A REVIEW OF FAST RADIO BURSTS

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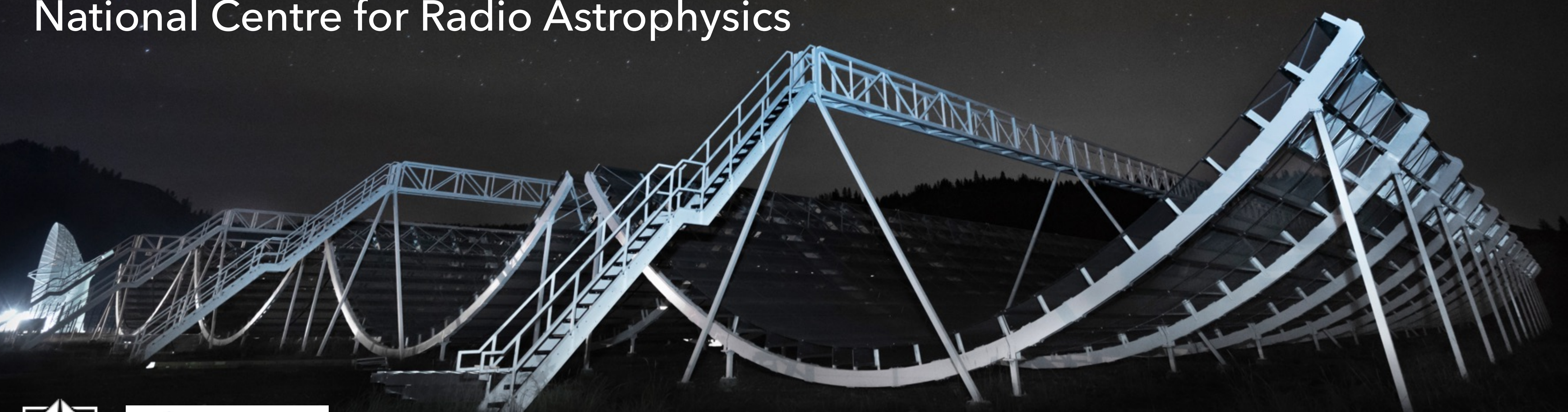

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CIFAR Azrieli Global Scholar,
Gravity & the Extreme Universe Program

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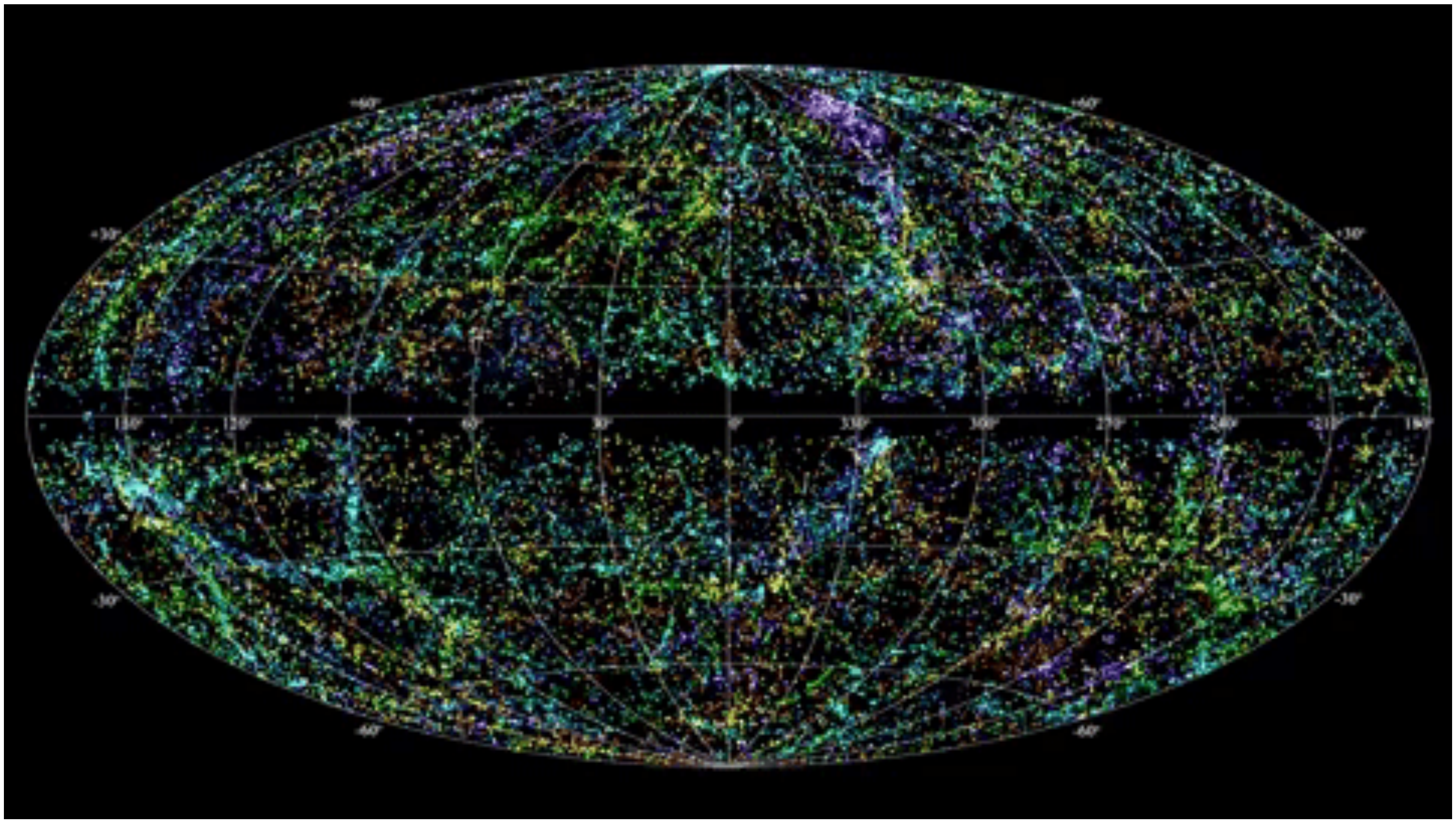
ASTROPHYSICAL MYSTERY!



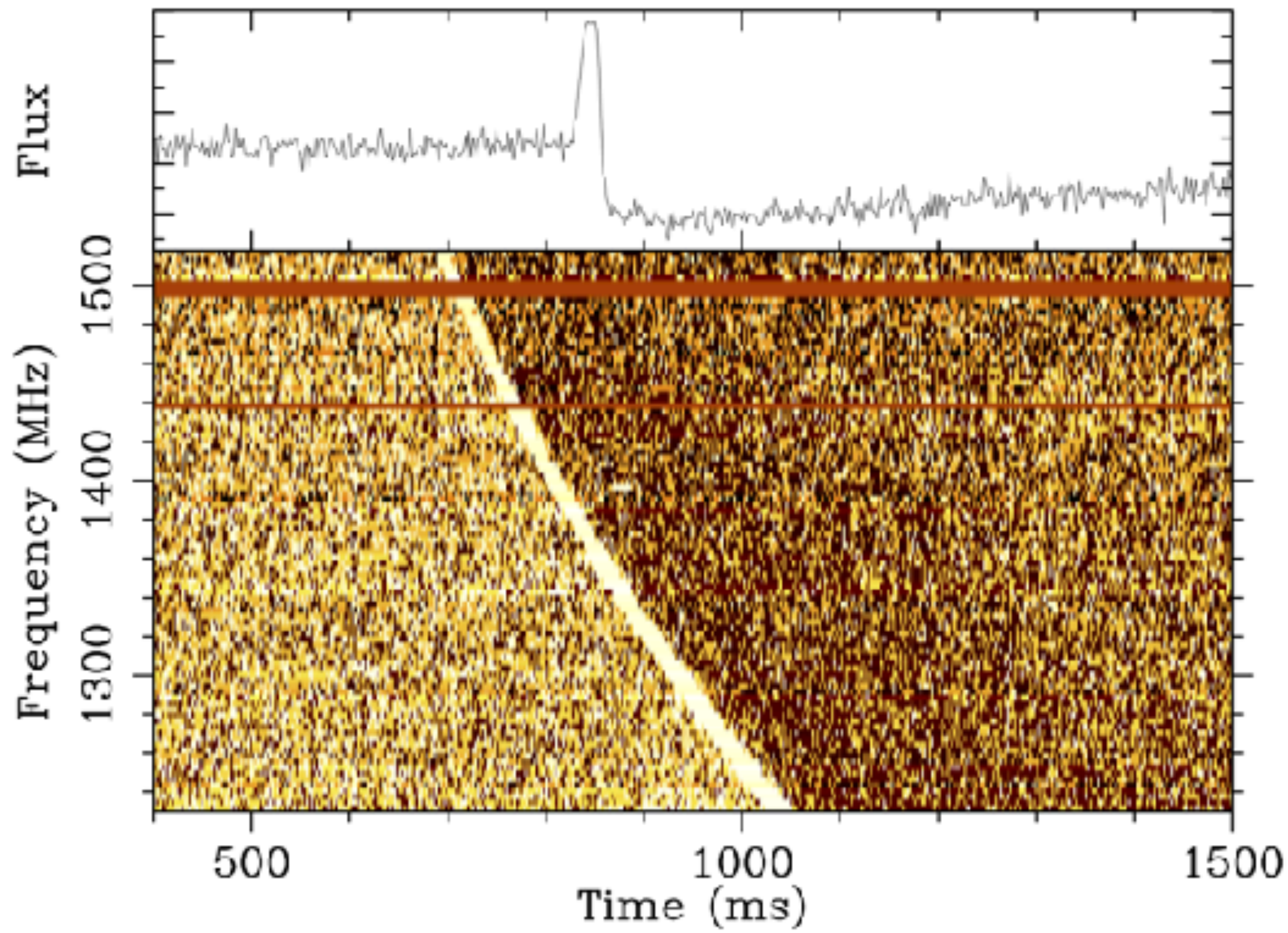
Short + Bright Radio Emission (few repeat!)

~600 per sky per day

(CHIME/FRB Collaboration+ 2021 at 5 Jy-ms, t_{scat} < 10ms)

ASTROPHYSICAL MYSTERY!

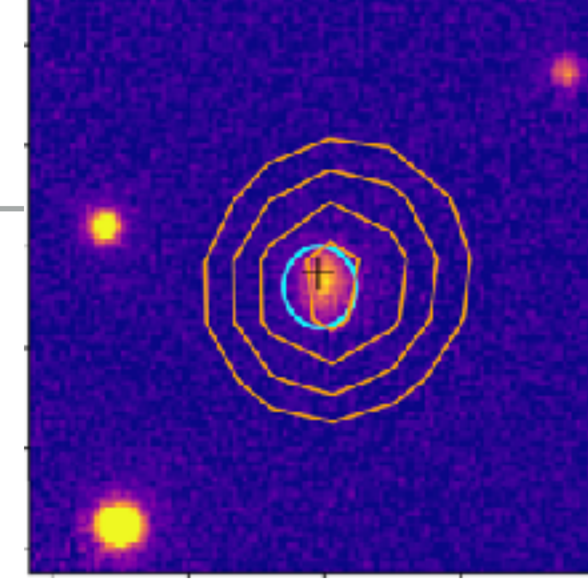
- Dispersed: arrival time is freq dependent
  $t_{arr} \propto DM\ \upsilon^{-2}$ $(\nu \ggg \nu_{plasma})$
- Dispersion measure
  $DM = \int n_e dl$
- DM not apriori known
  - Computationally expensive search
- Proxy for distance
  (after subtracting MW DM)



Lorimer et. al. 2007
(Fig from Petroff et al 2019)

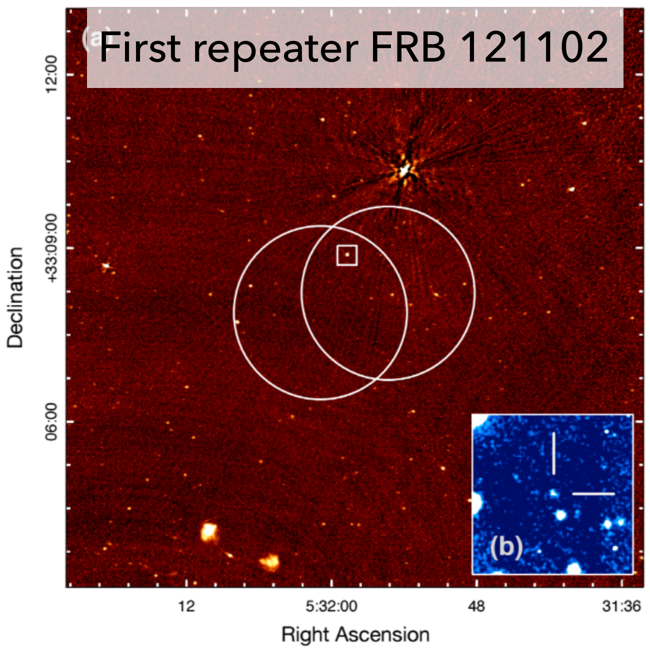
EXTRAGALACTIC LOCATIONS

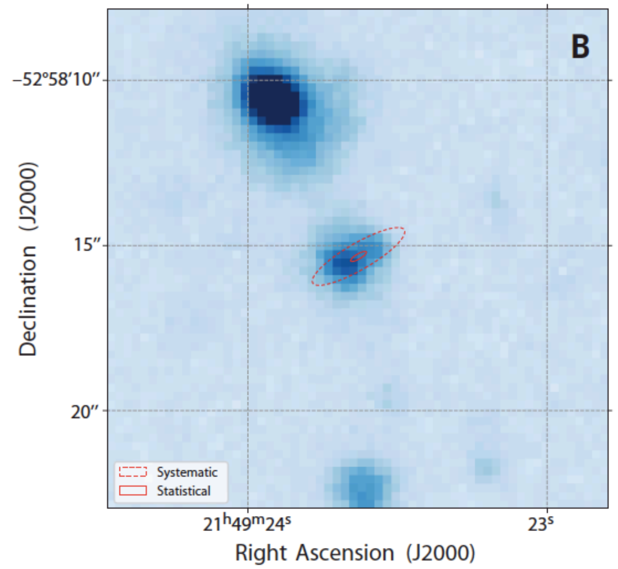
FRB 20201124A
z = 0.098
(Multiple groups)
Fig from Ravi et al 2021



Chatterjee .. SPT et al 2017
Tendulkar et al 2017

z = 0.197



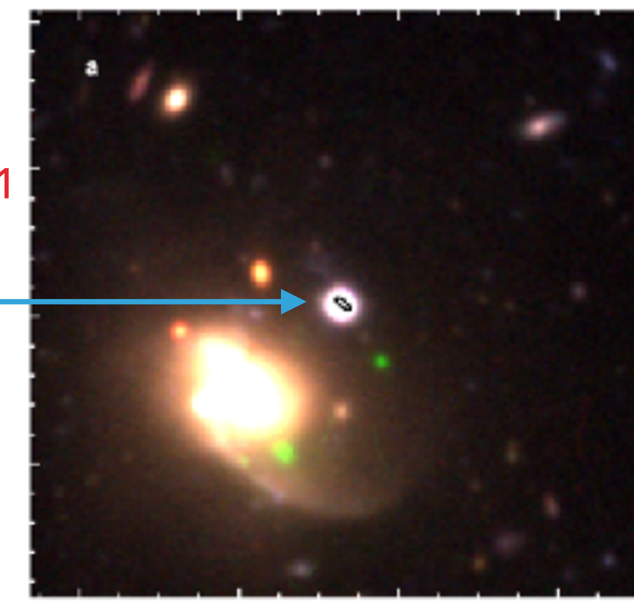


Prochaska et al. 2019

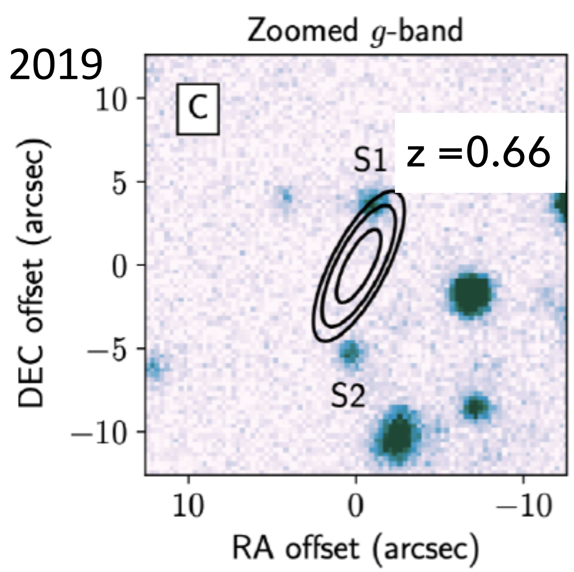
z =0.47

Repeater in a GC in M81

FRB 20200120E
d = 3.6 Mpc
Kirsten .. SPT et al 2022

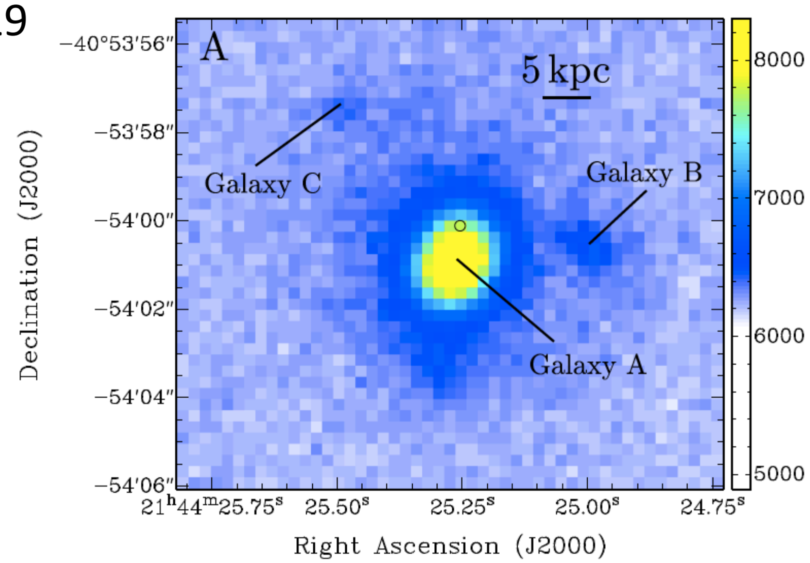


Ravi et al. 2019

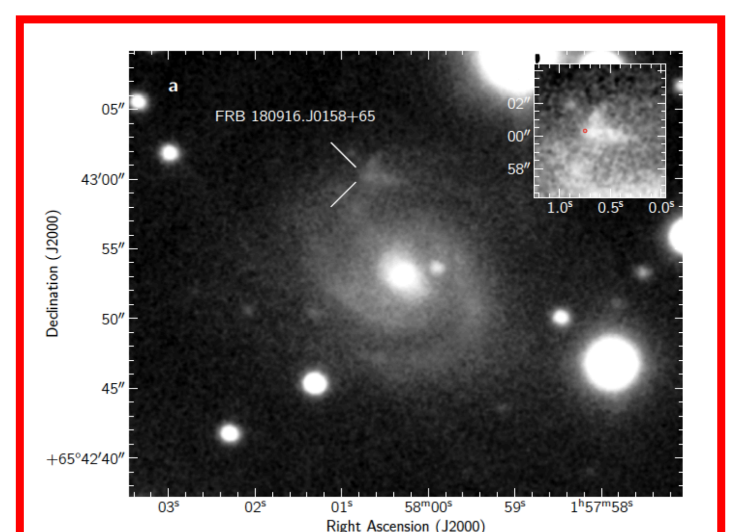


Bannister et al. 2019

z = 0.32



MOST FRBS ARE NOT LOCALISED TO THIS PRECISION YET



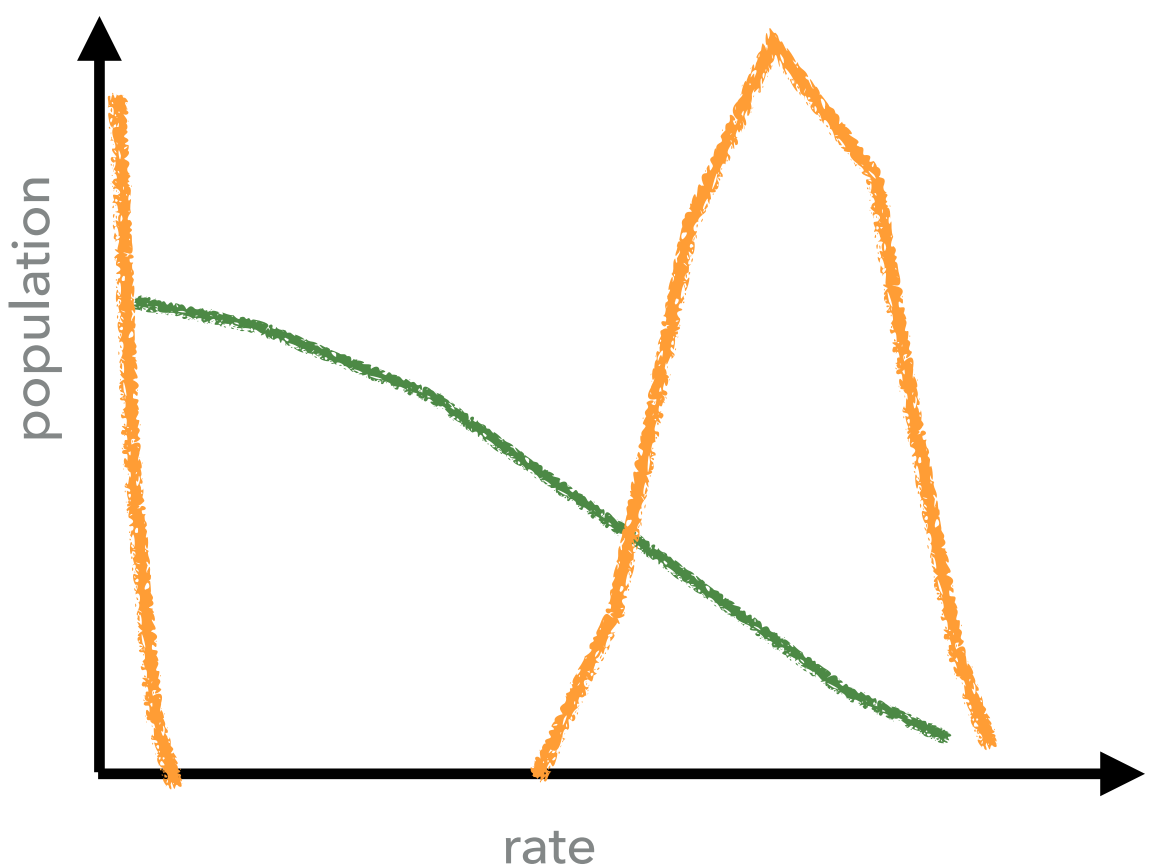
Marcote .. SPT et al 2020

z =0.03 (150 Mpc)

REPEATERS AND NON-REPEATERS

- Some FRBs repeat – same position, almost the same DM
  Most FRBs haven't been seen to repeat
  Despite ~10^1 – 10^3 hrs of obs

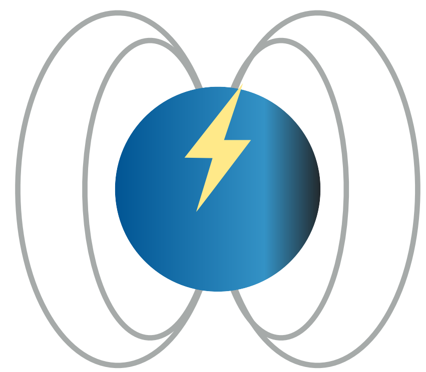
- Are they different populations? or different ends of the same population?



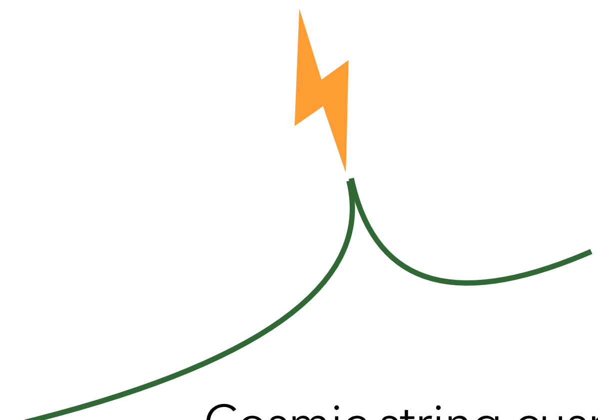
WHAT ARE THEY?

- ~10^{10-12} times brighter than Crab giant pulses
- Magnetar? NS Binary? More exotic?

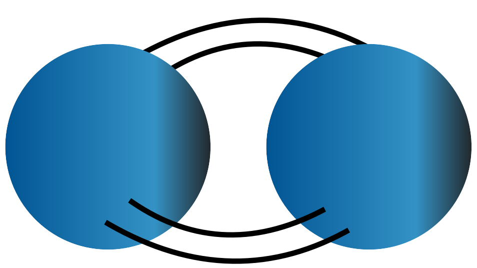
http://frbtheorycat.org Platts .. SPT et al 2019



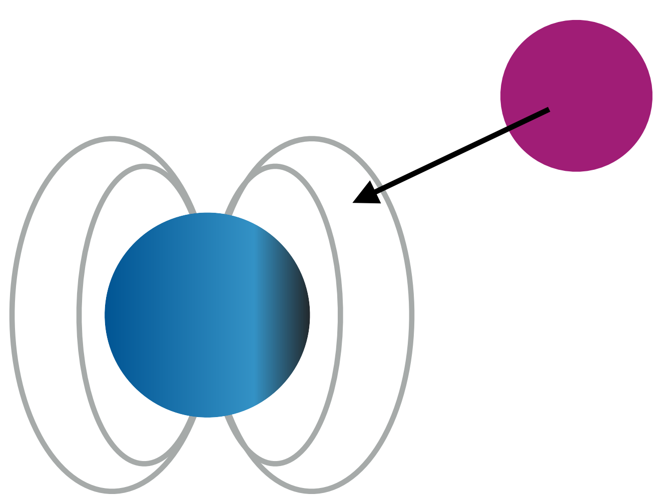
Magnetic field reconnection/ star quake



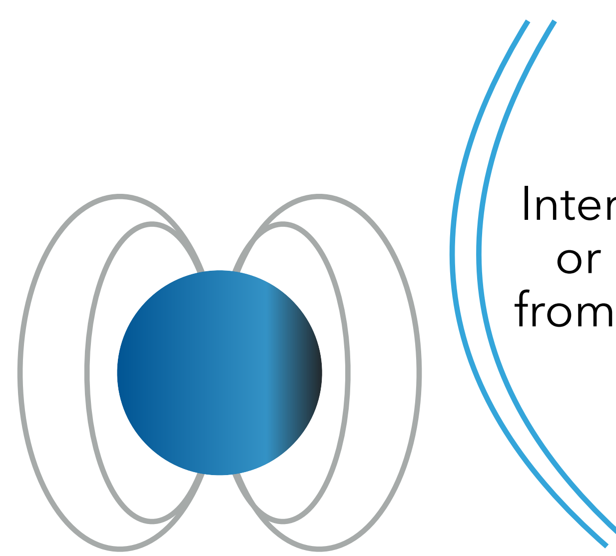
Cosmic string cusps



Merger/Coalescence



Interaction with asteroid/ axion nugget



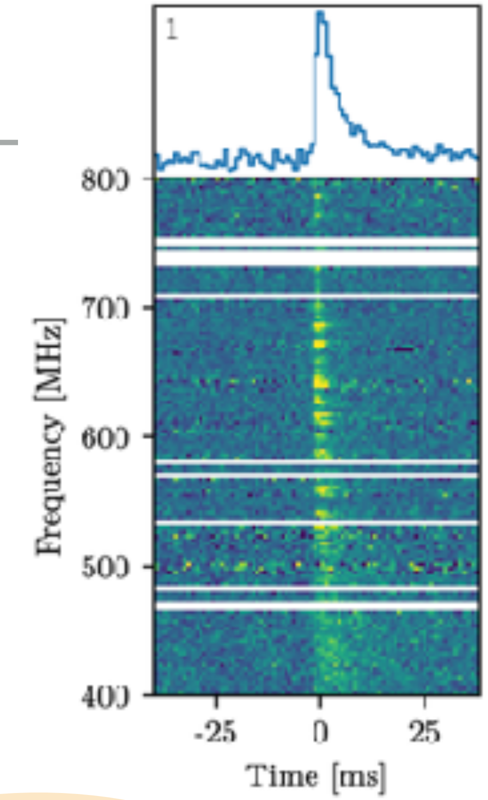
Interaction with winds or radiative shocks from pulsars, OB stars, AGNe

RATES OF TRANSIENTS

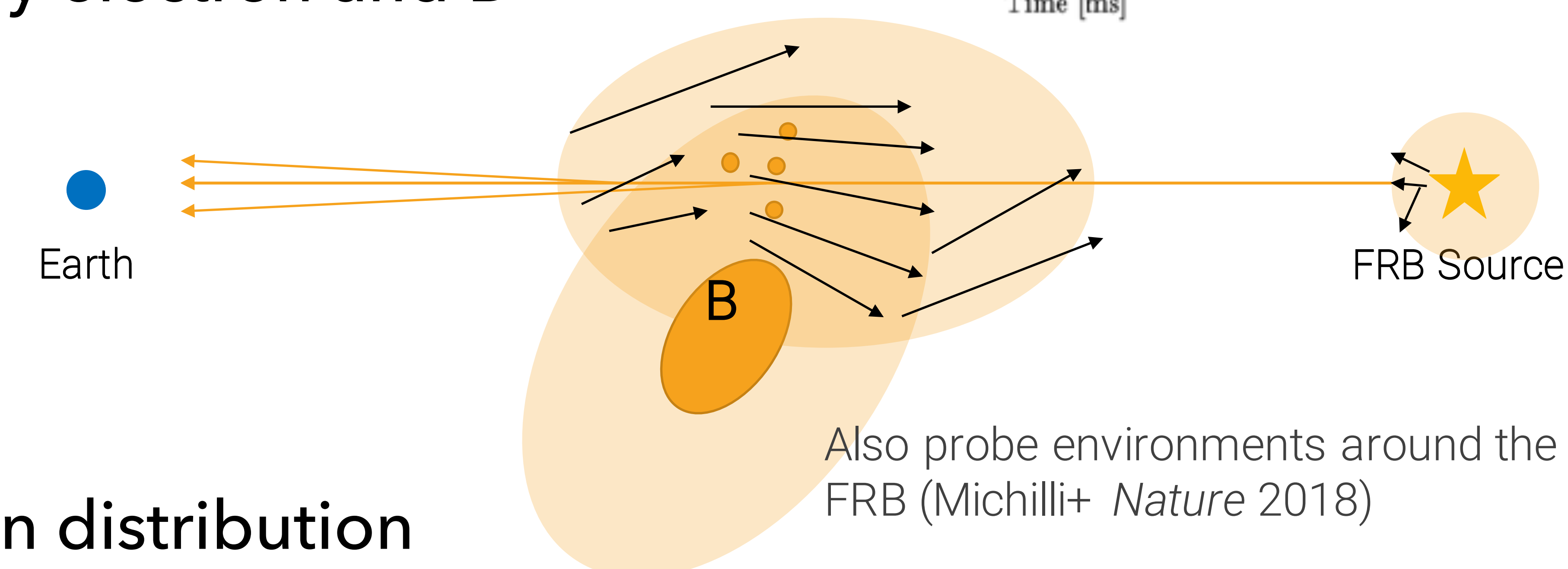
	All-sky, Detectable	Volumetric (Gpc^{-3} yr^{-1})
FRBs	10^3/day	~10^5
SGRBs	~0.3/day	~270 (z<0.5)
Binary NS mergers	1/year (will change in O5)	~200
LGRBs	~0.5-0.7/day	~100 (z<0.5)
Galactic Magnetar flares	~1/day (clustered in space and time)	
Core-collapse SN		~10^5
ULX/HMXB outbursts	10/year	
Type I SLSNe		~40 (z<0.5)

Refs: Nicholl et al (2017)

COSMOLOGICAL PROBES



- Polarized radio waves
- Interacts with every electron and B-field



Also probe environments around the FRB (Michilli+ *Nature* 2018)

- Turbulence, baryon distribution
  - HeII reionization at z~3
- Magnetic field distributions
- Gravitational lensing

FEASIBILITY MATRIX

"ROUTINE"

HARD

DREAM

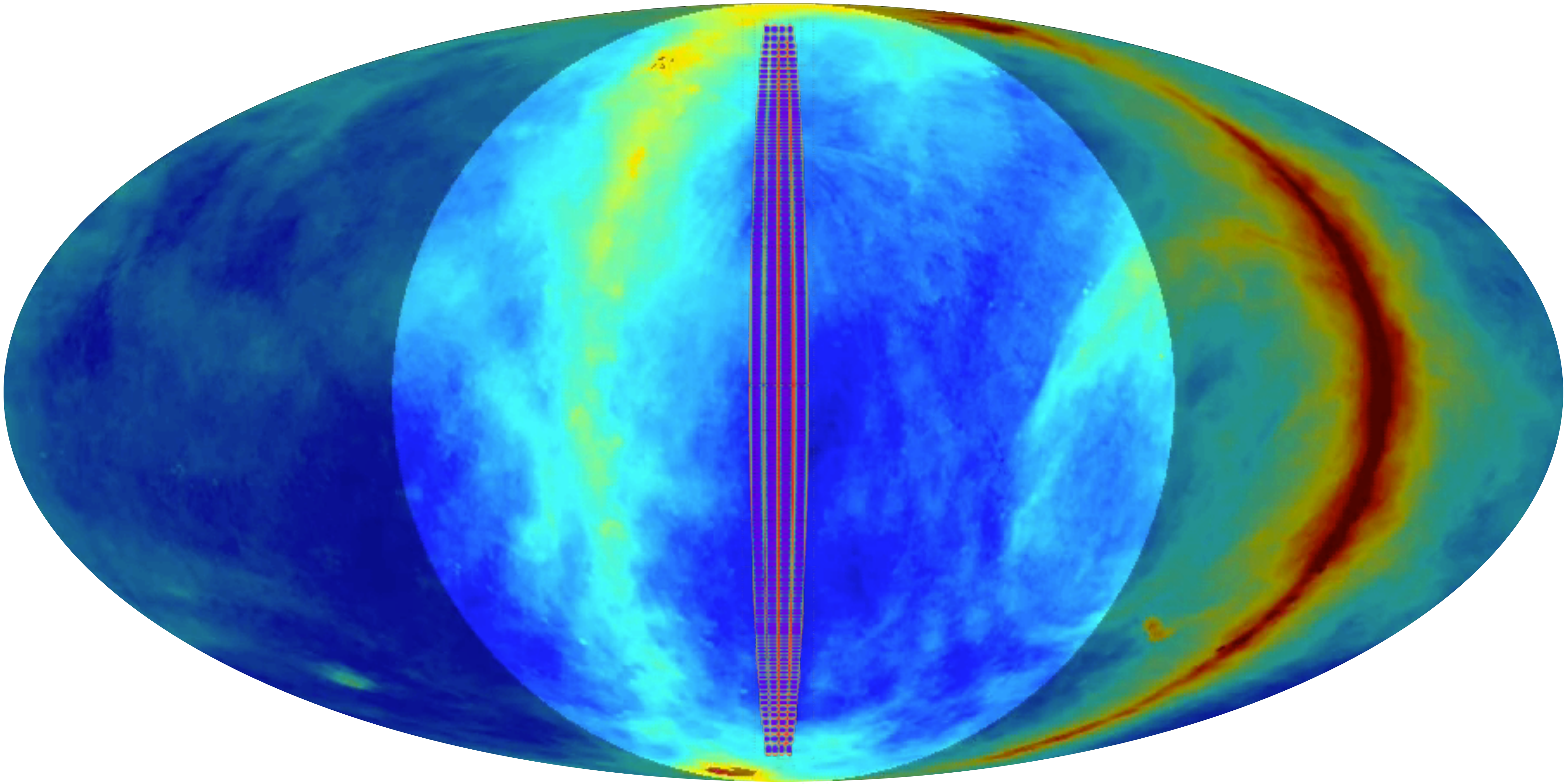
- FINDING FRBS
- ~10 ARCMIN LOCALIZATION
- "DAILY" MONITORING FOR REPEATS
- POLARIZATION
- MILLIARCSECOND LOCALIZATION OF REPEATERS
- ARCSECOND LOCALIZATION
- HOST GALAXIES + REDSHIFT
- MILLIARCSECOND LOCALIZATION OF ALL FRBS
- FRBS AT $z > 1$
- PROMPT MULTI-WAVELENGTH/ MESSENGER
- LENSED FRBS
- THOUSANDS OF HOST GALAXIES
- THOUSAND FRBS PER DAY
- $z > 4$
- 24X7 MONITORING FOR REPEATS

CHIME PARAMETERS

- 4 Cylinders - 20m x 100m each
- 1024 dual polarization feeds
- 250 sq deg field-of-view

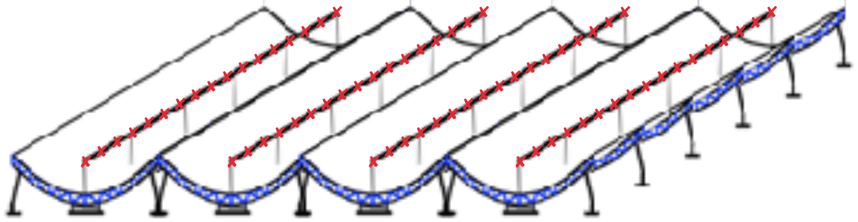
Bandpass	400 MHz	800 MHz
21 cm Redshift	2.5	0.8
Beam Size	0.52°	0.26°
E-W FoV	2.5°	1.3°
N-S FoV	~100°	
λ	0.75m	37.5cm

CHIME/FRB



256 FFT [N-S] x 4 Exact-formed beams [E-W]
Sky Coverage ~250 sq. Degrees

Equal to 1024 GBTs



130 Gb/s intensity data searched in real time

800 GB/s raw voltage data callback

CHIME/FRB Collaboration et al (2018)

@Cherry Ng

CHIME OUTRIGGERS

- Detecting FRBs is not enough
  - Need to localise to milliarcsecond precision
- VLBI telescopes are built for small field of view

  Cannot find non-repeating FRBs efficiently
- CHIME/FRB building outrigger telescopes

  Get 50 mas localization for every FRB (repeater and non-repeater)
- Aim to get ~1000 localized FRBs every year in 2 years

- First detection of FRBs at 400 MHz (CHIME/FRB Collaboration et al 2018a)
- 17 new repeating FRBs (CHIME/FRB Collaboration et al 2018b, 2019, Fonseca et al 2020)
- 16.35 day periodic activity in FRB 180916 (CHIME/FRB Collaboration et al 2020a)
- A Galactic FRB from SGR 1935+2154 (CHIME/FRB Collaboration et al 2020b)
- Seven new Galactic RRATs and a binary pulsar (Good et al 2020)
- A repeater in M81 at 3.6 Mpc! (Bhardwaj et al 2021, Kirsten et al 2022)

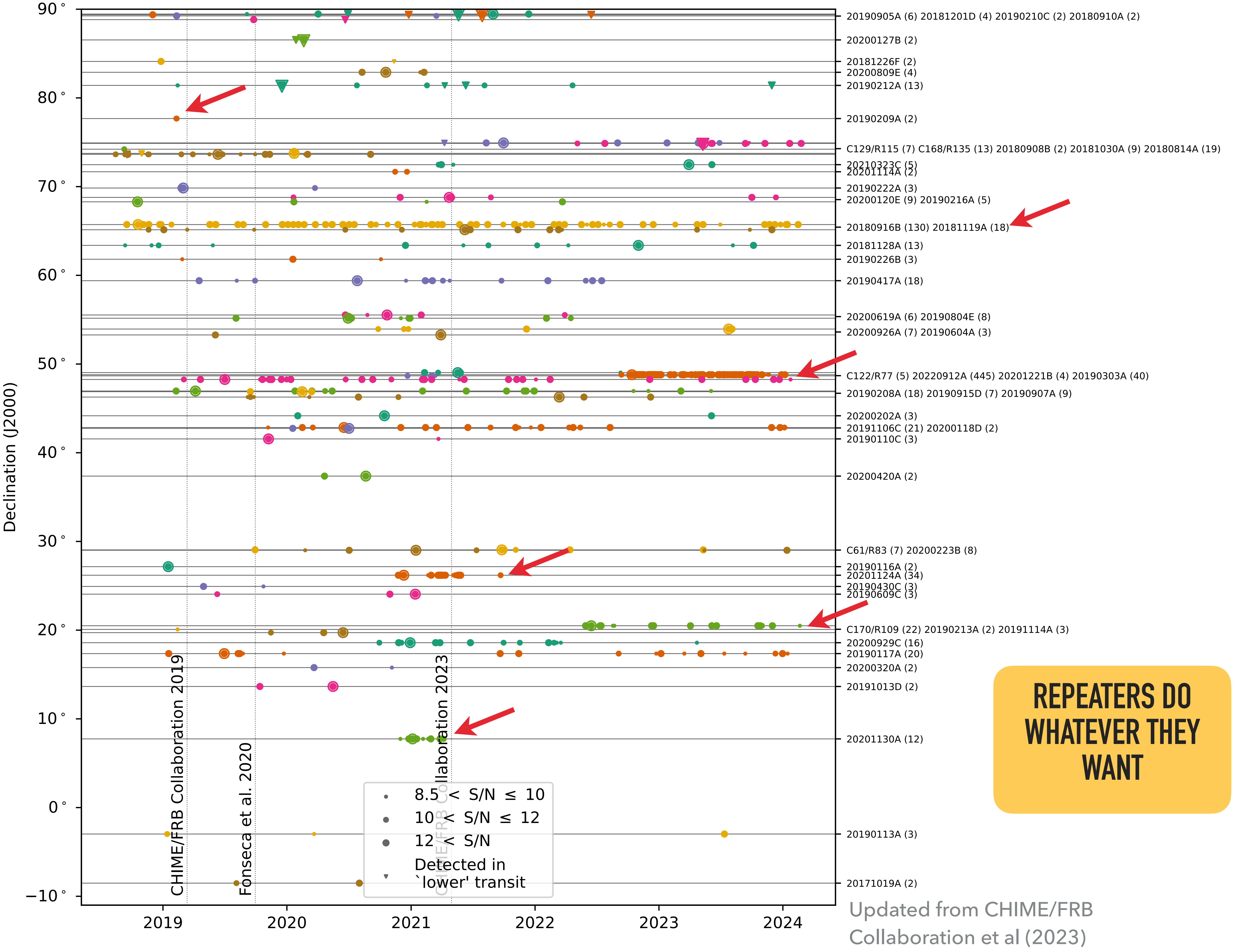
Plus many more off-shoot papers

First catalog paper and related papers on FRB populations published last year

- CHIME/FRB Catalog, rate, logN/logS
- FRB Morphology (Pleunis et al 2021)
- Scattering properties of FRBs (Chawla et al 2021)

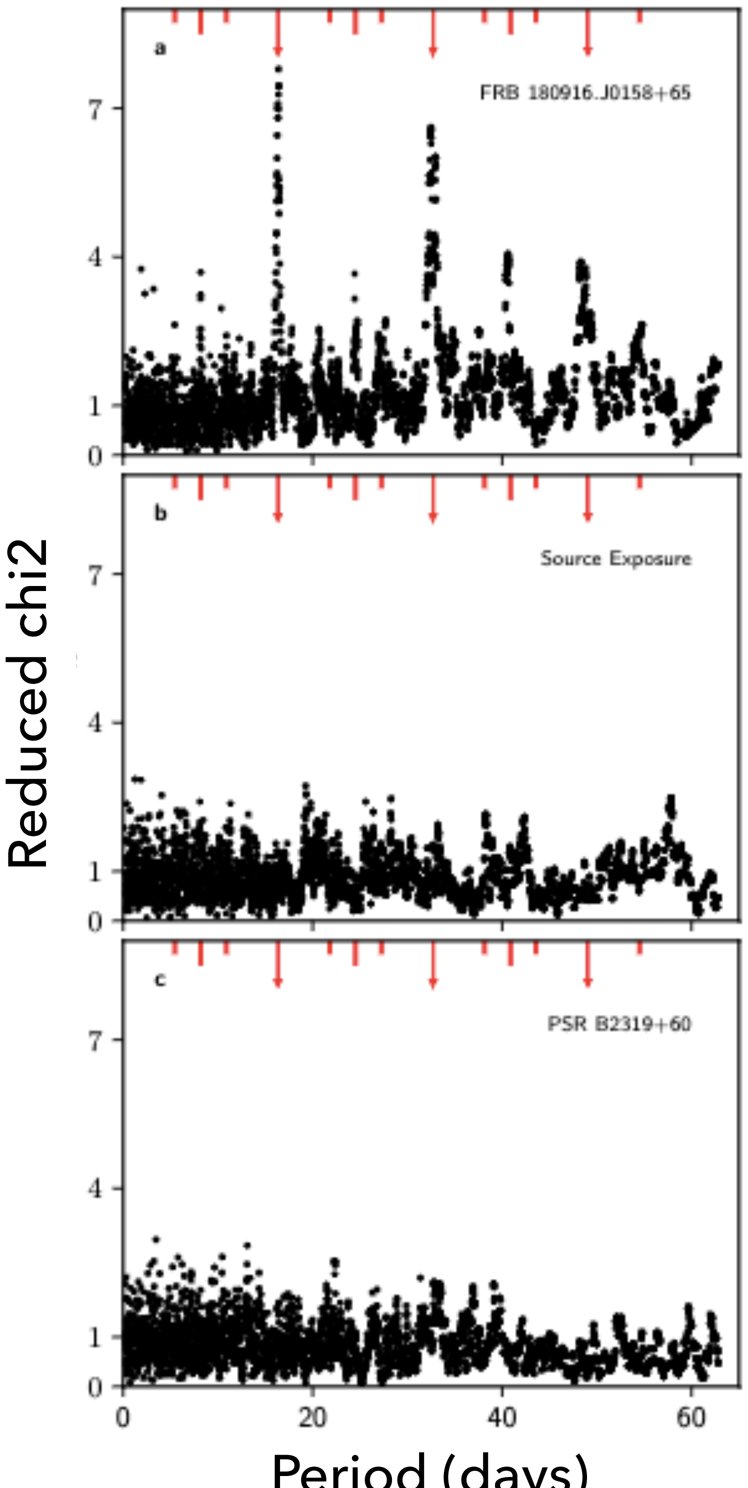
- Galactic distribution of FRBs (Josephy et al 2021)
  –> Observed FRB distribution is not affected by the Milky Way
- Cross-correlation of FRBs with galaxy catalogs (Ravandi-Rafiei et al 2021)
  –> FRB positions correlate with haloes in $0.3 \lesssim z \lesssim 0.5$
  –> Small population of FRBs with DM_host ~ 400 pc cm^{-3}

REPETITION



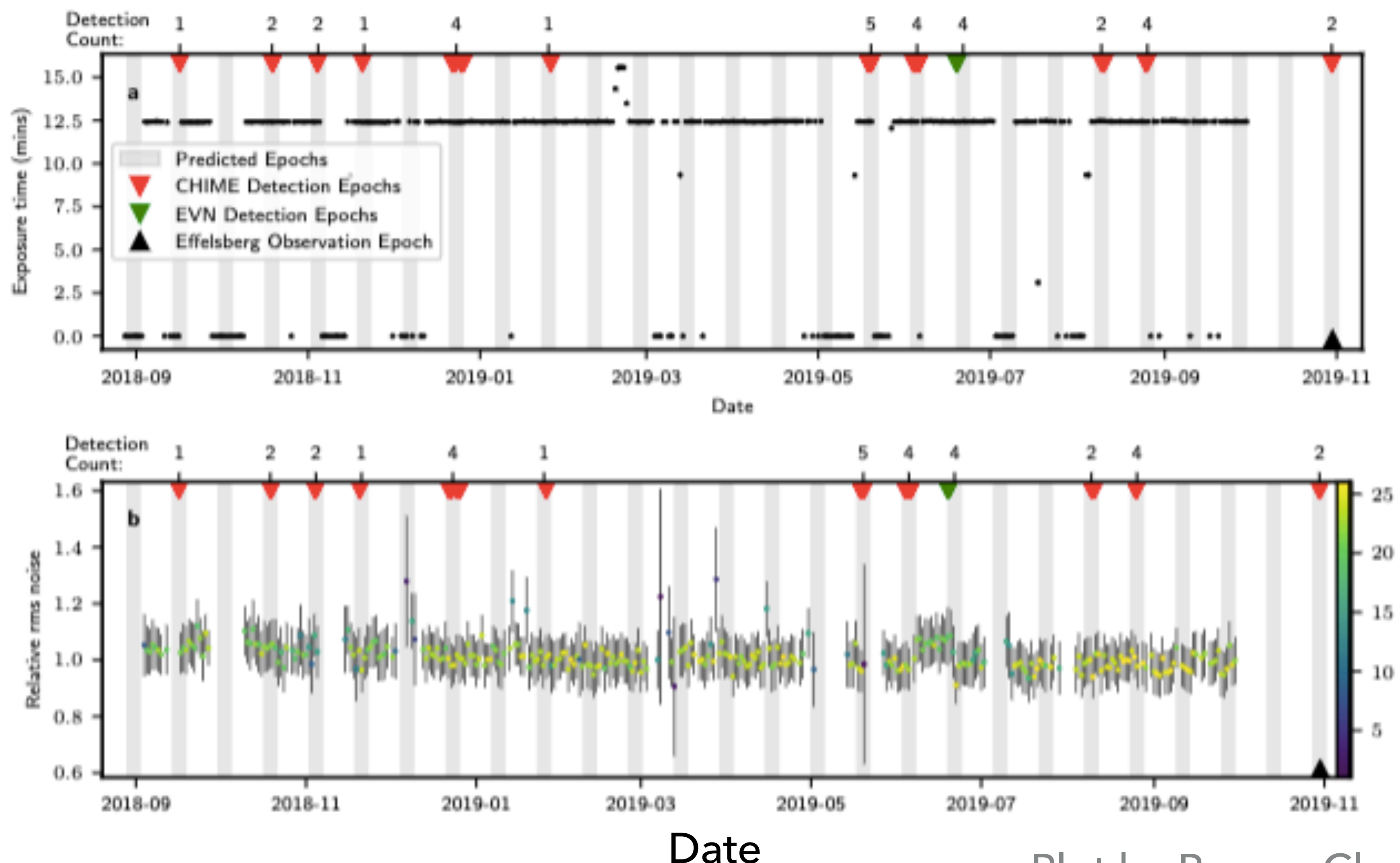
Declination (J2000)
90°
80°
70°
60°
50°
40°
30°
20°
10°
0°
−10°
2019
2020
2021
2022
2023
2024
CHIME/FRB Collaboration 2019
Fonseca et al. 2020
CHIME/FRB Collaboration 2023
8.5 < S/N ≤ 10
10 < S/N ≤ 12
12 < S/N
Detected in `lower' transit
20190905A (6) 20181201D (4) 20190210C (2) 20180910A (2)
20200127B (2)
20181226F (2)
20200809E (4)
20190212A (13)
20190209A (2)
C129/R115 (7) C168/R135 (13) 20180908B (2) 20181030A (9) 20180814A (19)
20210323C (5)
20201114A (2)
20190222A (3)
20200120E (9) 20190216A (5)
20180916B (130) 20181119A (18)
20181128A (13)
20190226B (3)
20190417A (18)
20200619A (6) 20190804E (8)
20200926A (7) 20190604A (3)
C122/R77 (5) 20220912A (445) 20201221B (4) 20190303A (40)
20190208A (18) 20190915D (7) 20190907A (9)
20200202A (3)
20191106C (21) 20200118D (2)
20190110C (3)
20200420A (2)
C61/R83 (7) 20200223B (8)
20190116A (2)
20201124A (34)
20190430C (3)
20190609C (3)
C170/R109 (22) 20190213A (2) 20191114A (3)
20200929C (16)
20190117A (20)
20200320A (2)
20191013D (2)
20201130A (12)
20190113A (3)
20171019A (2)
REPEATERS DO WHATEVER THEY WANT
Updated from CHIME/FRB Collaboration et al (2023)

PERIODIC BURST ACTIVITY FROM FRB 180916 (R3)



Plot by Dongzi Li, Hsu-Hsien Lin

CHIME/FRB Collaboration (2020)

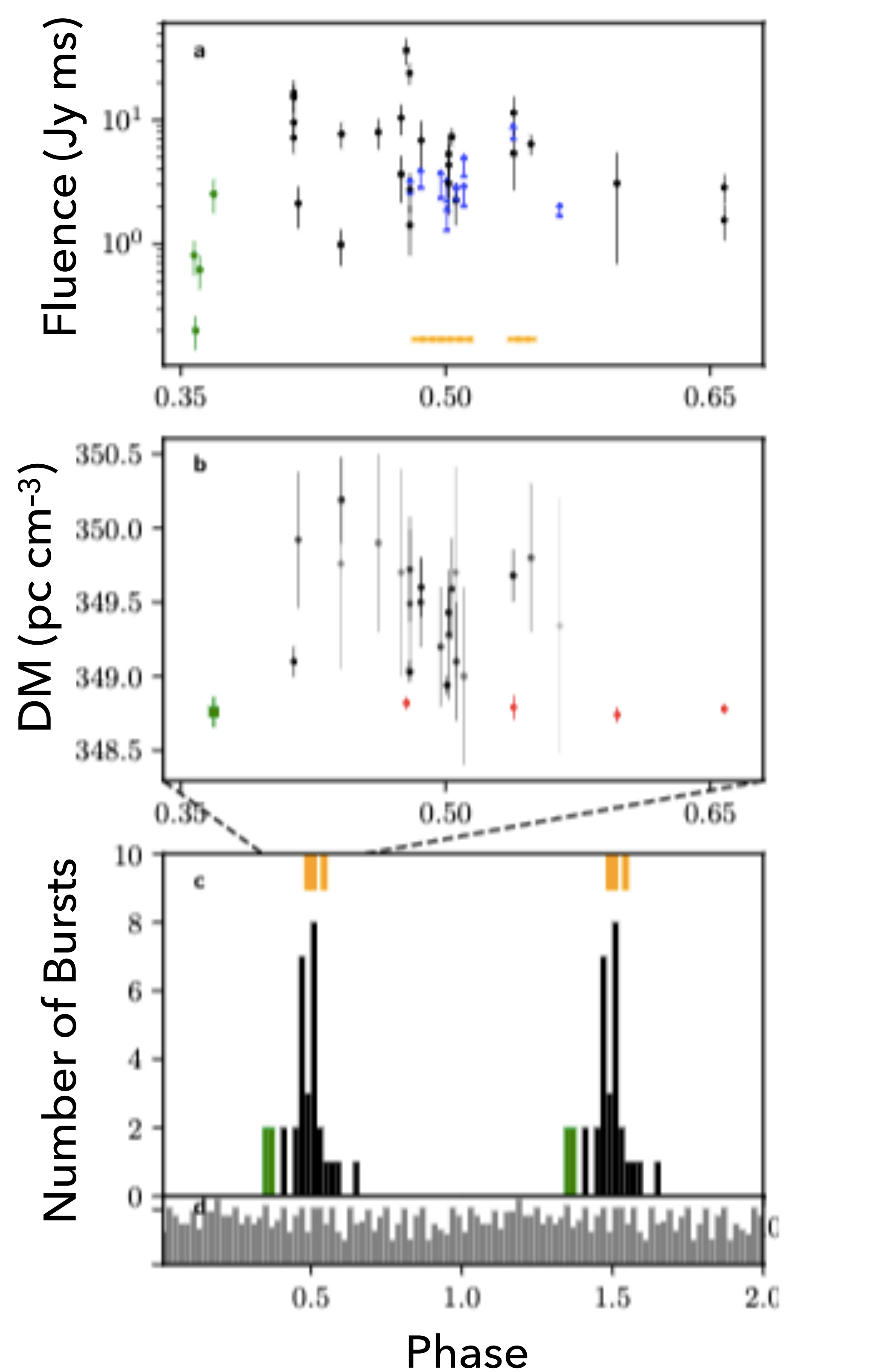


Plot by Pragya Chawla

PERIODIC BURST ACTIVITY

- Source shows activity at 16.35 day period
- Bursts arrive in a 4 day window (at 400-800 MHz)
- Duty cycle is not 100%
- Timescale – rotation? orbit? precession?
    - Is there another underlying periodicity?

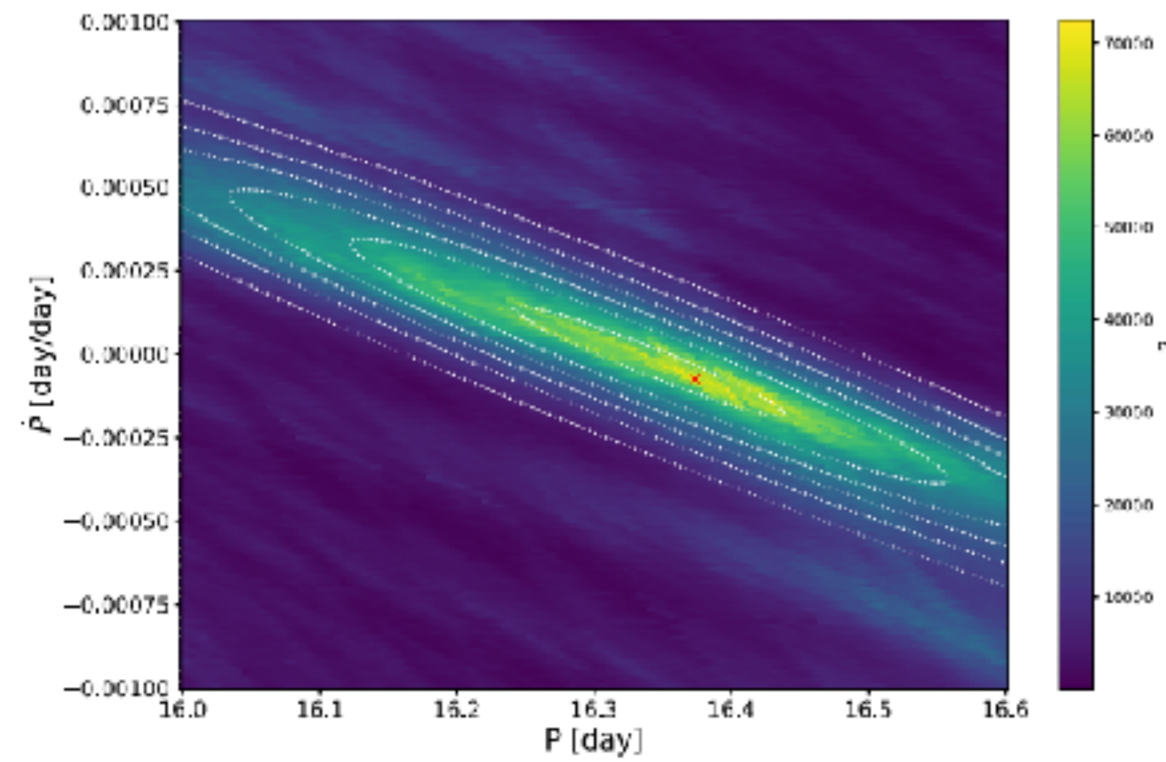
FRB 121102 WAS ALSO FOUND TO BE PERIODIC WITH 160-DAY PERIOD
(RAJWADE ET AL 2020, CRUCES ET AL 2020)



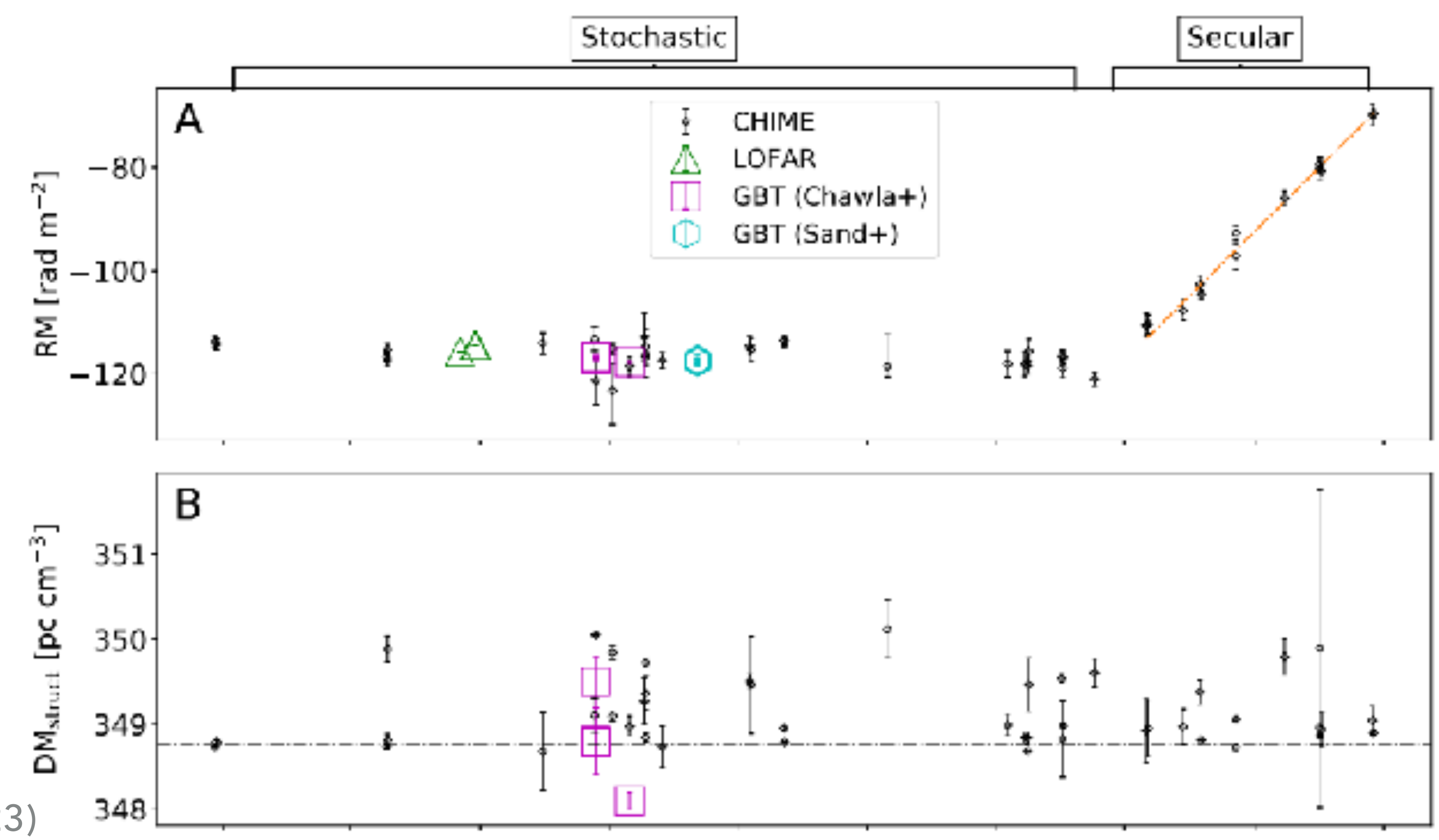
Plot by Bridget Anderson, Ziggy Pleunis, Dongzi Li

PERIODIC BURST ACTIVITY

- 2018 Aug to 2021 Dec (3.5 yrs)
- $|\dot{P}| < 1.5 \times 10^{-4}\ (1-\sigma)$
- Sudden secular increase in rotation measure (RM)
- No corresponding change in DM
- Is there some local structure?



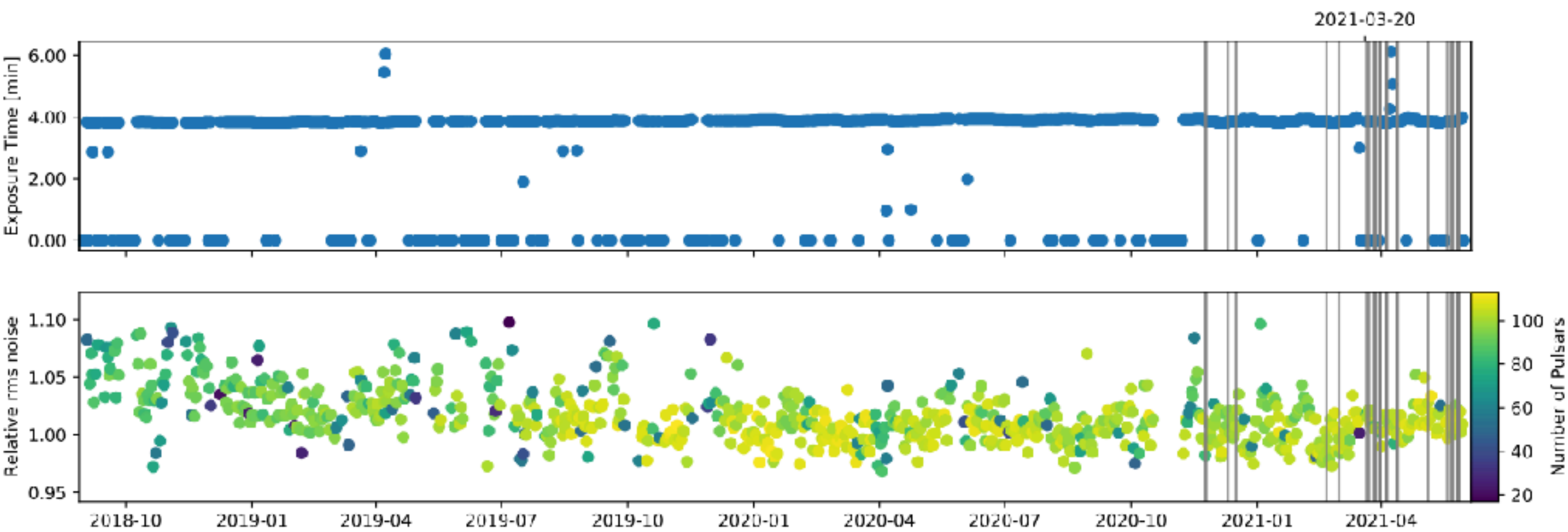
Sand et al (2023)



Mckinven et al (2023)

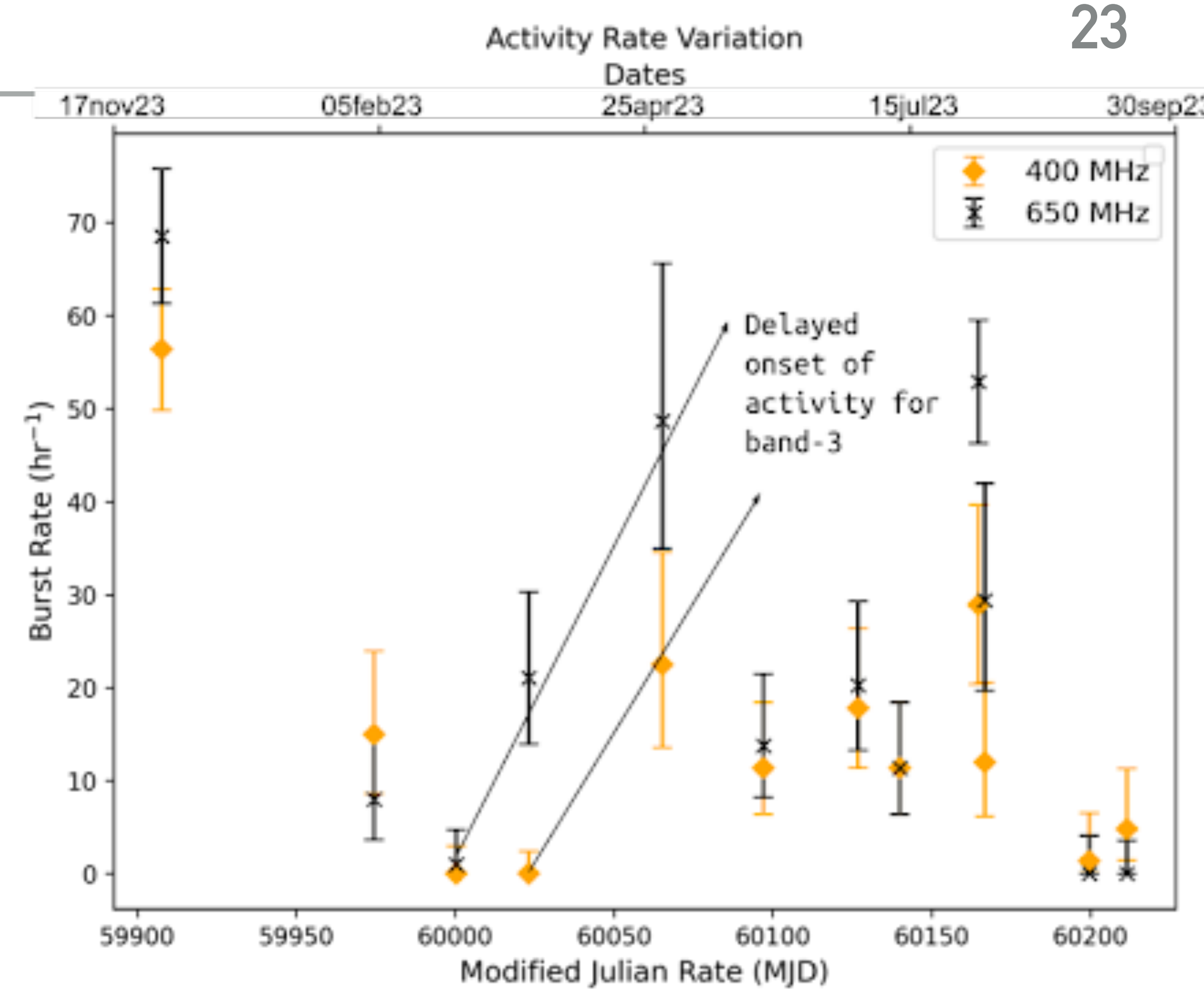
HYPERACTIVE REPEATERS

- 3 years of nothing – then 100's bursts per day
- FRB 20201124A (Lanman et al 2022)
- Couple of other repeaters like this



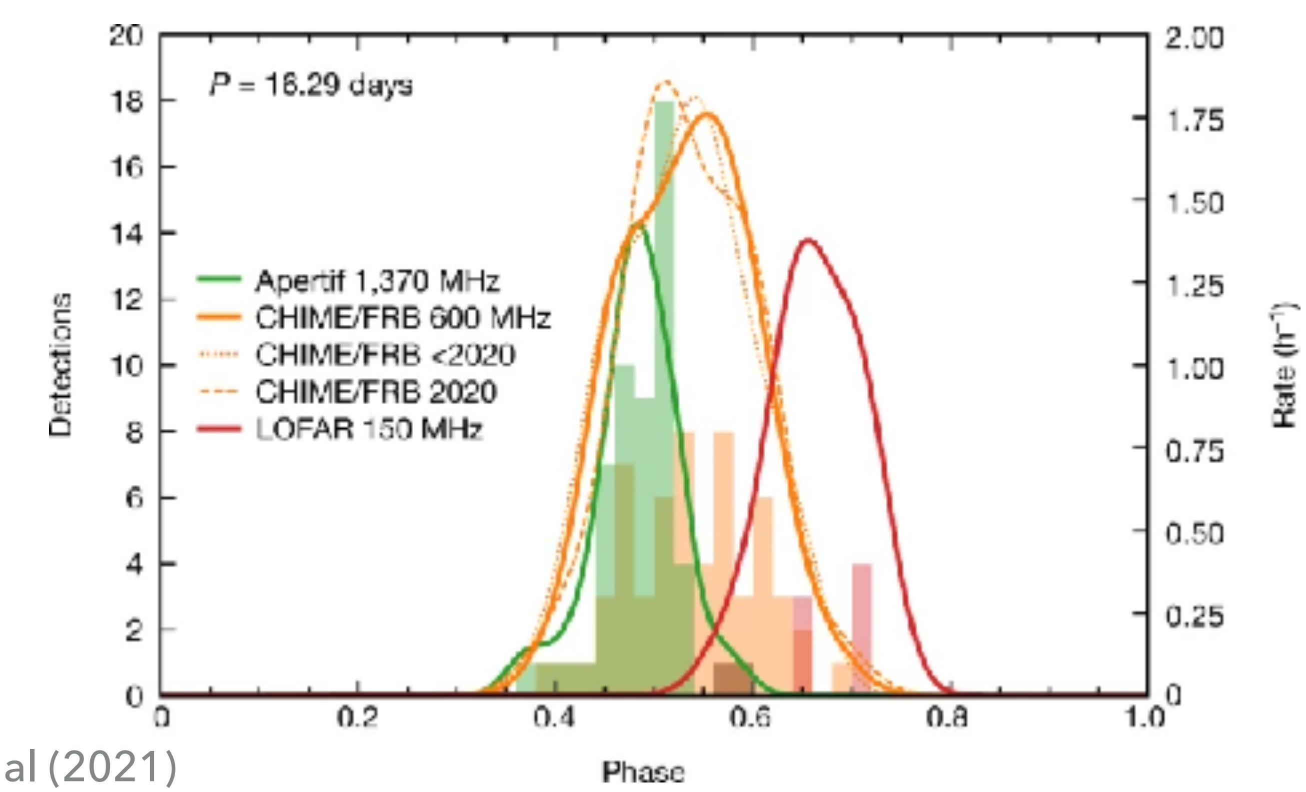
FREQUENCY DEPENDENT RATES

- GMRT Dual band simultaneous observations (300-500 MHz/ 550-750 MHz)
- Frequency dependent rates



Kumar et al (in preparation)

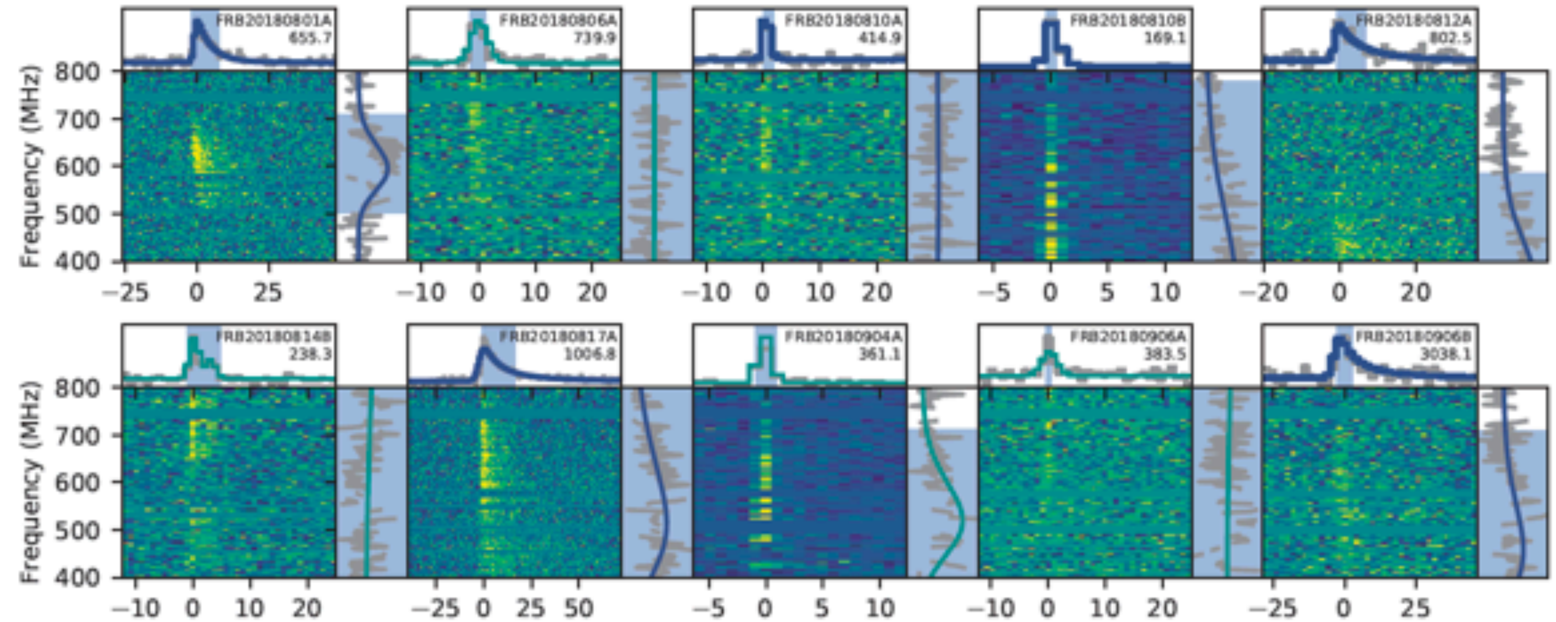
- For periodic repeater – frequency dependent phase activity
- High freq early, low freq late



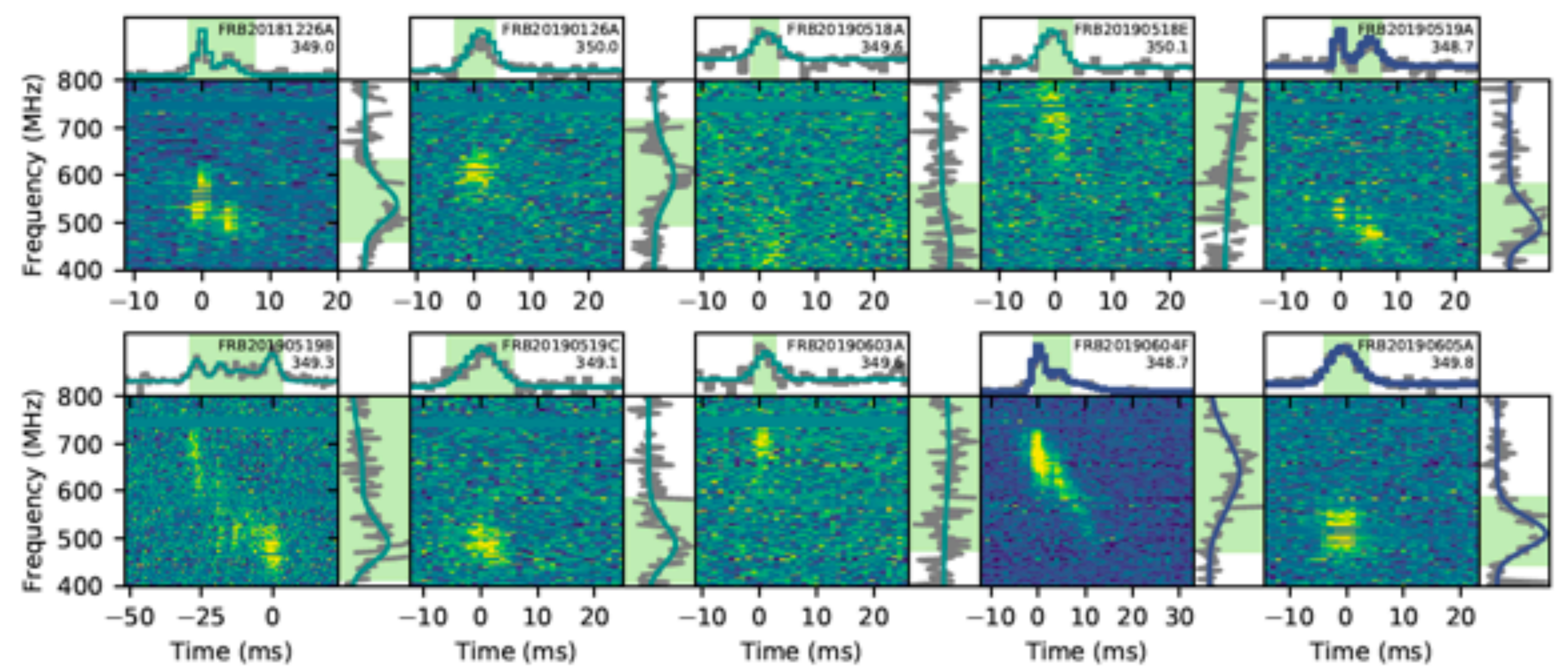
Pastor-Marazuela et al (2021)

CHIME FRB CATALOG

- Some FRBs are broadband and single component



- Others have multiple components and are narrowband



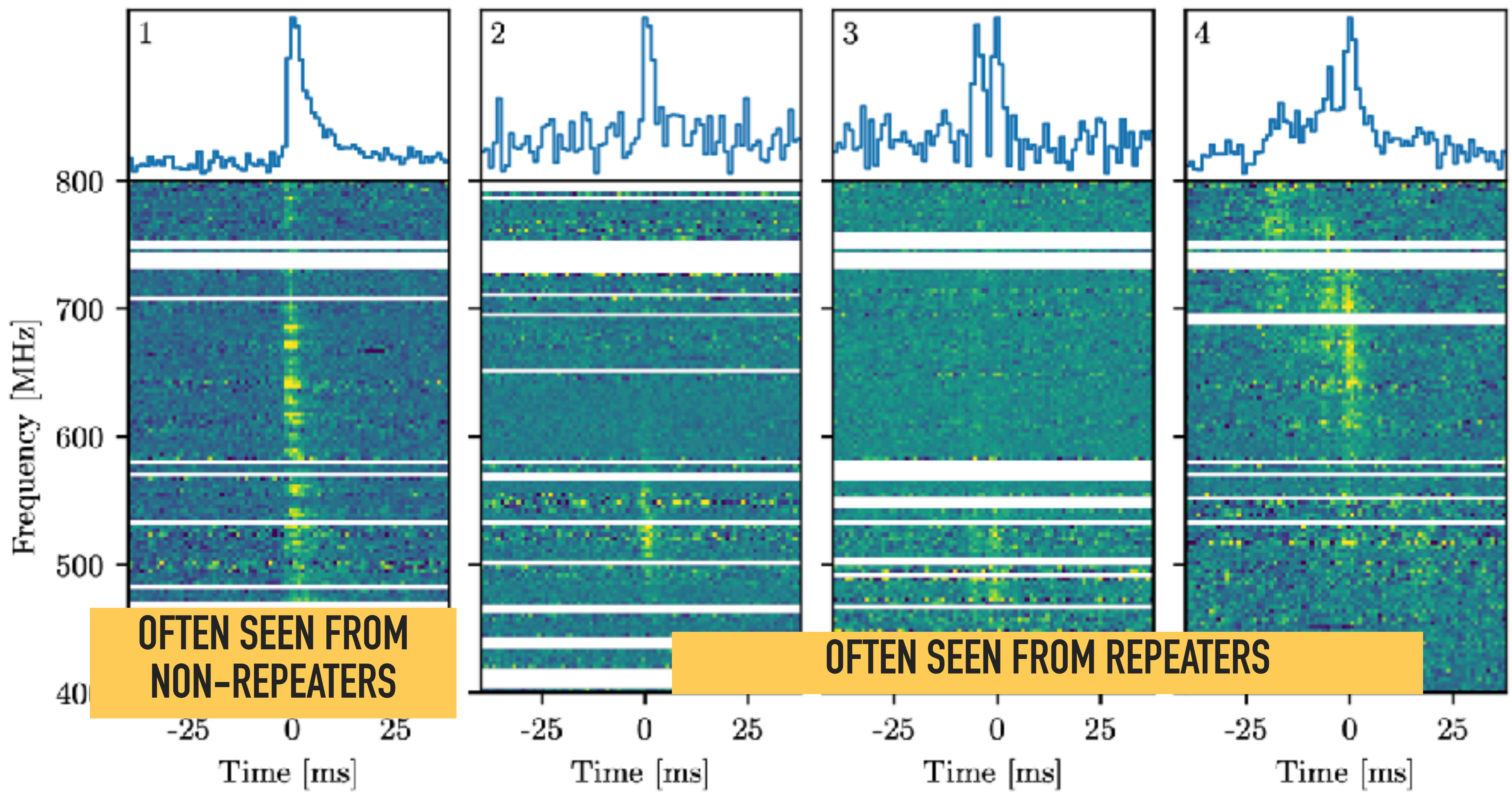
FRB ARCHETYPES

Single component, broadband

Single component, narrowband

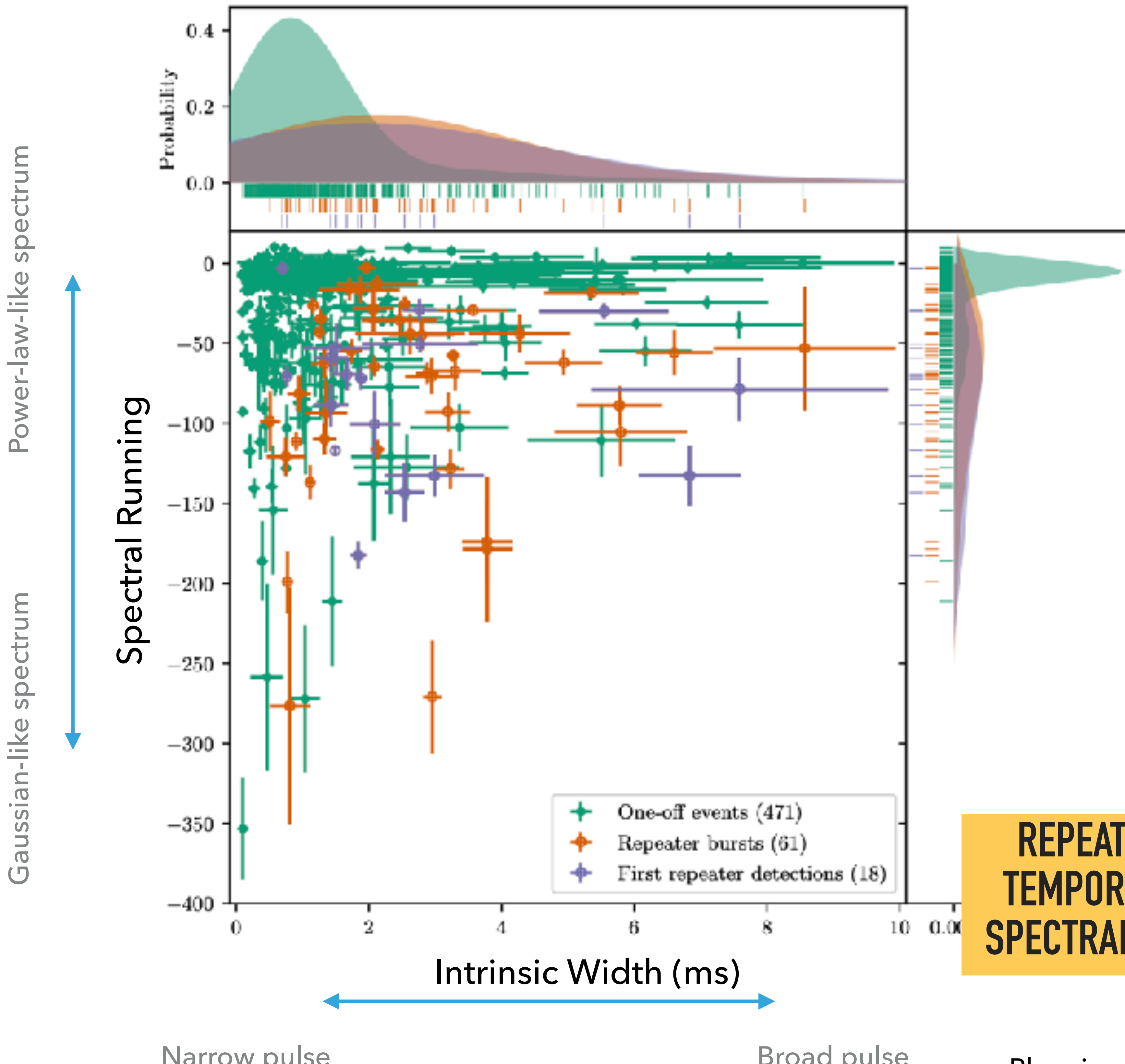
Multiple components similar spectra

Multiple components downward drifting



Beware of beam effects –> see the details

Pleunis et al (2021)



REPEATER BURSTS ARE TEMPORALLY WIDER AND SPECTRALLY NARROWBAND

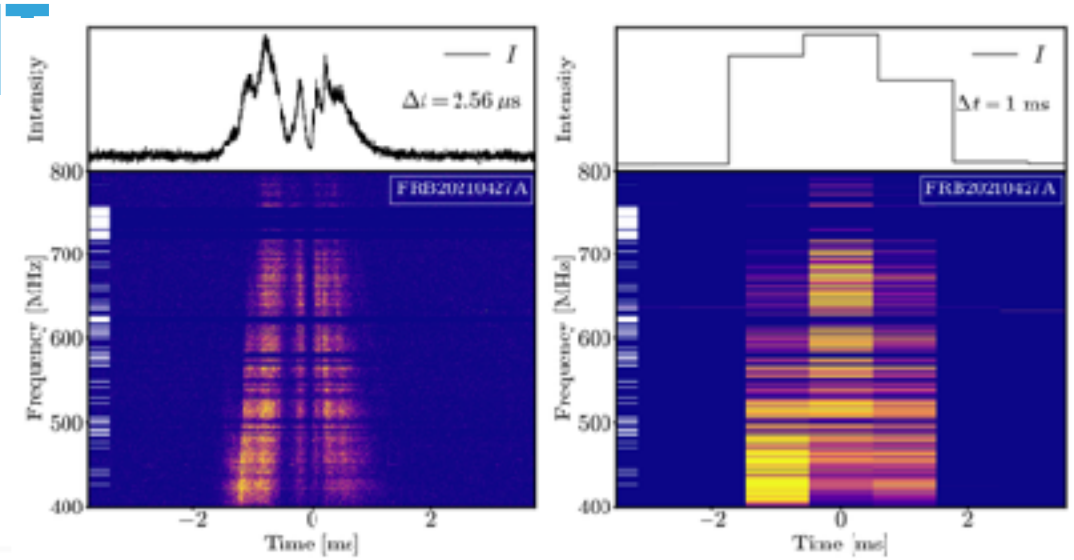
Pleunis et al (2021)

TWO POPULATIONS?

- There are some differences between bursts from repeaters and “as-yet” non-repeaters
- Can burst properties change with repetition rate?
  Rapid repeaters –> complex bursts, Rare repeaters –> simple bursts?
- Can this be propagation or beaming effects?
  Narrower beaming –> rarer repetition –> simple bursts?
- On-going studies with polarisation differences, rates etc…
- Could help guide repeater follow up
  (but avoid biasing catalogs!)

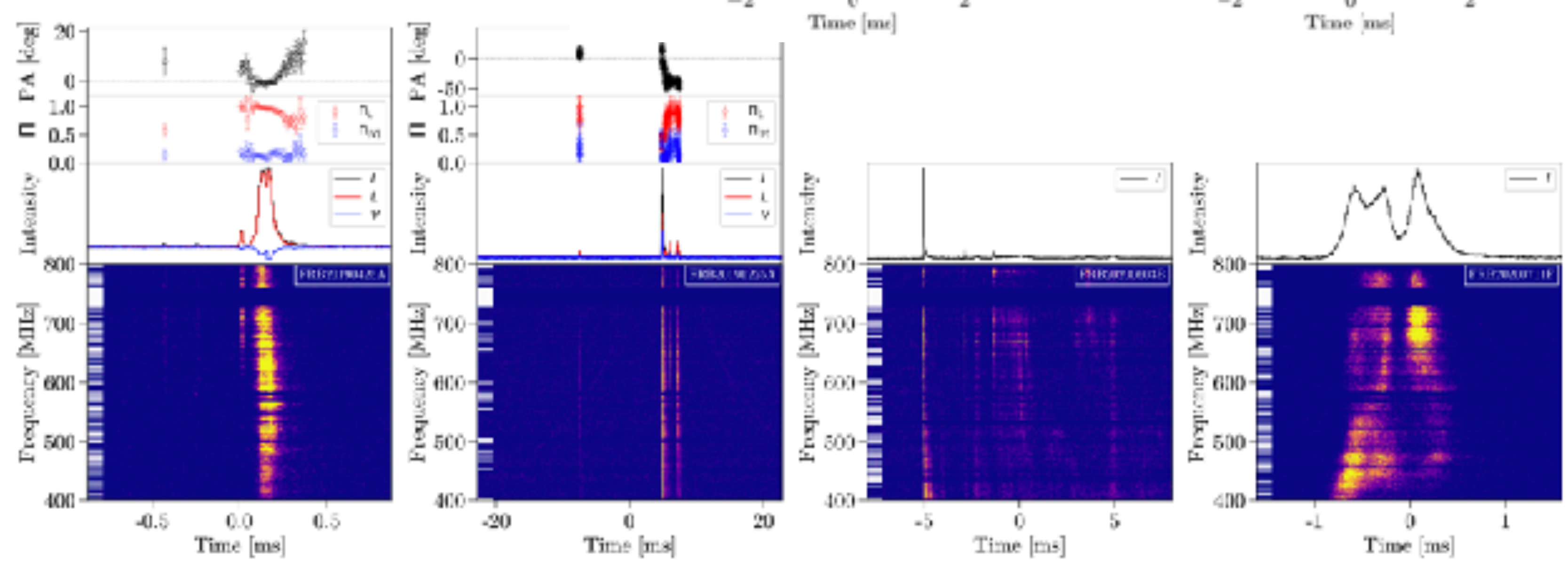
Faber et al (2024)

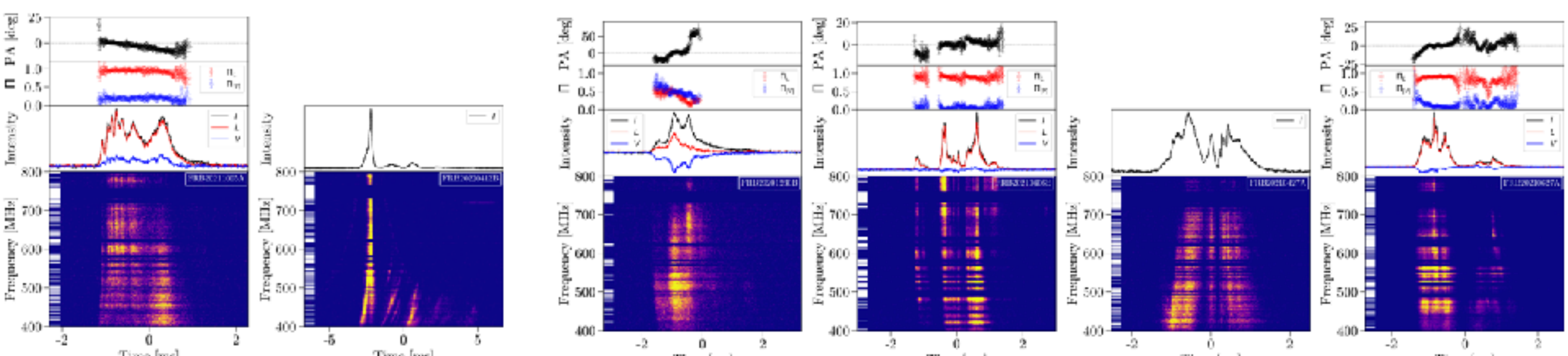
MORPHOLOGY IS TIMESCALE DEPENDENT



- Smallest timescales are ~100ns to microseconds

- Zooming in shows a rich forest of structures, even for non-repeaters!

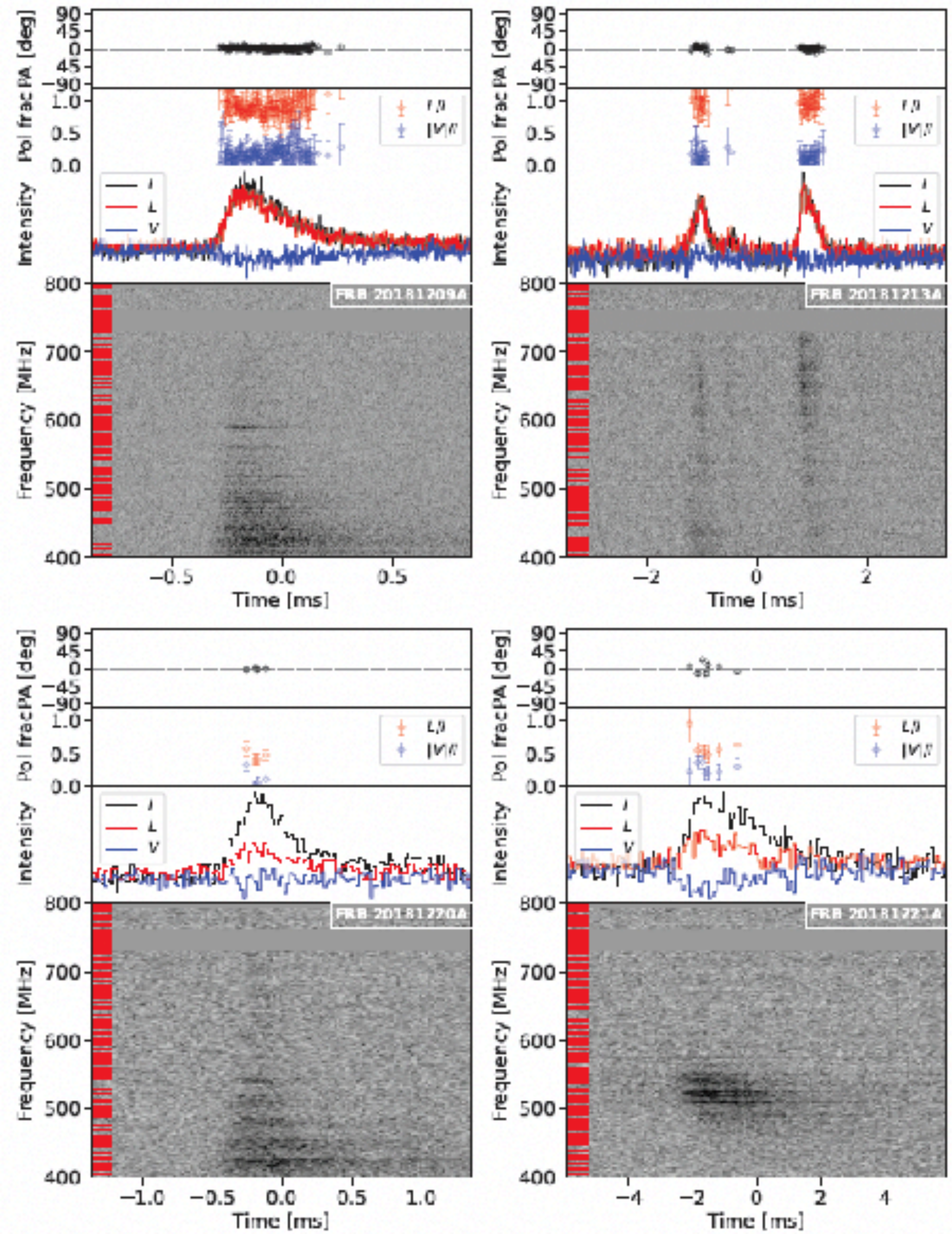




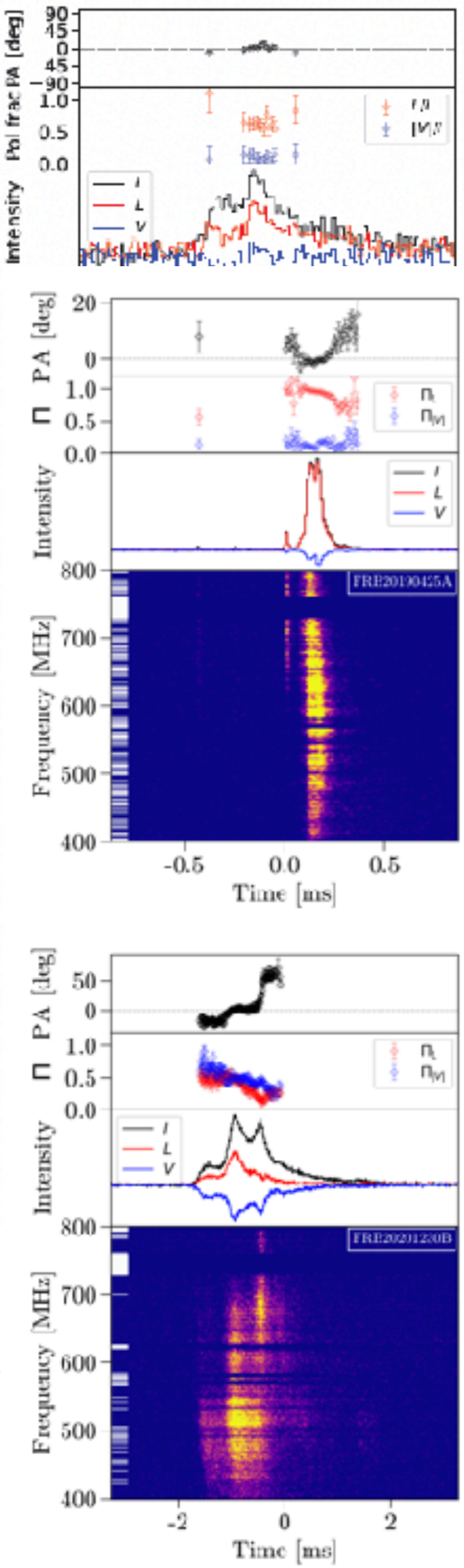
POLARIZATION

FRB POLARIZATION

- ~70% FRBs are highly linearly polarized (~100%)
- But all over the place!
- Often has very flat position angle (unlike pulsars) BUT

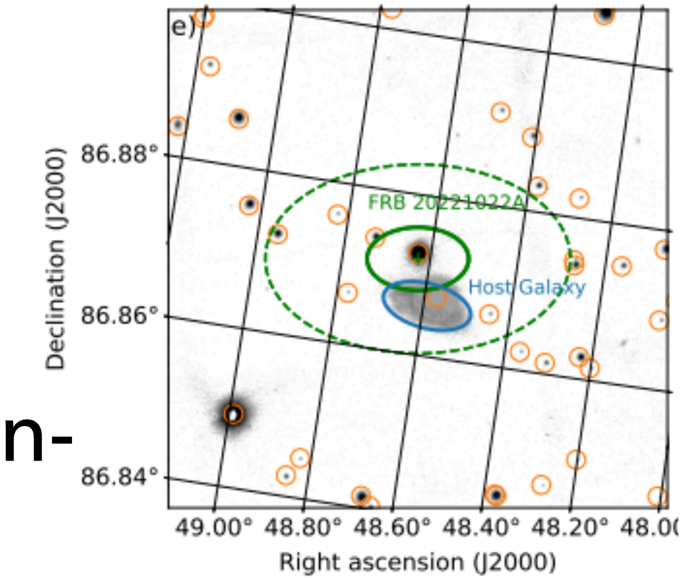


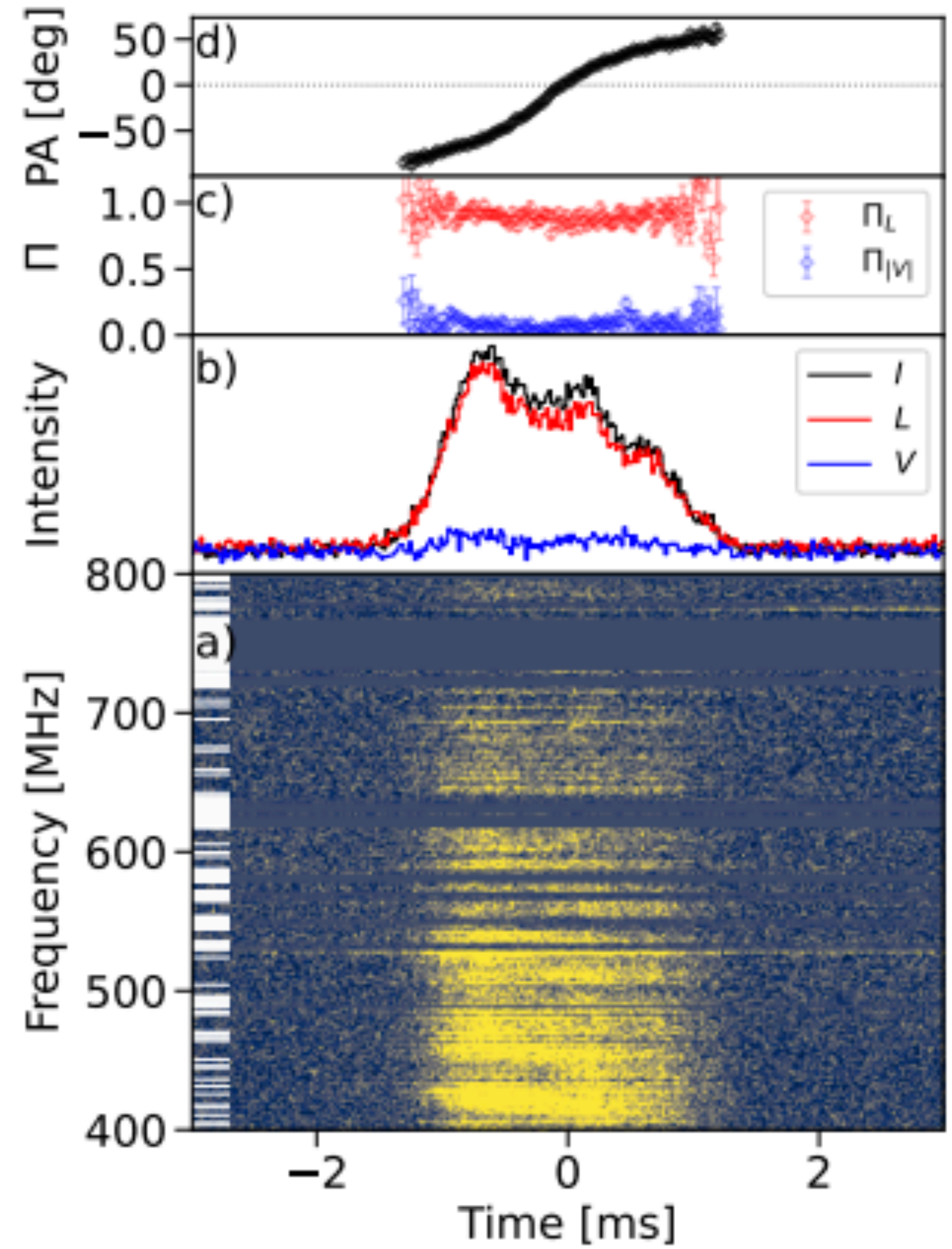
CHIME/FRB Polarization Catalog (128 FRBs – 2024)



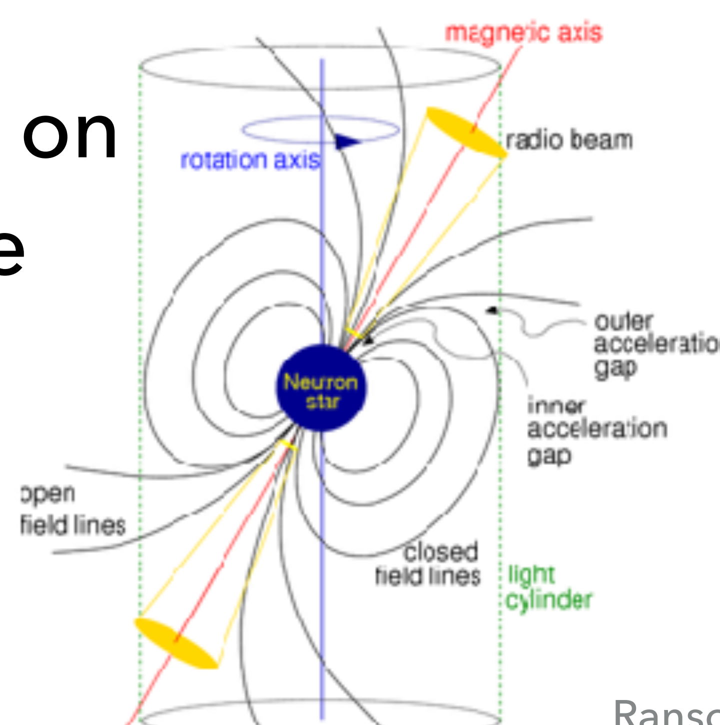
PULSAR-LIKE SWING

- Bright, seemingly non-repeating FRB
- Pulsar-like PA swing – very well fit by a rotating vector model
- Suggests constraints on geometry – but there are no repeats!





McKinven et al (2024)



Ransom S. (Essentials of Radio Astronomy)

POLARIZATION AND LOCAL ENVIRONMENTS OF REPEATERS

Comparison of $B_\parallel^{local}$ Estimates for a Selection of Repeating FRB Sources and Pulsars[a]

Source	$B_\parallel^{local}$ (μG)	$\|\Delta RM\|$ (rad m^{-2})	$\|\Delta RM\|$ %	Timescale	RM Evolution	Associated Structure	References
FRB 20200120E[b]	⋯	~30	~100	Weeks–months	⋯	Globular cluster	Bhardwaj et al. (2021); Nimmo et al. (2022)
PSR J1825–1446	~0.2	~20	~9	~2 yr	Secular	SNR	Johnston et al. (2021)
FRB 20190117A	≳4	~9	~9	1031 days	⋯	⋯	this work
FRB 20190212B	≳16	~4.6	~10	220 days	⋯	⋯	this work
PSR J0908–4913 (B0906–49)	~20	~4	~40	~3000 days	Secular	SNR	Johnston & Lower (2021)
PSR B0833–45[c]	≳22	~10	~26	~15 yr	Secular	SNR	Hamilton et al. (1985)
FRB 20180301A	≳50	~43	~8	<1 day	Stochastic	⋯	Luo et al. (2020) + this work
FRB 20180916B	≳55	~50	~40	~9 months	Secular and stochastic	⋯	(Mckinven et al. 2022)
FRB 20190208A	≳80	~35	~100	~200 days	Secular (nonmonotonic)	⋯	this work
FRB 20201124A[d]	≳100	~500	≳100	≲0.5 months	Secular	SF region/PRS[e]	Hilmarsson et al. (2021a); Kumar et al. (2022a); Xu et al. (2021)
PSR J0540–6919 (B0540–69)	115 ± 15	~15	~6	~5 months	Secular	SNR	Geyer et al. (2021)
PSR B0531+21[f]	150–200	6.6	~14	20 months	Secular	SNR	Rankin et al. (1988)
FRB 20181119A	≳2200	~860	~100	~200 days	⋯	⋯	this work
FRB 20190303A	≳3000	~500	~100	~2 yr	Secular (nonmonotonic)	⋯	this work
PSR B1259–63	~500 – 10, 000	≲15, 000	⋯	~0.5 months	⋯	Pulsar–Be star binary	Johnston et al. (2005)
FRB 20190520B	≳4000	~26,000	⋯	~7 months	Secular	PRS	Anna-Thomas et al. (2022); Dai et al. (2022)
PSR J1745–2900[g]	≳10, 000	~3500	~5	~16.5 months	Secular	Sgr A*	Desvignes et al. (2018); Katz (2021)
FRB 20121102A	3000 – 17, 000	15,000/4000	20/5	160 days/450 days	Secular	SF region/PRS[h]	Hilmarsson et al. (2021a); Katz (2021)

McKinven et al (2023)

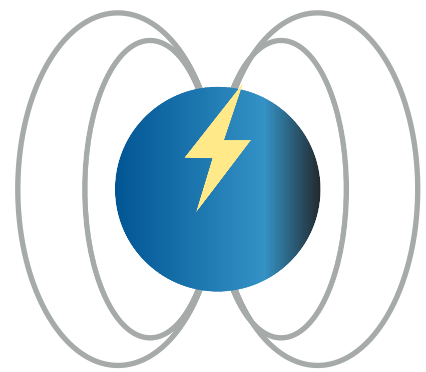
ORIGINS OF FRBS

CONNECTIONS TO OTHER TRANSIENTS

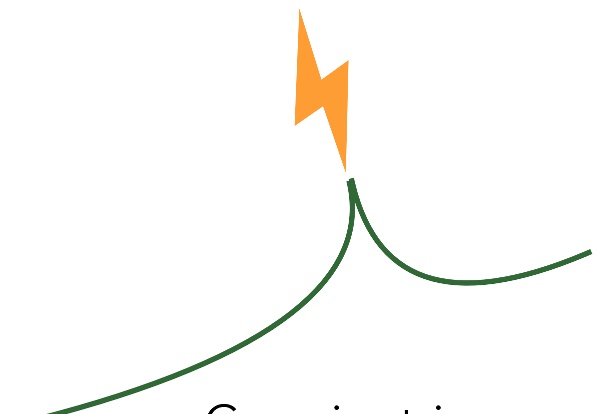
WHAT ARE THEY?

http://frbtheorycat.org Platts .. SPT et al 2019

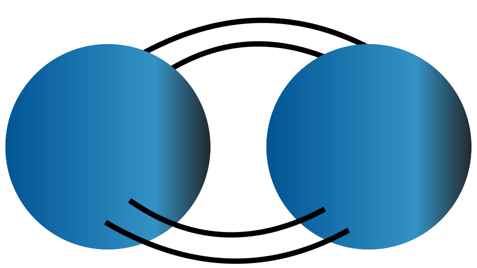
- ~10^{10-12} times brighter than Crab giant pulses
- Magnetar? NS Binary? More exotic?



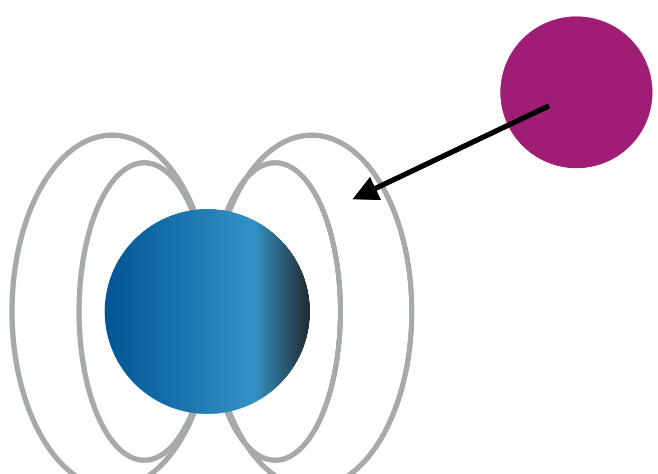
Magnetic field reconnection/ star quake



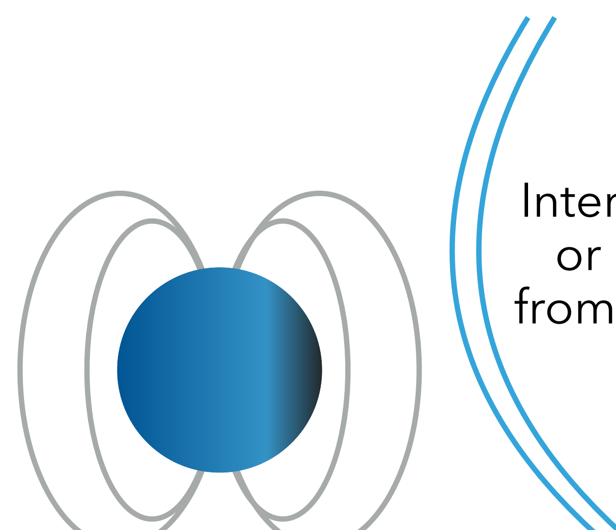
Cosmic string cusps



Merger/Coalescence



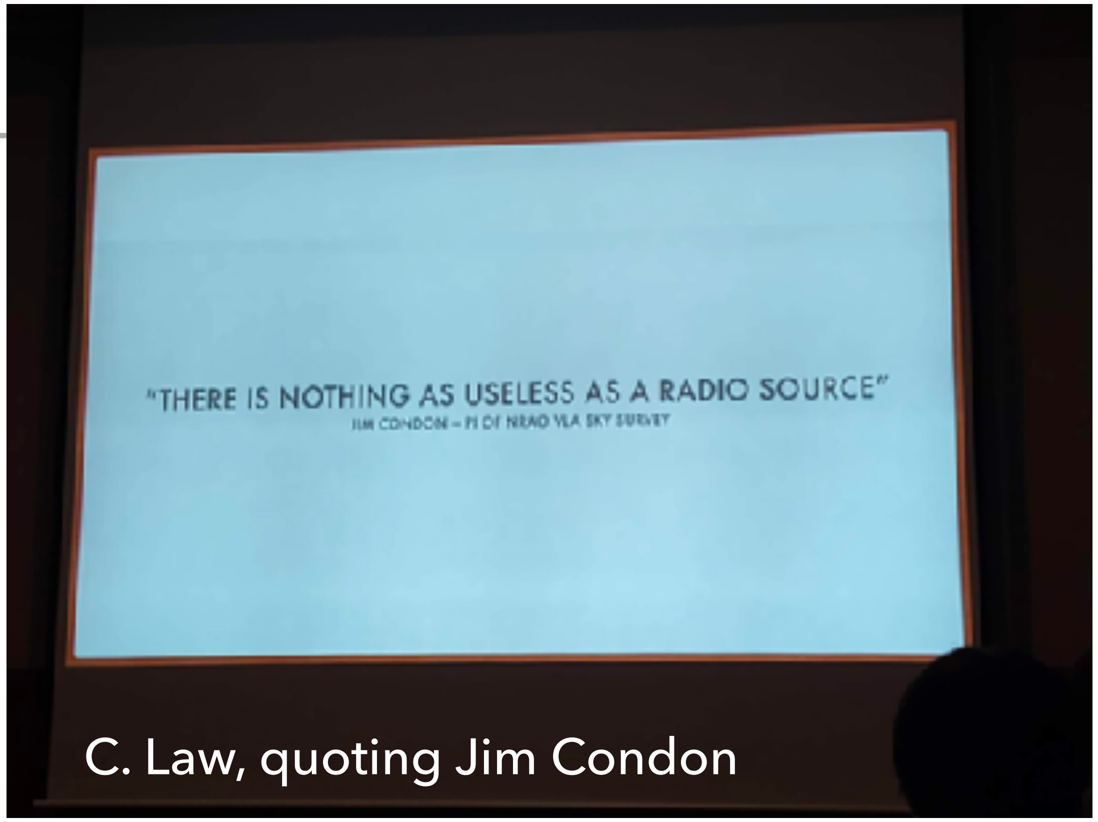
Interaction with asteroid/ axion nugget



Interaction with winds or radiative shocks from pulsars, OB stars, AGNe

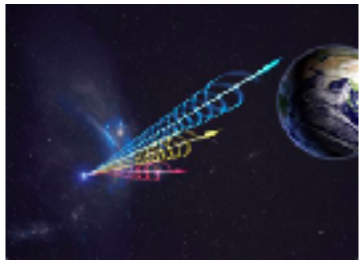
MULTIWAVELENGTH COUNTERPARTS

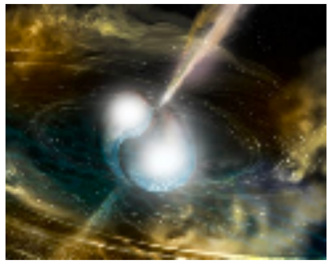
- Radio telescopes are too darn sensitive
    - Detect almost any cosmic blip
    - Not very discerning
- Need more information about the emission processes
- Multi-wavelength/multi-messenger (MWMM) inputs are crucial
- Links different transients together

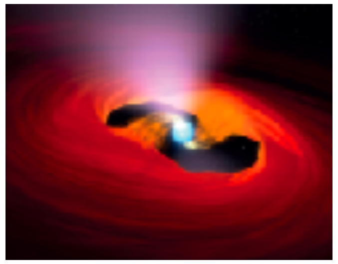


C. Law, quoting Jim Condon

10^{41-44} ergs << 10^{51-52} ergs







MULTI-WAVELENGTH

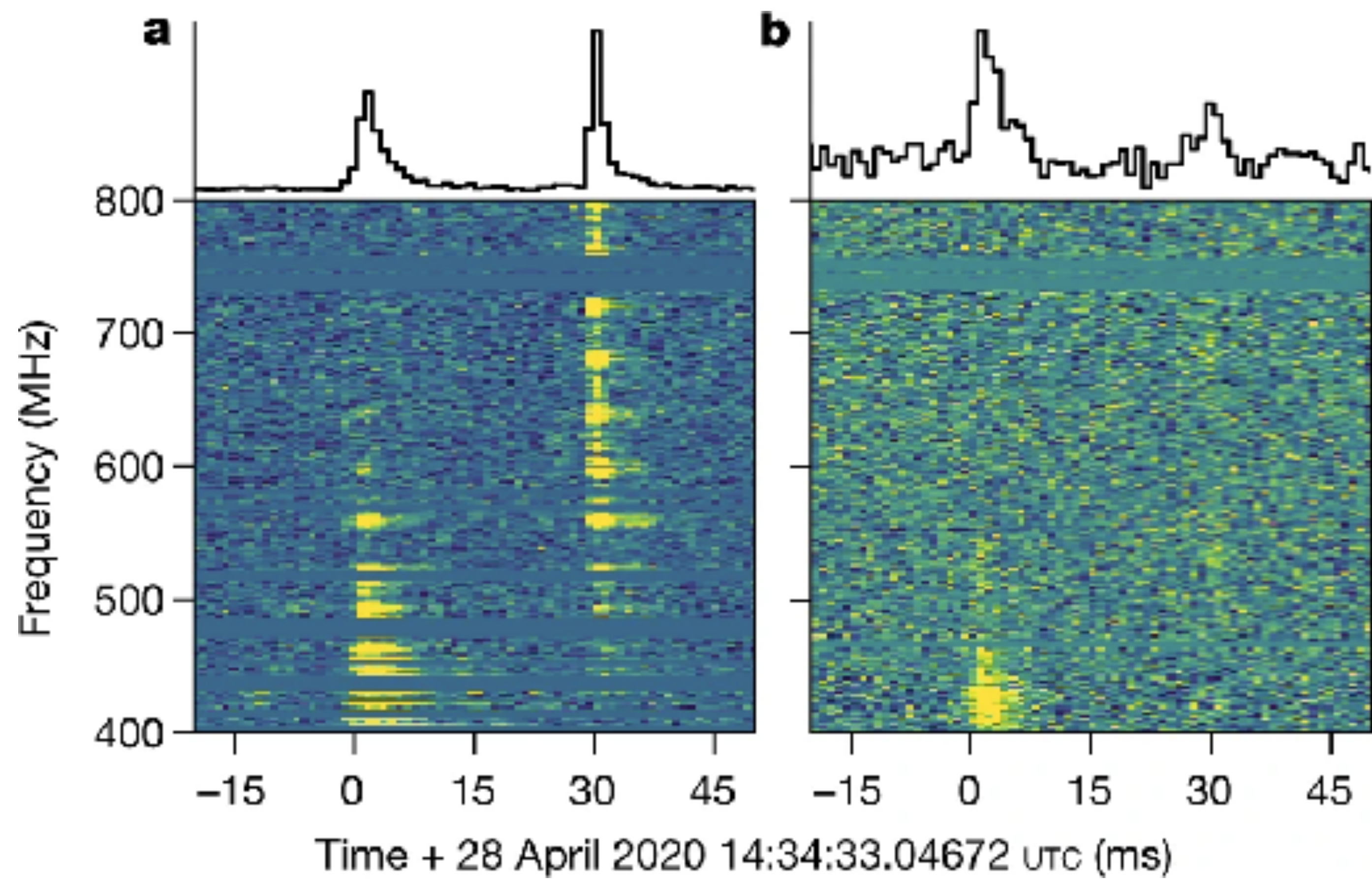
A GALACTIC "FRB"

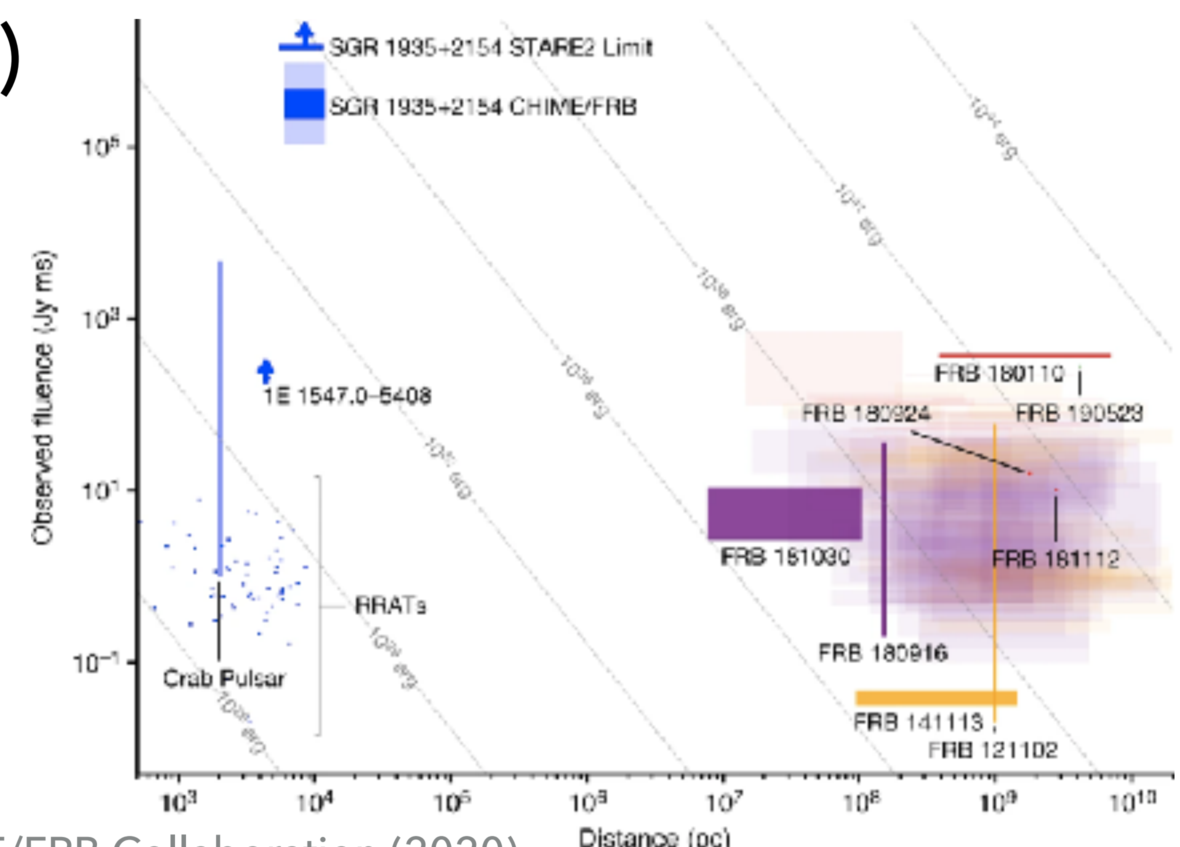
- Since Nov 2019:
  SGR 1935+2154 active
  X-ray flares/bursts

- 28th April 2020: CHIME/FRB detected a very bright radio burst (also detected by STARE2)

  - Lower end of the energetics (still MJy!)

- First FRB from a canonical magnetar

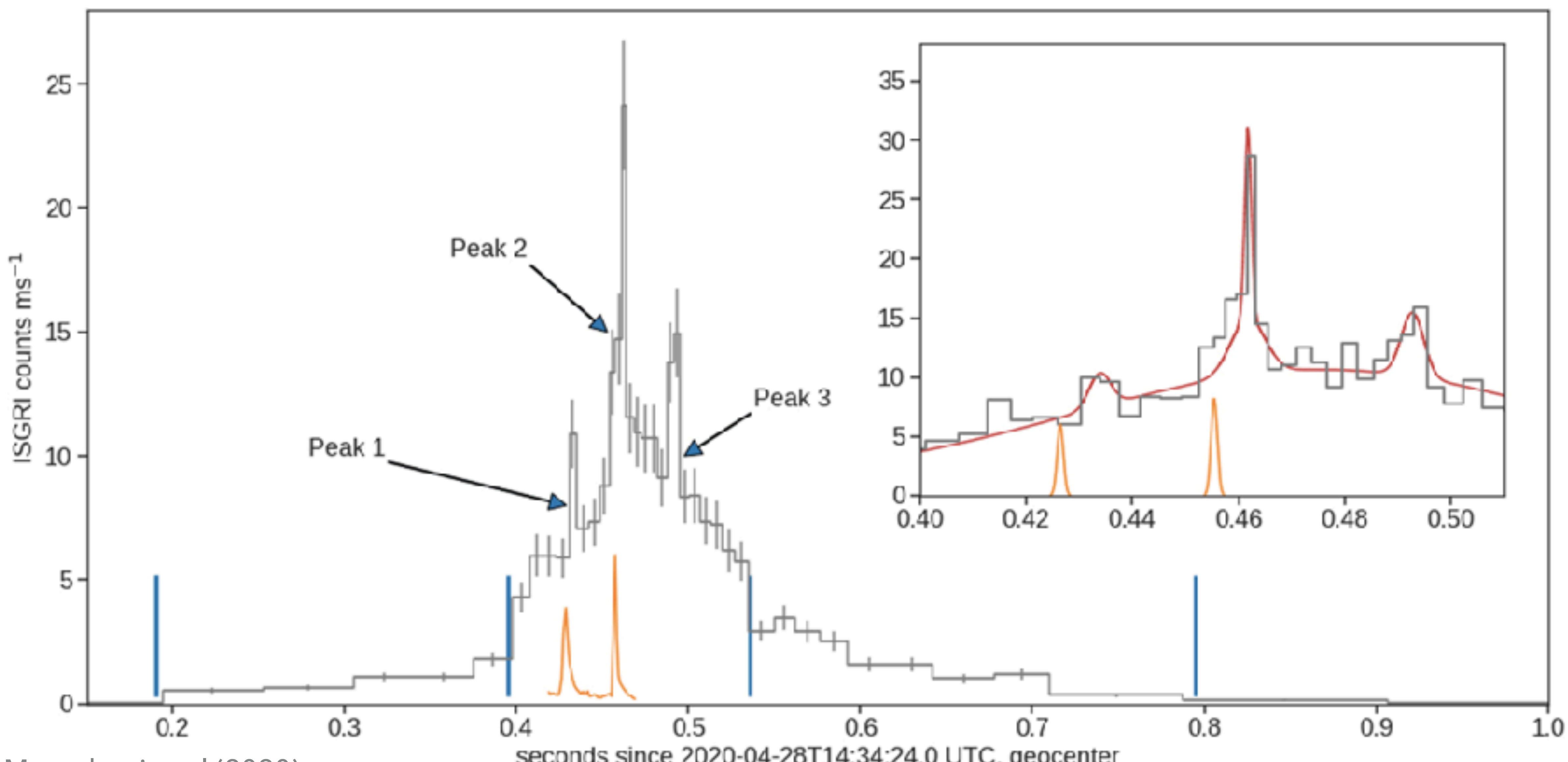




CHIME/FRB Collaboration (2020)

A GALACTIC "FRB"

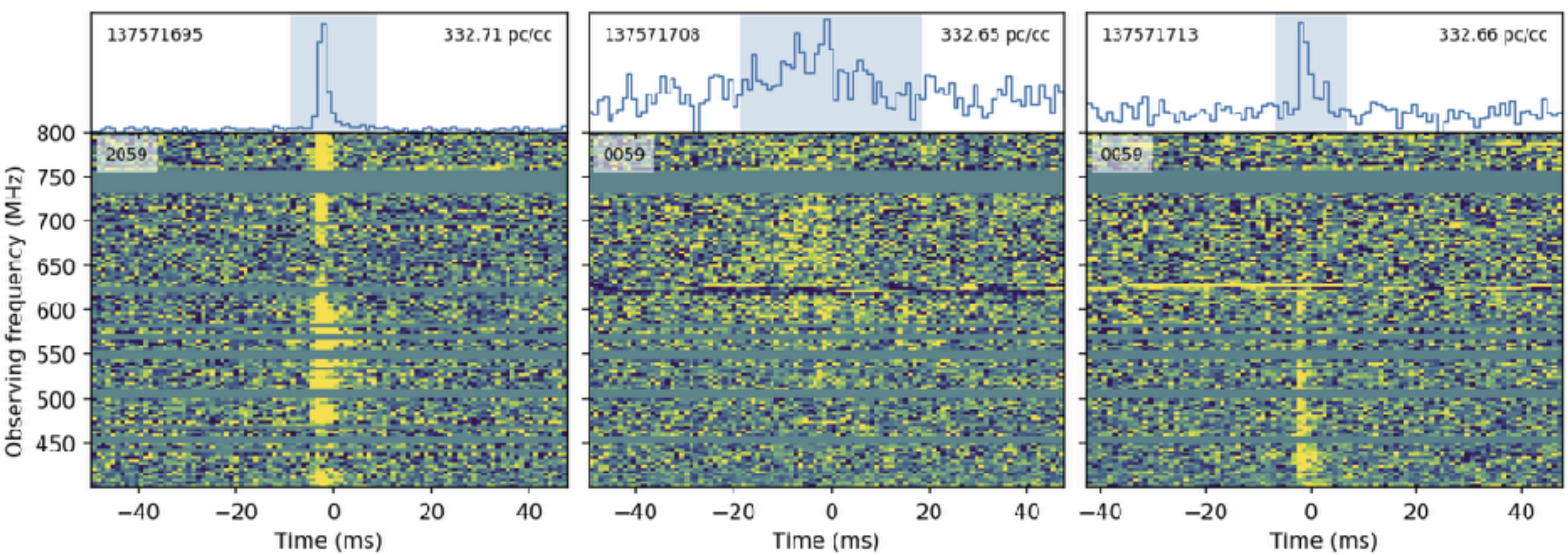
- Multi-peaked 'hard' X-ray burst just after radio



Mereghetti et al (2020)

A GALACTIC "FRB"

- Multi-peaked 'hard' X-ray burst just after radio
- BUT – many other X-ray bursts w/o radio (CHIME/FRB Coll 2020, Lin et al 2020)
- Many radio bursts w/o X-ray (CHIME/FRB Coll. 2020, Kirsten et al 2020)



MORE BURSTS

- Another radio + X-ray burst from SGR 1935+2154: 14th Oct 2022

CHIME/FRB Detection of a Bright Radio Burst from SGR 1935+2154

ATel #15681; *Fengqiu Adam Dong (University of British Columbia), on behalf of the CHIME/FRB Collaboration*
*on **15 Oct 2022; 02:09 UT***
Distributed as an Instant Email Notice Transients
Credential Certification: Kaitlyn Shin (kshin@mit.edu)

Subjects: Radio, X-ray, Gamma Ray, Neutron Star, Soft Gamma-ray Repeater, Star, Transient, Pulsar, Fast Radio Burst, Magnetar

Referred to by ATel #: 15682, 15686

Konus-Wind detection of a short X-ray burst coincident with a bright radio burst from SGR 1935+2154

ATel #15686; *D. Frederiks, A. Ridnaia, D. Svinkin, A. Lysenko, M. Ulanov (all - Ioffe Institute), and A. Tsvetkova (Ioffe Institute/University of Cagliari)*
*on **16 Oct 2022; 15:51 UT***
Credential Certification: Dmitry Frederiks (fred@mail.ioffe.ru)

Subjects: X-ray, Gamma Ray, Neutron Star, Soft Gamma-ray Repeater, Fast Radio Burst, Magnetar

Konus-Wind (KW) detected a short X-ray burst on 2022-10-14 in time interval from 19:21:39.205 UTC to 19:21:42.149 UTC. Corrected for the propagation from low-Earth orbit to Wind (~1.05 s), the burst arrival time is consistent with the detection time of a bright short X-ray burst from SGR 1935+2154, reported by GECAM and HEBS (Atel #15682), which, in turn, is consistent with the dedispersed topocentric time of a bright radio burst detected from SGR 1935+2154 by CHIME (Atel #15681). The event was detected by KW

[Previous | Next]

GBT detection of bright 5 GHz radio bursts from SGR 1935+2154, coincident with X-ray and 600 MHz bursts

ATel #15687; *Yogesh Maan (NCRA - TIFR, India), Joeri van Leeuwen (ASTRON, NL), Samayra Straal (NYU Abu Dhabi, UAE) and Ines Pastor-Marazuela (UvA, NL)*
*on **19 Oct 2022; 13:45 UT***
Credential Certification: Yogesh Maan (maan@astron.nl)

Subjects: Radio, X-ray, Neutron Star, Soft Gamma-ray Repeater, Transient, Magnetar

Referred to by ATel #: 15698

Triggered by recent X-ray activity (GCN #32675, ATel #15667, #15672), we observed SGR 1935+2154 with the Green Bank Telescope (GBT) on 2022 Oct 14. During a C-Band session, we detected at least 5 bursts with high signal to noise ratio. All these bursts were detected within a time span of 1.5 seconds, i.e., well within one rotation of the magnetar, but over a range of phases. Throughout the entire duration of the two brightest bursts, the receiver system is clearly strongly saturated.

GECAM and HEBS detection of a short X-ray burst from SGR J1935+2154 associated with radio burst

ATel #15682; *C. W. Wang, S. L. Xiong, Y. Q. Zhang, J. C. Liu, C. Zheng, W. C. Xue, W. J. Tan, S. L. Xie, Q. B. Yi, Y. Zhao, Y. Wang, C. Cai, S. Xiao, Y. Huang, X. Ma, R. Qiao, P. Wang, X. Y. Zhao, P. Zhang, X. Q. Li, X. Y. Wen, W. X. Peng, L. M. Song, S. J. Zheng, Y. Q. Du, D. Y. Guo, B. Li, X. B. Li, J. Liang, Y. Q. Lu, J. Wang, H. Wu, X. Y. Song, W. H. Yu, Z. Zhang, Z. H. An, P. Y. Feng, M. Gao, K. Gong, X. J. Liu, Y. Q. Liu, X. L. Sun, J. Z. Wang, Y. B. Xu, S. Yang, D. L. Zhang, F. Zhang, C. K. Li, G. Li, J. Y. Liao, G. Chen, F. J. Lu, S. N. Zheng (IHEP) report on behalf of GECAM and HEBS teams:*
*on **15 Oct 2022; 06:35 UT***
Credential Certification: Yu-Peng Chen (chenyp@ihep.ac.cn)

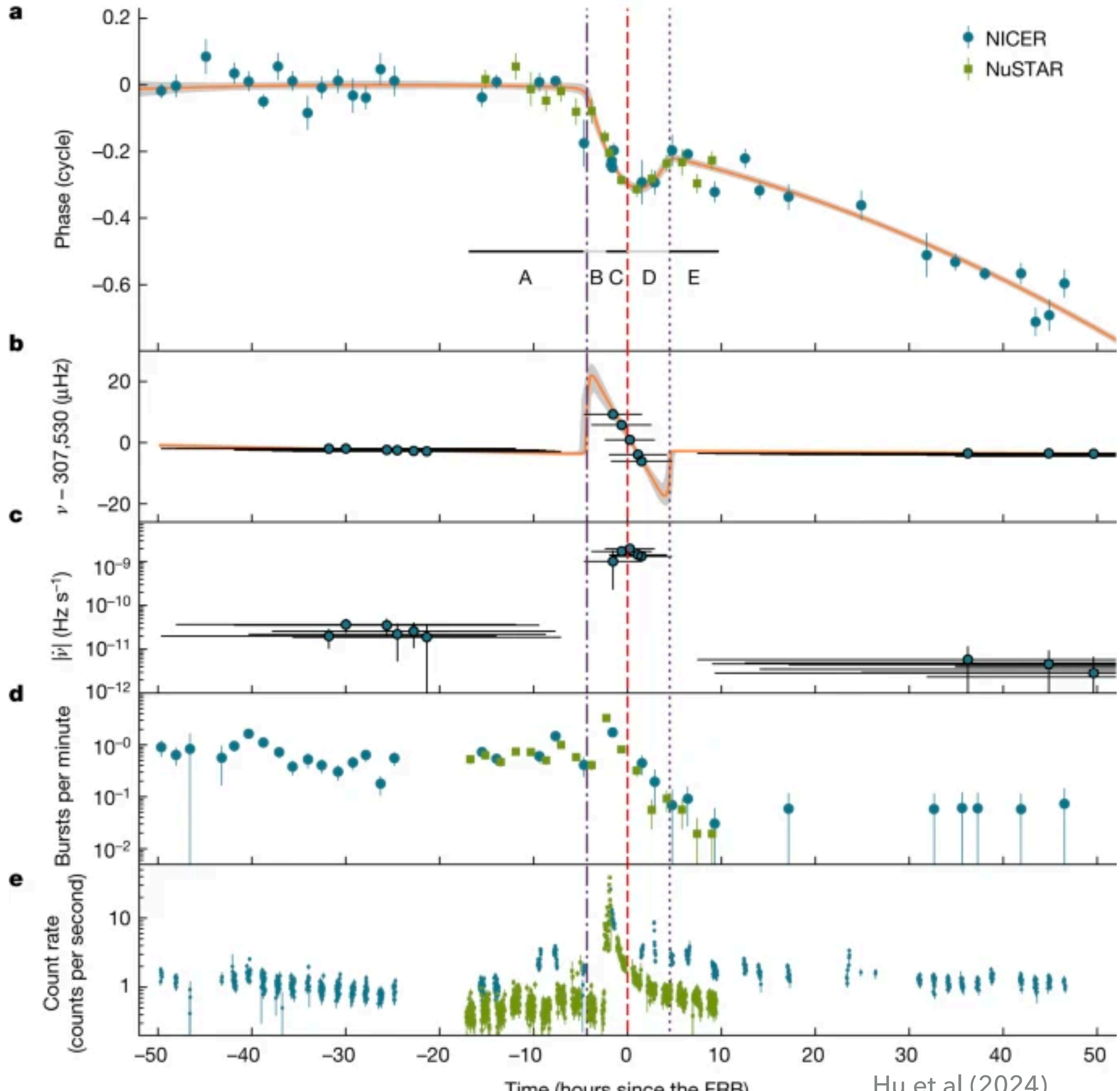
Subjects: Gamma Ray, Gamma-Ray Burst, Neutron Star

- Broad spectrum coverage (thermal/non-thermal?)
- Bursts from magnetars in nearby galaxies

SGR 1935 GLITCH

- Glitch with 14 Oct 2022 Burst
- Largest glitch yet observed
- Two glitches

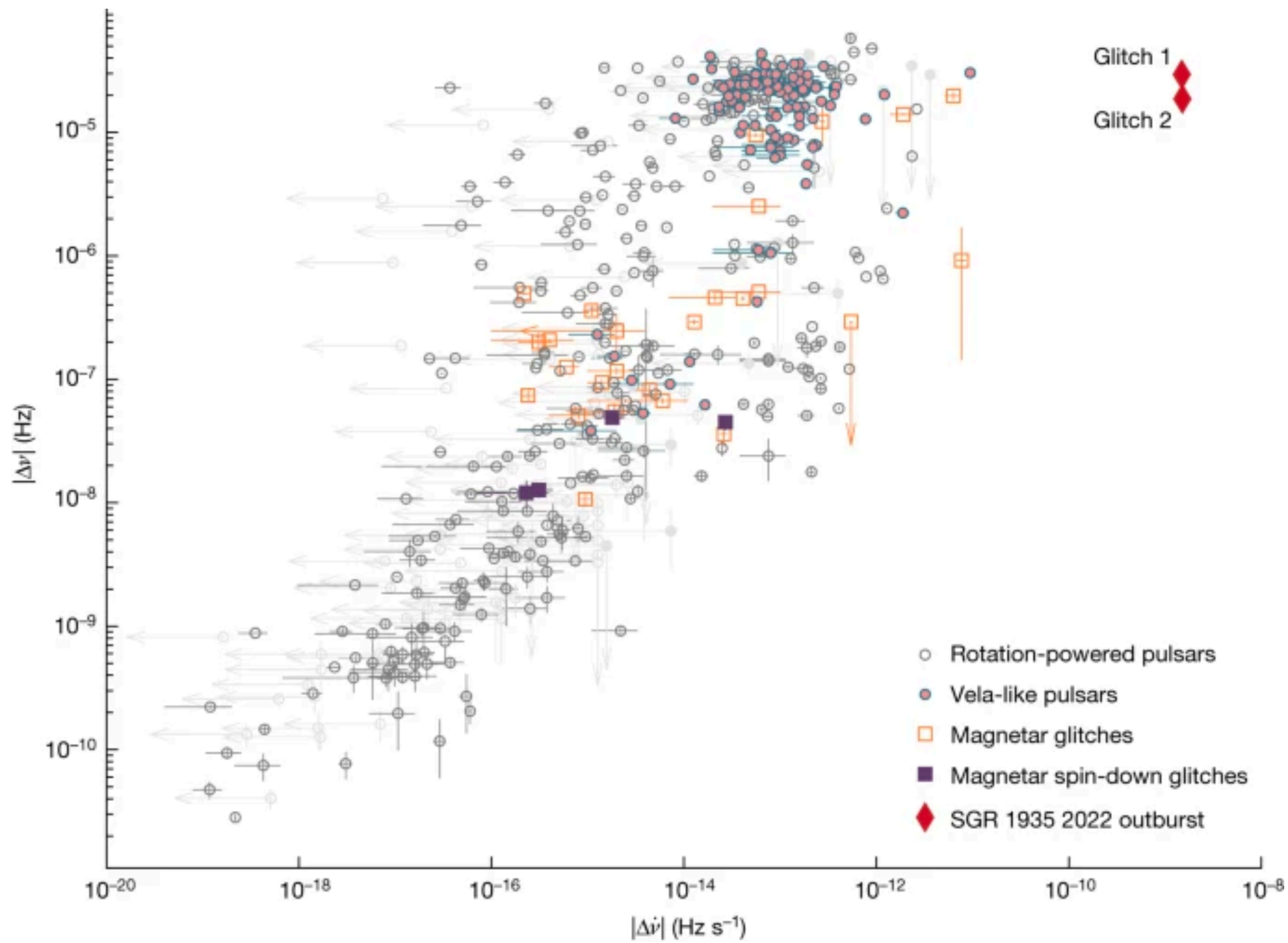
Glitch – sudden increase in spin frequency
Anti-glitch – sudden decrease



Hu et al (2024)

SGR 1935 GLITCH

- Glitch with 14 Oct 2022 Burst
- Largest glitch yet observed
- Two glitches

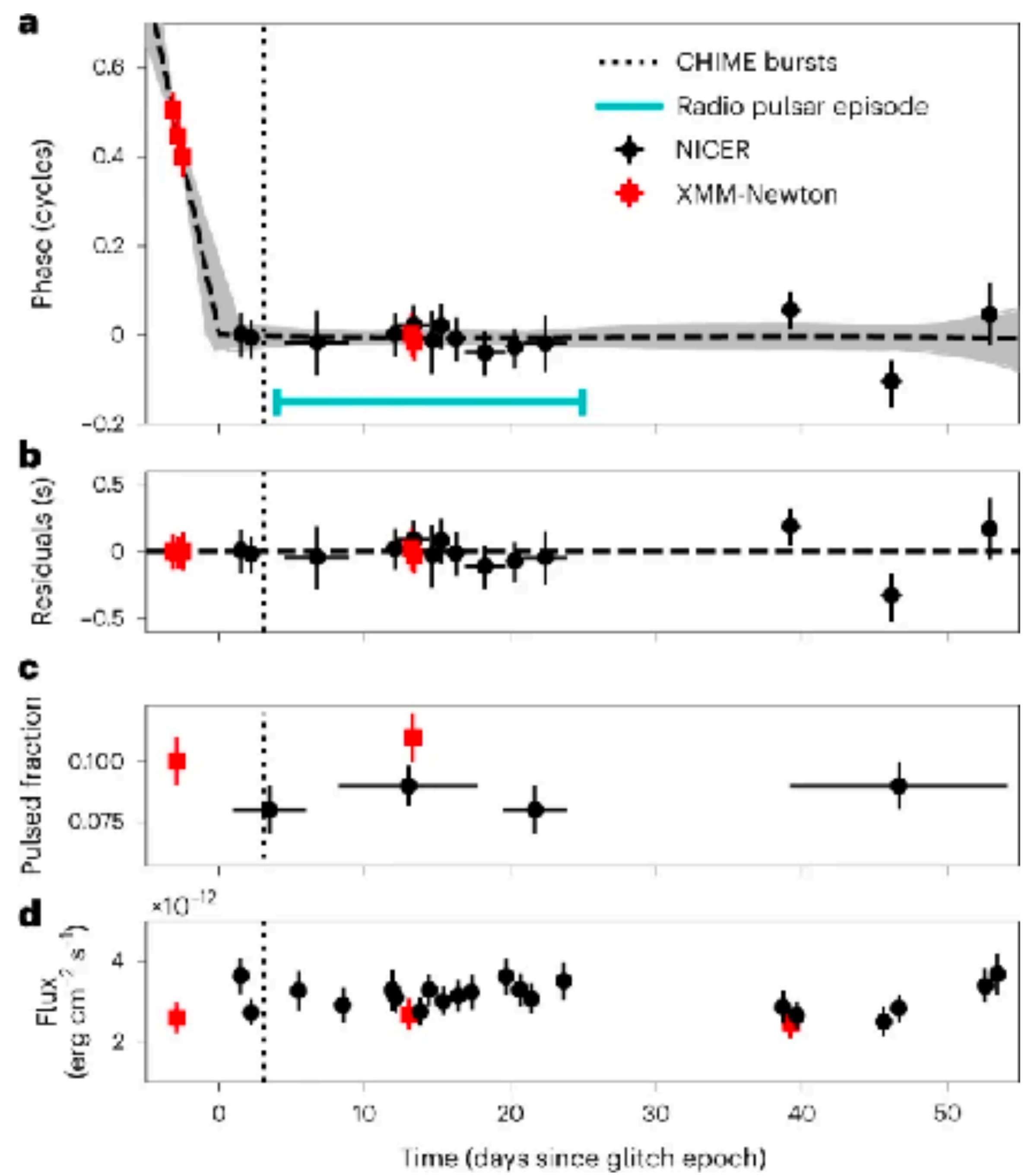


Glitch – sudden increase in spin frequency
Anti-glitch – sudden decrease

Hu et al (2024)

SGR 1935 GLITCH (5 OCT 2022)

- Younes et al (2023)
- 5th Oct 2022 (before the actual FRB-like burst)
- *Spindown* glitch (anti glitch)

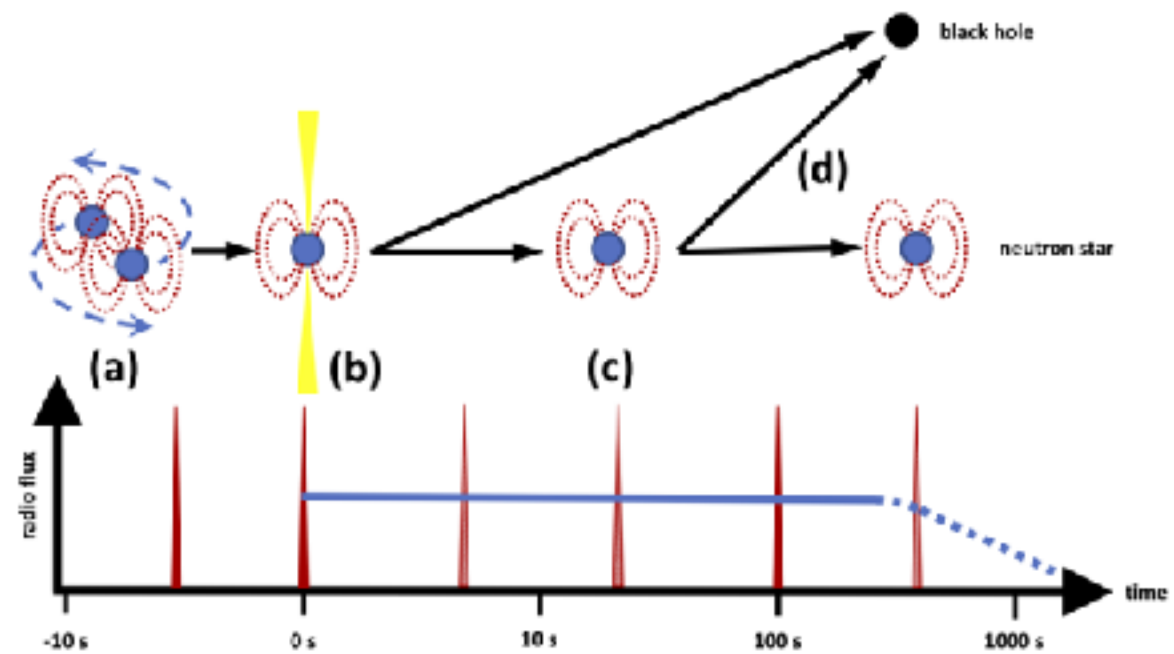


SO DOES THAT SOLVE ALL OUR PROBLEMS?

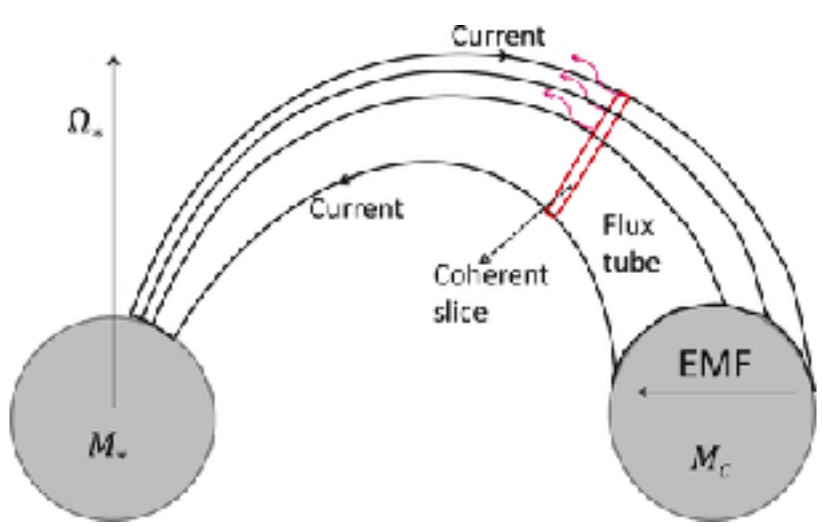
- SGR 1935+2154-like magnetars likely don't explain all FRBs
- The occurrence rate may be consistent with the volumetric rate as a population
- But individual FRBs (repeaters and non-repeaters) have behavior/activity that SGR 1935+2154 (or other magnetars) have not replicated

X-RAYS/GAMMA-RAYS

- Multiple models for FRB - short GRB connection
  - Inspiral phase, Actual merger, Post merger



Rowlinson et al (2019)



Wang et al (2016)

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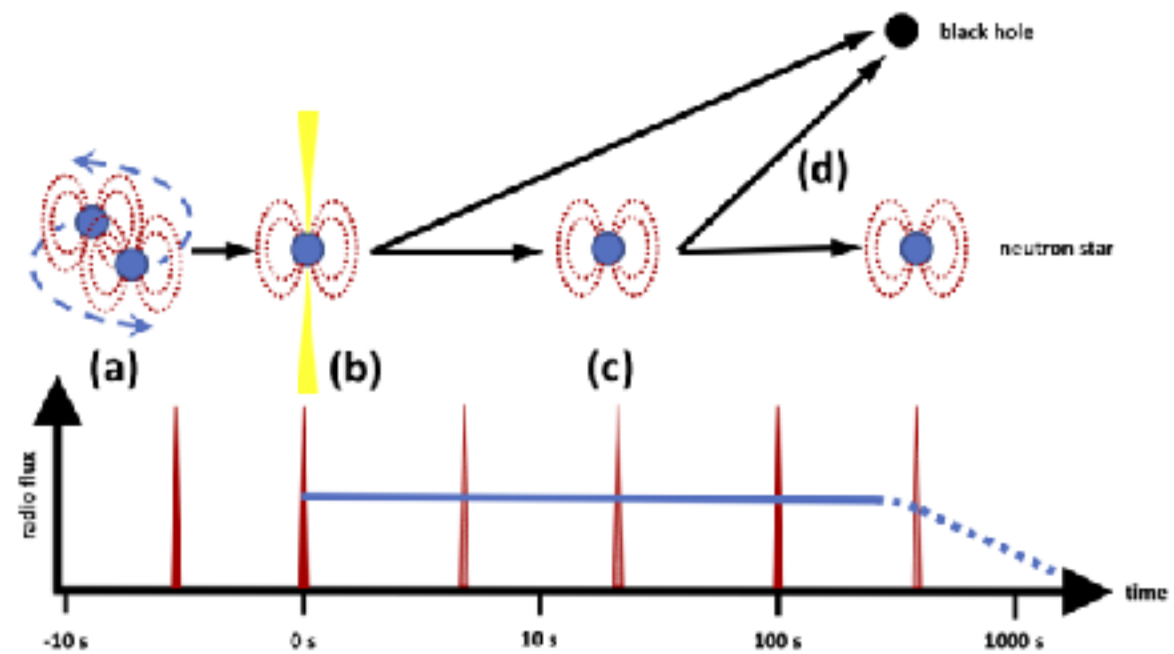
Take away message:
Lots of different models about when and how FRBs can form — before, during, or after BNS/NSBH mergers.

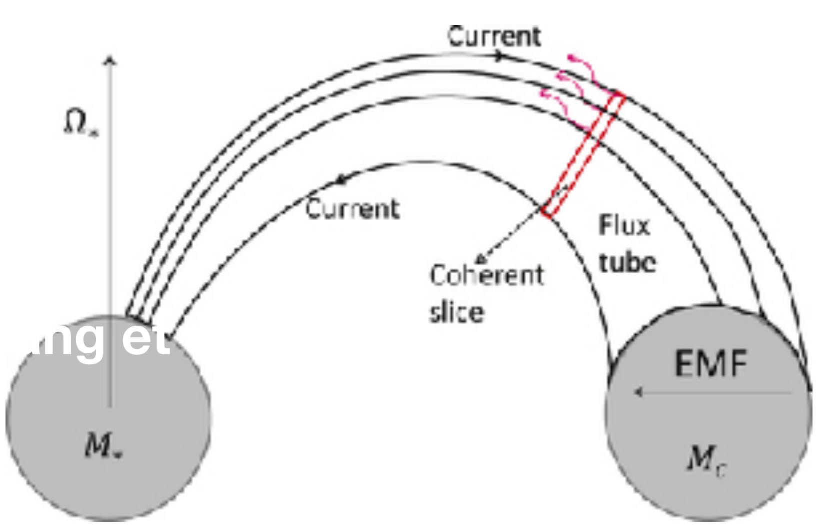
With apologies for incompleteness

X-RAYS/GAMMA-RAYS

- Multiple models for FRB - short GRB connection
  - Inspiral phase, Actual merger, Post merger



Rowlinson et al (2019)



ng et

merger

BUT:

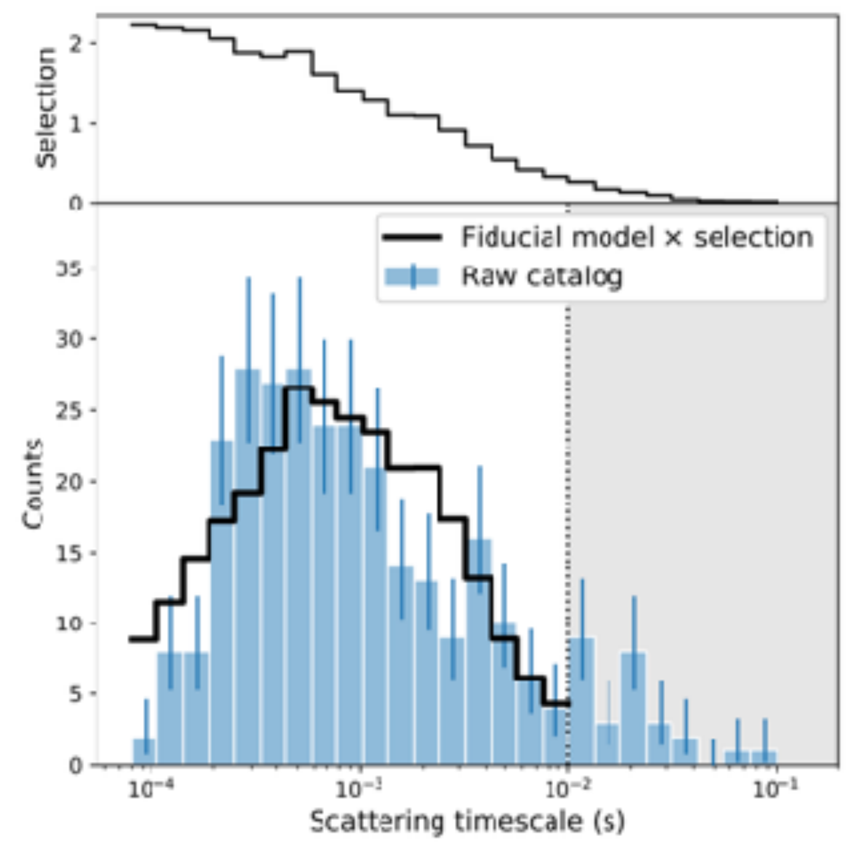
Differential beaming, dirty environments can prevent joint detection of FRBs + GRBs

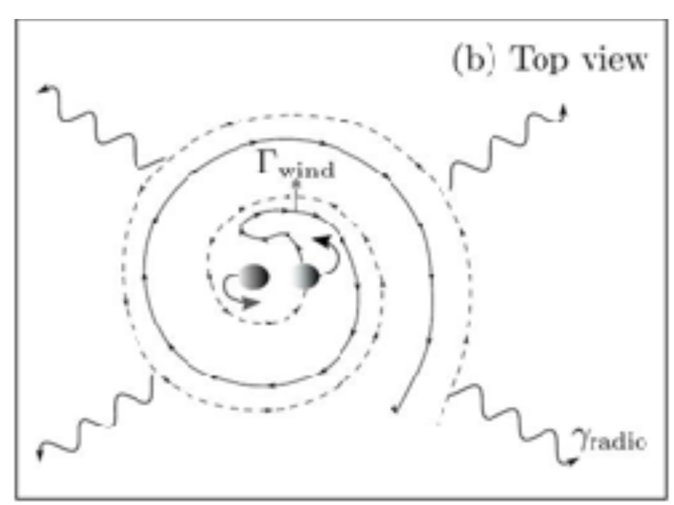
With apologies for incompleteness

Sujay Mate, Kevin Luke, Arvind Balasubramanian, Yash Bhusare

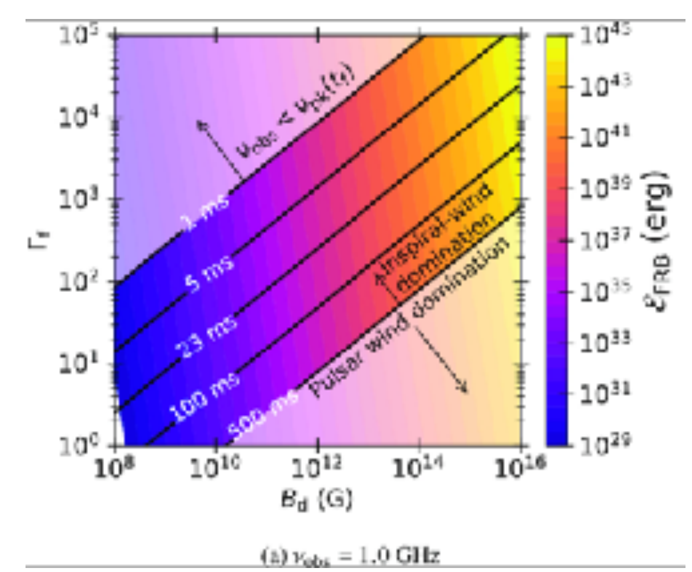
NOT-SO-FAST RADIO BURSTS (NSFRBS)

- CHIME/FRB is not very sensitive to bursts wider than ~30 ms.
    - Scattered FRBs,
    - Possible WD bursts, M-dwarf flares
    - EM counterparts of binary NS mergers
- Separate pipeline searching from ~30 ms – ~5 seconds in timescale
- Unexplored phase space
- Currently building the pipeline, piggybacking on CHIME/Slow Pulsar Search





Sridhar & Metzger (2021)



PROBING BARYON DISTRIBUTIONS

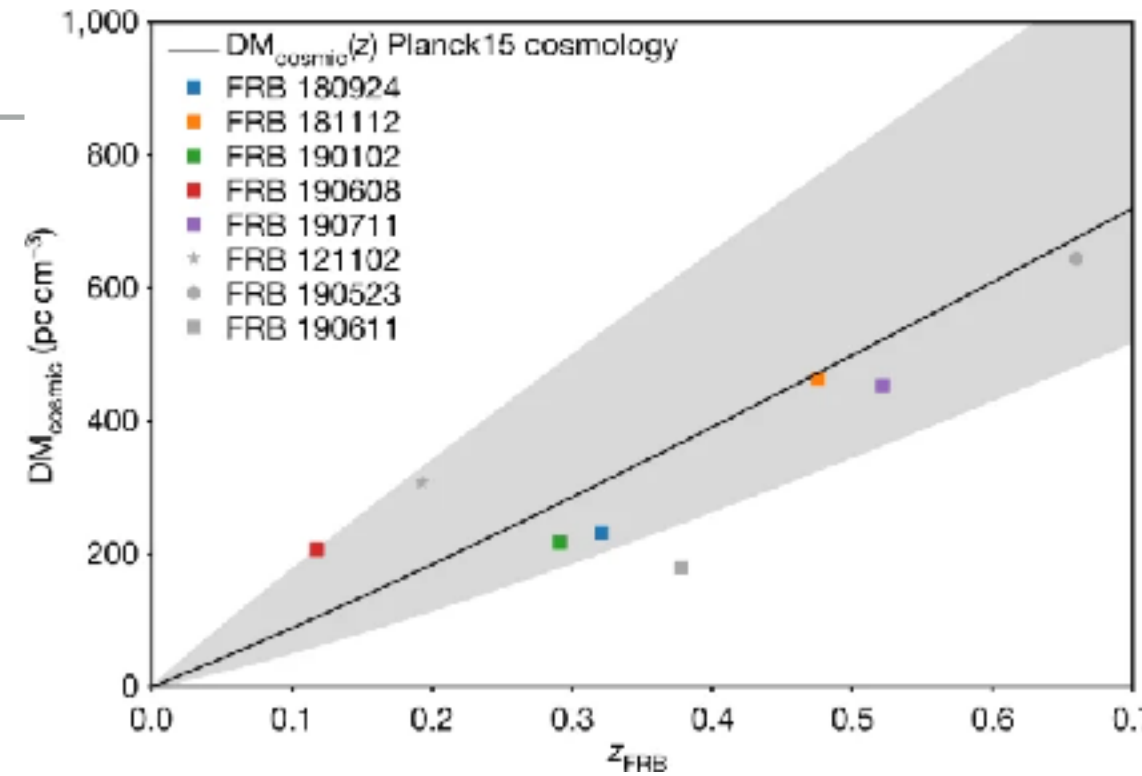
MACQUART RELATION

- DM can be translated to redshift, with some scatter

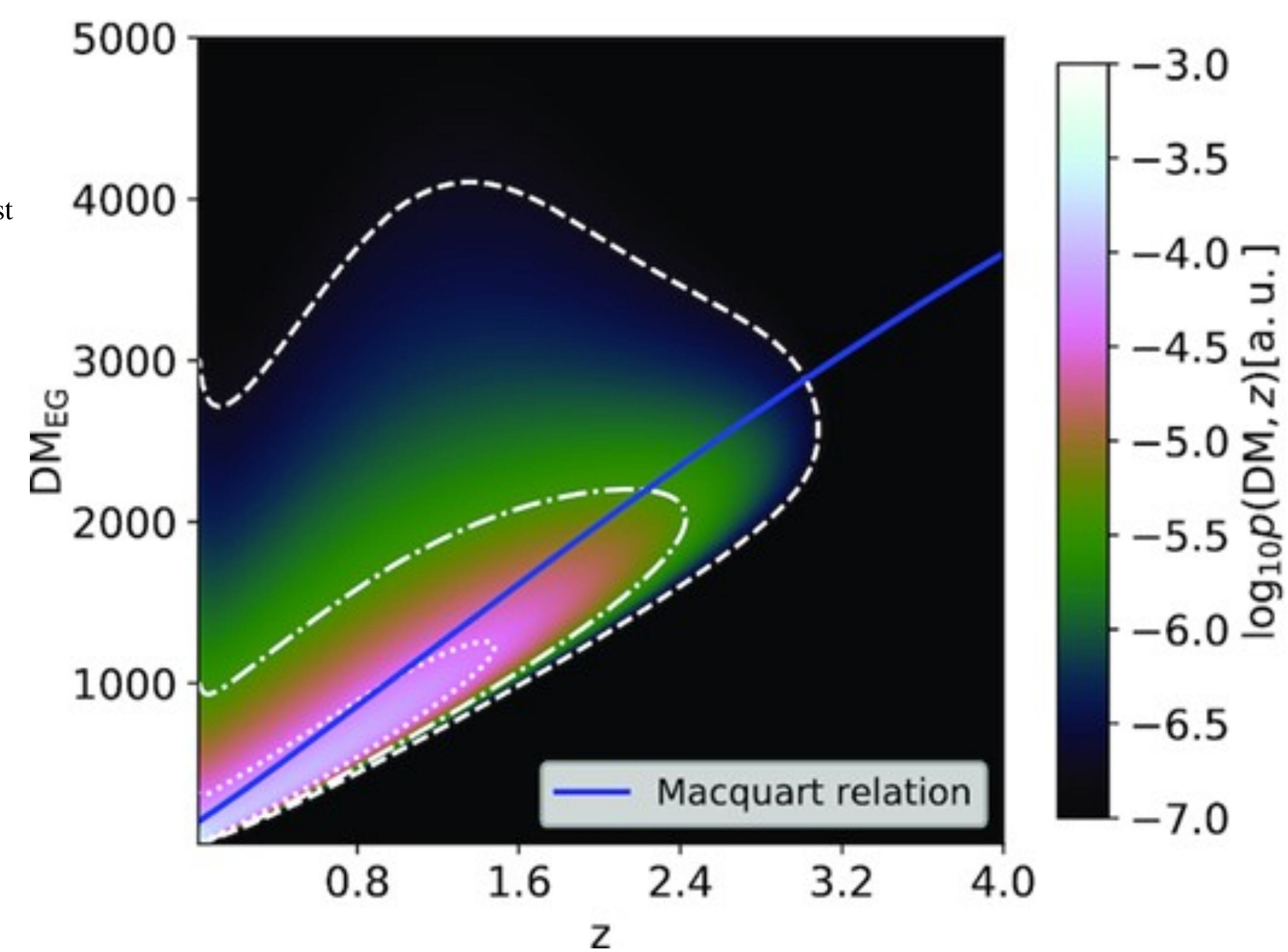
- $DM_{FRB} = DM_{MW} + DM_{Halo} + DM_{IGM} + (DM_{CGM}) + DM_{Host}$

- If we can estimate some terms, we get others

- At high DM –> turnover



Macquart et al (2020

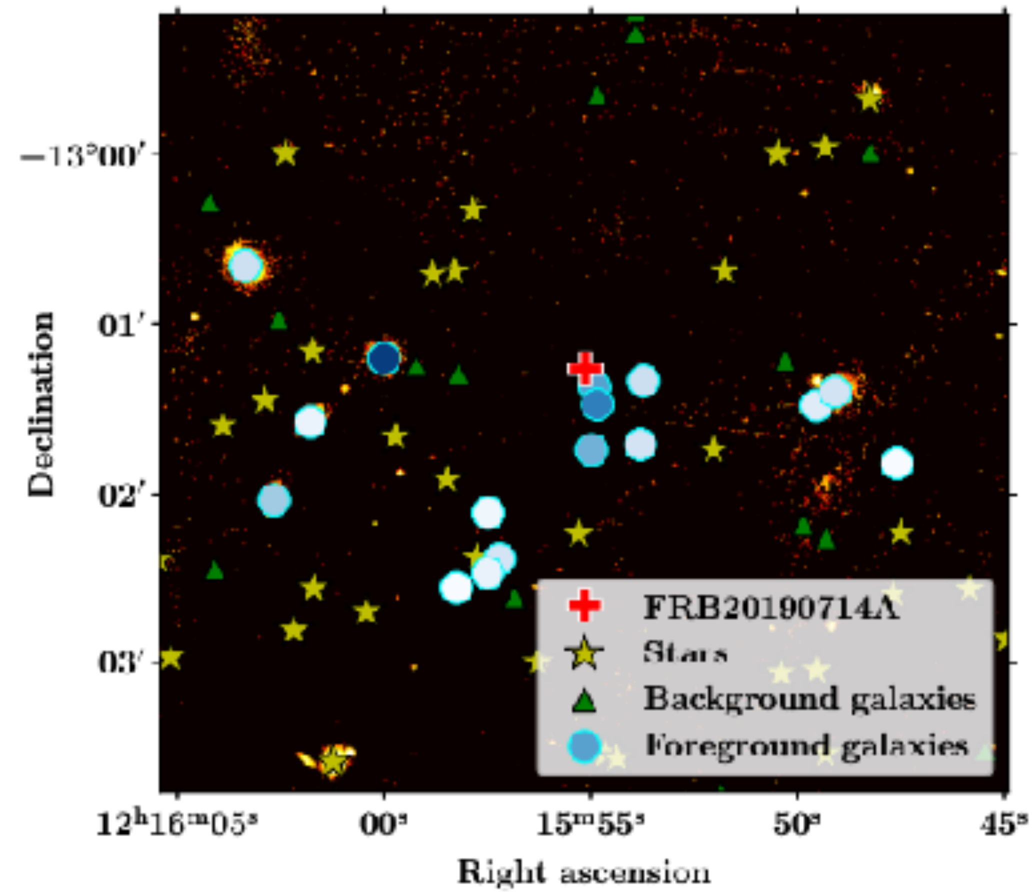


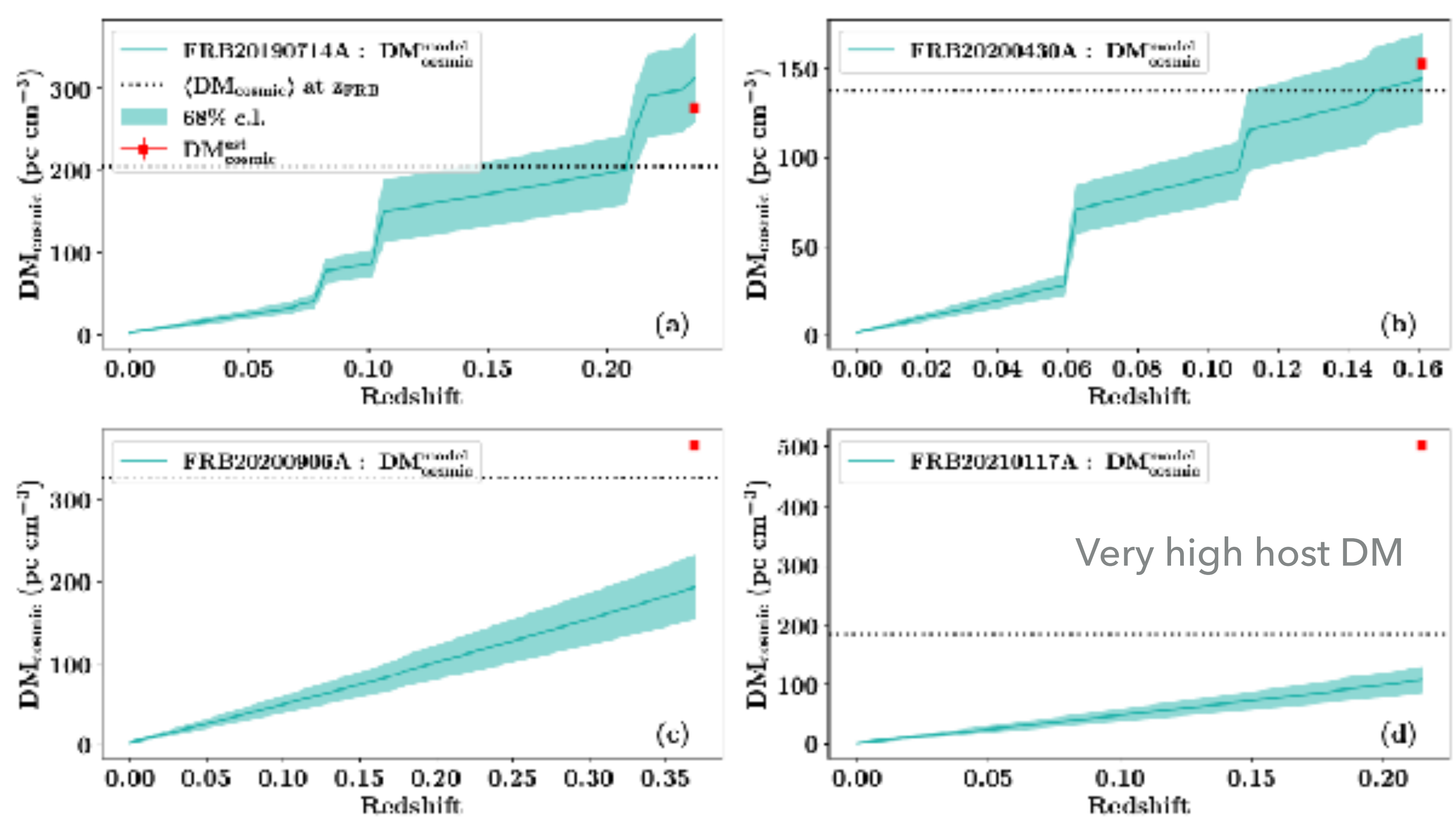
Simha et al (2023)

FLIMFLAM SURVEY

- z_spec along FRB sightline
- Many intervening halos
- Model DM contribution (w.r.t impact parameter etc)
- Repeat for many FRBs

  Very expensive in telescope time





FLIMFLAM SURVEY

- $N \simeq 100$ FRBs would be enough to achieve a ≈5 per cent precision on f_{igm} (Lee et al 2022)
- Next few years?

Table 2. Partition of cosmic baryons at $z = 0.1$, in Simba simulation runs characterised by different feedback prescriptions.

Run	Stars	ISM	HI	CGM: Clusters ($\geq 10^{14} M_\odot$)	CGM: High-mass groups ($10^{13} M_\odot - 10^{14} M_\odot$)	CGM: Low-mass groups ($10^{12} M_\odot - 10^{13} M_\odot$)	CGM: Galaxies ($10^{10} M_\odot - 10^{12} M_\odot$)	IGM
Simba-100	3.70%	0.82%	0.79%	3.15%	2.10%	0.76%	1.82%	86.78%
Simba-50	3.67%	0.75%	0.76%	2.04%	2.91%	0.74%	1.63%	87.34%
No-X-ray	5.33%	0.99%	0.93%	2.02%	2.79%	0.93%	1.75%	85.06%
No-Jet	10.65%	1.66%	1.15%	2.58%	6.51%	4.17%	2.48%	70.55%
No-AGN	12.20%	1.30%	1.05%	2.64%	6.60%	3.84%	2.64%	69.51%
No-feedback	21.27%	1.64%	0.46%	2.01%	4.89%	3.34%	2.67%	58.82%

SIMBA-100 –> 100 h^{-1} cMpc box, Simba-50 –> 50 h^{-1} cMpc box

Khyrkin et al (2024) SIMBA sims

SUMMARY

"ROUTINE"

- FINDING FRBS
- ~10 ARCMIN LOCALIZATION
- "DAILY" MONITORING FOR REPEATS
- POLARIZATION
- MILLIARCSECOND LOCALIZATION OF REPEATERS
- ARCSECOND LOCALIZATION
- HOST GALAXIES + REDSHIFT

HARD

- MILLIARCSECOND LOCALIZATION OF ALL FRBS
- FRBS AT Z > 1
- PROMPT MULTI-WAVELENGTH/MESSENGER
- THOUSANDS OF HOST GALAXIES

DREAM

- LENSED FRBS
- THOUSAND FRBS PER DAY
- Z > 4
- 24X7 MONITORING FOR REPEATS