# Searches for Fast Radio Bursts with the MeerKAT telescopes.

## What are Fast Radio Bursts?

Fast Radio Bursts (FRBs) are enigmatic bursts of radio emission of roughly millisecond duration. FRBs, their origins and how those extragalactic phenomena can be used to study the Universe are currently one of the hottest topics in astronomy. FRBs originate from cosmological distances of up to $O(10^9)$ light years and since their discovery in 2007, only about 130 bursts have been published. Most FRBs are seamingly one-off events, but about 20 sources have been seen to repeat with different levels of activity.


**ABOUT ME**

**DR FABIAN JANKOWSKI.** I am a postdoctoral researcher at the Jodrell Bank Centre for Astrophysics at The University of Manchester. I work for the MeerTRAP project in which we search for FRBs and radio pulsars with the MeerKAT telescope array in a South African desert.

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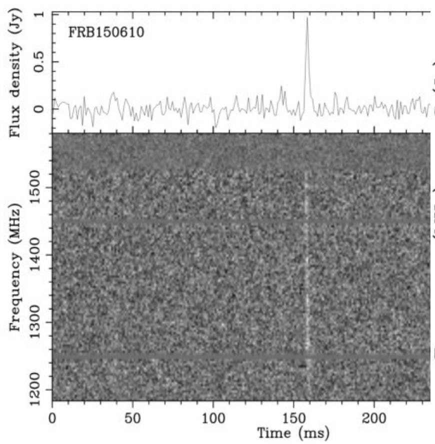
## FRBs are energetic and numerous.

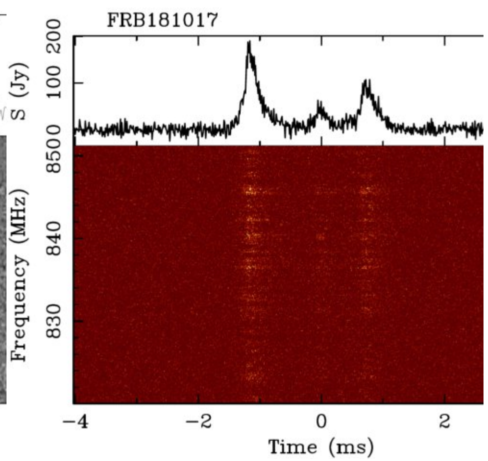
ISOTROPIC ENERGY RELEASE. Their measured flux densities together with their large inferred distances means that FRBs are created in extremely energetic processes. In fact, their isotropic energies are $O(10^{33})$ Joule.

ALL-SKY RATE. Based on the detections in previous FRB surveys, the inferred all-sky rate of FRBs is high, i.e. $O(1000)$ FRBs per full sky per day, above a certain burst energy threshold and at a frequency of 1.4 GHz. This makes FRBs apparently fairly common events.

## How do they look like?




(Bhandari et al. 2018, MNRAS)




(Farah et al. 2019, MNRAS)

Higher time resolution!

## FRBs come from cosmological distances.

*DISPERSION MEASURE. The electro-magnetic waves of the FRBs suffer dispersion due to the free electrons (and ionised atoms) in the interstellar, intergalactic and host media. That is, the longer radio waves arrive later at Earth than their shorter counterparts. We measure those frequency-dependent time delays and can therefore infer the total number of free electrons that an FRB has passed through. The total number of electrons, the so-called dispersion measure, is a proxy for the distance.*

*HOST GALAXY REDSHIFTS. A small number of FRBs have been localised to their host galaxies in which they were produced. Optical observations of atomic emission lines and in particular their shift in frequency with respect to their rest-frame emission frequency allow us to estimate the distance of the host galaxies.*

## How are FRBs created?

ORIGIN UNKNOWN. One of the most intriguing questions is the origin of the FRBs, i.e. how they are created. A multitude of theories have been put forward, from exploding, collapsing, colliding, merging, or otherwise interacting objects to more exotic ones. However, no general theory has been observationally identified yet!

CATACLYSMIC VS REPEATING ORIGIN. The discoveries of repeating FRBs meant that at least some FRBs are produced by non-cataclysmic events, in which the progenitors survive the FRB emission. It is unclear if all FRBs repeat, or if there are multiple sub-populations.

# Why are Fast Radio Bursts so interesting?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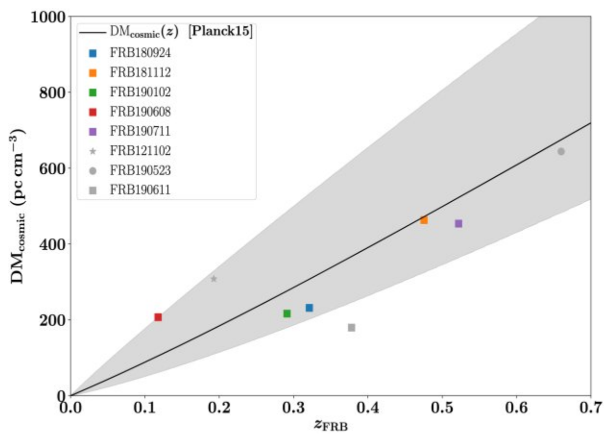
## FRBs from magnetars.

Magnetars are intensely magnetised neutron stars, city-sized objects with masses close to 1.4 times the mass of our Sun. Their emission is believed to be powered by their strong magnetic fields, rather than their rotation.

FRB – MAGNETAR CONNECTION. In April 2020 an FRB-like radio burst was detected coincident with a strong X-ray/gamma-ray burst/flare from a magnetar in our Galaxy. That is extremely exciting, as it suggests that at least some FRBs could be produced by magnetars at extragalactic distances. If that holds true for other, or even all FRBs is completely unclear.

## FRBs as cosmological probes.

The large distances the FRBs travel make them ideal probes to study the Universe and in particular its cosmology. As recently demonstrated, a sample of well-localised FRBs, together with their host galaxy redshifts, allows us to infer cosmological parameters that are compatible with those measured using more classical methods. FRB cosmology complements classical cosmological tools as an independent technique.




(Macquart et al. 2020, Nature)

## Some open questions.

1. What is the origin of FRBs?
2. Do all FRBs repeat?
3. Do magnetars create all FRBs?
4. What physical mechanism causes FRB emission?
5. What causes the differences in emission/detection activity observed in repeating FRBs?
6. Why do some repeating FRB apparently show periodic activity cycles?

## The MeerKAT telescope array.

We use the MeerKAT telescope, the largest and most sensitive telescope in the Southern hemisphere. It is an array of 64 individual 13.96 m diameter dishes in the Karoo desert in South Africa and was inaugurated in 2018. The voltage signals from the antennas are combined coherently to form a telescope equivalent in size to a 112 m dish.

# How do we search for FRBs?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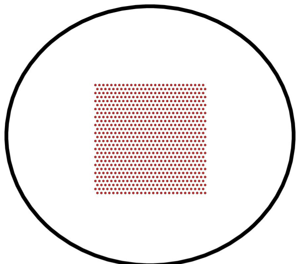
## Forming beams on the sky.

We utilise a supercomputer to form ~800 narrow beams on the sky in real-time, that are located inside the field-of-view of the telescope. These so-called tied-array beams have full telescope sensitivity and provide initial localisation of an FRB from multi-beam information, via a technique roughly similar to triangulation.



tied-array beams

## Our real-time single-pulse detection pipeline.

Another supercomputer runs our single-pulse search software in real-time. The software performs the computationally intensive task to search the data streams from all ~800 tied-array beams for narrow radio bursts. It efficiently does a brute-force search in start time, dispersion measure (how much a burst is delayed across the frequency band) and pulse width, while estimating the signal-to-noise ratio of each burst. Multiple detections are combined into event clusters and thresholds are applied to guarantee genuine detections.

# Current status of our FRB search project.

## Current status.

In July 2018 we installed the MeerTRAP supercomputer in the Karroo desert in South Africa. Since then, we have successfully developed the software for and have commissioned the MeerTRAP search instrument. Refinement of the search pipeline is ongoing, as well as the development of a real-time candidate classifier. Since September 2019, our instrument regularly participates in science observations. However, the number of observing hours have only recently increased drastically.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## Galactic sources.

Similar to the extragalactic FRB, we have discovered bursts from a number of previously unknown Galactic neutron stars. Follow-up of these sources is ongoing to characterise their nature and to establish their properties. Our discoveries contribute already significantly to the field, because most of our new Galactic sources have well-constrained positions, essential for follow-up.

## Our first FRB discovery!

A HIGH DISPERSION MEASURE FRB. We got extremely excited when we discovered our first FRB as part of the project earlier this year. It has a dispersion measure of about 1990 units, which places it at an inferred comoving distance of ~19 x $10^9$ light years or a redshift of 2.3. It is currently the second most distant FRB and is among the most energetic ones.

Details of the discoveries and the survey so far will appear in the published scientific literature soon.

## Future work.

MACHINE-LEARNING CLASSFIER. We are in the process of commissioning a machine-learning software to classify FRB candidates in real-time. It will run on the instrument's supercomputer and will allow us to retain higher time-resolution (few microseconds) voltage data of FRBs. This is crucial to understand the temporal morphology of the bursts, which helps to identify possible emission mechanisms.

HIGH-PRECISION LOCALISATION. The high-resolution data will allow us to make radio images of the areas around FRBs and will enable us to localise the burst to arcsecond precision, which is essential in the hunt for FRB host galaxies and redshifts.