

# The first CHIME/FRB catalog: Fast Radio Burst morphologies and differentiating repeaters

Ziggy Pleunis for the CHIME/FRB Collaboration

YITP Workshop

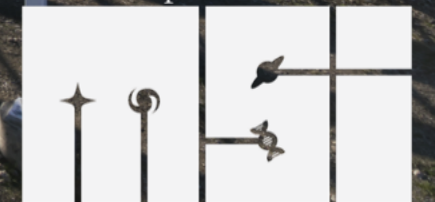
February 8, 2021



Department of Physics,  
McGill University

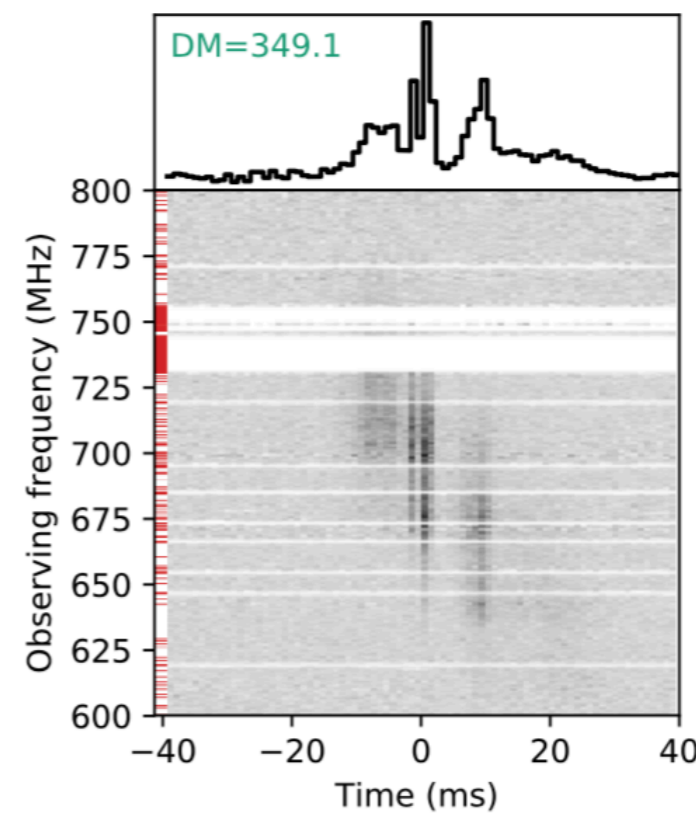
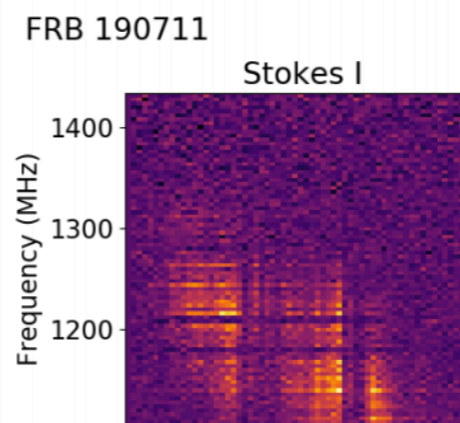
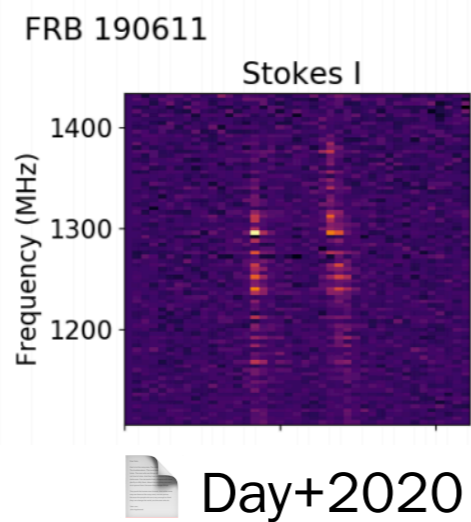
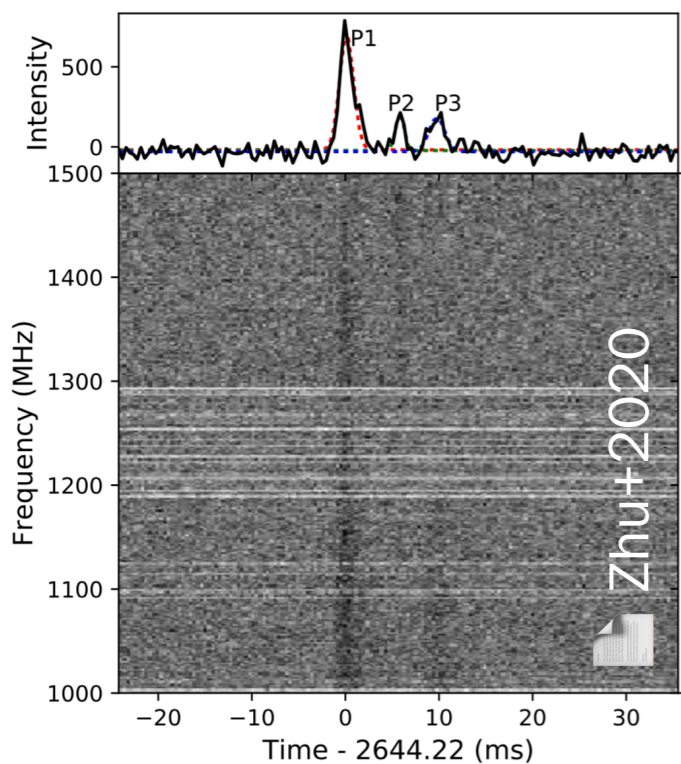
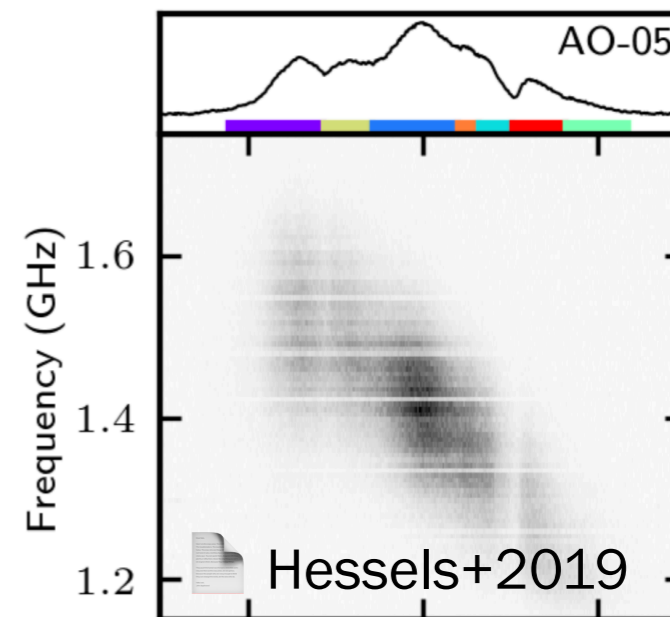
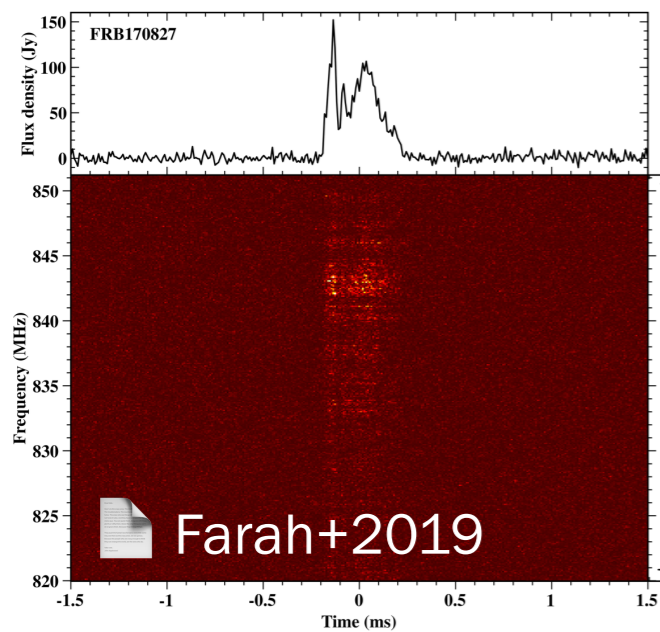
 Andre Renard

Institut Spatial de McGill



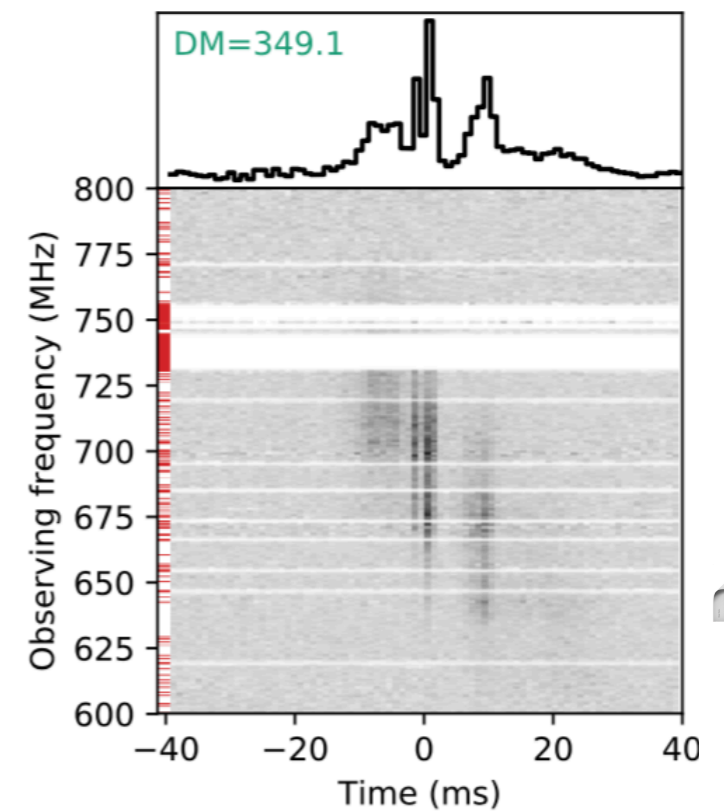
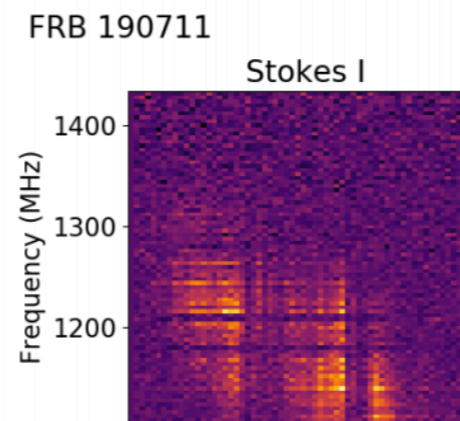
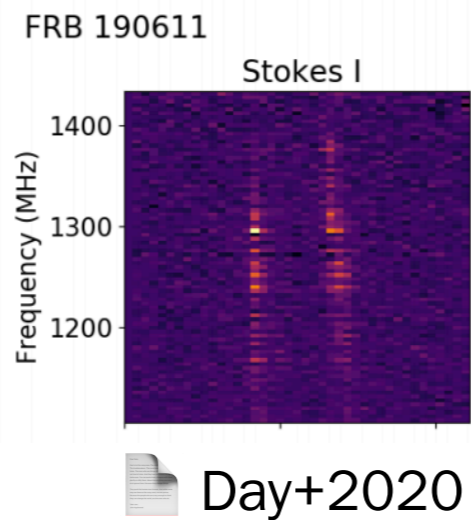
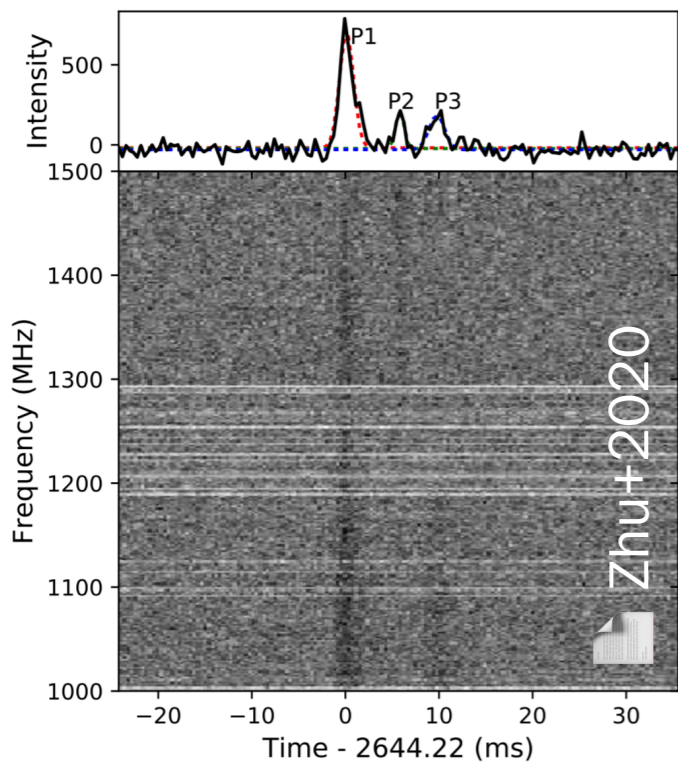
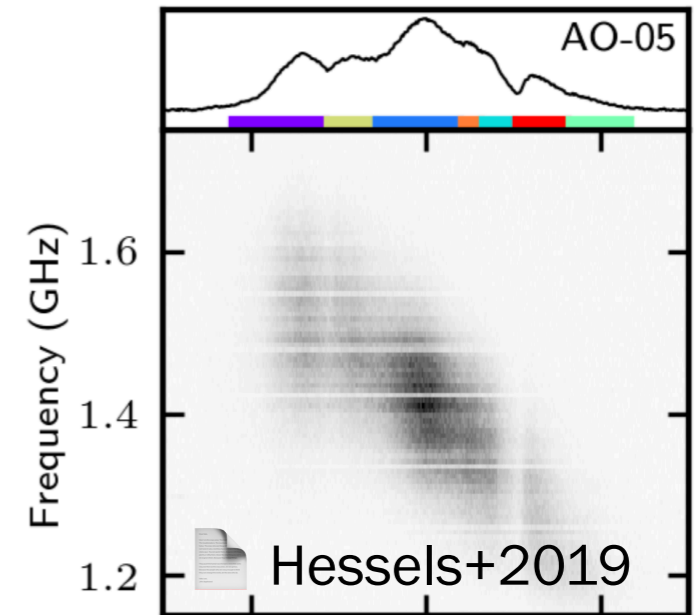
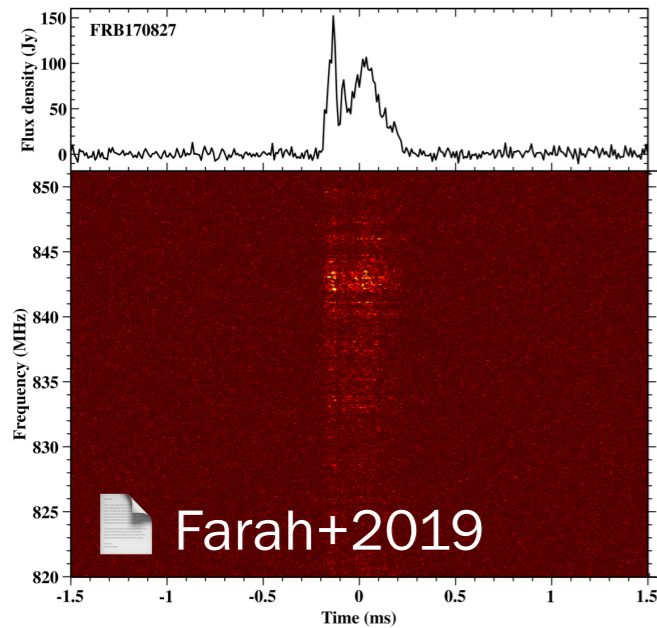
McGill Space Institute

# Fast radio burst (FRB) morphology



# Fast radio burst (FRB) morphology

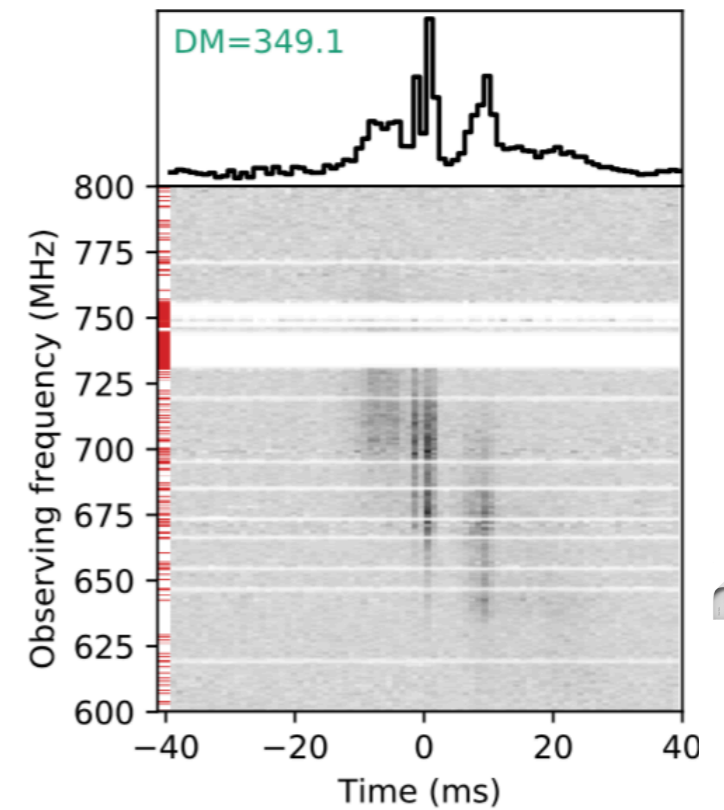
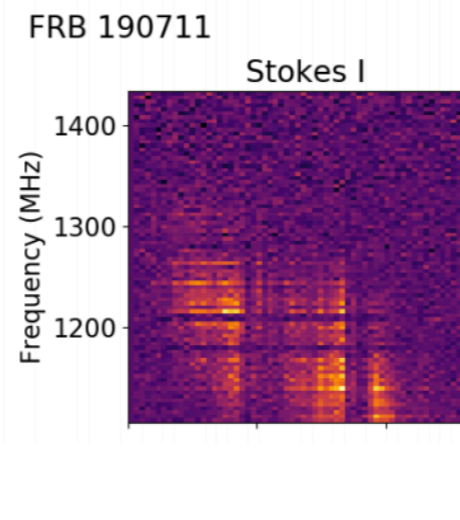
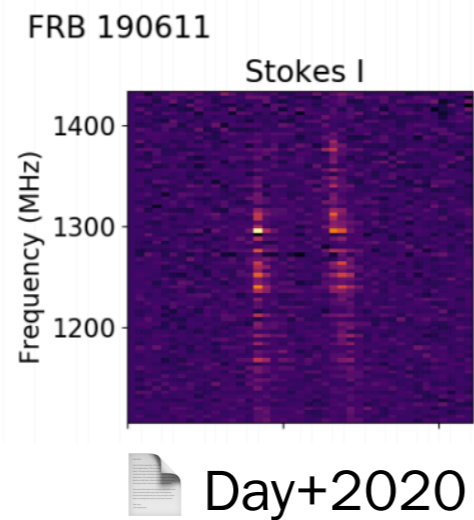
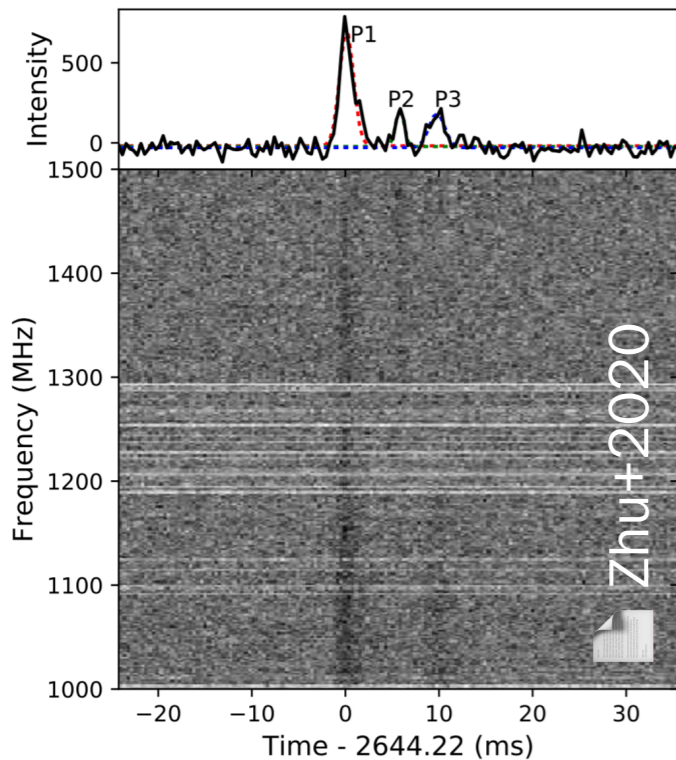
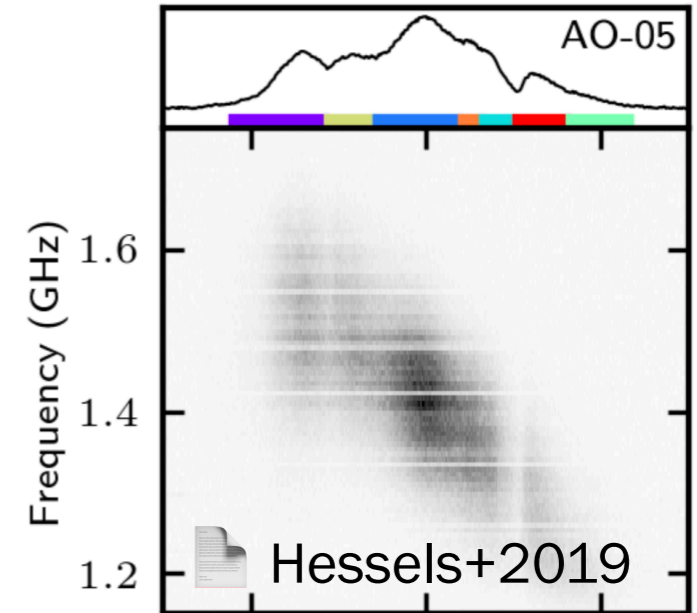
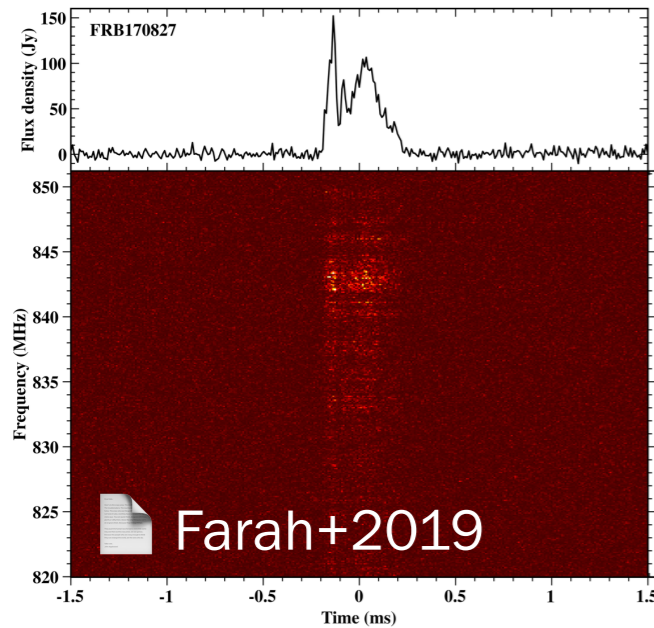
Shaped by an unknown emission mechanism



# Fast radio burst (FRB) morphology

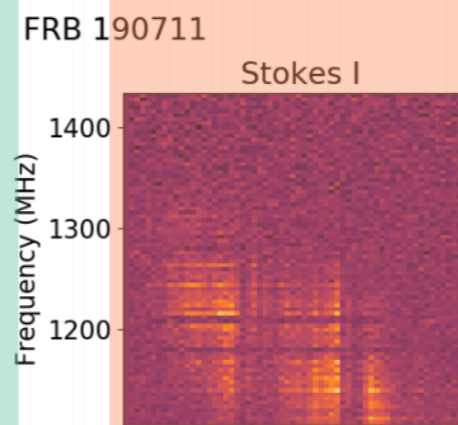
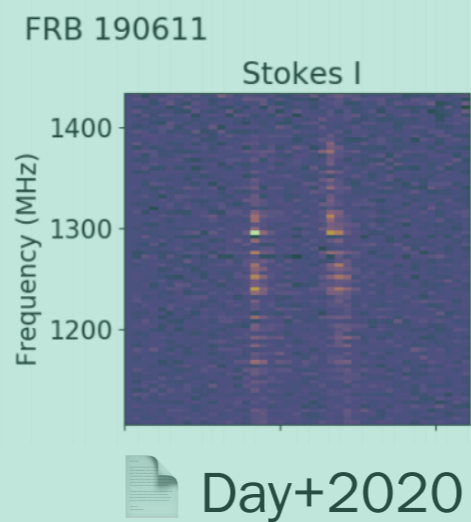
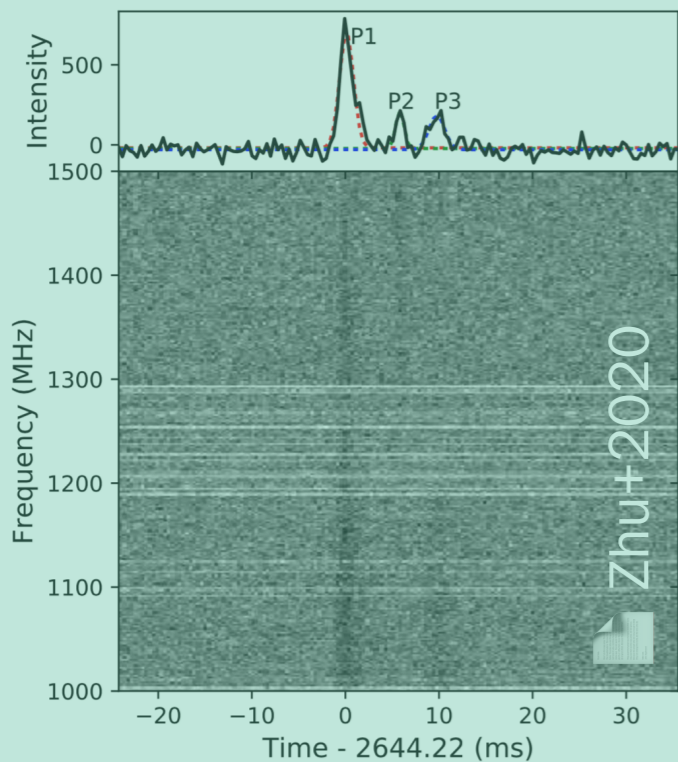
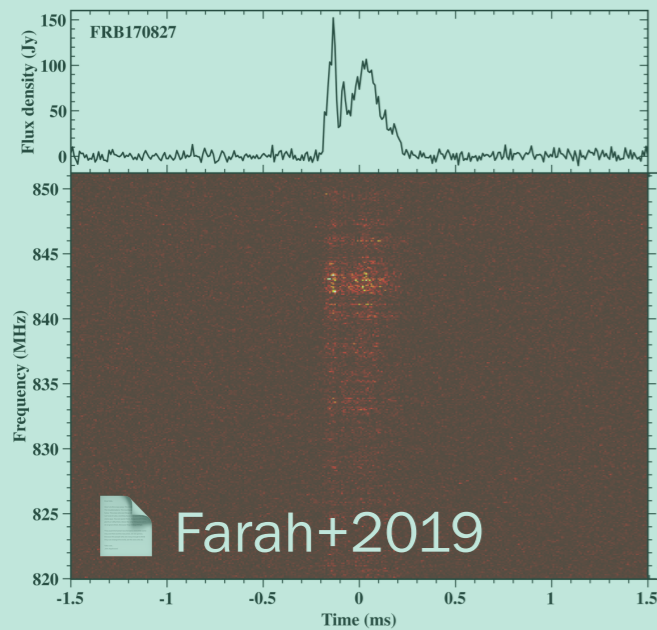
Shaped by an unknown emission mechanism

Transformed by propagation through an ionized and inhomogeneous medium

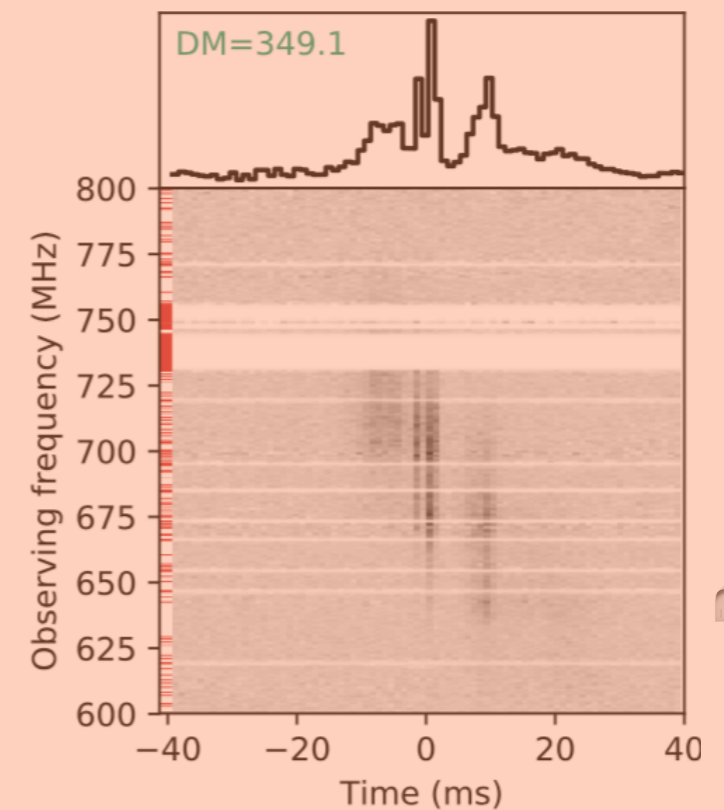
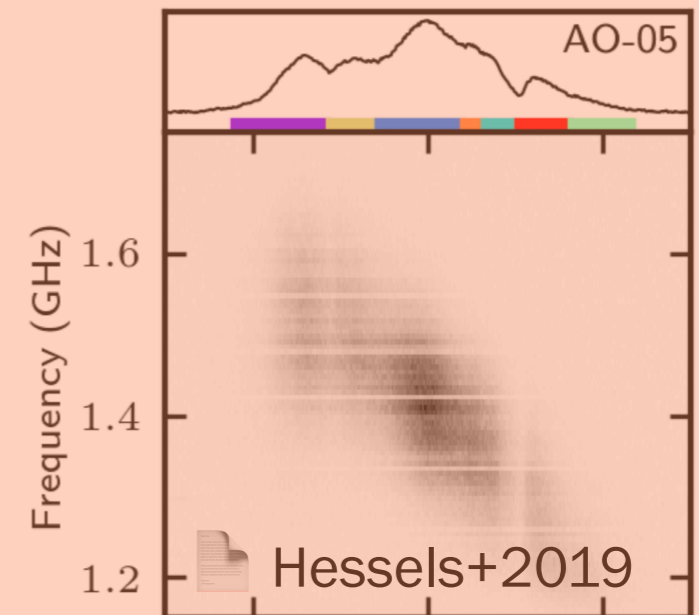


# Fast radio burst (FRB) morphology

## One-off events

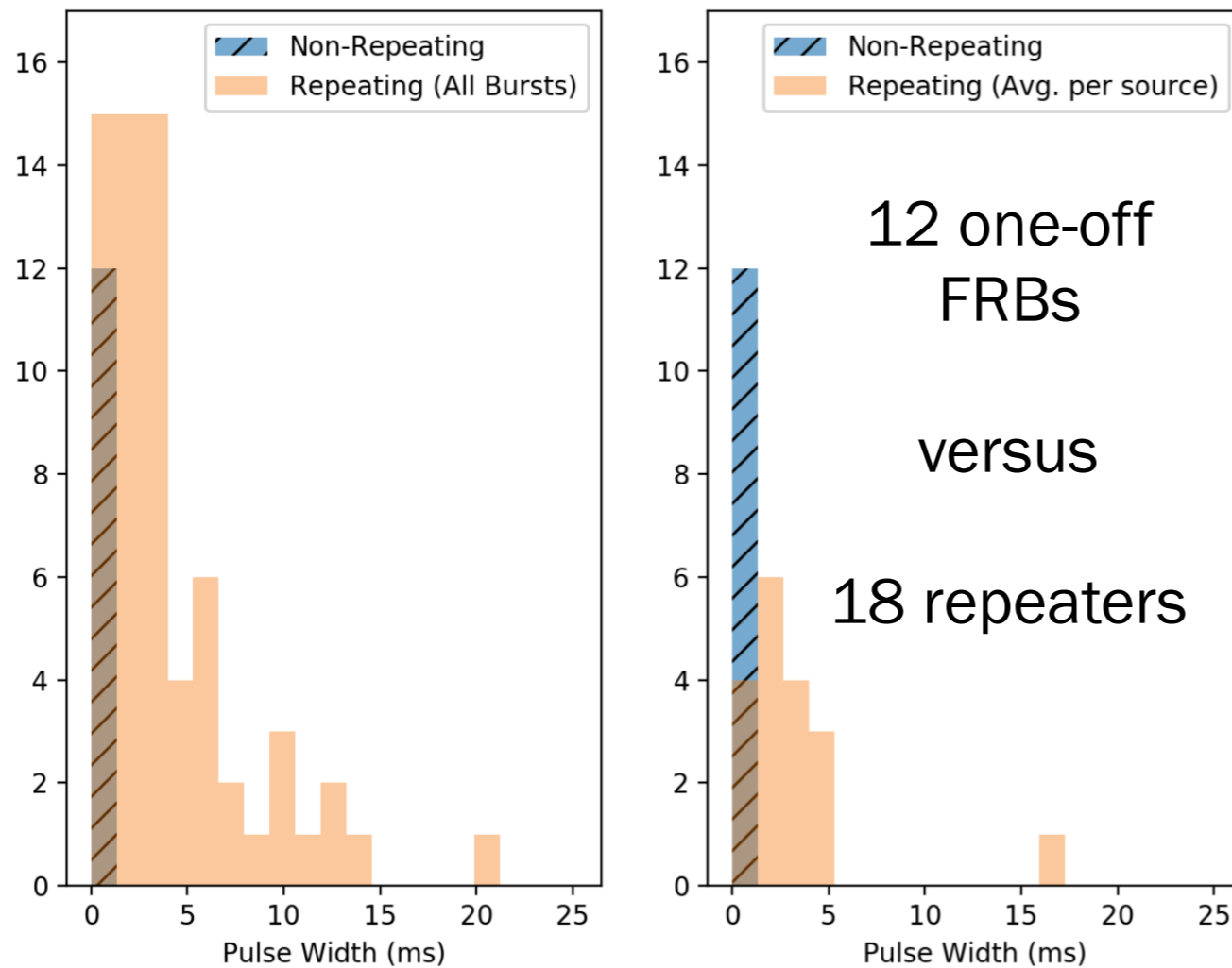


## Repeater bursts



# One-off FRBs versus repeater bursts

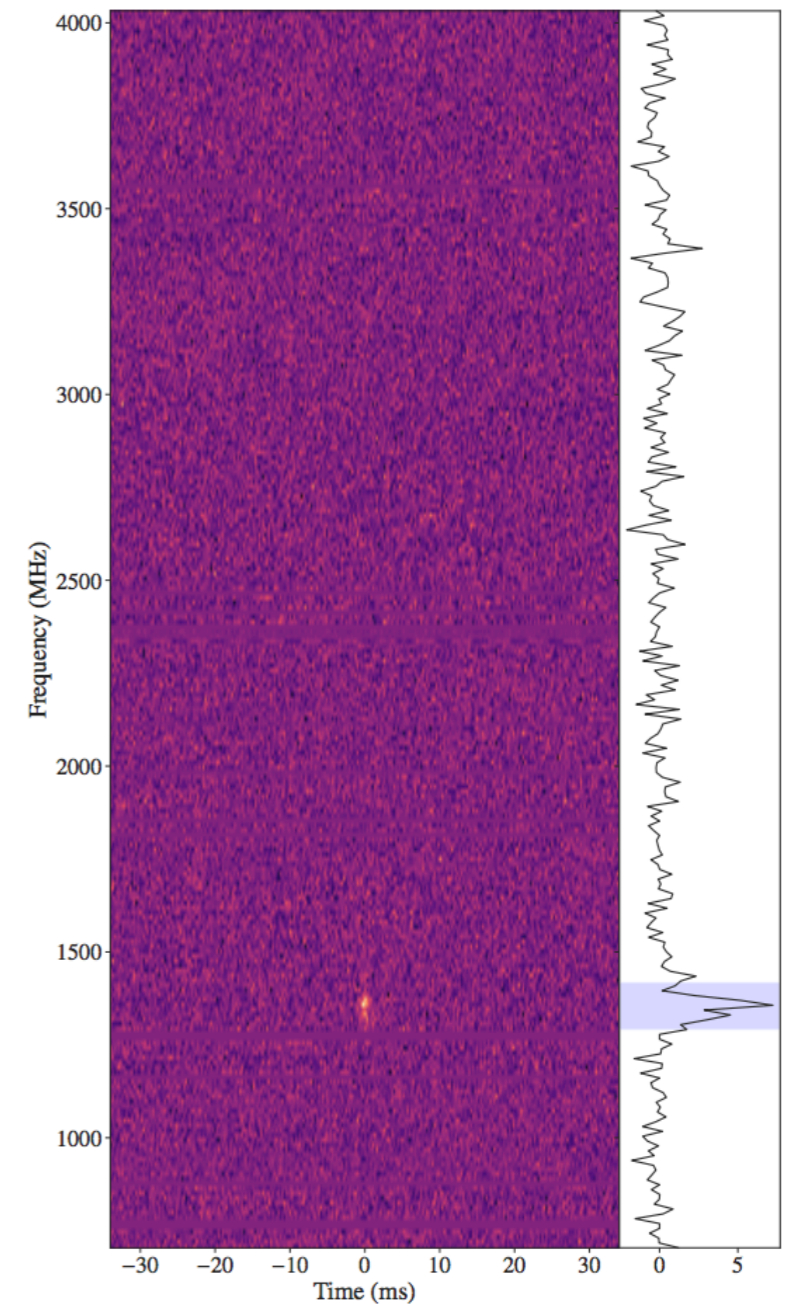
## Repeater bursts are wider



 CHIME/FRB Collaboration+2019

 Fonseca+2020

## Repeater bursts can have narrow bandwidths



 Kumar+2020

# Canadian Hydrogen Intensity Mapping Experiment (CHIME)



 CHIME collaboration

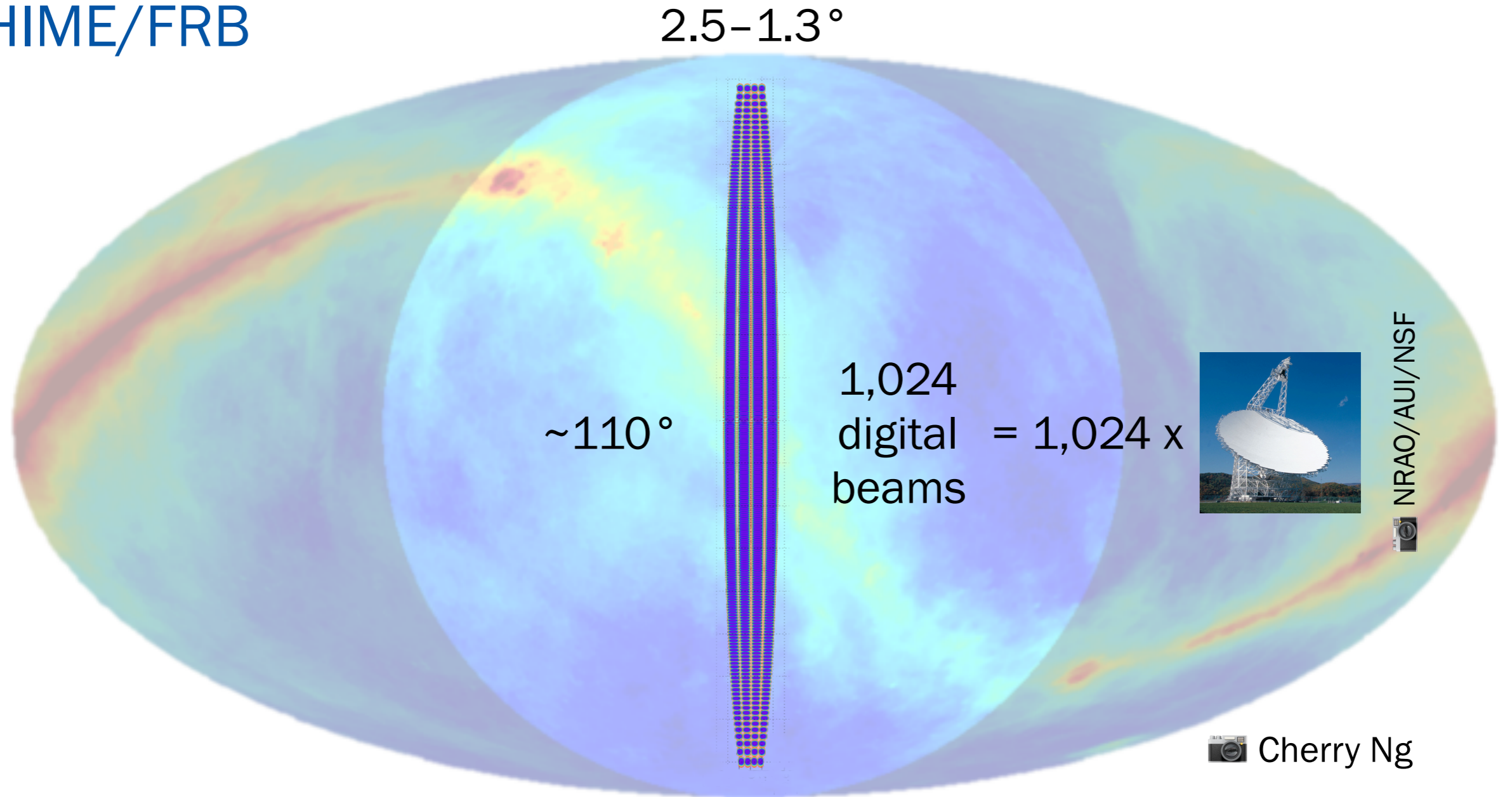
# Canadian Hydrogen Intensity Mapping Experiment (CHIME)




400 to 800 MHz  $\Leftrightarrow$   $z = 2.5$  to  $0.8$  for 21 cm



# CHIME/FRB



 CHIME/FRB collaboration+ 2018




# First catalog of CHIME fast radio bursts



 CHIME/FRB Collaboration, submitted

474 one-off FRBs, 61 repeater bursts

- ▶ 2018 July 25 to 2019 July 2
- ▶ exposure and sensitivity
- ▶ Transient Name Server  FRB names
- ▶ localizations based on beam detection S/N ratios;  $\sim 15'$  (68%)
- ▶ burst model fits on max-S/N beam intensity data (1 ms, 24 kHz): DM, width, scattering, spectra
- ▶ rate estimate
- ▶  $\log N/\log S$

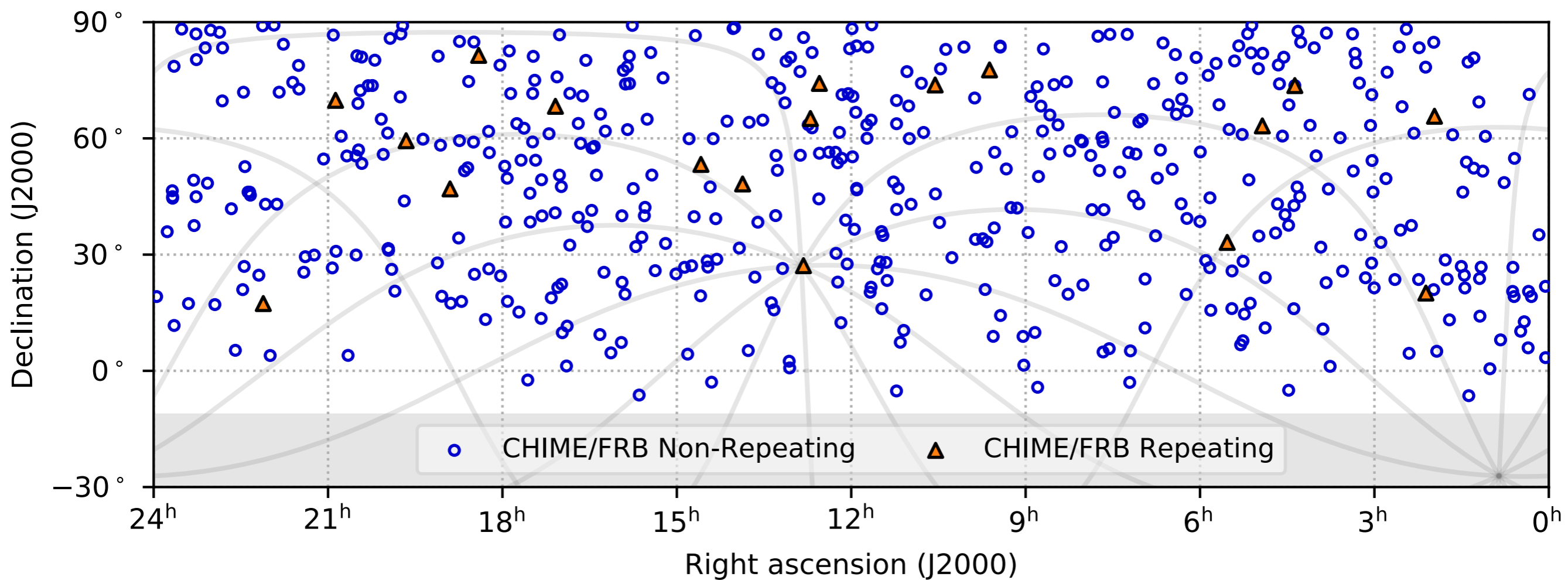
Accompanying analyses in prep.:

- ▶ large-scale structure cross-correlation
- ▶ Galactic latitude (in)dependence
- ▶ repetition statistics
- ▶ DM—scattering relation (Pragya Chawla's talk)
- ▶ burst morphology (Pleunis+ in prep.; this talk)

# First catalog of CHIME fast radio bursts

PRELIMINARY

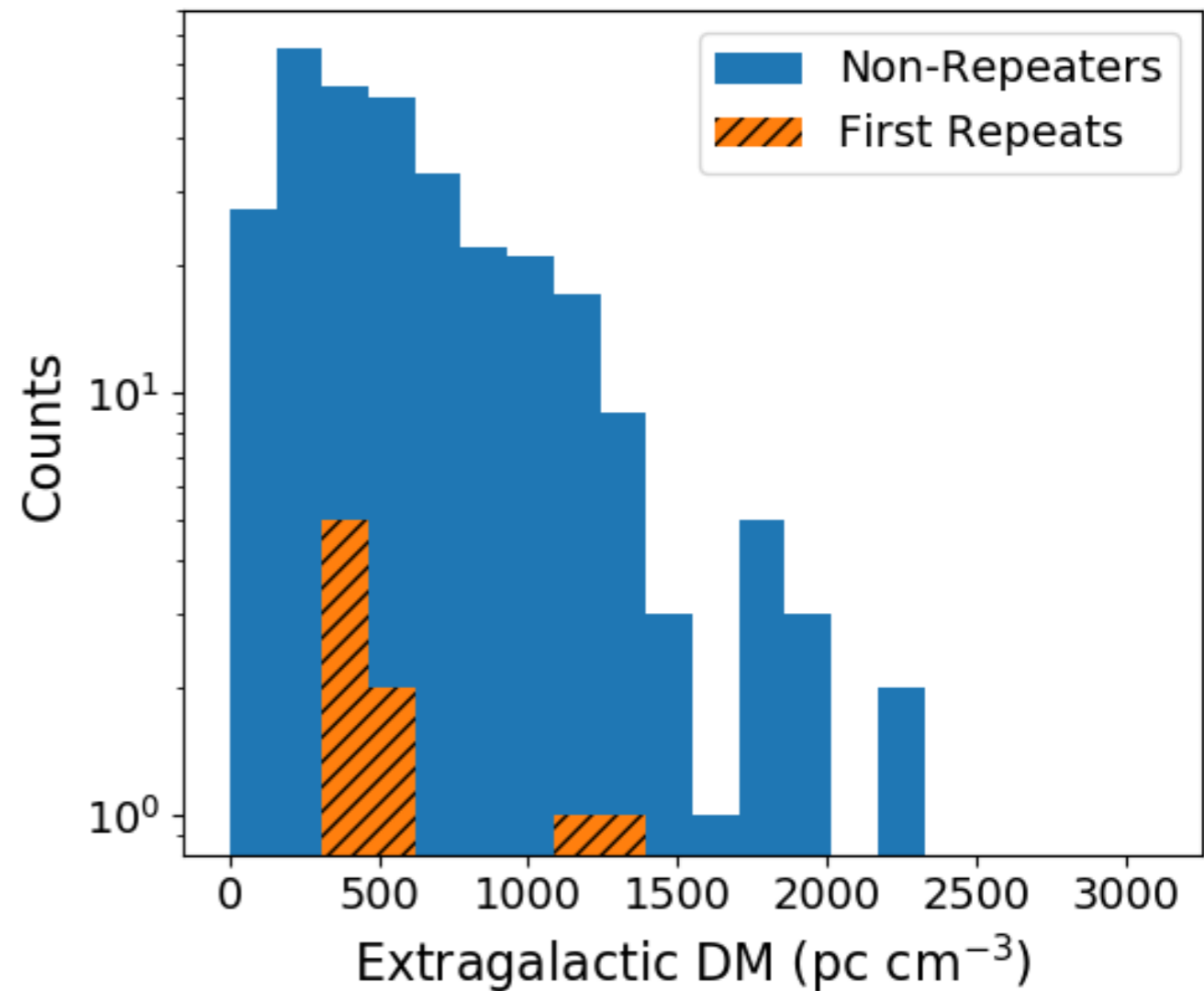
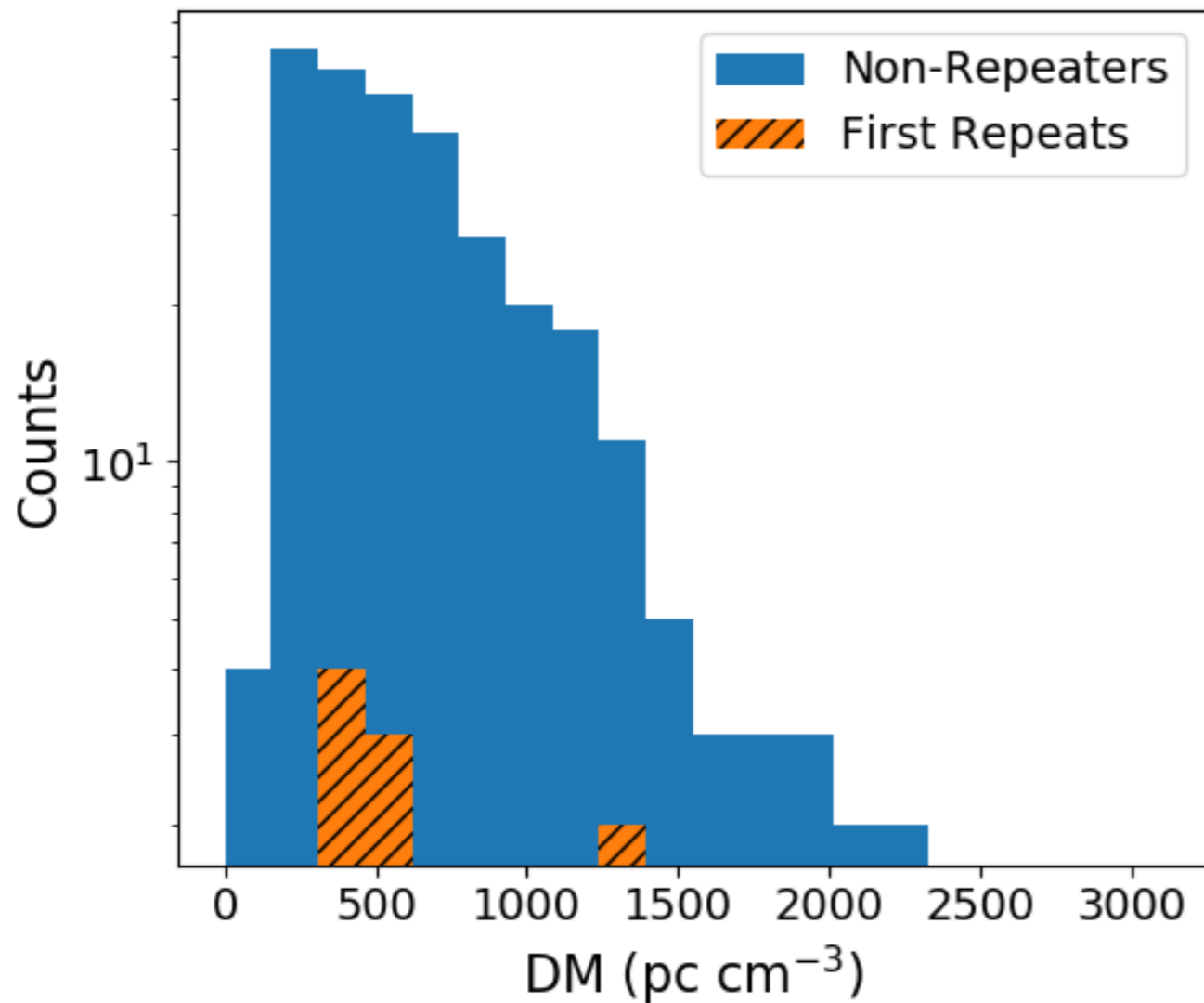
CHIME/FRB Collaboration, submitted



# Repeaters versus apparent non-repeaters

PRELIMINARY

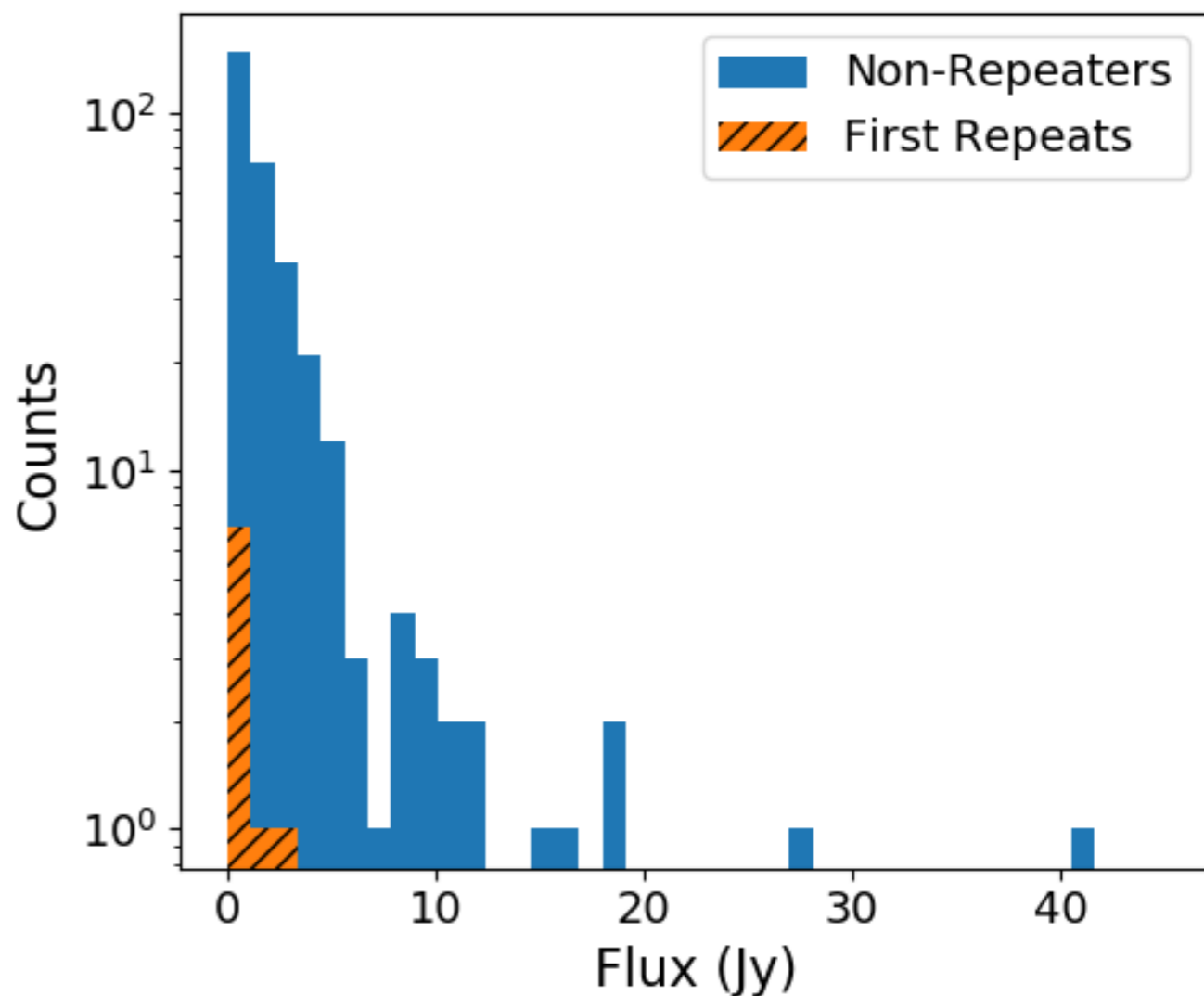
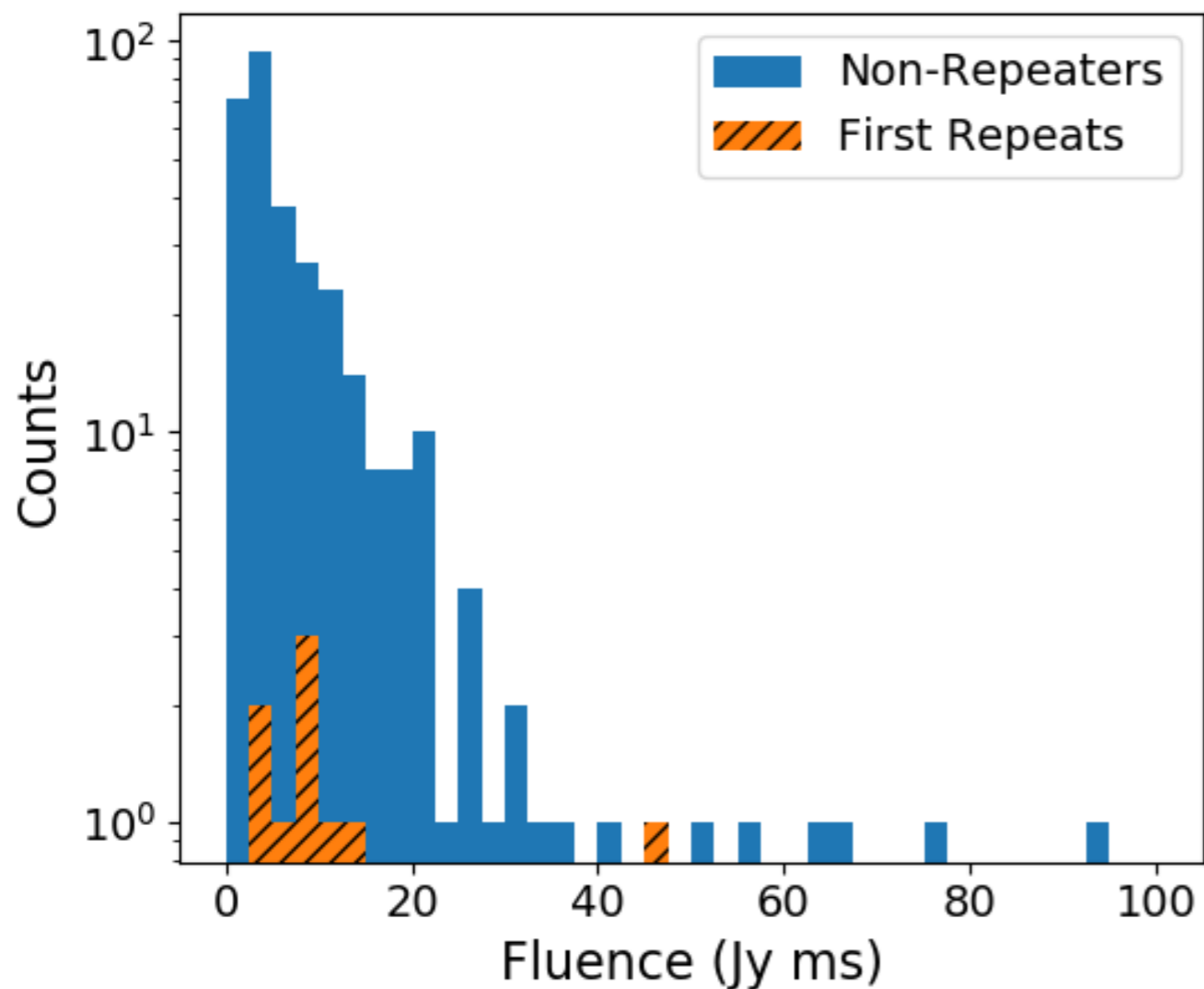
CHIME/FRB Collaboration, submitted



# Repeaters versus apparent non-repeaters

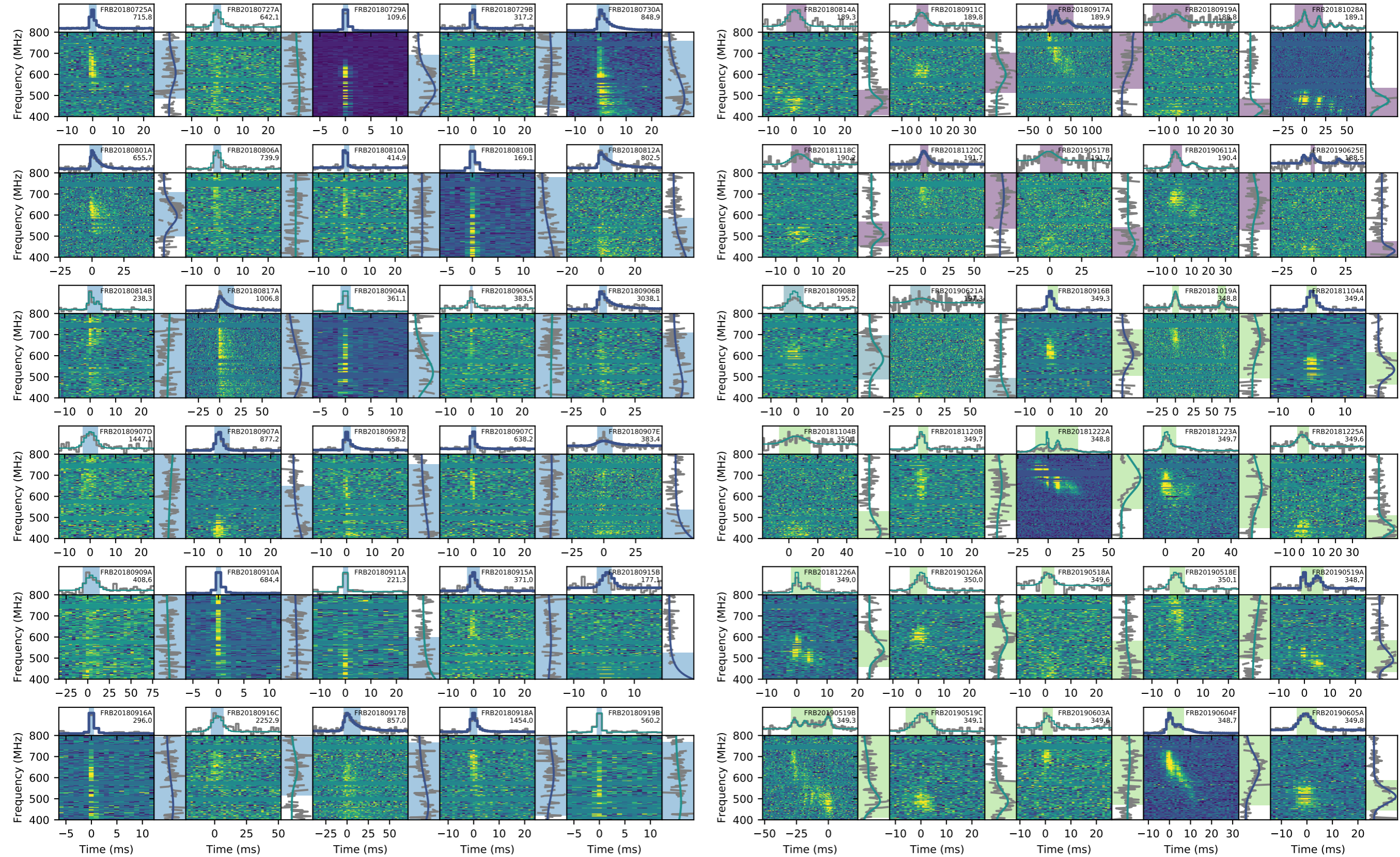
PRELIMINARY

CHIME/FRB Collaboration, submitted



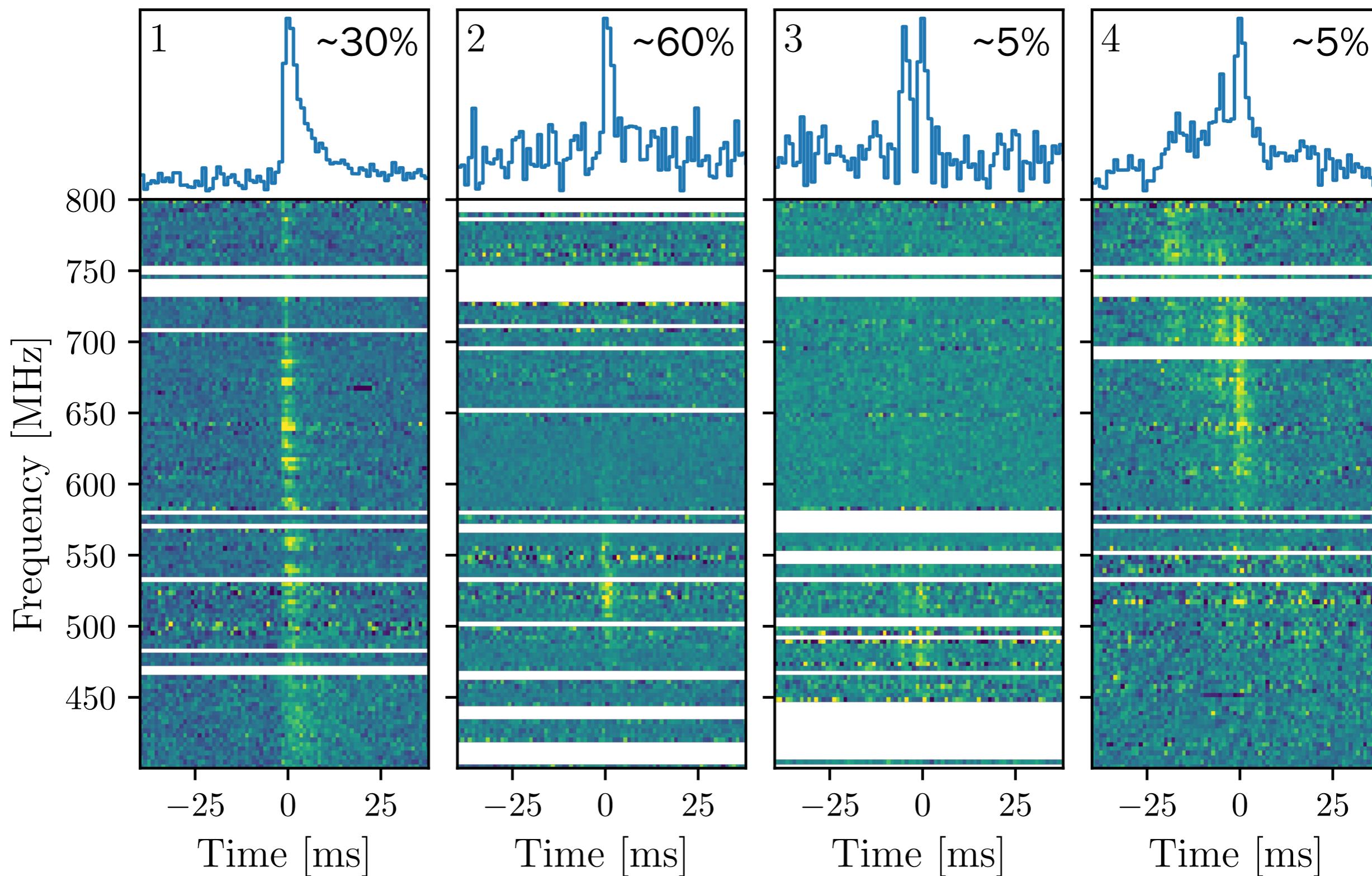
# Burst morphologies

CHIME/FRB Collaboration, submitted



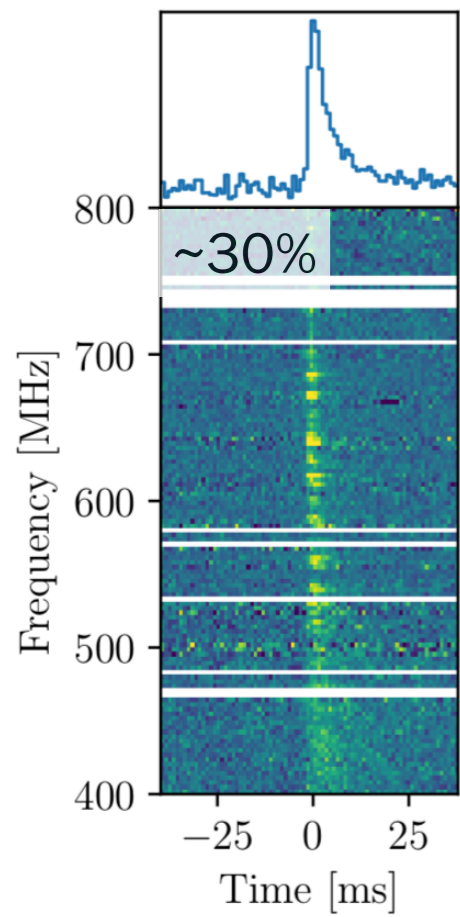
# Observed fast radio burst archetypes

Stokes I  
 $t_s \sim 1$  ms

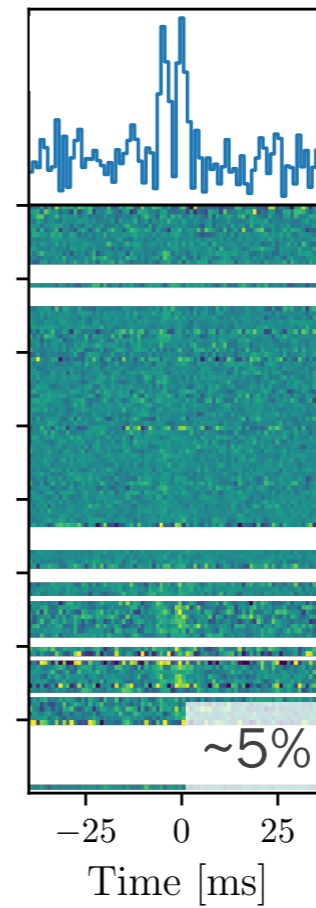


# Observed fast radio burst archetypes

Stokes I  
 $t_s \sim 1$  ms

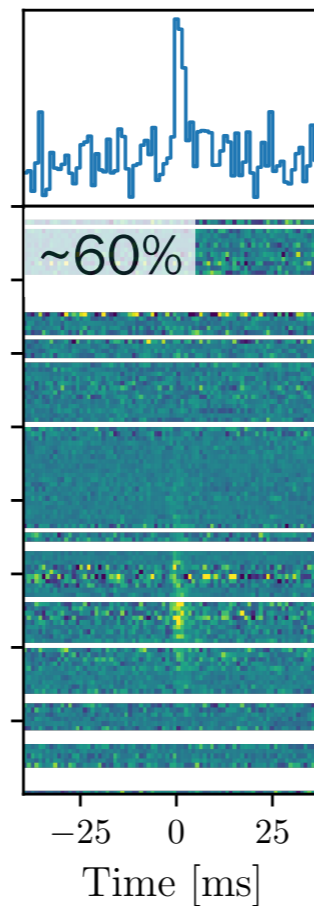


Broadband  
one peak

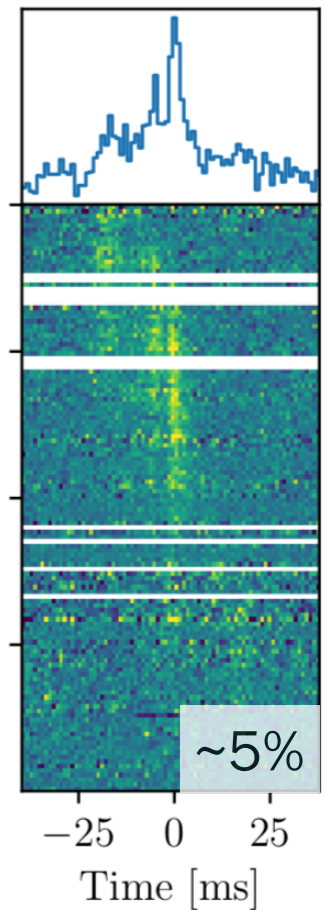


Multiple  
peaks

Narrowband  
one peak



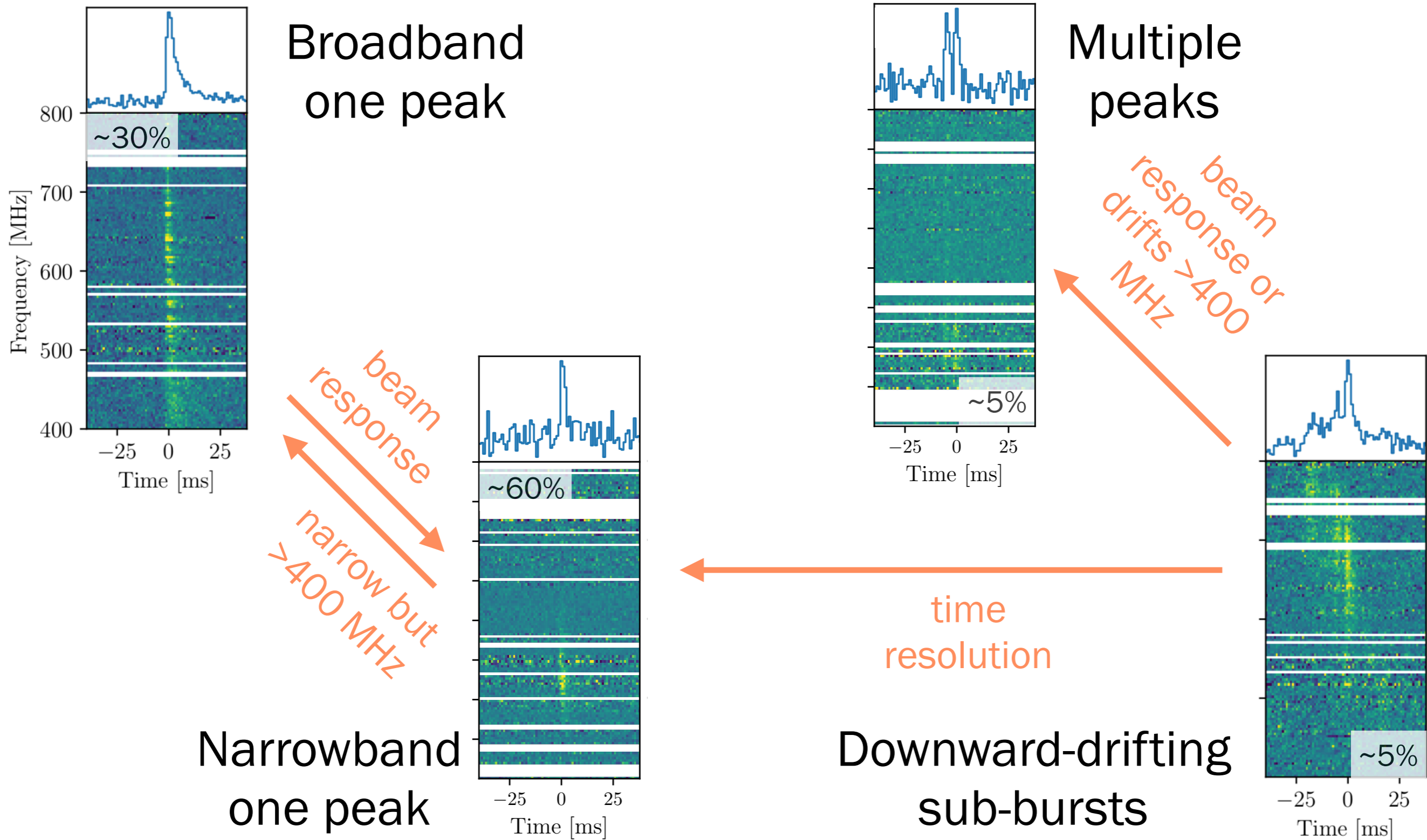
Downward-drifting  
sub-bursts





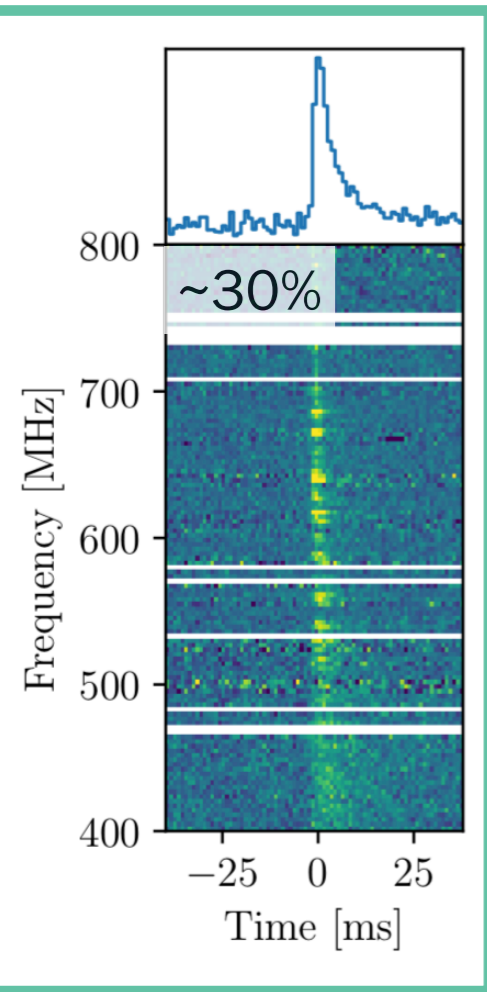
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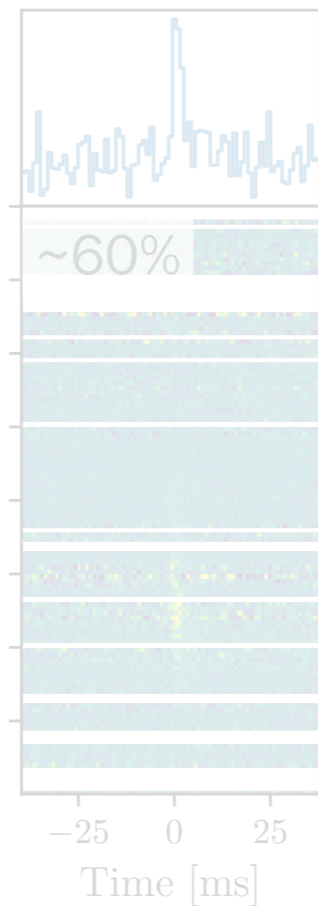


Broadband  
 one peak

Associated with  
 non-repeaters

beam  
 response  
 narrow but  
 $>400$  MHz

Narrowband  
 one peak

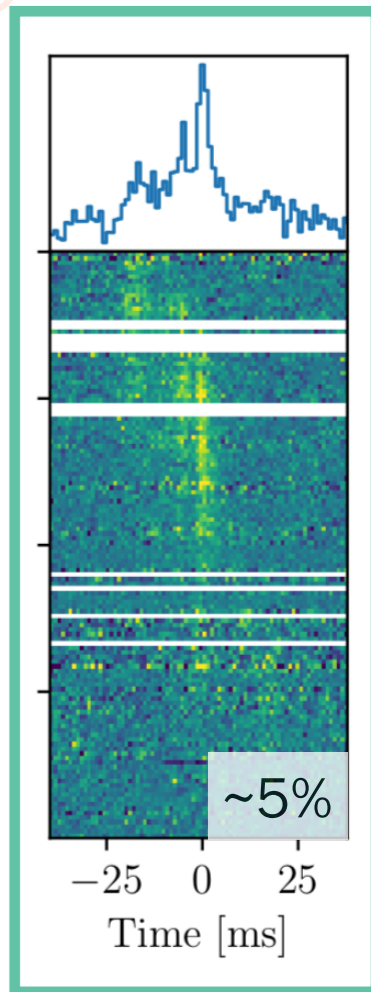


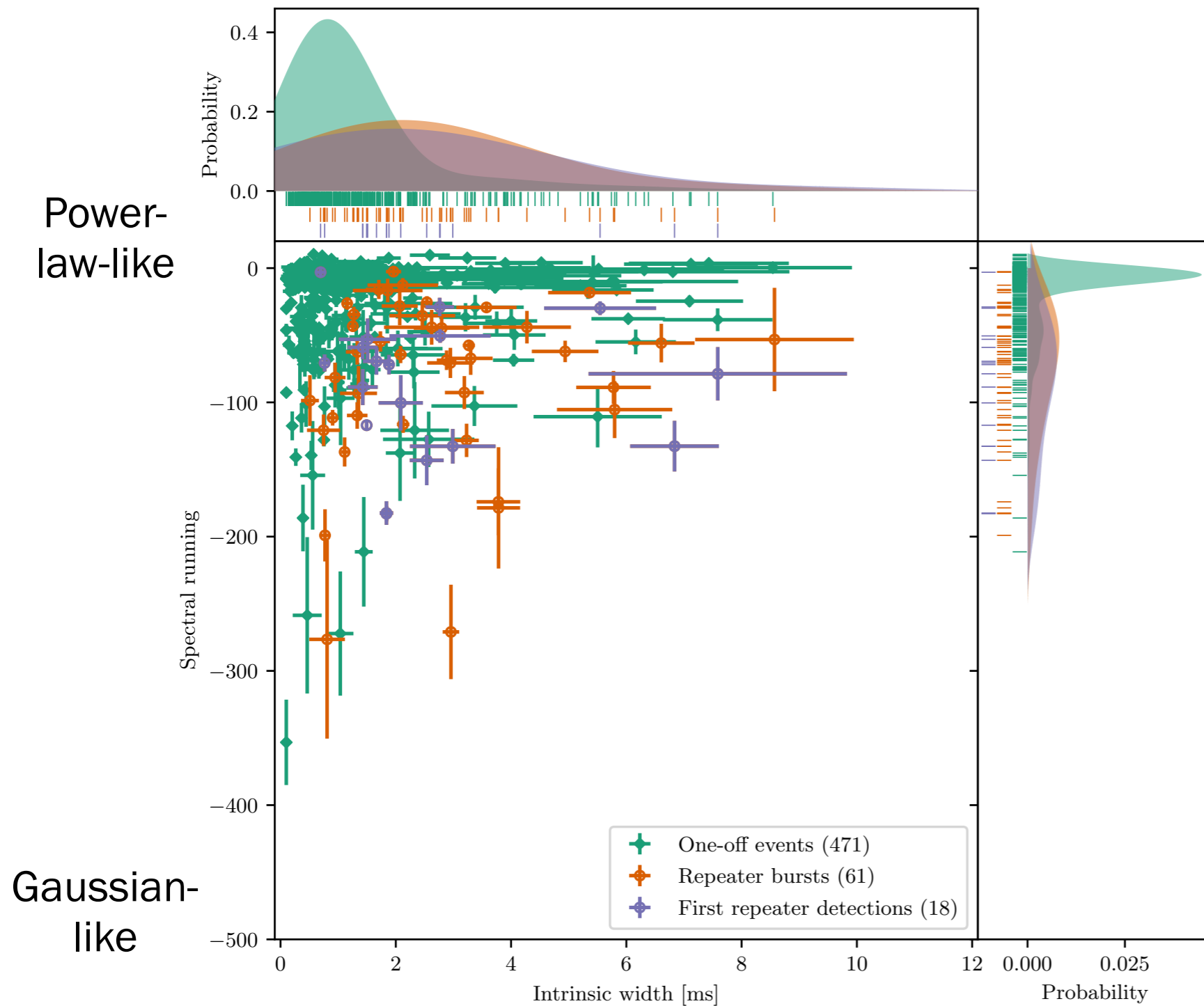
Multiple  
 peaks

beam  
 response or  
 drifts  
 $>400$  MHz

time  
 resolution  
 Associated with  
 repeaters

Downward-drifting  
 sub-bursts



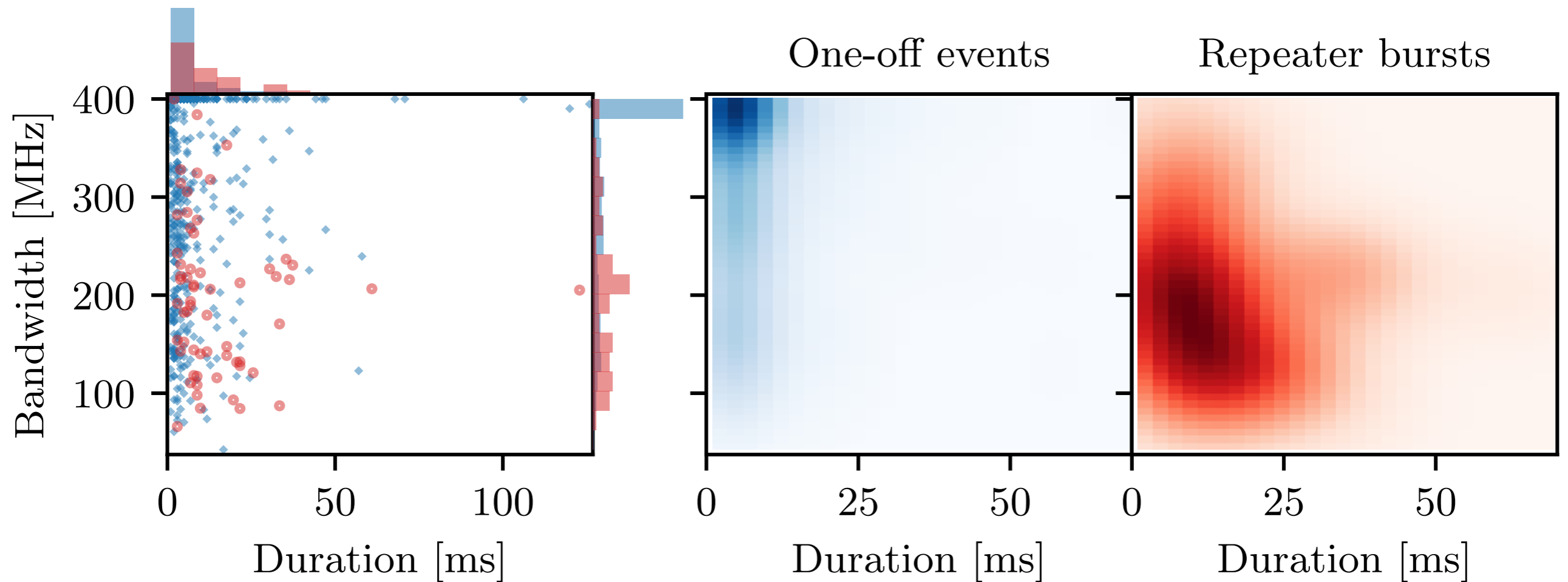


Comparing 474 one-off FRBs with 61 repeater bursts from 18 different sources

Repeaters, on average, have longer durations and narrower bandwidths than one-off events

# One-off FRBs versus repeater bursts

PRELIMINARY



Potential for predictive classifier!

# What causes the observed width and bandwidth differences?

Maybe intrinsic?

Repeater bursts made up of sub-bursts?  
Different burst mechanism?

Maybe propagation effect?

Related to periodic activity?  
Plasma lensing?

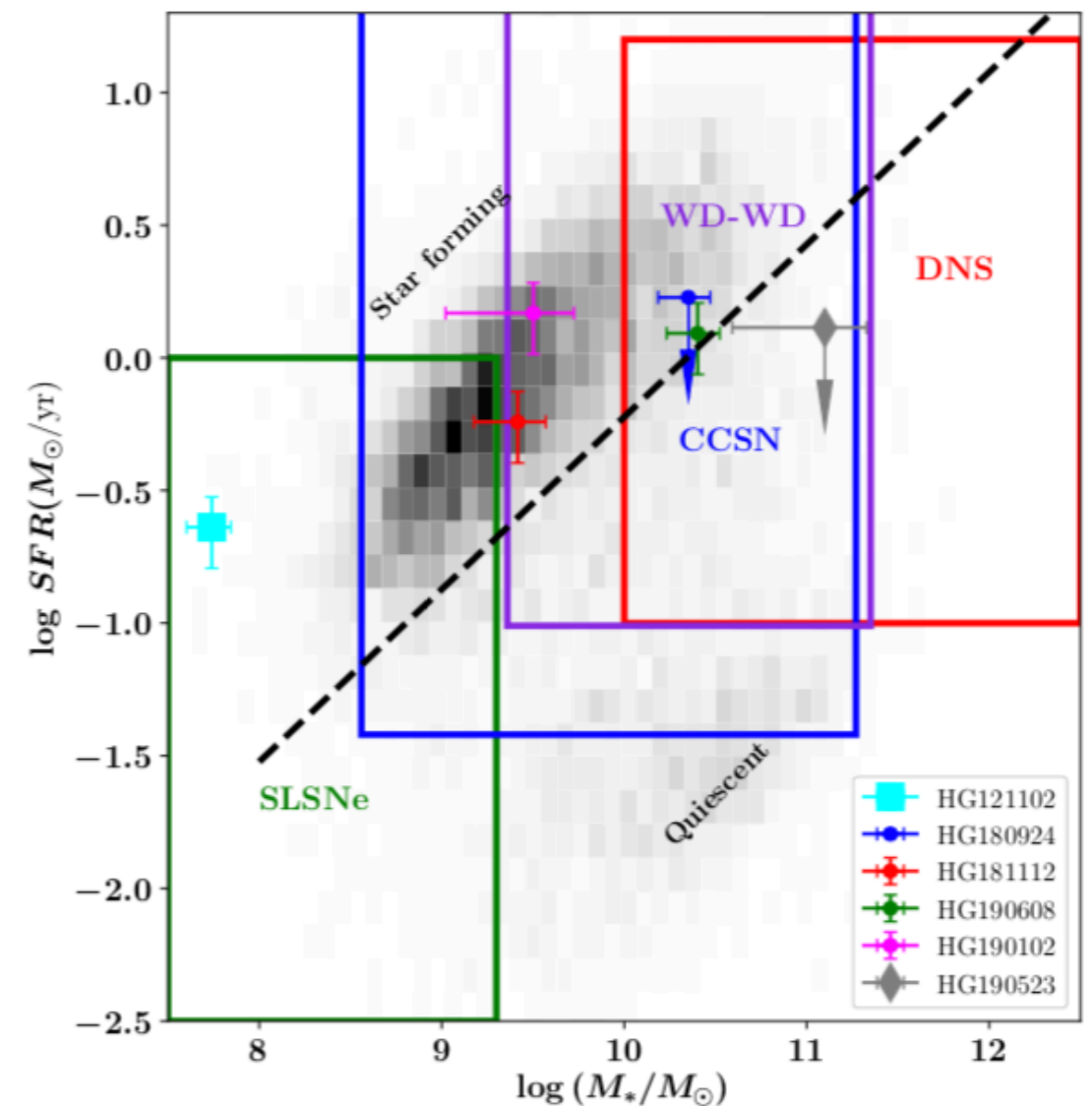
Beaming geometry?  Connor+2020

Combine morphology with Faraday rotation, polarization and host association

e.g.

 Bhandari+2020

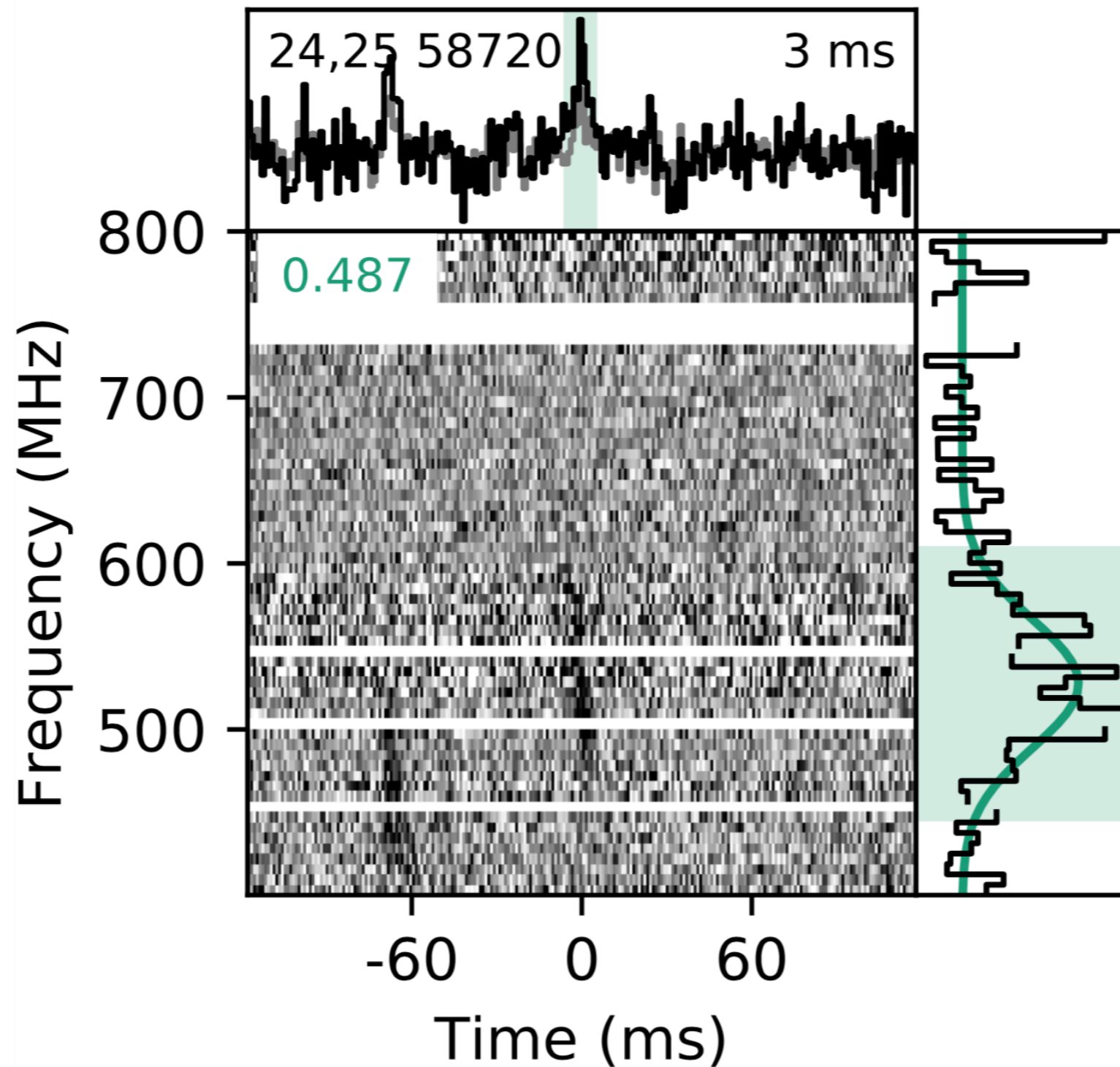
see also  Heintz+2020



# One burst envelope or two bursts?

Periodically active FRB 20180916B

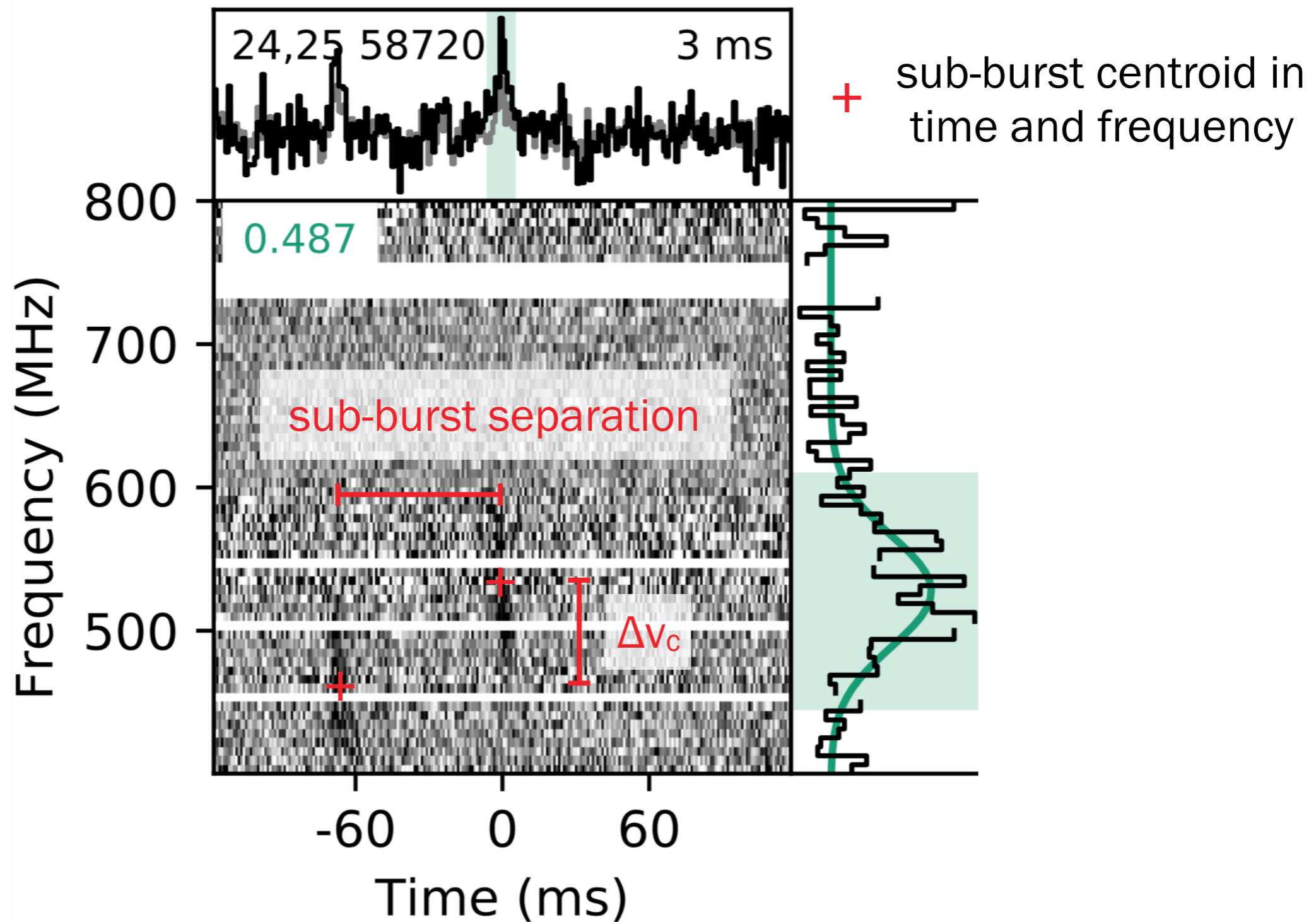
CHIME/FRB Collaboration+2020



# One burst envelope or two bursts?

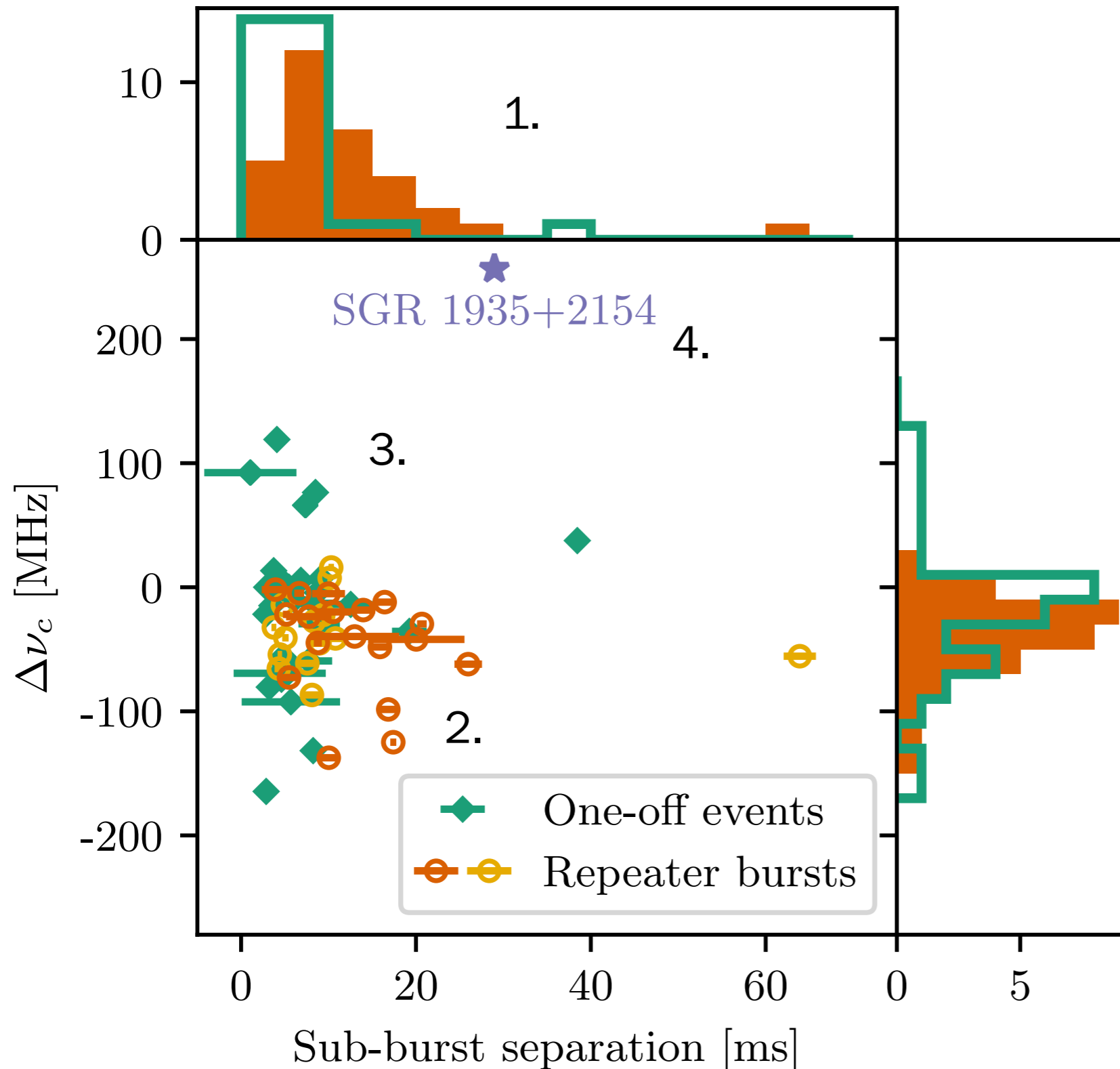
Periodically active FRB 20180916B

CHIME/FRB Collaboration+2020



# Sub-burst separations

PRELIMINARY

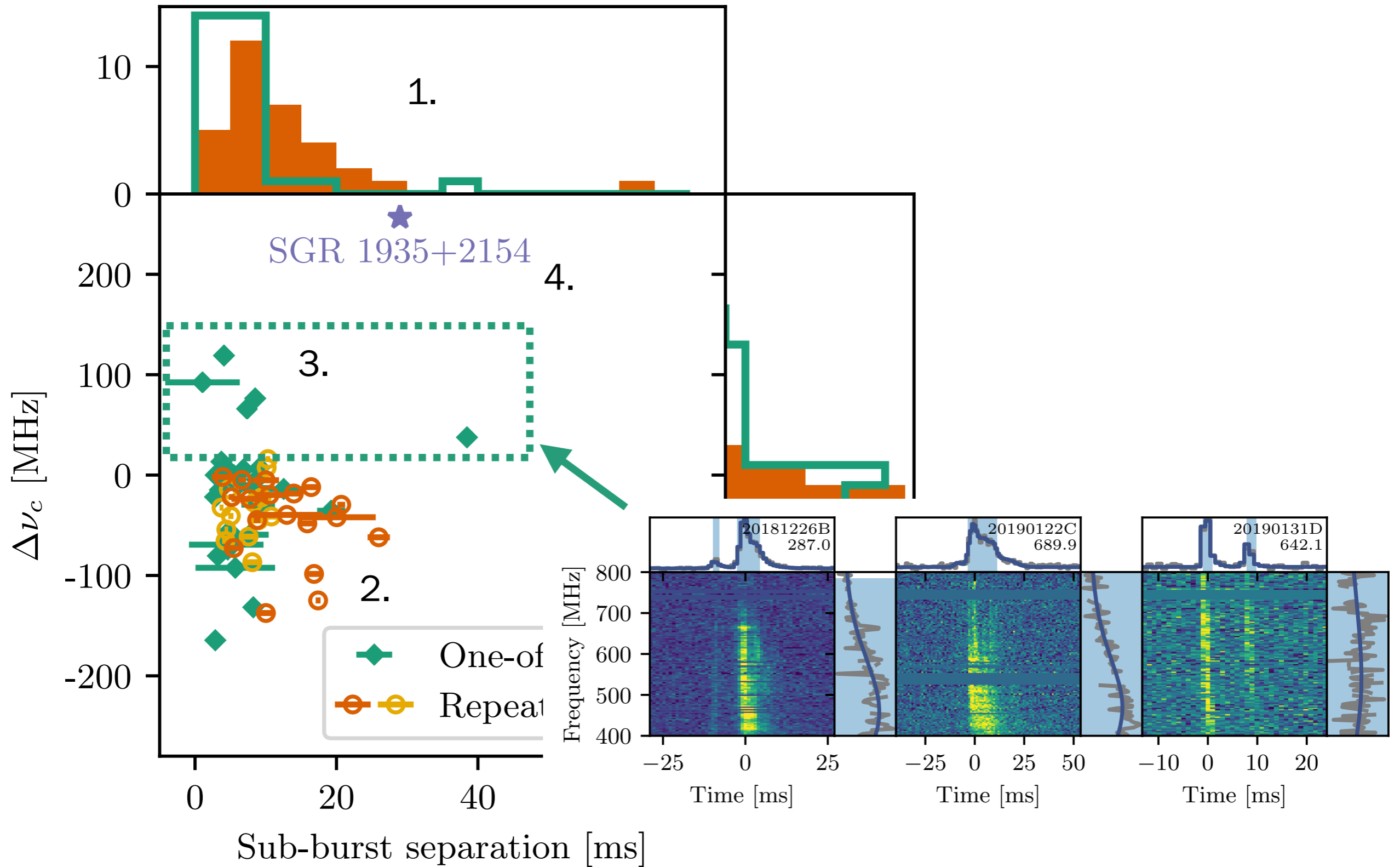


1. No bimodality in separations in time
2. One-off events overlapping with cluster of repeater bursts might be “repeaters in waiting”
3. Apparent upward drifters may be related to centre frequency uncertainty
4. Magnetar burst not like repeater bursts; but also exceptionally high S/N!



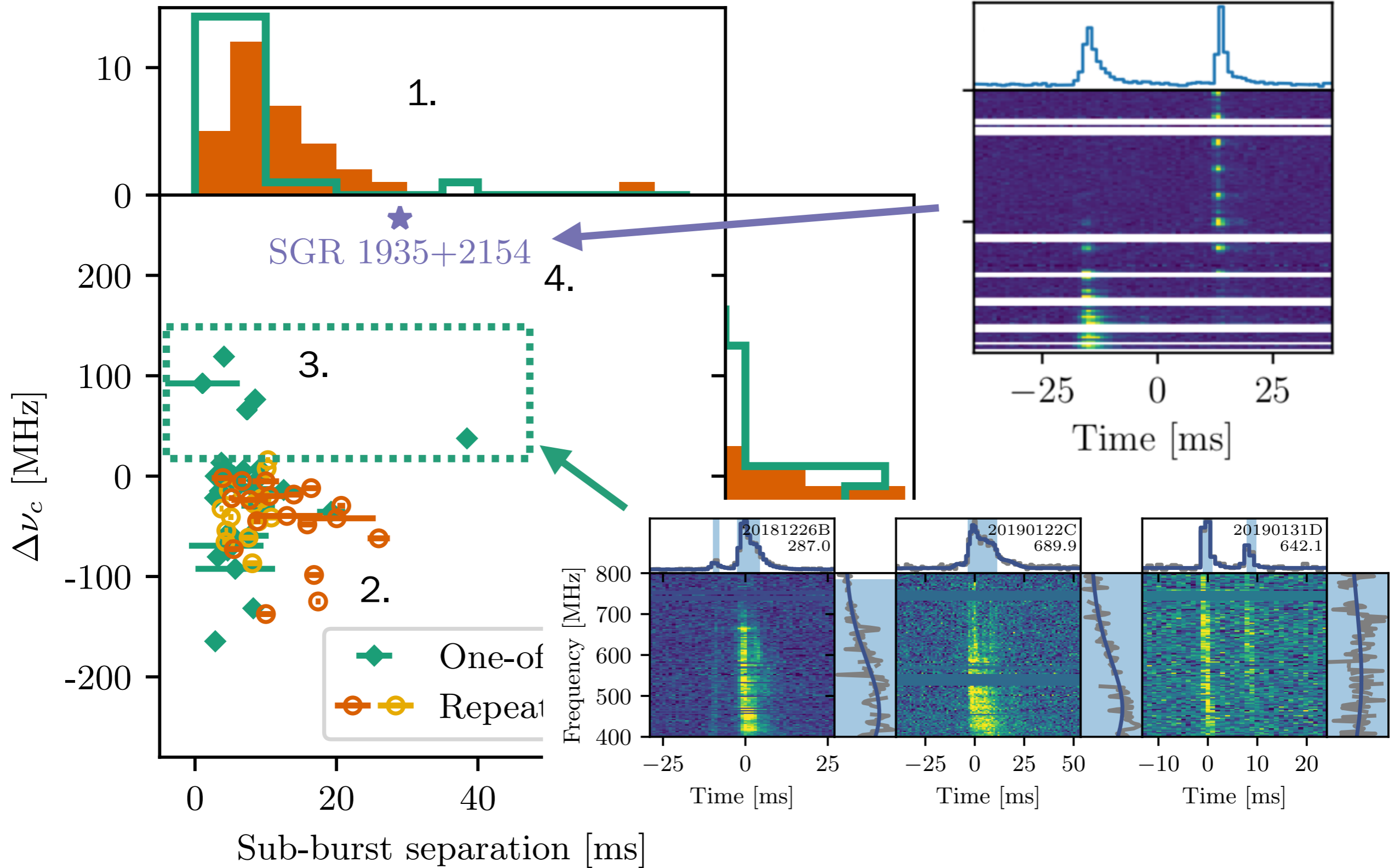
# Sub-burst separations

PRELIMINARY

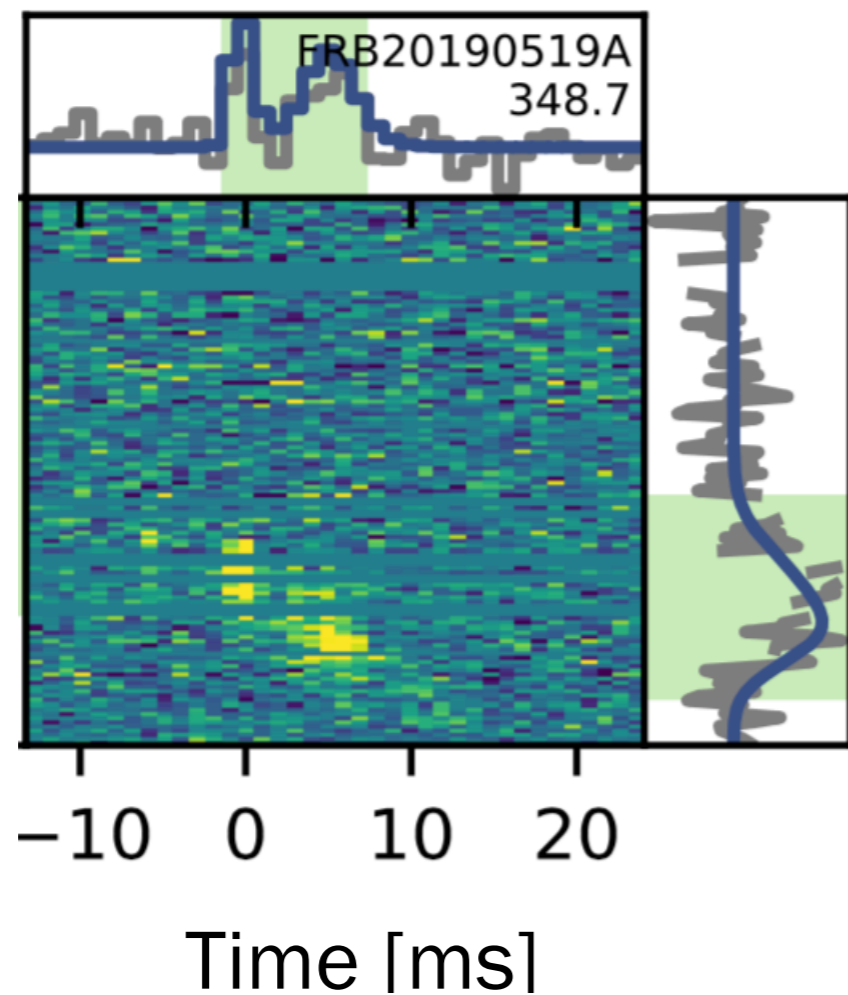


# Sub-burst separations

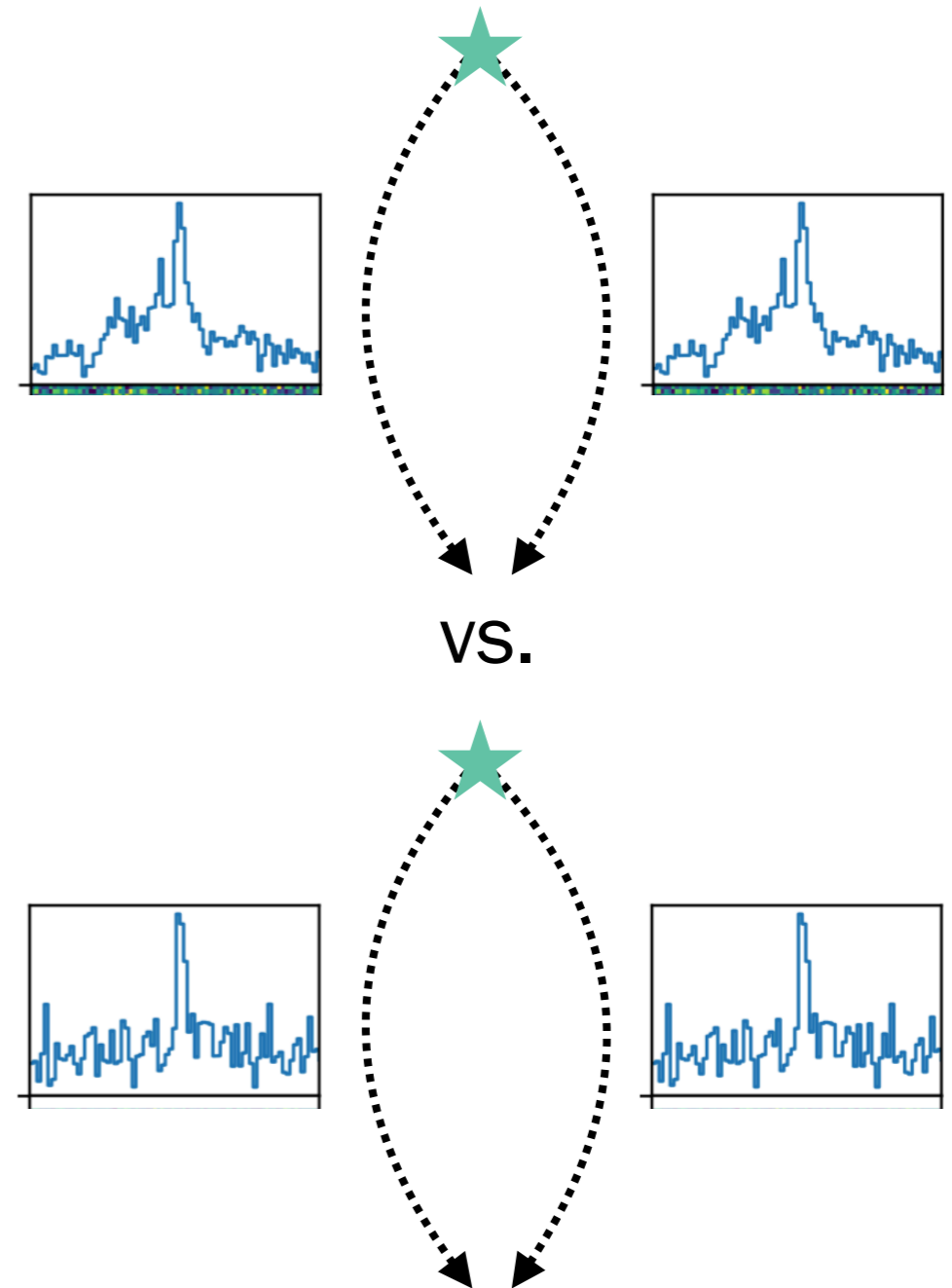
PRELIMINARY



# Morphology and FRBs as tools

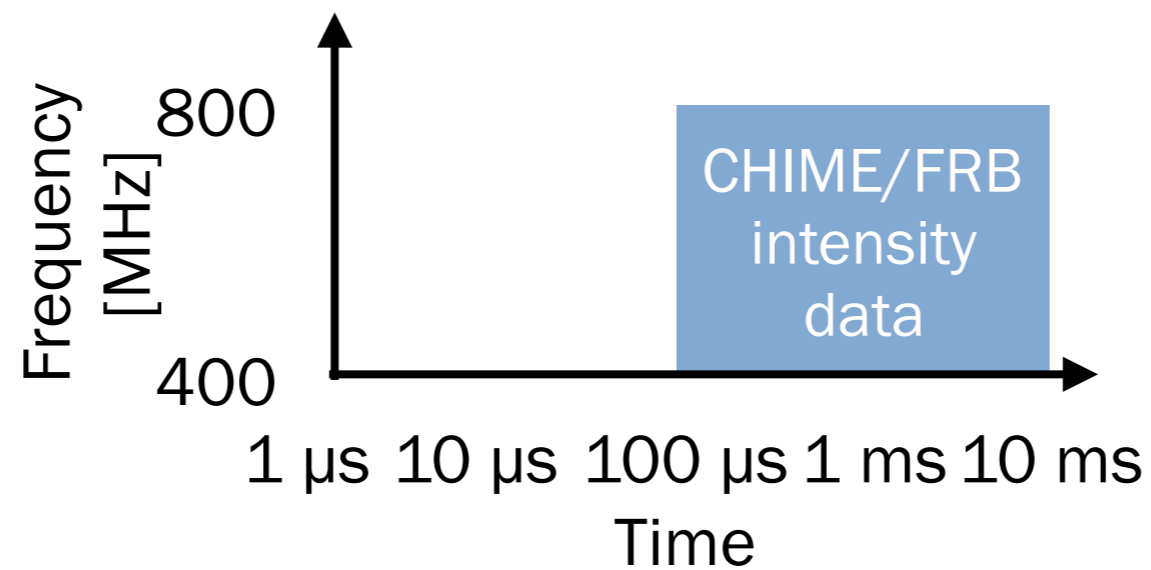


For multi-component bursts dispersion delay and scattering timescales are more difficult to measure precisely because of covariance between parameters

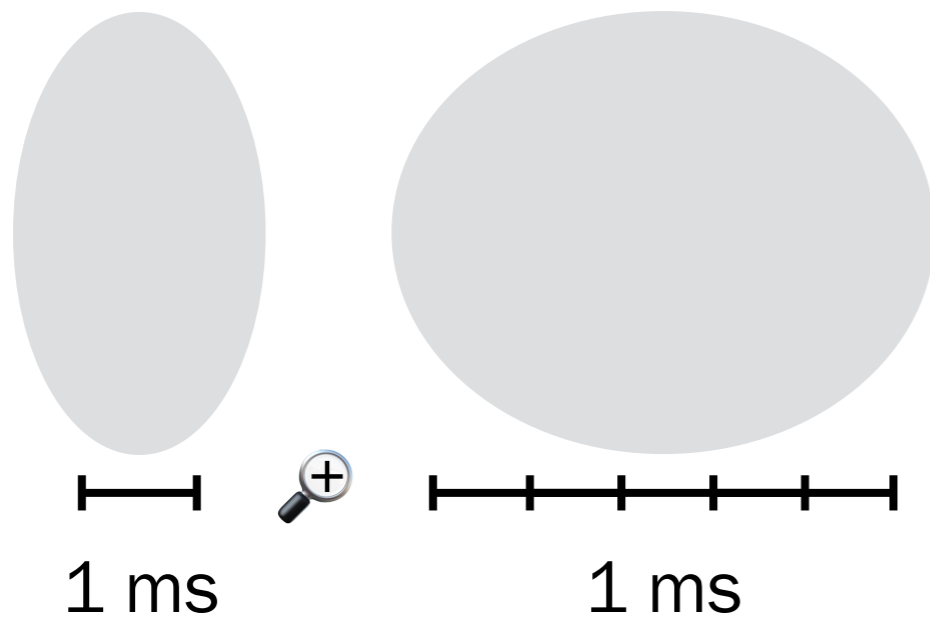


Bursts with complex structure might ease selection of lensed candidates

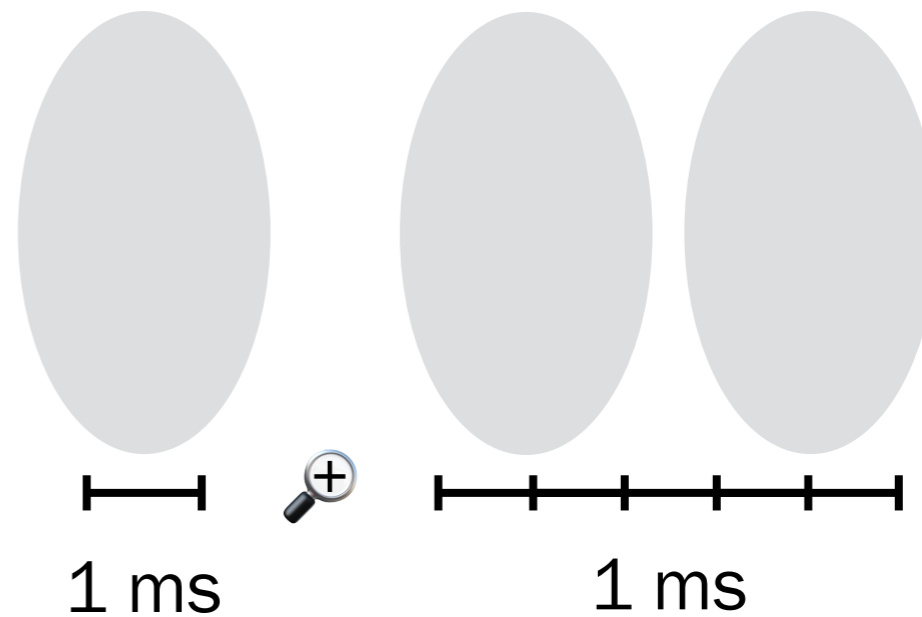
# Mapping out the distribution



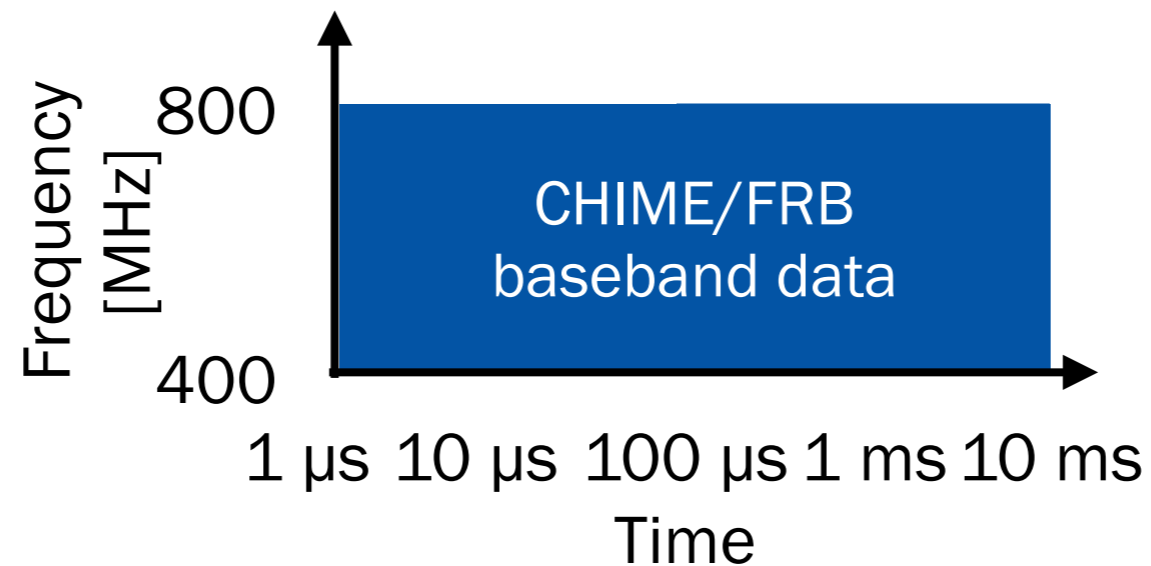
1 burst = 1 burst



1 burst = 2 bursts

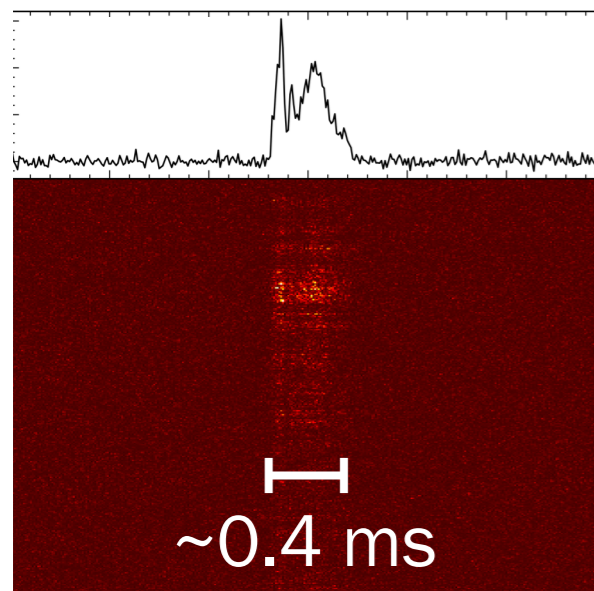


# Mapping out the distribution

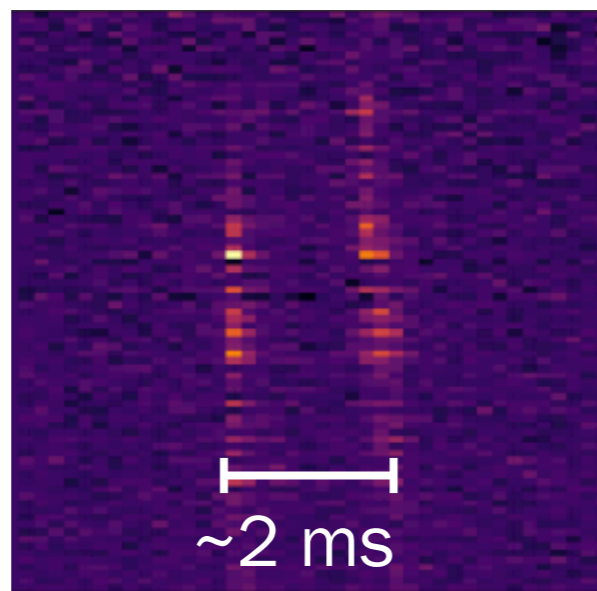


one-offs events

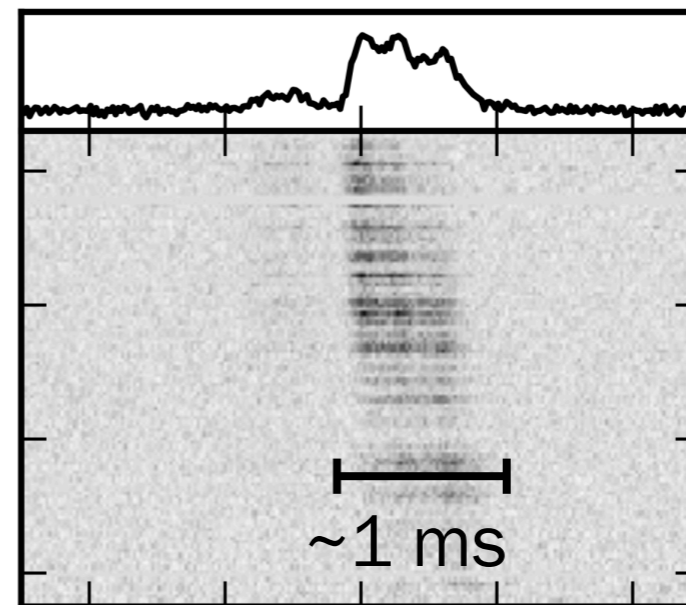
repeater bursts



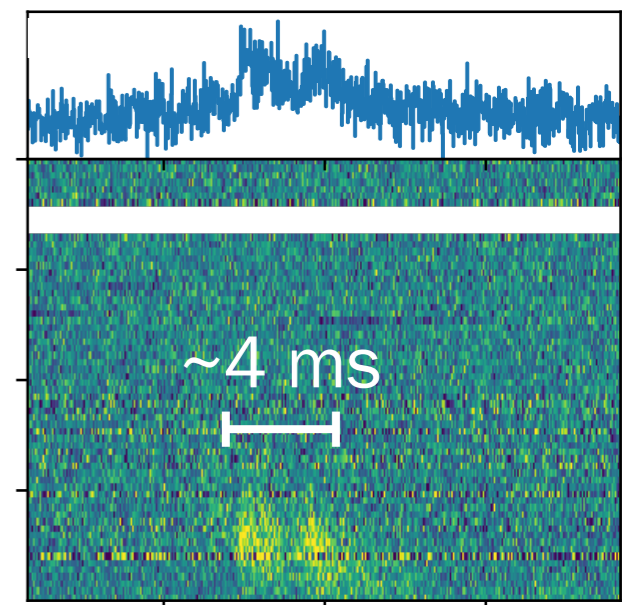
Farah+2018



Day+2020



Michilli+2018



CHIME/FRB  
Collaboration+2020

Also Farah+2019, Cho+2020 and Nimmo+2020

# Fast radio burst morphology with CHIME/FRB

First CHIME/FRB catalog is submitted

DM and flux/fluence distributions of one-off events and repeater bursts are similar

One-off events and repeater bursts have different observed **width** and **bandwidth** distributions:  
unclear if intrinsic or due to propagation

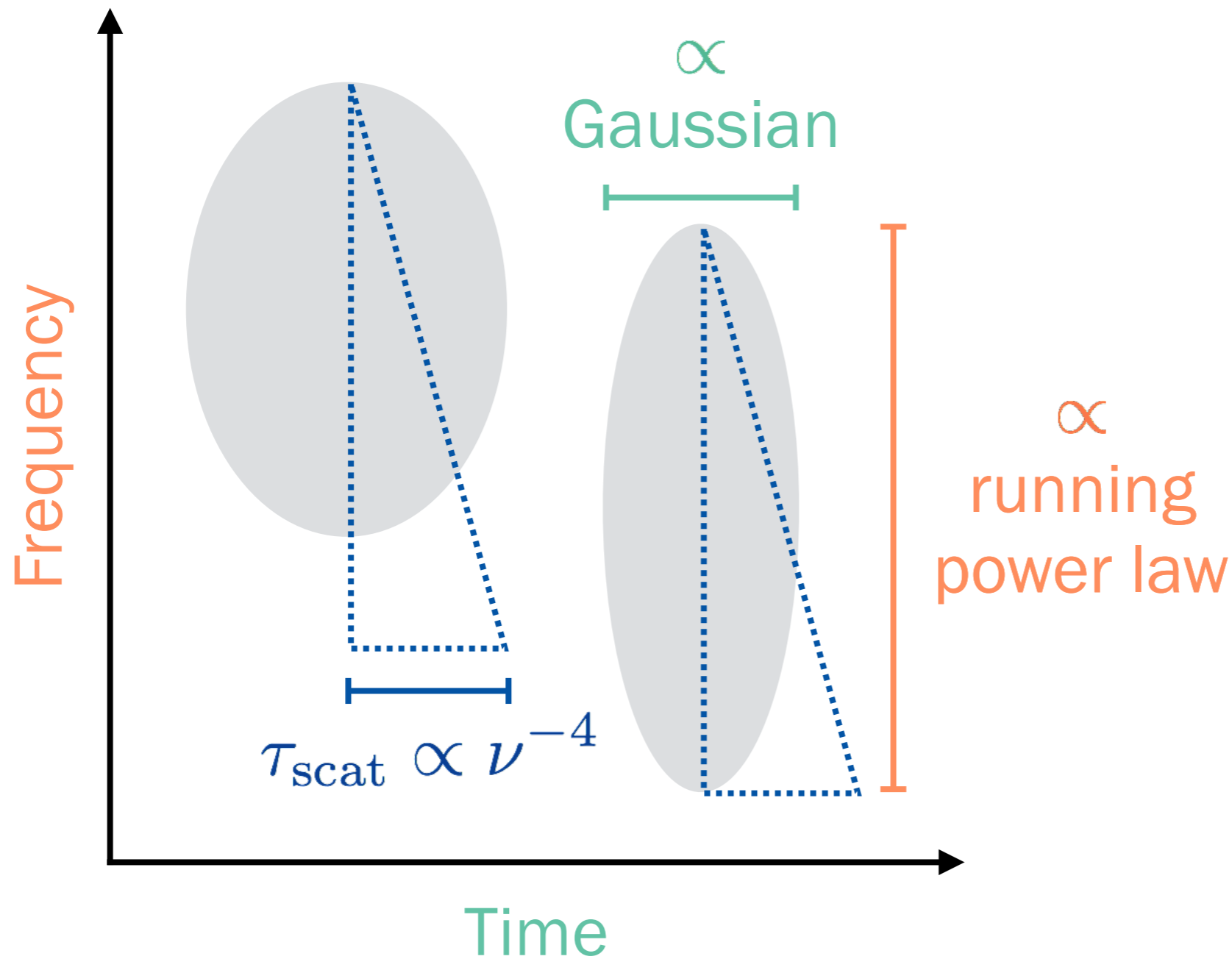
When studying morphology with CHIME/FRB intensity data, have to be wary of instrumental biases; look out for high-time resolution studies

# Appendix

# Burst modeling

One DM, one  $\tau_{\text{scat}}$

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

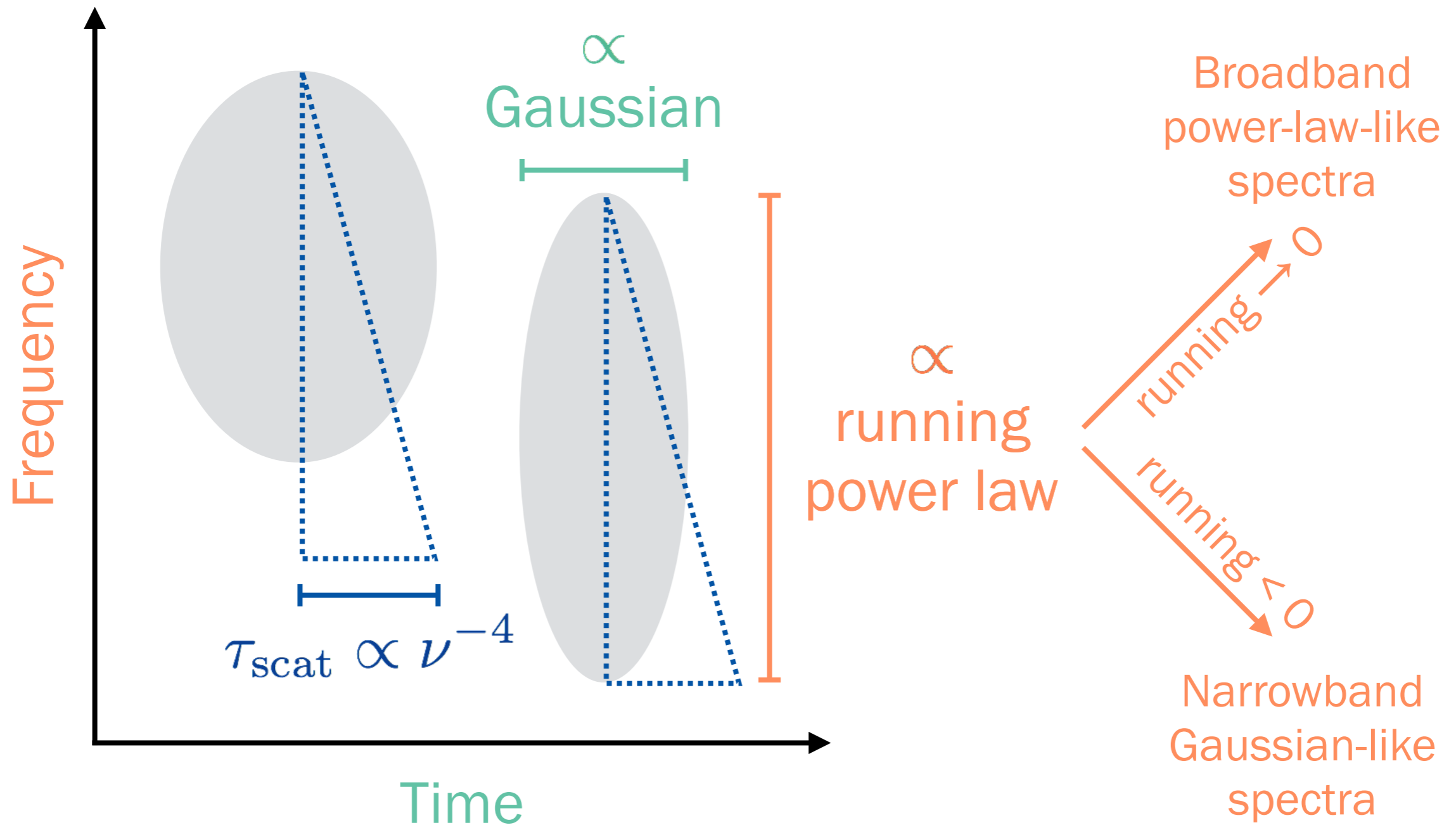




# Burst modeling

One DM, one  $\tau_{\text{scat}}$

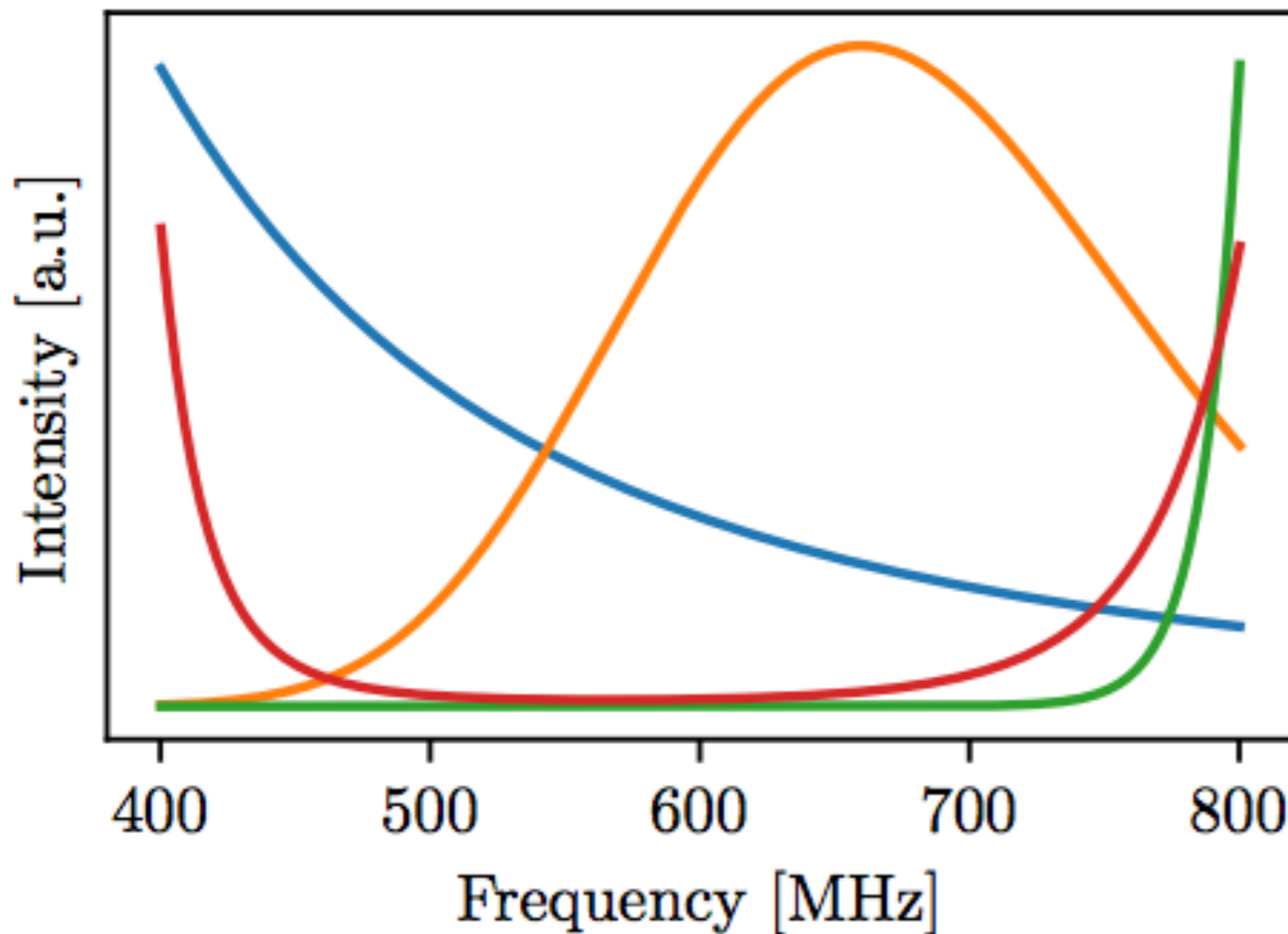
$$I(\nu) = A (\nu/\nu_0)^{\alpha + \beta \ln(\nu/\nu_0)}$$



# Burst modeling

Empirical spectral model is a power-law function with spectral index  $\alpha$  and spectral “running” term  $\beta$ :

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



Can describe both extremes of observed FRB spectra

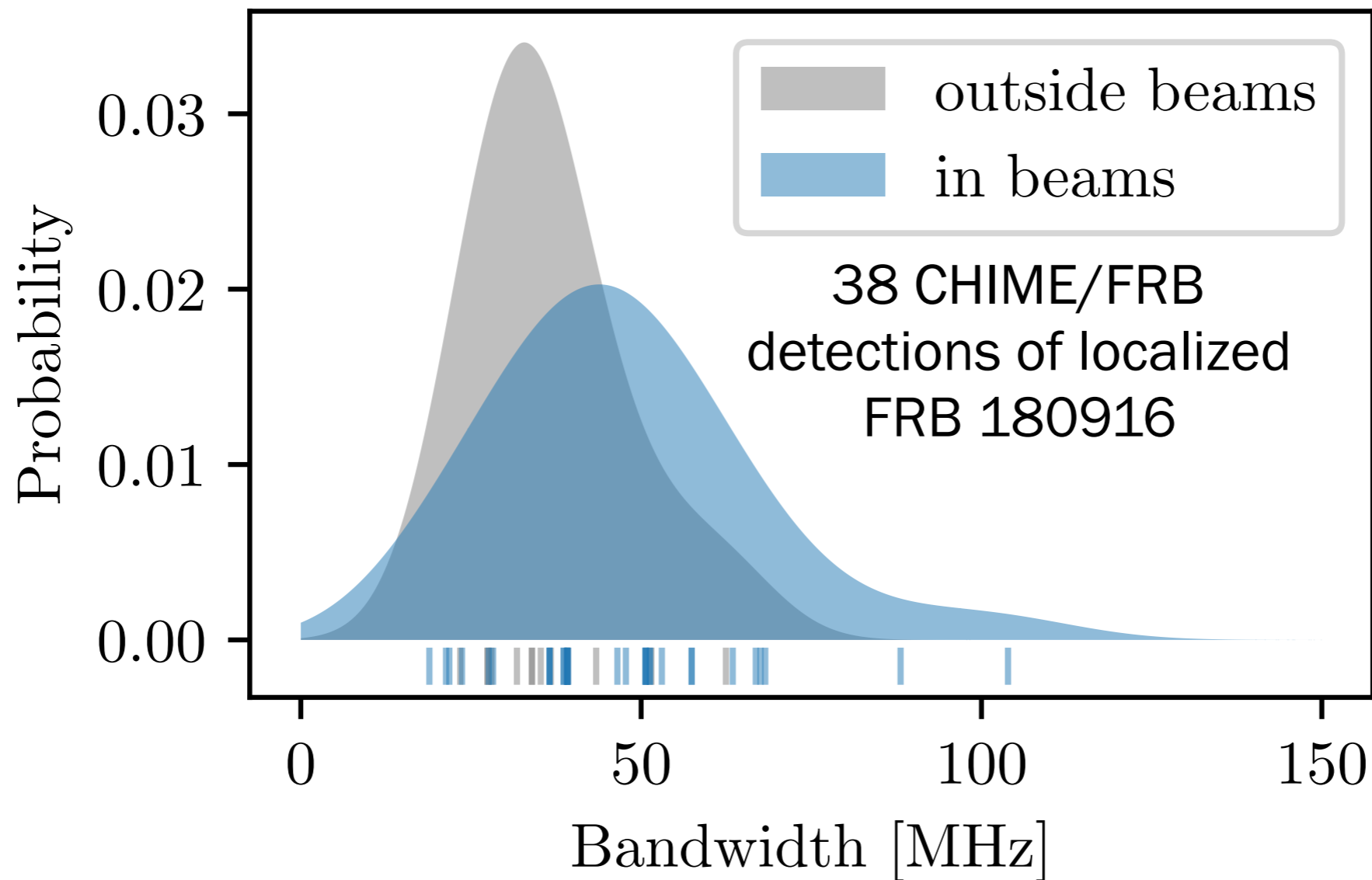
$\beta \rightarrow 0$ : Power-law

$\alpha > 0, \beta < 0$ : Gaussian-like

Can convert to peak frequency and bandwidth

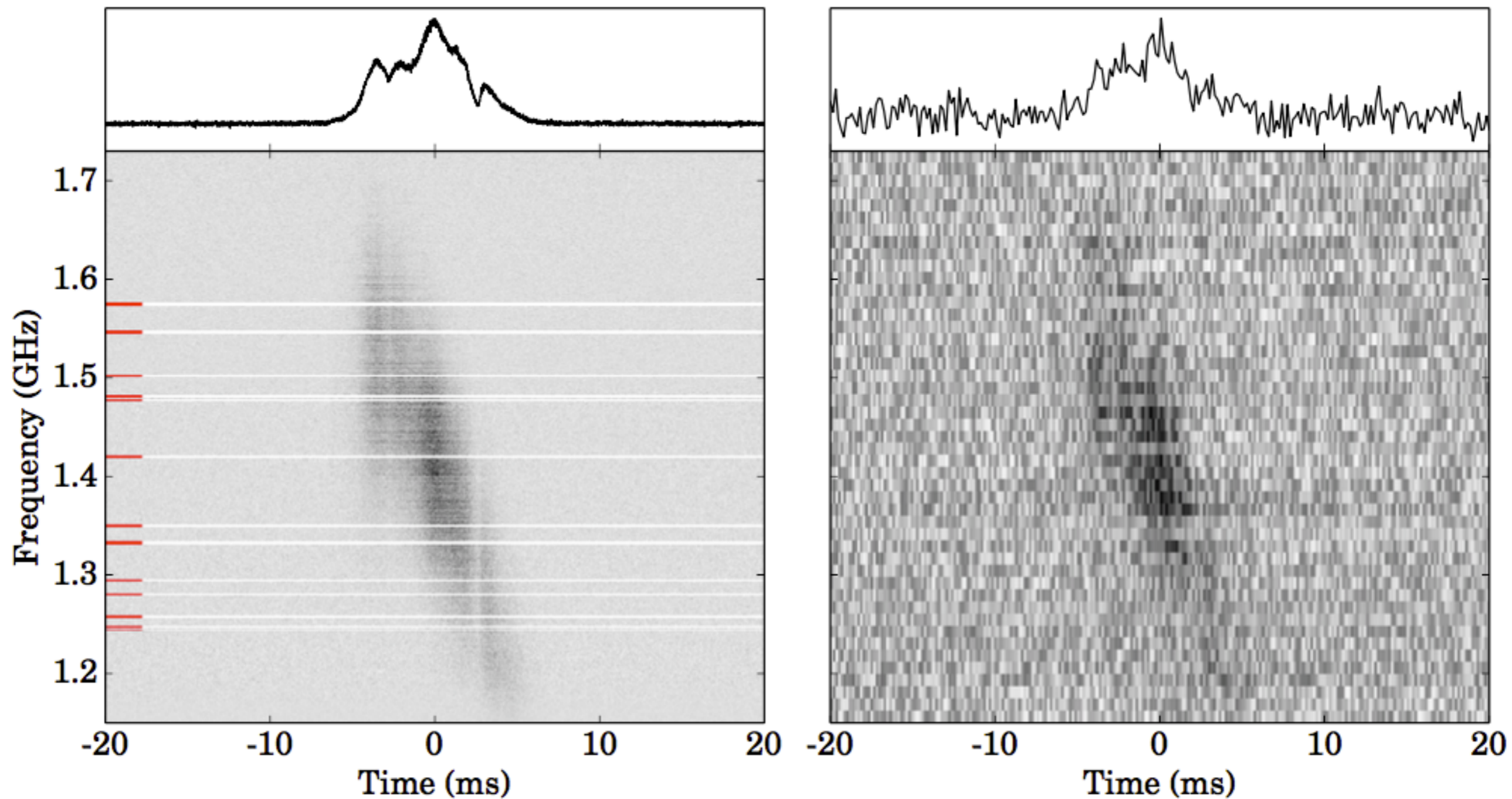
# What causes the observed bandwidth difference?

Instrumental effect? **no**, populations are subject to same biases



Bandwidths taken from  
CHIME/FRB Collaboration+2019  
CHIME/FRB Collaboration+2020

# Low signal-to-noise bursts



 Gourджи+2019