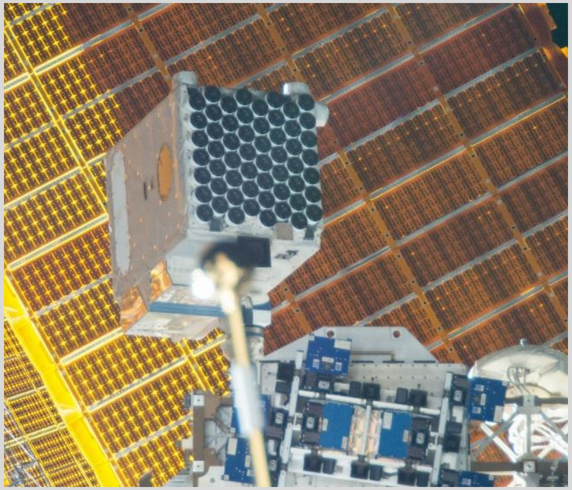
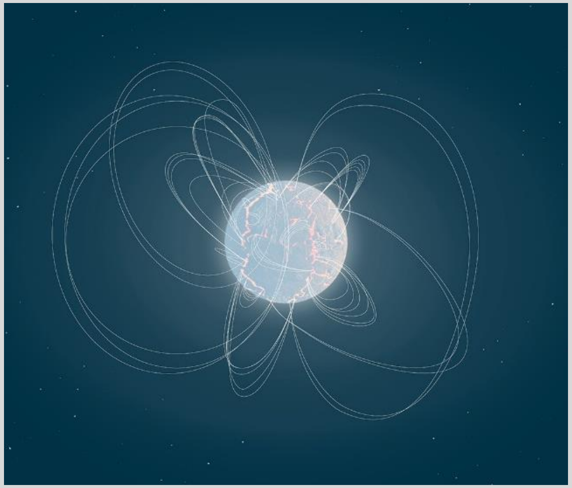
Multiwavelength Studies of Transient Radio Signal from Neutron Stars

Chin-Ping Hu

National Changhua University of Education



© GSFC/NASA



© ESA

Enoto, T., Terasawa, T., Kisaka, S., Arzoumanian, Z., Gendreau, K. C., and the NICER collaboration.

Dec. 10, 2021 @ Institute of Physics, Academia Sinica

About Me

- Current Position
  - Assistant Professor, NCUE
  - Visiting Scientist, RIKEN
- Work Experience
  - JSPS Fellow, Kyoto University (2018-2020)
  - Postdoctoral Fellow, The University of Hong Kong (2015-2018)
- Education
  - Ph. D., National Central University (2014)

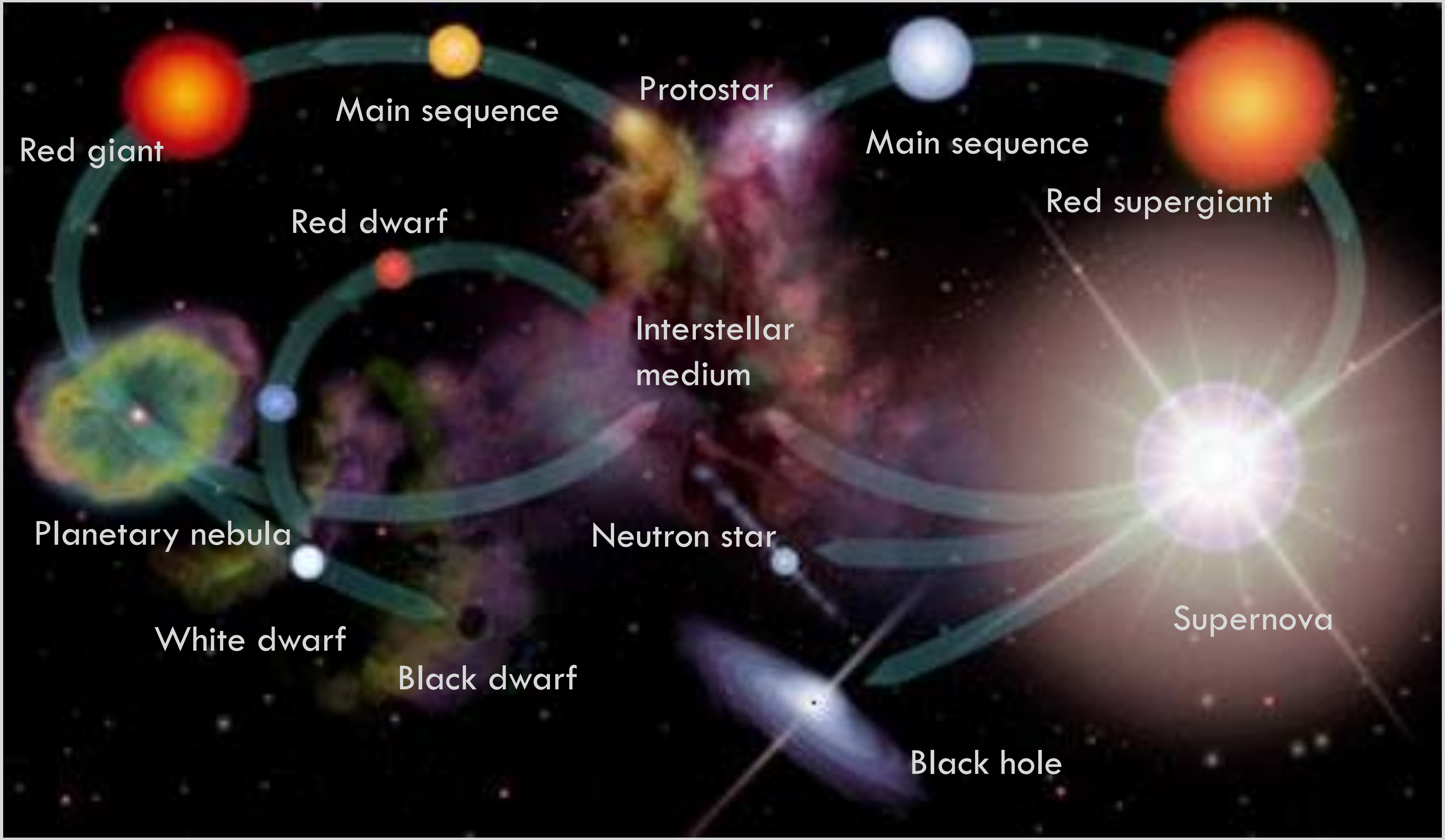
- Research Projects
  - Non-linear and non-stationary phenomena
    - Long-term X-ray modulation in X-ray binaries and ultraluminous X-ray sources
    - Quasi-periodic oscillations
    - Transient and continuous gravitational-wave signals
  - Effects of high magnetic fields and high accretion rates on compact objects
    - Timing and spectral behaviors of magnetars and rotation-powered pulsars (RPPs)
    - Disk-magnetosphere interaction in ultraluminous X-ray pulsars
    - Particle acceleration in pulsar winds
  - Instrumentation and mathematical algorithms
    - Development and application of advanced timing and time-frequency analysis
    - X-ray CubeSats (RIKEN project “NinjaSat”)

Steller Evolution

-- in a nutshell

Low-mass stars

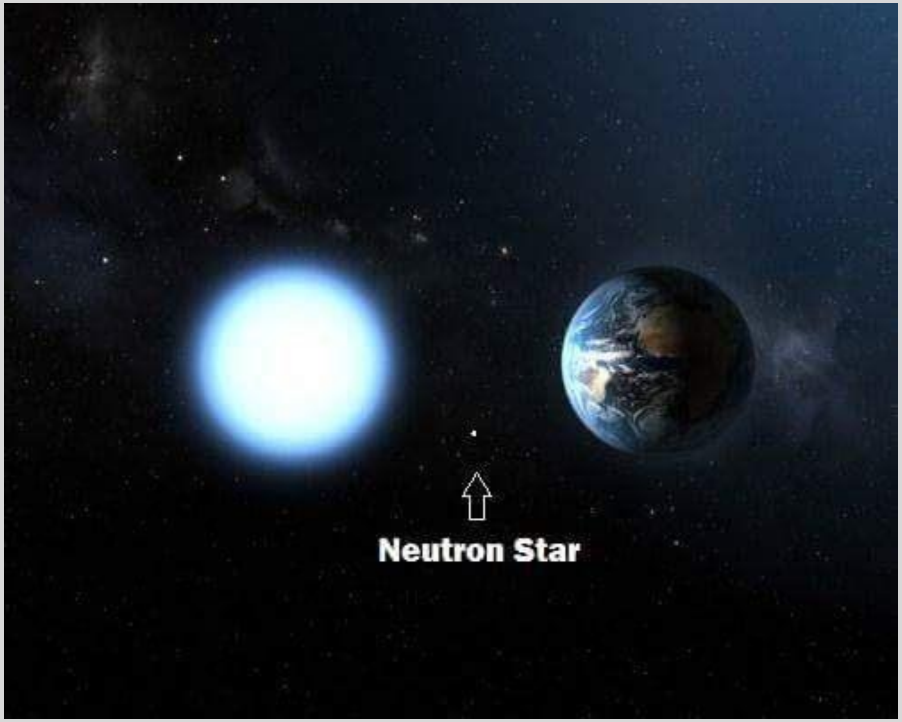
Massive stars



© NASA/GSFC

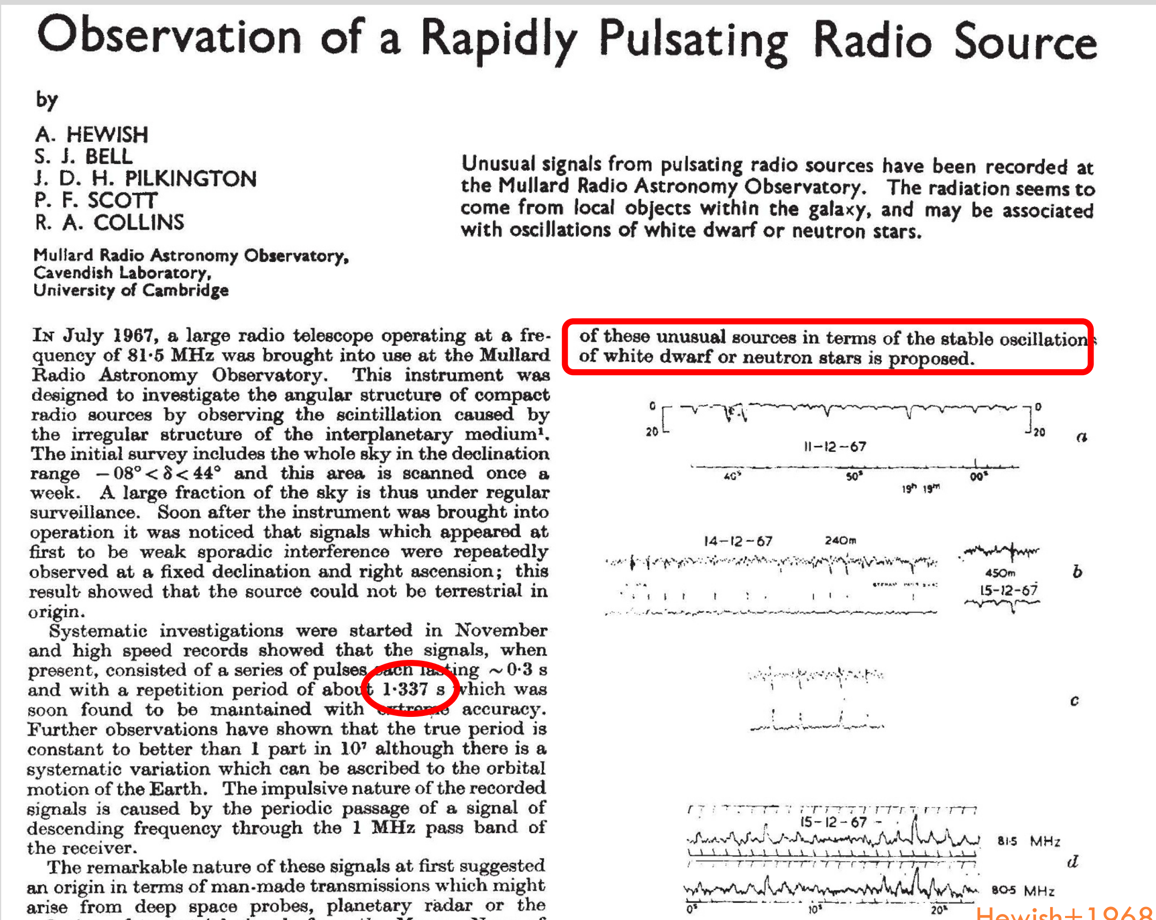
Discovery of Neutron Star

- The neutron was discovered by James Chadwick in 1932.
- In 1934, Baade and Zwicky presented an idea of "neutron star" at the APS meeting
  - NSs are too faint to be detected



Discovery of Neutron Star

- A series of radio pulses is discovered by S. J. Bell and A. Hewish in 1967
    - Pulsating radio source (Pulsar)



Observation of a Rapidly Pulsating Radio Source

by

A. HEWISH
S. J. BELL
J. D. H. PILKINGTON
P. F. SCOTT
R. A. COLLINS

Mullard Radio Astronomy Observatory,
Cavendish Laboratory,
University of Cambridge

Unusual signals from pulsating radio sources have been recorded at the Mullard Radio Astronomy Observatory. The radiation seems to come from local objects within the galaxy, and may be associated with oscillations of white dwarf or neutron stars.

In July 1967, a large radio telescope operating at a frequency of 81·5 MHz was brought into use at the Mullard Radio Astronomy Observatory. This instrument was designed to investigate the angular structure of compact radio sources by observing the scintillation caused by the irregular structure of the interplanetary medium[1]. The initial survey includes the whole sky in the declination range $-08° < \delta < 44°$ and this area is scanned once a week. A large fraction of the sky is thus under regular surveillance. Soon after the instrument was brought into operation it was noticed that signals which appeared at first to be weak sporadic interference were repeatedly observed at a fixed declination and right ascension; this result showed that the source could not be terrestrial in origin.

Systematic investigations were started in November and high speed records showed that the signals, when present, consisted of a series of pulses each lasting ~0·3 s and with a repetition period of about 1·337 s which was soon found to be maintained with extreme accuracy. Further observations have shown that the true period is constant to better than 1 part in 10^7 although there is a systematic variation which can be ascribed to the orbital motion of the Earth. The impulsive nature of the recorded signals is caused by the periodic passage of a signal of descending frequency through the 1 MHz pass band of the receiver.

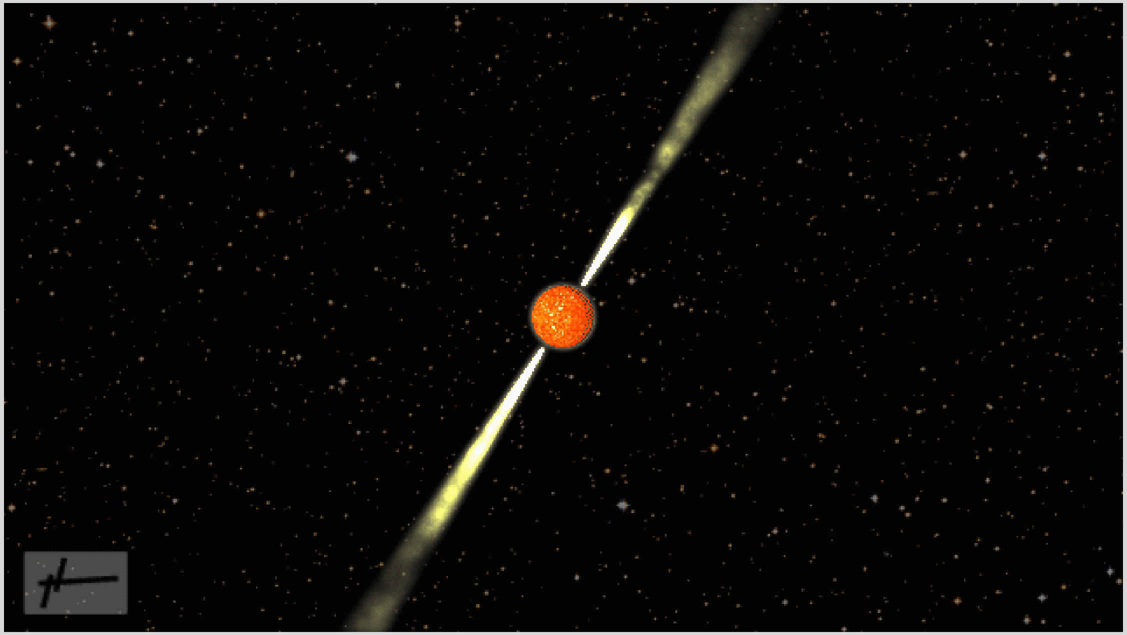
The remarkable nature of these signals at first suggested an origin in terms of man-made transmissions which might arise from deep space probes, planetary radar or the reflexion of terrestrial signals from the Moon. None of

of these unusual sources in terms of the stable oscillations of white dwarf or neutron stars is proposed.

Hewish+1968

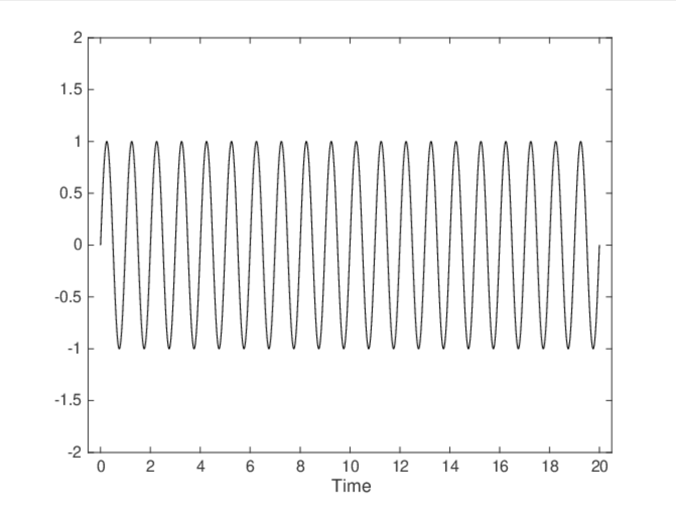
Pulsars

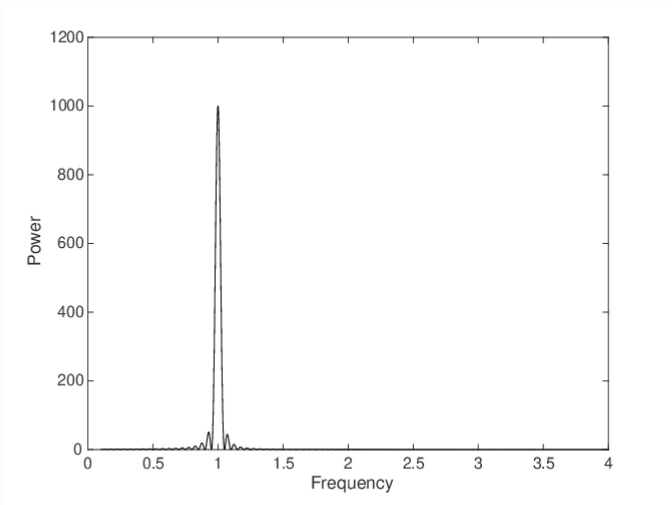
- Fast rotating neutron stars with high magnetic fields
- Lighthouse effect



Search for Pulsation

- As the computing power increases, astronomers can search for periodic signal with Fourier transform.
  - Periodic signals can be detected even if they are hidden in noises.
  - Roughly 2000 pulsars are discovered





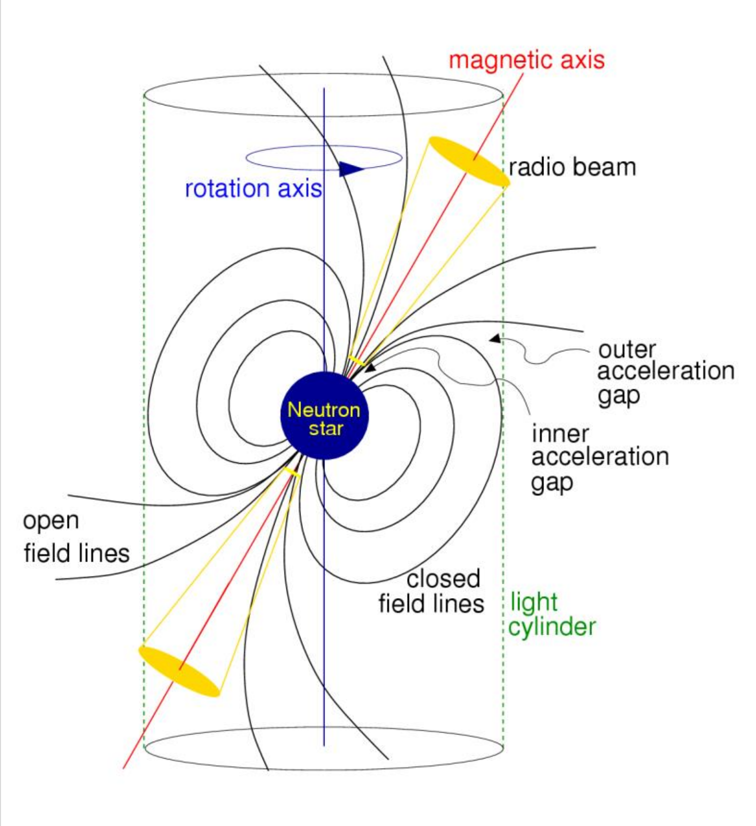
Pulsar: Basics

- Magnetic Dipole
  - Synchrotron radiation from magnetosphere.
  - B-field line: corotate with the NS
  - Open field line: non-thermal emission
- The rotational energy decreasing, minimum magnetic field, and characteristic age of a pulsar can be derived by its rotation period and period decay.

$$\frac{dE_{rot}}{dt} = -\frac{4\pi^2 I\dot{P}}{P^3}$$

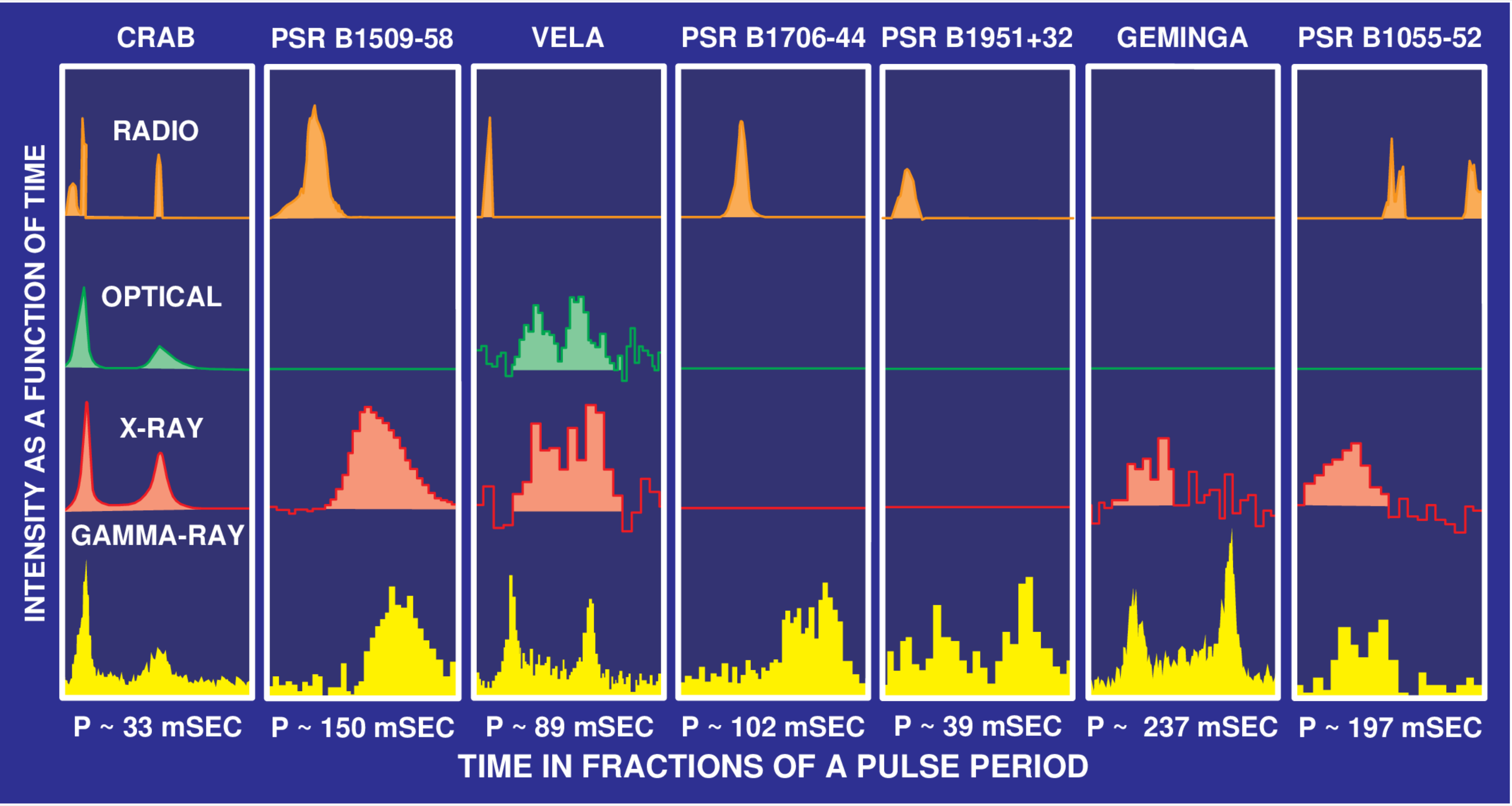
$$B > \left(\frac{3c^3 I P\dot{P}}{8\pi^2 R^6}\right)^{1/2}$$

$$\tau = \frac{P}{2\dot{P}}$$

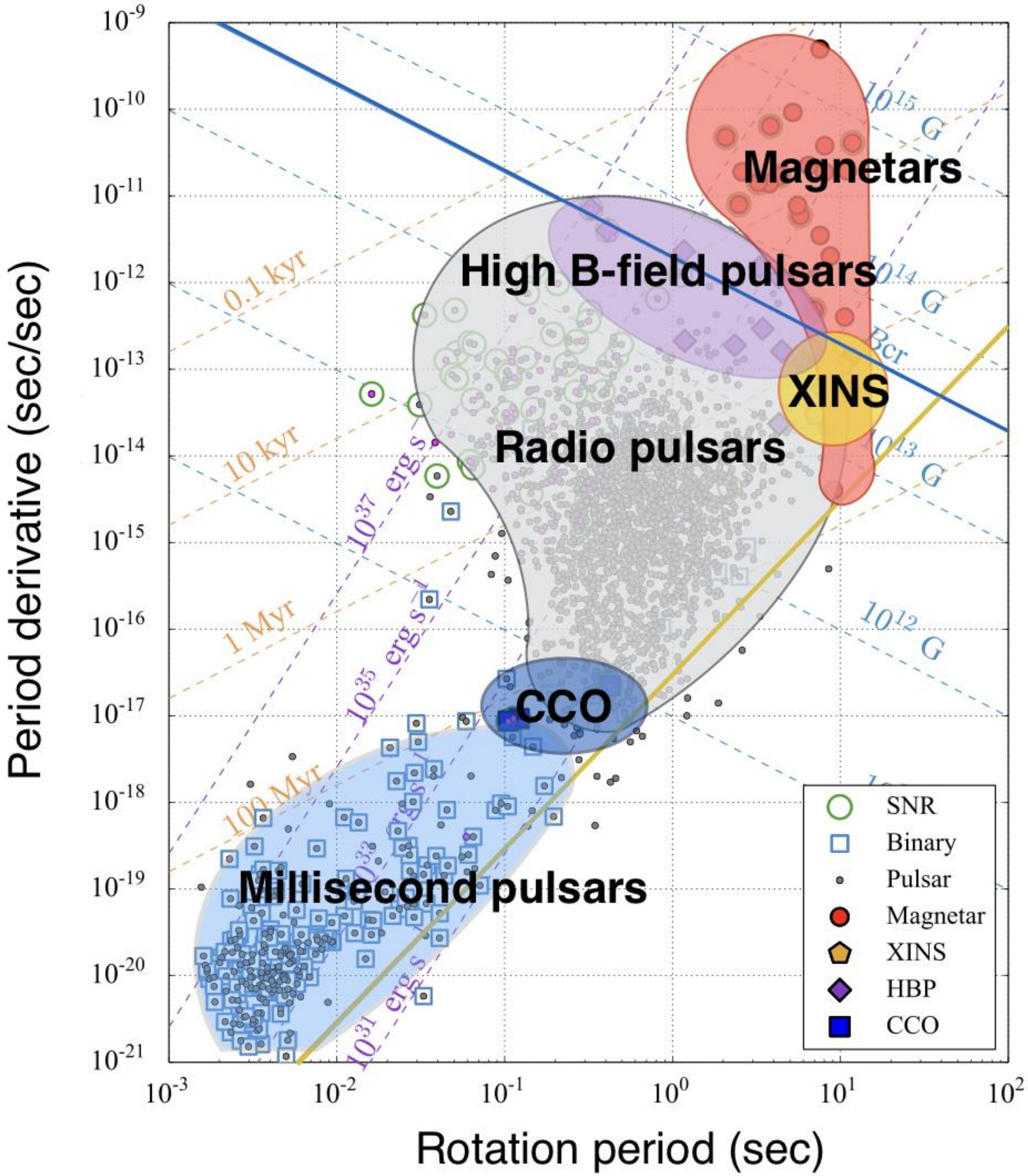


© Lorimer & Kramer

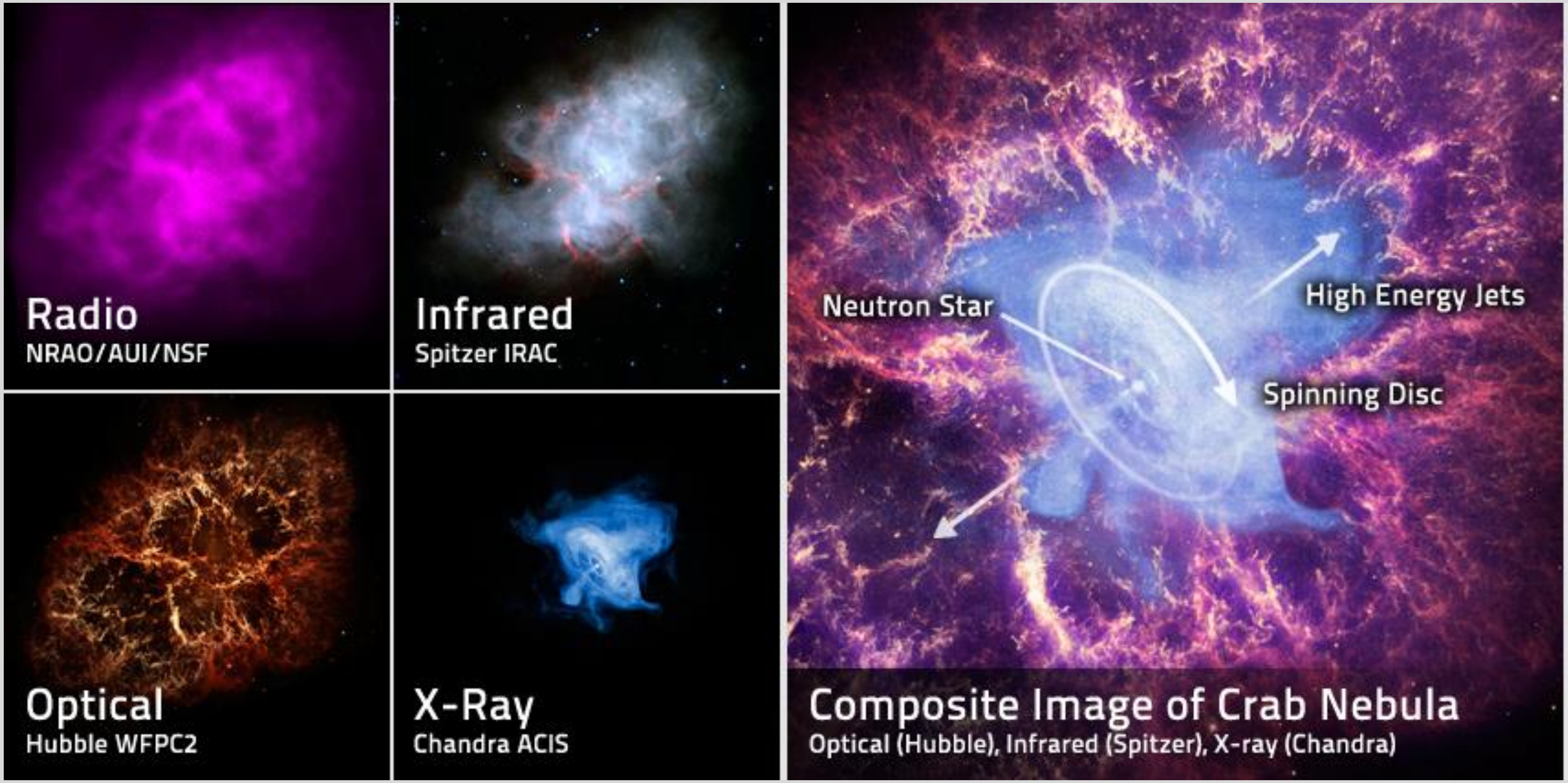
Pulse shapes of well-known pulsars



© D.J. Thompson (NASA/GSFC)

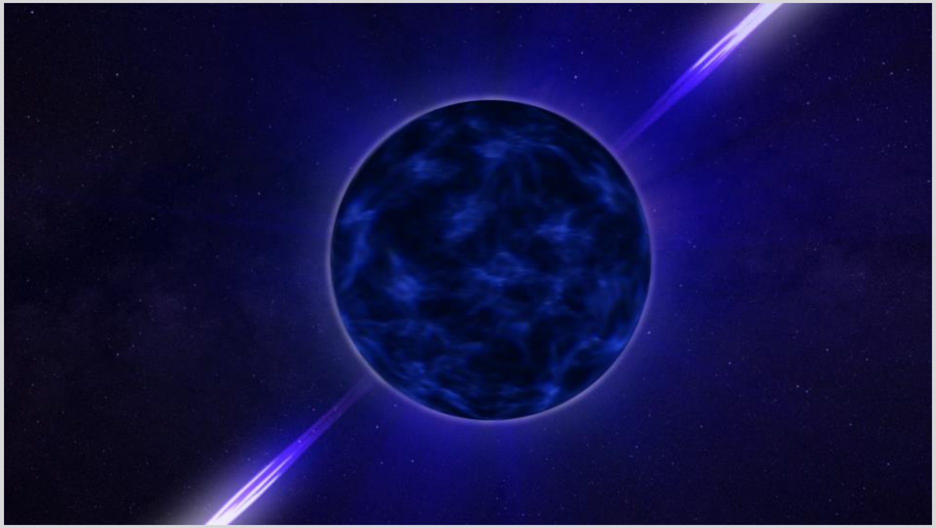

Magnetars
High B-field pulsars
XINS
Radio pulsars
CCO
Millisecond pulsars
0.1 kyr
10 kyr
1 Myr
100 Myr
10^{15} G
10^{14} G
10^{13} G
10^{12} G
Bcr
10^{37} erg s^{-1}
10^{35} erg s^{-1}
10^{33} erg s^{-1}
10^{31} erg s^{-1}
SNR
Binary
Pulsar
Magnetar
XINS
HBP
CCO
Period derivative (sec/sec)
Rotation period (sec)
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^{-14}
10^{-15}
10^{-16}
10^{-17}
10^{-18}
10^{-19}
10^{-20}
10^{-21}
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}

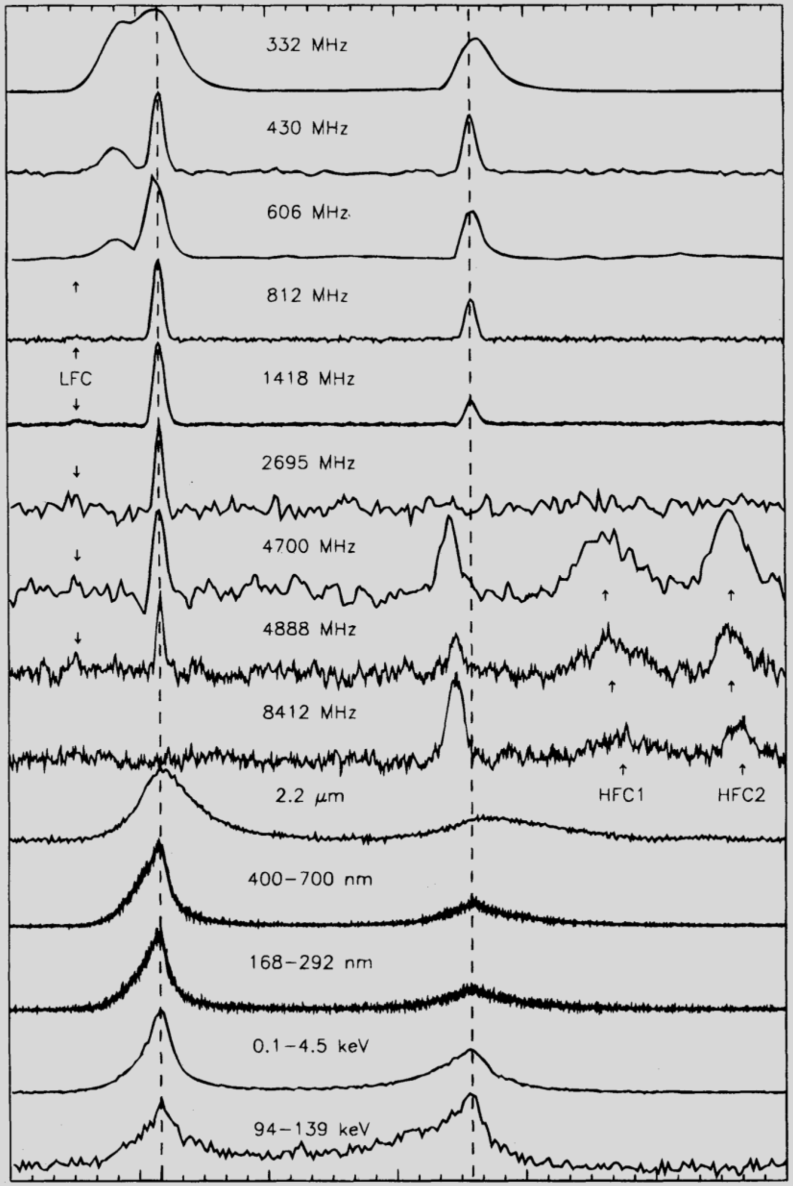
Crab Nebula


Radio
NRAO/AUI/NSF
Infrared
Spitzer IRAC
Optical
Hubble WFPC2
X-Ray
Chandra ACIS
Neutron Star
High Energy Jets
Spinning Disc
Composite Image of Crab Nebula
Optical (Hubble), Infrared (Spitzer), X-ray (Chandra)

Crab Pulsar

- The pulsation can be seen in all wavelength bands (radio, optical, X-ray, Gamma-ray)
- P=0.033s



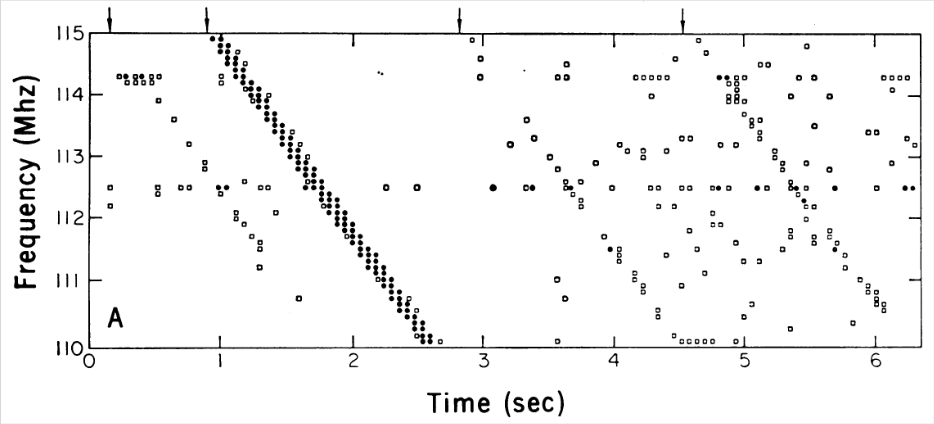


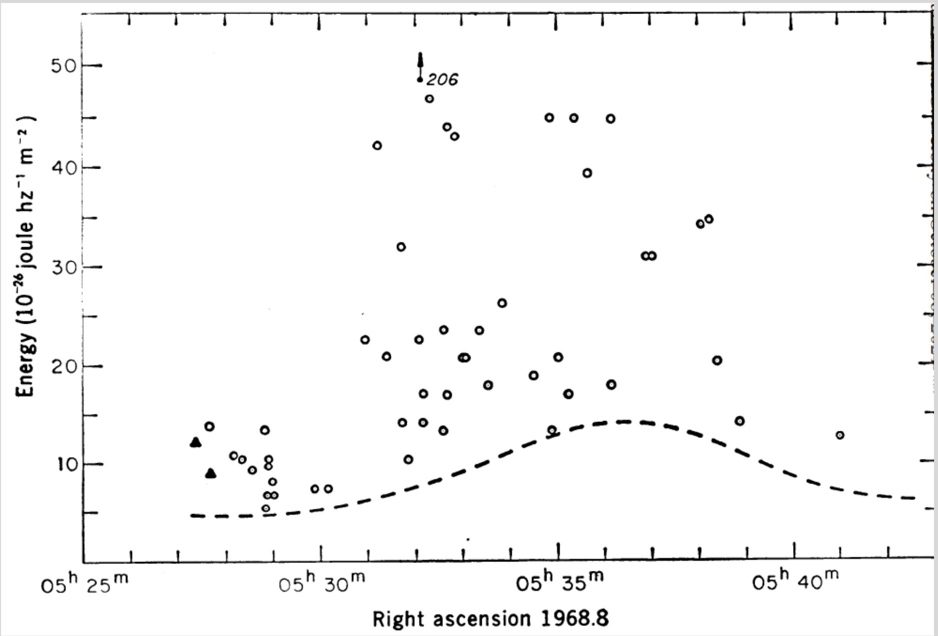
Moffat+1996

Giant Radio Pulses

Pulsating Radio Sources near the Crab Nebula

Abstract. *Two new pulsating radio sources, designated NP 0527 and NP 0532, were found near the Crab Nebula and could be coincident with it. Both sources are sporadic, and no periodicities are evident. The pulse dispersions indicate that 1.58 ± 0.03 and 1.74 ± 0.02 × 10^{20} electrons per square centimeter lie in the direction of NP 0527 and NP 0532, respectively.*





Staelin+1968

Dispersion Measure

A radio pulse with a frequency of ν and distance of d. When it pass through electron plasmas with a number density of n_e, the pulse arrival time is

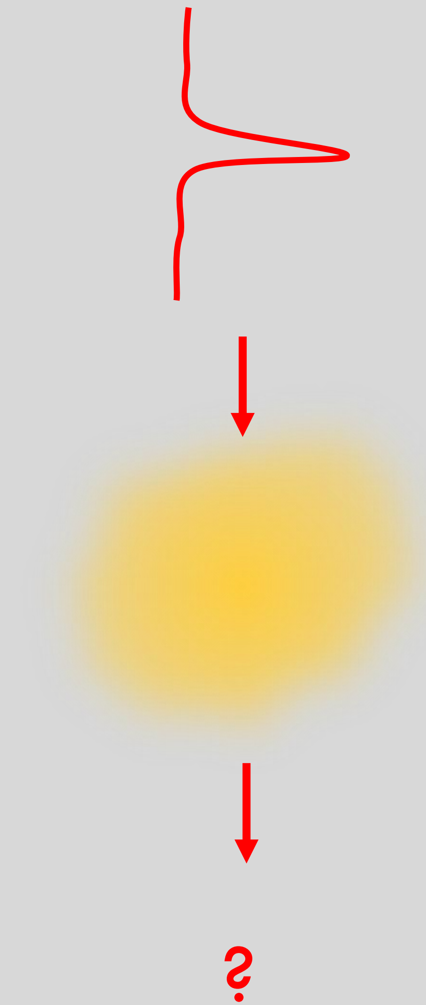
t_d(delay)

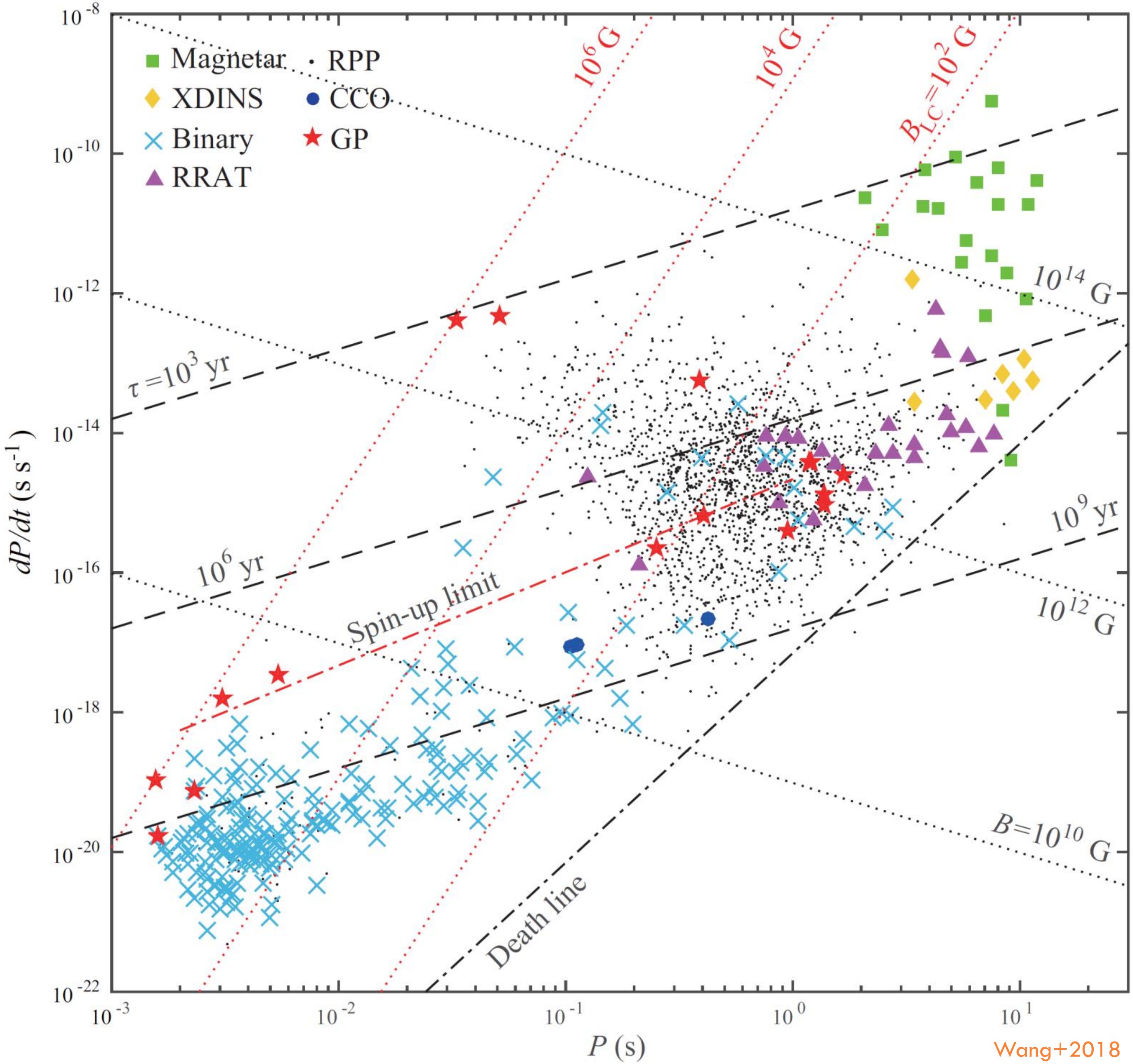
$$t_p = \frac{d}{c} + \frac{e^2}{2\pi m_e c}\frac{\int_0^d n_e dl}{\nu^2}$$

DM

$$t_d = 4140\left(\frac{DM}{cm^{-3}\ pc}\right)\left(\frac{\nu}{1\ MHz}\right) s$$

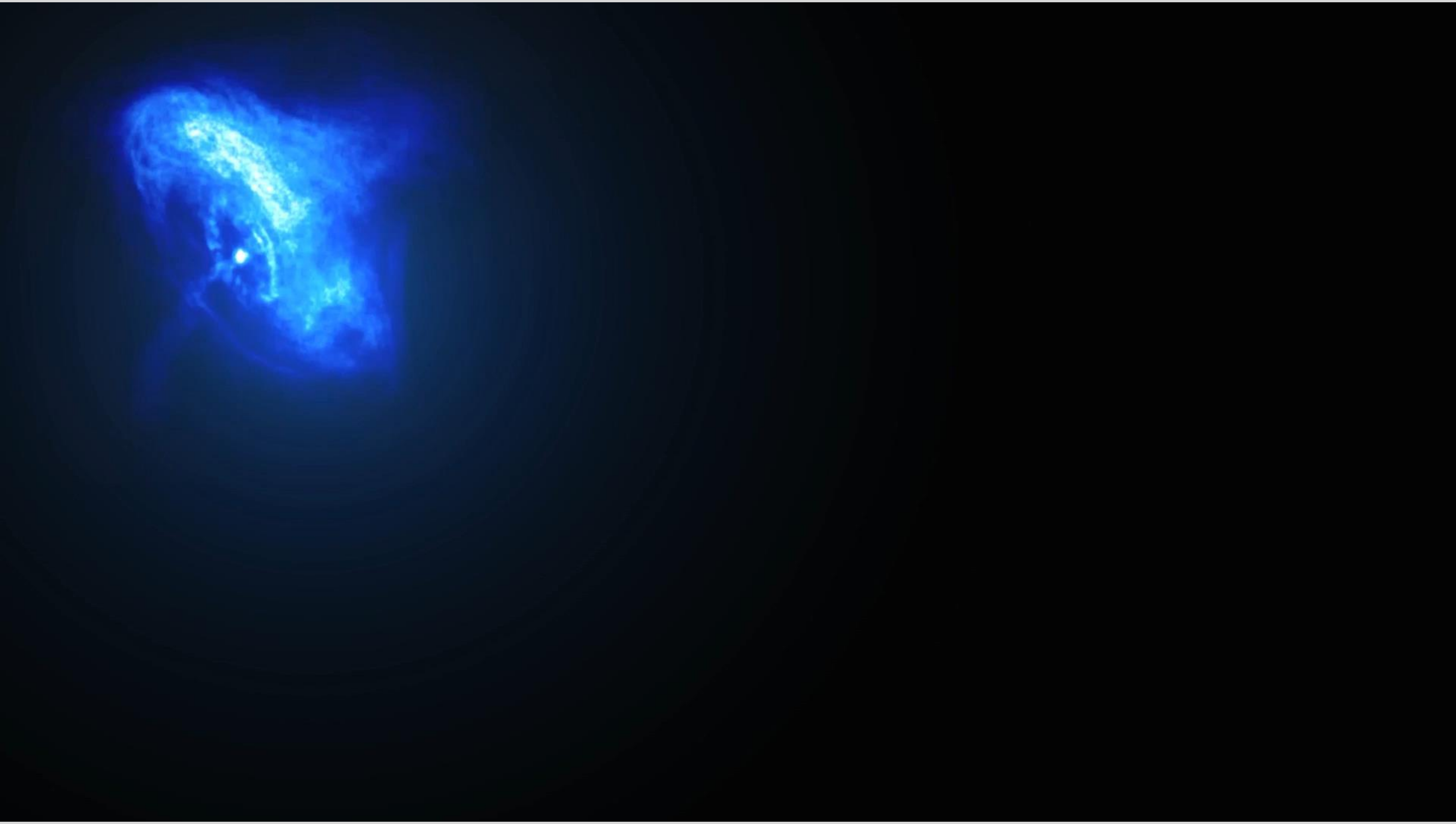
Crab DM = 56.8



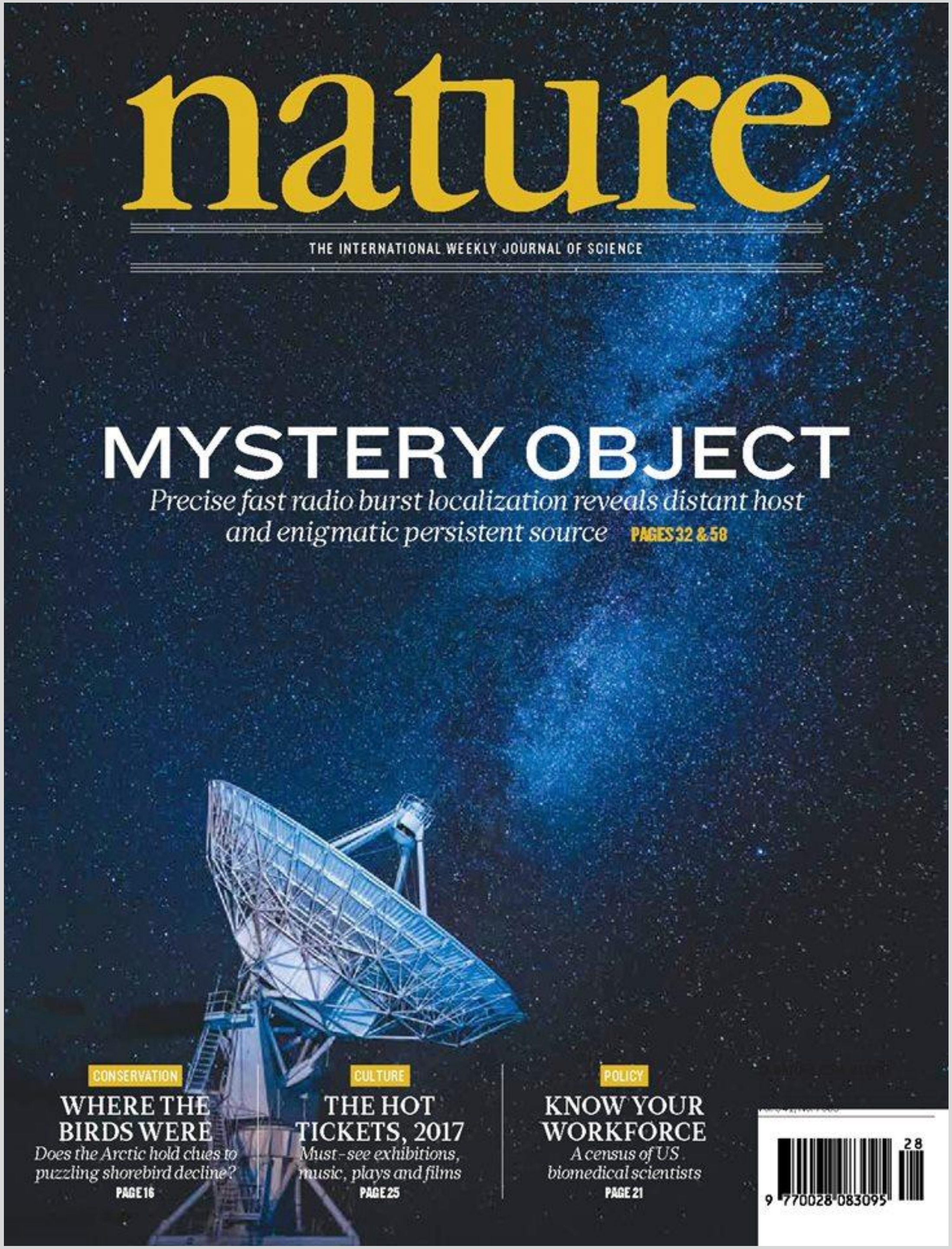

Magnetar
RPP
XDINS
CCO
Binary
GP
RRAT
10^6 G
10^4 G
B_LC=10^2 G
10^14 G
10^12 G
B=10^10 G
τ=10^3 yr
10^6 yr
10^9 yr
Spin-up limit
Death line
dP/dt (s s^-1)
P (s)

Wang+2018

Giant Radio Pulses – Remain Mysterious

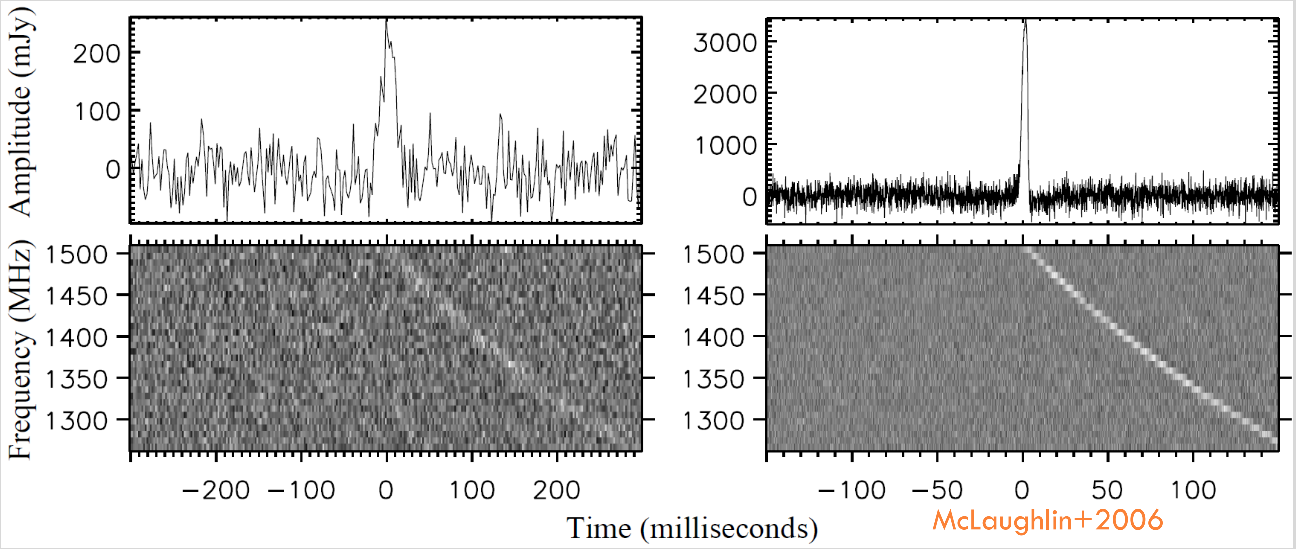


- Candidates for Fast Radio Burst?

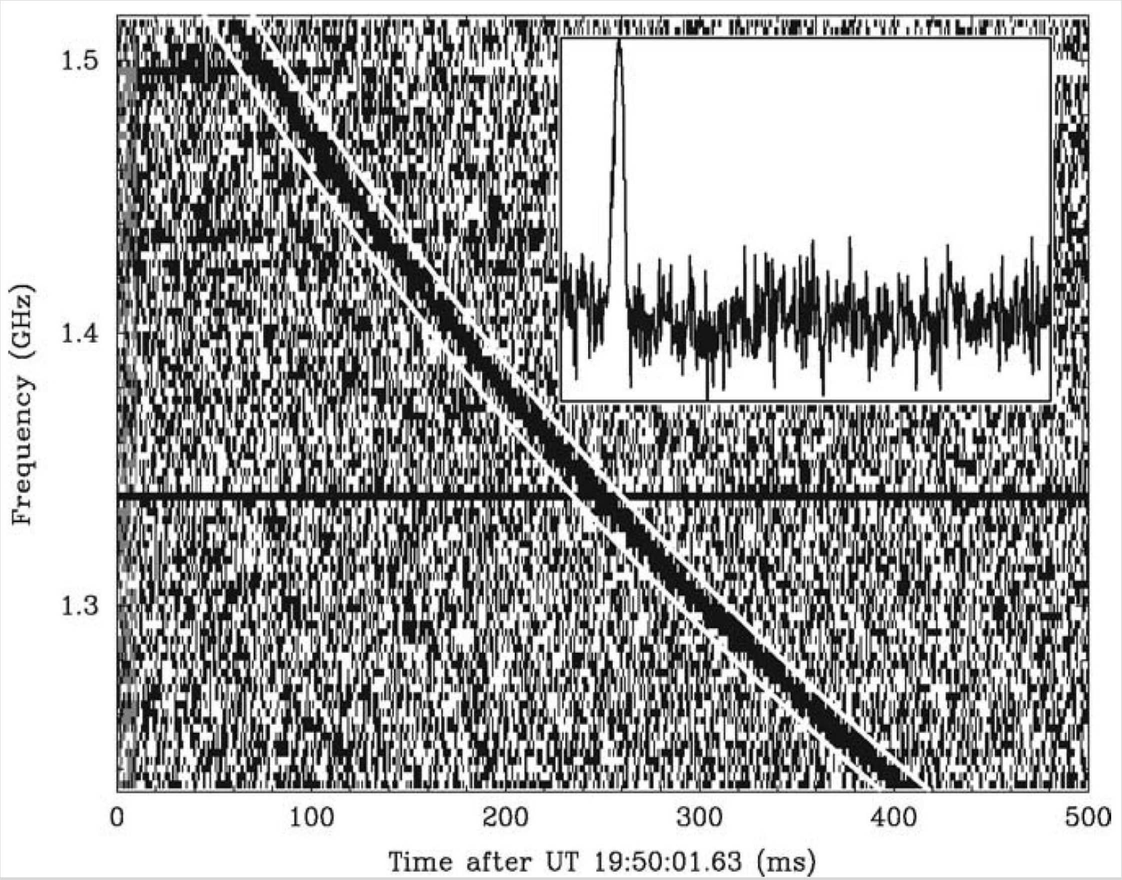

nature
THE INTERNATIONAL WEEKLY JOURNAL OF SCIENCE
MYSTERY OBJECT
Precise fast radio burst localization reveals distant host and enigmatic persistent source
PAGES 32 & 58
CONSERVATION
WHERE THE BIRDS WERE
Does the Arctic hold clues to puzzling shorebird decline?
PAGE 16
CULTURE
THE HOT TICKETS, 2017
Must-see exhibitions, music, plays and films
PAGE 25
POLICY
KNOW YOUR WORKFORCE
A census of US biomedical scientists
PAGE 21

Back to Transient Radio Sky

- Fourier analysis helps finding periodic signals even single pulses cannot be observed.
  - The number of pulsars was > 2000 in the early 21th century.
- Then, rotating radio transients (RRATs) was discovered.
  - Their DM suggests that they are galactic sources
  - The pulsation period cannot be obtained with timing analysis.
  - The NS nature is confirmed with X-ray observation



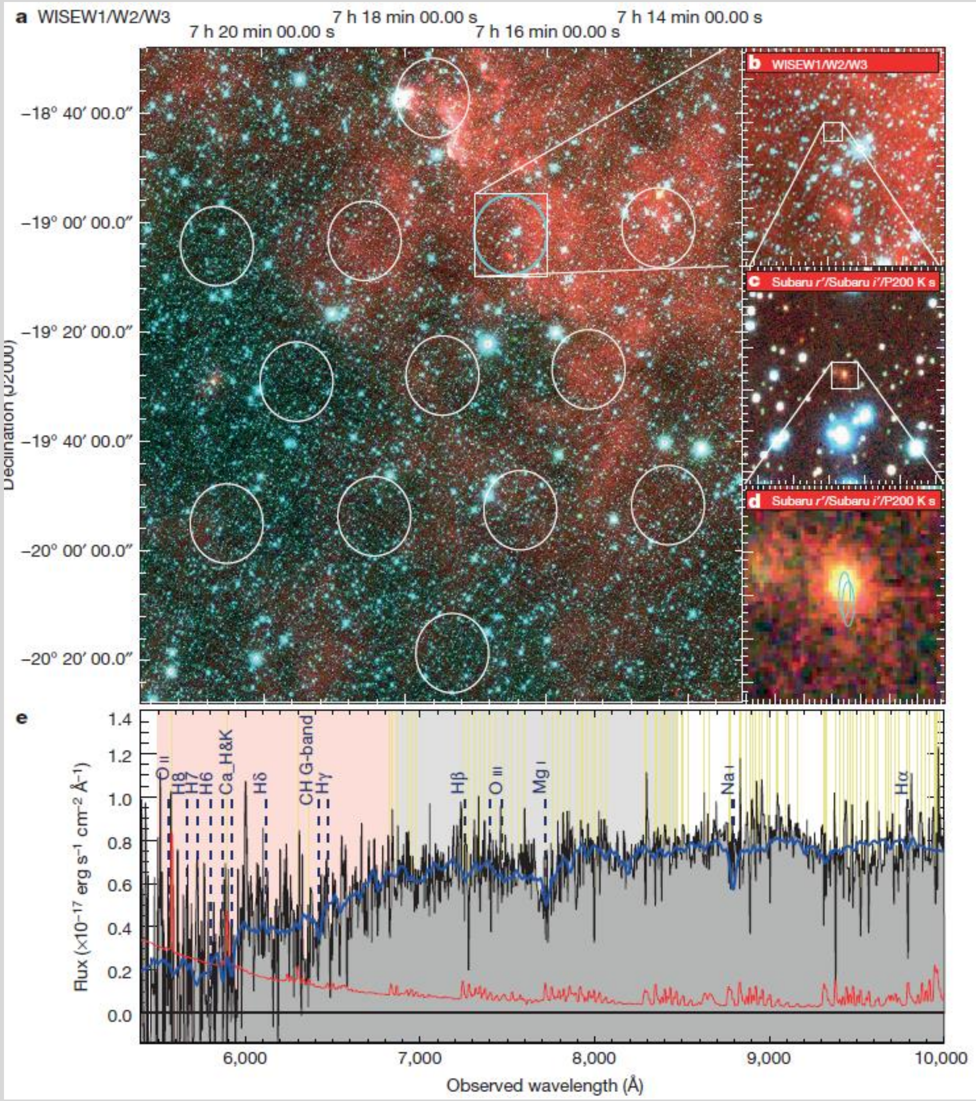
The Lorimer Burst



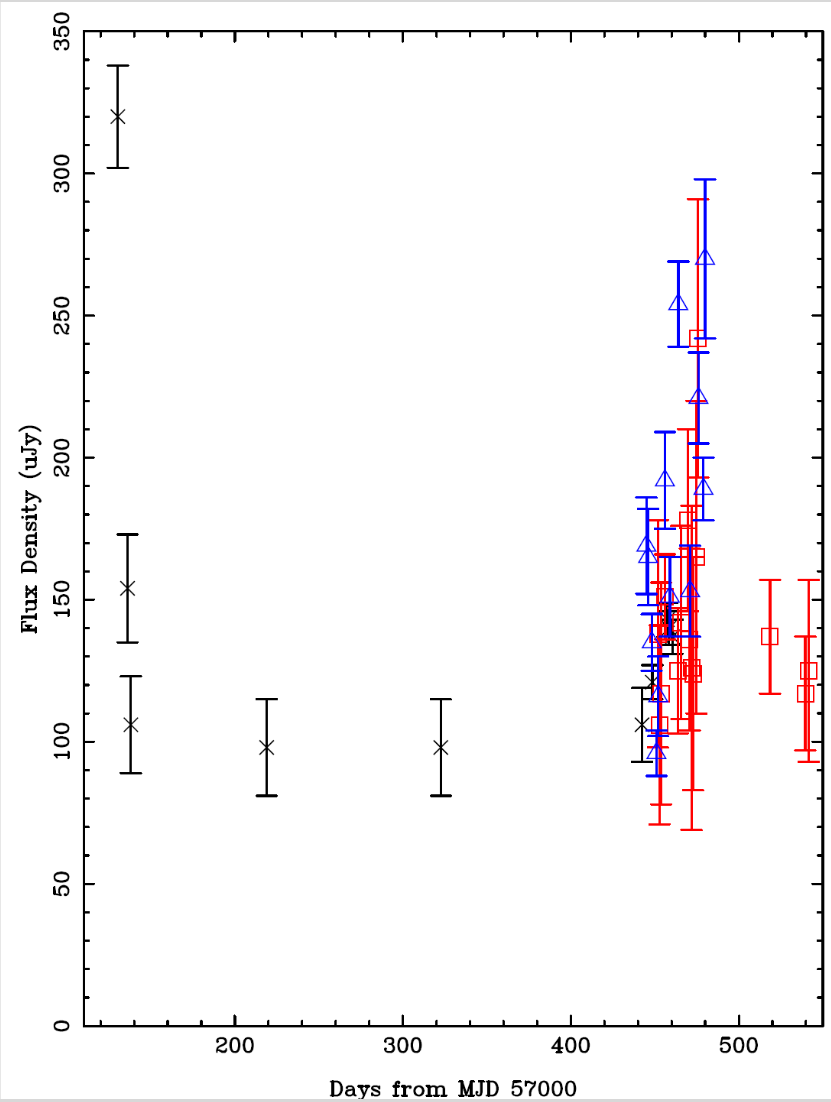
Lorimer+2007

- DM=375
  - Extragalactic origin
  - Extremely high luminosity… $10^{40} - 10^{43}$ erg/s

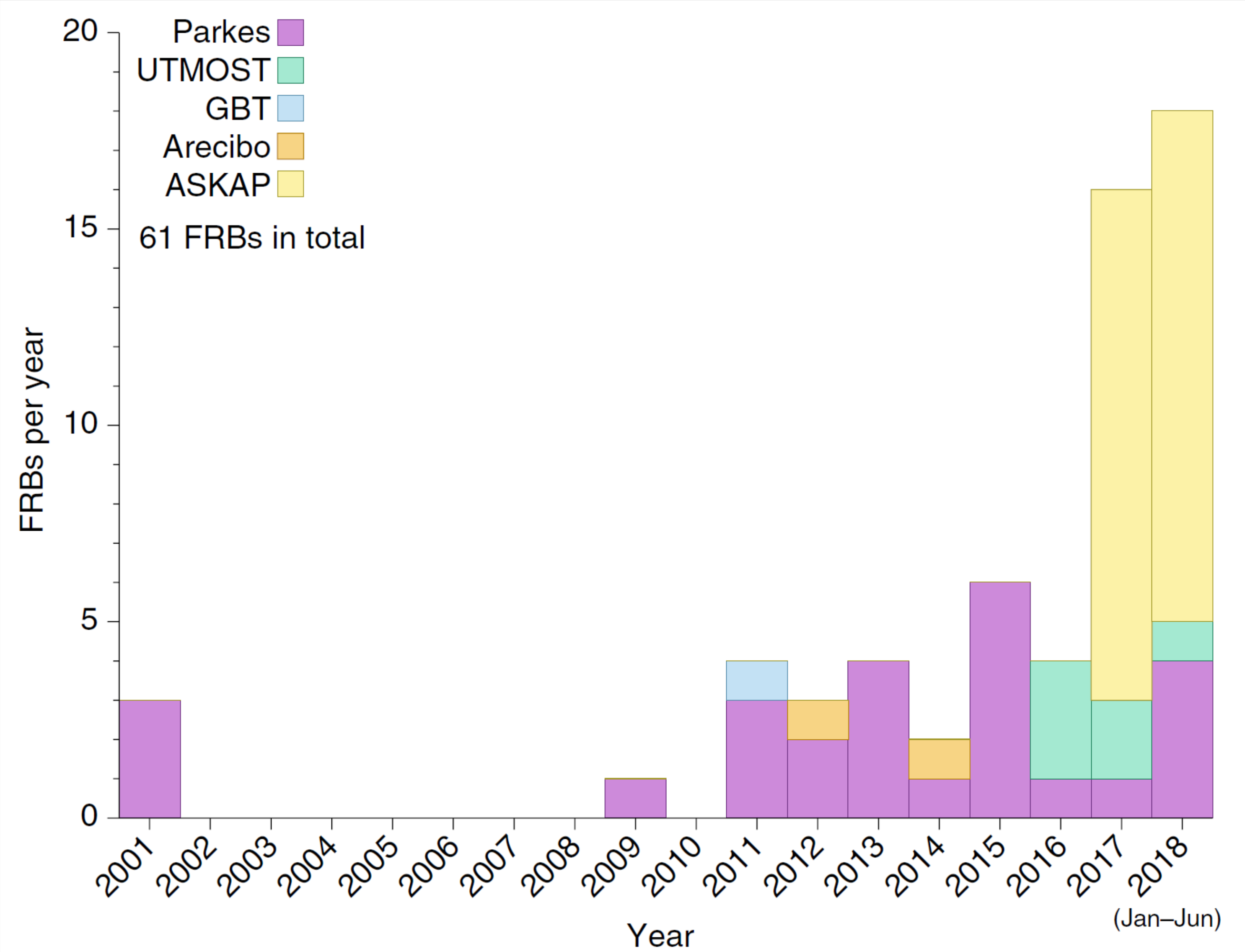
FRB 150418: Repeating FRB



Keane+2016



Johnston+2017


Parkes
UTMOST
GBT
Arecibo
ASKAP
61 FRBs in total
FRBs per year
20
15
10
5
0
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
(Jan–Jun)
Year

Keane+2018

A Living Theory Catalogue for Fast Radio Bursts

E. Platts[a,*], A. Weltman[a], A. Walters[b,c], S. P. Tendulkar[d], J.E.B. Gordin[a], S. Kandhai[a]

[a] *High Energy Physics, Cosmology & Astrophysics Theory (HEPCAT) group, Department of Mathematics and Applied Mathematics, University of Cape Town, Rondebosch, 7700, South Africa*

[b] *Astrophysics & Cosmology Research Unit, School of Chemistry and Physics, University of KwaZulu-Natal, Durban, 4000, South Africa*

[c] *NAOC-UKZN Computational Astrophysics Centre (NUCAC), University of KwaZulu-Natal, Durban, 4000, South Africa*

[d] *Department of Physics & McGill Space Institute, McGill University, 3600 University Street, Montreal QC, H3A 2T8, Canada*

Abstract

At present, we have almost as many theories to explain Fast Radio Bursts as we have Fast Radio Bursts observed. This landscape will be changing rapidly with CHIME/FRB, recently commissioned in Canada, and HIRAX, under construction in South Africa. This is an opportune time to review existing theories and their observational consequences, allowing us to efficiently curtail viable astrophysical models as more data becomes available. In this article we provide a currently up to date catalogue of the numerous and varied theories proposed for Fast Radio Bursts so far. We also launched an online evolving repository for the use and benefit of the community to dynamically update our theoretical knowledge and discuss constraints and uses of Fast Radio Bursts.

Keywords: Fast Radio Bursts, transients, neutron stars, black holes

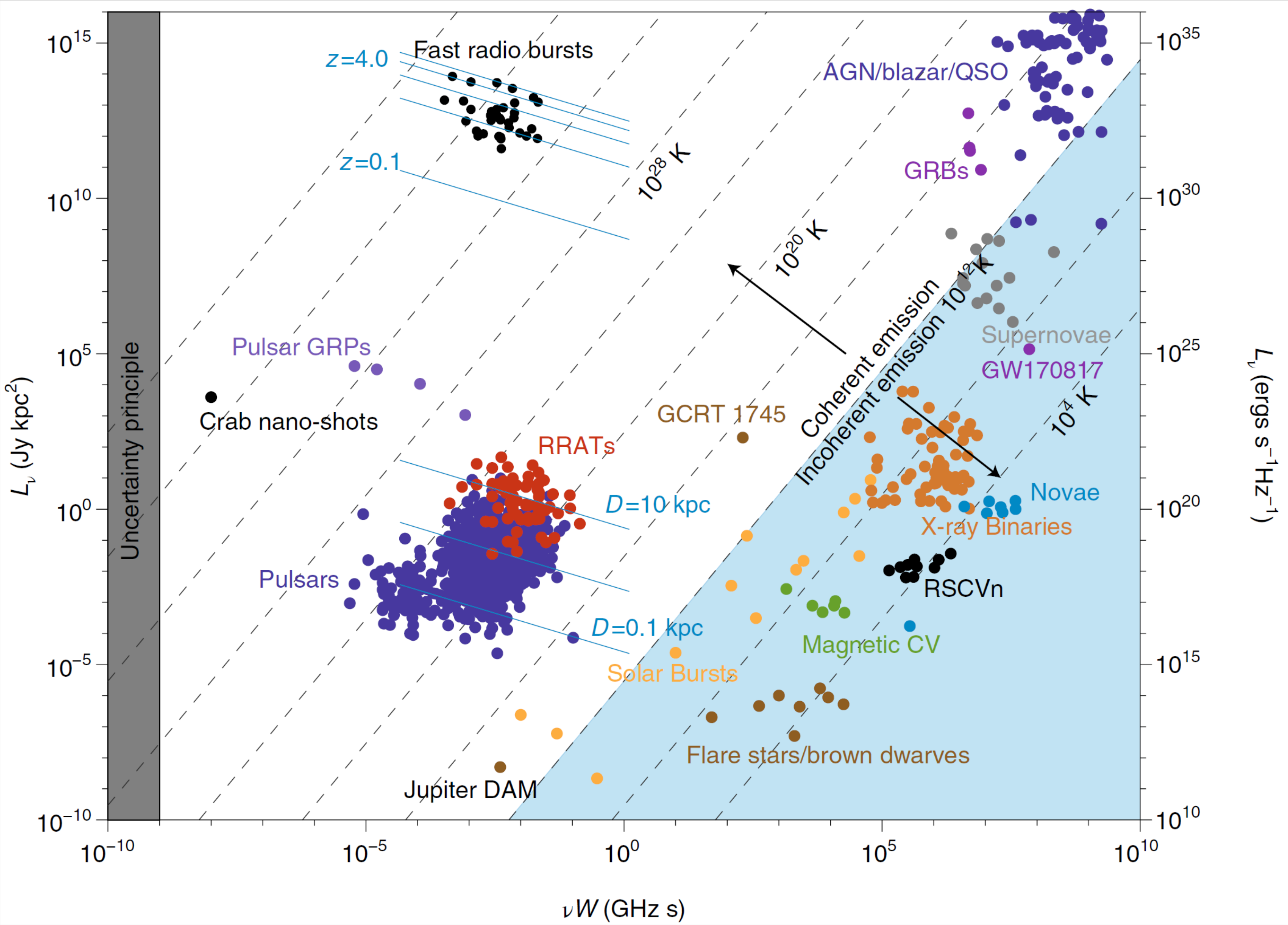
---

	Progenitor	Mechanism	Emission	Counterparts	Type	References
Merger	NS–NS	Mag. brak.	—	GW, sGRB, afterglow, X-rays, kilonovae	Single	Totani (2013)
		Mag. recon.	Curv.		Both	Wang et al. (2016)
		Mag. flux	—		Both	Dokuchaev and Eroshenko (2017)
	NS–SN	Mag. recon.	—	None	Single	Egorov and Postnov (2009)
	NS–WD	Mag. recon.	Curv.	—	Repeat	Gu et al. (2016)
		Mag. recon.	Curv.	—	Single	Liu (2018)
	WD–WD	Mag. recon.	Curv.	X-rays, SN	Single	Kashiyama et al. (2013)
	WD–BH	Maser	Synch.	X-rays	Single	Li et al. (2018a)
	NS–BH	BH battery	—	GWs, X-rays, γ-rays	Single	Mingarelli et al. (2015)
	Pulsar–BH	—	—	GWs	Single	Bhattacharyya (2017)
	KNBH–BH (Inspiral)	Mag. flux	Curv.	GWs, sGRB, radio afterglow	Single	Zhang (2016a)
	KNBH–BH (Magneto.)	Mag. recon.	Curv.	GW, γ-rays, afterglow	Single	Liu et al. (2016)
Collapse	NS to KNBH	Mag. recon.	Curv.	GW, X-ray afterglow & GRB	Single	Falcke and Rezzolla (2014) Punsly and Bini (2016) Zhang (2014)
	NS to SS	β-decay	Synch.	GW, X- & γ-ray	Single	Shand et al. (2016)
	NS to BH	Mag. recon.	Curv.	GW	Single	Fuller and Ott (2015)
	SS Crust	Mag. recon.	Curv.	GW	Single	Zhang et al. (2018)
SNR (Pulsar)	Giant Pulses	Various	Synch./ Curv.	—	Repeat	Keane et al. (2012) Cordes and Wasserman (2016) Connor et al. (2016)
	Schwinger Pairs	Schwinger	Curv.	—	Single	Lieu (2017)
	PWN Shock (NS)	—	Synch.	SN, PWN, X-rays	Single	Murase et al. (2016)
	PWN Shock (MWD)	—	Synch.	SN, X-rays	Single	Murase et al. (2016)
SNR (Mag.)	MWN Shock (Single)	Maser	Synch.	GW, sGRB, radio afterglow, high energy γ-rays	Single	Popov and Postnov (2007) Murase et al. (2016) Lyubarsky (2014)
	MWN Shock (Clustered)	Maser	Synch.	GW, GRB, radio afterglow, high energy γ-rays	Repeat	Beloborodov (2017)
AGN	Jet–Caviton	e^- scatter	Bremsst.	X-rays, GRB, radio	Repeat	Romero et al. (2016)
					Single	Vieyro et al. (2017)
	AGN–KNBH	Maser	Synch.	SN, GW, γ-rays, neutrinos	Repeat	Das Gupta and Saini (2017)
	AGN–SS	e^- oscill.	—	Persistent GWs, GW, thermal rad., γ-rays, neutrinos	Repeat	Das Gupta and Saini (2017)
	Wandering Beam	—	Synch.	AGN emission, X-ray/UV	Repeat	Katz (2017b)

Platts+2018

Collision/Interaction	NS & Ast./ Comets	Mag. recon.	Curv.	None	Single	Geng and Huang (2015) Huang and Geng (2016)
	NS & Ast. Belt	e^- stripping	Curv.	γ-rays	Repeat	Dai et al. (2016) Bagchi (2017)
	Small Body & Pulsar	Maser	Synch.	None	Repeat	Mottez and Zarka (2014)
	NS & PBH	Mag. recon.	—	GW	Both	Abramowicz et al. (2017)
	Axion Star & NS	e^- oscill.	—	None	Single	Iwazaki (2014, 2015a,b) Raby (2016)
	Axion Star & BH	e^- oscill.	—	None	Repeat	Iwazaki (2017)
	Axion Cluster & NS	Maser	Synch.	—	Single	Tkachev (2015)
	Axion Cloud & BH	Laser	Synch.	GWs	Repeat	Rosa and Kephart (2018)
	AQN & NS	Mag. recon.	Curv.	Below IR	Repeat	van Waerbeke and Zhitnitsky (2018)
Other	Starquakes	Mag. recon.	Curv.	GRB, X-rays	Repeat	Wang et al. (2018)
	Variable Stars	Undulator	Synch.	—	Repeat	Song et al. (2017)
	Pulsar Lightning	Electrostatic	Curv.	—	Repeat	Katz (2017a)
	Wandering Beam	—	—	—	Repeat	Katz (2016a)
	Tiny EM Explosions	Thin shell related	Curv.	Higher freq. radio pulse, γ-rays	Repeat	Thompson (2017b,a)
	WHs	—	—	IR emission, γ-rays	Single	Barrau et al. (2014, 2018)
	NS Combing	Mag. recon.	—	Scenario	Both	Zhang (2017, 2018)
	Neutral Cosmic Strings	Cusp decay	—	GW, neutrinos, cosmic rays, GRBs	Single	Brandenberger et al. (2017)
	Superconducting Cosmic Strings	Cusp decay	—	GW, neutrinos, cosmic rays, GRBs	Single	Costa et al. (2018)
	Galaxy DSR	DSR	Synch.	—	Both	Houde et al. (2018)
	Alien Light Sails	Artificial transmitter	—	—	Repeat	Lingam and Loeb (2017)
Inviable	Stellar Coronae	N/A	N/A	N/A	N/A	Loeb et al. (2014) Maoz et al. (2015)
	Annihilating Mini BHs	N/A	N/A	N/A	N/A	Keane et al. (2012)

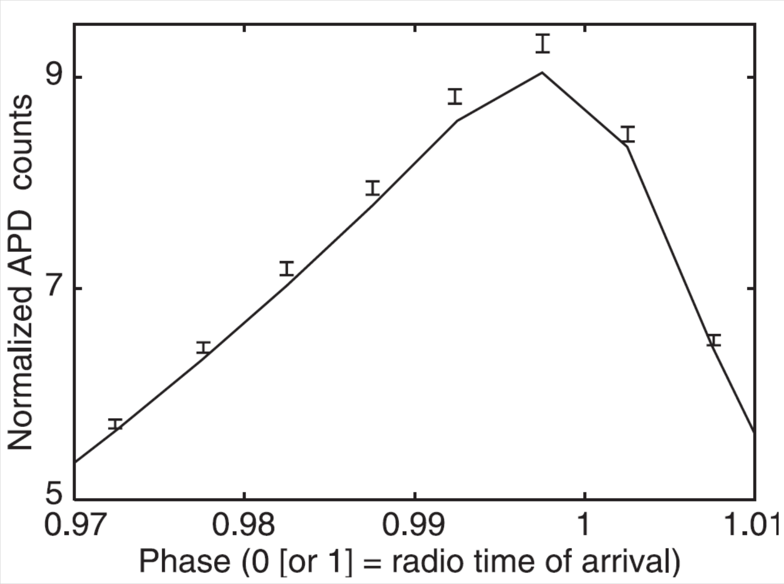
Platts+2018



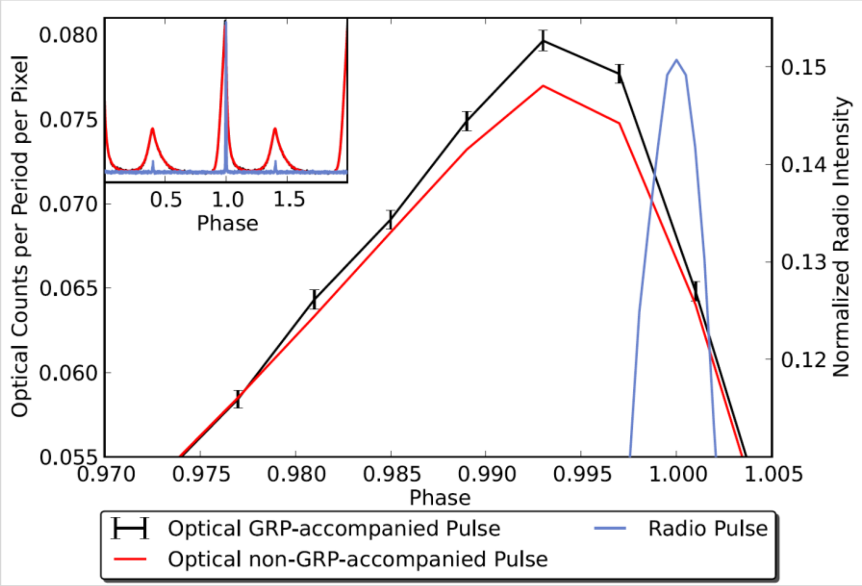
Uncertainty principle
Fast radio bursts
z=4.0
z=0.1
AGN/blazar/QSO
GRBs
10^{28} K
10^{20} K
10^{12} K
10^{4} K
Coherent emission
Incoherent emission
Supernovae
GW170817
Pulsar GRPs
Crab nano-shots
GCRT 1745
RRATs
D=10 kpc
D=0.1 kpc
Novae
X-ray Binaries
Pulsars
RSCVn
Magnetic CV
Solar Bursts
Flare stars/brown dwarves
Jupiter DAM
L_ν (Jy kpc^2)
L_ν (ergs s^{-1}Hz^{-1})
νW (GHz s)
10^{15}
10^{10}
10^{5}
10^{0}
10^{-5}
10^{-10}
10^{35}
10^{30}
10^{25}
10^{20}
10^{15}
10^{10}
10^{-10}
10^{-5}
10^{0}
10^{5}
10^{10}

Keane+2018

Optical Enhancement



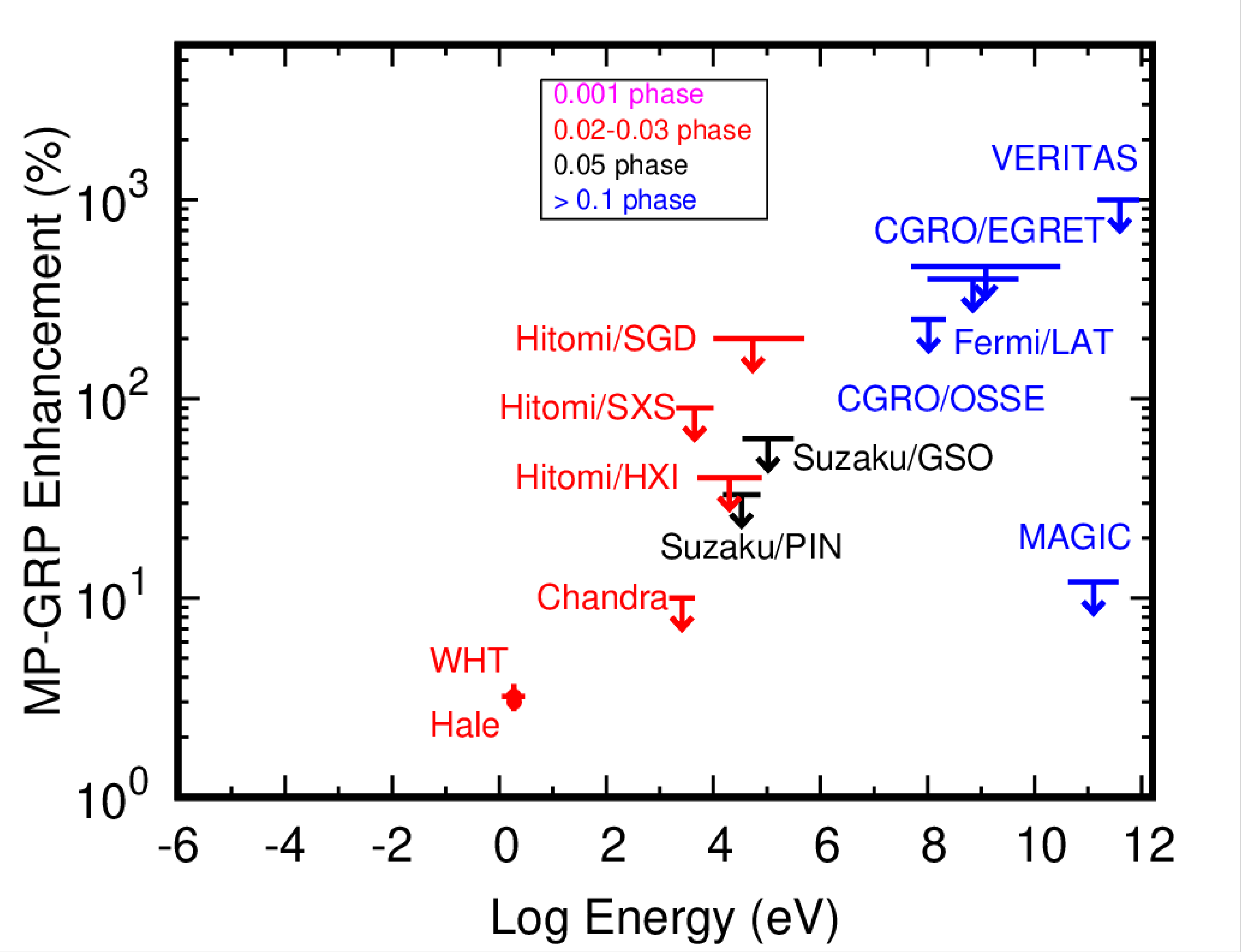
Shearer+2003



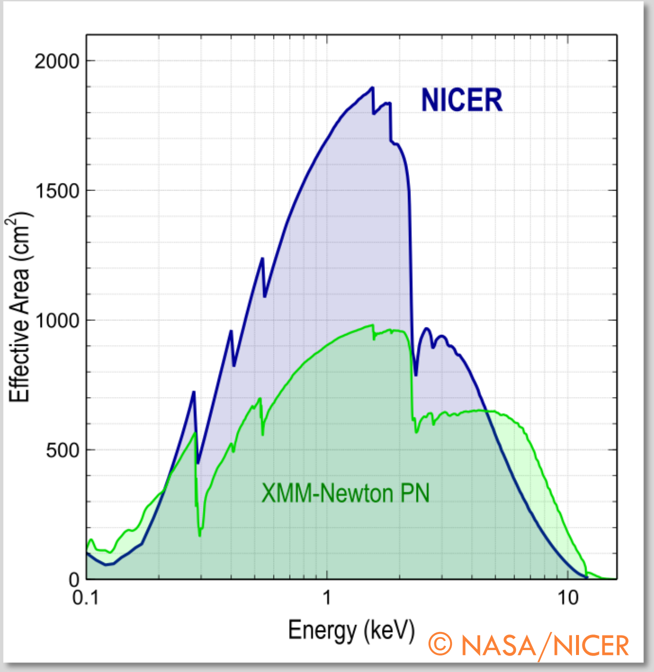
Strader+2013

- Enhancement of the optical pulse: ~3.2%
  - Optical and Radio emission is causally linked
- No spectral change is seen
  - The same emission mechanism

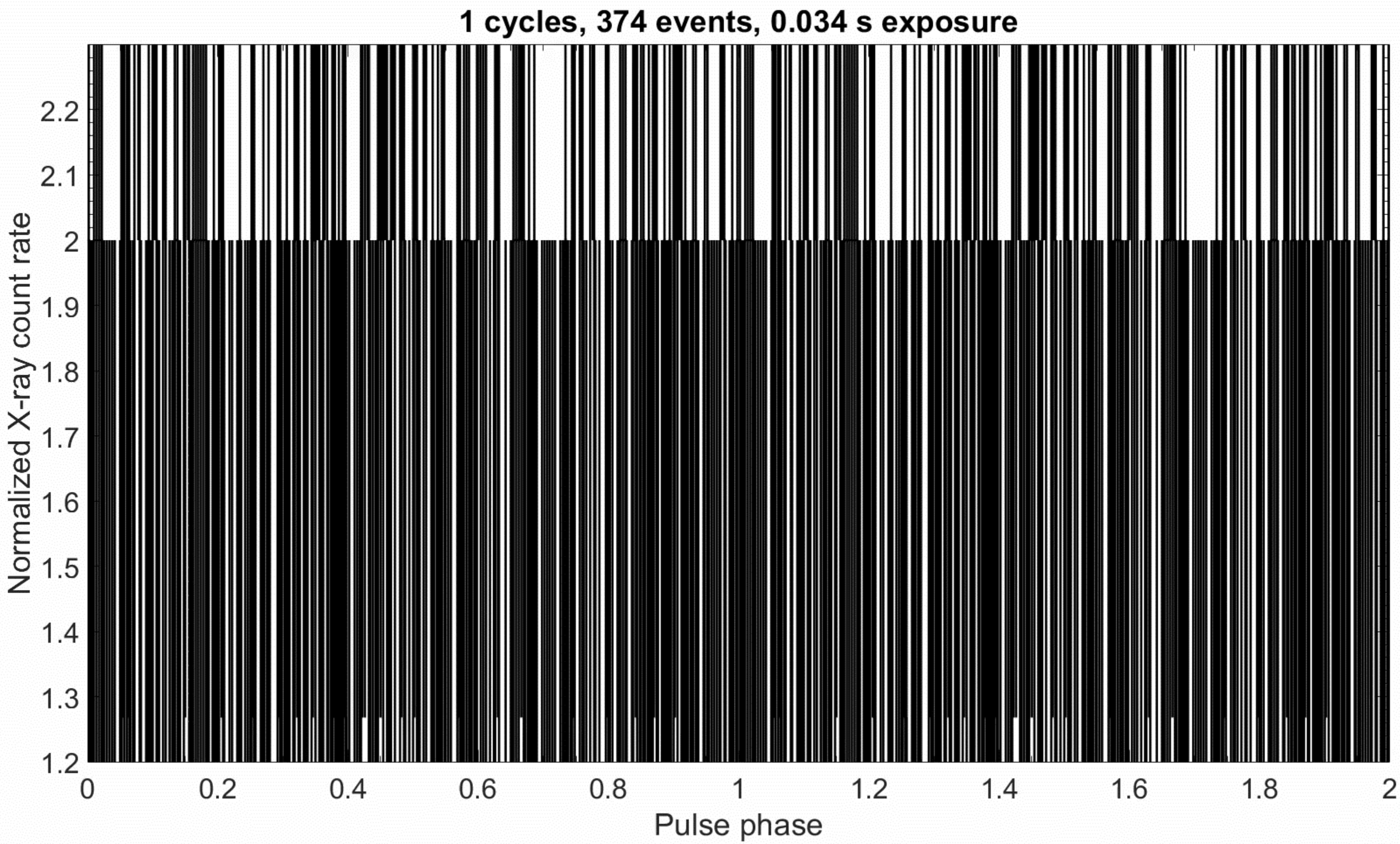
Enhancement in X-ray/Gamma-ray?



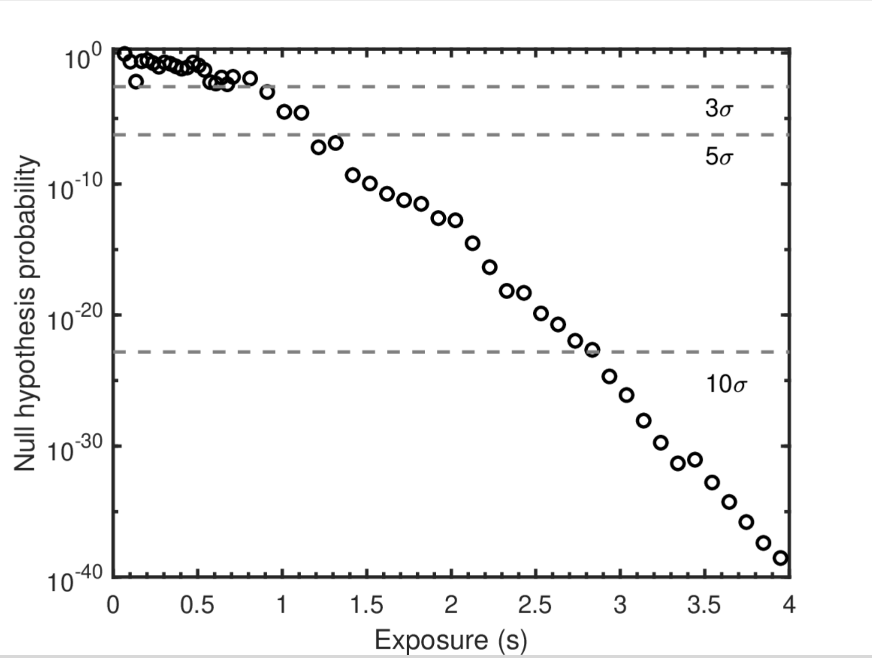
NICER

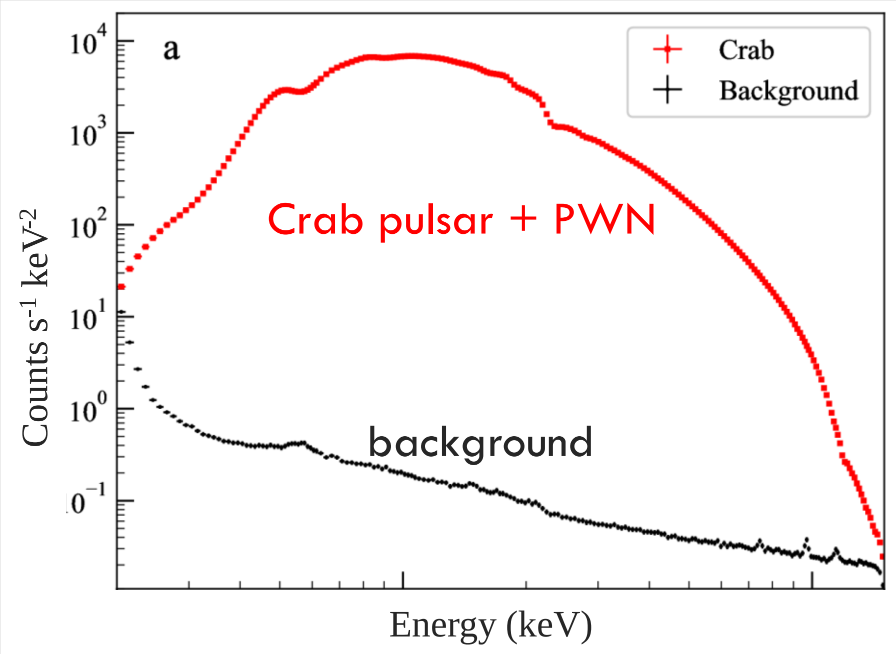


- Launched in 2017
- Largest effective area in soft X-ray (0.2-12 keV) band
- Non-imaging X-ray telescope
- High time resolution (<100 ns)


1 cycles, 374 events, 0.034 s exposure
Normalized X-ray count rate
2.2
2.1
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Pulse phase

Detection of X-ray Pulse





- The pulsation can be detected with ~1 s exposure (> 3 sigma)
- Crab pulsar + PWN: 1.1×10^4 cps (0.3-10 keV)
  - ~ 370 photons/cycle

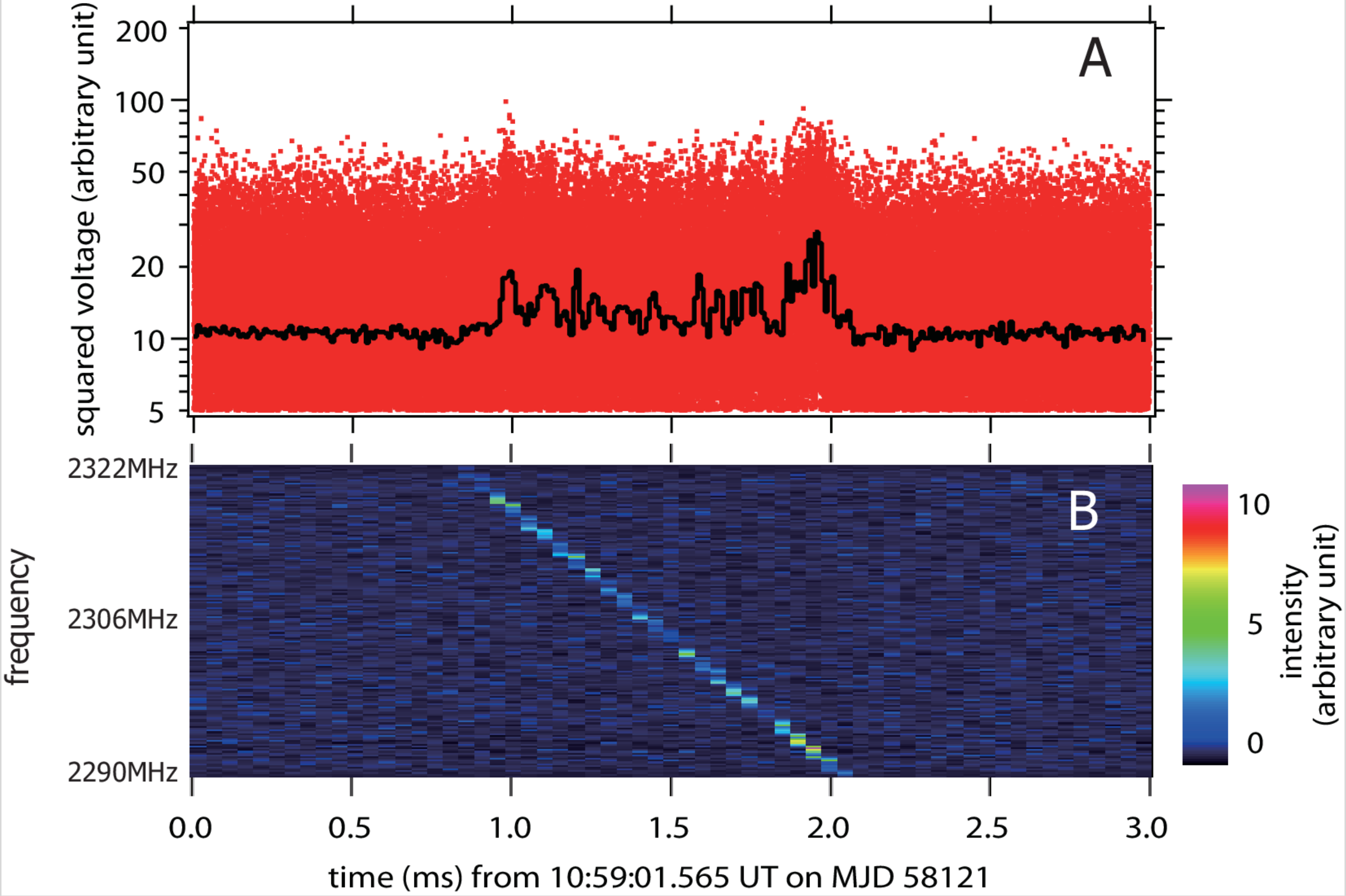
Radio Observation

© Usuda Deep Space Center

© Kashima Space Technology Center

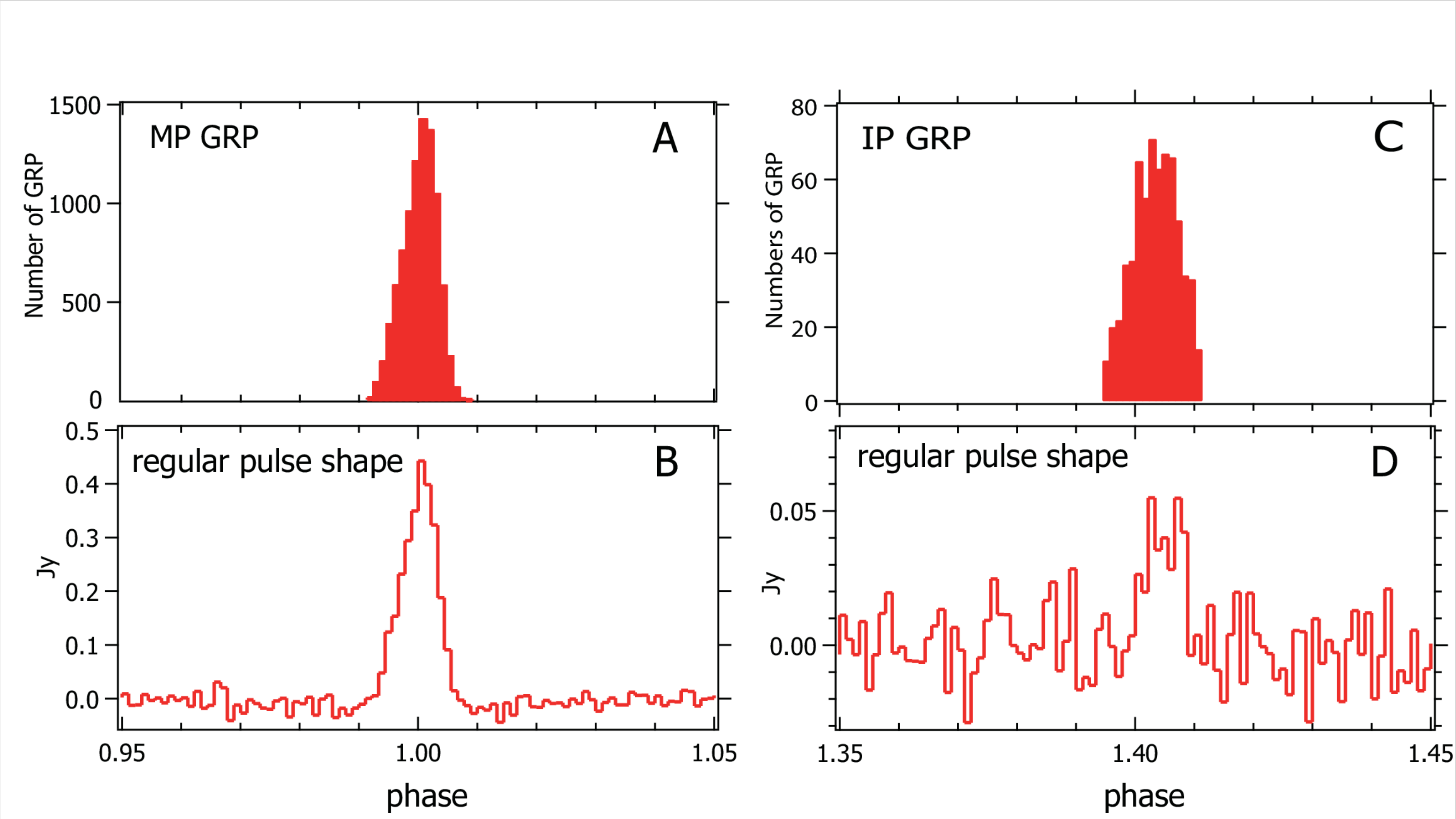
- We use Usuda (臼田, 64m) and Kashima (鹿島, 34m) to observe the Crab pulsar jointly with NICER.
  - Total overlap time ~ 126 ks
  - Frequency = 2GHz
- A number of 2.5×10^4 GRPs were detected

An Example of GRP



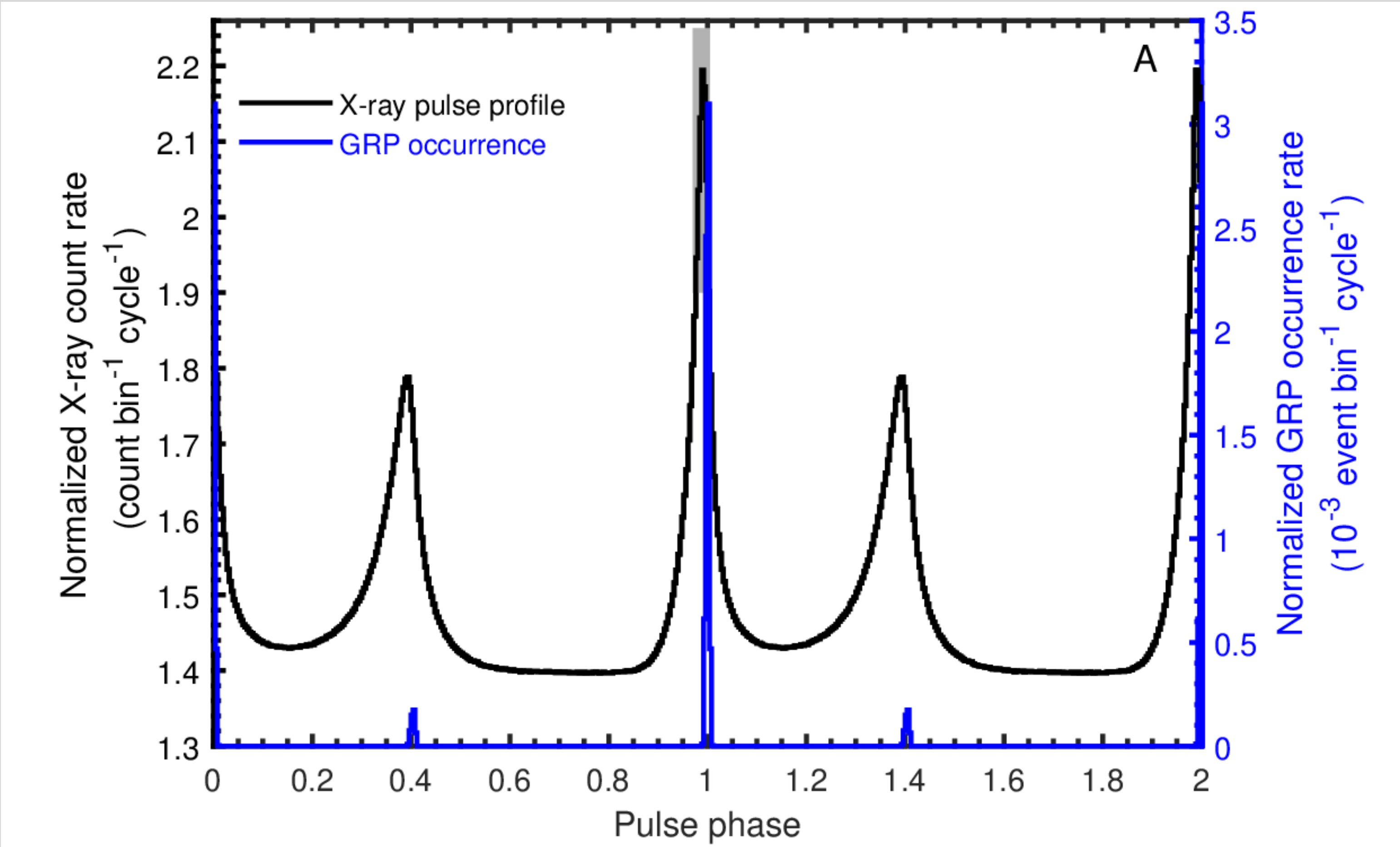
- Duration ~ 3 ms
  - After de-dispersion, the duration is ~16 ns

Phase Distribution of GRPs



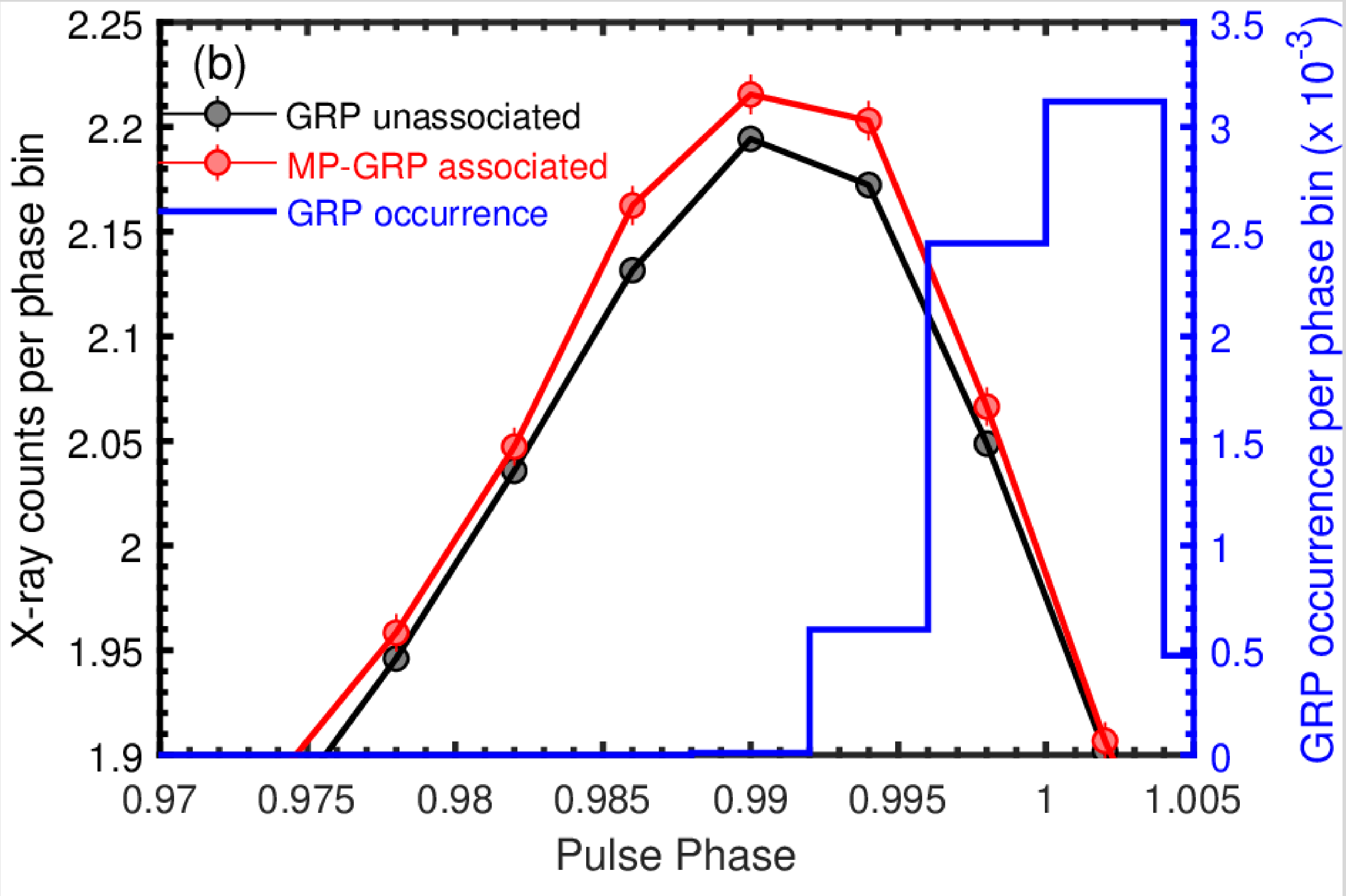
- The GRP histograms are similar to the averaged normal pulses.

Result



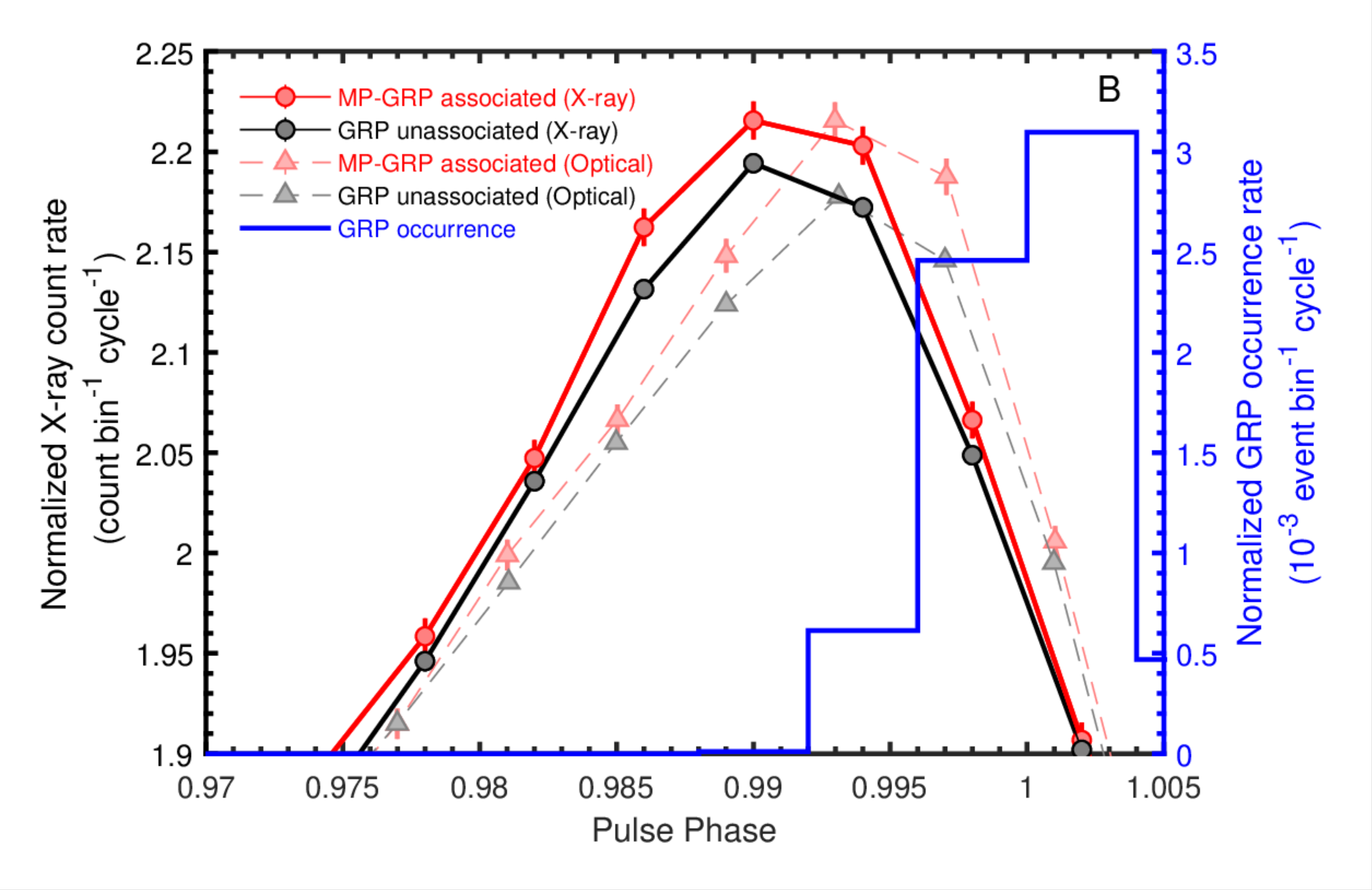
- We detected 2.5×10^4 GRPs.
- During the simultaneous Radio-X-ray GTI, we collected 1.4×10^9 X-ray photons in 0.3 – 10 keV.

Result

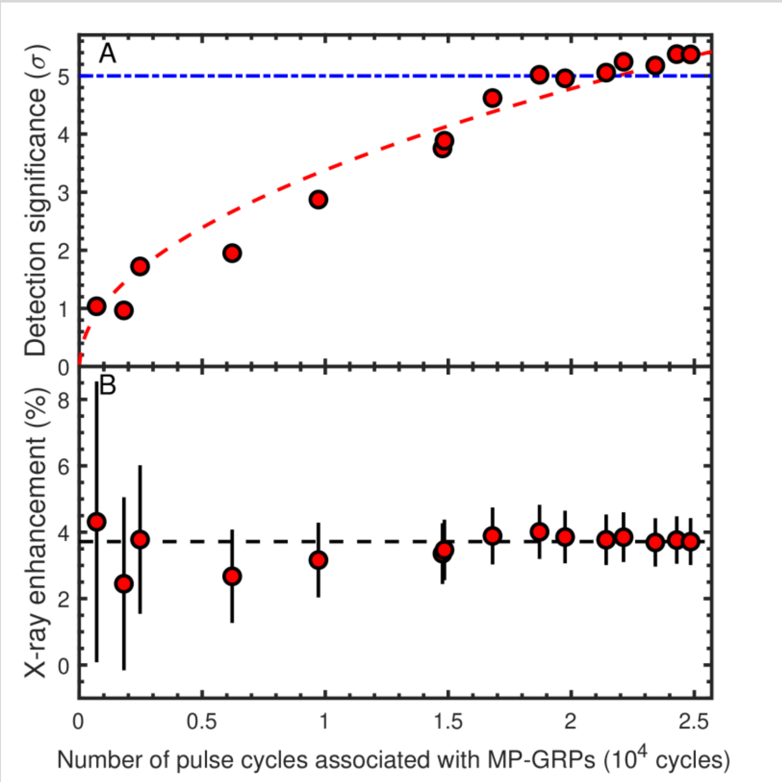


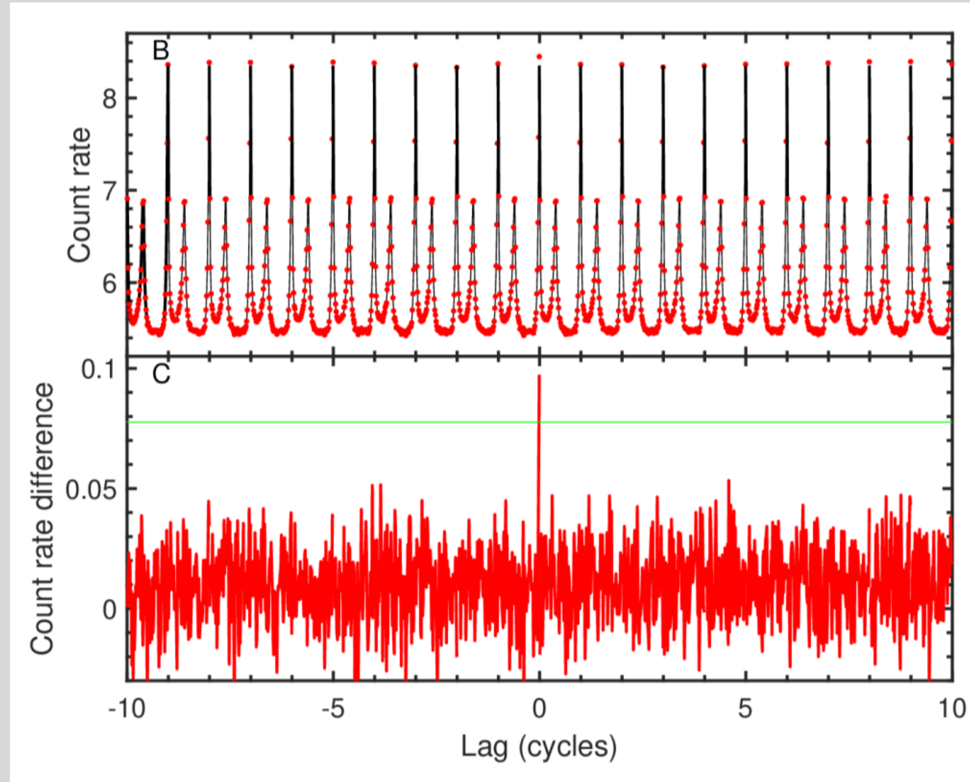
- X-ray flux at $\phi = 0.985 - 0.997$ is enhanced by 3.8 ± 0.7 %

Compared to the Optical Pulse Profile



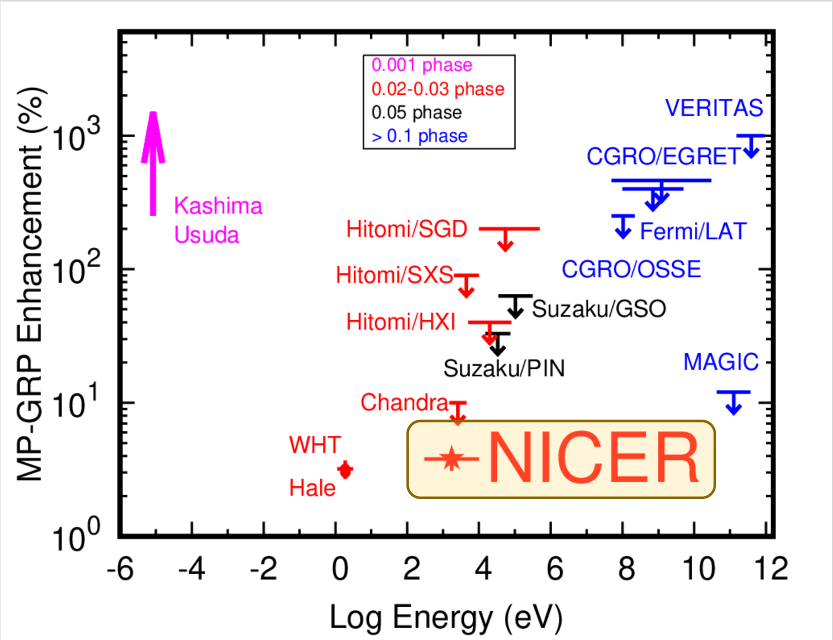
Significance and Lag Analysis

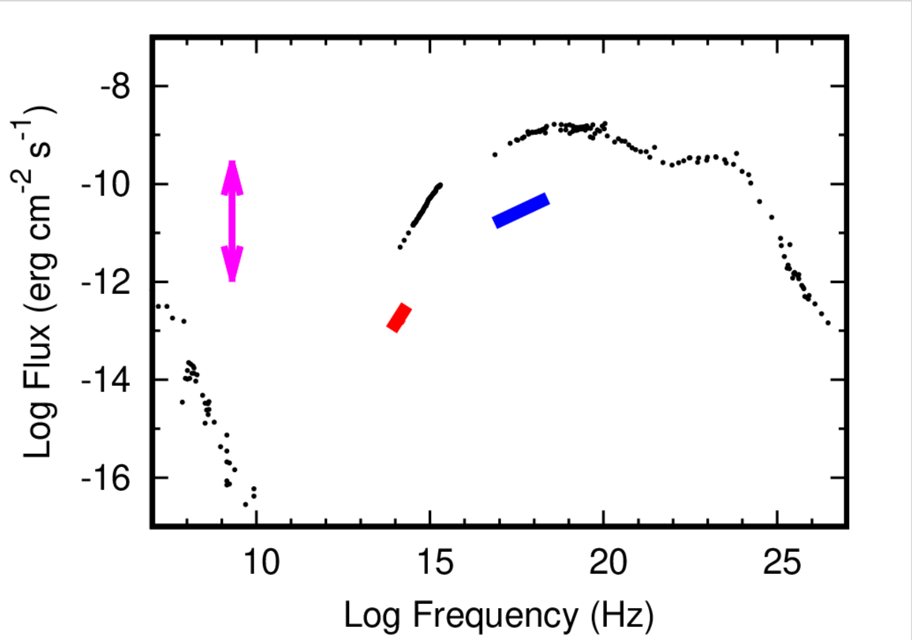




- The detection significance of the X-ray enhancements follows $\sqrt{N}$
- Neighboring cycles have no significant enhancements.

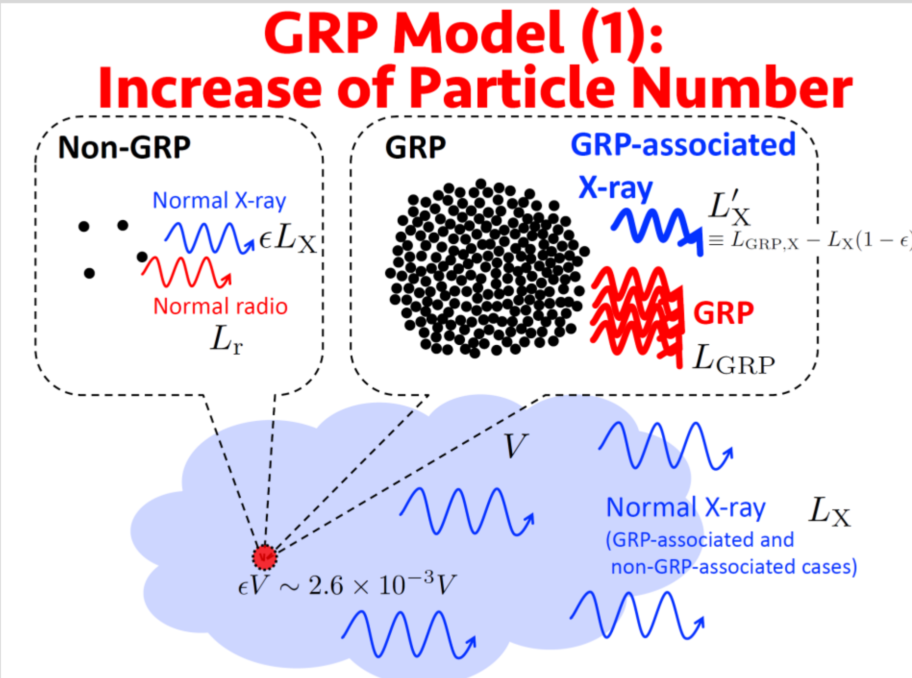
Spectral Energy Distribution

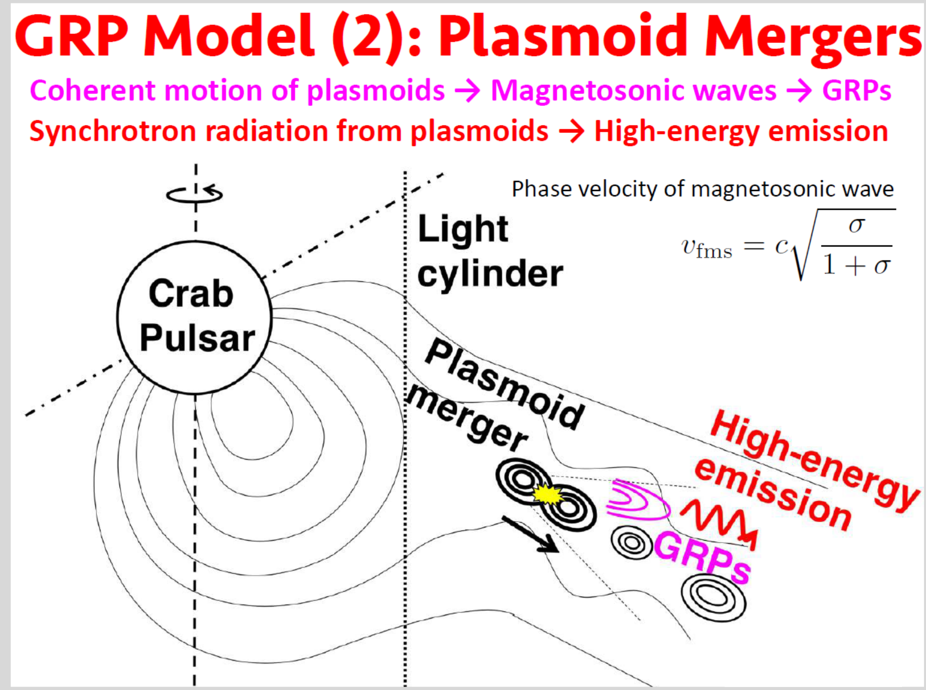




- The X-ray flux is $\sim 4 \times 10^{-9}\ \mathrm{erg\ s^{-1}\ cm^{-2}}$
  - 10^3 higher than the optical flux; 10^7 higher than the radio flux
  - The total energy released from a GRP is 10-100 times higher than expected.
  - No significant spectral change is found for MP-GRP

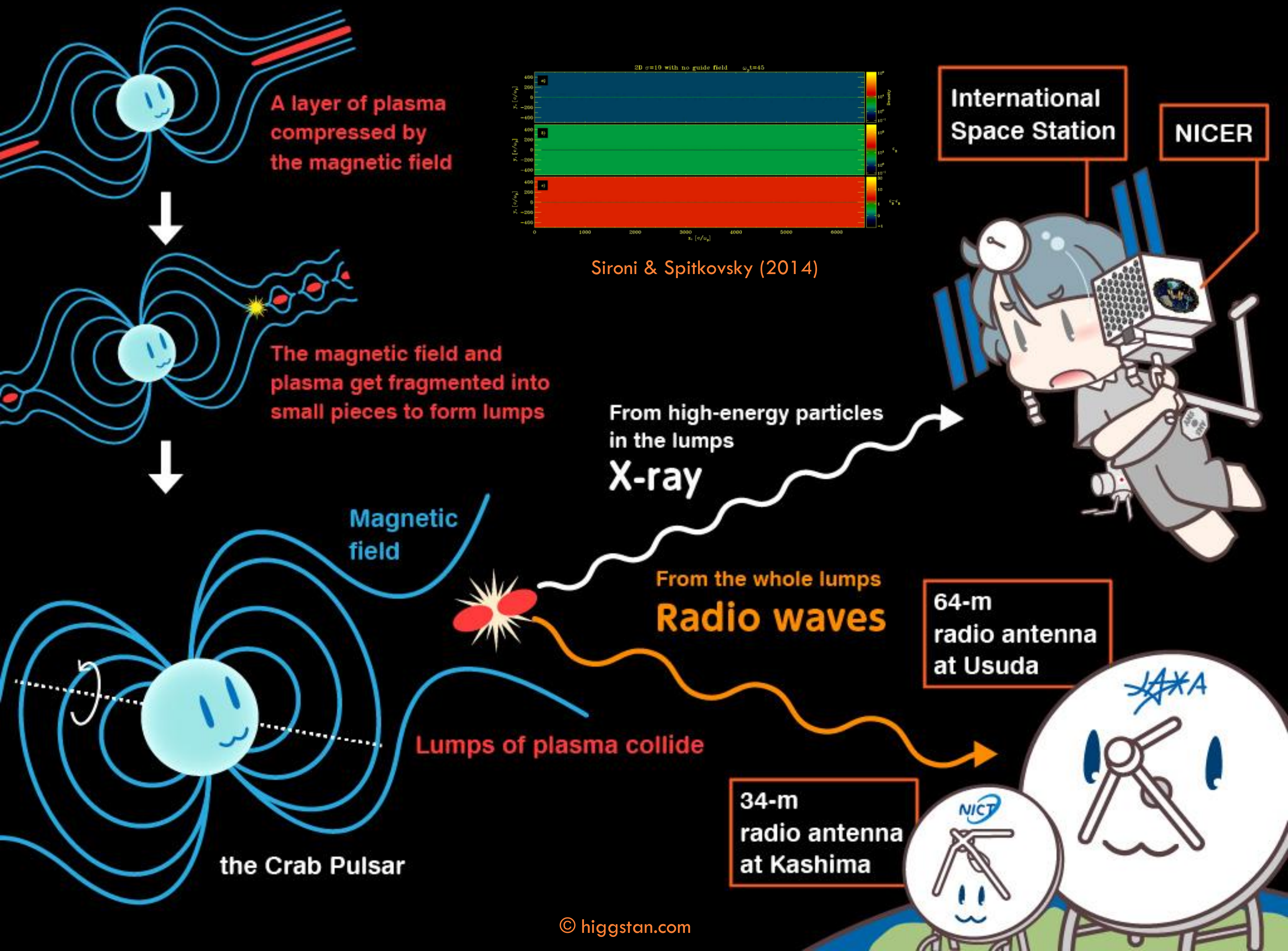
Possible Models





From S. Kisaka

- Increase of particle number ($L_X \propto N$) or magnetic reconnection.
  - The current GRP-FRB model is disfavored – The radio emission efficiency η is constrained. A GRP-FRB model would yield a spin-down rate much larger than the observed value.



Sironi & Spitkovsky (2014)

© higgstan.com

RESEARCH

TIME-DOMAIN ASTRONOMY

Enhanced x-ray emission coinciding with giant radio pulses from the Crab Pulsar

Teruaki Enoto[1]†*, Toshio Terasawa[2,3,4]†*, Shota Kisaka[5,6,7]†*, Chin-Ping Hu[1,8,9]†*, Sebastien Guillot[10], Natalia Lewandowska[11], Christian Malacaria[12,13], Paul S. Ray[13], Wynn C.G. Ho[11,15], Alice K. Harding[16,17], Takashi Okajima[16], Zaven Arzoumanian[16], Keith C. Gendreau[16], Zorawar Wadiasingh[16,18], Craig B. Markwardt[16], Yang Soong[16], Steve Kenyon[16], Slavko Bogdanov[19], Walid A. Majid[20,21], Tolga Güver[22], Gaurava K. Jaisawal[23], Rick Foster[24], Yasuhiro Murata[25,26,27], Hiroshi Takeuchi[25,27], Kazuhiro Takefuji[26,28], Mamoru Sekido[28], Yoshinori Yonekura[29], Hiroaki Misawa[30], Fuminori Tsuchiya[30], Takahiko Aoki[31], Munetoshi Tokumaru[32], Mareki Honma[33,34,35], Osamu Kameya[33,35], Tomoaki Oyama[33], Katsuaki Asano[2], Shinpei Shibata[36], Shuta J. Tanaka[37]

Giant radio pulses (GRPs) are sporadic bursts emitted by some pulsars that last a few microseconds and are hundreds to thousands of times brighter than regular pulses from these sources. The only GRP-associated emission outside of radio wavelengths is from the Crab Pulsar, where optical emission is enhanced by a few percentage points during GRPs. We observed the Crab Pulsar simultaneously at x-ray and radio wavelengths, finding enhancement of the x-ray emission by 3.8 ± 0.7% (a 5.4σ detection) coinciding with GRPs. This implies that the total emitted energy from GRPs is tens to hundreds of times higher than previously known. We discuss the implications for the pulsar emission mechanism and extragalactic fast radio bursts.

NASA's NICER Finds X-ray Boosts in the Crab Pulsar's Radio Bursts

A global science collaboration using data from NASA's Neutron star Interior Composition Explorer (NICER) telescope on the International Space Station has discovered X-ray surges accompanying radio bursts from the pulsar in the Crab Nebula. The finding shows that these bursts, called giant radio pulses, release far more energy than previously suspected.

Observations from NASA's Neutron star Interior Composition Explorer (NICER) show X-ray boosts linked in the Crab pulsar's random giant radio pulses. Watch to learn more.
Credit: NASA's Goddard Space Flight Center
Download this video in HD formats from NASA Goddard's Scientific Visualization Studio

A pulsar is a type of rapidly spinning neutron star, the crushed, city-sized core of a star that exploded as a supernova. A young, isolated neutron star can spin dozens of times each second, and its whirling magnetic field powers beams of radio waves, visible light, X-rays, and gamma rays. If these beams sweep past Earth, astronomers observe clock-like pulses of emission and classify the object as a pulsar.

宇宙の灯台「かにパルサー」に隠れていたX線のきらめき

－巨大電波パルスに同期したX線増光の検出に成功－

英語ページ

理化学研究所（理研）開拓研究本部の榎戸輝揚理研白眉研究チームリーダー、フー・チンピン客員研究員（國立彰化師範大學助教）、東京大学宇宙線研究所の寺澤敏夫名誉教授、浅野勝晃准教授、広島大学の木坂将大助教、宇宙航空研究開発機構の村田泰宏准教授、情報通信研究機構の関戸衛研究マネージャー、アメリカ航空宇宙局のキース・ジェンドルーNICERチーム代表、ザベン・アルゾメニアンNICERチーム共同代表らの国際共同研究グループは、高速で自転する中性子星[1]「かにパルサー」で発生する「巨大電波パルス（GRP）[2]」に同期して増光するX線を検出しました。

本研究成果は、過去20年にわたり複数のグループが挑戦してもなしえなかったものであり、宇宙遠方で発生する高速電波バースト（FRB）[3]の起源や発生メカニズムの解明にも貢献すると期待できます。

かにパルサーは、時折劇的に明るくなるGRPを発生します。このようなパルスの増光は電波でしか起こらないと考えられてきました。しかし近年、GRPに同期して可視光パルスがわずかに増光する現象が発見されたことから、よりエネルギーの高いX線やガンマ線でも同様の現象が起こるのかどうかに大きな関心が寄せられていました。

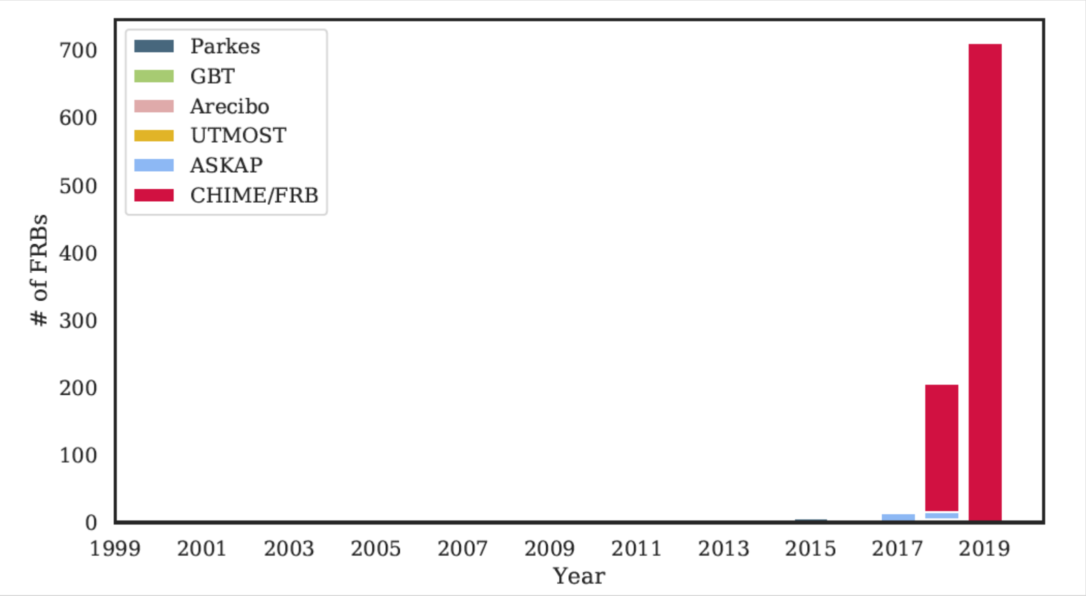
今回、国際共同研究グループは、国際宇宙ステーションに搭載されたアメリカ航空宇宙局のX線望遠鏡NICER[4]（ナイサー）と日本の二つの電波望遠鏡を連携させ、2017年からX線と電波の同時観測を続けた結果、GRPが発生する瞬間にX線パルスも4%ほど増光することを突き止めました。これにより、GRPがこれまで考えられていたよりもはるかに大きなエネルギーを解放することが分かりました。

本研究は、科学雑誌『*Science*』（4月9日号）の掲載に先立ち、オンライン版（4月8日付：日本時間4月9日）に掲載されます。

かにパルサーを見るNICERと臼田・鹿島さん

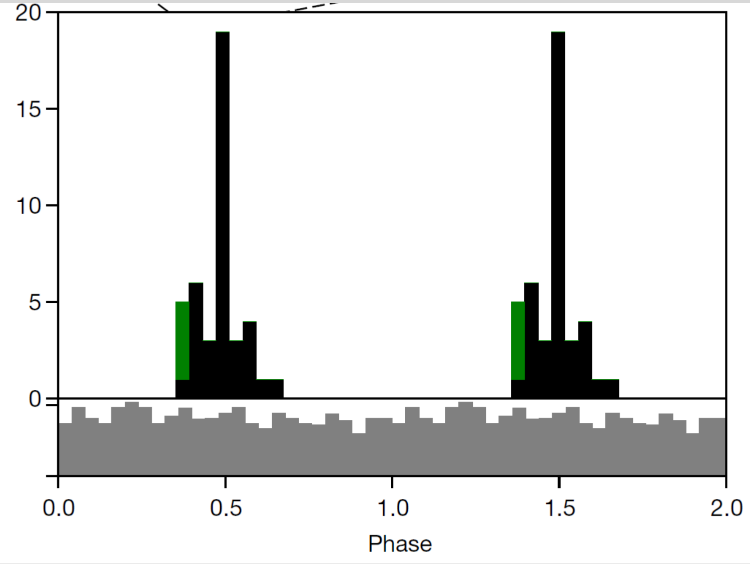
NICER, Usuda, and Kashima are watching the Crab Pulsar

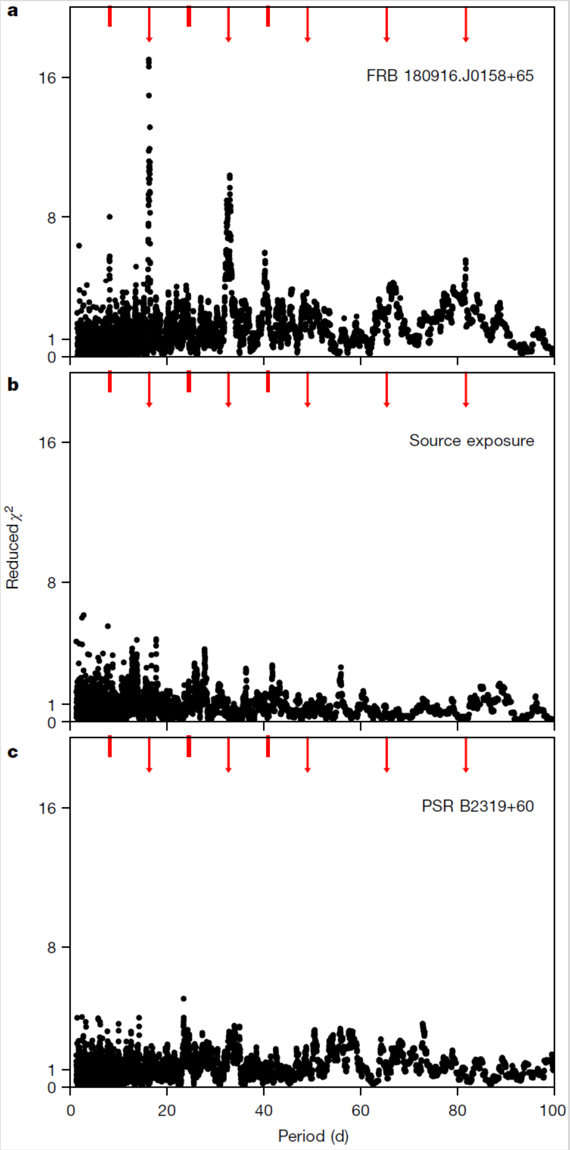
CHIME/FRB Project



© CHIME/FRB Collaboration

Periodic FRB

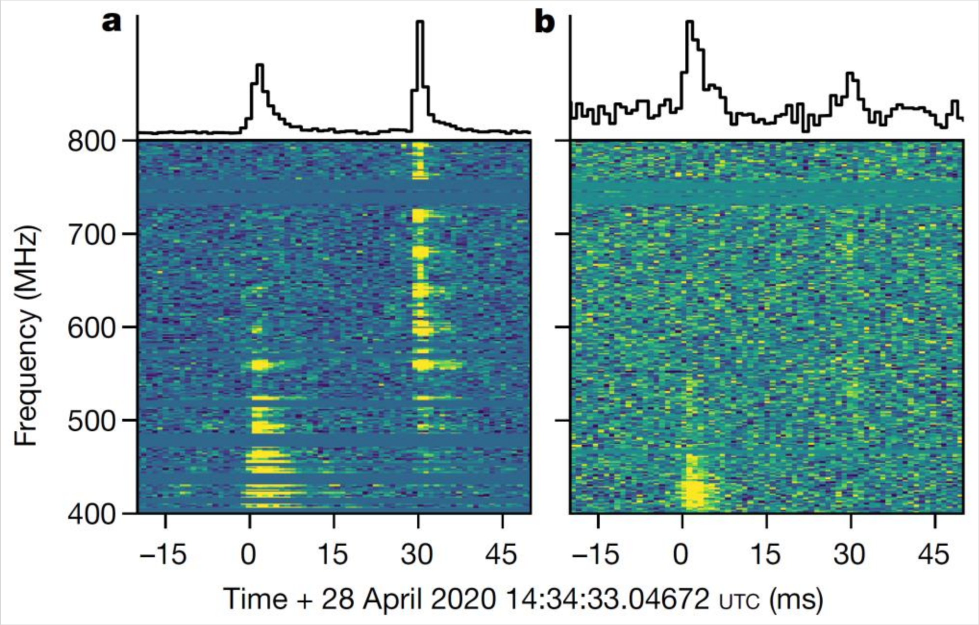


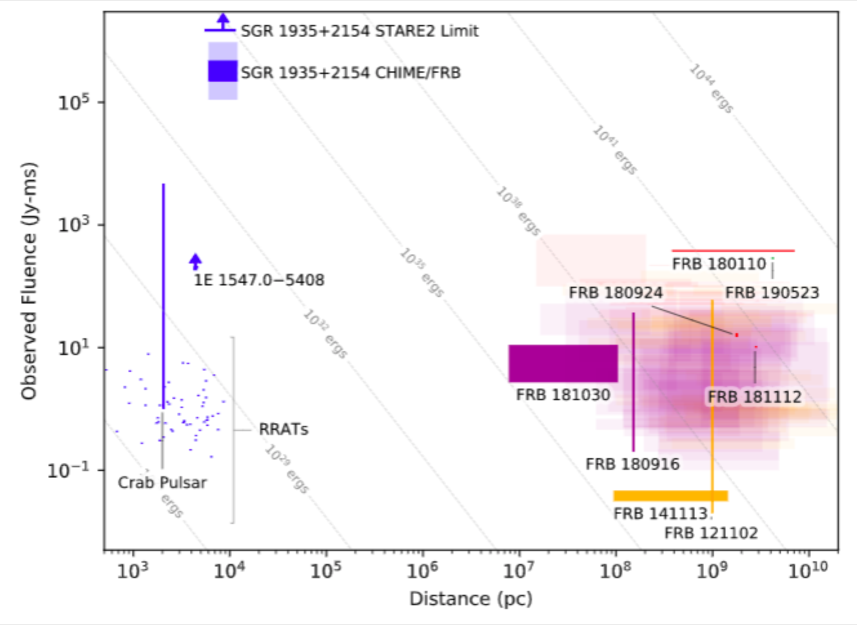


- A period of $P = 16.35 \pm 0.15$ days is found
  - Orbital motion (binary system)?
  - Phase-dependent emission/absorption?
  - Sporadic emission is not favored (e.g., GRP and magnetars)

CHIME/FRB Collaboration (2020)

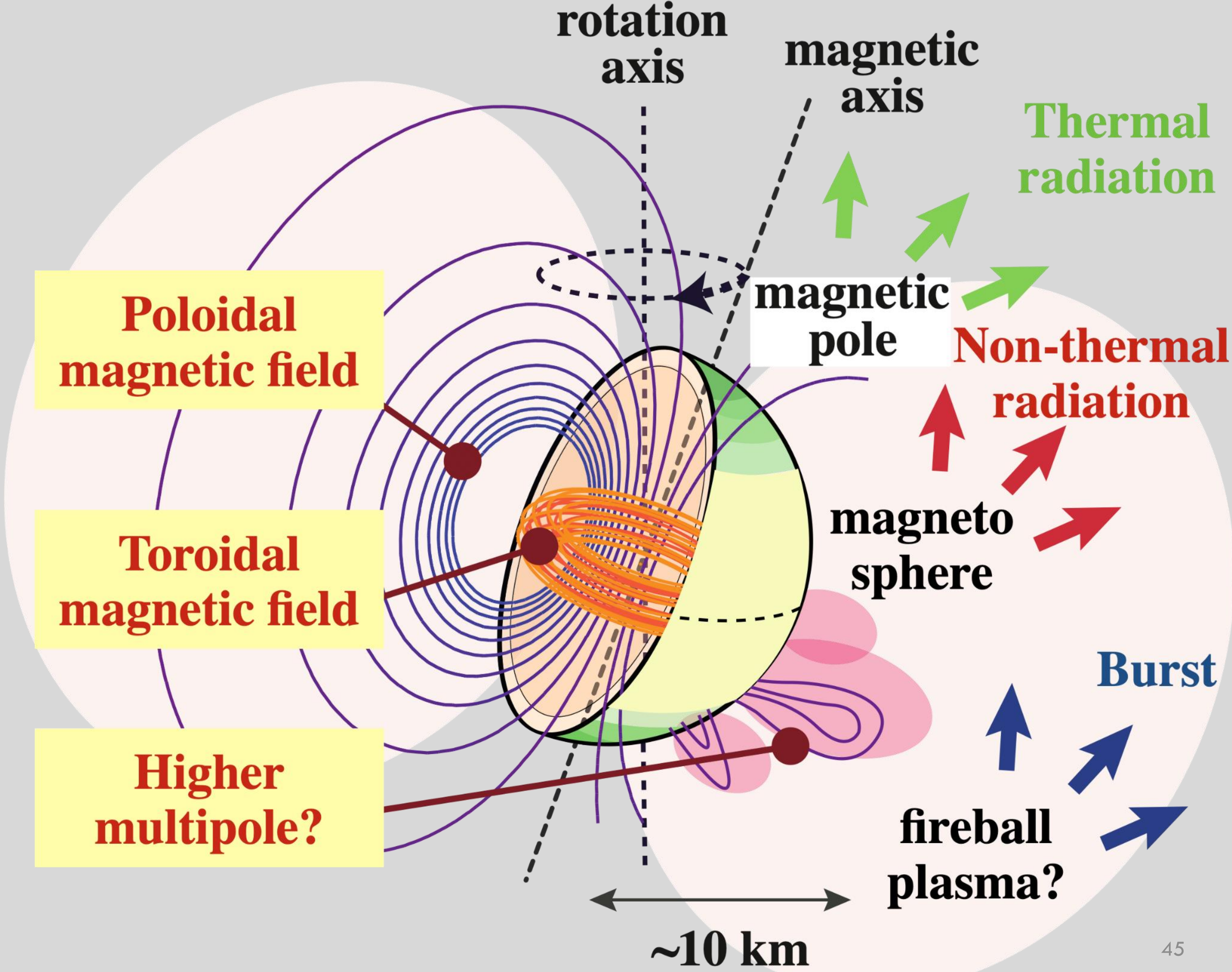
Galactic FRB



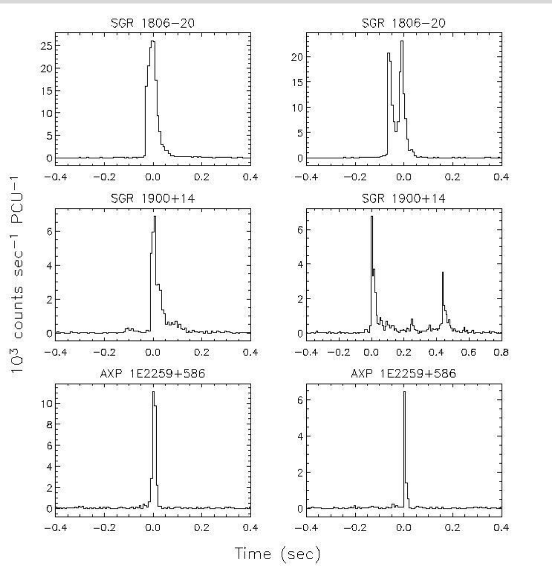


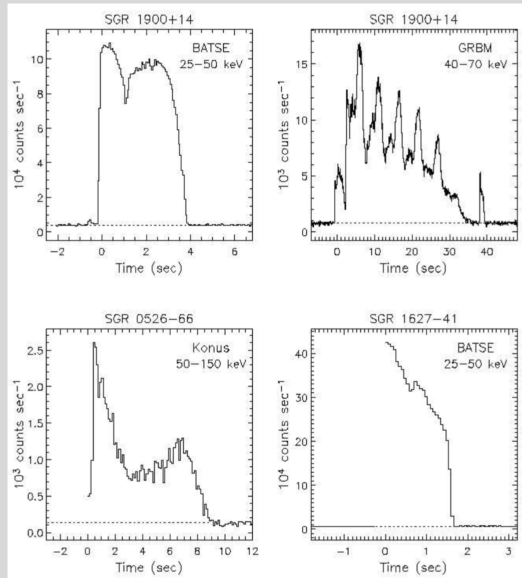
CHIME/FRB Collaboration (2020)

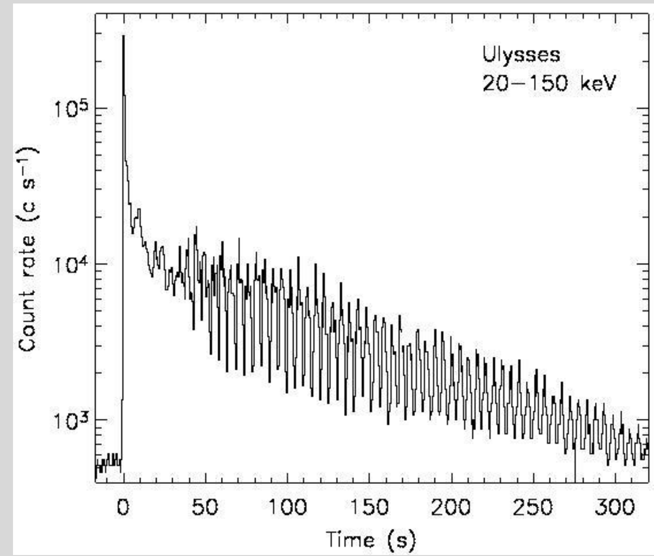
- A galactic FRB is detected from SGR 1935+2154
  - FRB 200428
  - A magnetar underwent outburst!
  - Roughly the same as the low-fluence-end of extragalactic FRBs
  - FRBs have different populations?


rotation
axis
magnetic
axis
Thermal
radiation
Poloidal
magnetic field
magnetic
pole
Non-thermal
radiation
Toroidal
magnetic field
magneto
sphere
Burst
Higher
multipole?
fireball
plasma?
~10 km

X-ray Short Bursts



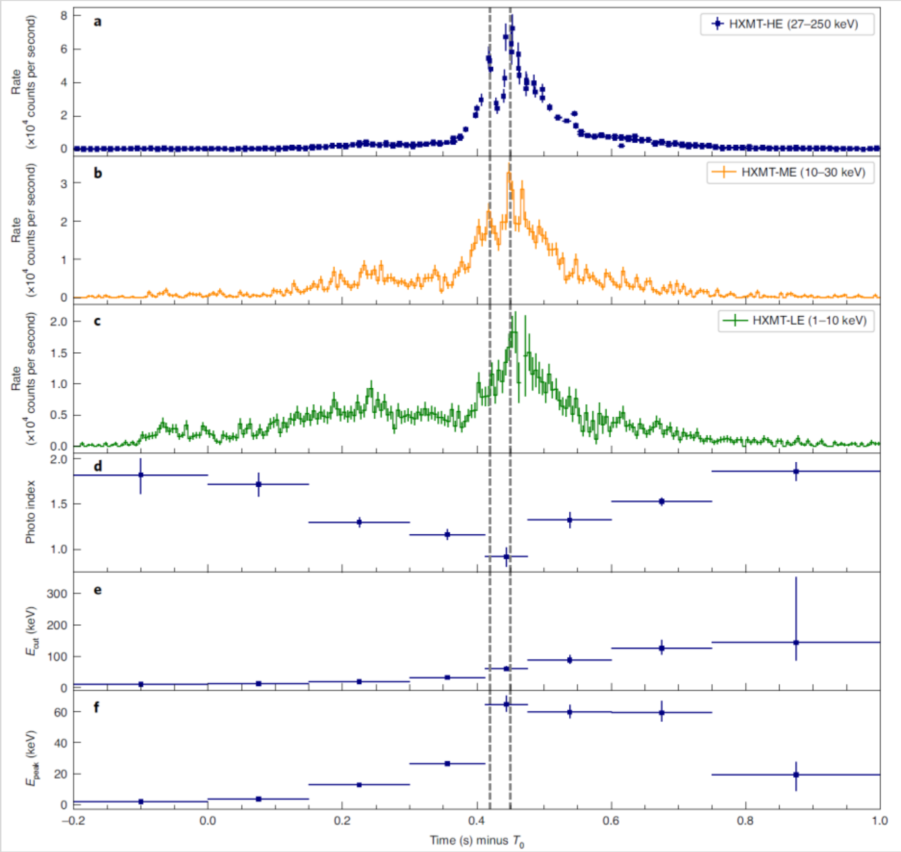


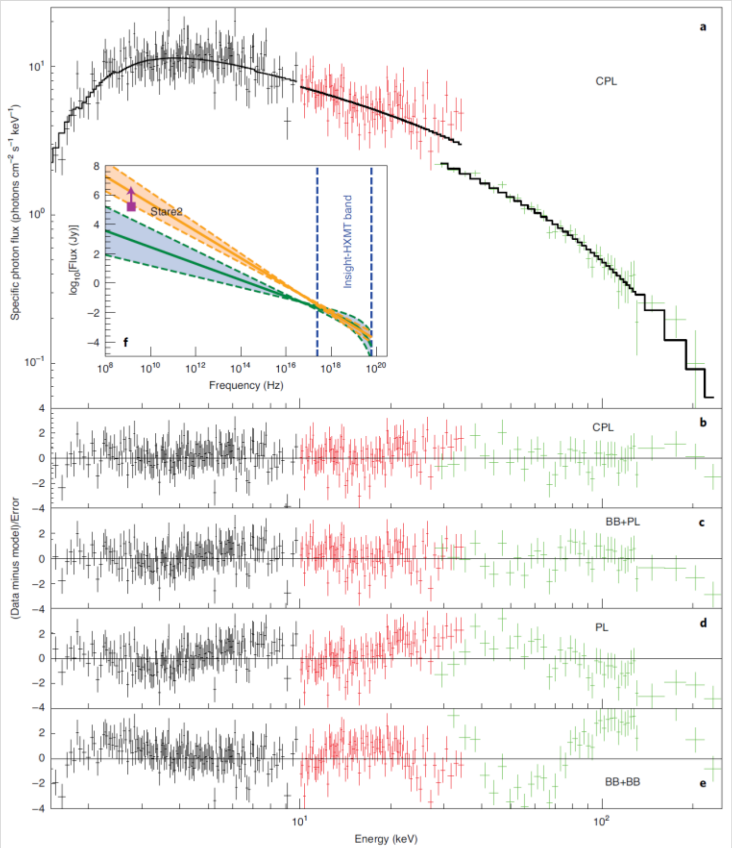


Woods & Thompson (2004)

- Short and intermediate bursts and giant flares
  - Three sources are found to have giant flares
  - $L = 10^{47}$ erg/s
  - Not detected in radio band

X-ray Short Burst

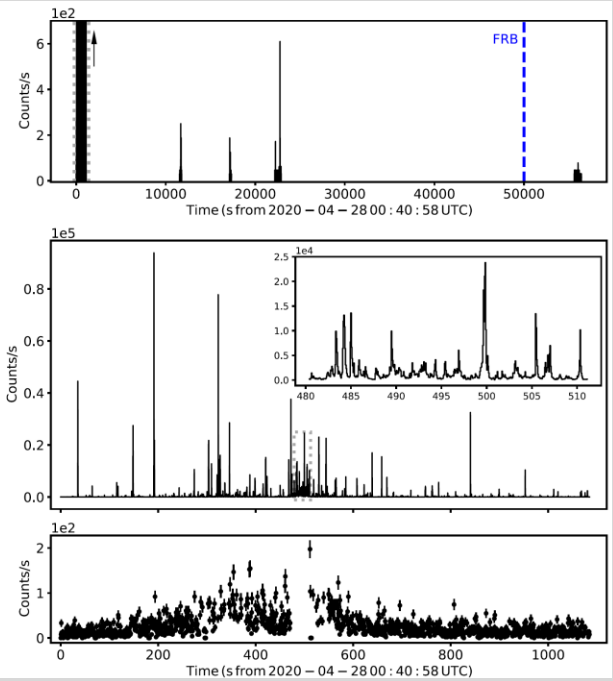




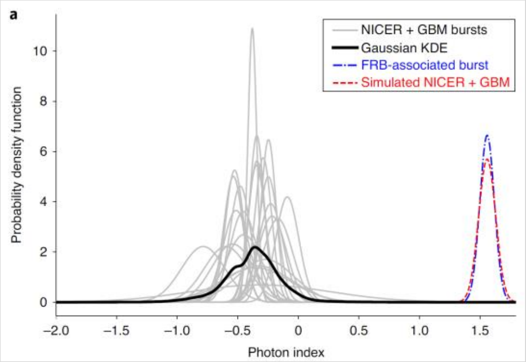
Li et al. (2020)

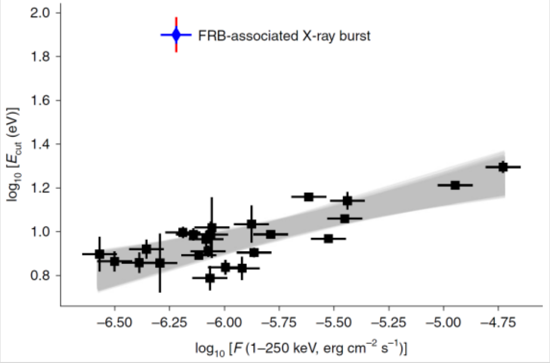
- An X-ray burst coincide with FRB is detected by Insight-HXMT
  - Power-law dominated – non-thermal origin
  - Magnetosphere related emission?

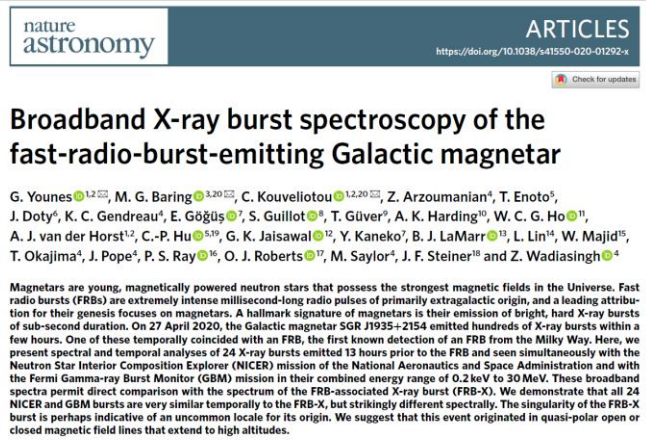
NICER Observation



Younes et al. (2020, 2021)







nature astronomy ARTICLES
https://doi.org/10.1038/s41550-020-01292-x

Check for updates

Broadband X-ray burst spectroscopy of the fast-radio-burst-emitting Galactic magnetar

G. Younes[1,2], M. G. Baring[3,20], C. Kouveliotou[1,2,20], Z. Arzoumanian[4], T. Enoto[5], J. Doty[6], K. C. Gendreau[4], E. Göğüş[7], S. Guillot[8], T. Güver[9], A. K. Harding[10], W. C. G. Ho[11], A. J. van der Horst[1,2], C.-P. Hu[5,19], G. K. Jaisawal[12], Y. Kaneko[7], B. J. LaMarr[13], L. Lin[14], W. Majid[15], T. Okajima[4], J. Pope[4], P. S. Ray[16], O. J. Roberts[17], M. Saylor[4], J. F. Steiner[18] and Z. Wadiasingh[4]

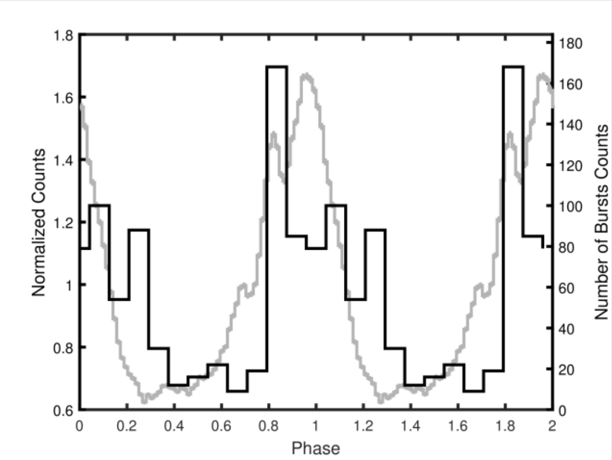
Magnetars are young, magnetically powered neutron stars that possess the strongest magnetic fields in the Universe. Fast radio bursts (FRBs) are extremely intense millisecond-long radio pulses of primarily extragalactic origin, and a leading attribution for their genesis focuses on magnetars. A hallmark signature of magnetars is their emission of bright, hard X-ray bursts of sub-second duration. On 27 April 2020, the Galactic magnetar SGR J1935+2154 emitted hundreds of X-ray bursts within a few hours. One of these temporally coincided with an FRB, the first known detection of an FRB from the Milky Way. Here, we present spectral and temporal analyses of 24 X-ray bursts emitted 13 hours prior to the FRB and seen simultaneously with the Neutron Star Interior Composition Explorer (NICER) mission of the National Aeronautics and Space Administration and with the Fermi Gamma-ray Burst Monitor (GBM) mission in their combined energy range of 0.2 keV to 30 MeV. These broadband spectra permit direct comparison with the spectrum of the FRB-associated X-ray burst (FRB-X). We demonstrate that all 24 NICER and GBM bursts are very similar temporally to the FRB-X, but strikingly different spectrally. The singularity of the FRB-X burst is perhaps indicative of an uncommon locale for its origin. We suggest that this event originated in quasi-polar open or closed magnetic field lines that extend to high altitudes.

- NICER did not catch the FRB burst.
  - A series of “burst storms” were observed half days before the FRB
  - The spectral behaviors of bursts in the storms are different from that of the FRB burst.
  - Populations of magnetar bursts?
    - Burst storm vs regular bursts vs FRB bursts

Bursts in Recently Discovered Magnetars

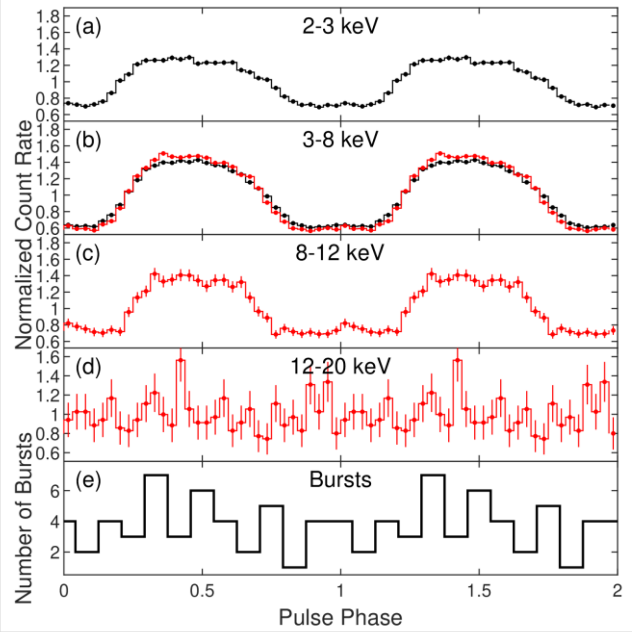
SGR 1830-0645

Evidence of hotspot migration



Younes et al. (2021)

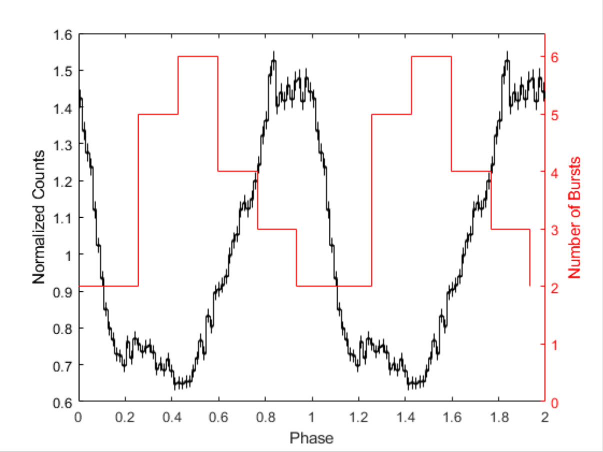
Swift J1555.2-5402



Enoto et al. (2020)

Swift J1818.0-1607

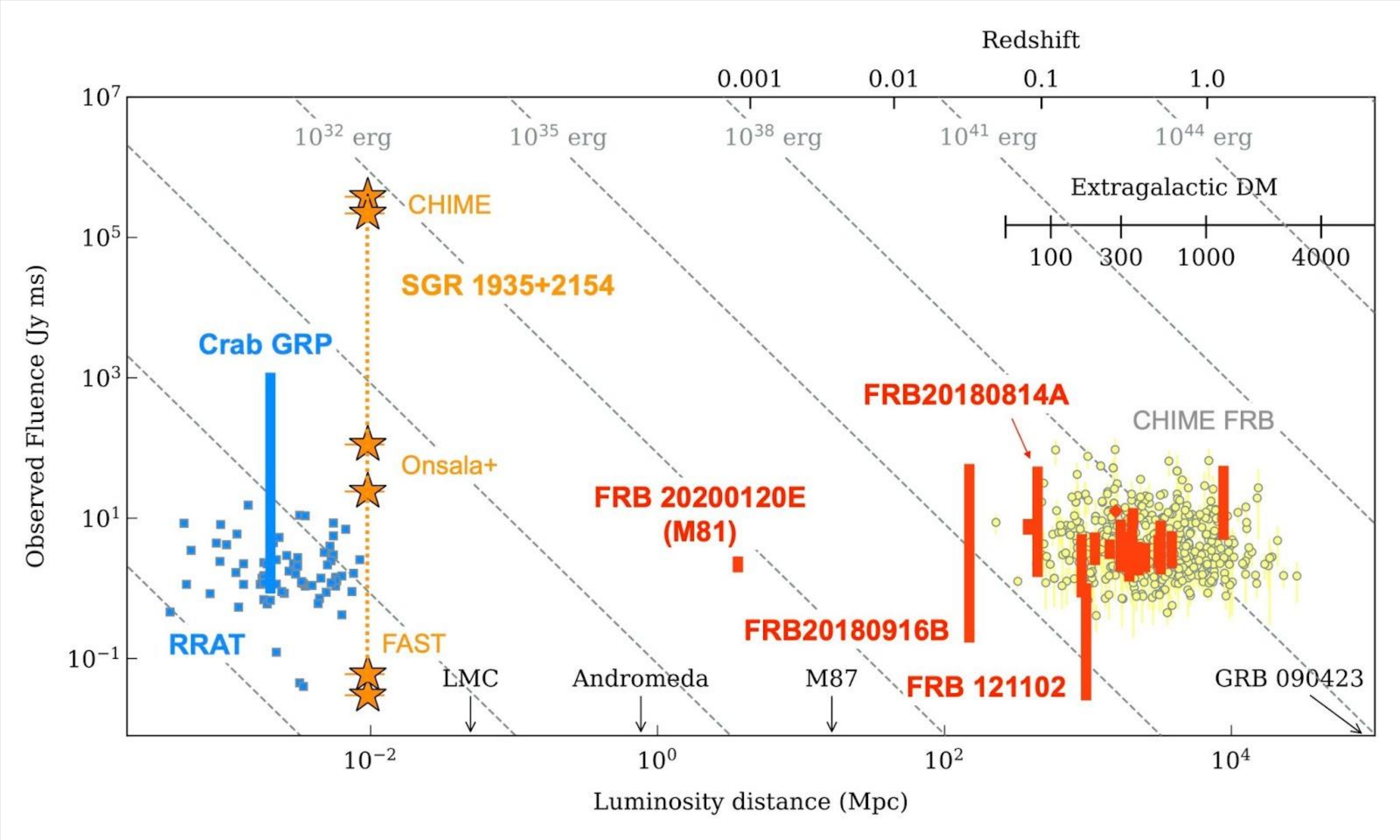
A missing link between magnetars and RPPs



Hu et al. (2020)

- Spin phase distribution of bursts may vary between magnetars
  - So do fluence distribution and maybe spectral behaviors
  - A comprehensive study of short burst is needed.
  - Originated from magnetosphere/surface?

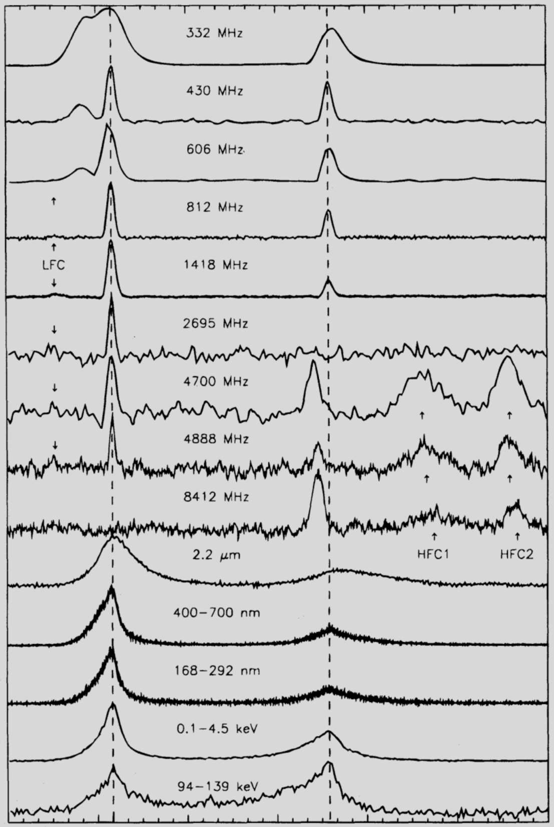
FRB Follow-up/monitoring

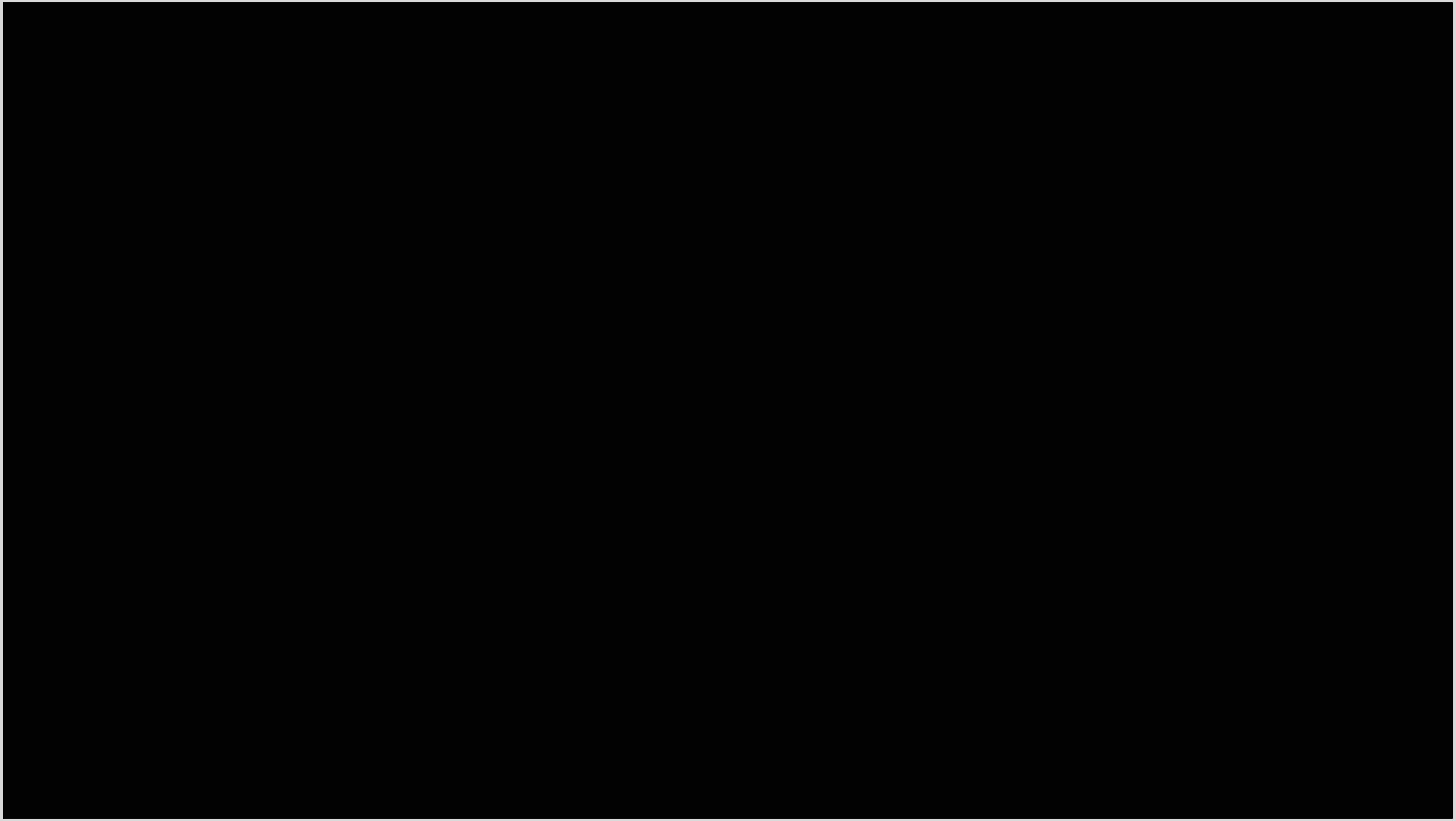


- FRBs (low-fluence) are magnetar bursts, giant pulses, or both?

Summary and Future Work

- We detected a 4% flux enhancement in the X-ray band coincide with GRPs.
  - Any X-ray enhancements associated with GRPs in other radio wavelengths?
  - GRP in 4700-8000 MHz, IP-GRPs?
- The result disfavored a few models, including the GRP-FRB model.
  - Parts of FRBs may be originated from magnetars
  - Connection between GRP and FRB remains possible.
  - Neutron star magnetosphere is one of the most promising origin.
  - High energy observations are key to understanding the FRB engine
- Magnetar bursts may have different populations
  - Systematic search + population study





https://www.youtube.com/watch?v=U9GT0IAcjCk https://www.youtube.com/watch?v=ejVNUMo5Nzw

Thank You