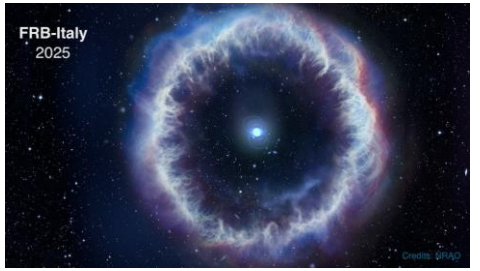


AGILE MW campaigns for FRB High Energy counterparts search

Francesco Verrecchia, Claudio Casentini

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

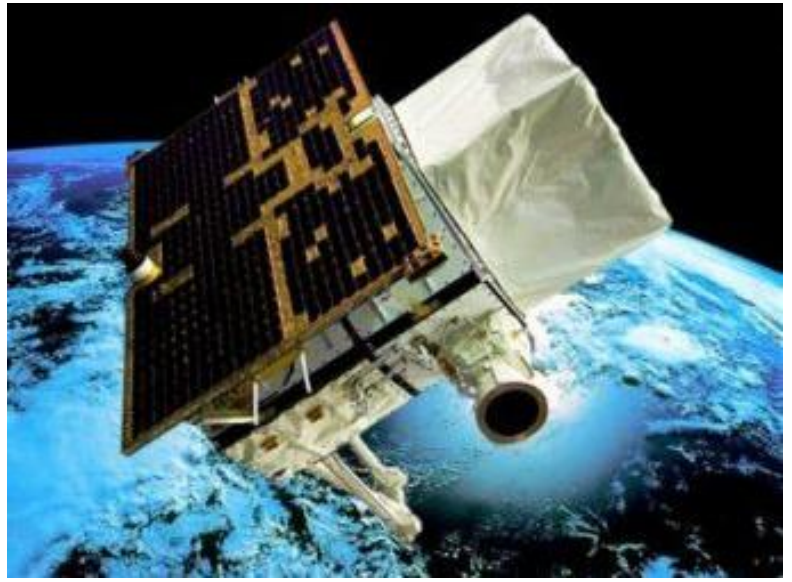
and ***Matteo Perri***

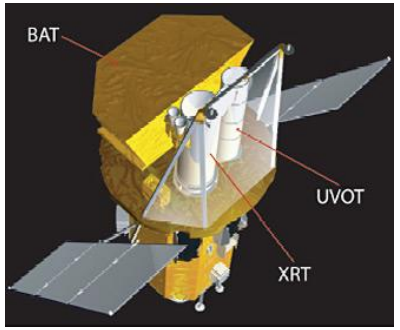
FRB-Italy

Bologna, 08/05/2025

Outline

- Short intro to FRBs
- AGILE results on FRBs summary and some detail on first works
- MW campaign on FRB20180916B history and results, the work on-going;
- MW campaigns on FRB20220912A and FRB20240114A;
- Recent AGILE results
- Future prospective

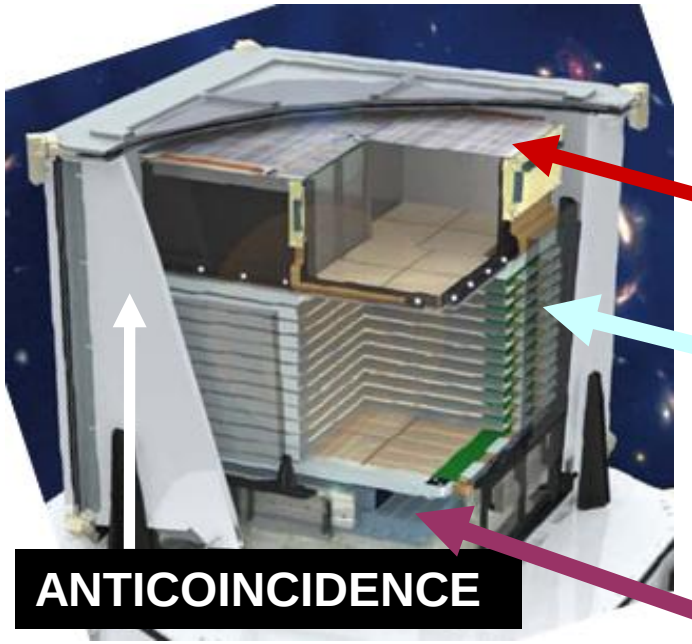




The AGILE instrument

- A combination of two co-aligned imaging detectors, in hard X-ray (SuperA) and gamma-ray (GRID) with large FoVs
+ omidirectional Mini Calorimeter
+ Anticoincidence (80 – 200 keV)
- Coverage of 70% -- 80% of the whole sky in about 7min

- 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

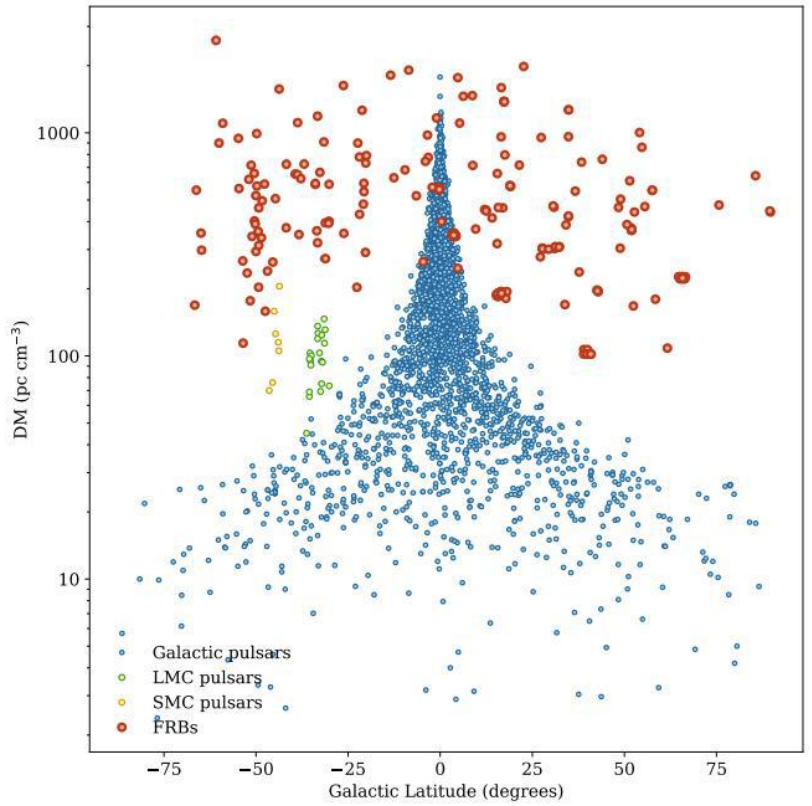
(MINI) CALORIMETER

Energy Range: 0.3–100 MeV

MCAL had sub-ms triggering capability!

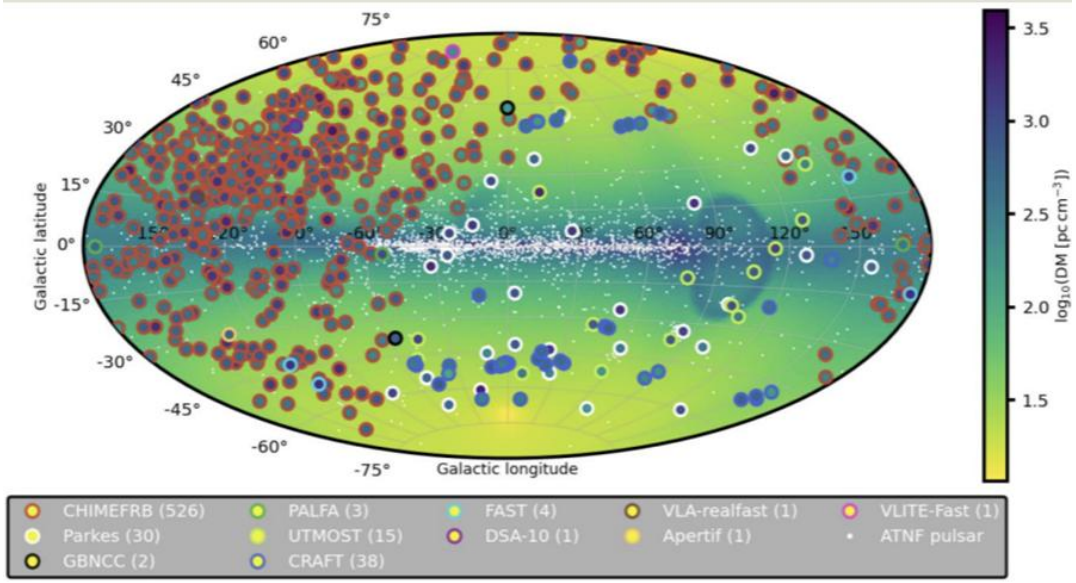
FRBs phenomena

- 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.

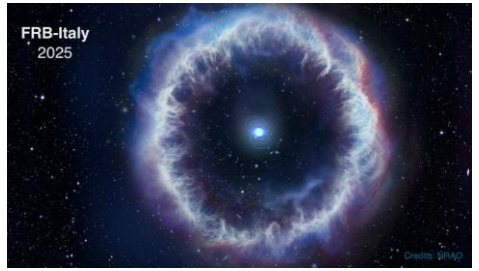


- DM_{IGM} ($DM - DM_{MW} - DM_{host}$) can be used as DISTANCE ESTIMATOR: DM_{IGM} -z relation

Up to now the FRB population consist of **862** total sources, divided in one-off and repeaters (R-FRB). Currently there are **69** R-FRB known and only 2 with periodic activity.



AGILE and FRBs: history

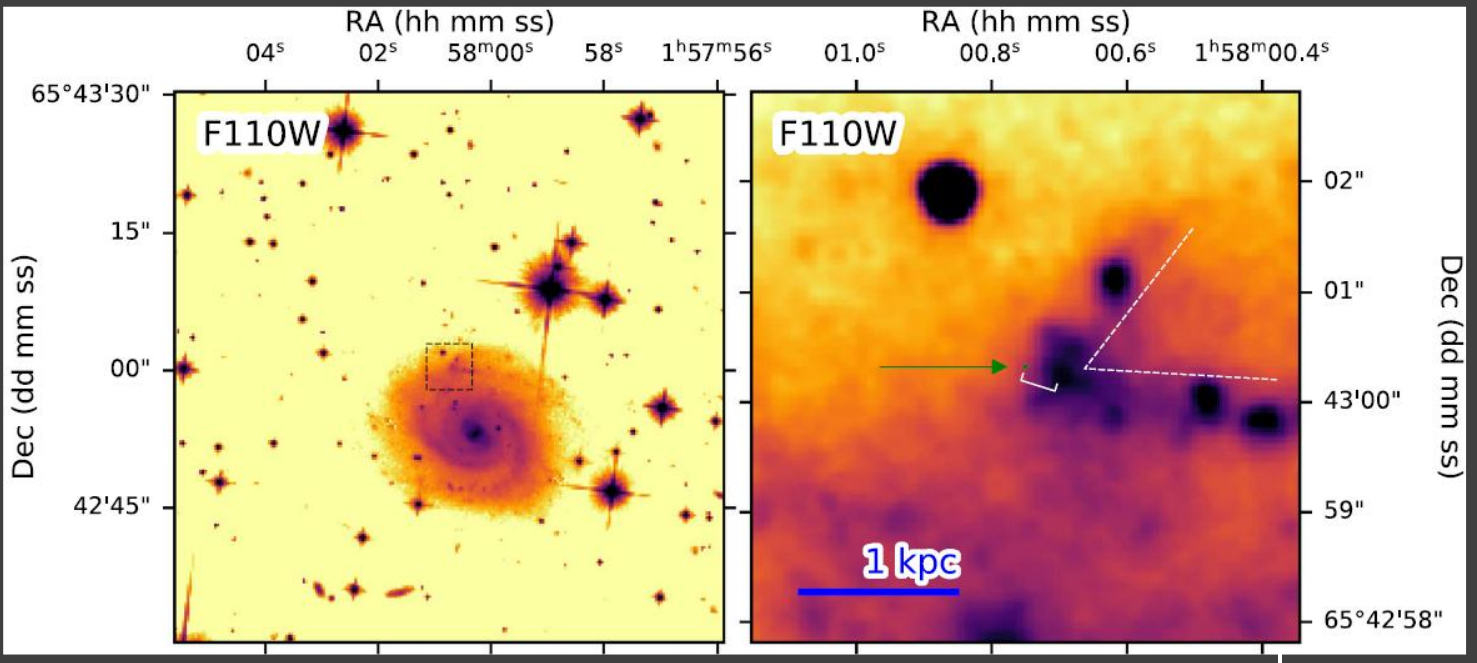


The AGILE activity for FRB HE studies: the activity started on the search for HE counterpart in the AGILE data for sources in the rapidly increasing catalog of FRB sources, FRBCAT.

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; Geminardi et al submitted, and others

6. **New results! Paper on a sample of R-FRBs just published, Casentini et al 2025! See Claudio next talk!**



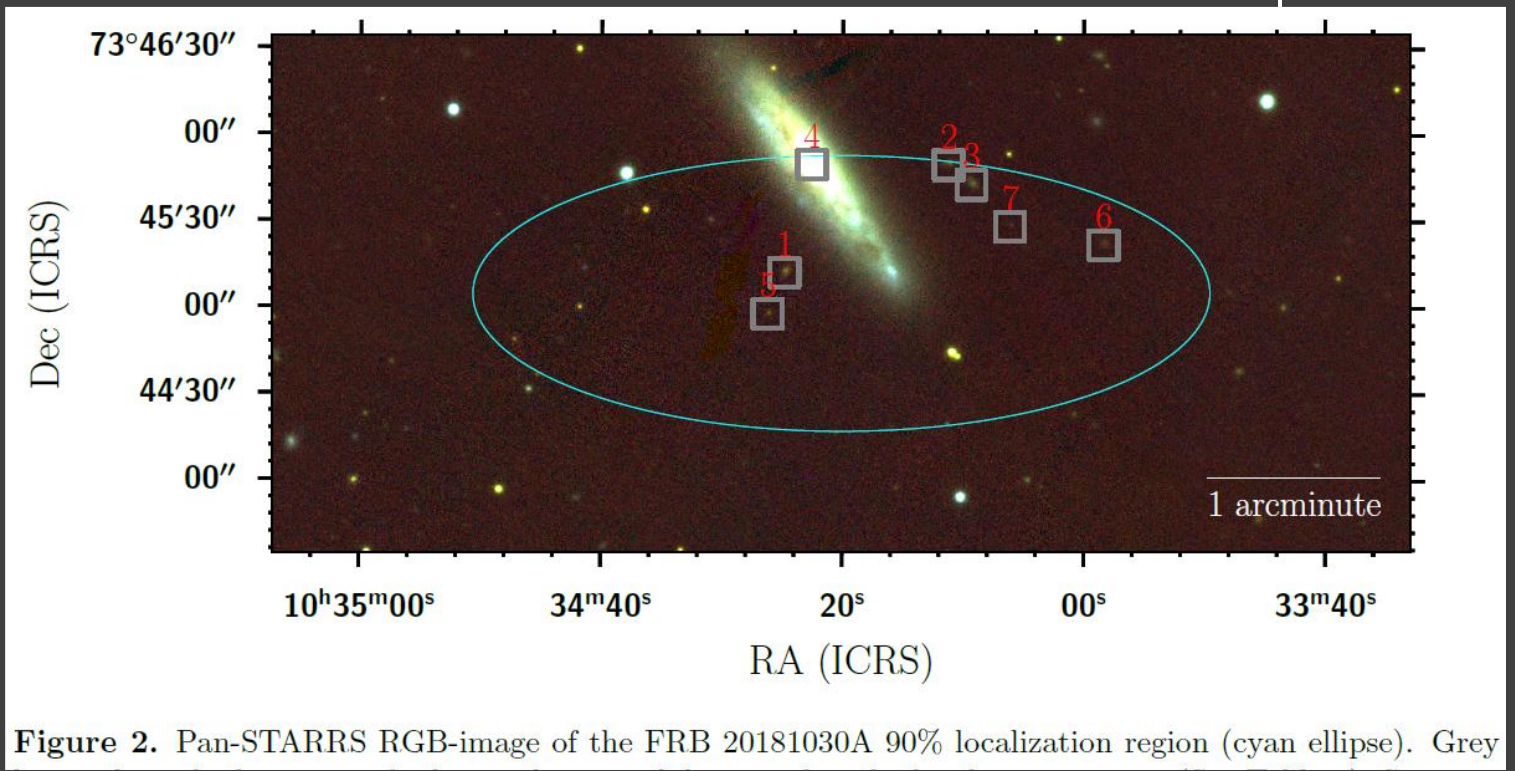
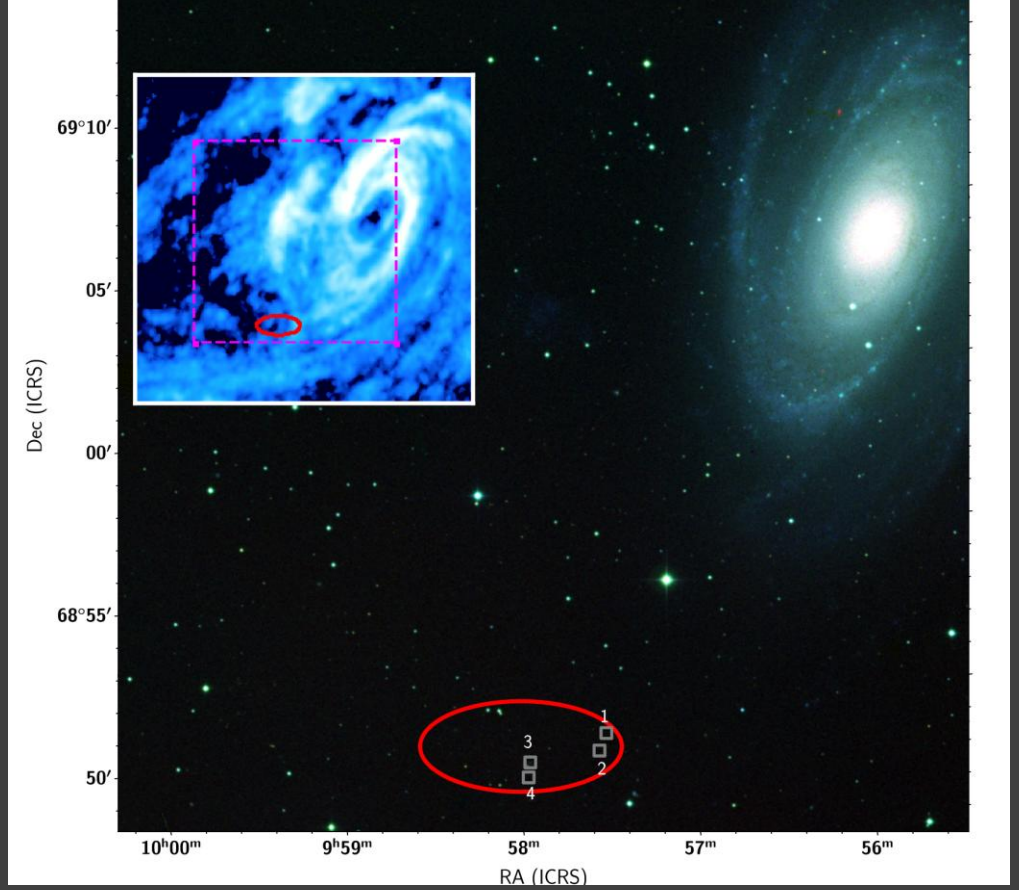


Figure 2. Pan-STARRS RGB-image of the FRB 20181030A 90% localization region (cyan ellipse). Grey

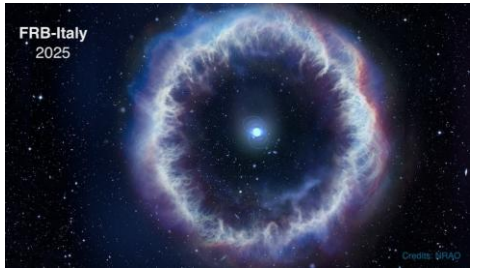
The FRB20180916B "case":
a "cusp"!

.. the FRB20181030A
one
(it was the nearest)



.. FRB20200120E: near M81, currently the nearest

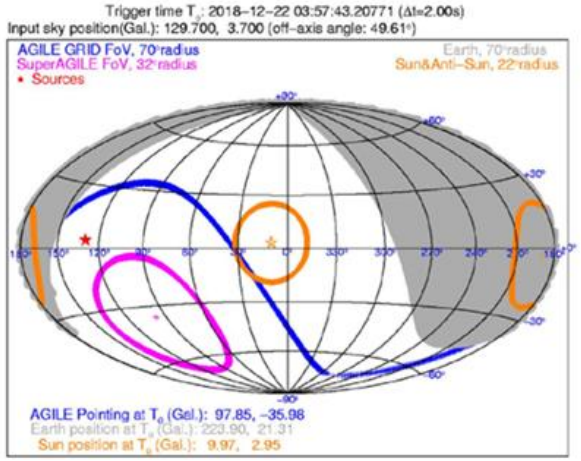
AGILE and FRBs 1°: Casentini et al. 2020



- 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:

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

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

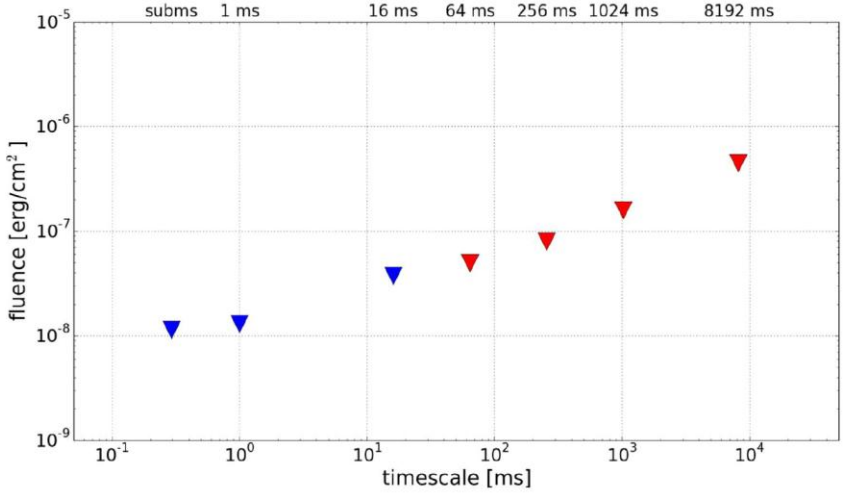


- We suppose a magnetar-like engine ($R_m \sim 10^6 cm, B \sim 10^{16} G$):

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

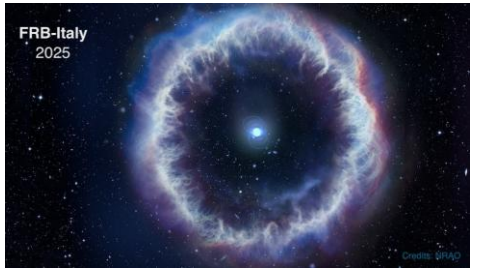
that excludes an emission like the giant burst of SGR 1806-20 ($E_{MeV} \sim 2 \times 10^{46} erg$) for both short and long timescales.

=> $E_{\mathrm{radio,iso}} \,/\, E_{\mathrm{MeV,UL}} \sim 10^{-8}$



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

AGILE and FRBs 2°: Tavani et al. 2020a



In 2020 was discovered the periodic radio activity phases ($P \sim 16.3\ d$) of **FRB20180916B**.

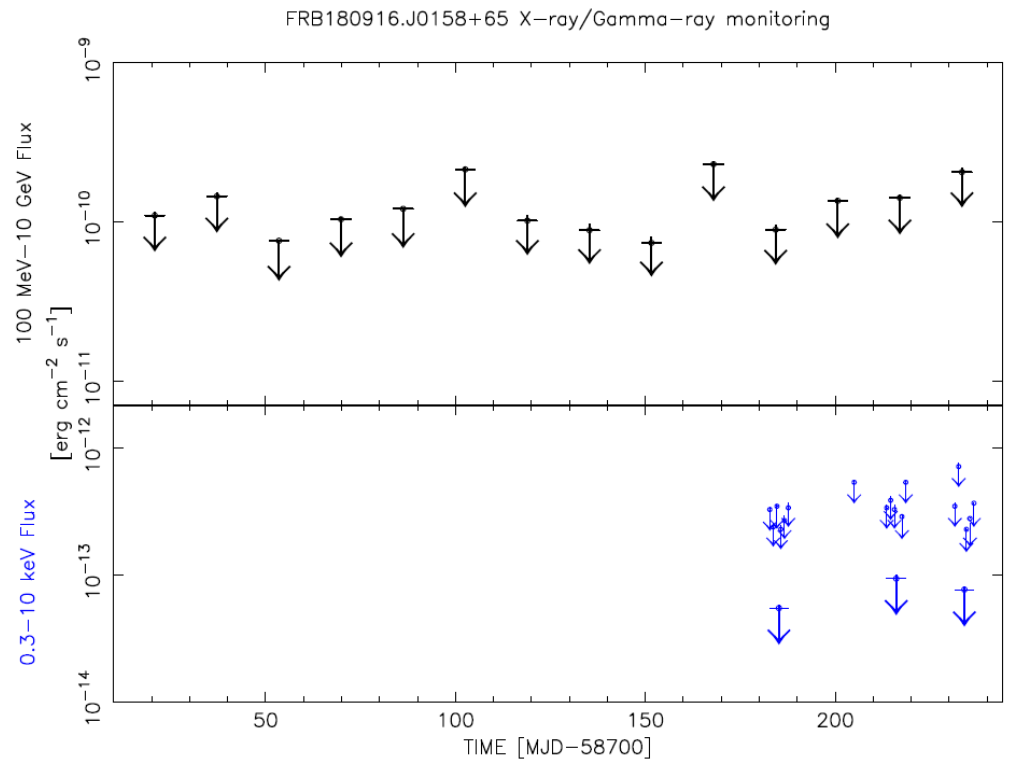
→ ***knowing when to look for HE emission increases the probability of detections***;

We began 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

$\tau_{d,11}$: 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 $10^6\ cm$;

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

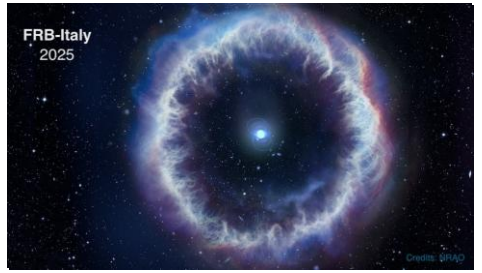
Northern Cross reactivation

- From 2019 Northern Cross upgrading!

to restore/improve the original detection capabilities

- CHIME

AGILE and FRBs 3°: 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**.

FRB20200428

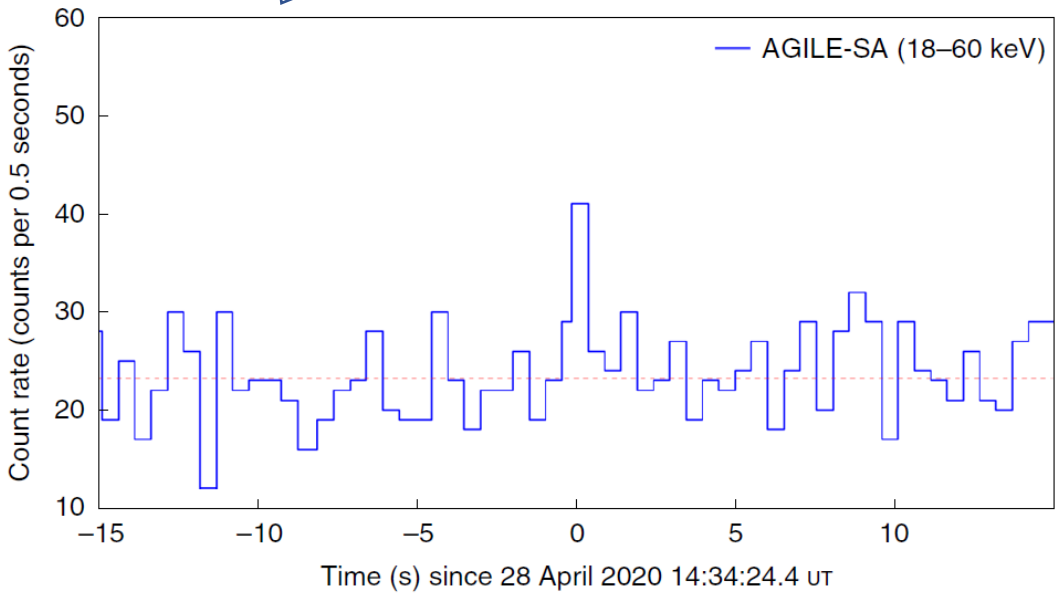
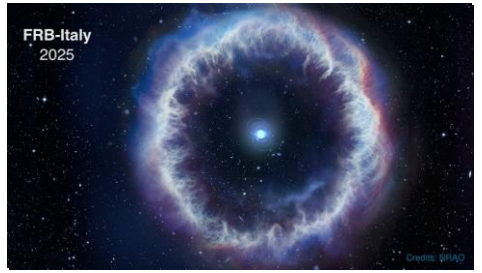


Fig. 2 | Detection of the X-ray burst in temporal coincidence with the very intense radio burst from SGR 1935+2154. The panel shows the light curve of the AGILE-SA RM with data in the energy range 18–60 keV displayed with 0.5 s binning.

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 FRBs 3°: Tavani et al. 2020b



FRB20180916B Swift&XRT campaign strategy:

- started in PC mode to investigate either transient or persistent emission summing the PC data (2.5 s time resolution)
- after publication of Chandra results, at $10^{-15} erg/s/cm^2$ (Scholz et al. 2020), we decided to apply for WT mode data with higher time resolution (1.8 ms) to investigate transient only emission

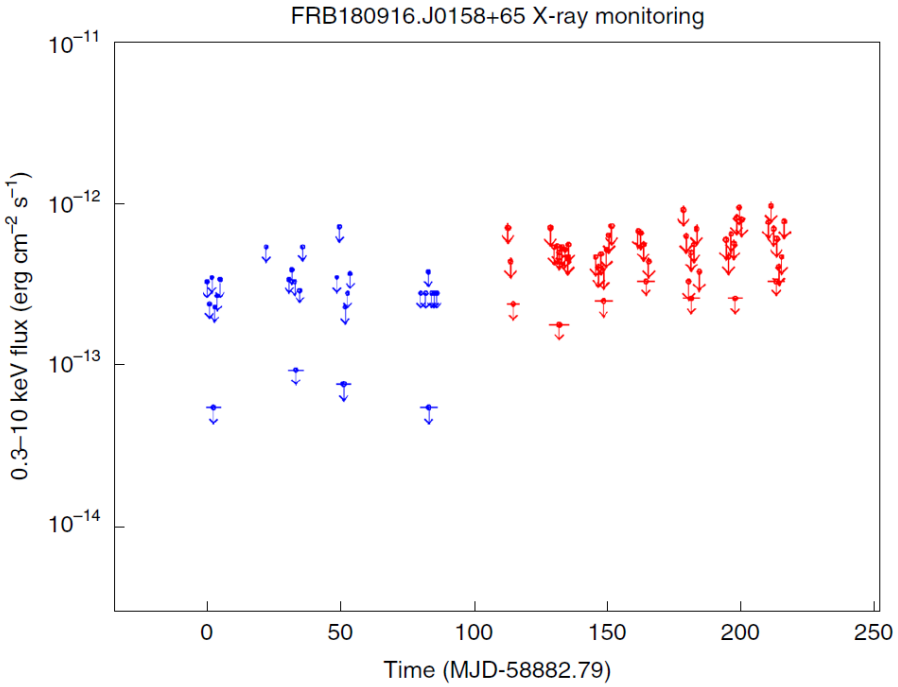
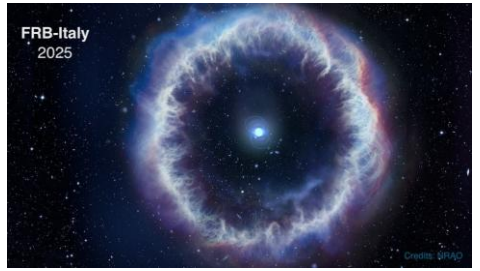
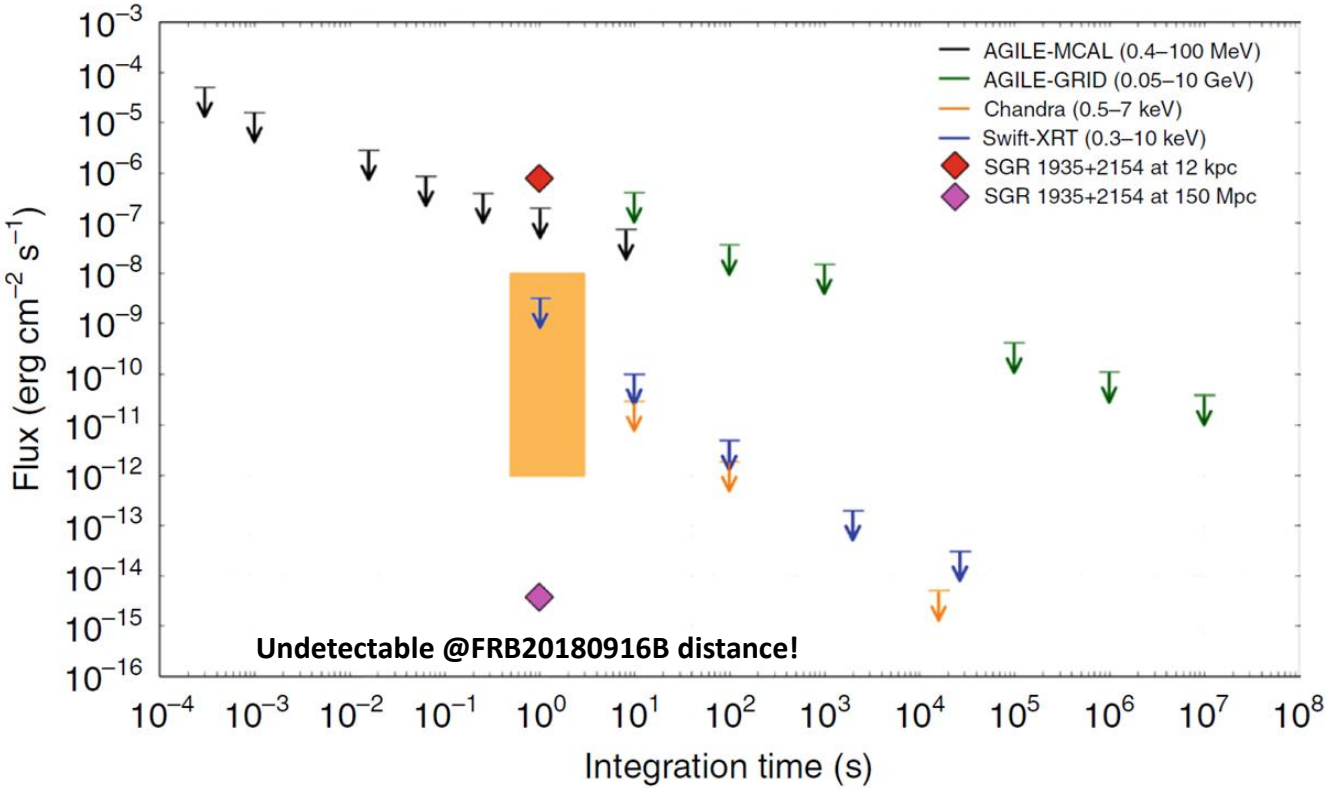


Fig. 5 | X-ray monitoring by Swift-XRT of the nearby repeating FRB 180916 (3 February 2020 to 7 September 2020) during its five-day active time intervals of expected radio bursting based on periodicity. Small arrows indicate flux upper limits in the range 0.3–10 keV obtained for XRT

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 FRBs: Tavani et al. 2020b



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

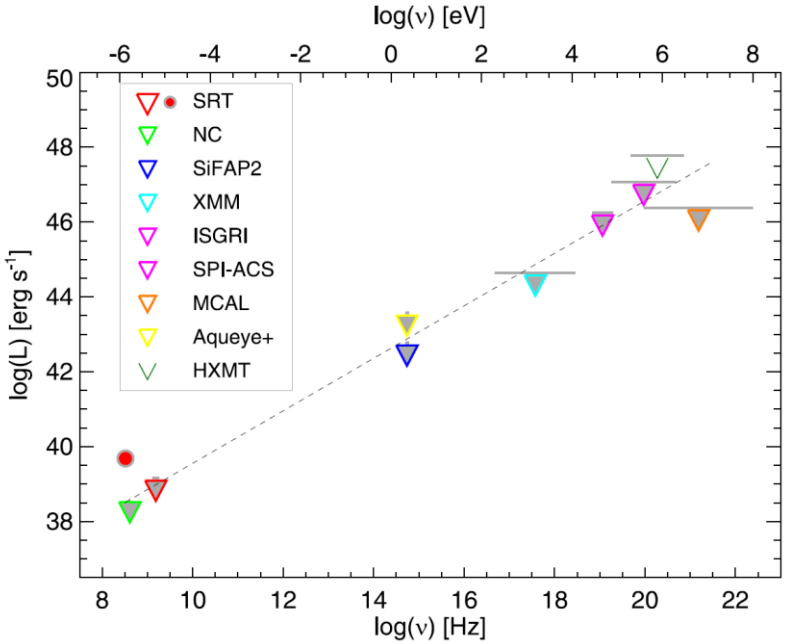
Tavani, M., Casentini, C., Ursi, A., Verrecchia, F. *et al.*
An X-ray burst from a magnetar enlightening the mechanism of fast radio bursts.
Nat Astron **5**, 401–407 (2021).

AGILE and FRBs: radio-NC papers!

Results from the campaign on **FRB20180916B** in three papers

1) **Pilia et al. 2020**: radio SRT campaign on **FRB20180916B** + MW campaign FIRST results!
   =>DISCOVERY of NC new bursts!

=>Again results from AGILE within a larger campaign



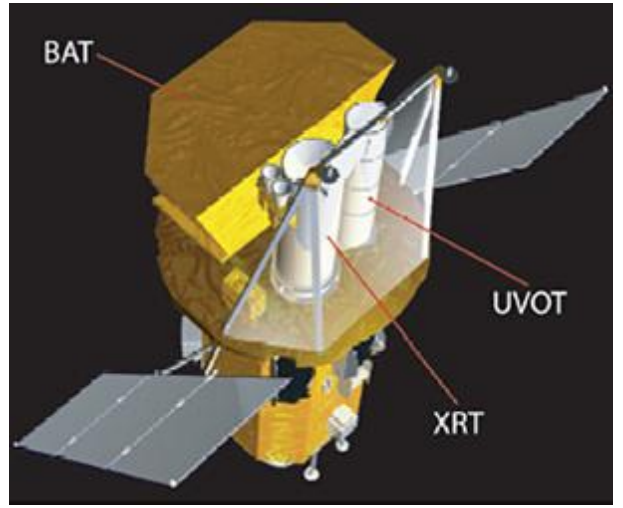
2) **Trudu et al. 2022**: radio NC campaign on **FRB20180916B**, 20181030A, 20200120E and 20201124A :
   - detection of 3 bursts from 20180916B and none from the others
   - =>Estimation of lower limits on burst rate from NON detection;

3) **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

$E_{optical} / E_{\text{radio}} < 10^7$; $E_{\text{X-ray}} / E_{\text{radio}} \sim 10^7$

AGILE and FRBs: FRB20180916B MW campaign status

- Final paper on the campaign: more than 3 years of Swift observations of FRB180916B cycles completed (in collaboration with M. Perri):
  - 51 approved Swift ToO
  - Data covering from Feb. 03, 2022 to Sep. 23, 2023: for a total about 425 ks
- Data reanalysis: review for final archive data version and using recent and homogeneous HEAsoft + CALDB versions
  - XRT and UVOT data
- No detected emission ->A complete review of Flux ULs under conclusion
- Burst times coverage: radio burst --X-ray time correlation reviewed: till now just **ONE** burst exposed see below



Begin	End	Target ID	Seg.	Target Name	XRT Mode	UVOT Mode	Merit	PPST Time (s)	AFST Time (s)
2020-02-03 18:42:00	2020-02-03 19:12:00	13201	2	FRB180916.J0158+65	PC	0x015c	90	1800	1680
2020-02-04 15:43:00	2020-02-04 17:19:00	13201	3	FRB180916.J0158+65	PC	0x0191	90	2160	1970
2020-02-05 15:23:00	2020-02-05 15:53:00	13201	4	FRB180916.J0158+65	PC	0x01bc	90	1800	1740
2020-02-06 15:29:00	2020-02-06 17:06:00	13201	5	FRB180916.J0158+65	PC	0x01bc	90	2280	2010
2020-02-07 15:22:00	2020-02-07 17:00:00	13201	6	FRB180916.J0158+65	PC	0x01bc	90	2280	2020
2020-02-08 15:15:00	2020-02-08 17:06:00	13201	7	FRB180916.J0158+65	PC	0x01bc	90	2340	1270

=>Future: different strategy, acquire data on a larger time window than the 5.2 d activity window; improve coordination and exposure?

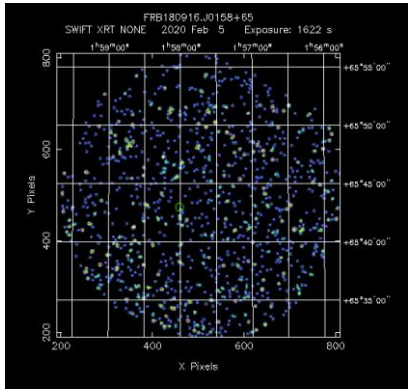
2022-07-23 01:13:00	2022-07-23 01:28:00	13201	252	FRB180916.J0158+65	WT	0x015c	90	900	740
2022-07-23 04:37:00	2022-07-23 04:52:00	13201	253	FRB180916.J0158+65	WT	0x015c	90	900	740
2022-07-24 04:21:00	2022-07-24 04:45:00	13201	254	FRB180916.J0158+65	WT	0x015c	90	1440	1350
2022-07-25 04:06:00	2022-07-25 04:30:00	13201	255	FRB180916.J0158+65	WT	0x015c	90	1440	1340
						Total:		405,873	356,201

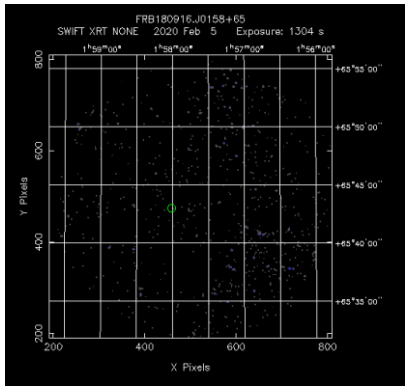
FRB180916.J0158+65	WT	0x01bc	90	1740	1630
FRB180916.J0158+65	WT	0x015c	90	1800	1585
FRB180916.J0158+65	WT	0x015c	90	1920	0
FRB180916.J0158+65	WT	0x015c	90	1800	1635
FRB180916.J0158+65	WT	0x015c	90	2100	1910
			Total:	81,360	68,465

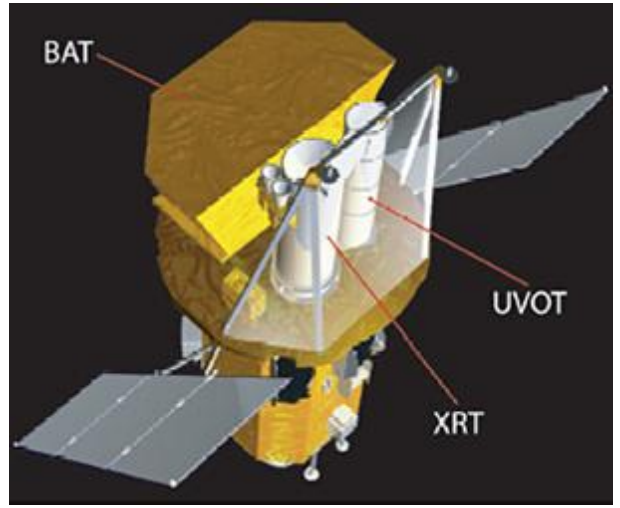
Showing 1 to 46 of 46 entries

AGILE and FRBs: status of MW campaign on FRB20180916B

Careful cleaning XRT data

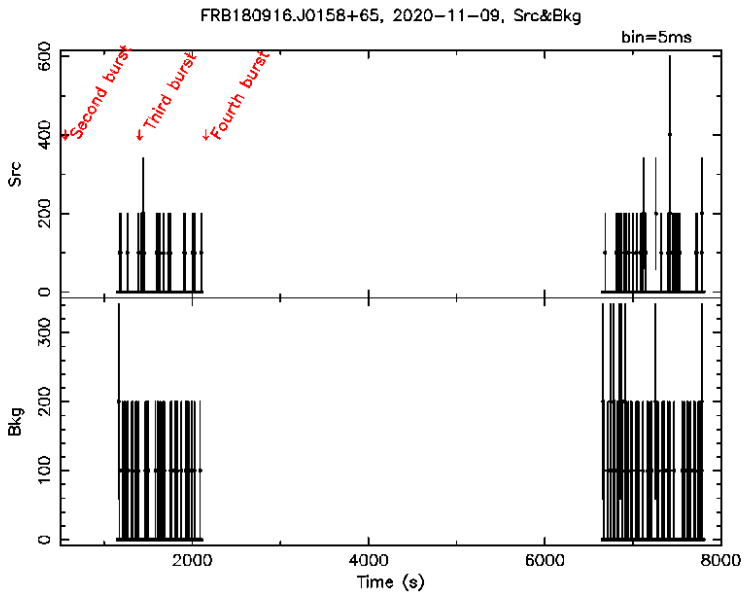




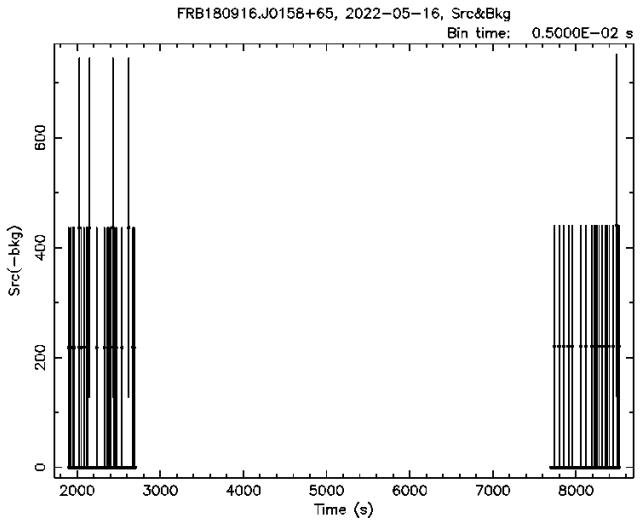


The single burst covered by Swift/XRT exposure found till now.

included in Trudu et al. 2023!



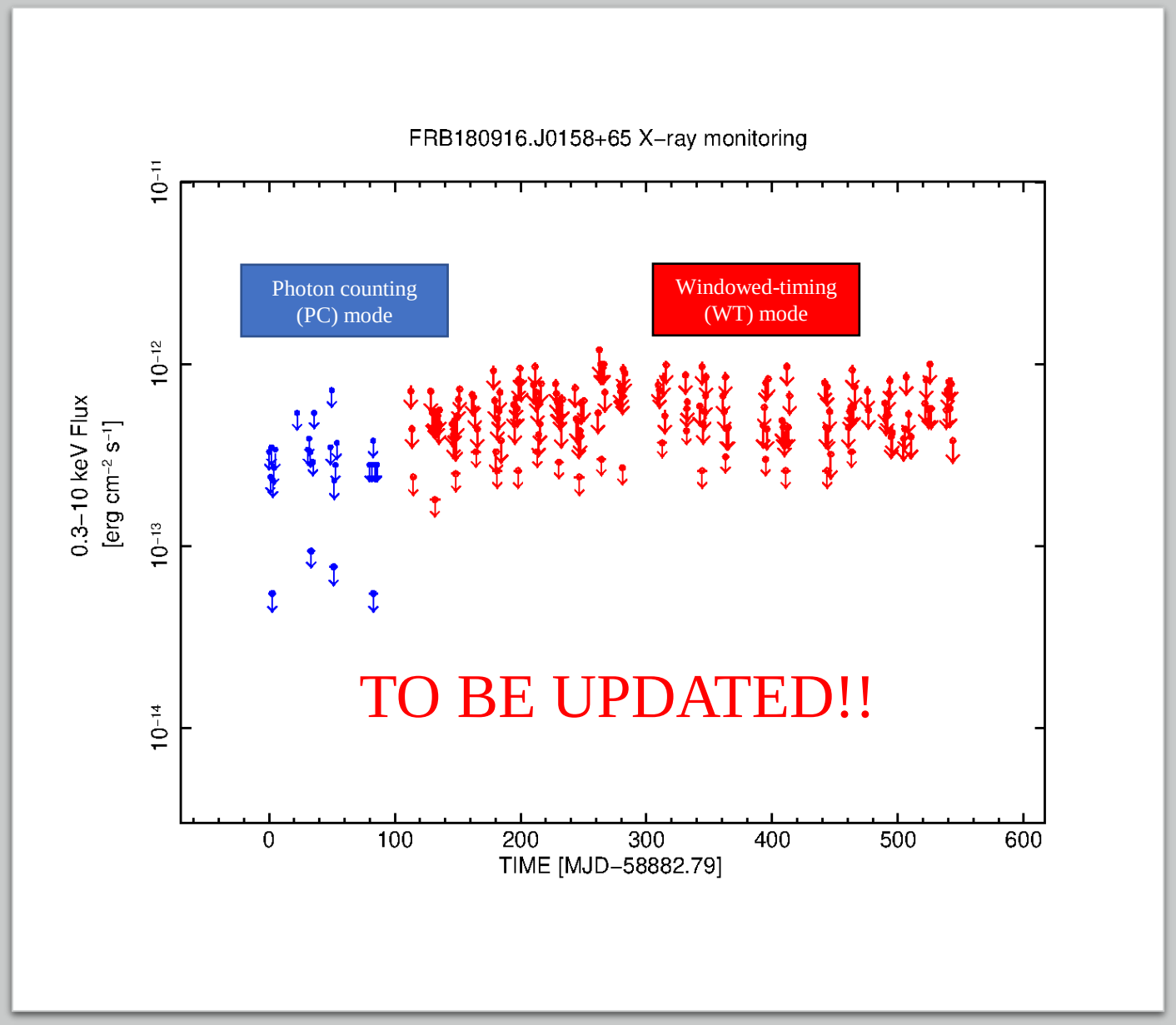
Detailed exposure coverage check within each data time interval



FRB20180916B MW campaign end (?)

- More than 3 years of *FRB20180916B* cycles observations completed:
  - No counterpart observed;
  - Decreasing X-ray «deep» UL values
- Data analysis from SRT and 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**!
- No Super-AGILE counterpart;
- **Swift/XRT U.L. ‘’lightcurve”** (Feb. 3, 2020 – Oct. 5, 2021)

TO BE UPDATED!!



FRB20180916B MW campaign end (?)

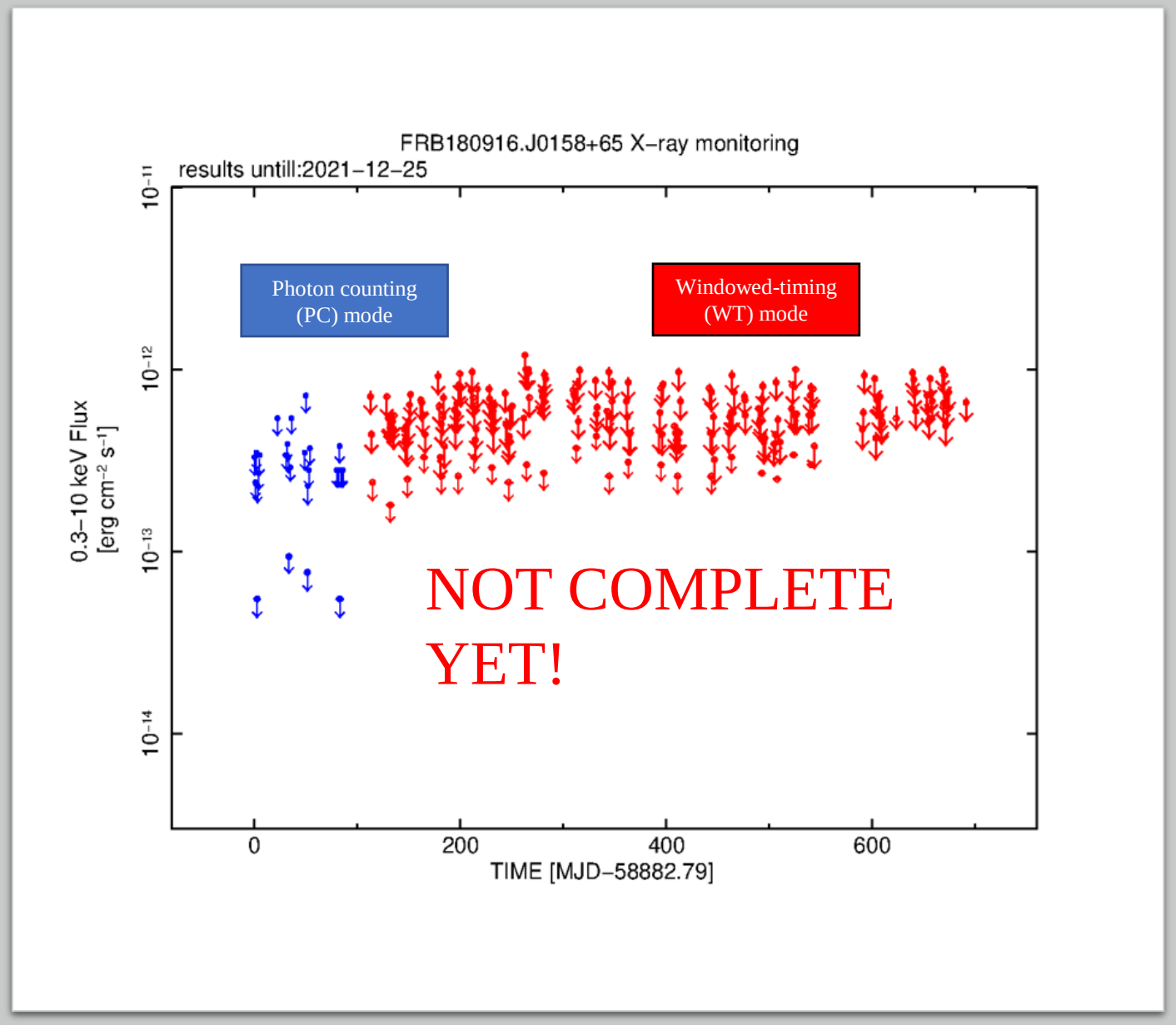
- **Swift/XRT U.L. ‘’lightcurve”** (Feb. 3, 2020 – Dec. 31, 2021)

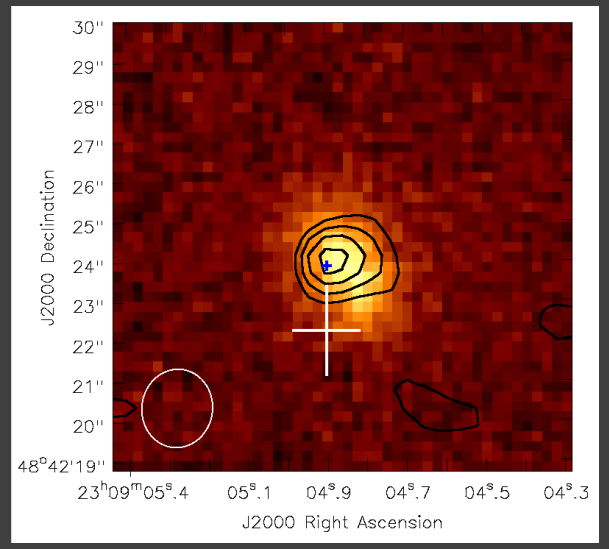
STILL TO BE COMPLETED!

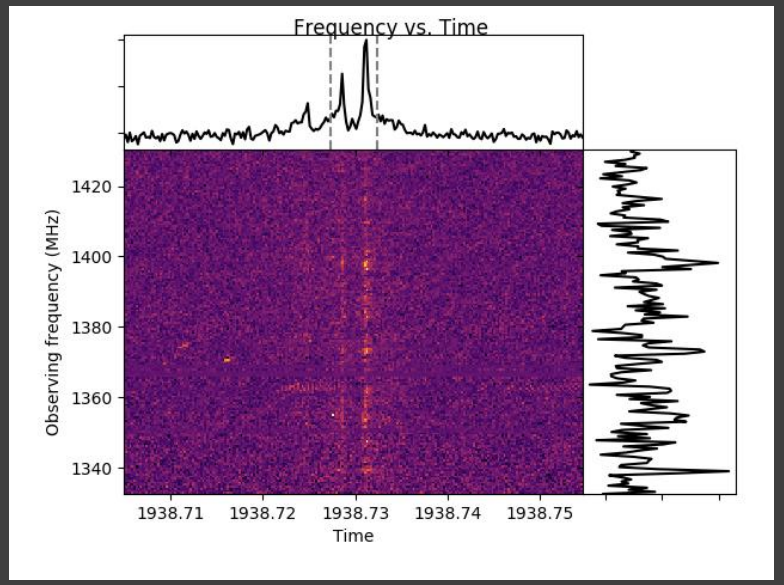
- **Swift/UVOT analysis on-going**

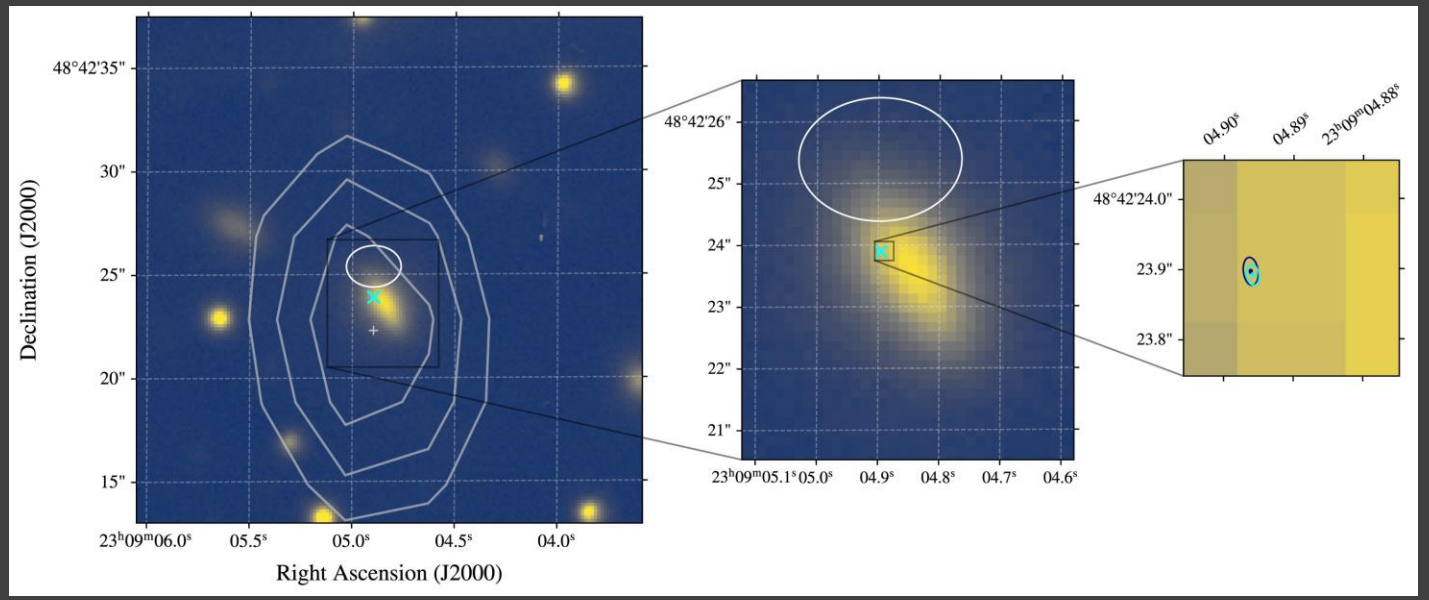
Continuing the campaign?

Other possible strategies: studies outside the activity phase



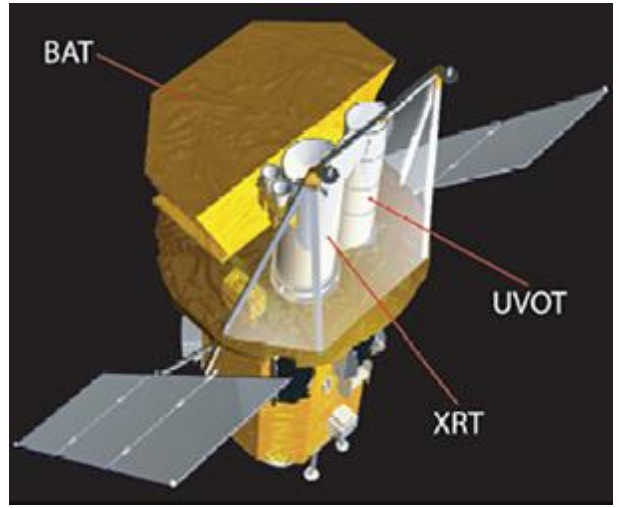






..and FRB20220912A: highly active source

AGILE and FRBs: FRB20220912A MW campaign

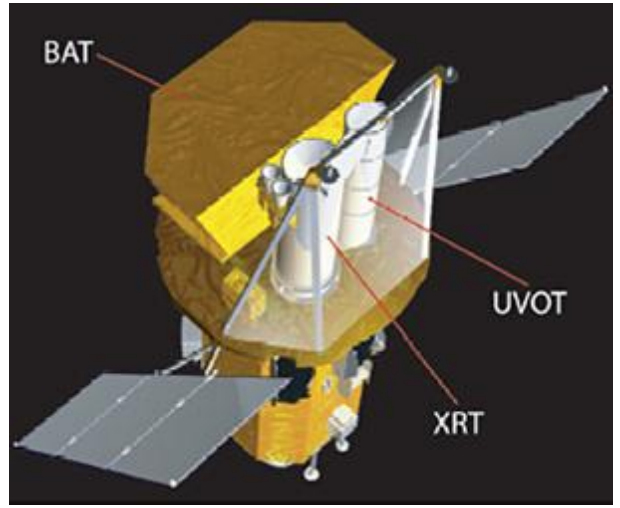


- An high activity FRB discovered in 2022: no periodicity but high rate reported and good localization for a nearby source, $DM_{exc} < 100$ pc cm^{-3}
- Burst rate (~400 hr^{-1} at 1.4 GHz) much higher than other sources
- Burst detected by NC
- Due to high burst rate Swift ToO similar to FRB20180916B, for transient emission, were accepted supposing higher probability of burst exposure
  - 4 WT mode (ours) and 3 PC mode approved Swift ToO
  - Data covering from Ocy. 03, 2020 to Sep. 23, 2023: for a total about 62 ks
- Preliminary results on XRT and UVOT data extracted
- No detected emission ->Flux Uls first published in ATel #16221 in Sep. 2023
- No more active since then

=>Final results: reprocessed last version of XRT data, and included in Pelliciari et al 2023

2023-10-01 21:57:00	2023-10-01 22:27:00	15380	42	FRB20220912A	WT	0x01bc	90	1800	1655
2023-10-02 21:33:00	2023-10-02 22:03:00	15380	43	FRB20220912A	WT	0x01bc	90	1800	1655
2023-10-03 21:29:00	2023-10-03 21:59:00	15380	44	FRB20220912A	WT	0x01bc	90	1800	1665
2023-10-04 21:15:00	2023-10-04 21:45:00	15380	45	FRB20220912A	WT	0x01bc	90	1800	1665
2023-10-05 21:06:00	2023-10-05 21:31:00	15380	46	FRB20220912A	WT	0x01bc	90	1500	1345
						Total:		70,800	62,620

AGILE and FRBs: FRB20220912A MW campaign



- An high activity FRB discovered in 2022: no periodicity but high rate reported and good localization for a nearby source, $DM_{exc} < 100$ pc cm^{-3}
- Burst rate (~400 hr^{-1} at 1.4 GHz) much higher than other sources
- Burst detected by NC
- Due to high burst rate Swift ToO similar to FRB20180916B, for transient emission, were accepted supposing higher probability of burst exposure
  - 4 WT mode (ours) and 3 PC mode approved Swift ToO
  - Data covering from Oct. 03, 2020 to Sep. 23, 2023: for a total about 62 ks
- Preliminary results on XRT and UVOT data extracted
- No detected emission ->Flux Uls first published in ATel #16221 in Sep. 2023
- No more active since then

=>Final results: reprocessed last version of XRT data, and included in Pelliciari et al 2023

2023-10-01 21:57:00	2023-10-01 22:27:00	15380	42	FRB20220912A	WT	0x01bc	90	1800	1655
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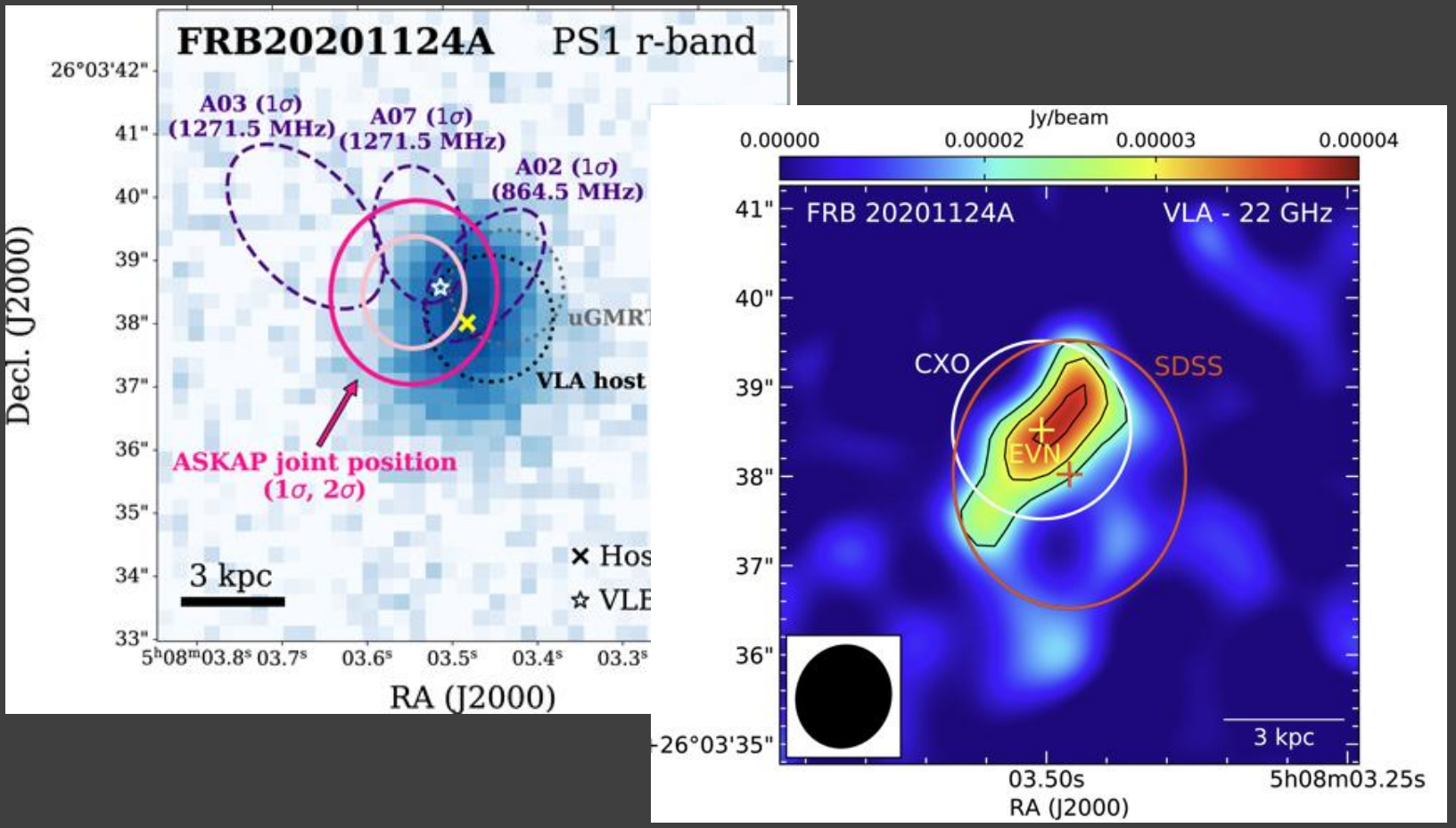
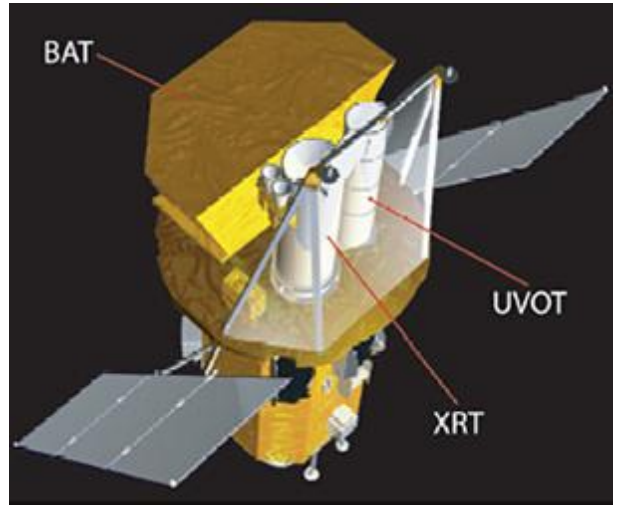
2023-10-04 21:15:00	2023-10-04 21:45:00	15380	45	FRB20220912A	WT	0x01bc	90	1800	1665
2023-10-05 21:06:00	2023-10-05 21:31:00	15380	46	FRB20220912A	WT	0x01bc	90	1500	1345
						Total:		70,800	62,620



..and FRB20201124A: persistent radio and X-ray emission

AGILE and FRBs: FRB20240114A MW campaign

- A VERY high activity FRB discovered in 2024: no periodicity but high rate reported and good localization for a nearby source, $DM_{exc} < 100$ pc cm^{-3}
- Burst rate (~400 hr^{-1} at 1.4 GHz) stil higher than previous source
- Burst detected by NC
- Again, due to high burst rate, Swift ToO similar to FRB20180916B, for transient emission, were accepted
  - 2 WT mode (ours) and 1 PC mode approved Swift ToO
  - Data covering from May. 07, 2024 to Jul. 31, 2024: for a total about 15 ks
- Preliminary results on XRT and UVOT data extracted
- No detected emission ->Flux ULs first published in ATel #16645 in Sep. 2024
- Also this source no more active since then



2024-06-20 14:48:00	2024-06-20 15:09:00	16629	11	FRB 20240114A	PC	0x011e	88	1260	1095
2024-07-28 00:09:00	2024-07-28 02:15:00	16629	13	FRB 20240114A	WT	0x015c	90	1980	1600
2024-07-29 06:23:00	2024-07-29 11:26:00	16629	14	FRB 20240114A	WT	0x015c	70	1920	1675
2024-07-30 09:15:00	2024-07-30 23:42:00	16629	15	FRB 20240114A	WT	0x015c	70	1920	795
2024-07-31 08:54:00	2024-07-31 21:31:00	16629	16	FRB 20240114A	WT	0x015c	70	1800	980
						Total:		19,800	14,647

Showing 1 to 14 of 14 entries

THE AGILE LEGACY

With AGILE in-orbit operational phase end, January 14th 2024, the acquisition of data is closed but a new phase of scientific work on the satellite legacy data archive opens.

AGILE archives and catalogs following VO standards and FAIR principles are available to the community through the ASI SSDC.
Science activities continue. All AGILE-GRID data **up to January 15, 2024 have been published. A data reprocessing is in progress.**

Work in progress on new AGILE catalogs with and without **Machine Learning** techniques, and of course on FRB sources.

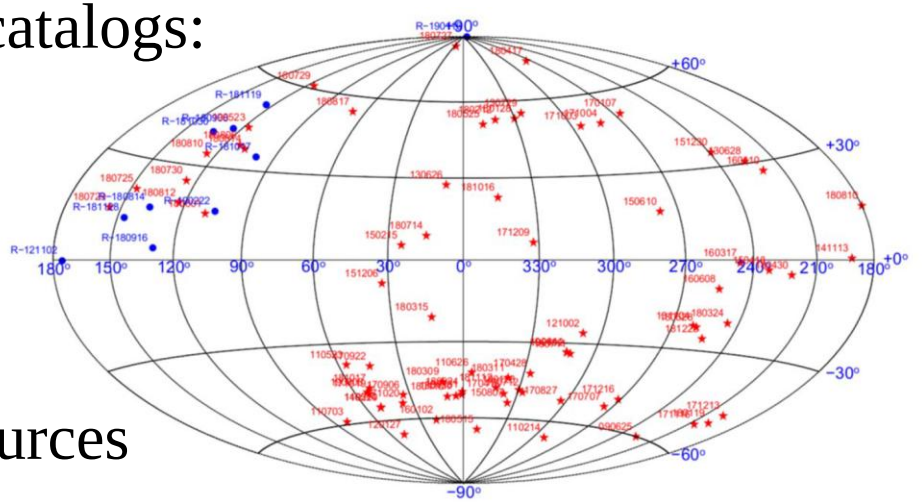
→the more recent example is Casentini et al. 2025, more later

=>moreover, we will continue the MW campaigns using data from other space missions, for instance the case of FRB20201124A

AGILE and FRBs: works on a sample

From **Verrecchia et al. 2021**: search for HE counterpart in the AGILE 13 years archive from a sample including mainly one-off sources from the update catalogs:

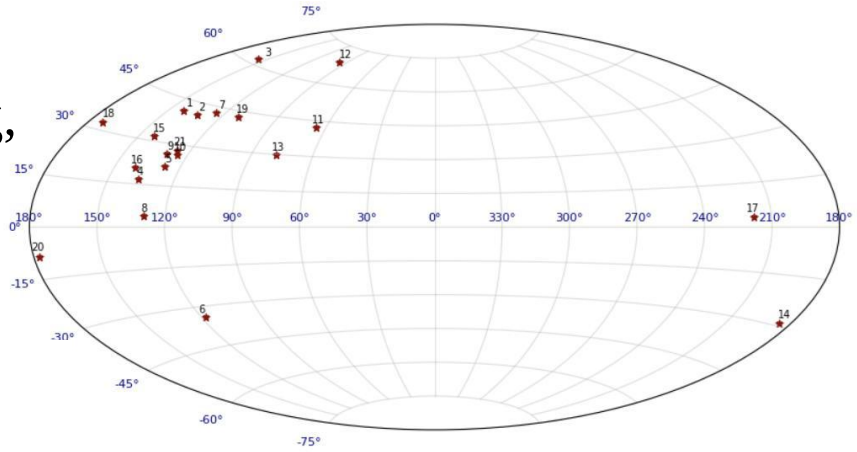
89 sources included, 10 R-FRB , FRBCAT and CHIME/FRB online databases; focus on a sample of one-off sources, but also considered nearer R-FRB sources;



To **Casentini et al. 2025**: search for HE counterpart in the AGILE 17 years archive from a sample including R-FRB sources only from updated catalogs:

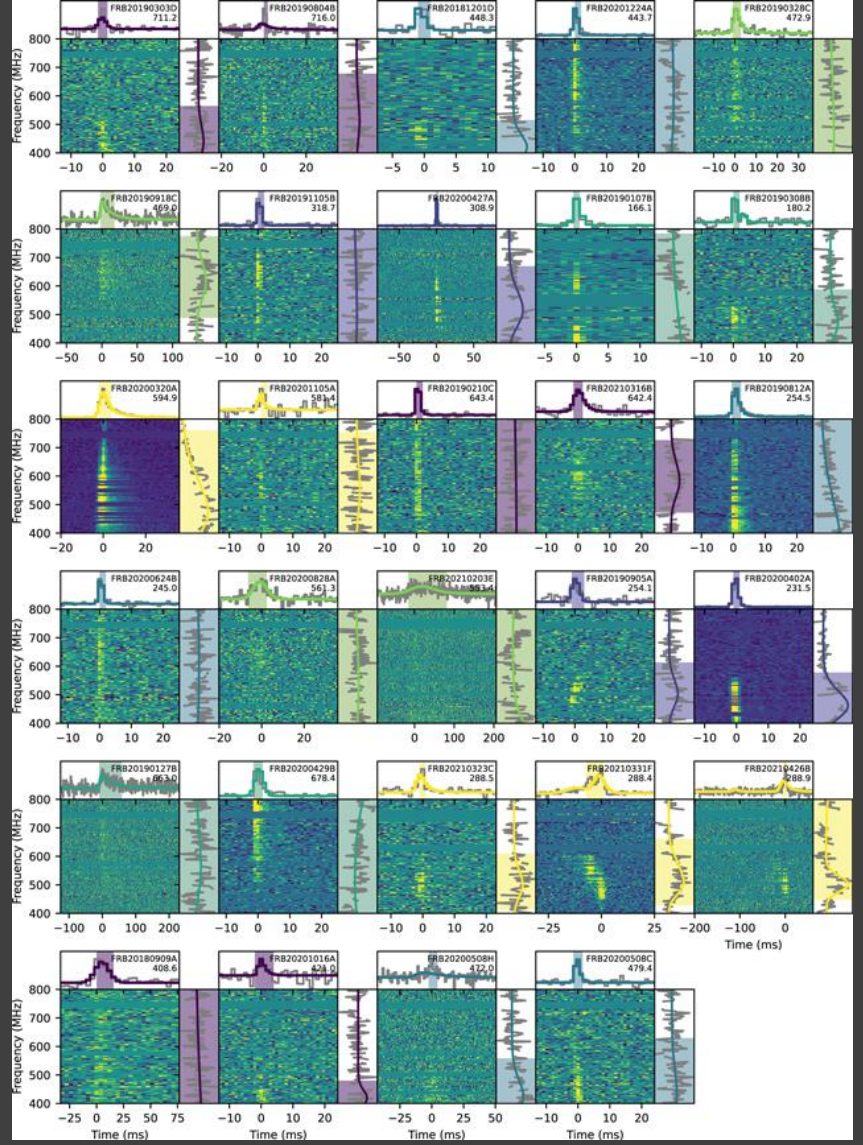
21 R-FRB sources included, mainly from Blinkverse, CHIME/FRB, TNS online databases and those discovered by Italian radiotelescopes (SRT, NC)

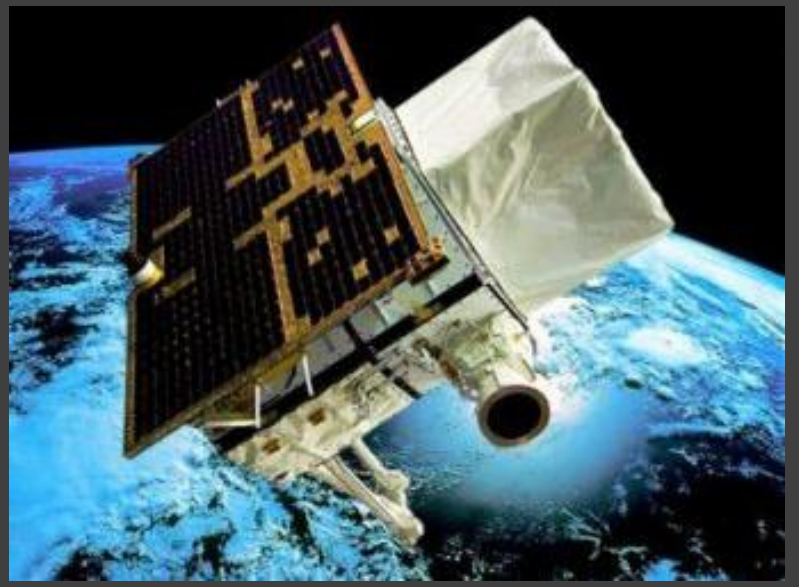
- **Improved pipeline for MCAL ULs**, applying CPL spectral modeling, and GRID analysis on larger dataset
- use of SuperAGILE data
- Comparison of ULs with various magnetar bursts and with results of other missions



Claudio's next talk!

BACKUP SLIDES





AGILE MW campaigns for FRB High Energy counterparts search

May 7, 2025

Verrecchia F., Casentini C., Tavani M.