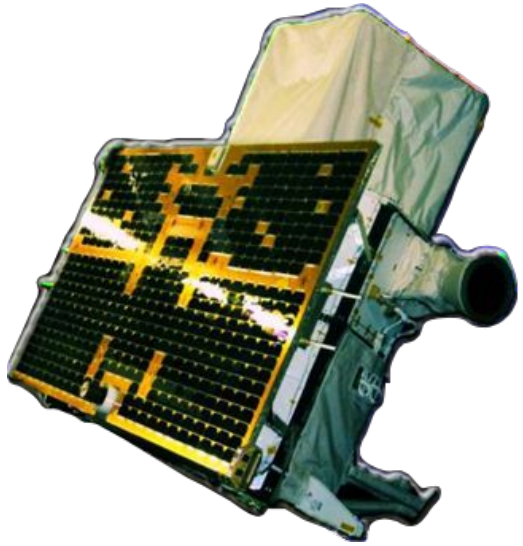


AGILE legacy for CTAO

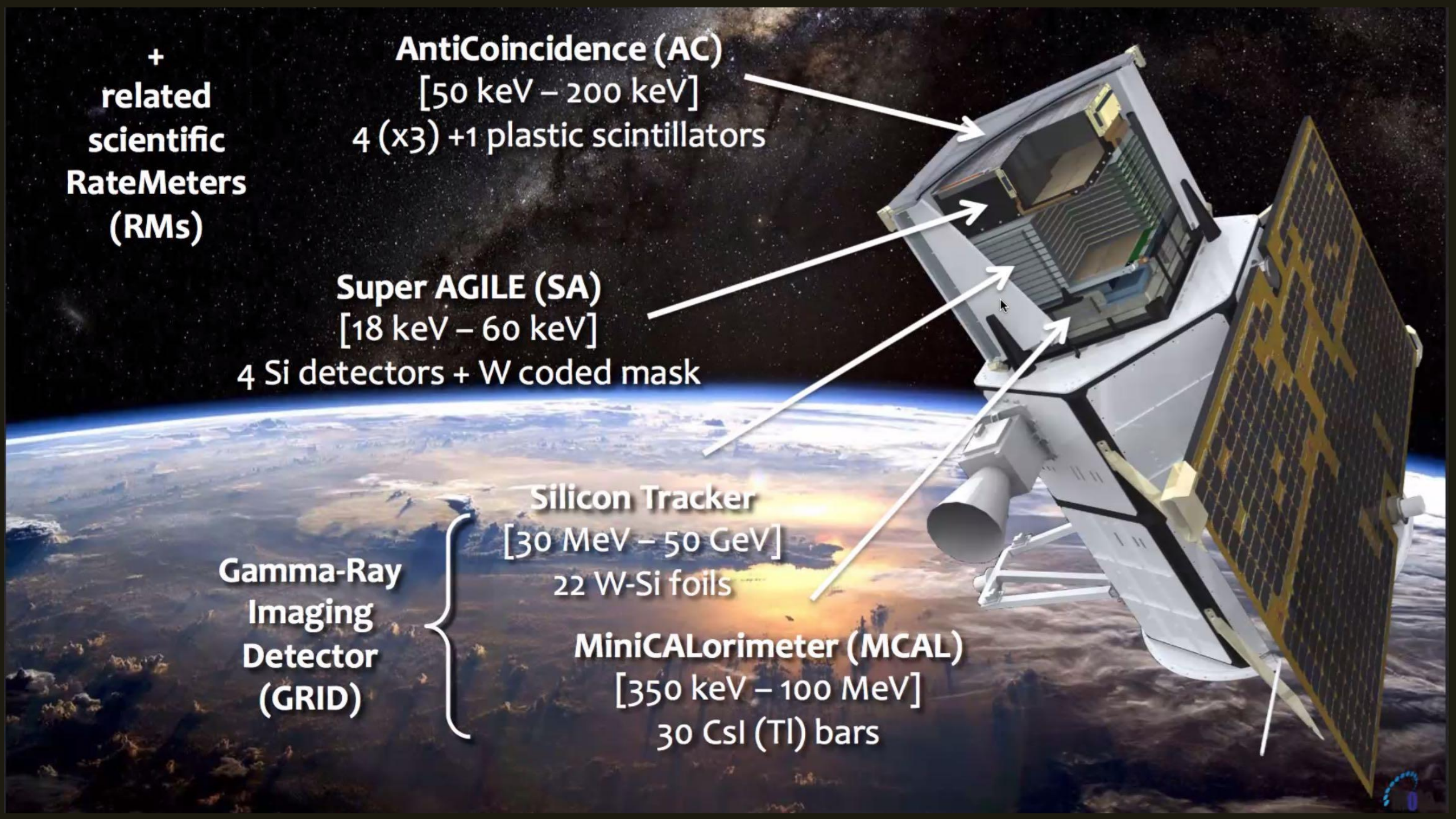
Marco Tavani and Carlotta Pittori (INAF)
on behalf of the AGILE Team

CTAO Science Symposium, 15-18 April 2024. Bologna, 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 nominal status till the end, and active in:

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

Time Control

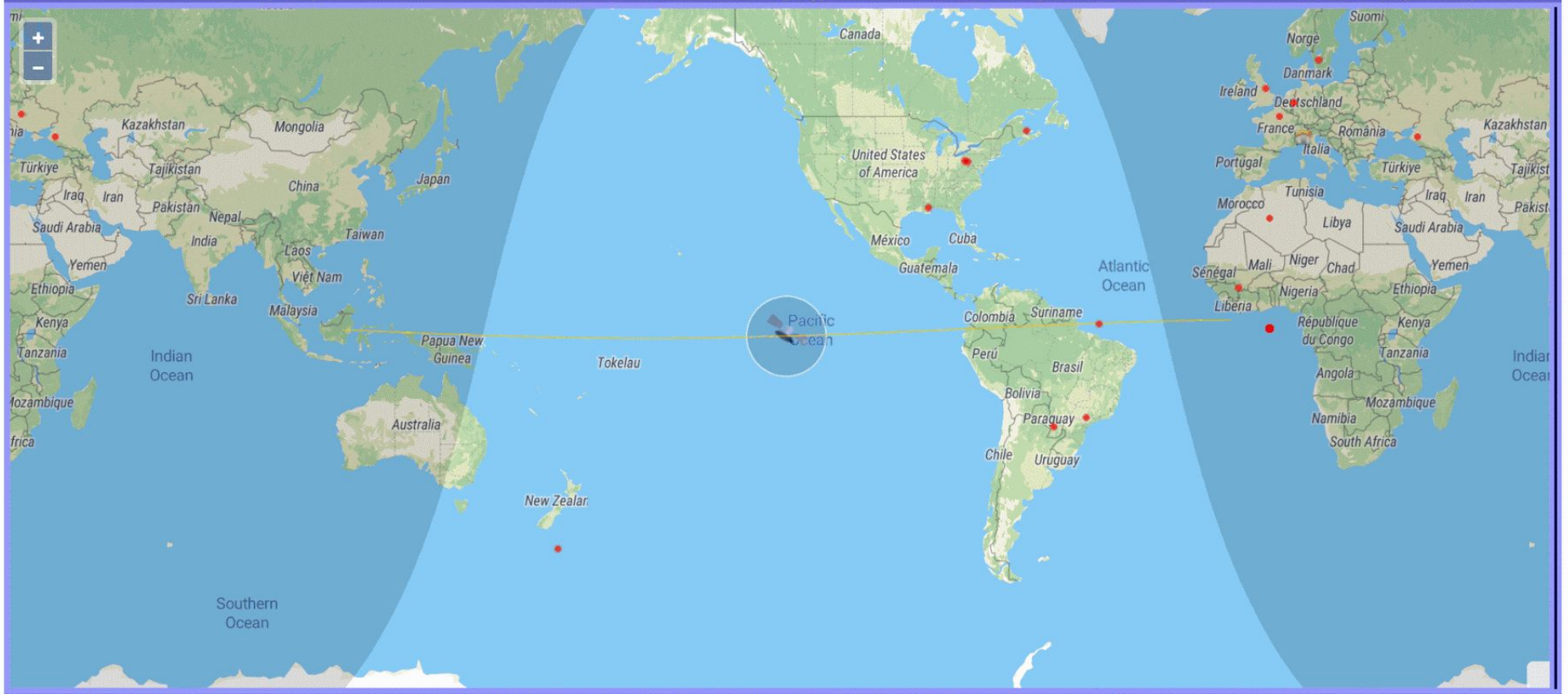
H+	M+	S+
H-	M-	S-
--	<0>	++
TTS	II	▶

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°

Scientific status of AGILE

- **AGILE science observations ended on January 18, 2024. Satellite re-entry on February 13, 2024, as a consequence of natural decay of its low Earth orbit after almost 17 years.**

- **Nominal status till the end of observations.** Actively involved in the hunt for high-energy electromagnetic counterparts of gravitational waves (GW) during the current LIGO-Virgo-Kagra (LVK) O4 observing run, started in May 2023, up to the end of first part (O4a) on Jan 16, 2024.

- AGILE was strongly affected by **limited ground operations at ASI-Malindi** due to the **COVID-19 pandemic.** For more than one year, from March 2020 to May 2021, AGILE has operated with the GRID in standby, only MCAL and ratemeters (RM) on, due to the limited telemetry budged from Malindi (only **3 AGILE passes/day** served, instead of 14).

- **On May 6, 2021,** Malindi has resumed serving ~ 7 passes/day to the AGILE mission, and the **GRID observations** could finally be **restarted**. **Since March 21, 2022 ~ 10 pass/day: GRID on and MCAL (often) at its full sensitivity configuration.**

- "Make virtue of necessity": during the limited TM period, **much improved RM analysis**, **automatic processing and burst identification**. The system was also updated for the follow-up of **Solar flares**.

AGILE CONTROL ROOM

Control Room - Data Flow

Next Contact

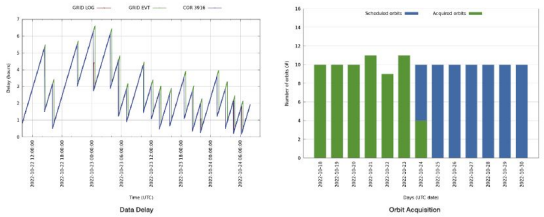
Contact Number = 80625
Configuration = MCAL BASE
Time For Contact = 83 minutes
Start: 2022-10-24 06:02:31 (UTC)
Stop: 2022-10-24 09:22:06 (UTC)
Next Contact Time For Data (Prevision)
MCAL @ Bologna = 2022-10-24 09:47:06 (UTC)
GRID @ Bologna = 2022-10-24 09:52:06 (UTC)

Orbit List

Contact Time (UTC)	Orbit Number	Scheduled	Conf
2022-10-24 01:02:58	80620	Yes	MCAL BASE
2022-10-24 02:42:51	80621	Yes	MCAL1 ON
2022-10-24 04:22:41	80622	Yes	MCAL1 ON
2022-10-24 06:02:31	80623	Yes	MCAL1 ON
2022-10-24 07:42:19	80624	Not	MCAL BASE
2022-10-24 09:22:06	80625	Yes	MCAL BASE
2022-10-24 11:01:54	80626	Yes	MCAL1 ON
2022-10-24 12:41:41	80627	Yes	MCAL1 ON
2022-10-24 14:21:27	80628	Yes	MCAL1 ON
2022-10-24 16:01:14	80629	Yes	MCAL1 ON

Full List

Data Flow Status



Operational Snapshot as of Oct 24, 08:07 UTC

Detector	Status	Duration
GEO 600	Unlocked	2:10
LIGO Hanford	Down	>134:19
LIGO Livingston	Down	>134:19
Virgo	Info too old	
KAGRA	Down	>134:21

Detector status summary pages LVK

Ratemeters pipeline - Home Page

AGILE RM | Home | Control Room

Contact List

Show 50 entries Search:

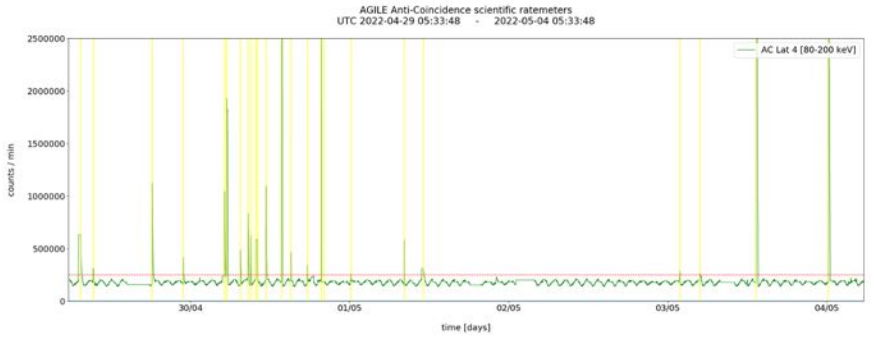
Contact Number	Time Start (UTC)	Time Stop (UTC)	Contact Detail			
080623	2022-10-24T04:21:41	2022-10-24T06:10:51	Contact RM	Solar Monitoring LC	Monitoring AC4	Contact Checked
080622	2022-10-24T02:25:51	2022-10-24T04:23:21	Contact RM	Solar Monitoring LC	Monitoring AC4	Contact Checked
080621	2022-10-24T00:03:57	2022-10-24T02:34:47	Contact RM	Solar Monitoring LC	Monitoring AC4	Contact Checked
080620	2022-10-23T21:38:31	2022-10-24T00:09:21	Contact RM	Solar Monitoring LC	Monitoring AC4	Contact Checked

MCAL pipeline: GRBs, GRBlikes, Sub-threshold events (STEs), TGFs:

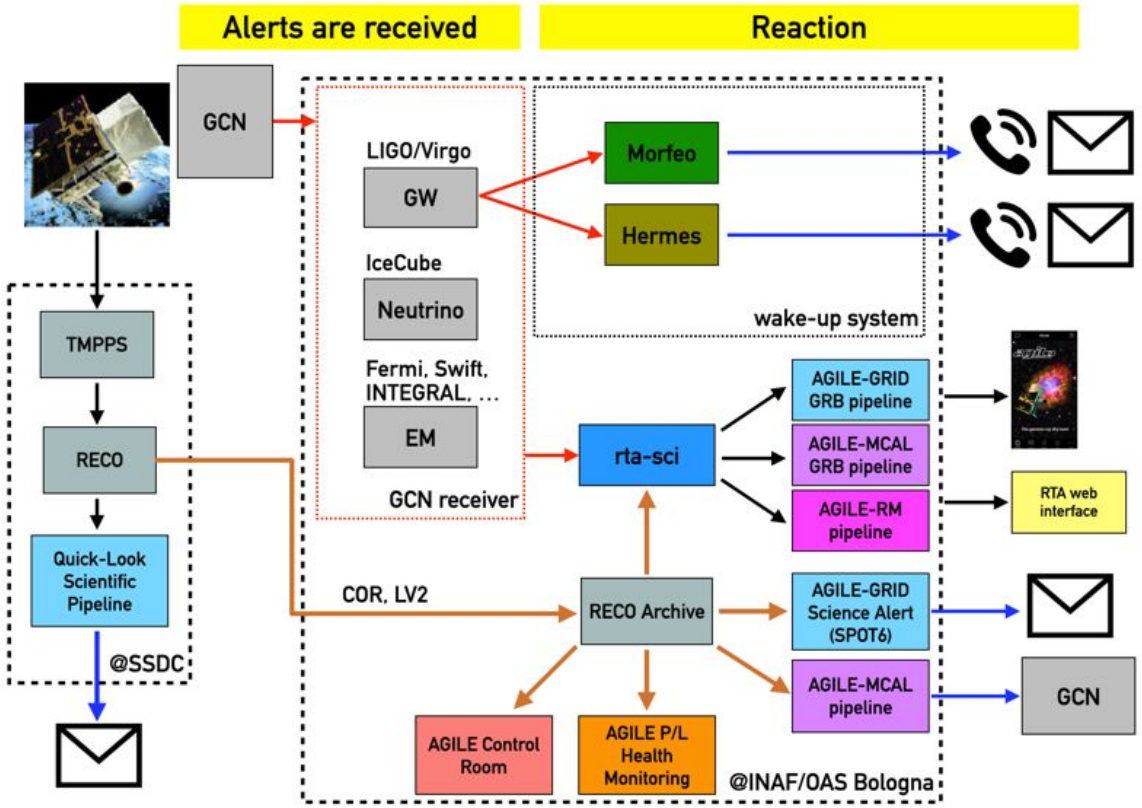
MCAL last 5 contacts

Contact Number	First Trigger (UTC)	Last Trigger (UTC)	N of triggers	GRBs	GRBlikes	STEs	TGFs	Actions
085641	2023-10-04 18:15:28	2023-10-04 20:09:35	133	0	4	0	0	Orbit Trend Triggers GRB GRBlike STE TGF
085640	2023-10-04 15:29:04	2023-10-04 18:14:42	59	0	1	0	0	Orbit Trend Triggers GRB GRBlike STE TGF
085638	2023-10-04 13:34:06	2023-10-04 15:29:04	123	0	3	0	0	Orbit Trend Triggers GRB GRBlike STE TGF
085637	2023-10-04 11:24:19	2023-10-04 12:29:22	65	0	0	0	0	Orbit Trend Triggers GRB GRBlike STE TGF
085635	2023-10-04 09:05:05	2023-10-04 10:57:36	96	0	1	0	0	Orbit Trend Triggers GRB GRBlike STE TGF

Automatic Solar monitoring:



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**

PhD Nicolò Parmiggiani: National award for research on big data and artificial intelligence 2021!

See Poster ID-044 N. Parmiggiani et al.: *"The AGILE Real-Time Analysis software system"*

- 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

AGILE main results and work in progress

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 ATel** and **>300 GCN**. 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 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

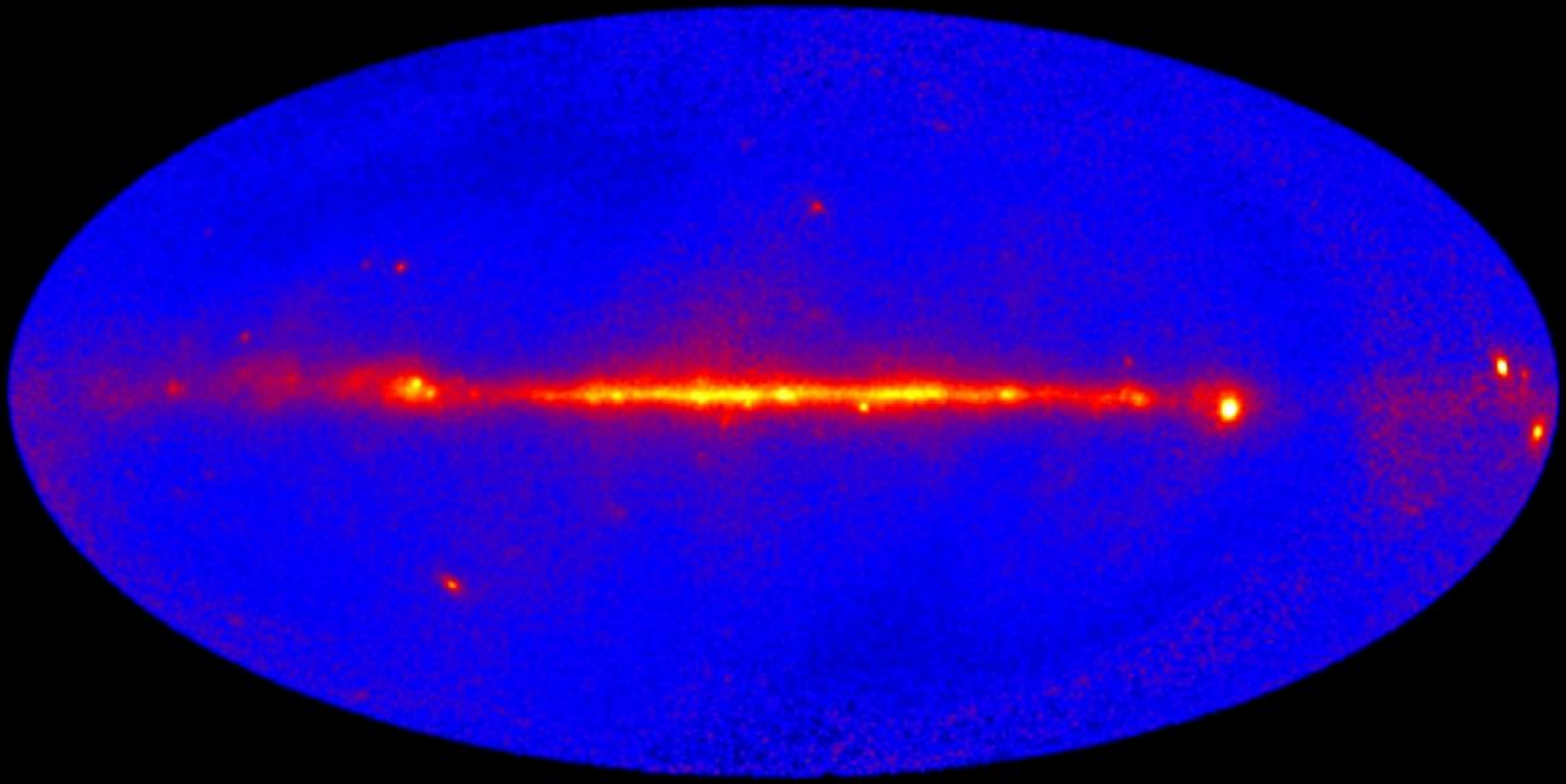
#	DOI	Descrizione	
1	10.1051/0004-6361/200810527	Titolo: The AGILE Mission Autori:M. Tavani and G. Barbiellini and A. Argan and F. Boffelli and A. Bulgarelli and P. Caraveo and P. W .... Publisher:EDP Sciences Rivista: Astronomy \& Astrophysics Anno pubblicazione:2009	The AGILE Mission
2	10.1126/science.1200083	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

Two 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!**

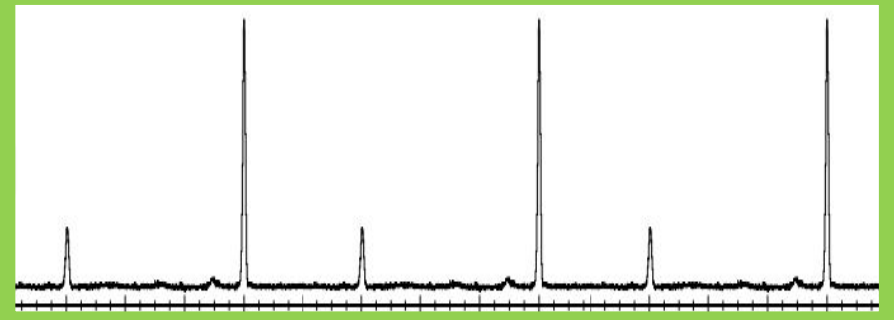
- **First direct evidence of cosmic ray acceleration in Supernovae remnants with the AGILE observations of the SNR W44 (2017 Matteucci Medal of the National Academy of Sciences to Marco Tavani)**

The AGILE Gamma-ray Sky



The Crab Nebula: expanding remnant of a SN explosion recorded by Japanese and Chinese astronomers in 1054 A.D

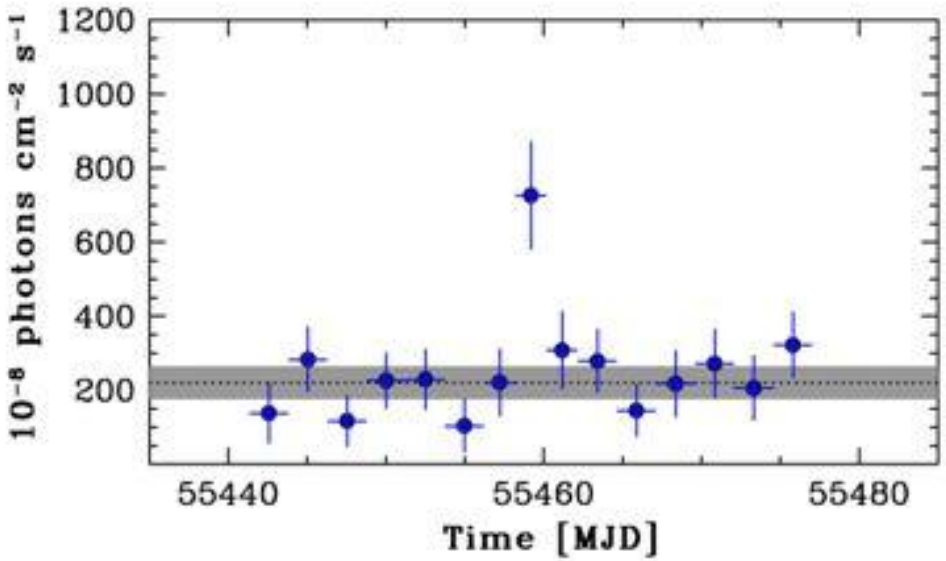
The Crab Nebula
(X rays, 1-10 keV, Chandra)



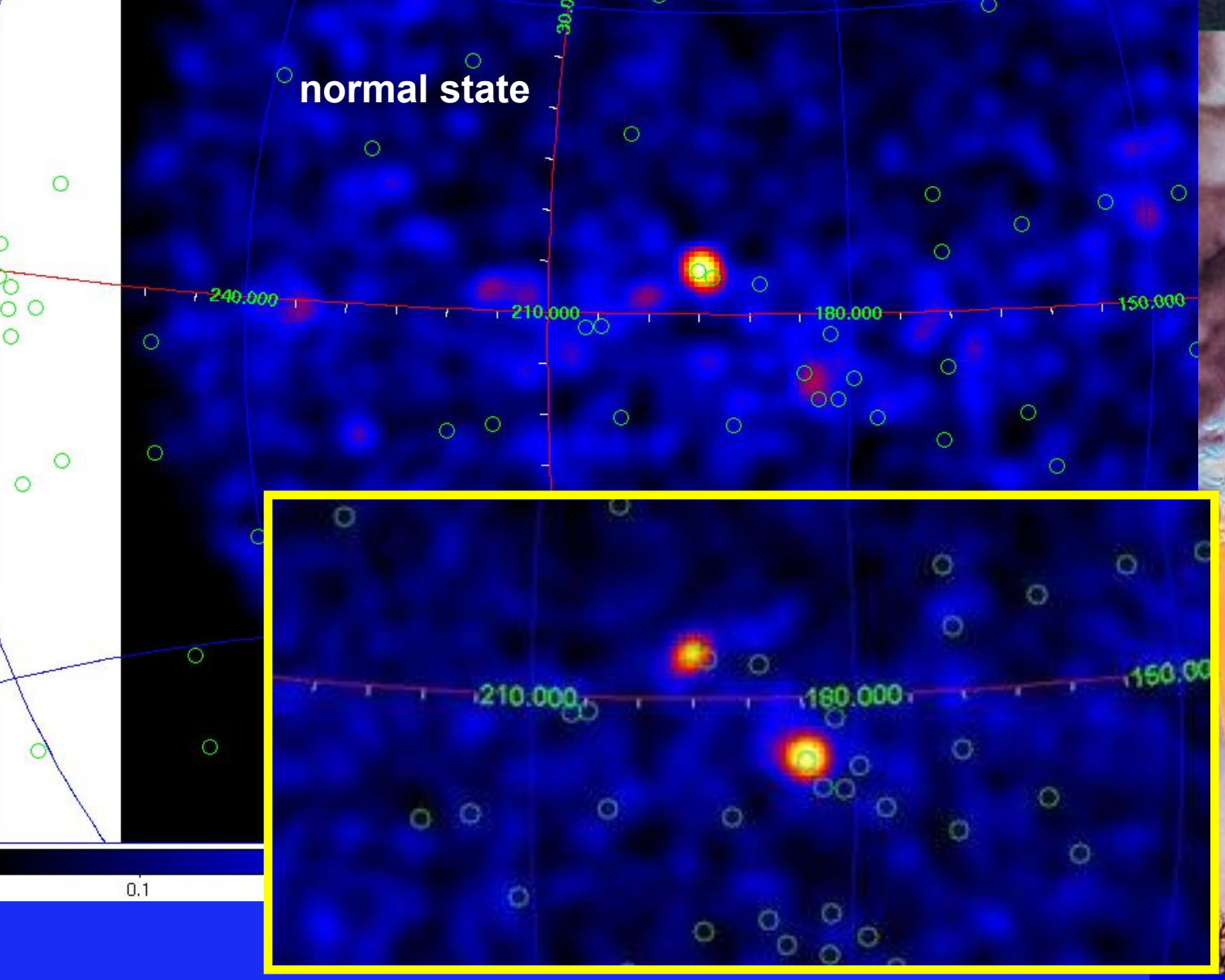
radio-pulsar at the center

but … the Crab is flaring in gamma-rays !!!

FIRST PUBLIC ANNOUNCEMENT Sept. 22, 2010: AGILE issues the Astronomer's Telegram n. 2855



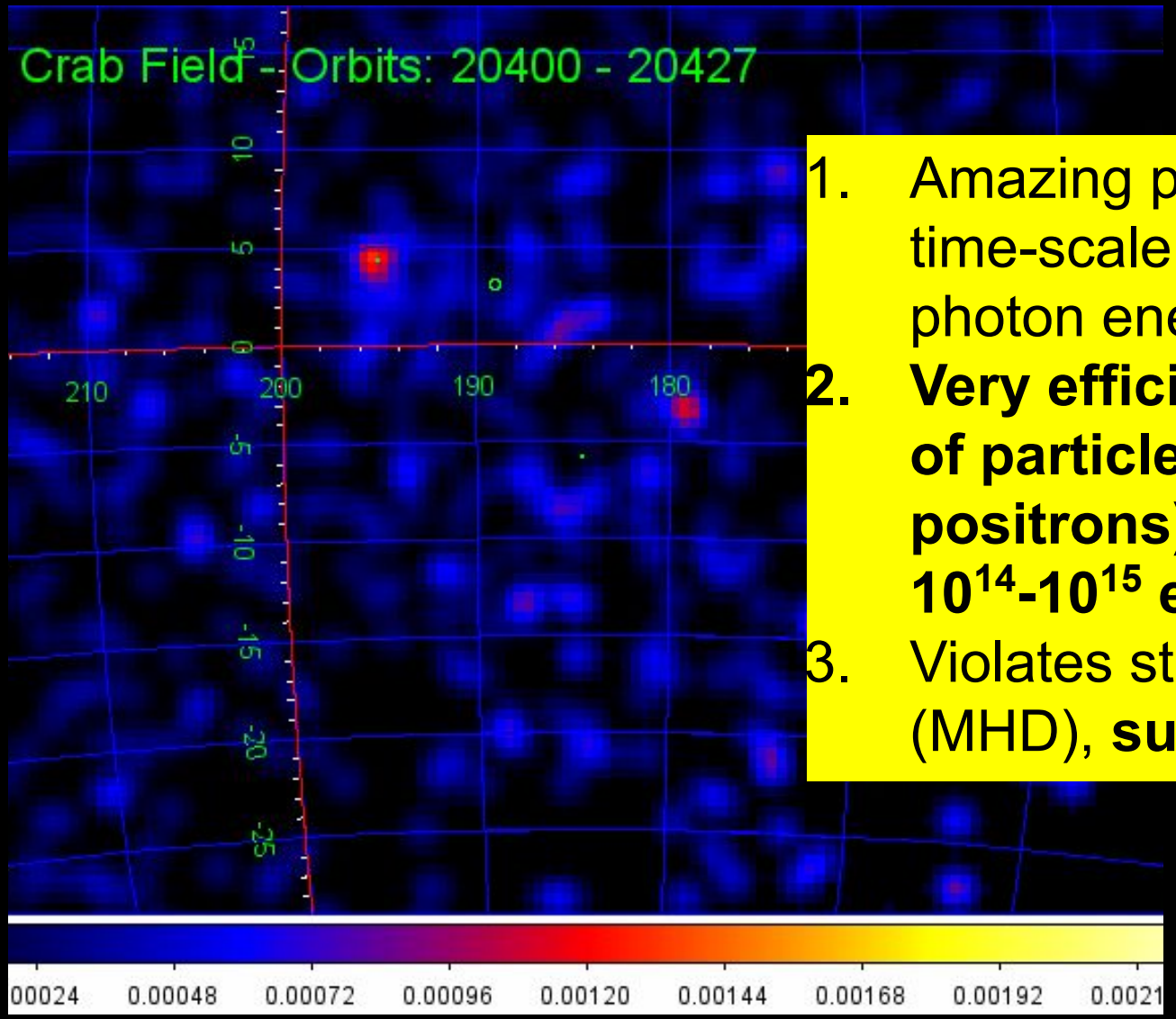
Science Express **(6 January 2011)**



Gamma-ray flaring state: 20-21 Sept. 2010

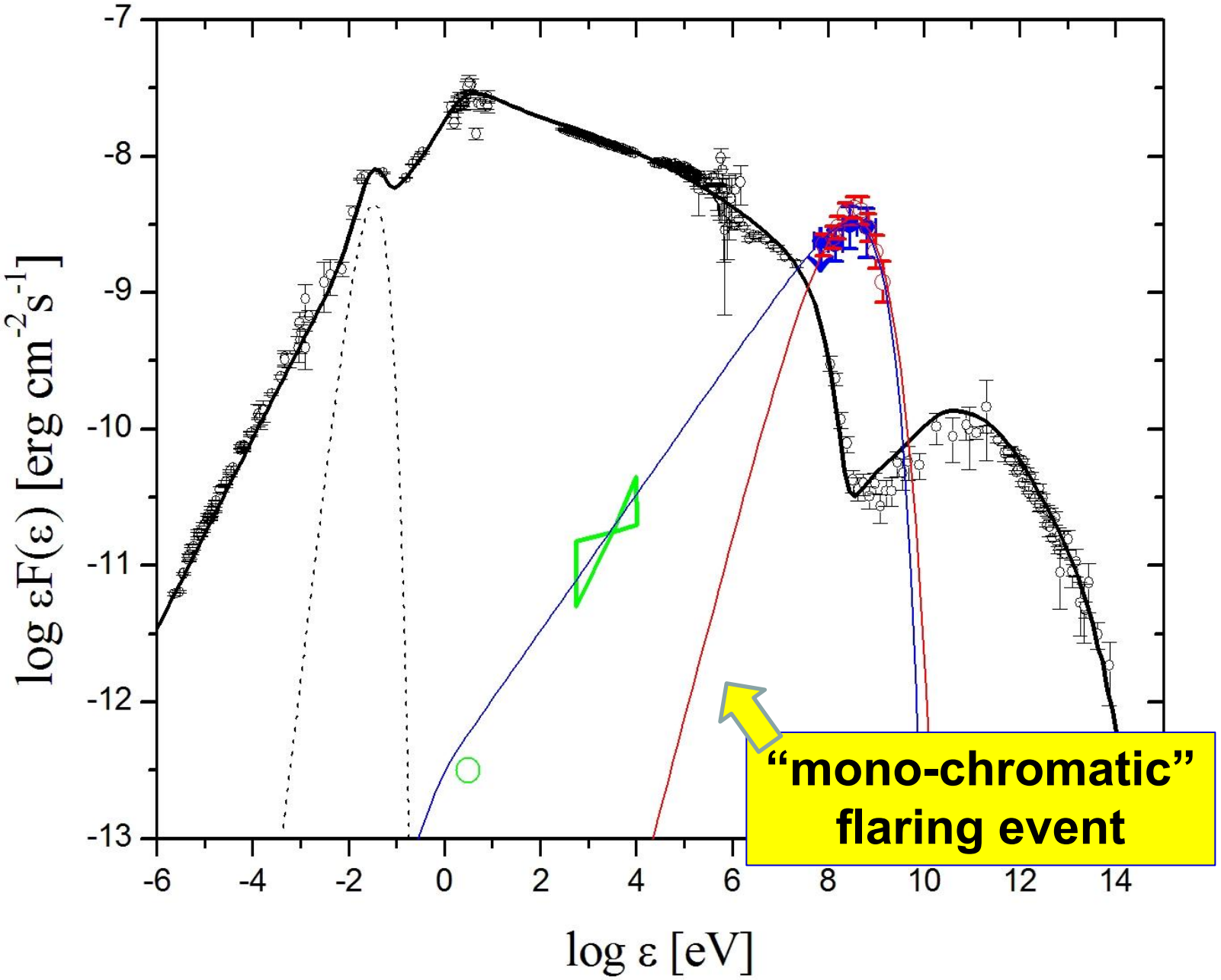
CRAB: not a "standard candle" in gamma-rays!!!

Crab Nebula variable gamma-ray emission
(AGILE, April 2011)

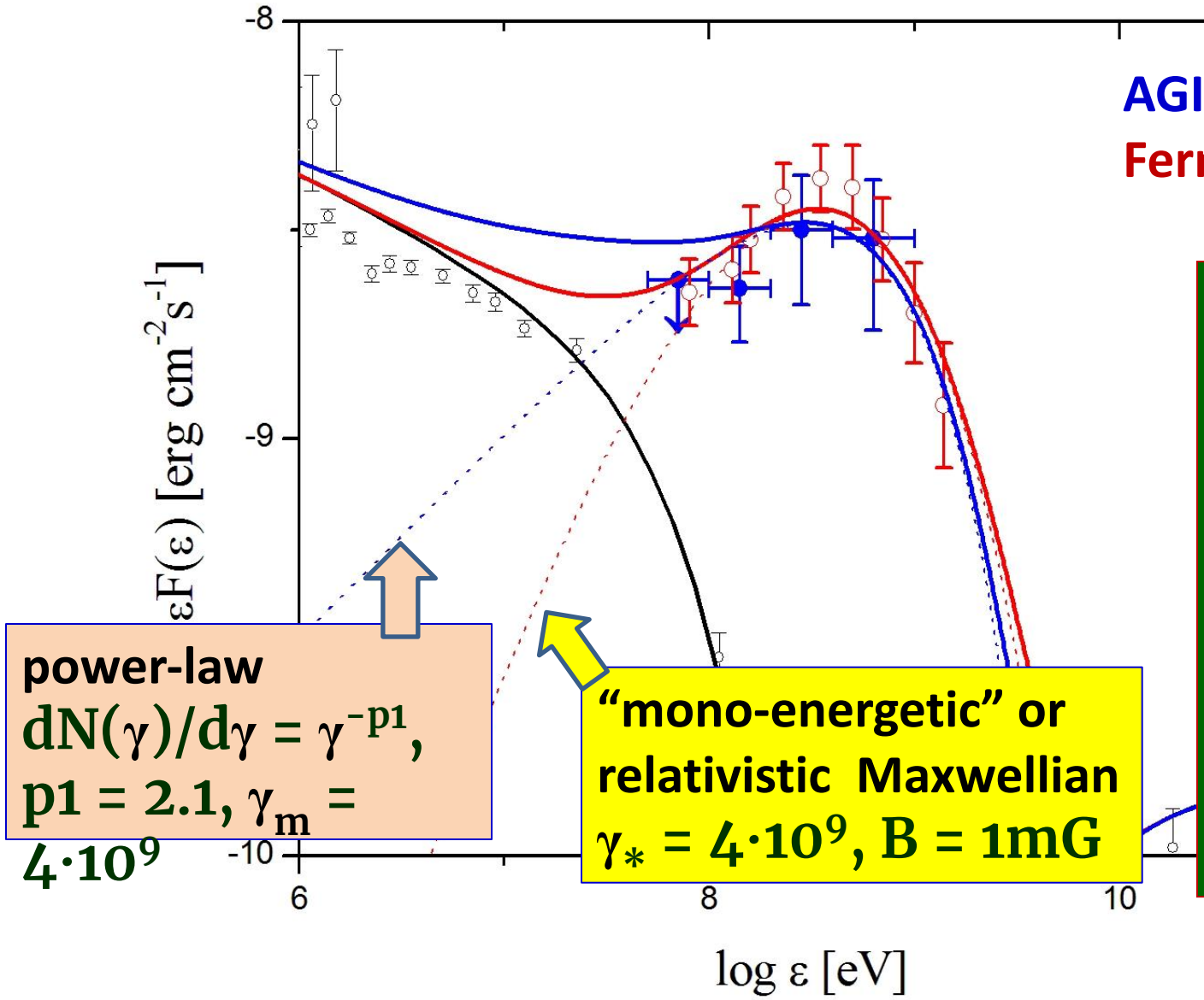


1. Amazing phenomenon, time-scale of **a few hours**, photon energies at GeV.
2. **Very efficient acceleration of particles (electrons and positrons) of energy 10^{14}-10^{15} eV.**
3. Violates standard conditions (MHD), **super-acceleration**.

April 2011 event: Crab gamma-ray flare spectrum at its peak



Modelling of the April 2011 super-flare



power-law
$dN(\gamma)/d\gamma = \gamma^{-p1}$,
$p1 = 2.1$, $\gamma_m = 4 \cdot 10^9$

"mono-energetic" or relativistic Maxwellian
$\gamma_* = 4 \cdot 10^9$, B = 1mG

E/B ≳ 3 !

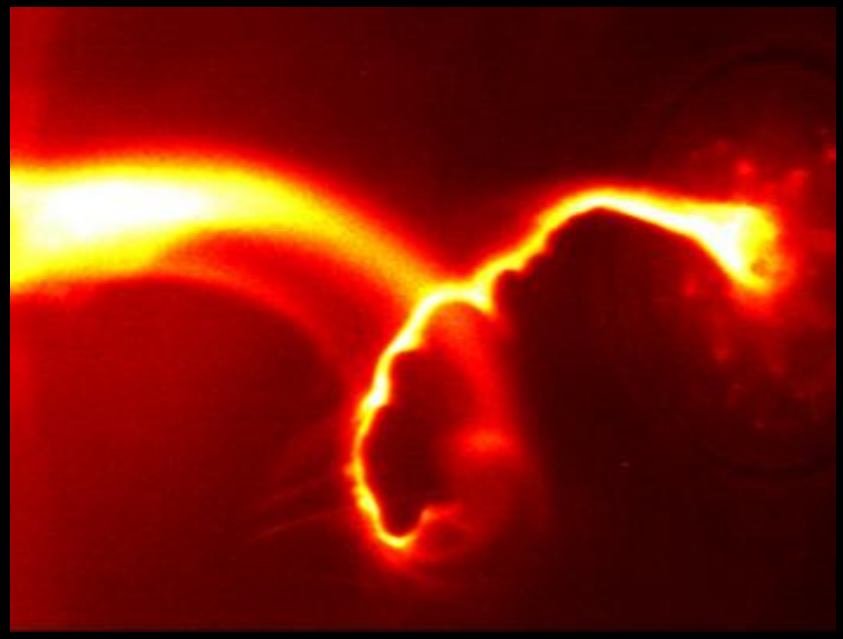
Not diffusive super-acceleration !

Magn. field reconnection

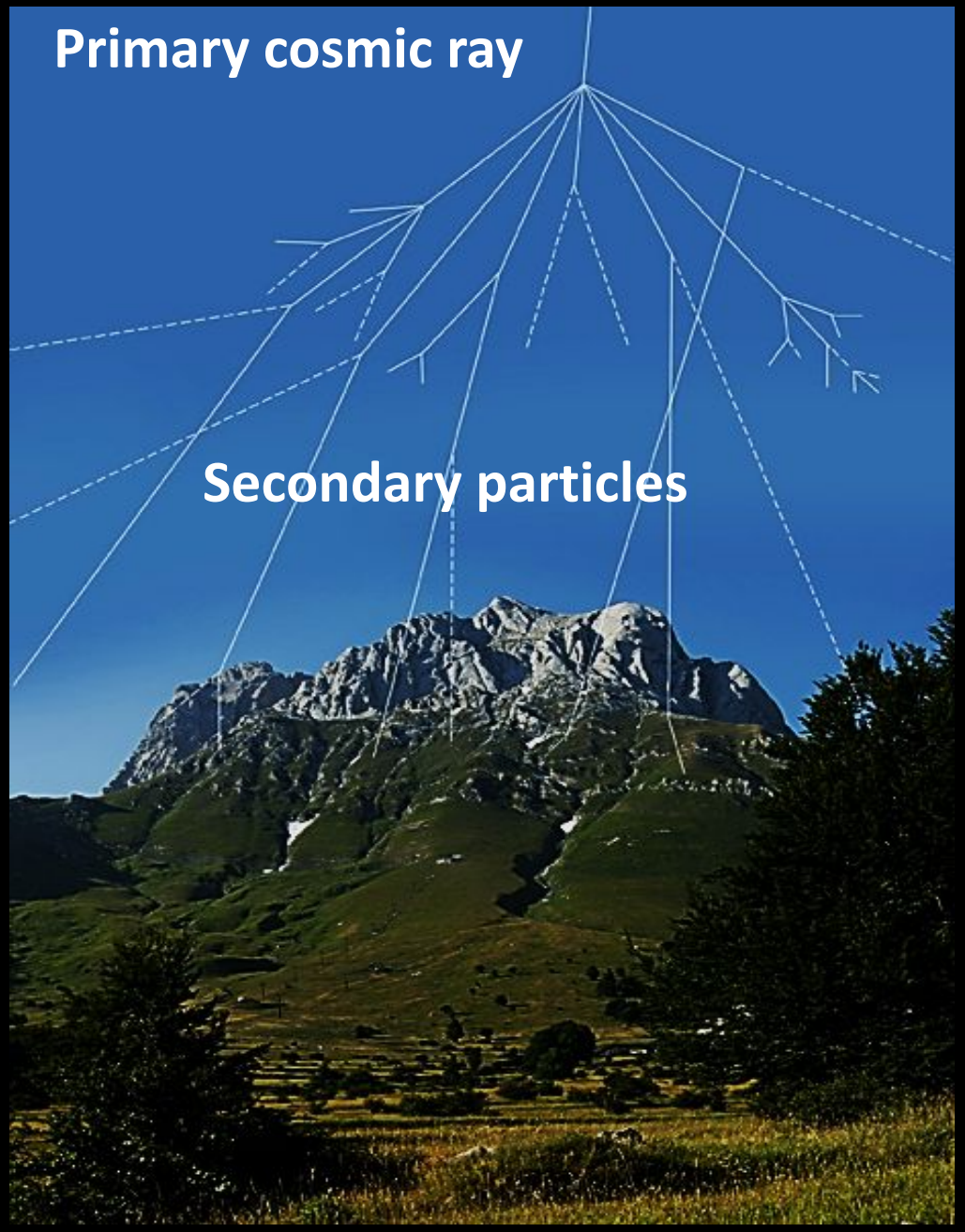
WHERE ?

Plasma magnetic instability

1. Reconnection of the magnetic field in 'islands' of instabilities.
2. **Particle acceleration in magnetic reconnection events.**
3. Link with laboratory plasma experiments for nuclear fusion energy production.



A.L. Moser, P. Bellan, Nature , 482, 379 (2012)

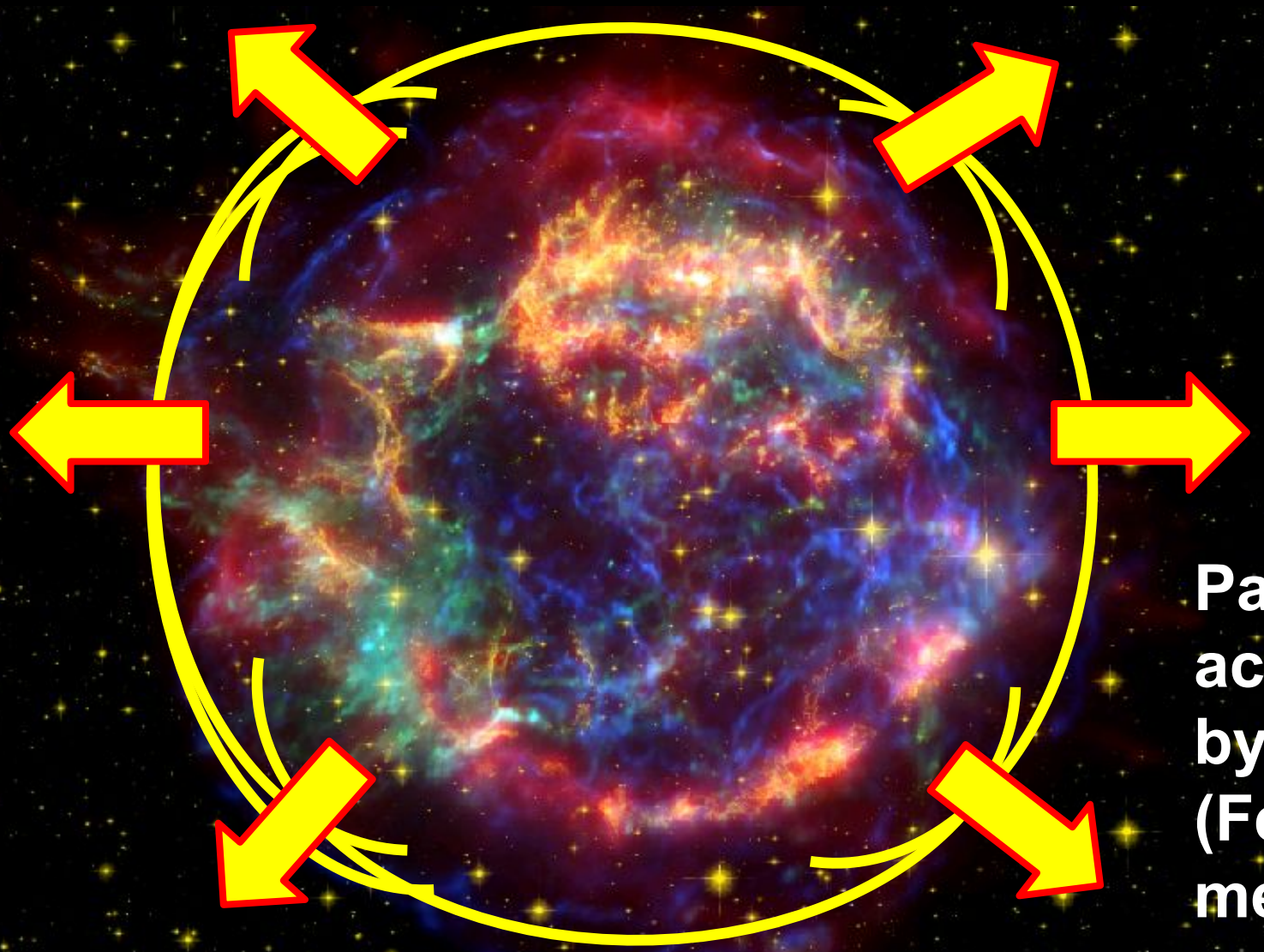


Cosmic Rays (protons and ions)

as yet unidentified origin :

- **Galactic (up to 10^{15}-10^{16} eV)**
- **Extragalactic (up to 10^{20} eV)**

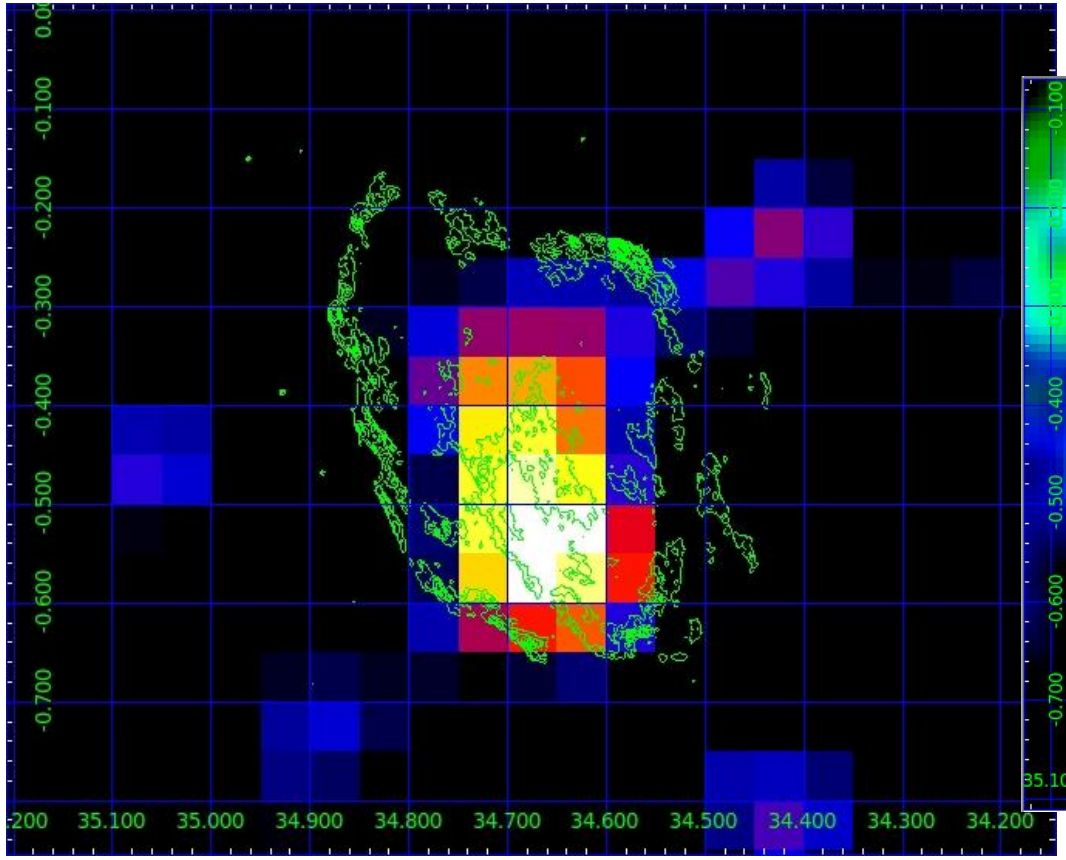
Cosmic Rays origin from Supernova Remnants ?



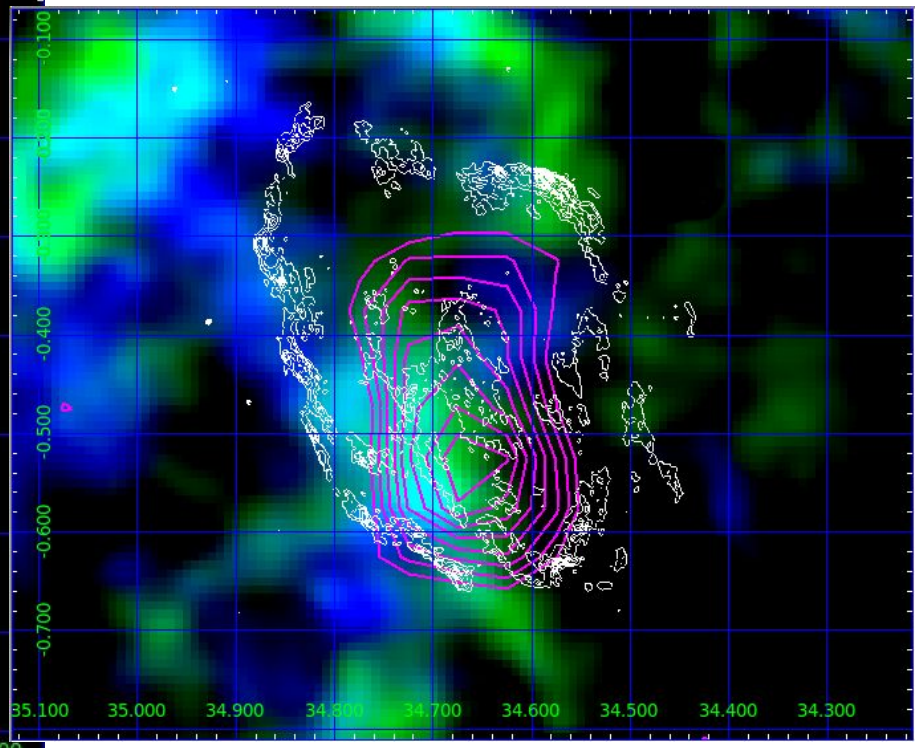
Particles accelerated by shocks (Fermi mechanism)

SNR Cas A (1680).
Credit NASA

W44

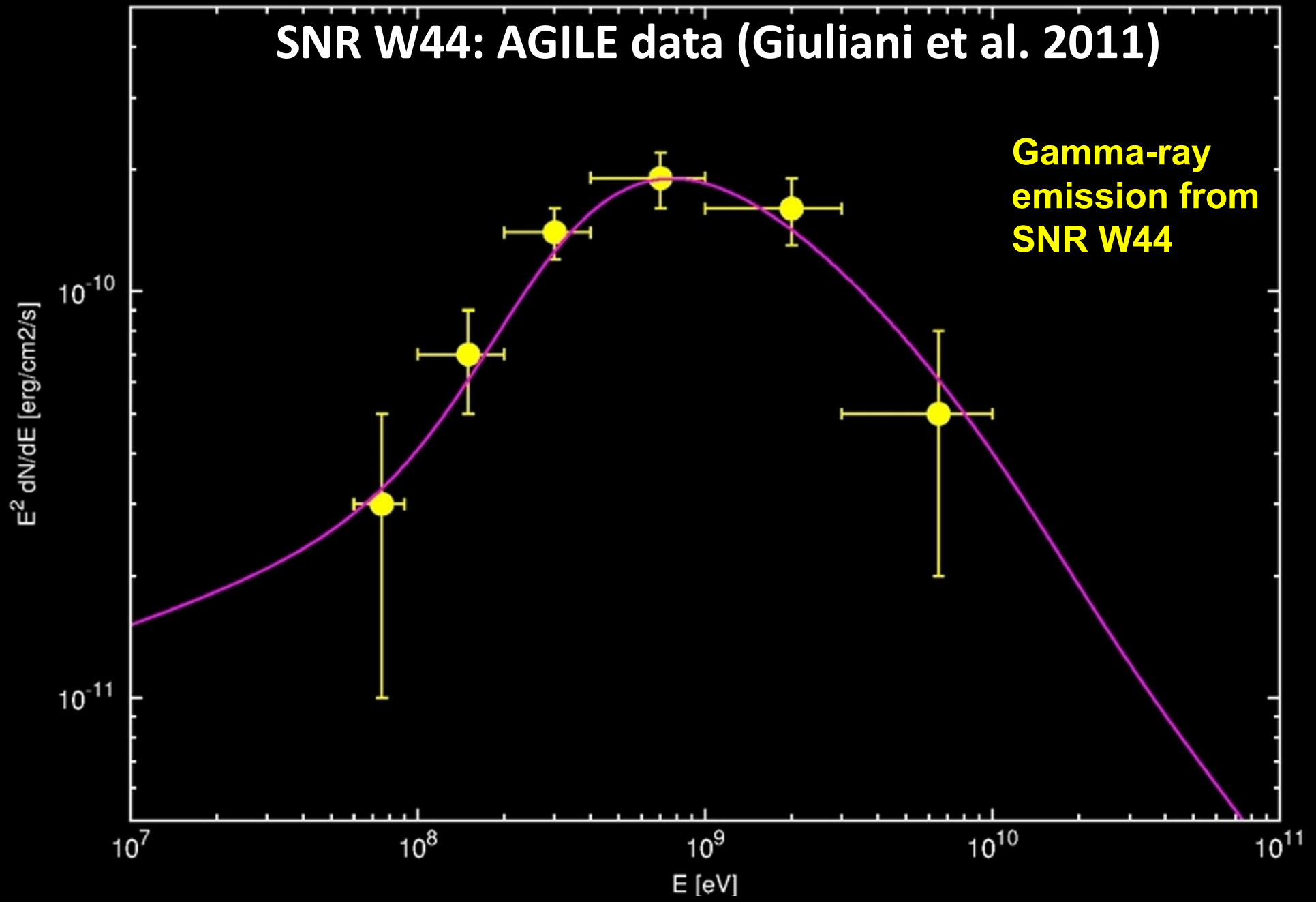


AGILE intensity map E: 400-10000 MeV
VLA contours

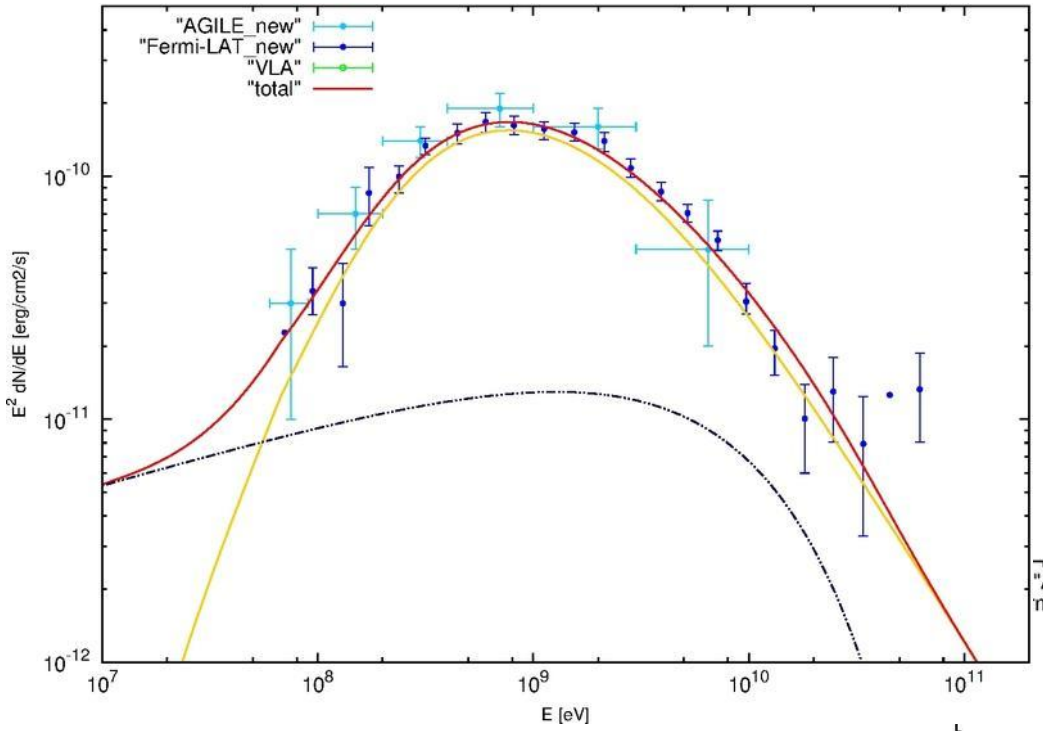


NANTEN2 CO map
41 km/s (green), 43 km/s (blue)
AGILE 400-10000 MeV cont. (magenta)
VLA contours (white)

SNR W44: AGILE data (Giuliani et al. 2011)



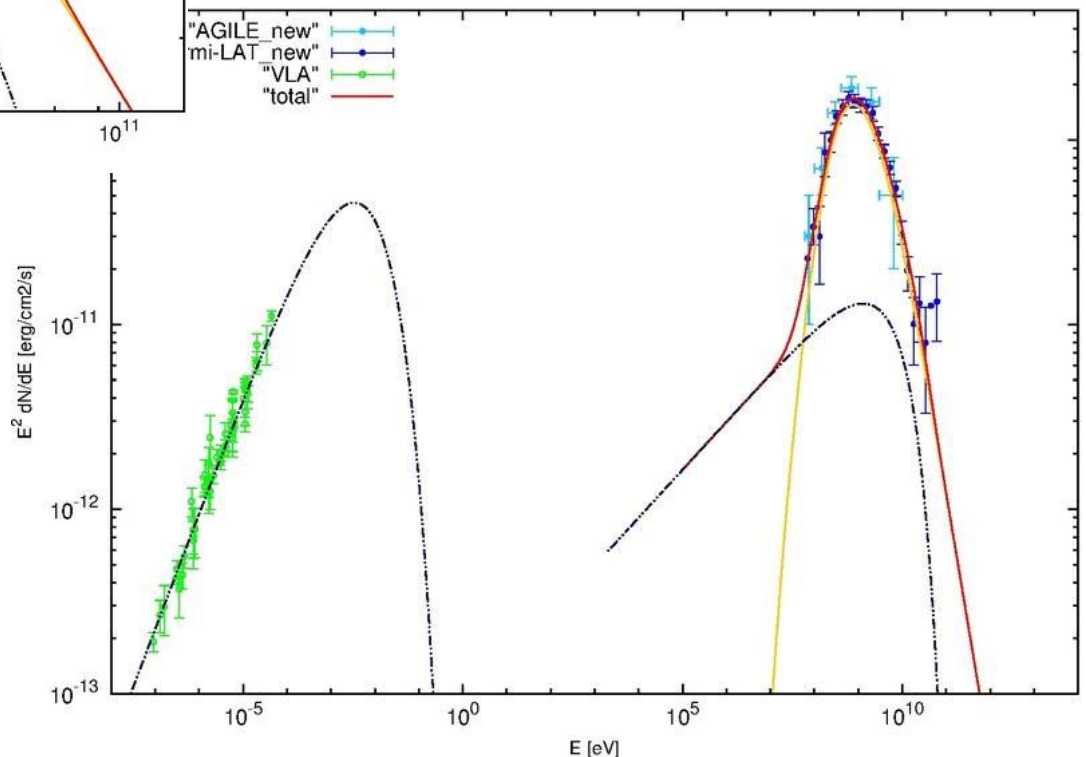
W44



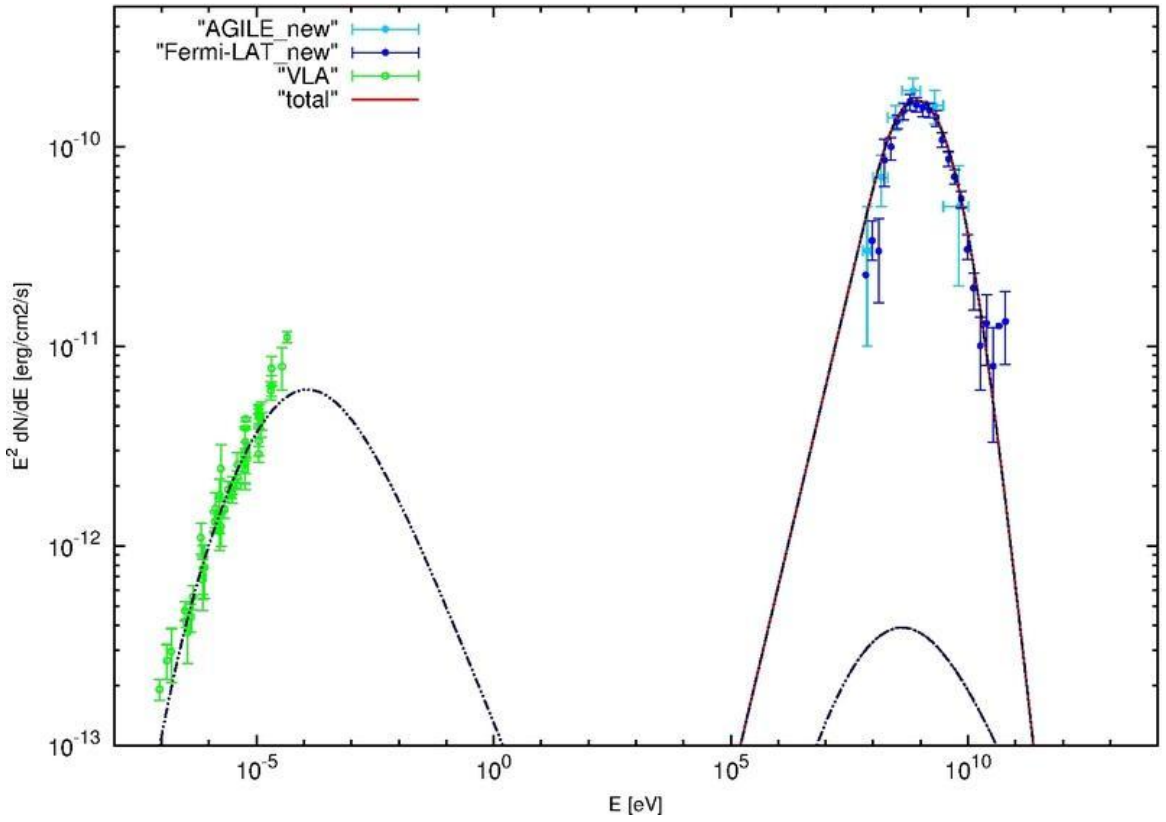
Best hadronic model:

- B=160 microG
- n=300 cm^-3
- Broken power law for hadrons with: p1=2, p2=3.5

-Simple power law for leptons: e1=1.74



W44



***ad hoc* leptonic model:**

- B=25 microG
- n=300 cm^-3
- Broken power law with:

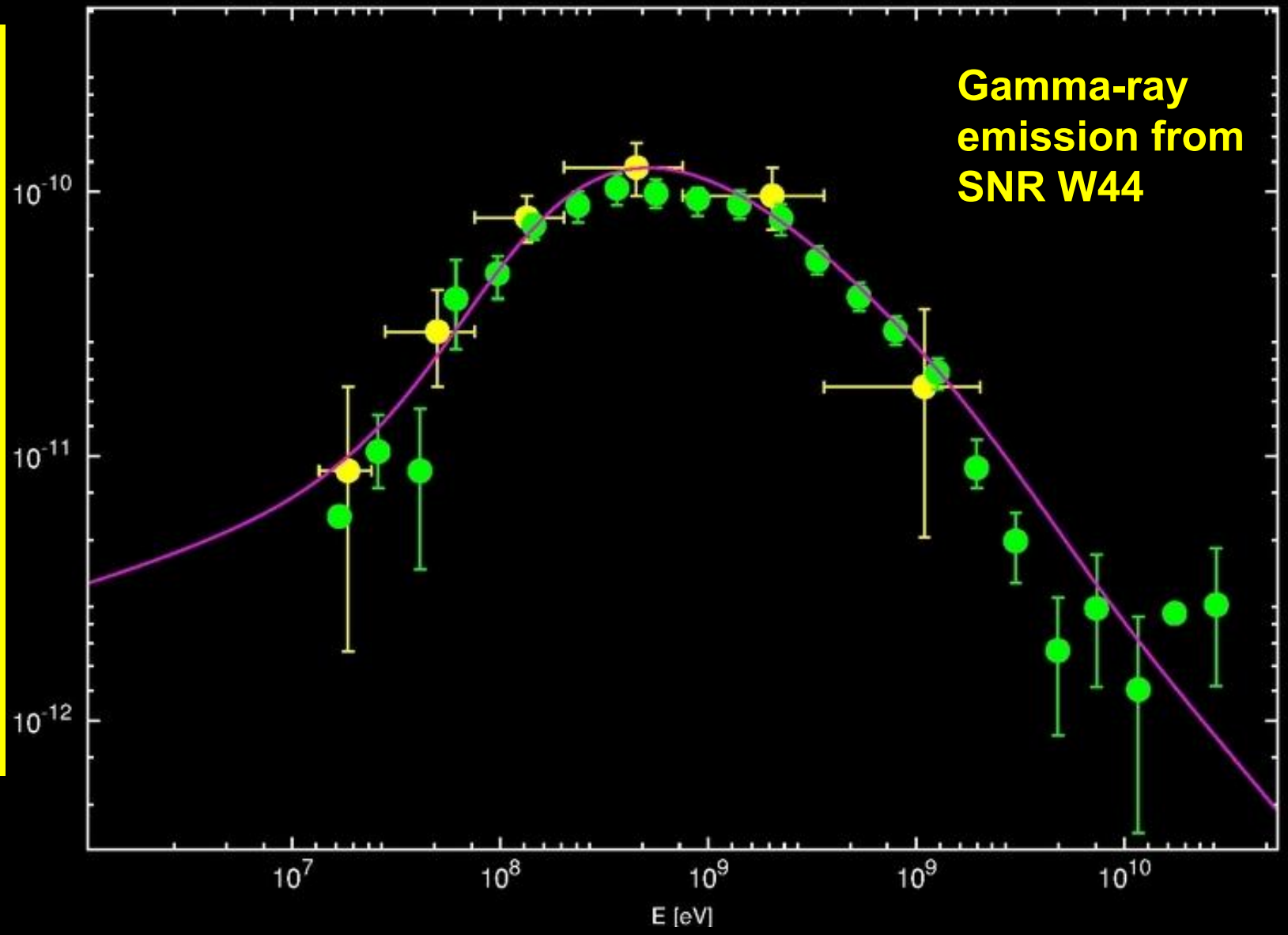
e1=1.74, e2=4.2

-No good fit with radio data

- No good fit low-energy gamma-ray data

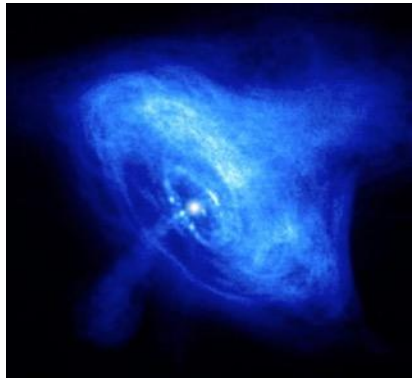
SNR W44: AGILE data (yellow) and Fermi data (green)

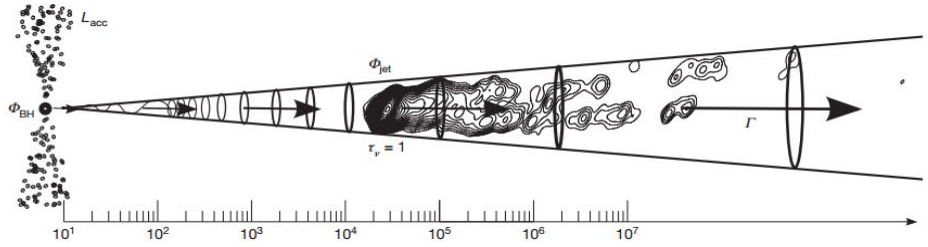
1. First evidence of proton/ion acceleration in a SNR: "pion bump"
2. **Ion acceleration is very effective in young SNR.**
3. Ongoing search for gamma emission from SNR in accordance with expectations for high-energy cosmic rays of 10^{15} eV.



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]
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[2] Università degli Studi di Roma Tor Vergata, via della Ricerca Scientifica 1, I-00133 Roma (RM), Italy
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[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
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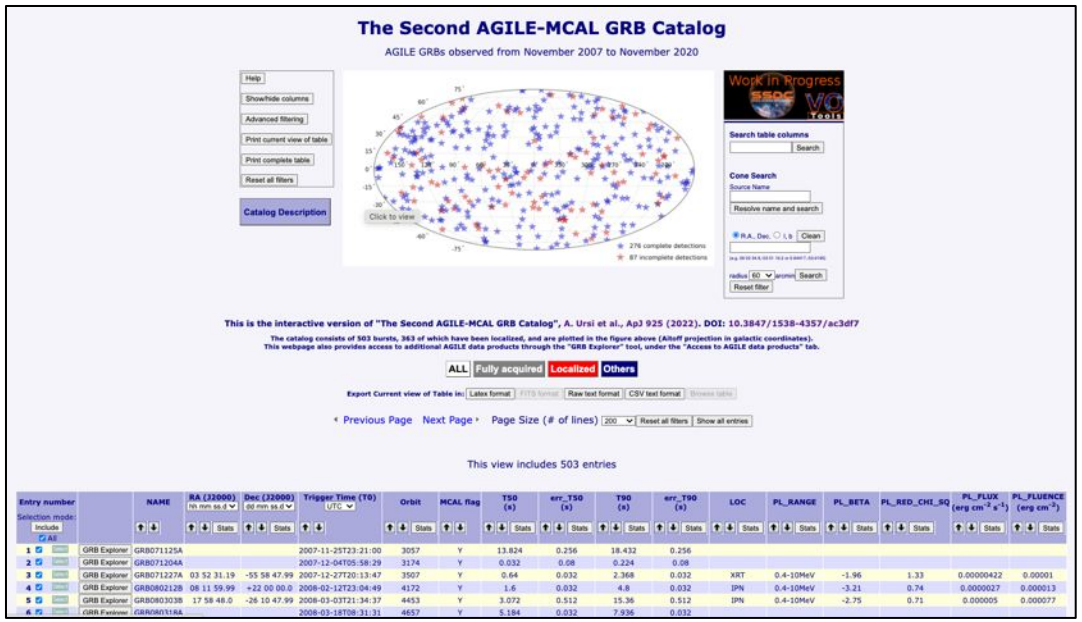
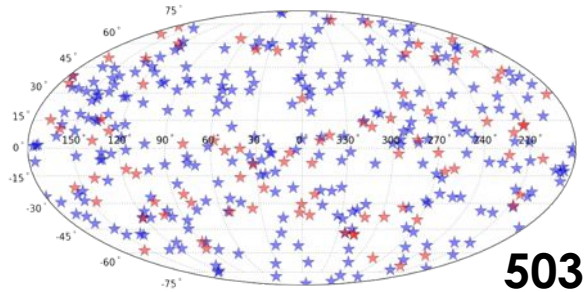
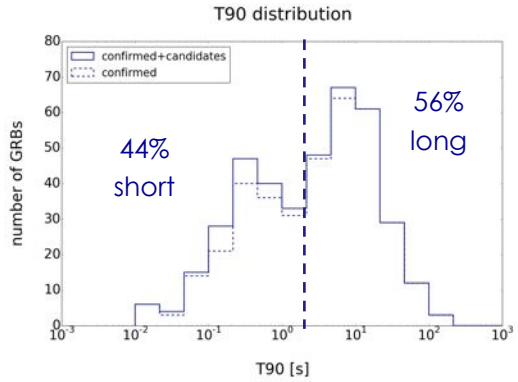
[10] School of Physics, Wits University, Johannesburg, South Africa
[11] Dipartimento di Fisica, Università di Trieste and INFN, via Valerio 2, I-34127 Trieste (TR), Italy
[12] INAF—Osservatorio Astronomico di Brera, via E. Bianchi 46, I-23807 Merate (LC), Italy
Received 2021 July 8; revised 2021 November 8; accepted 2021 November 24; published 2022 February 2

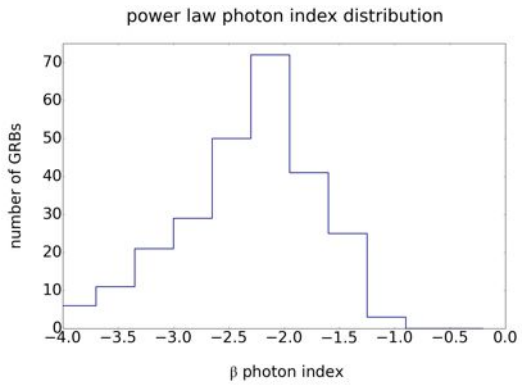


SSDC interactive web page
https://www.ssdc.asi.it/mcal2grbcat/



503 GRBs



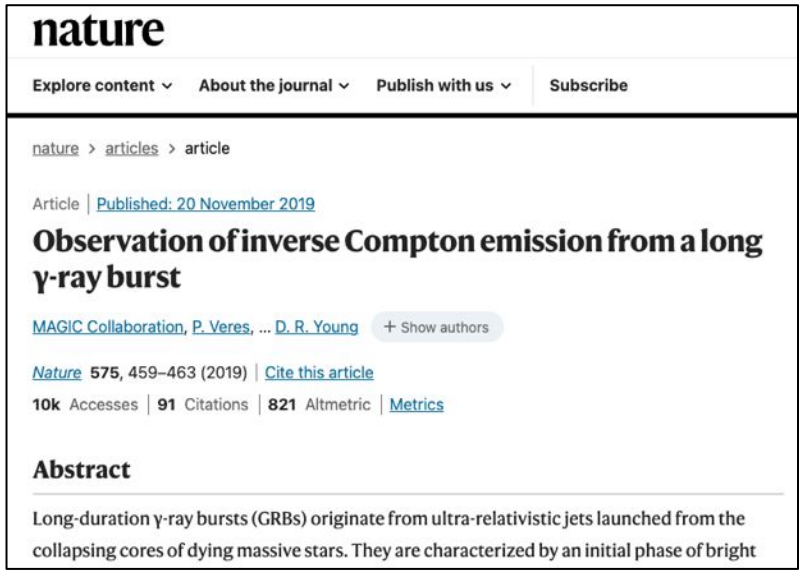


Spectra mostly fittable with power-laws (high-energy tail of the spectra in MCAL band)

GRB 190114C

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

- 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*]



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Article | Published: 20 November 2019

Observation of inverse Compton emission from a long γ-ray burst

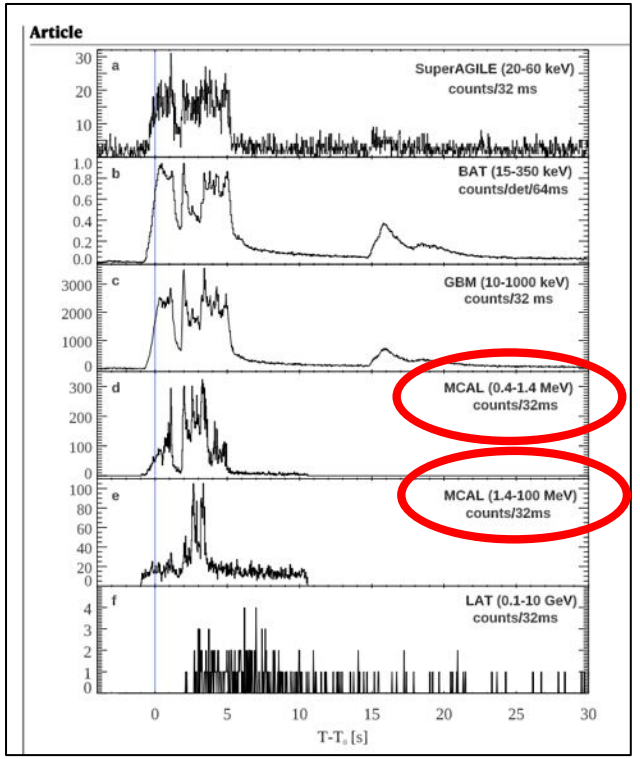
MAGIC Collaboration, P. Veres, ... D. R. Young + Show authors

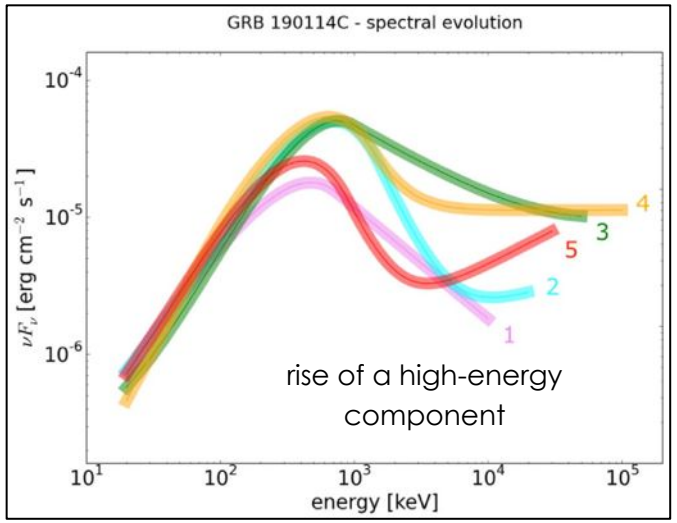
Nature **575**, 459–463 (2019) | Cite this article

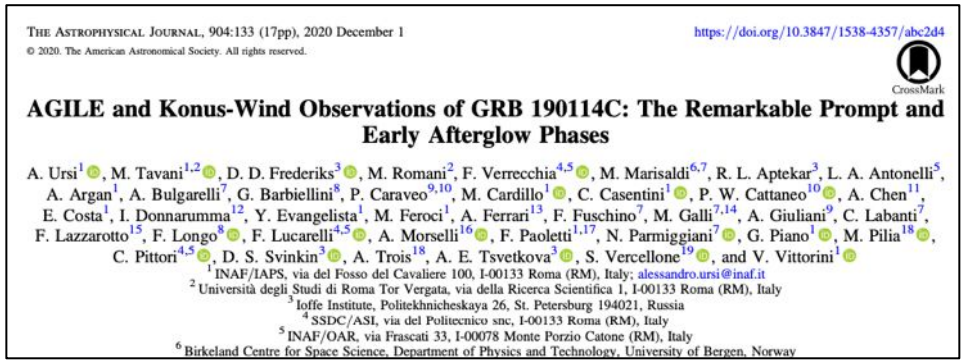
10k Accesses | **91** Citations | **821** Altmetric | Metrics

Abstract

Long-duration γ-ray bursts (GRBs) originate from ultra-relativistic jets launched from the collapsing cores of dying massive stars. They are characterized by an initial phase of bright







The Astrophysical Journal, 904:133 (17pp), 2020 December 1 https://doi.org/10.3847/1538-4357/abc2d4

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AGILE and Konus-Wind Observations of GRB 190114C: The Remarkable Prompt and Early Afterglow Phases

A. Ursi[1], M. Tavani[1,2], D. D. Frederiks[3], M. Romani[2], F. Verrecchia[4,5], M. Marisaldi[6,7], R. L. Aptekar[3], L. A. Antonelli[5], A. Argan[1], A. Bulgarelli[7], G. Barbiellini[8], P. Caraveo[9,10], M. Cardillo[1], C. Casentini[1], P. W. Cattaneo[10], A. Chen[11], E. Costa[1], I. Donnarumma[12], Y. Evangelista[1], M. Feroci[1], A. Ferrari[13], F. Fuschino[7], M. Galli[7,14], A. Giuliani[9], C. Labanti[7], F. Lazzarotto[15], F. Longo[8], F. Lucarelli[4,5], A. Morselli[16], F. Paoletti[1,17], N. Parmiggiani[7], G. Piano[1], M. Pilia[18], C. Pittori[4,5], D. S. Svinkin[3], A. Trois[18], A. E. Tsvetkova[3], S. Vercellone[19], and V. Vittorini[1]

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[6] Birkeland Centre for Space Science, Department of Physics and Technology, University of Bergen, Norway

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

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]

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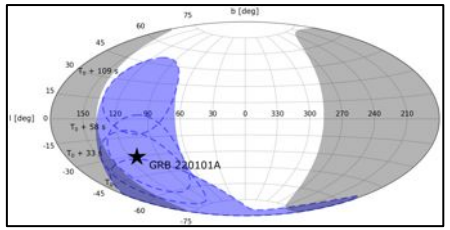
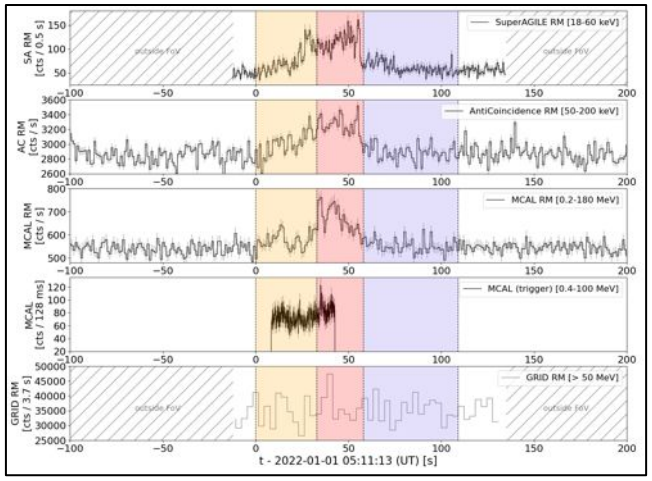
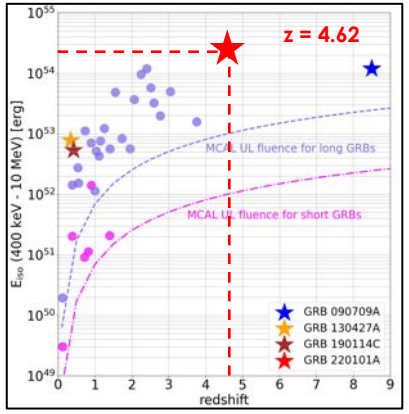
Received 2022 March 1; revised 2022 May 20; accepted 2022 May 27; published 2022 July 15

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







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

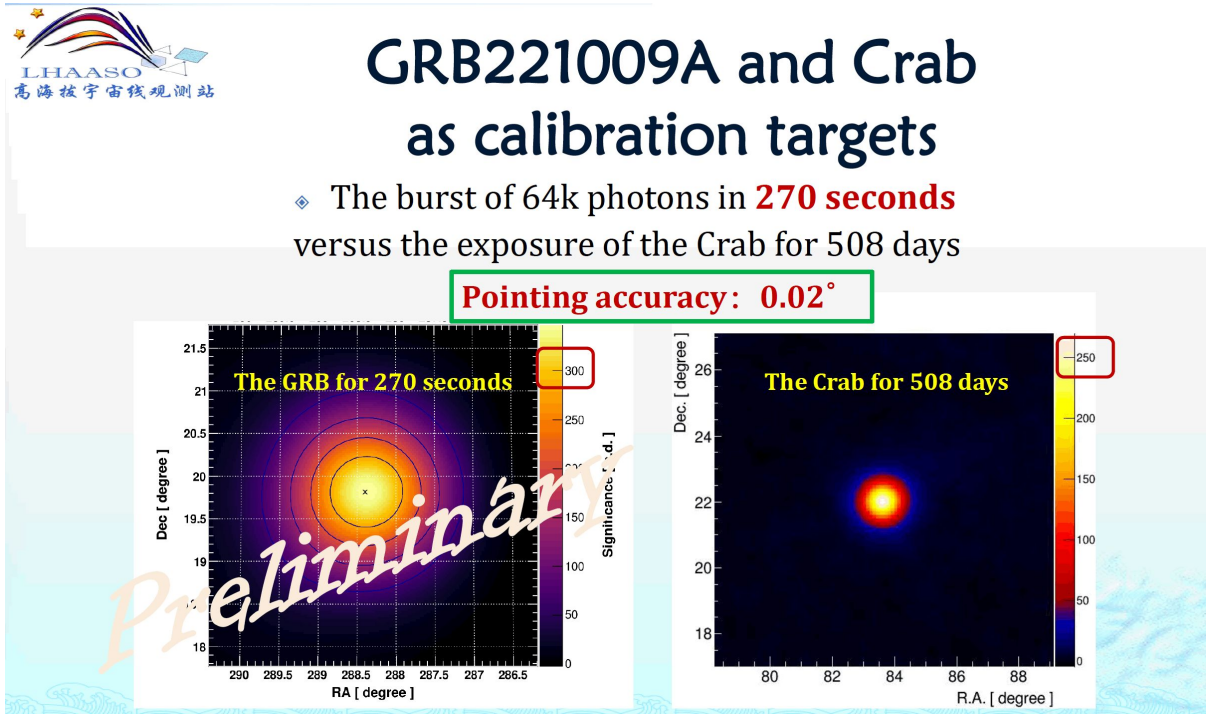
Marco Malaspina 03/01/2022 Tweet Condividi 1321

news on Media INAF

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

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*

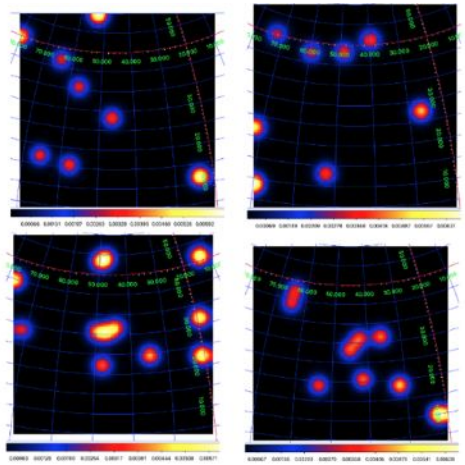
See Poster ID-062: G. Piano et al. *"The BOAT: GRB 221009A as detected by AGILE"*

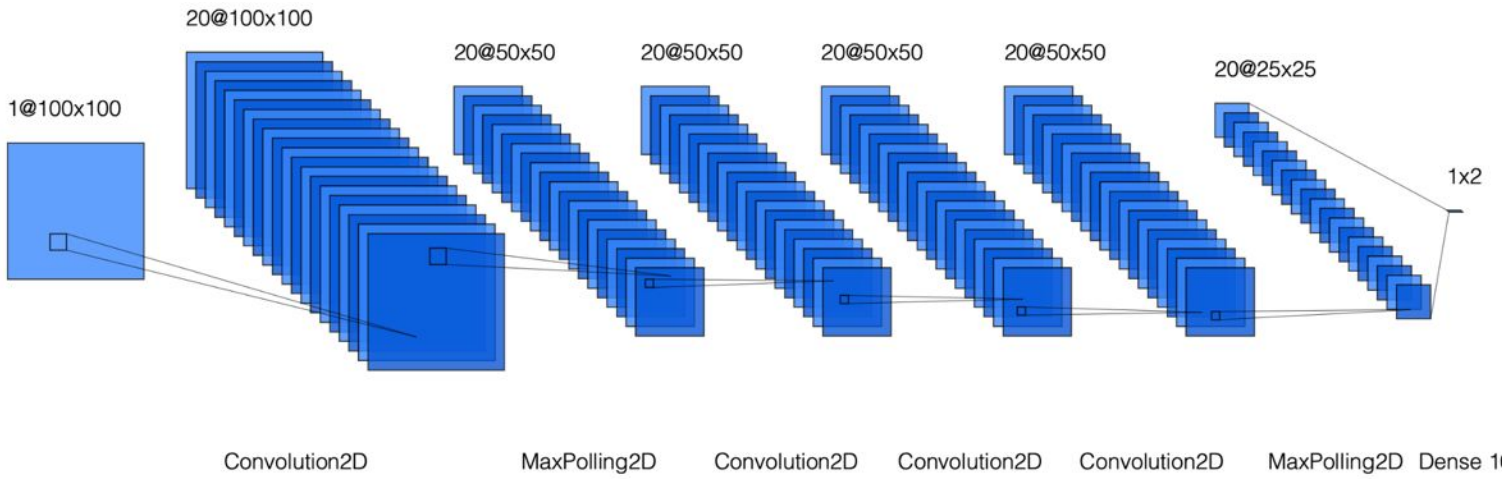
See (EARLY CAREER) Talk by L. Foffano: *"AGILE perspective of GRB221009A: theoretical implications of MeV-GeV coexistence in a MWL context".* Wed, 17 April 2024 at 15:40

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

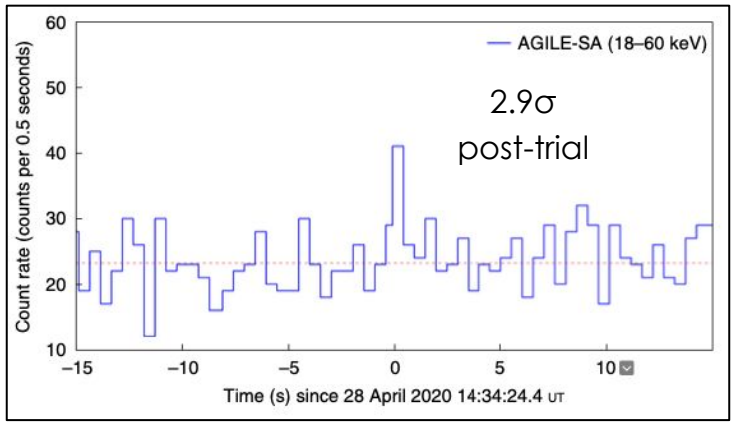
https://doi.org/10.1038/s41550-020-01276-x

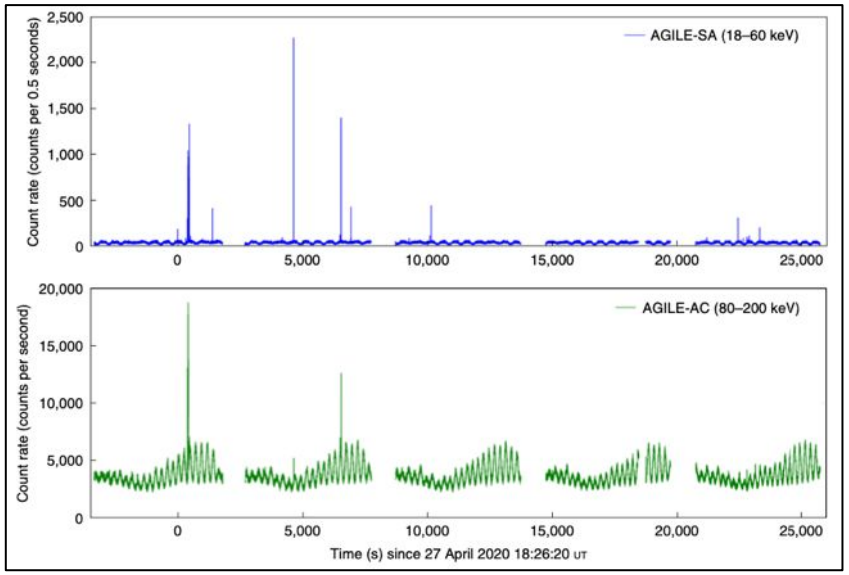
Check for updates

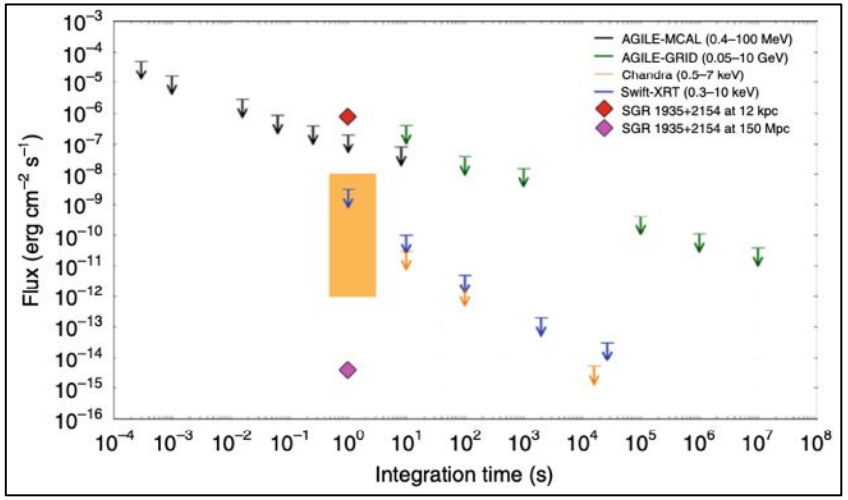
An X-ray burst from a magnetar enlightening the mechanism of fast radio bursts

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

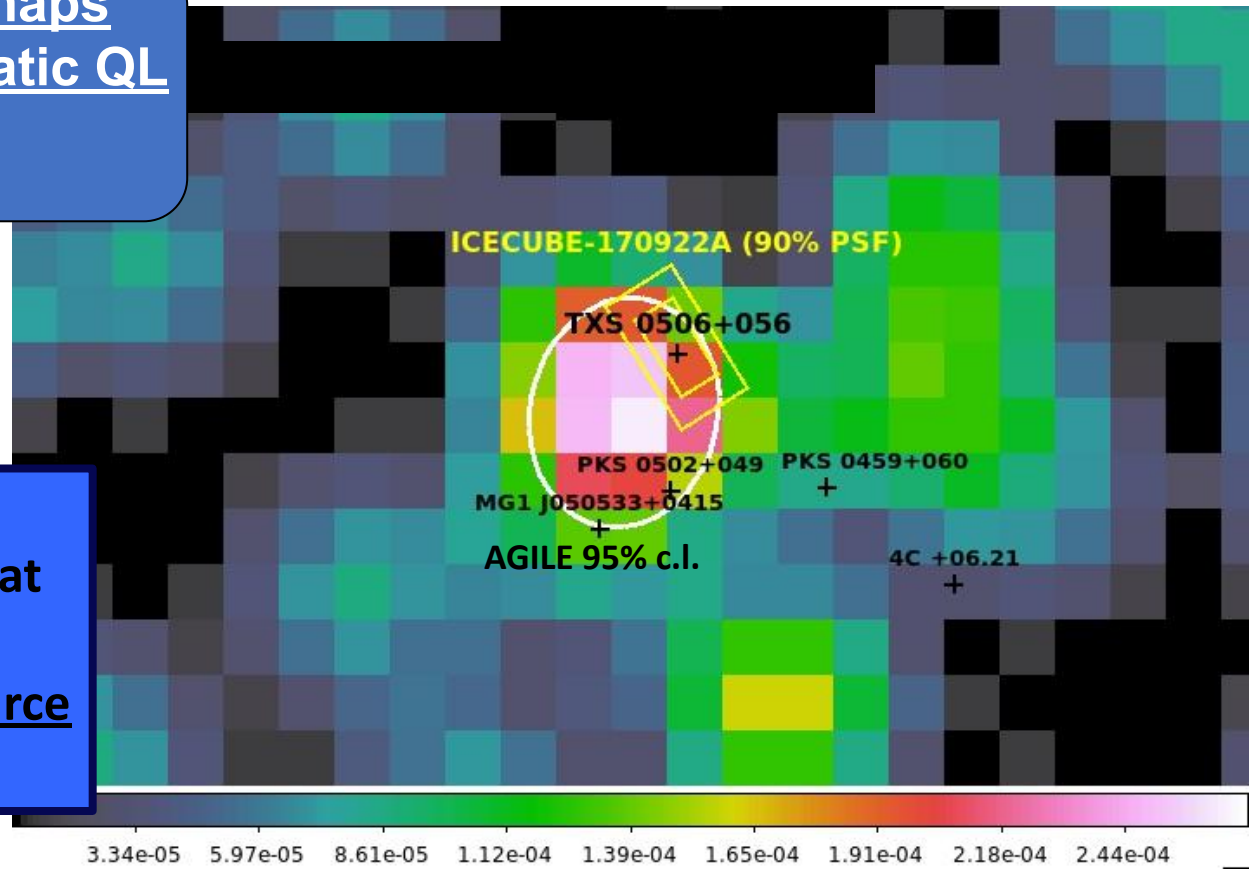
⇒ Identification as the IC-170922 neutrino emitter

"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. "*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). Paper in preparation

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
- AGILE observations provided the fastest response and **the most significant upper limits above 100 MeV to all GW events (pre-O4) (**

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


Springer Link

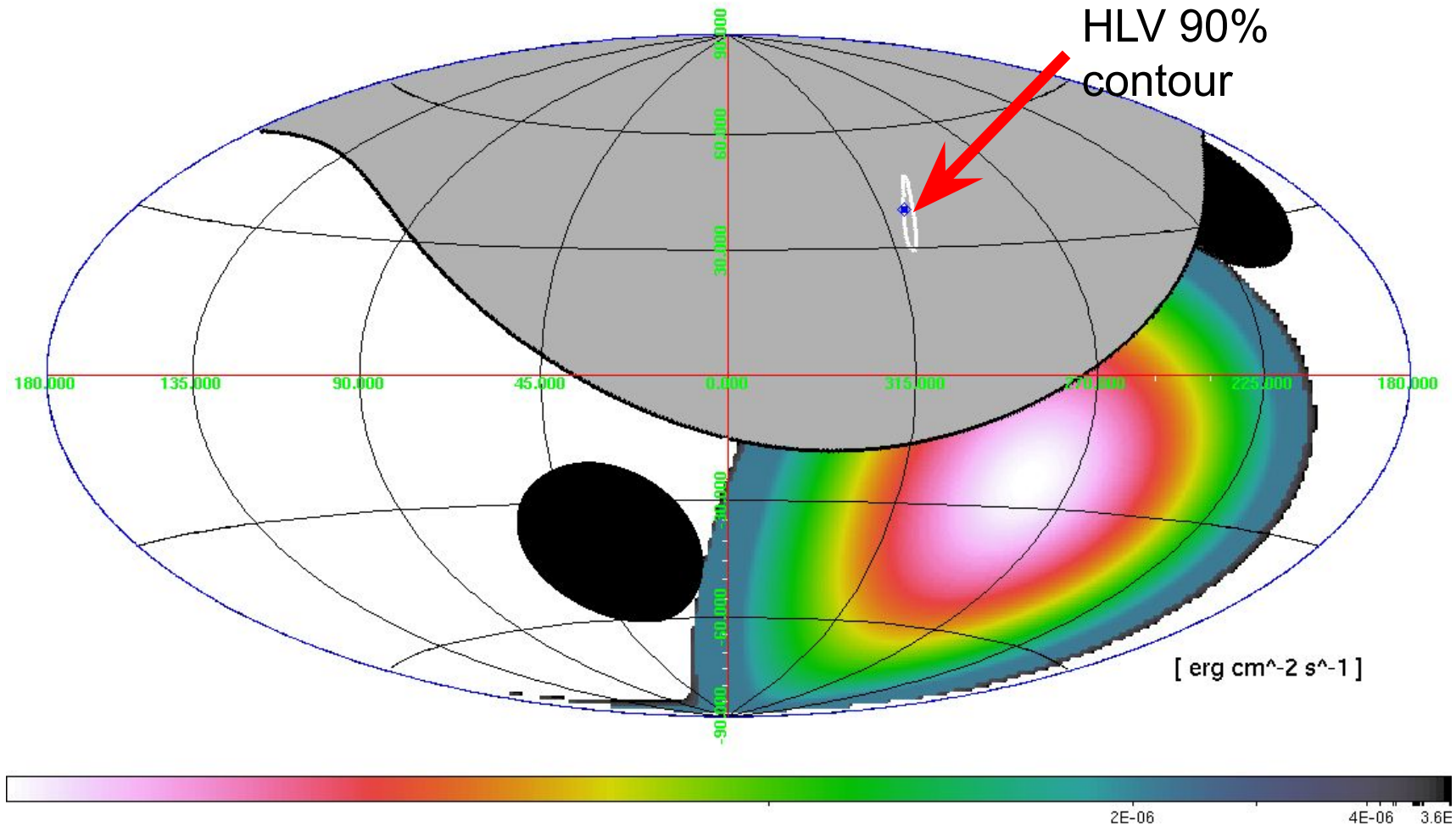
A Decade of AGILE | Published: 05 November 2019

AGILE search for gamma-ray counterparts of gravitational wave events

Francesco Verrecchia, Marco Tavani, Andrea Bulgarelli, Martina Cardillo, Claudio Casentini, Immacolata Donnarumma, Francesco Longo, Fabrizio Lucarelli, Nicoló Parmiggiani, Giovanni Piano, Maura Pilia, Carlotta Pittori, Alessandro Ursi the AGILE Team

Rendiconti Lincei. Scienze Fisiche e Naturali **30**, 71–77(2019) | Cite this article

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

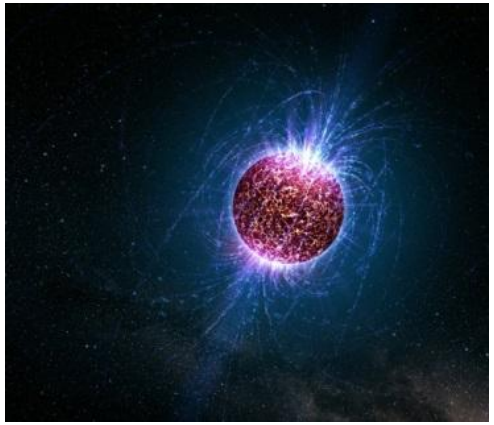


NS-NS merger GW170817-GRB170817A

- **AGILE and GW170817: nevertheless first γ-ray instrument with exposure on the localization region starting at ~ T_0 + 930 s**
  (F. Verrecchia et al., ApJL 850, 2017)

- 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**.

See Poster ID-061 C. Casentini et al.: *"AGILE Contribution to Electromagnetic Counterpart Search of GW Events"*

Last but not least:
AGILE and Solar Flares

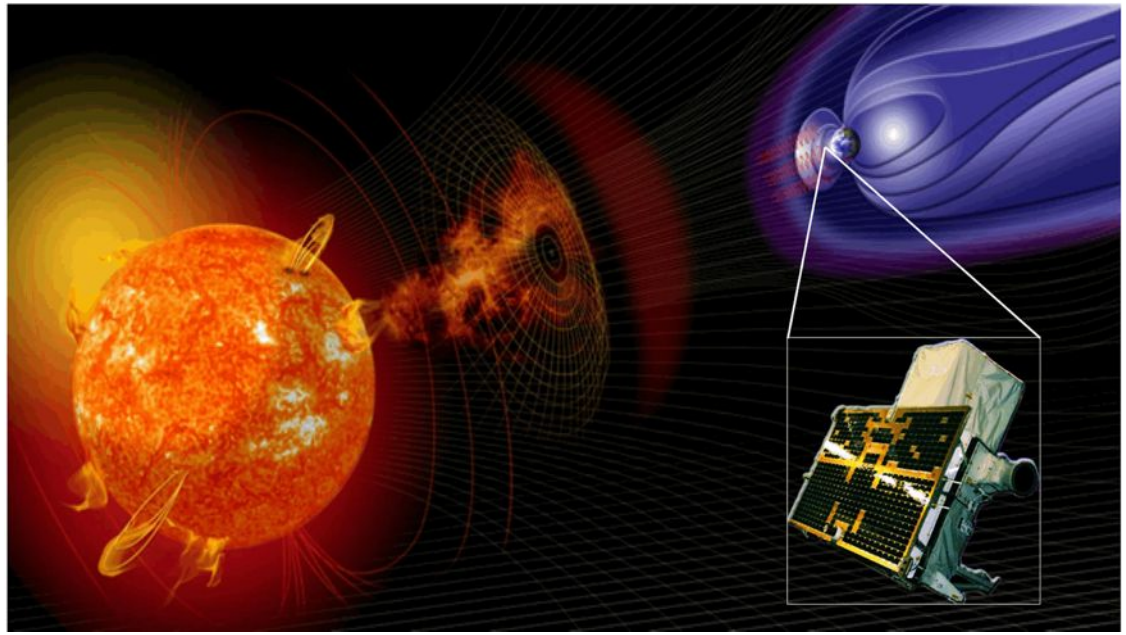
The First AGILE Catalog of Solar Flares: more than 15 years of observations

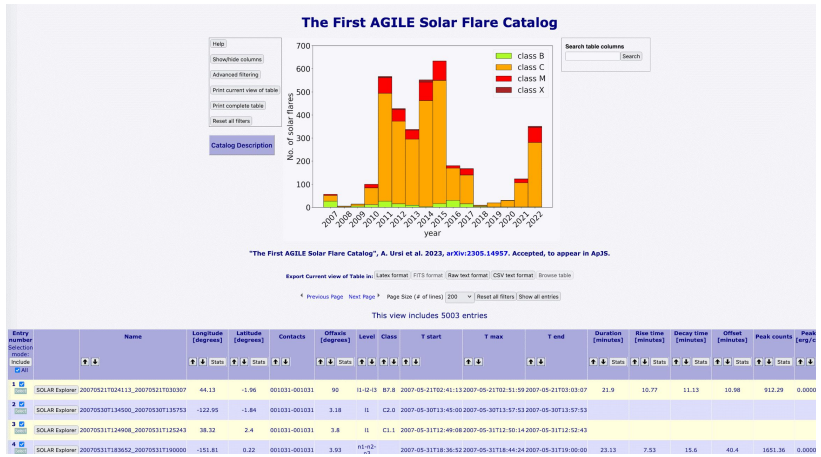
"The First AGILE Solar Flare Catalog", **A. Ursi et al., ApJS 267, 2023**

- 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.**

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.

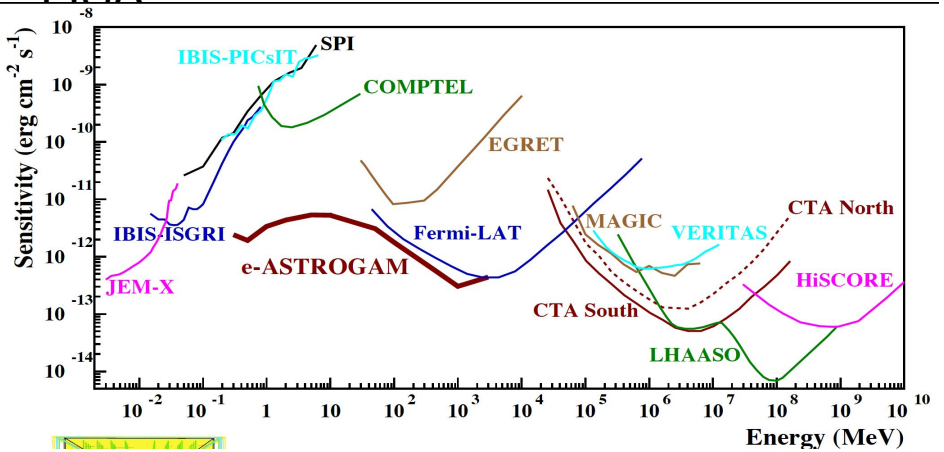
Work in progress on new catalogs with and without Machine Learning techniques. **Stay tuned for further results**.

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, **CTA**, IceCube, KM3NeT, LISA

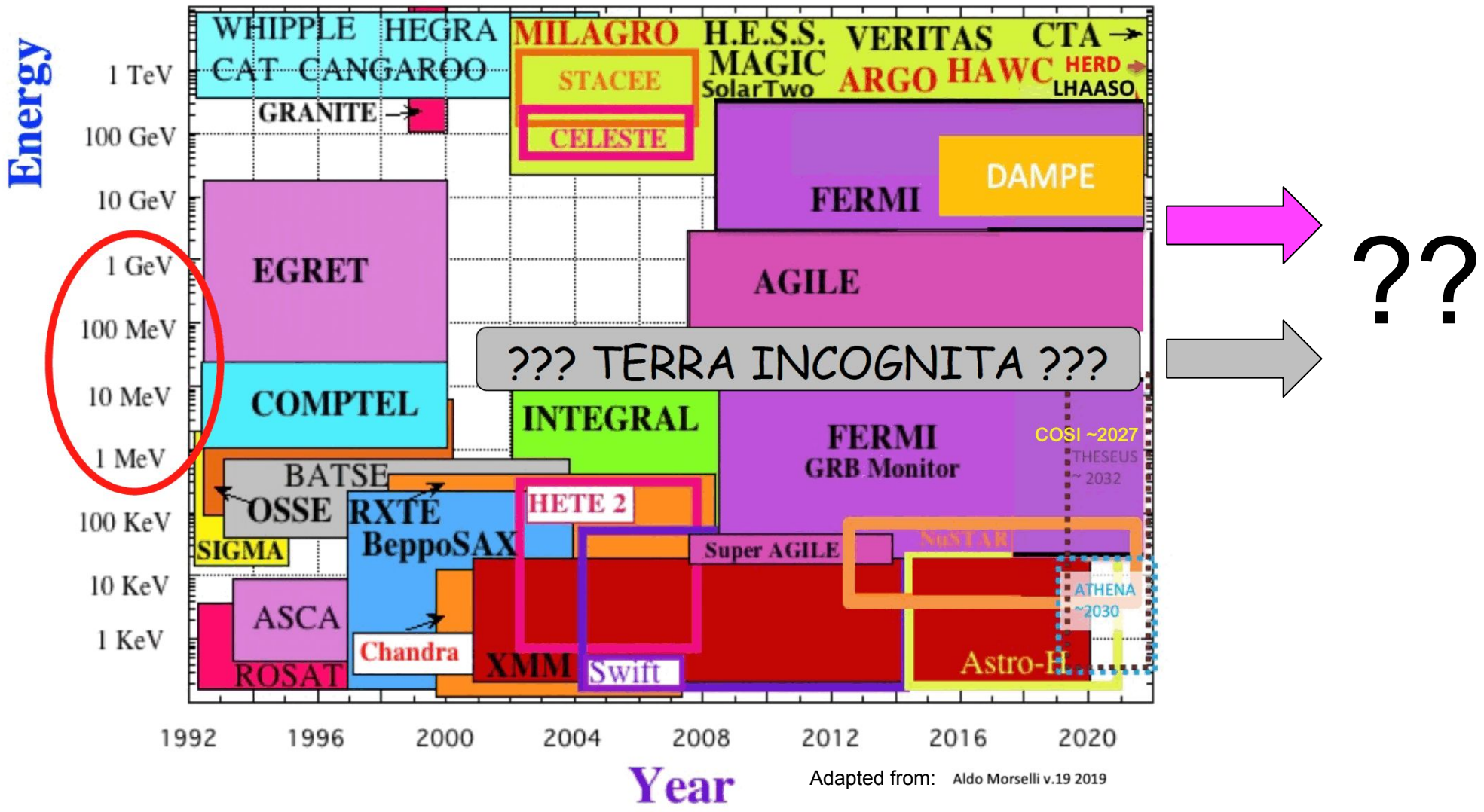


Looking forward to future opportunities in MeV/GeV astronomy in close synergy with CTAO

Thank you!

BACK UP SLIDES

Future prospects for MeV/GeV astronomy



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Adapted from: Aldo Morselli v.19 2019

A single instrument for a complete coverage of the spaceborne gamma-ray domain