Low-frequency fast-transient with NenuFAR

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Image credit: Nançay Radio Observatory

URSI2023@Sapporo

NenuFAR radio telescope

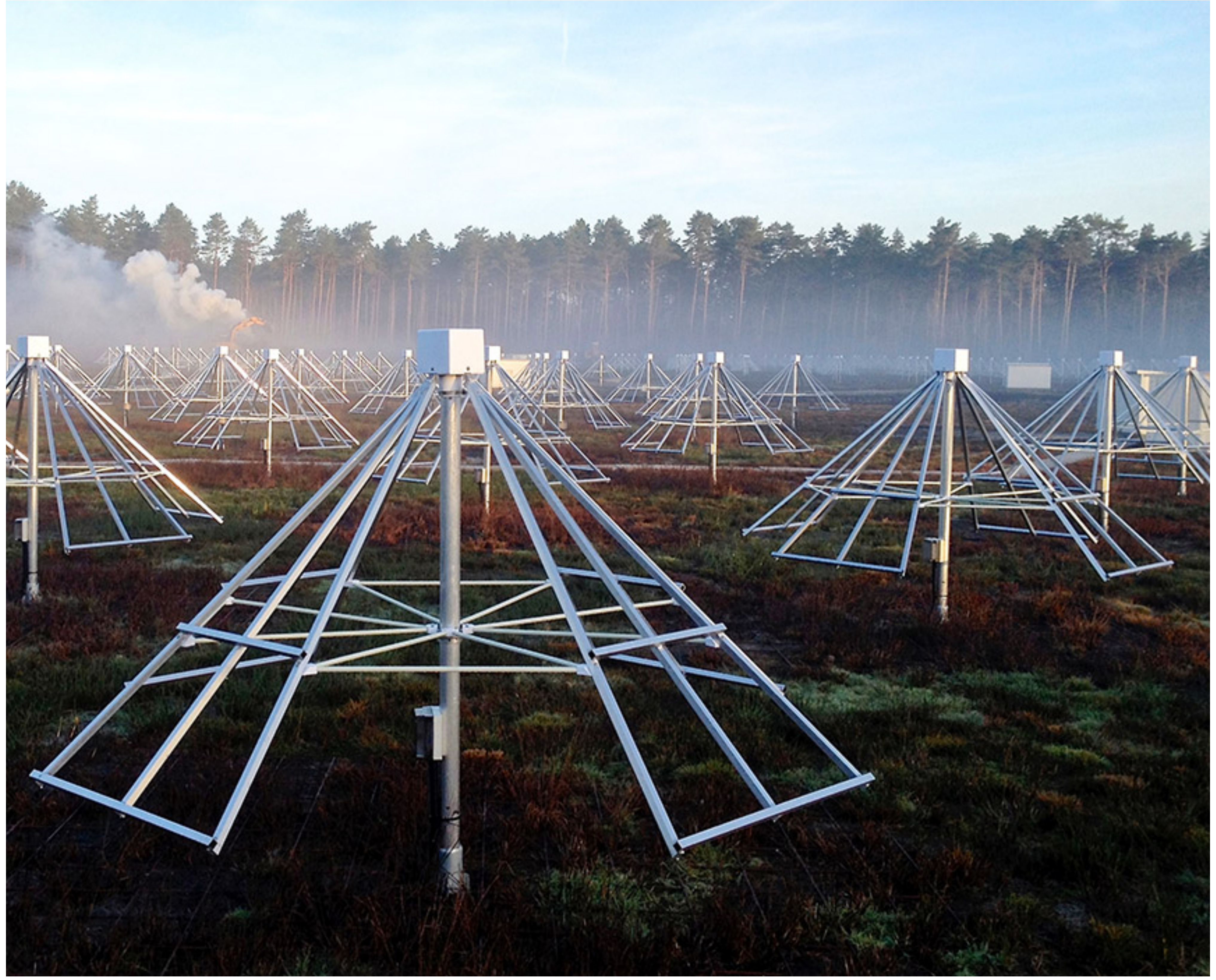
New **e**xtension in **N**ançay **u**pgrading **LOFAR = NenuFAR**

A LOFAR Super Station (LOFAR2.0 from ~2025)

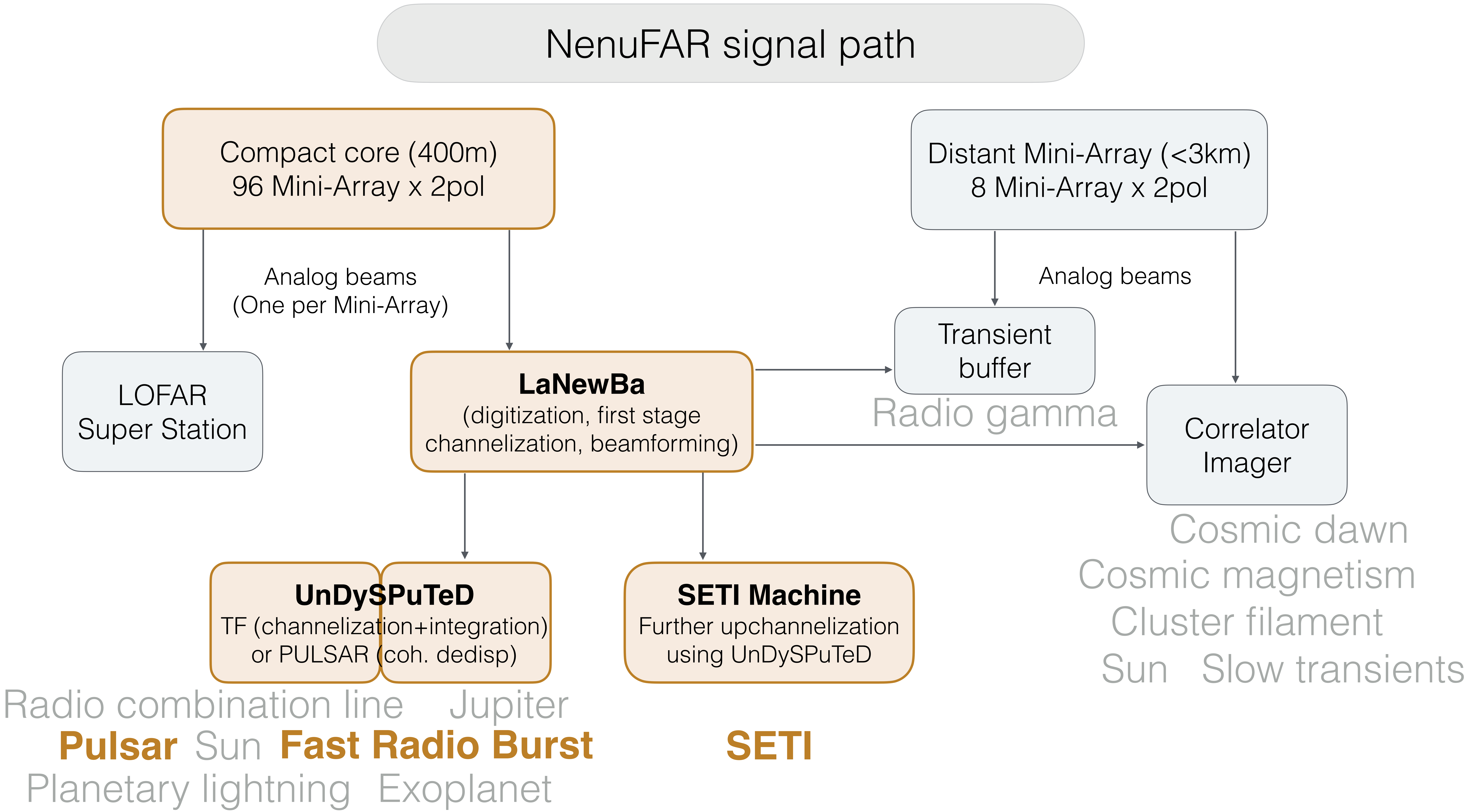
Also stand-alone operations since 2019, full array in 2024.

NenuFAR radio telescope

New **e**xtension in **N**ançay **u**pgrading **LOFAR = NenuFAR**



- First light in 2019, full array in 2024
- 96+8 mini-arrays each with 19 antennas —> total 1976 antennas
- 10-85 MHz — lowest radio freq from ground


NenuFAR signal path
Compact core (400m)
96 Mini-Array x 2pol
Distant Mini-Array (<3km)
8 Mini-Array x 2pol
Analog beams
(One per Mini-Array)
Analog beams
LOFAR
Super Station
LaNewBa
(digitization, first stage channelization, beamforming)
Transient buffer
Radio gamma
Correlator Imager
Cosmic dawn
Cosmic magnetism
Cluster filament
Sun
Slow transients
UnDySPuTeD
TF (channelization+integration)
or PULSAR (coh. dedisp)
SETI Machine
Further upchannelization
using UnDySPuTeD
Radio combination line
Jupiter
Pulsar
Sun
Fast Radio Burst
SETI
Planetary lightning
Exoplanet

Why pulsars with NenuFAR?

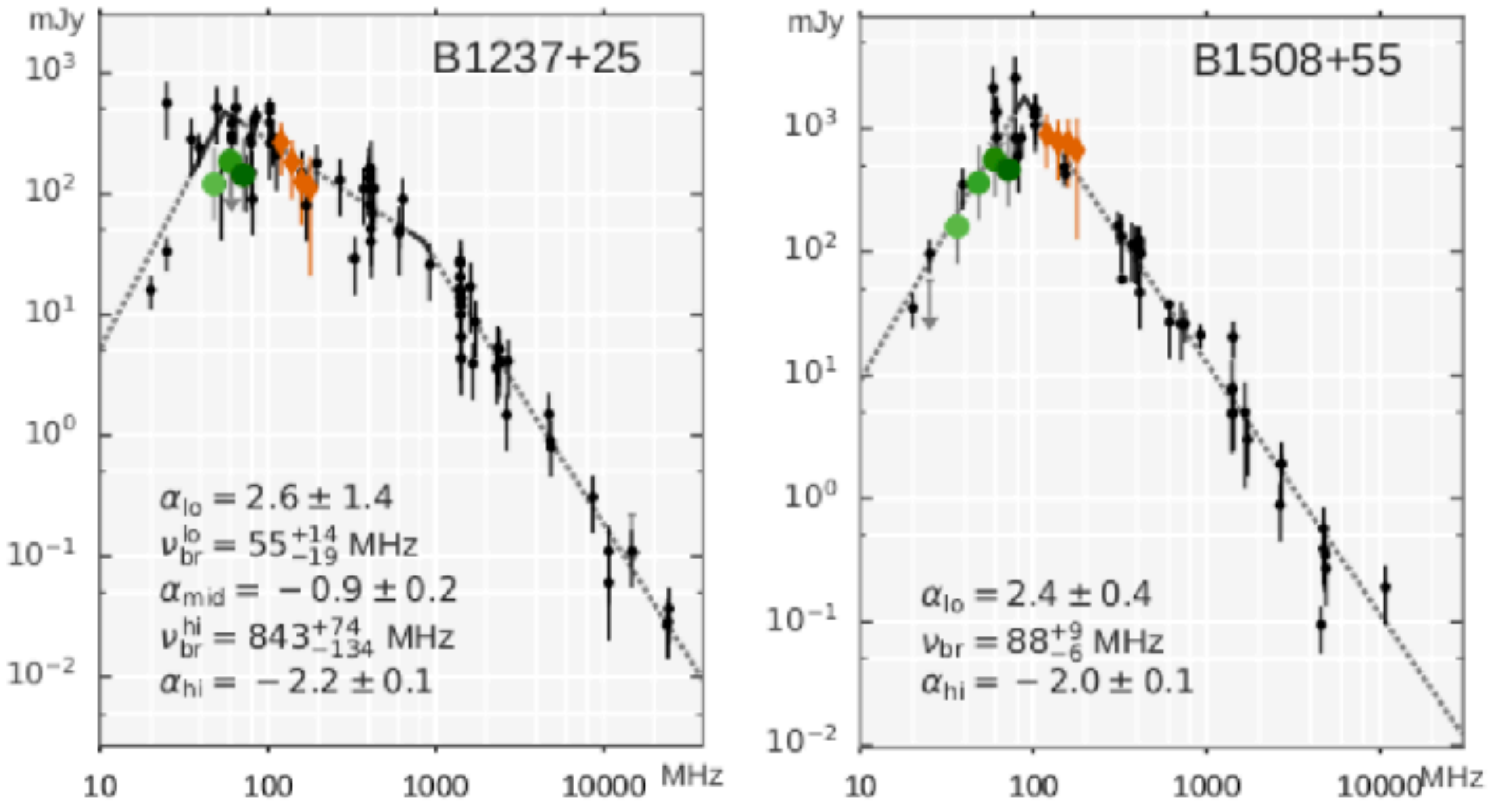
Motivations:

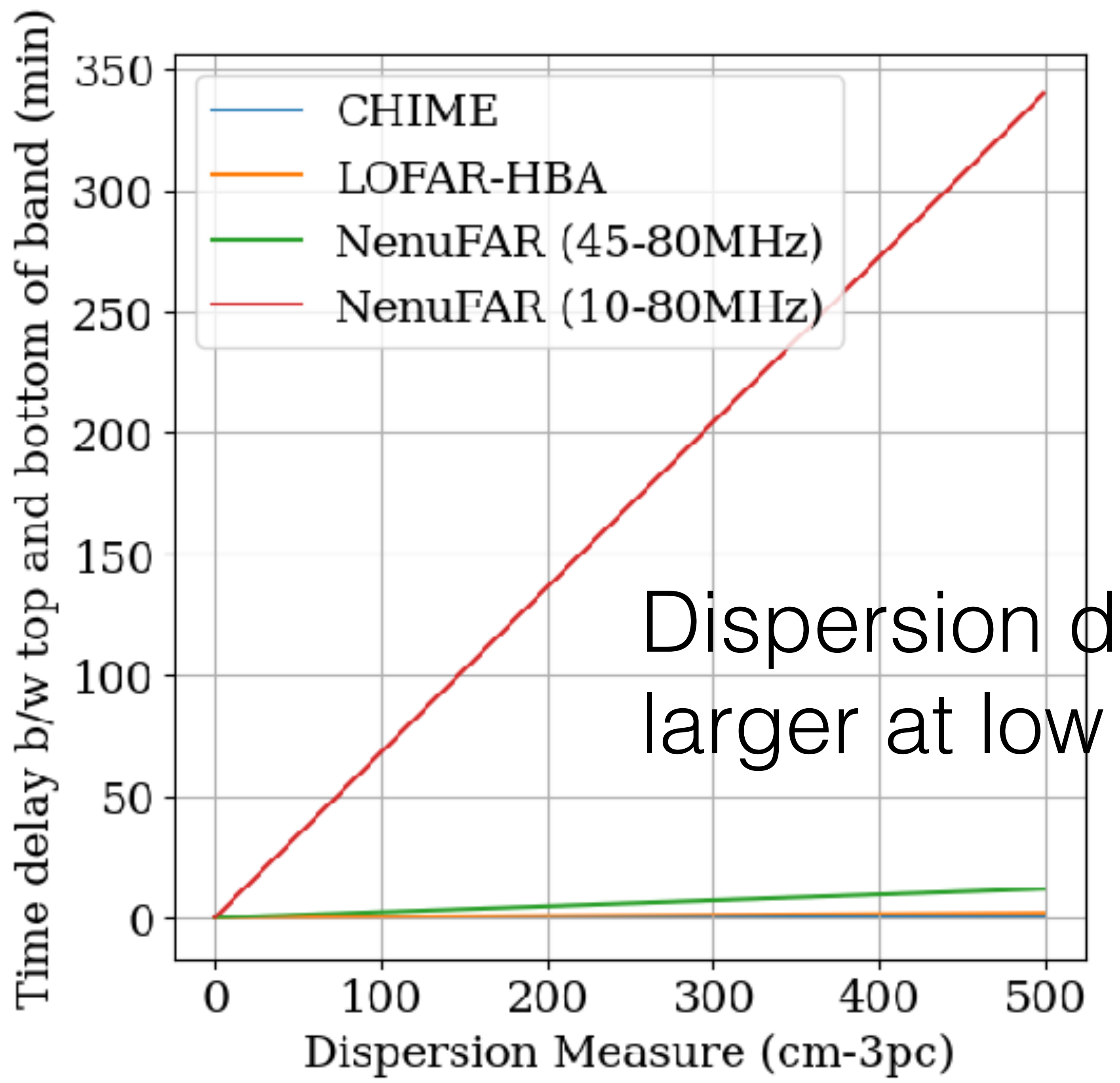
- High precision constraints on frequency-dependent effects (DM, scattering…)
- Emission mechanism study, e.g. use low-freq data to probe high altitudes and large volume of magnetosphere in the RFM model
- Profile evolution

Challenges:

- turnover at 80-140 MHz for many pulsars
- high sky temperature (galactic background)
- strong dispersion, scattering, scintillation, ...

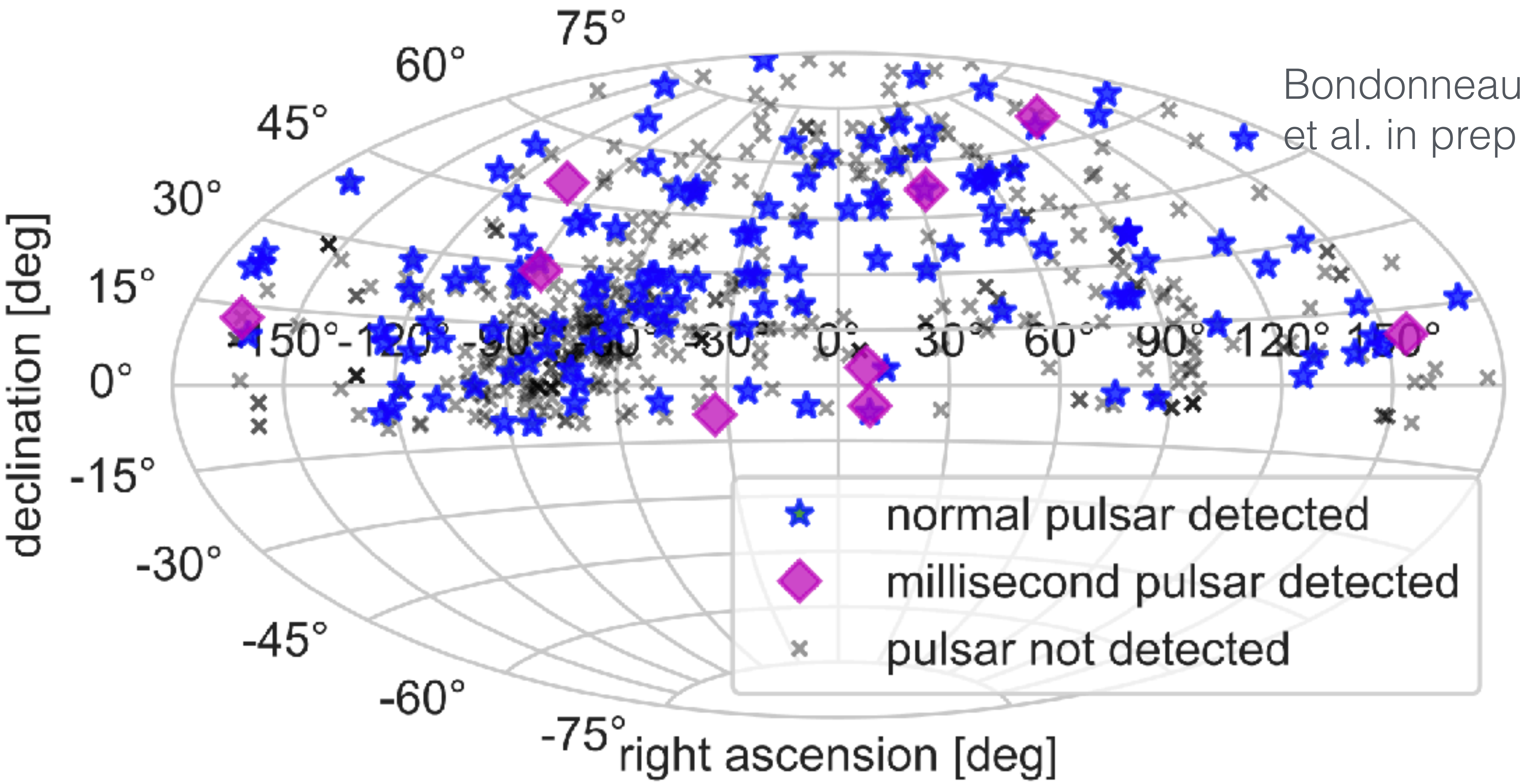
Bilous et al., 2020





Dispersion delay larger at low freq

Known pulsar census

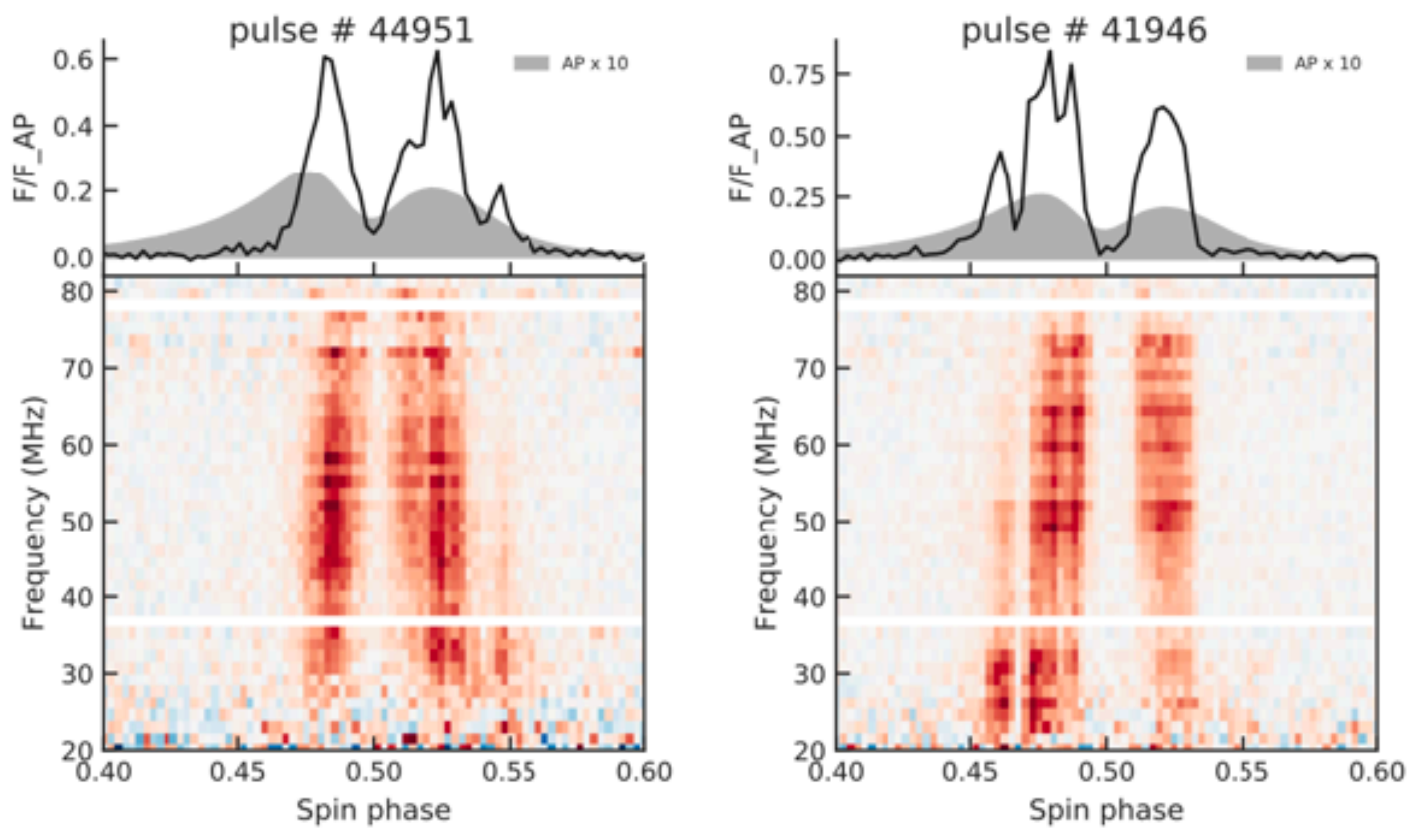


Bondonneau et al. in prep

- Census sample: 700+ known pulsars with DEC > -20° and DM < 100 pc/cm³ (nearby pulsars)
- 184 pulsar detected (~100 for the first time <100 MHz)
- 12 MSPs detected (8 for the first time <100 MHz)
- Possibly a few more from the recent psrcat additions

Multi-frequency pulsar studies

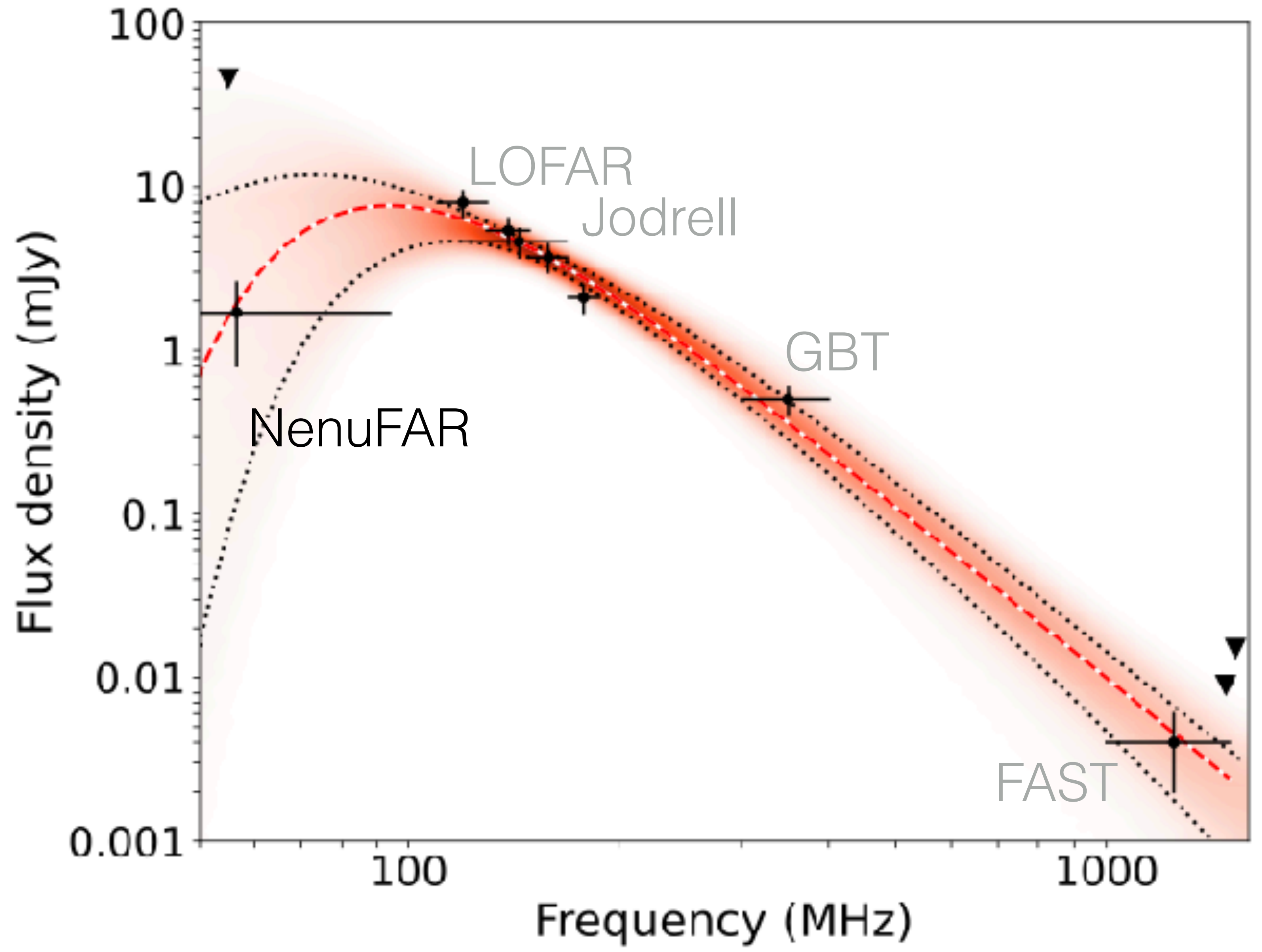
Bilous et al., 2022



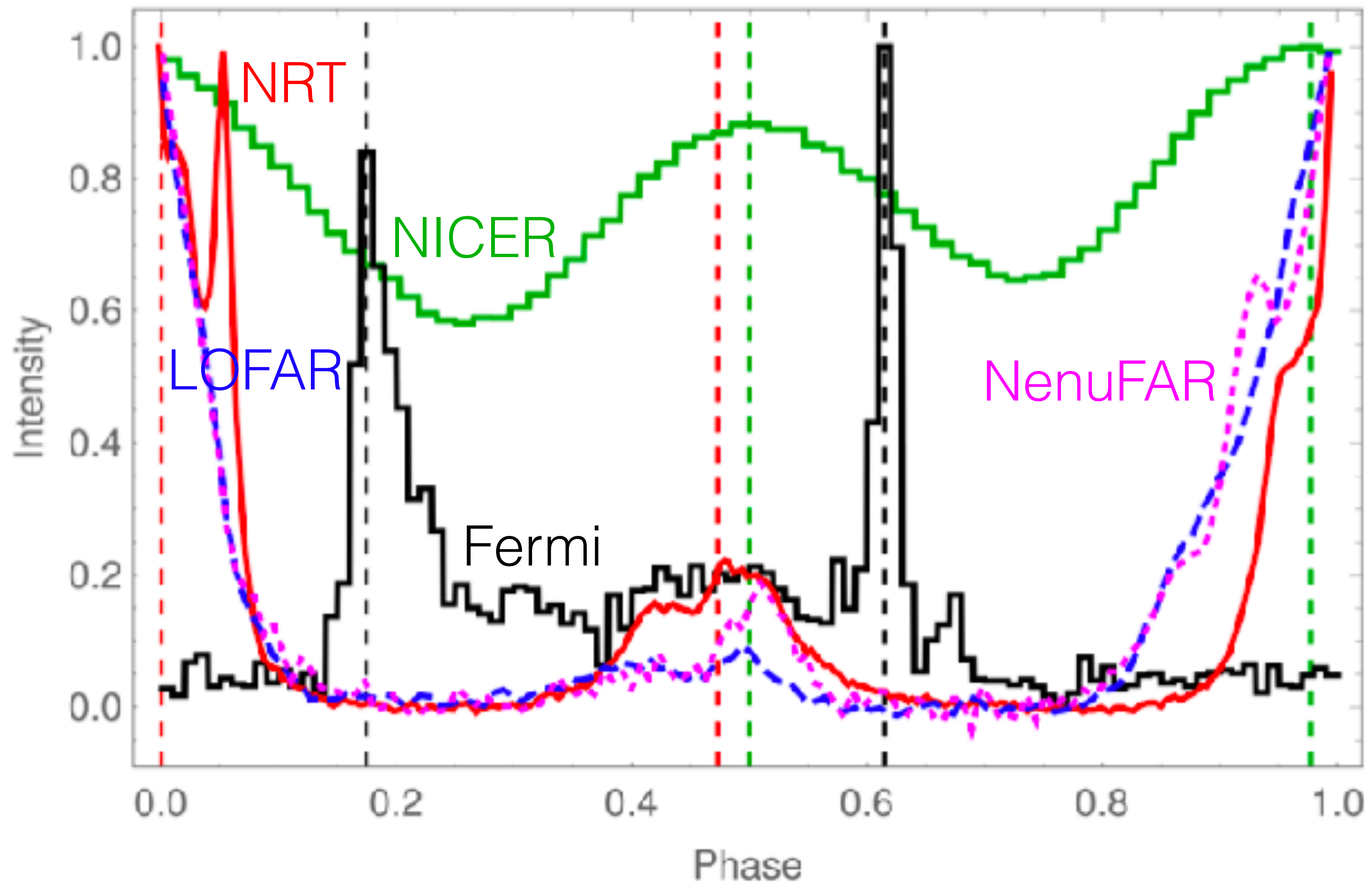
Dual-frequency single-pulse study of PSR B0950+08

- Fluence fluctuation due to ISM
- Upward and downward drifting similar to repeating FRBs

Agar et al., 2021



Pétri et al., submitted



Radio/X-ray/Gamma-ray profile analysis on PSR B0030+0451

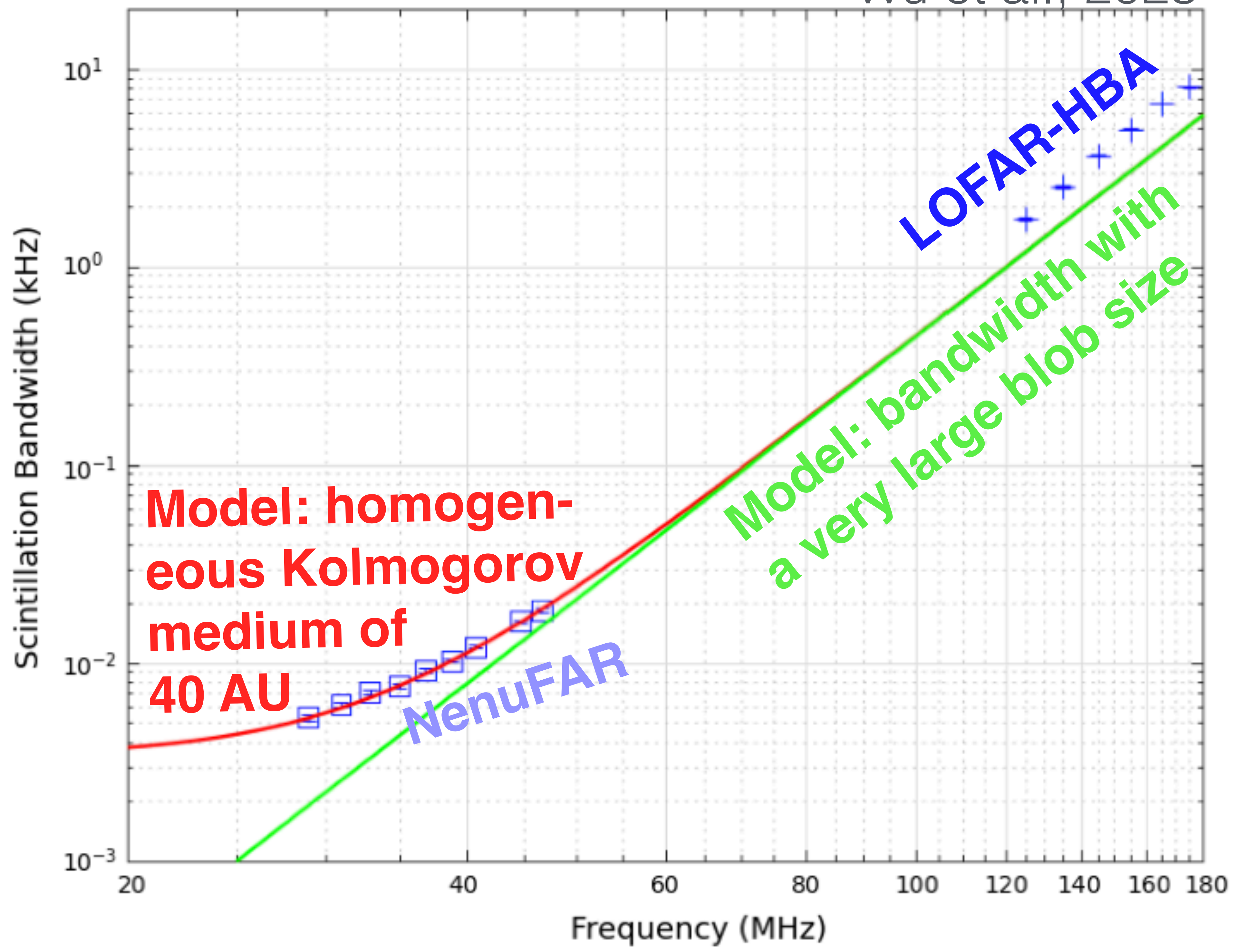
- Constrain emission region and magnetic dipole obliquity by fitting geometry model to data

A broadband study of the slowest-spinning radio PSR J0250+5854

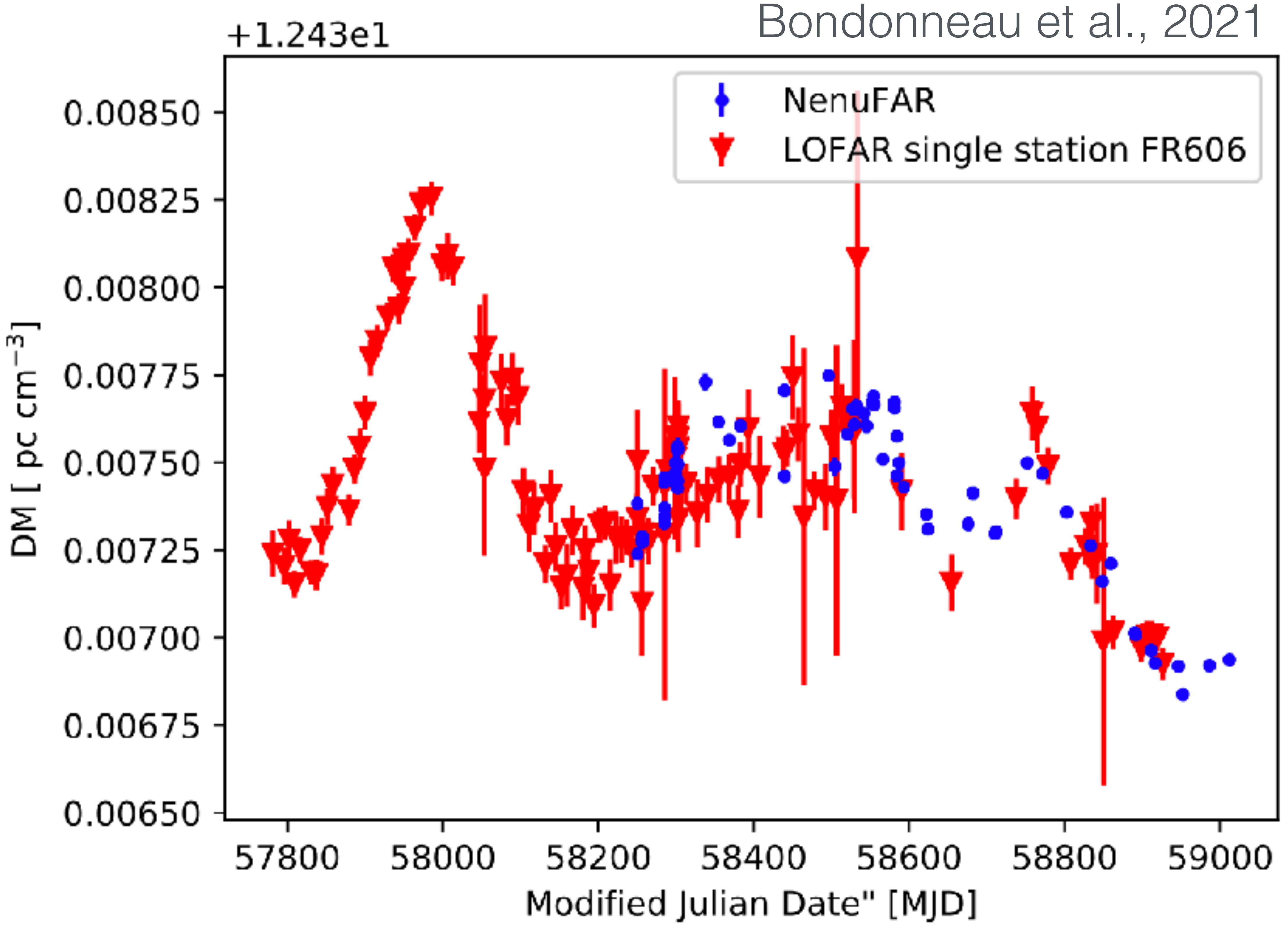
- Exceptionally steep spectral index of -3.5 with turnover below ~95 MHz
- Intrinsic width decreases dramatically with increasing freq, contrary to RFM prediction

Propagation effects

Wu et al., 2023



Bondonneau et al., 2021



Near simultaneous study on PSR J0826+2637 (nearby PSR with DM=19.5 pc/cm^3) using NenuFAR and LOFAR-HBA

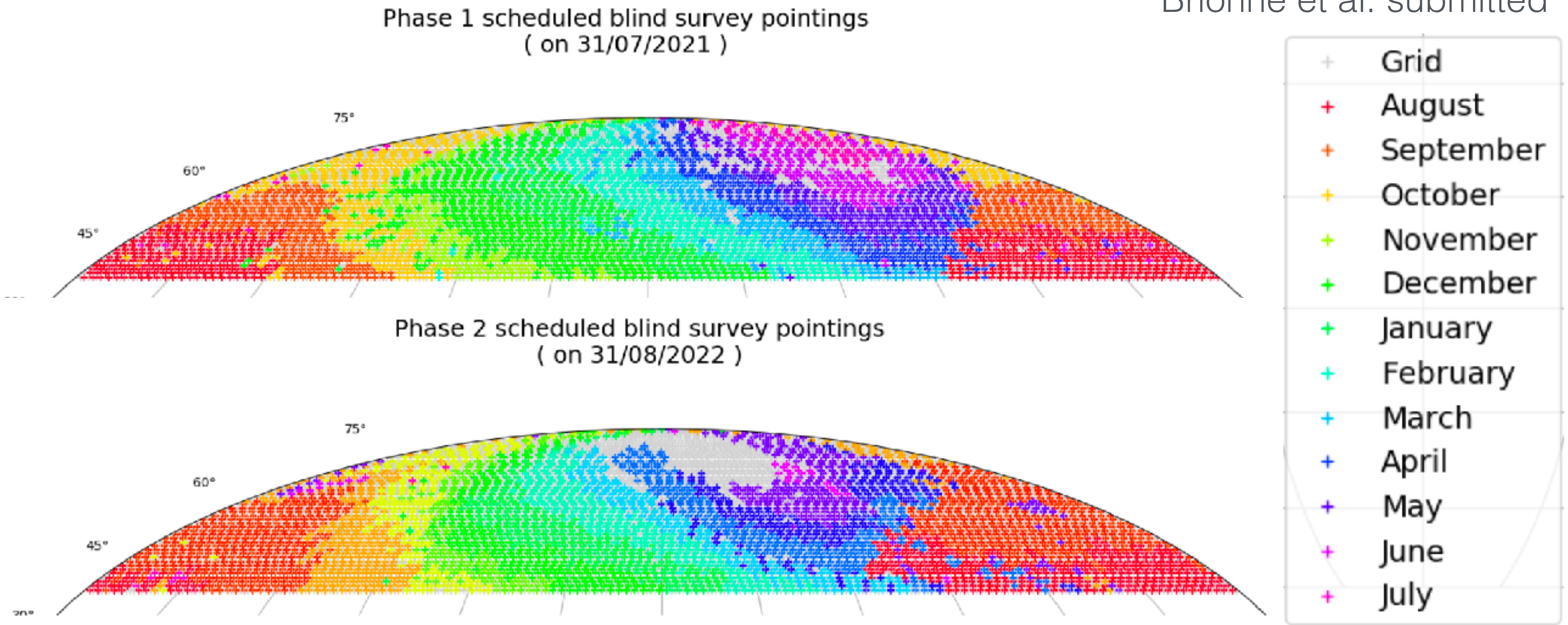
—> frequency dependent scattering properties

DM variation study of PSR B1919+21

- High precision of ~10^{-5} pc/cm^3
- DM monitoring, statistics of "DM events"
- improve timing (e.g. for pulsar timing arrays)

Blind pulsar search

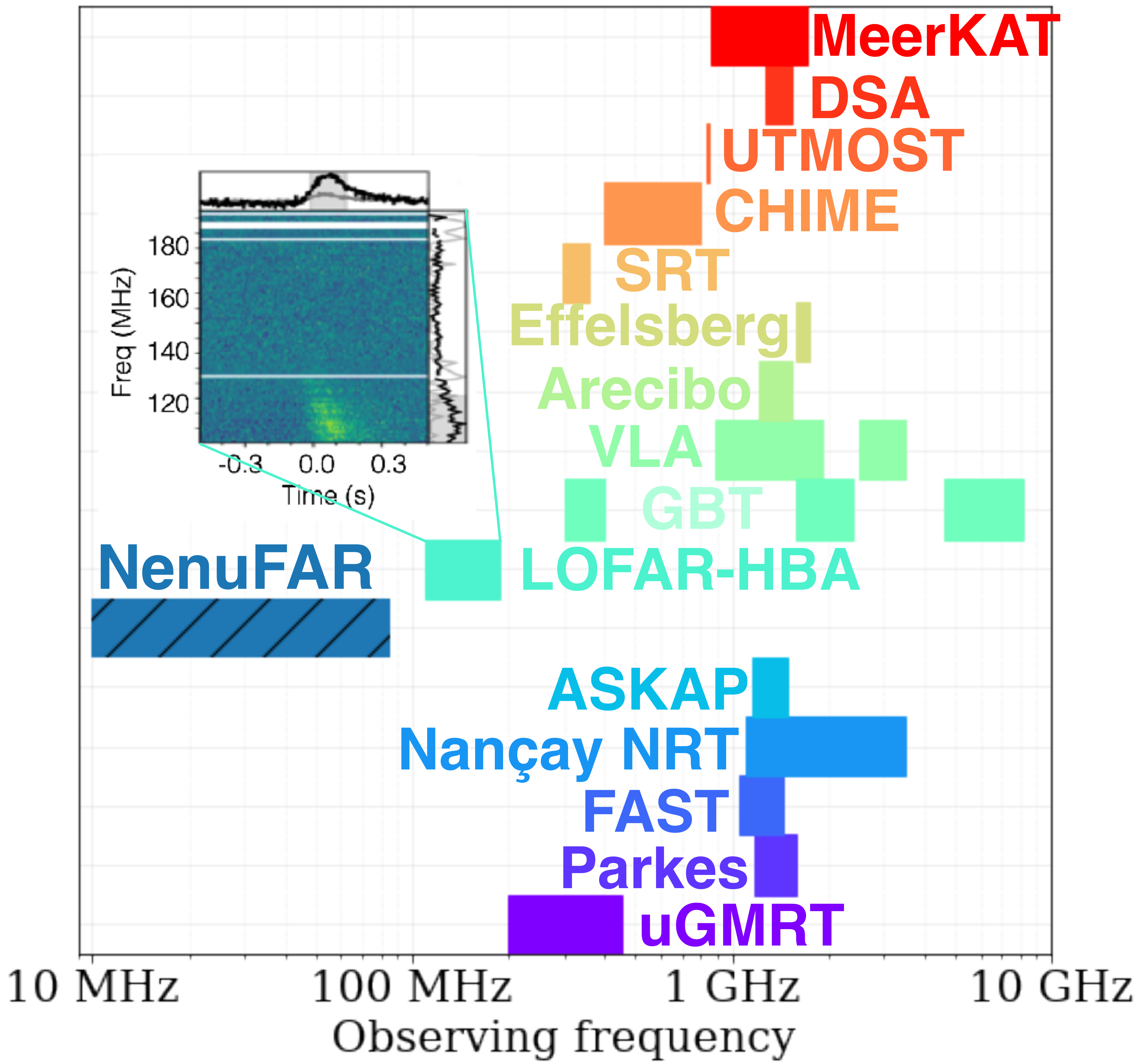
Brionne et al. submitted



- North polar cap (DEC > 39°), 39-77 MHz
- ~8000 pointings taken between 2020–2023
- Search space: DM <70 pc/cm^3 and Period >80 ms
- Psrpop expectation: ~80–100 re-detections, 0–6 discoveries
  - Faint, steep spectrum, slow pulsars
- Currently following up a number of candidates

FRB repeaters with NenuFAR

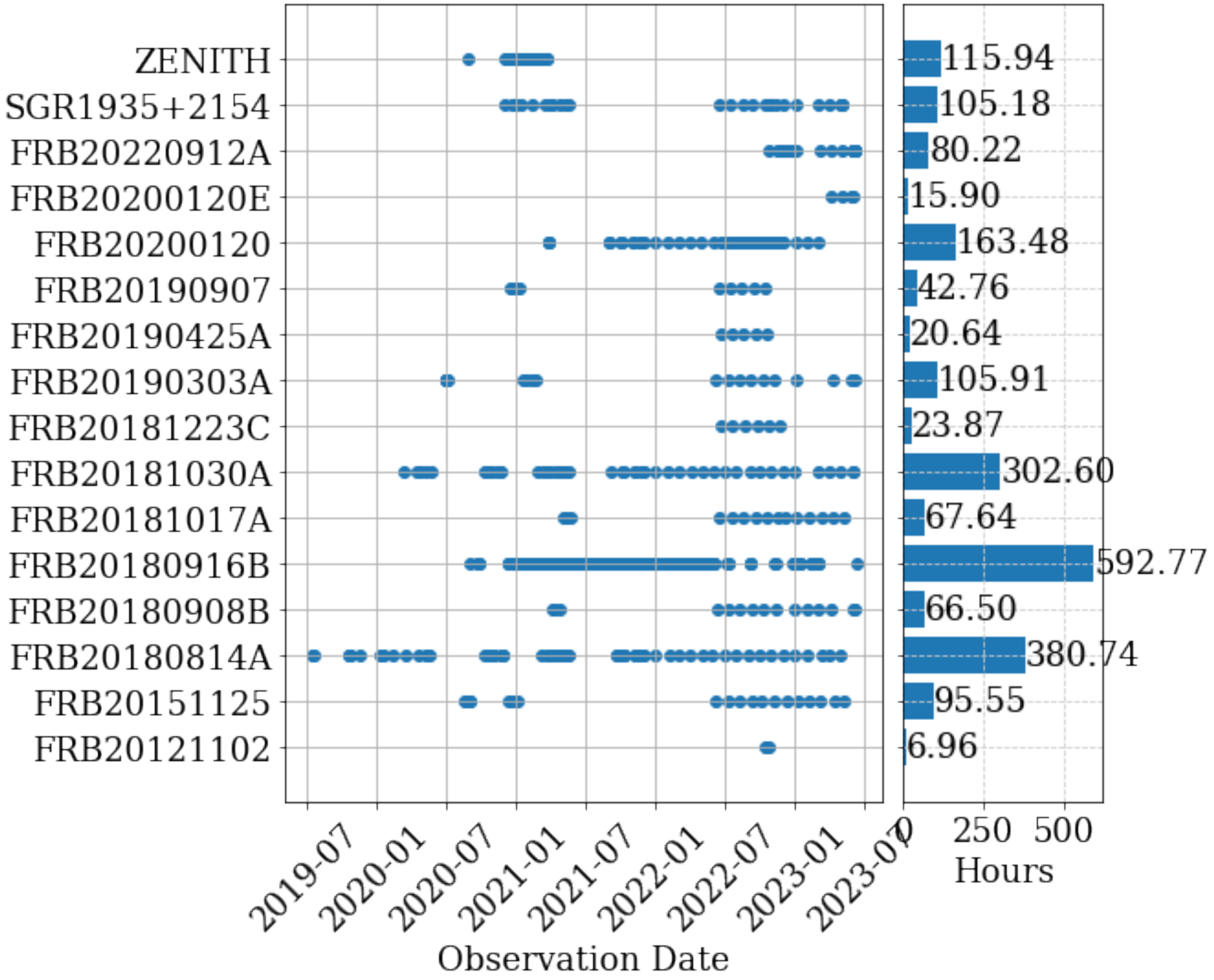
- Fast Radio Bursts: yet unknown origin
- So far detected by 15+ radio telescopes between 110 MHz and 8 GHz, no conclusive multi-wavelength counterparts yet, except the Galactic magnetar FRB
- LOFAR-HBA detection still bright at 110MHz band edge
- NenuFAR can open a new window at low frequencies — study emission mechanisms



FRB repeaters with NenuFAR

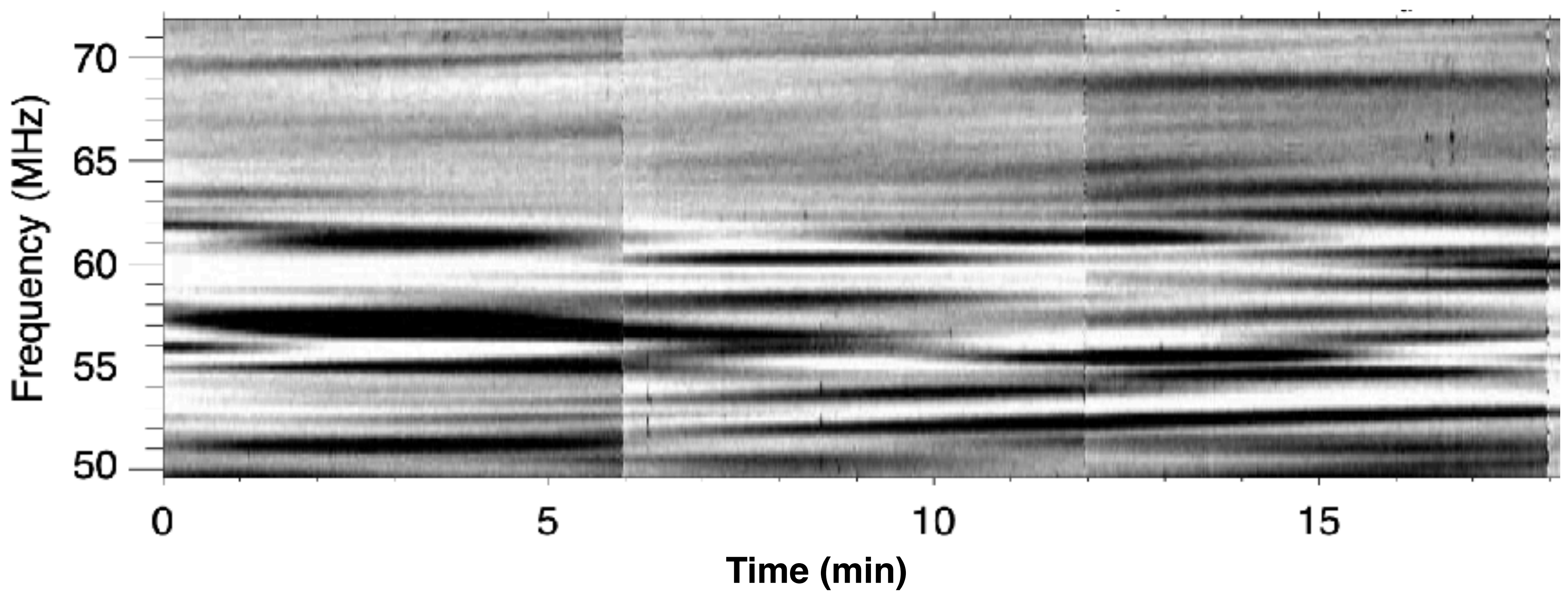
- Large dispersion+scattering —> focus on 10 repeaters with known DM (coherent dedispersion)
- >500 observations (216+ hours) being analyzed
- Triggered observations with CHIME & LOFAR — a few days of delay window c.f. FRB20180916 (R3)
- Simultaneous observations with the Nançay Radio Telescope (NRT)

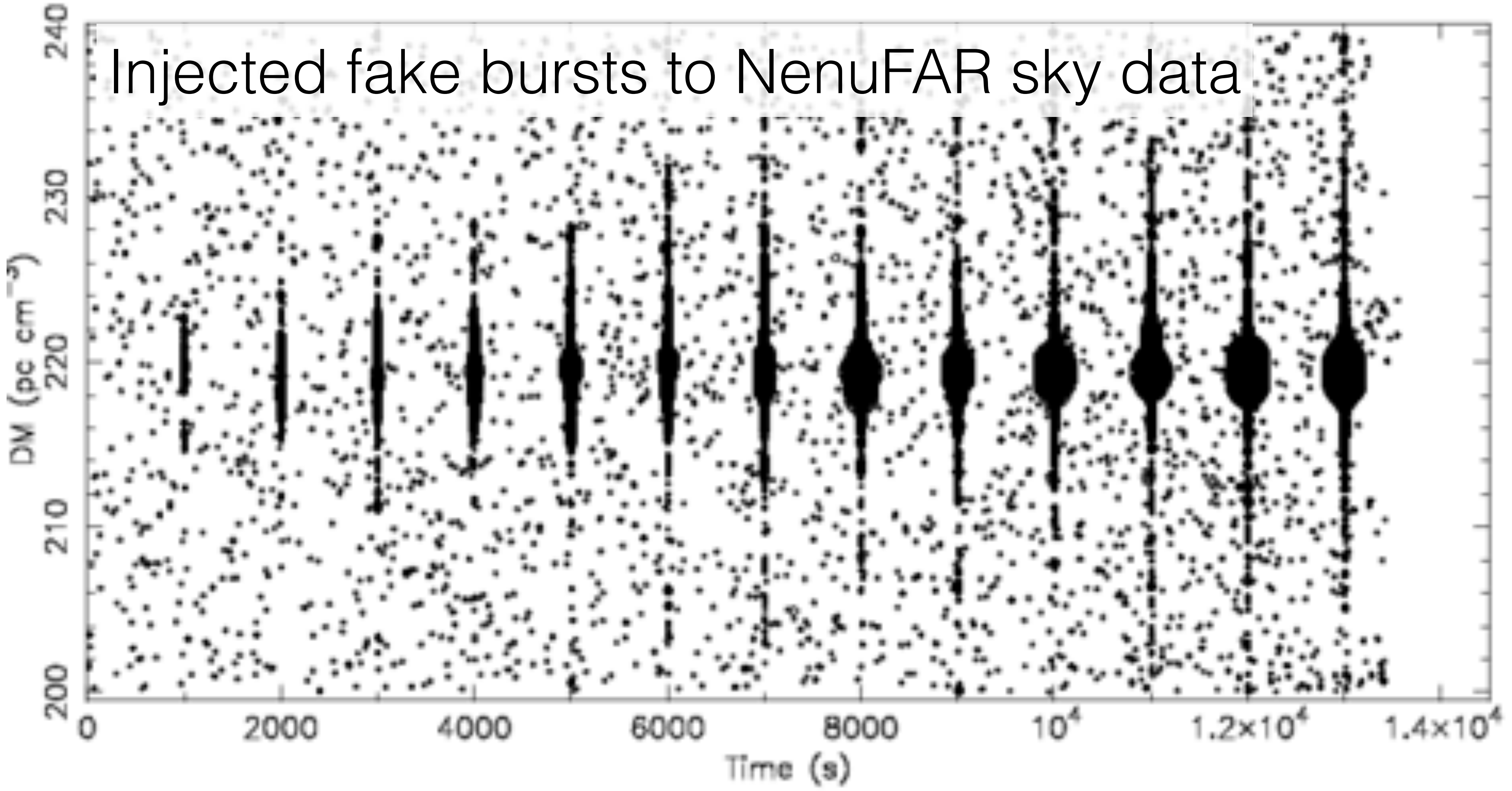
Analysis by Pierre Gaspari, Nada Moukaddem and Ugo Laine



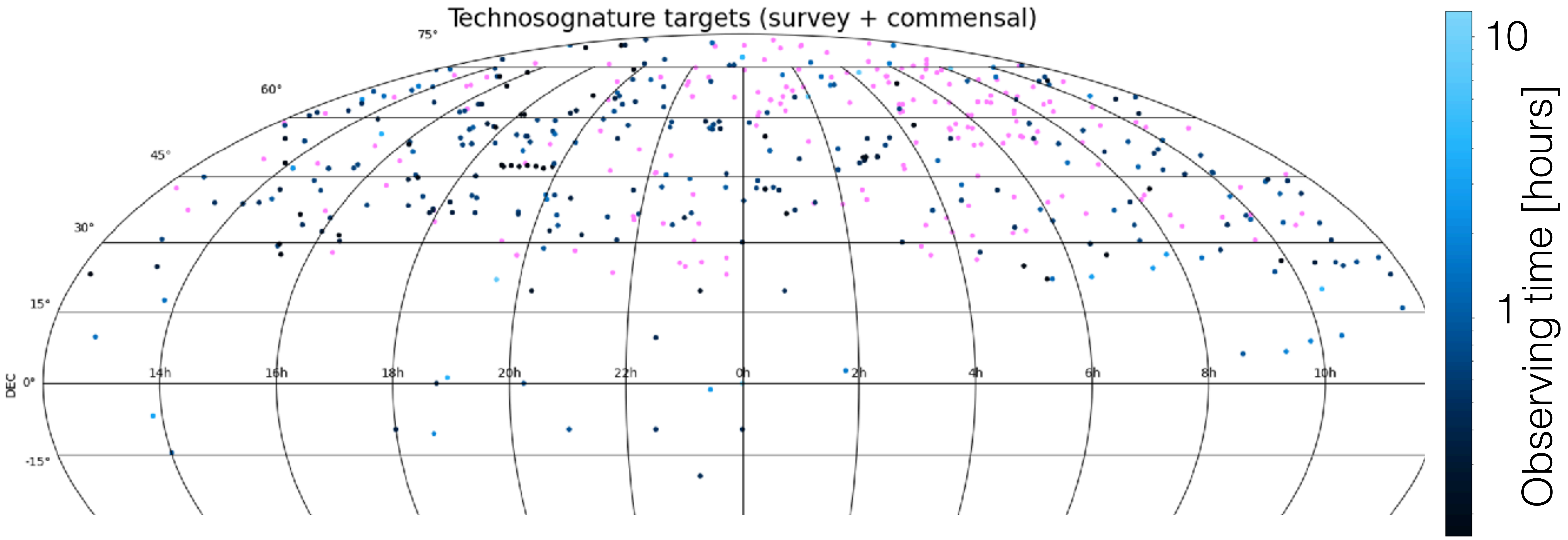
FRB repeaters with NenuFAR

- Pre-processing: flatten bandpass e.g. due to the 6-min analog beamformer adjustment, bright objects passing through side-lobes of the telescope beam
- Simulations of bursts with different properties (e.g. SNR, width, scattering time) to optimize search space
- Employ Machine Learning (fetch code [Agarwal et al., 2020])
- Subband search to target band-limited emission of repeaters





SETI with NenuFAR



- Dedicated SETI backend (1x RTX 2080 Ti GPU, 144 TB storage)
- Fine channelization + data integration : 1.49 Hz / 671 ms
- Targeted observation of TESS sources (274 sources observed with 175 hr on sky) + commensal observations (commissioning)
- Data reduction pipeline optimization on-going
- In collaboration with Breakthrough Listen, Caltech and Trinity College Dublin (TCD)

Cycle #3 Call for proposals!

Cycle #3: 1st December 2023 to 31 May 2024

Submission deadline : Friday Sept 15, 2023, 12 UT

Proposals to be sent to nenufar-proposals@obs-nancay.fr