ONLINE ICRC 2021

Virtually in Berlin,
14 July 2021

Detection of the third class of gamma-ray bursts

Magnetar giant flares

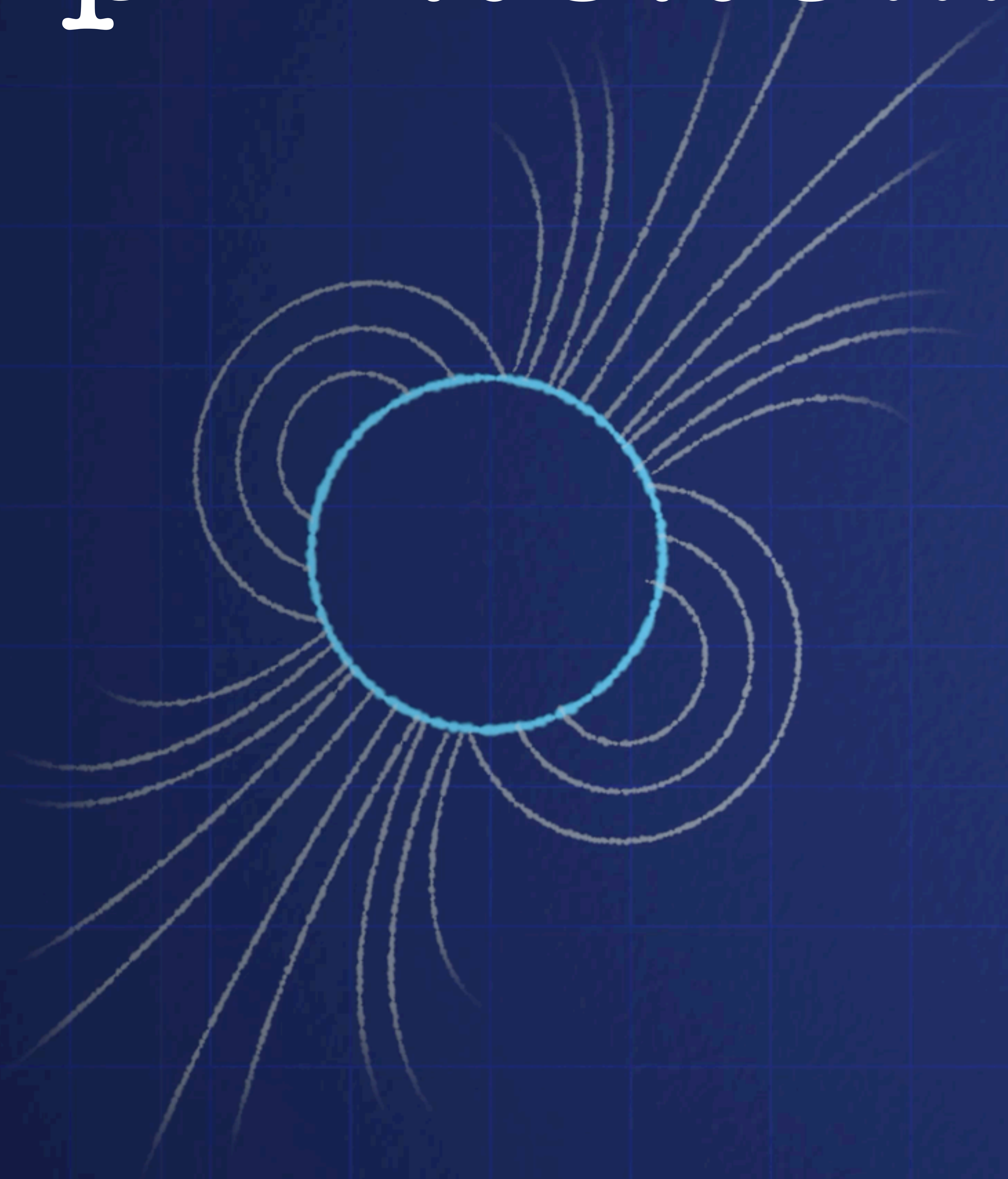
Burns et al. 2021 ApJL DOI: 10.3847/2041-8213/abd8c8

Michela Negro, CRESST-GFSC/UMBC (mnegro1@umbc.edu)

- On behalf of the working team -

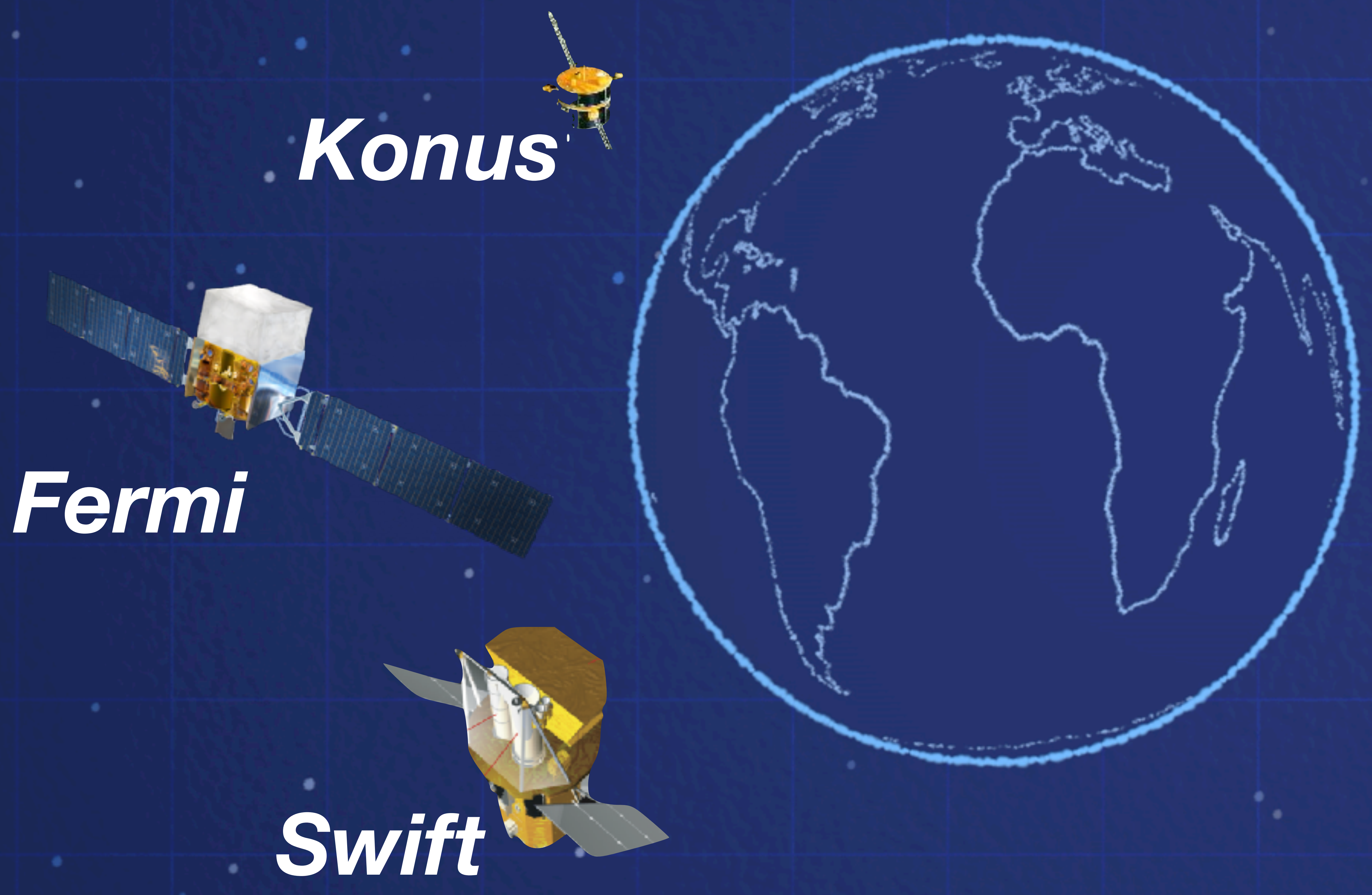
11.4 Million years ago...

15 April 2020...



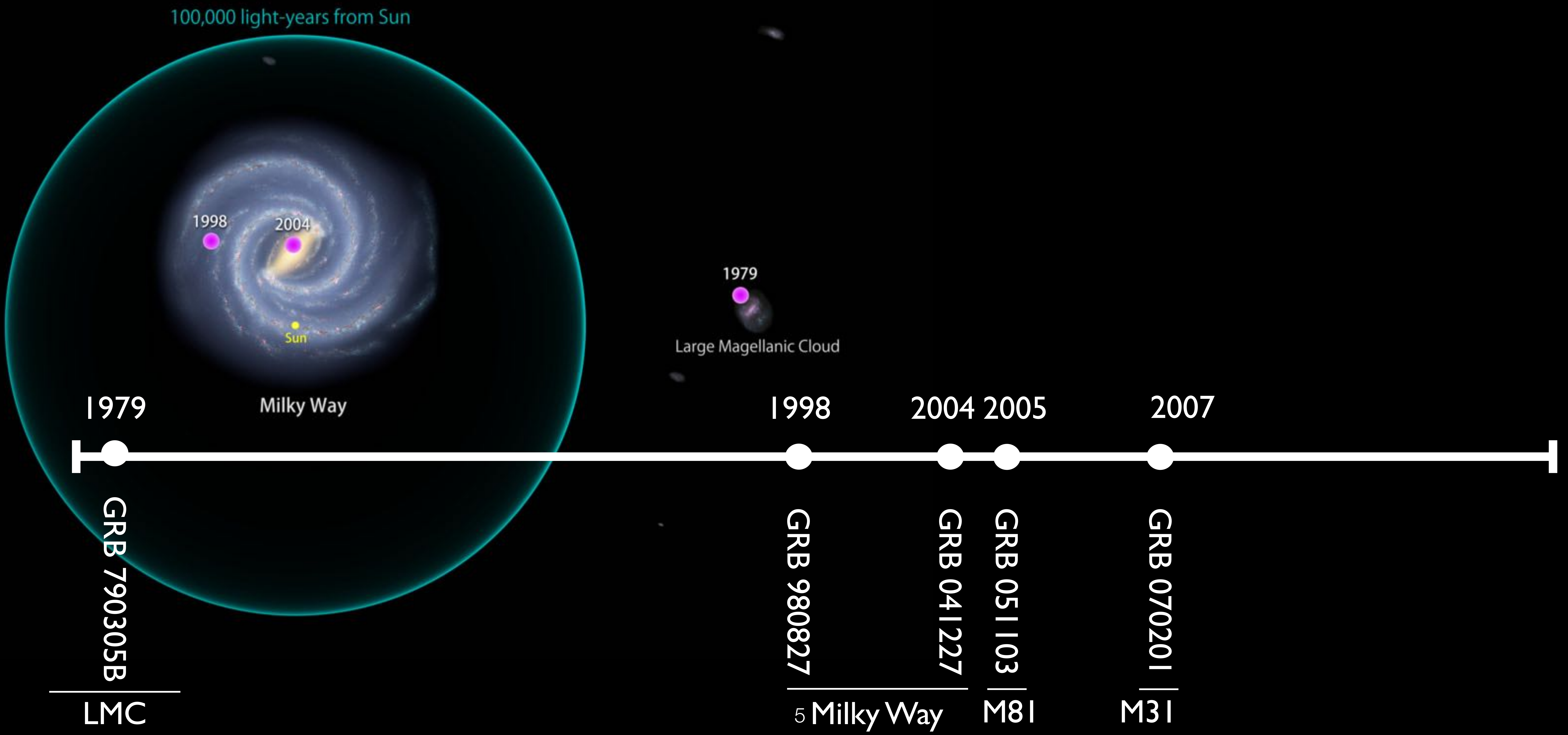
Video Credit: NASA

15 April 2020…



For details on Fermi-LAT detection of GRB 200415 See ***N. Di Lalla's invited talk***
For details on Fermi-GBM detection of GRB 200415 See ***E. Bissaldi's talk***

A Population of MGFs



Extragalactic MGFs and GRB

Known nearby MGF sample: GRB 790305B, GRB 980827, GRB 041227 → **HIGH INTRINSIC RATE!**

↓ Extragalactic counterparts observed as GRBs

Only two extragalactic MGF candidates in literature: GRB 051103, GRB 070201 → SGRB

↓

Set upper bound:
SGRB to have MGF origin < 8%*

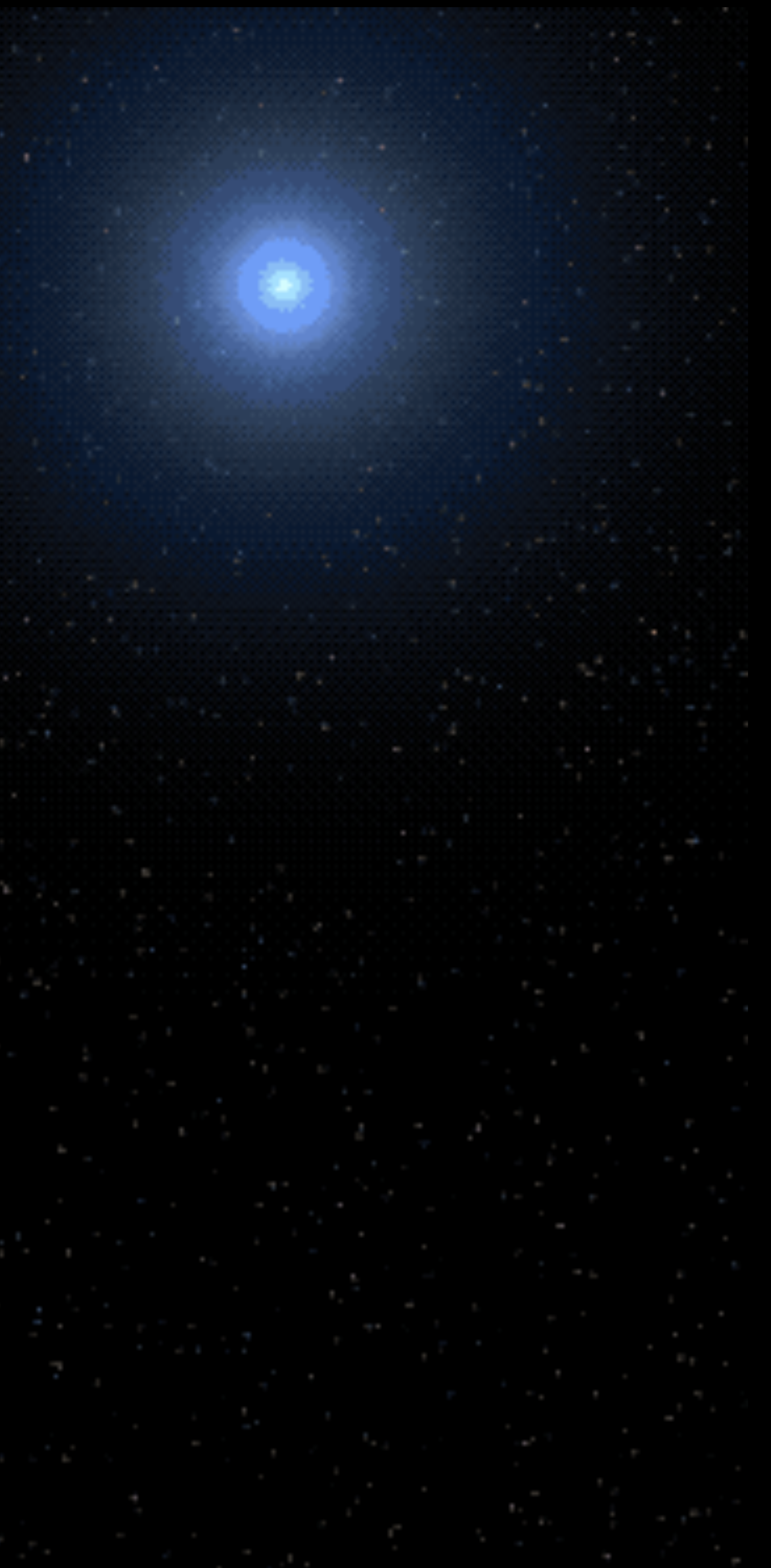
Set lower bound:
SGRB to have MGF origin > 1%*

*These studies and their conclusions generally assumed that the brightest MGFs could be detectable to tens of Mpc.

E. Burns et al. (MN). 2021, Published in Ap. J. Letters

Extragalactic MGFs and GRB

How to understand that MGFs are progenitors of a class of SGRB?



Video Credit: NASA

PROBLEM:

Loss of the smoking gun signature

We carried out a study based on spatial information:

SGRBs with MGF origin have to be consistent with local* known galaxies

* within 50 Mpc

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Galaxies sample

Info for each galaxy:

- ✳ Position —> **(RA, DEC, d)**
- ✳ Angular extent (if > any resolution = ellipse)
- ✳ Star formation rate (SFR)

z=0 Multiwavelength Galaxy Synthesis: **z0MGS = GALEX** (UV) + **WISE** (IR)

+ supplement <10 Mpc with the Local Volume Galaxy (LVG) Catalog
+ SFR, ang. ext. from Census of the Local Universe (CLU) Catalog

>100,000 galaxies (0.5-200 Mpc)

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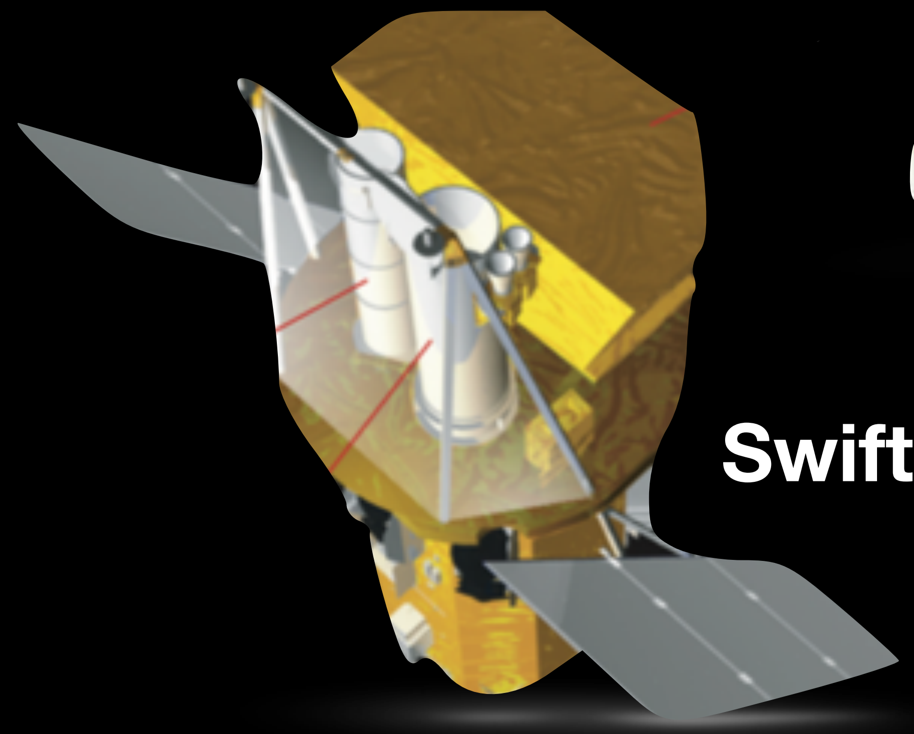
GRB sample

GRB selection and info:

- ✳ SHORT! (T90 < 2 s)
- ✳ Measured bolomertic fluence at Earth (1 keV - 10 MeV) —> **S**
- ✳ Well localized (from all available info, IPN*, Localization area (90% confidence) < ~4 deg^2)

* this work required additional 100 IPN locations:

Konus

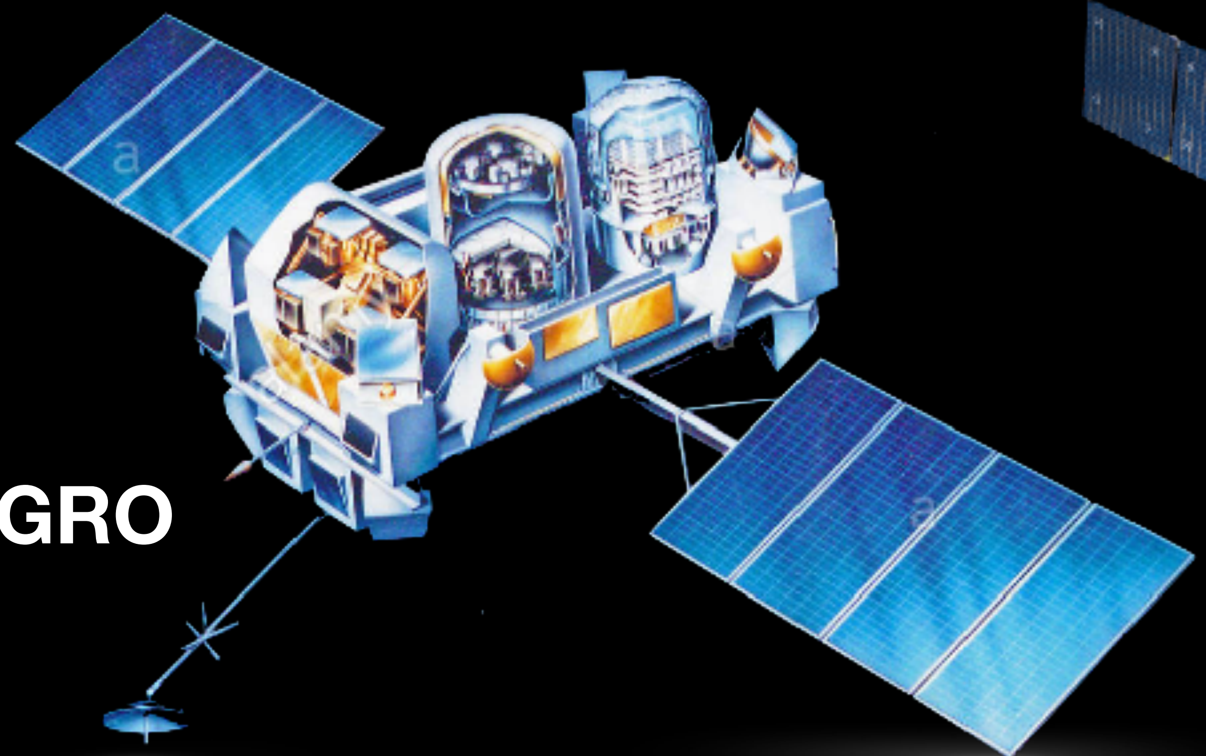


Swift

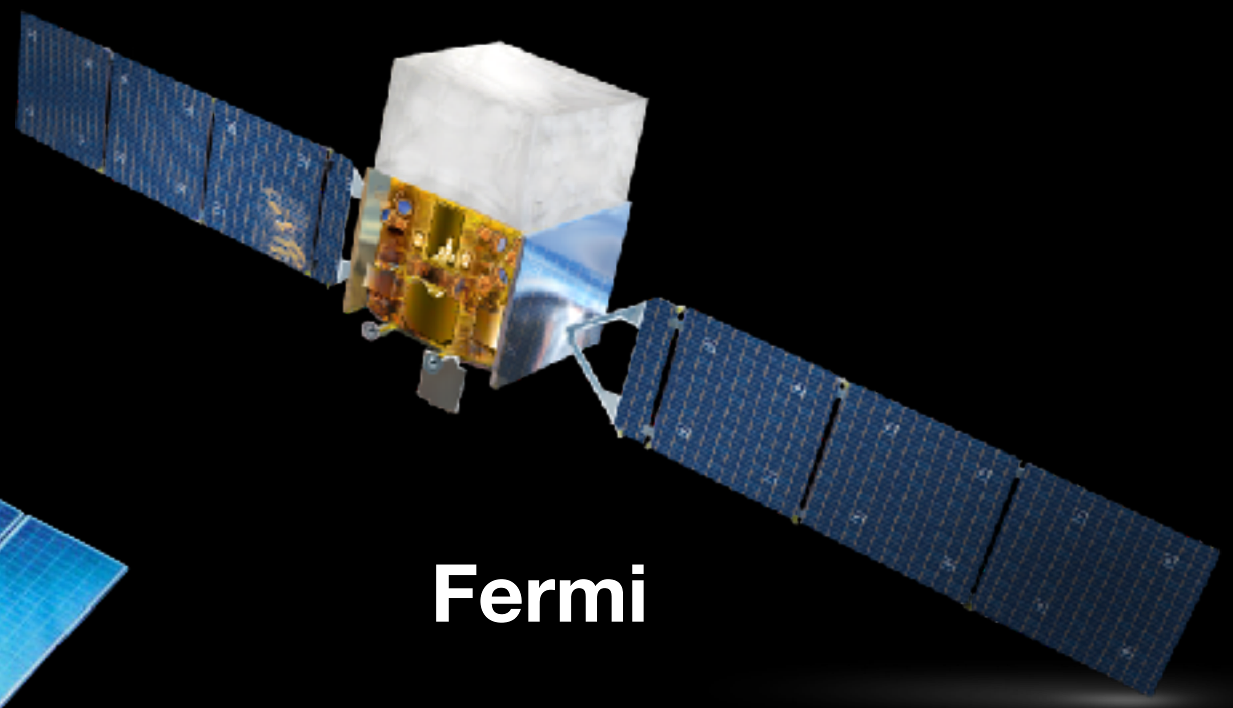
CGRO-BATSE + Konus-WIND + Swift-BAT + Fermi-GBM

+ additional info from the IPN

250 SGRB



CGRO



Fermi

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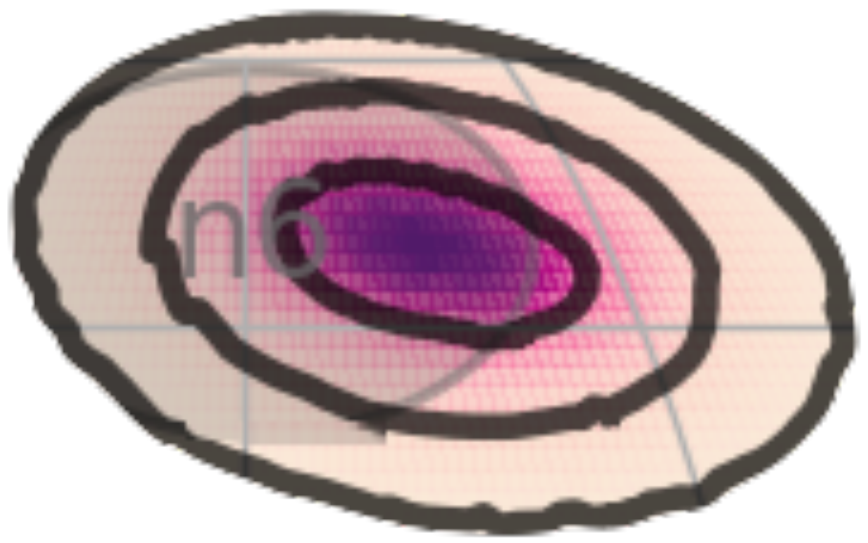
The search

GRB probability distribution function at the i^th sky position:

NSIDE = 8192 (order 13, pixel width= 0.5 arcmin)

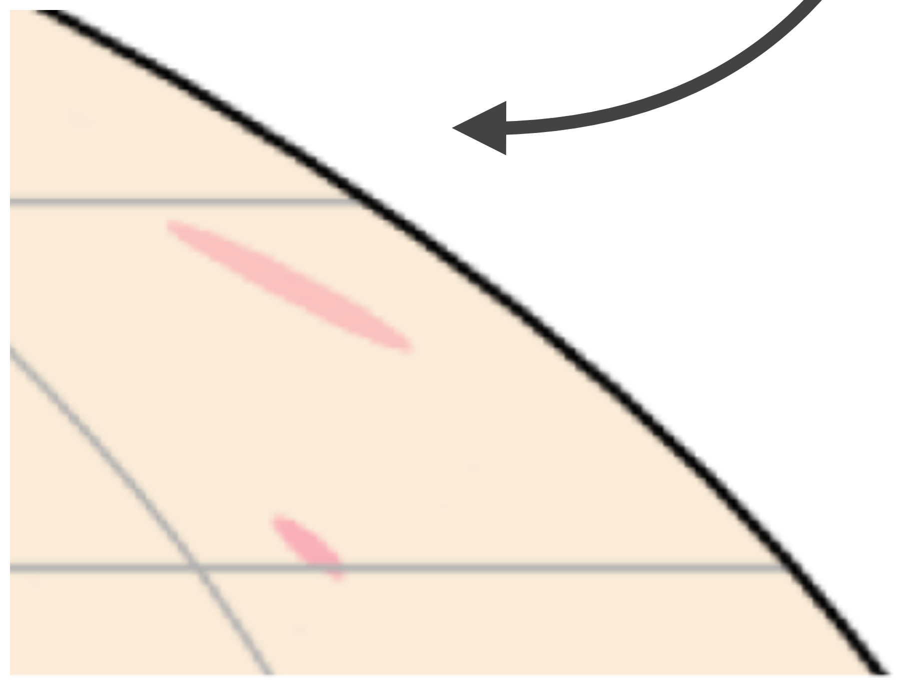
$$P_i^{GRB}$$



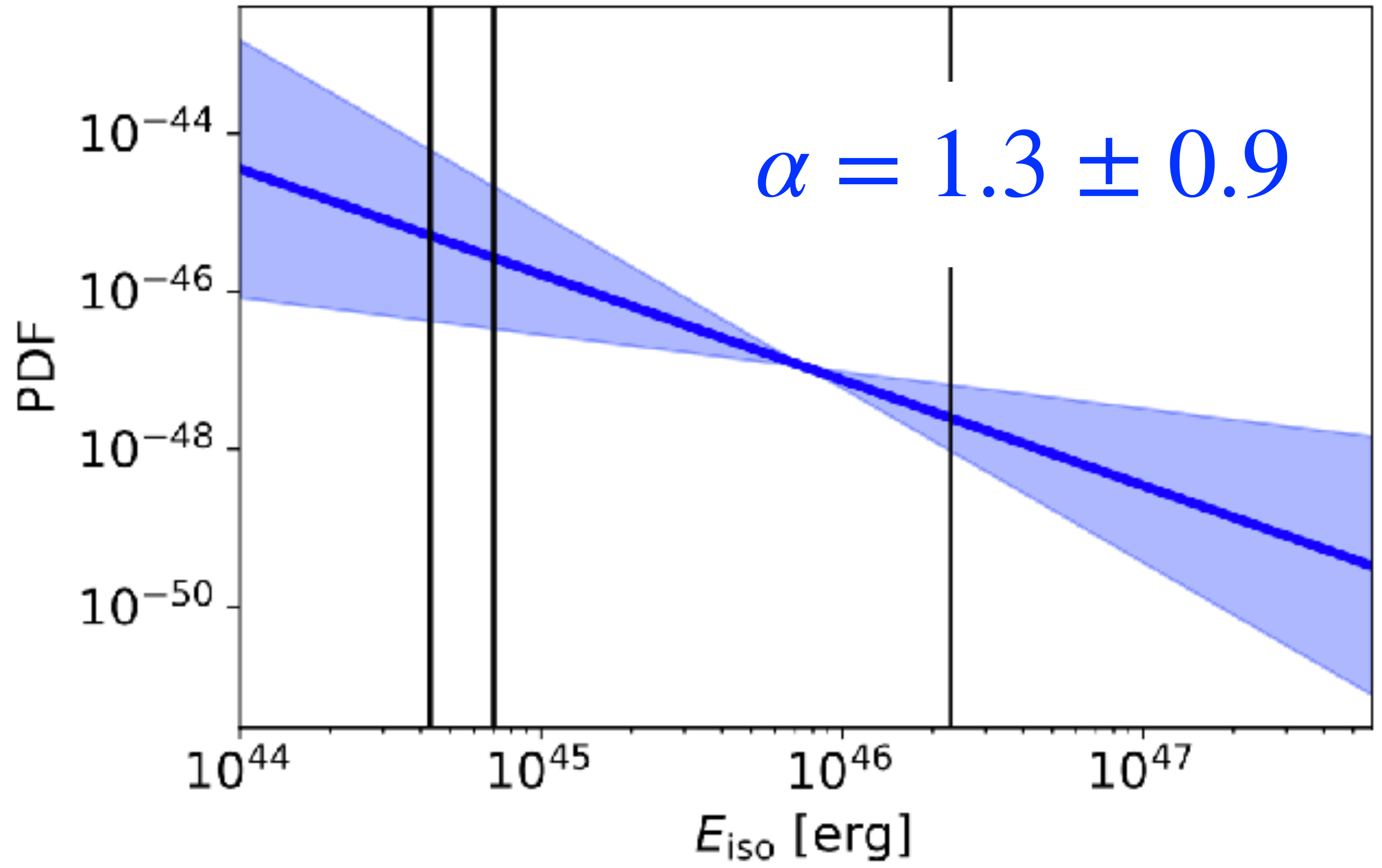
Probability that a given position is to produce a MGF with a particular fluence at Earth

$$P_i^{MGF}$$

$$P_i^{MGF} = SFR_i \cdot PDF(E_{\rm iso})$$



$$E_{\rm iso} = \frac{4\pi d^2}{S}$$



Likelihood that a given GRB has an MGF origin:

$$\Omega = 4\pi \sum_i \frac{P_i^{GRB} P_i^{MGF}}{A_i}$$

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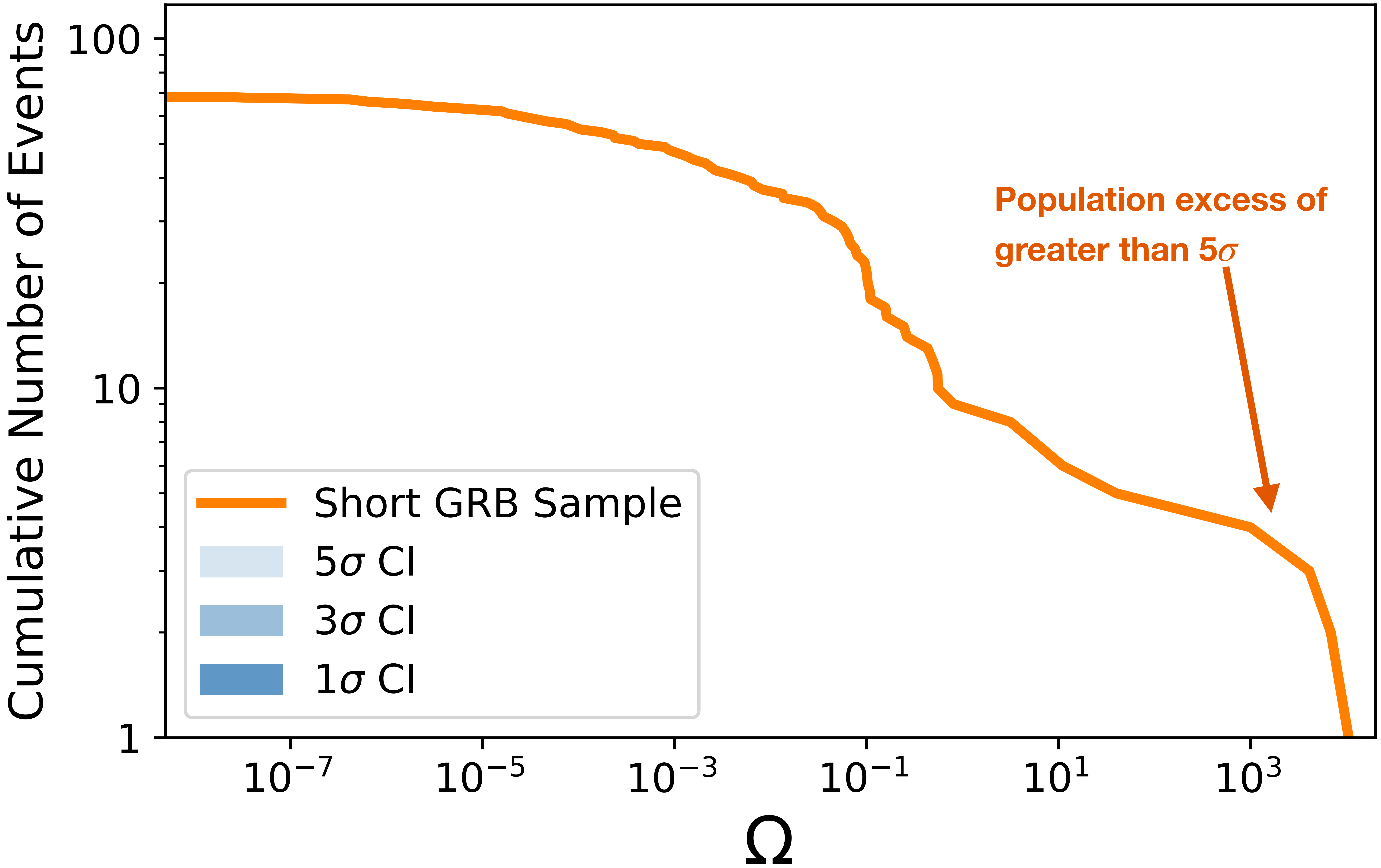
Discovery of local extragalactic population of GRBs



4 events:

~2% of detected short GRB.

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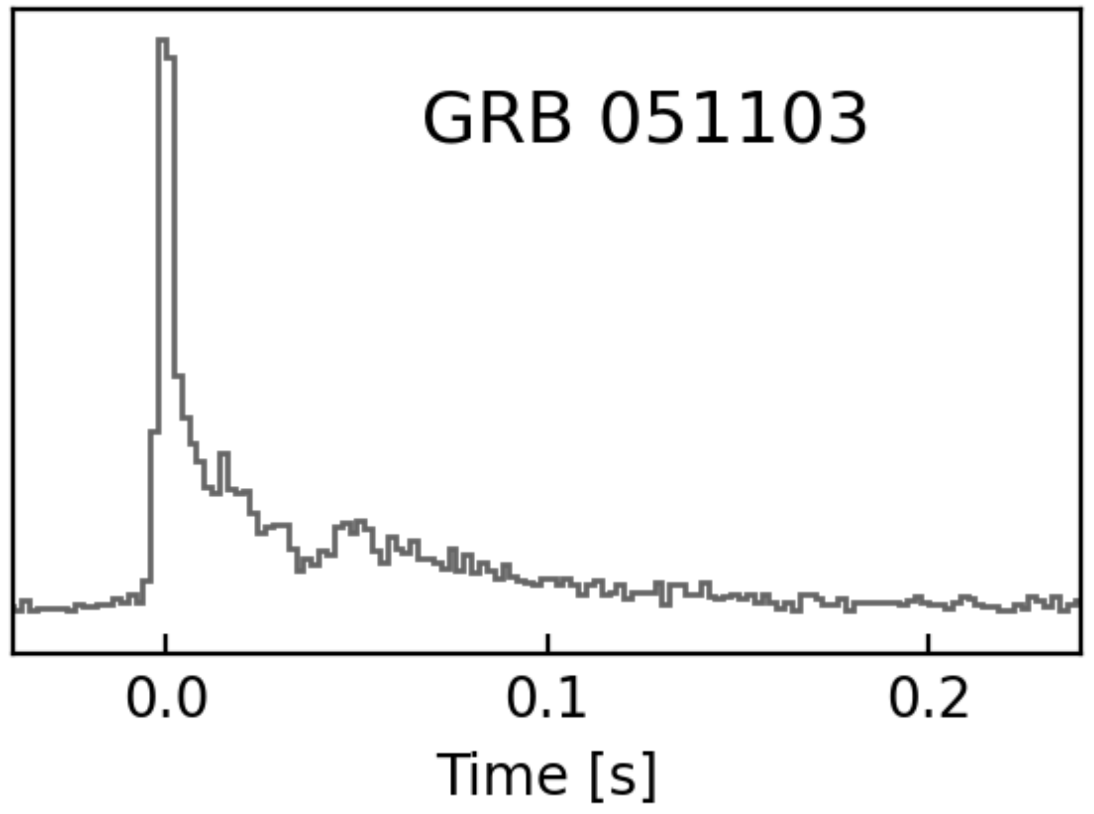
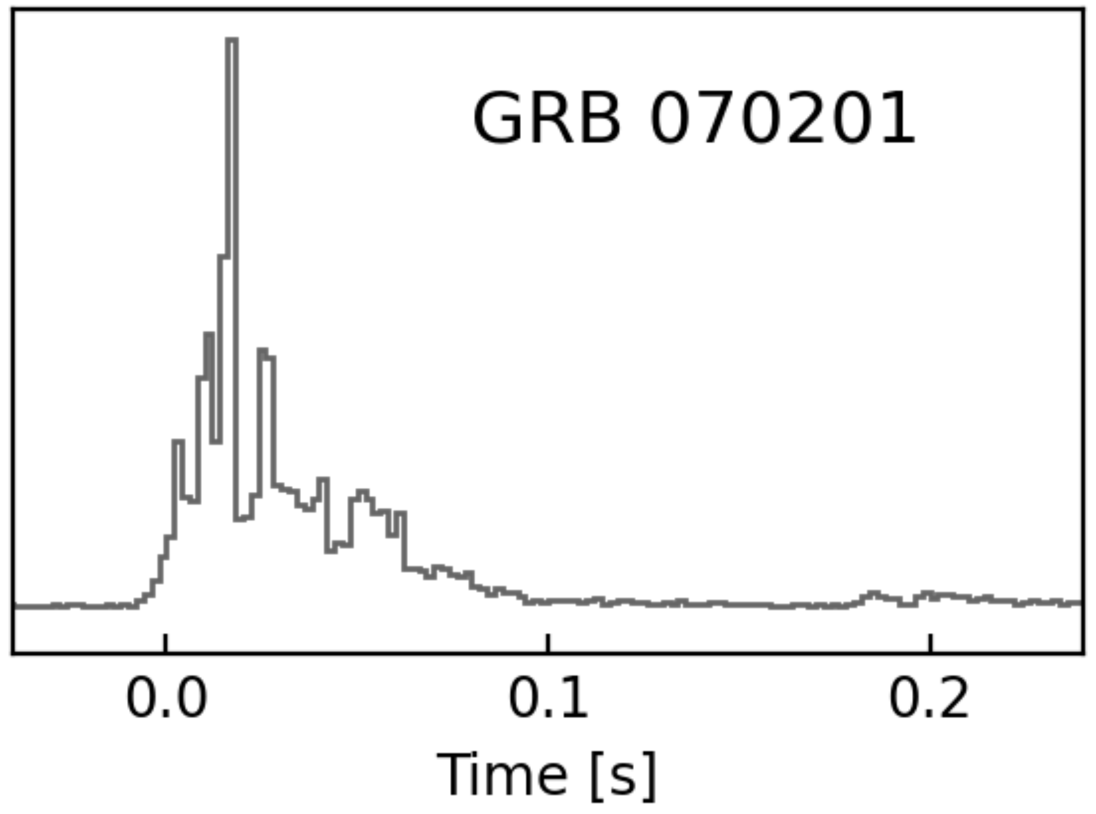
Four local GRBs, hosts, odds of chance alinement

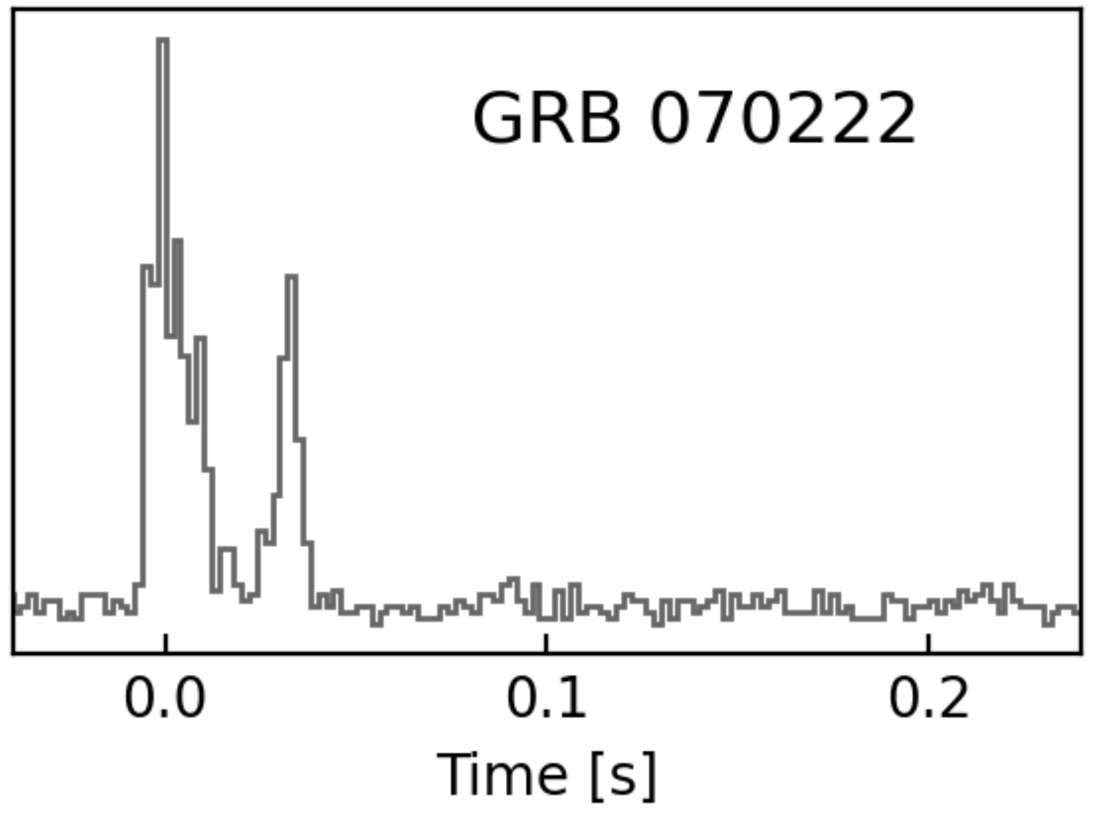
2005 2007

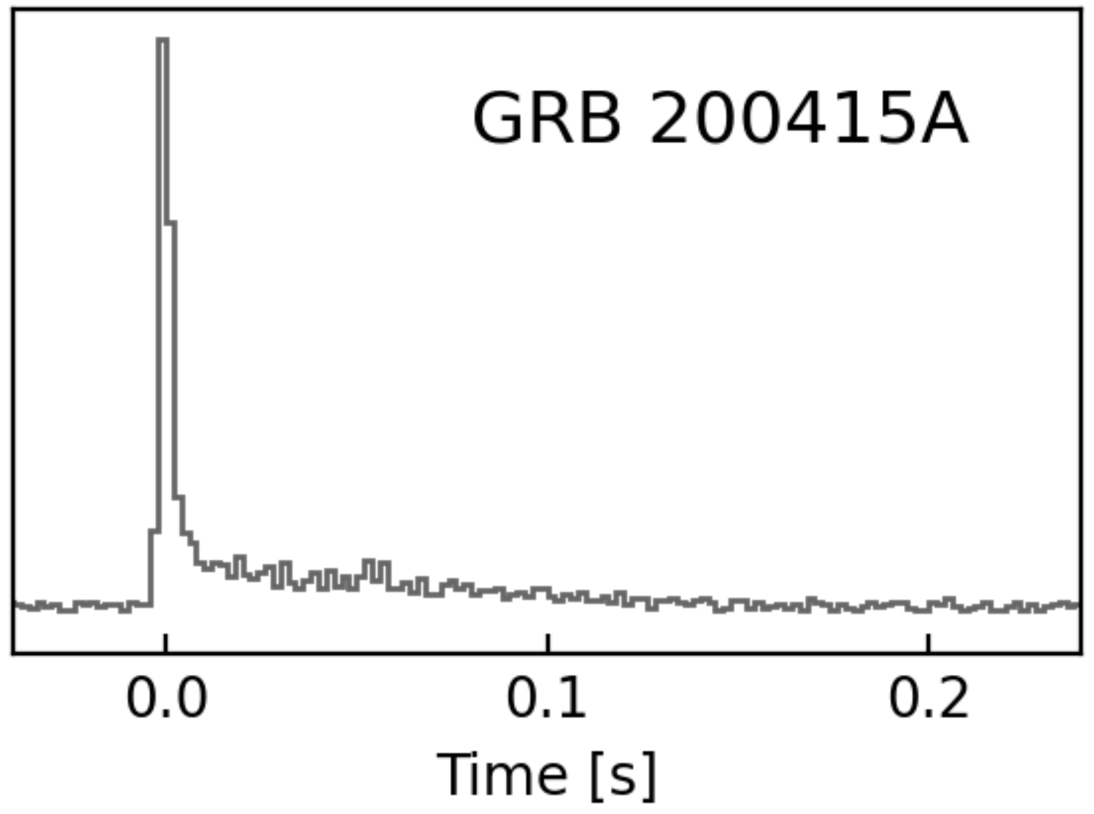
GRB 051103
M81

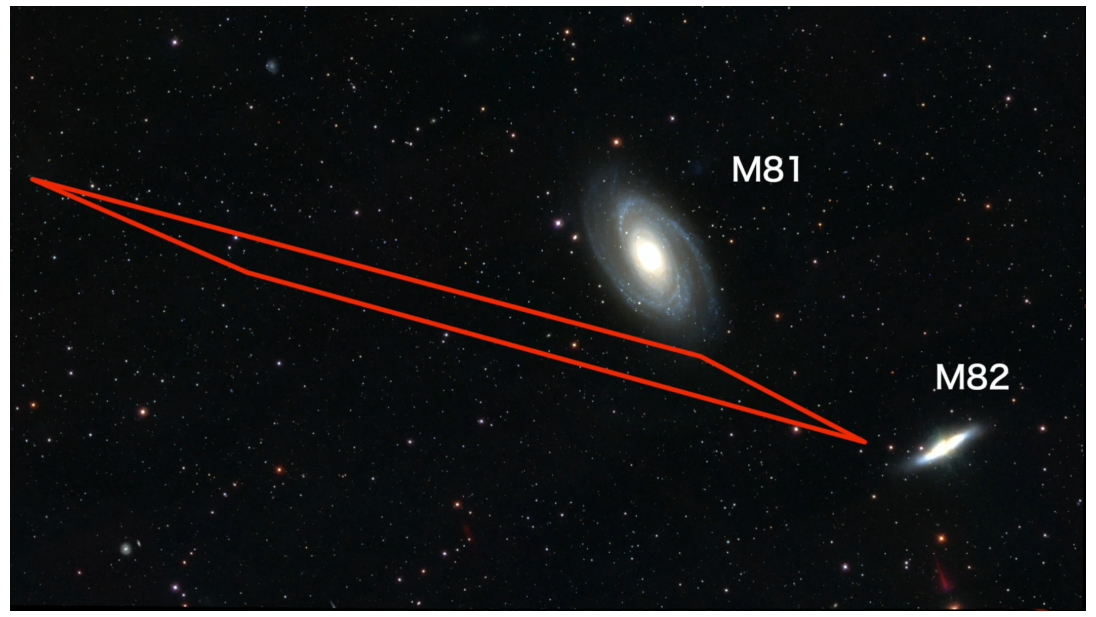
GRB 070201
M31











1 in 70,000

1 in 10,000

1 in 130,000

1 in 230,000

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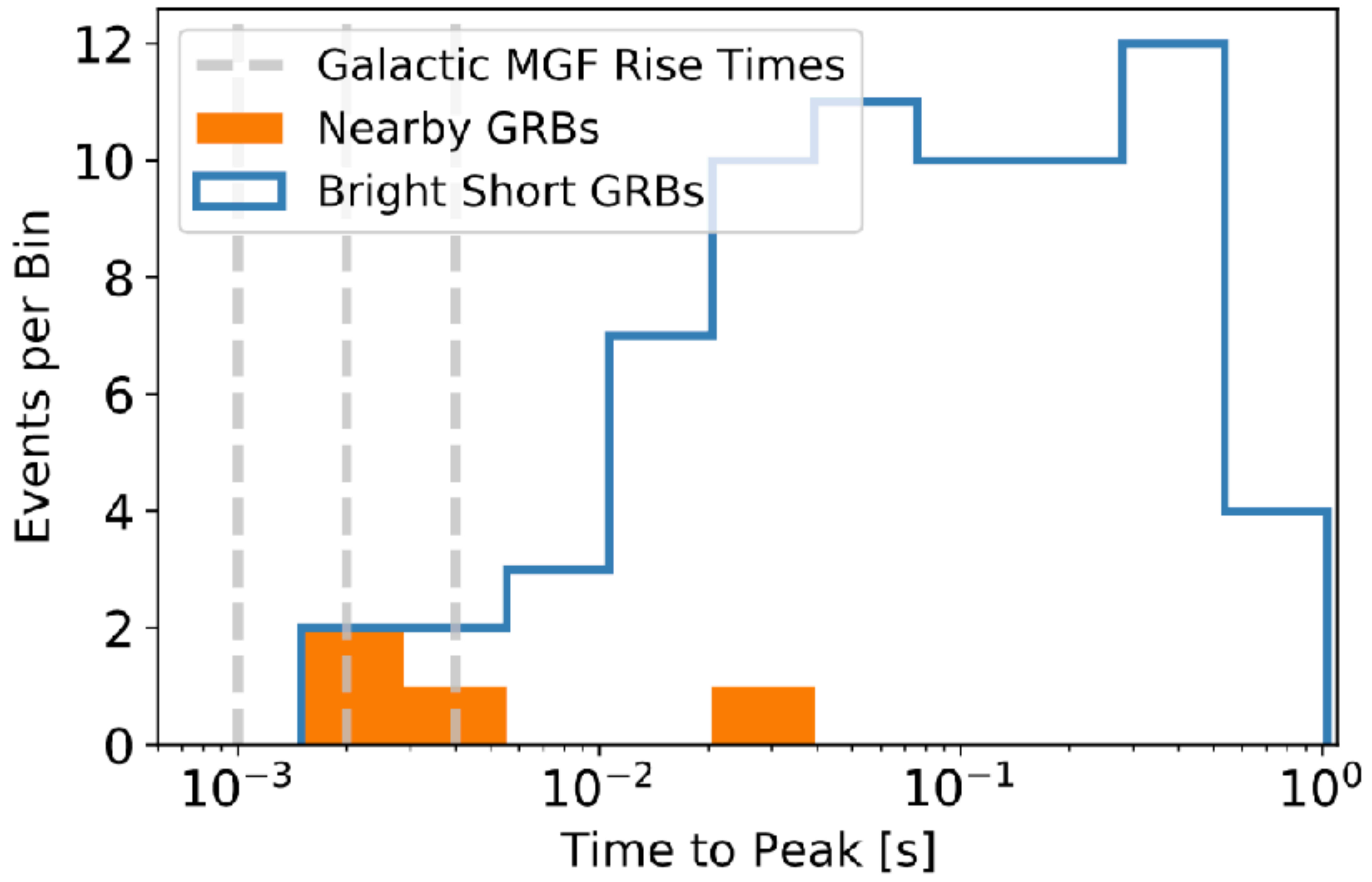
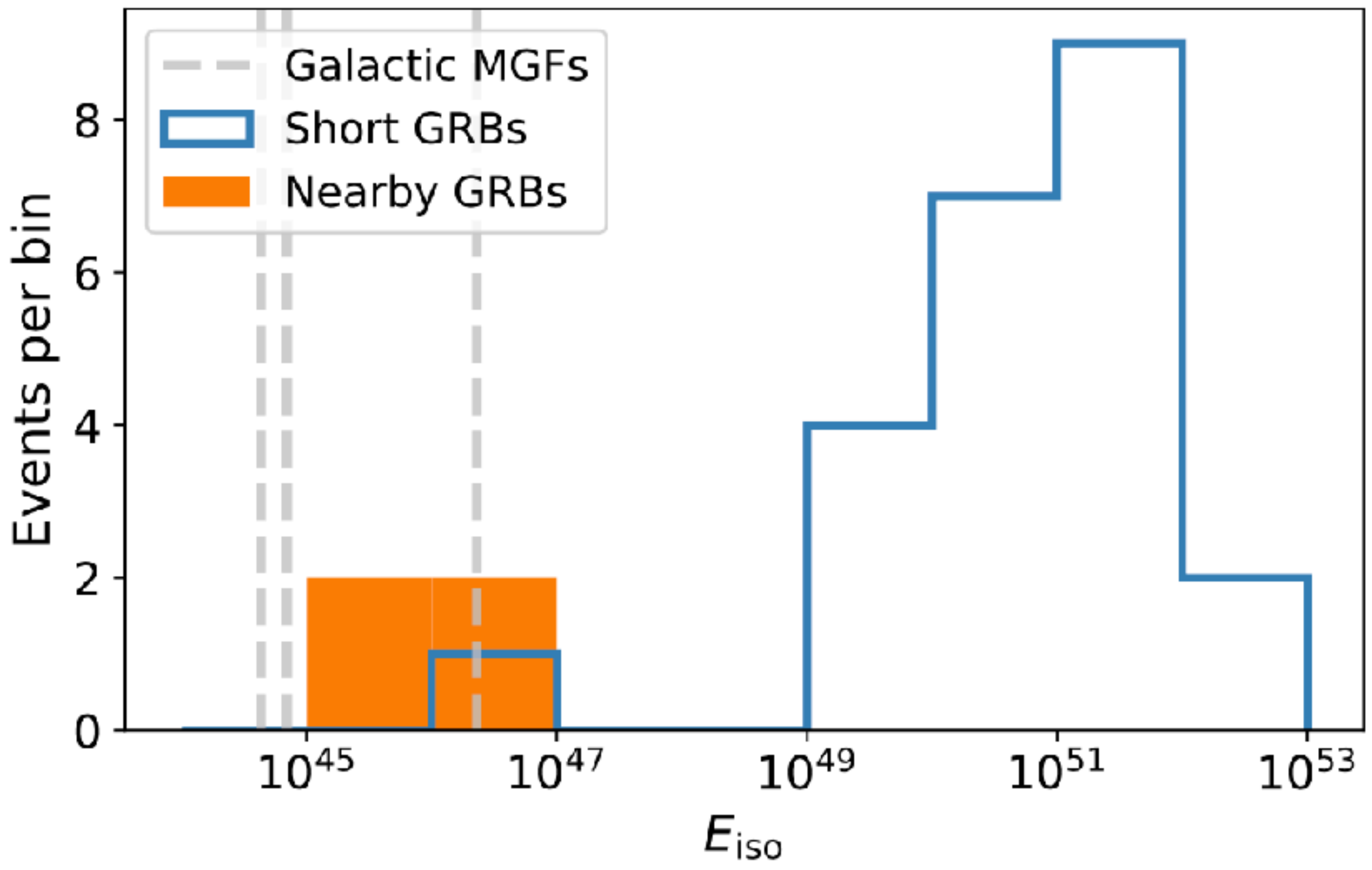
Key parameters comparison

Two main characteristics distinguish SGRB candidate to have a MGF origin from the rest SGRBs:

- ✳ Very short rise time (a few milli-seconds: far way shorter than cosmological GRBs)
- ✳ Intrinsic energetic (orders of magnitude fainter than cosmological GRBs)





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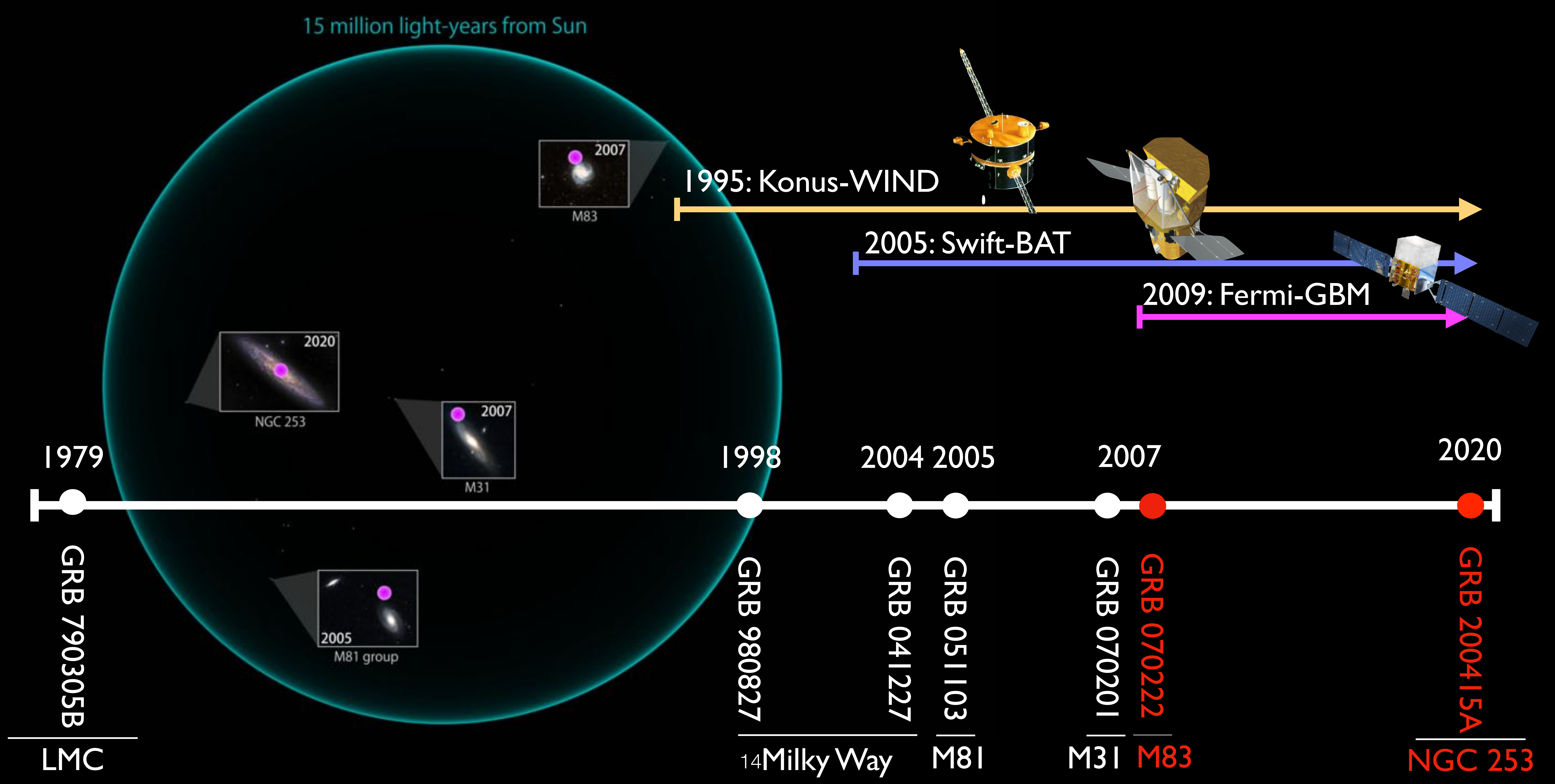
A Population of MGFs

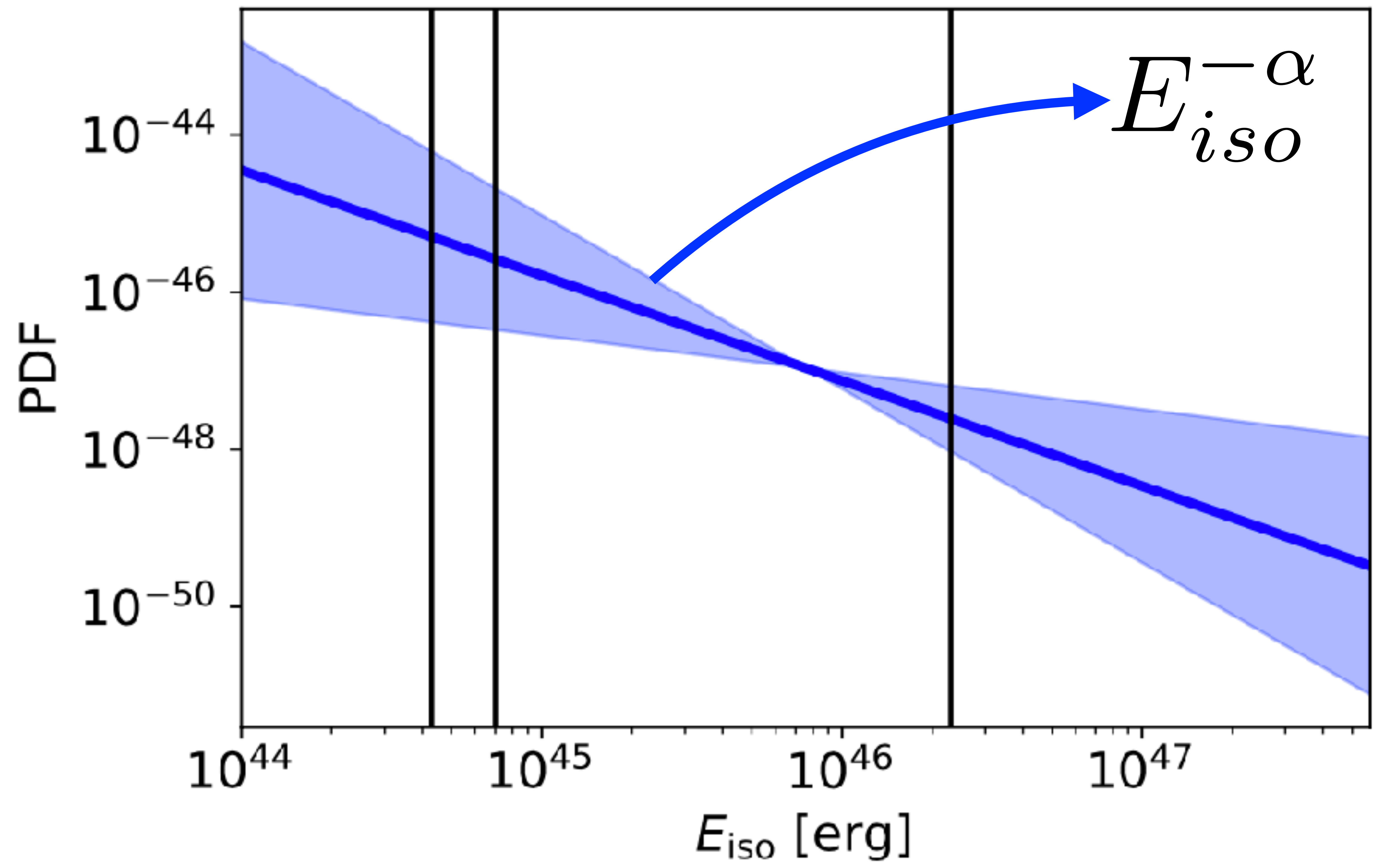


MGFs Intrinsic Energetic

Simulate a large number of extragalactic MGFs:

- E_{iso} from PDFs over a range of α values
- Each assigned to specific host galaxy (weighted by its SFR and distance)

Detected events: those where the sampled E_{iso} and distance produce a flux greater than our detection threshold.



Anderson-Darling k-sample test to compare the detected simulated populations to the real one (4 eMGFs)

$$\alpha = 1.7 \pm 0.4$$

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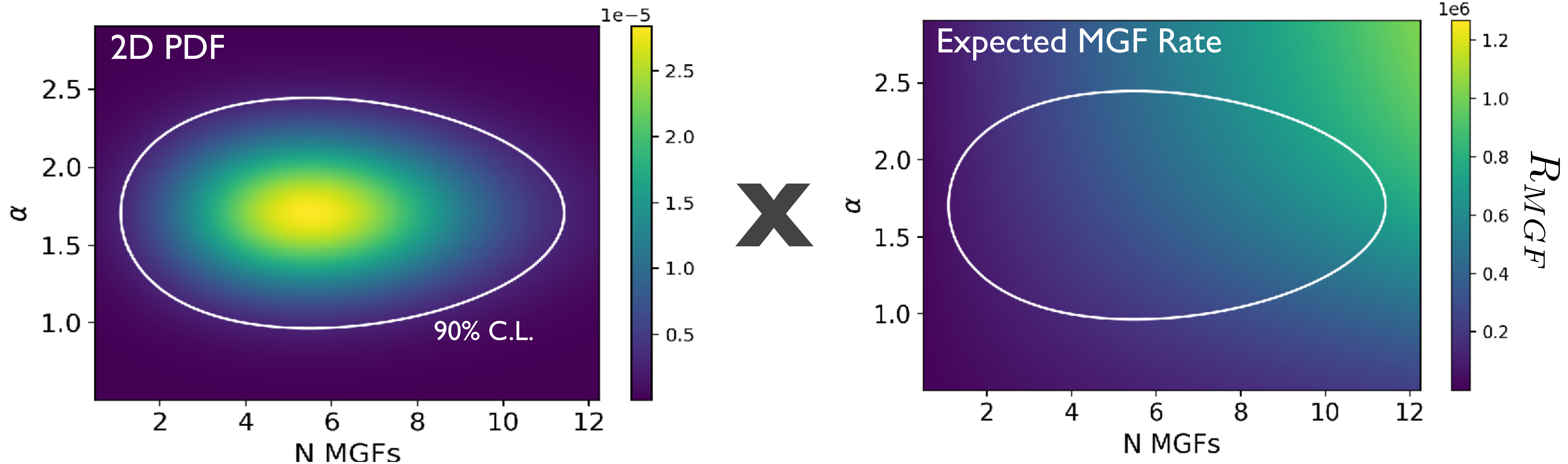
MGFs Intrinsic Rate

Convolution of

- ✳ 2D PDF for alpha VS number of detected MGFs (6*)
- ✳ Intrinsic rate expected for a given alpha and number of detected MGFs

$$R_{MGF} = 3.8^{+4.0}_{-3.1} \times 10^5 \ \mathrm{Gpc}^{-3}\mathrm{yr}^{-1}$$



* the first detected MGF used a different IPN calibration, so we discarded it

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Summary

- 4 short GRBs occurred within ~5 Mpc which are the closest events by an order of magnitude in distance
- They are inconsistent with a collapsar or neutron star merger origin (lack of SN or GW counterparts)
- Their prompt emission is inconsistent with the properties of cosmological GRBs
- They originate from star-forming galaxies, including those with metallicity that prevents collapsars from occurring
- 4 out of 250 SGRBs have MGFs origin: ~2% of detected short GRBs
- Intrinsic energetics distribution of MGFs: a power-law with index $\alpha = 1.7 \pm 0.4$
- The volumetric rates are $R_{MGF} \sim 380000\ Gpc^{-3} yr^{-1}$.
- The rates and host galaxies of these events favor CCSN as the dominant formation channel for magnetars, requiring at least 0.5% of CCSN to produce magnetars.
- Our results suggest that some magnetars produce multiple MGFs: this would be the first known source of repeating GRBs.
- GRB 070222 suggests MGFs can have multiple pulses.
- MGFs may not be detectable to tens of Mpc with existing instruments due to their spectral hardness.
- The LAT detection is the first GeV detected emission form a MGFs
- LAT detected delay suggests the prompt MeV emission and GeV emission are generated in different regions opening new windows for possible explanations.

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Thank you for watching!

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Backup slides for the discussion

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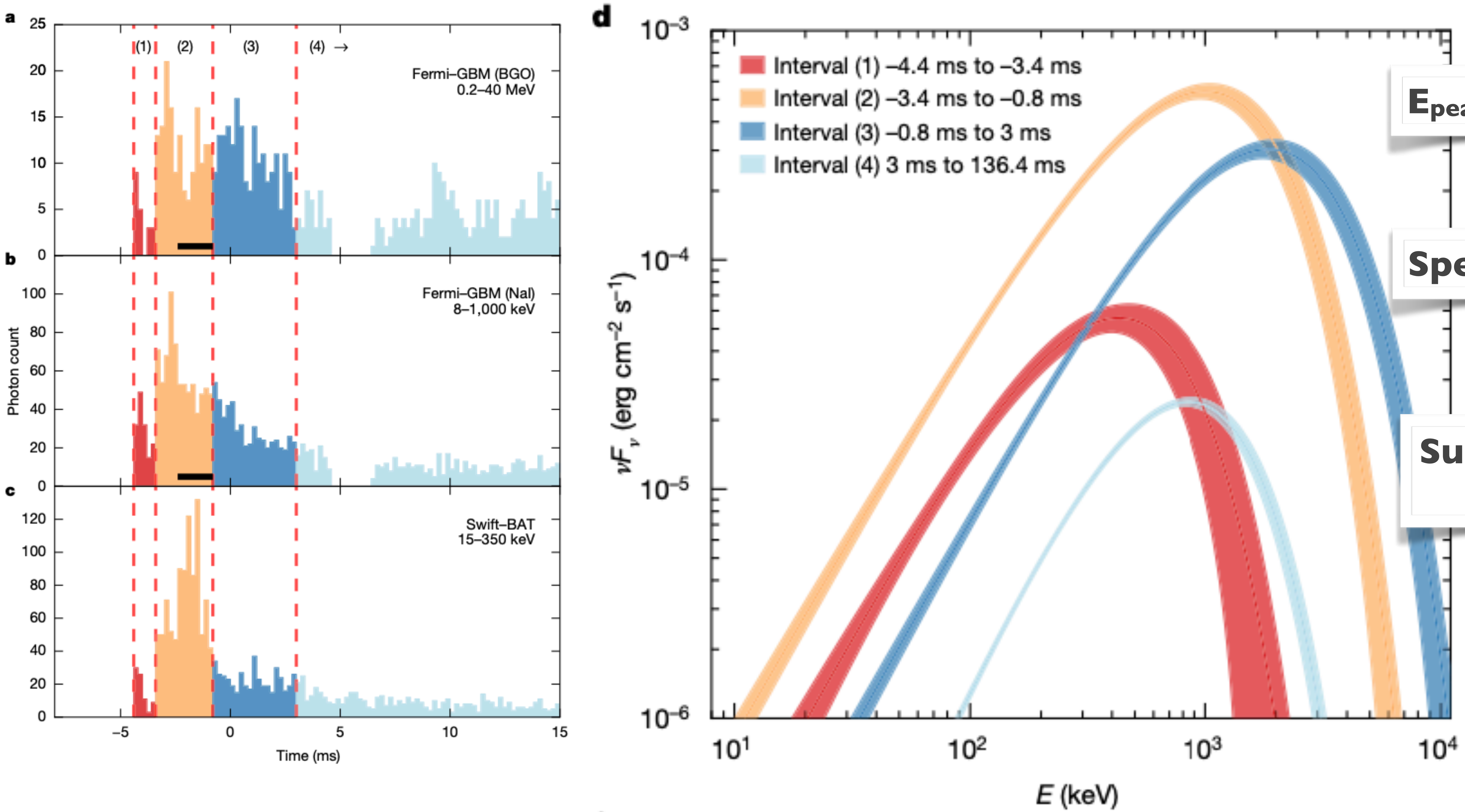
Fermi-GBM detection



E_{peak} ~ 1.5 MeV

Typical value for SGRB is ~ 0.6 MeV

Spectral index ~ 0

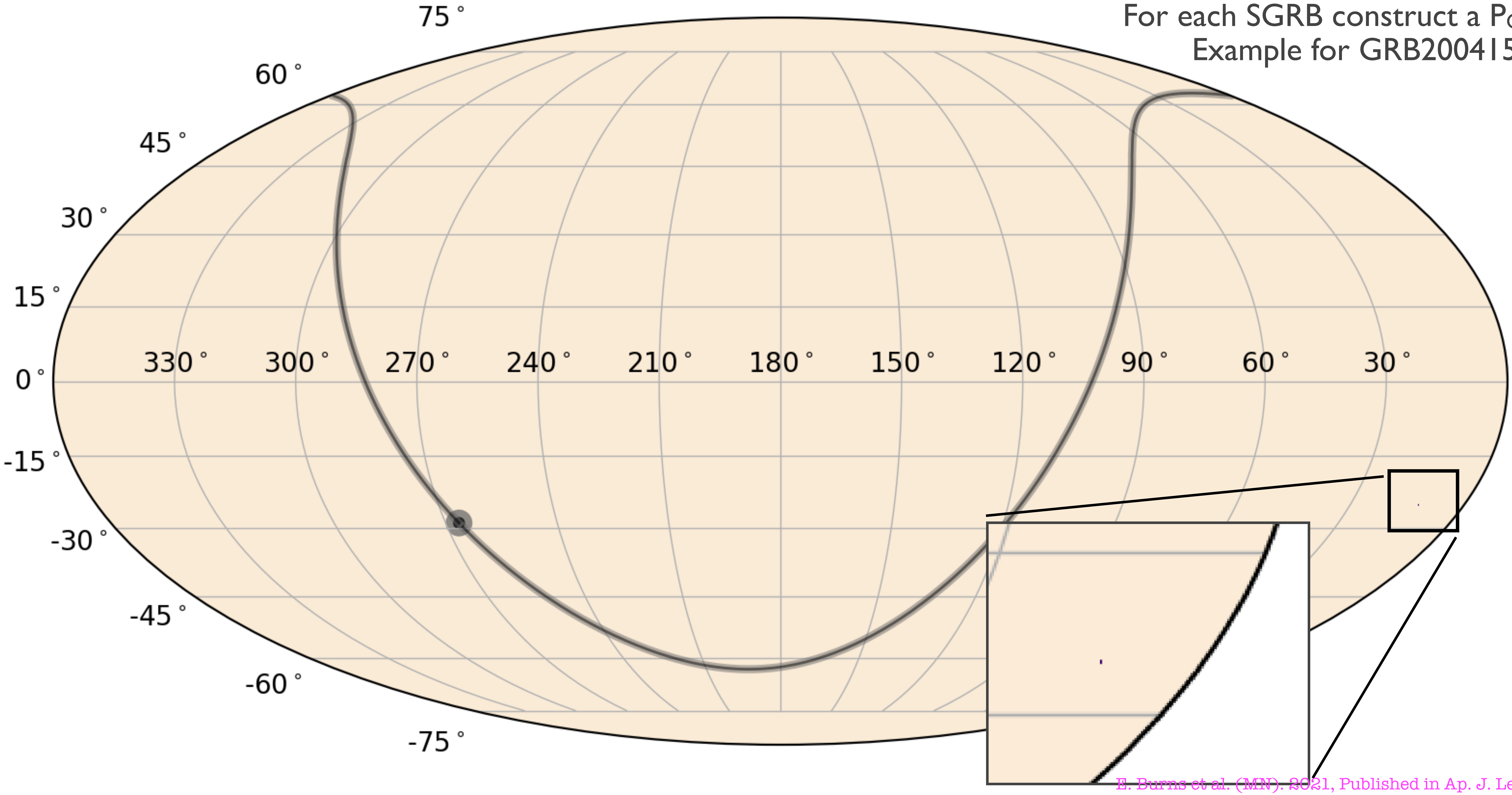
Typical value for SGRB is ~ -0.4

Sub-ms spectral evolution

O.j. Roberts, et al. 2021, Published in Nature

P_{GRB}

For each SGRB construct a P_{GRB}
Example for GRB200415A:



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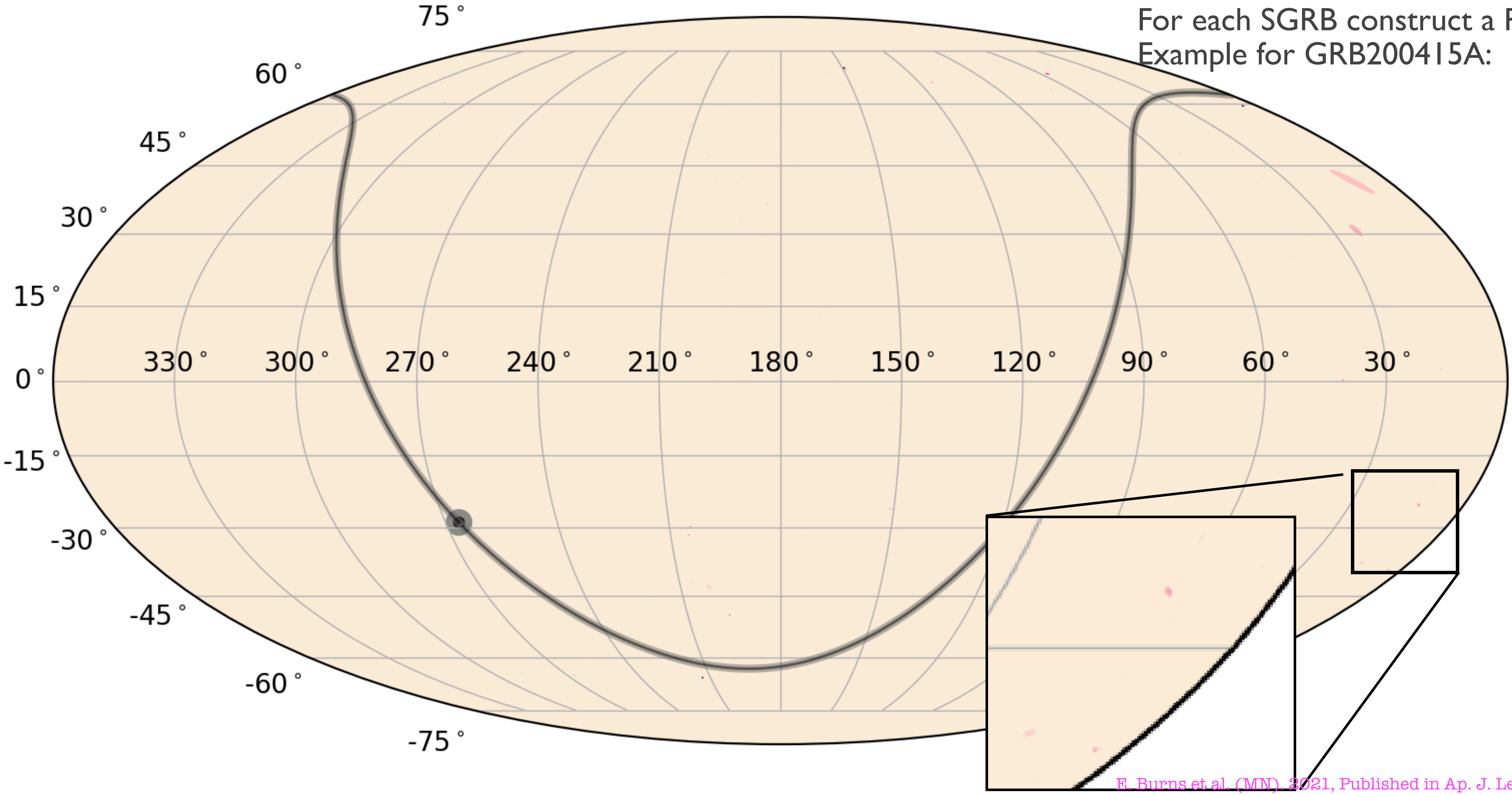
P_{MGF}

For each SGRB construct a P_{MGF}
Example for GRB200415A:



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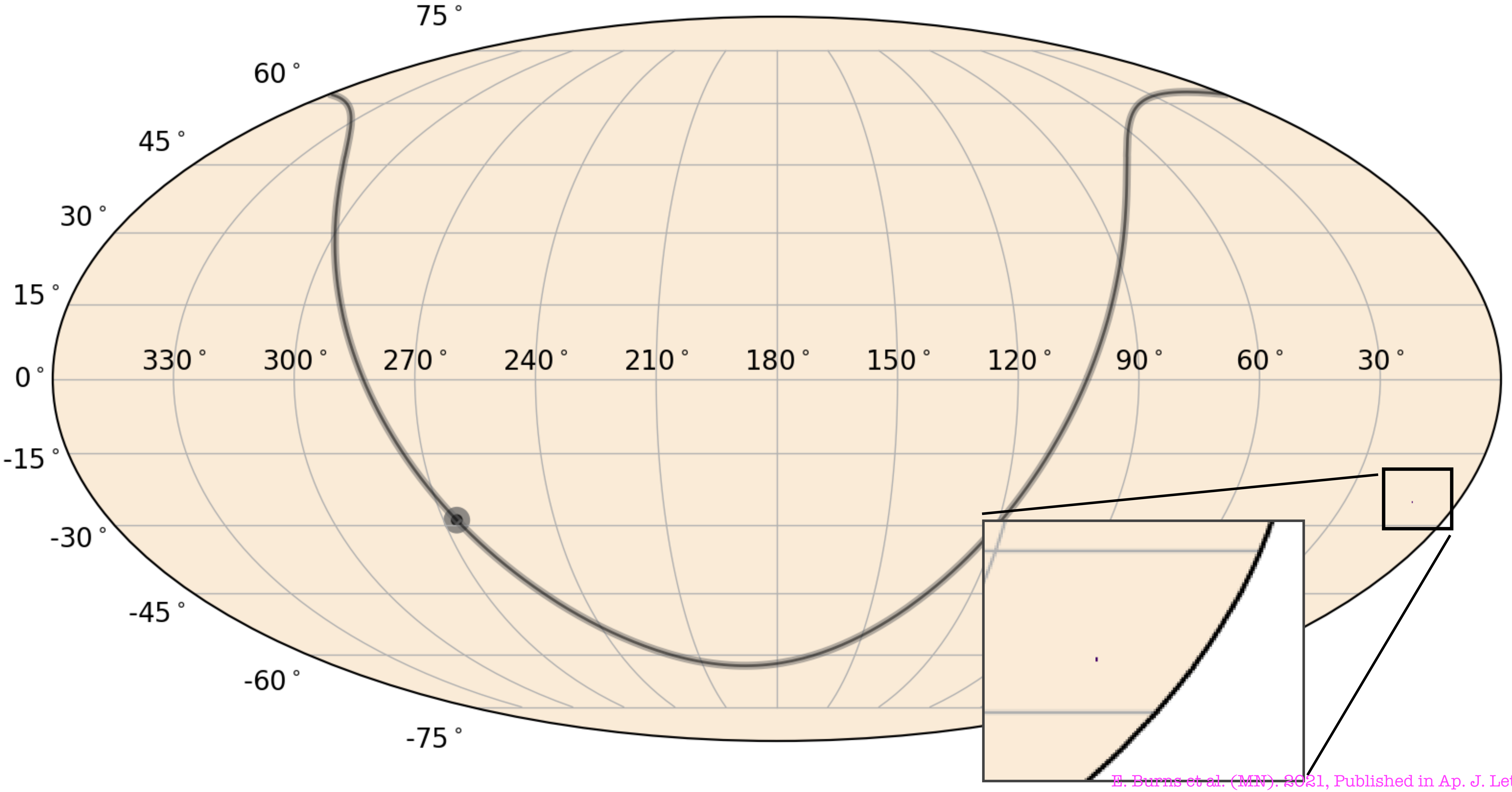
P_{MGF} x P_{GRB}



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MGF Intrinsic Rate

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Event	Local Rates (Gpc^{-3} yr^{-1})	Identified events
Magnetar Giant Flares	380,000	7
Neutron Star Mergers (short GRBs)	320[a]	~ 2000
Collapsars (long GRBs)	~100[b]	~10,000
Type Ia Supernovae	30,100[d]	~15,000[e]
Core-Collapse Supernovae	~70,000[d]	~ 8000[e]

a – LSC 2020 arXiv:2010.14527
b – D. Siegel, et al. 2019 Nature 569, 241
c - S. Prajs, et al. 2017 MNRAS 464, 3
d – W. Li, et al. 2011 MNRAS 412, 3
e - https://sne.space/

Why have we not identified MGFs more and to greater* distances?

*they were thought to be detectable to tens of Mpc

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MGF Intrinsic Rate

As appeared from GRBs 200415A, 051103 and 070222:

SPECTRALLY HARD and HIGHER PEAK ENERGY!

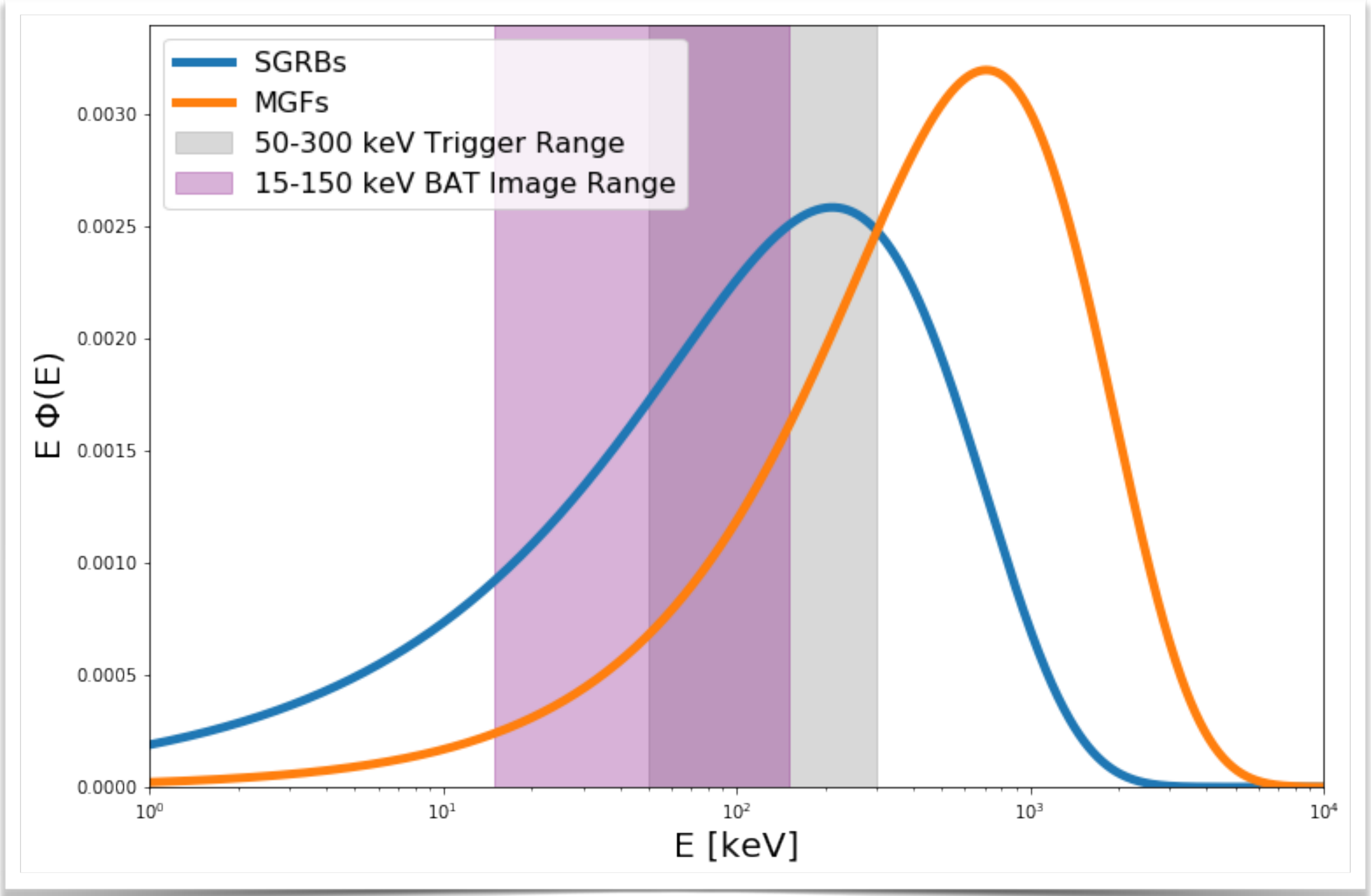
GRB detector are triggered by photon counts: Detectable MGF number is reduced by ~ x5 (x >100 in volume)

Comptonized Spectrum:

$$\frac{dN}{dE} = \left(\frac{E}{100\ keV}\right)^{\alpha} e^{-(\alpha+2)\frac{E}{E_{peak}}}$$

$$\alpha^{SGRB} \approx -0.4 \qquad \alpha^{MGF} \approx 0$$

$$E_{peak}^{SGRB} \approx 0.6 MeV \qquad E_{peak}^{MGF} \approx 1.5 MeV$$



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Magnetar formation channels

Different formation scenarios could produce magnetars, e.g.:

- **common CCSN**
- low-mass mergers
- a rare evolution of white dwarfs
- collapsars
- superluminous supernovae (SLSN)

$$R_{MGF} = 3.8^{+4.0}_{-3.1} \times 10^5 \ \mathrm{Gpc}^{-3}\mathrm{yr}^{-1}$$

$$R_{Event} = 7 \times 10^4 Gpc^{-3} yr^{-1}$$

$$\mathbf{R_{MGF} = R_{Event}\, f_M\, \tau_{Active}\, r_{MGF/M}}$$

- R_{Event}: rate of events that may form magnetars
- f_M: fraction that successfully form magnetars (0.4*)
- τ_{Active}: timescale that magnetars can produce MGFs
- $r_{MGF/M}$: rate of MGFs per magnetar

Favored CCSN:

- Our model favor high SFR (disfavor low-mass mergers)
- Host galaxies of MGF have high-metallicity (disfavor collapsars and SLSN)
- Intrinsic rate favors CCSN
- only CCSN track star-forming regions and have a comparable rate (lat)

Other considerations:

- some magnetars produce multiple MGFs
- observational constraints on $f_M > 0.005$

*Beniamini et al. 2019

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