AST3100 Astrophysical transients

“You don’t observe the same Universe twice!”

Ziggy Pleunis

Meeting 1 Week 5

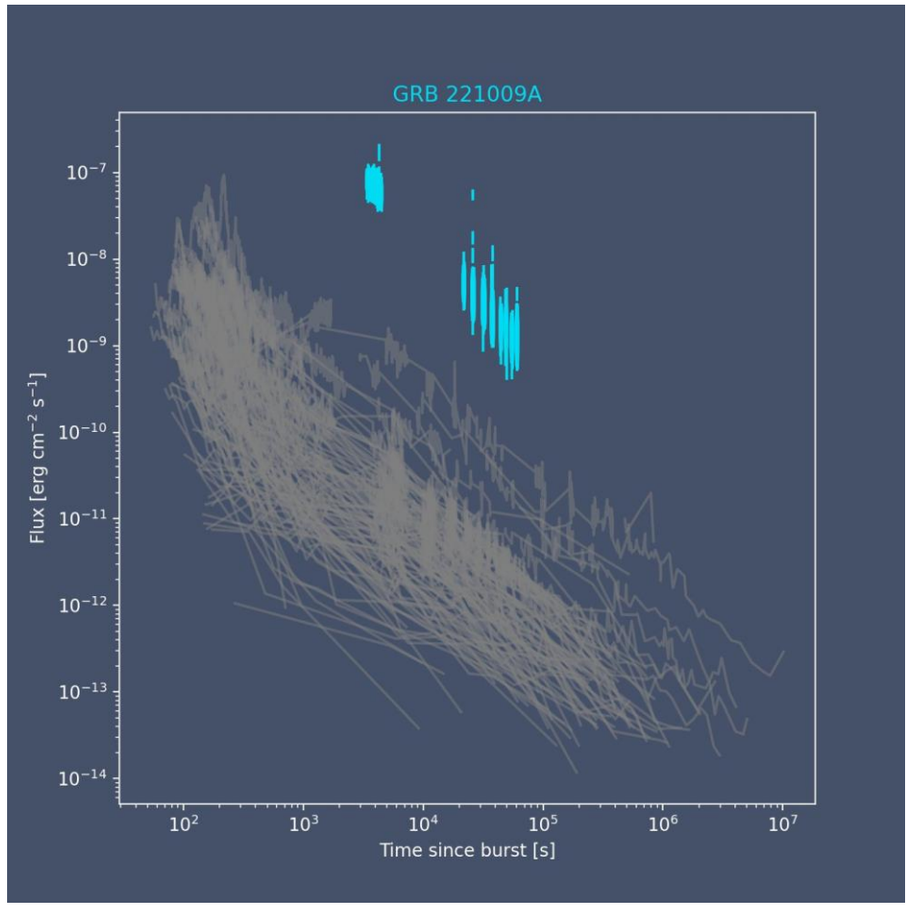
2022 October 13

X-ray: NASA/CXC/GSFC/ B.Williams et al; Optical: DSS

Breaking news: GRB 20221009 is the brightest ever detected!

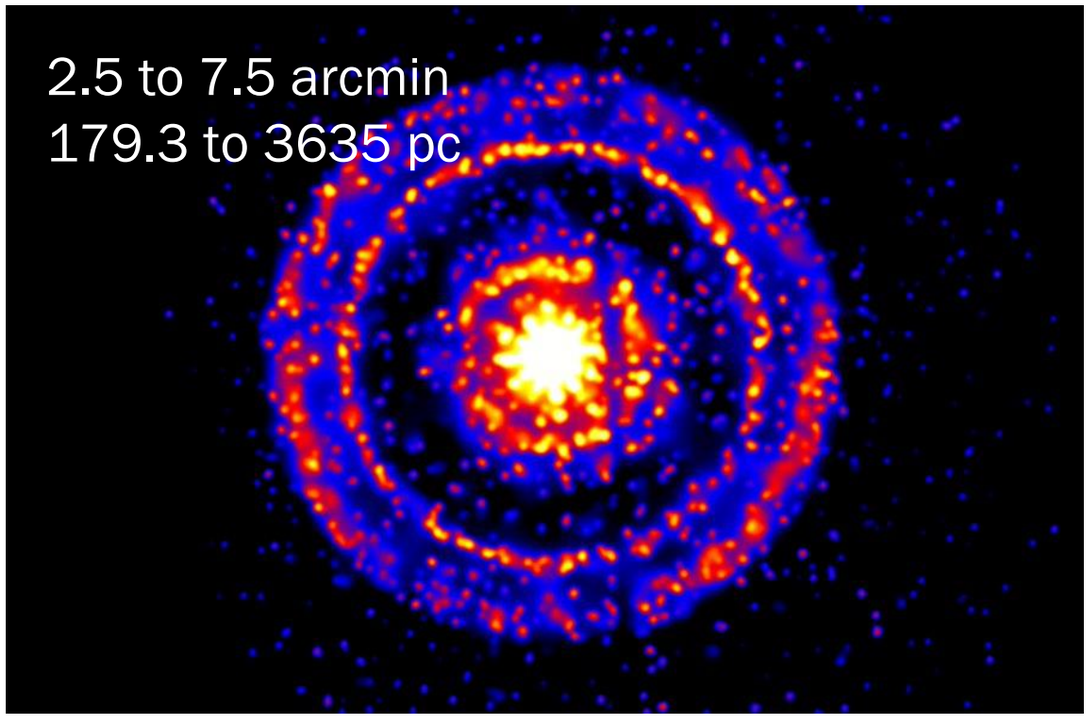
Related

15671	GRB221009A/Swift J1913.1+1946: RATAN-600 measurements
15669	Swift J1913.1+1946/GRB 221009A: detection of a 250-TeV photon-like air shower by Carpet-2
15668	BVRI photometry of the GRB 220019A afterglow
15665	GRB 221009A: NuSTAR Detection
15664	GRB 221009A: NICER follow-up observations
15663	GRB221009A: INTEGRAL detection of Hard X-ray emission up to 38 hours after trigger
15662	GRB 221009A/Swift J1913.1+1946: AGILE-GRID detection
15661	Swift/XRT discovery of multiple dust-scattering X-ray rings around GRB 221009A
15660	Insight-HXMT observation of GRB221009A/Swift J1913.1+1946
15656	GRB 221009A: Fermi-LAT refined analysis
15655	GRB221009A/Swift J1913.1+1946: ATA follow-up observations
15653	AMI-LA observations of the candidate gamma-ray burst GRB221009A/Swift J1913.1+1946
15651	MAXI/GSC detection of the new X-ray transient Swift J1913.1+1946
15650	Swift J1913.1+1946 a new bright hard X-ray and optical transient



Credit: Astro-COLIBRI
https://twitter.com/AstroColibri/status/1579478412678561792

Photons up to 18 TeV from LHAASO?
https://gcn.gsfc.nasa.gov/gcn3/32677.gcn3



Credit: Jon Miller
https://www.astronomerstelegram.org/?read=15661
https://twitter.com/jonastrox/status/1579816995729833984


nature
THE INTERNATIONAL WEEKLY JOURNAL OF SCIENCE
MYSTERY OBJECT
Precise localization of fast radio burst reveals distant host and enigmatic persistent source
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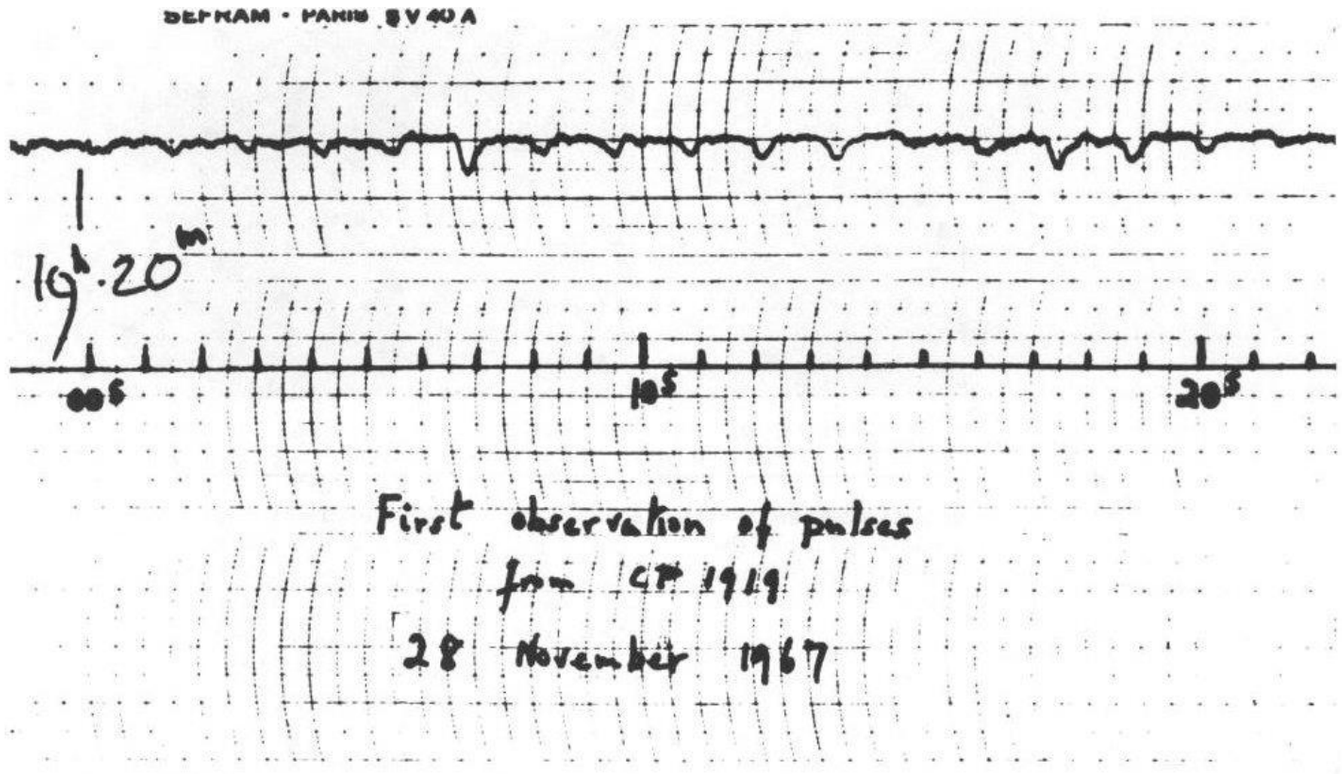
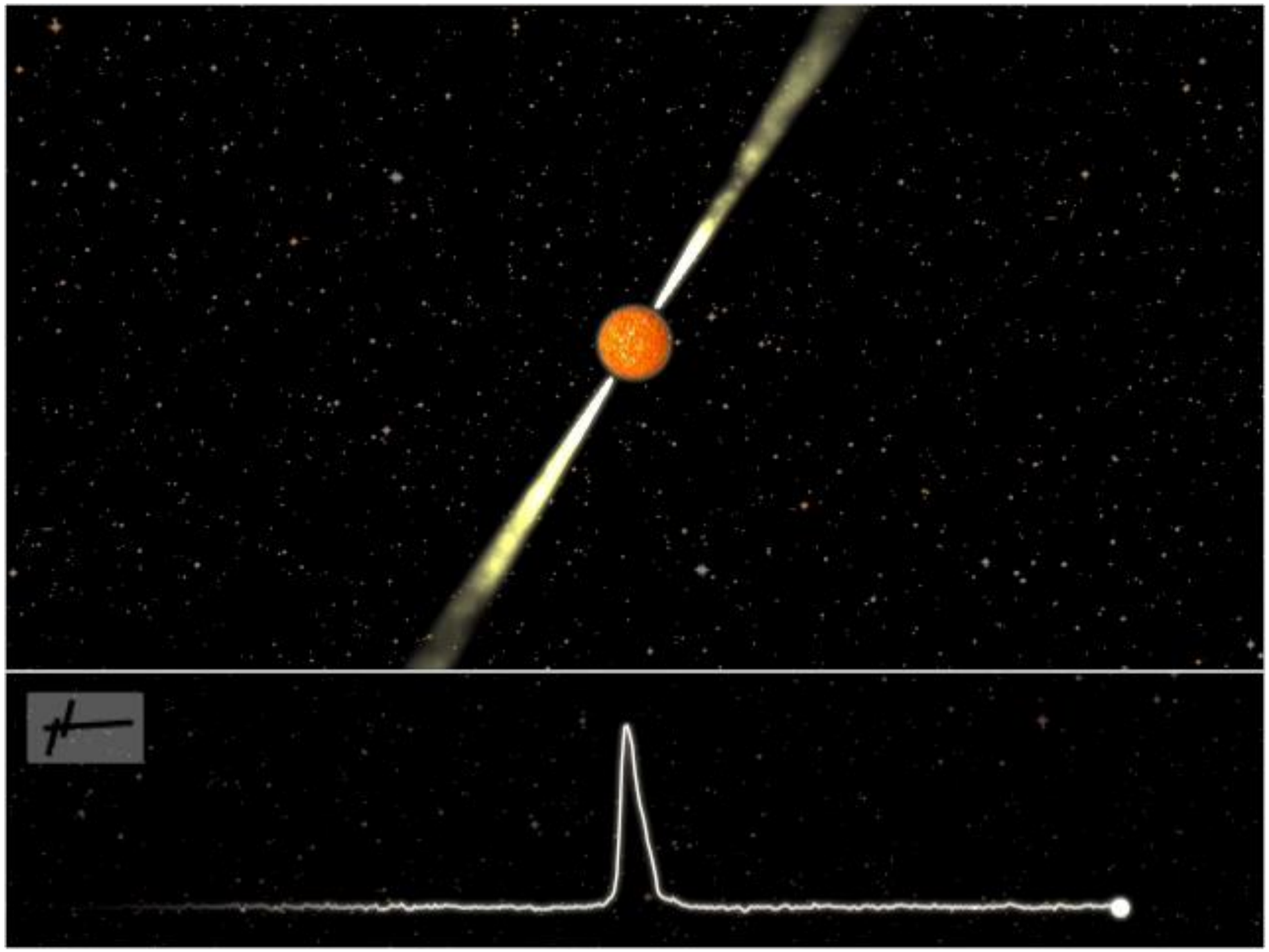
Pulsars

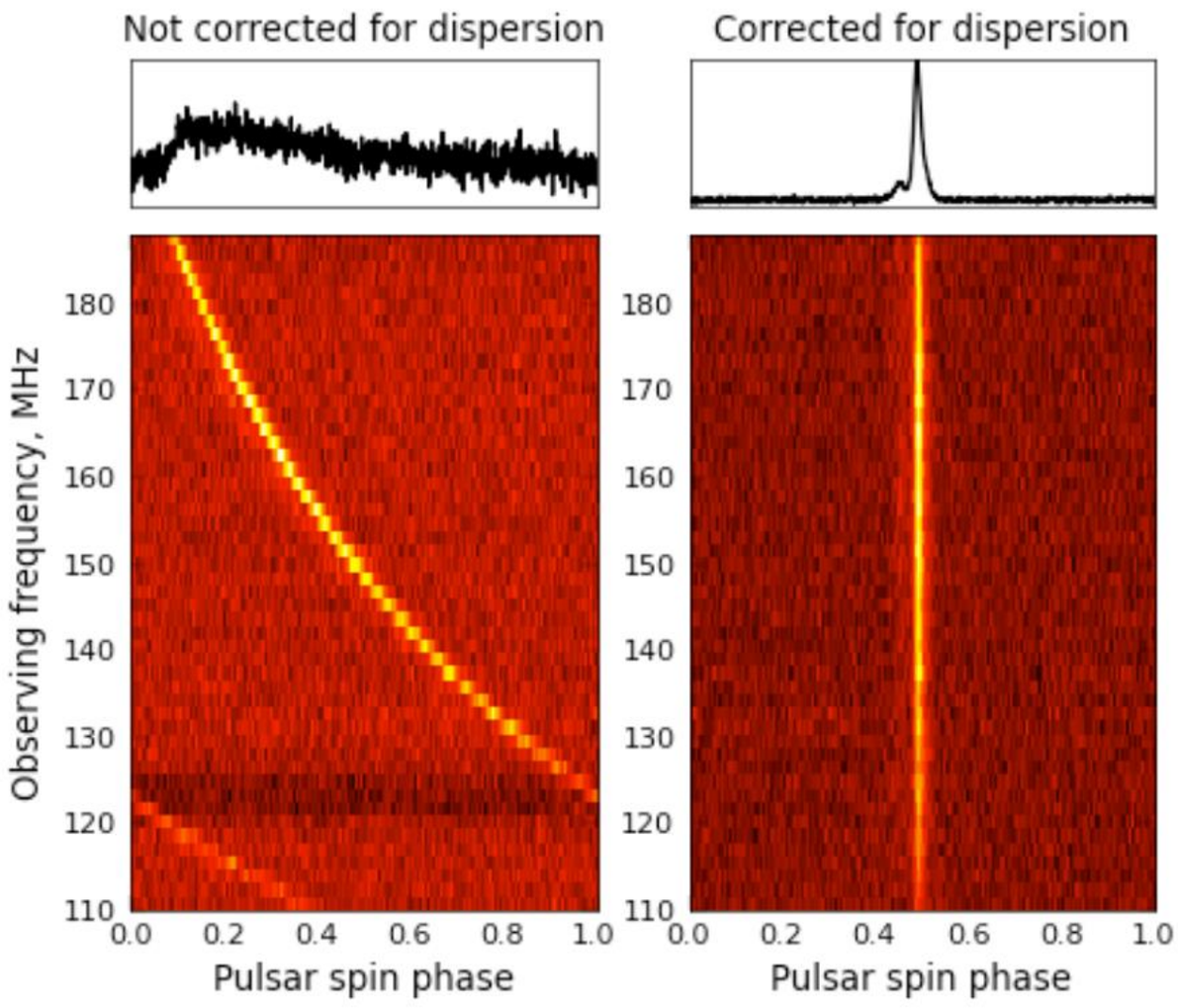
- Discovered in 1967 by Jocelyn Bell Burnell



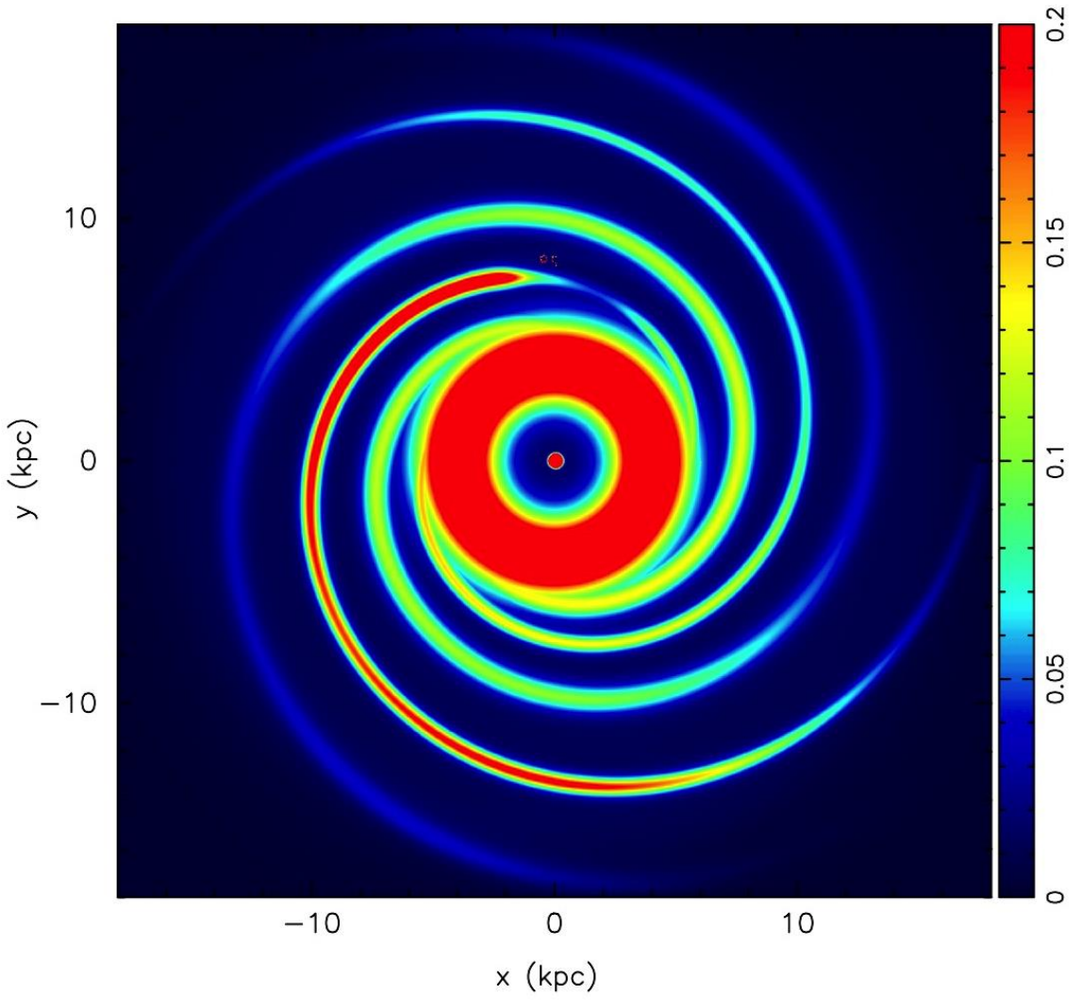
Pulsars



Dispersion in the interstellar medium



📷 Anna Bilous

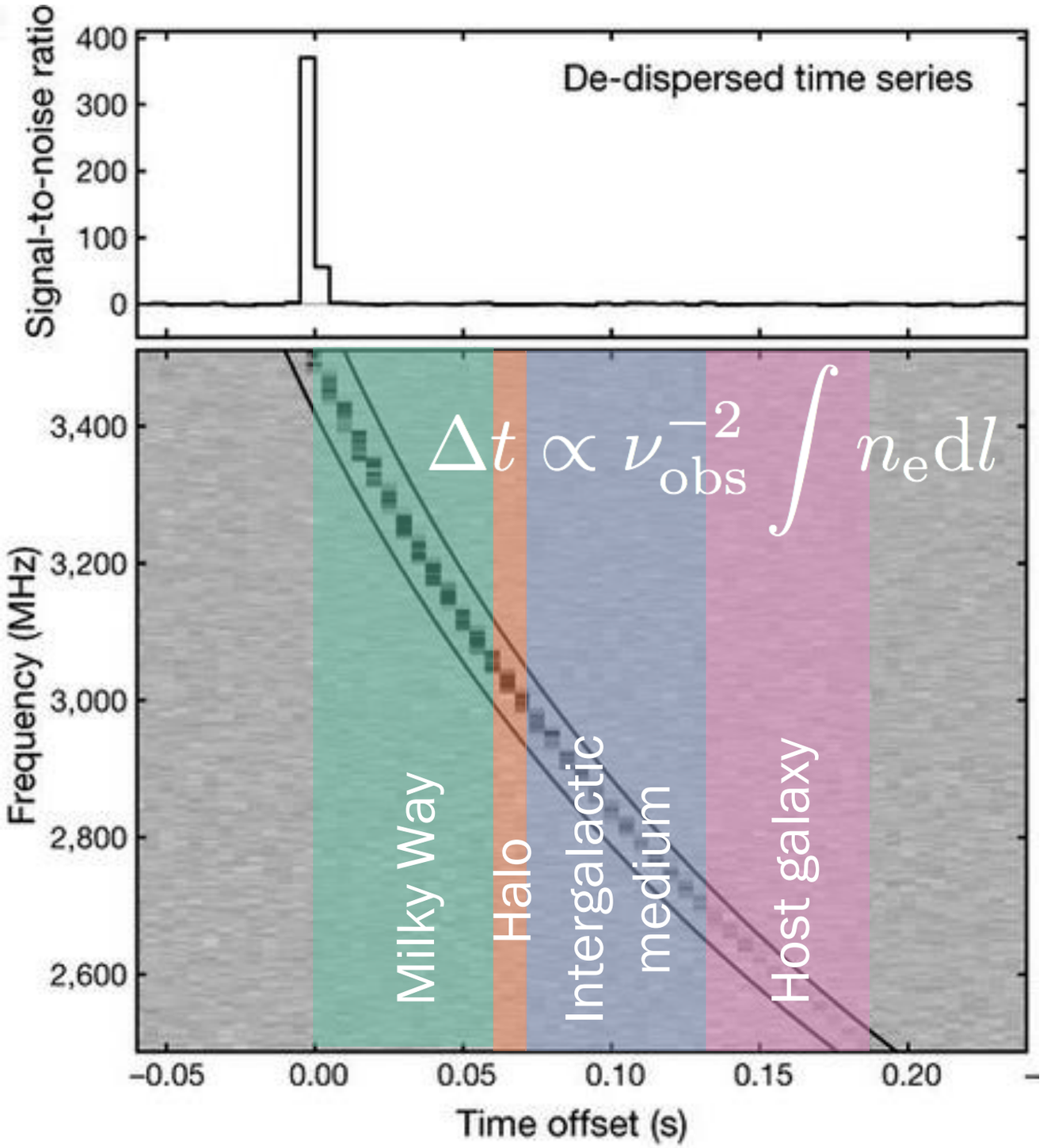


📷 Yao, Manchester & Wang

$$\Delta t \propto \nu_{\rm obs}^{-2} \int n_{\rm e} {\rm d}l$$

Quantified as
“Dispersion Measure”
or “DM”

Fast radio bursts (FRBs)



- First discovered in 2007
- Duration ~ ms
- Extragalactic
- $T_B \sim 10^{36}$ K
- $\sim 10^3$ sky^{-1} day^{-1}
- At least a few dozen sources repeat

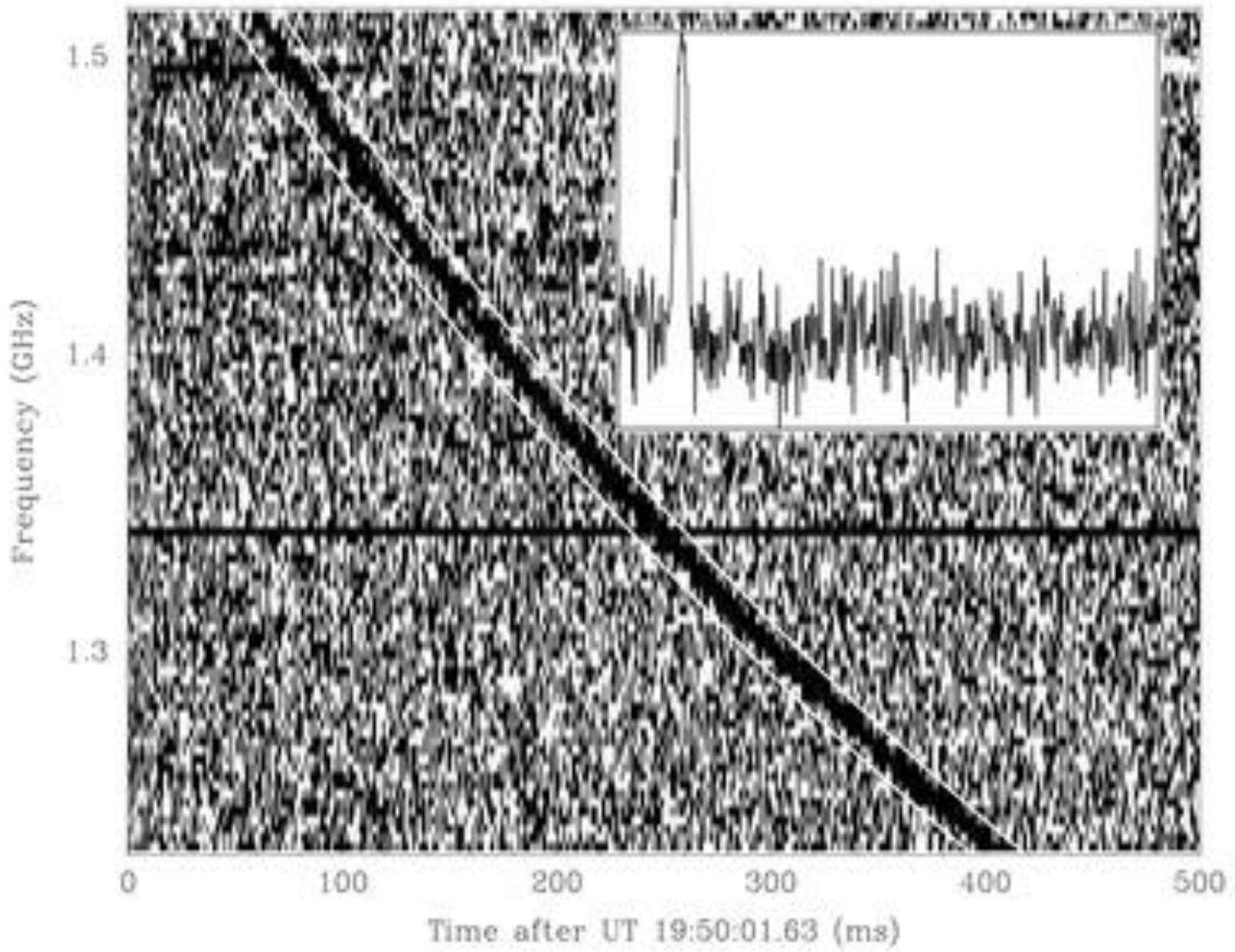
- Origin unknown
- Unique probes of the intergalactic medium and potentially cosmology

2007 — Initial discovery

(in data from 2001)

Lorimer et al.

- “Lorimer burst”
- Duration ~ ms
- Extragalactic based on DM (< 1 Gpc)
- Hundreds such events each day
- Supernova or binary star merger?



2007 — Initial discovery

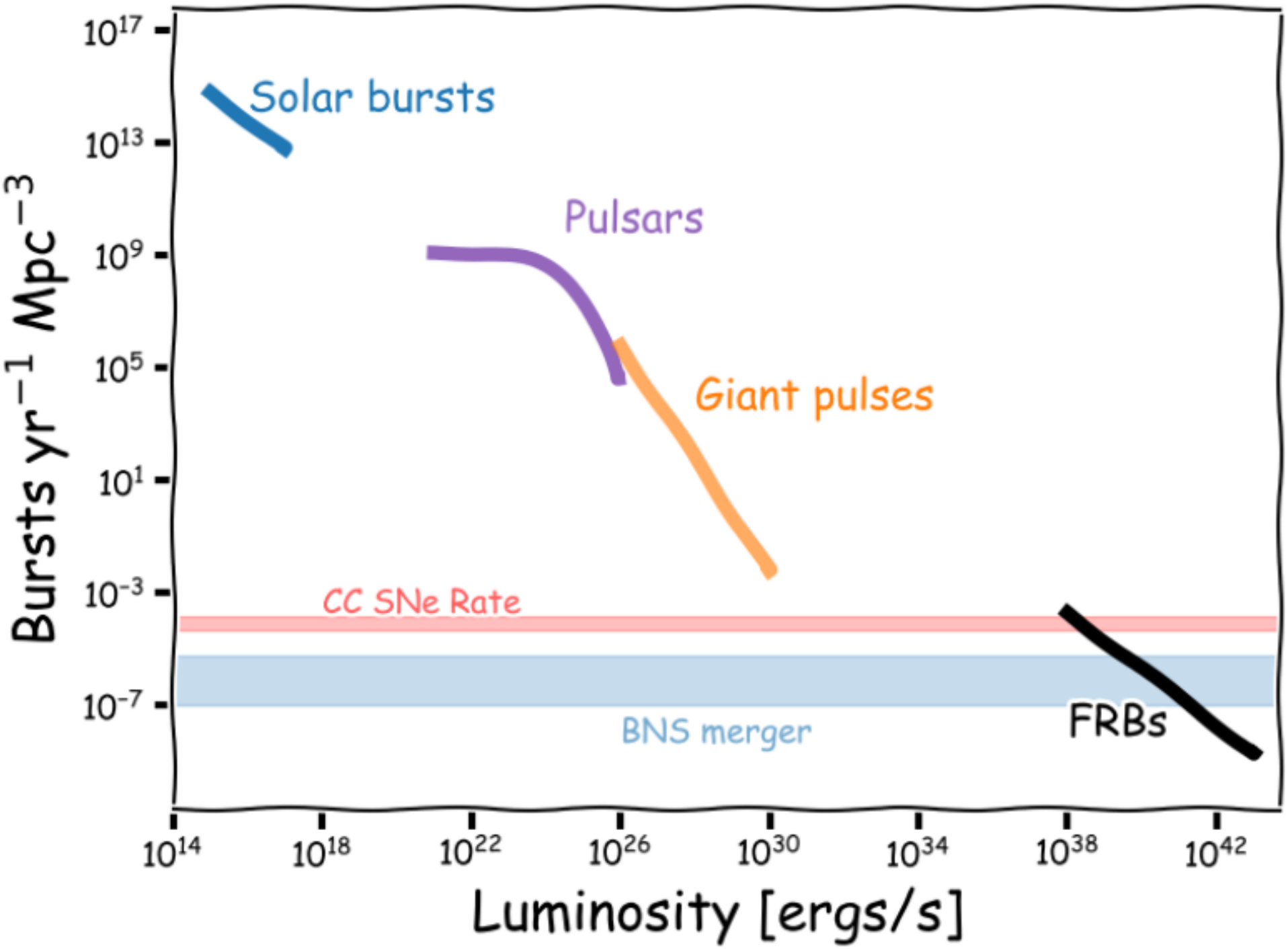
Lorimer et al.

$$\Delta t = R\zeta^2 / 2c\Gamma^2$$

~ms transient observable from ~Gpc distance -> brightness temperature ~10^{36} K, energy releases of ~10^{33} J and a source size ~< 10^3 km -> coherent emission from a compact object

O(1000) sky/day

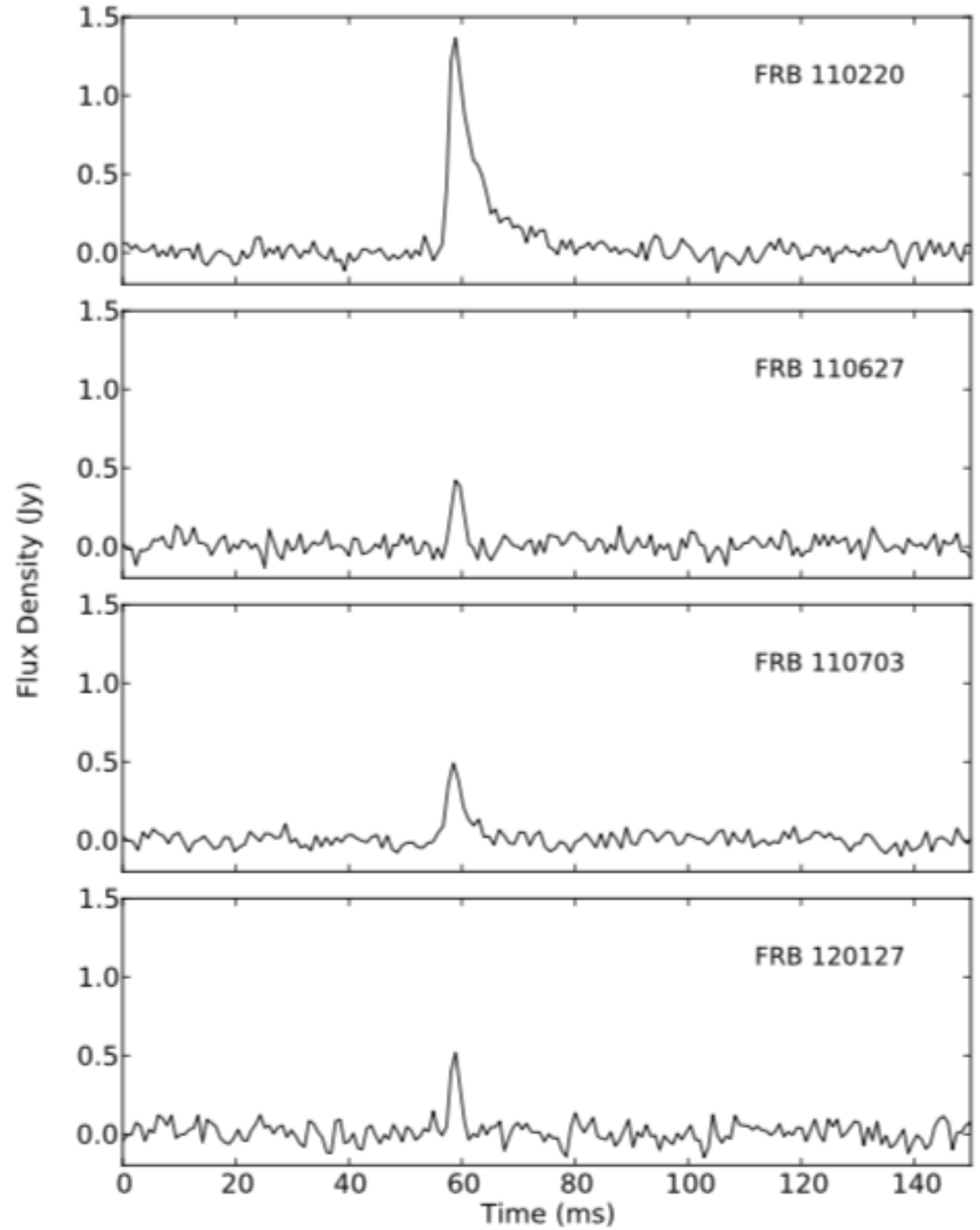
2007 — Initial discovery



2013 — A population of FRBs

Thornton et al.

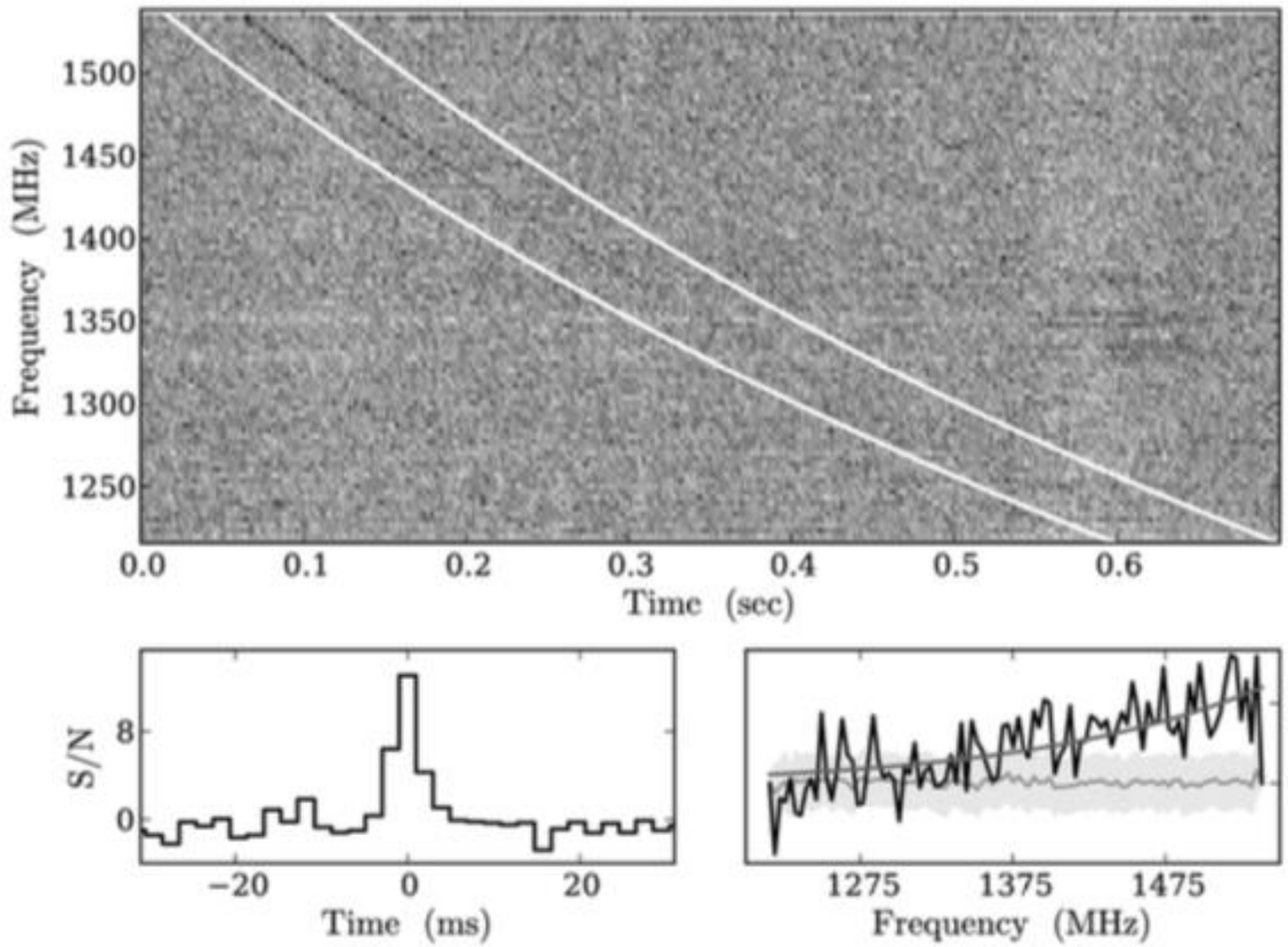
- “Lorimer burst” is not an anomaly



2014 — First FRB detected by a different telescope than Parkes

Spitler et al.

- FRBs are not generated locally at the Parkes telescope

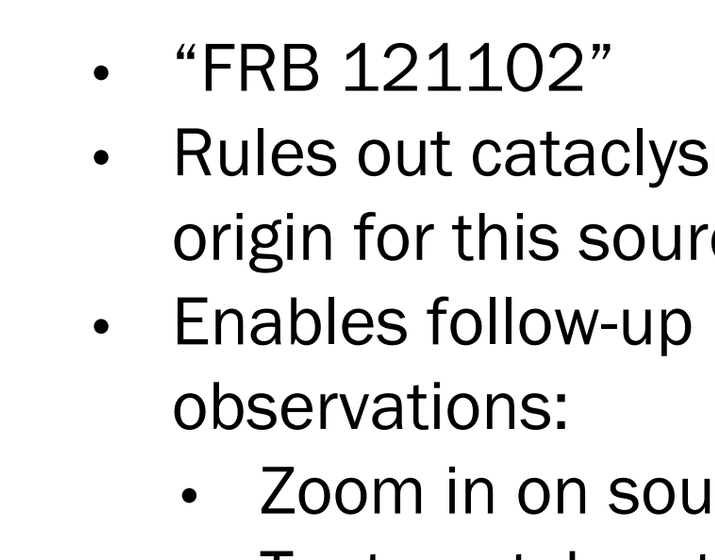


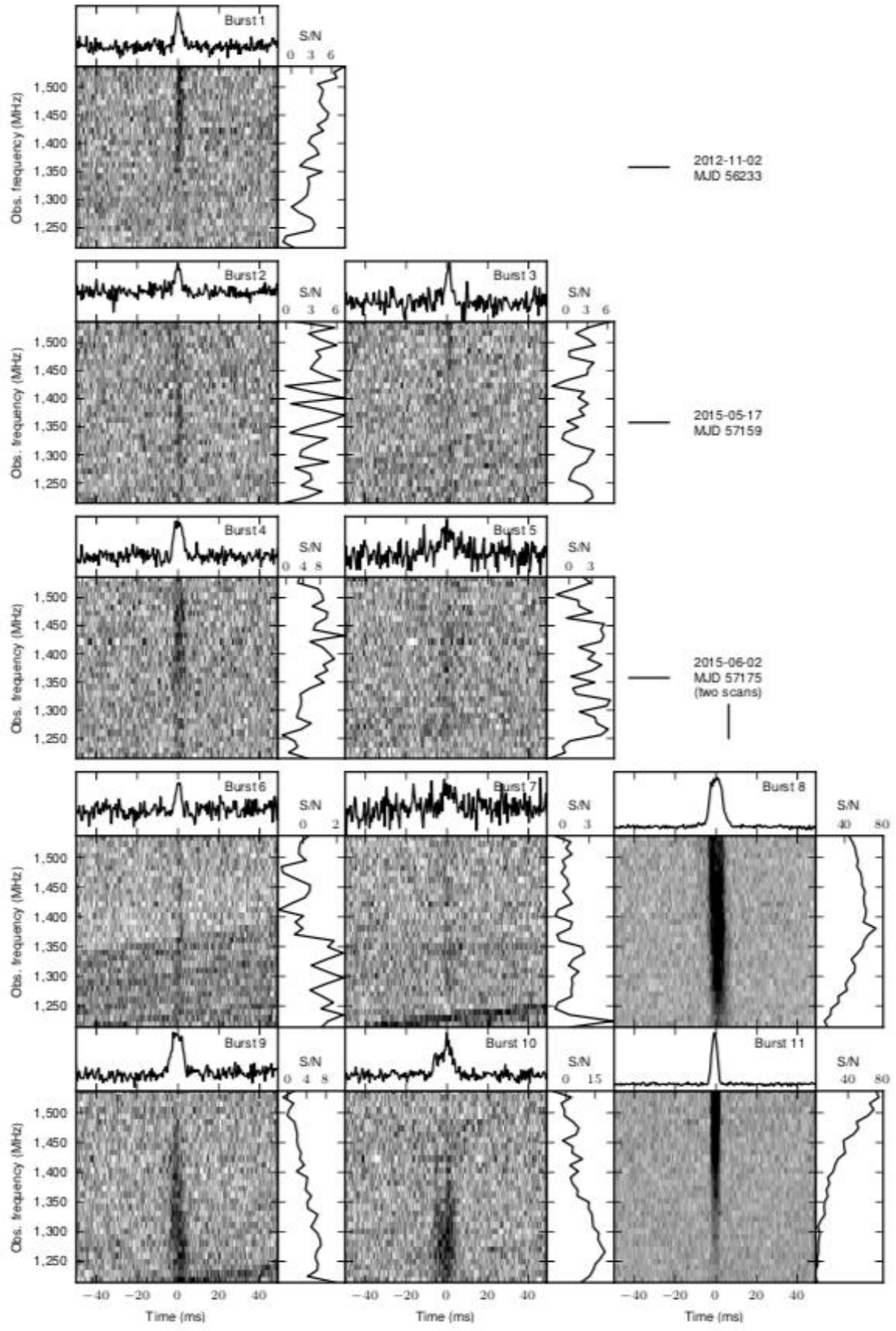
Dunlap fellow
Dr. Paul Scholz

2016 — First repeating source

Spitler et al.

- “FRB 121102”
- Rules out cataclysmic origin for this source
- Enables follow-up observations:
  - Zoom in on source
  - Try to catch optical light, X-rays, gamma-rays as well





2016 — First repeating source

$$E_{\rm bursts} = E_{\rm radio} \times F_b \times \eta^{-1} \times \zeta^{-1}, \qquad (5)$$

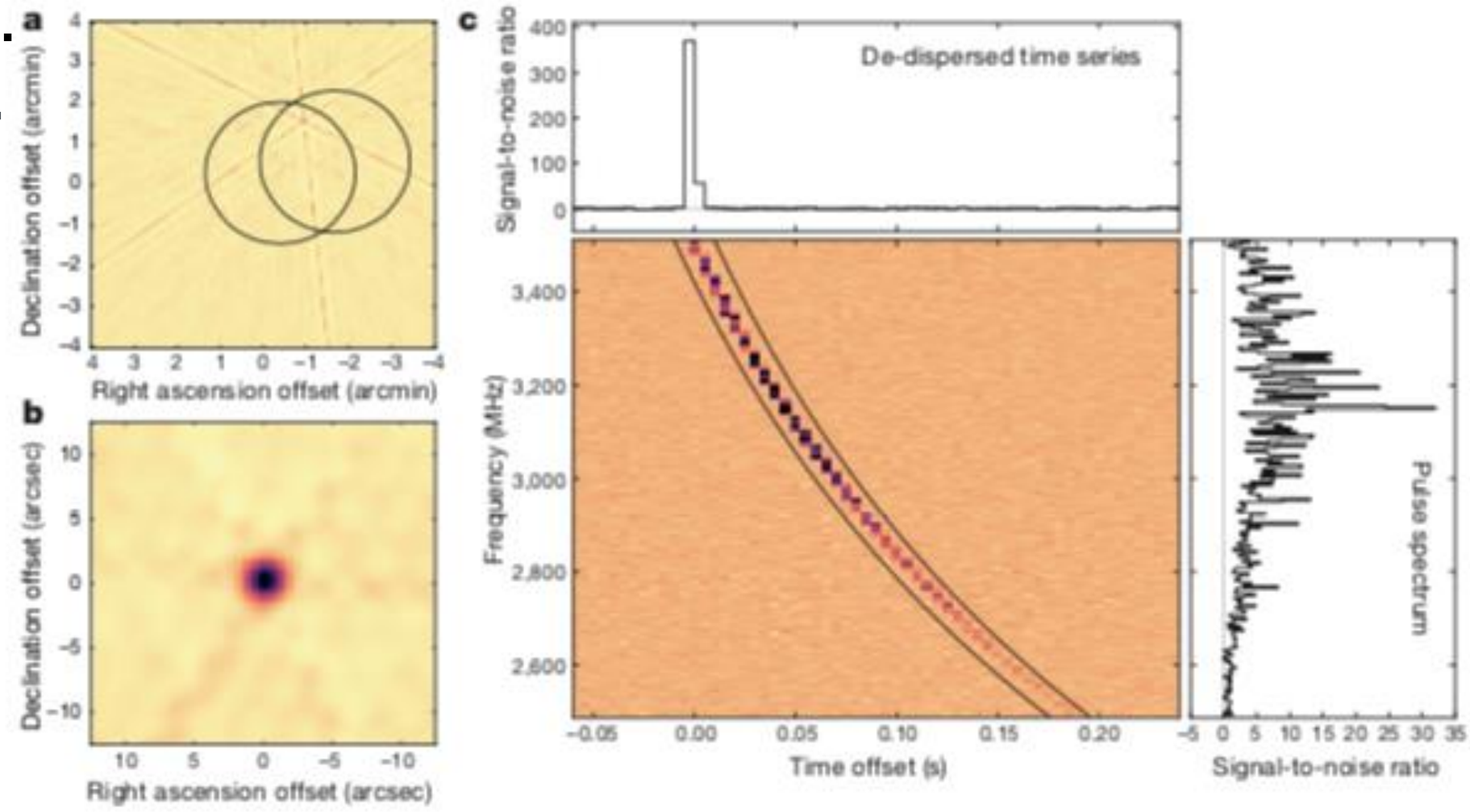
where $E_{\rm bursts}$ is the total energy emitted by FRB source during bursts, F_b is the beaming factor, η is the radio efficiency which is normalized to $\sim 10^{-5}$ (similar order to FRB 20200428), and ζ is the observation duty cycle.

Taking the nominal values of $\eta = 10^{-5}$ and $F_b = 0.1$, the total burst energy released on September 28 has reached $(2.46 \times 10^{46}\ {\rm erg})\eta_{-5}^{-1} F_{b.-1}$. Compared with the total dipolar magnetic energy of a magnetar $E_{\rm mag} = (1/6)B_p^2 R^3 \sim (1.7 \times 10^{47}\ {\rm erg}) B_{p,15}^2 R_6^3$, the burst energy emitted on this day already exceeded $14.3\%\ \eta_{-5}^{-1} F_{b,-1}$ of the available magnetar energy.

2017 — First localized FRB

(after tens of hours of observing and 1 year of trying)

- Chatterjee et al.
- Tendulkar et al.
- Bassa et al.
- Law et al.



- Host is a star-forming dwarf galaxy
- Redshift measurement ($z \sim 0.19$) puts the source firmly outside of the Milky Way

2017 — First localized FRB

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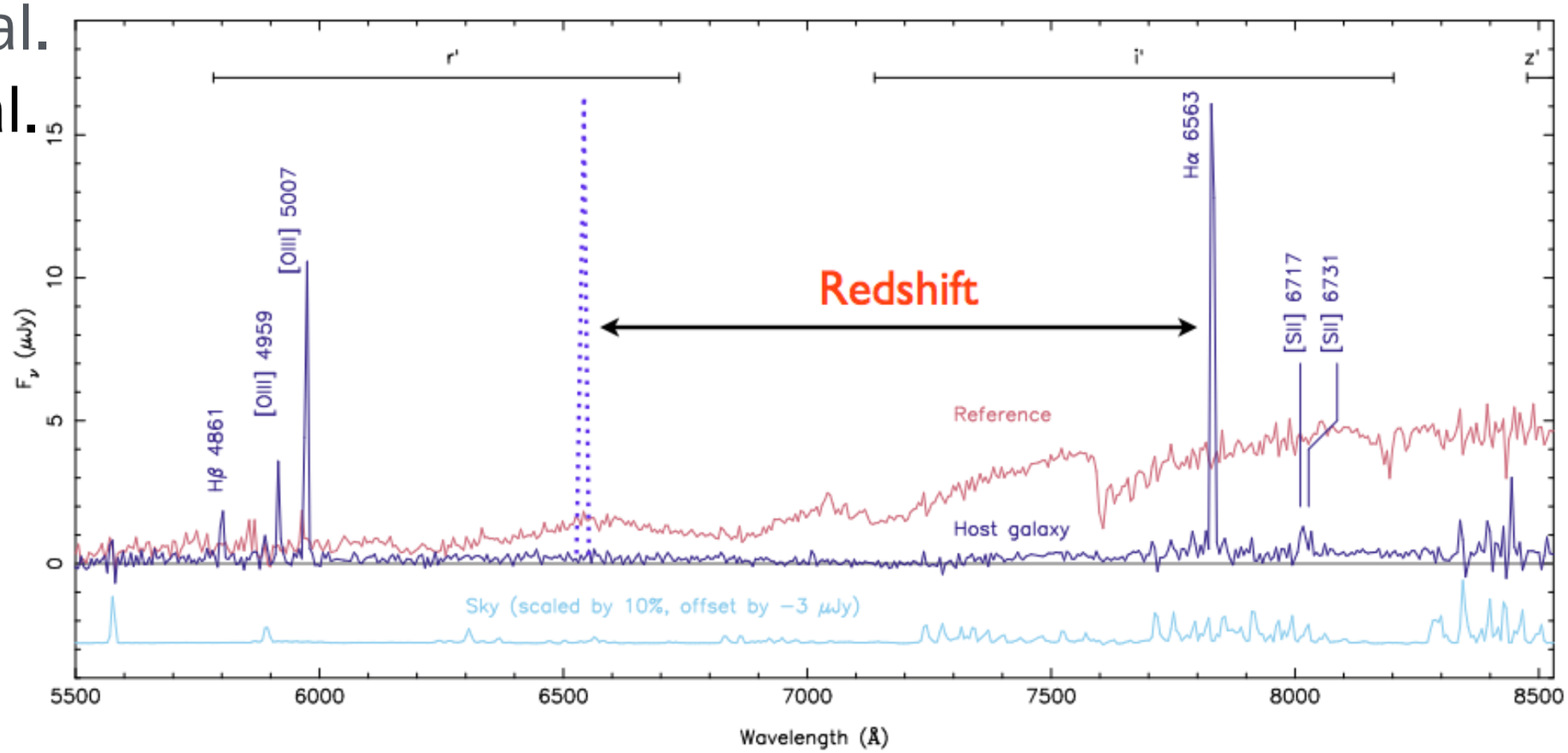

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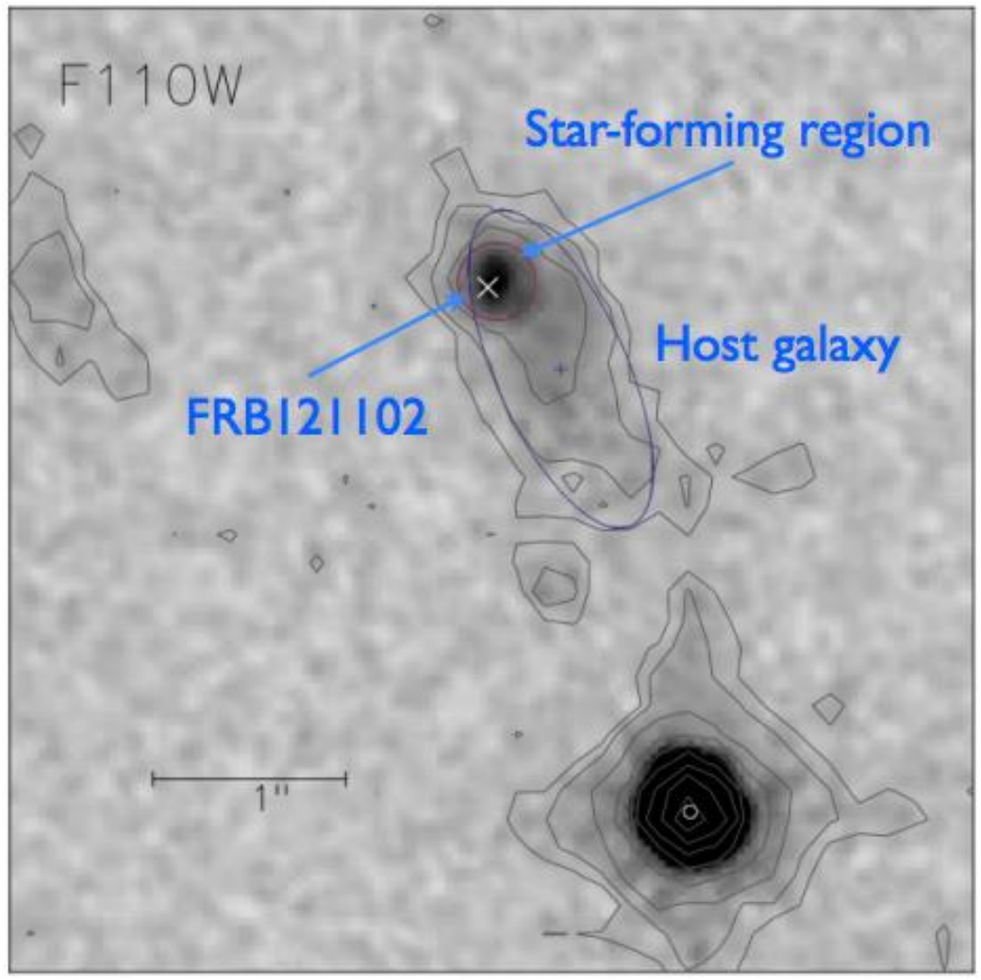

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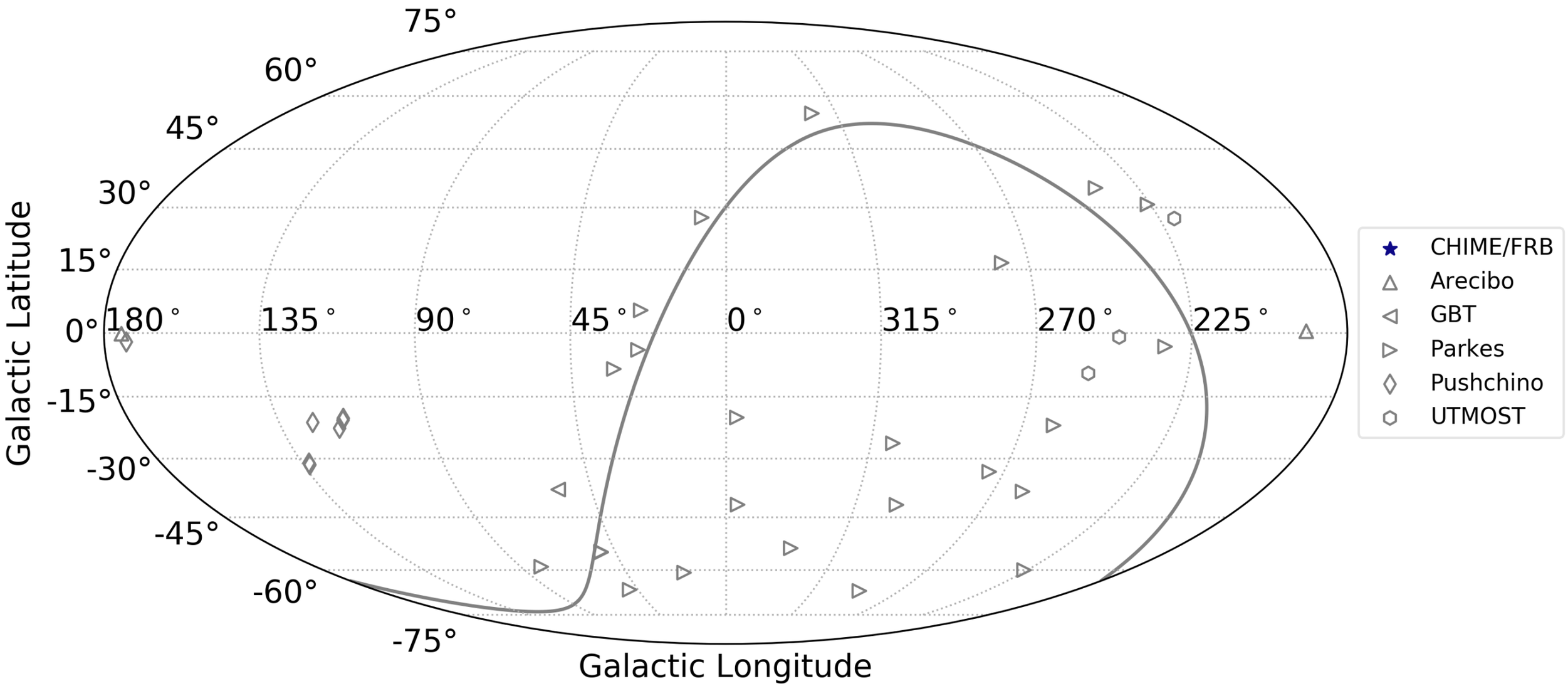
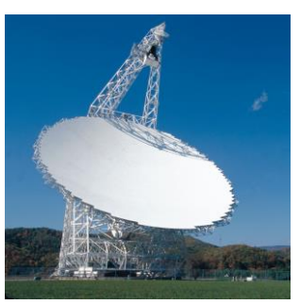
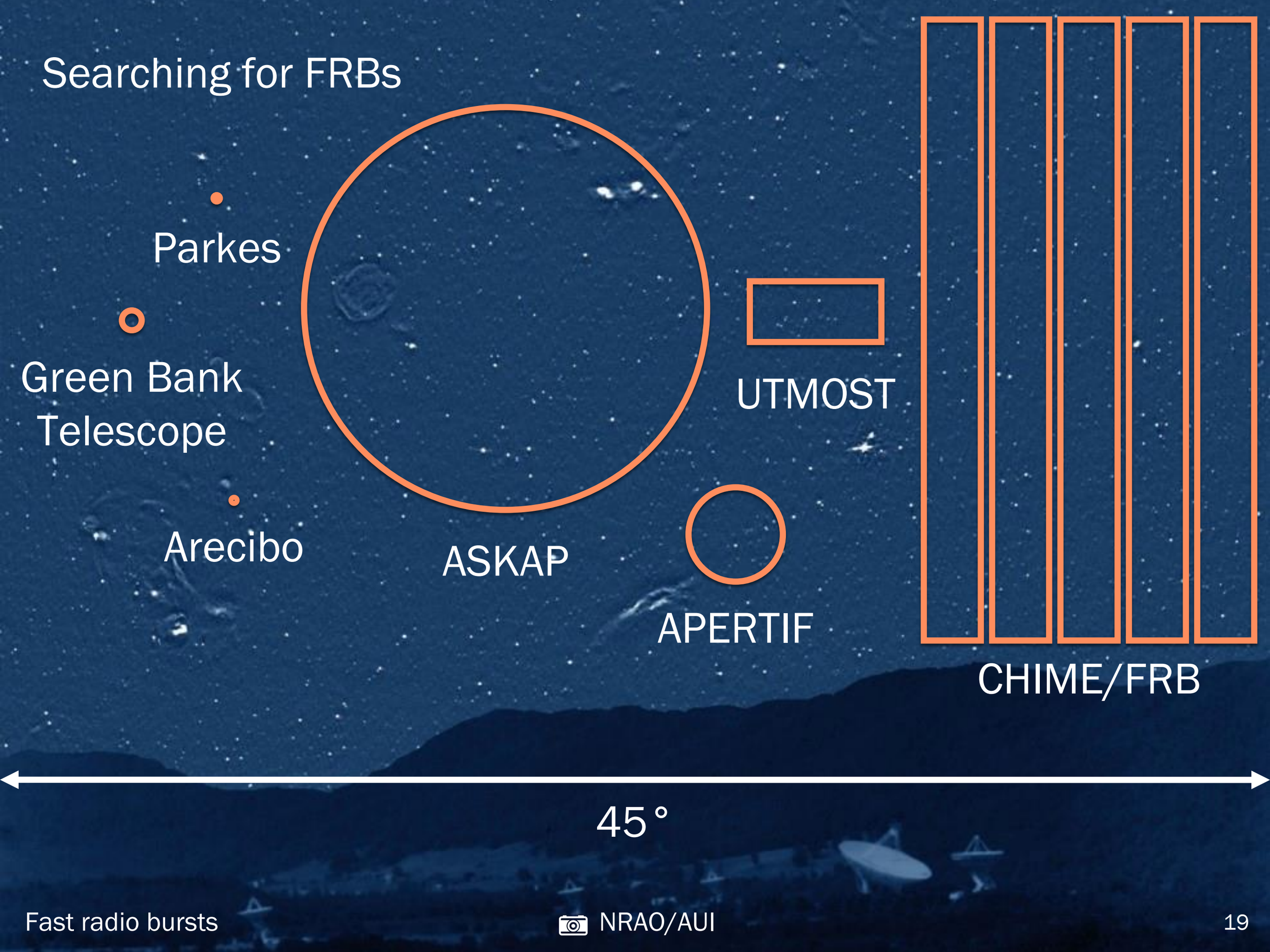
Fast radio bursts 2007–2016



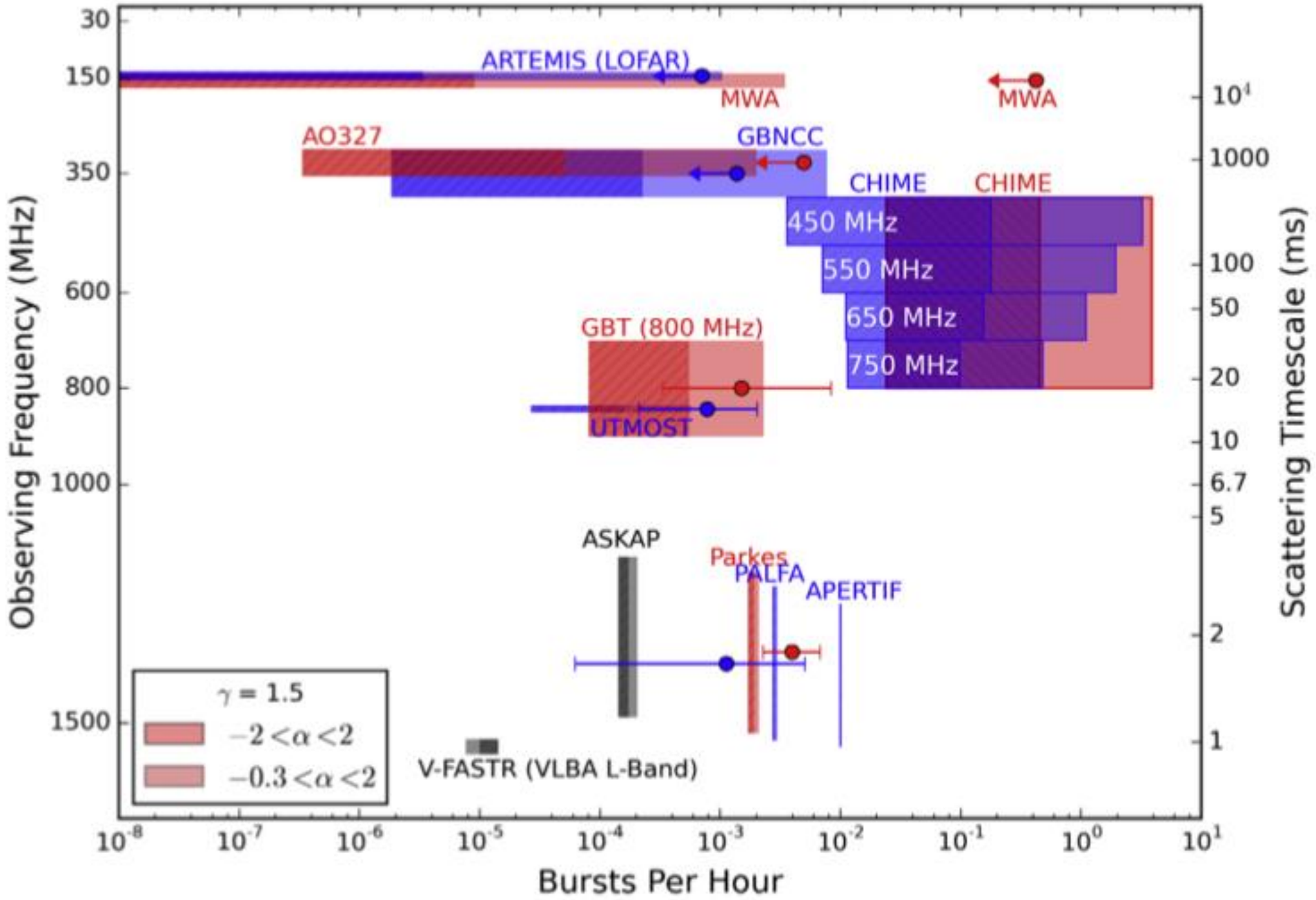



Searching for FRBs



NRAO/AUI

Detection rate predictions



CHIME/FRB Collaboration, 2018 after Chawla et al. 2017

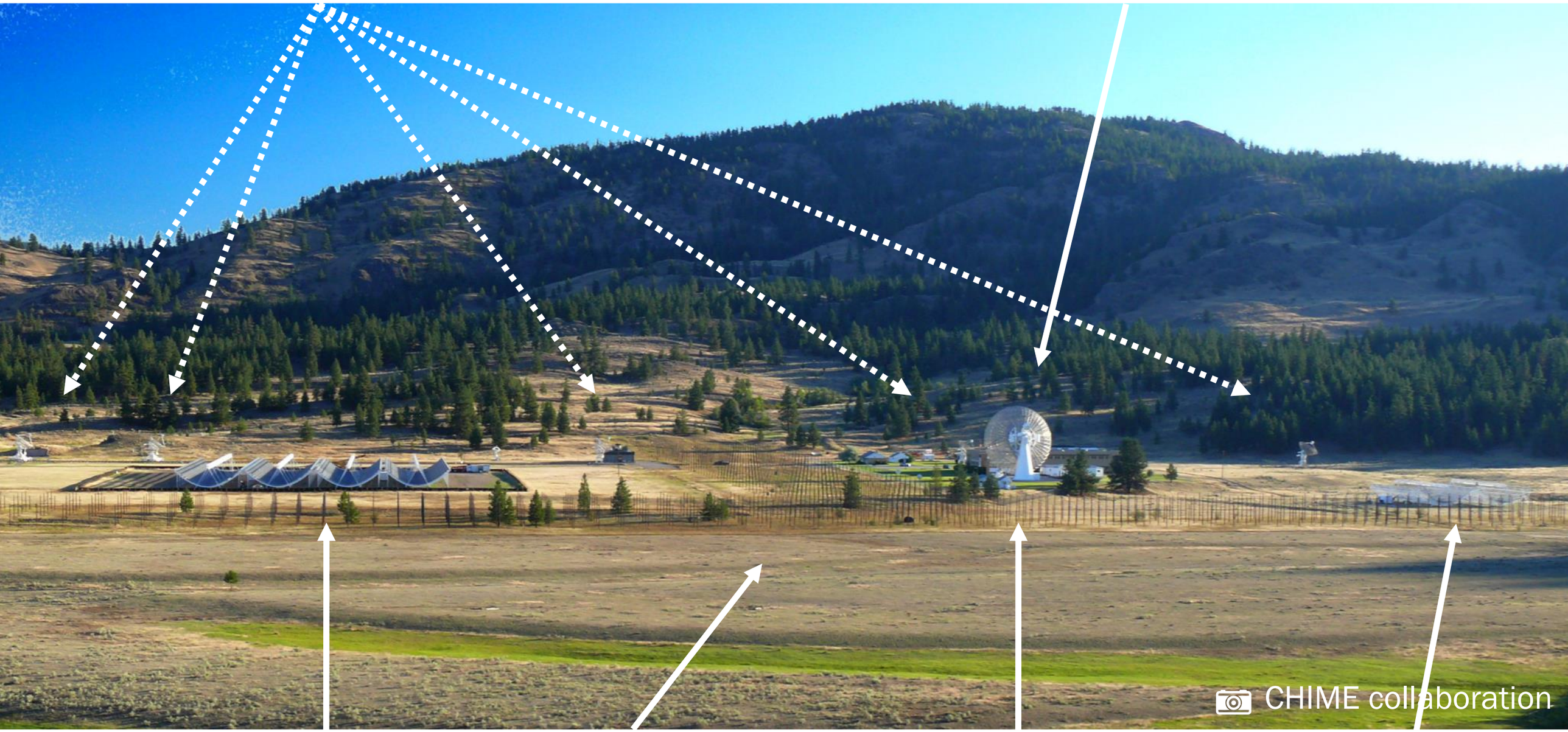
Dominion Radio Astrophysical Observatory, Penticton, B.C.

Shiny Brar

Dominion Radio Astrophysical Observatory, Penticton, B.C.

DRAO Synthesis Telescope

John A. Galt 26-m Telescope



CHIME

Main building

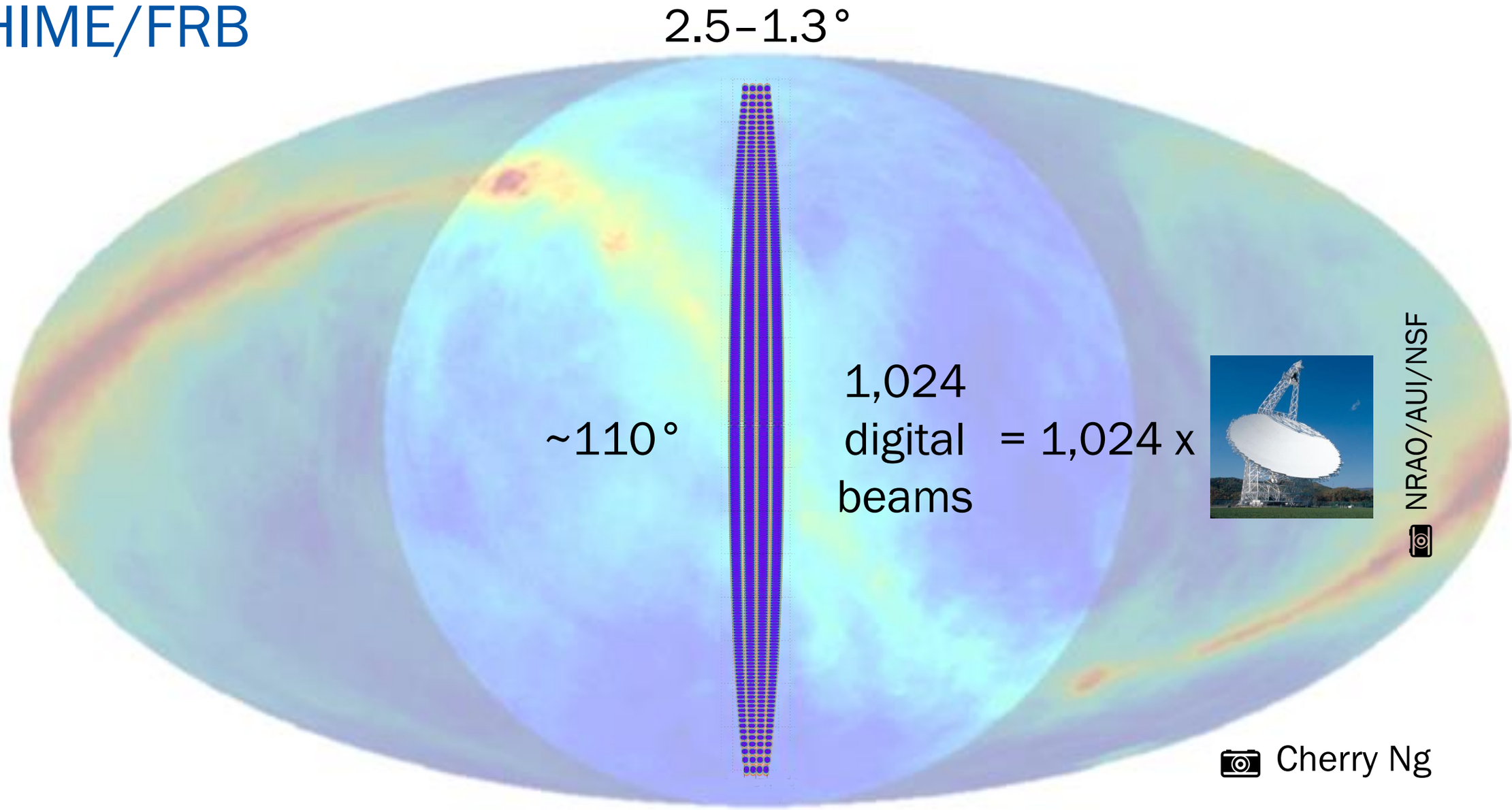
Pathfinder

22-MHz Telescope (decommissioned)

Canadian Hydrogen Intensity Mapping Experiment (CHIME)

400 to 800 MHz ⇔ z = 2.5 to 0.8 for 21 cm

CHIME/FRB



NRAO/AUI/NSF

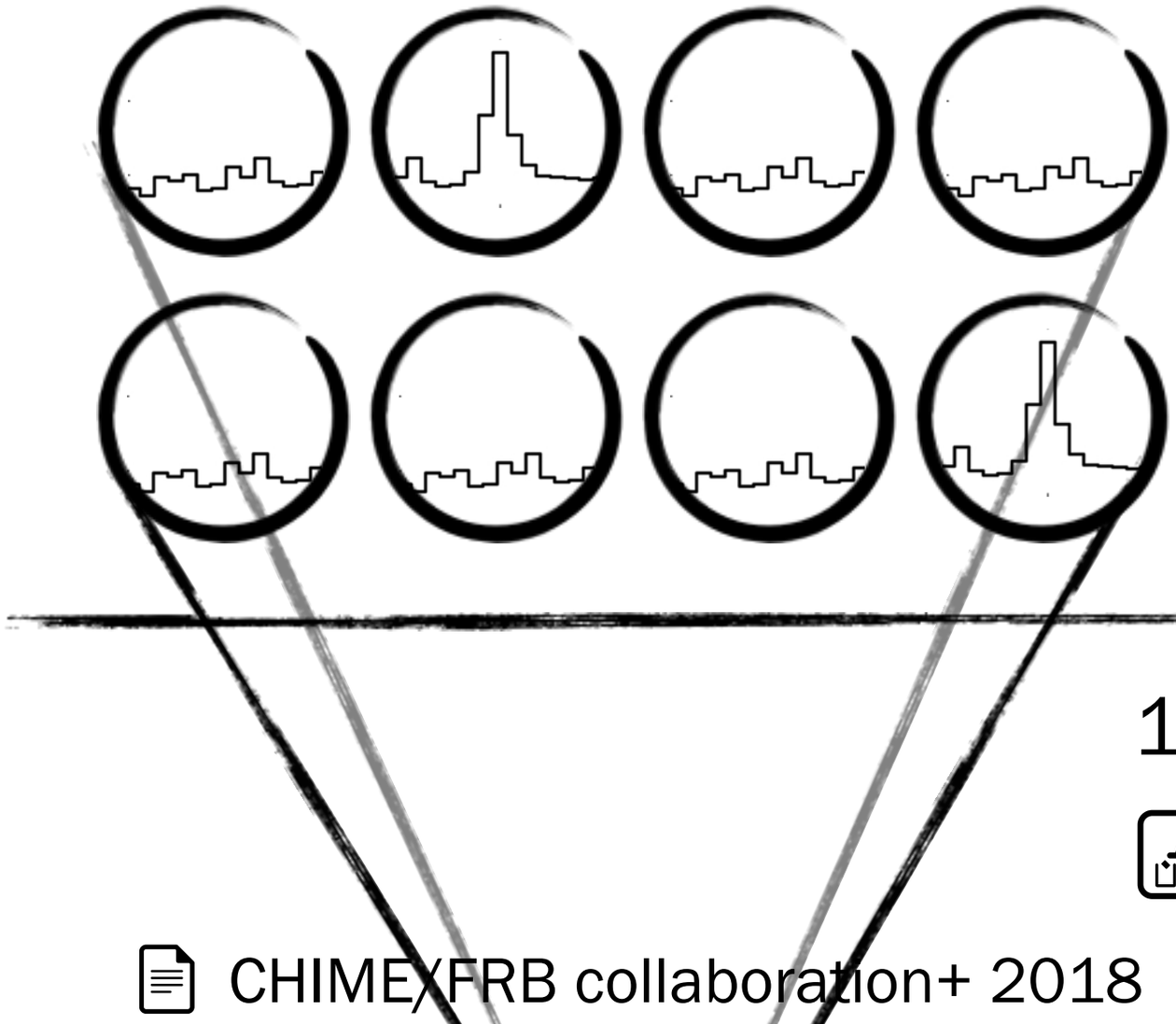
Cherry Ng

CHIME/FRB collaboration+ 2018

CHIME/FRB

400–800 MHz

Frequency channels: 16,384



Time resolution: 0.983 ms

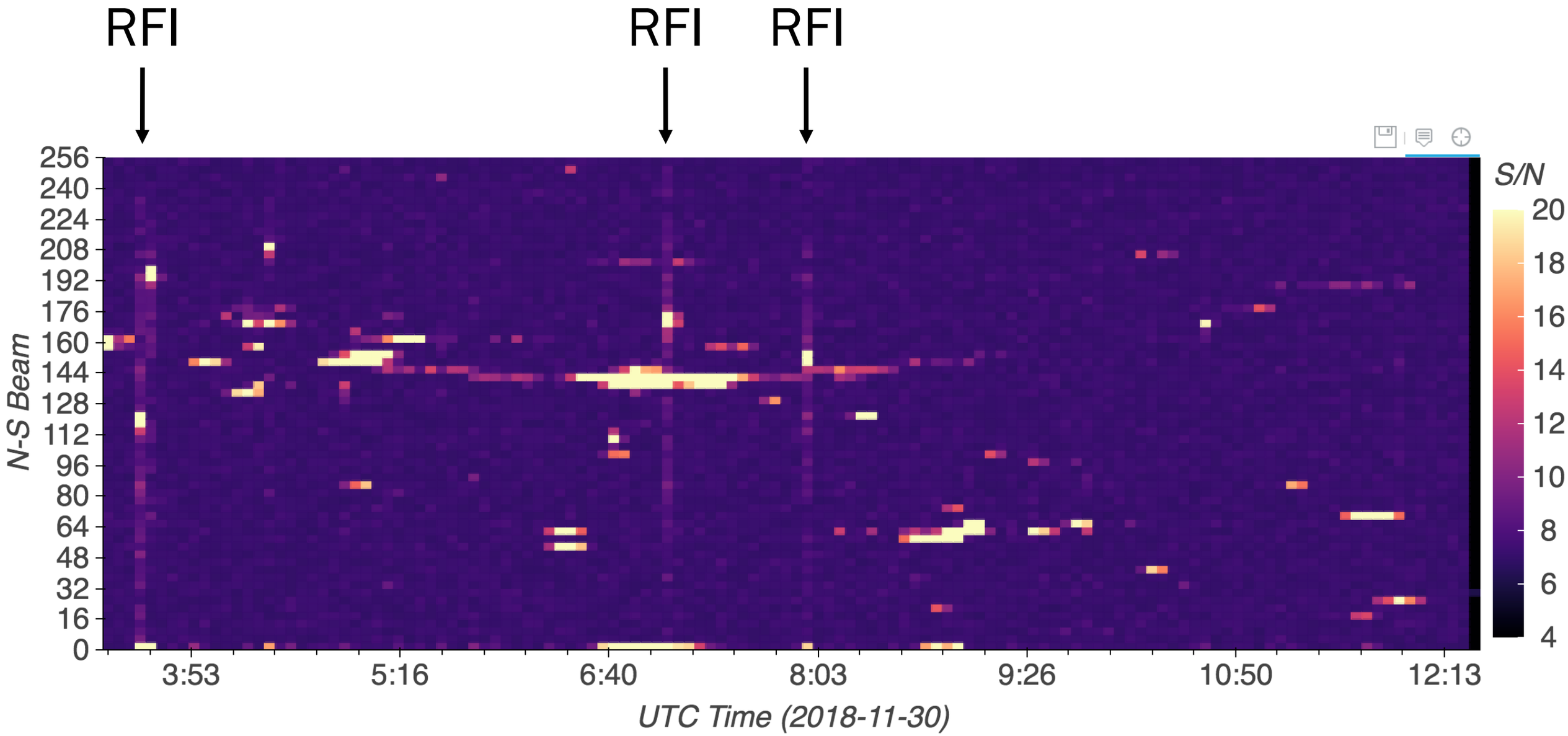
+

142 Gb/s

or

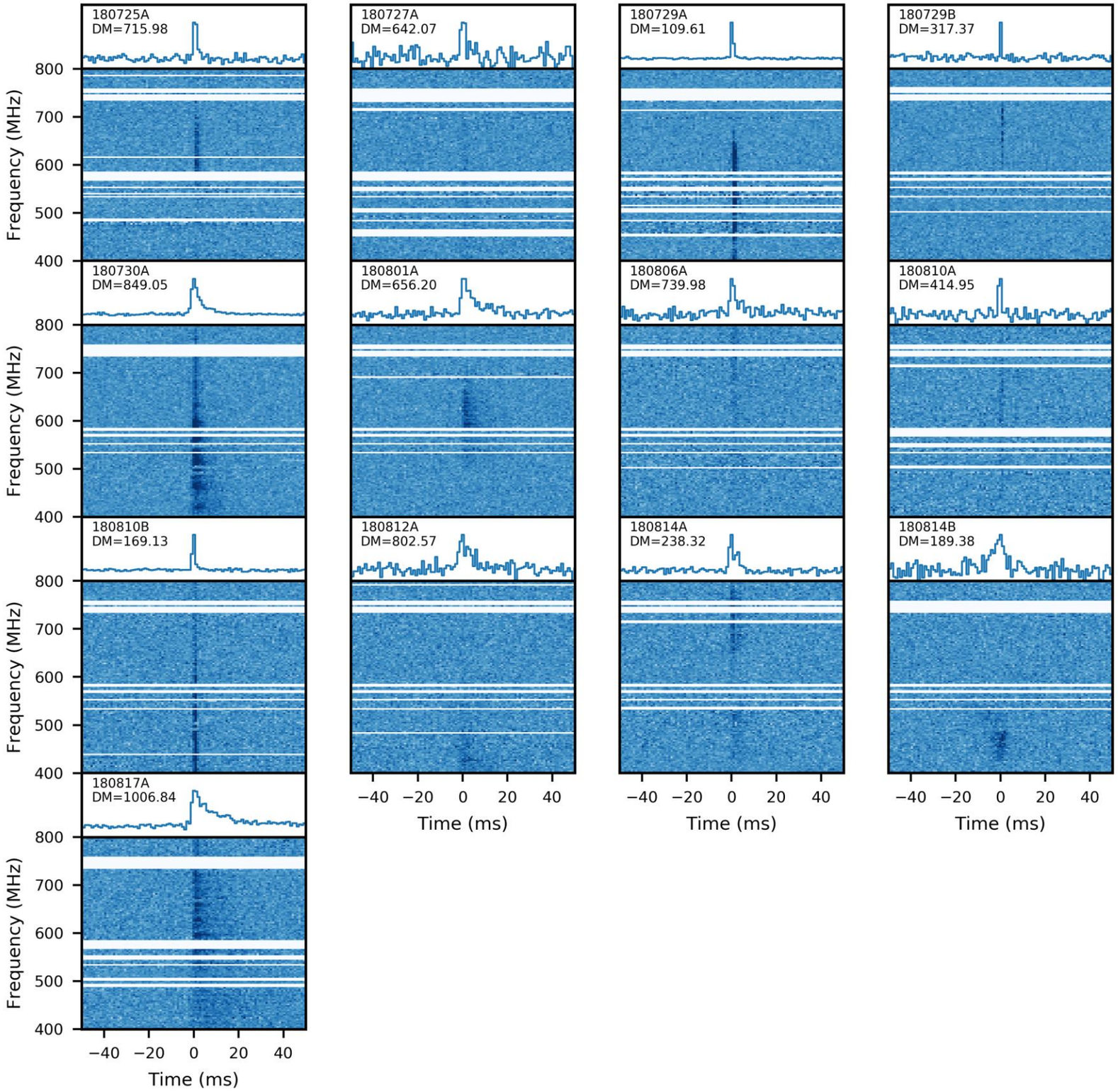
CHIME/FRB collaboration+ 2018

Per-beam triggers



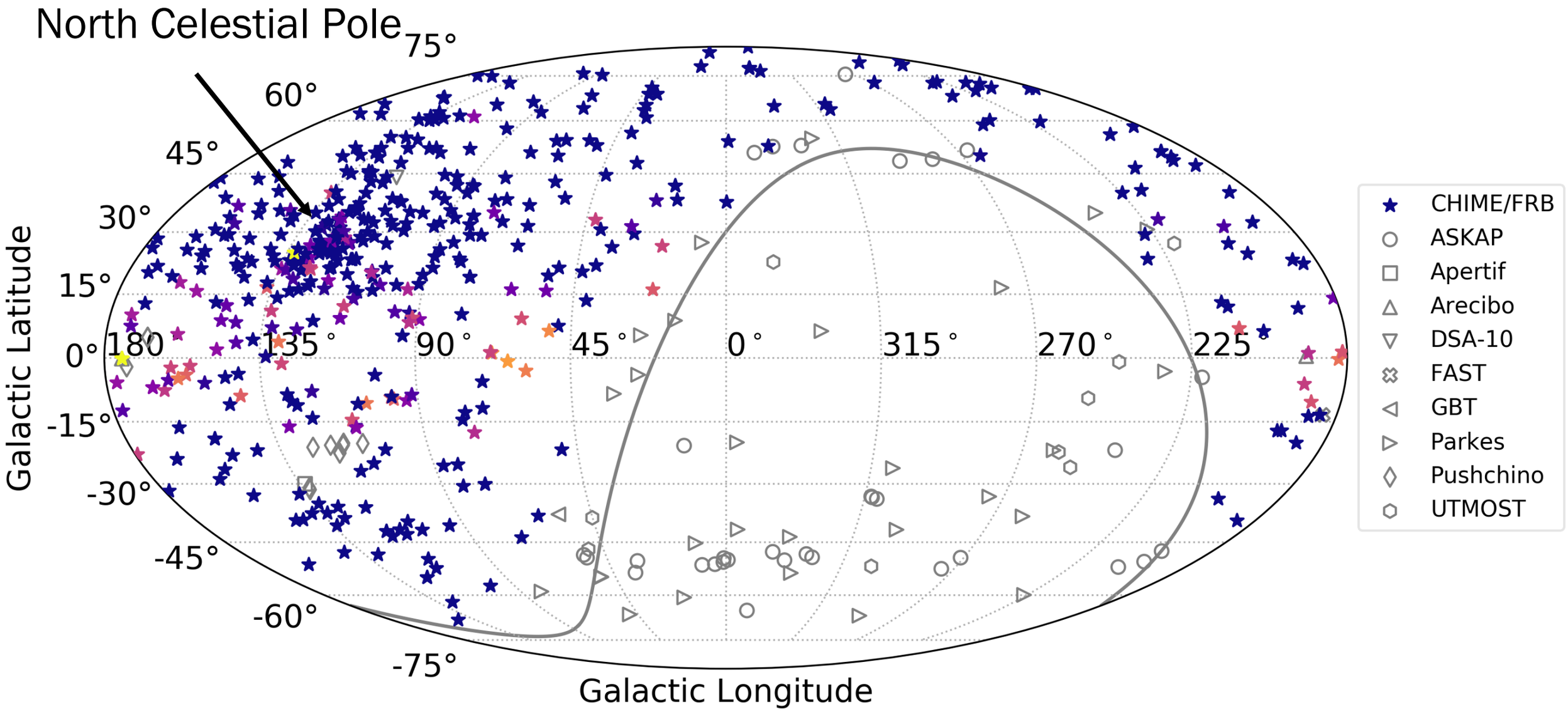
Signal collapsed over 4 East-West beams

Detection of FRBs down to 400 MHz



CHIME/FRB Collaboration, Nature, 2019

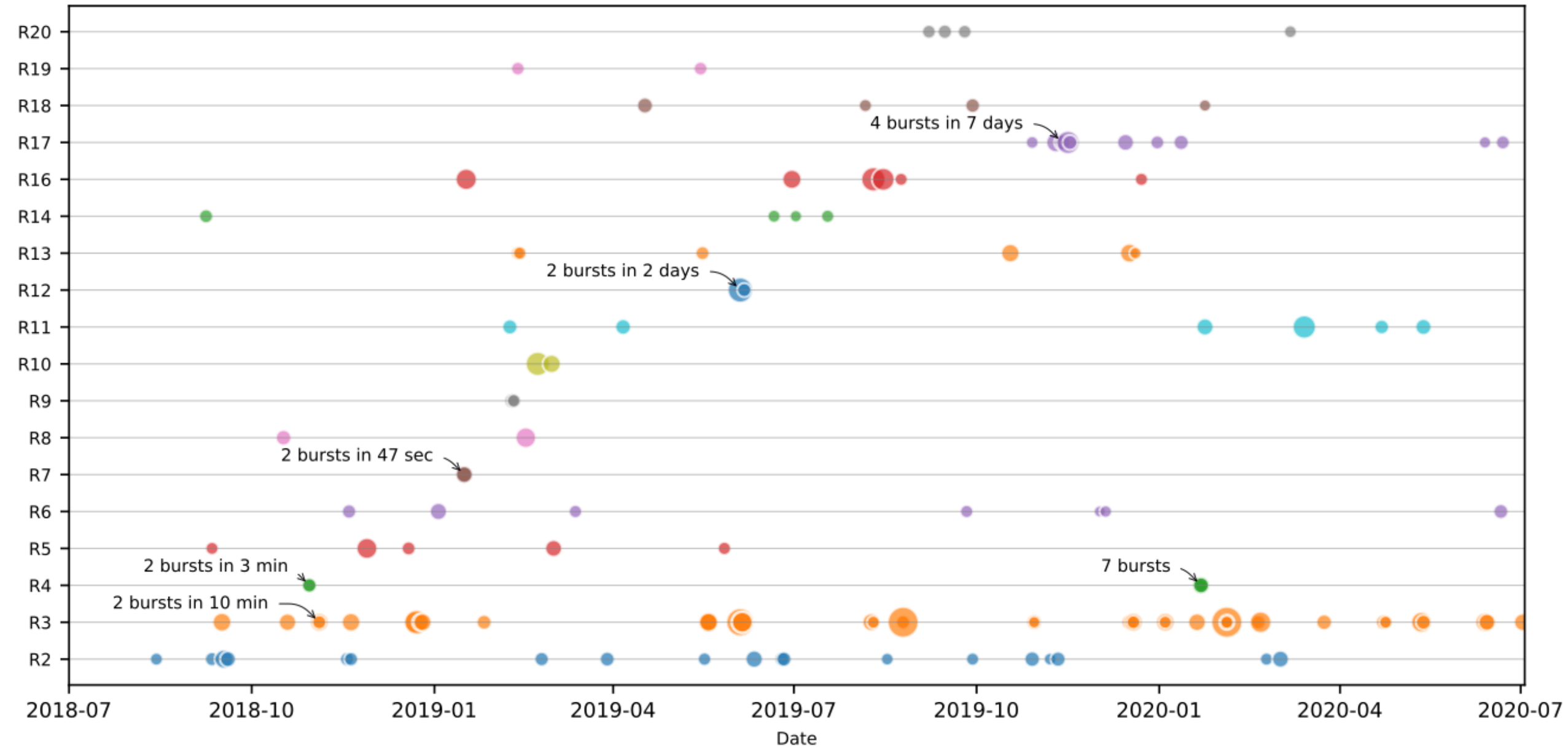
Fast radio bursts 2007–2020



NB not corrected for exposure

2019 — A population of repeating sources

Shriharsh Tendulkar



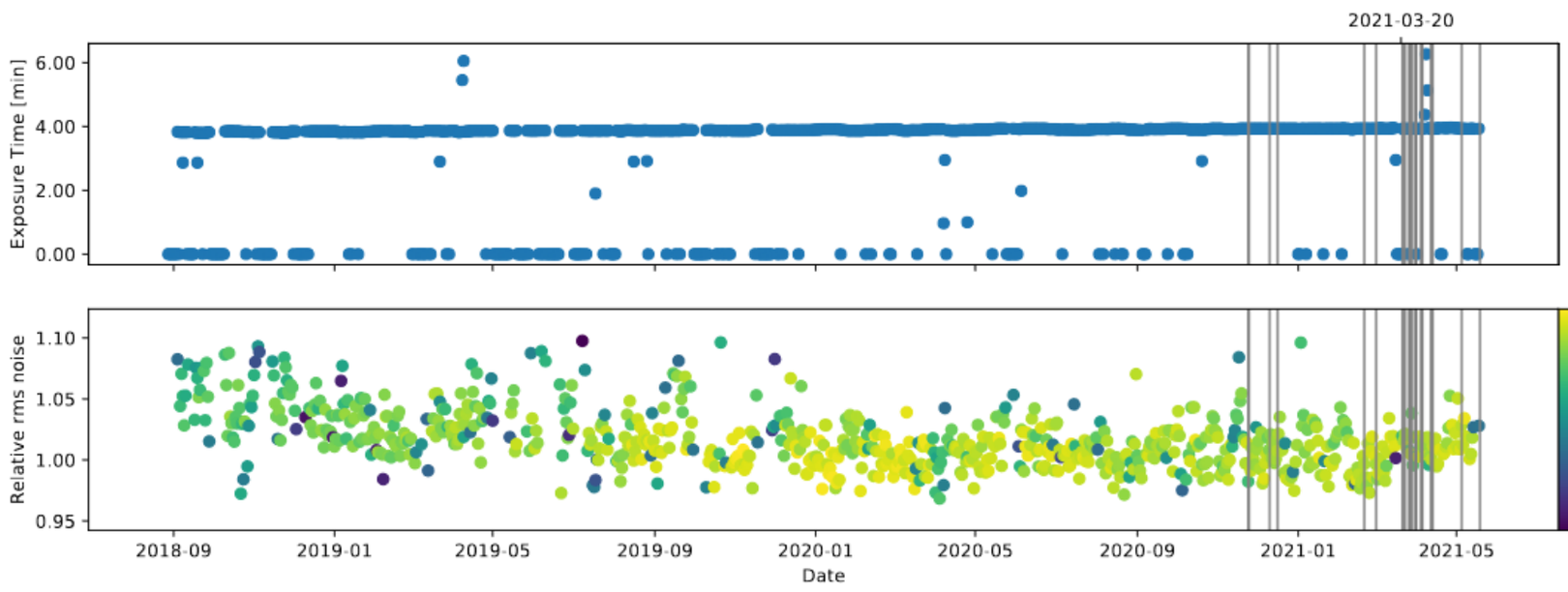
18 new repeating sources of FRBs

CHIME/FRB Collaboration 2019ab, Fonseca+ 2020

2019 — A population of repeating sources

FRB 20201124A

A suddenly highly active repeating source



Lanman+ 2021

2020 — Periodic activity from a repeating source

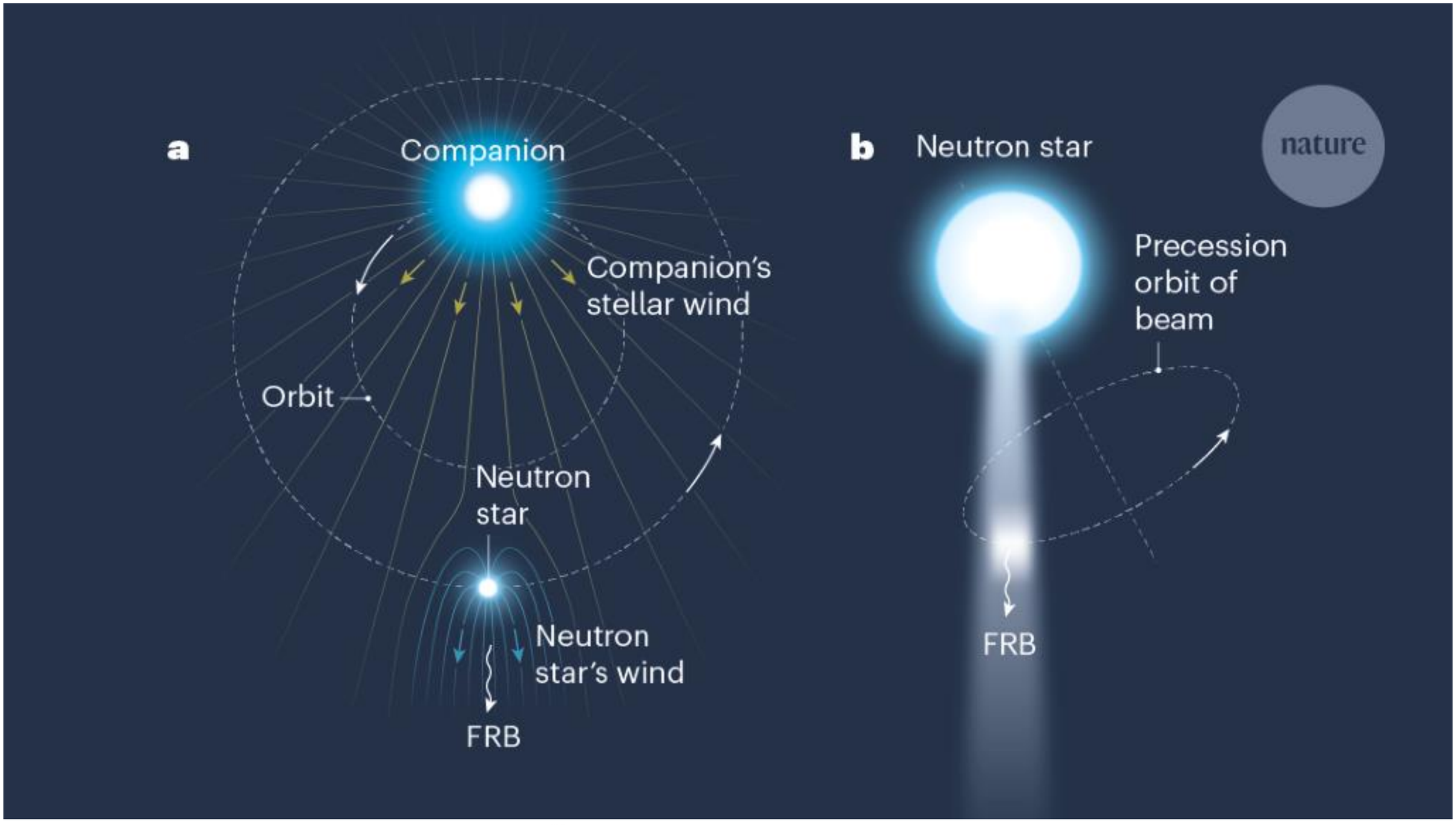
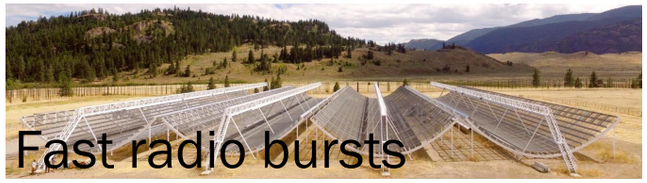


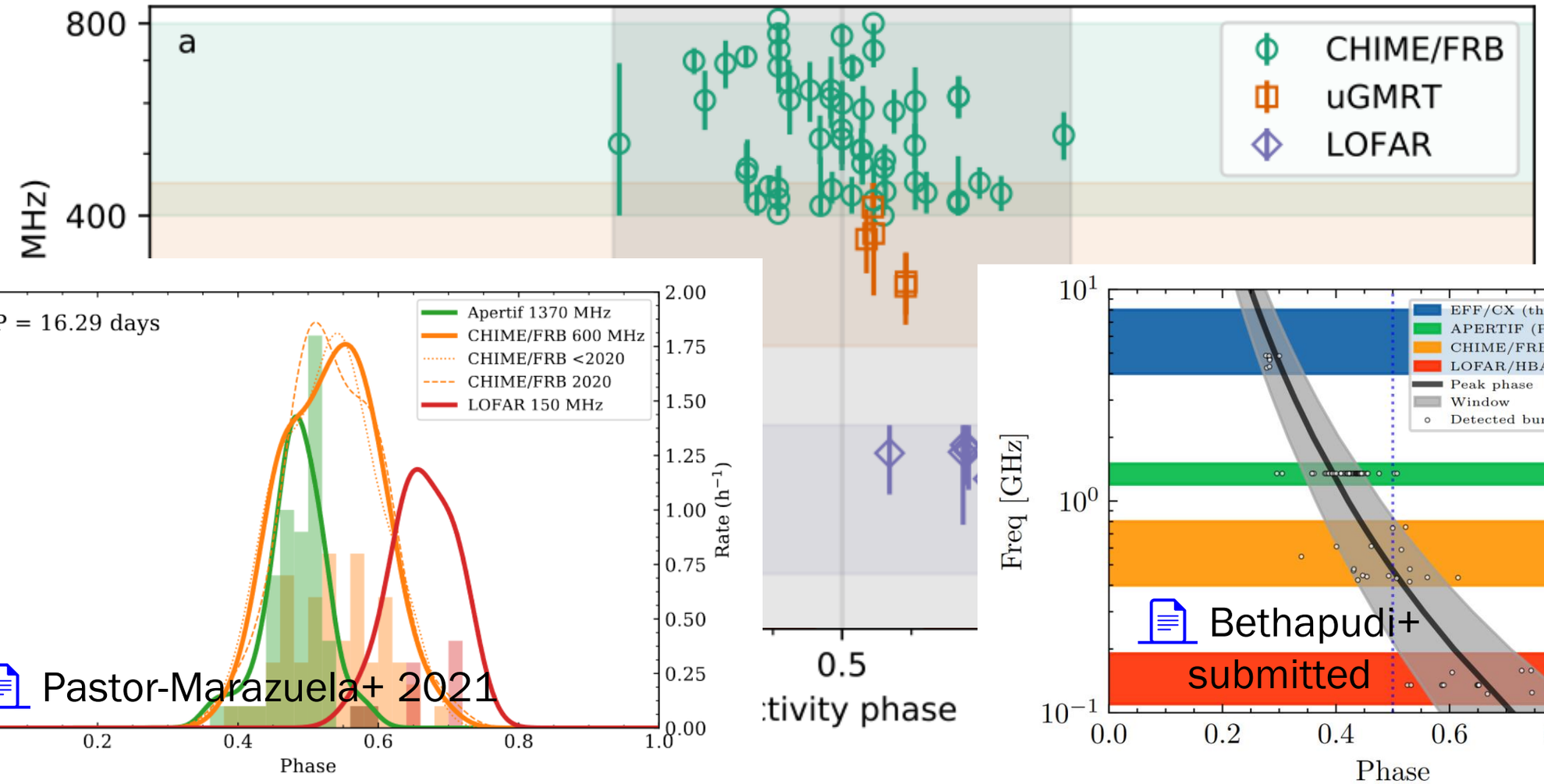
figure out source

- Enables even better follow-up observations



Fast radio bursts

2021 — Chromatic periodic activity from a repeating source



18 LOFAR bursts (purple) systematically delayed w/r/t CHIME/FRB (green): not because of exposure

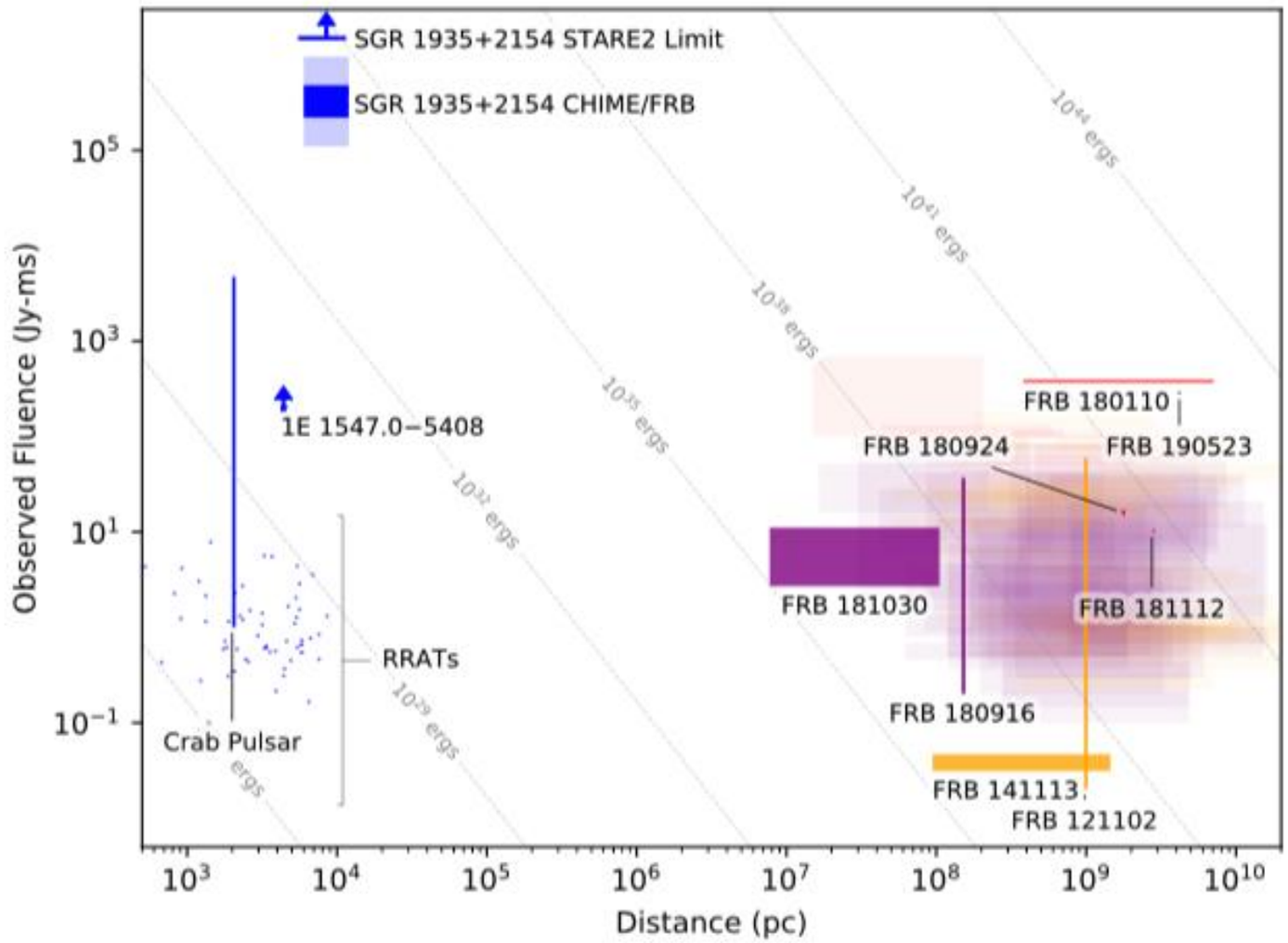
ZP+ 2021a, see also Pastor-Marazuela+ 2021

Bethapudi+ submitted

2020 — FRB-like burst from a Galactic magnetar

- CHIME/FRB Collaboration 2020
- Bochenek et al. 2020

- Very bright burst detected by multiple telescopes
- Bridge between Galactic and extragalactic radio bursts
- Likely that at least some FRBs are also from magnetars



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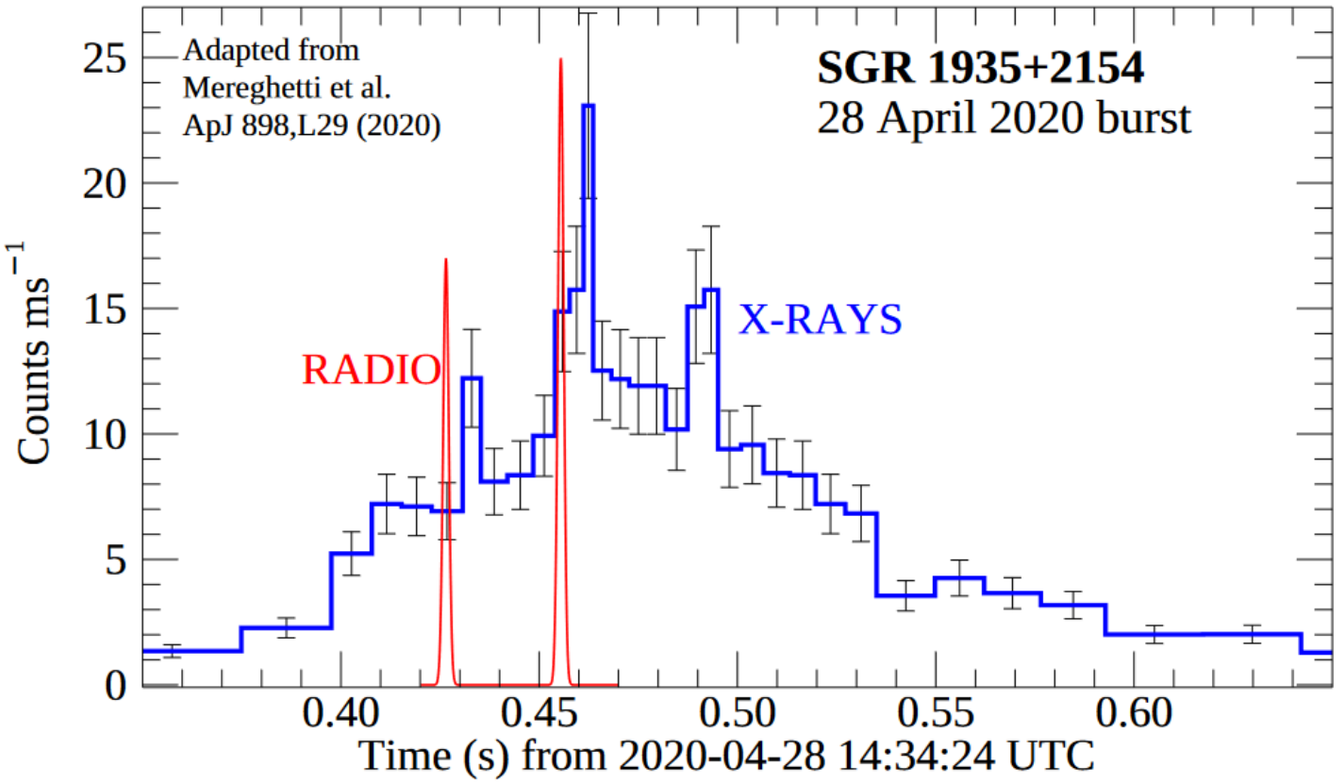
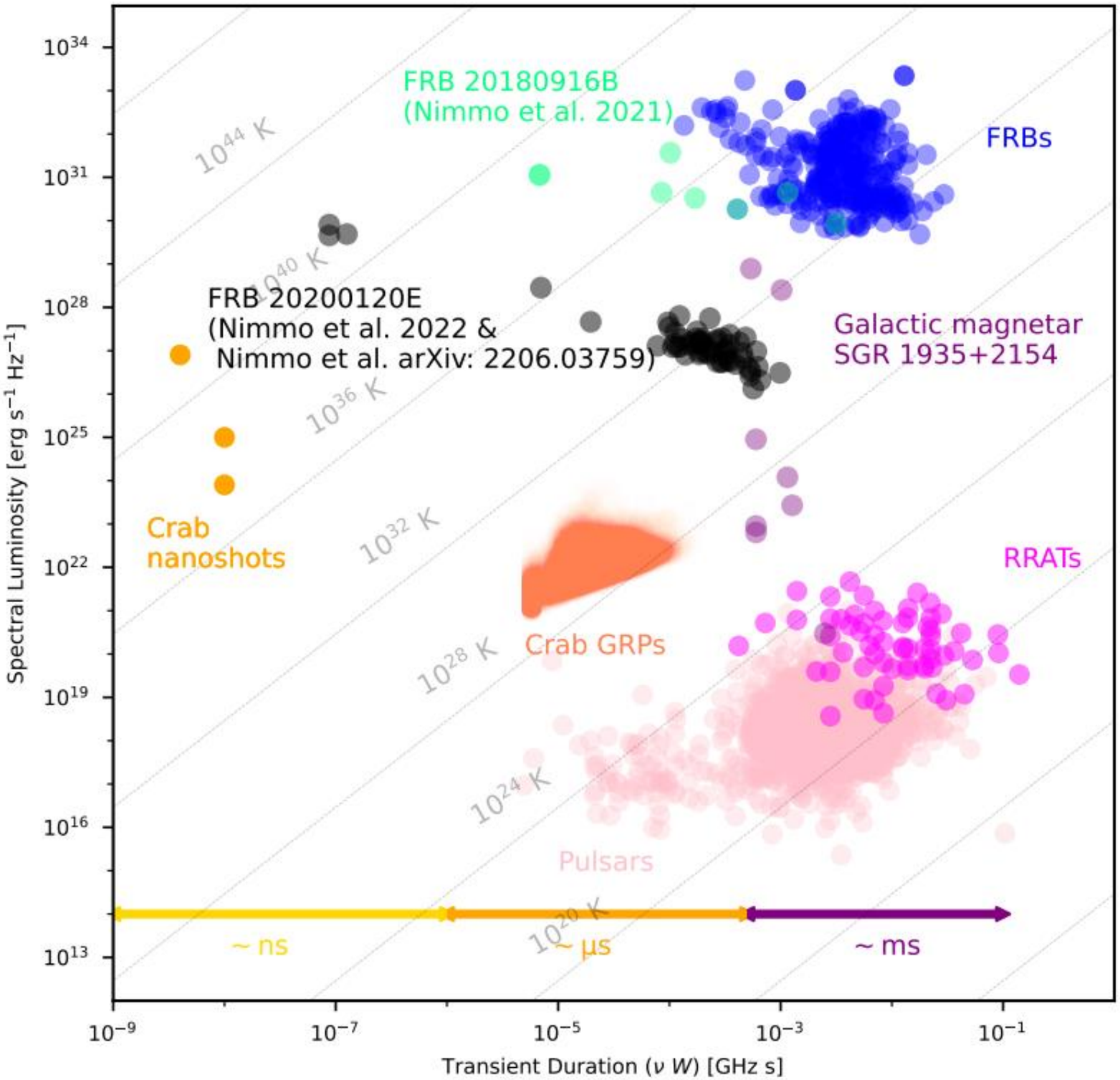
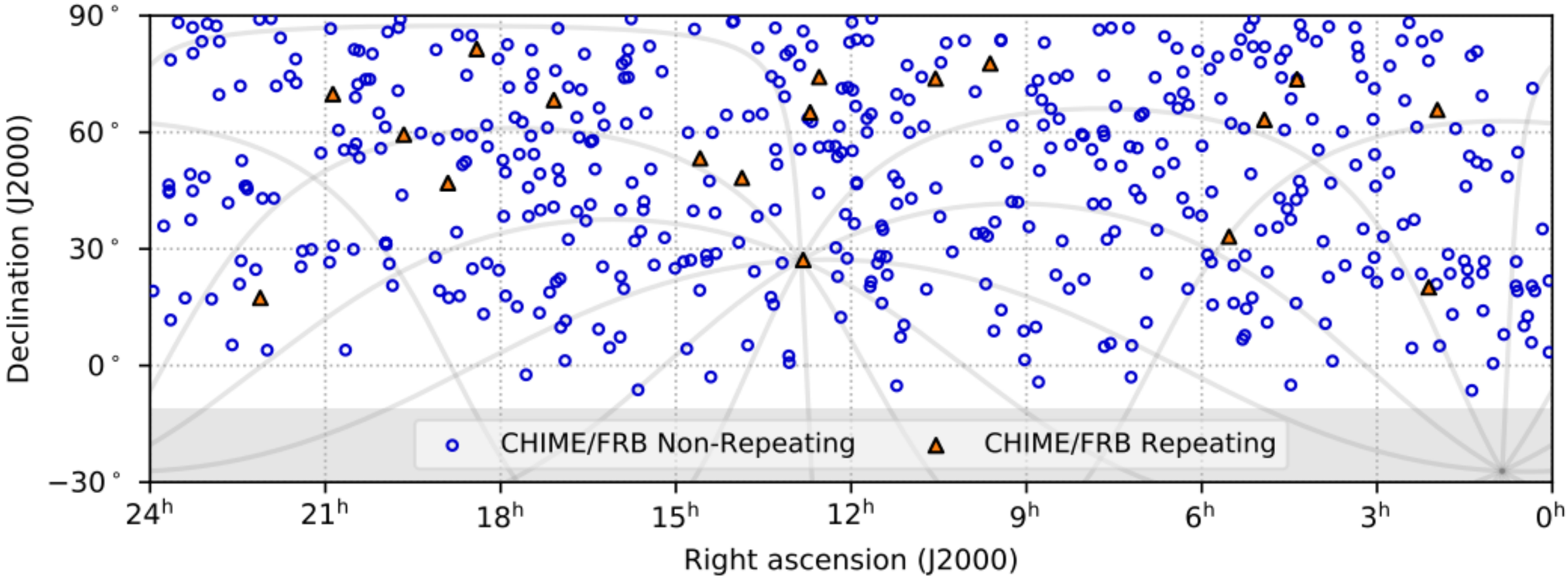


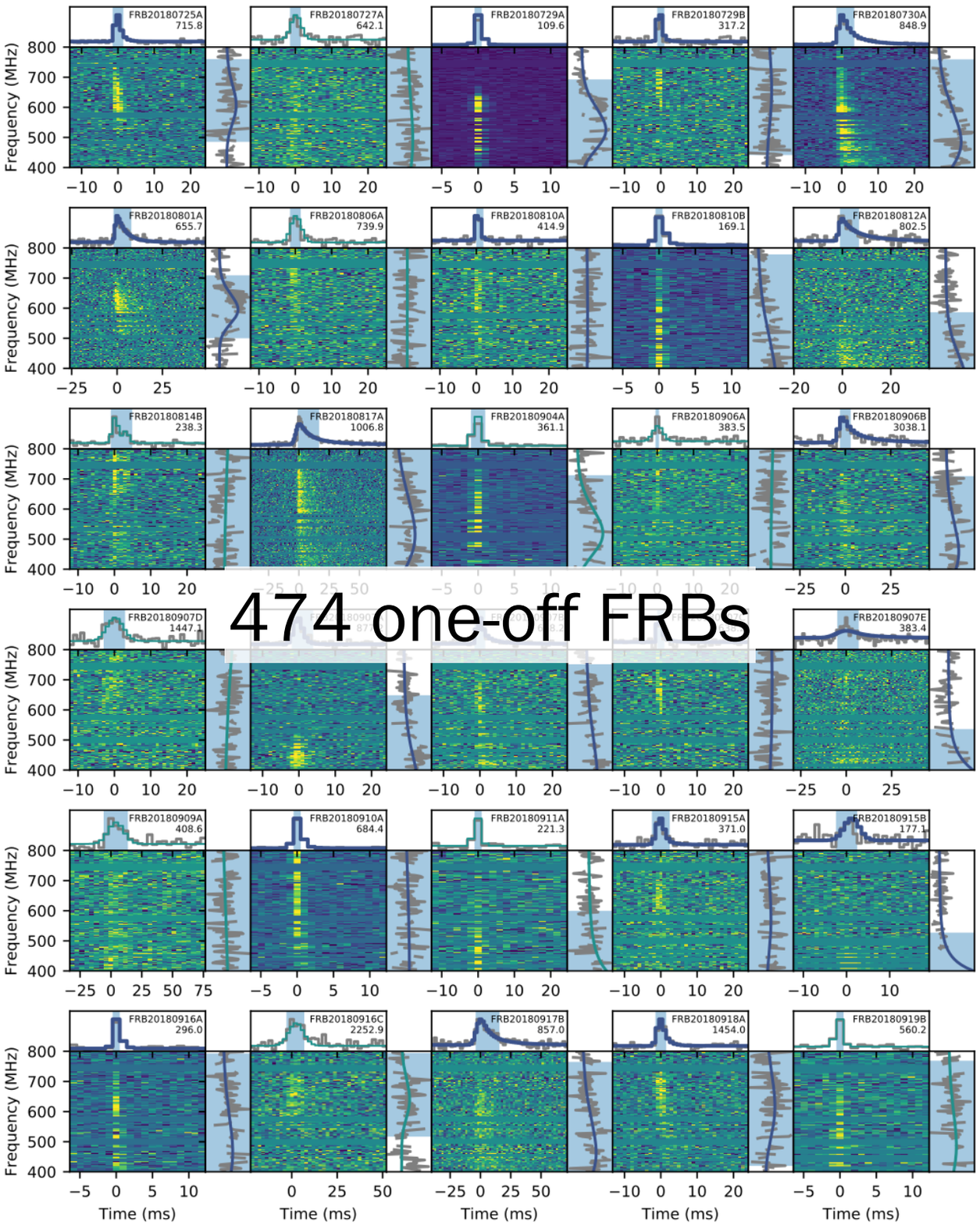
2020—present — Connecting Galactic and extragalactic transients



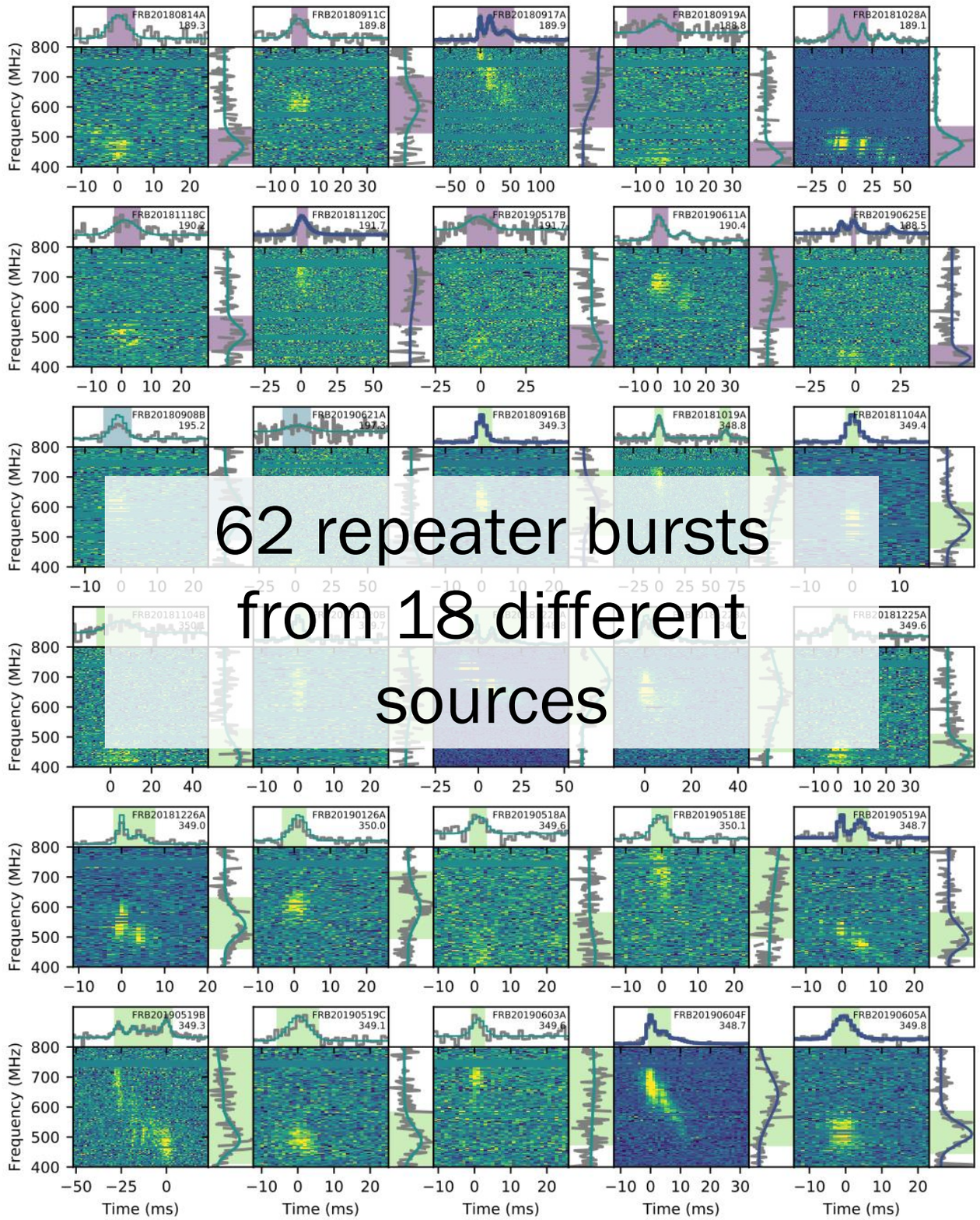
2021 — A population of FRBs



Zoo of FRBs detected with CHIME/FRB



474 one-off FRBs



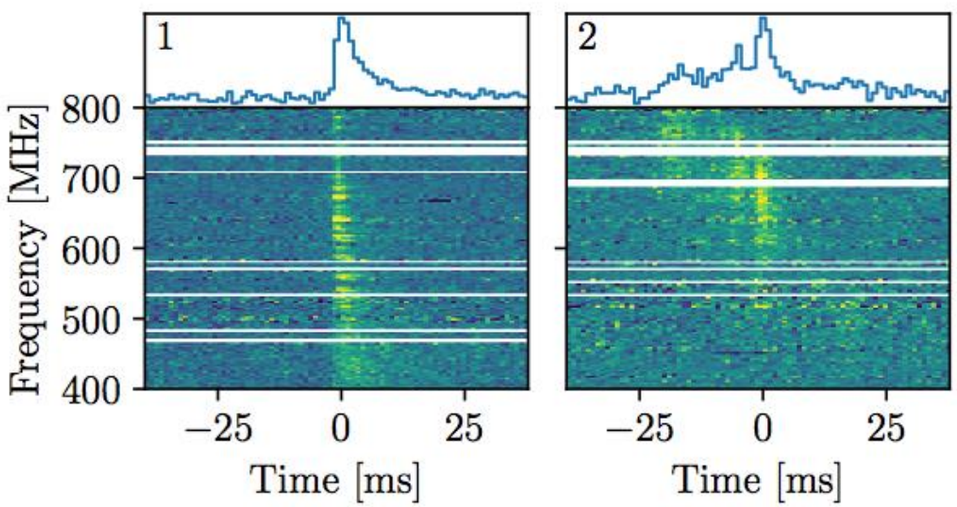
62 repeater bursts

from 18 different sources

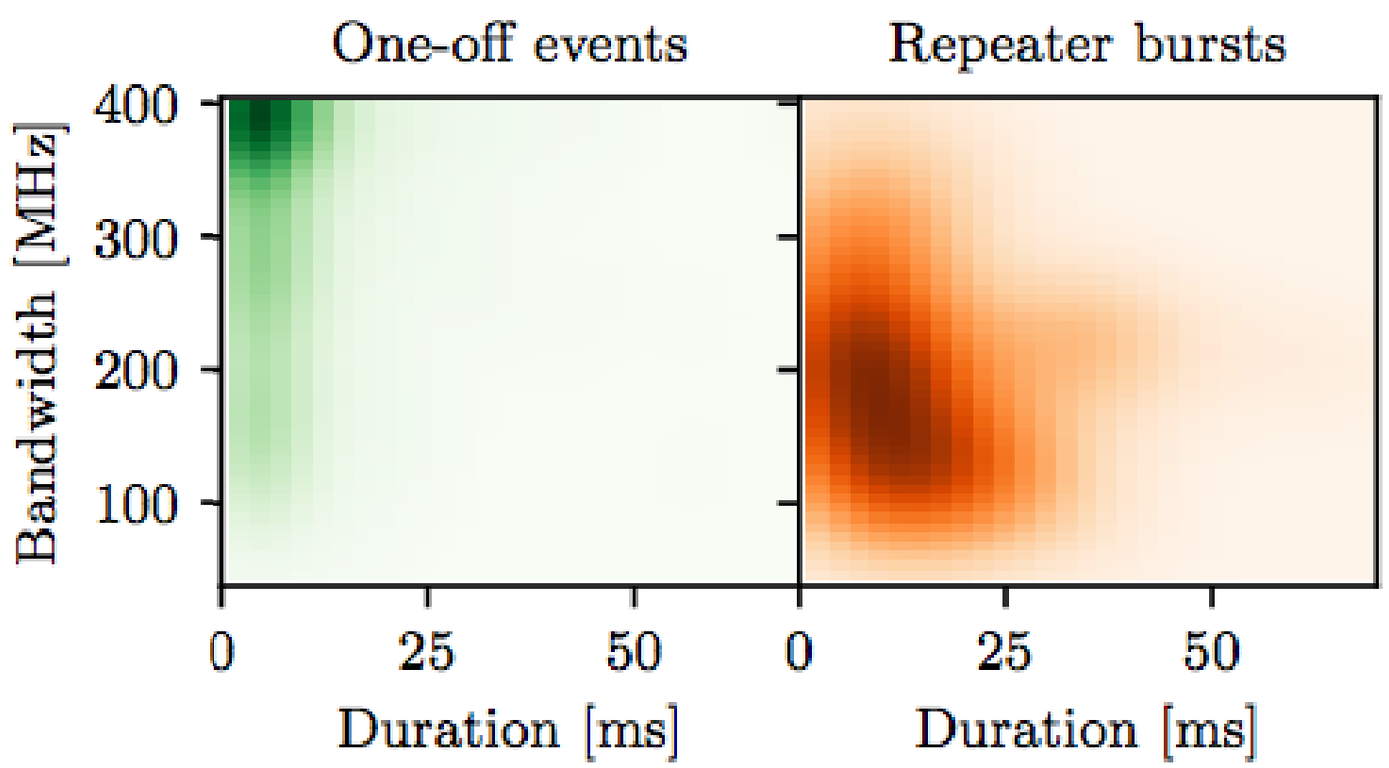
FRB morphology in the first CHIME/FRB catalog

Typical one-off FRB

Typical repeater burst



Repeater bursts on average have longer durations and more narrow bandwidths

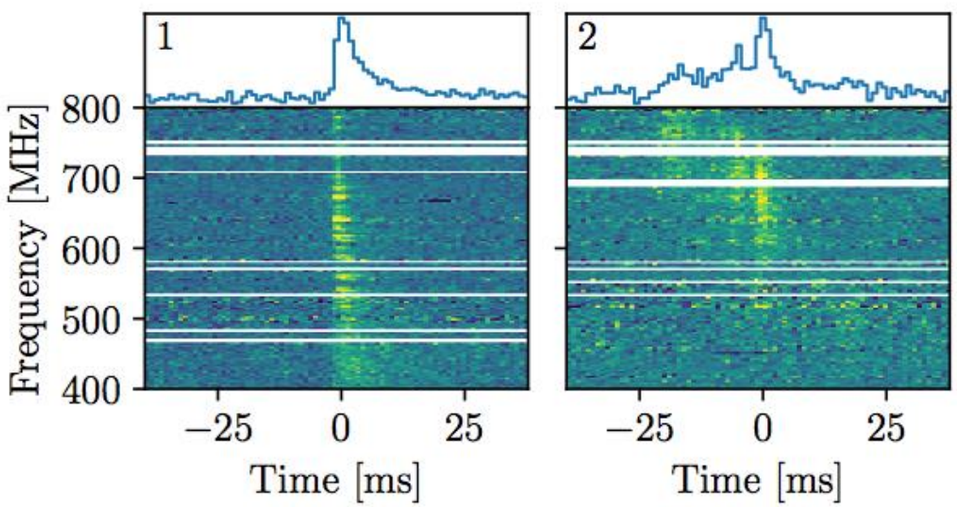


ZP+ 2021b

FRB morphology in the first CHIME/FRB catalog

Typical one-off FRB

Typical repeater burst



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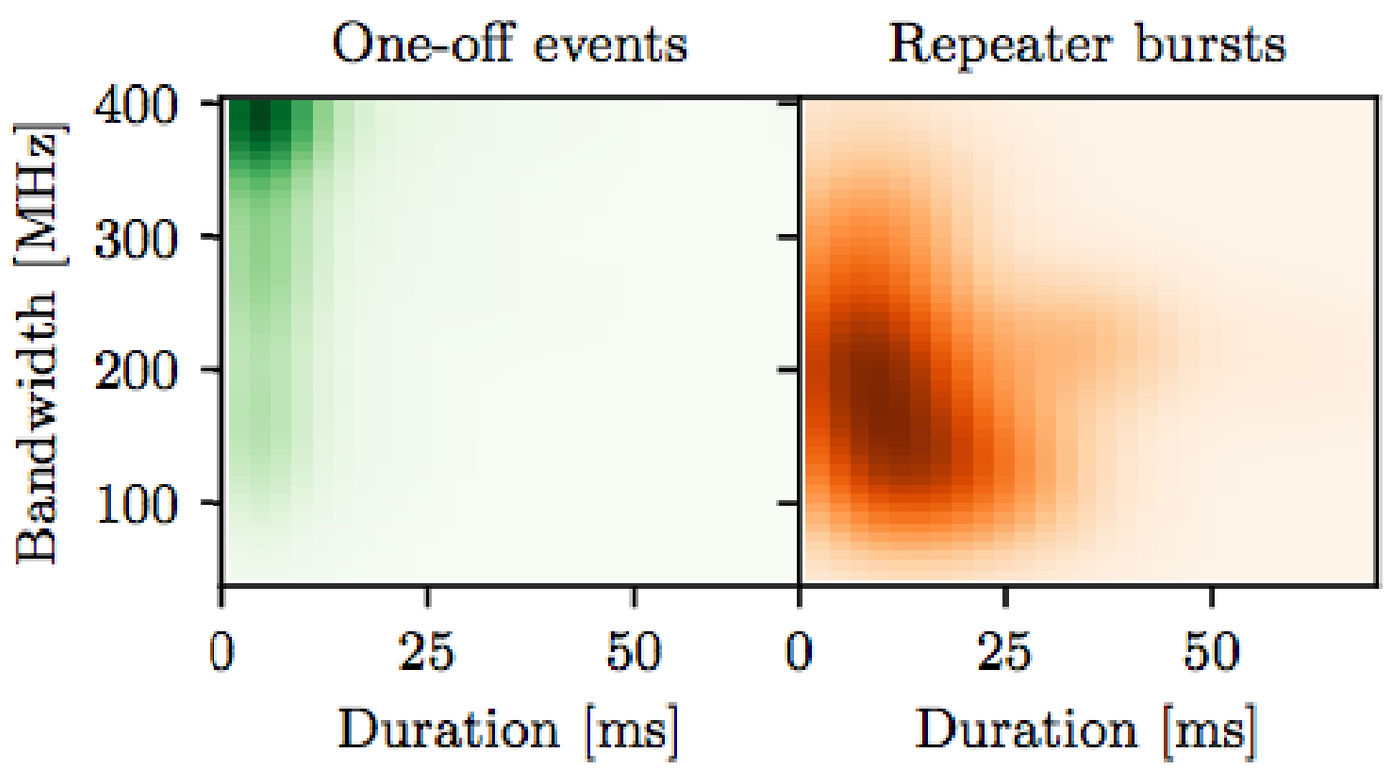
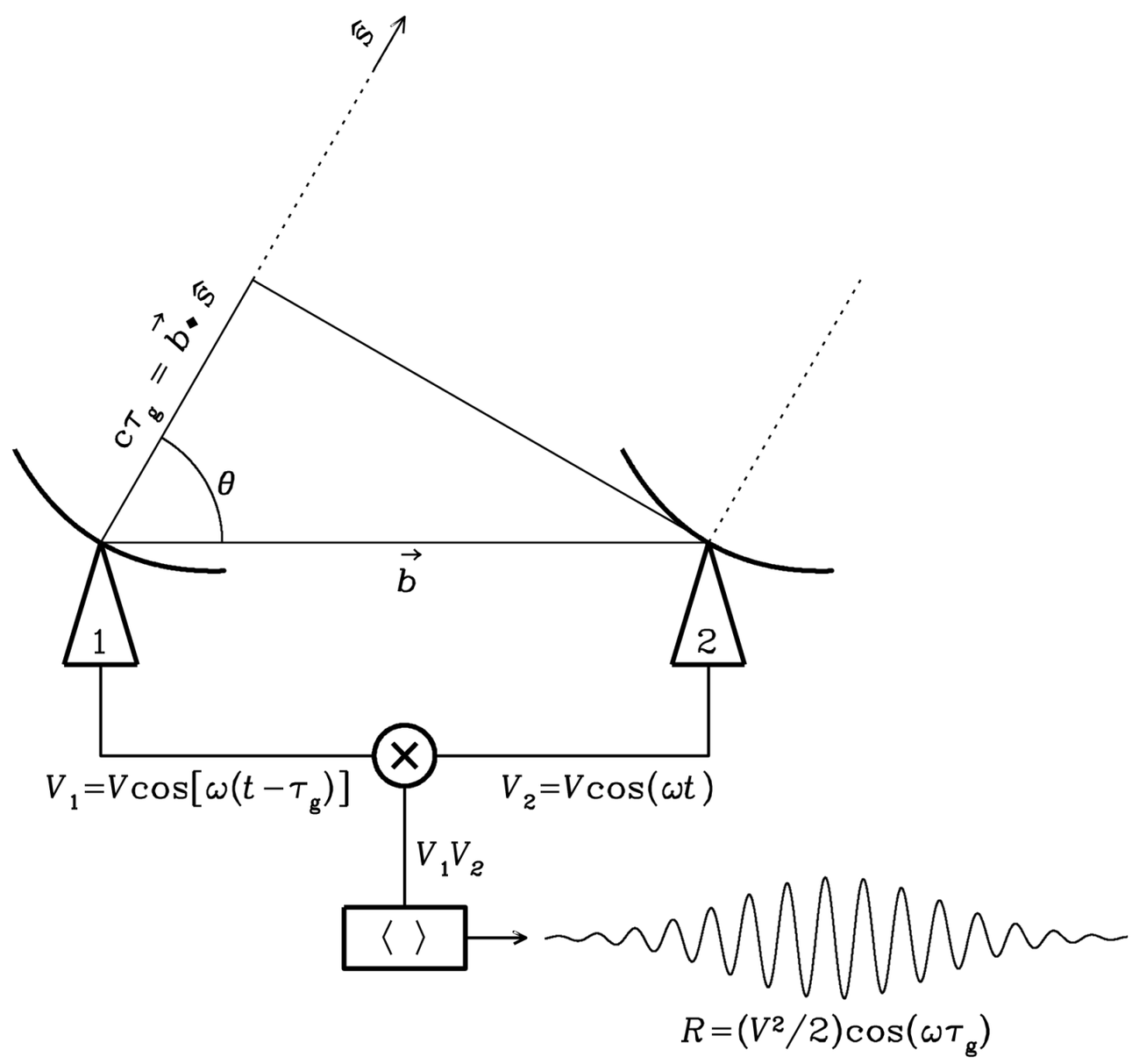


ZP+ 2021b

2017—present — Location, location, location

Telescope resolution scales as $\frac{\text{wavelength}}{\text{diameter}}$, need interferometry!



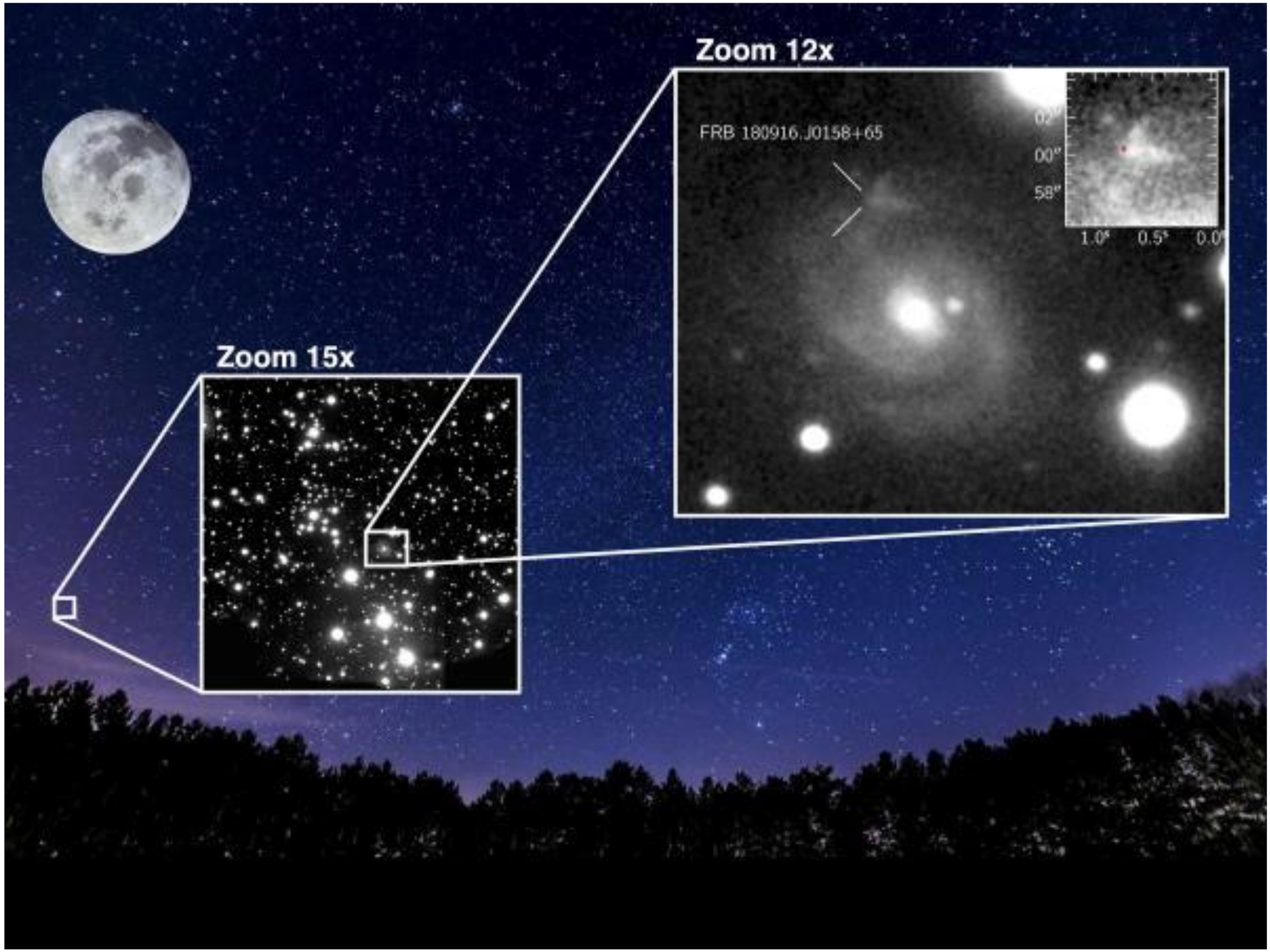
2017—present — Location, location, location

Karl G. Jansky Very Large Array

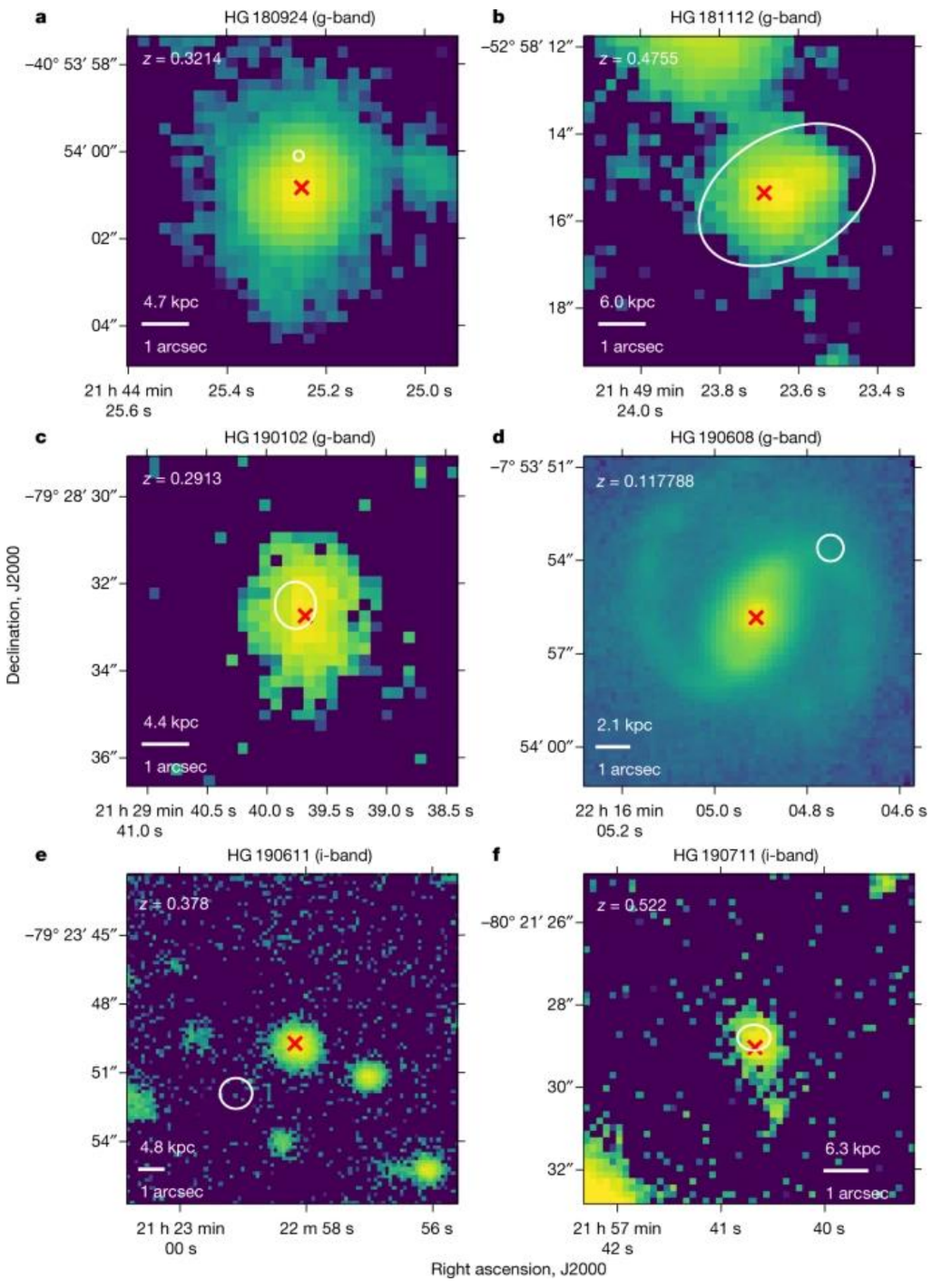
European VLBI Network

Australian SKA Pathfinder

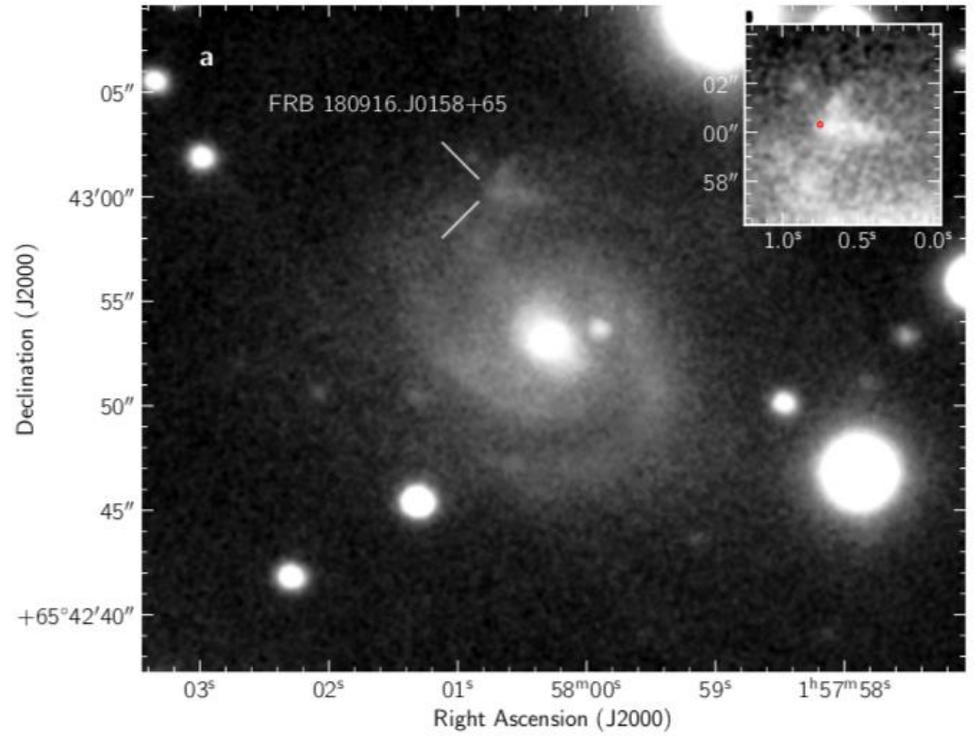
2017—present — Location, location, location



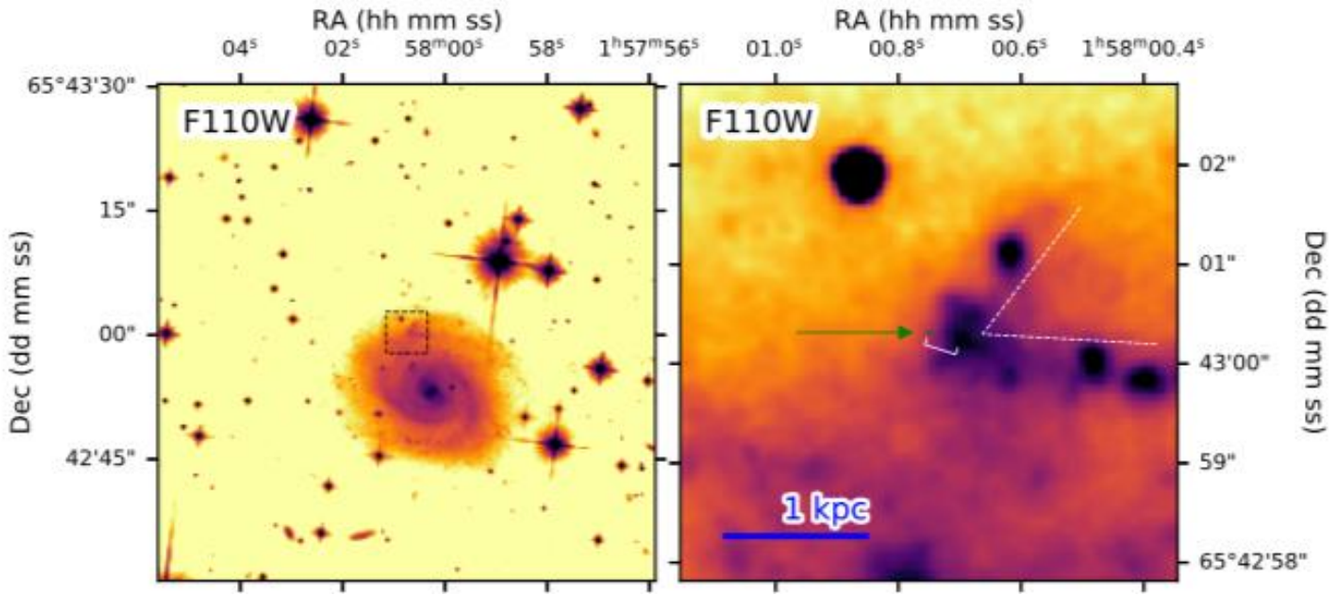
2017—present — Location, location, location



Macquart et al. 2020



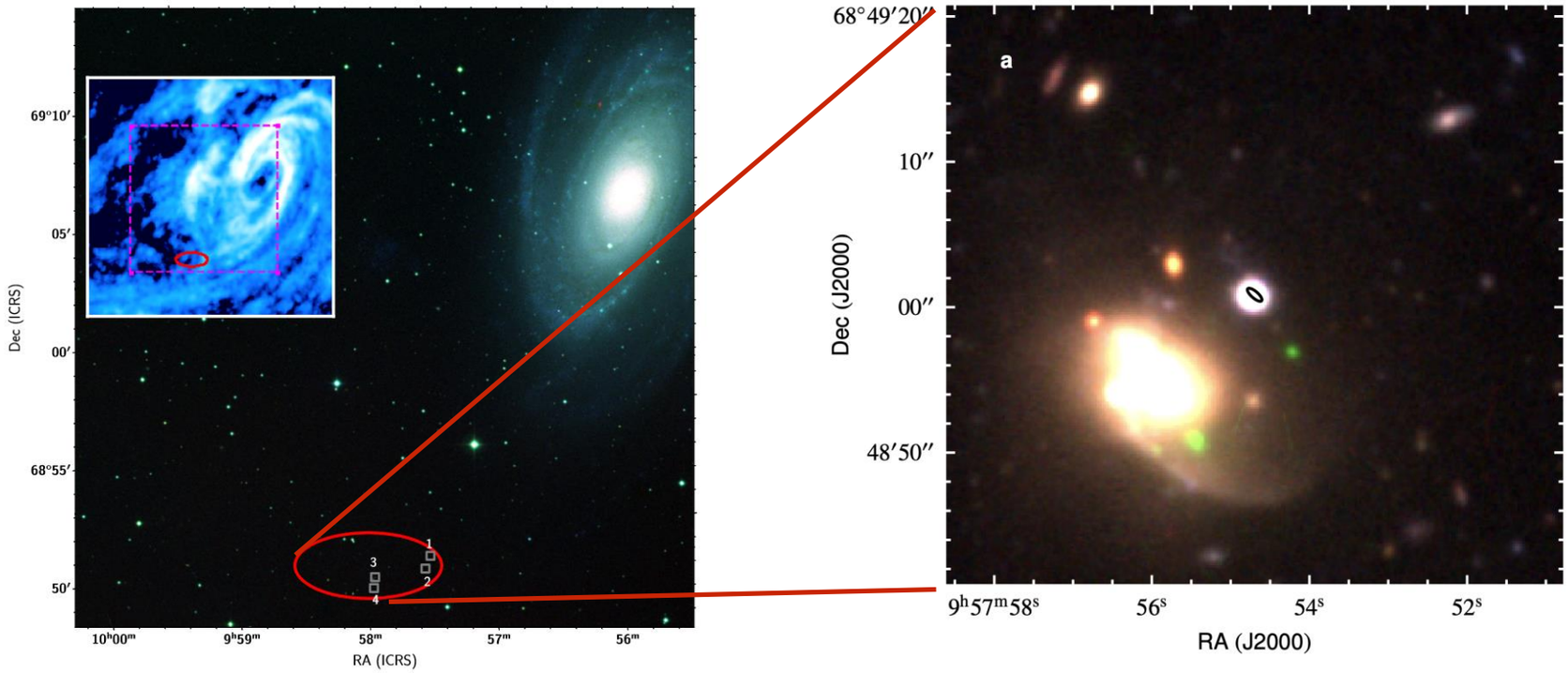
Marcote et al. 2020



Tendulkar et al. 2021

2017—present — Location, location, location

FRB 20200120E
A repeating source localized to a globular cluster associated with M81



Q What does this tell us about possible progenitors?

Bhardwaj+ 2021, Kirsten+ 2022

The origin(s) of FRBs

Do all FRBs repeat? Are there multiple classes of (repeating) FRBs?

Progenitor?

- Neutron star?
- Black hole?
- Something exotic?

Energy source?

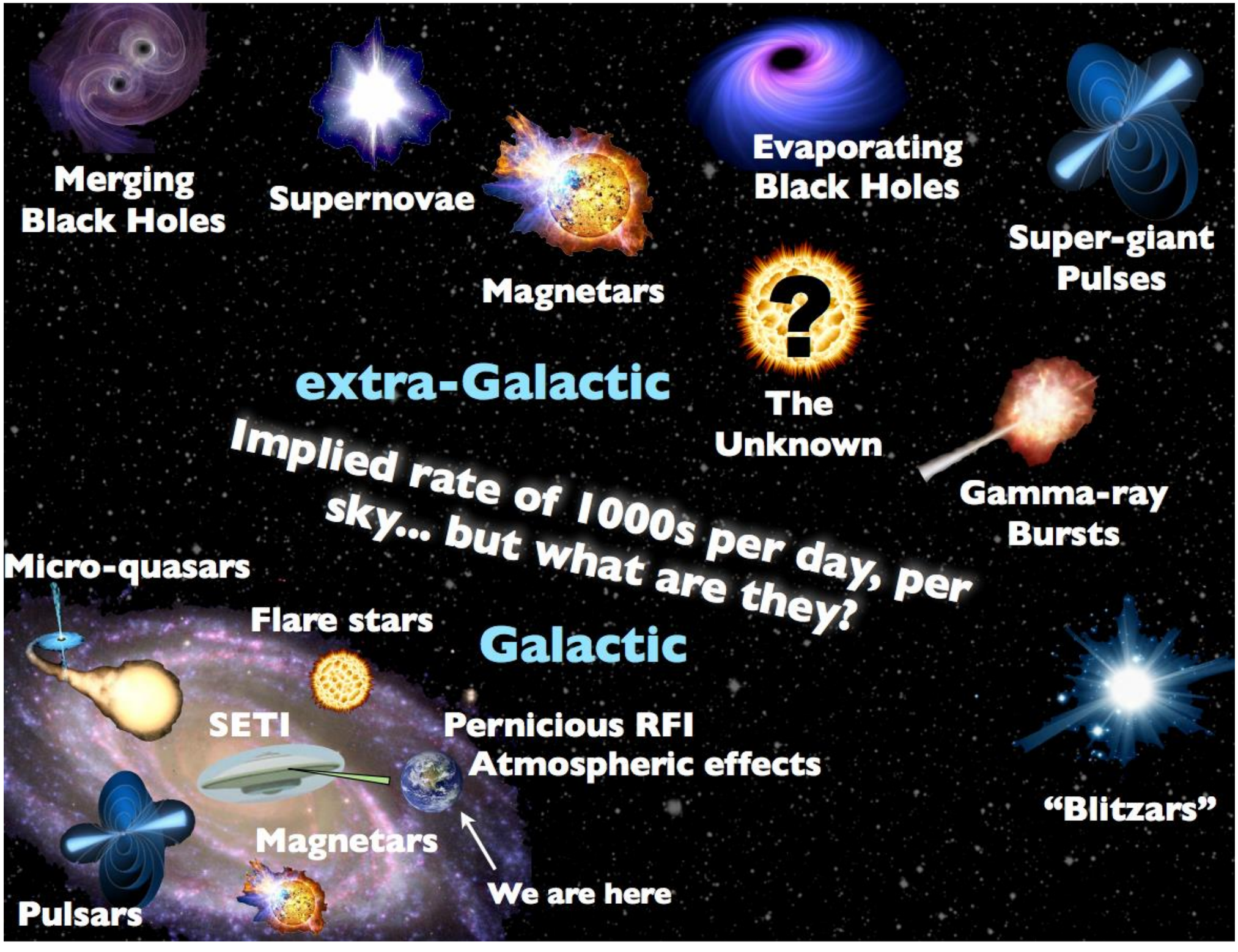
- Rotation?
- Magnetic field?
- Interaction?

Formation channel?

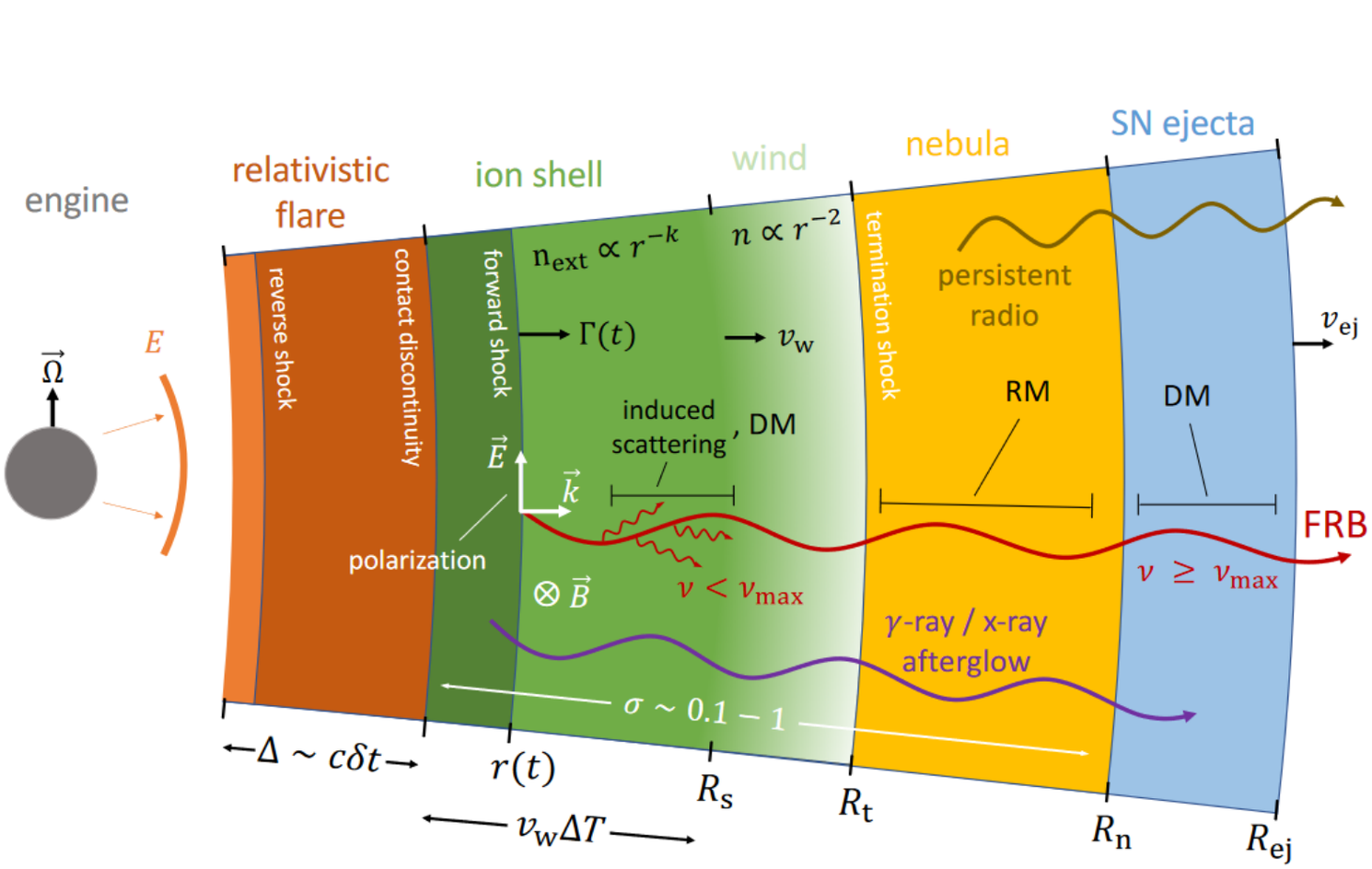
Emission mechanism?

- Maser instabilities?
- Curvature radiation?

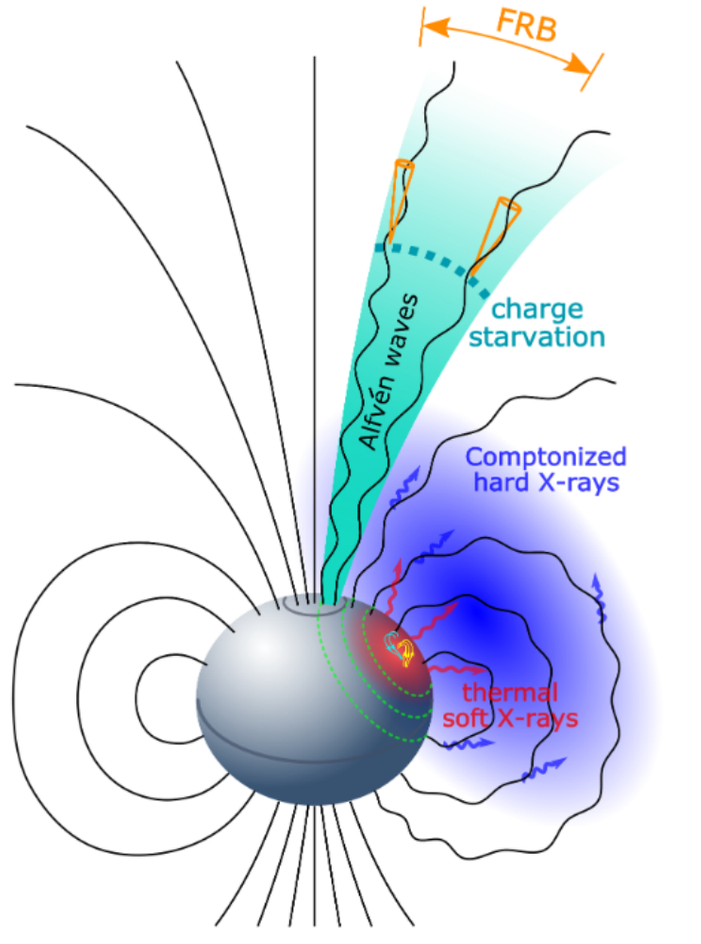
The origin(s) of FRBs



The origin(s) of FRBs



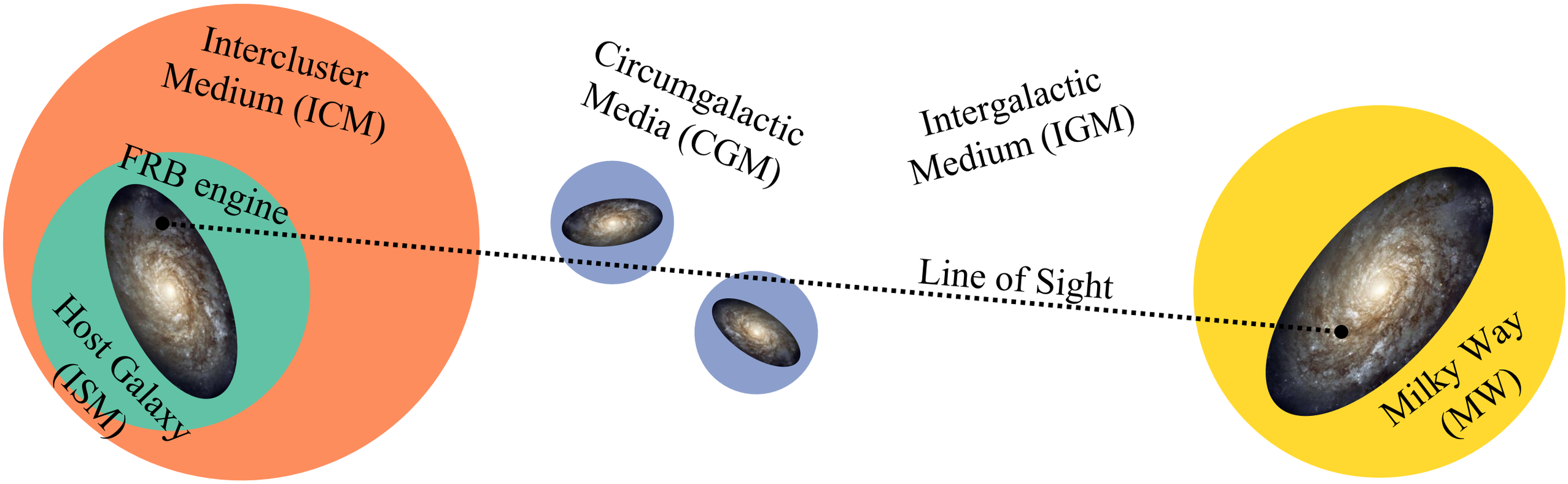
(a) Shock models



(b) Magnetospheric models

Fig. 10 Different models of FRB emission. (a) Shock model from Metzger et al. (2019) where the FRB is produced at large (10^{10} cm) radii from the compact central engine (e.g., a magnetar or black hole). (b) Magnetospheric model from Lu et al. (2020) where the FRB is produced in the neutron star magnetosphere.

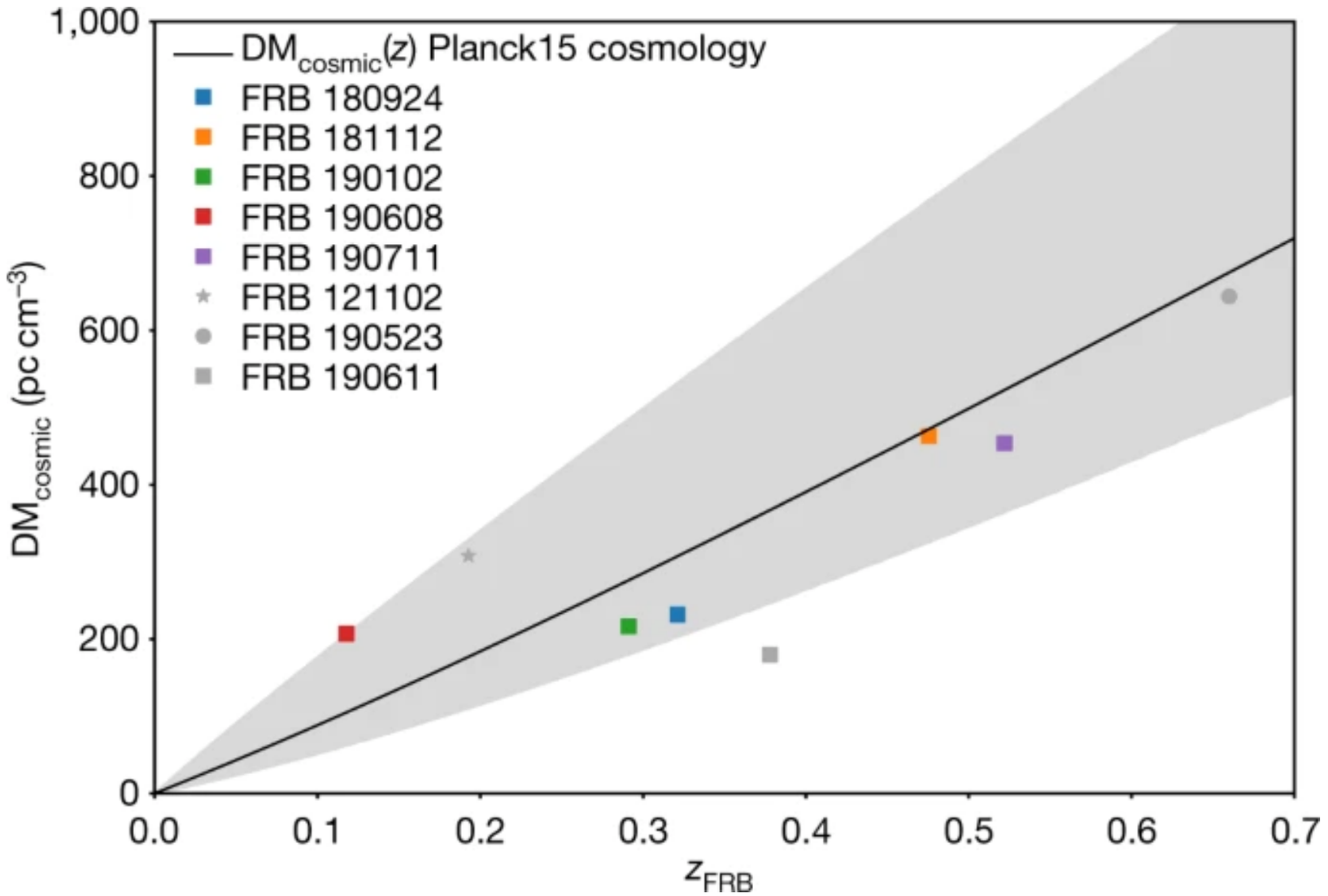
Using FRBs as probes of the unseen Universe



$$\mathrm{DM_{obs}} = \mathrm{DM_{engine}}(z) + \mathrm{DM_{ISM}}(z) + \mathrm{DM_{ICM}}(z) + \sum \mathrm{DM_{CGM}}(z_i) + \int \mathrm{DM_{IGM}}\mathrm{dz} + \mathrm{DM_{MW,halo}} + \mathrm{DM_{MW}}$$

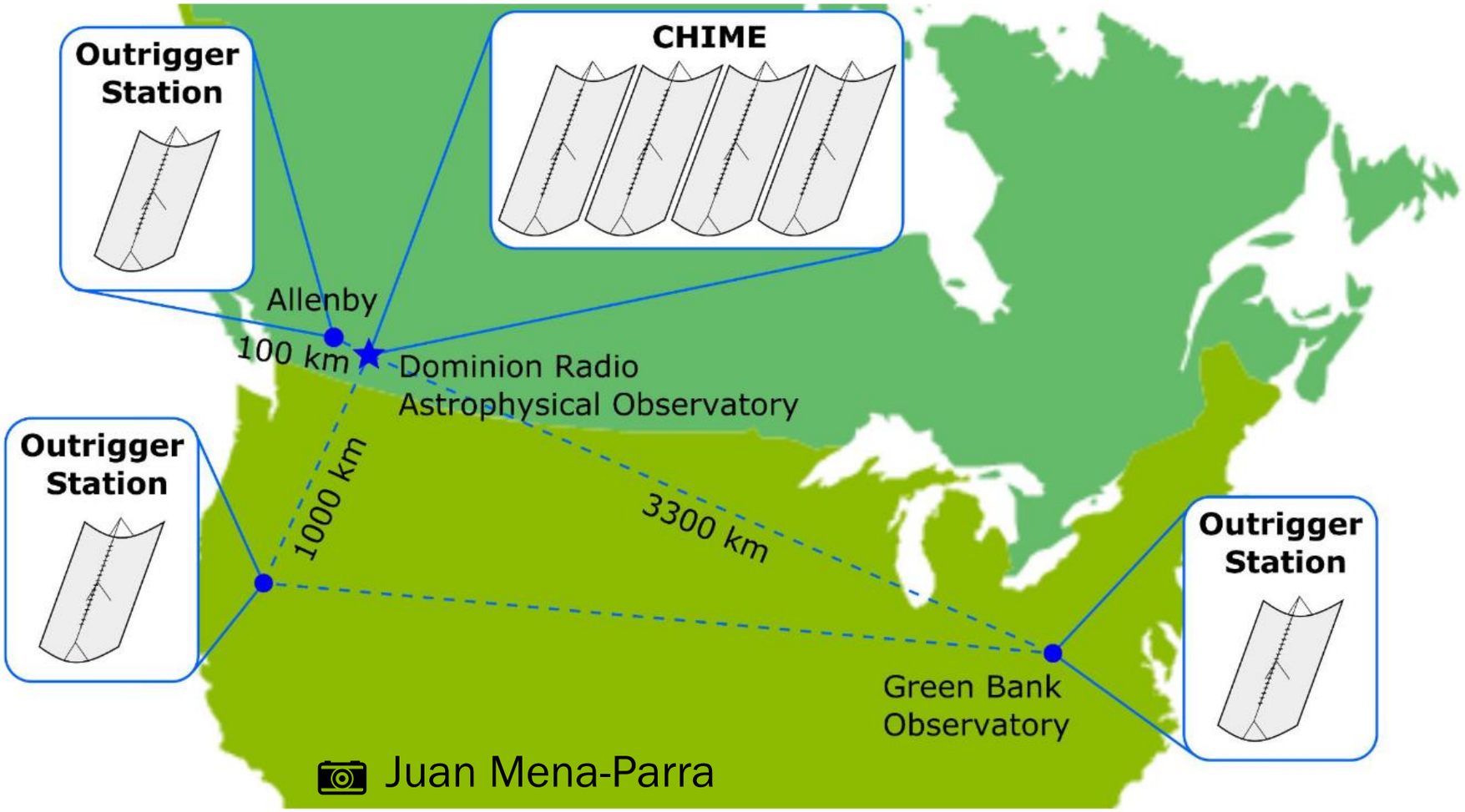
2020 — Finding the “missing” baryons

Macquart et al. 2020



- Half of the matter in the Universe was never directly detected
- From DMs and redshifts can measure the density of free electrons in the intergalactic medium

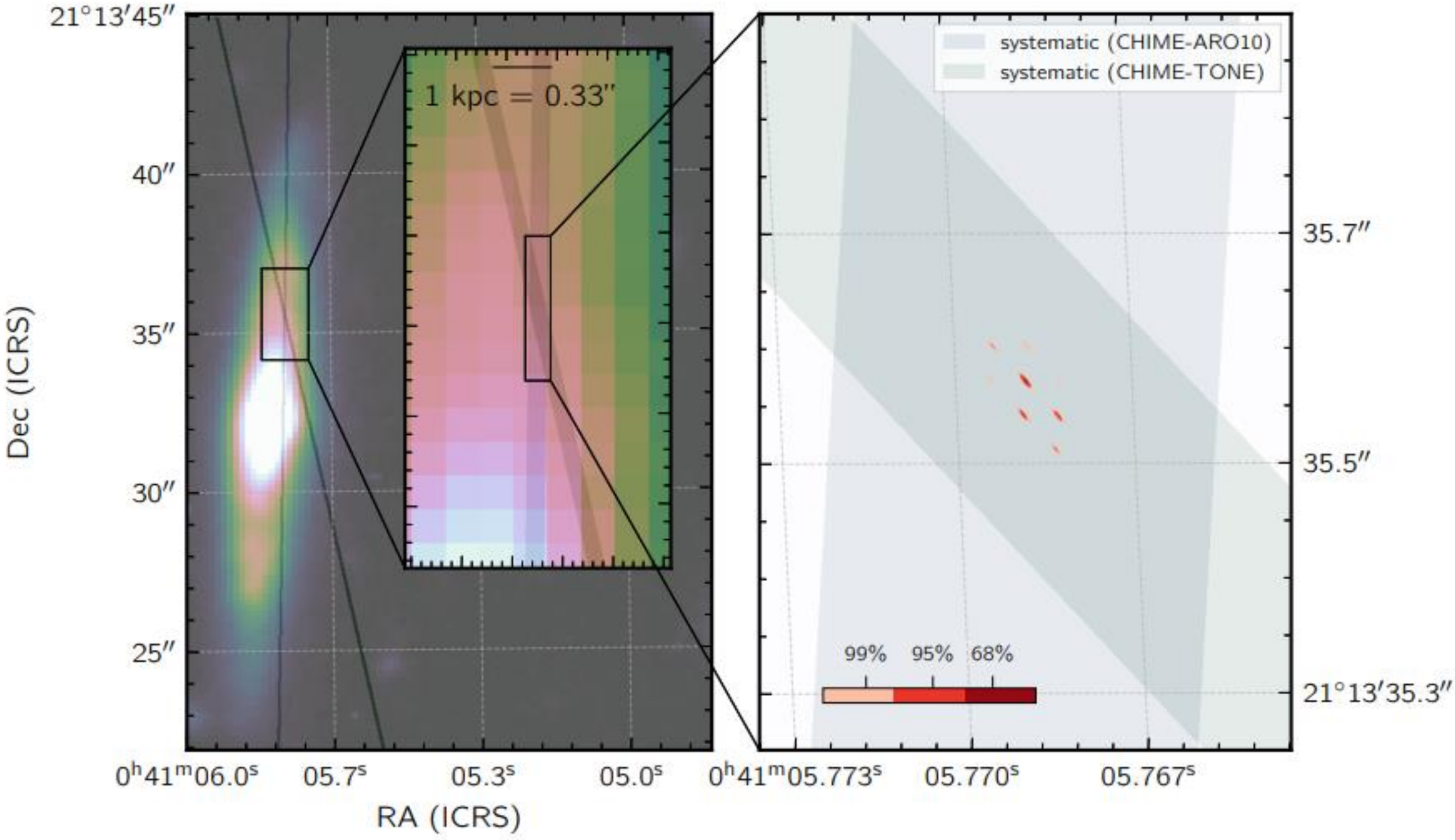
CHIME/FRB Outriggers



- Pinpointing all FRBs detected by CHIME/FRB to subarcsecond precision
- Allows for association within host galaxy and redshift determination

See, e.g., Leung+ 2021, Cassanelli+ 2021

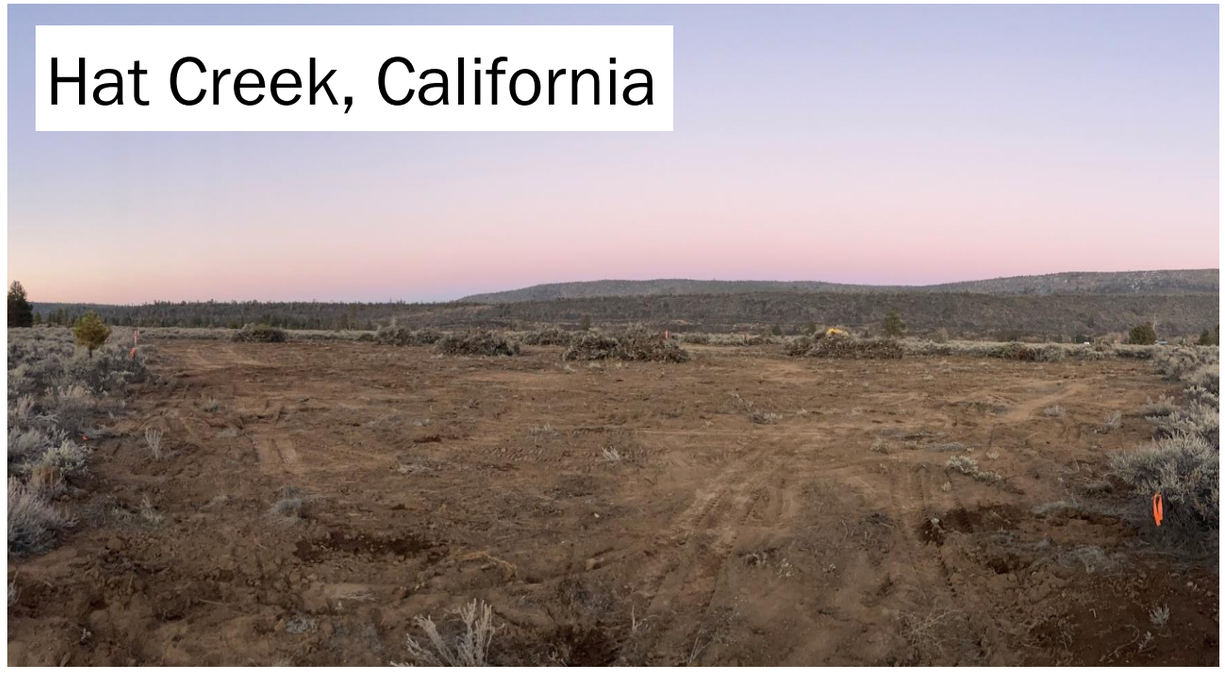
An FRB localized at detection to an edge-on galaxy using VLBI



Two baselines providing a localization ~< 51 mas to galaxy at z ~ 0.177

Cassanelli, Leung, Sanghavi+ submitted

Outriggers status



📷 CHIME/FRB Collaboration, Jane Kaczmarek, Andrew Seymour, Jojo Boyle

Catching nearby FRBs

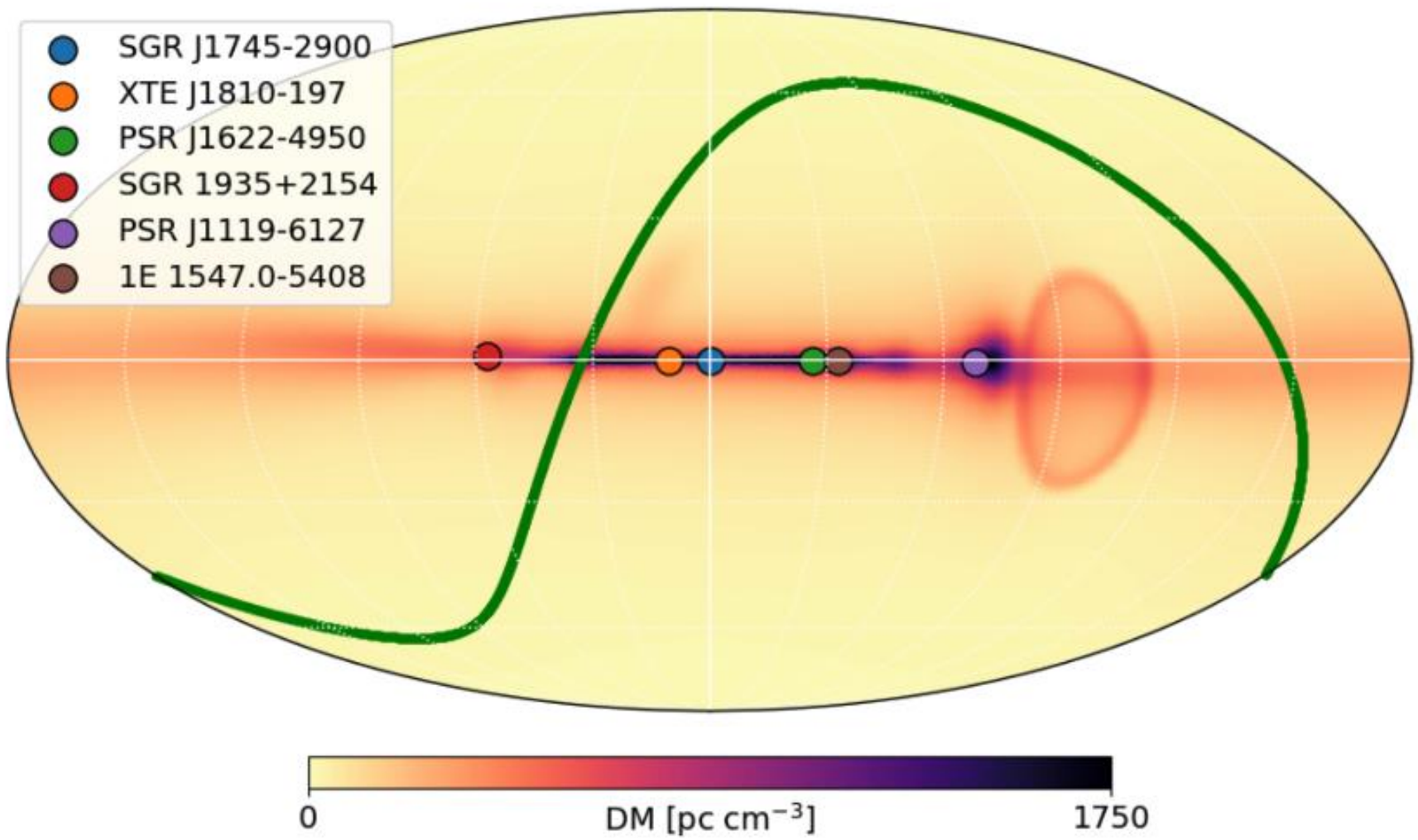
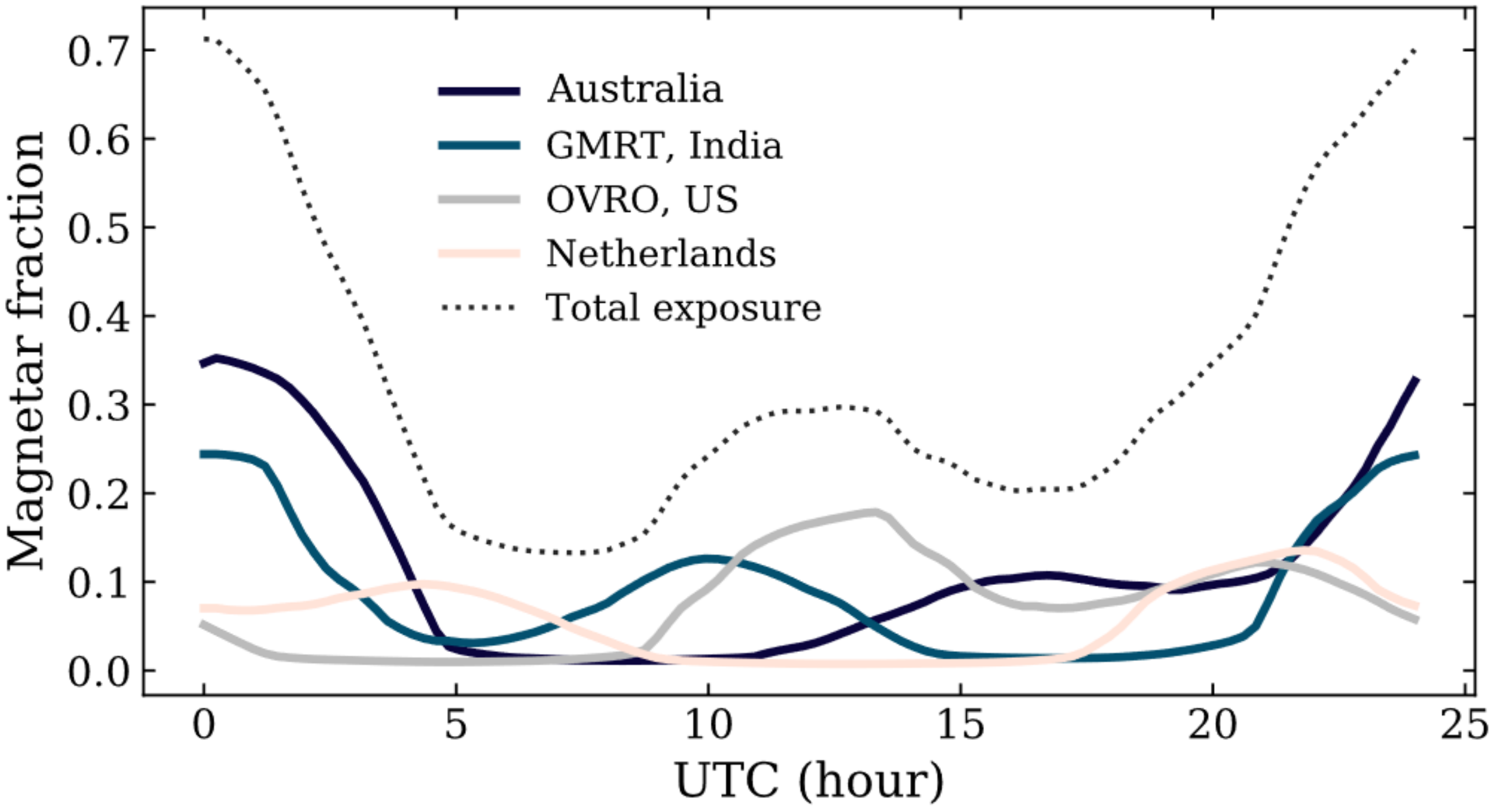


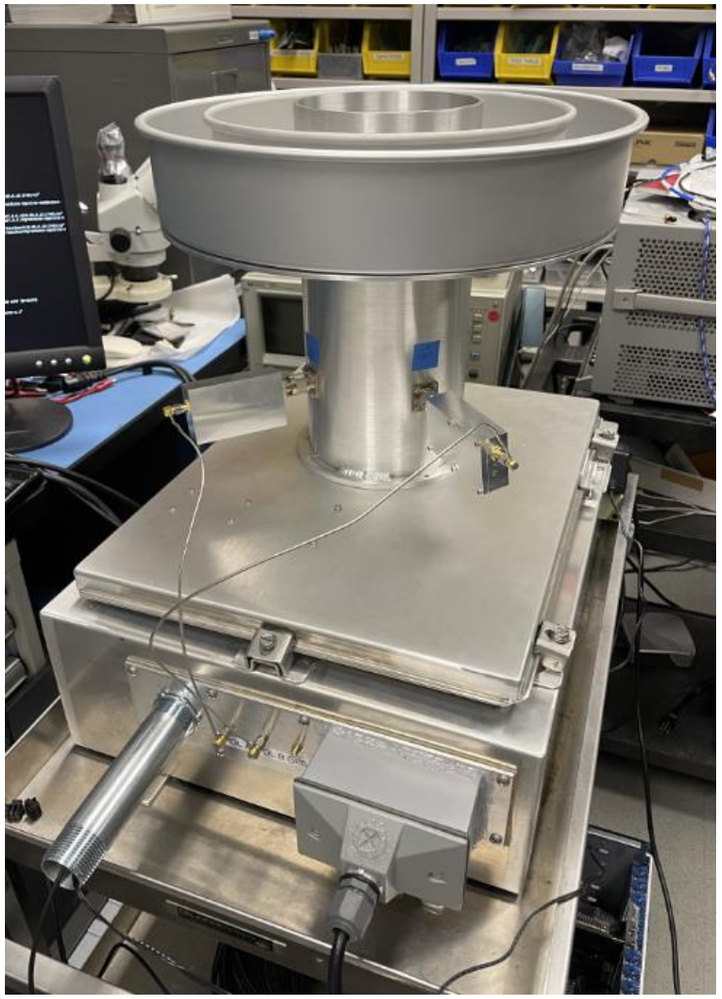
Figure 12. Positions of 6 magnetars for which radio detections have been made, shown in Galactic coordinates. The DM of the YMW16 model is shown in the background, and the green line marks the divide between the northern and southern hemispheres.

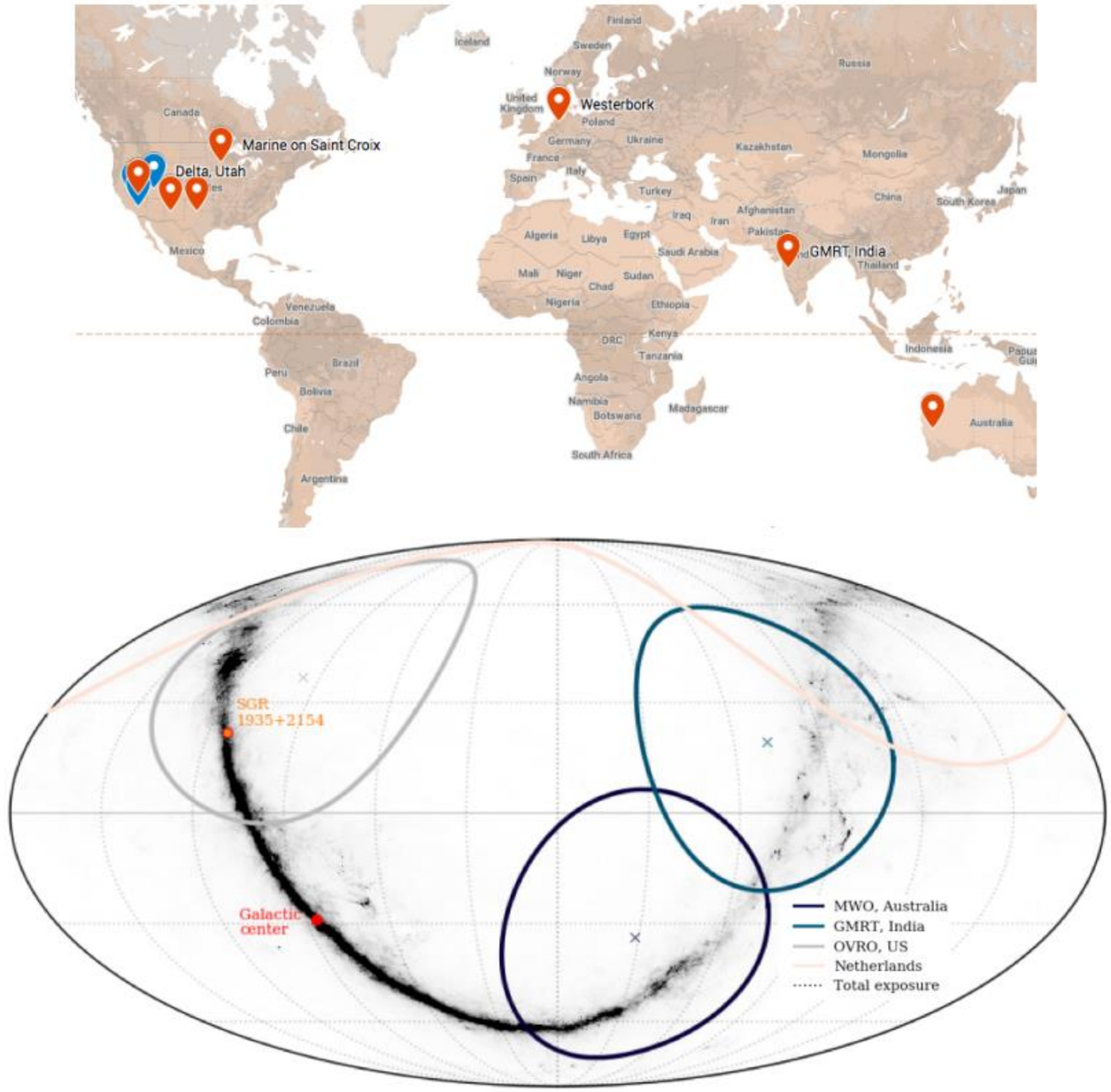
Catching nearby FRBs



Connor et al. 2021

Catching nearby FRBs

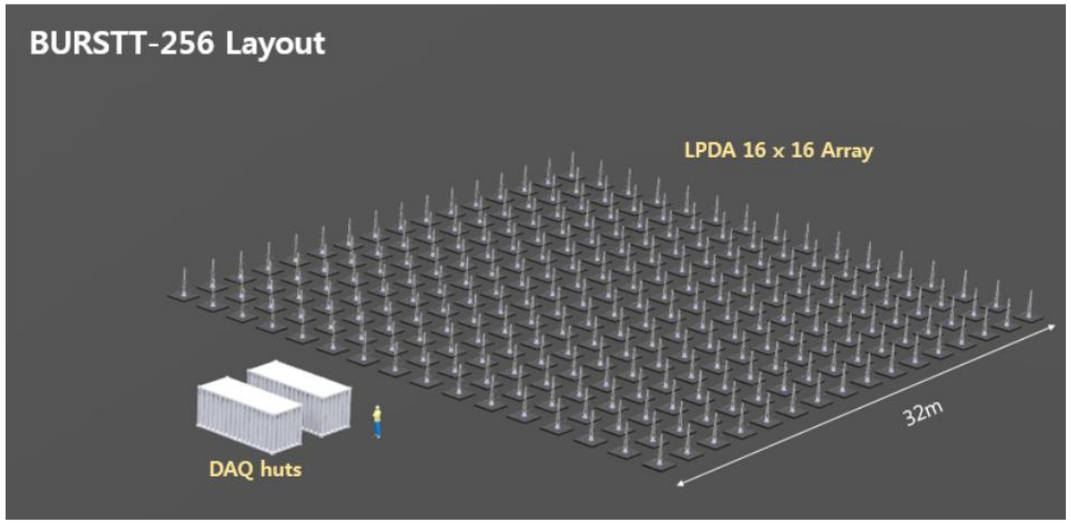


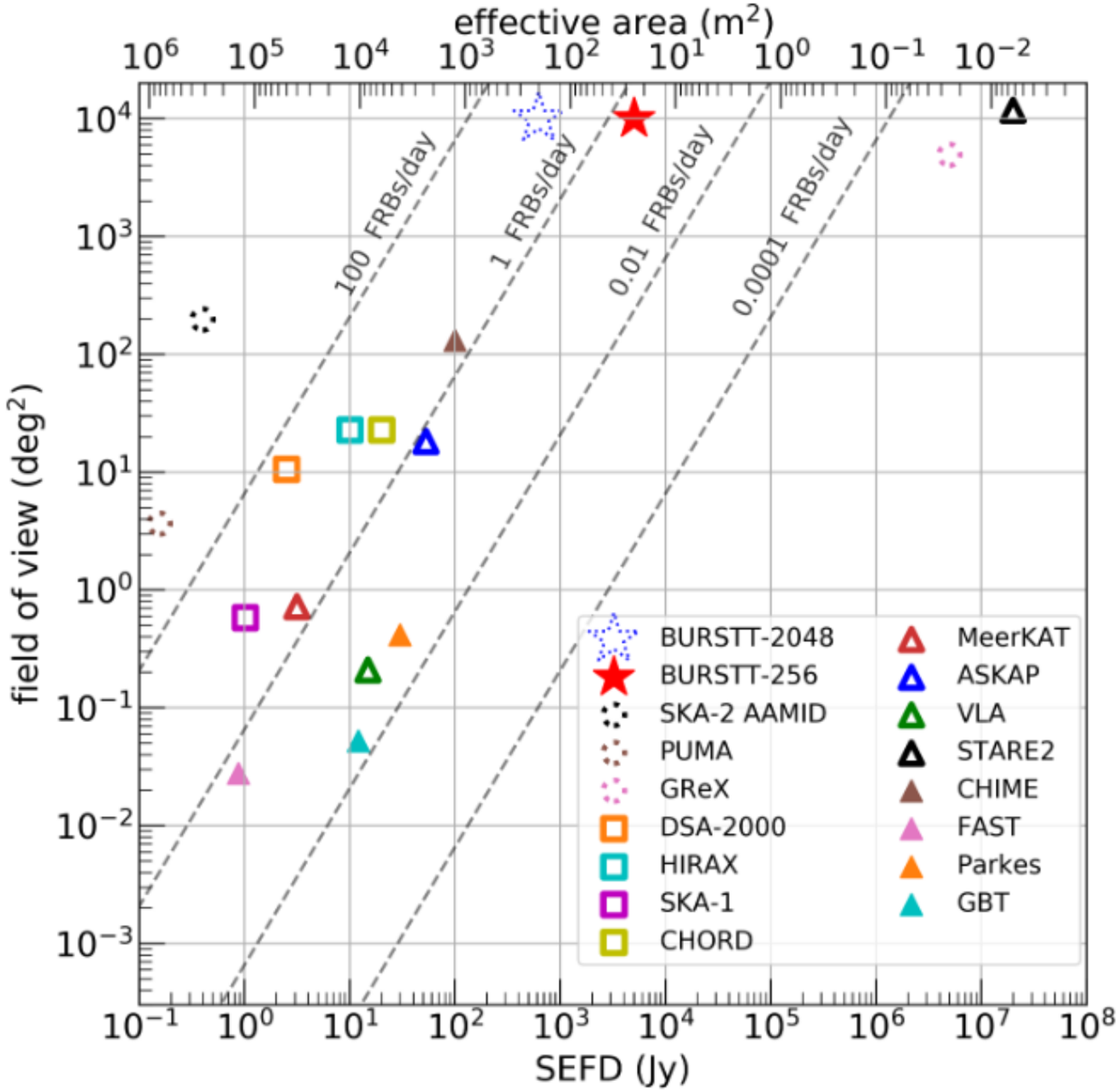


GReX being
developed at Caltech

Connor et al. 2021

Catching nearby FRBs



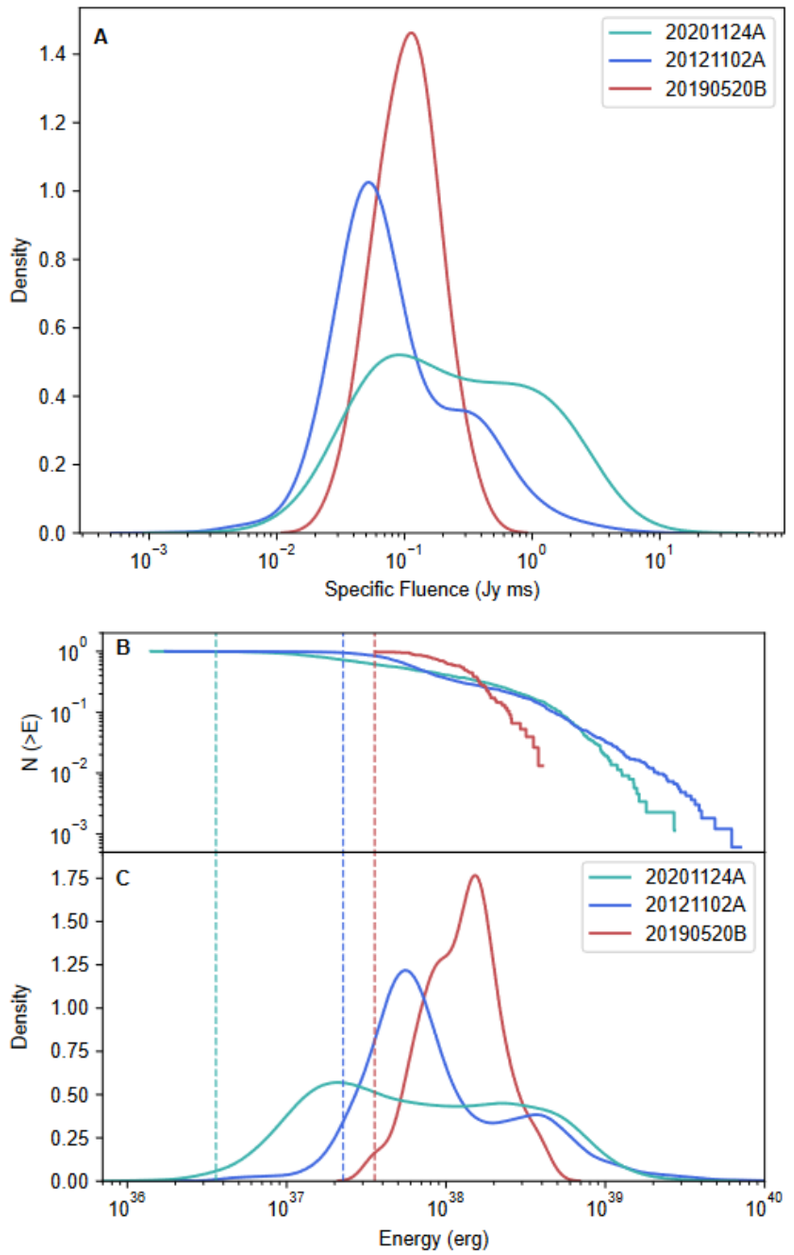


Lin+ 2022

Catching dim FRBs

Five hundred meter Aperture Spherical Telescope in China

Hundreds of bursts for three prolific repeaters



Zhang+ RAA in press