

Radio astronomy essentials: Brief overview of Fast Radio Bursts

MARCH 2026 @ UNDARK, ANNECY

Cherry



NG-GUIHENEUF



CENTRE NATIONAL
DE LA RECHERCHE
SCIENTIFIQUE



THE
SHAW
PRIZE
邵逸夫獎

MATTHEW
BAILES

DUNCAN
LORIMER

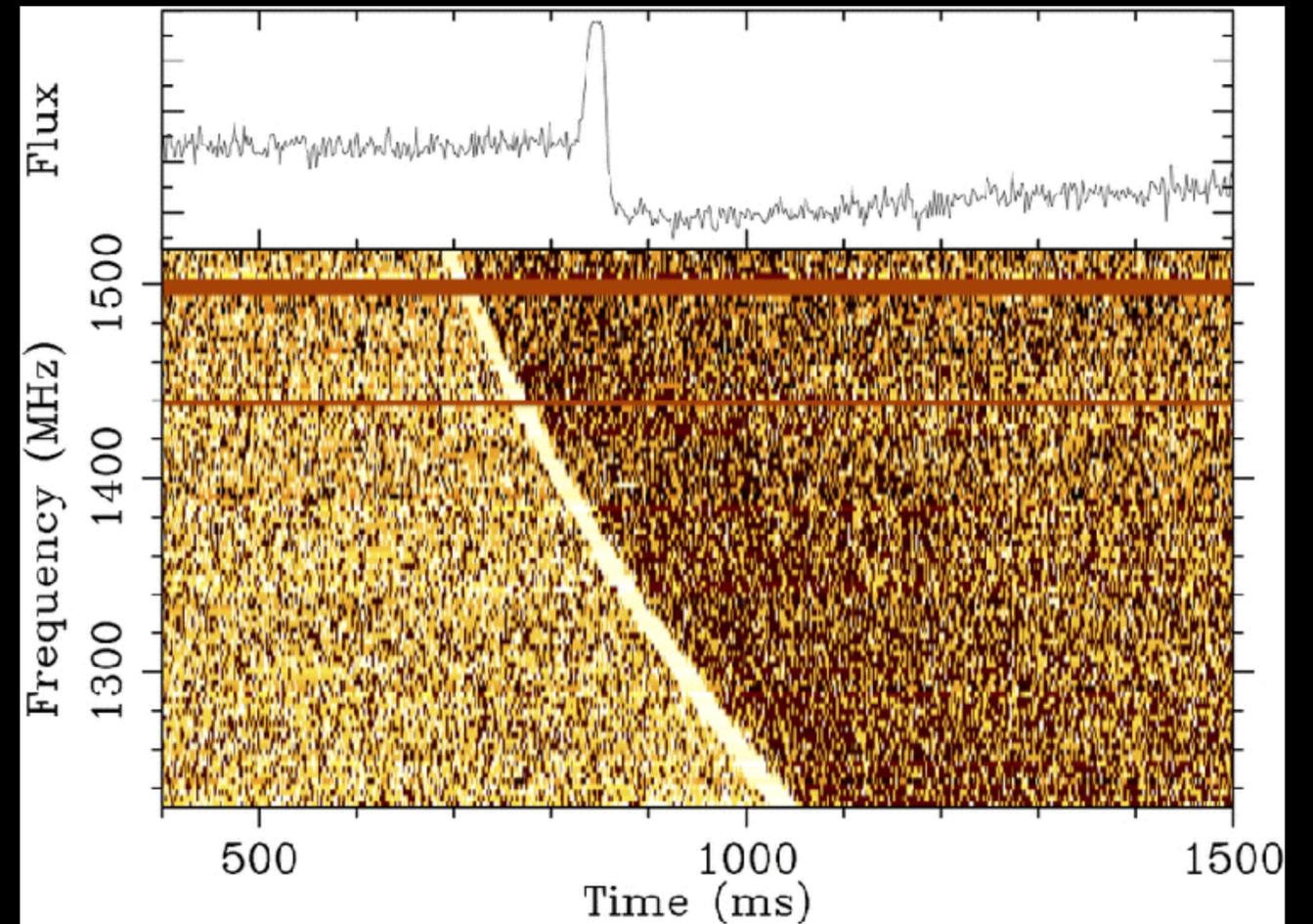
MAURA
MCLAUGHLIN

2023 SHAW LAUREATES IN

ASTRONOMY

Shaw prize in Astronomy 2023

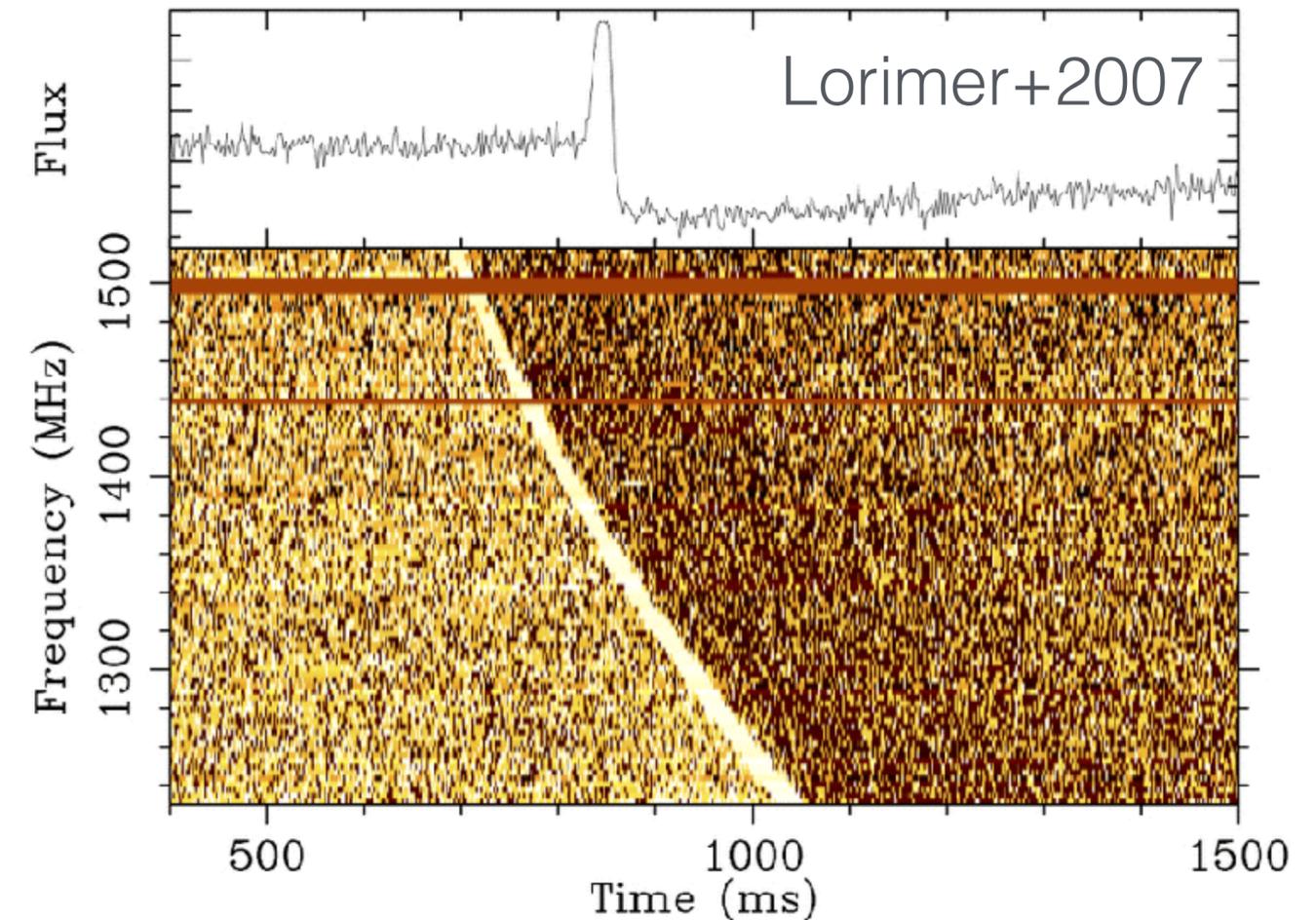
Discovery of Fast Radio Bursts



Lorimer+2007

FRB in a nutshell

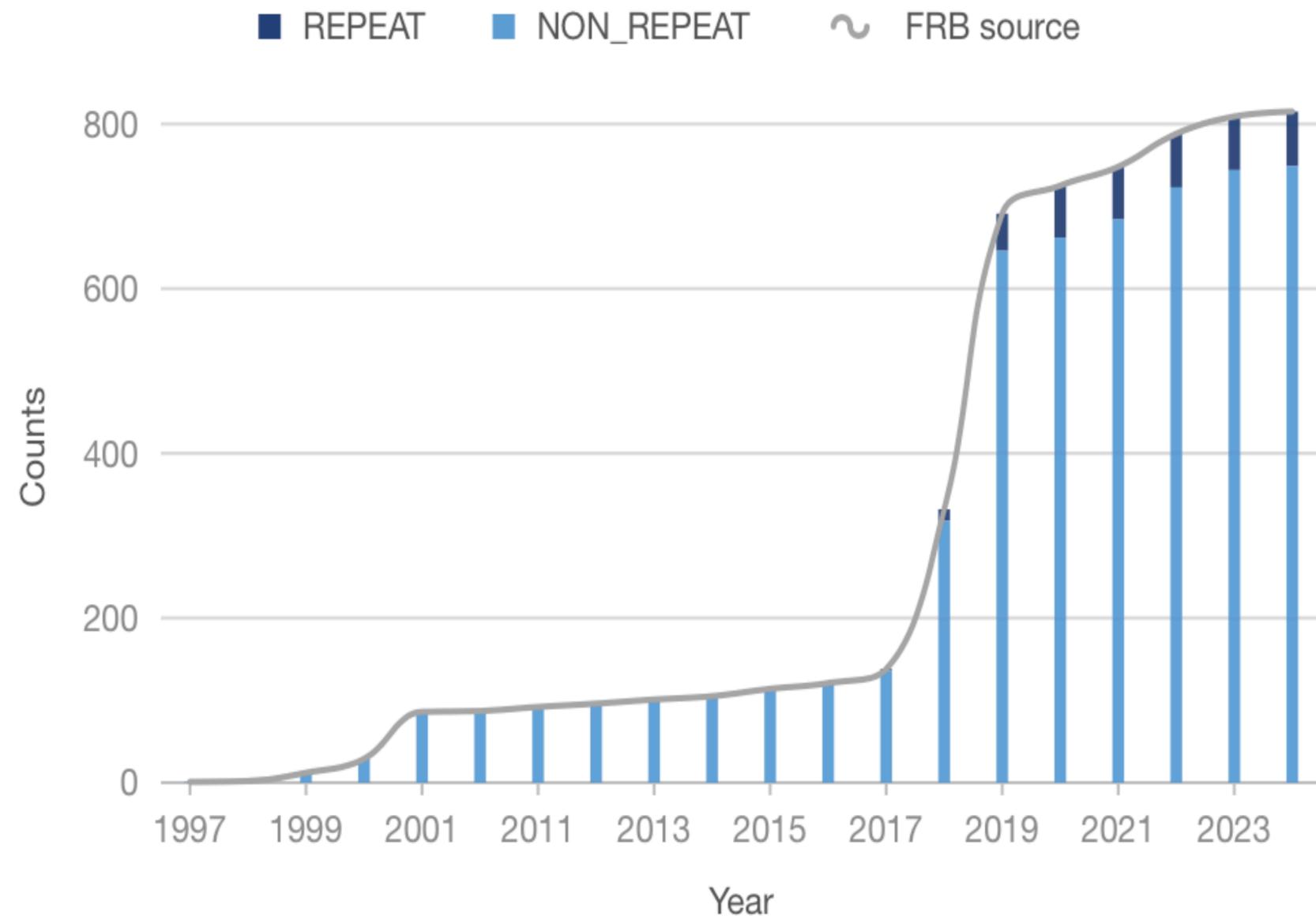
- Bright ($< 10^{44}$ erg s $^{-1}$) and short (\sim ms)
- High event rate ($\sim 5,000$ /sky/day)
 - Volumetric rate higher than ccSN
- Extragalactic ($\sim 0.03 > z > 2.1$)
- Over 5000 known FRBs, a few % repeats
- no conclusive MW counterparts yet, except the Galactic magnetar FRB SGR1935+2154
- So far, detected by 16+ radio telescopes between 110 MHz - 8 GHz
- Yet unknown origin(s)
- Useful as cosmological probe to study:
 - Sensitive to diffused baryons via dispersion
 - Ms-precision arrival time



λ^2 dispersive sweep due to LOS integral free electrons in cold plasma
→ Key observable: dispersion measure (DM)
→ traces baryons since most baryons in the Universe are ionized

Chronology of the FRB discoveries

Plot from Blinkverse website



CHIME radio telescope (Canada)

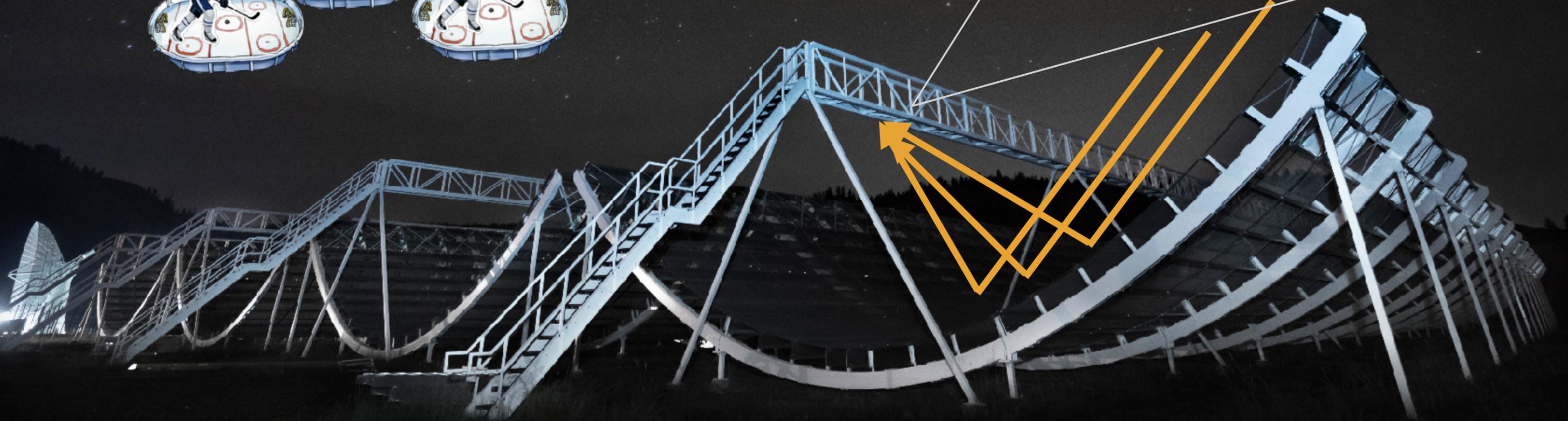


Transit telescope = a large field-of-view and a high discovery rate

- Catalog 1 = 536 FRBs (Aug 2018—July 2019)
- Catalog 2 = 4998 FRBs (Aug 2018—Sept 2023)

COMING SOON

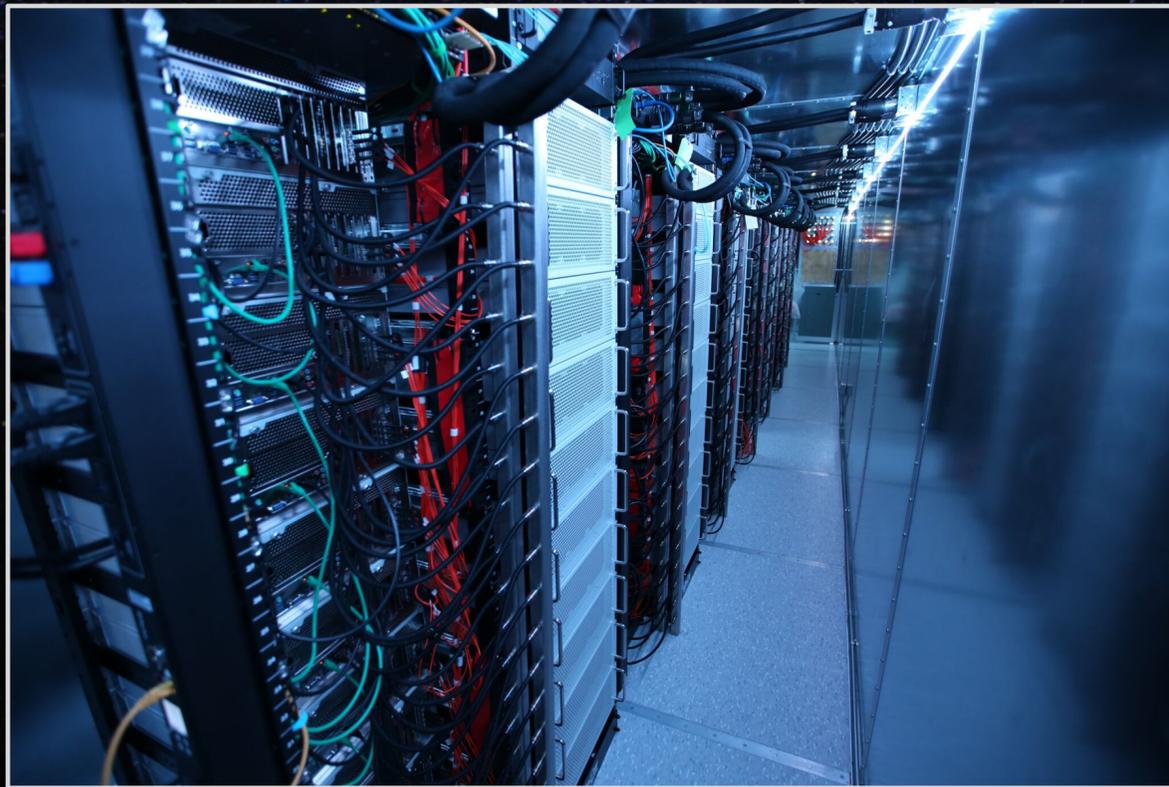
CHIME RADIO TELESCOPE



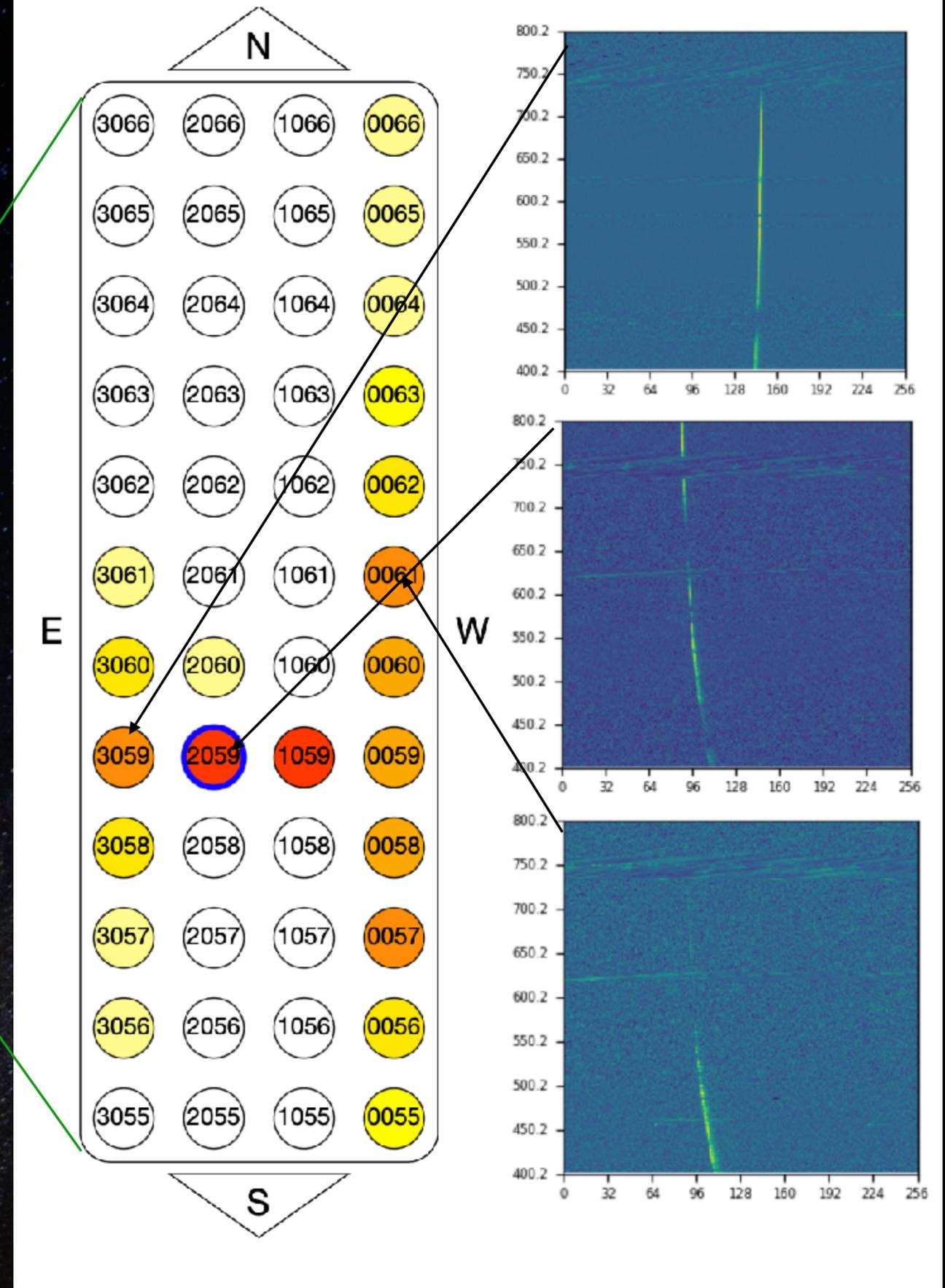
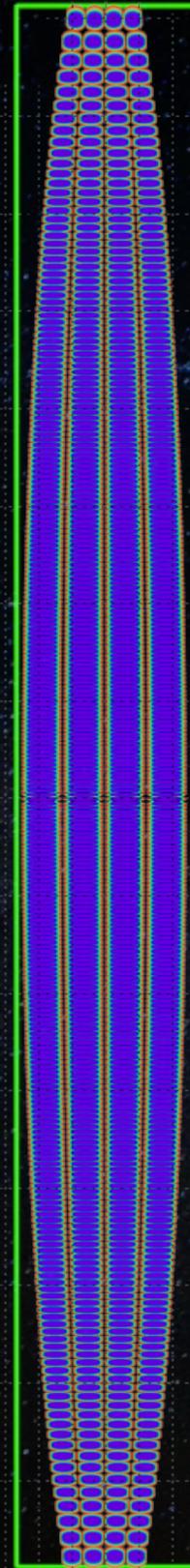
GPU BEAMFORMING ALGORITHM



[Ng+ 2017 \(1702.04728\)](#)



- data rate 13 Tb/s
- 1024 GPU correlator



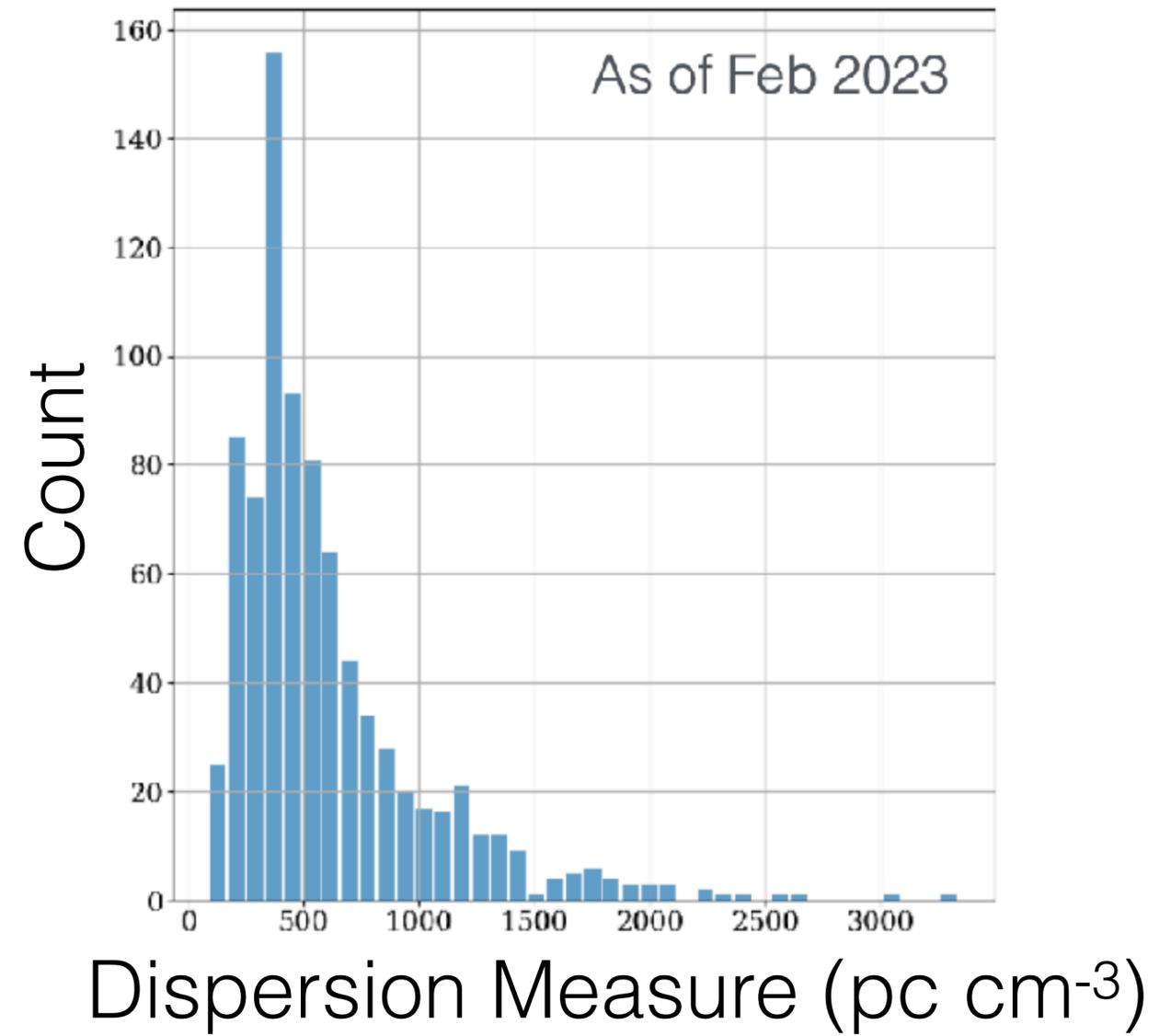
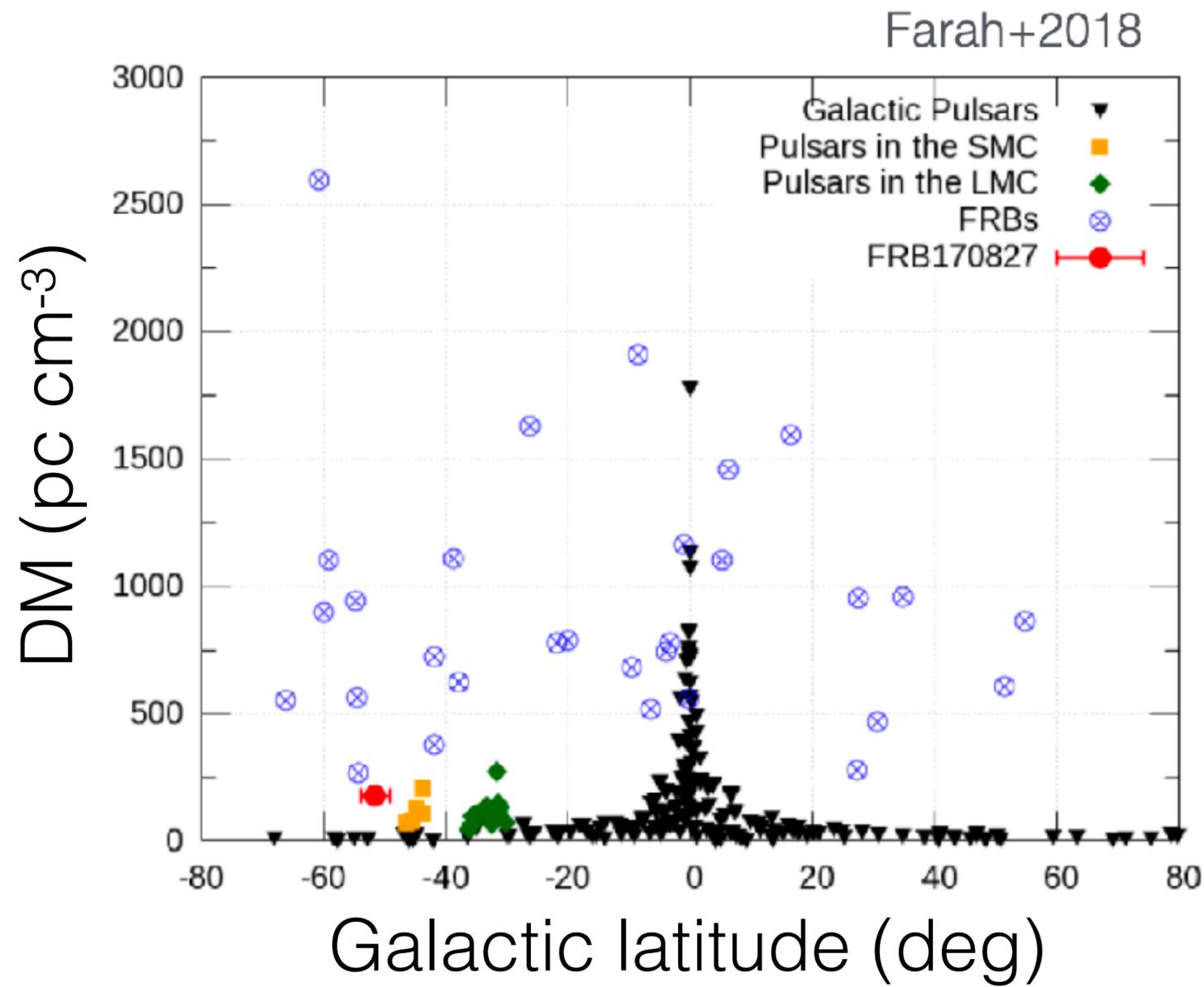
What do we know about FRBs?

FRBs being extragalactic

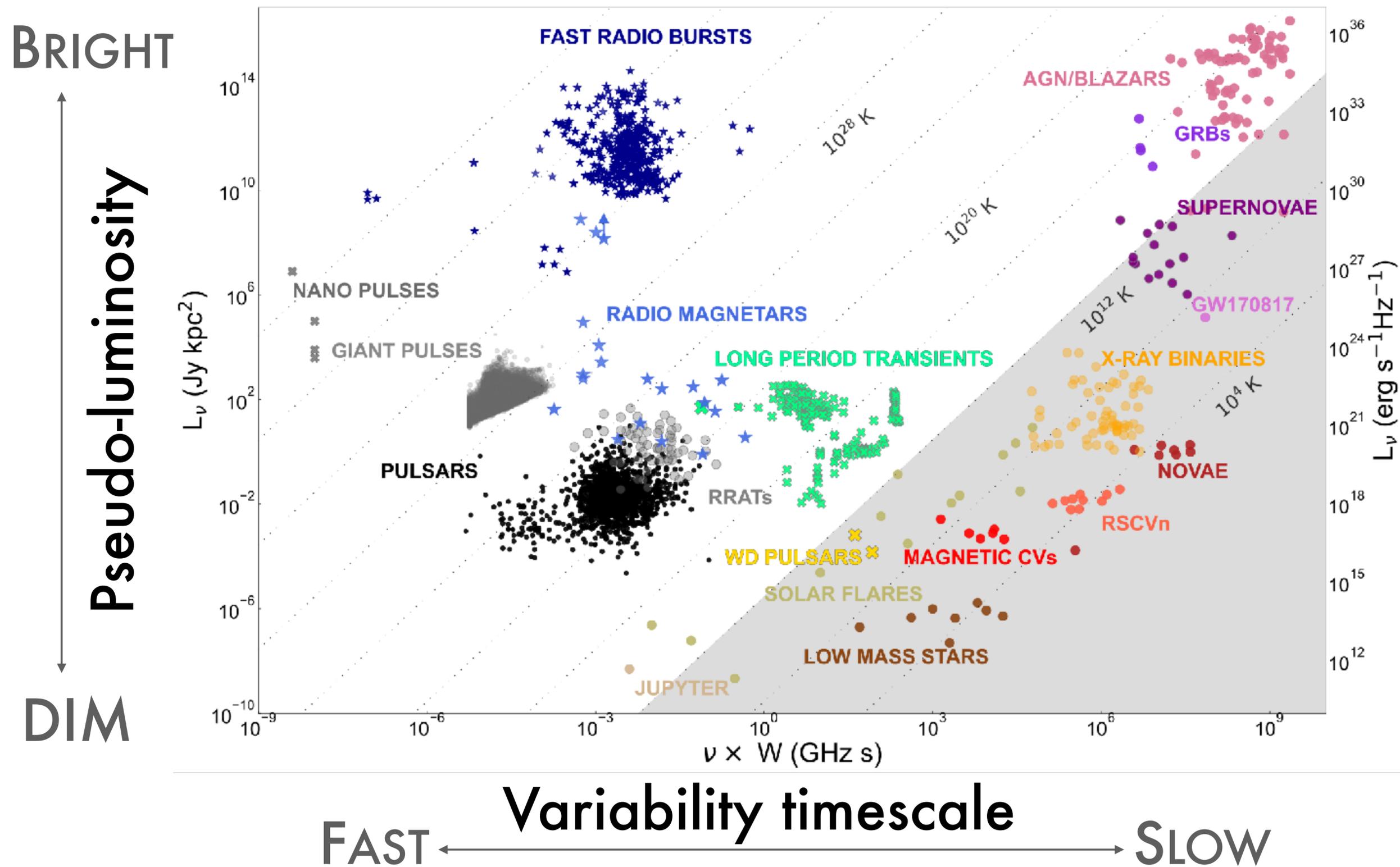
The pulse travel time (t_p) of an EM wave of freq ν emitted at a distance d propagating through an electron plasma with uniform number density n_e :

$$t_p = \frac{d}{c} + \frac{e^2}{2\pi m_e c} \frac{\int_0^d n_e dl}{\nu^2}$$

Dispersion measure (DM)



Radio Transient parameter space

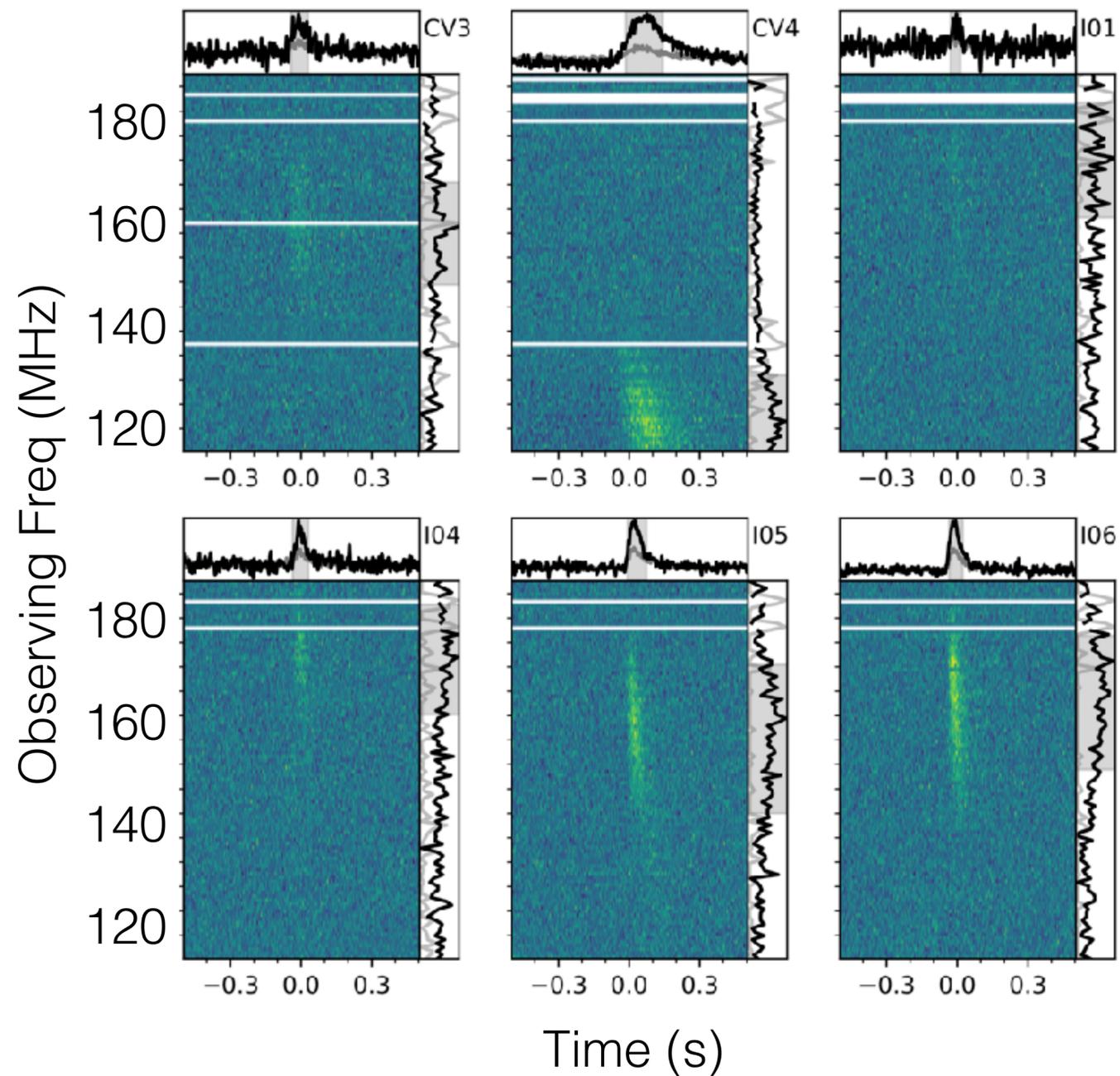


Rea, Hureay-Walker & Caleb 2025, review in prep
 Data from Keane+18, Nimmo+22, Hurley-Walker+22, Rea+22, Wang+25 and reference therein

Repeating FRBs

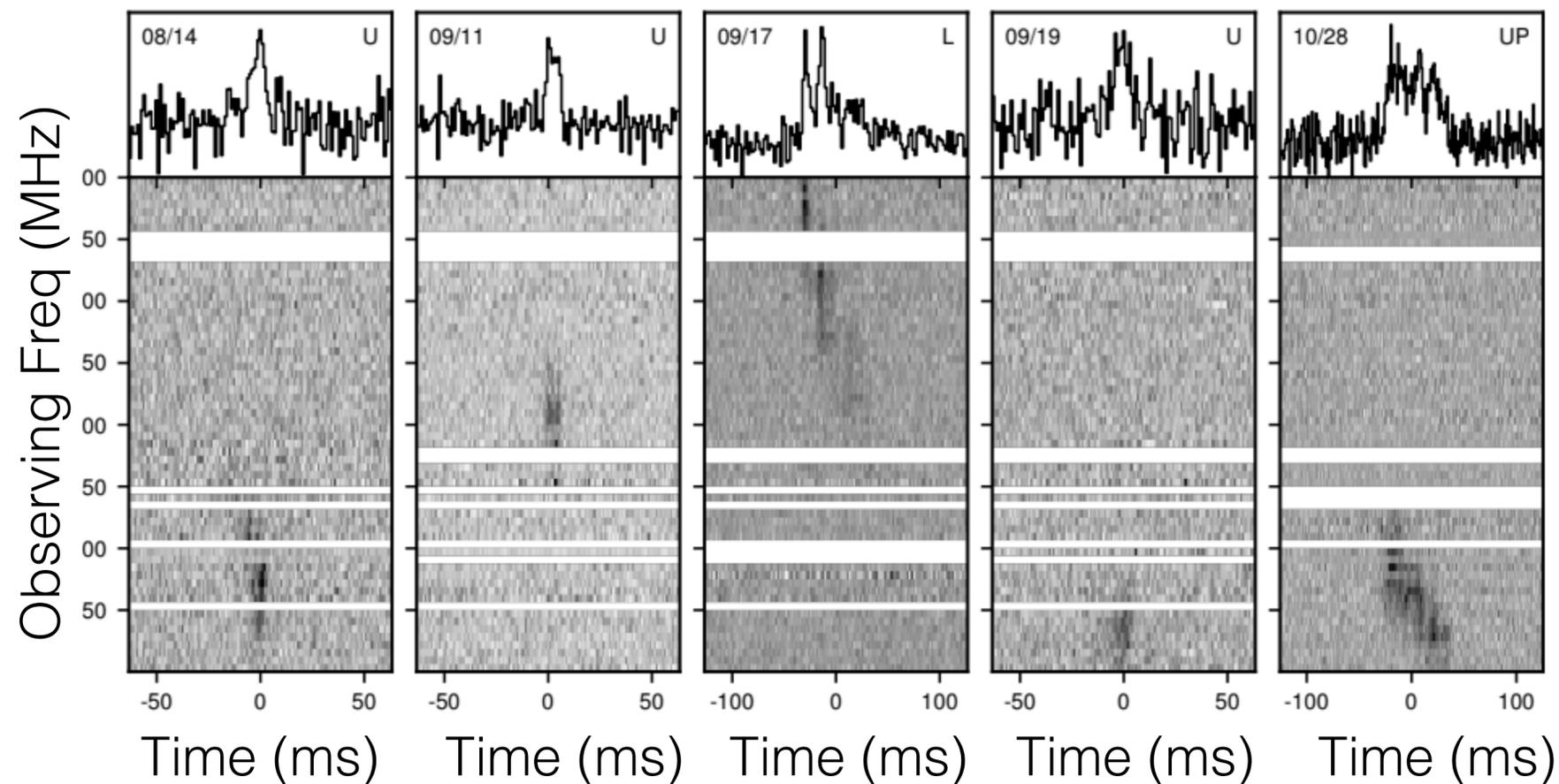


Pleunis+ (2021)



Repeater FRB 20180916B

Collab. CHIME/FRB (2019)

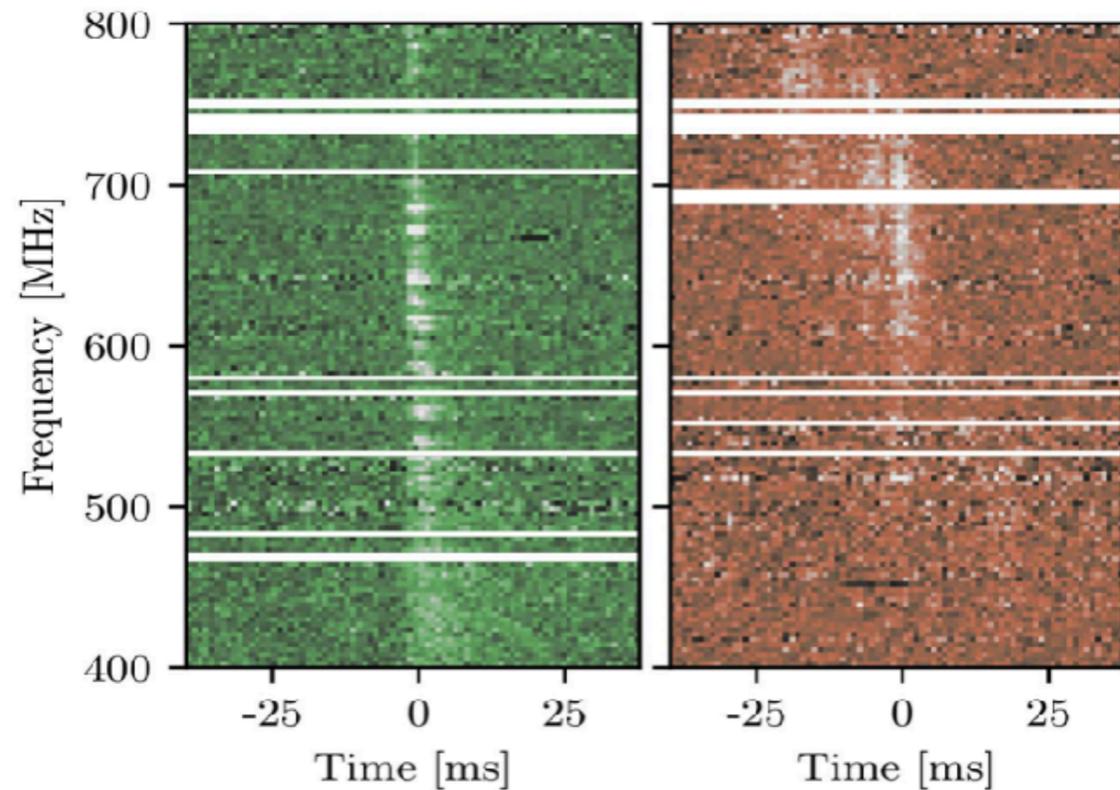


Repeater FRB 20180814

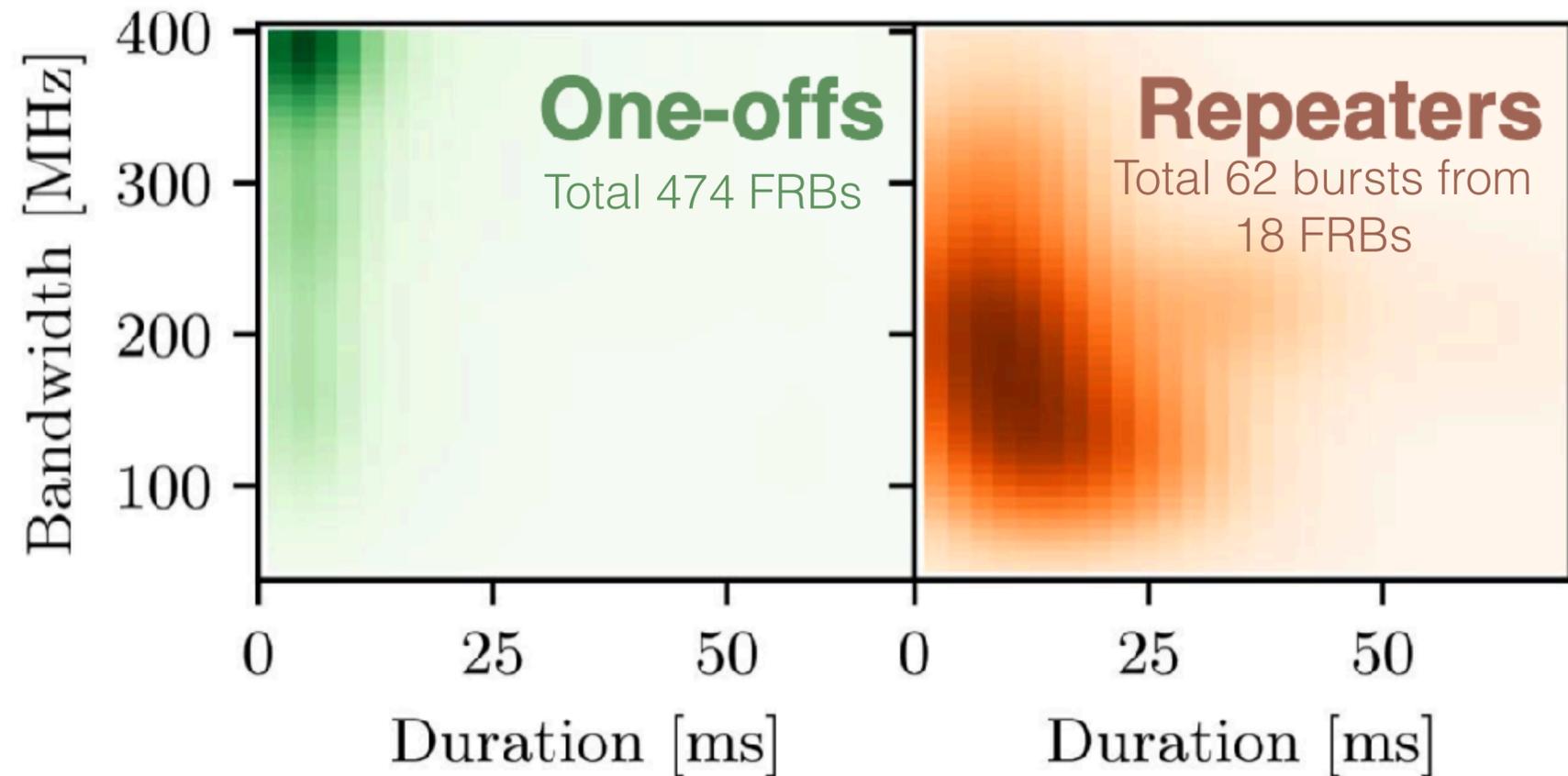
Multiple population

FRB20190527C
One-off

FRB20190117A
Repeater

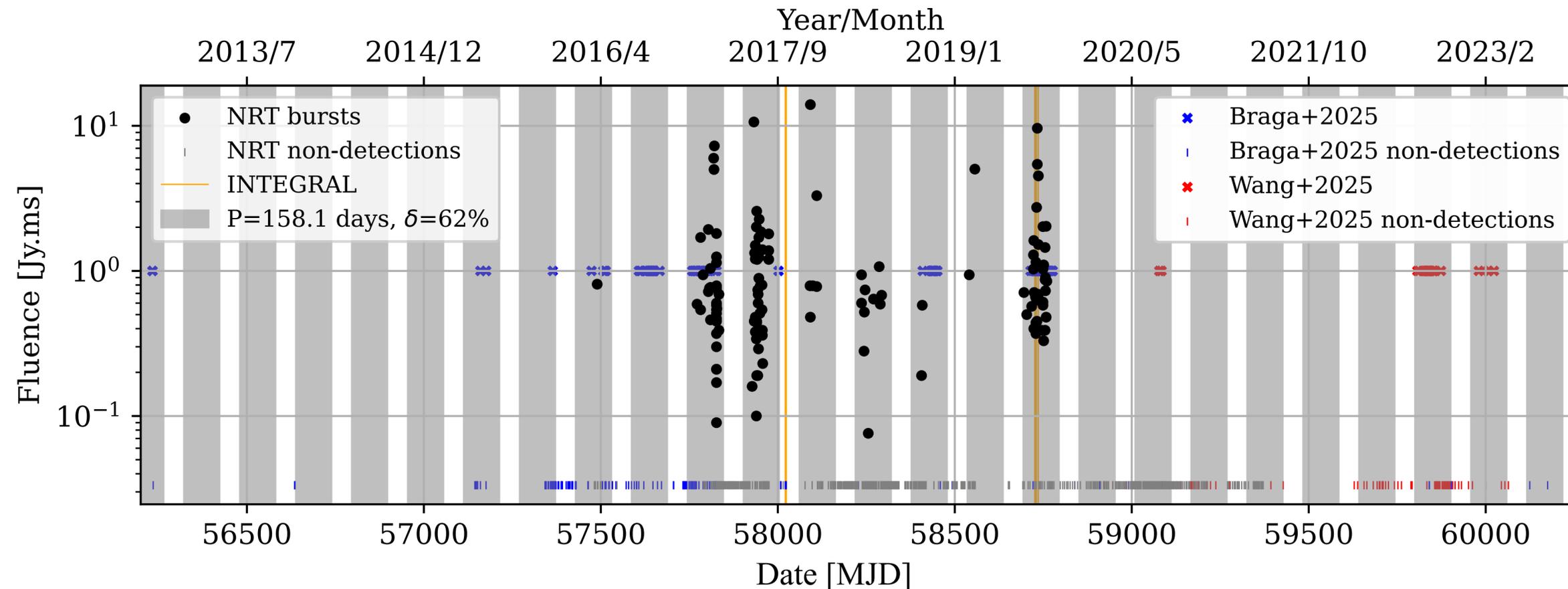


Pleunis+ 2021



- 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

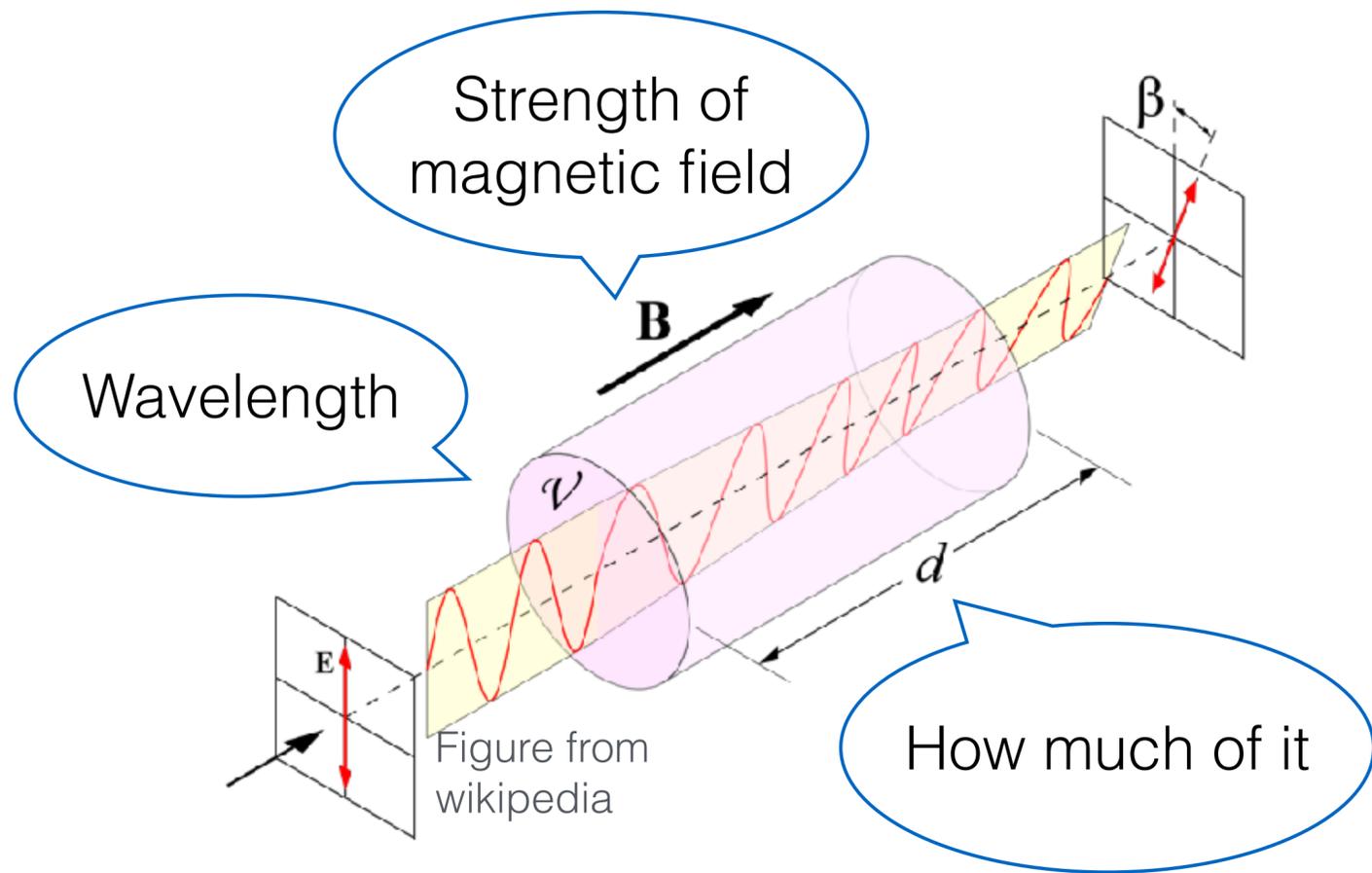
Repeating FRB periodic activities



Gouiffès+Ng+,
2025

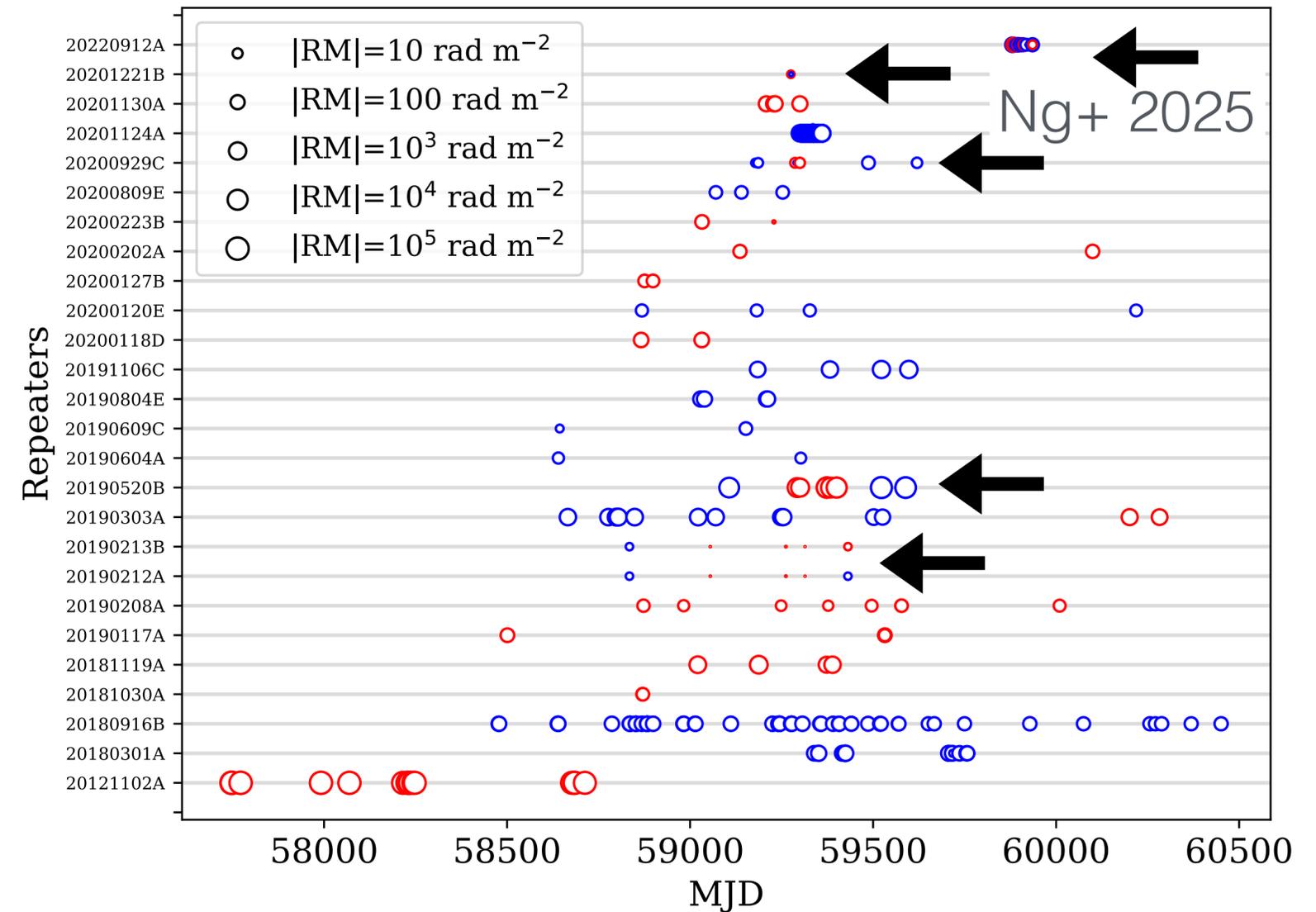
- CHIME repeater database: <https://www.chime-frb.ca/repeaters>
- Periodic activity cycle (not strict periodicity!) :
 - 16 days for FRB 20180916 (CHIME/FRB Collab, 2020, Pastor-Marazuela+, 2021)
 - ~160 days for FRB 20121102A (Rajwade+2020, Cruces+2020, Gouiffès+Ng+2025)

Repeating FRB polarizations



Rotation measure (RM) = how much the light's orientation has twisted at different wavelengths.

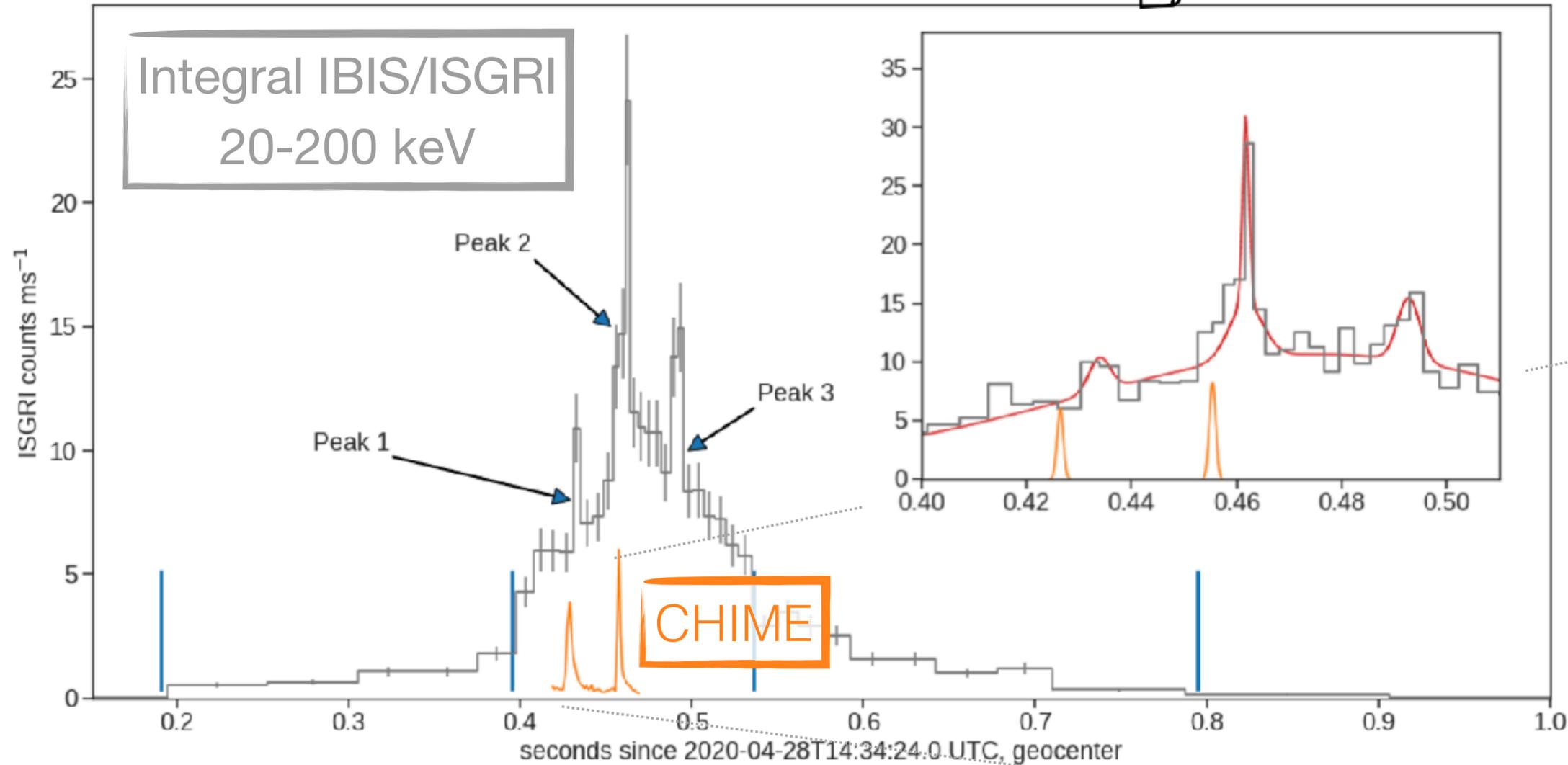
High RM = strong / extended magnetic field



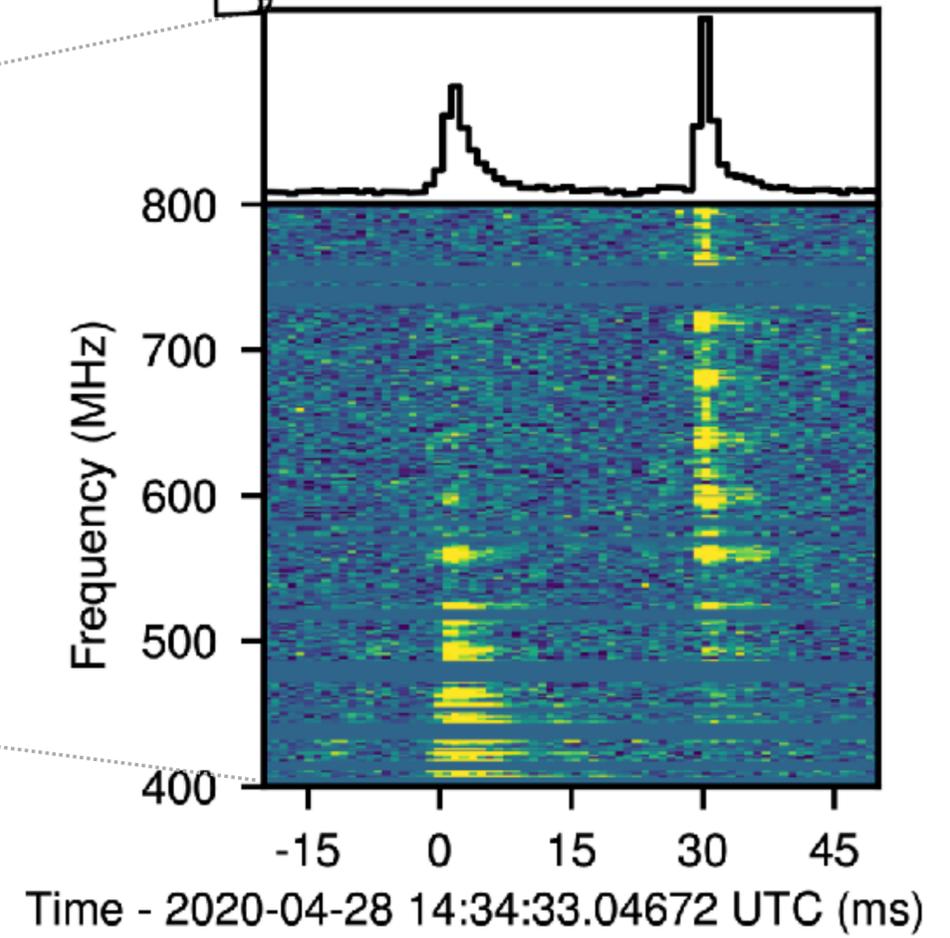
- 26 repeaters with RM/time info
- Wide range of $|RM|$, a few with RM sign changes \rightarrow highly dynamic and magnetized environment

Magnetar SGR 1935

Mereghetti et al. 2020



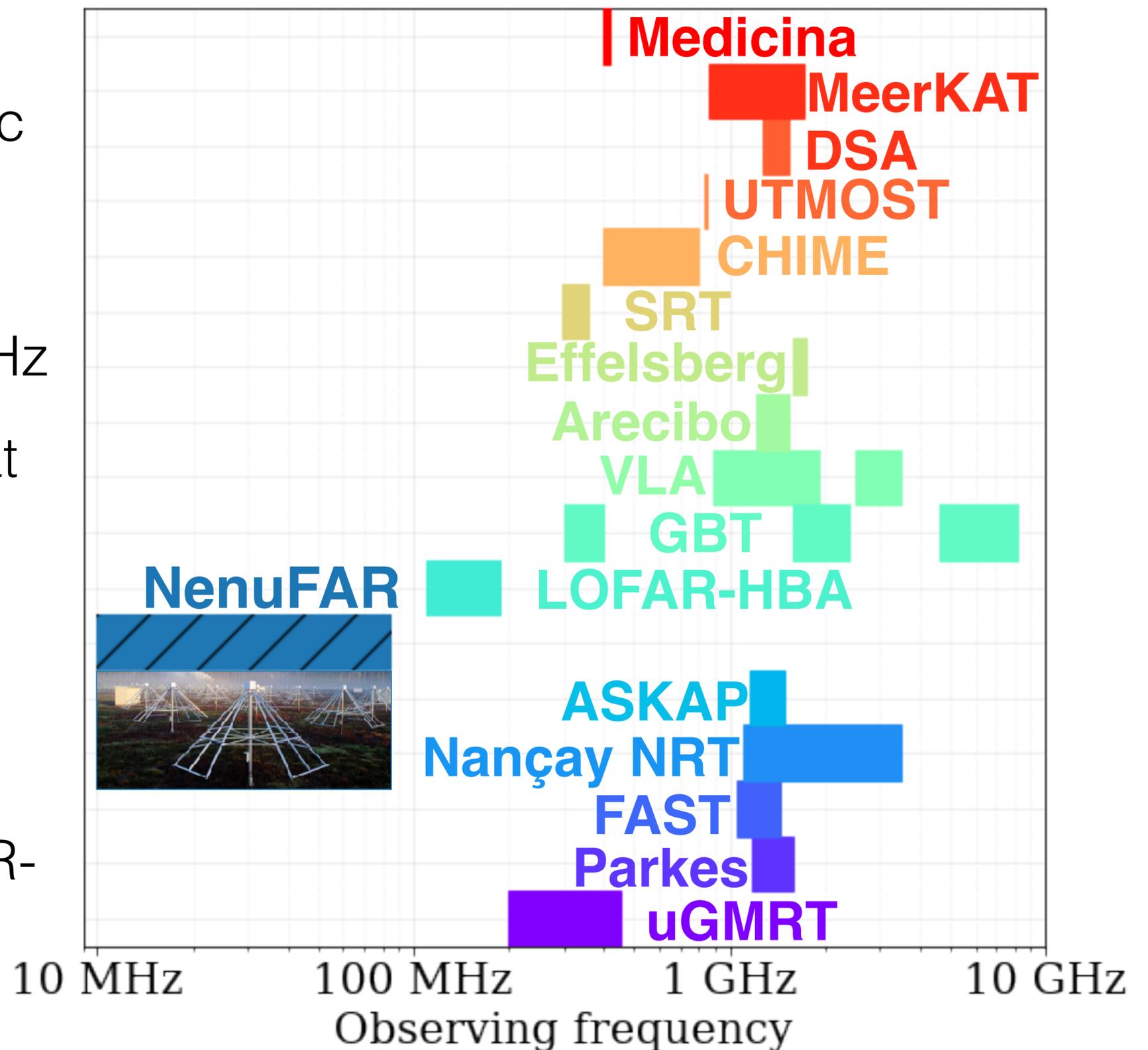
collab. CHIME/FRB, 2020



- 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 emission frequencies

- 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
- Low freq detection particularly good for cosmology (clean)
- But seems quite challenging: LOFAR-HBA only detected 2 FRBs so far



FRBs host galaxy associations

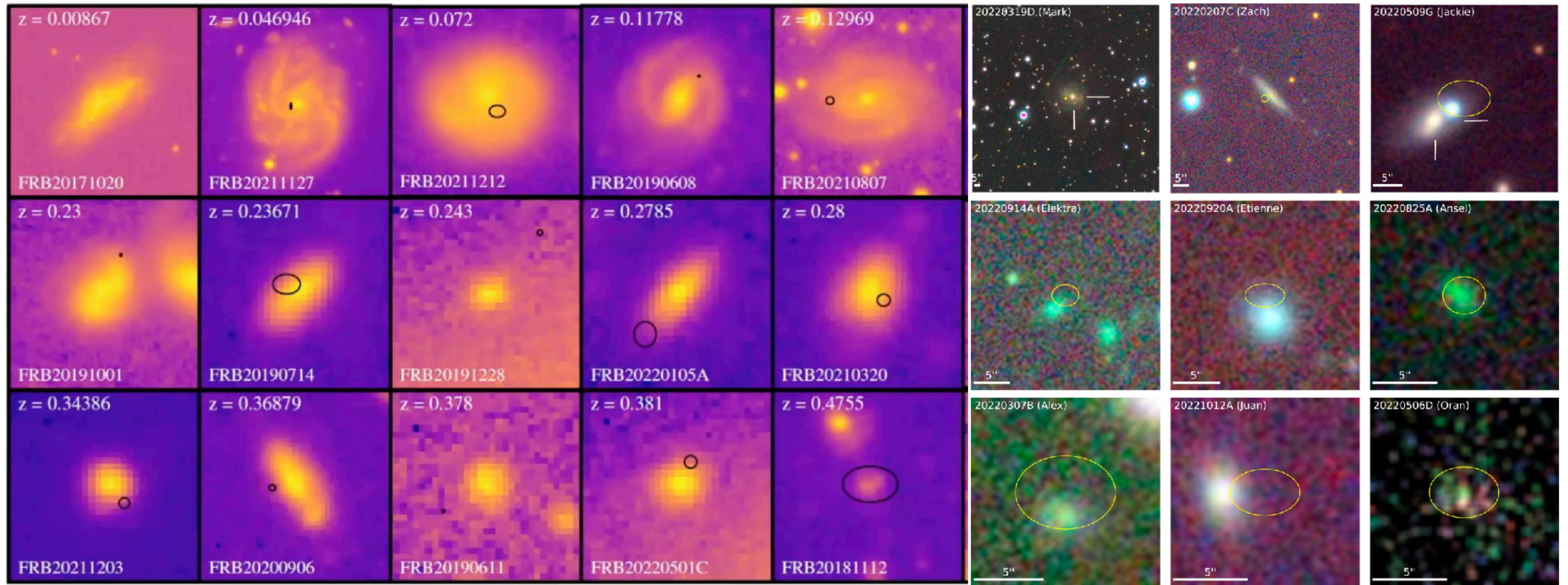


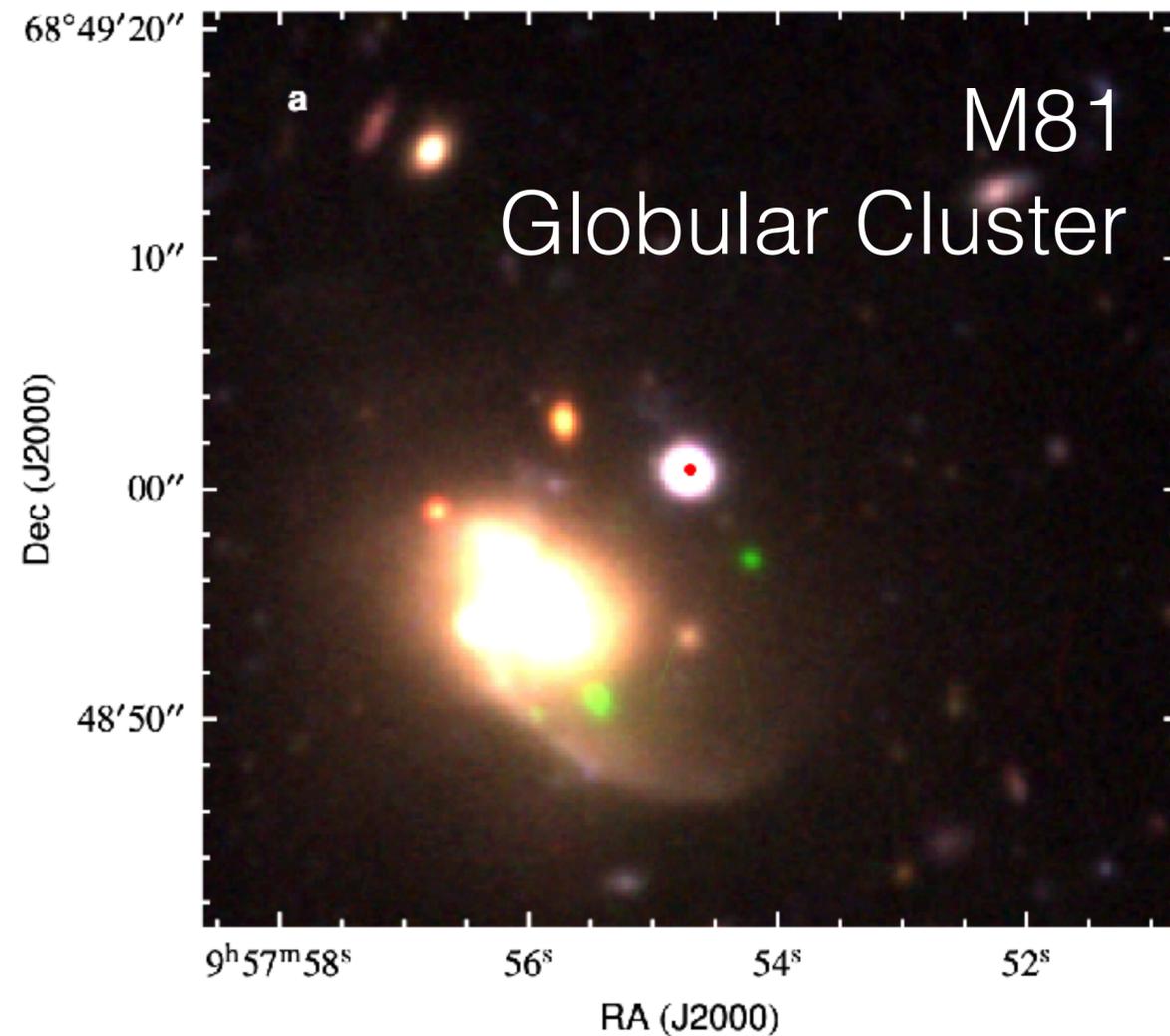
Image from Lachlan Marnoch

Law+2024

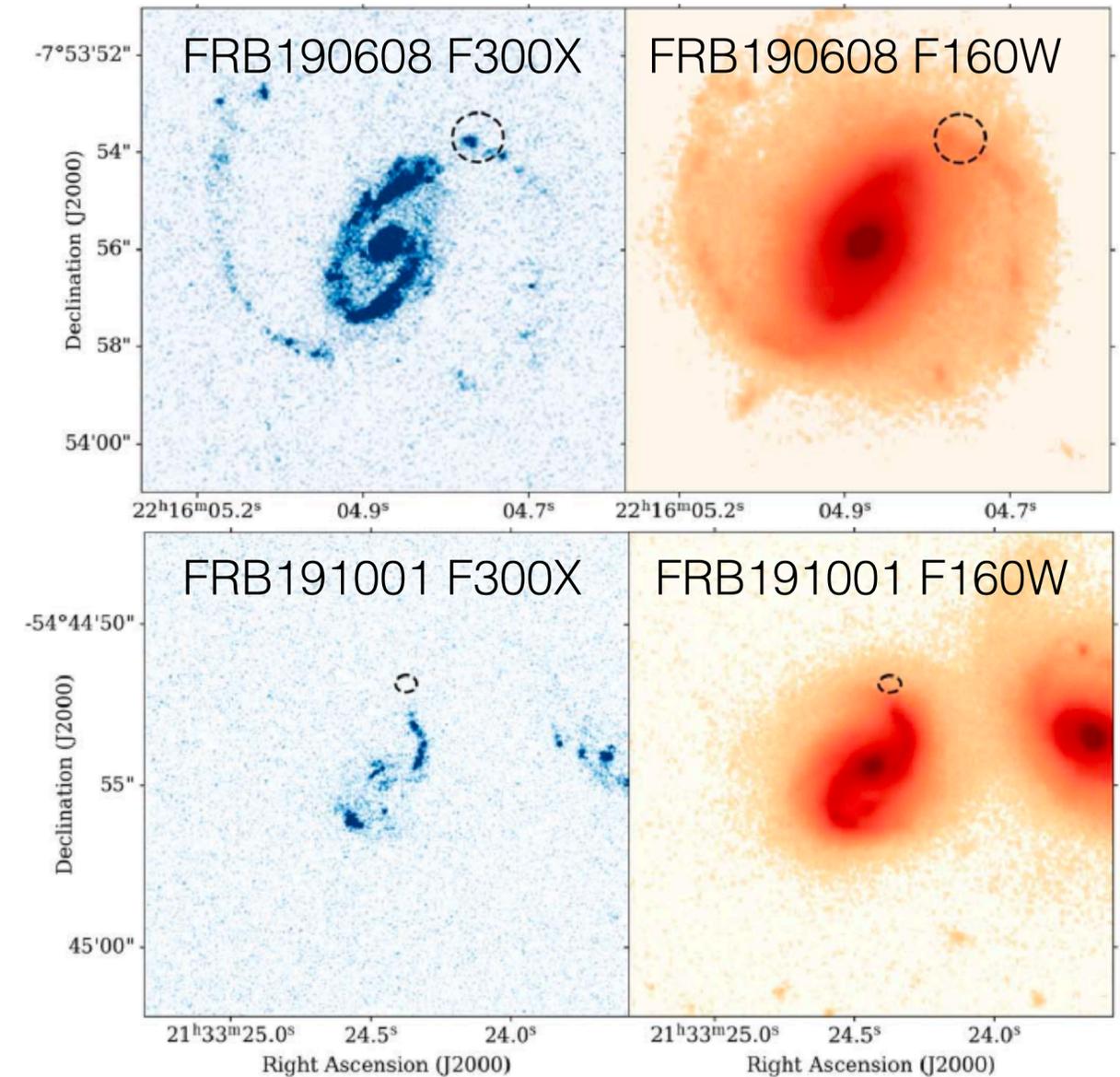
- ~100 localized to host galaxies, with $z \leq 2.1$ (Caleb+2025)
- Mostly spiral galaxies (star forming galaxies), but also some lenticular galaxies

Local host environment

Kirsten et al., 2021



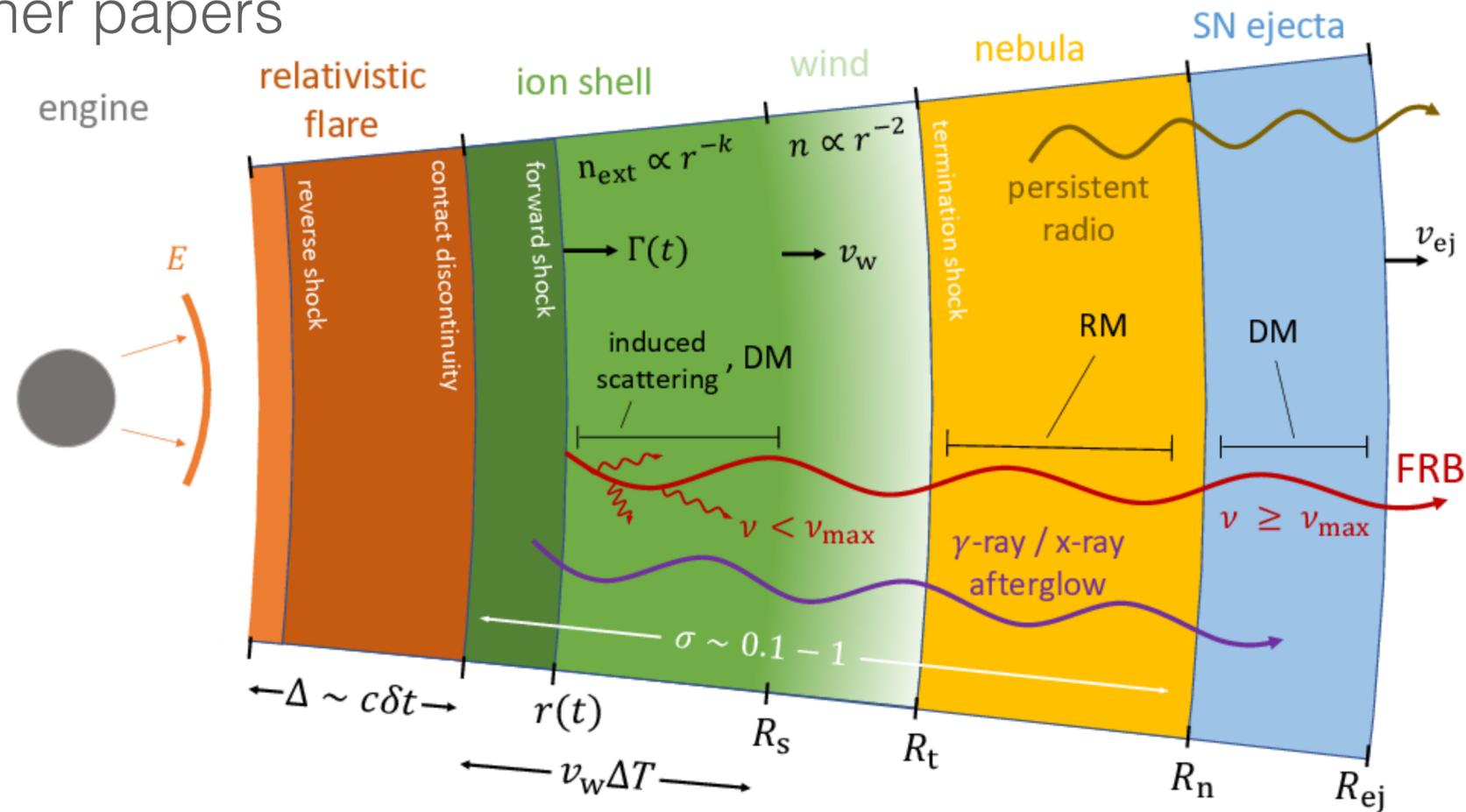
Mannings et al., 2021



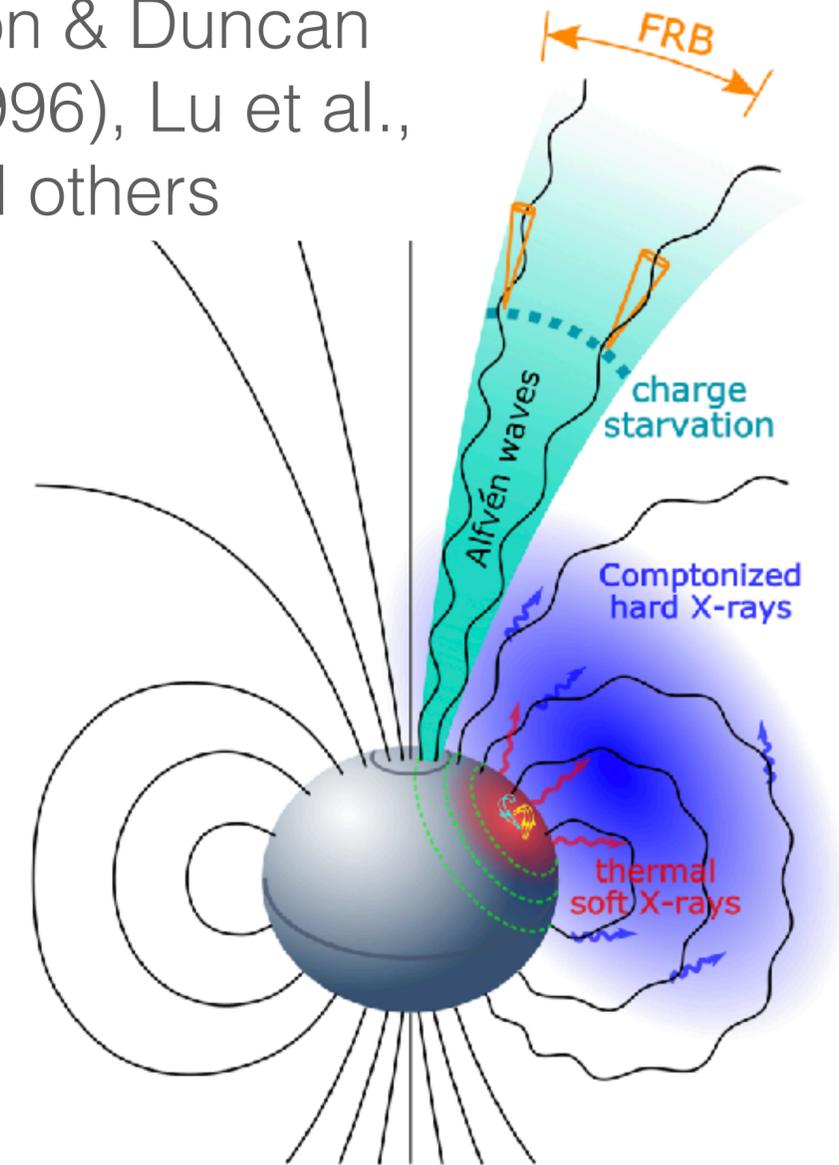
FRBs come from diverse local host environment and various types of host galaxies. Not always in the centre.

Theoretical models

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



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



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

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

GRBs

FRBs

Are they astrophysical?

1967: Discovery
1973: Yes (first paper published)

2007: Discovery
2013–15: Yes (new FRBs and microwave-oven-origin of perytons)

Are there multiple types?

1979: Soft gamma-ray repeaters
1992: Long versus short

2016: Repeaters
2020: Do all FRBs repeat?

Where are they?

1979: SGRs are Galactic (or nearby)
1997: Long GRBs are cosmological
2004: Short GRBs are cosmological

2017: Extragalactic and comological (FRB 121102)
2020: Galactic (FRB 200428)

What makes them?

1998: SGRs from magnetars
1998: Long GRBs from massive star core collapse
2017: Short GRBs from neutron star–neutron star mergers

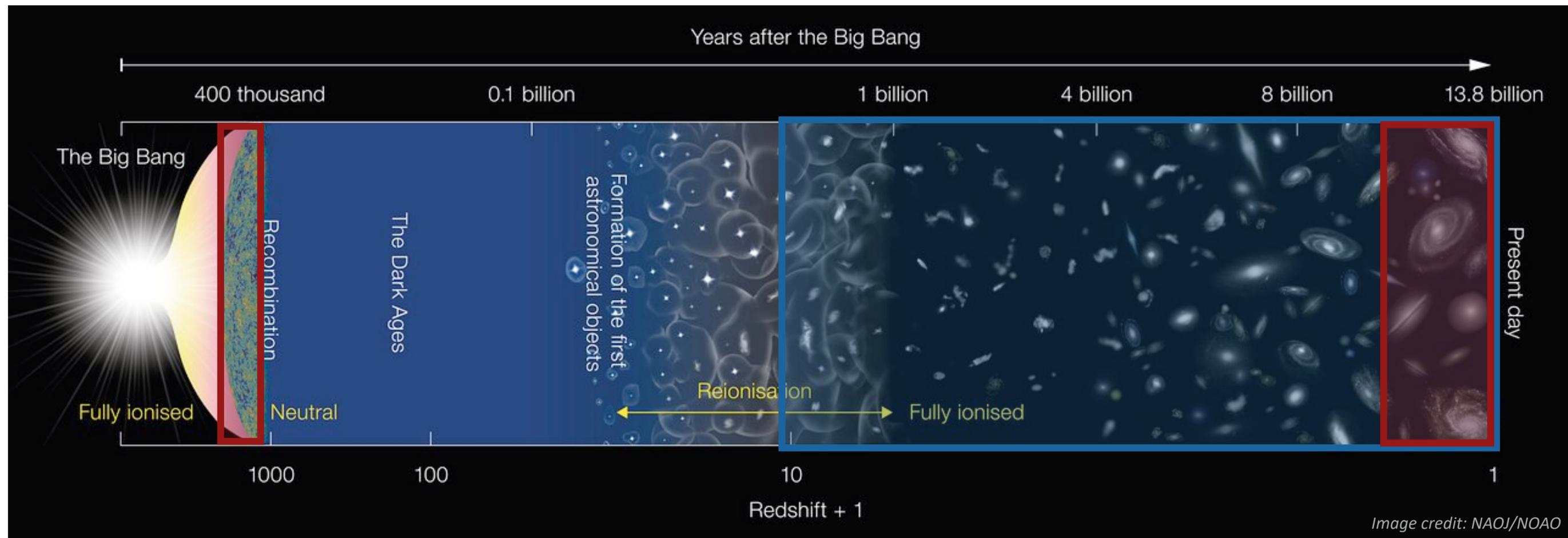
2020: FRB 200428 from a magnetar
2020: Can other sources produce FRBs?

Why should I care about FRBs?

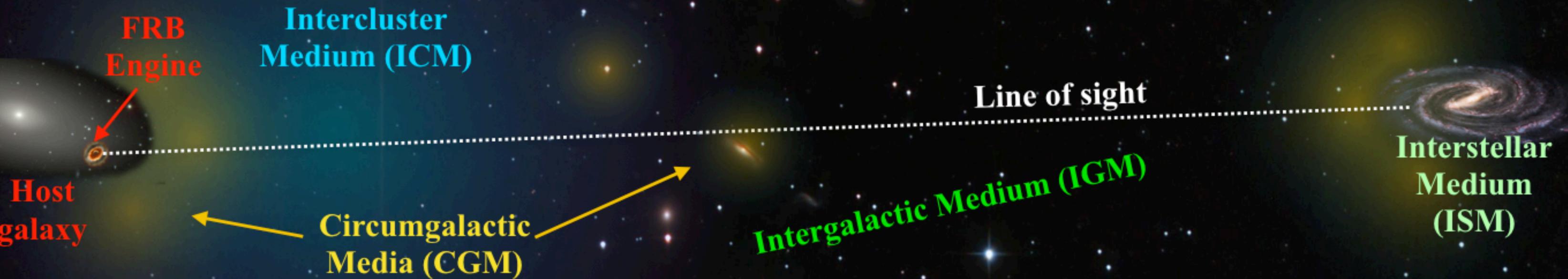
Complement other cosmological probes



Partial information, missing intermediate redshifts



- 10s of FRBs per day with ~ 1 mas localization from upcoming radio telescopes such as CHORD, DSA-2000, and the Square Kilometre Array (SKA)
- Orthogonal to existing probes

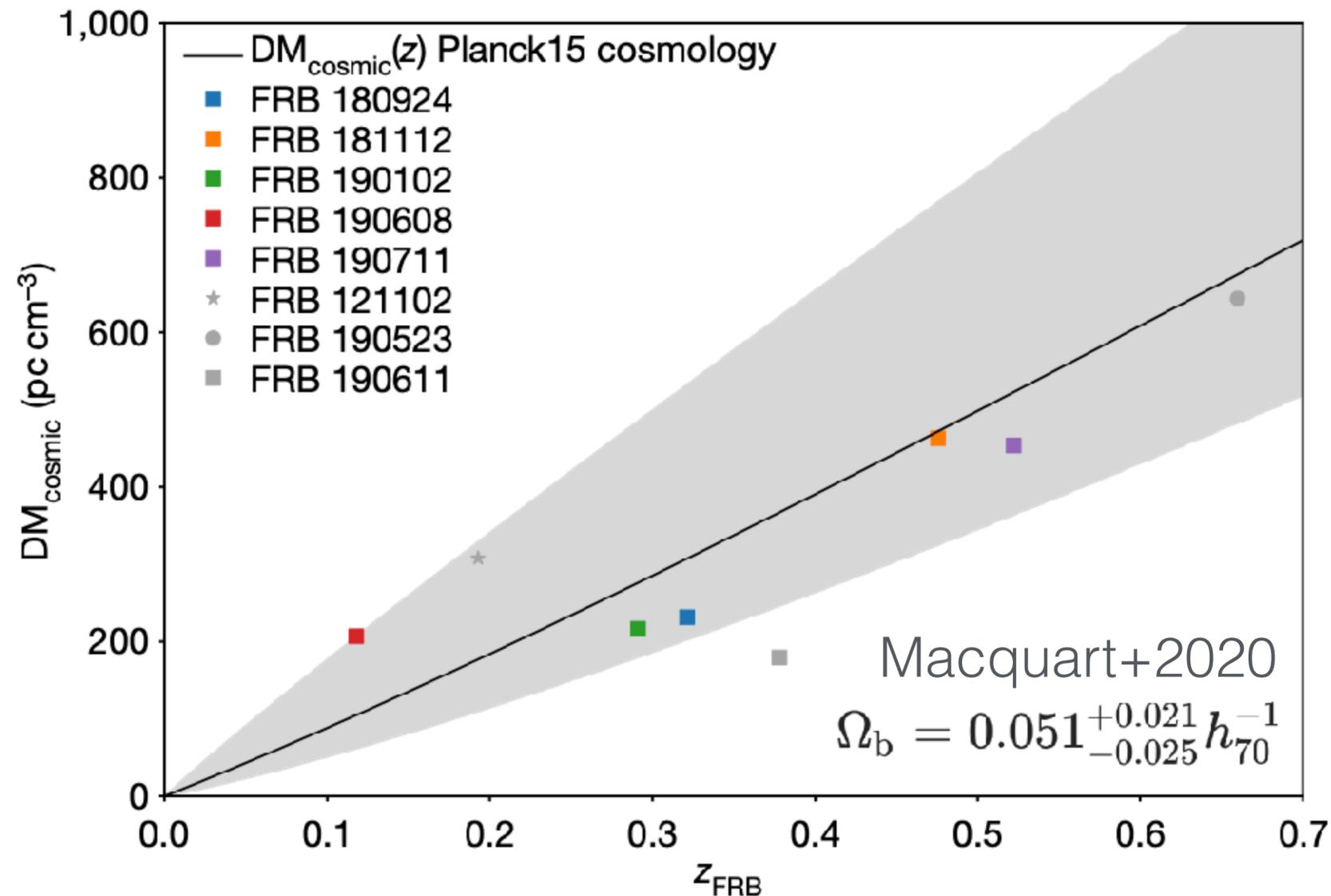


$$\mathbf{DM}_{\text{obs}} = \mathbf{DM}_{\text{engine}}(z) + \mathbf{DM}_{\text{ISM}}(z) + \mathbf{DM}_{\text{ICM}}(z) + \Sigma \mathbf{DM}_{\text{CGM}}(z_i) + \int \mathbf{DM}_{\text{IGM}} dz + \mathbf{DM}_{\text{MW}}$$

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

Missing baryon problem — solved!

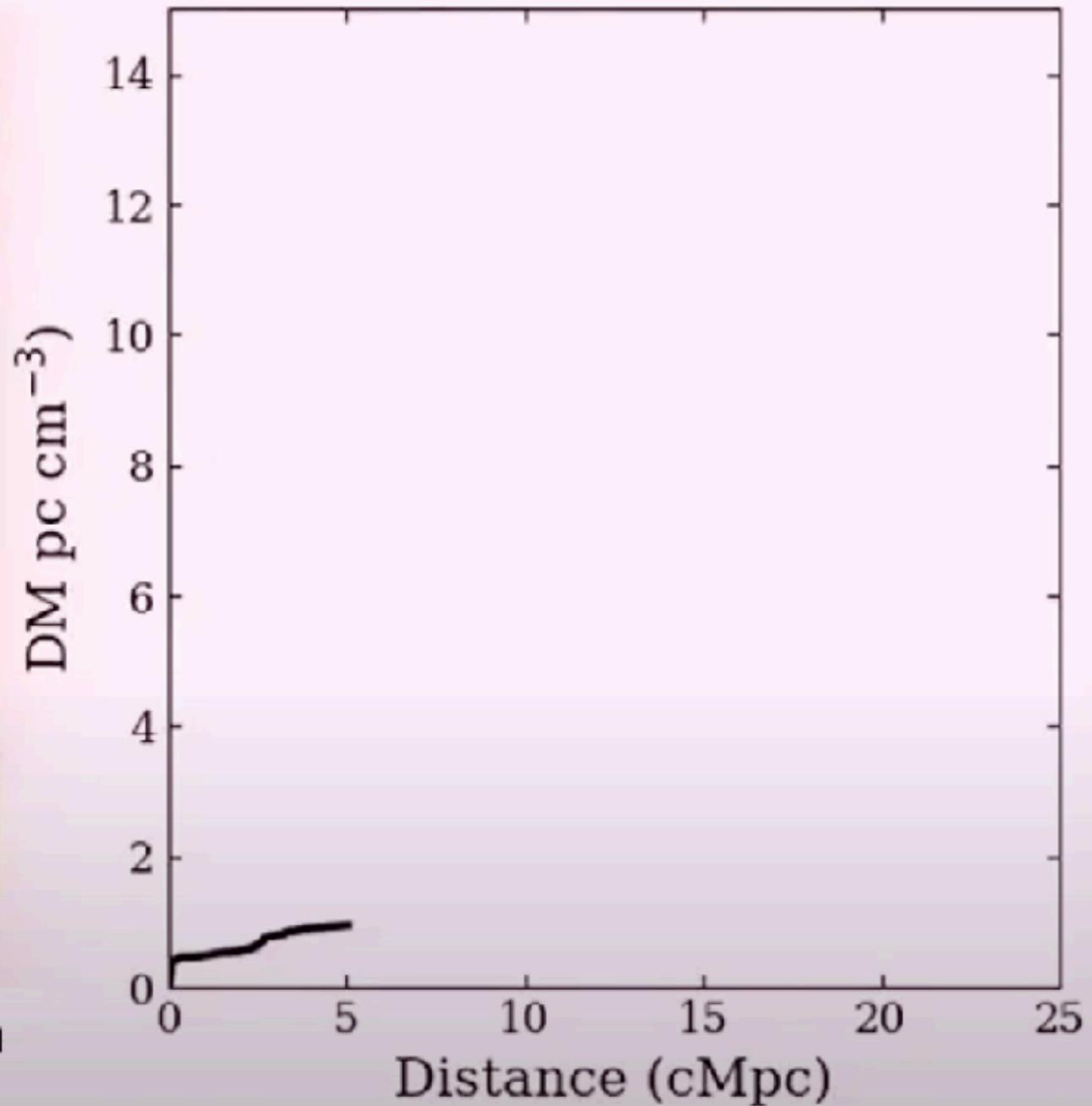
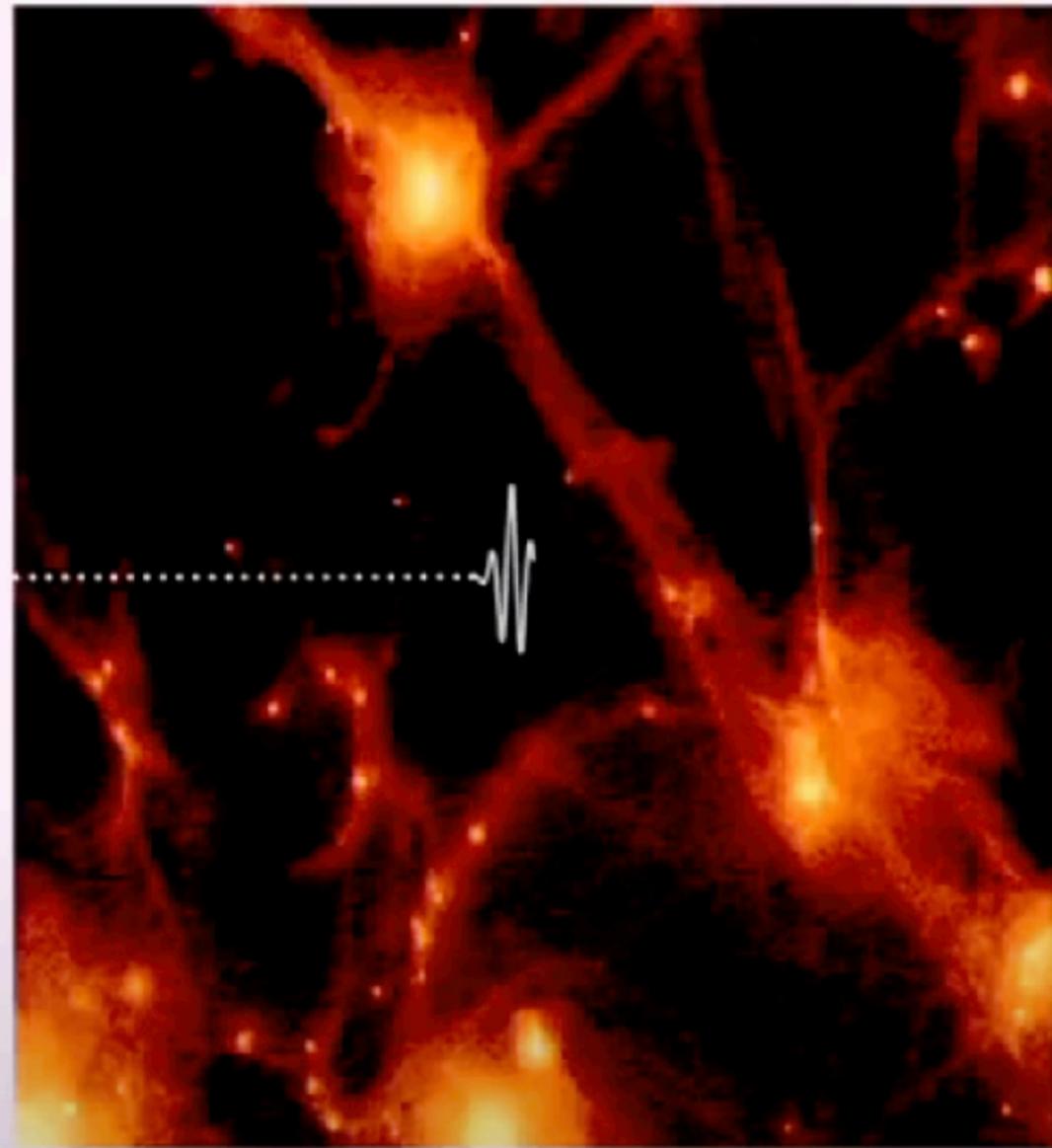


Shaded region = scatter in IGM (90% of DM_{cosmic} from a model for ejective feedback in Galactic haloes) and it is consistent with the observed DM scatter

- 40-50% missing baryons at low z , suspected in warm-hot intergalactic medium (WHIM), but hard to detect directly in X-rays/UV
- strong correlation b/w FRB cosmic DMs & z → Macquart relation
- FRBs align with Planck2015 predictions from CMB measurements (solid line)
- Determines the electron column density along each LOS and accounts for every ionized baryon

Line-of-sight simulation in Illustris TNG300

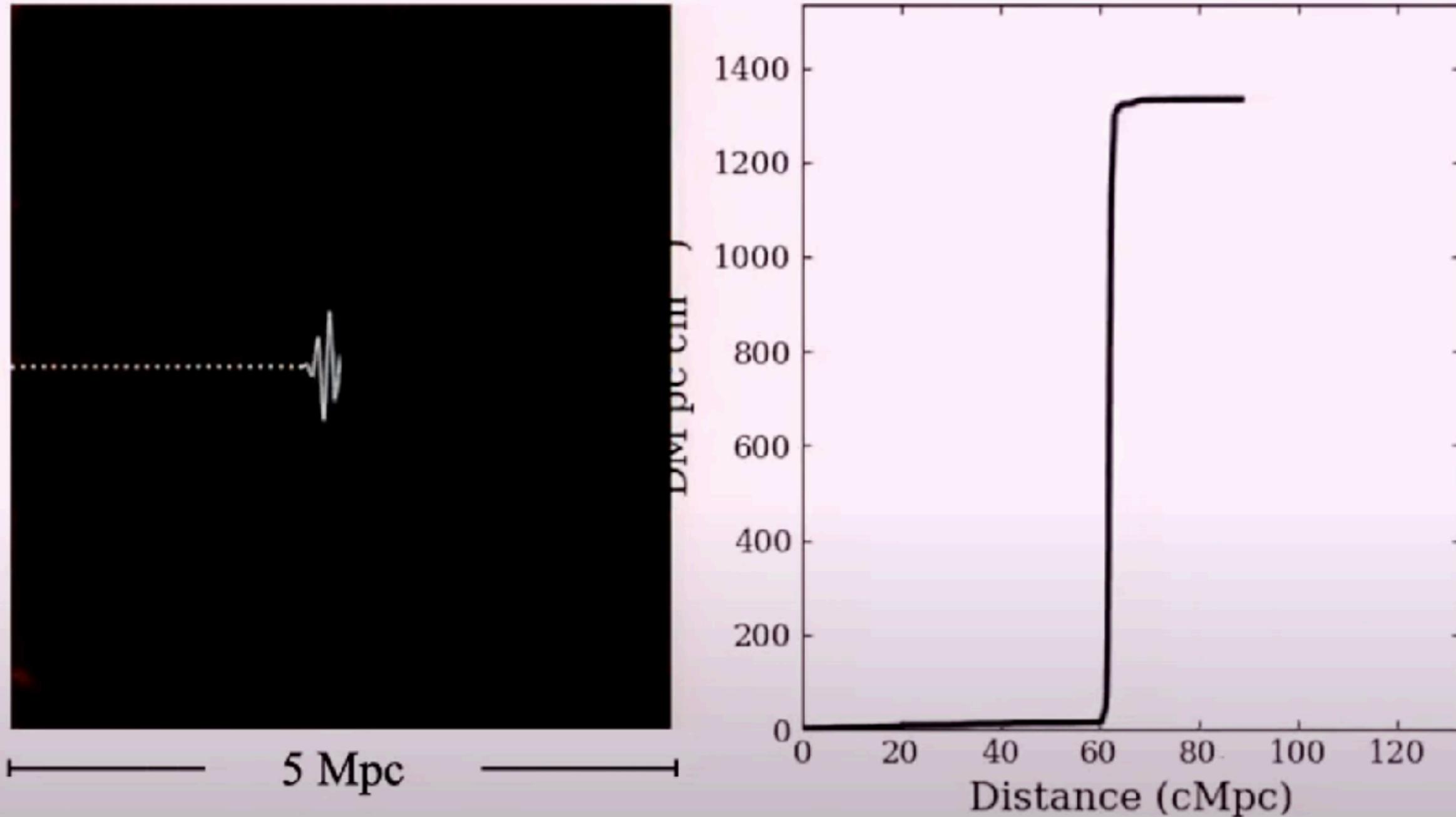
Animation from Liam Connor (Harvard)



- ! Non-linear DM budget, unknown fractional contribution
- 💡 Each DM term has diff prob. distribution and z dependence — Many FRBs

Line-of-sight simulation in Illustris TNG300

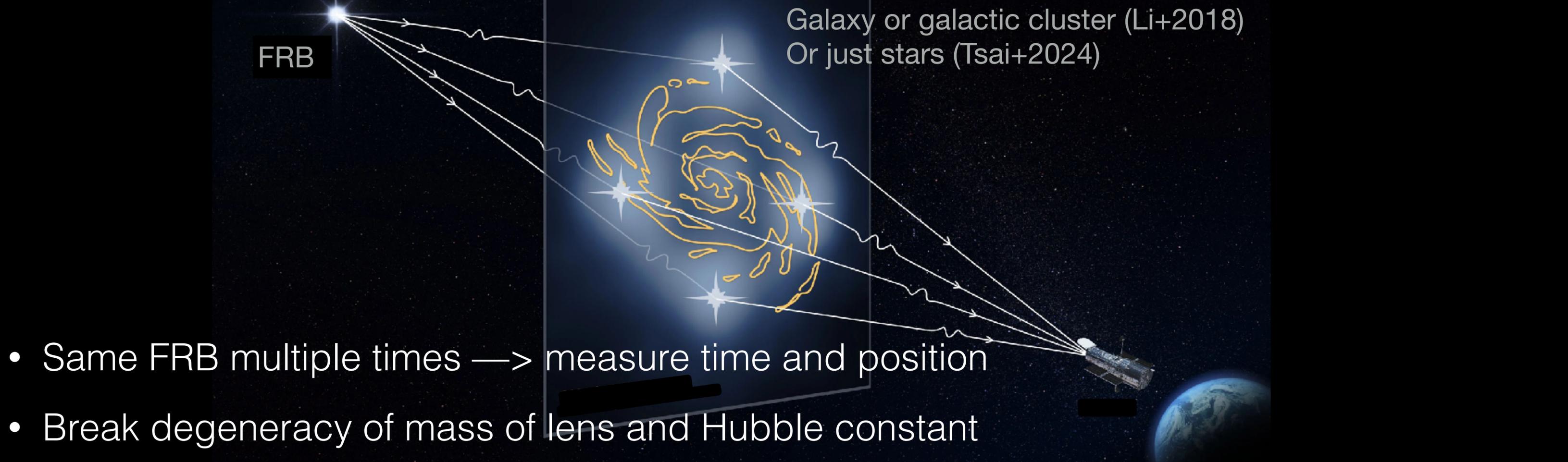
Animation from Liam Connor (Harvard)



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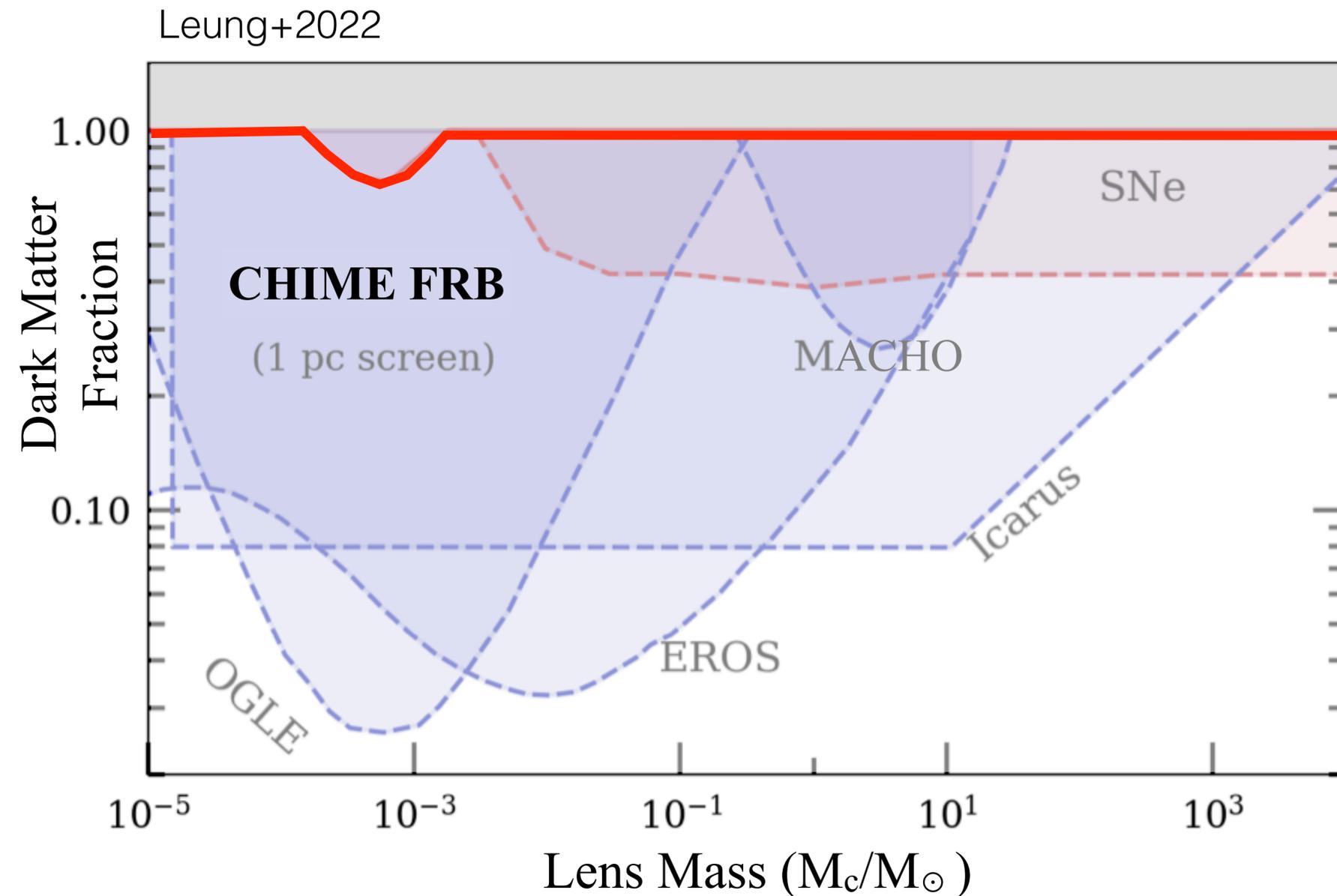
FRB lensing

Image adapted from NASA, ESA, and D. Player (STScI)



- FRB timing is much more precise than other current methods (e.g. AGN variabilities)
- Lensed repeater (does it exist??):
 - Change in arrival time b/w images w.r.t cosmological expansion (Zitrin+2021)
 - Change of the change (power spectrum) in arrival time — clumpy dark matter (WIMP/axions) substructure passing across sight-lines (Xiao+2024)

Constraints on Dark Matter

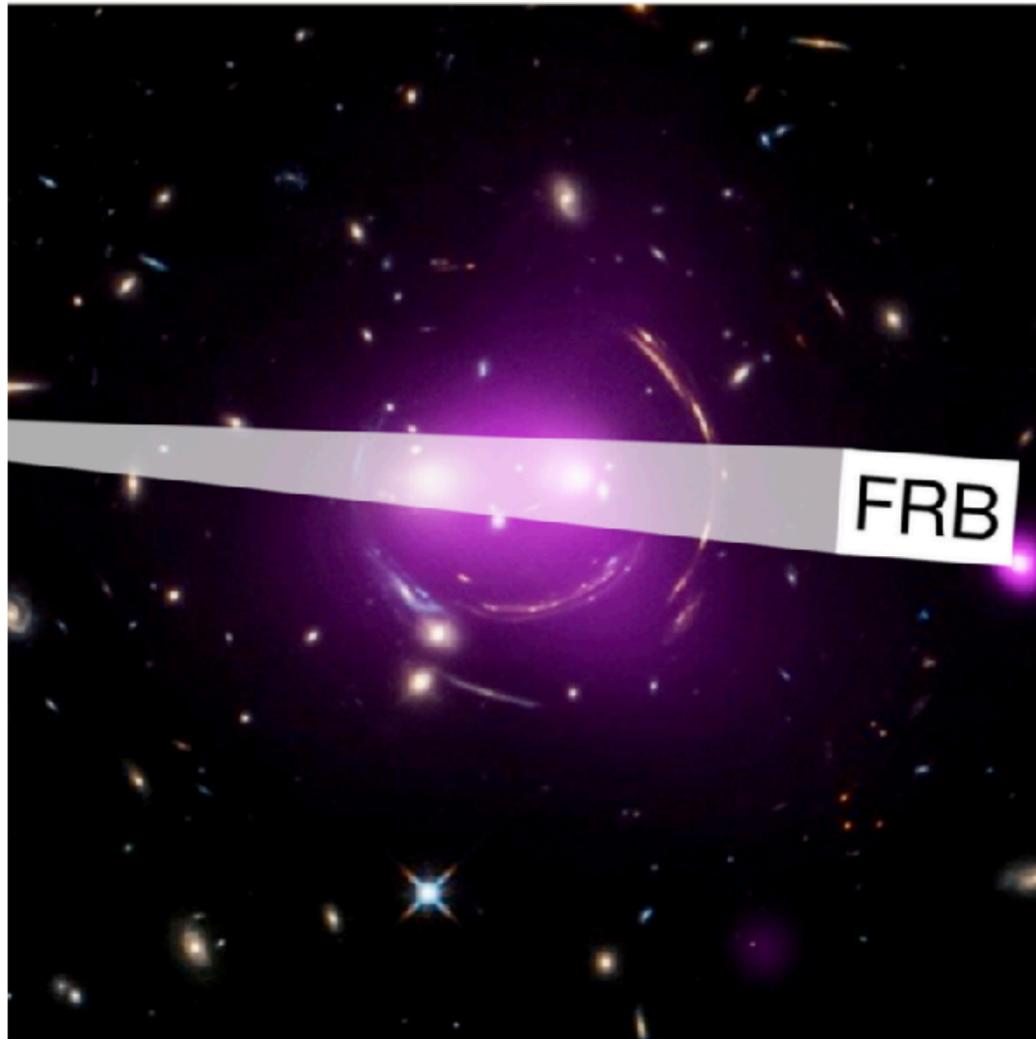


- Search for FRBs whose emission is coherently deflected by gravitational lensing around a foreground compact object such as a primordial black hole (PBH)
- Observed no lenses in 172 bursts from 114 independent sight-lines through the cosmic web
- Constrain the fraction of dark matter made of compact objects, such as PBHs, to be $f < 0.8$, if their masses are $\sim 10^{-3} M_\odot$

FRB as a probe for the Universe

$10^3 - 10^4$ FRBs

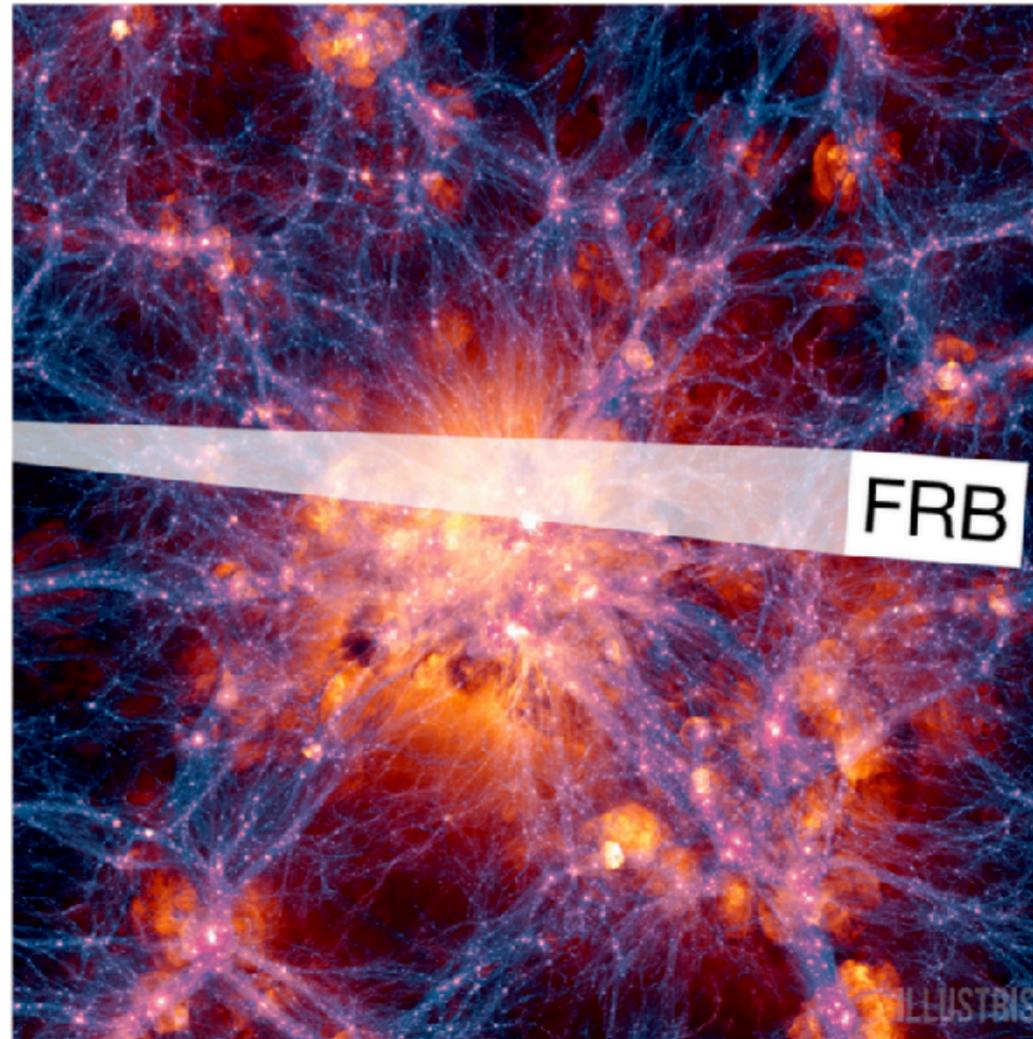
Detection of CGM/IGrM/ICM – CGM cooling – compact-object dark matter



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

$10^4 - 10^5$ FRBs

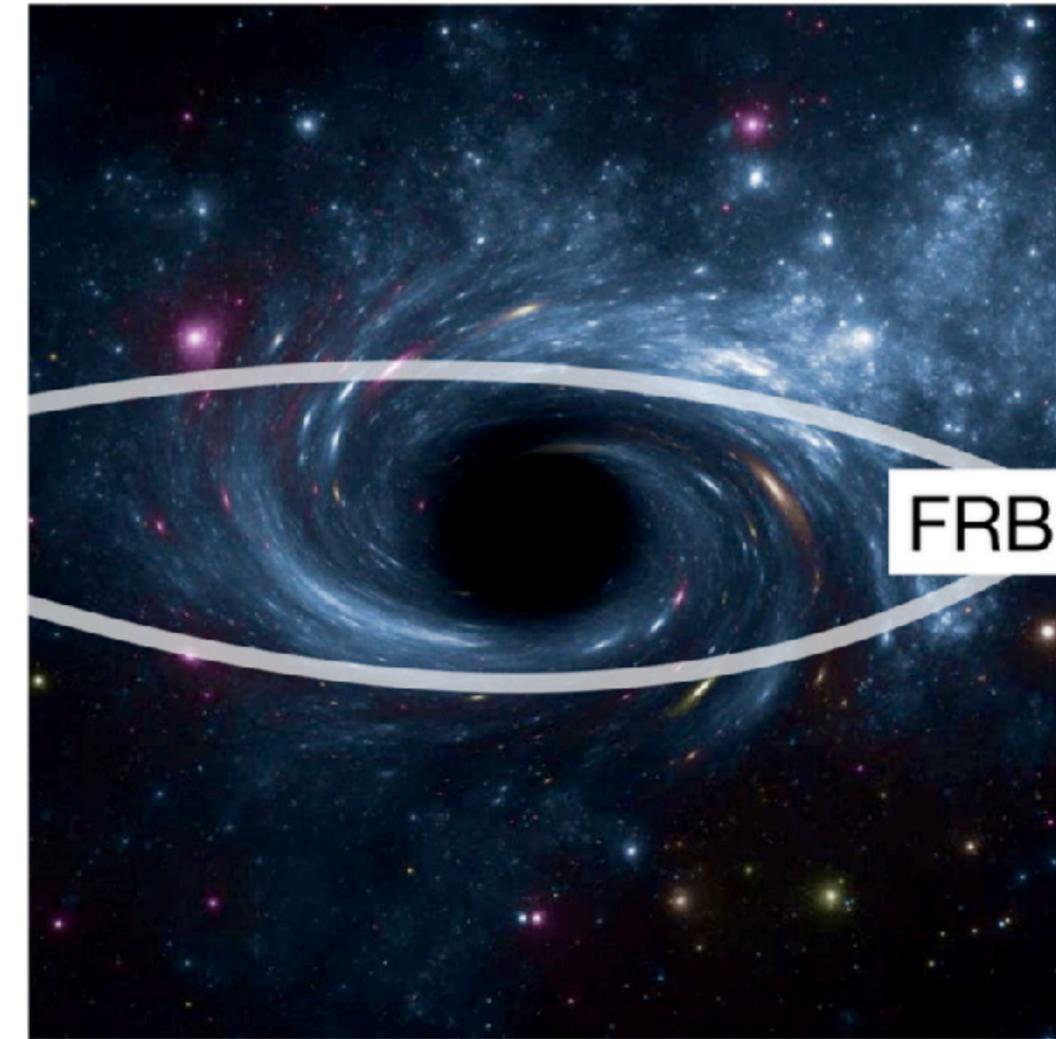
Cosmic web density – Helium reionization – DM-space clustering



Illustris Collaboration / Illustris Simulation

$10^5 - 10^6$ FRBs

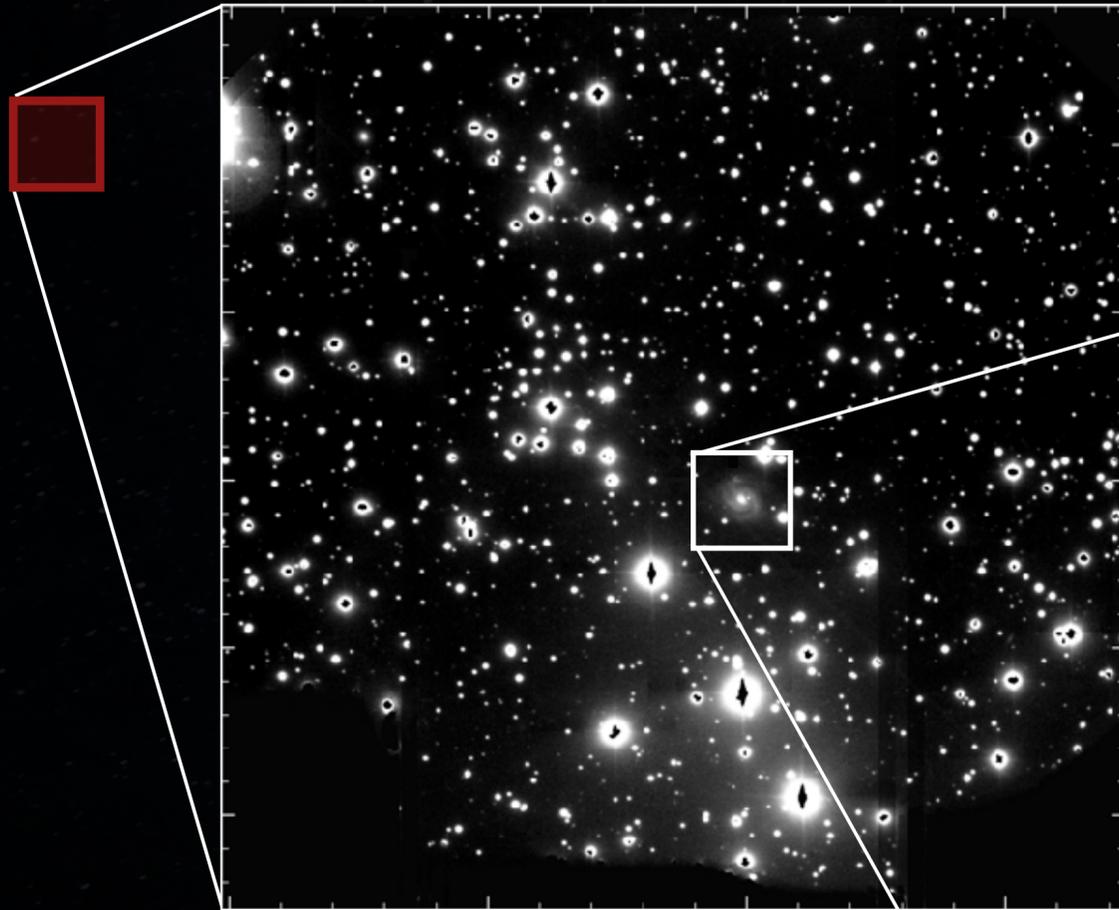
kSZ synergy – extragalactic micro- and nano-lenses



Upcoming telescope facilities

A new digitized age: precise localisation

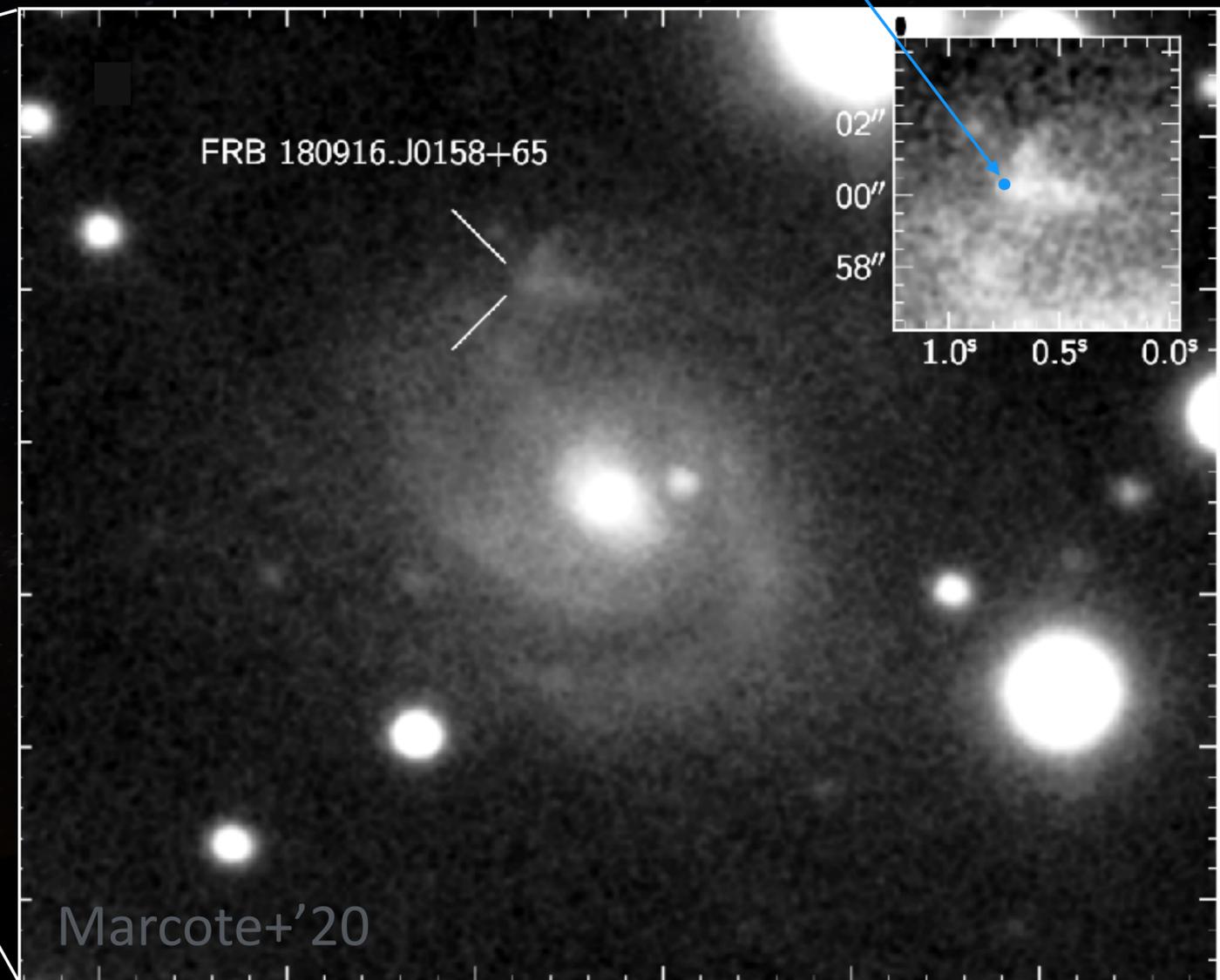
SLIDE DESIGN INSPIRED BY JASON HESSELS (MCGILL/UVA)



CHORD outriggers provide
milliarcsecond localization



Poor localization



Next-generation radio telescopes

CHORD



Image credit: Tracy Zhao
(Artist rendering)

SKA

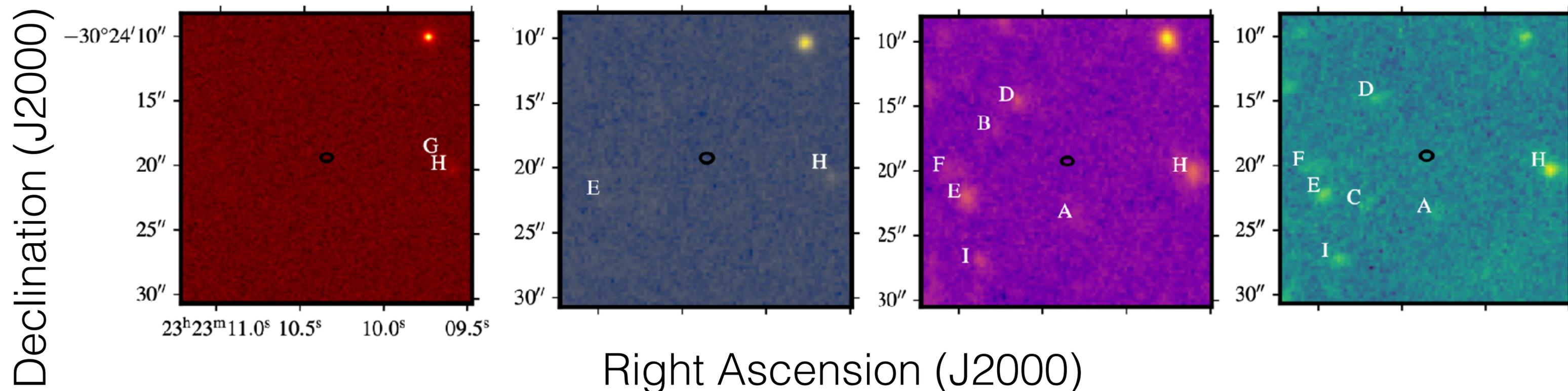


DSA-2000

- Thousands of FRBs per year
- Localized to tens of milliarcseconds
- Out to redshift of a few units
- Also all-sky instruments like BURSTT, CASM, CHARTS, Cosmic Antennae...

FRB with no host

- ASKAP FRB20210912A - unseen host galaxy despite deep optical ($R > 26.7$ mag) and near-infrared ($K_s > 24.9$ mag) VLT imaging
—> high DM (1233.7) suggests high-redshift ($z > 0.7$) origin (Marnoch+ 2023)
- Could be a problem for cosmology studies if many similar cases



Summary and on-look

- Diverse observational properties —> yet unknown origin
 - Next breakthroughs: Multi-wavelength and host localizations ?
- FRB as a probe for our Universe :
 - Localizing missing baryons, galactic halo, constrain H_0 , deionization of He-II, lensing, IGM magnetic field...
- A large, well-localized FRB sample soon:
 - CHORD, DSA2000, SKA : >500 mas-localisations per month
 - Synergies with publicly available catalogues (PanSTARRS, SDSS, DESI, Rubin/LSST, Euclid, SPHEREx..) for host galaxy studies
 - Challenge: host galaxy identification vs high discovery rate

Useful links

Databases:

- CHIME FRB repeaters (<https://www.chime-frb.ca/repeaters>)
- CHIME VOEvents (<https://www.chime-frb.ca/voevents>)
- Blinkverse database (<https://blinkverse.alkaidos.cn/>)
- TNS Database (www.wis-tns.org)
- FRBSTATS (<https://www.herta-experiment.org/frbstats/>)

Conferences:

- FRB2023 (<https://www.youtube.com/watch?v=AyvXSKjk0lw&list=PLDTm-GculgCkdkEM2X8SJ2jj7ifNLU2zE>)