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Ministero dell'Università e della Ricerca

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PIANO NAZIONALE DI RIPRESA E RESILIENZA

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The Northern Cross Fast Radio Burst project: status update and future perspectives

PNRR NG-CROCE

IRA - Bologna

Maura Pilia

The NC as an SKA pathfinder

Work in progress..

Fast Radio Bursts

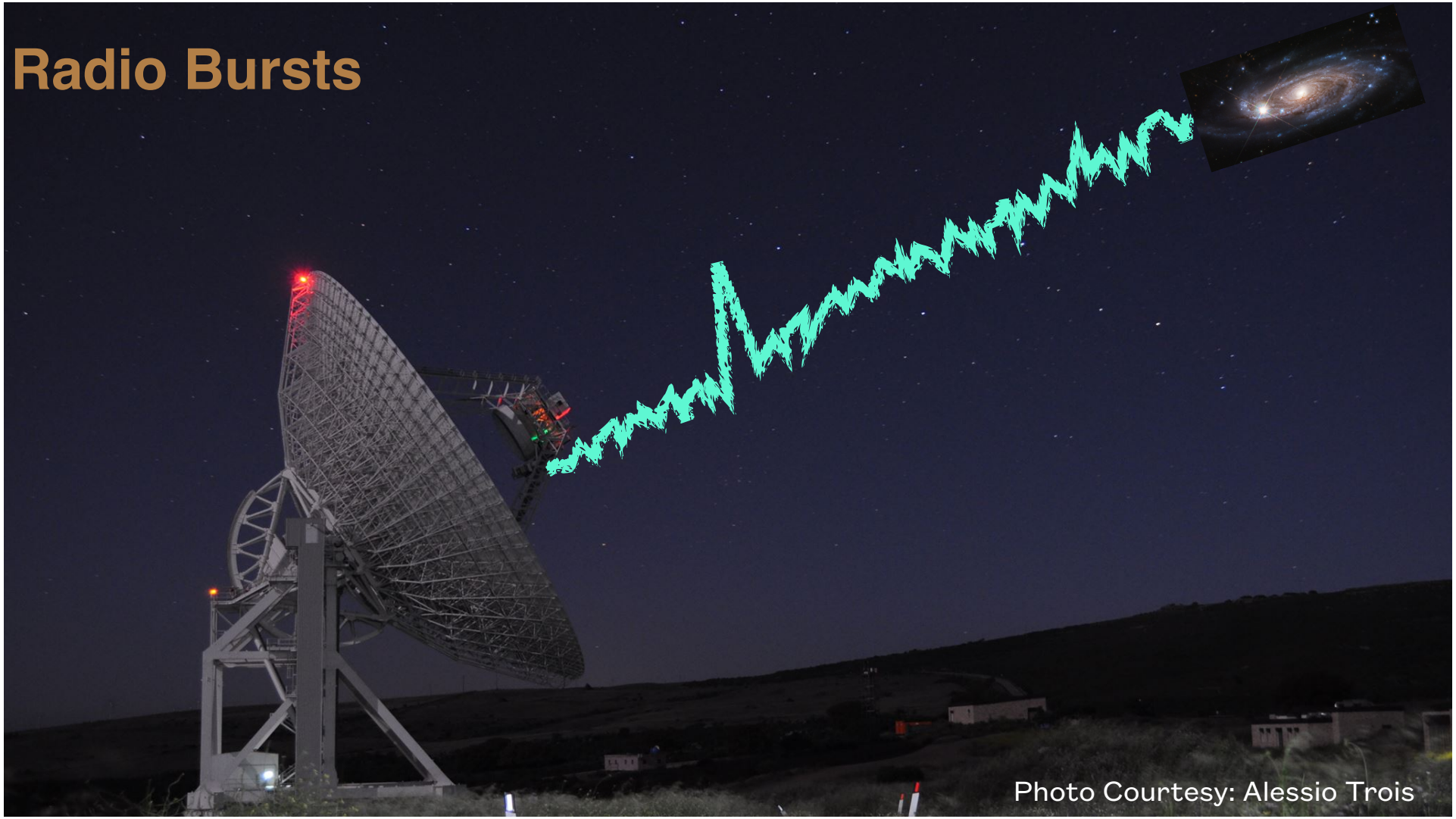
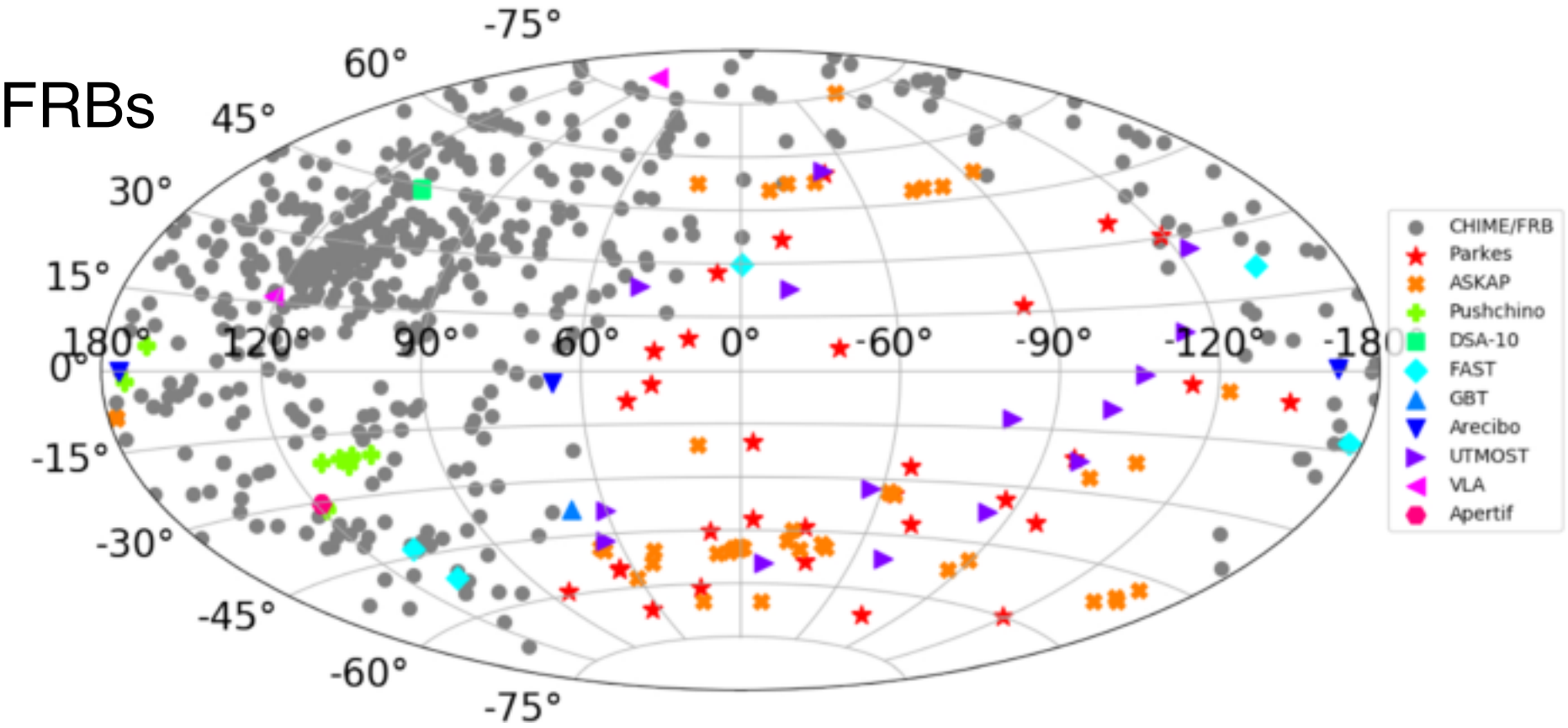


Photo Courtesy: Alessio Trois

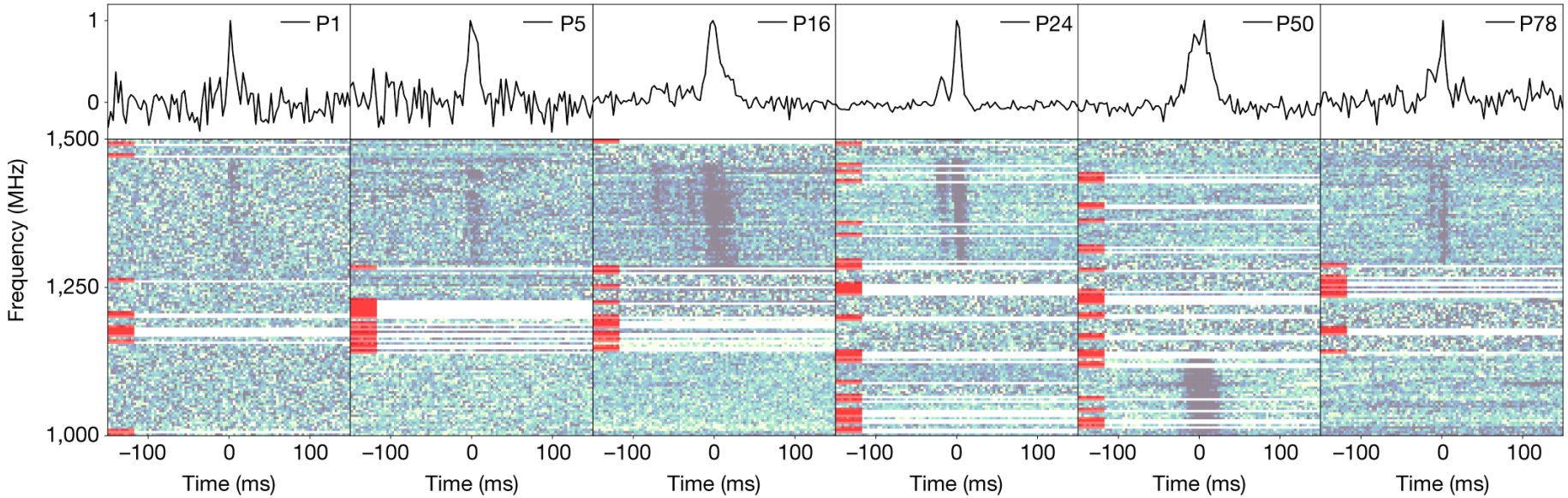
FRBs in numbers:

- ~ 850 known FRBs



FRBs in numbers:

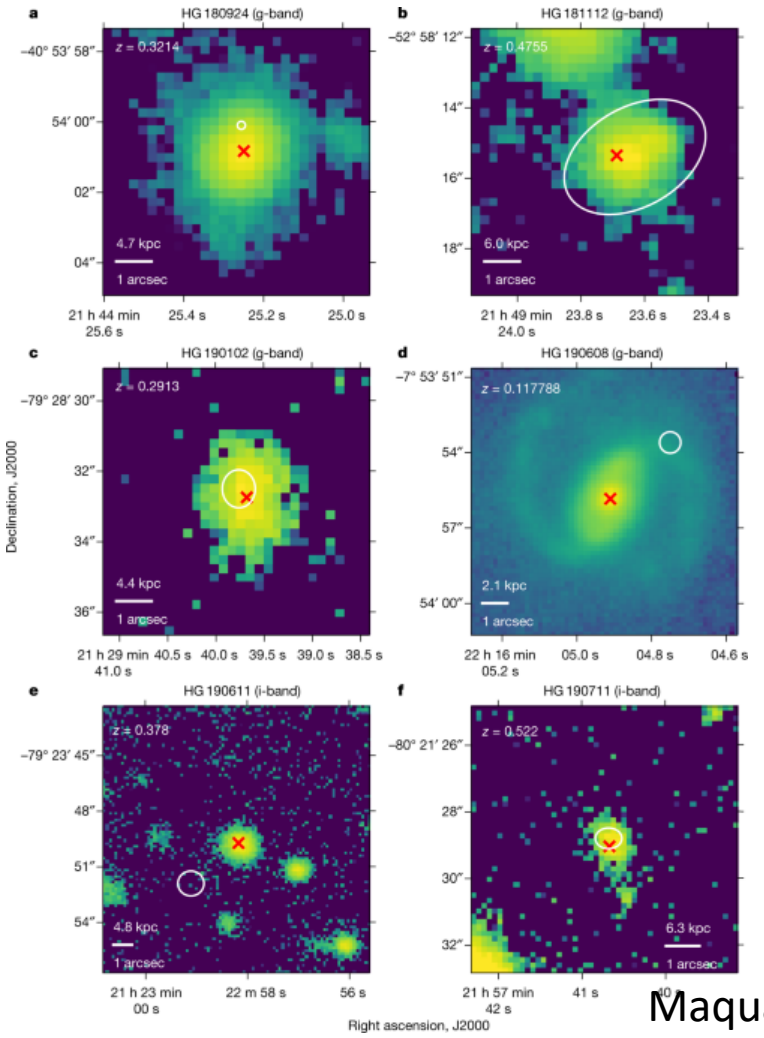
- ~ 850 known FRBs
- ~ 60 repeaters



FRBs in numbers:

- ~ 850 known FRBs
- ~ 60 repeaters
- ~ 100 localised

See D. Pelliciari's talk

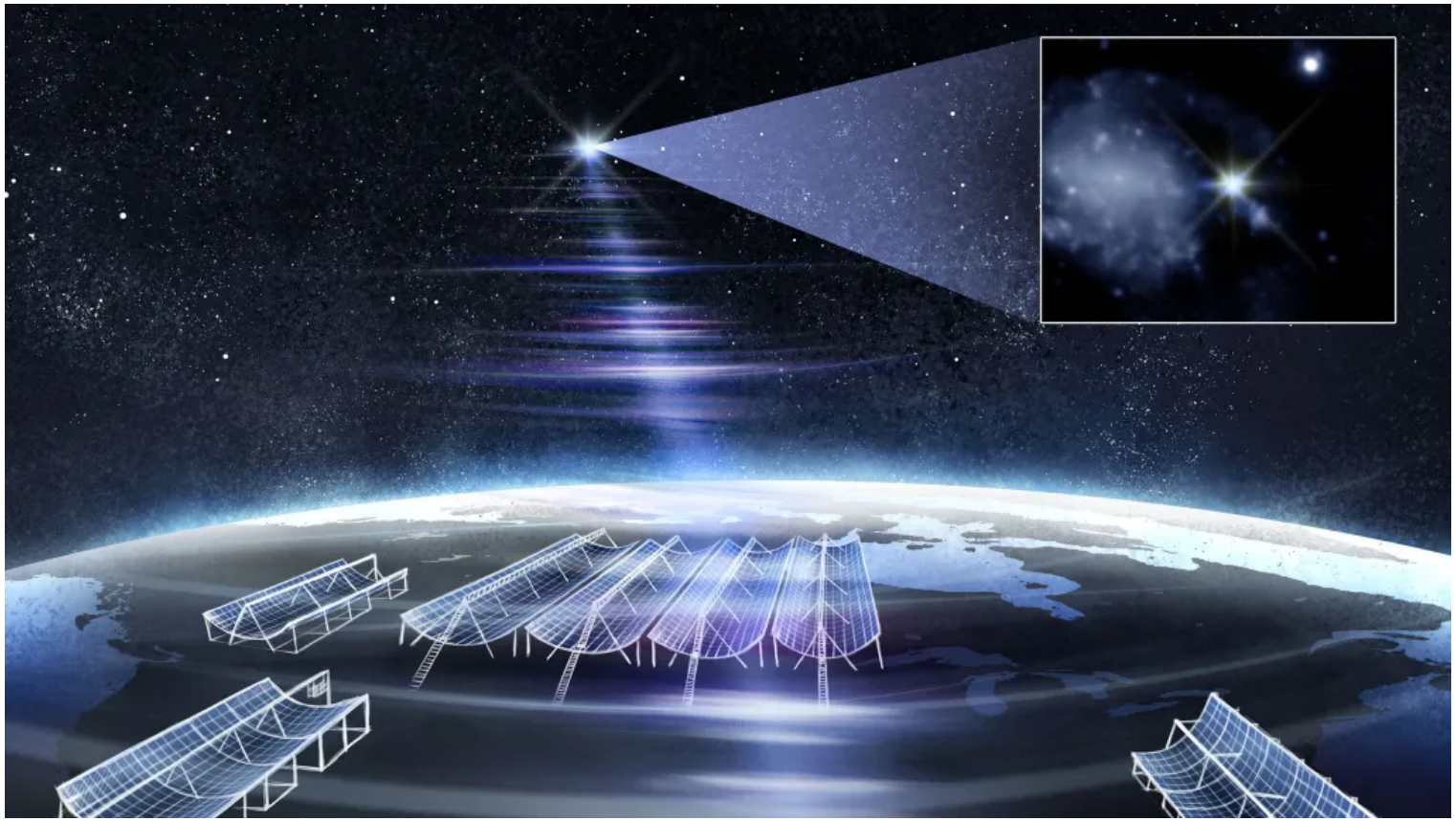


Maquart et al. 2020, Nature

The importance of FRB localisation

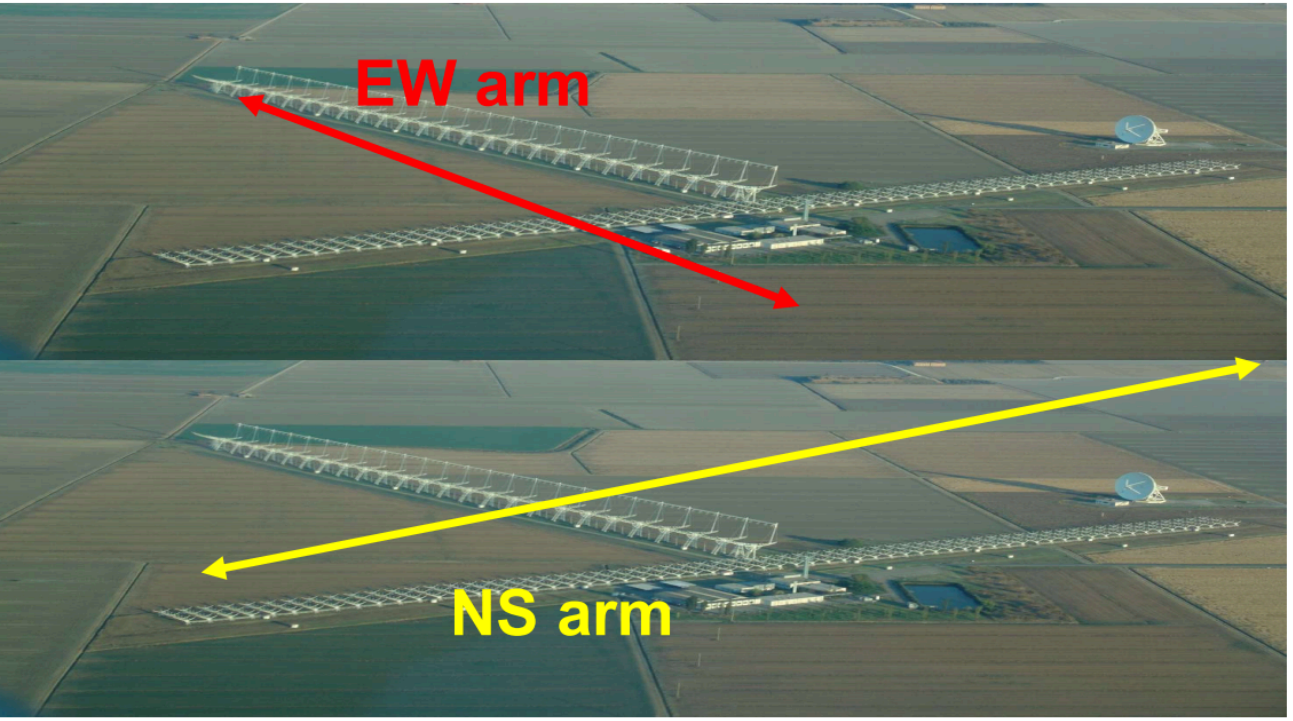
Maquart et al. 2020, Nature

How do we detect them? (CHIME)



Credits: GBO

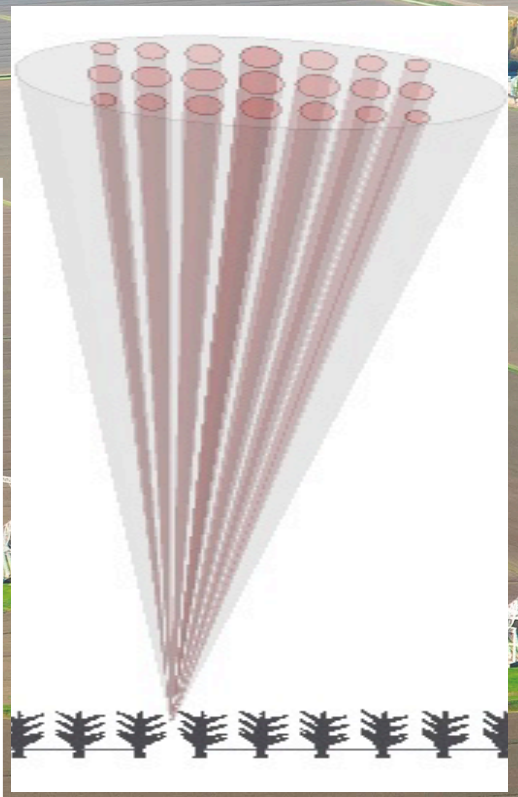
The Northern Cross radio telescope



- T-shape array operating at 408 MHz;
- NS arm: array of 64 cylinders, 640 m × 23.5 m (11200 m^2 vs 8000 m^2 for CHIME), 64 dipoles per cylinder;
- EW arm: array of single dipoles, 564 m × 35 m;

The Northern Cross as an FRB facility

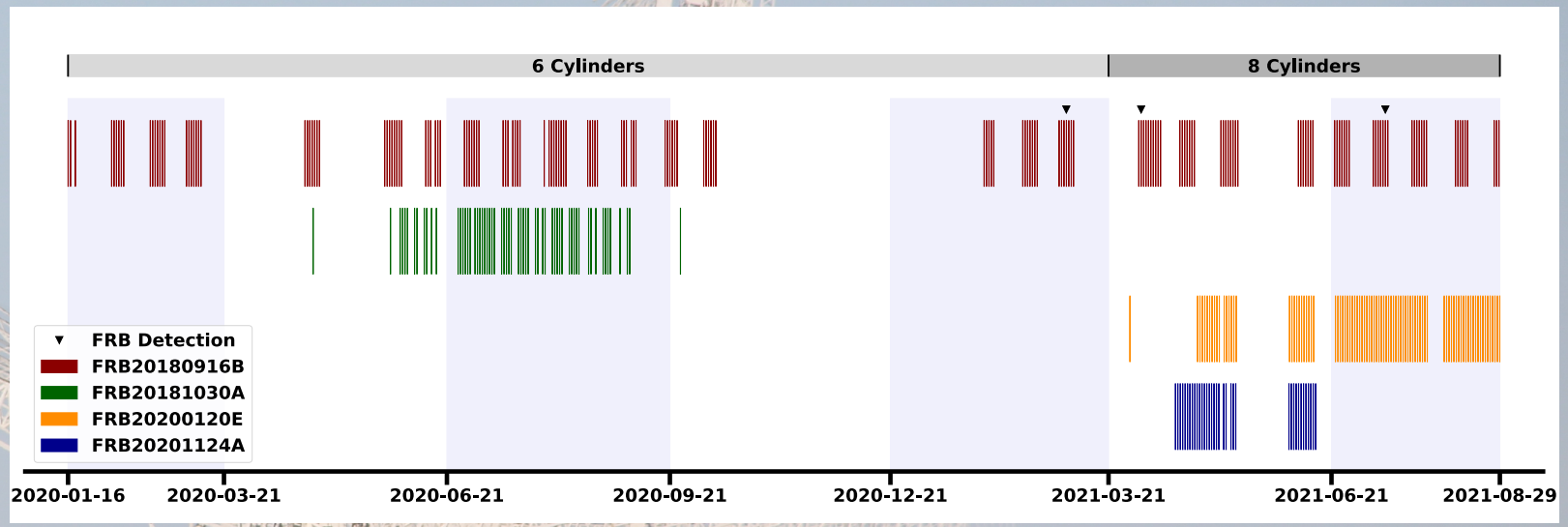
- Analogue beam former 16 dipoles (one receiver) are grouped together within each cylinder;
- New LNAs installed on the focal line, signals send RF over fibre to an acquisition board (digitisation and channelisation);
- FPGA channelisation: 16 MHz bandwidth, 781.25 kHz channel width; 1.08 μs time resolution. Digital beam forming:
  - 16 cylinders, 1 beam: 1.6°× 0.25°; 16-bit filterbank, 138 μs time resolution, 14 kHz channel resolution.
  - 1 sigma sensitivity ~ 1 Jy ms

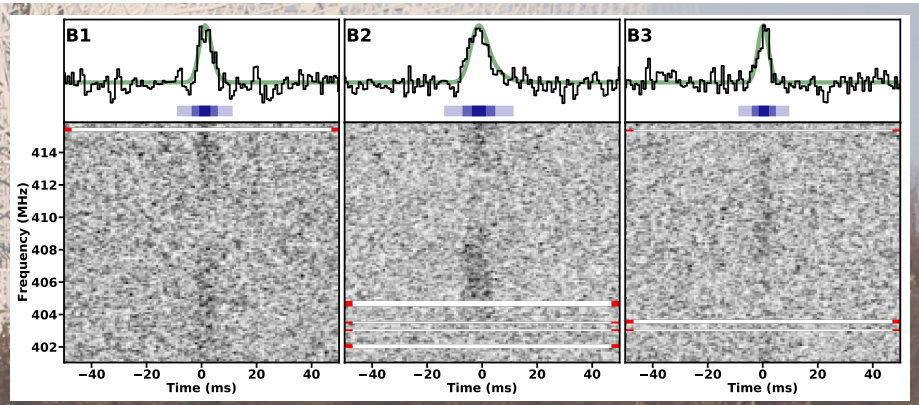


Locatelli et al. 2022, MNRAS

Northern Cross - FRB: Monitoring

- Regular monitoring of 4 active repeaters
- First light: detection of 3 bursts from R3
- Limit on rates of the other repeaters



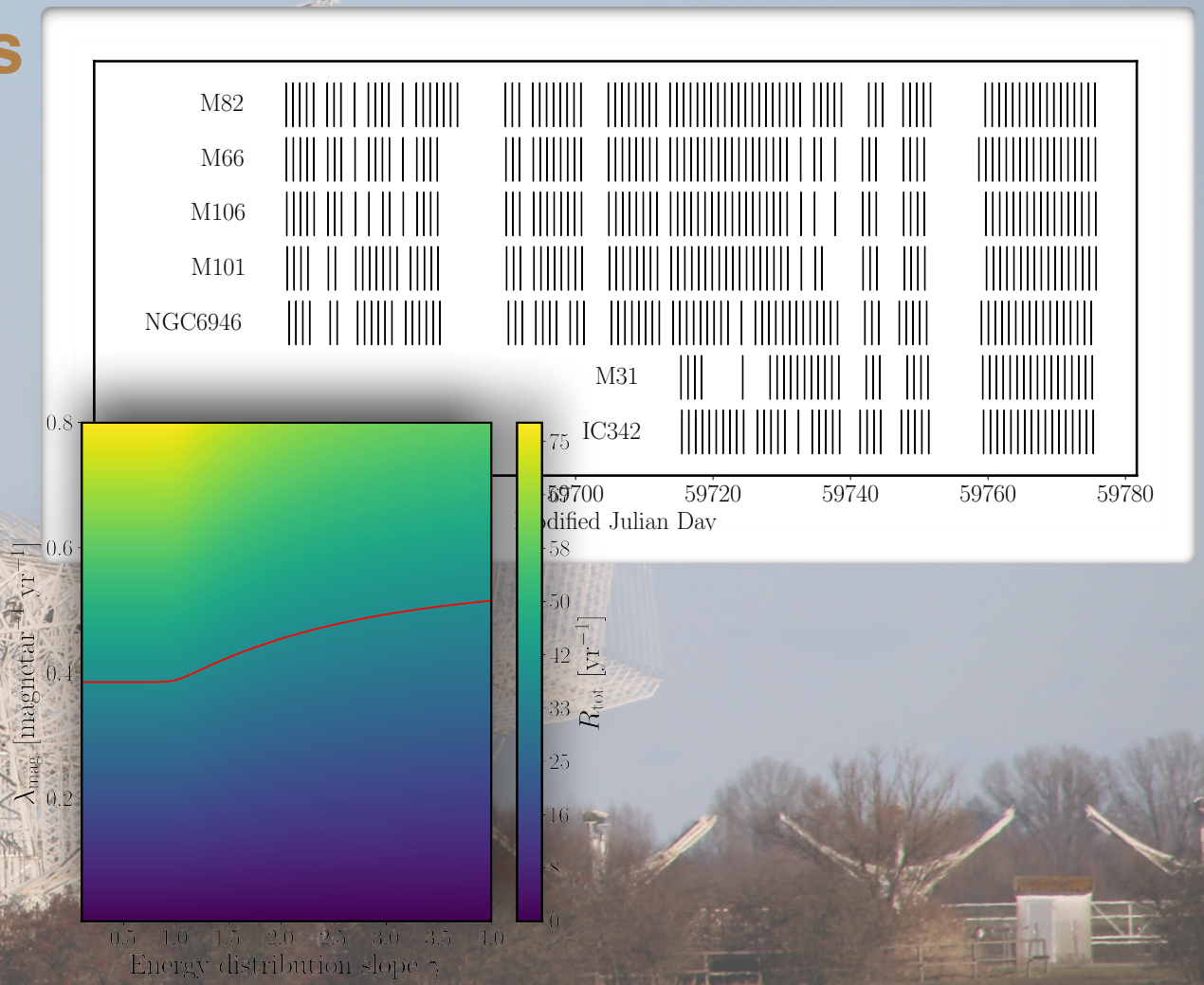


Trudu et al. 2022, MNRAS

Northern Cross - FRB: Surveys

- 7 nearby galaxies with high star formation rate
- Search for magnetars like SGR 1935
- No FRBs discovered in more than 700 hours
- Magnetars like SGR less common than expected

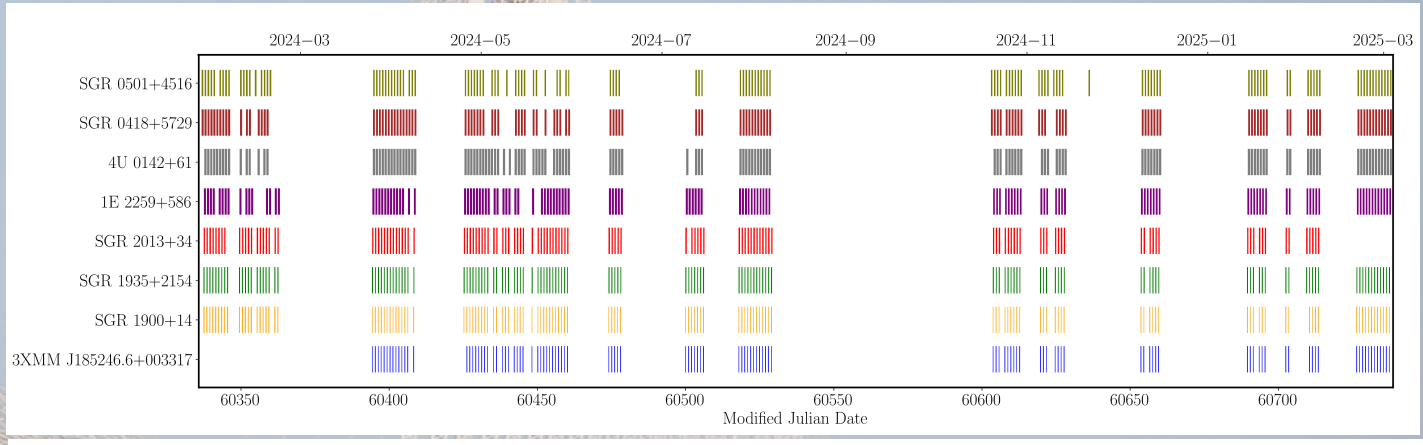
Pelliciari et al. 2023, A&A

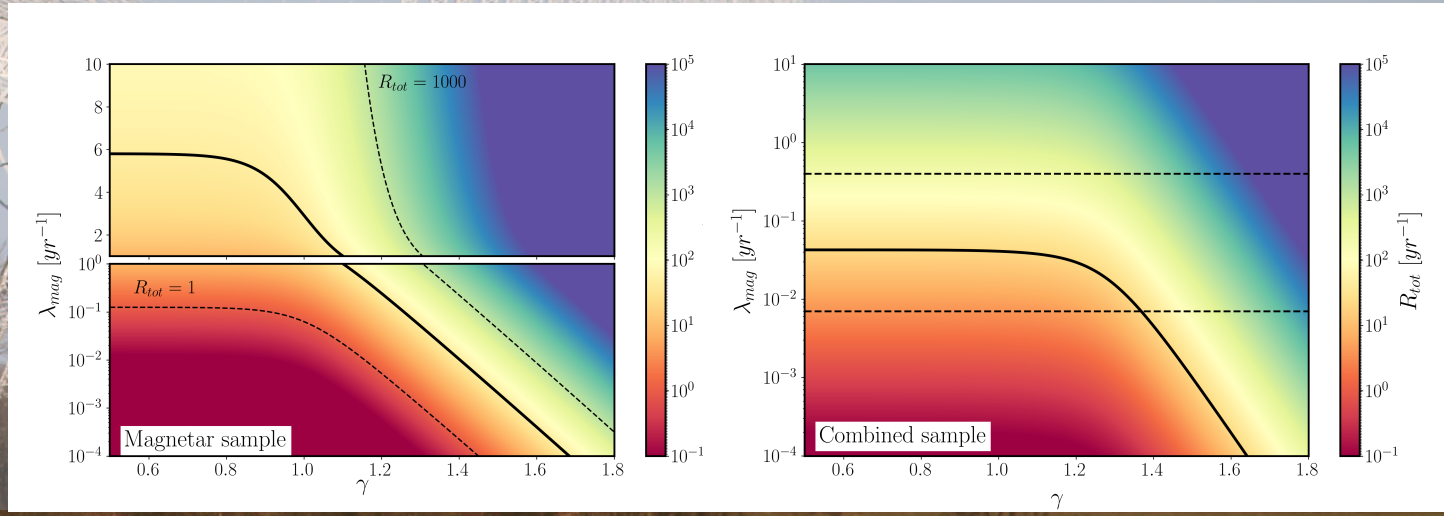


Northern Cross - FRB: Surveys

- Galactic magnetars
- No FRBs or radio pulses discovered in more than 500 hours
- Events like the galactic FRB200428 seem subdominant in the global budget of FRB events

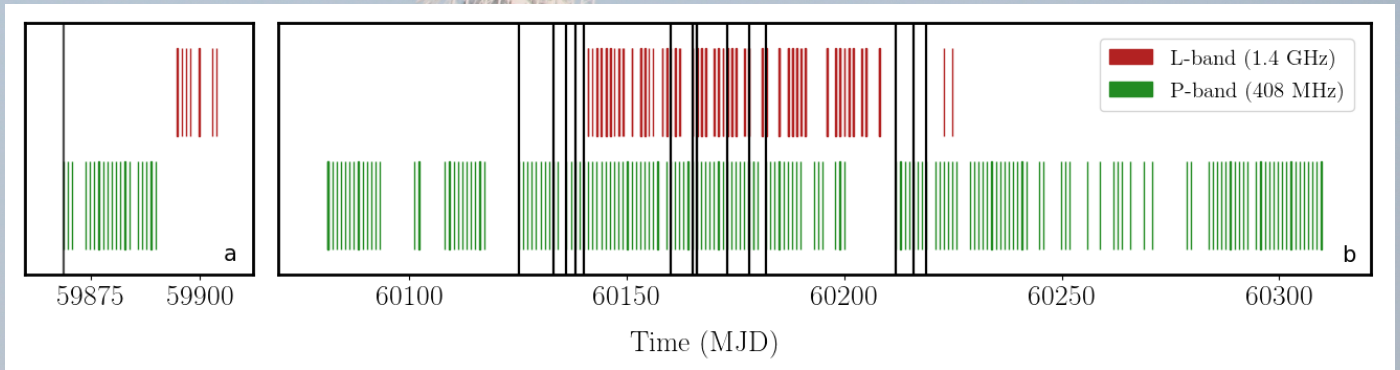
Geminardi et al. 2025, A&A

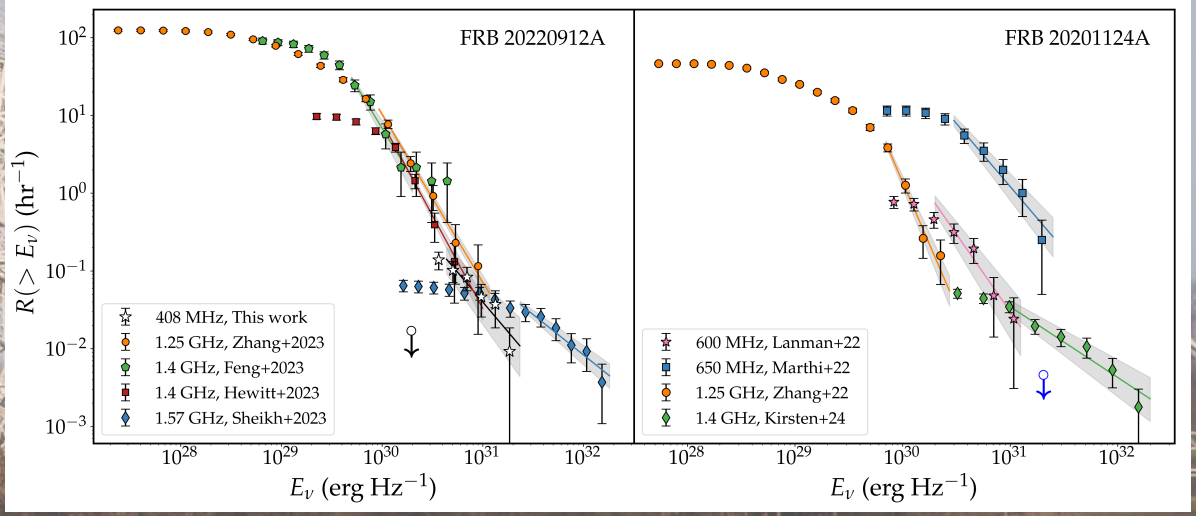




Northern Cross - FRB: Monitoring

- FRB 20220912A
- 16 new bursts with fluence up to 147 Jy ms
- None detected at L-band
- Cumulative spectral energy rates





Pelliciari et al. 2024, A&A

Northern Cross - FRB: Monitoring

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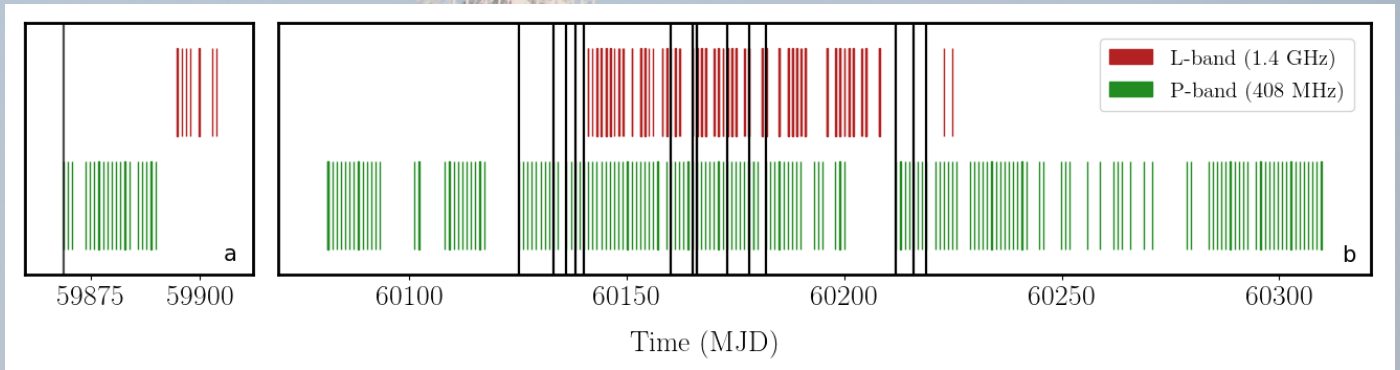
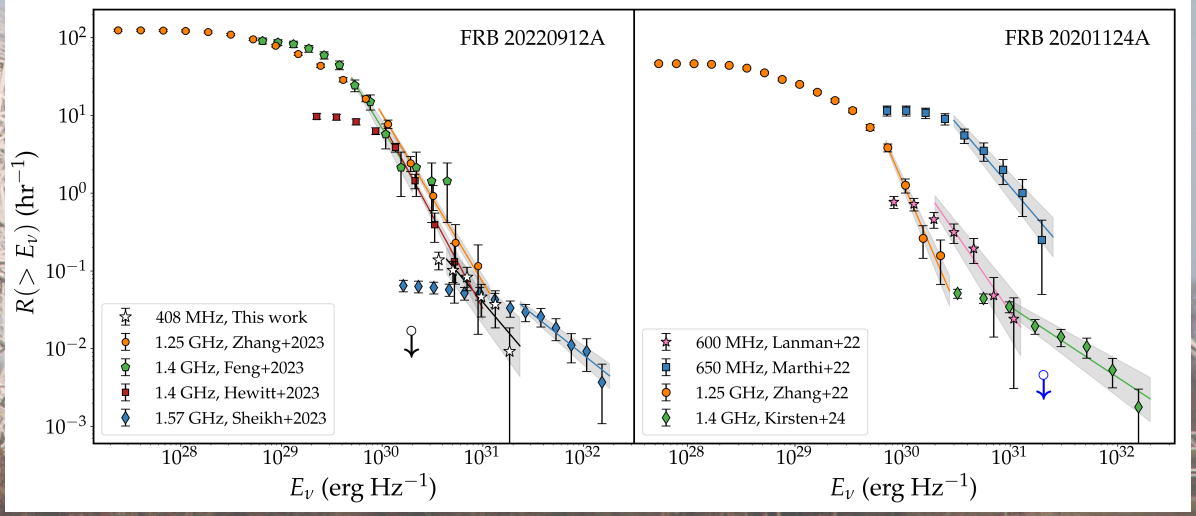
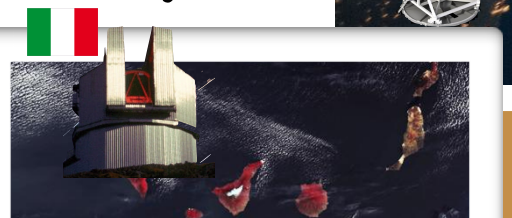




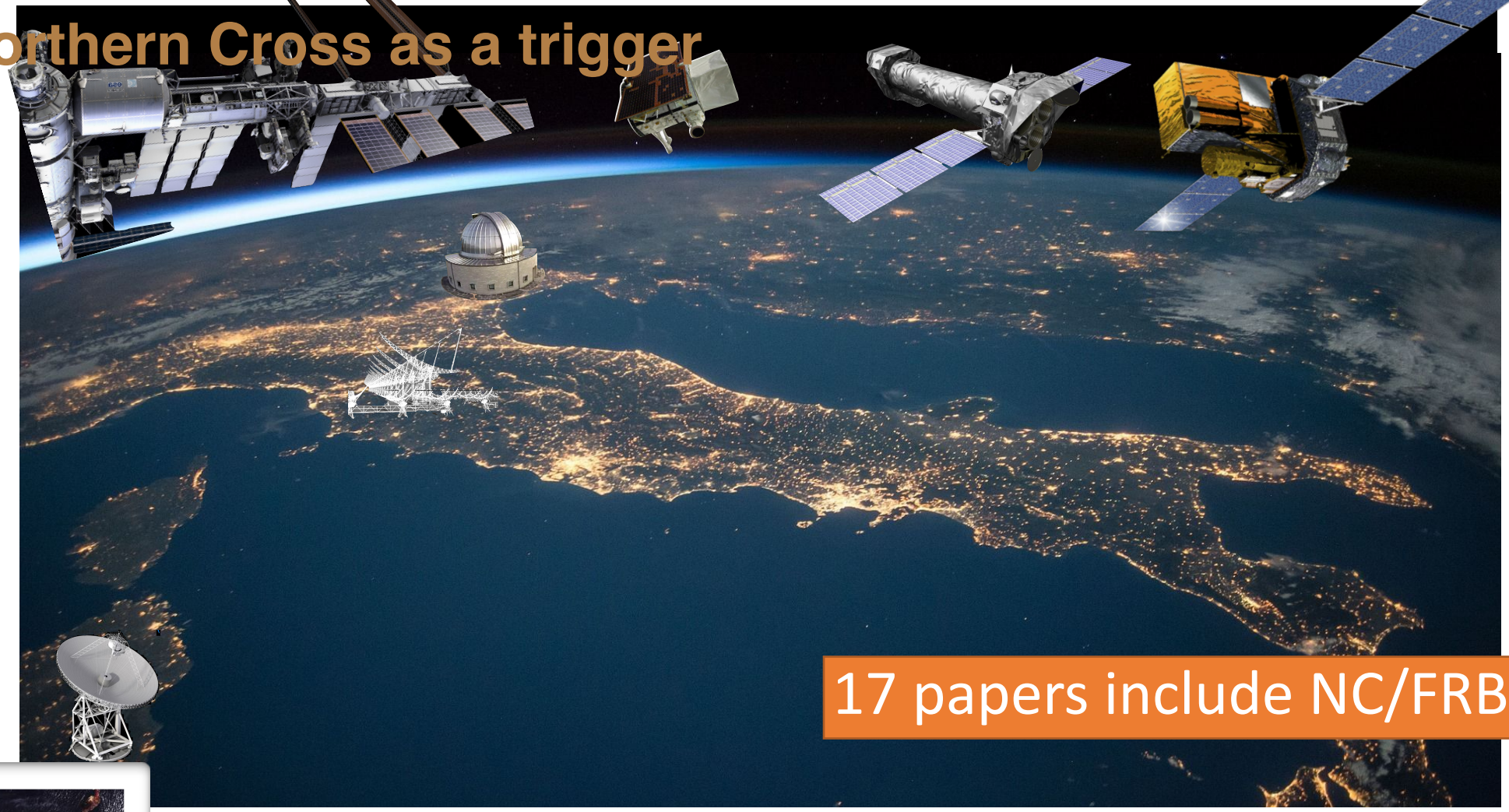
Pelliciari et al. 2024, A&A

+ Crab pulsar —> see L. Beduzzi's talk

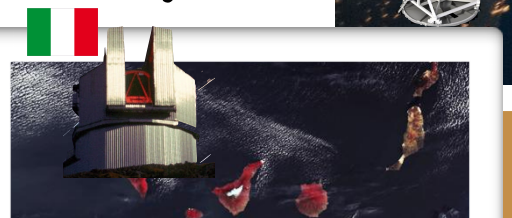
The Northern Cross as a trigger



The Northern Cross as a trigger



17 papers include NC/FRB data!



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Italian Northern Cross Archive of Radio Transients

NEXT GENERATION CROCE DEL NORD

Welcome to **INCART**! The archive collects observations of FRBs detected by the Northern Cross and Medicina-Grueff radio telescopes in Medicina (Bologna, Italy).
Download complete catalogue.fits or check it online.

ACKNOWLEDGEMENTS. These data are provided by the NC team and are owned by **INAF**. The filterbank data are also available through the IA2 service. If you use our database, please include the following acknowledgement:
This research used the facilities of the Italian Center for Astronomical Archive (IA2) operated by INAF at the Astronomical Observatory of Trieste.

Northern Cross radio inteferometer (*left*) and Medicina Grueff radio telescope (*right*). **Image credits**: Lesia Vasylchenko

Search by

- ○ **Complete catalogue**
- ◉ **FRB Name** FRB20220912A
- ○ **Date of observation** **from** gg/mm/aaaa **to** gg/mm/aaaa

Submit Reset

coming soon!

INCART

- sustainable **archive** for fully-processed observations
- **database** with derived physical quantities

Credits: L. Bruno

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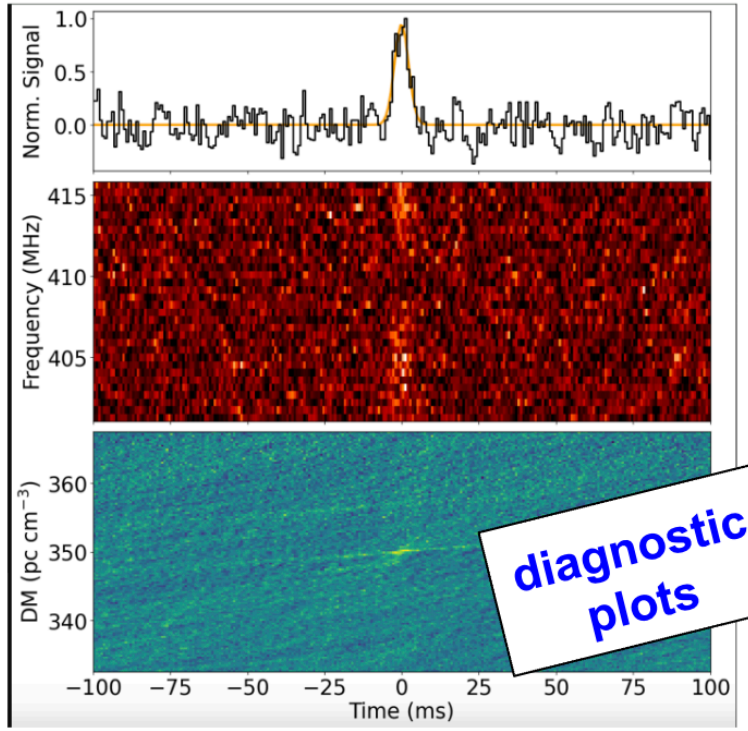
Result of your searching parameters

ID ▼	Name ▼	RA	DEC	Obs. Date ▼	ToA	SN_p	SN_{int}	DM	FWHM	S_p ▼	F_{rect}	F_{gauss} ▼	X_{red}^2	Plot	LogFile	FilFile	Notes	ProjID ▼
		deg	deg	yyyy-mm-dd	MJD (TOPO)			pc cm-3	ms	Jy	Jy ms	Jy ms						
2	FRB20180916B	29.503333	65.71675	2021-03-03	59276.59570715	7	18	350.3 ± 0.4	5.4 ± 0.5	17.2 ± 1.7	93.4 ± 12.6	94.9 ± 11.9	1.05	.PNG	.TXT	.FIL	1	NC-01-21
3	FRB20180916B	29.503333	65.71675	2021-04-03	59307.51674301	9	22	350.1 ± 0.2	8.8 ± 0.7	16.7 ± 1.4	147.6 ± 16.5	150 ± 15	0.98	.PNG	.TXT	.FIL	1	NC-01-21
21	FRB20180916B	29.503333	65.71675	2021-07-13	59408.25431054	6	14	349.7 ± 0.4	4.5 ± 0.5	19 ± 2.1	85.7 ± 13.5	87 ± 13	0.95	.PNG	.TXT	.FIL	1	NC-01-21
20	FRB20180916B	29.503333	65.71675	2022-04-30	59699.52958656	6	14	350.1 ± 0.2	7.4 ± 0.9	10.8 ± 1.2	79.4 ± 13	80.6 ± 12.5	0.94	.PNG	.TXT	.FIL	1	NC-01-21
22	FRB20180916B	29.503333	65.71675	2022-08-09	59800.25176396	10	22	350.2 ± 0.2	3.9 ± 0.3	24 ± 2	94.6 ± 10.9	96.1 ± 10	1.05	.PNG	.TXT	.FIL	1	NC-01-21
10	FRB20220912A	347.270417	48.707056	2022-10-16	-1	5	13	220 ± 0.1	4.8 ± 0.6	16 ± 1.9	76.2 ± 13.1	77.4 ± 12.8	1.01	.PNG	.TXT	.FIL	1	NC-01-21
1	FRB20220912A	347.270417	48.707056	2023-06-30	60125.24338107	6	13	220.2 ± 0.2	3.2 ± 0.4	7.7 ± 0.9	25.1 ± 4.4	25.5 ± 4.2	0.97	.PNG	.TXT	.FIL	0	NC-01-21
7	FRB20220912A	347.270417	48.707056	2023-07-08	60133.22531647	4	11	220.1 ± 0.2	9.2 ± 1.5	3.9 ± 0.6	35.5 ± 7.6	36.1 ± 7.5	1.07	.PNG	.TXT	.FIL	0	NC-01-21



diagnostic plots

```
Data file: burst1.fil
Data type: filterbank (topocentric)
Telescope: NC
Datataking Machine: ADU
Source Name: FRB20180916B
Source RA (J2000): 01:58:00.8
Source DEC (J2000): +65:43:00.3
Frequency of channel 1 (MHz): 415.854456
Channel bandwidth      (MHz): -0.014468
Number of channels: 1024
Number of beams: 1
Beam number: 1
Time stamp of first sample (MJD): 59276.595687820147
Sample time (us): 138.24000
Observation length (seconds): 18.1
Number of bits per sample: 16
Number of IFs: 1
Original relative TOA (s): 10.0752
Observation length (minutes): 64.9
Beam correction factor: 1.046771938356043
Note: Missing original full length file; re-analysis done on a cutout file
Cutout observation length (s): 2
Cutout relative TOA (s): 1.0
Time stamp of first sample cutout (MJD): 59276.59579285718
Cutout filename: FRB20180916B_burst1_cutout_9.0752s_to_11.0752s.fil
Channel flag fraction: 0.005859375
Downsampled bins: 256
Temporal window (ms): 200
Norm. Gauss Amp.: 0.942132715559616
Err. Norm. Gauss Amp.: 0.07702157821774641
Fit Width (ms): 5.4191383502462385
Err. Fit Width (ms): 0.511519311504938
Fit gauss center (ms wrt TOA): -0.074
Downsampled time (us): 781.25
SNR peak: 6.730343368906366
SNR integrated: 18.00869659349734
Gauss fit Chi2red: 1.0495013790550014
Number of cylinders: 8
Flux density peak (Jy): 16.470223400669
Err. Flux density peak (Jy): 1.578346697
Rectangular Fluence (Jy ms): 89.25441926
Err. Rectangular Fluence (Jy ms): 12.0056
Gaussian Fluence (Jy ms): 90.678574459841
Err. Gaussian Fluence (Jy ms): 11.323267005156987
Fit DM (pc cm-3): 350.343137254902
Err. Fit DM (pc cm-3): 0.36937134743132904
```

observation and analysis info

calibrated time chunk in filterbank format for independent re-analysis

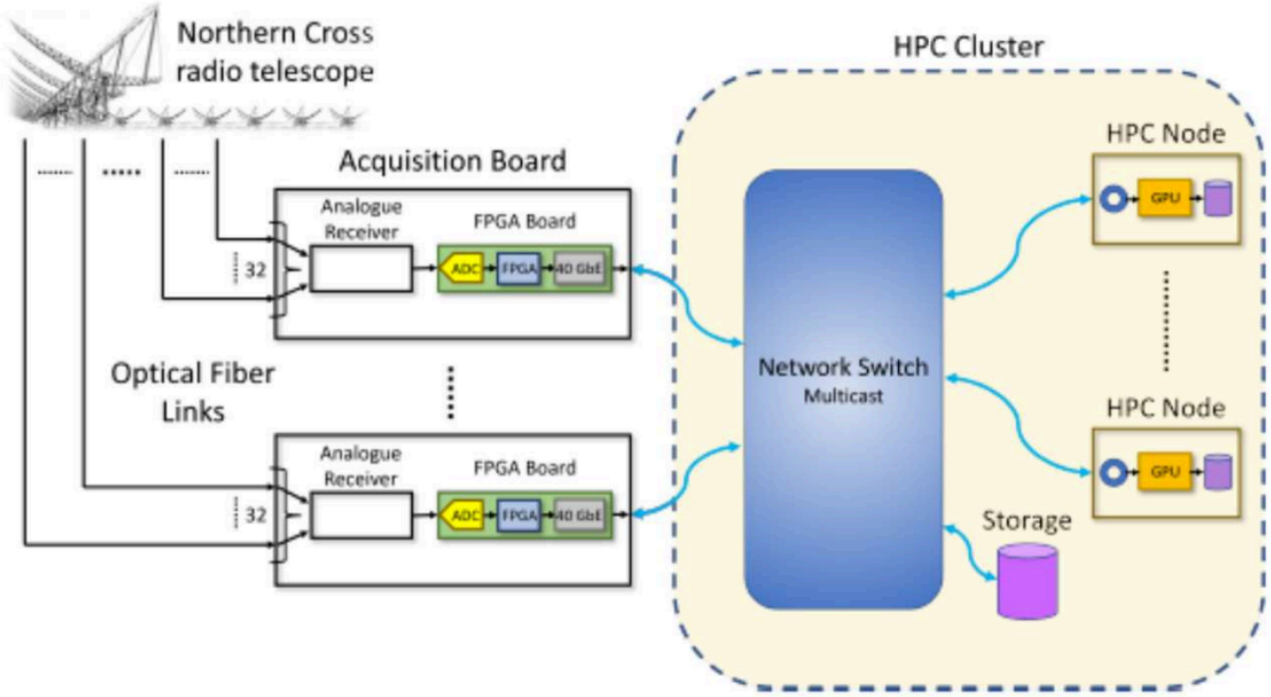
Credits: L. Bruno

The Next Generation Croce del Nord

- Refurbishment of the E-W arm
- Multibeam capabilities for the EW and NS arm
- Real-time processing and analysis

New backend system

- 672 analogue inputs (256 NS + 416 EW) are digitized by newly designed FPGA boards;
- (Multi)beam forming and FRB search performed in real time by an 18 HPC node cluster. Each node is equipped with:
  - Dual multi-core CPU;
  - 2 NVIDIA L40S GPUs;
  - 2 TB RAM;
  - 2x SSD;
- A total of 8 PB disk storage is available although no long term raw data archive is planned



Naldi et al. (2025)

The Next Generation Croce del Nord

- Collecting area: 10000 m² + 20000 m²
- Detection threshold: 1 Jy ms (10 sigma)
- Field of view: ~3 deg
- N. Beams: ~1000
- Spatial resolution: 5’
- Baseband data

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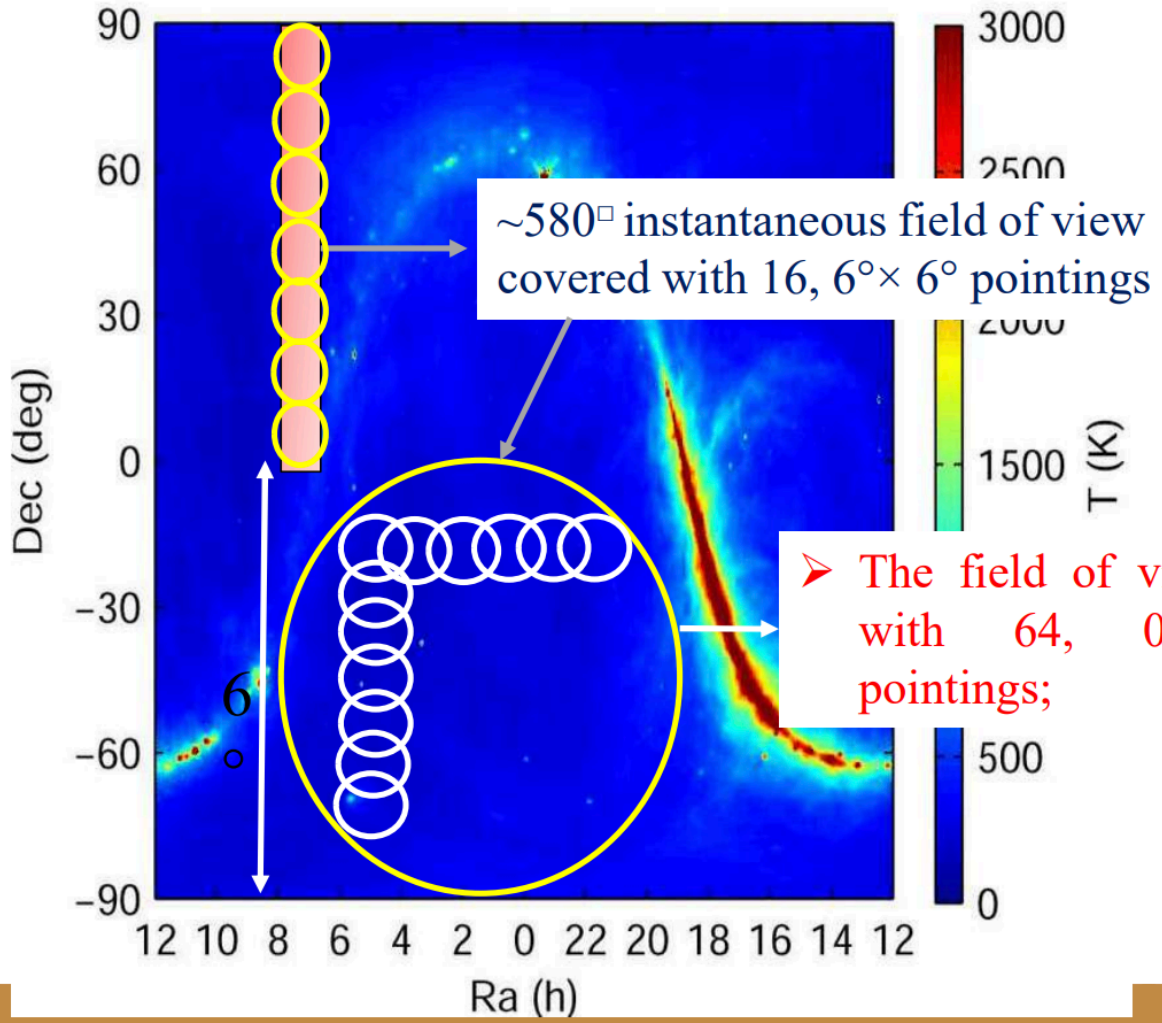
Future observing modes and capabilities

Large area case:

- Beamform 4 cylinders;
- Mechanically shift block of 4-cylinders
- 1σ sensitivity: ~ 4 Jy ms;
- 160 μs time resolution,
- 7.8 kHz frequency resolution;

→ ~1 burst every two days > 10 Jy ms

- Limited localization: ~arcmin for ~100 Jy ms bursts



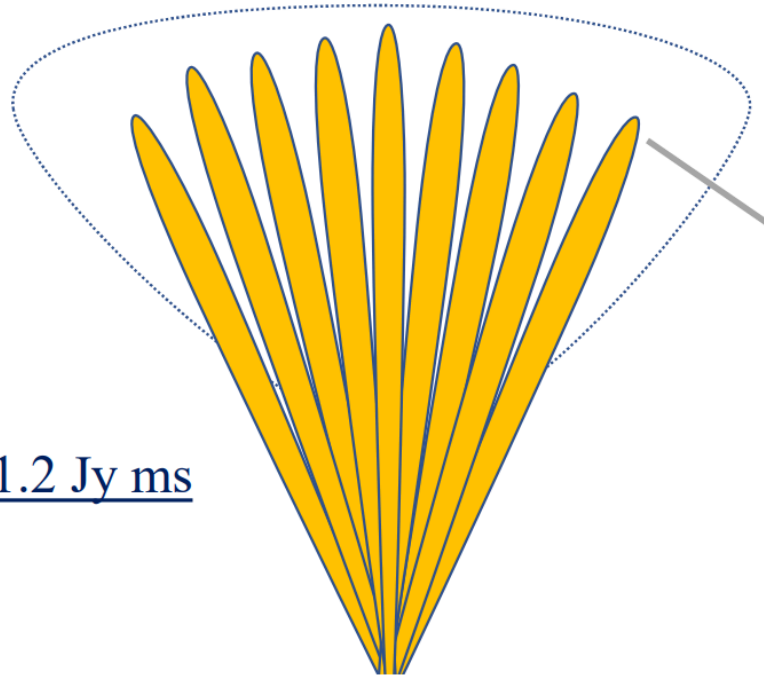
Future observing modes and capabilities: NS + EW

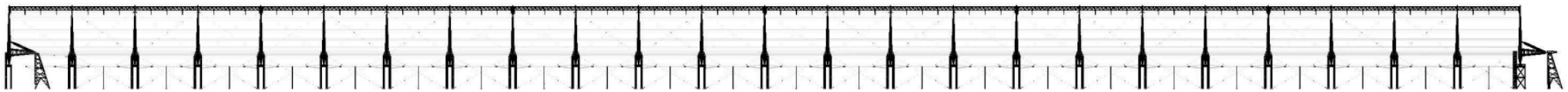
Large area case:

- EW doubles the NS collecting area
- 1σ sensitivity: ~ 120 mJy ms;
- 160 μs time resolution,
- 7.8 kHz frequency resolution;

EW→ ~1 burst every three days > 1.2 Jy ms

NS + EW → ~300 burst yr^{-1}





Conclusions

- We made the Northern Cross telescope capable of observing FRBs. The Northern Cross is the only INAF-owned radio array. We built an enthusiastic research group (includes promising young researchers, technologists, collaborators from four different institutes);

- We can run long observing campaigns (> 1500 h on the sky so far); still limited instantaneous sky coverage; ~30 bursts detected so far

- Simultaneous multifrequency observations 0.408 - 2.3 GHz (Northern Cross, Medicina, Noto) of well-localized bursts – unique in today's world landscape. Synergy with optical/high energy observations; (including 190 MHz when the LOFAR station will become operational in Medicina

- Current/future work (NG-Croce) will turn the NC into a CHIME-like telescope… looking forward to our own 500 burst catalogue;

THANK YOU

Next Generation – Croce del Nord

IR0000026
Intervento finanziato nell'ambito del PNRR - Piano Nazionale di Ripresa e Resilienza

M4C2
Missione 4 - *Istruzione e Ricerca* **Componente 2 - *Dalla Ricerca alla Impresa***
Linea di Investimento 3.1 - *Rafforzamento e creazione di Infrastrutture di Ricerca*

CUP C53C22000880006