AGILE Observations of a Sample of Repeating Fast Radio Burst Sources

Claudio Casentini, Francesco Verrecchia, Marco Tavani, Maura Pilia and Luigi Pacciani

FRB-Italy

Bologna, 08/05/2025

INAF ISTITUTO NAZIONALE DI ASTROFISICA

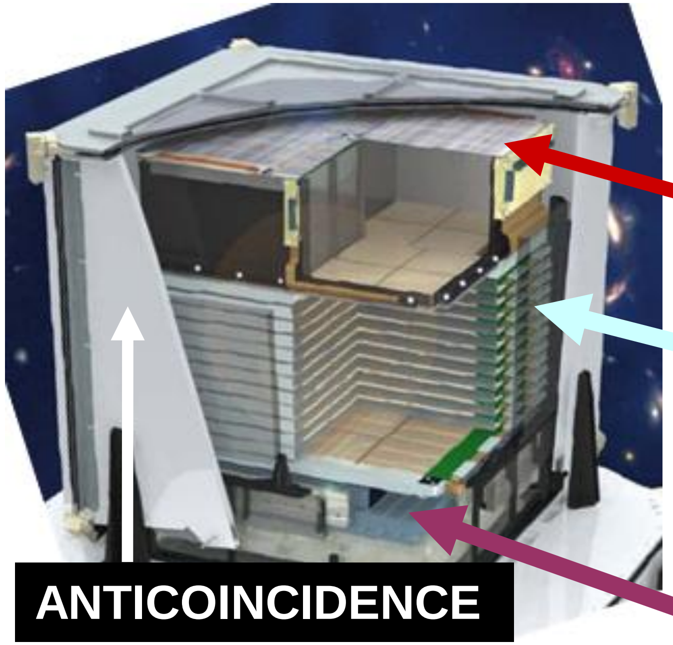
ASI Agenzia Spaziale Italiana

INFN Istituto Nazionale di Fisica Nucleare

The AGILE mission

- AGILE was a unique combination of X-ray and gamma-ray detectors for transient searches;
- Two co-aligned detectors in hard X-rays (20-60 keV; SuperAGILE) and gamma (30 MeV-10GeV; GRID) + MCAL (0.4-100 MeV);
- Anticoincidence detector (80-200 keV);

- Operational from April 23rd, 2007 up to January 18th, 2024;



HARD X-RAY IMAGER
SUPER-AGILE (SA)

Energy Range: 18–60 keV

SILICON TRACKER

GAMMA-RAY IMAGER (GRID)

Energy Range: 30 MeV – 30GeV

(MINI) CALORIMETER

Energy Range: 0.3–100 MeV

MCAL had sub-ms triggering capability!

Tavani et al., A&A, 502, **3**, 2009, pp. 995-1013

The AGILE mission

AGILE and FRB

History

The AGILE activity for FRB HE studies: the activity started on the search for HE counterpart in the AGILE data for sources in the rapidly increasing catalog of FRB sources, FRBCAT.

In 2019 after the new discoveries of probable nearby sources (low DM_{IGM}) and the localization of the first reapeter having periodical «activity» phases, our interest was focalized on some specific sources:

1. Paper on two reapeters, Casentini et al. 2020: due to the low DM_{IGM}, FRB 20180916B and FRB 20181030A;
2. Paper on the periodic R-FRBs FRB 20180916B, Tavani et al. 2020a: on the MW campaign with all AGILE detectors and Swift;
3. Paper on SGR1935+2154 radio and X-ray burst! Tavani et al. 2020b;
4. Paper on a sample of FRBs from FRBCAT, Verrecchia et al. 2021;
5. Radio collaboration papers: Pilia et al. 2020, Trudu et al. 2022 and 2023, Pellicciari et al. 2024 and the submitted Geminardi et al. 2025.

AGILE and FRB

Casentini et al. 2020

- FRB20180916B and FRB20181030A observed by CHIME radio telescope;
- Looking for MCAL and GRID coverage at the time of the bursts;
- No detection founds. Fluence (*MCAL*) and Flux (*GRID*) ULs estimation:

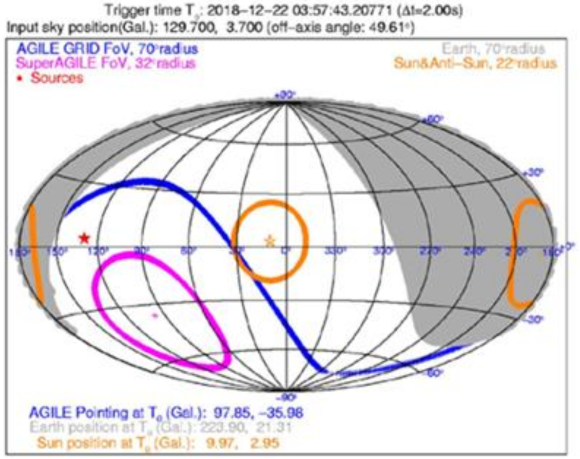
$$\mathcal{F}_{E>0.4MeV} \sim 10^{-8} \frac{erg}{cm^2} \; (@\ 1\ ms\ timescale)$$

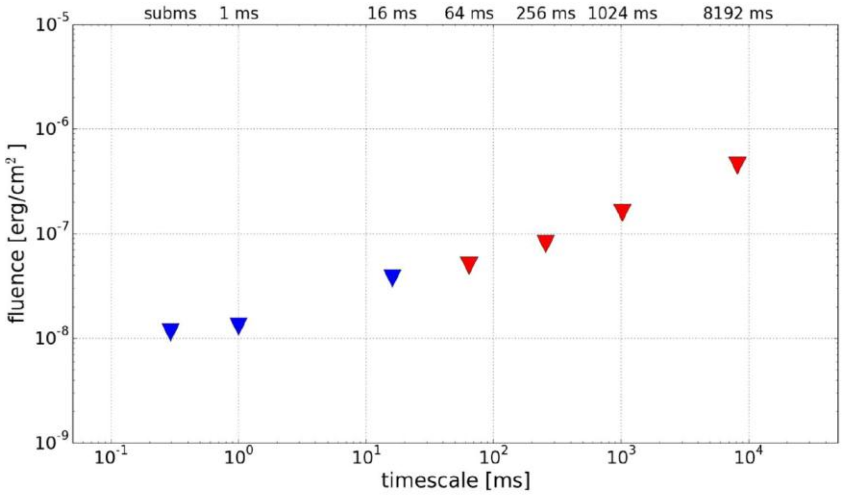
$$F_{\gamma} \sim (2-4) \times 10^{-11} \frac{erg}{cm^2 s} (@\ 100\ d\ timescale)$$

- We suppose a magnetar-like engine ($R_m \sim 10^6 cm, B \sim 10^{16} G$):

$$\boxed{\begin{cases} L_{\gamma,UL} \sim (5-10) \times 10^{43} d^2_{150Mpc} \, {}^{erg}/_{s} \\ L_{\gamma,UL} \sim (5-10) \times 10^{37} d^2_{100kpc} \, {}^{erg}/_{s} \end{cases}}$$

that excludes an emission like the giant burst of SGR 1806-20 ($E_{MeV} \sim 2 \times 10^{46} erg$) for both short and long timescales.





C. Casentini *et al.*
AGILE Observations of Two Repeating Fast Radio Bursts with Low Intrinsic Dispersion Measures.
2020 *ApJL* **890** L32.

AGILE and FRB

Tavani et al. 2020b

On April 28th, 2020, the AGILE satellite detected an X-ray burst in temporal coincidence with a bright FRB-like radio-burst from SGR 1935+2154.

It was detected also by GBM and INTEGRAL.

AGILE Super-A RMs detection of X-ray burst

- $\mathcal{F}_{(18-60\ kev)} = 5 \times 10^{-7}\ erg/cm^2$;
- $\Delta t = 0.5\ s$;
- $E_{X,iso} = 8.1 \times 10^{39}\ d^2_{10kpc}\ erg$.

Study of the SGR burst alongside all the known FRB bursts:

- Comparison of the SGR burst with the X-ray ULs from a sample of “nearby” FRBs;
- Direct comparison of the SGR X-ray flux with all the flux ULs from AGILE, Chandra and Swift satellites for FRB20180916B.

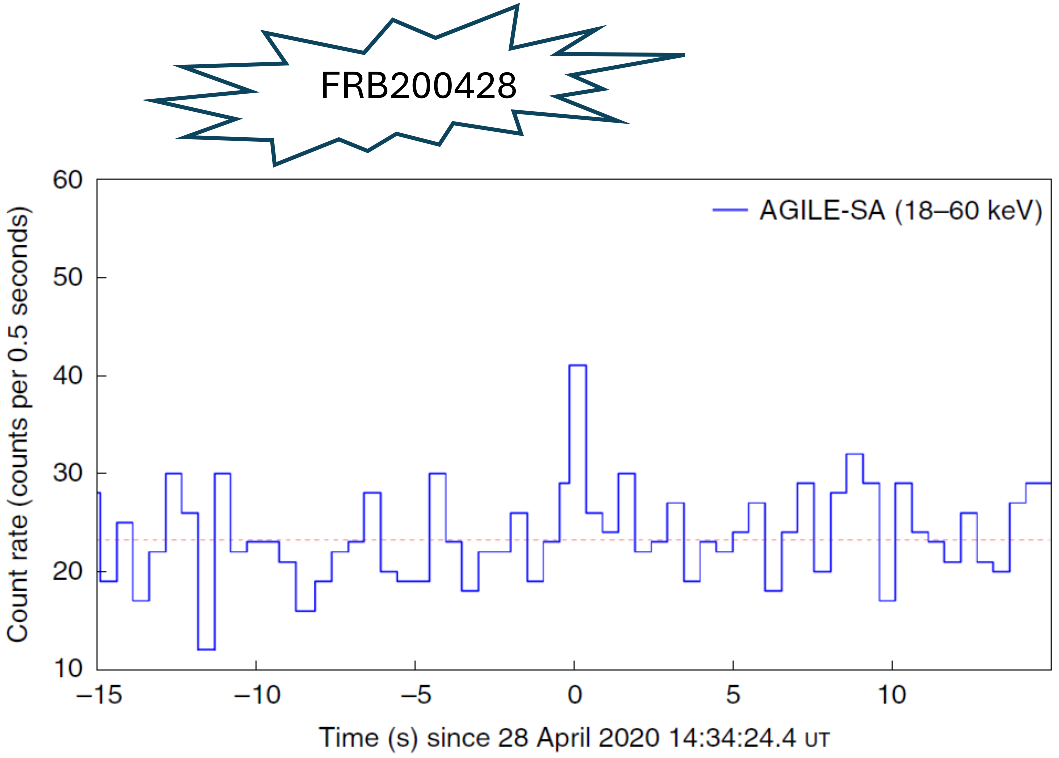


Fig. 2 | Detection of the X-ray burst in temporal coincidence with the very intense radio burst from SGR 1935+2154. The panel shows the light curve of the AGILE-SA RM with data in the energy range 18–60 keV displayed with 0.5 s binning.

Tavani, M., Casentini, C., Ursi, A., Verrecchia, F. *et al.*
An X-ray burst from a magnetar enlightening the mechanism of fast radio bursts.
Nat Astron **5**, 401–407 (2021).

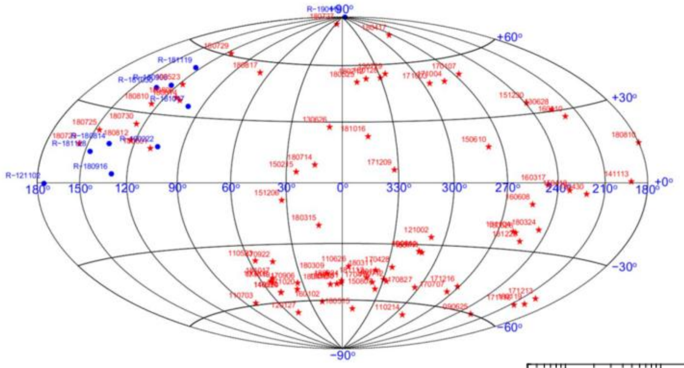
AGILE and FRB

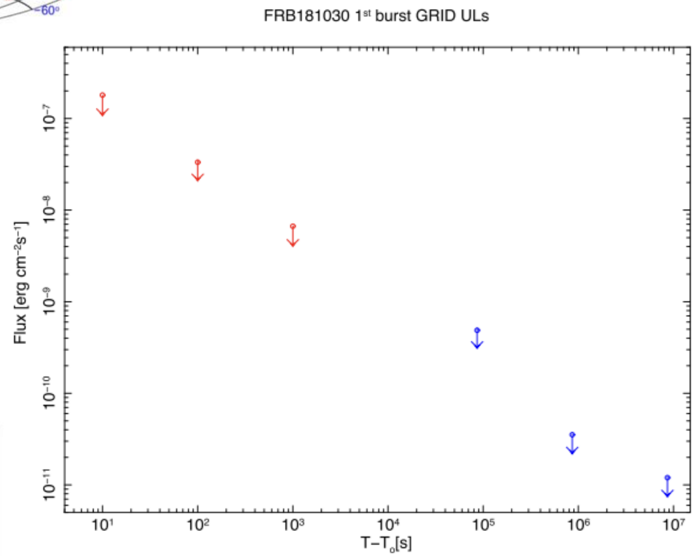
Verrecchia et al. 2021

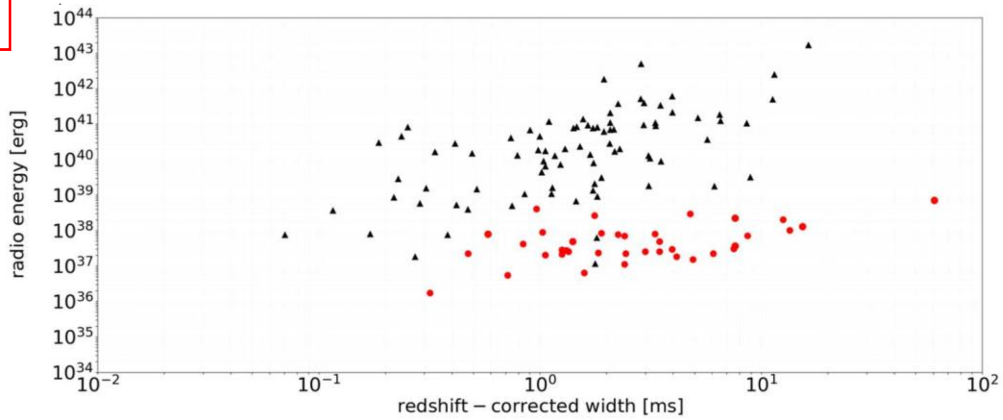
Search for HE counterpart in the AGILE 13 years archive from a sample of FRB sources from the online datasets:

- 89 sources included, 10 R-FRB , FRBCAT and CHIME/FRB online databases
- focus on a sample of mainly One-off sources:
    - checked AGILE MCAL and GRID coverage;
    - X- and gamma-ray ULs evaluation.
- MCAL UL (ms timescale):
    - again excluding giant SGR1806-20-like flares at $E_{iso} \sim 10^{46}$ erg
- GRID UL (100-day timescale):
    - $\boxed{L_{\gamma,UL} \sim (2-5) \times 10^{43} d^2_{150Mpc}}$

F. Verrecchia *et al.*,
AGILE Observations of Fast Radio Bursts.
2021 *ApJ* **915** 102.







AGILE and FRB

Casentini et al. 2025

- Since Verrecchia et al. 2021, new FRBs catalogs were published;
- Rapidly increasing number of FRB sources;
- We conducted a targeted search in the AGILE satellite datatsets using FRBs data coming from:
  - Blinkverse;
  - TNS;
  - CHIME FRB Catalog;
  - Public bursts from italian radiotelescope.
- Furtherly reviewed data analysis procedures with respect to Pelliciari et al 2024;
- A new paper, recently published, with MCAL, GRID and SuperAGILE data!

The Astrophysical Journal, 983:85 (13pp), 2025 April 10
https://doi.org/10.3847/1538-4357/adbe6f

AGILE Observations of a Sample of Repeating Fast Radio Burst Sources

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Received 2025 January 22; revised 2025 March 6; accepted 2025 March 7; published 2025 April 9

Abstract

Fast radio bursts (FRBs) are millisecond-duration bursts originating from distant sources. They are classified into two categories: non-repeating FRBs, which manifest as singular events, and repeater FRBs (R-FRBs), which emit multiple bursts over time. In this work, we report a search for X- and γ-ray counterparts to a selected sample of R-FRBs using data from the AGILE satellite. The sample focused on sources with an excess dispersion measure (DM) below 300 pc cm^{-3}. The analysis focused on the bursts covered by AGILE Mini-Calorimeter (MCAL) high-resolution data. No astrophysical signals were identified, and we derived upper limits (ULs) on the flux above 400 keV for the associated sources, adopting a spectral magnetar model, one of the leading models for FRB emission. Moreover, for a single burst of FRB 20200120E we estimated the flux ULs from the SuperAGILE detector data in the 18–60 keV energy range. We also performed a check of the GRID coverage for each burst in the 0.03–10 GeV energy band on short timescales, from 10 to 10^3 s, and on longer ones including the complete ~17 yr AGILE/GRID archive. We then considered the famous event FRB 200428 from the Galactic magnetar SGR 1935+2154 as a reference to extrapolate a possible X-ray emission in MCAL and SuperAGILE bands from the radio energies of R-FRBs using the E_X/E_{radio} of FRB 200428 as a fixed parameter. We compared these energies with historical magnetar X-ray bursts rescaled in the same bands. Our observations set useful constraints on the FRB magnetar model in particular, the MCAL ULs are currently the most stringent in the 0.4–30 MeV band.

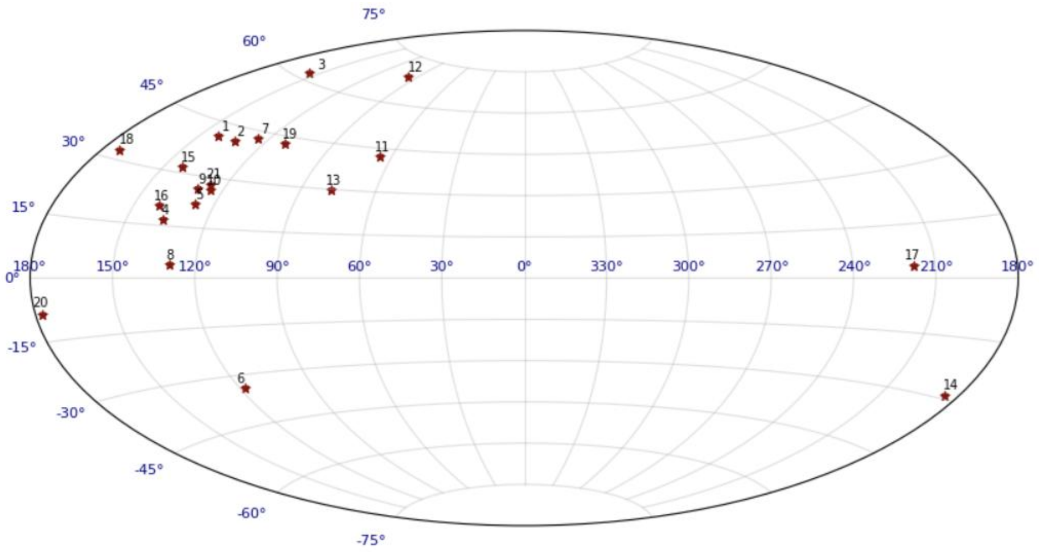
Unified Astronomy Thesaurus concepts: Radio transient sources (2008); Gamma-ray astronomy (628)

C. Casentini. *et al.*
AGILE Observations of a Sample of Repeating Fast Radio Burst Sources.
2025 *ApJ* **983** 85.

AGILE and FRB

Casentini et al. 2025 → Selection Criteria

- Only repeaters;
- $DM_{exc} < 300\, pc/cm^3$;



The Astrophysical Journal, 983:85 (13pp), 2025 April 10 Casentini et al.

Table 1
Properties of the R-FRBs Considered in This Work

FRB Name (1)	DM_{exc} (pc cm^{-3}) (2)	l, b (deg) (3)	N_b (4)	Width (ms) (5)	f (Jy ms) (6)	z_s (Mpc) (7)
FRB 20200120E	18.0 (88.0)	142°.19, +41°.22	80	0.01–0.70	0.04–2.40	0.0008 (3.6)
FRB 20181030A	33.5 (103.7)	133°.40, +40°.92	9	0.59–1.43	4.50–7.30	0.004 (17.3)
FRB 20220912A	67.1 (222.1)	155°.41, +61°.81	1529	0.09–32.9	0.002–37.7	0.077 (343)
FRB 20180814A	72.4 (189.4)	136°.42, +16°.60	22	7.90–63.0	3.40–66.0	0.078 (347)
FRB 20190107B	73.1 (173.1)	127°.14, +21°.75	2	0.98	4.30	0.11 (500)
FRB 20200223B	125.5 (201.5)	118°.07, −33°.88	10	1.26–2.29	1.06–14.4	…
FRB 20180908B	127.8 (195.8)	124°.74, +42°.86	4	1.60–9.00	1.10–2.90	0.17 (800)
FRB 20180916B	150.7 (349.4)	129°.71, +3°.74	290	0.06–158	0.08–318	0.033 (150)
FRB 20181226F	152.1 (240.1)	129°.79, +26°.20	3	…	…	…
FRB 20190905A	153.3 (240.4)	124°.64, +26°.25	6	0.75–1.13	1.79–18.0	…
FRB 20190110C	156.3 (222.0)	65°.56, +42°.15	3	2.95	1.40	0.22 (1050)
FRB 20190303A	164.1 (223.1)	97°.48, +68°.94	38	0.89–7.20	0.78–10.4	0.064 (285)
FRB 20190812A	170.7 (249.1)	78°.05, +29°.83	2	0.42–0.60	0.65–13.0	…
FRB 20201130A	202.3 (288.3)	185°.33, −29°.15	12	0.47–6.55	1.31–20.4	…
FRB 20210323C	204.7 (285.2)	142°.59, +31°.54	11	0.83–5.00	2.32–7.60	…
FRB 20191105B	210.3 (313.8)	140°.59, +20°.40	2	0.55–0.71	2.70–19.7	…
FRB 20190113A	217.6 (426.5)	218°.04, +3°.43	3	1.82–3.03	5.70–9.40	0.29 (1450)
FRB 20190907A	226.8 (309.8)	173°.39, +32°.26	7	0.54–3.00	0.70–6.90	…
FRB 20201114A	253.9 (321.9)	111°.18, +42°.63	2	0.72–1.04	2.45–4.70	…
FRB 20201124A	257.6 (414.1)	177°.60, −8°.50	2883	0.91–316	0.005–640	0.098 (445)
FRB 20200127B	267.0 (351.0)	126°.63, +28°.02	2	0.45–0.61	4.70–7.70	…

Note. Column (1) lists the names of the FRB sources. Column (2) provides DM_{exc}, with the mean DM_{tot} given in parentheses. Column (3) shows the Galactic coordinates of the sources in degrees. Column (4) N_b indicates the total number of bursts observed to date for each source. Columns (5) and (6) give for each source the minimum and maximum burst widths in milliseconds and the minimum and maximum radio fluence values in Jy ms, respectively. Column (7) lists the spectroscopic redshift z_s associated with each source (where available), with the estimated luminosity distance (D_L) in Mpc in parentheses.

- 21 R-FRBs (more than 4800 bursts) included;
- Distances between 3.6 Mpc up to Gpc scale;

AGILE and FRB

Casentini et al. 2025 → MCAL analysis

We added more criteria to select events within the MCAL FoV with coincident data taking:

- Only burst with infinite freq. topocentric arrival time available → **784** bursts left from ***21*** R-FRBs;
- Only those burst not covered by Earth at arrival time → **539** burst left from ***21*** R-FRBs;
- Only those burst which are covered by MCAL high resolution data → **25** bursts from ***5*** R-FRBs.

The Astrophysical Journal, 983:85 (13pp), 2025 April 10 Casentini et al.

Table 2
Summary of the Selected Bursts, Their Visibility in MCAL, and the Evaluated ULs

FRB Name (1)	Selected Bursts (2)	Within MCAL FoV (3)	Data @$T_{\rm burst}$ (4)	MCAL $\mathscr{F}$ UL $\times 10^{-8}$ (erg cm^{-2}) (5)
FRB 20200120E	13	10 (77%)	1 (∼8%)	⋯
FRB 20181030A	9	9 (100%)	⋯	1.7–9.2
FRB 20220912A	469	311 (66%)	15 (∼3%)	⋯
FRB 20180814A	22	19 (86%)	2 (∼9%)	⋯
FRB 20190107B	2	2 (100%)	⋯	3.1–5.2
FRB 20200223B	9	4 (44%)	⋯	1.8–4.2
FRB 20180908B	4	4 (100%)	1 (∼25%)	⋯
FRB 20180916B	136	108 (79%)	6 (∼4%)	⋯
FRB 20181226F	3	3 (100%)	⋯	3.0–4.3
FRB 20190905A	6	6 (100%)	⋯	1.6–3.2
FRB 20190110C	3	3 (100%)	⋯	1.8–2.6
FRB 20190303A	34	21 (62%)	⋯	1.8–9.3
FRB 20190812A	2	2 (100%)	⋯	1.8–1.9
FRB 20201130A	12	9 (75%)	⋯	1.8–5.3
FRB 20210323C	10	5 (50%)	⋯	3.0–4.2
FRB 20191105B	2	2 (100%)	⋯	2.9–3.1
FRB 20190113A	3	1 (33%)	⋯	3.2–5.1
FRB 20190907A	7	2 (29%)	⋯	1.6–5.2
FRB 20201114A	2	2 (100%)	⋯	1.5–1.8
FRB 20201124A	34	14 (41%)	⋯	1.7–5.3
FRB 20200127B	2	2 (100%)	⋯	1.9–4.3

Note. Column (1) lists the R-FRB. Column (2) provides the number of repetitions for each R-FRB selected after the exclusion of those not having all the radio information required. Column (3) gives the number of events in visibility for MCAL, with the percentage shown in parentheses. Column (4) indicates the number of bursts for which MCAL was in visibility and simultaneous high-resolution data from the calorimeter was available. Column (5) lists the ULs in fluence for all bursts not having high-resolution data, based on the onboard triggering logic thresholds.

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Table 3
List of 25 Bursts of R-FRBs in Temporal Coincidence with MCAL Data Acquisition

FRB Name	Burst ID	Telescope Name	Topocentric MJD @ infinite freq.	$F_{[0.4-30]\rm MeV}$ UL $\times 10^{-8}$ (erg cm^{-2} s^{-1})
FRB 20200120E	200206	CHIME	58885.36858507	2.57
FRB 20220912A	221020	CHIME	59872.22447255	1.28
FRB 20220912A	221023D	CHIME	59875.20976605	3.00
FRB 20220912A	221107E	CHIME	59890.17072415	3.60
FRB 20220912A	221114C	CHIME	59897.15290155	3.60
FRB 20220912A	221203H	CHIME	59916.09782005	1.50
FRB 20220912A	221220D	CHIME	59933.05681718	3.60
FRB 20220912A	230201	CHIME	59976.93469302	8.99
FRB 20220912A	230407B	CHIME	60041.75513516	2.57
FRB 20220912A	230414	CHIME	60048.73058087	5.99
FRB 20220912A	230418	CHIME	60052.72499415	4.49
FRB 20220912A	230504B	CHIME	60068.67979849	2.25
FRB 20220912A	230510B	CHIME	60074.66564847	3.00
FRB 20220912A	B09	Croce del Nord	60166.04590747	2.06
FRB 20220912A	B10	Croce del Nord	60166.04590824	2.04
FRB 20220912A	B11	Croce del Nord	60173.03121566	2.00
FRB 20220814A	180911	CHIME	58372.56991025	1.63
FRB 20220814A	180919	CHIME	58380.52513716	2.57
FRB 20180908B	190718	CHIME	58682.04953763	3.00
FRB 20180916B	210129A	CHIME	59243.04936674	2.00
FRB 20180916B	SRT-P-11	SRT	59244.93891227	1.07
FRB 20180916B	uGMRT-01	uGMRT	59441.02524327	1.03
FRB 20180916B	uGMRT-06	uGMRT	59441.09399652	1.09
FRB 20180916B	uGMRT-07	uGMRT	59441.10061893	2.36
FRB 20180916B	221231	CHIME	59944.14644154	1.50

Note. In the fifth column, we report the related 3σ flux ULs in [0.4–30] MeV energy band.

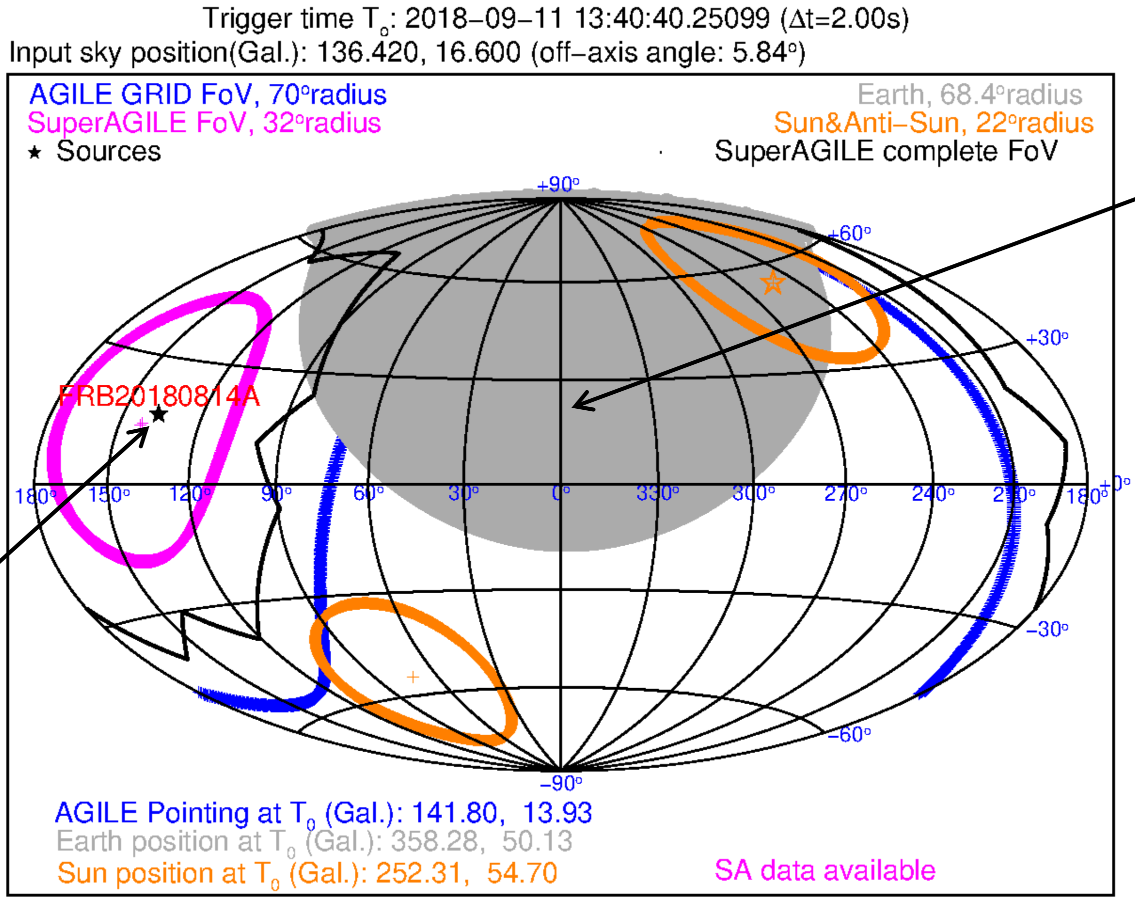
Max flux UL among all

Min flux UL among all

- No reliable detection found;
- Cut-off power law spectral model (Mereghetti et al. 2021) for flux UL estimation in 0.4-30 MeV.

AGILE and FRB

Casentini et al. 2025 → MCAL analysis → example



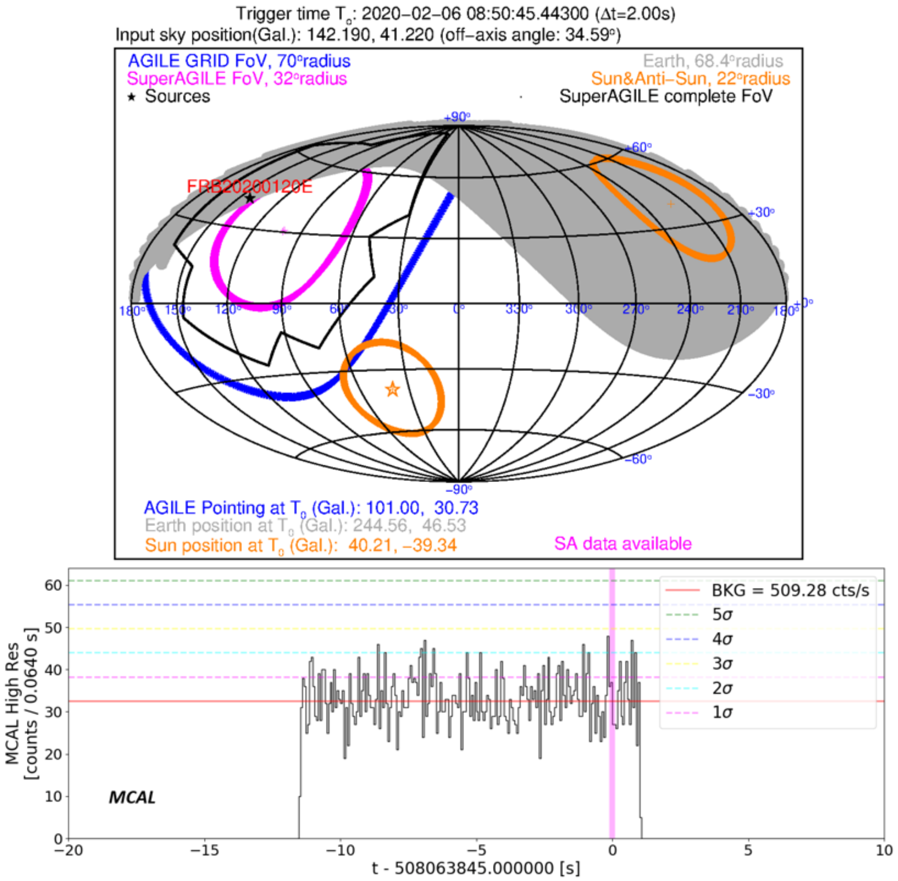
Earth exclusion radius (68,4°)

Source in MCAL visibility

AGILE and FRB

Casentini et al. 2025 → MCAL analysis → FRB 20200120E case

- We found only one burst covered by MCAL data for the closest known R-FRB, FRB 20200120E;
- The event lies on the edge of the MCAL FoV;
- We found no evidence of astrophysical signal in the MCAL high resolution data;



AGILE and FRB

Casentini et al. 2025 → GRID analyses → Short timescale analysis

- We executed the analysis in different temporal windows: ±10 s, ±100 s and ±1000 s;
- We obtain a few low pre-trial significance detections applying the Li&Ma analysis;
- We discarded them as not reliable due to their position at the border of the exposed FoV, or related to diffuse background;
- We evaluated the 2σ flux ULs in the 50 MeV-10 GeV ranging in (10^{-9} - 10^{-6}) erg cm^{-2} s^{-1}.
- Regarding FRB 20200120E, we performed a spectral modeling on 10 s integration, applying a power law spectral model with photon indices -2.0, -2.5 and -3.0 obtaining the ULs 1.1×10^{-7}, 1.8×10^{-7} and 2.0×10^{-7} erg cm^{-2} s^{-1}, respectively.

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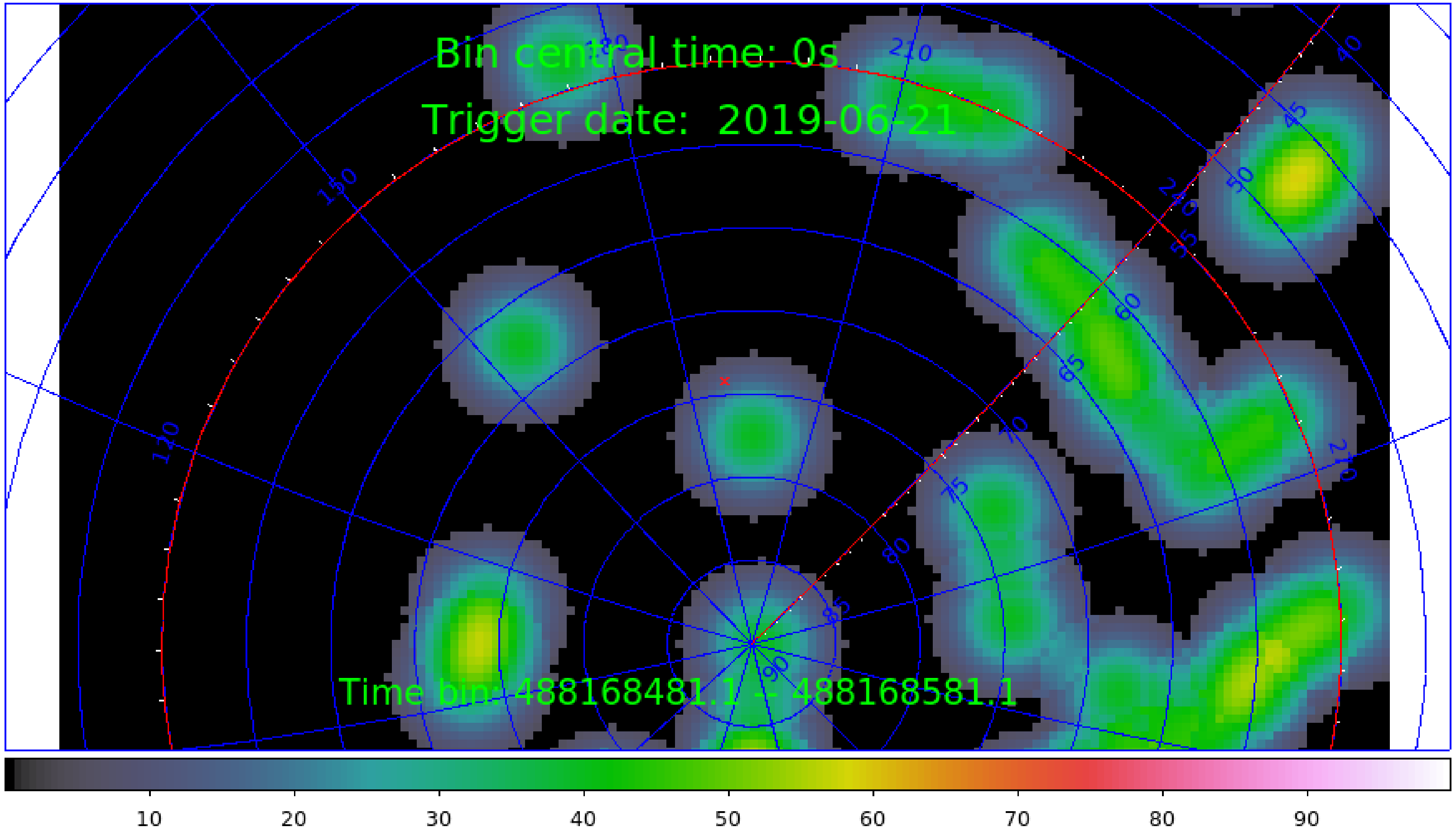
Table 4
R-FRBs GRID Short-timescale 2σ Flux ULs in the 50 MeV–10 GeV Energy Band, When Available

FRB Name	Pre-T_0 Min/Max Value T_{start}: 1000 s; 100 s; 10 s	Post-T_0 Min/Max Value T_{stop}: 10 s; 100 s; 1000 s
	$\times 10^{-7}$ (erg cm^{-2} s^{-1})	
FRB 20200120E	0.085–0.320; 0.049–0.850; —	1.400; 0.410–1.800; 0.083–1.400
FRB 20181030A	0.069–0.210; 0.250–3.500; 2.300	5.100; 2.600–12.000; 0.070–1.100
FRB 20220912A	0.061–4.331; 0.221–7.019; 1.168–7.019	1.203–7.006; 0.202–8.748; 0.064–7.032
FRB 20180814A	0.063–0.174; 0.299–14.076; —	1.194–7.036; 0.236–1.418; 0.064–0.201
FRB 20190107B	0.086–0.307; 0.479–0.768; 1.456–1.456	1.272–1.284; 0.217–0.255; 0.058–0.079
FRB 20200223B	0.247; — ; —	— ; — ; —
FRB 20180908B	0.072–4.333; 0.271–4.500; 1.447	2.142; 0.437–1.896; 0.078–0.224
FRB 20180916B	0.061–4.548; 0.193–9.379; 0.902–7.064	0.902–7.062; 0.233–3.531; 0.067–7.005
FRB 20181226F	0.088–0.202; 0.402; —	1.291 ; 0.340–0.698; 0.072–0.080
FRB 20190905A	0.061–0.083; 0.244–3.345; 3.764	1.344–1.733; 0.226–0.526; 0.058–0.091
FRB 20190110C	0.083–0.181; — ; —	— ; 0.530 ; 0.071
FRB 20190303A	0.078–6.904; 1.063–7.047; 4.205–7.047	1.400–2.348; 0.214–1.173; 0.060–13.264
FRB 20190812A	0.101; 0.232; —	2.391; 1.196; 0.084
FRB 20201130A	0.073–0.216; 0.323; 7.031	— ; — ; 0.145
FRB 20210323C	0.082–0.168; 0.168; 0.168	0.168; 0.168; 0.065–0.168
FRB 20191105B	0.079; 0.338; 1.303	1.305; 0.460; 0.221
FRB 20190113A	— ; — ; —	— ; — ; —
FRB 20190907A	0.105; 7.081; —	4.939; 0.279; 0.235
FRB 20201114A	— ; — ; —	— ; — ; —
FRB 20201124A	0.059–1.615; 0.206–0.498; 0.498–1.863	0.498–4.153; 0.498–2.076; 0.081–0.498
FRB 20200127B	0.073–0.092; 0.311; —	— ; 1.189; 0.078–0.0911

Note. Start/stop times are in seconds with respect to each burst time. The "—" marks refer to a lack of exposure in the specific integration time.

AGILE and FRB

Casentini et al. 2025 → GRID analyses → Short timescale analysis example



AGILE and FRB

Casentini et al. 2025 → GRID analyses → Long timescale analysis

- The long timescale analysis (AML, Bulgarelli et al. 2012), was performed per each burst, on 5 and 17 yr integration times;
- No reliable detection found;
- We evaluated the 2σ flux ULs in the 100 MeV-10 GeV, considering a PL spectral model with spectral index -2.0;
- $F_{\gamma,17yr} \leq 10^{-13}$ erg cm^{-2} s^{-1}.
- We tested also spectral indeces -2.5 and -3.0, obtaining ULs values in the same order of magnitude of the previous.

AGILE and FRB

Casentini et al. 2025 → SuperAGILE analysis

- We selected, within SuperAGILE high resolution data, the covered burst at T0 that falls in the fully coded FoV part only;
- A total of 6 events were found to be covered by the instrument FoV;
- No reliable detection found;
- We extracted, applying the burst pipeline (Feroci et al 2007), the 3σ flux ULs per each covered source.
- 3σ flux ULs ranging from 4.4×10^{-8} erg $cm^{-2}s^{-1}$ to 9.0×10^{-8} erg $cm^{-2}s^{-1}$.

Table 5
List of the Bursts of R-FRBs in the SuperAGILE FoV and Covered by Its Real-time Data Acquisition

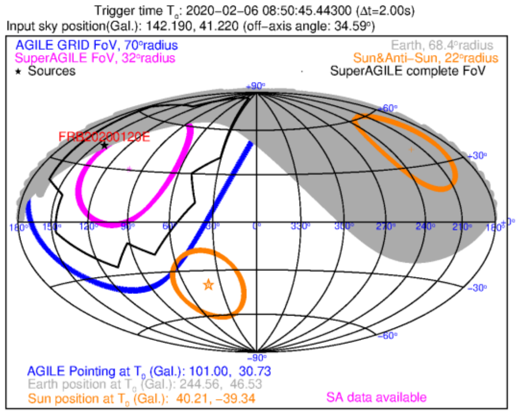
FRB Name	Burst ID	Telescope Name	Topocentric MJD @ infinite freq.	$F_{[18-60]\mathrm{keV}}$ UL $\times 10^{-8}$ (erg cm^{-2} s^{-1})
FRB 20200120E (*)	200206	CHIME	58885.36858507	9.0
FRB 20180814A	180911	CHIME	58372.56991025	4.4
FRB 20190107B	190107	CHIME	58490.14044364	5.2
FRB 20190107B	190308	CHIME	58550.46699474	6.6
FRB 20180916B	220328	CHIME	59666.89952457	5.8
FRB 20181226F	190201	CHIME	58515.65015015	5.7
FRB 20191105B	191105	CHIME	58792.44450878	5.3

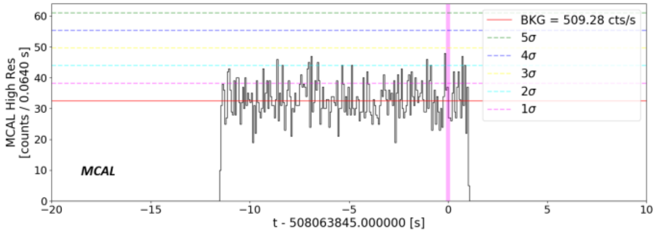
Note. We also include the case of the burst of FRB 20200120E (marked here with *), shown in Figure 3, even if the event occurs when the source was on the edge of the SuperAGILE fully coded mask. In fifth column we report the related 3σ flux ULs in [18–60] keV energy band.

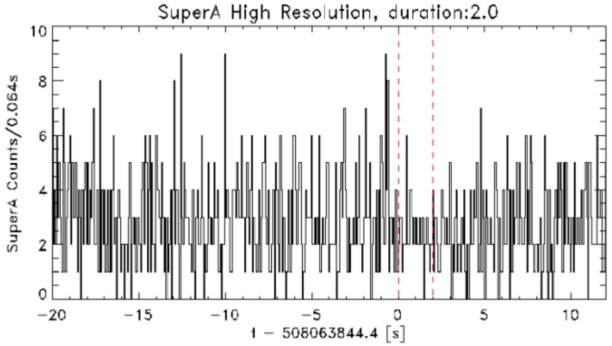
AGILE and FRB

Casentini et al. 2025 → SuperAGILE analysis example

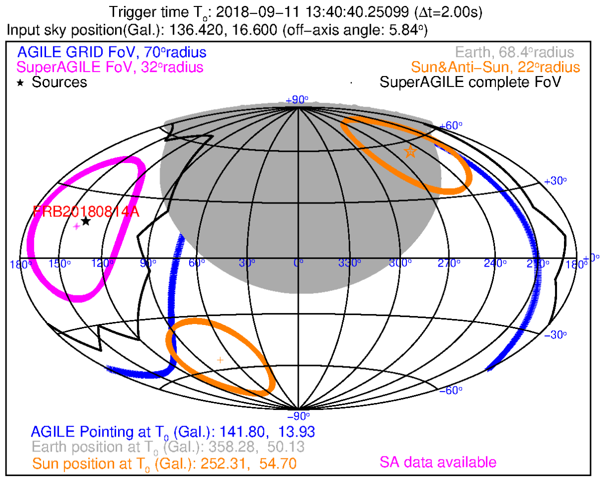
FRB 20200120E

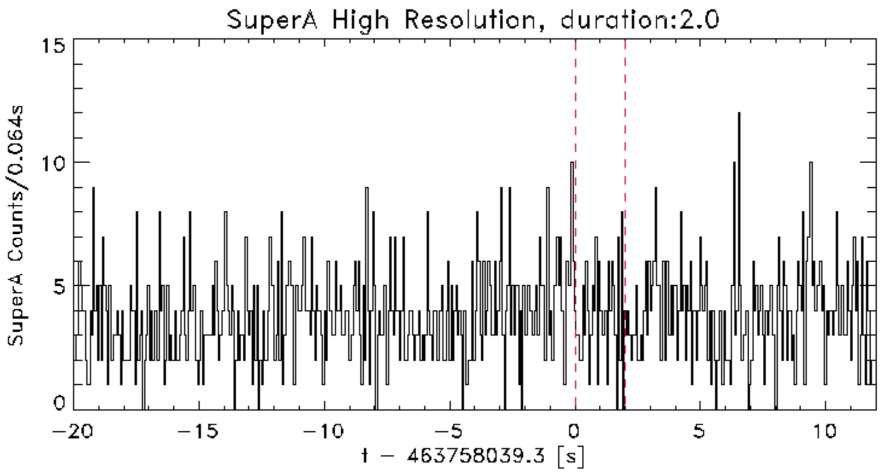


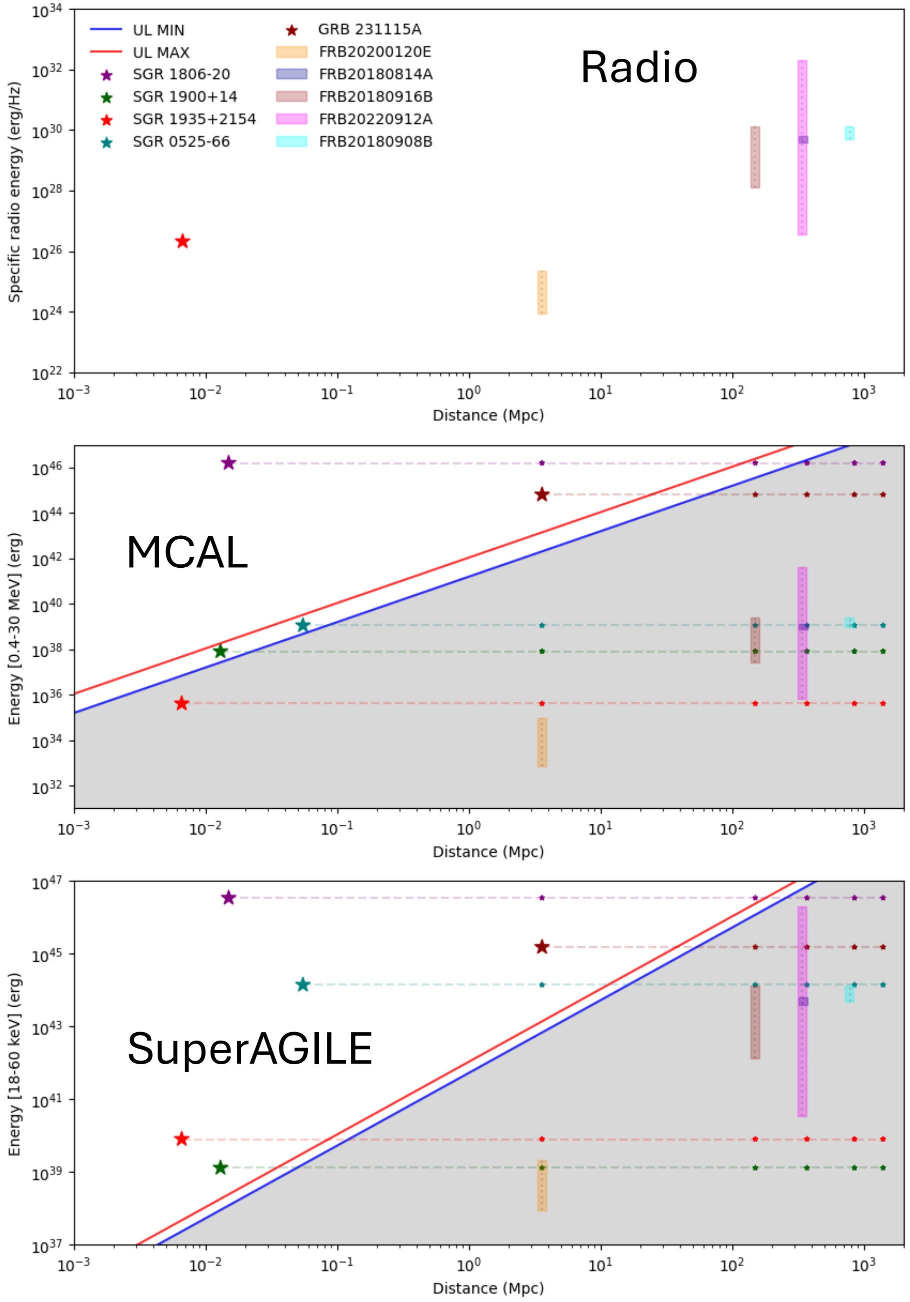




FRB 20180814A

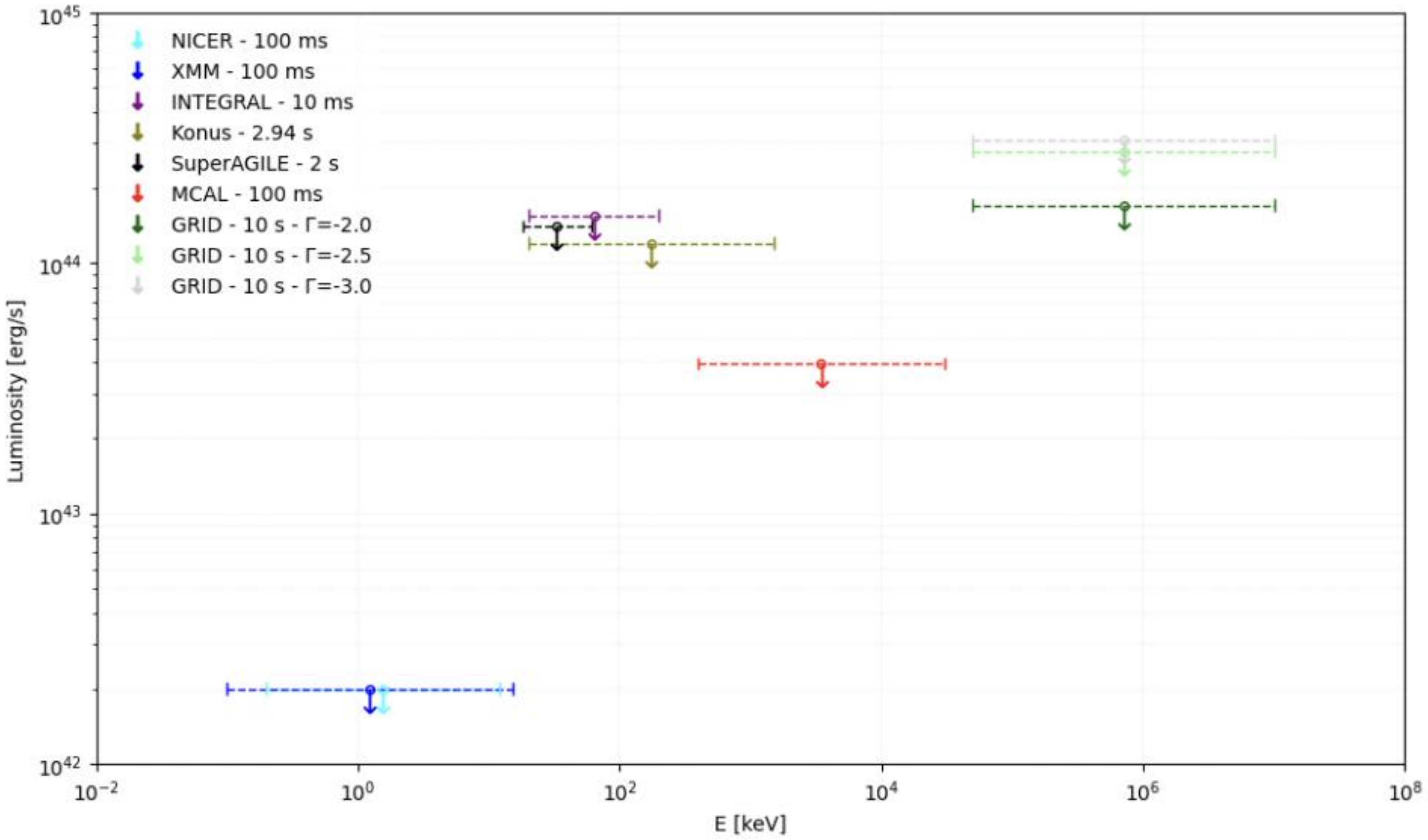






AGILE and FRB

Casentini et al. 2025 → AGILE sensitivity to FRBs



AGILE results on FRB 20200120E compared with similar results by other high-energy space mission.

Summary

- Large sample of R-FRB analysed with AGILE data;
- No high-energy counterpart found;
- Improved flux UL determination in MCAL and GRID band;
- Added AGILE contribution in the 18-60 keV band with SuperAGILE high-resolution data;
- We are planning new studies on one-off sources including the stacking analysis on GRID data considering the whole 17 years catalog.