

Giant Flares from extragalactic magnetars

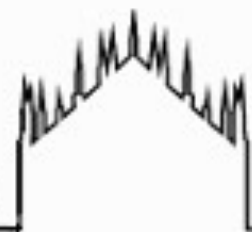
Sandro Mereghetti
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INAF



ISTITUTO NAZIONALE DI ASTROFISICA
NATIONAL INSTITUTE FOR ASTROPHYSICS

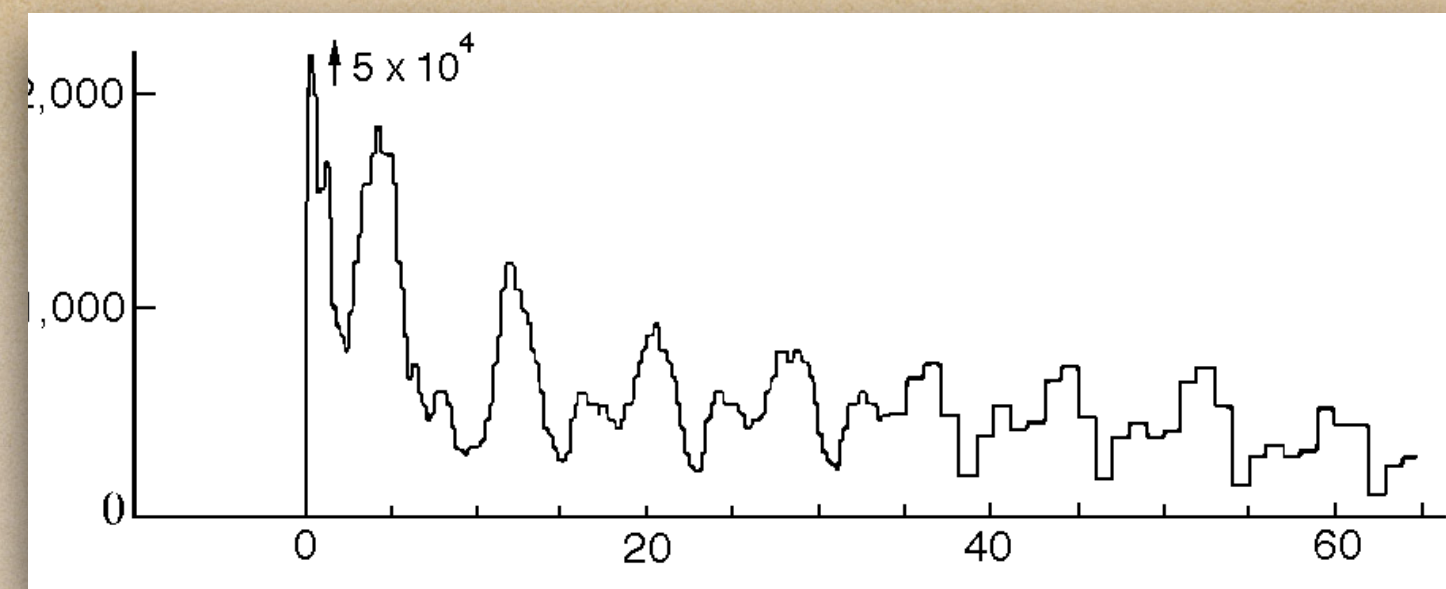
Istituto di Astrofisica Spaziale e Fisica cosmica di Milano



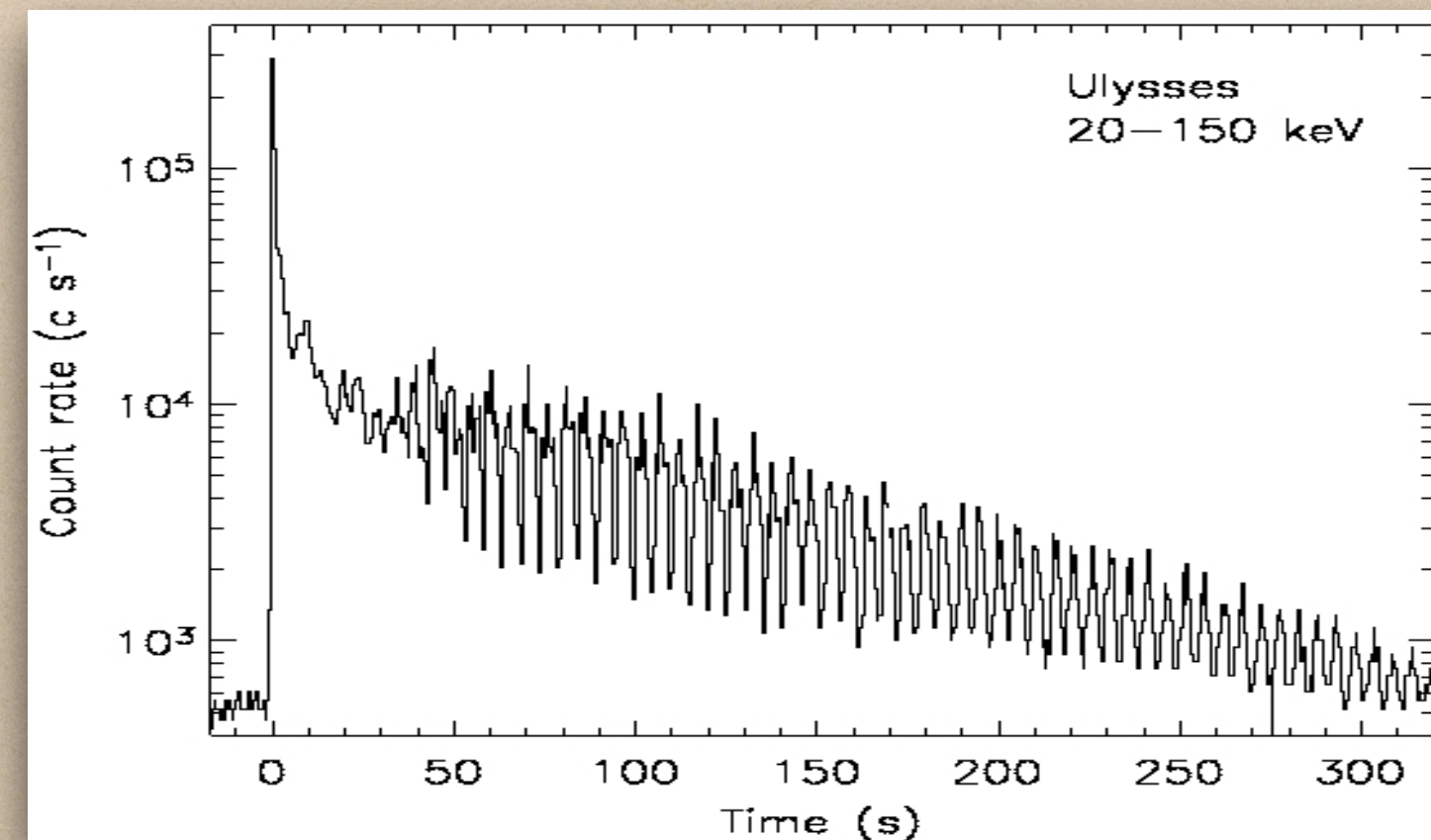
Celebrating 20 years of Swift discoveries
24-28 March 2025 - Florence, Italy

Giant Flares

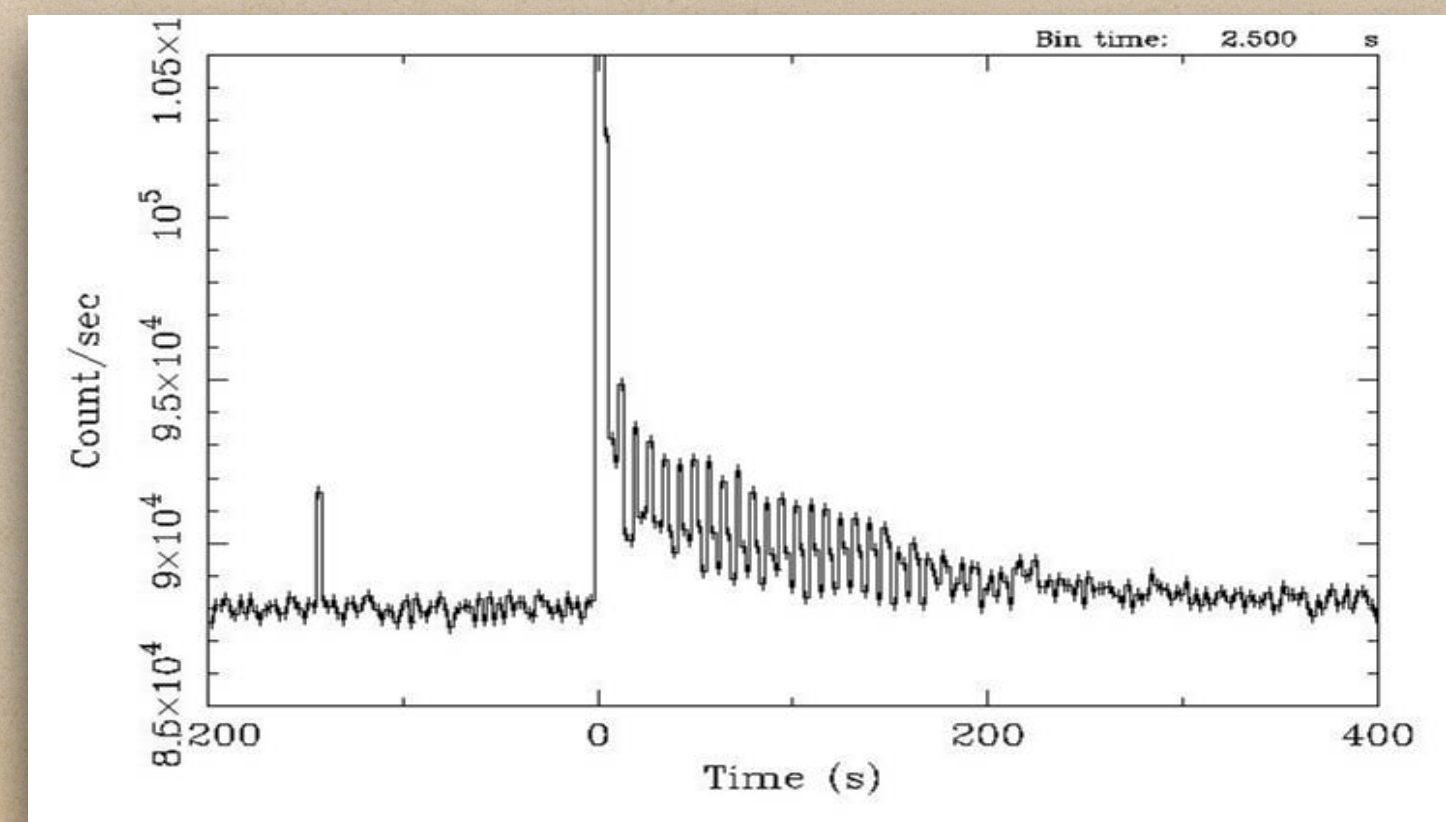
1979 March 5
SGR 0526-66



1998 August 27
SGR 1900+14



2004 Dec 27
SGR 1806-20



Main evidence for very high B

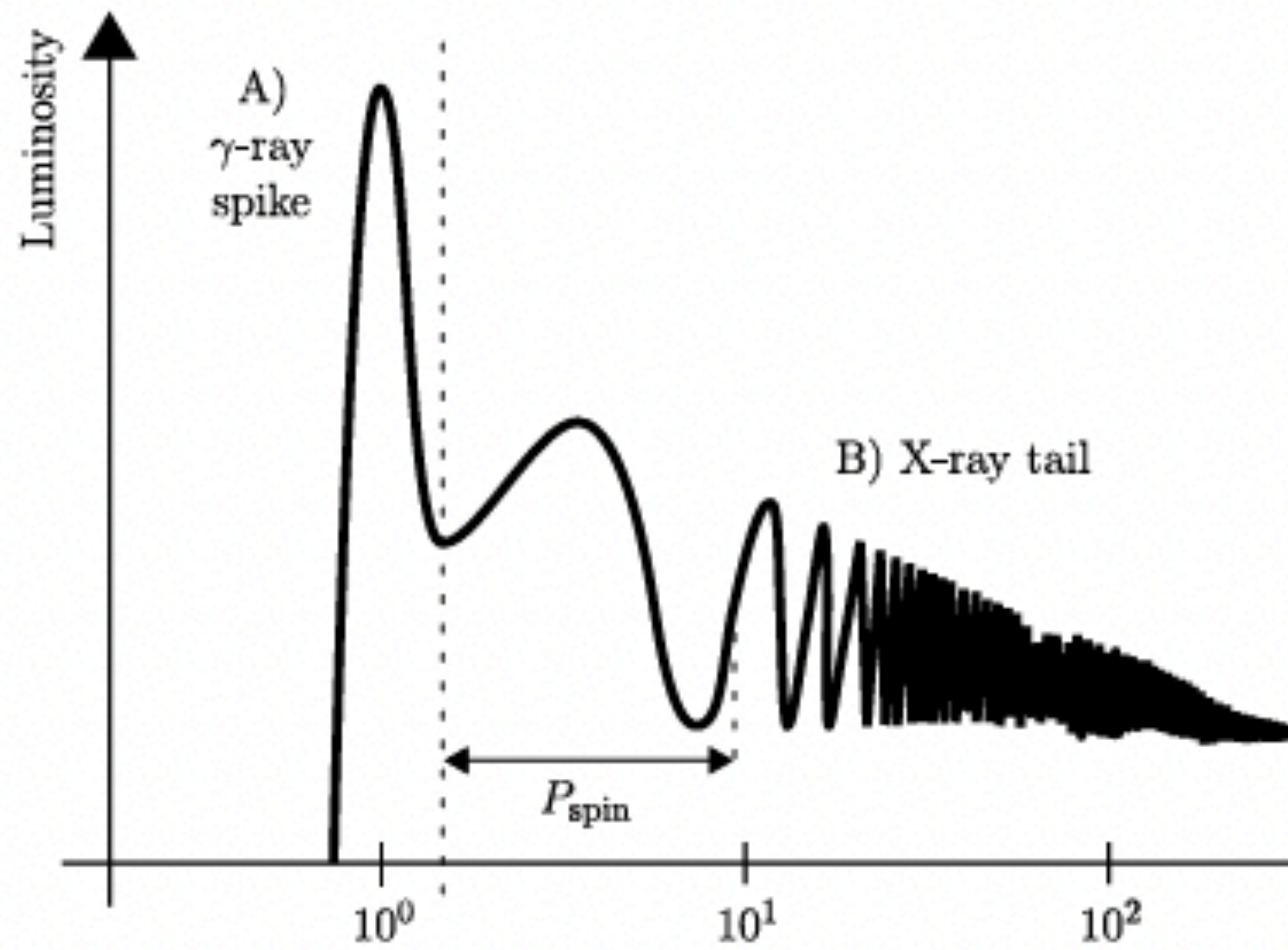
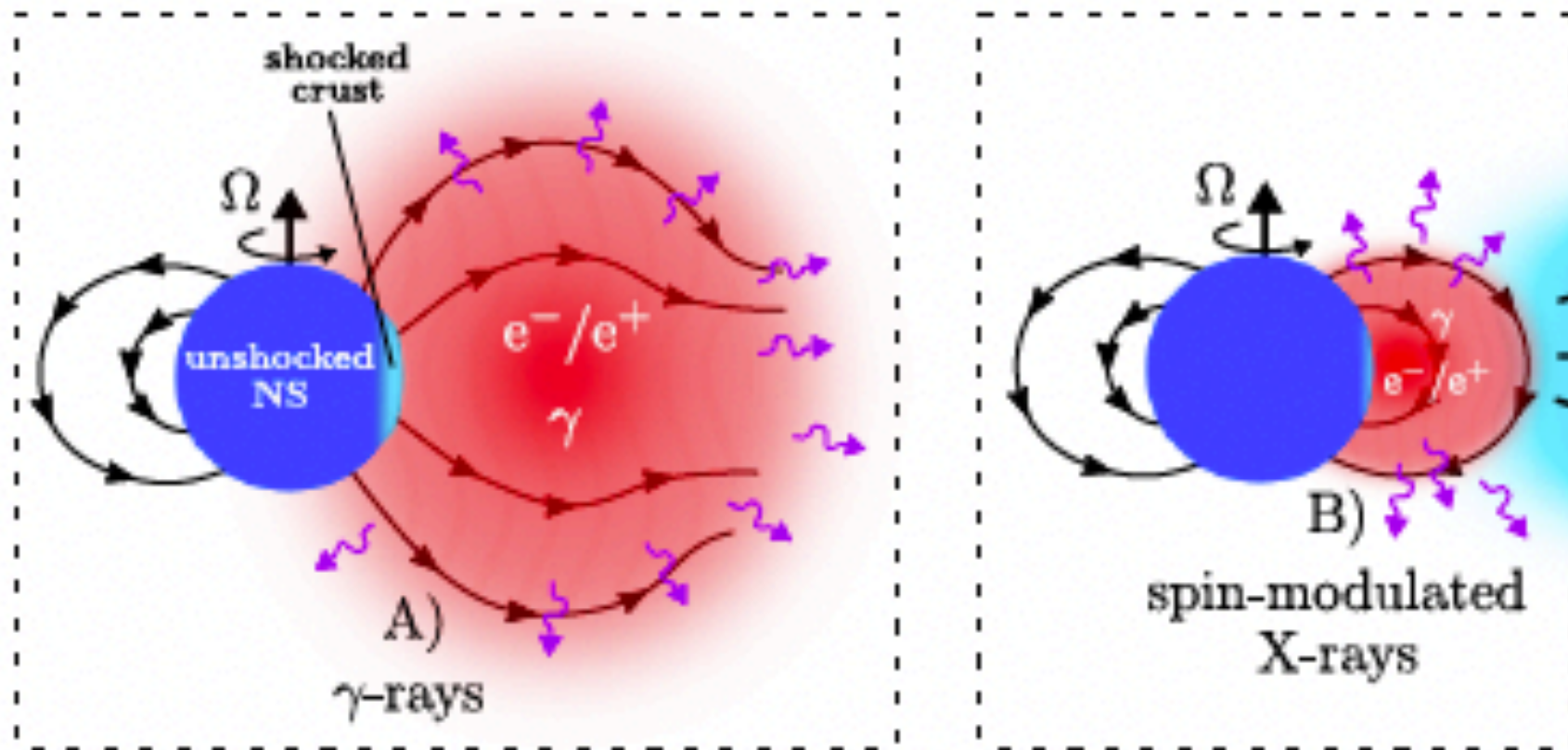
Only three GF observed in our Galaxy +
LMC in ~ 50 yrs

Short (< 0.2 s) and hard ($E_p \sim 200-500$
keV) initial spike $L_{\text{peak}} \approx 10^{45-47}$ erg/s

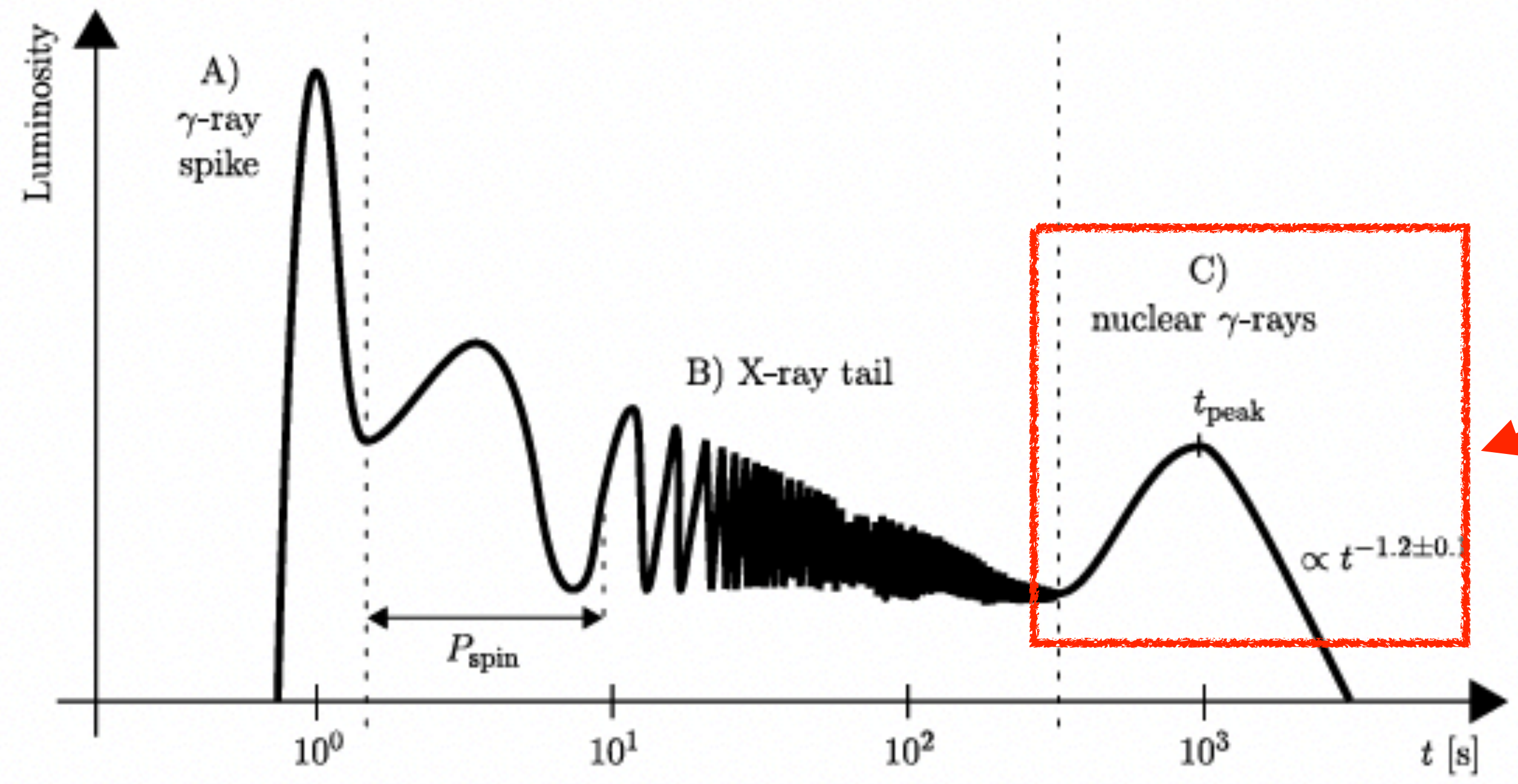
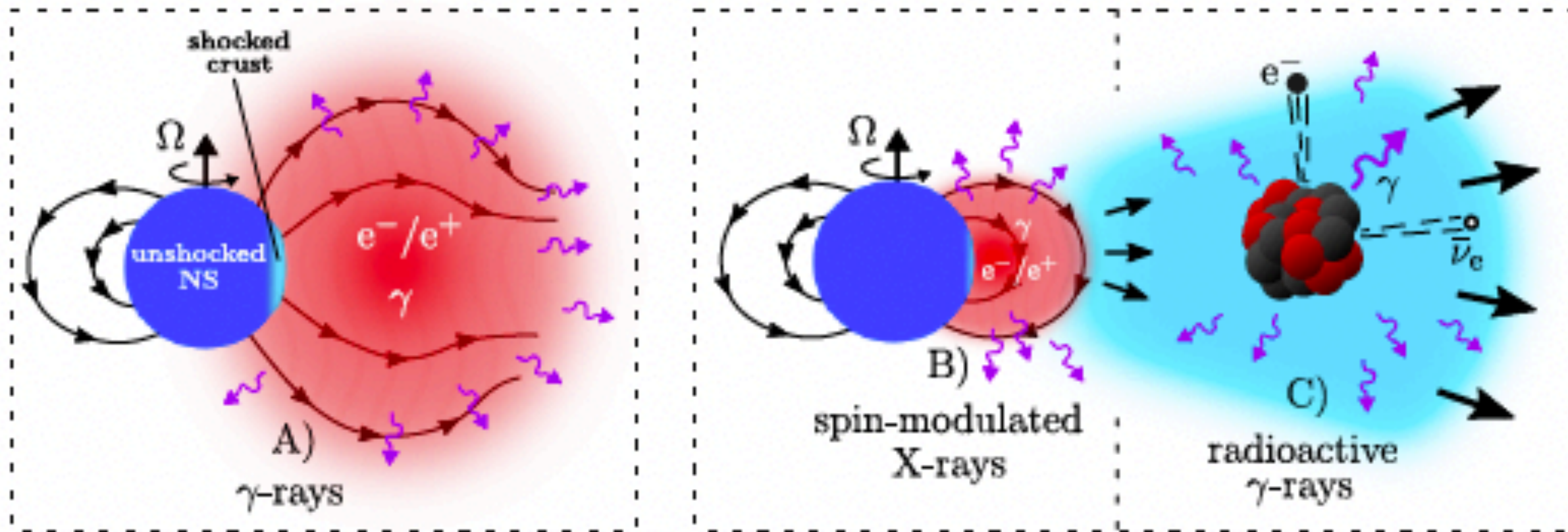
+ minutes-long pulsed tail ($E \sim 10^{44}$ erg)
with softer spectrum (similar to that of
short bursts)

+ hours-long "afterglows"

A. PATEL ET AL.



A. PATEL ET AL.



- Discovered with INTEGRAL in 2004 [Mereghetti+2005]
- Explained in 2024 as “Nova Brevis” powered by decay of r-process elements [Cehula+2024, Patel+2025a/b]

MGF key questions

- Origin

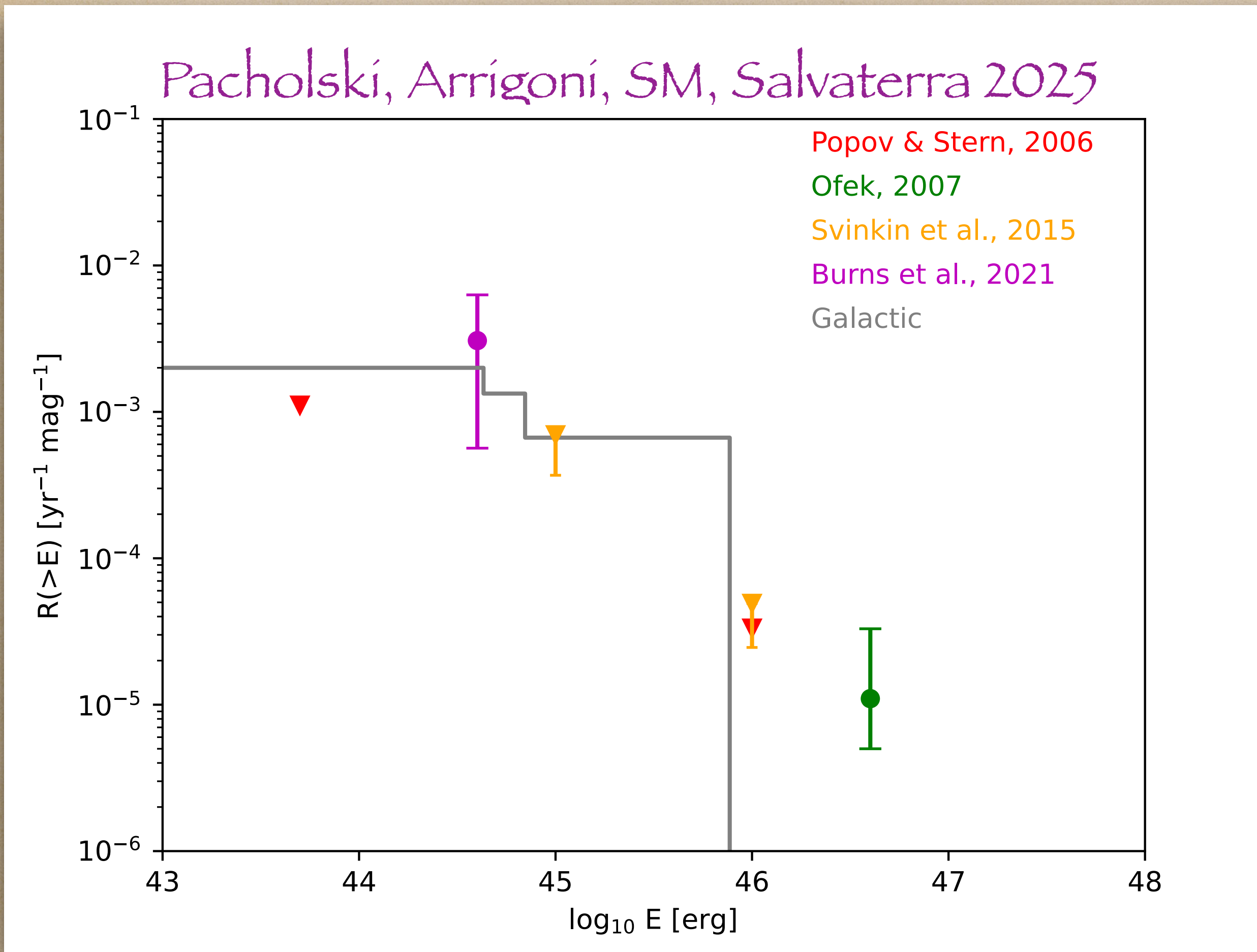
- Rate

MGF key questions

- Origin
 - “normal” bursts with extreme properties
 - or a completely different process?
- Rate
 - Overall budget of magnetic energy
 - Contribution to heavy elements in the Universe

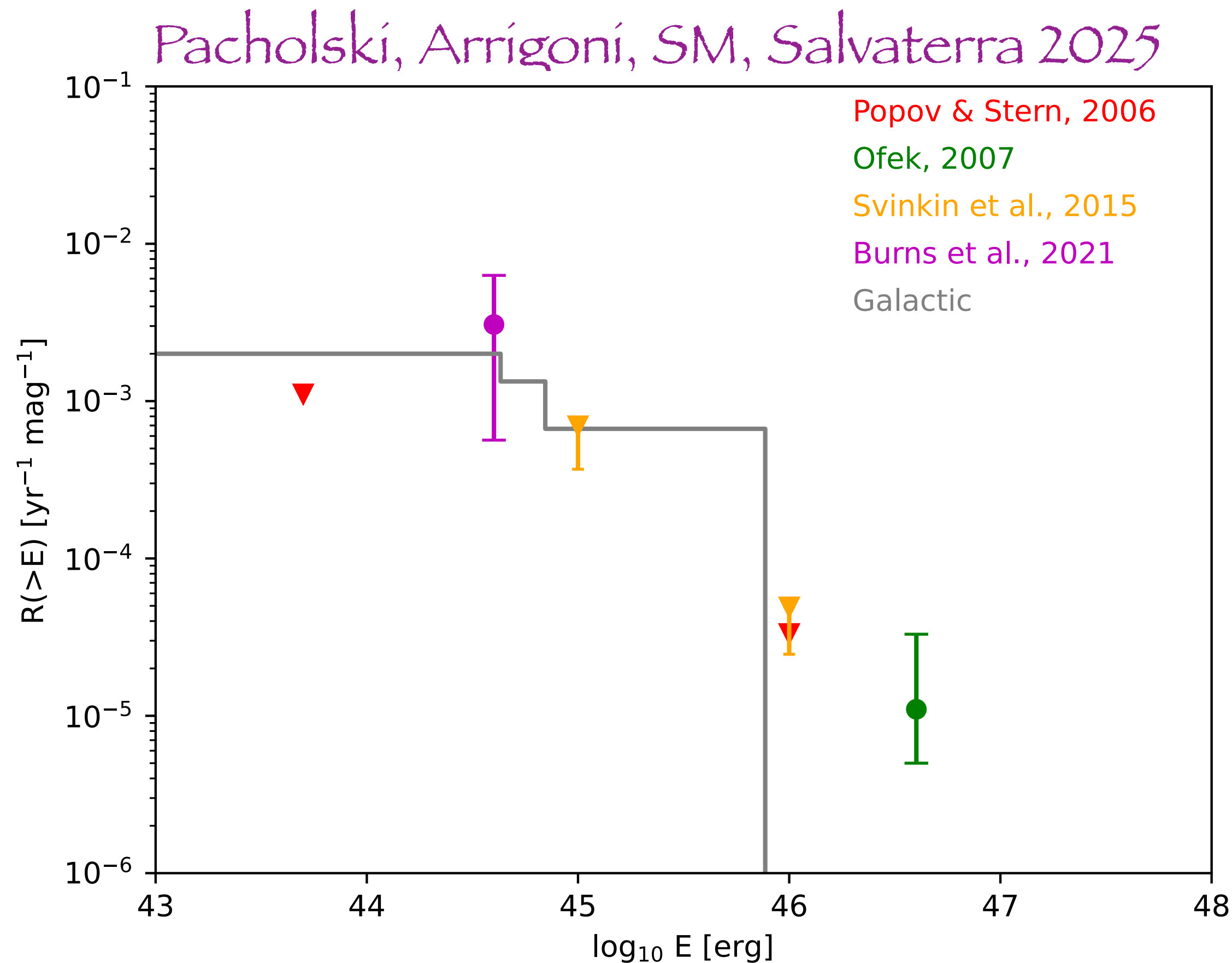
Estimates of MGF rates (how many short GRBs are MGFs?)

[Lazzati+ 2005, Palmer+ 2005, Tanvir+ 2005, Popov & Stern 2006, Nakar+2006, Ofek 2007, Svinkin+ 2015, Burns+ 2021, Pacholski+ 2025, Beniamini+ 2025,...]



Estimates of MGF rates (how many short GRBs are MGFs?)

[Lazzati+ 2005, Palmer+ 2005, Tanvir+ 2005, Popov & Stern 2006, Nakar+2006, Ofek 2007, Svinkin+ 2015, Burns+ 2021, Pacholski+ 2025, Beniamini+ 2025,...]

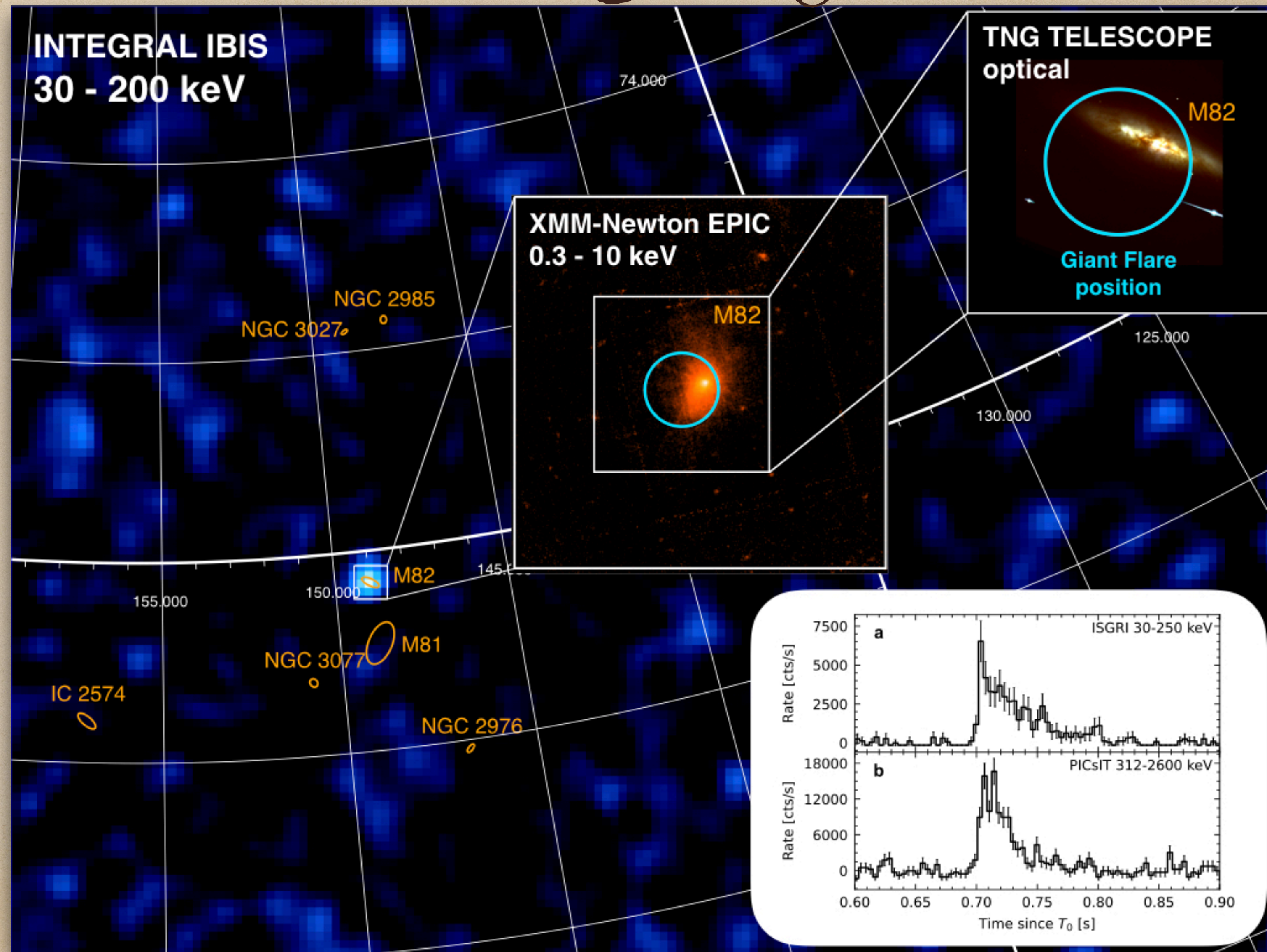


- METHOD: Correlate catalogs of short GRBs with nearby (high star forming rate) galaxies
- UNCERTAINTIES : many assumptions, small numbers, sensitivity and sky coverage, star formation rate, number of galactic magnetars, lifetime, ...
- ADVANTAGE: extragalactic MGF provide the best way to increase the sample

	Galaxy	Distance (Mpc)	E_{150} 10^{45} erg	
790305	LMC	0.055	0.7	Mazets+ 1979
980827	MW	0.0125	0.43	Hurley+ 1999, Mazets+ 1999
041227	MW	0.0087	7.7	Palmer+2005, Mereghetti+ 2005
051103	M 81 (or M82?)	3.7	53	Frederiks+ 2007, Ofek+ 2006
070201	M 31	0.78	1.5	Mazets+ 2001, Ofek+ 2008
070222	M 83	4.5	6.2	Burns+ 2001
180128A	NGC 253	3.5	0.6	Trigg+ 2024
200415A	NGC 253	3.5	13	Svinkin+ 2021, Roberts+ 2021
231115A	M 82	3.6	1	Mereghetti+ 2023
241107A	PGC 86046	4.1	1.6	Rodi+ 2025

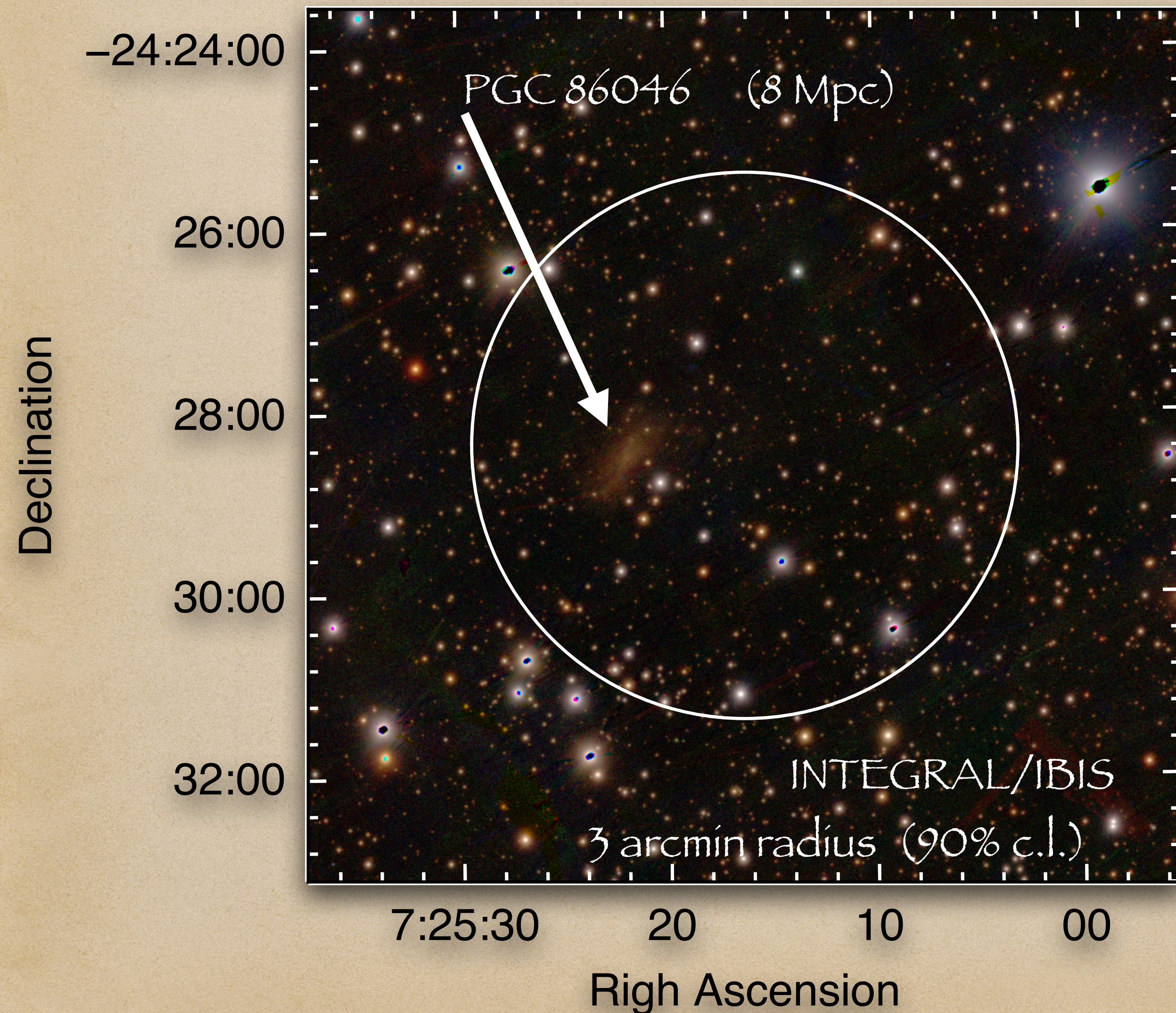
MGF 231115A in starburst galaxy M82

Small error region ($R \sim 2$ arcmin)
automatically distributed by
IBAS after 13 s



Short GRB 241107A: a MGF in PGC 86046 ?

Rodi, Pacholski, SM+ 2025



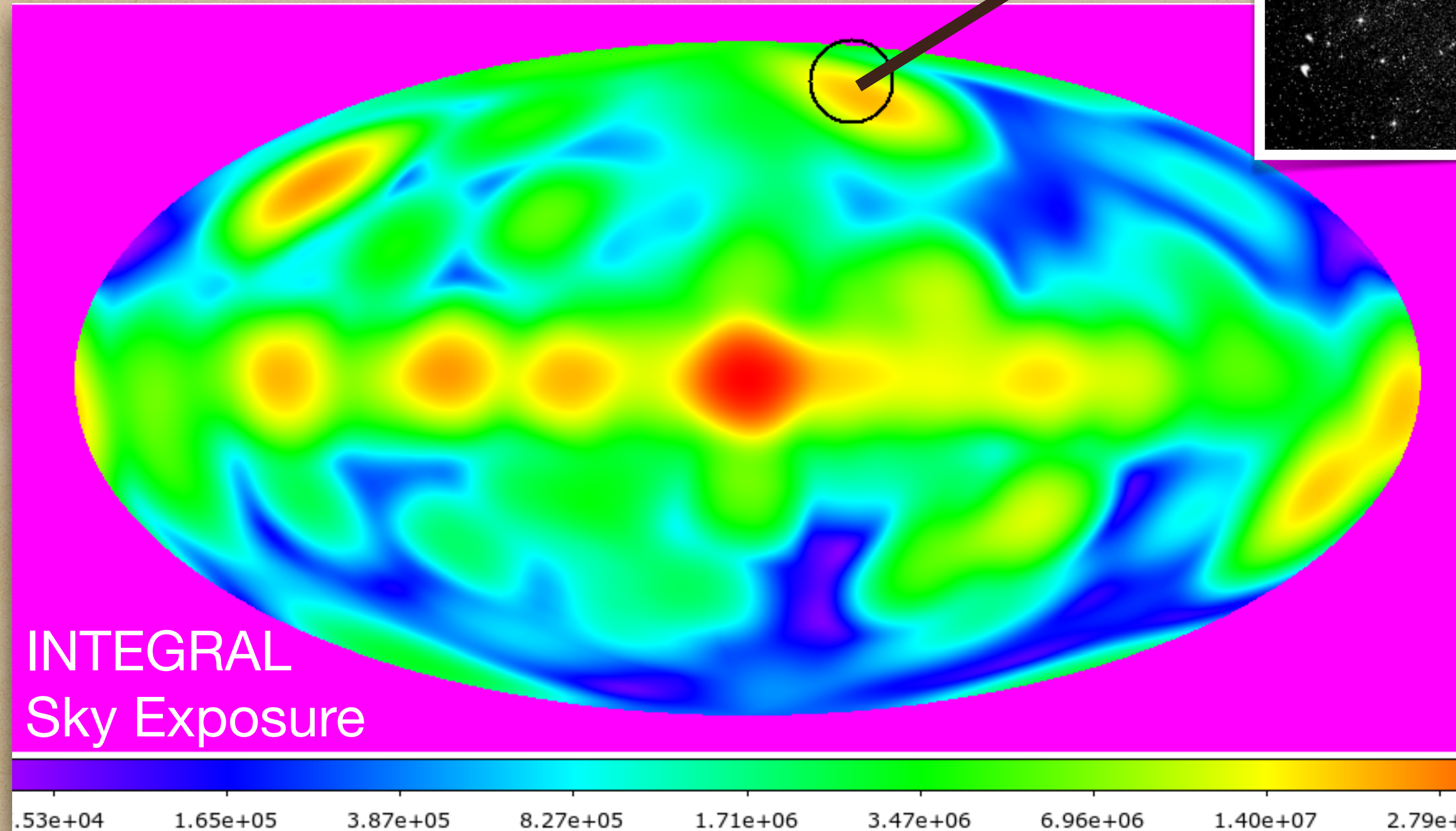
- Short GRB discovered by SVOM/GRM
- Triangulated with INTEGRAL SPI/ACS and Konus/Wind → 1 deg²
- Inside INTEGRAL/IBIS and Swift/BAT FoV (too faint for automatic trigger) → few arcmin position obtained few days later

***INTEGRAL* search for magnetar giant flares from the Virgo Cluster and in nearby galaxies with high star formation rate**

Dominik Patryk Pacholski^{1,2*}, Edoardo Arrigoni,^{1,2} Sandro Mereghetti¹ and Ruben Salvaterra¹

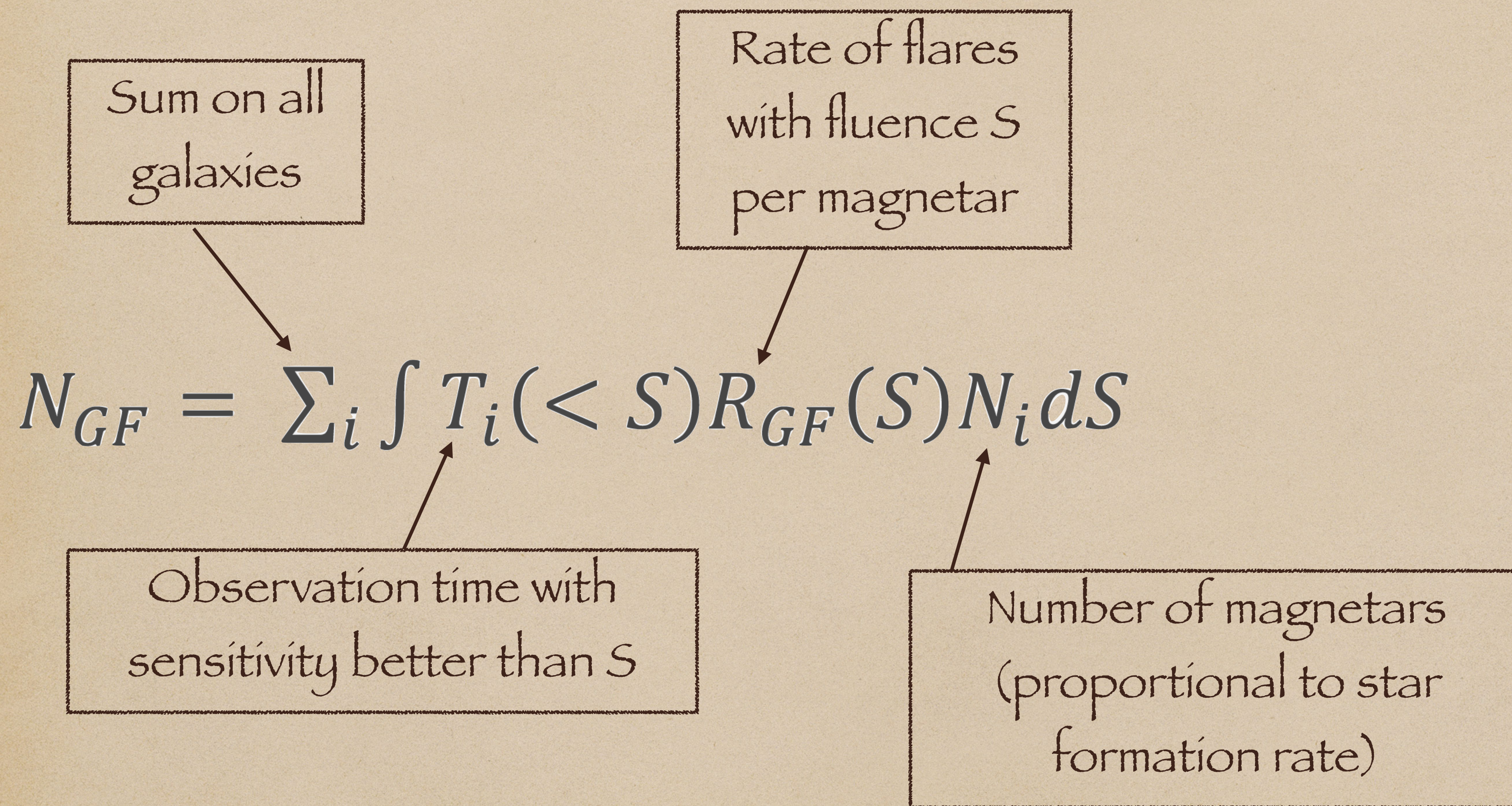


Virgo Cluster
16.5 Mpc
~1500-2000 galaxies



Large INTEGRAL
net exposure ~35 Ms

Number of Virgo MGF expected in INTEGRAL/IBIS data



Number of Virgo MGF expected in INTEGRAL/IBIS data

Sum on all galaxies

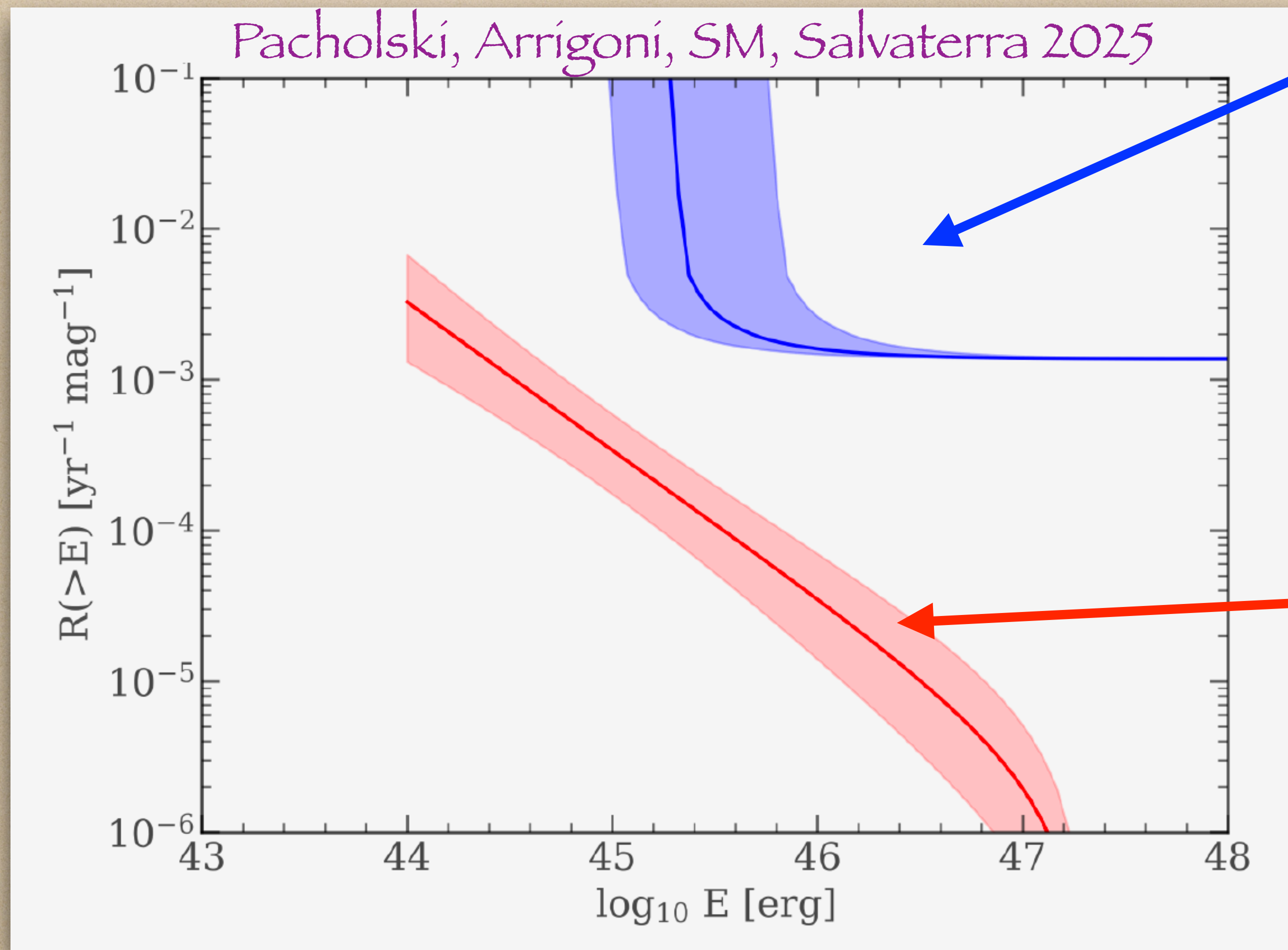
Rate of flares with fluence S per magnetar

$$N_{GF} = \sum_i \int T_i(< S) R_{GF}(S) N_i dS = 0.15 [0.05-0.3]$$

Observation time with sensitivity better than S

Number of magnetars (proportional to star formation rate)

Constraints from Virgo



Upper limit (90% cl) from lack of MGF in INTEGRAL observations of Virgo Cluster

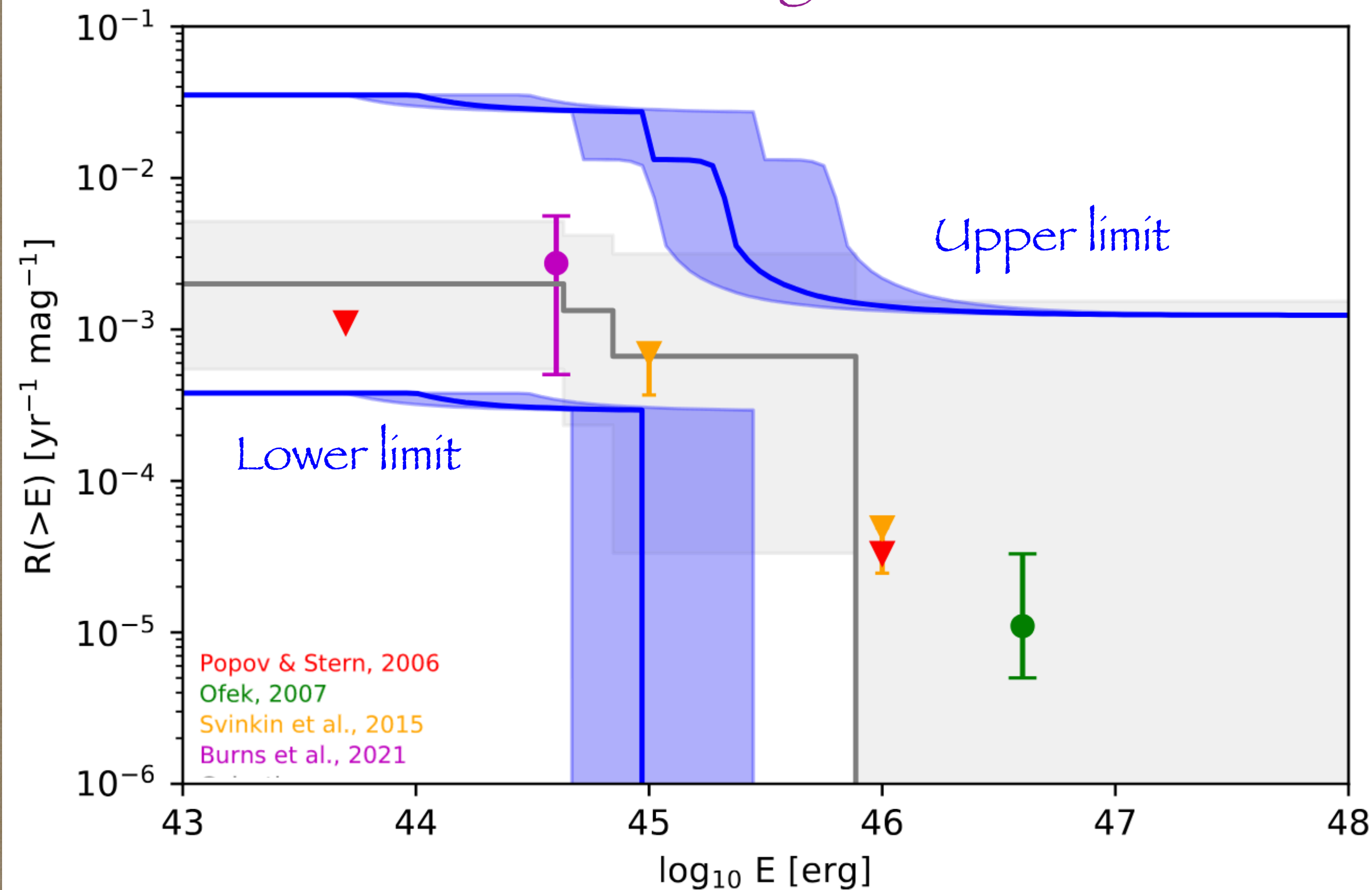
Best estimate from complete subsample of galactic and extragalactic GF

We extended the search for MGF to 7 nearby galaxies with high star formation rate observed by INTEGRAL

Galaxy	D (Mpc)	SFR ($M_{\odot} \text{ yr}^{-1}$)	Exposure (Ms)
NGC 253	3.5	4.9	0.6
M81	3.4	0.5	25.5
M82	3.6	7.1	26.1
M83	4.5	4.2	5.2
NGC 4945	3.4	1.5	17.9
IC 342	2.3	1.9	7.2
PGC 50779	4.2	3.9	20.8

INTEGRAL search for MGF in Virgo Cluster and in 7 nearby galaxies with high star formation rate

Pacholski, Arrigoni, SM, Salvaterra 2025



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One MGF found (in M82)
 → lower and upper limits

Conclusions

- INTEGRAL provided the two last-discovered MGF candidates:

231115A in M82 and 241107A in PGC 86046

- Only one MGF in INTEGRAL observations of Virgo Cluster and 7 nearby galaxies with high SFR → upper and lower limits (90% cl) on integrated rate $R(>E)$ of MGFs

at $E < 10^{45}$ erg : one every 2500 yr $< R(>E)$ [magnetar $^{-1}$ yr $^{-1}$] $<$ one every 50 yr

at $E > 3 \cdot 10^{45}$ erg : $R(>E)$ [magnetar $^{-1}$ yr $^{-1}$] $<$ one every 500 yr

Conclusions

- INTEGRAL provided the two last-discovered MGF candidates:
231115A in M82 and 241107A in PGC 86046
- Only one MGF in INTEGRAL observations of Virgo Cluster and 7 nearby galaxies with high SFR → upper and lower limits (90% cl) on integrated rate $R(>E)$ of MGFs
at $E < 10^{45}$ erg : one every 2500 yr < $R(>E)$ [magnetar $^{-1}$ yr $^{-1}$] < one every 50 yr
at $E > 3 \cdot 10^{45}$ erg : $R(>E)$ [magnetar $^{-1}$ yr $^{-1}$] < one every 500 yr
- Increasing sample of extragalactic MGF is crucial to better constrain the rate of these events → Swift, SVOM, EP.... Theseus
- Search for (orphan) pulsed tails

SCIENCE & EXPLORATION

Mission accomplished for Integral, ESA's gamma-ray telescope

February 28, 2025

28/02/2025 5596 VIEWS 71 LIKES

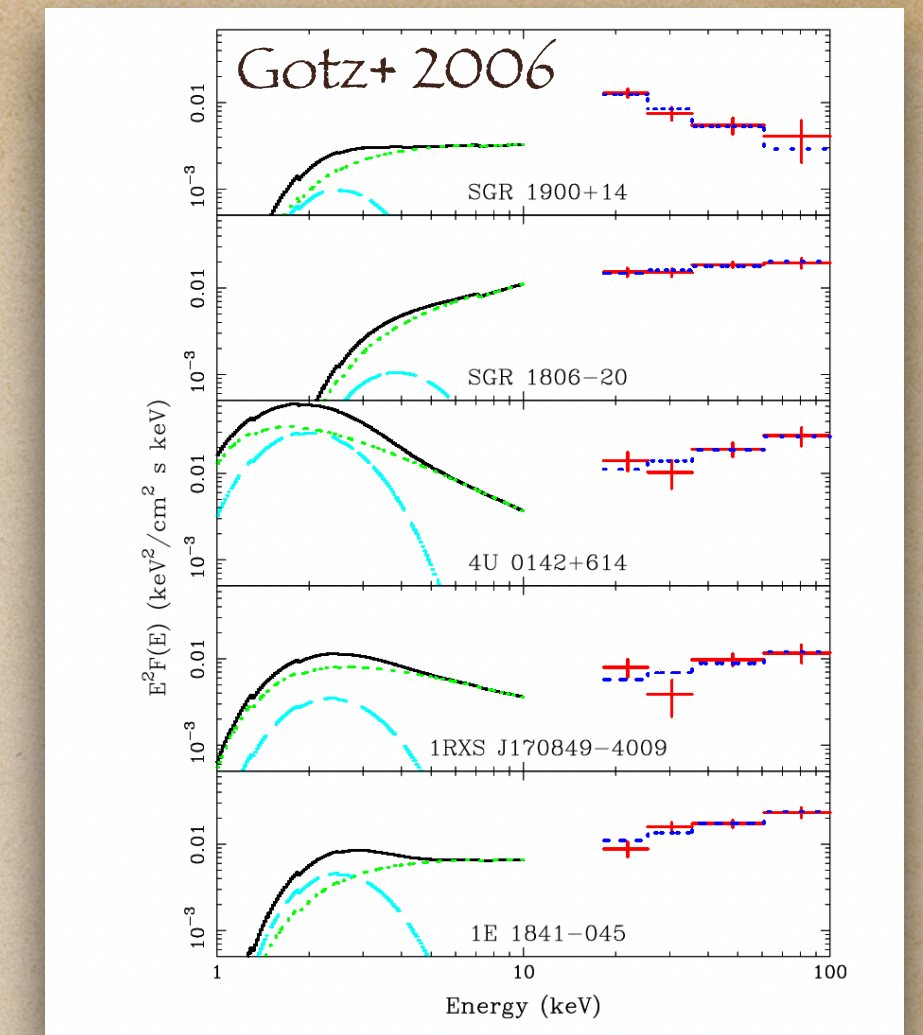
“After 2886 orbits and 22 years gazing into the depths of our cosmos, today Integral’s sensitive instruments will stop collecting scientific data. But the legacy of ESA’s gamma-ray observatory will serve scientists for many more years to come,” concludes Matthias Ehle, Integral’s Mission Manager at ESA.

EXTRA SLIDES

INTEGRAL and Magnetars

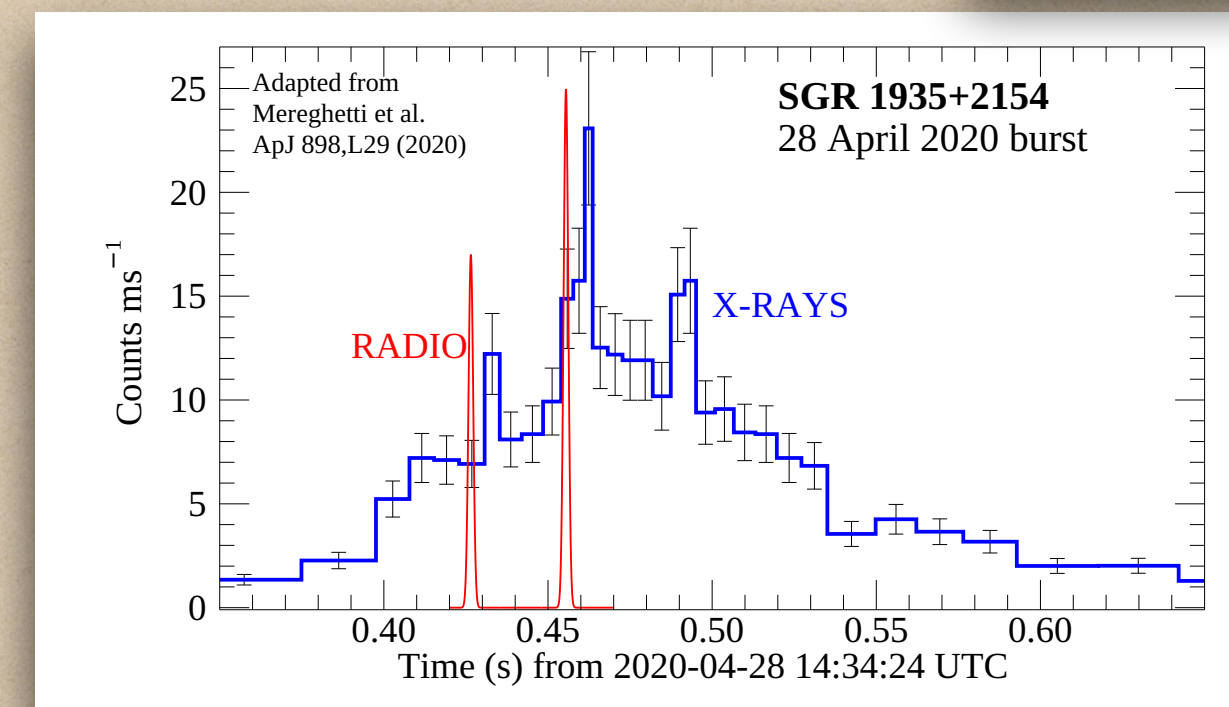
- Persistent emission → unexpected discovery of hard tails

Molkov+2004; Kuiper+2004,2006,2012; Mereghetti+2005;
Gotz+2006,2007; den Hartog+2008a/b; Ducci+2015



- Short bursts → Magnetar/ FRB connection

Mereghetti+2020

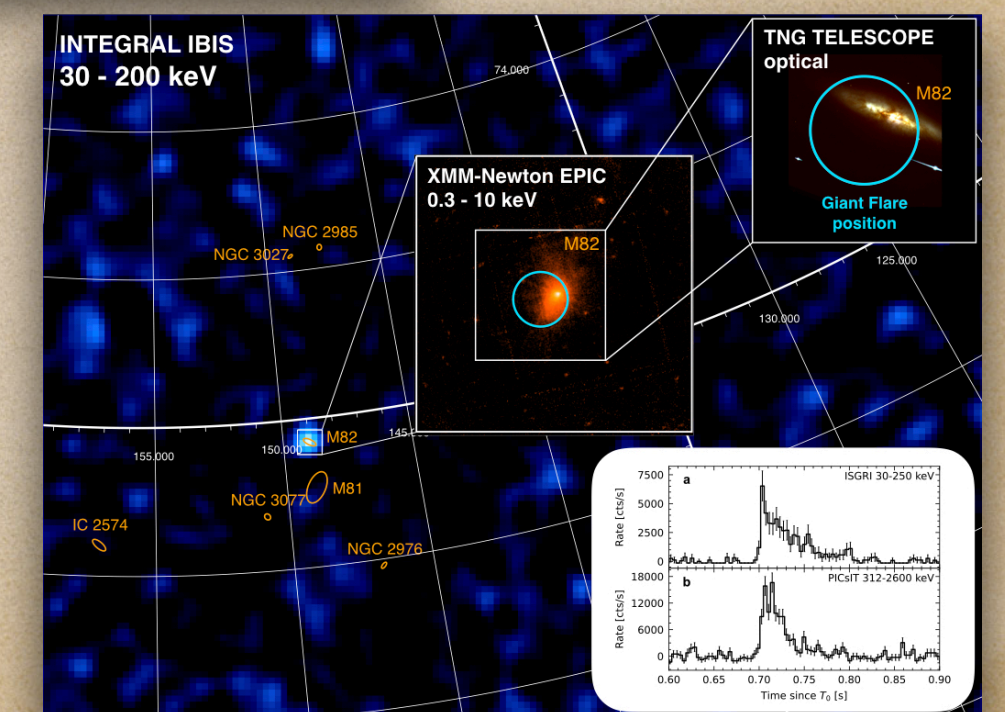
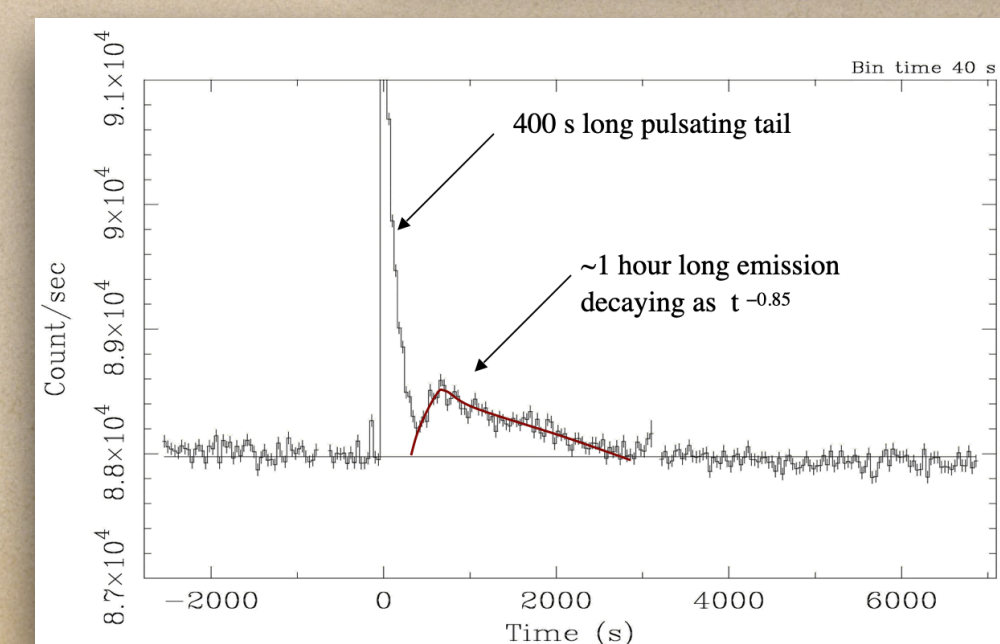


- Giant Flares

→ SGR 1806-20: r-process hard tail

→ extragalactic GF in M82 and PGC 86046

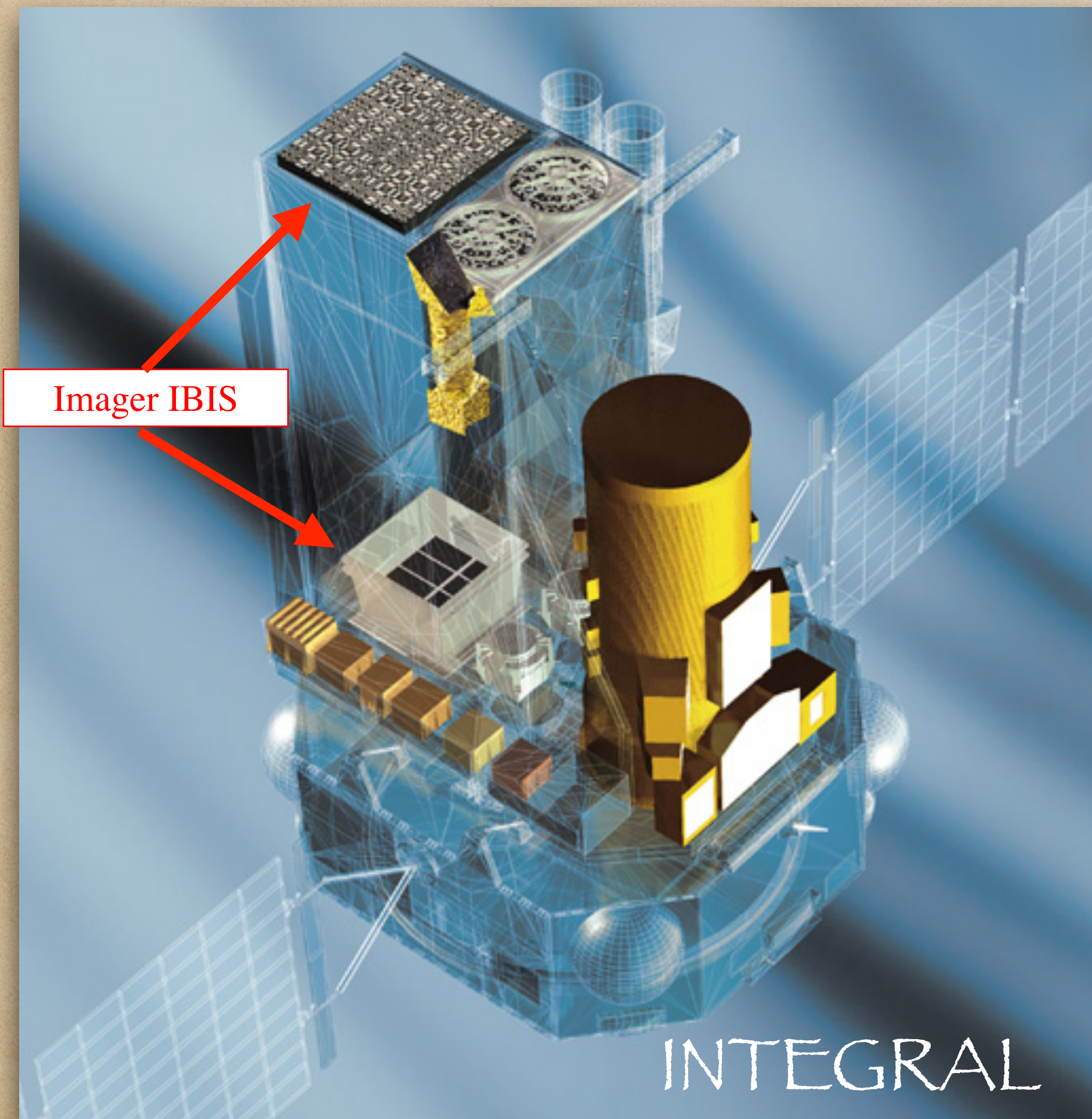
Mereghetti+2005,
Mereghetti+2024, Rodi+2025



INTEGRAL Burst Alert System



Mereghetti+ 2003



Continuous downlink of data

IBIS good imaging over $30 \times 30 \text{ deg}^2$ FoV

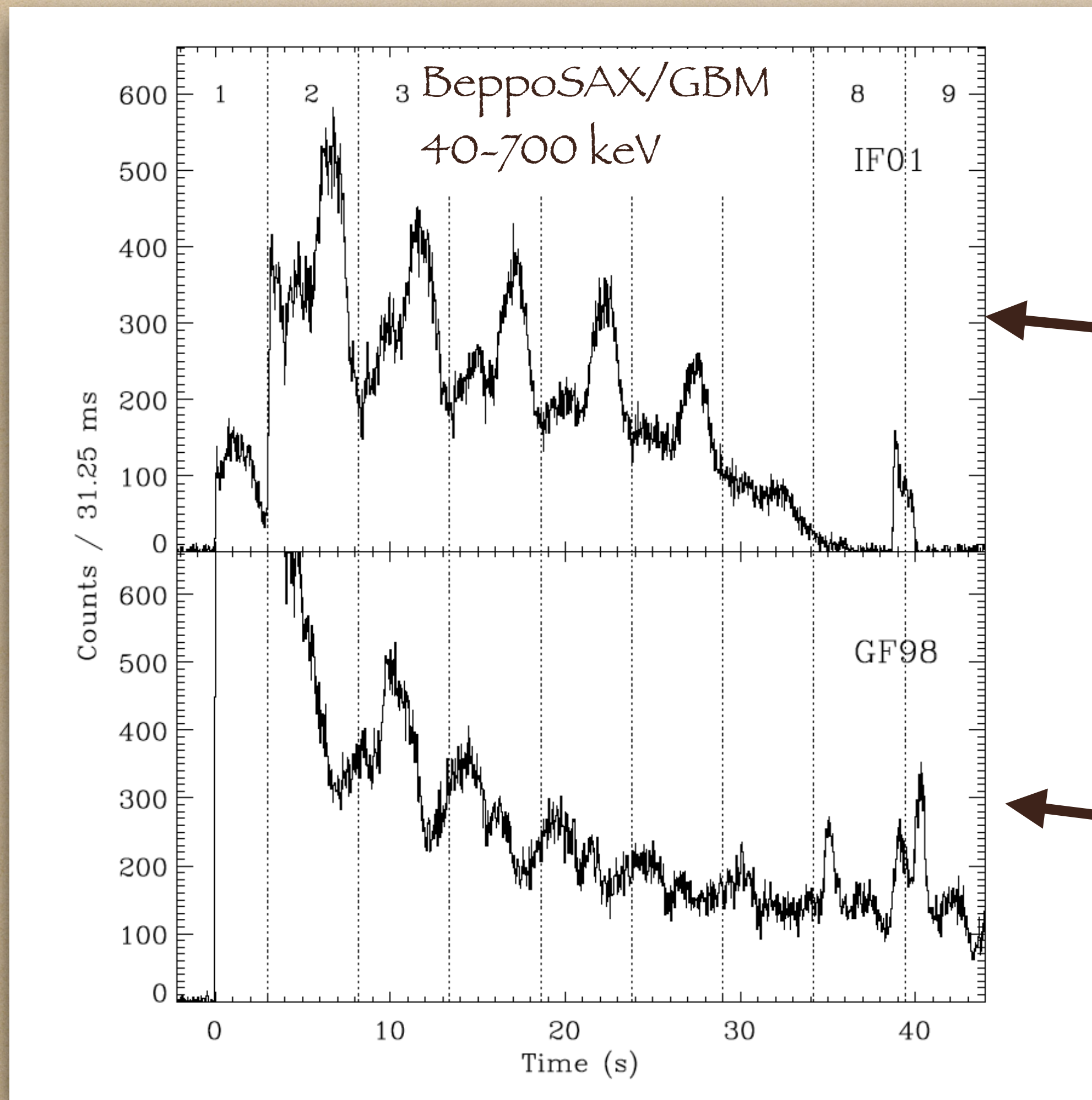
arcmin positions distributed in real time

(154 GRBs from Nov 2002 to Feb 2025)

SPI/ACS \rightarrow full sky at high sensitivity

Pulsed tails without initial spike

Guidorzi+ 2004



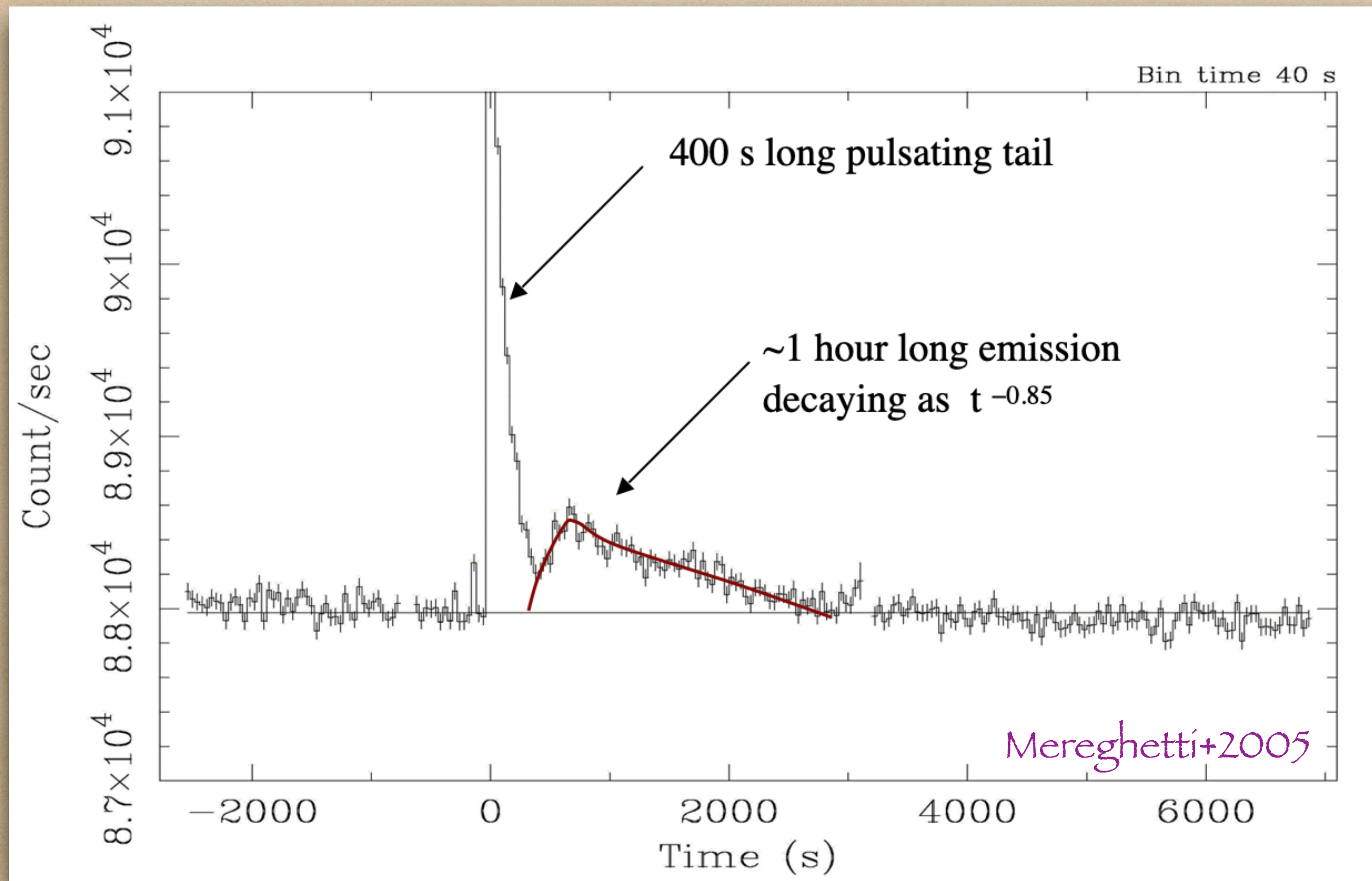
SGR 1900+14

April 18, 2001
"Intermediate" Flare

Aug 27, 1998
Giant Flare

2004 Dec 27 SGR 1806-20: the brightest GF

Long lasting (~1 hr) hard X-ray emission with SPI/ACS

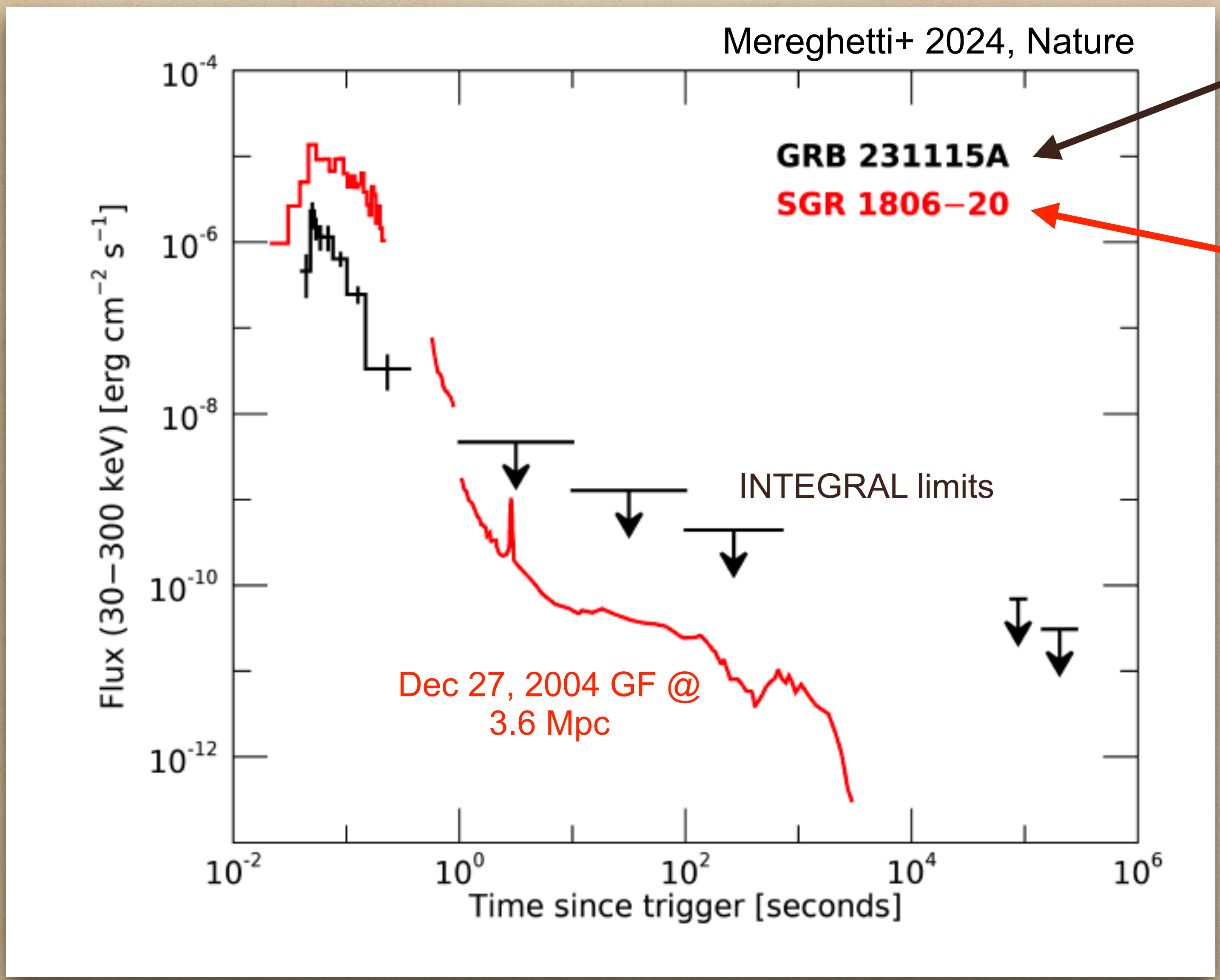


Hard spectrum:

PL $\Gamma \approx 1.7$

or Brems. $kT = 1.9$ MeV

[Frederiks+07, Boggs+07]



The most reliable
extragalactic MGF

The most energetic Galactic
GF rescaled at M82 distance

MGF 231115A in M82: Have we been lucky?

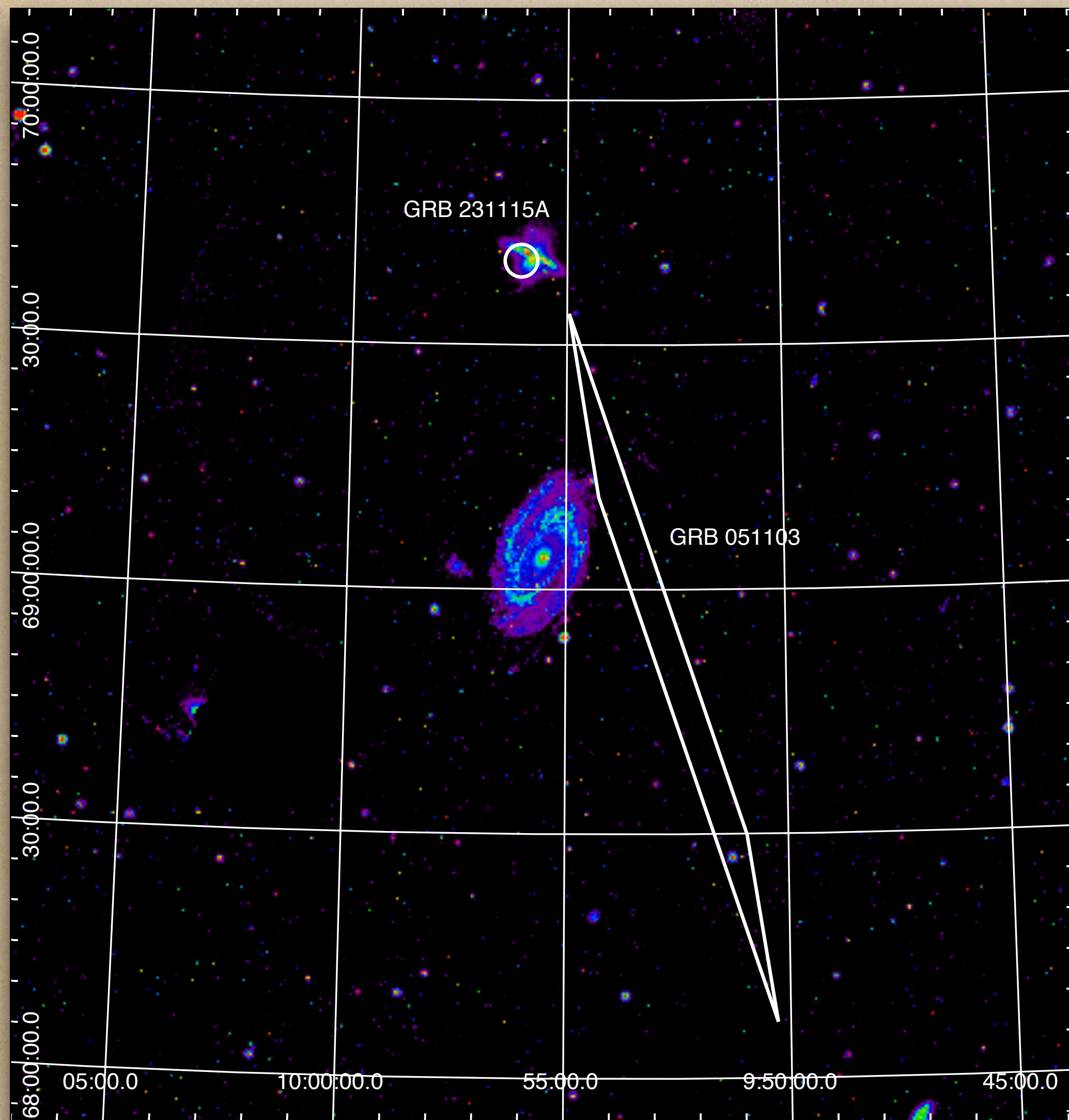
- Volumetric rate of
 $3.8 [^{+4.0}_{-3.1}] \times 10^5 \text{ Gpc}^{-3} \text{ yr}^{-1}$ (Burns+2021)
- Rescale for star forming rate
 $\text{SFR}_{\text{M82}} = 7.1 M_{\odot} / \text{yr}$ wrt $4,000 M_{\odot} / \text{yr}$
within 50 Mpc (Leroy+2019)
- Power-law distribution of the GF
energies with slope 1.7
- Total INTEGRAL exposure on M82 is 6
months from 2002 to 2024
No other flares were seen



We expect in M82
 $\sim [0.04 - 0.4] \text{ GF/yr}$
with $E_{\text{iso}} > 10^{45} \text{ erg}$

—> Probability of one
GF seen by INTEGRAL
is $\sim [2\% - 18\%]$

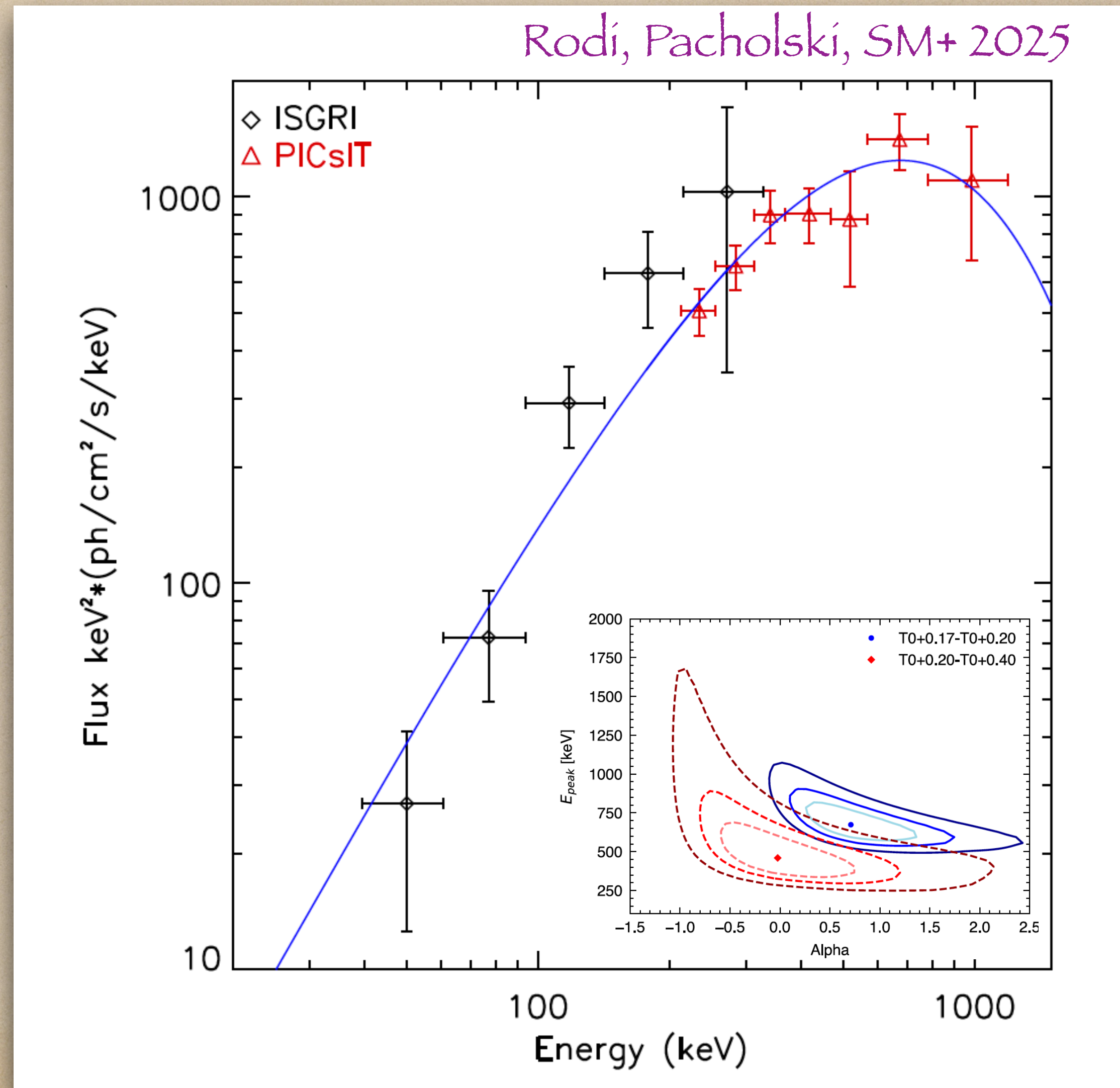
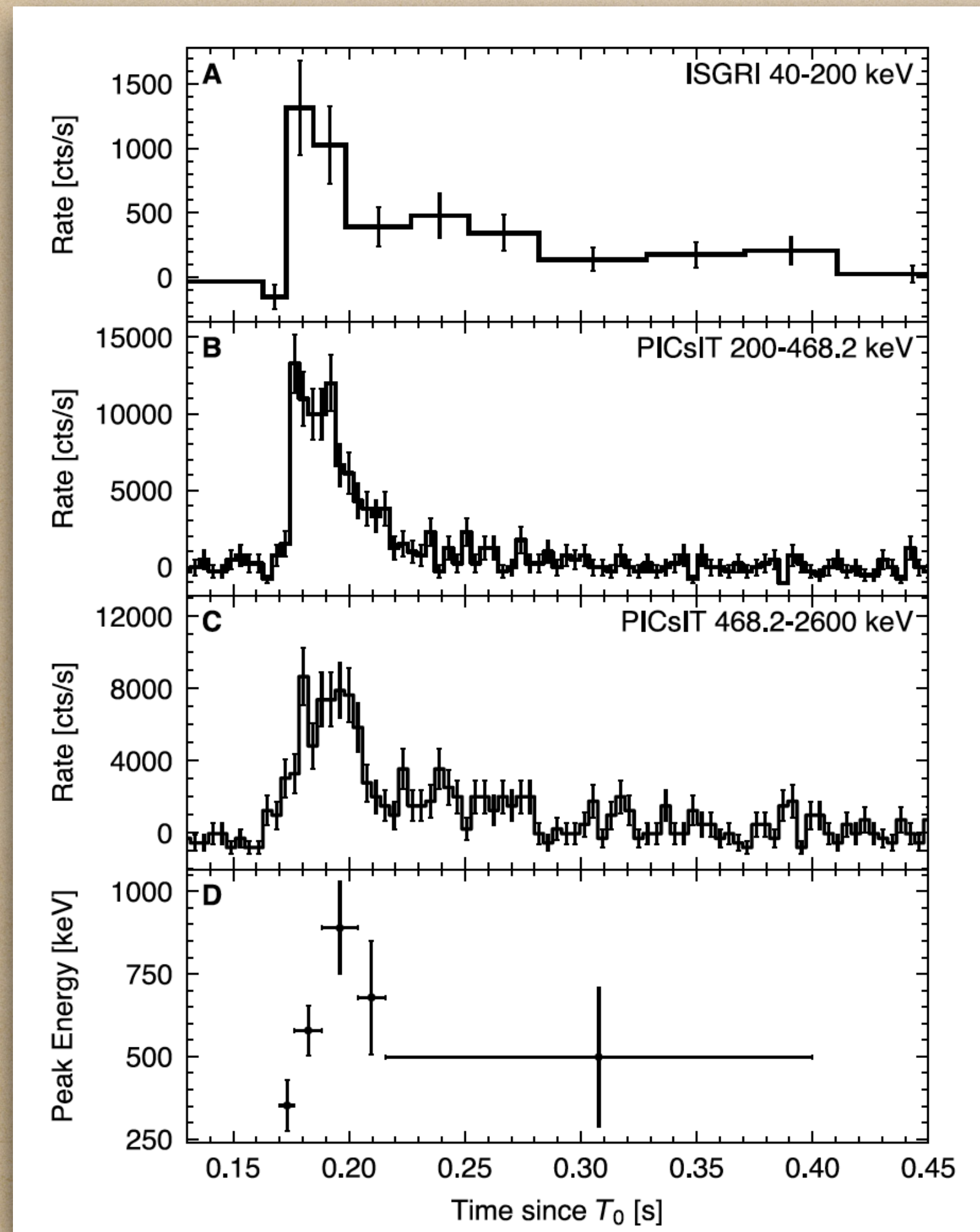
Two GFs in M82 in 20 years?



GRB 051103 possible MGF in M81
group [Frederiks+06].

According to a detailed statistical
analysis,
M82 is the most likely host [Burns+21]

Short GRB 241107A: a MGF in PGC 86046?



Short GRB 241107A: a MGF in PGC 86046?

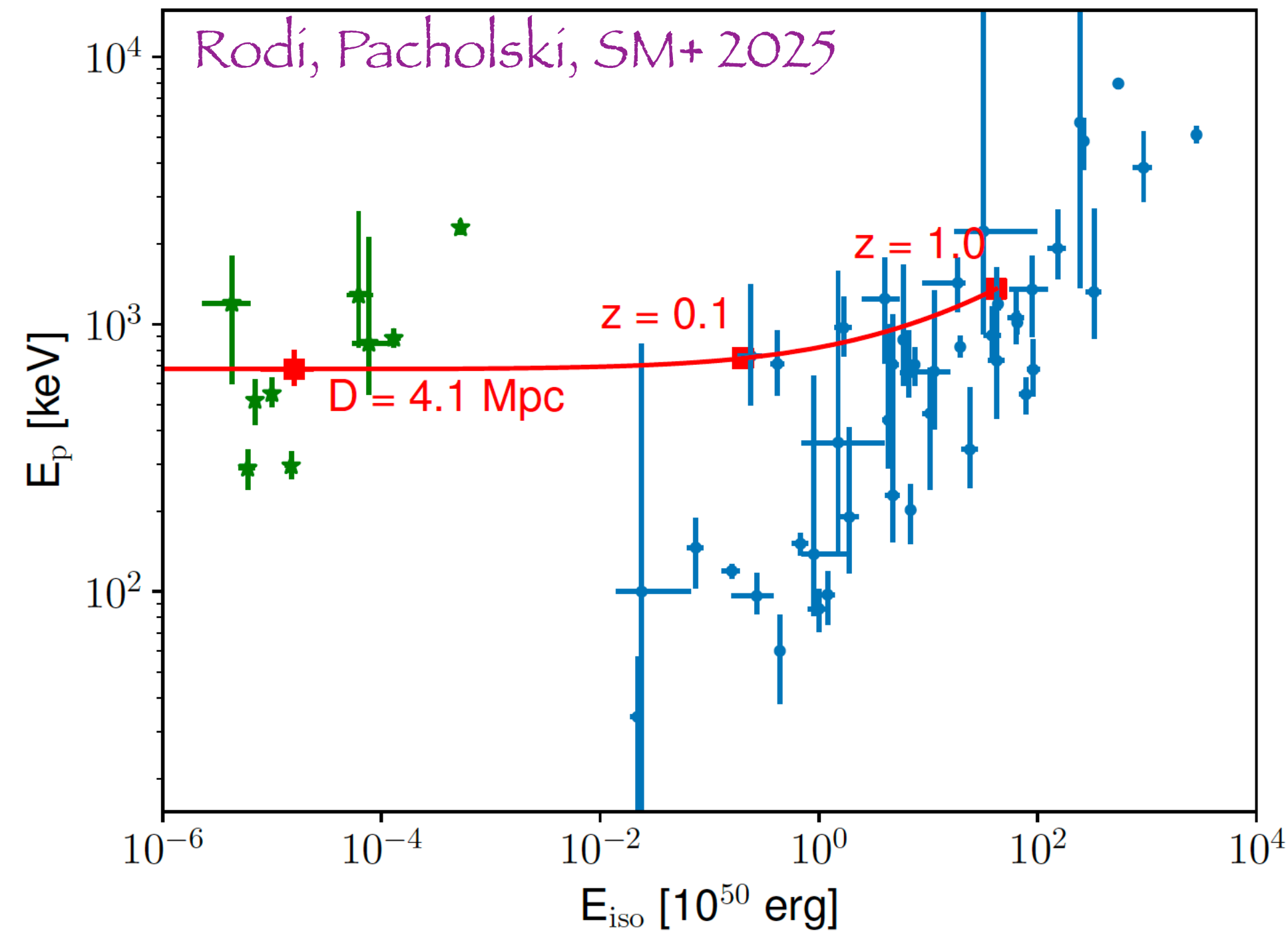
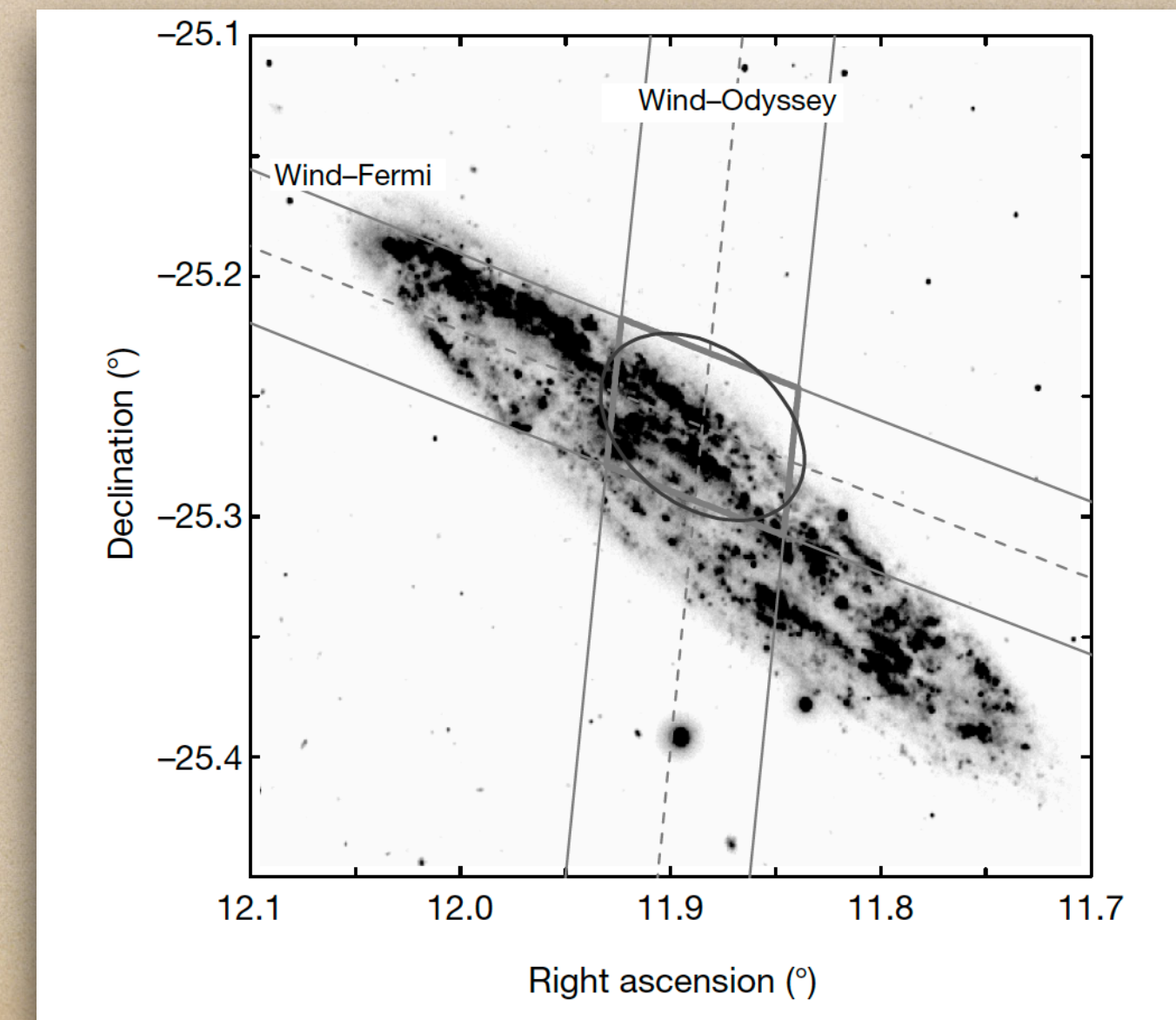
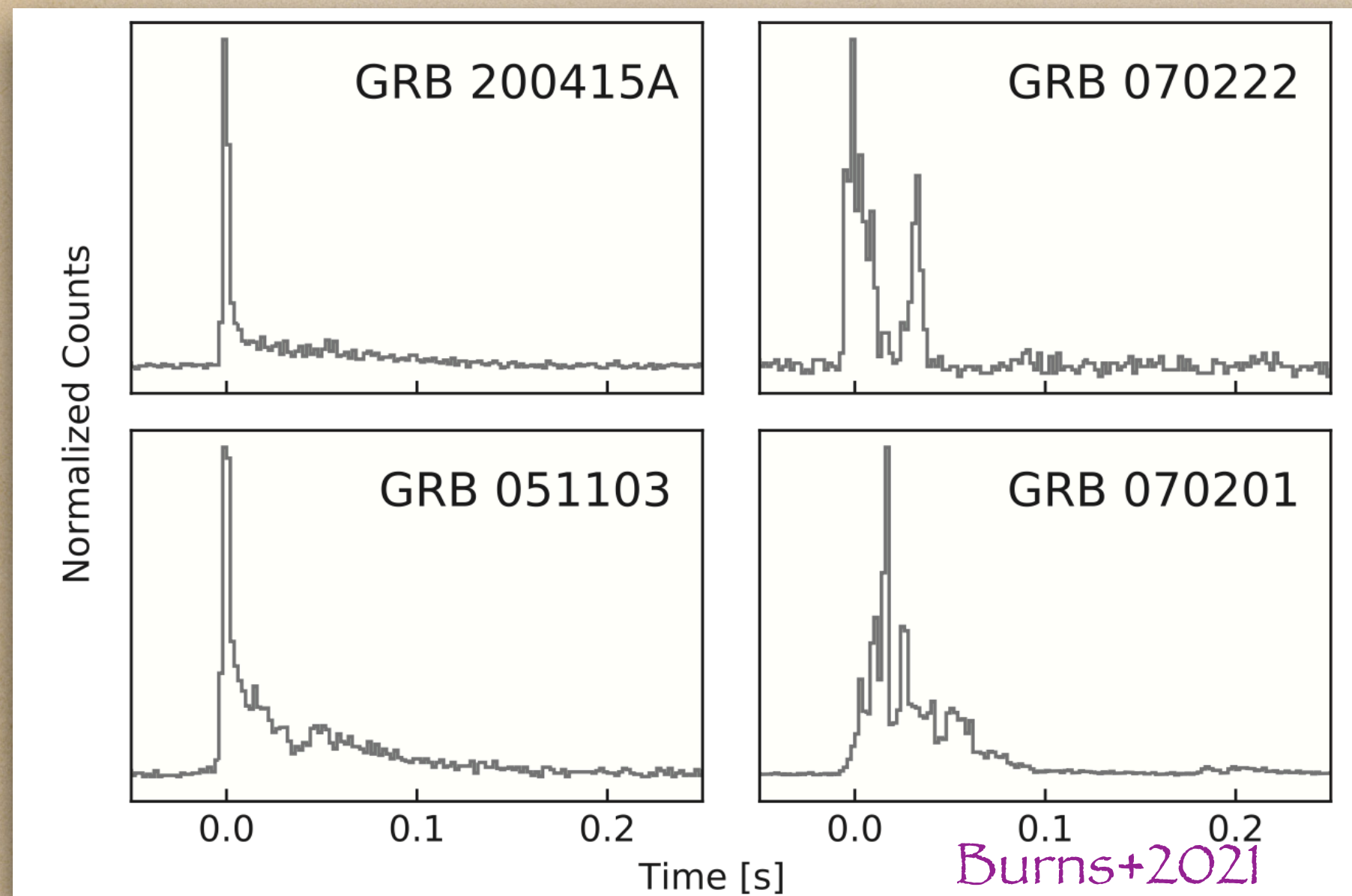
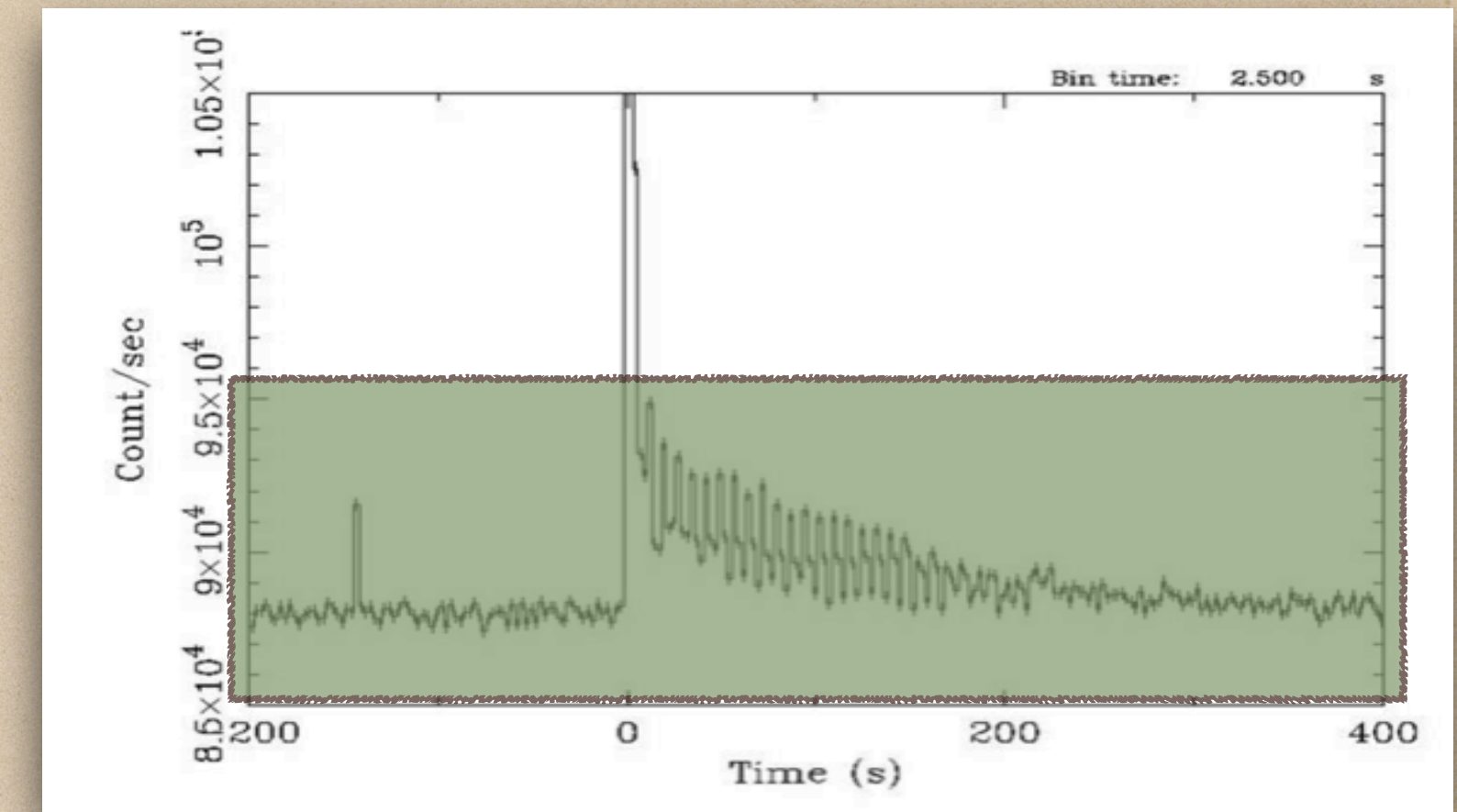


Figure 5. Position of GRB 241107A (red square) in the E_p versus E_{iso} plane. The sample of short GRBs (blue) is taken from [Minaev & Pozanenko \(2020\)](#). The three con-

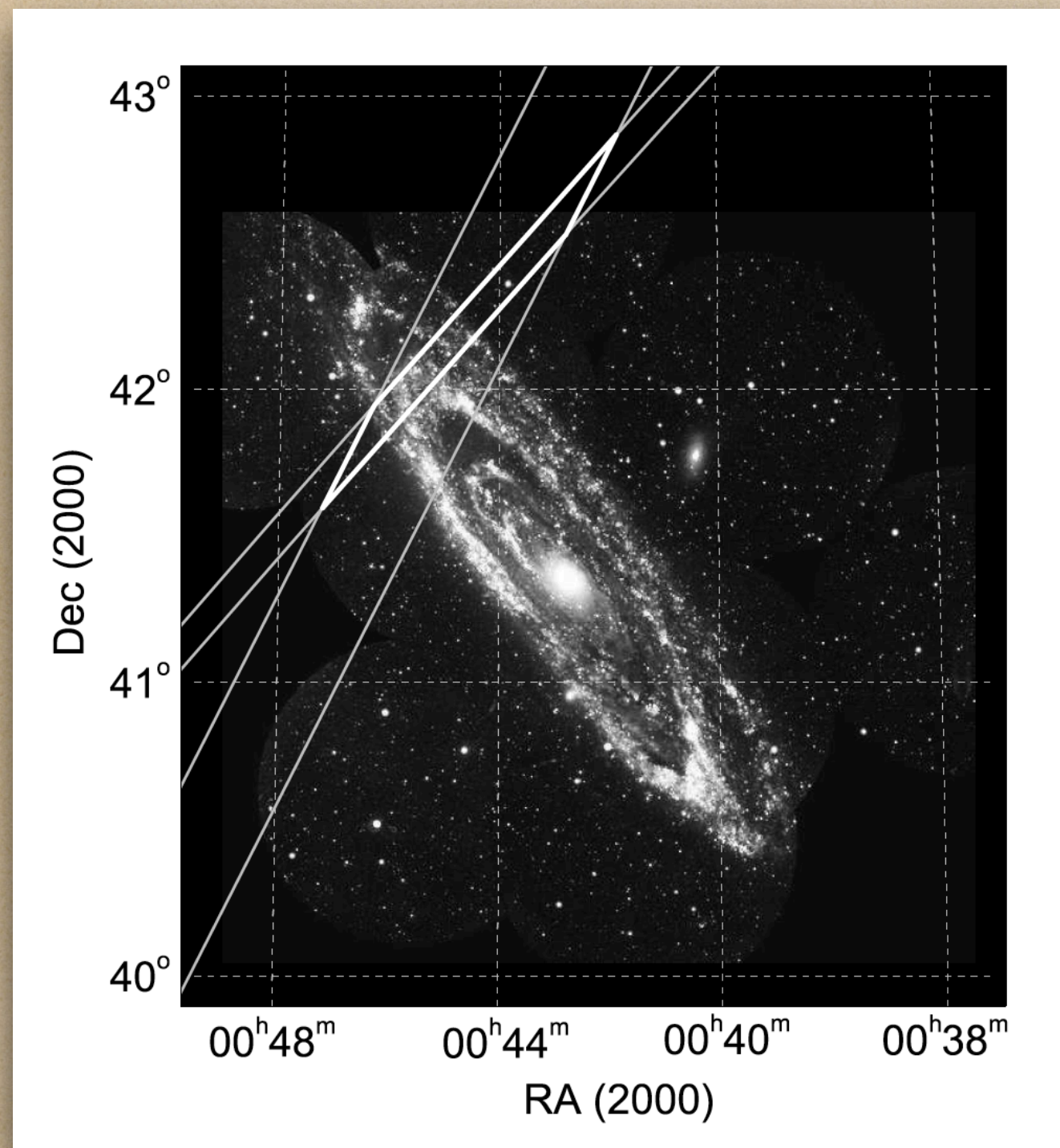
Candidate Giant Flares in nearby Galaxies

Given their luminosities of 10^{47} erg/s, MGF can be detected up to distances of few tens of Mpc

But only the initial hard peak \rightarrow they look similar to short GRBs

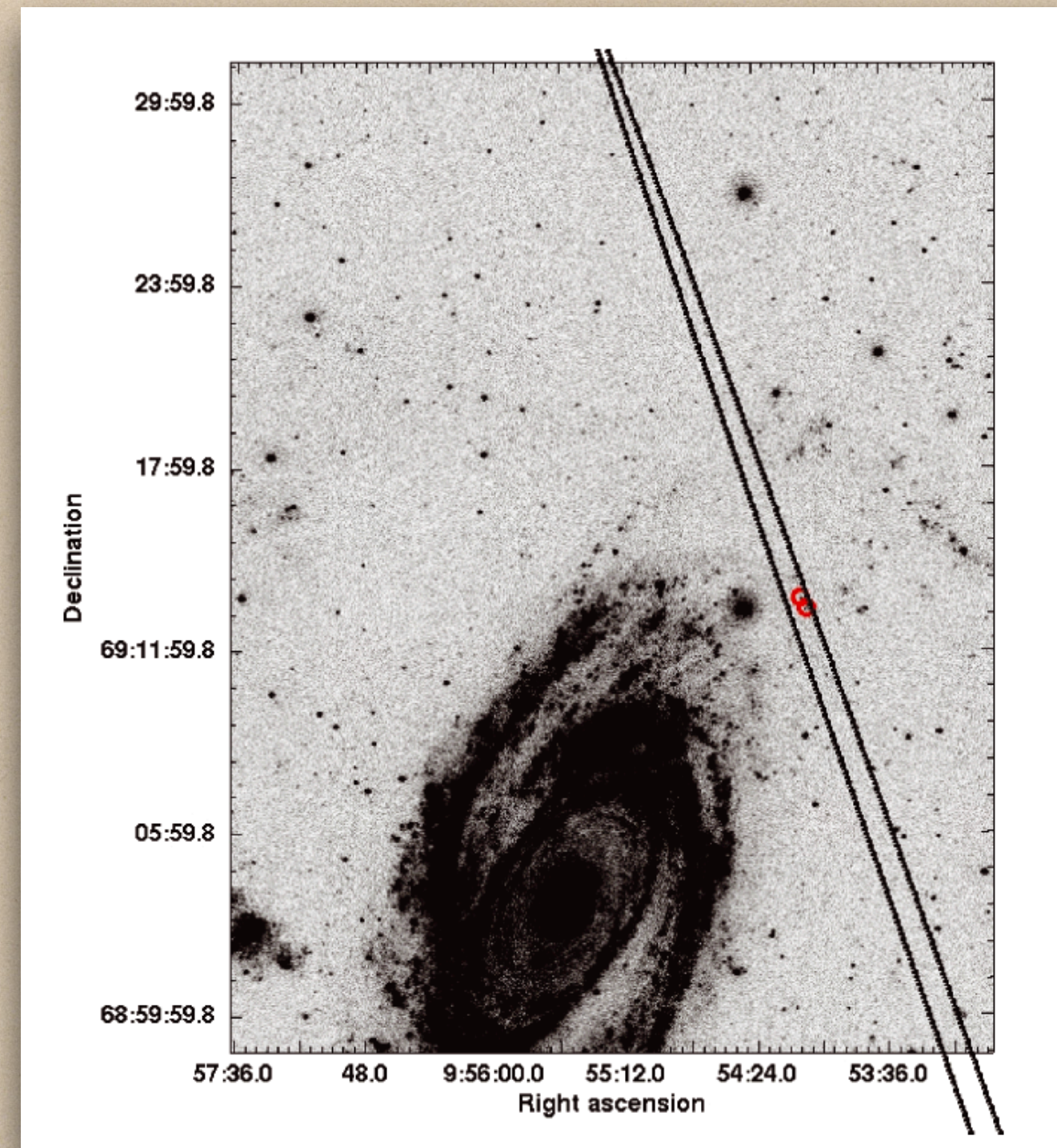


Candidate Giant Flares in nearby Galaxies



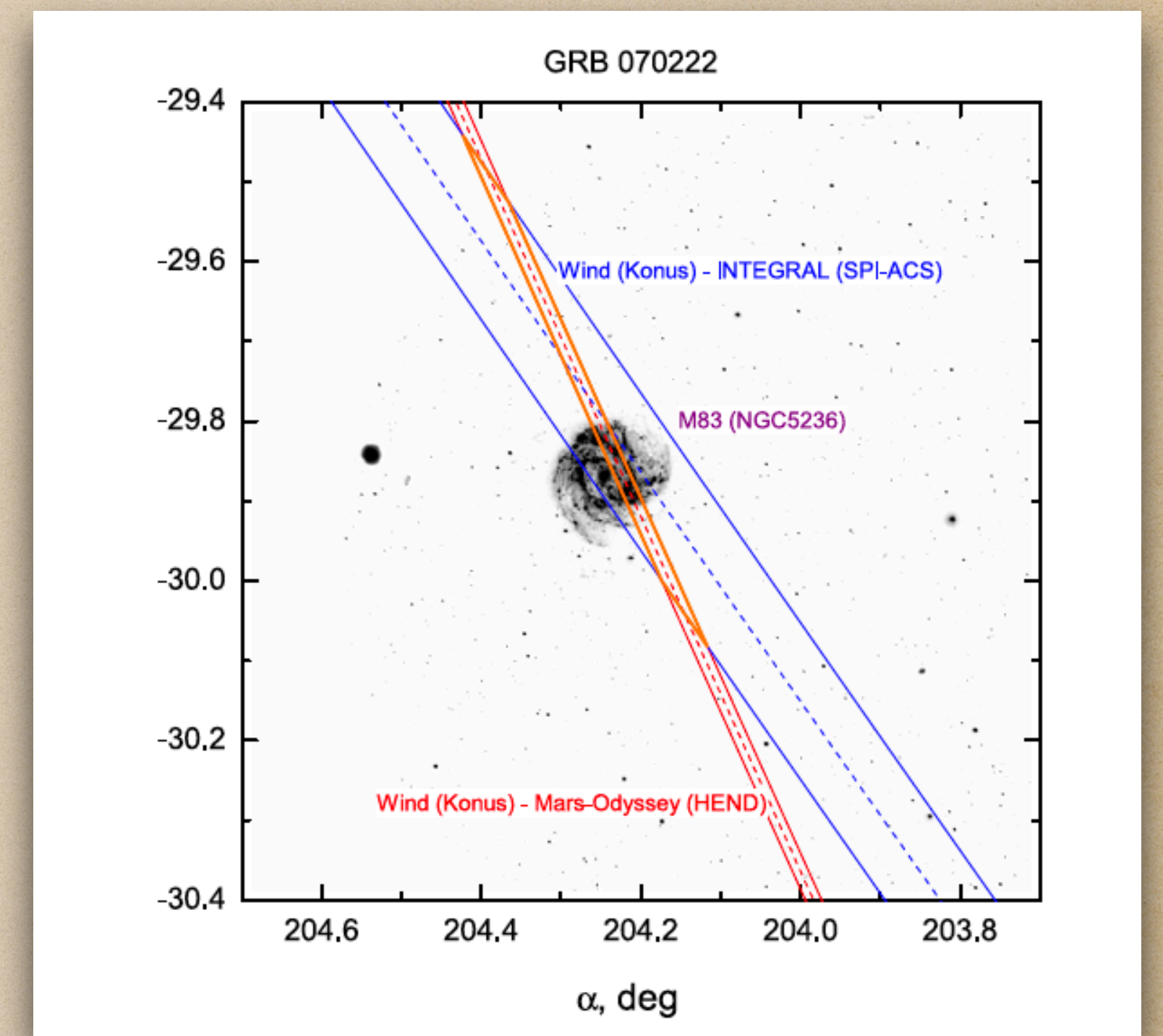
GRB 070201 in M31

Mazets+2008



GRB 051103 in M81

Hurley+2010

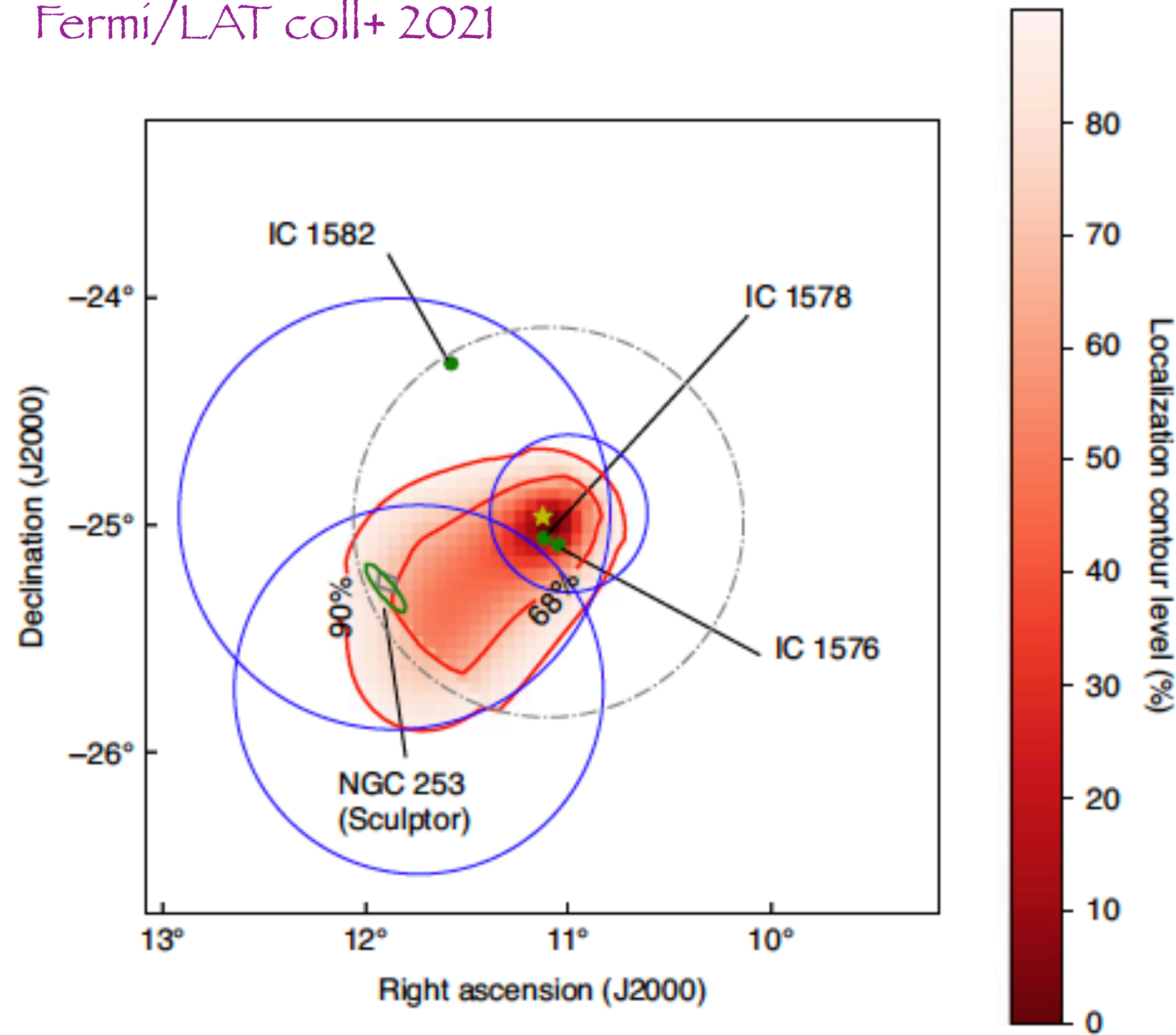


GRB 070222 in M83

Burns+2021

Candidate MGF in NGC253

Fermi/LAT coll+ 2021



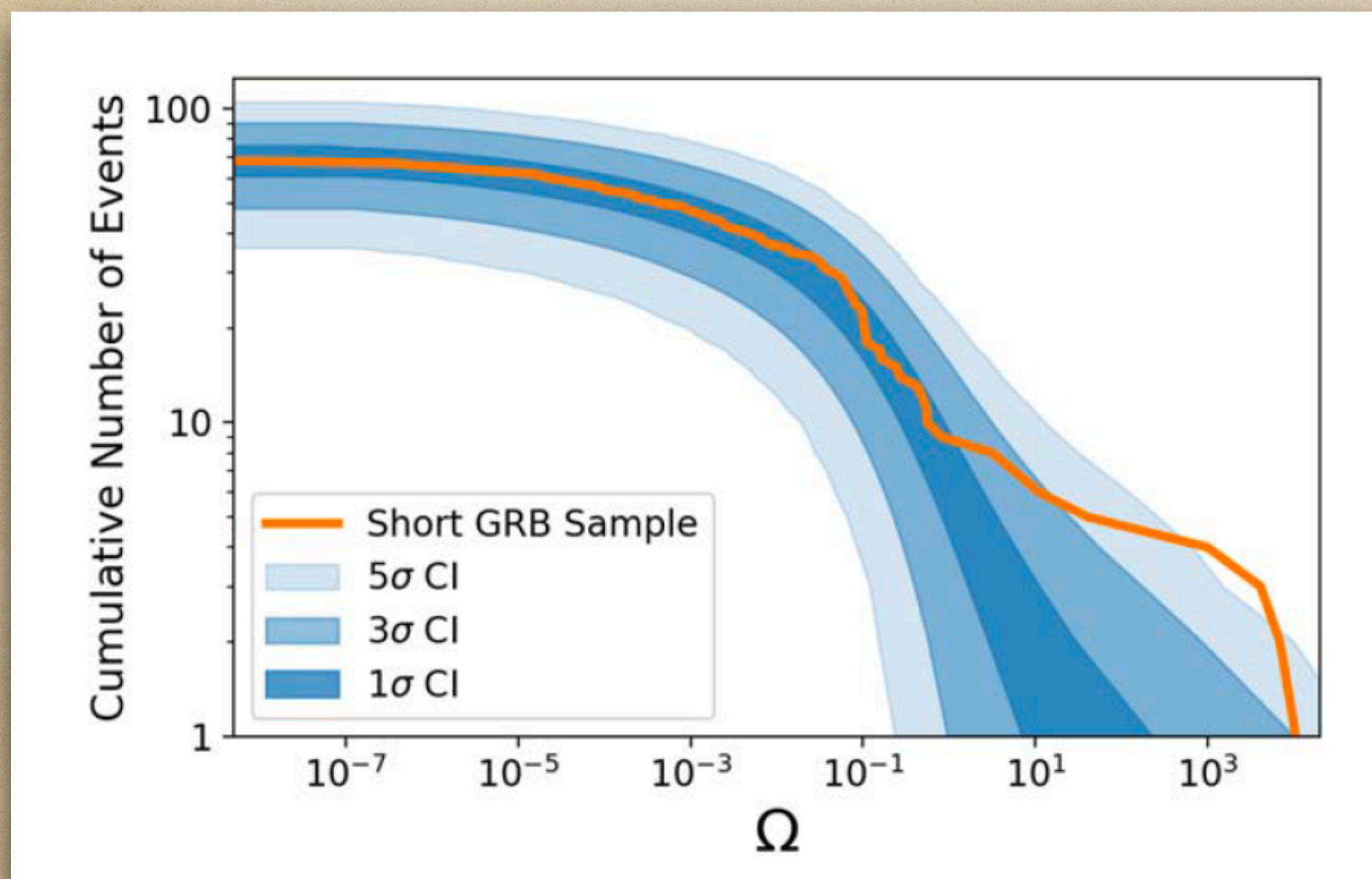
Detection in the GeV range
with Fermi/LAT

3 photons !!!

- A. 480 MeV at $t_0 + 19$ s
- B. 1.3 GeV at $t_0 + 180$ s
- C. 1.7 GeV at $t_0 + 284$ s

Statistical analysis of MGF candidates → Solid statistical evidence for a population of nearby MGF accounting for ~2% of short GRBs

Burns+2021



Ω quantifies the likelihood that a GRB has a MGF origin

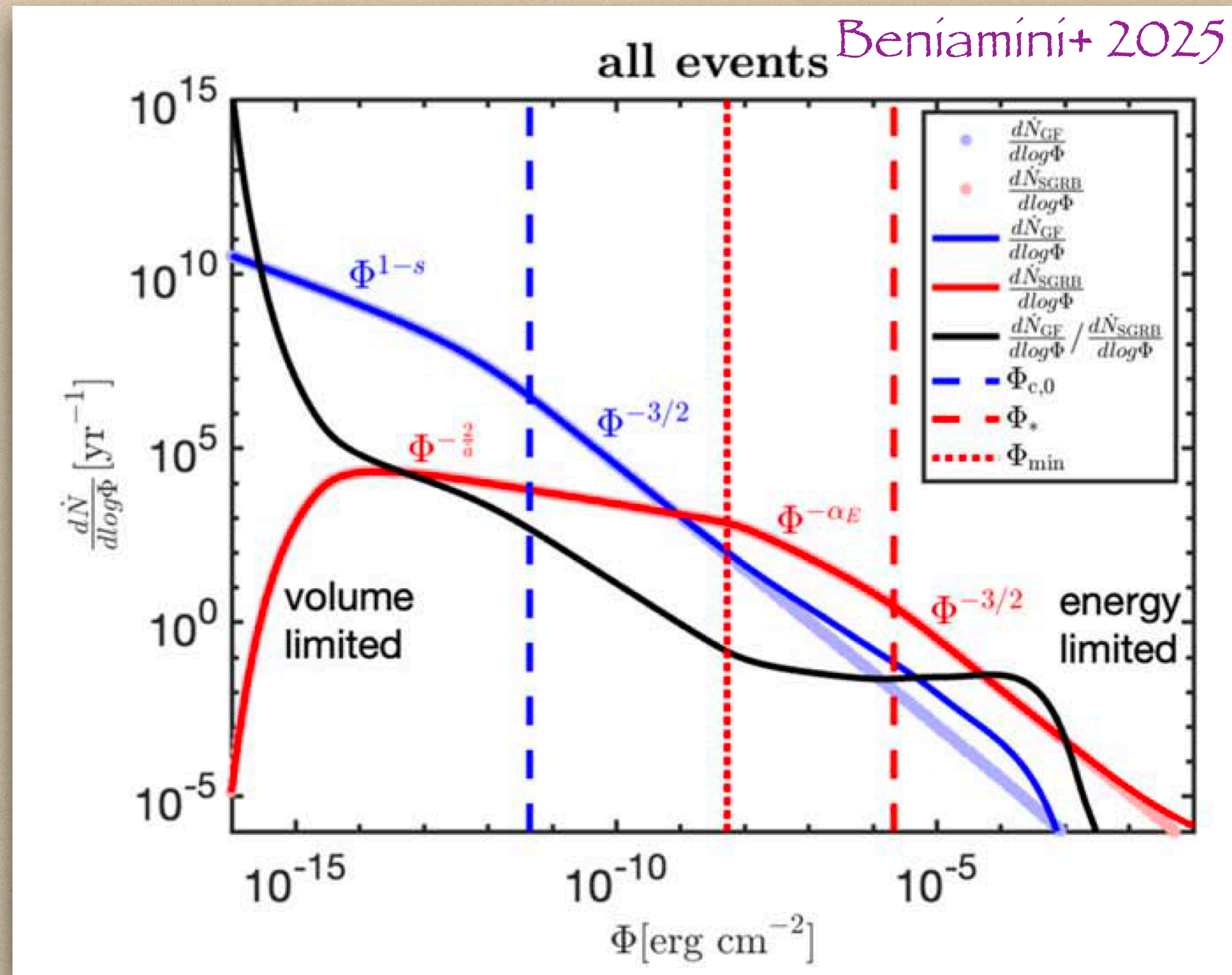
Takes into account probability of spatial coincidence, galaxy SFR, energy distribution of GF

Volumetric rate of GF with $E > 4 \times 10^{44}$ erg

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

Extragalactic MGF wrt short GRB rate

Rate per logarithmic
unit of fluence



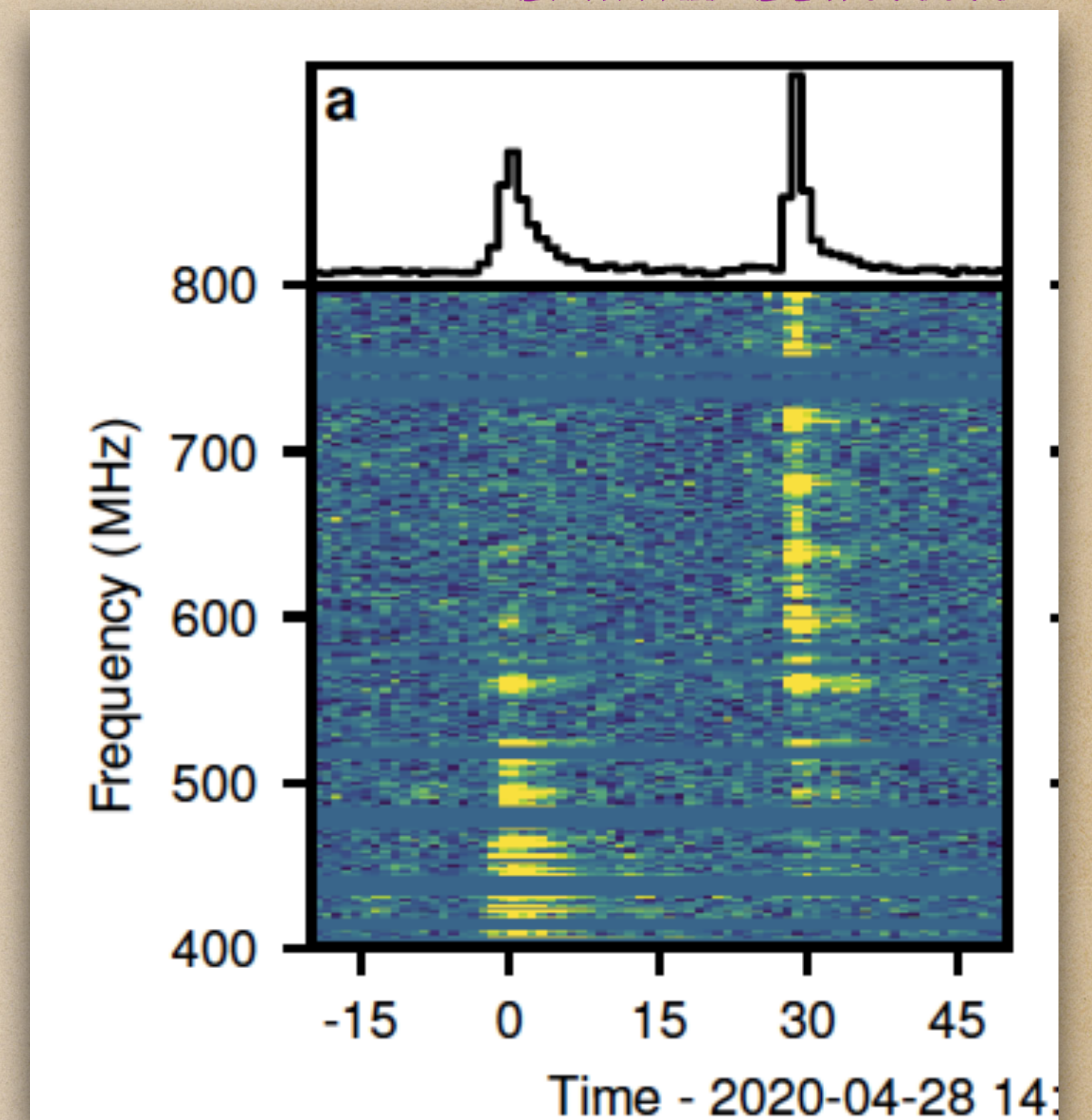
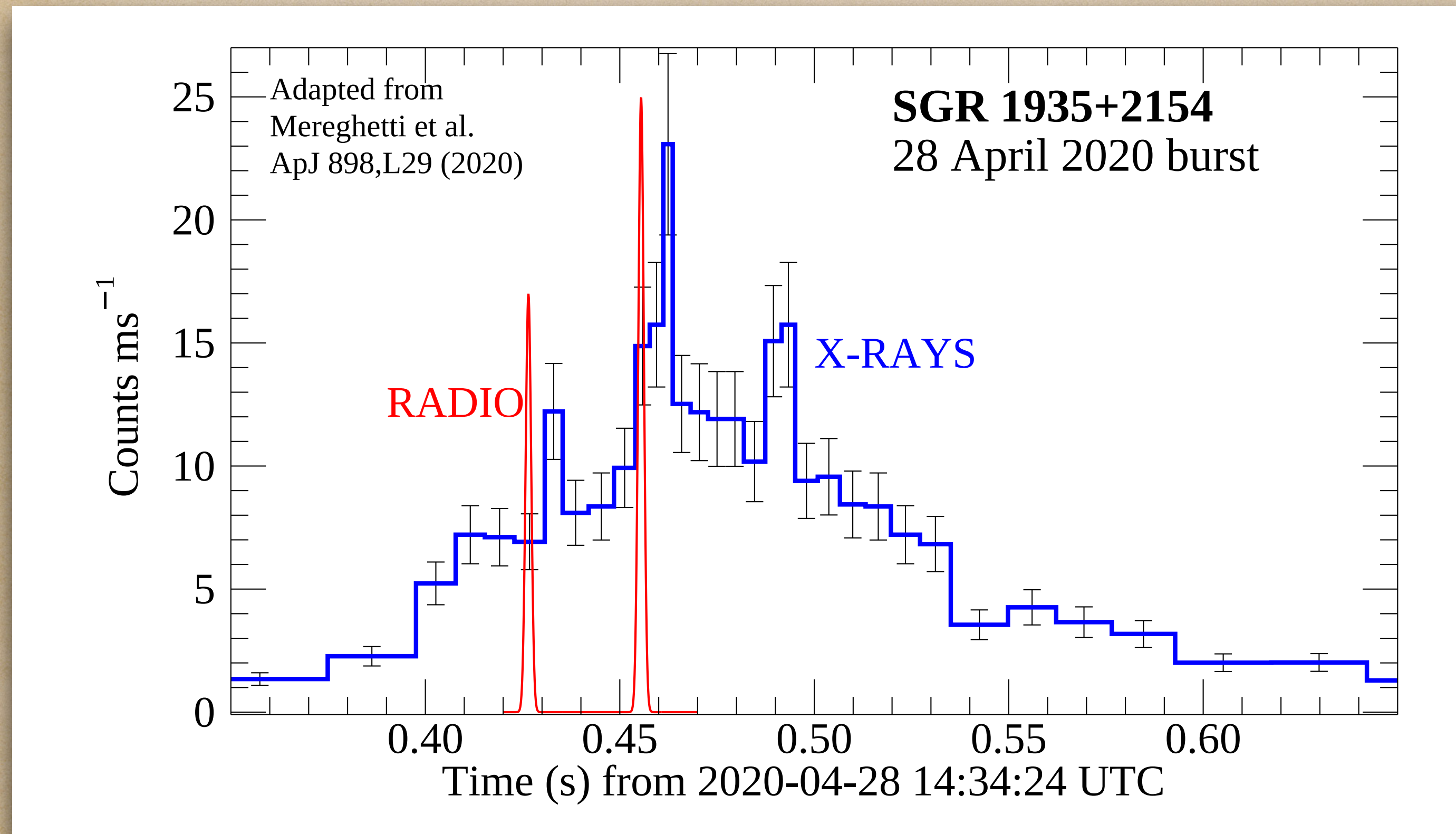
Fluence

At current sensitivity limit
short GRBs dominate over
MGFs

For future instruments
(Fluence $< 10^{-10}$ erg/cm²)
it will be the opposite

SGR 1935+54 X-ray / radio burst

CHIME Coll 2020



Broad X-ray pulse starts before the radio
Narrow X-ray peaks with 6.5 ± 1 ms lag wrt the radio

Fluence $480 + 220$ kJy ms [600 MHz]

1.5 MJy ms [1.4 GHz]

DM = 332.7 pc/cm³

Radio energy $2 \cdot 10^{35}$ erg

Peak luminosity = $7 \cdot 10^{36}$ erg/s

MAGNETAR	SNR	LOCATION
CXO J0100-72	MC SNR J1000-7211	SMC
4U 0142+61		
SGR 0418+5729		
SGR 0501+4516		
SGR 0526-66	N49	LMC
1E 1048-5937		
1E 1547-5408	G327.24-0.13	
Sw J1555.2-5402		
PSR J1622-4950	G333.9+0.0	
SGR 1627-41	G337.0-00.1 (CTB33)	
CXOU J1647-4522		Massive star cluster (Westerlund 1)
1RXS J1708-4009		
CXOU J1714-3810	G348.7+00.3 (CTB37B)	
SGR 1745-2900		2.4 arcsec from GC
SGR 1806-20		Massive star cluster
XTE J1810-197		
Sw J1818.0-1607	Radio shell ?	
Sw J1822.3-1606		
SGR 1830-0645		
SGR 1833-0832		
Sw J1834.9-0846		
1E 1841-045	G027.4+00 (Kes 73)	
3XMM J1852+0033		
SGR 1900+14		Massive star cluster
SGR 1935+2154	G057+0.08	
1E 2259+586	G109.1-01.0 (CTB 109)	

9-10 associations
with SNRs
(~ 33%)

3 associations
with clusters of
massive stars