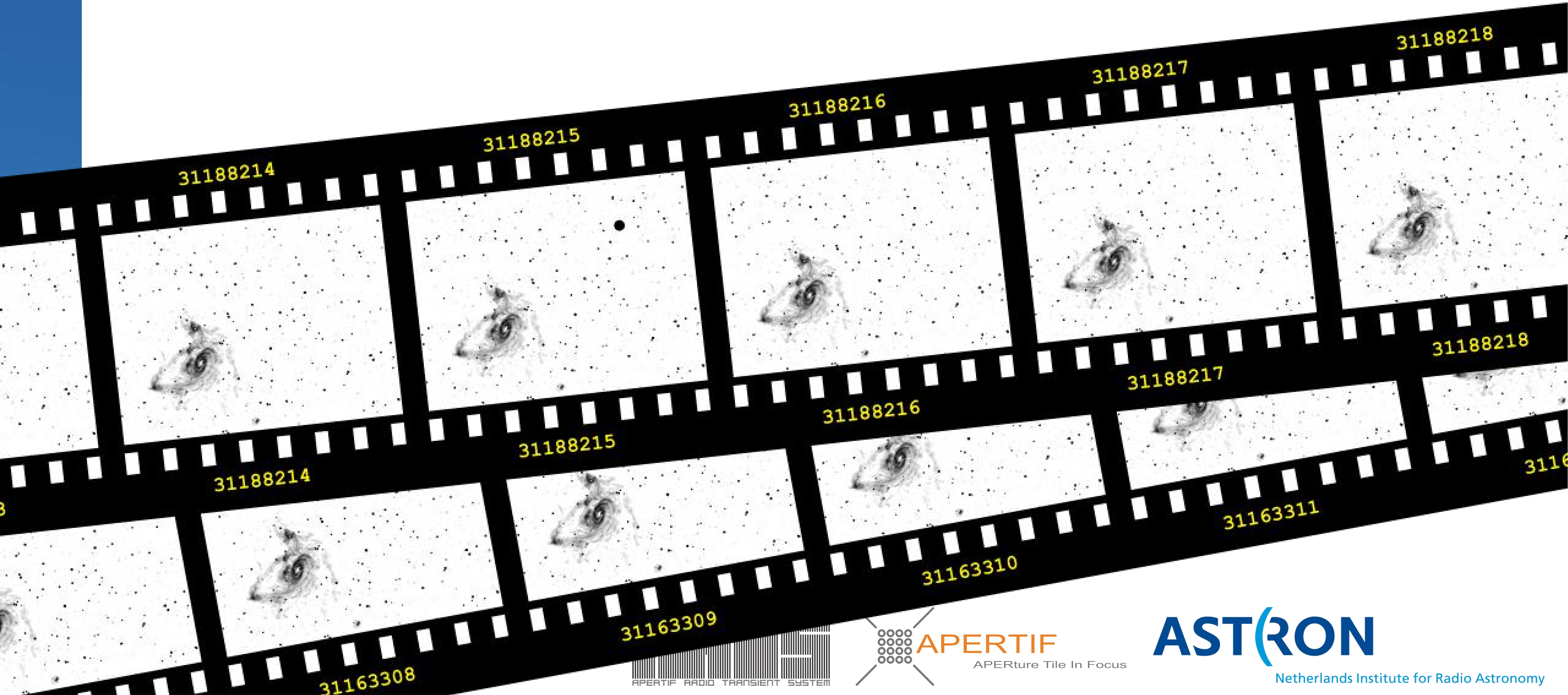
The Fast Radio Burst Sky as revealed by Apertif & LOFAR

Joeri van Leeuwen (ASTRON)

Time domain on interferometers



APERTIF RADIO TRANSIENT SYSTEM

APERTIF
APERture Tile In Focus

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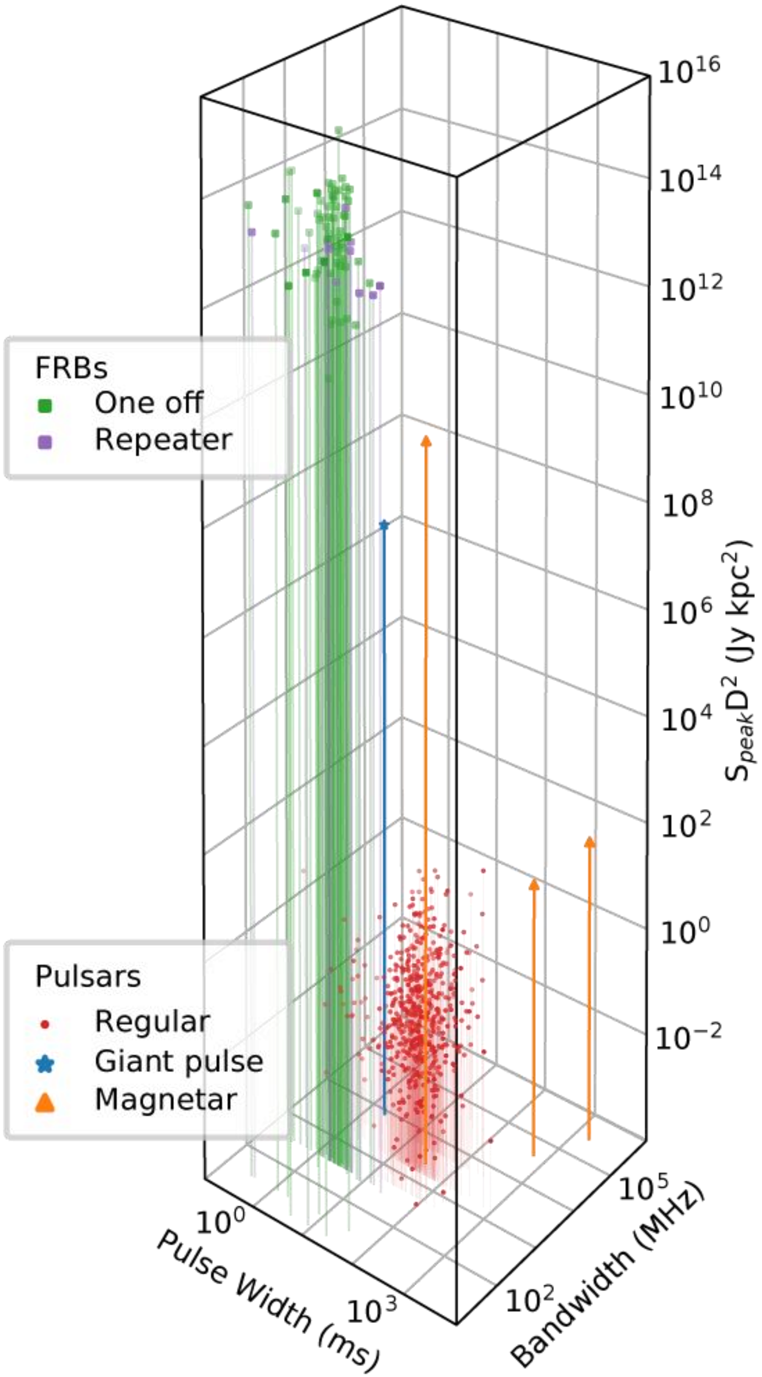
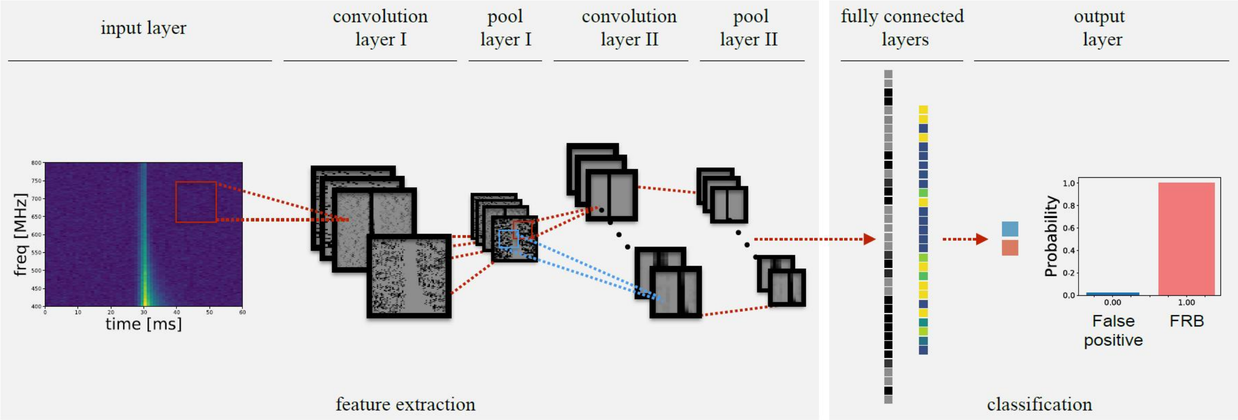

FRBs
One off
Repeater
Pulsars
Regular
Giant pulse
Magnetar
10^{16}
10^{14}
10^{12}
10^{10}
10^{8}
10^{6}
10^{4}
10^{2}
10^{0}
10^{-2}
$S_{peak}D^2$ (Jy kpc^2)
10^{0}
10^{3}
Pulse Width (ms)
10^{2}
10^{5}
Bandwidth (MHz)

Real–time processing

Hybrid supercomputer (Top 100 Equiv.) of

- Two FPGA-based beam formers + GPU cluster
- Real-time RFI excision
- AMBER search software
- Deep neural net detection



van Leeuwen et al. 2023, Vohl, Sclocco et al. 2016, 2020;
Maan & vL 2017, Connor & vL 2018

amber
apertif monitor for bursts encountered in real-time
APERTIF RADIO TRANSIENT SYSTEM
APERTIF
APERture Tile In Focus
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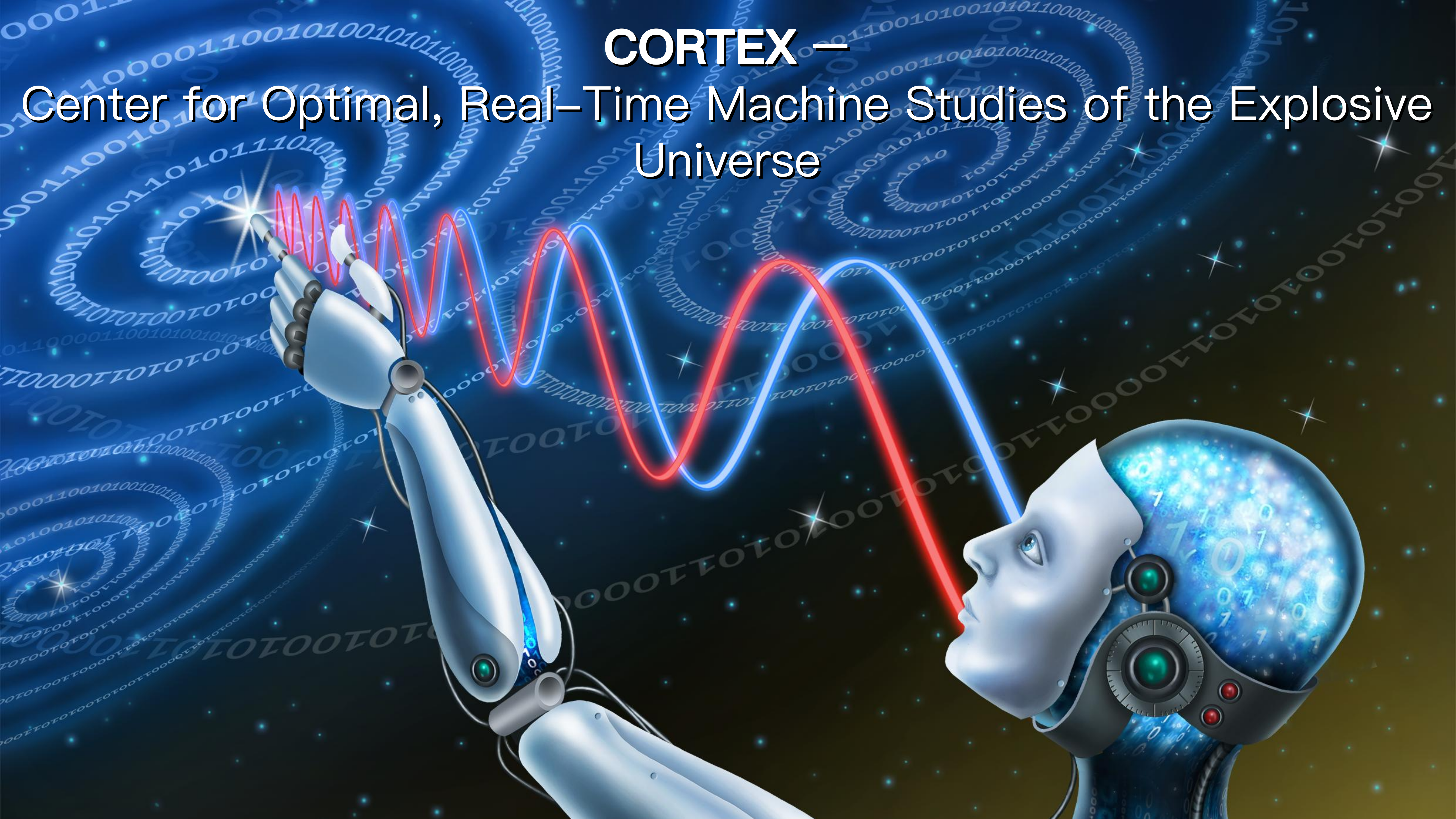
CORTEX –
Center for Optimal, Real-Time Machine Studies of the Explosive Universe

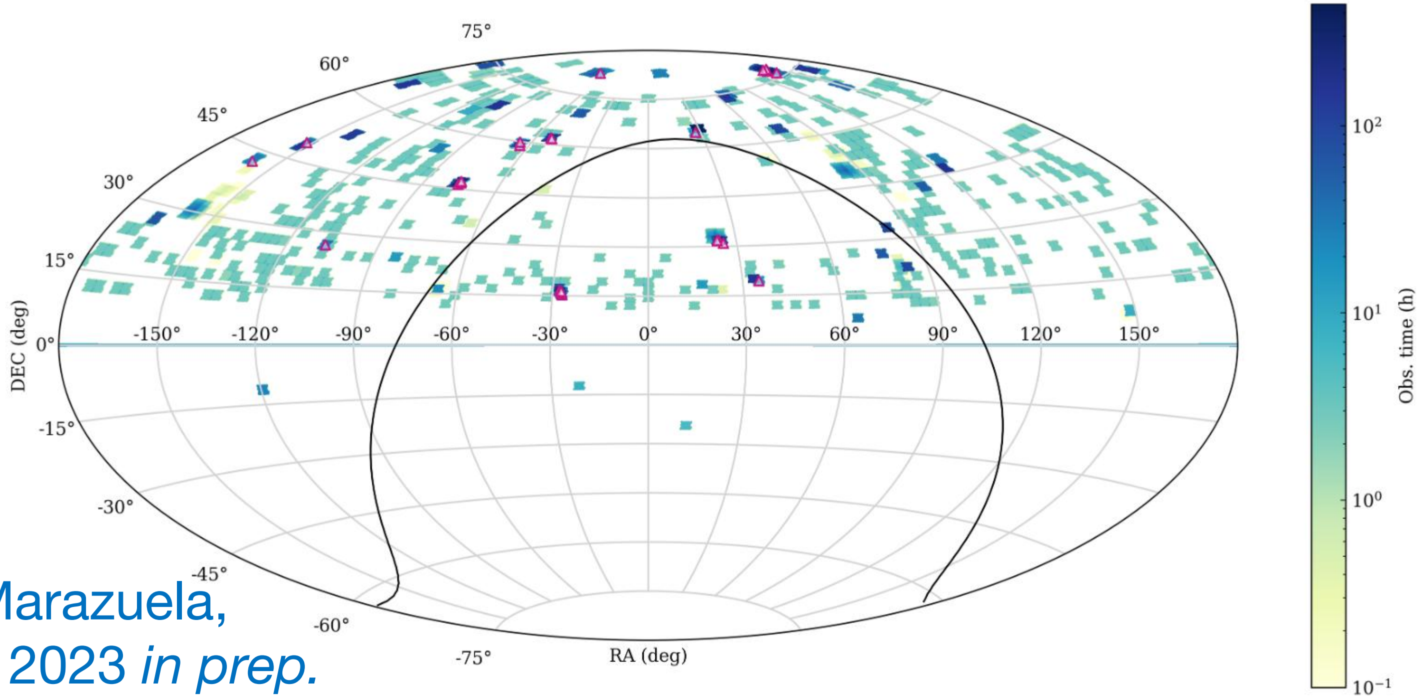


Pointing vs commensal

Field priorities *localization — characterization — detection*

1—2 weeks on, 4 weeks off ; 3 hr pointings

Operation 2.5 yrs, Jul 2019 .. Feb 2022.



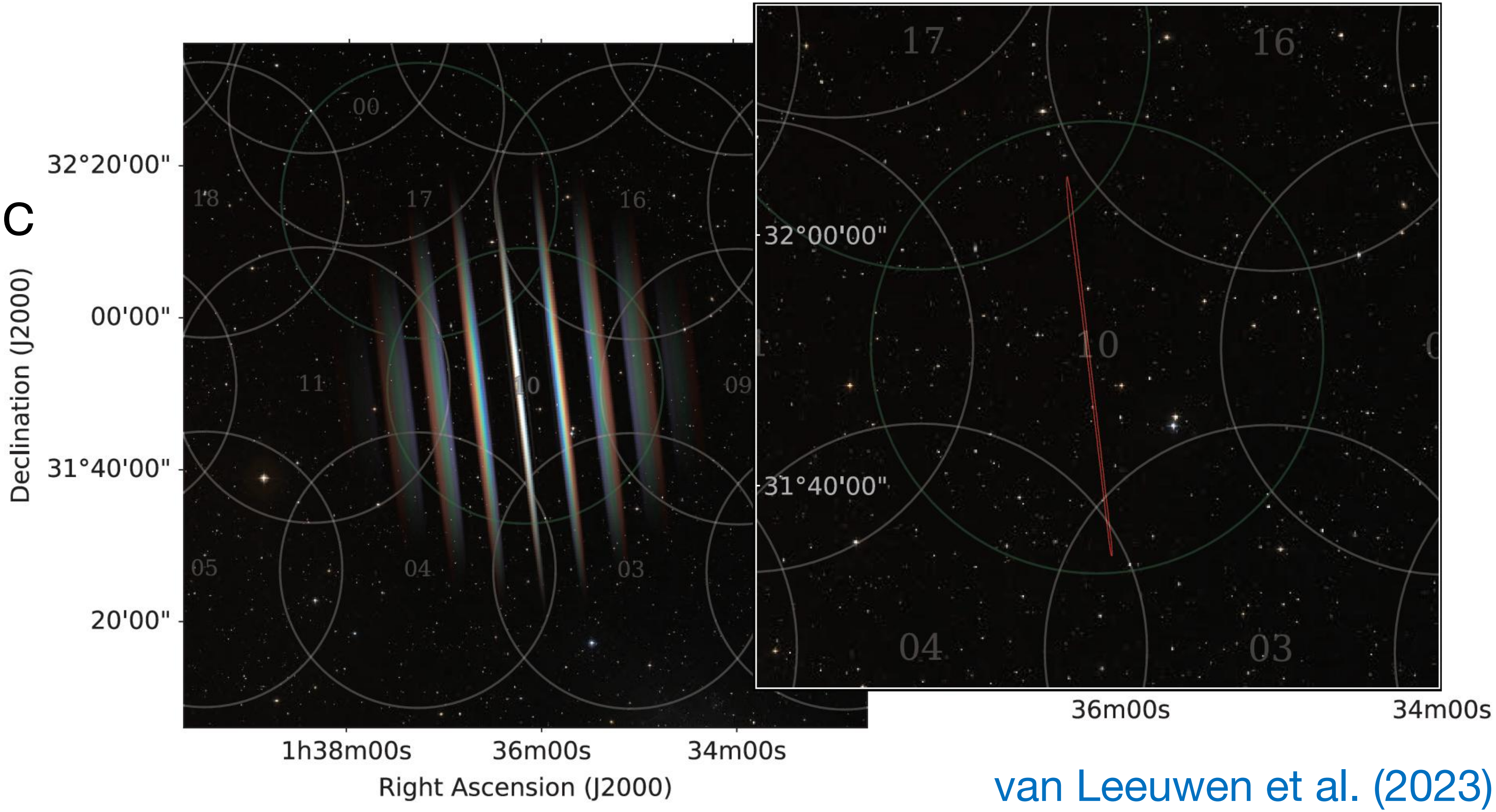
Pastor-Marazuela,
vL, et al. 2023 *in prep.*

Education and outreach

Apertif — first FRB detection

FRB 190709

DM = 663 pc/cc



van Leeuwen et al. (2023)

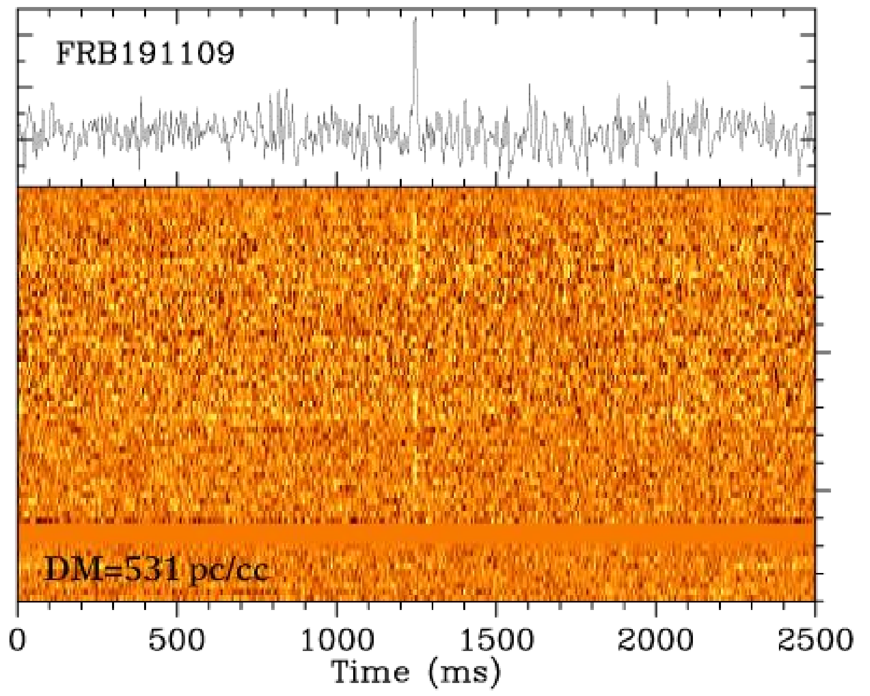
Discovered 24 new FRBs

One FRB every ~7 days of observing

One of most productive L–band surveys in the world

High DM, very narrow, quite broadband

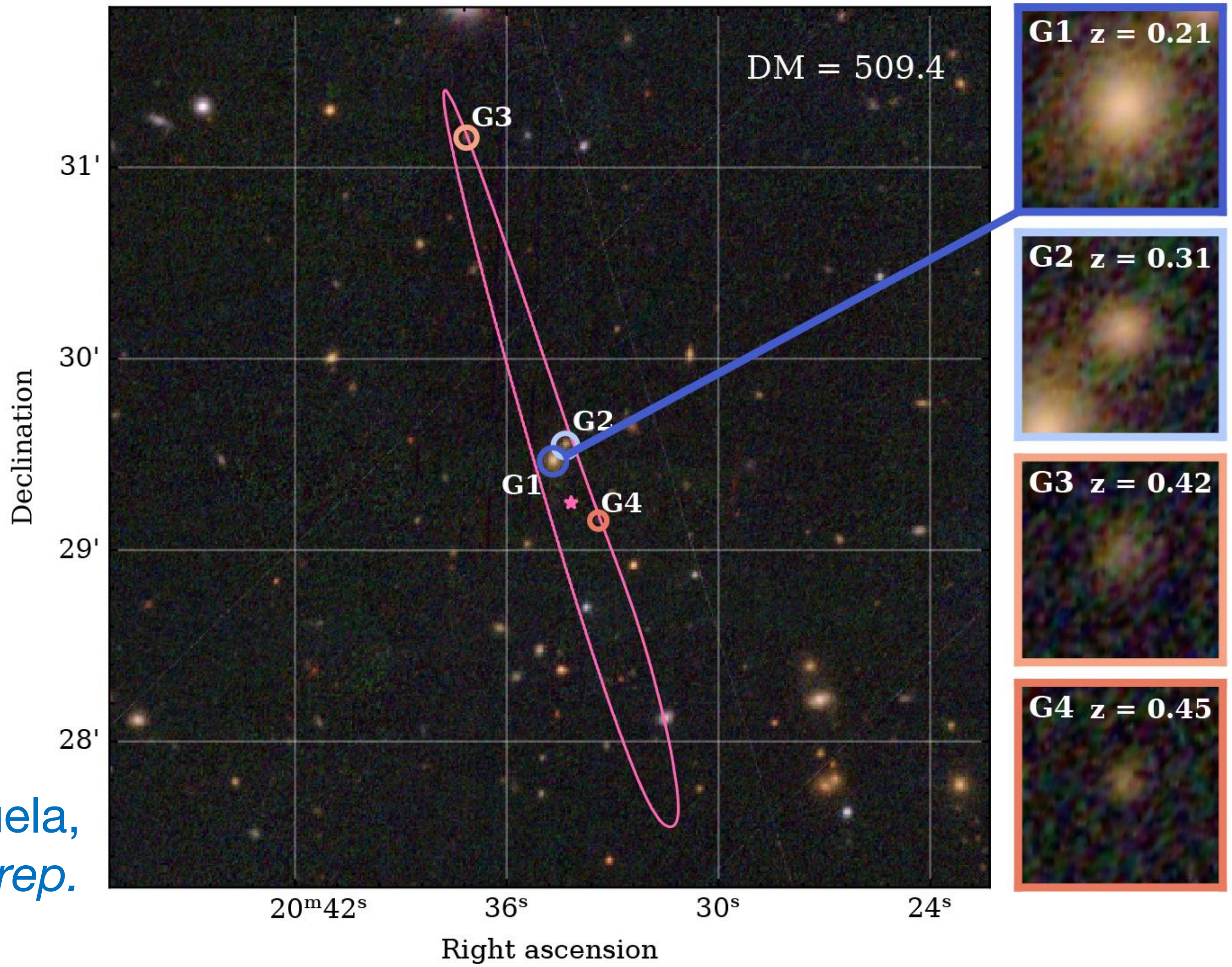
Interferometric localization



vL et al. 2023 (A&A, arxiv:2205.12362)
Pastor-Marazuela, vL et al. 2023 *in prep.*

Survey detection rate and localization

Interferometric host detection to $z = 0.21$:

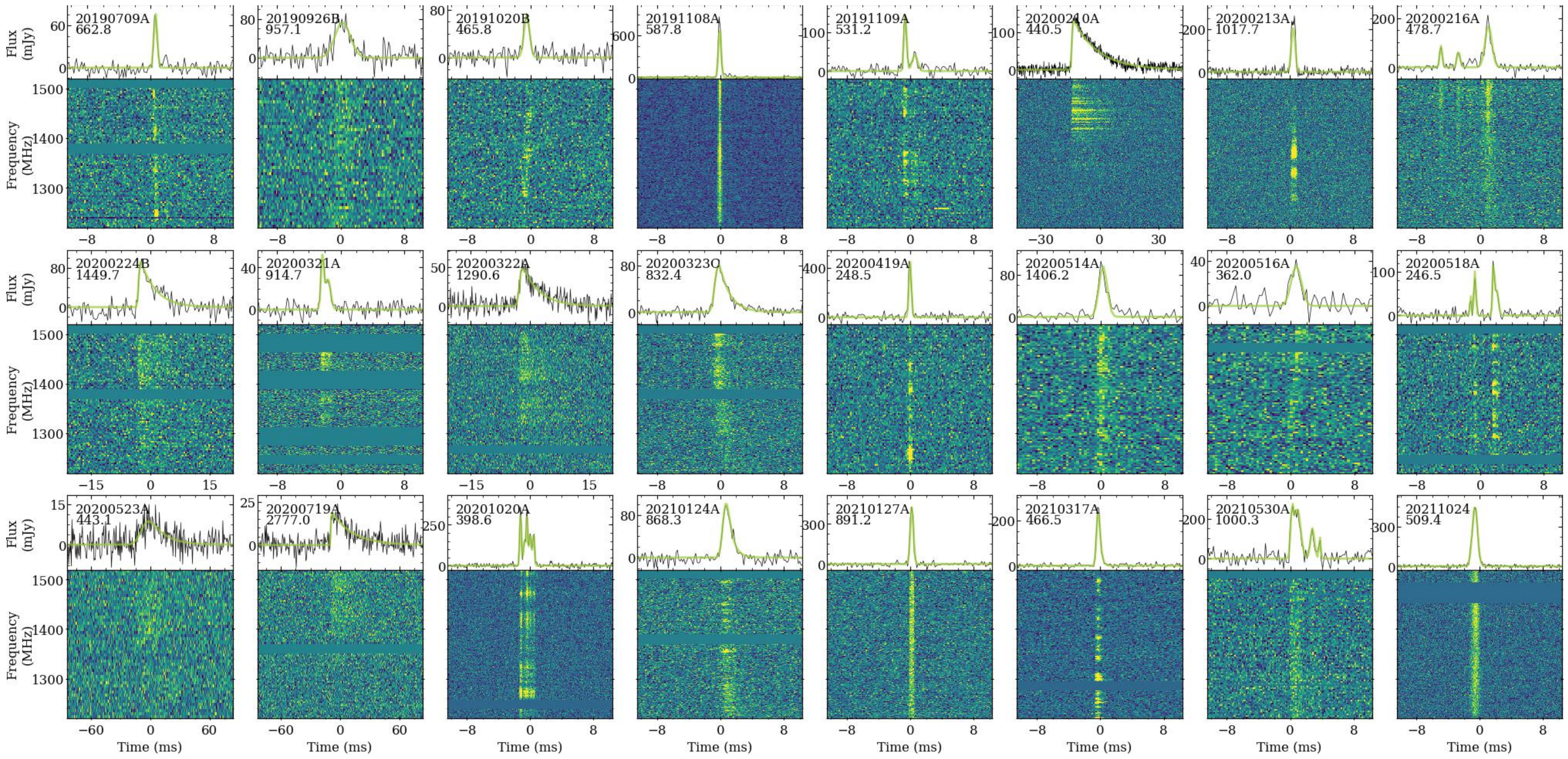


Pastor-Marazuela, vL et al. 2023 *in prep.*

Discovered 24 new FRBs

Interesting morphologies, multi-component, scattered:

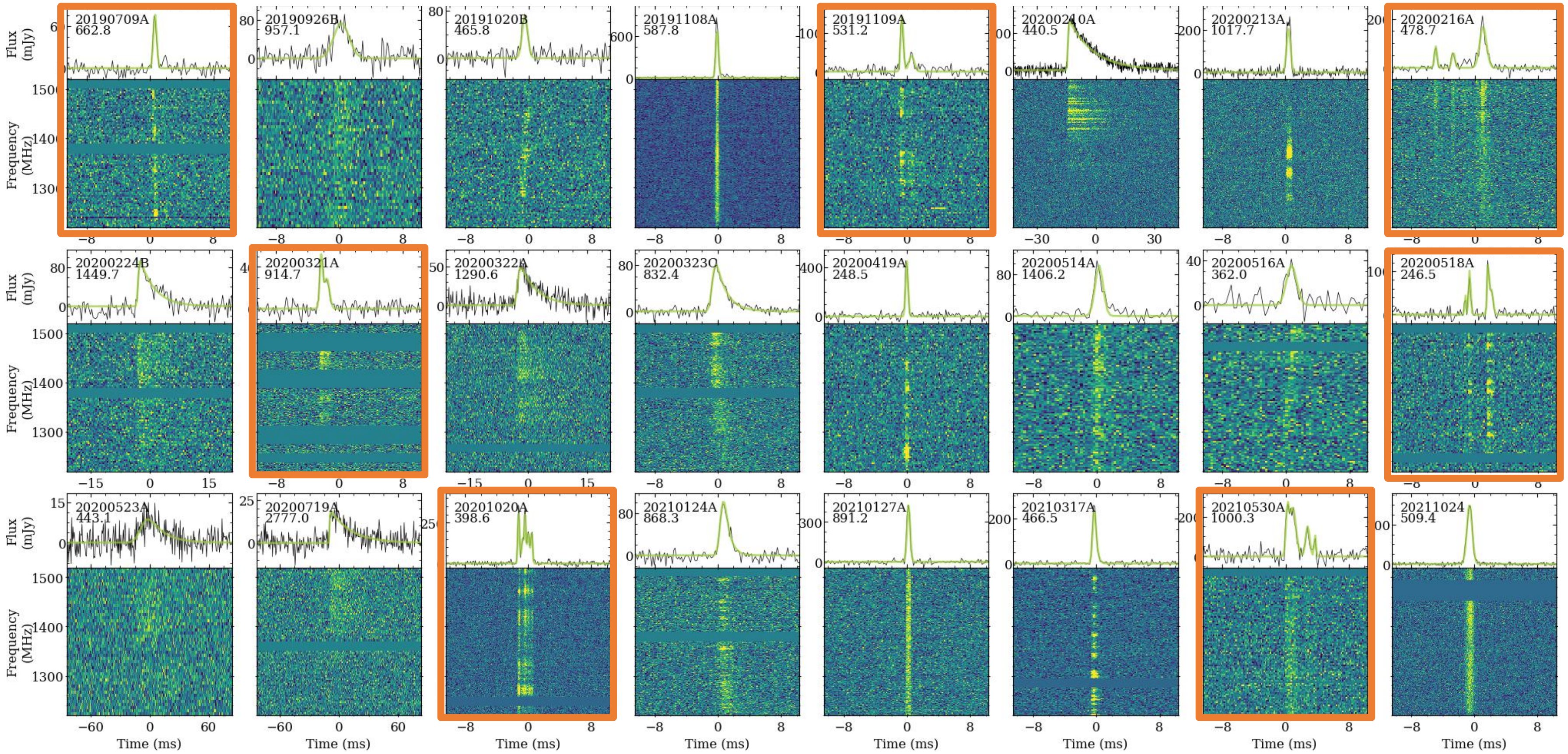
vL et al. 2023
PM, vL et al. 2023



Discovered 24 new FRBs

Higher multi-component fraction than @ CHIME

vL et al. 2023
PM, vL et al. 2023



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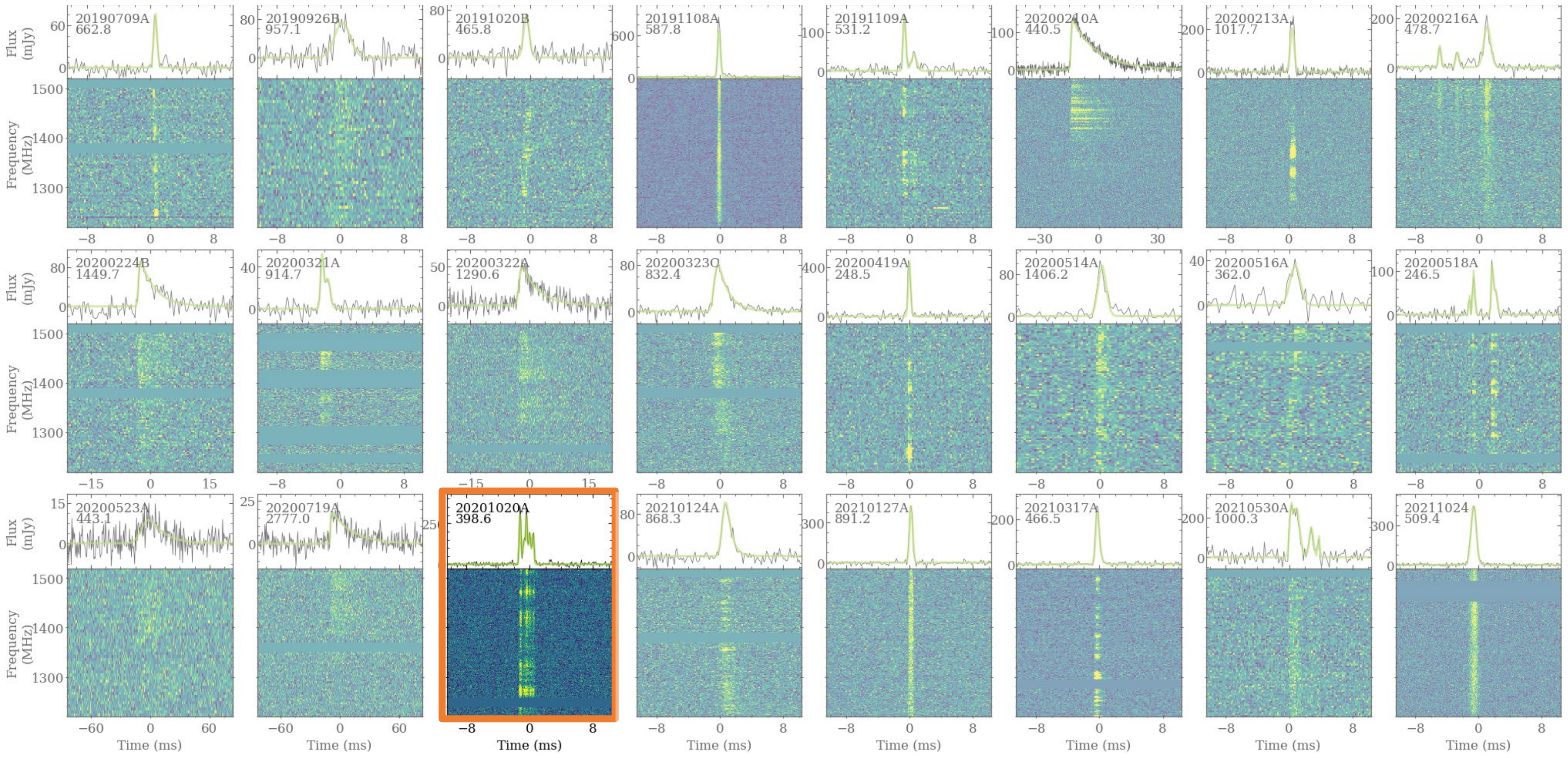


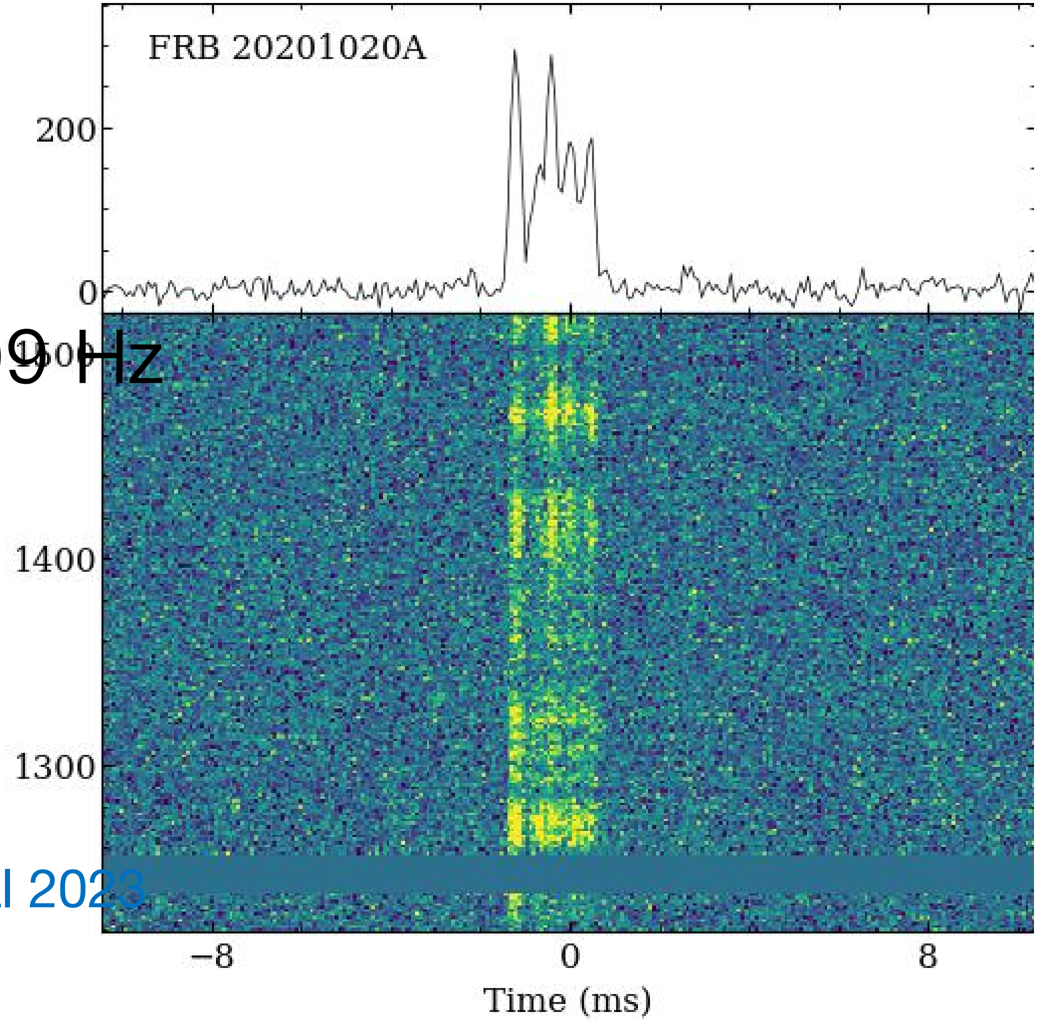
Discovered 24 new FRBs

Sub–ms pseudo–periodic structure:

5 components

Spacing 0.415 ms ➡ frequency ~2409 Hz

Periodicity significance 2.5σ

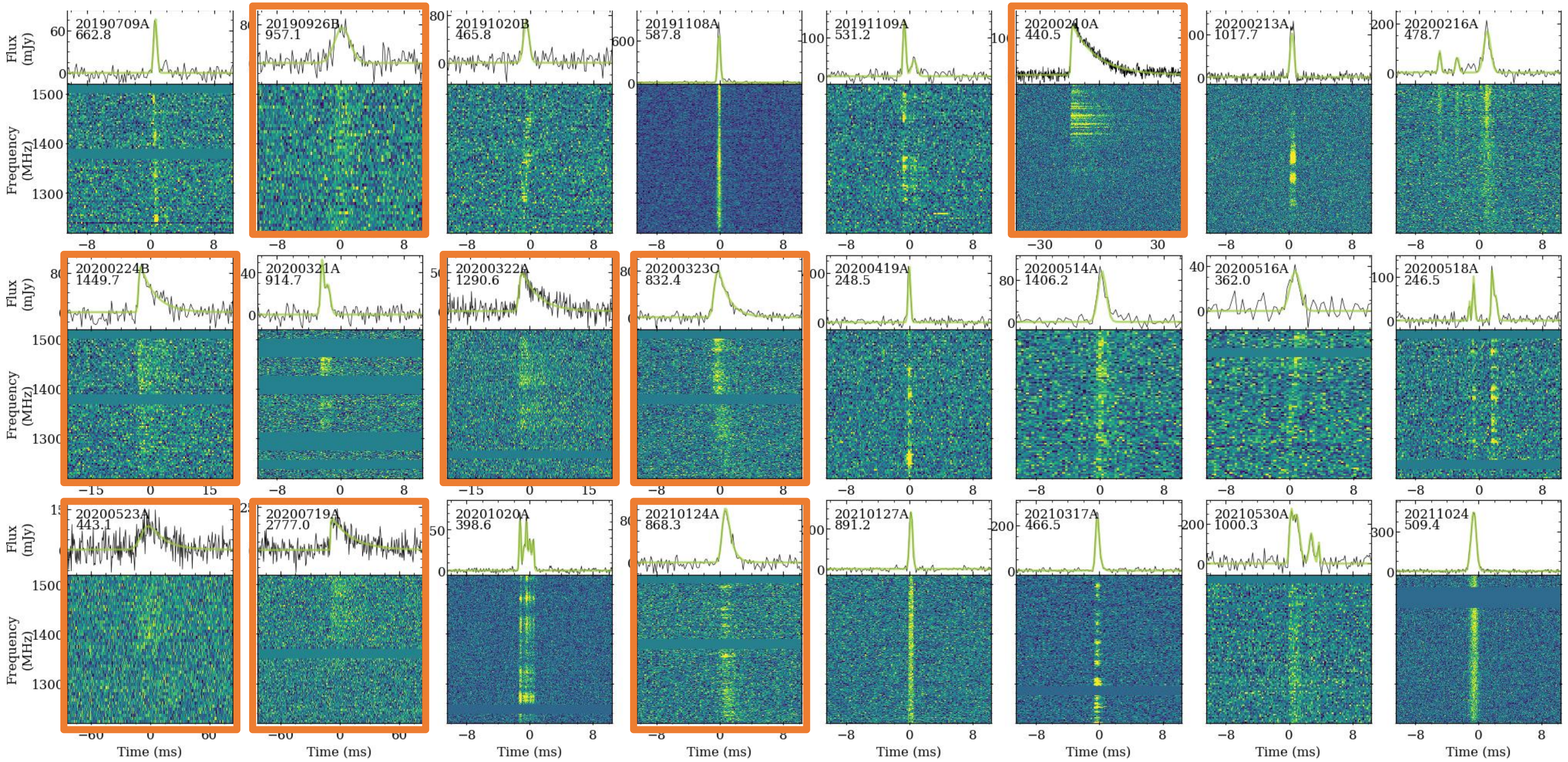


Pastor-Marazuela, vL, et al 2023
(arxiv:2202.08002)

Discovered 24 new FRBs

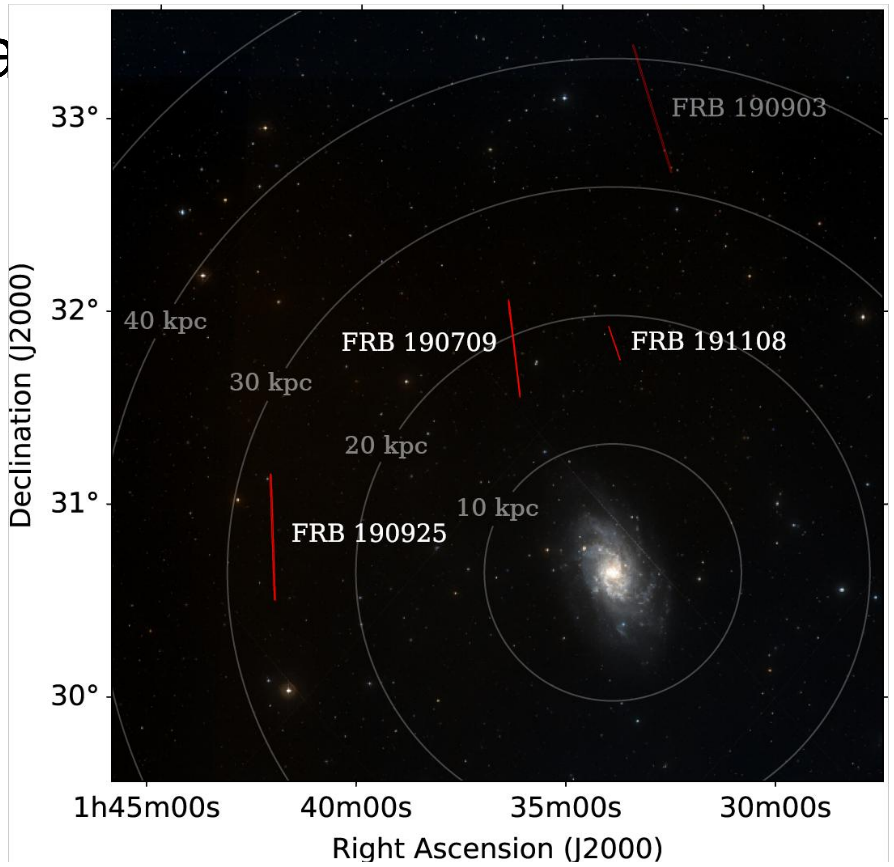
Scattering:

vL et al. 2023
PM, vL et al. 2023



Probing the M33 halo

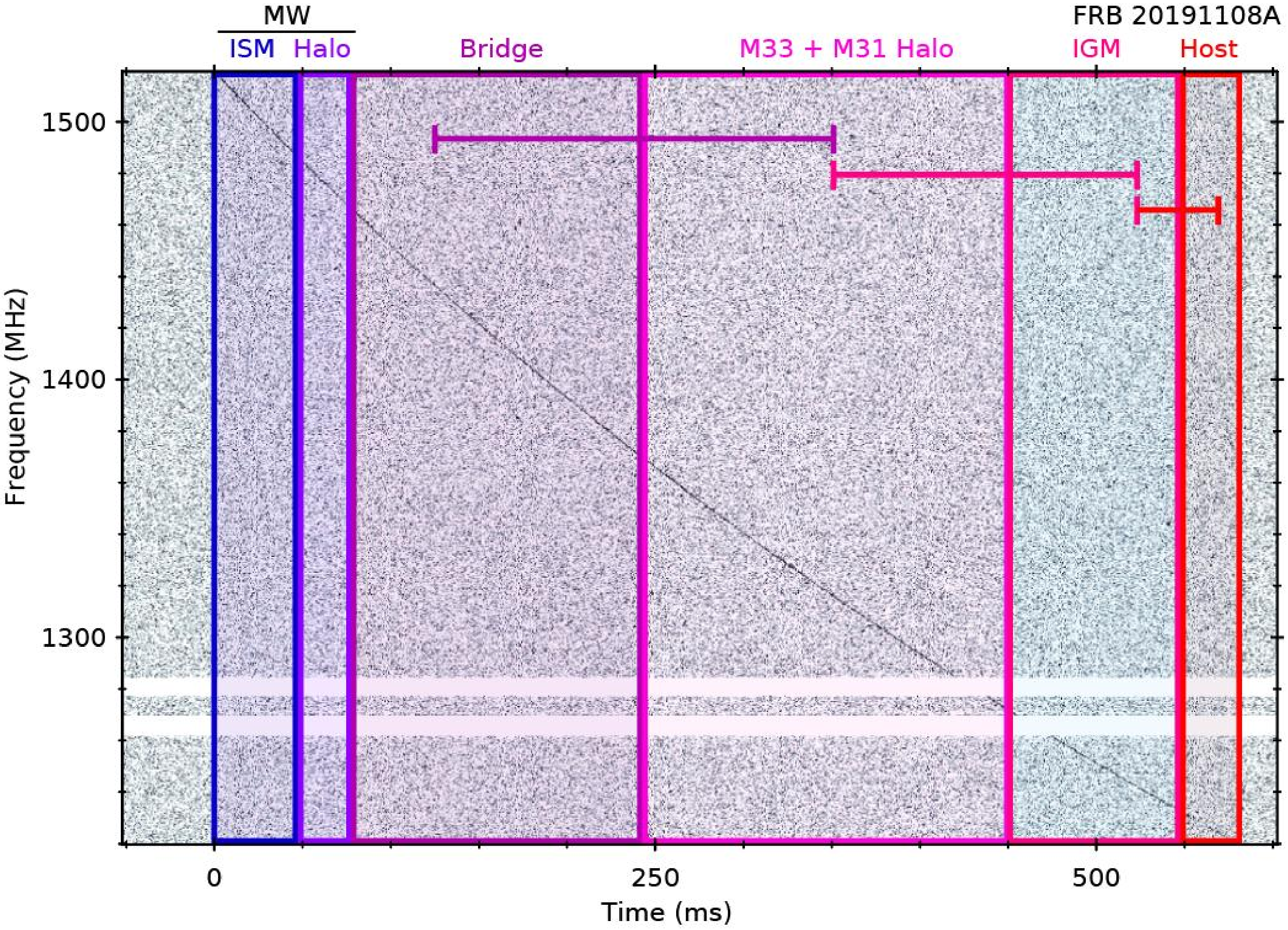
3 out of first 4 FRBs skewer M33/M31 ha
FRB 191108 is localised to 5” x 7’ ellipse
Cuts within a degree (~18 kpc) of M33



Connor et al. (2020, MNRAS 499, 4716)
van Leeuwen et al. (2023, A&A 672, A117)

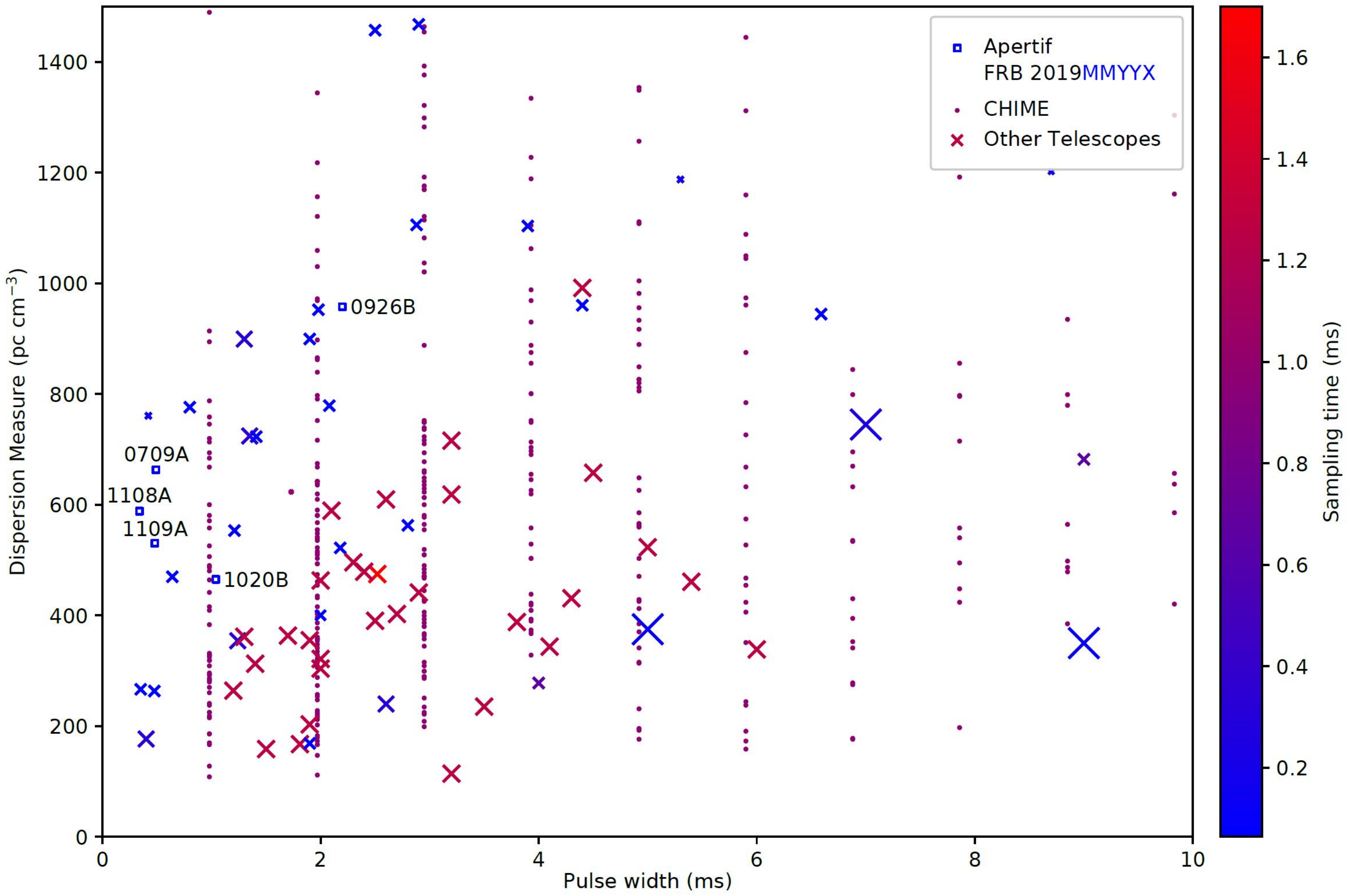
Probing the M33 halo

Skewers halo + CGM



Characteristics of the discovered sample

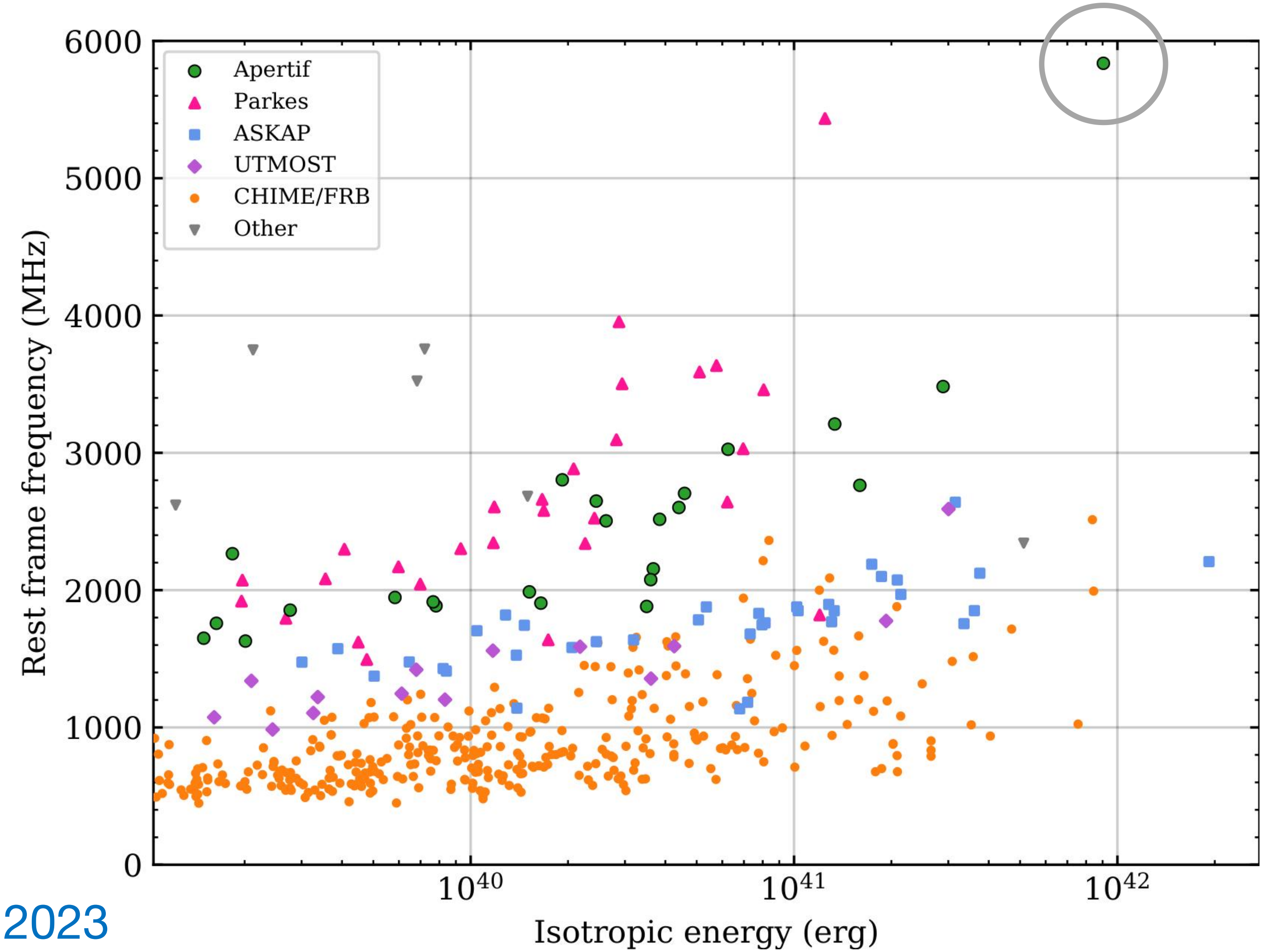
The Apertif FRBs are among the narrowest known, and have high dispersion measure.



Van Leeuwen et al. 2022

Characteristics of the discovered sample

FRB 20200719A is the 3rd most dispersed FRB known to date, and its rest frame shows FRB emission frequencies reach 6 GHz.



PM, vL et al. 2023

Intrinsic FRB Characteristics

Order–of–magnitude speedup of **`frbpoppy`**

+

National supercomputer "Snellius"

=

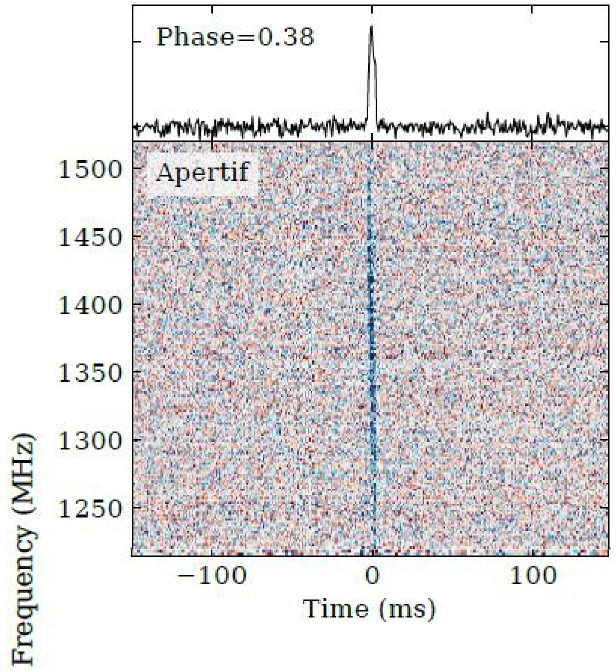
Full MCMC

frbpoppy

Gardenier & van Leeuwen 2021
Yuyang Wang, vL et al. *in prep*

Repeater FRB 20180916B at Apertif + LOFAR

We detected repeating FRB 20180916B



Pastor-Marazuela et al. 2021, *Nature* 596, 505

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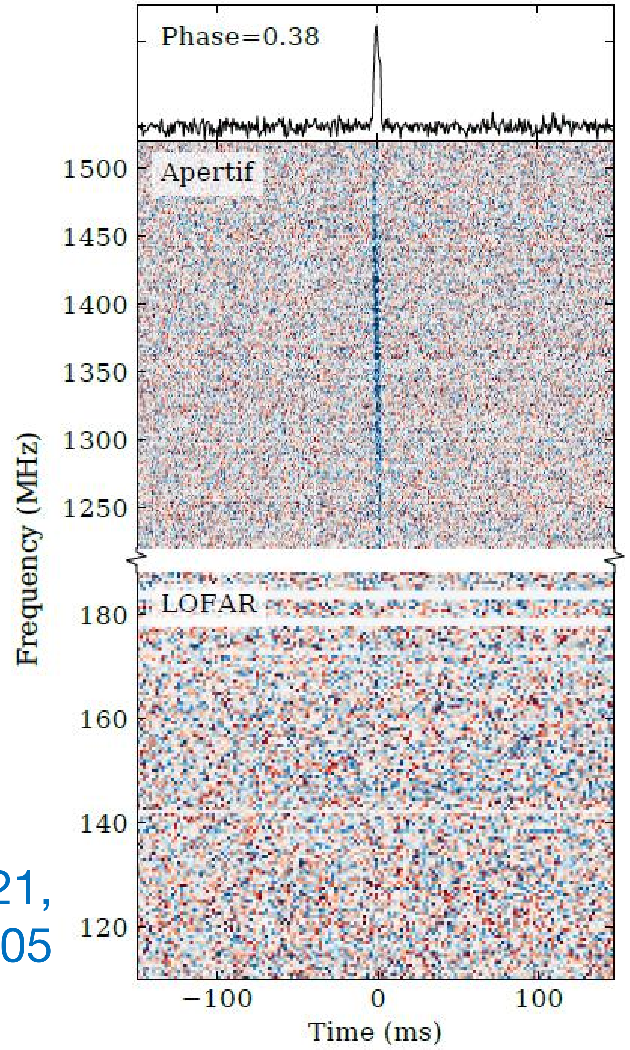

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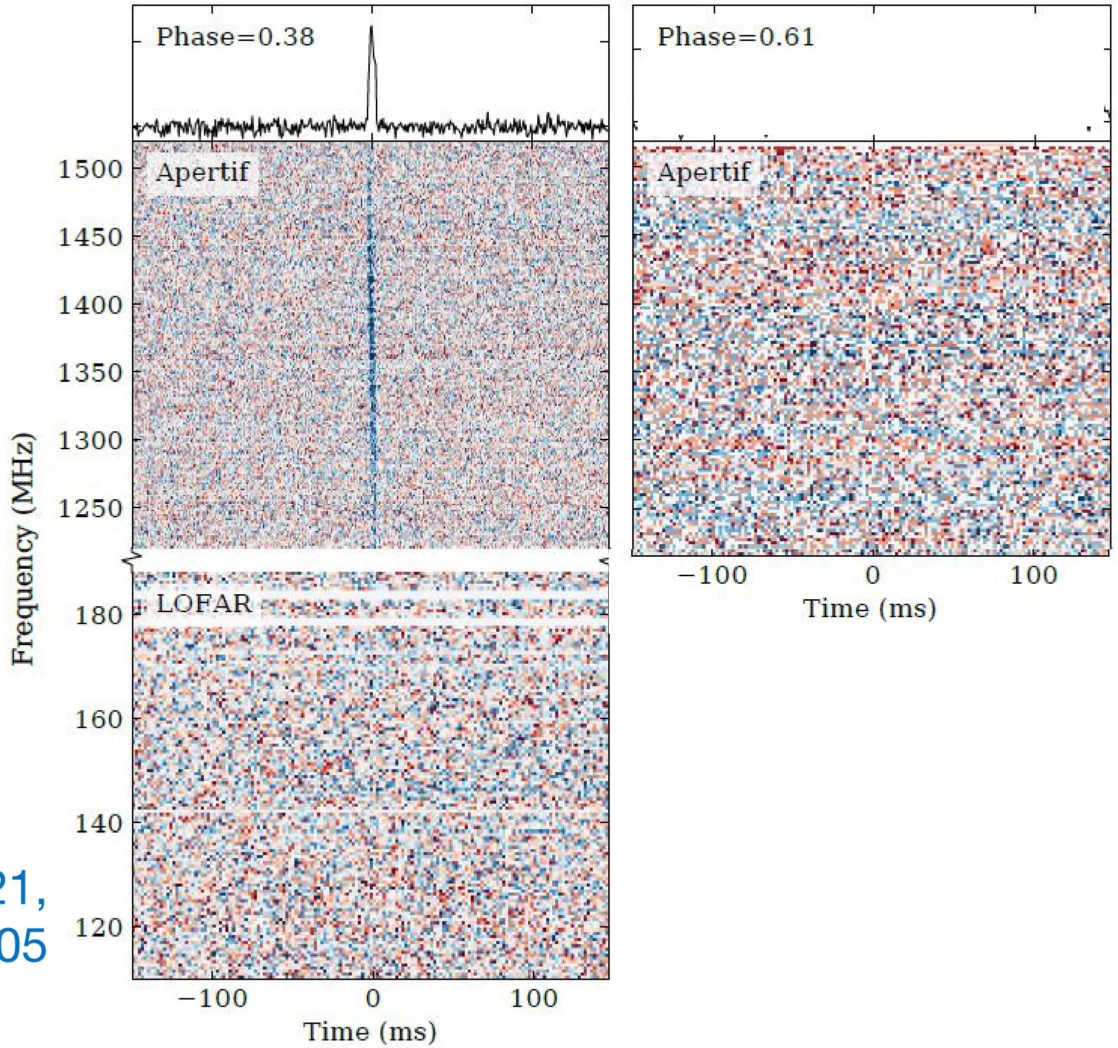
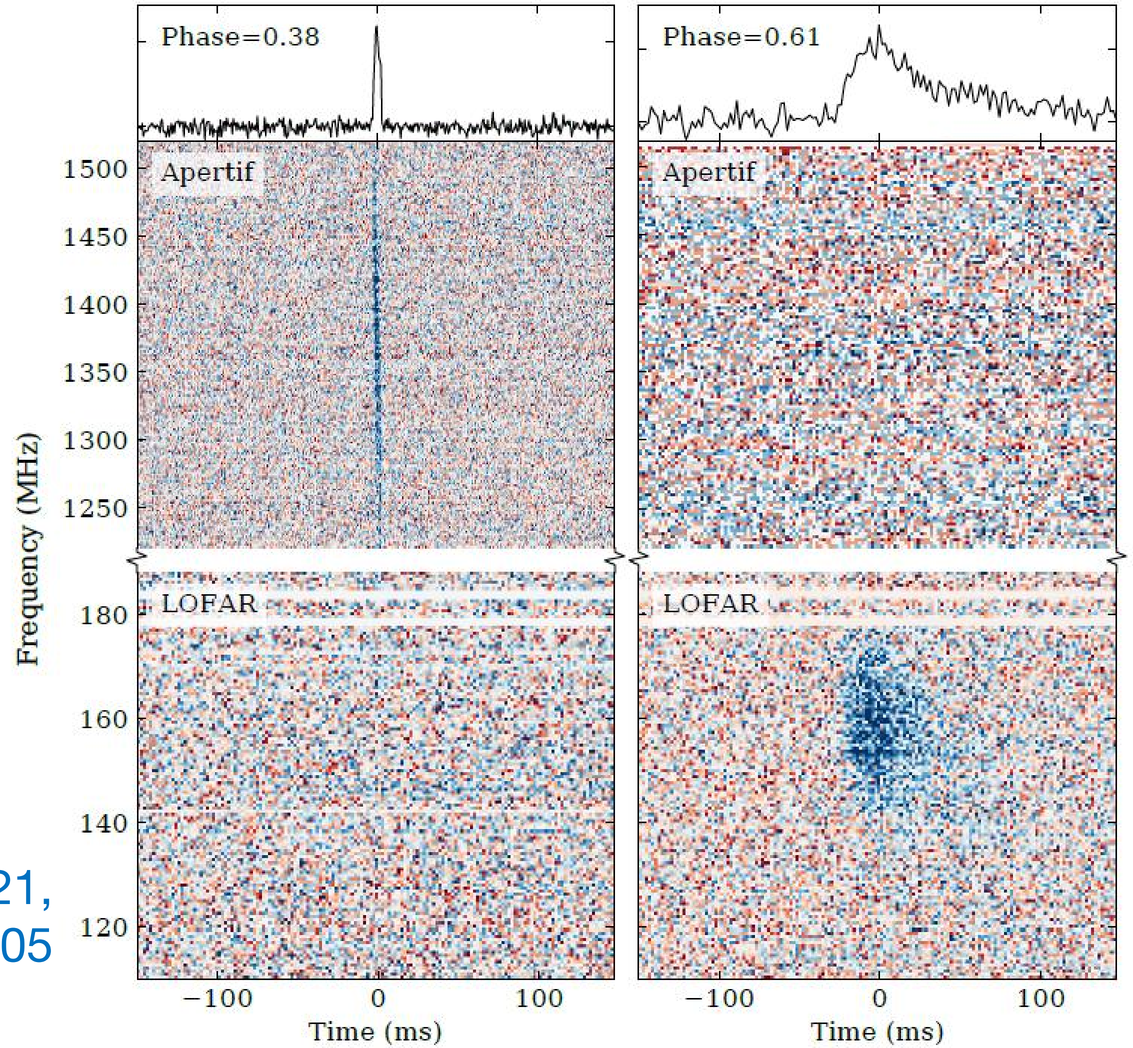


Pastor-Marazuela et al. 2021,
Nature 596, 505

Repeater FRB 20180916B at Apertif + LOFAR

We detected repeating FRB 20180916B at both telescopes; but never at the same time.

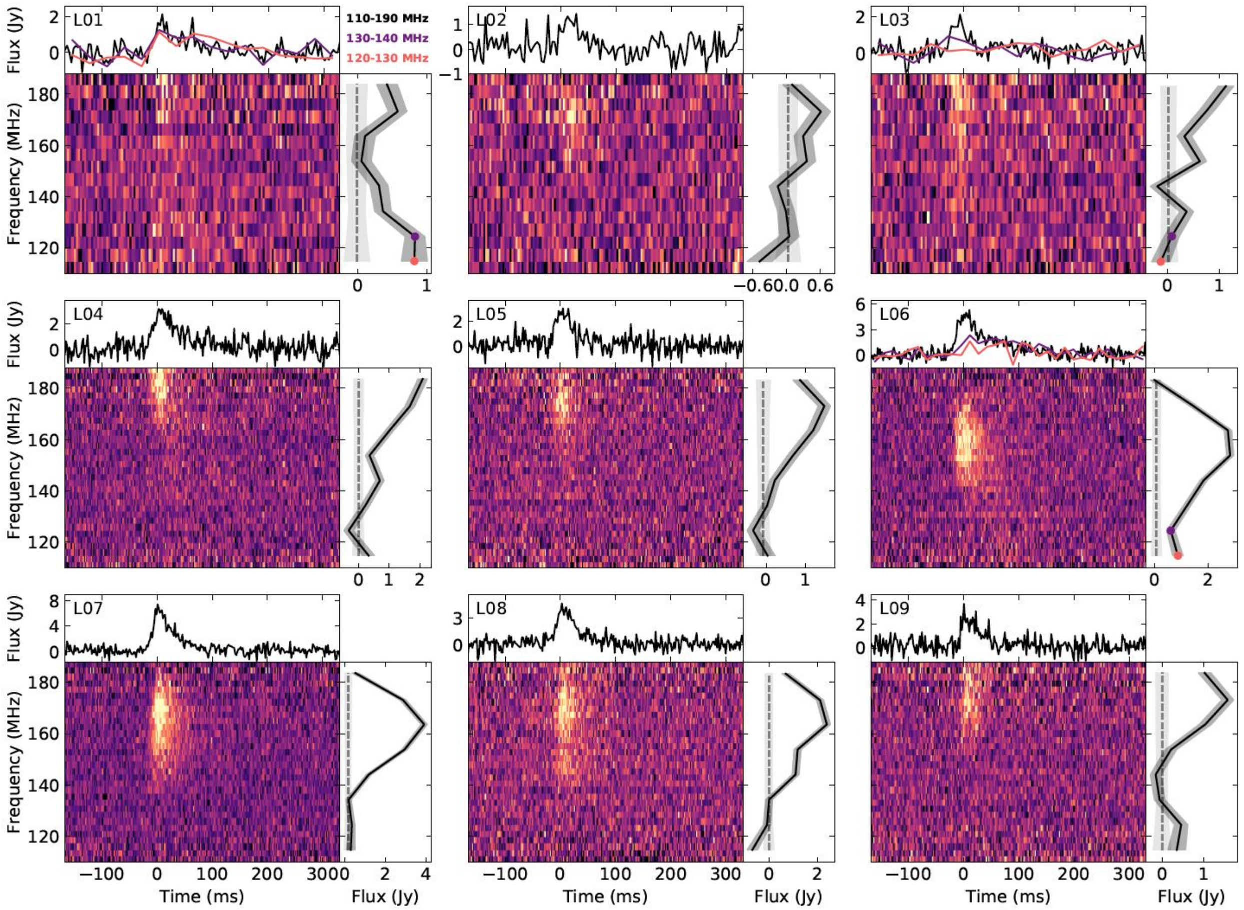


Pastor-Marazuela et al. 2021, *Nature* 596, 505

Repeater FRB 20180916B at Apertif + LOFAR

First FRB ever seen with LOFAR.

Low–frequency FRB emission escapes local medium — clean environment, important for cosmology applications.



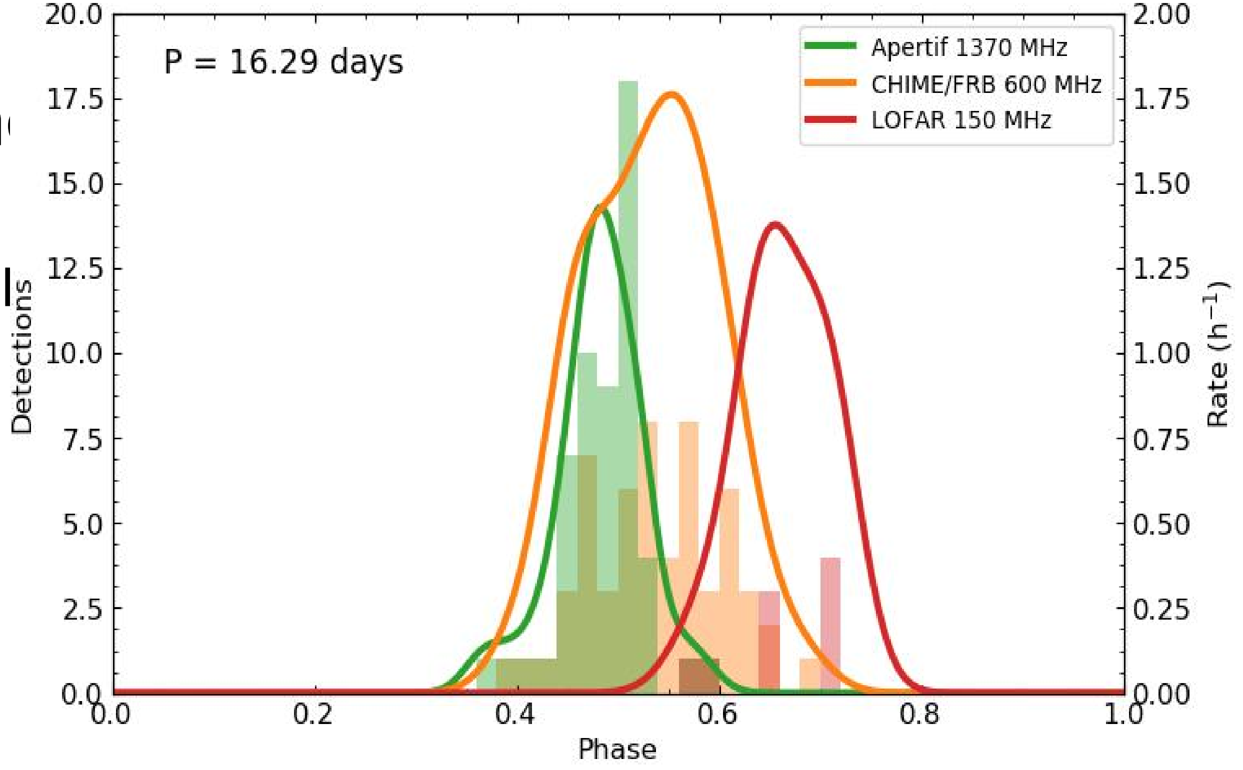
Pastor-Marazuela et al. 2021, *Nature* 596, 505

Repeater FRB 20180916B at Apertif + LOFAR

Activity *peaks earlier* and *is narrower* at higher frequencies than at lower frequencies.

This FRB lives in clean environm
Opposite to binary wind models.
Ultra–long period magnetars wo

Pastor-Marazuela et al. 2021, *Nature*
Pleunis al. 2021 supports this trend



Conclusions

The Era of Interferometers

Full coherent–addition sensitivity + good localization:
Discovered 24 one–off FRBs (1/week), including high–freq emitters:
Good rates *and* localization.

We showed solid rates + mapping magneto–ionic material along well–defined lines of sight is starting:
Galaxy evolution & cosmology with FRBs.
LOFAR detection helps constrain local environments.

erc European Research Council Established by the European Commission
NWO
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netherlands eScience center
NOVA

EXTRA

LOFAR2.0 capabilities

- More receivers and processing capacity at the stations, enabling
  - Simultaneous LBA-HBA observing, or
  - Double the LBA or HBA beams*bandwidth

Station capability	LOFAR1	LOFAR2.0
NL	48 LBA or 48 HBA	96 LBA and 48 HBA
International	96 LBA or 96 HBA	96 LBA and 96 HBA

- Distribution of a central clock to all NL stations (White Rabbit)
- COBALT2.0 LOFAR Mega Mode

Slide: Wim van Cappellen

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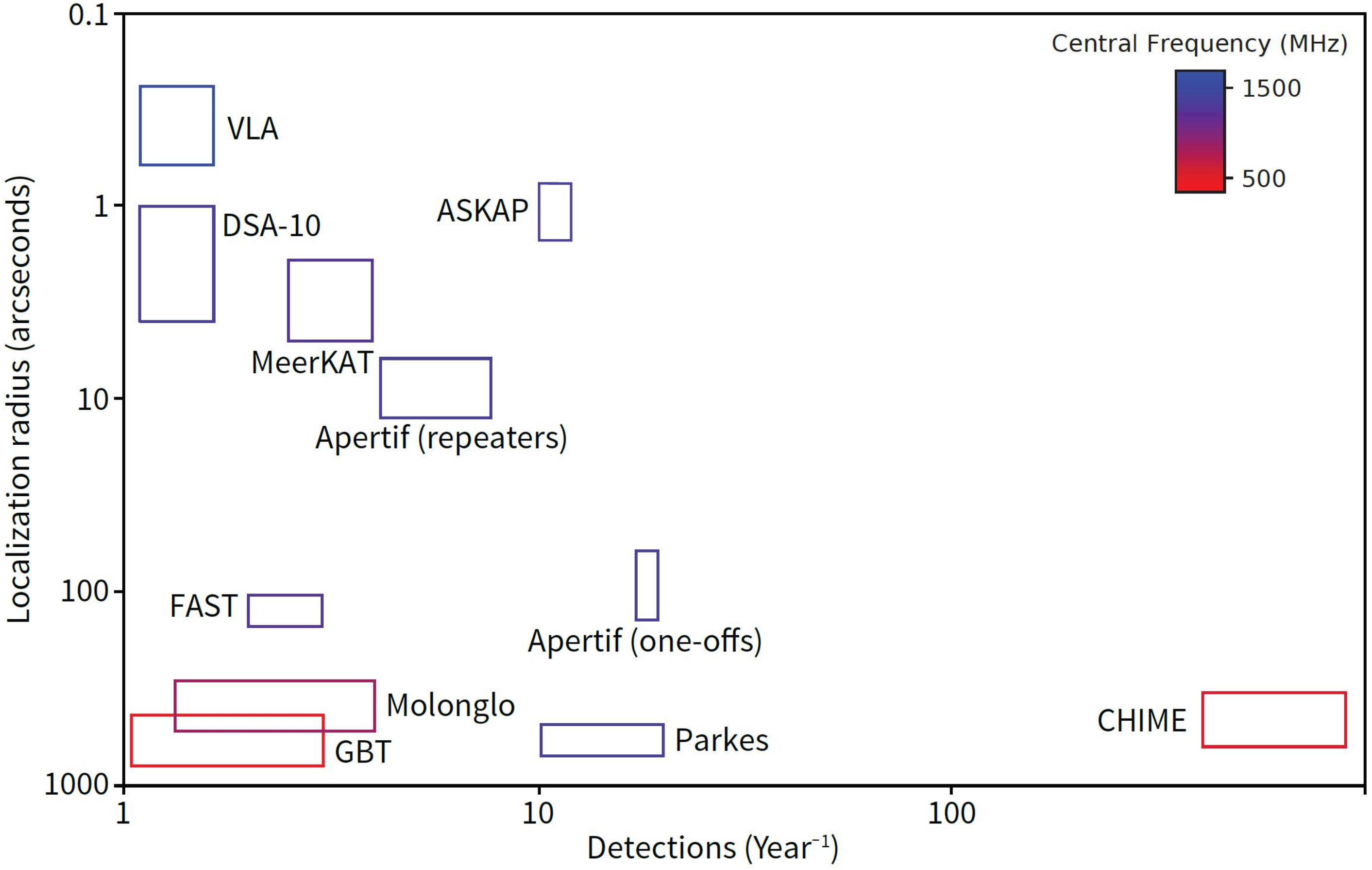
Survey detection rate and localisation

ASKAP, CHIME and Apertif each have their own trade off between rate and localisation accuracy, with Apertif providing both.



Van Leeuwen et al. 2022