Unveiling Extragalactic Magnetar Giant Flares with Fermi GBM:

A Comparative Study of GRB 231115A and GRB 180128A

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The Plan

- Magnetars and magnetar giant flares (MGFs)
- Galactic vs. extragalactic MGFs
- GRB 200415A (Next talk by Dr. Matthew Baring)
- GRB 180128A and GRB 231115A
  - Temporal and spectral analyses
  - Follow-up observations
    - X-ray search

Magnetars

- Young neutron stars: ~10^4 yrs
- Extreme magnetic fields: >10^{13} G
- Rotational periods: 2-12 s
- ~30 known objects
- Quiescent X-ray emission
- Host to wide variety of high energy transient activity

Magnetar Giant Flares (MGFs)

- Prompt (~0.1 s) emission
- $L_{\text{peak}} \sim 10^{44} - 10^{48}\ \text{erg s}^{-1}$
- As of 2020, 7 identified:
  3 Galactic, 4 extragalactic
- Inferred volumetric rate:
  $R_{MGF} = 3.8^{+4.0}_{-3.1} \times 10^{5}\text{Gpc}^{-3}\ \text{yr}^{-1}$
  (Burns et al. 2021)

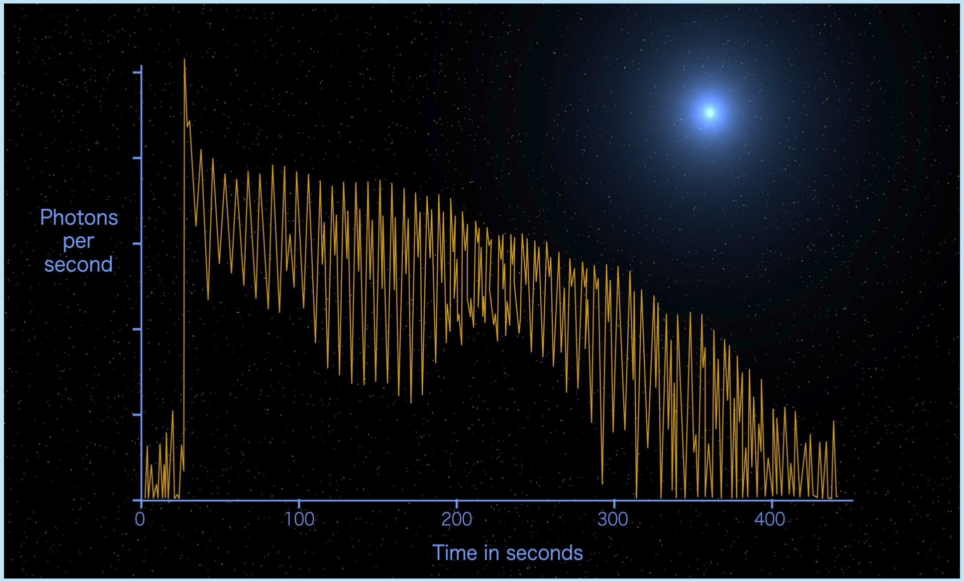
Galactic vs. Extragalactic MGFs

Galactic MGFs:

- Prompt (ms) emission
- Followed by periodic tail

Extragalactic MGFs:

- Current instrumentation has not sensitive to periodic tail emission at these distances
- Many could be masquerading as short GRBs
- Identification requires spatial alignment with nearby star forming galaxies



Credit: NASA Goddard/S. Wiessinger

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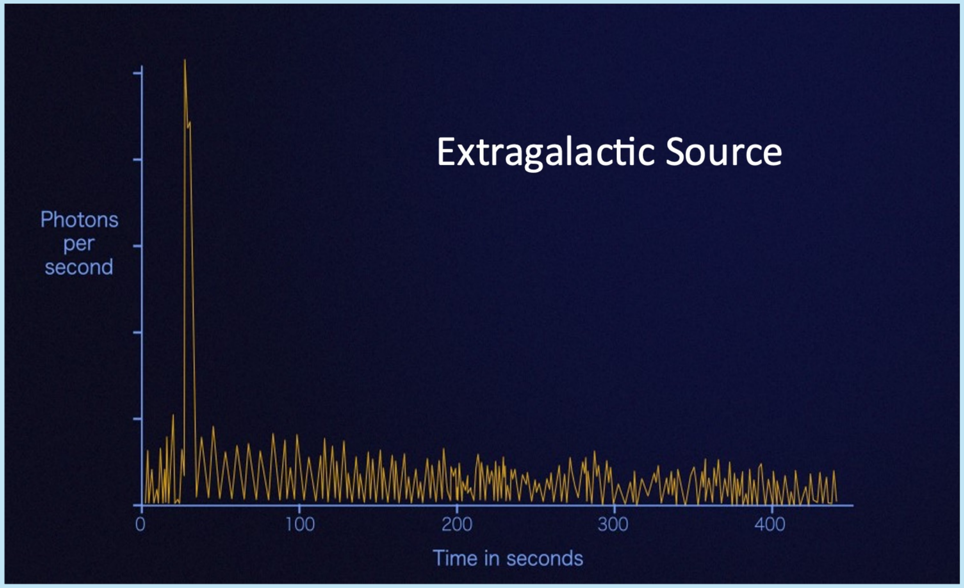
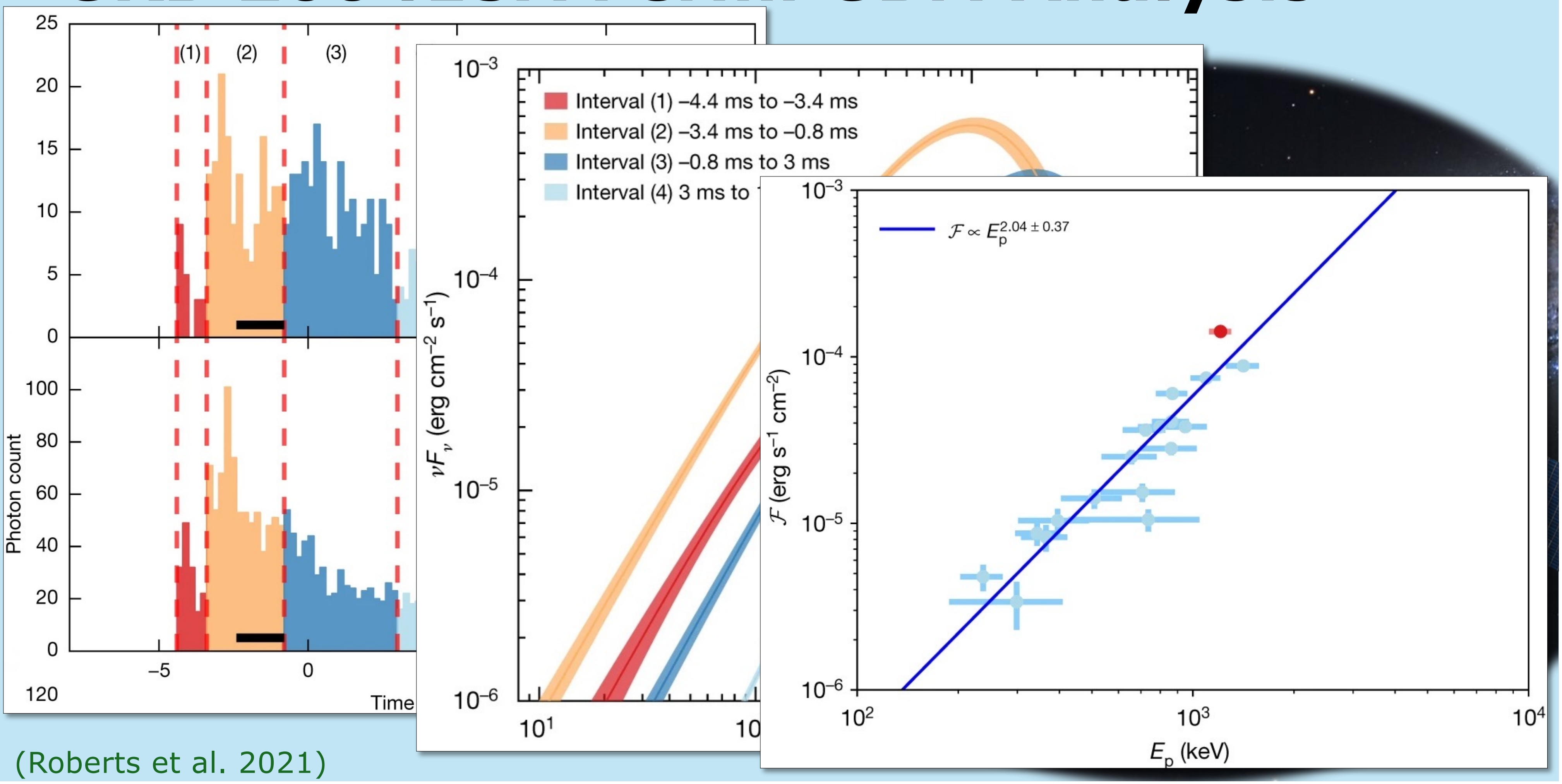


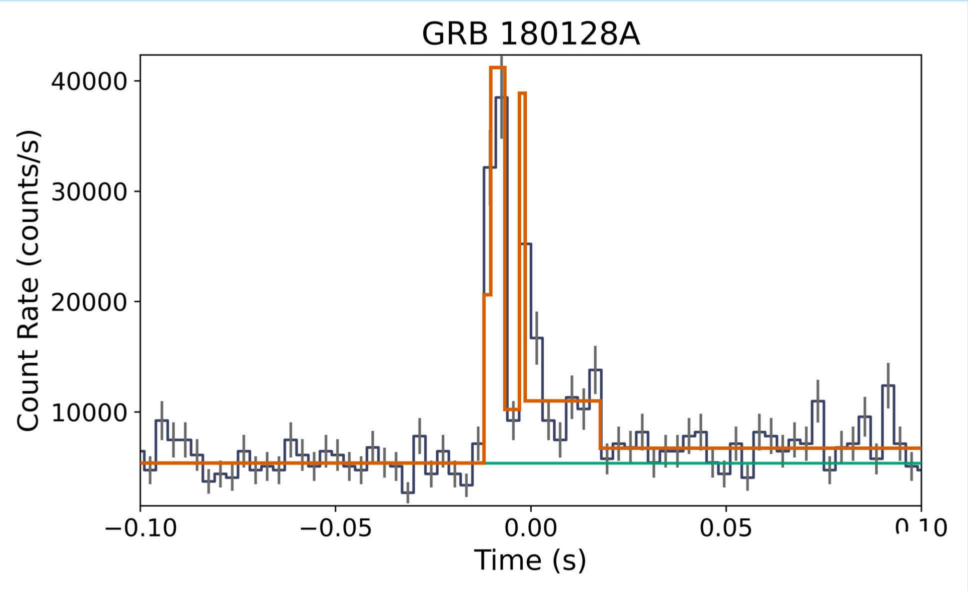
Credit: NASA Goddard/S. Wiessinger

GRB 200415A Fermi GBM Analysis

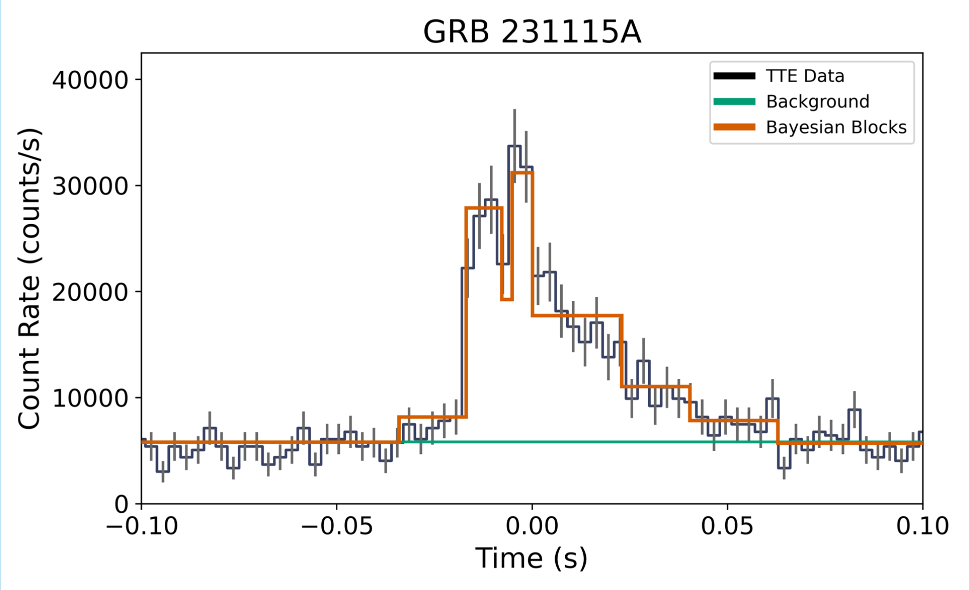


(Roberts et al. 2021)

Two More MGFs Seen by Fermi



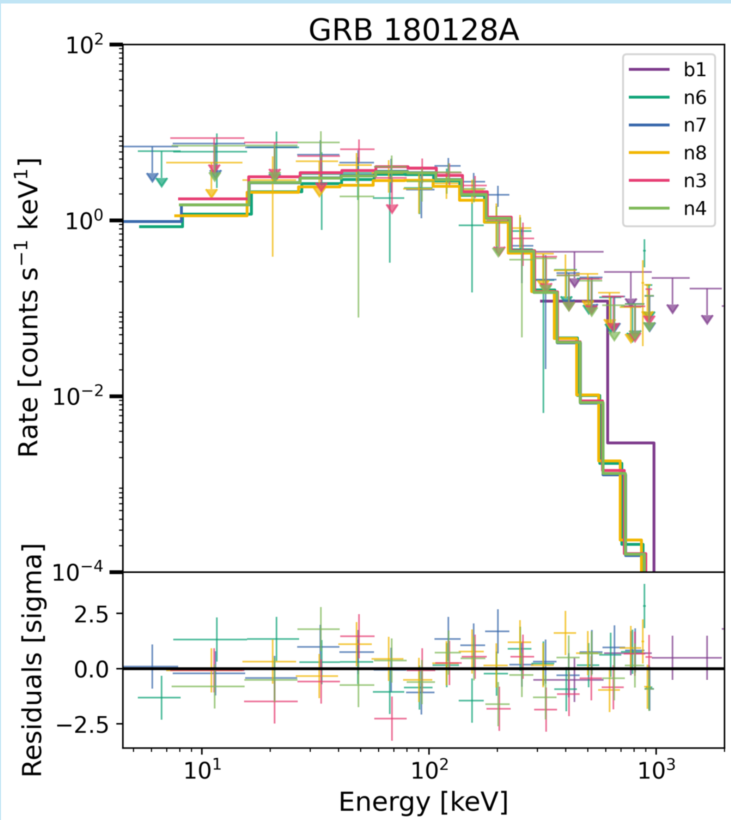
- Localized to NGC 253
- Identified in archival Fermi GBM data search (Trigg et al., 2024)



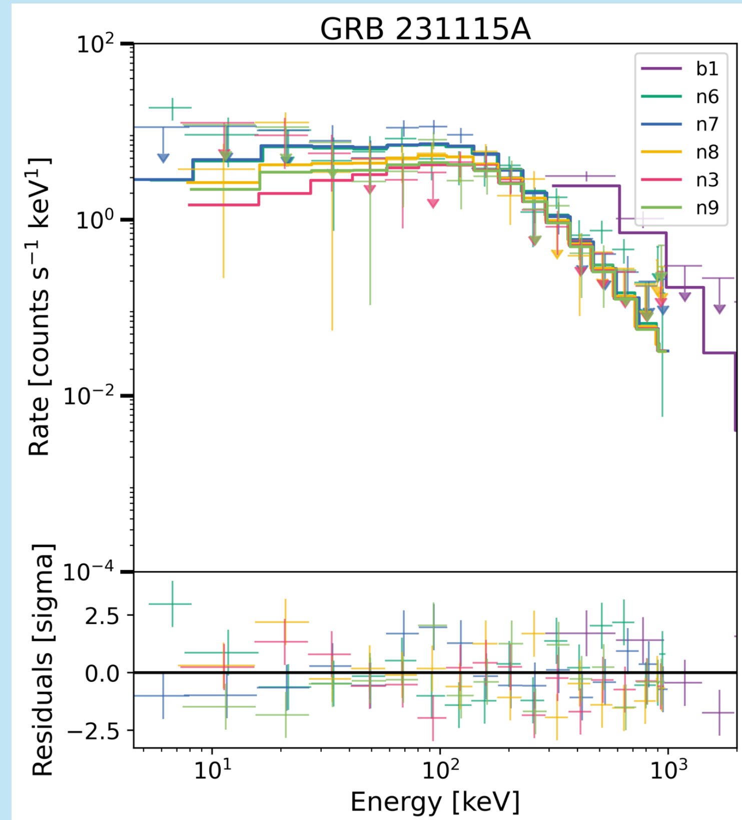
- Localized to M82
- Promptly identified as an MGF by INTEGRAL (Mereghetti et al., 2023)

Each marks the second occurrence of such an event within its respective galaxy or galaxy group

Time-Integrated Spectral Analysis



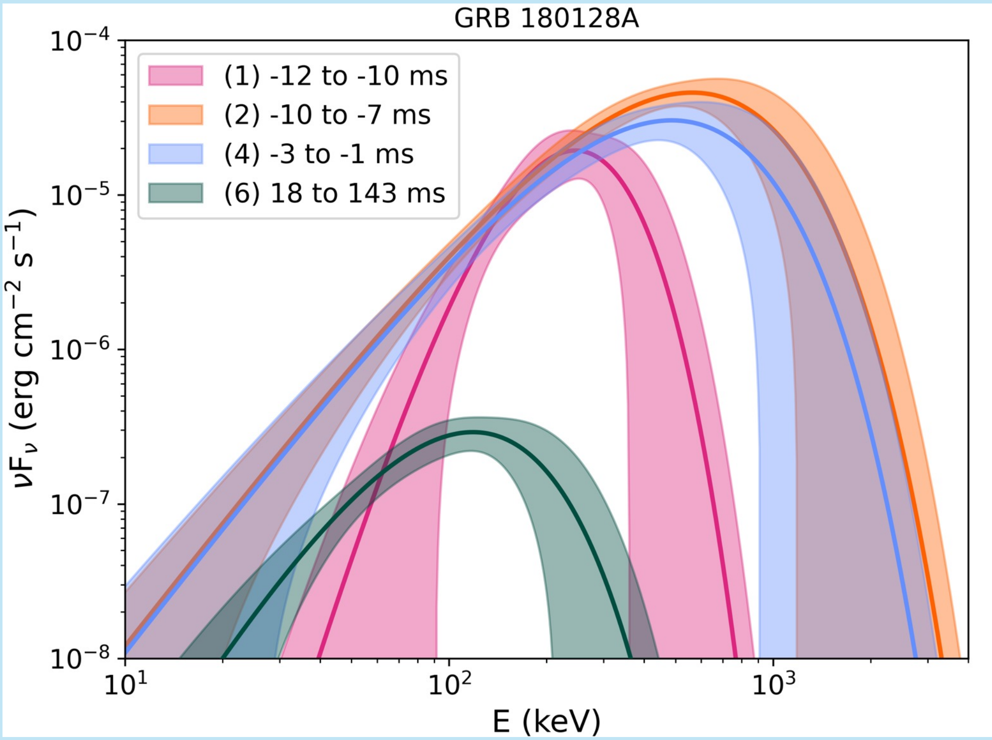
- Both well fit by Comptonized spectral model
- E_p and α fall within expectations of MGF model
- E_{iso} values consistent with all known MGFs

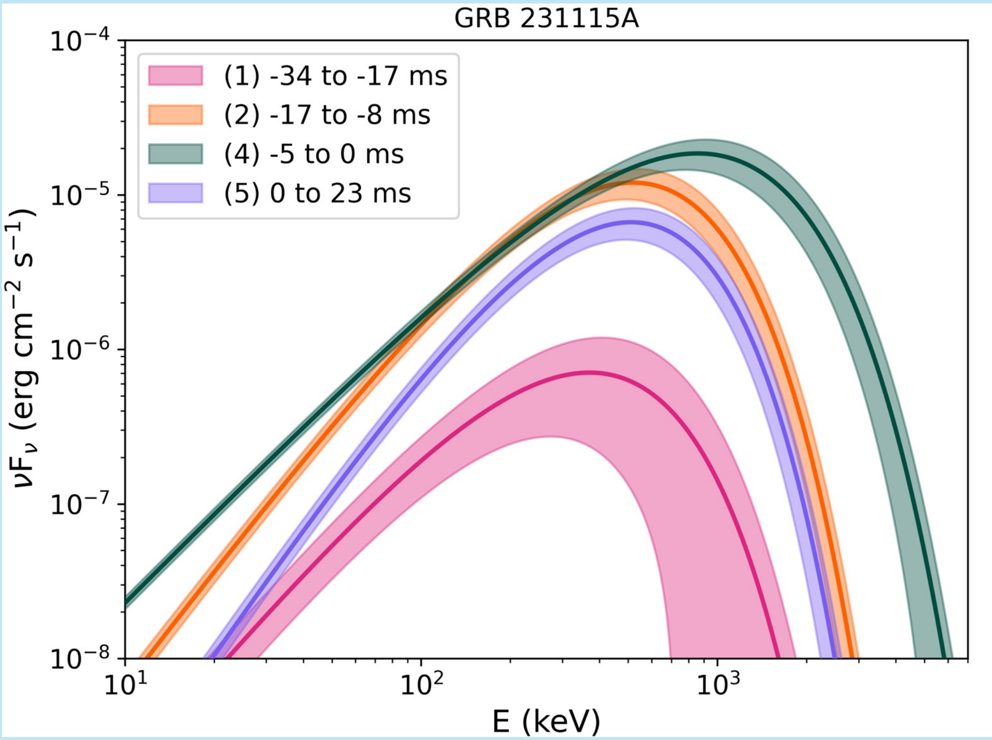


- $E_p = (290 \pm 50)\text{keV}$ $\alpha = 0.6 \pm 0.5$
- $E_{iso} = 6.0\times10^{44}\text{erg}$ (Trigg et al., 2024)

- $E_p = (600 \pm 60)\text{keV}$ $\alpha = 0.1 \pm 0.2$
- $E_{iso} = 1.15\times10^{45}\text{erg}$ (Trigg et al., submitted)

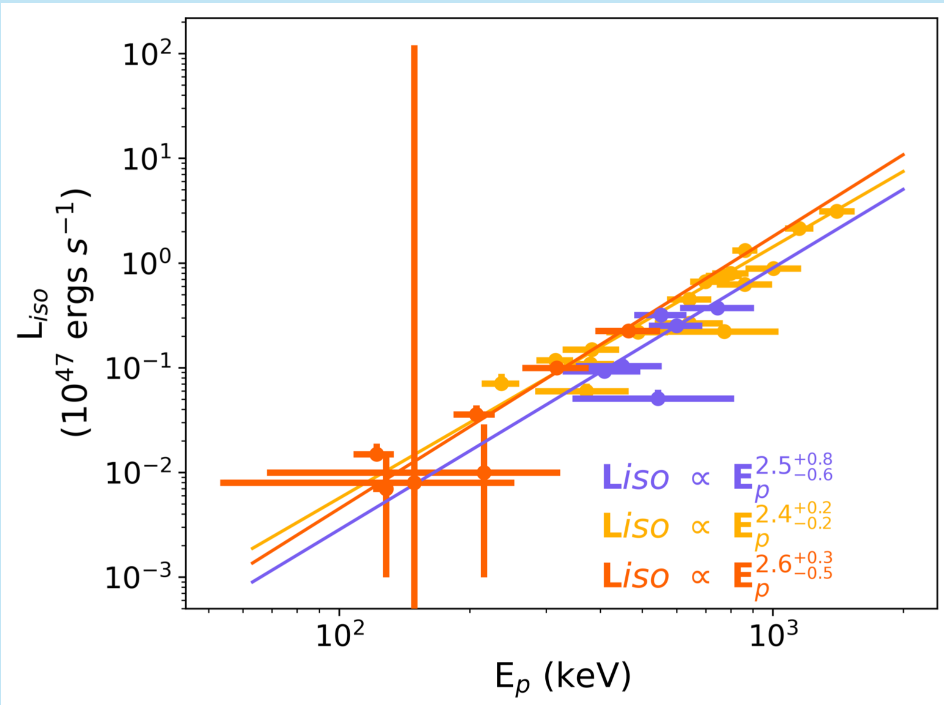
Spectral Evolution: Relativistic "Lighthouse"

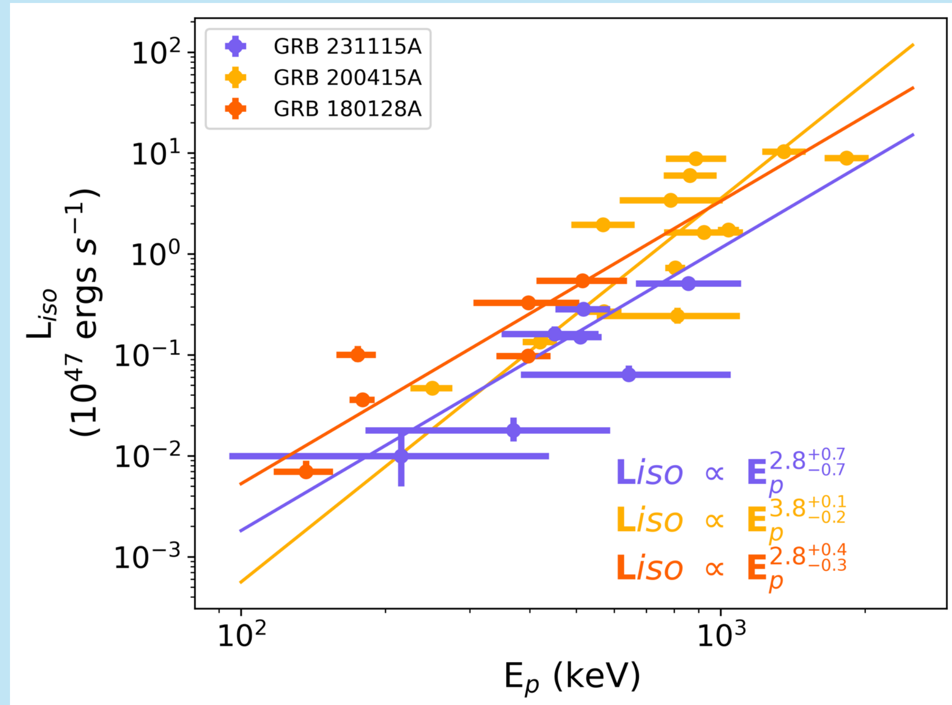




- Soft-to-hard-to-soft spectral evolution in time-resolved analyses
- This behavior is consistent with a comptonized relativistic wind origin for the prompt emission
- Both consistent with underlying model in Roberts et al. 2021

Isotropic Luminosity-Peak Energy Correlation





- Fixed interval time binning
  - $L_{\rm iso} \propto E_{\rm p}^{2}$ Strong signature of relativistic wind (Doppler boosting)
  - Agnostic binning (flux)

- Bayesian blocks binning
  - $L_{\rm iso} \propto E_{\rm p}^{2}$ relation not recovered
  - $L_{\rm iso} \propto E_{\rm p}^{4}$ for shorter binning (intensity)

Follow-up Observations

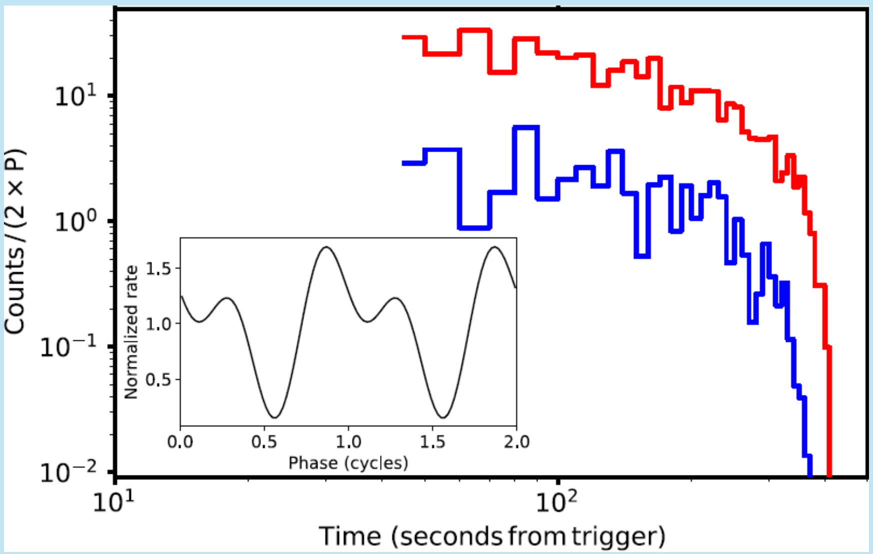
GRB 180128A

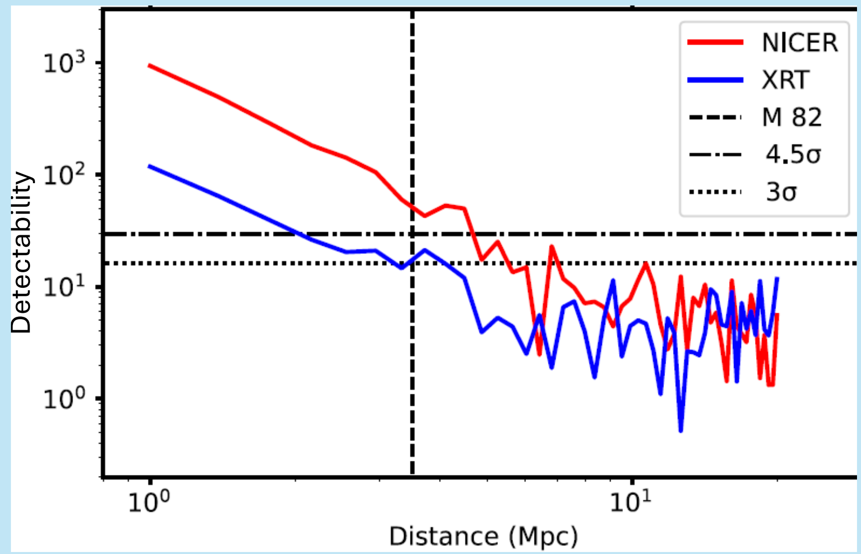
- Relied on archival data from other observatories
  - No gravitational wave signal
  - No contemporaneous radio signal
  - No supernova around time of burst

GRB 231115A

- Prompt localization and alerts allowed for follow-up by the larger community
  - No gravitational wave signal
  - No contemporaneous radio signal
  - No optical signals
    - Optical follow-up with telescope at Wendelstein Observatory, Germany.
  - No X-ray signal

GRB 231115A – MGF Tail Detection





- Simulated MGF tail light curve with XRT (blue) and NICER (red)
  - assumes properties observed in the SGR 1806−20 MGF tail
  - Scaling it to the M82 distance of 3.5 Mpc.
  - The inset shows the modulation that is embedded in the light curve.

- Pulsation detection in XRT and NICER as a function of MGF distance.
- Dot-dashed and dotted lines show 4.5σ and 3σ detection significance (single-trial), respectively.
- The vertical dashed line is the M82 distance of 3.5 Mpc.

Conclusion

- 3 extragalactic MGFs observed by Fermi *GBM*
- All consistent with expectations of MGFs
- Support model outlined in Roberts et al. 2021
- Rapid X-ray follow-up is crucial for detecting the fading signals from periodic tail