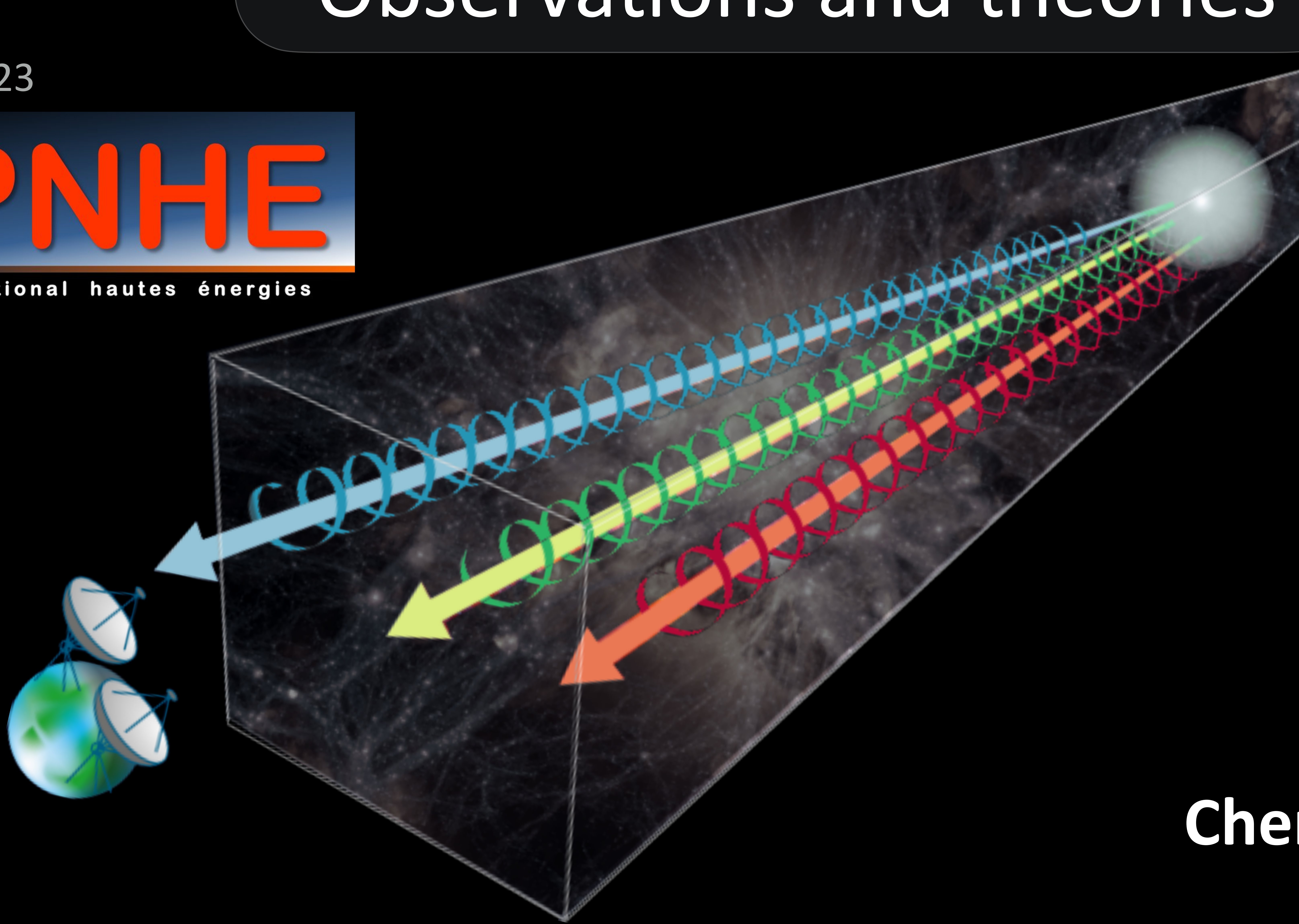
Fast Radio Bursts: Observations and theories

Sept 6-8, 2023

PNHE
Programme national hautes énergies



Cherry Ng-Guihéneuf

LPC2E/CNRS

Fast Radio Bursts (FRB) in a nutshell

- Bright (< 10^{44} erg s-1) and short (~ms)
- High event rate (~5,000/sky/day)
- Extragalactic (~0.03 >z > 1)

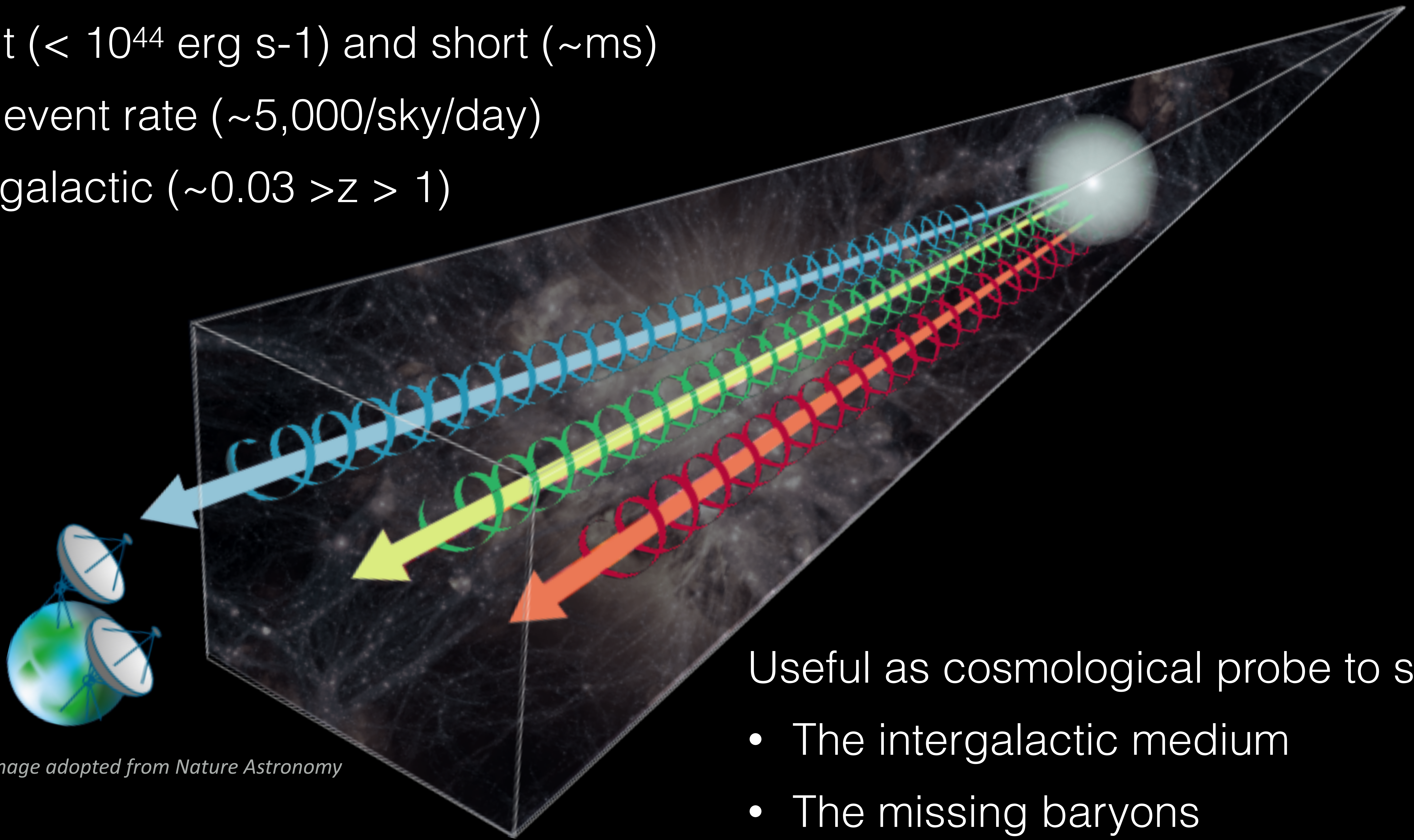


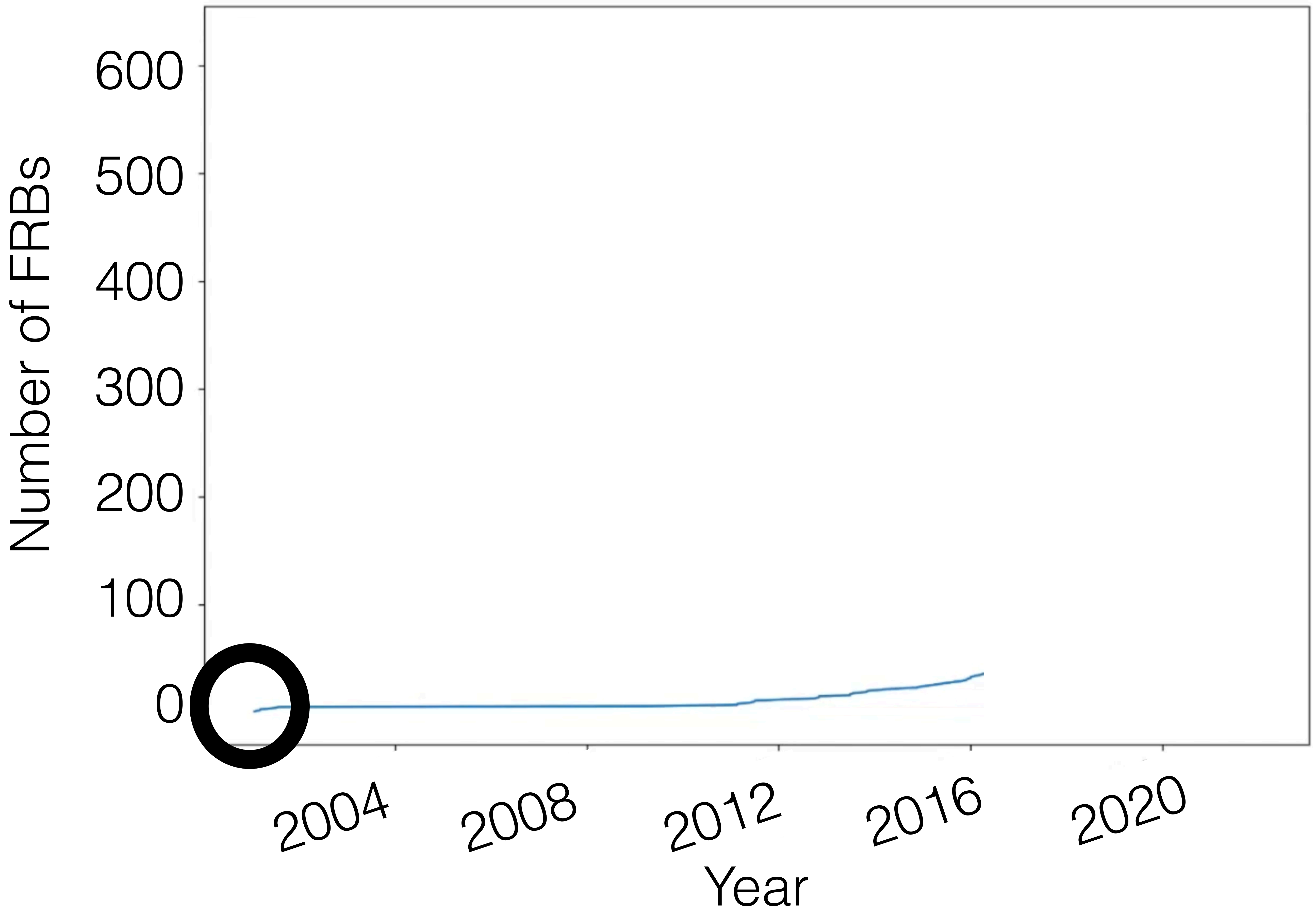
Image adopted from Nature Astronomy

Useful as cosmological probe to study:

- The intergalactic medium
- The missing baryons

Chronology of the FRB discovery

Plot adopted from Xavier Prochaska

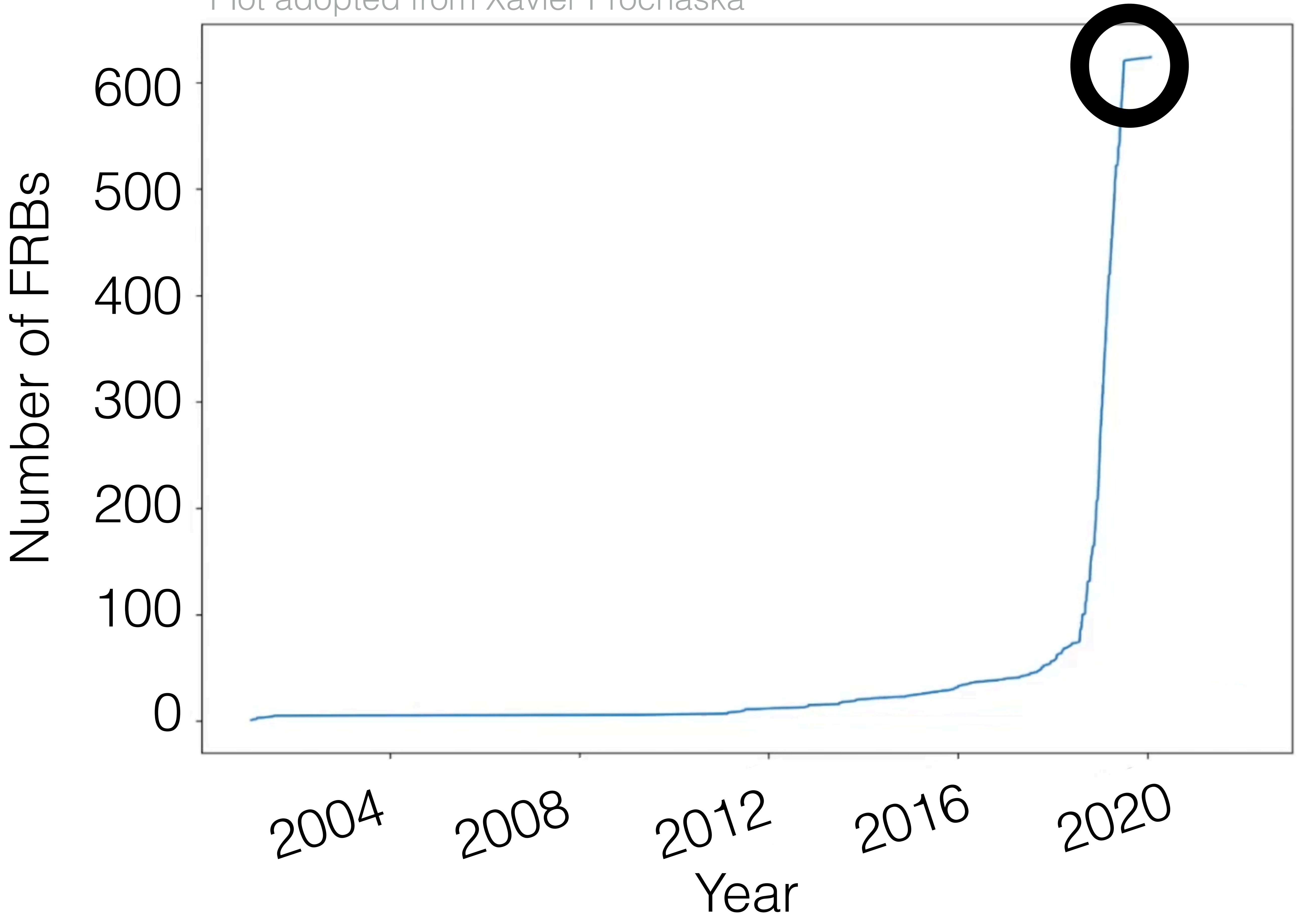


Parkes radio telscope (Australia)

FRB discovered in the archival data of pulsars

Chronology of the FRB discovery

Plot adopted from Xavier Prochaska



CHIME radio telscope (Canada)

Transit telescope = a large field-of-view and a high discovery rate

Chronology of the FRB discovery

CHIME radio telscope (Canada)

Transit telescope = a large field-of-view
and a high discovery rate

Chronology of the FRB discovery

CHIME radio telscope (Canada)

Transit telescope = a large field-of-view and a high discovery rate

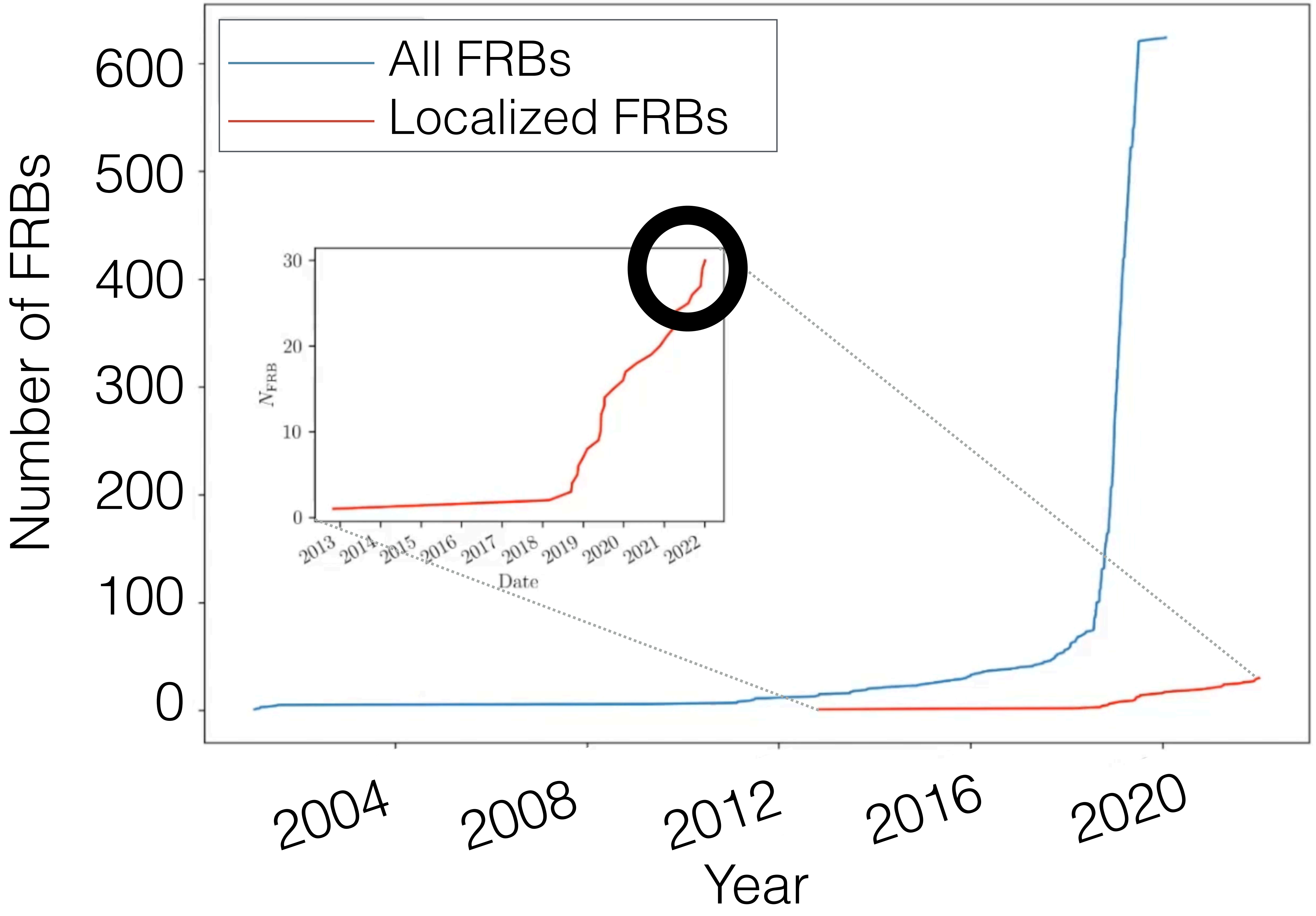
Localisation not precise enough for the identification of the host galaxy

Chronology of the FRB discovery

Interferometric telescopes =
arcseond localizations

Chronology of the FRB discovery

Plot adopted from Xavier Prochaska



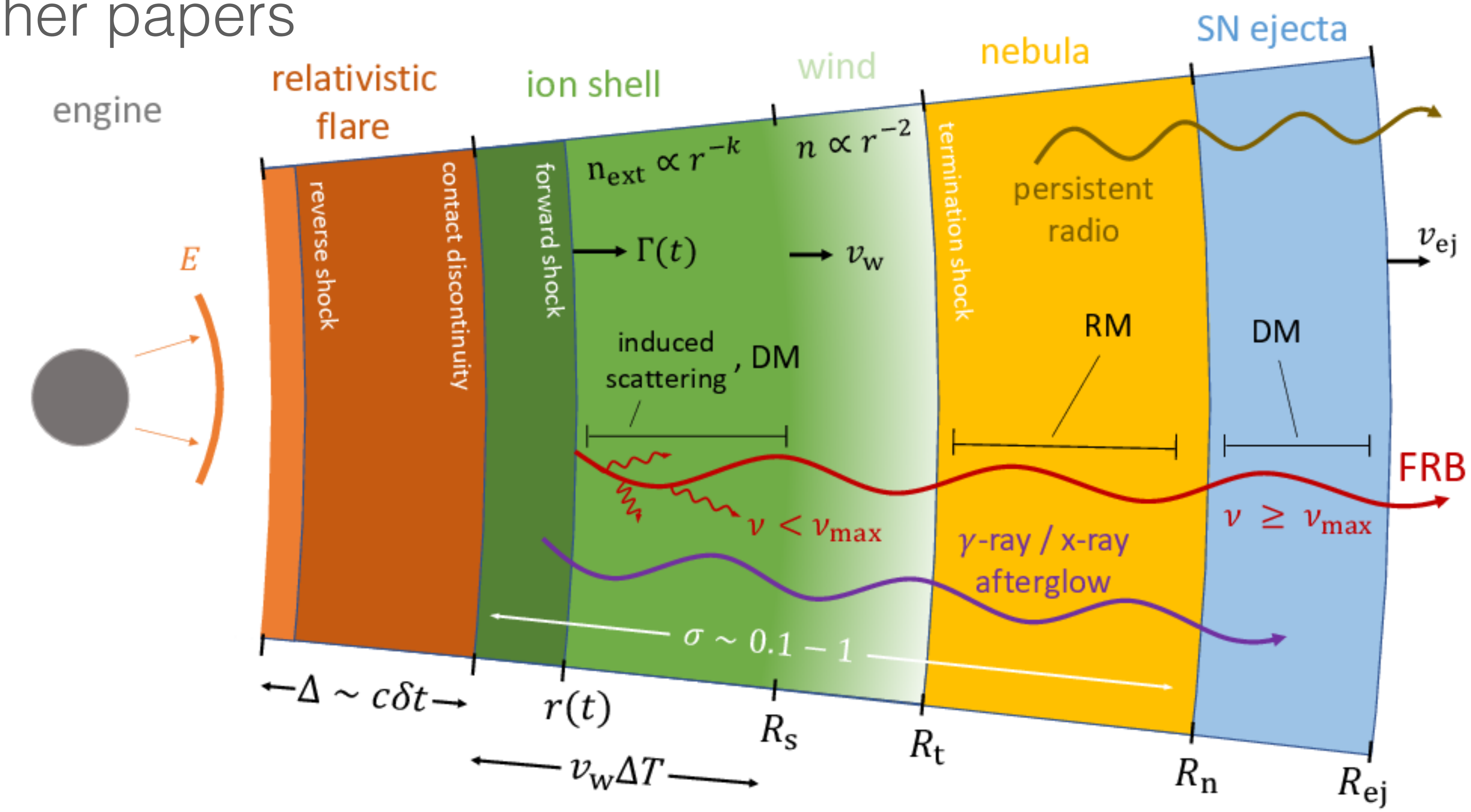
- Published counts: ~700 FRBs, ~40 localized
- Plus a lot more unpublished
- A new astrophysical phenomenon!

Interferometric telescopes = arcseond localizations

What do we know about FRBs so far?

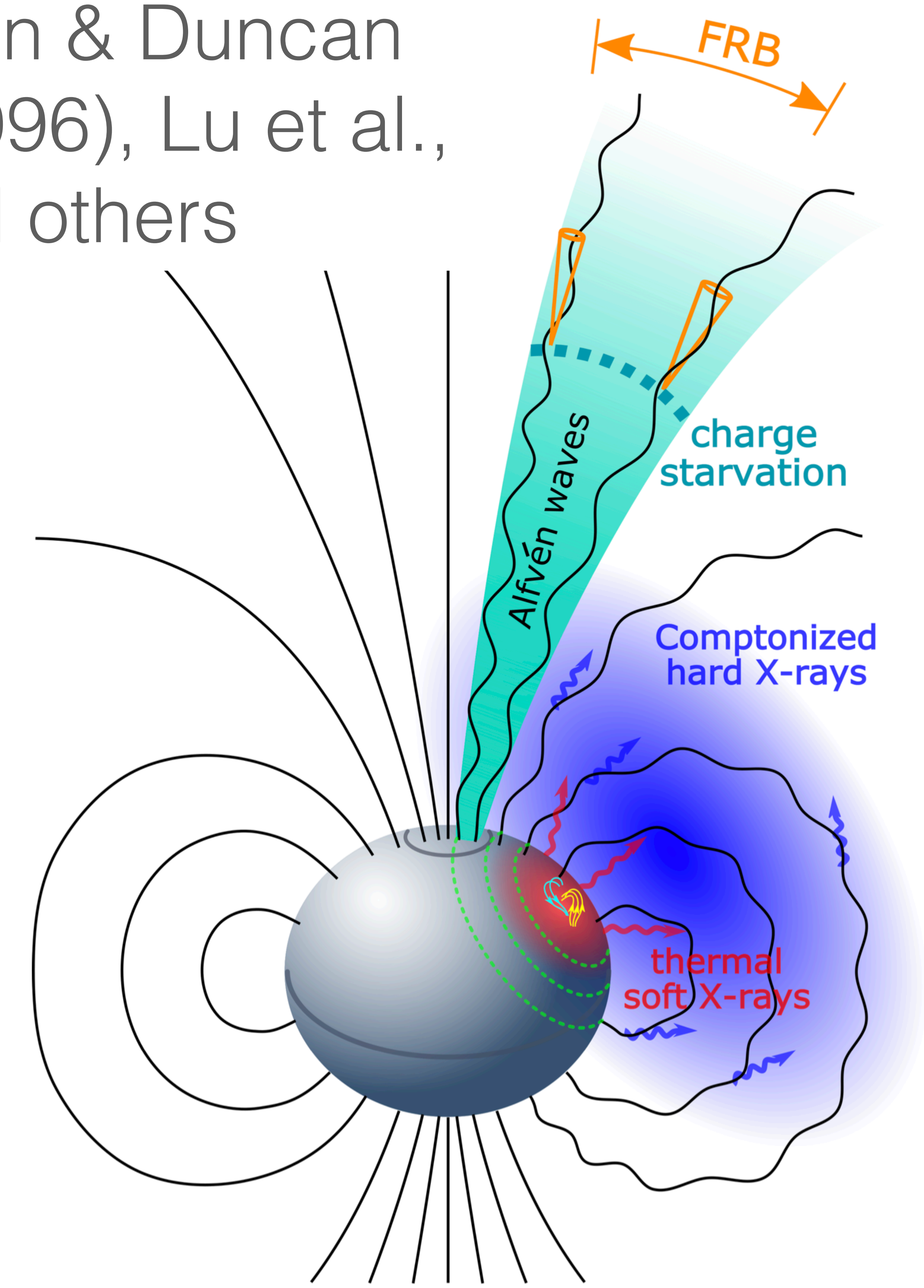
Theoretical models

Metzger et al., 2019 and quite a few other papers



Synchrotron maser emission: relativistic flare collides with an ion shell —> shell decelerates through shock waves —> FRB

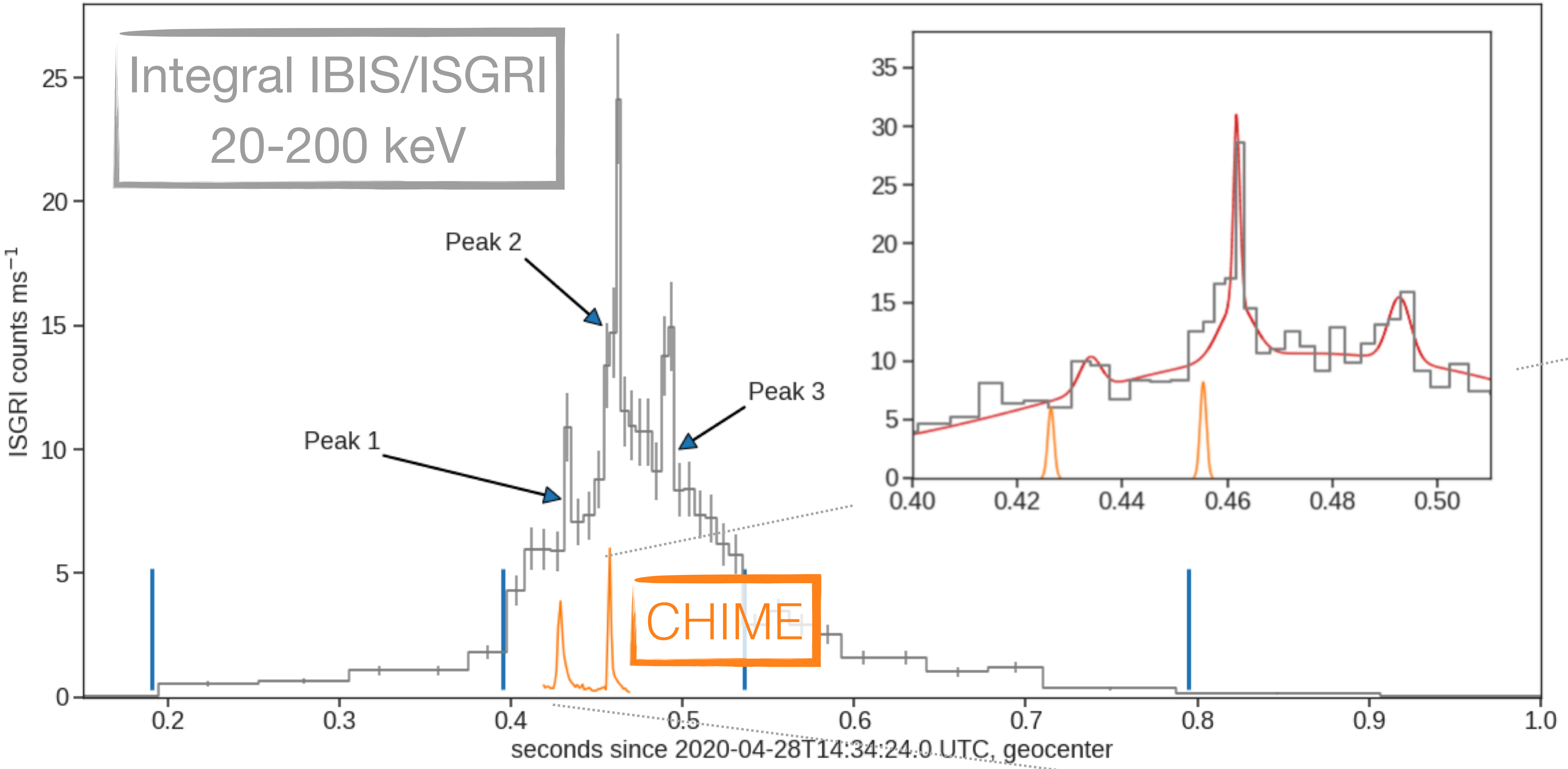
Thompson & Duncan (1995, 1996), Lu et al., 2020 and others



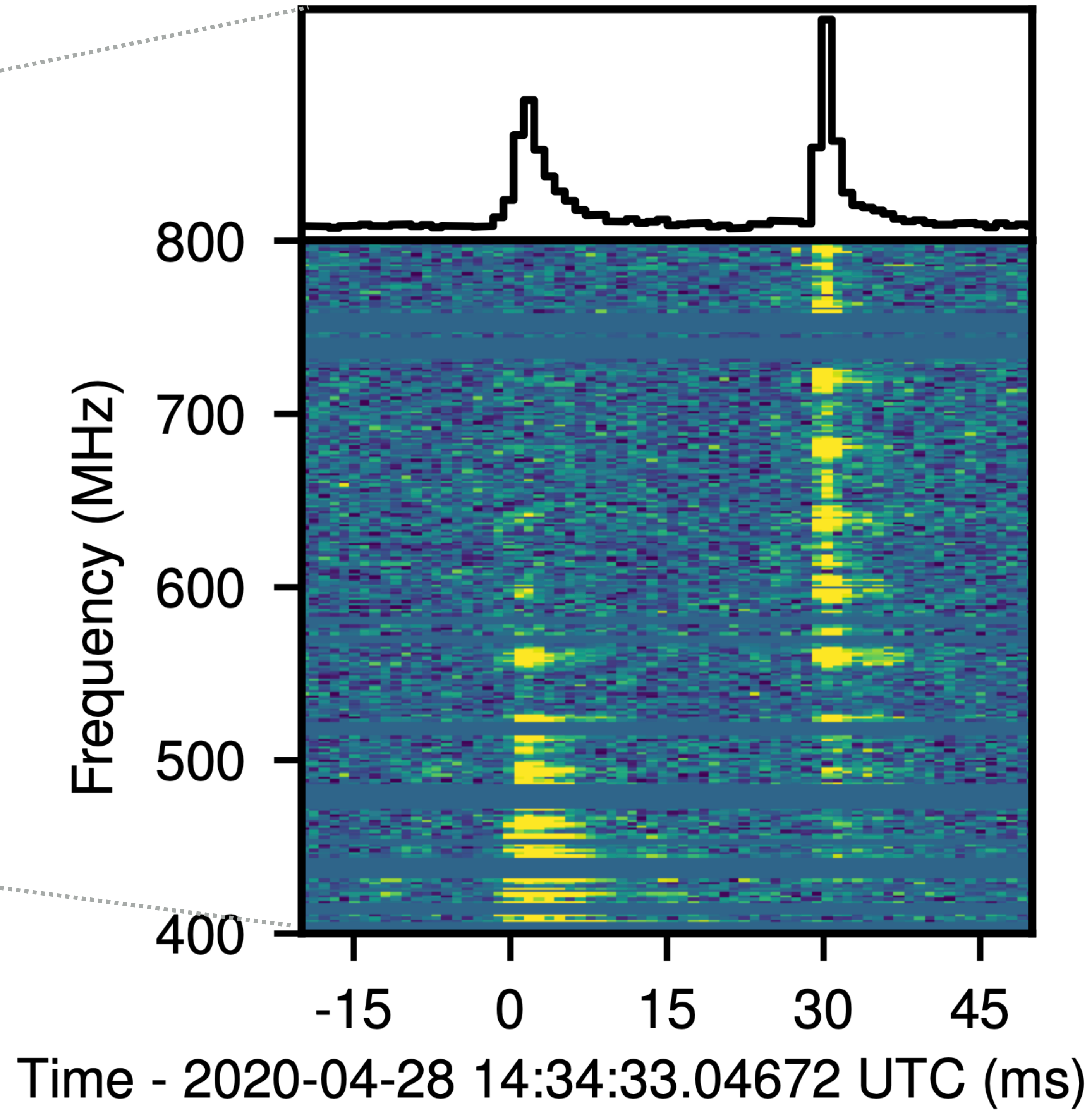
“Classic” Magnetar flare —> trapped fireball —> thermal X-ray and comptonization

Magnetar SGR 1935

Mereghetti et al. 2020



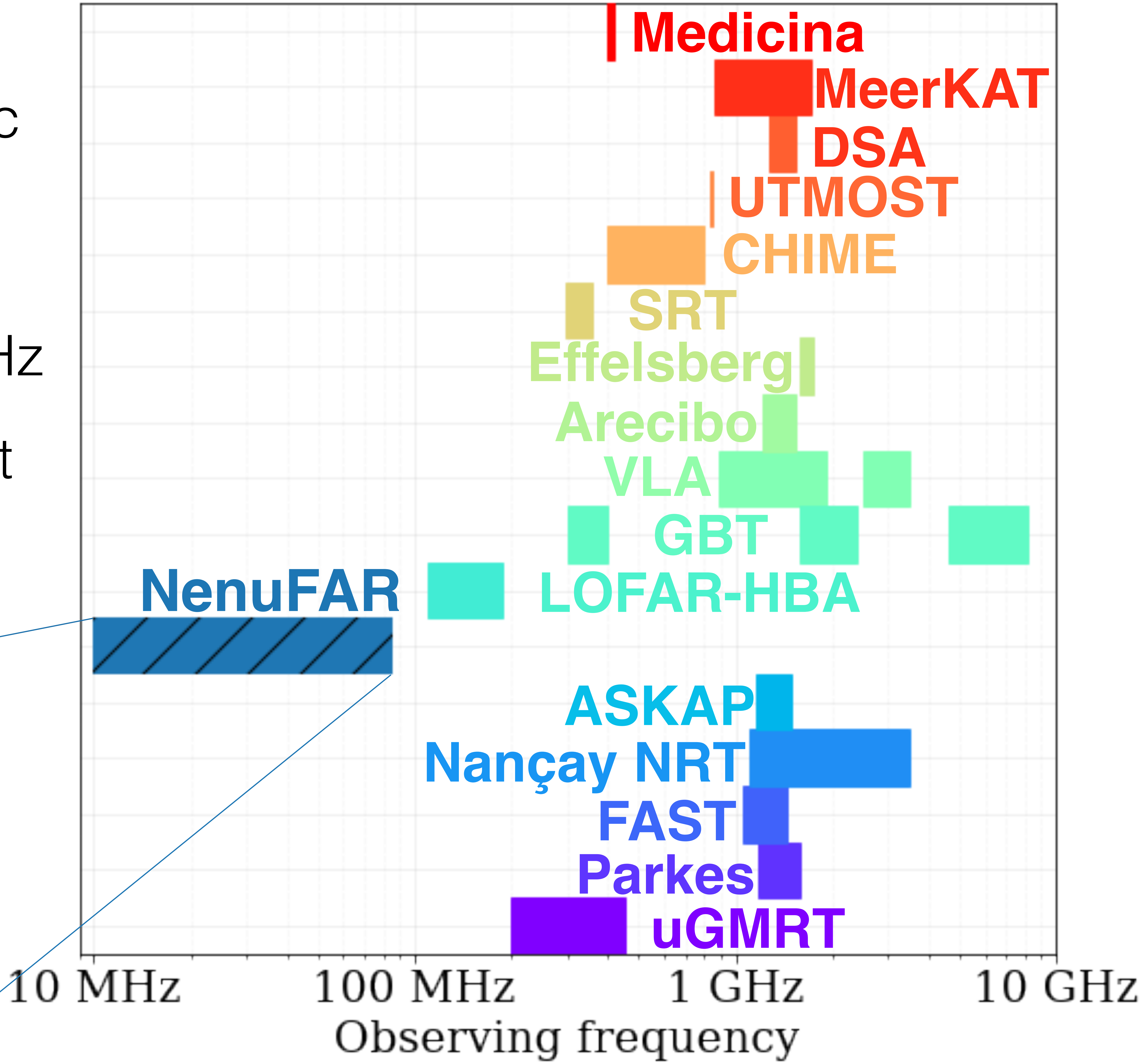
collab. CHIME/FRB, 2020



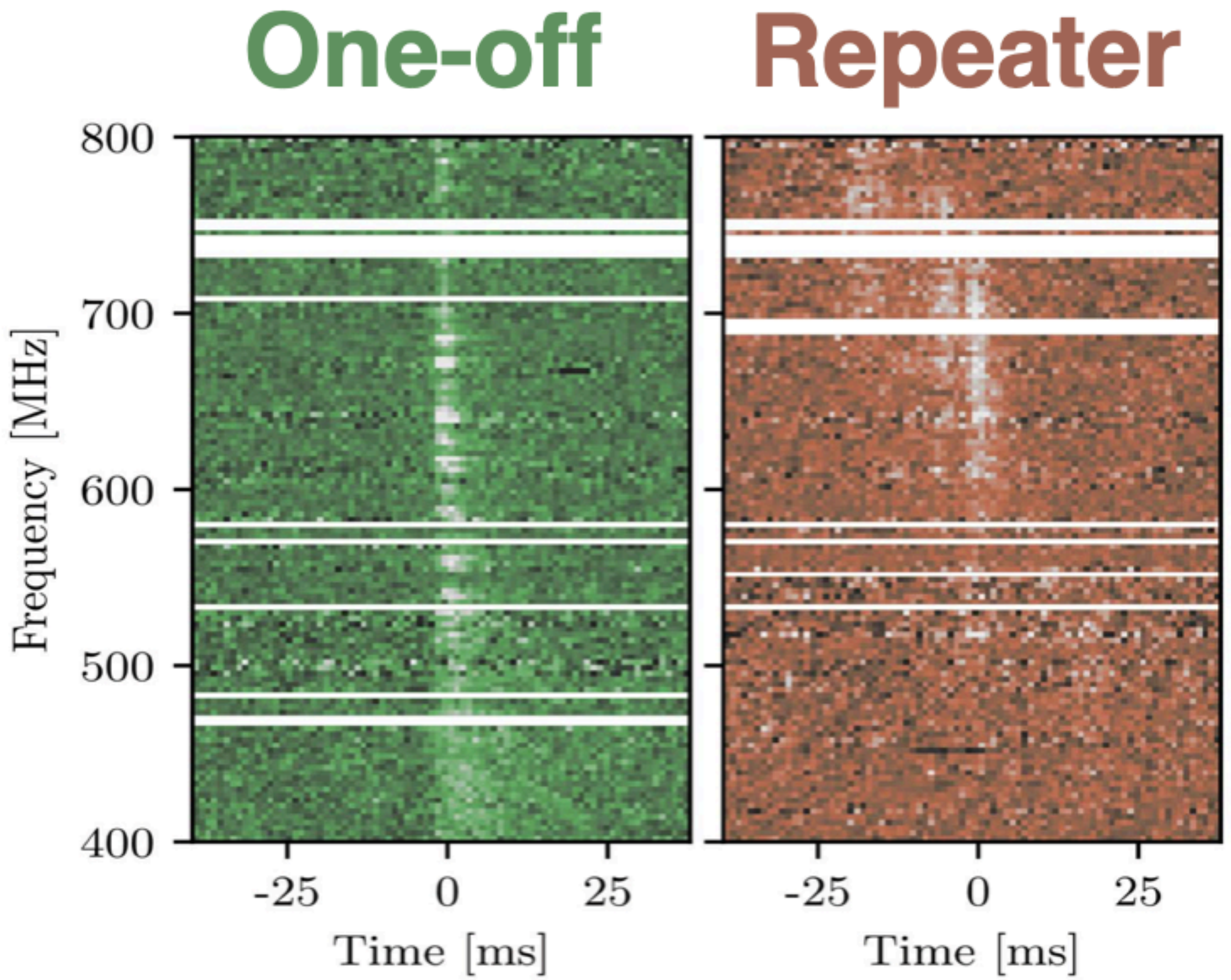
- Detected by CHIME+STARE2 (**radio**) and NICER, Chandra, XMM, Swift XRT (**X-ray**), Swift BAT, Fermi, NuSTAR, Integral (**Gamma ray**)
- Associated to a magnetar in our Milky Way

FRB observing frequency

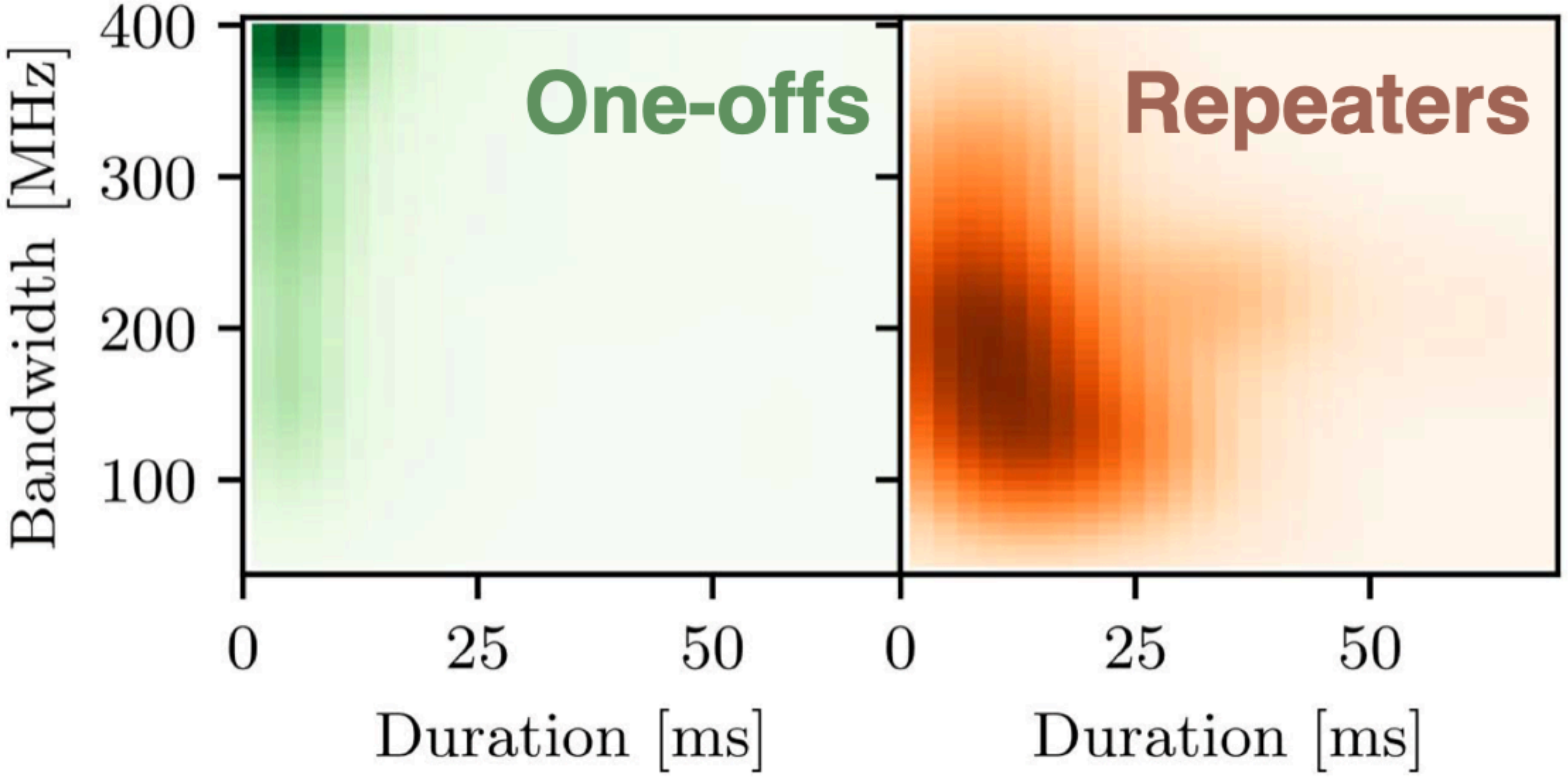
- no conclusive multi-wavelength counterparts yet, except the Galactic magnetar FRB
- So far detected by 16+ radio telescopes between 110 MHz - 8 GHz
- NenuFAR can open a new window at low frequencies — study emission mechanisms



Multiple populations ?

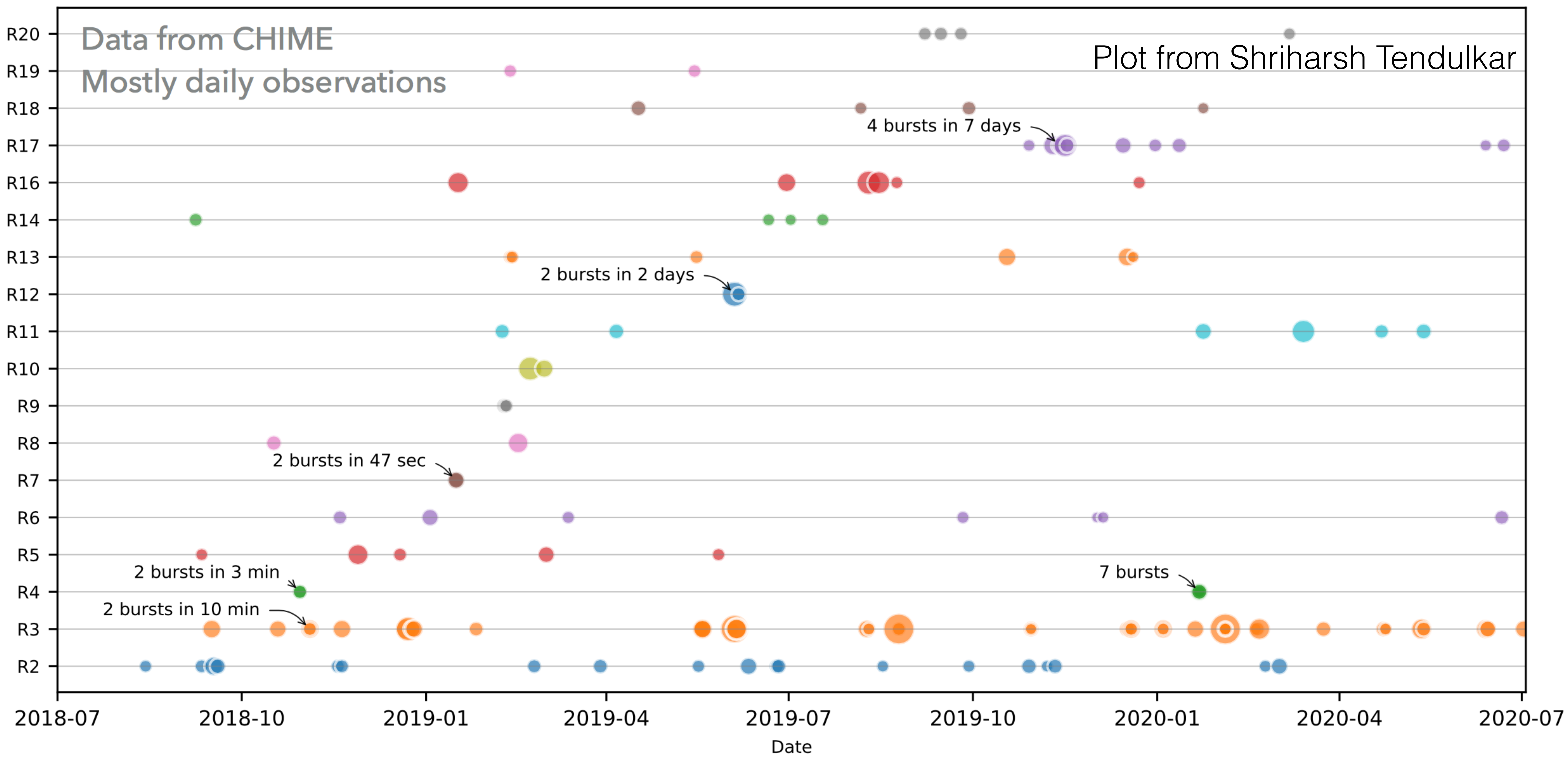


Pleunis+2021 (2106.04356)



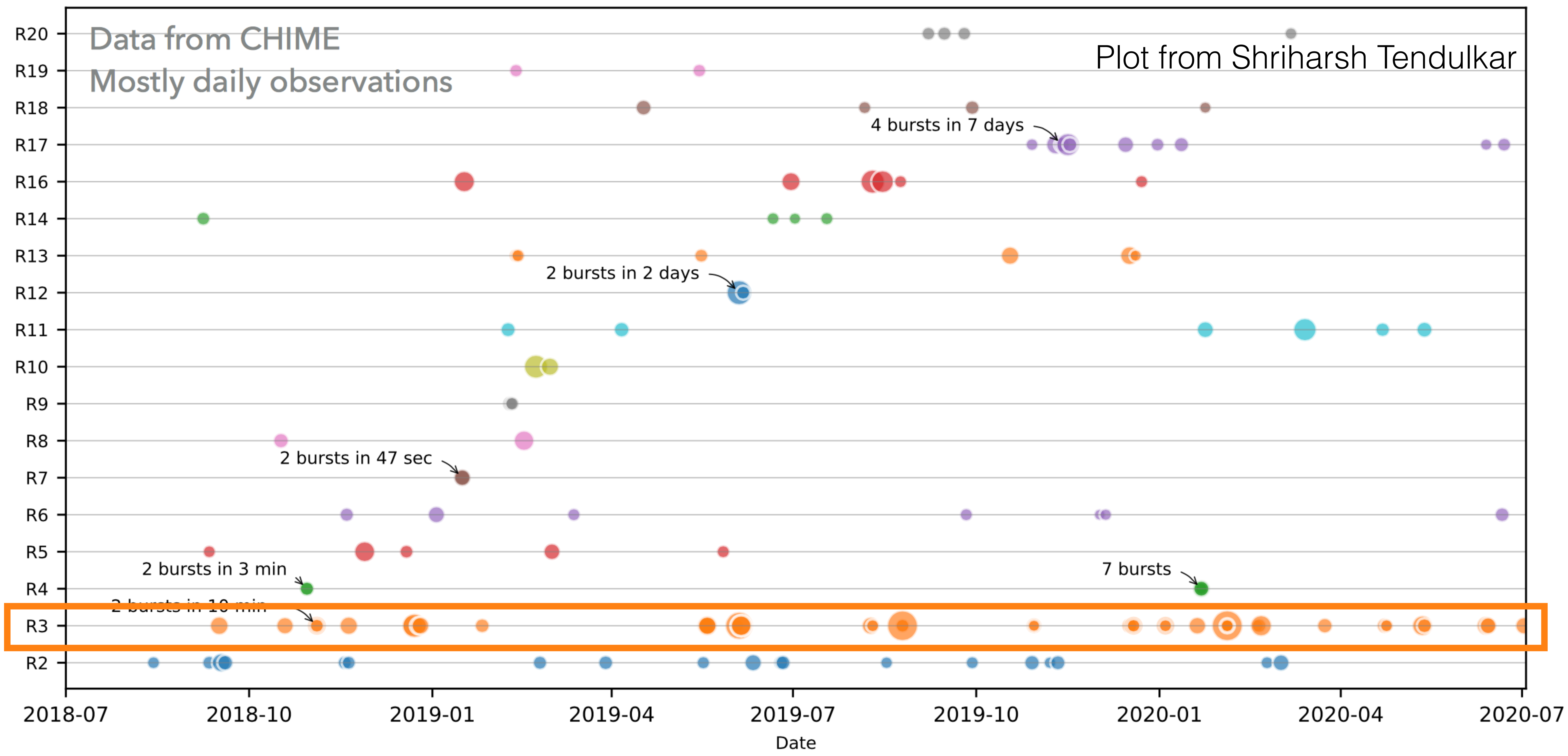
- Only a few % of FRBs seem to repeatedly burst
- The repeaters tend to have wider bursts and a narrow emission band compared to one-off FRBs
- Although, not clear if « one-offs » are truly non-repeating

Repetition



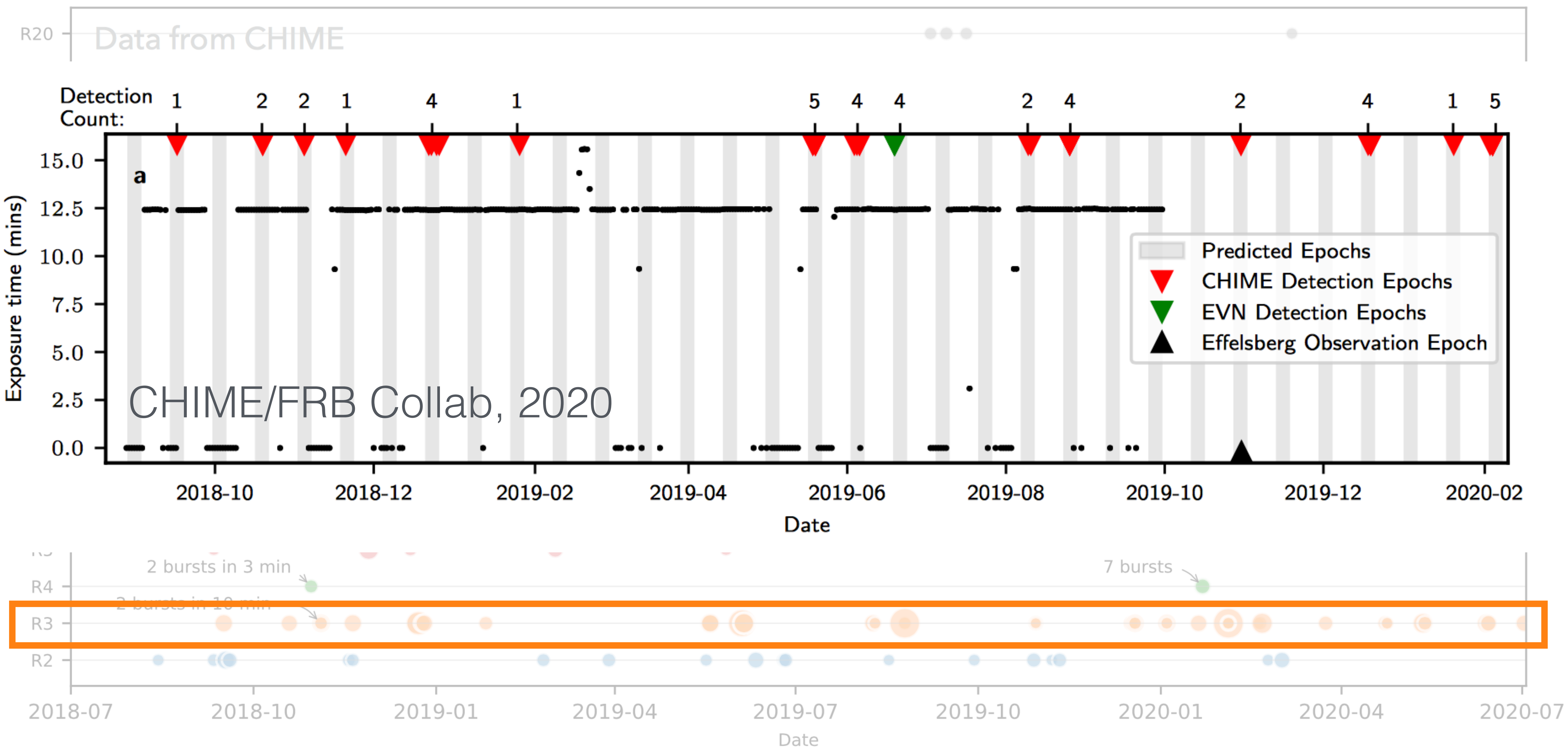
- Clustering in time and energy distribution

Repetition



- Clustering in time and energy distribution

Periodicity



- Clustering in time and energy distribution
- 2 FRBs have periodic activity cycles: 16 days (CHIME/FRB Collab, 2020) and ~160 days (Rajwade+2020, Cruces+2020)

FRB host galaxy associations

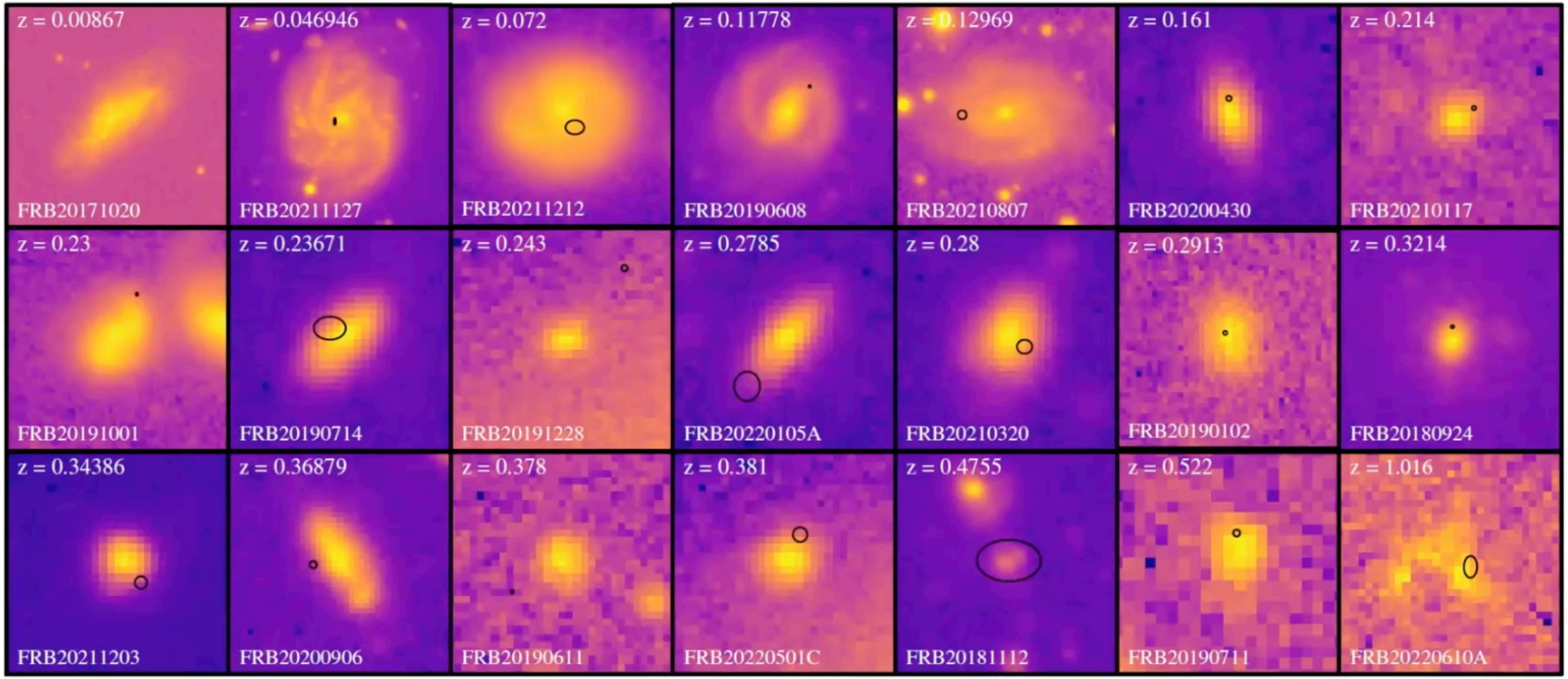
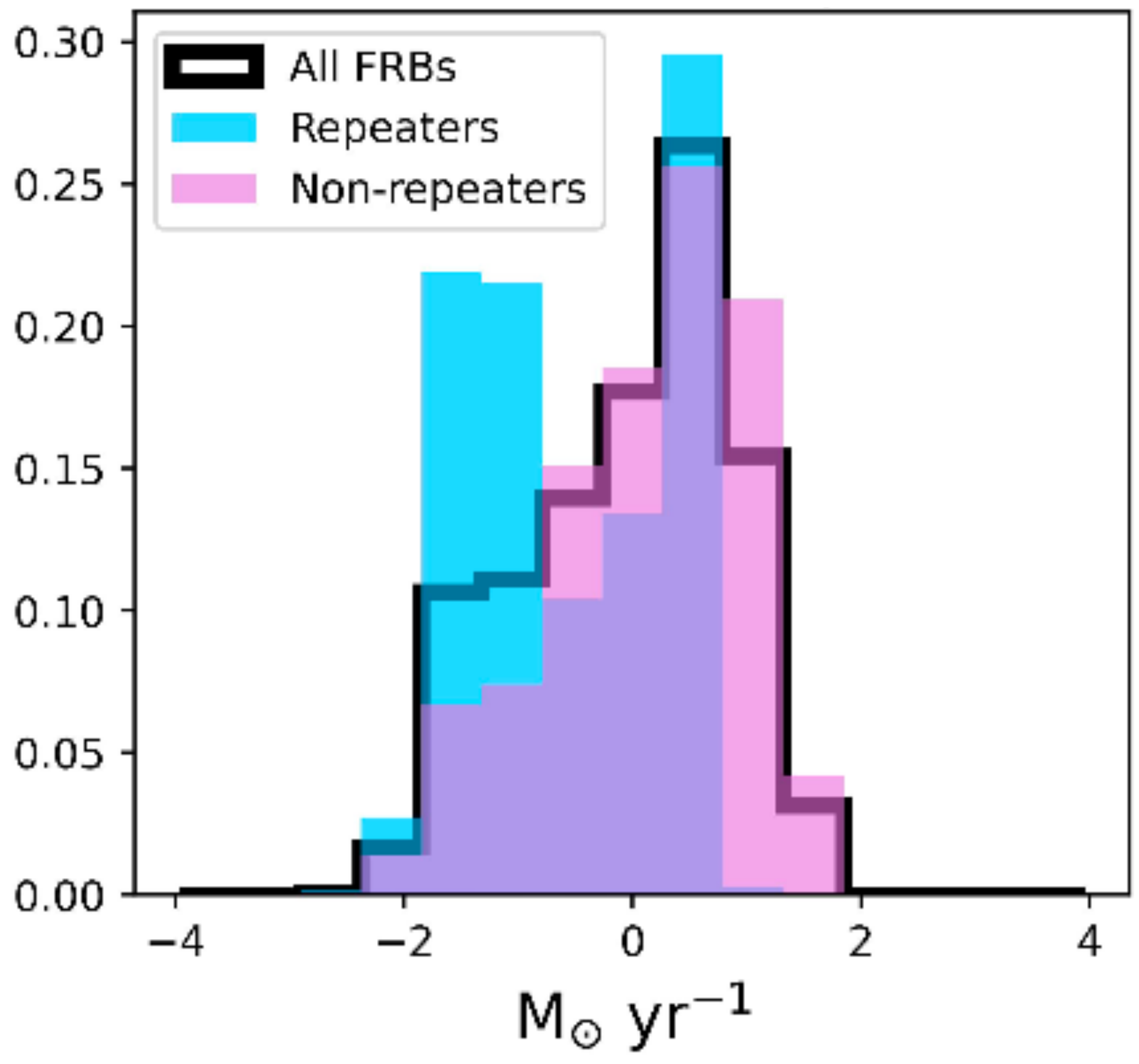


Image from Lachlan Marnoch

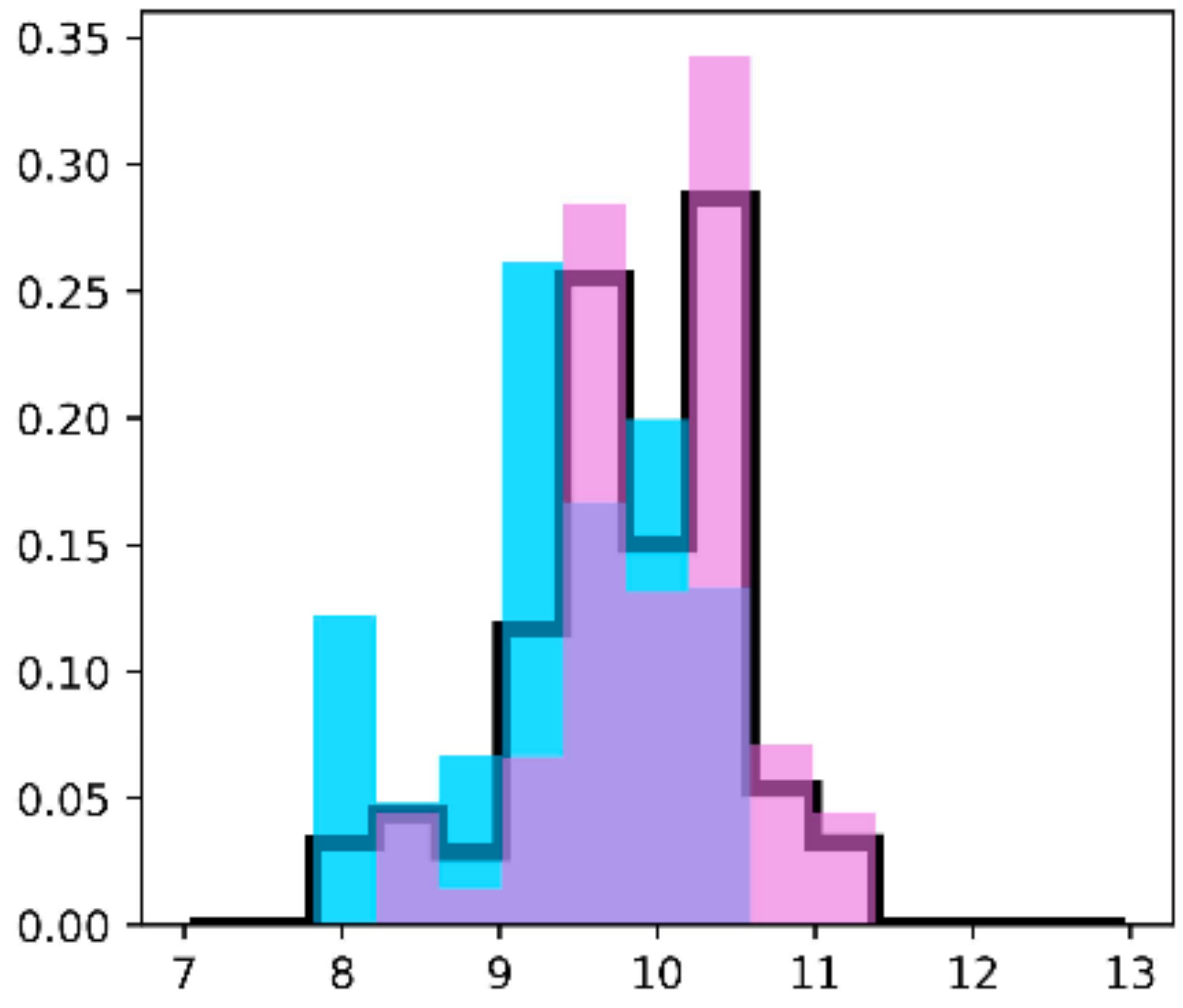
- ~40 localized to host galaxies, with z<=1
- Mostly spiral galaxies (star forming galaxies), but also some lenticular galaxies

Posterior distribution of the host galaxies

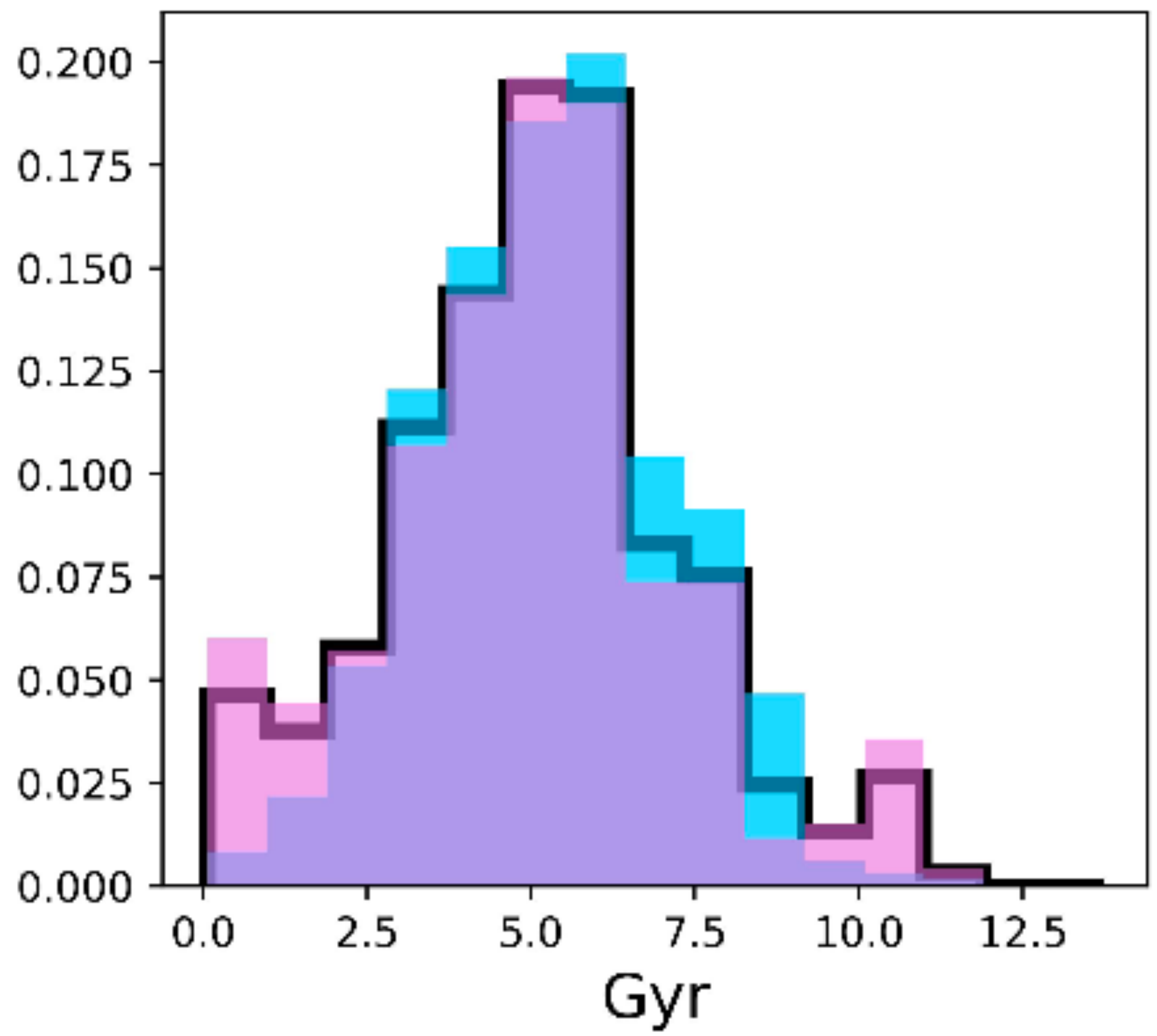
Gordon et al., 2023



Wide range of star formation rate. Median ≈ 1.3 M⊙/yr



Median stellar mass ≈ 10^9.9 M⊙

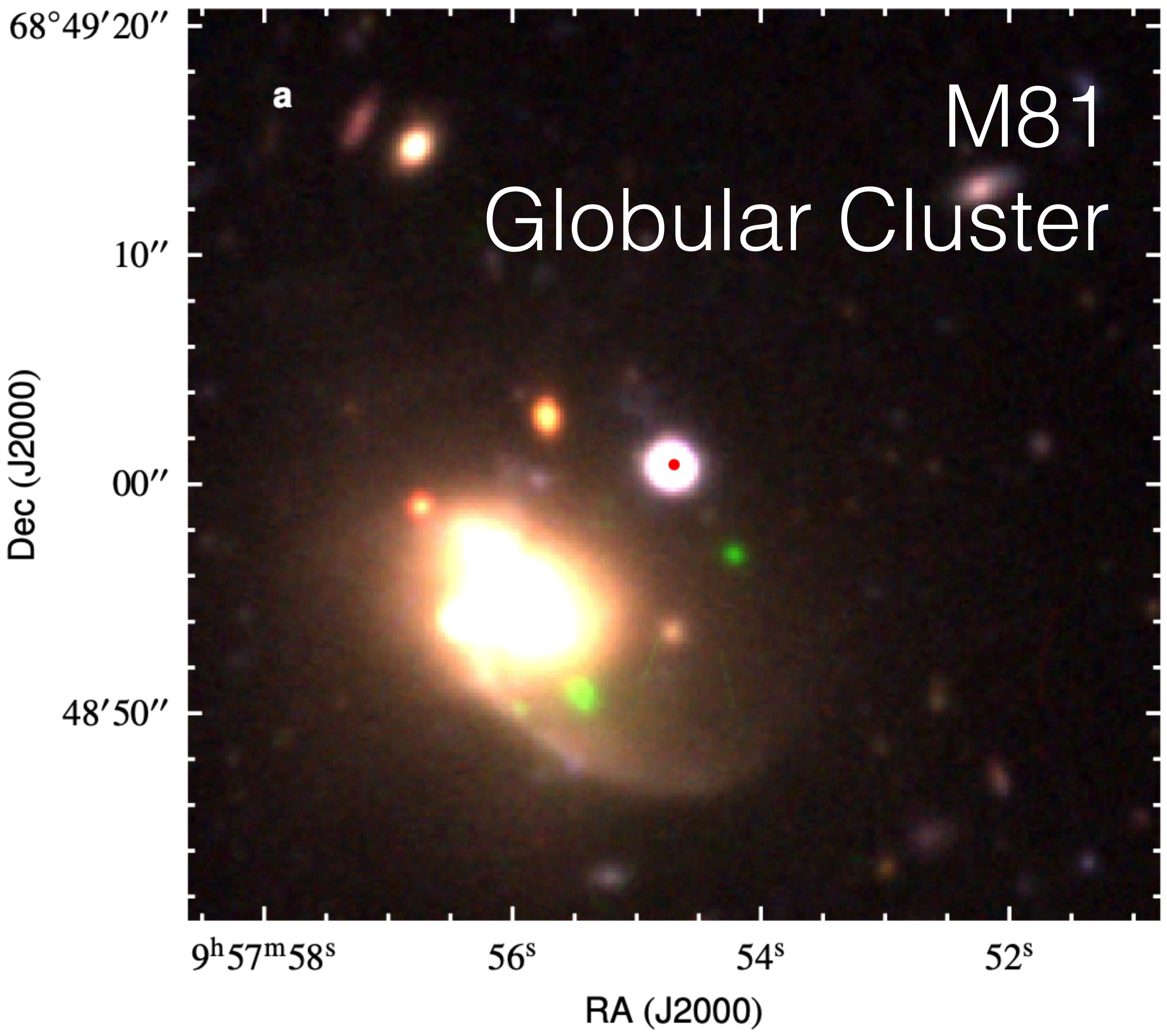


Mass-weighted median age ≈ 5.1 Gyr

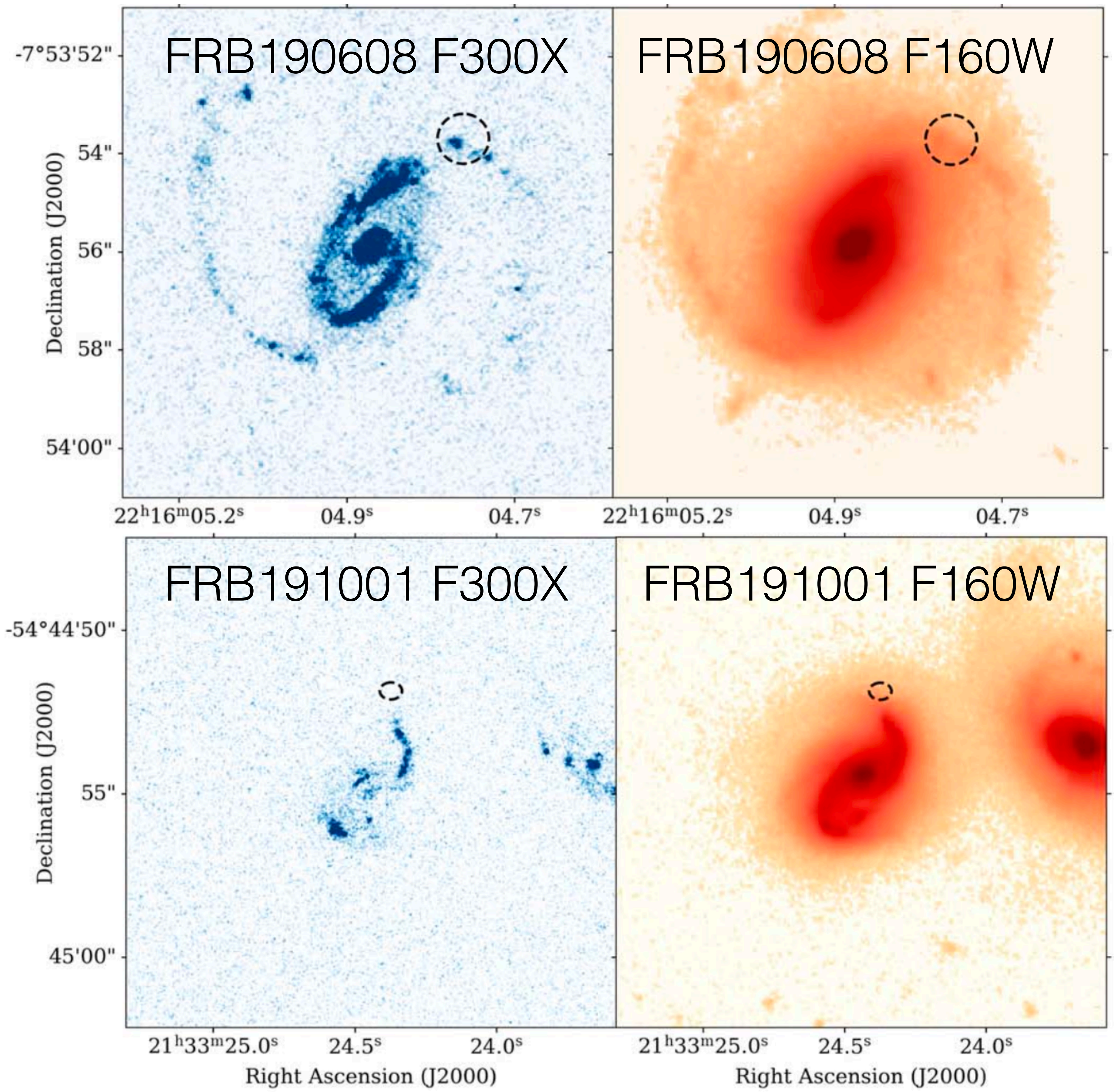
No statistically significant distinction between the hosts of repeaters and non-repeaters

Local host environments

Kirsten et al., 2021



Mannings et al., 2021



FRBs come from diverse local host environment and various types of host galaxies. Not always in the centre.

Why are FRBs important?

FRB as a probe of the Universe

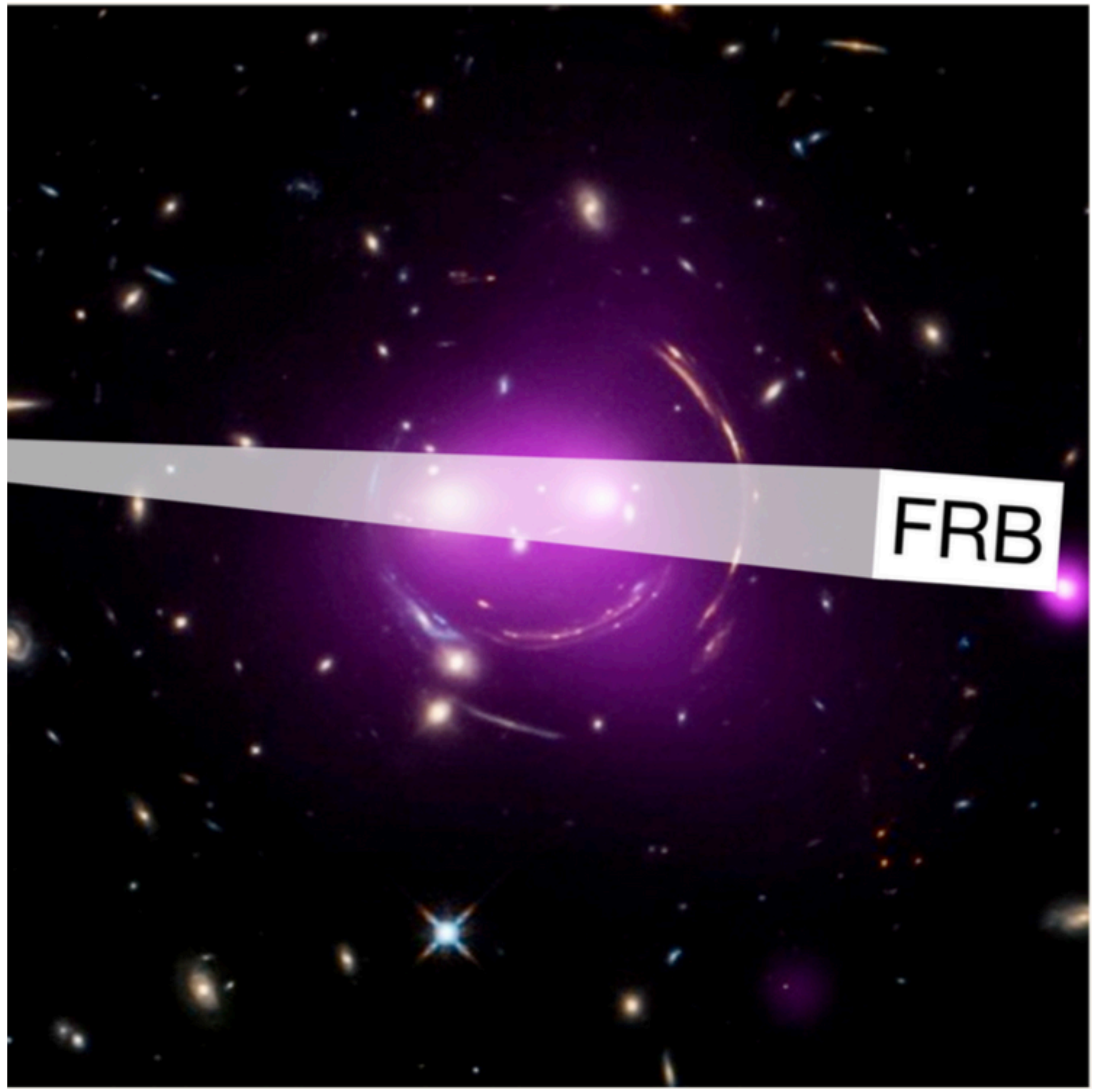
FRBs are the shortest-duration extragalactic transients, and the most compact known extragalactic sources of electromagnetic radiation.

—> FRB provides a clean signal to study these otherwise very hard to probe components

FRBs as a probe of the Universe

10^3 - 10^4 FRBs

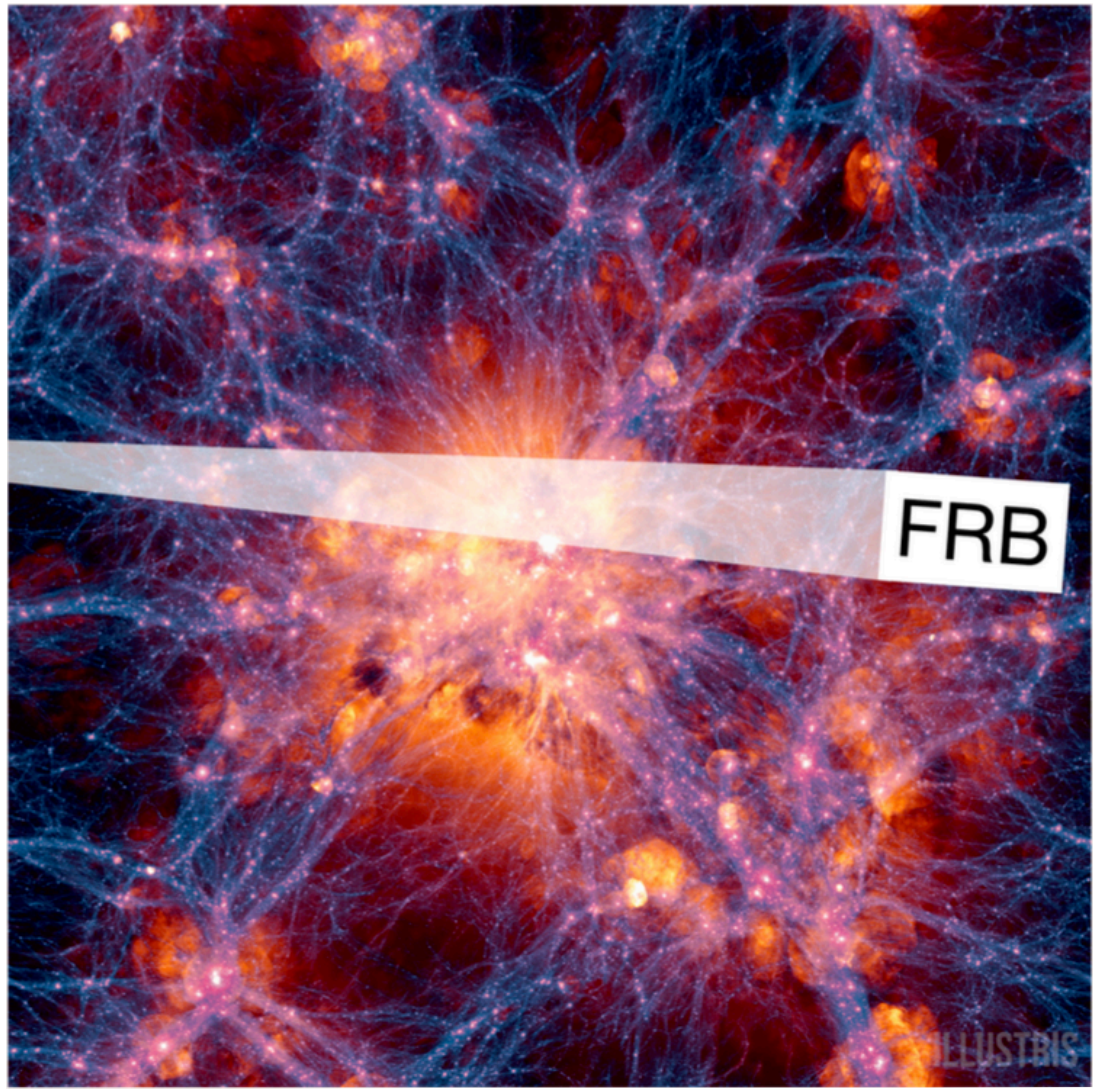
Detection of CGM/IGrM/ICM — CGM cooling — compact-object dark matter



X-ray: NASA/CXC/UA/J.Irwin et al; Optical: NASA/STScI

10^4 - 10^5 FRBs

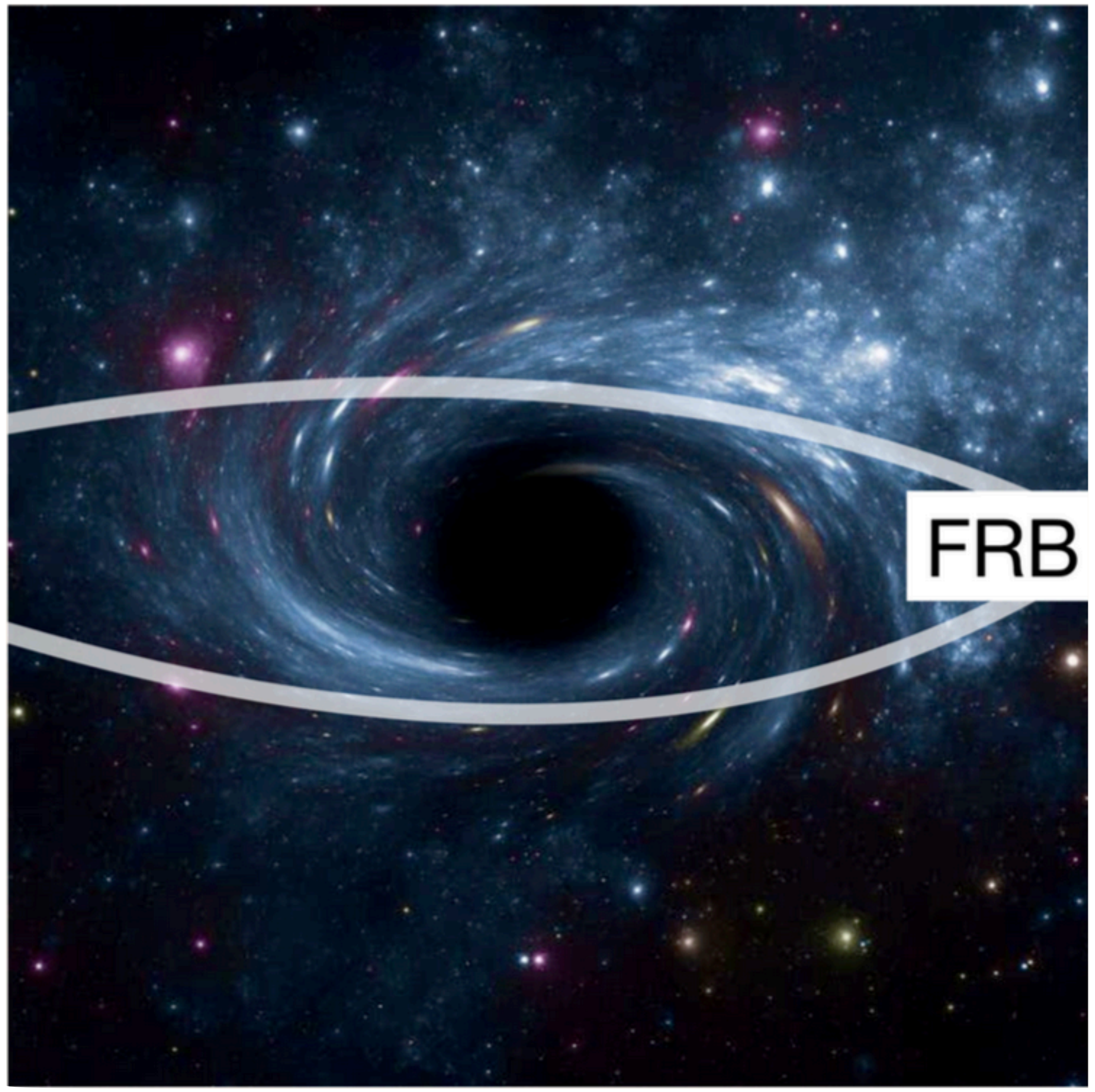
Cosmic web density — Helium reionization — DM-space clustering



Illustris Collaboration / Illustris Simulation

10^5 - 10^6 FRBs

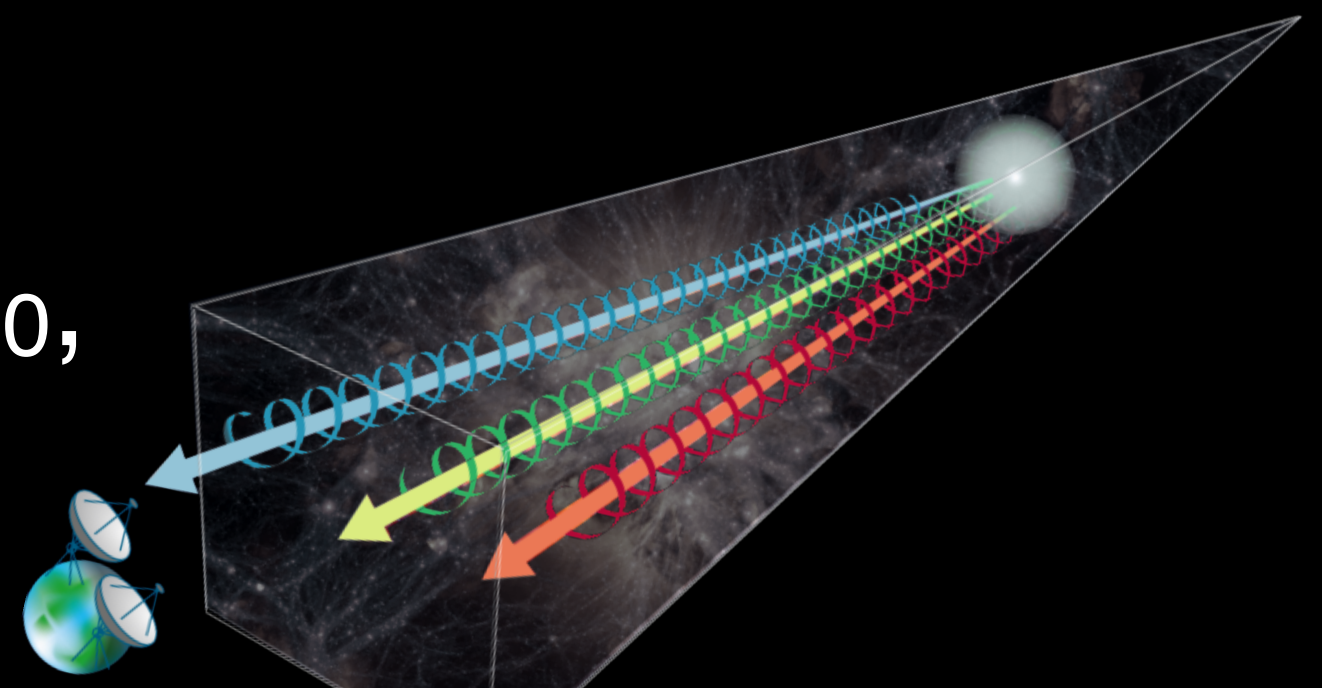
kSZ synergy — extragalactic micro- and nano-lenses



Vikram Ravi (Astro2020 White paper)

Summary and on-look

- Diverse observational properties —> yet unknown origin
- Next breakthroughs will probably come from Multi-wavelength observations and host localizations
- A large, well-localized FRB sample could soon be a reality:
  - CHORD, DSA2000, SKA : >500 mas-localisations per month
  - Challenge: how will the host galaxy identification be able to keep up with this high discovery rate?
- FRB as a probe for our Universe :
  - Localizing missing baryons, galactic halo, constrain H_0, deionization of He-II, lensing, IGM magnetic field…



Annexes

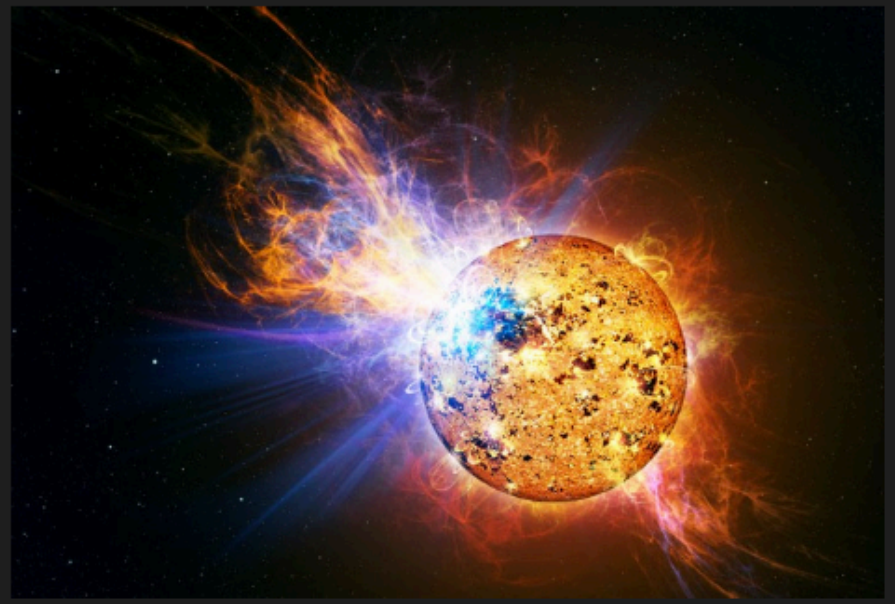
Back-up slides

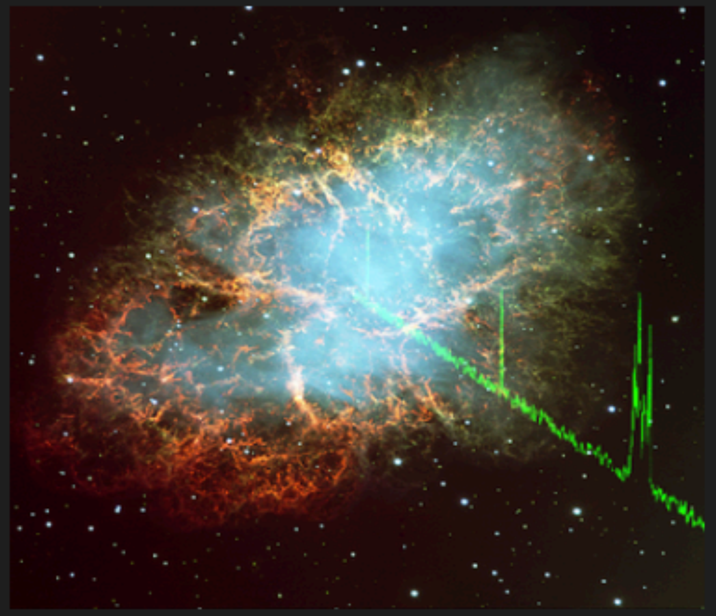
FRB MODELS

From Ben Stappers

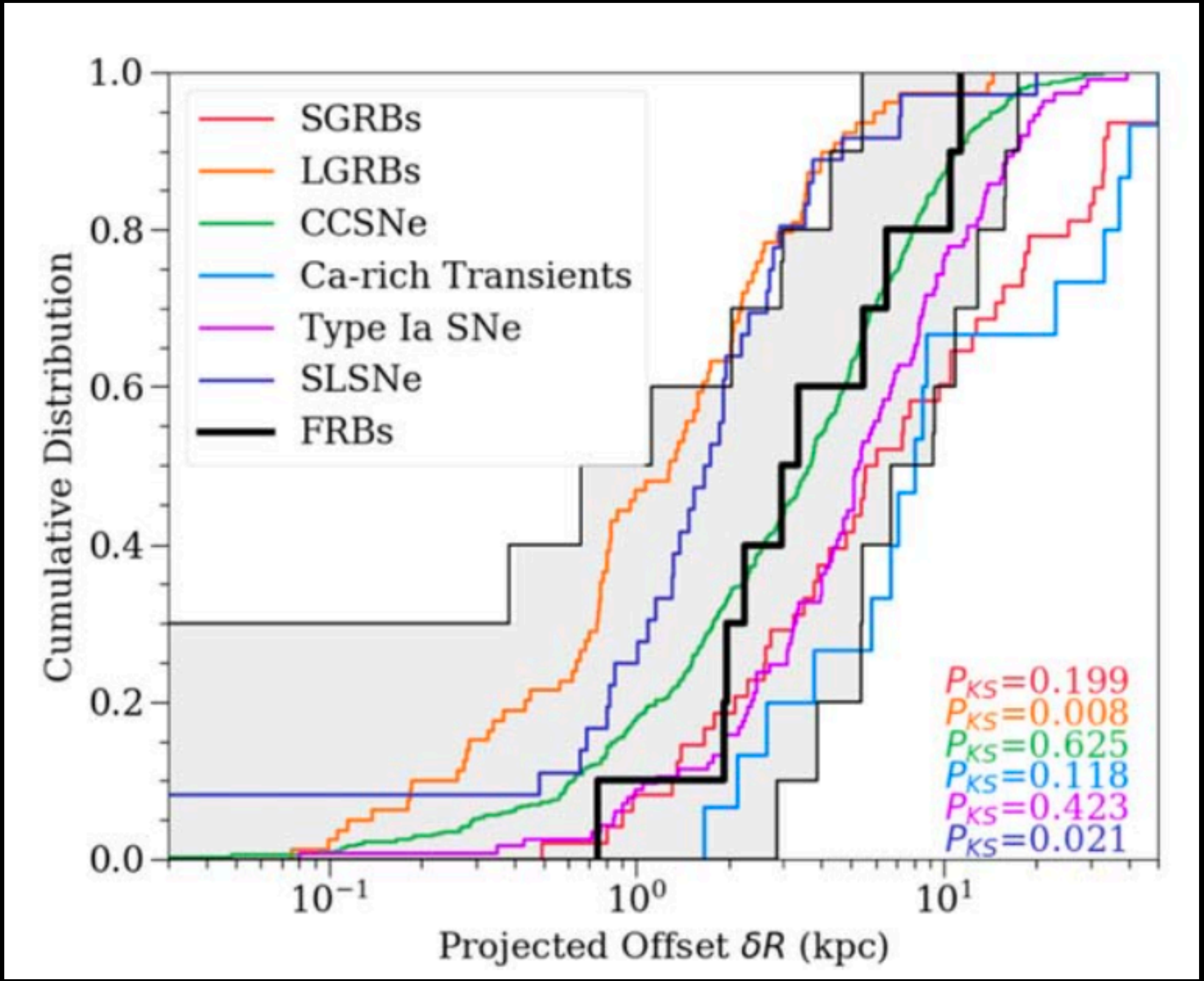
- Magnetospheric origin
- Shock wave models

Magnetars:	Pulsars:	White dwarfs:	Compact-object mergers:
Young magnetar from SLSN	Pulsar giant flares	WD from WD-WD merger	NS-NS merger
Magnetar from CCSN	Young SNR pulsars	White dwarf collapse (AIC)	WD-WD merger
Magnetar from DNS merger			NS-BH merger
			BH-BH merger





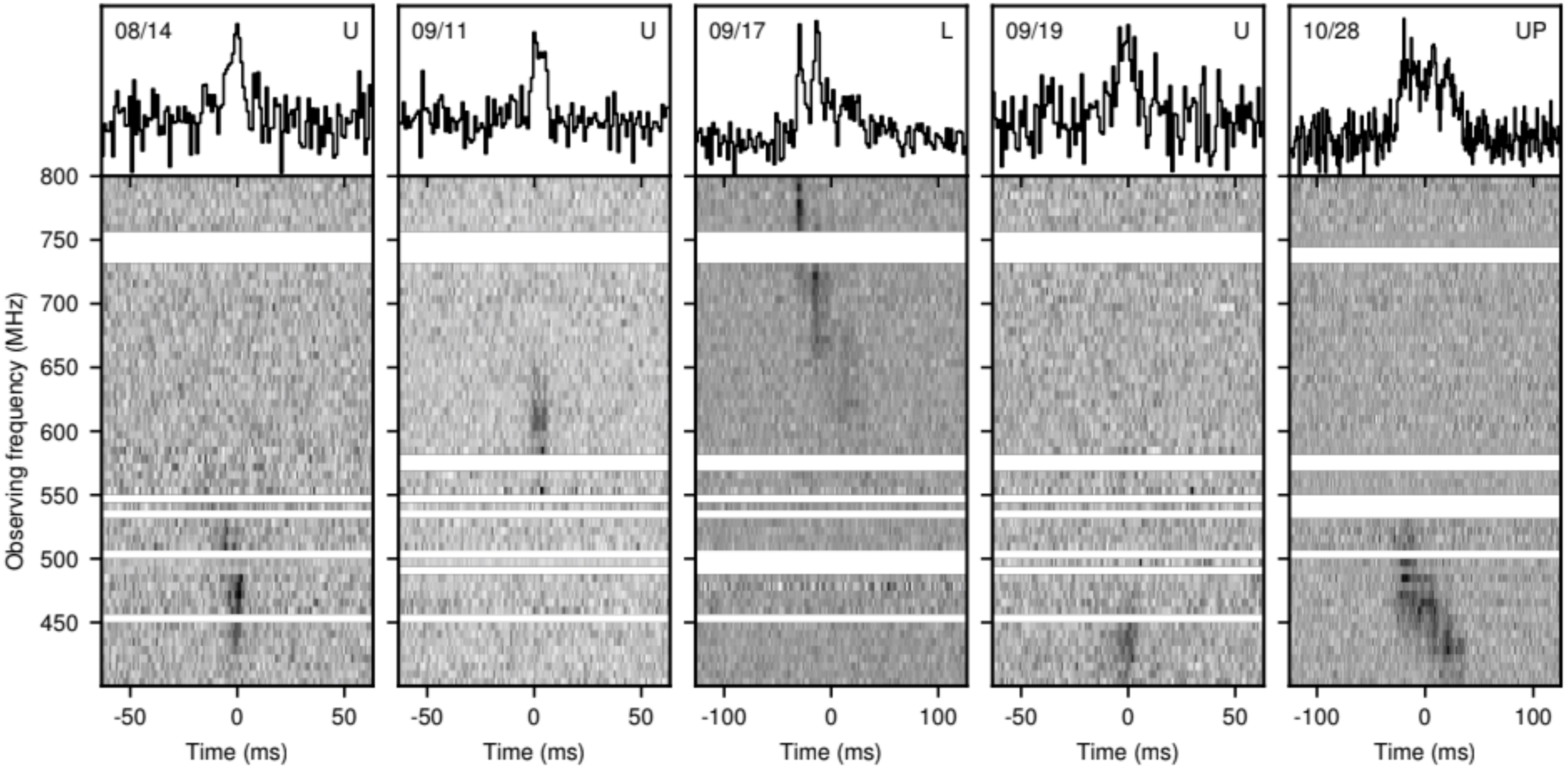
www.frbtheorycat.org



SGRBs
LGRBs
CCSNe
Ca-rich Transients
Type Ia SNe
SLSNe
FRBs
P_{KS}=0.199
P_{KS}=0.008
P_{KS}=0.625
P_{KS}=0.118
P_{KS}=0.423
P_{KS}=0.021
Cumulative Distribution
Projected Offset δR (kpc)

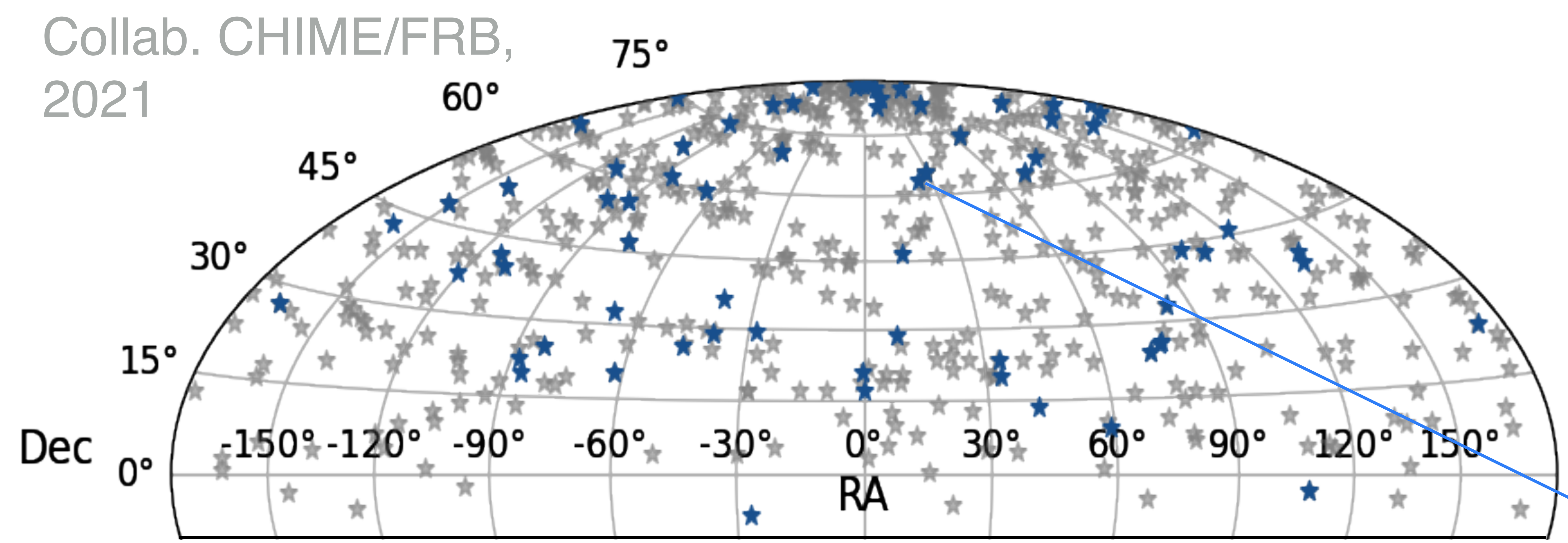
Les premiers résultats de CHIME

Collab. CHIME/FRB + Ng* 2019, Nature, 566, 235
*l'auteure correspondante



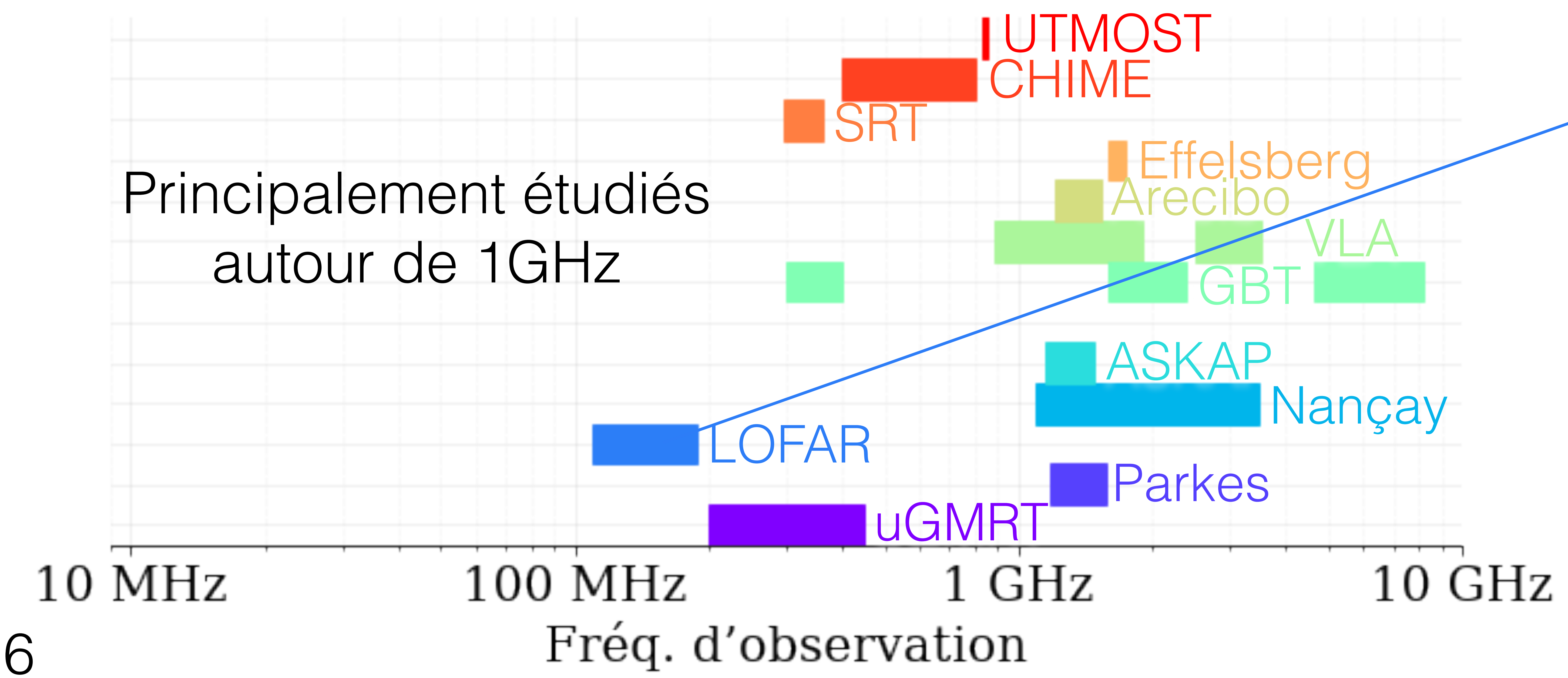
- Les FRBs sont abondants aux basses fréquences
- Certains sont récurrents

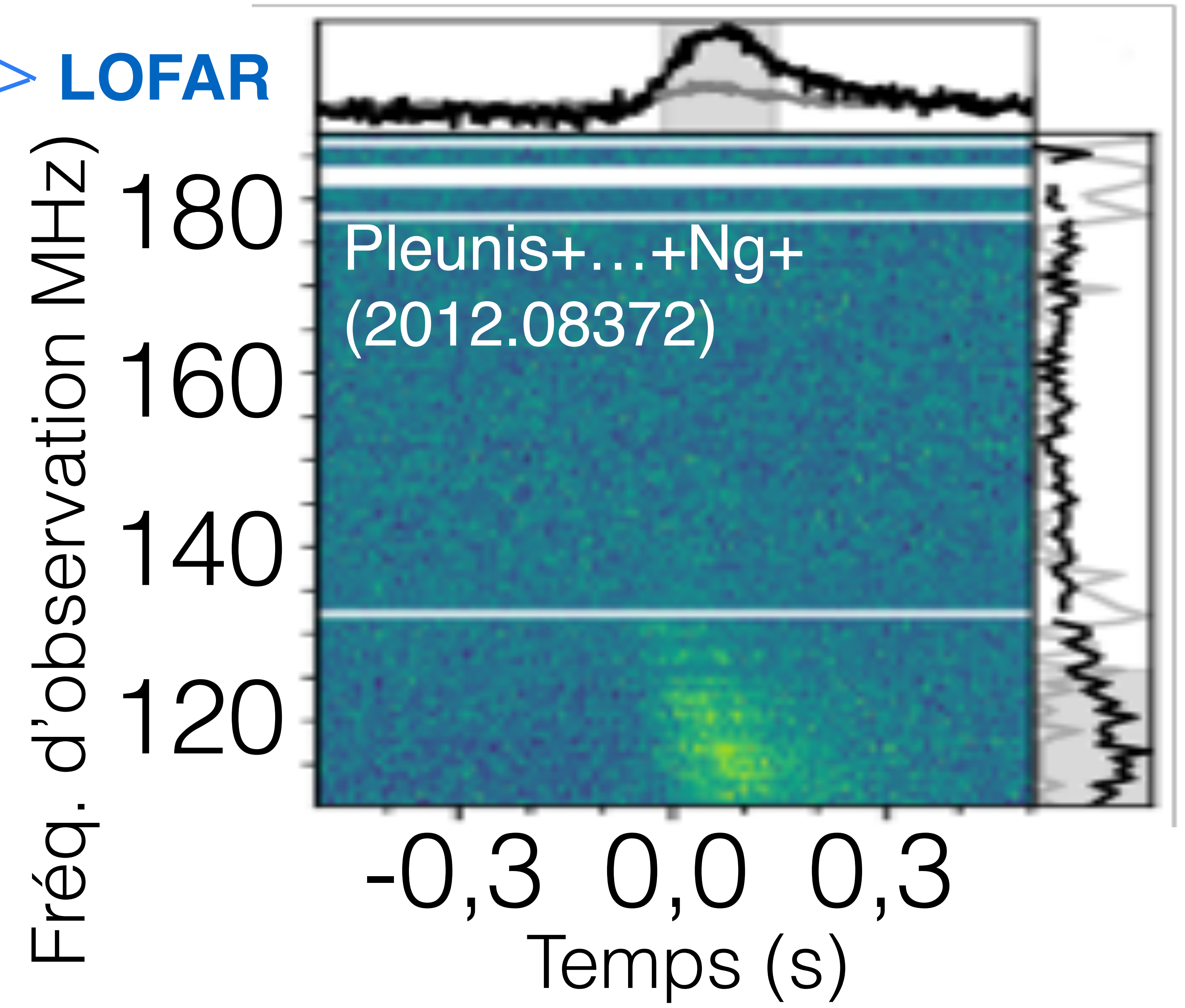
La bande basse fréquence de NenuFAR



Le 1er catalogue de CHIME contient :

- 535 FRBs

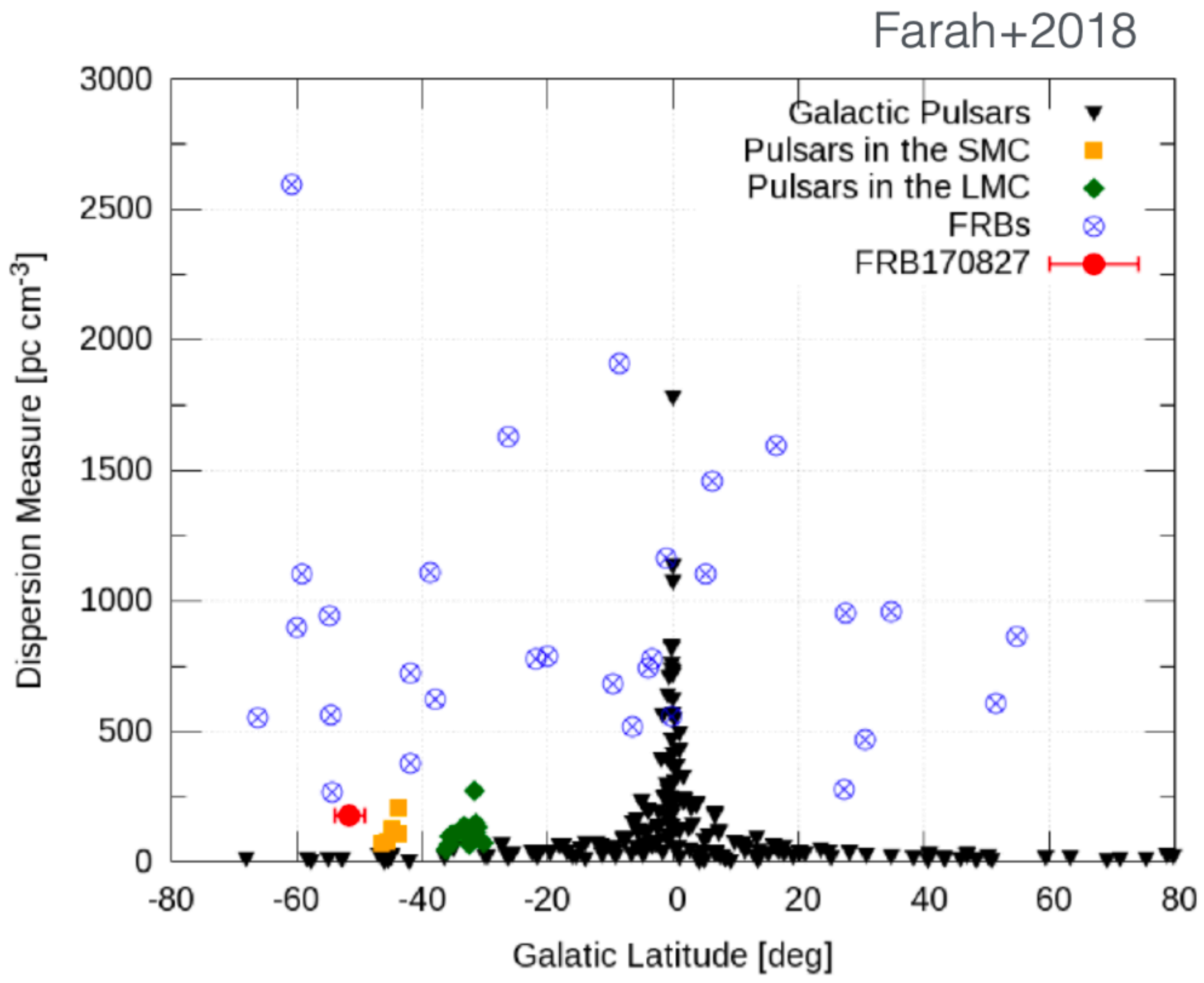


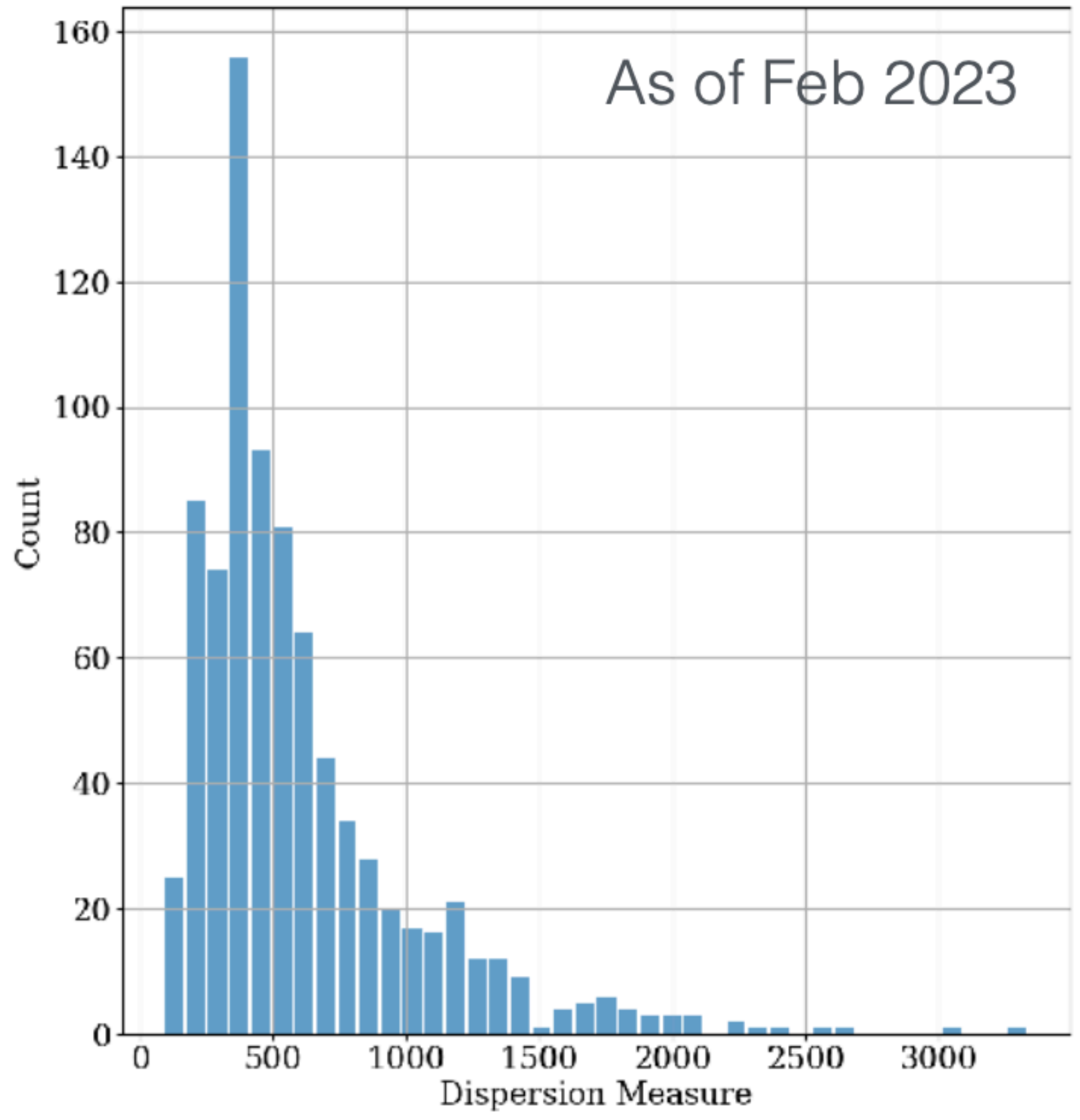


FRB localization (14 currently, 5 repeating)

	FRB121102	FRB180916	FRB180924	FRB181112	FRB190523	20190711A	SGR 1935+2154	20200120E	20181030
redshift	0,2	0,0337	0,32	0,47	0,66	0.522	0	−0.000113 (3.6Mpc)	N/A (20 Mpc)
galaxy type	low metallicity, irregular dwarf SF region	SF, massive spiral	massive elliptical / early spiral, luminous, negligible SF	massive elliptical	high metallicity, massive elliptical or SF	Massive, SF	MW	M81 - spiral galaxy Globular cluster (old stars)	NGC3252 - star-forming spiral
burst	repeating, clustered, perioidic (160d)	repeating (R2), periodic (16d)	One-off	One-off	One-off	Repeating	One-off so far	Repeating (R3)	Repeating (R4)
Model	HMXB?	HMXB					Magnetar	AIC magnetar GP from MSP	
Discover ed by	Arecibo	CHIME	ASKAP	ASKAP	DSA10	ASKAP	CHIME STARE2	CHIME	CHIME

FRB being extragalactic





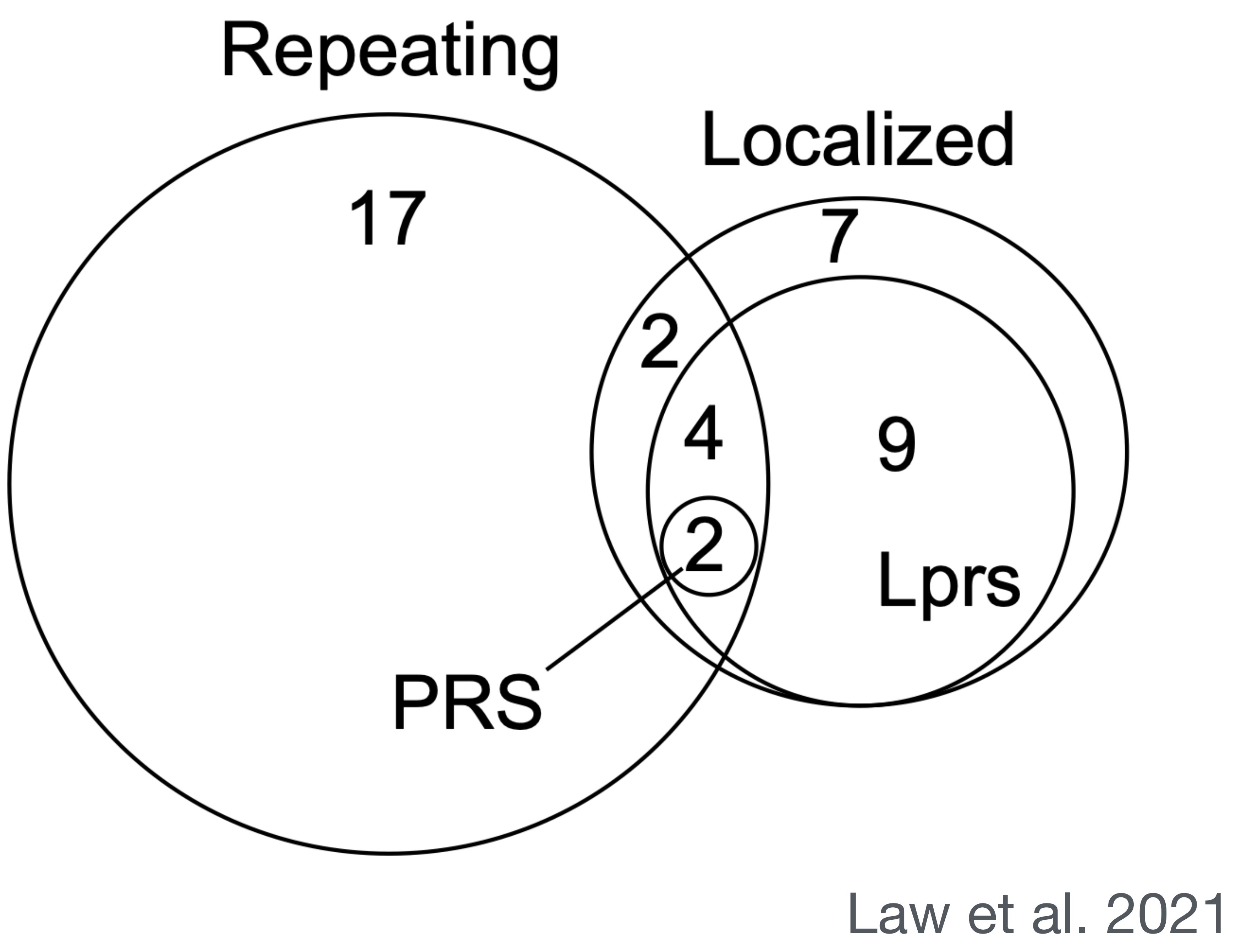


Figure 1. A Venn diagram showing how FRBs can be assigned to subgroups. The "repeating" circle includes 21 repeating FRBs listed in the Transient Name Server (http://wis-tns.org). The "localized" circle includes all sources shown in Table 1. The "Lprs" circle includes the subset of localized FRBs with detections or luminosity limits $L_{r,PRS} <= 10^{29}\,\mathrm{erg\,s^{-1}\,Hz^{-1}}$; this sample is also shown in Figure 2. Finally, the "PRS" circle shows the two localized FRBs with PRSs.

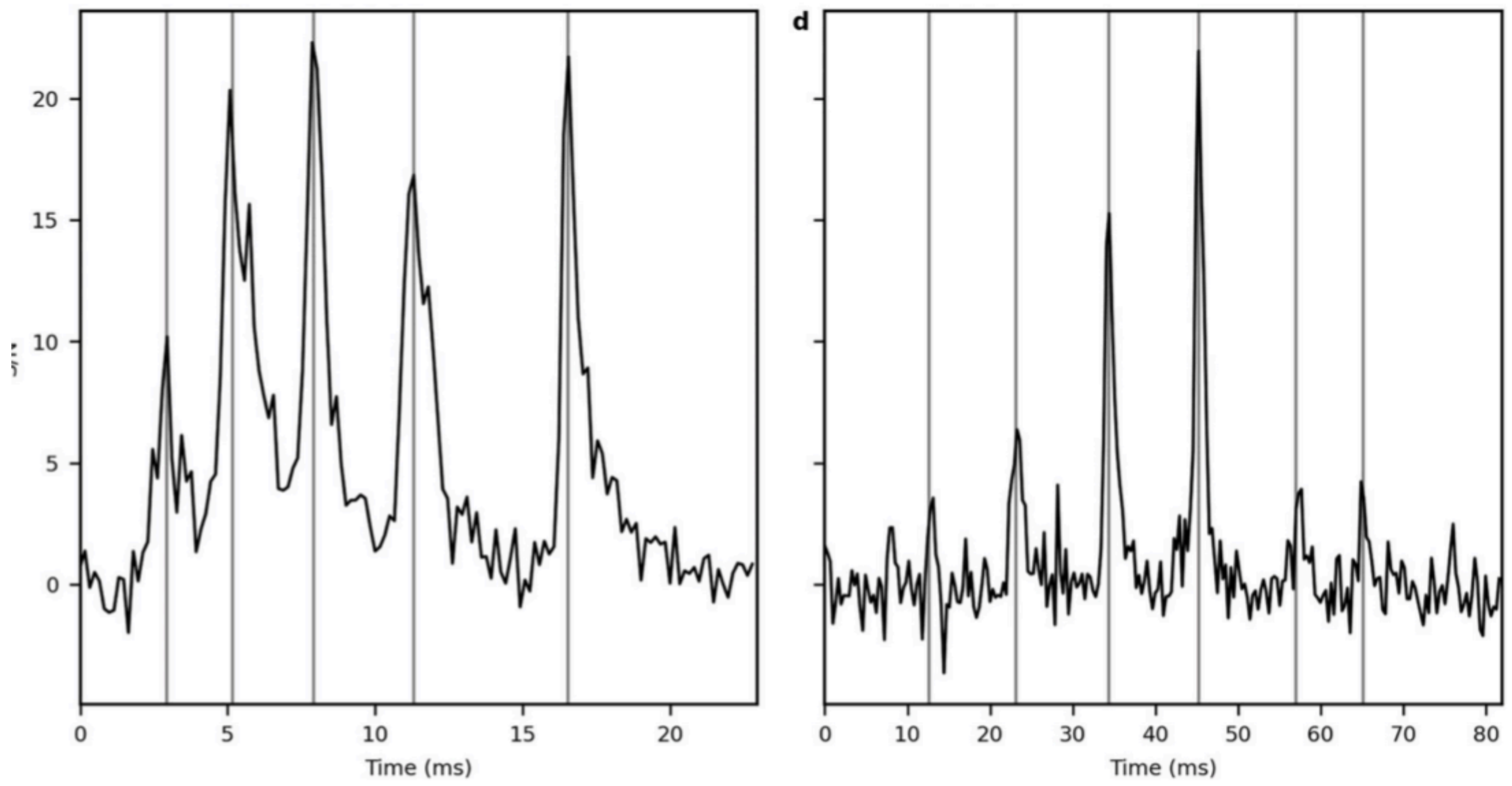
Periodic Fast Radio Burst?

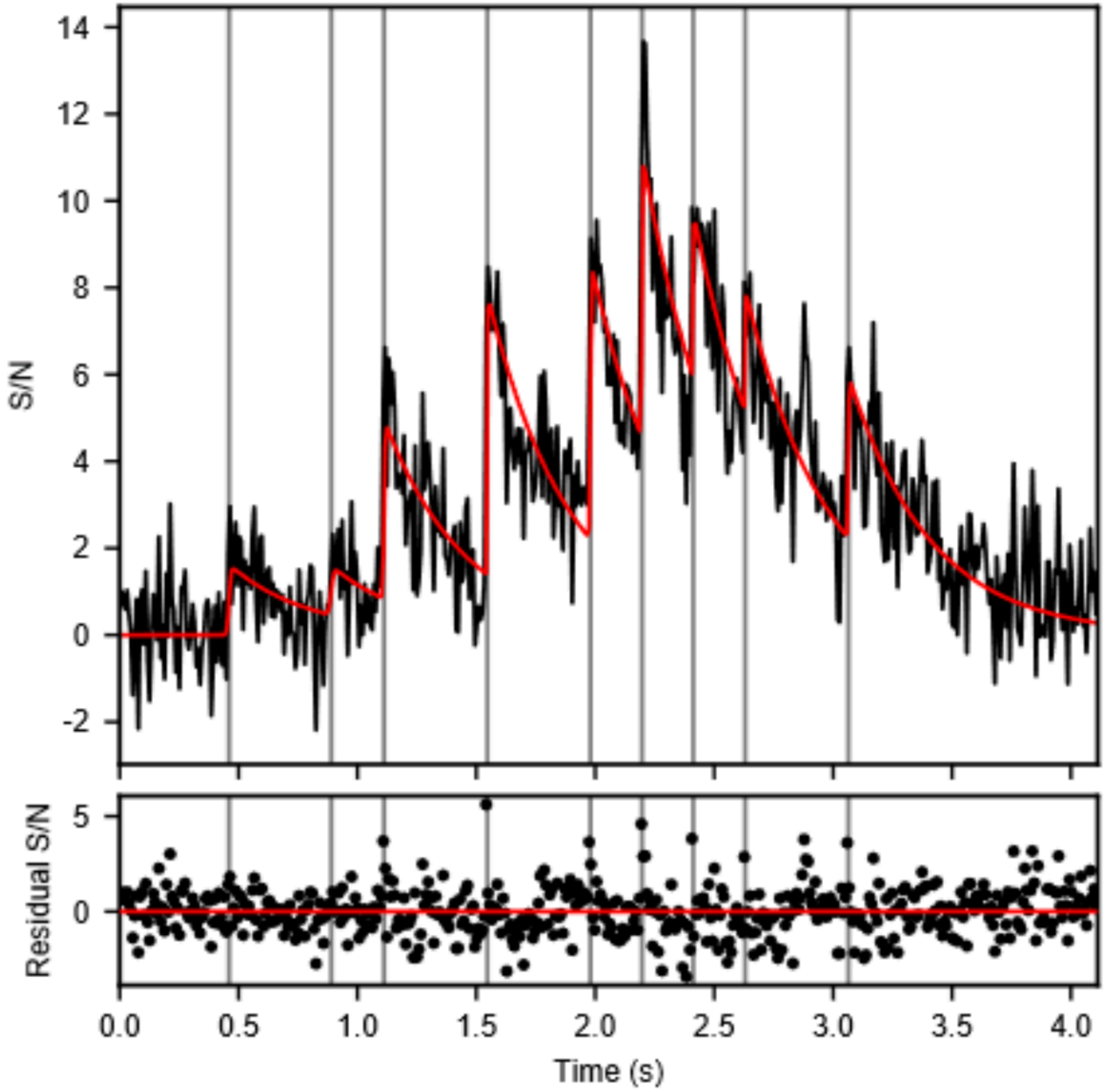
Slide from Paul Scholz

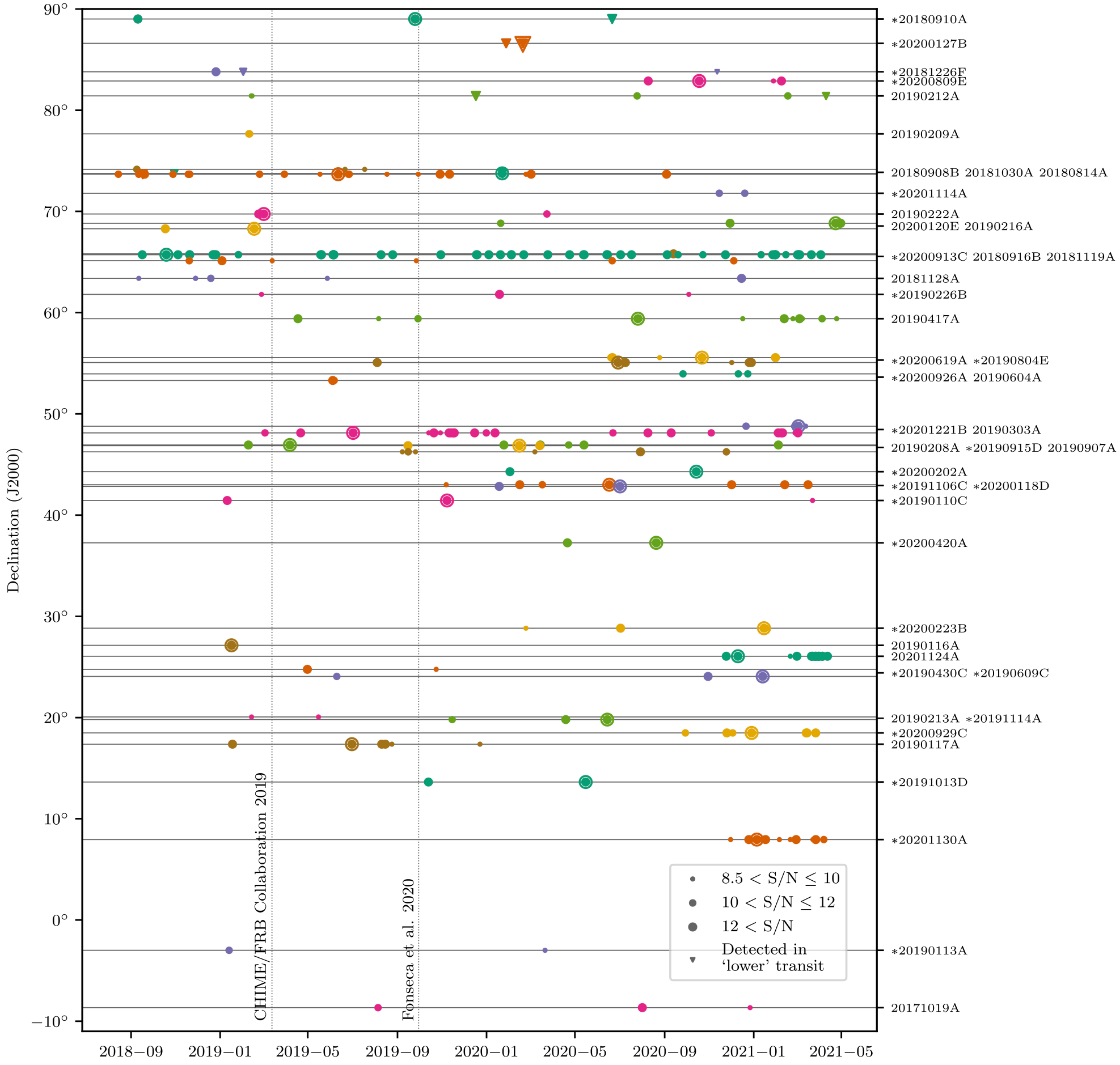
Sub-second periodicity in a fast radio burst (CHIME/FRB Collaboration 2022)

216.8(1) ms periodicity in ~3 second long burst.

Other similar ones:



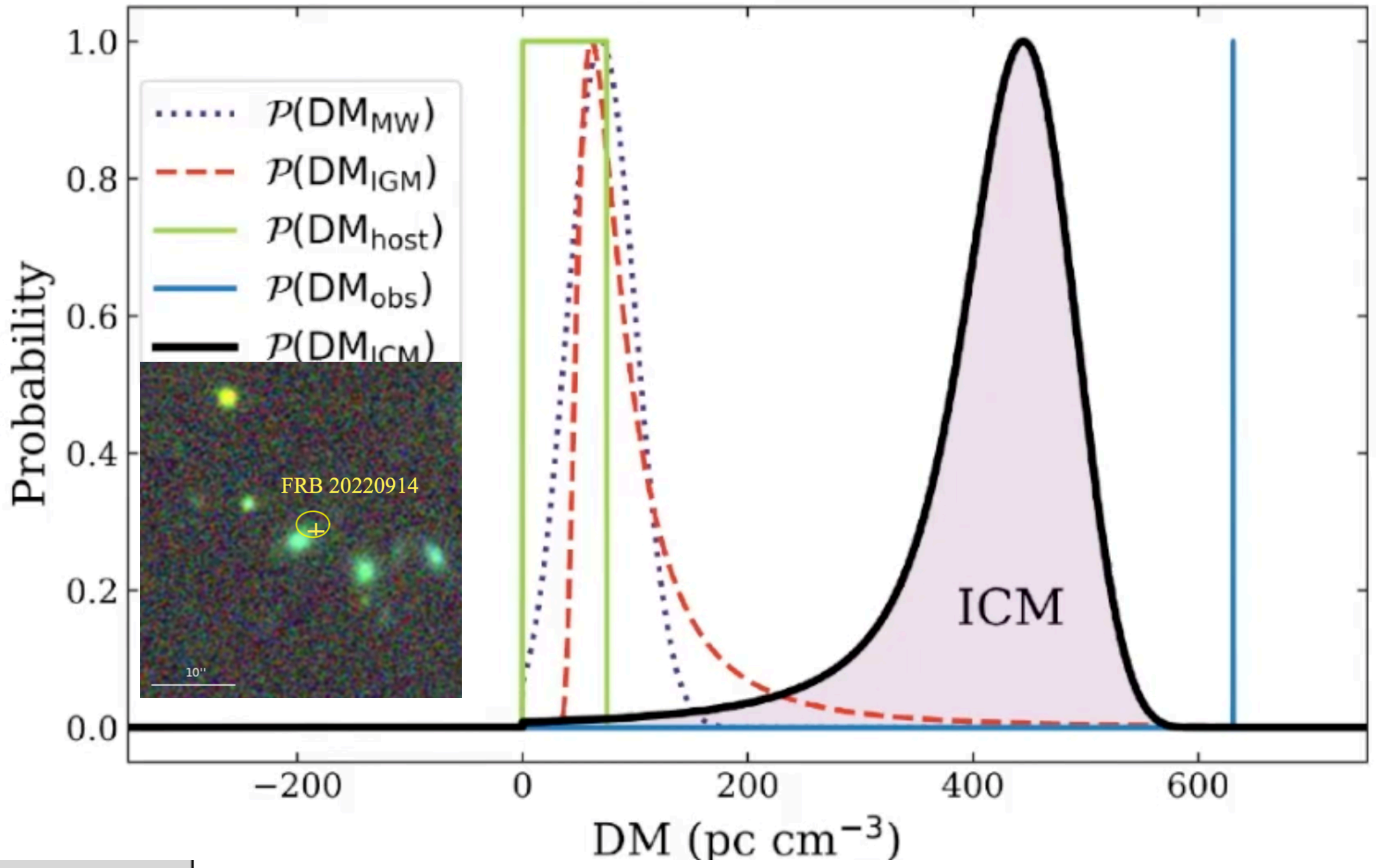




Declination (J2000)
90°
80°
70°
60°
50°
40°
30°
20°
10°
0°
−10°
2018−09
2019−01
2019−05
2019−09
2020−01
2020−05
2020−09
2021−01
2021−05
CHIME/FRB Collaboration 2019
Fonseca et al. 2020
8.5 < S/N ≤ 10
10 < S/N ≤ 12
12 < S/N
Detected in 'lower' transit
*20180910A
*20200127B
*20181226F
*20200809E
20190212A
20190209A
20180908B 20181030A 20180814A
*20201114A
20190222A
20200120E 20190216A
*20200913C 20180916B 20181119A
20181128A
*20190226B
20190417A
*20200619A *20190804E
*20200926A 20190604A
*20201221B 20190303A
20190208A *20190915D 20190907A
*20200202A
*20191106C *20200118D
*20190110C
*20200420A
*20200223B
20190116A
20201124A
*20190430C *20190609C
20190213A *20191114A
*20200929C
20190117A
*20191013D
*20201130A
*20190113A
20171019A

FRB comme sonde pour notre Univers

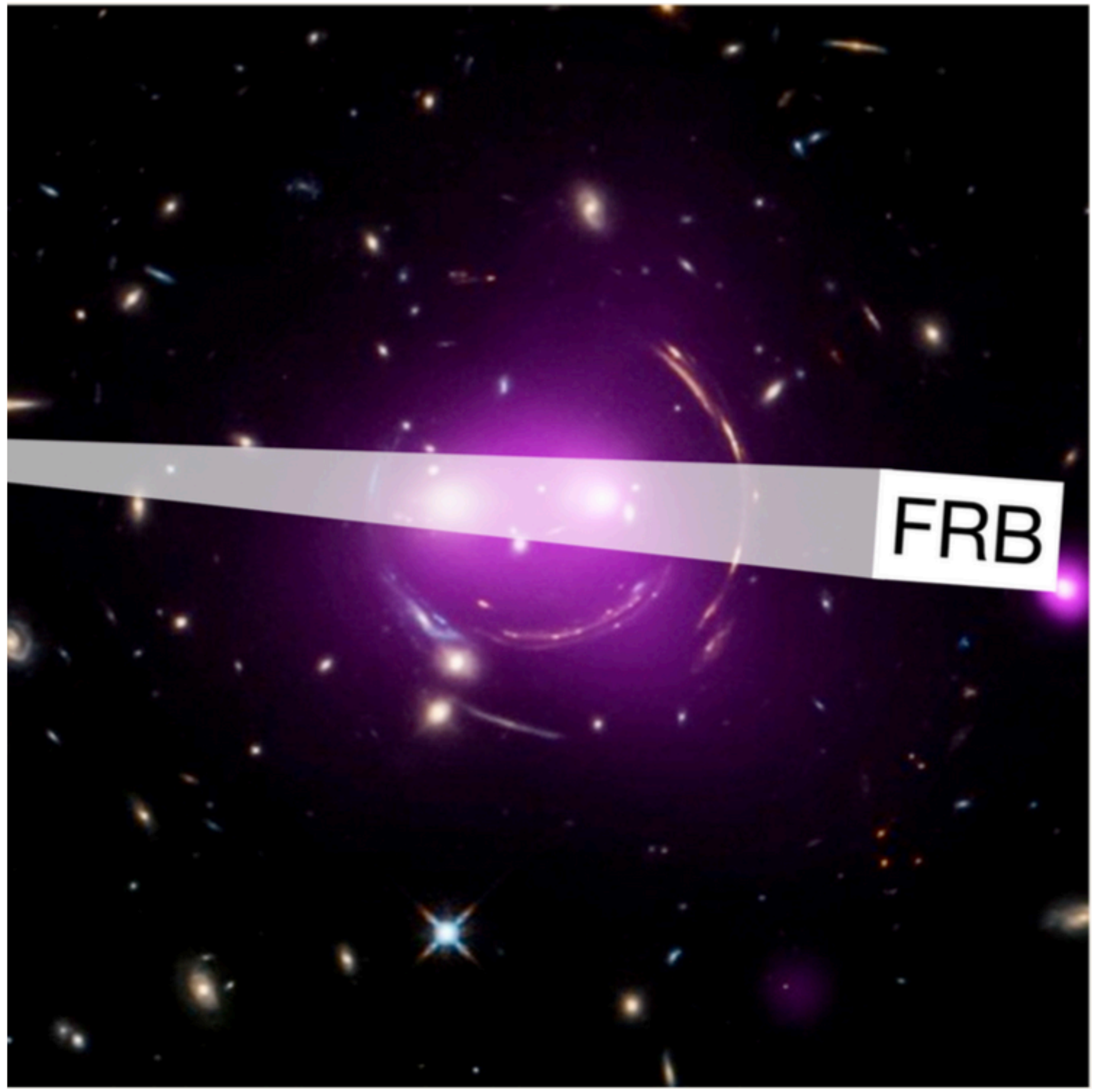
Connor et al., 2023



Étudier le milieu intracluster (ICM) des amas Abell.

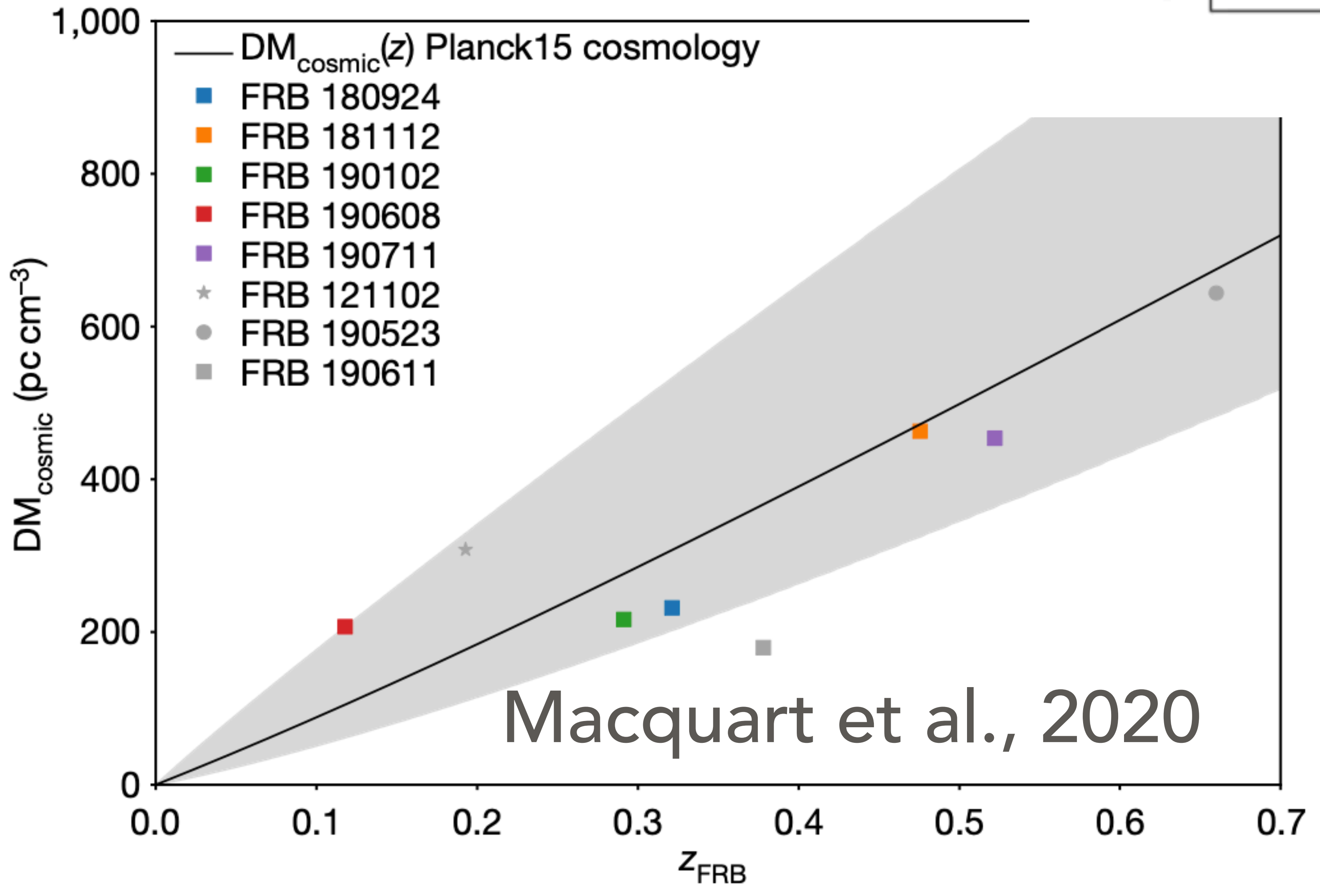
10^3 - 10^4 FRBs

Detection of CGM/IGrM/ICM — CGM cooling — compact-object dark matter



X-ray: NASA/CXC/UA/J.Irwin et al; Optical: NASA/STScI

Vikram Ravi (Astro2020 White paper)



Détection des baryons manquants.