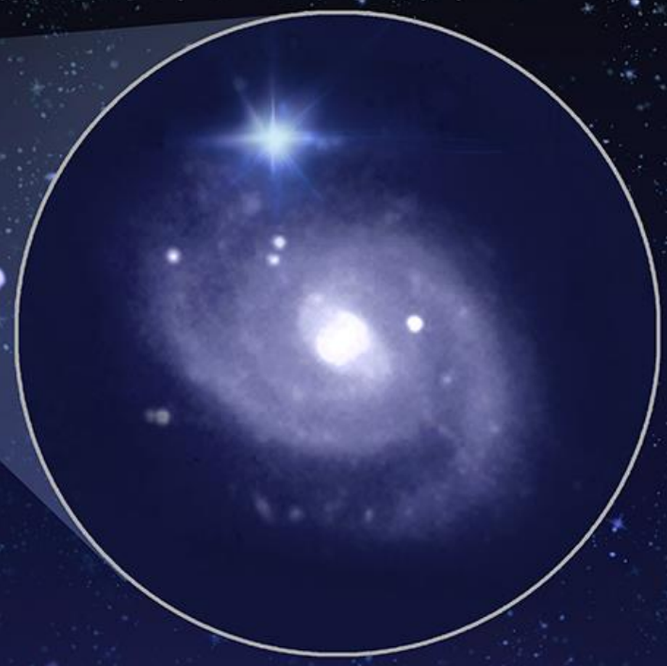
Fast transients
< 300 MHz



Ziggy Pleunis

Veni fellow, University of Amsterdam

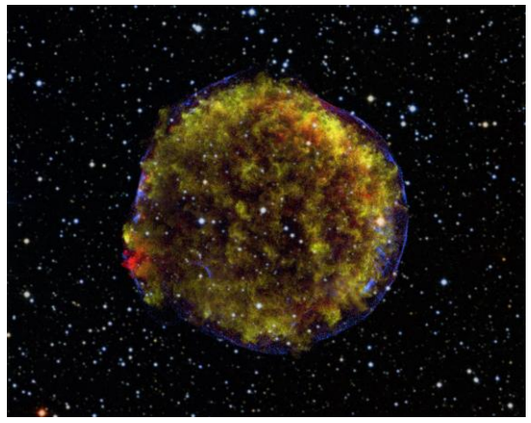
Visiting scientist, ASTRON

LOFAR Family Meeting
2024 June 5

CHIME/FRB
Collaboration

Futselaar / ASTRON / Tendulkar

You don’t observe the same universe twice!

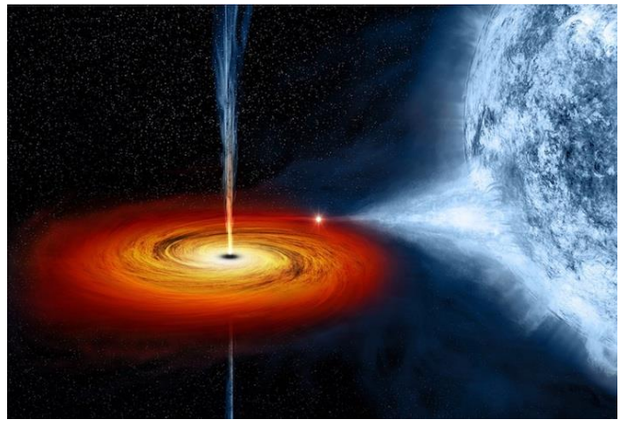


X-ray: NASA/CXC/GSFC/B.Williams et al; Optical: DSS

Supernovae

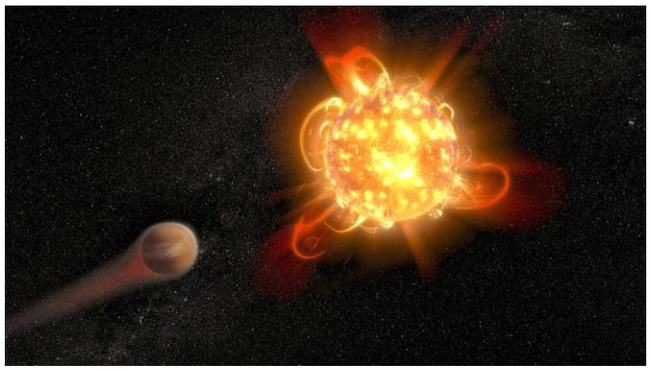
NASA/GSFC

Magnetar flares



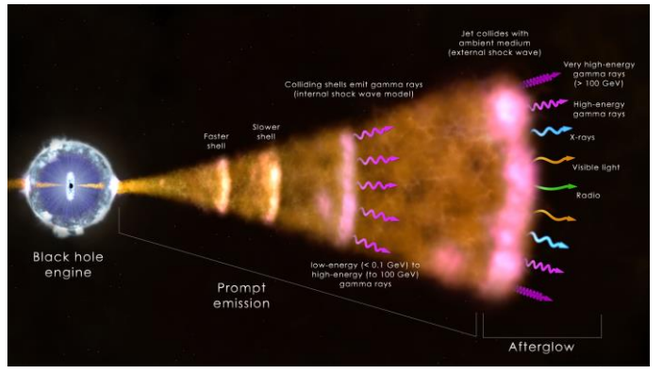
NASA/CXC/M.Weiss

X-ray binaries



NASA, ESA, and D. Player (STScI)

Flare stars



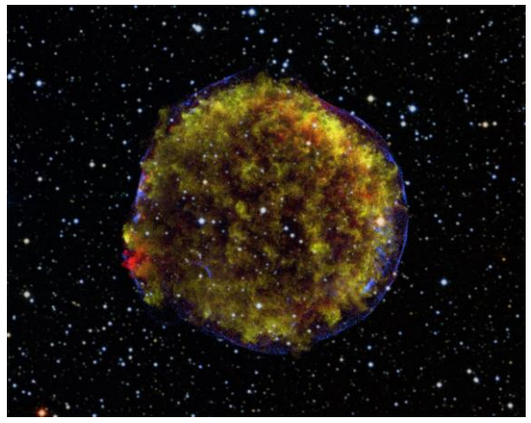
NASA/Goddard Space Flight Center/ICRAR

Gamma-ray bursts

DESY, Science Communication Lab

Tidal disruption events

You don't observe the same universe twice!

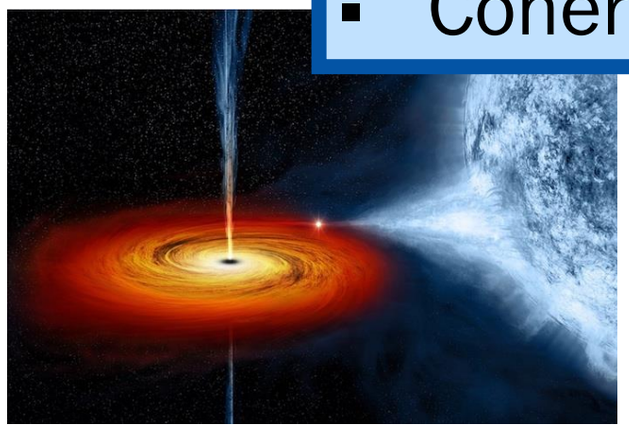


X-ray: NASA/CXC/GSFC/B.Williams et al; Optical: DSS

Supernovae

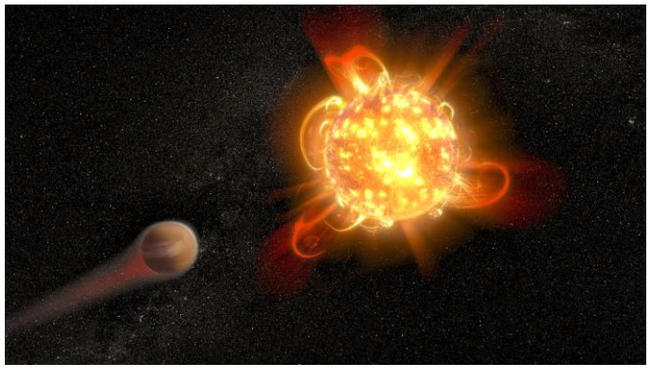
Unique probes of:

- Compact objects, the extreme end results of stellar evolution
- Physics of jet launching
- Coherent emission processes



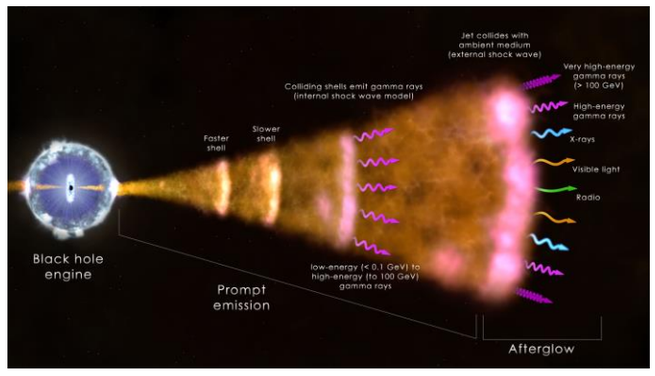
NASA/CXC/M.Weiss

Magnetar flares



NASA, ESA, and D. Player (STScI)

Flare stars



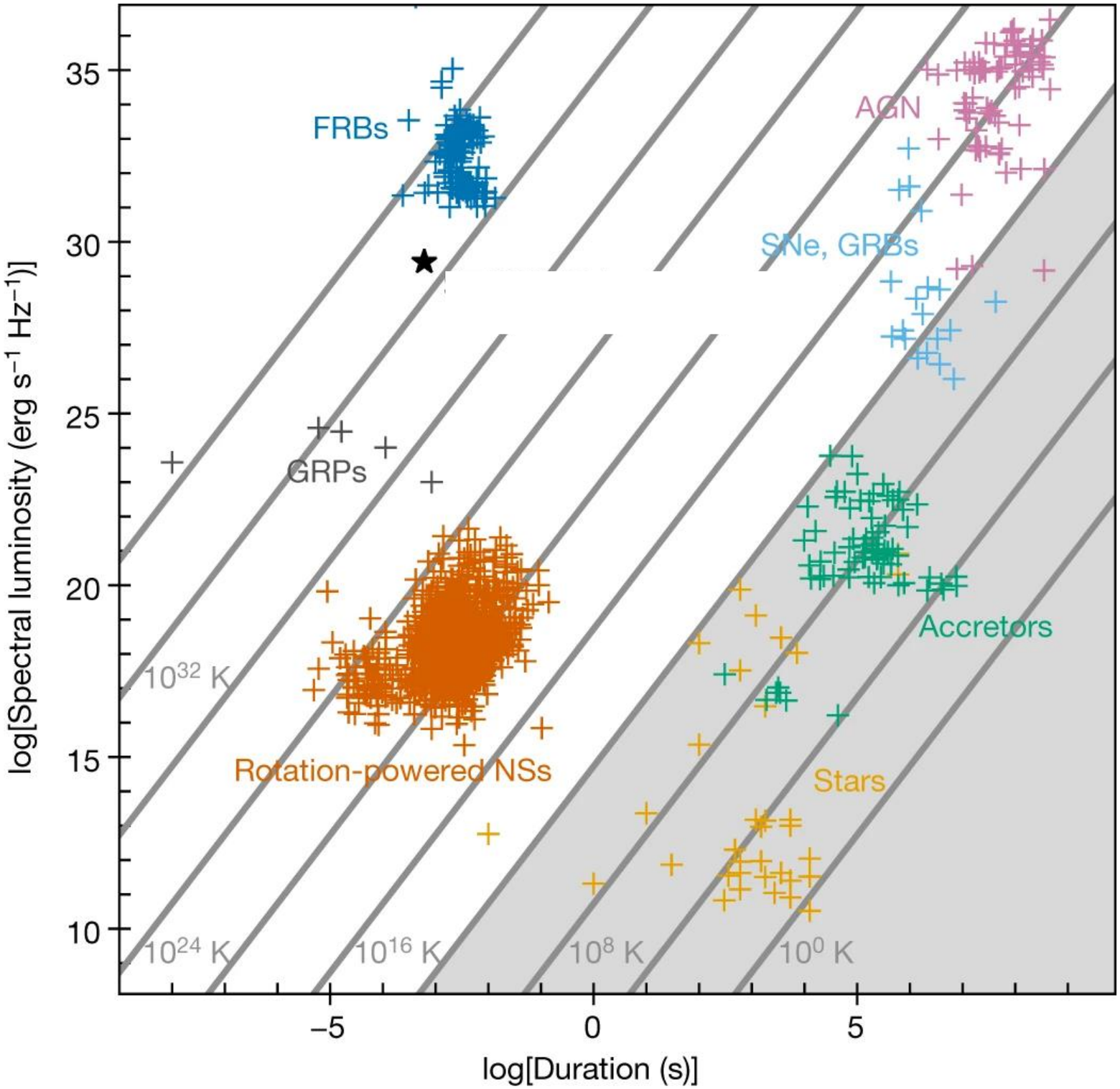
NASA/Goddard Space Flight Center/ICRAR

Gamma-ray bursts

DESY, Science Communication Lab

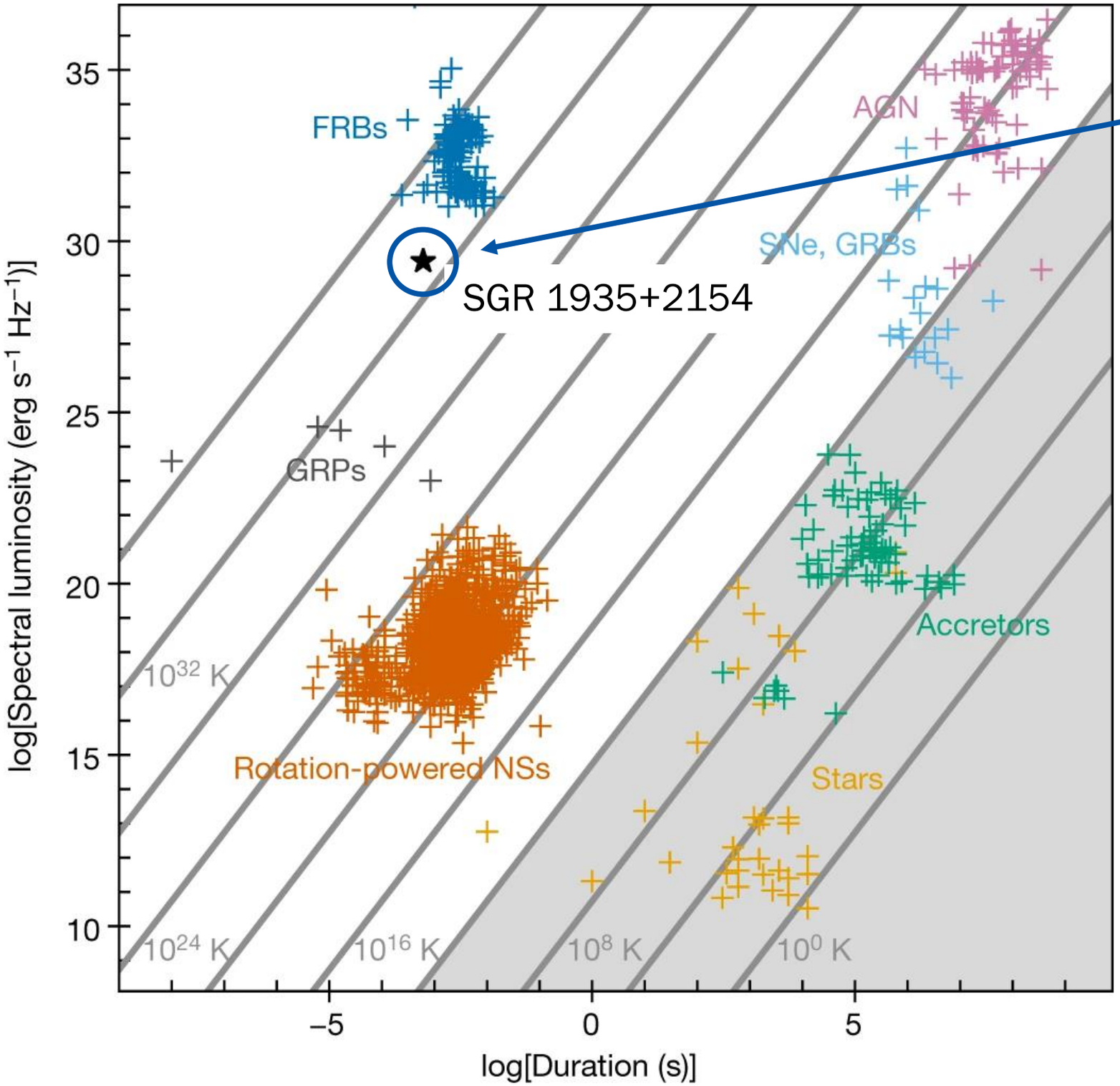
Tidal disruption events

Fast radio transients



~ms variability
→ Coherent emission from a compact object

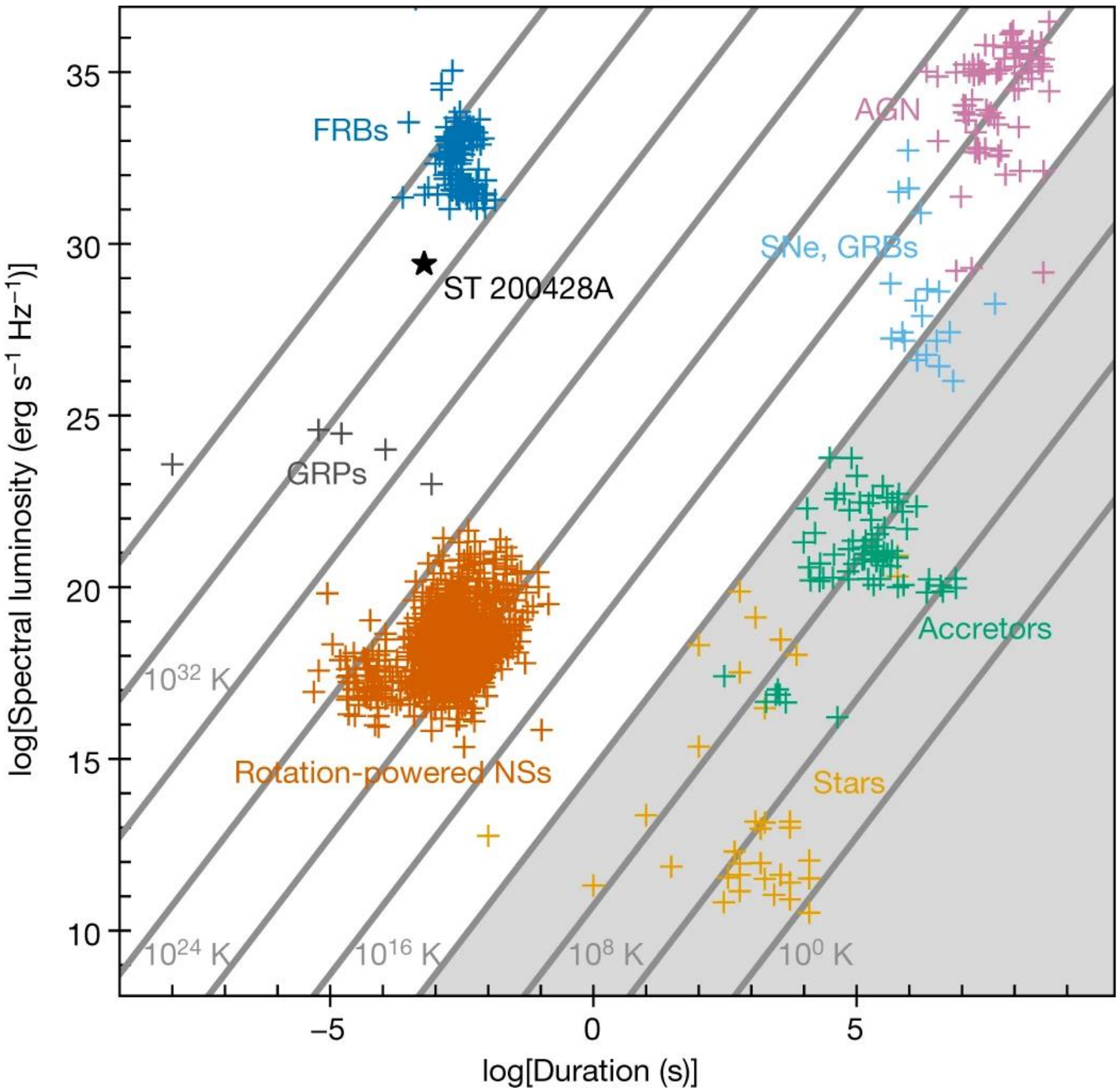
Fast radio transients



~ms variability
→ Coherent emission from a compact object

Some fast radio bursts are magnetars!

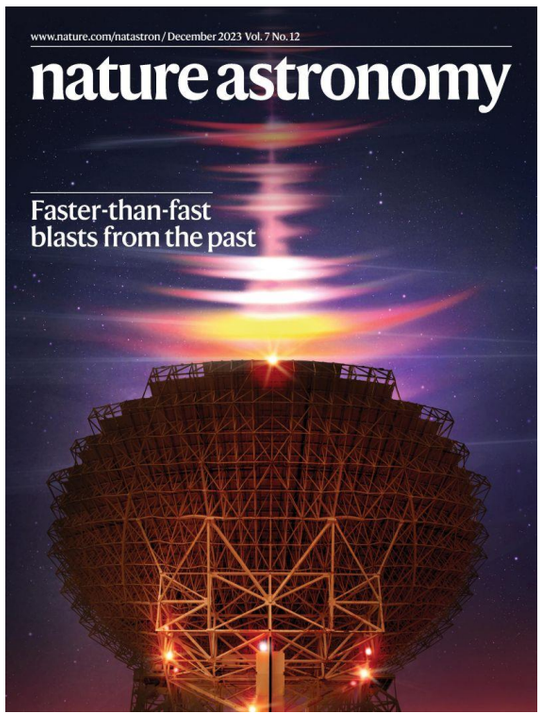
Fast radio transients



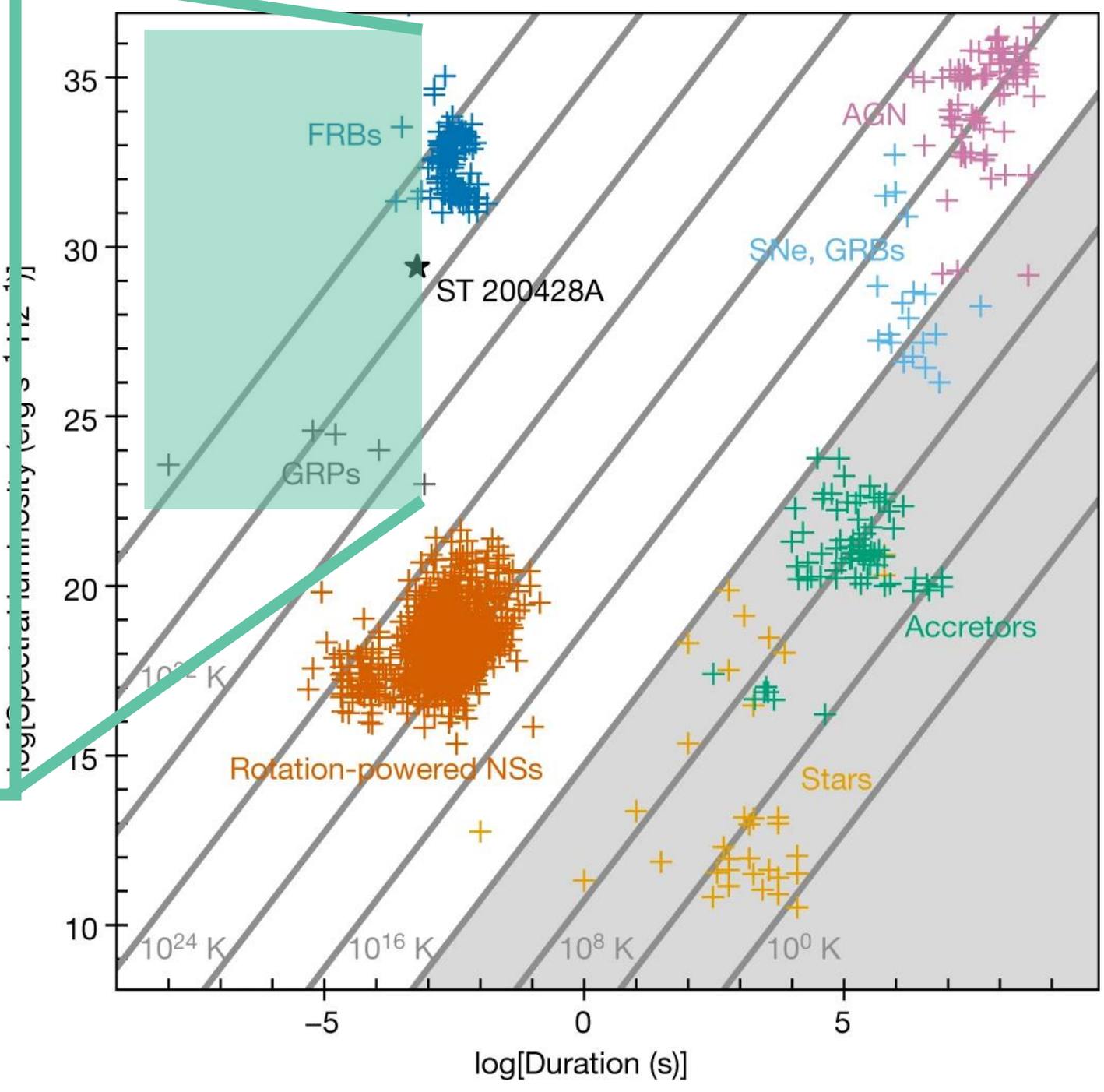
Bochenek+ 2020

Fast radio transients

Ultra-fast radio transients (~μs)



Snelders+ 2023



Bochenek+ 2020

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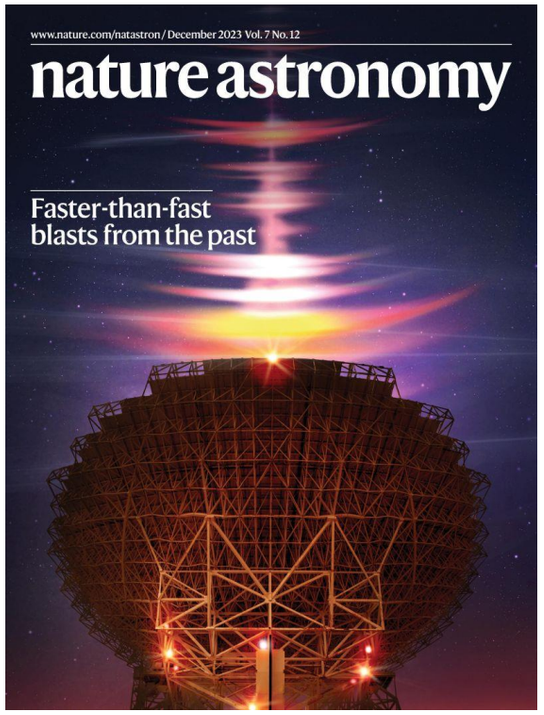
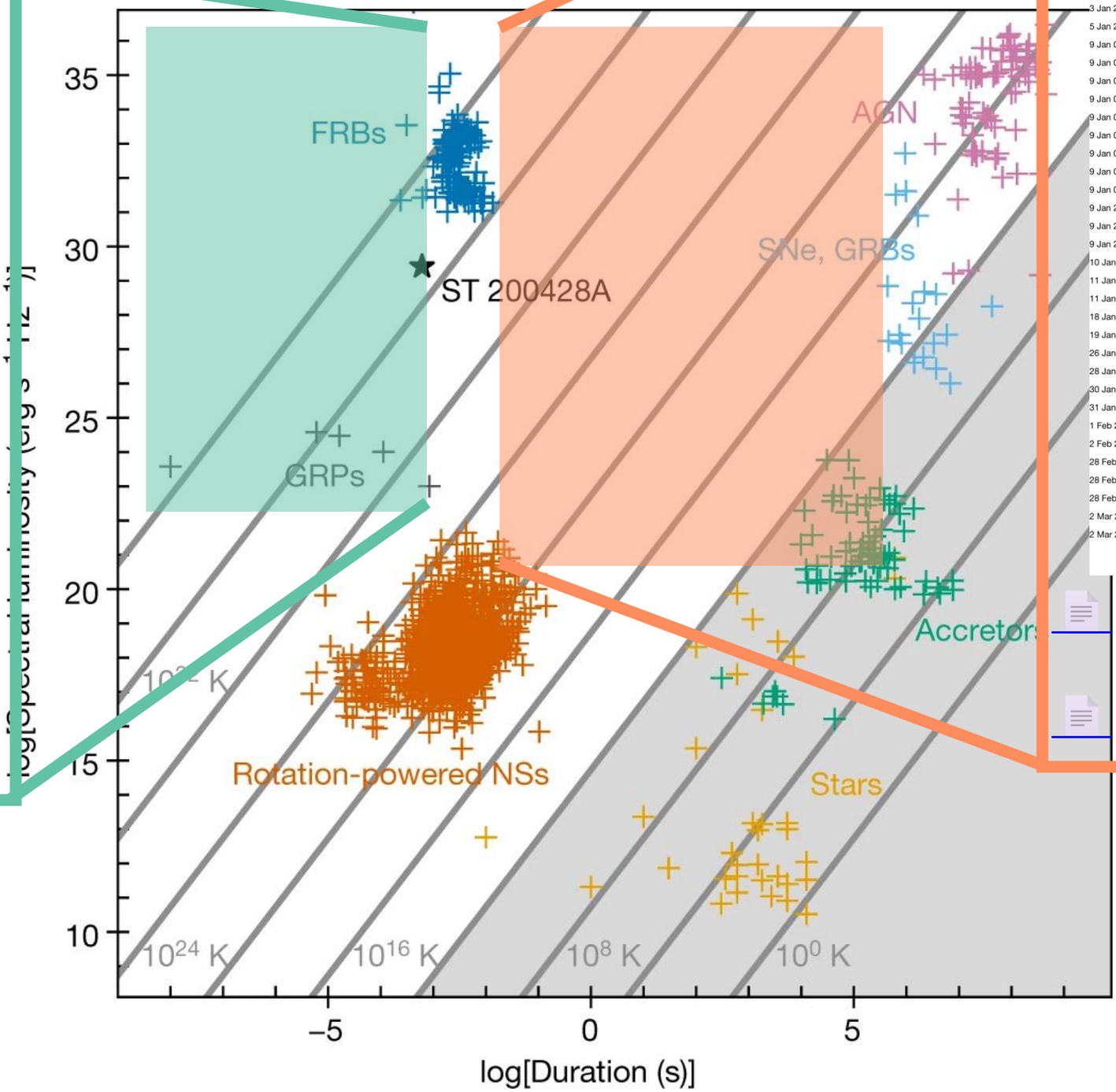
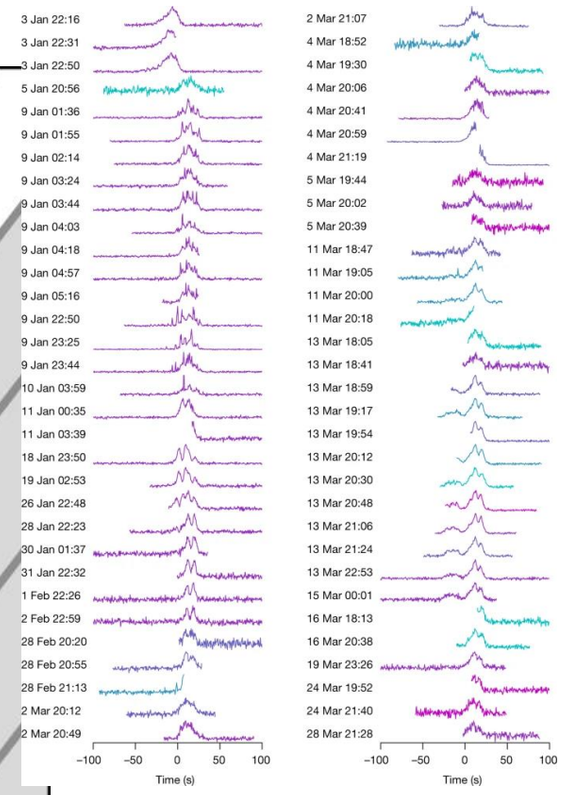


Snelders+ 2023



Bochenek+ 2020

"Slow" radio transients (~s)



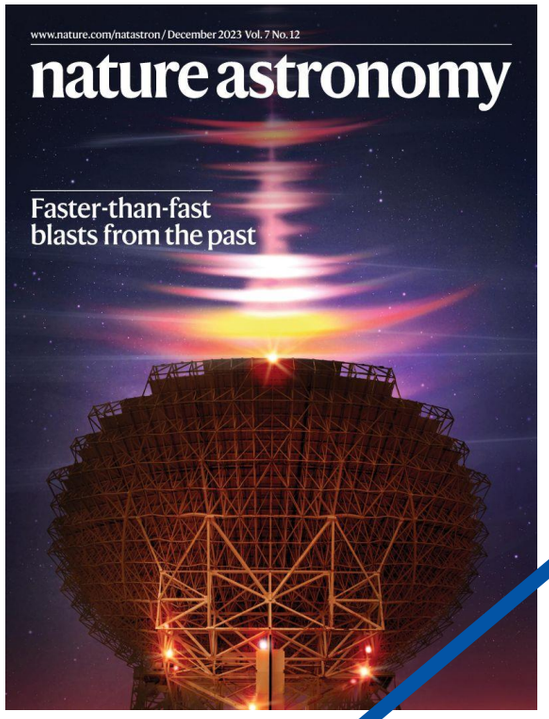
Hurley-Walker+ 2022

Caleb+ 2022

Hurley-Walker+ 2023

Fast radio transients

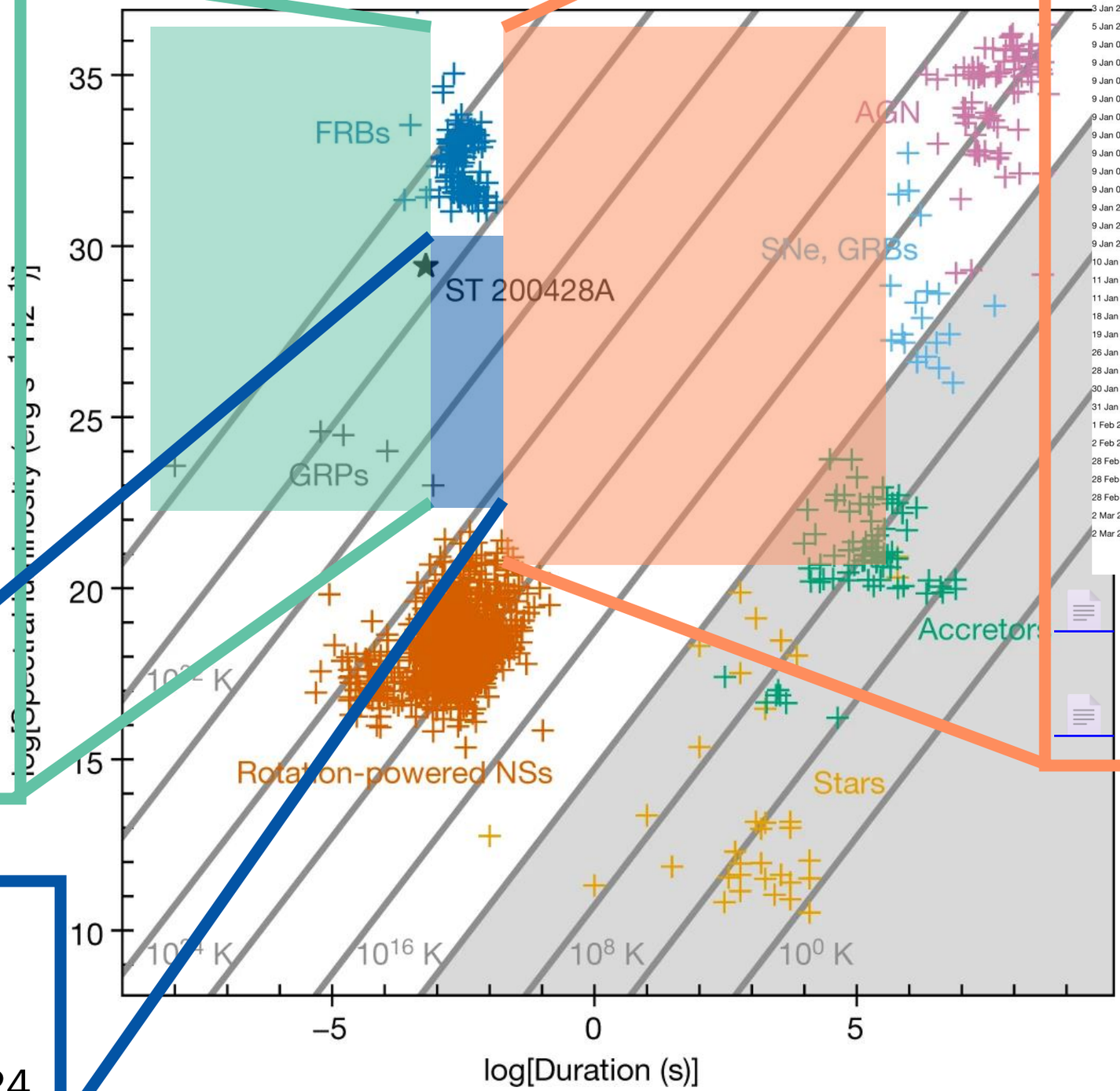
Ultra-fast radio transients (~μs)



Snelders+ 2023

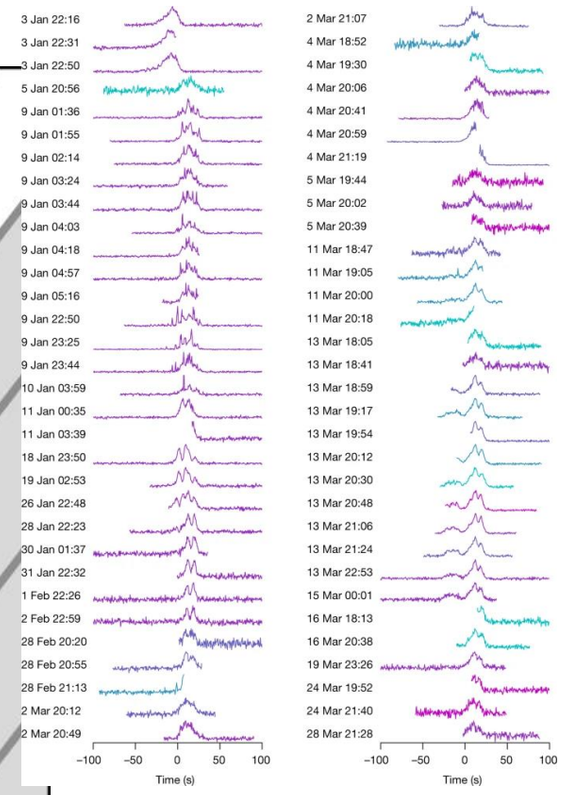
Rare radio transients

Kirsten+ 2024



Bochenek+ 2020

"Slow" radio transients (~s)



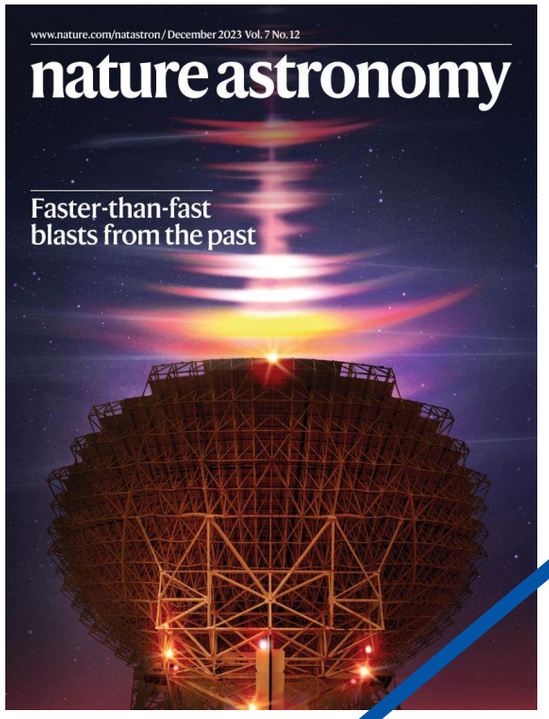
Hurley-Walker+ 2022

Caleb+ 2022

Hurley-Walker+ 2023

Fast radio transients

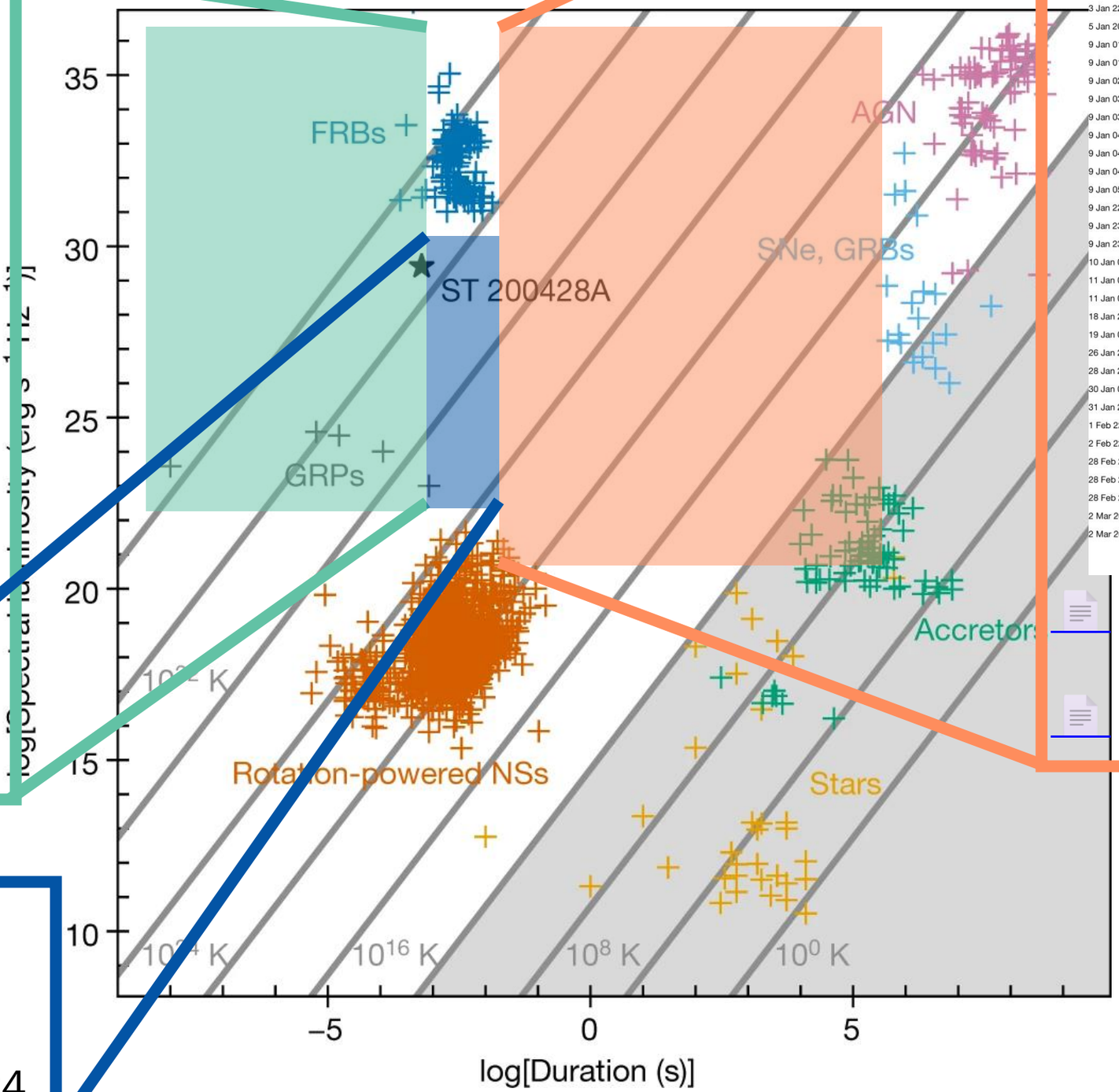
Ultra-fast radio transients (~µs)



Snelders+ 2023

Rare radio transients

Kirsten+ 2024



Bochenek+ 2020

“Slow” radio transients (~s)

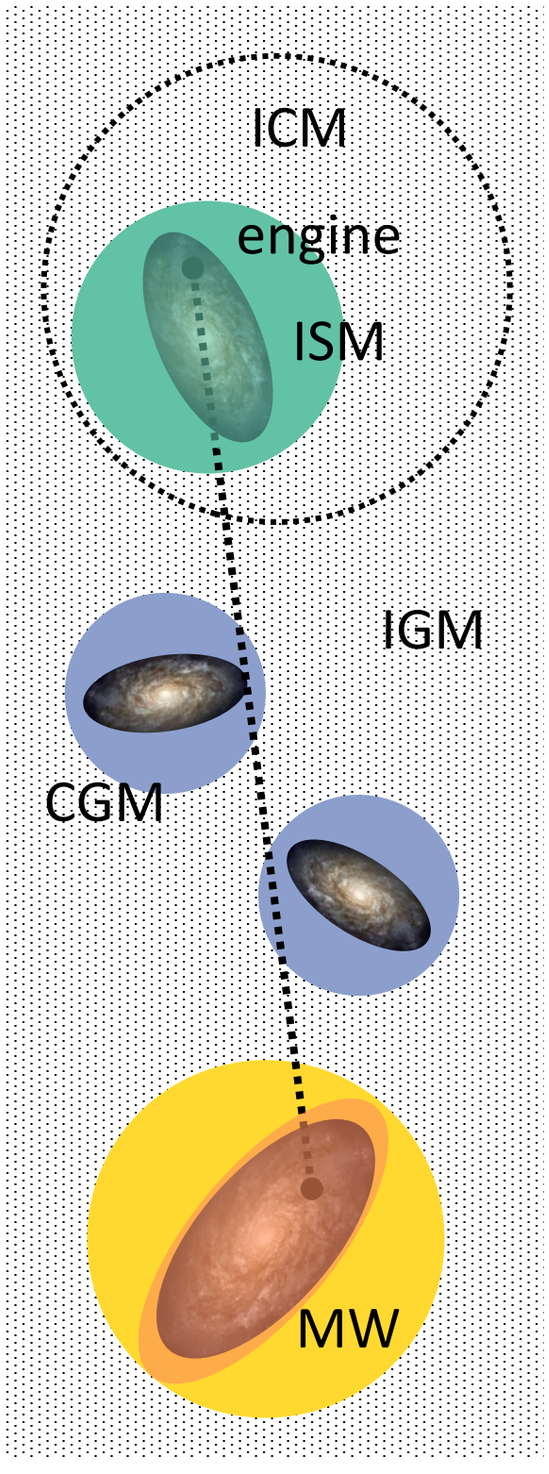
See talk bij Iris de Ruiter earlier today!

Hurley-Walker+ 2022

Caleb+ 2022

Hurley-Walker+ 2023

Using fast transients as astrophysical tools

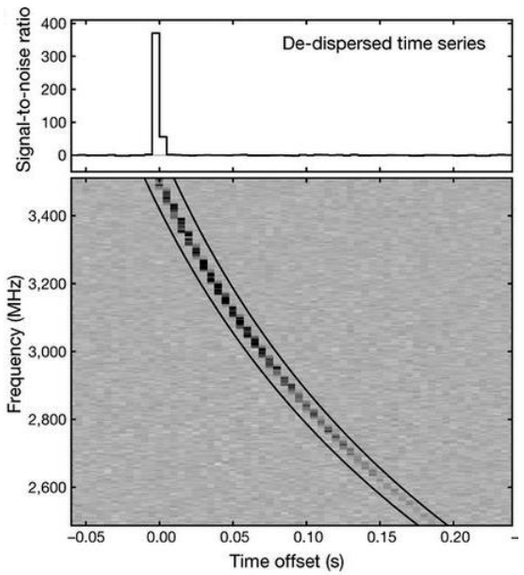


Perfect point sources at extragalactic (Mpc—Gpc) distances

Impulses in the radio band that encode interactions with intervening media

Using fast transients as astrophysical tools

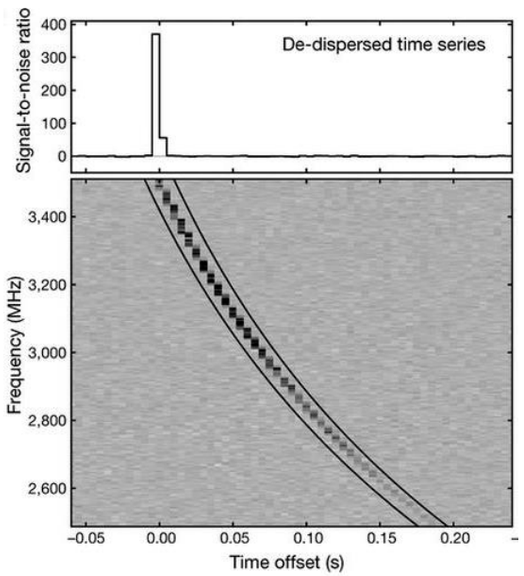
Free electrons
cause dispersion
→ DM



Chatterjee+ 2017

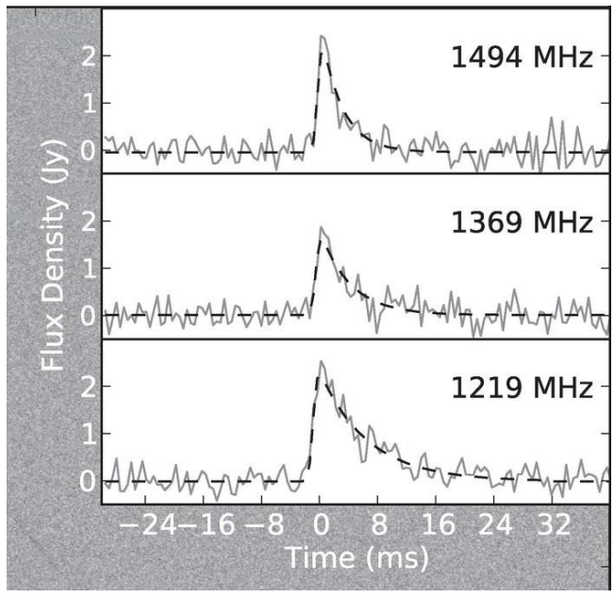
Using fast transients as astrophysical tools

Free electrons cause dispersion → DM



Chatterjee+ 2017

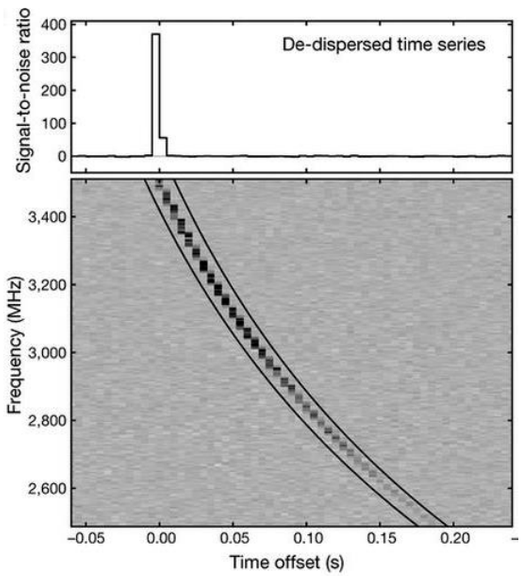
Inhomogeneities cause scattering → τ_s, θ_s



Thornton+ 2013

Using fast transients as astrophysical tools

Free electrons cause dispersion → DM



Chatterjee+ 2017

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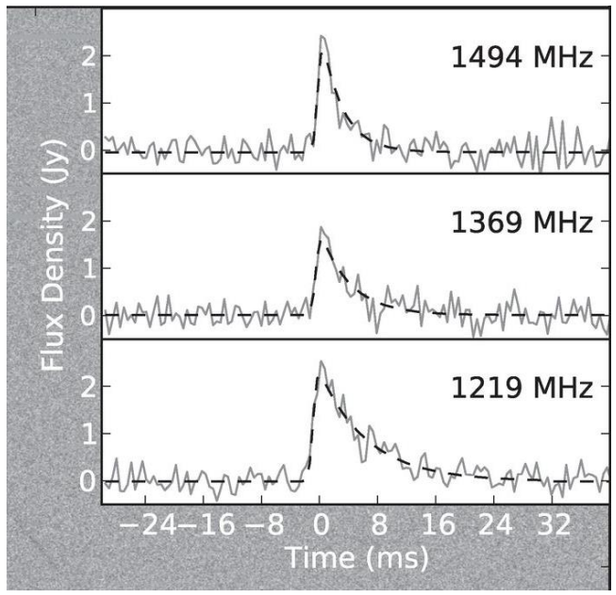
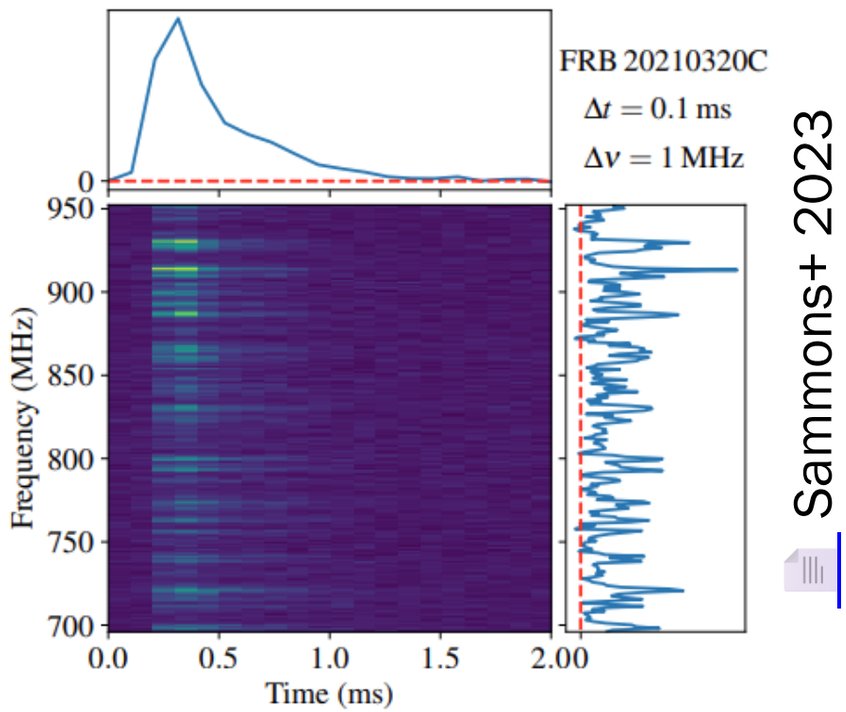


Thornton+ 2013

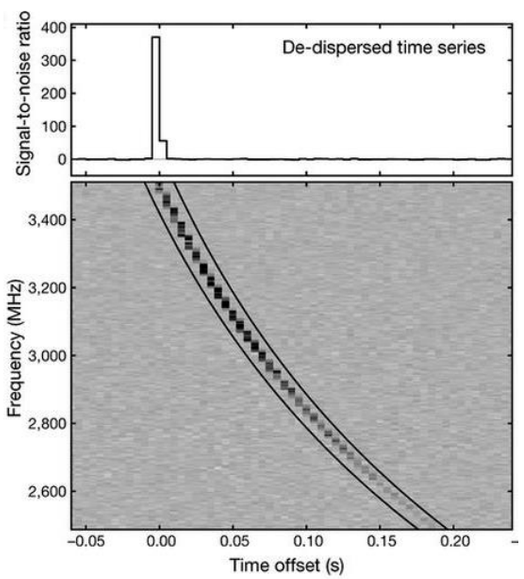
and scintillation → Δν



Sammons+ 2023

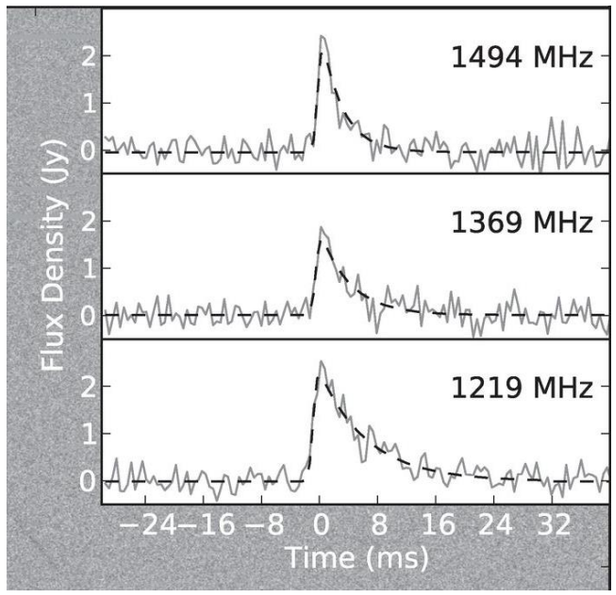
Using fast transients as astrophysical tools

Free electrons cause dispersion → DM



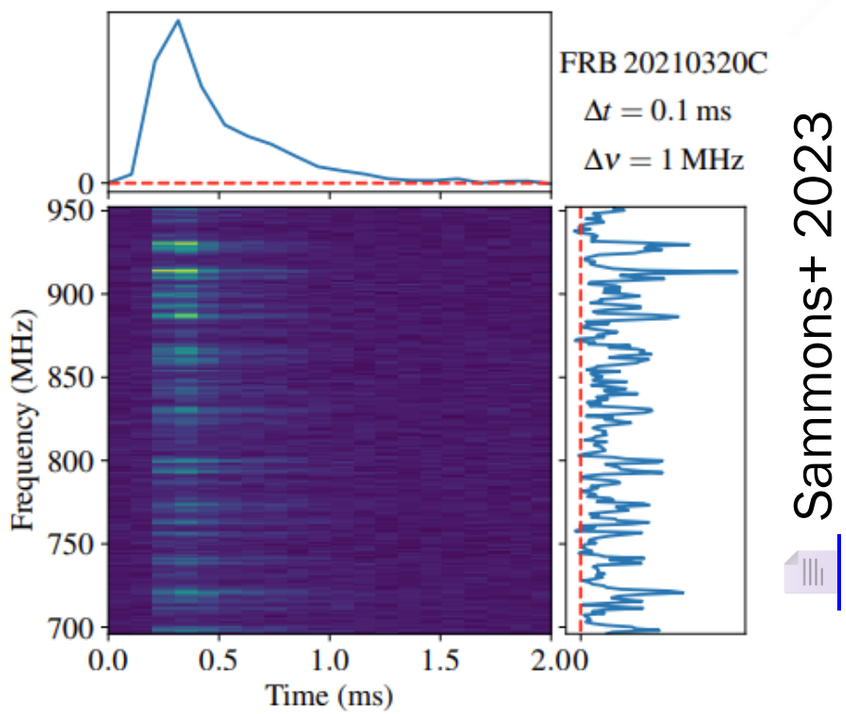
Chatterjee+ 2017

Inhomogeneities cause scattering → τ_s, θ_s



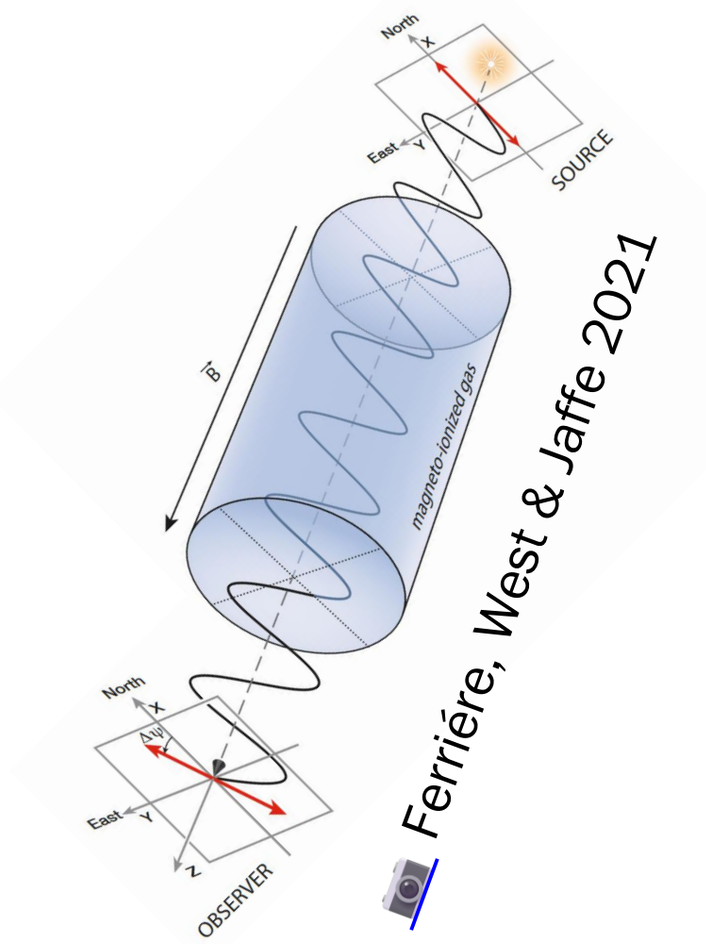
Thornton+ 2013

and scintillation → Δν



Sammons+ 2023

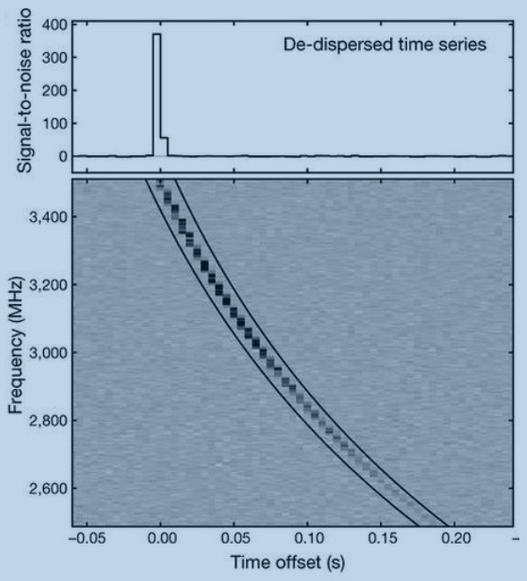
Magnetic fields cause Faraday rotation → RM



Ferrière, West & Jaffe 2021

Using fast transients as astrophysical tools

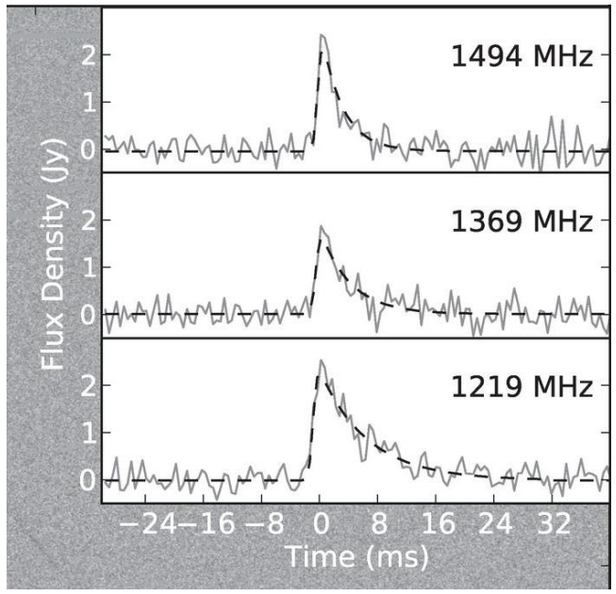
Free electrons cause dispersion → DM



Chatterjee+ 2017

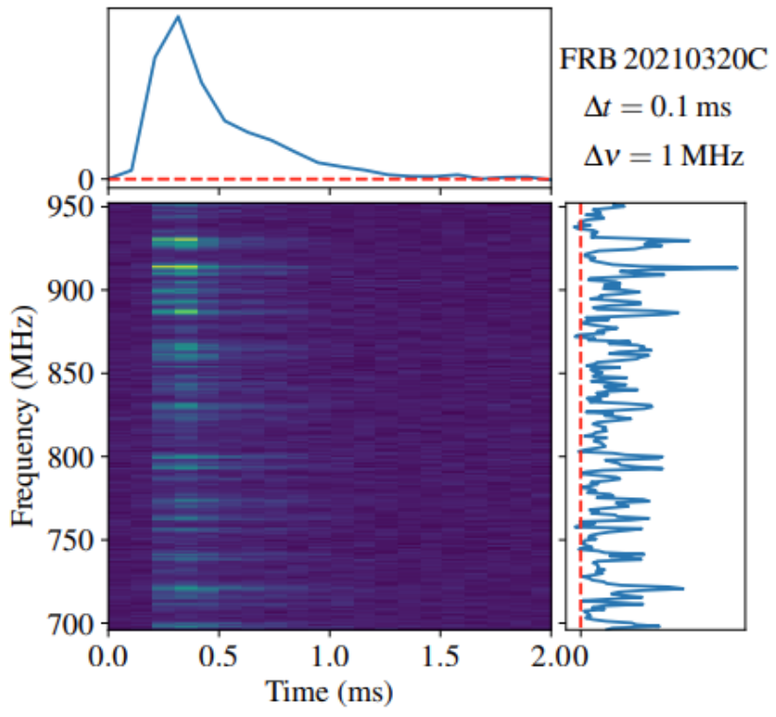
Total amount

Inhomogeneities cause scattering → τ_s, θ_s



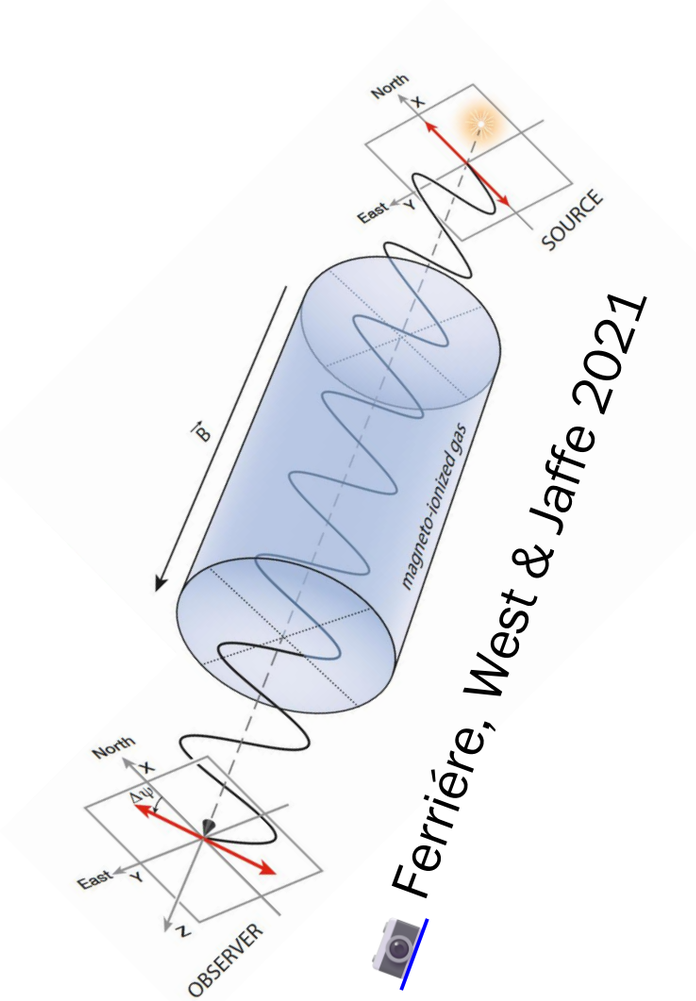
Thornton+ 2013

and scintillation → Δν



Sammons+ 2023

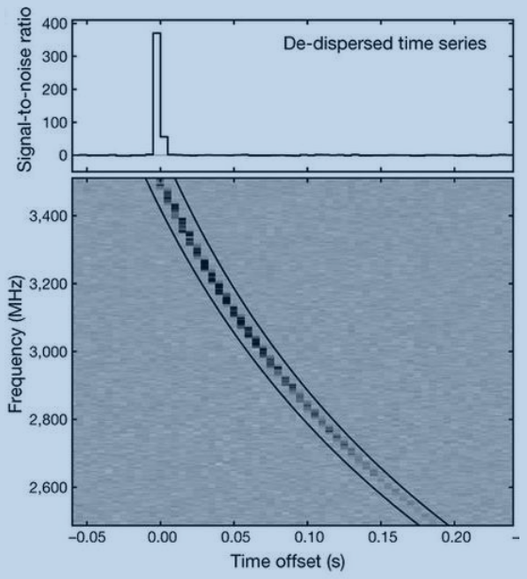
Magnetic fields cause Faraday rotation → RM



Ferrière, West & Jaffe 2021

Using fast transients as astrophysical tools

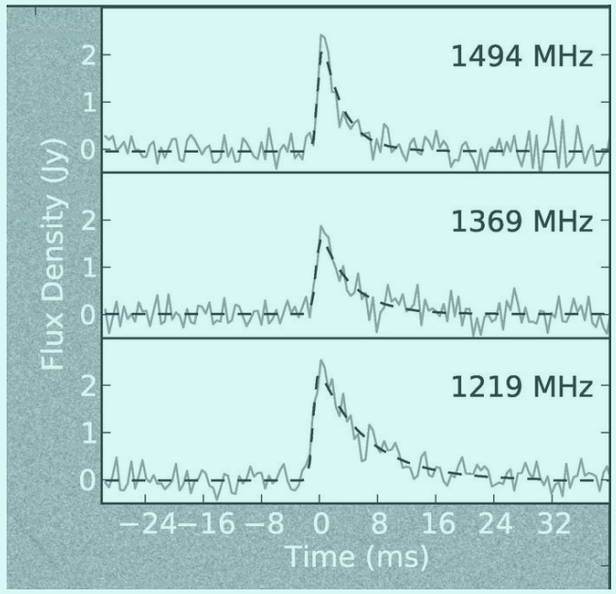
Free electrons cause dispersion → DM



Chatterjee+ 2017

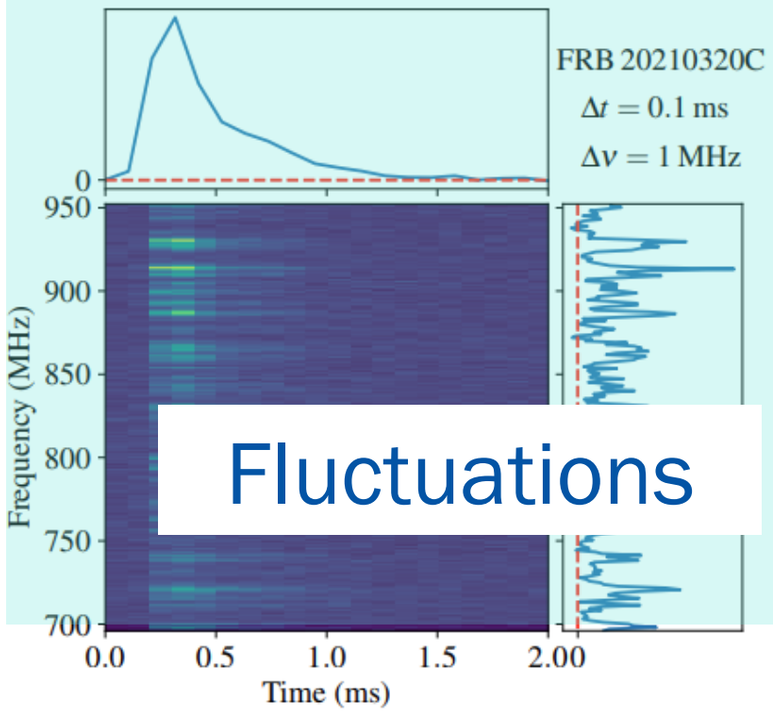
Total amount

Inhomogeneities cause scattering → τ_s, θ_s



Thornton+ 2013

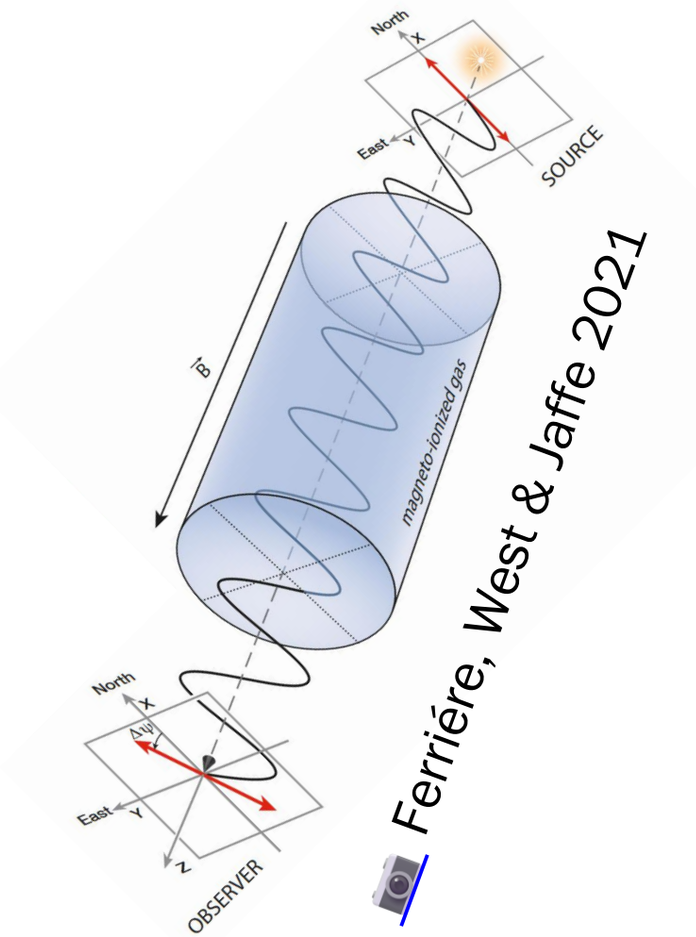
and scintillation → Δν



Sammons+ 2023

Fluctuations

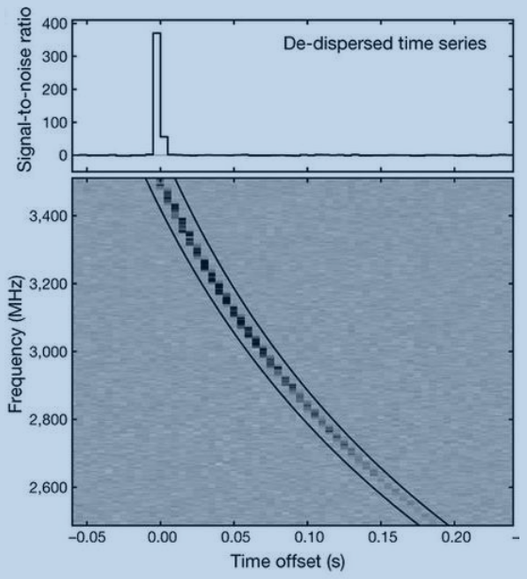
Magnetic fields cause Faraday rotation → RM



Ferrière, West & Jaffe 2021

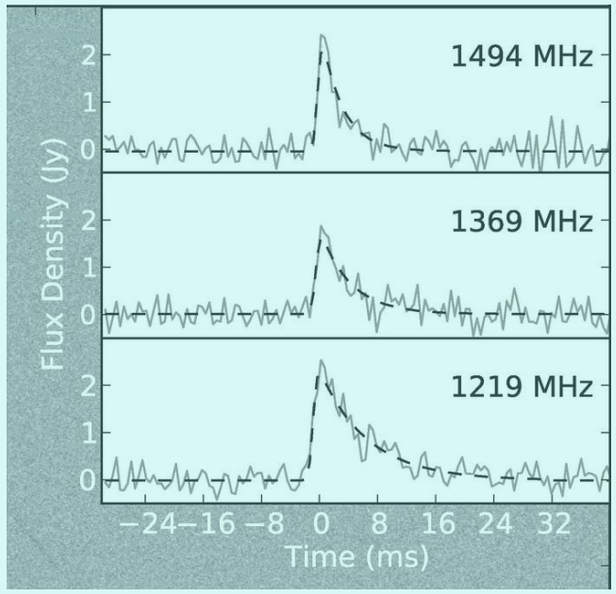
Using fast transients as astrophysical tools

Free electrons cause dispersion → DM



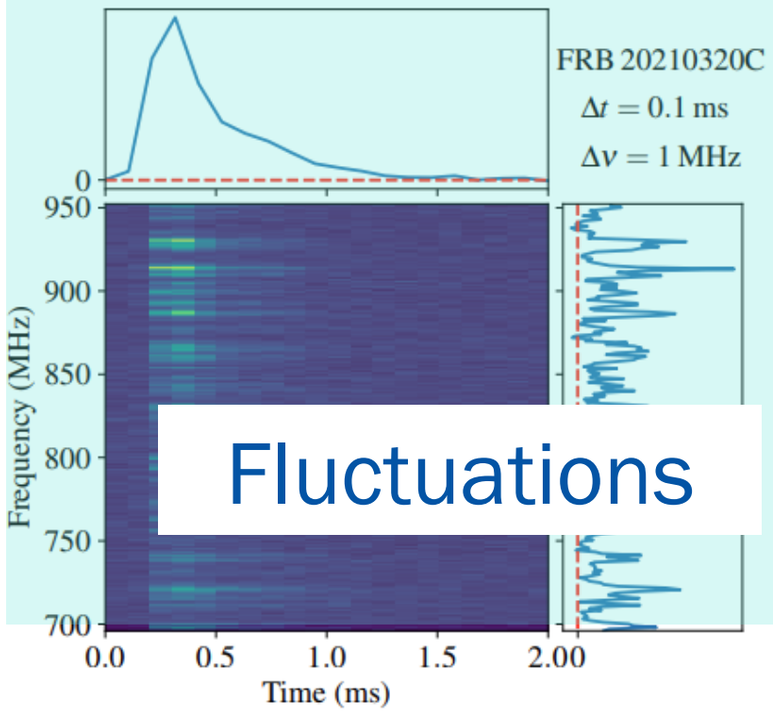
Chatterjee+ 2017

Inhomogeneities cause scattering → τ_s, θ_s



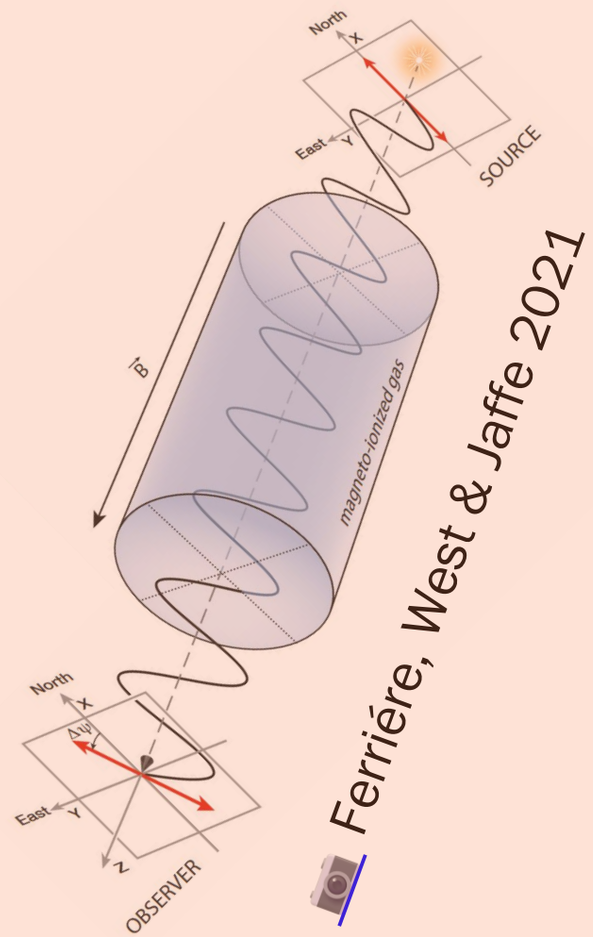
Thornton+ 2013

and scintillation → Δν



Sammons+ 2023

Magnetic fields cause Faraday rotation → RM

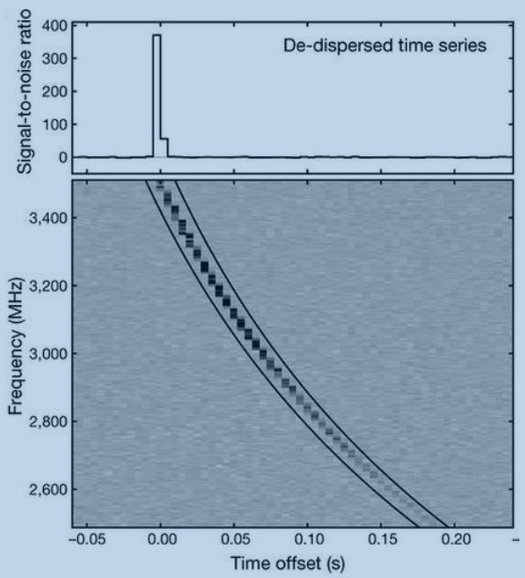


Ferrière, West & Jaffe 2021

Total amount | **Fluctuations** | **Magnetization**

Using fast transients as astrophysical tools

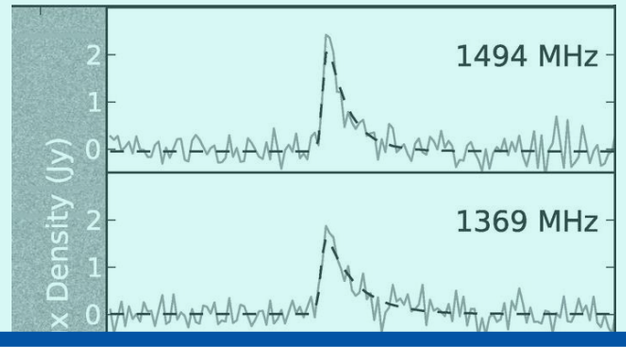
Free electrons cause dispersion → DM



Chatterjee+ 2017

Total amount

Inhomogeneities cause scattering → τ_s, θ_s

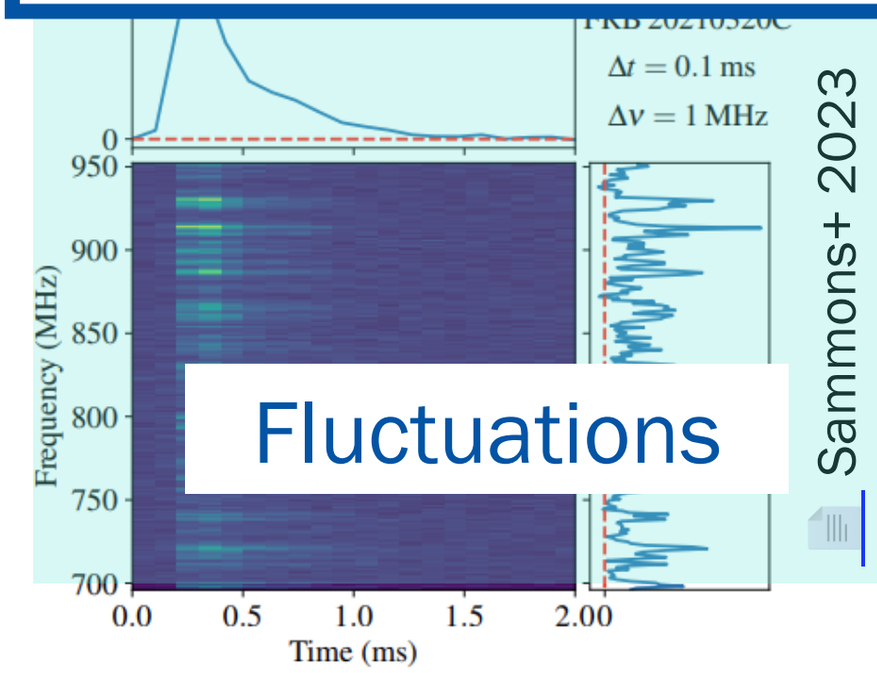


Ton+ 2013

< 300 MHz

- Redshift
- Free-free absorption

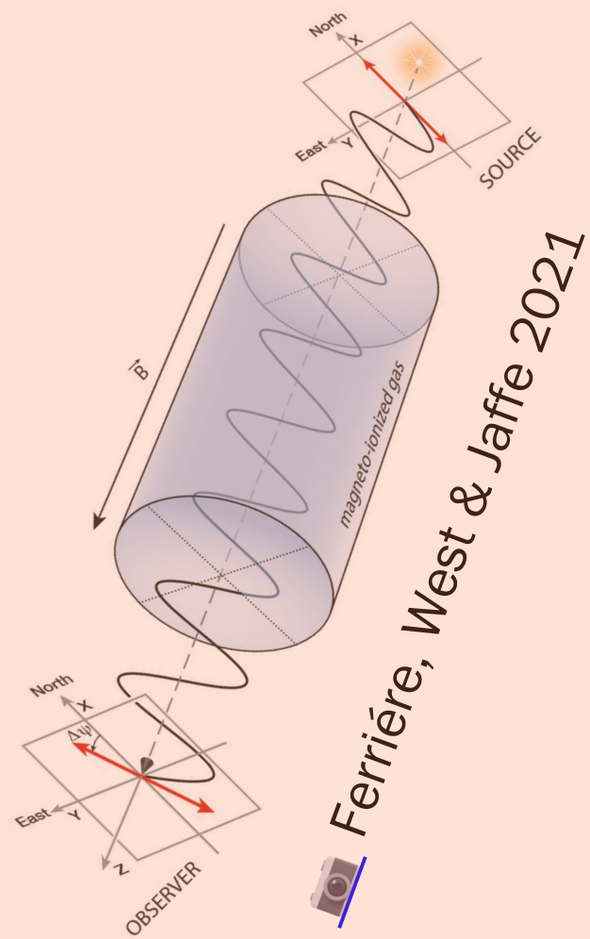
also very relevant!



Sammons+ 2023

Fluctuations

Magnetic fields cause Faraday rotation → RM

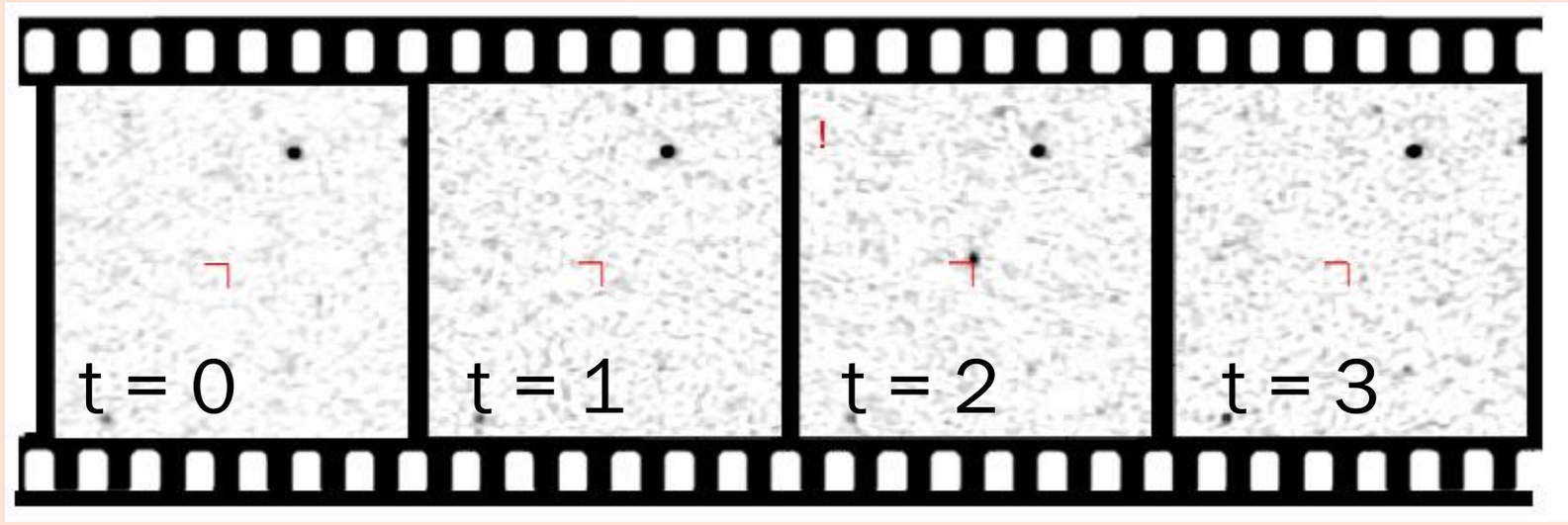


Ferrière, West & Jaffe 2021

Magnetization

Finding radio transients

Imaging

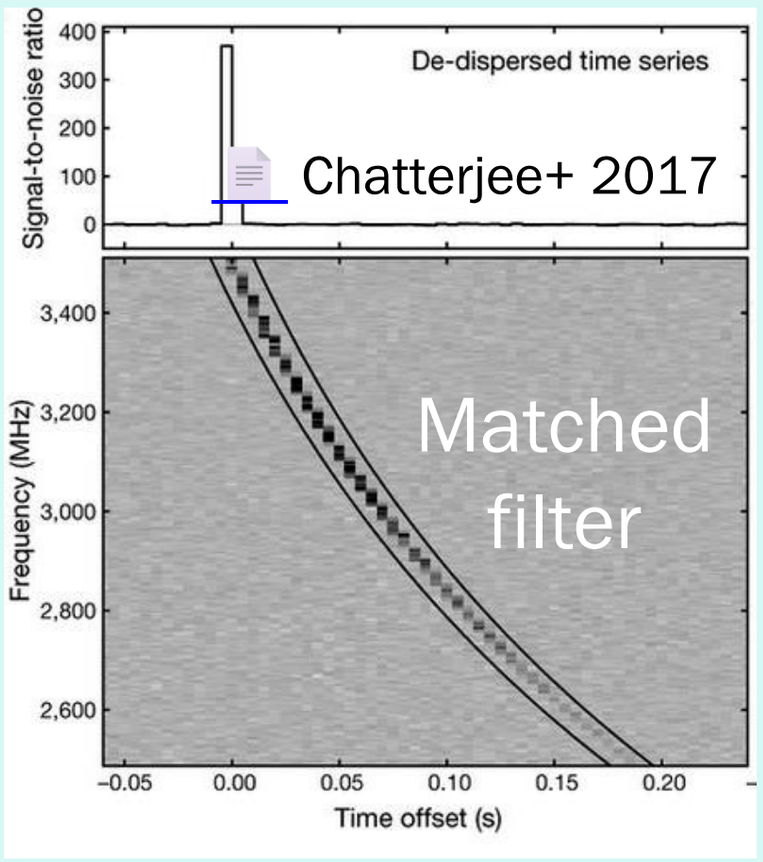


Iris de Ruiter

Beamformed

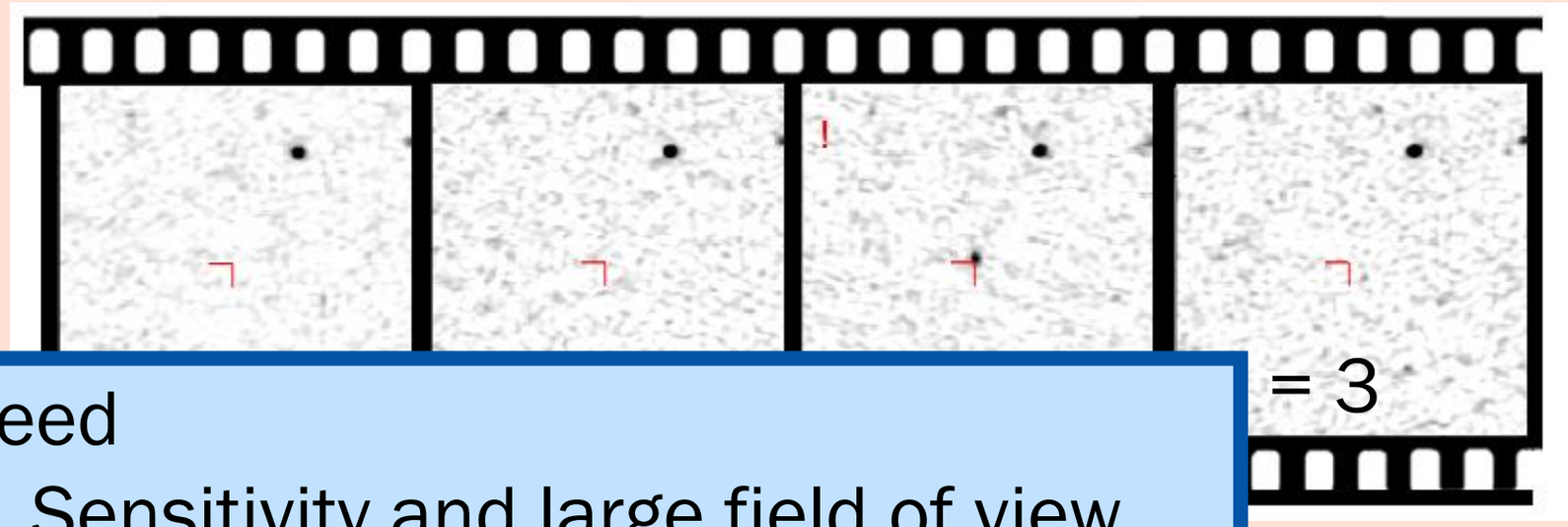
1 dynamic spectrum per beam

Stappers+ 2011



Finding radio transients

Imaging

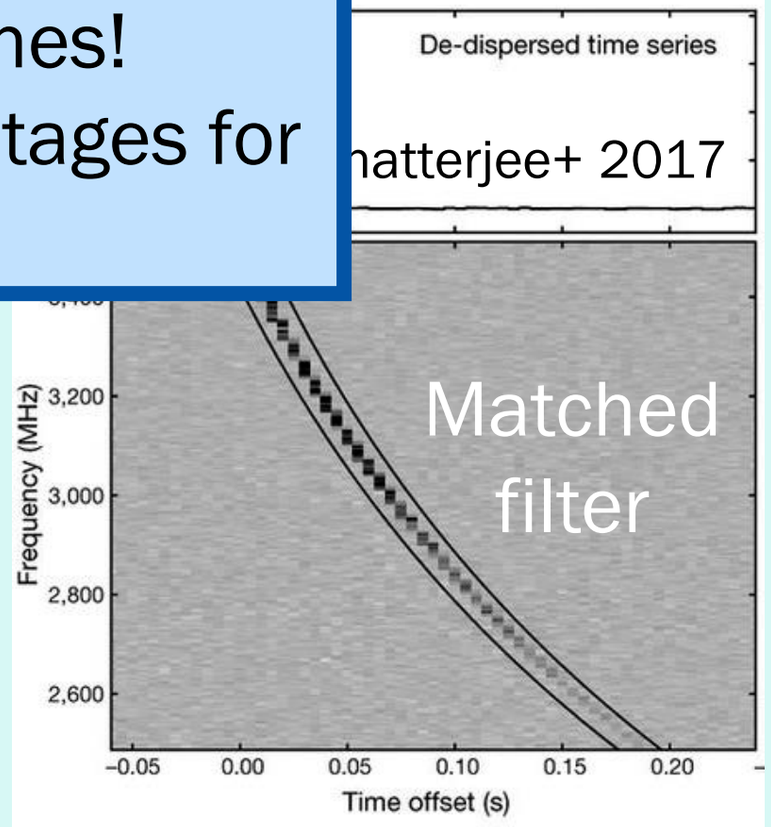


Iris de Ruiter

Need
- Sensitivity and large field of view
- High time resolution
- Lots of compute for searches!
- Ability to save complex voltages for polarization information

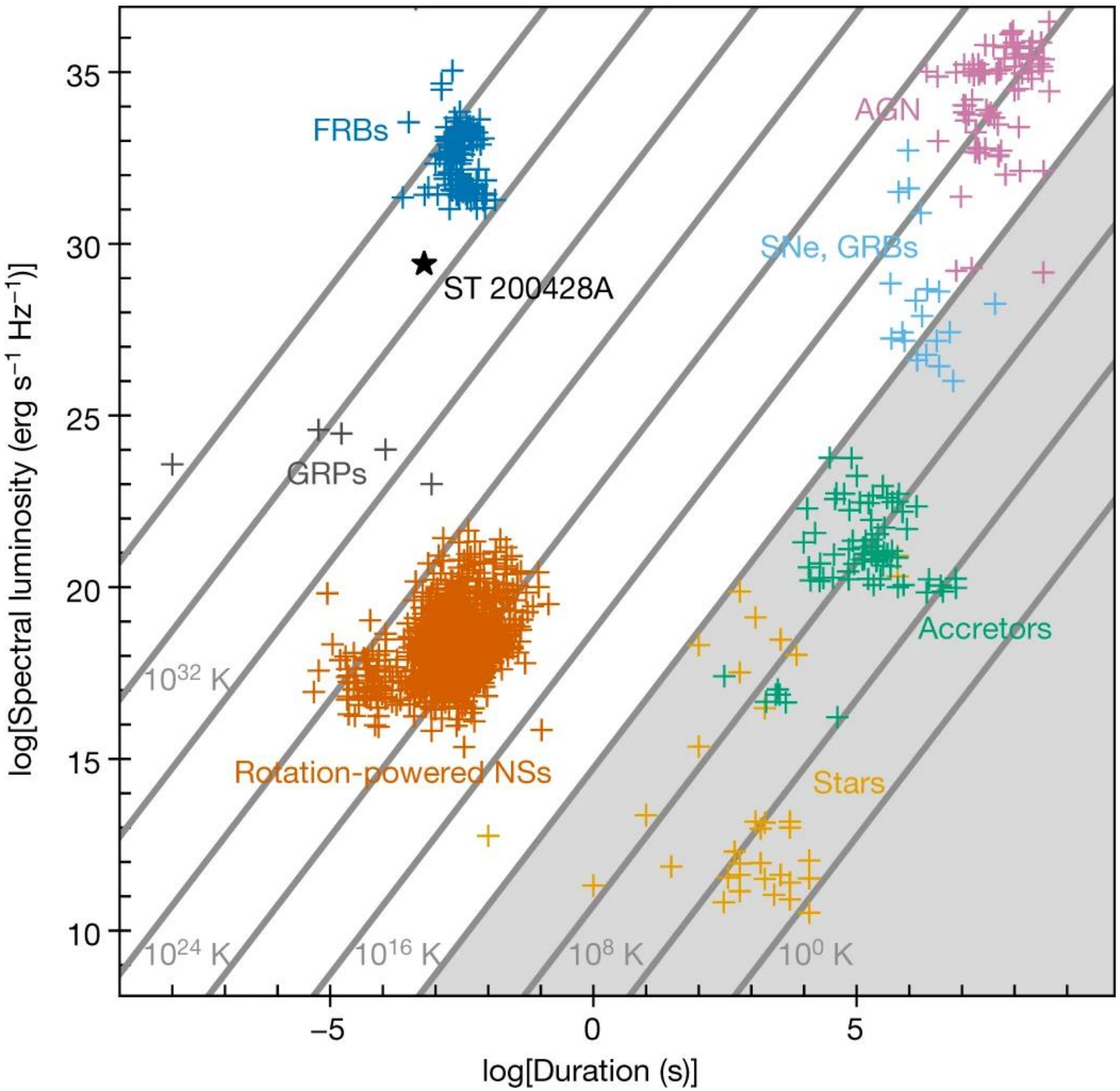
Beamformed

Stappers+ 2011



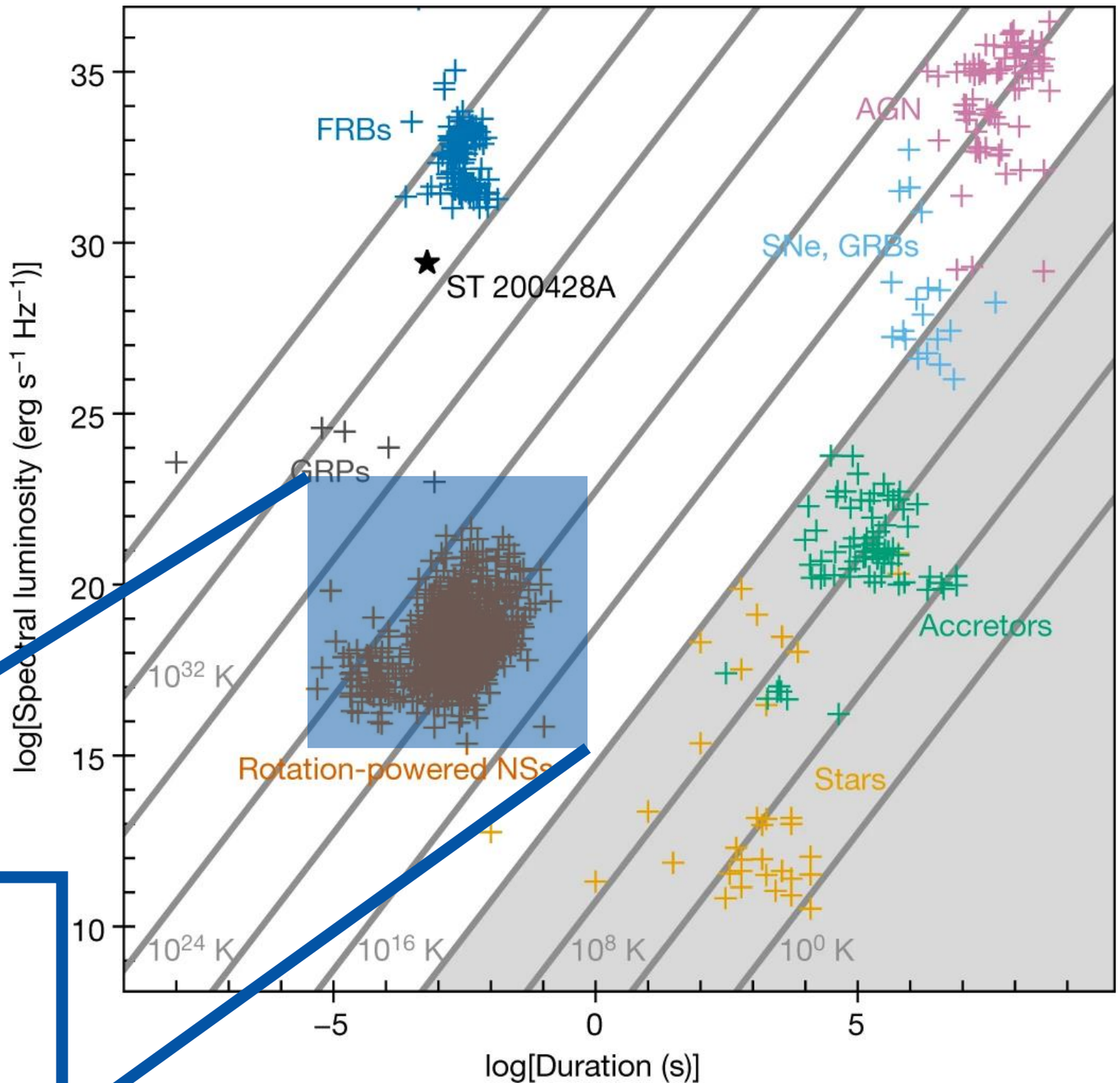
Chatterjee+ 2017

Outline



Bochenek+ 2020

Outline



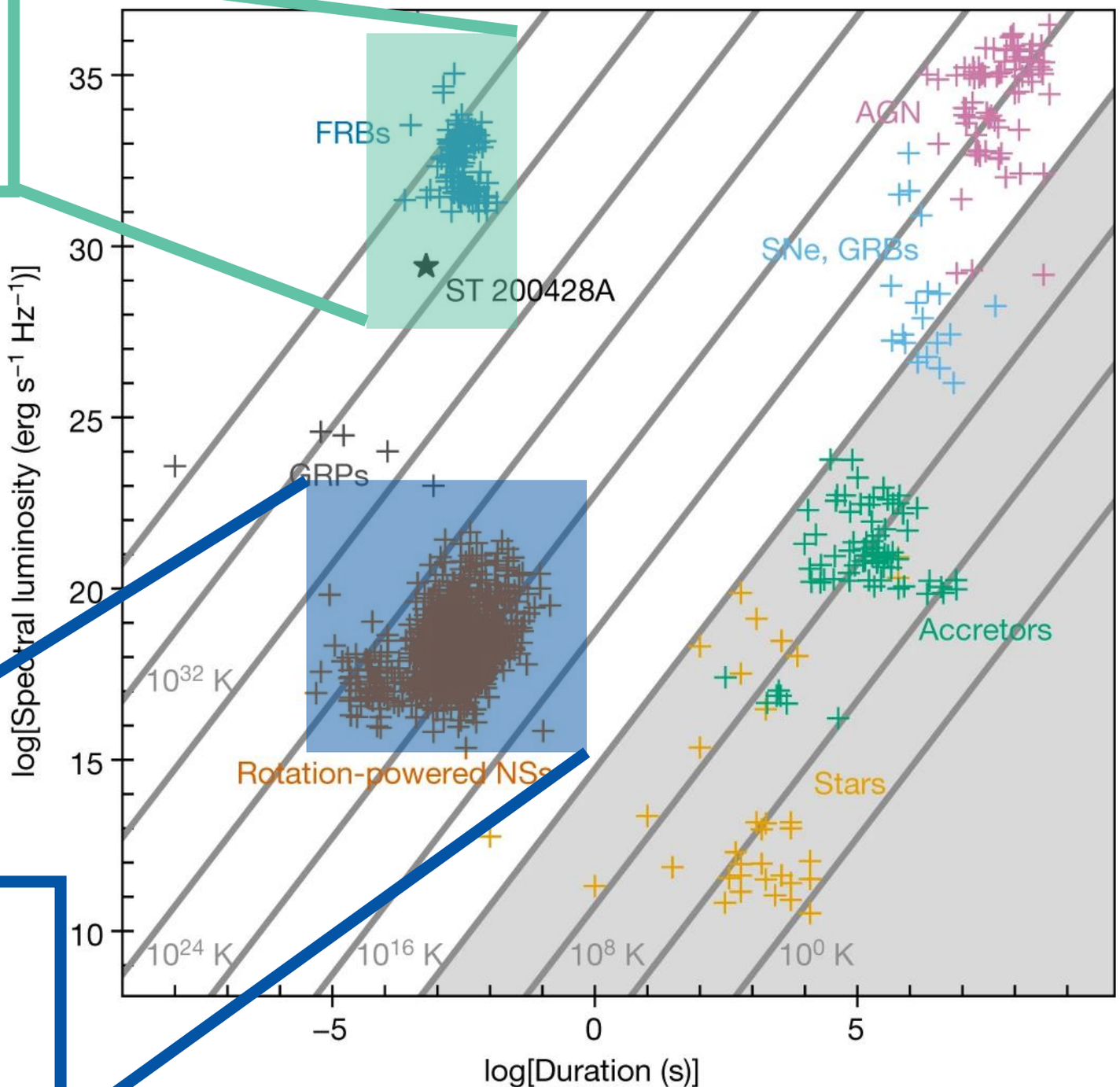
1. Pulsars

Bochenek+ 2020

Outline

2. Fast radio bursts

1. Pulsars

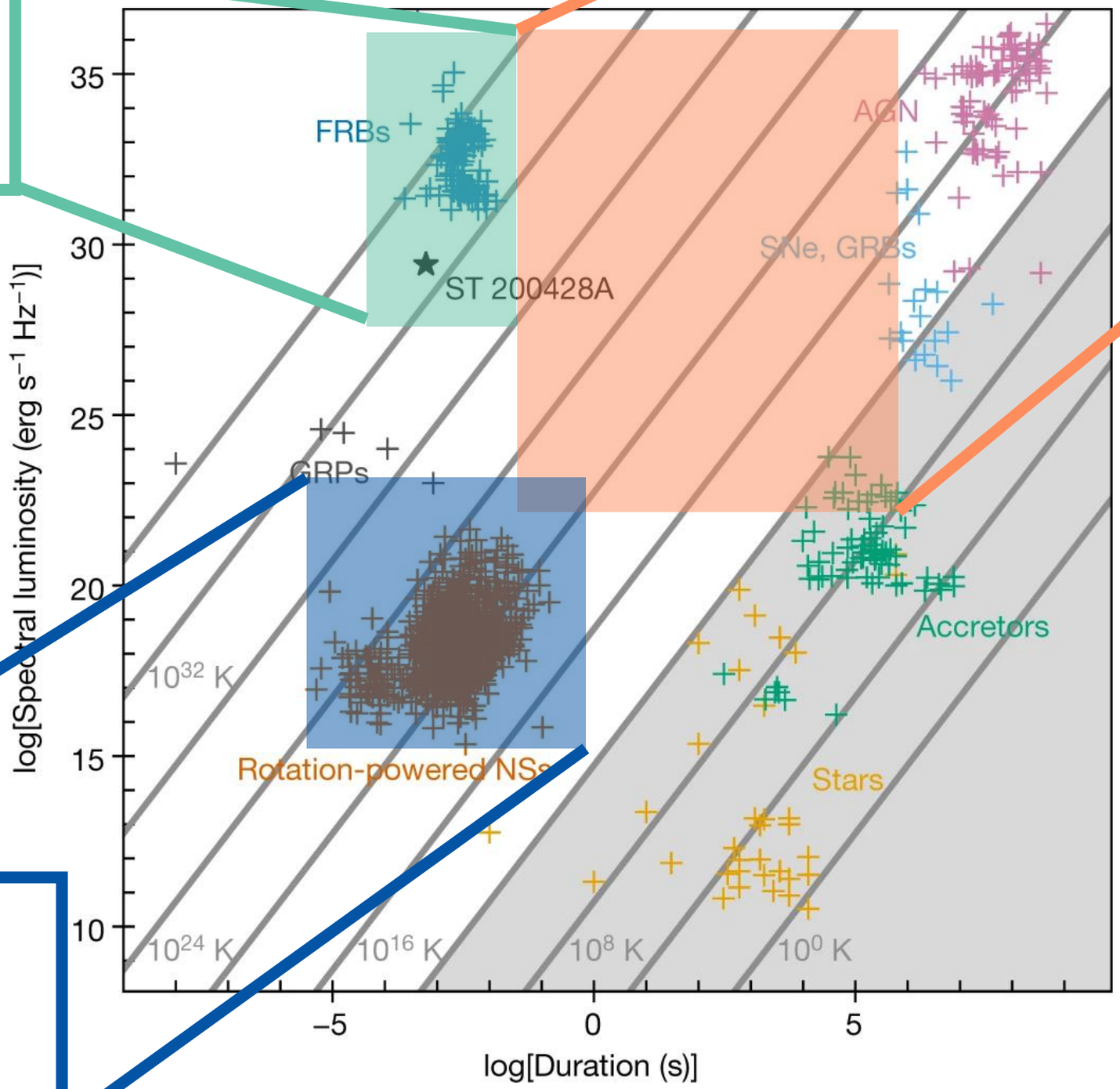


Bochenek+ 2020

Outline

3. “Slow” radio transients (~s)

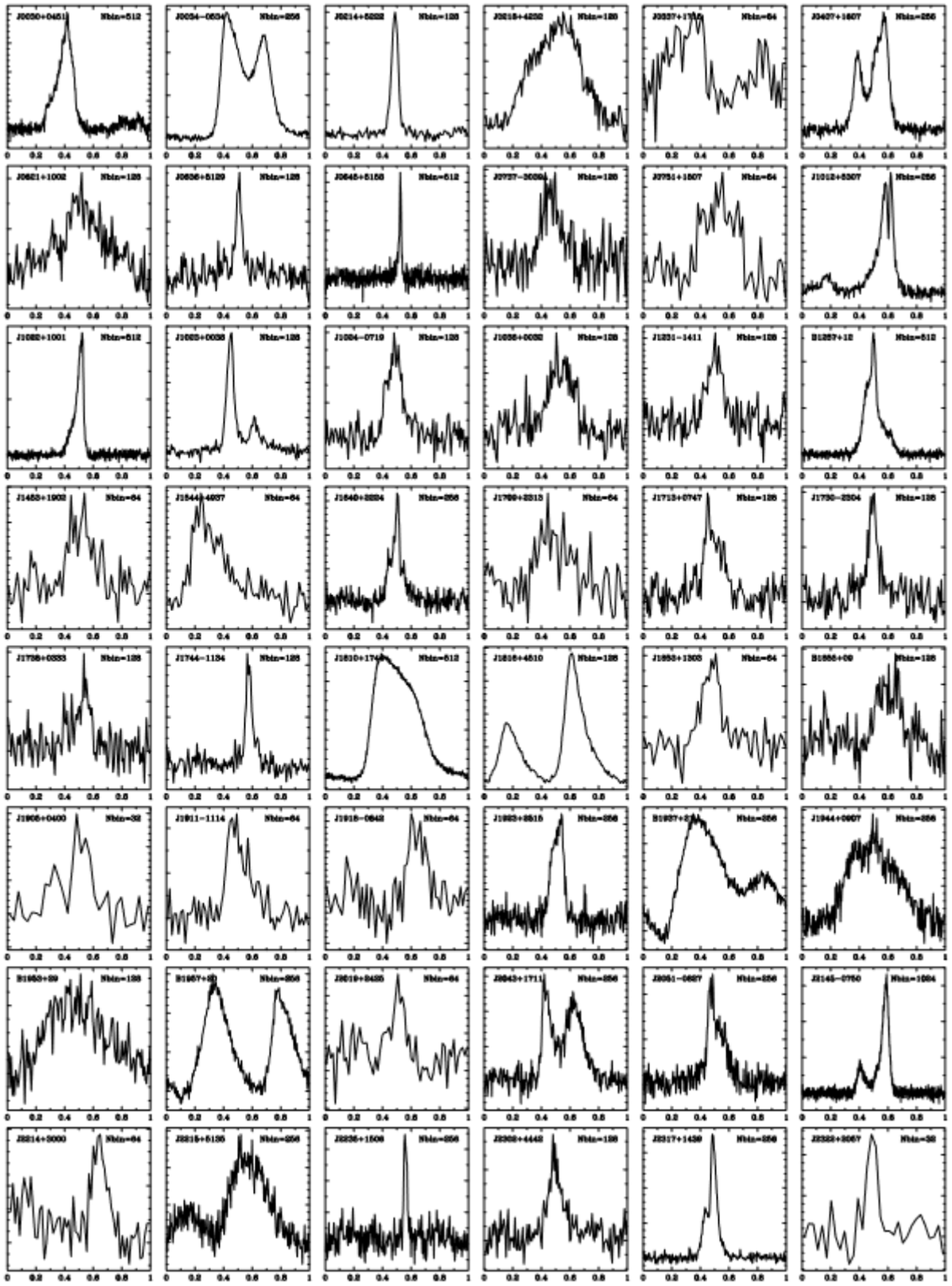
2. Fast radio bursts

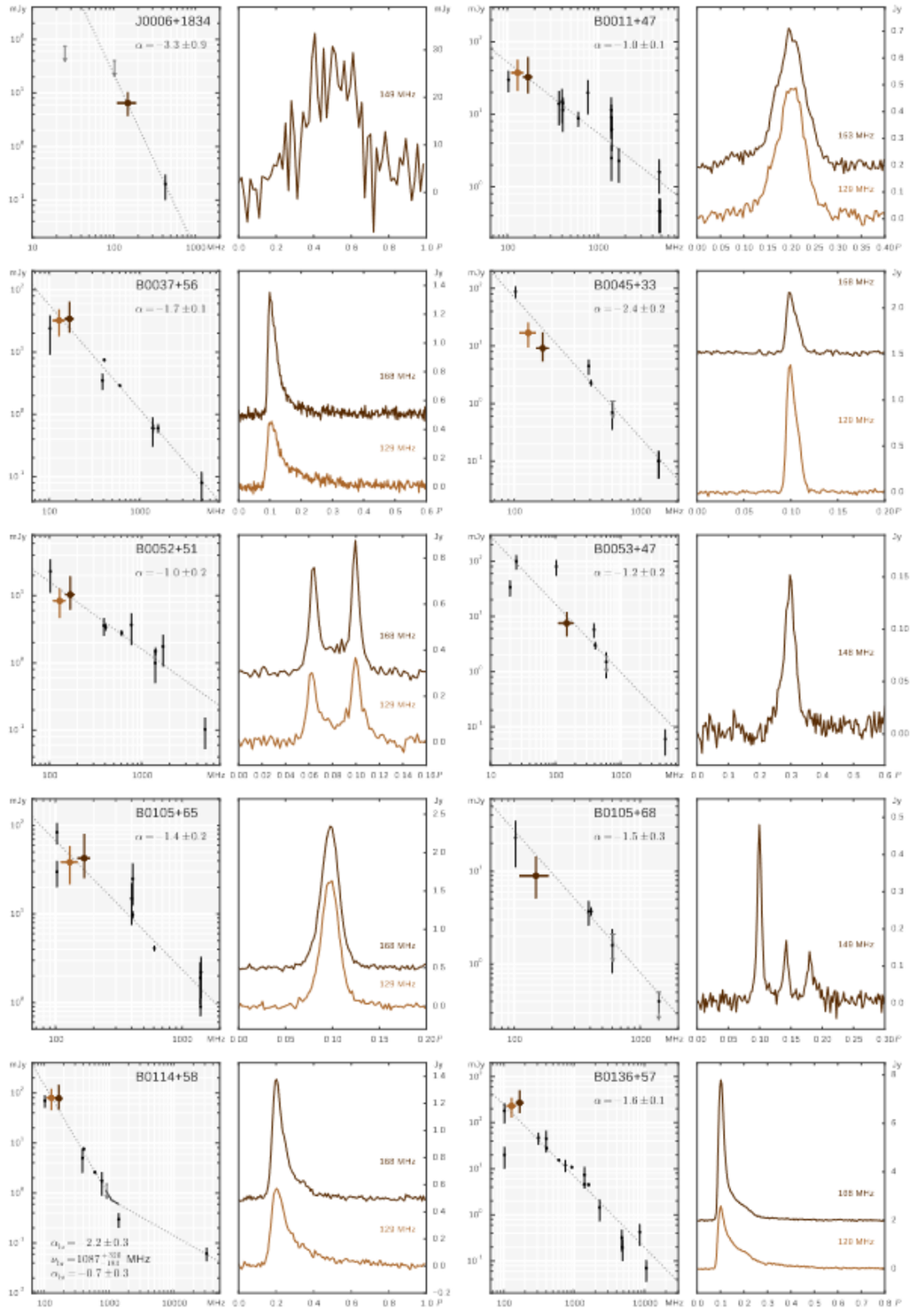


1. Pulsars

Bochenek+ 2020

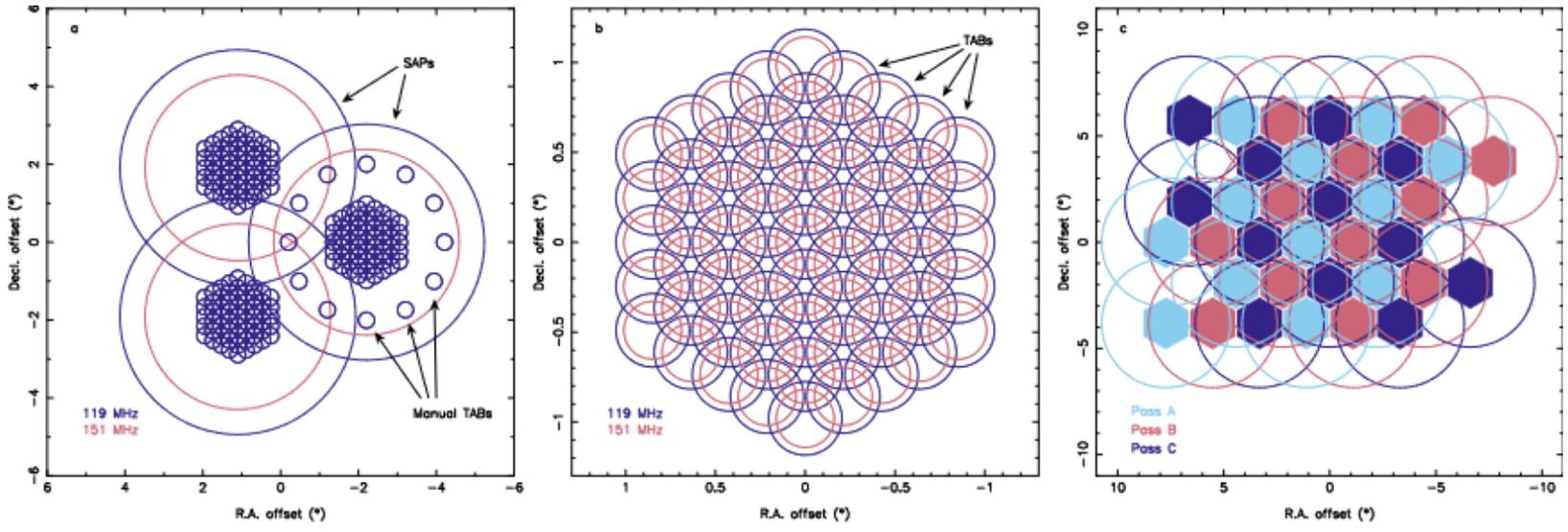
Pulsar census with LOFAR

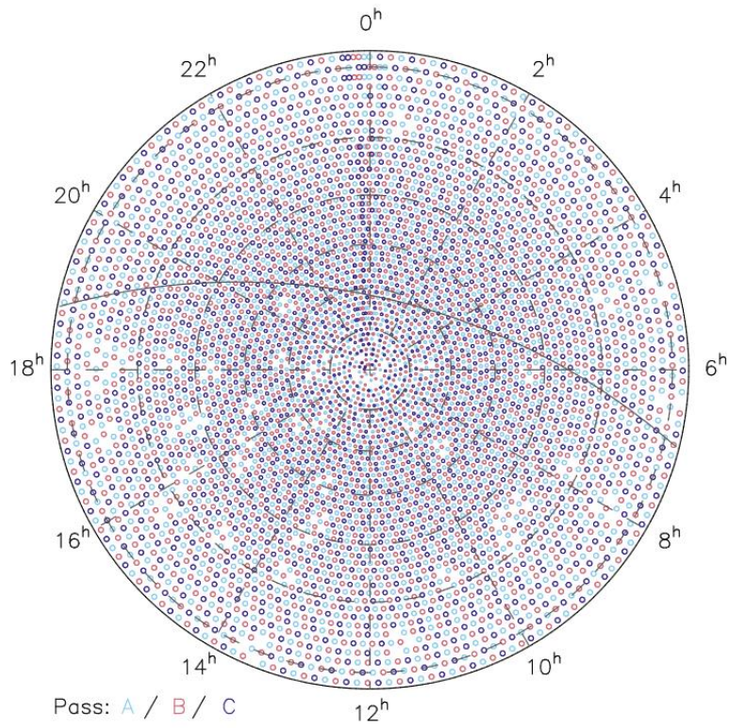




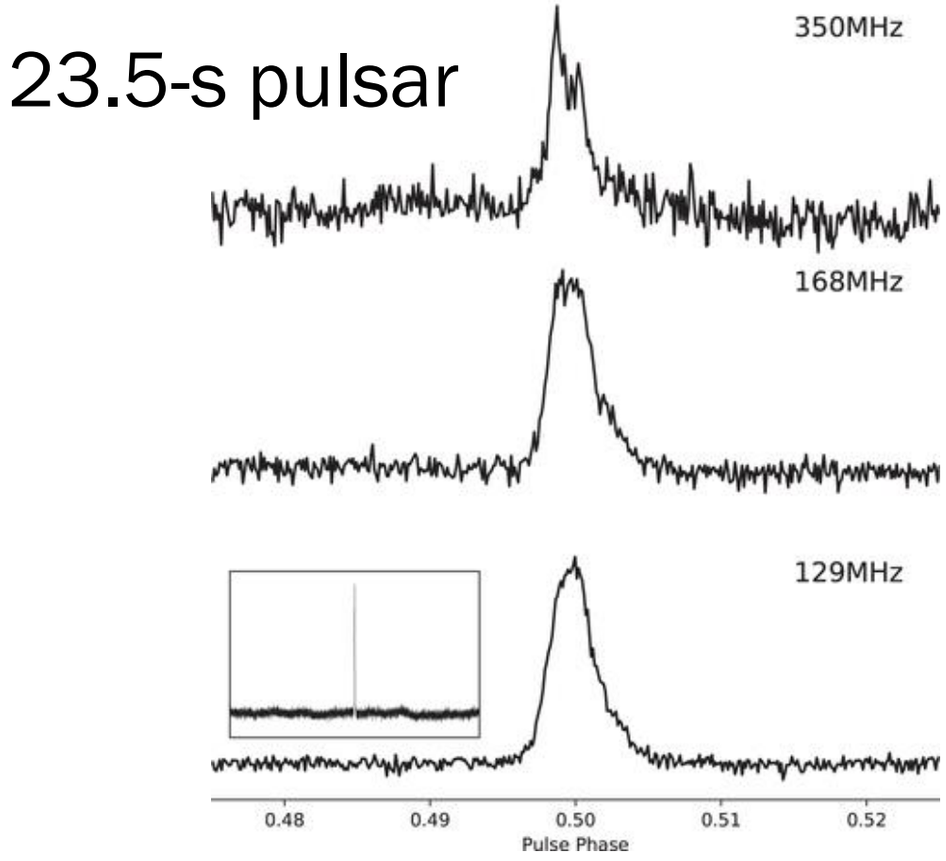
Kondratiev+ 2016 Bilous+ 2016

Pulsar survey with LOFAR: LOTAAS



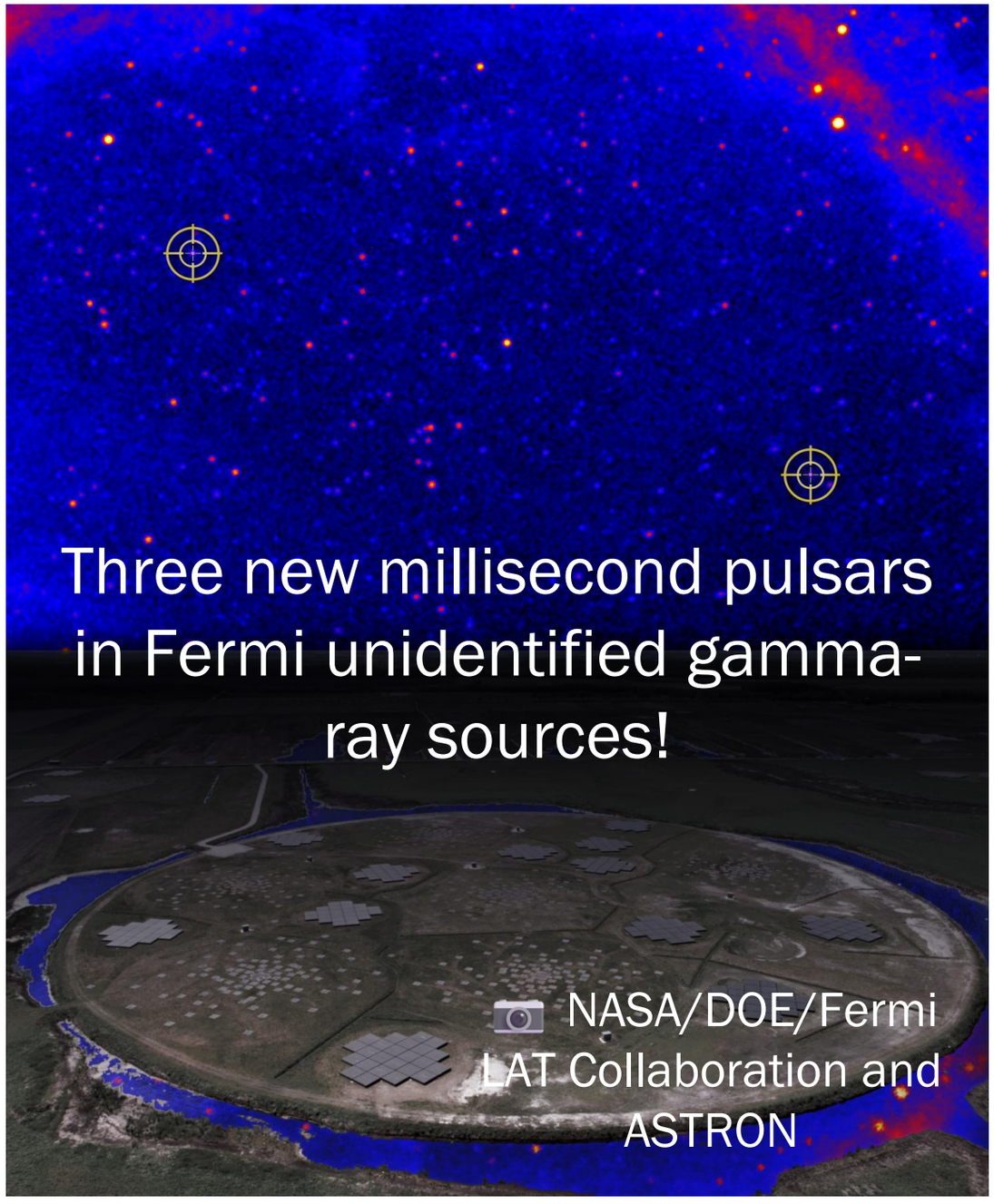


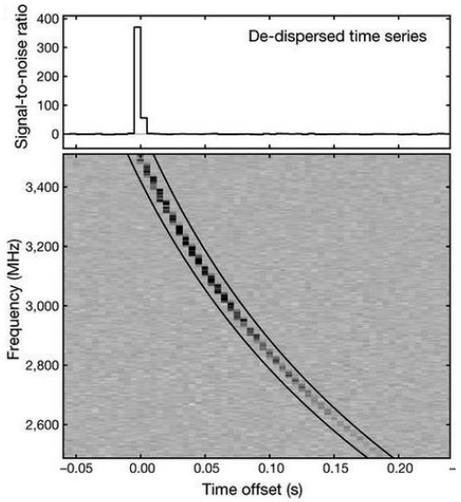
- 0.5 ms time resolution
- 1 hr integration per pointing
- 73 pulsar discoveries, including longest-period pulsar
- No fast transients through single pulse searches
- Reprocessing LOTAAS data on Long Term Archive with current knowledge may yield discoveries



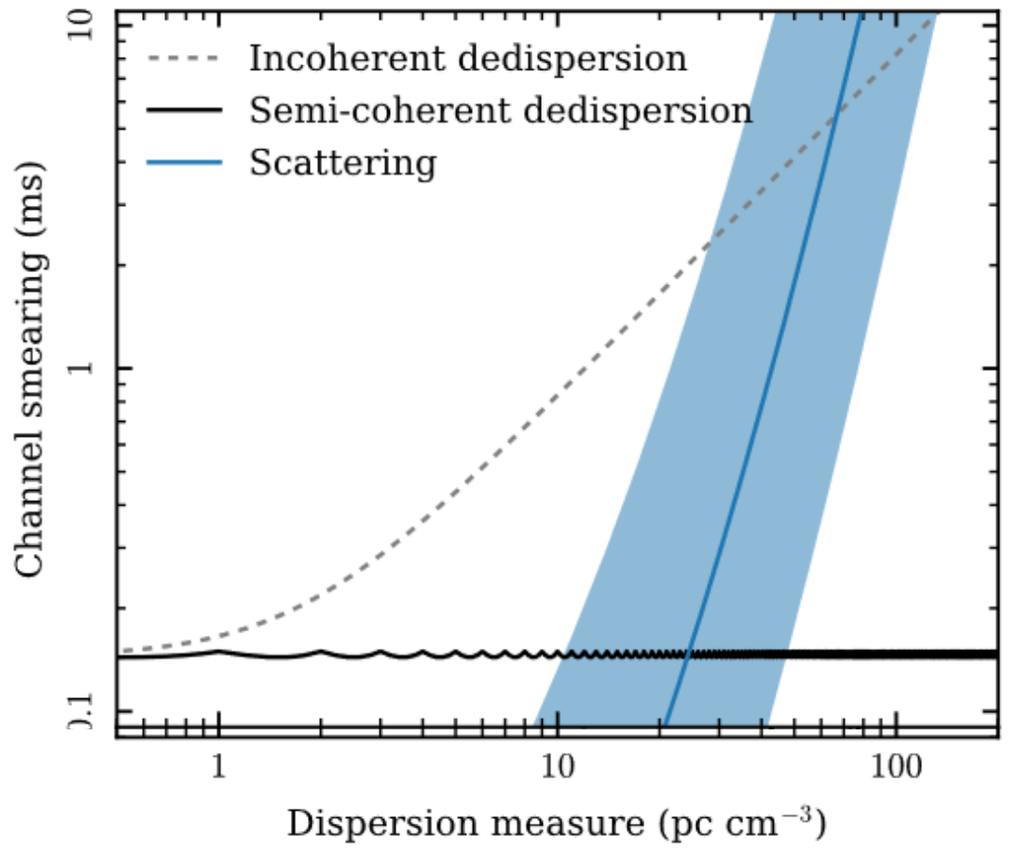
Sanidas+ 2019 Tan+ 2018

Ways around dispersion smearing



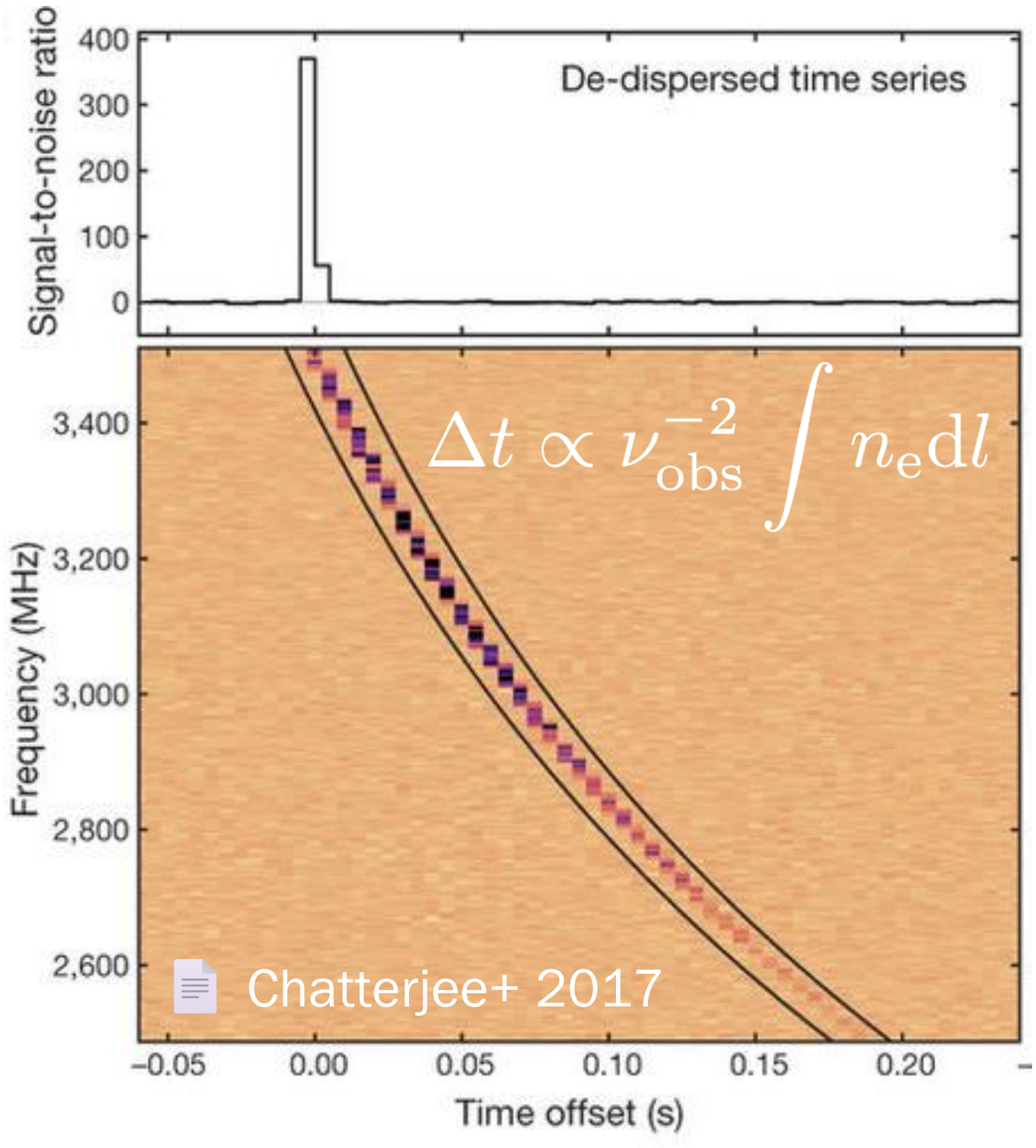


Chatterjee+ 2017



- Useful for fast transient searches, but computationally intensive!
- Scatter-broadening may dominate!

Fast radio bursts (FRBs)



- Discovered in 2007, now 700+ published
- Some sources repeat
- Origin unknown
- Almost 50 in total with associated host galaxy and redshift

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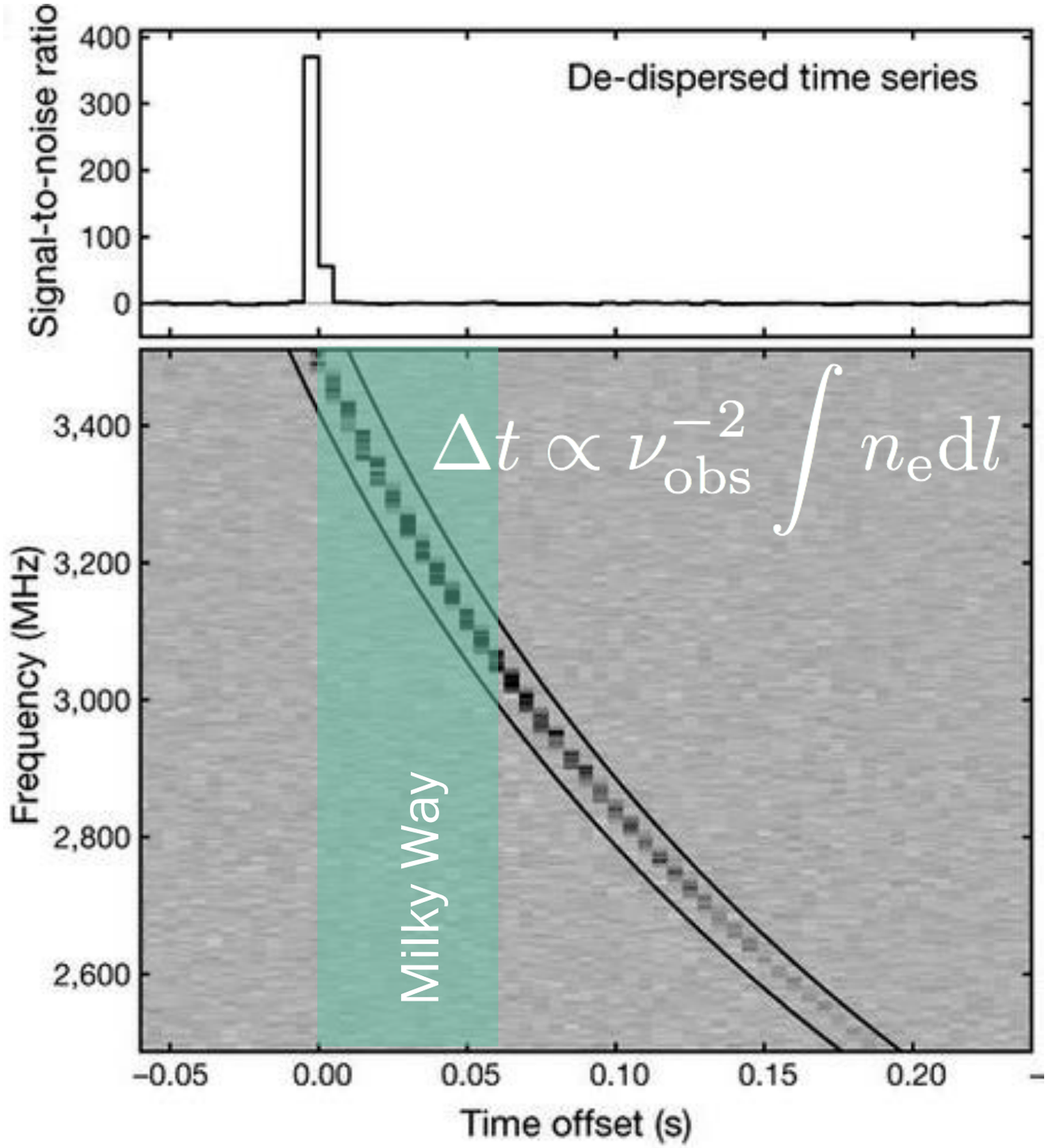

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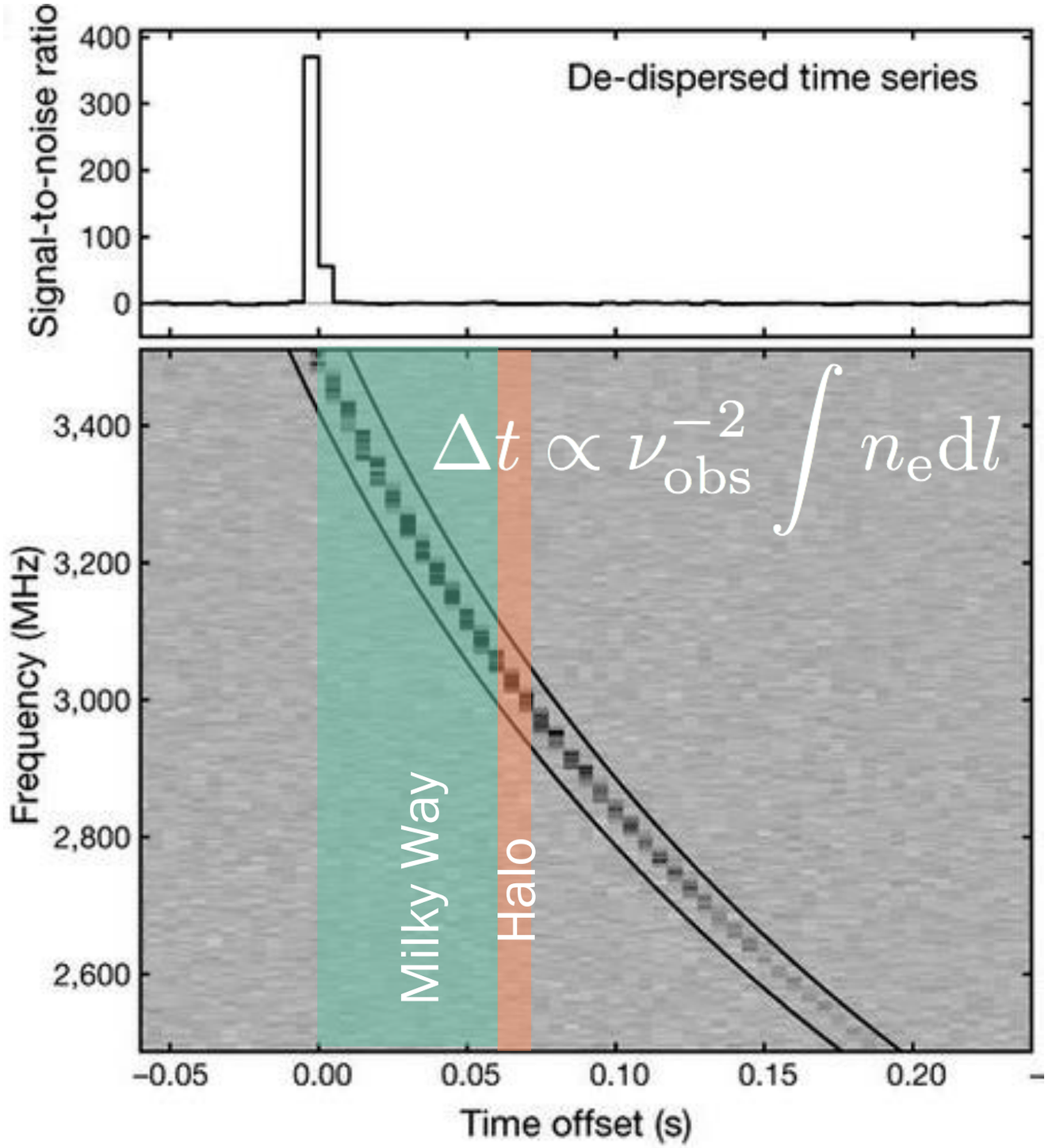

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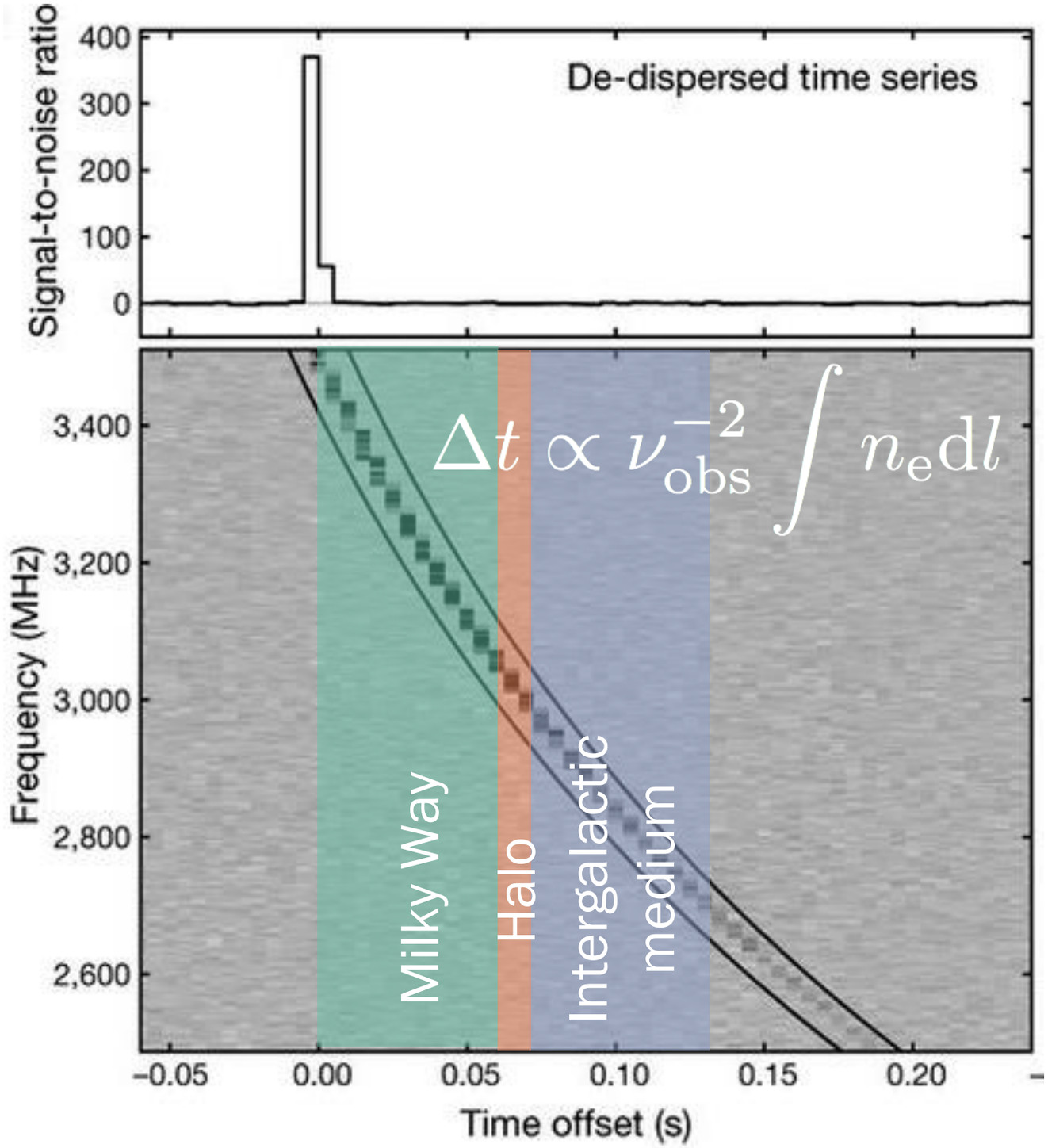

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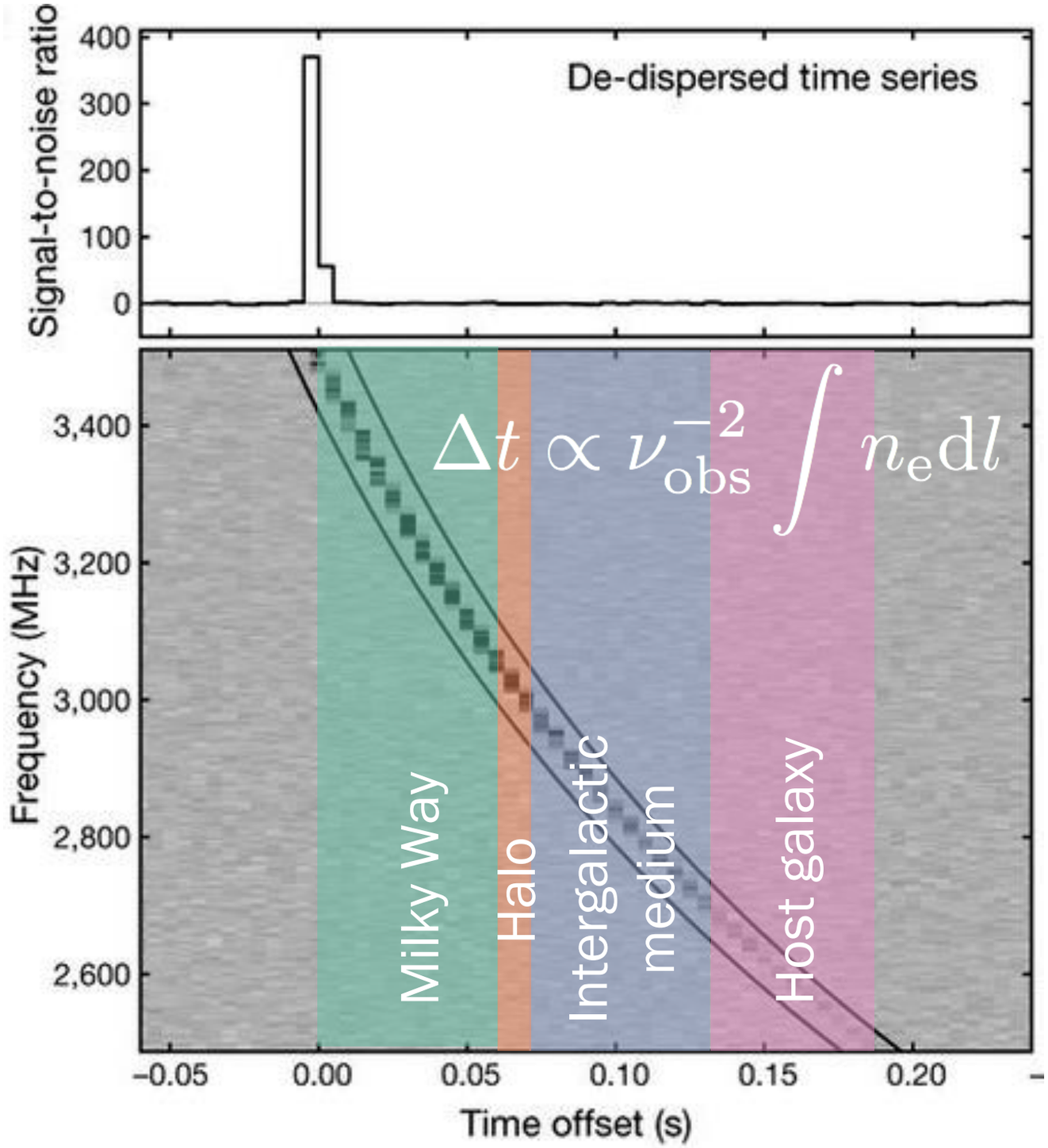

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FRB spectra

- Probe FRB emission and propagation
- Low-frequency cutoff constrains source environments

10 GHz

NRAO/AUI/NSF

Up to 8 GHz
Gajjar+2018

Most FRBs are detected at 600 MHz and at L-band*

1 GHz

NRAO/AUI/NSF

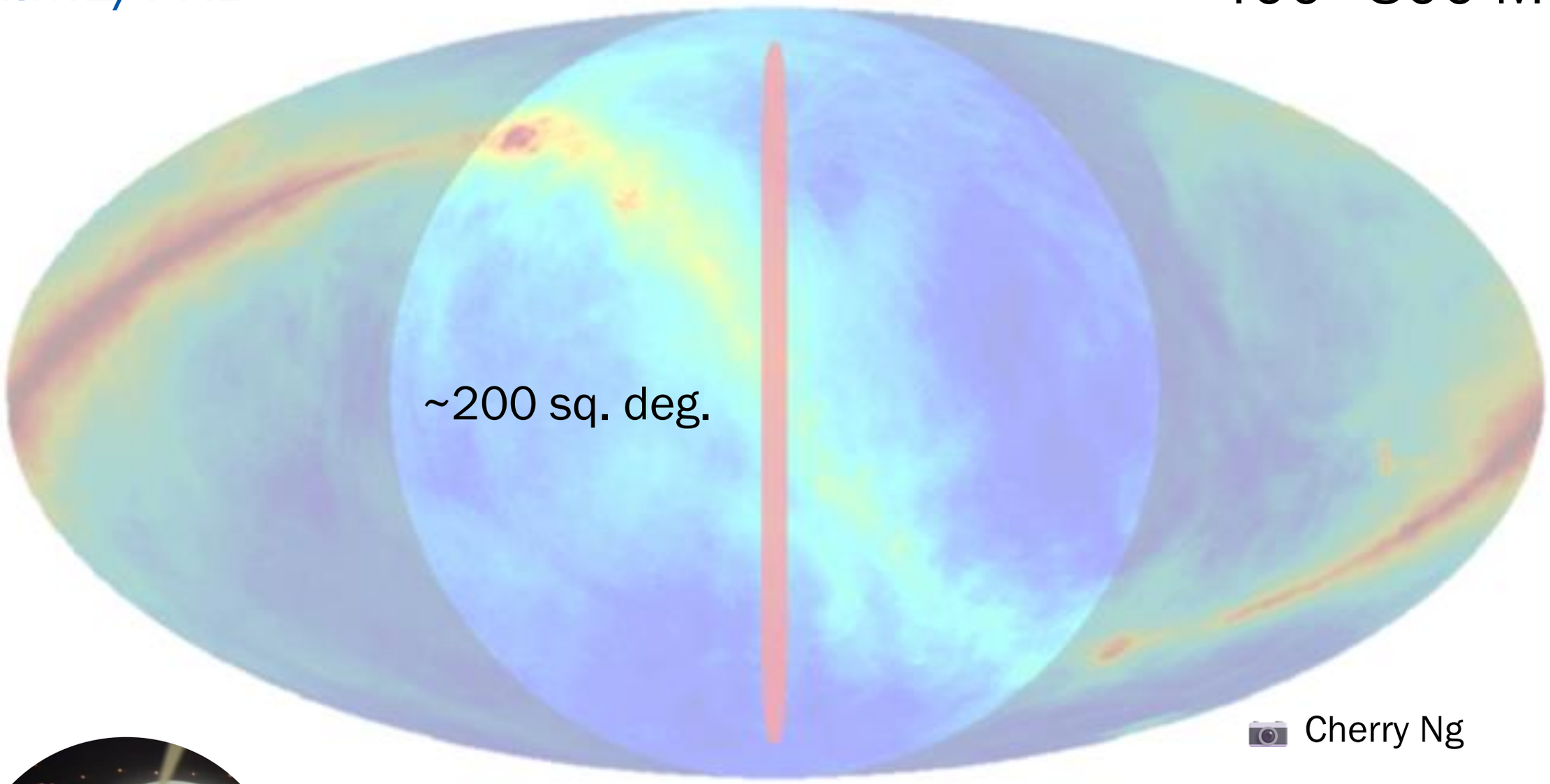
Mike Peel

Down to 300 MHz
Chawla+2020; Pilia+2020

100 MHz

CHIME/FRB

400–800 MHz

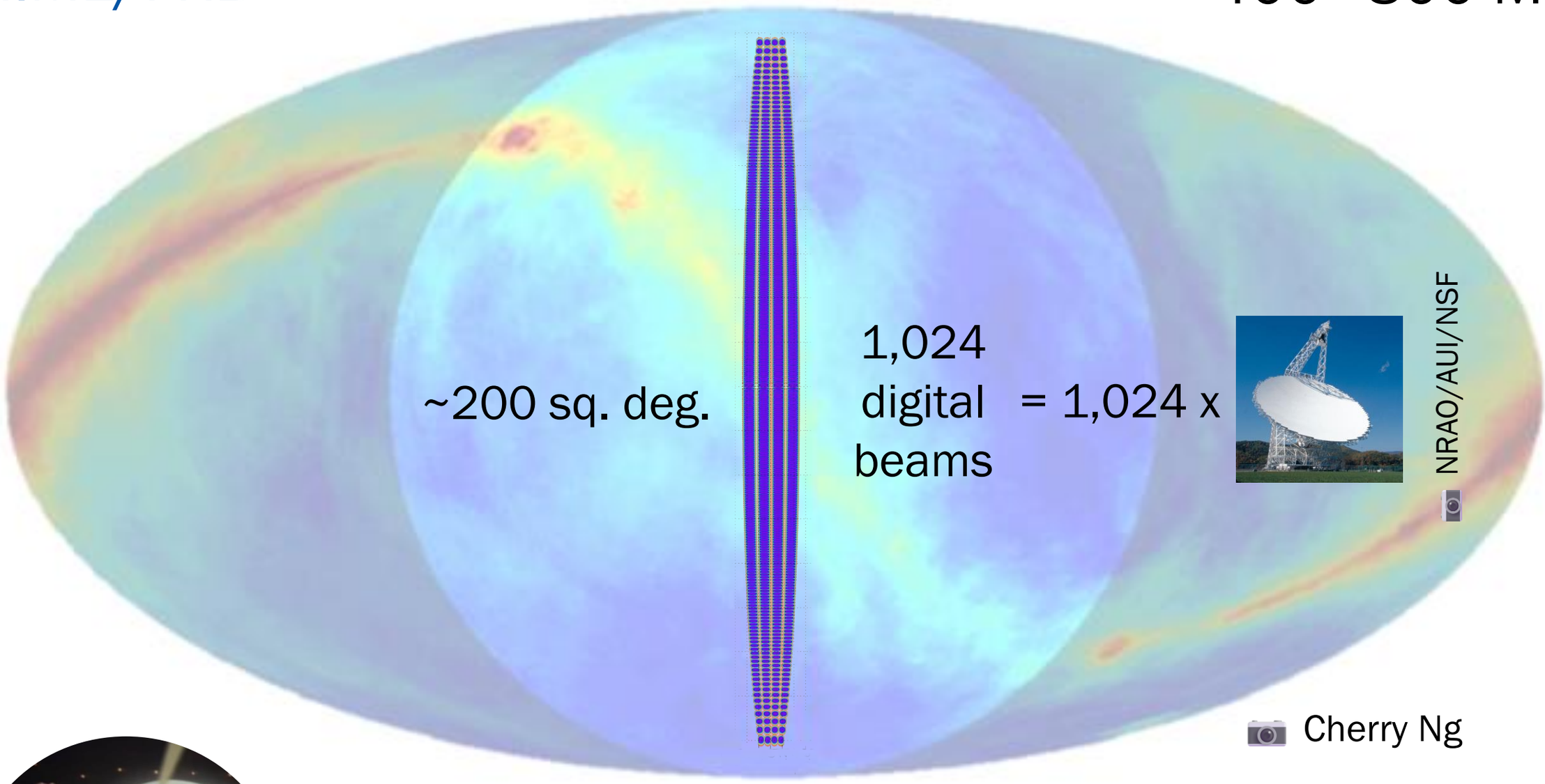


Cherry Ng

CHIME/FRB collaboration+ 2018

CHIME/FRB

400–800 MHz



NRAO/AUI/NSF

Cherry Ng

CHIME/FRB collaboration+ 2018

CHIME/FRB

400–800 MHz

☺ Mapping speed

Detecting few FRBs per day, up almost 24/7 and year round

☺ Searching for repeat bursts

Revisiting same sky every day

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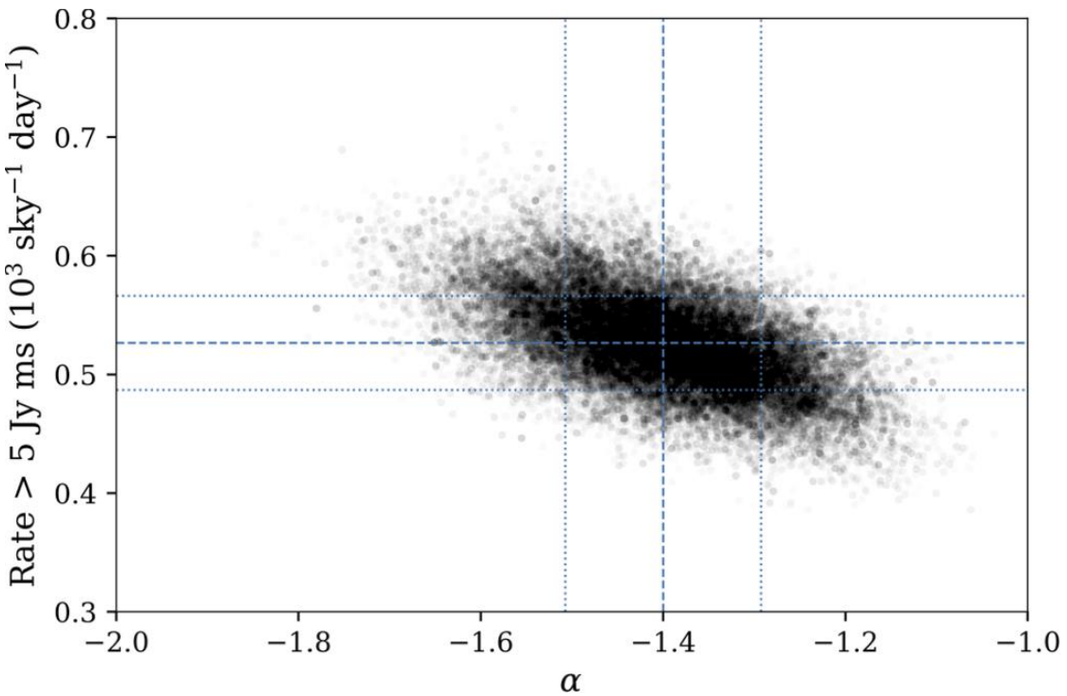
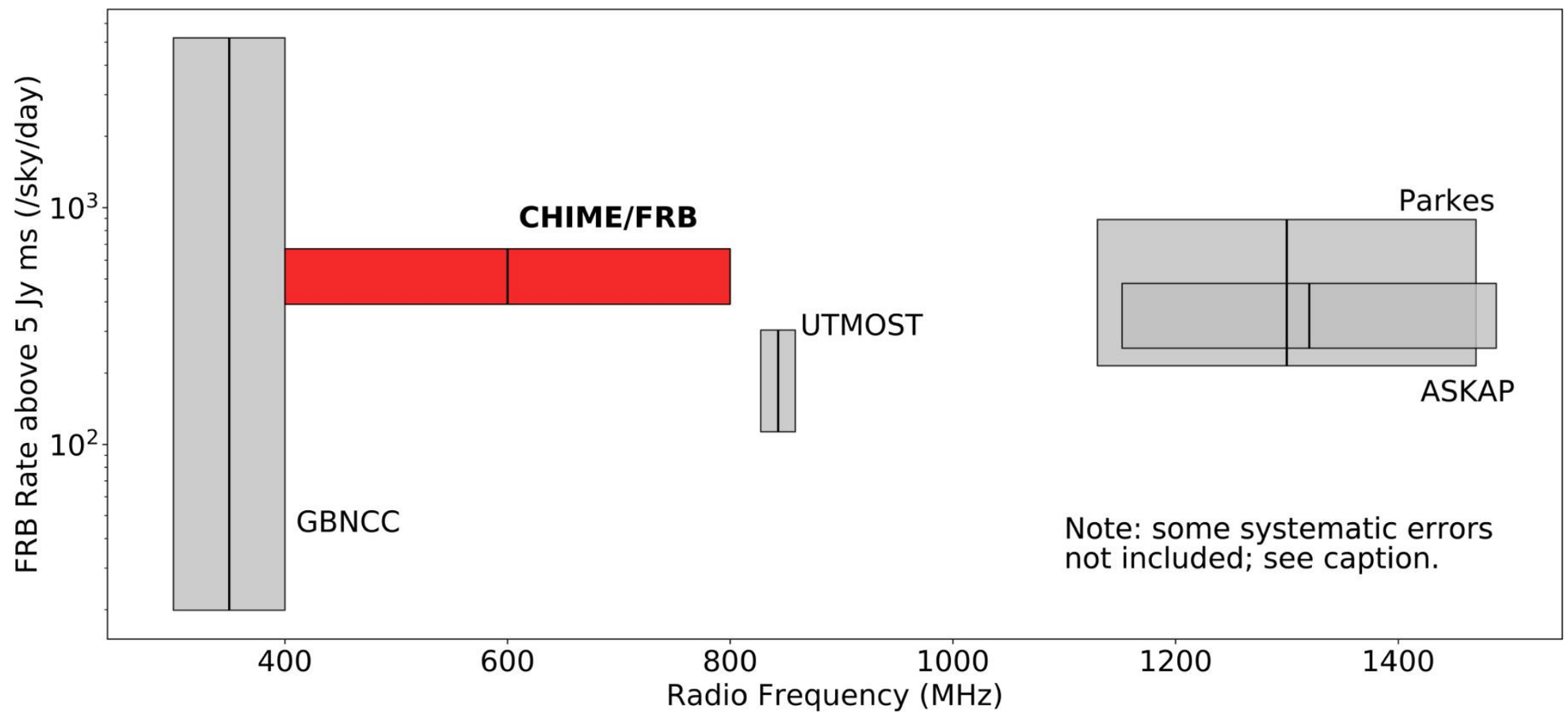
CHIME/FRB collaboration+ 2018

CHIME

CHIME/FRB rates



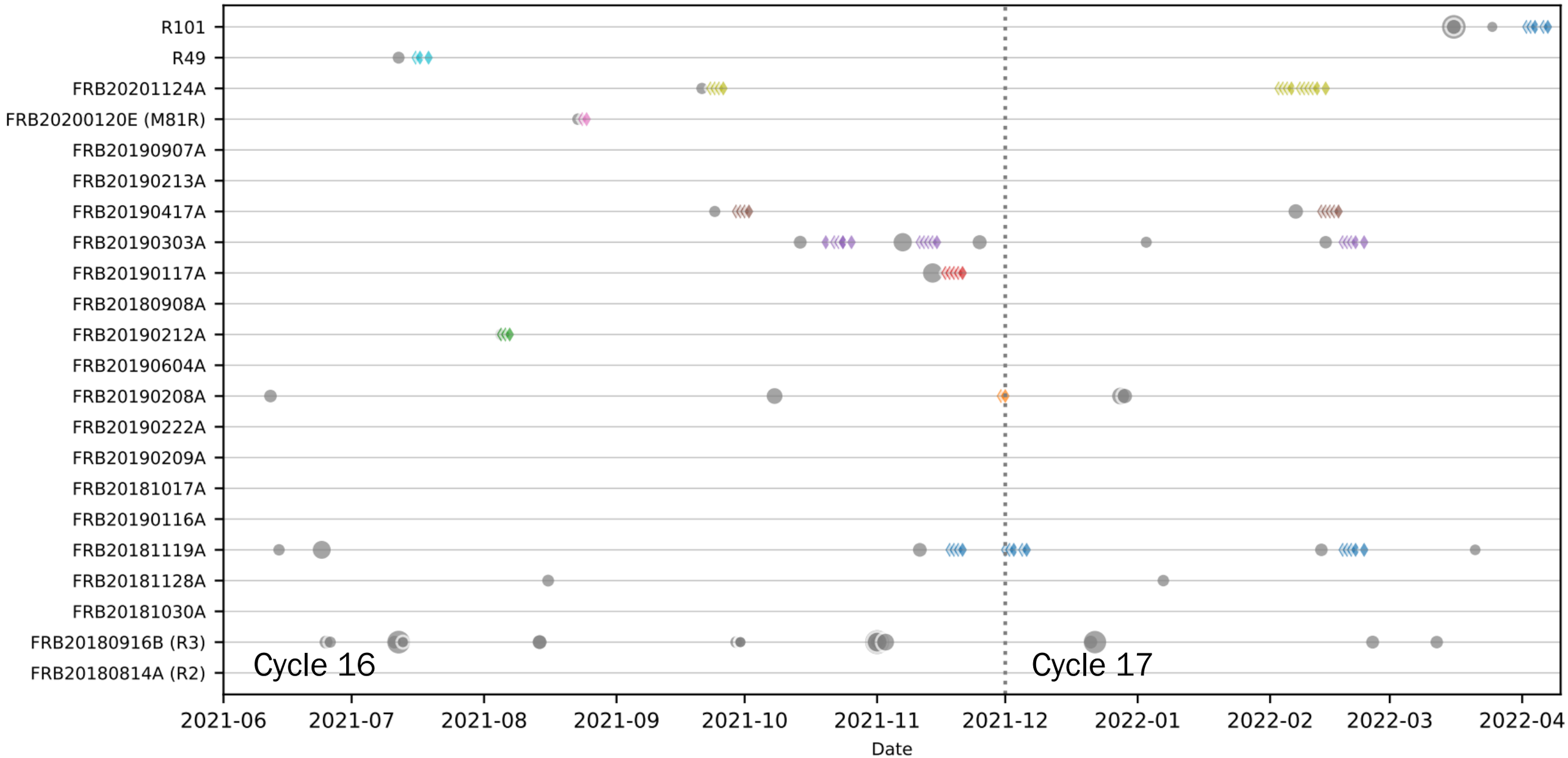
400–800 MHz



CHIME/FRB collaboration+ 2021

LOFAR follow-up of CHIME/FRB repeaters

Trigger LOFAR observations upon CHIME/FRB detection

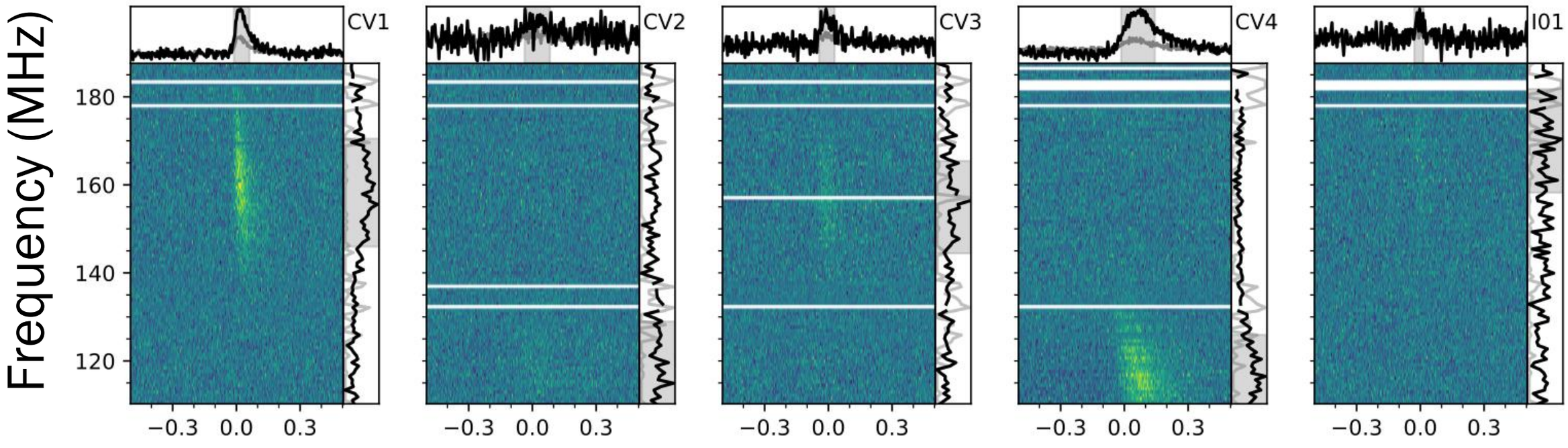


CHIME/FRB detection

LOFAR observation

Lowest-frequency FRBs

~16 day period



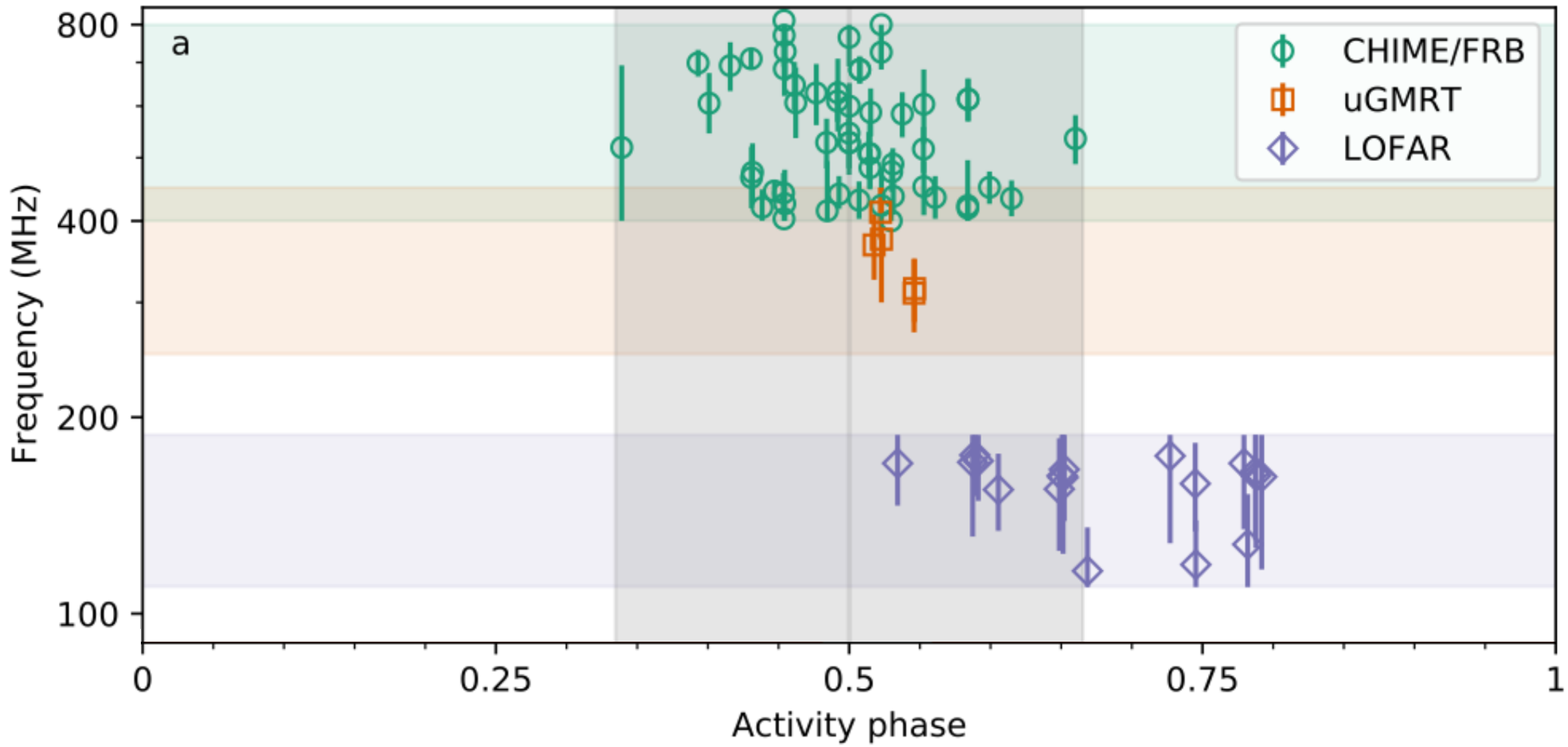
LOFAR detection of emission down to 110 MHz

Best constraints on free-free absorption at the FRB source

ZP+ 2021b, see also Pastor-Marazuela+ 2021

Frequency-dependent activity

~16 day period



LOFAR bursts (purple) systematically delayed w/r/t CHIME (green): not because of exposure

ZP+ 2021b, see also Pastor-Marazuela+ 2021
now also Gopinath, Bassa, ZP+ 2024

Frequency-dependent activity

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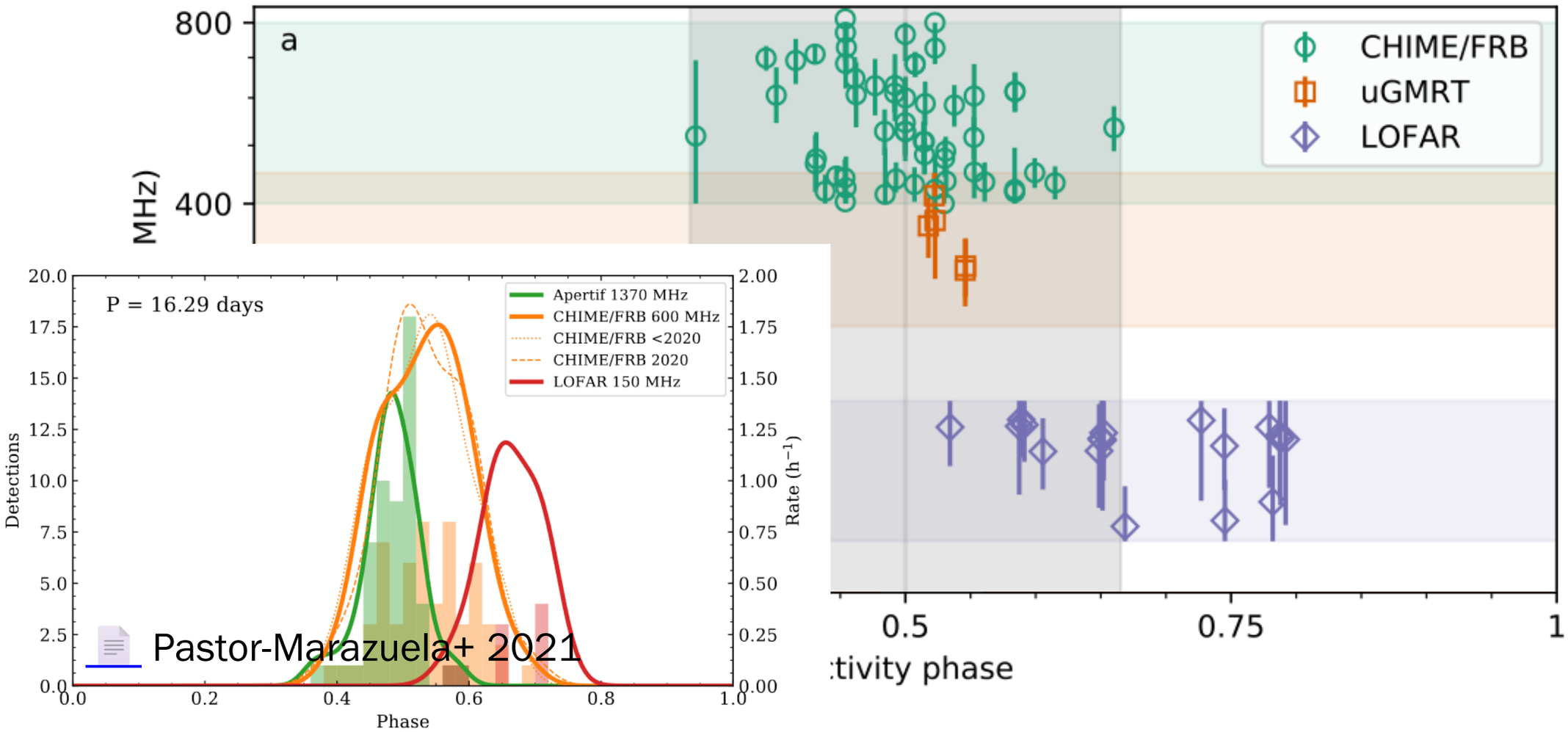

Pastor-Marazuela+ 2021

LOFAR bursts (purple) systematically delayed w/r/t CHIME (green): not because of exposure

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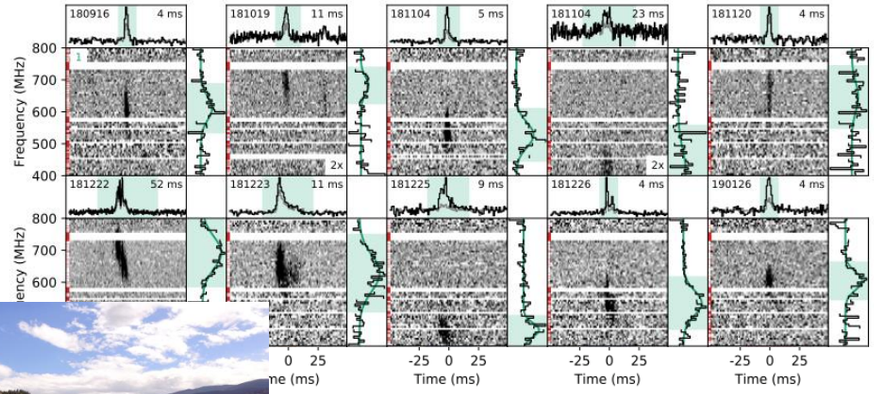
now also Gopinath, Bassa, ZP+ 2024

FRB 20180916B = R3

~16 day period

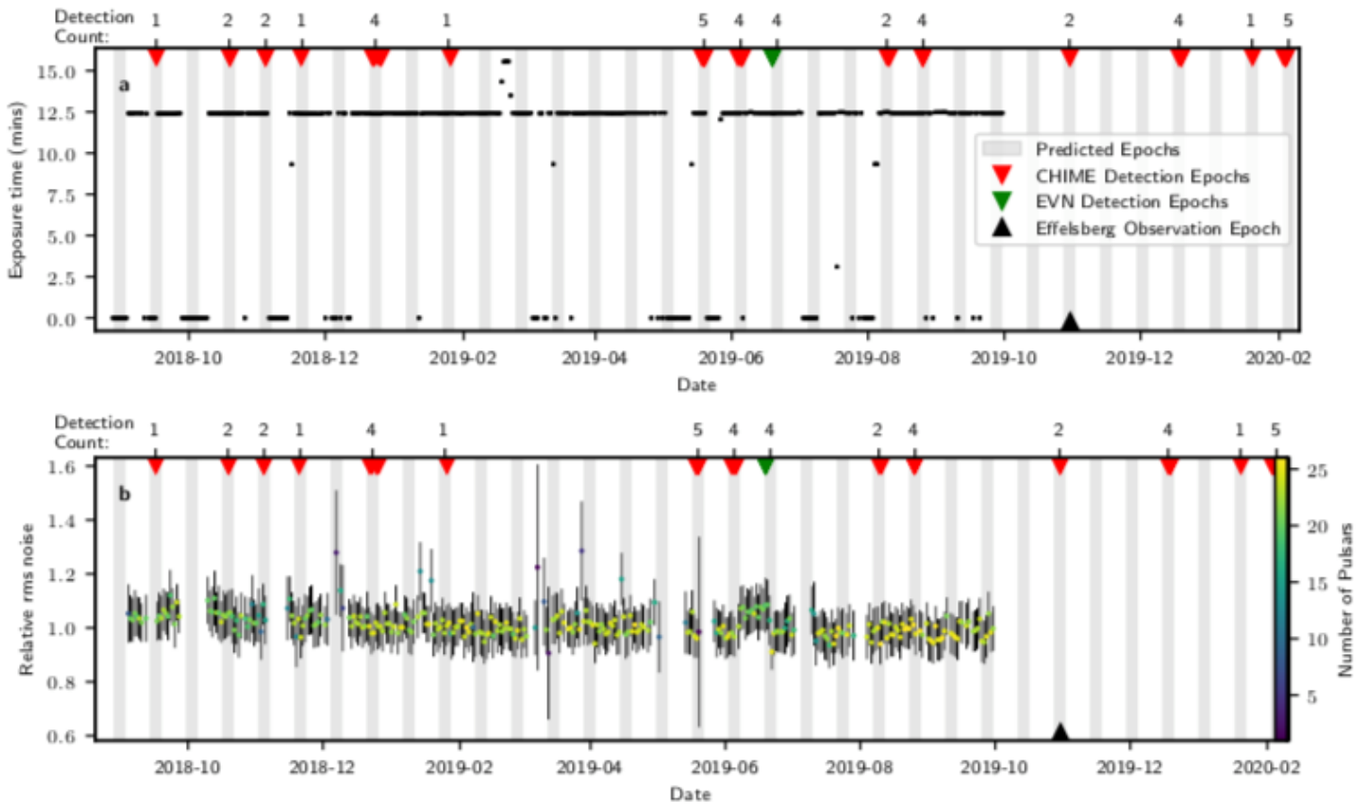
Discovery

CHIME/FRB Collaboration 2019



Periodic activity

CHIME/FRB Collaboration+ 2020



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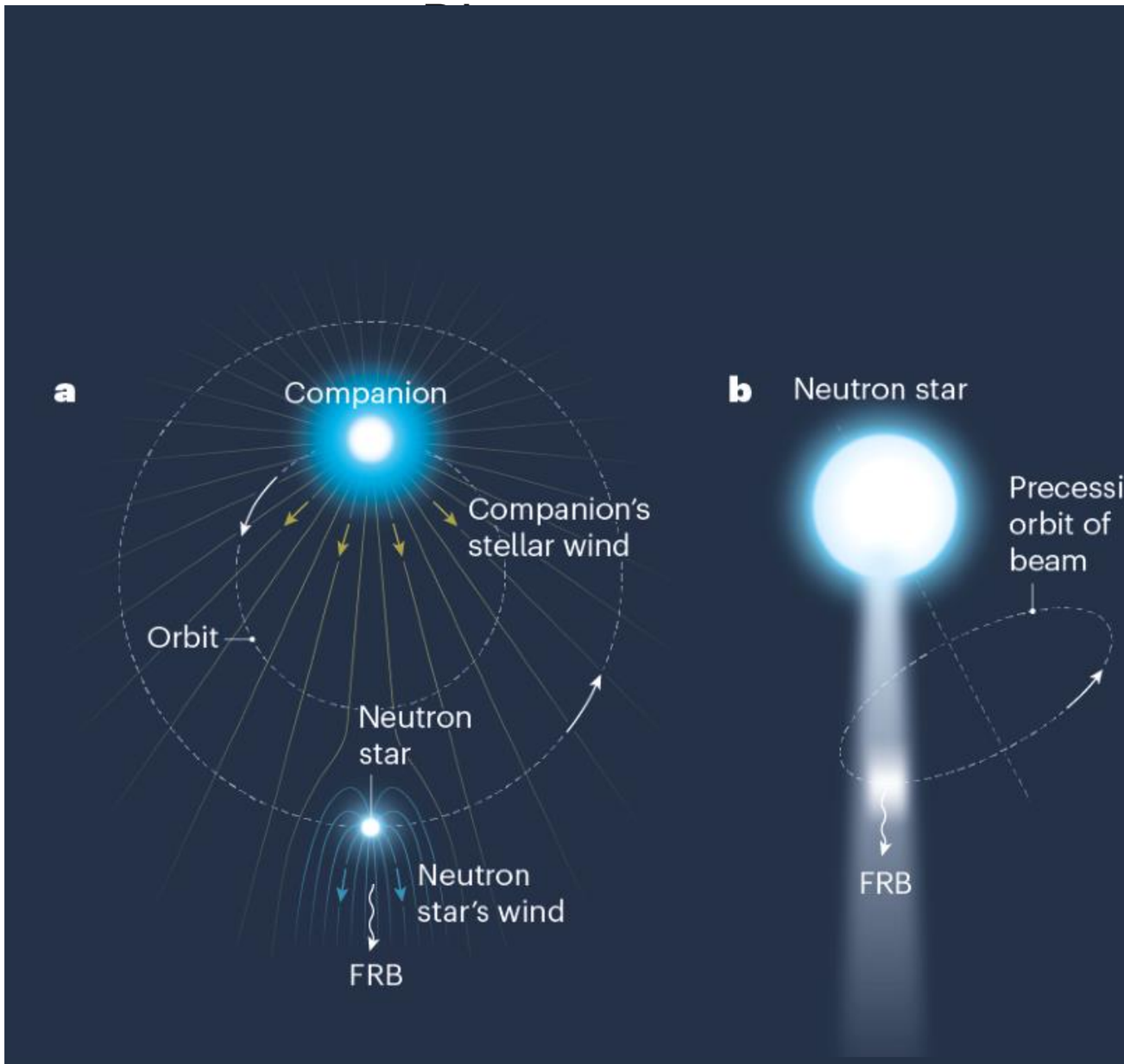
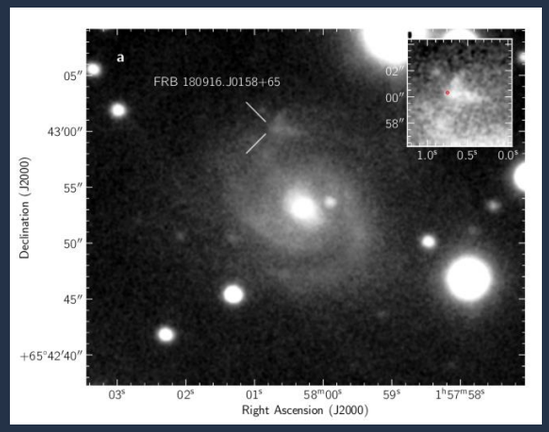


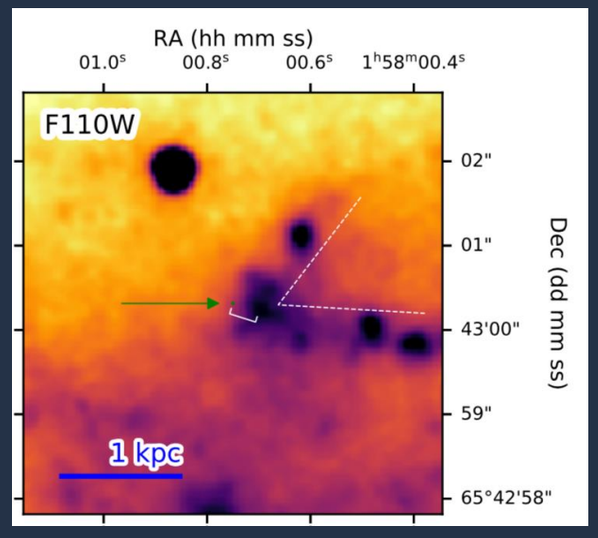
Host galaxy at 149 Mpc

Marcote+ 2020



Offset from star-forming region

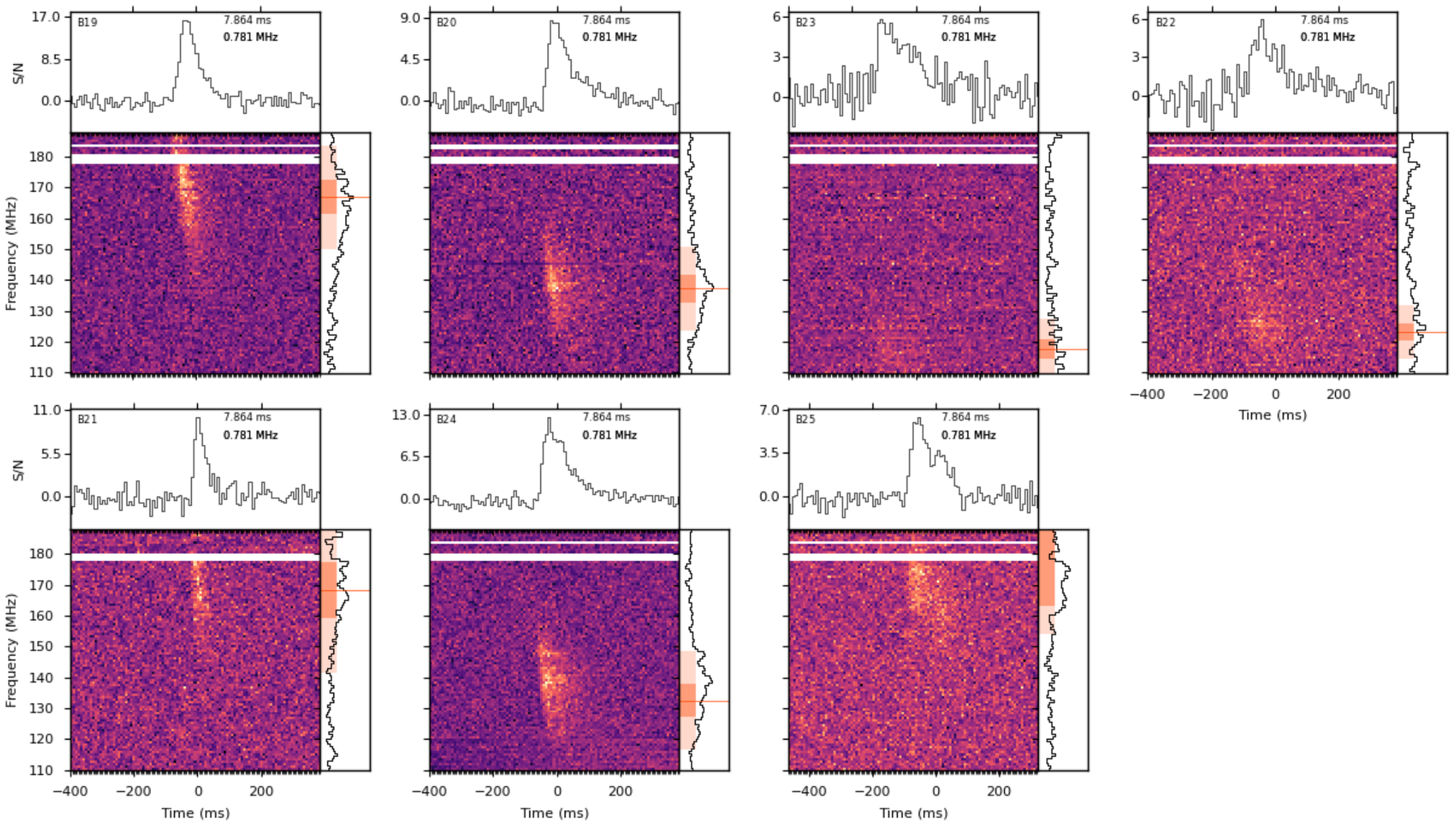
Tendulkar+ 2021



c A long-period magnetar

LOFAR monitoring of FRB 20180916B

Work led by
Akshatha Gopinath
at the University of
Amsterdam



Gopinath, Bassa, ZP+ 2024

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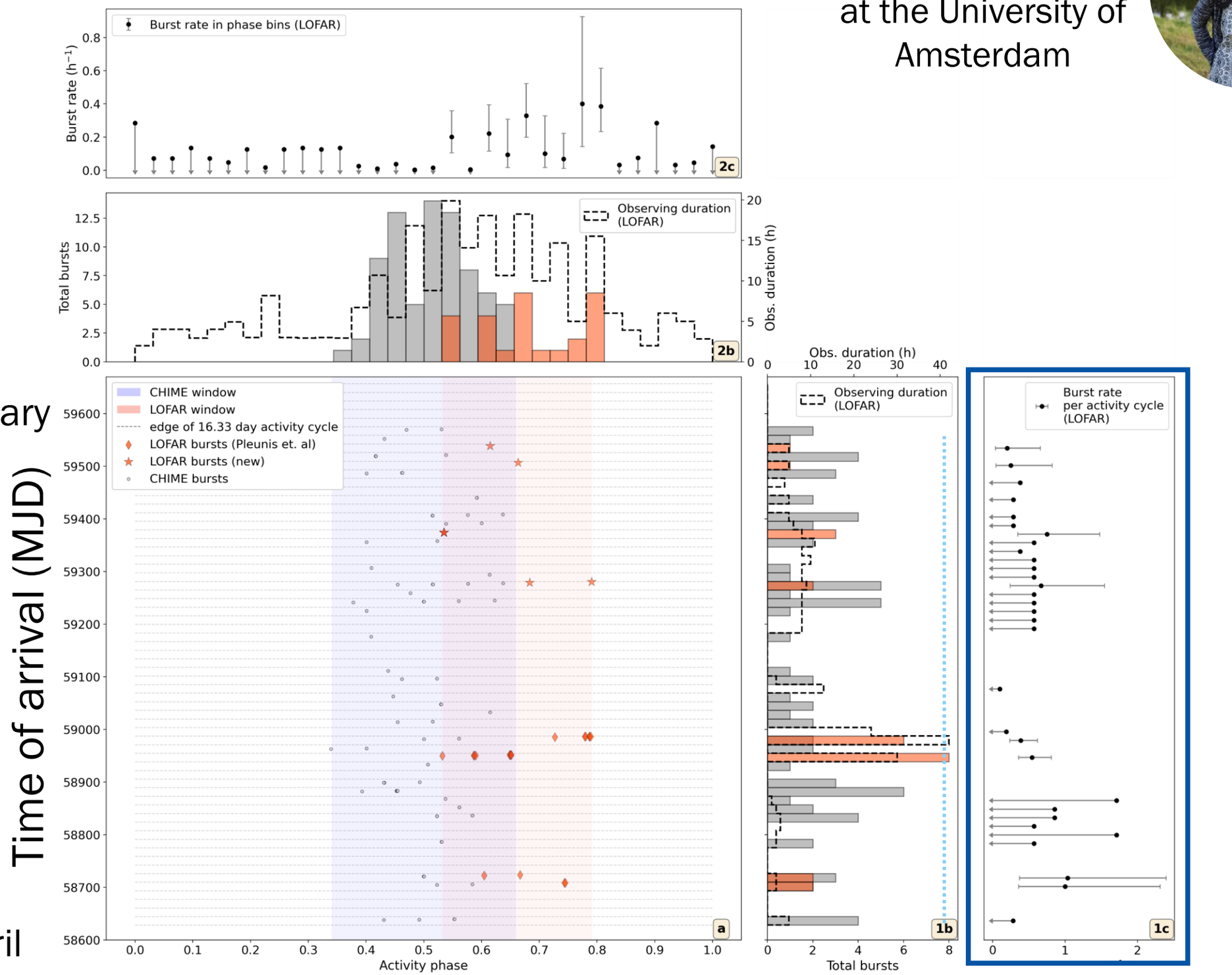

Gopinath, Bassa, ZP+ 2024

Changes in the local environment?

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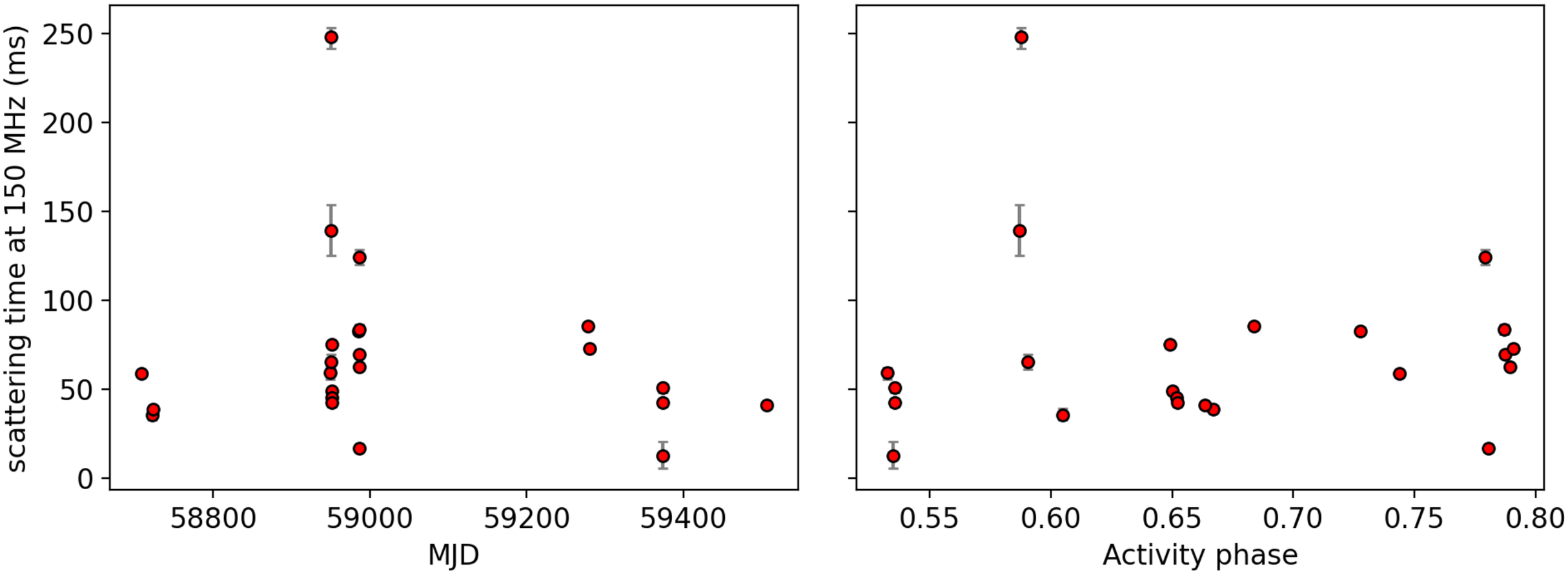


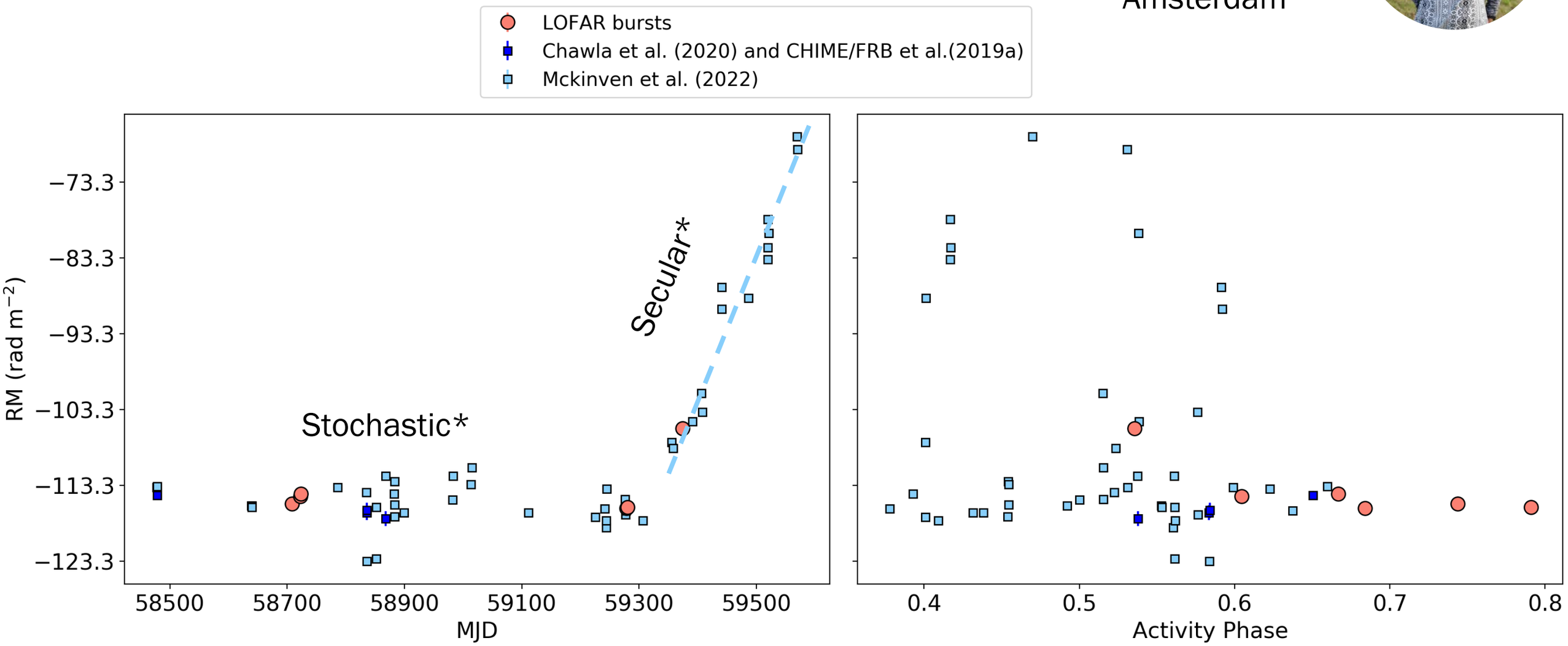
Scattering traces inhomogeneities in the local medium

No correlation with burst rate decrease, maybe more clear in 400—800 MHz CHIME/FRB band

Gopinath, Bassa, ZP+ 2024

Changes in the local environment?

Work led by Akshatha Gopinath at the University of Amsterdam



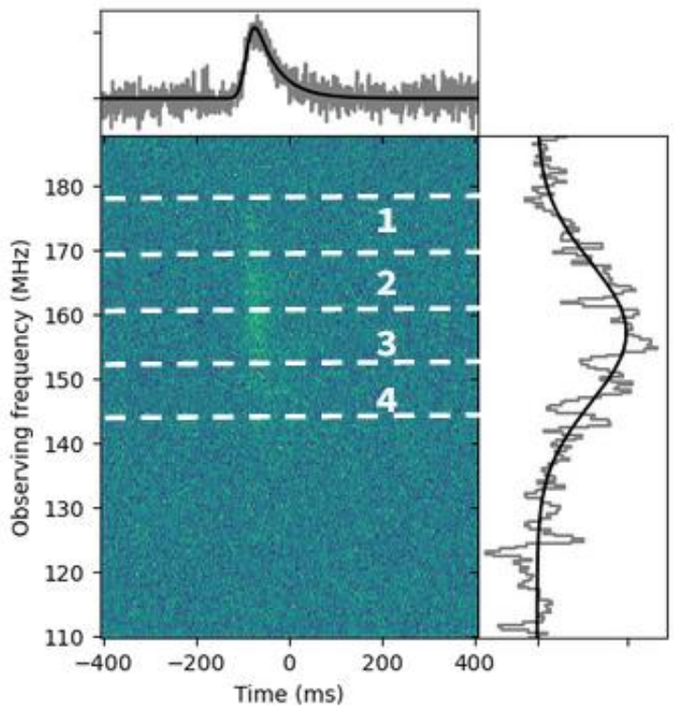
Faraday rotation traces magnetic field in the local medium

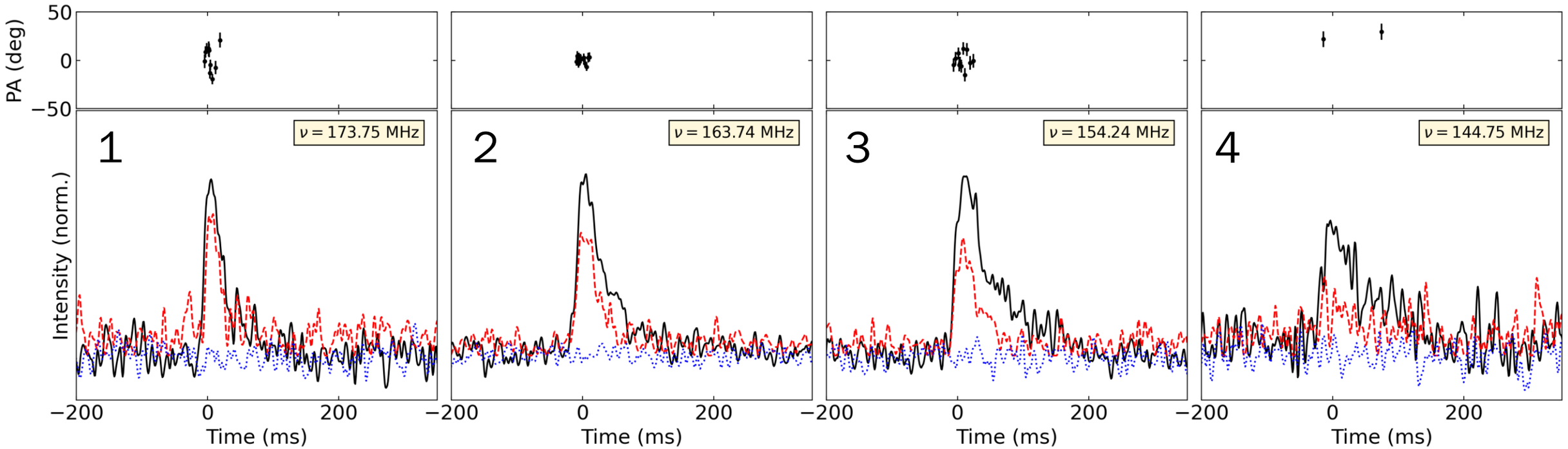
Gopinath, Bassa, ZP+ 2024

*As identified by Mckinven+ 2022

Depolarization towards lower frequencies

Work led by Akshatha Gopinath at the University of Amsterdam





Gopinath, Bassa, ZP+ 2024

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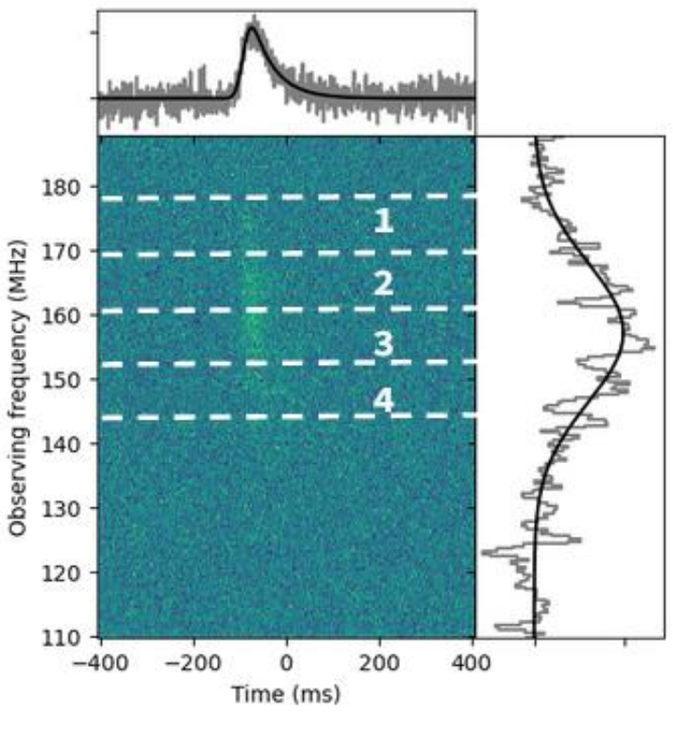
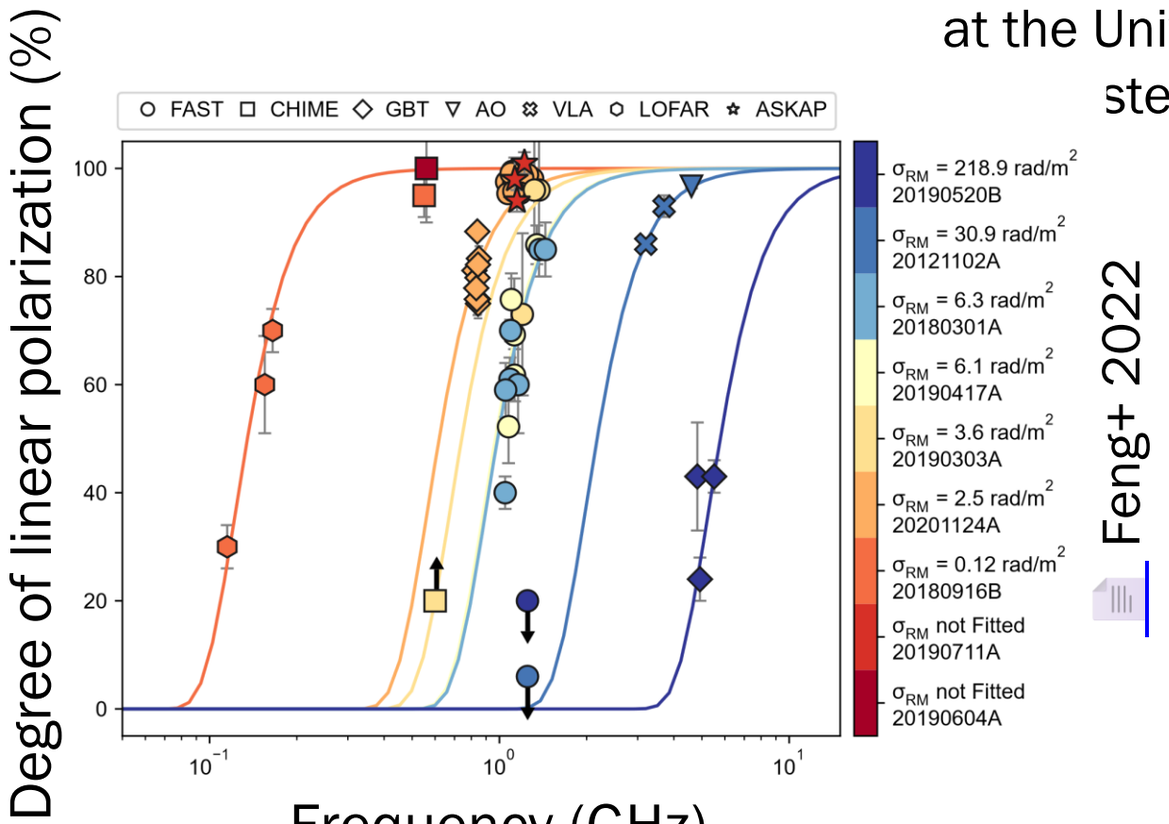
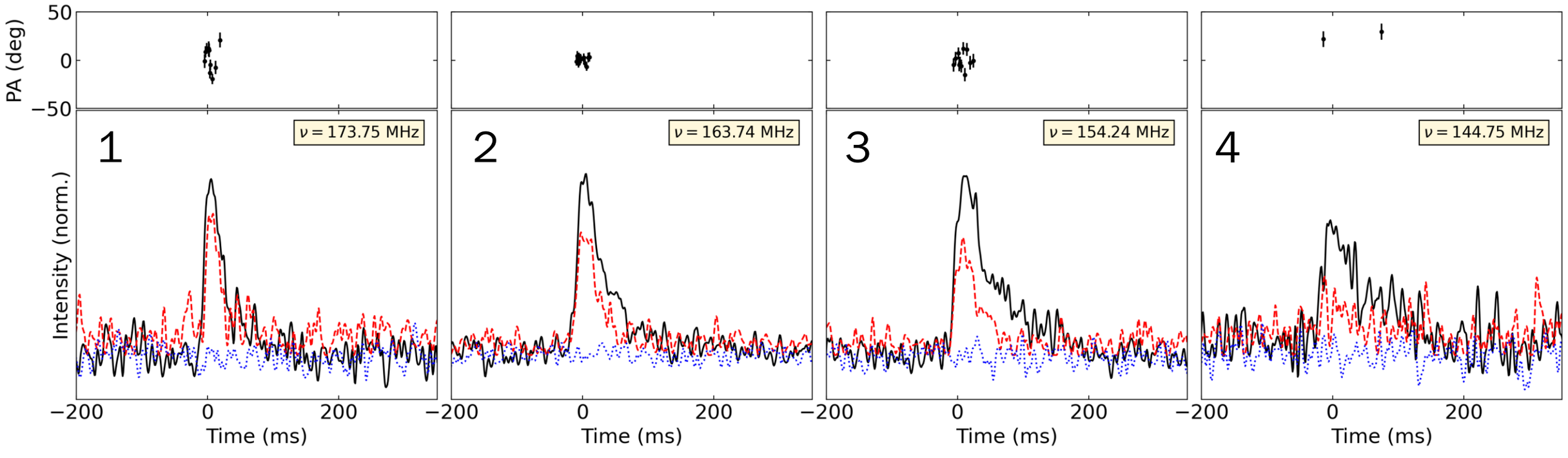




Feng+ 2022

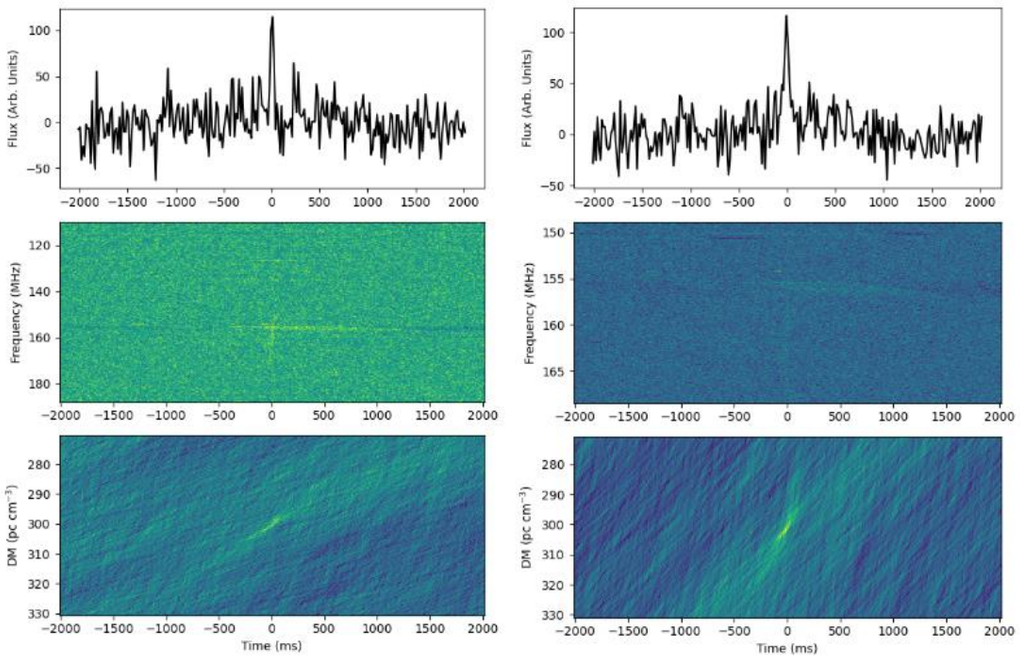


Gopinath, Bassa, ZP+ 2024

LOFAR 2.0

See Jason Hessels's talk later today

FRB20190212A = R14:
The second FRB
detected < 300 MHz



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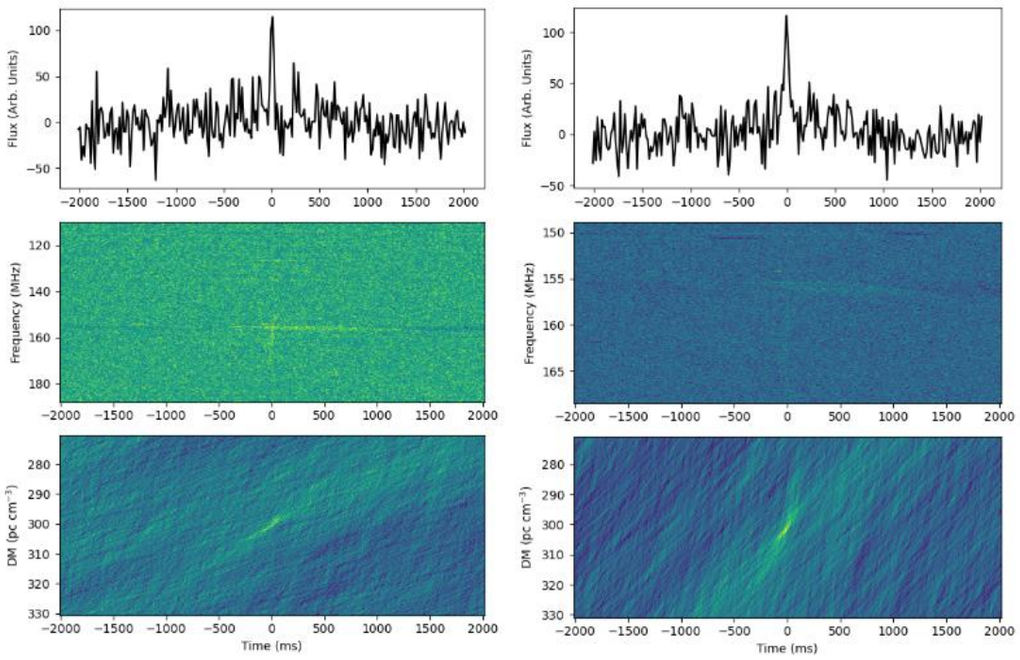

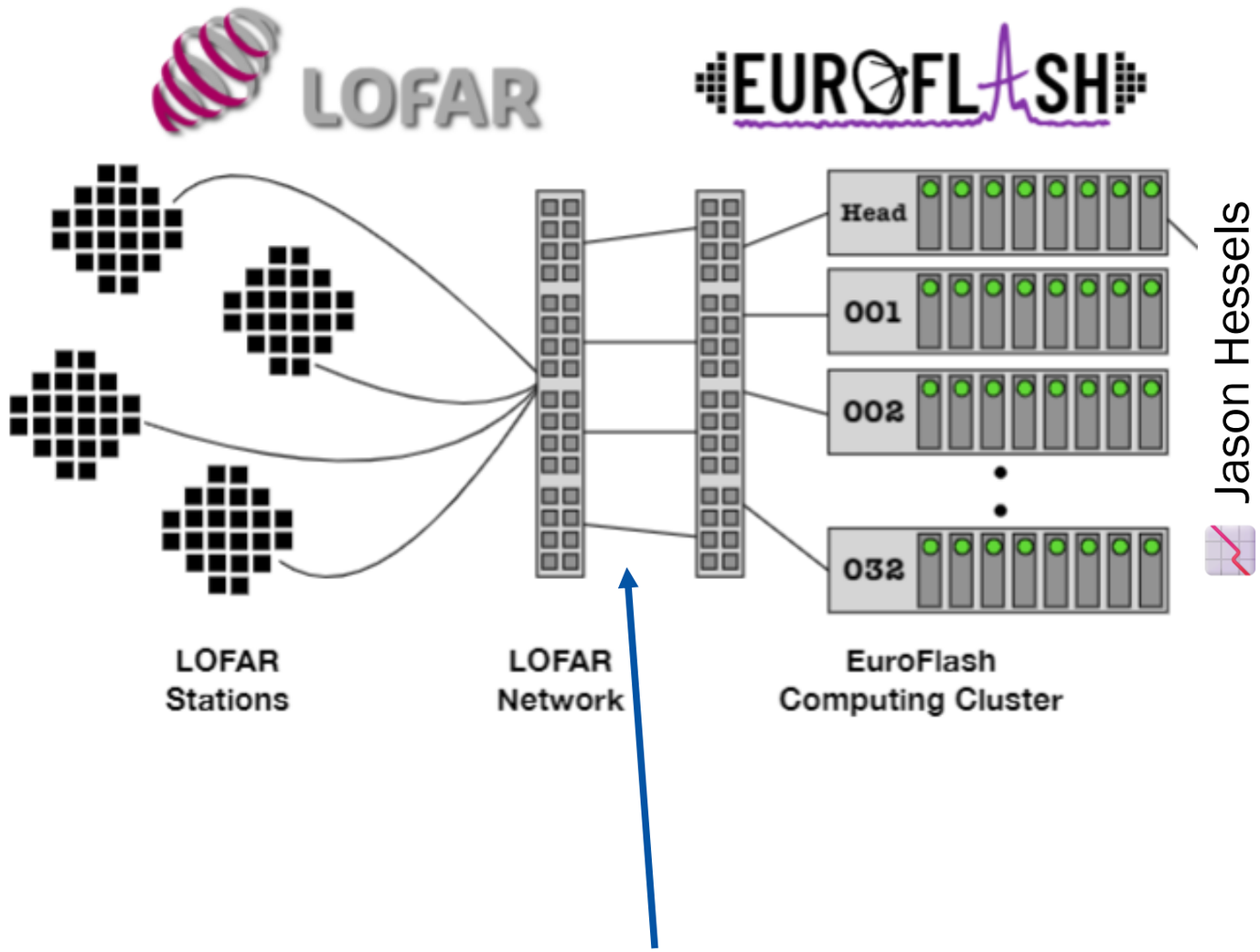

Copy data stream from
regular observing to
FRB searching cluster,
just like CHIME/FRB

LOFAR 2.0

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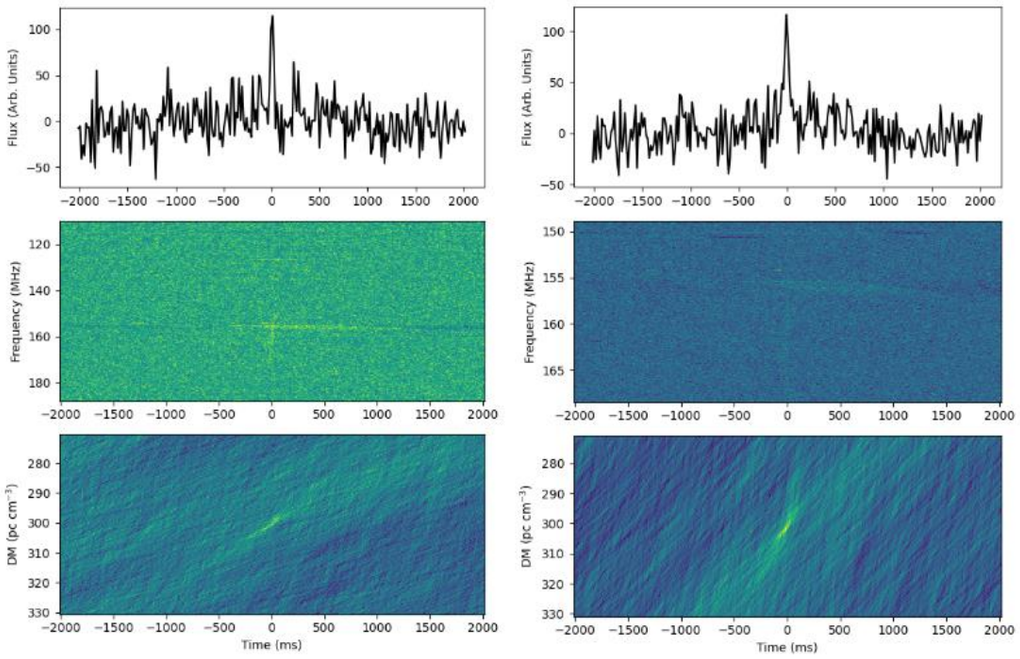
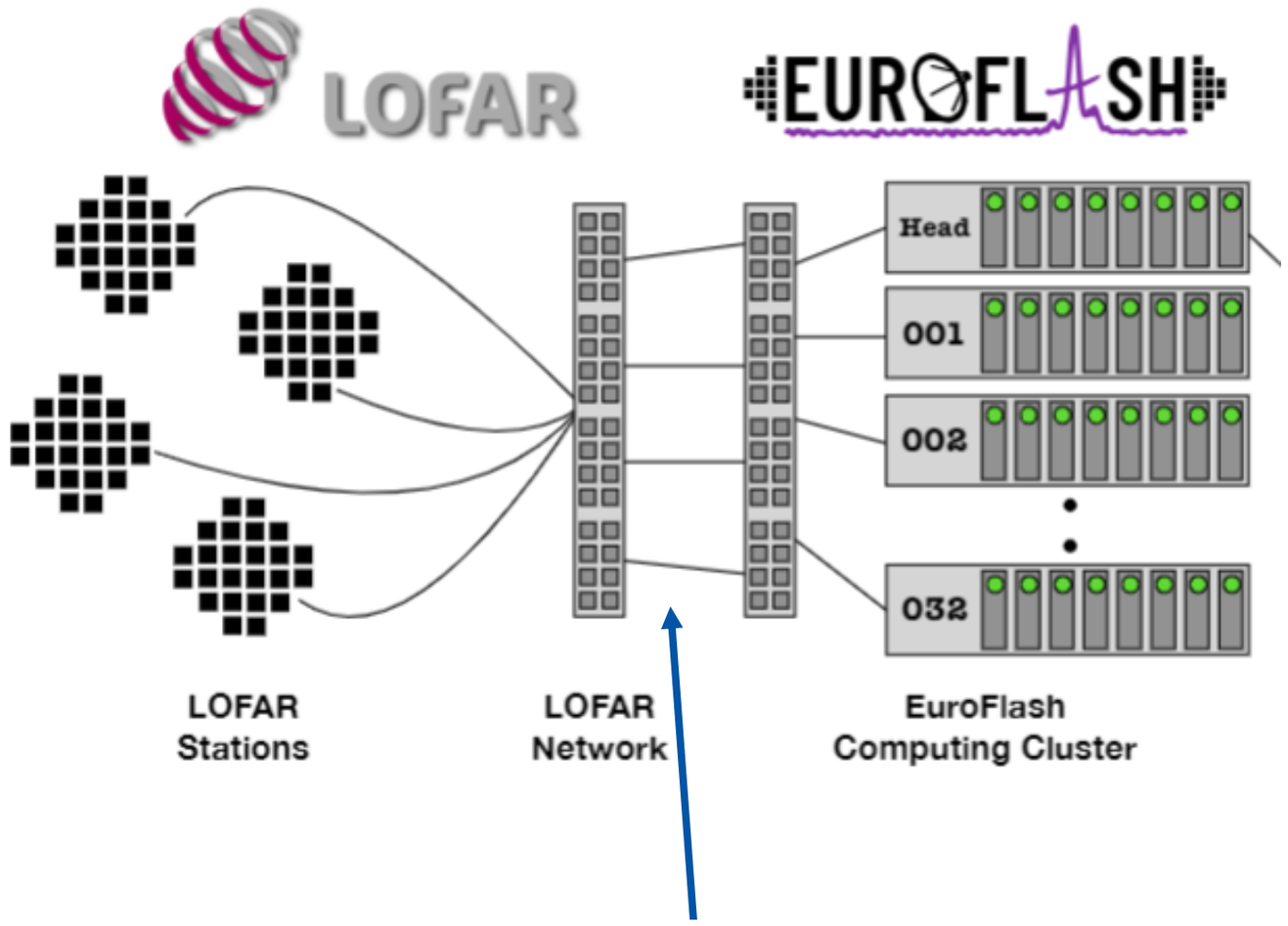




☺ Mapping speed

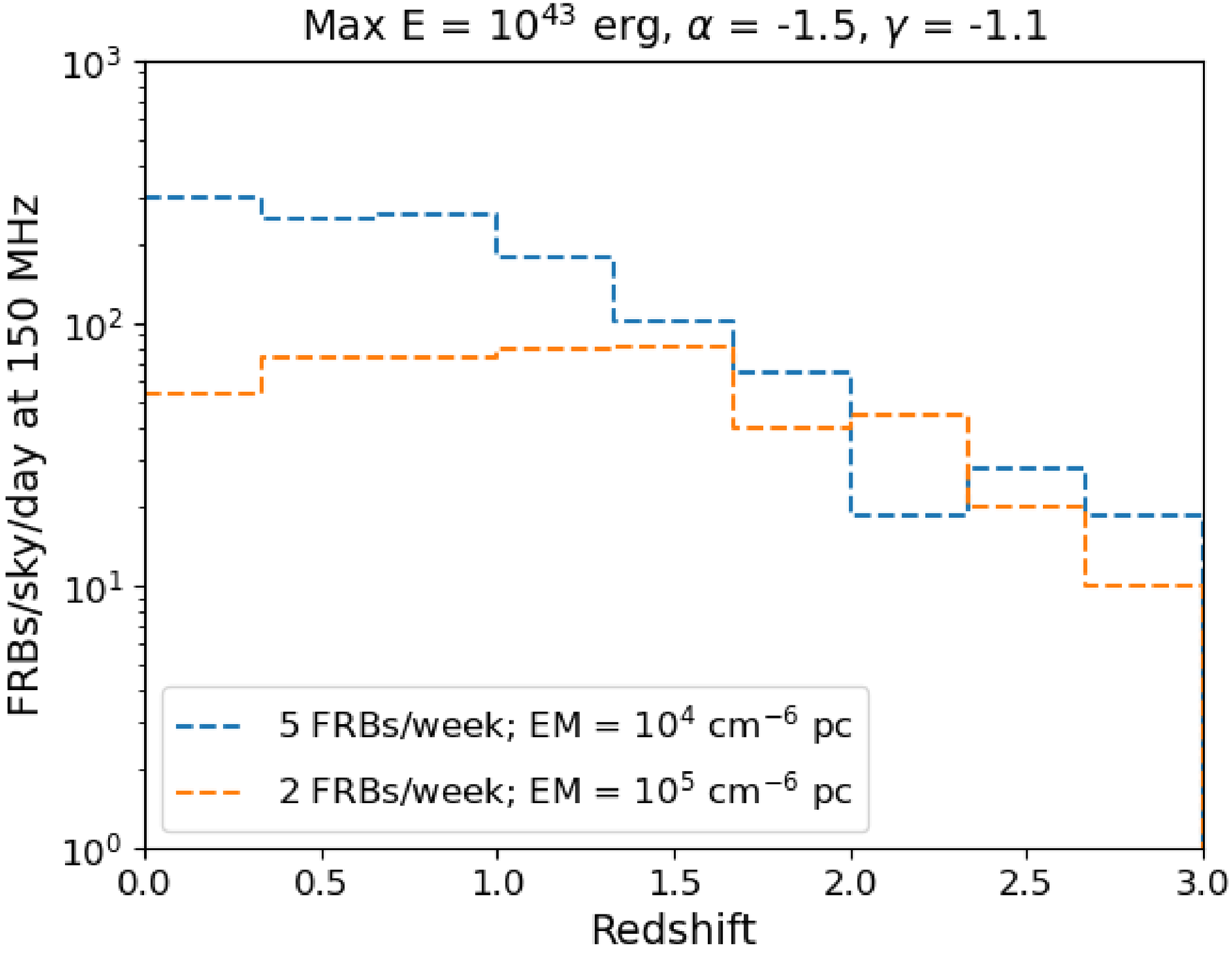
Detecting ? FRBs per day, up almost 24/7 and year round

☺ Searching for repeat bursts

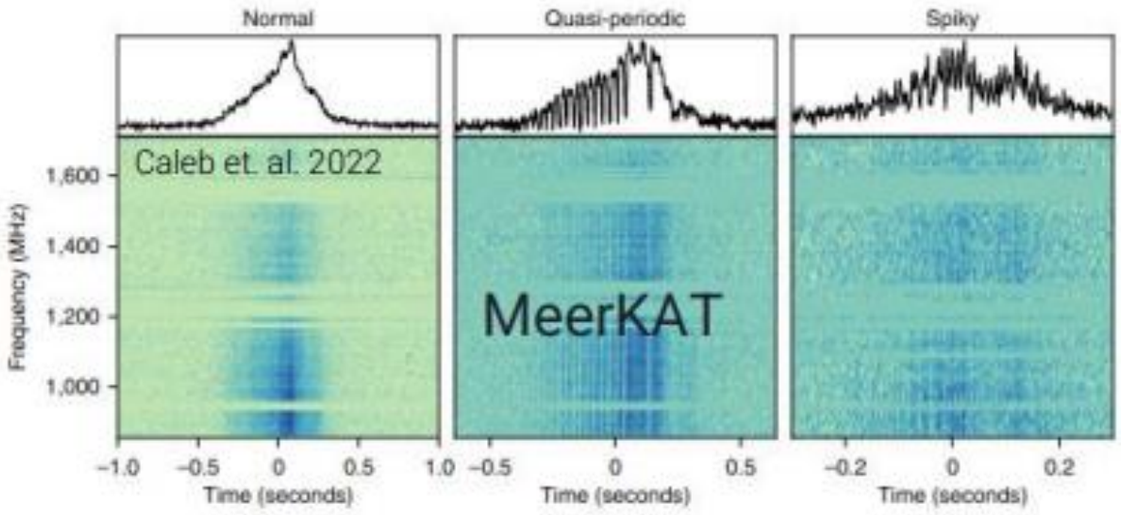
Revisiting same sky every day

Searching for other LOFAR FRBs

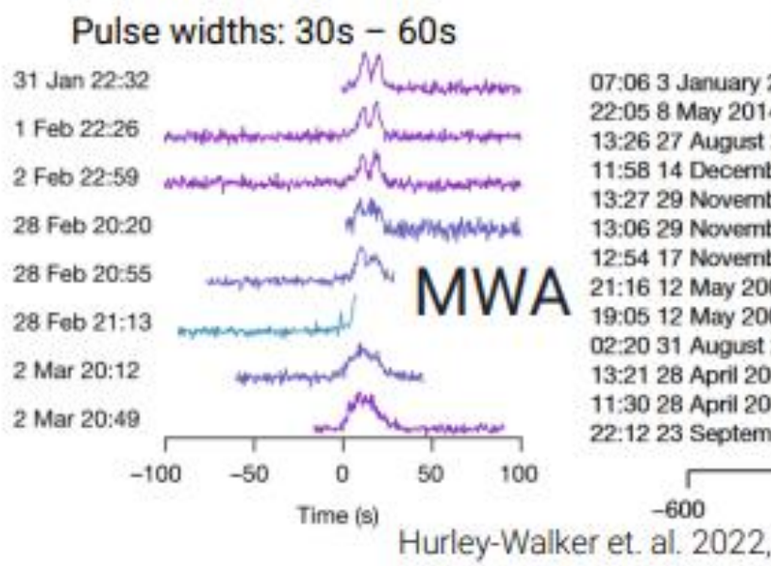
Work led by Pragya Chawla at ASTRON

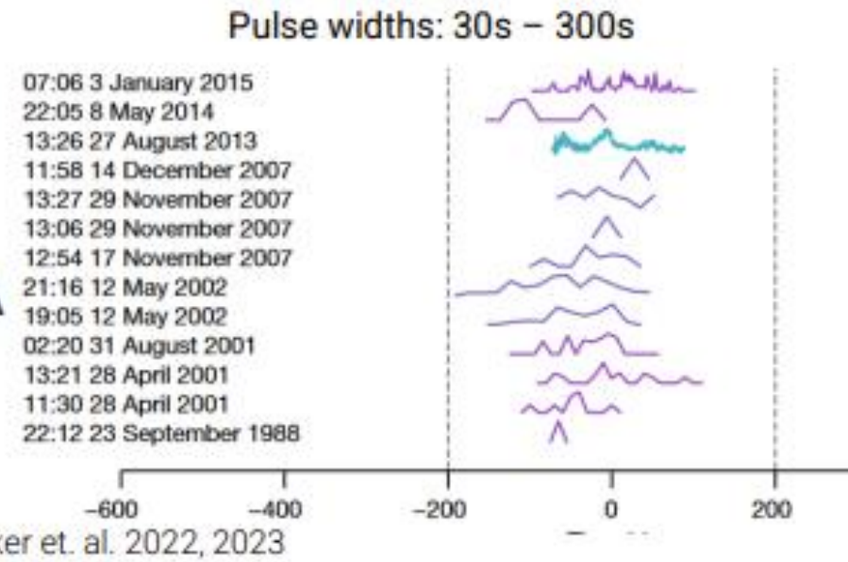


“Slow” radio transients

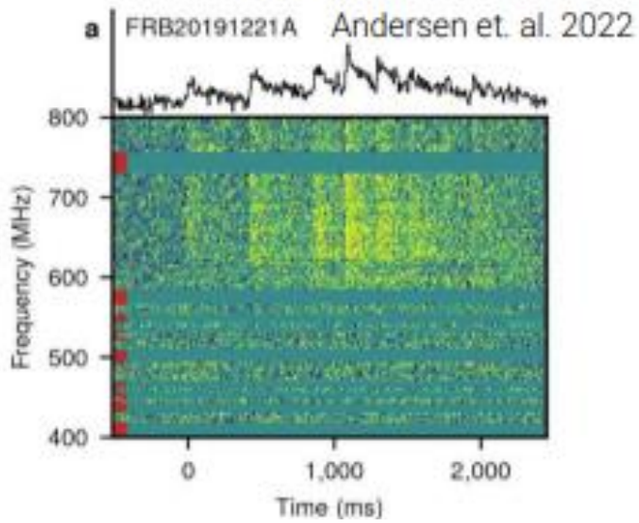


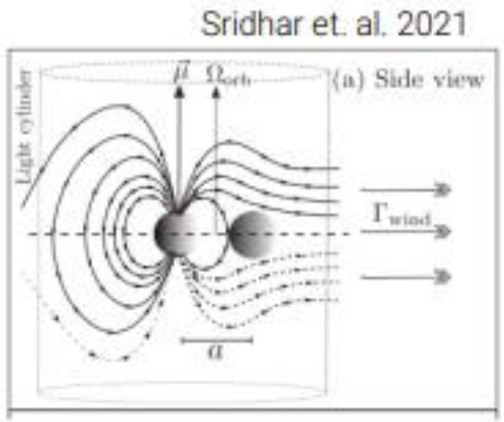
CHIME/FRB

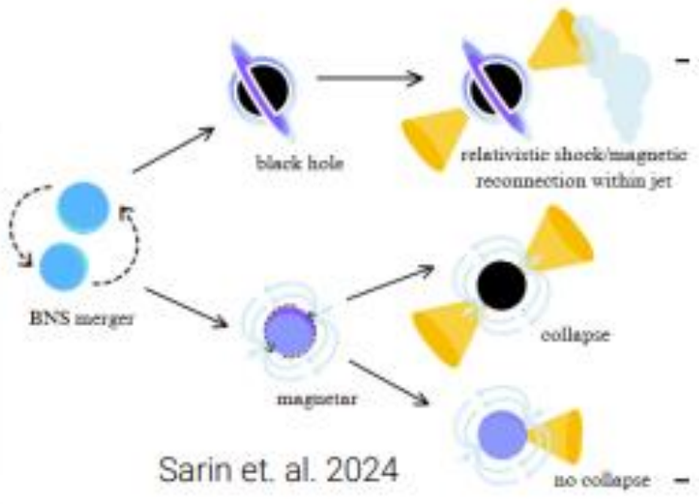


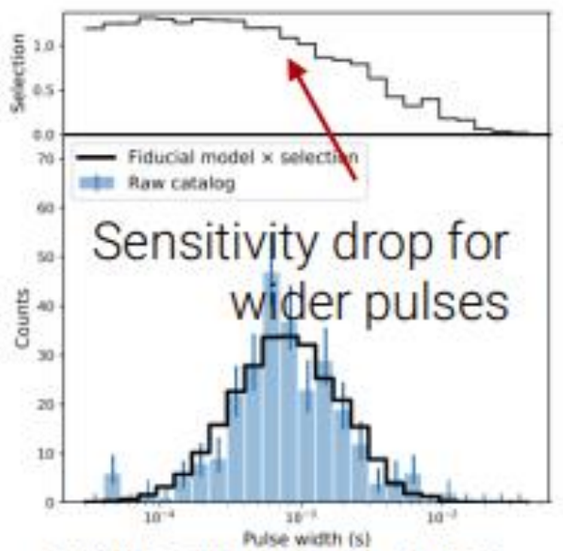


Hurley-Walker et. al. 2022, 2023





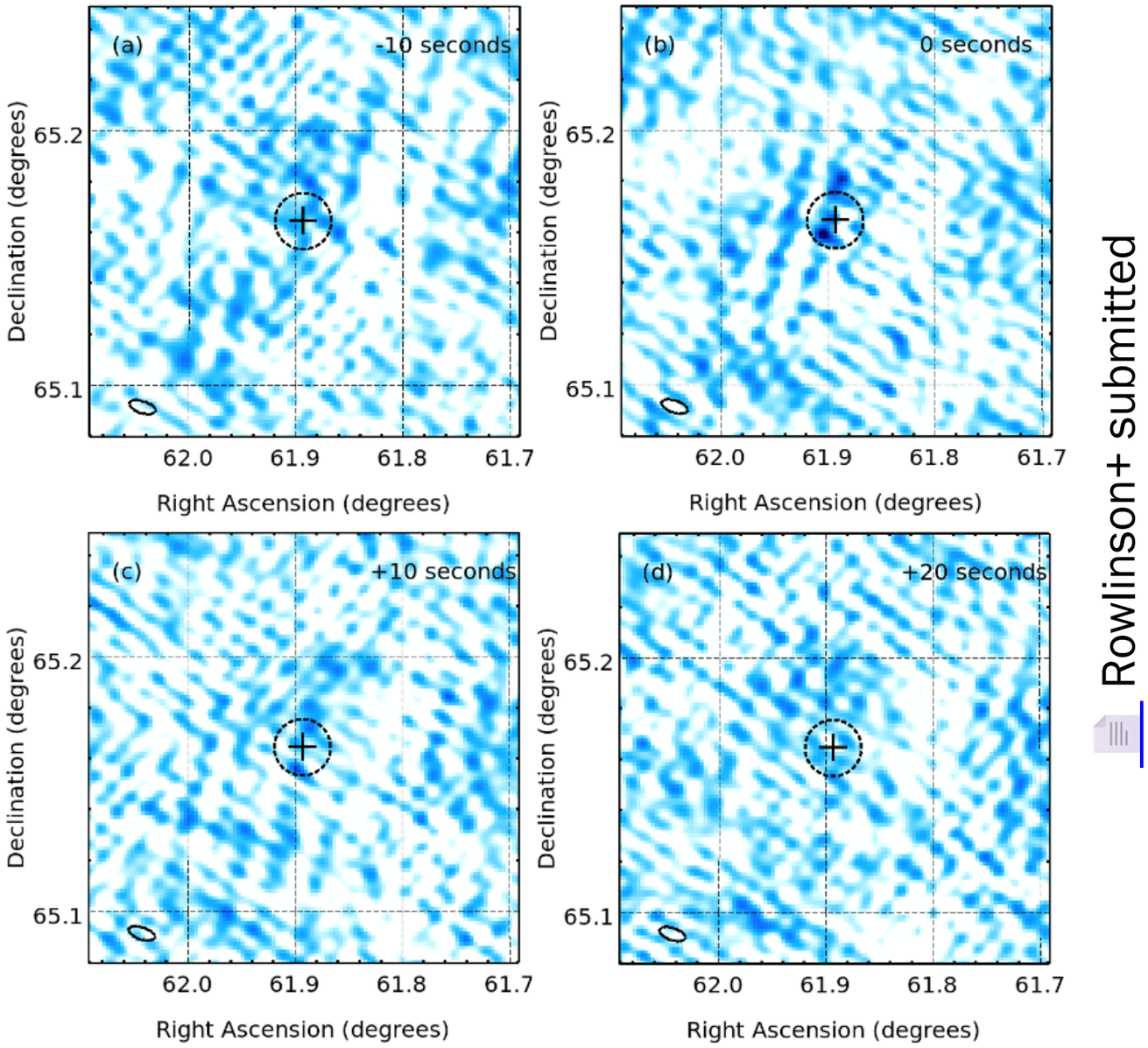




Possible radio emission from BNS/NS-BH mergers

“Slow” radio transients

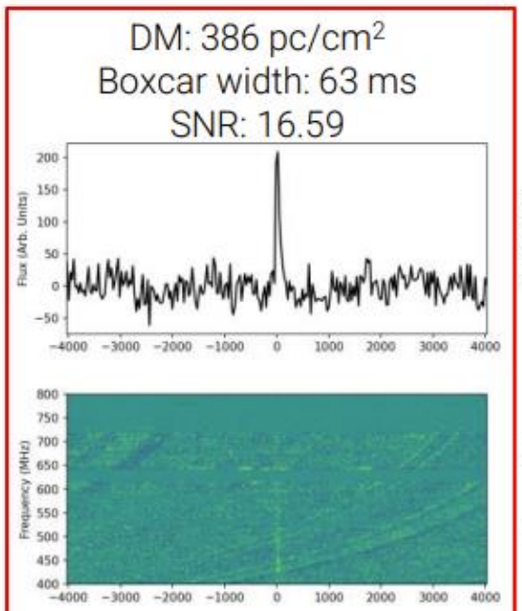
A candidate coherent radio flash in LOFAR images 76.6 minutes after a neutron star merger



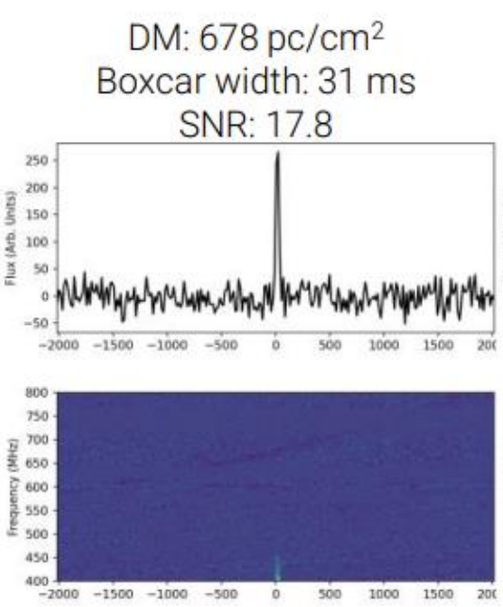
Rowlinson+ submitted

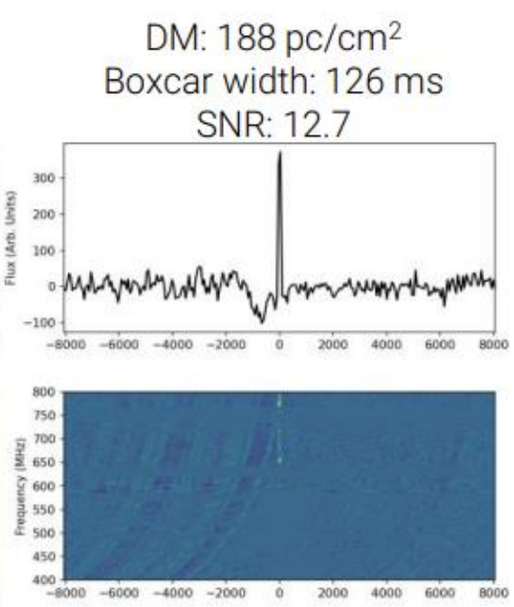
“Slow” radio transients

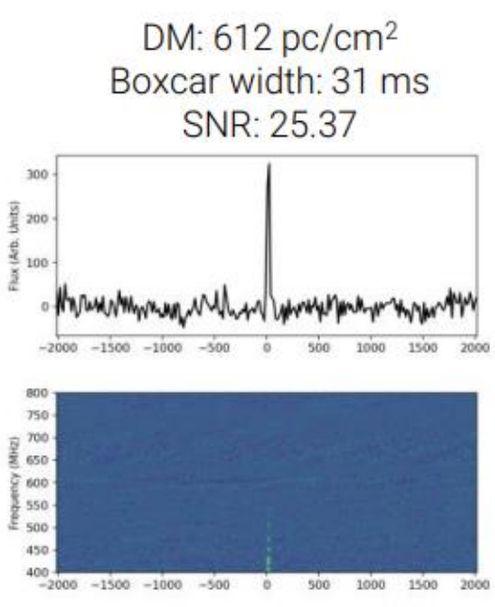
Pilot slow transient search in CHIME data from 50 ms—5 s, plan to run this realtime soon

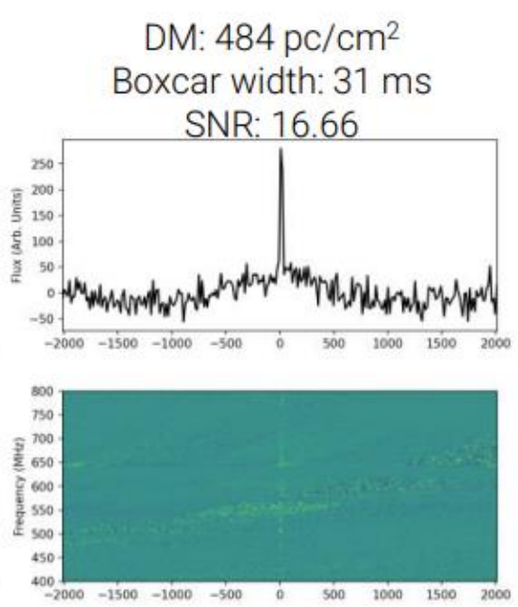


Also detected by CHIME/FRB, but in sidelobes

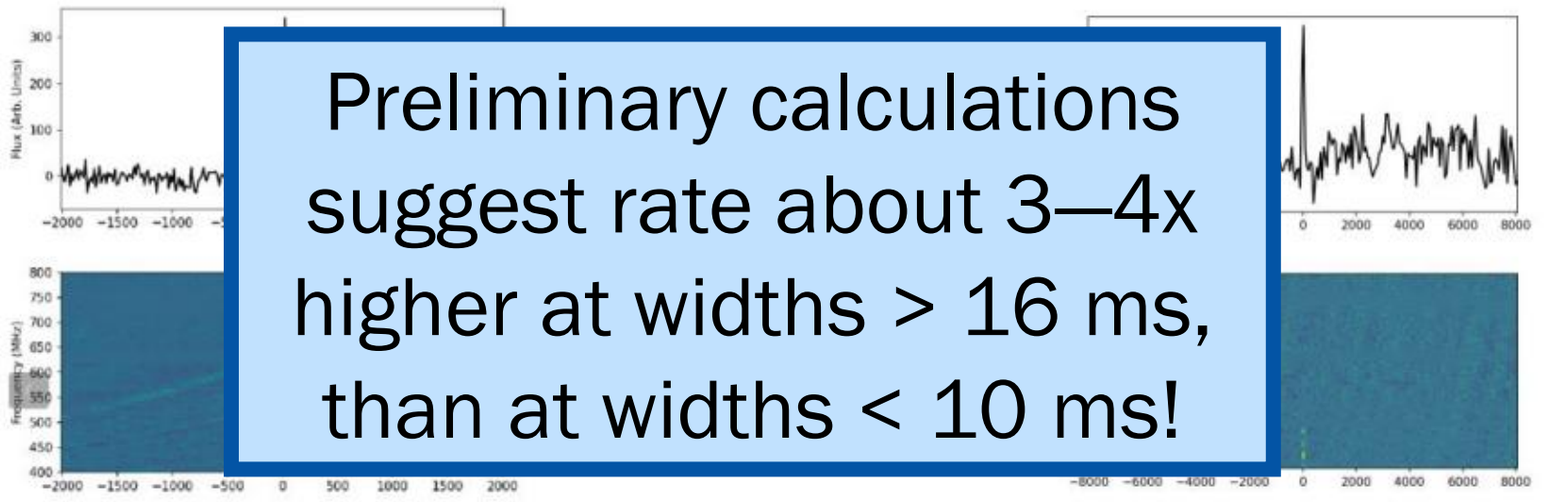








In addition, 8 bursts from very active repeating FRB R117 or FRB 20220912A



Preliminary calculations suggest rate about 3—4x higher at widths > 16 ms, than at widths < 10 ms!

Fast transients < 300 MHz with LOFAR 2.0

Fast radio transients are unique probes of extreme astrophysics and the unseen intervening Universe

< 300 MHz we are especially sensitive to propagation effects: a blessing and a curse

Best rates from CHIME/FRB down to 400 MHz bode well for transient searches < 300 MHz

We need to rethink search strategies for LOFAR: lower time resolution, larger field of view (i.e. more beams), try not to be too clever

Exciting new results from LOFAR imaging searches!

Feel free to reach out with questions/comments:
z.pleunis@uva.nl

Backup slides

Subburst drift rate varies with frequency

Work led by Akshatha Gopinath at the University of Amsterdam