

Searching for and Modelling PRSs Associated with Localised FRBs

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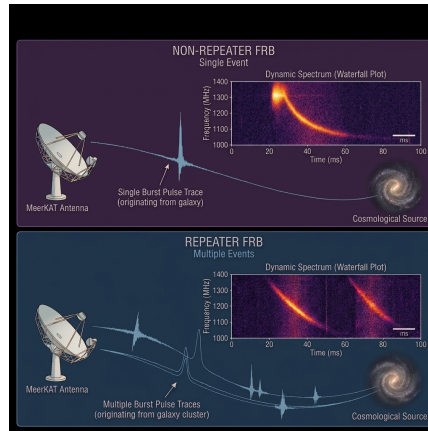
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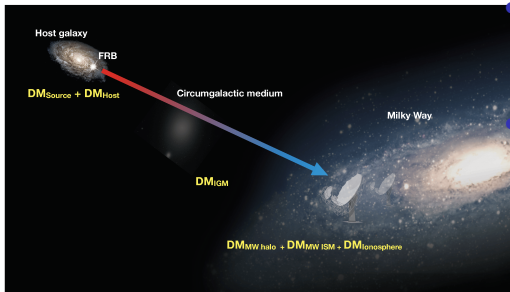


What are Fast Radio Bursts (FRBs)?

- Millisecond-duration radio bursts
- Extremely bright and energetic
- High dispersion measure (extragalactic)
- **Today:** 4500+ bursts discovered, 124 repeaters (FRB Newsletter, September 2026)
- Two populations: Repeaters and one-off FRBs



Where do FRBs Come From?

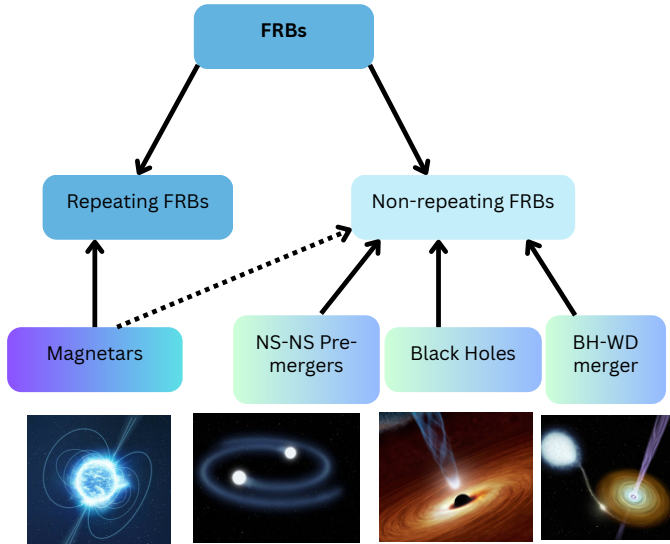


- Localized to host galaxies

- The origin of FRBs are unknown

Figure: Caleb and Keane, 2021

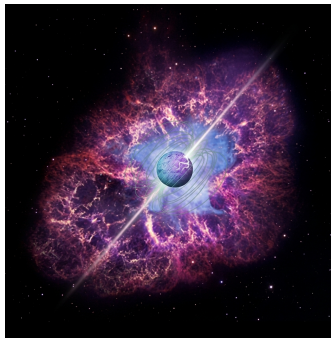
Fast Radio Bursts: Multiple Sources Proposed



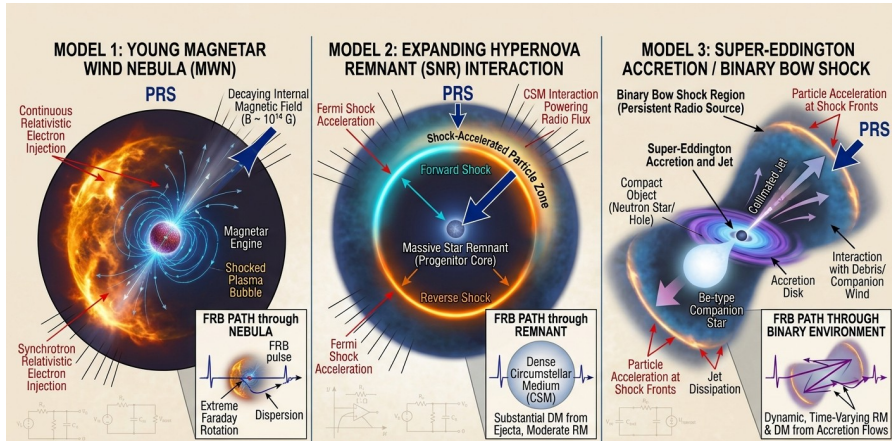
Magnetar is a leading progenitor model

Persistent Radio Sources (PRSs) linked to repeating FRBs

- A small fraction of localised repeating FRBs are associated with persistent radio sources (PRSs)
- Steady non-thermal origin
- Luminous ($\sim 10^{39}$ erg/s)
- Compact (0.7 pc)
- Rare (Only 4 confirmed)
 - ① FRB20121102A
 - ② FRB20190520B
 - ③ FRB20190417A
 - ④ FRB20240114A
- PRSs provide clues to the local environment and the FRB central engine



PRSs: Multiple Models Proposed



The Magnetar Wind Nebula (MWN) is a leading model

The Mystery of FRBs: Open Questions

- ① What is the origin of FRBs?
- ② Do all FRBs repeat?
 - Are one-off FRBs just a result of instrument sensitivity?
- ③ Do repeating and one-off FRBs have the same progenitor?
- ④ Are PRSs linked to repeating FRBs only?
 - Faint PRSs as counterparts to one-off FRBs

My PhD Work: Approach to Addressing These Questions

Note: Repeating FRBs are well studied compared to one-off FRBs.

Key Question:

- Are PRSs linked to repeating FRBs only?

Approach: broken into three parts:

- ① Search for PRSs around well-localised one-off FRBs using the MeerKAT radio telescope
- ② High-resolution confirmation – eMERLIN+EVN
- ③ Modelling of candidate PRSs

1. MeerKAT Search for PRSs

MeerKAT Telescope

- Karoo region, Northern Cape, South Africa
- 64 Antennas
- Dish diameter is 13.5 m
- Observed at L-band (1.4 GHz)
- Resolution $\sim 5 - 8$ arcseconds



Figure: A MeerKAT dish

1. Searching for PRSs using the MeerKAT Telescope

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A MeerKAT search for persistent radio sources towards twenty-five localised Fast Radio Bursts

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- 25 FRBs detected and localised by ASKAP and MeerTRAP
- 38 FRB fields observed over multiple epochs
- 14 radio detections from 25 positions, 21 FRB fields over multiple epochs

1. Searching for PRSs using MeerKAT Telescopes

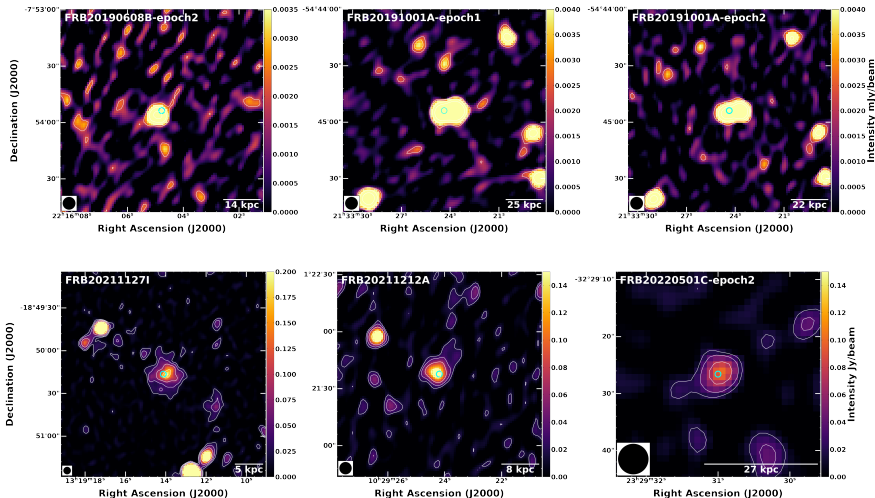


Figure: MeerKAT detections: cyan circle is the FRB position, the black circle is the MeerKAT beam.

1. Searching for optical emission toward radio detections

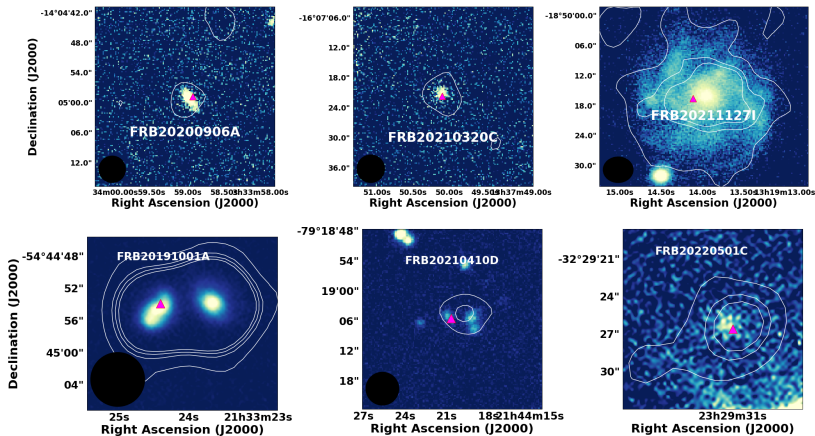


Figure: Blue background is the optical fluxes (Pan-STARRS and DESI archives), white contours are the MeerKAT radio emission. The magenta triangle is the FRB position. The black circle is the MeerKAT beam.

1. Searching for X-ray flux towards radio detections

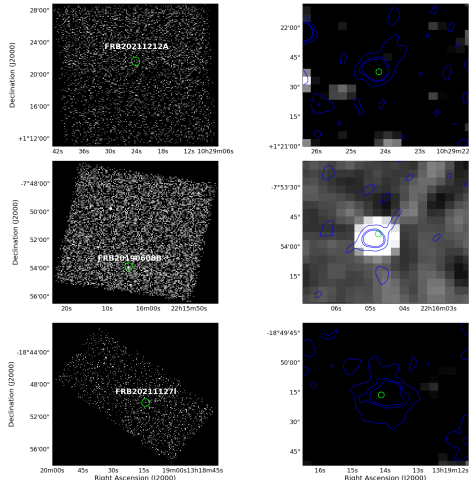


Figure: Black background is the X-ray image and the blue contours are the radio MeerKAT emission. The green circle is the FRB position.

1. Searching for PRSs using MeerKAT Telescopes

Key Findings and Conclusions

- 14 unresolved radio sources
- Radio emission probably results from star-formation
 - Computed radio-to-optical ratio to identify radio excess.
- Therefore probably:
 - There are no PRSs in our observed sample
 - Faint PRSs may be embedded in the host galaxy
- Thus a high-resolution telescope is required to confirm the nature of our sources.

2. High-Resolution Follow up

2. High-Resolution Confirmation

- Submitted an e-MERLIN+EVN proposal
- Approved for: e-MERLIN+EVN+MeerKAT
- Submitted four candidates
- Only one candidate accepted
- L-band (~ 1.4 GHz)
- Resolution ranges from $\sim 4 - 5$ mas



3. Modelling PRSs

Emission Mechanism of PRSs

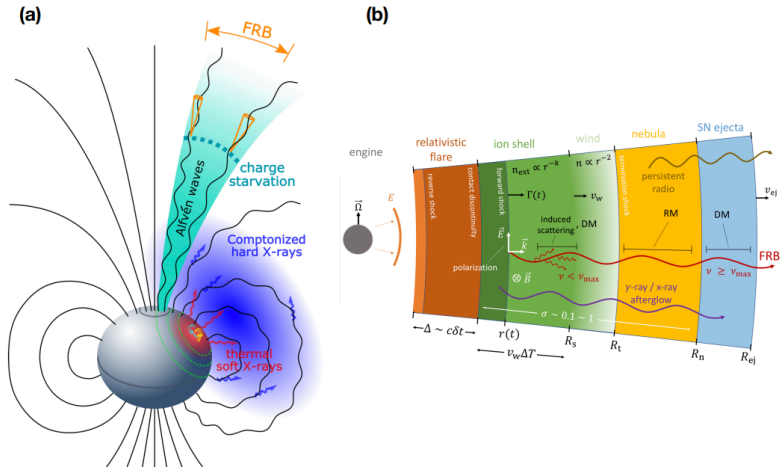


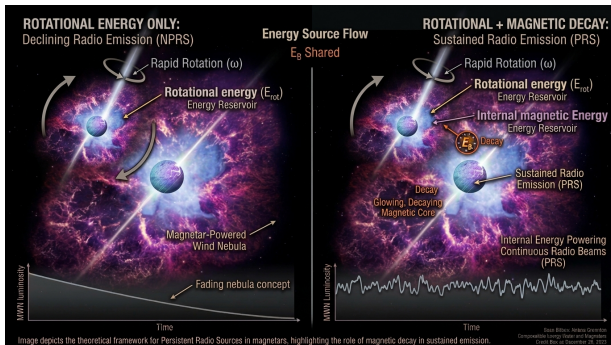
Figure: Zhang, 2020

3. Modelling PRSs Candidates

- **Main Question:** Can a leptonic PWN transport model be adapted for persistent radio emission?
- The PWN Model has successfully modelled
 - Relativistic electron populations
 - Synchrotron radiation and inverse Compton
 - Particle cooling (diffusion, advection, convection and radiative losses)
 - Magnetic field evolution
- Assumption:
 - Similar physical processes operate in magnetar-powered nebulae.
- Objective:
 - Adapt an existing leptonic PWN model to the MWN scenario.
 - Determine magnetar and nebula parameter set

Pulsar to Magnetar: Incorporating Magnetic Decay

- Central engine: young magnetar
- Energy injection: rotational + magnetic decay energy
- **Insufficient Rotational Energy**
 - Rotational energy alone decays quickly
- **Strong Fields**
 - The decay provides enough non-thermal electrons over decades
- **Sustained Injection Timescales**
 - Magnetic energy reservoir maintains the observed PRS flux



3. MWN Preliminary Parameters

Parameter	Value
Age	10 yr
Dipole Magnetic Field ($B_{\star,d}$)	10^{14} G
Spin-down Power ($E_{\text{sd},0}$)	10^{43} erg
Internal Magnetic Field ($B_{\star,\text{int}}$)	10^{15} G
Magnetic Energy ($E_{d,0}$)	10^{49} erg
Initial Spin Period (P)	0.01 s
Spin-down Rate ($\dot{P}$)	1.0^{12} s/s
Nebular Magnetic Field (B_{N})	13 mG
Distance (d)	972 Mpc

Table: Preliminary fit parameters found when fitting the data of PRS20121102A by eye.

Preliminary Results: Fits to Radio Data

- Model the synchrotron emission
- Fit the SED to the observational data

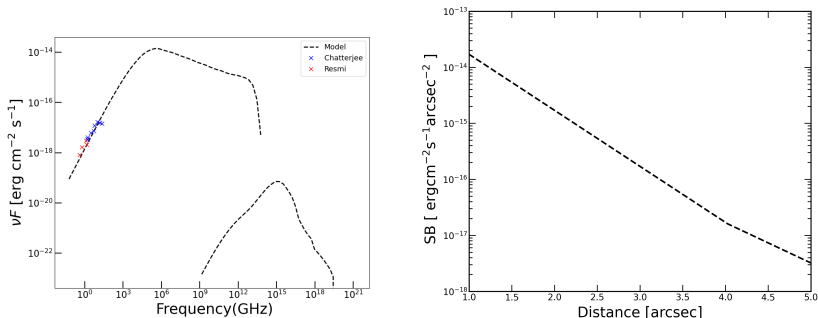


Figure: **Left:** The SED with the radio data of PRS20121102A from VLA (Chatterjee et al., 2017) and uGMRT (Resmi et al., 2021). **Right:** predicted surface brightness of the MWN.

Ongoing Work: Comprehensive Parameter Study

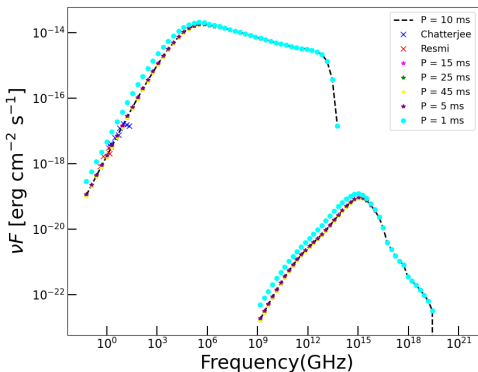


Figure: SED for MWN with a change in the period of the magnetar

Ongoing Work: Comprehensive Parameter Study

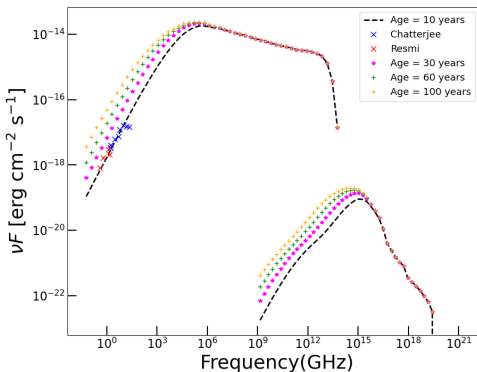


Figure: SED for MWN with a change in the age of the MWN

Ongoing Work: Comprehensive Parameter Study

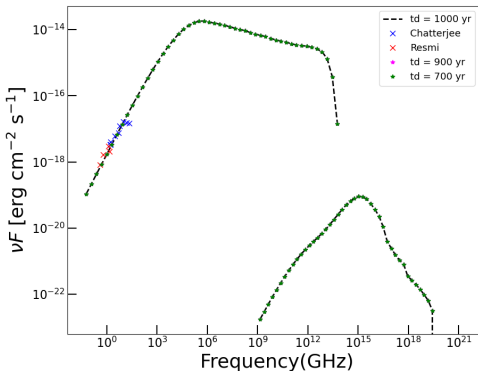


Figure: SED for MWN with a change in the magnetic decay timescale of the MWN

- **Observations:**

- Focus on up-coming e-MERLIN+EVN+MeerKAT data

- **Modelling:**

- Predict the evolution of DM and RM vs time
- Predict X-ray or gamma-ray emission
- Submitted MeerKAT Proposal for follow-up on variability

Thank You!!!