FRBs and pulsars with MeerKAT and the Nançay Radio Observatory telescopes

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Part 1: Discovery of an FRB sample with MeerKAT

On behalf of the MeerTRAP team

F. Jankowski,[1,2]* M. C. Bezuidenhout,[1,3] M. Caleb,[1,4,5] L. N. Driessen,[1,6] M. Malenta,[1] V. Morello,[1] K. M. Rajwade,[1,7] S. Sanidas,[1] B. W. Stappers,[1] M. P. Surnis,[1,8] E. D. Barr,[9] W. Chen,[9] M. Kramer,[9,1] J. Wu,[9] S. Buchner,[10] M. Serylak,[11] and J. Xavier Prochaska[12,13]

arXiv ID: 2302.10107

European Research Council

Established by the European Commission

MEERTRAP

MANCHESTER 1824

The University of Manchester

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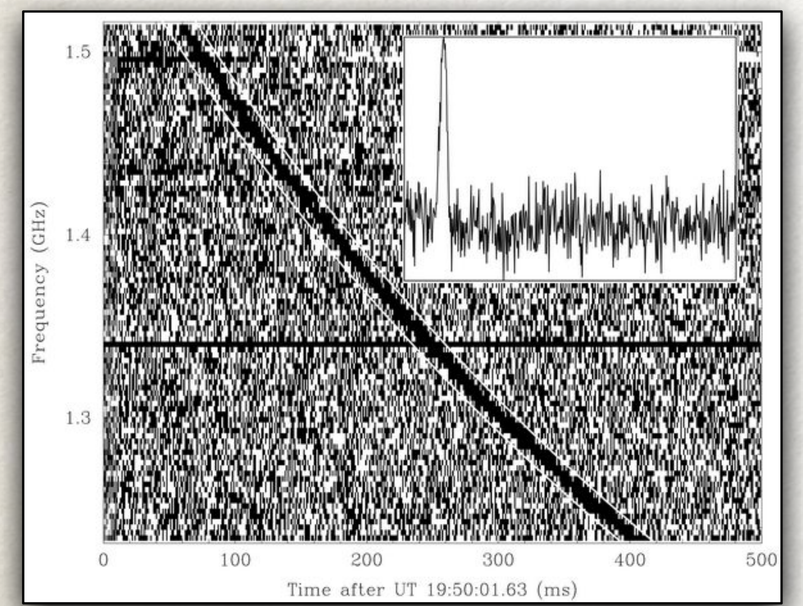
arXiv ID: 2302.10107

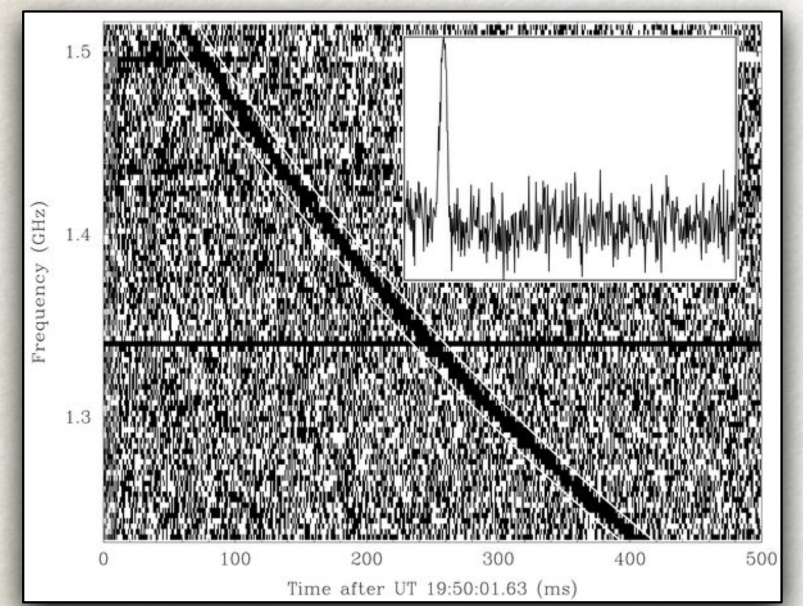
FRB open questions



Lorimer+ 2007

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

FRB open questions



Lorimer+ 2007

Shaw Prize 2023!
Bailes, Lorimer, McLaughlin

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The MeerTRAP transient surveys

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

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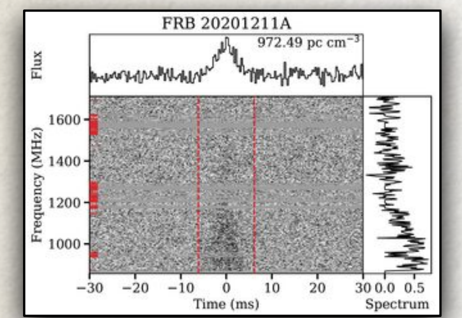
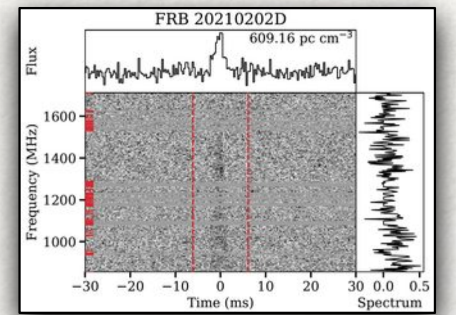
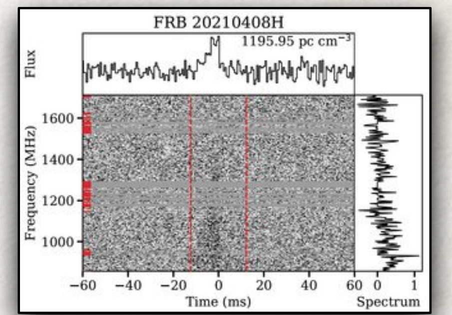
- Two surveys at the same time
  - incoherent, wide FoV (~1 deg^2), less sensitive
  - coherent, smaller FoV (~0.2 deg^2), ~5x more sensitive
- Operating since late 2019, in earnest since late 2020

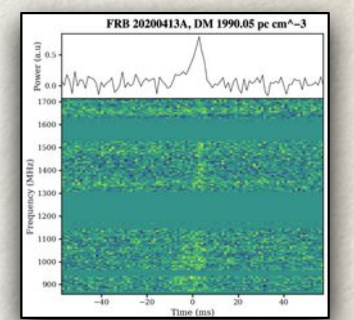
FJ

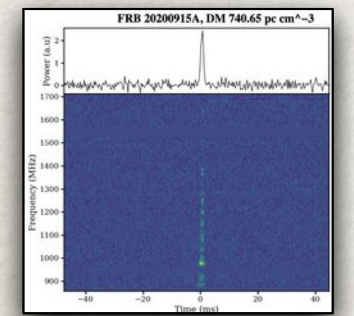
The FRB sample discovered

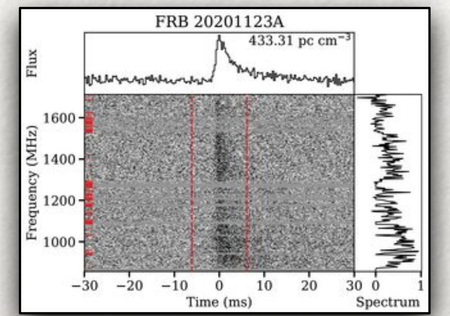


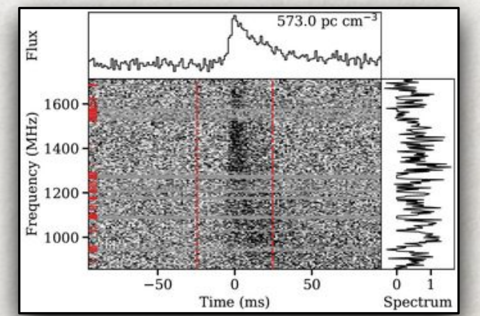


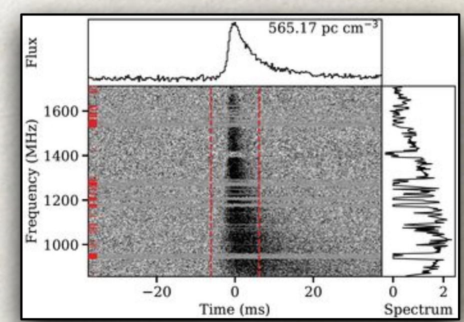


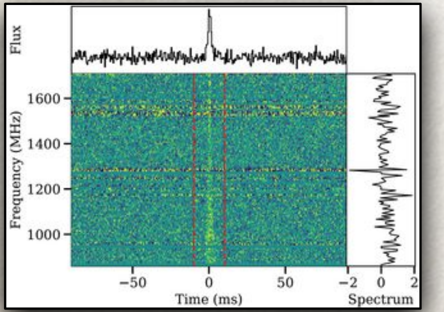


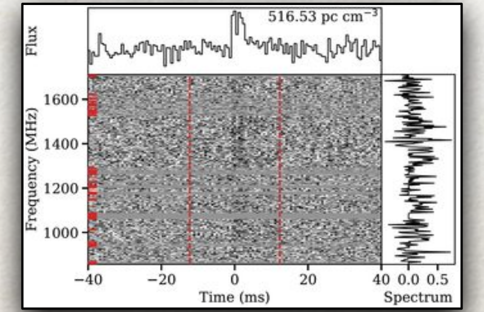


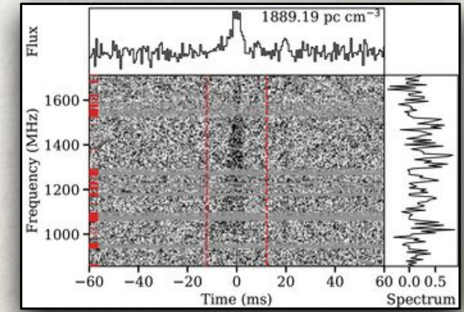










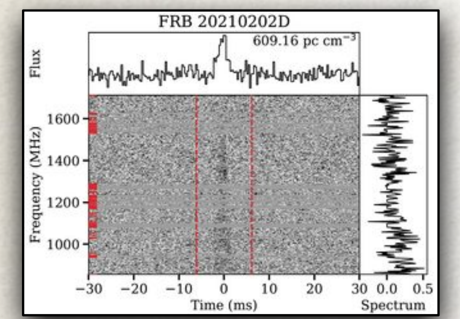


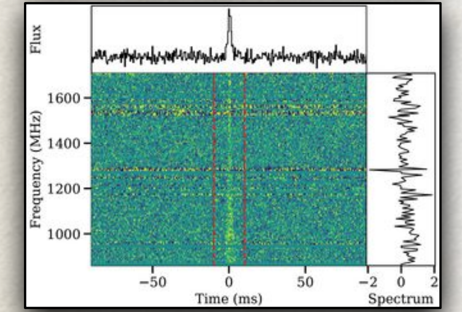
FJ+ 2023; Rajwade+ 2022; Driessen+ submitted; Caleb+ 2023

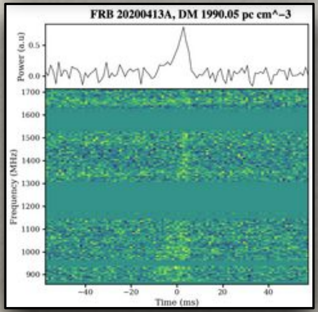
arXiv IDs: 2302.10107; 2302.09787; 2302.09754

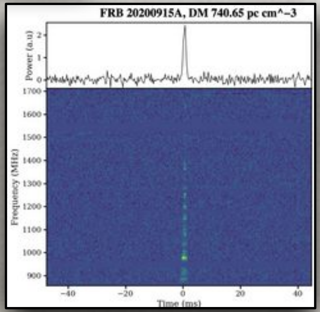
Fast Radio Burst types

Unresolved

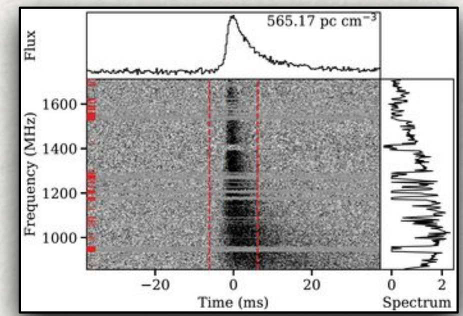


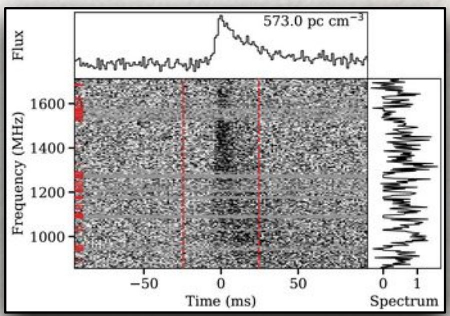


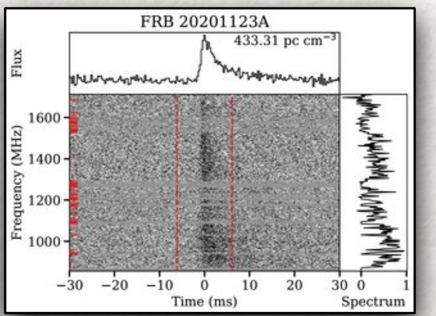


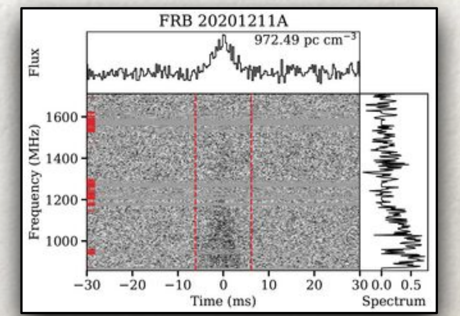


Scattered

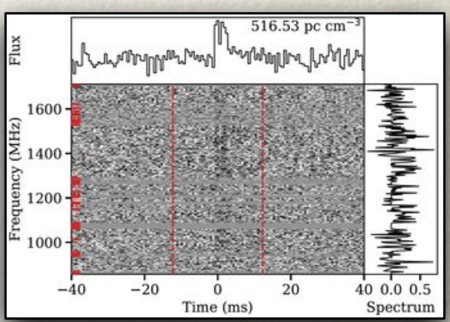


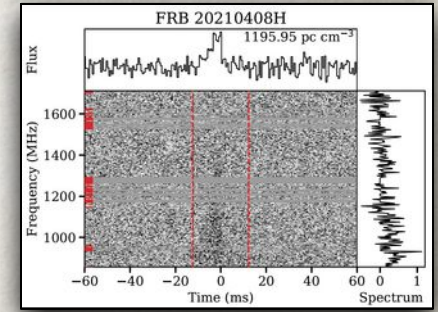


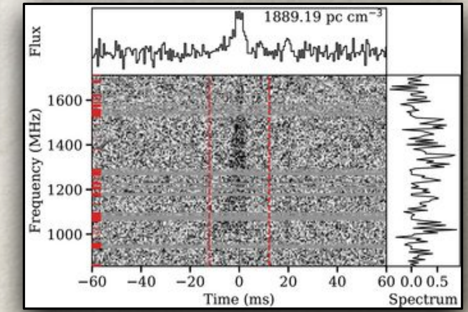




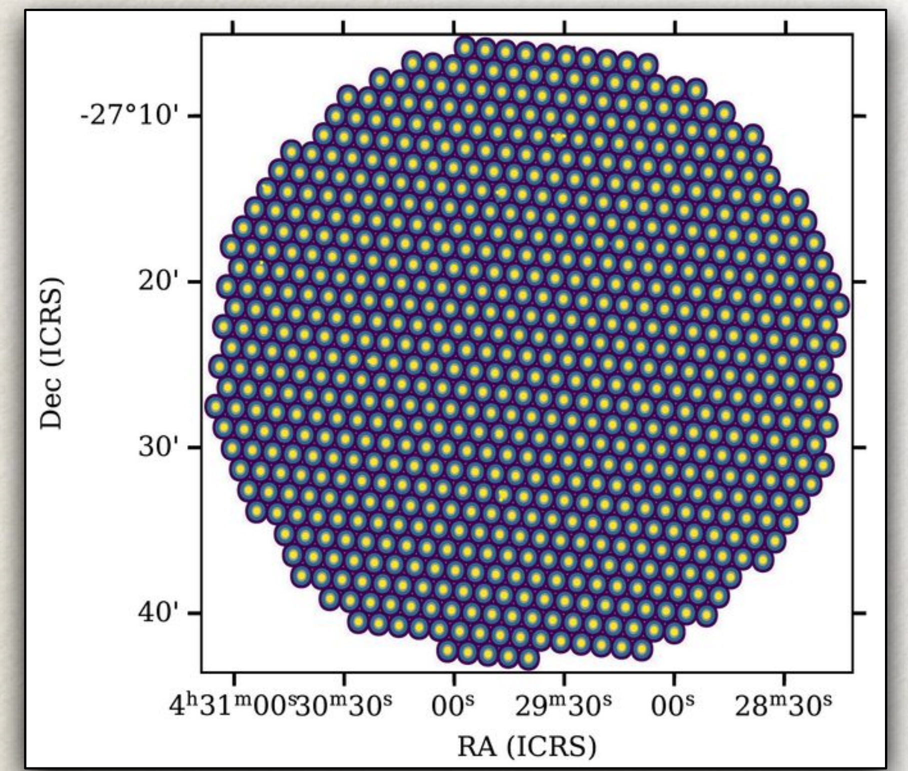
Complex





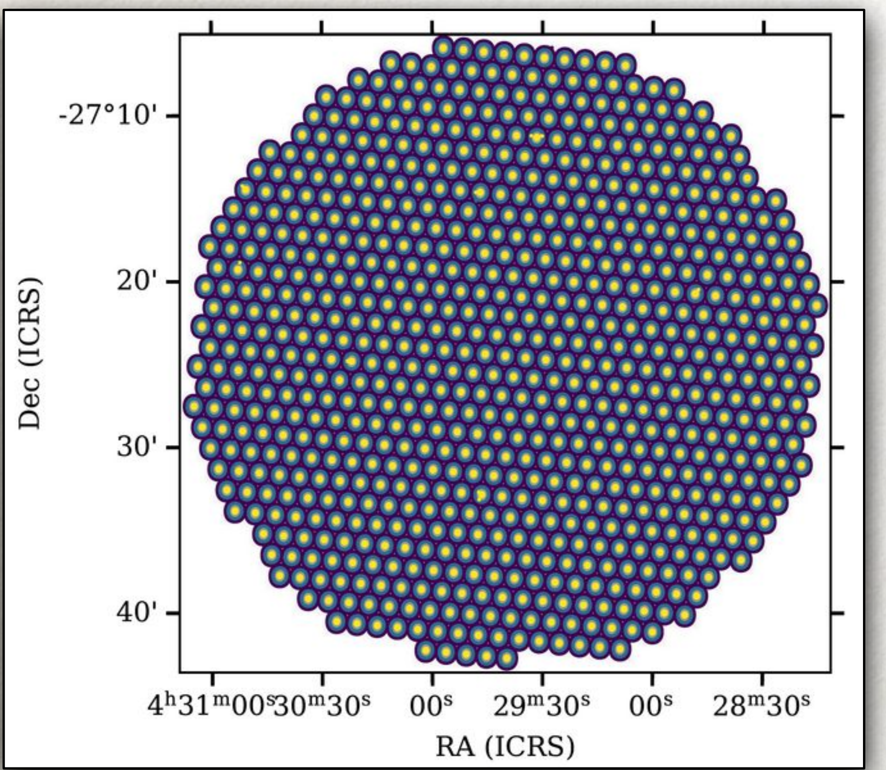


FRB localisation



Bezuidenhout+ 2023

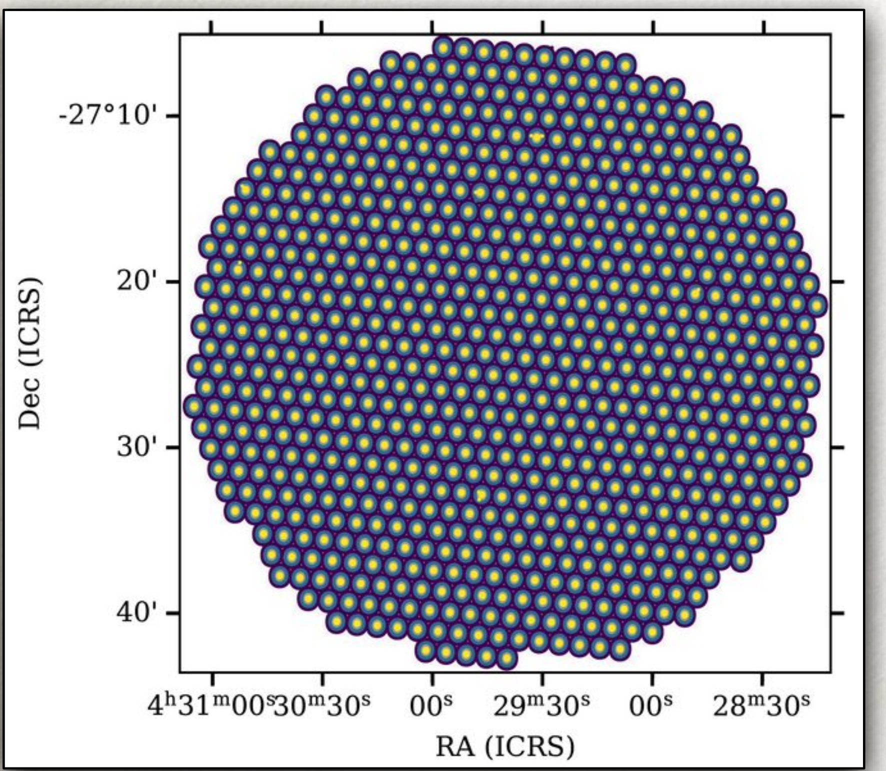
FRB localisation



- “TABLo” method implemented in “SeeKAT” software
  - Tiaan Bezuidenhout’s PhD work
- Based on (non) detection in neighbouring beams

Bezuidenhout+ 2023

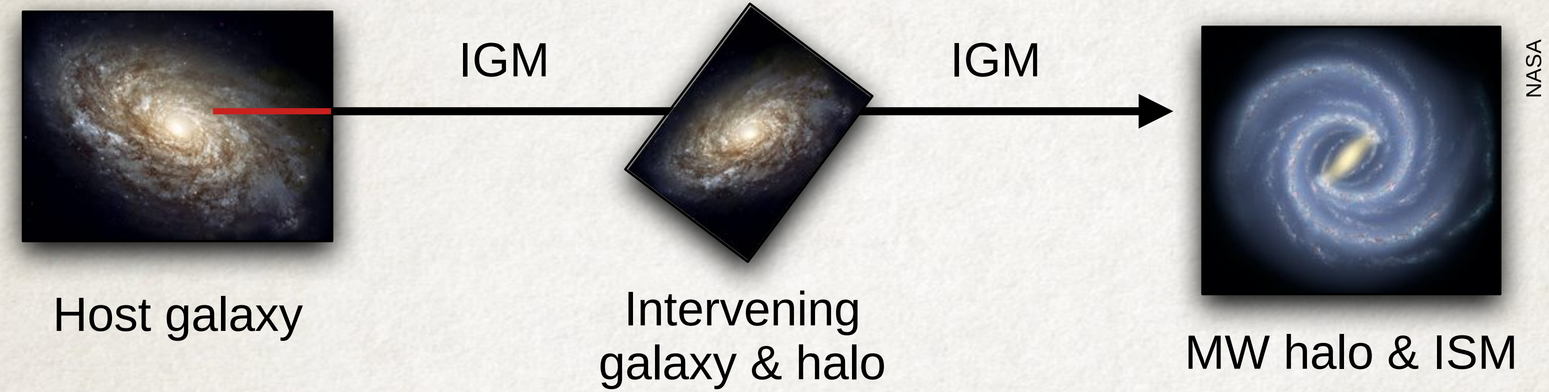
FRB localisation

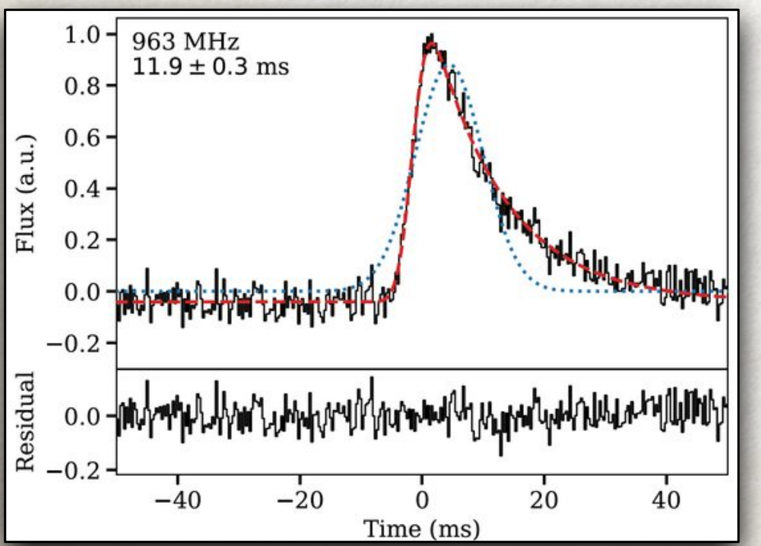


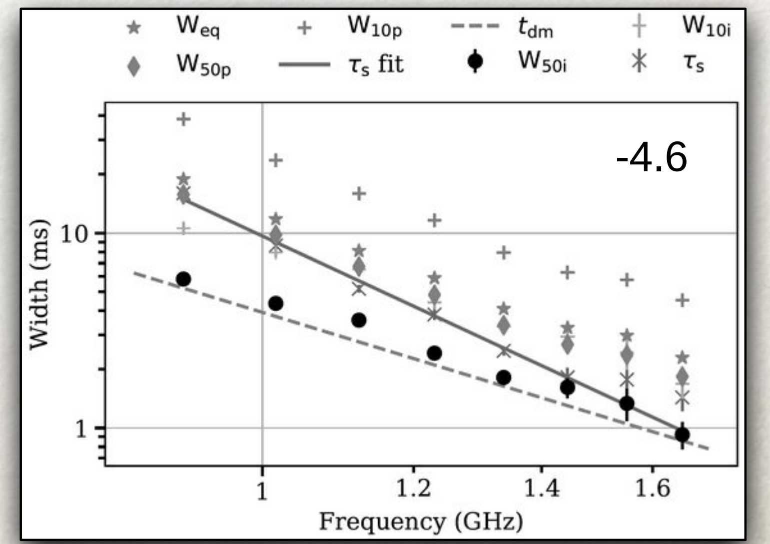
- “TABLo” method implemented in “SeeKAT” software
  - Tiaan Bezuidenhout’s PhD work
- Based on (non) detection in neighbouring beams
- Precision
  - Single-beam: ~0.9 arcmin^2
  - Multi-beam: O(100) arcsec^2
  - Synthesis image: O(1) arcsec^2

Bezuidenhout+ 2023

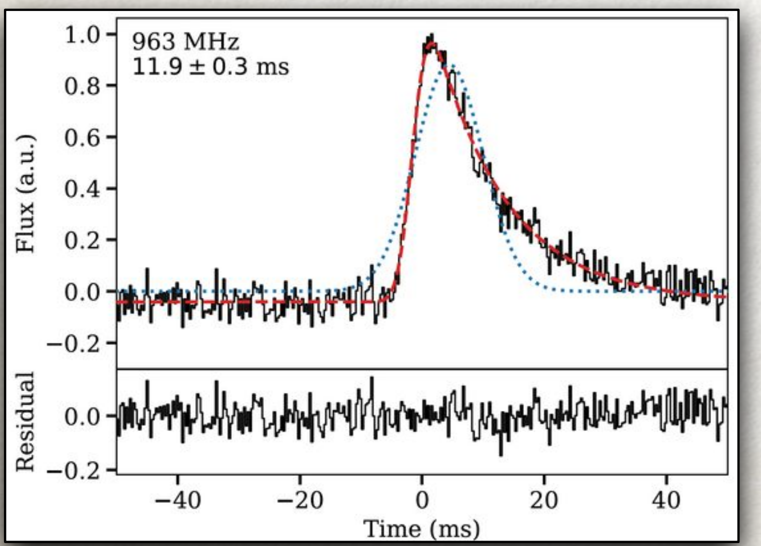
Scattering

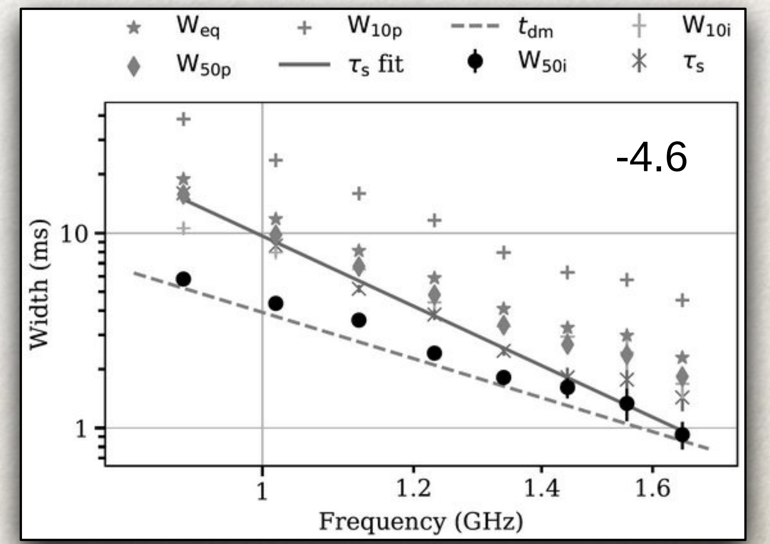

IGM
IGM
NASA
Host galaxy
Intervening galaxy & halo
MW halo & ISM


963 MHz
11.9 ± 0.3 ms
Flux (a.u.)
Residual
Time (ms)


W_eq
W_10p
t_dm
W_10i
W_50p
τ_s fit
W_50i
τ_s
-4.6
Width (ms)
Frequency (GHz)

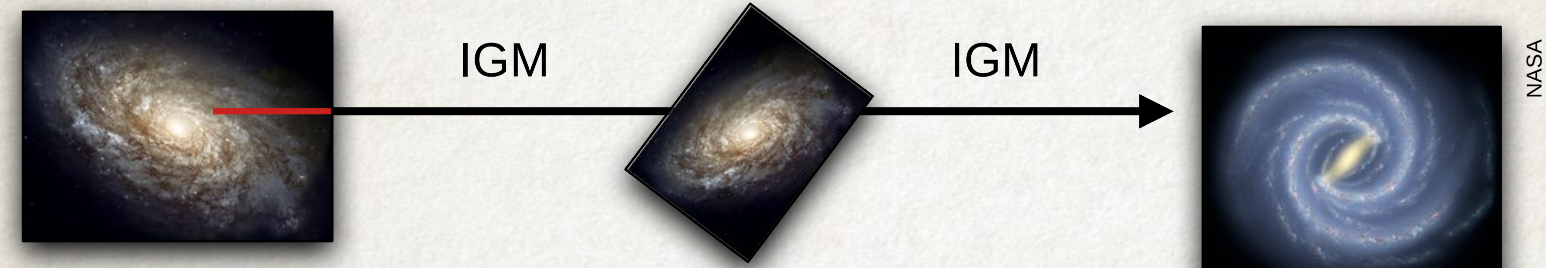
Scattering





- 3 FRBs show significant scattering
- 1 shows hint
- Several limited by DM smearing
- Close to Kolmogorov

Scattering

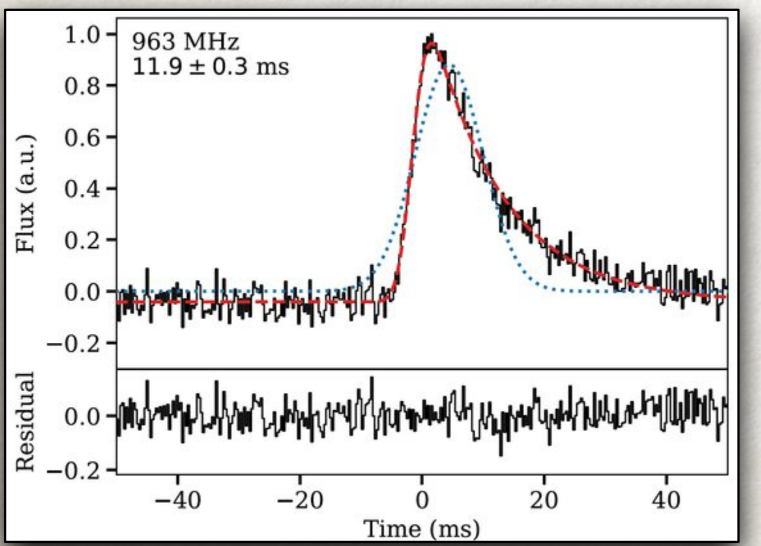


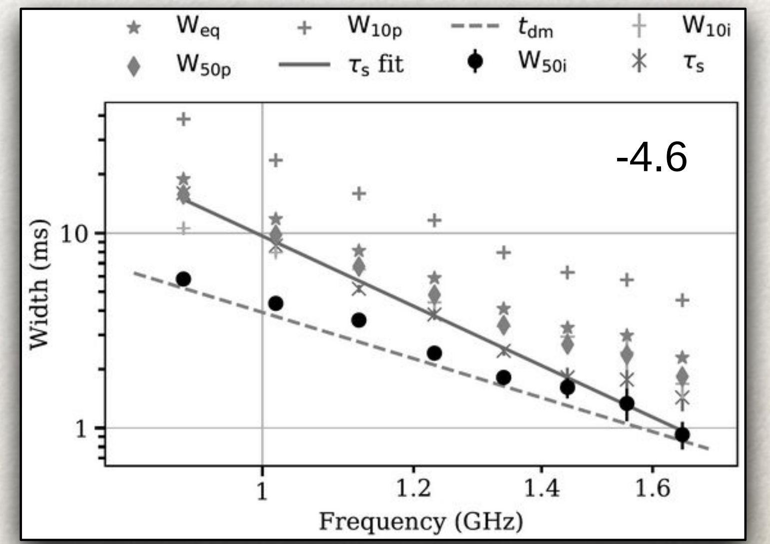
Host galaxy

e.g. M101

Intervening galaxy & halo

MW halo & ISM





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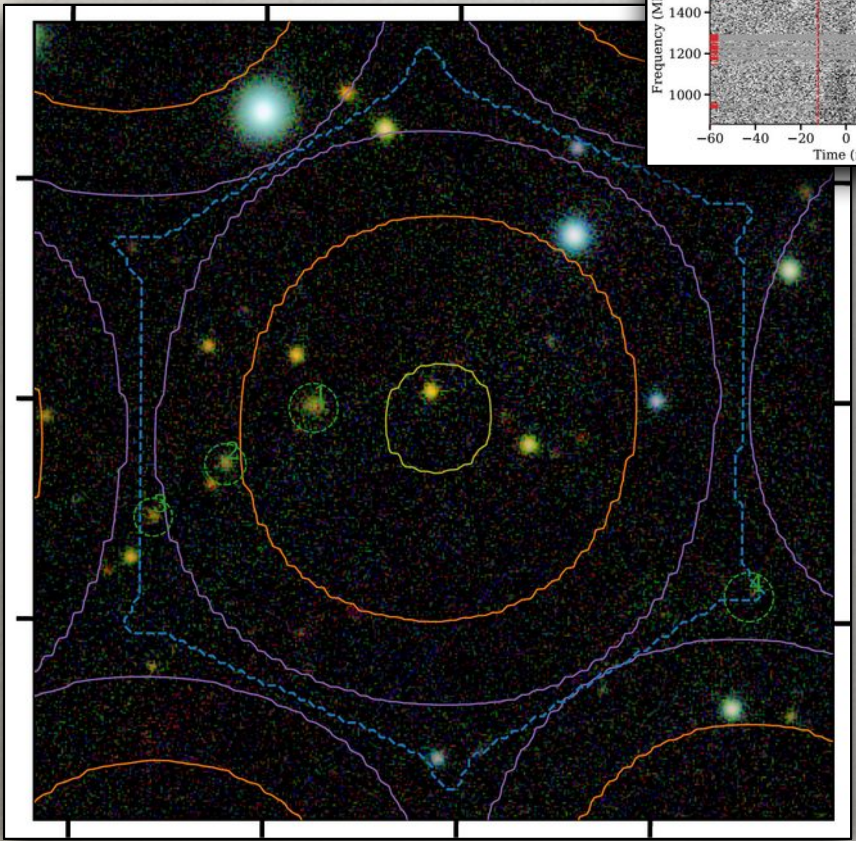
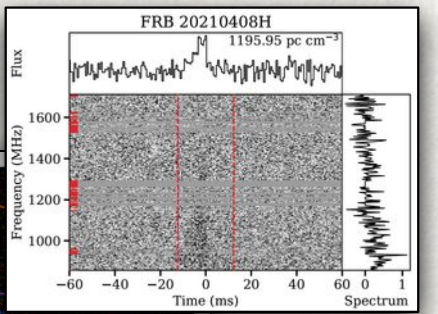
Host galaxy association





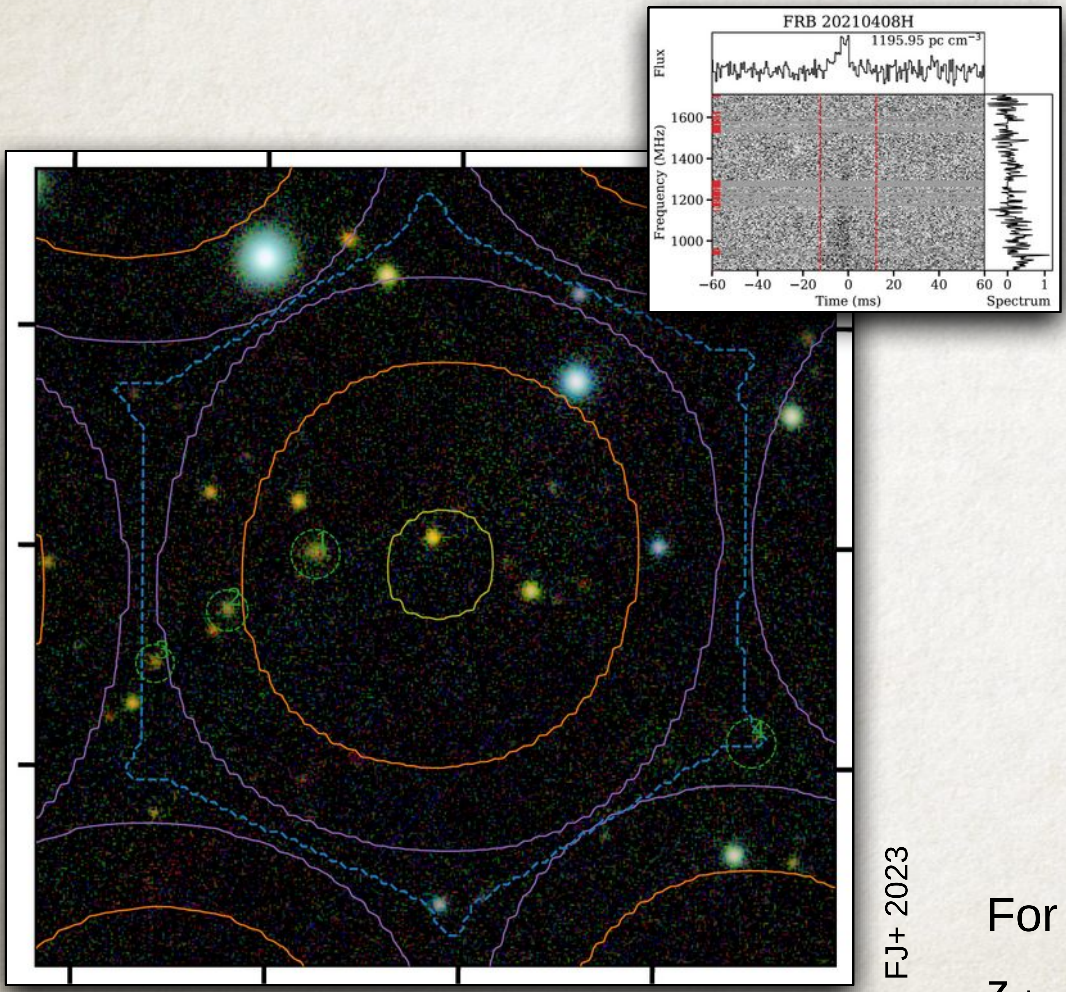
FJ+ 2023

- Aim: Host galaxy spectroscopic redshift
- Two distance measurements
- Calibrate DM_{cosmic} – redshift relation
- Probabilistic Association of Transients to their Hosts (PATH) software

#	p(O|x)	p(O)	m_i (mag)	r_{50} (“)
1	0.35	0.31	20.1	3.3
2	0.17	0.16	20.8	2.8
3	0.09	0.11	21.2	2.6
4	0.04	0.08	21.5	3.3

p(M|x) = 0.34

Host galaxy association



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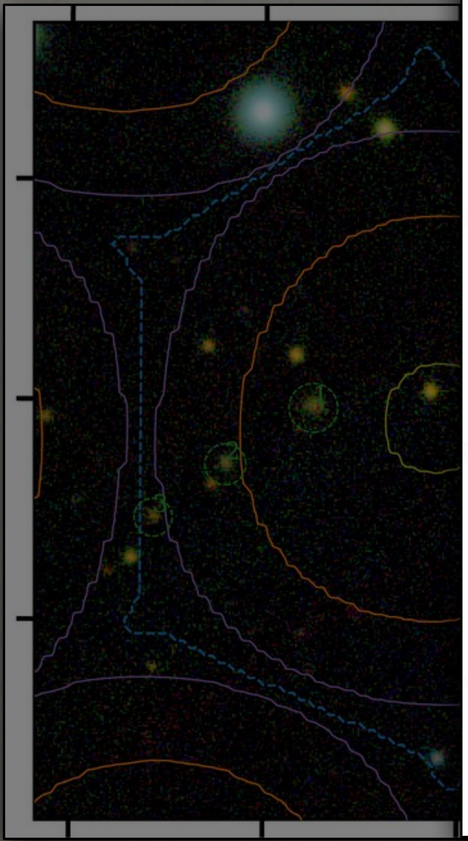
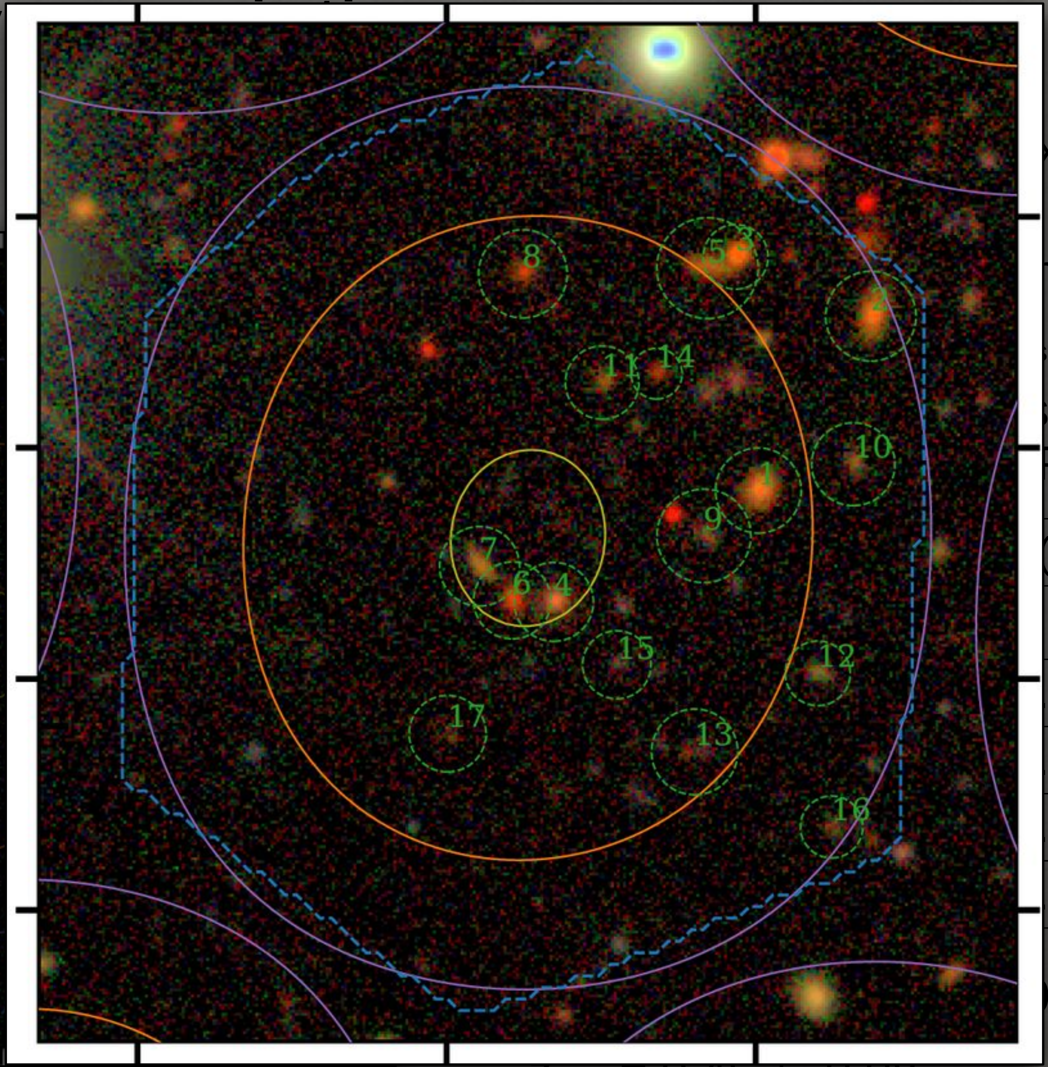
$p(M|x) = 0.34$

For $p(M) = 0$, $p(O_1|x) = 0.53$

$z_{phot} = 0.45 \pm 0.08$

Host galaxy





xy spectroscopic

neasurements

smic – redshift relation

ssociation of Transients
PATH) software

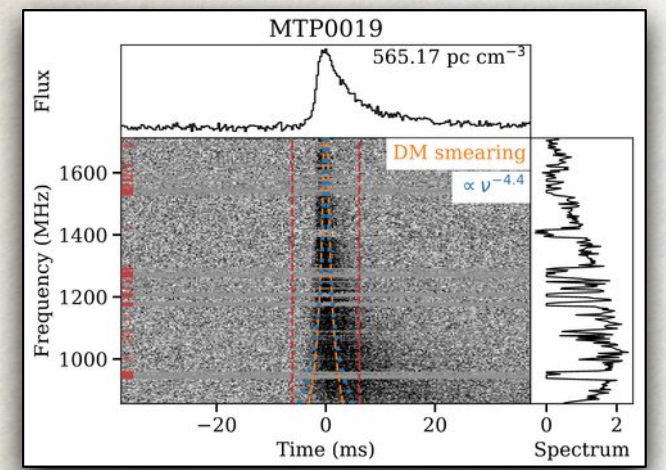
(O)	m_i	r_{50}
	(mag)	(“)
308	20.12	3.32
160	20.77	2.79
110	21.16	2.59
084	21.45	3.34

$p(M|x) = 0.34$

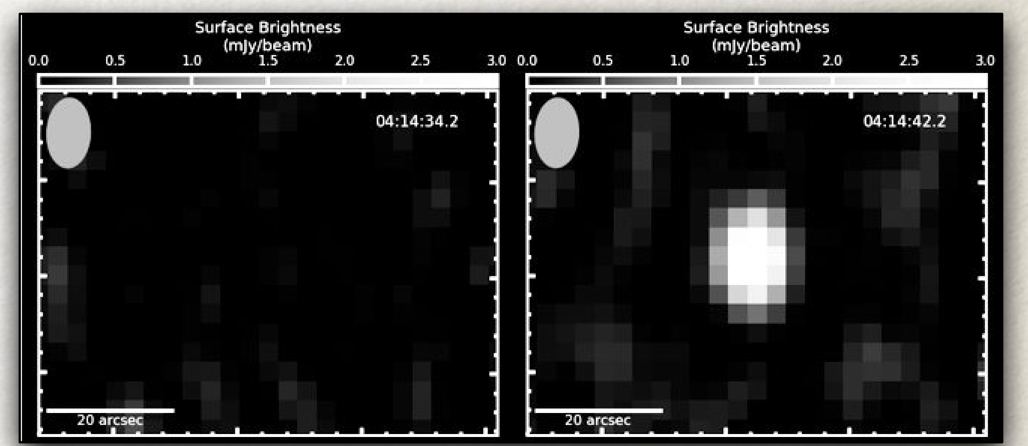
.53

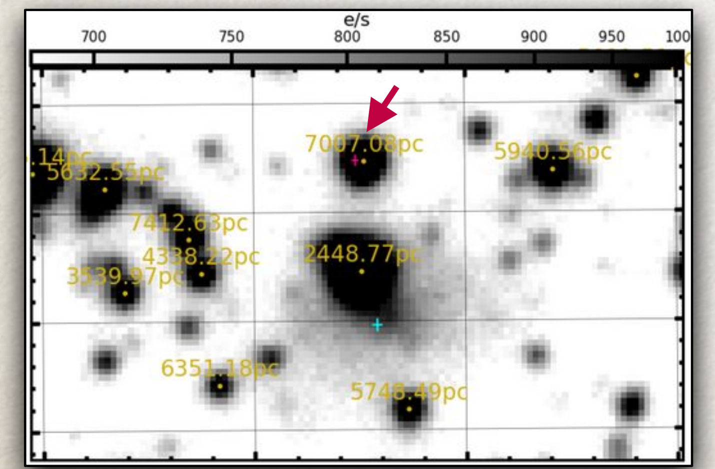
$z_{phot} = 0.45$ +- 0.08

Host galaxies – MTP0019



Driessen+ in prep.

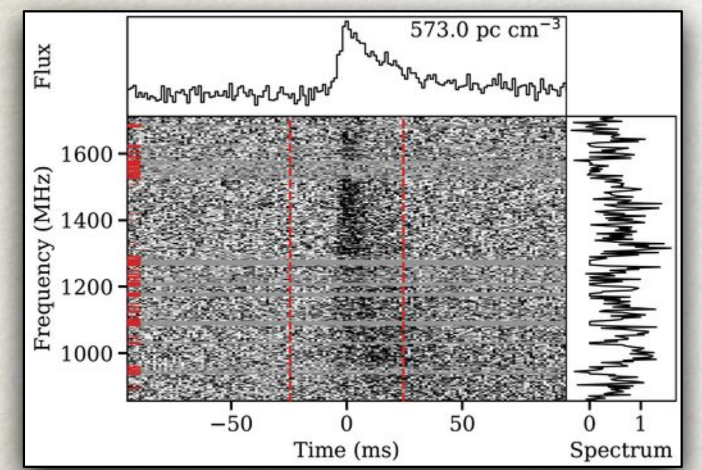




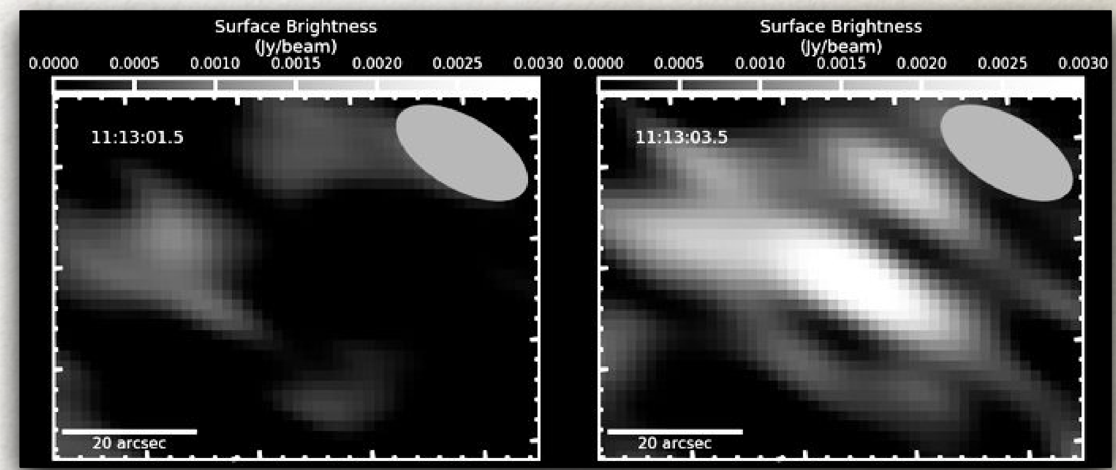
- Sub-arcsec localisation
- Galactic vs extragalactic?
- Faint optical source and persistent radio source,7.4” offset
- Galaxy obscured by foreground star. Star-forming spiral
- z_{spec} = 0.066
- Host DM ~30 units

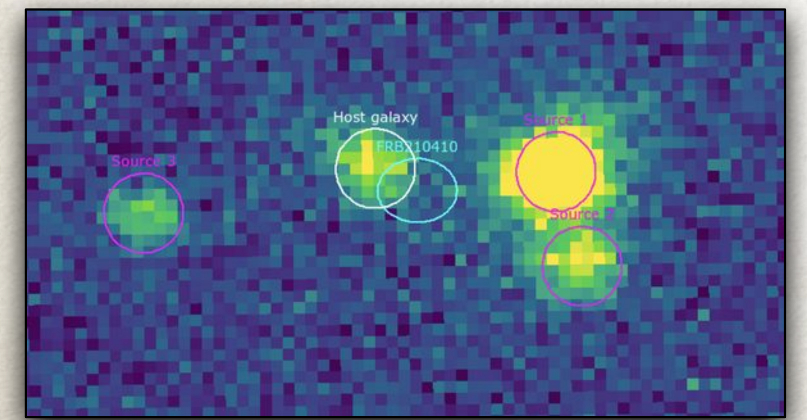
arXiv ID:
2302.09787

Host galaxies – FRB 20210410



Caleb+ 2023

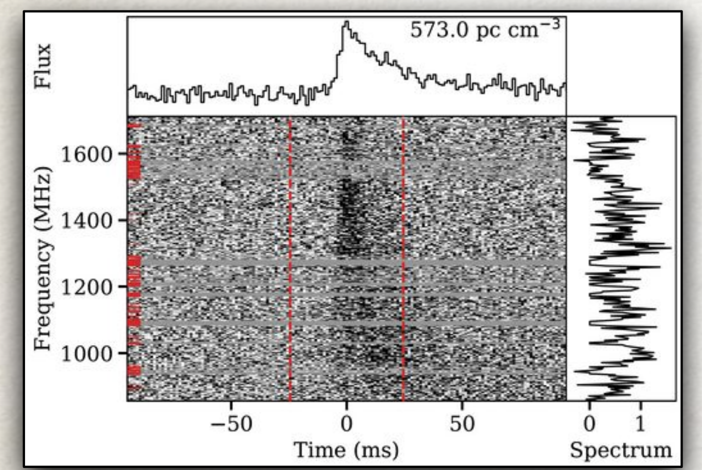




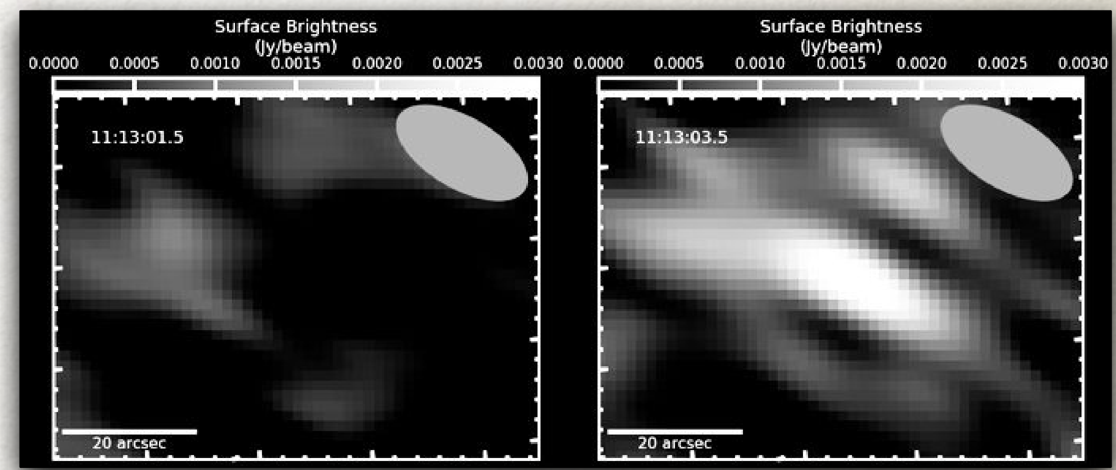
- Localised from 2-s corr. dump
- Normal galaxy
- $z_{spec} = 0.14$
- Complex field
- MUSE image

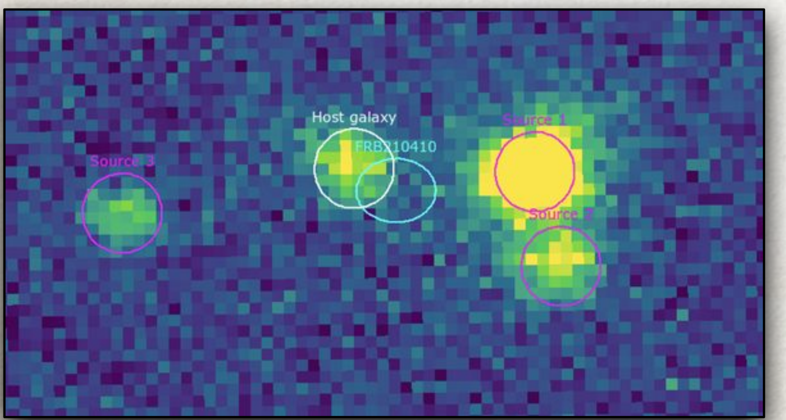
arXiv ID:
2302.09754

Host galaxies – FRB 20210410



Caleb+ 2023





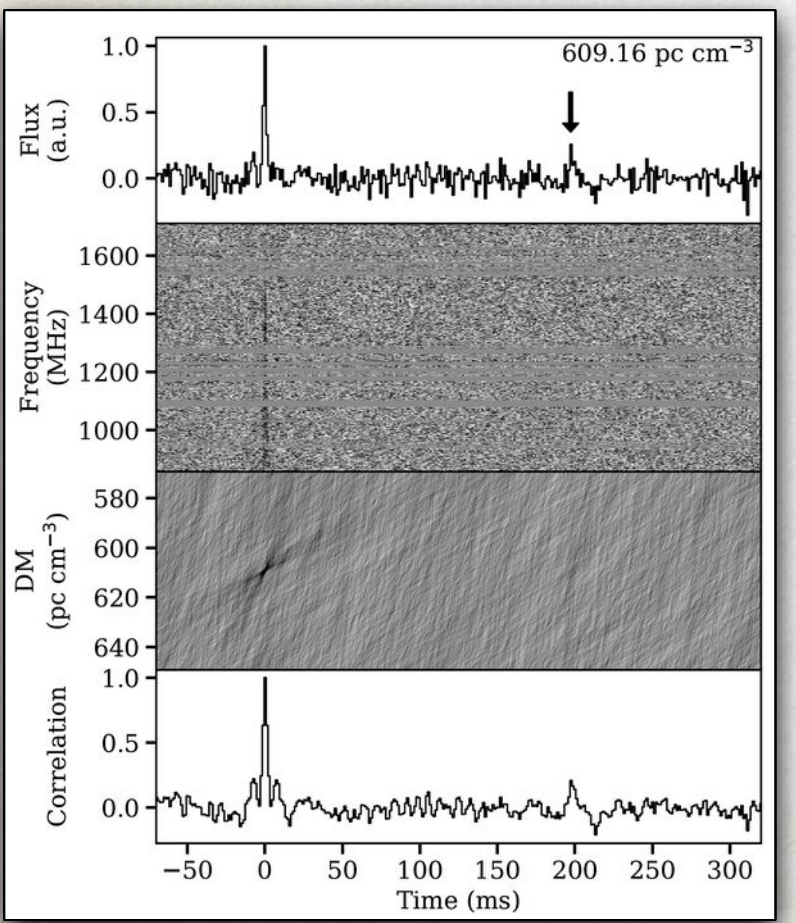
- Localised from 2-s corr. dump
- Normal galaxy
- $z_{spec} = 0.14$
- Complex field
- MUSE image

arXiv ID: 2302.09754

Summary

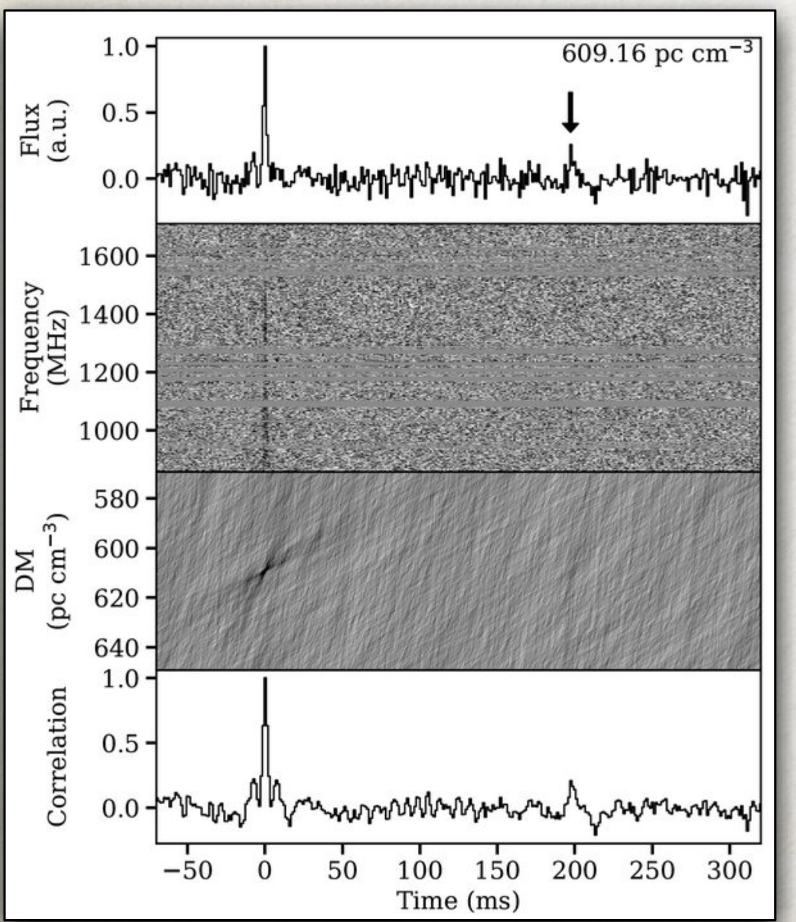
- 2 sub-arcsecond localisations → 2 host galaxies
- Another secure PATH association with p(O|x) > 0.8

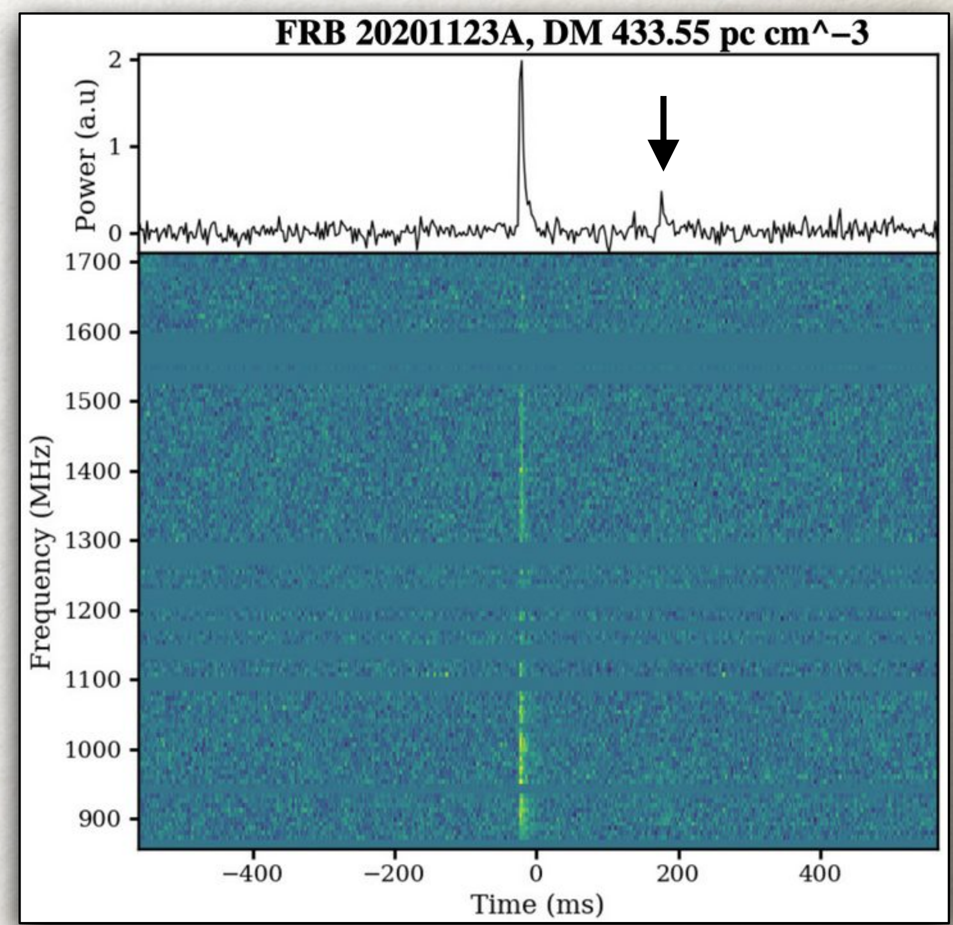
Post-cursor burst detections



FJ+ 2023

Post-cursor burst detections

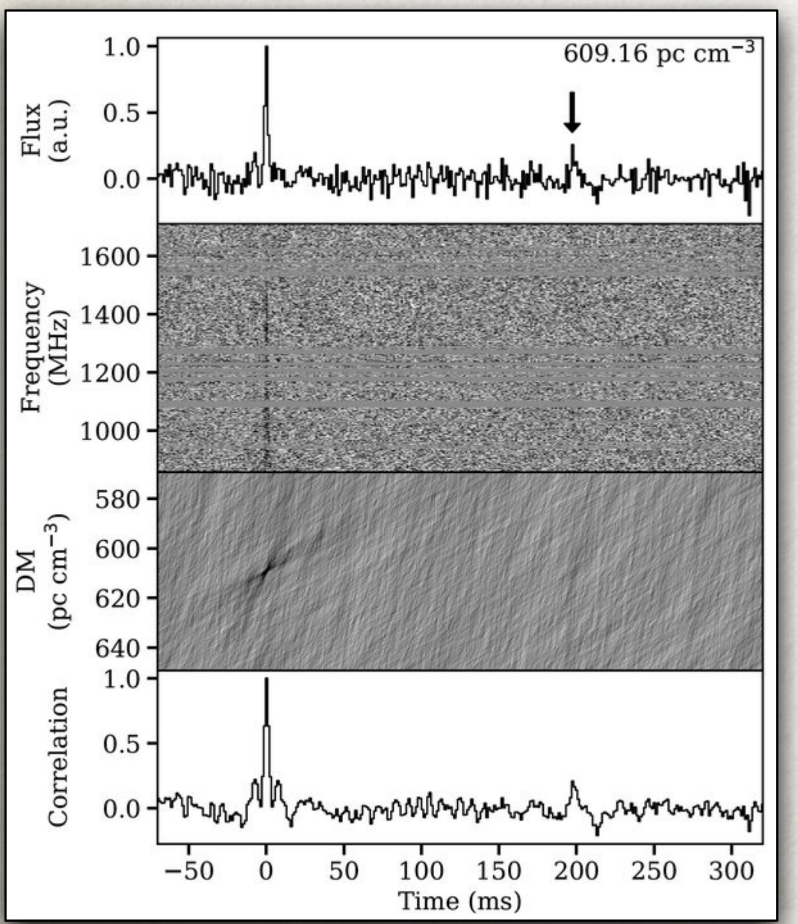




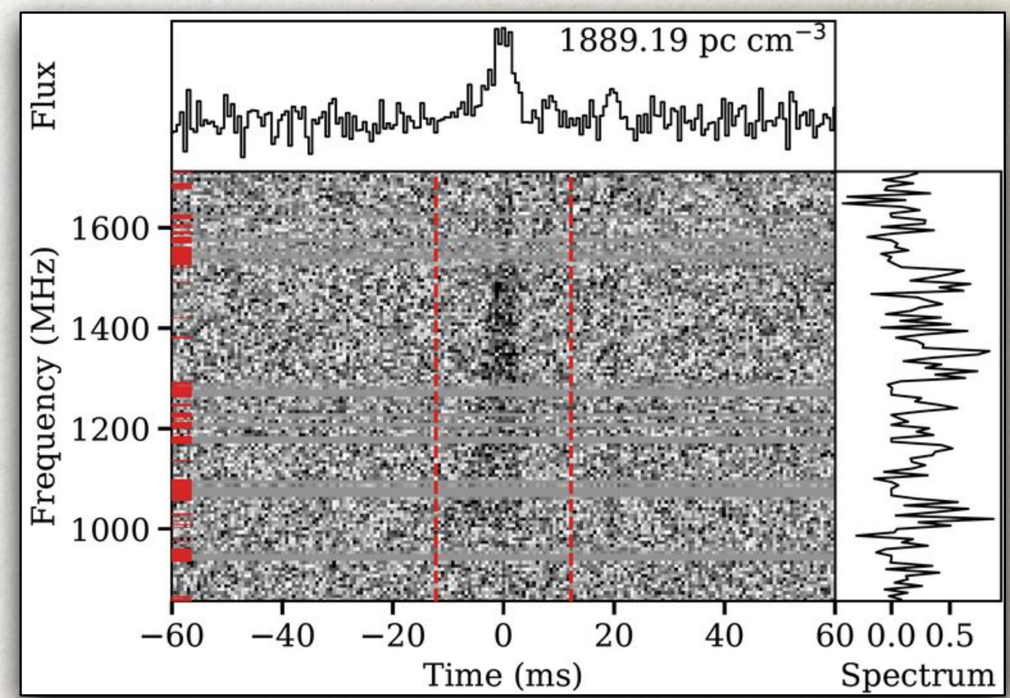
FJ+ 2023

Rajwade+ 2022

Post-cursor burst detections



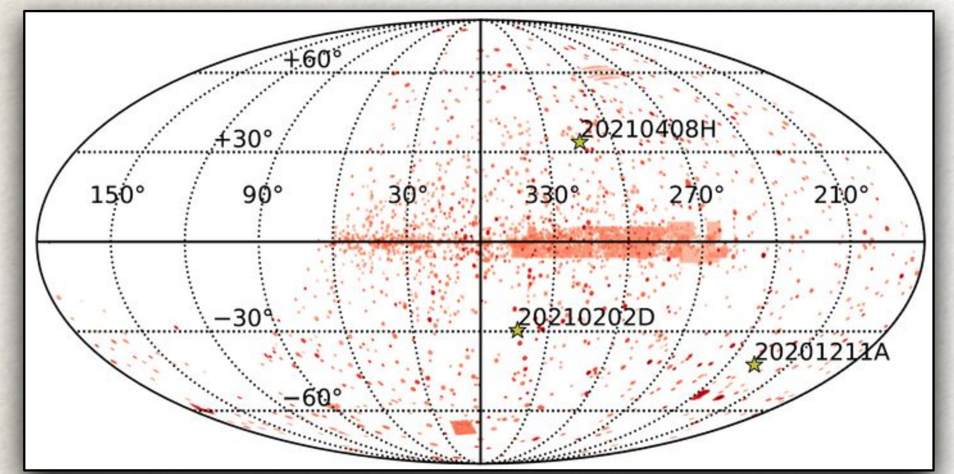
FJ+ 2023



MeerTRAP in prep.

Understanding the MeerTRAP surveys & FRB all-sky rates

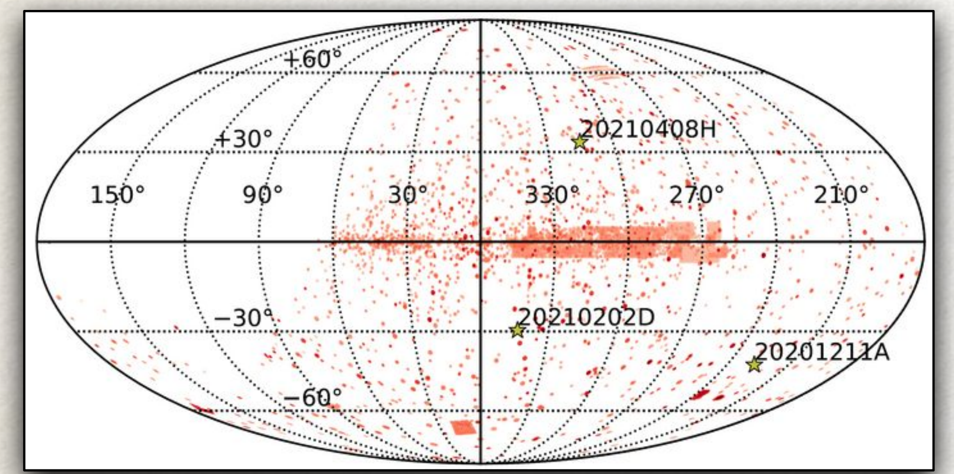
Understanding the MeerTRAP surveys & FRB all-sky rates



FJ+ 2023

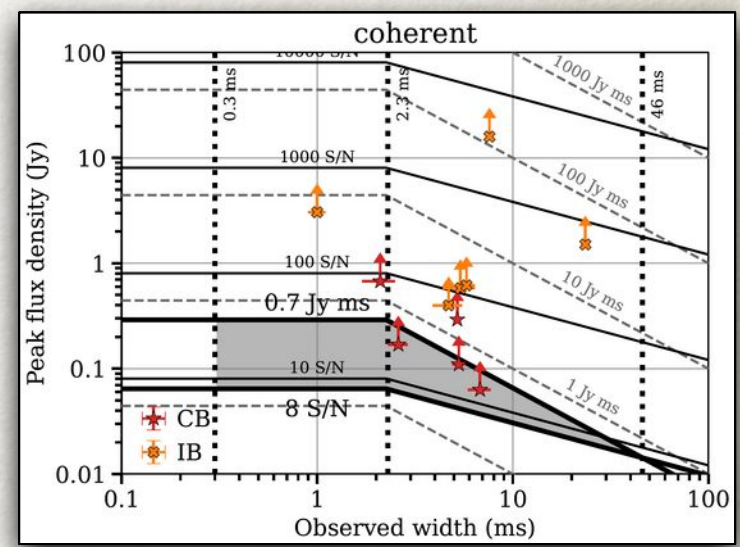
317.5 days on-sky time!

Understanding the MeerTRAP surveys & FRB all-sky rates



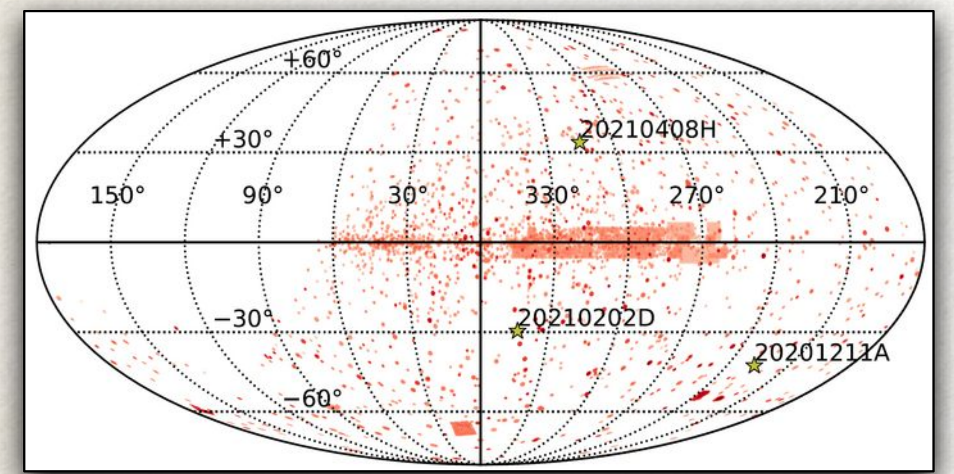
FJ+ 2023

317.5 days on-sky time!



F_c: 0.7 & 3.4 Jy ms

Understanding the MeerTRAP surveys & FRB all-sky rates



FJ+ 2023

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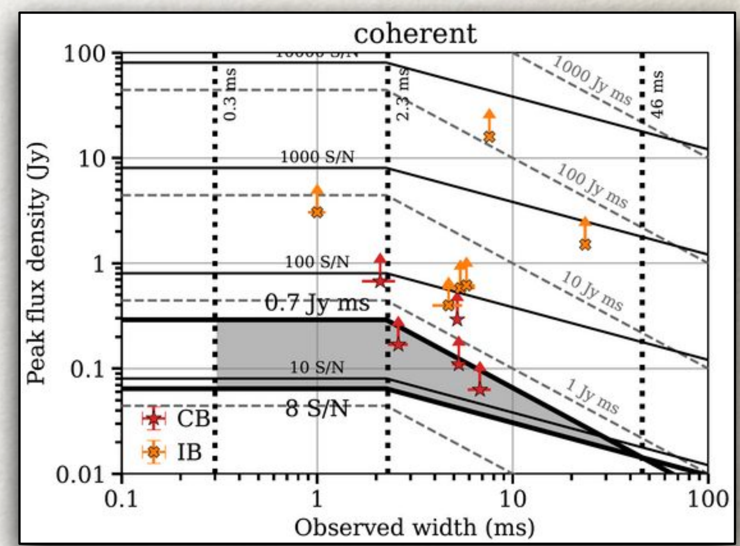


F_c: 0.7 & 3.4 Jy ms

Limiting fluence

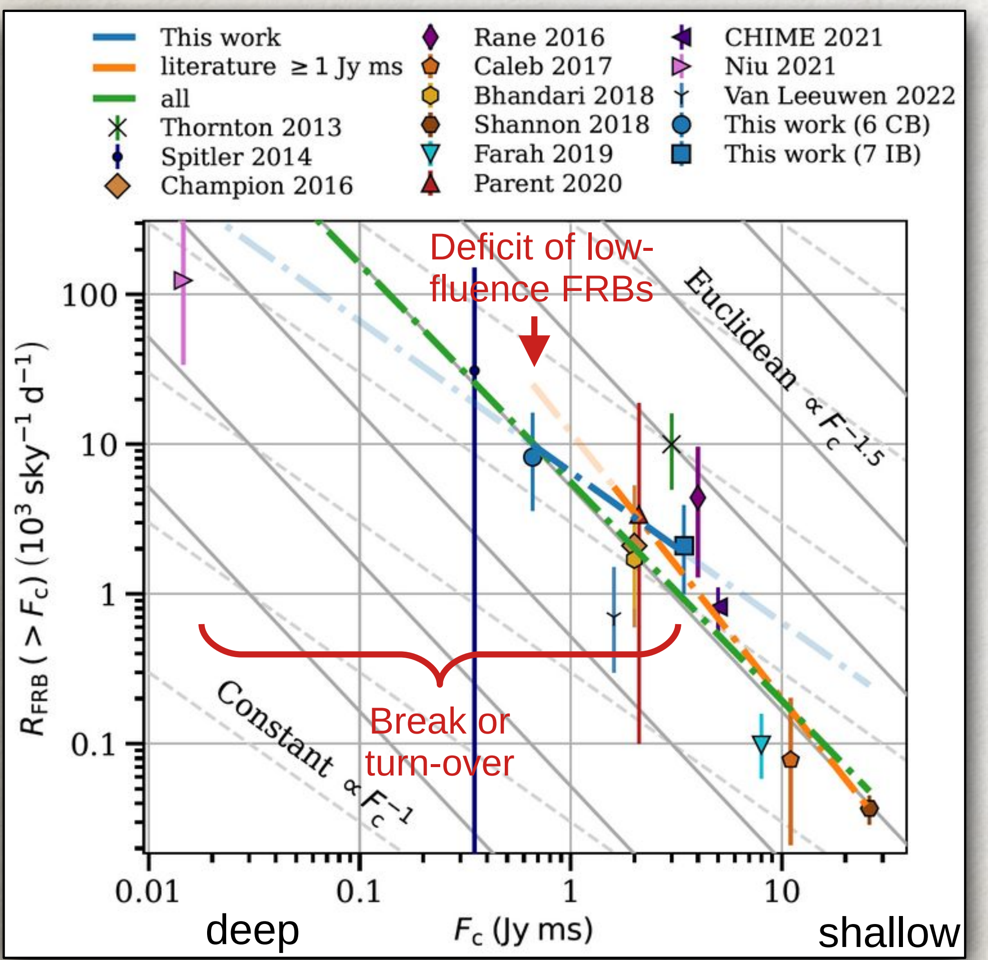
All-sky rate

Survey	$t_{\rm obs}$ (d)	$\langle A_{0.5}\rangle$ (deg^2)	c_s (deg^2 h)	$F_{\rm c}$ (Jy ms)	$N_{\rm FRB}\,(>F_{\rm c})$	$R_{\rm FRB}\,(>F_{\rm c})$ (10^3 sky^{-1} d^{-1})
Coherent	317.5	0.19	1448	0.66	6	$8.2^{+8.0}_{-4.6}$
Incoherent (total)	317.5	0.97	6662	3.44	7	$2.1^{+1.8}_{-1.1}$
Incoherent (subtracted)	317.5	0.78	5944	3.44	5	$1.7^{+1.8}_{-1.0}$

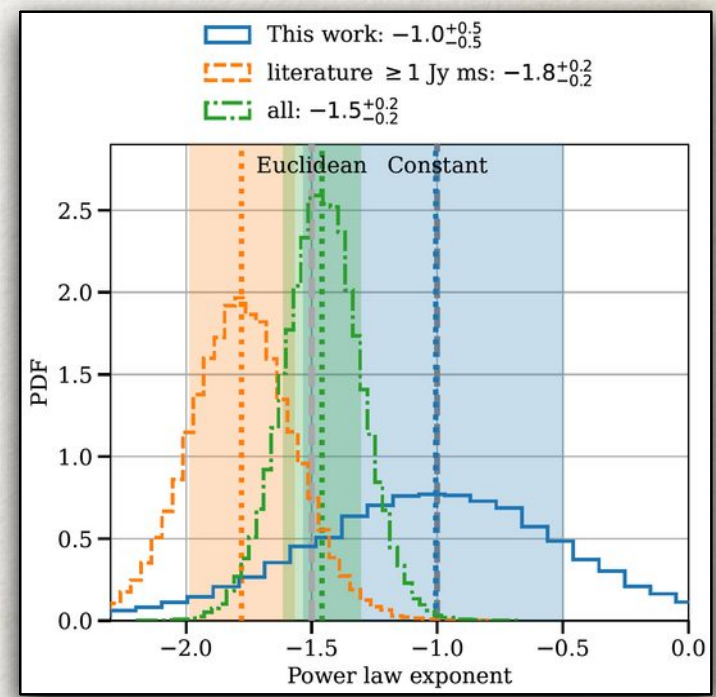
~2100 and 8200 FRBs per sky per day!

FRB all-sky rates → cosmology

All-sky rate



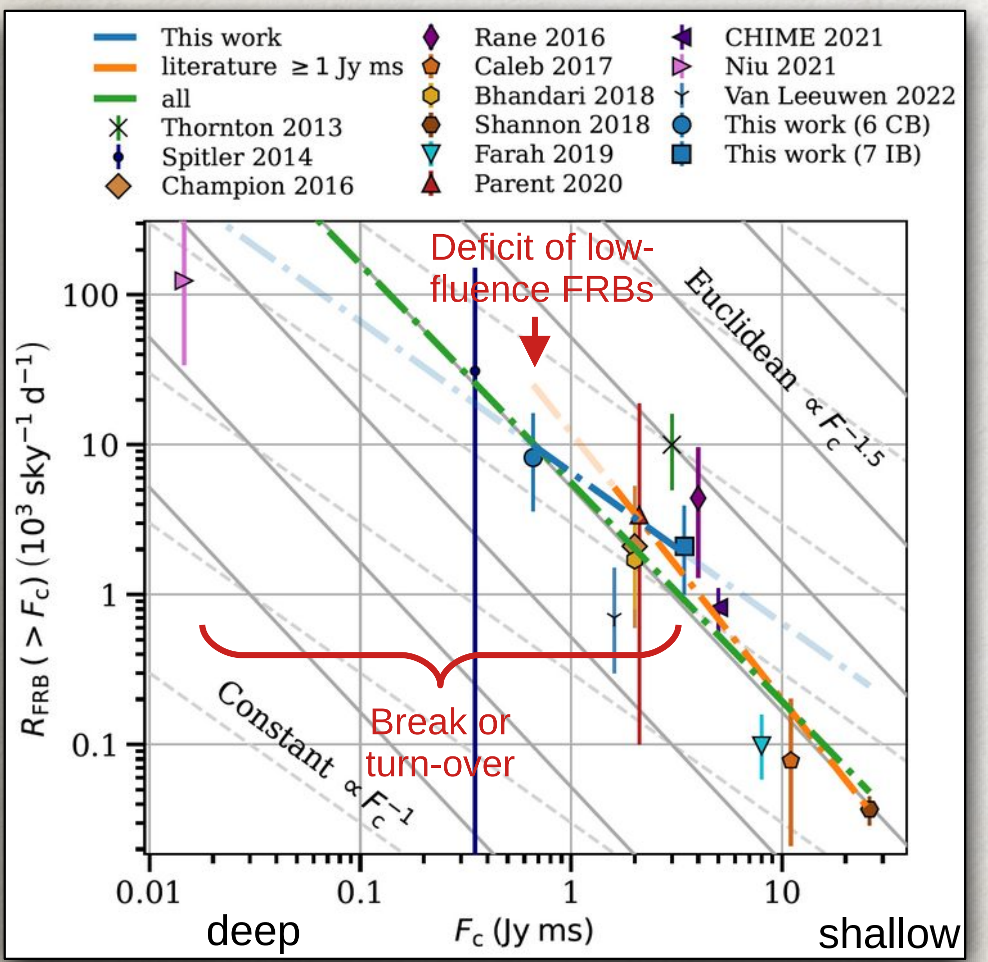
Survey sensitivity



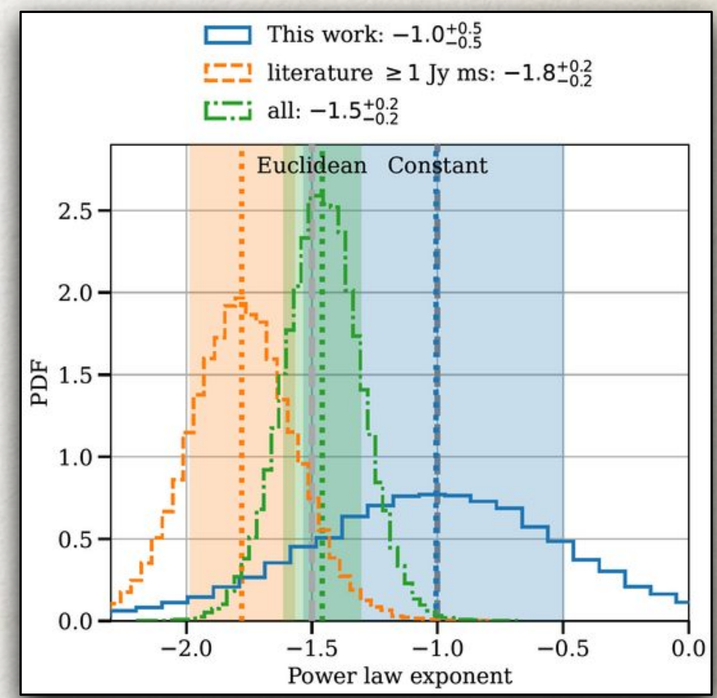
FJ+ 2023

FRB all-sky rates → cosmology

All-sky rate



Survey sensitivity



FJ+ 2023

- Deficit of low-fluence FRBs
- Due to cosmological effects or progenitor evolution

Part 2: A multi-telescope single-pulse campaign with the Nançay telescopes & uGMRT

On behalf of Jean-Mathias Grießmeier, Killian Lebreton,
Gilles Theureau, Mayuresh Surnis,
NenuFAR pulsar team

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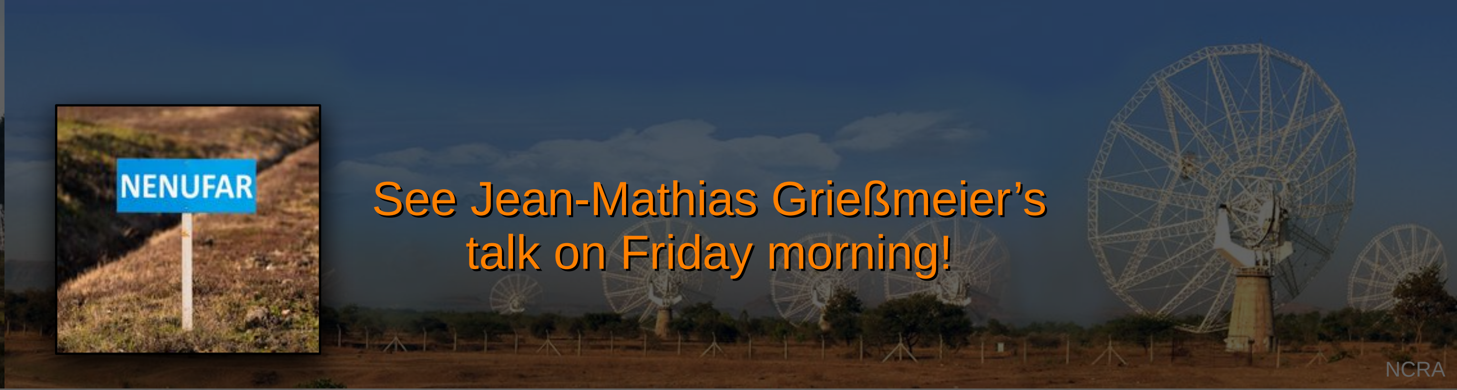
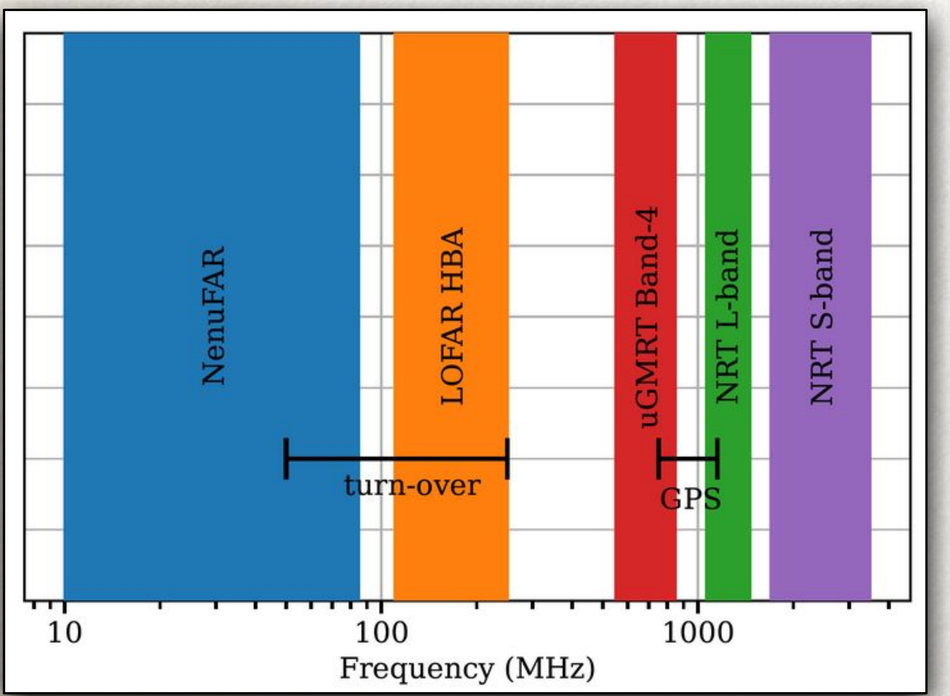


See Jean-Mathias Grießmeier's
talk on Friday morning!

Part 2: A multi-telescope single-pulse campaign with the Nançay telescopes & uGMRT

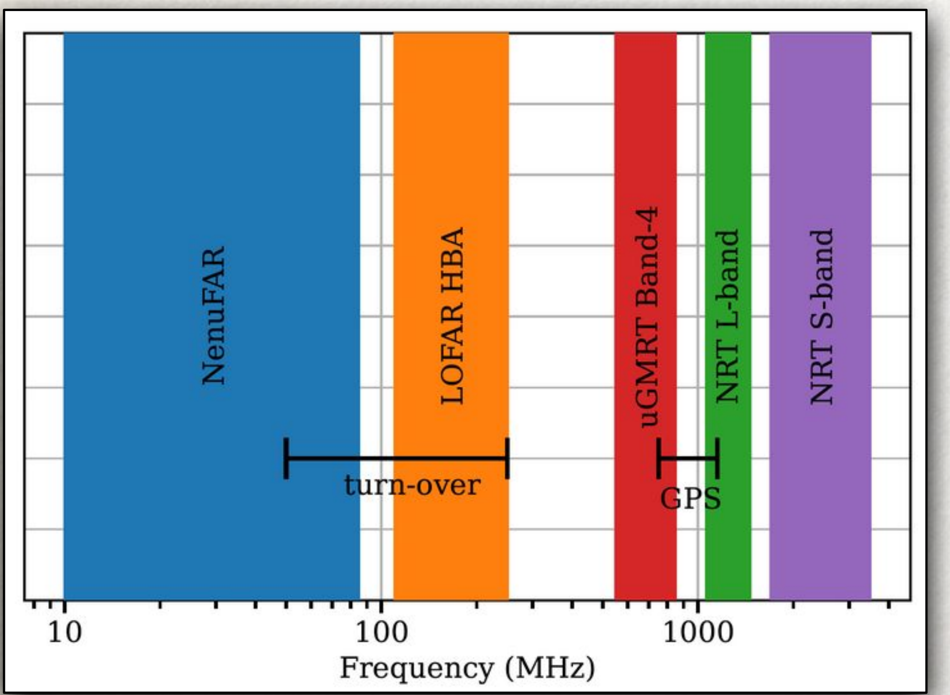
On behalf of Jean-Mathias Grießmeier, Killian Lebreton,
Gilles Theureau, Mayuresh Surnis,
NenuFAR pulsar team

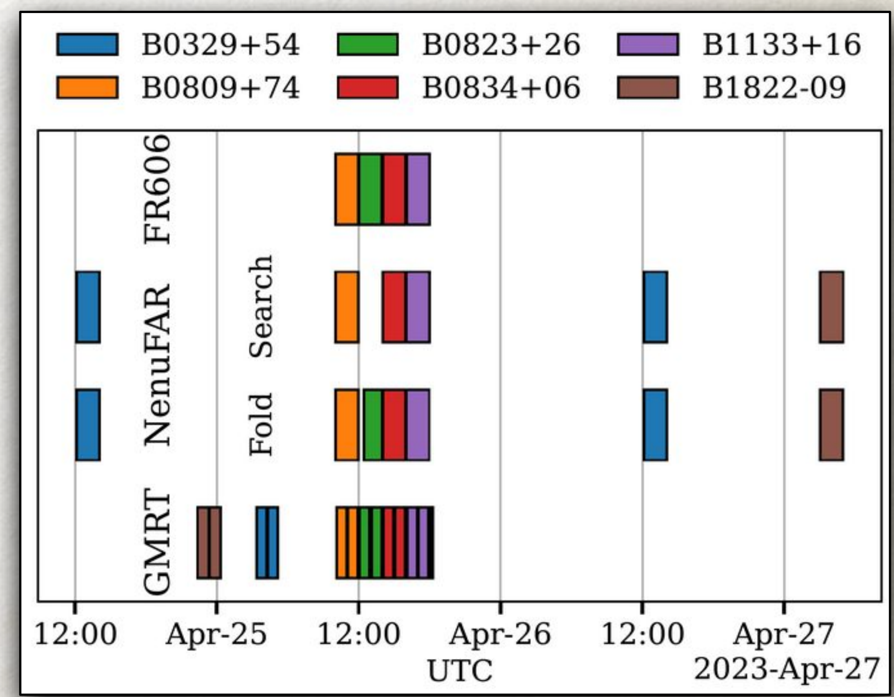
Understanding the wide-band single-pulse properties of radio pulsars



- Aims:
  - Test relationship between FRBs and pulsar single-pulses
  - Study single-pulse properties (PE distributions, modulation, SP polarimetry)
  - Others: pulse profiles, modes, RFM, flux densities, spectra
- Focus on mode-changing and sub-pulse drifting pulsars
  - Master’s M2 project – Killian Lebreton

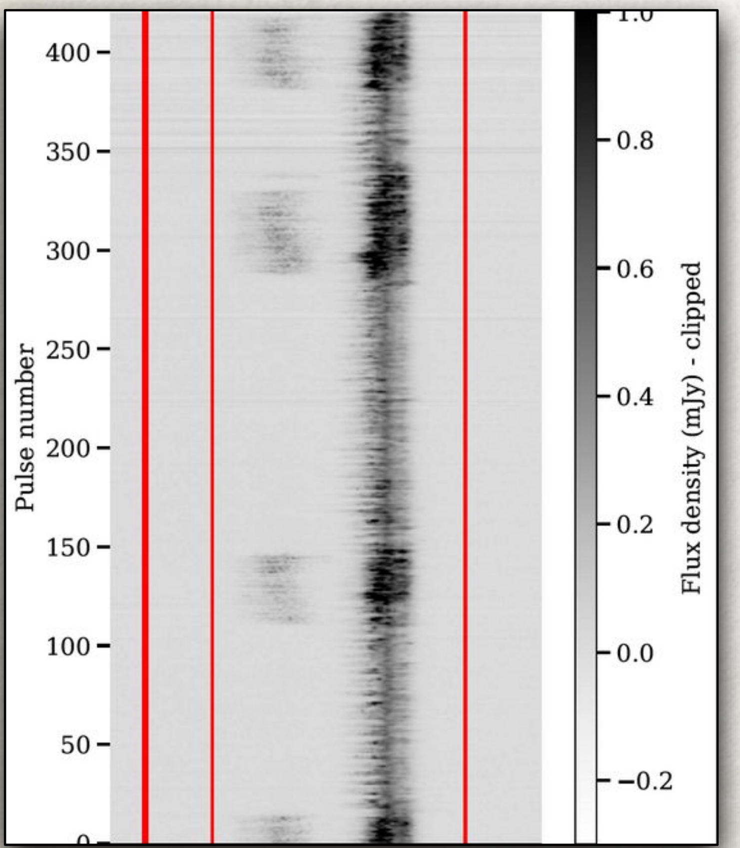
A multi-telescope multi-frequency single-pulse campaign

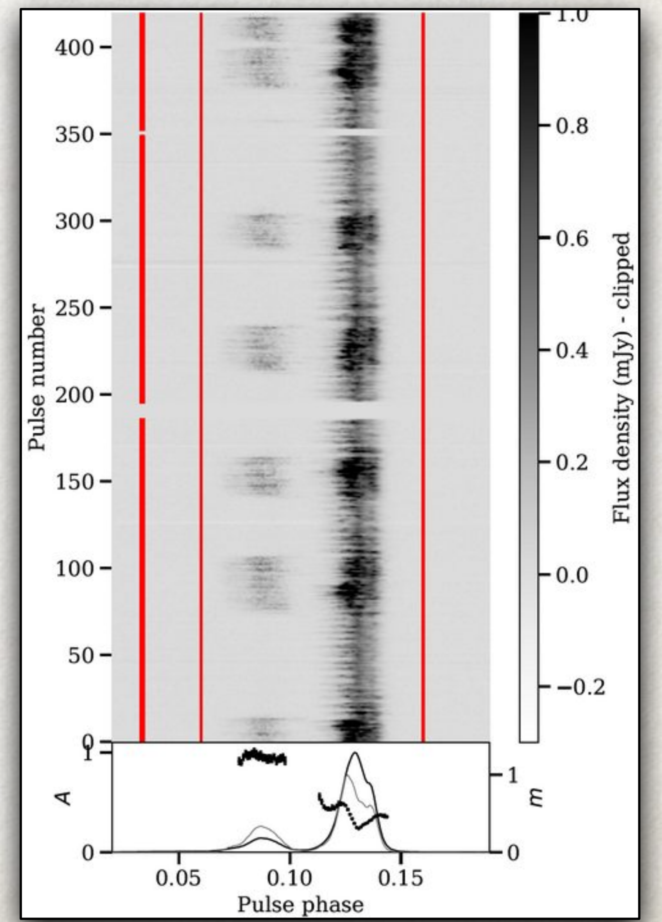




First results – PSR B1822-09 moding

uGMRT data

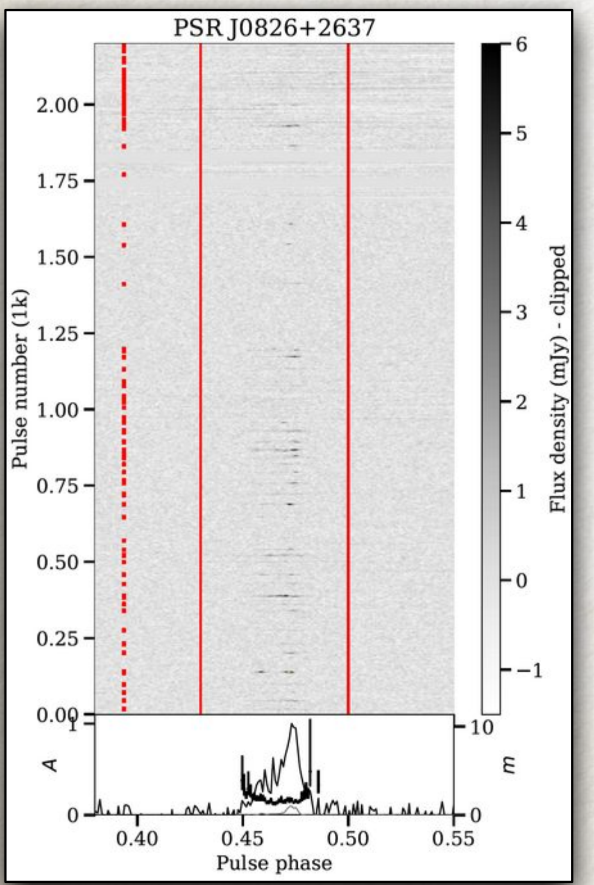


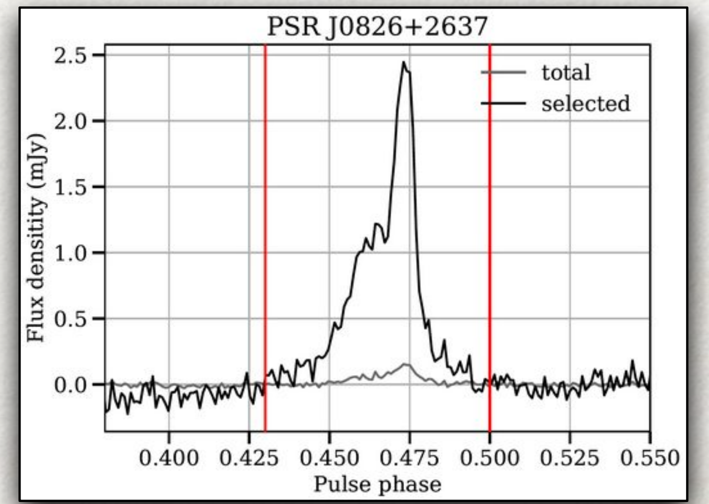


- 550 – 750 MHz
- 200 MHz bw
- simple RFI excision
- S/N ~ 5000 – 10,000!

PSR B0823+26 quiet mode detection

uGMRT





- P = 513 ms, DM = 19.48, tau = ~5 Myr, Edot = 4.5 x 10^{32} erg/s
- Synchronous radio & X-ray moding (Hermsen+)
- B, Q, N modes
- Faintly detected with NenuFAR
  - Spectral index constraint

Summary

MeerKAT

- 11 new FRBs discovered
- Localised to <1 arcmin^2
- Substantial DMs [400, 2000], extragalactic [100, 1900], redshifts [0.1, 2.0]
- S_{peak} > [60, 1400] mJy, F > 0.4 Jy ms
- 3 FRBs scattered, 1 hint, limited by smearing
- Several host galaxy associations
- Post-cursor bursts (broad-band rep. pulses)
- Surveys: 317.5 days on sky, >0.7 & 3.4 Jy ms
- Rates: $2.1_{-1.1}^{+1.8}$ & $8.2_{-4.6}^{+8.0}$ x 10^3 sky^{-1} d^{-1}
- Power law idx flatter than at higher fluences
- Deficit of low-fluence FRBs due to cosmology or progenitor evolution

Nançay telescopes & uGMRT

- B1822-09 moding
- B0823+26 quiet mode detection
- Work ongoing

arXiv ID: 2302.10107

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https://fabian.jankowskis.org