INTEGRAL observations of Galactic magnetars and search for extragalactic giant flares

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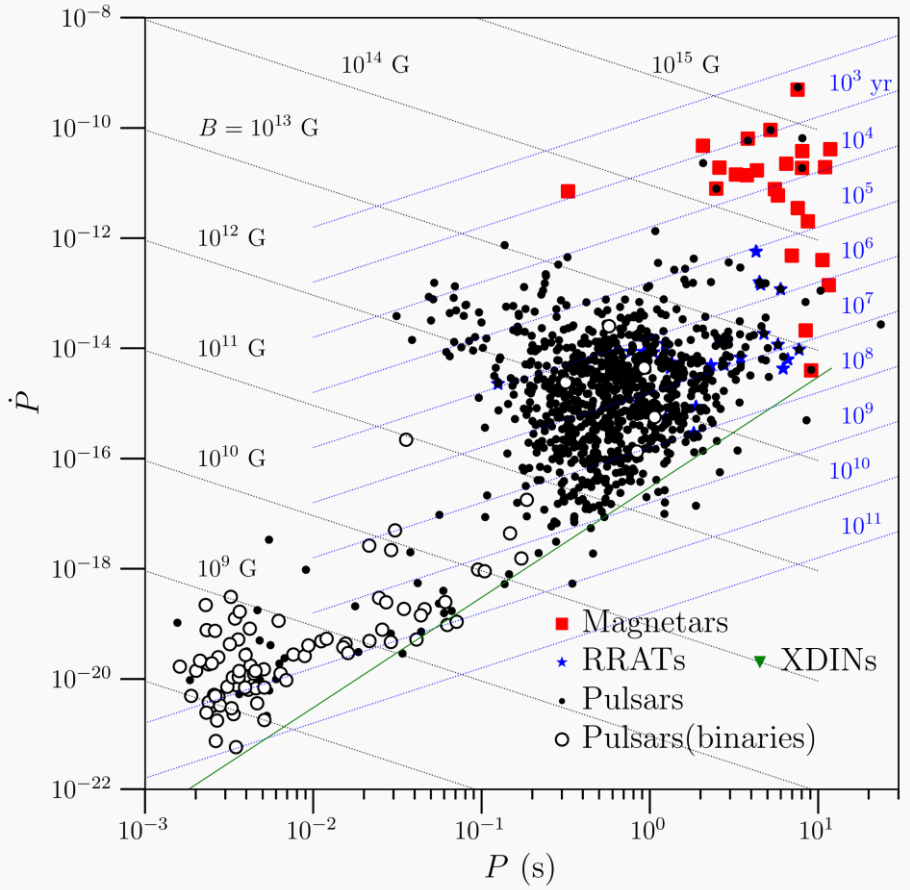
Magnetars

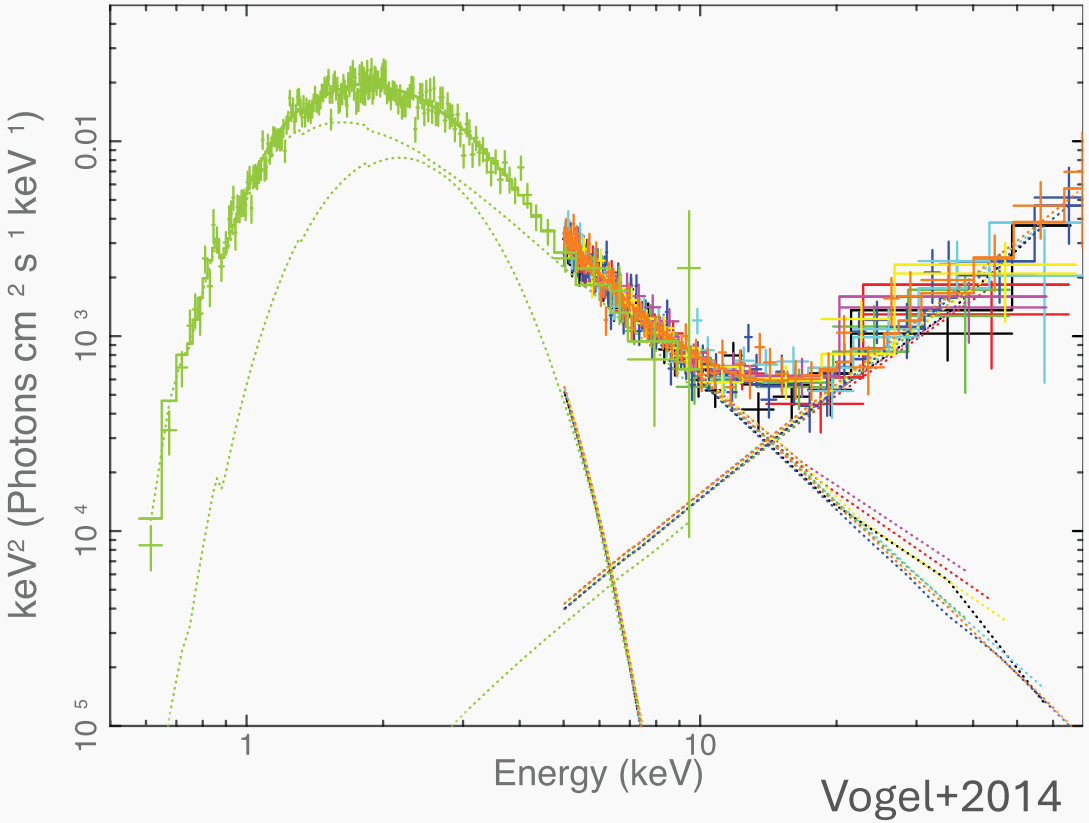
- Young Galactic isolated neutron stars
- Magnetic field $\sim 10^{14} - 10^{15}$ G
- Powered by magnetic energy
- P $\sim$ 2 – 12 s, spinning down



Andrew W. Steiner (neutronstars.utk.edu)

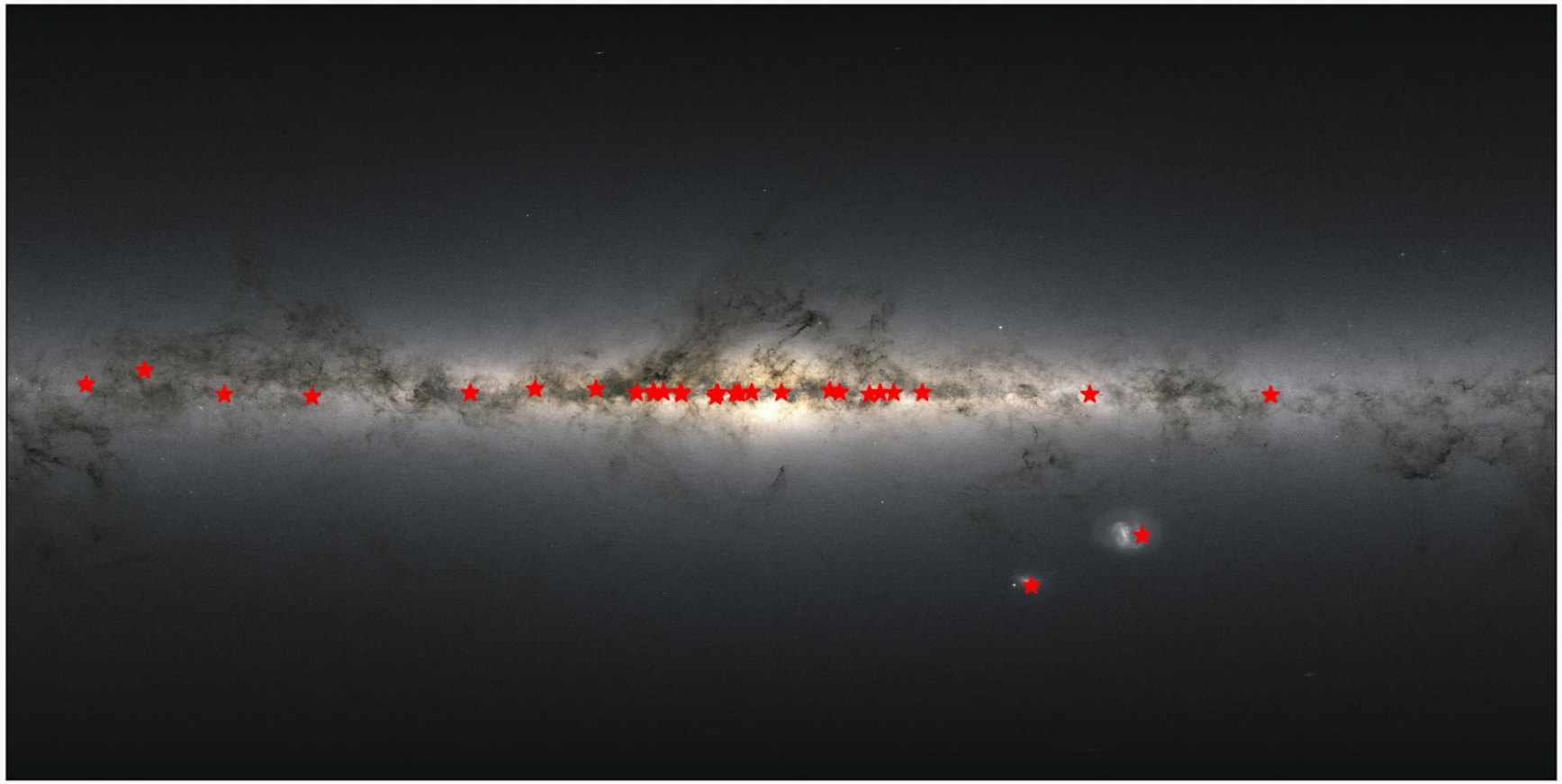
Magnetars

- A few detected at hard X-ray
- > 20 keV; power law ($\Gamma \sim 0.5 - 2$)



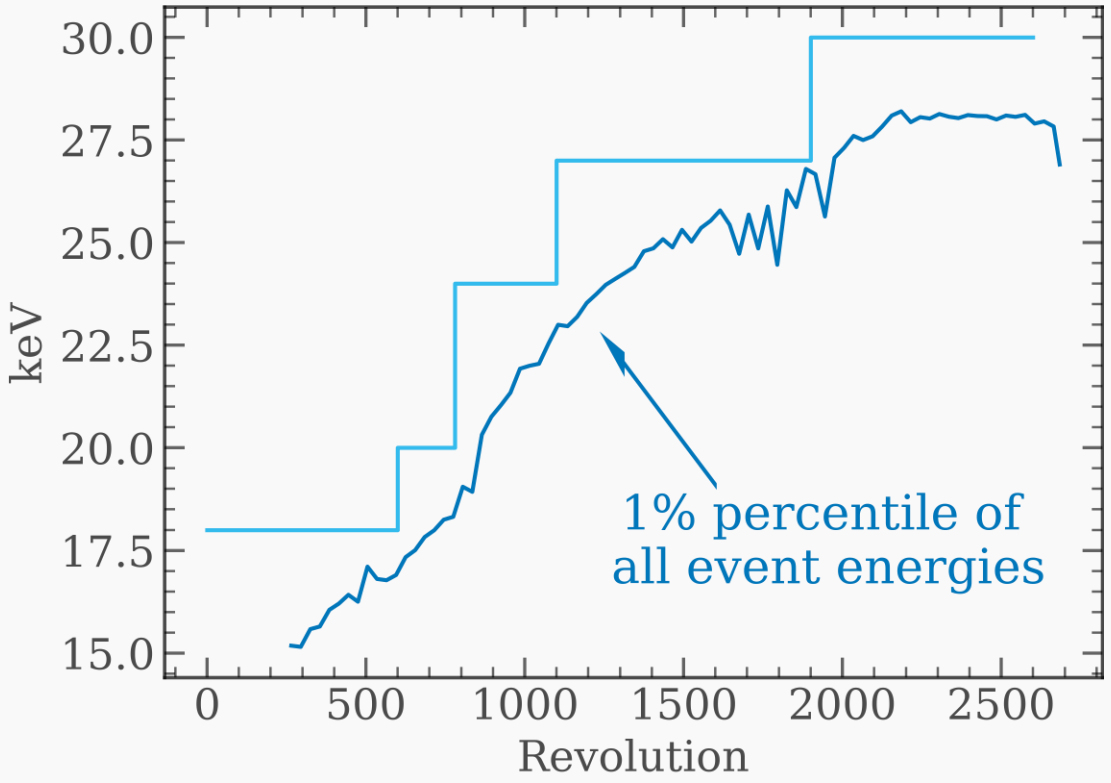
Vogel+2014

Magnetars

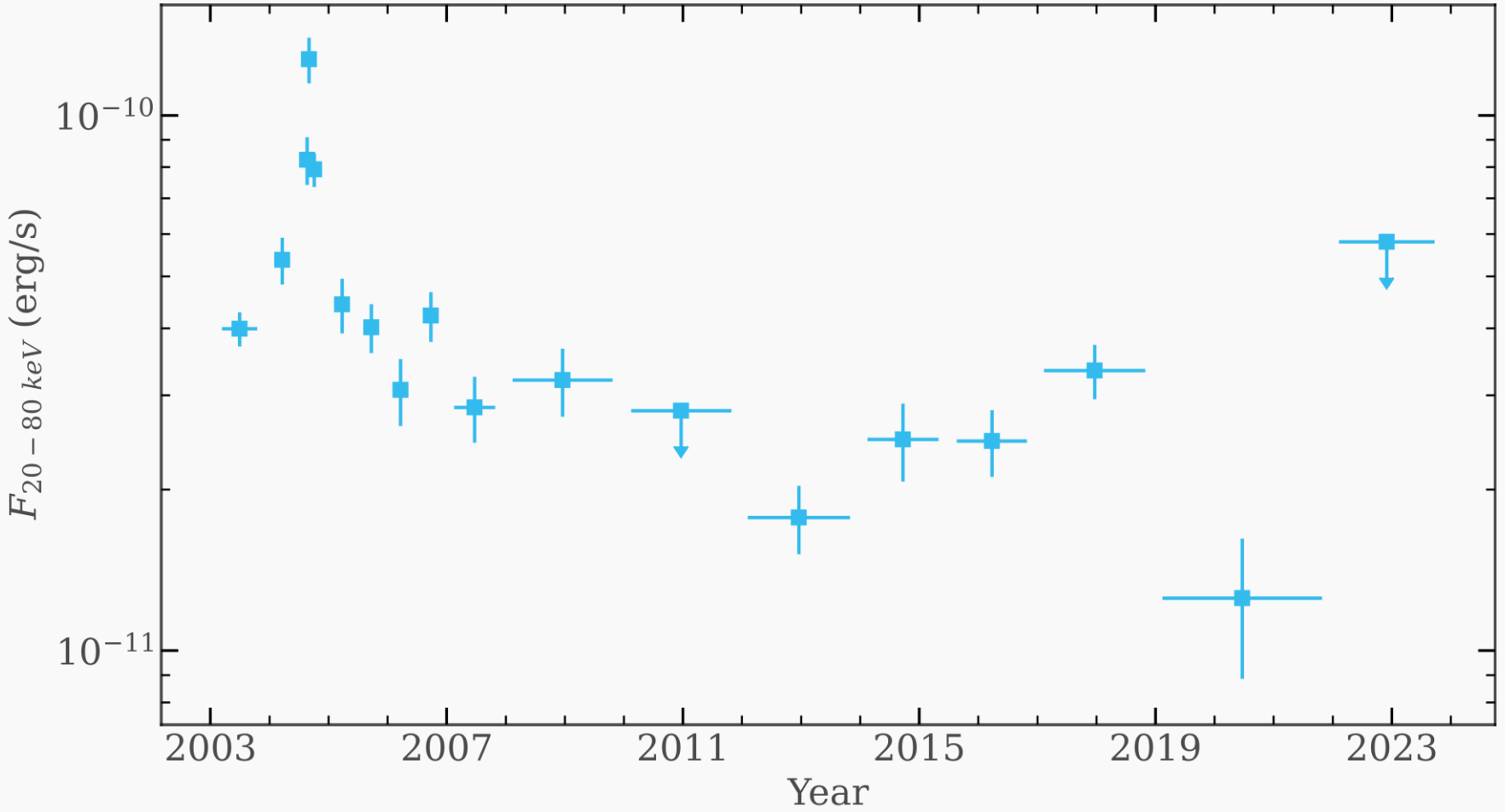


IBIS/ISGRI

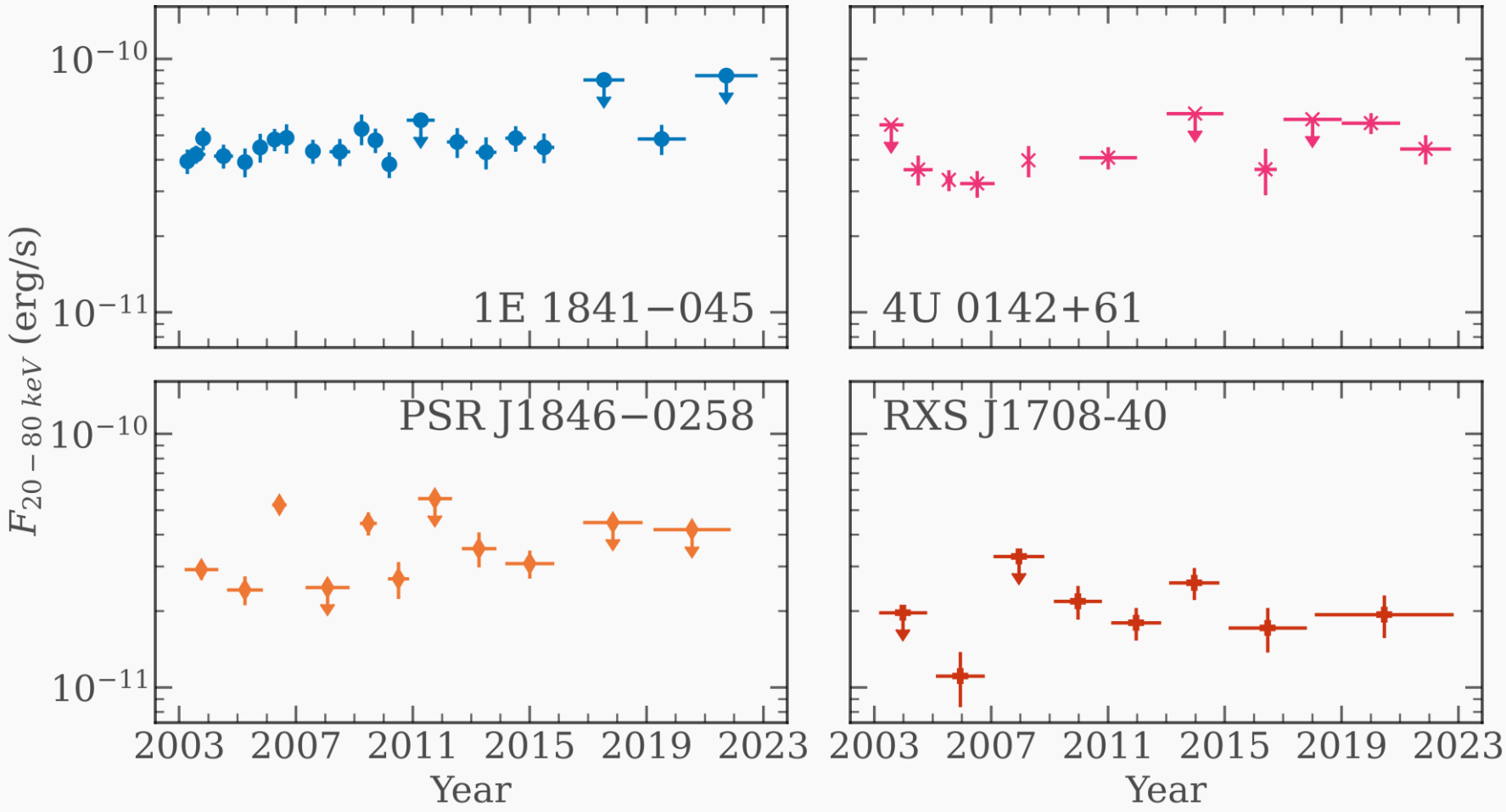
- Energy ranges:
  - 18-80 keV
  - 20-80 keV
  - 24-80 keV
  - 27-80 keV
  - 30-80 keV



SGR 1806-20

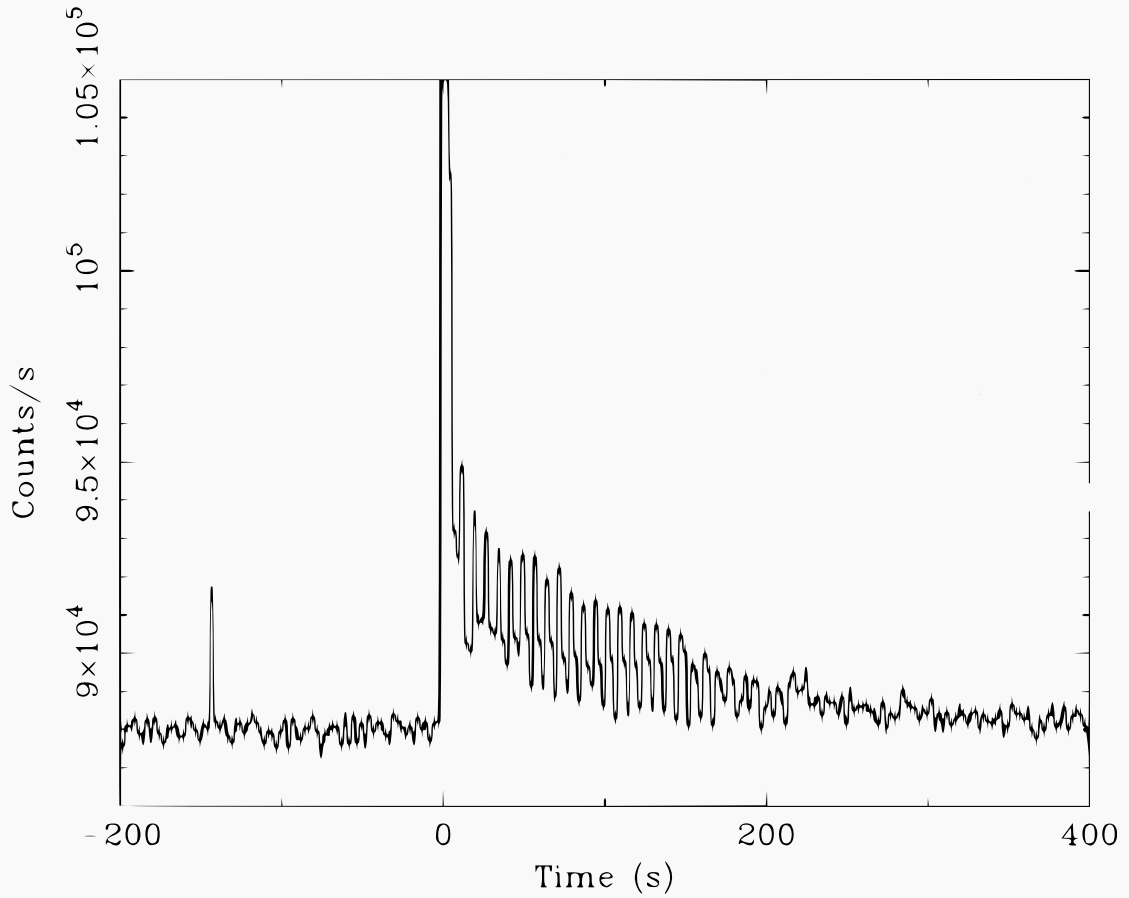


Other sources



Magnetar Giant Flare (MGF)

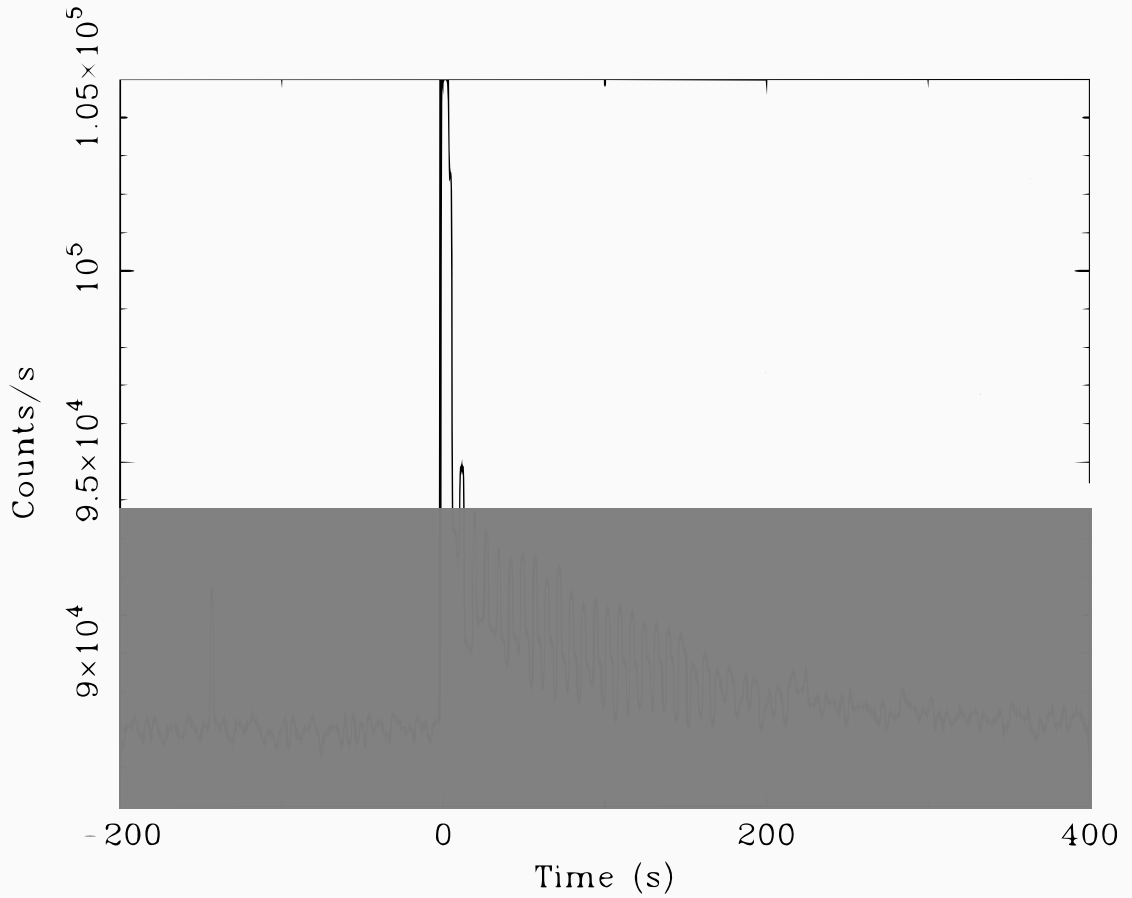
- <1s peak, followed by pulsed tail
- $L \sim 10^{44-46}$ erg s^{-1}
- Only 3 Galactic observed



SGR 1806-20 (Mereghetti+2005)

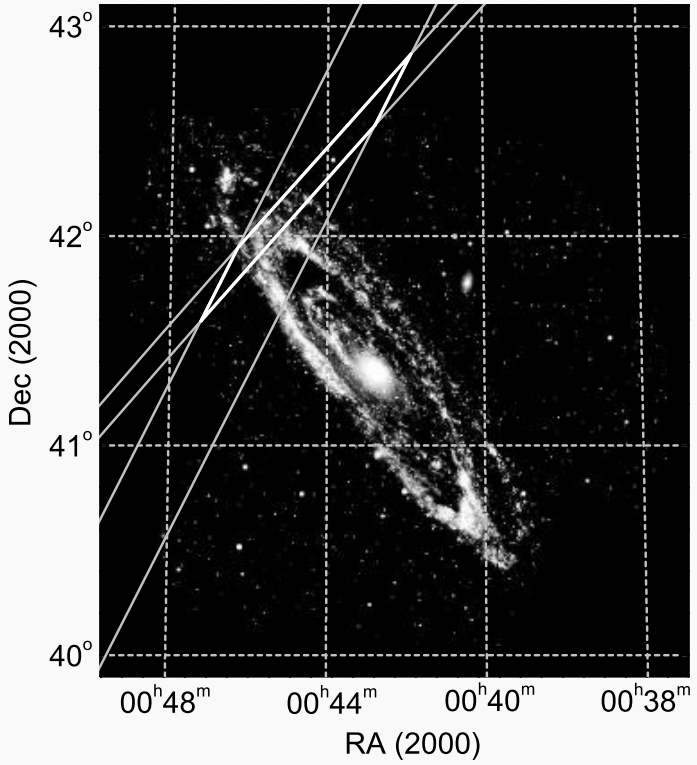
Extragalactic MGF

- Detectable up to a few tens of Mpc
- Only peak would be visible
- Similar to short GRB



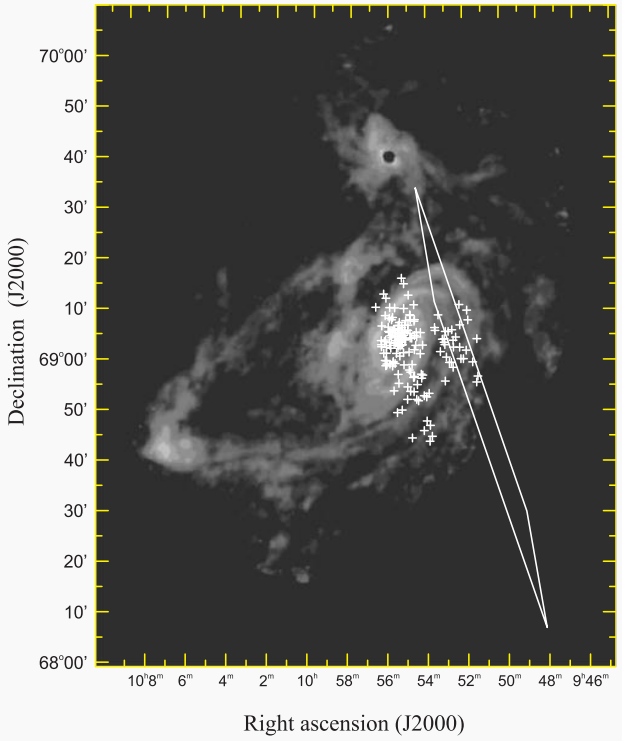
SGR 1806-20 (Mereghetti+2005)

Candidate MGFs in nearby Galaxies



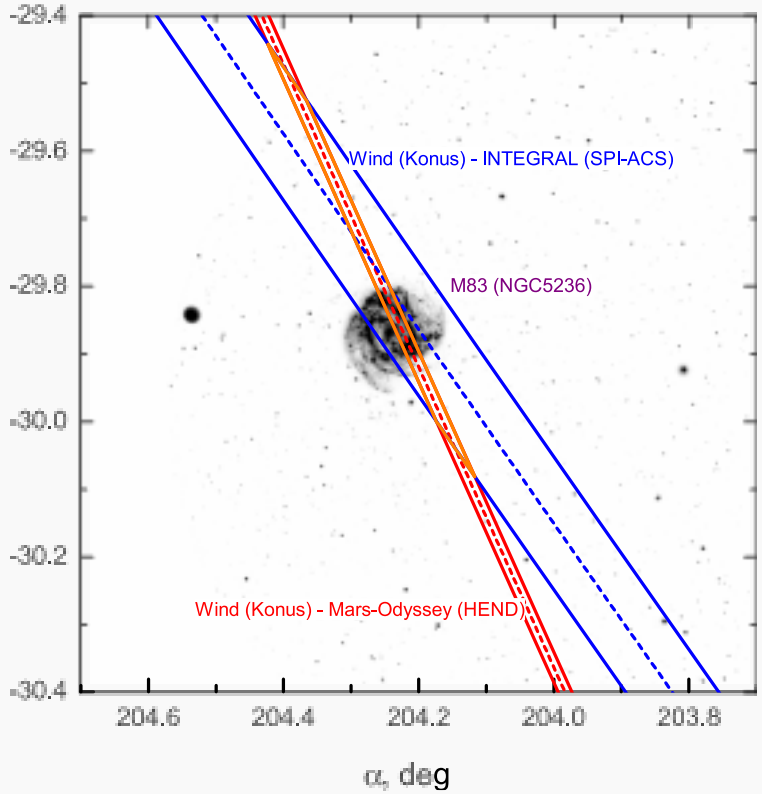
GRB 070201 in M31

Mazets+2008



GRB 051103 in M81 (or M82?)

Frederiks+06; Hurley+2010

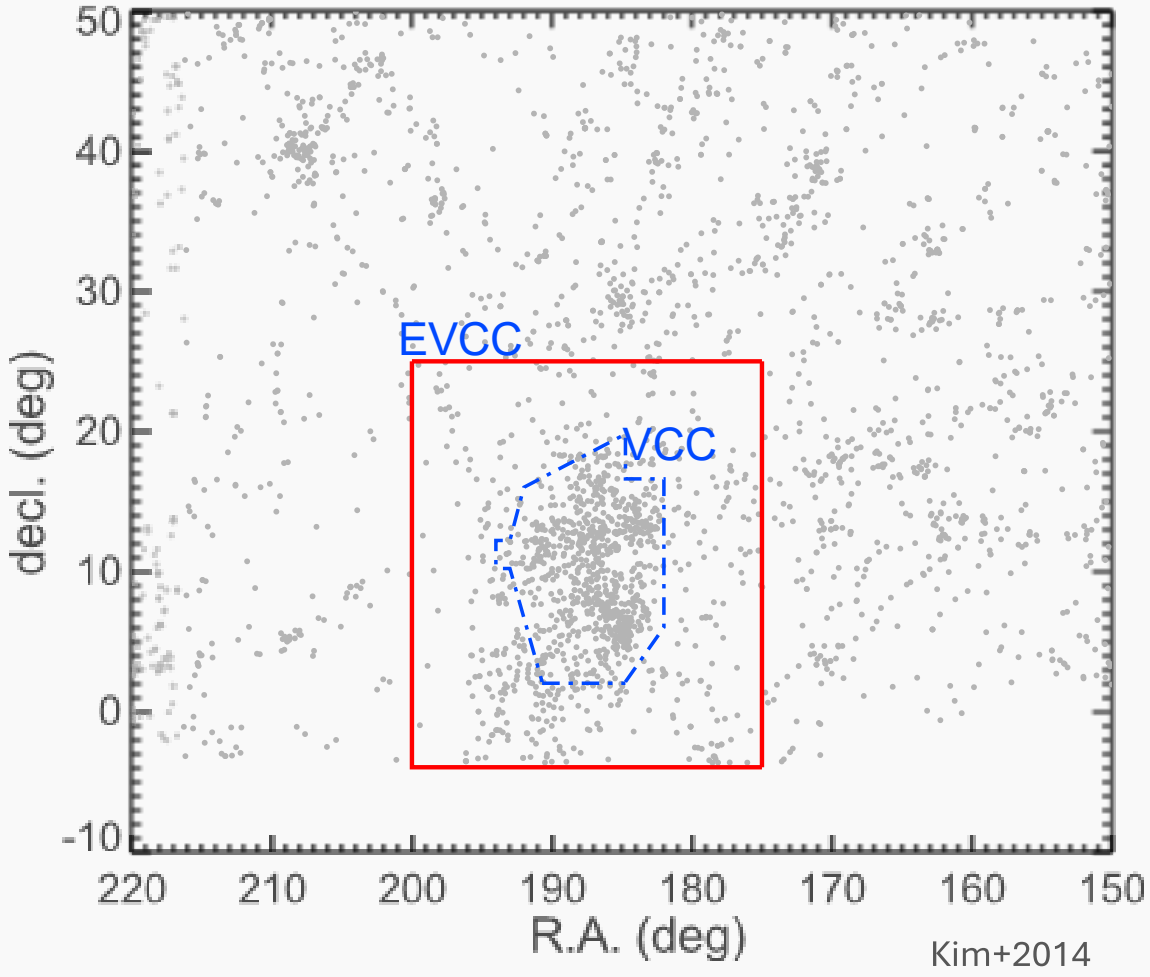


GRB 070222 in M83

Burns+2021

Search for MGFs in Virgo Cluster

- Closest cluster ~16.3 Mpc
- 975 Virgo galaxies from Extended Virgo Cluster Catalog (Kim+2014)
- Large exposure with INTEGRAL



Kim+2014

Expected number of MGFs in INTEGRAL observations

- $N_{GF} = \sum_i \int T_i(< S) R_{GF}(S) N_i dS,$

  where R_{GF} is rate of GF with fluence $S = \frac{E}{4\pi d_i^2}$ emitted by a magnetar.

- Assume number of magnetars proportional to the star formation rate

$$N_i = N_{MW+LMC}\left(\frac{SFR_i}{SFR_{MW+LMC}}\right)$$

MGFs & candidates

$$\sum_i \int T_i(< S)\boldsymbol{R_{GF}}(\boldsymbol{S})N_i dS$$

Source	Galaxy	d (Mpc)	E_{GF} (10^{45} erg)	L (10^{46} erg s^{-1})	$\boldsymbol{a}$	E_p(keV)
SGR 0526-66	LMC	0.055	0.7	0.65	-	500
SGR 1900+14	MW	0.0125	0.4	2.3	-	1200
SGR 1806-20	MW	0.0087	7.7	12	-0.70	850
051103	M81	3.6	53	180	-0.30	2300
070201	M31	0.78	1.5	12	-0.98	296
040222	M83	4.5	6.2	40	-1.00	1290
1801218A	NGC 253	3.5	0.6	11	0.60	290
200415A	NGC 253	3.5	13	140	0.00	887
231115A	M82	3.6	1	1	0.04	551

Energy distribution of MGF

$$\sum_i \int T_i(< S)\boldsymbol{R_{GF}}(\boldsymbol{S})N_i dS$$

- Assume power law energy distribution:

$$N(E) = kE^{-\gamma}$$

- Estimated k and γ with maximum likelihood method based on a complete subsample of Galactic & extragalactic MGFs

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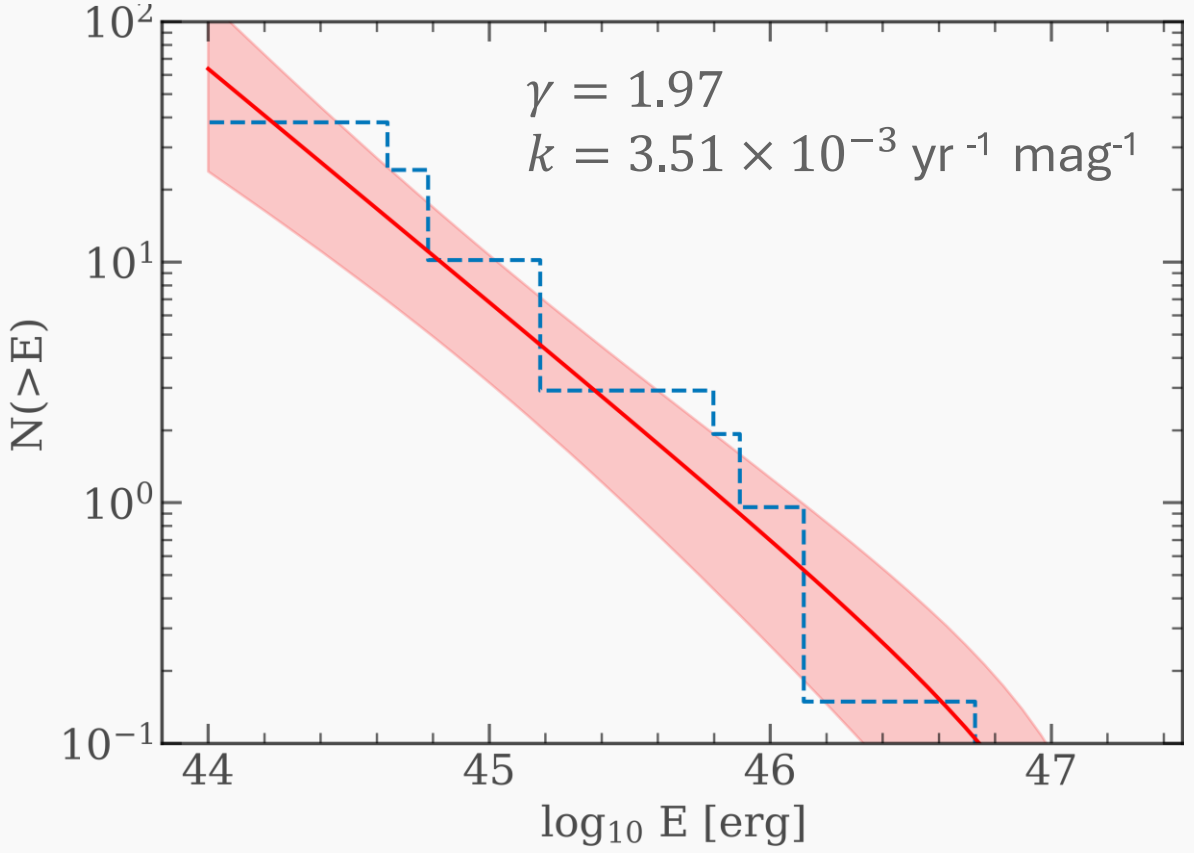
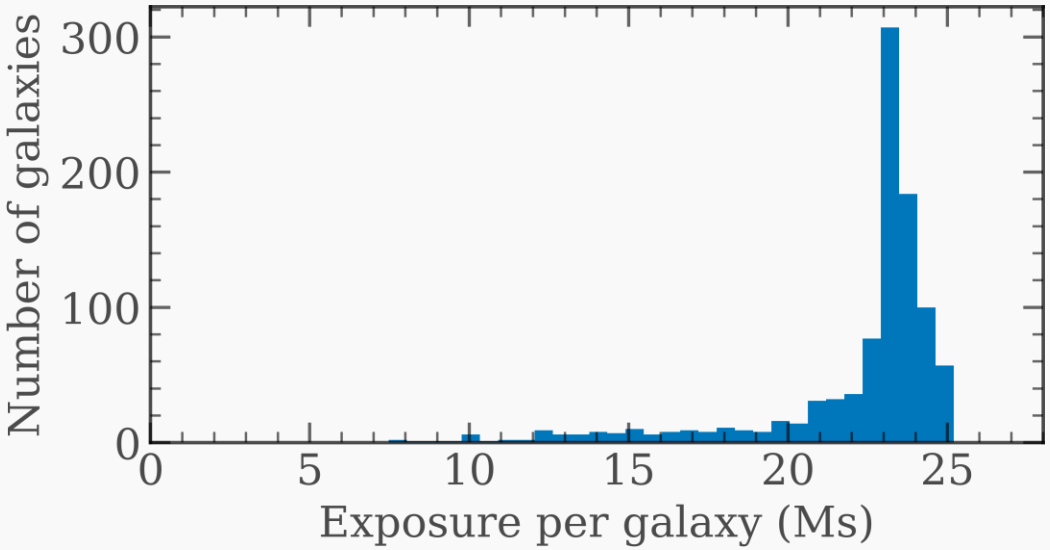
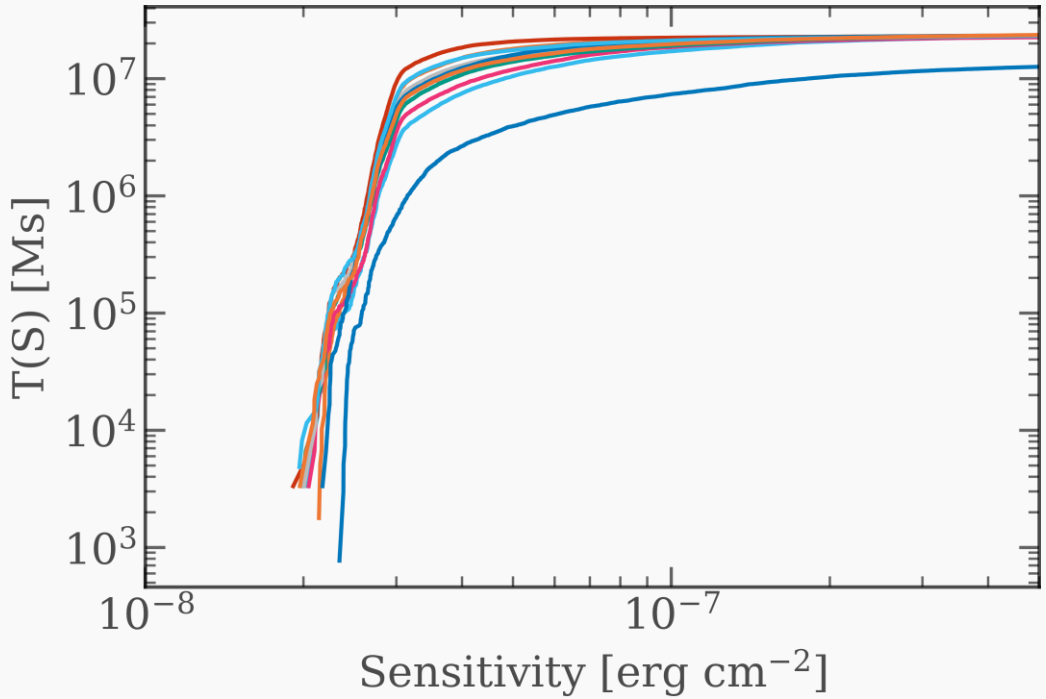


Data selection

$$\sum_i \int \boldsymbol{T_i}(< \boldsymbol{S}) R_{GF}(S) N_i dS$$

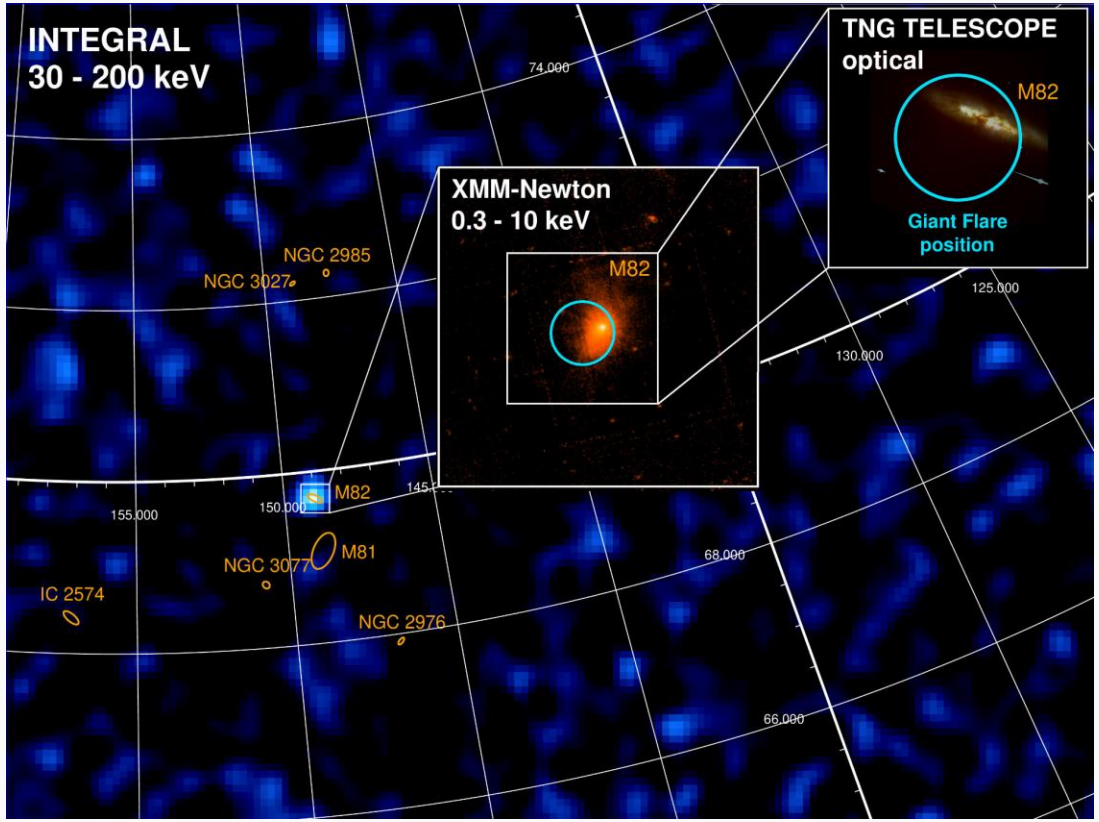
- 10,886 ScWs for a total of 34.8 Ms of exposure
- On average 22 Ms per galaxy





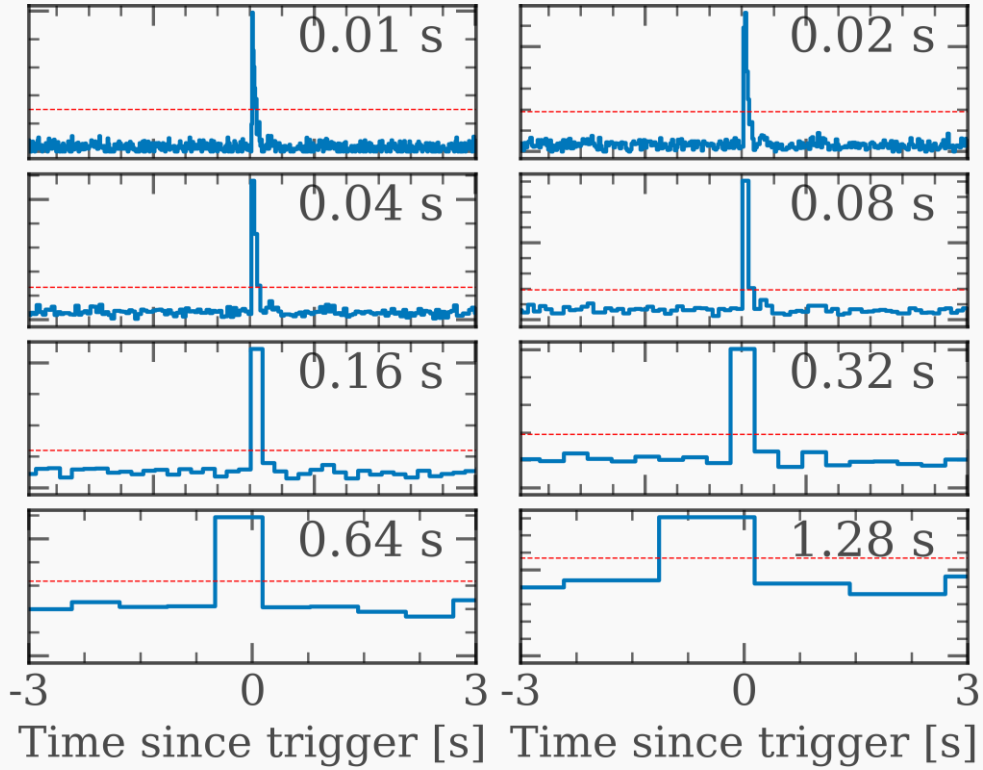
Expected number of GF in Virgo

- Spectral shape of the 231115A ($\alpha = 0.04$ and $E_p = 551$ keV):
$$\boldsymbol{N_{GF} = 0.15}$$
- For $\alpha \in [-1.0, 0.6]$ and $E_p \in [300, 2300]$ keV:
$$\boldsymbol{N_{GF} = 0.05 - 0.30}$$



Search in the INTEGRAL data

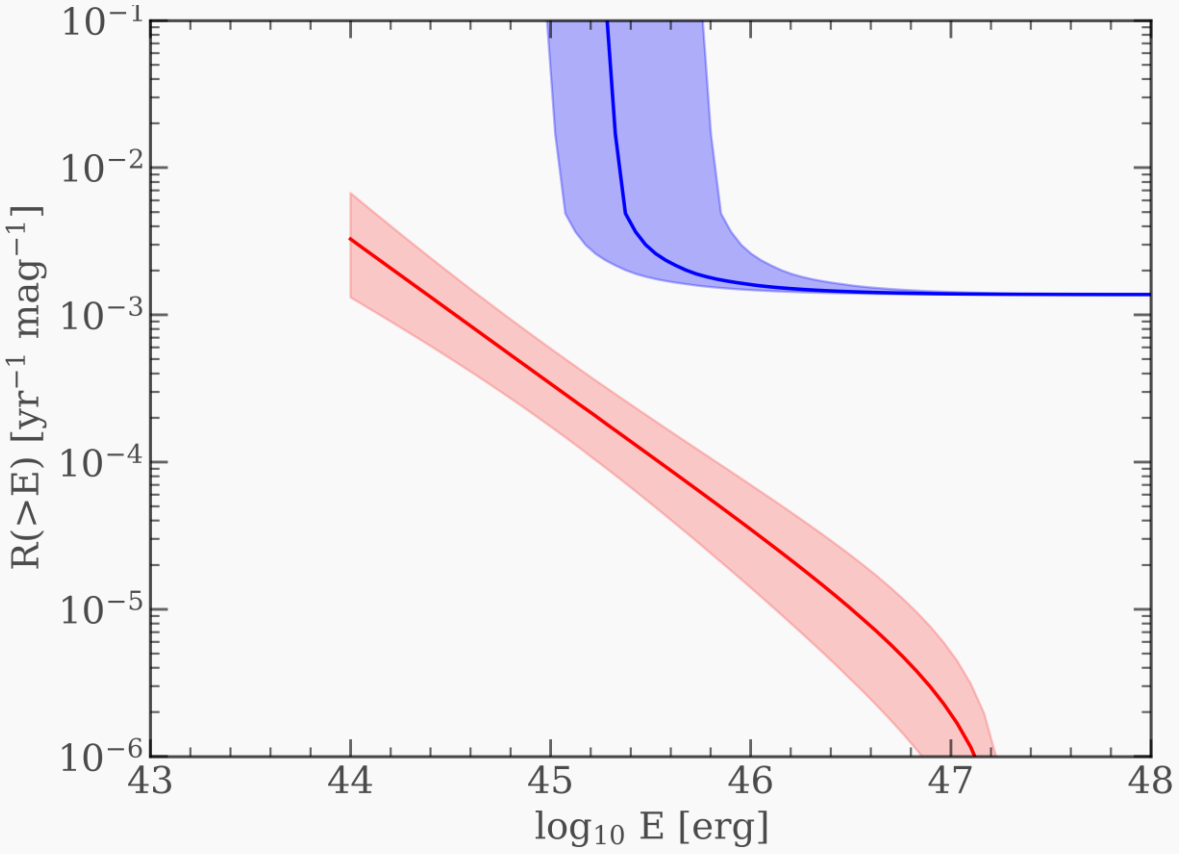
- 8 logarithmically spaced time bins: 0.01 – 1.28 s
- Bursts verified by imaging



Constraints on the rate of GF – Virgo

$$R_{up}(S) = \frac{N_{up}}{\sum_i T_i(<S) N_i},$$

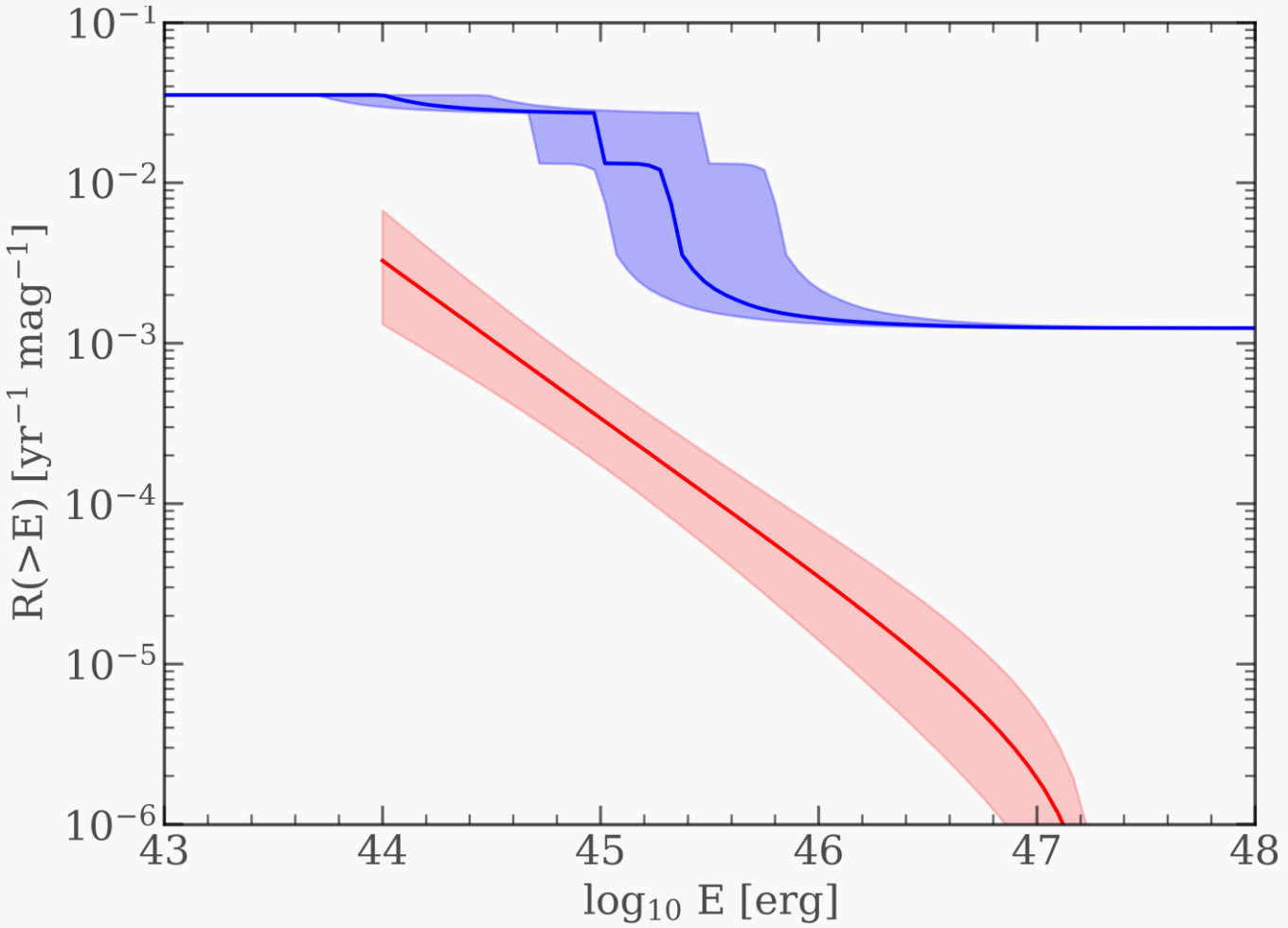
where $N_{up} = 2.303$ (Gehrels+1986)



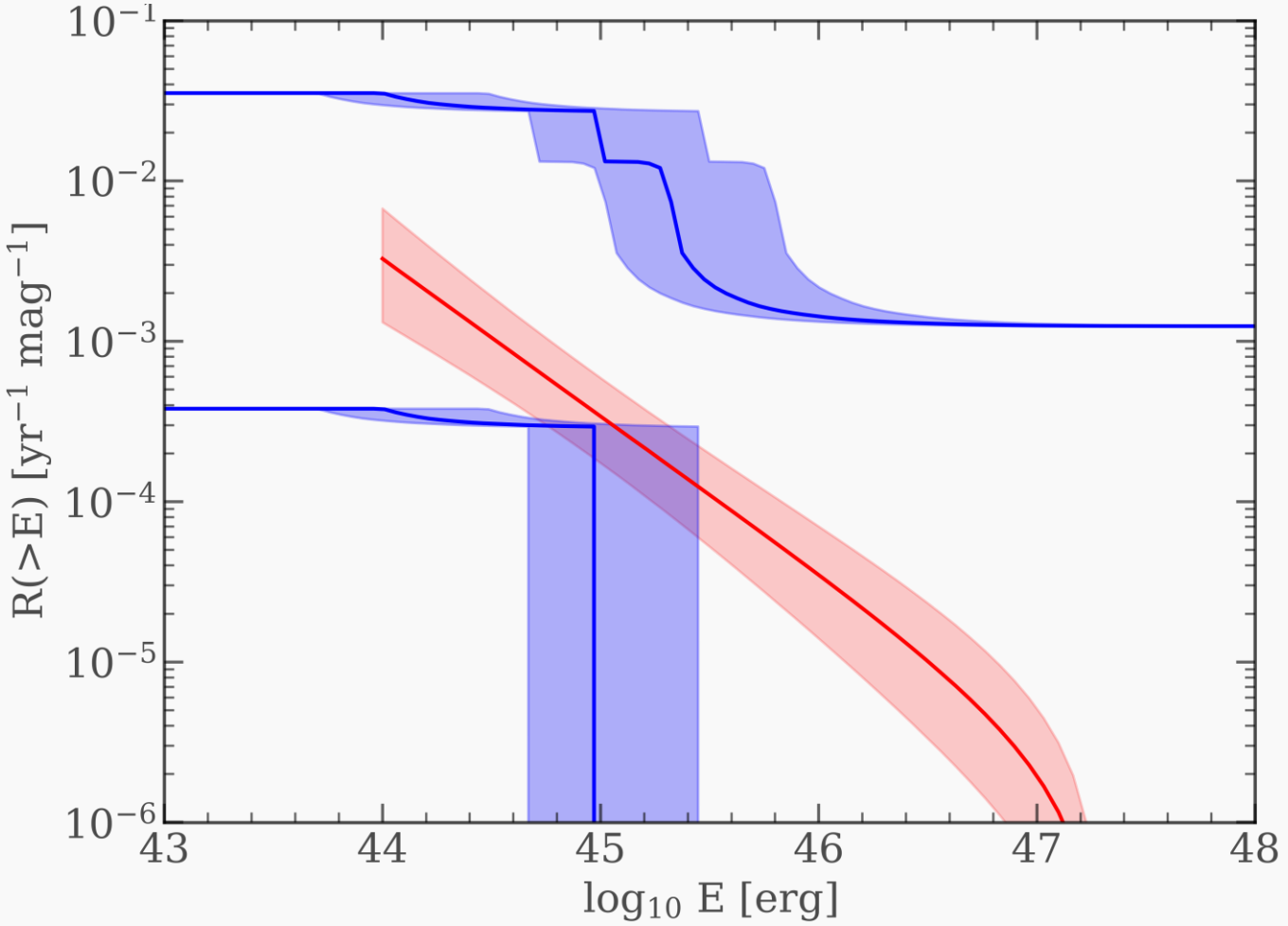
7 nearby galaxies with high SFR

Galaxy	D (Mpc)	SFR ($M_\odot$ 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

Constraints on the rate of GF



Constraints on the rate of GF



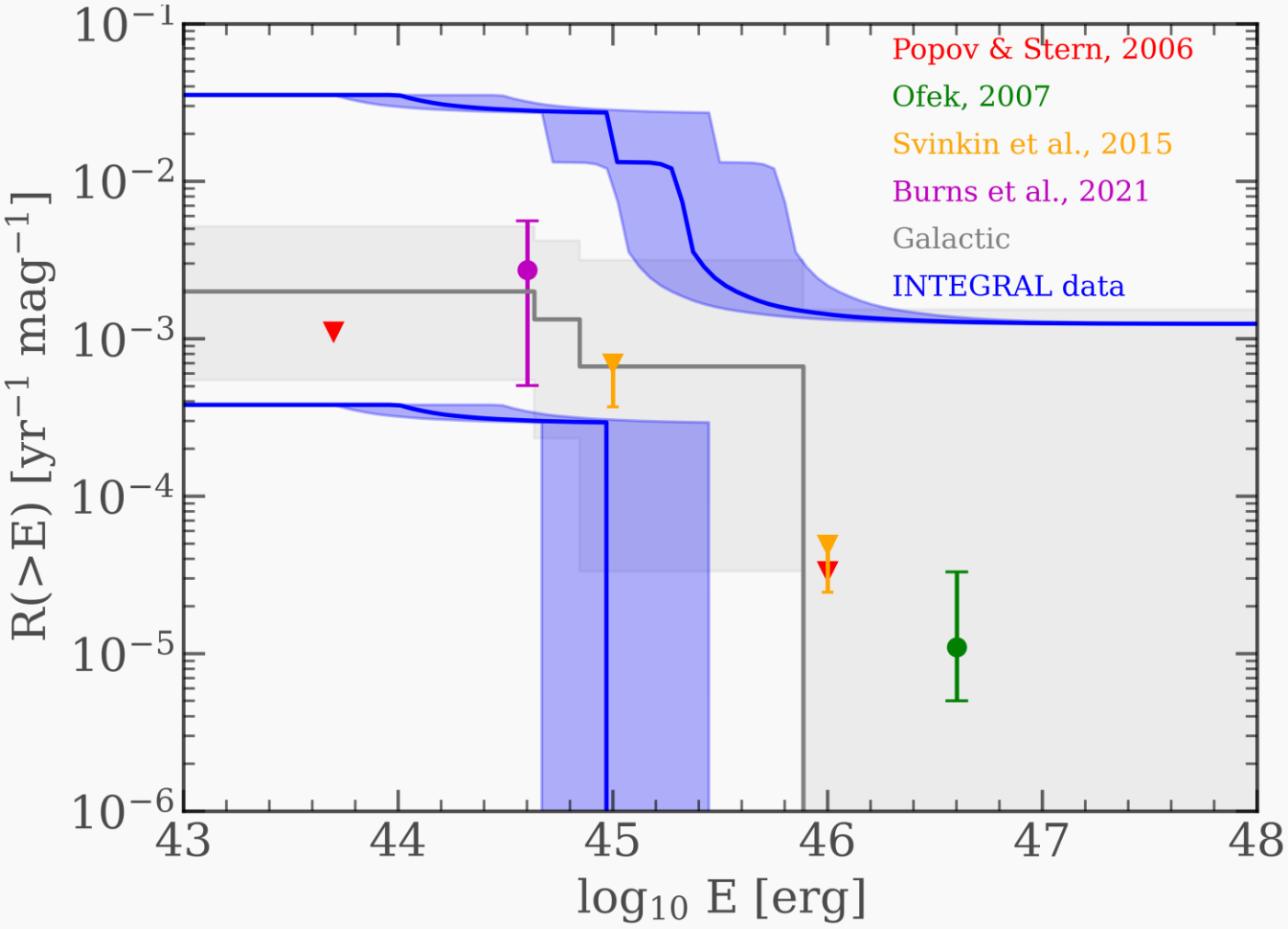
Summary

- Long-term light curves of 5 magnetars in the hard X-ray

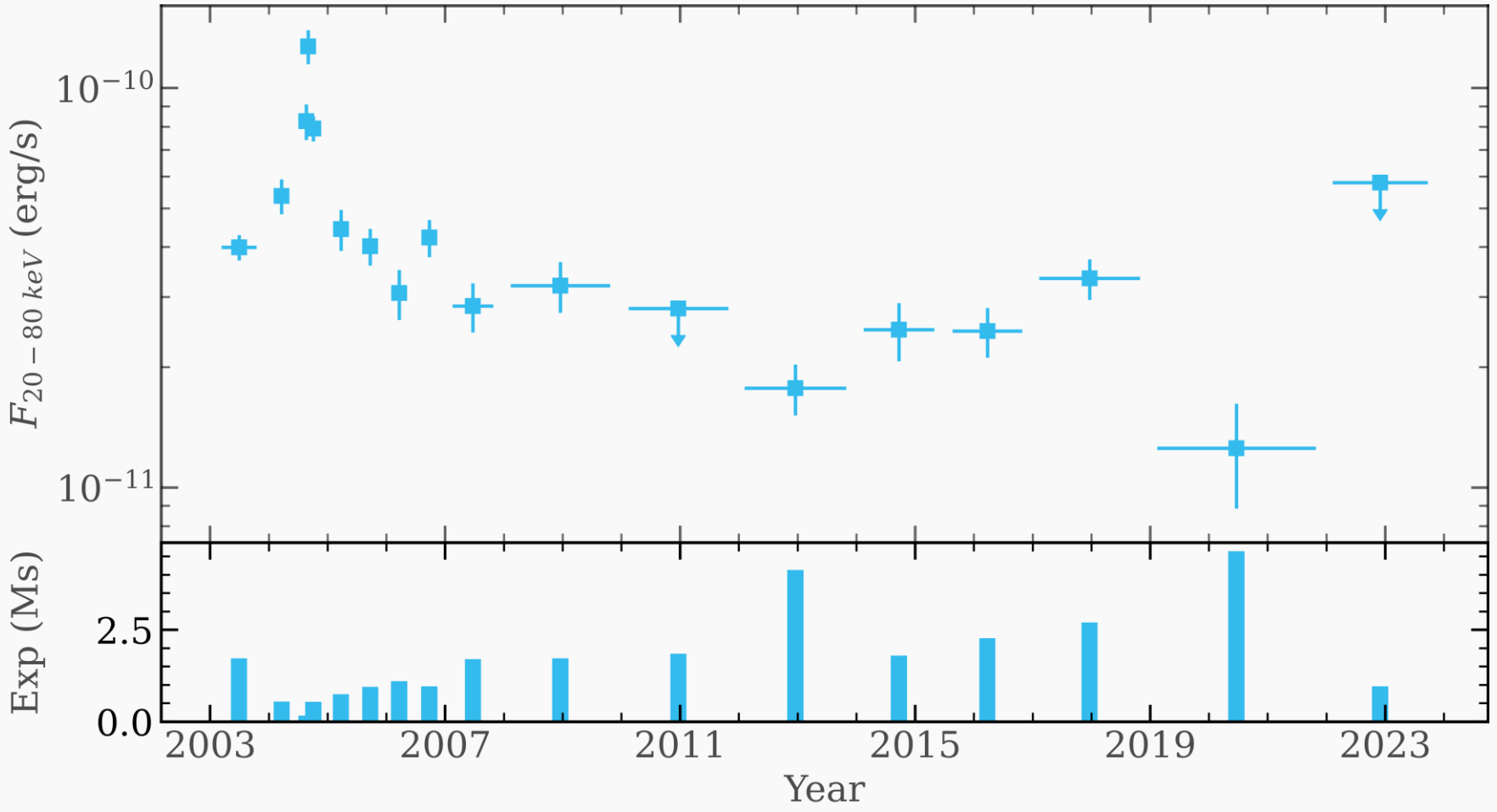
- Searched for extragalactic MGFs in ~ 140 Ms of observation data
- Derived upper limit on the rate of MGF with $E > 3 \times 10^{45}$erg of $\sim 2 \times 10^{-3}$ yr^{-1} per magnetar and a lower limit of $R(E) > \sim 4 \times 10^{-4}$ yr^{-1} magnetar^{-1} for $E < 10^{45}$erg

Backup slides

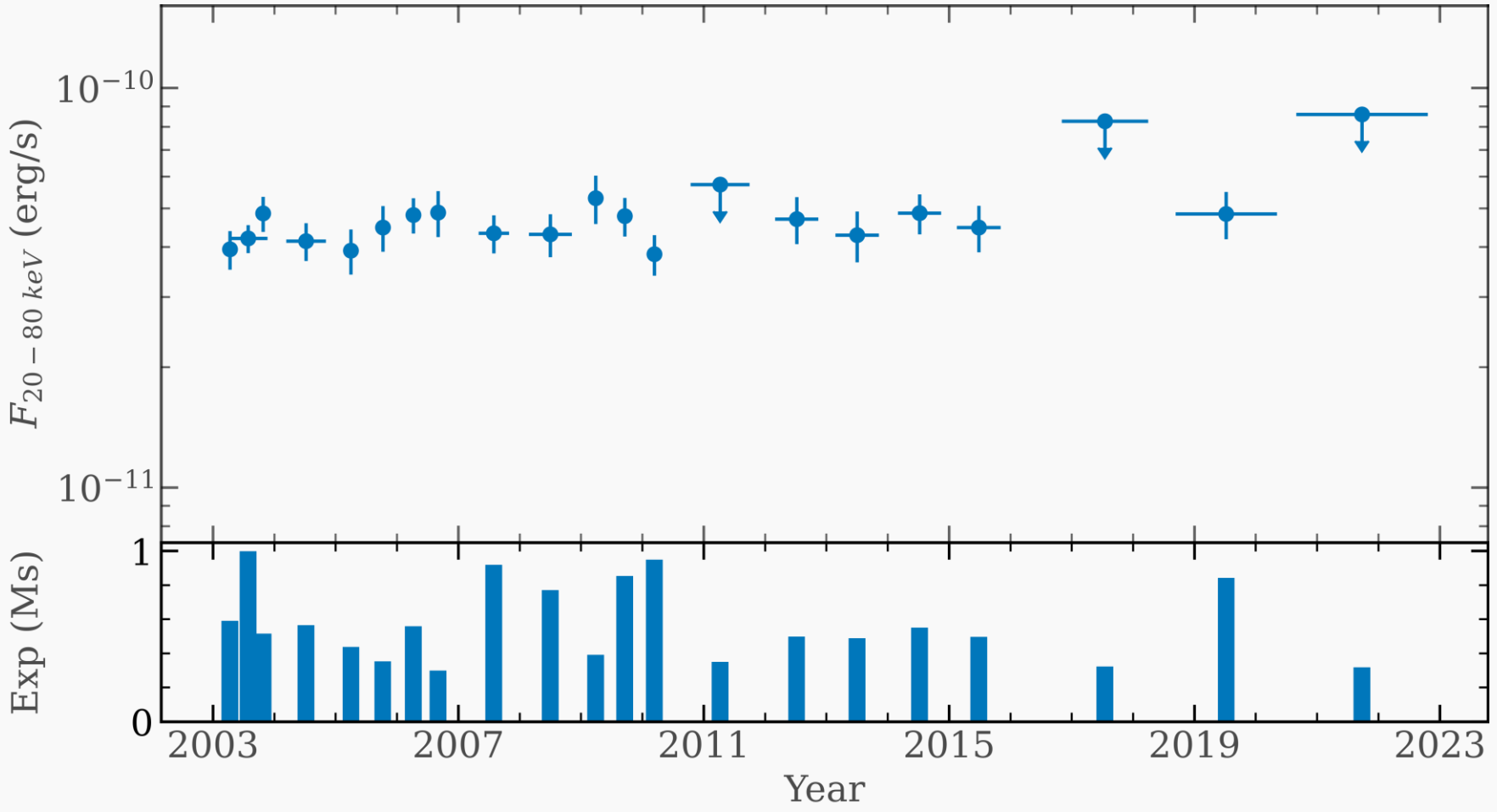
Constraints on the rate of GF



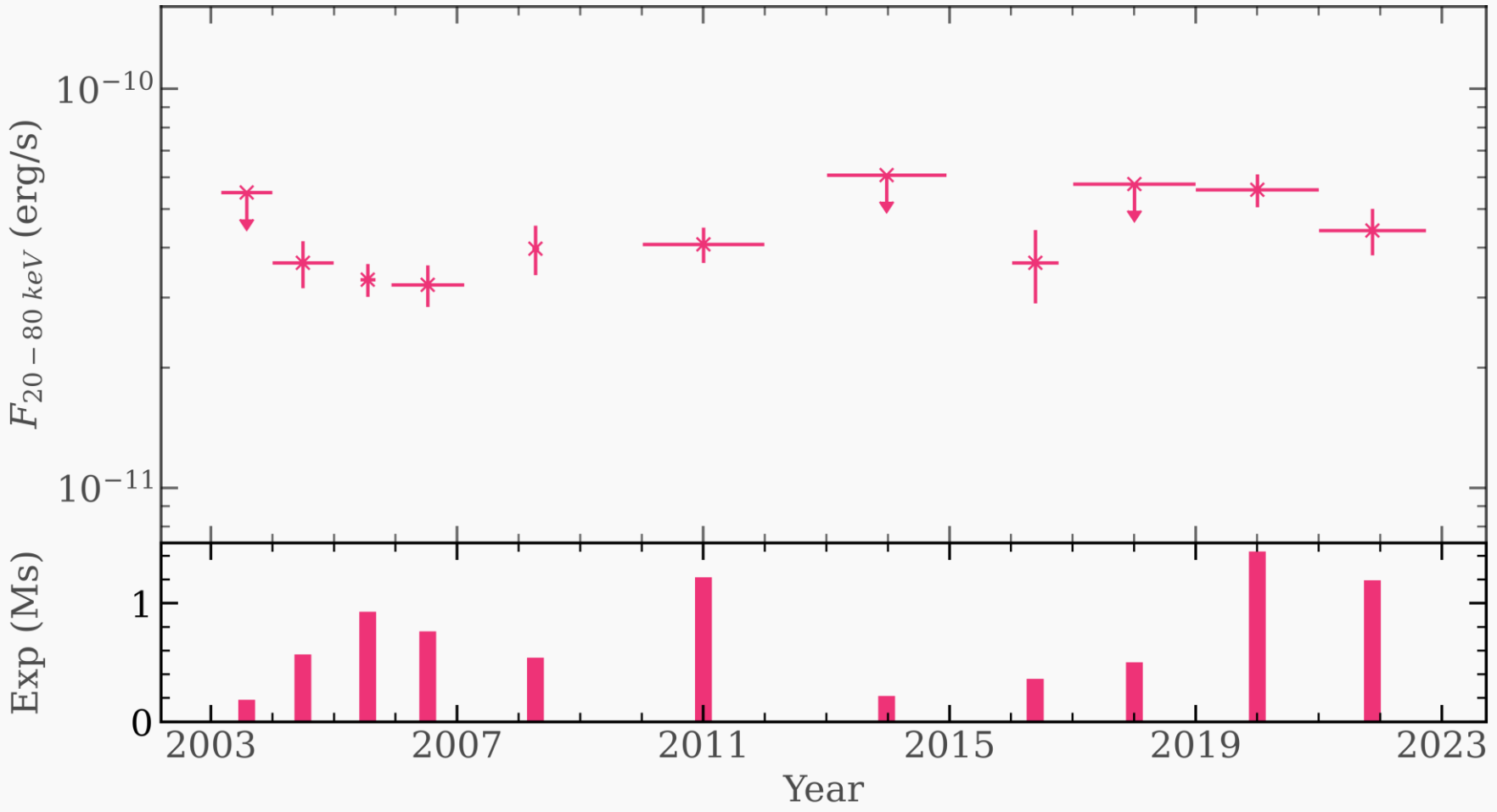
Exposure plots – SGR 1806-20



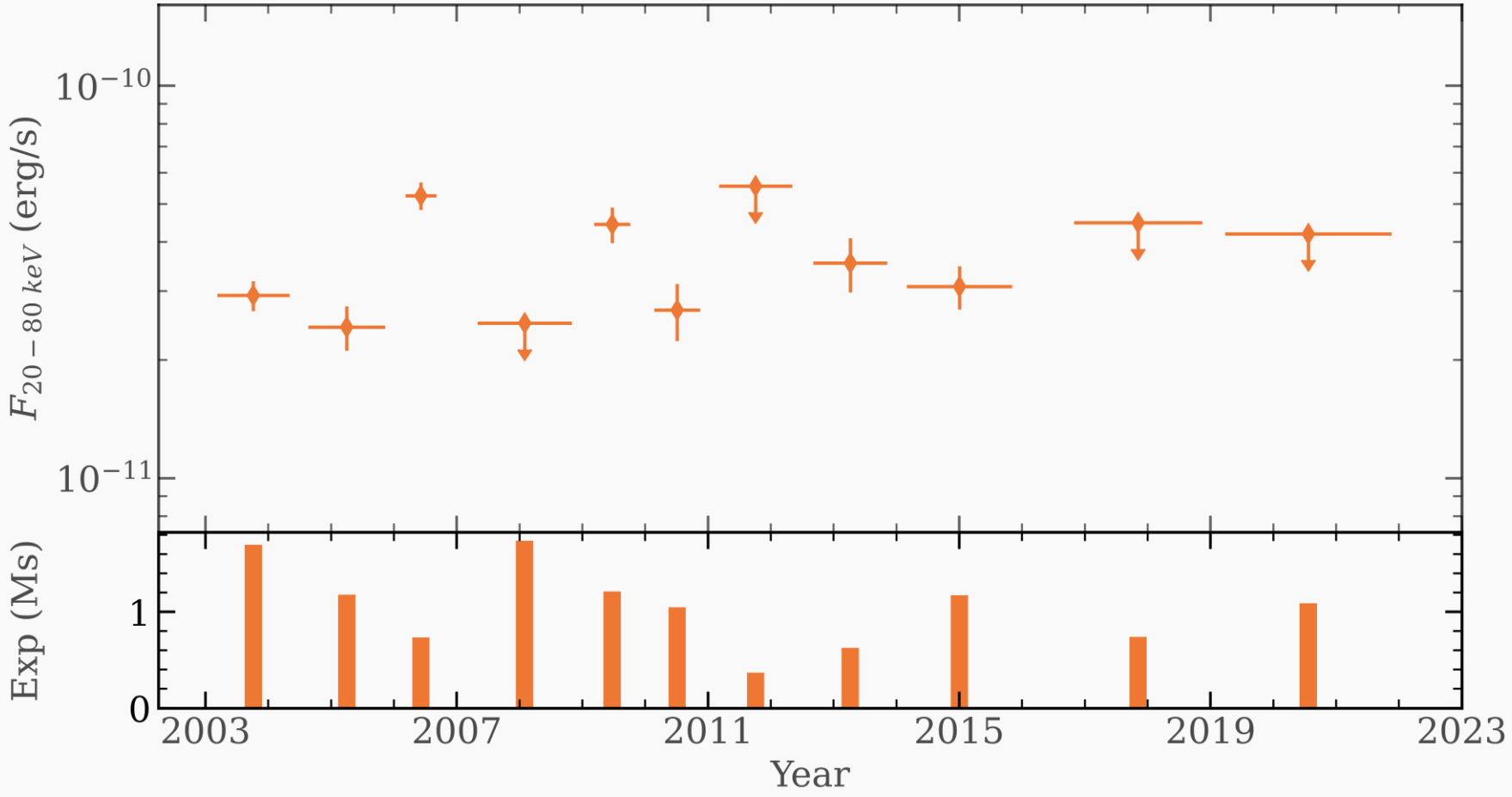
Exposure plots – 1E 1841−045



Exposure plots – 4U 0142+61



Exposure plots – PSR J1846−0258



Exposure plots – RXS J1708-40