Sample Properties and Implications from the MeerTRAP FRBs Discovered with MeerKAT

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The MeerTRAP project is an effort to search for and precisely localise radio transients, such as Fast Radio Bursts (FRBs), Galactic radio pulsars, and other radio-emitting neutron stars. Our team developed, commissioned, and operates two user-supplied instruments at the MeerKAT telescope site. These are the FBFUSE beam-former and the TUSE real-time transient and pulsar search system. The instruments survey the sky fully commensally with the primary telescope users, i.e. mainly the MeerKAT Large Survey Projects, Open Time, or DDT time allocations. Since late 2019, our team spent tens of thousands of commensal observing hours piggybacking observations at L-, UHF- and S-band frequencies. Science highlights are the discoveries and characterisation of several dozen FRBs, their precision localisation to their host galaxies, the discovery of long-period neutron stars (e.g. 76-s pulsar), and almost 100 other radio pulsars through their single pulses.

The MeerTRAP Project

- MeerTRAP is a fully commensal real-time search project at the MeerKAT telescope that piggybacks most observations.
- It consists of two user-supplied supercomputers at the telescope site, the FBFUSE beamformer and the TUSE real-time search cluster.
- Our primary aims are to search for, characterise, and precision localise FRBs to understand what creates FRBs and to determine what host galaxies they originate from.
- It is a large international project with several partner institutes (Bonn, Oxford, SARAO).
- Over the last five years, we designed, implemented, and commissioned observing and search software for the instrument, which we installed at the telescope site.
- We typically form about 768 tied-array beams on the sky that we search independently for transients.

Fig. 1: The author in front of some of the MeerKAT core antennas during our TUSE server installation trip.

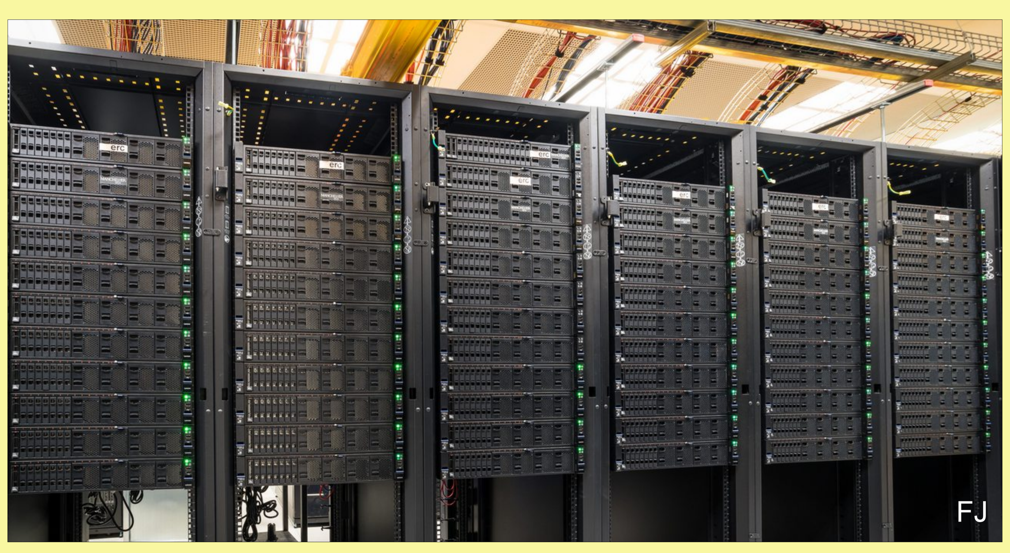

Fig. 2: The MeerTRAP TUSE high-performance compute cluster at the MeerKAT telescope site.

FRB – Host Galaxy Association

- An FRB discovered in a single coherent beam is typically localised to about 1 arcmin. Multi-beam detection information can be used to reduce this. If voltage buffer dump data are available, the imaging localisation precision is below 1 arcsec at L-band.
- We used the *PATH* software to probabilistically assign the FRBs to their optical host galaxies based on the hosts' extent, brightness, and separation.

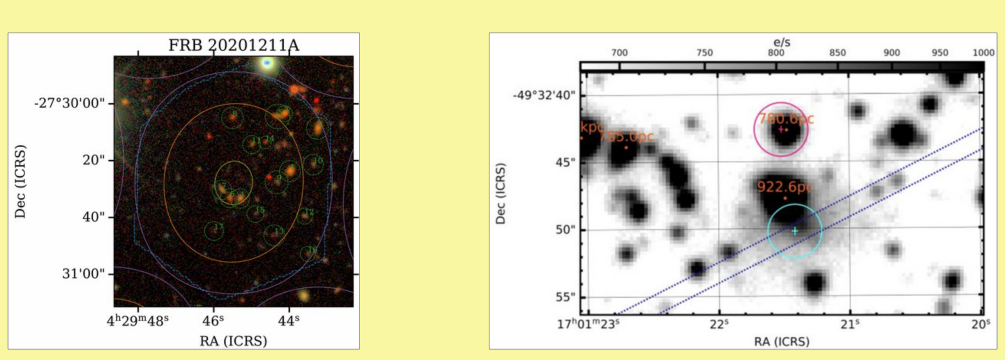

Fig. 3: Examples of arcmin (left) and arcsec localised FRBs (right) compared with optically imaged galaxies in the field (Jankowski et al. 2023, Driessen et al. 2024).

Fast Radio Burst Types

- We analysed the total intensity burst morphologies of all the 11 L-band FRBs discovered until the end of 2021 (Jankowski et al. 2023, Caleb et al. 2023, Driessen et al. 2024, Rajwade et al. 2022, in prep).
- Four FRBs appear unresolved or are limited by instrumental intra-channel dispersion smearing in our data. Four show significant single-sided exponential scattering tails. Three appear to have more complex profiles with multiple components or bifurcations.

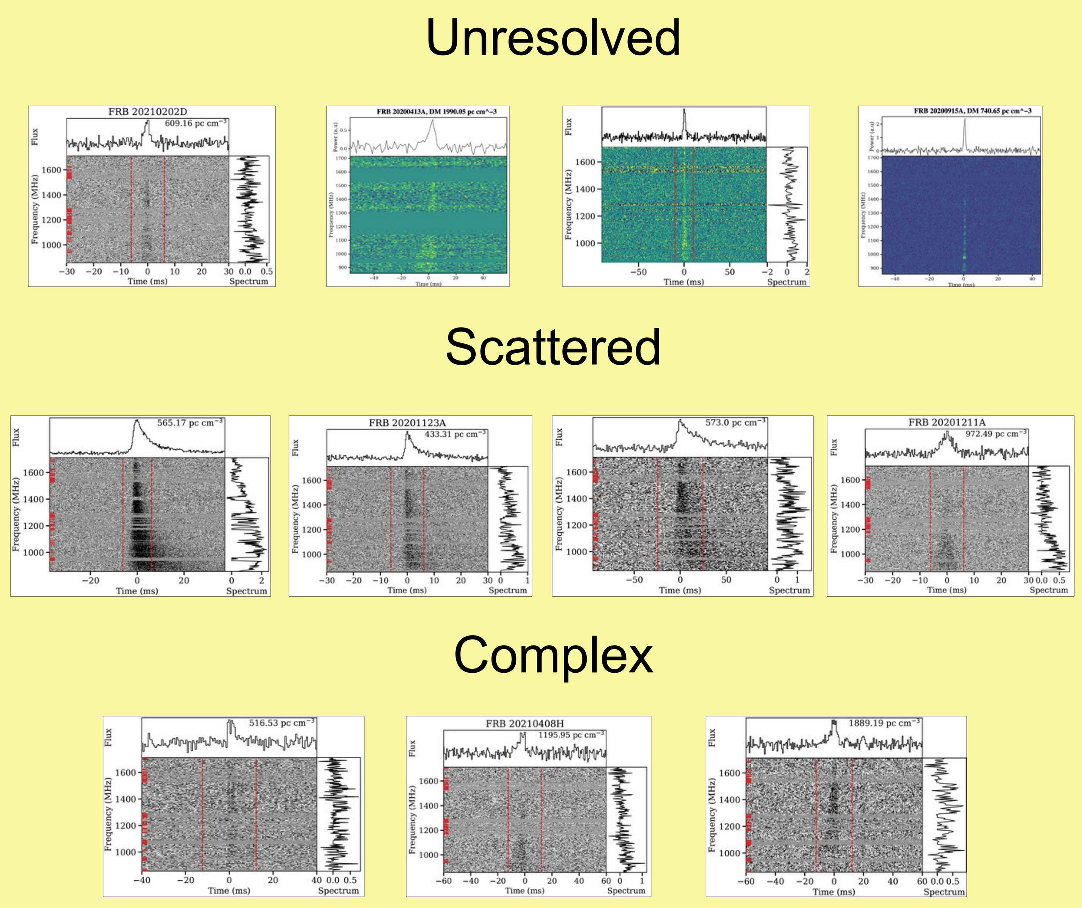

Fig. 4: Total intensity burst morphologies of the MeerTRAP FRBs discovered at L-band until the end of 2021. We show the three main burst types.

Scatter Broadening

- The low S/N of some MeerTRAP FRBs and instrumental intra-channel dispersion smearing make it challenging to measure their scattering properties. In particular, fitting tools from the pulsar domain built for the high-S/N regime are not well suited for those data.
- We implemented a new modelling and fitting software called *scatfit* that is tuned for MeerTRAP data (Jankowski 2022, Jankowski et al. 2023).
- For those FRBs that show scattering, it is significantly above that expected from the Milky Way. The scattering indices are largely consistent with Kolmogorov turbulence (-4.4).

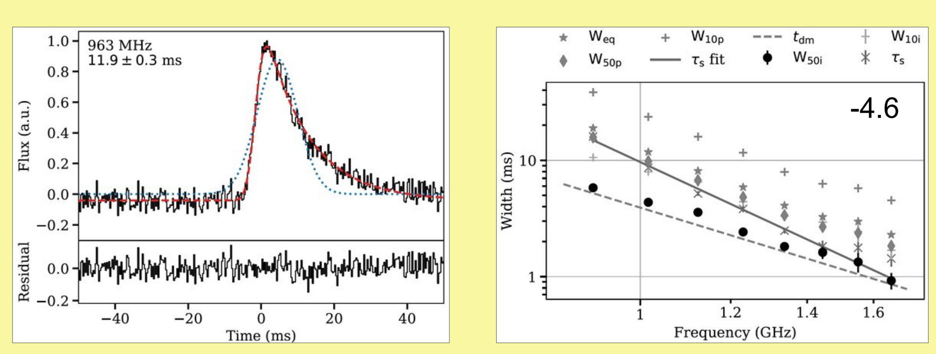

Fig. 5: Our best scattering fit in one band (left) and scattering index plot (right; Driessen et al. 2024).

Postcursor Bursts

- Our search pipeline saves a filterbank file snippet of several seconds per candidate. While searching the snippets around our FRBs, we serendipitously discovered postcursor bursts in two FRBs at a similar separation (200 ms) from the primaries.
- They might be genuine low-S/N repeat bursts or due to plasma or gravitational microlensing.

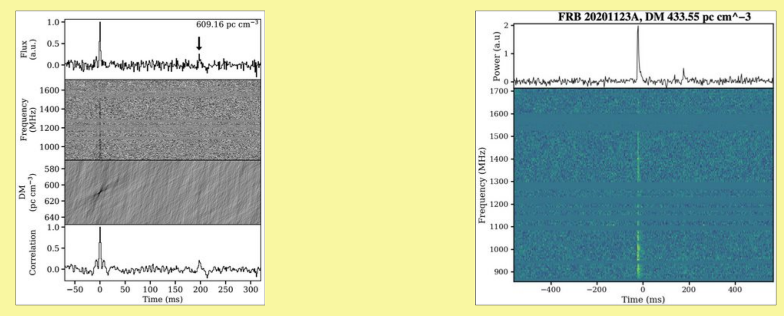

Fig. 6: Postcursor bursts discovered in two unrelated FRBs (Jankowski et al. 2023, Rajwade et al. 2022).

MeerTRAP Survey Properties

- MeerTRAP is unique because we simultaneously perform two largely independent transient surveys (coherent and incoherent beams).
- We estimated the sky exposures based on our pointing database and our numerical beam models, and the fluence completeness limits. We then inferred the FRB all-sky rates above the completeness limits for each survey.

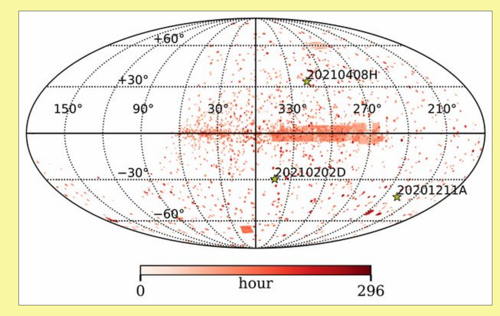

Fig. 7: Skymap in Galactic coordinates of the exposure time of the MeerTRAP incoherent beam survey until the end of 2021 (Jankowski et al. 2023).

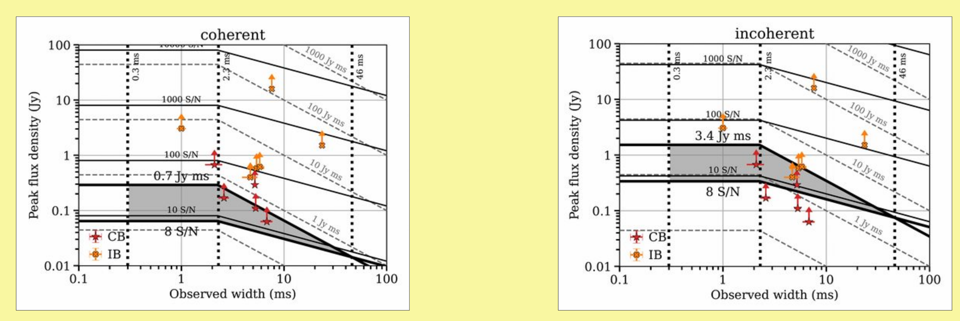

Fig. 8: Triangle completeness plots for the coherent (left) and incoherent (right) MeerTRAP surveys. The samples of FRBs discovered are marked (Jankowski et al. 2023).

FRB Population Properties

- We compared our inferred FRB all-sky rates with the literature and noticed a slightly flatter power law scaling between our measurements. The MeerTRAP data match an Euclidean scaling (-1.5) but are closer to a constant scaling (-1.0).
- This could indicate that we already probe more distant Universe FRBs, where cosmological effects or population evolution become more apparent.

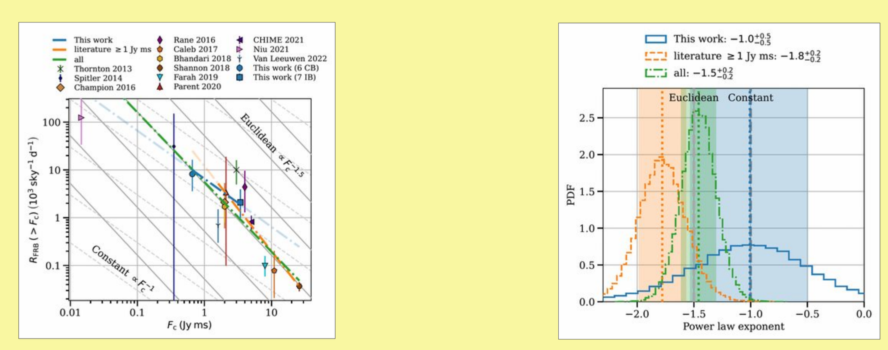

Fig. 9: All-sky rate versus fluence completeness limits compared with the literature (left) and posterior samples from our power law fit (right; Jankowski et al. 2023).

Conclusions:

- We discovered several dozen FRBs, 11 of which are described here.
- The FRBs are well localised. Four show significant scattering, which is consistent with Kolmogorov turbulence. Four have more complex profiles.
- We found postcursor bursts in two unrelated FRBs with similar separations, which might be genuine repeat bursts or due to lensing effects.
- We carefully estimated the survey coverages, fluence limits, and inferred FRB all-sky rates.
- The rate scaling with fluence limit is slightly flatter than in the literature. This could point to cosmological effects of progenitor evolution.

References:

Jankowski et al. MNRAS **524**, 4275 (2023)
Jankowski ASCL, 2208.003 (2022)
GitHub: https://github.com/fjankowsk/scatfit
Caleb et al. MNRAS **524**, 2064 (2023)
Driessen et al. MNRAS **527**, 3659 (2024)
Rajwade et al. MNRAS **514**, 1961 (2022)