MAGNETAR GIANT FLARES AS GAMMA-RAY BURSTS

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Burns et al. 2021
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Fermi Gamma-ray Space Telescope

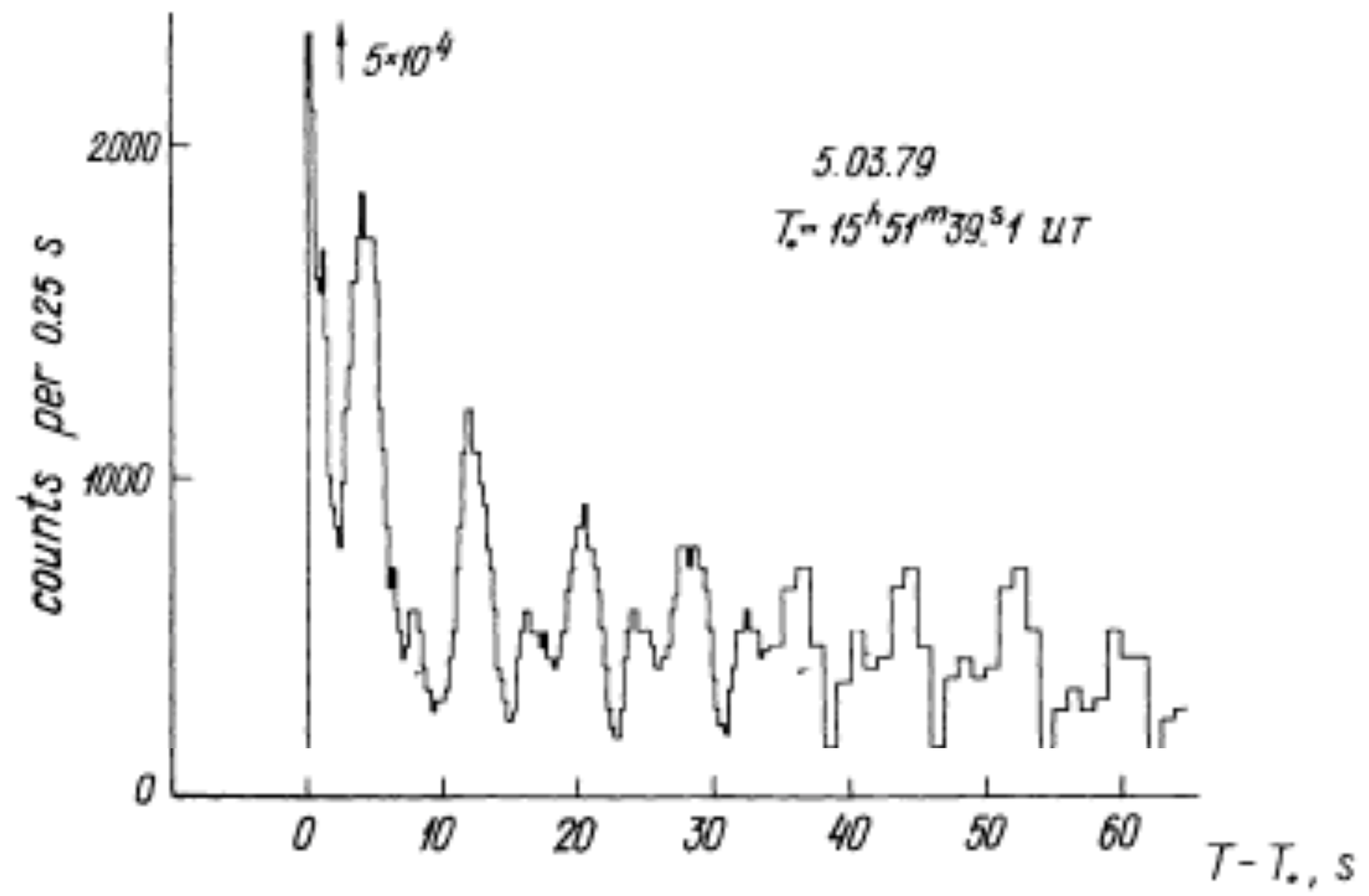
MAGNETAR GIANT FLARES

Magnetars are neutron stars (NSs) with magnetic field ~$10^{13\text{-}15}$ G

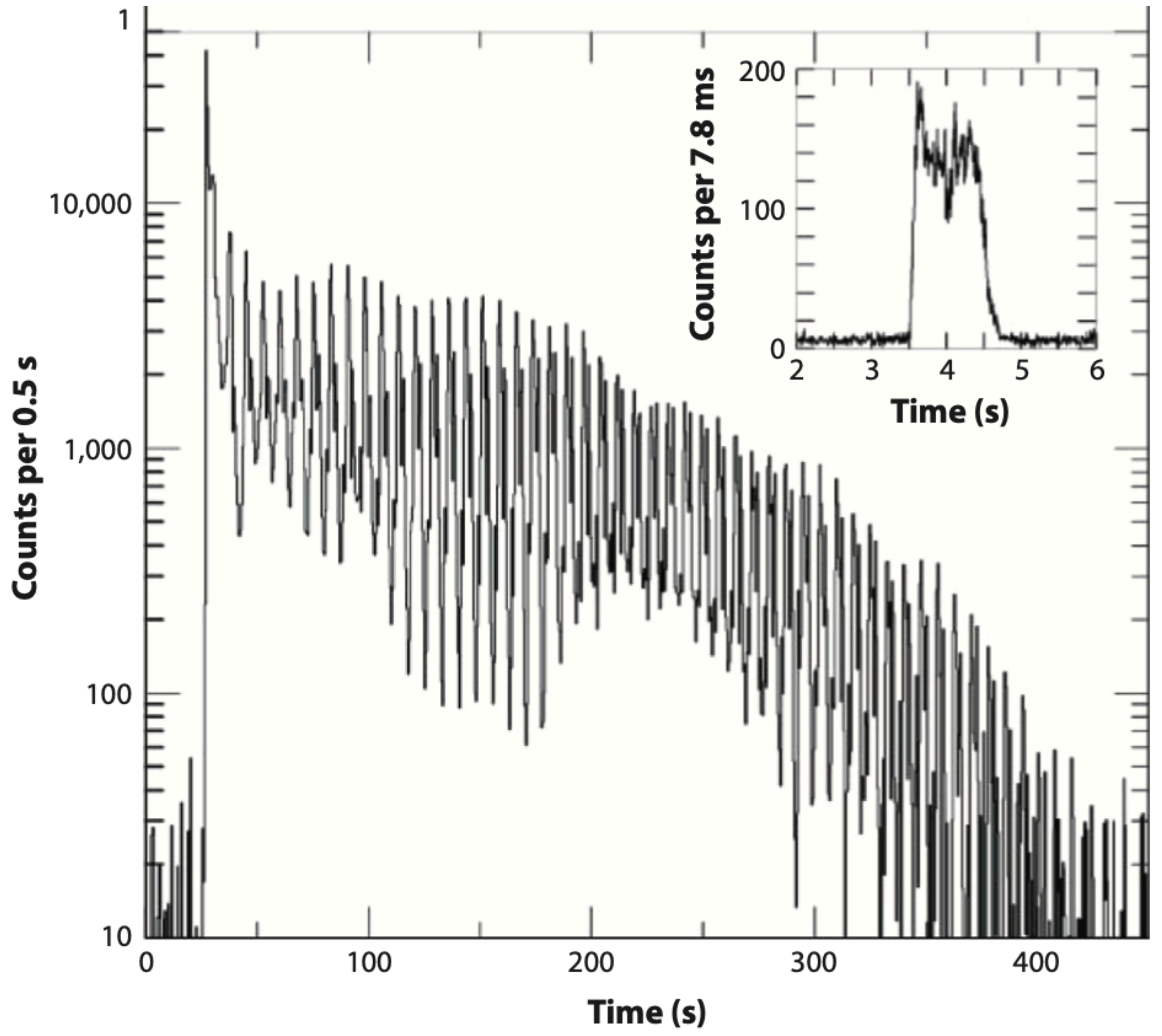
Normal flare energy released ~ 10^{37} - 10^{40} ergs

MGF energy released ~ 10^{44} - 10^{46} ergs

Giant flares result from NS starquakes and reconfiguration of the magnetic field



E.P. Mazets et al., 1979, *Nature*



Hurley et al, 2005, Nature

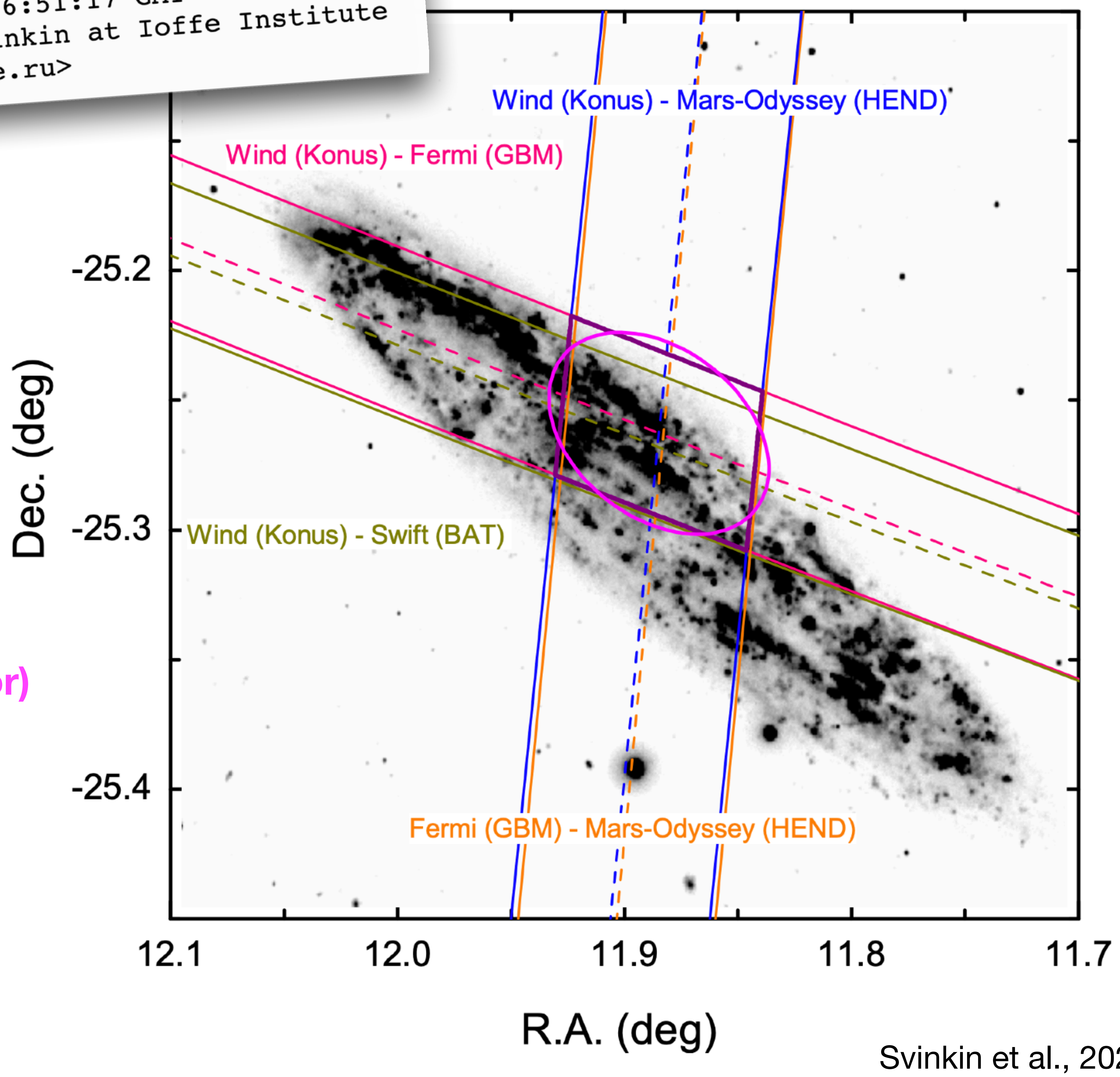
- Key signature: Long periodic tail modulated by rotation of NS
- Known MGFs all occur within Milky Way or Large Magellanic Cloud

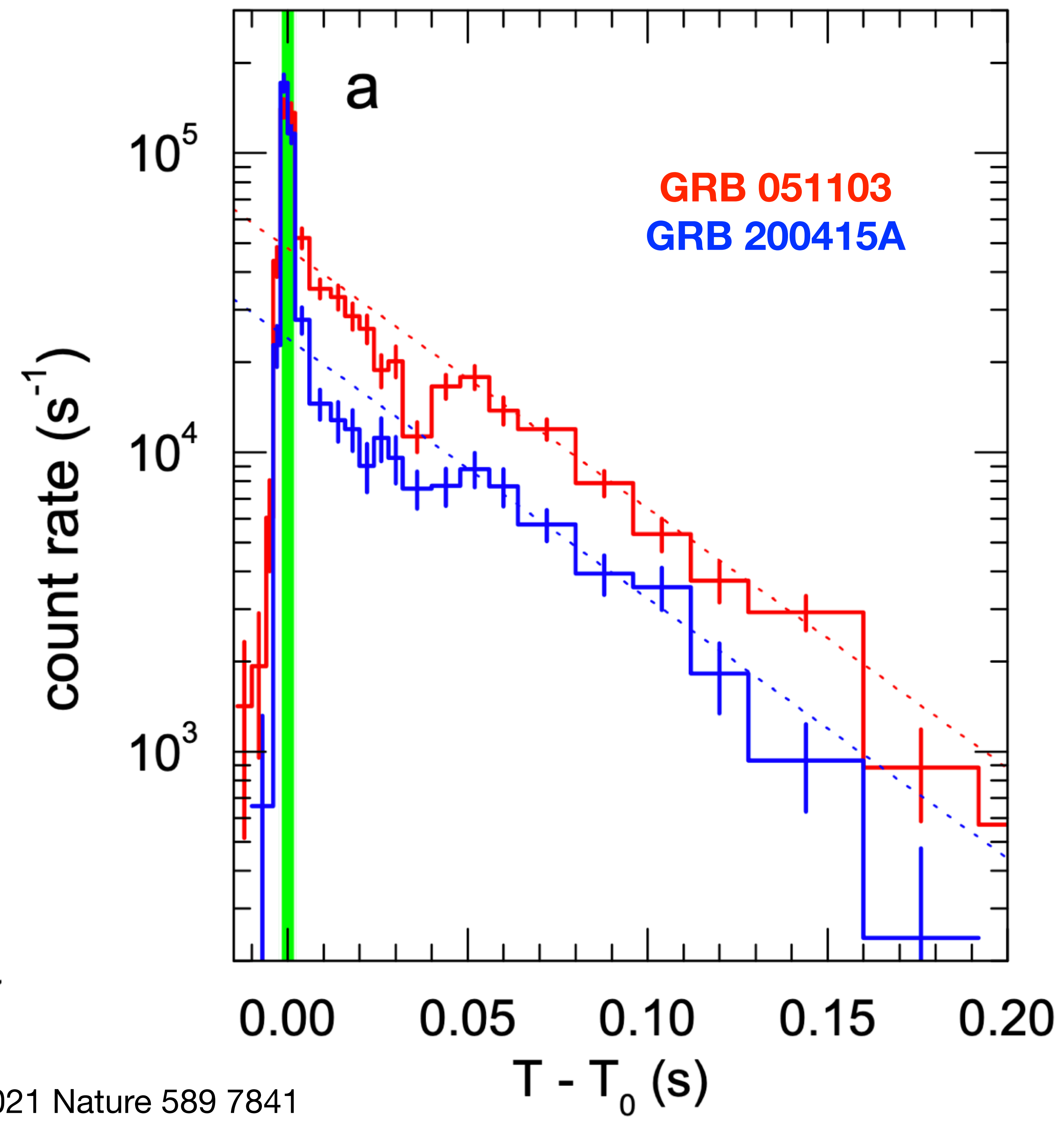
GRB 200415A

TITLE: GCN CIRCULAR
NUMBER: 27585
SUBJECT: IPN triangulation of GRB 200415A (possible Magnetar Giant Flare in Sculptor Galaxy?)
DATE: 20/04/15 16:51:17 GMT
FROM: Dmitry Svinkin at Ioffe Institute <svinkin@mail.ioffe.ru>

* GeV detection by LAT (next talk by N. Di Lalla)
* Poster 194 (P. Veres) - GBM+BAT observations

Localization box:
20 arcmin^2 (3σ error)



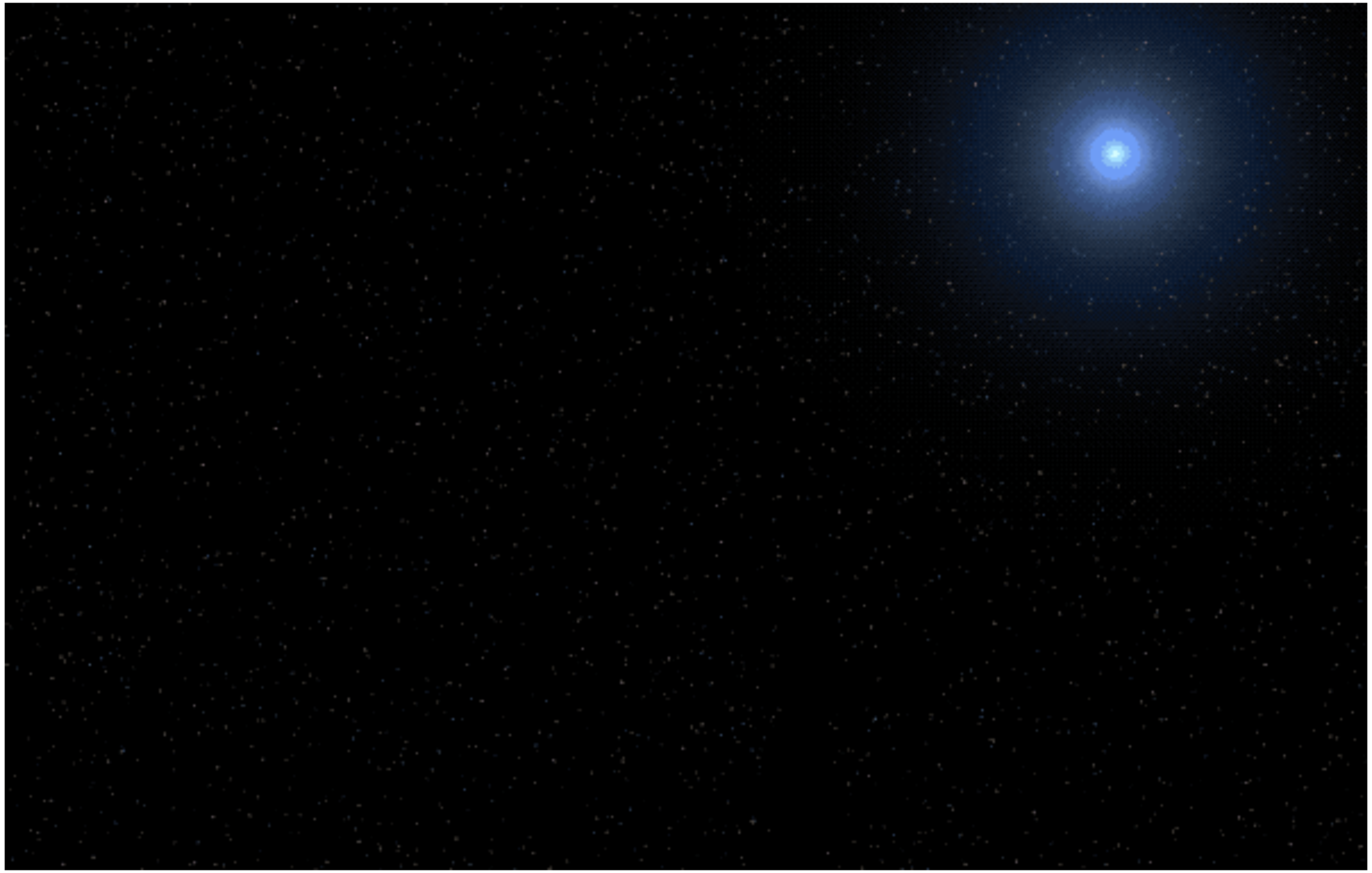


Svinkin et al., 2021 Nature 589 7841

T90 ~ 0.1 s
Flare onset ~ 77 μs
E_{iso} ~ 10^{46} ergs

- Identified as MGF by Konus IPN team
- **Clearest example of an extragalactic magnetar giant flare**. Unsaturated spectra allowed detailed investigation of emission mechanisms.
- No modulated tail observed after initial spike

EXTRAGALACTIC MGFS AS GRBS



Credit: NASA's Goddard Space Flight Center

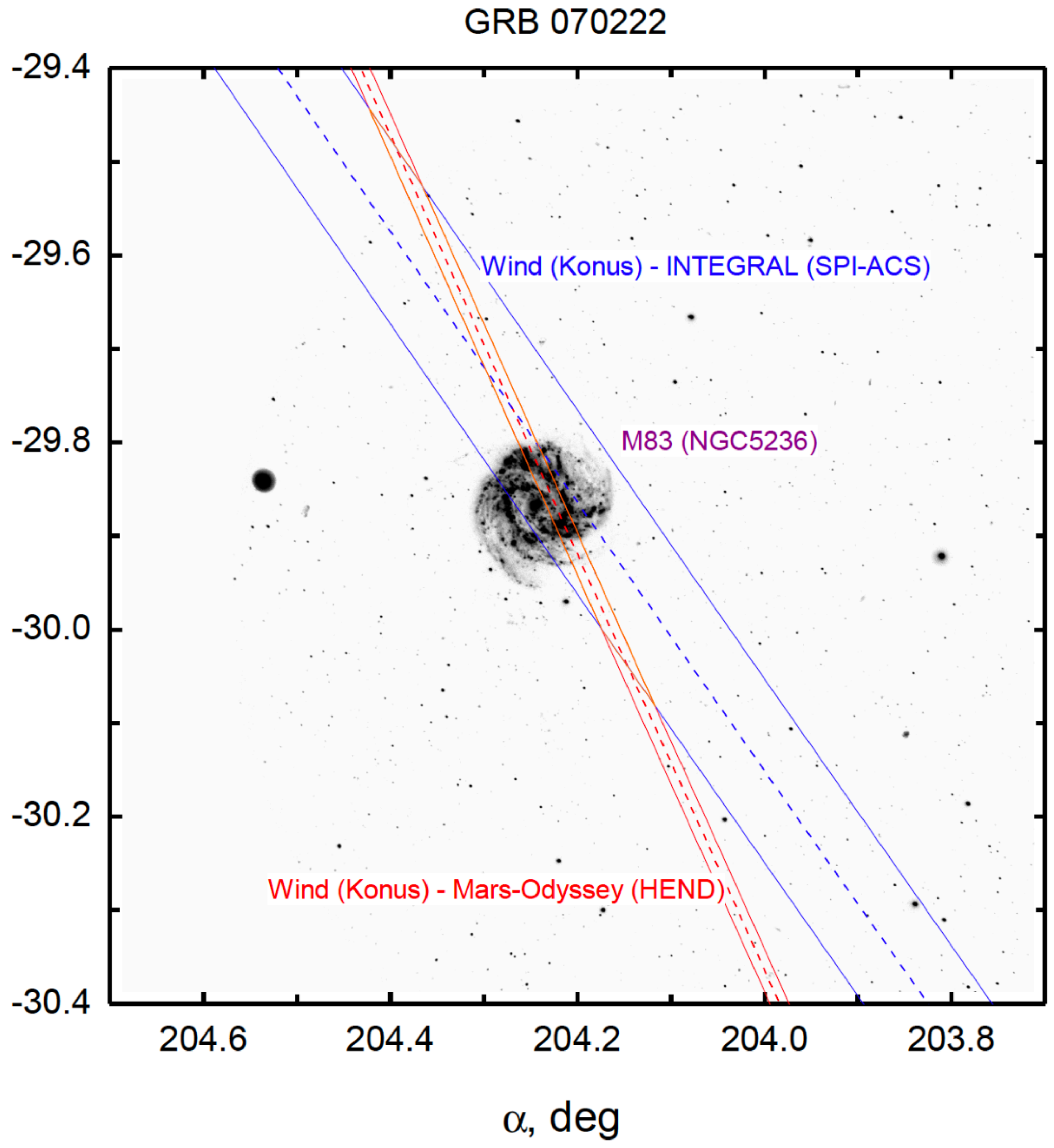
At extragalactic distances, only the initial short spike would be visible, imitating morphology of a short GRB (Hurley et al., 2005)

POPULATION ANALYSIS

- Without signature of modulated tail, analysis must focus on spatial information
- Main idea: If a well-localized short GRB is an MGF, it should occur within ~50 Mpc and be consistent with a catalogued galaxy

- Known sample of 3 nearby MGFs
  - GRB 790305B (Mazets et al. 1979, Barat et al. 1997, Evans et al. 1980)
  - GRB 980827 (Mazets et al. 1999b, Hurley et al. 1999a)
  - GRB 041227 (Hurley et al. 2005; Palmer et al. 2005; Frederiks et al. 2007a)

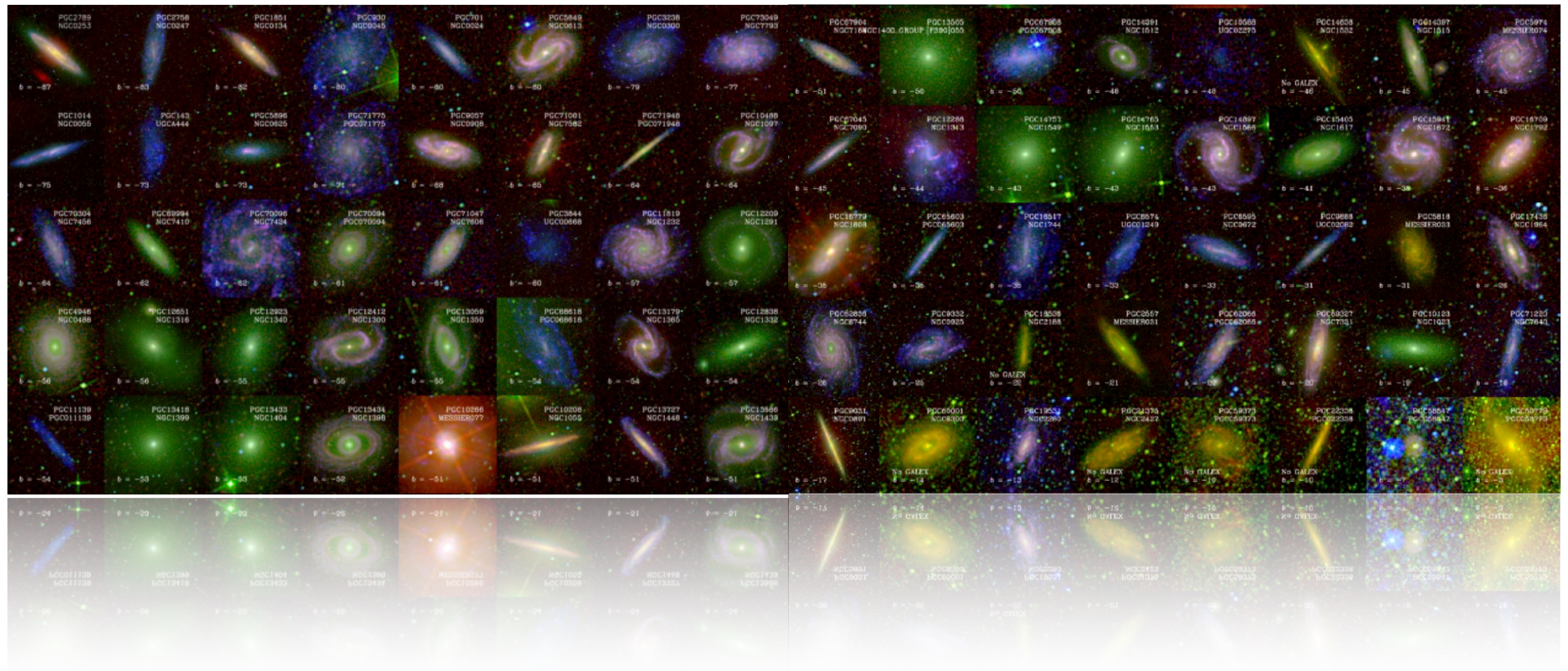
- Extragalactic MGF candidates
  - GRB 051103 (Ofek et al. 2006, Frederiks et al. 2007b, Hurley et al. 2010)
  - GRB 070201 (Mazets et al. 2008, Ofek et al. 2008)



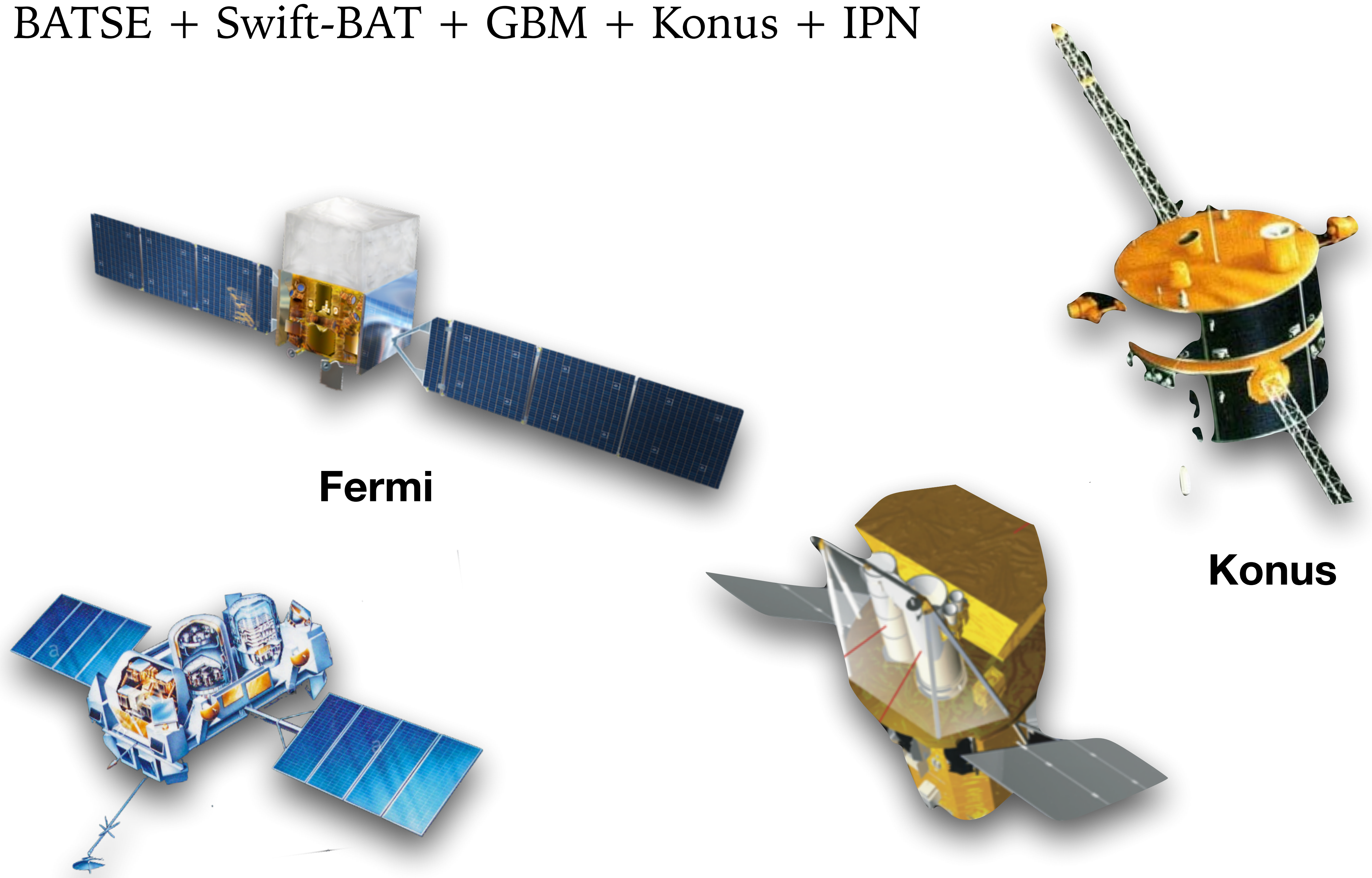
Burns et al., 2021 ApJL

DATA SAMPLE

- 100,000+ galaxies
    - Position (RA, DEC, angular extent)
    - Star formation rate (SFR)
    - 0.5 - 200 Mpc
- z0MGS* catalog = GALEX (UV) + WISE (IR)
- Supplemented <10 Mpc with Local Volume Galaxy (LVG) Catalog
- SFR & angular extent from Census of the Local Universe (CLV) Catalog



- 250 GRBs
    - T90 < 2 s
    - Bolometric fluence (1 keV - 10 MeV)
    - Localization area (90% confidence) < ~4 deg^2 (additional >100 IPN localizations performed)
    - Bursts with redshift removed
- BATSE + Swift-BAT + GBM + Konus + IPN



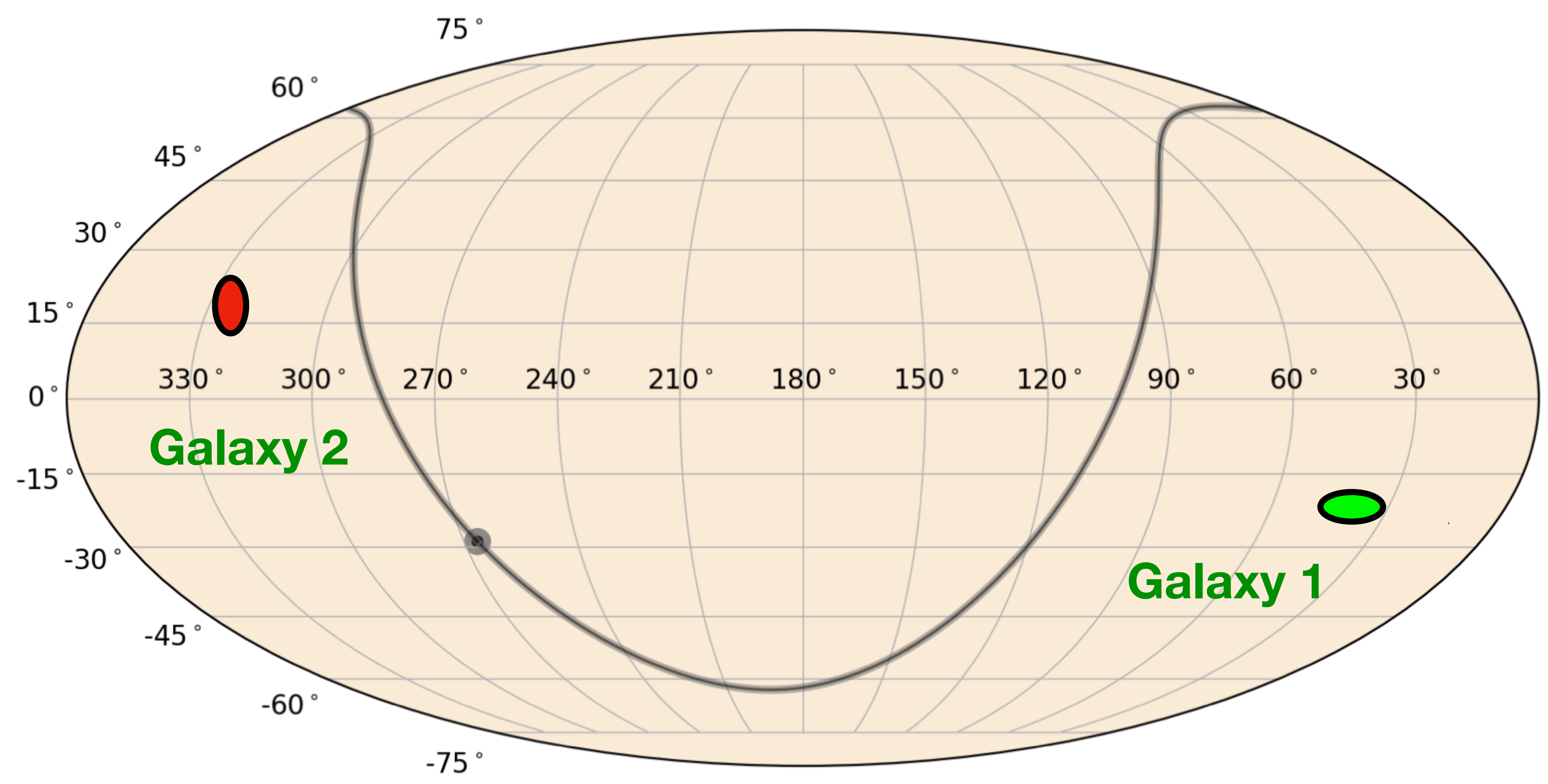
* z=0 Multiwavelength Galaxy Synthesis (Leroy et al., 2019)

THE SEARCH

For each burst, the belief it is an MGF from a known galaxy (Ω) is quantified through comparison of 2 probability maps

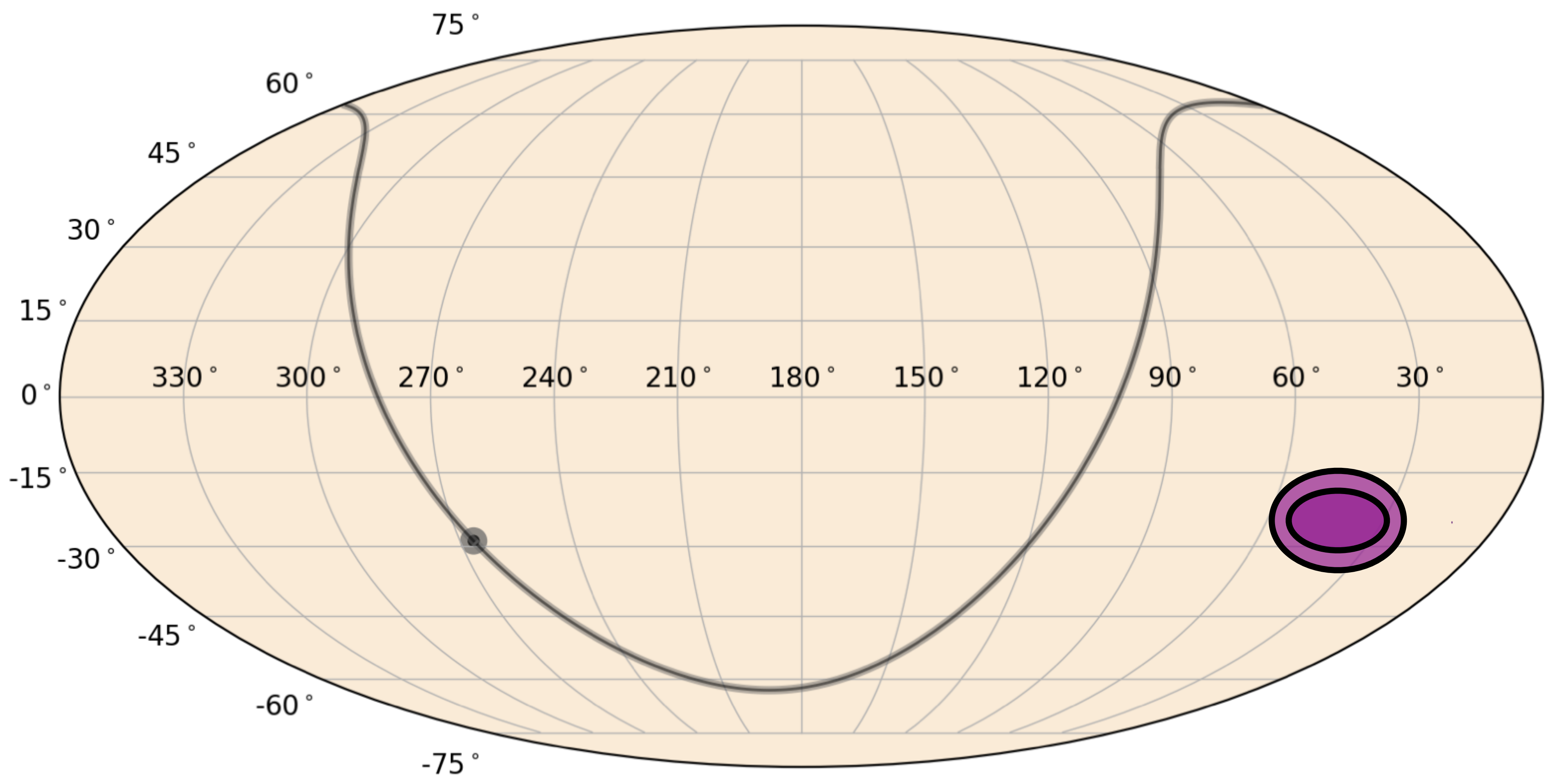
$$\Omega = 4\pi \sum_i \left(\frac{P_i^{MGF} P_i^{GRB}}{A_i} \right)$$

summation index *i* - HEALPix pixel index
(pixels all of equal area ~ 0.5 arcmin²)



P_i^{MGF} — **probability that *i*th sky position will produce an MGF with the GRB's fluence at Earth**

X



P_i^{GRB} — **GRB localization probability at *i*th sky position**

THE SEARCH

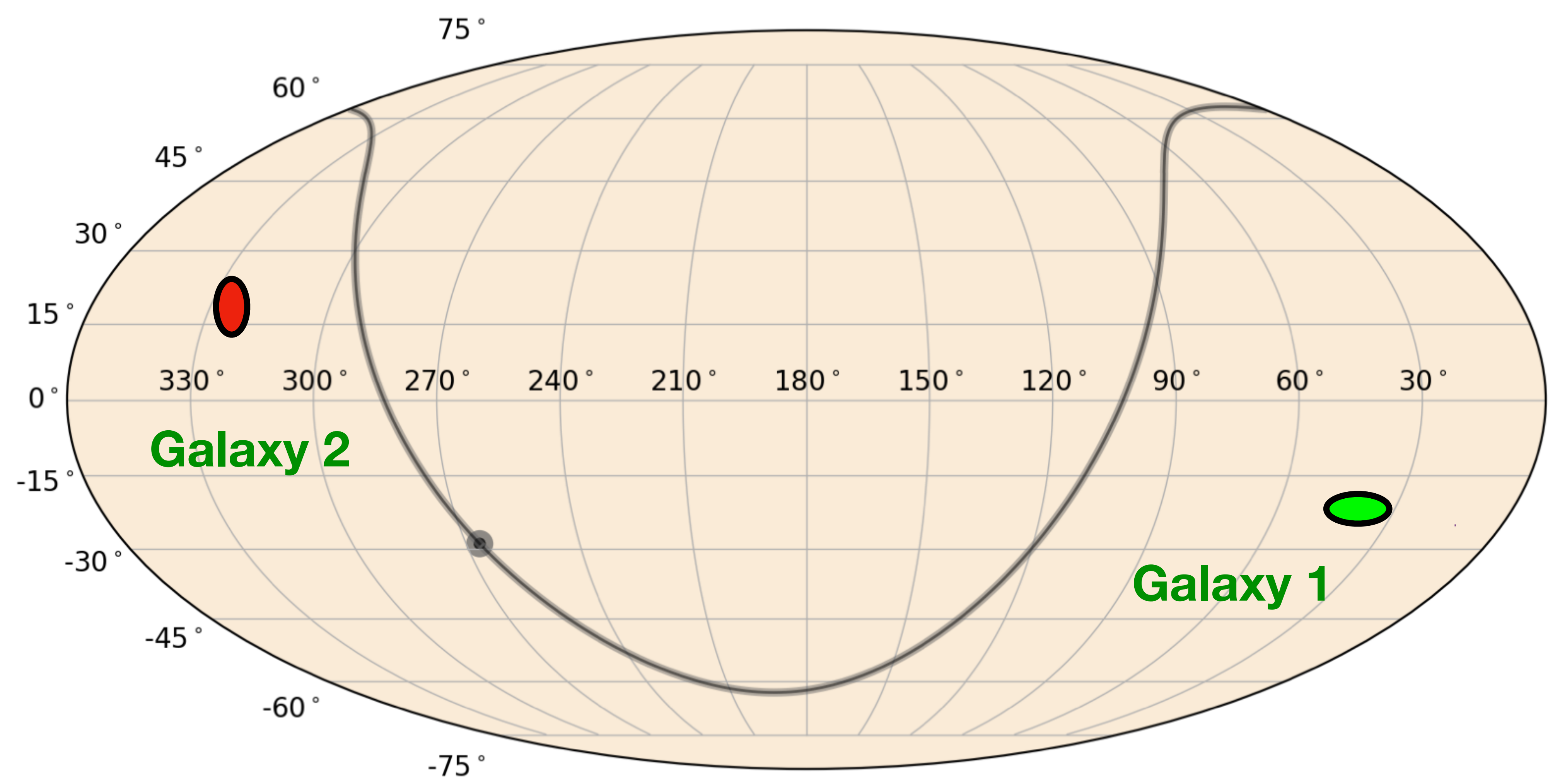
For each burst, the belief it is an MGF from a known galaxy (Ω) is quantified through comparison of 2 probability maps

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

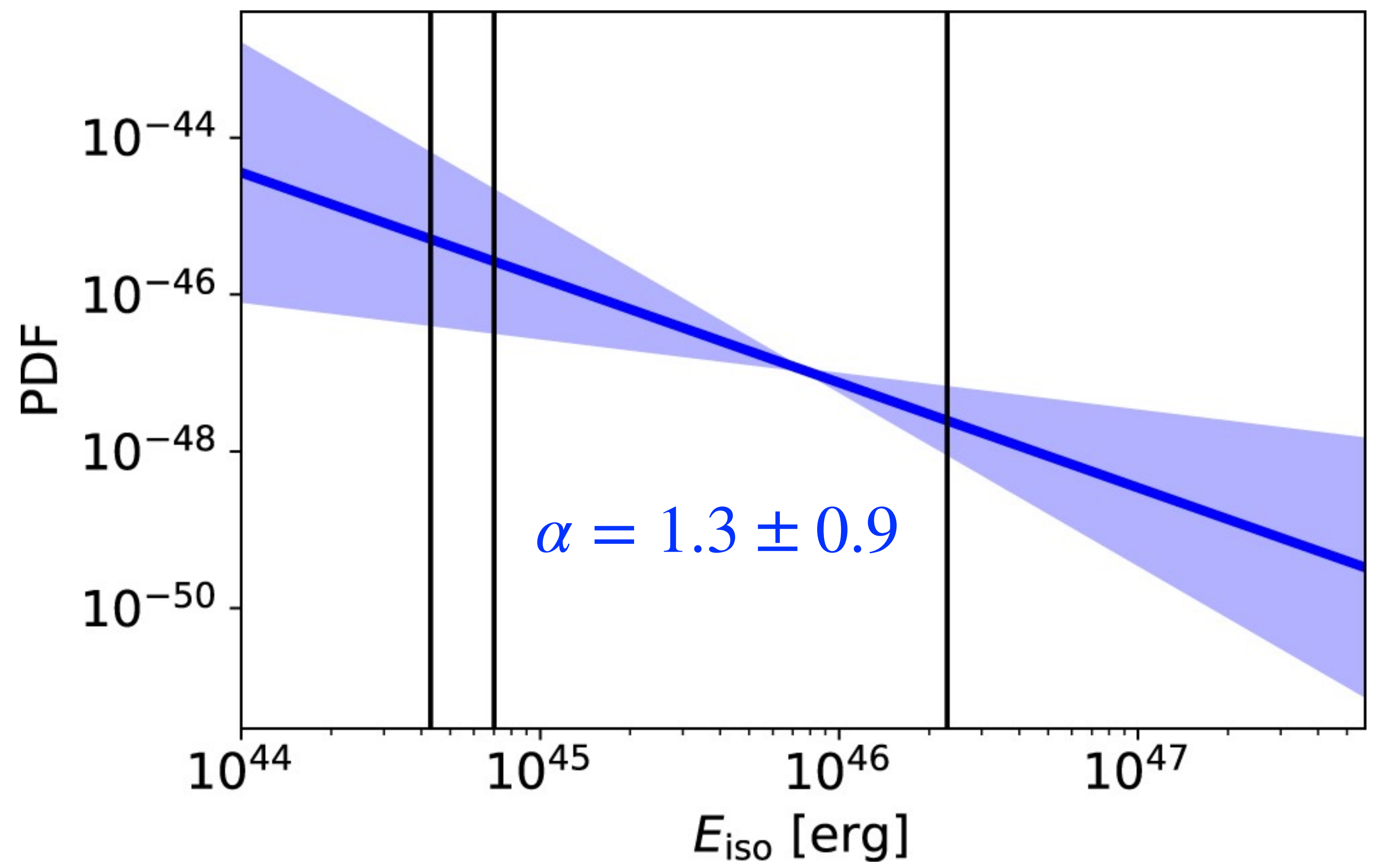
$$E_{\rm iso} = \frac{4\pi d^2}{S}$$

host galaxy

GRB

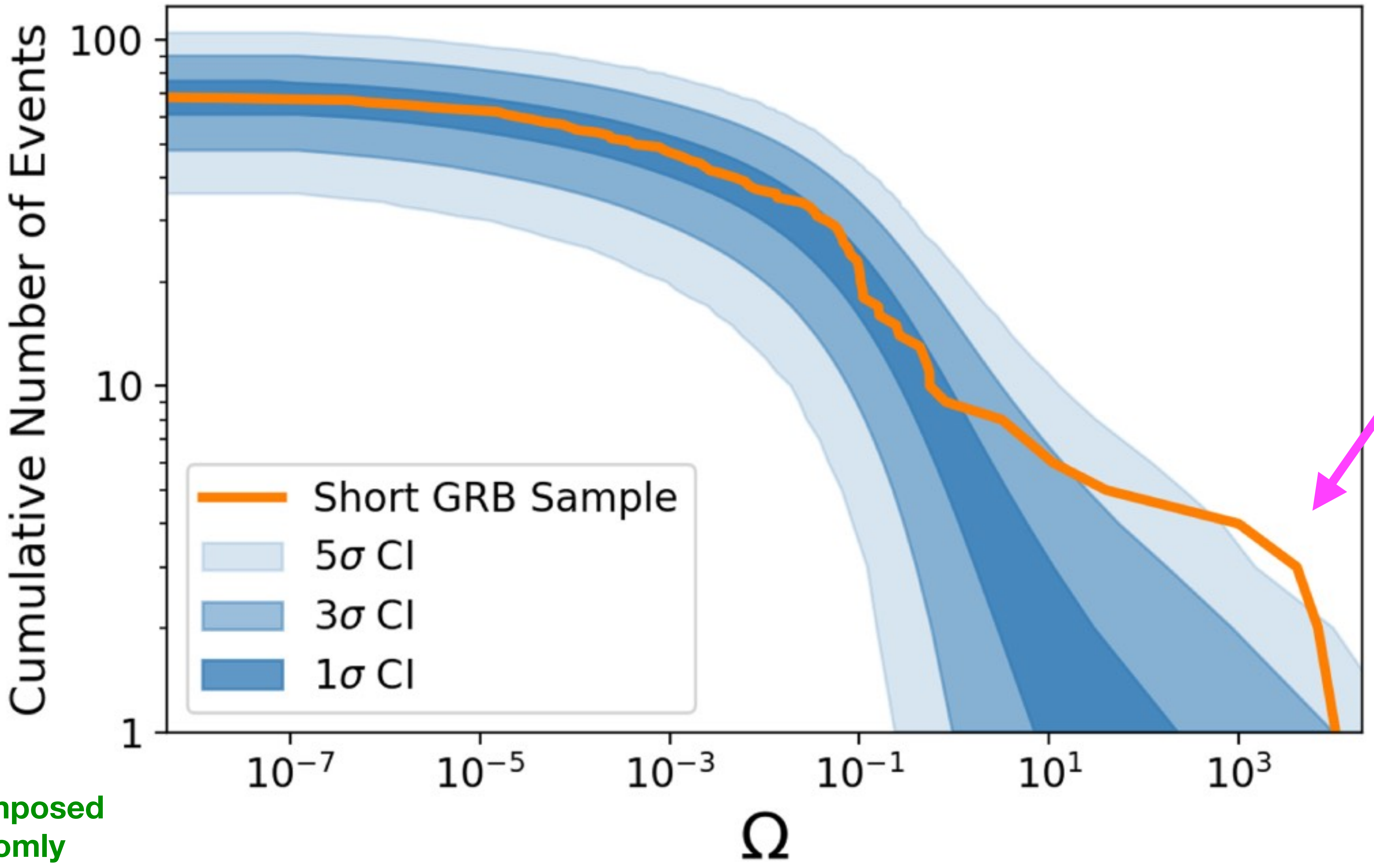


P_i^{MGF} — **probability that *i*th sky position will produce an MGF with the GRB's fluence at Earth**



Burns et al., 2021 ApJL

DISCOVERY OF LOCAL EXTRAGALACTIC GRB POPULATION



Population excess of greater than 5σ

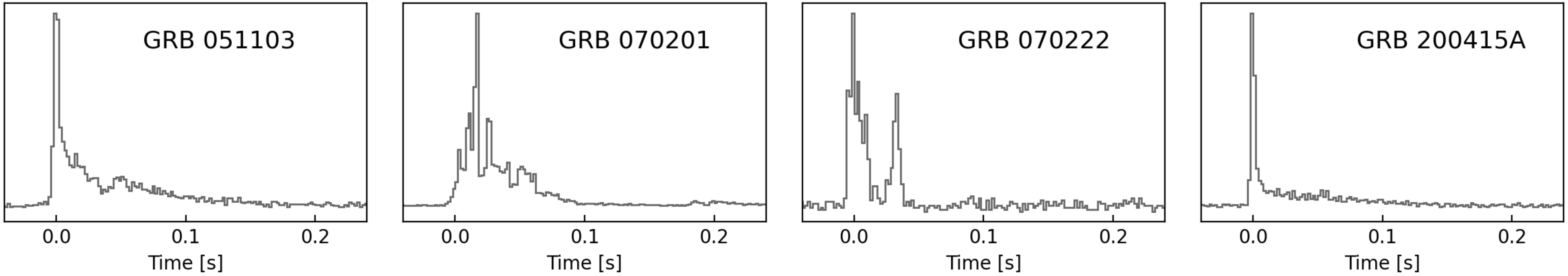
Background composed of GRBs randomly assigned to uniformly rotated galaxies.

Burns et al., 2021 ApJL

EXTRAGALACTIC MGF POPULATION

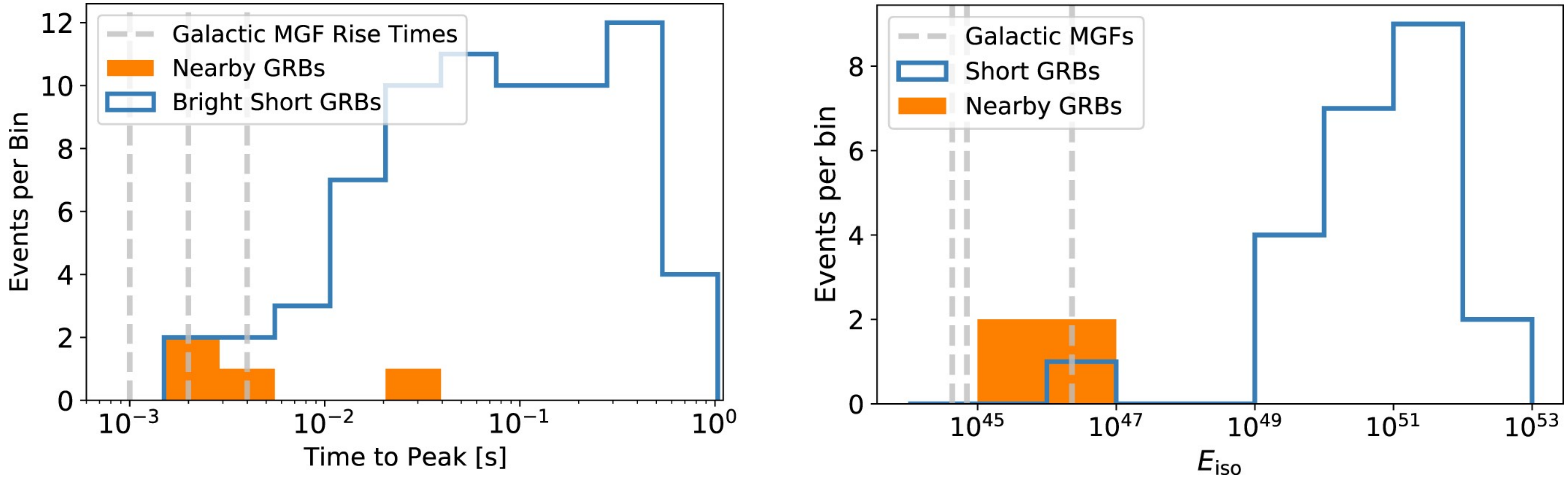
- Prompt emission inconsistent with collapsar origin
- No associated SNe or GW signals (Li et al. 2011b; Abbott et al. 2008; Abadie et al. 2012; Aasi et al. 2014)
- All assigned hosts are star-forming galaxies/regions lying within 5 Mpc

New MGF candidate



1 in 70,000 | 1 in 10,000 | 1 in 130,000 | 1 in 230,000

PARAMETER COMPARISON



Burns et al., 2021 ApJL

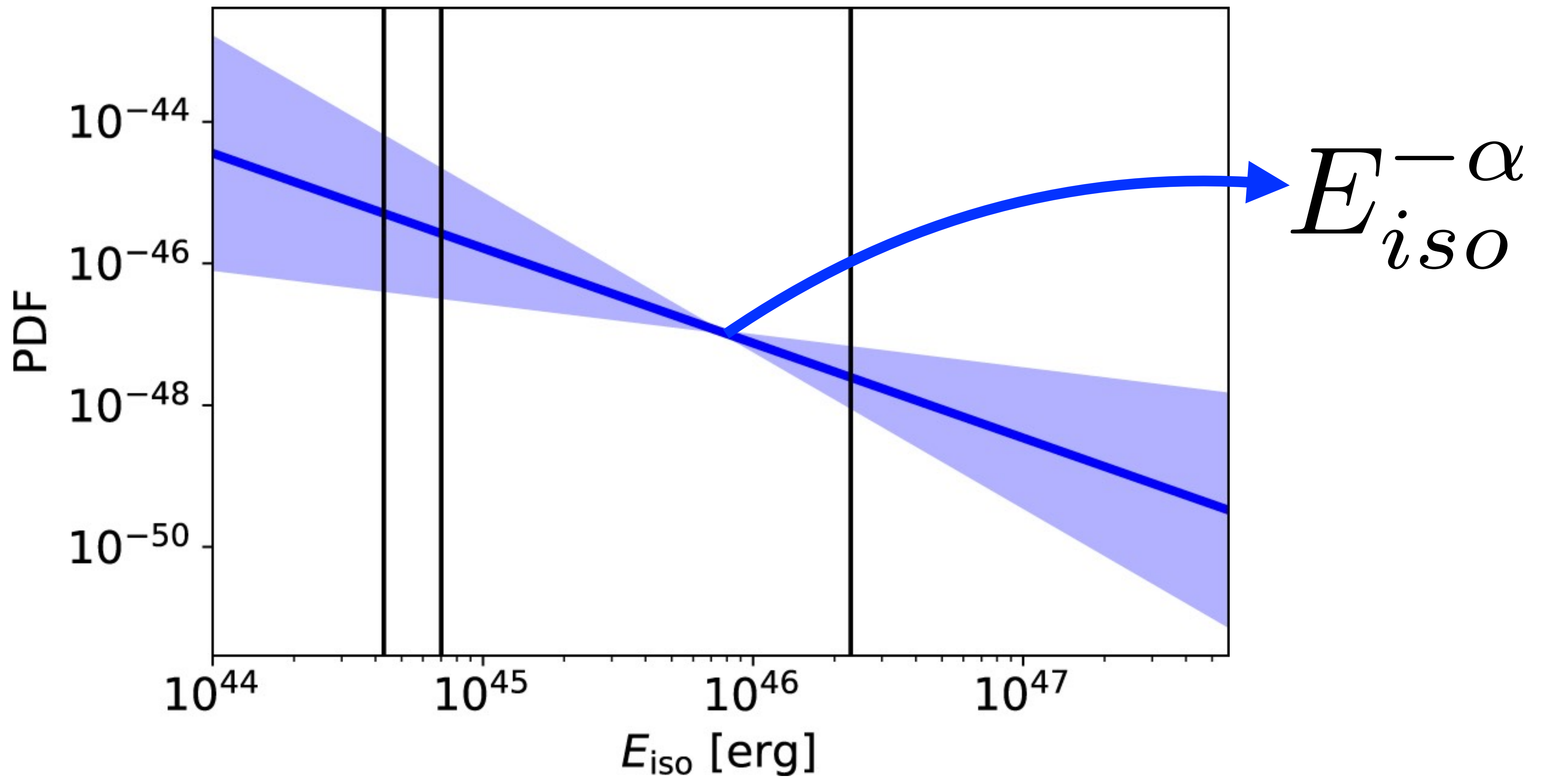
Properties are distinct from short GRBs but consistent with known MGFs:

- Rise times are order of a few ms less than that of most bright short GRBs
- Intrinsic energetics are OoM fainter
- Anderson-Darling k-sample tests for both parameters reject the null hypothesis of extragalactic MGFs coming from the short GRB population at >99.9% confidence

MGF INTRINSIC ENERGETICS

The slope of the E_iso distribution can give hints as to the physical process that produces MGFs.

1. **Simulate large number of extragalactic MGFs:**
   - Max host galaxy distance of 5 Mpc
   - Restrict GRB sample to last 27 year
2. **Draw E_{iso} from pdfs using a range of alpha values.**
3. **Randomly assign host galaxy and use distance to get flux**
4. **Number of detections are those whose flux > threshold**



Burns et al., 2021 ApJL

Anderson-Darling k-sample test yields: $\alpha = 1.7 \pm 0.4$

Consistent with previous reports (e.g., Cheng et al. 1996, Gotz et al. 2006)

MGF INTRINSIC RATE

From observations, naive MGF rate: $R_{MGF} \approx 70{,}000 \times N_{MGF}$ Gpc^{-3} yr^{-1}

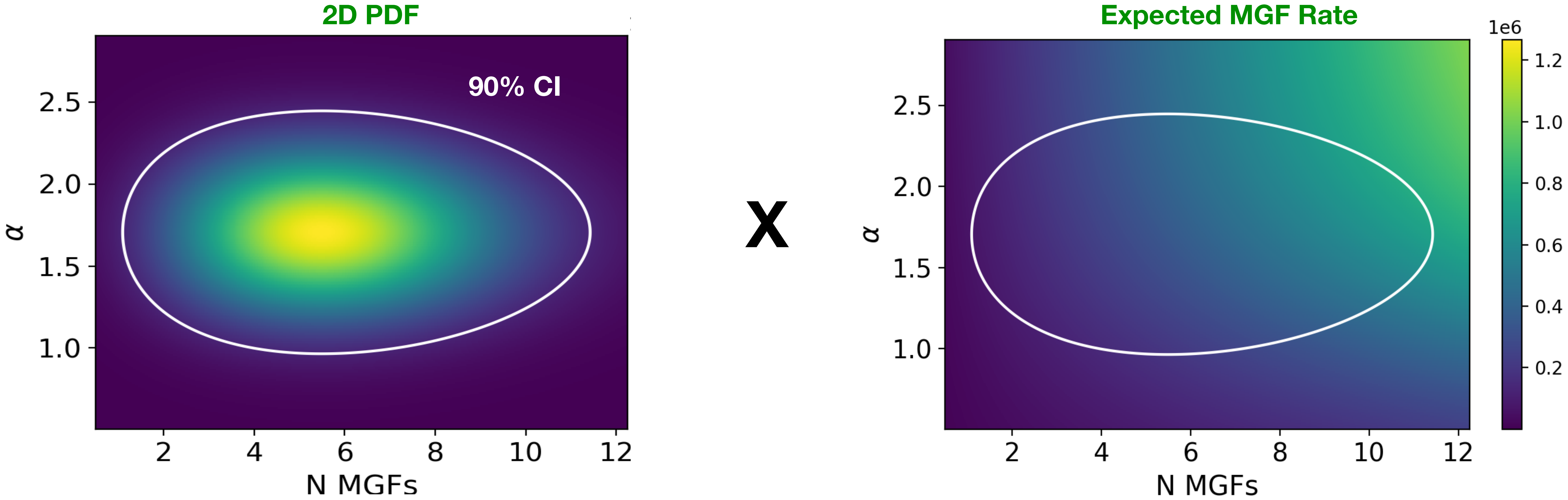
Necessary corrections:

(1) over-density of local star formation (decreases rate by factor of ~9)

(2) intrinsic energy distribution (simulations of α determine completeness)

(3) Poisson uncertainty of observed sample

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



FUTURE OF MGFS!

- Even though we've only seen 7 events, MGFs might be the most common high-energy transient detected beyond the Milky Way!
- Possible sources of FRBs (Bochenek et al., 2020) and GWs
- Need sensitive instruments to learn more about the properties of MGF and magnetar physics

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/

StarBurst
Selected for non-competitive Phase A