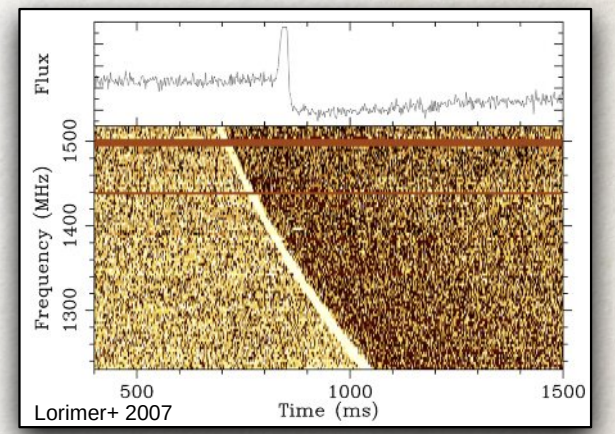
Fast Radio Bursts:
An Observational Perspective



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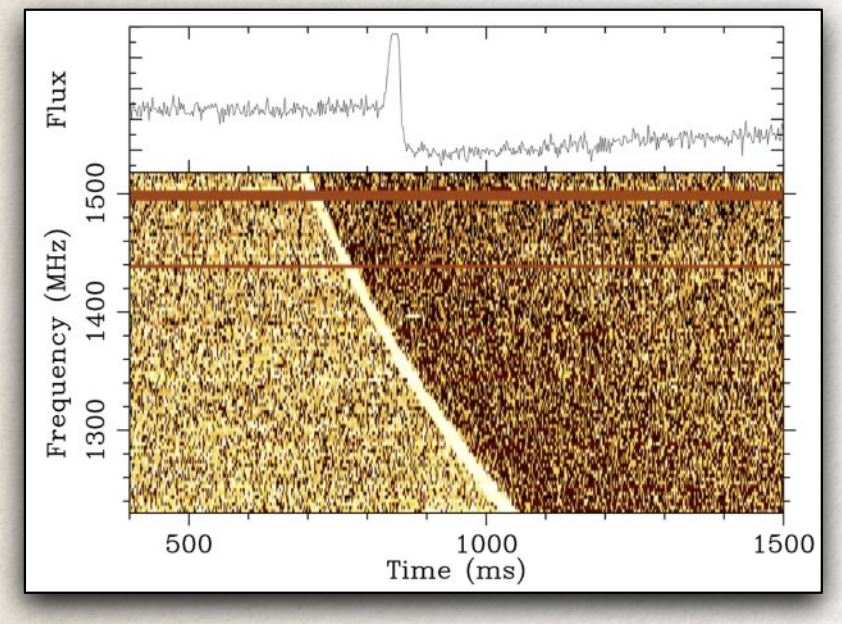
Talk Outline

1. Introduction
2. Observational Properties
3. Recent Results
4. Multi-wavelength Constraints
5. Outlook
6. Conclusions

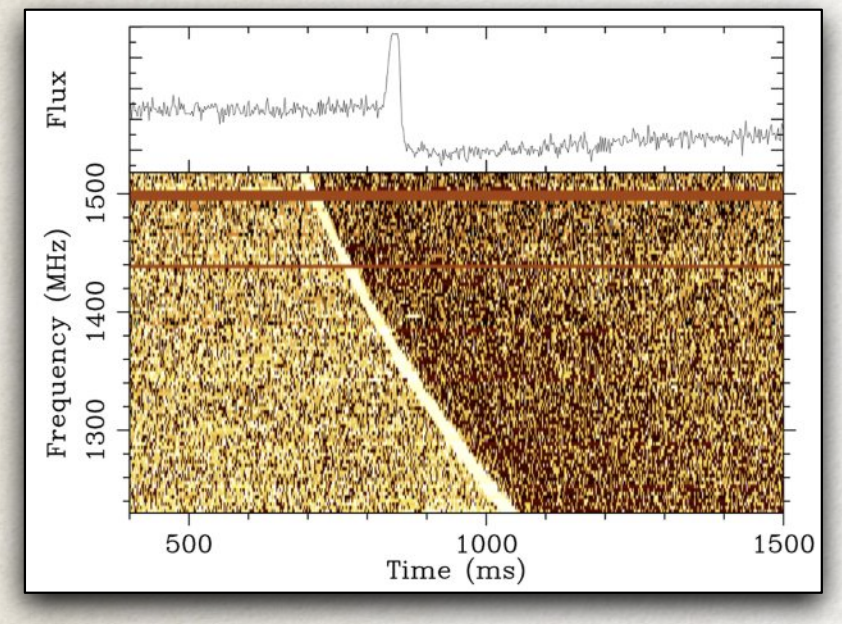
1. Introduction

Fast Radio Burst Discovery



Lorimer+ 2007 (Science)

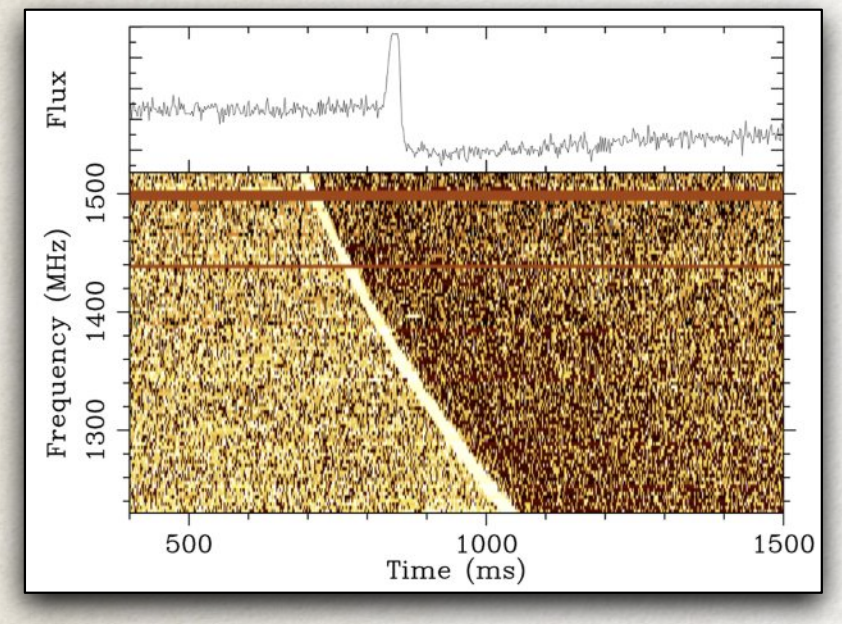
Fast Radio Burst Discovery



Lorimer+ 2007 (Science)

- Micro to millisecond duration
- Dispersive sweep
  - Cold plasma dispersion $\Delta t \sim DM\ \nu^{-2}$
  - DM is the “dispersion measure”
- High DM indicates extragalactic origin
  - Inferred redshifts up to ~2 – 3
- Extreme energy released

Fast Radio Burst Discovery



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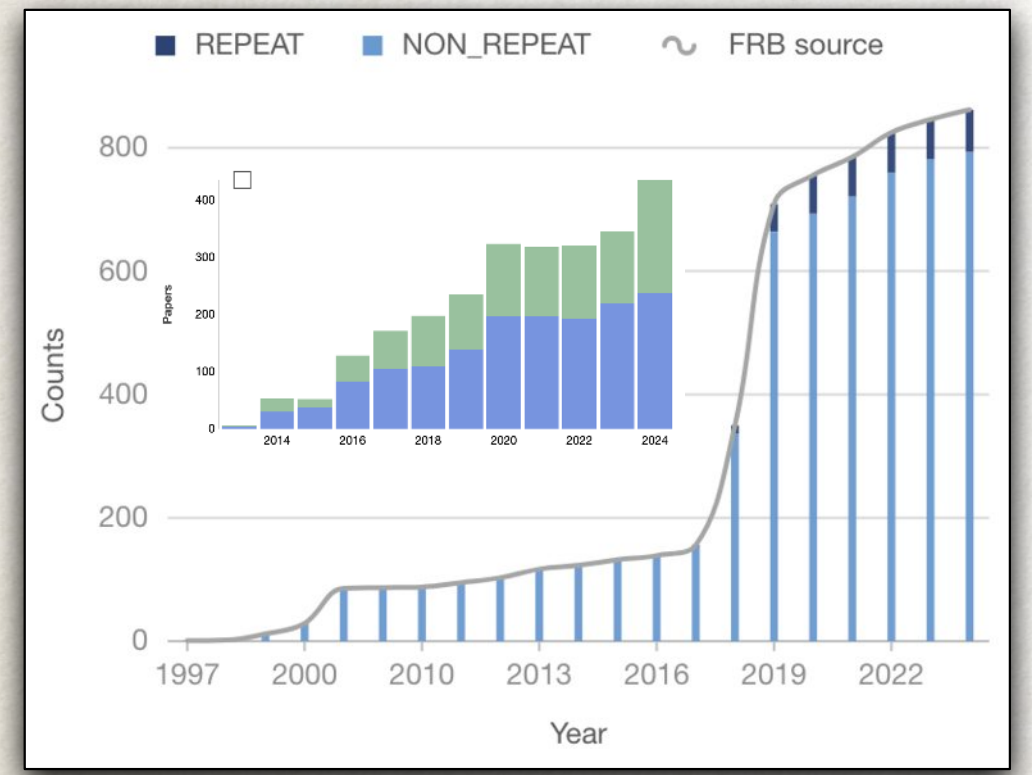
Shaw Prize in Astronomy 2023!
“Nobel of the East”

Shaw Prize

A Brief History of FRBs



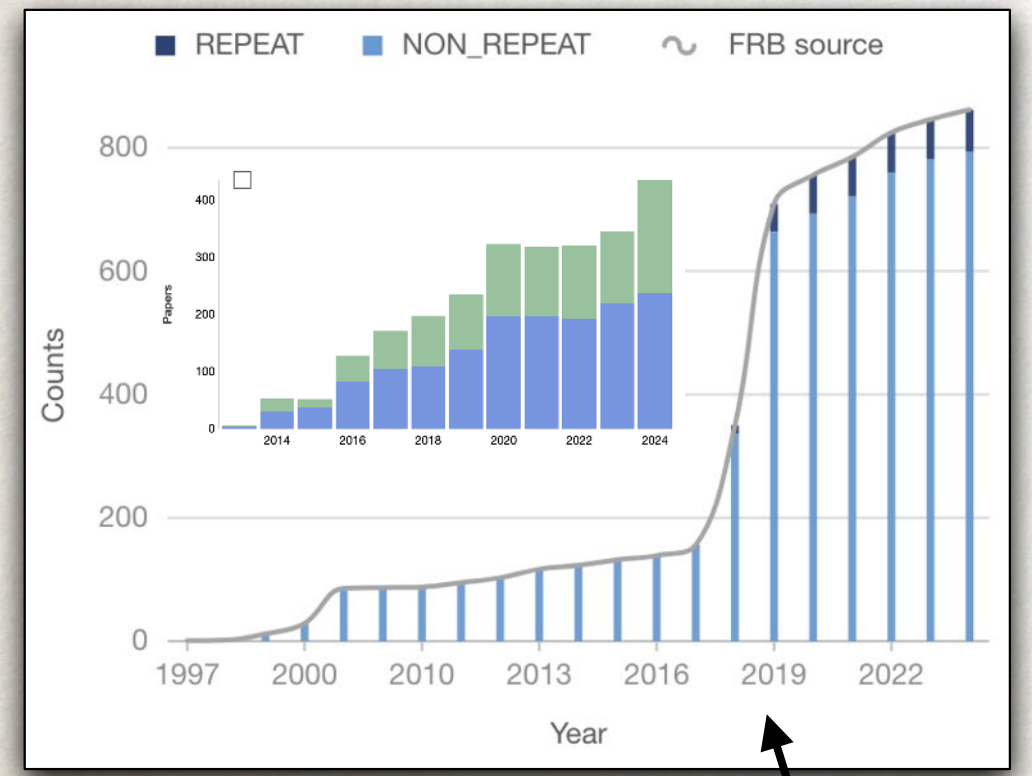
Blinkverse & NASA ADS

A Lot of Firsts

- 2007: First FRB (Lorimer+ 2007)
- 2013: First FRB **sample** (4; Thornton+ 2013)
- 2016: First **repeating** FRB (Spitler+ 2016)
- 2017: First **host galaxy** (R1; Chatterjee+ 2017, Tendulkar+ 2017)

A Brief History of FRBs

Blinkverse & NASA ADS



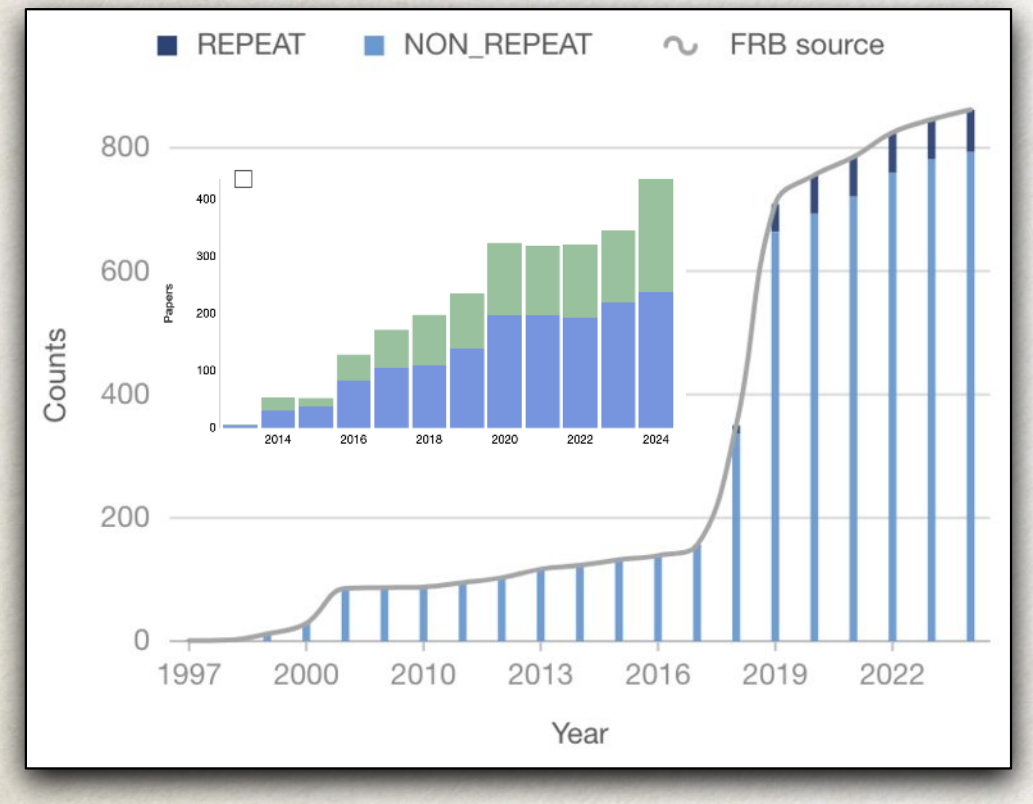
CHIME telescope

A Lot of Firsts

- 2007: First FRB (Lorimer+ 2007)
- 2013: First FRB **sample** (4; Thornton+ 2013)
- 2016: First **repeating** FRB (Spitler+ 2016)
- 2017: First **host galaxy** (R1; Chatterjee+ 2017, Tendulkar+ 2017)
- 2020: FRB-like burst from **SGR 1935+2154** (Bochenek+ 2020, CHIME 2020)
- 2021: CHIME FRB **Catalogue 1** (~500 FRBs; 2021)
- 2023: More **repeaters** (25; CHIME 2023)
- 2025: **Pulsar-like** polarisation (Mckinven+ 2025)

Current Status

Blinkverse & NASA ADS



As of March 2025

- ~840 FRBs
- ~60 repeaters
- ~110 secure host galaxies
- 1–3 FRBs with periodic activity windows

Three Mysteries

Location

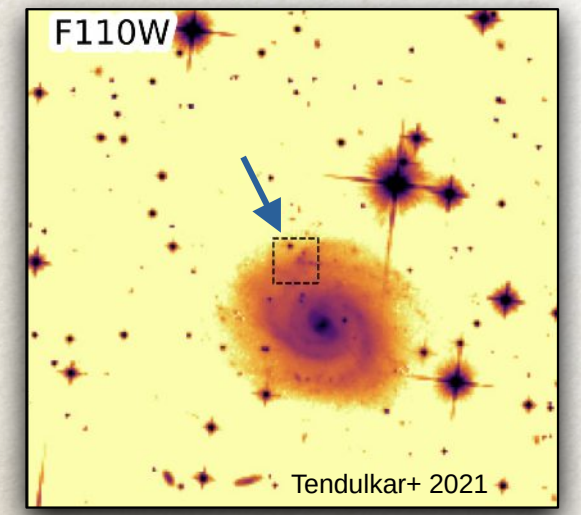
Where do they come from?

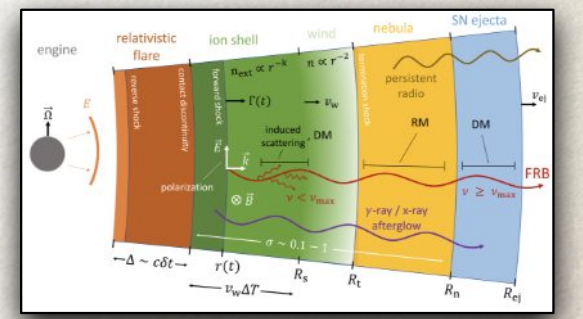
Progenitors

What objects create them?

Physics

How do these objects create them?



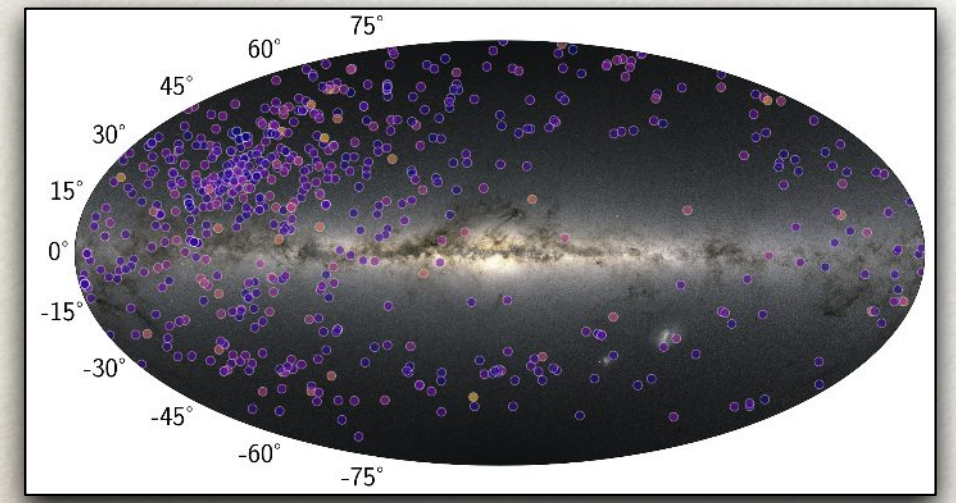


Metzger+ 2019

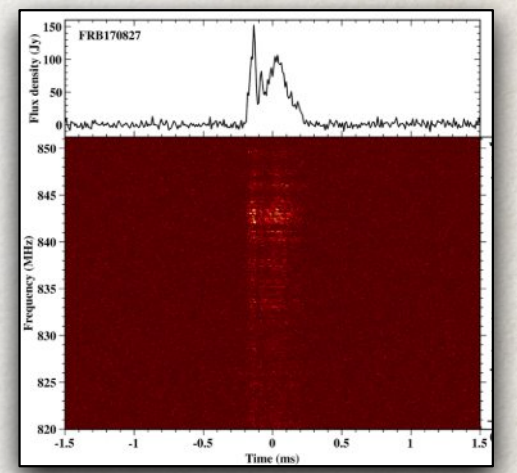
2. Observational Properties

Repeaters versus One-off FRBs

- Two main classes (repeaters vs one-offs)
- Repeaters have broader bursts and narrow-band emission
  - Down-drifting in frequency
- Isotropic on the sky
- High all-sky rate



HeRTA Experiment

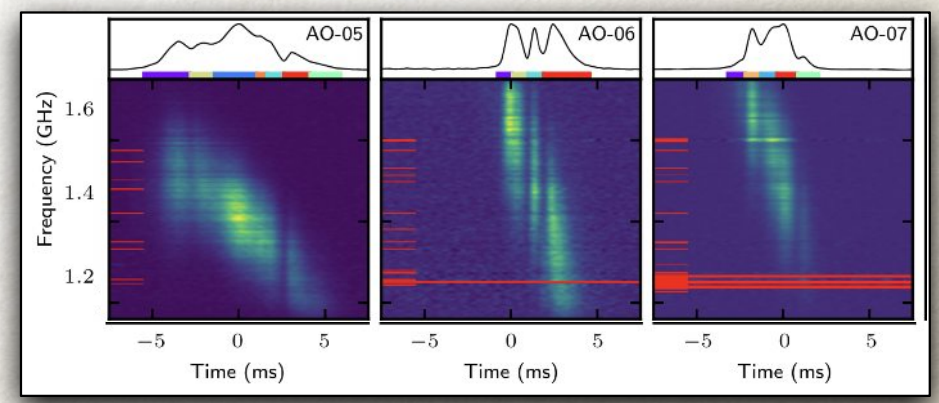


Frequency (MHz)

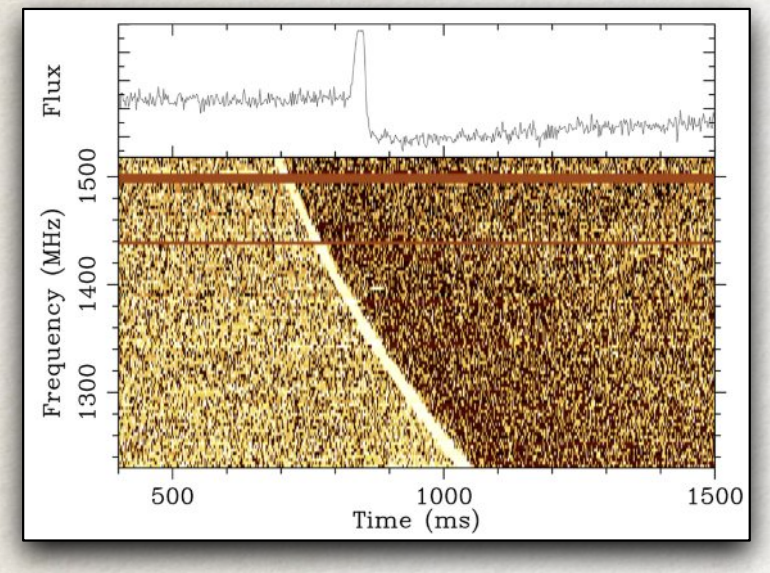
Time (ms)

Farah+ 2018, FJ

Hessels+ 2019



Dispersion Measures



$$DM_{obs} = \int_0^d dl\, n_e(l)$$

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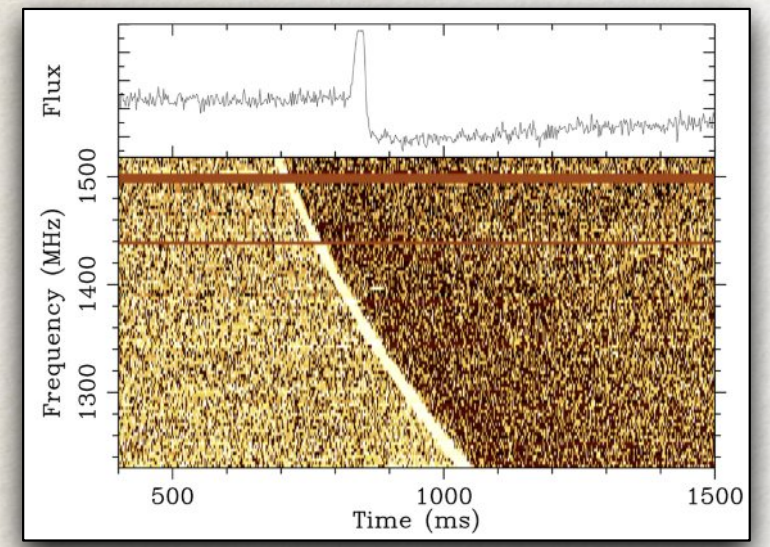

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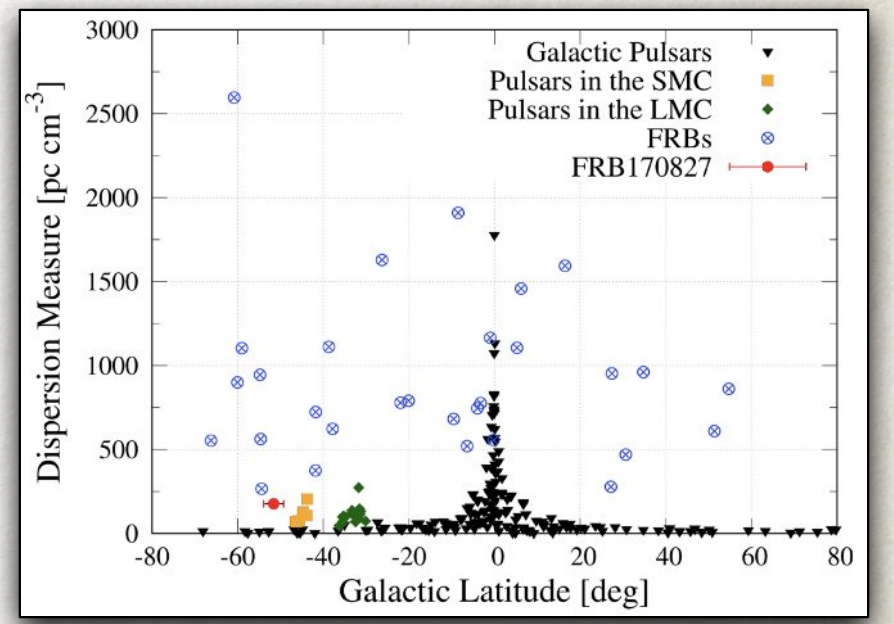
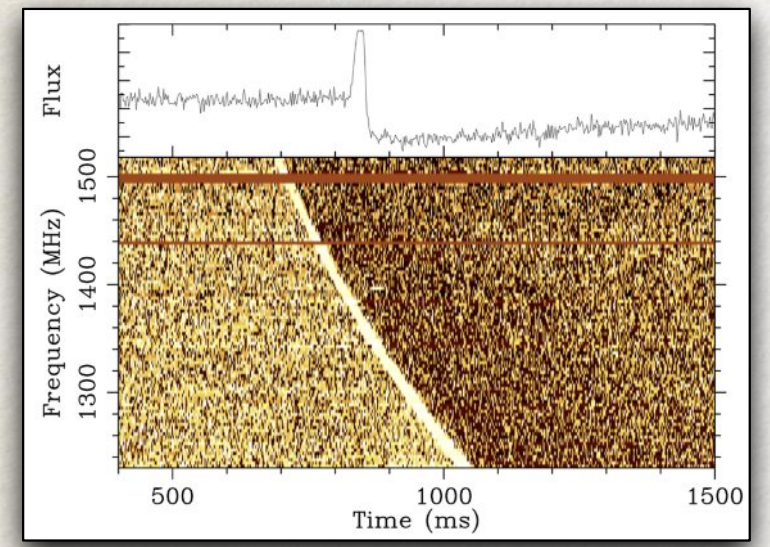
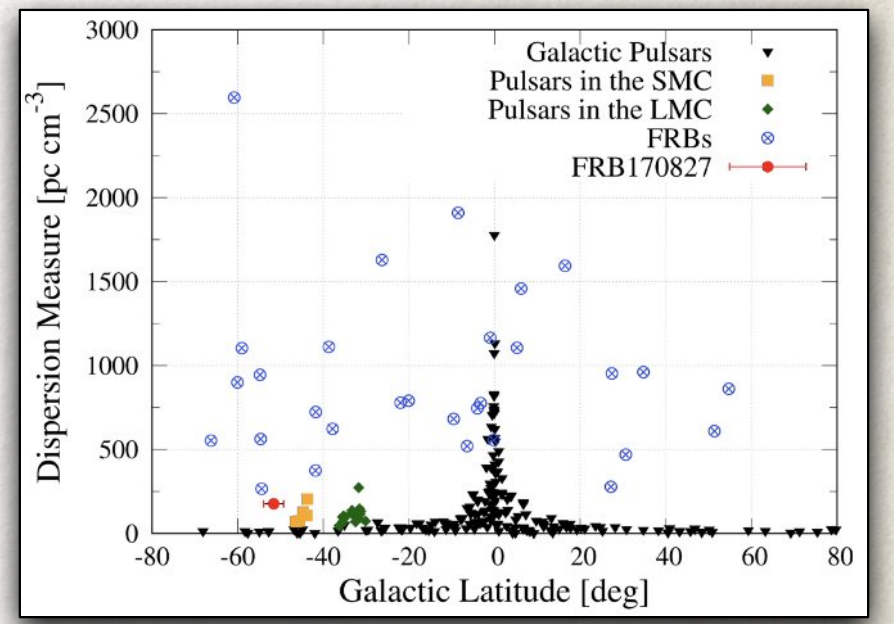


Farah+ 2018, FJ

Dispersion Measures



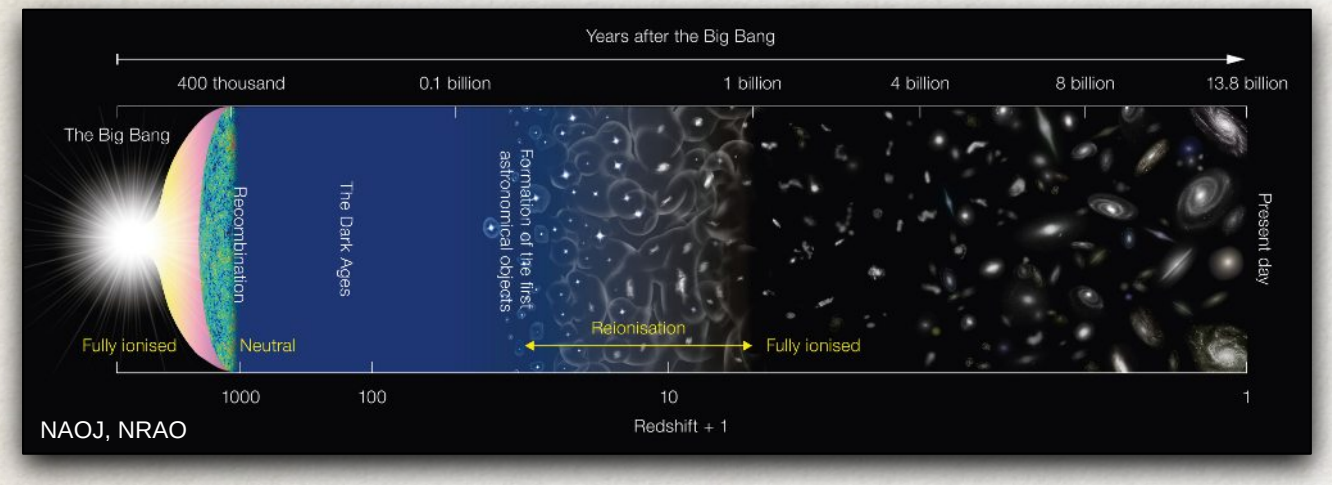


Farah+ 2018, FJ

$$DM_{obs} = \int_0^d dl\, n_e(l)$$

$$DM_{obs} = DM_{MW} + DM_{halo} + DM_{IGM}(z) + DM_{host}/(1+z)$$

FRBs are Ideal Cosmological Probes

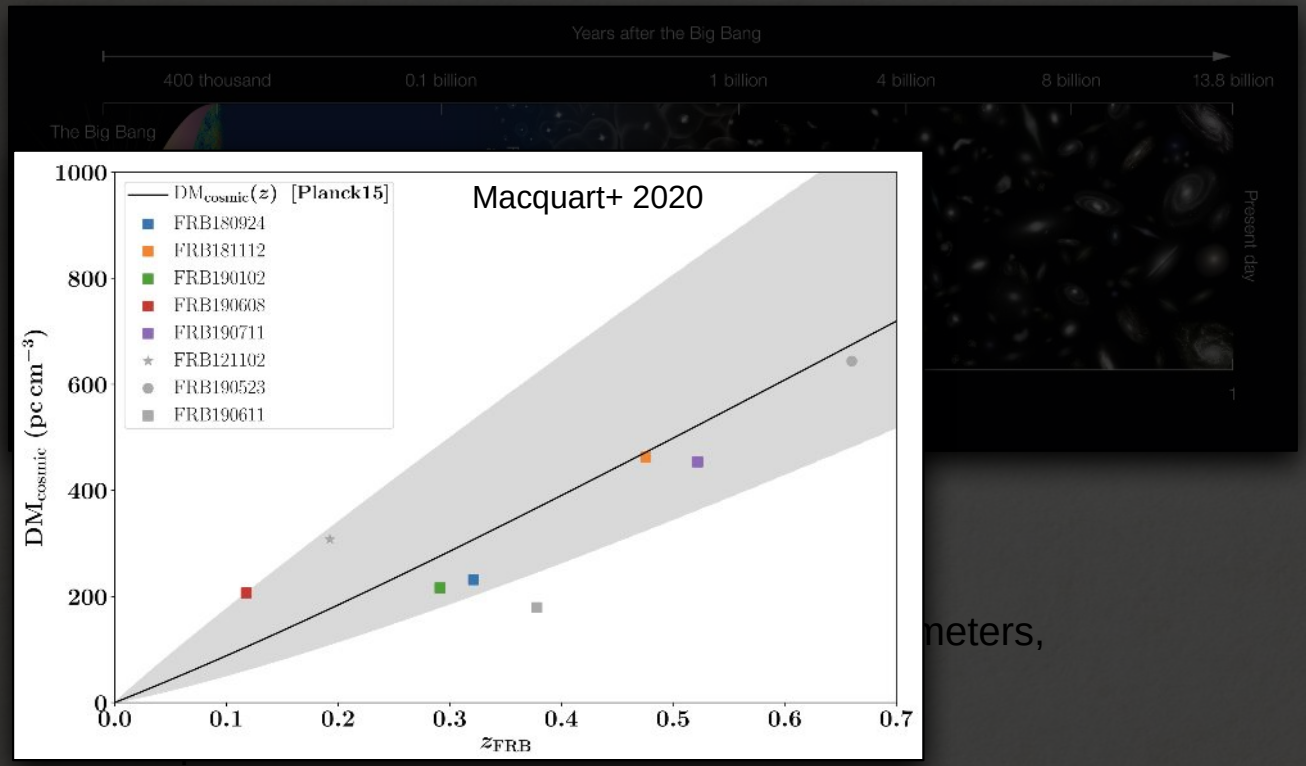


- Study the missing baryons
- Independent measurement of cosmological parameters, e.g. matter density and Hubble constant H_0.
  - Independent “vote” on Hubble tension
- Determine the re-ionisation history of the Universe
- Plasma lensing & gravitational lensing

Fabian Jankowski

FRBs are Ideal Cosmological Probes

Extragalactic DM (radio)



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- Determine the reionisation history of the Universe
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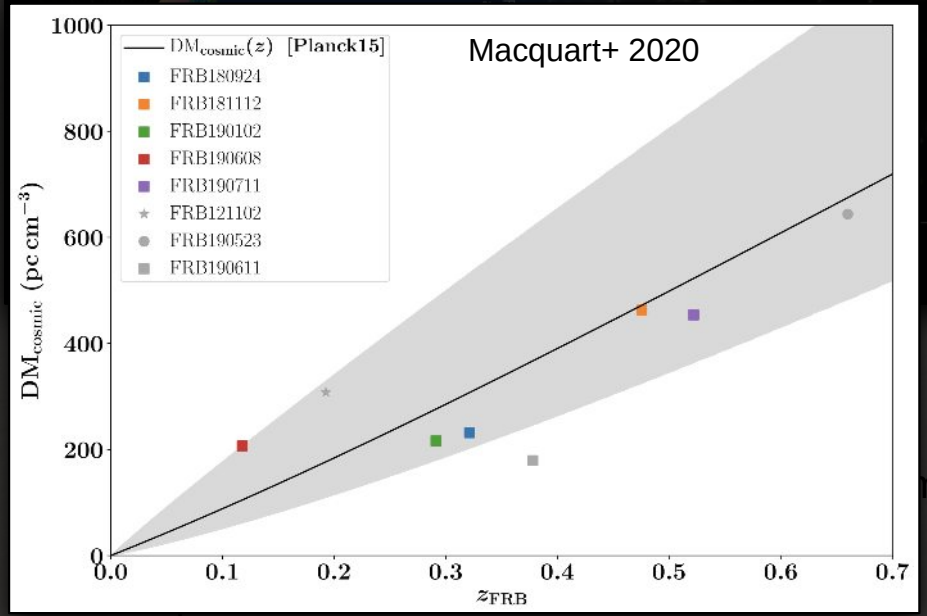
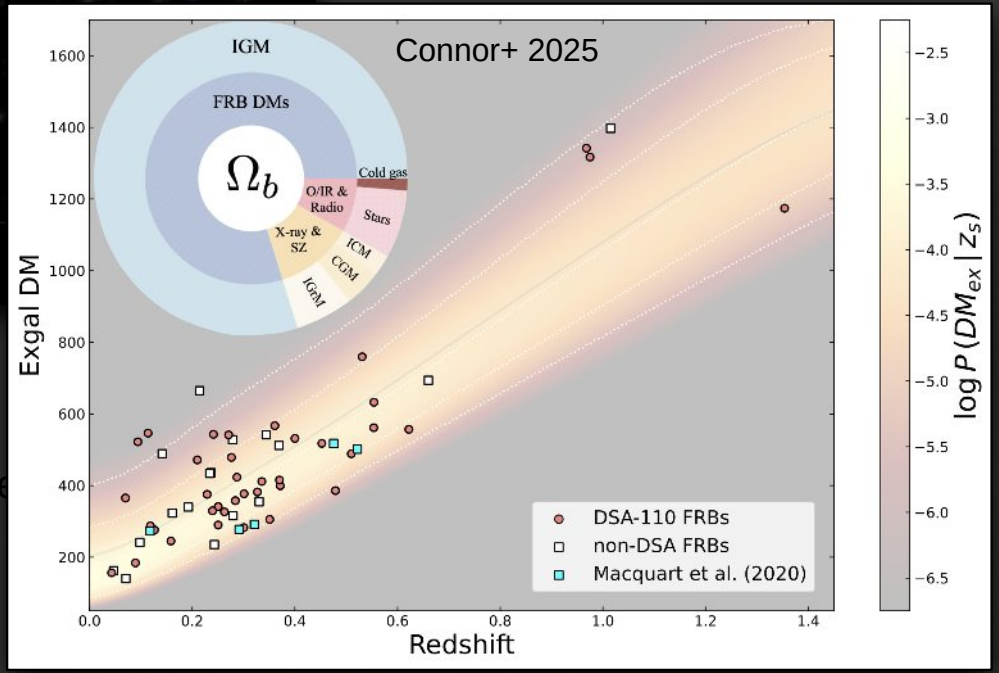
Host galaxy redshift (optical)

Fabian Jankowski

FRBs are Ideal Cosmological Probes

Extragalactic DM (radio)





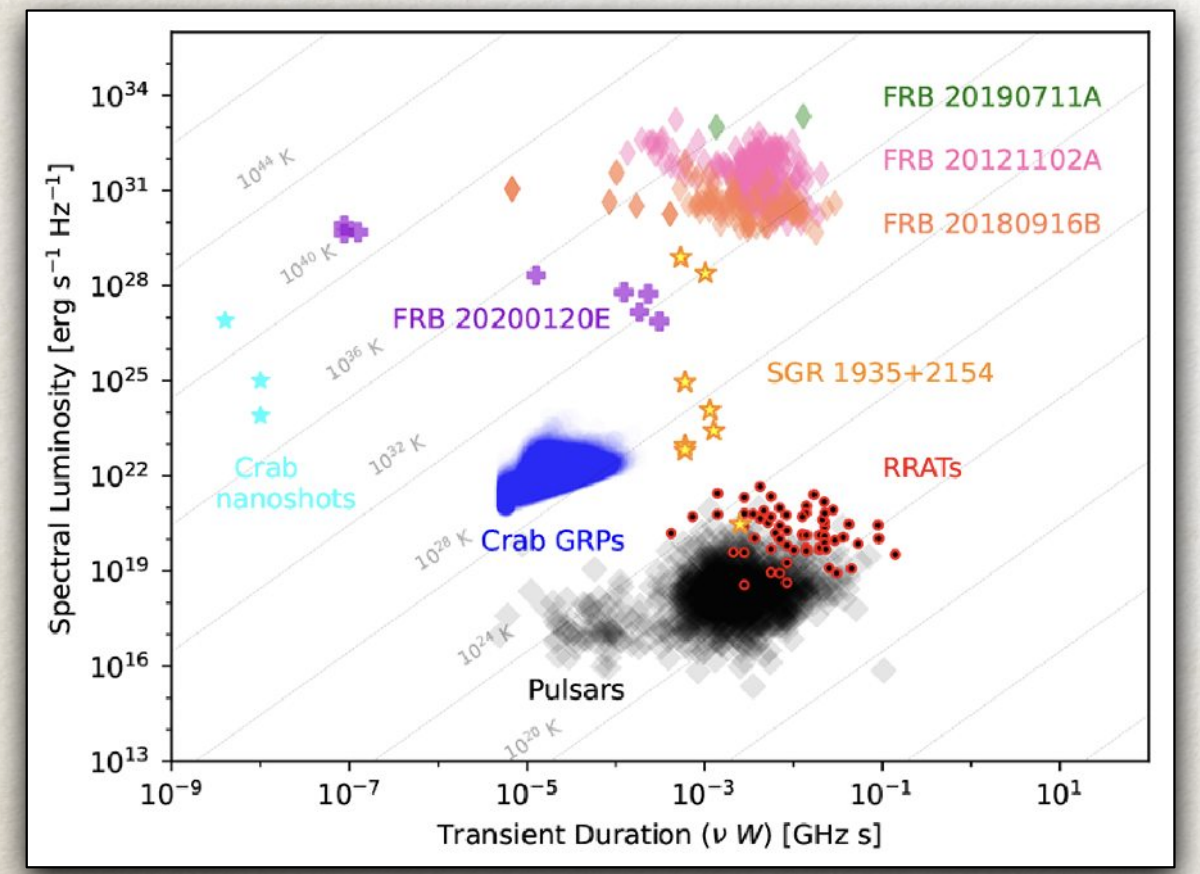
Host galaxy redshift (optical)

- Determine the ionization history of the Universe
- Plasma lensing & gravitational lensing

Fabian Jankowski

Burst Energies and Luminosities

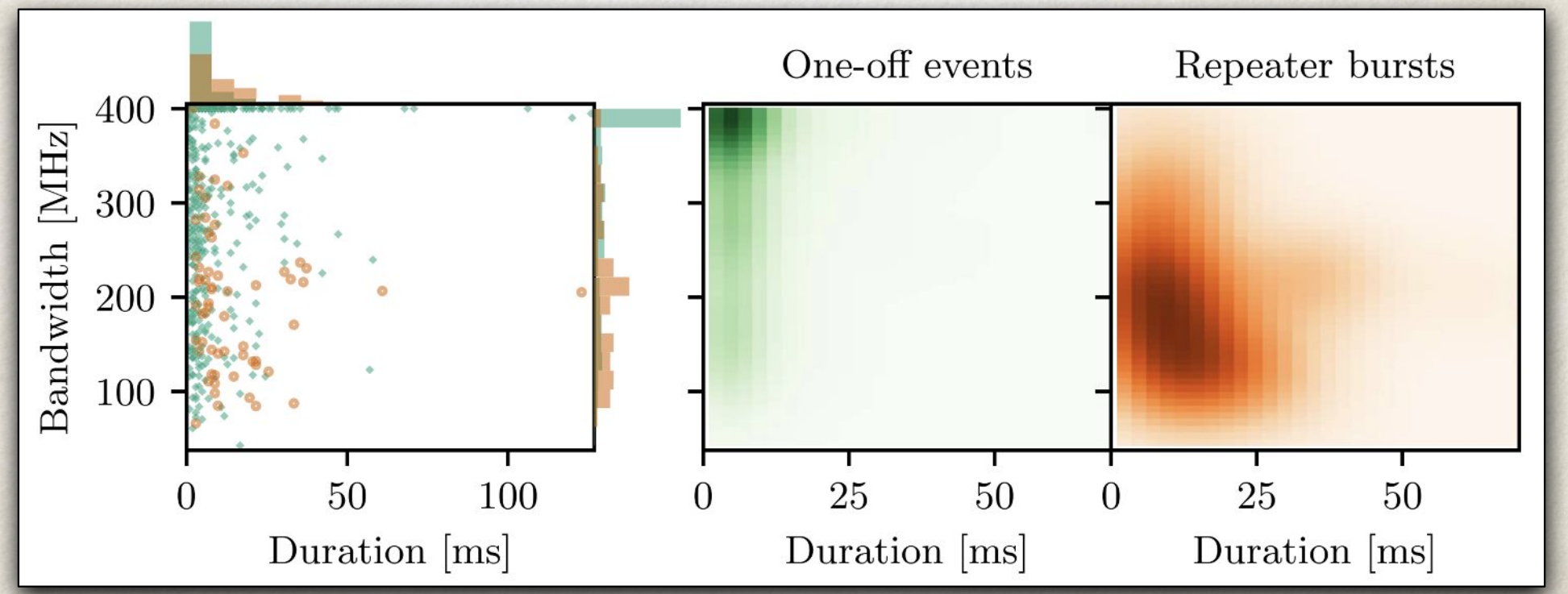
Transient phase space



Nimmo+ 2022

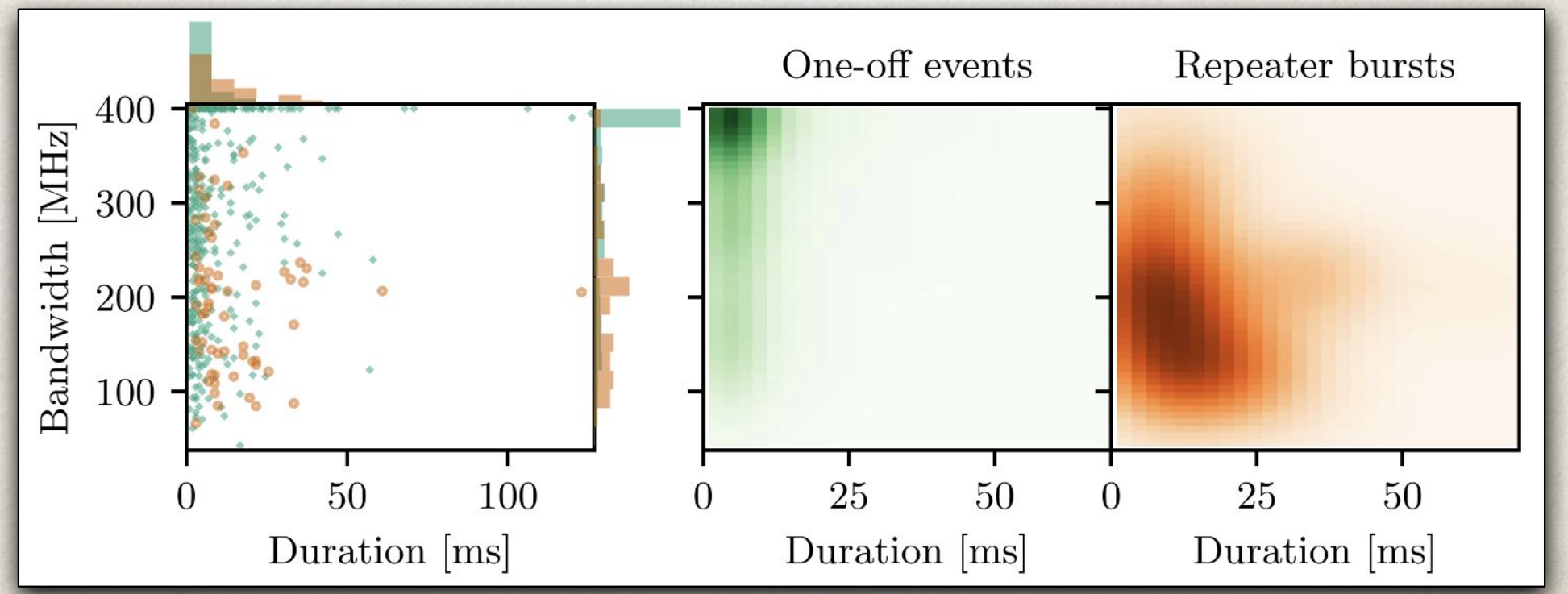
- Brightness temperatures ~10^{32} – 10^{36} K
- Spectral luminosities ~10^{31} erg s^{-1} Hz^{-1}

Burst Widths and Spectral Occupancy



Pleunis+ 2021

Burst Widths and Spectral Occupancy

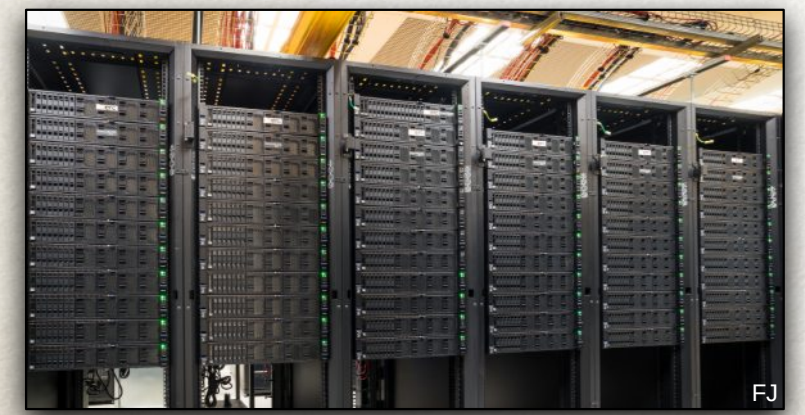


Pleunis+ 2021

One-offs narrow bursts and broadband, repeaters wider bursts but narrowband.

FRB Localisation Mystery and Host Galaxies

Commissioned the MeerTRAP Instrument at MeerKAT



- Primary aims
  - Understanding what creates FRBs
  - Localising FRBs to their host galaxies

MEERTRAP

erc
European Research Council

MANCHESTER 1824
The University of Manchester

FRB Localisation Mystery and Host Galaxies

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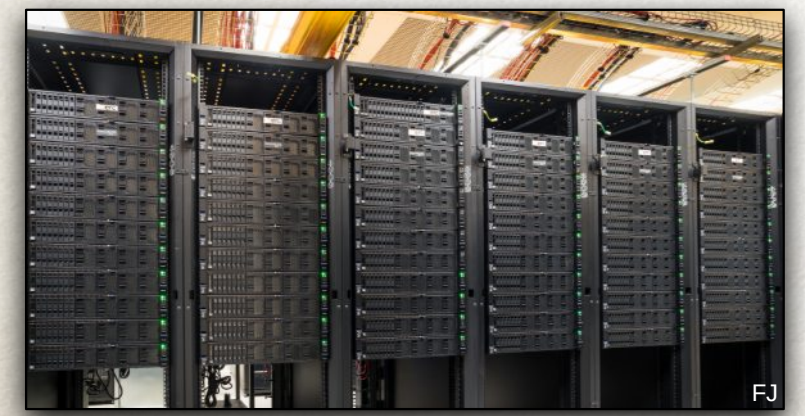


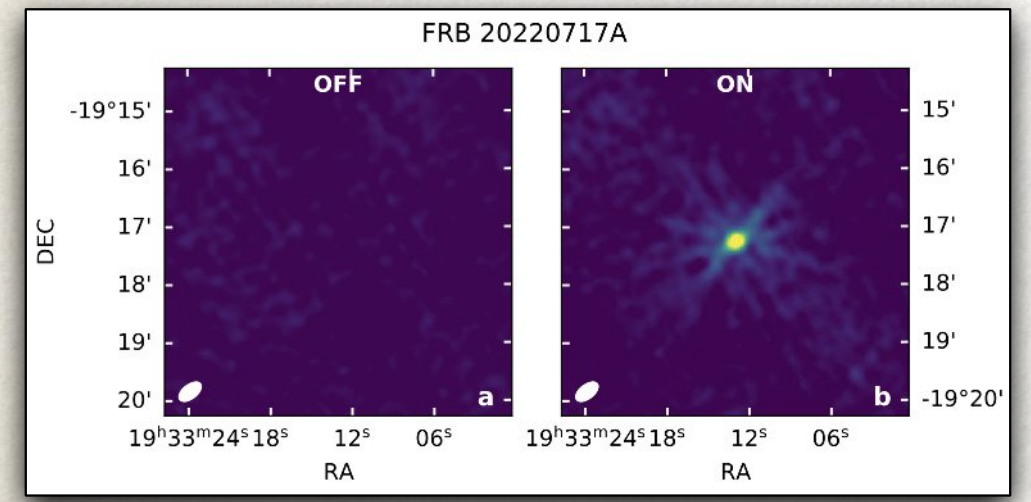
- Primary aims
  - Understanding what creates FRBs
  - Localising FRBs to their host galaxies
- Several million EUR project with various partner institutes (Bonn, Oxford, SARAO)
- Installed high performance servers at telescope site (user-supplied equipment)
- Designed, implemented, and commissioned observing & search software
- Scientific exploitation

MEERTRAP

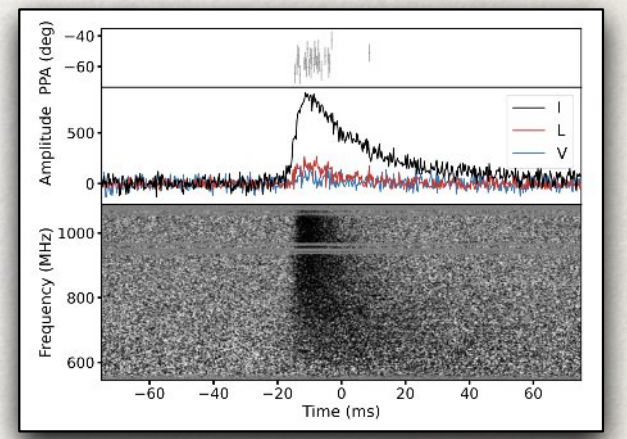
erc European Research Council

MANCHESTER 1824 The University of Manchester

Localisation and Host Galaxies



Rajwade+ 2024, FJ

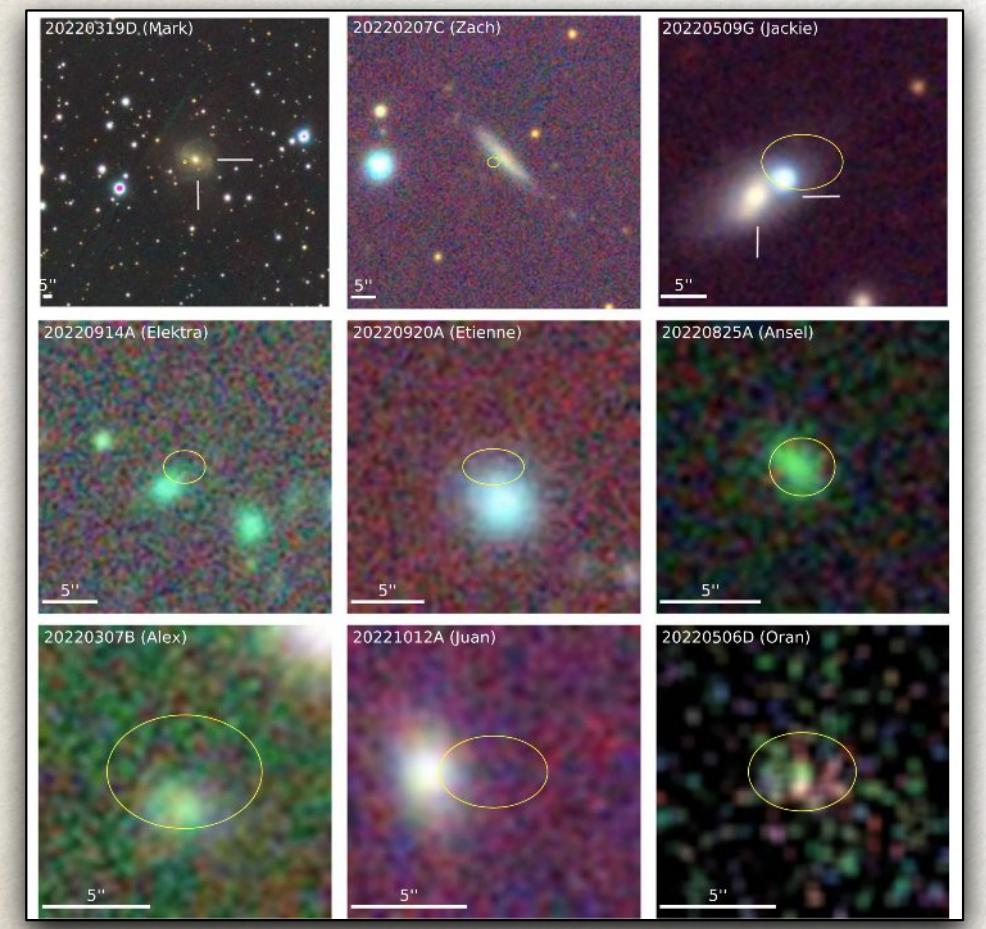


- Precision localisation via VLBI techniques
- Sub arcsecond precision
- Host galaxies and local environments

FJ

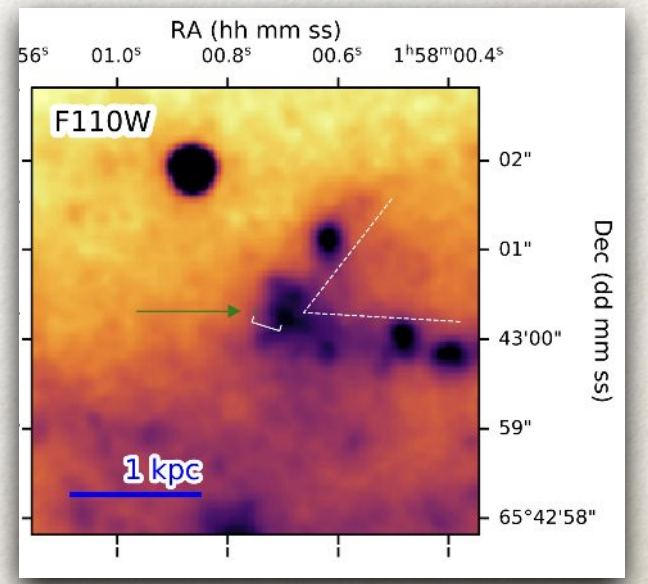
Localisation and Host Galaxies

Law+ 2024



Location

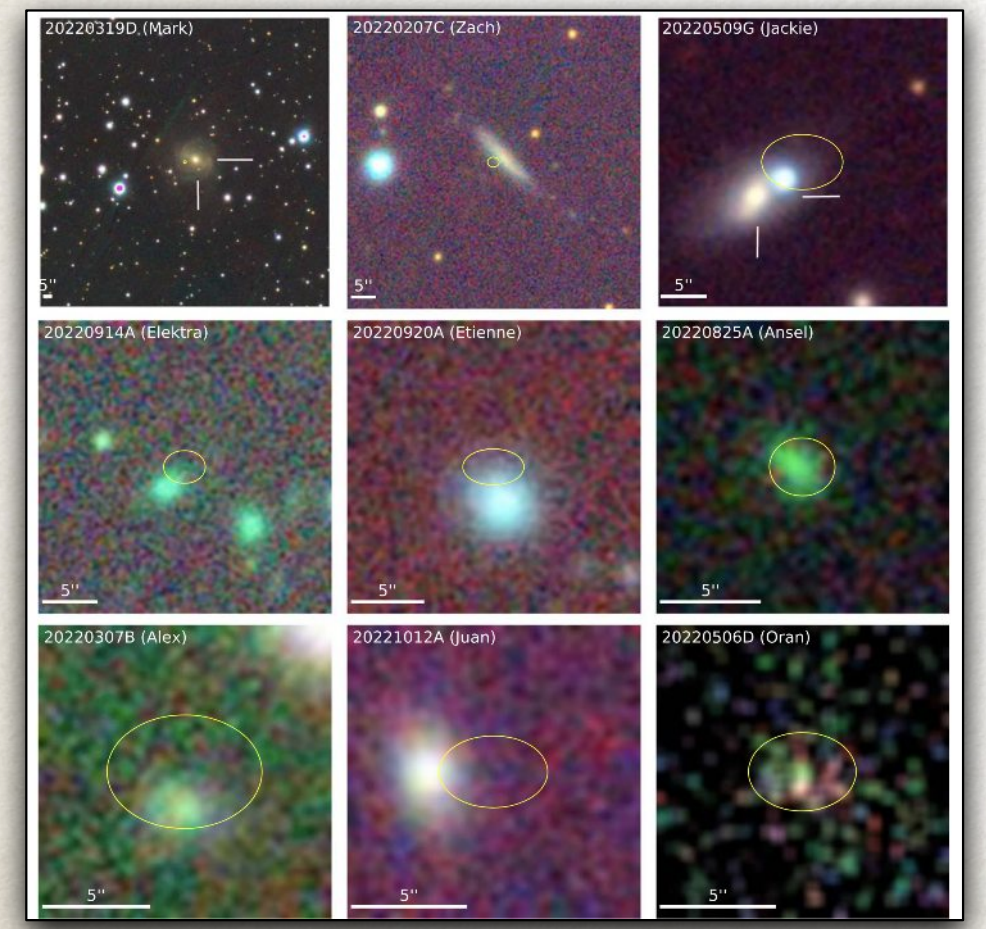
Where do they come from?



Tendulkar+ 2021

Localisation and Host Galaxies

Law+ 2024



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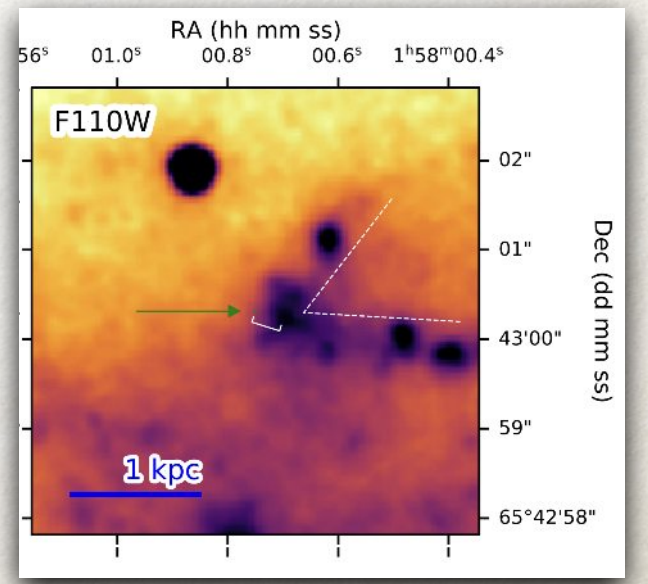
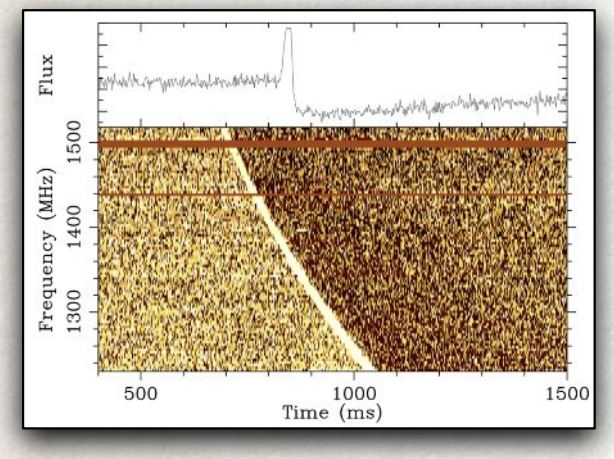
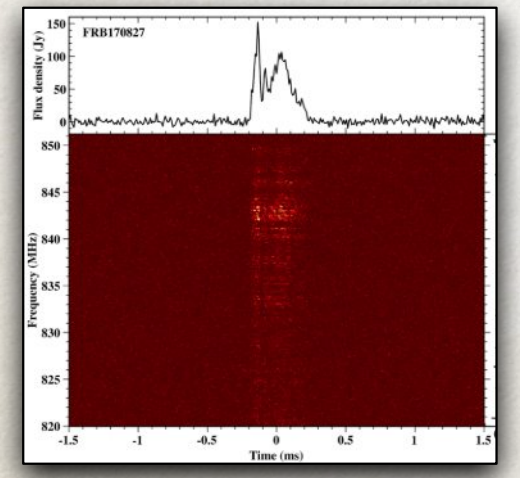


Tendulkar+ 2021

FRB Progenitor Mystery – What Creates FRBs?



Lorimer+ 2007



Frequency (MHz)

Time (ms)

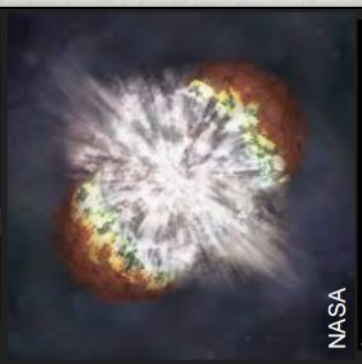
Farah+ 2018, FJ

Open Questions

- What are their progenitors?
- Are there multiple classes of FRBs?
- Are the repeating and non-repeating FRBs from different objects?
- What is the physical mechanism that generates the bursts (high brightness temperature)?
- What other applications are there for FRBs?

Possible FRB Progenitors

Merging Black Holes



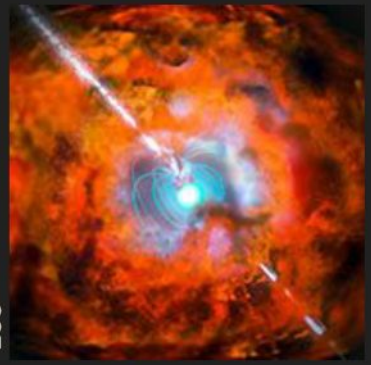
Kilonova

Blitzar

Merging Neutron Stars

Gamma Ray Burst

Hyper Pulses

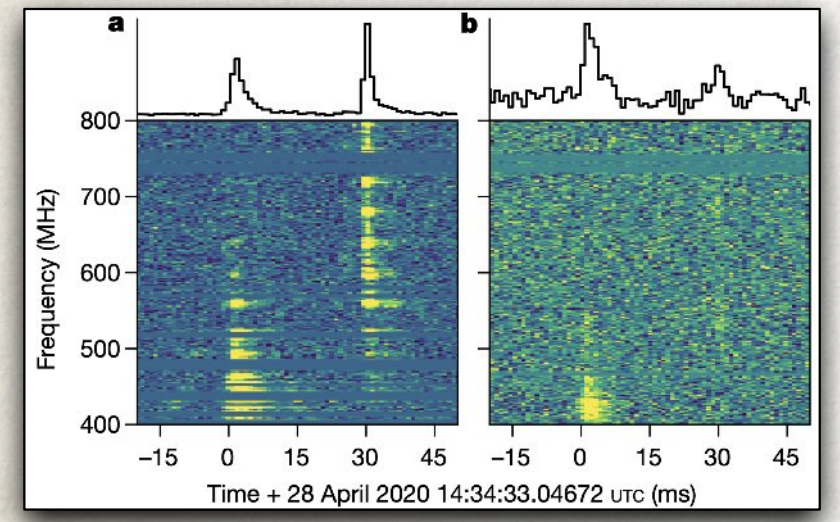


Magnetar

Surnis; FRB theory catalogue; Platts+ 2018

- Cataclysmic vs repeating; magnetospheric (close) vs relativistic shocks (far)

The FRB – Magnetar Connection



CHIME/FRB 2020

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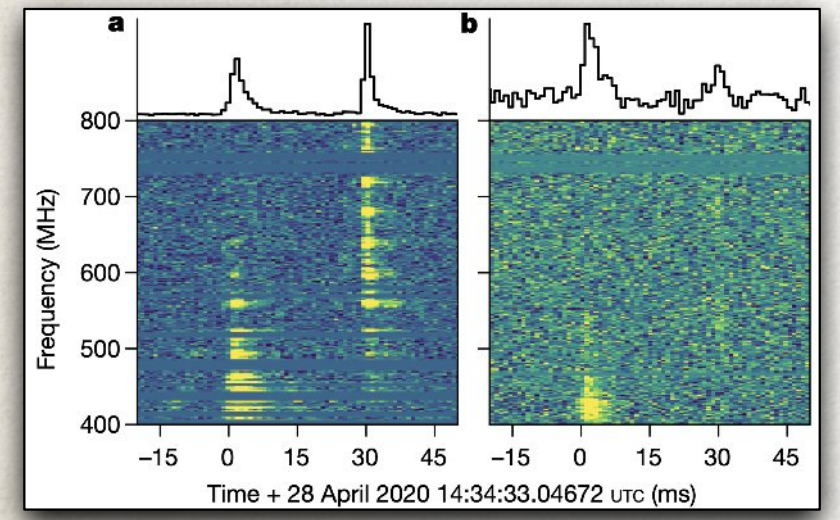

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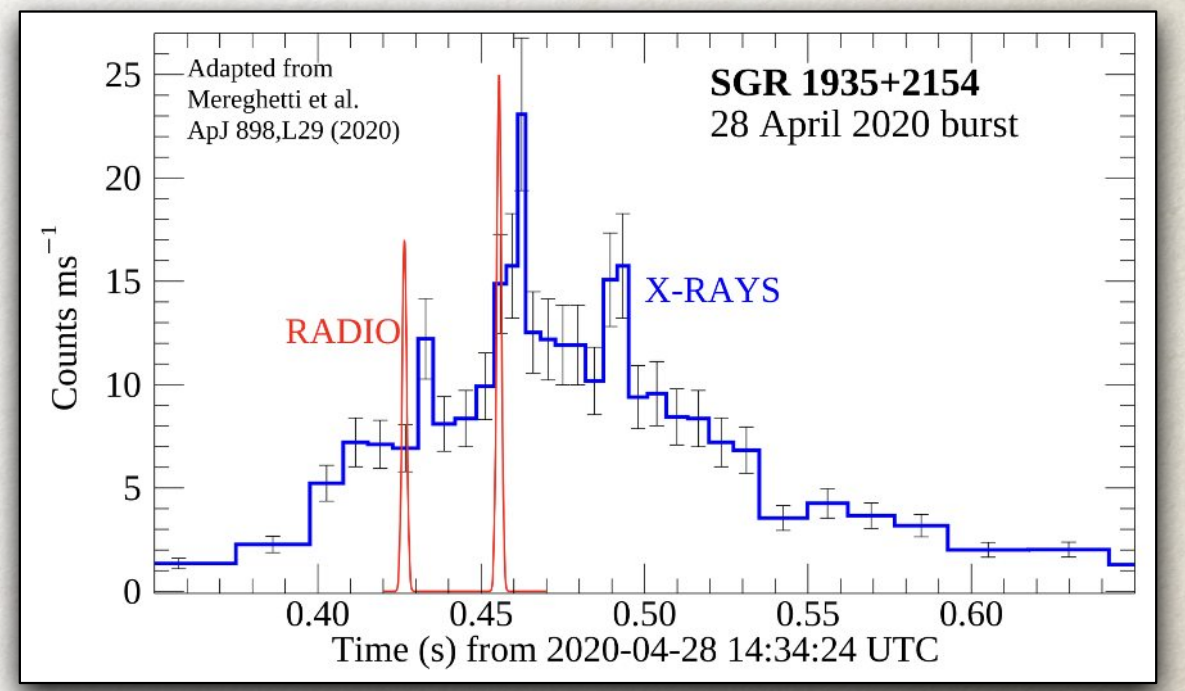

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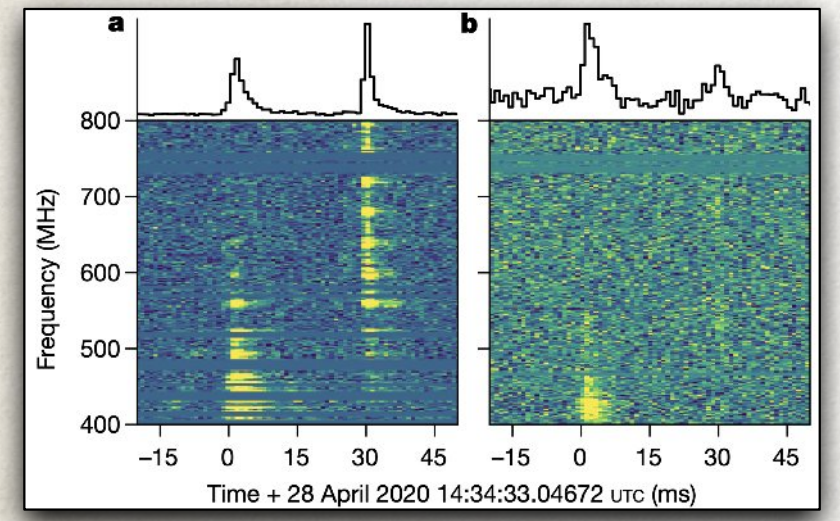

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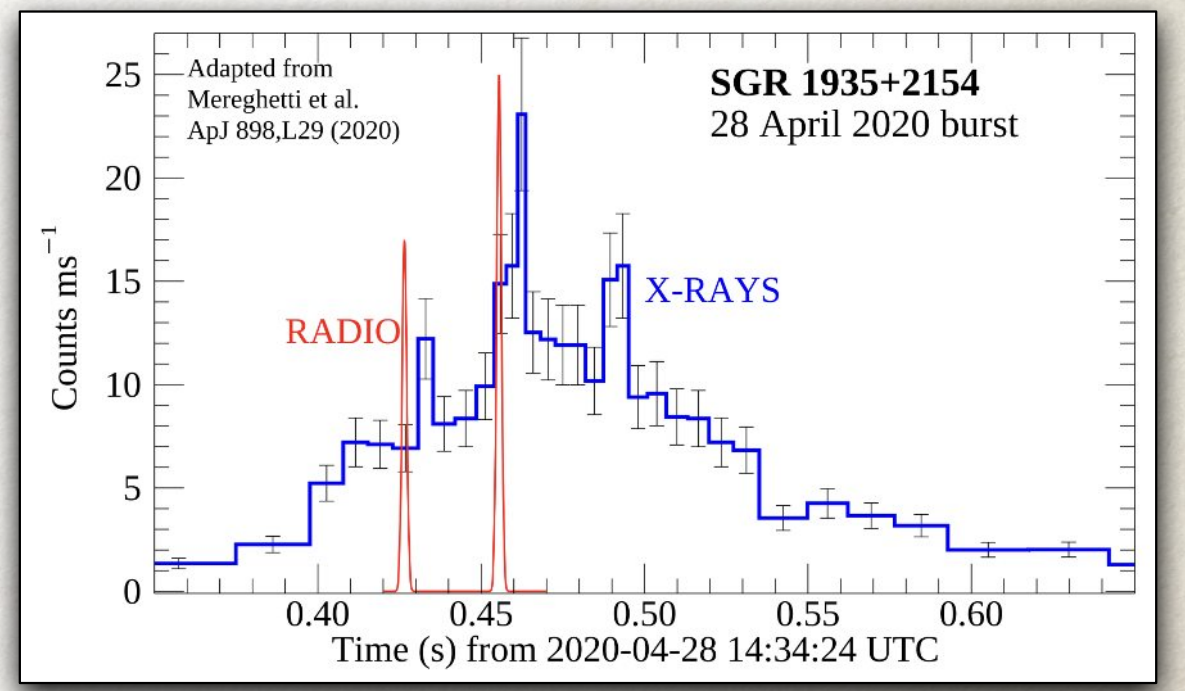


Magnetars can produce FRB-like radio bursts.

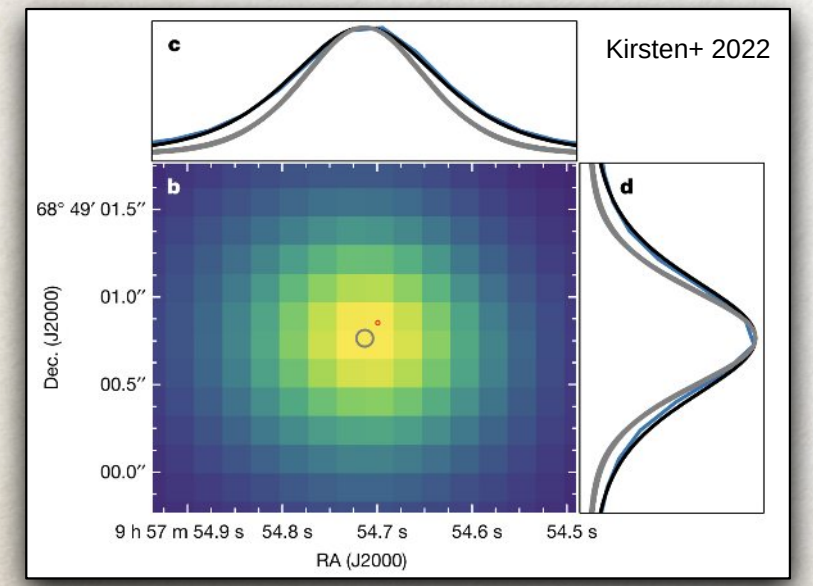
However, Repeaters in Globular Clusters

Two repeaters in GCs

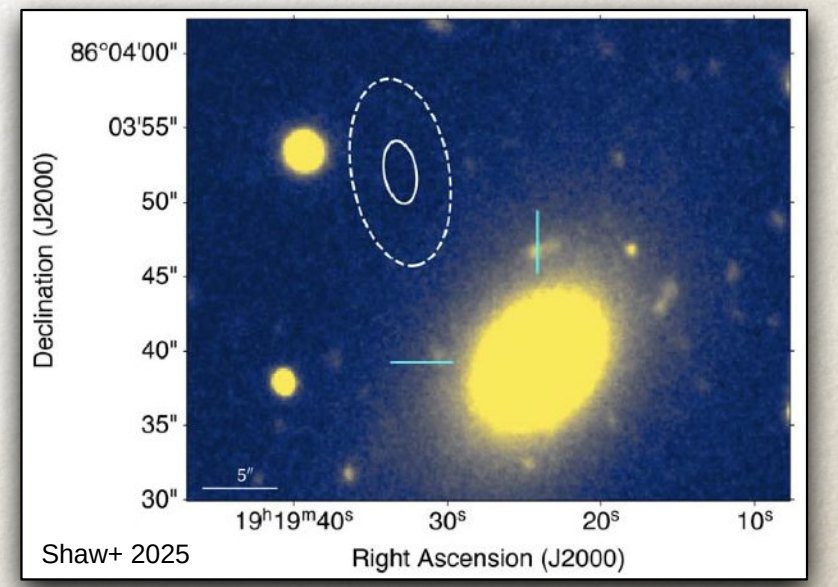
- FRB 20200120E (M81; Kirsten+ 2022, EVN)
- FRB 20240209A (Shah+ 2025, CHIME)

Progenitors

What objects create them?



Kirsten+ 2022



Shaw+ 2025

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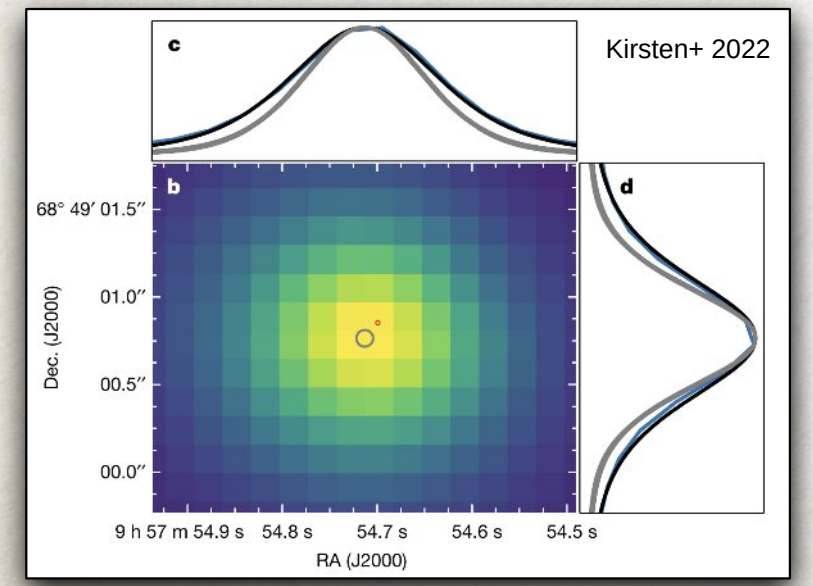
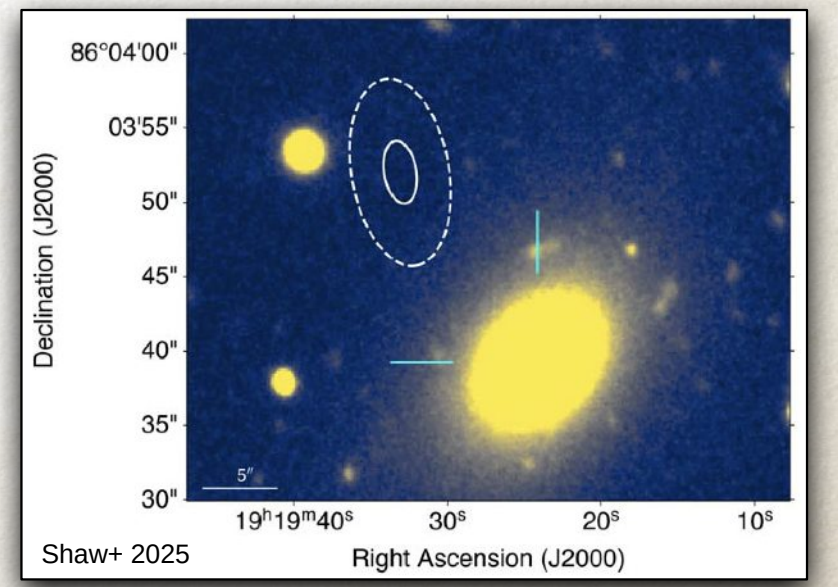


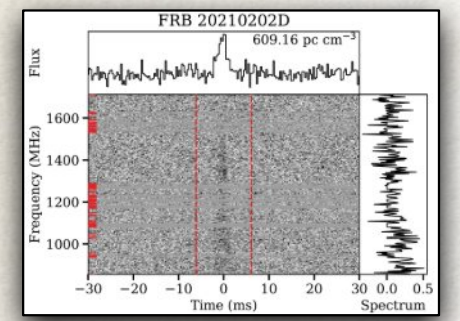
Kirsten+ 2022

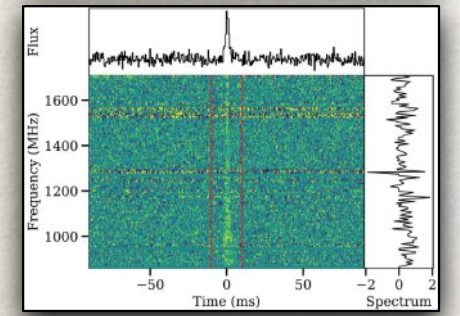


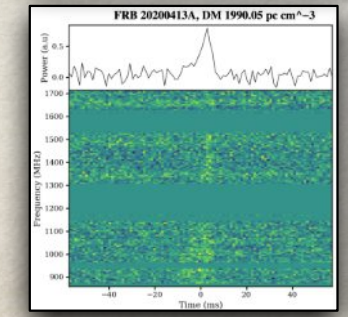
Shaw+ 2025

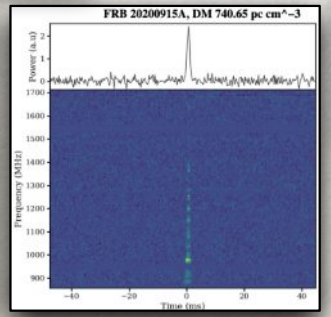
FRB Physics Mystery – Burst Morphology

Unresolved

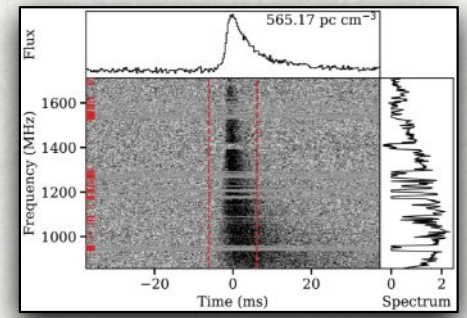


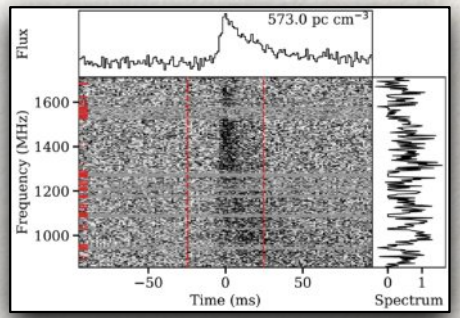


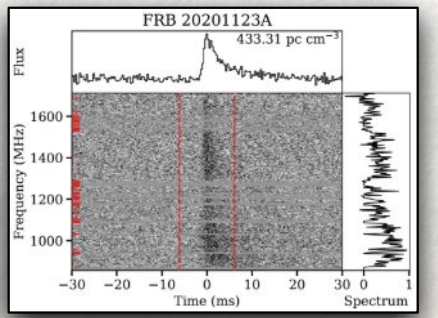


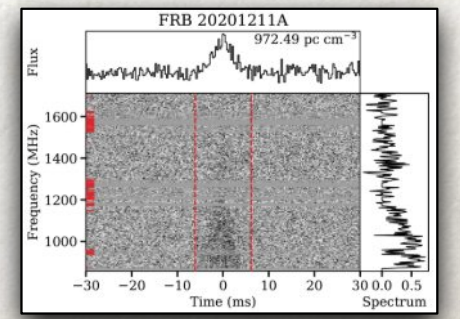


Scattered

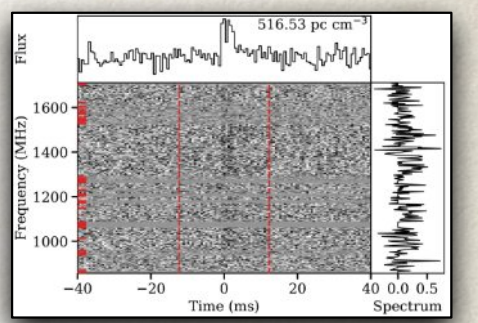


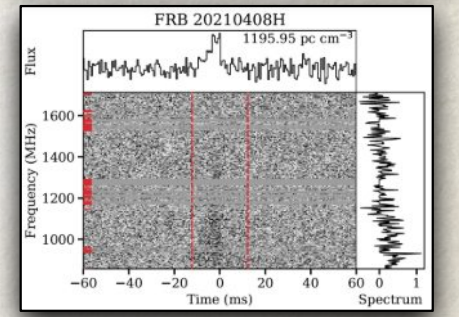


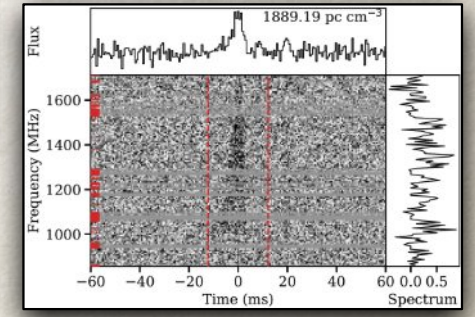




Complex





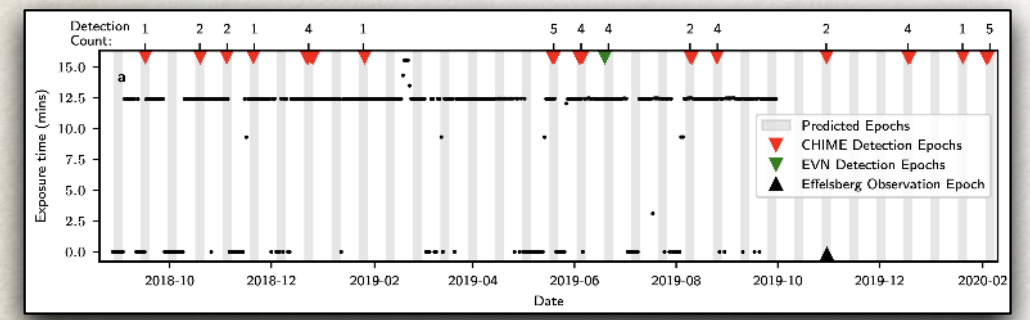


FJ+ 2023; Rajwade+ 2022; Driessen+ 2024; Caleb+ 2023

Periodic Activity Windows

Short period?

- None found, but recent claims

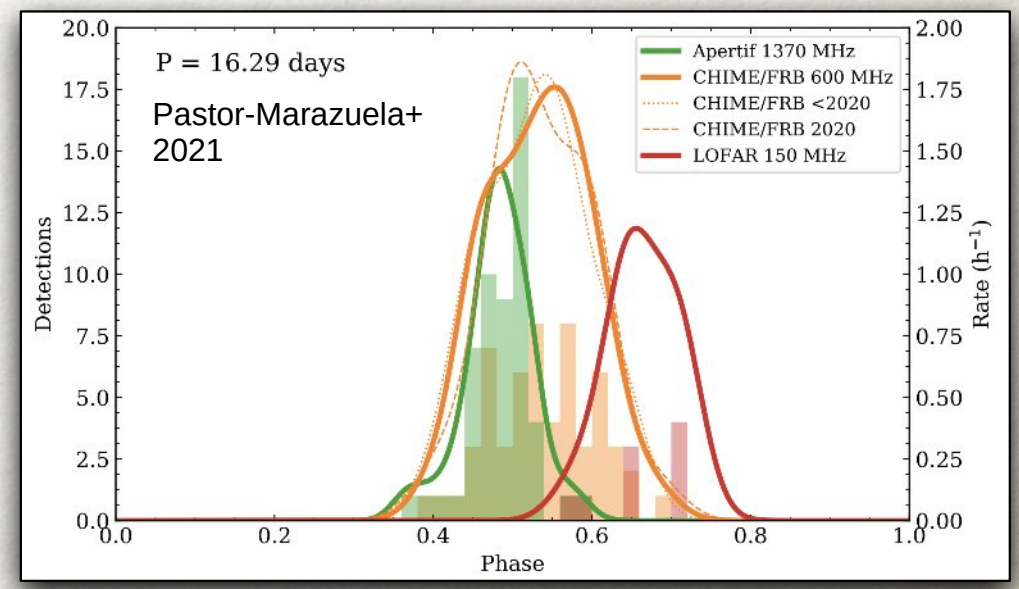


CHIME/FRB 2020

Orbital motion in binary system? Asteroids?

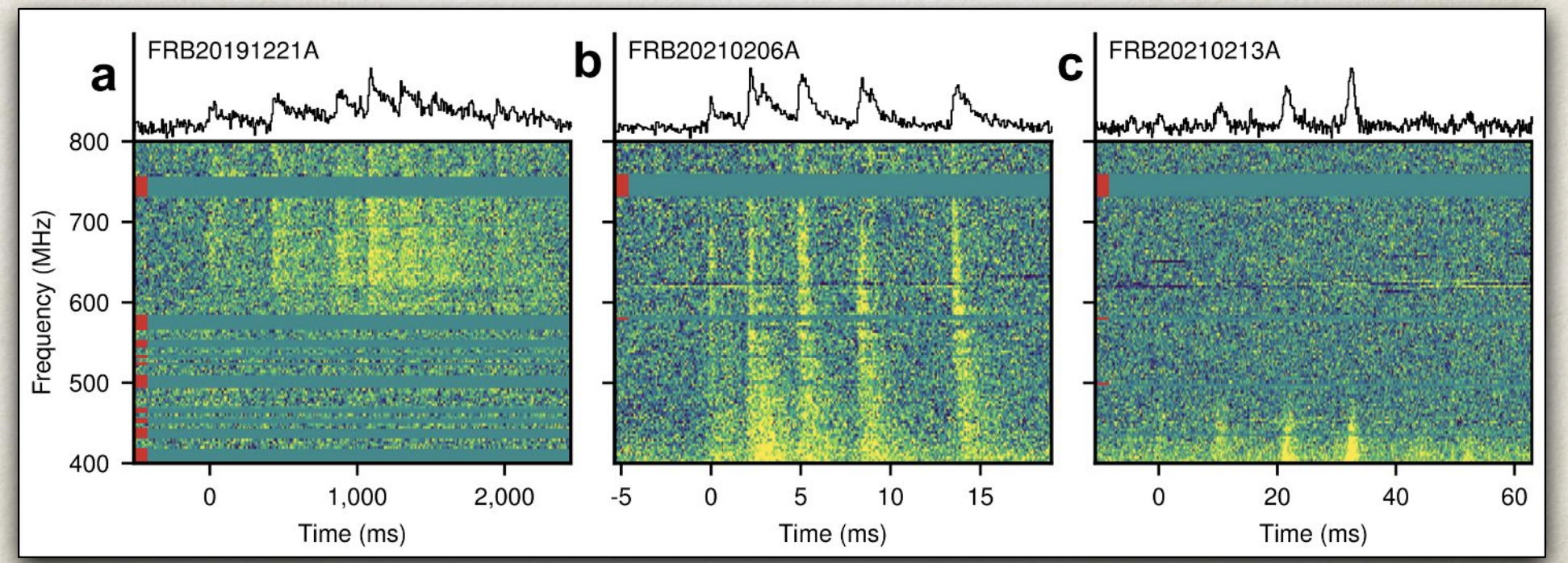
Activity Window

- 16 days (FRB 20180916B, R3)
  - Chromatic activity window (Pastor-Marazuela+ 2021)
- 154 days (FRB 20121102A, R1)



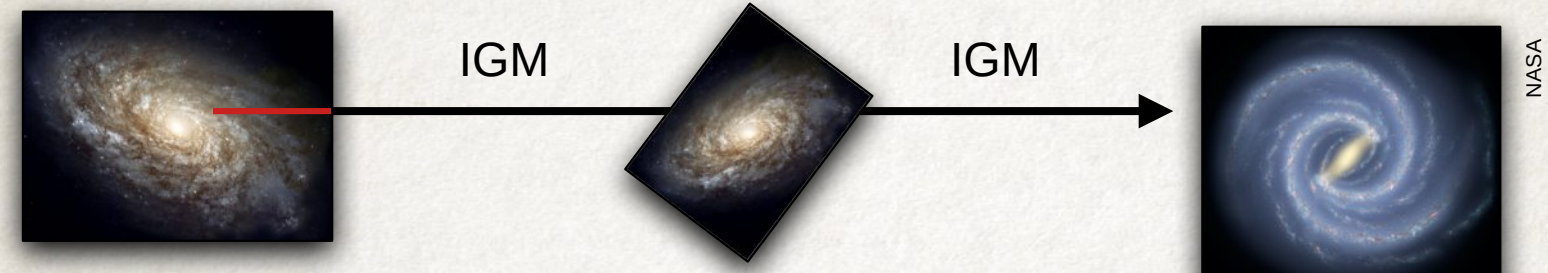
Quasi-periodicity

CHIME/FRB 2021



Oscillatory modes?

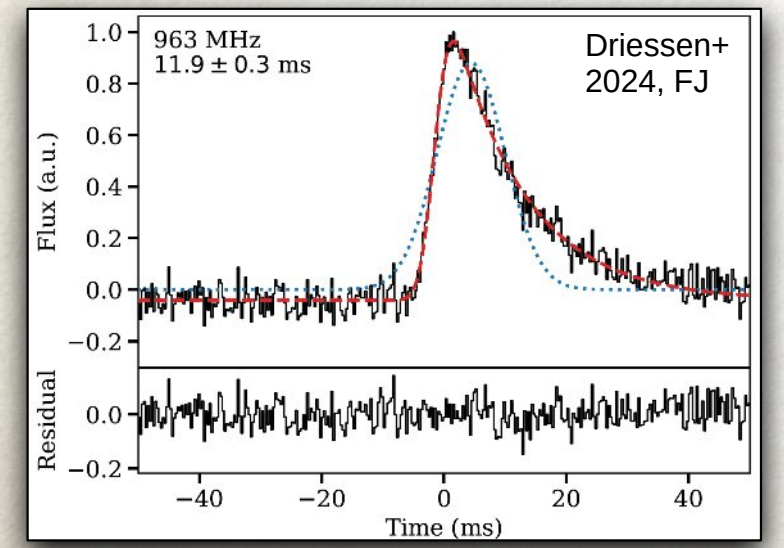
Propagation Effects – Scattering

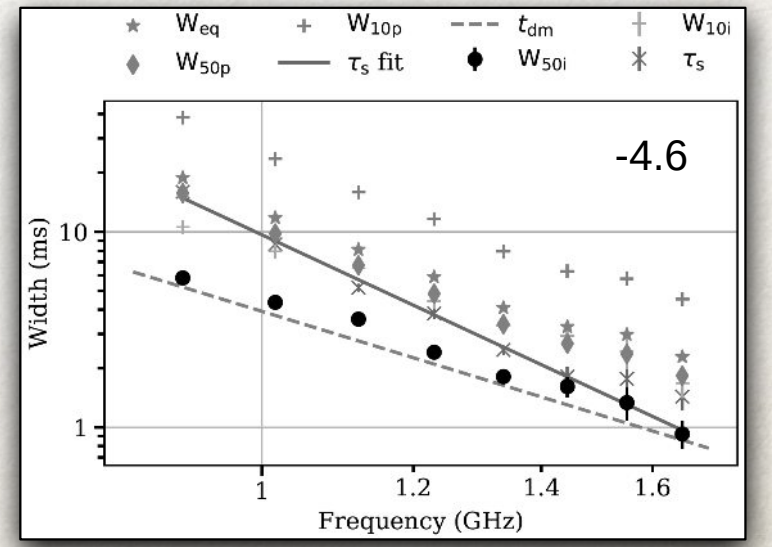


Host galaxy

Intervening galaxy & halo

MW halo & ISM





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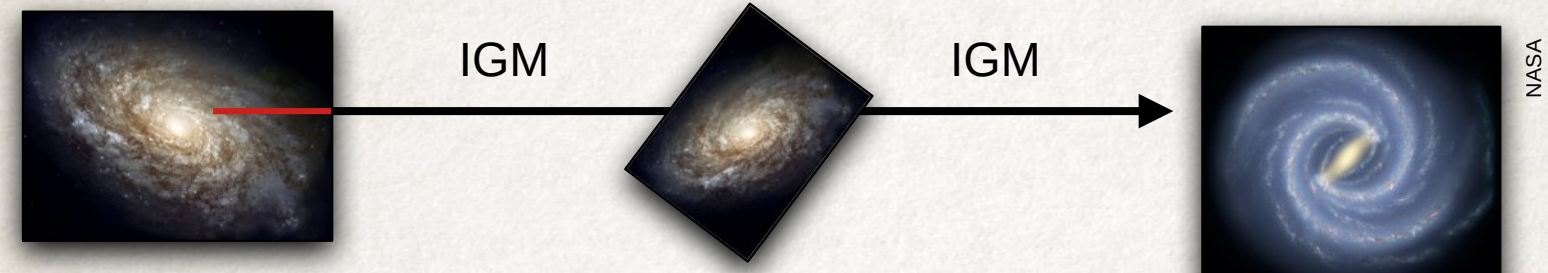

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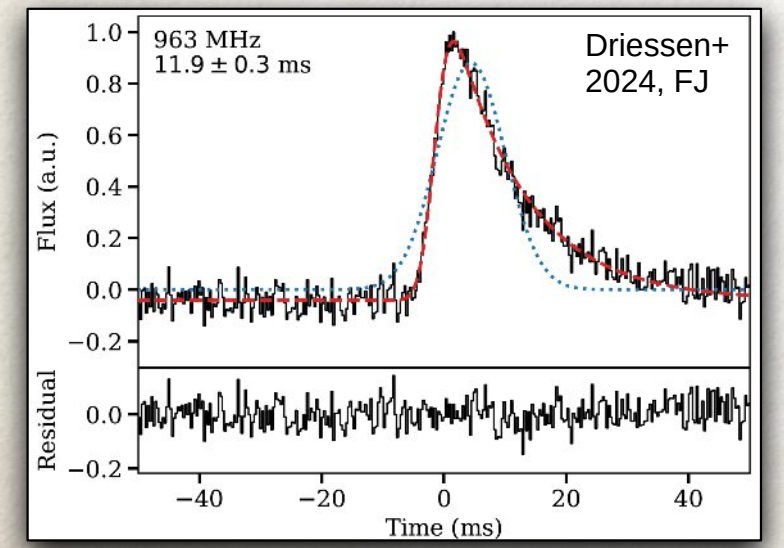
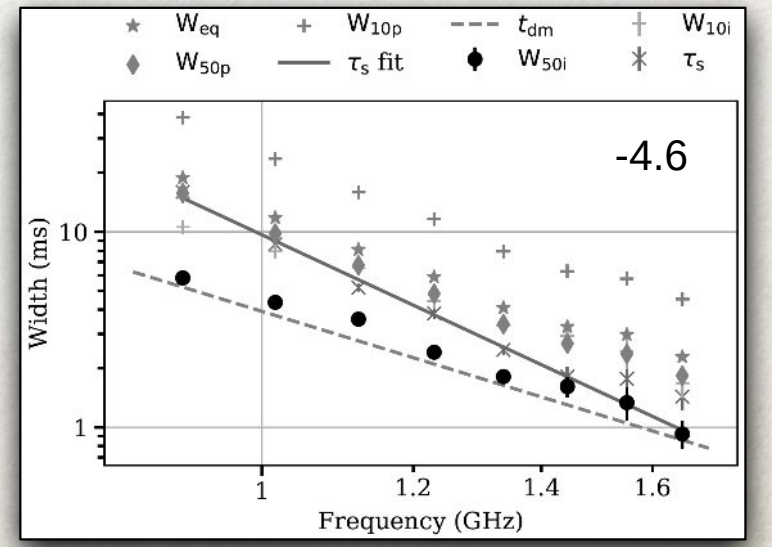
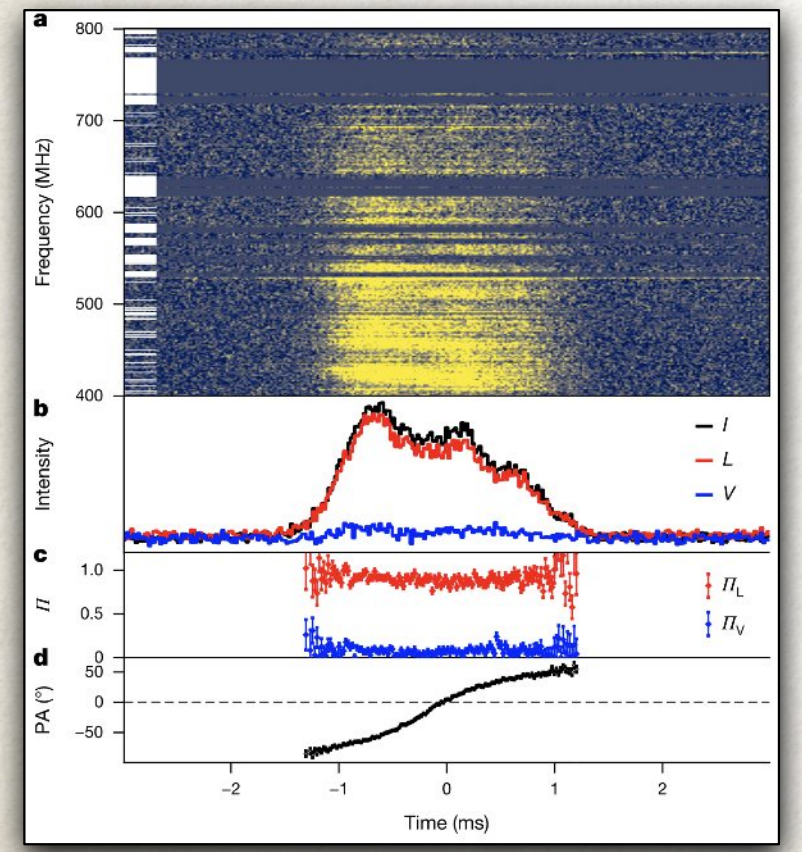


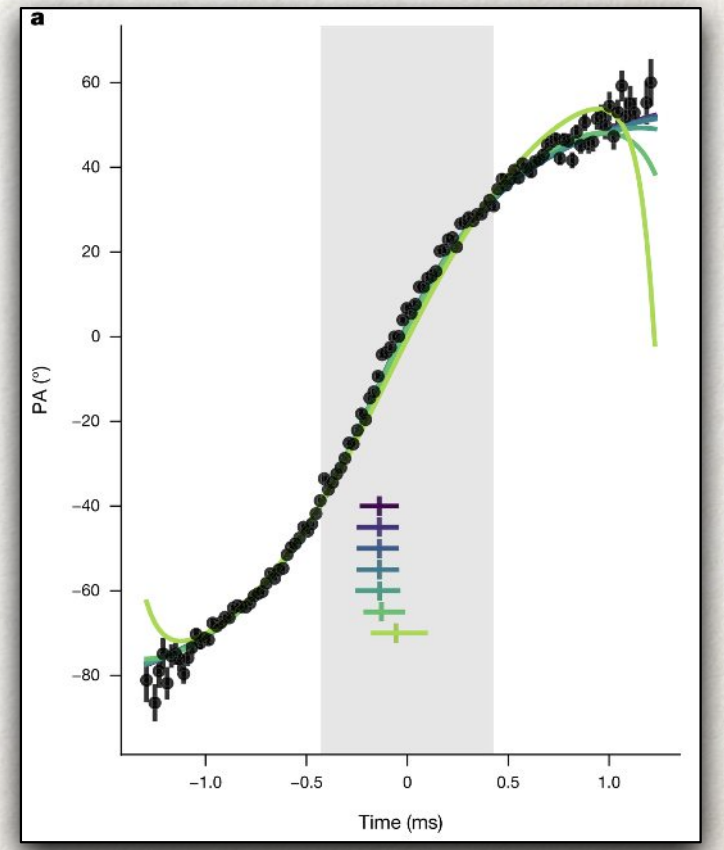


- Most close to Kolmogorov
- Scintillation and Faraday Rotation also seen

3. Recent Results

Evidence of Magnetospheric Origin





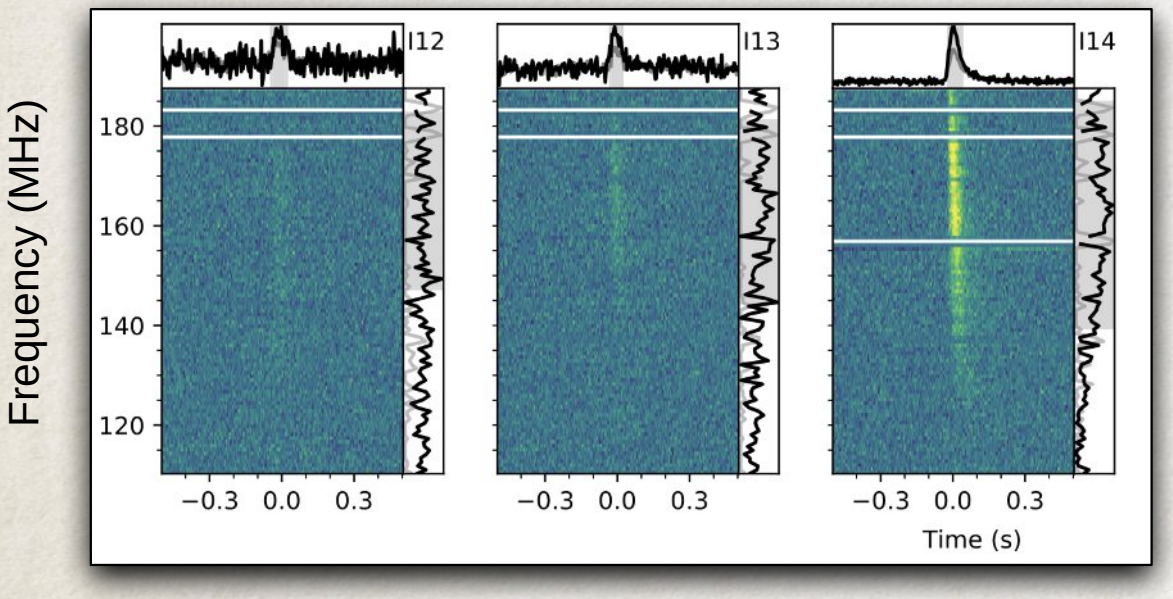
- Hot off the press
- FRB 20221022A repeater
- Pulsar-like PPA sweep
- RVM fit

Mckinven+ 2025, CHIME

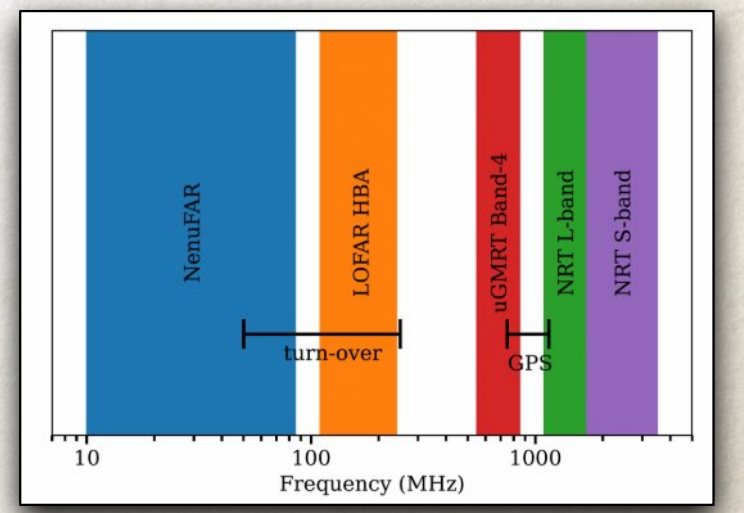
4. Multi-wavelength Constraints

Radio: Pushing Down in Frequency

NenuFAR FRB Search



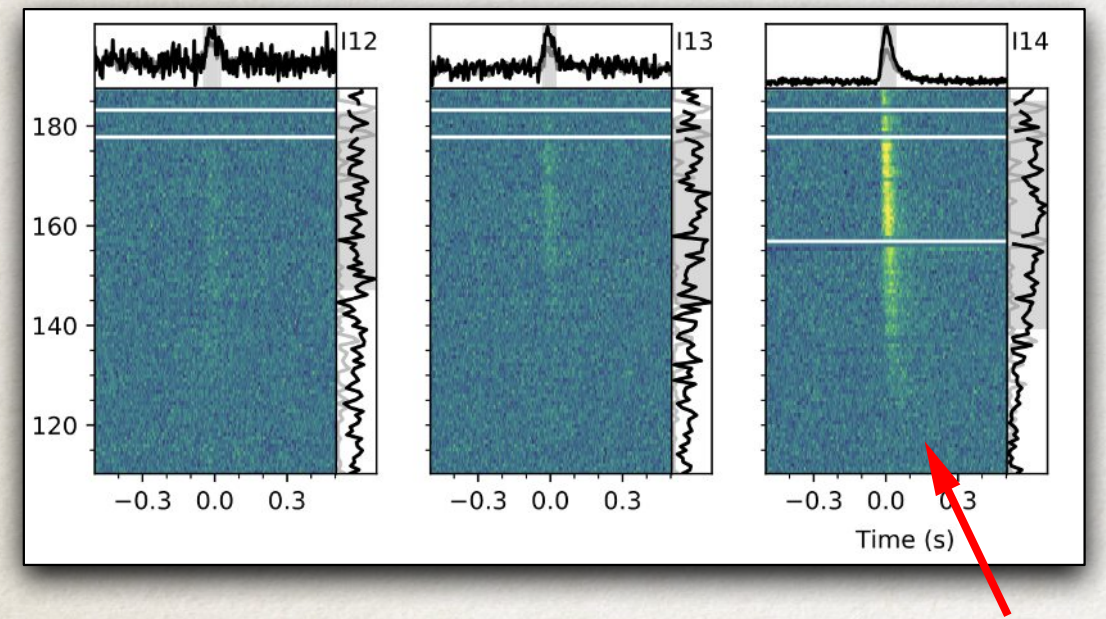
LOFAR HBA, Pleunis+ 2021



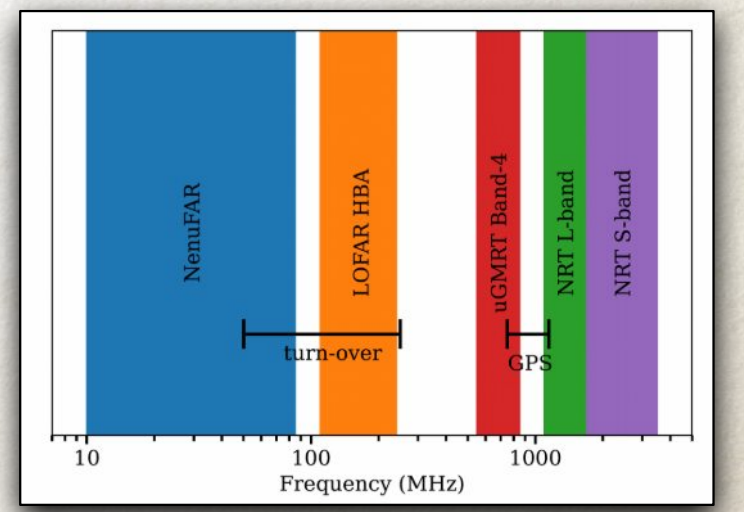
FJ+ 2025

Radio: Pushing Down in Frequency

NenuFAR FRB Search



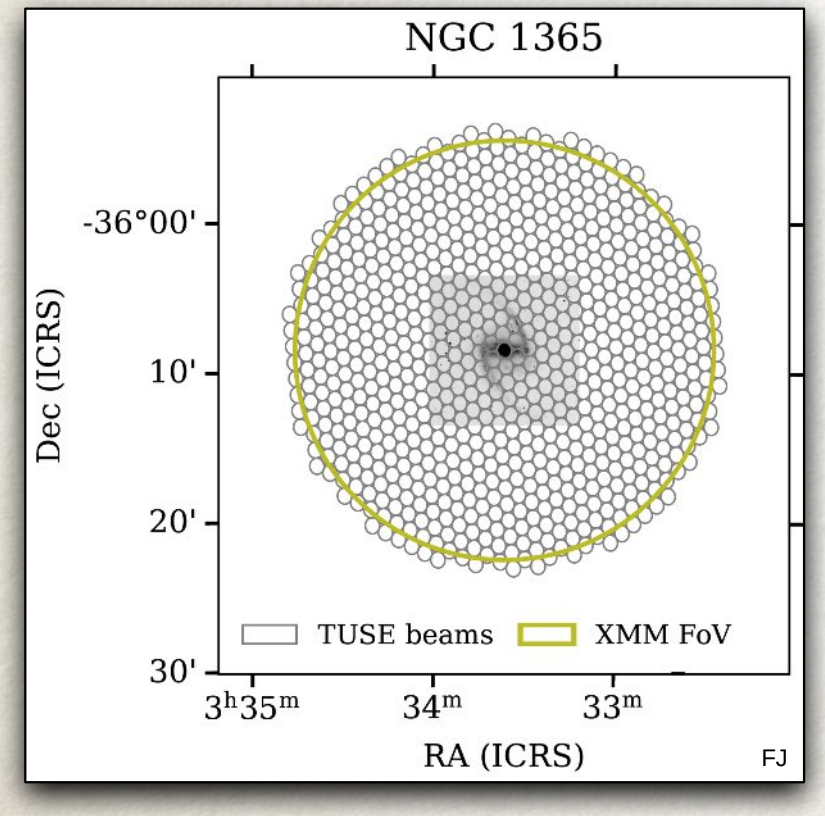
LOFAR HBA, Pleunis+ 2021



FJ+ 2025

X-ray: *XMM-Newton* – MeerKAT FRB Search Project

ESA, XMM-Newton



- Aims
  - Shadow *XMM-Newton* pointings on nearby (redshift < 0.2) galaxies with MeerKAT
  - Detect bright magnetar flares

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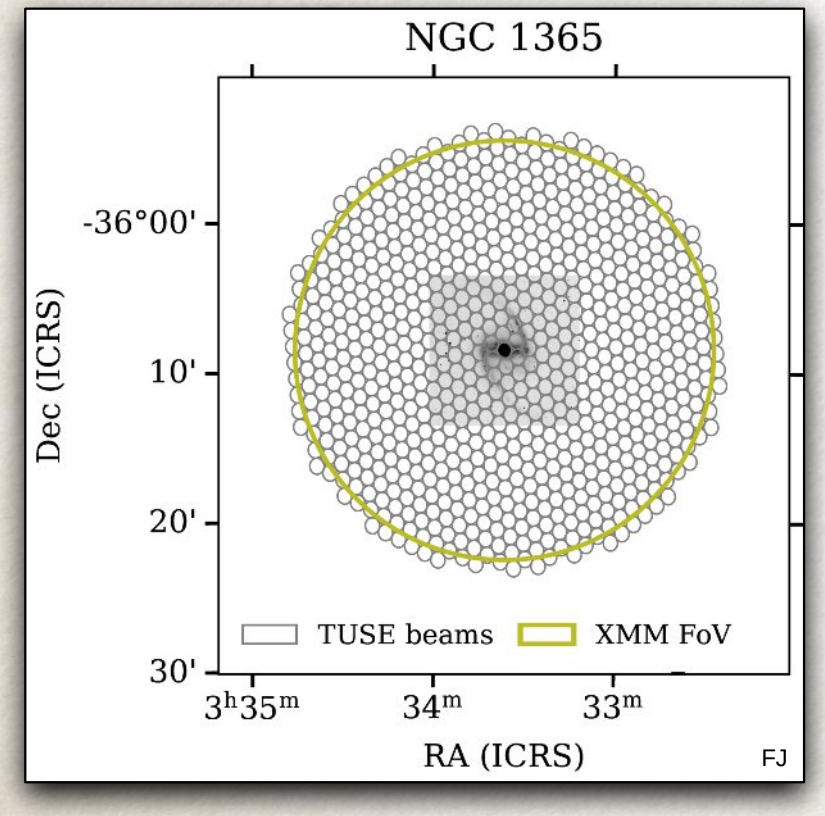
UNIVERSITÄT
WÜRZBURG

X-ray: *XMM-Newton* – MeerKAT FRB Search Project

ESA, XMM-Newton



- Aims
  - Shadow *XMM-Newton* pointings on nearby (redshift < 0.2) galaxies with MeerKAT
  - Detect bright magnetar flares
- Motivated by Galactic “FRB” – X-ray burst connection (SGR 1935+2154)
- Team: PI Eppel, Uni Würzburg, D-MeerKAT, X-ray experts, FJ Technical Lead
- 20 hours of MeerKAT time granted in 2023/24
- No detection so far

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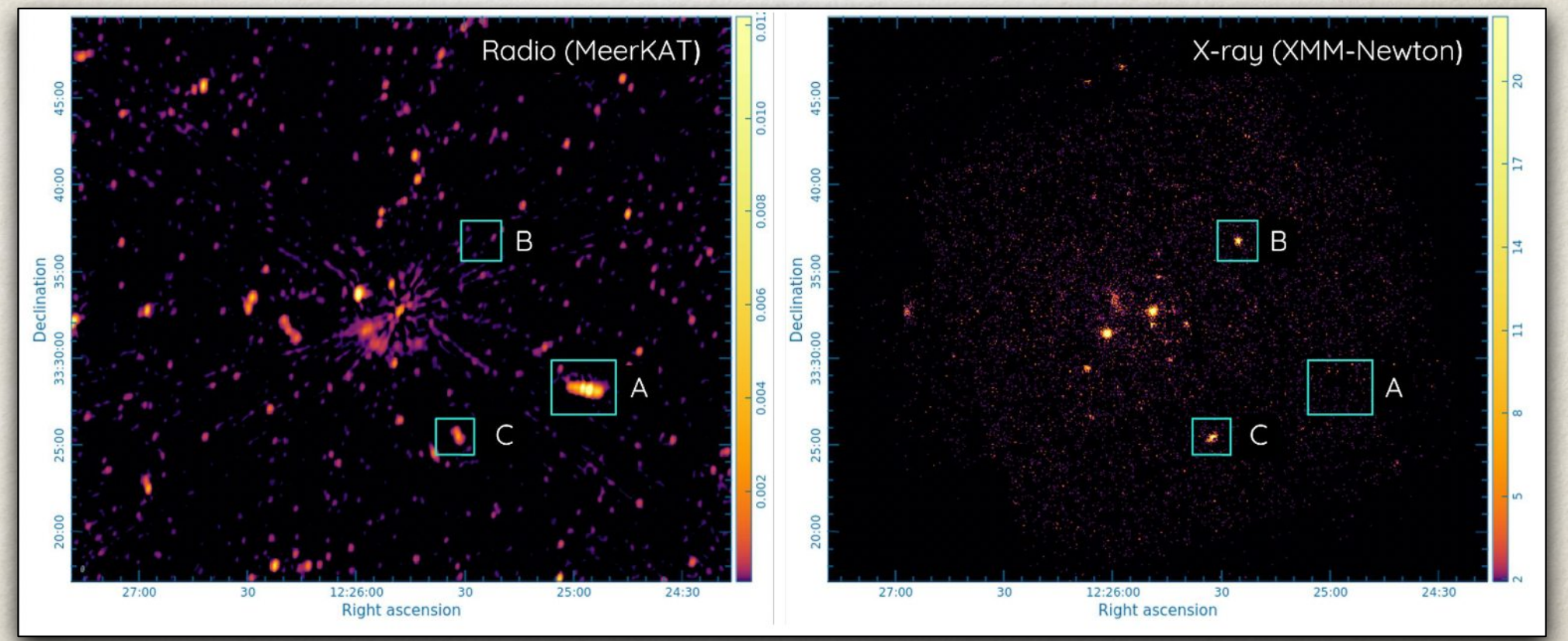
Secondary Radio – X-ray Science

Credit: Florian Eppel



Build up simultaneous X-ray & radio coverage

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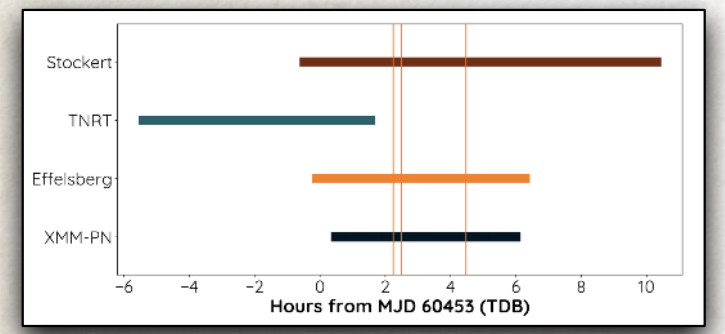
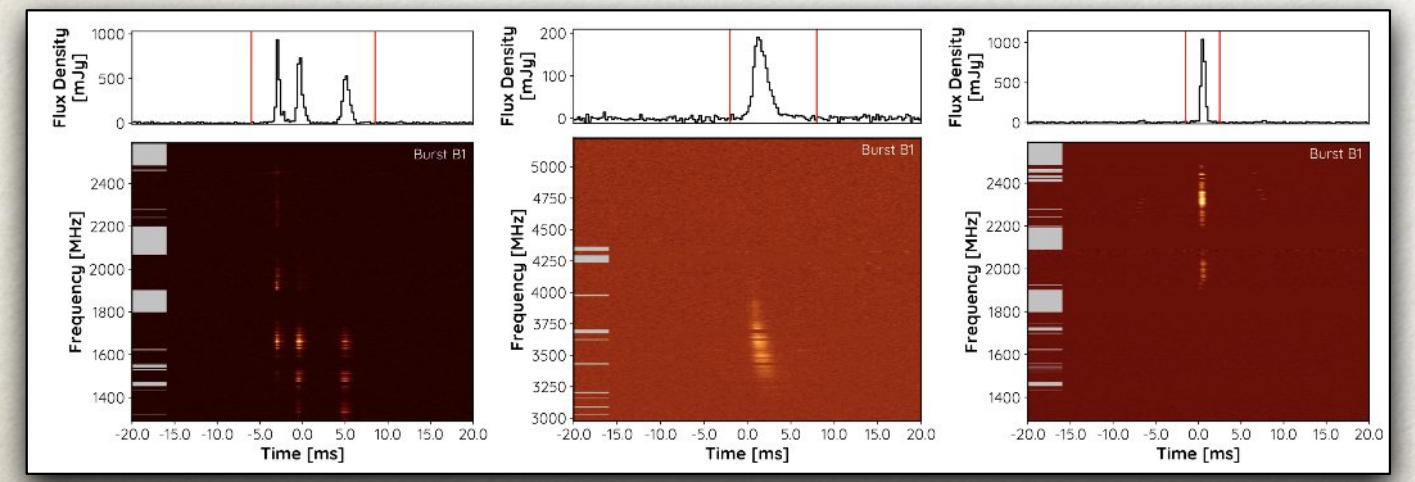
X-ray: *XMM-Newton* – Repeater Campaign

ESA, XMM-Newton



Eppel+ 2025, FJ



- Hyperactive repeater FRB 20240114A
- F_X / F_{radio} ≤ 2.4 x 10^6
  - SGR 1935: F_X / F_{radio} ≈ 2.5 x 10^5
- Consistent with magnetar progenitor

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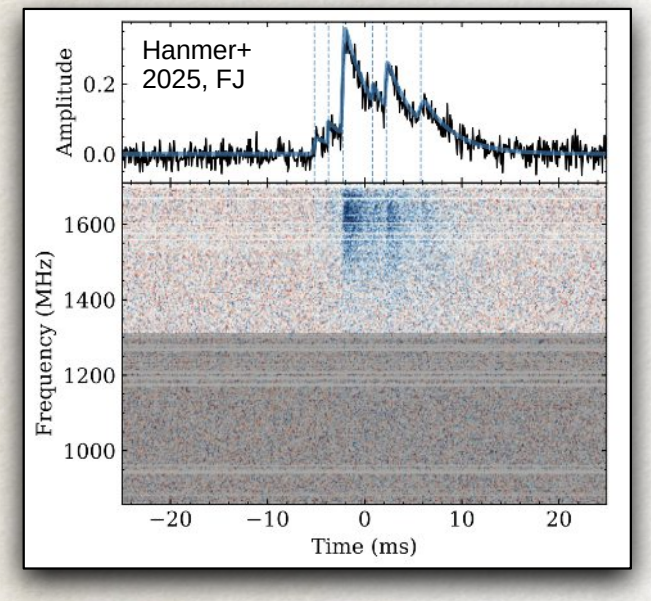
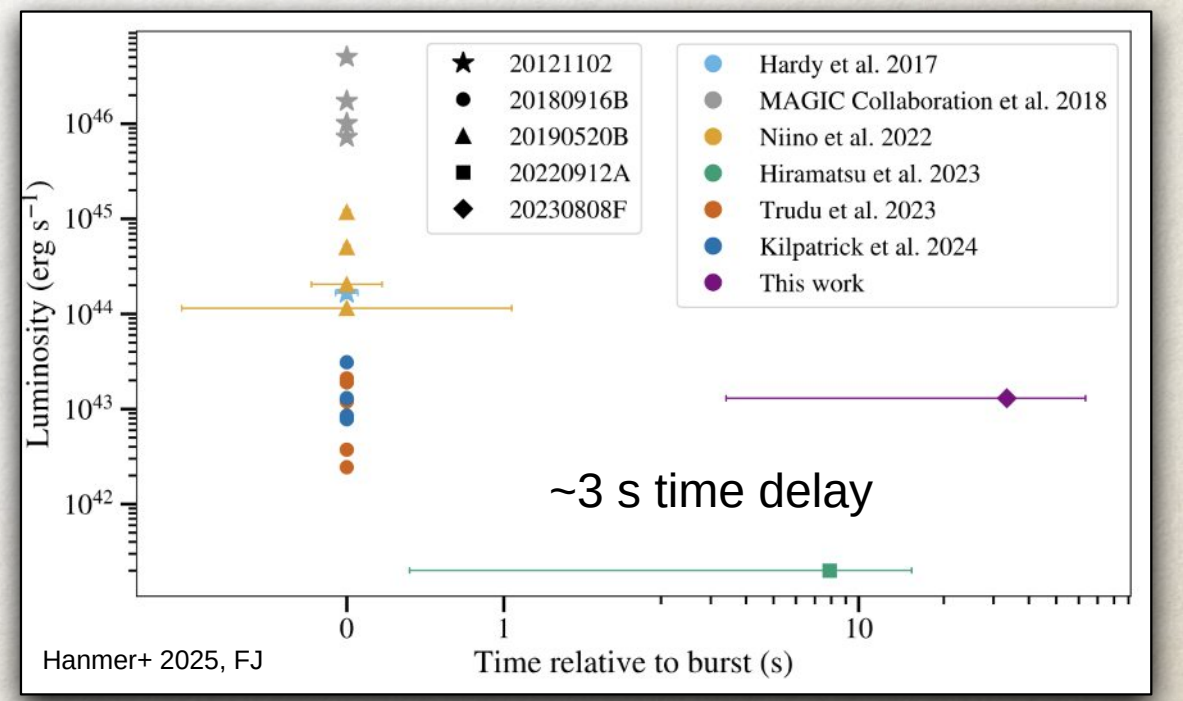
Optical: FRB Optical Constraints



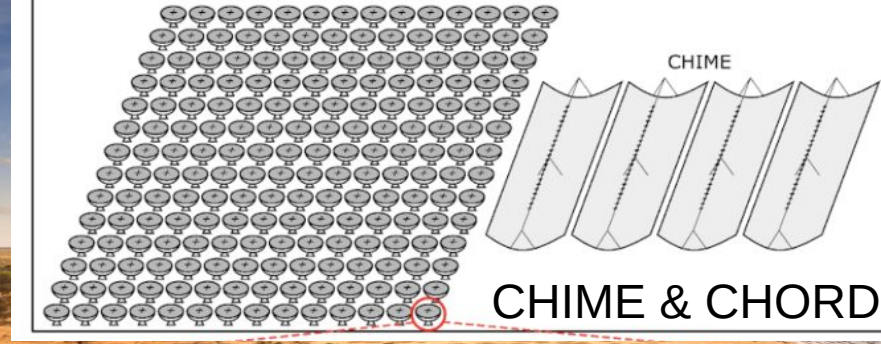
- FRB 20230808F
- MeerKAT & MeerLICHT
- First one-off constraint!
- $F_{opt} / F_{radio} \leq 0.023$



5. Outlook

Future Radio Telescopes

SKA Mid & Low



CHIME & CHORD

DSA-2000

6. Conclusions

Conclusions

Location

Where do they come from?

- Getting there ✓
- Radio interferometers, VLBI, and upcoming facilities
- Limited by optical & X-ray follow-up capabilities

Progenitors

What objects create them?

- Magnetospheric origin preferred model for repeaters ✓
- Unclear if multiple progenitor classes
- Are the one-offs slow repeaters?
- What about GC repeaters?

Physics

How do these objects create them?

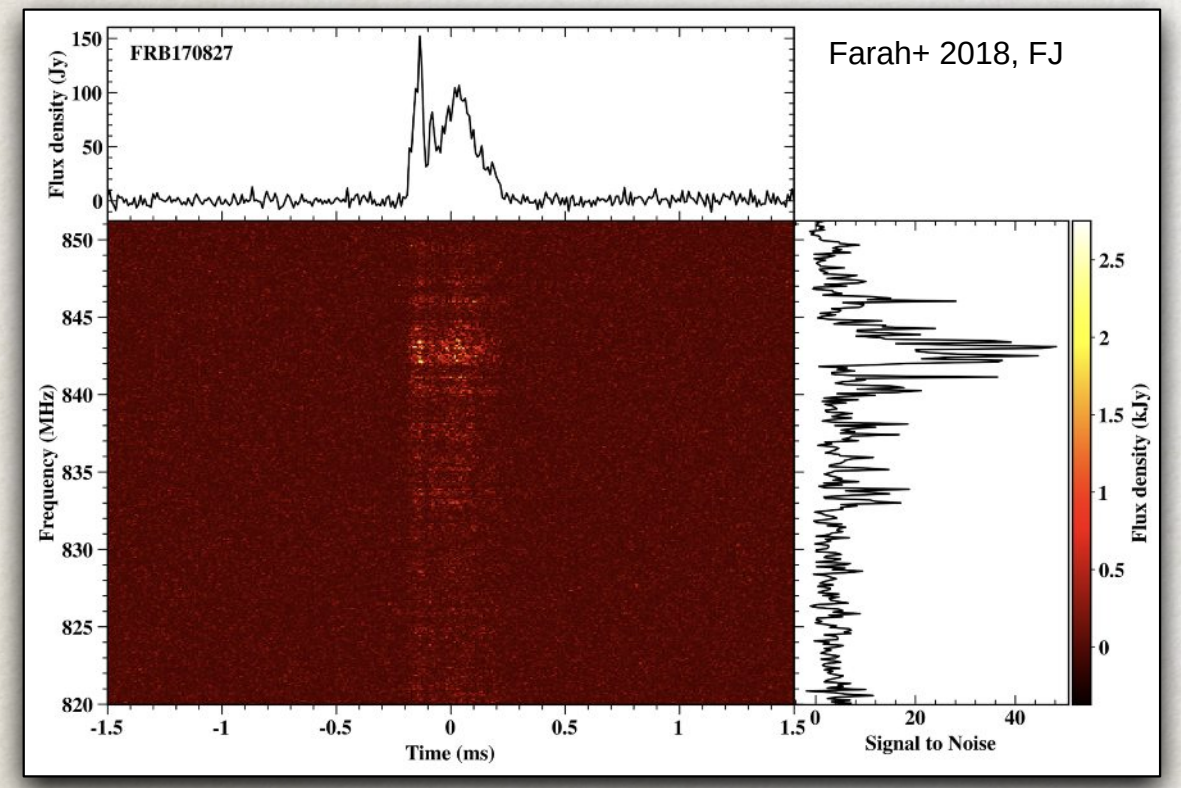
- Multi-wavelength observations crucial
- Some advancements, but still challenging
- See next talk!

Fabian Jankowski

fabian.jankowski@cnrs-orleans.fr

Extra Slides

Burst Microstructure



Farah+ 2018, FJ

Fabian Jankowski

The MeerTRAP Project

- Fully-commensal project
  - Piggybacks almost all projects
  - Huge amount of time on sky and sky coverage (~20,000 h over 5 yr)
- Real-time transient detection
- Excellent sensitivity (T_{sys} ~ 23 K, A_e/T_{sys} ~ 6.5 m^2/K at L-band)

FJ

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- Two surveys at the same time
  - Incoherent beam, ~1 deg^2 FoV, Parkes sensitivity
  - ~800 coherent beams, ~0.2 deg^2 FoV, GBT sensitivity
- Operating since late 2020

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