AGILE activity on FRBs high-energy counterpart search

Claudio Casentini and ***Francesco Verrecchia***

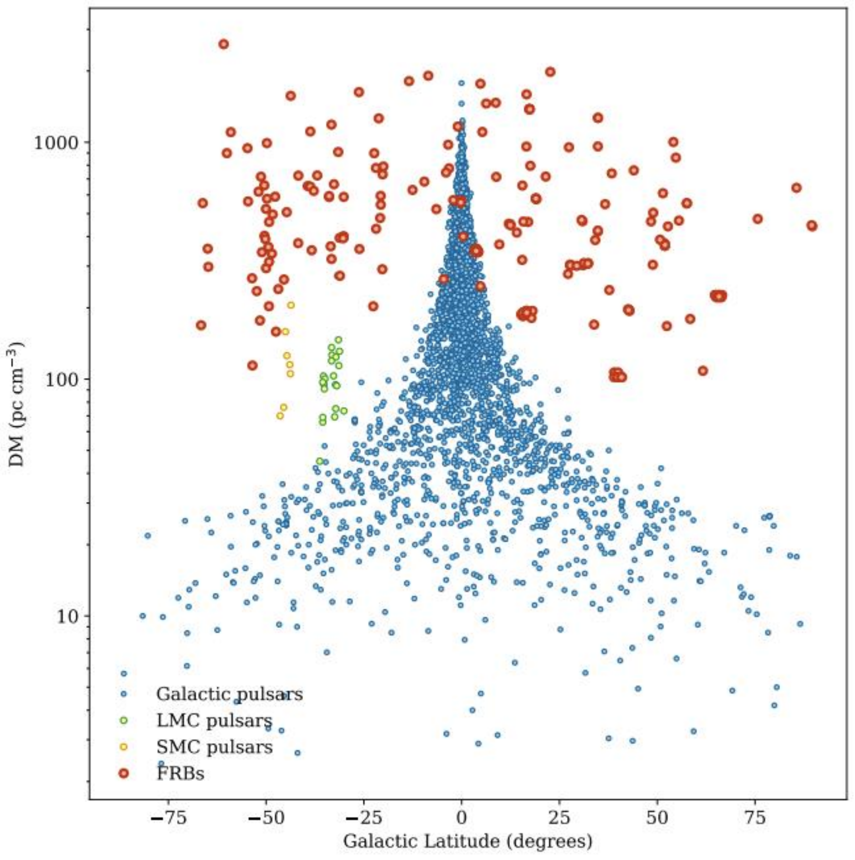
on behalf of the ***AGILE Team***

Frascati (RM), 25/09/2024

FRB

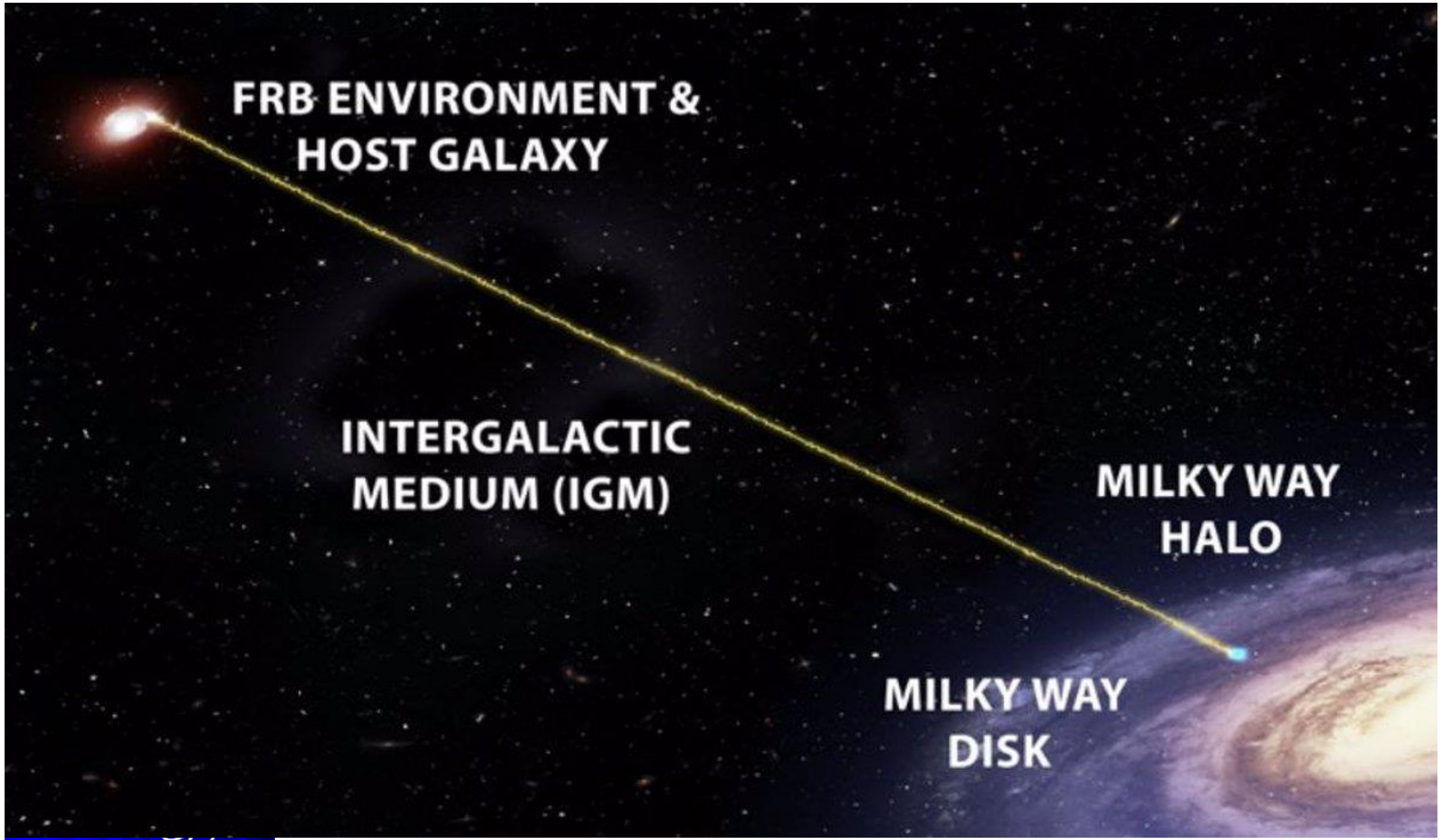
- Bright radio transients still of unknown origin.
- From low to very high dispersion measures
- Uncertain distances → Uncertain energetics; unknown engine;
- ms to s timescale;
- Bandwidth between 200 MHz and 2 GHz;
- Fluences between $10^{-2} - 900\ Jy\ ms$
- Very high all sky rate: > 1000 FRBs/sky/day.

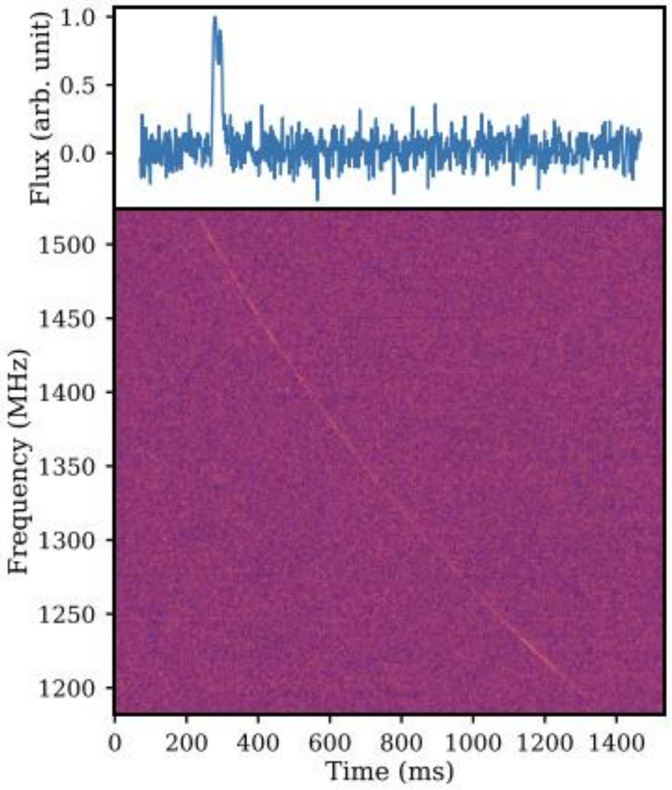
Up to now the FRB population consist of 816 total sources, divided in one-off and repeaters (R-FRB). Currently there are 67 R-FRB known and only 2 with periodic activity.



Chatterjee (2021), Cordes & Chatterjee (2019)

FRB distance - Dispersion measure (DM)





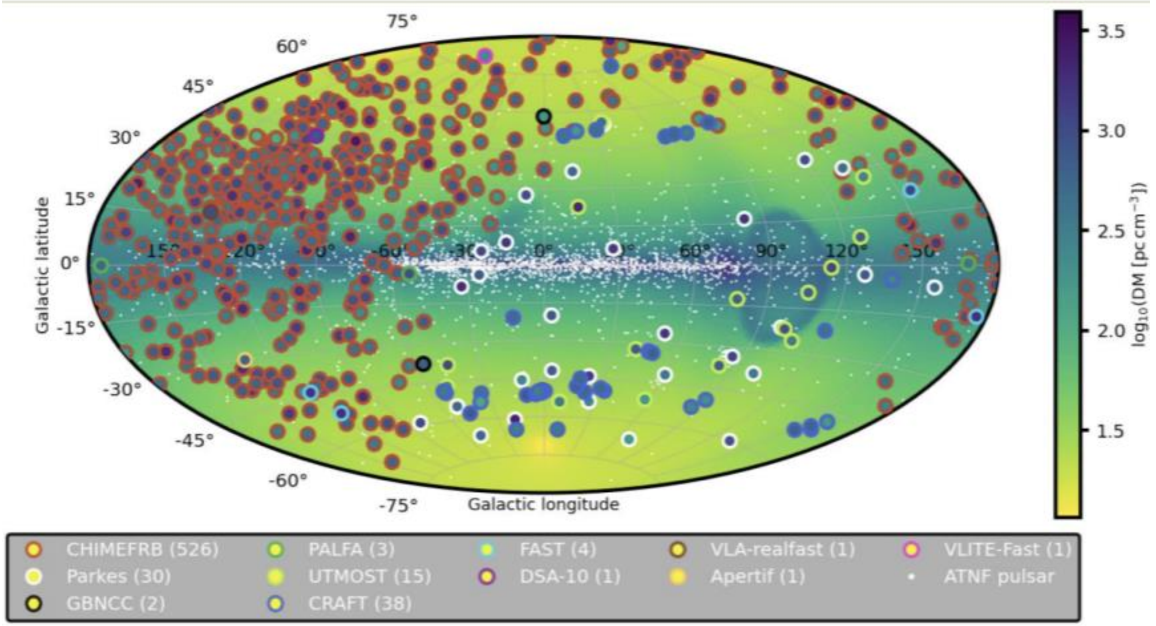
DM_{IGM} can be used as DISTANCE ESTIMATOR: DM_{IGM} -z relation

Macquart, JP et al., *Nature* **581**, 391–395 (2020)

FRB selection

R-FRBs of interest:

- FRB20180916B:
  - Distance: 150 Mpc;
  - Periodic: Yes;
  - Number of bursts: 290;
  - Discovered by: CHIME.
- FRB20220912A:
  - Distance: 332 Mpc;
  - Periodic: No;
  - Number of bursts: 1077;
  - Discovered by: CHIME;
- FRB20121102A:
  - Distance: 819 Mpc;
  - Periodic: No (?);
  - Number of bursts: 2370;
  - Discovery by: Arecibo.
- FRB20201124A:
  - Distance: 422 Mpc;
  - Periodic: No;
  - Number of bursts: 2883;
  - Discovered by: CHIME.

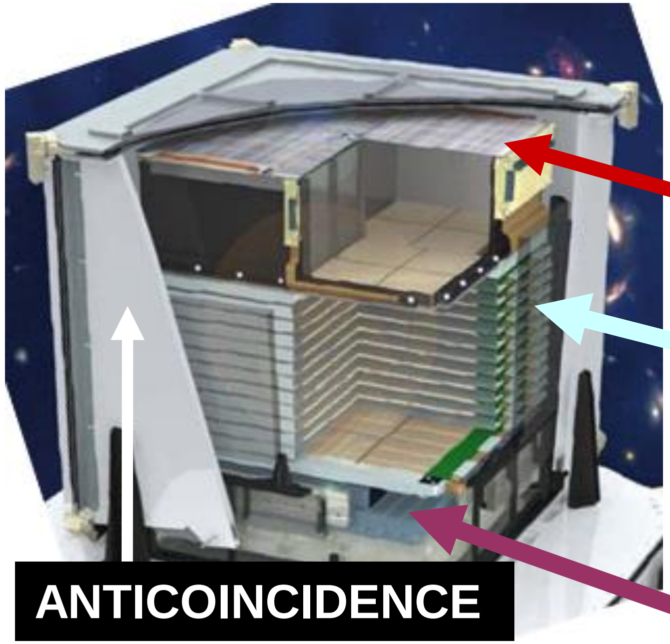


Caleb, and Keane, Univ. **2021**, 7(11), 453

The AGILE satellite

- 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; Super-A) 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

For more details about the AGILE mission see Carlotta Pittori’s talk and slides

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 IGM-DM) 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 IGM-DM, FRB180916.J0158+65 and FRB181030.J1054+73
2. Paper on the periodic R-FRBs FRB20180916B, 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, 2023; Pellicciari et al. 2024, and others

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:

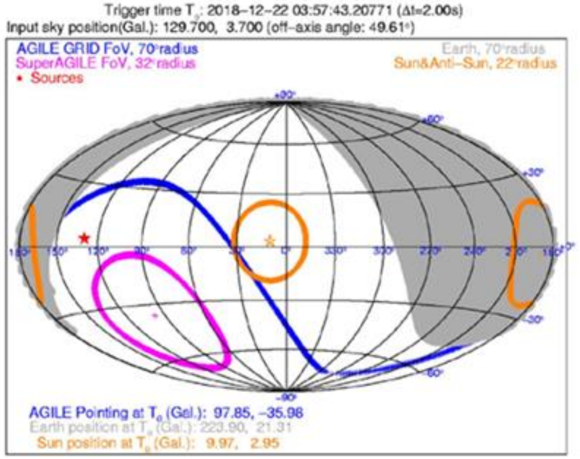
$$\mathcal{F}_{E>0,4MeV} \sim 10^{-8} \frac{erg}{cm^2} \ (@\ 1\ ms\ timescale)$$

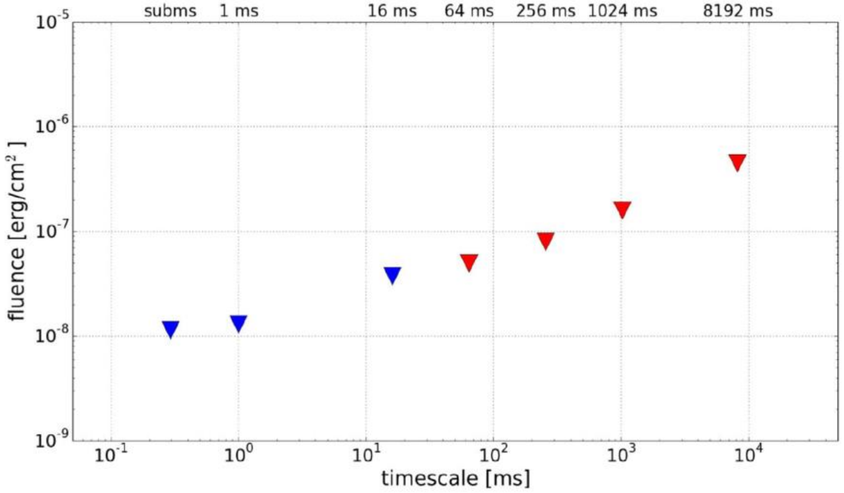
$$F_{\gamma} \sim (2-4) \times 10^{-11} \frac{erg}{cm^2 s} (@\ 100\ d\ timescale)$$

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

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

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. 2020a

In 2020 was discovered the periodic radio activity phases ($P \sim 16{,}3\ d$) of FRB20180916B. → ***knowing when to look for HE emission increases the probability of detections***;

We deploy a MW campaign on it with **AGILE** and **Swift** satellites and with **NC** and **SRT** radiotelescope:

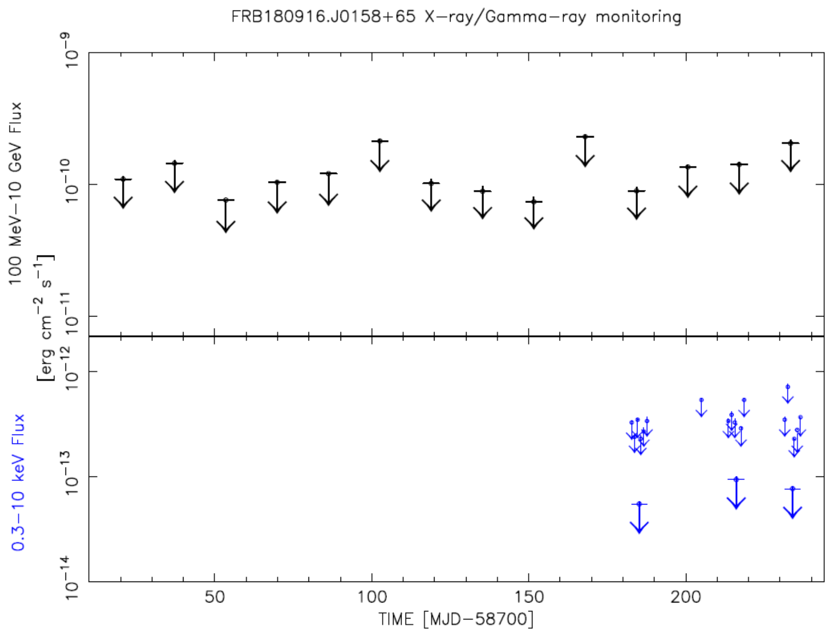
- Swift observations ranging from Feb. 3 up to Mar. 28, 2020;
- AGILE data during the period 2019 August–2020 March;
- Northern Cross and SRT from Feb. 3 up to Mar. 28, 2020.

- No high-energy (X and gamma) detection;

$$\begin{cases} F^{XRT}_{X,26,8\ ks} \sim 3{,}1 \times 10^{-14} erg/s/cm^2 \\ F^{GRID}_{\gamma,11,5\ yr} \sim 8{,}2 \times 10^{-13} erg/s/cm^2 \end{cases}$$

- *Magnetar-like high B progenitor model* -> a factor $10^3 - 10^4$ enhancement with the respect average L_m needed to reach U.L.!

$$L_m \sim E_m/\tau_d \sim (10^{38} erg\ s^{-1}) R^3_{m,6} B^2_{m,16} \tau^{-1}_{d,11}$$ *Thompson and Duncan (1996)*



NOT IMPOSSIBLE FOR AN EXTREME MAGNETAR

M. Tavani *et al.*
Gamma-Ray and X-Ray Observations of the Periodic-repeater FRB 180916 during Active Phases.
2020 *ApJL* **893** L42

$\tau_{d,11}$: Dissipation time in units of 10^{11} s;
$B_{m,16}$: Magnetar inner magnetic field in units of $10^{16}\ G$;
$R_{m,6}$: Magnetosferic radius of the magnetar in order of $10^6\ cm$;

AGILE and FRB: Tavani et al. 2020b

FRB20200428

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.

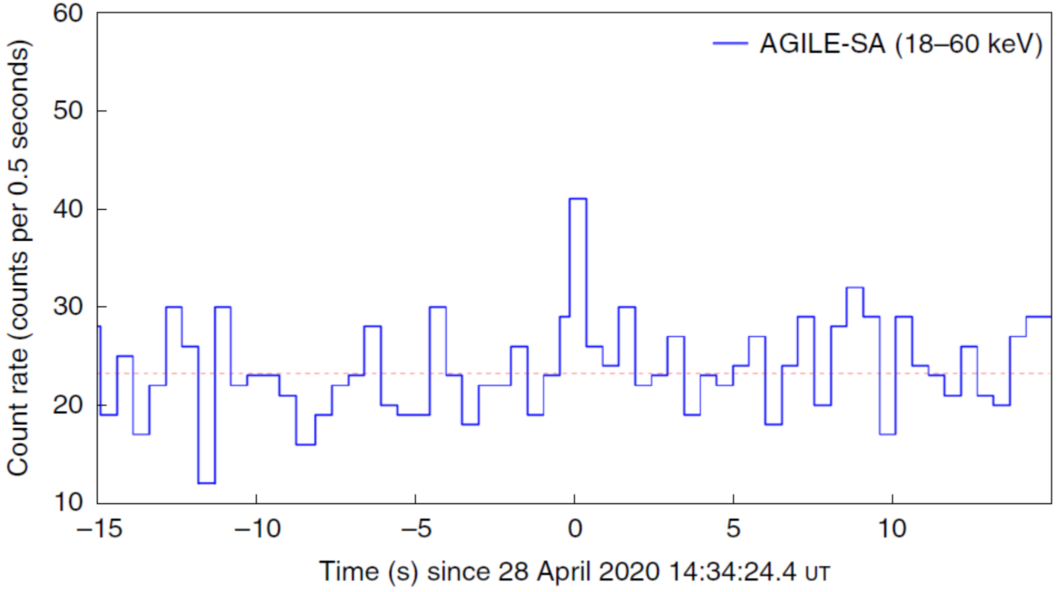
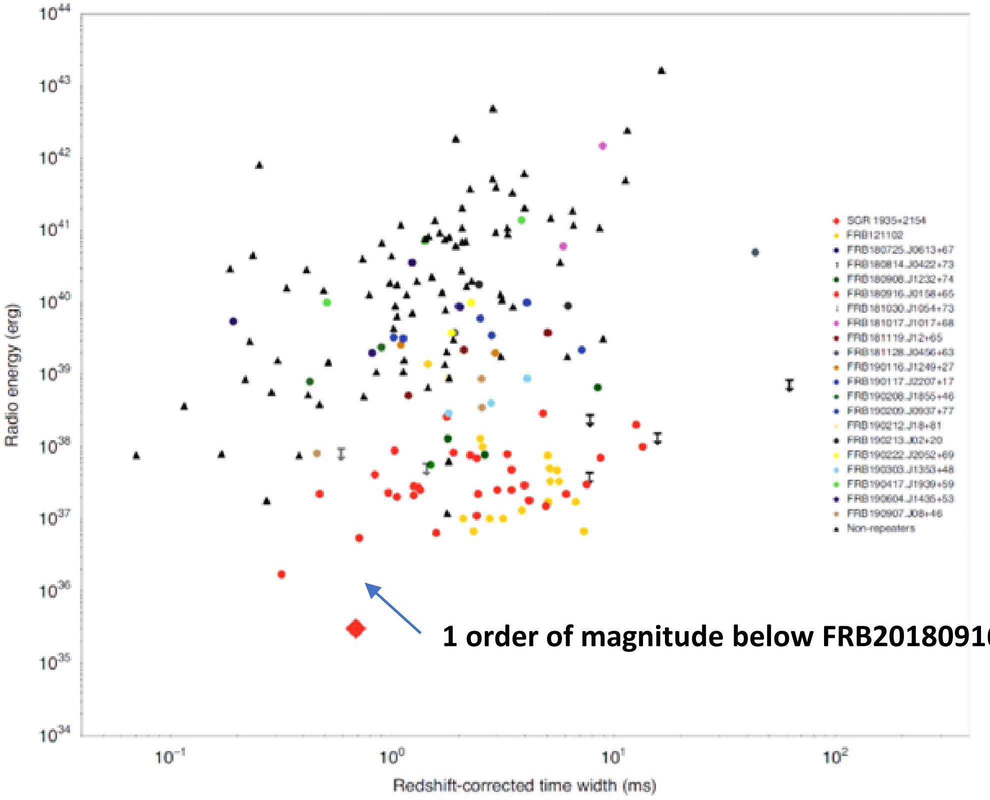


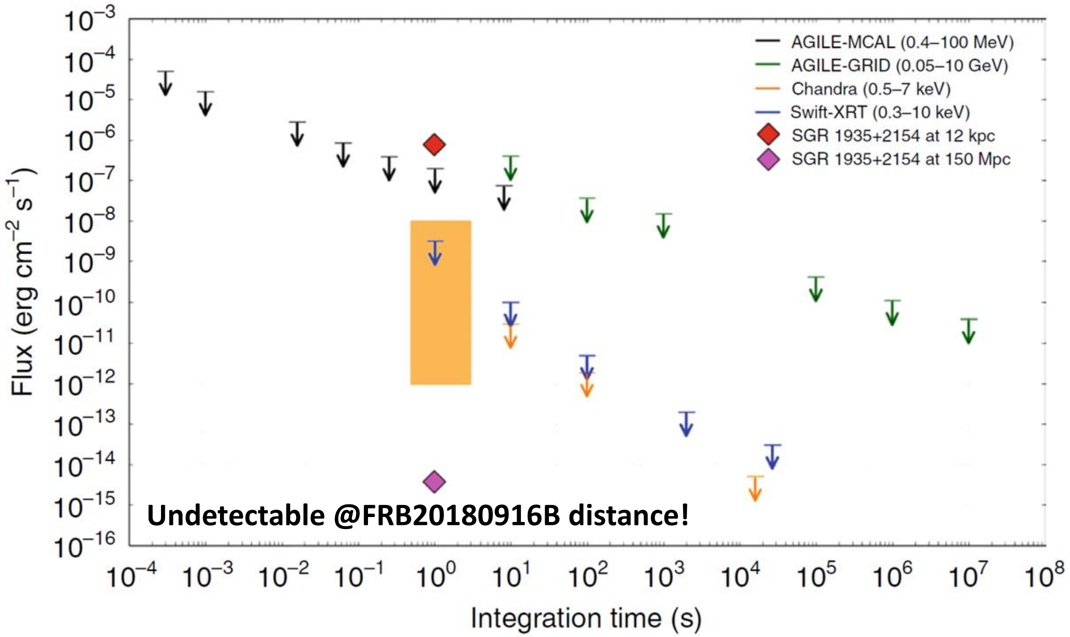
Fig. 2 | Detection of the X-ray burst in temporal coincidence with the very intense radio burst from SGR 1935+2154. The panel shows the light curve of the AGILE-SA RM with data in the energy range 18–60 keV displayed with 0.5 s binning.

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: Tavani et al. 2020b



1 order of magnitude below FRB20180916B!



Undetectable @FRB20180916B distance!

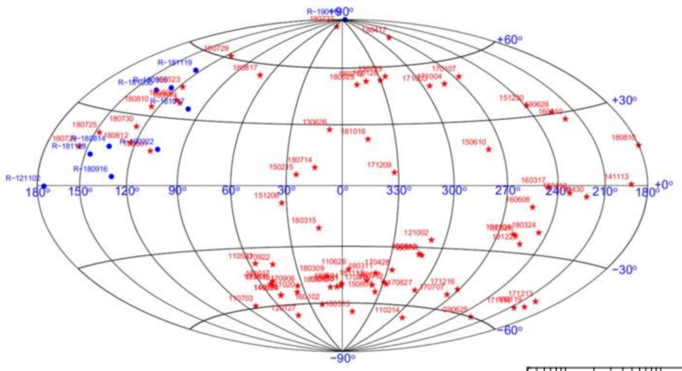
Orange region: Range of possible X-ray outburst from nearby magnetar rescaled for FRB20180916B

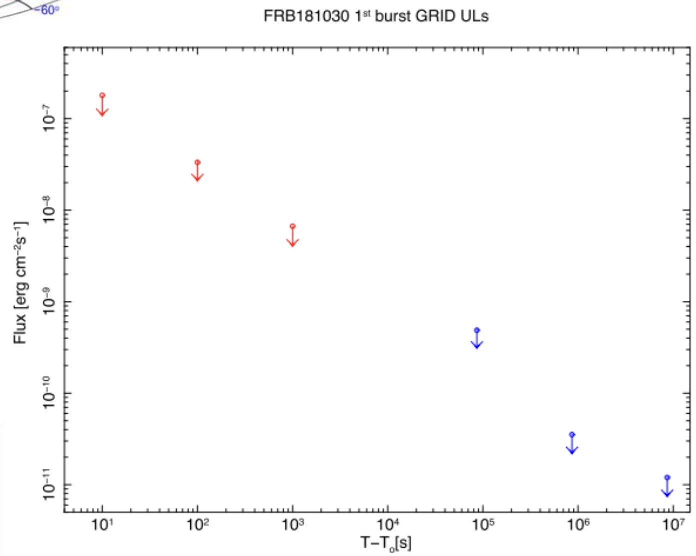
Tavani, M., Casentini, C., Ursi, A., Verrecchia, F. *et al.*
An X-ray burst from a magnetar enlightening the mechanism of fast radio bursts.
Nat Astron **5**, 401–407 (2021).

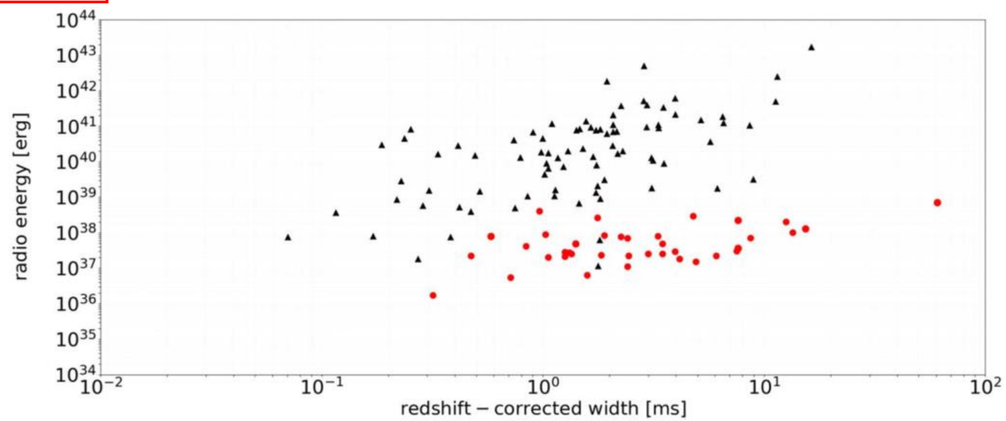
AGILE and FRB: Verrecchia et al. 2021

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 nearby 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):
  - $L_{\gamma,UL} \sim (2-5) \times 10^{43} d^2_{150Mpc}\, erg/s$



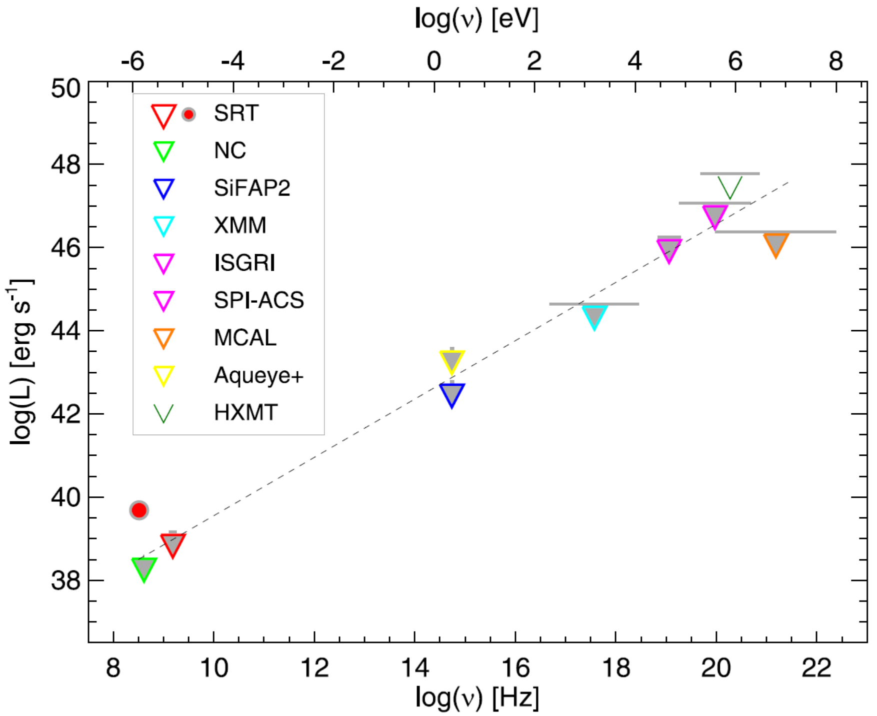




F. Verrecchia *et al.*,
AGILE Observations of Fast Radio Bursts.
2021 *ApJ* **915** 102.

AGILE and FRB: radio collaboration papers

- **Pilia et al. 2020**: radio SRT campaign on FRB20180916B + MW campaign FIRST results:
  - Discovery of SRT new bursts;
  - Again results from AGILE within a larger campaign.
- **Trudu et al. 2022**: radio NC campaign on FRB20180916B, 20181030A, 20200120E and 20201124A:
  - Detection of 3 radio-bursts from 20180916B and none from the others;
  - Estimation of lower limits on burst rate from NON detection.
- **Trudu et al 2023**: a new simultaneous radio SRT & uGMRT and MW campaign on FRB20180916B:
  - Discovery of 14 new bursts;
  - Again results from AGILE and Swift data within a larger campaign:
    - $E_{optical} / E_{\mathrm{radio}} < 10^7$; $E_{\mathrm{X\text{-}ray}} / E_{\mathrm{radio}} \sim 10^7$



AGILE and FRB: current status

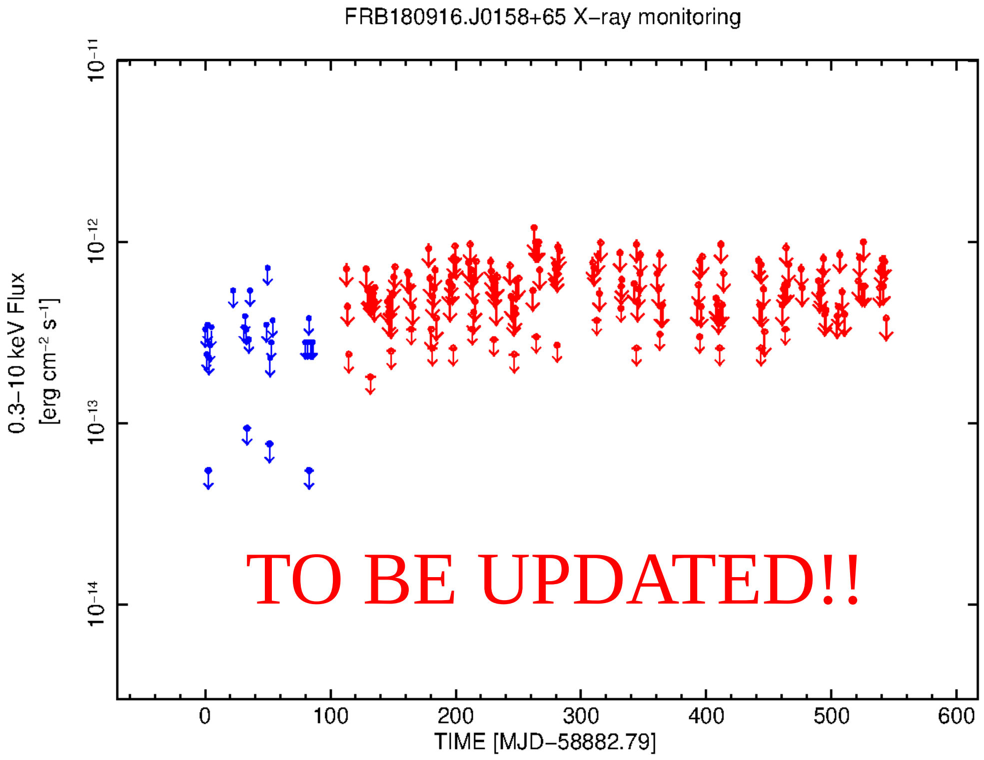
- AGILE more recent activity:
  - Multiwavelength campaign about FRB20180916B together with SRT, Medicina NC and Swift/XRT:
    - Search for new radio bursts mainly with NC, SRT and other italian radio-telescopes (Pilia, Bernardi+);
    - Swift data reprocessing on-going, goal is a further MW AGILE paper;
    - Support for other eventual papers from radio and MW collaborators;
    - Final paper on the MW campaign on FRB20180916B: analysis in revision.

  - Possible futher MW observations & campaigns for other sources:
    - FRB20220912A;
    - FRB20240114A, FRB20240619D.

  - Archival analysis of past FRB emission using on-line catalogues (CHIME/FRB, TNS and Blinkverse):
    - AGILE data analyses procedure upgrade;
    - Archival radio & X/gamma-ray burst searches:
      - executed a revised «repeaters» data analysis;
      - update paper on «one-off» & «repeaters»: writing with an updated sample.

AGILE and FRB: FRB20180916B MW campaign

- More than 3 years of *FRB20180916B* cycles observations completed (Feb. 3, 2020 – Sep. 23, 2023):
  - No counterpart observed;
  - Decreasing X-ray «deep» UL values
- Data analysis from SRT and Medicina NC brought to the discovery of various new bursts in 2022-2023:
  - MW AGILE et al. Contemporary X- & gamma-ray emission search! ***NOT YET DETECTED!***
- Further observations suspended at NC on 2023, **restarted in 2024**!
- Super-A data partially processed: no counterparts till now;
- **Swift/XRT U.L. ''lightcurve''** (Feb. 3, 2020 – Oct. 5, 2021).



AGILE and FRB: summary

Since the end of 2018 the AGILE team began the search for high energy counterpart of FRBs. The activity started on the 2019 CHIME/FRB discovery of new R-FRBs, including some sources that have low DM-IGM.

The analysis procedures allow to extract very interesting flux and fluence X- / gamma-ray ULs either short (ms) and long (days to years) timescales. These ULs, in particular those from FRB20180916B, are among the lowest in this energy band (>0,4 MeV up to 50 GeV).

We could verify that an X-ray burst like the one from SGR 1935+2154 at the distance of FRB20180916B could have been detectable by AGILE MCAL.

In 2020 the detection of a weak X-ray burst from SGR 1935+2154 during a renewed activity phase having a bright a very short radio counterpart confirmed that magnetars can produce X-ray burst coincident to ms-radio bursts similar to the emission from FRB sources. Then models involving a magnetar as progenitor of the radio burst, become the most interesting, for HE emission at least for nearby sources.

Further works are in progress using the whole 17 years AGILE archive and data from dedicated MW-campaigns.

BACKUP SLIDES

Dispersion measure (DM)

- The **Dispersion Measure (DM)** is a key parameter in radio astronomy that quantifies the total amount of free electrons between a radio source and the observer;
- It is a measure of the integrated column density of electrons along the line of sight and is expressed in units of **pc/cm³** (parsecs per cubic centimeter).

$$DM = \int_0^D n_e(s)ds$$

- **Frequency-dependent delay**: As radio waves from distant objects travel through the interstellar medium (ISM), higher frequency waves travel faster than lower frequency waves. The dispersion measure helps quantify the delay across different frequencies.

$$t_{DM}(\nu) = \frac{4.15\ \times DM}{\nu_{GHz}^2}\ ms$$

DM can be used as DISTANCE ESTIMATOR: DM-z relation

Macquart, JP et al., *Nature* **581**, 391–395 (2020)