Pinpointing FRBs with VLBI

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FRB localisation

- Identify host galaxy to assign distance, determine absolute quantities, calibrate DM-z relation - requires ~arcsecond accuracy
- Identify emission region within host galaxy to characterise environment and constrain progenitor type
- Interferometry is necessary (with luck and skills, can work for one-off events)
- VLBI can be arranged for repeaters

VLBI challenges/strategies/pros

- Extremely low efficiency (true for all instruments)
  - strategies to improve efficiency: observe periodic sources at right times, follow reports of active states, shadowing (increased value rather than chances)
- Only correlate data if there is a burst: reduce cost, but requires one trigger
- Trade off in number of stations/baselines: with signal only present in one integration time, extremely sparse coverage of uv-plane and ill posed image reconstruction
  - groups of bursts greatly help, a fair number of stations too
- Search for/constrain PRSs “for free”

PRECISE operation model

- Started with individual telescope applications - INAF radio telescopes involved since 2019
- Since 2023, proposed and approved by EVN as EVN-lite project (limited number of stations, use of correlator resources - only correlate in case a burst occurs, can be interrupted if high priority project is triggered)
- One session per month, including one large telescope, at L-band (not entirely uniform frequency coverage; 128/256 MHz bandwidth in 1254-1510 MHz range)

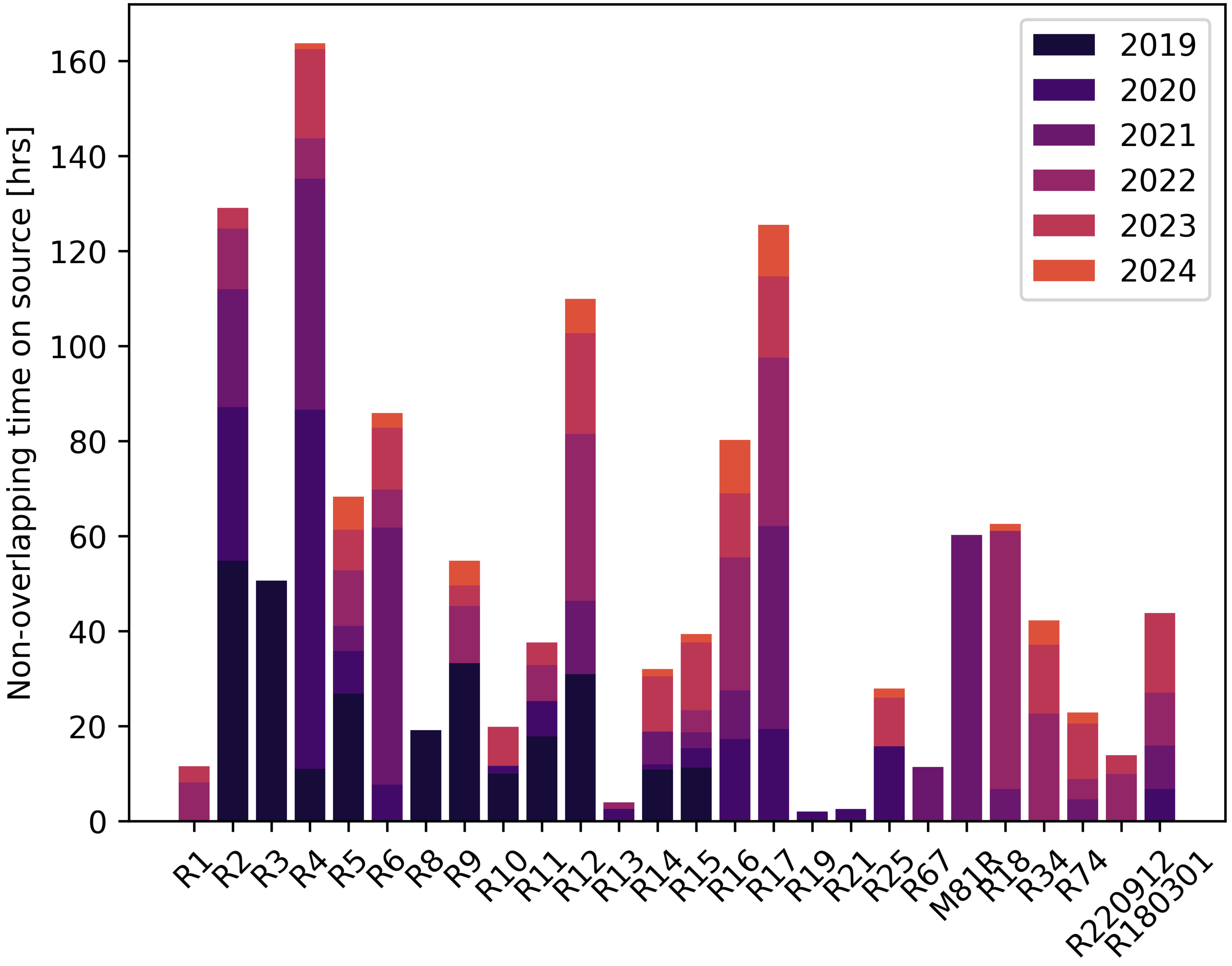
PRECISE Team members

- Primary contacts
  - Franz Kirsten
  - Jason Hessels

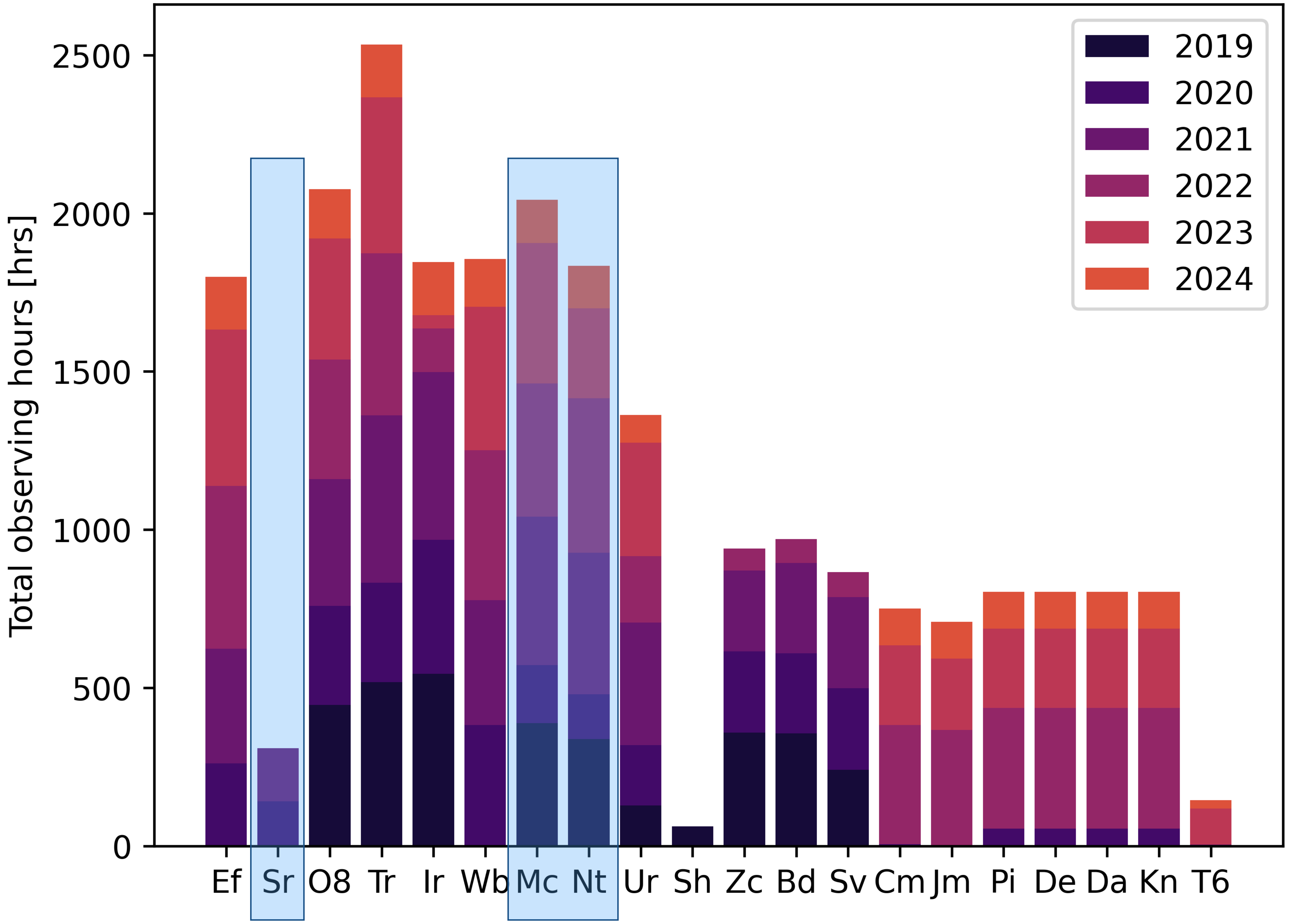
- Other members
  - IRA: M. Giroletti, T. Venturi, G. Maccaferri, S. Buttaccio
  - OA-Cagliari: M. Burgay, A. Corongiu, M. Pilia, A. Possenti, G. Surcis, M. Trudu
  - Groups/individuals at MPIfR, VIRAC, Chalmers/OSO, NCU, Torun, U. of Amsterdam, JIVE, RAS/IAA, ASTRON, XAO, ShAO

PRECISE statistics

https://www.ira.inaf.it/precise/



Number of hours spent on each target

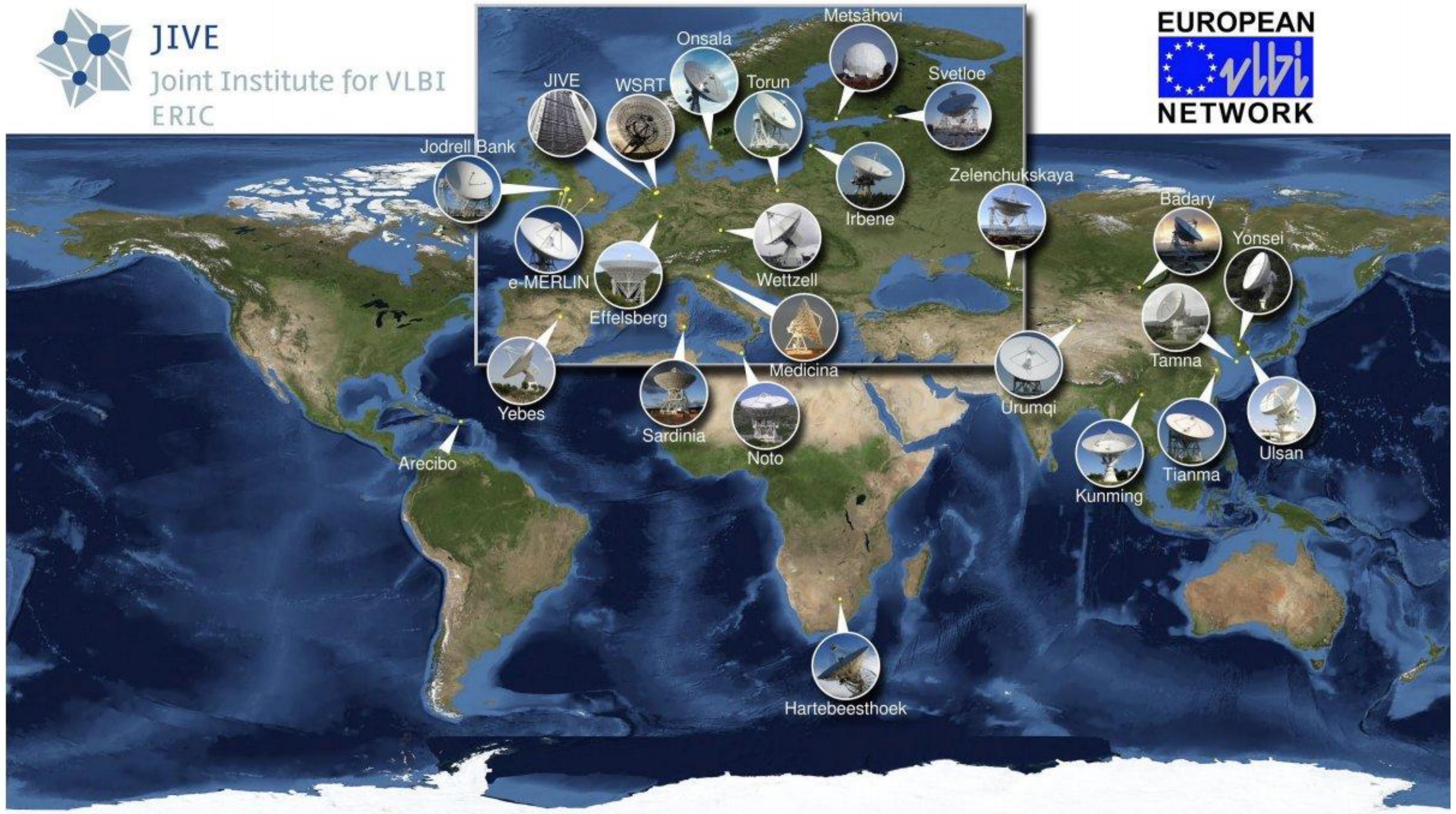


Number of hours at each radio telescope

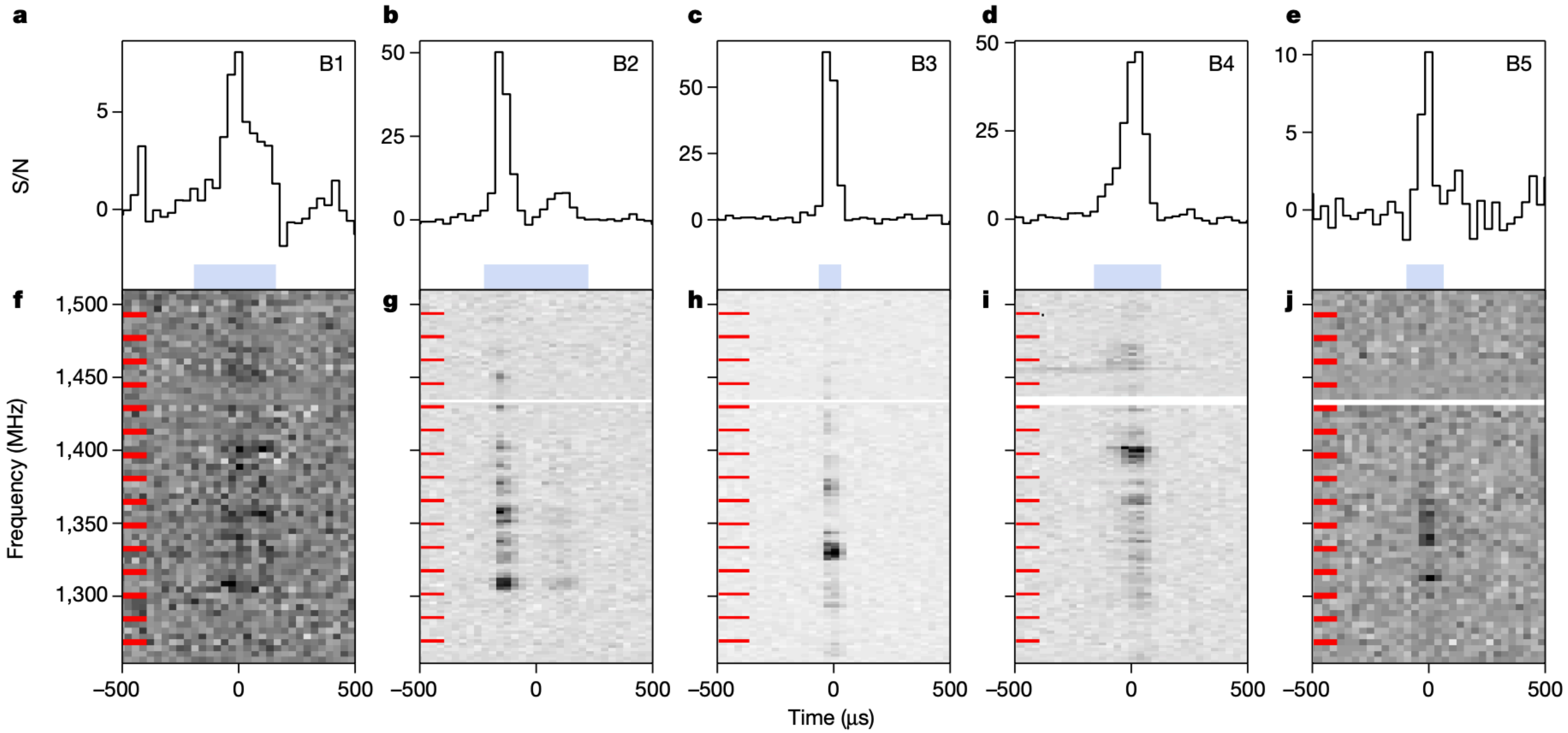
VLBI localisations

- 7 FRBs with VLBI localisation, all with the EVN
- allow optical follow-up observations with the HST, Gemini, Subaru, and other world-leading facilities

- FRB 20121102A (Marcote et al. 2017)
- FRB 20180916B (Marcote et al. 2020)
- **FRB 20201124A** (Nimmo et al. 2022)
- **FRB 20200120E** (Kirsten et al. 2022)
- **FRB 20190520B** (Bhandari et al. 2023
- FRB 20240114A (Snelders et al. 2024)
- **FRB 20220912A** (Hewitt et al. 2024)

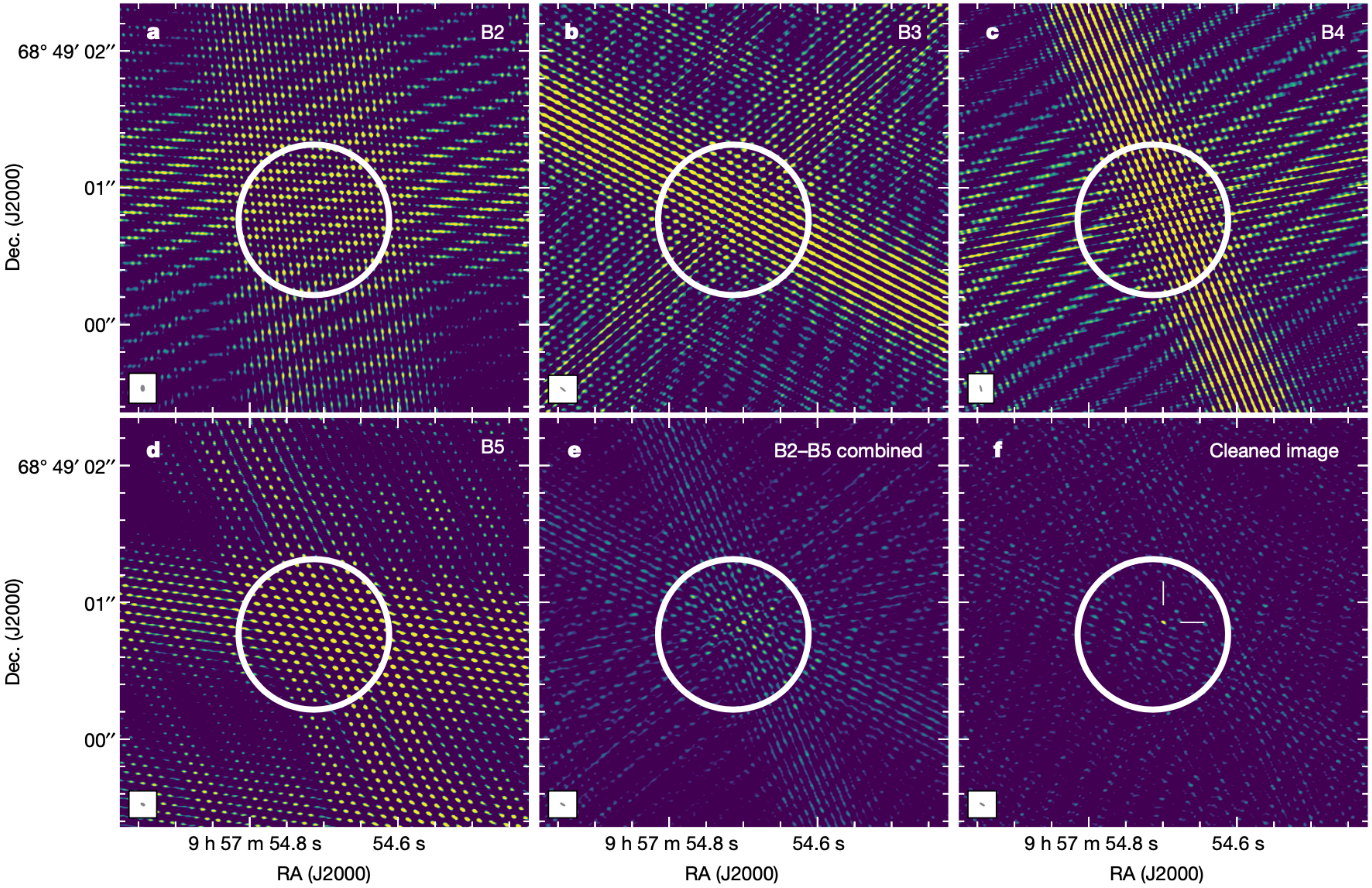


FRB 20200120E, Kirsten et al. 2022, Nature



- FRB 20200120E detection reported to be in the direction of the nearby galaxy M81 (DM = 87.8 pc cm^{-3},)
- several PRECISE runs during Feb/May 2021 with an array composed of up to 11 radio telescopes (including Mc/Nt/Sr)
- five bursts detected over three epochs

FRB 20200120E



RA 09^{h}57^{m}54.69935^s±1.2 mas
dec 68°49′0.8529″±1.3 mas

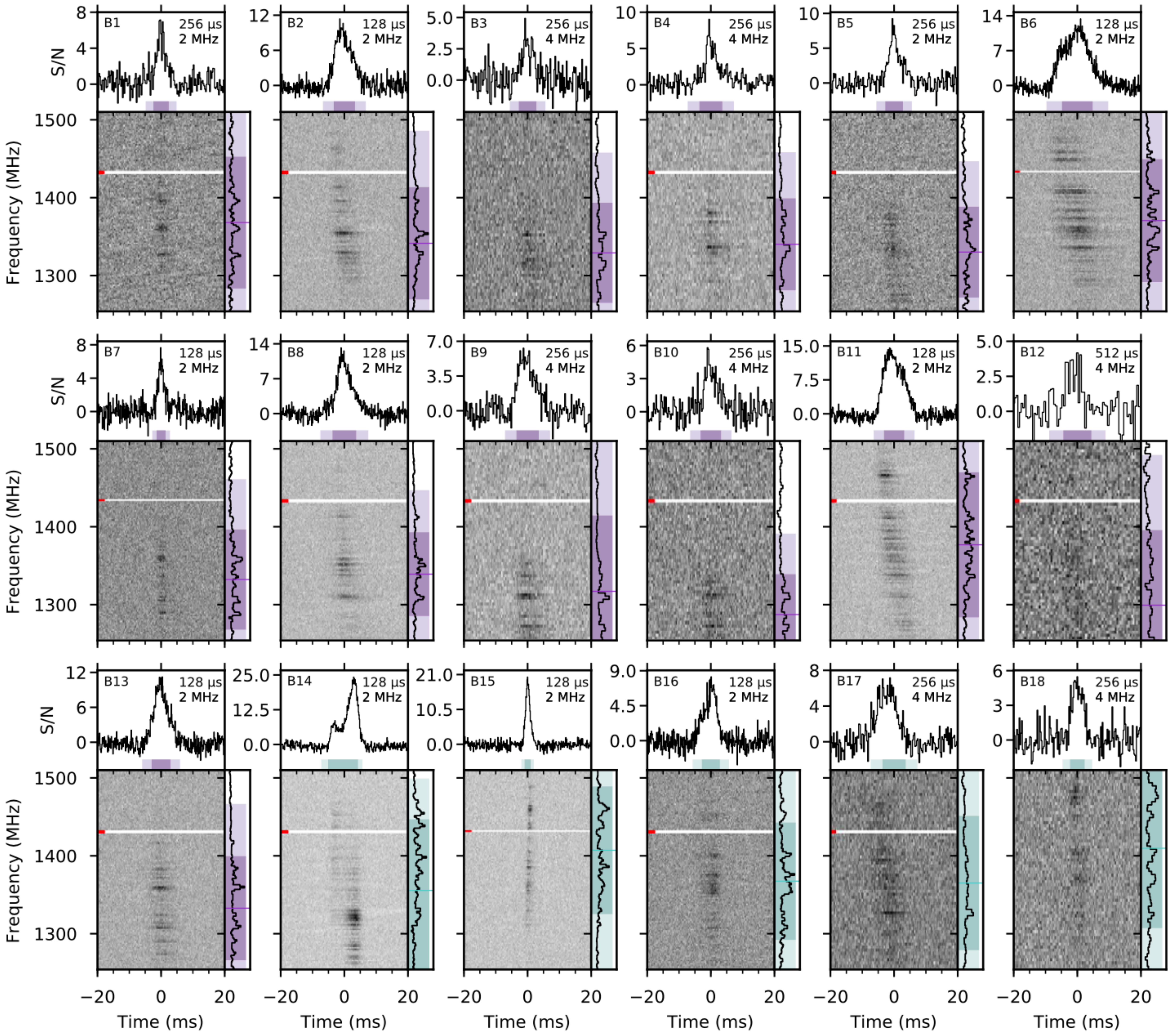
~116 mas offset from the optical centre of light

Subaru telescope location of [PR95] 30244

FRB 20200120E

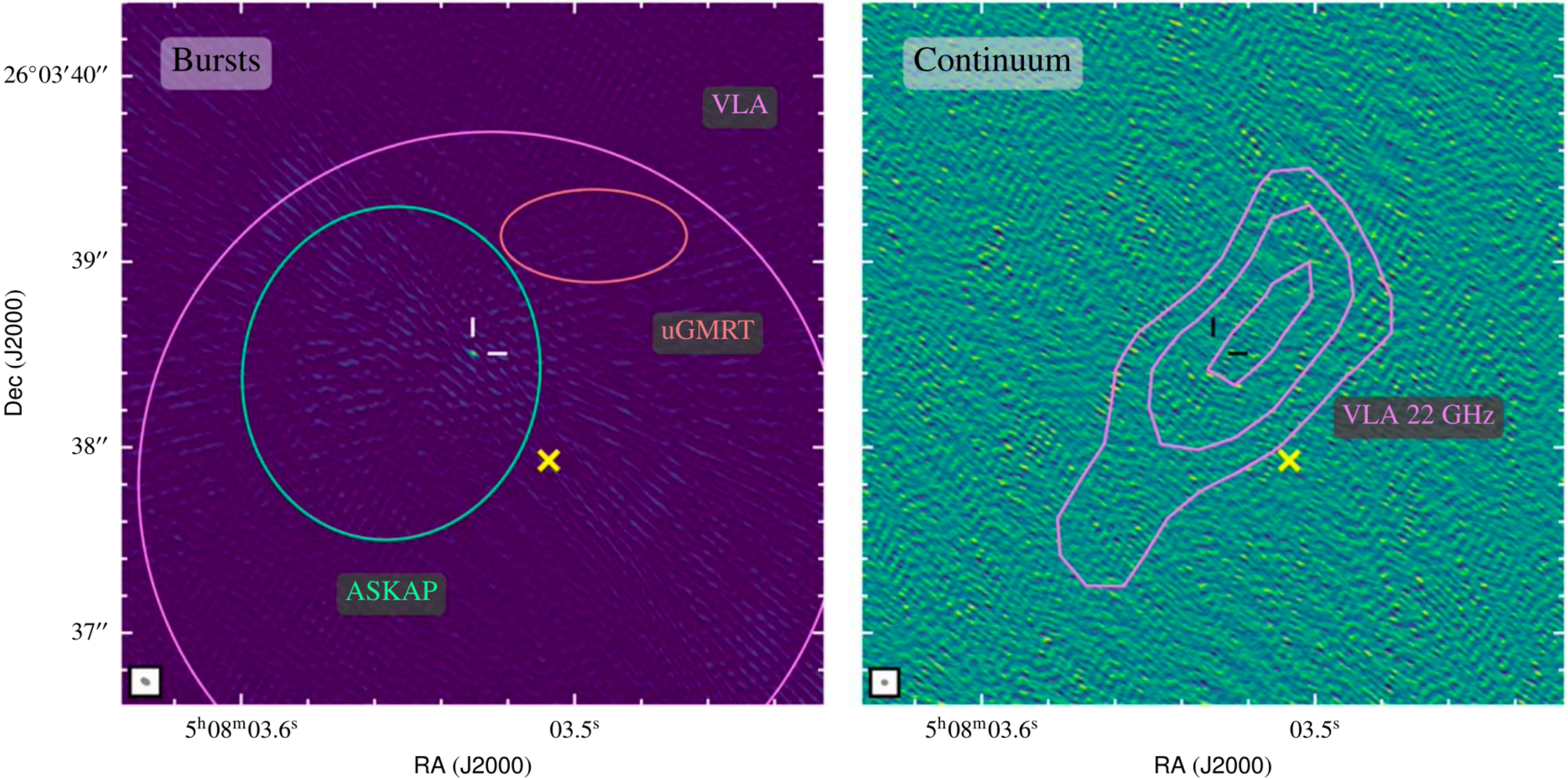
- probability of chance alignment $<1.7\times10^{-4}$
- no PRS above 50 μJy beam^{-1} (5σ rms - NB no emission in VLA images either); $L_\nu < 3.1 \times 10^{23}$ erg s^{-1} Hz^{-1}
- hard to reconcile with young magnetised pulsar through standard CCSN channel
- accretion- or merger-induced collapse (AIC/MIC)
- magnetic reconnection in LMXBs? (no FRB from galactic ones, though & no X-ray/gamma-ray emission)

FRB 20201124A, Nimmo et al. 2022



- 18 bursts detected in two epochs
- participation of Sr (burst search), Mc, Nt
- DM = 412.0 ± 0.7 pc cm−3
- Epoch 1:
  - R. A.= $05^h08^m03^s.5076$± 2.8 mas, decl. = +26°03′38″.5035± 2.8 mas (S/N of 16.8).
- Epoch 2:
  - R. A.=05h08m03s.5073 ± 2.9 mas, decl. = +26°03′38″.5081 ± 2.7 mas (S/N 18.5)

FRB 20201124A



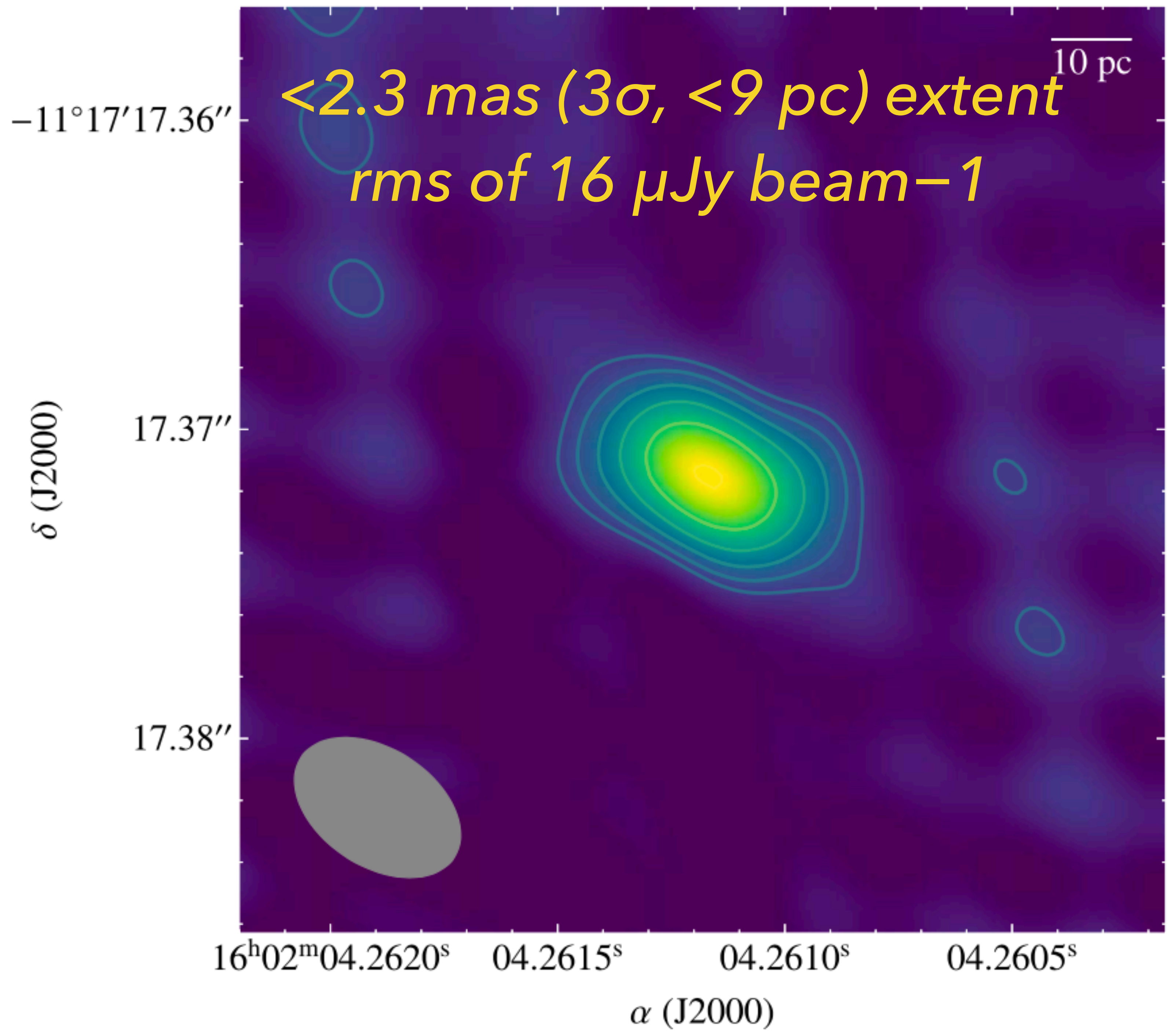
- peak side-lobe level in the dirty map is on average 97% of the main lobe
  - ambiguity in the individual burst positions, at a level comparable to the spacing between side lobes
- alternative approach: fit smooth Gaussian functions to the dirty map pattern fringe pattern
  - safer approach to determine individual burst positions, <u>with <20 baselines</u>

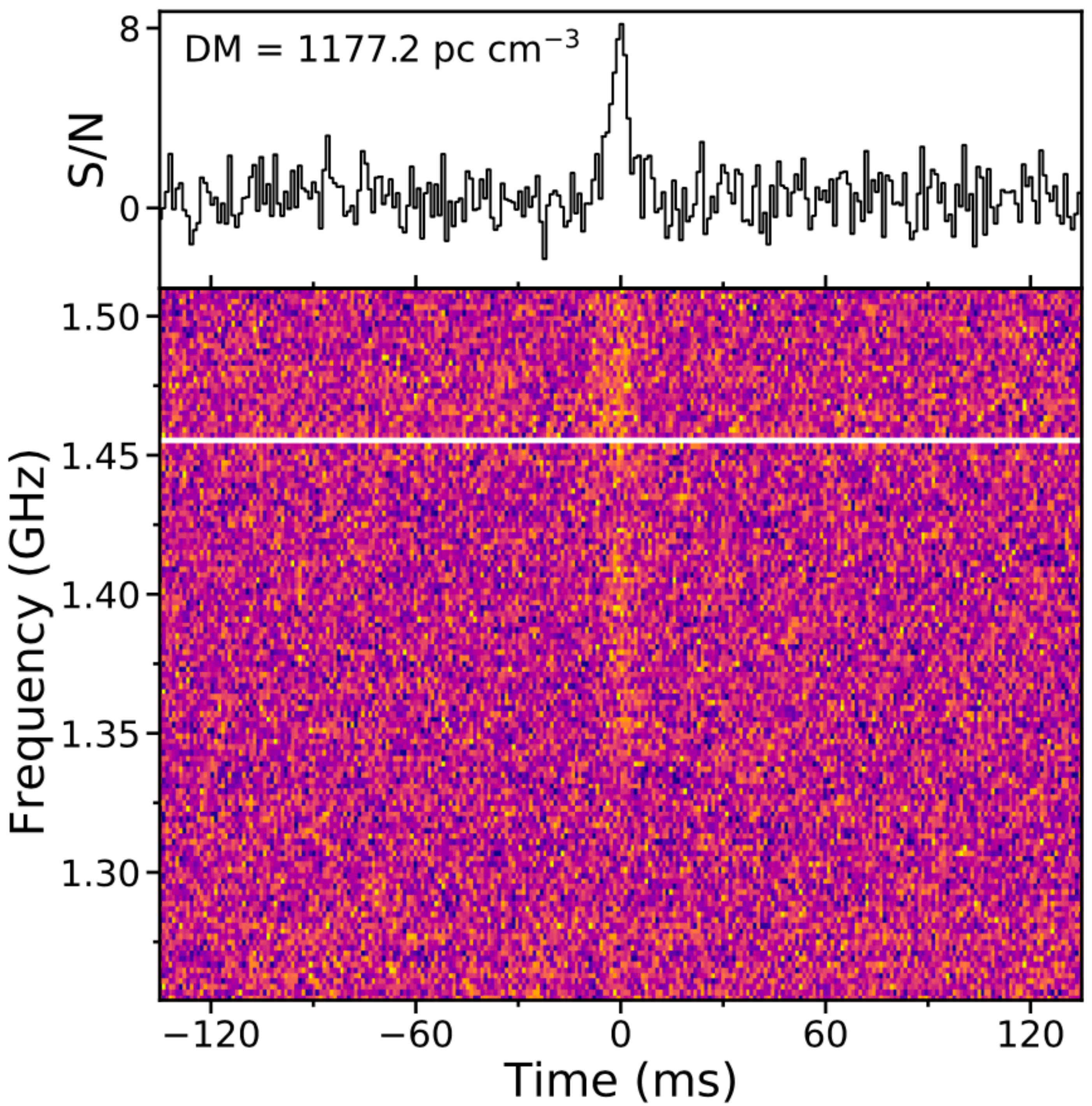
FRB 20201124A

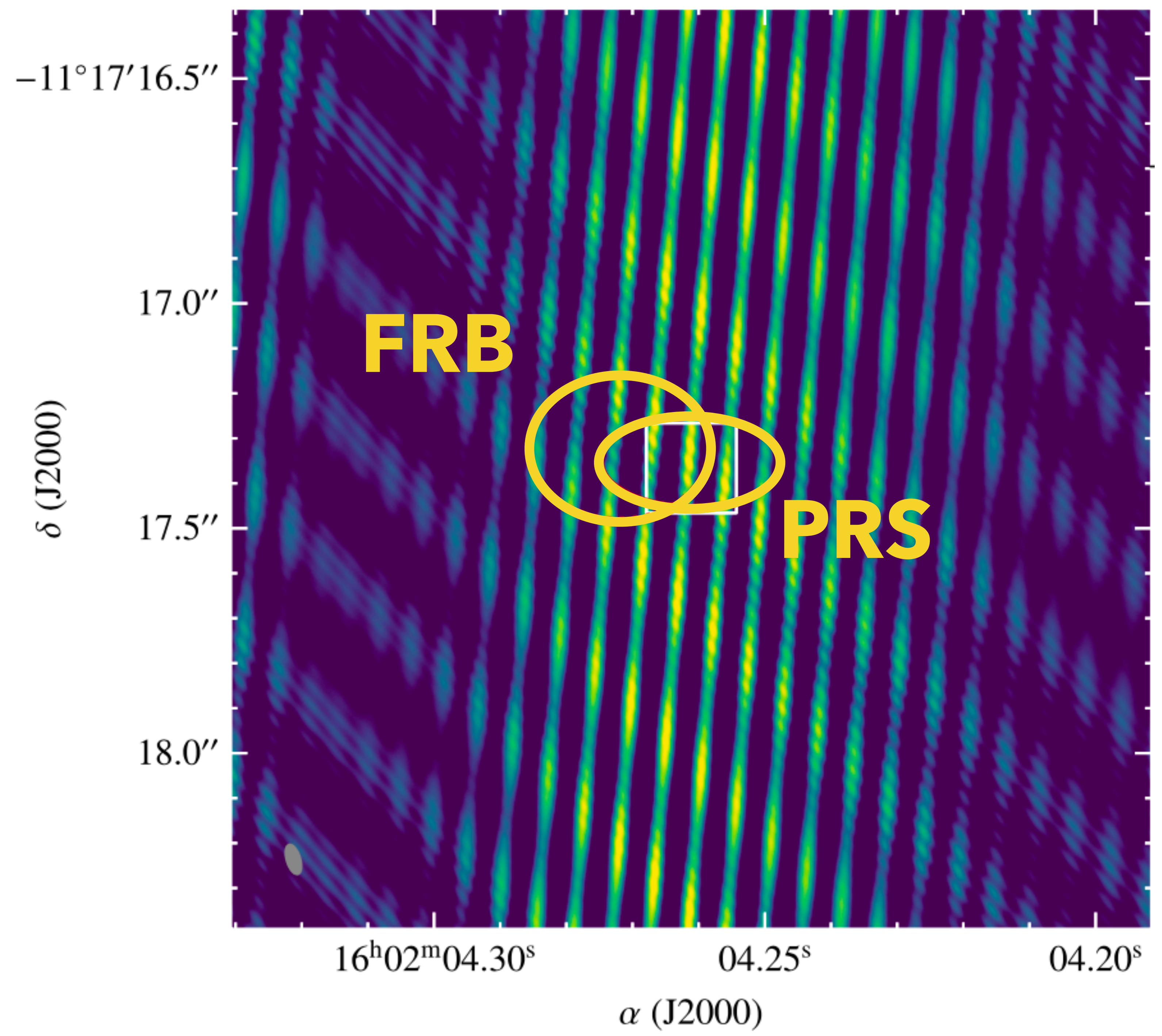
- host is a massive, star forming galaxy at z=0.098
- unresolved persistent emission in VLA, uGMRT data (Ricci+21, Wharton+21, Piro+21)
- lack of compact emission in EVN observations: star formation; but see Bruni et al. (2024) + Gabriele's presentation
- FRB separation from host: 710 ± 30 mas (~1.3 kpc projected); from VLA emission: 175 ± 180 mas (dominated by uncertainty on VLA)

FRB 20190520B, Bandari et al. 2023

- PRS candidate $S_{3\,GHz}$~200 μJy, $L_{3\,GHz}$~10^{29} erg s^{-1} Hz^{-1}, $\alpha=-0.41 \pm 0.04$ ($S_\nu \sim \nu^\alpha$)
- DM = 1205 ± 4 pc cm^{-3}, hosted in a dwarf galaxy at z=0.241
- host DM factor of ~5 larger than typical
- PRS from dedicated EVN observation, FRB from 1 burst in 4-tel (Nt) PRECISE run

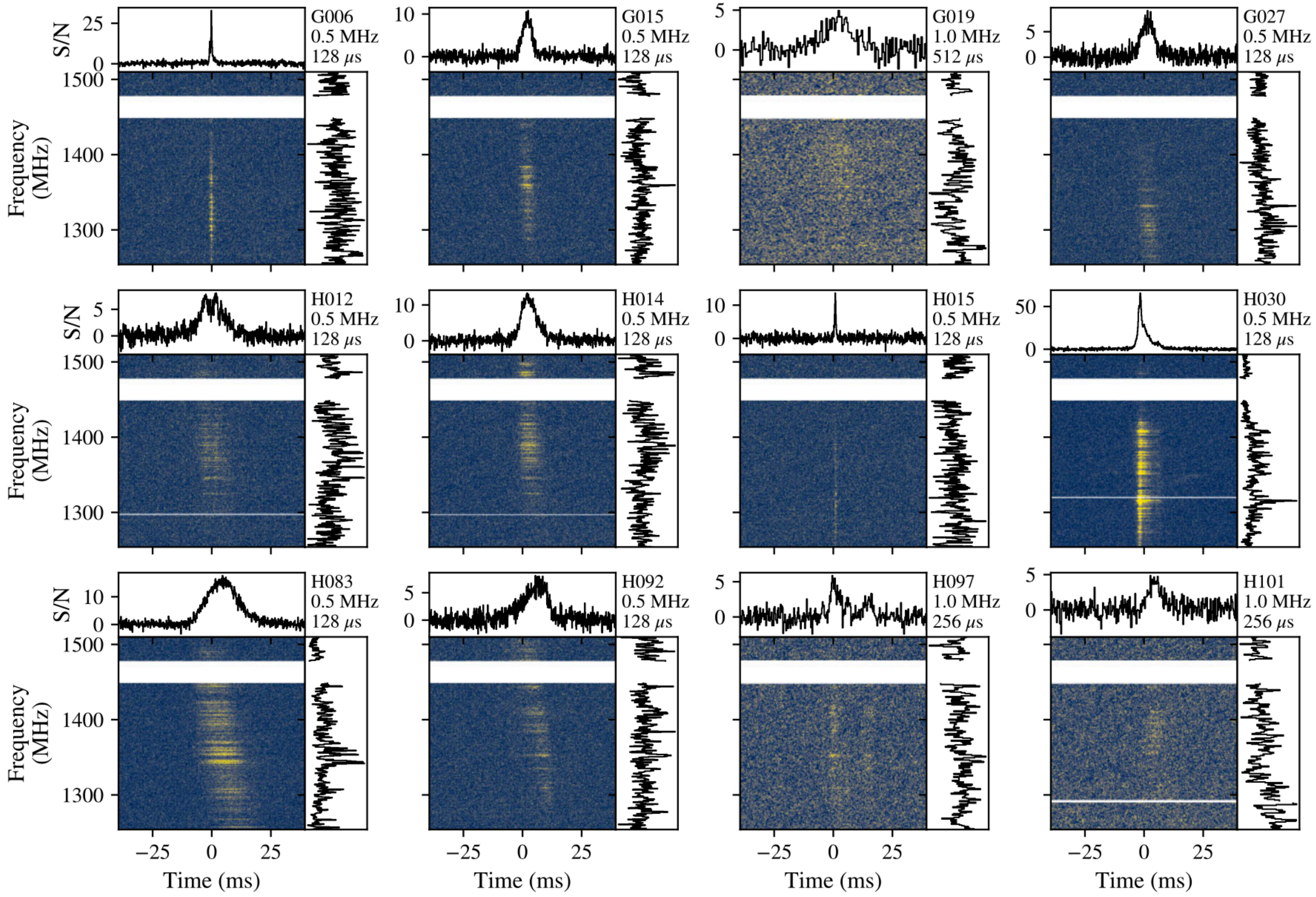






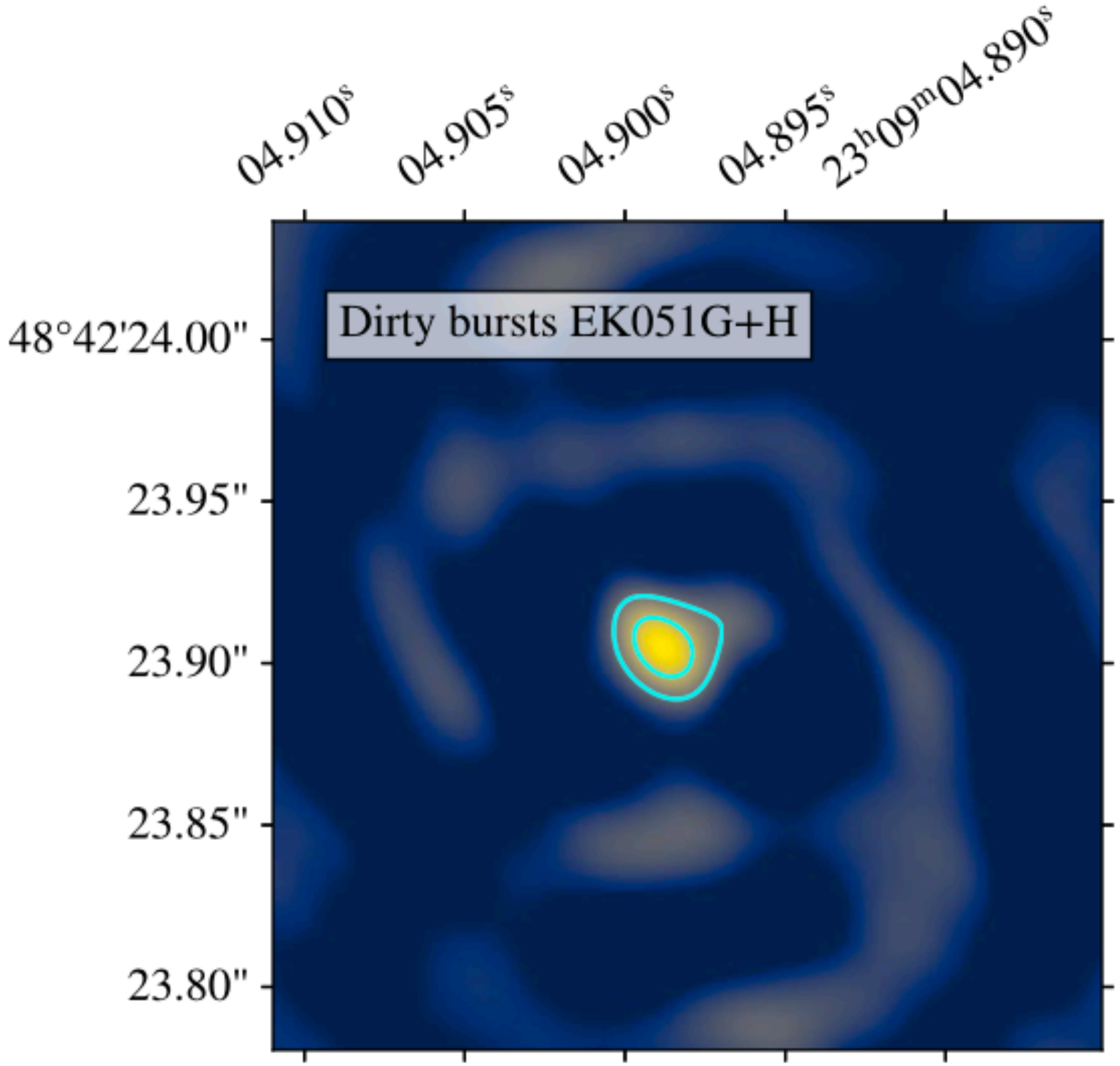
FRB 20220912A, Hewitt et al. 2024

- hyperactive repeater,
- star forming, dusty, massive host galaxy
- 150 bursts detected in two epochs
- Mc, Nt
- DM of 219.37 pc cm^{-3}

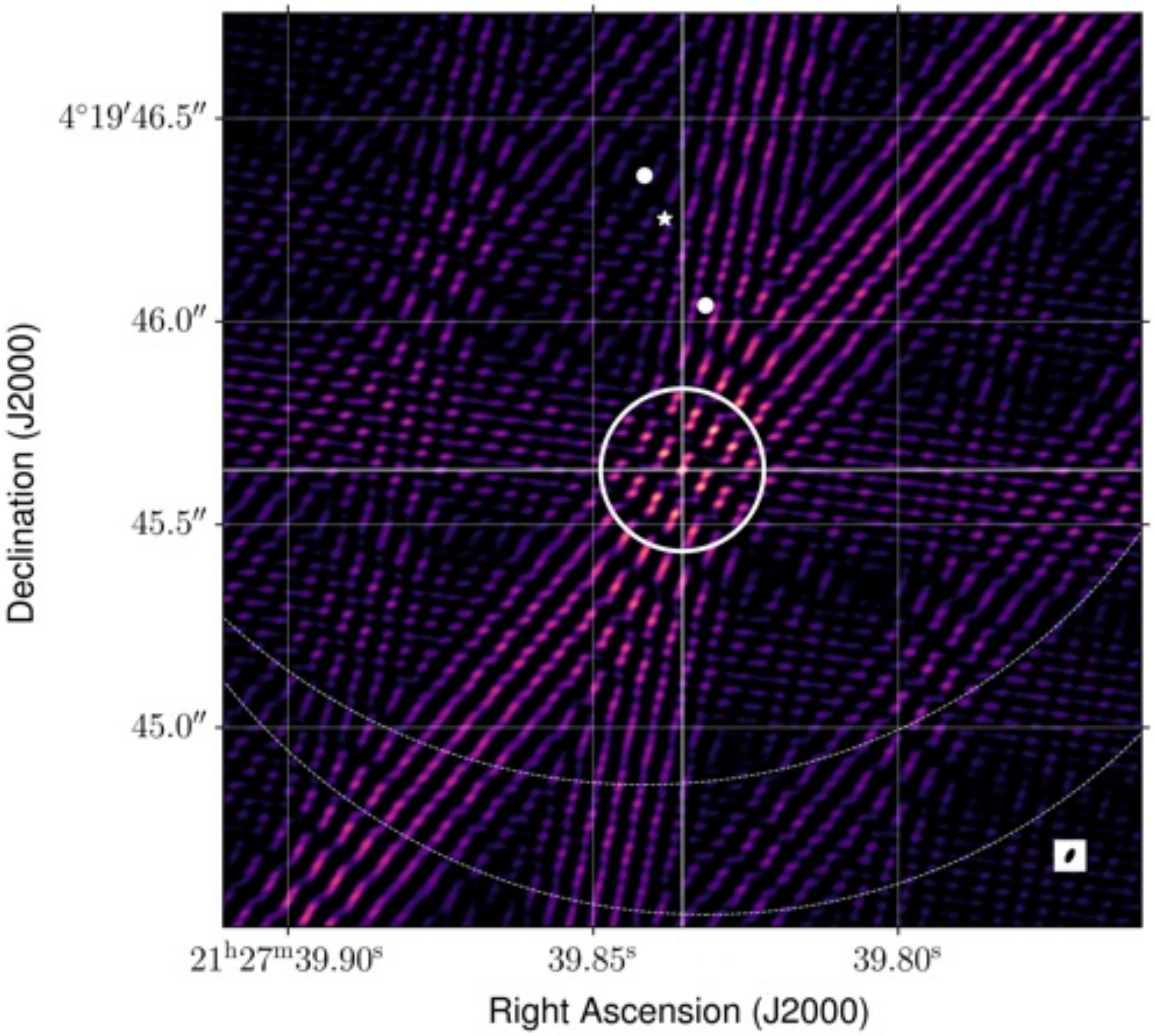


FRB 20220912A, Hewitt et al. 2024

- localisation precision <few mas (10pc)
- closer than expected (0.8 kpc projected) to host nucleus (still significant offset)
- high resolution optical imaging required
- no compact persistent emission (5σ limit of 120 μJy, or 1.8×10^{28} erg s^{-1} Hz^{-1}, more than an order of magnitude below those associated with 20121102A/20190520)
- surprising, given hyperactivity - yet compatible with low RM (clean, non-turbulent environment)



in the pipeline… FRB 20240114A



Single burst reported in ATel #16542 (Snelders et al. 2024)

just two months after discovery!

6 telescopes (incl. Nt)+e-Merlin

Consistent with MeerKAT position

…and more FRBs being processed! Stay tuned

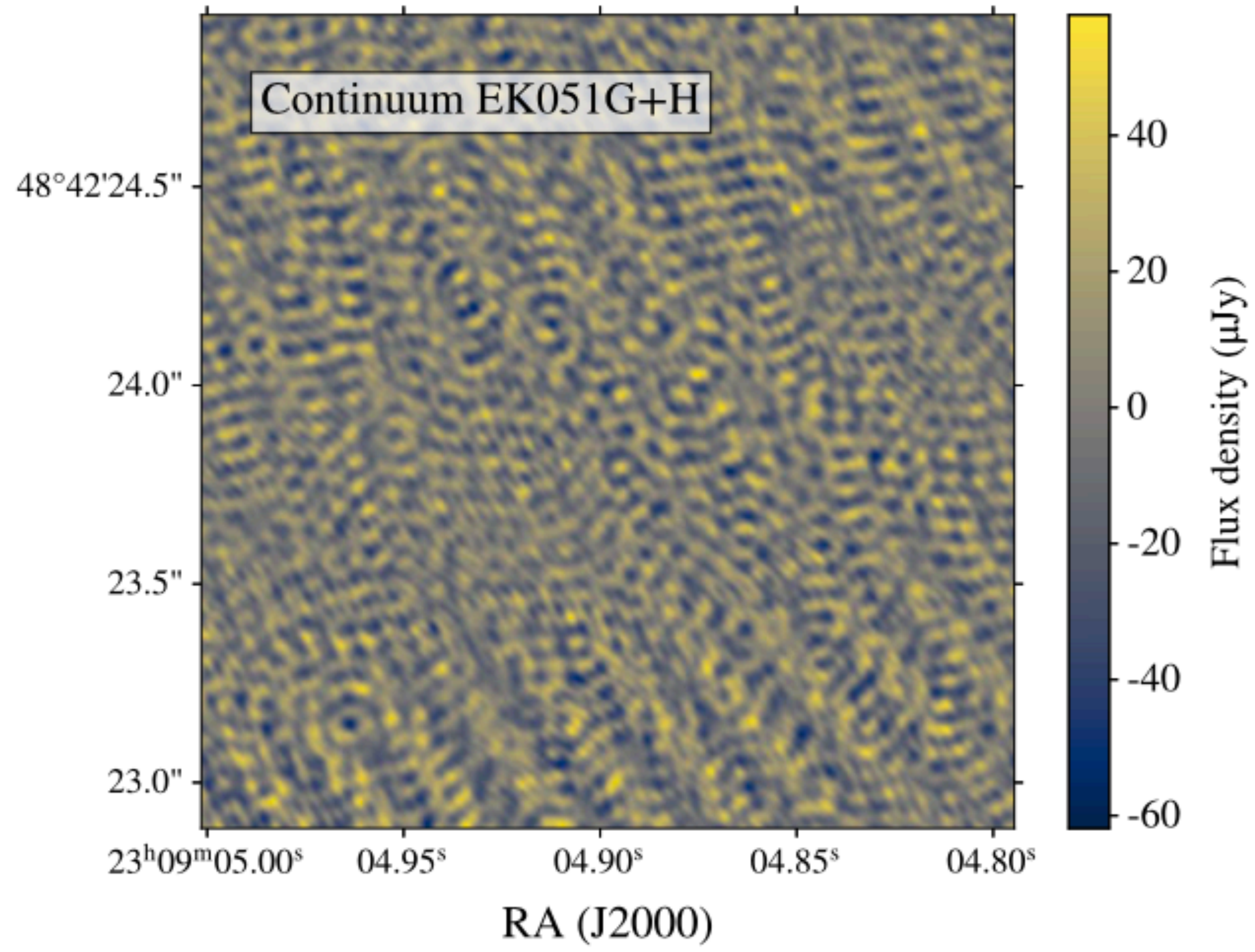
PRECISE future

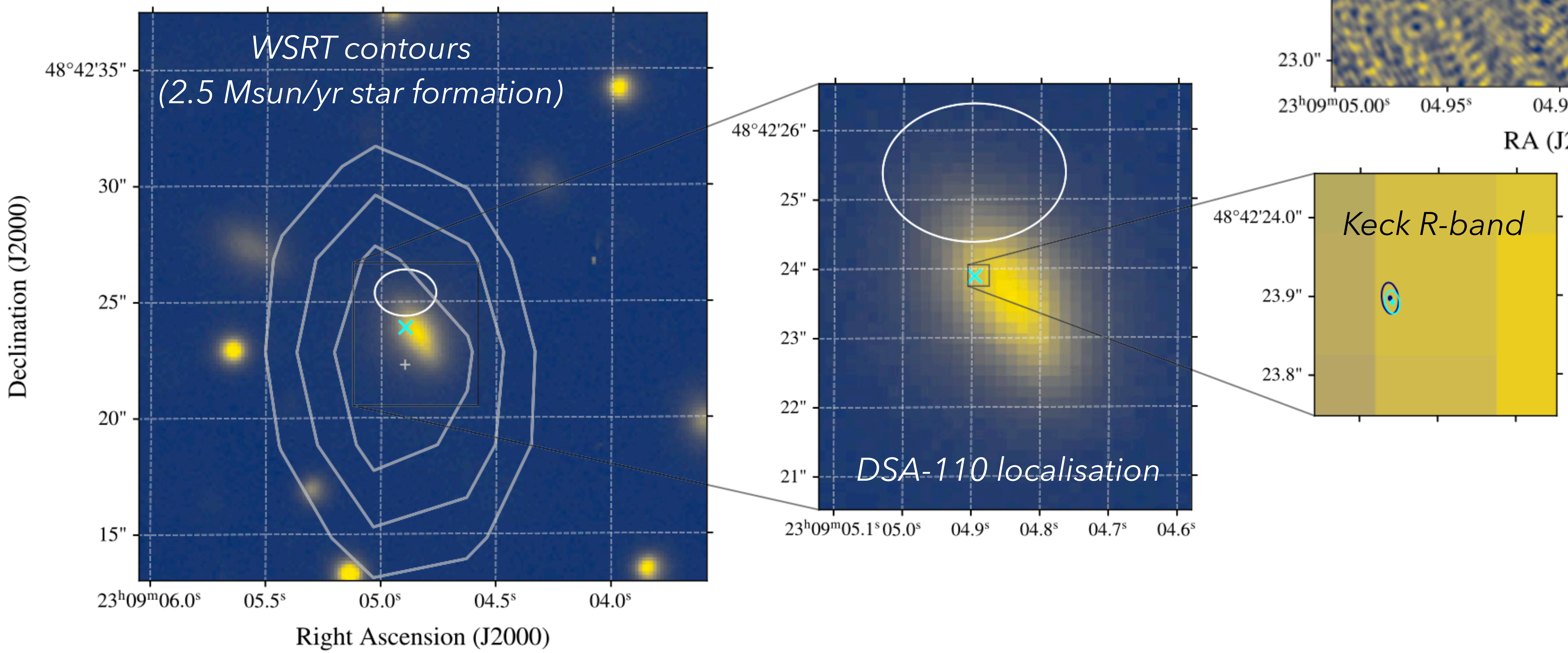
- include e-Merlin (for more sensitivity to PRS on intermediate angular scales), uGMRT (for sensitivity, coverage/localisation)
- more SRT hours to complement Effelsberg in burst searches
- INAF “sub”-PRECISE?
  - several tests on existing data; need for several bursts or additional baselines (Matera?)
  - coordination with Northern Cross/FAST (?)
  - more involvement in PRECISE analysis

Backup

FRB 20201120E

FRB 20220912A





Abstract

- One key aspect required to understand the origin of FRBs is to know the type of environment they are emitted in. Thus, not only the host galaxy of an FRB is of importance, but also the precise location within that host need to be determined to solve the FRB-puzzle. Such accurate measurements are only possible with Very Long Baseline Interferometry. I will review the cases of FRBs localised with milliarcsecond precision, describing the technique, the main results and their implications, and the future prospects.

- 20121102
- 20180916
- 20190520
- 20200120
- 20201124
- 20220912
- 20240114