Investigating the FRB-Magnetar Link Through Low-Energy Radio Emissions

Banshi Lal

Collaborators: Yogesh Maan (NCRA), Moaz Abdelmaguid (NYUAD), Joseph Gelfand (NYUAD), Visweshwar Marthi (NCRA)

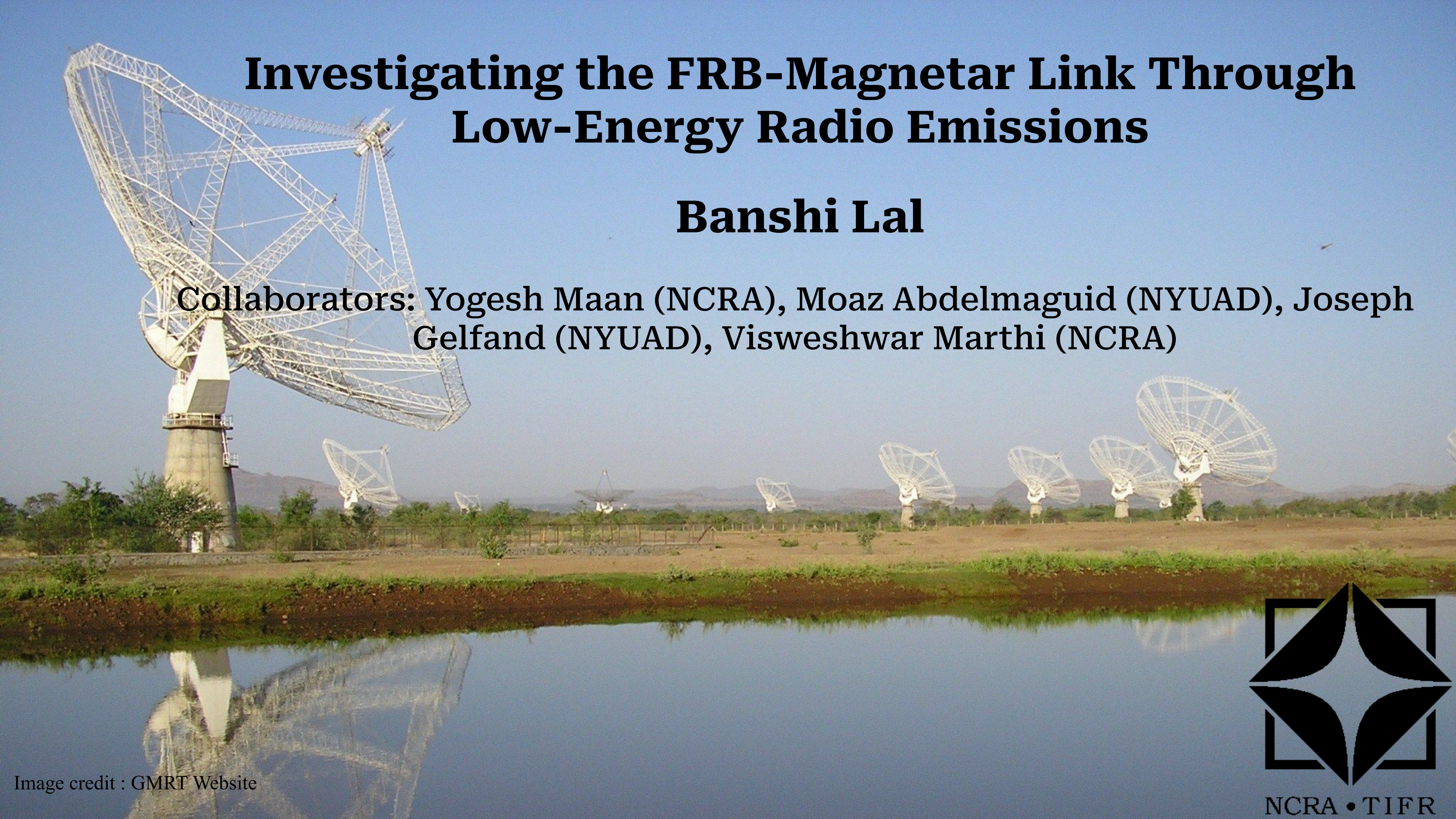


Image credit : GMRT Website

NCRA • TIFR

Magnetars

- Young Neutron stars
- High magnetic field (B ~ 10^{15}G)
- Slow rotation compare to pulsars
  - Period ranges from few seconds to minutes
- Powered by decay of internal magnetic field
- Magnetic field increases crustal stress
- Sudden fractures in the magnetar crust "Star-quake"

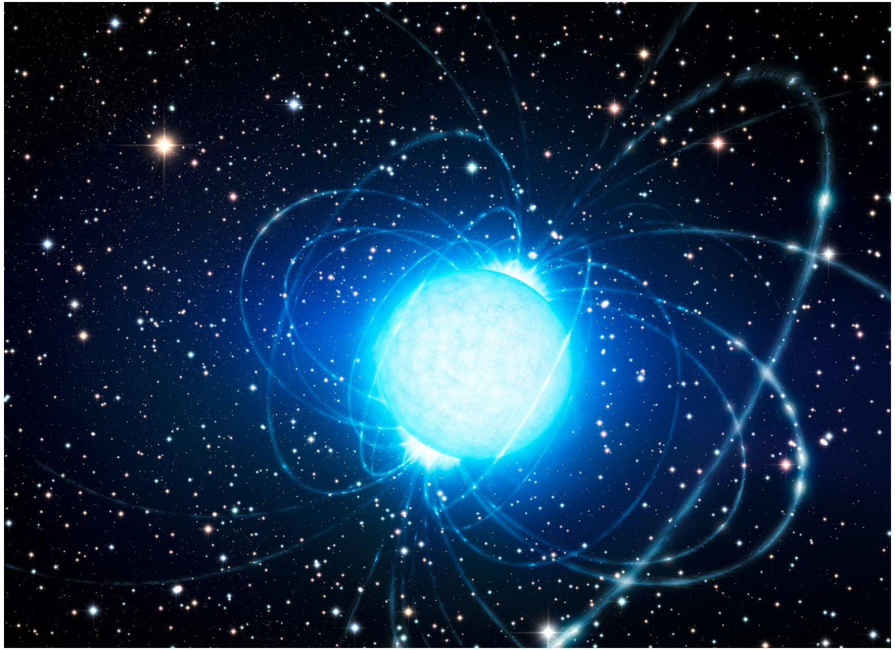


Image credit: https://www.eso.org

Magnetars

- Mostly detected via high energy emission
- Persist (Luminosity > 10^{33} ergs s^{-1} and DR<100) and transient sources
- Transient radio emission (e.g. XTE J1810-197)
- Emission
  - Short-duration bursts (typically < 1s)
  - Outburst, sudden flux enhancement with a long decay time
  - Giant flares (GF), sudden release of enormous energy (~10^{44} ergs)

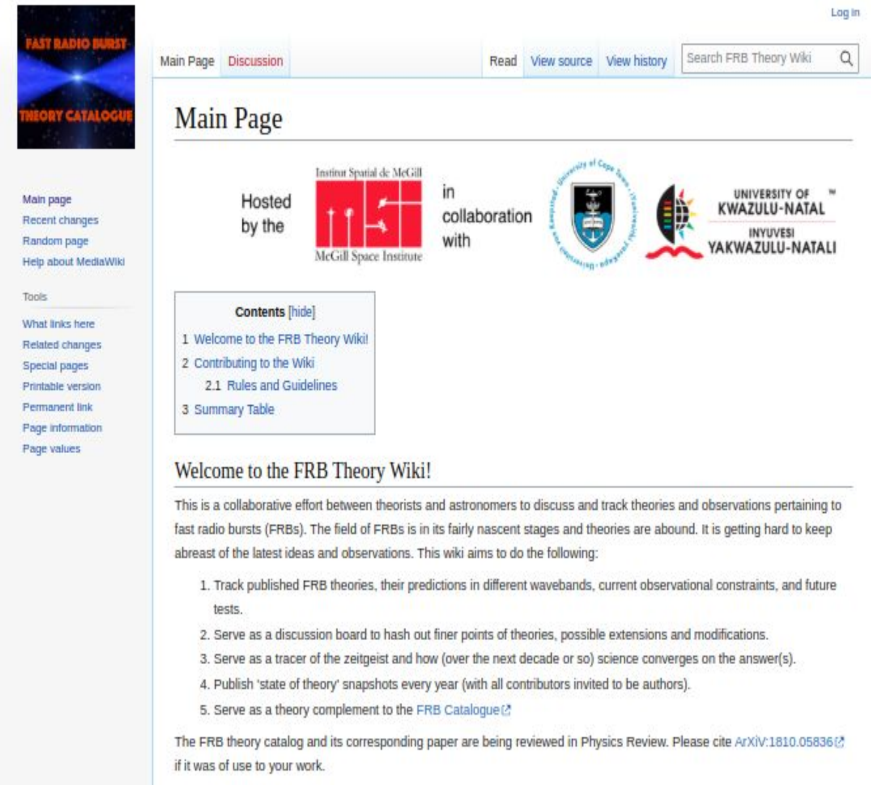
FRB origin?

frbtheorycat.org

- 50 theories
- Progenitors

  Neutron star (Pulsar, Magnetar), Black Hole, AGN, White dwarf, Strange star, Asteroid/comets, …

- Many theories propose magnetar as progenitor


Log in

Main Page | Discussion | Read | View source | View history | Search FRB Theory Wiki

Main page
Recent changes
Random page
Help about MediaWiki

Tools
What links here
Related changes
Special pages
Printable version
Permanent link
Page information
Page values

Main Page

Hosted by the Institut Spatial de McGill / McGill Space Institute in collaboration with University of Cape Town, University of KwaZulu-Natal / Inyuvesi YaKwaZulu-Natali

Contents [hide]

1 Welcome to the FRB Theory Wiki!
2 Contributing to the Wiki
2.1 Rules and Guidelines
3 Summary Table

Welcome to the FRB Theory Wiki!

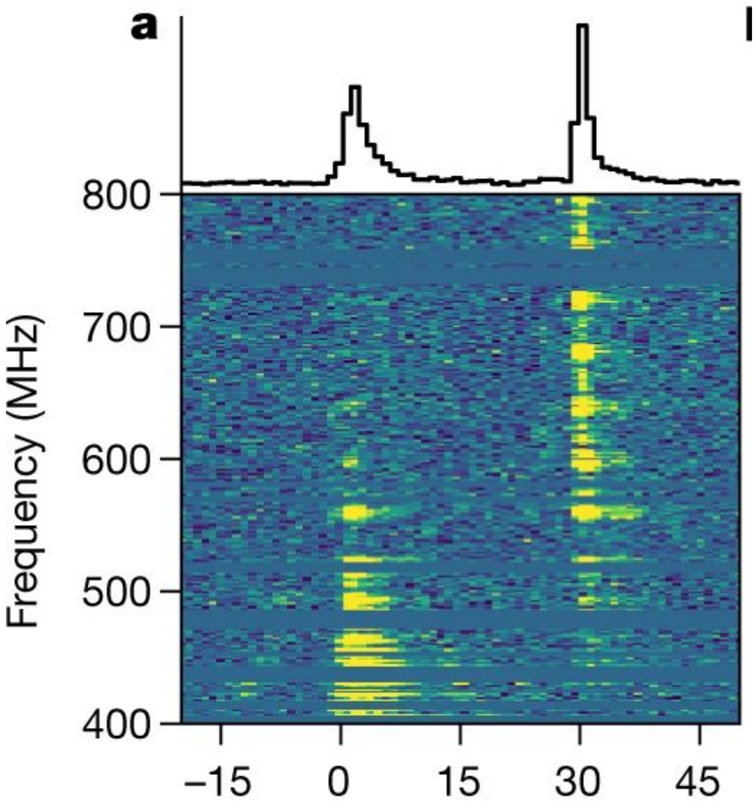
This is a collaborative effort between theorists and astronomers to discuss and track theories and observations pertaining to fast radio bursts (FRBs). The field of FRBs is in its fairly nascent stages and theories are abound. It is getting hard to keep abreast of the latest ideas and observations. This wiki aims to do the following:

1. Track published FRB theories, their predictions in different wavebands, current observational constraints, and future tests.
2. Serve as a discussion board to hash out finer points of theories, possible extensions and modifications.
3. Serve as a tracer of the zeitgeist and how (over the next decade or so) science converges on the answer(s).
4. Publish 'state of theory' snapshots every year (with all contributors invited to be authors).
5. Serve as a theory complement to the FRB Catalogue

The FRB theory catalog and its corresponding paper are being reviewed in Physics Review. Please cite ArXiV:1810.05836 if it was of use to your work.

Galactic FRB (FRB 20200428D)

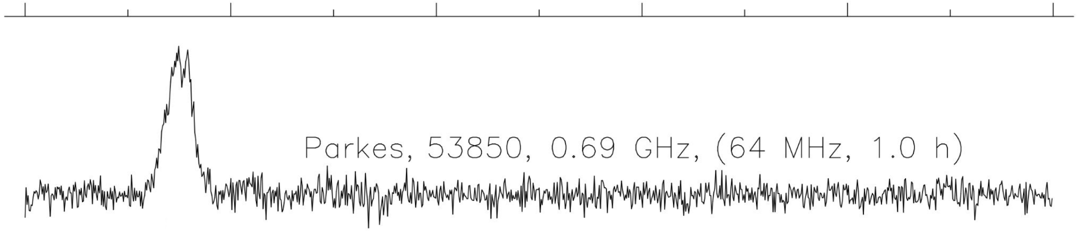
- Associated with SGR 1935+2154
- Chime burst has fluence of 700 KJy ms
- STARE-2 detected with 1.5 MJy ms
- At least some FRBs are originated From magnetars
- Magnetars normally give few Jy ms pulses
- Study of single pulses from J1810-197



CHIME/FRB collab 2020, Bochenek et al. 2019

Magnetar XTE J1810-197

- This magnetar was discovered during an outburst in 2004 — Ibrahim et al. 2004
- First ever magnetar detected in radio — Camilo et al. 2006
- Flux density decreased with time — Camilo et al. 2016
- It became undetectable in 2008
- Detected another outburst in late 2018 — Lyne et al. 2018
- Period 5.54s
- DM 178.85 pc cm^{-3}



Camilo et al. 2006

Dataset

- XTE J1810-197 is being regularly observed with uGMRT
- December 2018 to August 2023 (~4.7 years)

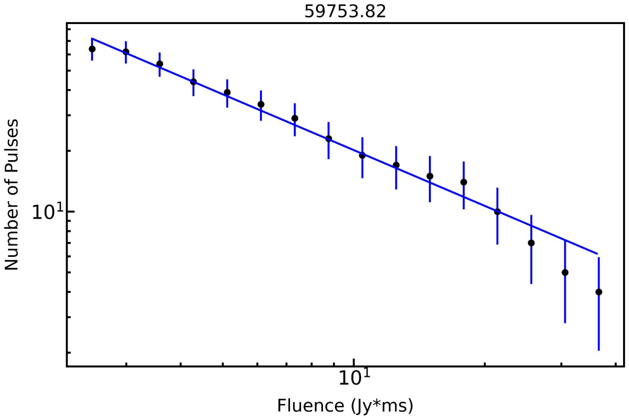
Maan et al. 2022

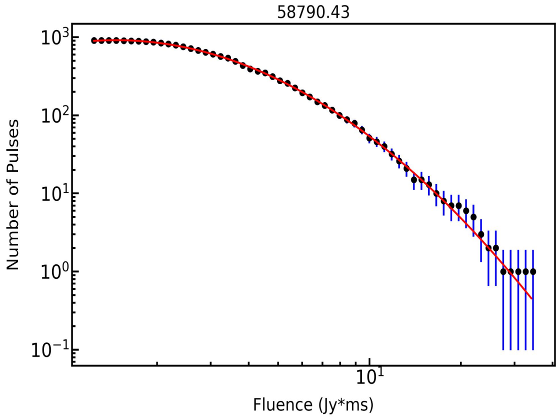
Telescope	Frequency Band	Frequency Range* (MHz)	Central Frequency** (MHz)	Sampling Time (µs)	Number of Observations	Observation Duration (Hours)	Single Pulses above 13 sigma
GMRT	3	300-500	**400**	655.36	61	35.3	16311
GMRT	4	550-750	**650**	163.84	104	73.9	43139
GMRT	5	1260-1460	**1360**	163.84	20	15.1	10987
GBT	L	1000-1900	**1500**	40.96	23	6.4	10127
GBT	S	1600-2400	**2000**	40.96	11	3.6	8281
GBT	C	4650-6150	**5400**	21.84	23	5.4	8422
GMRT+GBT		**300-6150**			**242**	**139.7**	**97411**

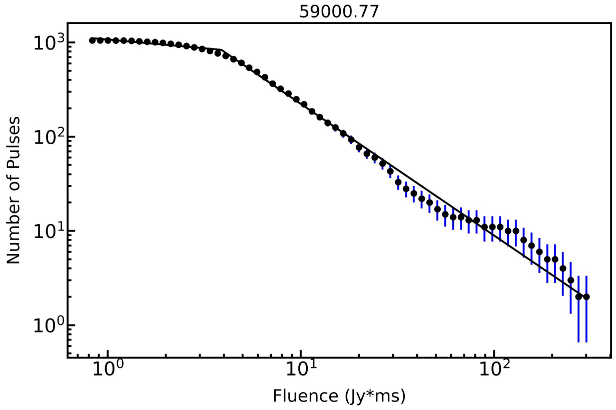
- Fluence and fluence distribution computed for all the pulses

Fluence Distribution

- Distributions characterized by one of the four models, Power law, Broken power law, Lognormal, MLP (Modified Lognormal Power-law)

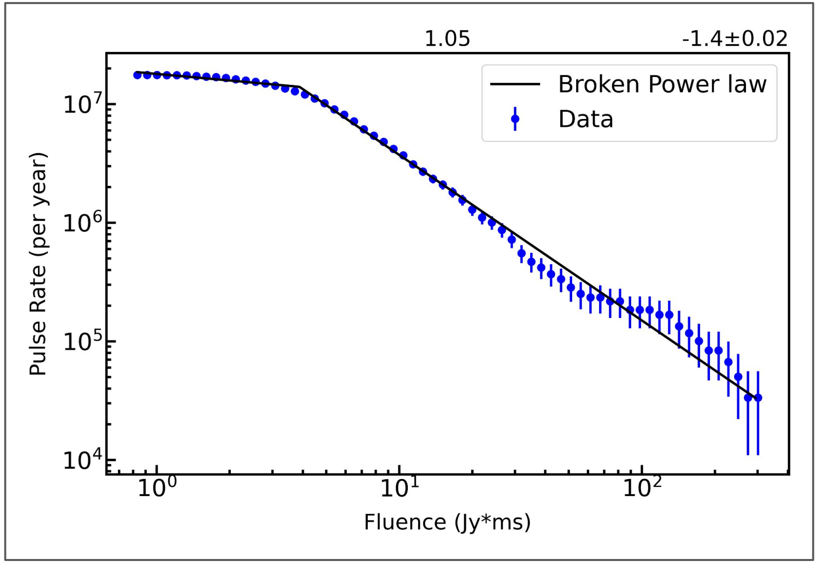






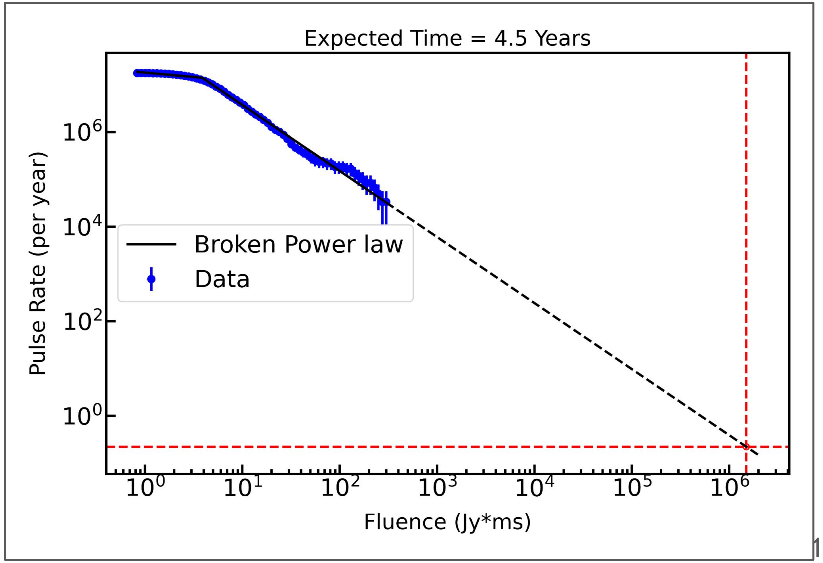
Timescale

- The distribution model gives us the rate function
  - N = f (x,*a*,*b*,...)
  - If we divide the equation by the observation duration
  - Rate ~ f (x,*a*,*b*,...)

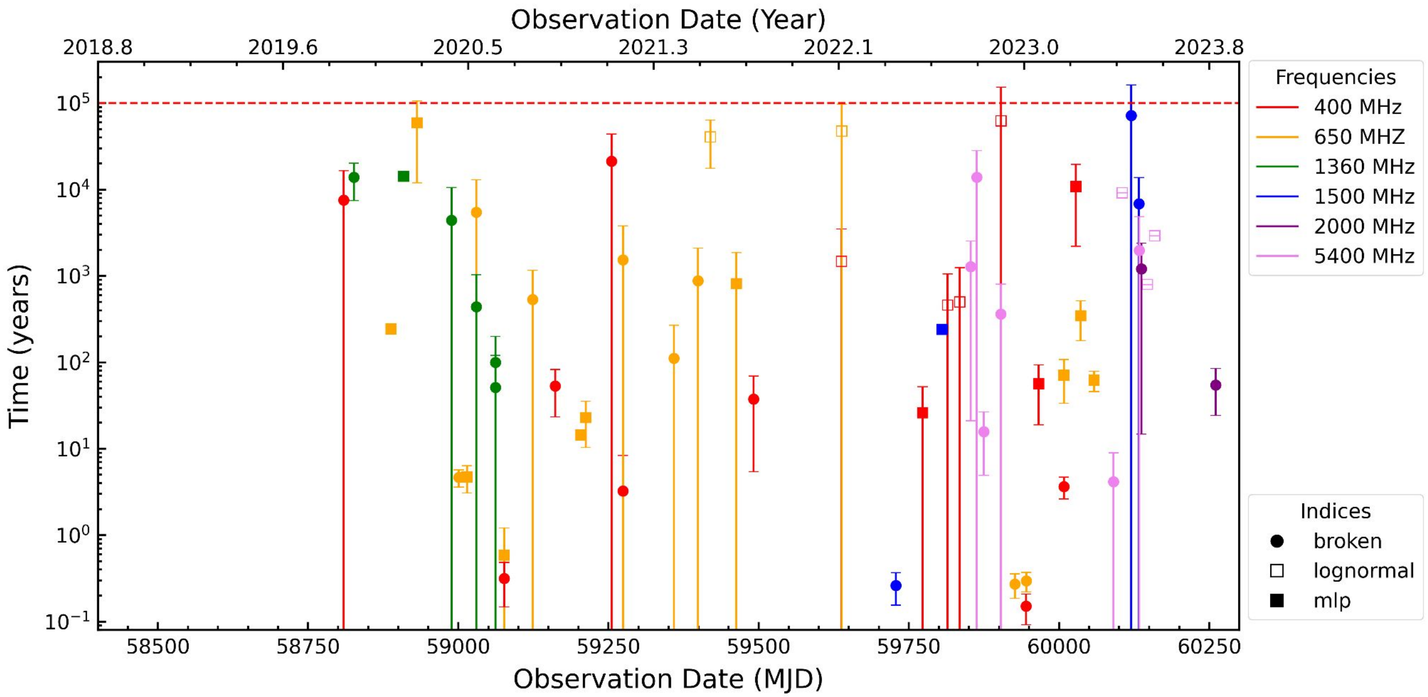


Timescale

- The distribution model gives us the rate function
  - N = f (x,*a*,*b*,…)
  - If we divide the equation by the observation duration
  - Rate ~ f (x,*a*,*b*,…)
- Extrapolation of the rate function gives time scale to detect a pulse with desired Fluence
- Computed timescale for a fluence of 1.5 MJy ms



Expected Timescale



- Power law is followed by giant pulses in pulsars
- FRBs can be giant pulses from magnetars

Timescale for Crab Pulsar

- Timescale for crab-like pulsar is a few hundreds of years (index ~2.8) Bera et al. 2019
- The power-law index does not changes much with time
- Energy budget is also low for Crab-like pulsars

Table 4
Comparison of Differential Power-law Indices for the MP and IP at Both 1.2 GHz and 330 MHz between This Work and Previously Published Values

Frequency (MHz)	Differential Power-law Index (MP)	Differential Power-law Index (IP)	Reference
112	3.3[a]	...	Smirnova & Logvinenko (2009)
146	3.5	3.8	Argyle & Gower (1972)
200	2.7[a]	...	Bhat et al. (2007)
330	2.5–3.0	2.4–3.1	This work
430	2.3	...[b]	Cordes et al. (2004)
600	3.2	3.0	Popov et al. (2009)
812	3.3[a]	...	Lundgren et al. (1995)
1200	2.7–4.2	2.6	Popov & Stappers (2007)
1200	2.1–3.1	2.4–2.8	This work
1300	2.3[a]	...	Bhat et al. (2008)
1400	2.8	3.1	Karuppusamy et al. (2010)
2100	3.0[a]	...	Zhuravlev et al. (2011)
4850	2.8[a]	...	Popov et al. (2008)

Notes.
[a] MP and IP GPs were combined in these analyses.
[b] No measurement was taken for the IP.

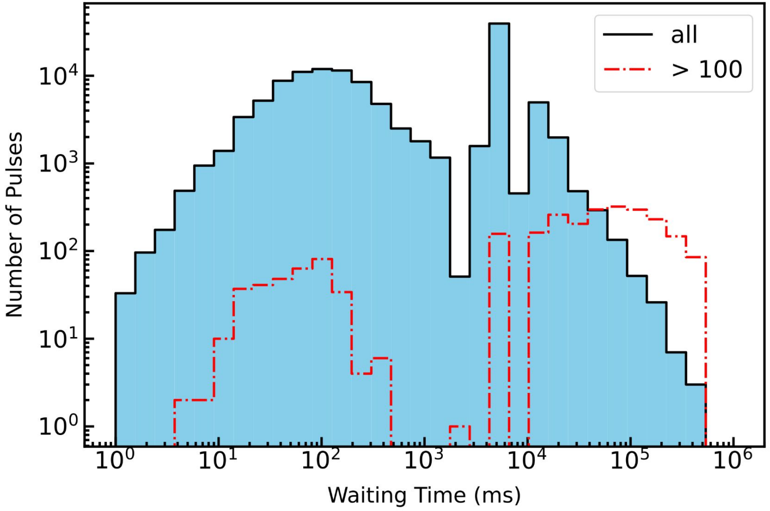
Mickaliger et al. 2012

Timescale

- The shorter timescales always include a power law tail
- In pulsars power-law followed by the giant pulses
- Timescale for crab-like pulsar is a few hundreds of years (index ~2.8), but the power-law index does not changes with time — Bera et al. 2019
- FRBs fluence also follows the power law (FRB 121102) — Zang et al. 2019
- *FRBs could be giant-pulses from magnetars (in their favorable emission-states)*

Waiting Time Distribution

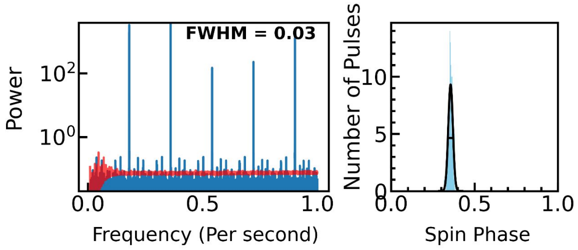
- Two cluster in distribution prominent for pulses with fluence > 100 Jy ms *(second part of distribution due to spin-period and harmonics)*
- FRBs also show similar distribution
- [1]FRB 20201124A 10.05 s and 51.22 ms
- [2]FRB121102 70 s and 3.4 ms



[1]Zhang et al. 2022, [2]Li et al. 2021

Periodicity in bright pulses

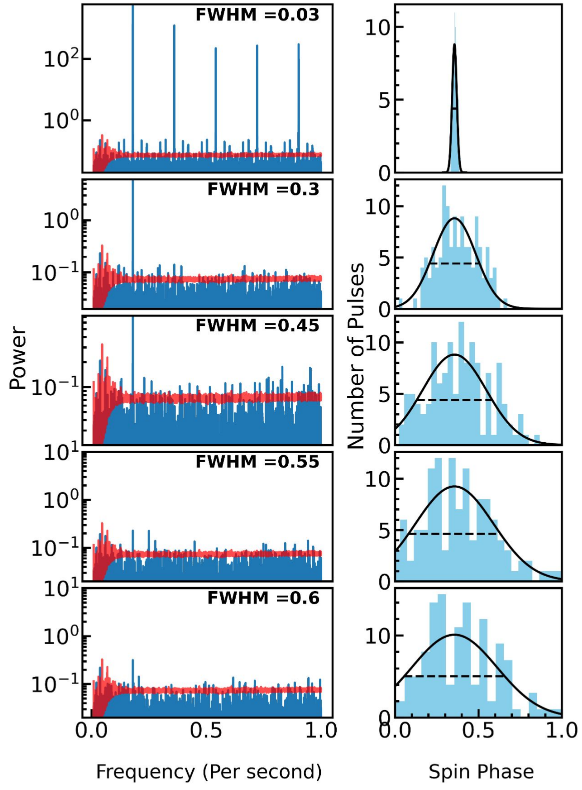
- 130 pulses with fluence > 100 Jy ms with a rate of ~ 197 hr^{-1} ; Narrow distribution or arrival-times in spin-phase
- Searched for periodicity using [1]Lomb-Scargle-Periodogram



[1]https://docs.astropy.org/en/stable/timeseries/lombscargle.html

Periodicity in bright pulses

- 130 pulses with fluence > 100 Jy ms with a rate of ~ 197 hr^{-1} ; Narrow distribution or arrival-times in spin-phase
- Searched for periodicity using [1]Lomb-Scargle-Periodogram
- Periodicity becomes undetectable even if the spread in spin phase is around or > 60%
- *FRBs need to be emitted just over adequately large range of spin-phases for the periodicity to be undetectable*
- J1622-4950 shows wide emission (Levin et al. 2012)



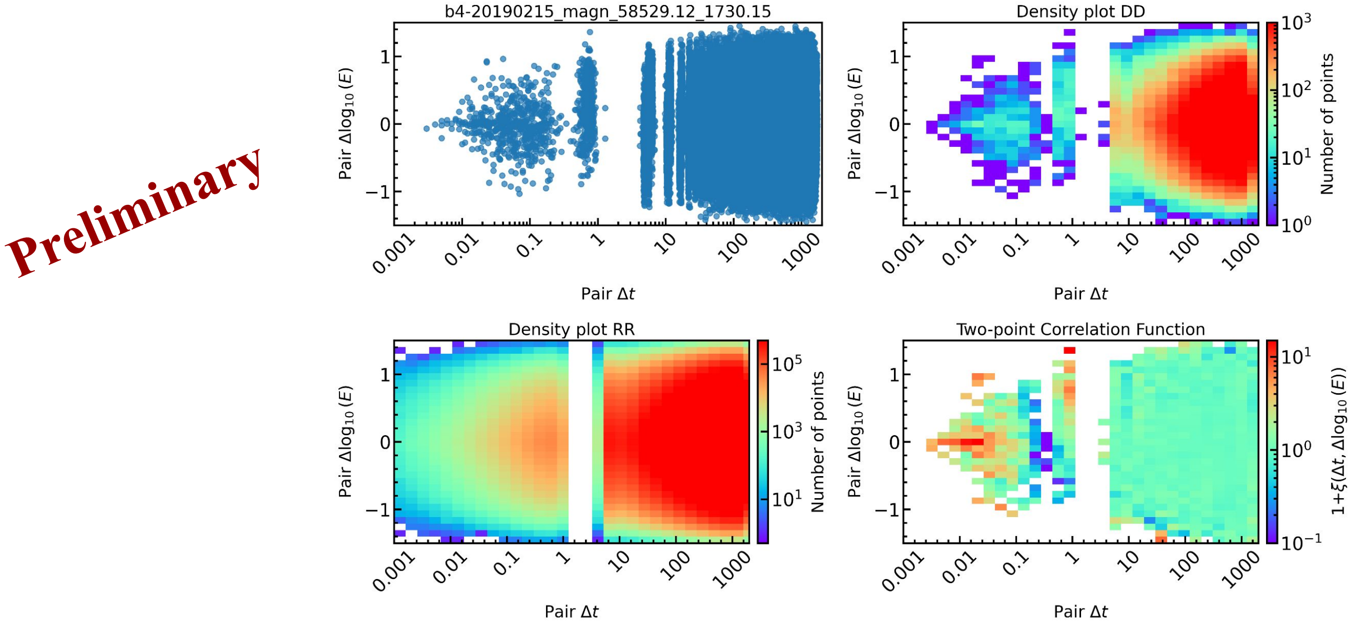
[1]https://docs.astropy.org/en/stable/timeseries/lombscargle.html

Magnetar emission and Starquake

- Explosive phenomena triggered by starquakes in star crusts
- Time energy correlation across the pulses
- Correlation function (ξ) is the access number of pairs over a uncorrelated case
- Compared to earthquakes (Cheng et al. 1996; GöğüŞ et al. 1999)
- FRBs also show similar correlation as earthquake (Totani & Tsuzuki, 2023)

Time-Energy correlation

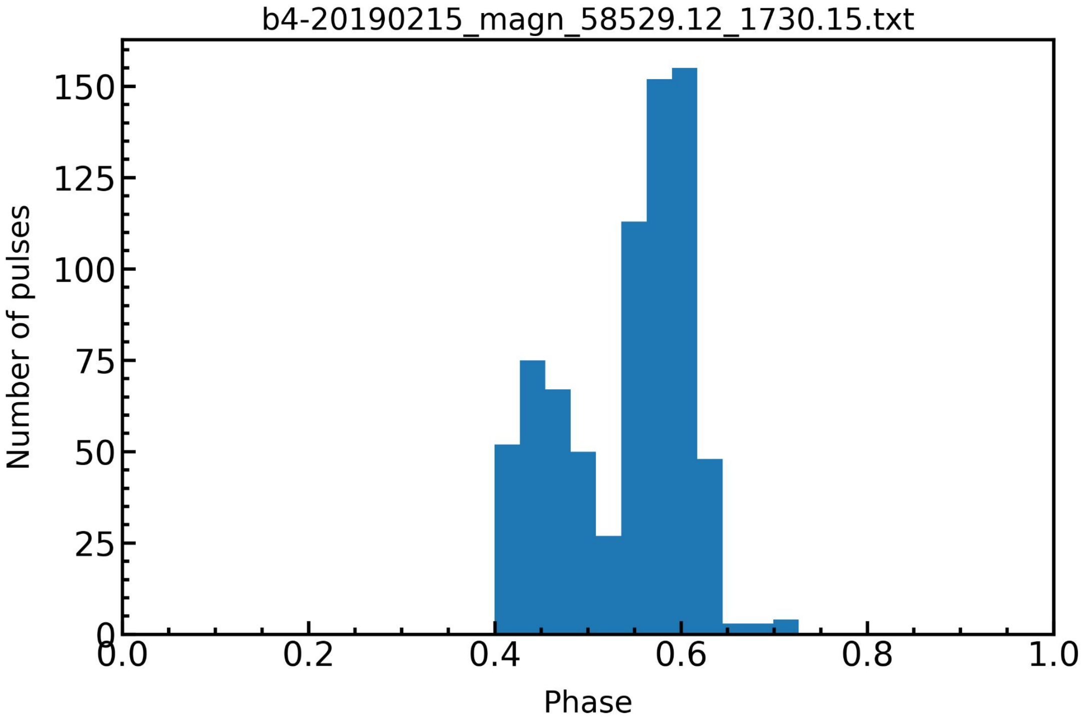
- Random numbers are generated at period grid using emission window



- At shorter timescales the correlation is present in time energy
- The correlation is more clear along the time axis compare to the energy

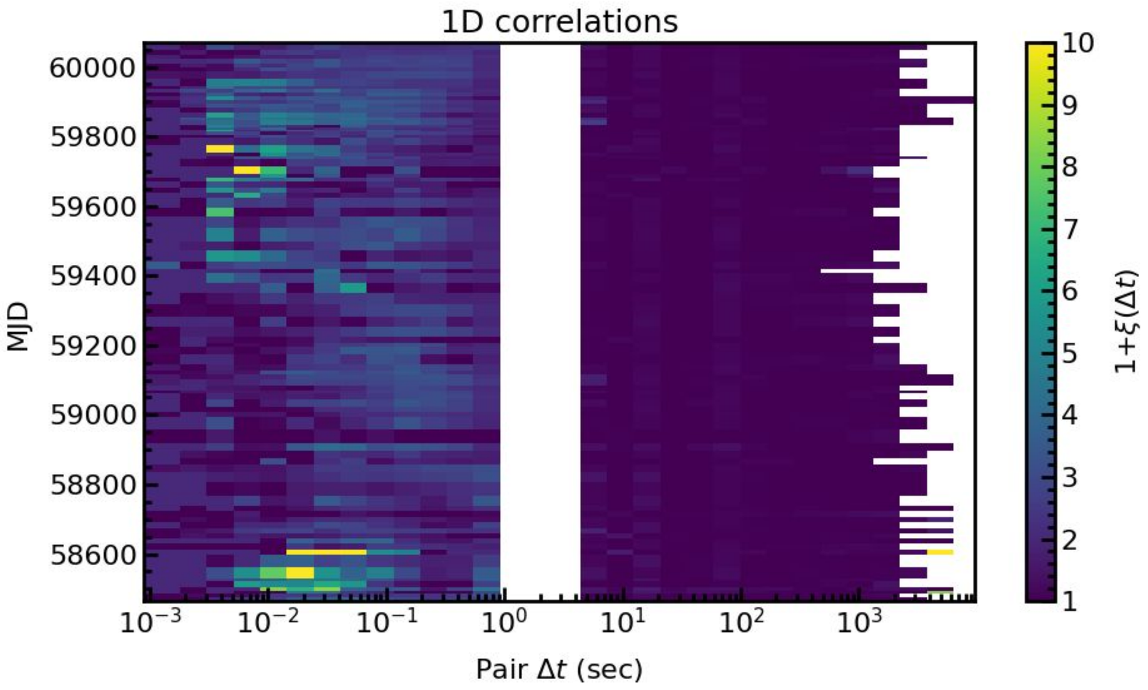
Conclusion

- Magnetar's emission-state changes with time and frequency.
- Magnetar could emit a FRB-like burst at reasonably short timescales in several emission-states.
- FRB-like emission could be giant-pulses from magnetars but highly unlikely from crab-like pulsars.
- Bright pulses show waiting time distribution similar to FRBs.
- Non-detection of periodicity in repeating FRBs might be due to arrival times being spread over large range of spin-phases.


b4-20190215_magn_58529.12_1730.15.txt
Number of pulses
0
25
50
75
100
125
150
0.0
0.2
0.4
0.6
0.8
1.0
Phase

1-D correlation

Preliminary



- Just after the outburst the correlation is relatively stronger for shorter timescale