FRB Observations with CHIME

Kaitlyn Shin on behalf of the CHIME/FRB Collaboration
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Masui Synoptic Radio Lab

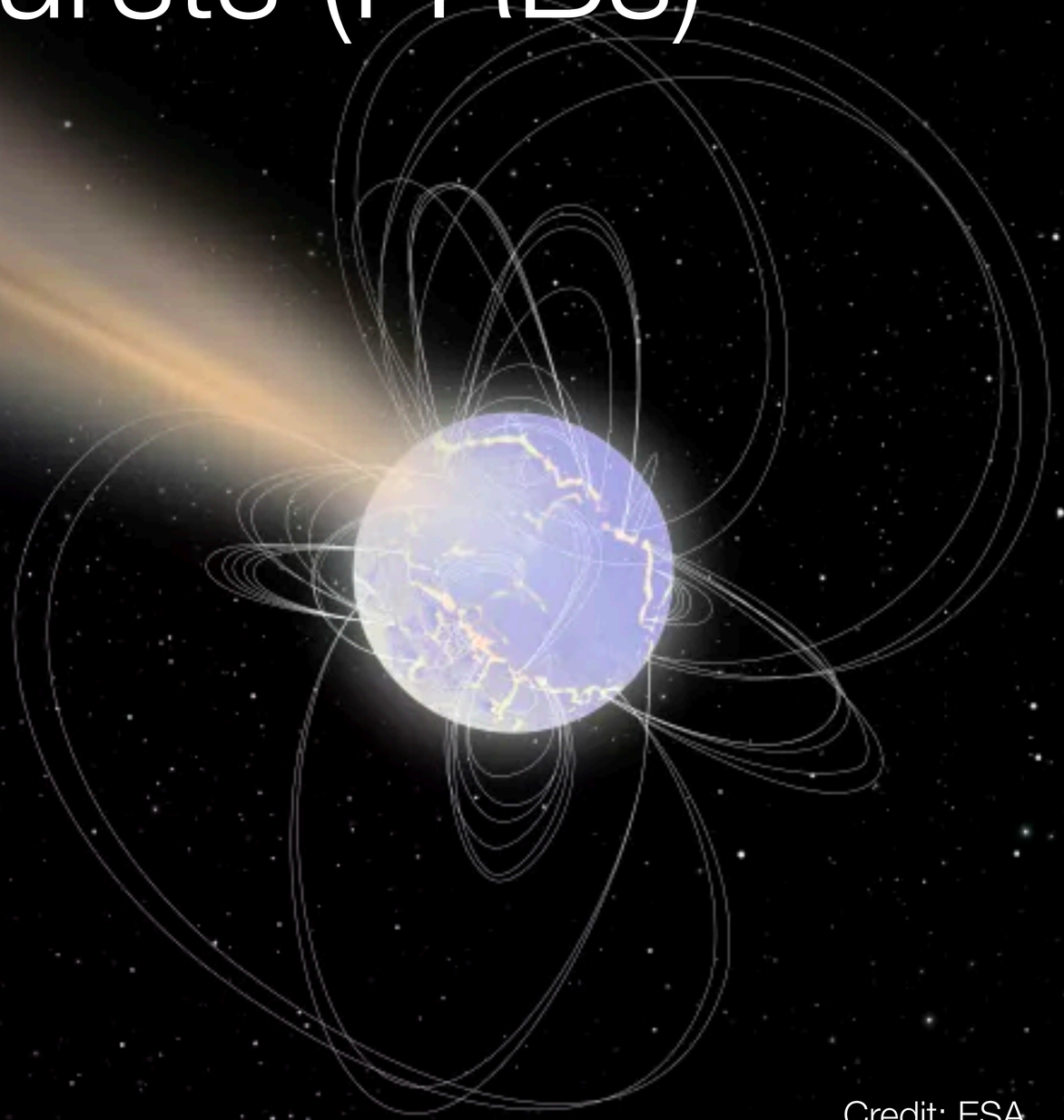
MIT KAVLI INSTITUTE

chime/frb

NSF GRFP

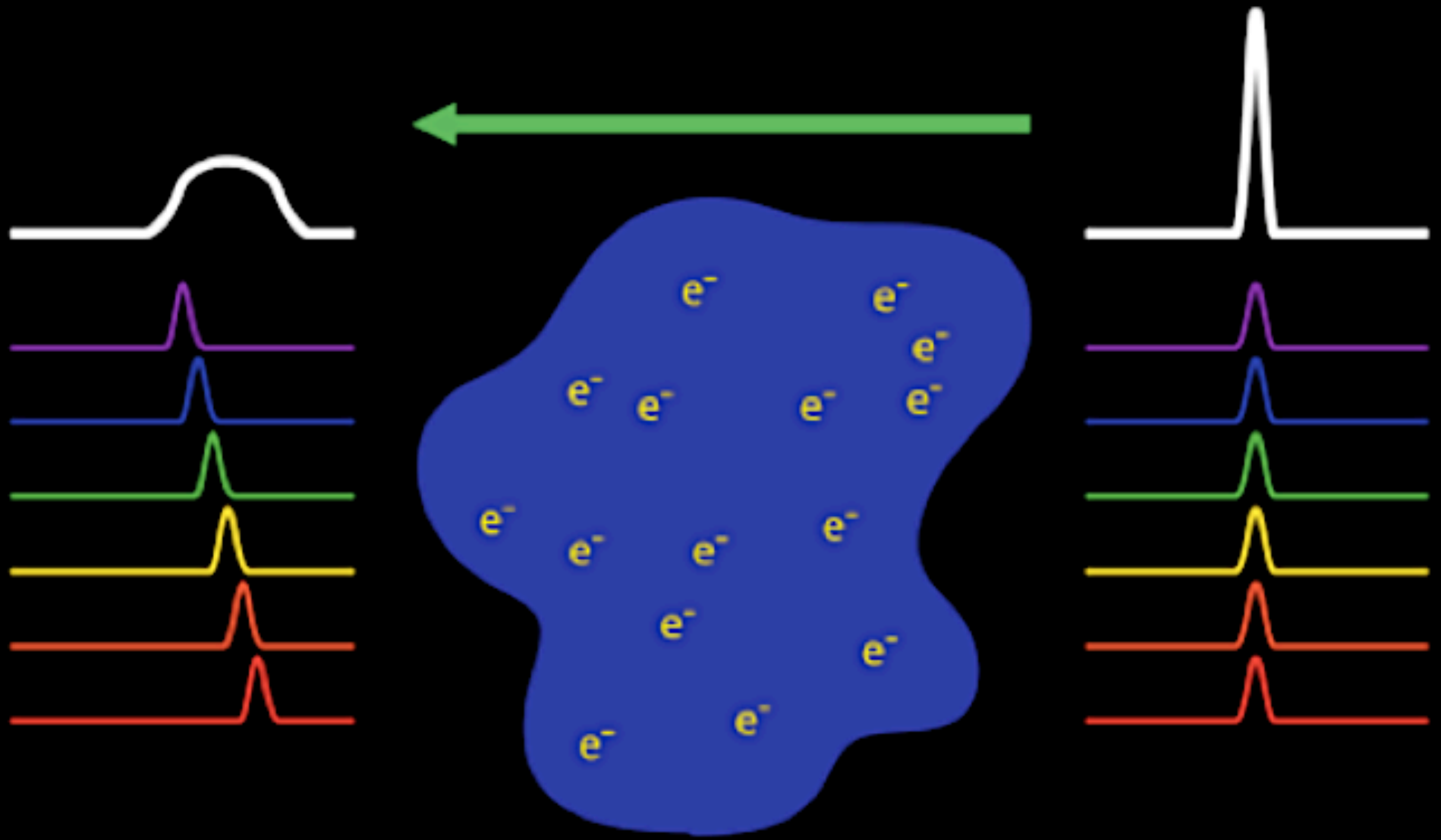
Fast Radio Bursts (FRBs)

- Brief (~ms)
- Energetic (~1–100 Jy;
  1 Jy = 10^{-26} W/m^2/Hz)
- Broadband radio frequencies
  (observed 110 MHz – 8 GHz)
- Ubiquitous (~10^3/sky/day)
- Some observed to repeat
- Diverse morphologies and
  spectra



Credit: ESA

FRBs: Dispersion Measure



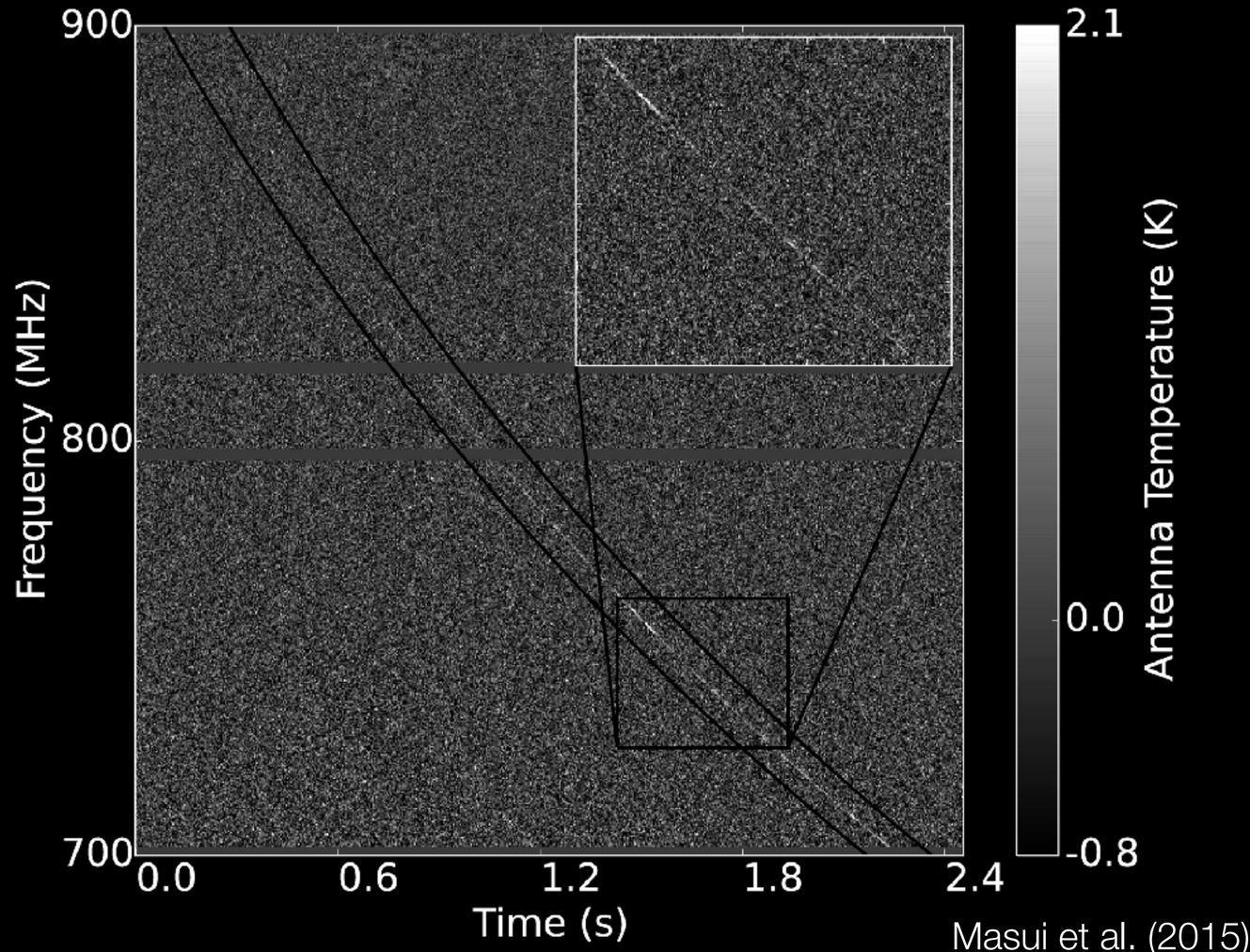
Credit: Erik Madsen

FRBs: Dispersion Measure

$$\mathrm{DM} = \int_{\mathrm{src}}^{\mathrm{obs}} n_e \, ds$$

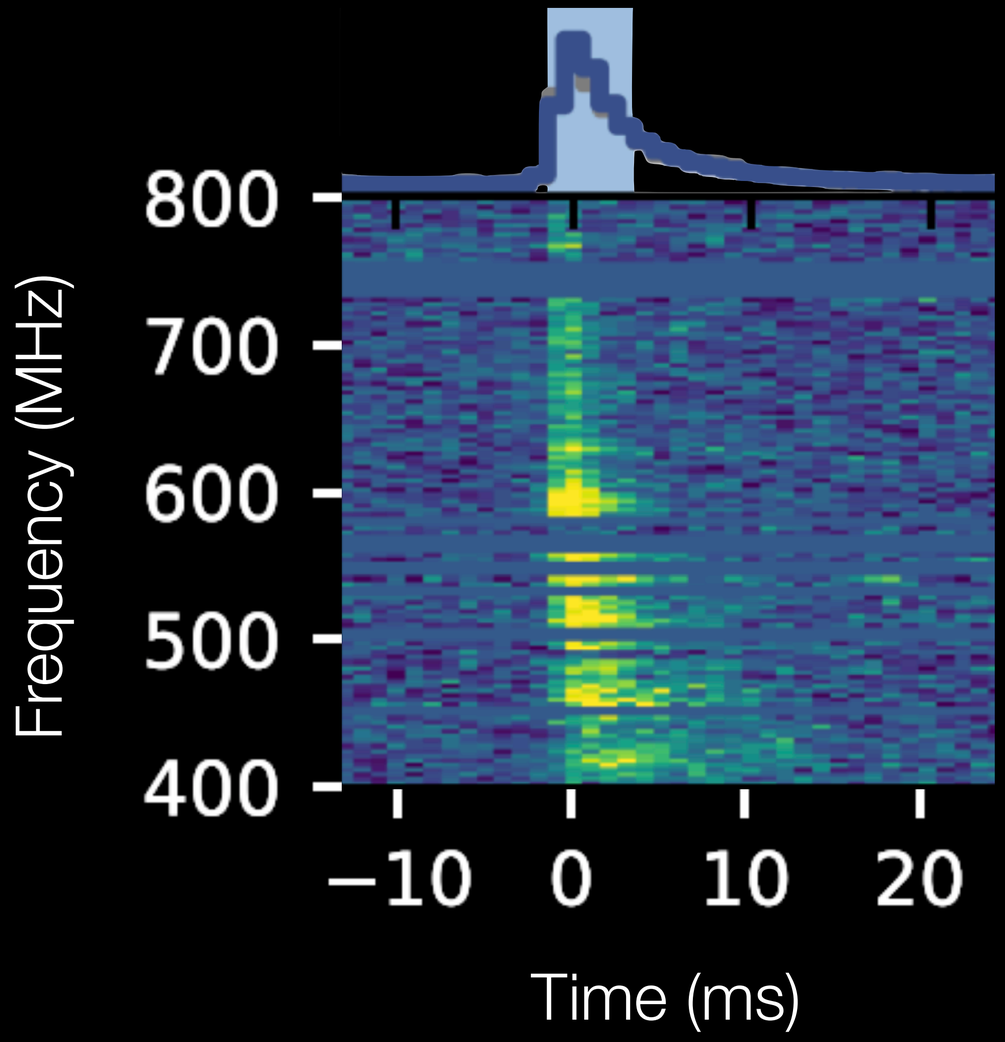
$$t_d \propto \mathrm{DM}\, \lambda^2$$

$$\mathrm{DM} = \mathrm{DM}_{\mathrm{MW,ISM}} + \mathrm{DM}_{\mathrm{MW,halo}} + \mathrm{DM}_{\mathrm{IGM}} + \mathrm{DM}_{\mathrm{host}}$$

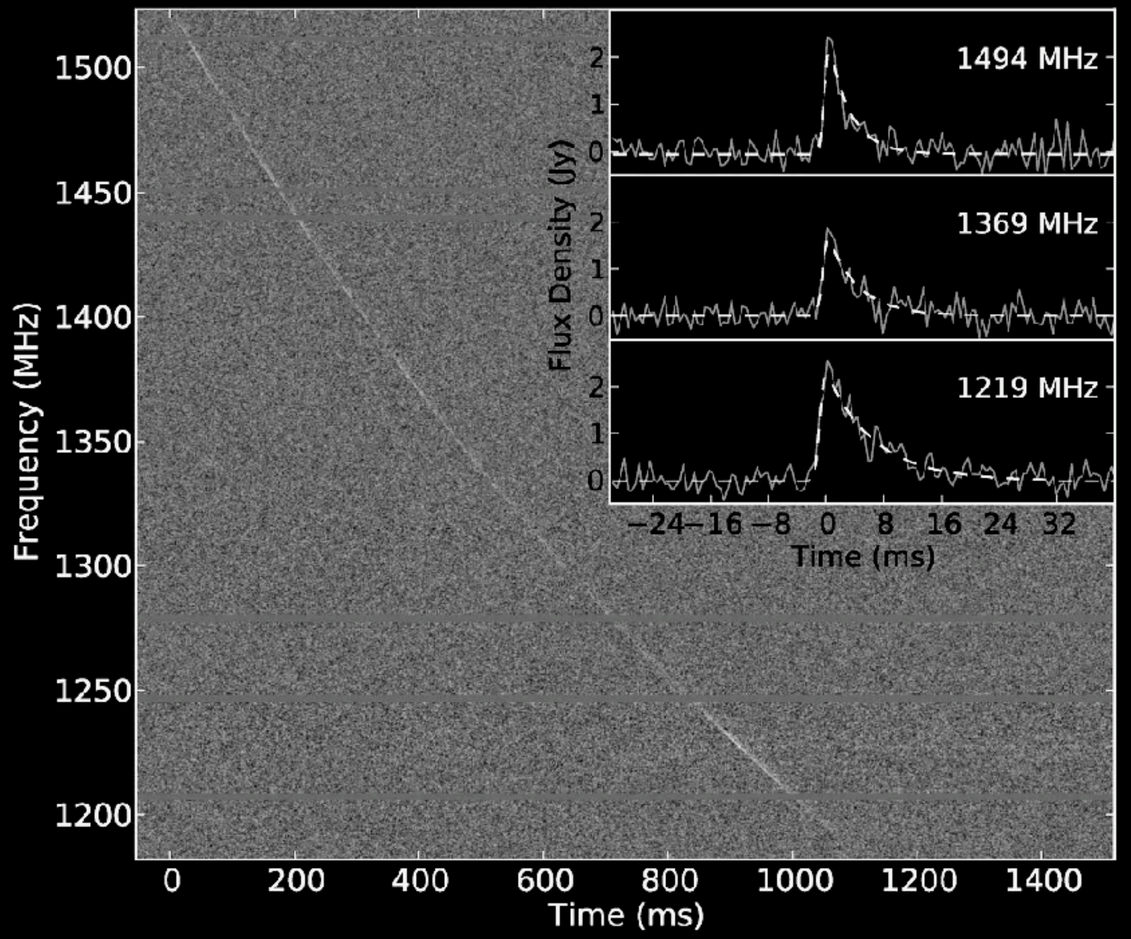


Masui et al. (2015)

FRBs: Scattering Timescale



CHIME/FRB Collaboration et al. (2021)



Thornton et al. (2013)

FRBs: Origins?

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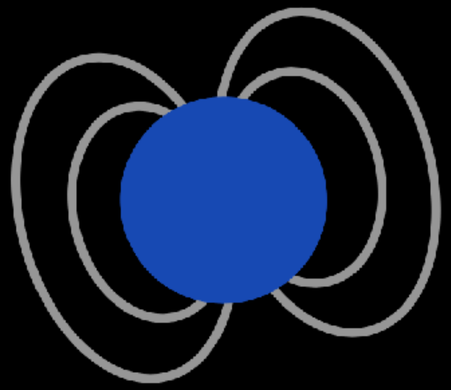
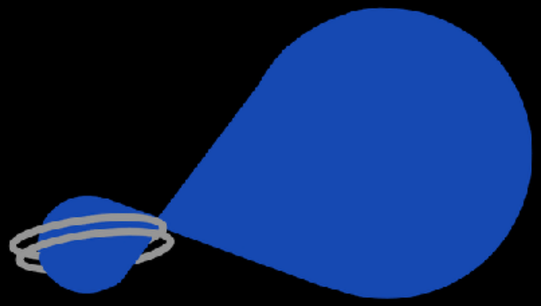
Progenitors?



SGR J1935+2154

(e.g., CHIME/FRB Collaboration et al., 2020; Bochenek et al., 2020)



FRB 20200120E

(e.g., Bhardwaj et al., 2021; Kirsten et al., 2022)

FRBs: Origins?

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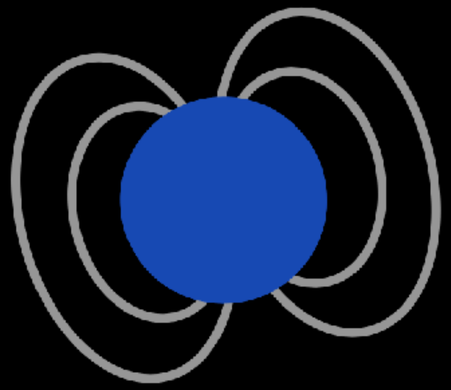

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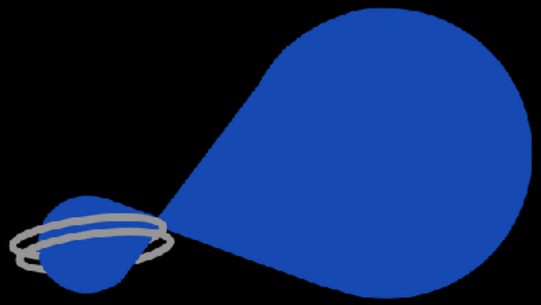

FRB 20200120E

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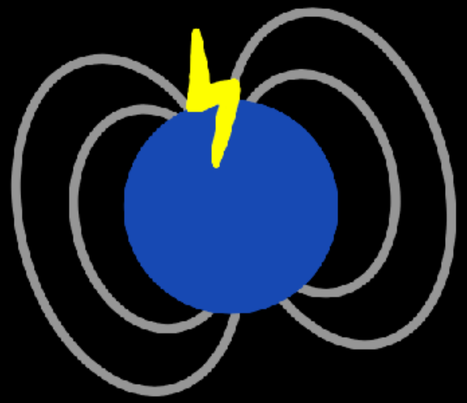
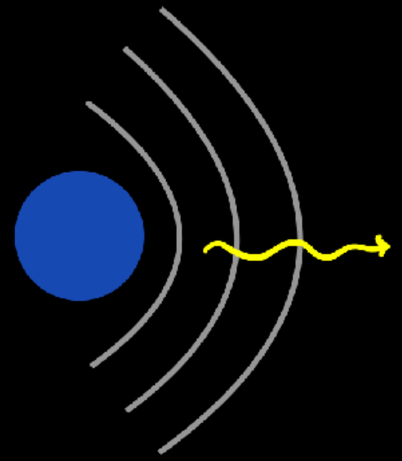
Emission mechanism?



magnetospheric

(e.g., Lu et al., 2020)



shock waves

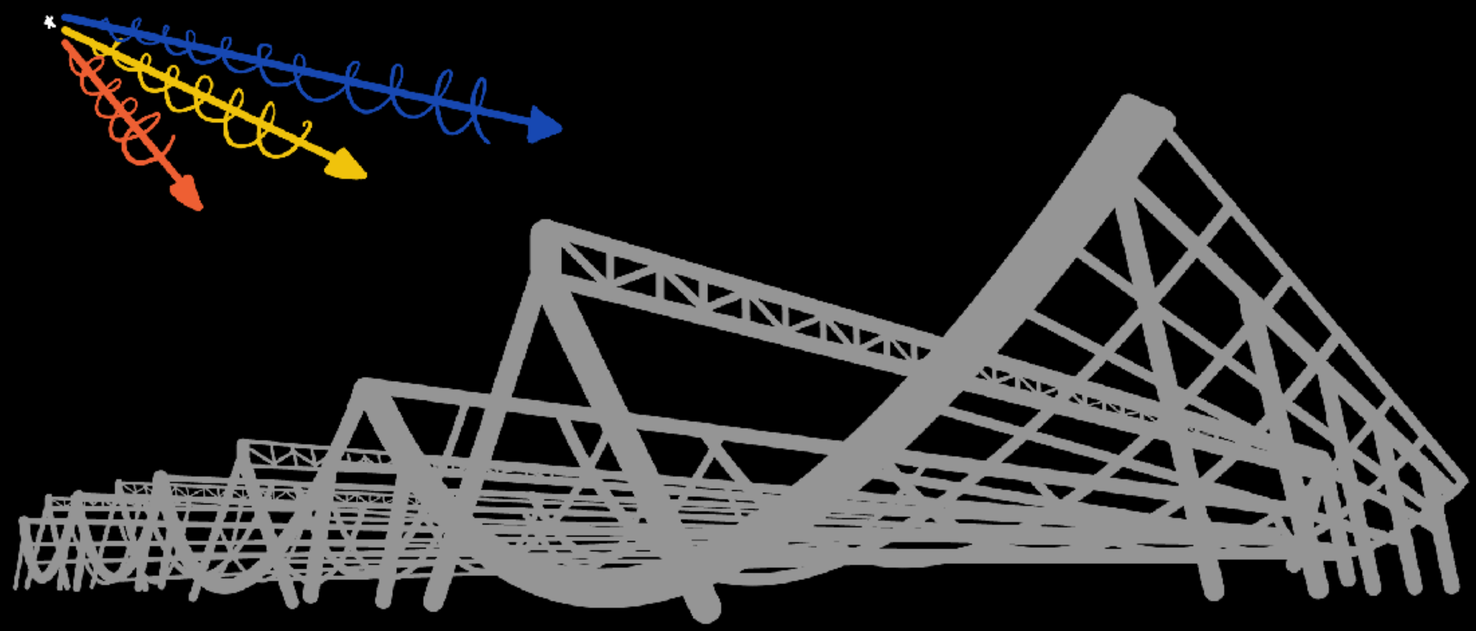
(e.g., Metzger et al., 2019)

2007–2018: ~50 FRBs

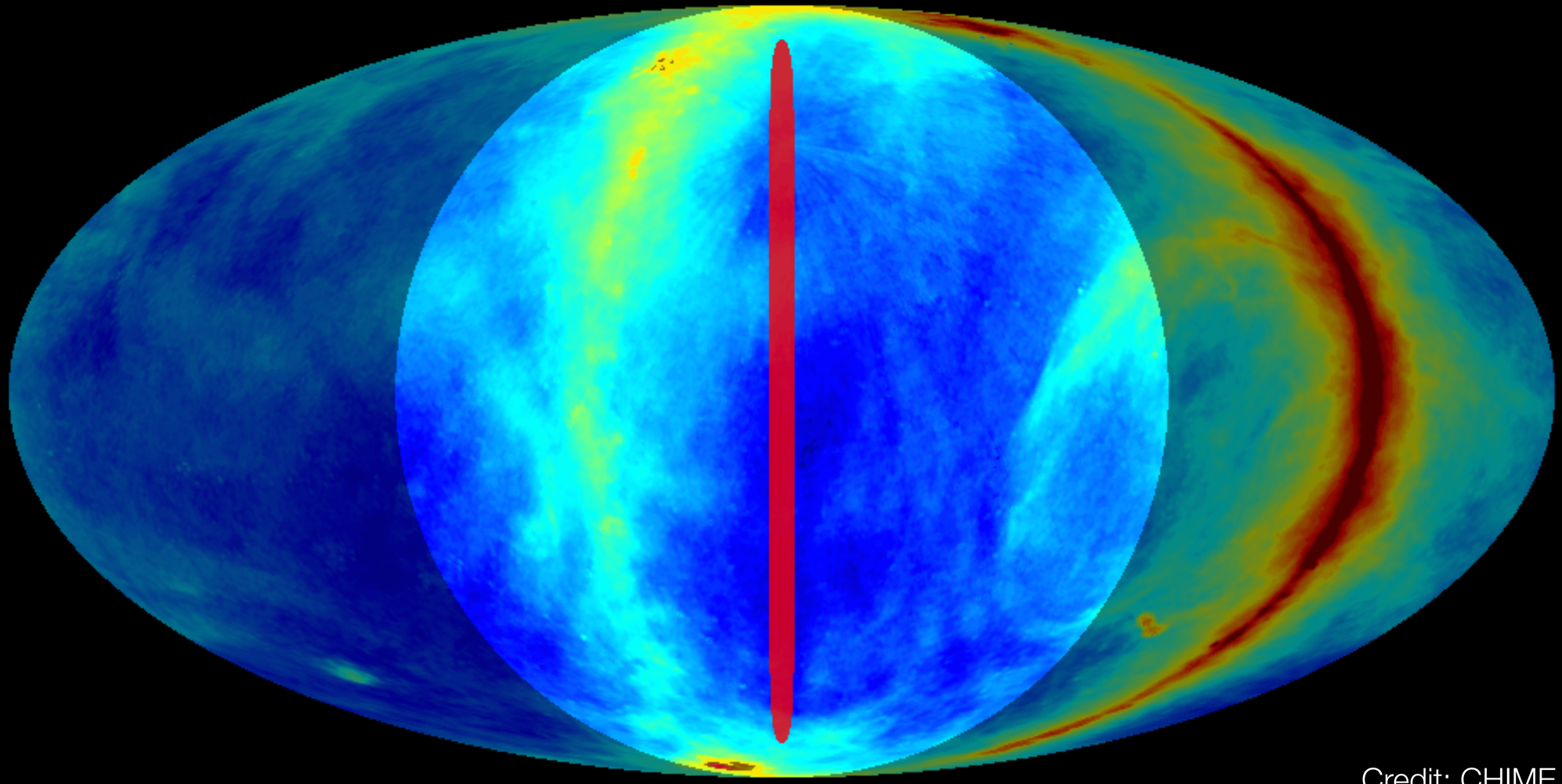
We need more FRBs!

CHIME telescope

- At Dominion Radio Astrophysical Observatory, British Columbia
- Transit telescope
- Observes at 400 – 800 MHz
- 1024 dual-polarization antennas
- Digitally forms 1024 interferometric synthesized beams

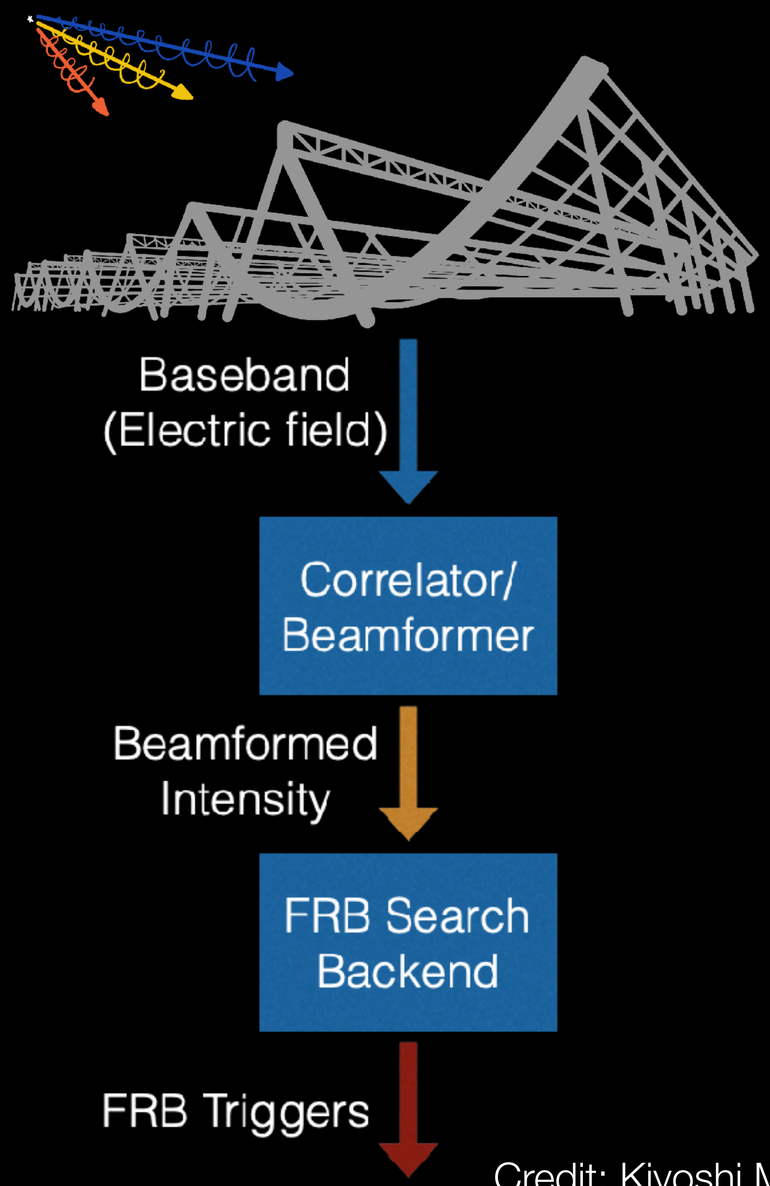


CHIME primary beam



Credit: CHIME

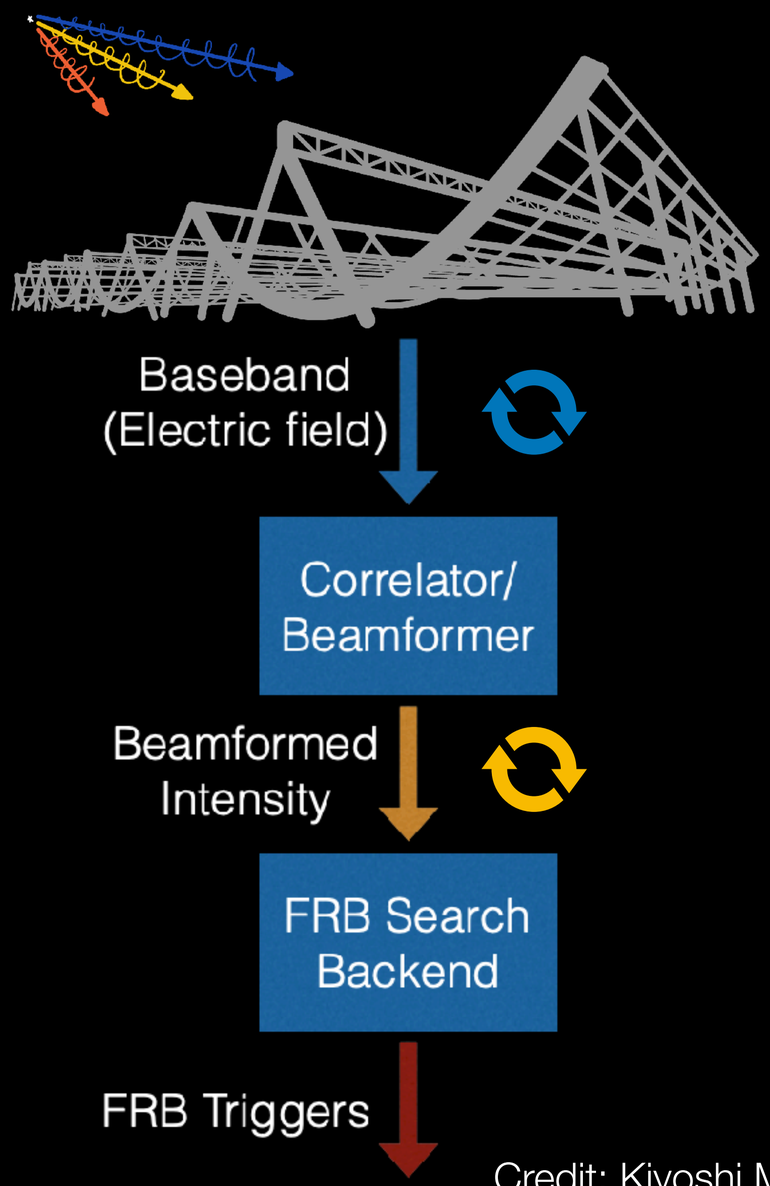
CHIME/FRB search



- Real-time search and detection pipeline
- Baseband data rate: 6.6 Tb/s
- Input data rate to search through: 1.5 PB/day
- 1 ms sampling cadence

Credit: Kiyoshi Masui

CHIME/FRB search



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Credit: Kiyoshi Masui

(paradigm-shifting!)

CHIME/FRB observations

- [2019] Observations of Fast Radio Bursts at Frequencies down to 400 Megahertz
- [2020] Periodic activity from a fast radio burst source
- [2020] A bright millisecond-duration radio burst from a Galactic magnetar
- [2021] A nearby repeating fast radio burst in the direction of M81 (Bhardwaj et al., *ApJL*)
- [2021] The First CHIME/FRB Fast Radio Burst Catalog

CHIME/FRB observations

- [2021] Statistically cross-correlating FRB positions with large-scale structure (Rafiei-Ravandi et al., *ApJ*)
- [2022] Modeling FRB dispersion and scattering properties (Chawla et al., *ApJ*)
- [2022] Constraining primordial black holes with FRB lensing search (Leung, Kader et al., *PRD*)
- [2022] Constraining FRB-like counterparts to GRBs (Curtin et al., submitted, *ApJ*)
- [2022] Inferring FRB energy and distance distributions (Shin et al., accepted, *ApJ*)

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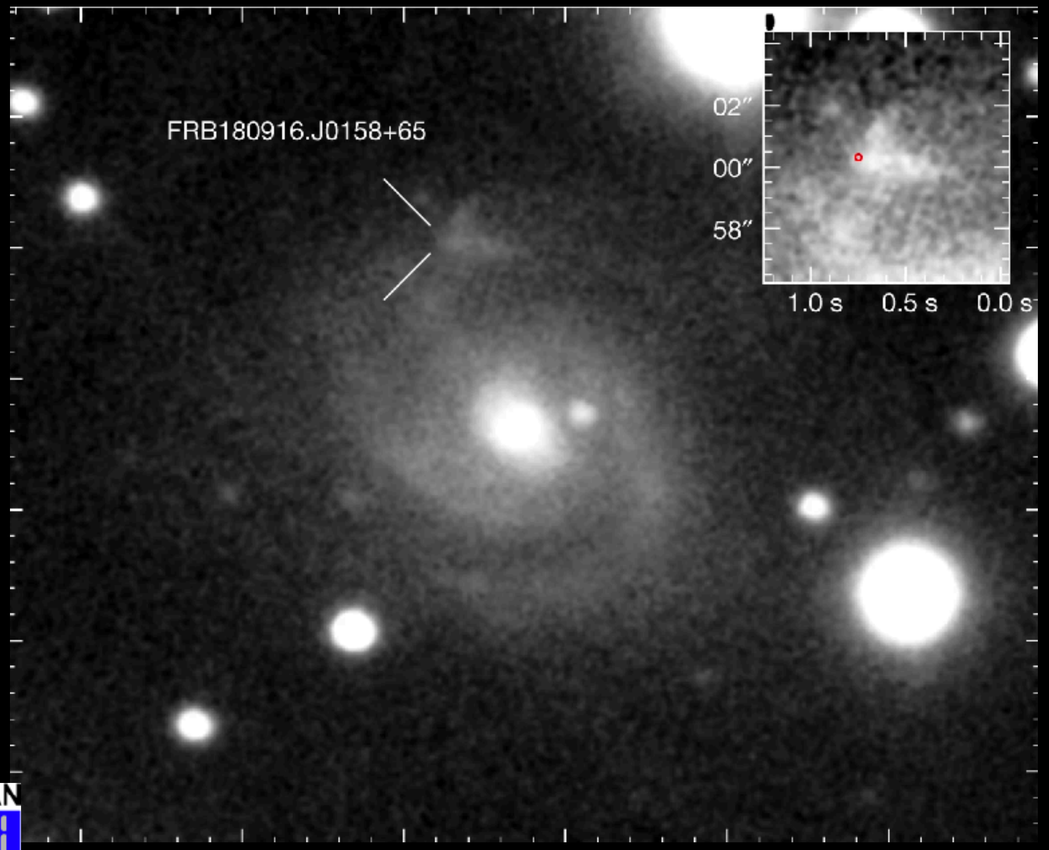
… and many, many more!

(paradigm-shifting!)

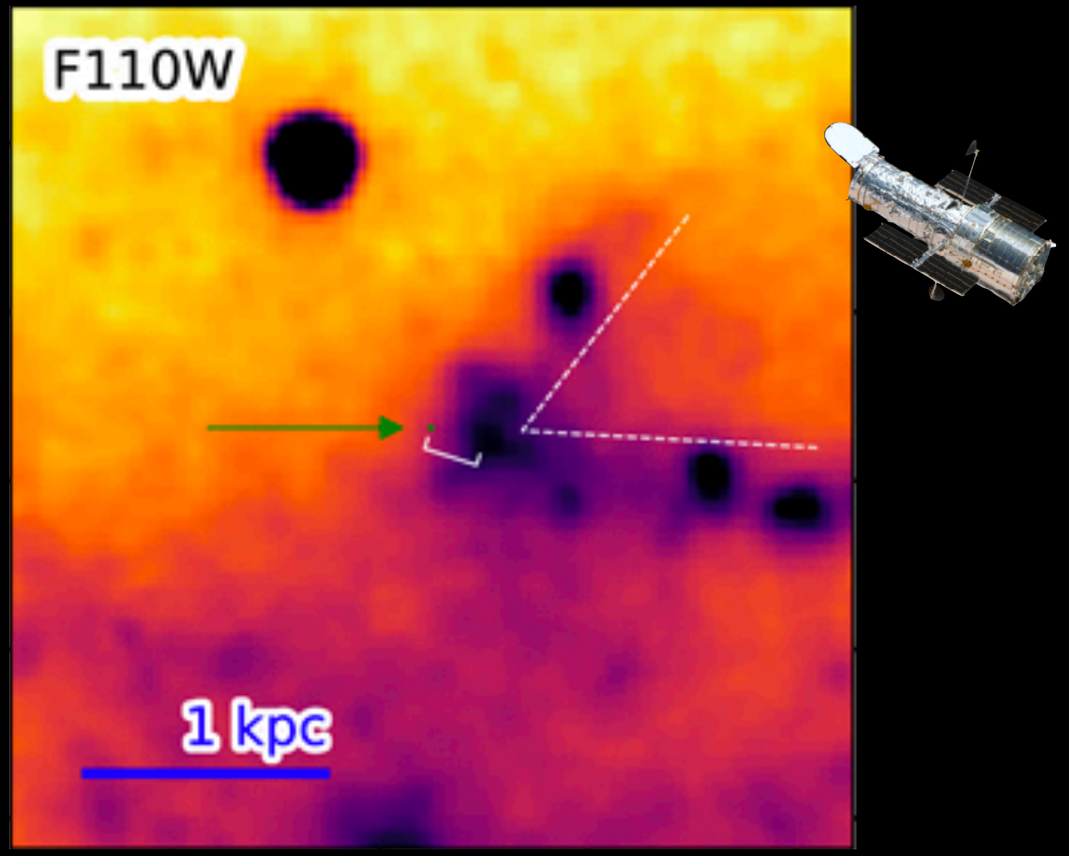
3 CHIME/FRB observations

Discovery of periodicity

- FRB 20180916B: localized to a massive spiral galaxy at z ~ 0.03; offset from star-forming region



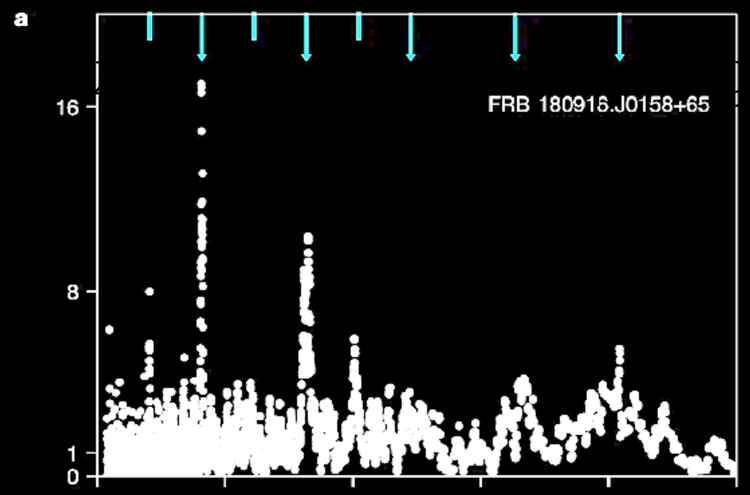
Marcote et al. (2020)



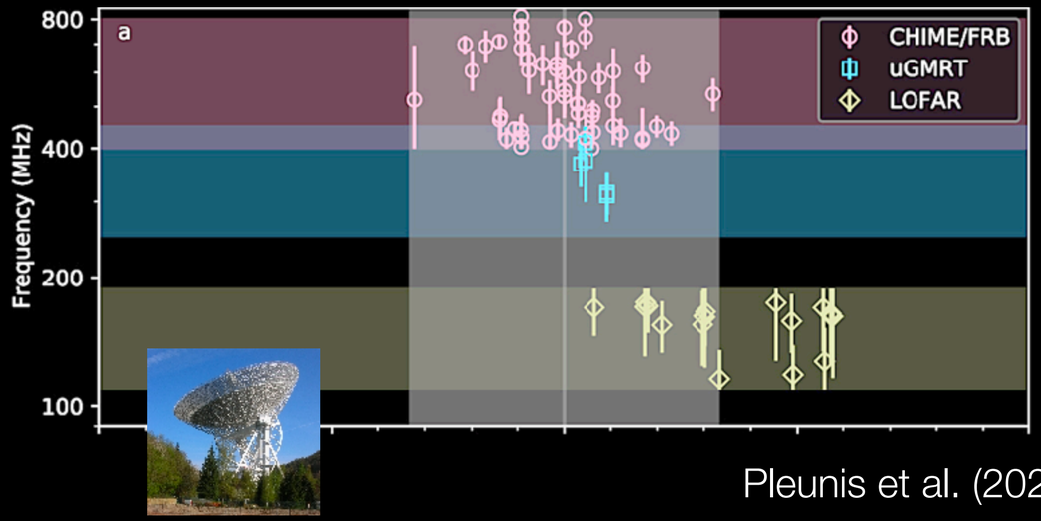
Tendulkar et al. (2021)

Discovery of periodicity

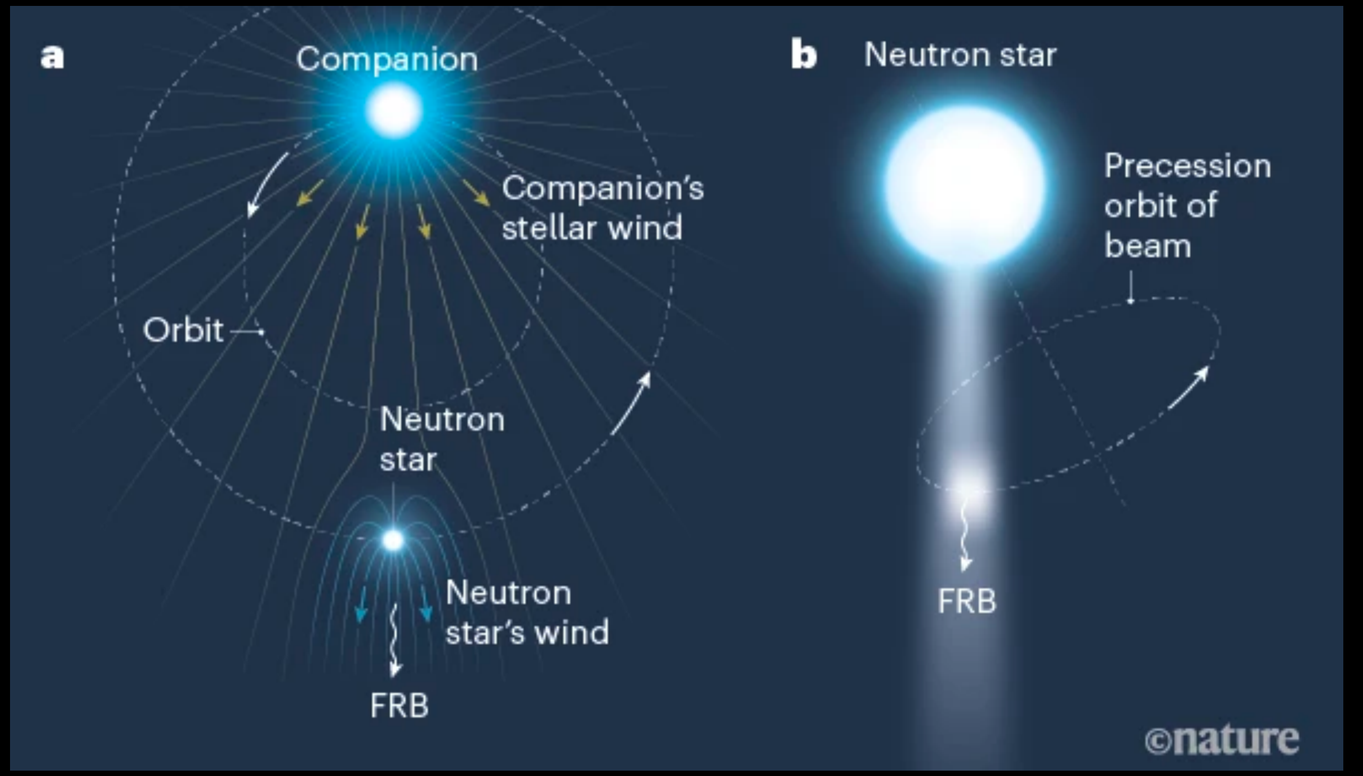
- ~16 day period, with frequency-dependent activity



CHIME/FRB Collaboration et al. (2020)



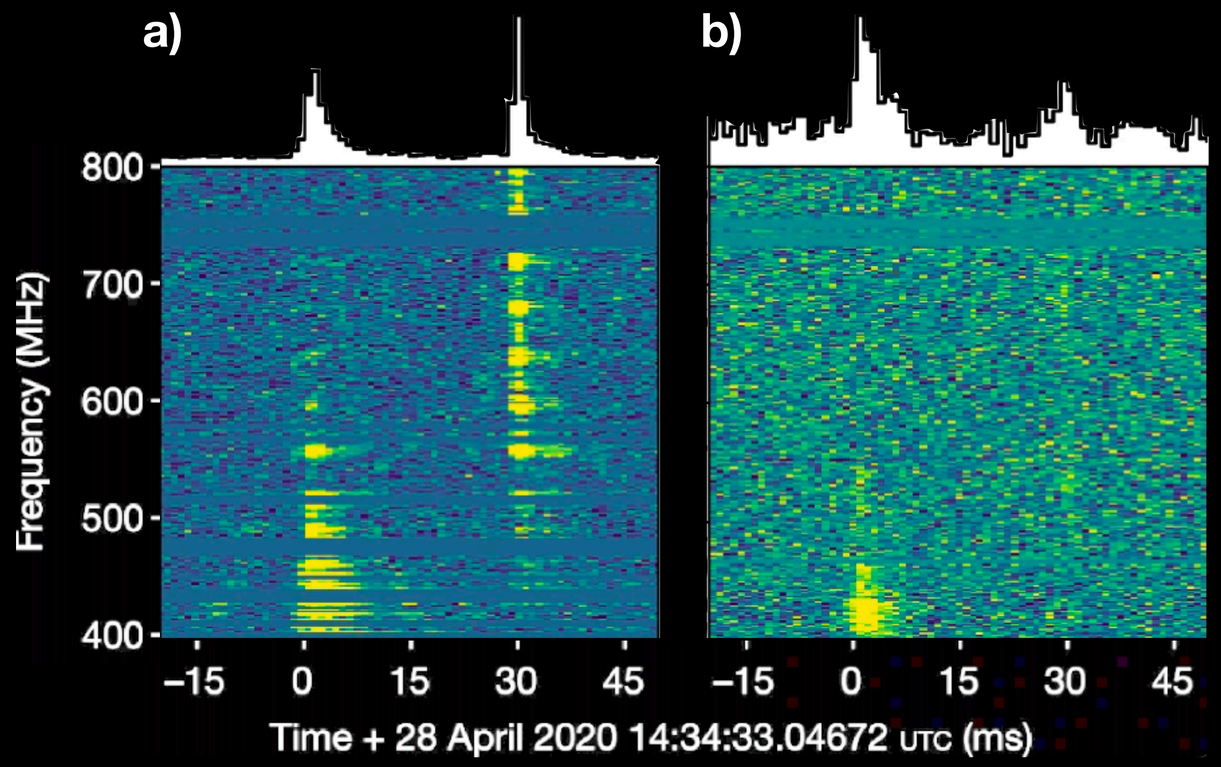
Pleunis et al. (2021)



Zhang/Nature (2020)

Association with a Galactic magnetar

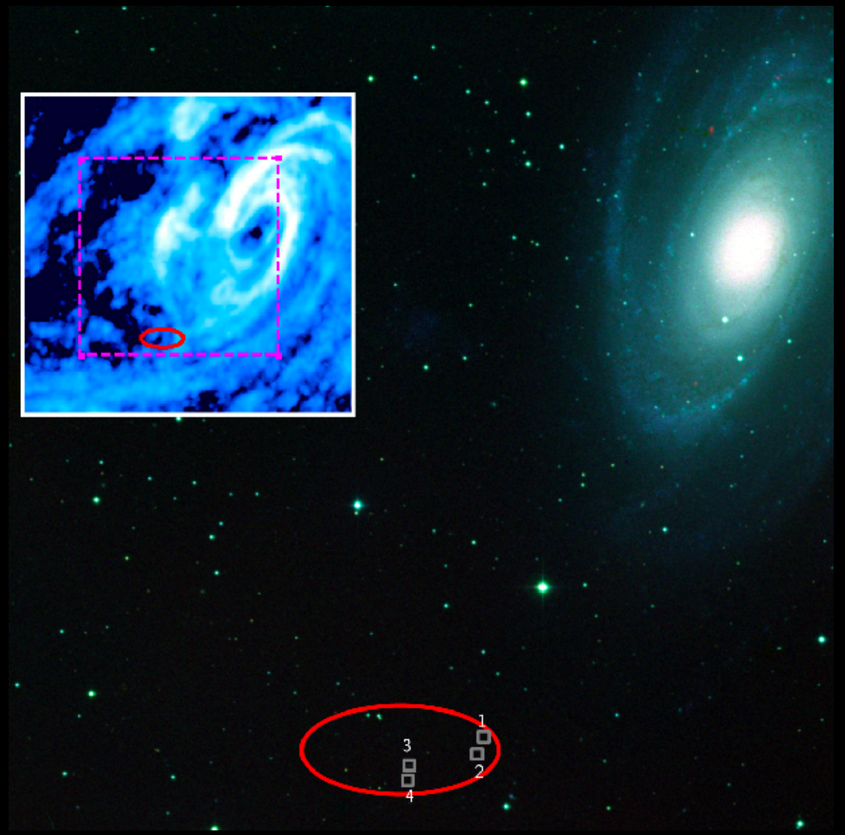
- April 2020: Unusually high X-ray activity from known magnetar SGR 1935+2154
- FRB 20200428A: Very bright radio burst caught by CHIME/FRB, STARE2
- Supports magnetar origin for at least some FRBs?



CHIME/FRB Collaboration et al. (2020)

Localization to a globular cluster

- FRB 20200120E: localized to a nearby galaxy, then a globular cluster
- Supports non-magnetar origin for some FRBs?

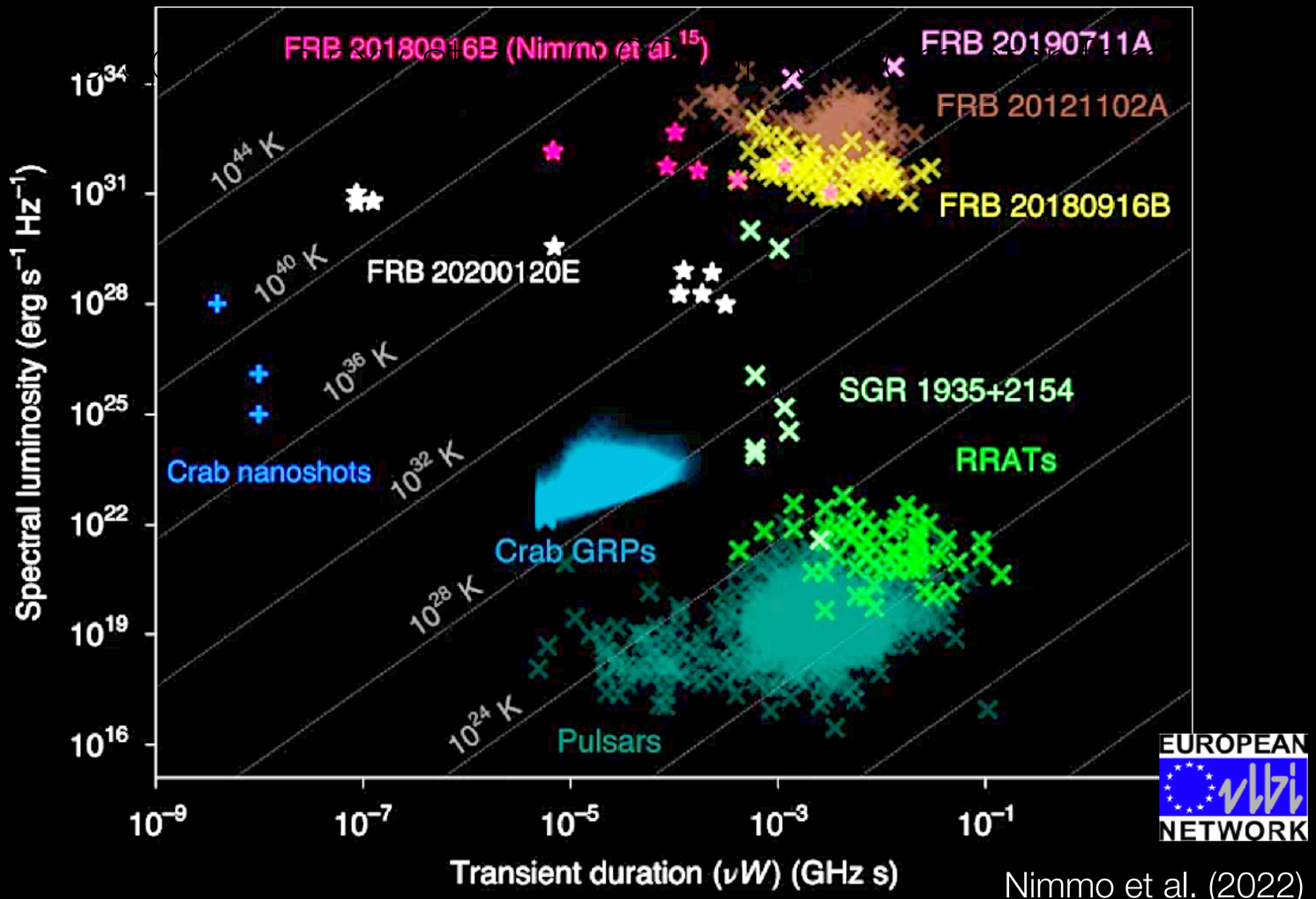


Bhardwaj et al. (2021)

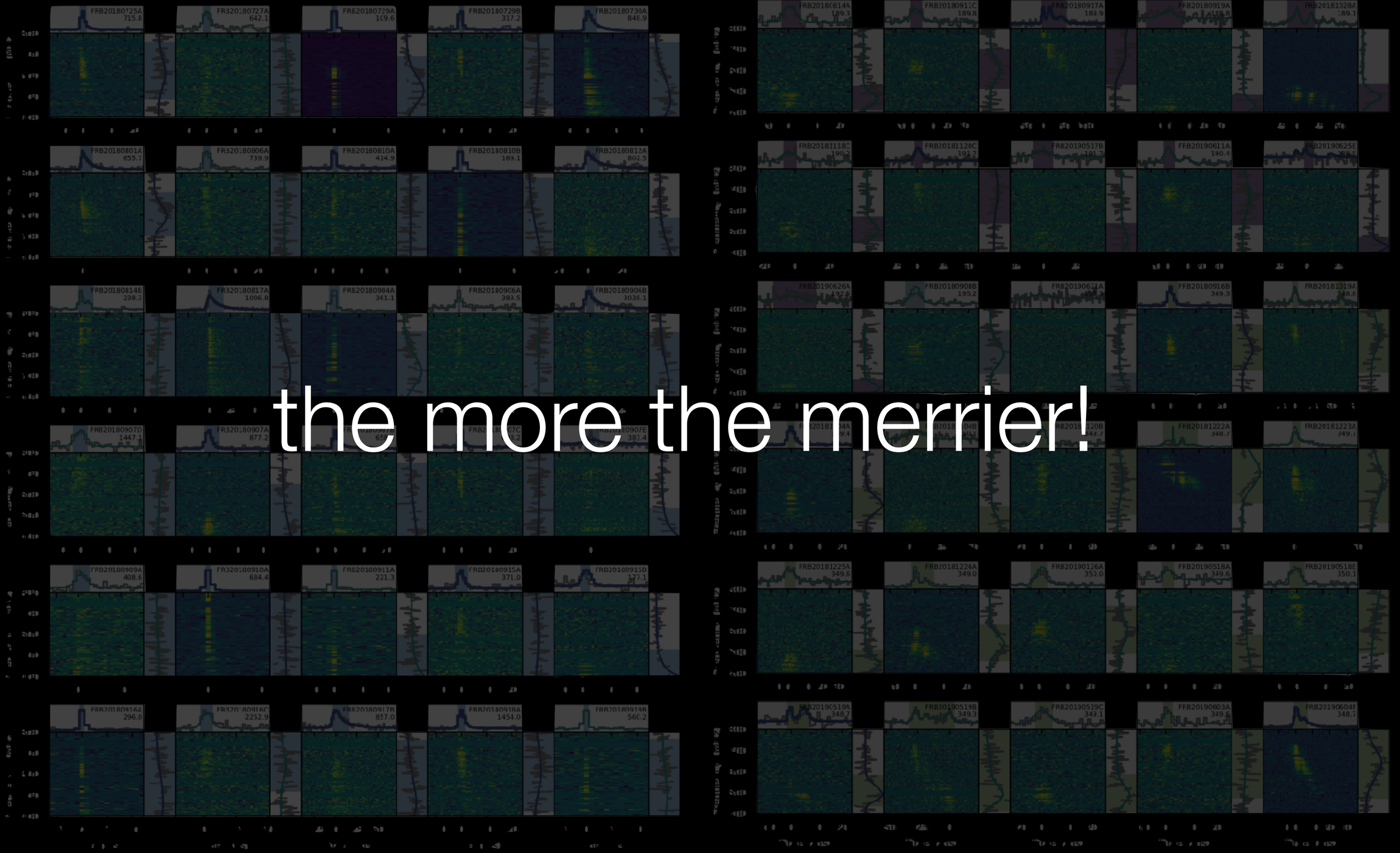
Kirsten et al. (2021)

Localization to a globular cluster

- Observational bridge between known Galactic radio transients and extragalactic FRBs



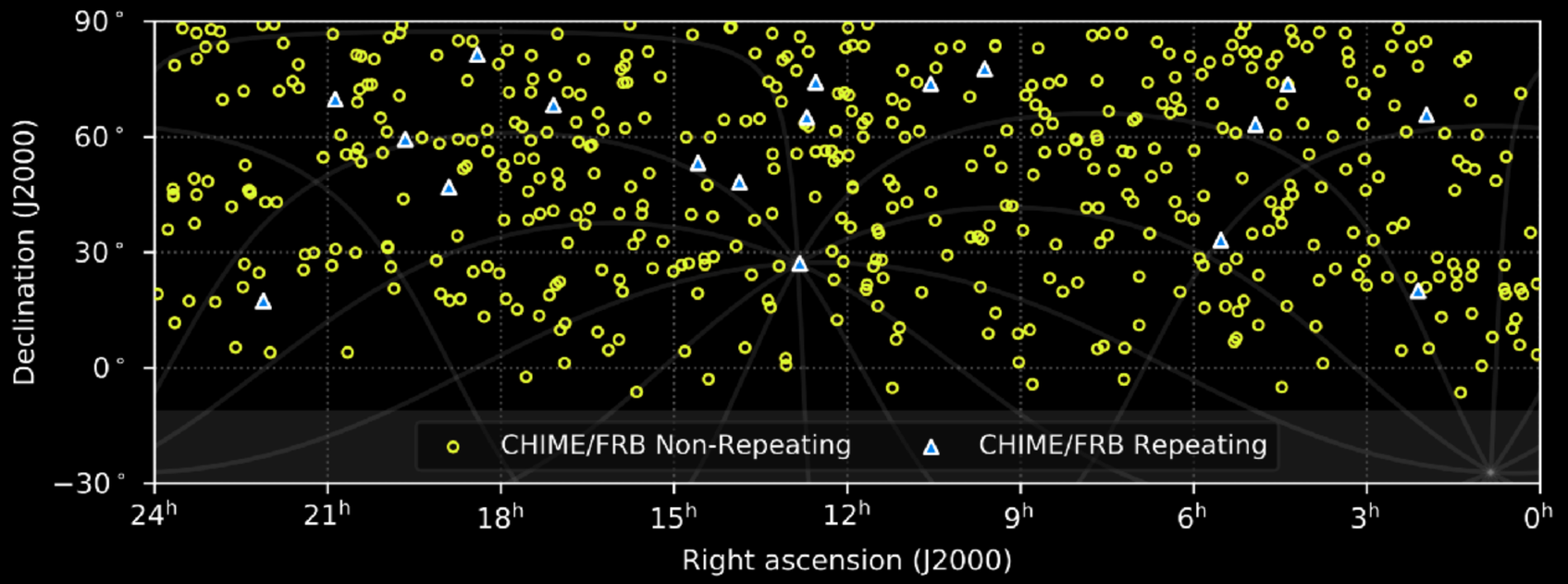
Nimmo et al. (2022)



the more the merrier!

CHIME/FRB Catalog 1

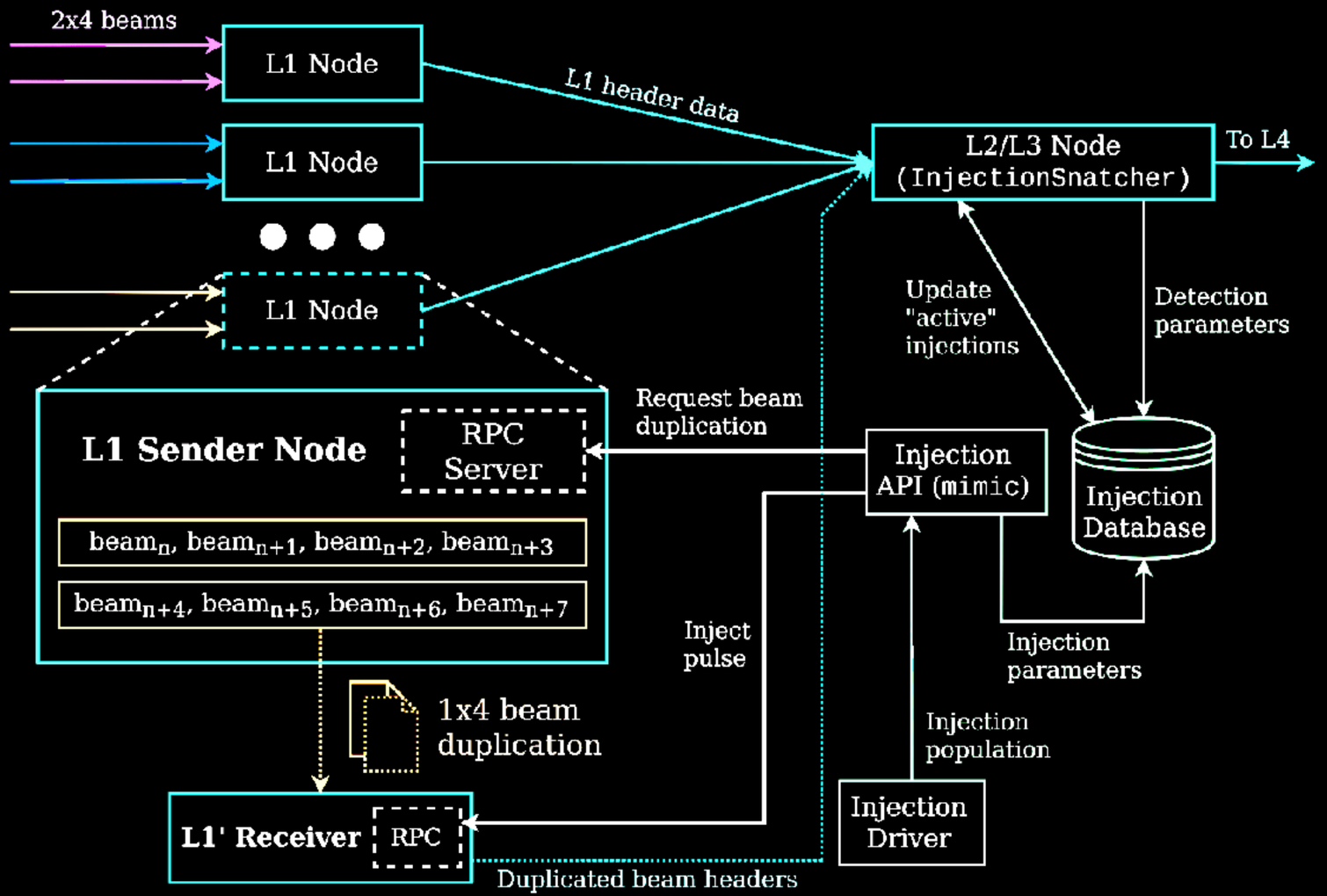
- **536 FRBs** detected between July 2018 and July 2019
- Sample includes 61 bursts from 18 repeating sources
- Each burst has measured properties
  (Fluence, DM, scattering timescale, intrinsic pulse width)



CHIME/FRB Collaboration et al. (2021)

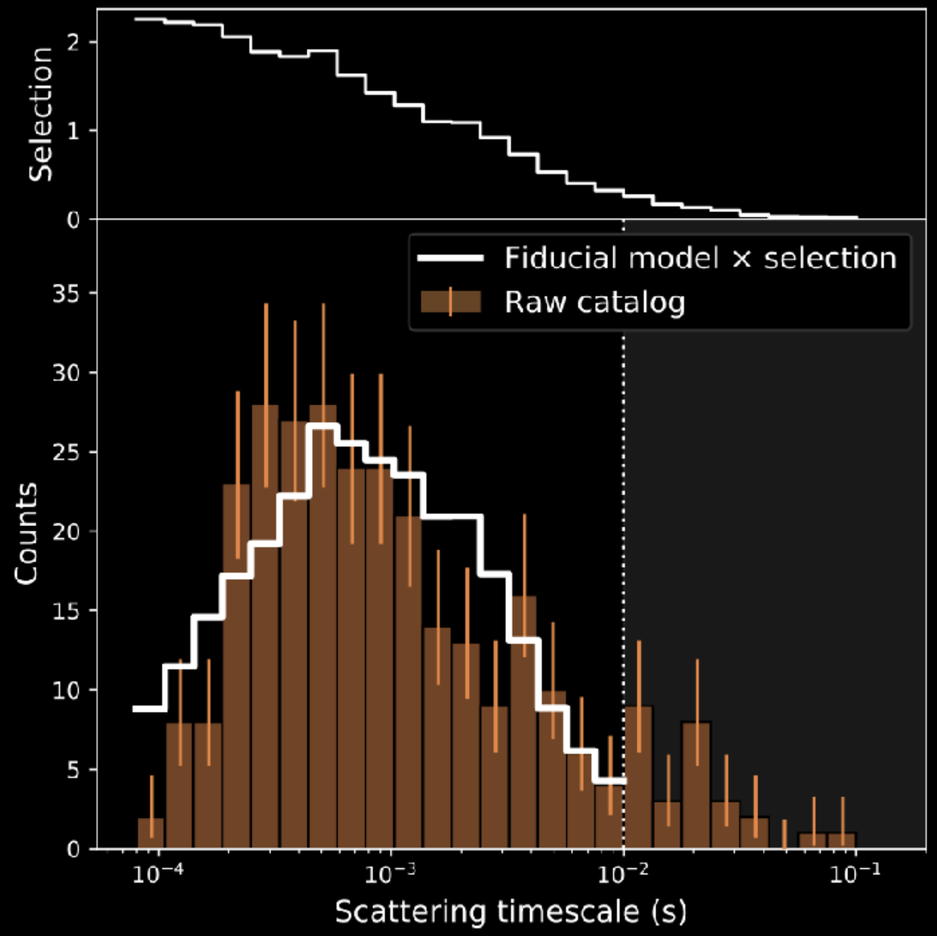
Injections System

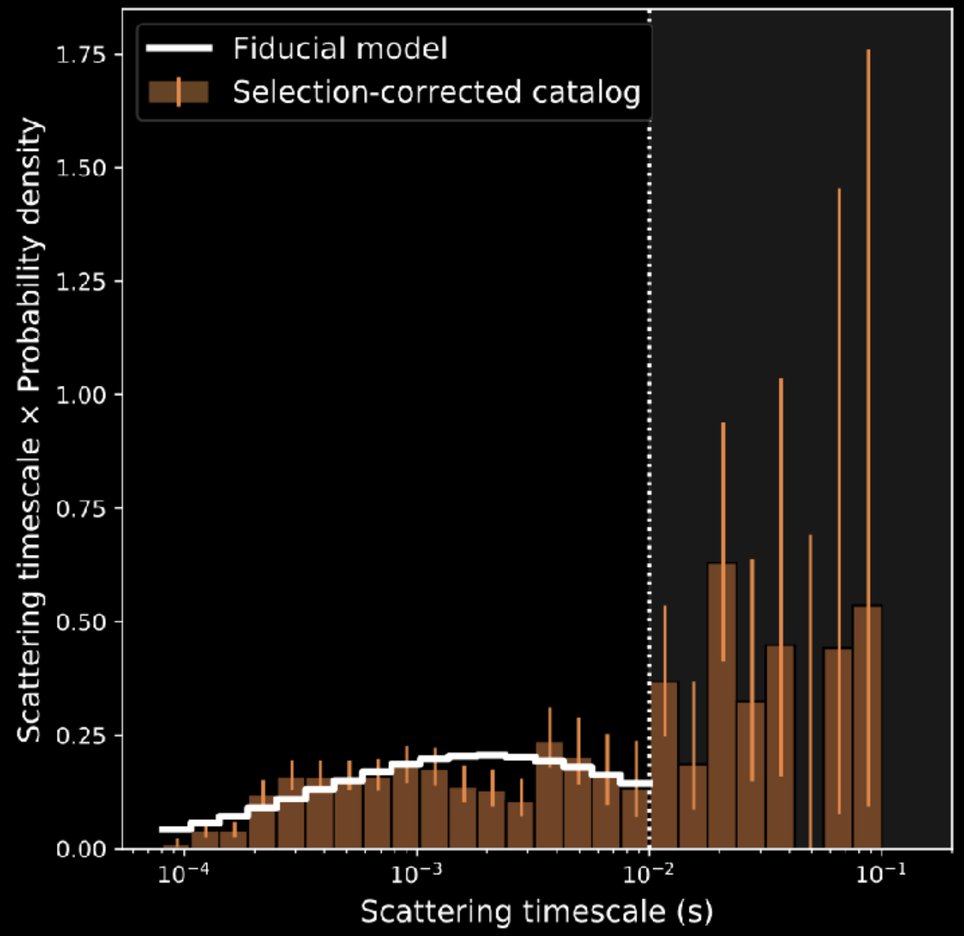
- Injecting a mock population of synthetic pulses directly into the **realtime search pipeline**
- Characterize telescope sensitivity to burst properties
- Allows us to correct for **selection biases**



Merryfield et al. (2022)

FRB scattering distribution

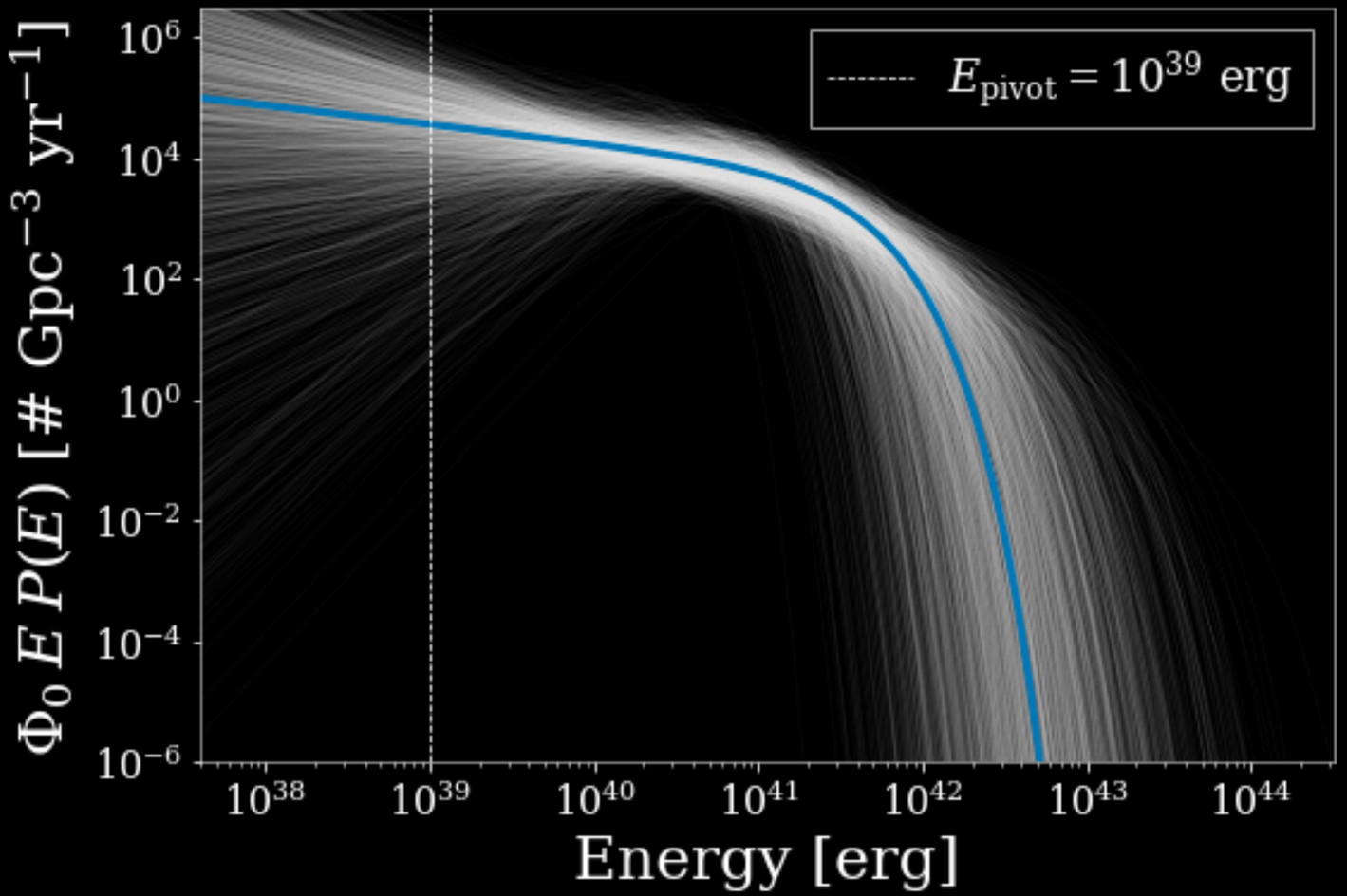




Substantial unobserved population of **highly scattered** FRBs?
(e.g., Chawla et al., 2022)

CHIME/FRB Collaboration et al. (2021)

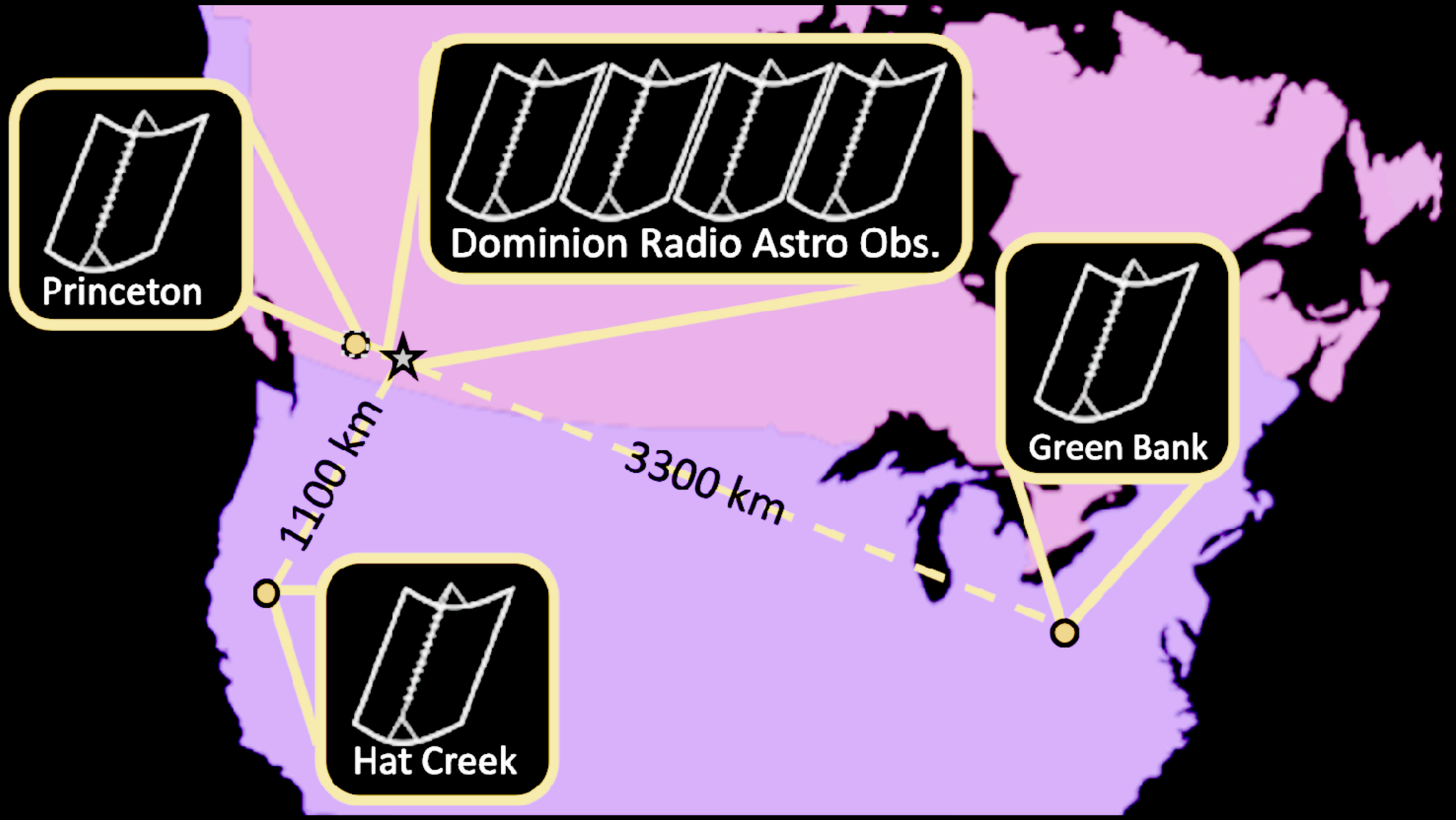
FRB energy function



Shin et al. (2022)

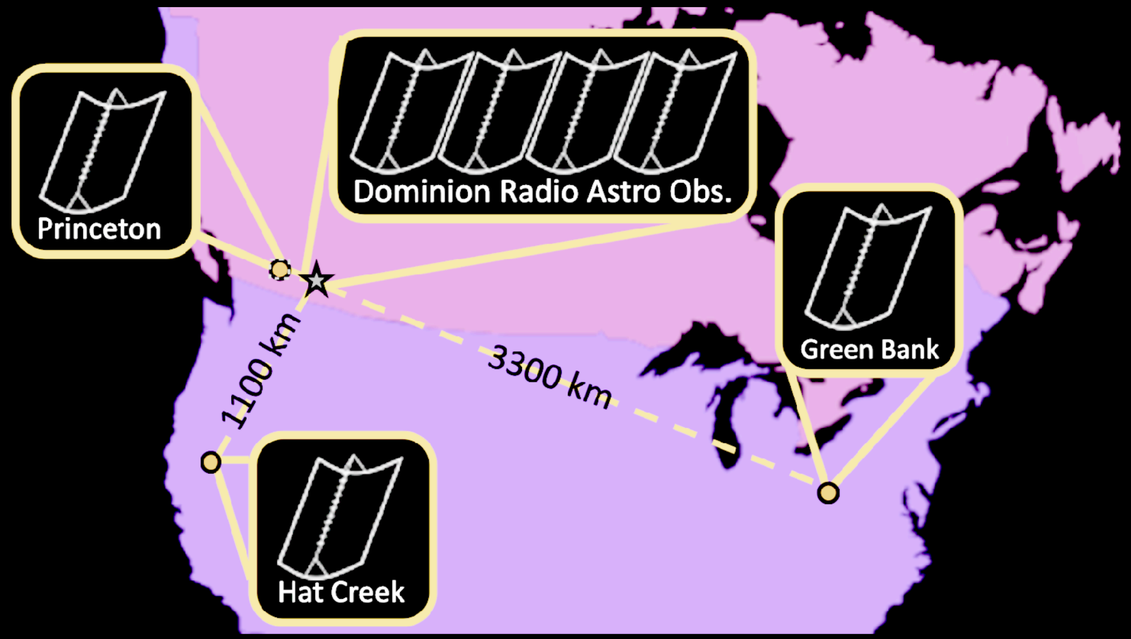
- **Volumetric rate** greater than rates of known one-off transient populations
- Well-constrained **energy function** of FRBs

CHIME/FRB Outriggers



Credit: Adam Lanman, McGill

CHIME/FRB Outriggers



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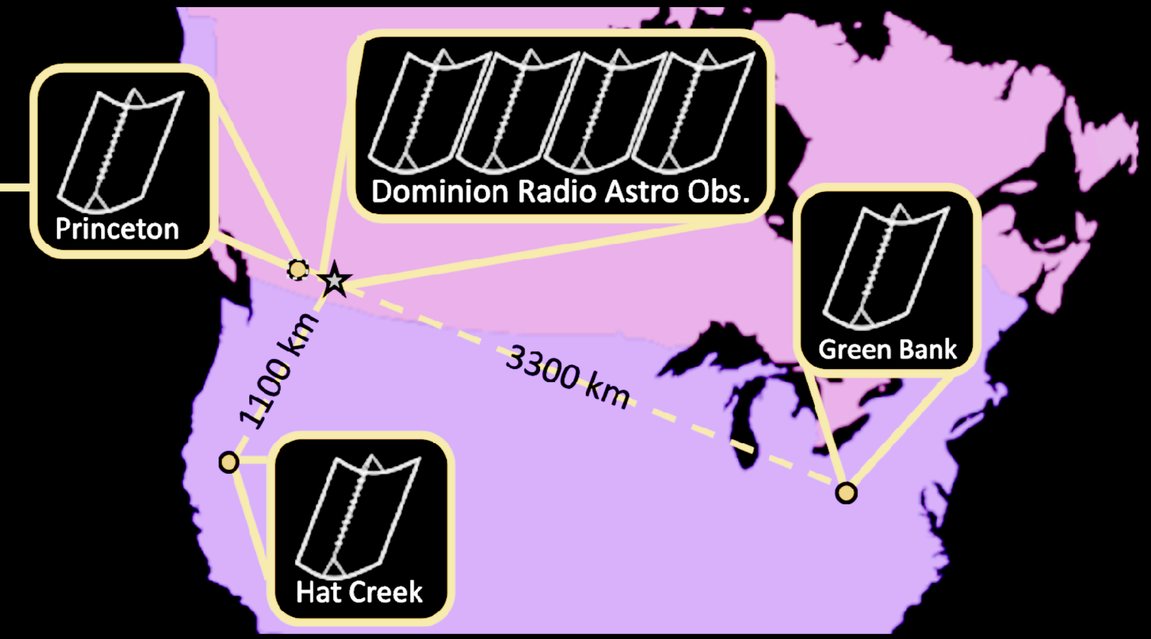

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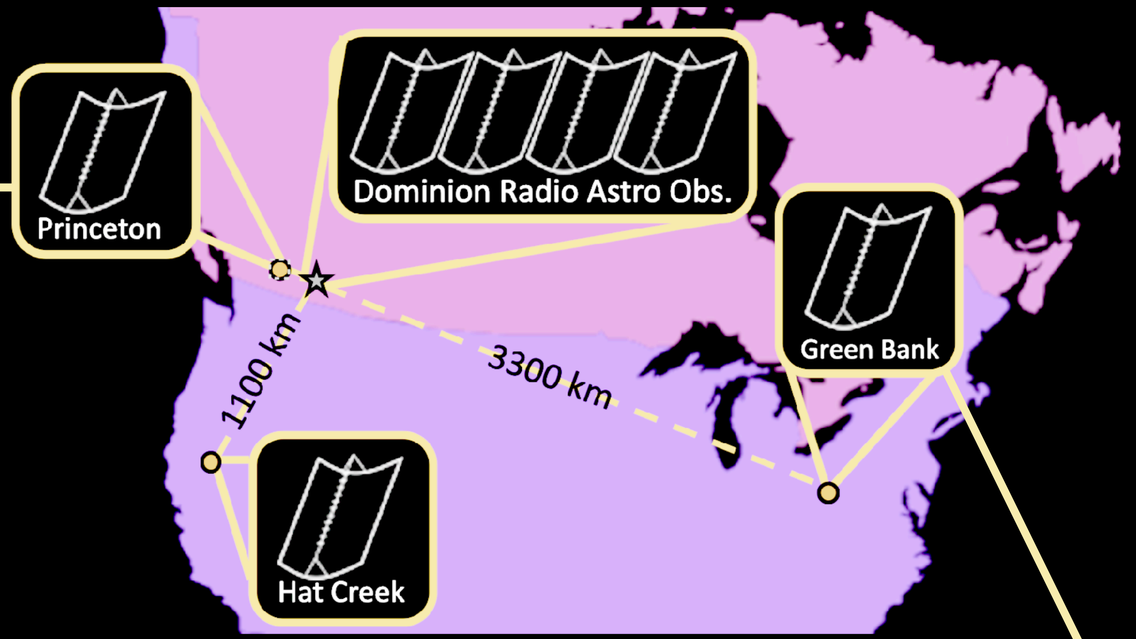

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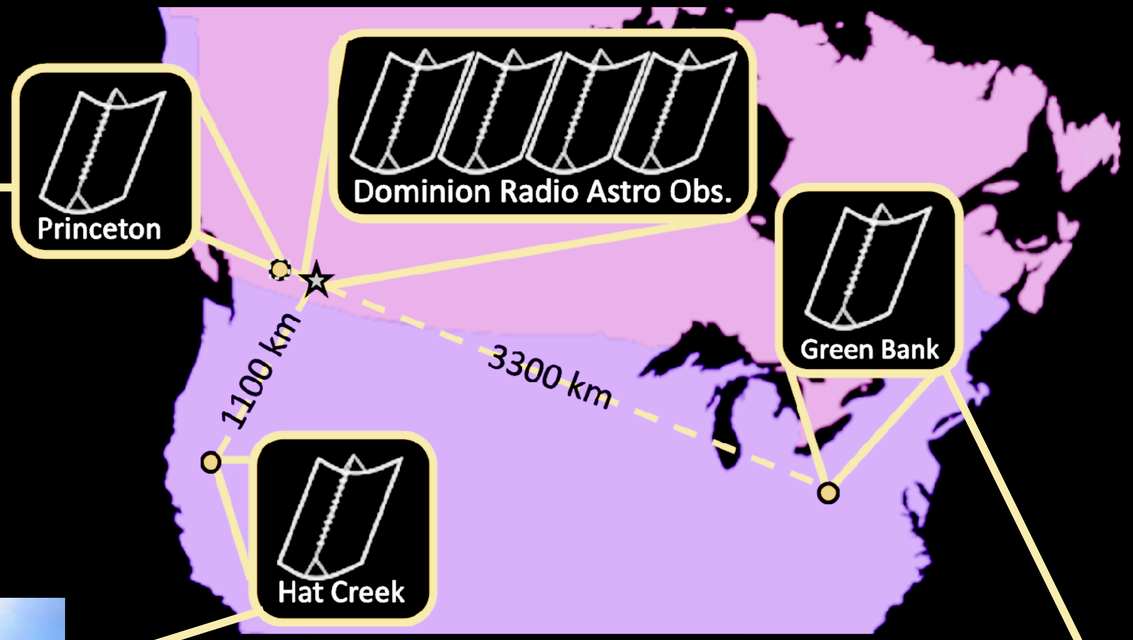
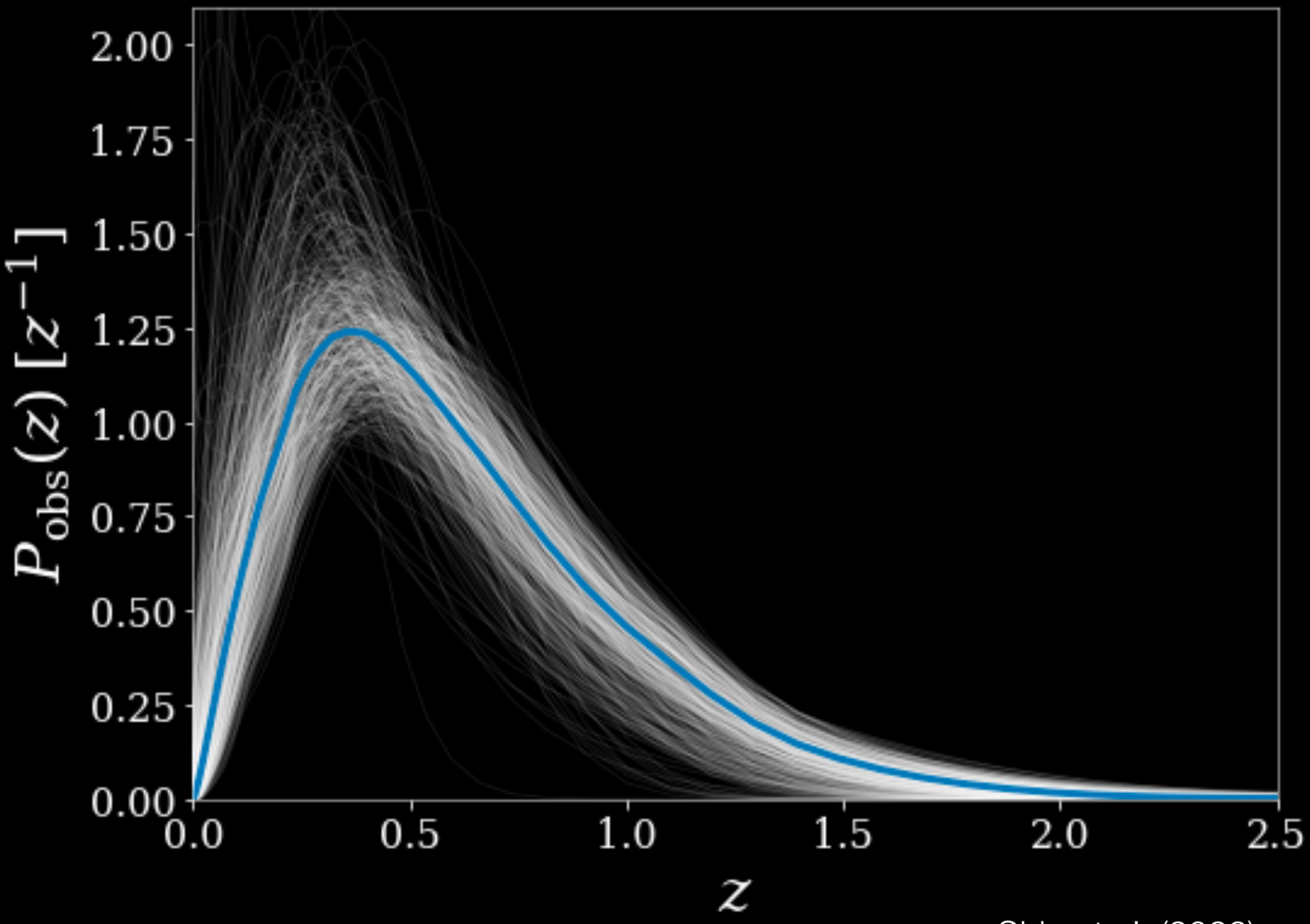


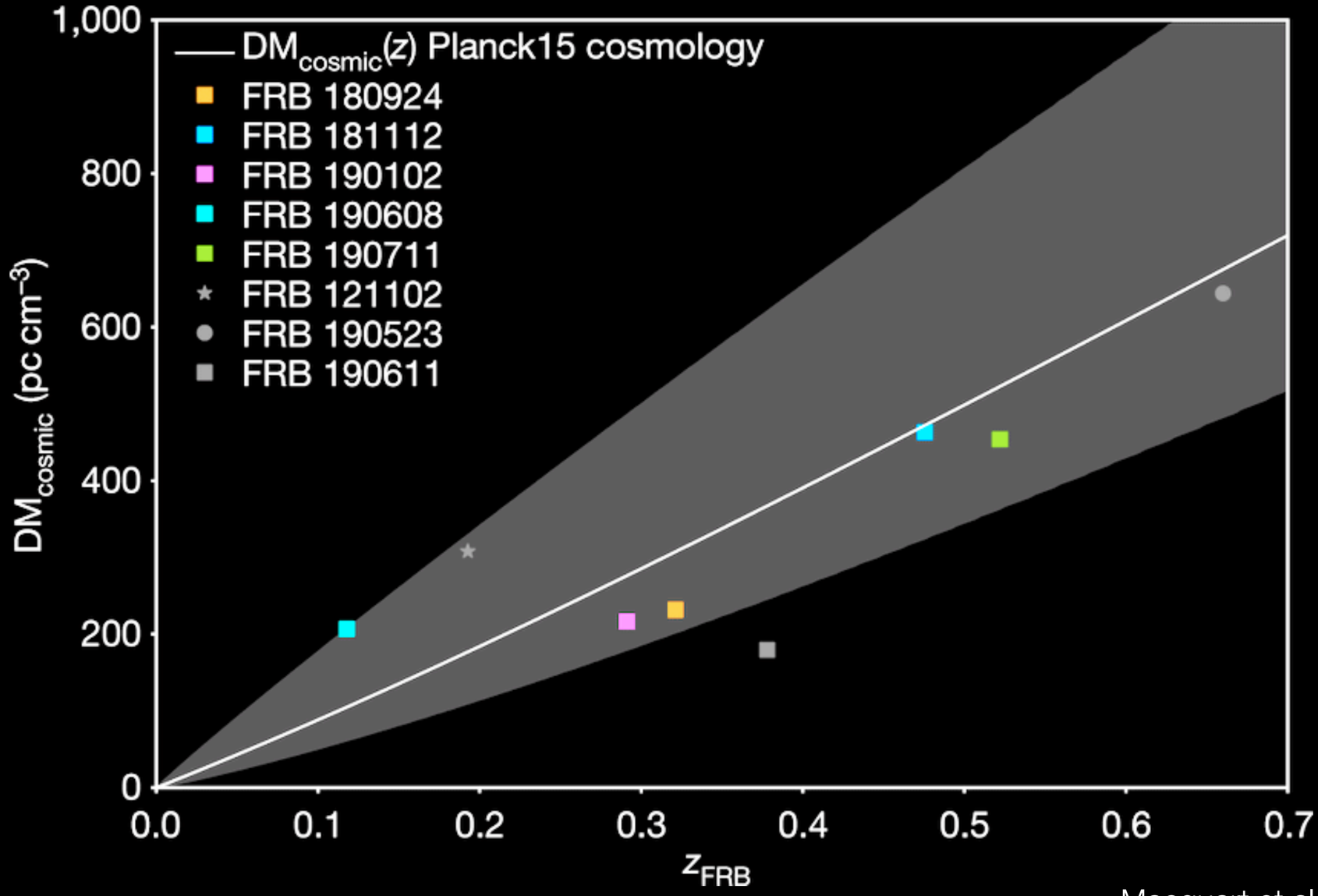
Predicting a $P_{\mathrm{obs}}(z)$

- Can predict $P_{\mathrm{obs}}(z)$ for certain CHIME/FRB-observed sources
- Peaks around $z \sim 0.36$
- >99% of area within $z \leq 2$



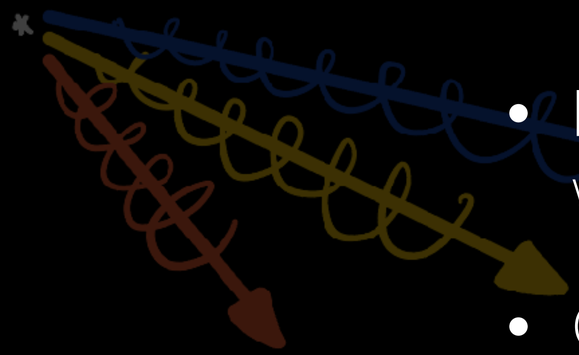
Shin et al. (2022)

DM-z Macquart Relation



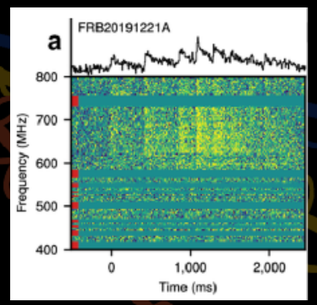
Macquart et al. (2020)

To wrap up



- Lots of data, progress, mysteries, & opportunities with FRBs!
- CHIME/FRB has enormous scientific impact on the community (papers, ATels, etc)
  - → Individual FRB sources ***and*** FRBs as a population
  - → 2007-2018: ~50 FRBs
    2018-2023: ~3,500 FRBs 👑
- **Simultaneously** building new telescopes, developing new analysis techniques, and working on groundbreaking science!

To wrap up



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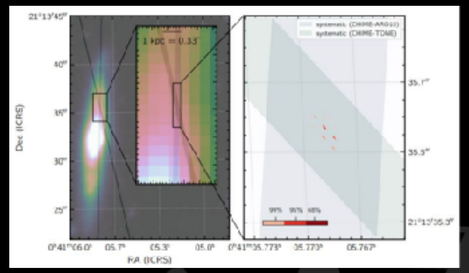

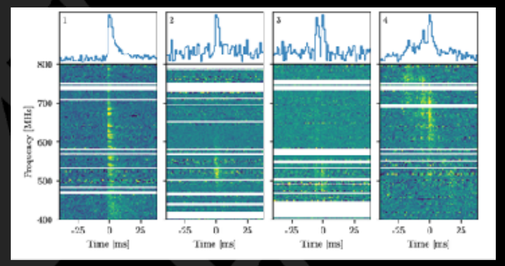

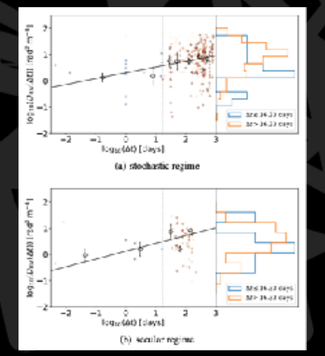

(and even more I couldn't fit in!)