Localizing Fast Radio Bursts at the highest angular resolution

on behalf of the PRECISE and AstroFlash projects

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FTSky Bangalore

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ASTROFLASH
erc
European Research Council
PANTERA Stars

Introduction to Fast Radio Bursts

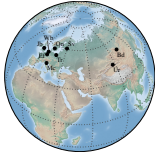
- Understanding Fast Radio Bursts
- Why are FRBs interesting?

Why Very Long Baseline Interferometry?

- Understanding the local environments
- Unveiling formation channels

PRECISE localizations with the EVN

- Different environments and formation channels?
- Most extreme population in dwarf galaxies?



Summary and conclusions

What is a Fast Radio Burst (FRB)?

Fast
Duration of $\sim$ 1 µs–10 ms

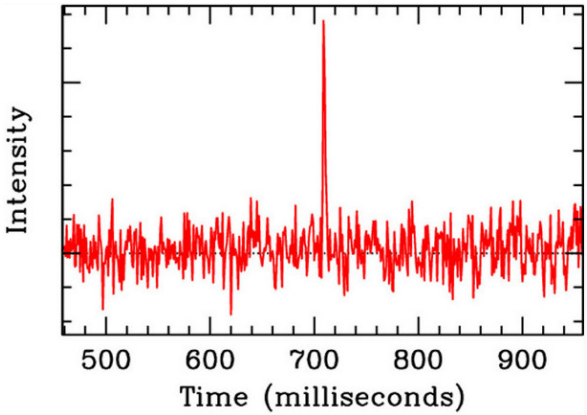
Radio
Observed at 0.2–8 GHz

Burst
Bright $\sim$ 0.1–100 Jy
($\sim 10^{40-44}$ erg s^{-1})

Discovered by Lorimer et al. (2007)

Thousands known to date

$\lesssim$ 4% show more than one burst

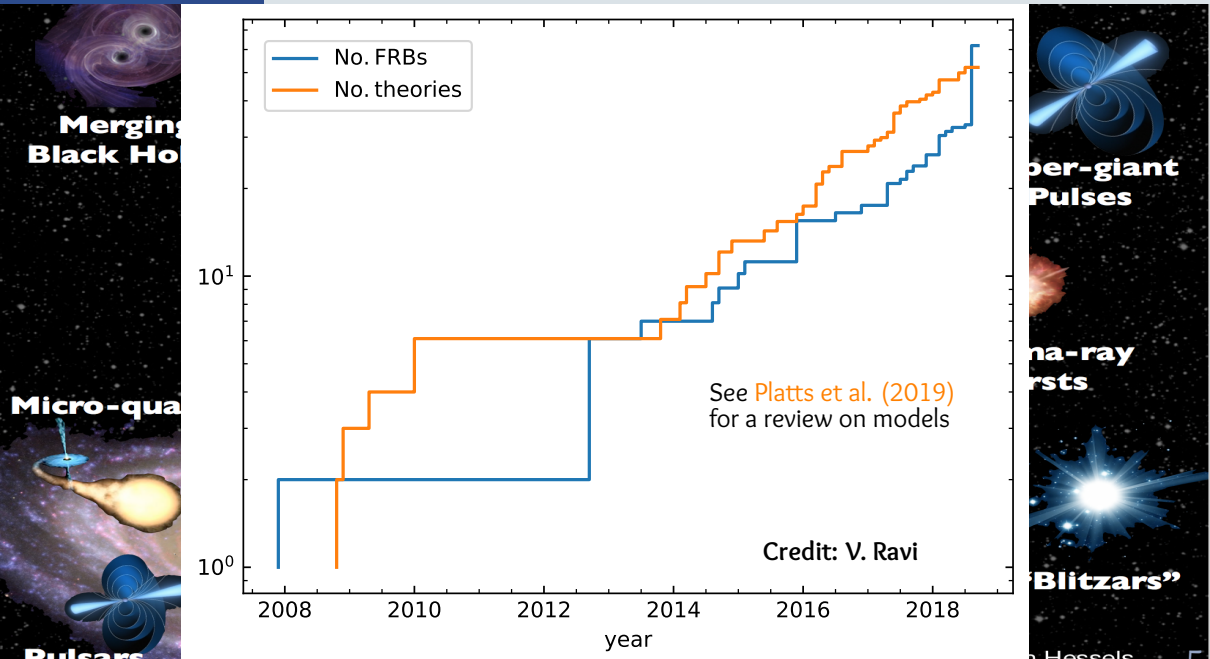


FRB 140514

$\sim 10^{3-4}$ FRBs sky^{-1} day^{-1}

$> 10^{5}$ FRBs Gpc^{-3} yr^{-1}


Merging Black Holes
Supernovae
Magnetars
Evaporating Black Holes
Super-giant Pulses
extra-Galactic
The Unknown
Gamma-ray Bursts
Implied rate of 1000s per day, per sky... but what are they?
Micro-quasars
Flare stars
Galactic
SETI
Pernicious RFI
Atmospheric effects
"Blitzars"
Magnetars
We are here
Credit: Jason Hessels


No. FRBs
No. theories
10^1
10^0
2008
2010
2012
2014
2016
2018
year
See Platts et al. (2019)
for a review on models
Credit: V. Ravi
Micro-qua
Pulsars
Blitzars”

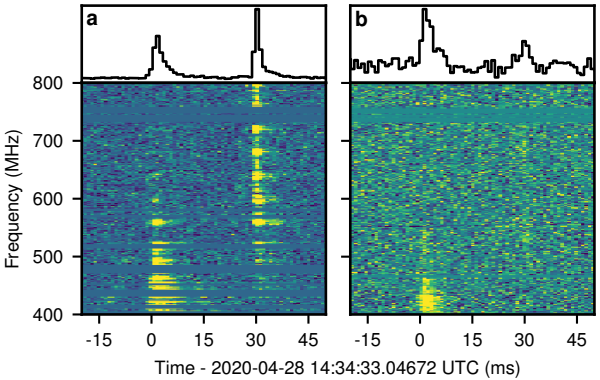
A Galactic Burst from SGR 1935+2154

SGR 1935+2154 is a Galactic magnetar

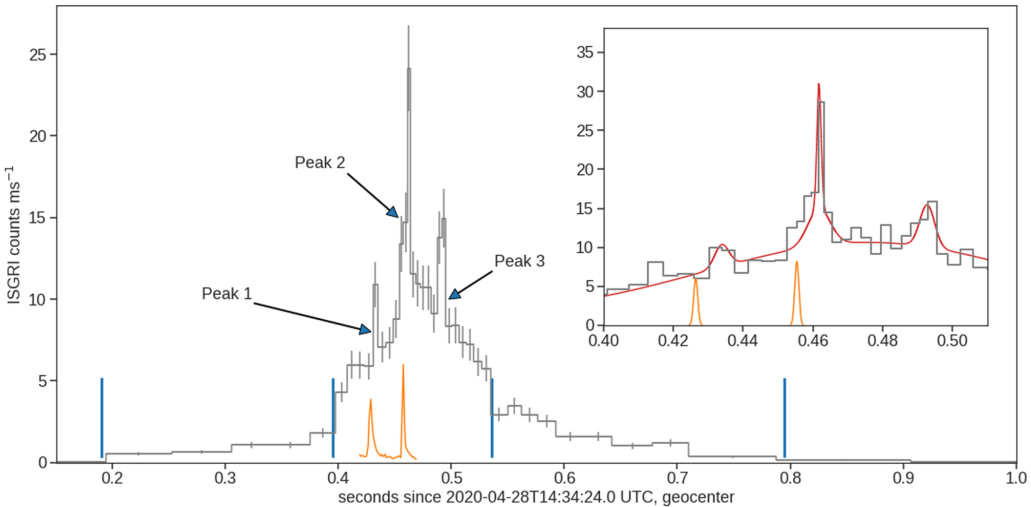
Recently entered into an active state producing high-energy bursts

On 28 April 2020...

- CHIME FRB detection: $\sim$ 1 kJy ms (CHIME/FRB Collaboration 2020)
- STARE2 FRB detection: $\sim$ 1.5 MJy ms (Bochenek et al. 2020)
- Simultaneous X-ray burst (Mereghetti et al. 2020)



A Galactic Burst from SGR 1935+2154



(Mereghetti et al. 2020)

Why are FRBs important?

FRBs look like single pulses from pulsars but $\sim$ **10^{10} brighter**.

Origin not fully understood, **multiple origins**?

Trace properties of the **intergalactic medium** and Galactic Halos (Prochska & Zheng 2019).

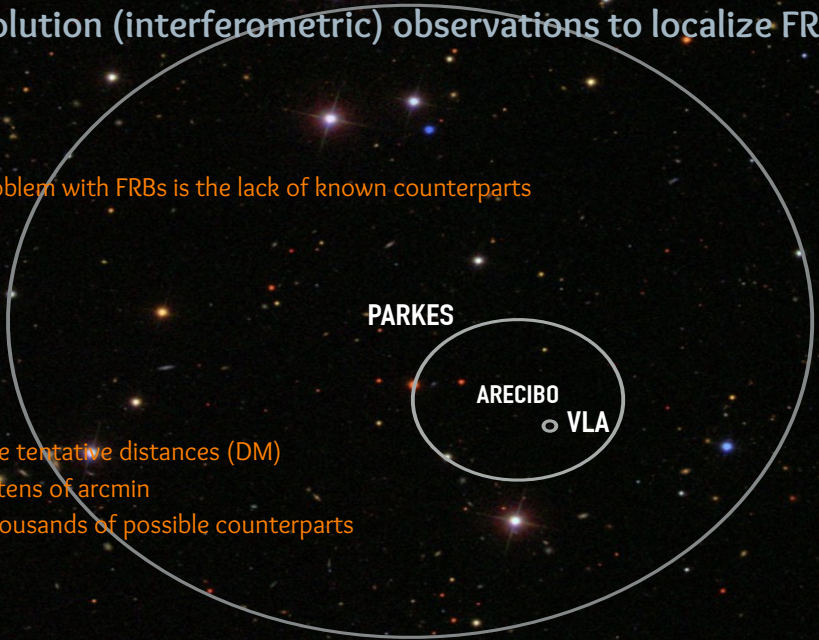
Can probe the **reionization history** of H and He in the Universe.

Constraints on **fundamental physics** (equivalence principle, photon mass,...).

Constrain the **baryon content of the Universe** (Macquart et al. 2020), ...

Higher resolution (interferometric) observations to localize FRBs

The main problem with FRBs is the lack of known counterparts



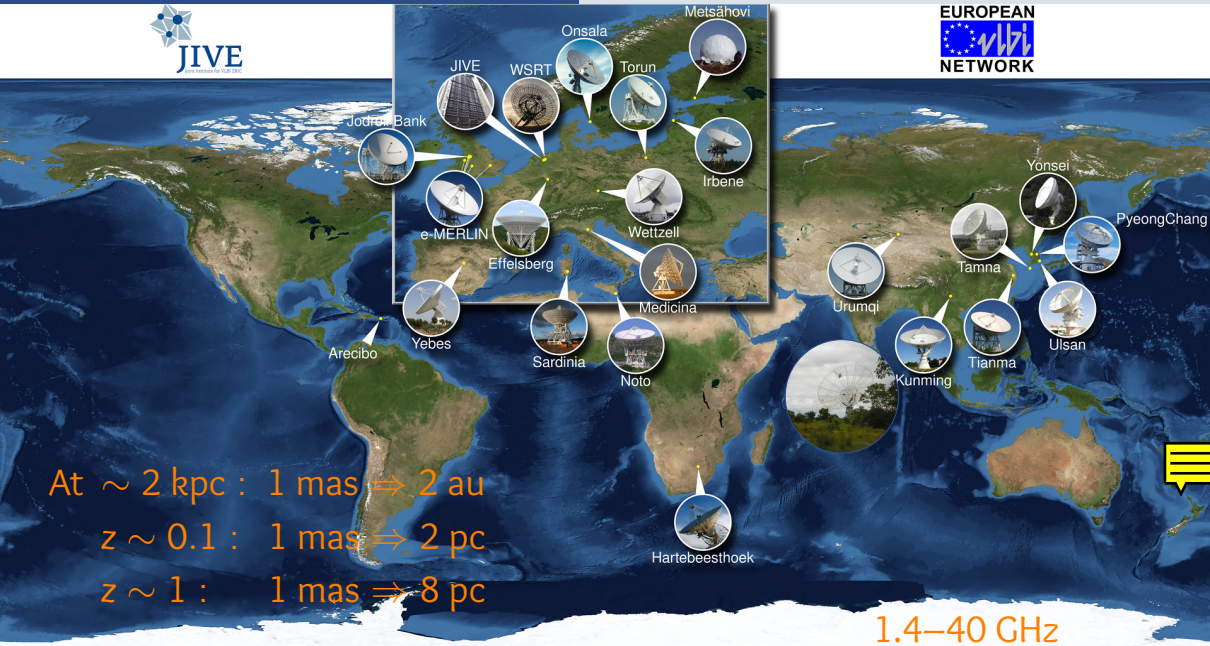
We only have tentative distances (DM)

Precision of tens of arcmin

Hundreds/thousands of possible counterparts

Progenitors

How and **where** FRBs are produced


JIVE
EUROPEAN
VLBI
NETWORK
Onsala
Metsähovi
JIVE
WSRT
Torun
Jodrell Bank
Irbene
e-MERLIN
Wettzell
Effelsberg
Medicina
Yonsei
PyeongChang
Tamna
Urumqi
Ulsan
Arecibo
Yebes
Sardinia
Noto
Kunming
Tianma
At ∼ 2 kpc : 1 mas ⇒ 2 au
z ∼ 0.1 : 1 mas ⇒ 2 pc
z ∼ 1 : 1 mas ⇒ 8 pc
Hartebeesthoek
1.4–40 GHz


JIVE
EUROPEAN
VLBI
NETWORK
Onsala
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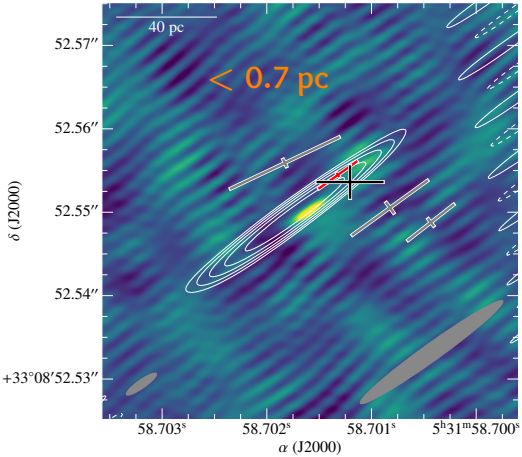
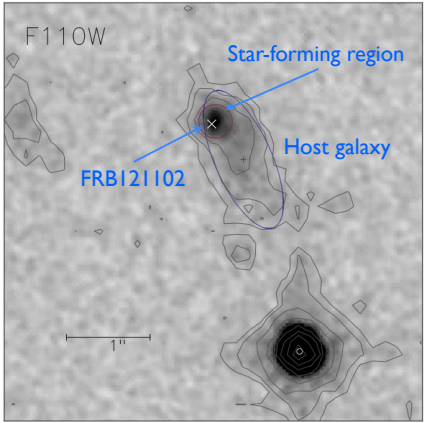
PyeongChang
Tamna
Urumqi
Ulsan
Arecibo
Yebes
Sardinia
Noto
Tianma
Kunming
PRECISE
Pinpointing Repeating ChIme Sources with EVN dishes
AstroFlash
astroflash-frb.github.io

The First Precise Localization of a Fast Radio Burst: FRB 20121102A



Chatterjee et al. (2017, Nature, 541, 58)

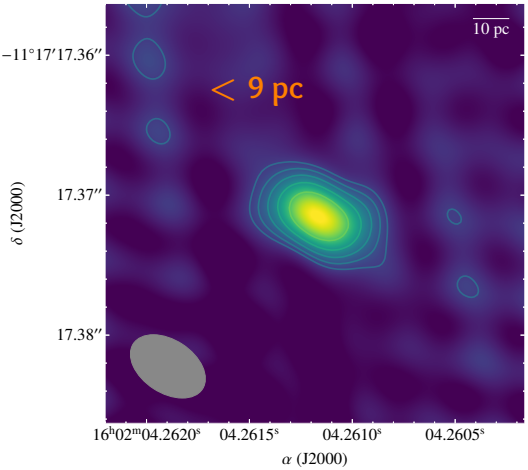
Marcote et al. (2017, ApJL, 834, 8)



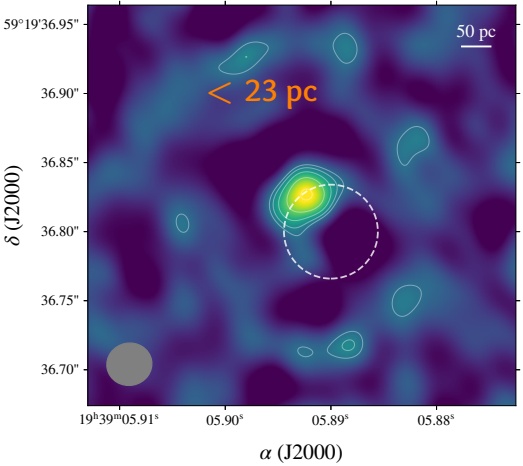
Tendulkar et al. (2017, ApJL, 834, 7)

Bassa et al. (2017, ApJL, 843, 8)

FRB 20190520B and FRB 20190417A

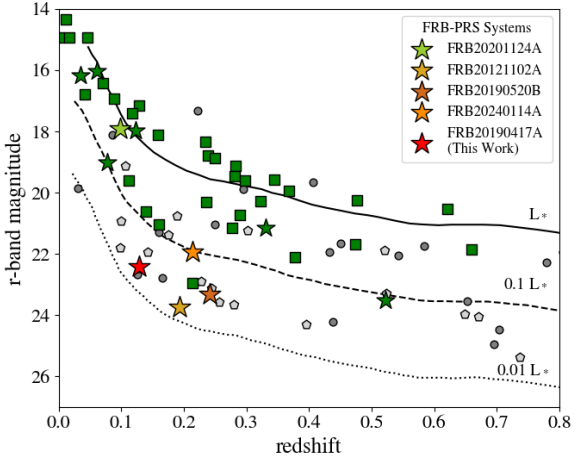


(Bhandari, Marcote, et al. 2023, ApJL, 958, L19)



(Moroianu et al. 2025, submitted)

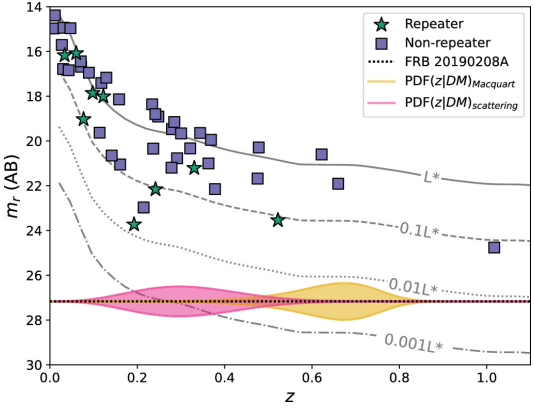
Persistent radio emission in dwarf-galaxy FRB hosts



(Moroianu et al. 2025, submitted)

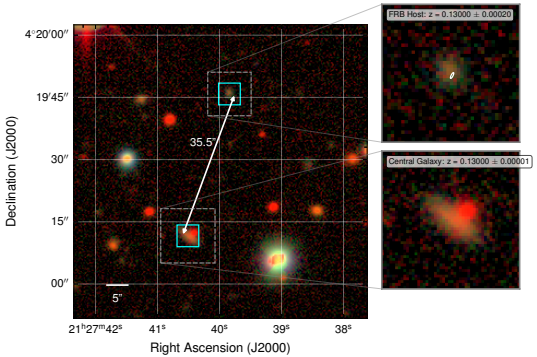
Very low luminosity dwarf galaxies

FRB 20190208A



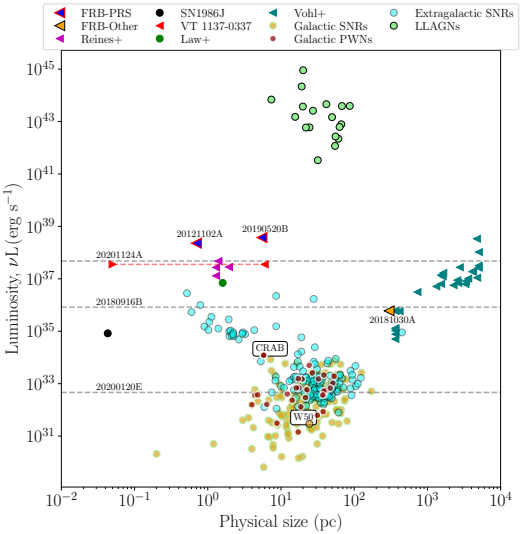
Hewitt et al. (2024, ApJL, 977, L4)

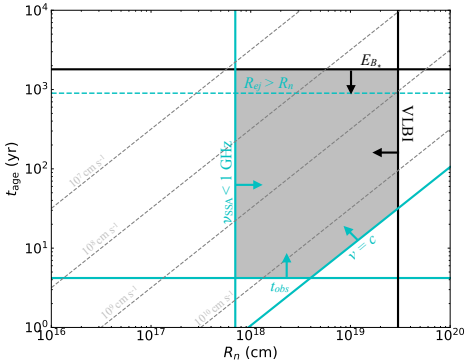
FRB 20240114A



Bhardwaj, Snelders et al. (2025, submitted)
(arXiv:2506.11915)

Constraining the persistent sources

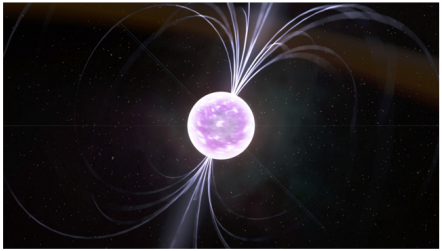




For a magnetar wind nebula model

(Bhandari, Marcote, et al. 2023, ApJL, 958, L19)

Possible origins of FRB 20121102A



Pulsar/magnetar powering up a young superluminous supernovae?
(e.g. Margalit et al. 2018, Metzger & Margalit et al. 2019)

Young pulsar/magnetar interacting with a massive black hole?
(e.g. Pen & Connor 2015, Cordes & Wasserman 2016, Zhang 2018)

...synchrotron maser (Ghisellini 2017), plasma cavitons (Romero et al. 2016, Vieyro et al. 2017),...

The Second Localized Repeating FRB: 20180916B

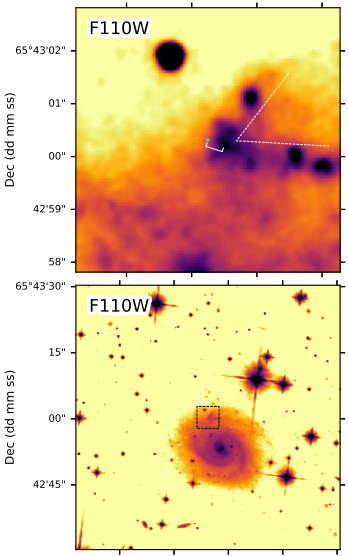
(CHIME/FRB et al. 2019, ApJL, 885, L24)

EVN: 4 bursts on 19 June 2019
localized to $\sim$ 2 mas
Marcote et al. (2020, Nature , 577, 190)

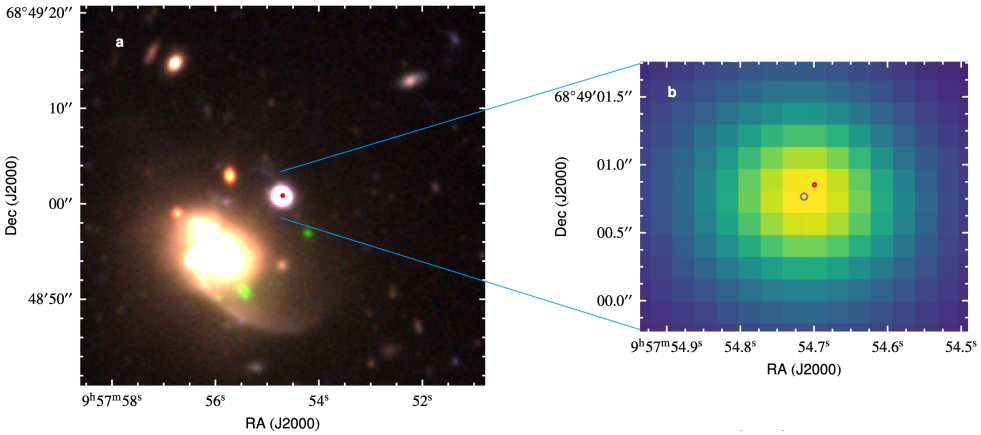
At the edge of a star-forming region
Tendulkar et al. (ApJL 2021, 908, L12)

The bursts appear in a $\sim$ 4-d window
with a period of 16.35 ± 0.15 days
(CHIME/FRB et al. 2020, Nature, 582, 351)

Shortest components of 3–4 μs
Nimmo et al. (2021, Nat Astr, 5, 594)

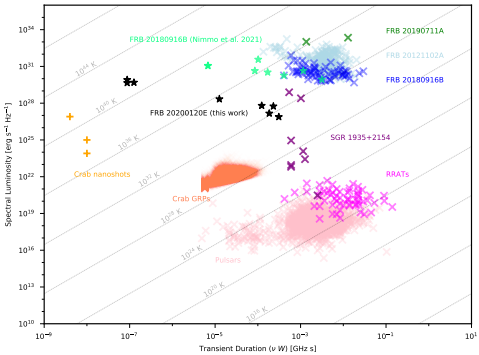


FRB 20200120E: an exceptionally old environment in M81



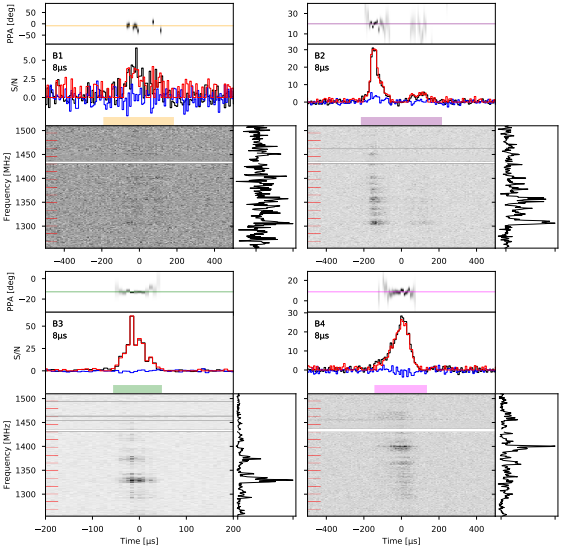
(Kirsten, Marcote et al. 2022, Nature, 602, 585)

FRB 20200120E: an exceptionally old environment in M81



Sub-components as narrow as 60 ns

(Nimmo et al. 2022, Nature Astronomy, 6, 393)



$$10^{-7}$$

$\gtrsim$ 3 000 *hours observed…*

… $\sim$ 1 *second of FRB signals!*

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Precise Localizations *Temporal resolution*

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$\gtrsim$ 3 000 *hours observed…*

… $\sim$ 1 *second of FRB signals!*

Precise Localizations *Temporal resolution* *Energy distribution*

Take home messages

Fast Radio Bursts are a remarkable new type of astrophysical objects of unknown nature.

VLBI observations are key to understand the local environments.

The EVN is the only instrument to achieve $\sim$ μJy sensitivity and milliarcsecond accuracy

The combination of GMRT and MeerKAT within the EVN will allow us to boost the sensitivity even more!

Is there a pattern of having the most extreme FRBs in dwarf galaxies/PRSs?

Deep high-resolution radio and optical observations are key to understand the local environments of FRBs

A variety of different progenitors/environments is possible.

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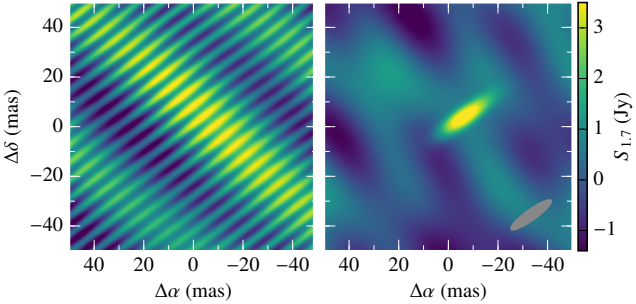
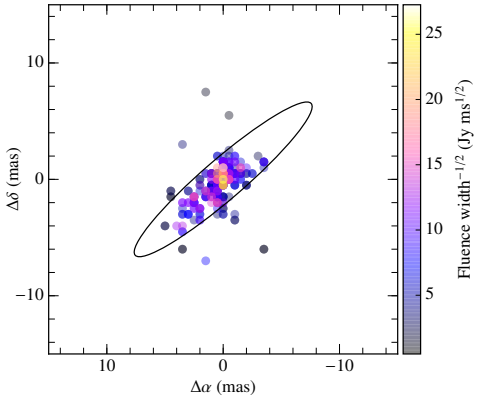
Thanks!

Localizing FRB 20121102A on milliarcsecond scales



Dirty and clean image from FRB 20121102A.

Astrometry limited by signal-to-noise ratio



Positions derived from 406 pulses from the pulsar B0525+21

Marcote et al. (2017, ApJL, 834, 8)

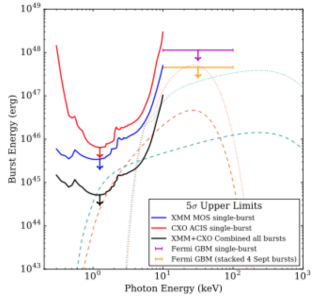
Simultaneous radio, optical, X-ray and TeV observations

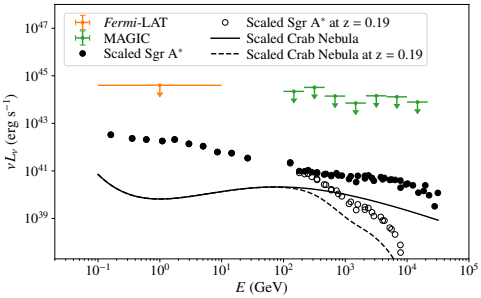
No emission reported outside radio wavelengths.

From simultaneous multiwavelength observations:

- X-ray/radio limits from *XMM* and *Chandra*:
  X-ray bursts $< 5 \times 10^{-10}$ erg cm^{-2}
  Persistent: $L_X < 3 \times 10^{41}$ erg s^{-1}
  (Scholz et al. 2017, ApJ, 846, 80)

- Optical/TeV/radio limits from MAGIC:
  Optical bursts < 8.6 mJy
  TeV bursts $< 5 \times 10^{49}$ erg s^{-1}
  Persistent: $L_{VHE} < 3 \times 10^{45}$ erg s^{-1}
  (MAGIC Coll. et al. 2018, MNRAS, 481, 2479)





HYPERFLASH

Westerbork

6,775 hours in 2024

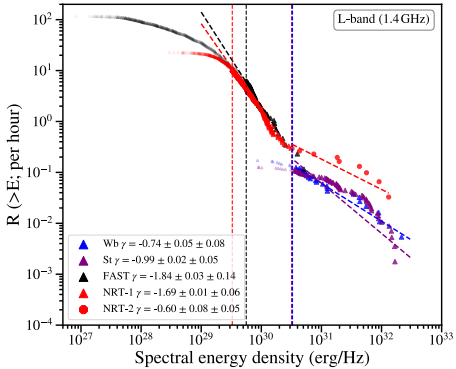
Stockert

Dwingeloo

Torun

Onsala

Energy distribution from FRB 20201124A



(Kirsten et al. 2024, Nature Astronomy, 8, 337)

(Ould-Boukattine et al. 2024, in press)