Searching for and Modelling PRSs Associated with Localised FRBs

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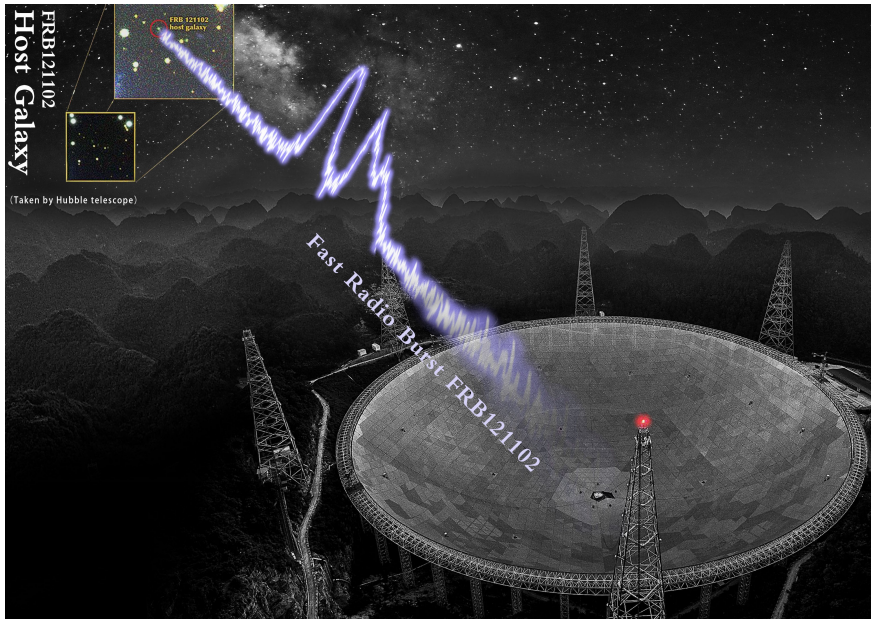
What are Fast Radio Bursts (FRBs)?

- Millisecond radio bursts
- Extremely bright and energetic
- High dispersion measure (extragalactic)
- High rotation measure
- High brightness temperature



A Brief History of FRBs

- **2007:** First FRB discovered (FRB20010724)
- **2013-2015:** More FRBs were confirmed to be real
- **2016:** First repeating FRB discovered (FRB20121102)
- **2020:** First FRB detected in our Galaxy
- **Today:** 3641 bursts discovered, 83 repeaters
- Two populations: Repeaters and one-off FRBs

Persistent Radio Sources (PRSs) linked to repeating FRBs

1. Phenomenology
   - Steady and slow varying emission
   - Non-thermal in origin
2. Observations Properties
   - Luminous, $L_\nu \sim 10^{39}$ ergs^{-1}
   - Compact, $d \leq 0.7$ pc
3. Rarity
   - Only 4 detected
   - Linked to repeating FRBs

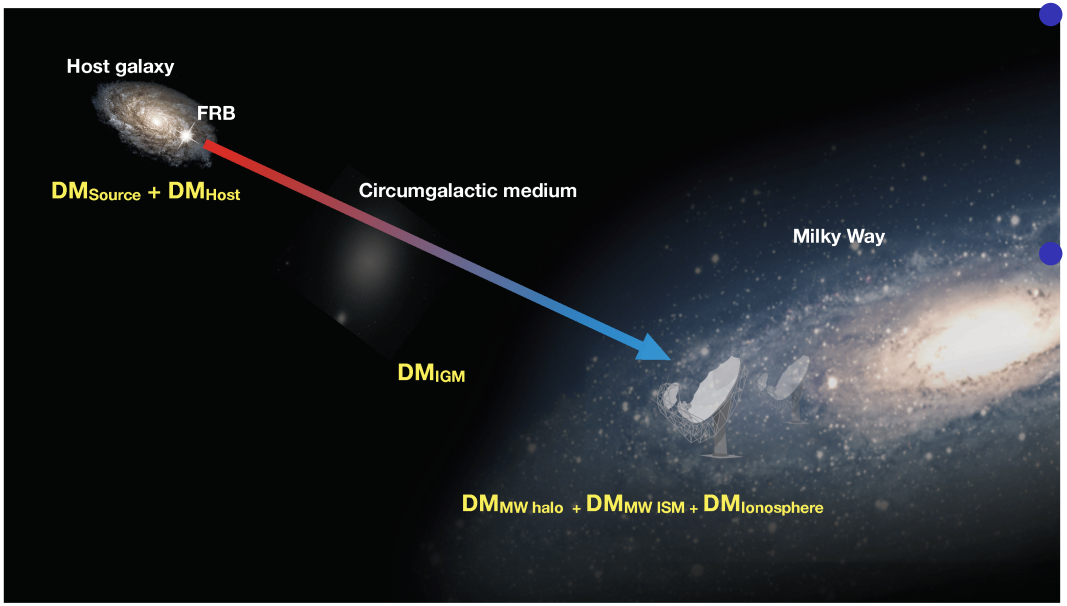
- FRB20121102A, FRB20190520B, FRB20190417A, FRB20240114A

What PRSs Reveal

PRSs trace FRBs environments and constrain the properties of the FRB progenitor

1. Steady and slow emission
   - Suggests long-lived central engine
2. Non-thermal emission
   - Indicates highly energetic processes
3. High luminosity
   - Suggests a powerful and stable energy source
4. The compact size
   - Implies a dense, energetic environment around the FRB progenitor

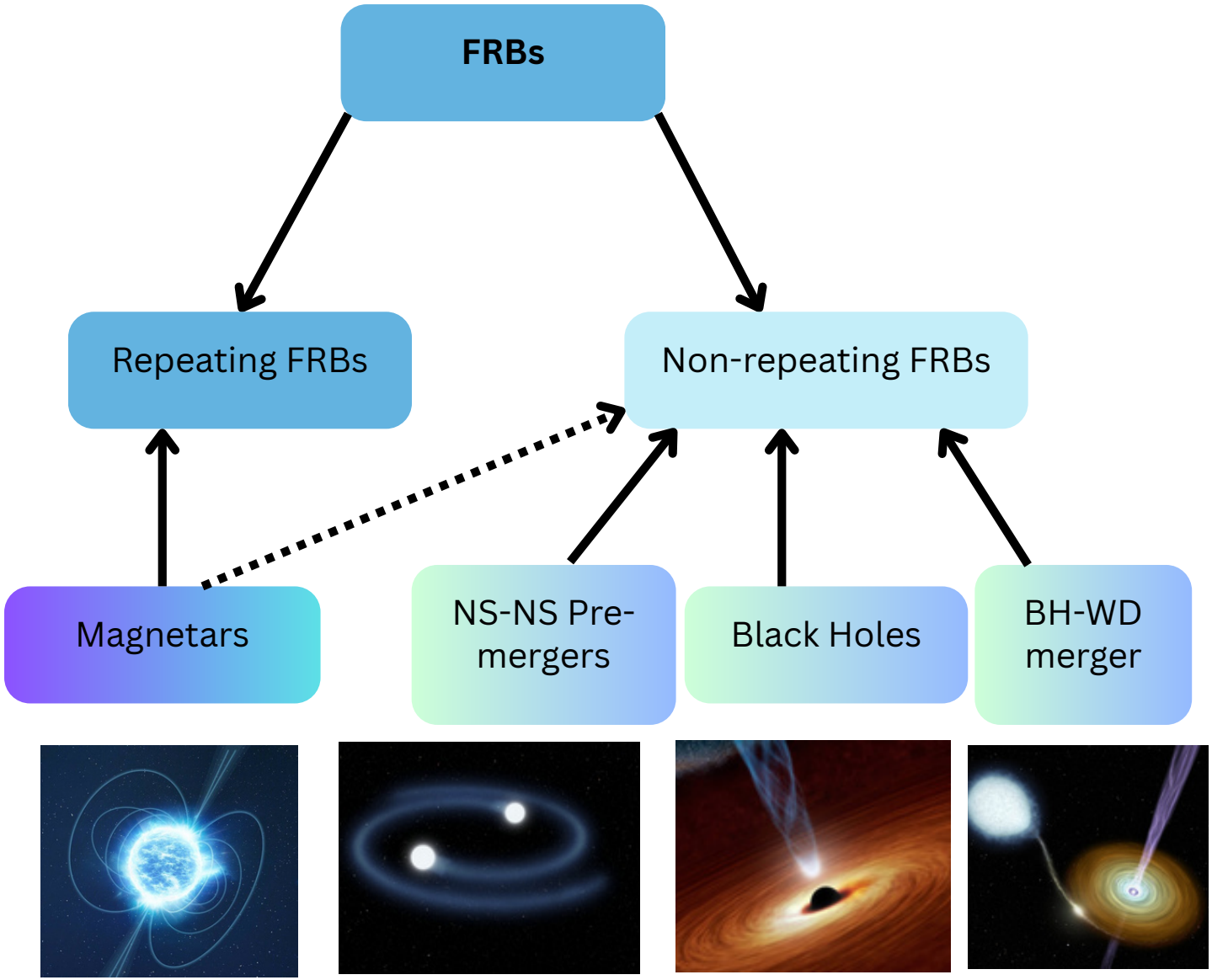
Where do FRBs Come From?



- Localized to host galaxies
- The origin of FRBs are unknown

Figure: Caleb and Keane, 2021

Multiple FRB Progenitor Channels



Magnetar as potential progenitor

Emission Mechanism: Magnetar-Model

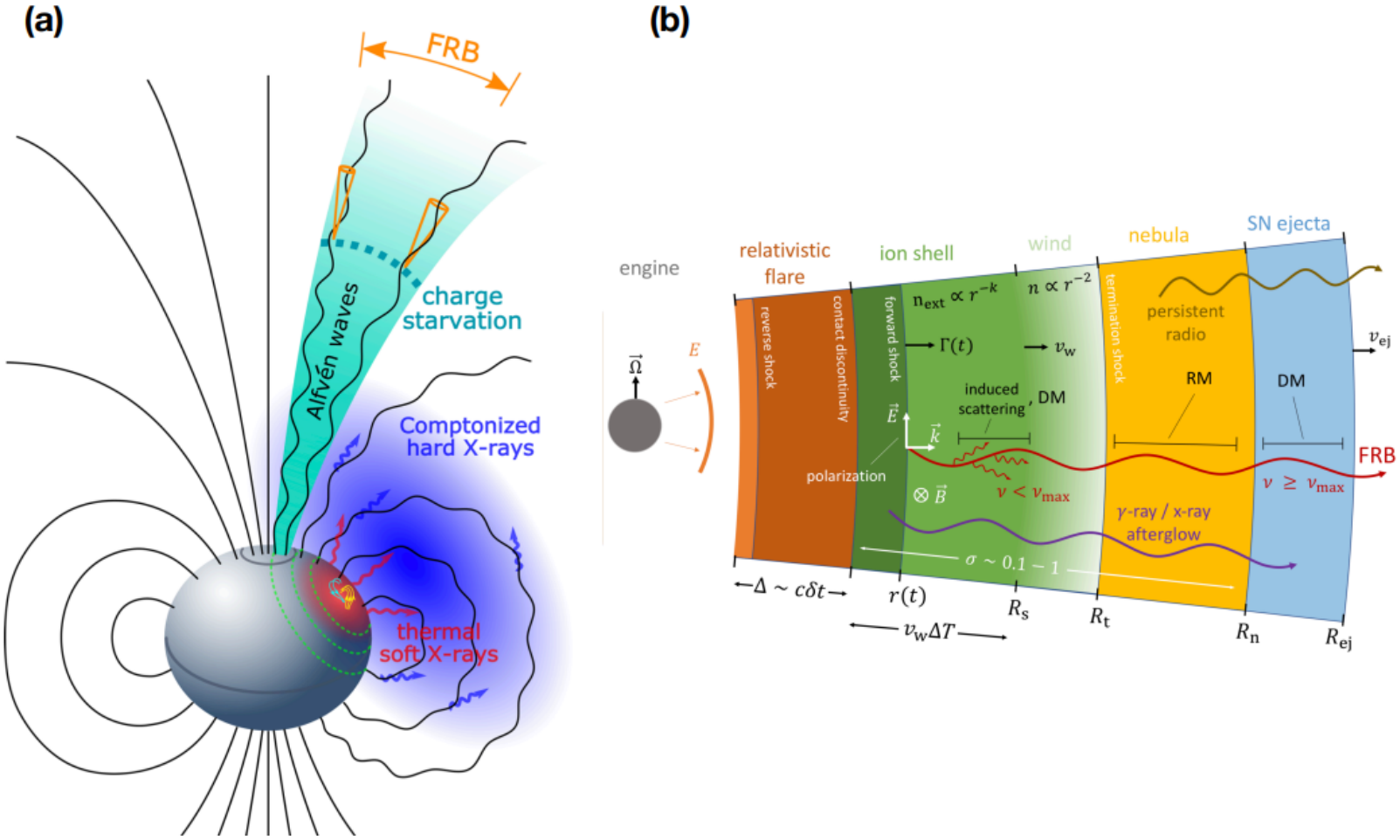


Figure: Zhang, 2020

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:

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

MeerKAT Telescope

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

Figure: The MeerKAT dish

1. Searching for PRSs using MeerKAT Telescopes

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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

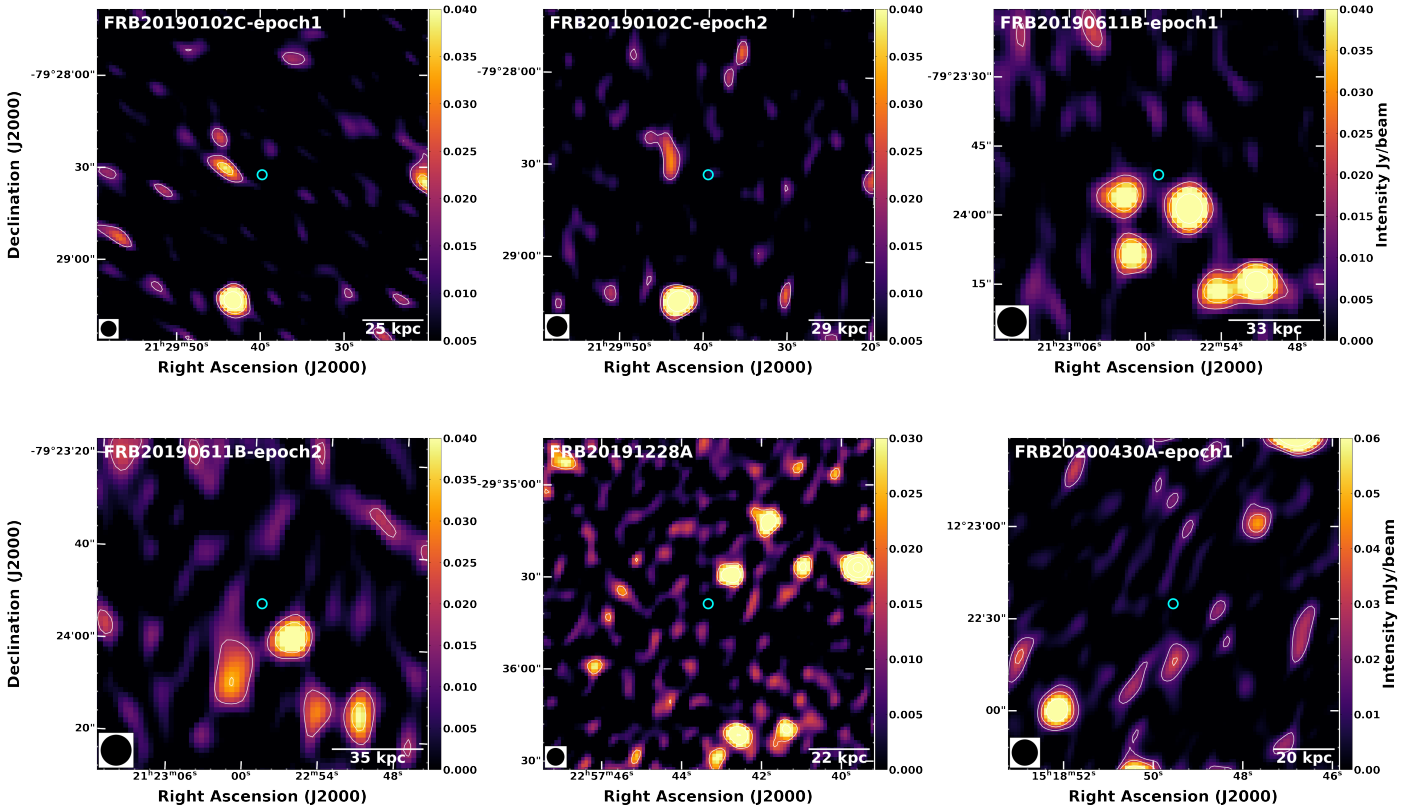

Figure: MeerKAT non-detections: cyan circle is the FRB position, the black circle is the MeerKAT beam.

1. Searching for PRSs using MeerKAT Telescopes

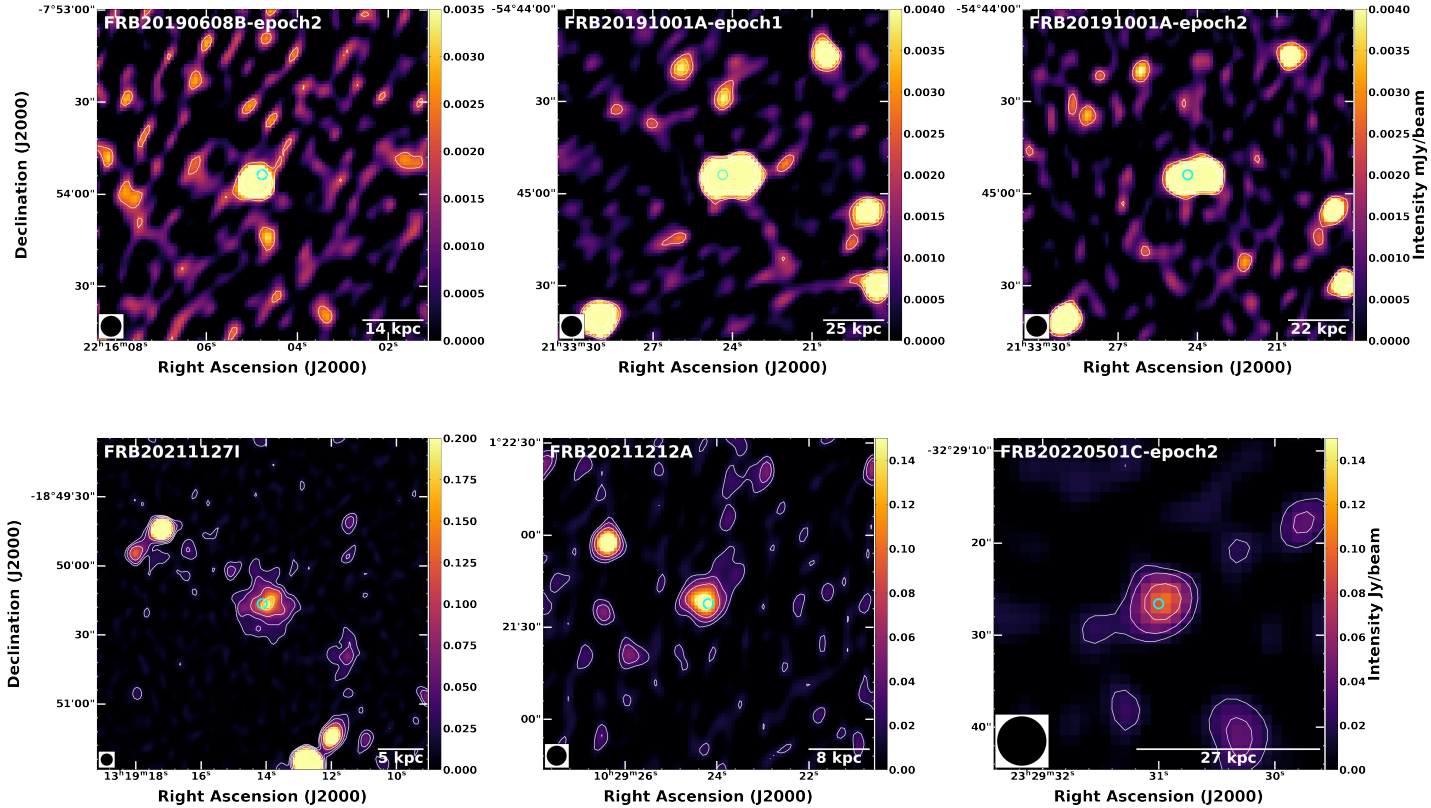

Figure: MeerKAT detections: cyan circle is the FRB position, the black circle is the MeerKAT beam.

1. Searching for PRSs using MeerKAT Telescopes

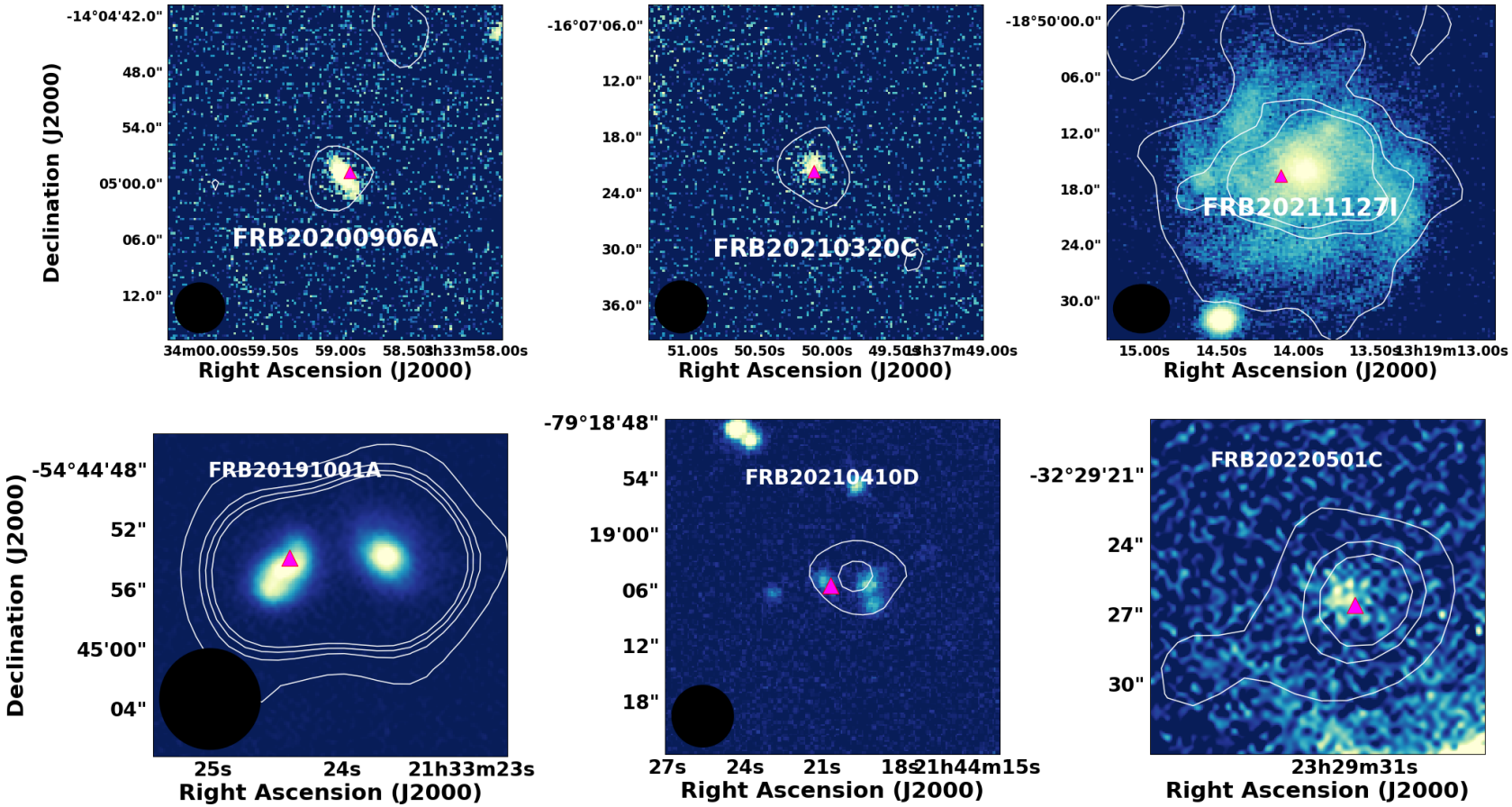

Figure: Blue background is the optical fluxes (Pan-STARRS and DESI archives), white contours are the MeerKAT radio emission. The magenta triangle is the FRB position. The black circle is the MeerKAT beam.

1. Searching for PRSs using MeerKAT Telescopes

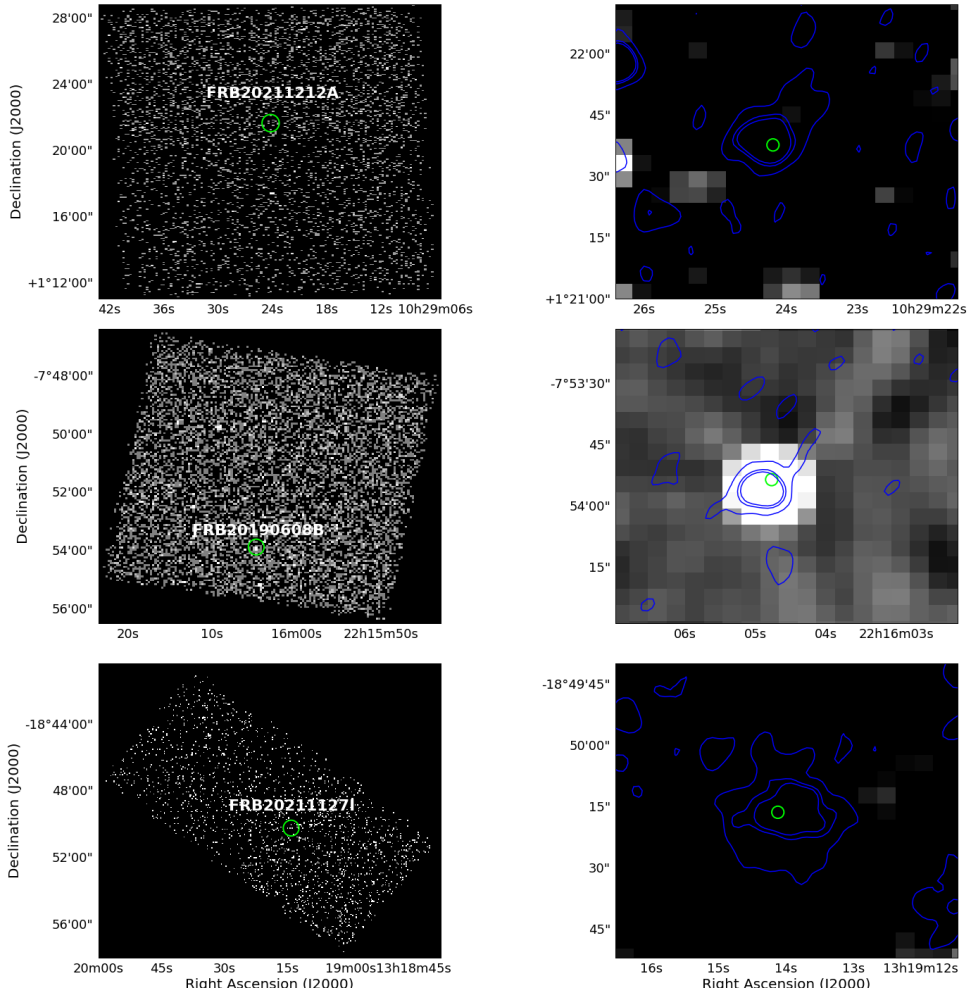

Figure: Black background is the X-ray image and the blue contours are the radio MeerKAT emission. The green circle is the FRB position.

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 few to no PRSs
  - Faint PRSs may be embedded in the host galaxy
- Thus a high-resolution telescope is required to confirm the nature of our sources.

ONGOING FOLLOW UP

2. High-Resolution Confirmation

- Submitted an e-MERLIN+EVN proposal
  - Submitted four candidates
  - L-band (~ 1.4 GHz)
  - Resolution ranges from $\sim 4 - 200$ mas

3. Modelling PRSs Candidates

Goal: Understand the physical properties of PRSs

Approach and Expectations:

- Adapt PWN $\rightarrow$ MWN model (van Rensburg et al. 2018)
  - Young magnetar progenitor
  - Energy injection: rotational + magnetic energy
- Model the synchrotron emission

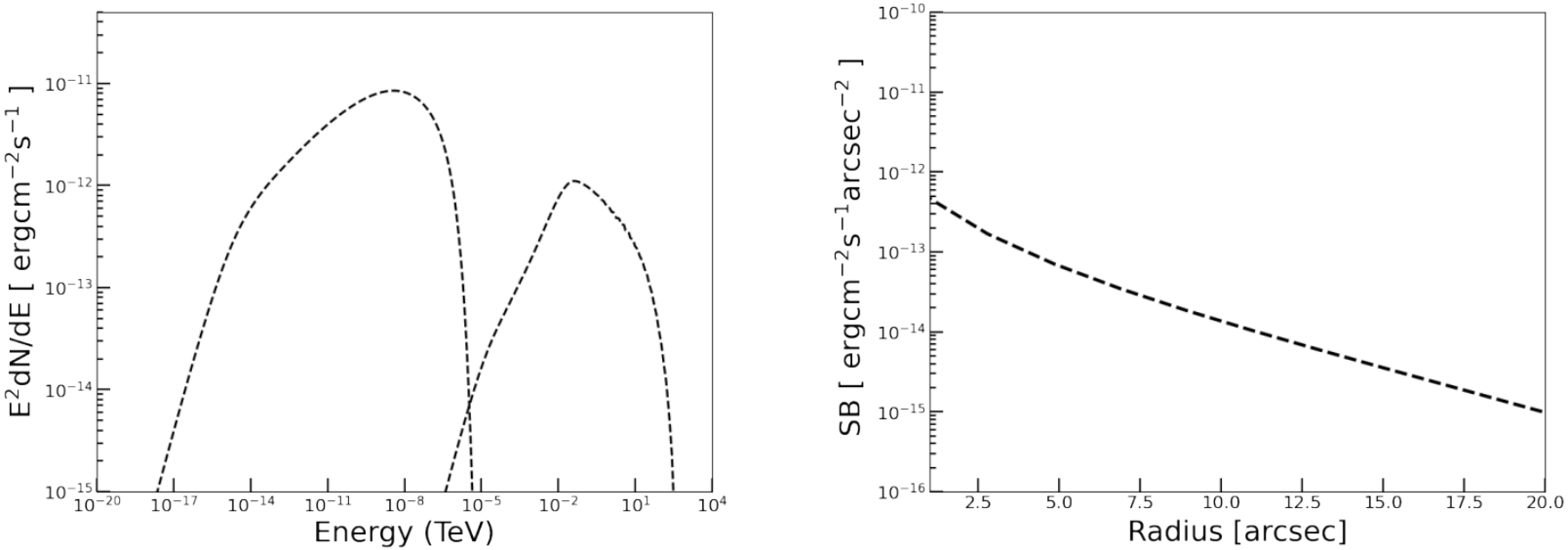

Figure: Kundu et al (2024)

3. Modelling PRSs Candidates

- Evolution of DM and RM

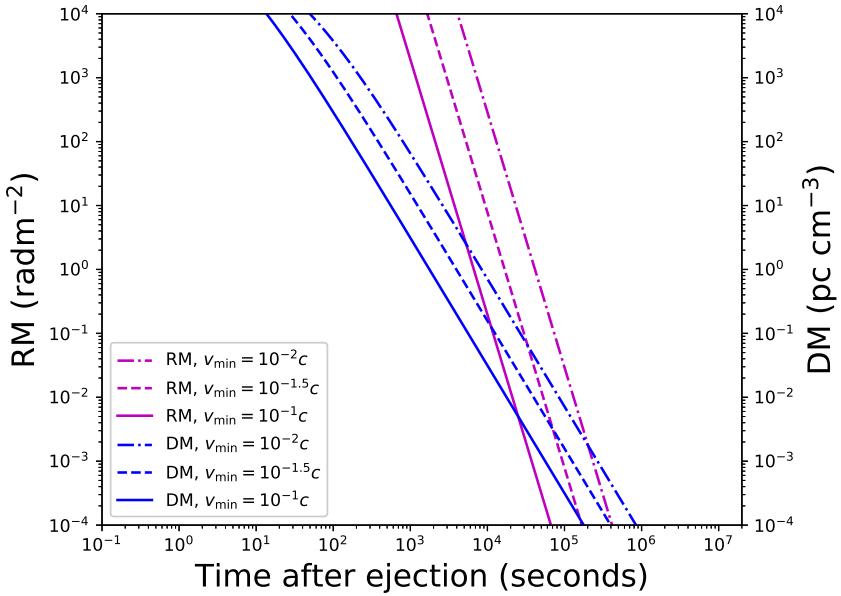

Figure: Xiao (2025)

Challenges:

- Moving boundary condition (expanding nebula)
- Limited observational data – weak constraints
- Uncertain evolutionary properties

Key Takeaways

- PRSs are rare
- PRSs are tracers of FRB environments
- Searches and modelling can provide insight of the non-repeating FRB environment
- Ongoing work: Modelling the PRSs

Thank You