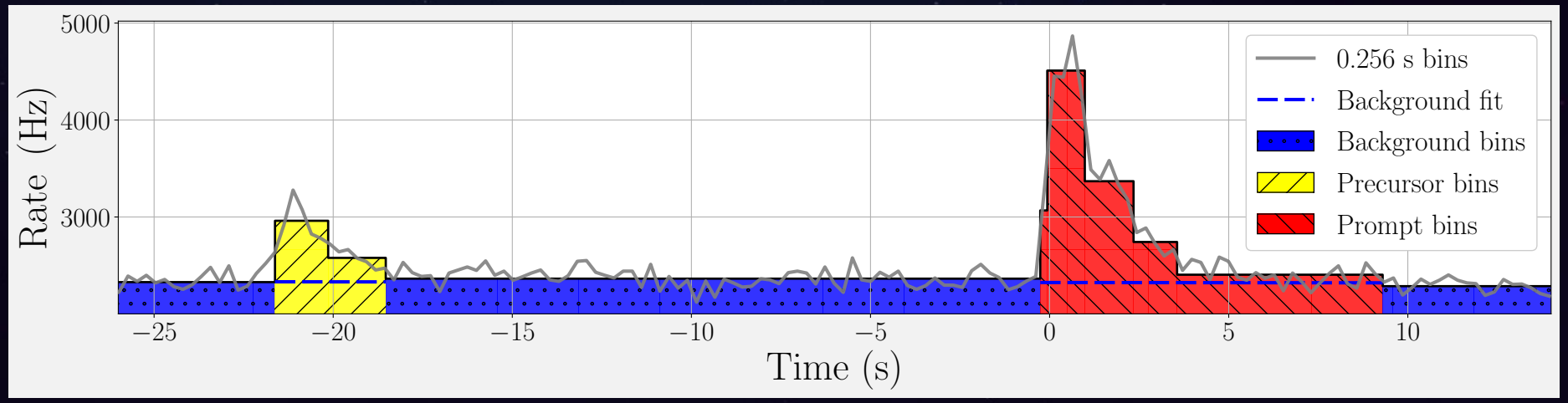
- Stage 1:
  - Identify time intervals in which rate is consistent with background
  - Generally done by hand
  - This analysis: fully automated!



Allows determination of background subtracted rate at later stage

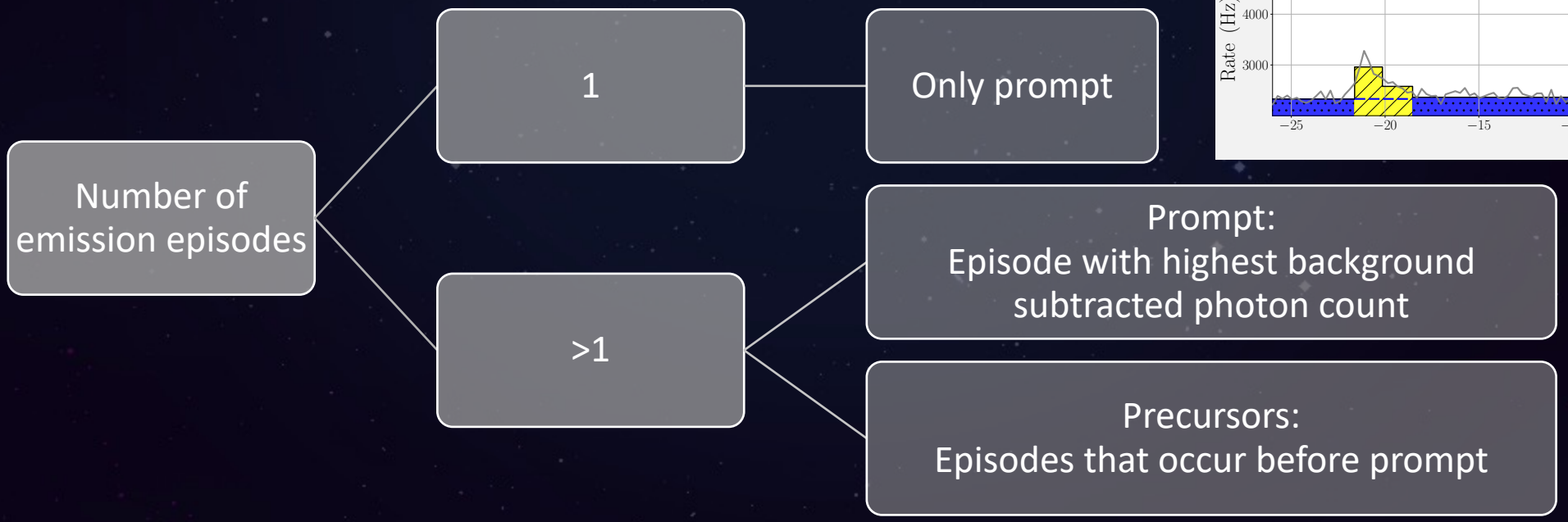
Analysis: light curve binning

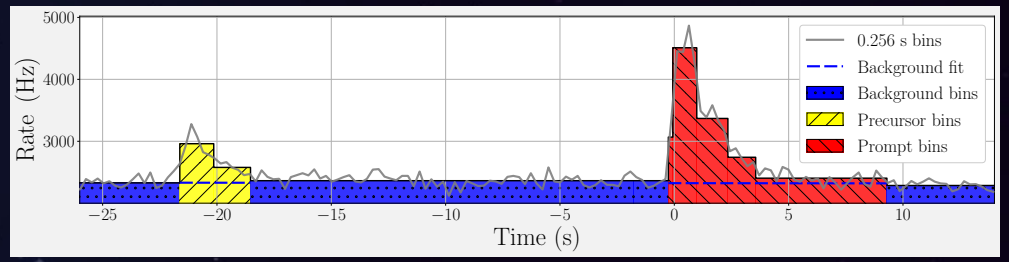
- Stage 2: Apply a suitable binning → Bayesian blocks DOI: 10.1086/306064
  - Number of bins optimized
  - Bin-edges optimized
  - Constructed for:
    - Each of the selected subdetectors
    - Summed data of selected subdetectors



Analysis: precursor tagging

- Calculate background subtracted photon rate r_f
- Require $r_f \gg 0$ Hz and signal observed by ≥ 2 subdetectors





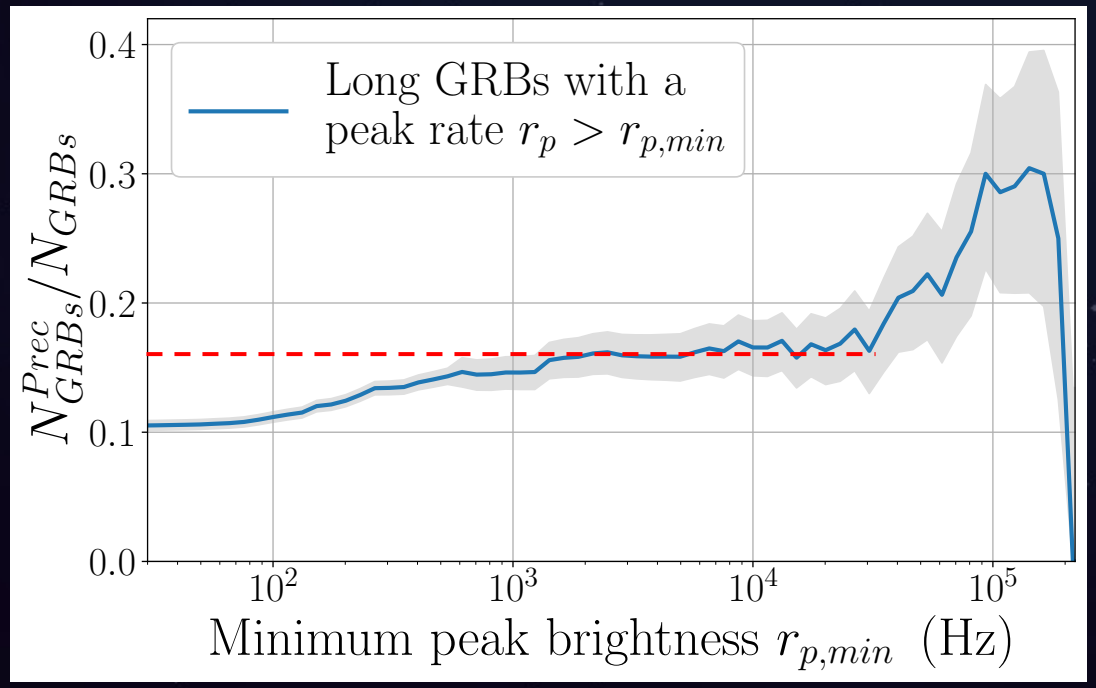
Results

- Out of 2364 analyzed bursts
  - 244 precursors
  - At most 3 precursors per GRB
    (192/23/2 GRBs have 1/2/3 precursors)
  - 217 GRBs with precursors
    - ~10% for long bursts
    - ~1% for short bursts

- Catalog & light curves available online:
  https://icecube.wisc.edu/~grbweb_public/Precursors.html

Results: fraction of GRBs with precursors

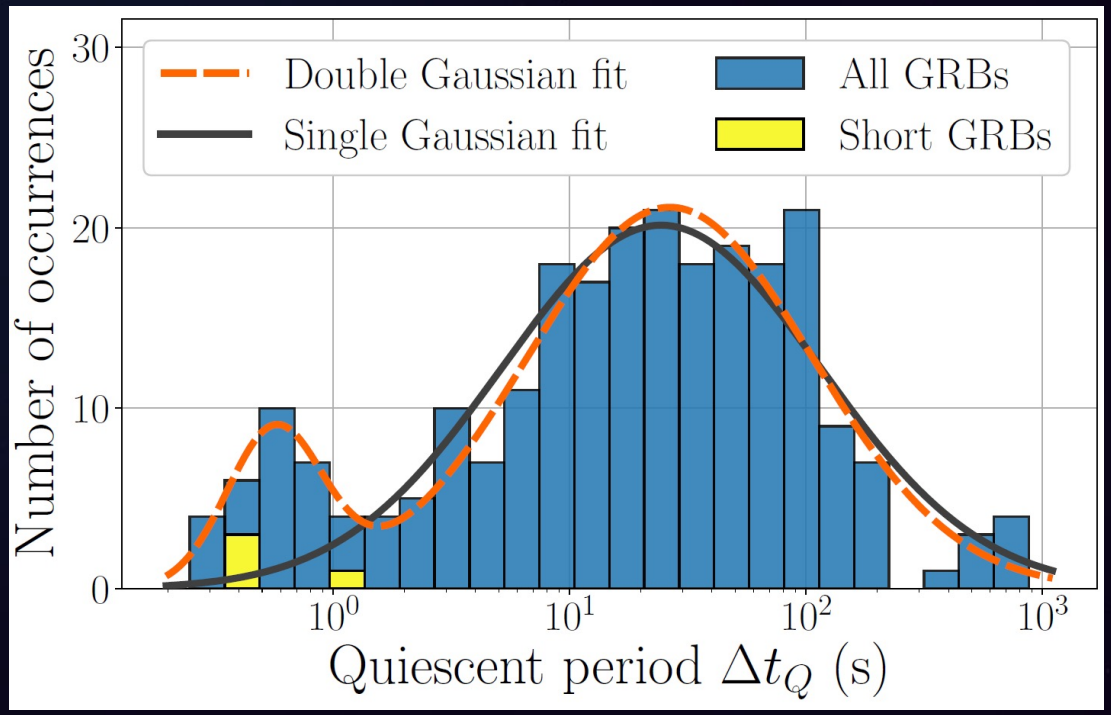
- Precursors not observable if burst is too dim / too far away
- Restrict analysis to long bursts above a minimal peak brightness



Initial increase observed which plateaus at ~16%

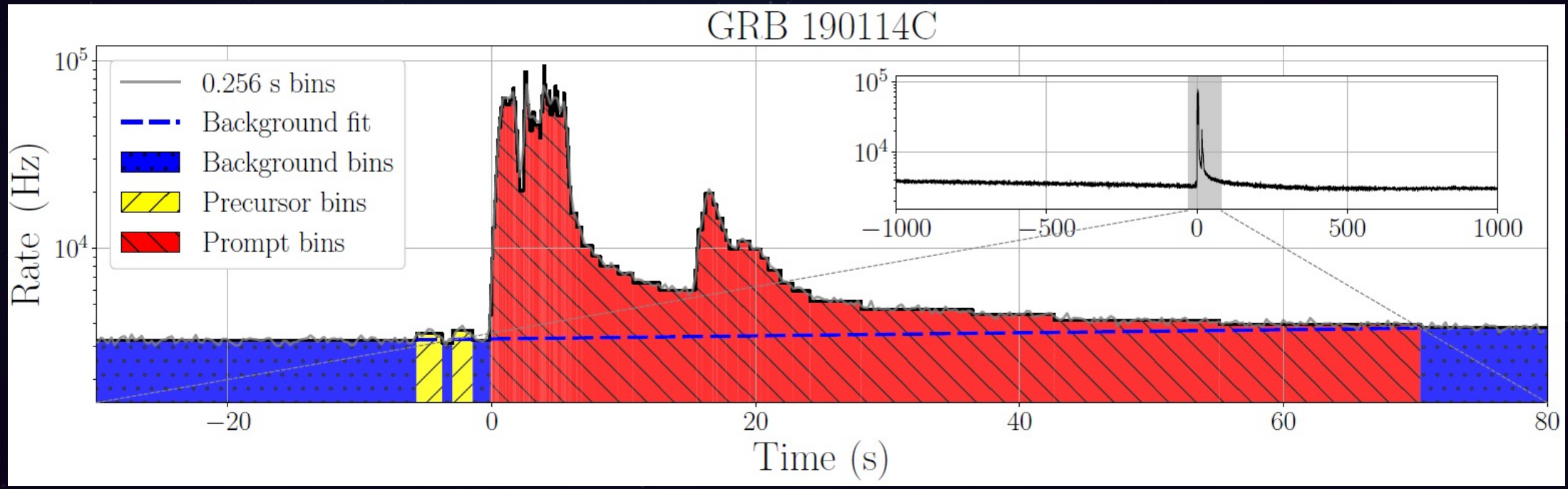
Results: quiescent time

- Quiescent time distribution (Time separating two emission episodes)
  - Two components
  - Precursors to short GRBs <2 s before prompt
  - Two populations for long GRBs
    - Single component Gaussian fit can be rejected at 3.9σ
    - Two different physical mechanisms?



Observed GRBs with > 100 GeV gamma rays

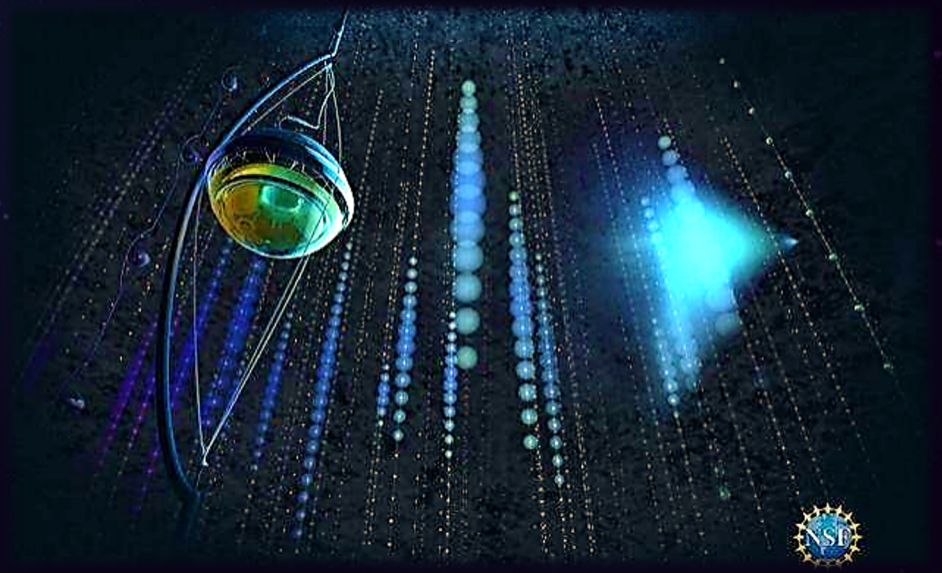
- GRB 190114C (MAGIC)
  Two HESS bursts: GRB 180720B & GRB 190829A also preceded by a precursor



Results: neutrino coincidence study

- IceCube:
  - Origin astrophysical neutrino flux largely unknown
  - Look for correlation with neutrino excess at the time of precursors

- See contribution #469



Conclusion

- Searched for precursors from GRBs detected by Fermi-GBM
- 2364 bursts analyzed using Bayesian blocks
- Results:
  - ~10% of long GRBs have precursor and ~1% of short bursts
    → More if only bright bursts are used
  - Precursors short bursts <2 s before prompt
  - 3 GRBs observed by MAGIC & HESS in our catalog

  Quiescent time precursors exhibits bimodal distribution
  → Two physical mechanisms?
- Catalog & light curves available online:
  https://icecube.wisc.edu/~grbweb_public/Precursors.html