LXVI Congresso nazionale della Società Astronomica Italiana
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AGILE: the small satellite that could do a lot (and did It)

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AGILE: Astrorivelatore Gamma ad Immagini LEggero

- Italian Space Agency (ASI) with INAF, INFN participation
- Small Mission (300 kg)
- Launched April 23rd, 2007 from Sriharikota ISRO base (India)
- Low Earth equatorial orbit (550 km, 2.5°) → ~14 orbits/day

PSLV C8 MISSION

PSLV-C8, the eight operational flight of Polar Satellite Launch Vehicle, is the first full commercial launch of ISRO. The launch is to inject AGILE, a 352 kg Italian Spacecraft developed for Italian Space Agency (ASI) into 550 km circular orbit with 2.5° inclination.

In addition to Agile, PSLV C8 will also carry an ISRO payload named Advanced Avionics Module (AAM) as co-passenger in Dual Launch Mode. Agile is mounted on top of the Dual Launch Adaptor (DLA), that sits over the tank of fourth stage of PSLV while AAM is inside the DLA.

MISSION SPECIFICATION

Orbit	: 550 km circular
Inclination	: 2.5°
Launch time	: 15:30 hrs IST (10:00 hrs GMT)
Launch station	: Second Launch Pad
Launch Azimuth	: 99°

PSLV-C8, is significant in the sense that this is the first mission that does not employ any of the solid strap-ons, that have been used in earlier flights. This configuration of the vehicle termed as PSLV-CA (Core Alone) has been chosen considering the lower payload capability required for Agile and capability of the vehicle as such. C8 is also the first flight in which PSLV is launching a satellite into a circular orbit of very low inclination (2.5°).

1

FLIGHT PROFILE

SEPARATION SEQUENCE AFTER PS4 CUT-OFF

EVENT	TIME (s)	ALTITUDE (km)	VELOCITY (km/s)
Ignition of PS1	0.0	0.025	0.452
Separation of PS1	112.9	50.07	1.737
Ignition of PS2	113.2	50.25	1.736
Heat Shield Separation	202.9	115.9	2.950
Separation of PS2	263.7	147.2	4.743
Ignition of PS3	264.9	147.8	4.742
Separation of PS3	517.8	282.8	7.581
Ignition of PS4	1033.0	507.7	7.317
Cut-off of PS4	1331.8	550.0	7.583
Agile Separation	1373.8	549.9	7.585

3

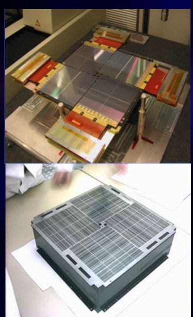
https://www.isro.gov.in/mission_PSLV_C8.html?timeline=timeline

India April 23, 2007: AGILE satellite launch

Everything went well (with a little help of a coconut)

AGILE: Astrorivelatore Gamma ad Immagini LEggero

AntiCoincidence (AC) → FoV
(BKG rejection and dir. rec.)
4 lateral+1top plastic scintillators, segmented,
Ratemeters as X-ray transients detector (50-200 KeV)



Super AGILE (SA)
[18 ÷ 60] keV
4 Si detectors + W coded mask,
Acquisition logic for transients

Silicon Tracker (ST)→ PSF
(Interaction, dir. rec., E)
[30 MeV ÷ 50 GeV]
12 W-Si foils, segmented

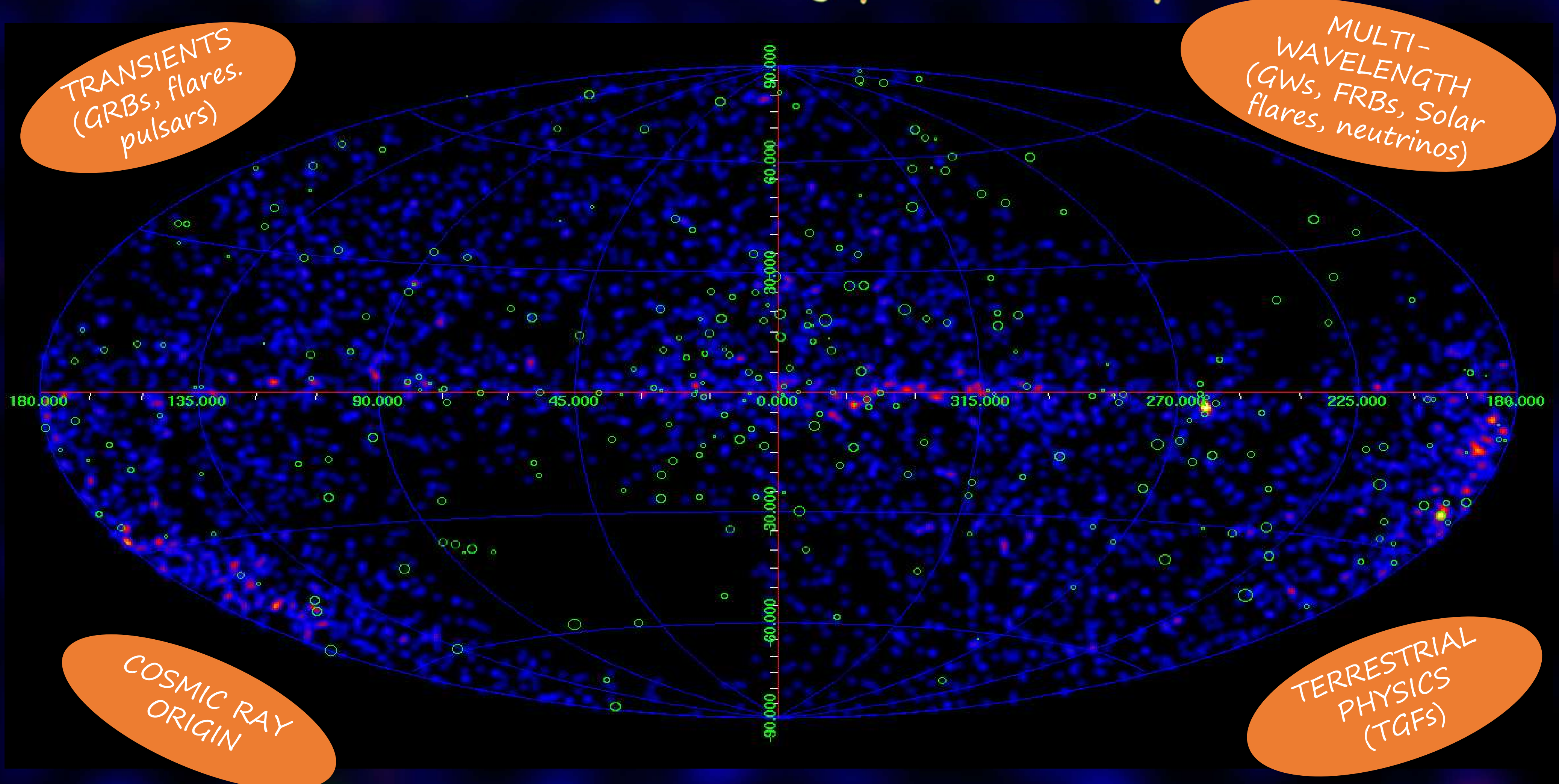
MiniCALorimeter (MCAL) → Edisp
(Energy)
[0.3 ÷ 100] MeV
30 CsI (Tl) bars, non-imaging,
Also standalone burst search algorithm
(0.35-100 MeV, sub-ms to s)

(Vercellone+., 2024)

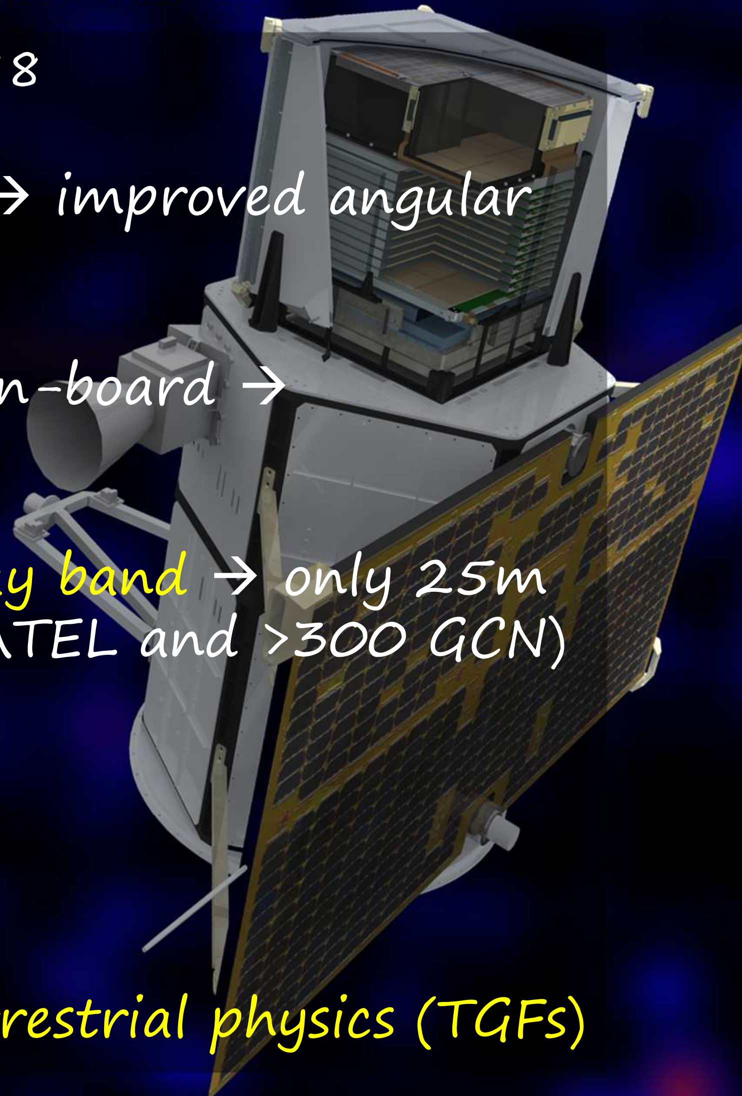
Gamma-ray Imaging Detector (GRID)	
Energy range	30 MeV–50 GeV
Field of view	~2.5 sr
Flux sensitivity ($E > 100$ MeV, 5σ in 3×10^6 s)	3×10^{-7} (ph cm^{-2} s^{-1})
Ang. resol. at 100 MeV (68% cont. radius)	3.5°
Ang. resol. at 400 MeV (68% cont. radius)	1.2°
Source localization acc. ($\|b\| > 10°$, 90% C.L.)	~15′
Energy resolution (at 400 MeV)	ΔE/E ~1
Absolute time resolution	~2 µs
Deadtime	~100–200 µs
Hard X-ray Imaging Detector (SA)	
Energy range	18–60 keV
Single (1-dim.) detector FoV (FWZI)	107° × 68°
Combined (2-dim.) detector FoV (FWZI)	68° × 68°
Sensitivity (18–60 keV, 5σ in 1 day)	~15–30 mCrab
Angular resolution (pixel size)	6 arcmin
Source location accuracy (S/N~10)	~1–2 arcmin
Energy resolution (FWHM)	ΔE ~ 8 keV
Absolute time resolution	~2 µs
Mini-Calorimeter (MCAL)	
Energy range	0.35–50 MeV
Energy resolution (at 1.3 MeV)	13% FWHM
Absolute time resolution	~3 µs
Deadtime (for each of the 30 CsI bars)	~20 µs

Fast-reaction ground segment
(Malindi-Telespazio- ASI Space Science Data Center)

AGILE: one-day photon map



AGILE: the first of its kind



First among the small mission programs in 1998

First mission using a solid state Silicon tracker → improved angular resolution and FoV

First γ-ray mission with hard X-ray monitor on-board → multiwavelength studies

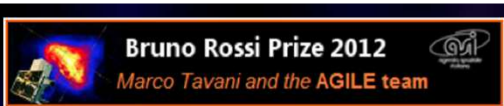
First time of a fast ground segment in the γ-ray band → only 25m from the download to Scientific results (>220 ATEL and >300 GCN)

First CR acceleration evidence from SNRs

First Crab Nebula flare detection

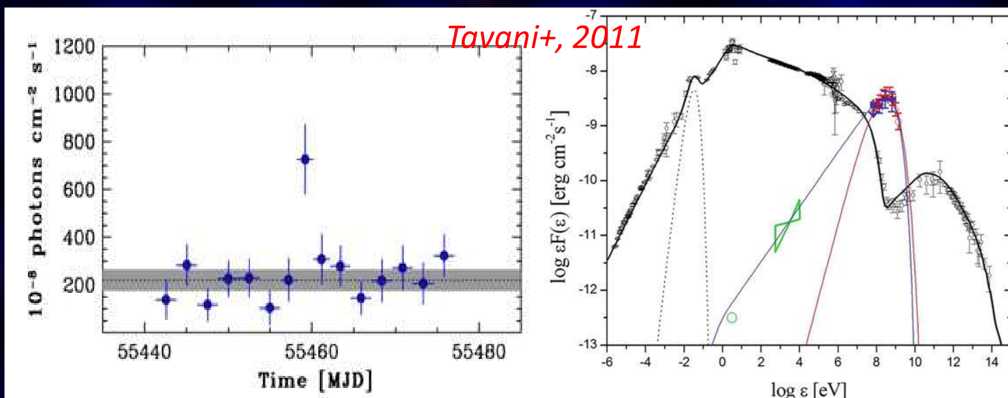
First gamma-ray mission to be an asset for Terrestrial physics (TGFs)


AGILE
17 bright years

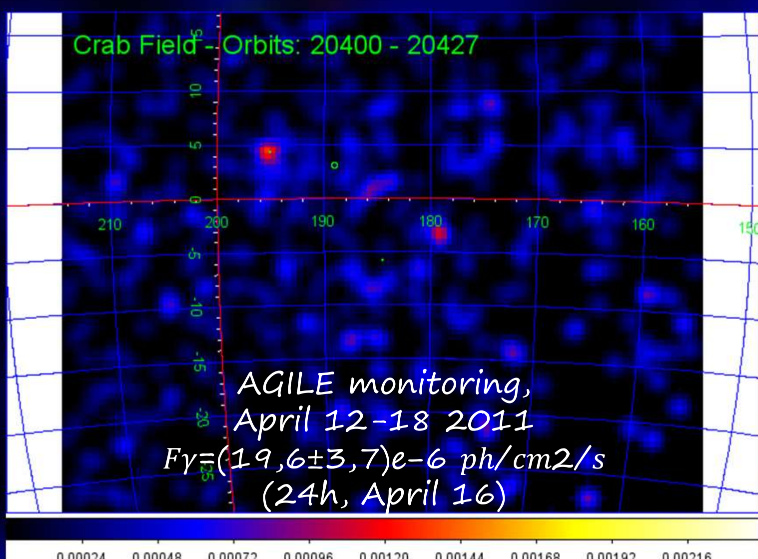


AGILE: three of the most important results – 1
Flaring Crab

AGILE, September 20-22, 2010



- The Crab nebula has an average constant multi-wavelength flux [F γ = (2.2 ± 0.1)e-6 ph/cm2/s] → calibration source
- September 2010: AGILE detected and reported a flare (ATEL 2855) w F=(7.2 ± 1.4)e-6 ph/cm2/s confirmed by Fermi-LAT
- October 2007: AGILE already detected a flare in its first Science Verification period → no communication
- Other flares (only in the γ-ray band), the greatest one in 2011
- Flares not related to pulsar and not seen in other frequencies → only in the γ-ray band → unknown acceleration phenomena



And now the Crab is showing new surprising features: it is a PeVatron!!!

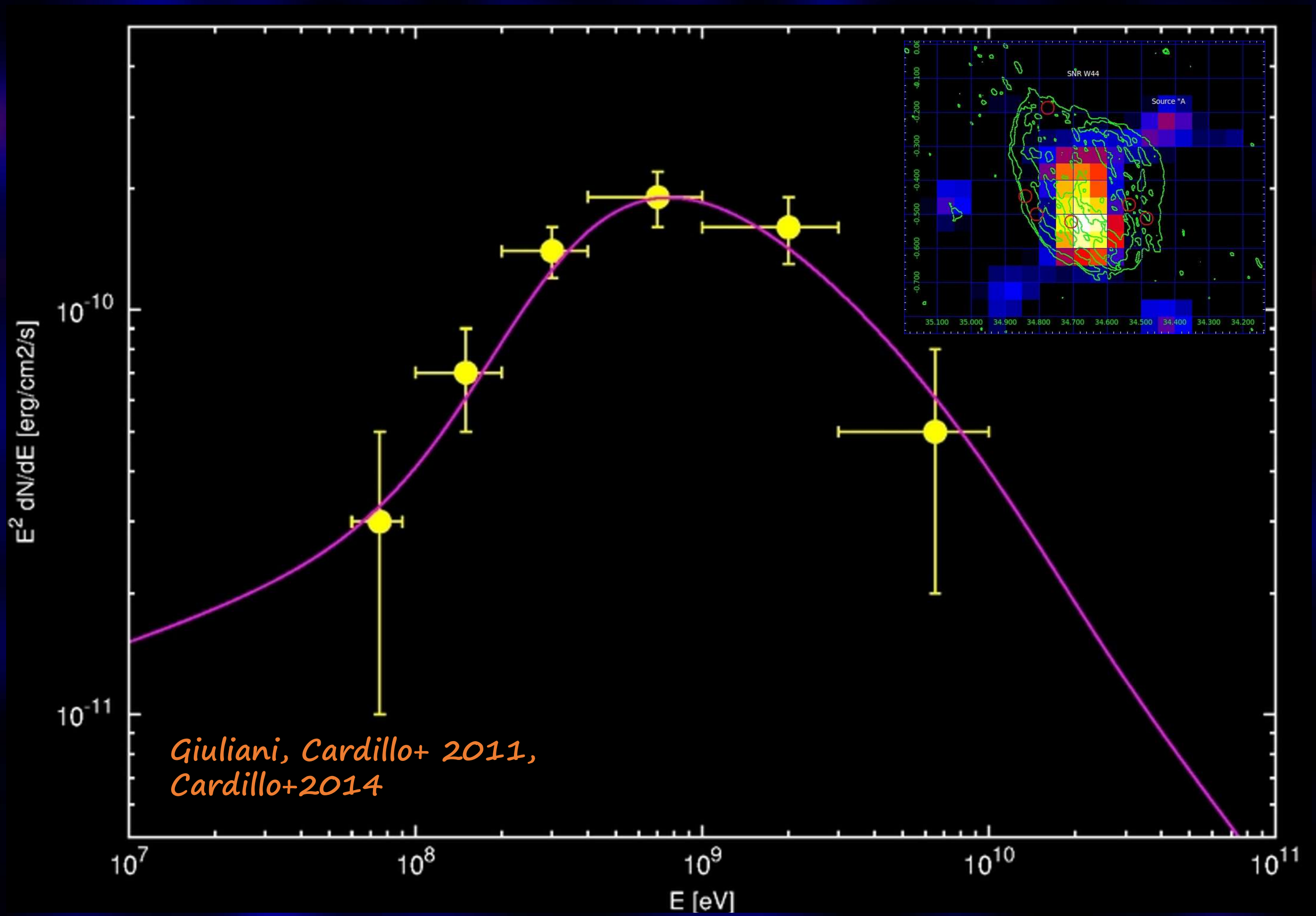
Flare Date	Duration (Days)	Peak γ-ray Flux $\times 10^{-6}$ Photons cm^{-2} s^{-1}	Instrument
2007 October	≈15	≈6	AGILE
2009 February	≈15	≈4	*Fermi*
2010 September	≈4	≈5	AGILE, *Fermi*
2011 April	≈2	≈0	*Fermi*, AGILE
2012 July	≈3	≈5	*Fermi*
2013 March	≈4	≈11	AGILE
2013 October	≈3	≈10	*Fermi*, AGILE
2014 August	≈4	≈7	*Fermi*
2016 October	≈13	≈7	AGILE, *Fermi*
2018 March	≈3	≈5	*Fermi*, AGILE
2018 October	≈10	≈11	*Fermi*, AGILE
2019 May	≈6	≈5	*Fermi*

(Vercellone+., 2024)

AGILE: three of the most important results – 2
CR ORIGIN

- ✧ CR origin is still an open issue in spite of their discovery in 1912. The SNRs were the main candidates
- ✧ The difficulty is distinguish hadronic γ-ray emission ($pp \rightarrow \pi 0 \rightarrow 2\ \gamma$) from the leptonic one
- ✧ The direct proofs are:
  - ✧ the "pion bump" detection (E<100 MeV)
  - ✧ Emission >100 TeV

AGILE was the first to detect the "pion bump" hint below 200 MeV → the SNRs accelerate CRs



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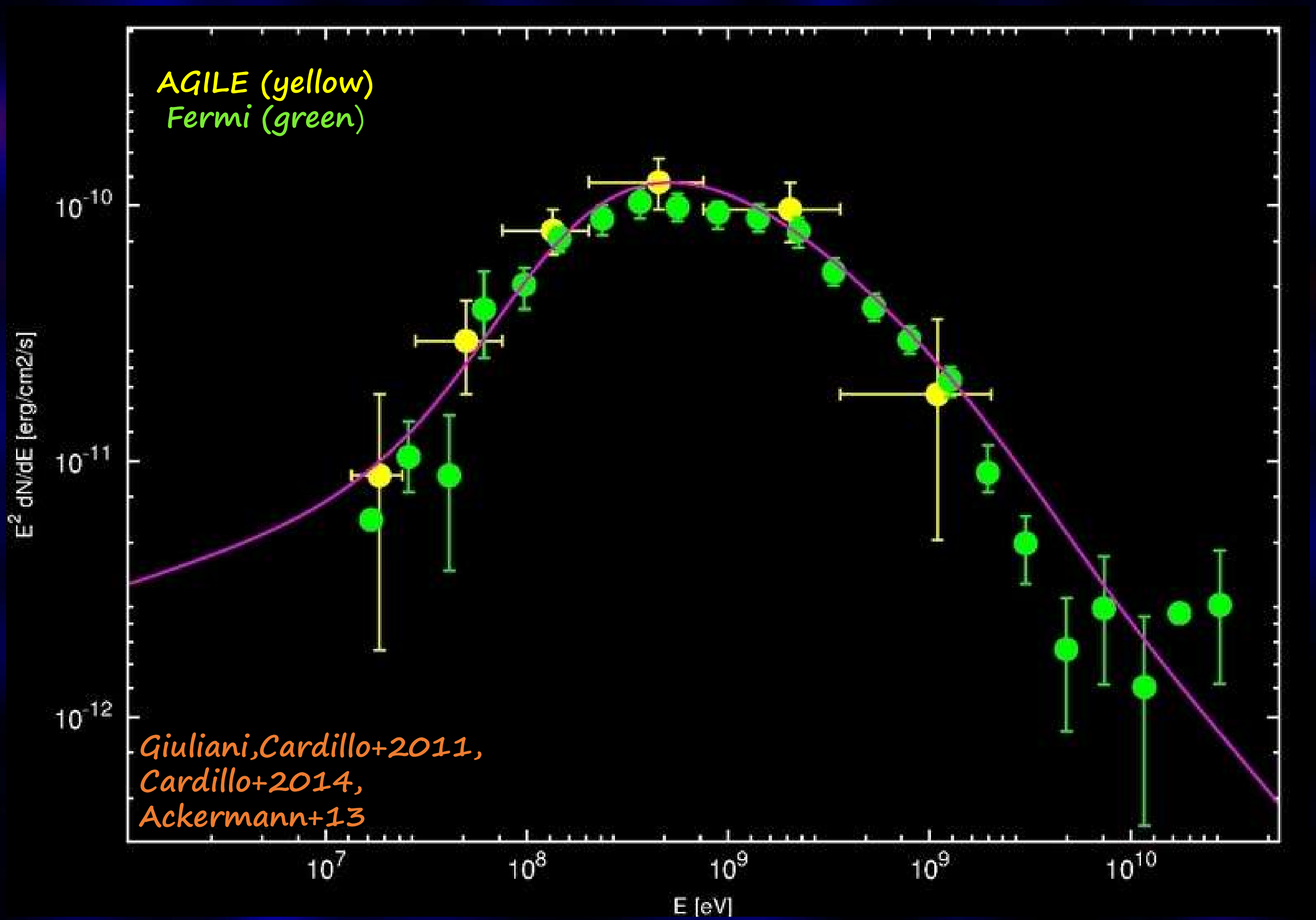
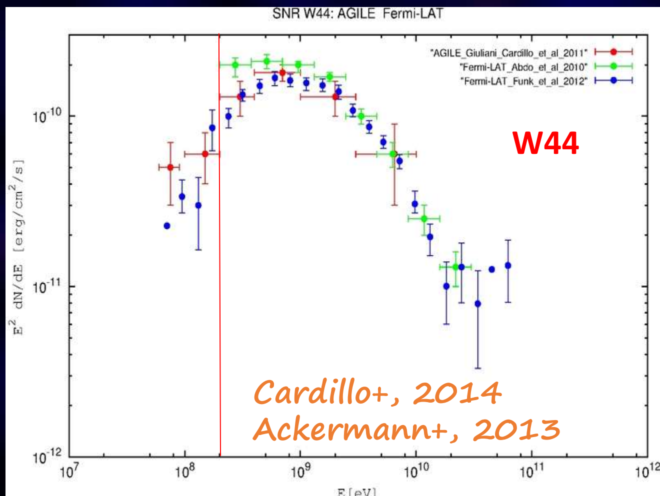
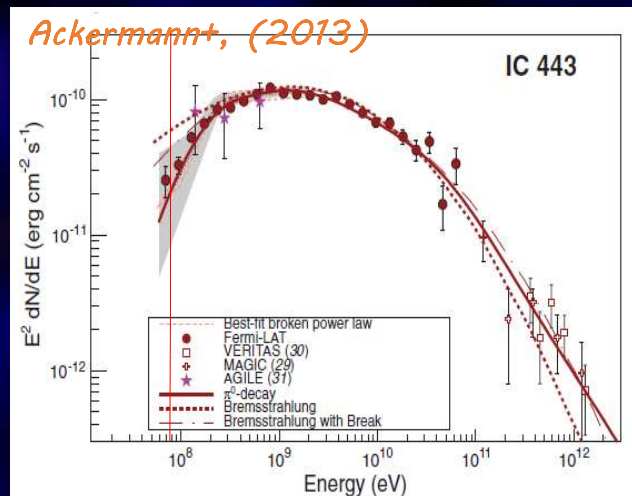
Fermi-LAT repeated the analysis and confirmed the AGILE results

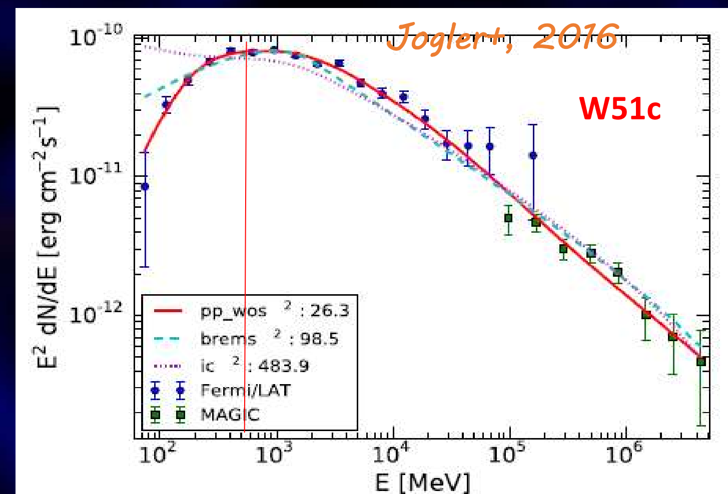


AGILE: three of the most important results – 2
CR ORIGIN

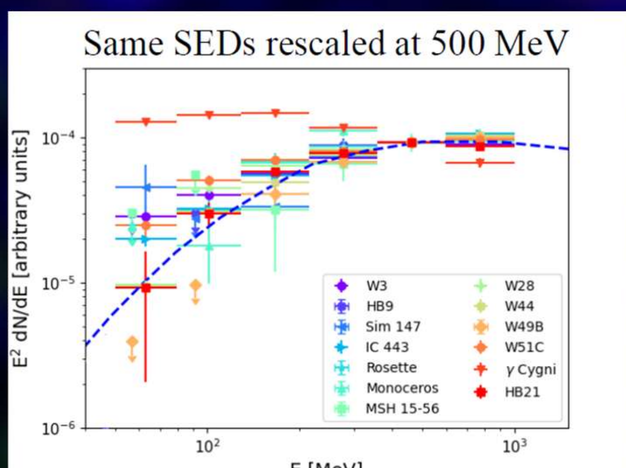
From the AGILE breakthough, a lot of other SNRs showed the same behavior







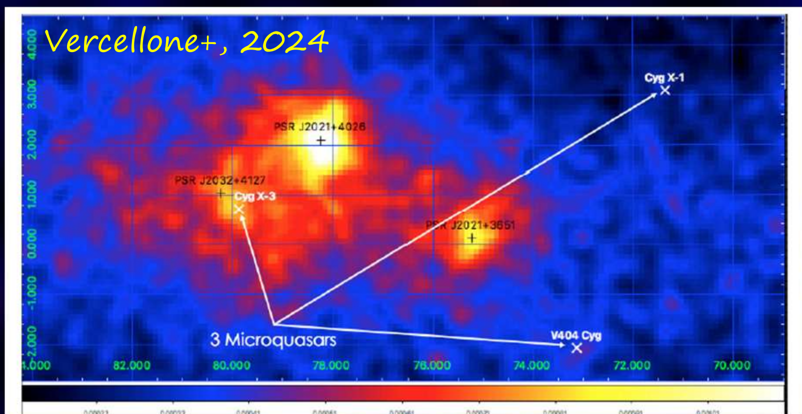
Lemoine-Goumard talk Gamma2022



After the recent new data from LHAASO et al., the "pion bump" remains the only smocking gun for CR acceleration (w neutrinos).

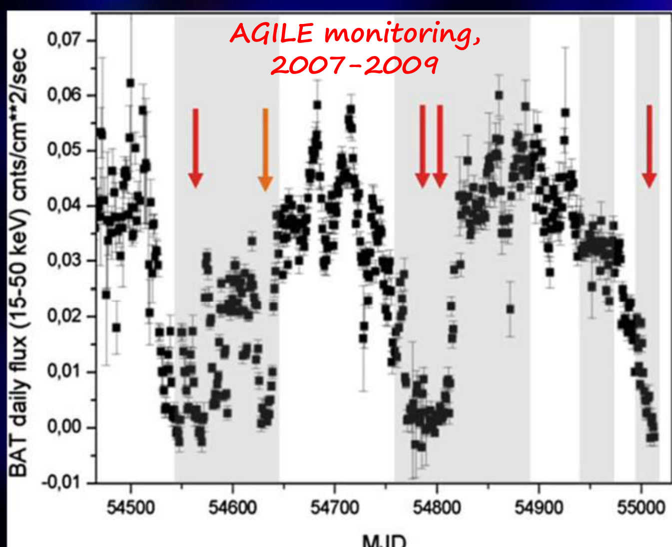
AGILE: three of the most important results – 3
Repetitive flares in Microquasars

Cygnus Region

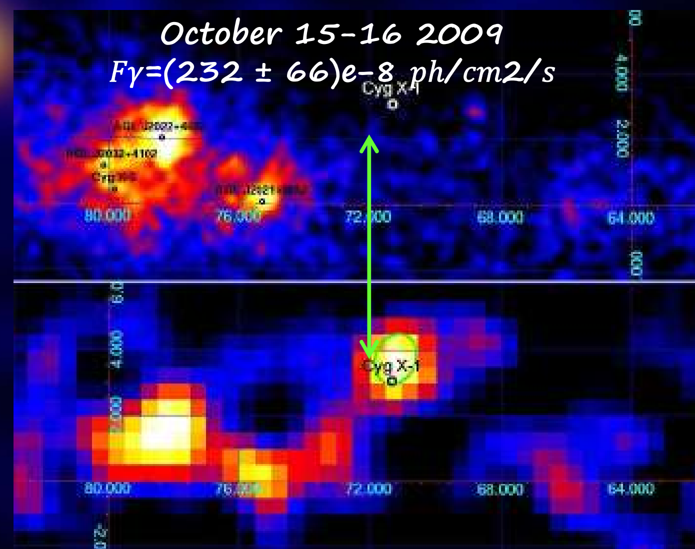


- Cygnus X-3: AGILE detected for the first time γ-ray flares at E> 100 MeV (10 times the steady state Fγ=(14 ± 3)e-8 ph/cm2/s) → repetitive patterns in coincidence with very low-flux in the hard X
- Flare in Cygnus X-1 (100 MeV – 3 GeV) [Fγ=(232 ± 66)e-8 ph/cm2/s]→ extreme particle acceleration 1-day scale
- Flare also from V404 Cygni (Fγ=(4.6 ± 1.5)e-6 ph/cm2/s) in coincidence w multi-frequencly outburst (June 24-26 2015) →MQ nature

MQs now are among the candidates for CR acceleration



Tavani+, 2009b, Nature, Piano+, 2011



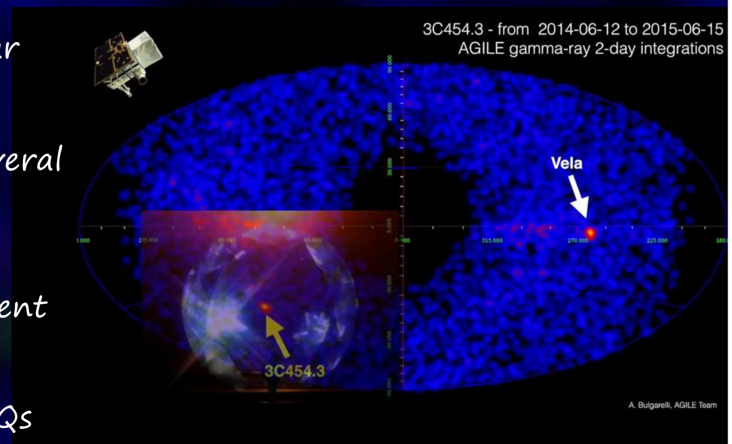
Sabatini+, 2012

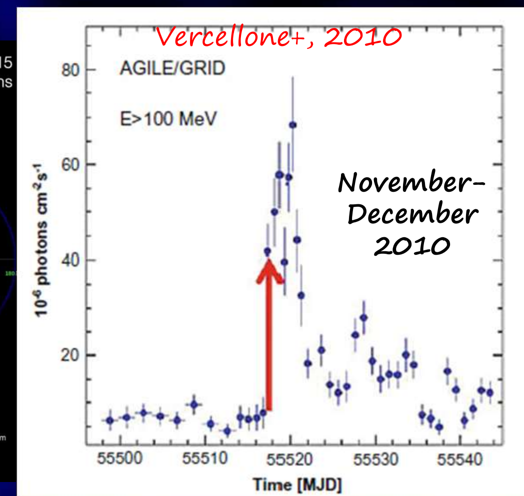
And a small part of all the other beautiful results

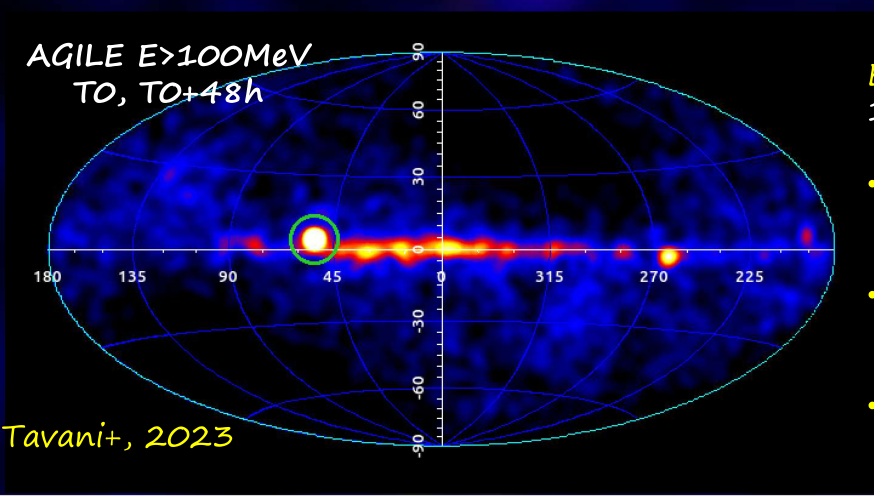
Fast flares from AGNs

Large FoV of AGILE → catch flaring extra-galactic objects. One example, the Flat-spectrum radio quasar (FRSQ) **3C 454.3**:

- Flare in October 3-4 2007 → the beginning of several flares in several years: the brightest γ-ray source (*Crazy Diamond*)
- *Flare 2010*: fastest time variability (6h) flaring event
- *Different behavior at different frequencies and Compton Dominance* then observed in several FSRQs







Gamma Ray Burst

Efficient Real Time Analysis (RTA) and SuperAGILE/GRID co-presence → 10/17 GRBs per y (2 AGILE cat), >500 tot from MCAL

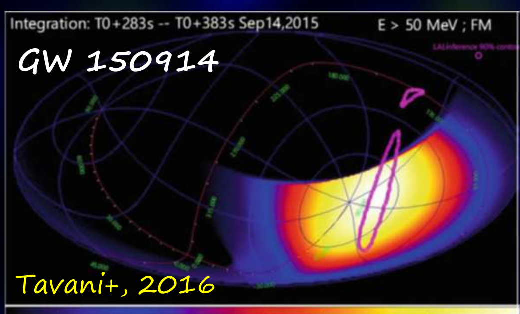
- *GRB 080514B*: X-ray 6s, γ-ray 13s and not coincidence of the peaks in the two frequencies
- *GRB 090510*: first (short) GRB with delayed γ-ray emission (reference as GW counterpart)
- *GRB 221009A* (BOAT): dramatic transition between prompt and afterglow w a coexistence phase between MeV and GeV (Foffano+, 2024)

The Multiwavelength and terrestrial contributions

Gravitational Waves

Large FoV+timing capability+spinning

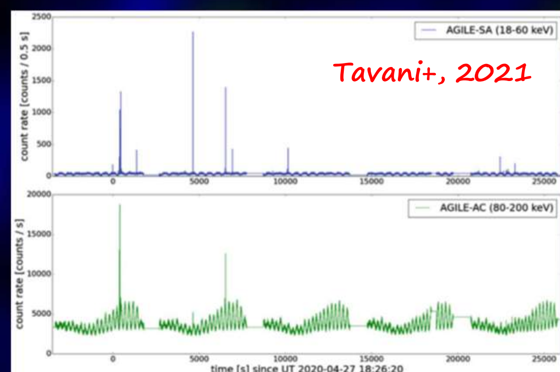
- Fastest and more significant ULs during LVK O-runs (24/7 teamwork, alert via APP)
- Gravitational Wave Transient Catalog (GWTC-1) (Ursi+, (2022)).



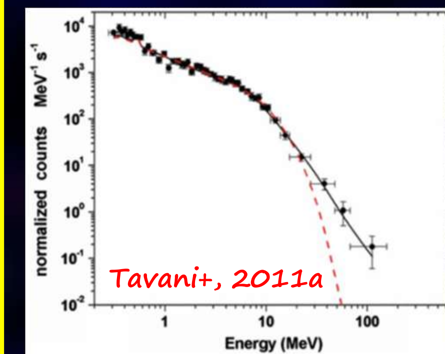
Fast Radio Burst

Simultaneous X-and γ-ray observations

- SGR 1935+2154: forest of X-ray bursts (SA)→ one in coincidence with a very bright radio burst: magnetars can produce radio & X-ray bursts
- An FRB Sample X-ray/ γ-ray study (Casentini+, 2025)



Terrestrial Gamma-Ray Flashes

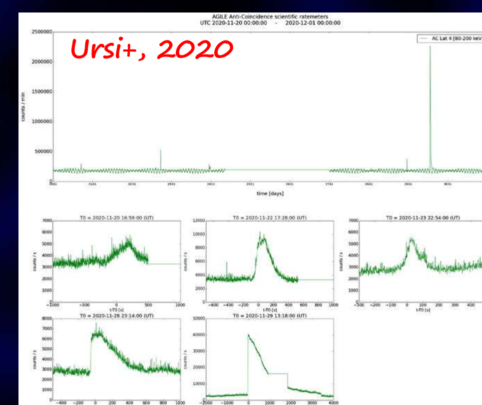


Optimized sub-ms MCAL trigger system→ several thousands of TGFs

- Discovery of a spectral component above 100 MeV
- Three AGILE cat.

Solar Flares

Ratemeter AC sun-oriented→ fast alert for hard X-ray flares from the Sun (first AGILE Solar flare catalog)



Neutrinos

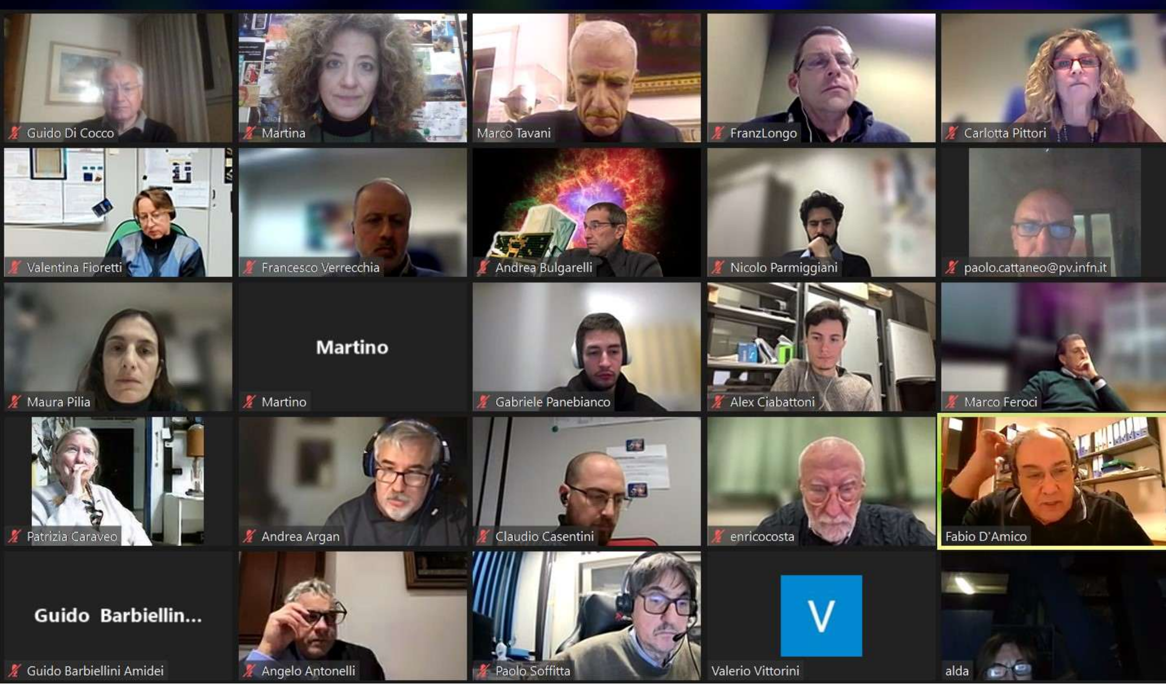
Large FoV+spinning → quickly reaction to neutrino alert

- IceCube-160731: γ-ray precursor flaring (no known counterpart) [Lucarelli+, 2017]
- 3 AGILE sources possible neutrino events candidates [Lucarelli+, 2019]
- IceCube 2017: flaring blazar TXS 0506+056

AGILE: The end of an era

January 18th, 2024 – end of operations

February 14th, 2024 – re-entered in the atmosphere



The AGILE satellite re–entered the atmosphere

After 17 years of thriving operations, the AGILE Italian scientific satellite re-entered the atmosphere, thus ending its intense activity as a hunter of some of the most energetic cosmic sources in the Universe that emit gamma and X-rays

After 17 years of thriving operations, the AGILE Italian scientific satellite re-entered the atmosphere, thus ending its intense activity as a hunter of some of the most energetic cosmic sources in the Universe that emit gamma and X-rays.

AGILE, built by ASI with contributions from INAF and INFN, Italian universities and industry, has been a unique and hugely successful space program in the landscape of Italian space activities. Observations acquired by the satellite were received on the ground by ASI's Luigi Broglio Space Center station in Malindi, Kenya. The data were then sent to the Telespazio Control Center through the ASINet operational network, and then to the ASI Space Science Data Center in Rome, which is responsible for all scientific operations: from management, analysis and archiving to distribution of the data and related catalogs accessible to the international community.

AGILE's scientific output consists of more than 800 bibliographic references, including more than 160 refereed articles and 12 mission catalogs published through January 2024 (also available as interactive SSDC webpages here).

AGILE's major scientific discoveries include: the first detection of galactic cosmic ray sources in Supernovae remnants, evidence of extremely rapid particle acceleration from the Crab Nebula with a rapidly rotating pulsar at its center (Bruno Rossi Prize 2012), and the detection of transient gamma-ray emission associated with relativistic jet emission from the galactic black hole binary system Cygnus X-3.

During its operational life, AGILE has also revealed many transient events of cosmic origin such as Gamma Ray Bursts (GRBs), searched for high-energy emission associated to neutrino events and Fast Radio Bursts (FRBs), detected thousands of solar flares, as well as events of terrestrial origin such as Terrestrial Gamma-ray Flashes (TGFs). AGILE has contributed with a leading role in the search for possible counterparts of gravitational wave (GW) sources, and AGILE's follow-up observations have provided the fastest response and most significant upper limits above 100 MeV on all GW events detected by the Ligo-Virgo-Kagra collaboration to date.

With the AGILE's re-entry, the in-orbit operational phase comes to a close, but a new phase of scientific work on the satellite legacy data archive opens: AGILE may still hold future surprises.

Additional links:

COMUNICATO STAMPA CONGIUNTO ASI-INAF-INFN (in italian): ASI news, INAF news

The AGILE legacy

- 17 years of data collected and an example to an Italian success story
- It anticipated missions like Fermi and complemented them over time
- Technological legacy: compact and efficient design, ideal for future micro-missions
- Operational experience: demonstrated long-duration capability and scientific flexibility (una missione dal "multiforme ingegno")
- Stimulus for new missions:
  - Renewed interest in the MeV-GeV range (e.g. e-ASTROGAM, AMEGO)
  - Need for new observatories for TGFs and γ-ray transients

Reviews:

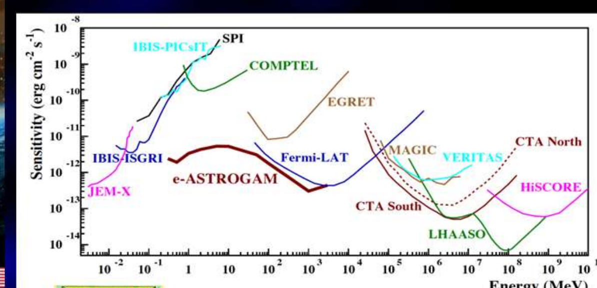
"The AGILE Mission and Its Scientific Results", https://link.springer.com/referenceworkentry/10.1007/978-981-16-4544-0_57-1

"Scientific Highlights of the AGILE Gamma-ray Mission", https://doi.org/10.3390/universe10040153

"The AGILE space mission: an Italian success story and its legacy for future space astronomy", https://doi.org/10.48550/arXiv.2501.12970

The newASTROGAM proposal for M8 in 2025

(e-ASTROGAM A. De Angelis, V. Tatischeff, M. Tavani et al. **ESA M7 2022**: well rated but not selected ☹



AGILE: the catalogs

Catalog Title	Description	Reference	Link
The 1st AGILE-GRID Catalog of High Confidence Gamma-ray Sources	Jul. 2007–Jun. 2008 47 Sources	(a)	1AGL
Monitoring the hard X-ray sky with SuperAGILE	Jul. 2007–Apr. 2009 53 Sources	(b)	1SA
The AGILE MCAL Gamma-ray Burst Catalog	Apr. 2007–Oct. 2008 84 Sources	(c)	1GRB
An updated list of AGILE bright γ-ray sources and their variability in pointing mode	Jul. 2007–Oct. 2009 54 Sources	(d)	1AGLR
Properties of Terrestrial Gamma-ray Flashes detected by AGILE MCAL below 30 MeV	Mar. 2009–Jul. 2012 308 Events	(e)	1TGF
Enhanced detection of Terrestrial Gamma-ray Flashes by AGILE	Mar.–Jun. 2015 279 Events	(f)	2TGF
Search of MeV-GeV counterparts of TeV sources with AGILE in pointing mode	Jul. 2007–Oct. 2009 52 Sources	(g)	1ATEV
The 2nd AGILE Catalog of Gamma-ray sources AGILE in pointing mode	Jul. 2007–Oct. 2009 175 Sources	(h)	2AGL
On The High-Energy Spectral Component and Fine Time Structure of Terrestrial Gamma-ray Flashes	Mar–Jun. 2015 84 Events	(i)	1HETGF
The 3rd AGILE/MCAL TGF Catalog	Apr. 2007–Jun. 2022 5344 Events	(j)	3TGF
The 1st AGILE/MCAL GRB Catalog	Nov. 2007–Nov. 2020 503 Sources	(k)	2GRB
The 1st AGILE Solar Flare Catalog	May 2007–Aug. 2022 5003 Events	(l)	1SOL

https://www.s

Vercellone+, 2024

Take-home pills

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

Science activities continue. We have just published on Apr. 9, 2025 a paper on the AGILE analysis of some FRBs. A data reprocessing is in progress.

Open-source Python software package **Agilepy** (INAF-OAS, new version 1.6.5, https://agilepy.readthedocs.io/en/1.6.5/quickstart/installation.html) and/or **SSDC AGILE-LV3 online data analysis tool** (https://www.ssdc.asi.it/mmia/index.php?mission=agilelv3mmia)

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.

AGILE is our Yoda:
"Do or do not. There is no try."

AGILE: La fine di un'era

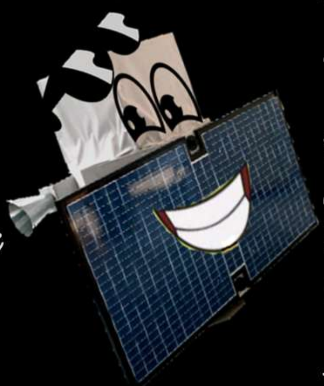
L' ultimo saluto ar piccolo granne AGILE (ner giorno degli innamorati)

"Ormai quasi ben diciassette anni fa,
da' a piccola base indiana de Sriharikota,
partiva 'n satellite piccolo e patriota,
che l' universo gamma voleva osserva'.

Er lancio anno' bene tra applausi e fervore,
AGILE era er nome e l' Italia er genitore .
Co' la sua messa in orbita e li primi risultati,
ricompensava lavoro e sacrificio de scienziate e
scienziati.

Io arivai a conoscelo solo un anno dopo,
affascinata da st'universo sconosciuto,
dall' entusiasmo de'chi lo aveva realizzato
e da'a scienza esplosiva che ciaveva come scopo.

Ero 'na pischella allora, quanno maneggiavo li suoi dati,
e da quer di' davvero tanti anni so' ormai passati.
Tanto che quer piccolo granne economico portento,
com' rammarico 'n mesetto fa' è dovuto esse spento.



Lui nun voleva, s'è pure in parte ribellato,
ma a'a fine s'è areso, dopo esse stato ingannato.
Pe chi l' ha cresciuto e pe noi che ne avemo usufruito,
quello de'a fine de n'epoca er sentimento è stato.

Sto satellitino in cui morti davvero nun credevano,
che ha lottato co'n cugino più grosso e de sòrdi pieno,
è riuscito a lascia' tracce importanti co'a sua presenza
mostranno cose che so'state 'na svorta ne'a scienza

Tra raggi cosmici, radiazioni strane e raggi gamma
da'a Tera,
ha mostrato quanto 'a capacità dell' Italia sia
autentica e sincera.
Quinni, se quarcuno 'a notte scorsa l'ha visto brucia' in
atmosfera,
spero abbia espresso 'n desiderio perché è cascata 'na
stella vera."


Grazie
a tutti voi!