The search for X-ray emission from Fast Radio Bursts: current status and future prospects

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York University

Fast Radio Bursts

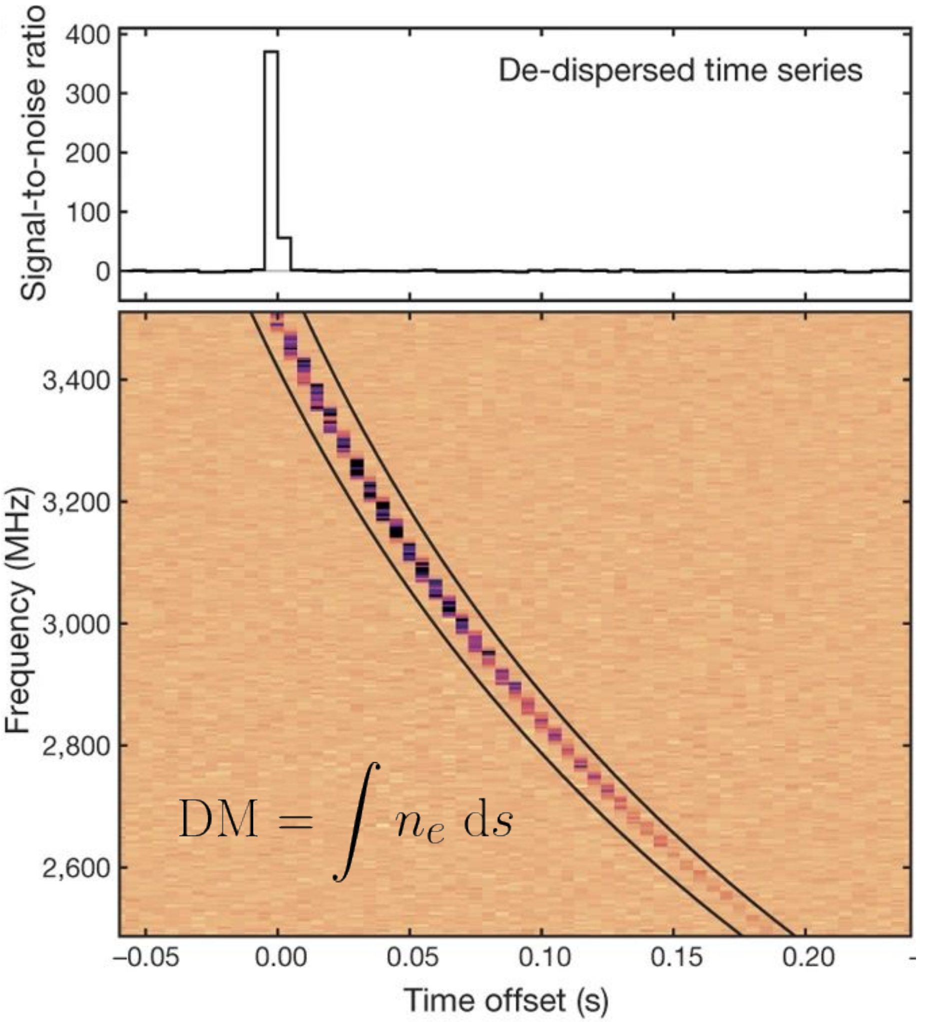
First discovered in 2007

Nanosecond - Millisecond duration (Fast!!)

Large dispersion measure (DM)
→ Extragalactic (up to z=3 so far)

Intrinsically energetic (10^{37} - 10^{42} erg)

Origin unknown!



Chatterjee et al. (2017)

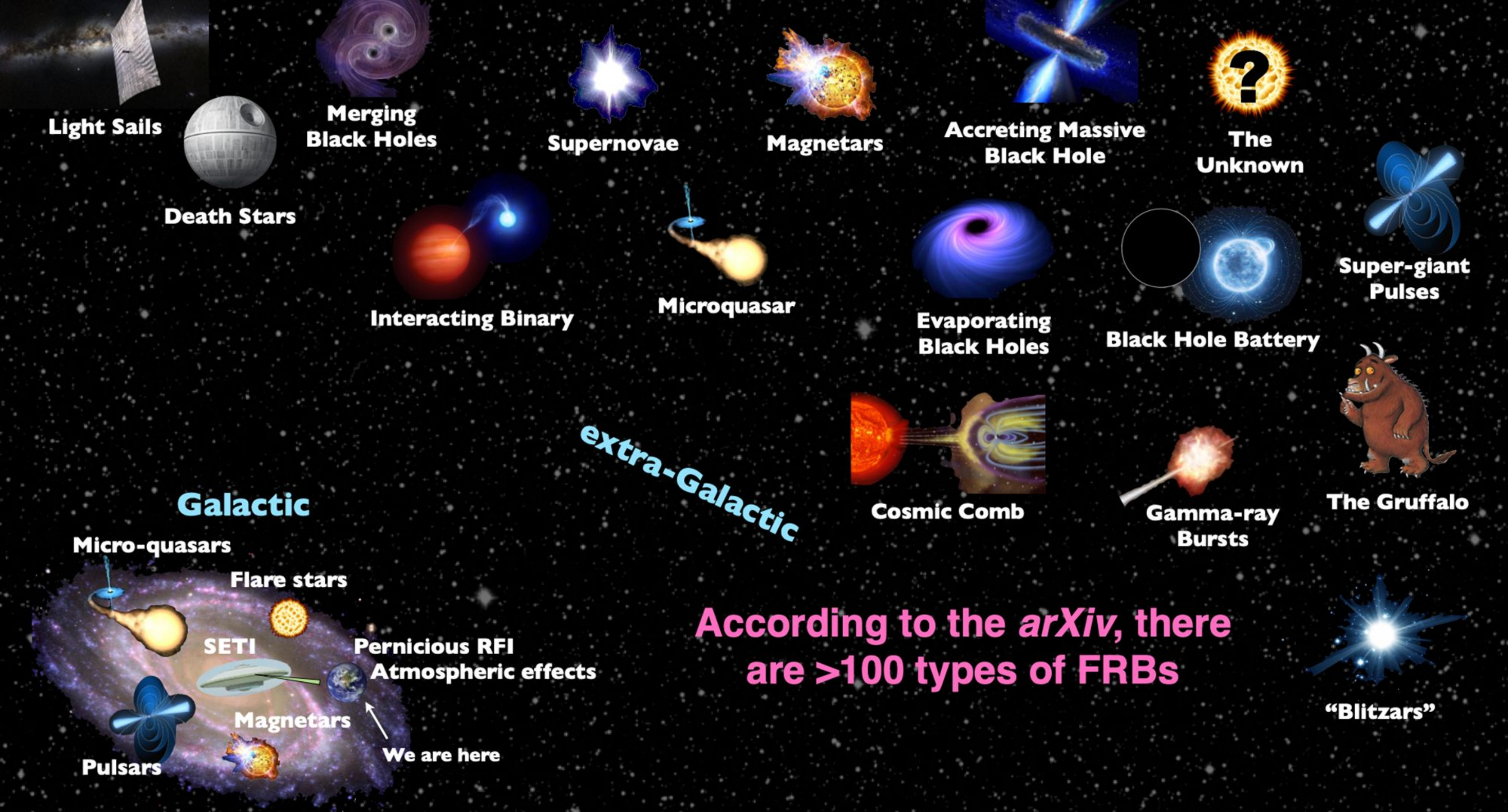


Figure: Hessels

frbtheorycat.org; Platts et al. 2019

Magnetic and relativistic explosions across the universe

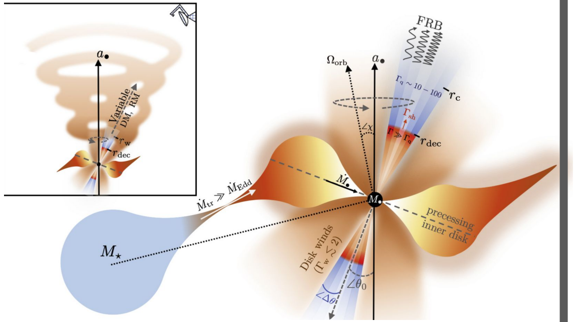
c x 1 ms = 300 km > R

Extreme energetics → Magnetic fields and/or relativistic shocks

FRBs will reveal extreme physics throughout the universe.

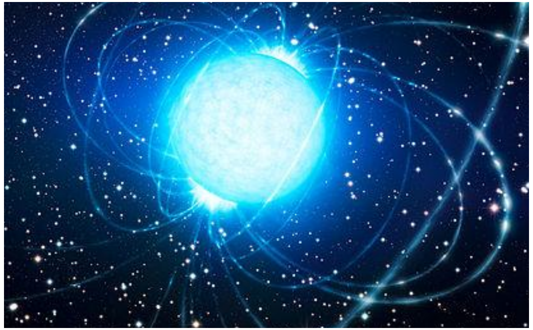
Repeatable

Sridhar et al. (2021)



Shocks in accreting binaries

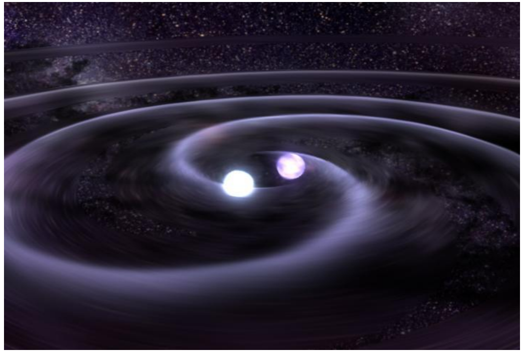
Image credit: ESO/L. Calçada



Giant flares and pulses from magnetars and pulsars.

Cataclysmic

Image credit: NASA/Goddard Space Flight Center



Compact object mergers

Collapse of compact object

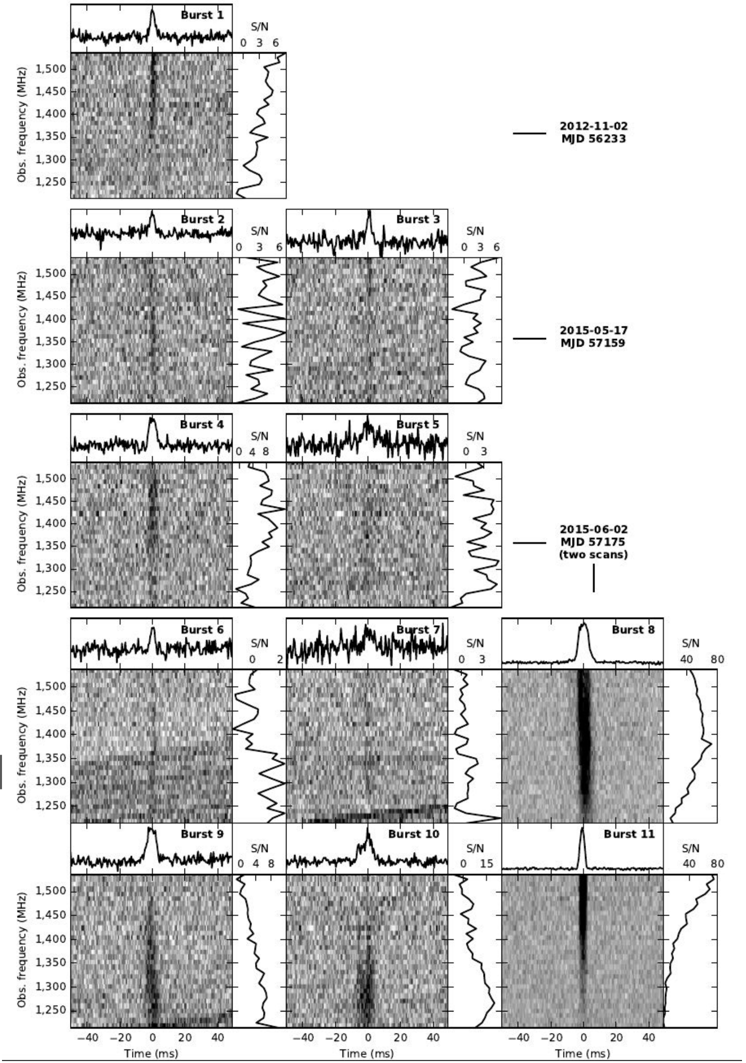
A repeating fast radio burst

(Spitler, Scholz et al. Nature, 2016)

- FRB 20121102A: First burst discovered in 2013 (Spitler et al. 2014)
- Nov 5, 2015: 10 more bursts!
- in 3 hr of follow-up using Arecibo in mid-2015

Implication: All cataclysmic models are ruled out for this source.

(At least some) FRB sources can repeat!



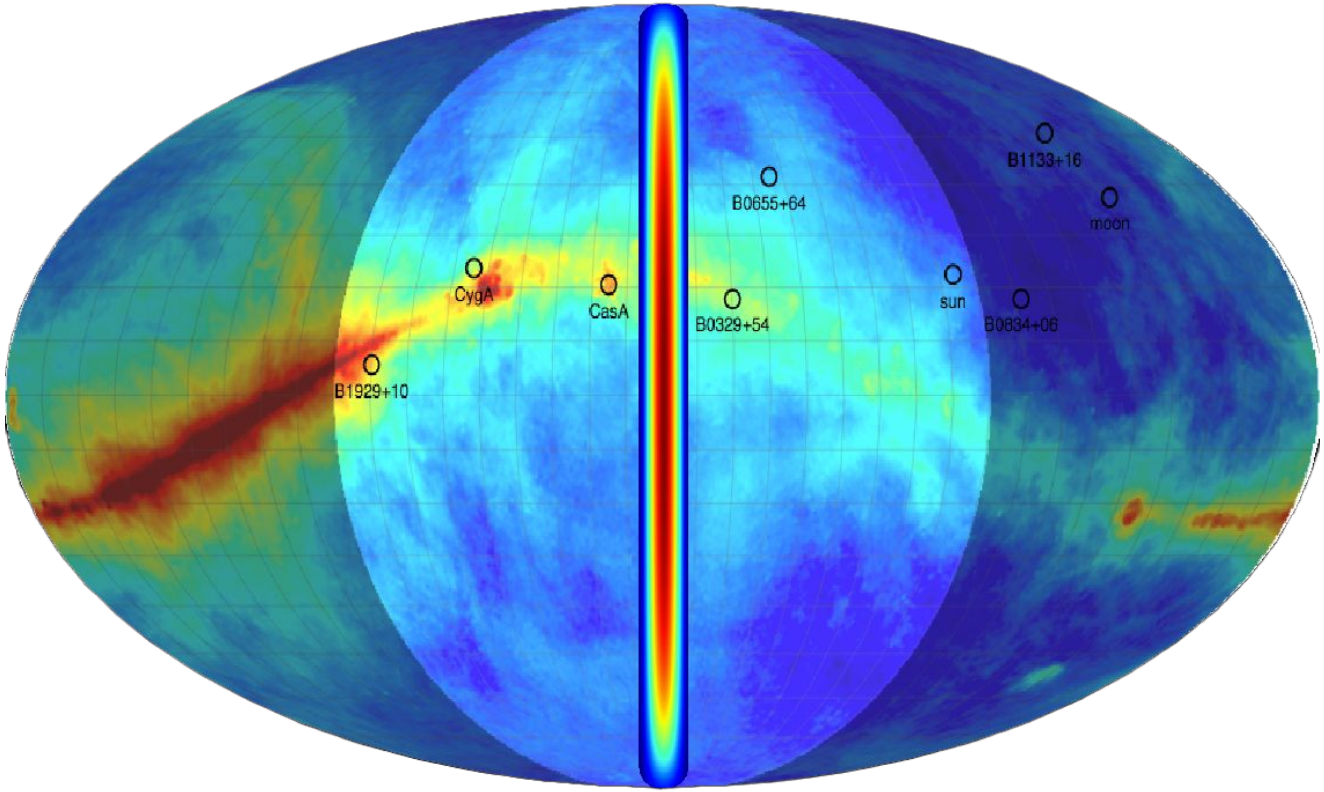
Current FRB search instruments: interferometers

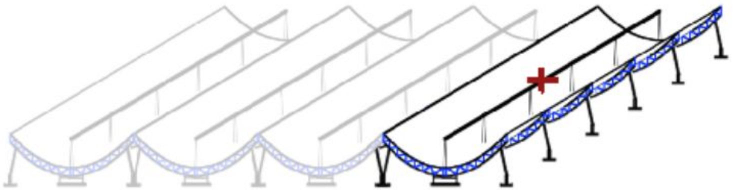
Canadian Hydrogen Intensity Mapping Experiment

chime

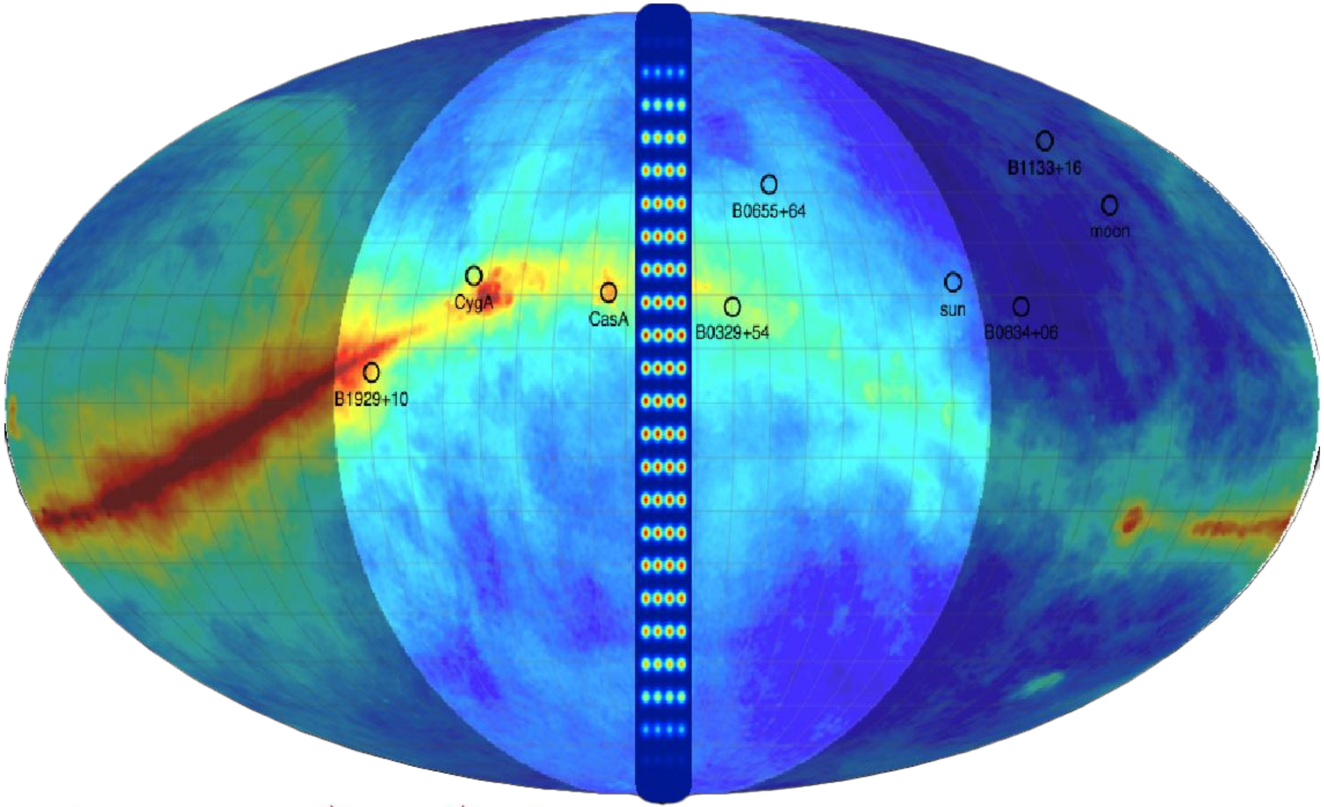
CHIME/FRB F2F meeting Jan 2025

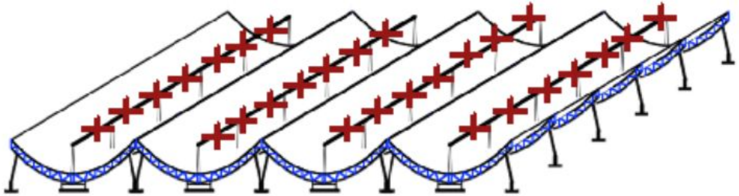
Image credit:
J. R. Shaw/
CHIME Collab.



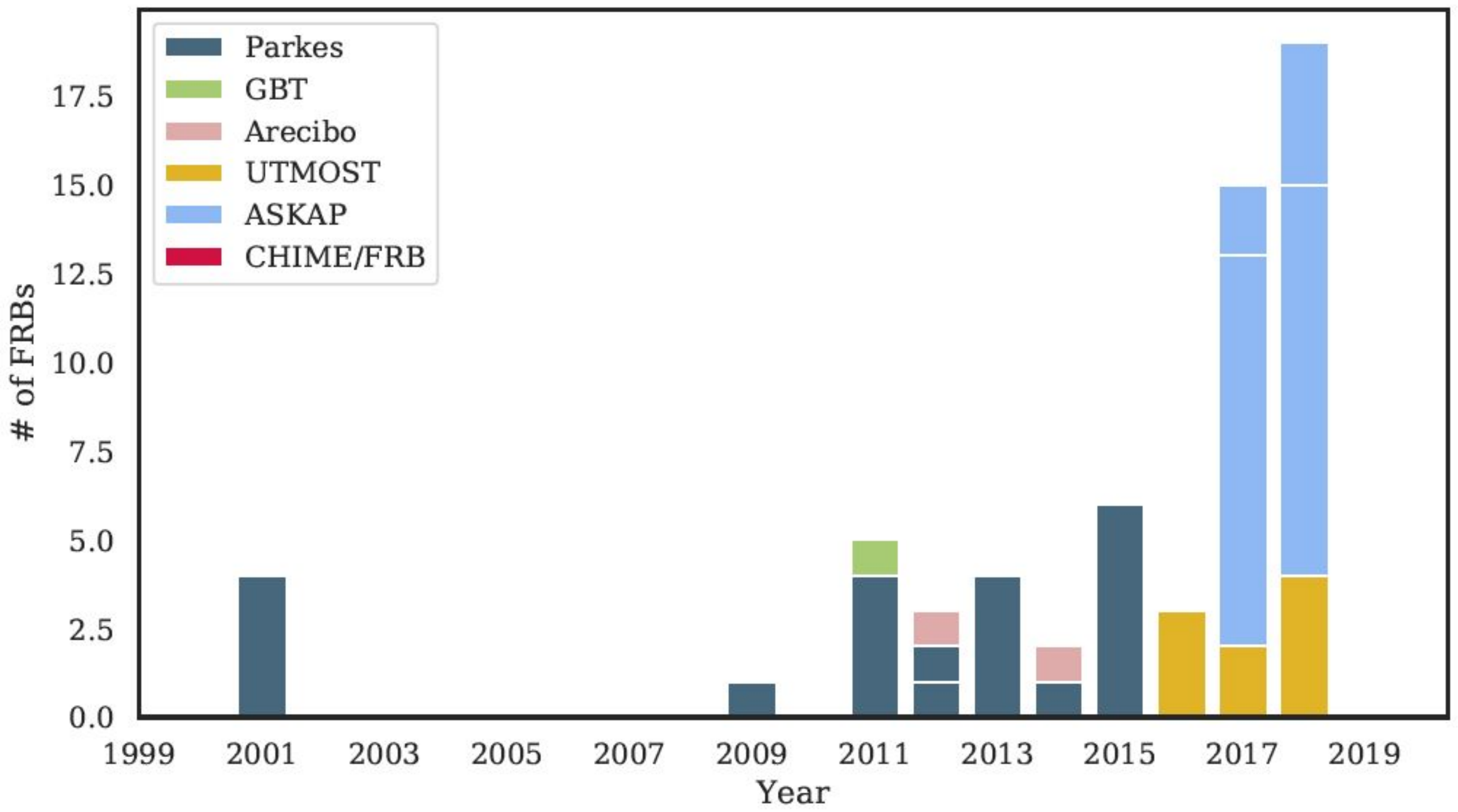


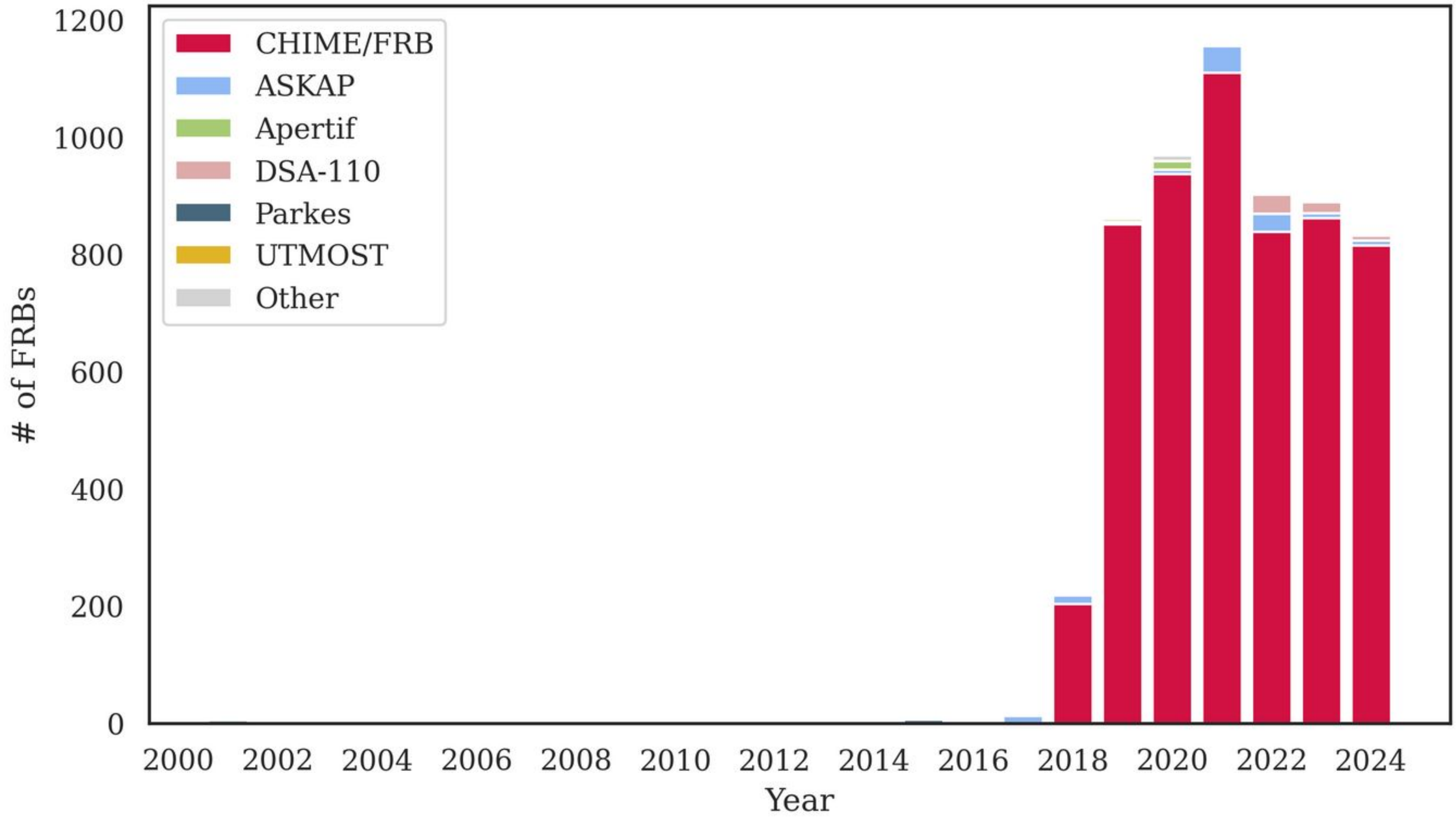
Cylinder focuses light only in E-W direction.
Leads to large field-of-view.

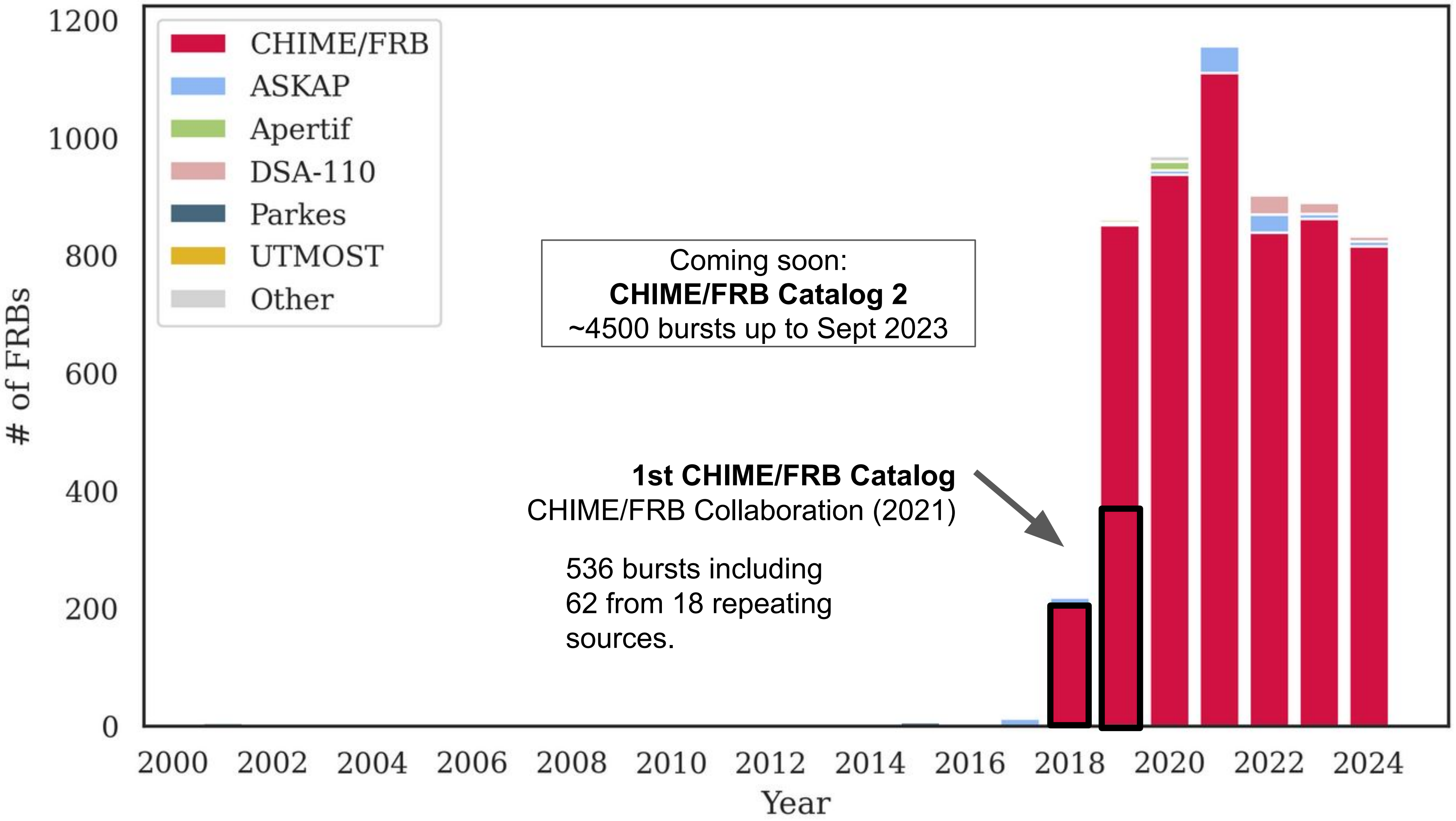




Form 1024 beams using signals from feeds on all 4 cylinders.


Parkes
GBT
Arecibo
UTMOST
ASKAP
CHIME/FRB
# of FRBs
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
1999
2001
2003
2005
2007
2009
2011
2013
2015
2017
2019
Year

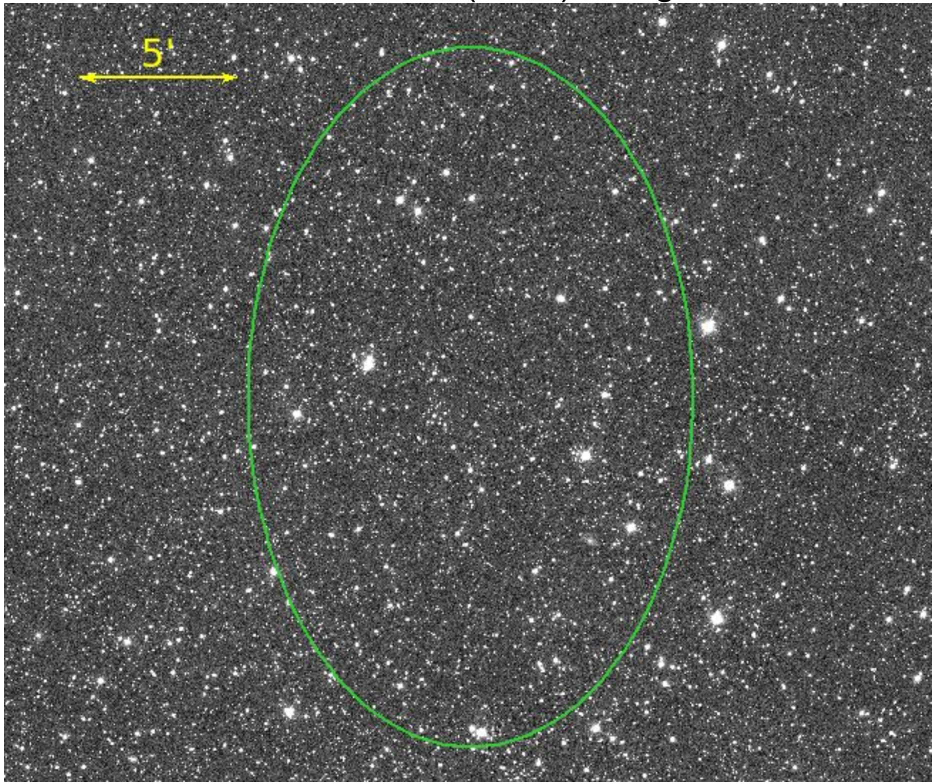

CHIME/FRB
ASKAP
Apertif
DSA-110
Parkes
UTMOST
Other
1200
1000
800
600
400
200
0
# of FRBs
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
Year



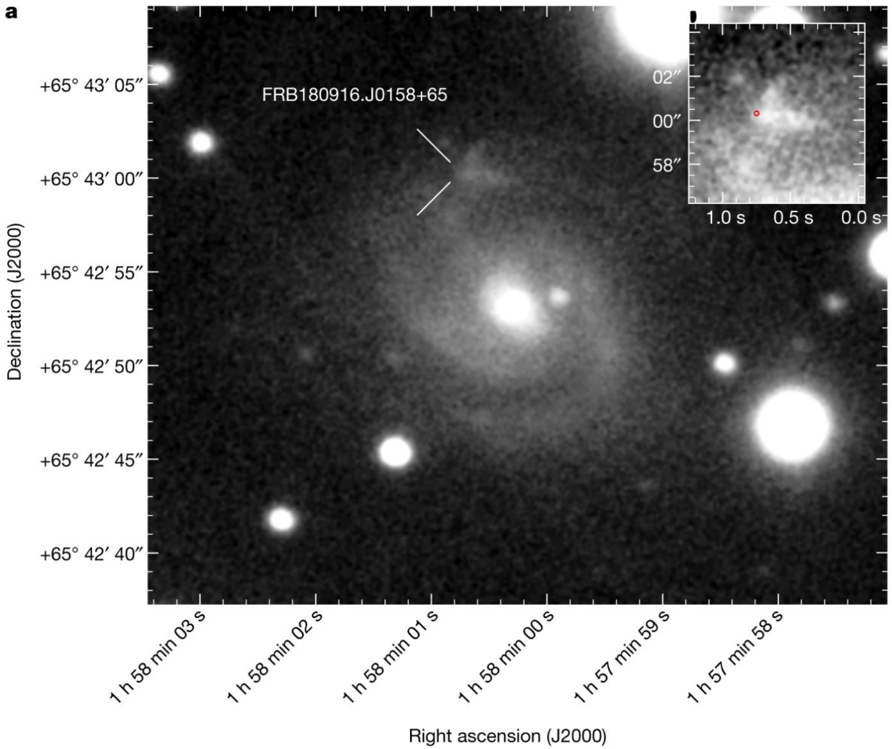
CHIME/FRB
ASKAP
Apertif
DSA-110
Parkes
UTMOST
Other
Coming soon:
CHIME/FRB Catalog 2
~4500 bursts up to Sept 2023
1st CHIME/FRB Catalog
CHIME/FRB Collaboration (2021)
536 bursts including
62 from 18 repeating
sources.
# of FRBs
Year
0
200
400
600
800
1000
1200
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024

Ok, but where are FRBs coming from? e.g FRB 20180916B

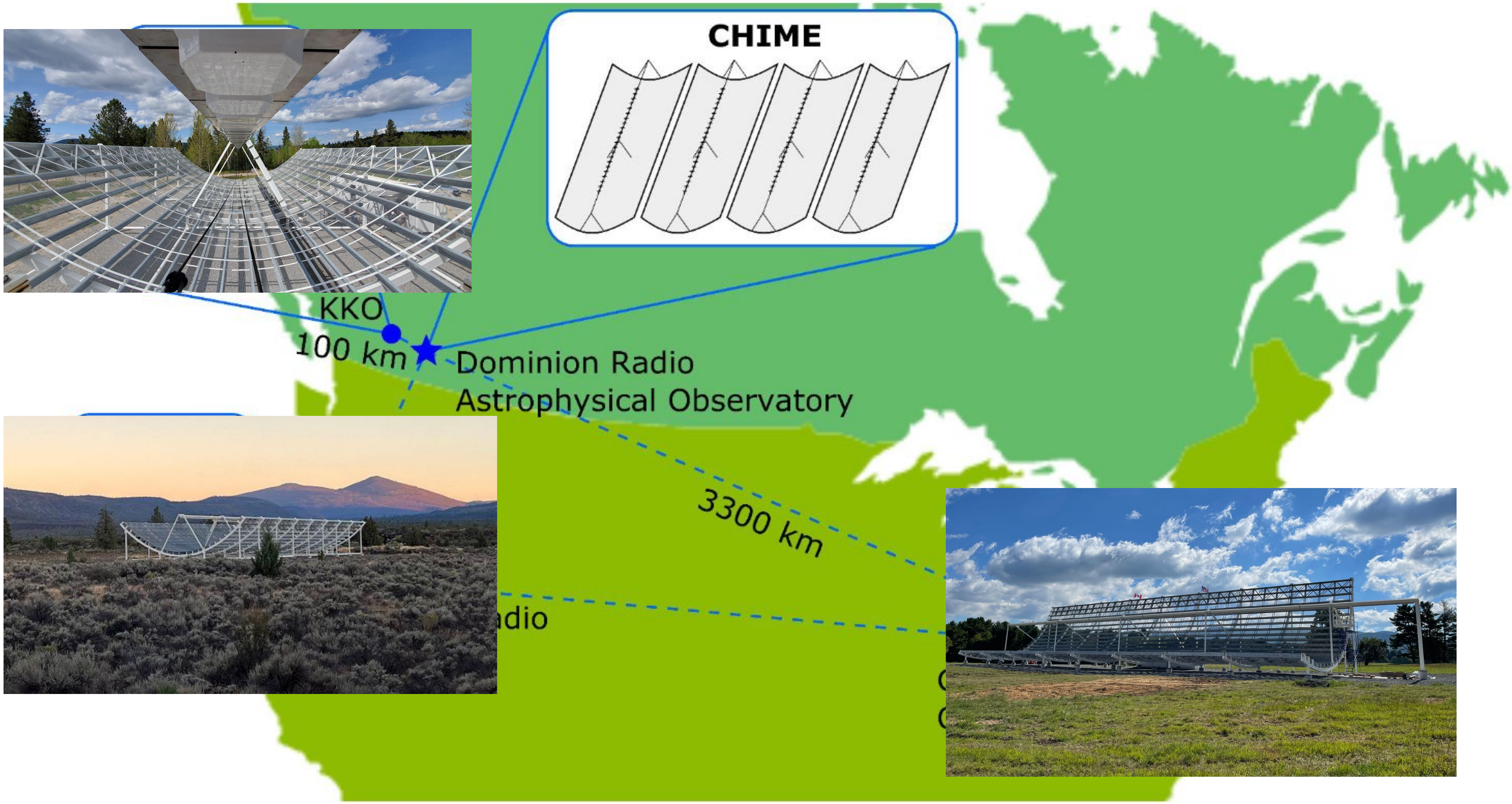
CHIME localization (~10 arcminutes):
CHIME/FRB Collaboration (2019), Image from SDSS



European VLBI Network localization (2 milliarcseconds):
Marcote et al. (2020)

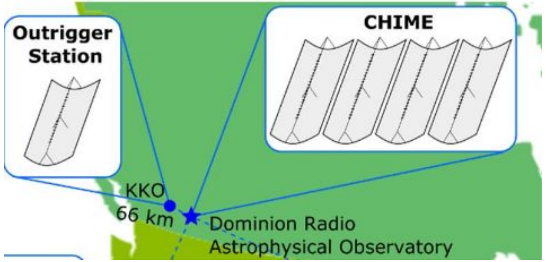


CHIME Outriggers

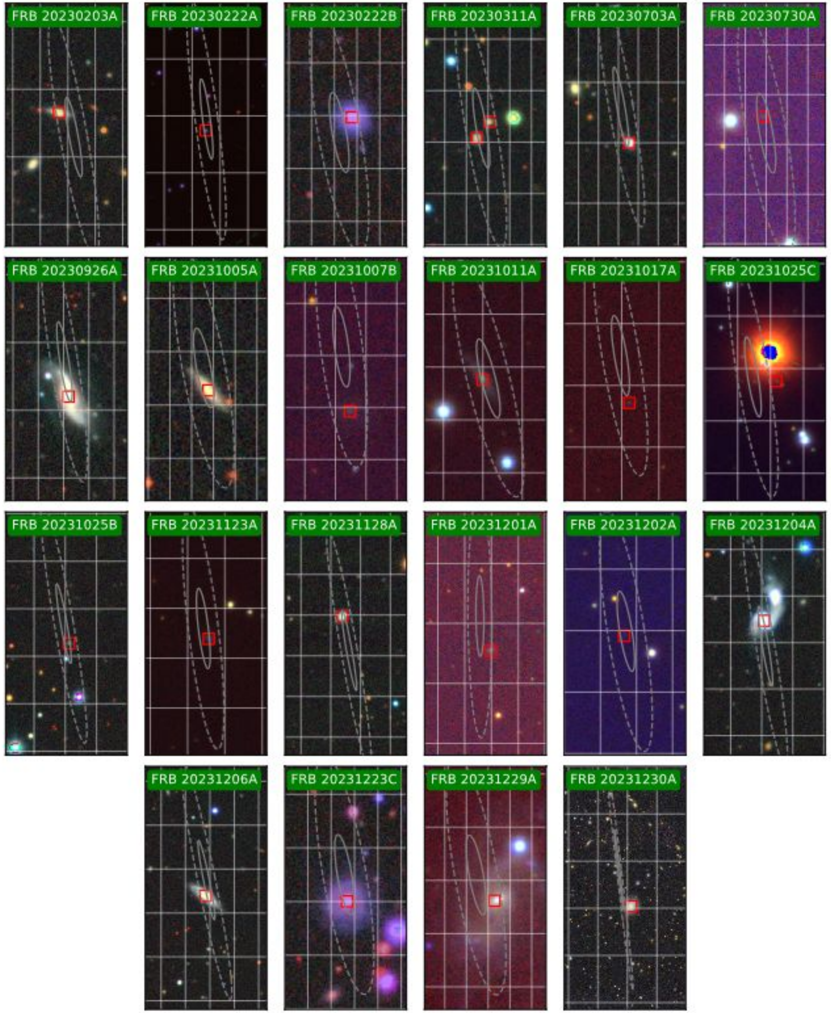


Outrigger localizations

First sample of CHIME/FRB Outrigger localizations.

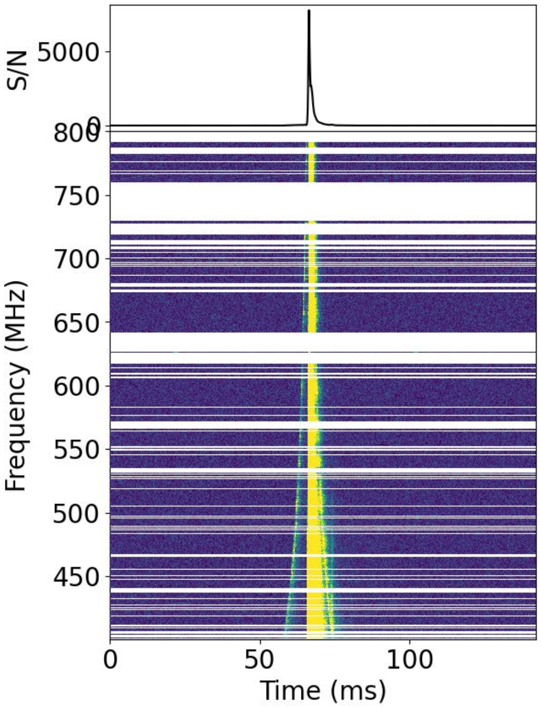


- 81 FRB localizations
- 21 new FRBs with host galaxies
- Near future: large catalogs of sub-arcsecond localized FRBs!

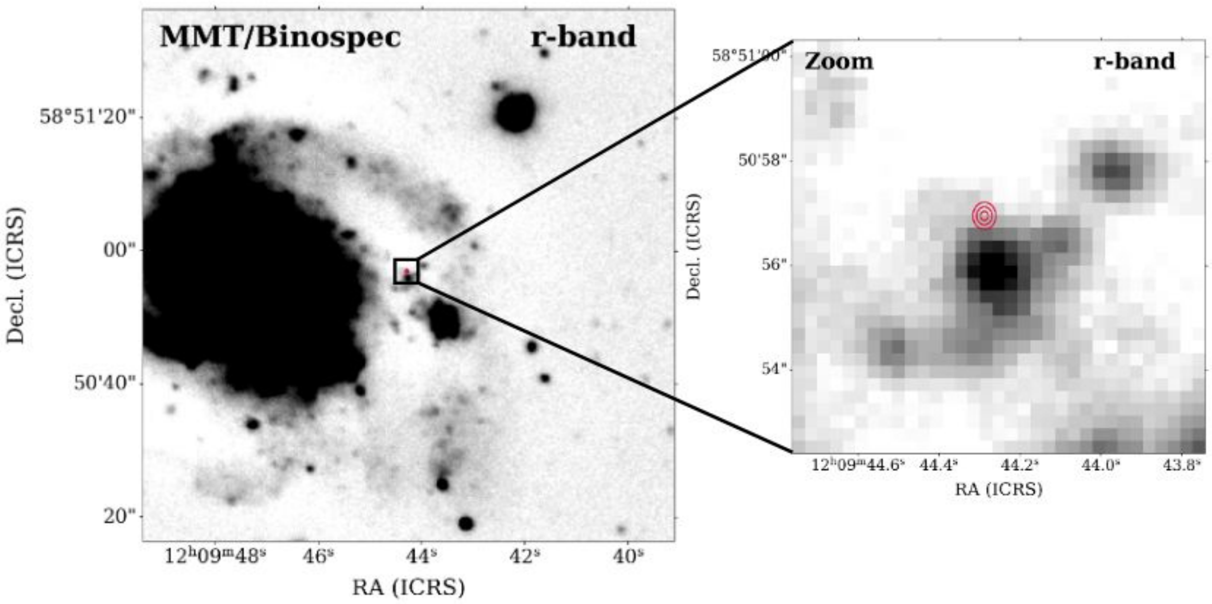


CHIME/FRB Collaboration (2025)

CHIME Outriggers: First full array localization!

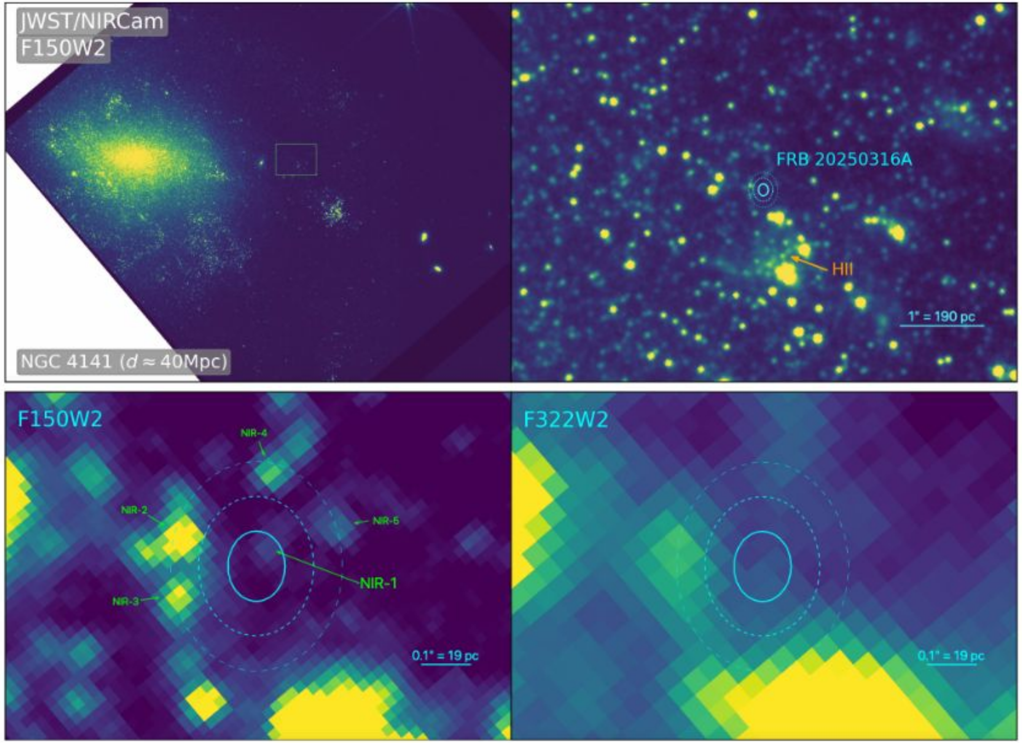


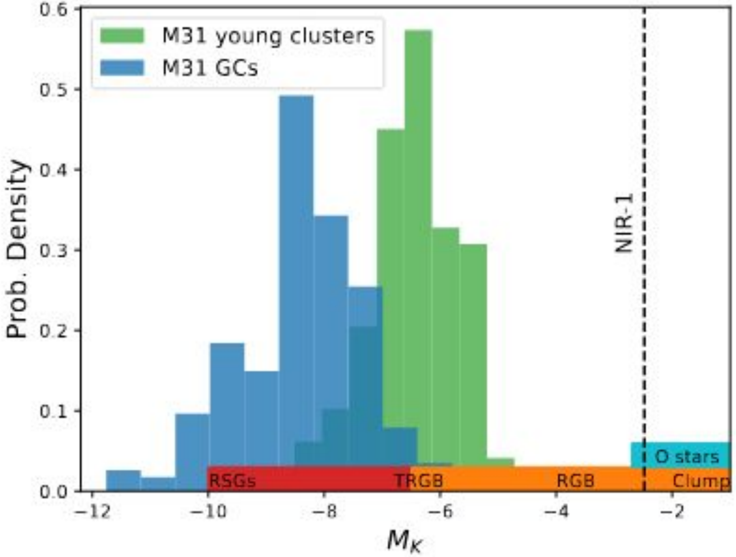
Ng and CHIME/FRB (2025), ATel #17081



CHIME/FRB Collaboration (2025)

Power of mas localizations!



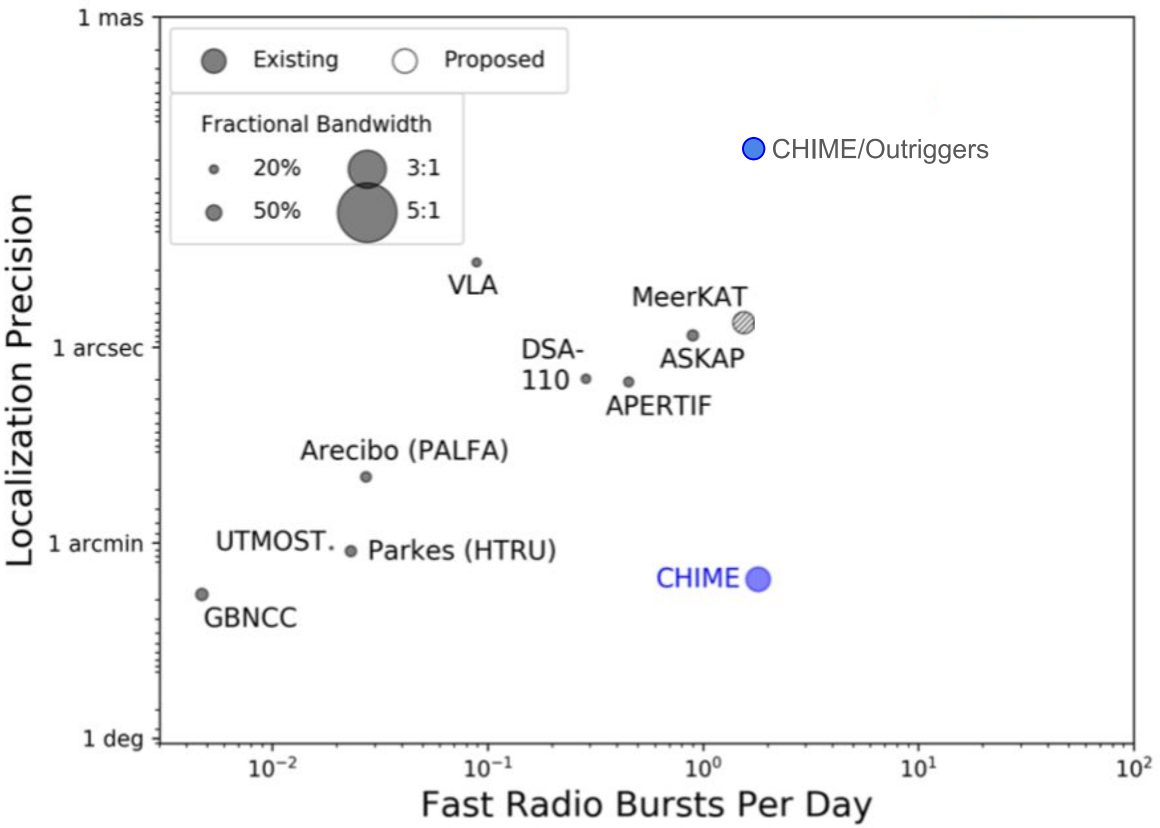


Blanchard et al. (2025)

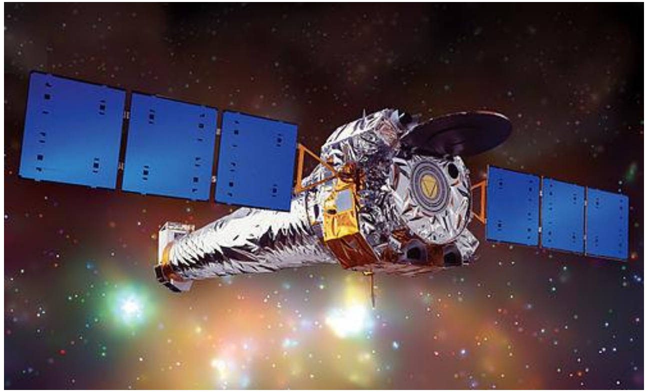
FRB localization

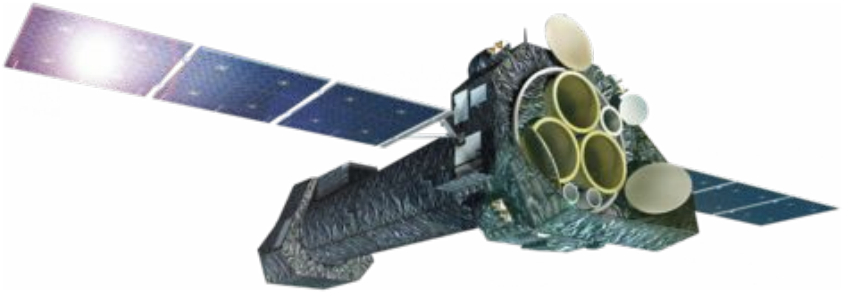
State of FRBs now:

- Thousands of FRBs discovered by CHIME. Mostly poorly localized.
- Dozens localized to host galaxies.
- CHIME/Outriggers over next few years: thousands with host-ID enabling localizations.

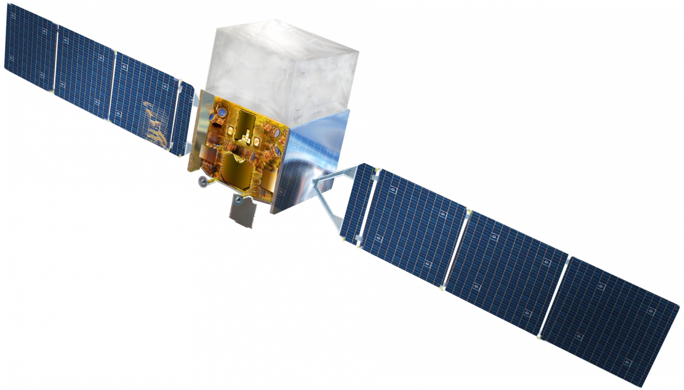


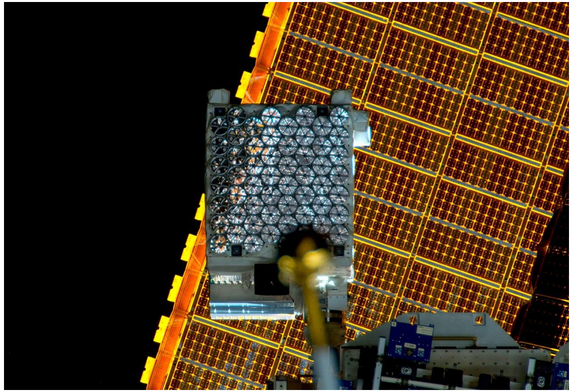
Vanderlinde et al. 2019





Current X-ray limits on FRBs





An FRB-like burst from a Galactic Magnetar

CHIME/FRB Collaboration (2020)
See also codetection by Bockenek et al. (2020)

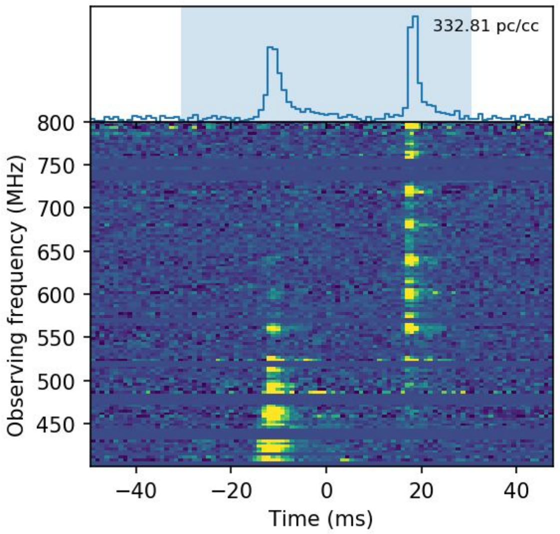
In April 2020: An extremely bright fast radio burst detected from a source within our galaxy: magnetar SGR 1935+2154

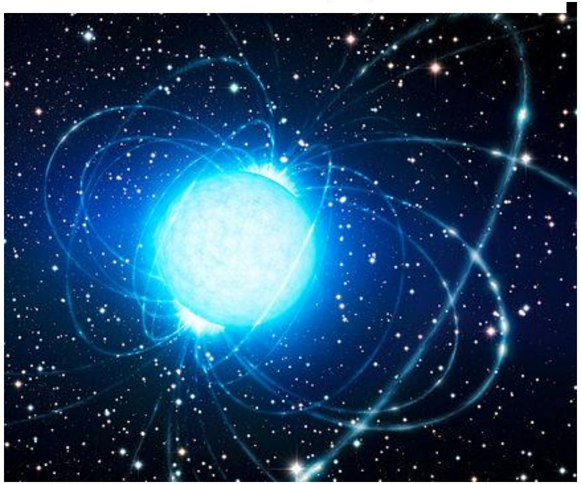
Would have been detectable from nearby galaxies.

Some FRBs are magnetars!

Follow-up question: Are all FRBs magnetars?

Problems: Energetics and environment.

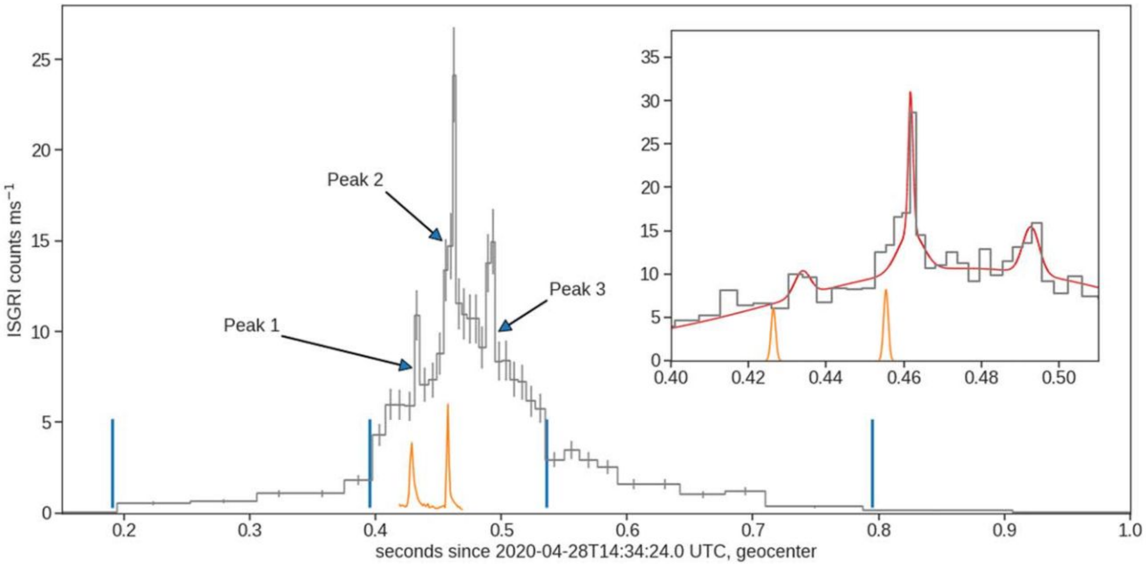




(Artist's Impression) Credit: ESO/L. Calçada

SGR 1935+2154

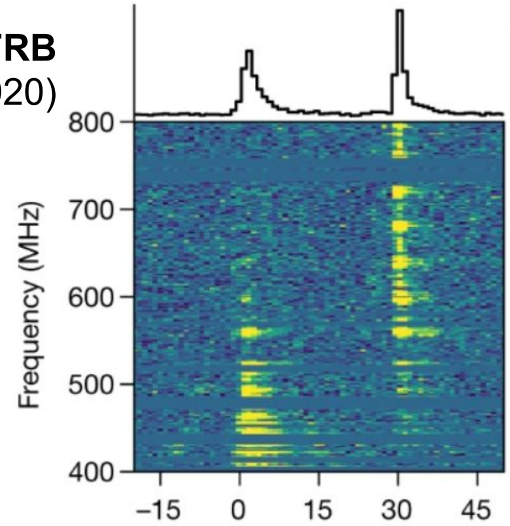
April 28, 2020 FRB-like event: X-ray counterpart!

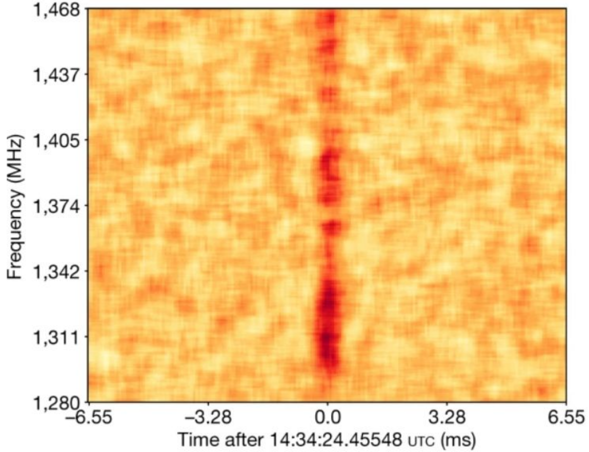


INTEGRAL Mereghetti et al. (2020)

Also detected by: **Insight-HXMT** (Li et al. 2020),
Konus-Wind (Ridnaia et al. 2020), **AGILE** (Tavani et al. 2020)

CHIME/FRB
(CHIME/FRB Collaboration 2020)





STARE2 (Bochenek et al. 2020)

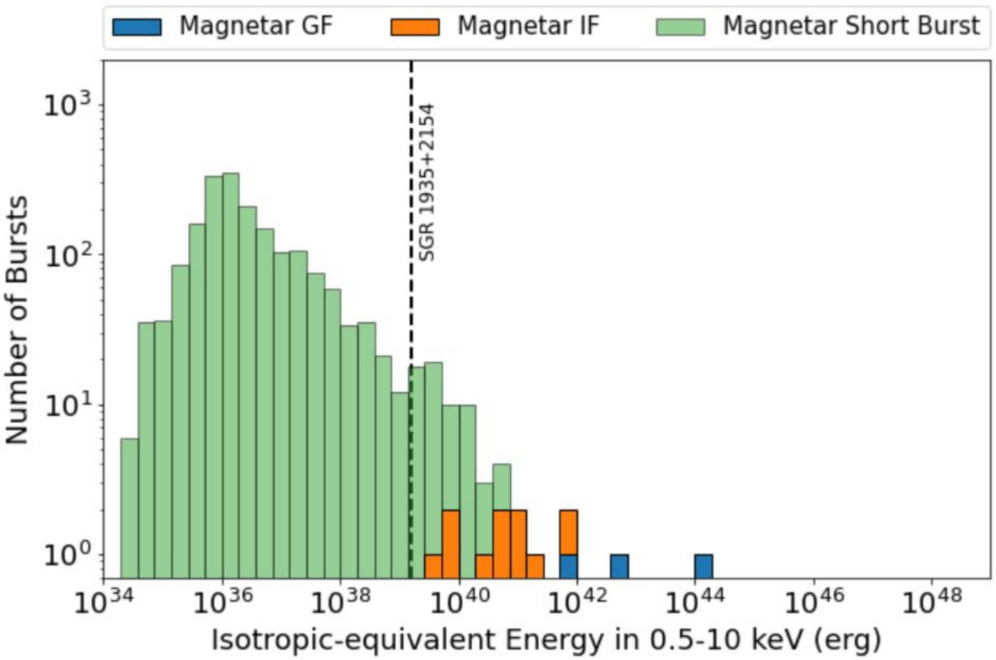
Current limits: Energy

Prompt Soft X-ray limits.

Green: Short X-ray bursts from Galactic magnetars.

Orange: Intermediate flares from Galactic magnetars

Blue: Giant flares from Galactic magnetars.



Pearlman, Scholz et al. 2025

Current limits: Energy

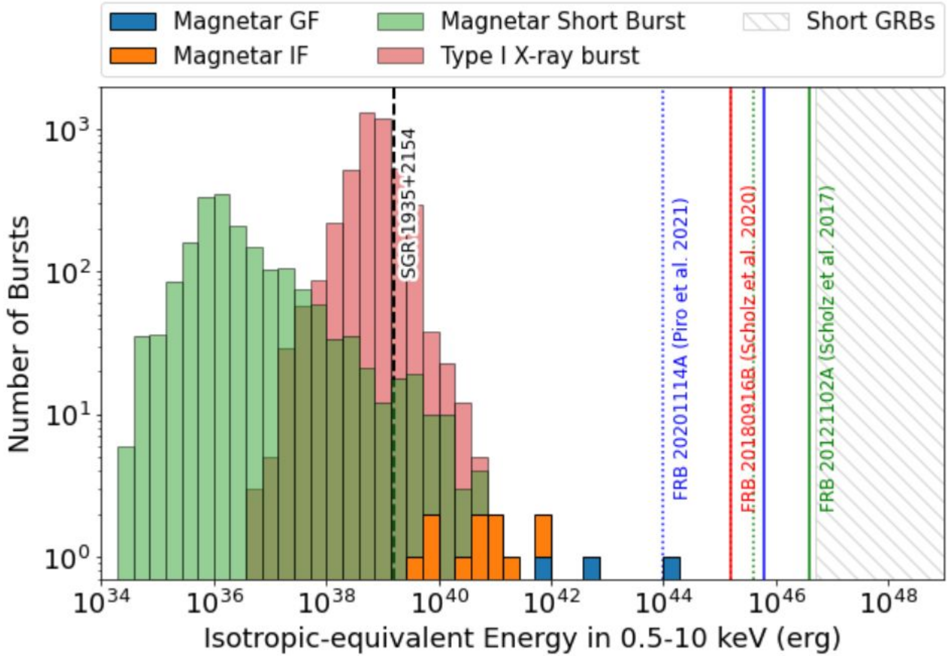
Prompt Soft X-ray limits:

Based on:

- Telescope fluence sensitivity (fixed): ~1 x 10^{-10} erg cm^{-2} (Chandra, XMM, NICER etc)
- Distance to source.

Want : Deeper in energy →
Need: closer sources,
Bigger X-ray telescopes.

Solid lines: 5σ single burst upper limits
Dotted lines: 5σ multi-burst upper limits
(12 for 20121102A, 49 for 20201114A)



Pearlman, Scholz et al. 2025

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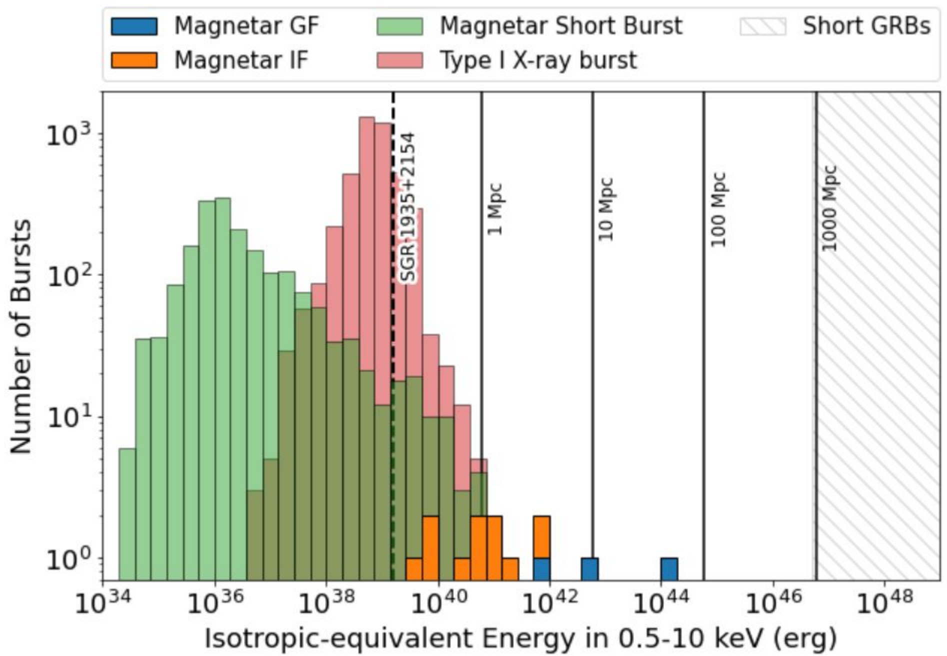
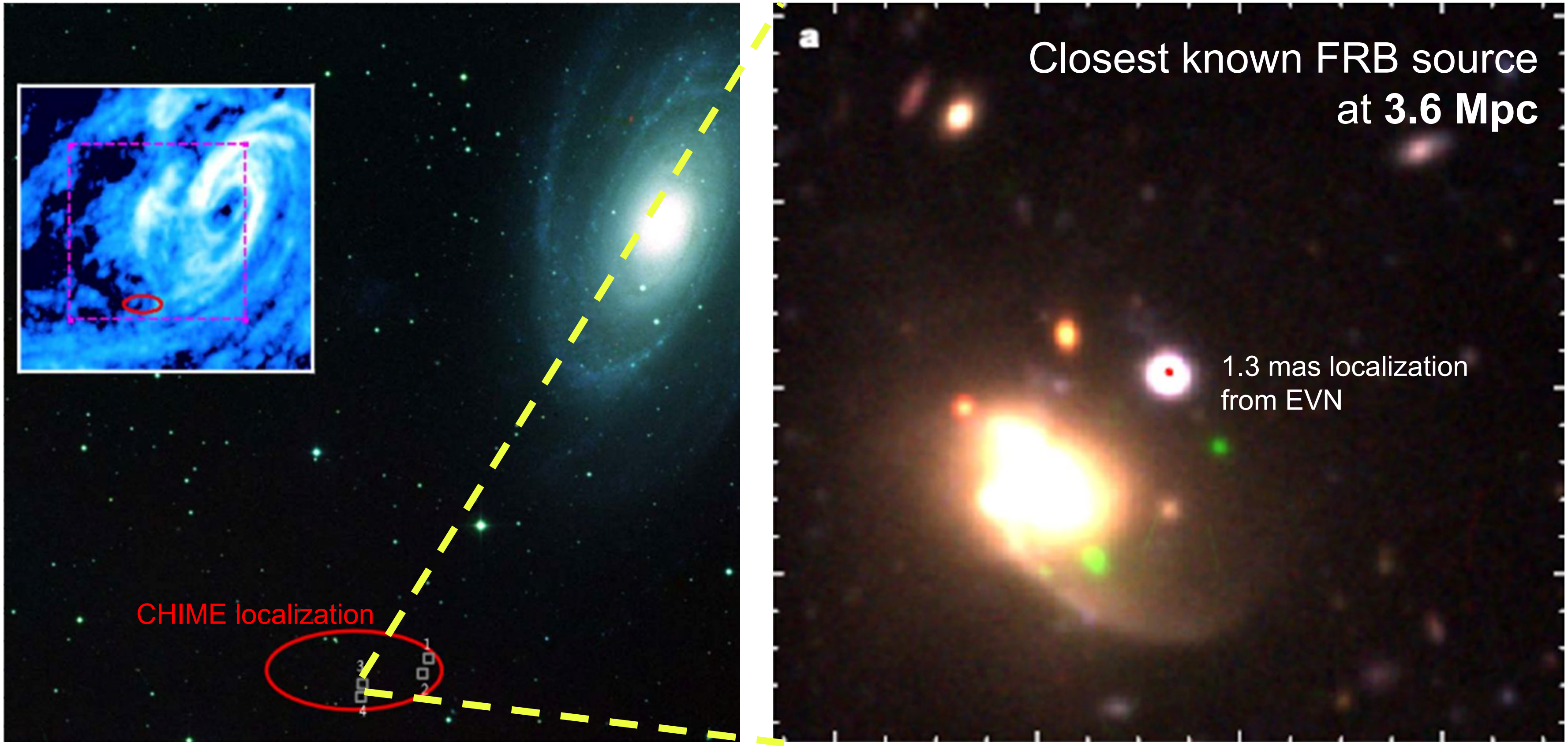


Pearlman, Scholz et al. 2025

FRB 20200120E: FRB in a M81 Globular Cluster

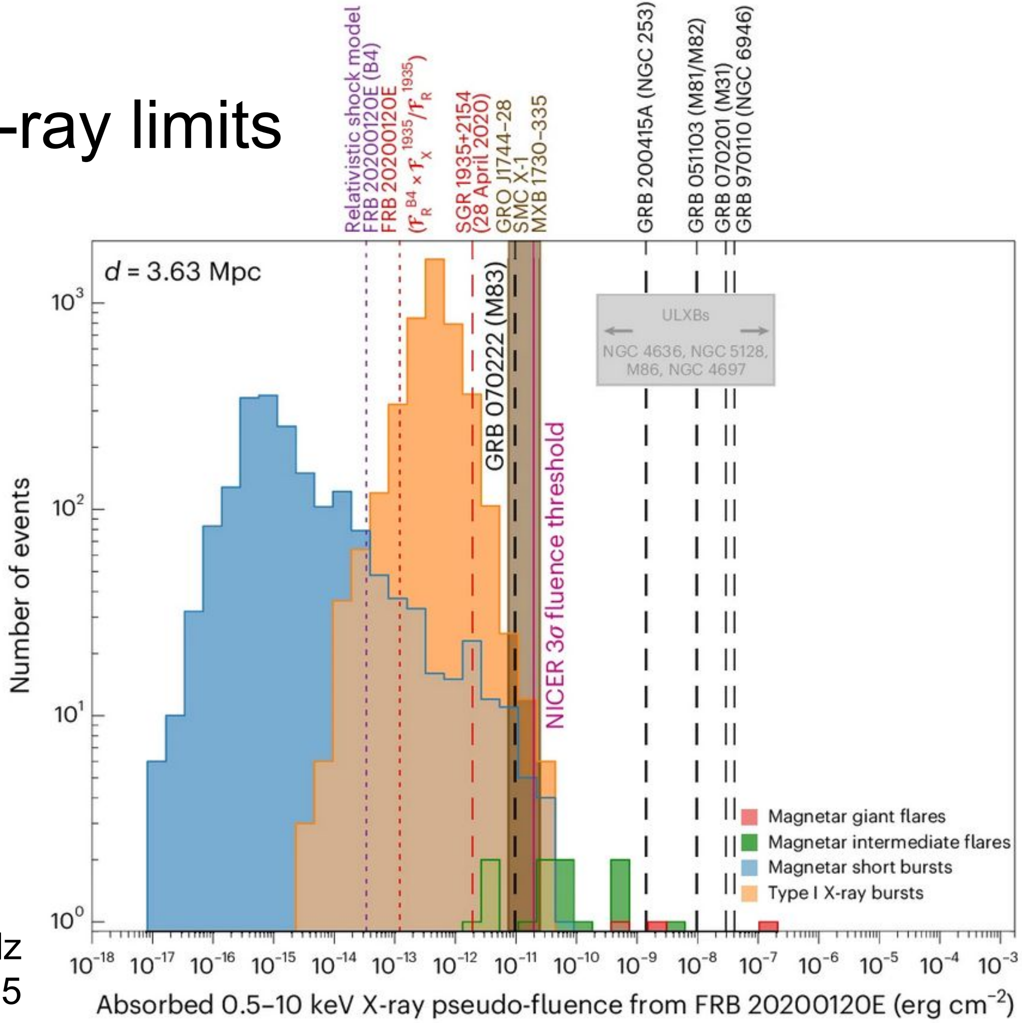


Bhardwaj et al. 2021

Kirsten et al. 2022

FRB 20200120E Prompt X-ray limits

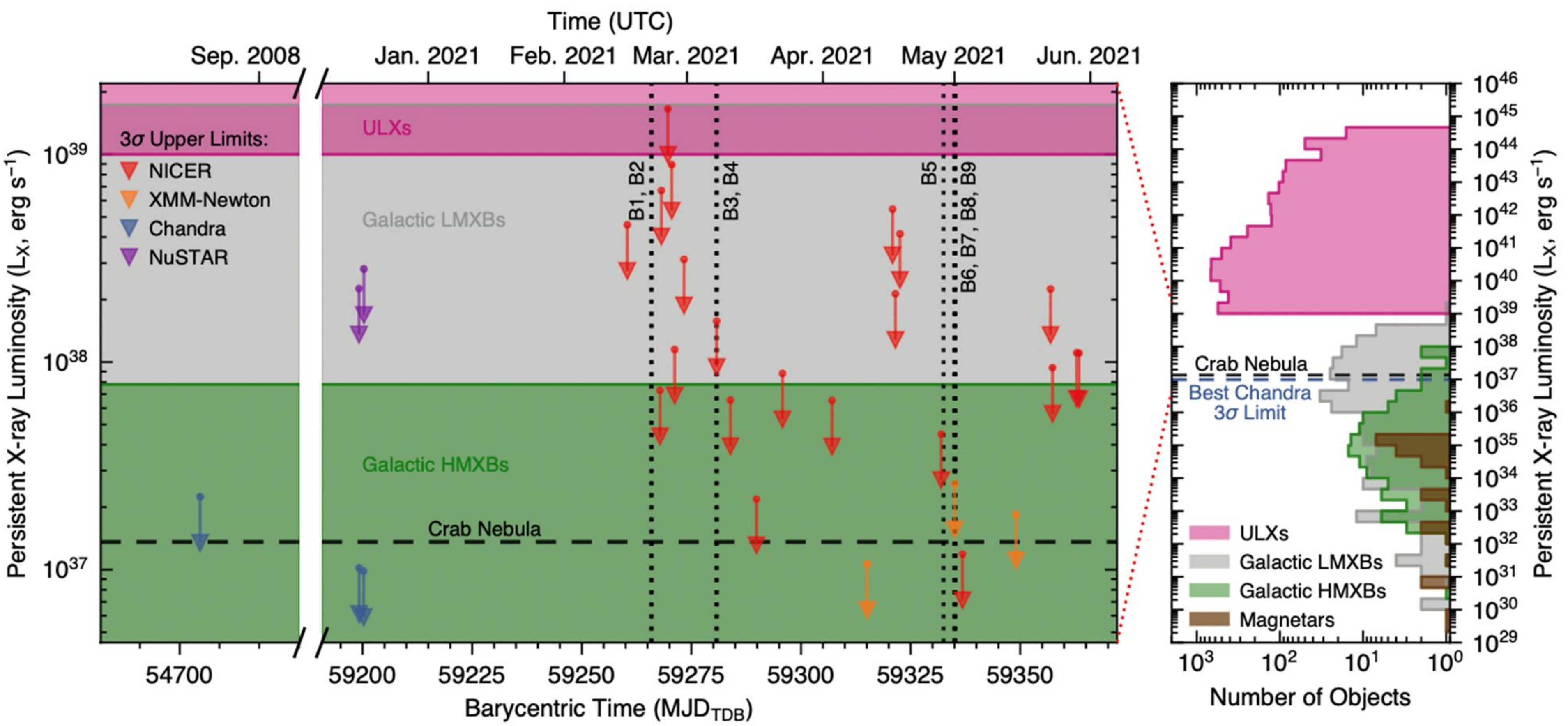
- X-ray bursts with ~10x fluence of the April 2020 would have been detected.
- All observed magnetar giant and most intermediate flares above our limits.
- Still a lot of fainter magnetar X-ray activity to probe!



Aaron Pearlman
McGill Postdoc

Pearlman, Scholz et al. 2025

FRB 20200120E Persistent X-ray limits



Pearlman, Scholz et al. 2025

Current limits: Fluence ratio

$\eta = F_{X\text{-ray}} / F_{Radio} = E_{X\text{-ray}} / E_{Radio}$

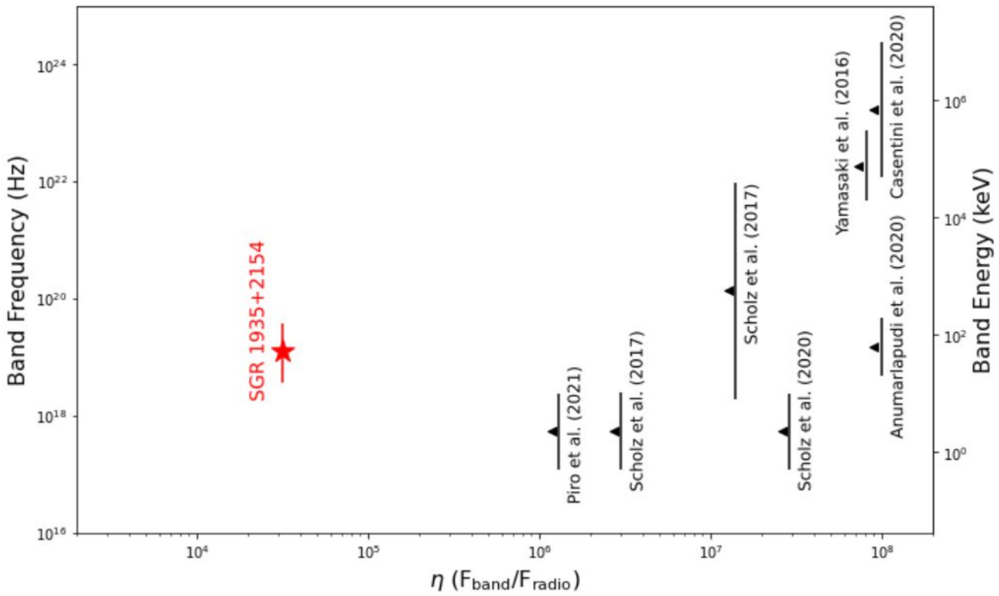
Bright FRB → Bright counterpart.

Independent of distance.

keV: XMM/Newton, Chandra (Scholz et al. 2017)
Chandra (Scholz et al. 2020, Piro et al. 2021)

keV - MeV: Fermi GBM: (Scholz et al. 2017),
AstroSat/CZTI (Anumarlapudi et al. 2019)

MeV-GeV: Fermi LAT (Yamasaki et al. 2016),
AGILE (Casentini et al. 2019)



Adapted from Chen et al. (2020)

Current limits: Fluence ratio

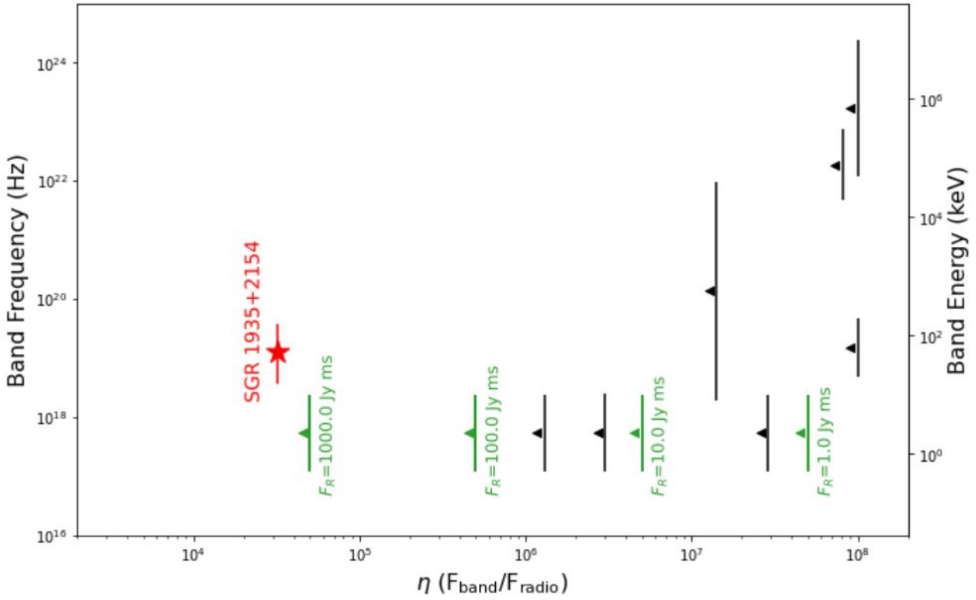
$\eta = F_{X\text{-ray}} / F_{Radio} = E_{X\text{-ray}} / E_{Radio}$

$F_{X\text{-ray}}$: Sensitivity of X-ray telescope.

F_{Radio} : FRB fluence.

Green:

- $F_{X\text{-ray}} < 1 \times 10^{-10}$ erg cm^{-2} (~XMM/NICER/Chandra at 100 ms)
- Range of F_{Radio}



Adapted from Chen et al. (2020)

Want : Deeper in η →

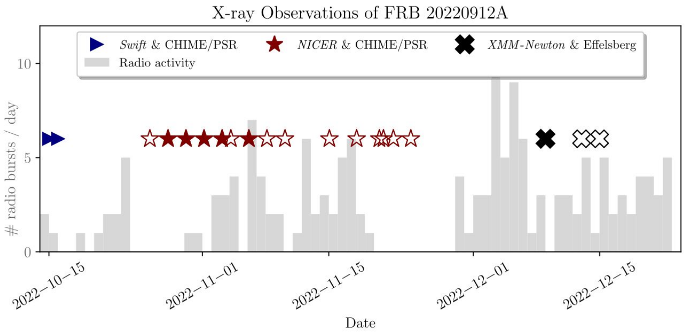
Need: Brighter FRBs,
Bigger X-ray telescopes

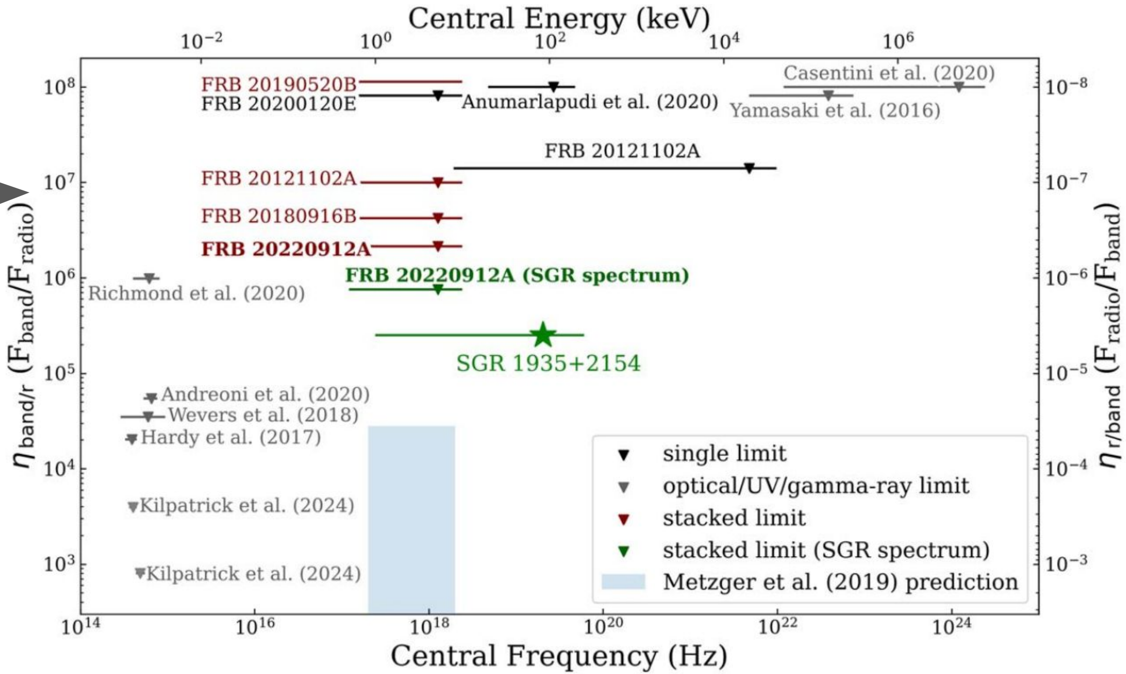
FRB 20220912A: A hyperactive source

Amanda Cook
McGill postdoc

With hyperactive sources:

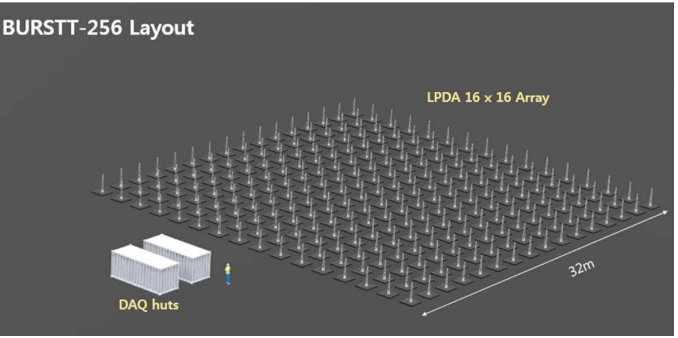
- Chance to get a super-bright radio burst
- Can produce stacked limits





Cook, Scholz et al. 2024

Future FRB surveys



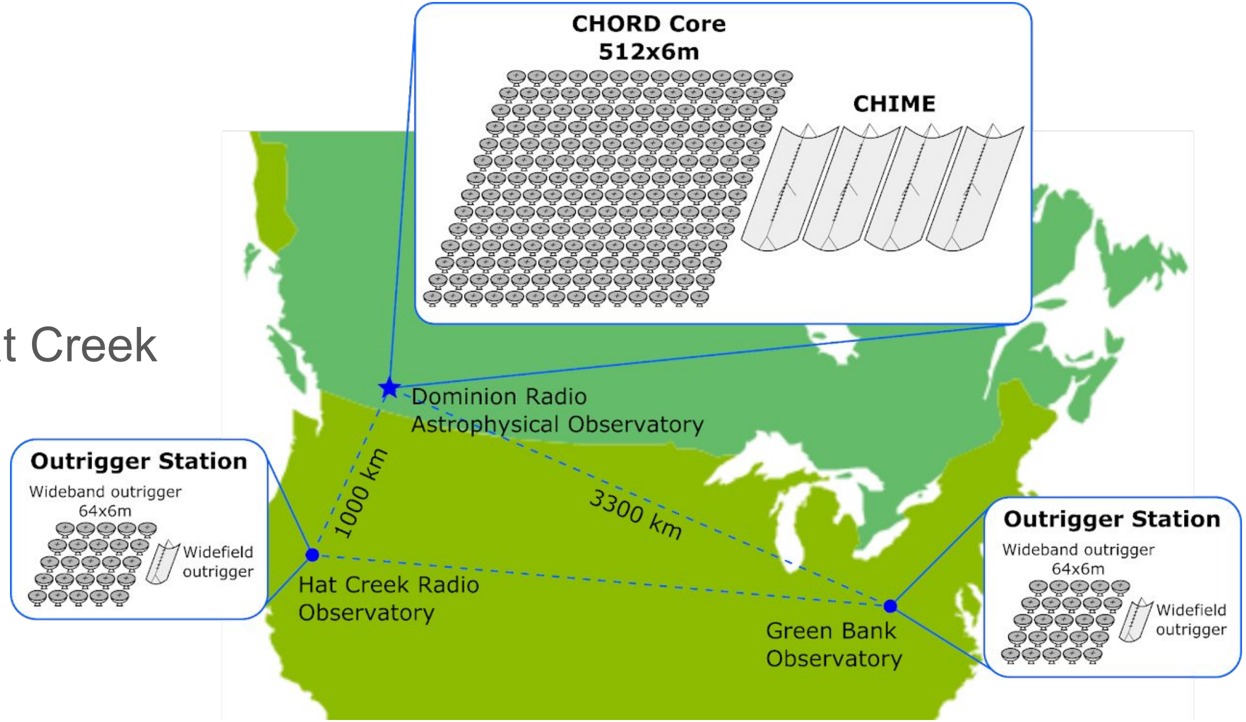
CHORD: The Observatory

A highly sensitive core:

- 512 6-m dishes

VLBI Outrigger stations:

- At Green Bank and Hat Creek observatories.
- 64 6-m dishes

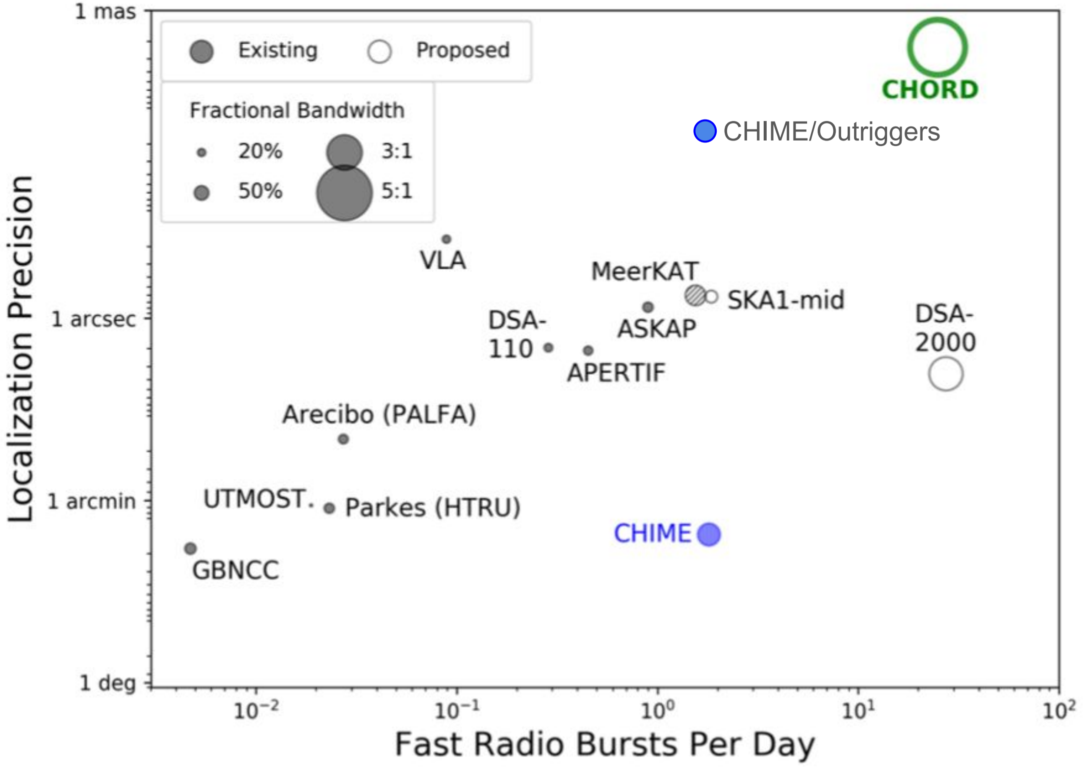


Future FRB detectors

CHORD, DSA-2000, SKA

- More sensitive
- Higher bandwidth

- Detect fainter and more distant FRBs

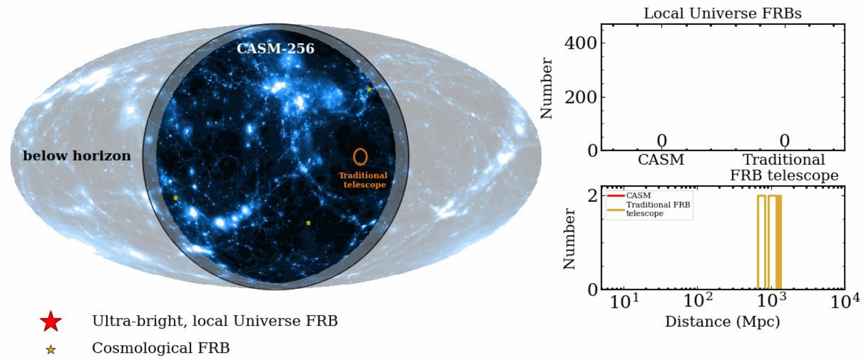


Vanderlinde et al. 2019 (CHORD)

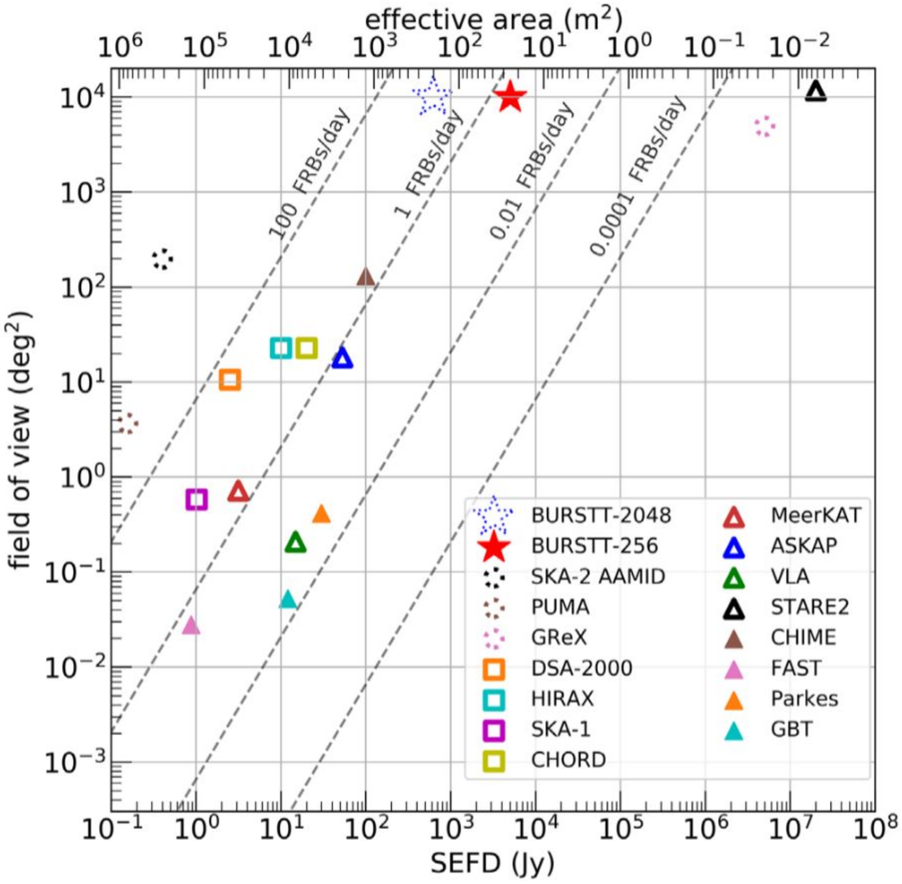
Future FRB detectors

BURSTT, CHARTS, CASM

- Huge fields-of-view
- Detect local universe FRBs
- Great targets for counterpart searches!



Credit: Liam Connor (CASM)

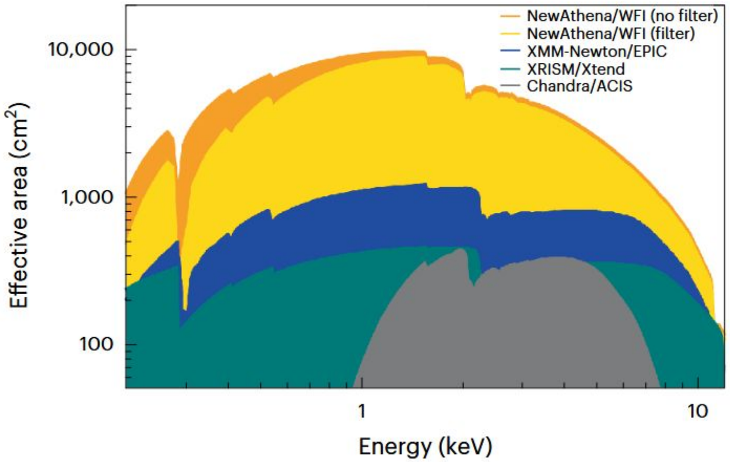


Lin et al. 2022 (BURSTT)

Future X-ray observations?

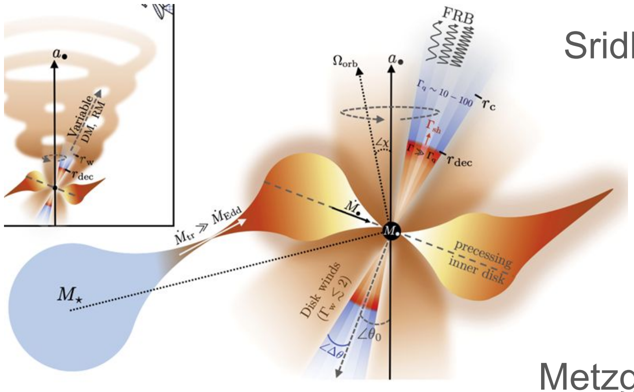
What will this look like in 2037?

- Large sample of FRBs
  - 100,000s total FRBs
  - a few thousand local universe FRBs (within ~100 Mpc)
- No shortage of targets to look for or characterize X-ray emission!
- We may have a counterpart detection by then and have an idea of what to expect, or may not.
- Athena will be a huge step forward in X-ray sensitivity!



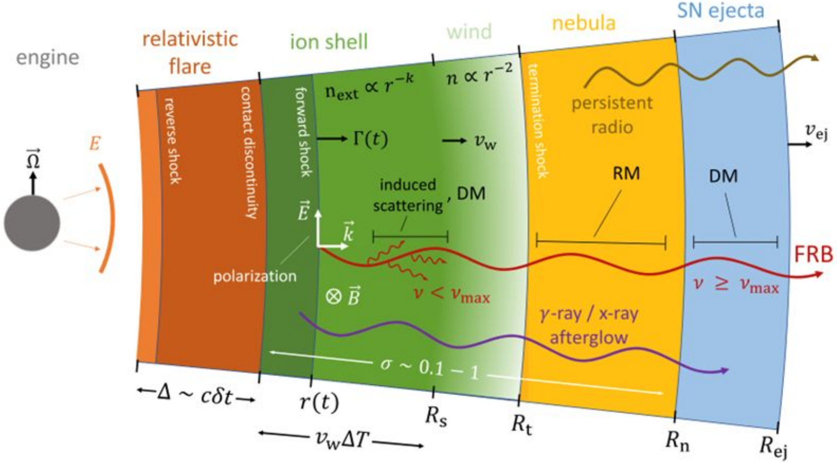
Cruise et al. 2024

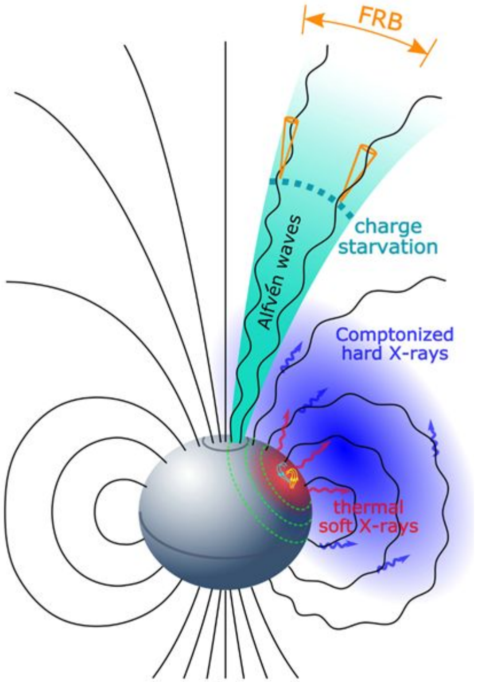
FRB emission models



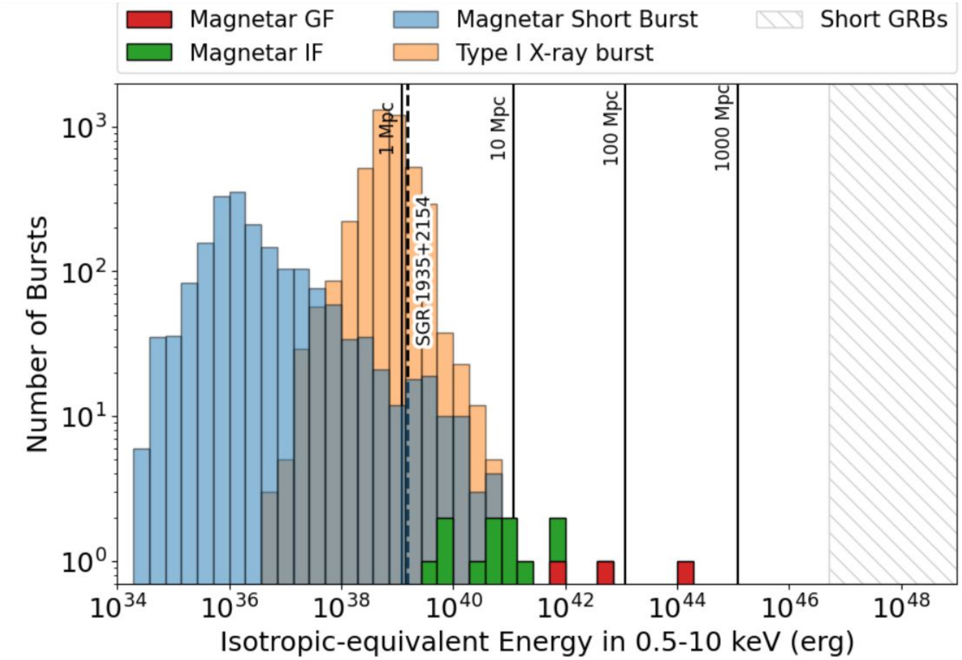
Sridhar et al. 2021

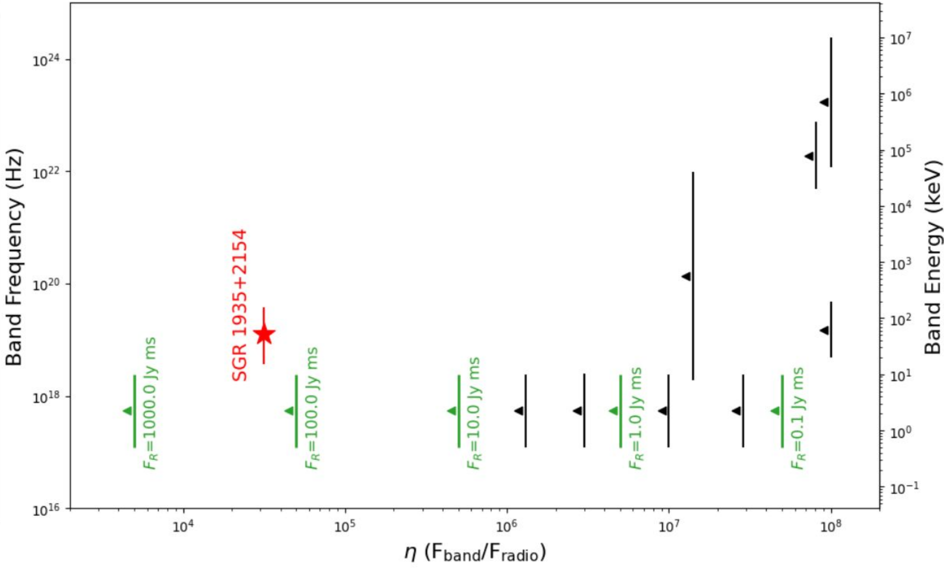
Metzger et al. 2019





Future X-ray: Prompt emission with NewAthena

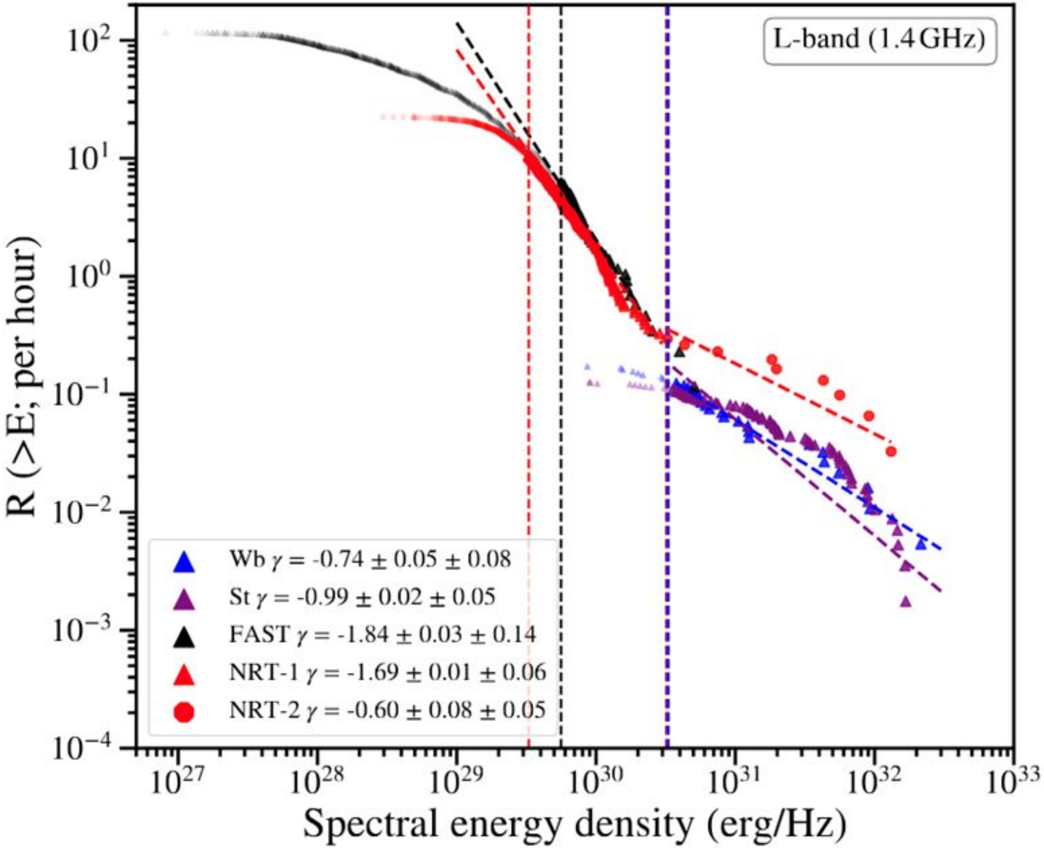




Adapted from Pearlman, Scholz et al. 2025

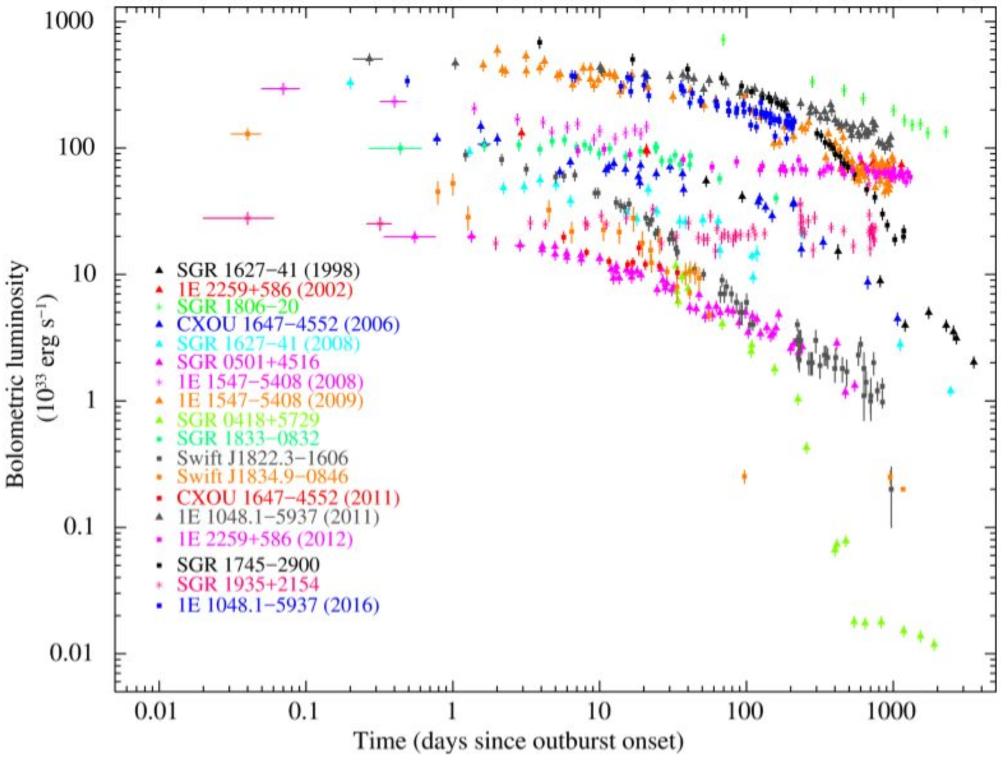
Rare bright FRBs from hyperactive repeaters

Hyperactive FRBs seem to have a tail of extremely bright bursts detectable with small radio telescopes.



Ould-Boukattine et al. 2024

Future X-ray: Persistent emission



Coti Zelati et al. 2018

- Athena sensitive to persistent X-ray emission from magnetars in nearby galaxies.
- Magnetars in outburst have persistent luminosity: $L_X \sim 10^{36}$ erg/s
- Athena sensitivity of $\sim 10^{-16}$ erg/s/cm^2 (100 ks exposure) can detect outbursting magnetars to ~10 Mpc.

Summary

- We are currently limited in our ability to probe for X-ray counterparts by:
  - X-ray telescope sensitivity
  - Low number of nearby and bright sources to observe
- Over the next decade both should improve:
  - Near future FRB Surveys will give us large samples of both distant and local Universe FRBs
  - NewAthena will provide a large step forward in X-ray sensitivity