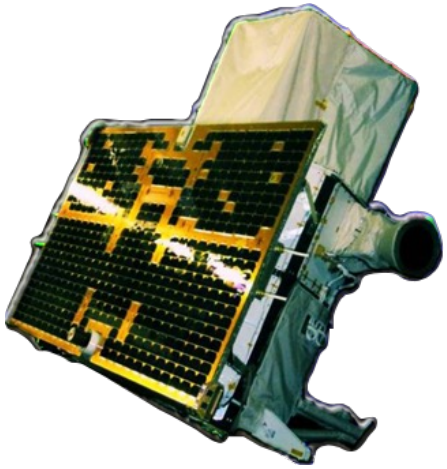


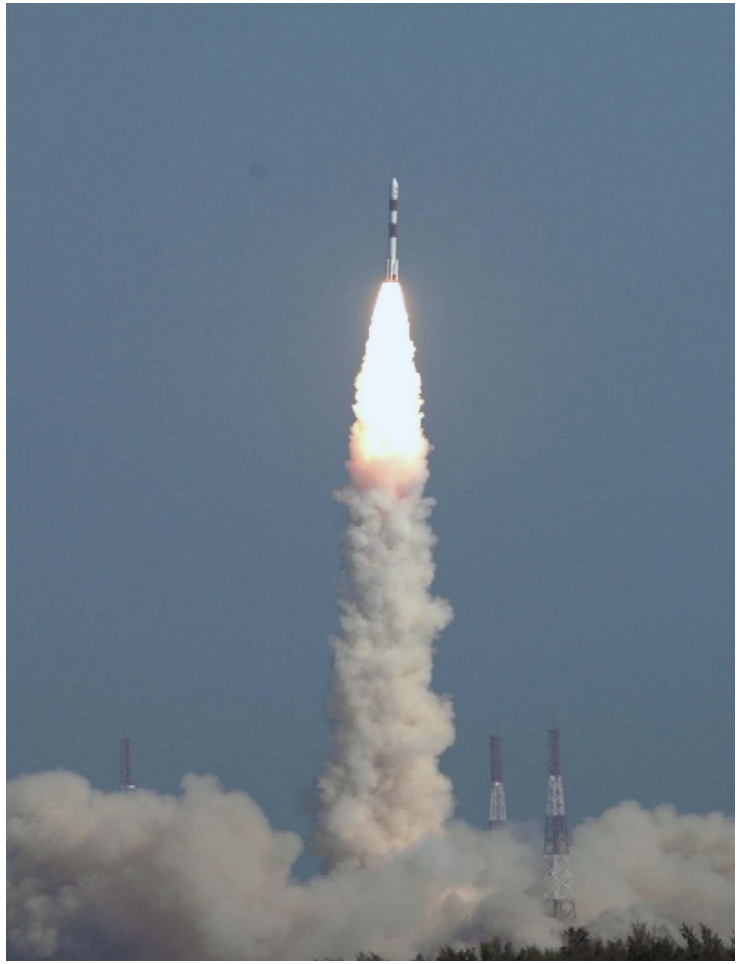
AGILE legacy

Carlotta Pittori
INAF-OAR and ASI-SSDC
on behalf of the AGILE Team

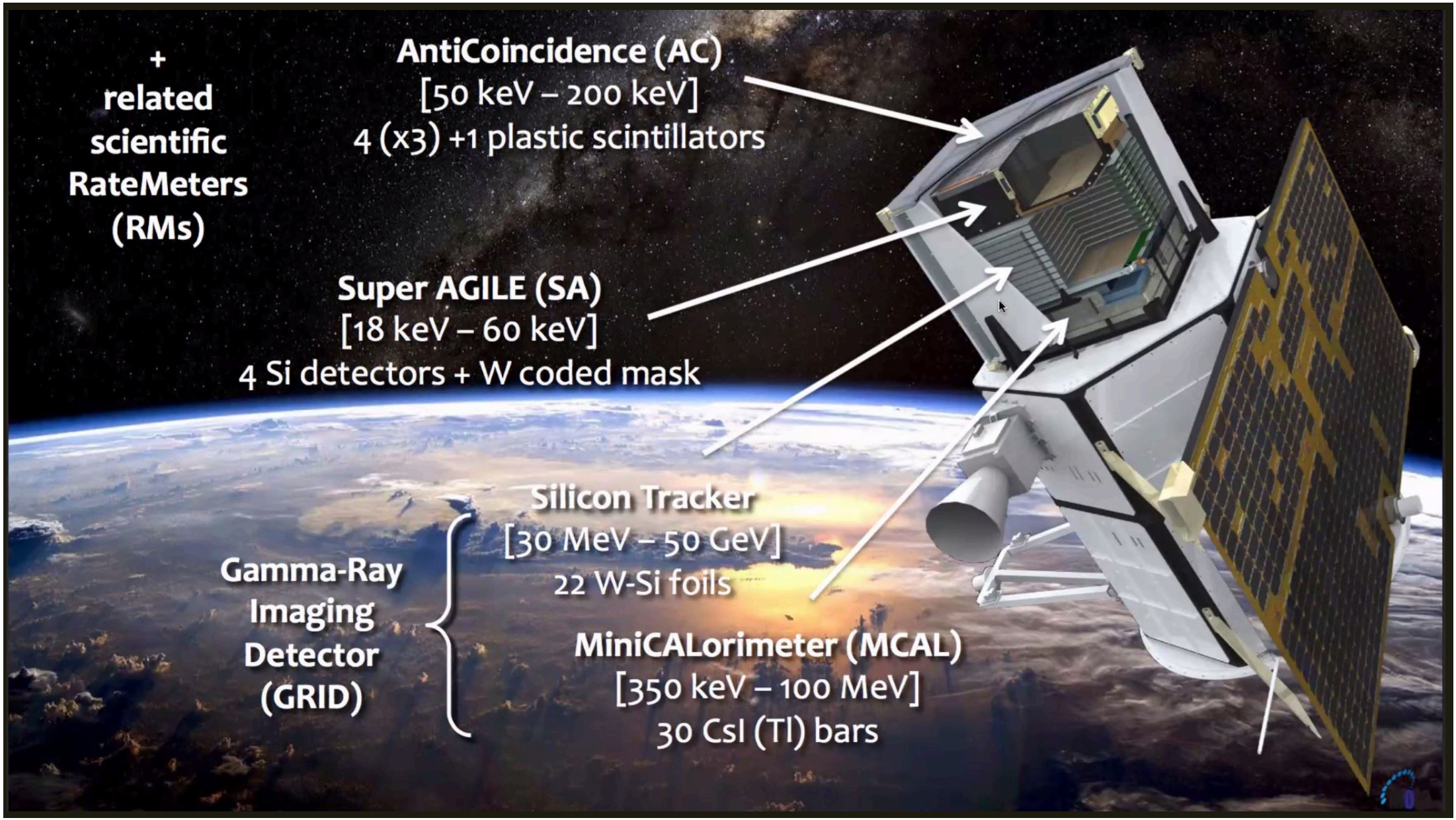
XIX Vulcano Workshop on Frontier Objects in Astrophysics and Particle Physics, May 26th - June 1st, 2024 - Ischia Island, Italy

India April 23, 2007: AGILE satellite launch

Low Earth equatorial orbit: 550 Km and < 3 deg inclination angle



Italian Space Agency (ASI) Mission with INFN, INAF participation


+
related
scientific
RateMeters
(RMs)
AntiCoincidence (AC)
[50 keV – 200 keV]
4 (x3) +1 plastic scintillators
Super AGILE (SA)
[18 keV – 60 keV]
4 Si detectors + W coded mask
Gamma-Ray
Imaging
Detector
(GRID)
Silicon Tracker
[30 MeV – 50 GeV]
22 W-Si foils
MiniCALorimeter (MCAL)
[350 keV – 100 MeV]
30 CsI (Tl) bars

AGILE: 16 years and 10 months of operations in space

- Gamma-ray detector (GRID): 50 MeV - 1 GeV
- Minicalorimeter (MCAL): 400 keV-100 MeV
- Super-AGILE X-ray detector: 18-60 keV
- Anticoincidence System (AC): 80-200 keV

Science observations ended on 18 January, 2024

Satellite re-entry: 13 February, 2024! 😩

Fully operational, payload in nominal status till the end, active in:

- gamma-ray astrophysics
- terrestrial atmosph. & magnetosph. physics
- search of GW counterparts, neutrinos, Fast Radio Bursts, Solar flares and other transients

SATFLARE

33387 Registered Users | Chat 4 | Join the observer community (Register/Login)

Time Control

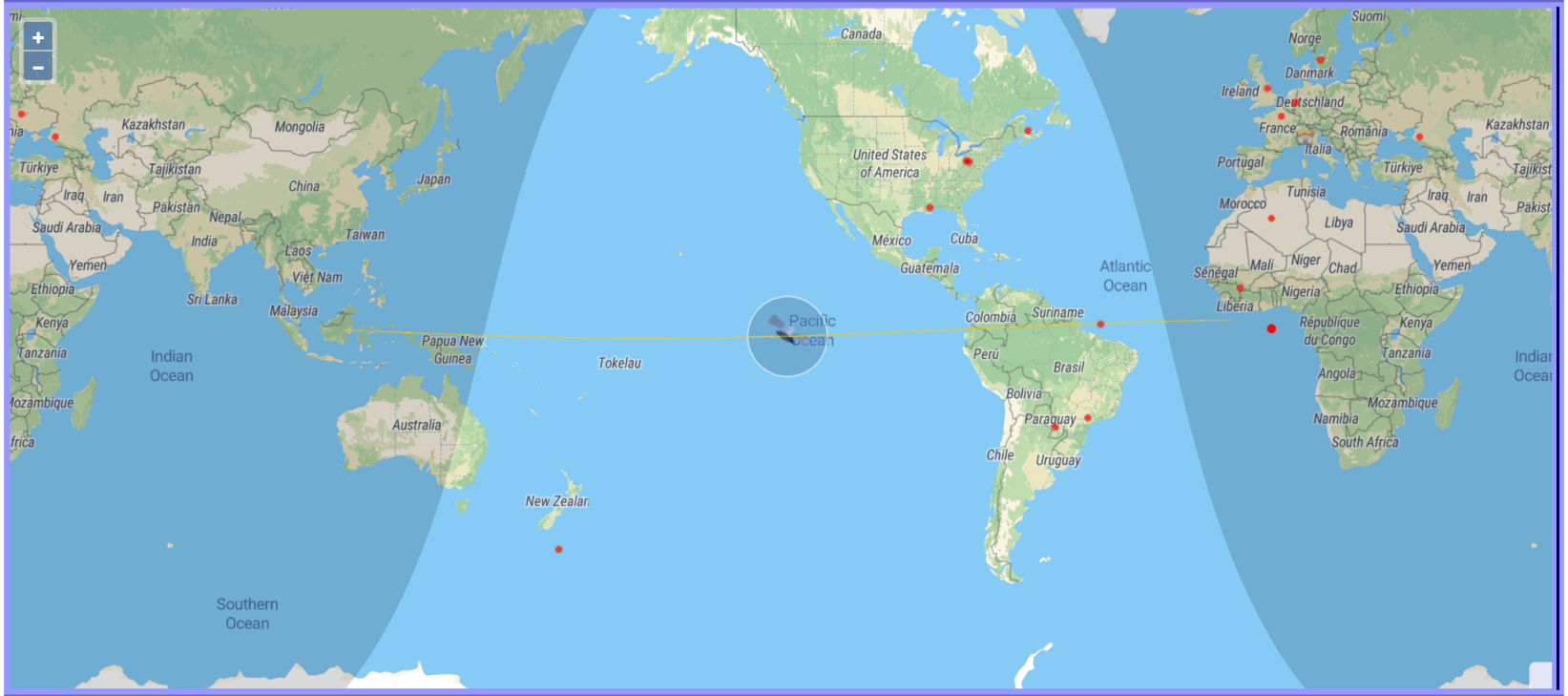
H+	M+	S+
H-	M-	S-
--	<0>	++
TTS	II	▶

AGILE (PROP. TO DECAY) (24044.784: 1 hour 14 min)

Add | Remove | Manage list

WARNING: This object has decayed on Tue, 13/02/2024 UTC. When plotted, the yellow track shows the re-enter window.

TIME	Tue, 13/02/2024 21:04:00	Latitude [deg]	-1.92	Altitude [km]	109.1	DEC J2000 [d:m:s]	-24:57:20	Sun El.[deg]	-34.9 (Deep Night)
(UTC)	Tue, 13/02/2024 20:04:00	Longitude [deg]	-127.42	Azimuth [deg]	305.9	RA J2000 [h:m:s]	19:56:08	Loaded SAT :	1
Time Off.	-64h 47m 50s (Past)	2460354.33611	JD	Elevation [deg]	-60.8	Magnitude	below horizon	Observer	(registered) 33387



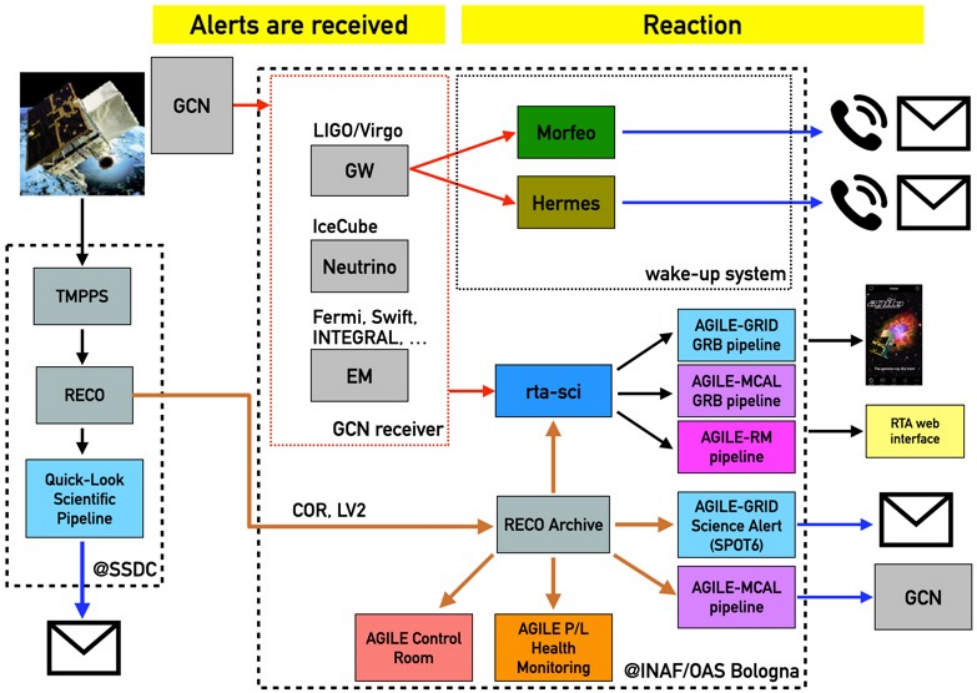
Visual SAT-Flare Tracker 3D - Online - SatFlare.com (c) All rights reserved.

☑ Lock on satellite ☑ Process only the selected satellite ☐ Hide Obs/board ☐ Clouds

Observer: Milan, Lat 45.4643°, Lon 9.1885°

AGILE main results
and work in progress

AGILE Fast Real-Time Analysis



- Distributed alert system between SSDC e INAF-OAS Bologna
- Automatic AGILE data analysis (GRID, MCAL, Ratemeters)
- **Fast reaction to external alerts** (GCN, e.g. GRB, neutrinos, GW, ...)
- **Internal automatic alert generation** (via email, SMS) and direct connection with the GCN network for MCAL notices.
- Development of similar pipelines starting from the **AGILE heritage for new missions** such as COSI, Gamma-FLASH and **CTAO**

- Parmiggiani, N. et. al.: "The RTApipe framework for the gamma-ray real-time analysis software development", A&C 2022 https://doi.org/10.1016/j.ascom.2022.100570
- Parmiggiani, N. et. al.: "The AGILE real-time analysis software system to detect short-transient events in the multi-messenger era", A&C 2023, https://doi.org/10.1016/j.ascom.2023.100726

Summary of AGILE results in >16 years of operations

- **Publications:** the scientific production of the AGILE Team consists of**> 800 bibliographic references in ADS, of which> 160 refereed articles.**
- The monitoring of the sky with a rapid and efficient alert system led to the publication of **>240 ATels** and **>300 GCNs**. From May 2019, **101 MCAL GCN automatic notices** have been published.

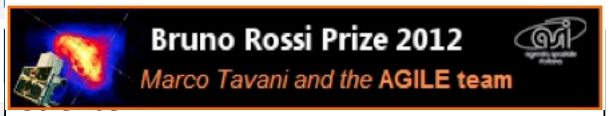
- The Quick Look system developed by INAF-OAS, distributed between the data center at SSDC and INAF-OAS in Bologna, produced **scientific results within ~ 25 min** from the data downlink to the ASI Malindi ground station: an absolute record for gamma astrophysics. The Team has also developed **AGILEScience - App on Google Play and App Store** to monitor and follow the observations of the AGILE satellite on mobile devices.

- **AGILE and the search for GW counterparts:** participation of Team members with shifts 24/7 during LIGO-VIRGO observational runs. AGILE follow-up of all **pre-O4 GW events**, with **96 GW-AGILE type GCNs published during O3** and collected in a dedicated web page in SSDC**:** *https://agile.ssdc.asi.it/news_gw.html*
  AGILE completed the follow-up of all GW events **up to the end of LVK O4a (first part) on Jan 16, 2024**.

- AGILE contribution to **Fast Radio Bursts** science: **very important discovery** on April 28, 2020 published in **Nature, Tavani et al. 2021** (2021NatAs...5..401T)

Main AGILE-led publications in descending order of citation in ADS

Therefore, neither important MW and MM publications nor the most recent ones are included in this list

#	DOI	Descrizione	
1	10.1051/0004-6361/200810527	Titolo: The AGILE Mission Autori:M. Tavani and G. Barbiellini and A. Argan and F. Boffelli and A. Bulgarelli and P. Caraveo and P. W .... Publisher:EDP Sciences Rivista: Astronomy \& Astrophysics Anno pubblicazione:2009	The AGILE Mission
2	10.1126/science.1200083	Titolo: Discovery of Powerful Gamma-Ray Flares from the Crab Nebula Autori:M. Tavani and A. Bulgarelli and V. Vittorini and A. Pellizzoni and E. Striani and P. Caraveo and M. .... Publisher:American Association for the Advancement of Science (AAAS) Rivista: Science Anno pubblicazione:2011	
3	10.1038/nature08578	Titolo: Extreme particle acceleration in the microquasar Cygnus\hspace0.167emX-3 Autori:M. Tavani and A. Bulgarelli and G. Piano and S. Sabatini and E. Striani and Y. Evangelista and A. T .... Publisher:Springer Science and Business Media LLC Rivista: Nature Anno pubblicazione:2009	Cyg X-3 mQSO flares, *Nature*
4	10.1088/2041-8205/742/2/L30	Titolo: NEUTRAL PION EMISSION FROM ACCELERATED PROTONS IN THE SUPERNOVA REMNANT W44 Autori:A. Giuliani and M. Cardillo and M. Tavani and Y. Fukui and S. Yoshiike and K. Torii and G. Dubner a .... Publisher:American Astronomical Society Rivista: The Astrophysical Journal Anno pubblicazione:2011	CR acceleration in SNR W44
5	10.1103/PhysRevLett.106.018501	Titolo: Terrestrial Gamma-Ray Flashes as Powerful Particle Accelerators Autori:M. Tavani and M. Marisaldi and C. Labanti and F. Fuschino and A. Argan and A. Trois and P. Giommi a .... Publisher:American Physical Society (APS) Rivista: Physical Review Letters Anno pubblicazione:2011	TGFs as powerful p.cle accelerators
6	10.1029/2009JA014502	Titolo: Detection of terrestrial gamma ray flashes up to 40 MeV by the AGILE satellite Autori:M. Marisaldi and F. Fuschino and C. Labanti and M. Galli and F. Longo and E. Del Monte and G. Barbi .... Publisher:American Geophysical Union (AGU) Rivista: Journal of Geophysical Research: Space Physics Anno pubblicazione:2010	HE TGFs seen by AGILE-MCAL
7	10.1016/j.nima.2007.07.147	Titolo: SuperAGILE: The hard X-ray imager for the AGILE space mission Autori:M. Feroci and E. Costa and P. Soffitta and E. Del Monte and G. Di Persio and I. Donnarumma and Y. E .... Publisher:Elsevier BV Rivista: Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment Anno pubblicazione:2007	SuperAGILE X-ray Imager on AGILE
8	10.1051/0004-6361/200911783	Titolo: First AGILE catalog of high-confidence gamma-ray sources Autori:C. Pittori and F. Verrecchia and A. W. Chen and A. Bulgarelli and A. Pellizzoni and A. Giuliani and .... Publisher:EDP Sciences Rivista: Astronomy \& Astrophysics Anno pubblicazione:2009	The 1AGL Catalog
9	10.1088/2041-8205/710/2/L151	Titolo: DIRECT EVIDENCE FOR HADRONIC COSMIC-RAY ACCELERATION IN THE SUPERNOVA REMNANT IC 443 Autori:M. Tavani and A. Giuliani and A. W. Chen and A. Argan and G. Barbiellini and A. Bulgarelli and P. C .... Publisher:American Astronomical Society Rivista: The Astrophysical Journal Anno pubblicazione:2010	CR acceleration in SNR IC443
10	10.1088/0004-637X/691/1/L13	Titolo: THE JUNE 2008 FLARE OF MARKARIAN 421 FROM OPTICAL TO TeV ENERGIES Autori:I. Donnarumma and V. Vittorini and S. Vercellone and E. Del Monte and M. Feroci and F. D\textquote .... Publisher:American Astronomical Society Rivista: The Astrophysical Journal Anno pubblicazione:2008	MWL analysis of flaring blazar Mrk 421

Three of the most important AGILE discoveries:

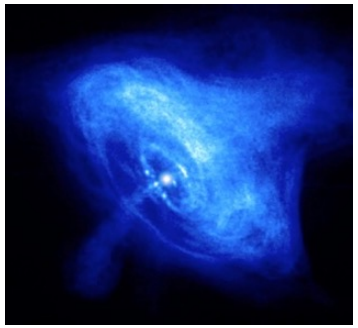
- **Discovery of a new acceleration mechanism inducing intense and rapid flux variations in the Crab Nebula in the energy band above 100 millions of elettronvolt!**

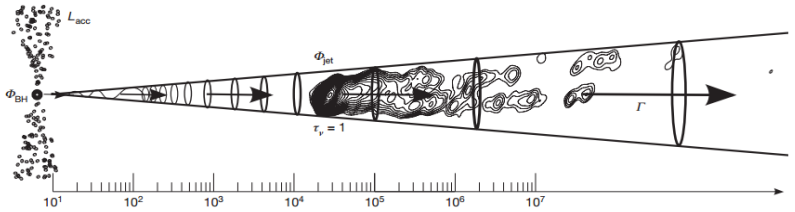
- **First direct evidence of cosmic ray acceleration in Supernovae remnants with the AGILE observations of the SNR W44 (2017 Matteucci Medal of the National Academy of Sciences to Marco Tavani).**

- **Direct evidence that extreme particle acceleration and non-thermalized emission above 100 MeV can occur in microquasars (Cyg X-3 and Cyg X-1) with a repetitive pattern.**

AGILE scientific lessons:

- **Large Field of View (~ 60 deg) HE sky monitoring: fast and intense variability discovered at all scales.**
- **Extragalactic, Galactic and even Terrestrial physics**
- **New acceleration mechanisms**
- **Role of local magnetic field enhancements**
- **Plasma instabilities**





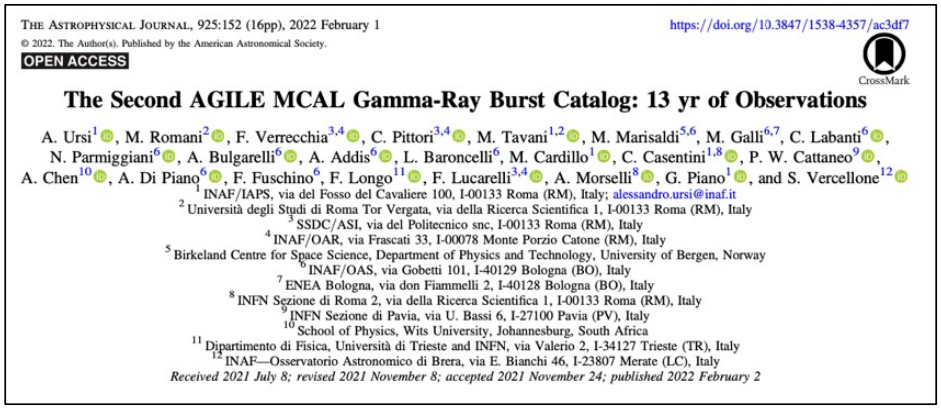
- ***Review: "The AGILE Mission and Its Scientific Results",*** M. Tavani, C. Pittori and F. Longo (2023), **Handbook of X-ray and Gamma-ray Astrophysics** *https://link.springer.com/referenceworkentry/10.1007/978-981-16-4544-0_57-1*

- ***Review: "Scientific Highlights of the AGILE Gamma-ray Mission***", S. Vercellone, C. Pittori and M. Tavani (2024), ***Universe*** *https://doi.org/10.3390/universe10040153*

Updates on AGILE and GRBs

AGILE MCAL second GRB catalog

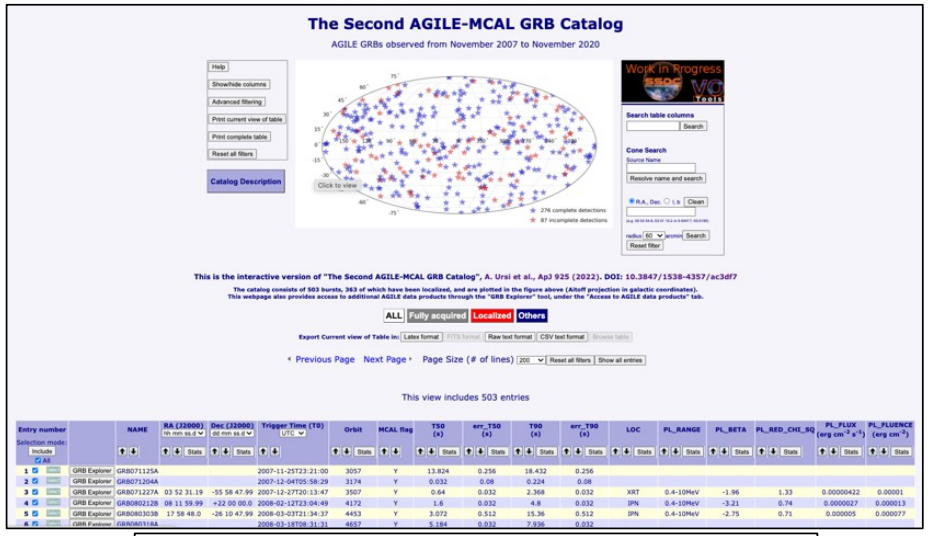
- Comprehensive catalog of all GRB detected by MCAL from 2007 to 2020 (*Ursi et al., ApJ 925, 2022*)



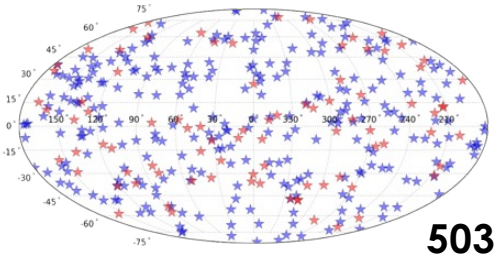
The Astrophysical Journal, 925:152 (16pp), 2022 February 1 https://doi.org/10.3847/1538-4357/ac3df7

The Second AGILE MCAL Gamma-Ray Burst Catalog: 13 yr of Observations

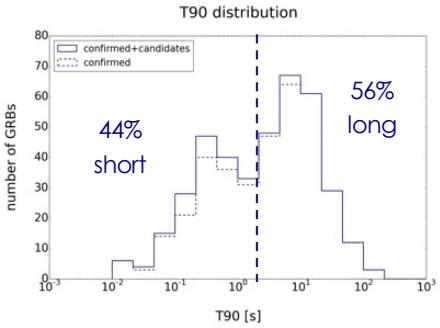
A. Ursi[1], M. Romani[2], F. Verrecchia[3,4], C. Pittori[3,4], M. Tavani[1,2], M. Marisaldi[5,6], M. Galli[6,7], C. Labanti[6], N. Parmiggiani[6], A. Bulgarelli[6], A. Addis[6], L. Baroncelli[6], M. Cardillo[1], C. Casentini[1,8], P. W. Cattaneo[9], A. Chen[10], A. Di Piano[6], F. Fuschino[6], F. Longo[11], F. Lucarelli[3,4], A. Morselli[8], G. Piano[1], and S. Vercellone[12]
[1] INAF/IAPS, via del Fosso del Cavaliere 100, I-00133 Roma (RM), Italy; alessandro.ursi@inaf.it
[2] Università degli Studi di Roma Tor Vergata, via della Ricerca Scientifica 1, I-00133 Roma (RM), Italy
[3] SSDC/ASI, via del Politecnico snc, I-00133 Roma (RM), Italy
[4] INAF/OAR, via Frascati 33, I-00078 Monte Porzio Catone (RM), Italy
[5] Birkeland Centre for Space Science, Department of Physics and Technology, University of Bergen, Norway
[6] INAF/OAS, via Gobetti 101, I-40129 Bologna (BO), Italy
[7] ENEA Bologna, via don Fiammelli 2, I-40128 Bologna (BO), Italy
[8] INFN Sezione di Roma 2, via della Ricerca Scientifica 1, I-00133 Roma (RM), Italy
[9] INFN Sezione di Pavia, via U. Bassi 6, I-27100 Pavia (PV), Italy
[10] School of Physics, Wits University, Johannesburg, South Africa
[11] Dipartimento di Fisica, Università di Trieste and INFN, via Valerio 2, I-34127 Trieste (TR), Italy
[12] INAF—Osservatorio Astronomico di Brera, via E. Bianchi 46, I-23807 Merate (LC), Italy
Received 2021 July 8; revised 2021 November 8; accepted 2021 November 24; published 2022 February 2

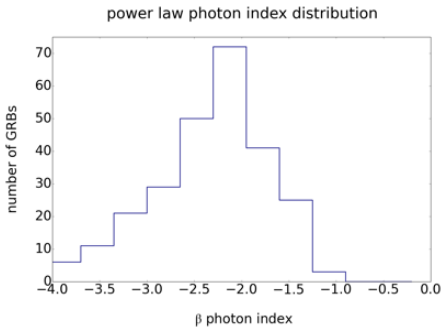


SSDC interactive web page
https://www.ssdc.asi.it/mcal2grbcat/



503 GRBs



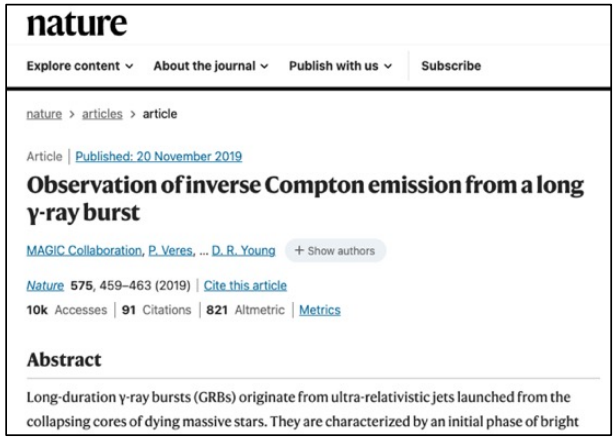


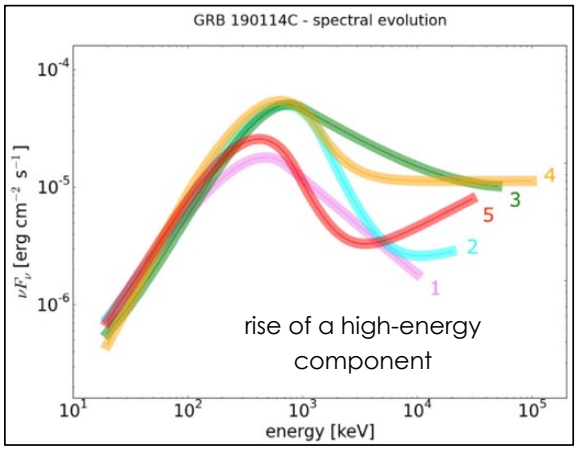
Spectra mostly fittable with power-laws (high-energy tail of the spectra in MCAL band)

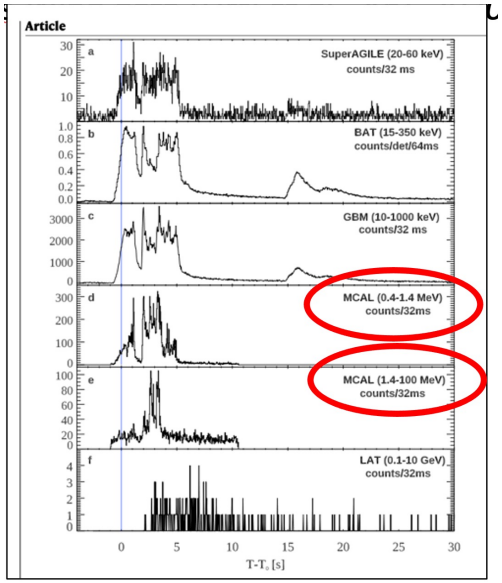
GRB 190114C: First GRB event detected at very high-energies by MAGIC!!

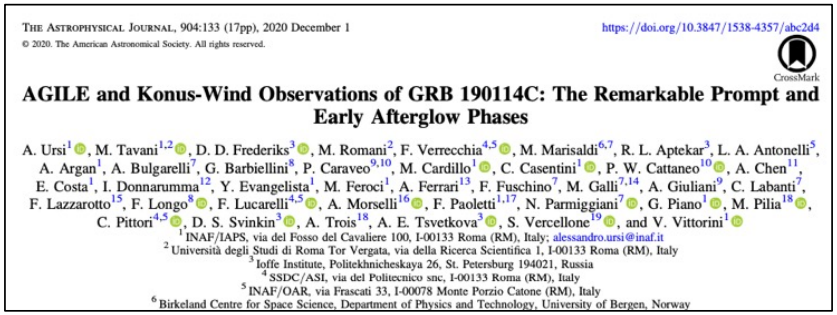
The AGILE contribution:

- participation to the multi-frequency paper [*MAGIC Collaboration, Nature, 2019*]
- Dedicated analysis of the prompt phase with AGILE and Konus-Wind data [*Ursi et al., ApJ, 2020*]









New Year's Burst GRB 220101A

Event with the highest E_{iso} ever detected up to Jan 2022

- analysis of the prompt phase using AGILE ratemeters data [*Ursi et al., ApJ, 2022d*]

The Astrophysical Journal, 933:214 (12pp), 2022 July 10 https://doi.org/10.3847/1538-4357/ac746c

OPEN ACCESS

AGILE Observations of GRB 220101A: A "New Year's Burst" with an Exceptionally Huge Energy Release

https://orcid.org/0000-0002-9332-5319

A. Ursi[1], M. Romani[2], G. Piano[1], F. Verrecchia[3,4], F. Longo[5], C. Pittori[3,4], M. Tavani[1,6], A. Bulgarelli[7], M. Cardillo[1], C. Casentini[1,8], P. W. Cattaneo[9], E. Costa[1], M. Feroci[1], V. Fioretti[7], L. Foffano[1], F. Lucarelli[3,4], M. Marisaldi[7,10], A. Morselli[8], L. Pacciani[1], N. Parmiggiani[7], P. Tempesta[11], A. Trois[12], and S. Vercellone[13]

[1] INAF/IAPS, via del Fosso del Cavaliere 100, I-00133 Roma (RM), Italy; alessandro.ursi@inaf.it
[2] Osservatorio Astronomico di Brera, Via Brera 28, I-20121 Milano (MI), Italy
[3] SSDC/ASI, via del Politecnico snc, I-00133 Roma (RM), Italy
[4] INAF/OAR, via Frascati 33, I-00078 Monte Porzio Catone (RM), Italy
[5] Dipartimento di Fisica, Università di Trieste and INFN, via Valerio 2, I-34127 Trieste (TR), Italy
[6] Università degli Studi di Roma Tor Vergata, via della Ricerca Scientifica 1, I-00133 Roma (RM), Italy
[7] INAF/OAS, via Gobetti 101, I-40129 Bologna (BO), Italy
[8] INFN Sezione di Roma 2, via della Ricerca Scientifica 1, I-00133 Roma (RM), Italy
[9] INFN Sezione di Pavia, via U. Bassi 6, I-27100 Pavia (PV), Italy
[10] Birkeland Centre for Space Science, Department of Physics and Technology, University of Bergen, Norway
[11] Telespazio SpA, Centro Spaziale del Fucino 23, Piana del Fucino, Via Cintarella, I-67050, Ortucchio (AQ), Italy
[12] INAF—Osservatorio Astronomico di Cagliari, via della Scienza 5, I-09047 Selargius (CA), Italy
[13] INAF—Osservatorio Astronomico di Brera, via E. Bianchi 46, I-23807 Merate (LC), Italy

Received 2022 March 1; revised 2022 May 20; accepted 2022 May 27; published 2022 July 15

TRA LE COSTELLAZIONI DI PEGASO E DI ANDROMEDA

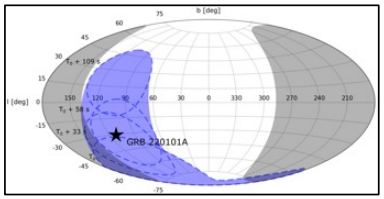
Capodanno col botto: visto un Grb da record

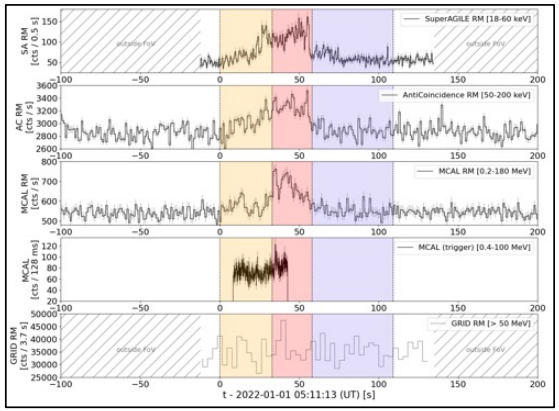
Ha viaggiato per oltre 12 miliardi di anni, è arrivato sulla Terra all'alba del primo gennaio ed è uno dei lampi di raggi gamma più potenti e lunghi mai registrati. Fra i primi strumenti al mondo a intercettarne e caratterizzarne il segnale, quelli a bordo del telescopio spaziale "made in Italy" Agile e quelli dei telescopi dell'Osservatorio di Asiago dell'Inaf di Padova. Na parliamo con due fra i protagonisti dell'osservazione, Alessandro Ursi e Lina Tomasella dell'Inaf

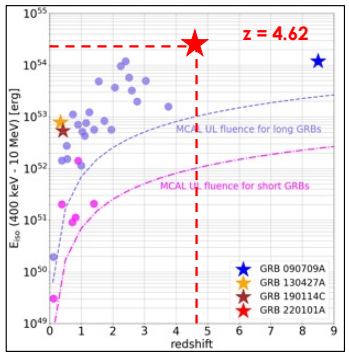
Marco Malaspina 03/01/2022 Tweet Condividi 1321

news on Media INAF

fully inside the AGILE FoV
for most of the duration
of the prompt phase



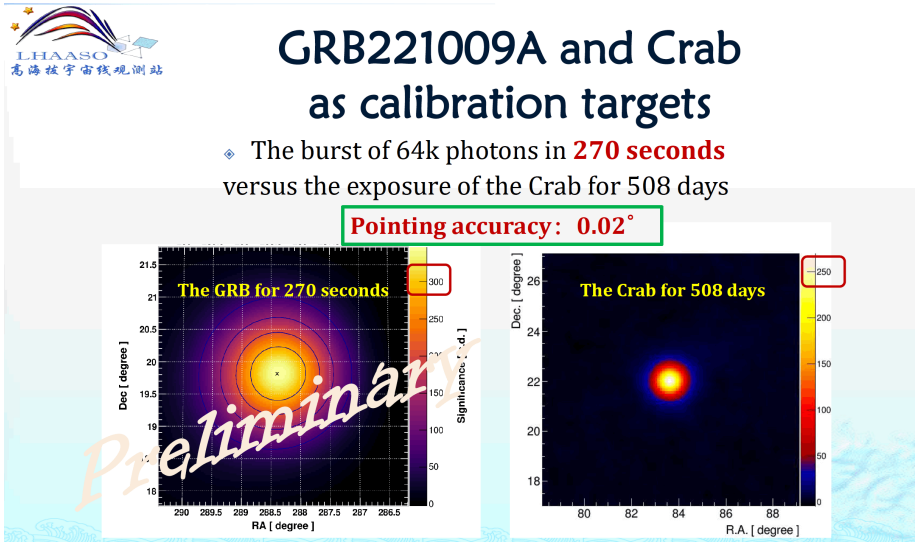




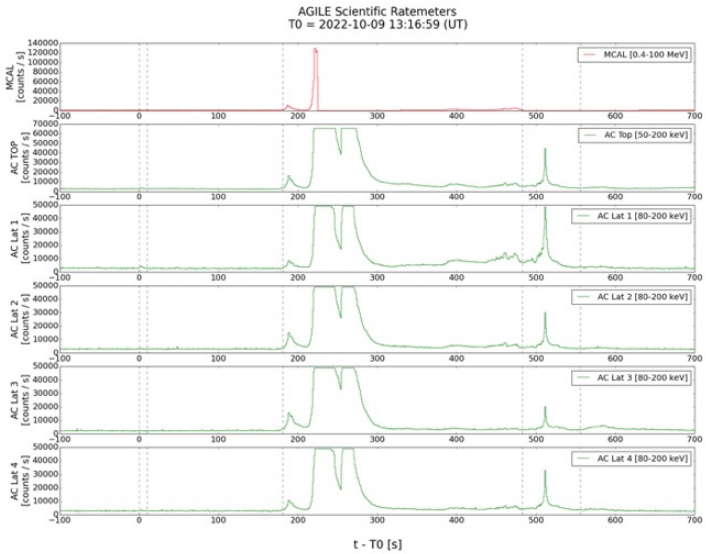
news on ASI website

Gamma-ray detection by AGILE of the exceptional GRB 221009A

The BOAT = Brightest Of All Time. Distance of 750 Mpc (z=0.15095)
LHAASO: first detection of photons **above 10 TeV** from GRBs (GCN #32677):



2022 October 9, T0 =13:16:59.00 UT



Saturated AGILE RM (GCN #32650)

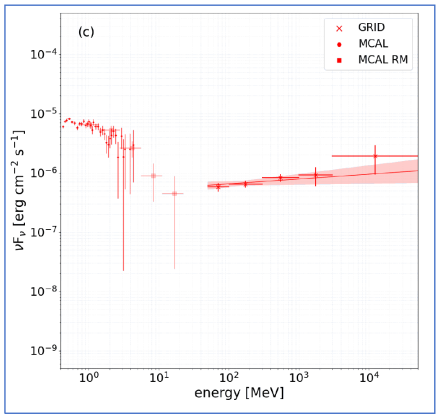
AGILE observations provide crucial flux and spectral gamma-ray information regarding the early phases of GRB 221009A during which emission in the TeV range was reported.

Transition between prompt and afterglow emission with a phase of coexistence of MeV and GeV emissions.
M. Tavani *et al.* 2023 *ApJL* 956 L23, *http://arxiv.org/abs/2309.10515*

Gamma-ray detection by AGILE of the exceptional GRB 221009A

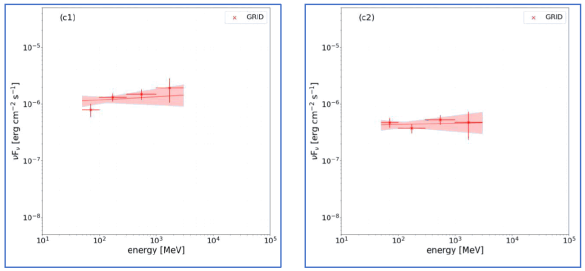
Spectral Analysis: Prompt + Early Afterglow

Tavani et al. (2023)

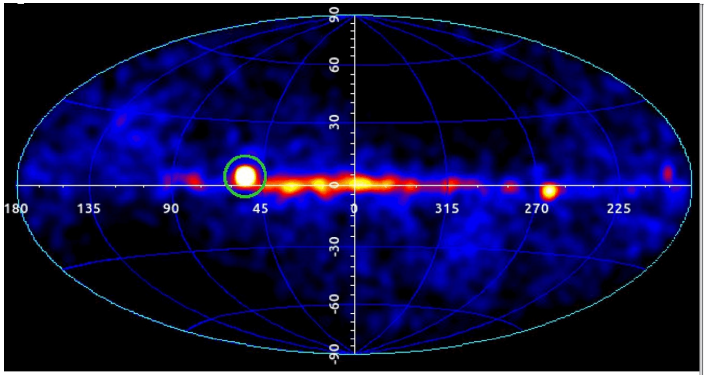


C) MAIN GAMMA EMISSION: 1st GRID WINDOW

- **Two different components coexist: peculiarity of GRB 221009 A**
- MCAL MeV emission: Prompt, Synchrotron
- GRID GeV emission: Early Afterglow, Inverse Compton



Time window	Time interval [s,s]	Energy range [GeV]	Detection Significance	Photon Index	Photon Flux [ph s^{-1} cm^{-2}]	Source counts
C	[273 ÷ 383]	[0.050 ÷ 50]	46.1 σ	1.92 ± 0.06	(8.4 ± 0.6) · 10^{-3}	206 ± 16
C1	[273 ÷ 303]	[0.050 ÷ 3]	32.7 σ	1.9 ± 0.1	(1.5 ± 0.2) · 10^{-2}	206 ± 16
C2	[303 ÷ 383]	[0.050 ÷ 3]	32.2 σ	2.0 ± 0.1	(5.4 ± 0.6) · 10^{-3}	206 ± 16



24h AGILE-GRID Intensity Map

Tavani et al. 2023,
Adapted from G. Panebianco

Transition between prompt and afterglow emission with a phase of coexistence of MeV and GeV emissions.

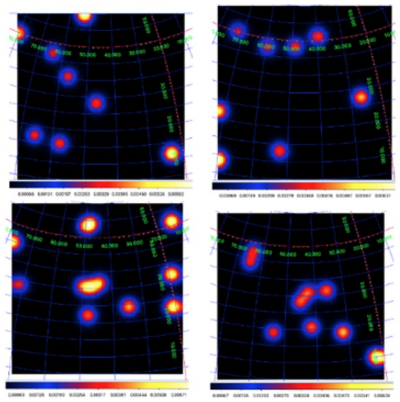
Maybe two different emitting regions:

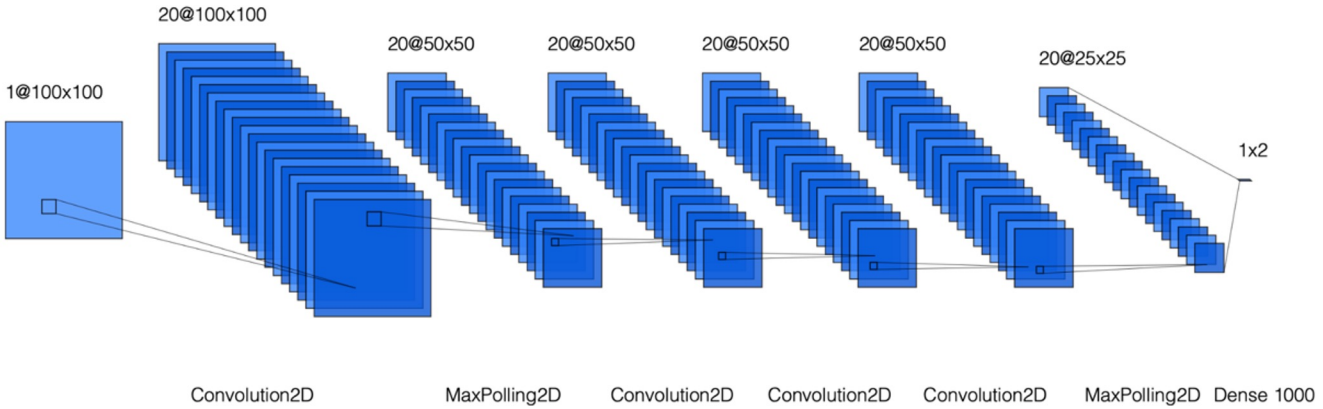
- An inner, probably optically thick region -> Synchrotron
- An optically thin, relativistically expanding region -> Inverse Compton

Deep Learning for AGILE GRB detection

INAF OAS BOLOGNA

- **Deep Learning technologies** to detect GRBs in the data (time series and sky maps) acquired by the detectors on board the AGILE space missions. **New phase of scientific work on the satellite legacy data archive in progress.**
- Convolutional Neural Network (CNN) to detect GRBs inside the AGILE Gamma-Ray Imaging Detector (GRID) counts maps when an external science alert is received.
- The CNN detected 21 GRBs in the AGILE/GRID data with a sigma > 3 from the list of GRBs obtained with Fermi and Swift catalogs outperforming the Li&Ma on the same list and with the same parameters:
  - Parmiggiani N., Bulgarelli A., Fioretti V. et al., "A Deep Learning Method for **AGILE/GRID Gamma-ray Bursts detection**", ApJ, 914, (2021)
- **Recent paper:** Parmiggiani N., Bulgarelli A., Fioretti V. et al., "A Deep-learning Anomaly-detection Method to Identify **Gamma-Ray Bursts in the Ratemeters of the AGILE Anticoincidence System**", ApJ, 945, (2023)
- In progress: GRB localization from GRID sky maps (Parmiggiani); A new DL Model for GRB lc simulation (R. Falco)





AGILE and FRB

FRB200428 from SGR 1935+2154

First correlation between an FRB-like radio burst and an X-ray flare from SGR

Analysis of the X-ray flare detected by the SuperAGILE ratemeters **[*Tavani et al., Nature, 2020*]**

nature astronomy

ARTICLES

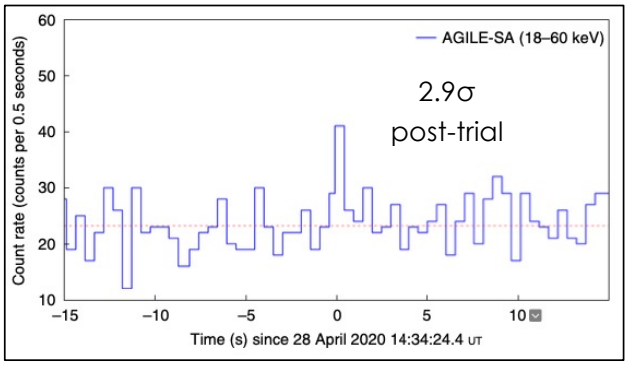
https://doi.org/10.1038/s41550-020-01276-x

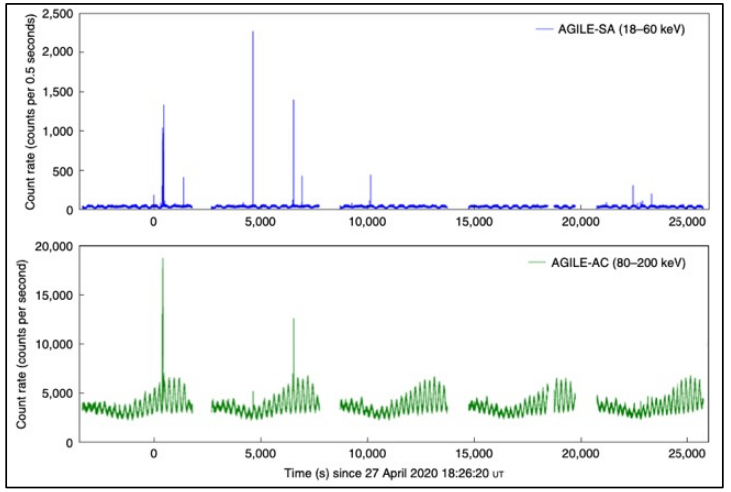
Check for updates

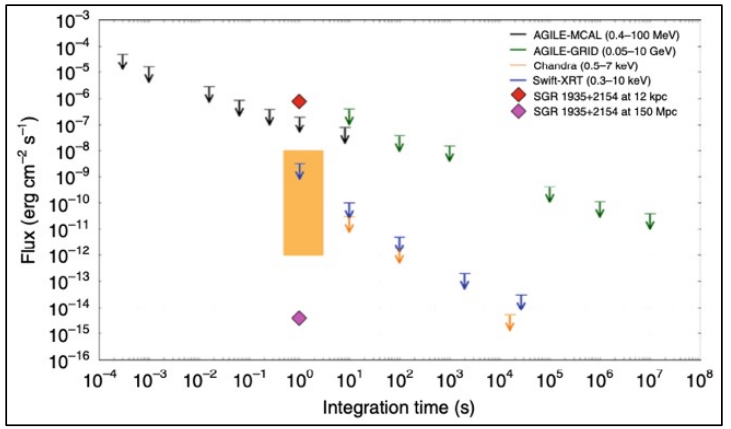
An X-ray burst from a magnetar enlightening the mechanism of fast radio bursts

M. Tavani[1,2], C. Casentini[1,3], A. Ursi[1], F. Verrecchia[4,5], A. Addis[6], L. A. Antonelli[5], A. Argan[1], G. Barbiellini[7,8], L. Baroncelli[6], G. Bernardi[9,10], G. Bianchi[9], A. Bulgarelli[6], P. Caraveo[11], M. Cardillo[1], P. W. Cattaneo[12], A. W. Chen[13], E. Costa[1], E. Del Monte[1], G. Di Cocco[6], G. Di Persio[1], I. Donnarumma[14], Y. Evangelista[1], M. Feroci[1], A. Ferrari[15,16], V. Fioretti[6], F. Fuschino[6], M. Galli[17], F. Gianotti[6], A. Giuliani[11], C. Labanti[6], F. Lazzarotto[1], P. Lipari[18,19], F. Longo[7,8], F. Lucarelli[4,5], A. Magro[20], M. Marisaldi[6,21], S. Mereghetti[11], E. Morelli[6], A. Morselli[3], G. Naldi[9], L. Pacciani[1], N. Parmiggiani[6], F. Paoletti[22], A. Pellizzoni[23], M. Perri[4,5], F. Perotti[11], G. Piano[1], P. Picozza[2,3], M. Pilia[23], C. Pittori[4,5], S. Puccetti[14], G. Pupillo[9], M. Rapisarda[11], A. Rappoldi[12], A. Rubini[1], G. Setti[9,24], P. Soffitta[1], M. Trifoglio[6], A. Trois[23], S. Vercellone[25], V. Vittorini[1], P. Giommi[4,26] and F. D'Amico[14]

Fast radio bursts (FRBs) are millisecond radio pulses originating from powerful enigmatic sources at extragalactic distances. Neutron stars with large magnetic fields (magnetars) have been considered as the sources powering the FRBs, but the connection requires further substantiation. Here we report the detection by the AGILE satellite on 28 April 2020 of an X-ray burst in temporal coincidence with a bright FRB-like radio burst from the Galactic magnetar SGR 1935+2154. The burst observed in the hard X-ray band (18–60 keV) lasted about 0.5 s, it is spectrally cut off above 80 keV and implies an isotropically emitted energy of about 10^{40} erg. This event demonstrates that a magnetar can produce X-ray bursts in coincidence with FRB-like radio bursts. It also suggests that FRBs associated with magnetars can emit X-ray bursts. We discuss SGR 1935+2154 in the context of FRBs with low-intermediate radio energies in the range 10^{38}–10^{40} erg. Magnetars with magnetic fields $B \approx 10^{15}$ G may power these FRBs, and new data on the search for X-ray emission from FRBs are presented. We constrain the bursting X-ray energy of the nearby FRB 180916 to be less than 10^{46} erg, smaller than that observed in giant flares from Galactic magnetars.







AGILE FRB studies

Paper	Production	Sign in	Sub.	Sub. to	Revision 1	Revision 2	Accepted for publication	Published
Casentini et al.	✓	✓	✓	*ApJL*	✓	✓	✓	✓
Tavani et al.	✓	✓	✓	*ApJL*	✓	✓	✓	✓
Pilia et al. (SRT coll. paper)	✓	✓	✓	*ApJL*	✓	✓	✓	✓
Tavani et al.	✓	✓	✓	*Nature astronomy*	✓	✓	✓	✓
Verrecchia et al.	✓	✓	✓	*ApJ*	✓	-	✓	-

5 published AGILE papers on FRB science up to now:

1. Casentini et al., ApJL 2020: paper on two low IGM-DM repeaters, FRB180916.J0158+65 and FRB181030.J1054+73. **(New paper on AGILE monitoring of R-FRB in progress)**
2. Tavani et al., ApJL 2020: paper on the periodic R-FRBs: FRB20180916B. MW campaign with all AGILE detectors and Swift
3. Pilia et al., ApJL 2020, SRT Collaboration Paper on the periodic FRB 180916 : The Lowest-frequency Fast Radio Bursts at 328 MHz
4. **Nature Astronomy**: "**An X-ray burst from a magnetar enlightening the mechanism of fast radio bursts", Tavani et al. 2021,** about SGR1935+2154 X-ray/radio flare
5. Verrecchia et al., ApJ 2021: search for HE counterparts in the AGILE data from sources in FRBCAT and TNS catalogues (89 sources included, 10 R-FRB)

AGILE and Neutrinos

IC-170922 MWL detections

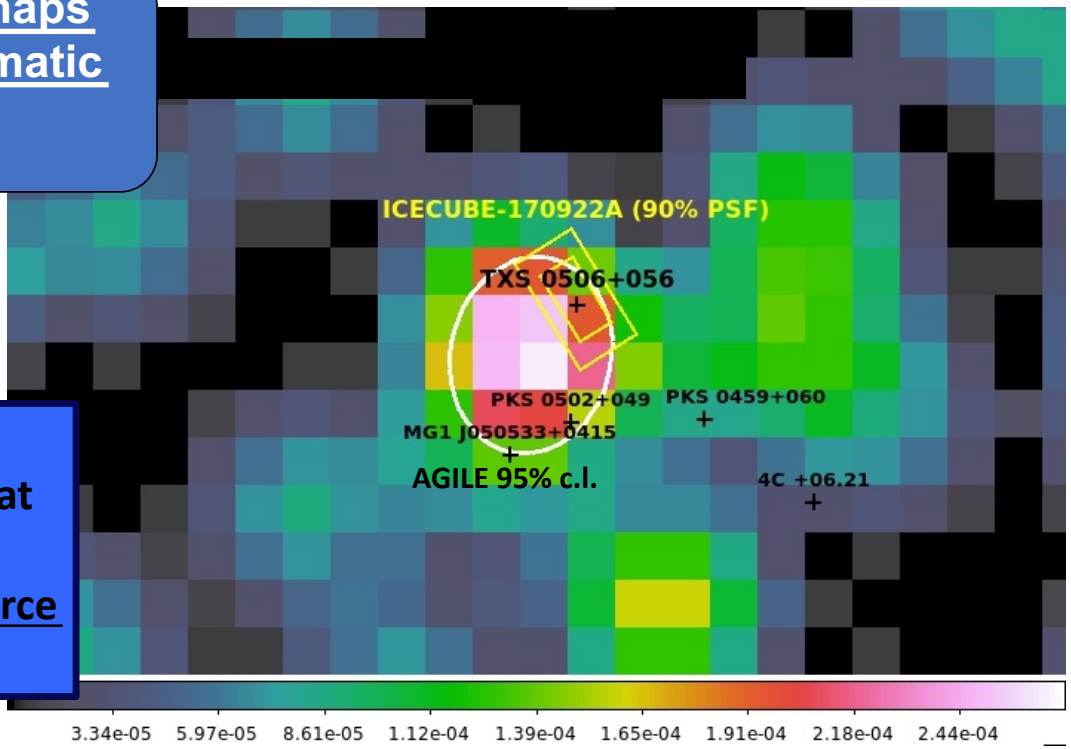
- EHE IceCube event announced on Sept. 22, 2017
- R.A., Decl. (J2000): (77.43, 5.72) deg
- HE γ-rays observed **both by AGILE and Fermi-LAT** consistent with the IceCube error box (ATels #10791 and #10801)
- VHE γ-rays observed by **MAGIC** a few days after the neutrino event T0 (ATel #10817)

The blazar TXS 0506+056 (also known as a 3FGL and 3FHL source) inside the IceCube error region
➔ Identification as the IC-170922 neutrino emitter

"Multimessenger observations of a flaring blazar coincident with high-energy neutrino IceCube-170922A", Science 361, 2018

AGILE observation of IC-170922

An AGILE detection over 2-day maps near event time T0 from the automatic QL detection systems



Consistent with the position of the BL Lac source TXS 0506+056, seen also at VHE by MAGIC near T_0 (Atel #10817). TXS 0506 as the first cosmic neutrino source ever detected!

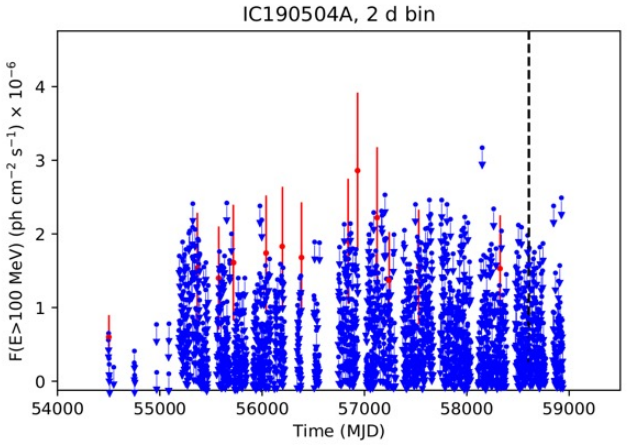
Blazars as possible neutrino sources! Further AGILE studies:

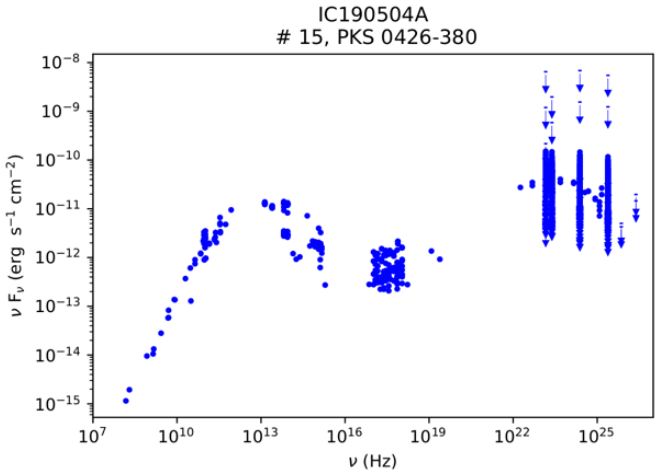
"*AGILE Detection of Gamma-Ray Sources Coincident with Cosmic Neutrino Events*", F. Lucarelli et al. ApJ 870, 2019

"*Search for Gamma-Ray counterparts of IceCube neutrino events in the AGILE public archive*": Master thesis by Elena Gasparri (2022). New paper in preparation.

UPDATE: Search for Gamma-Ray counterparts of IceCube neutrino events in the AGILE public archive

E. Gasparri, R. Poggiani, C. Pittori, F. Lucarelli, P. Giommi → See **R. Poggiani** talk @ TeVPa 2023



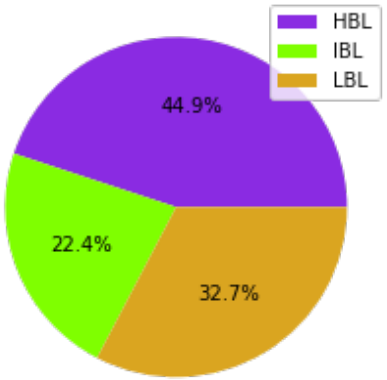


Blazars as possible neutrino sources.

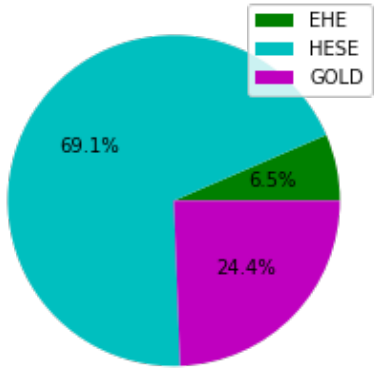
Master thesis by Elena Gasparri – Univ. Pisa (2022) - **Paper in preparation**

Analysis of 16 IceCube neutrino events from September 2018 to March 2020

- Full-mission (16 yrs) AGILE light curves using public data and AGILE-LV3 SSDC tool
- SED of identified candidates with VOU-Blazars
- 8/16 light curves show significant γ-ray detections ($\sqrt{TS} > 3$) within $T_0 \pm 1$ year:
  - 2/3 EHE neutrinos (IC-180908A e IC-190503A)
  - 3/6 HESE neutrinos (IC-190104A, IC-190221A, IC-190504A)
  - 3/7 GOLD neutrinos (IC-190619A, IC-190922A, IC-191001A)
  - 2/16 light curves with association to 2AGL catalog sources



Classes of candidate blazars



Candidate AGILE detections vs. neutrino event type

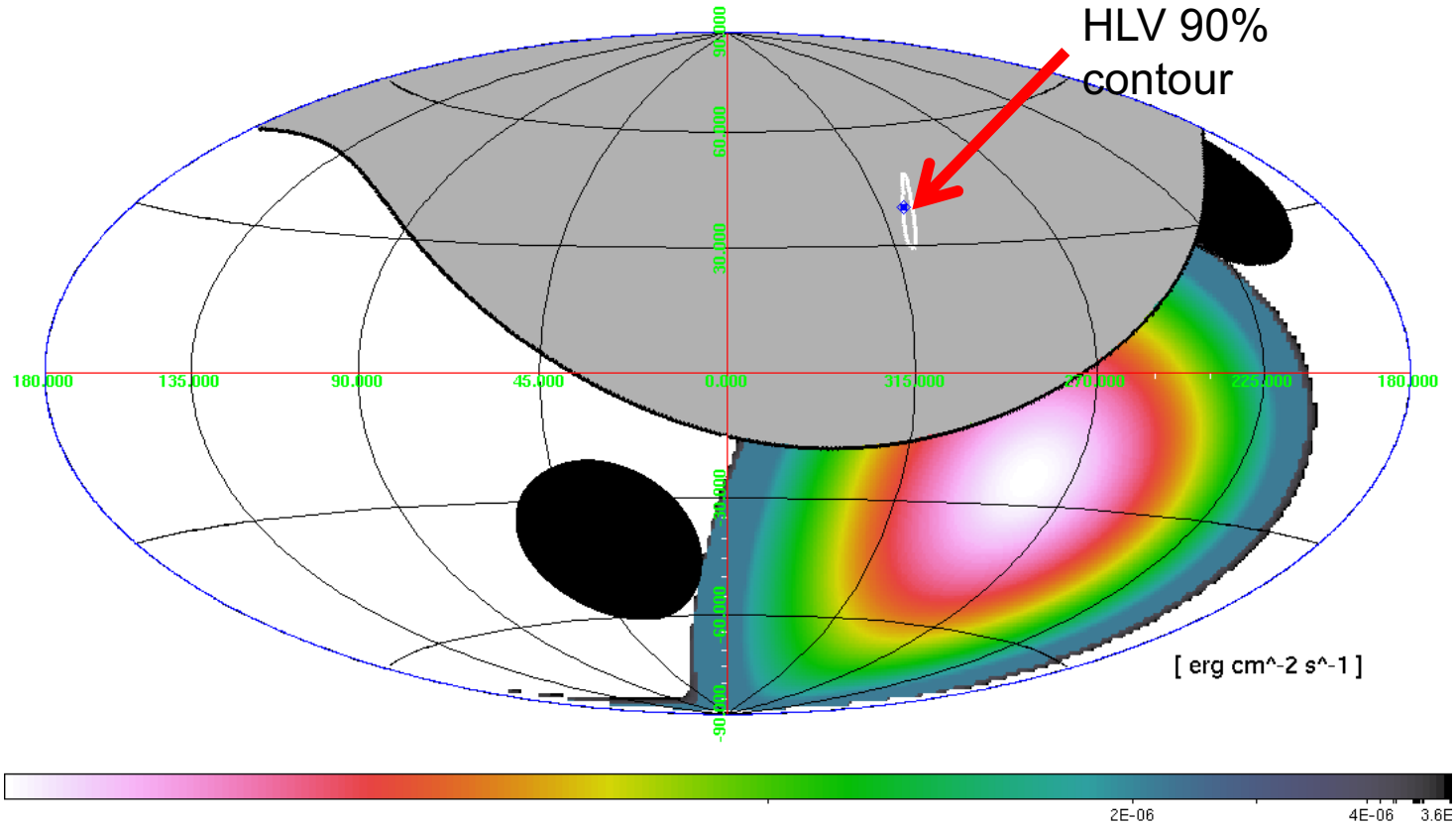
AGILE and Gravitational Waves

AGILE and GW

- AGILE **unique** combination of two co-aligned X-ray and γ-ray imaging detectors. Excellent for GW counterpart search.
- GRID very large field of view (2.5 sr)
- Spinning observation mode: ~200 passes/day over more than 80% of the sky (solar panel constraints).
- **Sensitivity ~ (1-2) 10^{-8} erg cm^{-2} s^{-1} in 100 sec.**
- Also two non-imaging detectors (**4 π**): MCAL (0.3 - 100 MeV), AC (50 keV - 10 MeV)
- GRB – like searches, MCAL, AC, RM

F. Verrecchia et al., AGILE review (2019)
DOI:10.1007/s12210-019-00854-0

GW170817-GRB170817A NS-NS merger
AGILE exposure at T0 (-2 / +2 sec): occulted by the Earth!

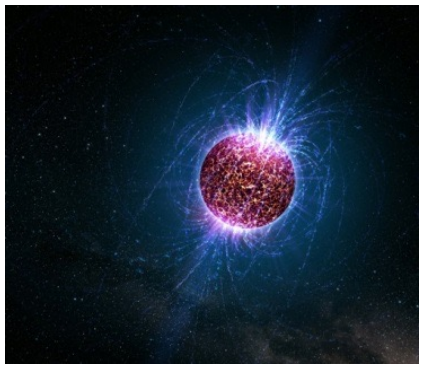


NS-NS merger GW170817-GRB170817A

- **AGILE and GW170817: nevertheless first γ-ray instrument above 100 MeV with exposure on the localization region starting at ~ T_0 + 935 s**
  (F. Verrecchia et al., ApJL 850, 2017). **Fermi-LAT in SAA, started the follow up at ~ T0 + 1153 s**

- AGILE observations provided the **fastest response and the most significant upper limits above 100 MeV to all GW events detected up to now!!**

- **AGILE limits on magnetar emission:** AGILE UL sets important constraints in the early phases to **exclude a highly magnetized magnetar for the remnant of GW170817- GRB170817**



AGILE and LIGO-Virgo-Kagra ongoing O4 run

- LIGO-Virgo-Kagra (LVK) O4 observing run, started on May 24, 2023. Indeed, the first 2023 GW event (S230518h) was published on May 18, 2023, prior to the official start of O4, during the last days of the so-called ***engineering run*** of the LIGO detectors.

- The LVK GW event **S230518h** has been identified as a significant GW compact binary merger candidate with high probability (86%) to be composed by a Neutron Star-Black Hole (**NSBH**) merger, which has a higher probability to have an electromagnetic counterpart.

- AGILE results from the fast follow-up of **GW S230518h** were published in the GCN Circular #33826, reporting the **AGILE/MCAL flux upper limits in the 0.4 - 1 MeV energy range**, for 1 s integration time from the GW T0, at different celestial positions within the accessible Localization Region (LR).

- The detection of a **short pulse** in the same energy band with **S/N ~ 5.7 at T0+10.77 s** was also reported by AGILE. FAR and FAP evaluation *in progress* (soft band E<1.4 MeV).

- **AGILE completed its follow-up of all GW events up to the end of LVK O4a (first part) on Jan 16, 2024**.

Last but not least:
AGILE and Solar Flares

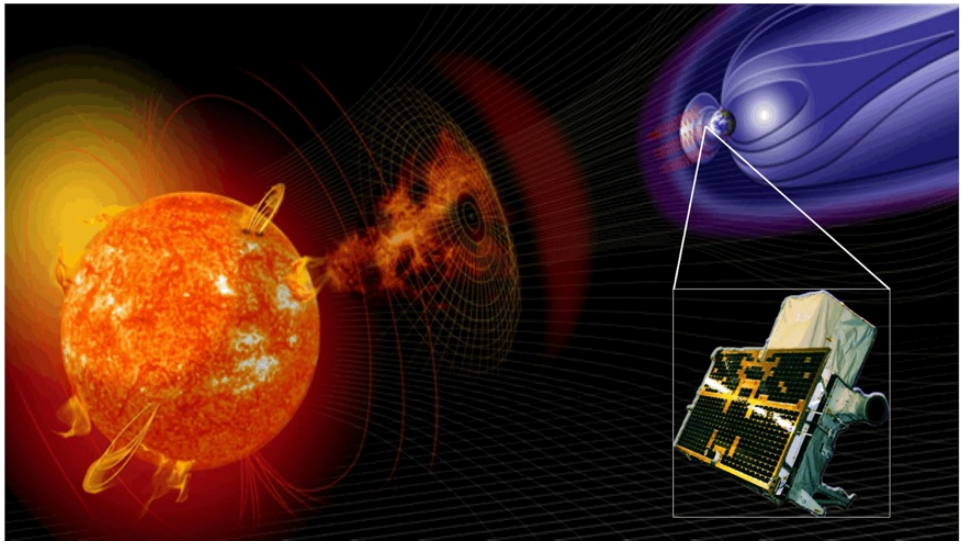
The First AGILE Catalog of Solar Flares: more than 15 years of observations

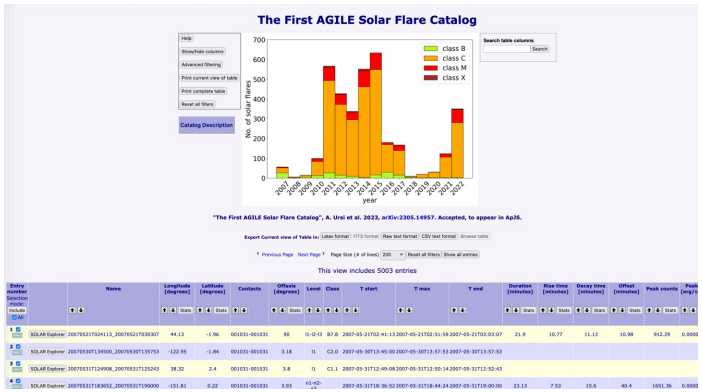
"The First AGILE Solar Flare Catalog", **A. Ursi et al., ApJS 267, 2023**

- Catalog of **more than 5000 events** from 2007 and 2022, all cross-related with the official **GOES**, **RHESSI and Fermi GBM**.

- **More than 1400 new "AGILE only"** events constituting a **new dataset** of solar flares detected in the hard X-ray energy band (80-200 keV).

- An **on-line version** of the AGILE solar flare catalog is available as an interactive web page at SSDC, providing access to additional data products (light curves, both in image and text format): *https://www.ssdc.asi.it/agilesolarcat/*





THE AGILE LEGACY

AGILE archives and catalogs are available to the community through the ASI SSDC.

Science activities continue. We have just published on Feb. 29, 2024 all AGILE-GRID data **up to January 15, 2024. A data reprocessing is in progress.**

Open-source Python software package **Agilepy** (INAF-OAS) and/or **SSDC AGILE-LV3 online data analysis tool.**

With AGILE's re-entry, the in-orbit operational phase ended, but a new phase of scientific work on the satellite legacy data archive opens.

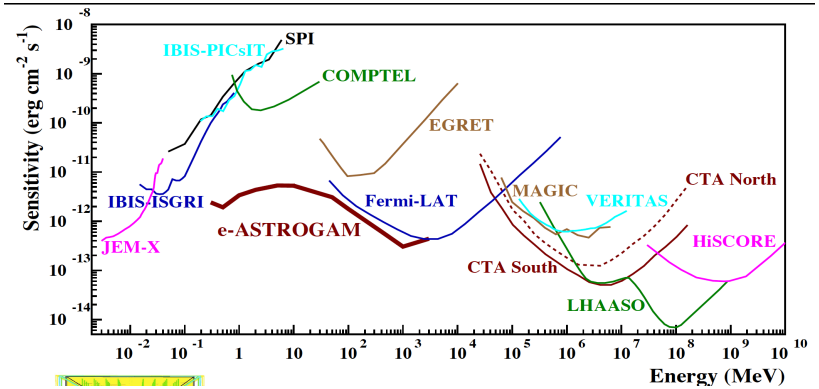
Work in progress on new catalogs with and without **Machine Learning** techniques. **Stay tuned for further results**.

Thank you AGILE!

Future prospects for MeV/GeV astronomy???
The e-ASTROGAM Proposal

A. De Angelis, V. Tatischeff, M. Tavani et al. ESA M7 2022: Not selected ☹

Compton scattering + Pair Tracking
E = 0.3 MeV – 3 GeV
~ years 2030:
Complementary to observatories such as LIGO-Virgo-GEO600-KAGRA, SKA, ALMA, E-ELT, TMT, LSST, JWST, Athena, **CTAO**, IceCube, KM3NeT, LISA...



Looking forward to future opportunities in MeV/GeV astronomy in crucial synergy with future missions CTAO, ET, ATHENA, ...

Backup slides

Future prospects for MeV/GeV astronomy