FRBs: Measuring their properties

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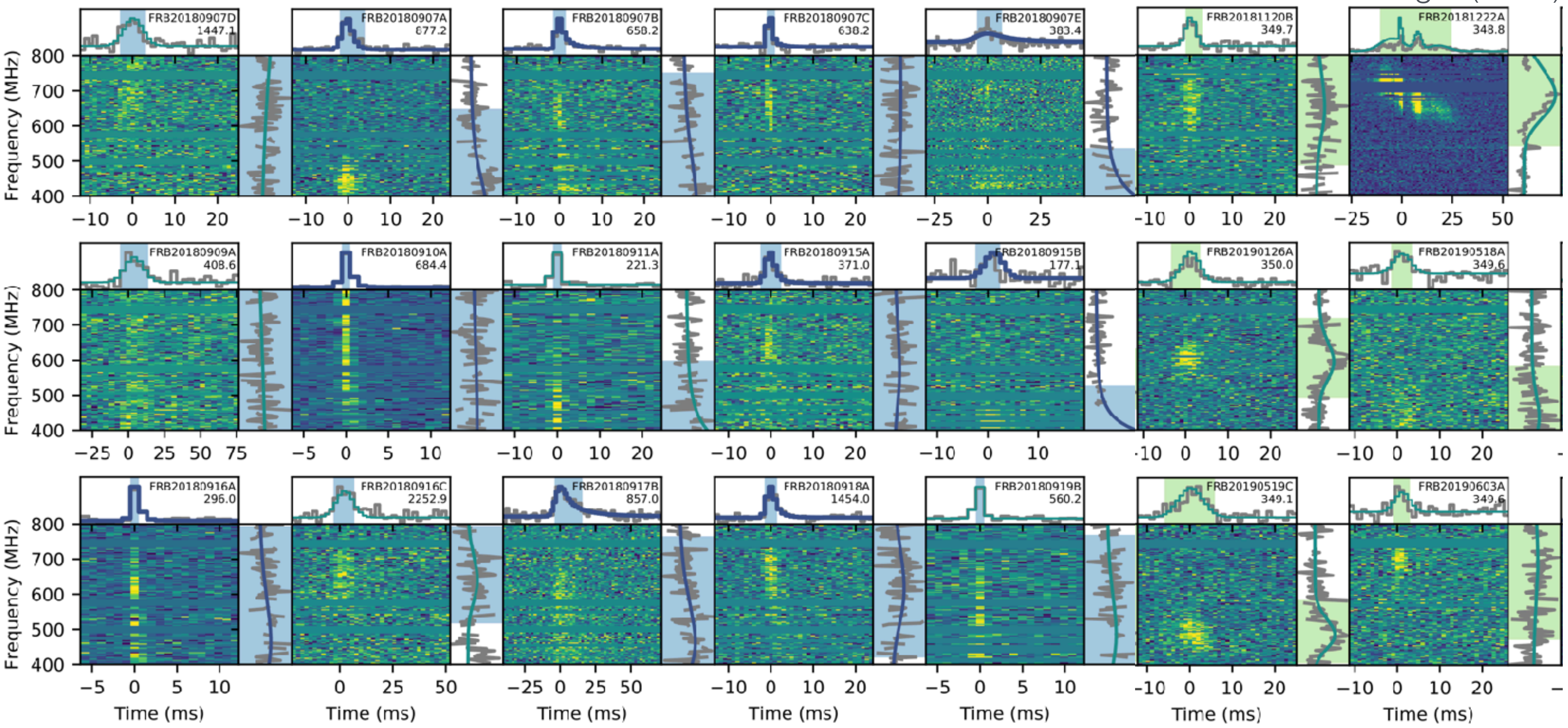
Primer talk for FRB2021 (remote)

Jingchuan Yu, Beijing Planetarum / NRAO

What can we measure from FRBs?

- Position
- DM
- Width
- Scattering/ Scintillation
- Spectral index/ running
- Drift rate
- Freq range
- SNR/Fluence
- Polarization
- RM
- Repetition

CHIME/FRB Catalog 1 (2021)



See Manisha Caleb's FRB2021 primer talk on astrophysical applications.

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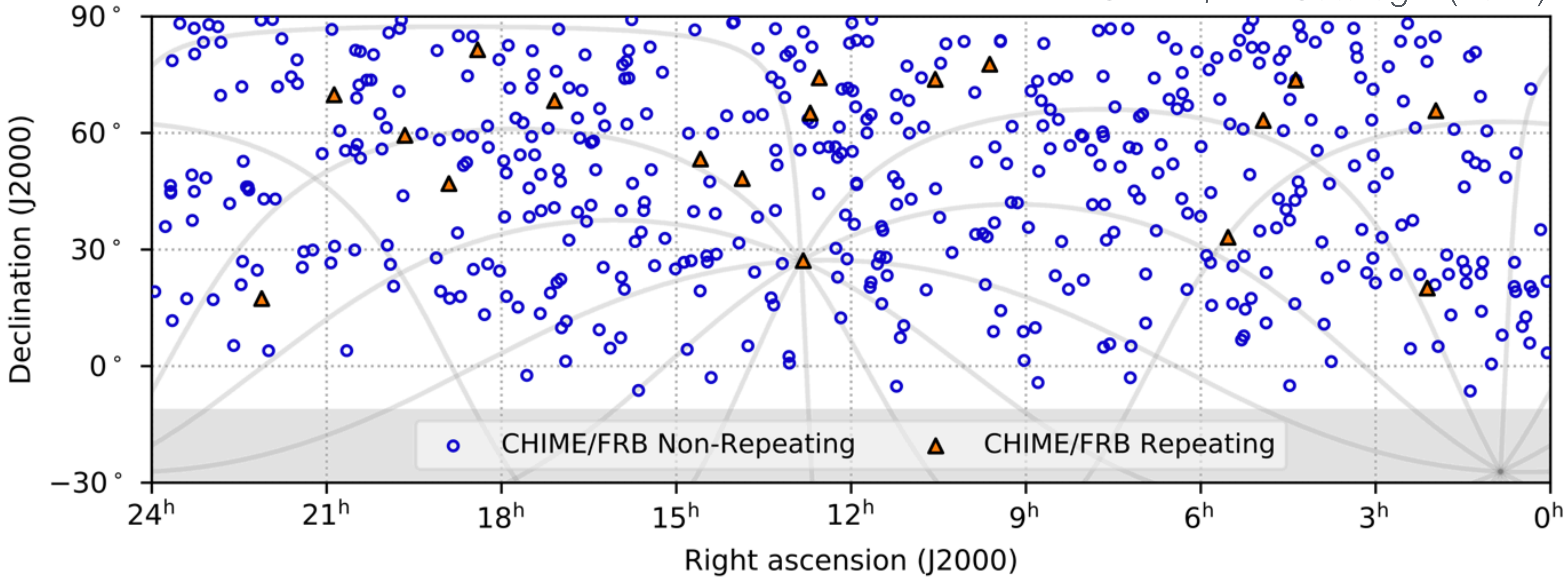
Sky positions

…..See Cherie Day's FRB2021 primer talk on localization.

CHIME/FRB Catalog 1 (2021)



- "No Evidence for Galactic Latitude Dependence of the Fast Radio Burst Sky Distribution" — Josephy+2021
- All sky event rate: ~ 800 FRBs / sky / day (CHIME/FRB Catalog 1, 2021)

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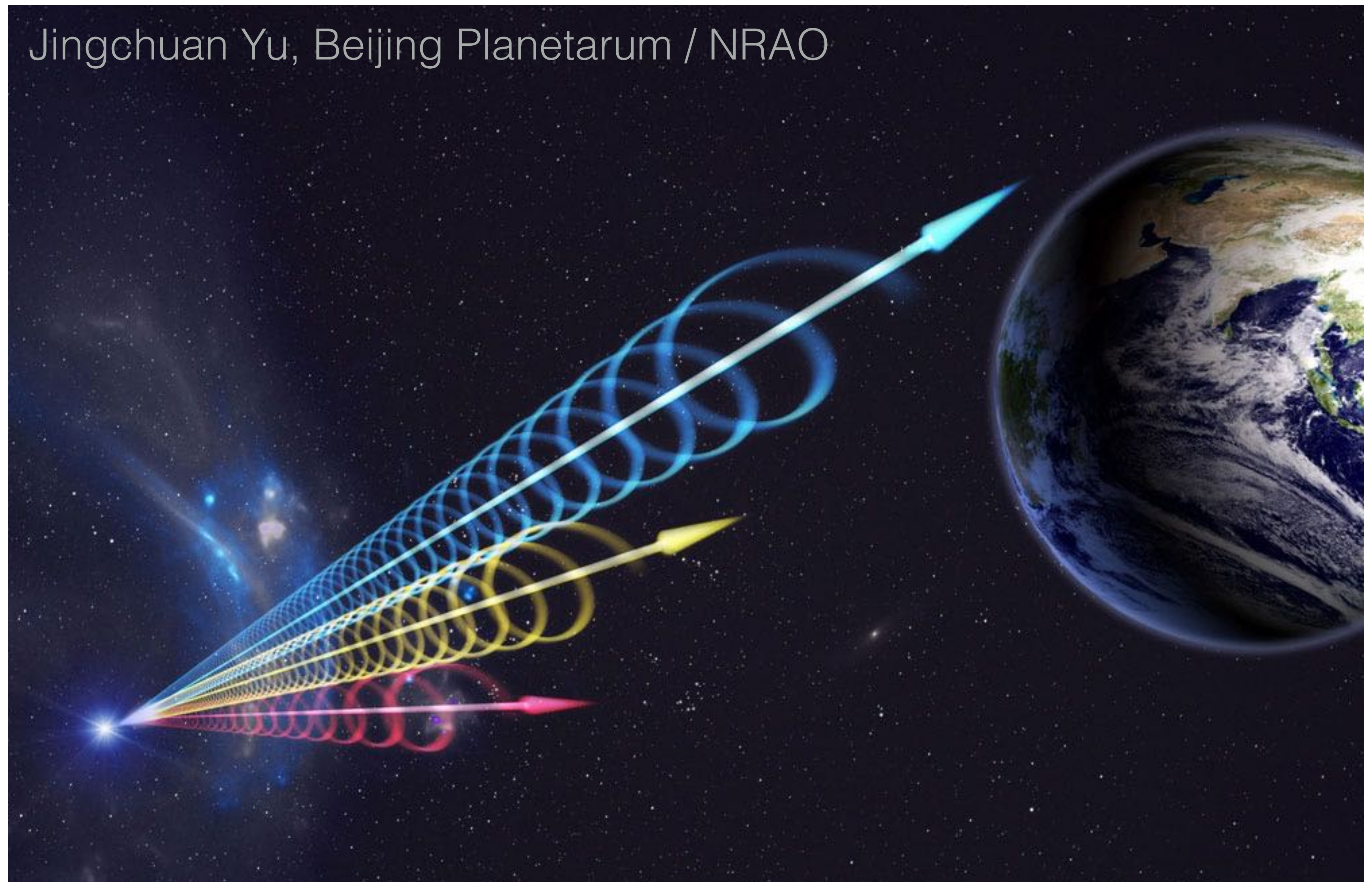
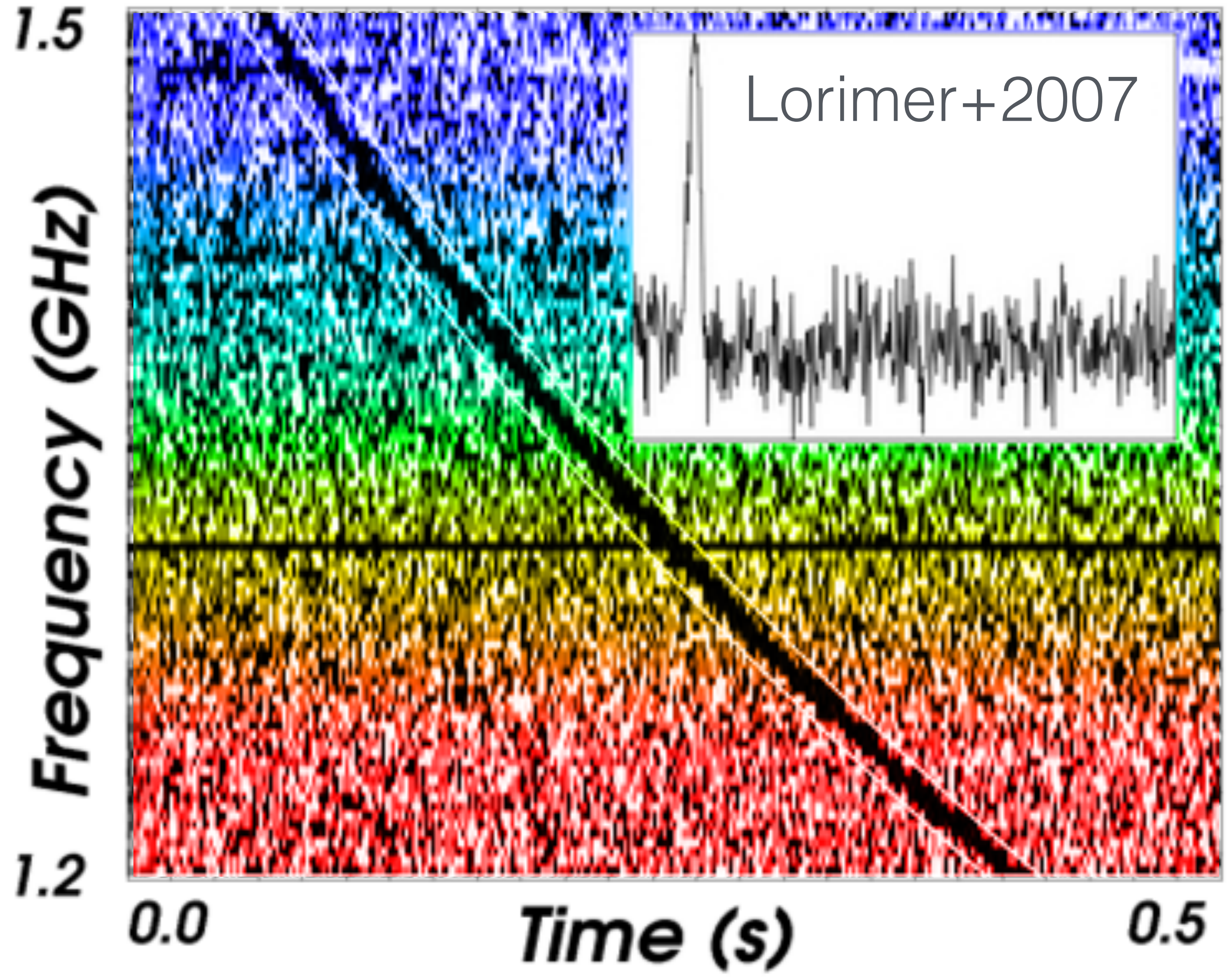
Dispersion Measure

Integrated column density of free electrons between an observer and an FRB.





$$\Delta t \propto \nu_{\mathrm{obs}}^{-2} \int n_e dl$$

Time delay | Obs. Freq | LOS electron density

- Dispersion delay is larger at low freq.
- DM can be obtained either with a pulse fitting algorithm or by the search code, typically with a precision of ~0.1 pc cm^{-3}.

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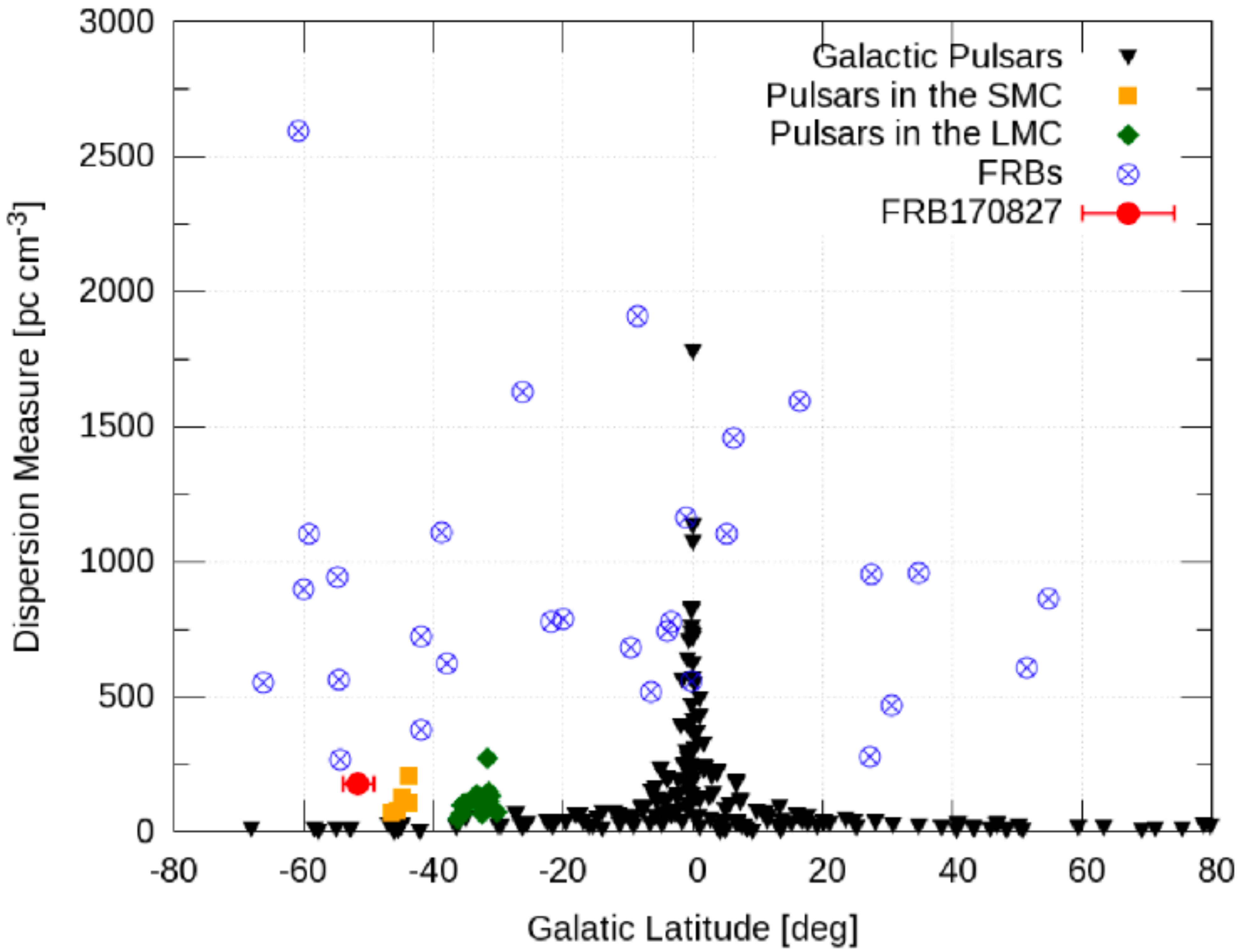
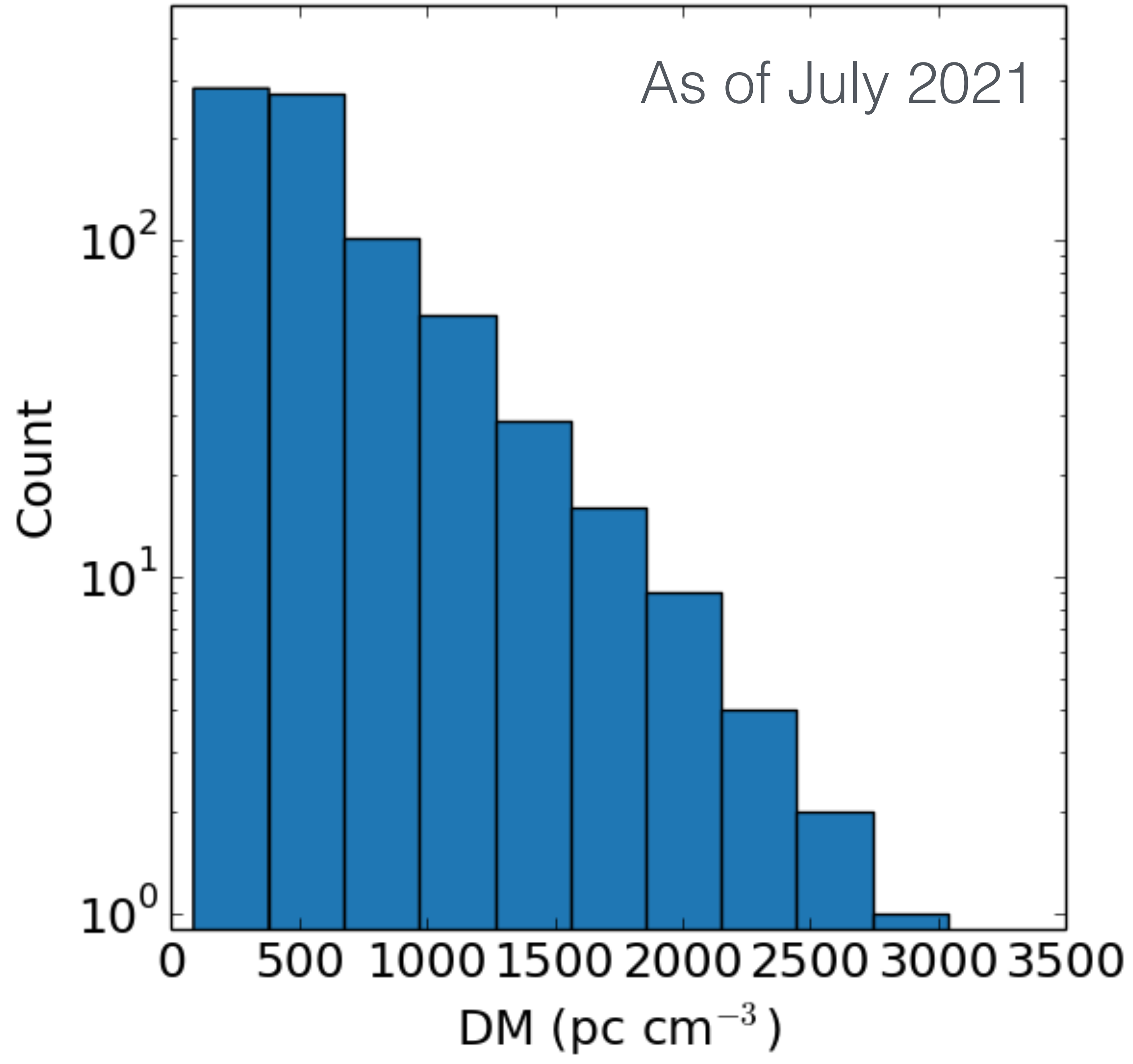
Dispersion Measure

Farah+2018





FRBs are extragalactic in nature with much higher DMs compared to galactic pulsars. Currently, FRBs have been seen with DMs from 88 to 3030 pc cm^{-3} .

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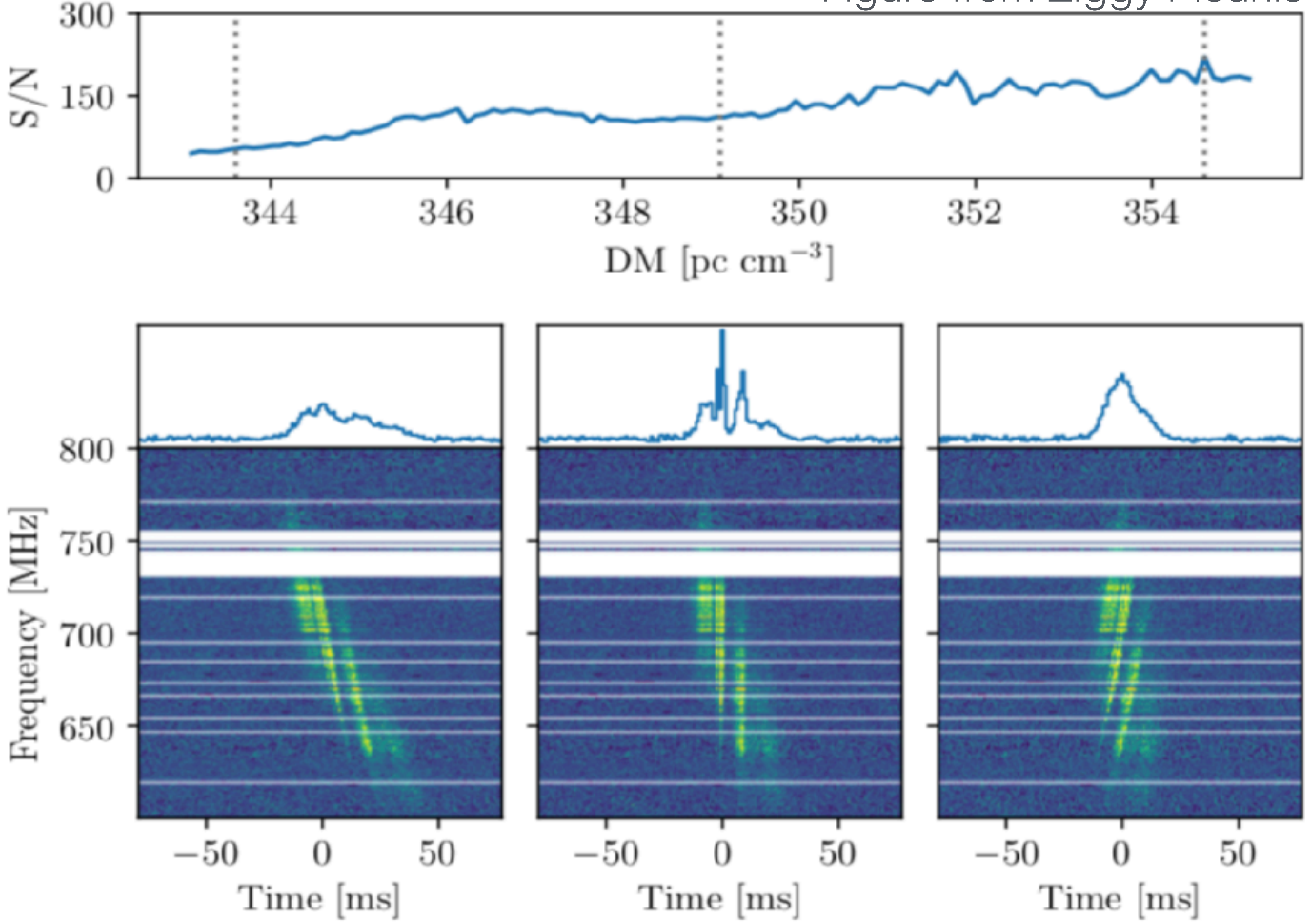
Dispersion Measure

Figure from Ziggy Pleunis



- Structure vs SNR maximized DM can be different
- Multi-peak bursts, a DM per peak?
- Temporal DM variation?

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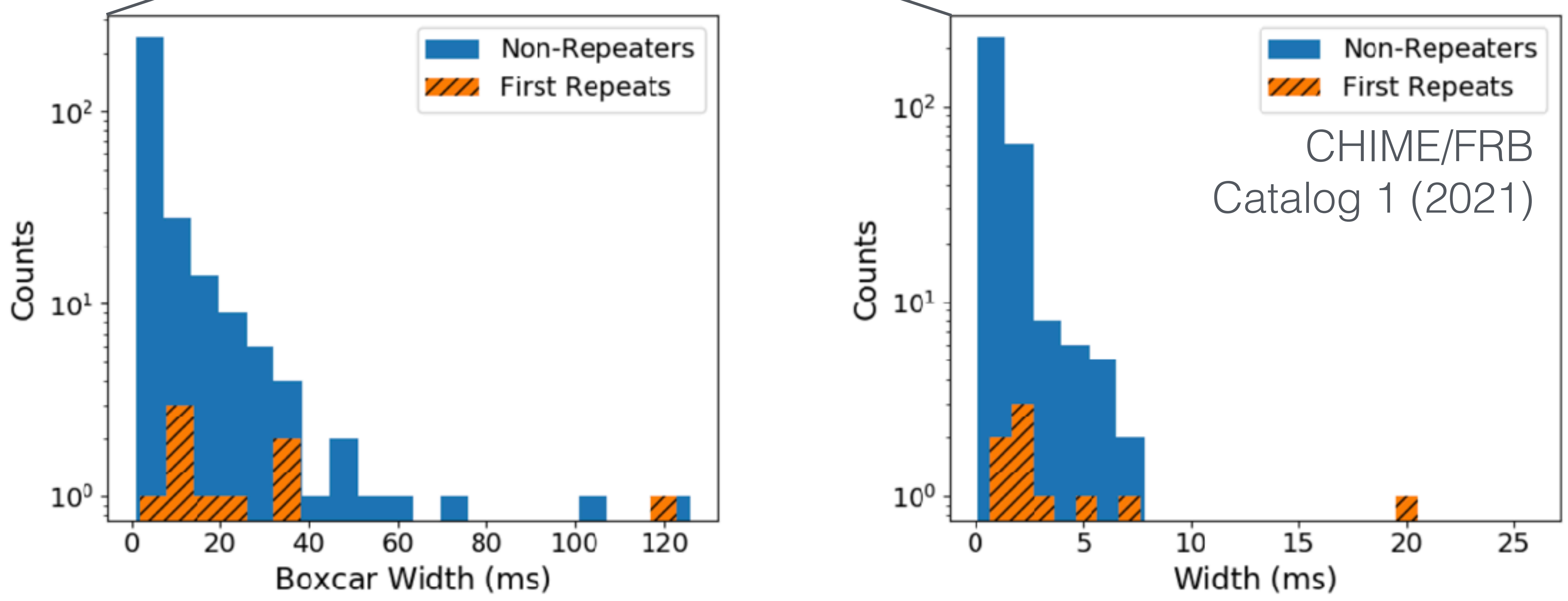
Burst width

$$W = \sqrt{W_{\mathrm{int}}^2 + t_{\mathrm{samp}}^2 + \Delta t_{\mathrm{DM}}^2 + \Delta t_{\mathrm{DMerr}}^2 + \tau_{\mathrm{s}}^2},$$



- CHIME's fitburst uses least-square fitting algorithm to determine the best fit parameters of the bursts, which include the ability to fit for bursts with multiple components (see, .e.g. Masui+2015).
- Majority of FRBs have us to ms timescale — "Fast" transient

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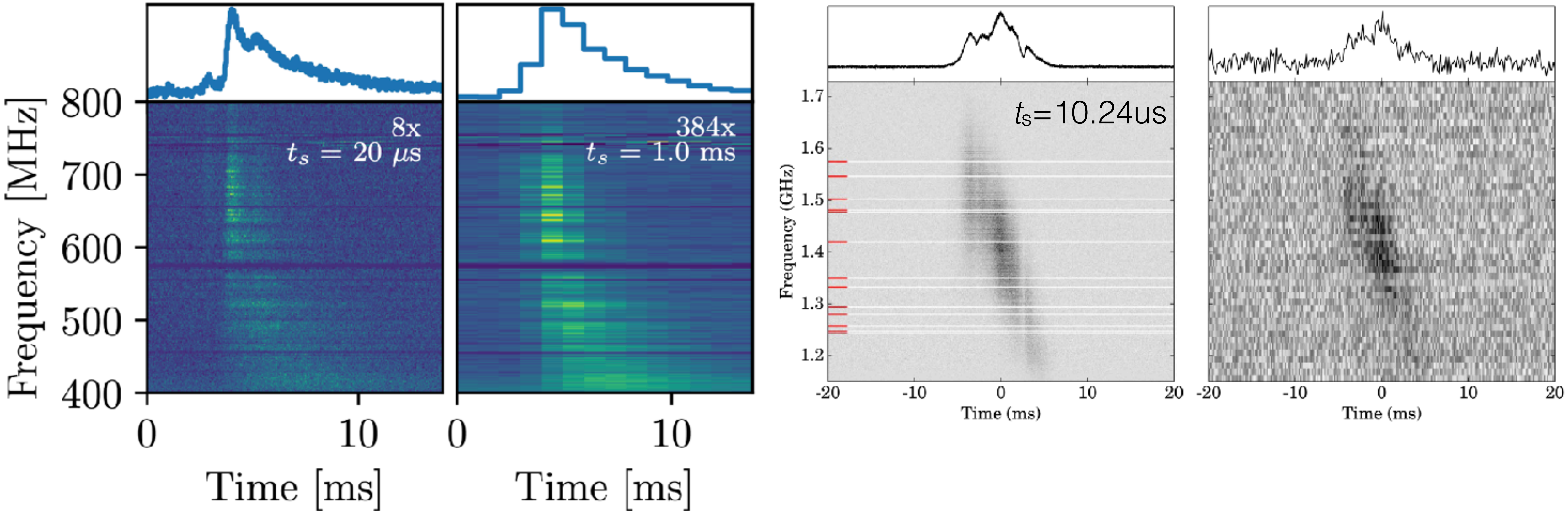
Burst width

Plot from Ziggy Pleunis

Gourdji+2019



- Rely on correctly dedispersed data
- Multi-peak bursts vs one wide burst? Need high time res. data
- Other broadening effects (channel smearing, scattering)

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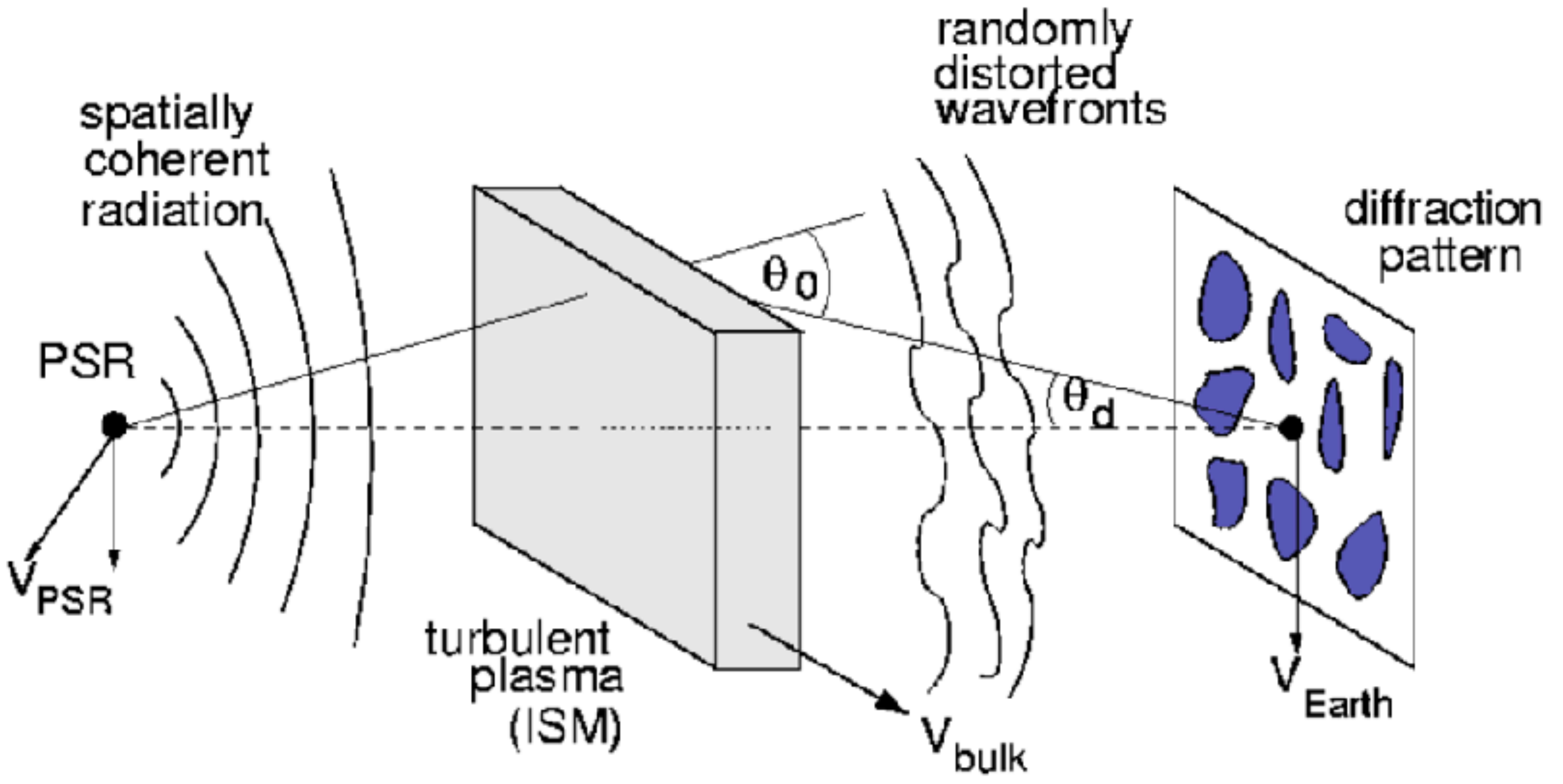
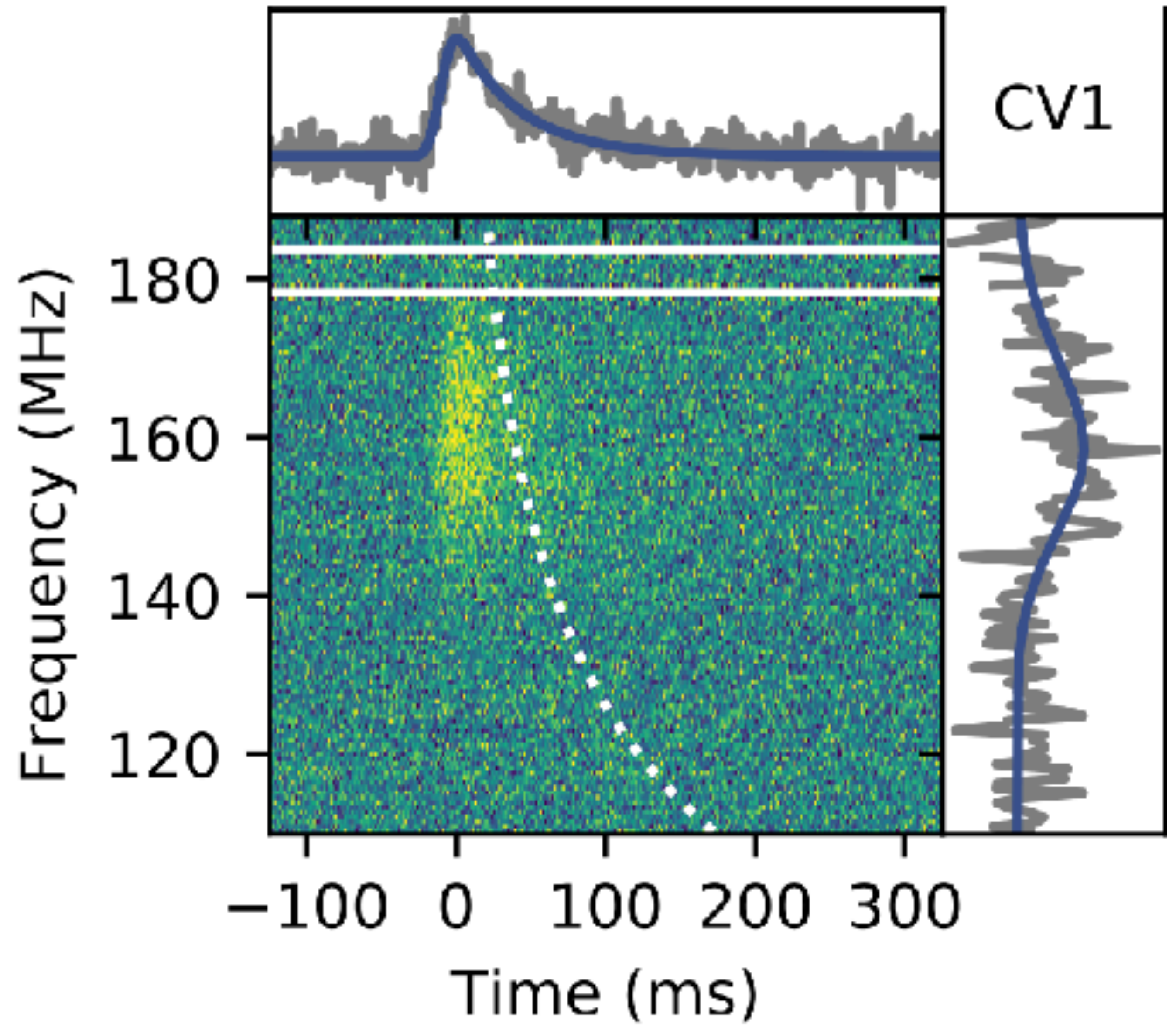
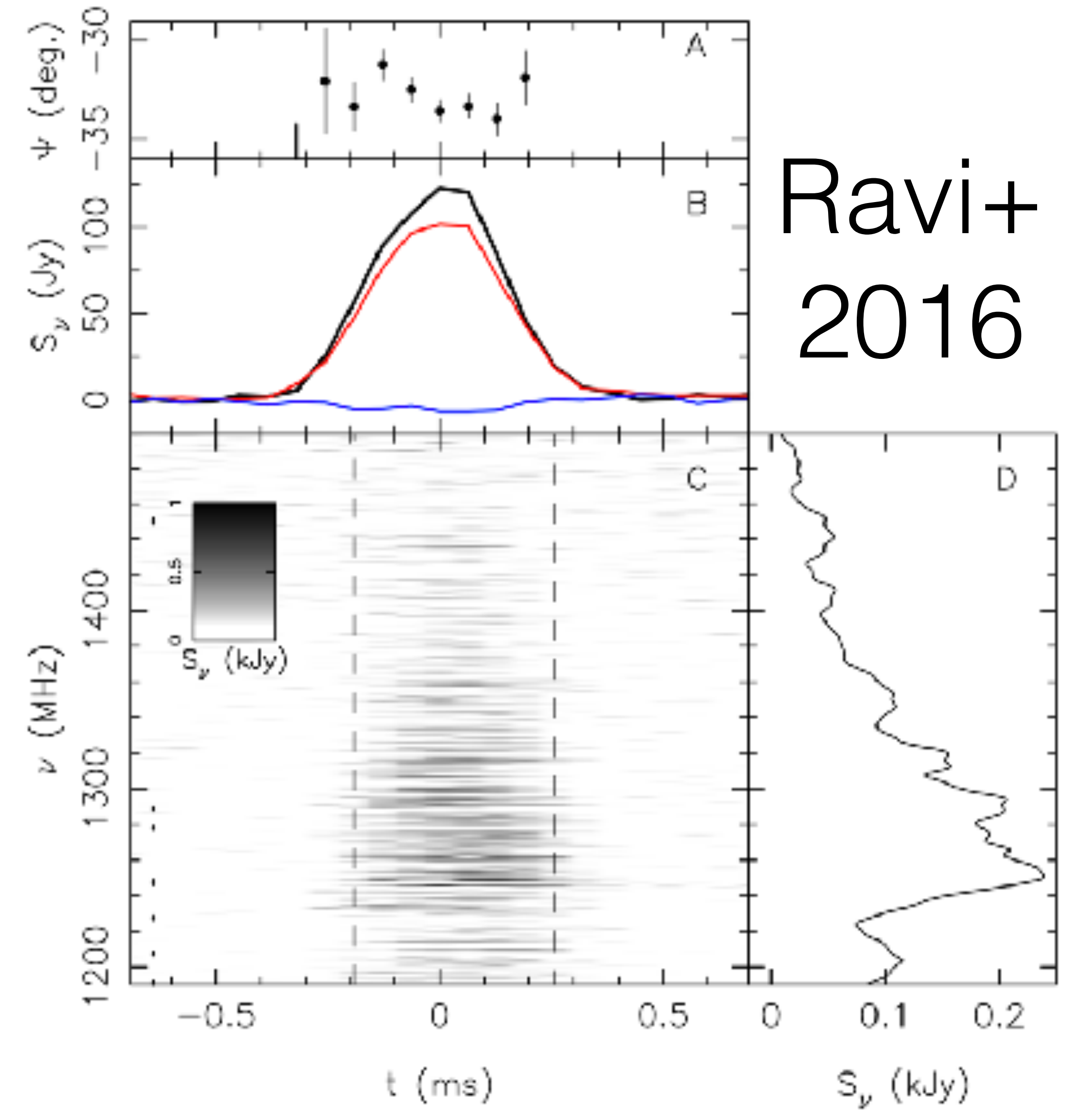
Scattering & Scintillation



Pleunis+2021



- $\tau_s \propto 1/\Delta\nu \propto \nu^{-4}$
- Effect most prominent at low frequencies, e.g. LOFAR detection above of ~50ms at 150MHz.
- Difficult to disentangle intrinsic broadening, scatter-broadening, sub-burst drifting and 2nd order effects



Ravi+ 2016

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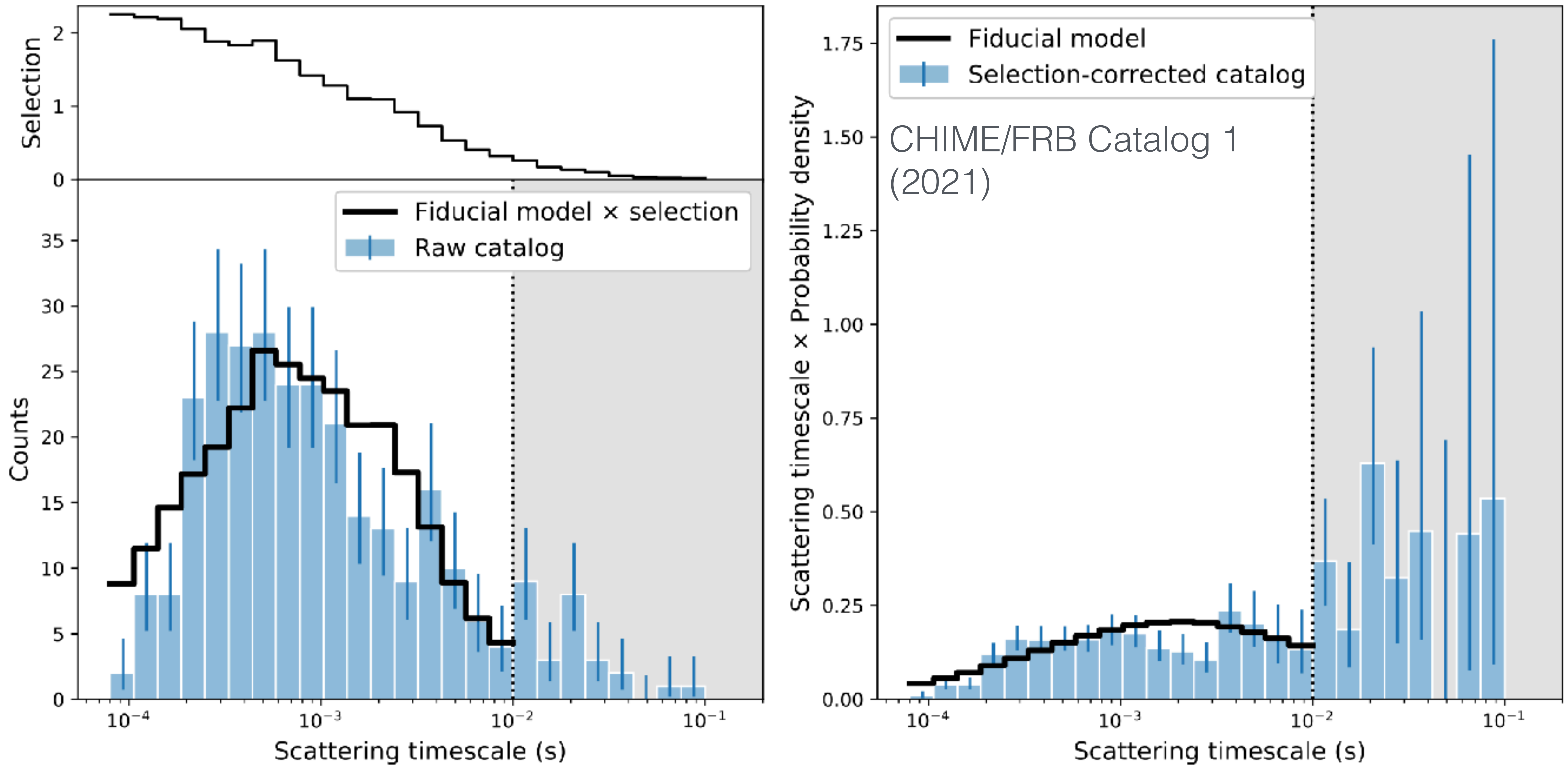
Scattering

See talks by Pragya Chawla and Kaitlyn Shin at FRB2021 Plenary 1



- Severe selection bias against events with scattering time >10 ms
- There may be a substantial unobserved population of highly scattered FRBs

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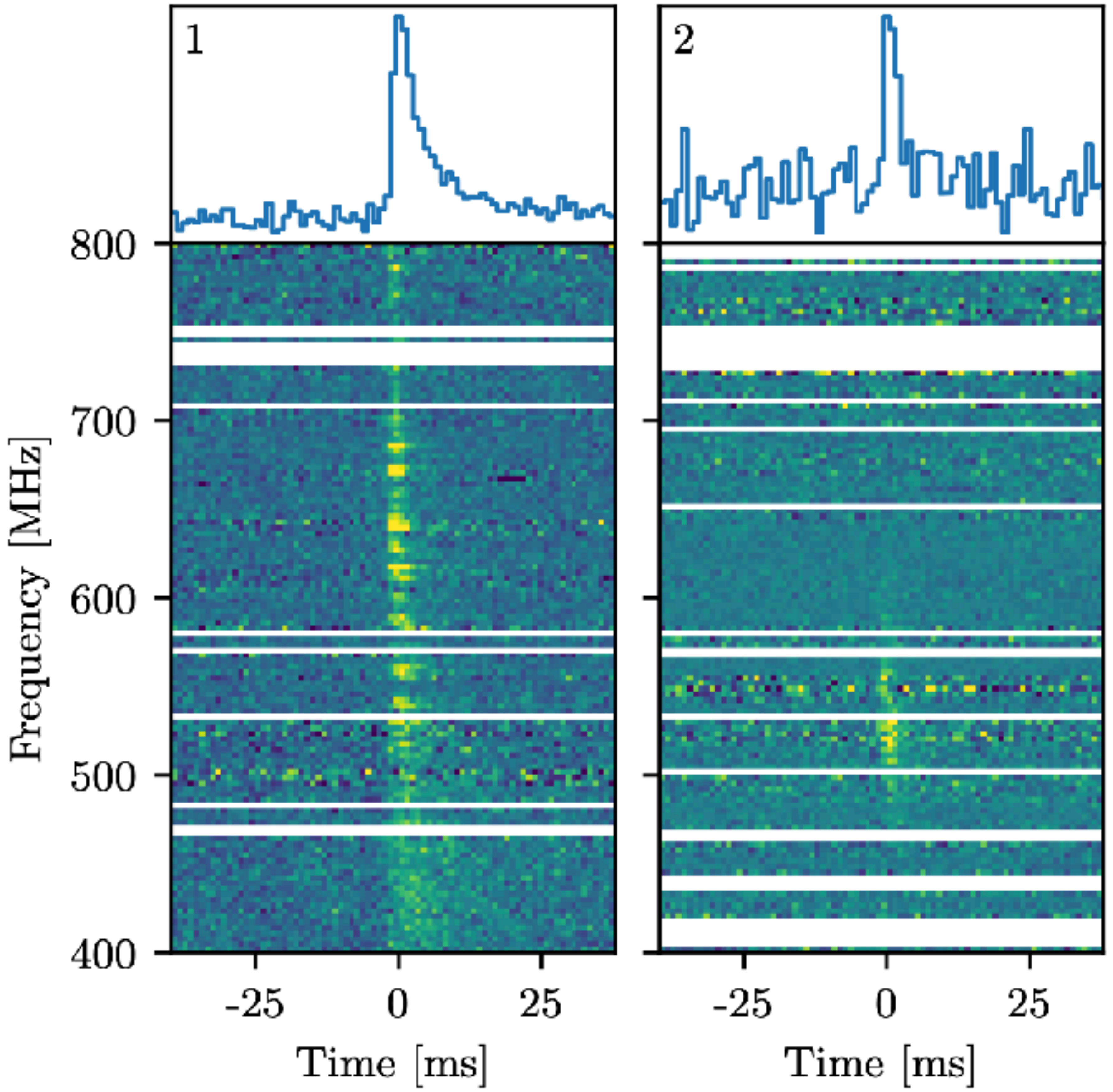
Spectral index/running

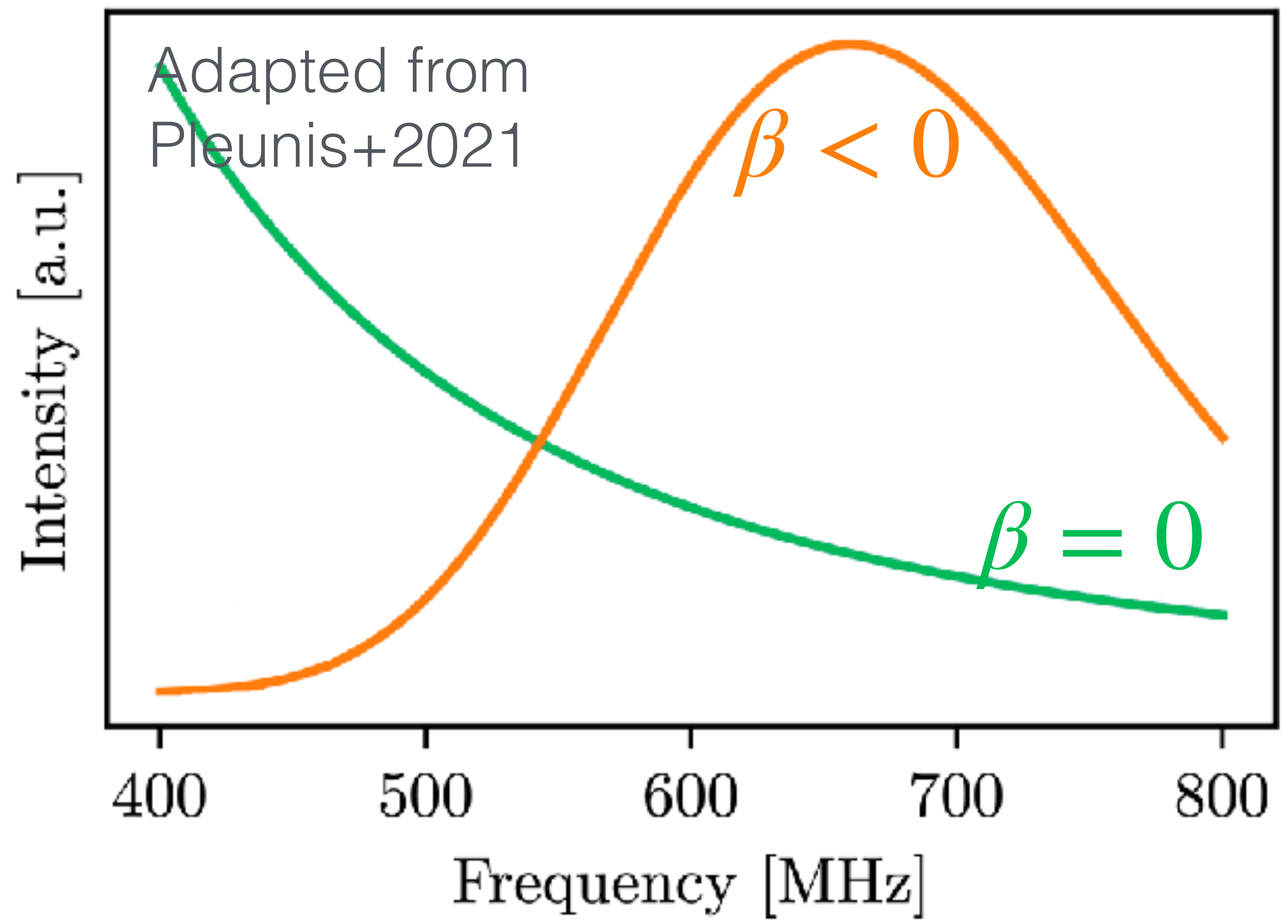
Pleunis+2021



$$I(\nu) = A(\nu/\nu_0)^{\alpha+\beta\ln(\nu/\nu_0)}$$

spectral index (α)

spectral running (β)



$\beta \to 0$: Power-law-like

$\beta < 0$: Narrowband Gaussian-like

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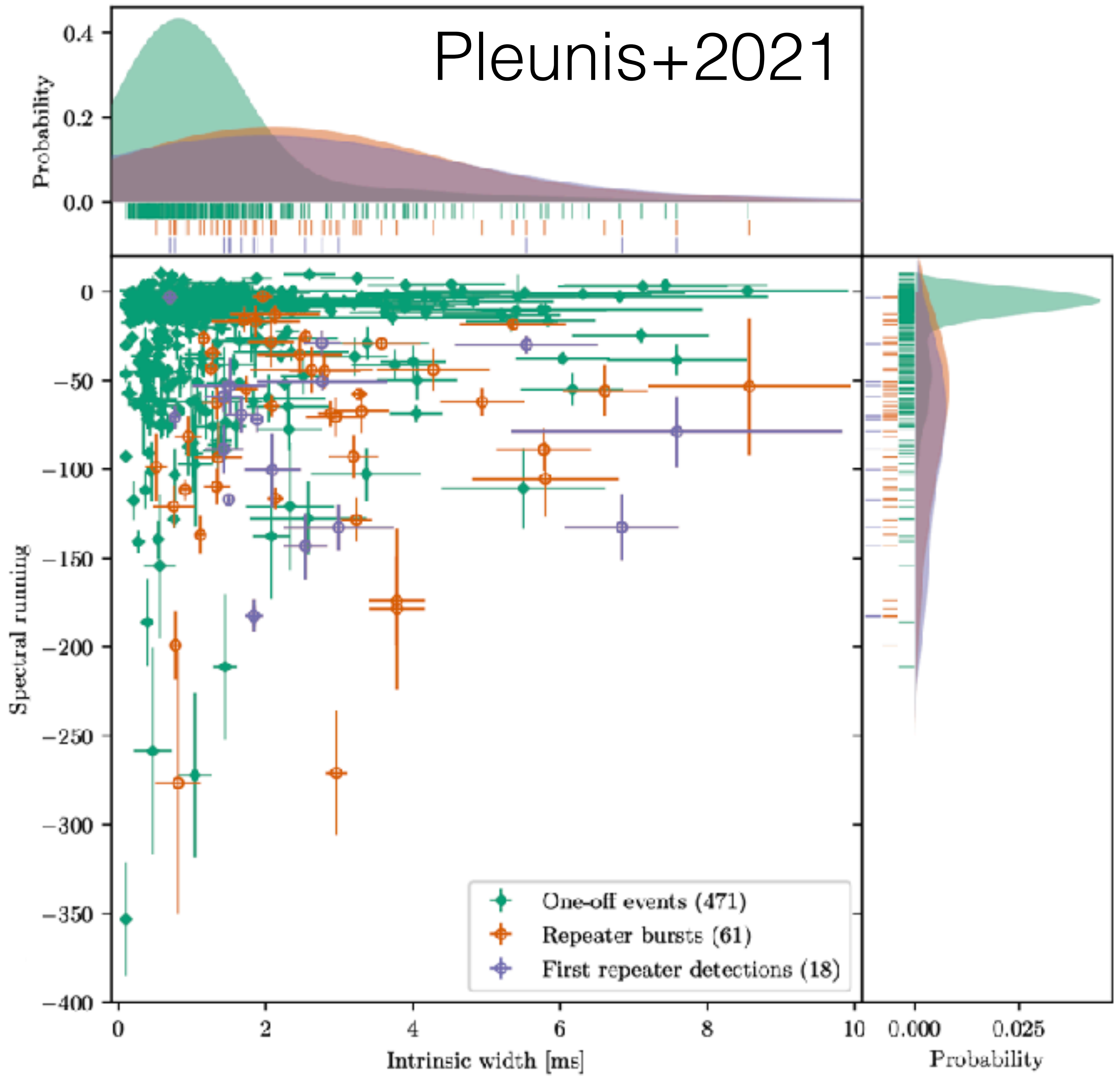
Width vs spectral running

Power-law-like

$\beta \to 0$

$\beta < 0$

Narrowband Gaussian-like



- Repeater bursts have narrow bandwidths (100-200 MHz) and they tend to be wider in width.
- ~30% of bursts are broadband with one peak, vs ~60% are narrow band with one peak (can be beam response)

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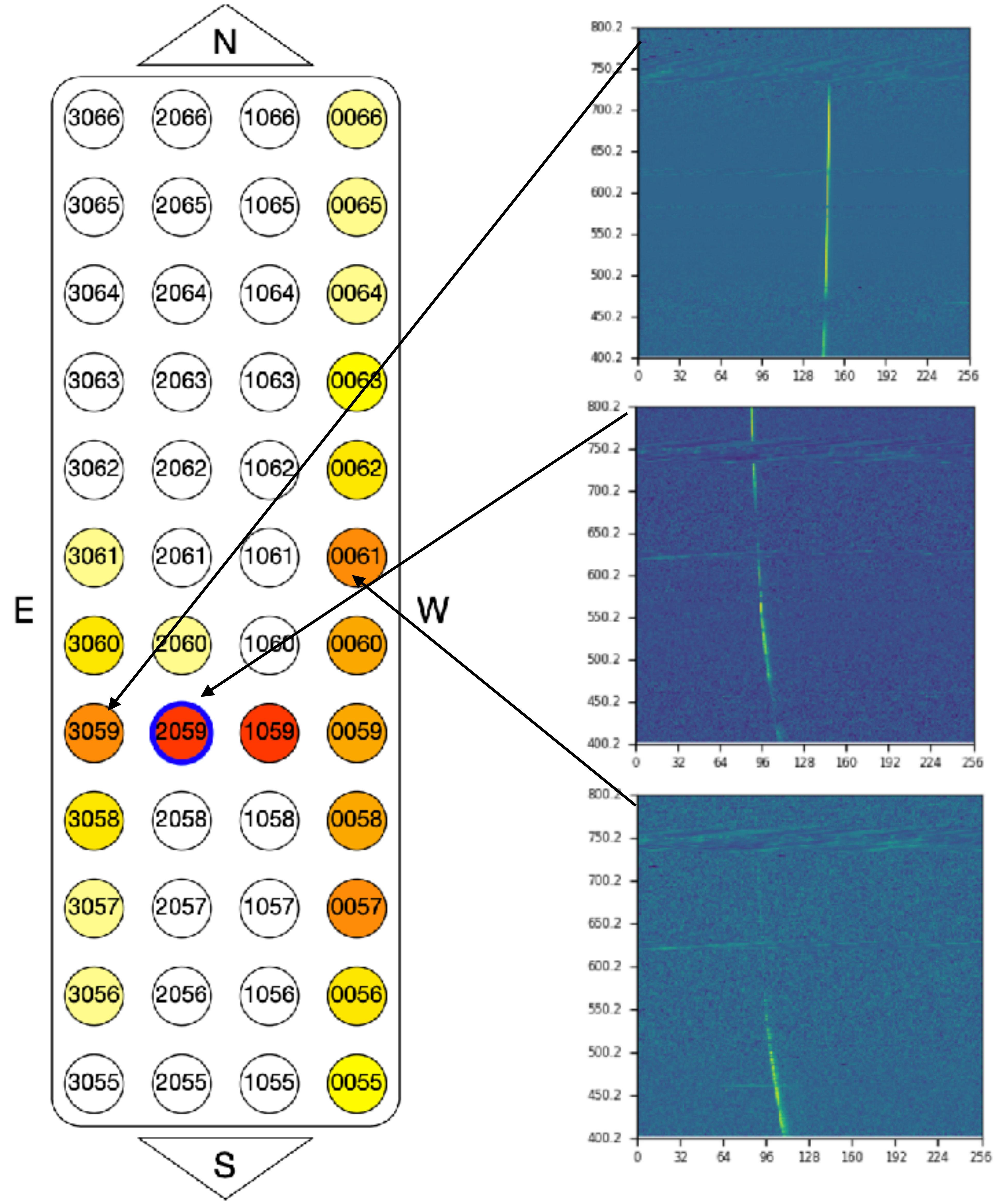
Spectral index/running



- Morphology and bandwidth occupancy can be entangled with beam response
- Same source can look very different in different beams

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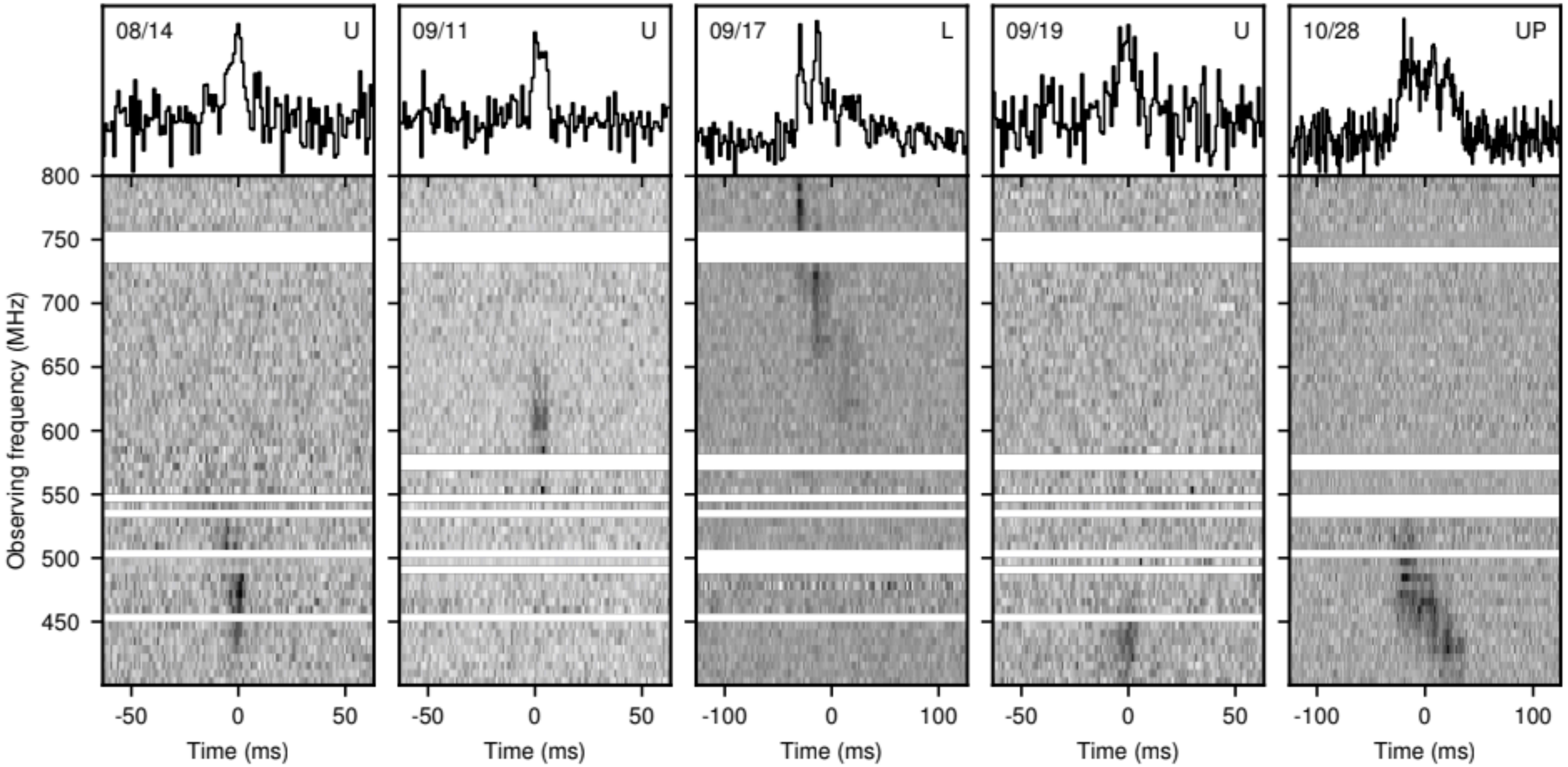
Spectral index/running

CHIME/FRB Collab, 2019



- Repeater bursts could “jump” around

- Position
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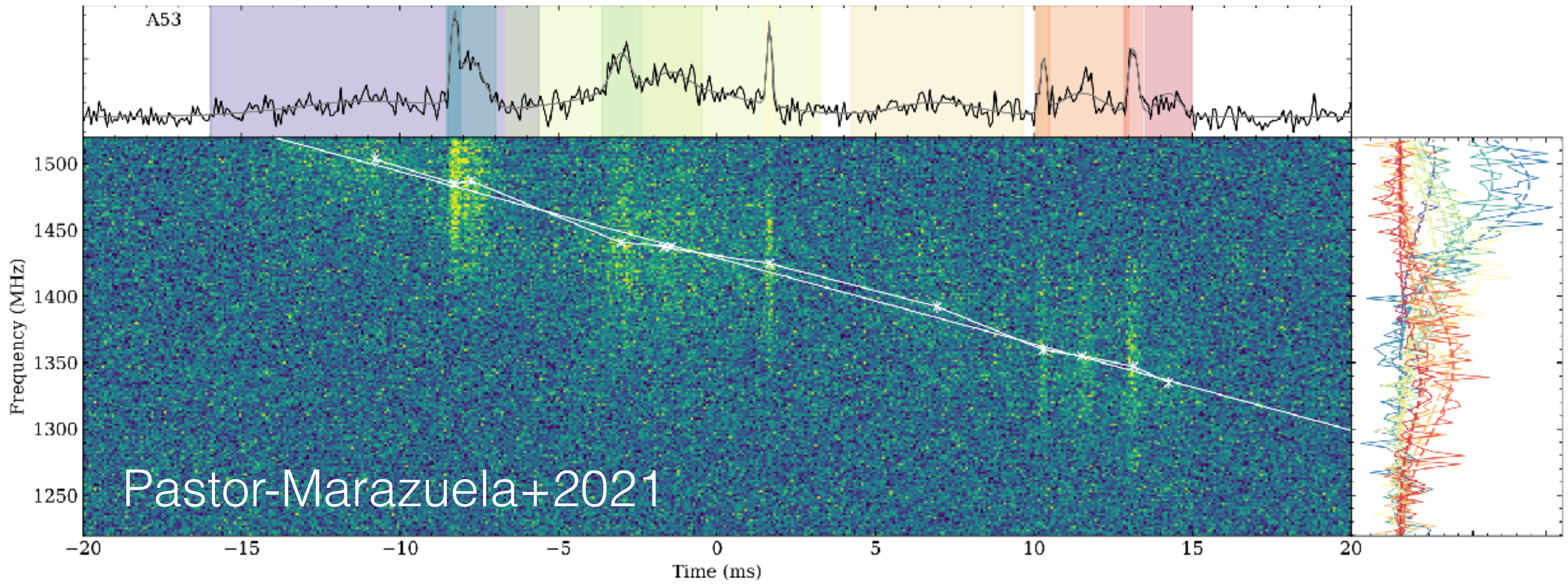
Drift rate



- So-called “sad trombone” effect, a downward drifting feature that has only been seen in repeaters?
- See open source package for measuring drift rate: https://github.com/zpleunis/dfdt

! Requires high time res. Otherwise looks like one wide burst

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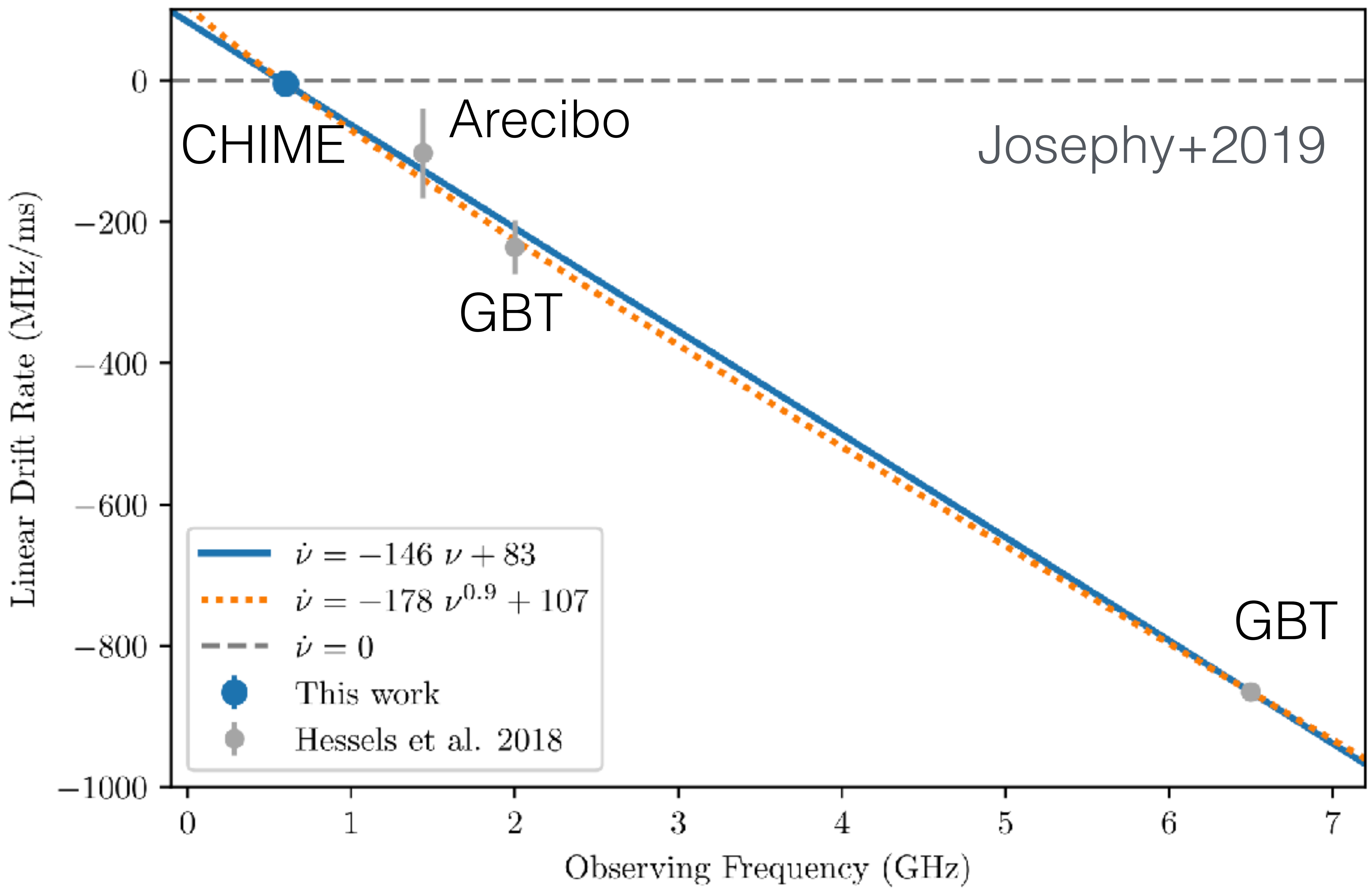
Drift rate



- See Caleb+2020, Pastor-Marazuela+ 2021 for more examples
- Linear drift rates of few to tens of MHz/ms

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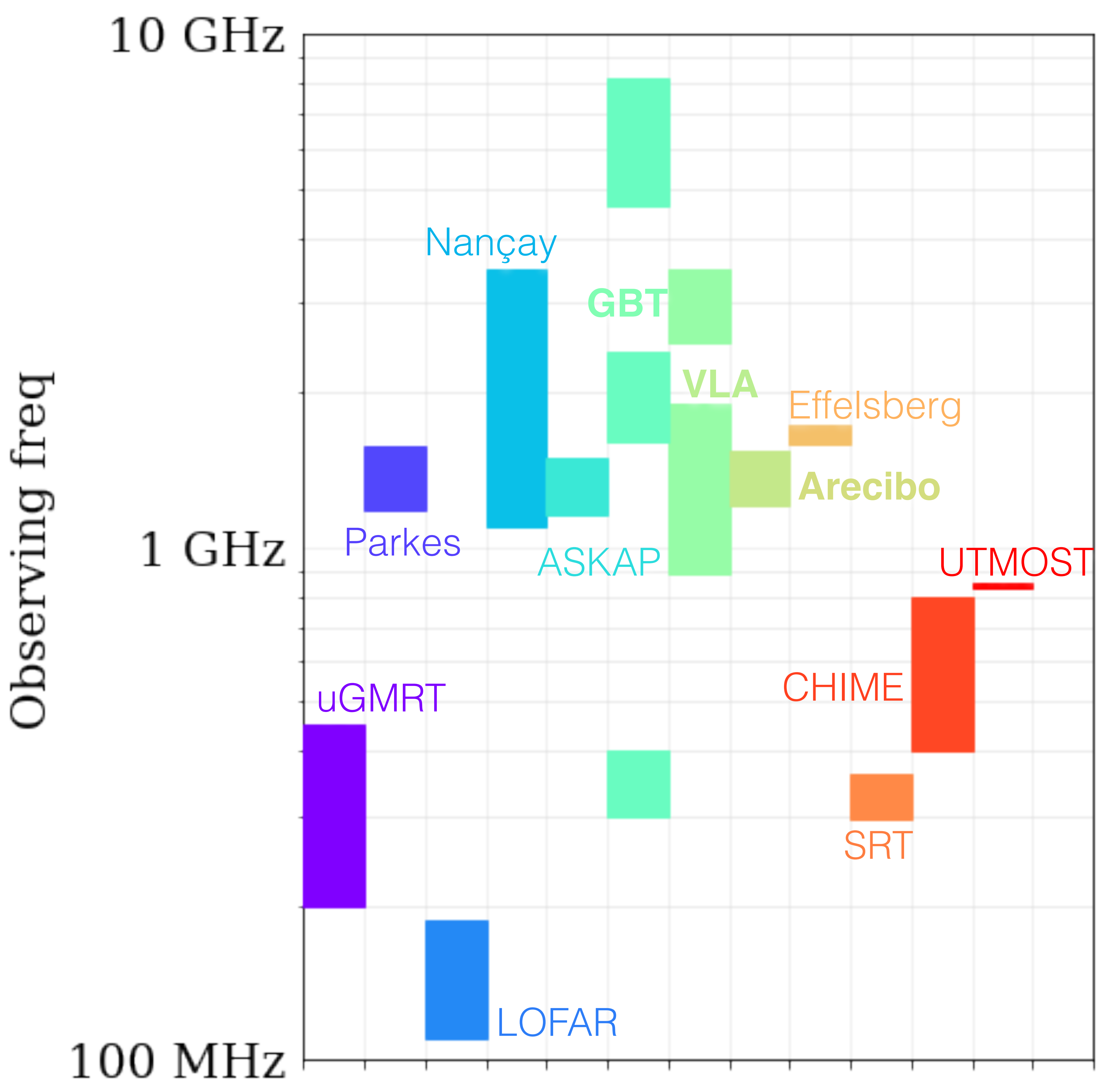
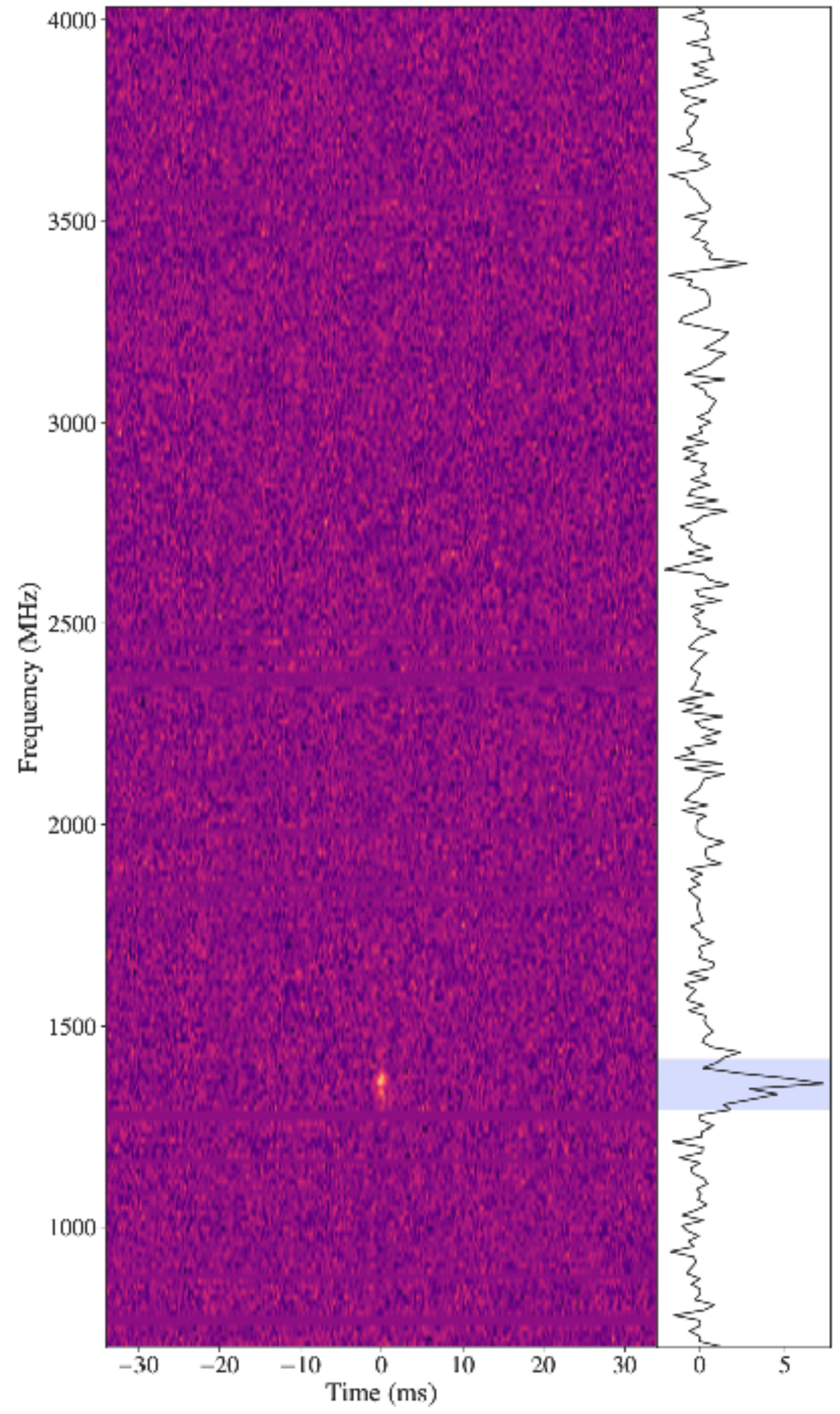
Frequency range



Kumar+2020



- Currently detected from observing frequencies from 110MHz up to 8GHz.
- FRB can be extremely band limited, e.g. UWL rcvr detection from Parkes.

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Signal-to-noise (SNR) & Fluence

$$F = S_{\text{peak}} W_{\text{eq}} = \int S(t)dt$$

Fluence — Flux — Top-hat width — The area under the burst curve in the dedispersed time series

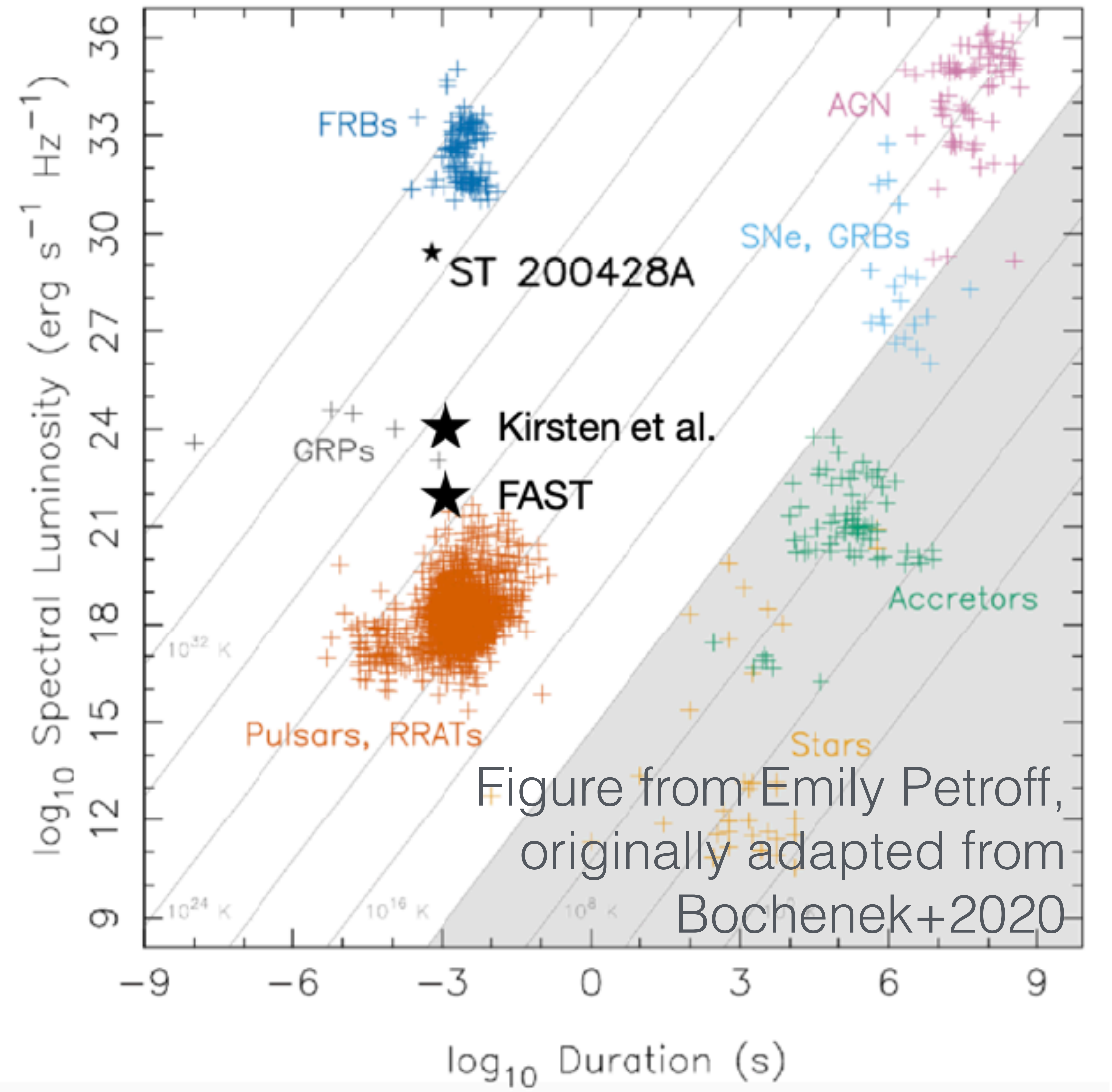

Figure from Emily Petroff, originally adapted from Bochenek+2020

- Flux & Fluence tend to be lower limited assuming boresight detection.
- Fluence of FRBs from SGR1935 varied by 7 orders of magnitude: 60 mJy ms in ATel 13699, ~100 Jy ms in Kirsten 2020, and ~MJy ms in Bochenek+2020, CHIME/FRB, 2020)

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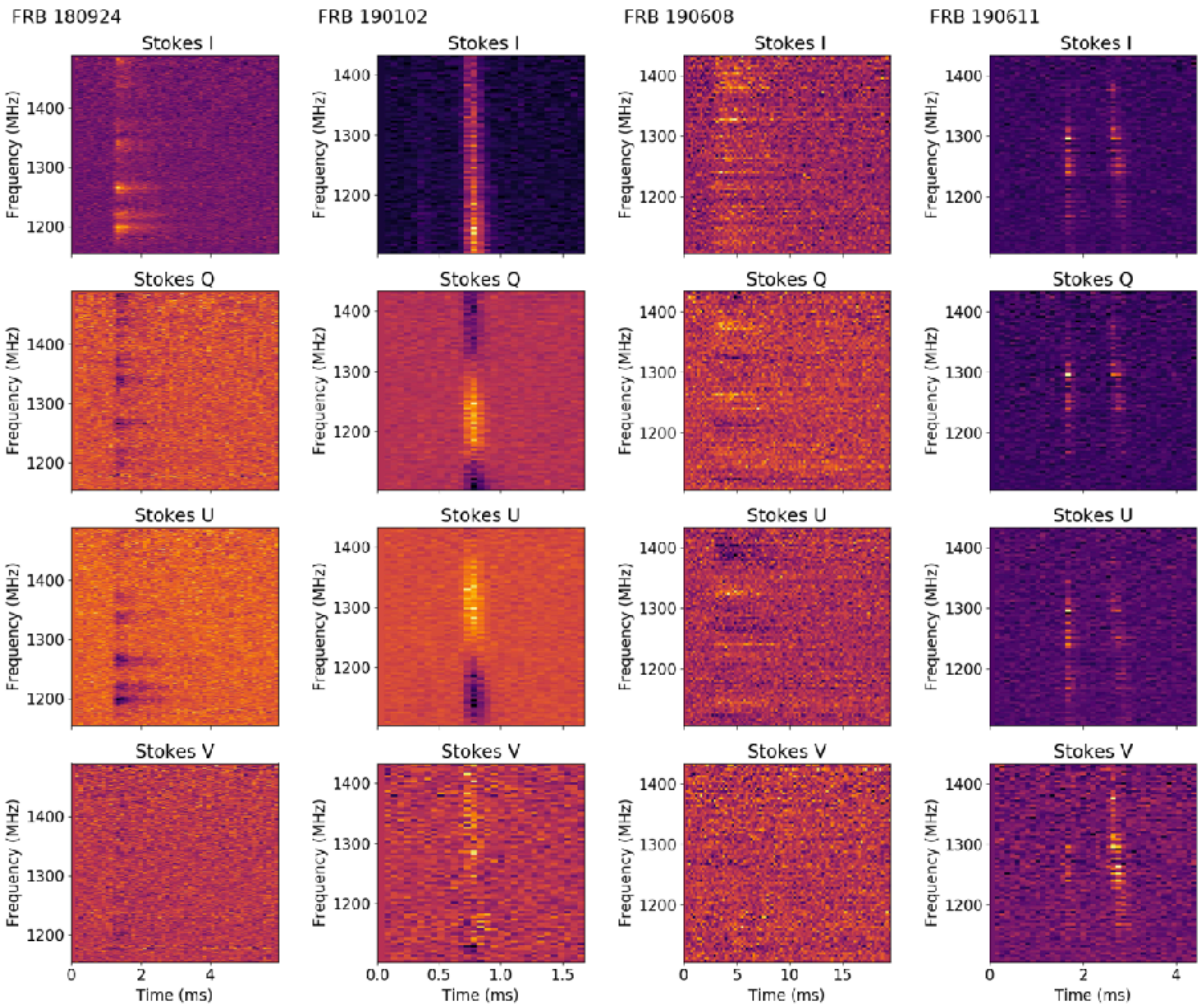
Polarization



$$I = \langle |X|^2 + |Y|^2 \rangle$$

$$Q = \langle |X|^2 - |Y|^2 \rangle$$

$$U = \langle 2\, real(XY^*) \rangle$$

$$V = \langle -2\, imag(XY^*) \rangle$$

Day+2020

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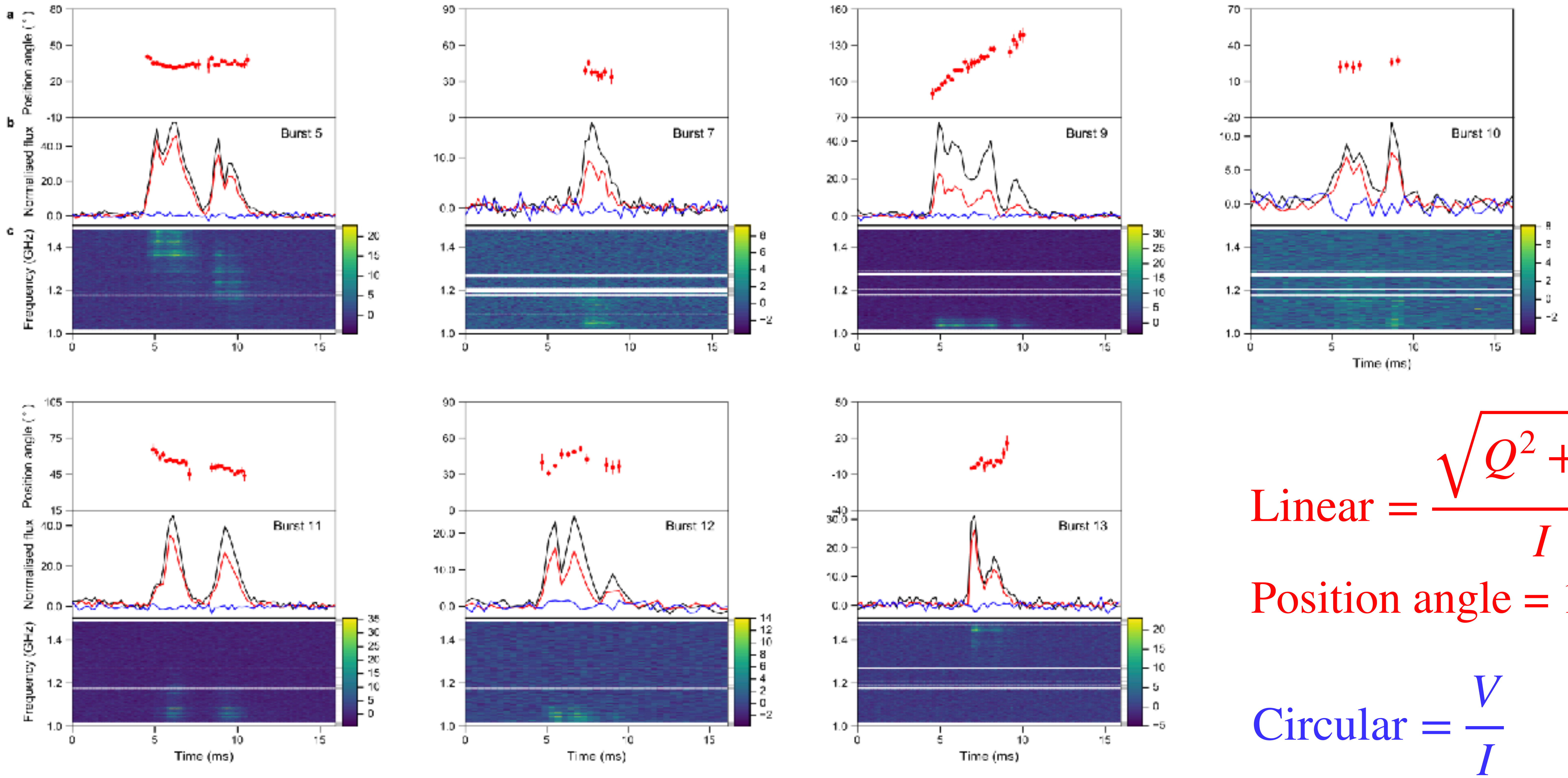
Polarization

Luo+2020



$$\text{Linear} = \frac{\sqrt{Q^2 + U^2}}{I}$$

$$\text{Position angle} = 1/2 \arctan(U/Q)$$

$$\text{Circular} = \frac{V}{I}$$

- A diversity of polarimetric properties detected with FRB 180301 by FAST.
- High degree of linear polarization, no obvious circular polarization
- Variations in polarization position angle (PA) swings across the pulse profiles.

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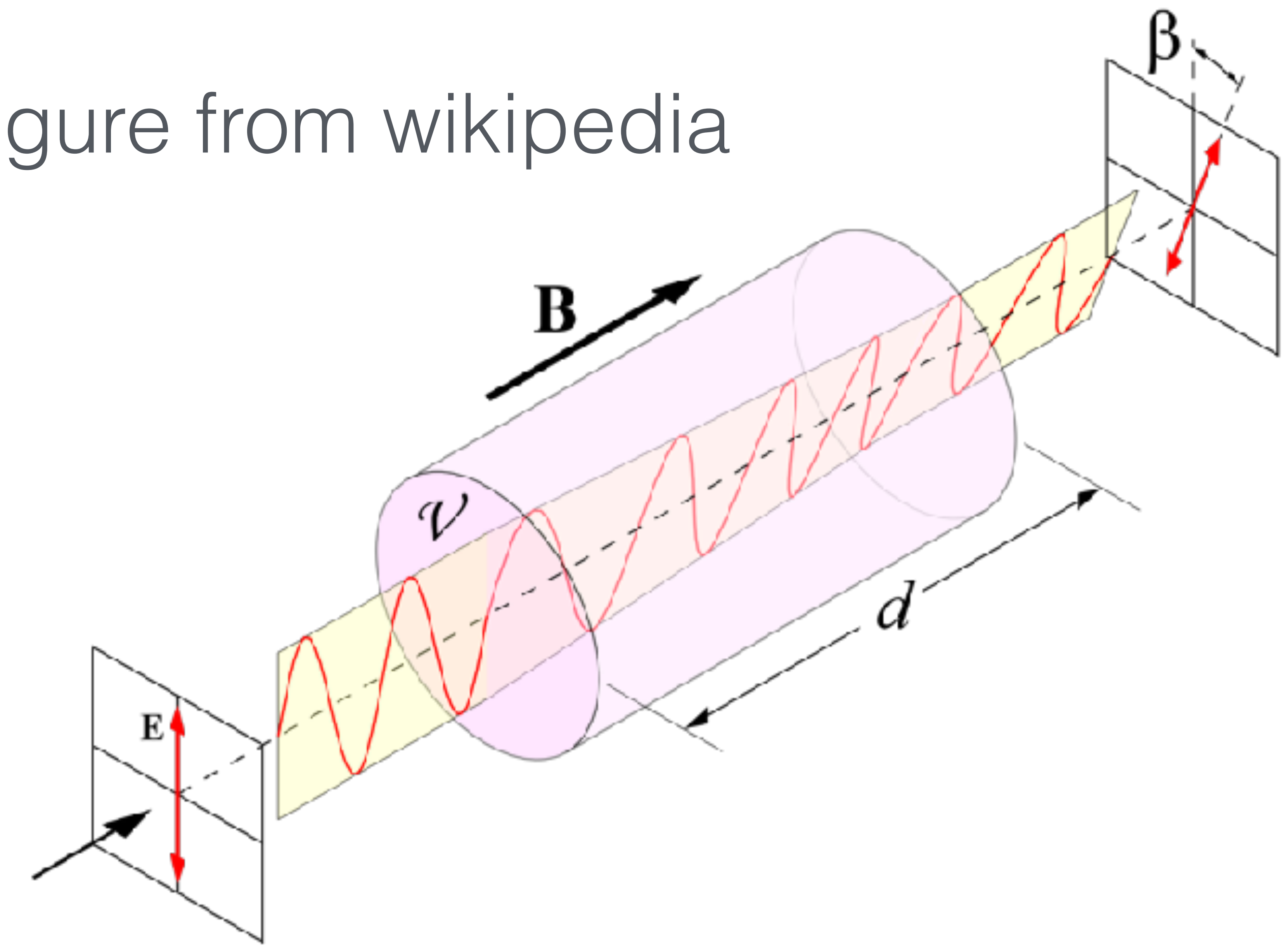
Rotation Measure

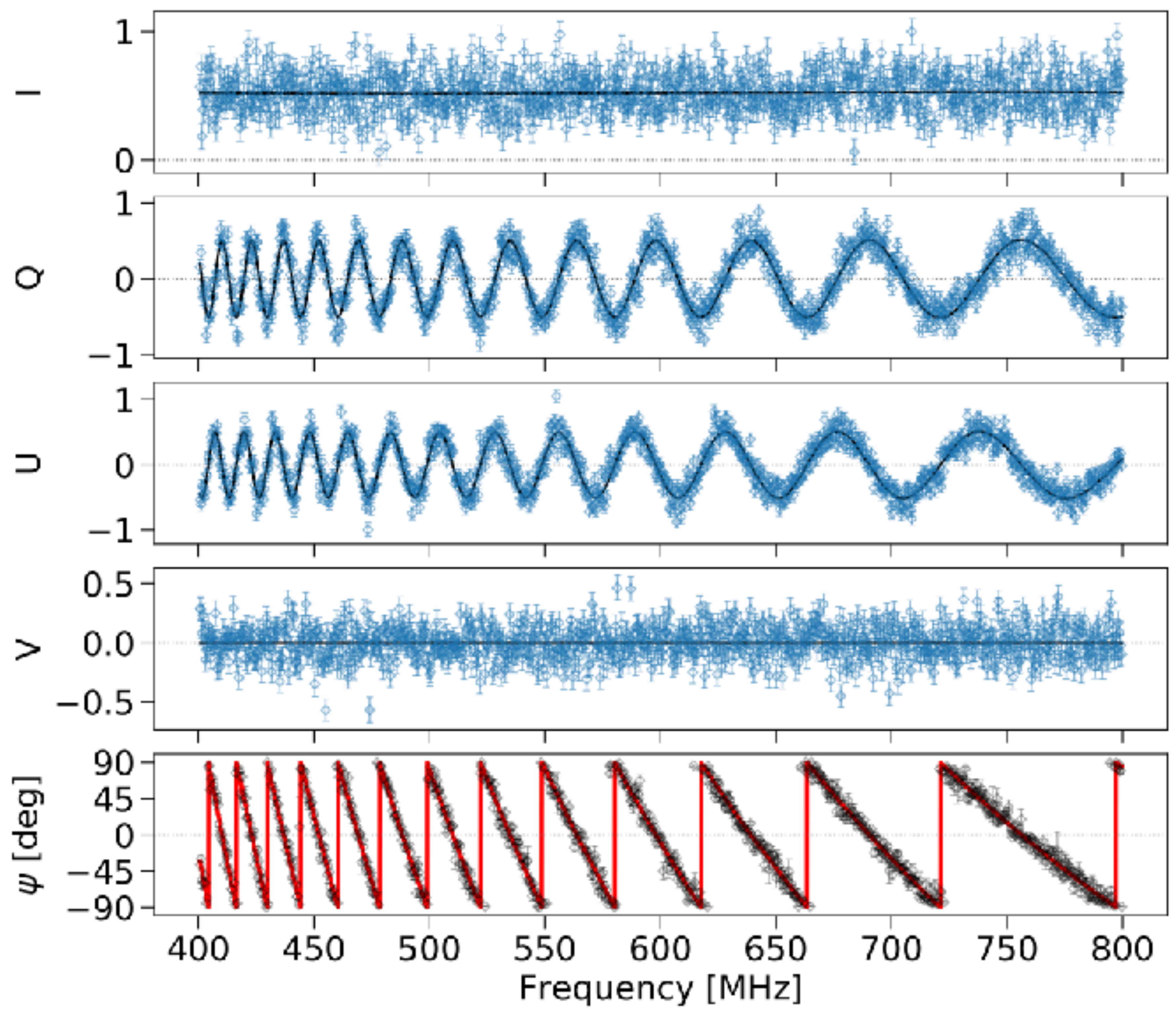
Figure from wikipedia



$$\Delta PA = RM\nu^2$$

$$RM \propto \int_{source}^{observer} \frac{n_e B \cdot dl}{(1+z)^2}$$

Mckinven+2021



Techniques such as QU fitting RM synthesis and can be used to determine the RM (see, e.g. https://github.com/CIRADA-Tools/RM-Tools)

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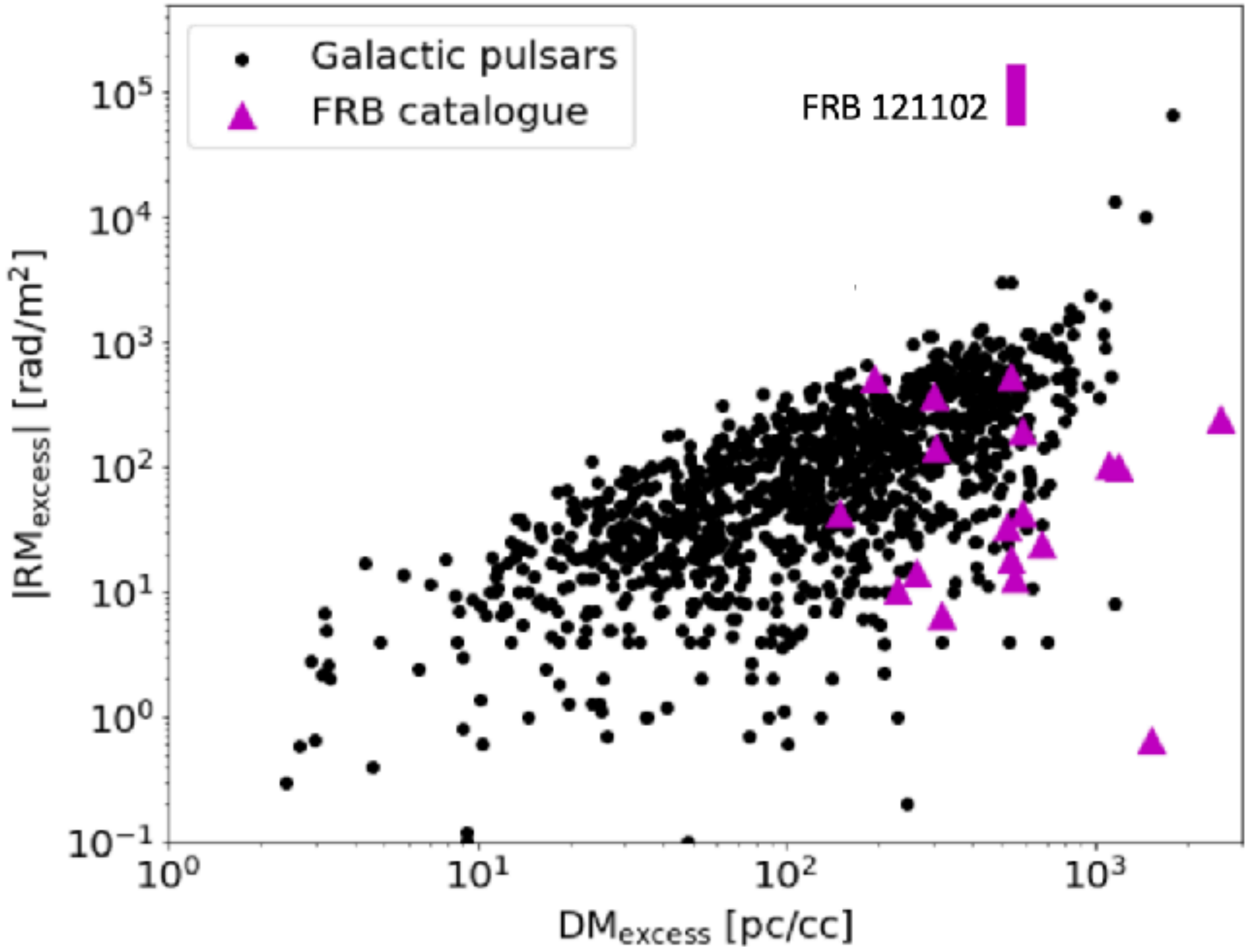
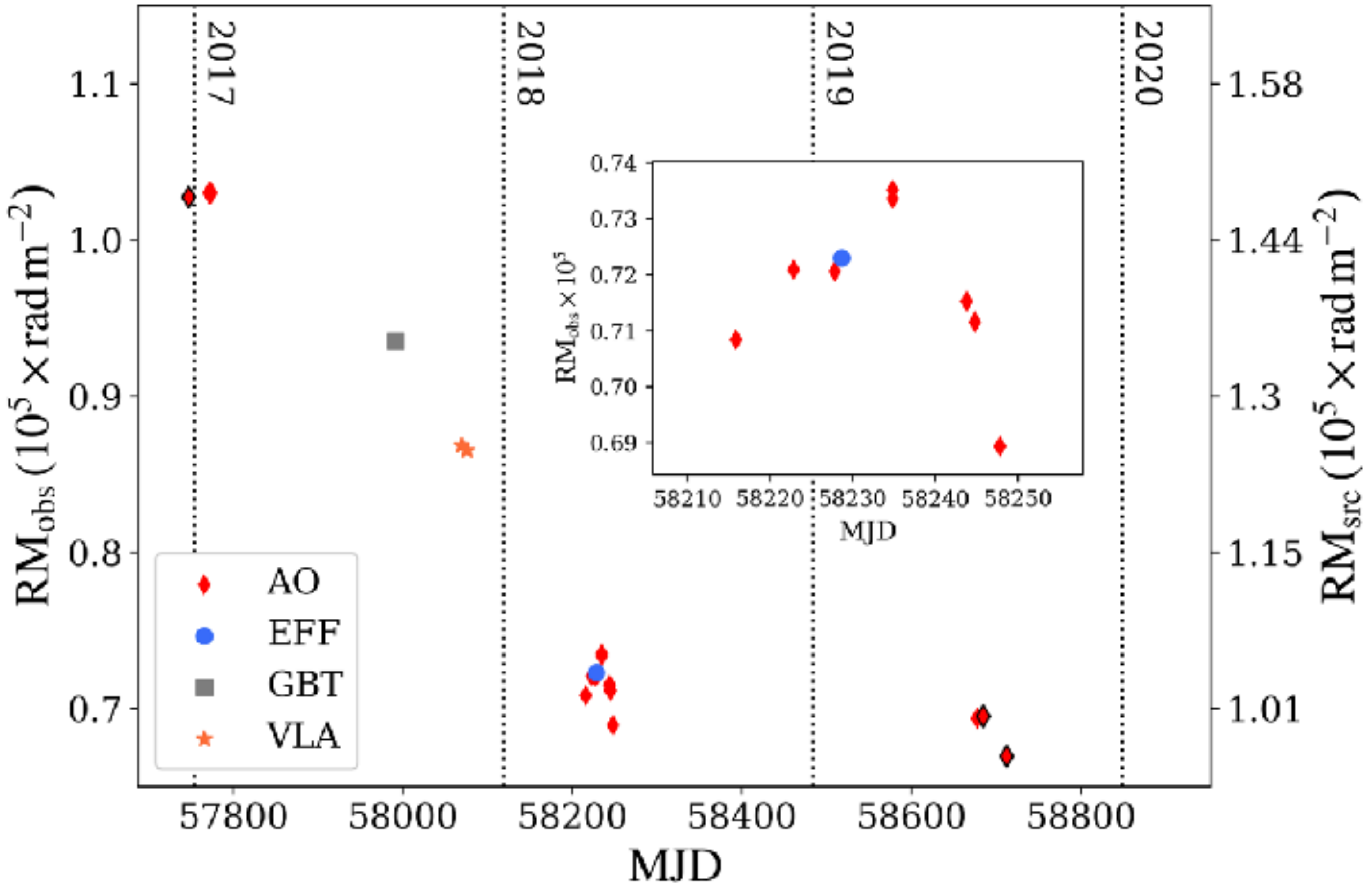
Plot from Ryan Mckinven



Hillmarsson+2021



- Record held by FRB121102 “R1” at 10^5 rad/m^2
- Most RMs came from repeaters, but also some one-offs (e.g. Masui+2015, Bannister+2019)
- Intra-channel depolarization affects very high RMs (Mckinven+2021)
- Temporal RM variation e.g. a 15%/yr drop in R1 (Hillmarsson+2021, see FRB2021 plenary 3)

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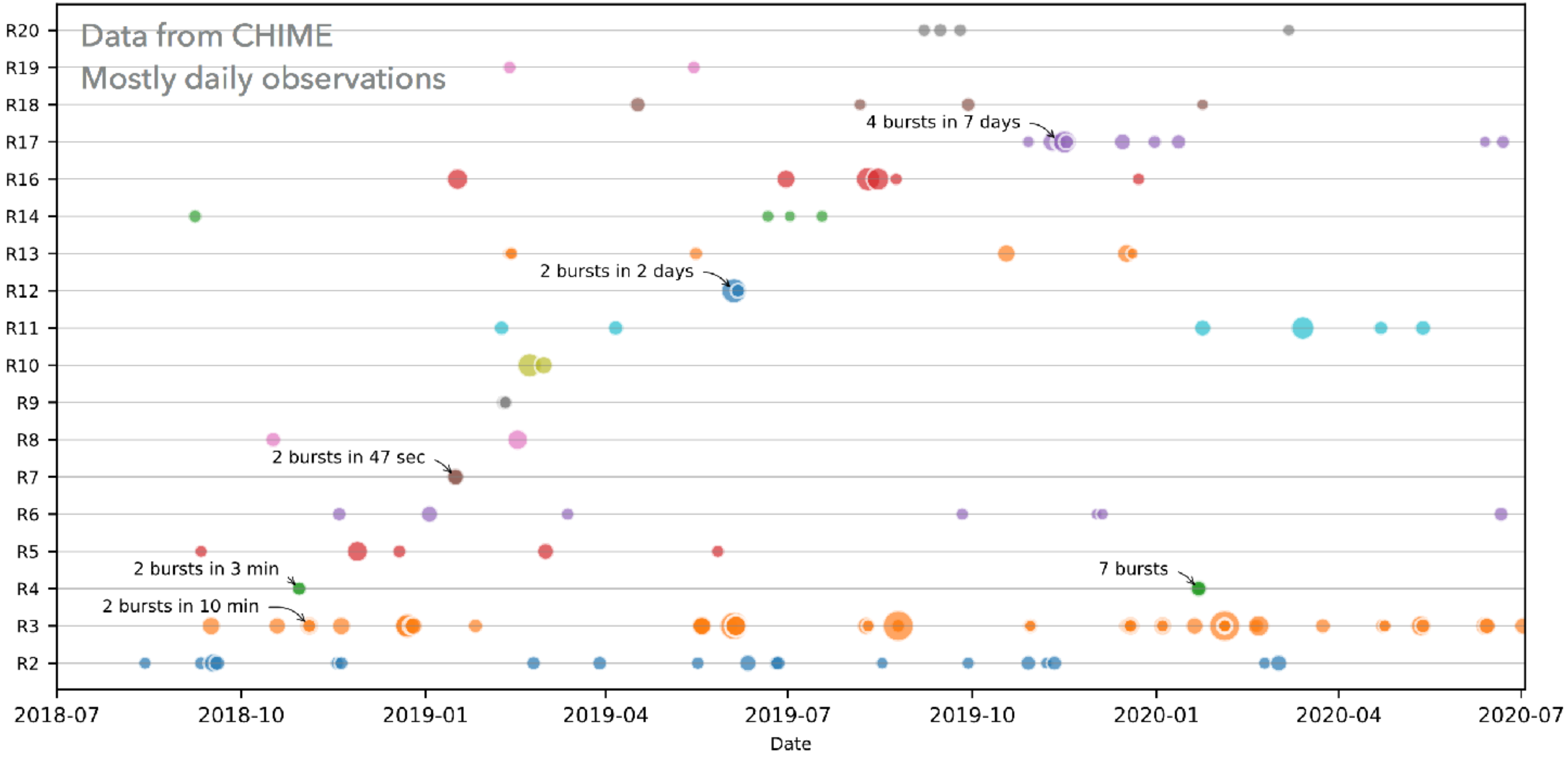
Repetition

Plot from Shriharsh Tendulkar



- Clustering in time, energy distribution

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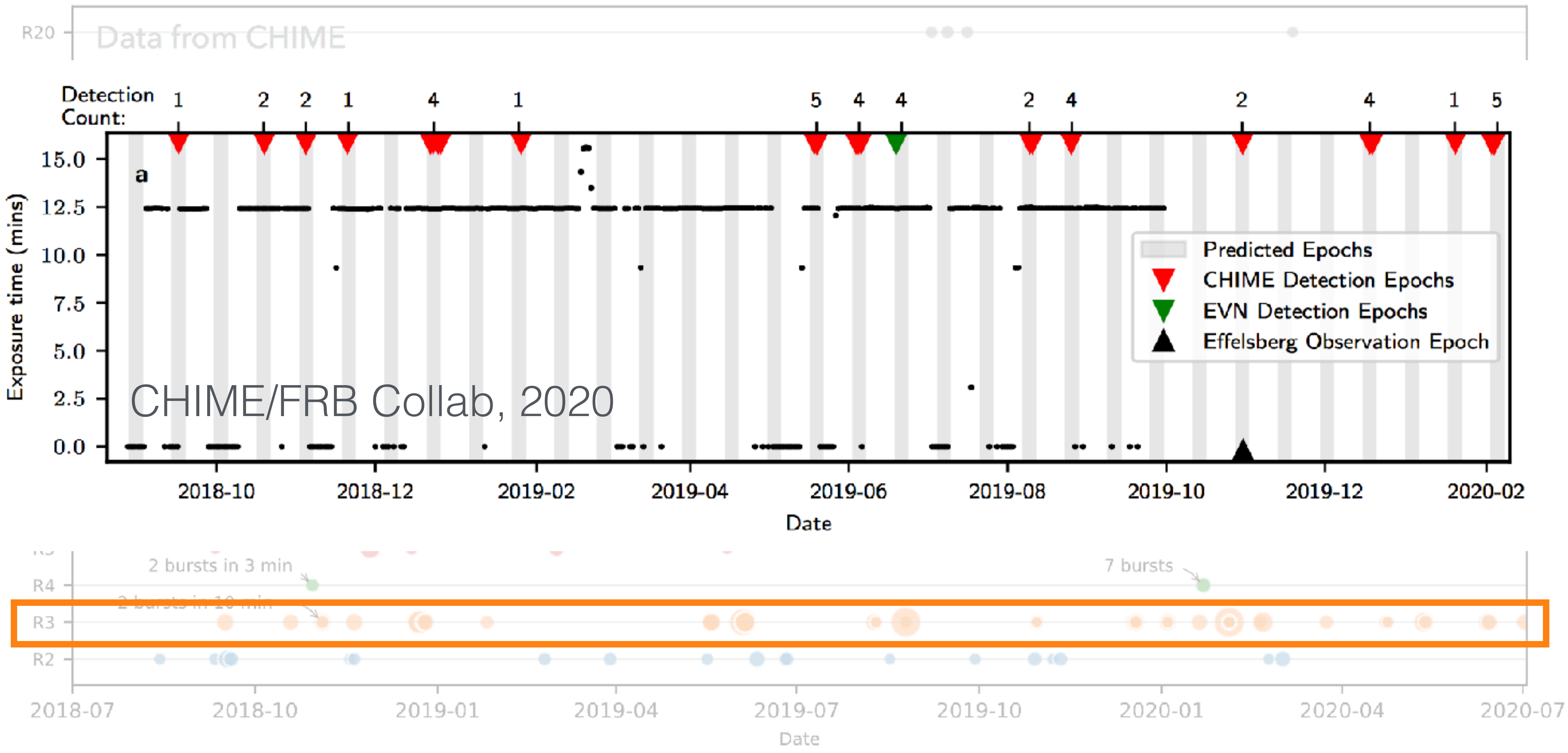
Repetition



- Clustering in time, energy distribution
- Two sources have periodic activity cycles, with 16 days (CHIME/FRB Collab, 2020) and ~160 days (Rajwade+2020, Cruces+2020), respectively.

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Final words…

- Database: TNS (www.wis-tns.org) and FRBSTATS (www.herta-experiment.org)
- High time resolution (us not ms) data is preferred, baseband data is the best (localization, polarization, microstructure)
- Wide instantaneous frequency coverage to study drift rate and frequency range
- Beware of instrumental effects and selection bias

Thank you!

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