X-ray Properties of Magnetar SGR J1935+2154

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Thank you, my collaborators!

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Matthew Barning @*Rice University*

The Insight-HXMT team @IHEP, CAS

The FAST-FRB collaboration

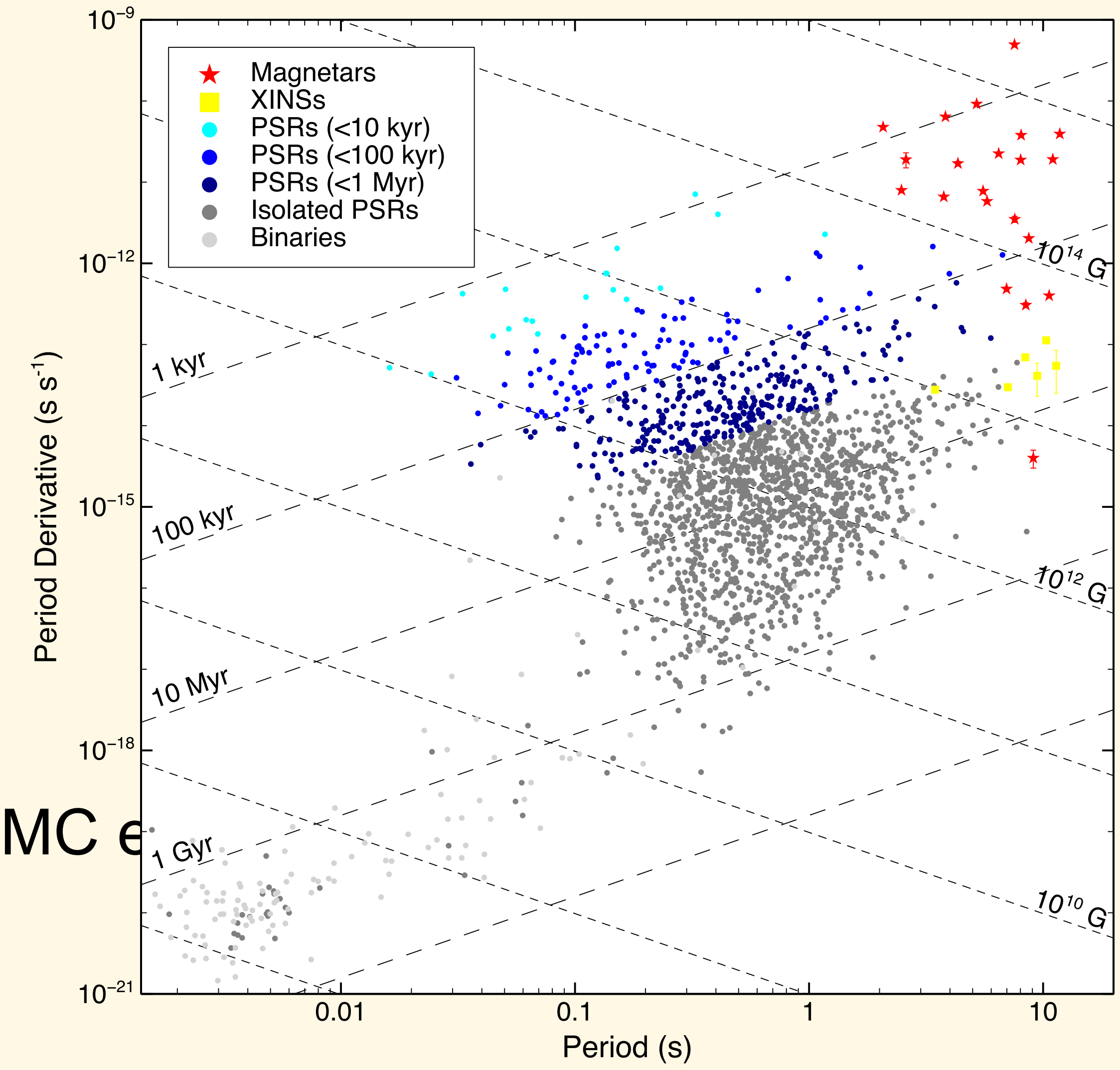
Outline

- The general behavior of Magnetars in X-rays
- The most active prolific transient: SGR J1935+2154
  - Bursts
  - Hard X-ray burst associated with FRB 200428
  - Outbursts
- The seeded players may be ….

Introduction: magnetars

Neutron stars with extremely strong magnetic fields

- Soft-Gamma Repeaters (SGRs)& Anomalous X-ray Pulsars (AXPs)
- $L_X \sim 10^{33} - 10^{35} \text{erg/s} > L_{rot}$
- $P = 2 \sim 12 \text{ s}, \dot{P} = 10^{-10} \sim 10^{-13} \text{ s} \cdot \text{s}^{-1}$
- $B_{surf} \sim 10^{14} - 10^{15} \text{ G}$
- ~ 30 known magnetars
- Most are galactic sources, only two in S/LMC e



SGR 0418+5729 low B?
RPPs with high B
SGR 0755-2933,P~308s HMXB?
CCO in SNR RCS103, P~6.67hr

Olausen & Kaspi 2014

Introduction: magnetars

Peak Luminosity

Giant Flare

~10^{45} erg s^{-1}

Intermediate Flare

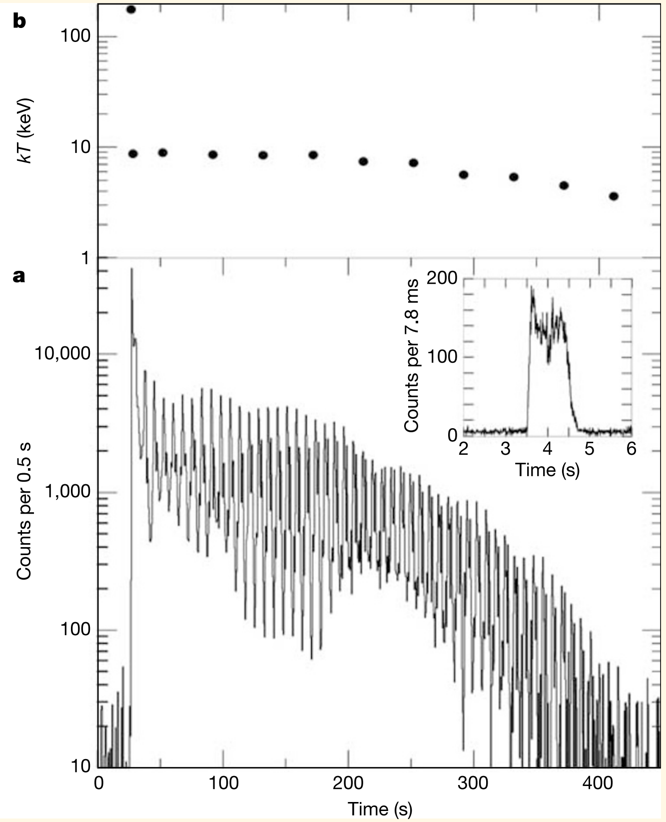
~10^{41} erg s^{-1}

Short Burst

Giant Flare: the most energetic but the rarest event

- Short hard spike + long soft periodic tail
- 3 GFs form 3 SGRs
  SGR 0526-66, 1979-3-5
  SGR 1900+14, 1998-8-27
  SGR 1806-20, 2004-12-27
- Radio NONE-detection of SGR 1806-20 GF with Parkes side lob

(Tendulkar et al. 2016)



Hurley et al. 2005

Introduction: magnetars

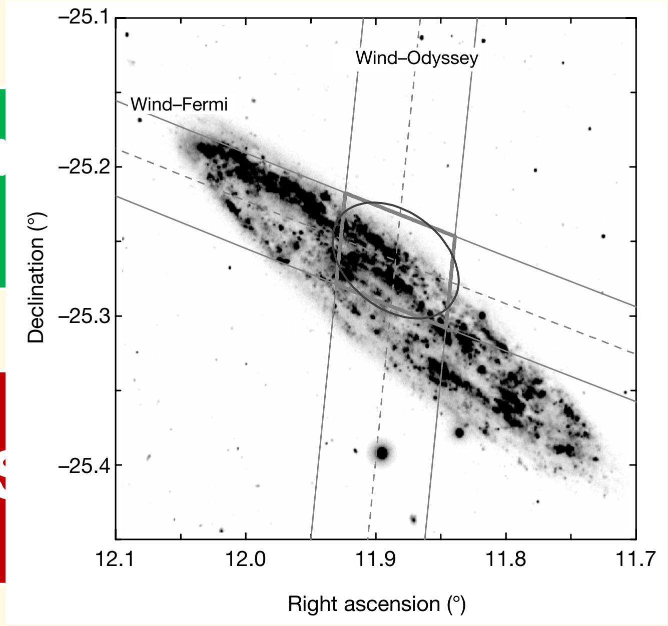
Peak Luminosity

Giant Flare: GRB 200415A @ The Sculptor Galaxy (3.5 Mpc)

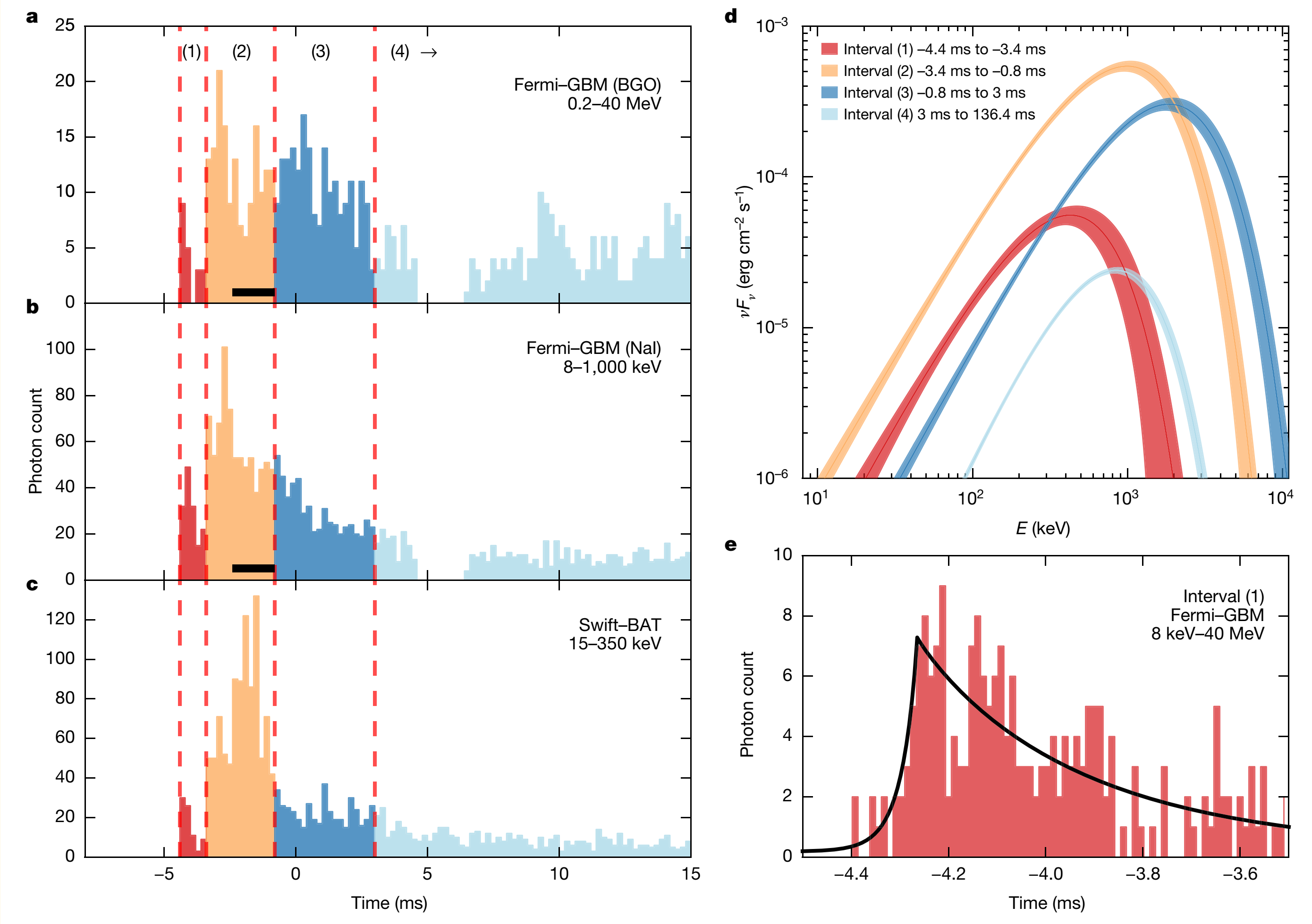
Giant Flare

~10^{45} erg s^{-1}

~10^{41} erg s^{-1}

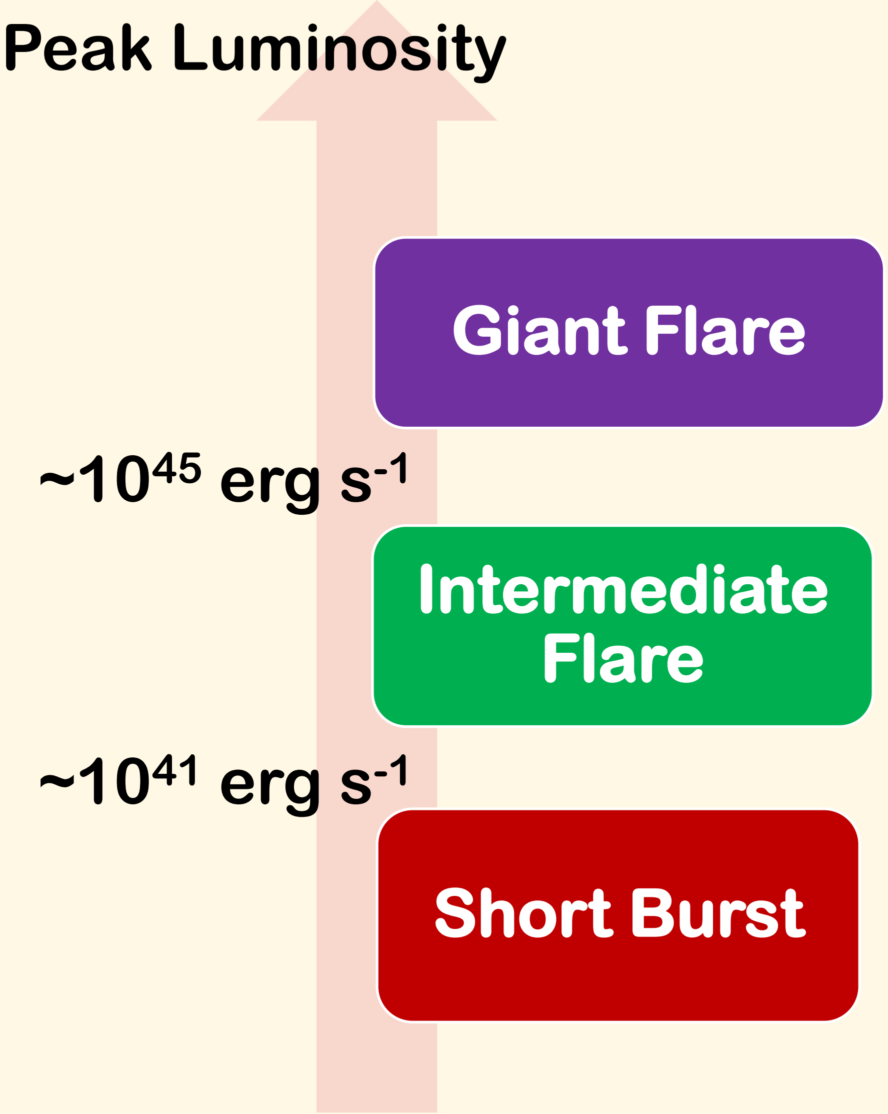


Svinkin et al. 2021 Nature



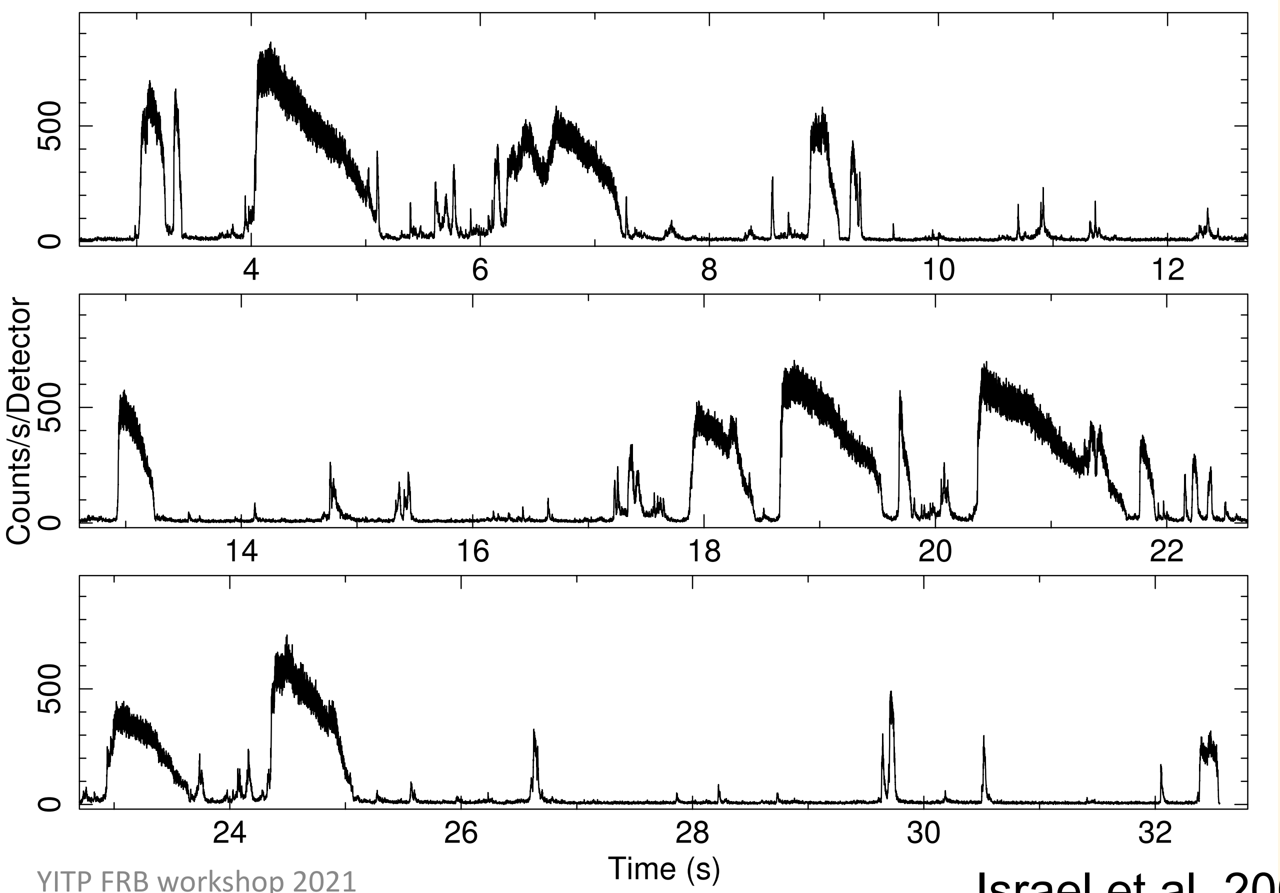
Roberts et al. 2021 Nature

Introduction: magnetars



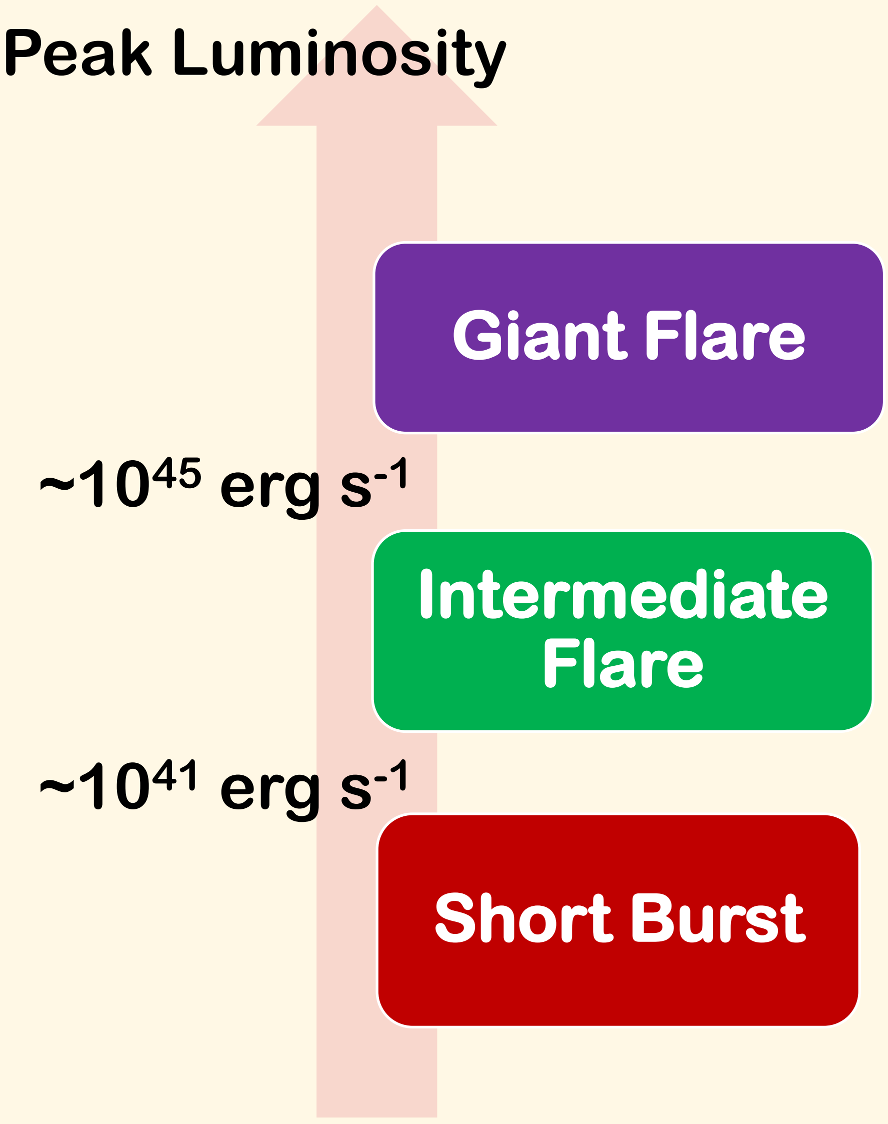
Intermediate Flares

Burst forest from SGR 1900+14 on 2006-3-29 observed with Swift/BAT in 15-100 keV



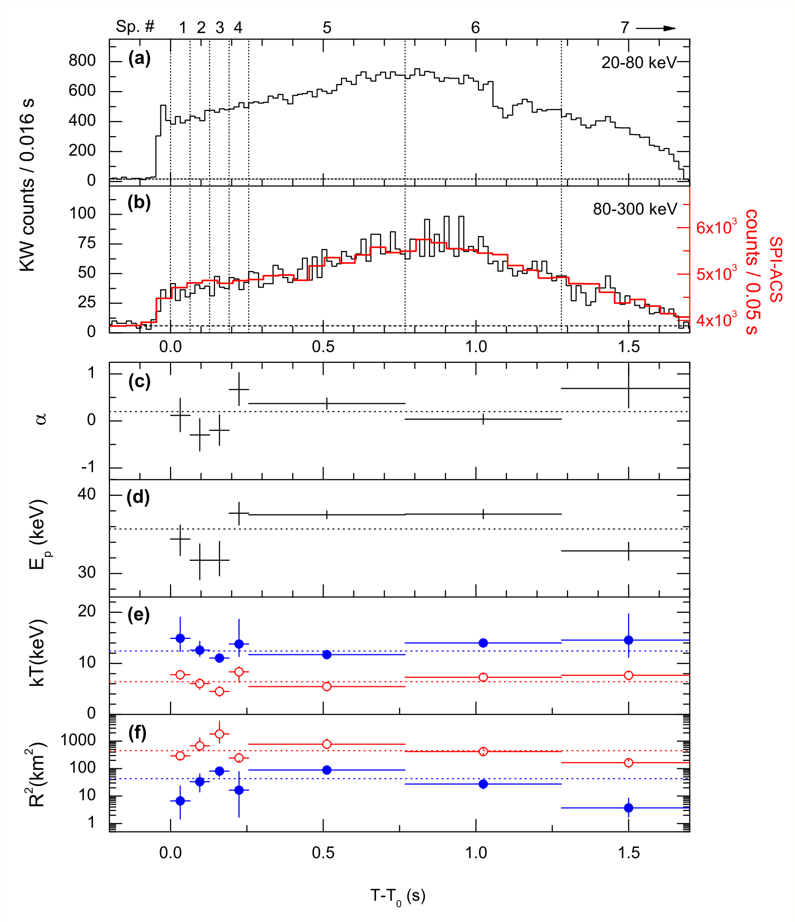
Israel et al. 2008

Introduction: magnetars



Intermediate Flares

An isolated IF from SGR 1935+2154 on 2015 April 12 observed with Konus-Wind.



Kozlova et al. 2016

Introduction: magnetars

Peak Luminosity

Giant Flare

$\sim 10^{45}$ erg s^{-1}

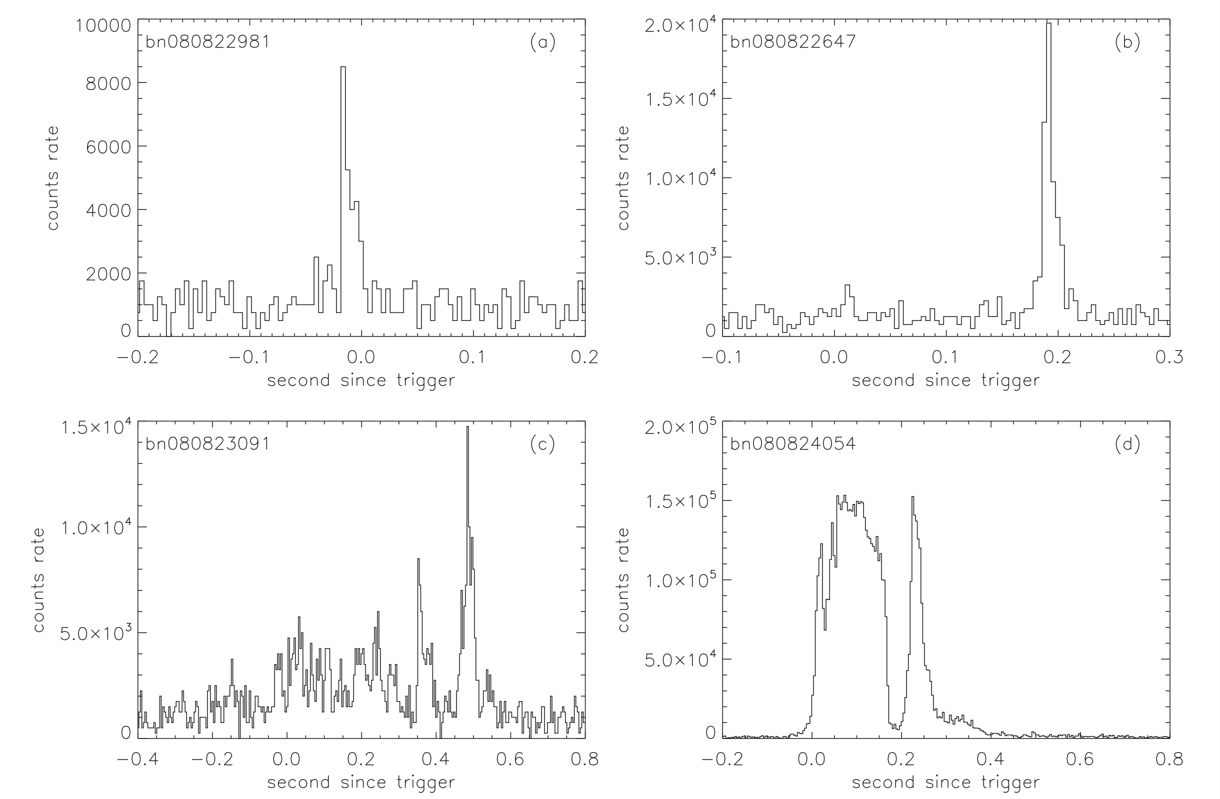
Intermediate Flare

$\sim 10^{41}$ erg s^{-1}

Short Burst

Short Burst

- The most common events but unpredictable
- From both SGRs and AXPs



SGR J0501+4516 Fermi/GBM Lin et al. 2011

Introduction: magnetars

The burst spectrum : almost all are thermal

<u>BB+BB:</u>

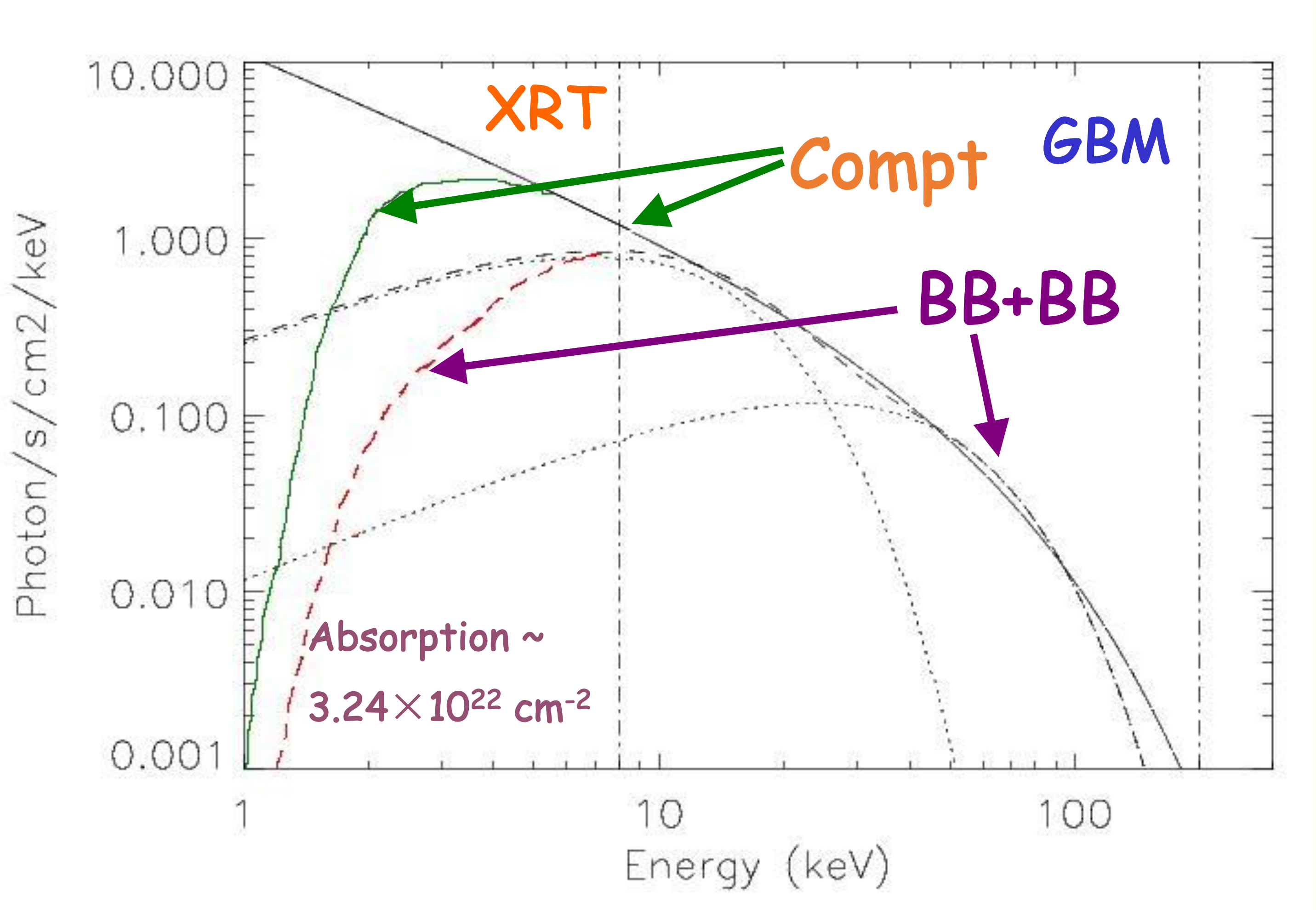
Low kT ~ 4.4 keV

High kT ~ 16 keV

<u>Cut-off PL:</u>

Epeak ~ 45 keV

We need the broad energy coverage (e.g. 1-200 keV) to study the burst spectra.

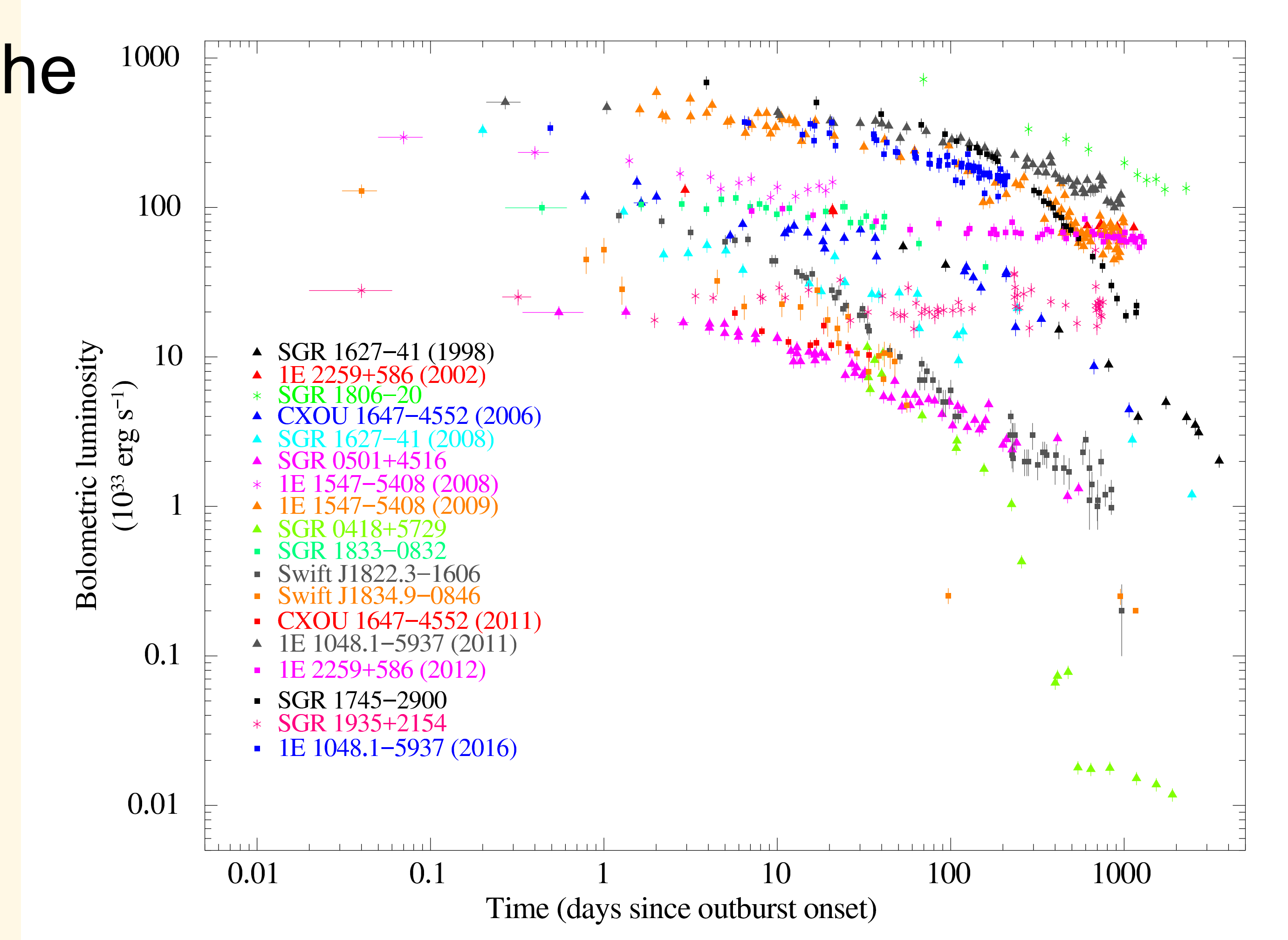


Israel et al. 2008, Lin et al. 2012

Introduction: magnetars

During a magnetar outburst the persistent emission may change in

- Luminosity, 1-2 order of mag.
- X-ray spectrum, harder
- pulse profile
- Glitch/anti-glitch



Coti Zelati et al. 2018

Introduction: magnetars

The outburst of magnetars

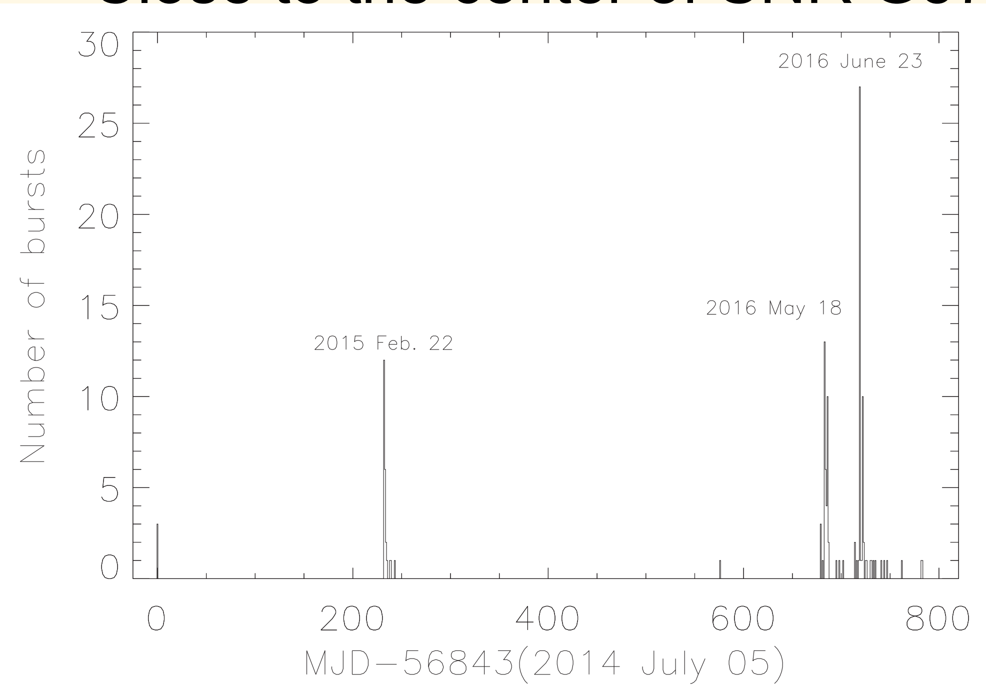
AXPs with bursts/flares	persistent flux stable	1E 1841-045
	persistent flux enhanced	1E 2259+586, 4U 0142+61, XTE J1810-197
SGRs: Transients	with a Giant Flare	SGRs 1806-20, 1900+14, 0526+66
	prolific transients	SGRs 1550-5418, **1935+2154**, 0501+4516, 1627-41
	with low burst rates	SGRs 0418+5729, 1833-0832

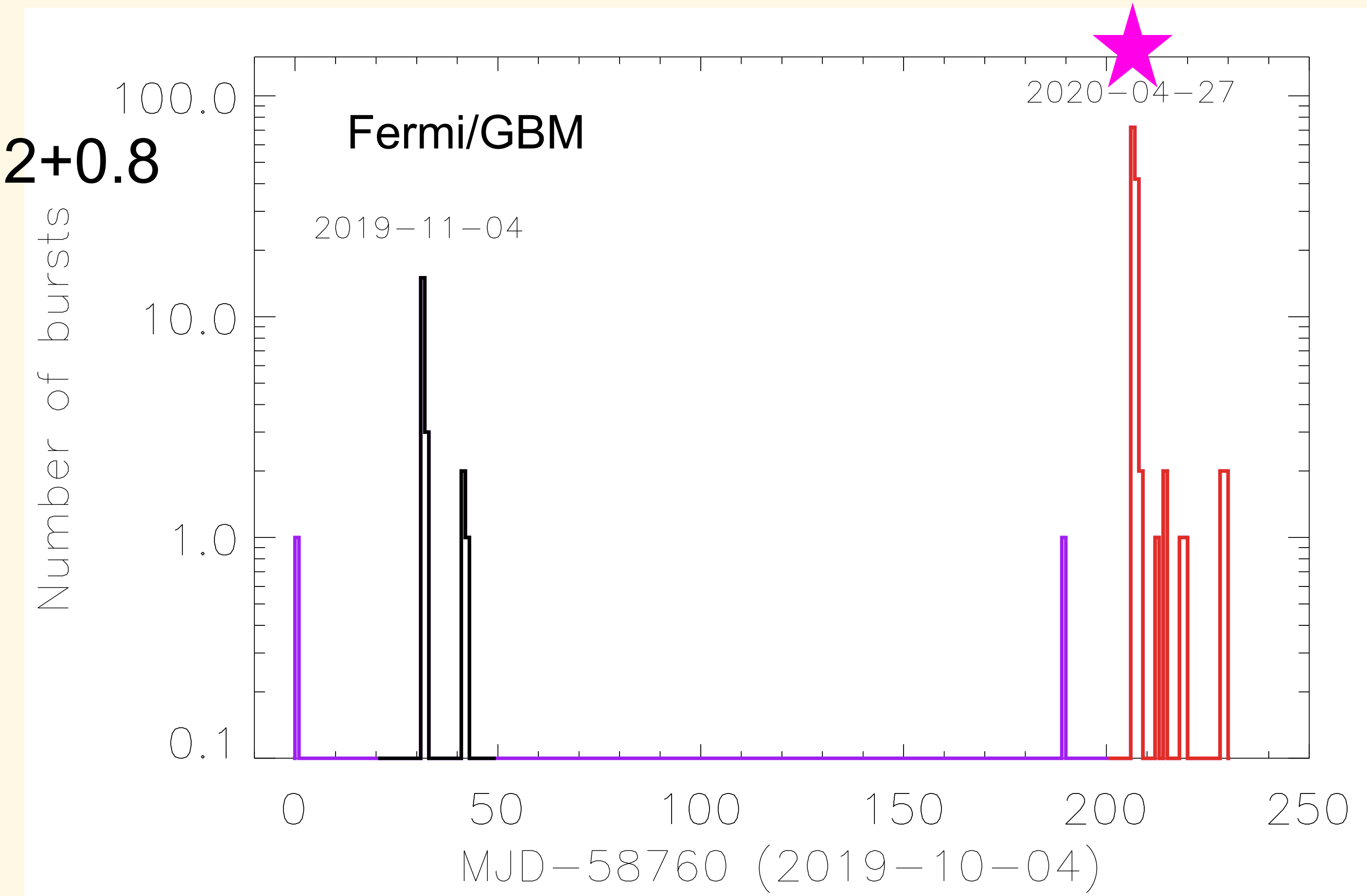
(Gogus et al. 2014)

SGR J1935+2154

One of the most active magnetars:
2014-07, 2015-02, 2016-05, 2016-06, 2019-11, 2020-04, 2021-01

- $P = 3.25\ \mathrm{s}, \dot{P} = 1.4 \times 10^{-11}\ \mathrm{s} \cdot \mathrm{s}^{-1}$
- $B_{surf} = 2.2 \times 10^{14}\ \mathrm{G}$
- Close to the center of SNR G57.2+0.8



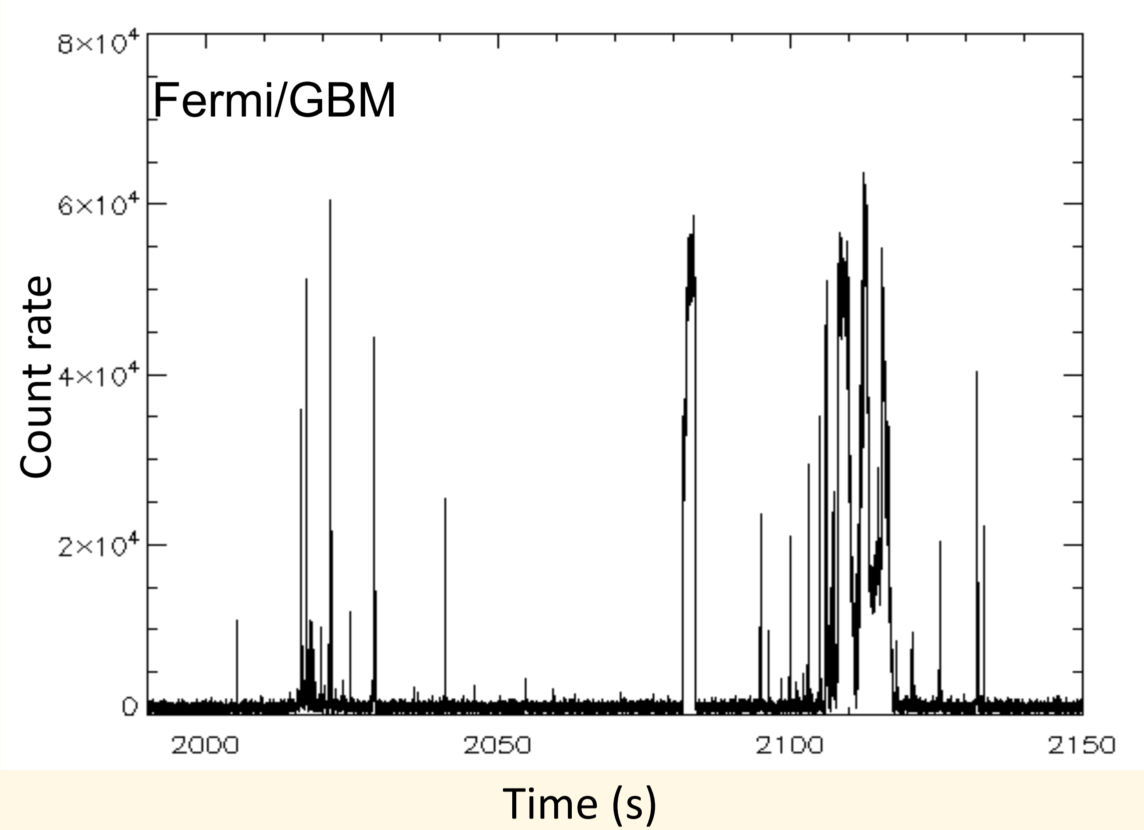


Lin et al. 2020 ApJ, ApJL

SGR J1935+2154

- A burst forest happened at the beginning of the 2020-04-27 activity, and lasted for ~130 s.

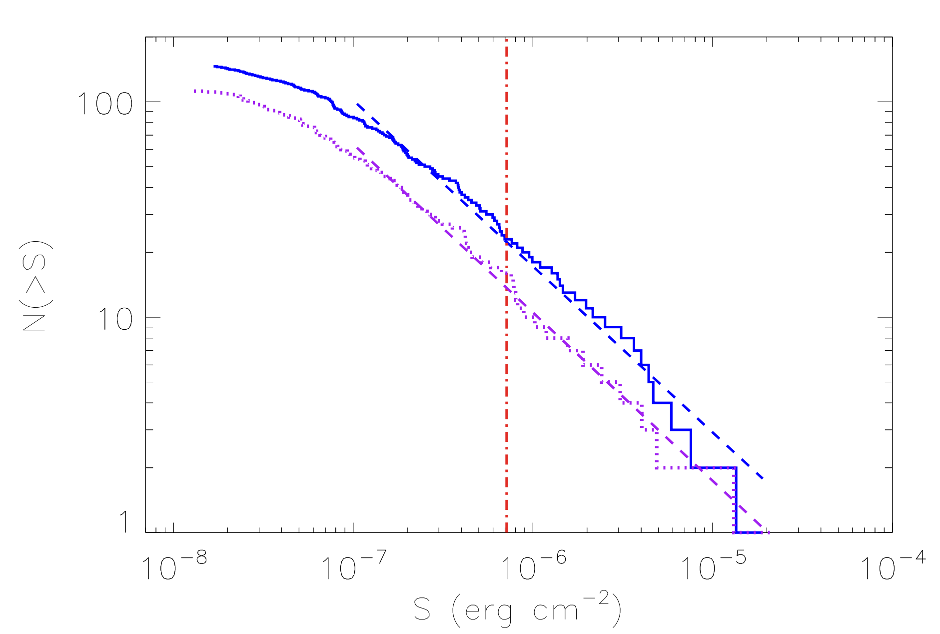
- These data are not included in the current analysis.

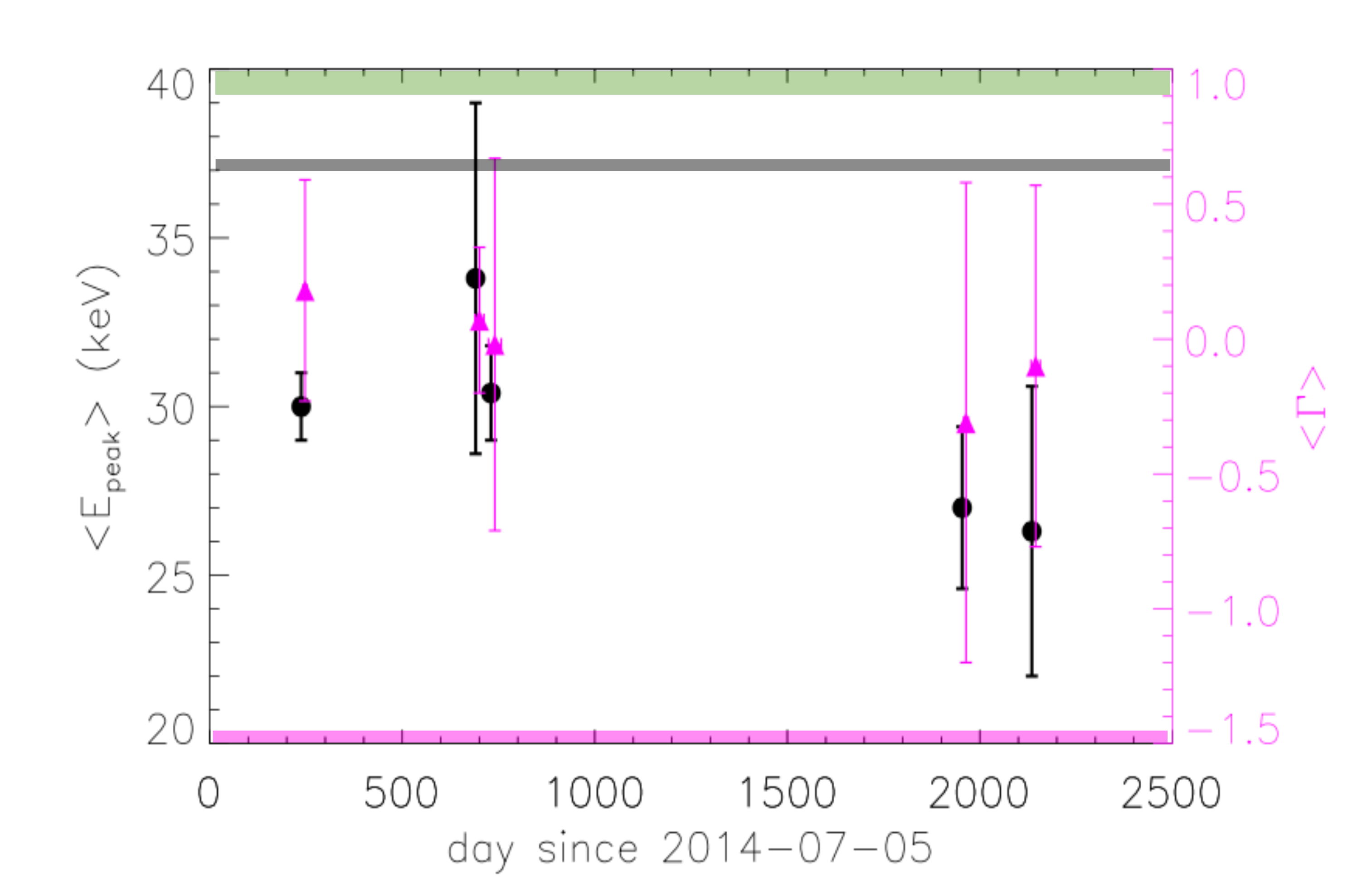


Kaneko et al. 2021 in prep

SGR J1935+2154

- Bursts are slightly softer than typical magnetar bursts.
- Bursts are slightly softer in later episodes.



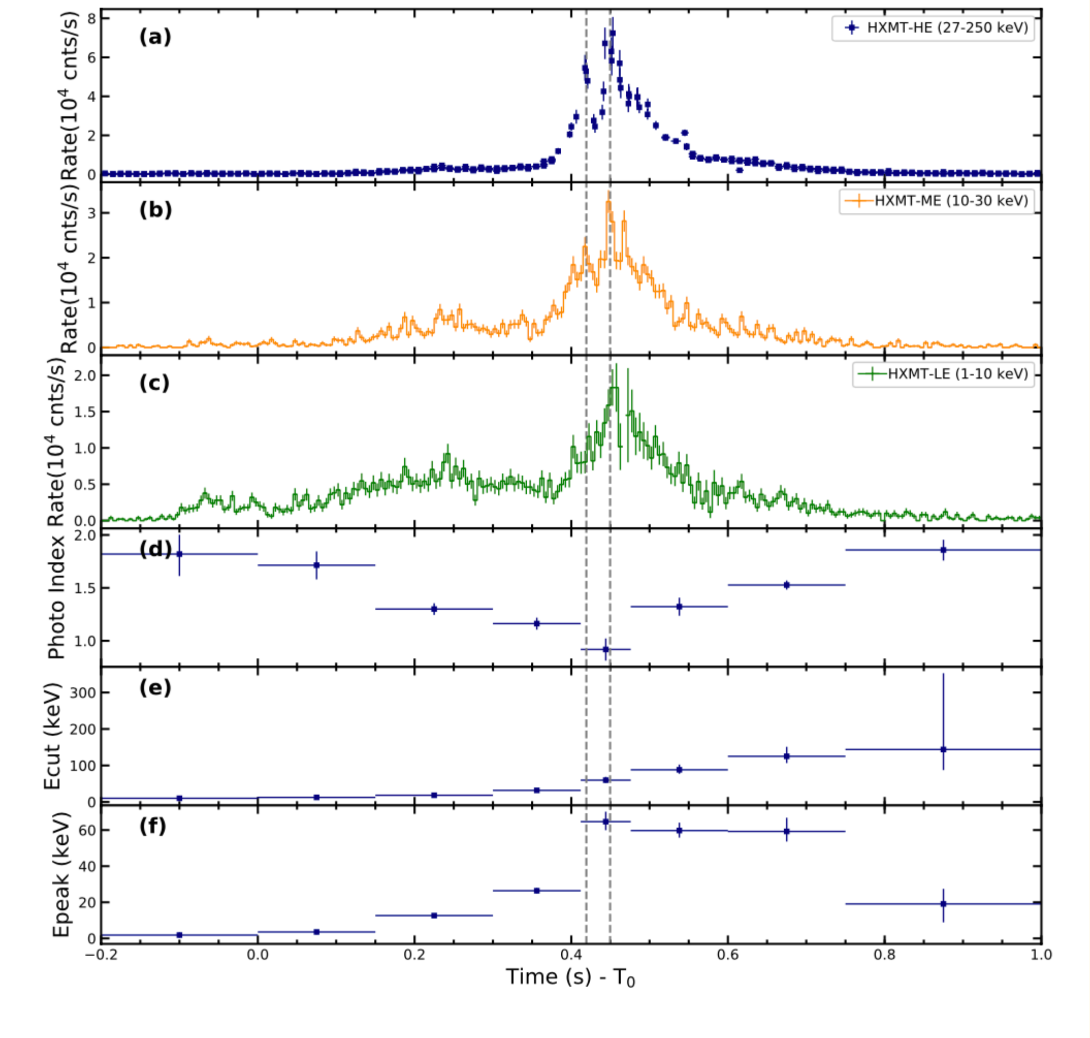


Lin et al. 2020 ApJL

The hard X-ray burst – FRB200428

11 Bursts detected with HXMT on April 28

Trigger time (UTC)	Fluence 10^{-8}erg cm^{-2}	Duration s	Δt s
2020-04-28T08:03:34.35	5.65 ± 1.14	0.11	-23458.65
2020-04-28T08:05:50.15	5.04 ± 1.39	0.07	-23322.85
2020-04-28T09:08:44.30	1.37 ± 1.86	0.06	-19548.70
2020-04-28T09:51:04.90	25.58 ± 2.51	0.42	-17008.10
2020-04-28T11:12:58.55	1.30 ± 1.41	0.06	-12094.45
2020-04-28T12:54:02.20	0.87 ± 1.09	0.40	-6030.80
2020-04-28T14:20:52.50	2.93 ± 1.17	0.60	-820.50
2020-04-28T14:20:57.90	2.06 ± 2.45	0.06	-815.10
2020-04-28T14:34:24.00	63.68 ± 6.62	0.53	-9.00
2020-04-28T17:15:26.25	0.25 ± 0.42	0.08	9653.25
2020-04-28T19:01:59.85	3.01 ± 1.22	0.16	16046.85



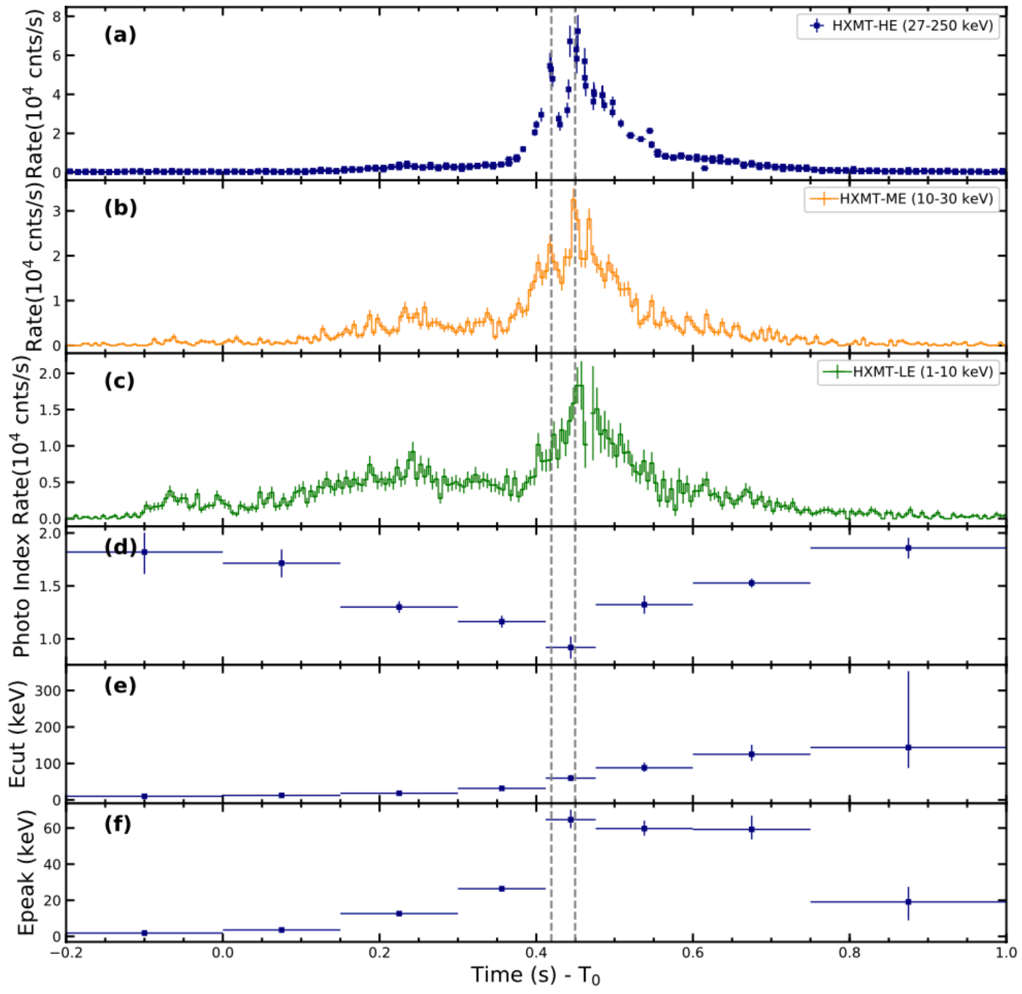
Li et al. arXiv:2005.11071

The hard X-ray burst – FRB200428

The radio LC (CHIME)v.s. the X-ray LC (HXMT)

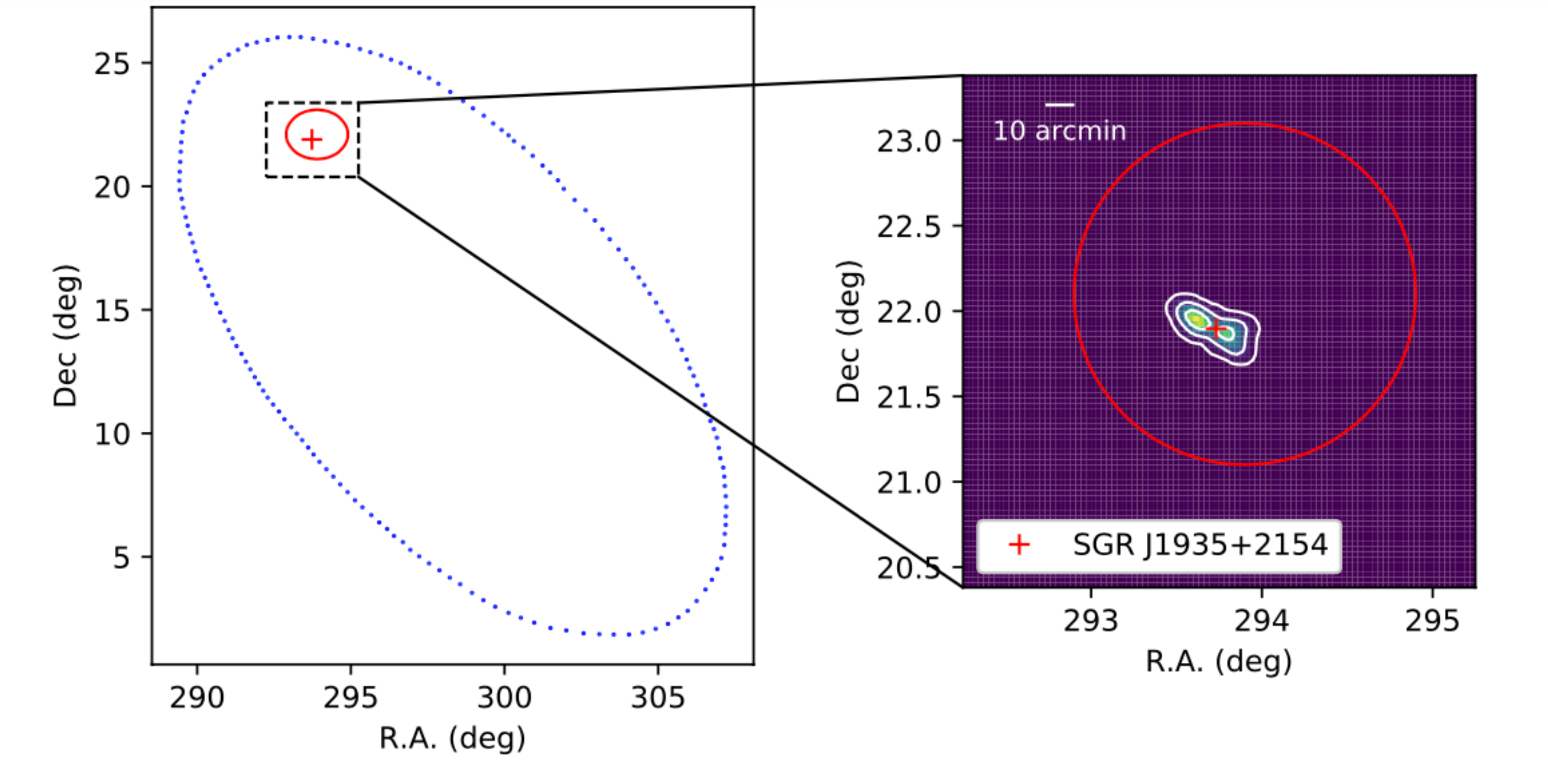
- Two short spikes, separated by ~30ms
- The time difference between radio and X-ray is ~8.62s， agree with the DM prediction.

These two spikes are the key evidence of the association between FRB and the hard X-ray burst.



Li et al. arXiv:2005.11071

The hard X-ray burst – FRB200428



The burst location using HXMT data is 3.7 arcmin away from SGR J1935+2154, with 1σ uncertainty of 10 arcmin.
This agrees with the Integral result.

Li et al. arXiv:2005.11071

The hard X-ray burst –

Non-thermal: cutoffPL

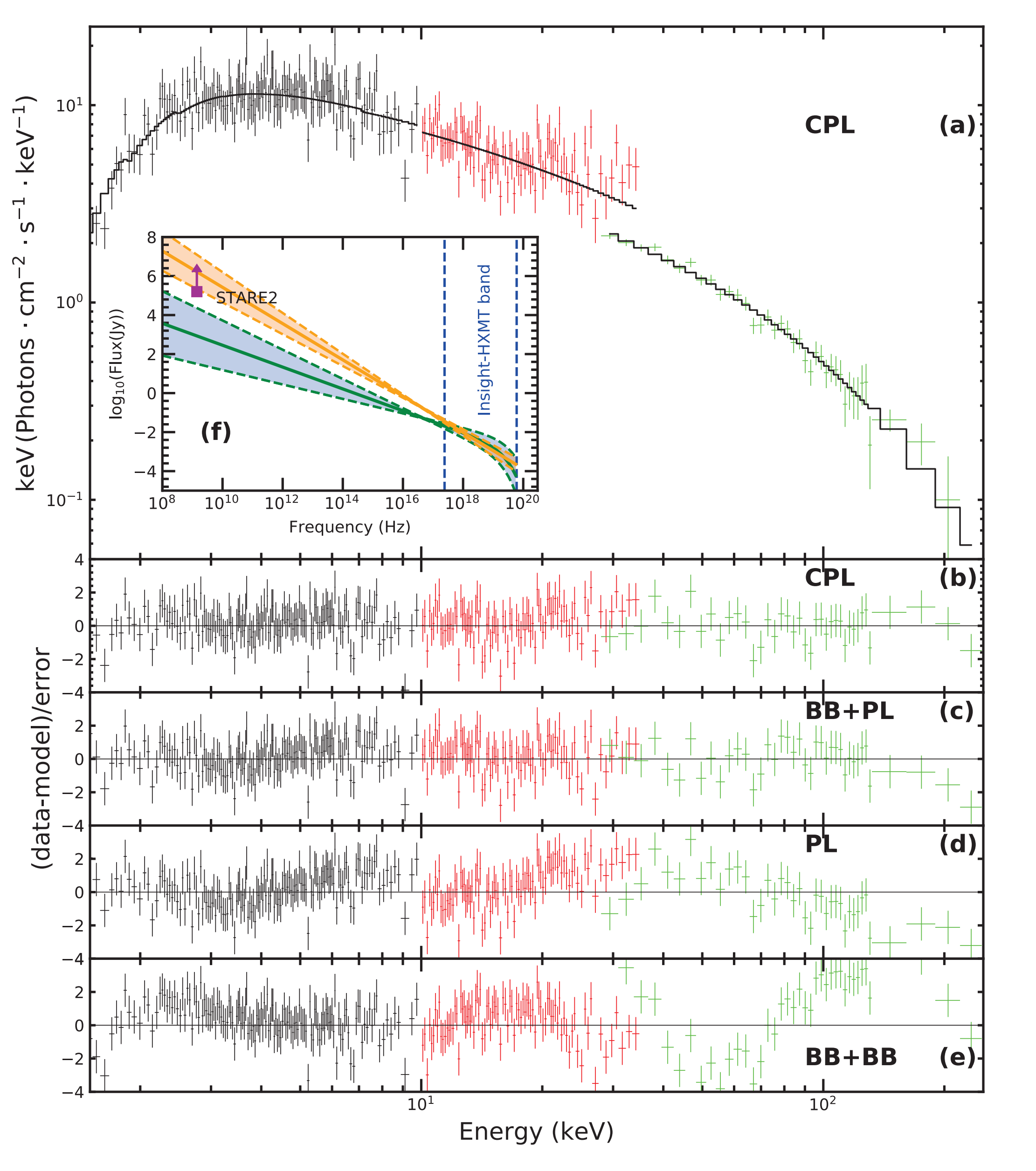
$$n_{\rm H} = (2.79^{+0.18}_{-0.17}) \times 10^{22}\ {\rm cm}^{-2}$$

Photon index $= 1.56 \pm 0.06$

$E_{\rm cut} = 83.89^{+9.08}_{-7.55}$ keV $\quad E_{\rm peak} \sim 37$ keV

The unabsorbed fluence is $(7.14^{+0.41}_{-0.38}) \times 10^{-7}$ erg cm^{-2}

Such an X-ray burst is non-detectable if placed at a normal FRB distance.

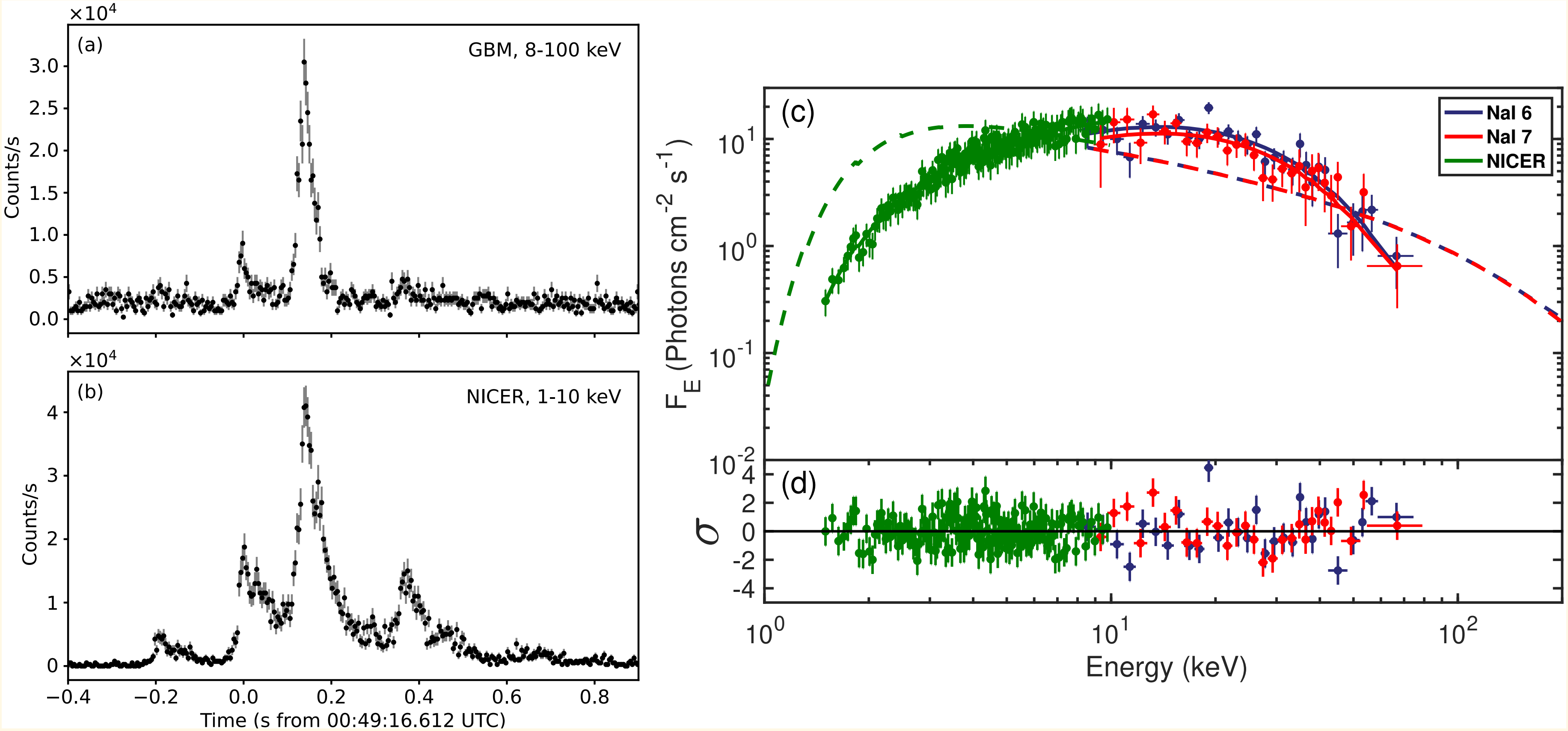


Li et al. arXiv:2005.11071

The hard X-ray burst – FRB200428

This burst is spectrally different.

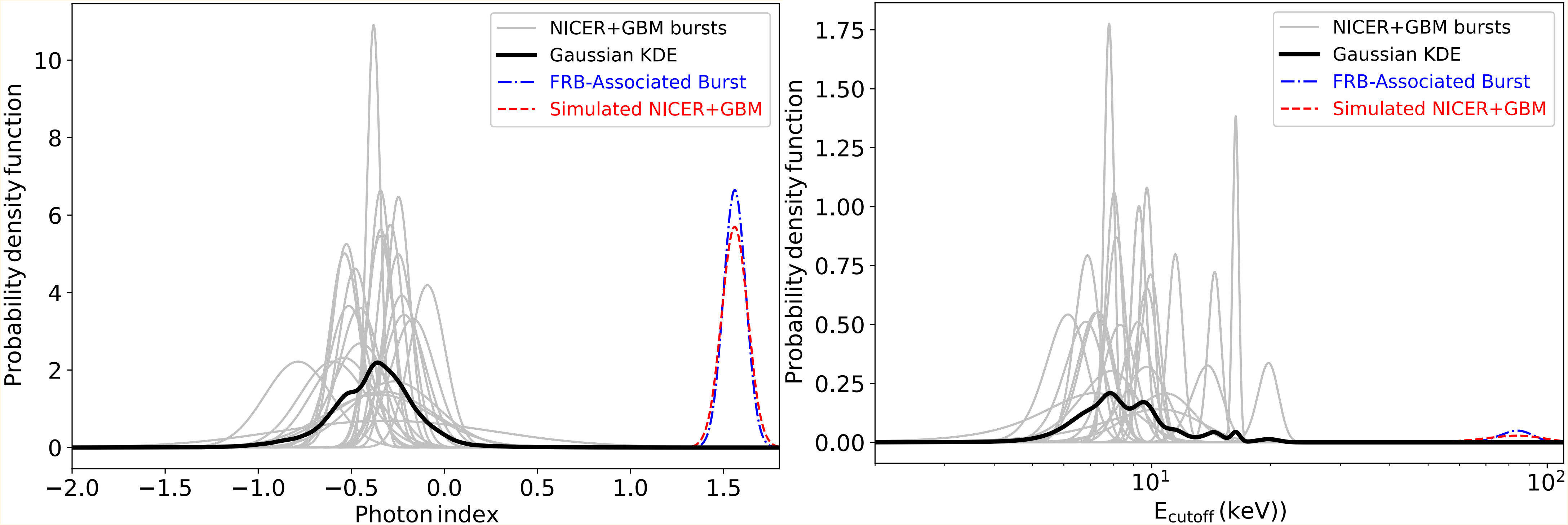
24 bursts observed with NICER-GBM



Younes et al. arXiv:2006.11358

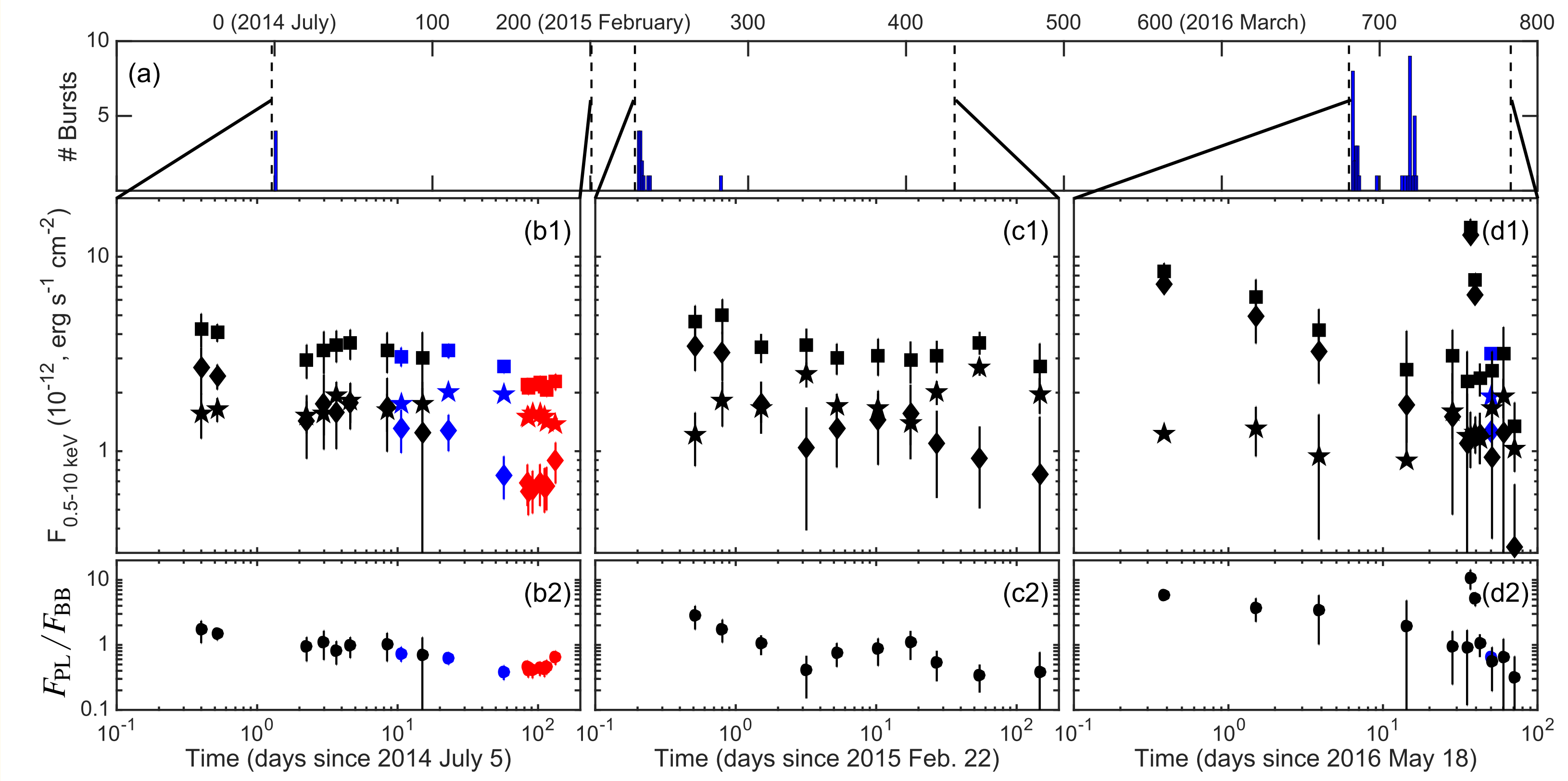
The hard X-ray burst – FRB200428

This burst is spectrally different.



Younes et al. arXiv:2006.11358

SGR J1935+2154: outbursts

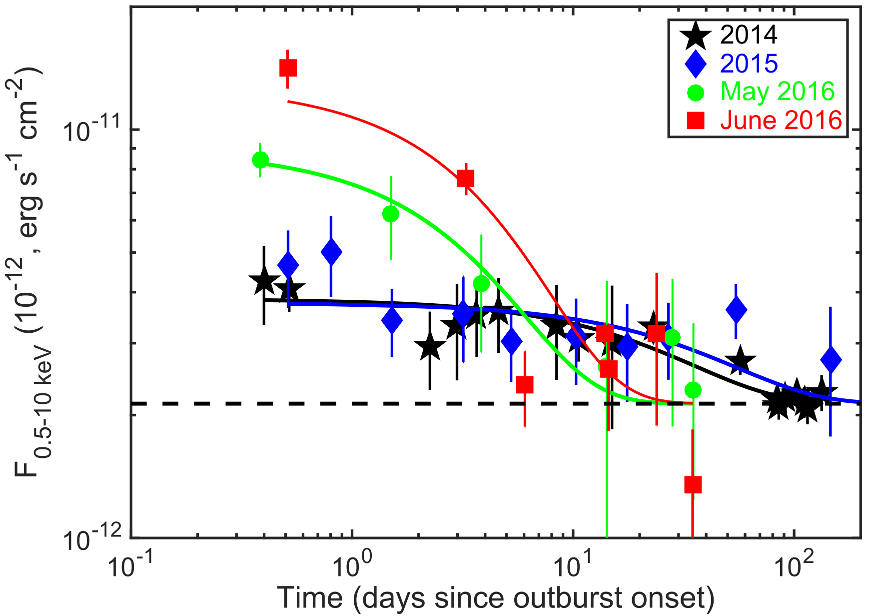


Swift/XRT, Chandra and XMM-Newton

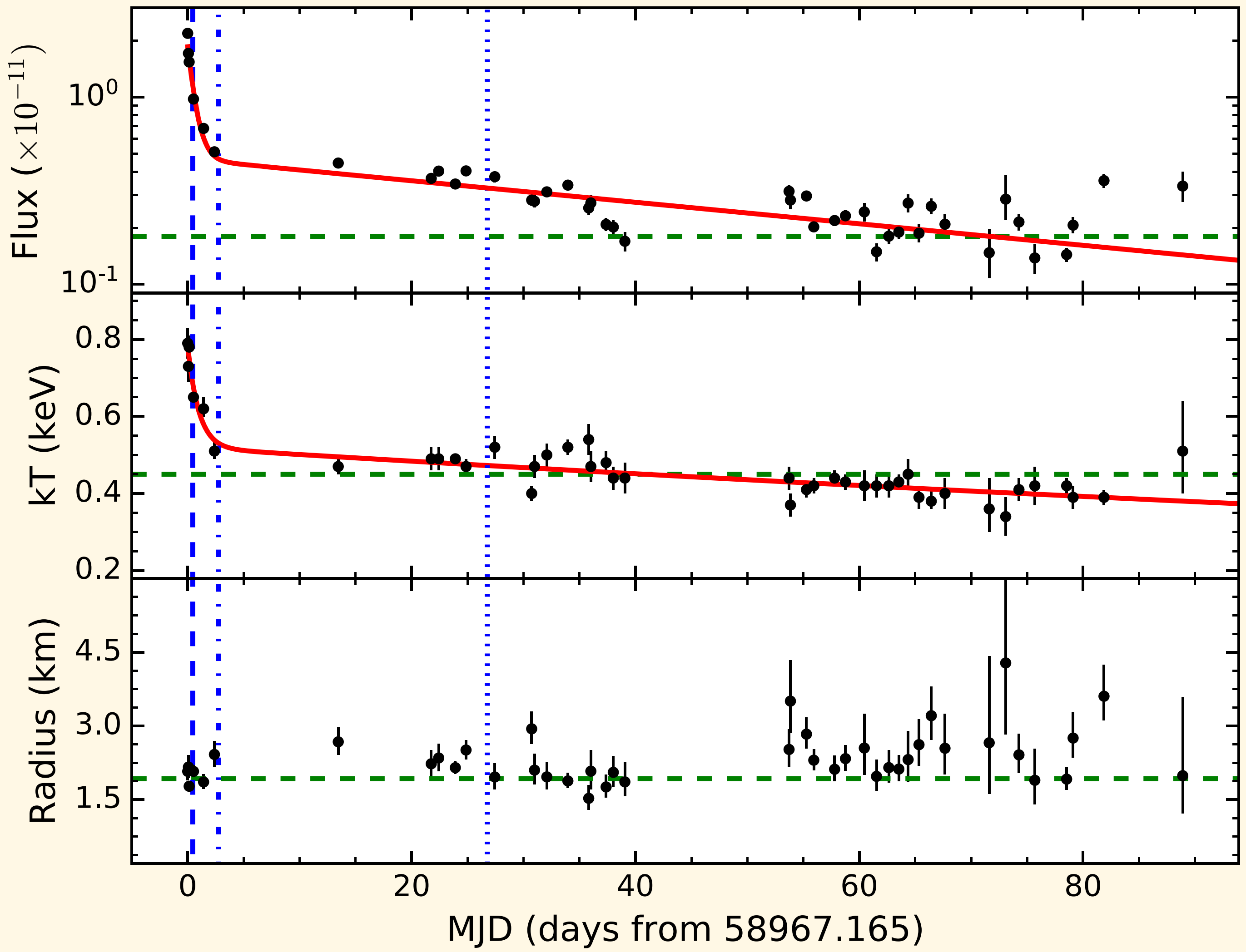
Younes et al. 2017

Outbursts in 2014-2016:

- Flux increase accompanied by hardening of spectra
- Flux increase ∝ total burst energy
- Decay slower in 2014-2015; faster in 2016



SGR J1935+2154: outbursts



Outbursts in 2020:

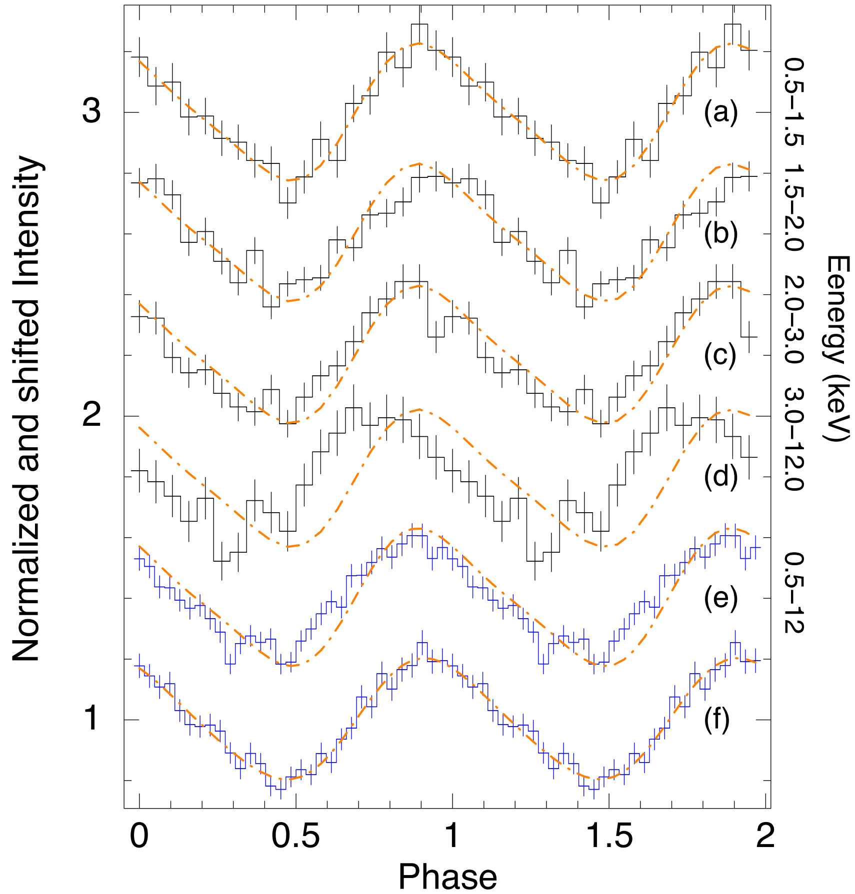
- Flux increase accompanied by hardening of spectra
- Flux increase ~10 times ∝ total burst energy
- Two decay trends ~0.65 day, ~75 day

- The spin-down rate is ~2.7 times larger than that measured in 2014
- The pulse profile changed

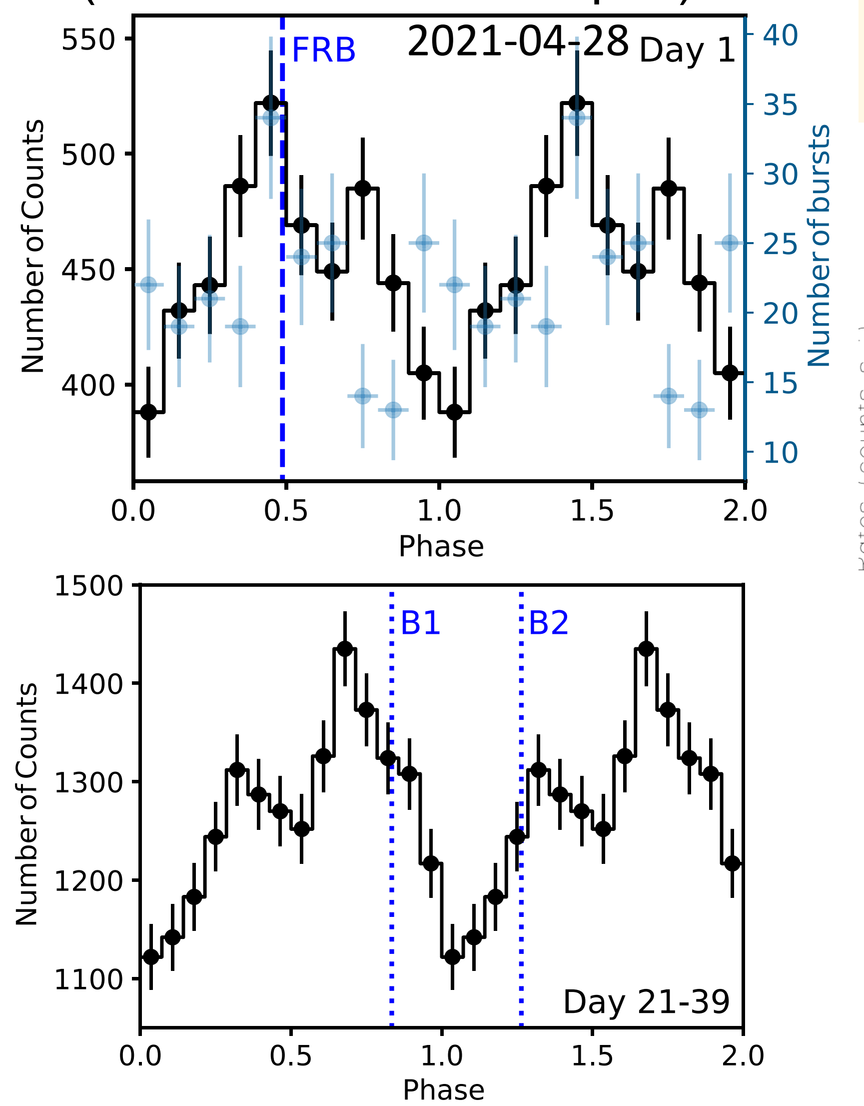
Younes et al. 2020 ApJL

SGR J1935+2154: outbursts

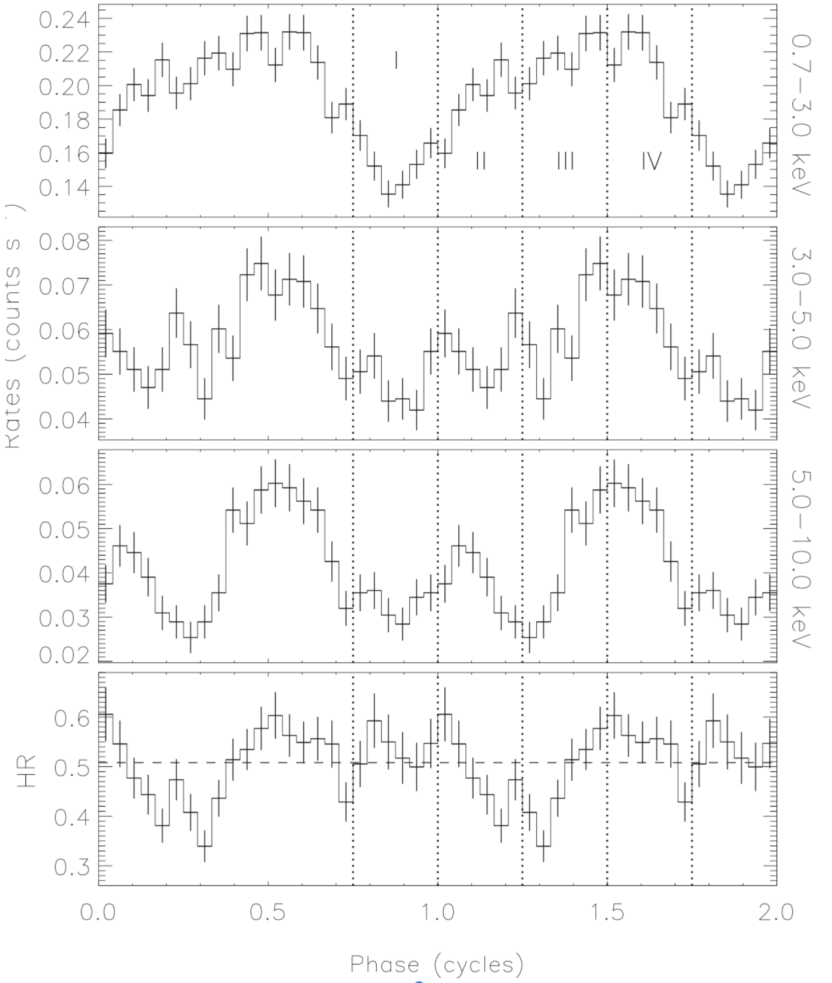
2014 outburst (Israel et al. 2016)



2020 outburst 1.5-5 keV
(Younes et al. 2020 ApJL)



2020 outburst @May 13-14
or Day 16-17
(Gogus et al. 2020 ApJL)

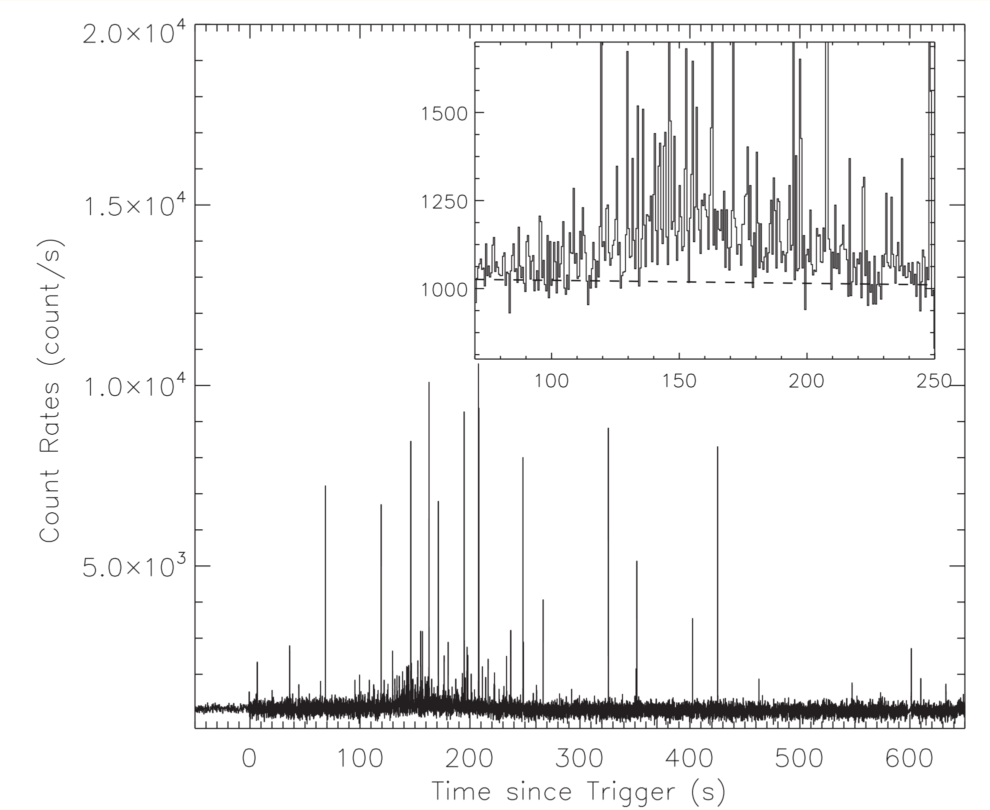


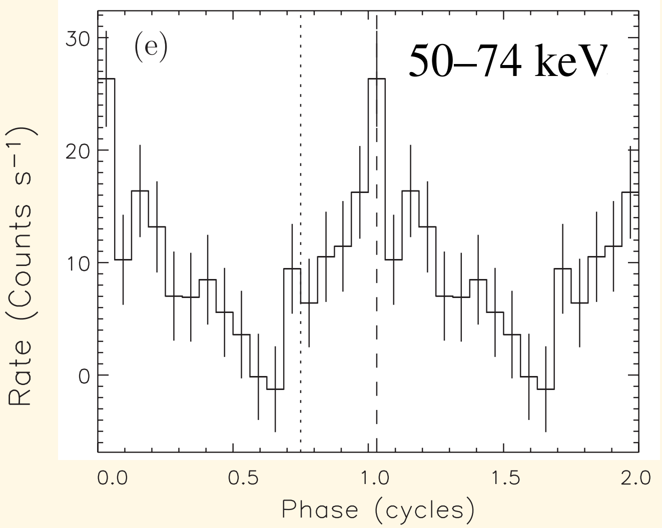
Prolific transients

- SGR J1550-5418
    - 3 active episodes in 2008-2009
    - Burst forest on Jan. 22, 2009
- SGR J1935+2154
    - 6 active episodes in 2014-2020
    - Burst forest on Apr. 27, 2020”

✓hundreds of bursts in several minutes

✓Enhanced hard X-ray persistent emission in GBM





SGR 1550-5418
Kaneko et al. 2010

Prolific transients

✓Burst spectral properties evolve

- SGR J1550-5418
  - The bursts in 2008 only need only one BB (von Kienlin et al. 2012)
  - The bursts in 2009 require BB+BB (Israel et al. 2008, van der Horst et al. 2009, Lin et al. 2012)
- SGR J1935+2154
  - Bursts are slightly softer in later episodes.

Prolific transients

✓Based on STEMS model, the surface magnetic field may change.

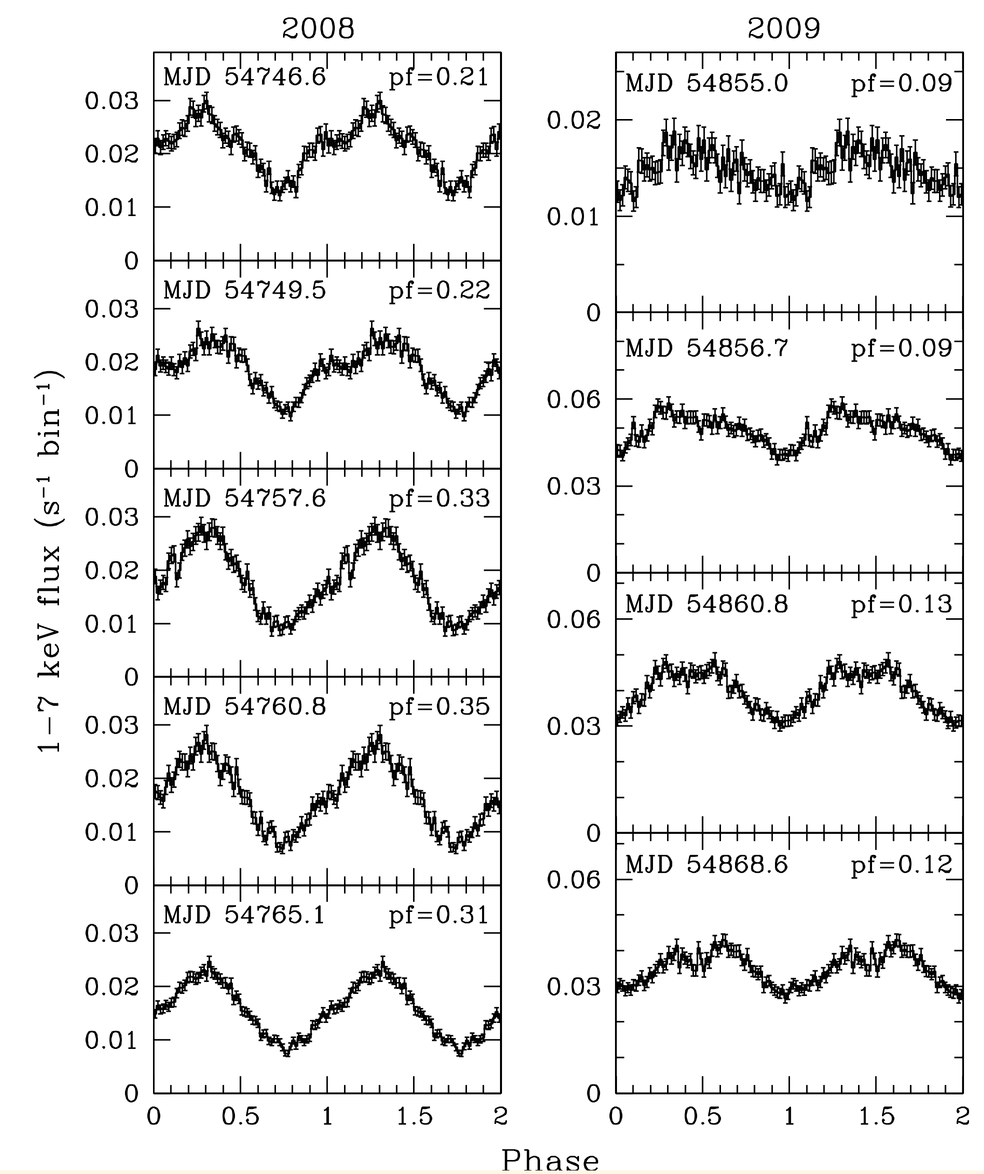
$$B_{surf} > B_{dip}$$

(Ng et al. 2010, Gogus et al. 2020)

✓X-ray pulse profile

- Pulse profile may change
- Pulse fraction reduced

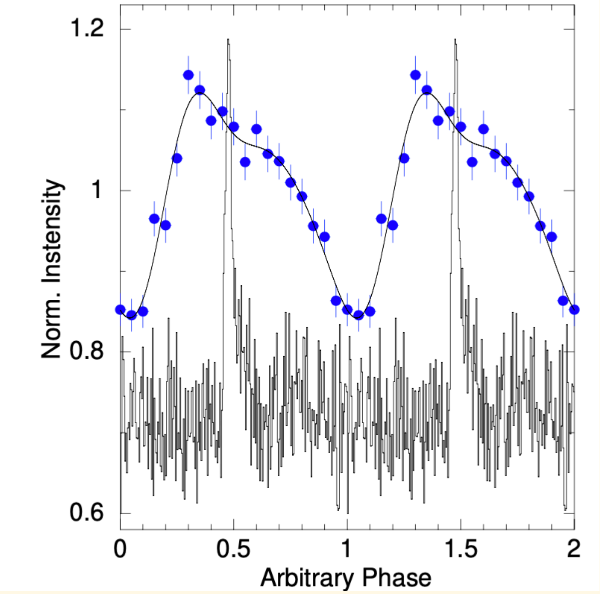
(Ng et al. 2010, Younes et al. 2020 submitted, Gogus et al. 2020 submitted)



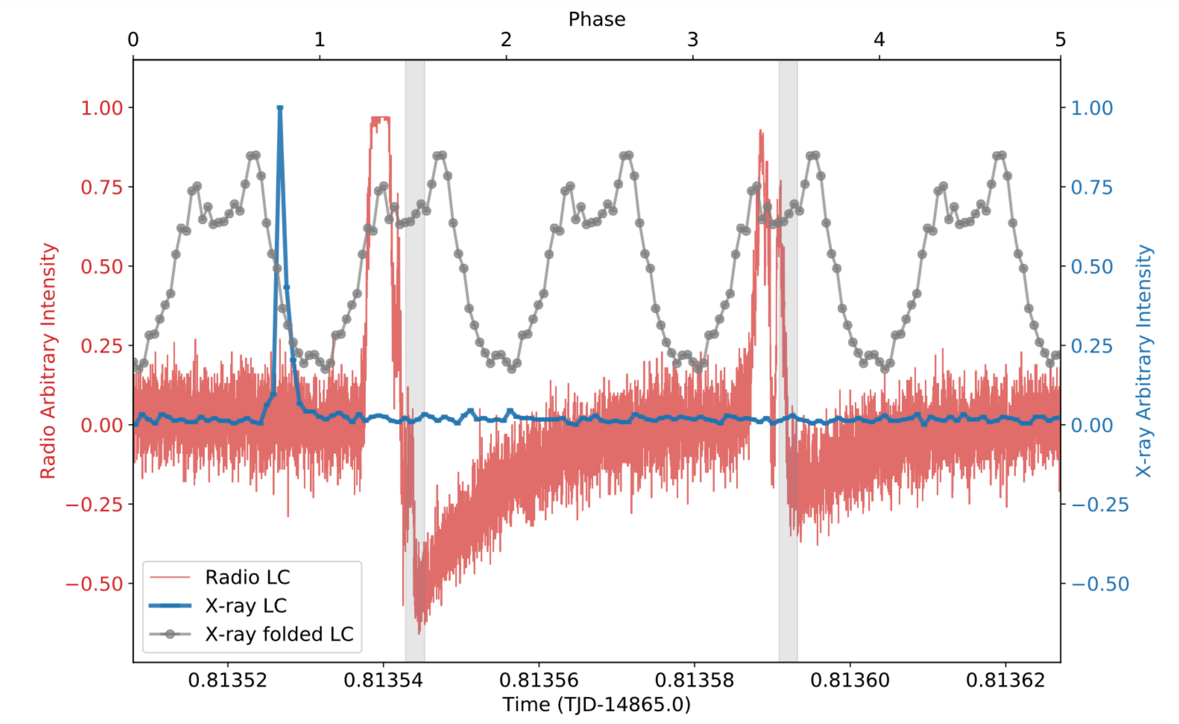
SGR 1550-5418
Ng et al. 2010

Prolific transients

Bright radio pulses from SGR J1550-5418 covered by X-ray observations



- 2019-02-03, ~5 days after the peak of the burst forest
- The radio pulse highly saturated the Parkes.
- The 6 GHz radio flux >1Jy, pulse width ~200 ms
- An X-ray burst was detected ~1 s ahead of one radio pulse



Israel et al. 2020

Summary and questions

- In general, magnetars are sources full of surprises.
- Bursts and outbursts
  - Trigger and emission mechanisms
  - Physical properties of magnetar
- SGR1935+2154: the most active prolific transient
- Magnetars with burst forest are the seeded players (to me)