Highly-magnetized neutron stars as one of the potential origins of FRBs

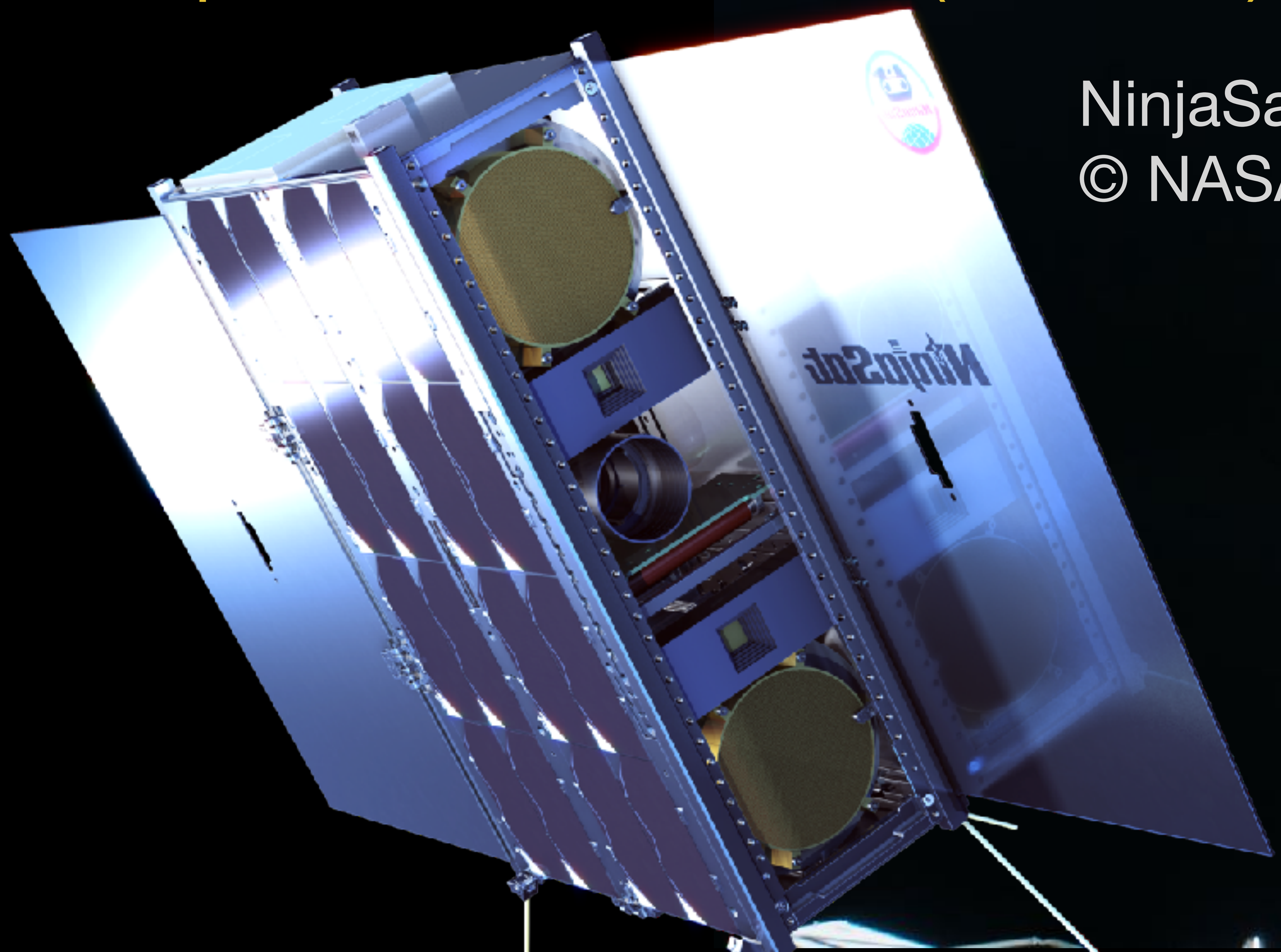
Teruaki Enoto

(RIKEN, Extreme natural phenomena RIKEN Hakubi team)

9:30-10:10 JST, February 12, 2021

YITP & YIPOS workshop “Fast Radio Bursts: A Mystery Being Solved?”, Kyoto University

- X-ray astronomer of neutron stars. Launched a new research group at RIKEN in January, 2020 (8 members).
- A chair of the Magnetar and Magnetosphere working group of the NICER X-ray observatory.
- We are planning to launch a 6U-size CubeSat X-ray observatory “NinjaSat” in 2022.
- Spin-off research for high-energy atmospheric physics of lightning (photonuclear reactions) and thunderstorms.
- Open for RIKEN SPDR (基礎特研) fellows.



NinjaSat
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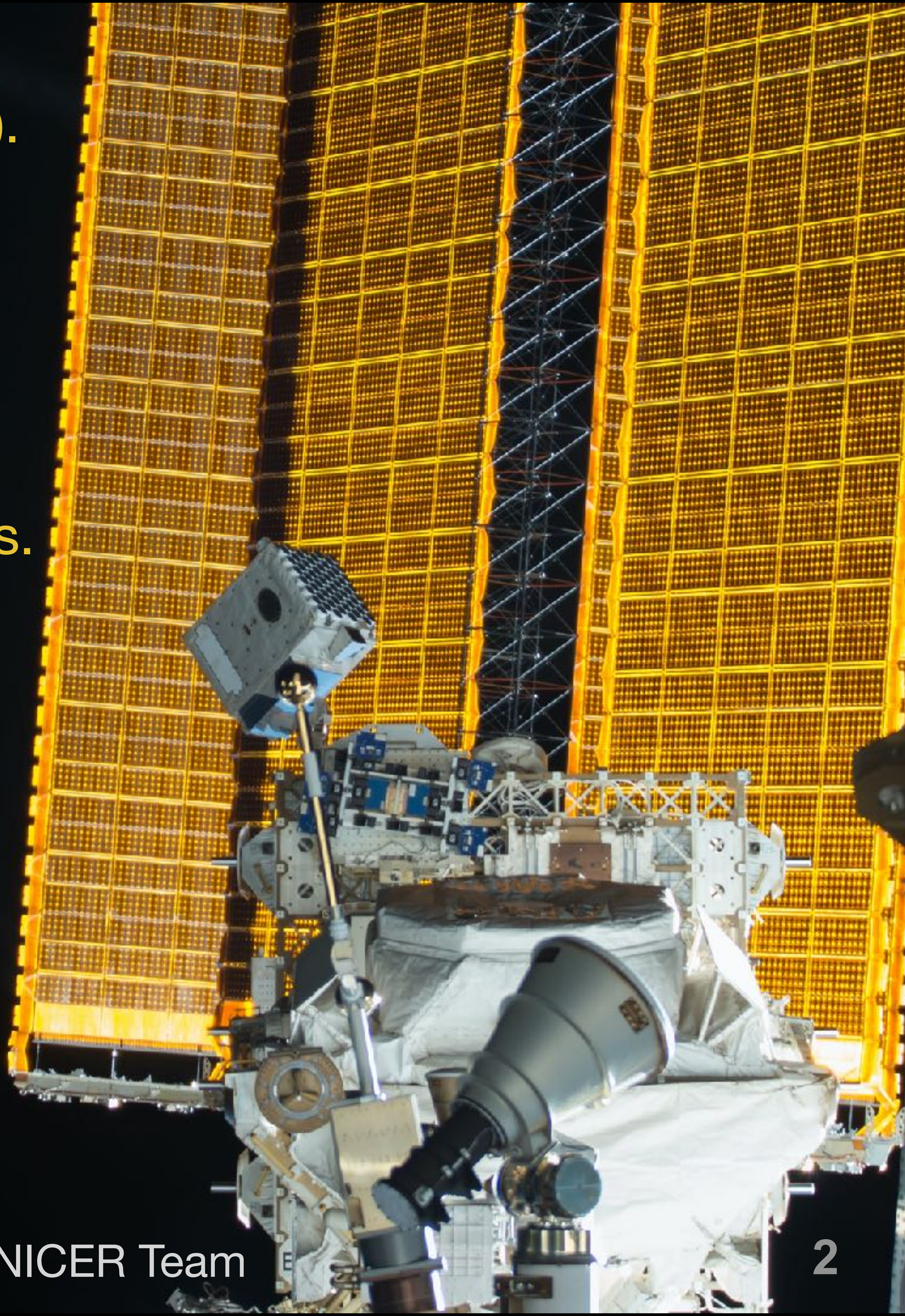

NICER
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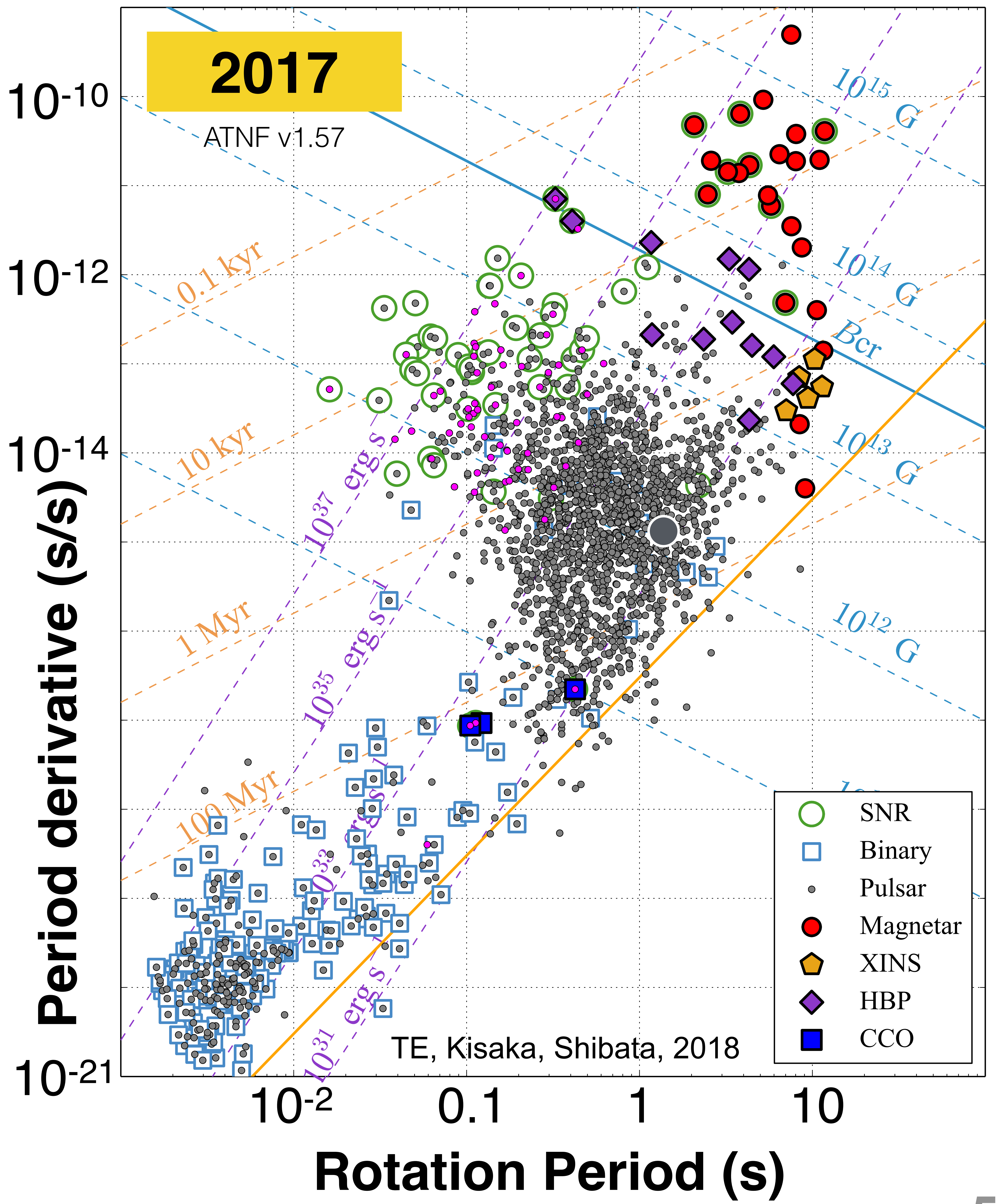
Contents

FRB observations → Highly magnetized NS?

- 2007 **Lorimer burst in 2001 was reported** (Lorimer et al., Science, 2007)
- 2013 **Further 4 FRBs reported from the Parkes** (Thronton et al., Science, 2013)
- 2015 **FRBs were discriminated from “Peyton”** (Petroff et al., MNRAS, 2015)
- 2016 **Repeating FRB 121102 was discovered** (Spitler et al., Nature, 2016)
- 2016 **Bright FRB 150827 with polarization detection** (Ravi et al., Science, 2016)
- 2017 **Host galaxy of FRB 121102 was identified** (Chatterjee et al., Nature, 2017) +2
- 2018 **DM-brightness of two populations?** (Shannon et al., Nature 2018)
- 2019 **The second repeating FRB was found** (CHIME/FRB collaboration, Nature, 2019)
- 2019 **Host galaxy of non-repeating FRB 180924 & 190523** (Bannister et al., 2019, Science; Ravi et al., Nature 2019)
- 2019 **New 8 repeating FRBs were reported** (CHIME/FRB collaboration, ApJ, 2019)
- 2020 **FRB from a Galactic magnetar SGR 1935+2154** (many papers…)
- 2020 **Periodicities detected from repeating FRBs** (CHIME/FRB collaboration+)

Diversity of neutron stars

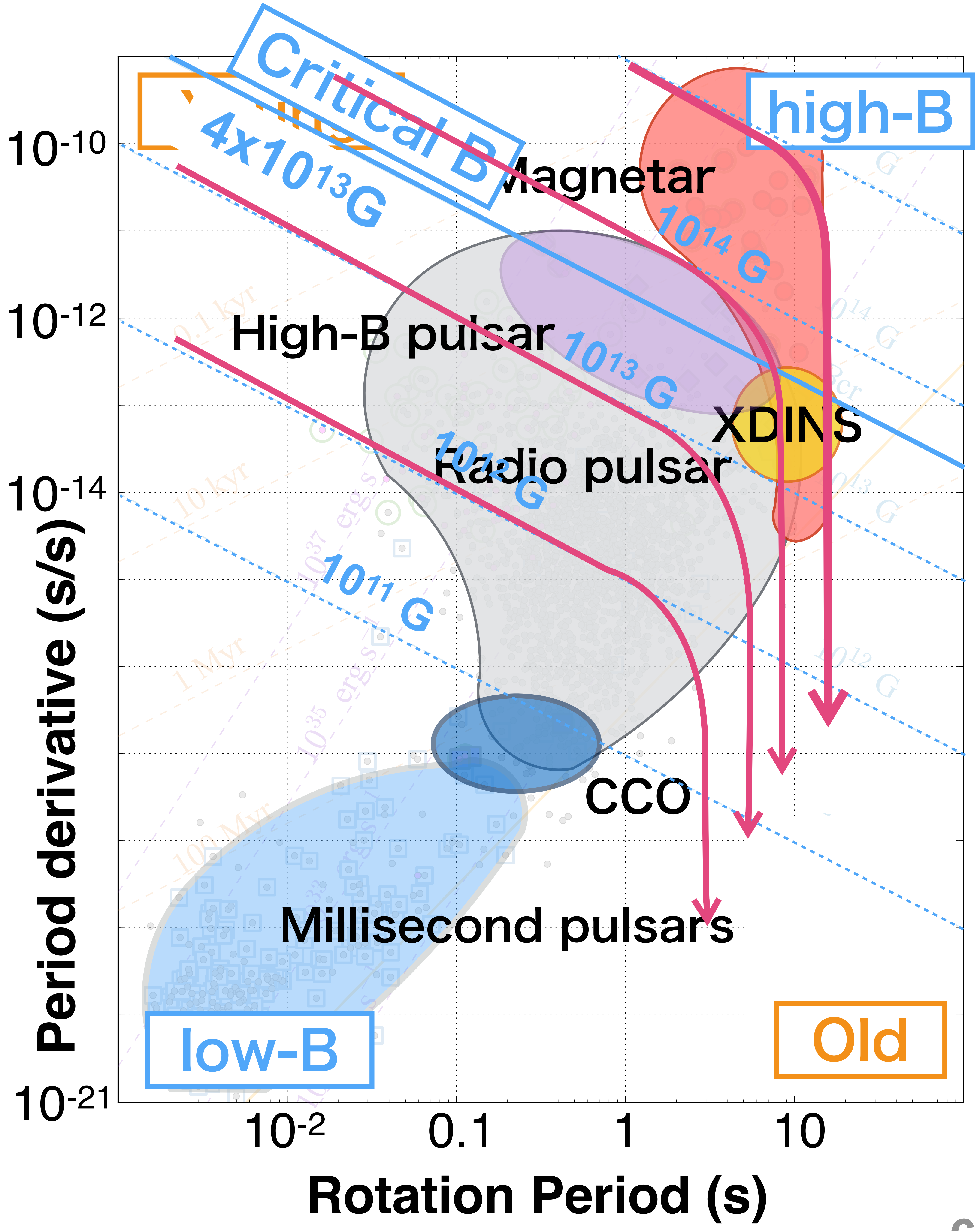
- >2,500 known pulsars
- 10^5 in our Galaxy?
- Multi-wavelength observations from radio, optical, X-rays, and gamma rays.



Diversity of neutron stars

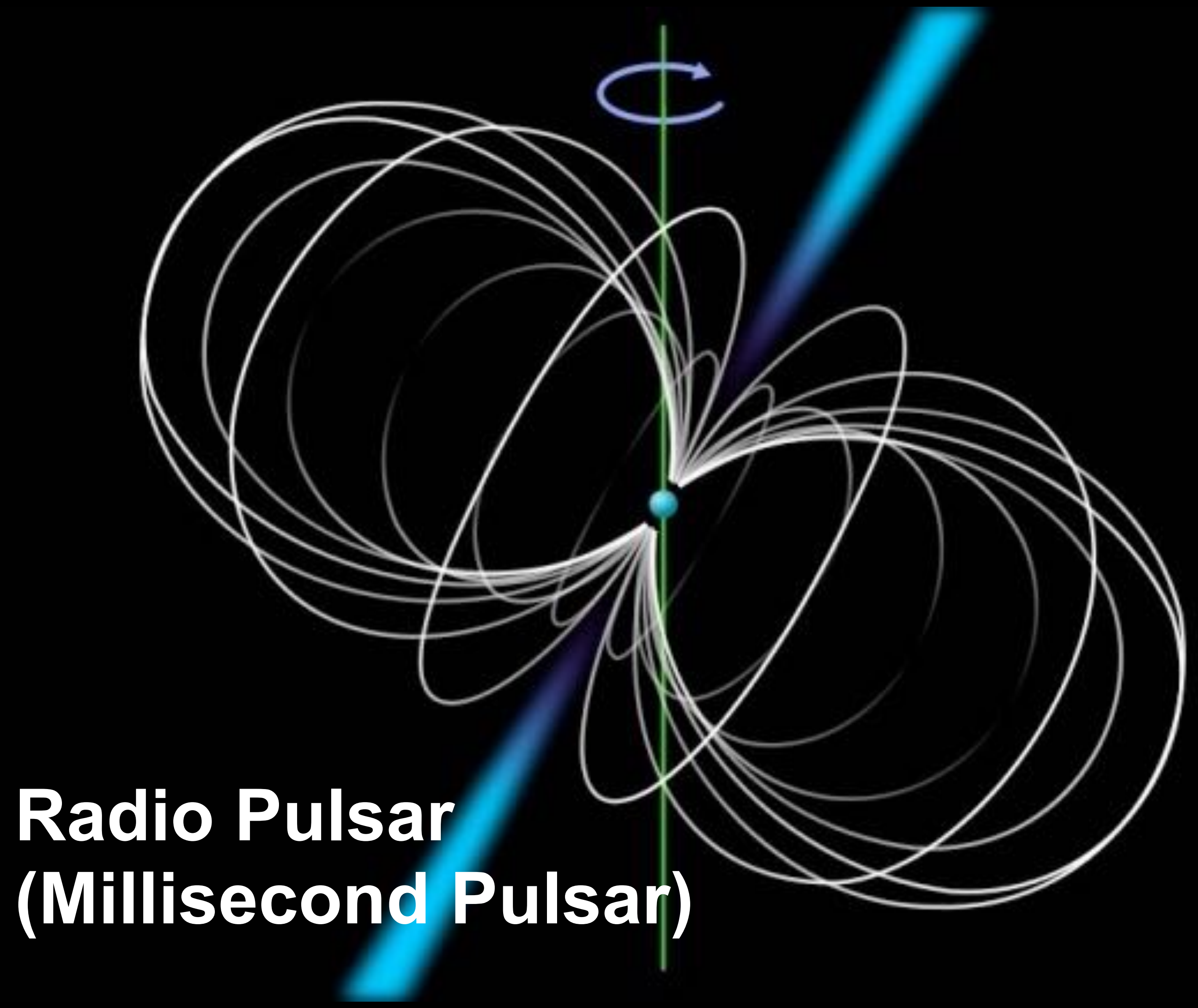
- >2,500 known pulsars
- 10^5 in our Galaxy?
- Multi-wavelength observations from radio, optical, X-rays, and gamma rays.
- Challenge to unification of different neutron star classes
- Some of FRB properties suggest young & highly magnetized neutron stars?

Which type of neutron stars or related phenomena are the origin of FRBs?

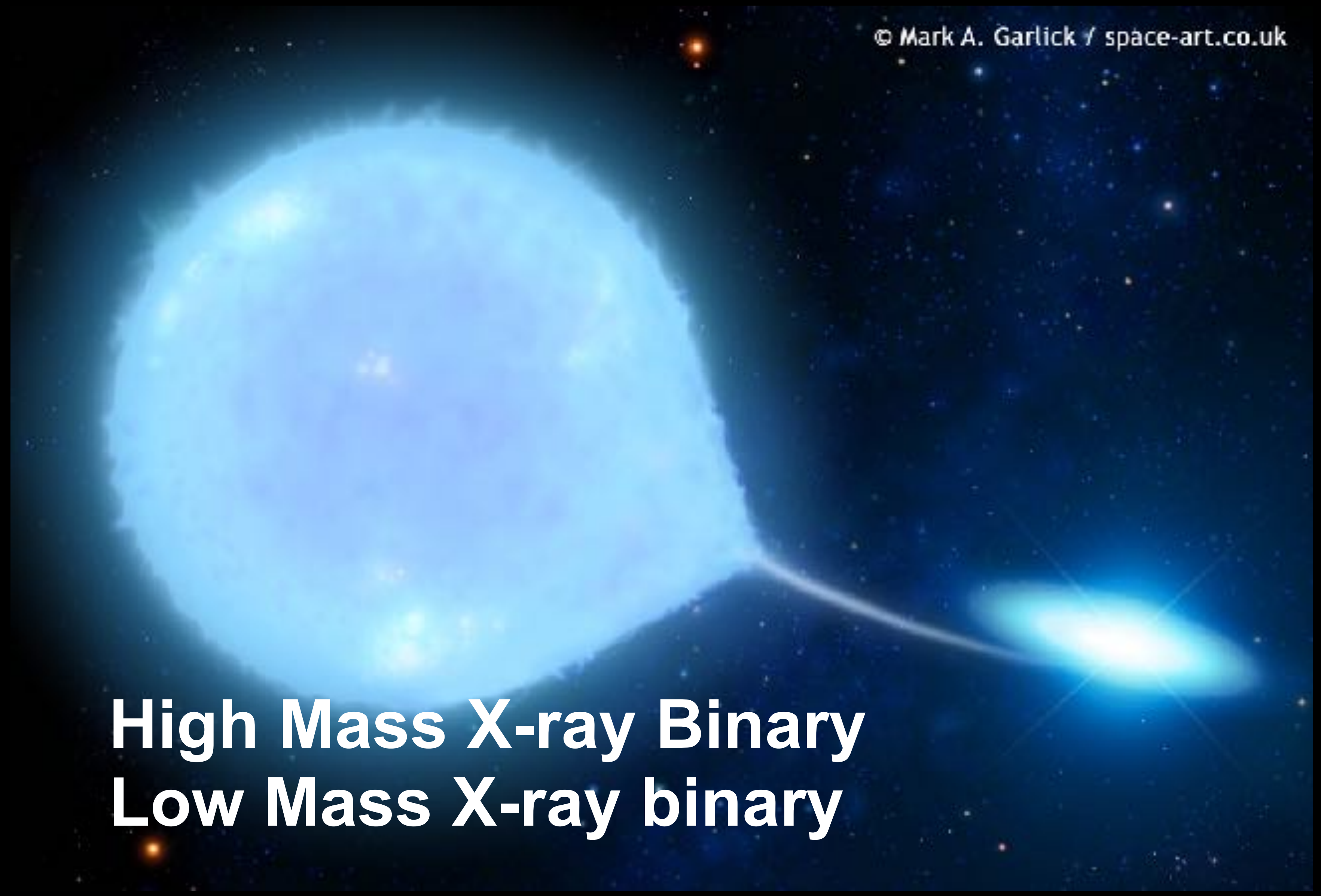


Energy sources of neutron stars

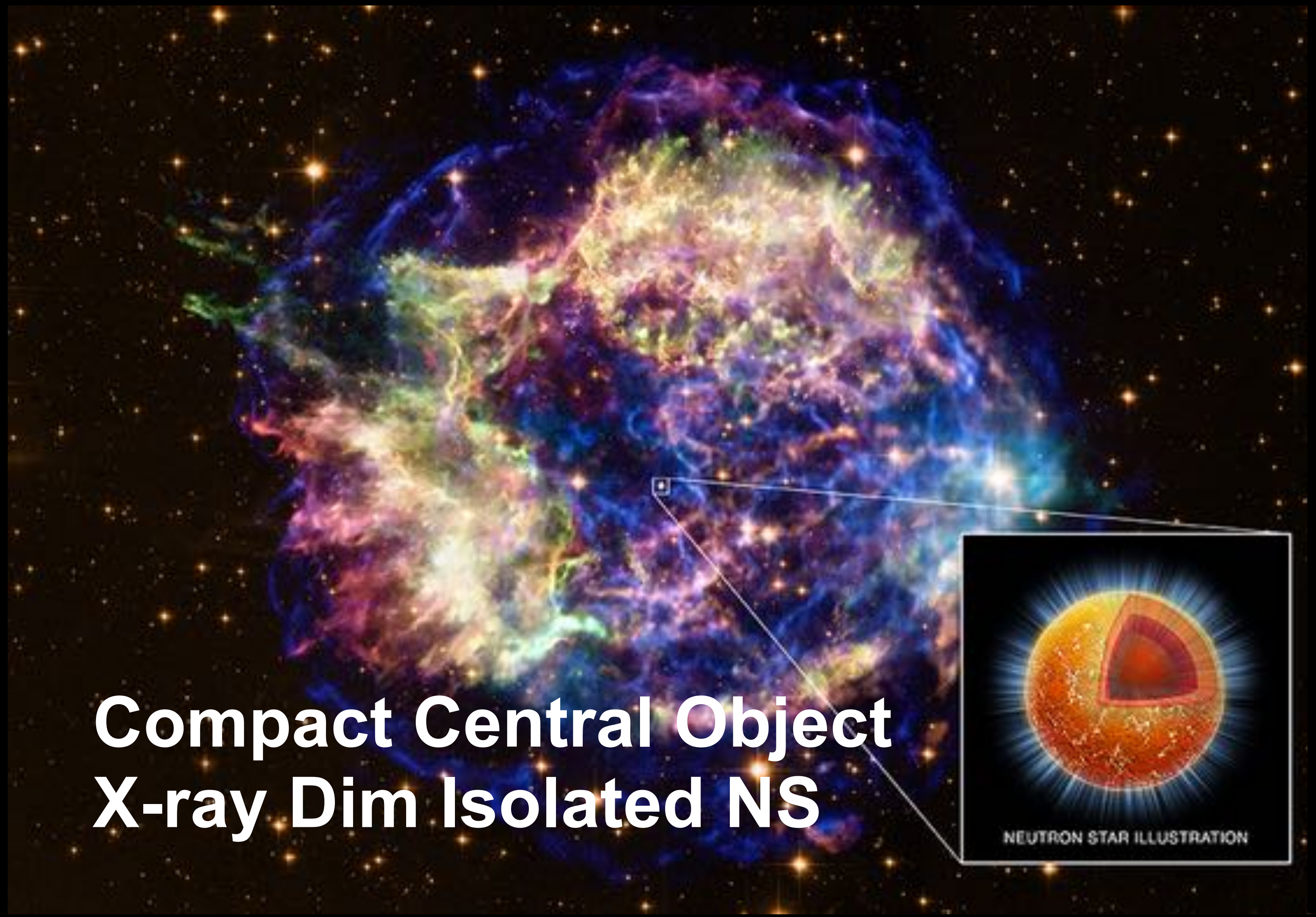
Rotation



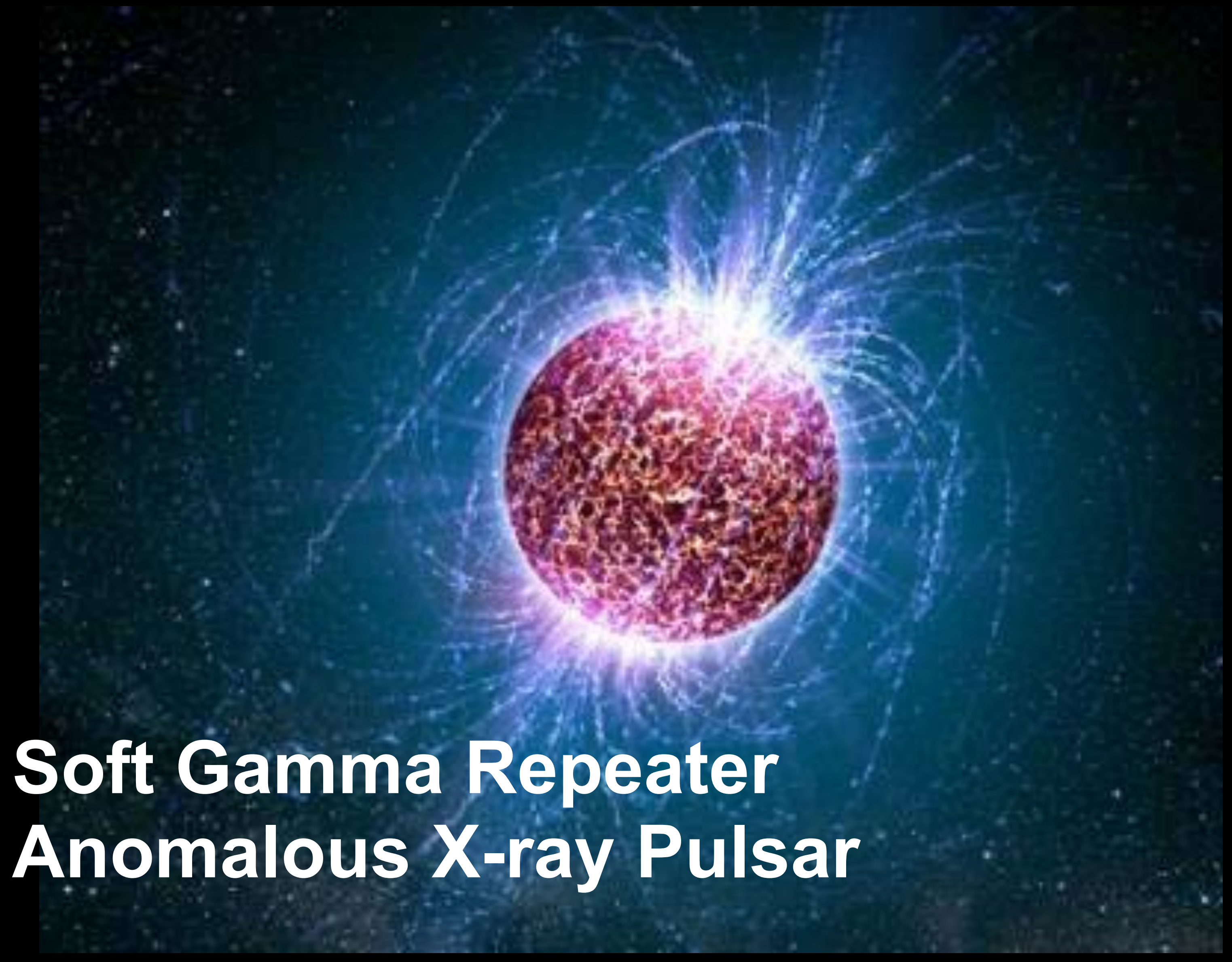
Accretion



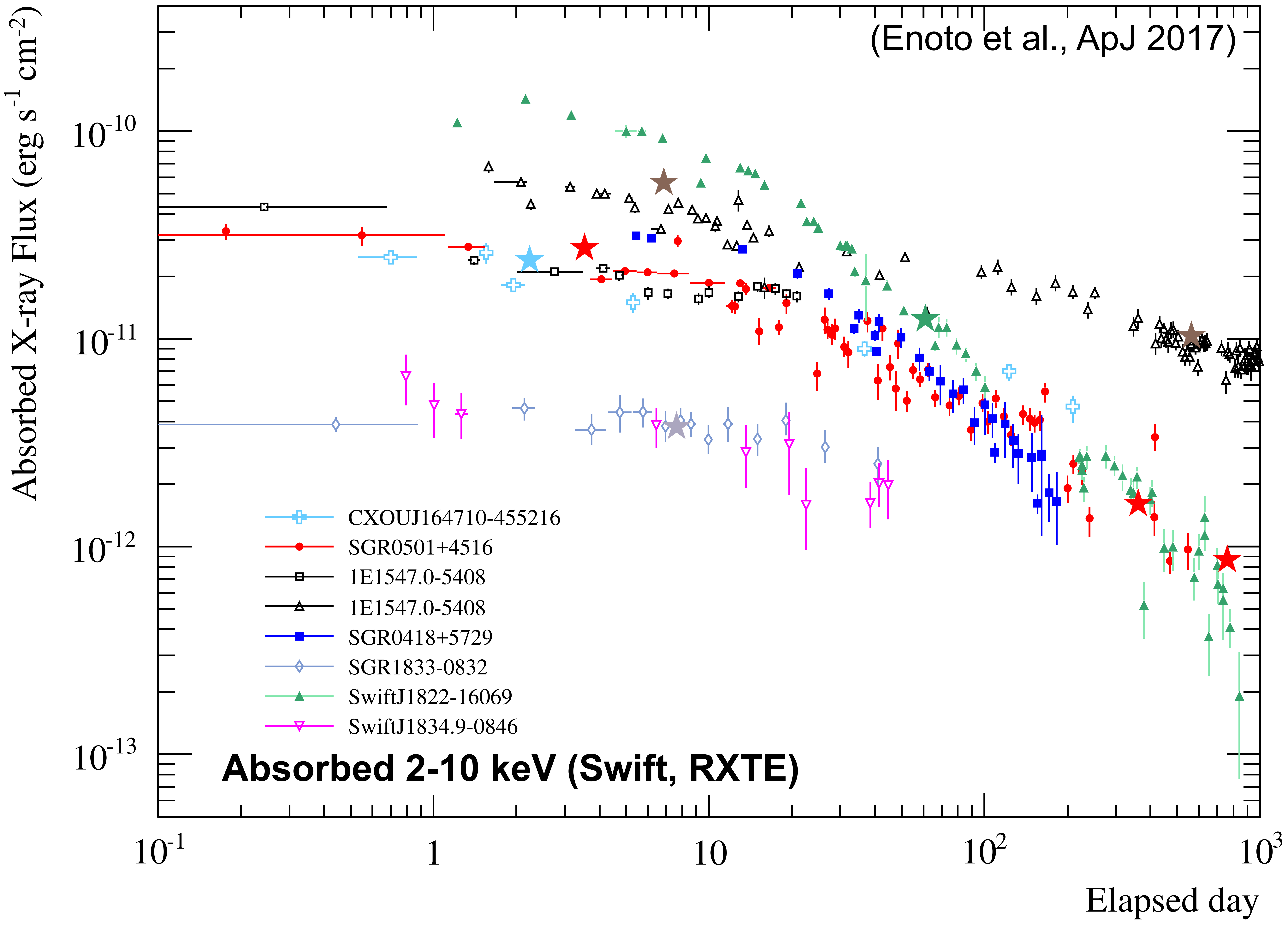
Thermal



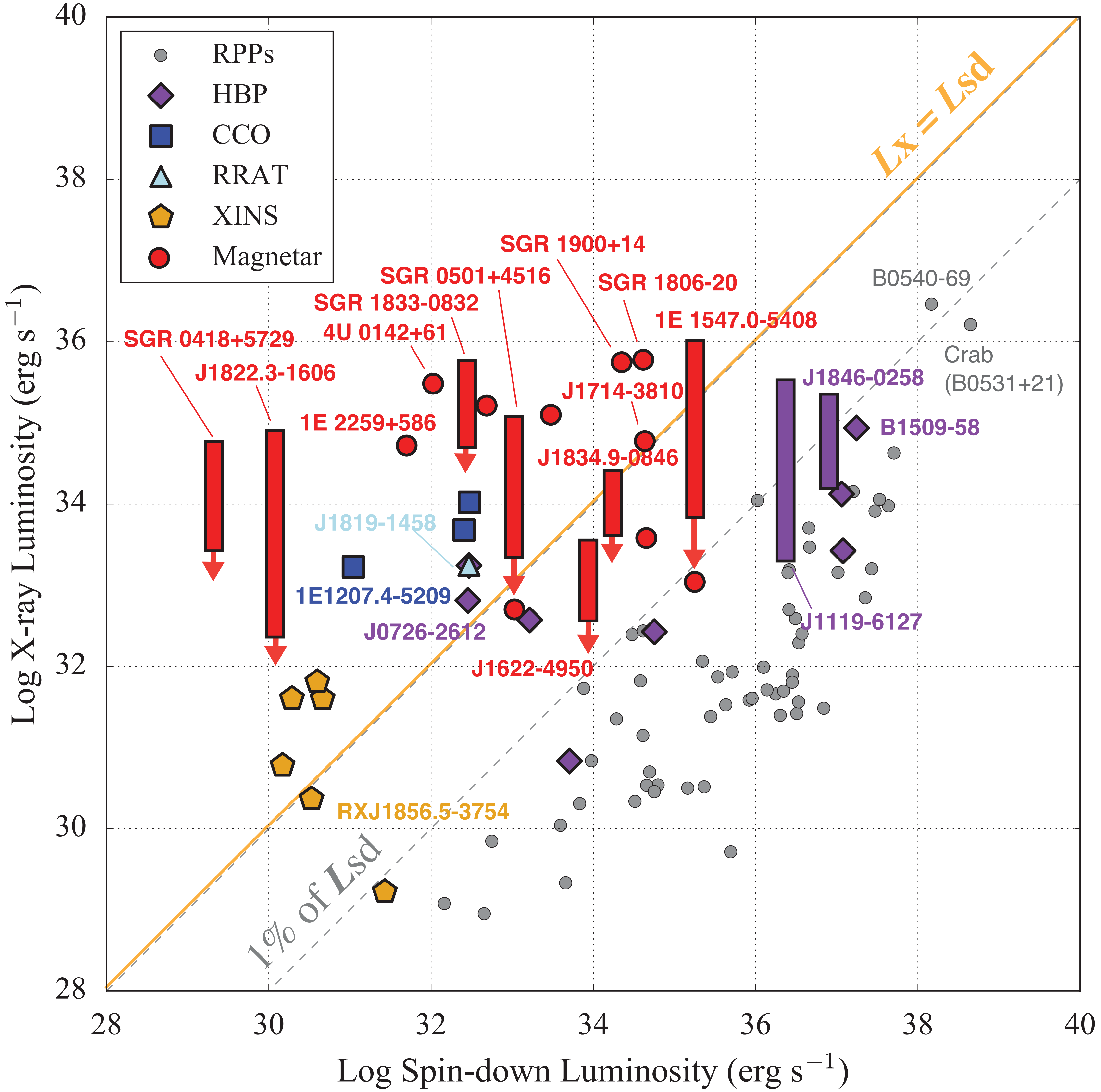
Magnetic



X-ray flux decay of outbursts of transient magnetars



Spin-down luminosity L_{sd} vs. X-ray luminosity L_x



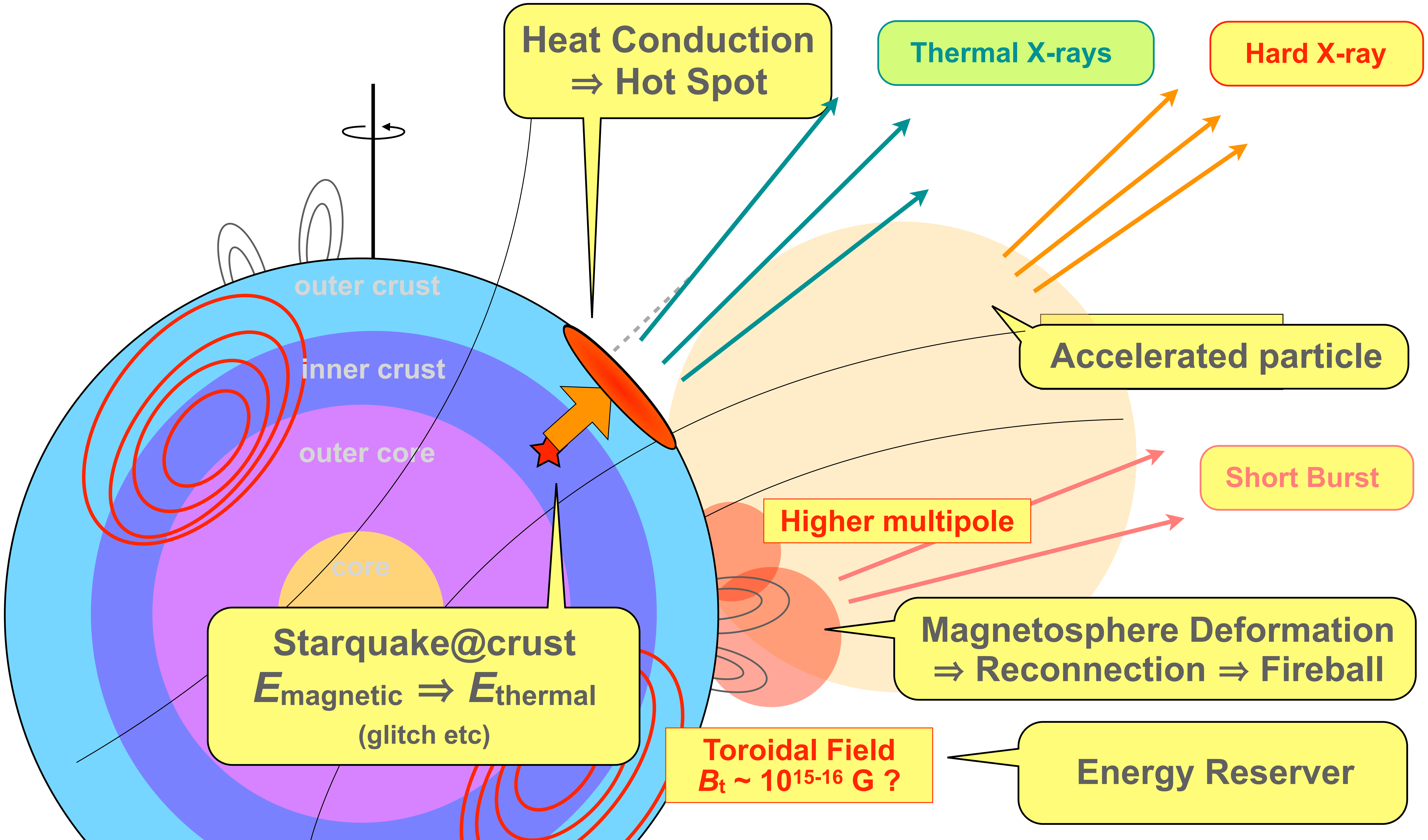
- Spin-down luminosity

$$L_{\rm sd} \propto \dot{P}/P^3$$

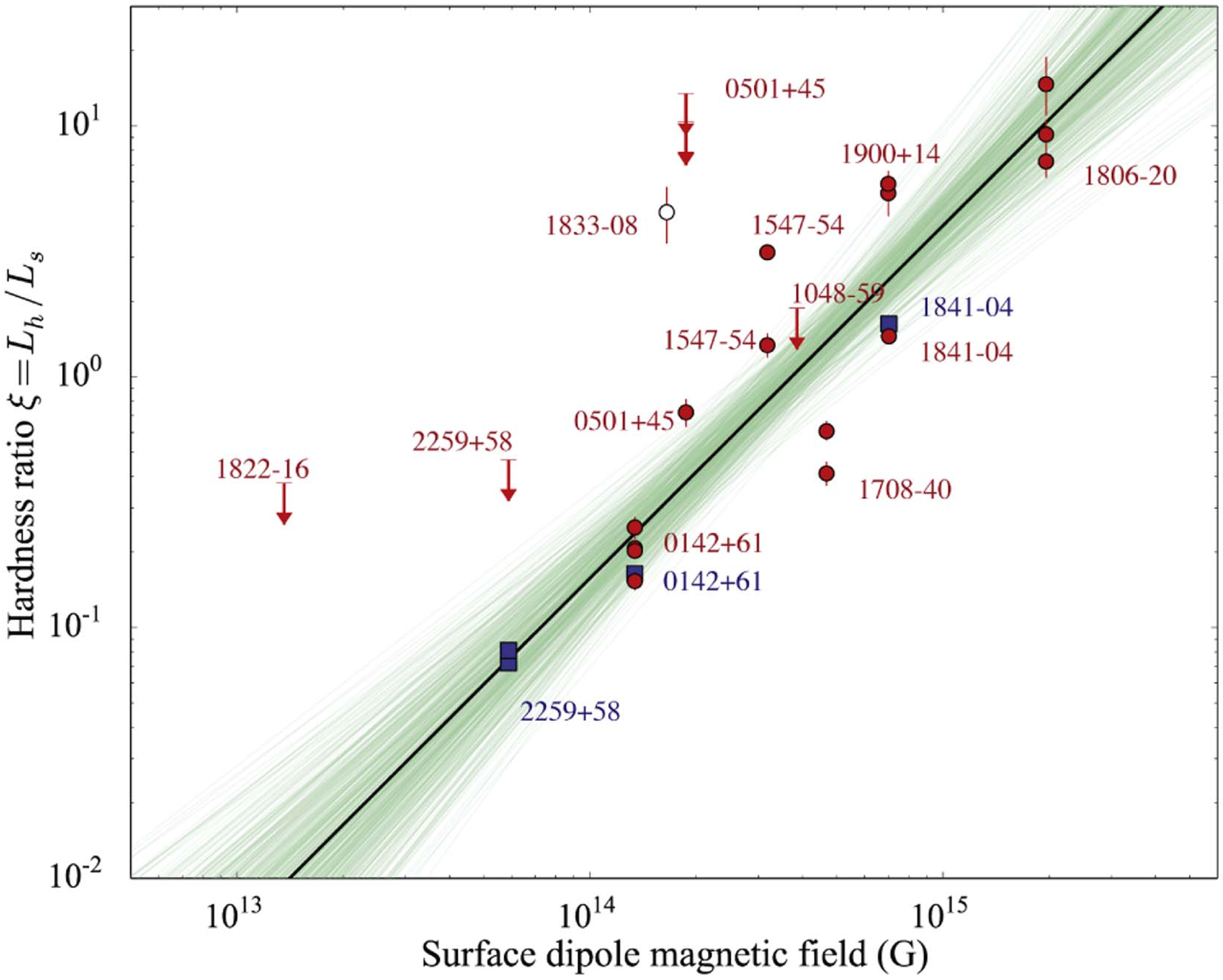
- Rotation powered pulsars: $L_x < L_{sd}$
  - c.f., Eddington luminosity ~10^{38} erg/s
- Persistent magnetars: L_x >~ L_{sd}
- Transient magnetars: $L_x \rightarrow <L_{sd}$
- Possibility that many neutron stars can exhibit magnetar-like outbursts?

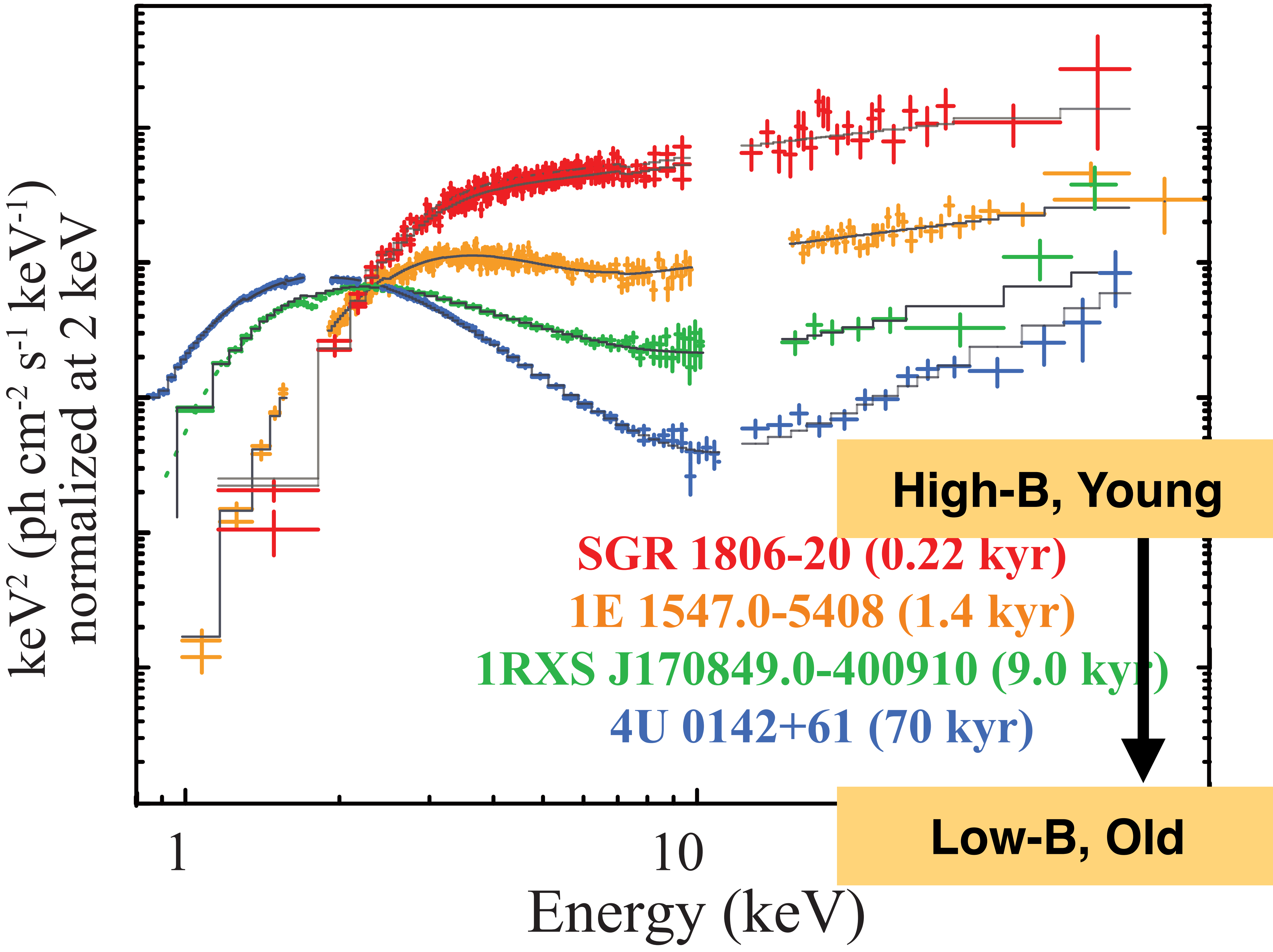
(Review) Enoto, Kisaka, and Shibata, ROPP (2019)
https://iopscience.iop.org/article/10.1088/1361-6633/ab3def

X-ray outburst of magnetars



Magnetar spectral evolution with B-field?





$$\xi = L_{\rm h}/L_{\rm s} = (0.045^{+0.024}_{-0.016}) \times (B_{\rm d}/B_{\rm QED})^{1.44\pm0.19}$$

Enoto et al., ApJL 2010
Enoto et al., ApJS 2017

IOP Publishing

Reports on Progress in Physics

Rep. Prog. Phys. **82** (2019) 106901 (54pp)

https://doi.org/10.1088/1361-6633/ab3def

Review

Observational diversity of magnetized neutron stars

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Corresponding Editor Professor Gordon Baym

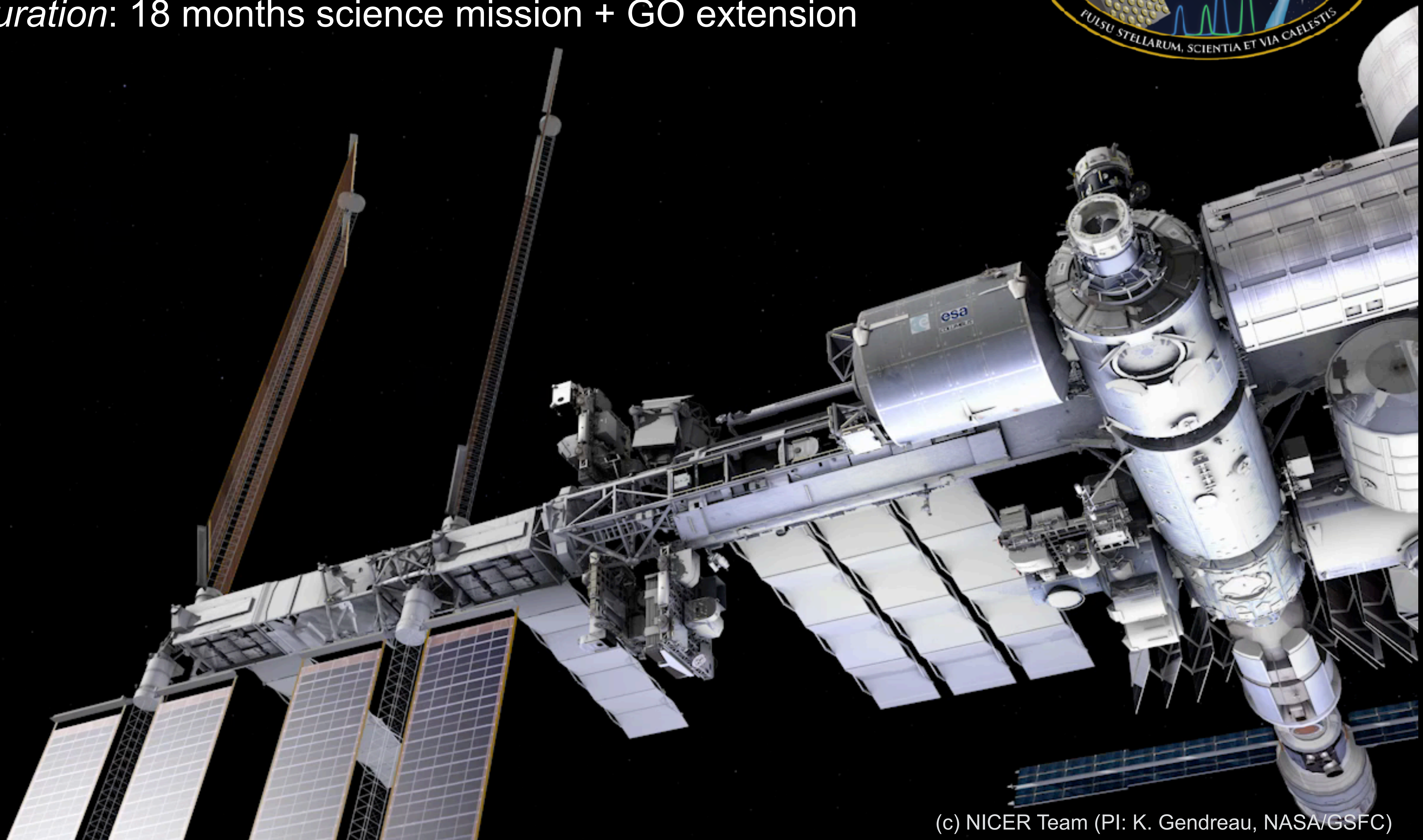
https://iopscience.iop.org/article/10.1088/1361-6633/ab3def

CrossMark

Python code to daw P-Pdot diagram
https://colab.research.google.com/drive/1hrA6KDAILf1IJT9NinFYlR6X9iskG_td

Neutron star Interior Composition ExploreR

- ***NICER** mission*: Soft X-ray (0.2-12 keV) timing spectroscopy for neutron star structure, dynamics, and energetics.
- *Platform*: ISS external attached payload with active pointing
  - Launched June 3, 2017; Installed on ISS, June 13
- *Duration*: 18 months science mission + GO extension



(c) NICER Team (PI: K. Gendreau, NASA/GSFC)

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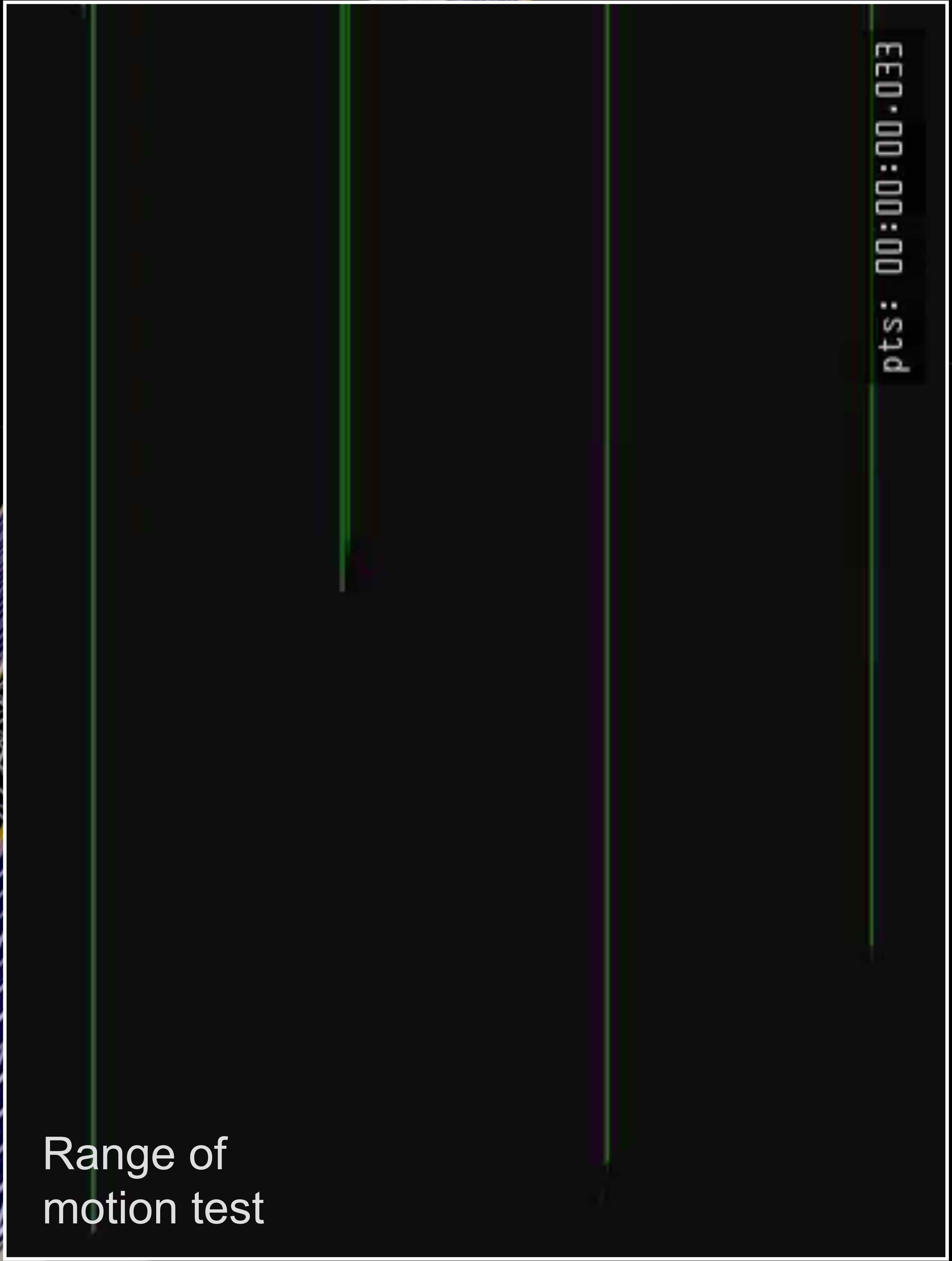
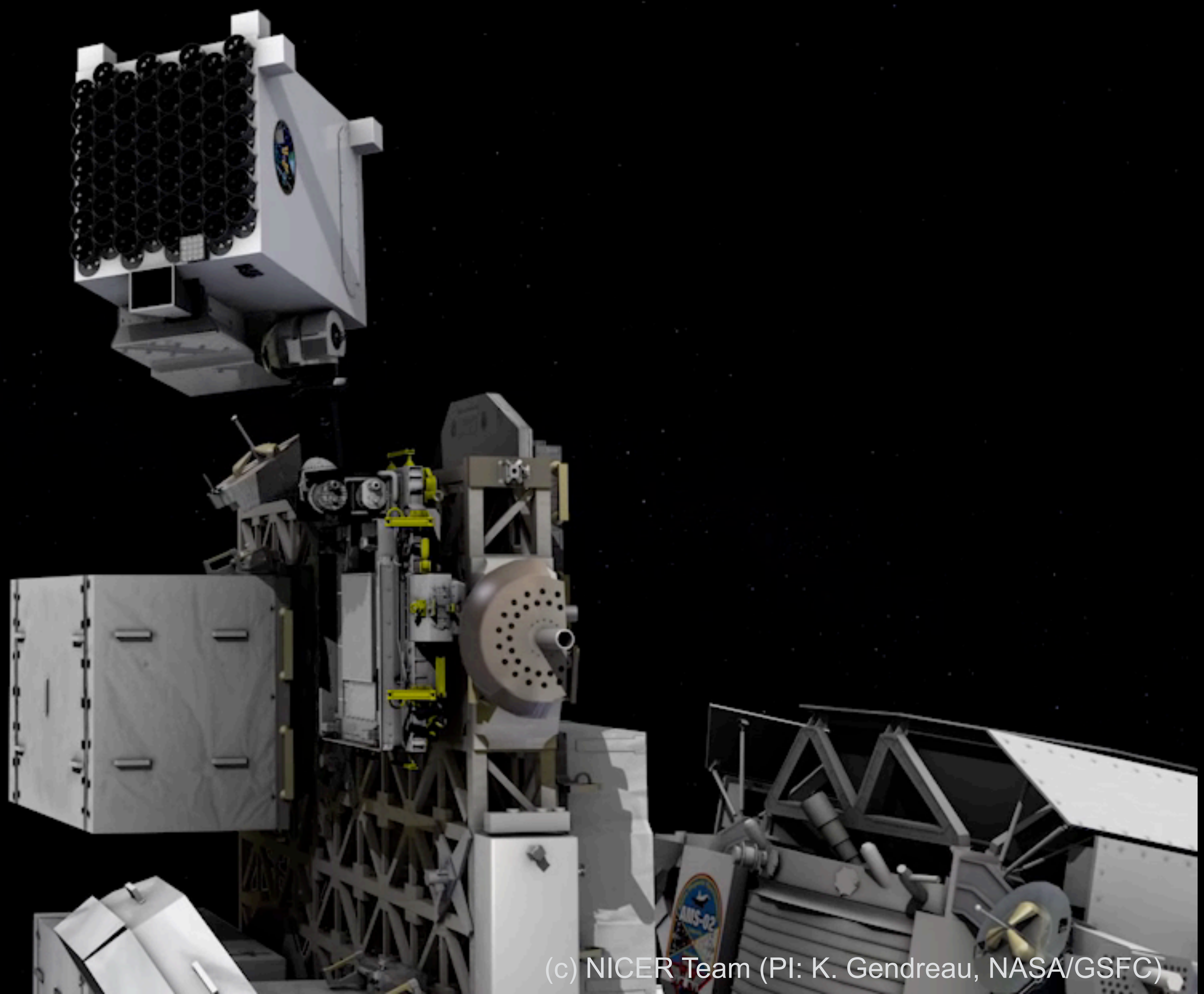




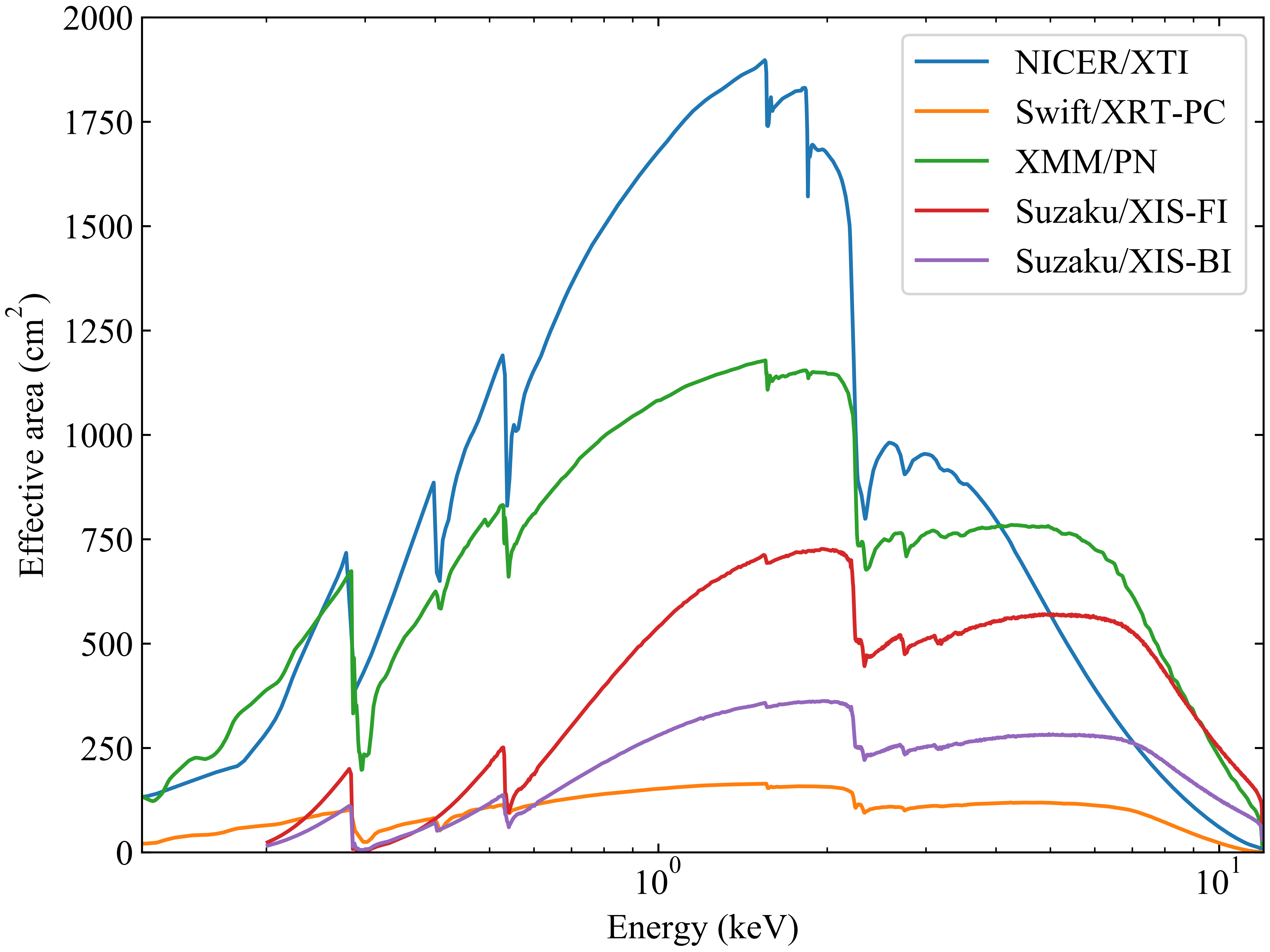
(c) NICER Team (PI: K. Gendreau, NASA/GSFC)

- Energy band : 0.2-12 keV (Resolution : 85 eV @ 1 keV, 140 eV @ 6 keV)
- Time resolution : <100 ns RMS (absolute)
- Non-imaging FOV 6 arcmin diameter
- Background : < 0.5 cps
- Sensitivity: 1×10^{-13} erg/s/cm^2 (5σ, 0.5-10 keV, 10 ksec exposure for Crab-like)
- Max rate: ~38,000 cps (3.5 Crab)

Gendreau et al., SPIE (2012), Arzoumanian et al., (2014)

Large Effective Area of NICER

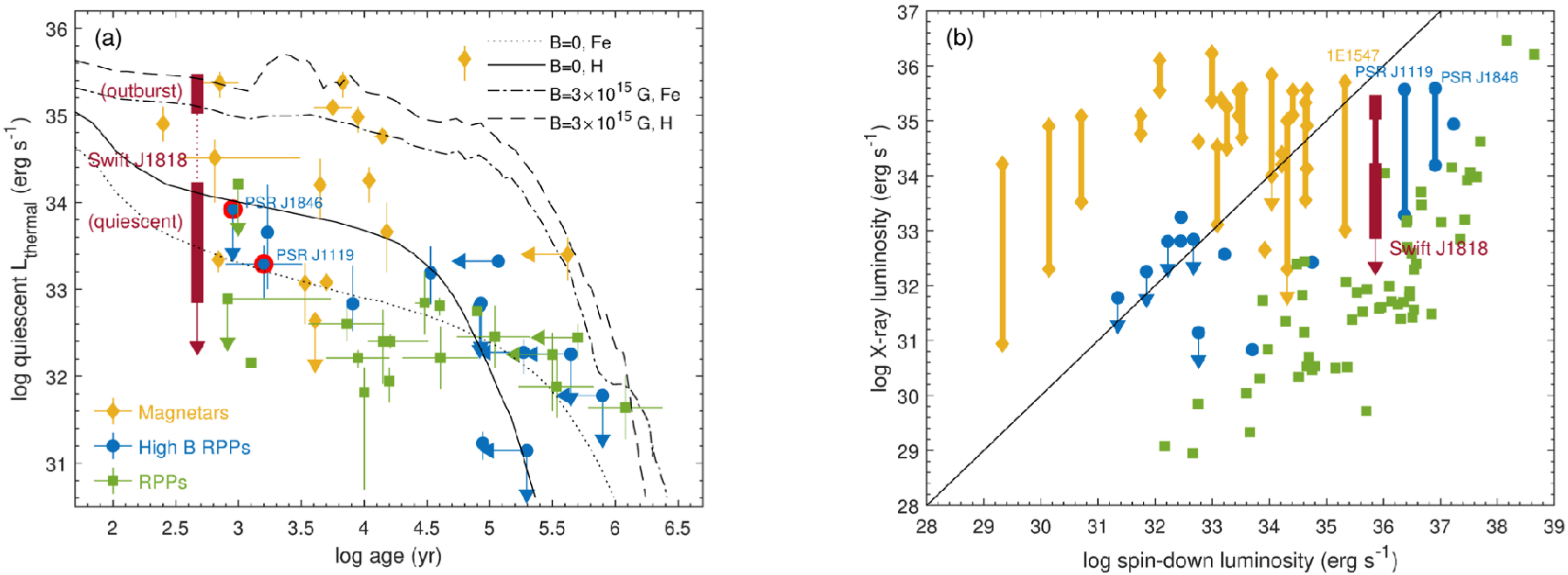
- 56 parallel X-ray Timing Instruments (XTIs)
- XTI = X-Ray Concentrator (XRC) + Sillicon Drift Detector (SDD)
- Large effective area (x2 of XMM at 1.5 keV), Dedicated to NS surface emission.



(K. Gendreau, et al., SPIE, 2012; Z. Arzoumanian, et al., SPIE, 2014)

A new magnetar Swift J1818.0-1607

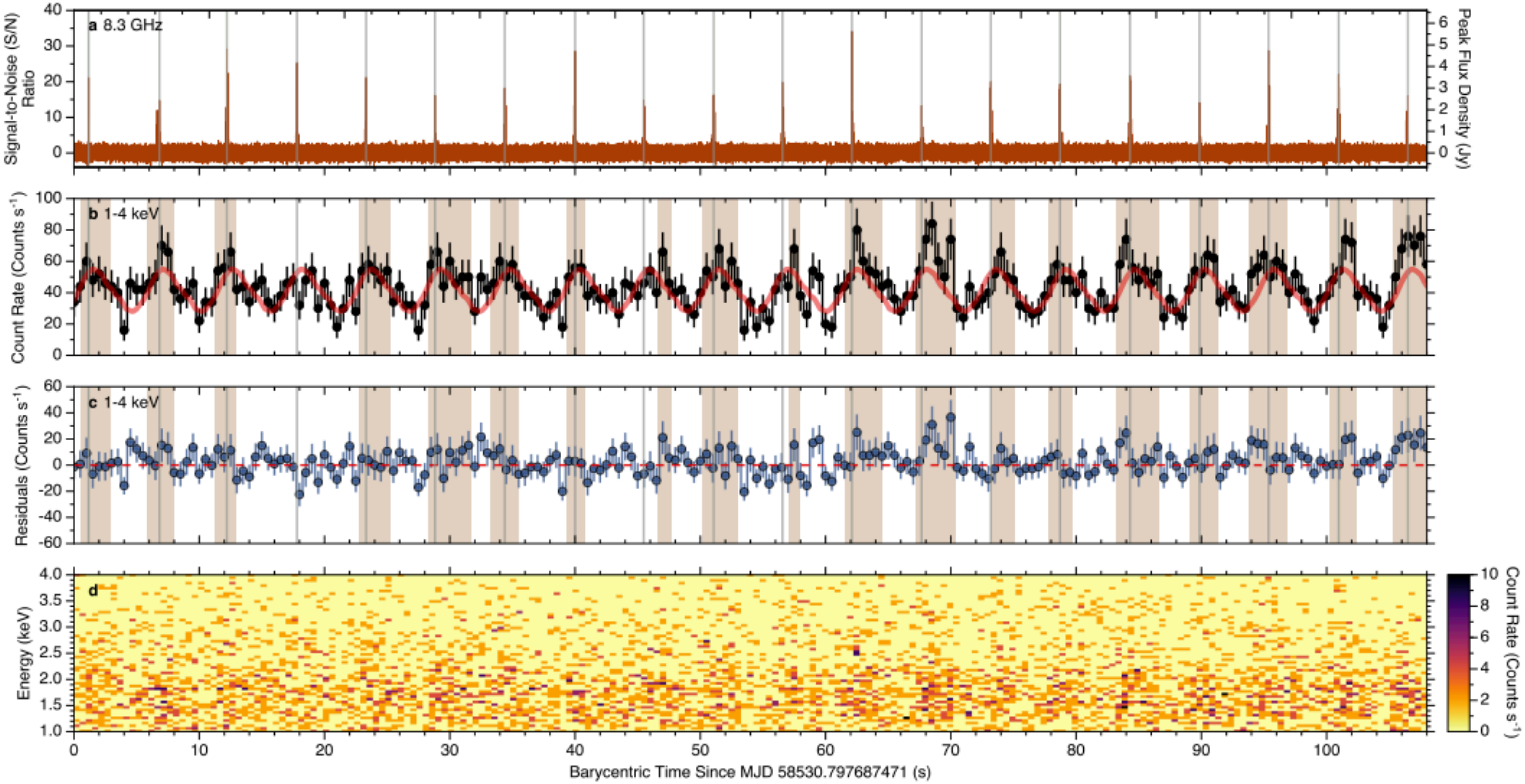
- Discovered by Swift and NICER on March 12, 2020. Radio and X-ray pulsation at 1.36 sec



- Very young characteristic age ~470 yr. A missing link between magnetars and high-B pulsars.

Hu et al., ApJ (2020)

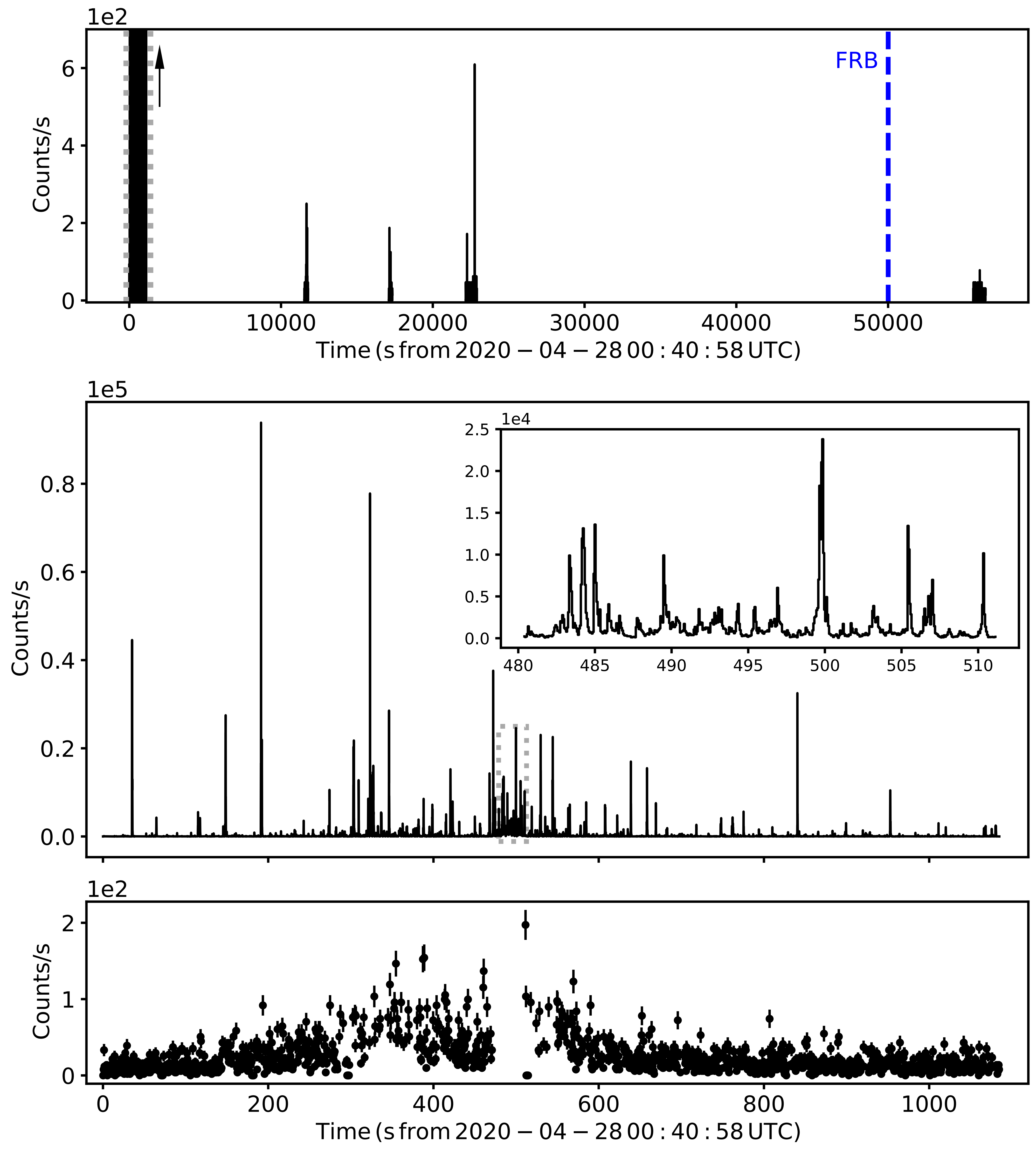
Detection of single X-ray pulses from XTE J1810-197



Pearlman et al., 2020, arXiv:2005.08410

NICER results of the Galactic FRB magnetar SGR 1935+2154

A FRB was found from a Galactic magnetar!!

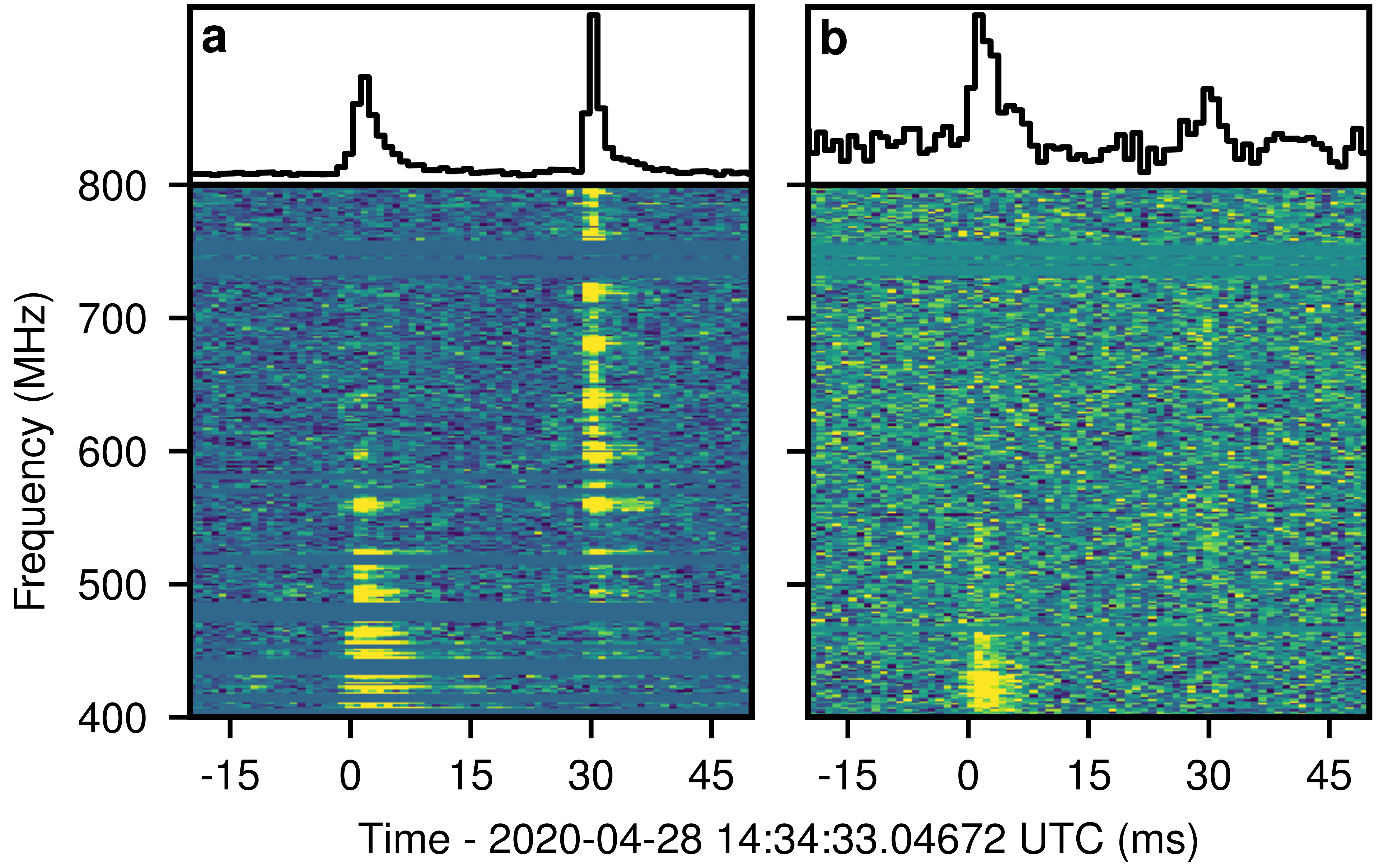


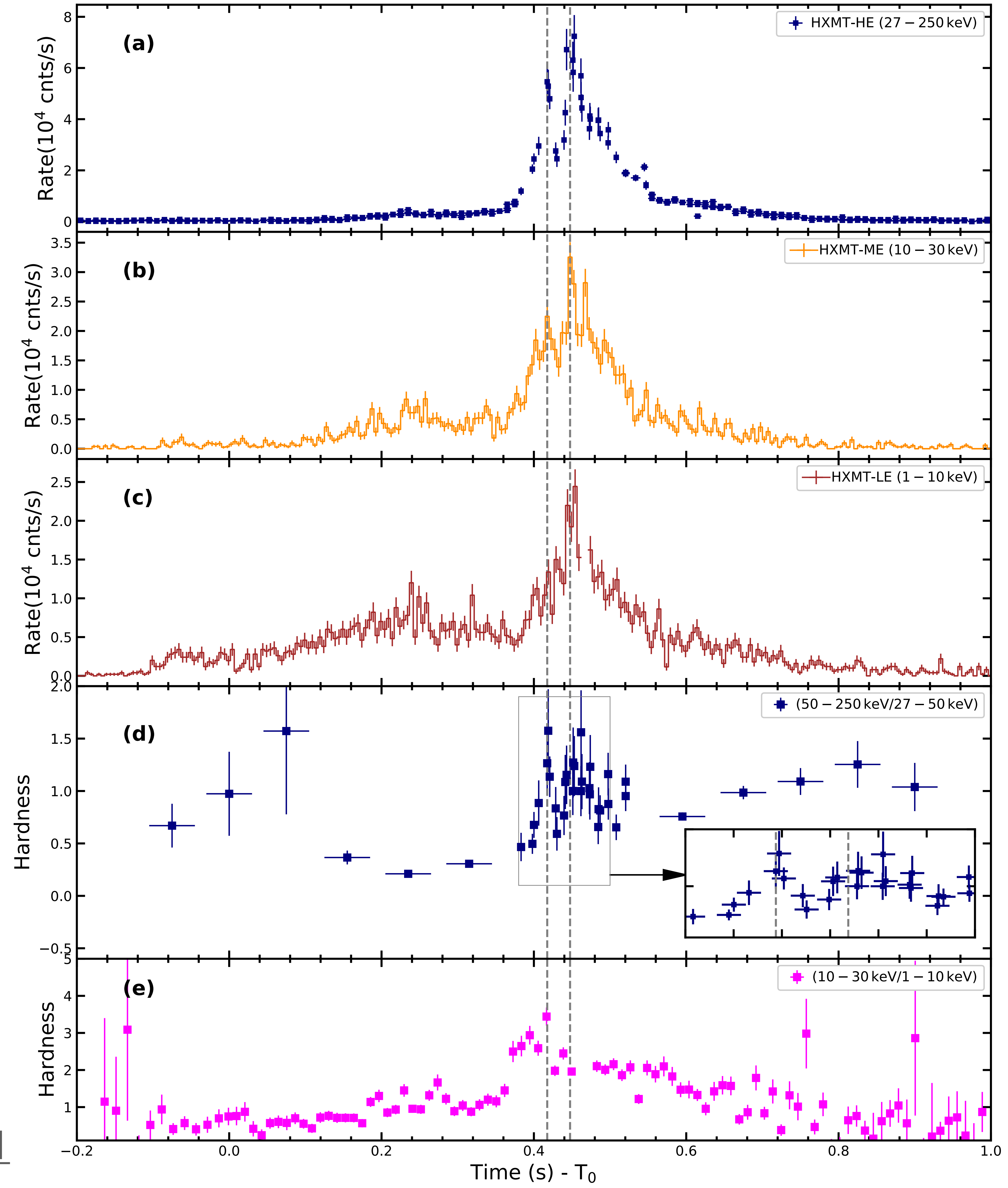
- Galactic magnetar SGR 1935+2154
  - discovered in 2014 (~9 kpc?)
  - P=3.24 s, Pdot=1.43e-11 s/s
  - B ~ 2.2e+14 G
- A burst was detected with Swift Burst Alert Telescope on April 27, 2020.
- X-ray follow-up monitoring by several X-ray observatories, including NICER.
- X-ray burst forest was found from the Galactic magnetar SGR 1935+2154 on 2020 April 28.
- A FRB was found during this activated state!

Younes et al., arXiv:2009.07886

A FRB was found from a Galactic magnetar!!

- Two-peak FRB coincided with a magnetar X-ray burst (Insight-HMXT, INTEGRAL, AGILE, and Konus-Wind)

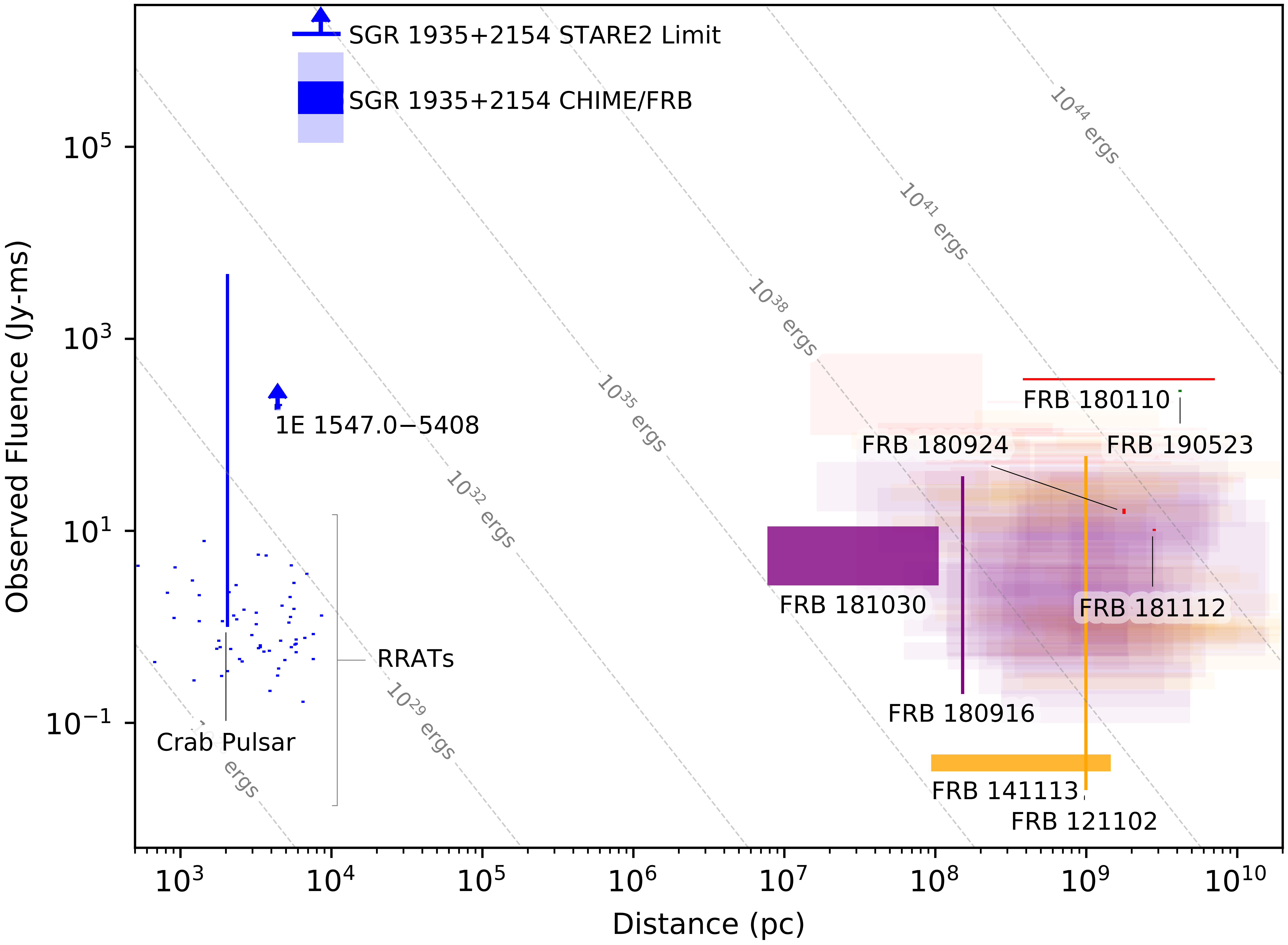




The CHIME/FRB Collaboration, arXiv:2005.10324

Li et al., arXiv 2005.11071

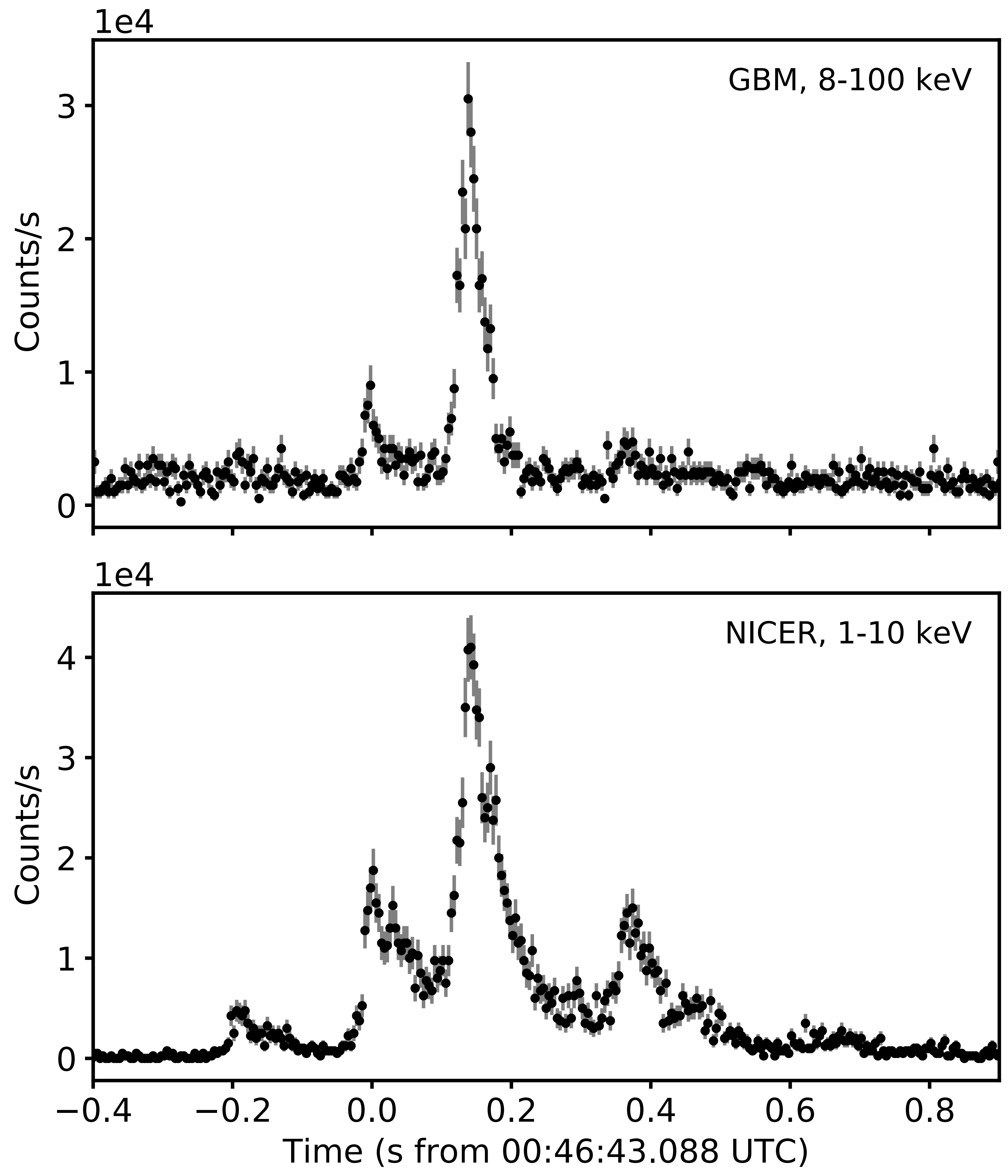
Galactic FRB vs. Cosmological FRBs

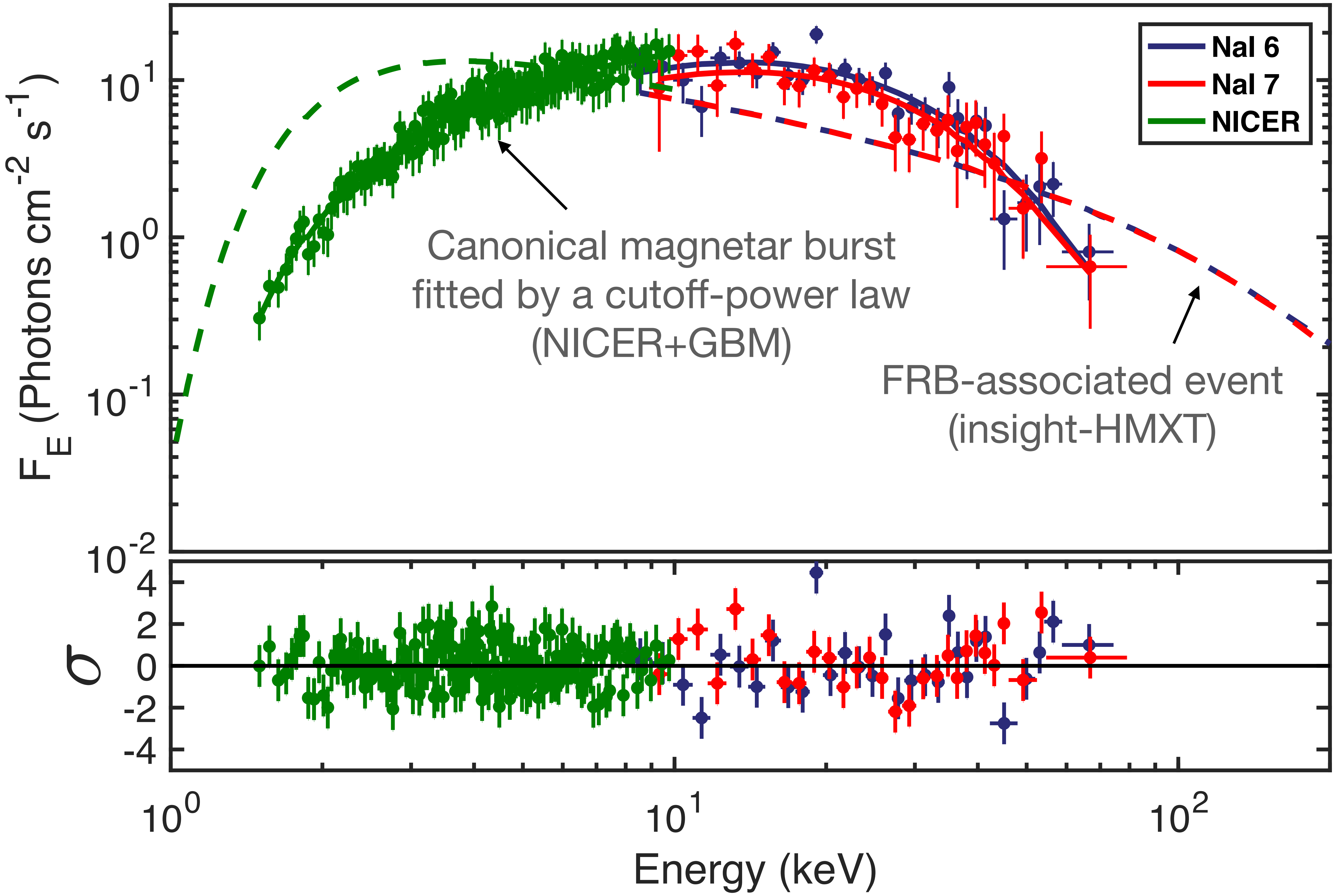


- Compared with extra-Galactic FRBs, this Galactic FRB is
  - Higher fluence
  - Lower luminosity
- Implication: FRB coherent (?) radio emission and incoherent X-ray burst are related with each other.

The CHIME/FRB Collaboration, arXiv:2005.10324

FRB-associated burst vs. Other magnetar bursts

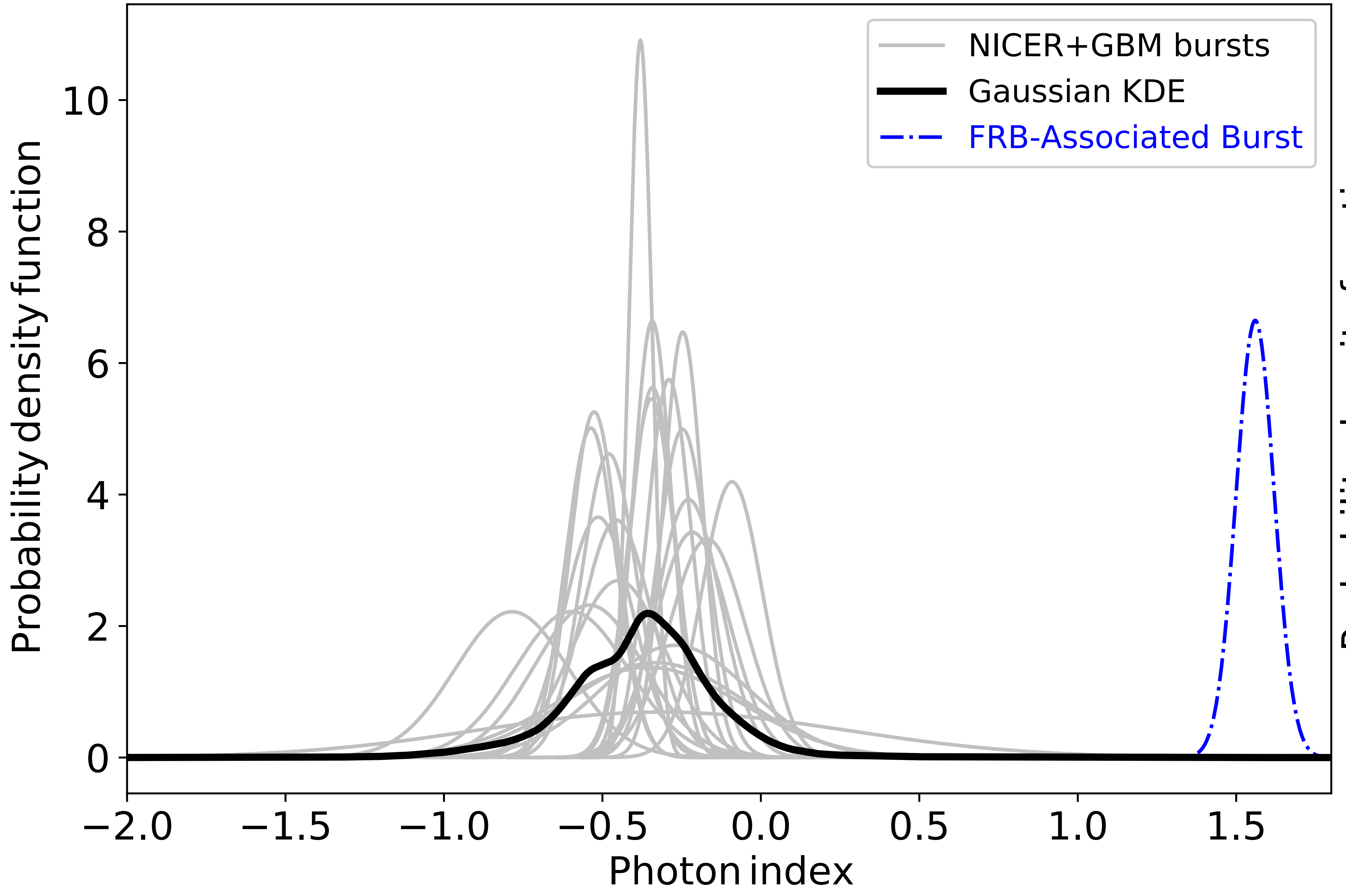


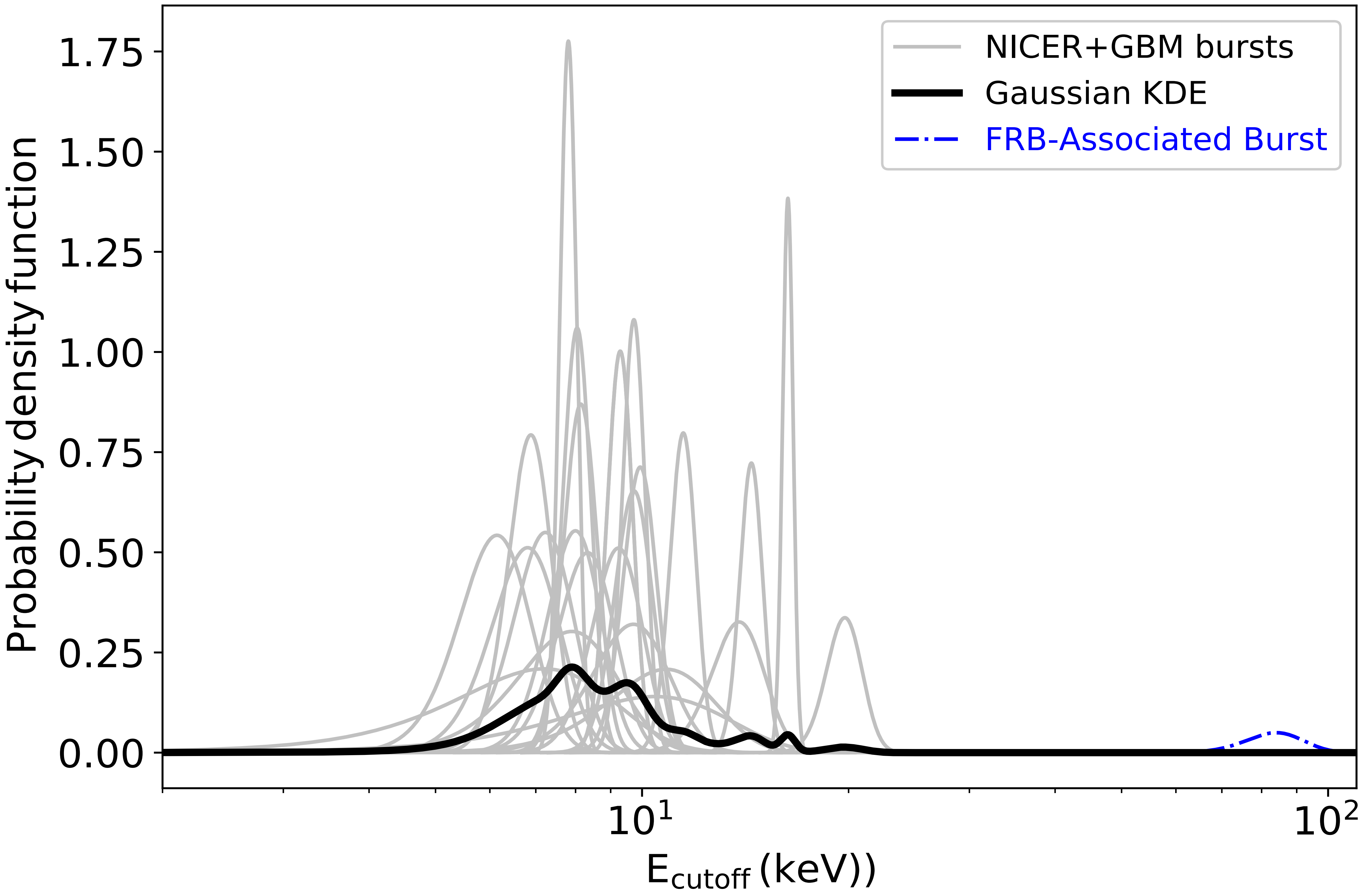


- Example of a magnetar short burst from SGR 1935+2154 observed with NICER+GBM compared with the FRB-associated event.

Younes et al.., arXiv: 200611358

X-ray burst spectrum: FRB-associated vs. others

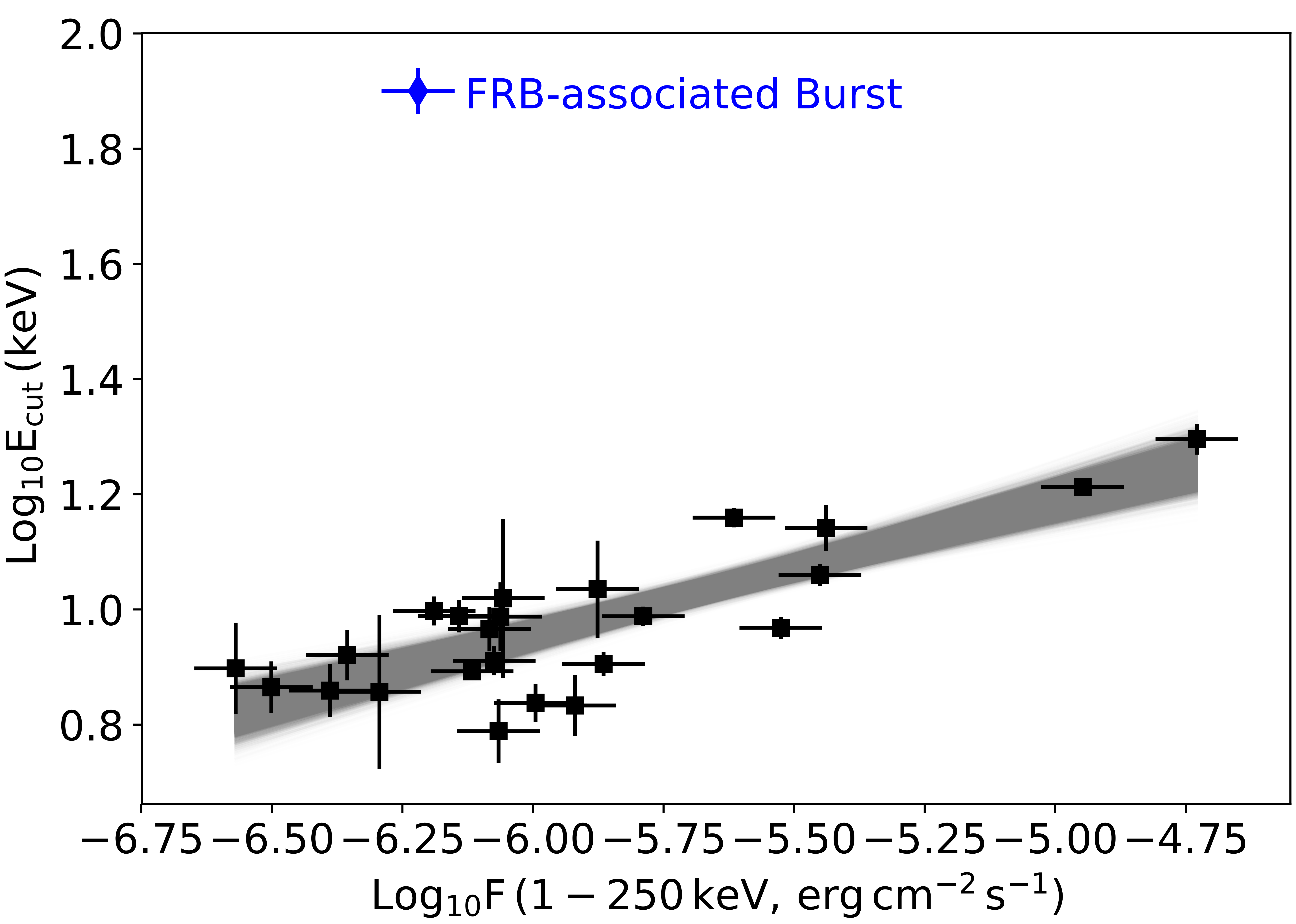




- Probability distribution function of X-ray spectral parameters of 24 short bursts from SGR 1935+2154: Cutoff power-law index (left) and cutoff energy (right).
- The FRB-associated burst is different from the other X-ray bursts?

Younes et al.., arXiv: 200611358

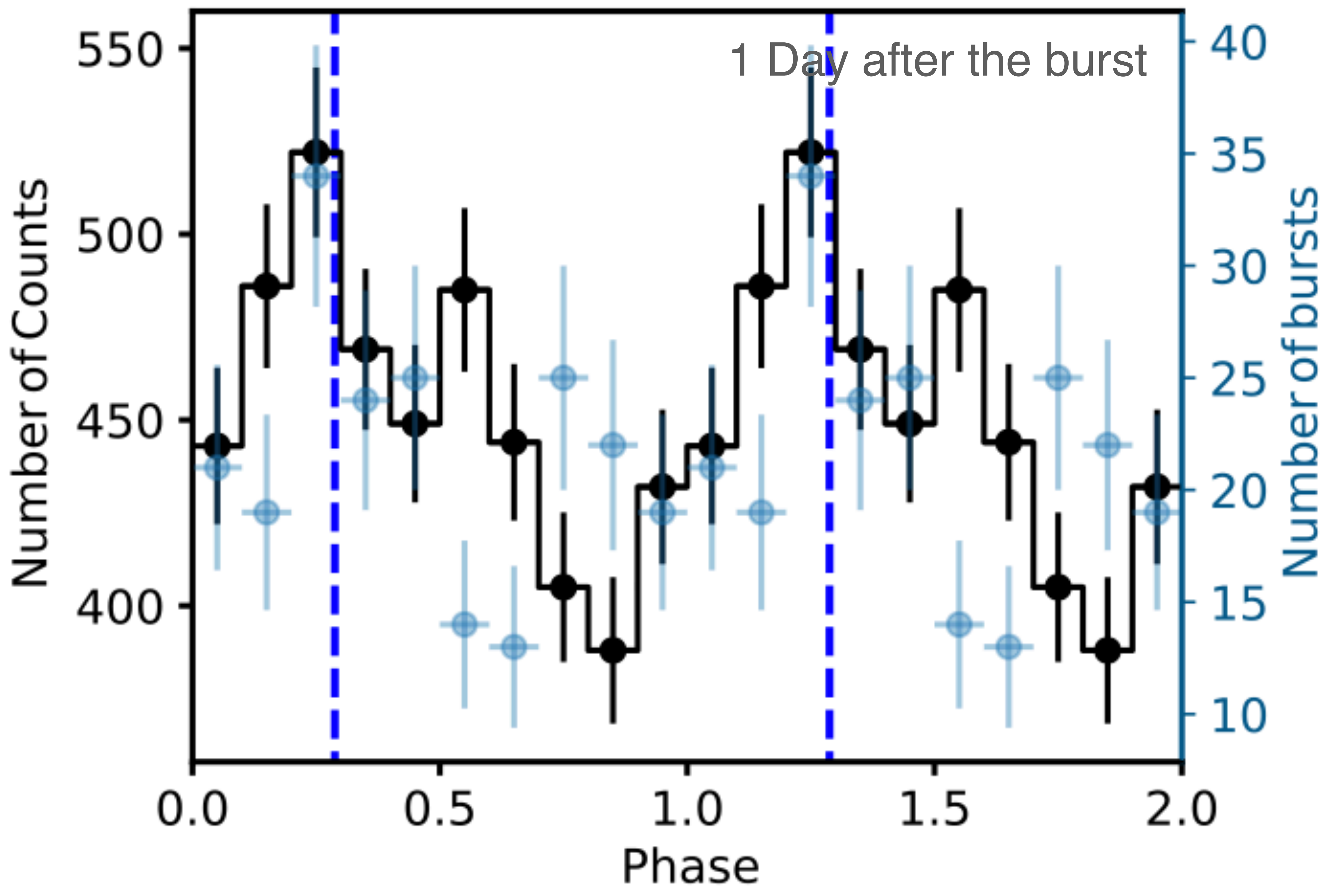
X-ray burst spectrum: FRB-associated vs. others

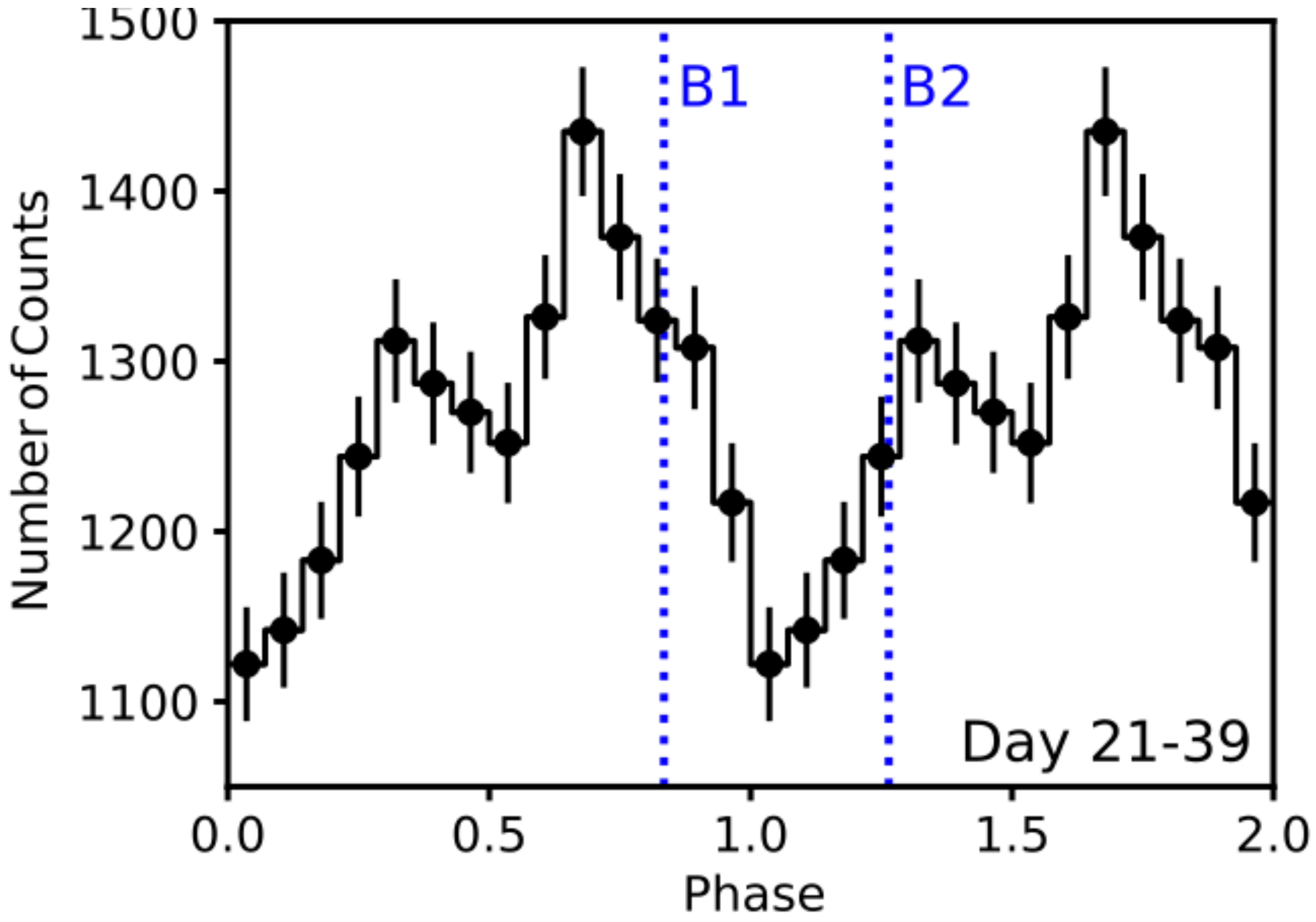


- Cutoff energy vs. X-ray flux in 1-250 keV.
- Brighter magnetar short burst shows higher cutoff energy.
- X-ray flux of the FRB-associated burst is in the distribution of the other (canonical) magnetar bursts.
- However, the cutoff energy of the FRB-associated one is higher than the others.

Younes et al.., arXiv: 200611358

At which pulse phase the FRB event happened?

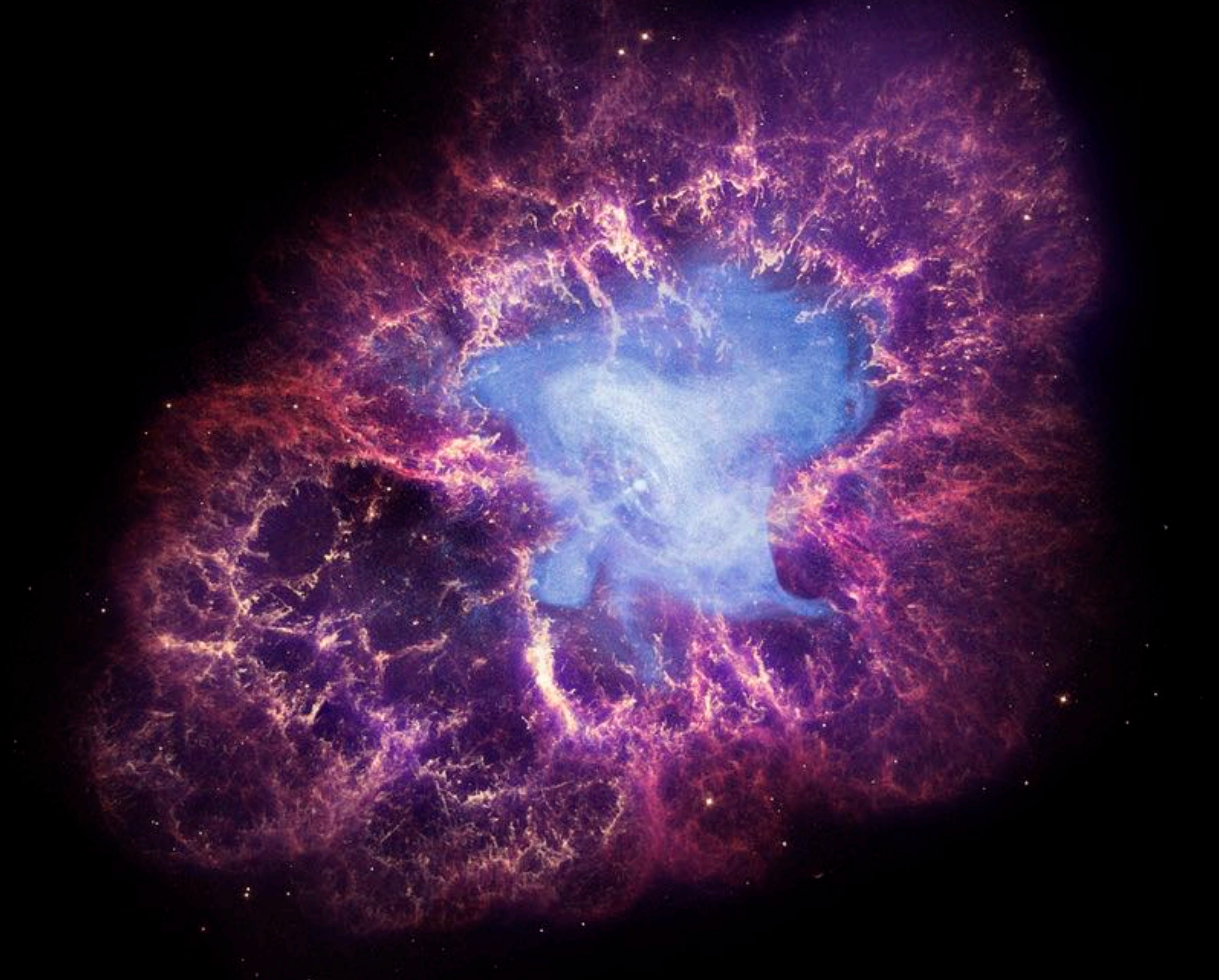




- Pulse profile of SGR 1935+2154 at 1 day and 21-39 days after the burst
- Folded burst peak time (light blue) does not show a clear pulse profile.
- The pulse phase of the FRB event happened at the peak of the pulse profile.

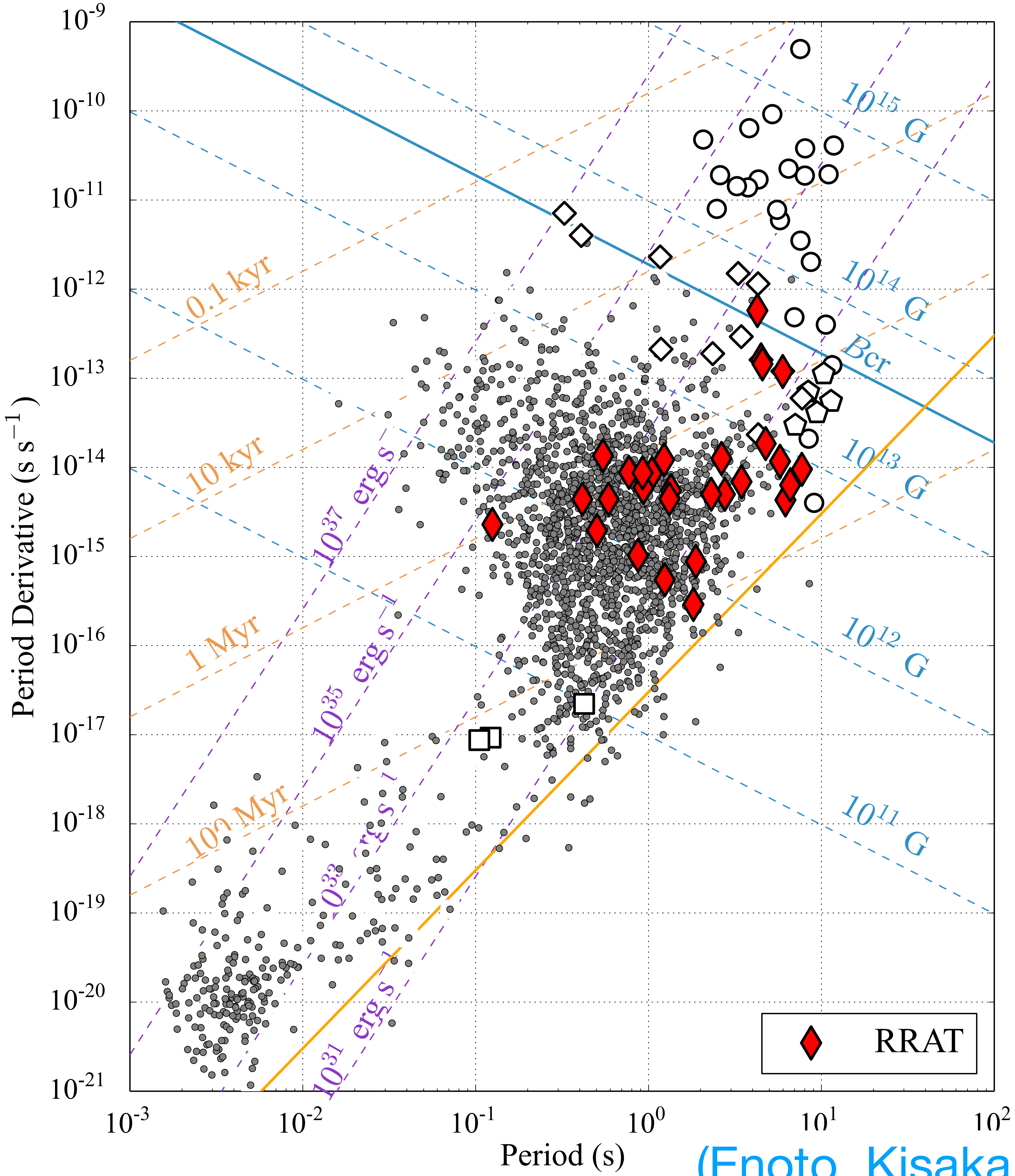
Younes et al., arXiv:2009.07886

X-ray enhancement associated with the Crab GRPs



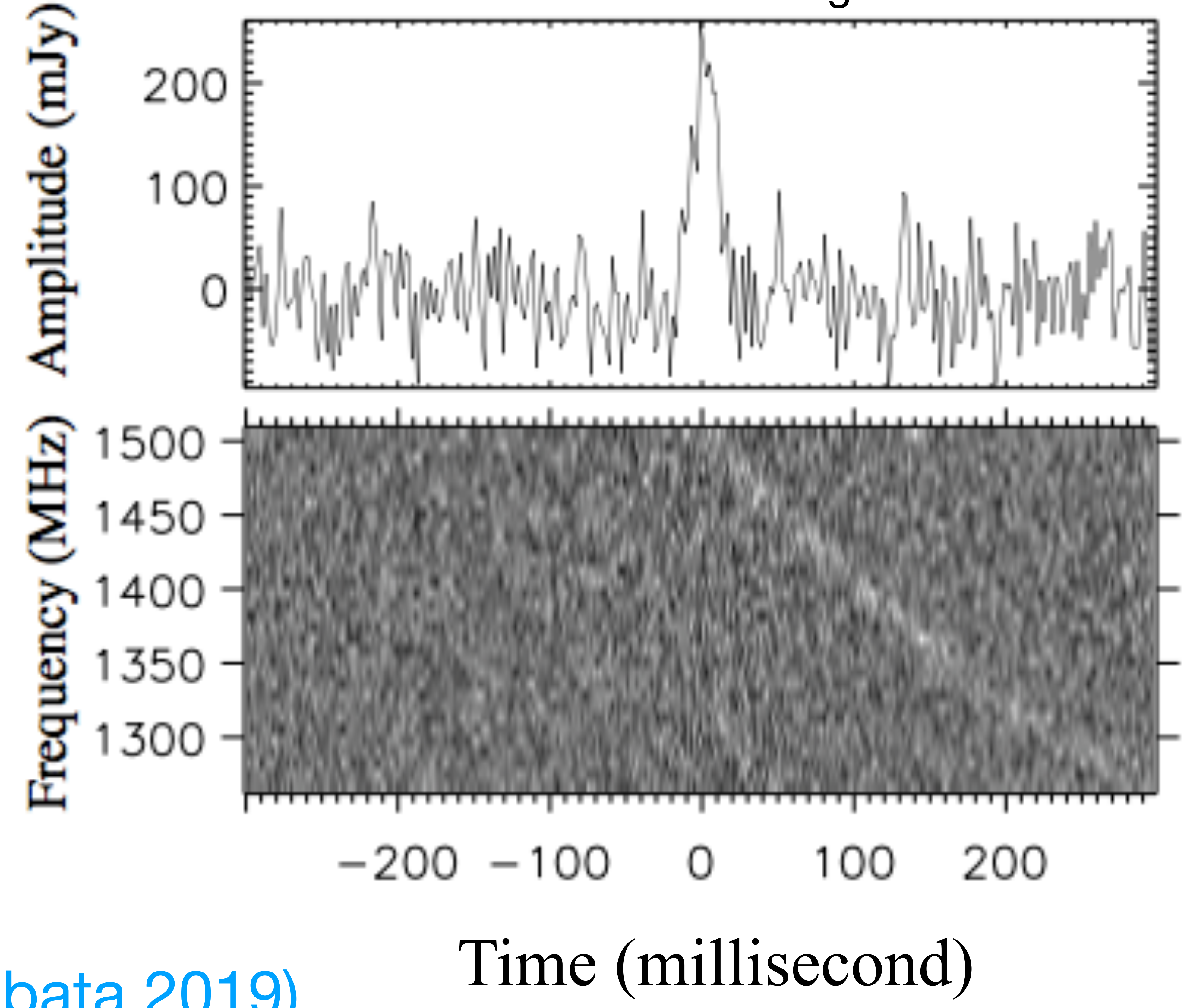
Chandra, Hubble, and Spitzer image (NGC 1952)

Rotating RAdio Transients = RRATs



- Rotating pulsars sometimes exhibit single radio pulses
- More than 100 RRATs have detected (P and Pdot measurements only for ~25% of them).

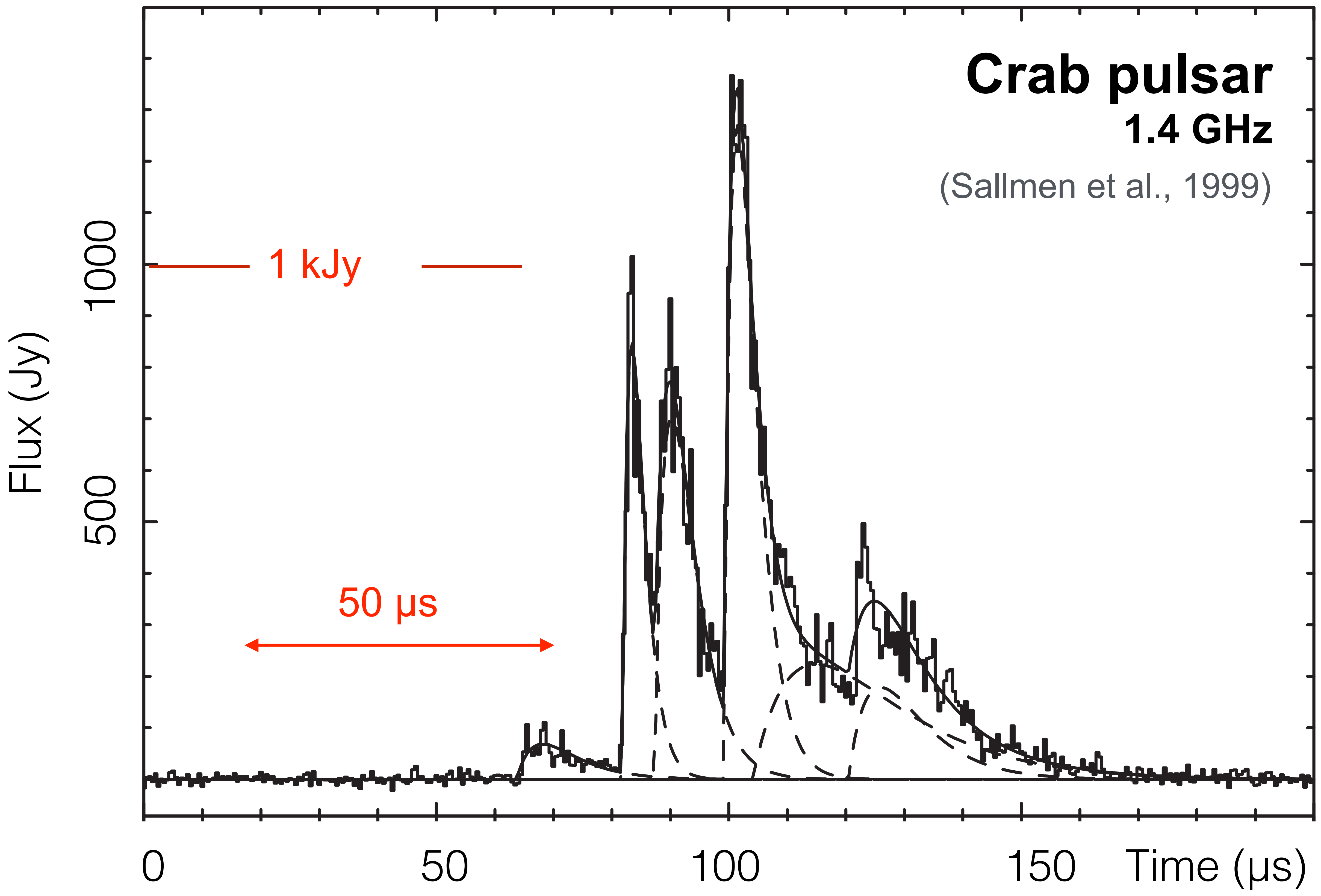
McLaughlin et al. 2005

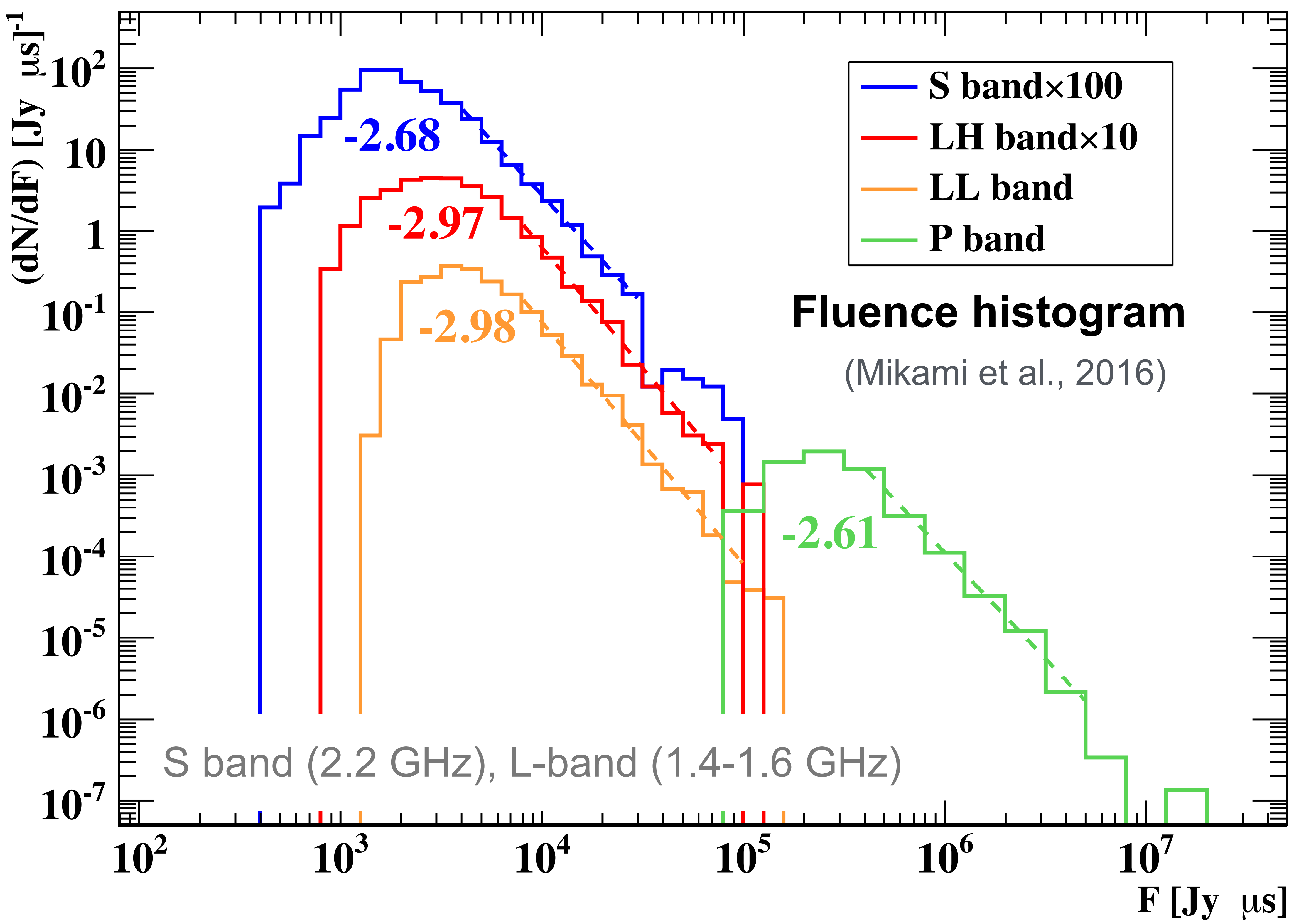


(Enoto, Kisaka, and Shibata 2019)

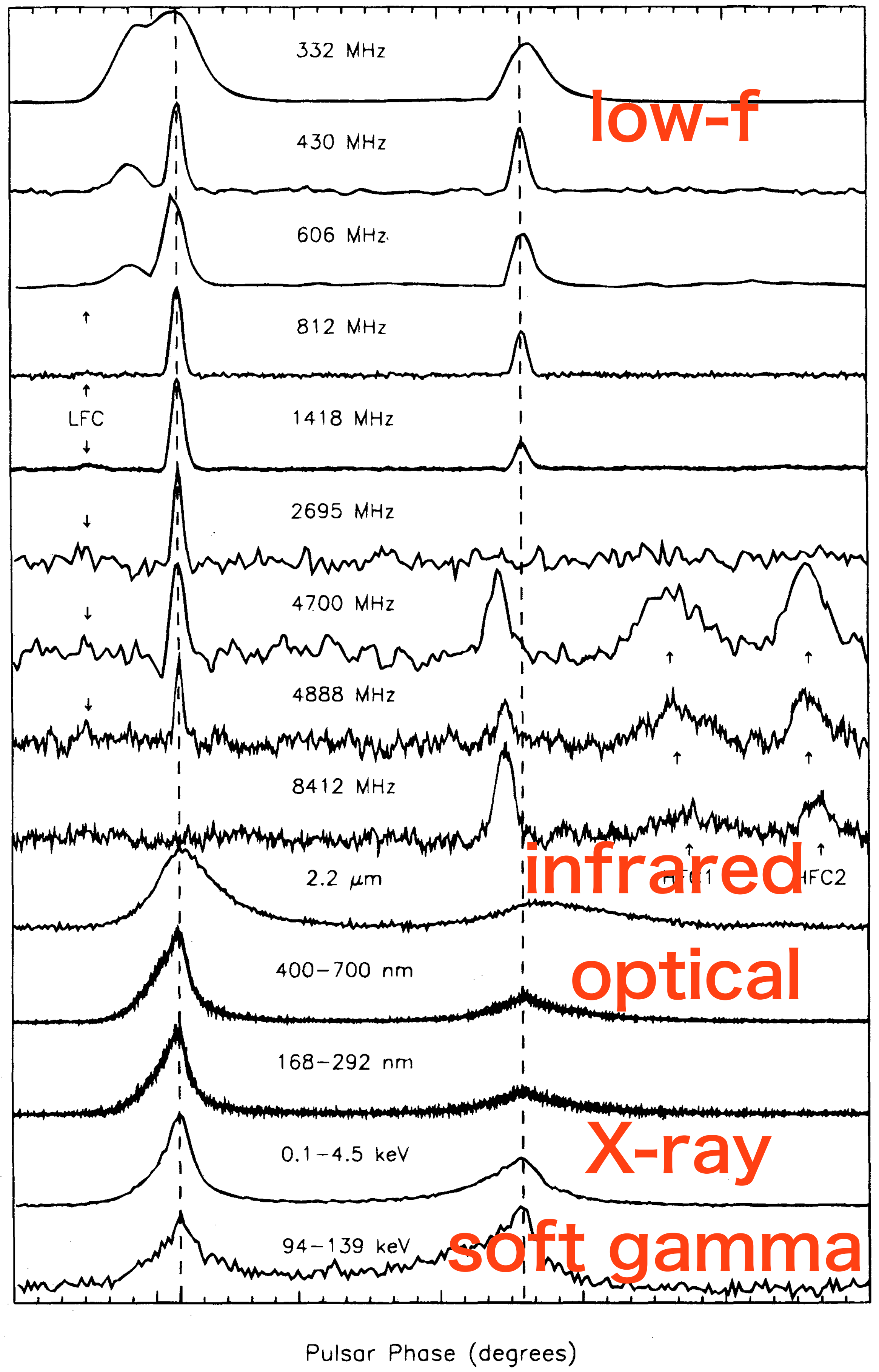
Giant radio pulses (GRPs)

- Sporadic sub-millisecond bursts $10^{2\text{-}3}$ times brighter than the normal radio pulses.
- Only from known ~12 sources, power-law fluence distribution,

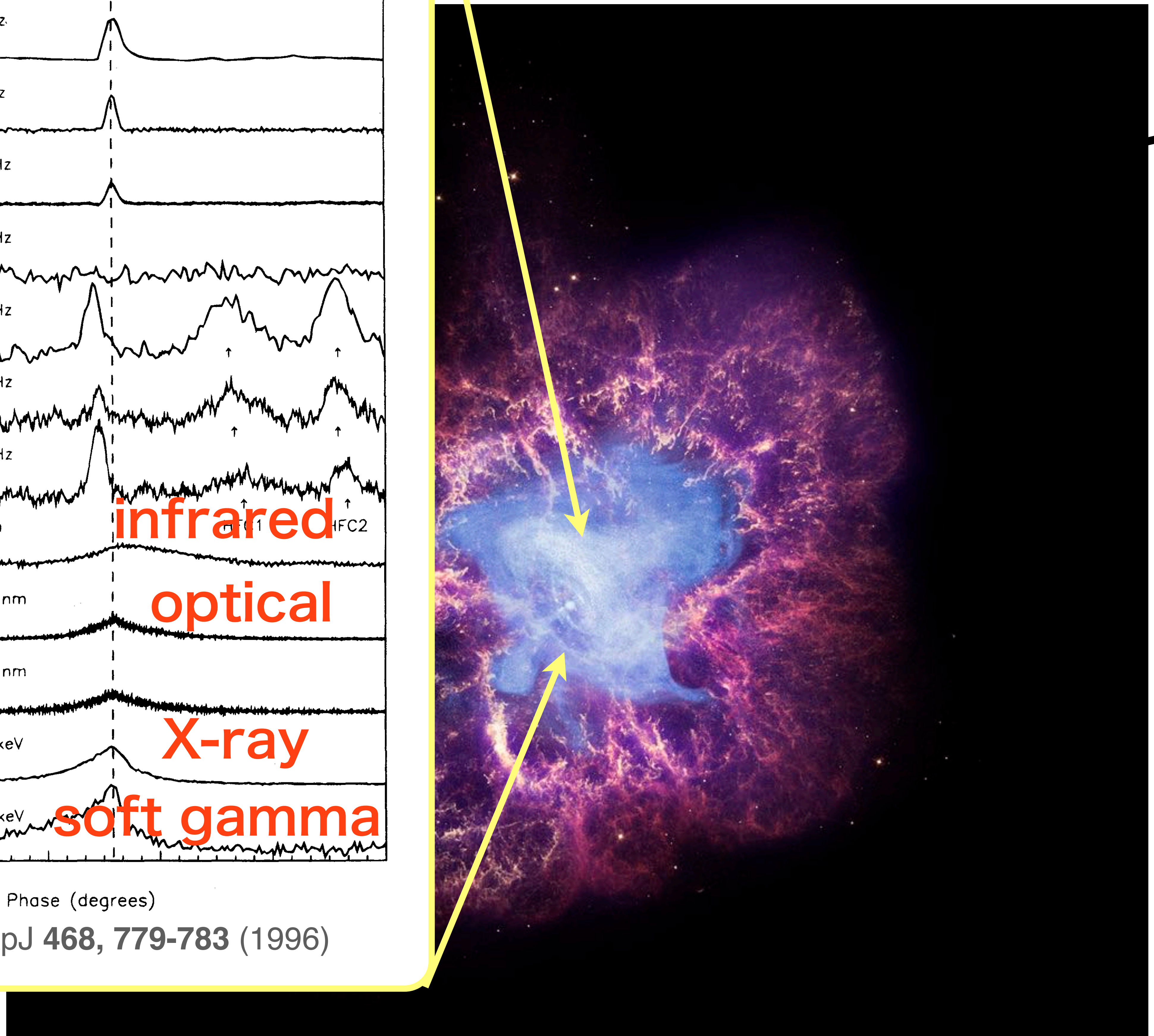




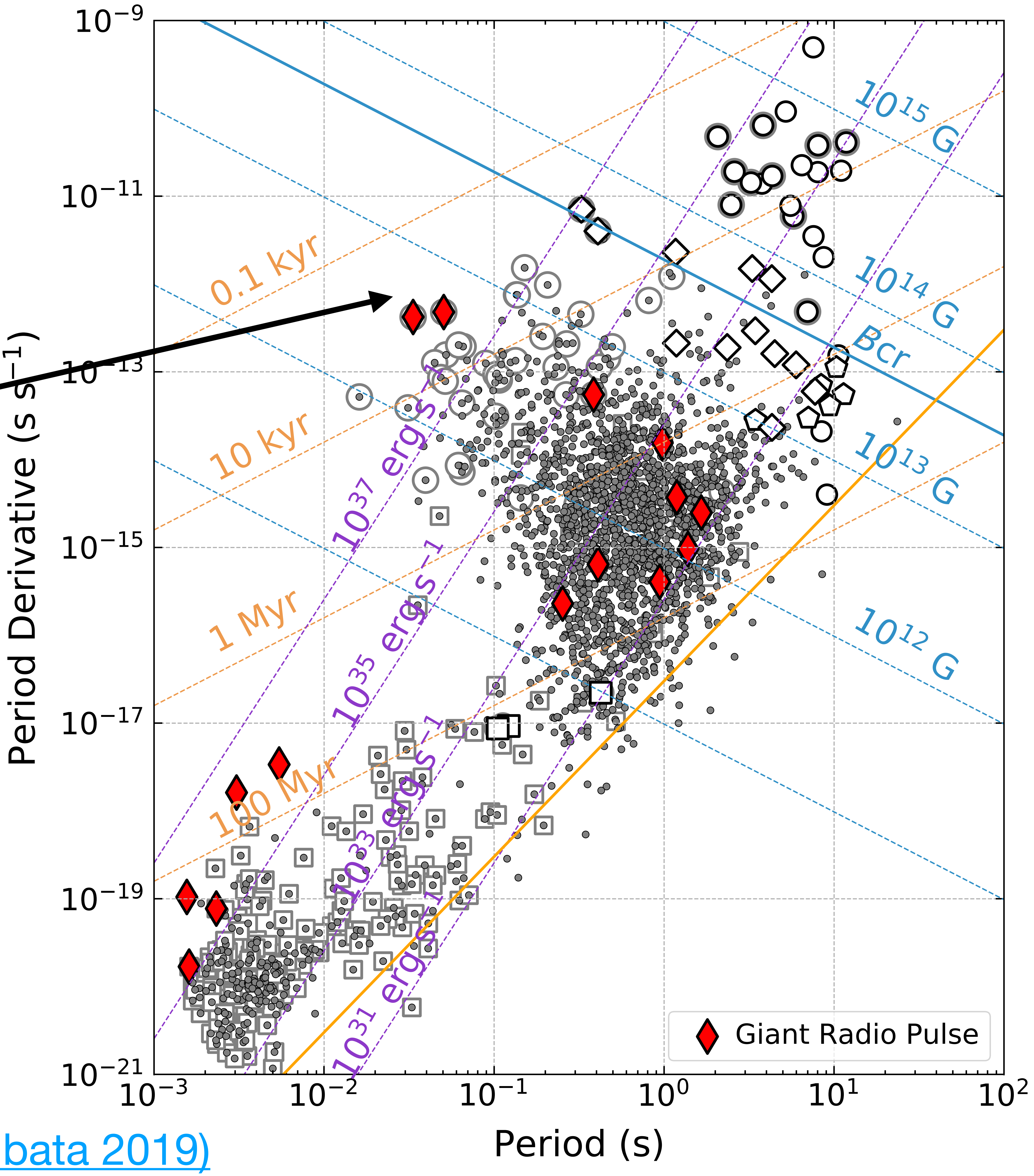
Giant radio pulses (GRPs)



David A. Moffett et al., ApJ **468, 779-783** (1996)

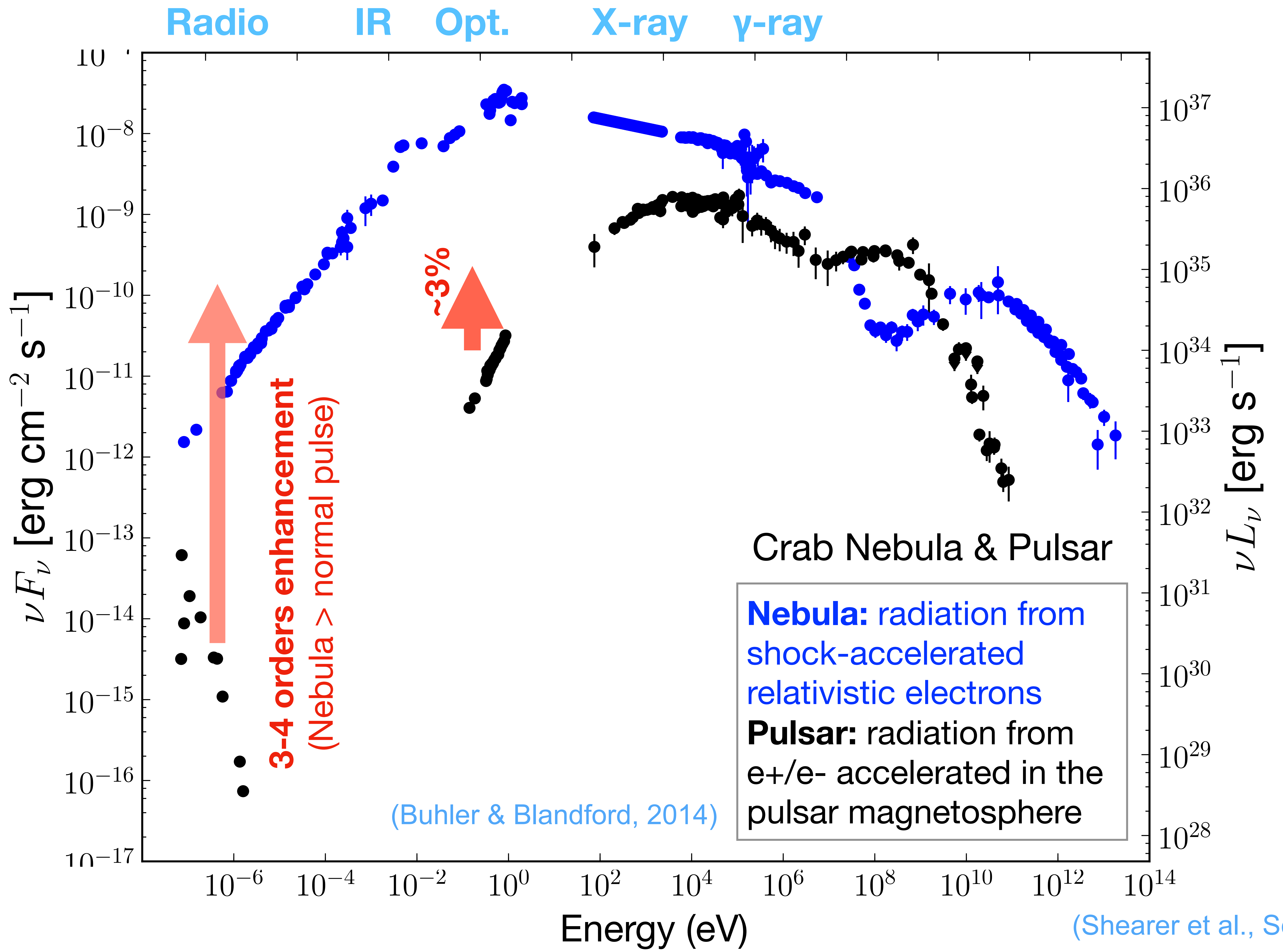


Chandra, Hubble, and Spitzer image (NGC 1952)



[(Enoto, Kisaka, and Shibata 2019)]

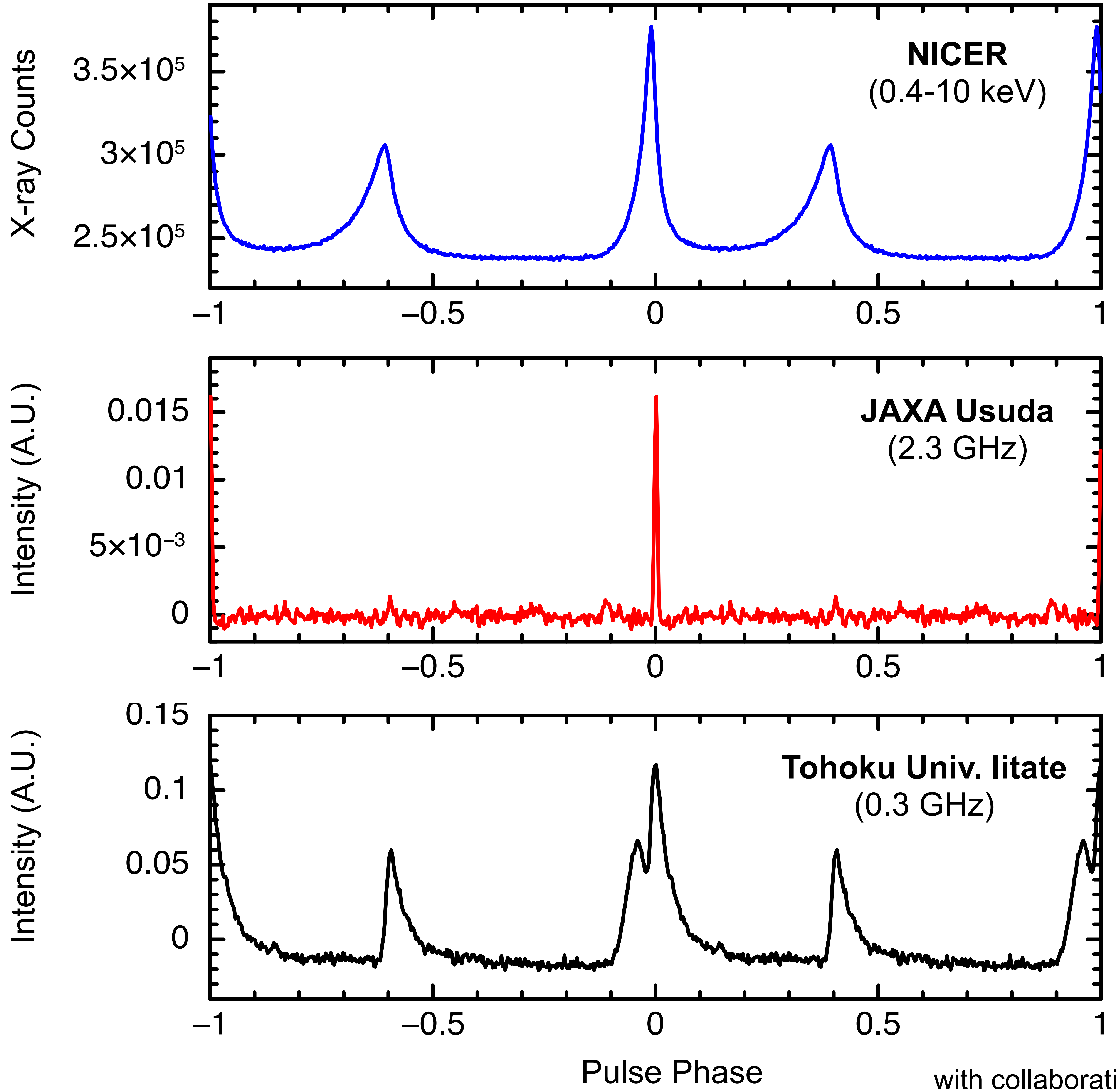
Optical enhancement coincided with GRPs



- Radio
  - $10^{3\text{-}4}$ enhancement
- Optical
  - Discovery of 3.2% enhancement (7.2σ) coincidences with Crab GRPs
- X-ray & Gamma rays
  - Only upper-limits from Chandra, Suzaku, Fermi… etc

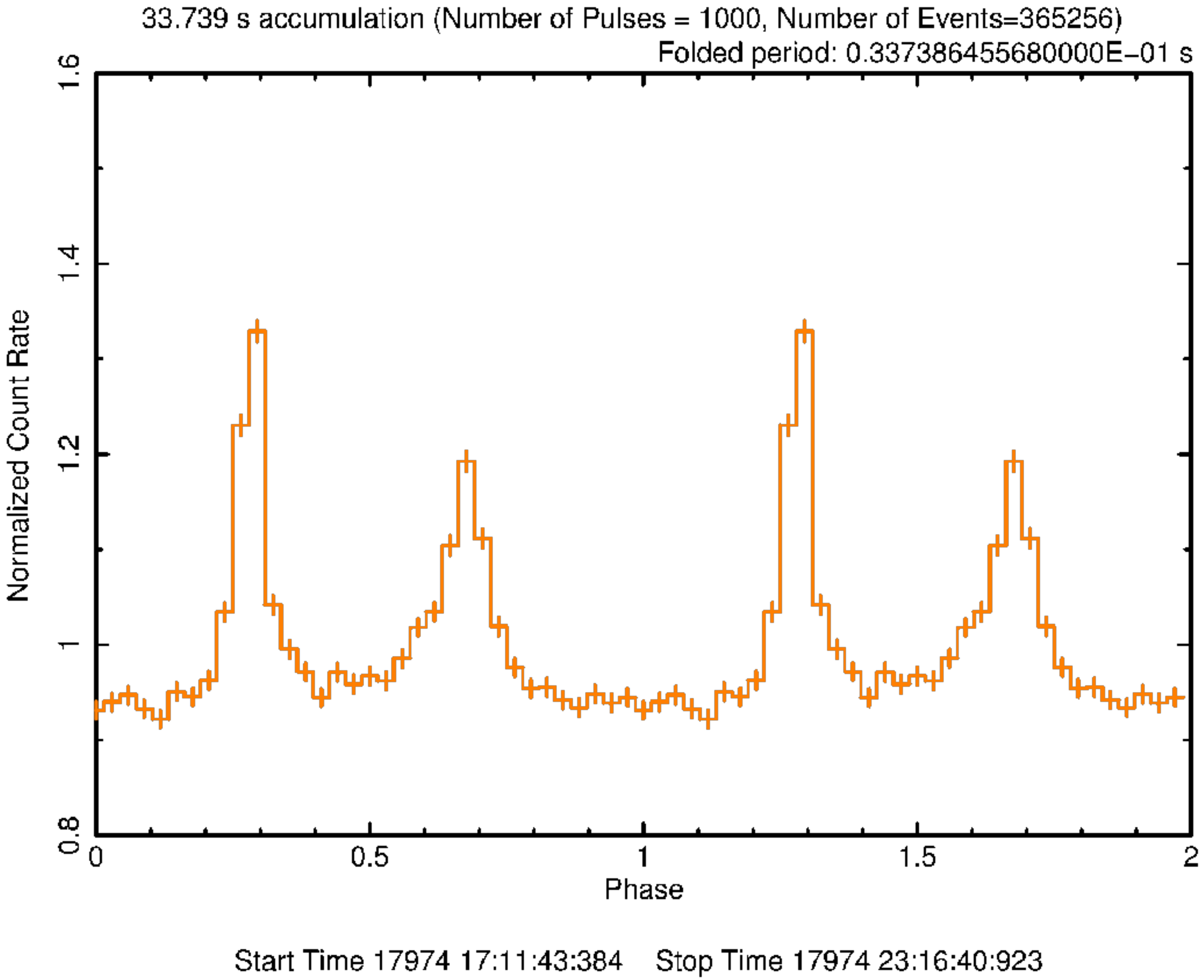
(Shearer et al., Science ,2003; Strader et al., ApJL 2013)

Crab Pulsar — Simultaneous with Radio



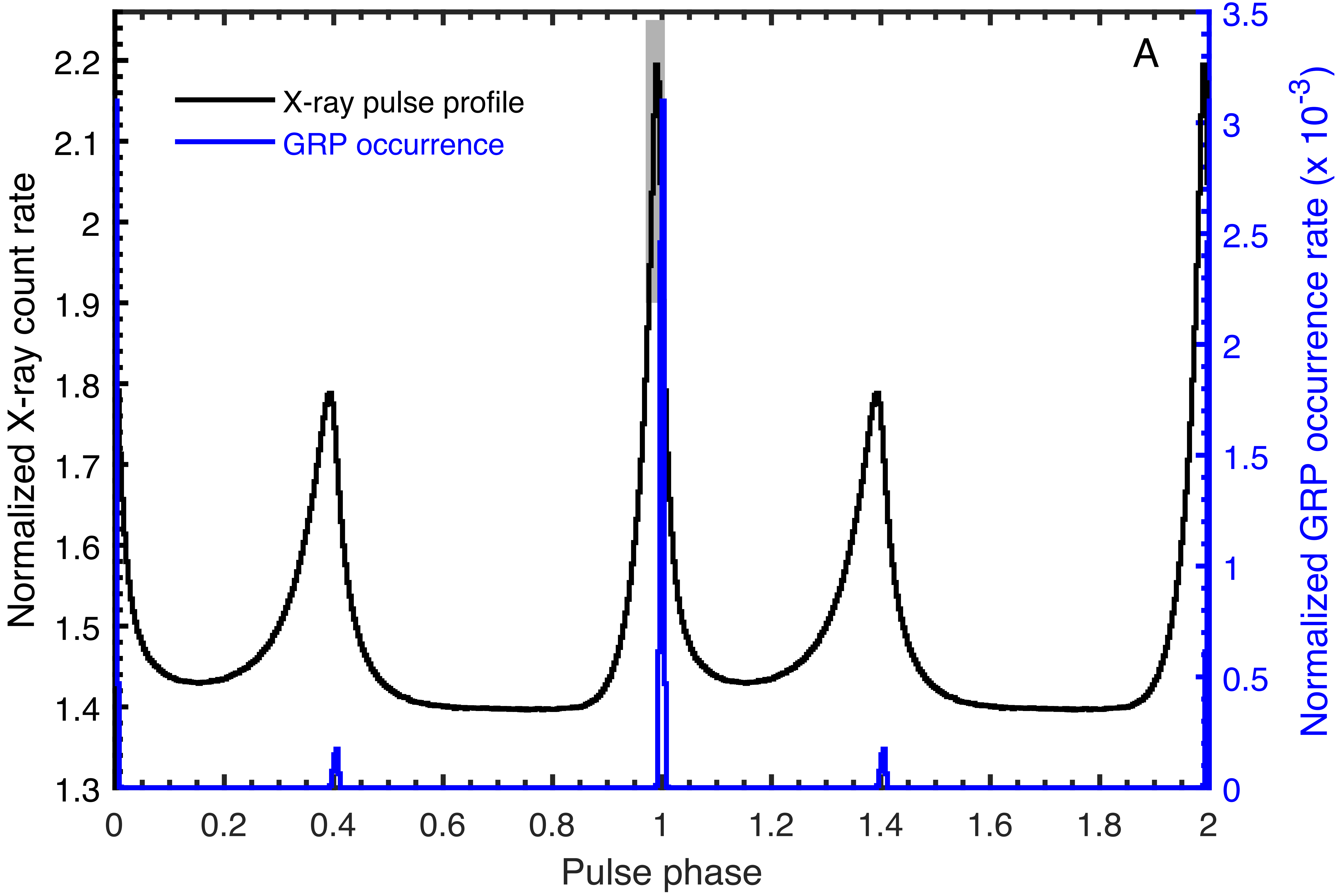
with collaboration for radio pulsar observation in Japan

Crab Pulsar — On-orbit actual NICER data



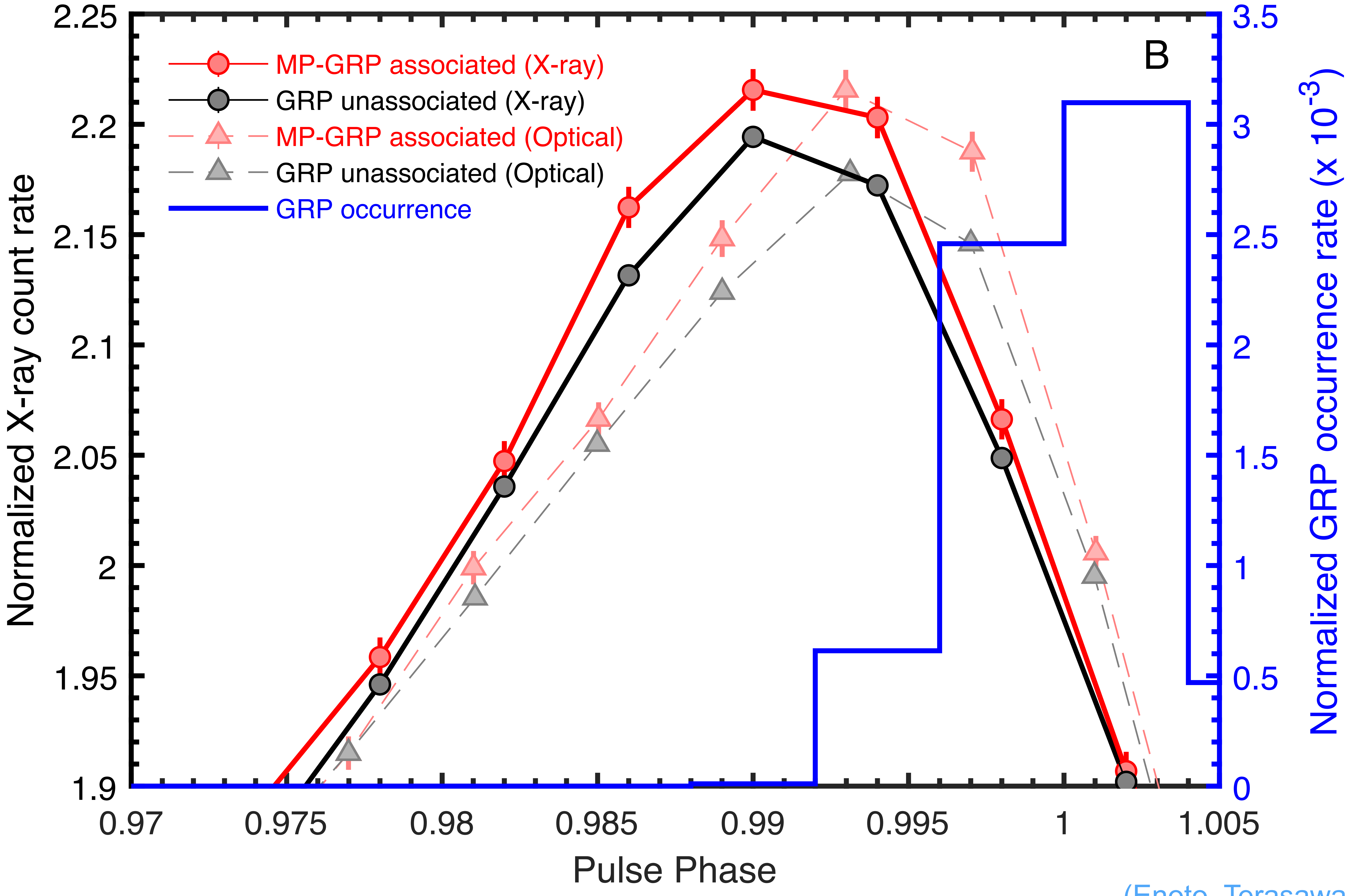
X-ray profile appears with accumulation in a short exposure (~1 sec) !

Discovery of X-ray enhancement at GRPs

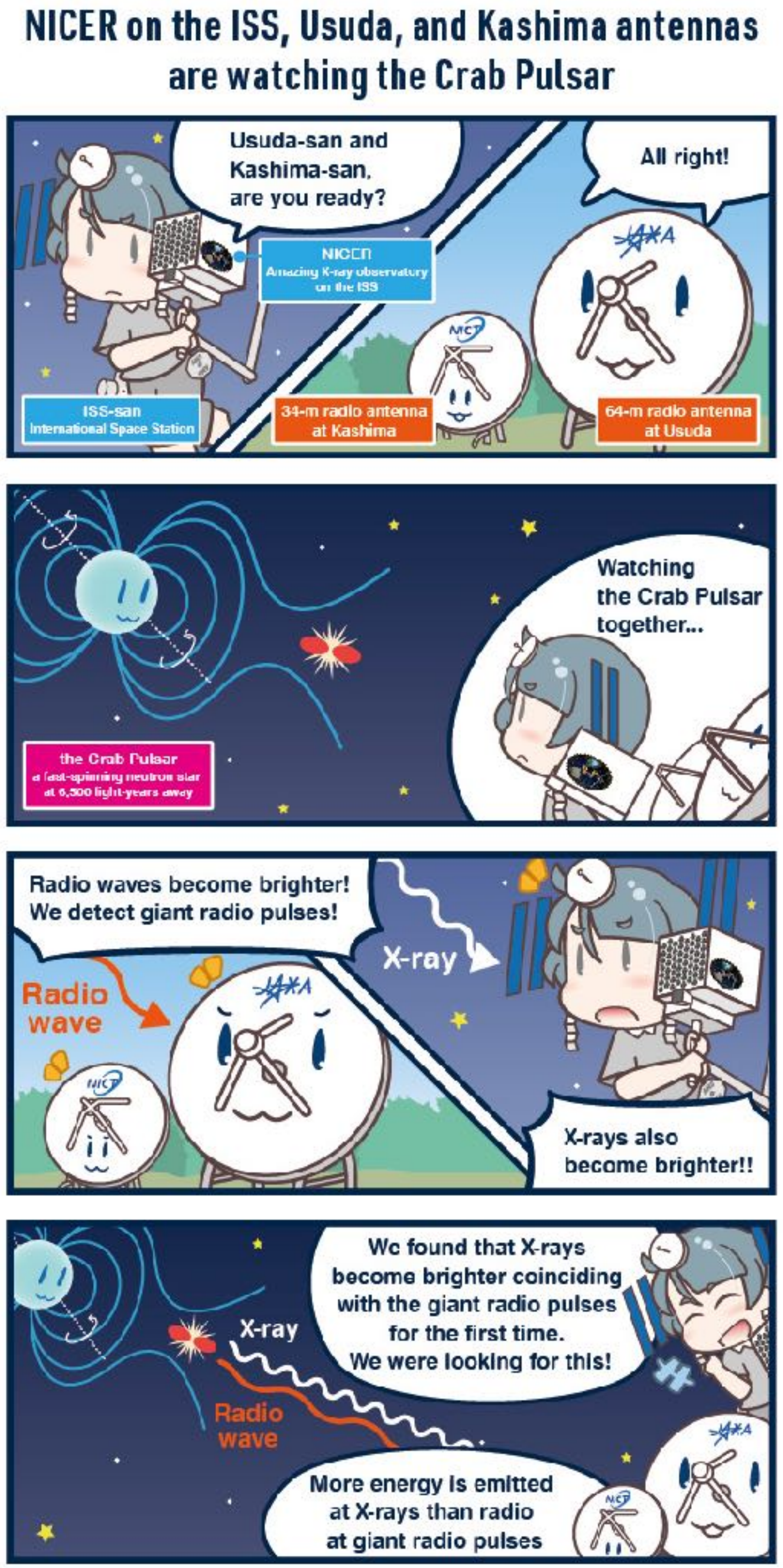


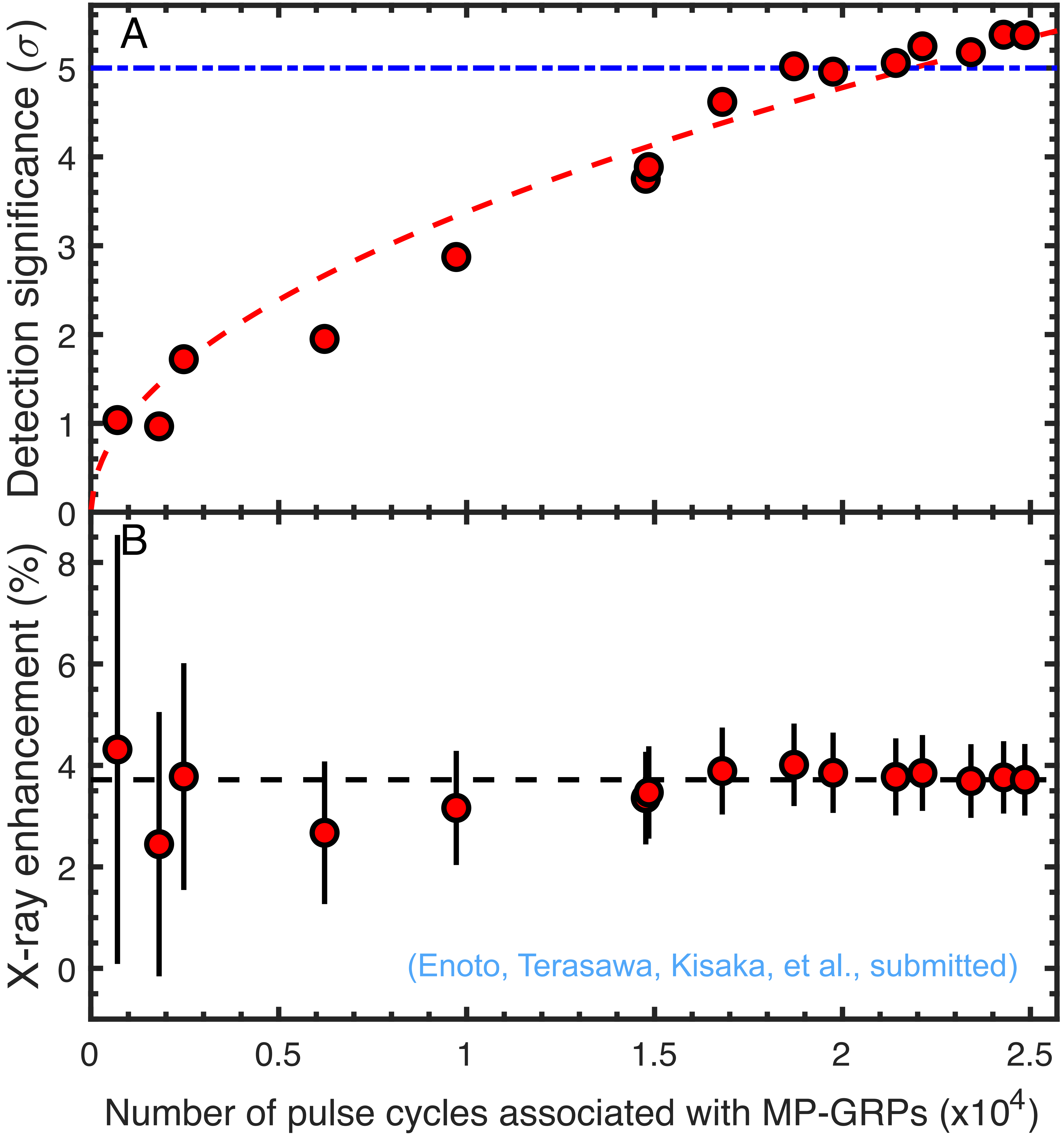
(Enoto, Terasawa, Kisaka, et al., submitted)

Discovery of X-ray enhancement at GRPs

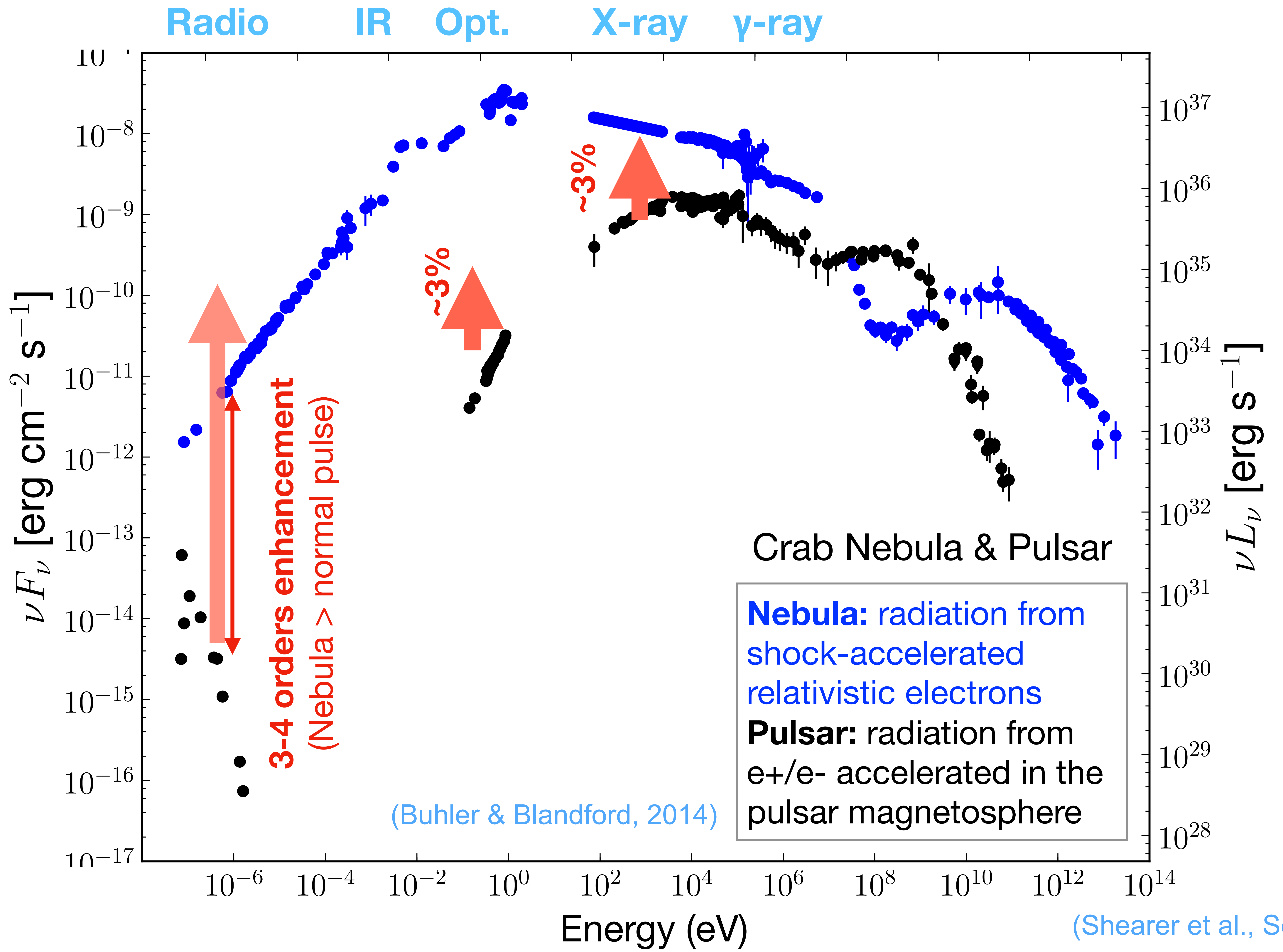


(Enoto, Terasawa, Kisaka, et al., submitted)


NICER on the ISS, Usuda, and Kashima antennas are watching the Crab Pulsar
Usuda-san and Kashima-san, are you ready?
All right!
NICER Amazing X-ray observatory on the ISS
ISS-san International Space Station
34-m radio antenna at Kashima
64-m radio antenna at Usuda
Watching the Crab Pulsar together...
the Crab Pulsar a fast-spinning neutron star at 6,500 light-years away
Radio waves become brighter! We detect giant radio pulses!
X-ray
Radio wave
X-rays also become brighter!!
We found that X-rays become brighter coinciding with the giant radio pulses for the first time. We were looking for this!
X-ray
Radio wave
More energy is emitted at X-rays than radio at giant radio pulses


A
B
Detection significance (σ)
X-ray enhancement (%)
Number of pulse cycles associated with MP-GRPs (x10^4)
0
0.5
1
1.5
2
2.5
(Enoto, Terasawa, Kisaka, et al., submitted)

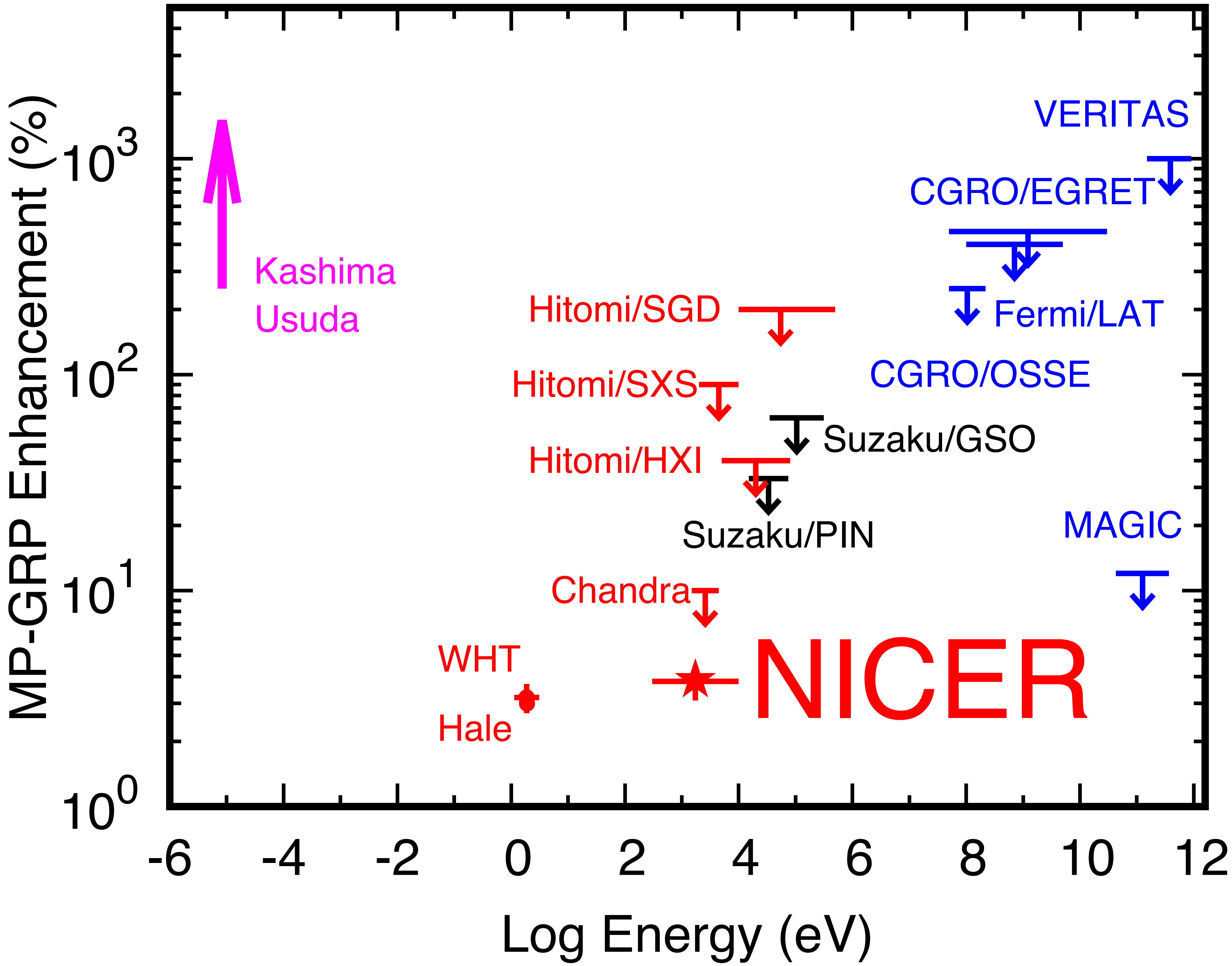
Optical enhancement coincided with GRPs



- Radio
  - $10^{3\text{-}4}$ enhancement
- Optical
  - Discovery of 3.2% enhancement (7.2σ) coincidences with Crab GRPs
- X-ray
  - Discovery of 3.8% enhancement

(Shearer et al., Science ,2003; Strader et al., ApJL 2013)

Discovery of X-ray enhancement at GRPs



- X-ray enhancement coincided with GRPs from the Crab Pulsar
  - Enhancement: 3.8±0.7 %
  - Significance: 5.4σ
- Since the energy band extends to X-rays, **the total emitted energy from a GRP is revealed to be tens to hundreds of times brighter than previously thought.**

(Enoto, Terasawa, Kisaka, et al., submitted)

Implication of X-ray detection of the Crab GRPs

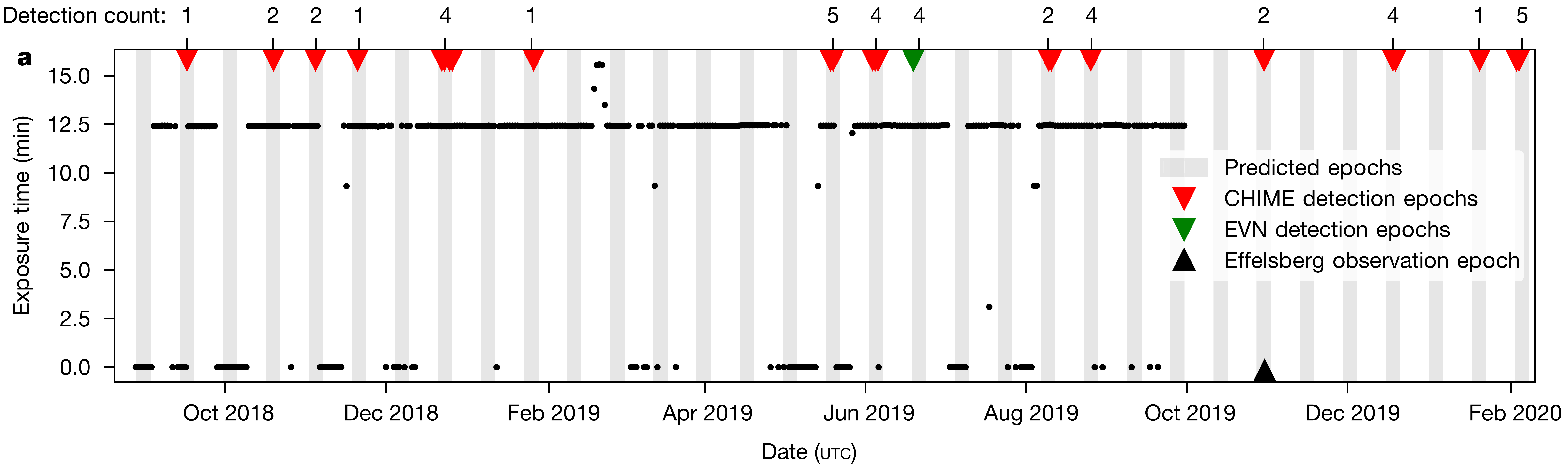
- Hypothetical bright GRP is a candidate for the origin of FRBs especially repeating source.
- The energy source of FRBs is assumed to be the spin-down luminosity.
- The discovery of X-ray enhancement suggests:
  - Since the broadband luminosity of the Crab pulsar GRPs, including the X-ray emission is revealed to be $10^{2\text{-}3}$ times higher than we previously thought, the simple GRP model became more difficult for the FRB origin.
  - the connection between the coherent radio emission and incoherent X-ray radiation in the neutron star magnetosphere. This is also shown the FRB-associated bursts from SGR 1935+2154.Hypothetical bright GRP is a candidate for the origin of FRBs especially repeating source.

Kashiyama & Murase, 2017; Kisaka, Enoto, Shibata 2017

Magnetar candidates in binary systems?

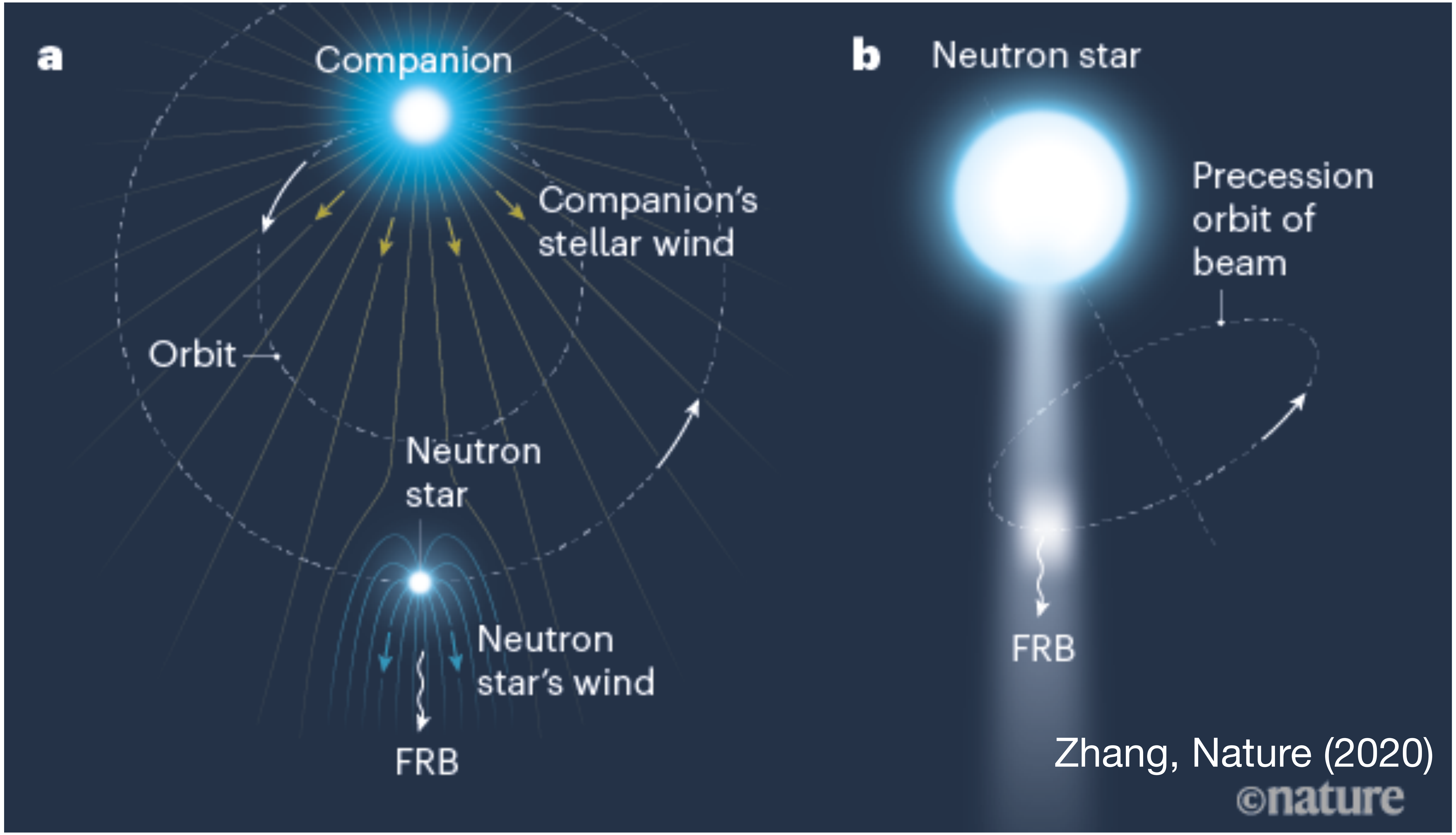
- Title

Reported periodicities of FRBs



- FRB 180916.J0158+65
  - 16.35±0.16 day periodicity (CHIME/FRB collaboration, Nature, 2020)
  - Burst-active phase depends on frequencies (150 MHz, 600 MHz, & 1.4 GHz)
- FRB 121102
  - 161 days periodicity (Rajwade+2020, Cruces+2021)

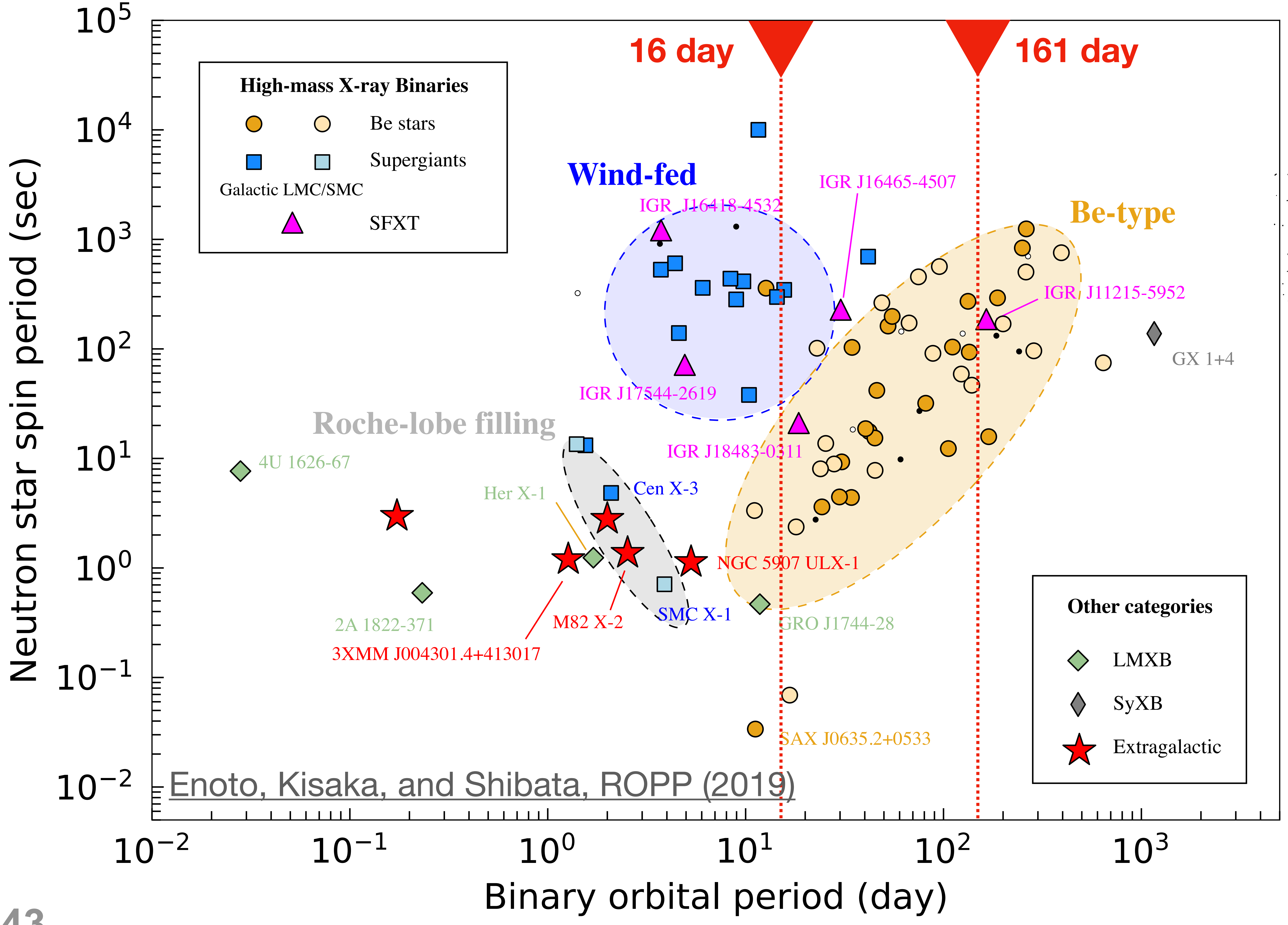
Two scenarios to explain the periodicities



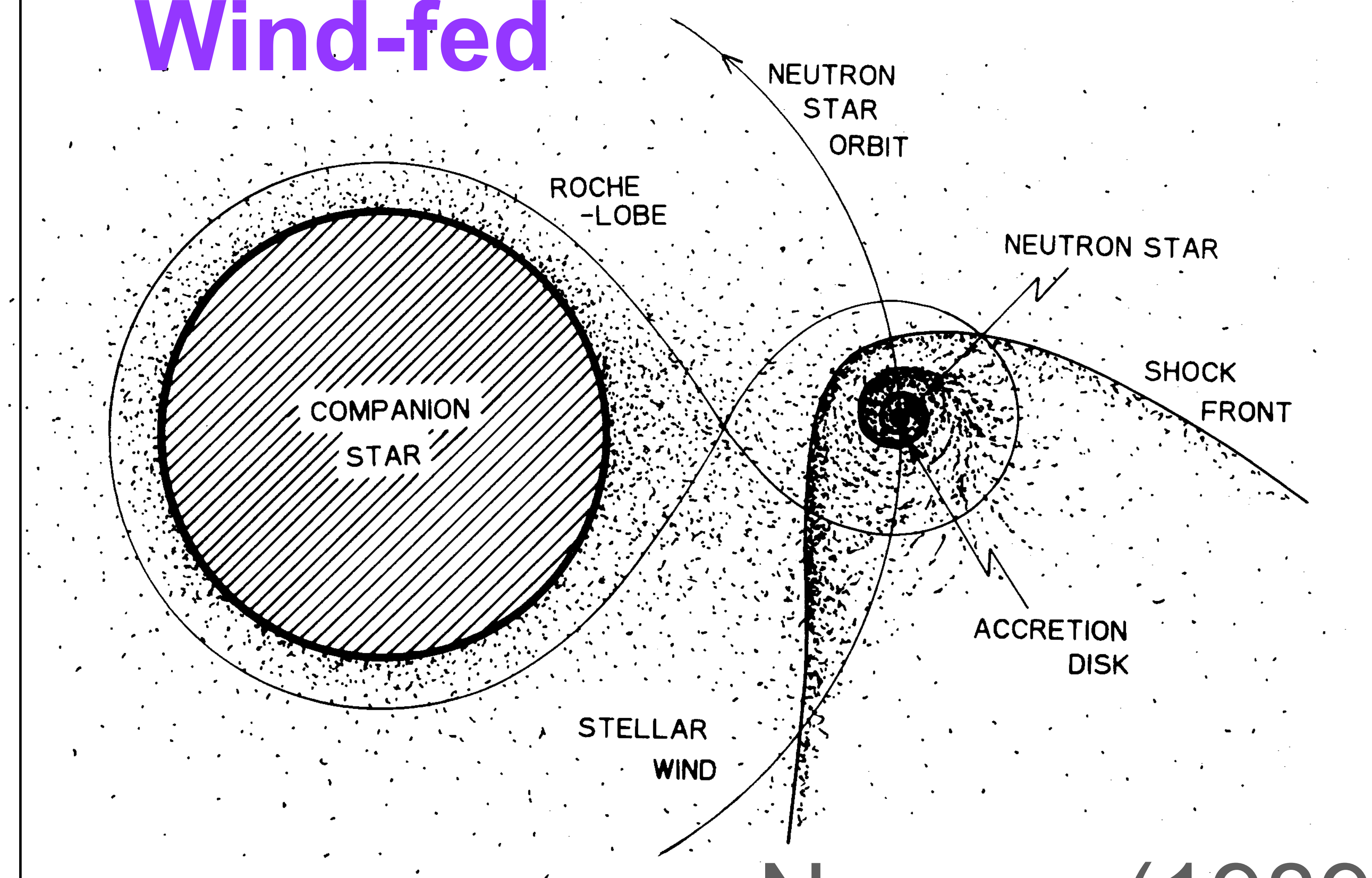
Zhang, Nature (2020)

- Binary model (e.g., Ioka & Zhang 2020)
  - NS binary motion (orbital separation & mass)
- Precession model (e.g., Levin et al. 2020)
  - NS deformation (ellipticity)

Binary model: Compared with the Corbet diagram

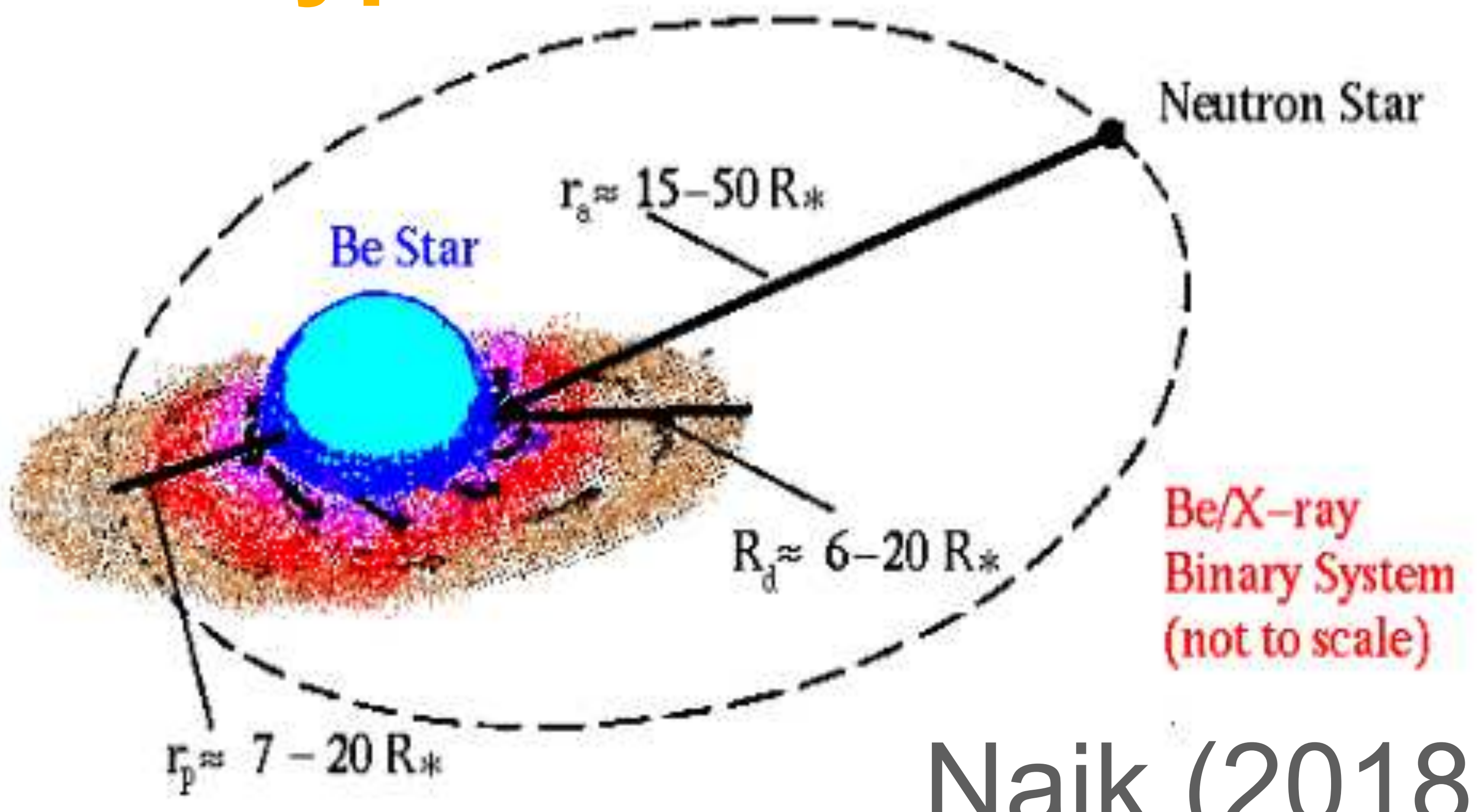


Wind-fed



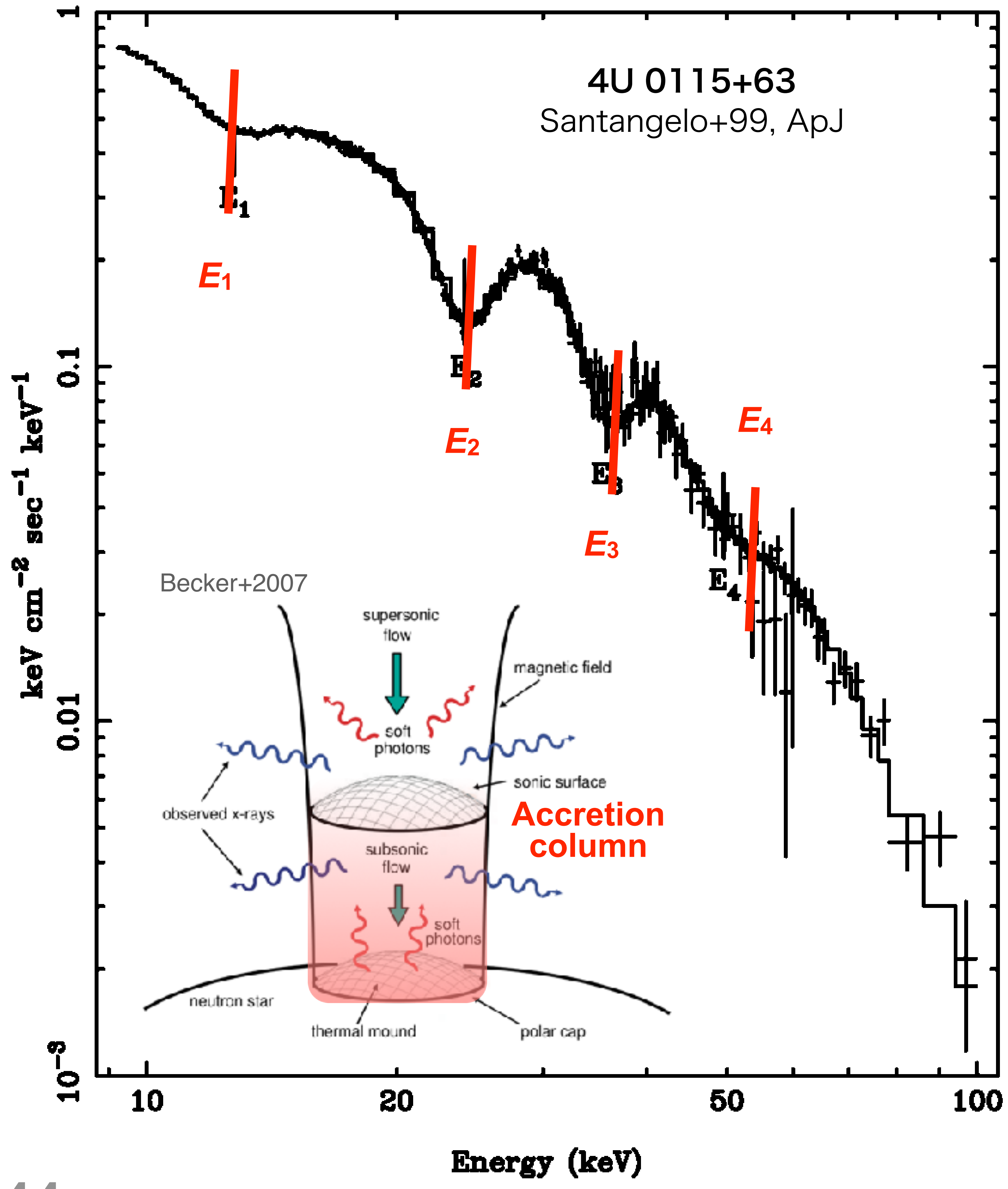
Nagase (1989)

Be-type



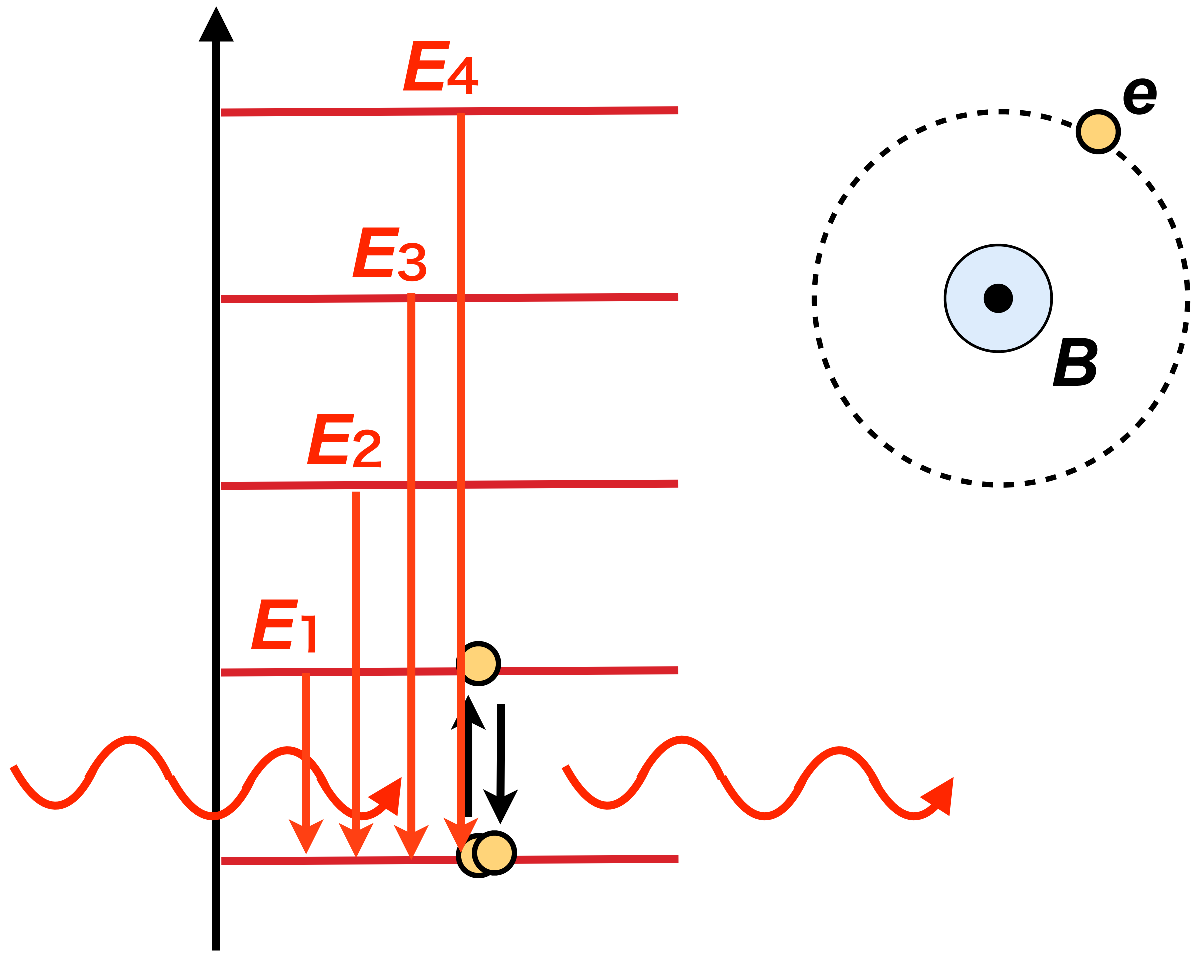
Naik (2018)

Magnetar in a binary system? (1) CRSF B-feild

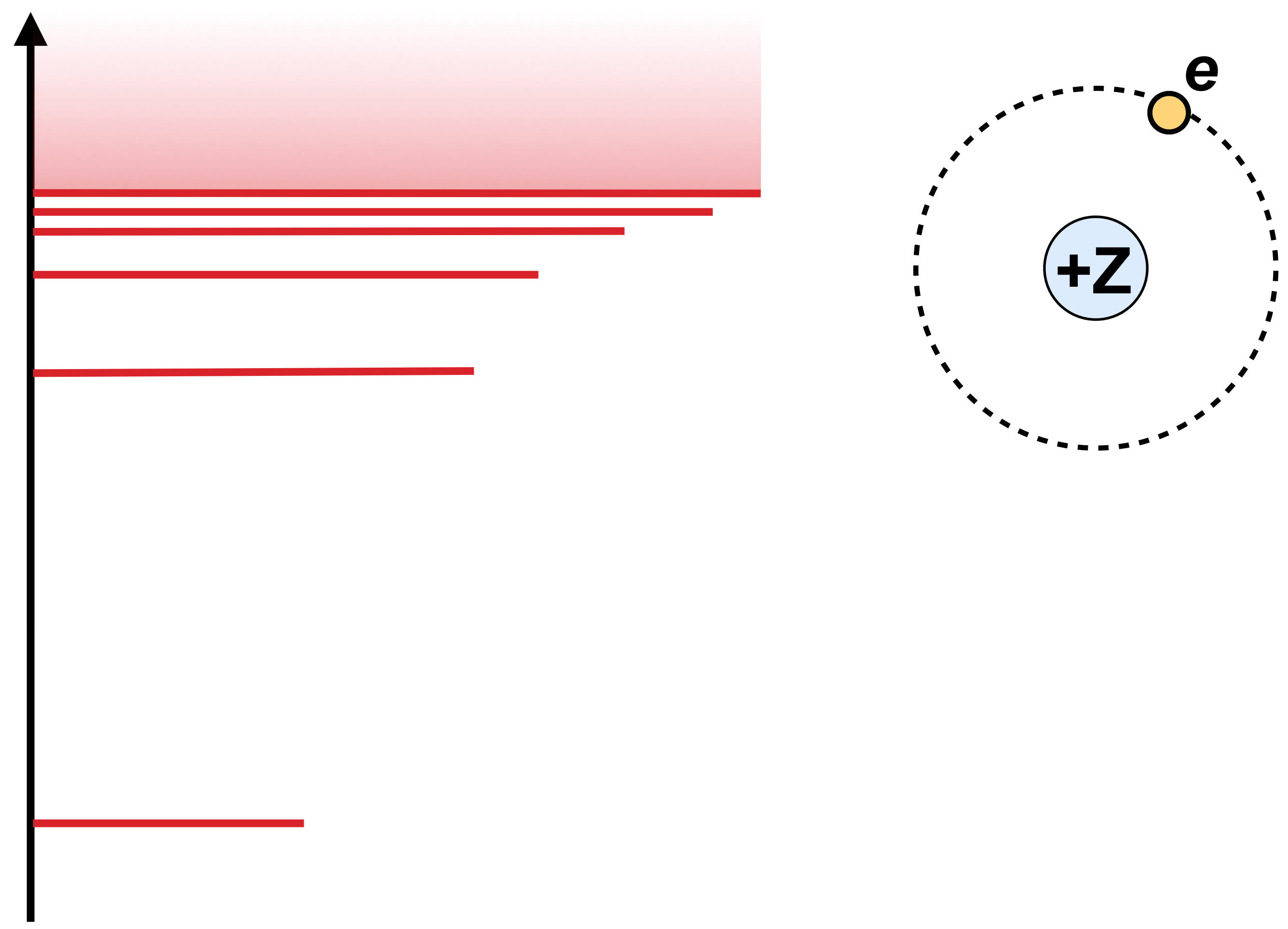


- Electron cyclotron resonance scattering features (CRSF) are detected from ~20 accretion powered X-ray pulsars as X-ray absorption lines.

electron in B-field



electron in an Atom



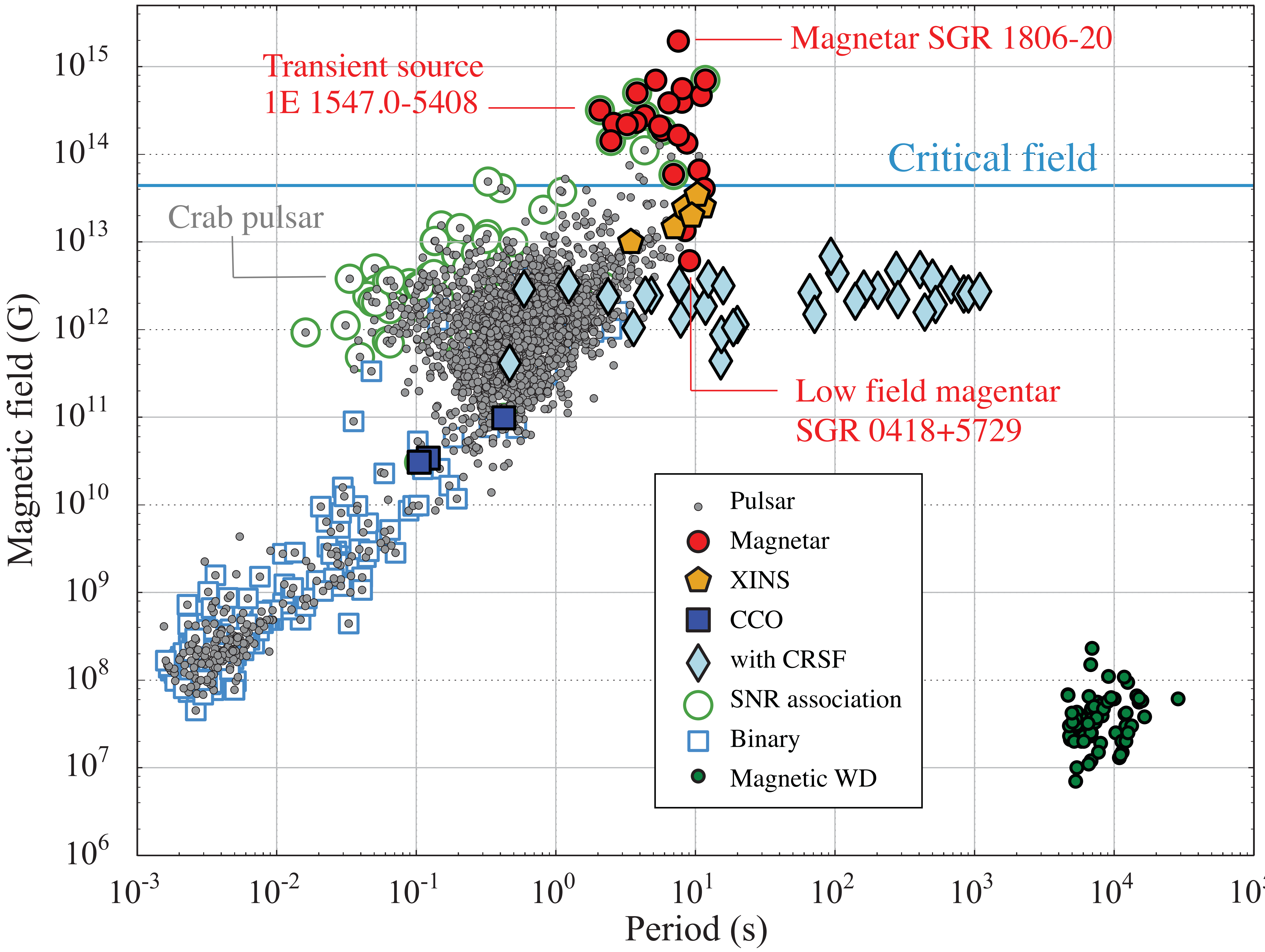
$$E_n = n\hbar\omega_c = m_e c^2 \frac{B}{B_c} \cdot n$$

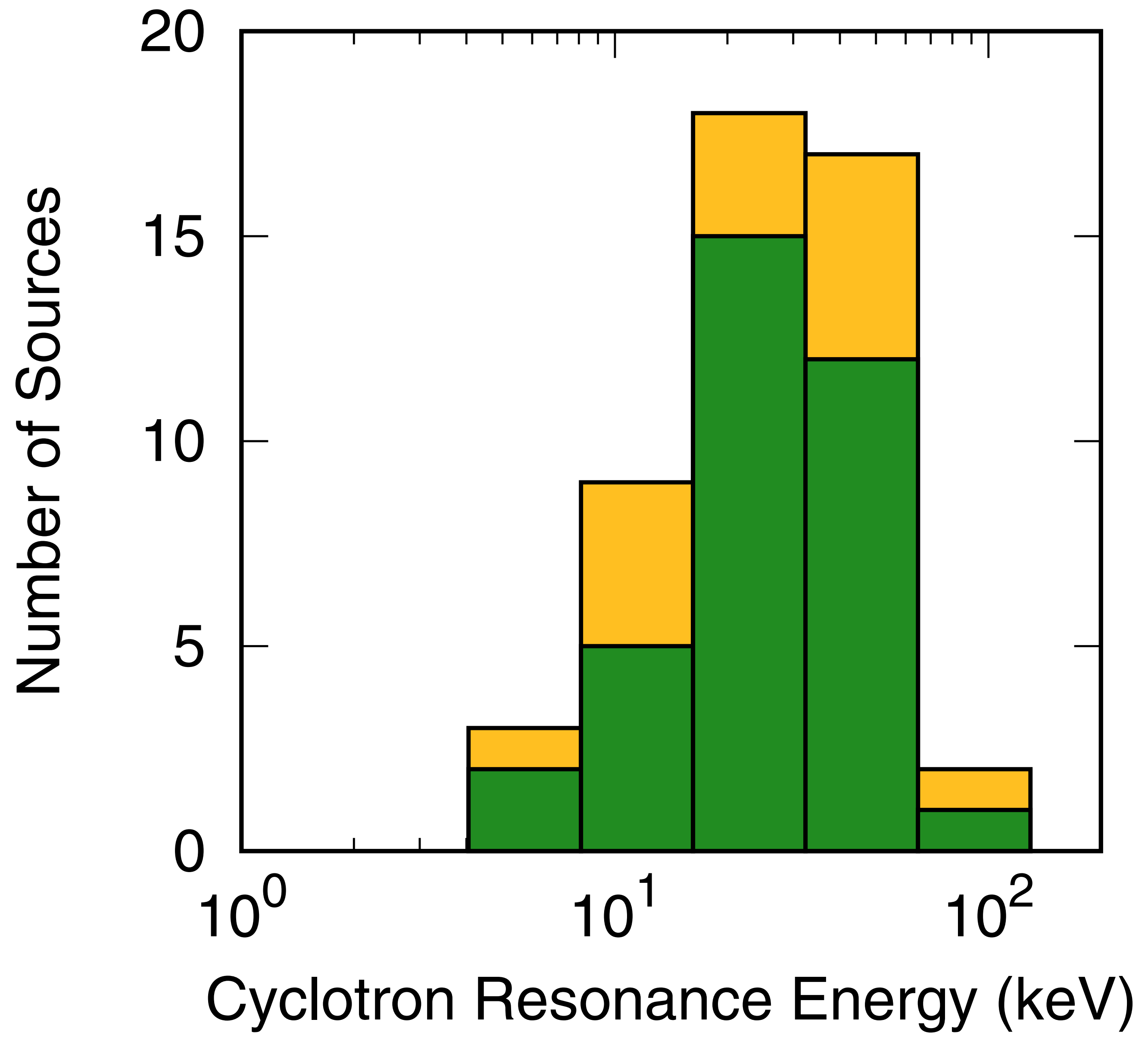
$$B_{cr} = \frac{m_e^2 c^3}{\hbar e} = 4.4 \times 10^9 \ \mathrm{T}$$

$$E_n = -\frac{\alpha^2}{2} m_e c^2 \cdot \frac{Z^2}{n^2}$$

E_n~ 13.6 eV for H (Z=1)
7~9 keV for Fe (Z=26)

Magnetar in a binary system? (1) CRSF B-feild





- Electron CRSF up to ~100 keV
- Magnetic fields up to 10^{13} G
- No confirmed magnetar in binary systems via the CRSF method.
- (Note) Proton CRSFs are reported from isolated magnetars

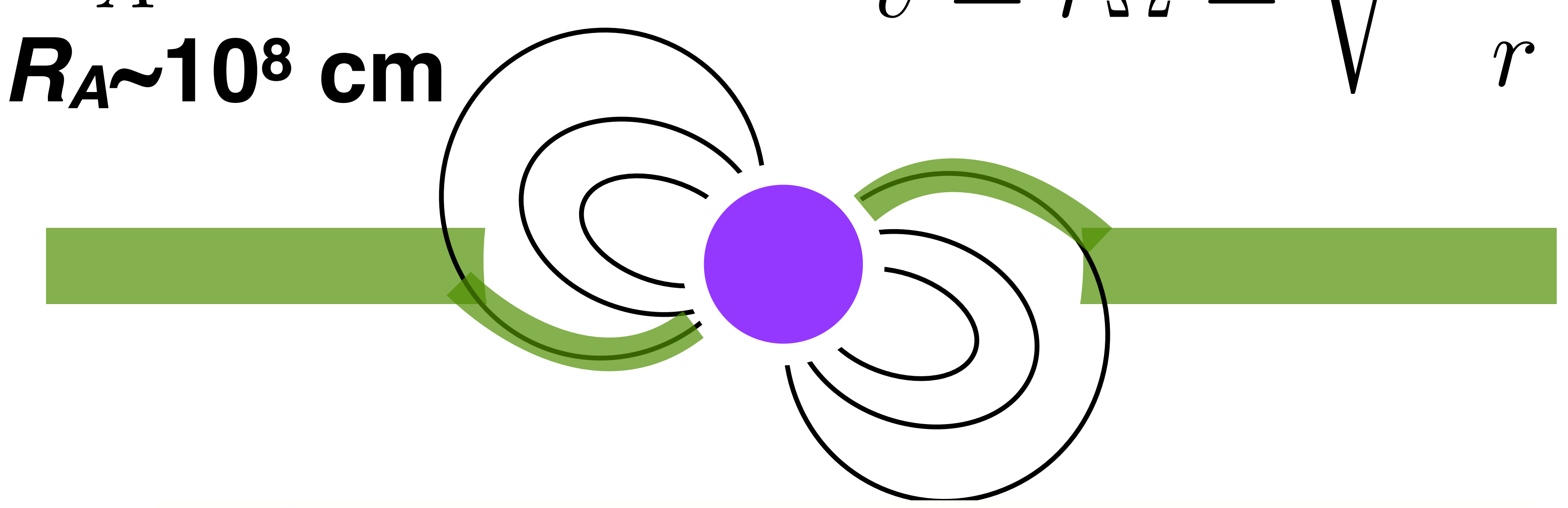
Enoto, Kisaka, and Shibata, ROPP (2019)

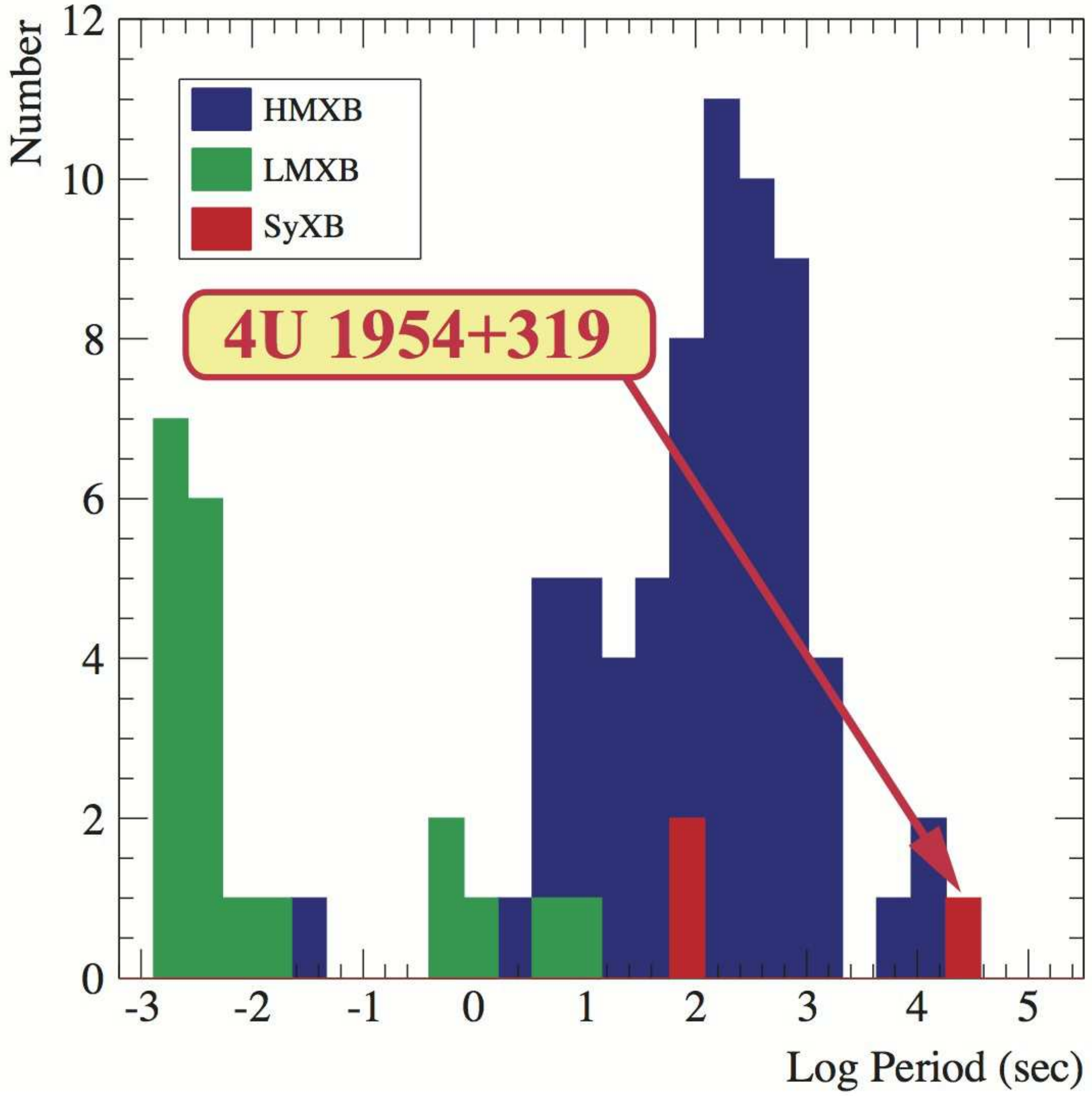
Magnetar in a binary system? (2) Spin period

$R_A \propto B^{4/7}$

$R_A \sim 10^8$ cm

$v = r\Omega = \sqrt{\frac{GM}{r}}$





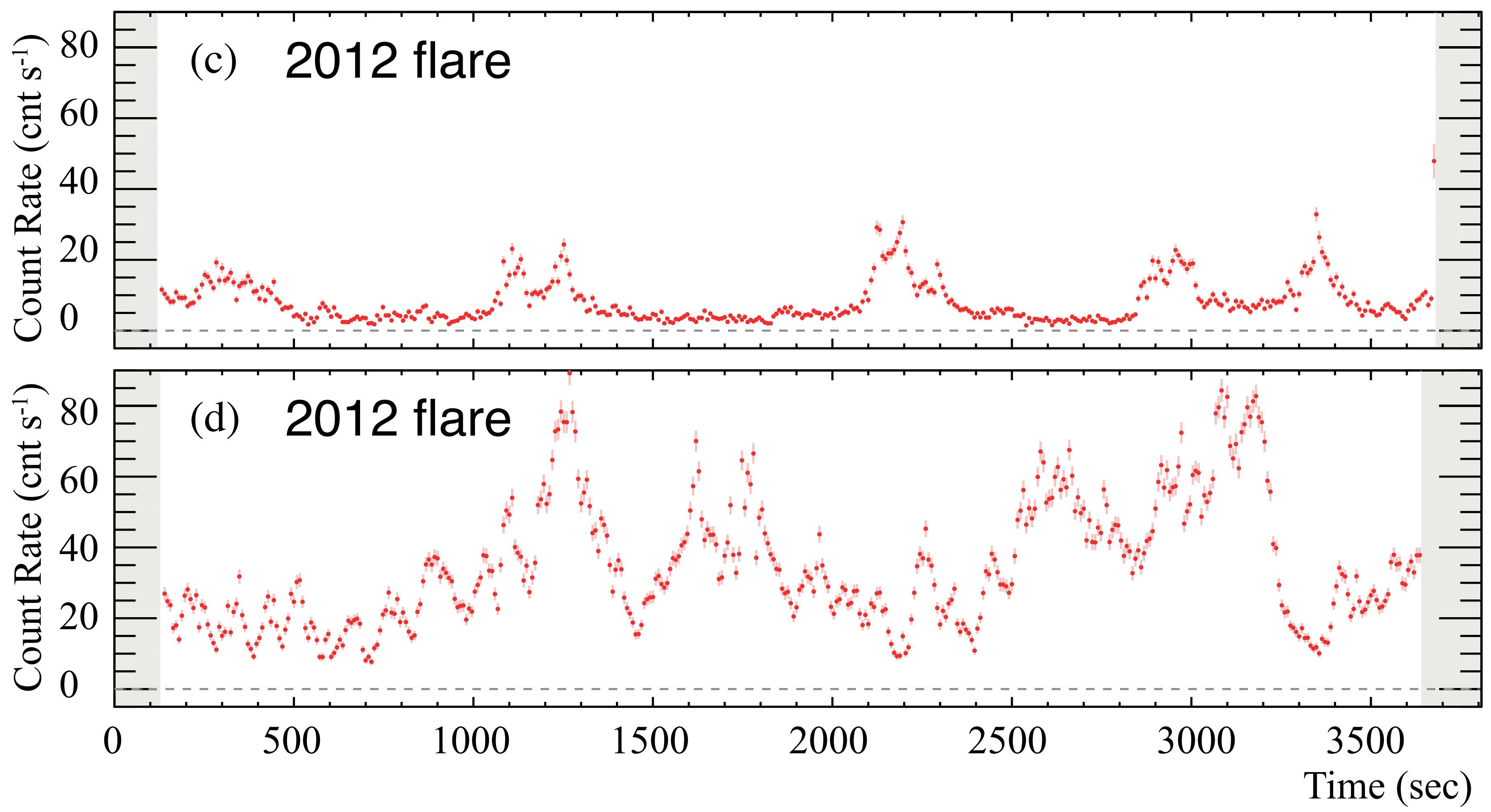
Enoto, et al., ApJ (2014)

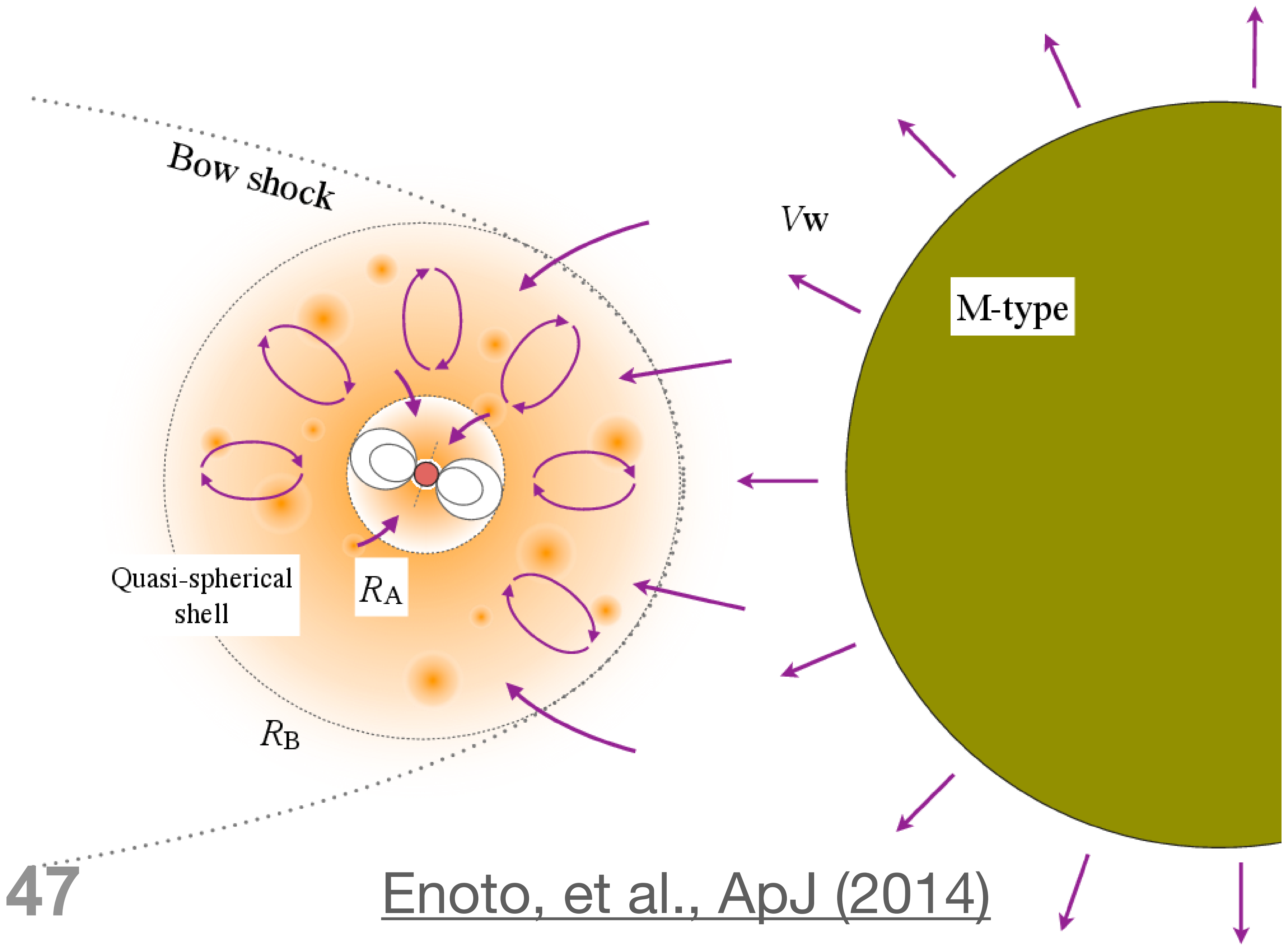
- Accretion disk rotate at the rotational (Keplerian) ferocity and interacts with a neutron star at the Alfven radius.
- Strongly-magnetized pulsars interact at larger Alfven radii where the disk rotates slowly. Thus, at the equilibrium, the NS rotates more slowly.
  - (e.g., B ∝ P 7/6 for disc accretion)

Davidson+1973, Alpar+82 etc; also wind/non-equilibrium models

- Are long-period pulsars in high-mass X-ray binaries (HMXBs) magnetars?
  - 4U 2206+54 (P~1.6 hour, Patel+2007)
  - IGR J16358-4726 (1.6 h, Reig+2002)
  - 4U 0114+65 (2.7 h, Li+1999)

Symbiotic X-ray binary 4U 1954+319 (P~5.4 hr)





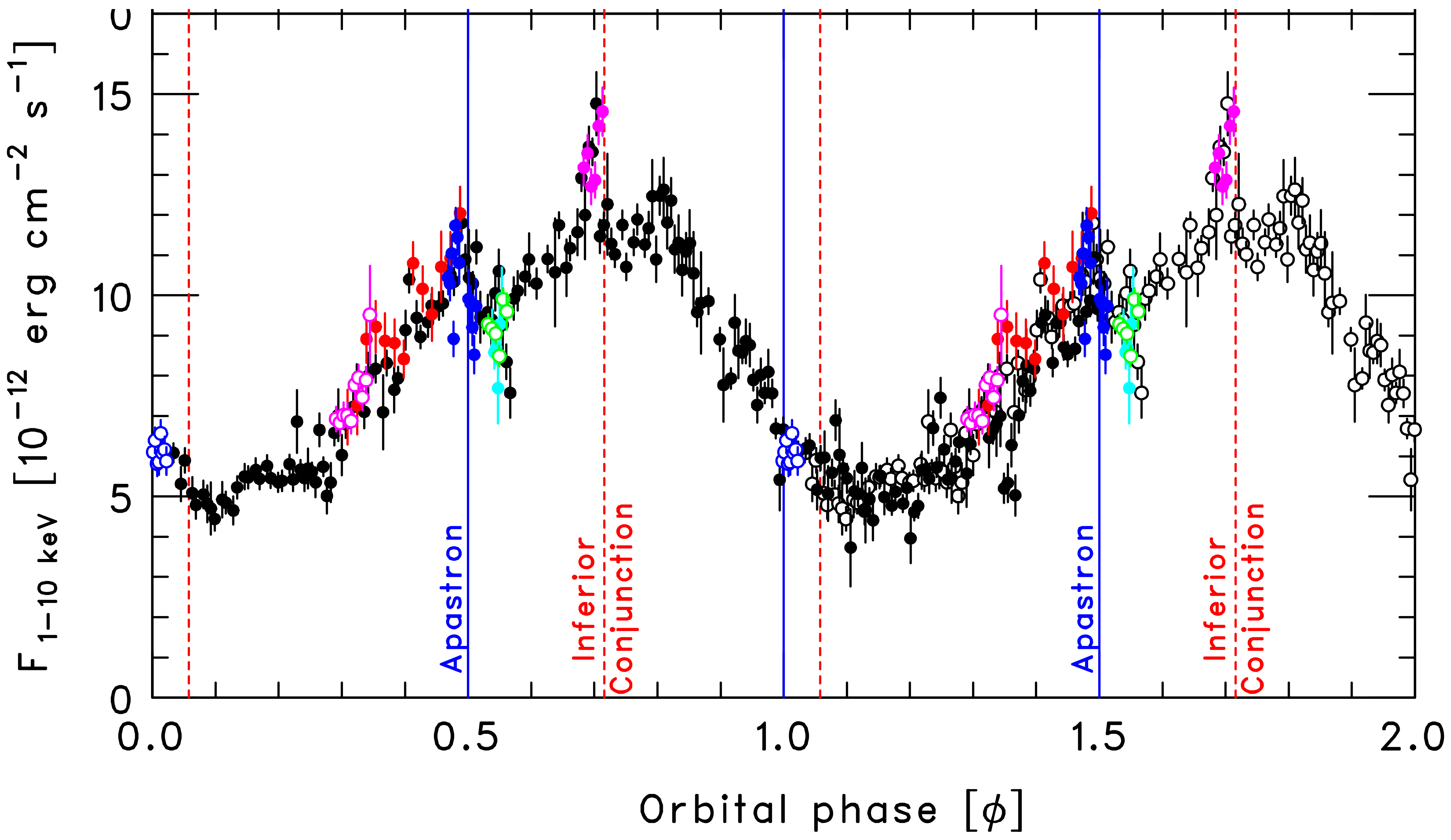
- Symbiotic X-ray binary (SyXB):
  - NS (long spin period) + an M-type giant
- Discovered in 1970's but virtually forgotten for 20 years. 5.4-hour pulsation varies by ~7% for 8 years → spin period close to the equilibrium.
- If the disk accretion, B >~ $10^{15\text{-}16}$ G
- No magnetar-like intense short bursts, but Irregular short flares (Δt ~10-10^3 s).
- Typical timing & spectral features of wind-fed X-ray pulsar of B > 10^{12} G field
- **Quasi-spheric accreting in a wind-fed system with a NS of B~10^{13} G can explain the long spin period and the duration of short flares.**

Enoto, et al., ApJ (2014)

Gamma-ray binaries as a candidate of the FRB binary model?

- Sub-class of high-mass X-ray binaries with different features from other X-ray binaries
  - Dominant non-thermal emission to TeV
  - 2 (or 3) systems have pulsars
- LS5039: Stable X-ray light curve → wind?
  - Orbital period 3.9 days, e=0.35
  - Companion star: O-type, 22.9 M_{sun}
  - Compact object: NS os BH, >1.5 M_{sun}

Kishishita+09

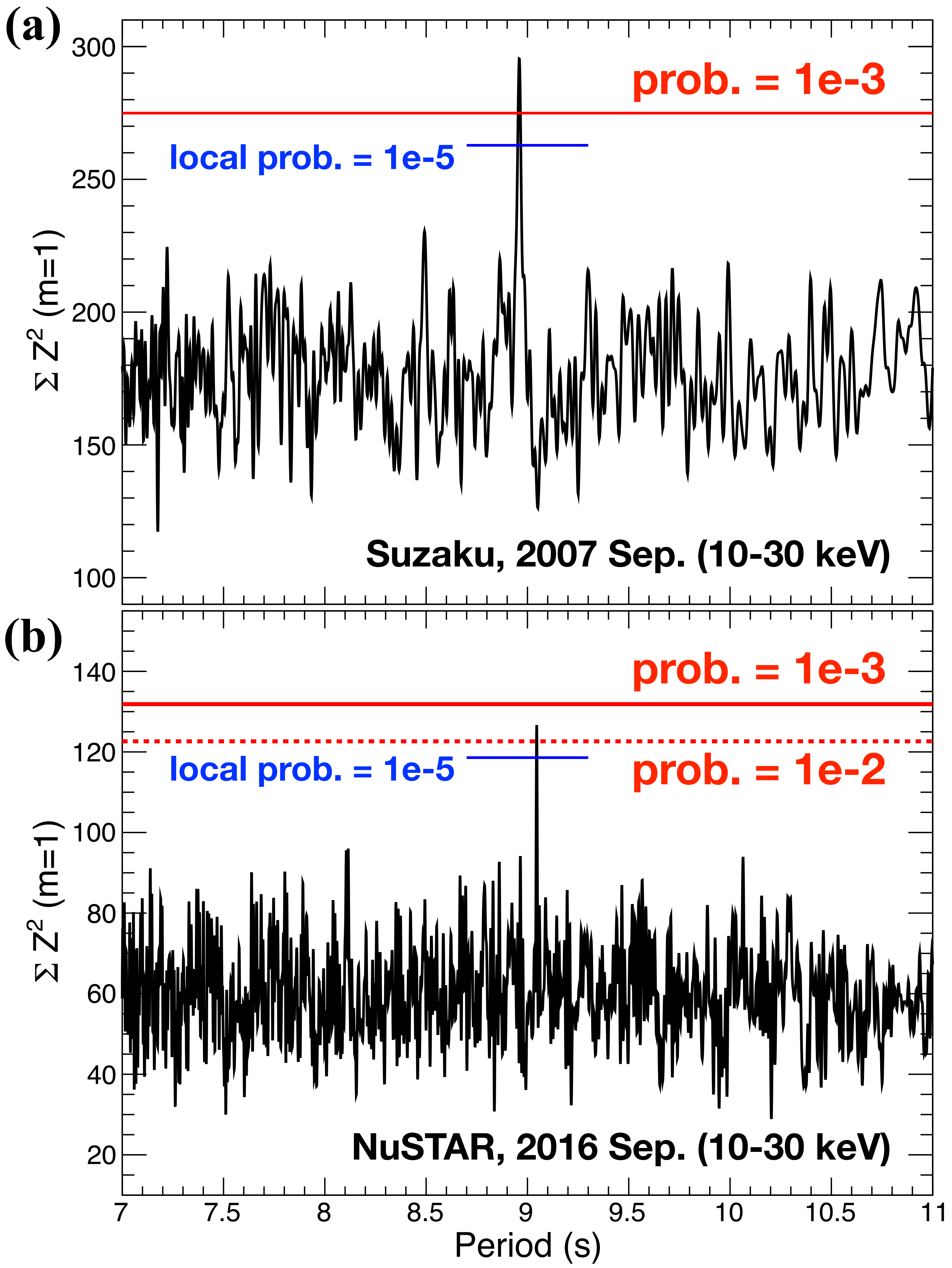


Source	Opt.	Period	Orbital
LS 5039	O	?	3.9 day
FGL J1018.6-5856	O	?	16.6 day
LMC P-3	O	?	10.2 day
4FGL J1405.1-6119	O	?	13.7 day

Source	Opt.	Period	Orbital
HESS J0632+057	Be	?	315.5 day
LS I+61 303	Be	?	26.5 day
PSR J2032+4127	Be	143 ms	50 year
PSR B1259-53	Be	43 ms	3.4 year

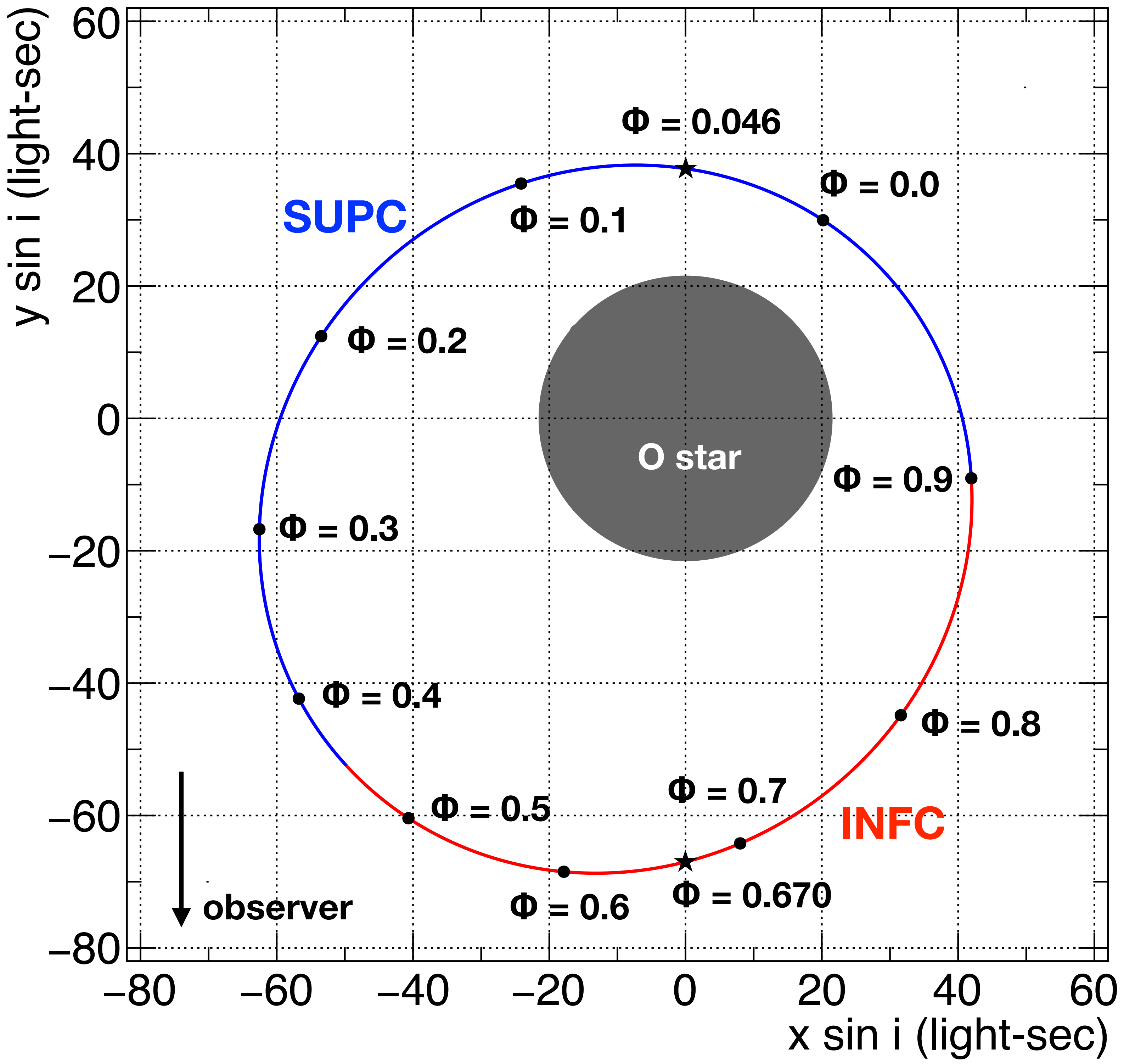
Signature for hard X-ray pulsations of LS 5039

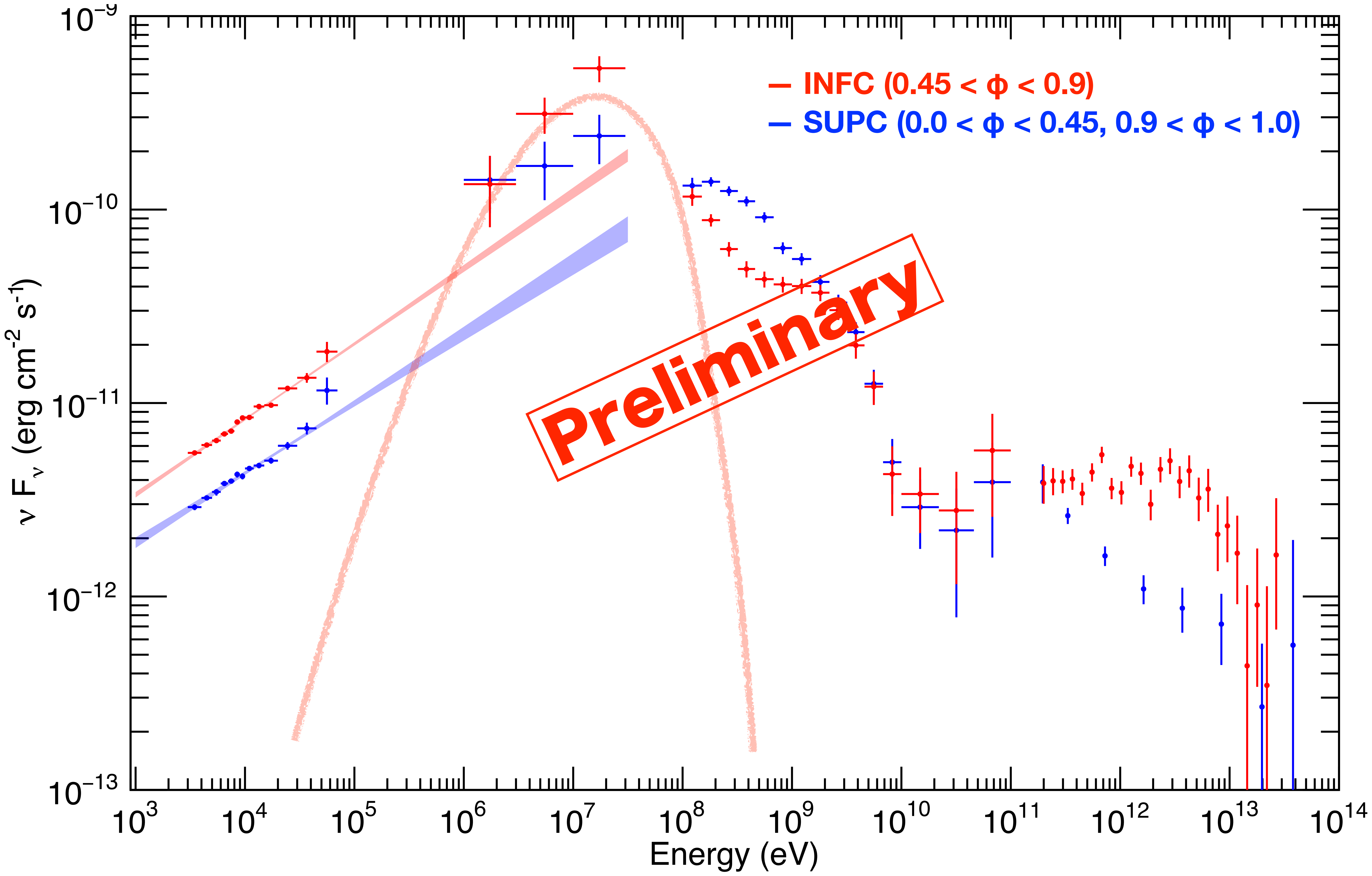
- LS5039 is the brightest gamma-ray binary with a short orbital period (3.9 day), being observed extensively over the entire orbit.
- We found a periodicity at 8.96±0.01 s from the Suzaku/HXD hard X-ray observation with a chance probability of 1.1×10^{-3}.
- In the NuSTAR data 11 years after the Suzaku one, the periodic signal was also found at 9.046±0.009 s with smaller significance.
- Further confirmation is needed. If the compact object is a 9-s rotating pulsar, period derivative is Pdot~3×10^{-10} s/s.



Yoneda, Makishima, Enoto et al., PRL (2020)

SED of LS 5039





- Is the dominant MeV component synchrotron emission in strong magnetic fields?
  - Peat at ~20 keV → efficient particle acceleration (η < 10)
  - Not to overestimate the TeV emission → strong magnetic field (B >~ 3 G)
  - Hard photon index → hard electron spectrum (s < 2)

Yoneda et al., in prep (2021)

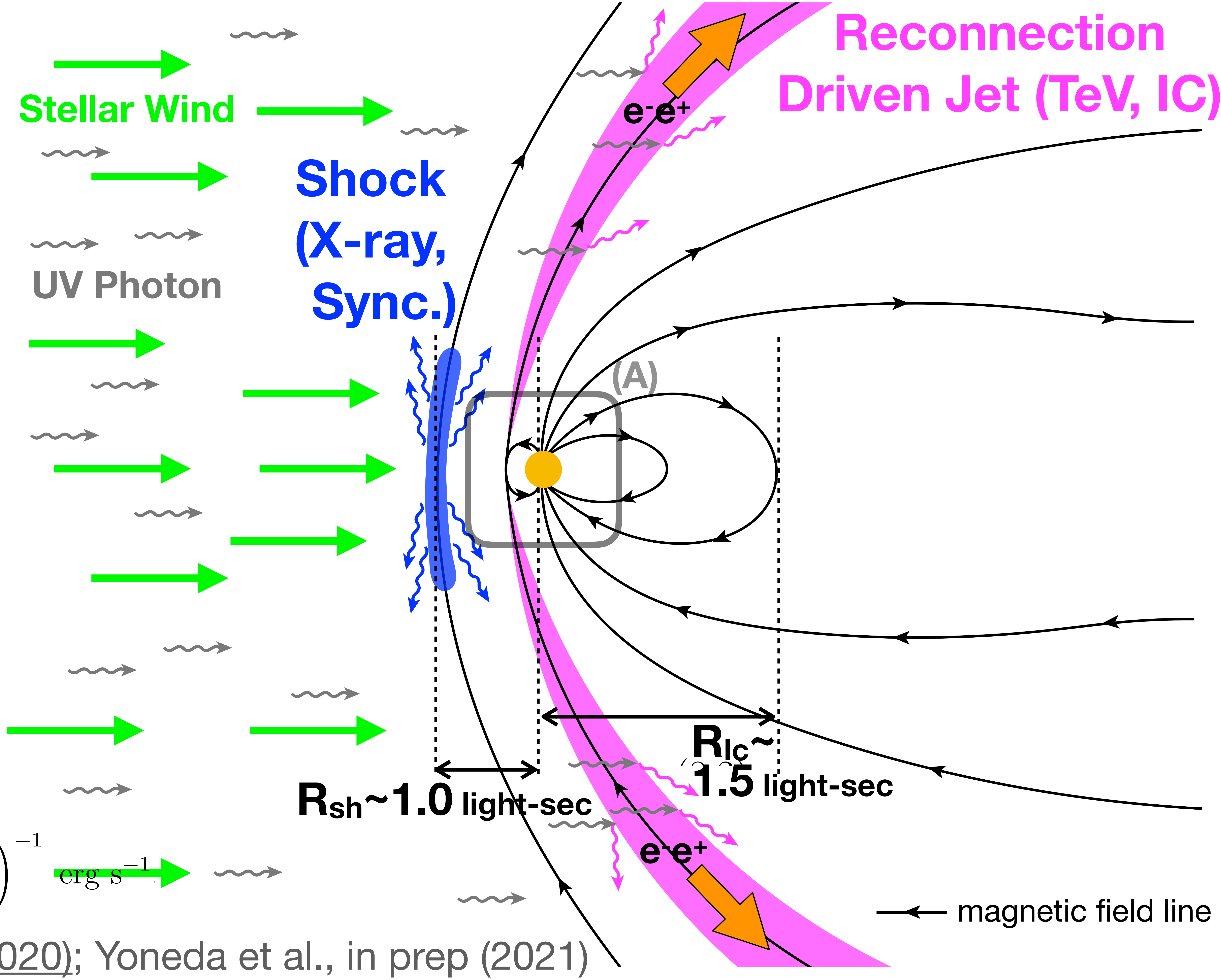
Reconnection model of a magnetar in a binary system?

- Observed $L\sim10^{36}$ erg/s
- Spin-down luminosity
  - P~9 s & $P_{\rm dot}$ ~ 3x10^{-10} s/s → $L_{\rm sd}$ ~ 10^{34} erg/s (not enough)
- Accretion powered?
  - Non-thermal, different from accreting powered pulsars, No timing variability
- Stellar wind

$$L_{\rm w} \sim \frac{1}{2}\dot{M}_{\rm w}v_{\rm w}^2 \times \frac{\pi R_{\rm A}^2}{4\pi D_{\rm sep}^2} = 6\times10^{31}\,{\rm erg\ s^{-1}}$$

- Magnetic energy (reconnection)

$$L_{\rm BF} = \frac{B_{\rm NS}^2 R_{\rm NS}^3}{6\tau} \sim 10^{37}\times\left(\frac{B_{\rm NS}}{10^{15}\ {\rm G}}\right)^2\left(\frac{R_{\rm NS}}{10\ {\rm km}}\right)^3\left(\frac{\tau}{500\ {\rm yr}}\right)^{-1}{\rm erg\ s^{-1}}$$



 Yoneda, Makishima, Enoto et al., PRL (2020); Yoneda et al., in prep (2021)

Pulsations discovered from LS I +61 303

FAST Detected A Transient Periodic Signal In The Direction of LS I +61 303

ATel #14297; *Shan-Shan Weng* (NJNU), ZhiChen Pan* (NAOC), Lei Qian* (NAOC), Peng Jiang (NAOC), Ming-Yu Ge (IHEP), Jing-Zhi Yan (PMO), Qing-Zhong Liu (PMO)*
on 1 Jan 2021; 00:00 UT
Credential Certification: Shan-Shan Weng (wengss@ihep.ac.cn)

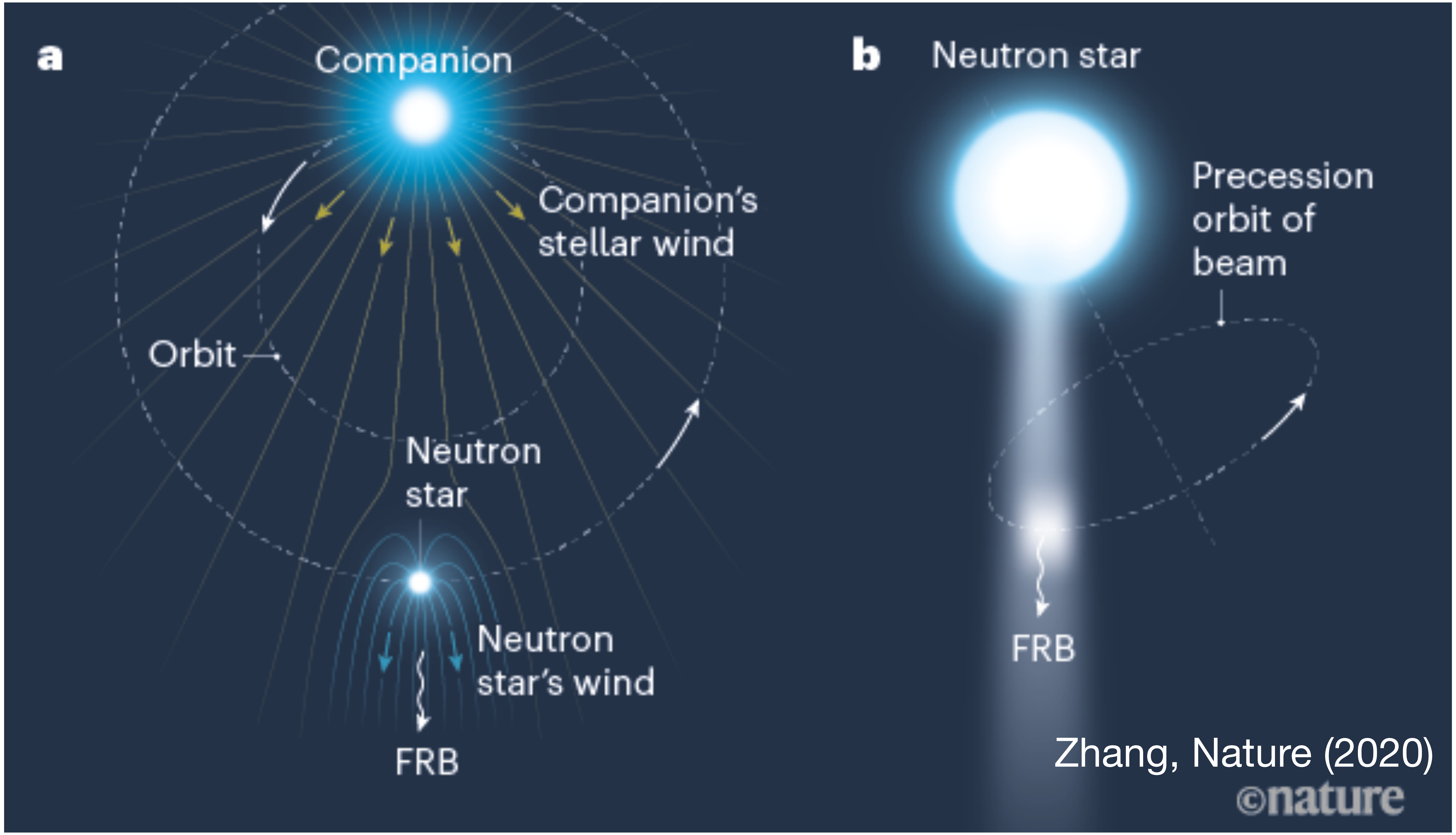
Subjects: Radio, Gamma Ray, Binary, Neutron Star, Pulsar

Tweet

The gamma-ray binary, LS I +61 303 contains a rapid rotating B0 Ve star and a compact object with unknown nature. The Five-hundred-meter Aperture Spherical radio Telescope (FAST, Nan et al. 2011, IJMPD, 20, 989; Jiang et al. 2019, SCPMA, 62, 959502) observed it for four times on 2019-11-02, 2020-01-07, 2020-09-02, and 2020-09-03, corresponding to the orbital phases of 0.07, 0.59, 0.58, and 0.62 (Aragona et al. 2009, ApJ, 698, 514). Observations with the 19-beam receiver covering 1.05-1.45 GHz lasted for 2-3 hours on average. We detected a periodic signal (20.8 sigma) with a period of 269.196 ms and a Dispersion Measure (DM) of 241 pc cm-3 in the data obtained on 2020-01-07. The slightly detectable acceleration of the signal might be the hint of a binary system. We adopted a DM range of 0-500 pc cm-3 but did not find any signal in any other data. As it is reported that a magnetar-like short burst was detected in the direction of LS I +61 303 (Torres et al. 2012, ApJ, 744, 106); therefore, this may indicate a strongly magnetized neutron star in the system. More FAST observations will be proposed to unveil the nature of LS I +61 303, and detailed data analysis will be reported later. FAST is a Chinese national mega-science facility, operated by National Astronomical Observatories, Chinese Academy of Sciences. We appreciate the FAST group for their support and assistance during the observations.

- LS I +61 303 is one of the brightest gamma-ray binary, but the compact object was yet unknown.
- FAST observed this object 4 times.
- They found a radio pulse from one of the observations.
- The period is 269.196 ms with 21 sigma level !
- This system also contains a pulsar?
- A magnetar-like X-ray burst was reported before (Torres+12)

Two scenarios to explain the periodicities

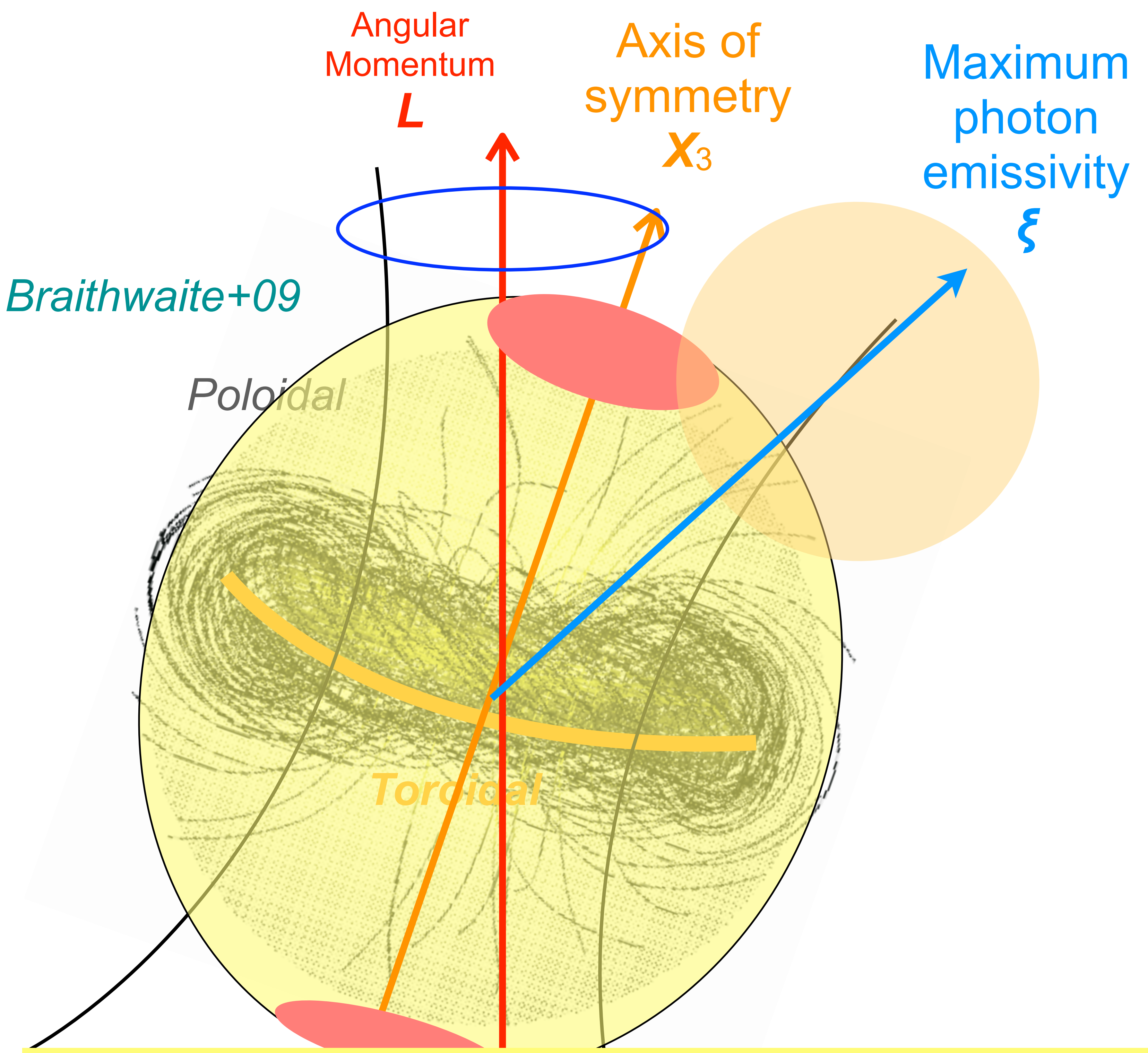


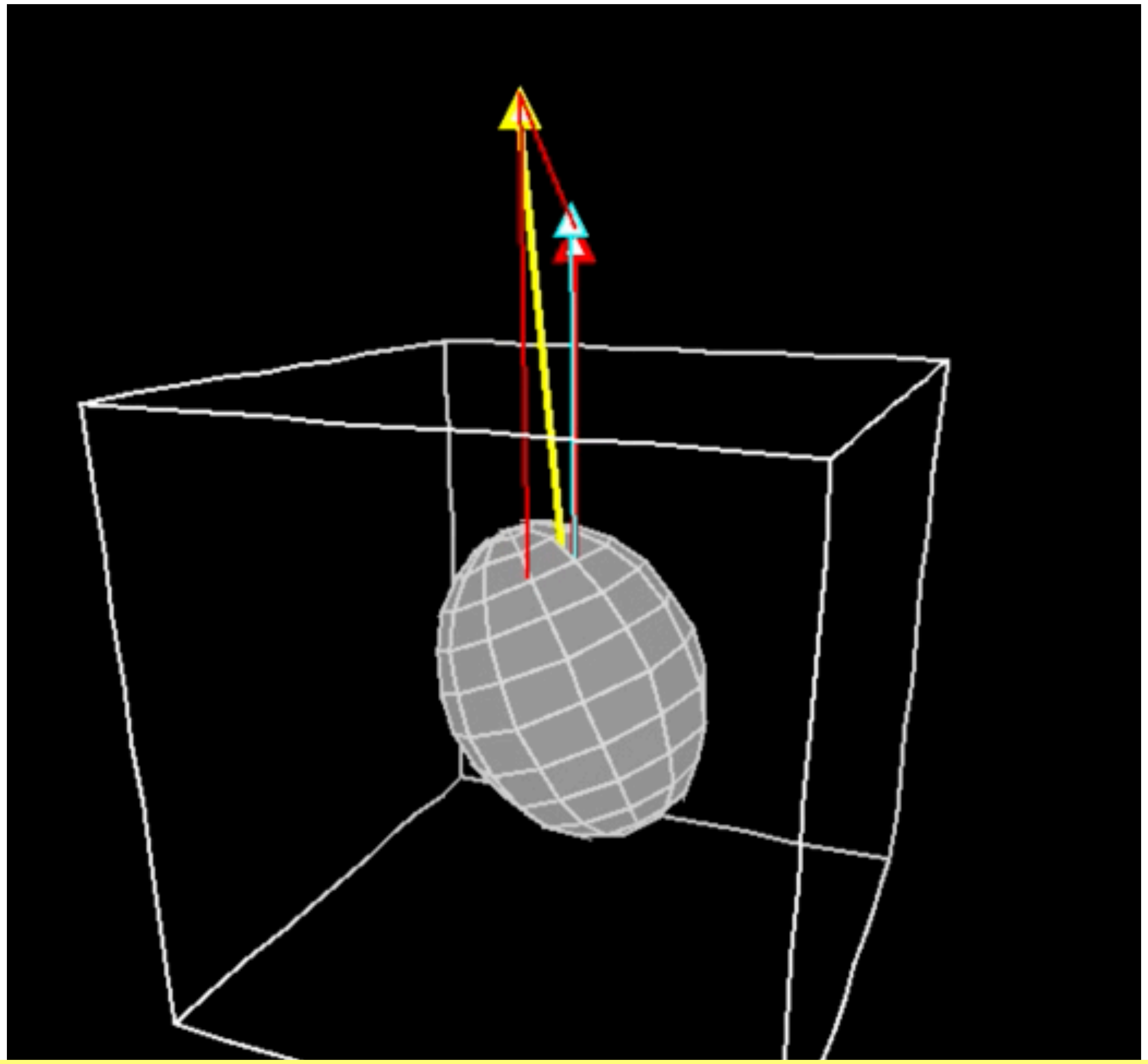
- Binary model (e.g., Ioka & Zhang 2020)
  - NS binary motion (orbital separation)
- Precession model (e.g., Levin et al. 2020)
  - NS deformation (ellipticity)

Toroidal magnetic field induced NS precession?

Huge energy reserver is needed inside the magnetars

⇒ Strong toroidal Field inside NSs? (can not be measured by P-P_{dot})





Toroidal B-field ⇒ Prolate shape

$$\epsilon = \frac{\Delta I}{I} \sim 10^{-4} \left(\frac{B_t}{10^{16}\,\mathrm{G}} \right)^2$$

Free Precession with period *Q*

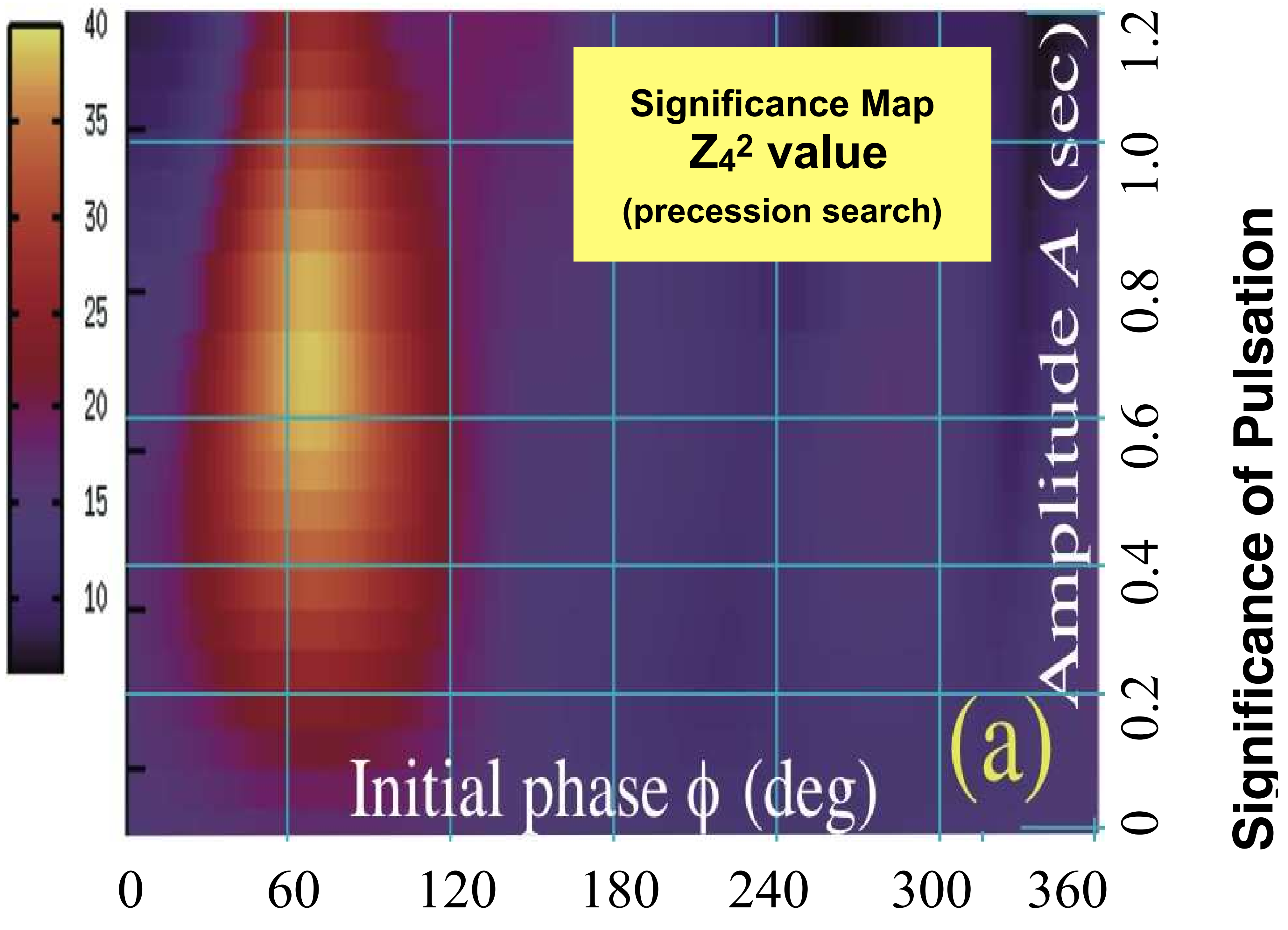
$X_3 \neq \xi$

$$Q = \frac{P_{\mathrm{spin}}}{\epsilon}$$

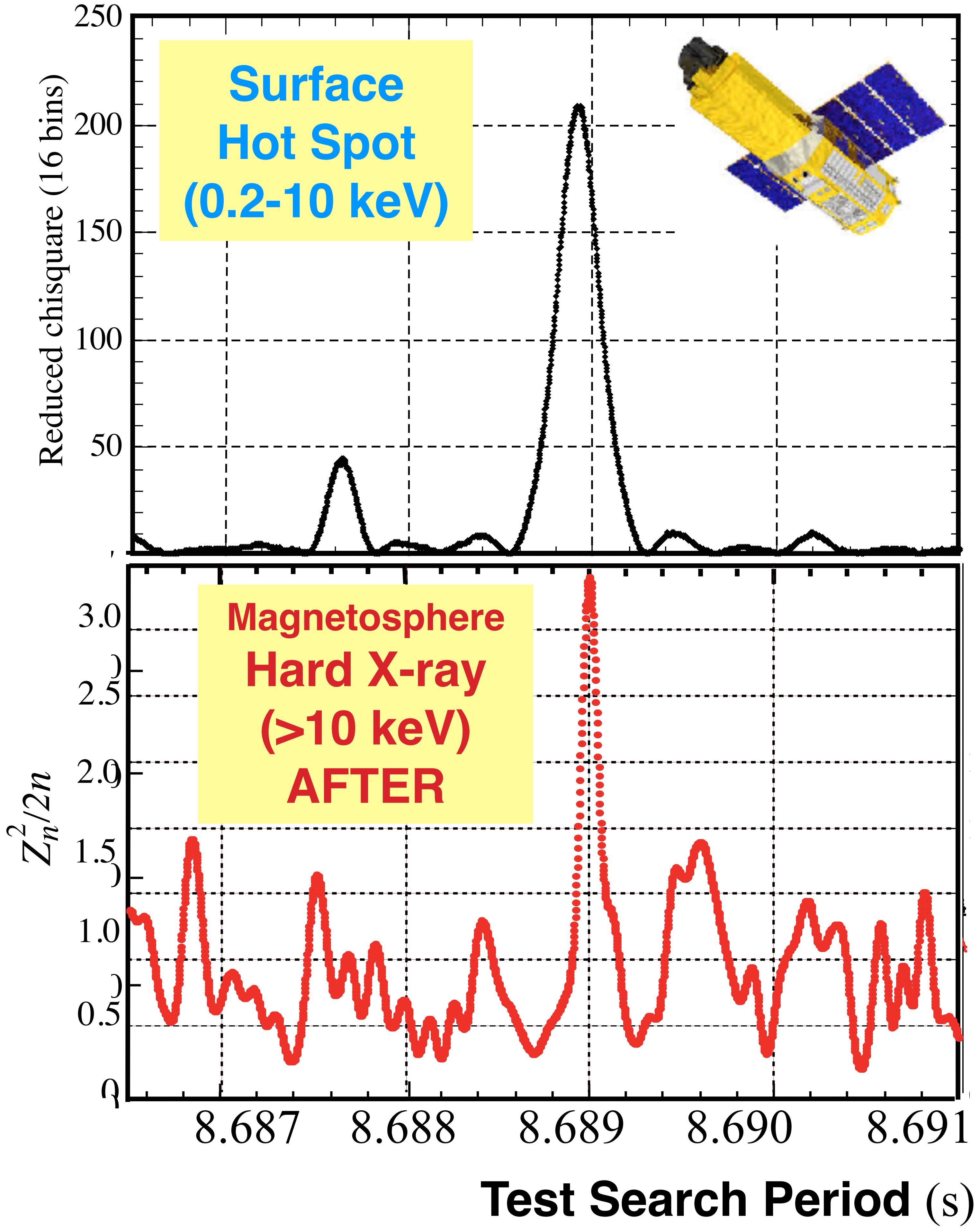
(see., e.g., Landau & Lifshitz textbook)

Evidence for NS precession?

Prototypical AXP 4U 0142+61 (P=8.69 s, Poloidal field B_d~1.3x10^{14} G)



Hard X-ray shows a sinusoidal, T=1.5 hour, phase modulation (amplitude 0.7 s)



Makishima, TE et al., PRL, 2014

$$\epsilon \sim \frac{8.69\,\mathrm{s}}{1.5\,\mathrm{h}} \sim 1.6 \times 10^{-4}$$

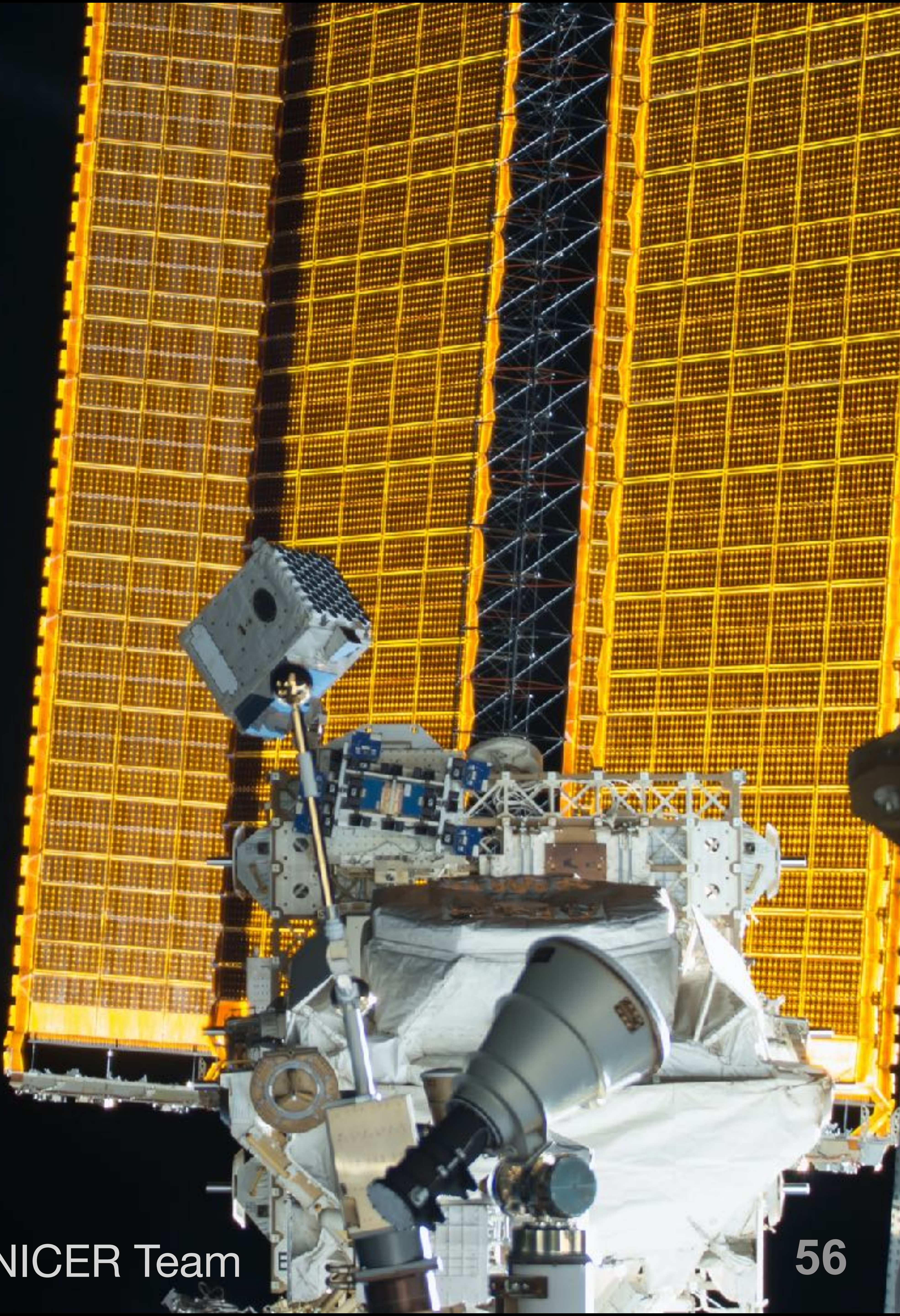
⇨ Toroidal B-field B_t ~ 10^{16} G

$$\epsilon \sim 10^{-4} (B/10^{16}\,\mathrm{G})^2$$

Confirmation with NuSTAR (Makishima+2019), Similar signature was detected from 1E 1547.0-5408 (Makishima+2020)

- The NICER M&M team is happy to collaborate with radio observatories for transient magnetars and galactic giant radio sources. Please let us know if you are interested in future collaboration.
- Today: Our reserved ToO was accepted for transient magnetars during the NICER Cycle 3.

Prop #	Title	PI Name	Abstract
4060	MAGNETAR OUTBURSTS AS A CLUE FOR UNDERSTANDING MAGNETIC ENERGY DISSIPATION AND FAST RADIO BURSTS	TERUAKI ENOTO	Magnetar X-ray outburst is sporadic magnetic energy dissipation of short bursts, giant flares, and persistent emission enhancement. The physics underlying this dissipation process is still unclear. Follow-up observations of transient magnetars with NICER have provided clues for this question, for example, detection of single X-ray pulses from the radio-loud magnetar XTE J1810-197, the burst forest from the Galactic FRB source SGR 1935+2154, and discoveries of Swift J1818.0-1607 and SGR 1830-0645. Prompt observations became much more critical after the discovery of the fast radio burst from the Galactic magnetar SGR 1935+2154 in 2020. Here we propose reserved NICER ToO observations of transient magnetar outbursts in soft X-rays coordinated with radio and hard X-ray simultaneous coverage.



NICER

Summary

1. NICER Magnetar and Magnetosphere (M&M) working group has been coordinating multi-wavelength (especially X-rays and radio) follow-up campaigns of transient magnetars.
    - New magnetar Swift J1818.0-1607
    - Single X-ray pulse detection from XTE J1810-197
    - X-ray burst properties of the Galactic FRB source SGR 1935+2154
2. Using the NICER and radio observatories, we discovered X-ray enhancement coincided with giant radio pulses from the Crab pulsar. The total emitted energy from a GRP is revealed to be tens to hundreds of times brighter than previously thought. The FRB-GRP model is disfavored.
3. There is no consensus whether magnetars are in binary systems. We reported a pulsation signature from LS 5039, which could be interpreted as a magnetar in the gamma-ray binary systems. There is also evidence for free precession from isolated magnetars.

RIKEN SPDR (基礎特研) & JRA (大学院生)

- RIKEN SPDR fellows (https://www.riken.jp/en/careers/programs/spdr/)
  - Period: 3 years
  - Salary: 487,000 JPY/month + commuting & house allowances
  - Research fund: 1,000,000 JPY/year
- RIKEN JRA for Ph.D students (https://www.riken.jp/en/careers/programs/jra/)
  - Period: maximum 3 years
  - Salary: 164,000 JPY/month + commuting allowances
- If you are interested in these systems, please let me know.
- RIKEN Extreme Natural Phenomena RIKEN Hakubi Team (http://enotolab.com)