



# **AGILE search of gamma-ray electromagnetic counterparts of gravitational waves**

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and

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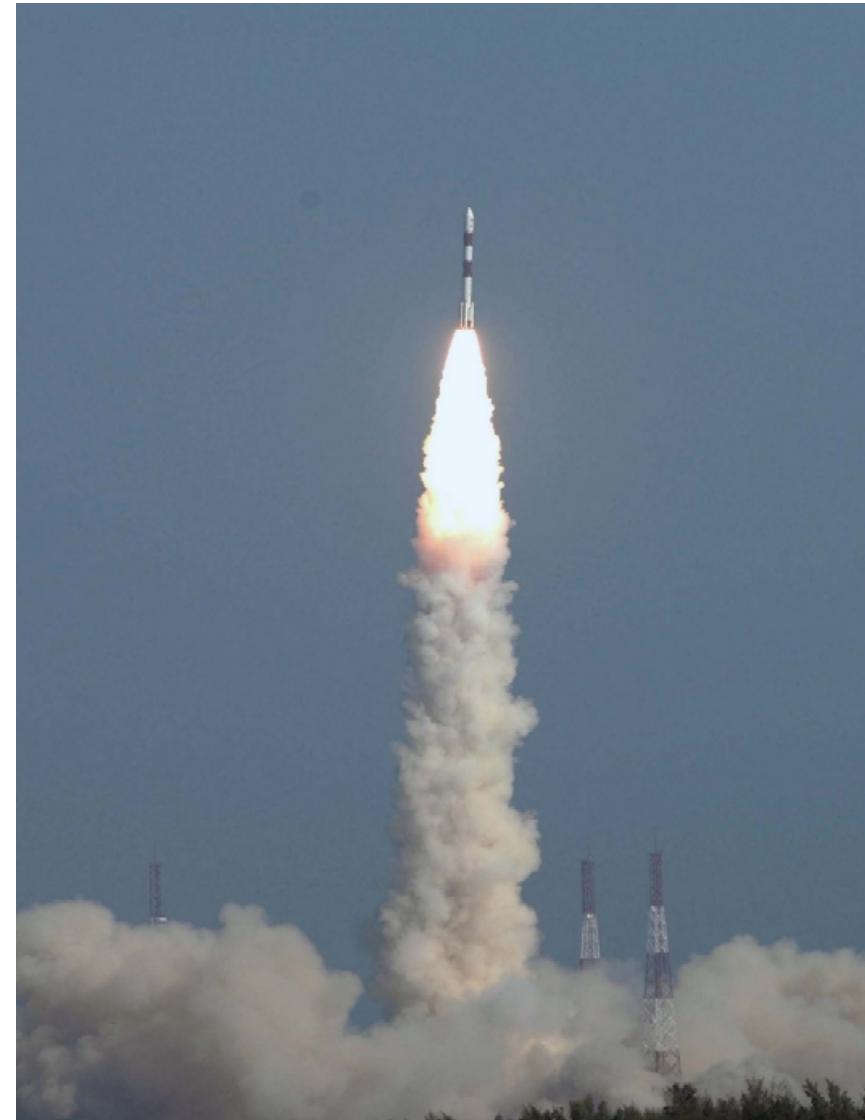
*on behalf of the AGILE Team*

**XXV SIGRAV Conference on General Relativity and Gravitation  
Trieste, September 4 – 8 , 2023**



# **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**

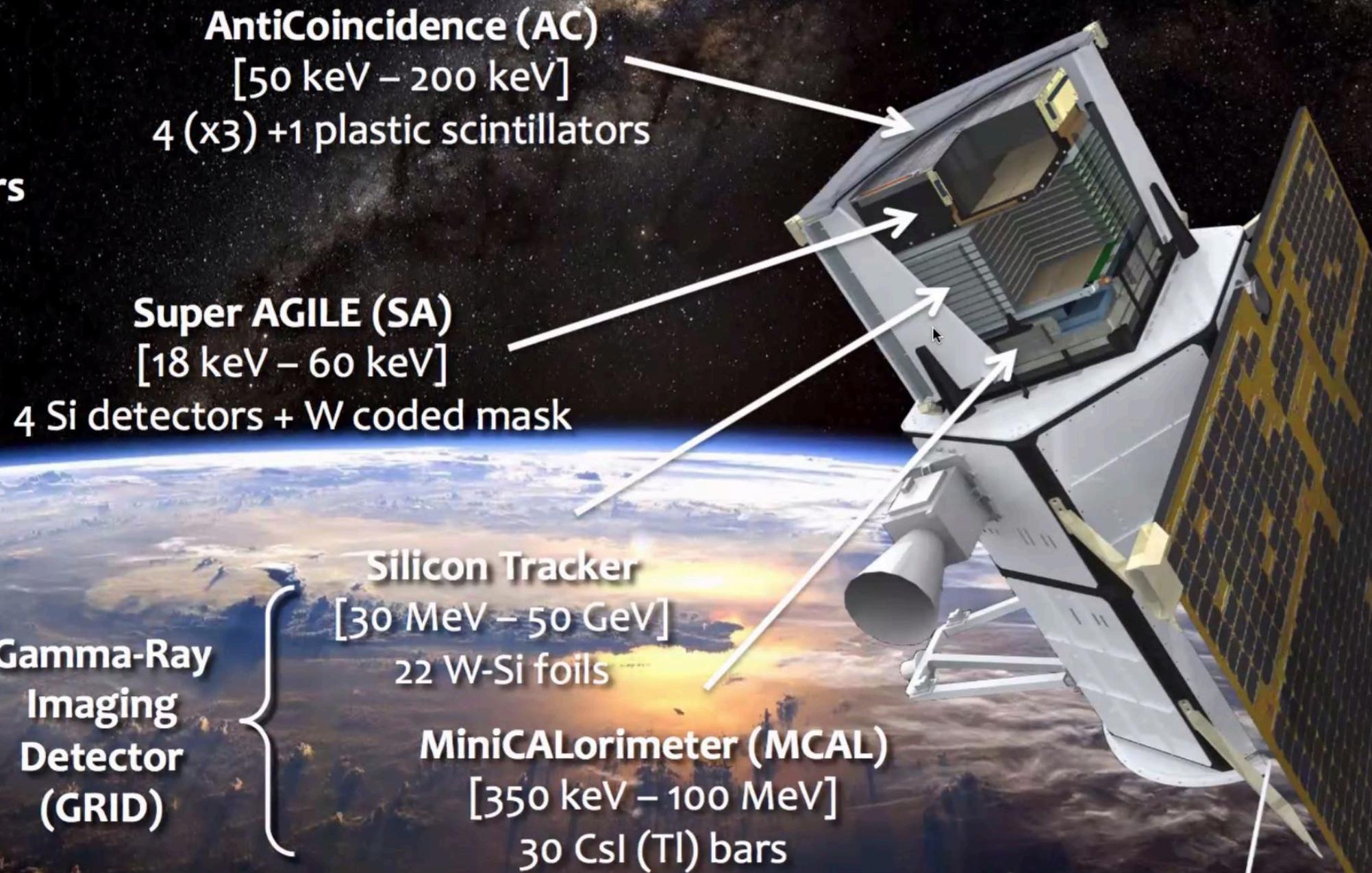
# AGILE: more than 16 years of operations in space

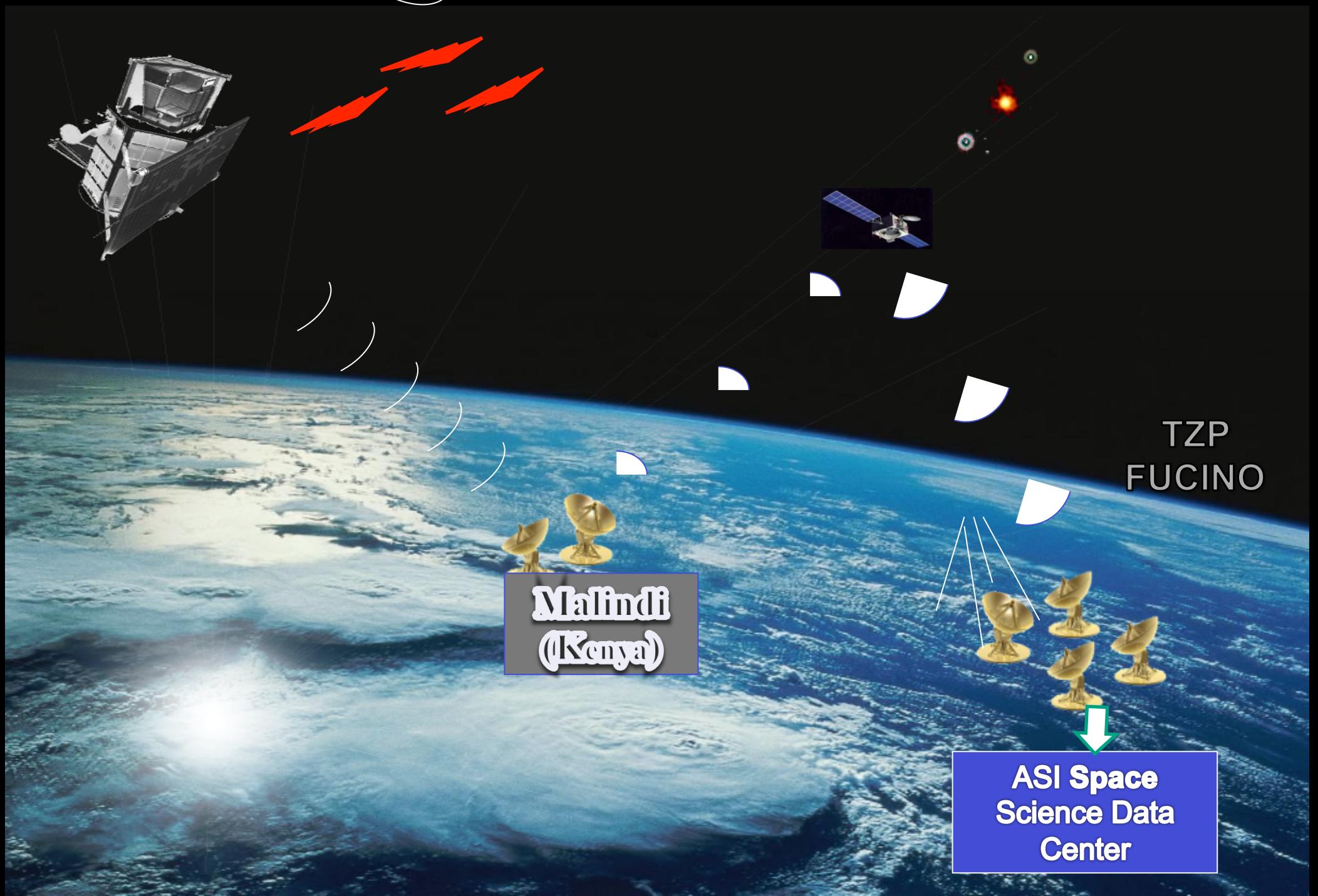
- **Gamma-ray detector (GRID): 50 MeV - 1 GeV**
- **Minicalorimeter (MCAL): 400 keV-100 MeV**
- **Super-AGILE X-ray detector: 18-60 keV**
- **Anticoincidence System (AC): 80-200 keV**

Fully operational, nominal status, and active in:

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

+  
related  
scientific  
rateMeters  
(RMs)





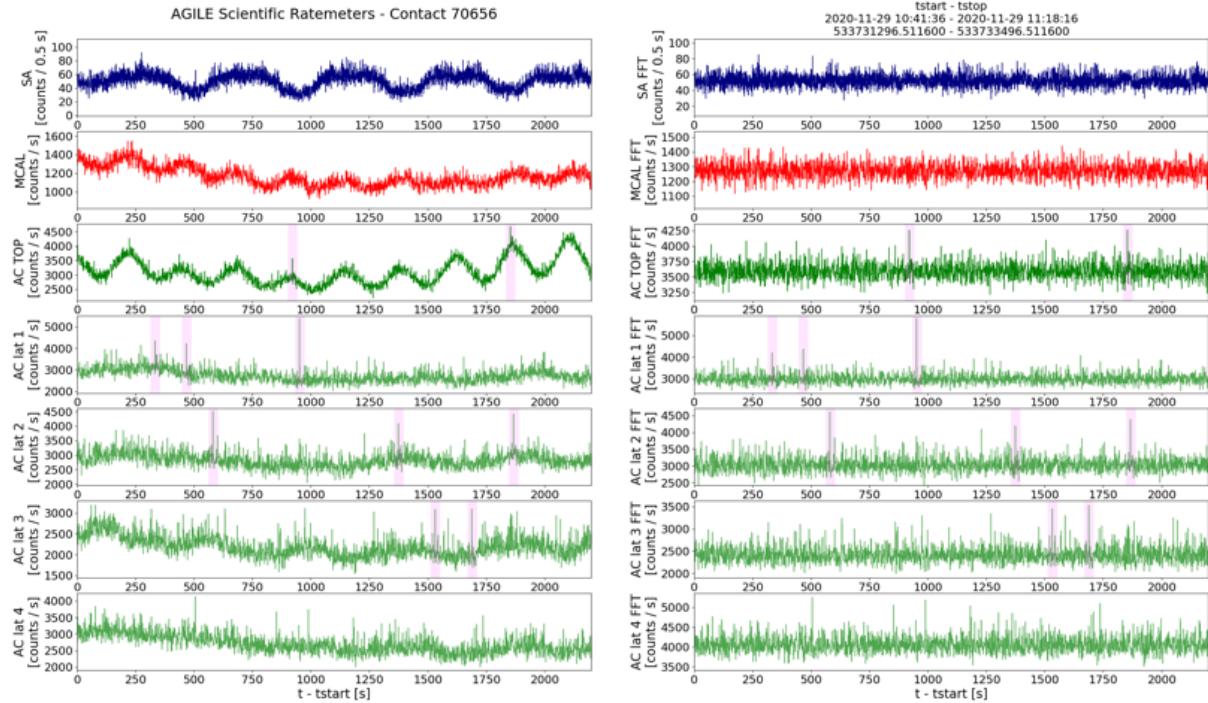
# Scientific status of AGILE

- **Nominal status.** 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.
- **Operations:** currently financed by ASI up to June 2024 (probable satellite reentry?)
- 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 budget 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**.

# Dedicated automatic pipeline for AGILE Ratemeters analysis

- RM SA
- RM MCAL
- RM AC top
- RM AC Lat 1, Lat 2, Lat 3 , Lat4.

(AC Lat4 always oriented towards the SUN)



(Spinning detrending on the right)

- Daily monitoring with 48-hour shifts → **24-h shifts during GW Run O4**
- MCAL automatic alerts published as Notices in the GCN Network
- Automatic solar flares alerts from AC Lat4 RM (internal emails)
- Automatic RM alerts (internal emails)

# AGILE CONTROL ROOM

## Control Room - Data Flow

### Next Contact

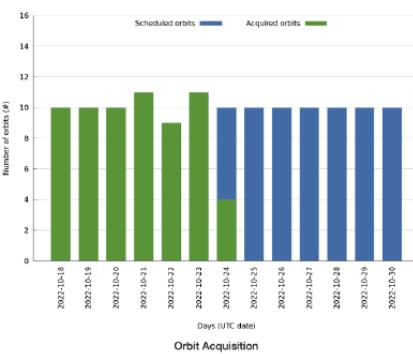
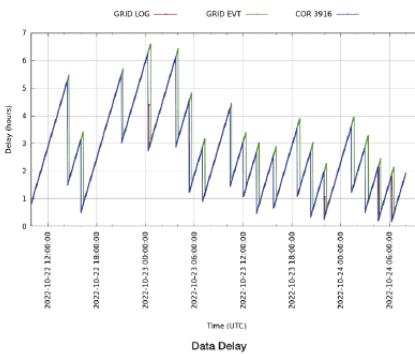
Contact Number = 80625  
Configuration = MCAL BASE  
Time For Contact = 83 minutes  
Start: 2022-10-24 06:02:31 (UTC)  
Stop: 2022-10-24 09:22:06 (UTC)  
Next Contact Time For Data (Prevision)  
MCAL @ Bologna = 2022-10-24 09:47:06 (UTC)  
GRID @ Bologna = 2022-10-24 09:52:06 (UTC)

### 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



gwistat

Detector	Status	Duration [hh:mm]	atenc
GEO600	Observing	00:31	24
LIGO Hanford	Observing	13:06	50
LIGO Virgo	Observing	13:15	14

# AGILE CONTROL ROOM

## Ratemeters pipeline - Home Page

AGILE RM    Home    Control Room

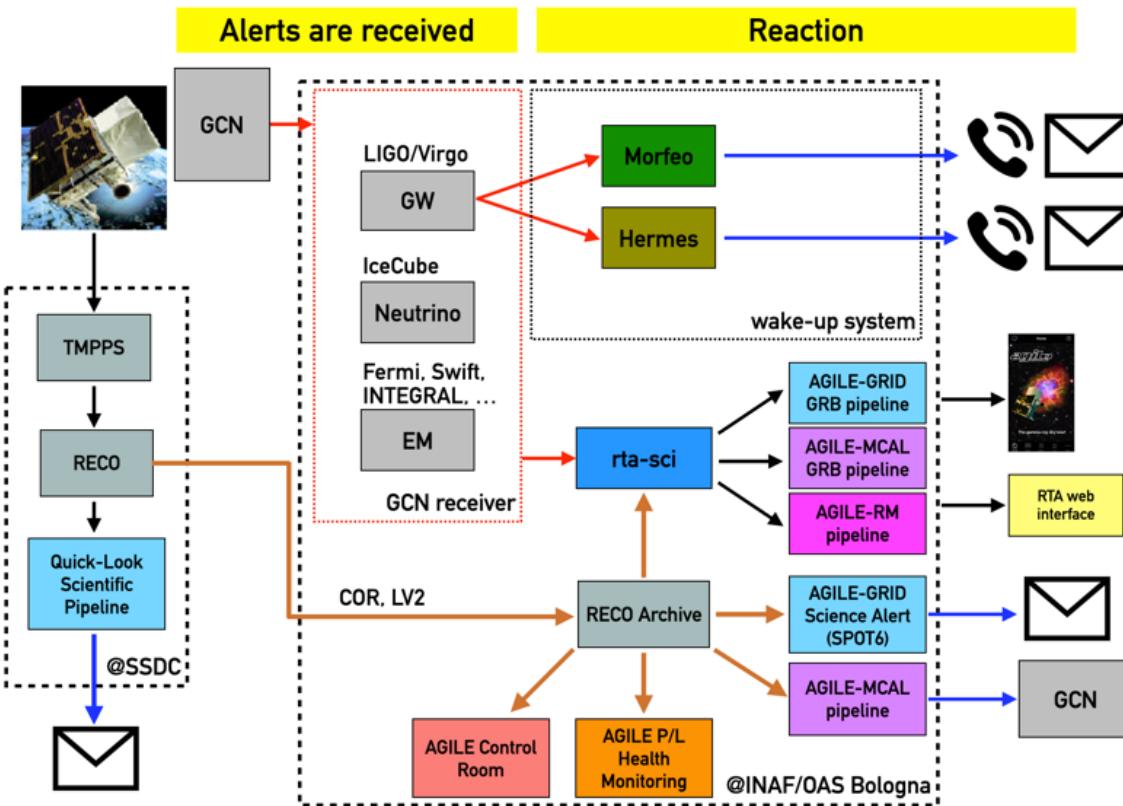
### Contact List

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	<button>Contact RM</button> <button>Solar Monitoring LC</button> <button>Monitoring AC4</button>	<b>Contact Checked</b> <input type="checkbox"/>
080622	2022-10-24T02:25:51	2022-10-24T04:23:21	<button>Contact RM</button> <button>Solar Monitoring LC</button> <button>Monitoring AC4</button>	<b>Contact Checked</b> <input type="checkbox"/>
080621	2022-10-24T00:03:57	2022-10-24T02:34:47	<button>Contact RM</button> <button>Solar Monitoring LC</button> <button>Monitoring AC4</button>	<b>Contact Checked</b> <input type="checkbox"/>
080620	2022-10-23T21:38:31	2022-10-24T00:09:21	<button>Contact RM</button> <button>Solar Monitoring LC</button> <button>Monitoring AC4</button>	<b>Contact Checked</b> <input type="checkbox"/>

# 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, CTA ...

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

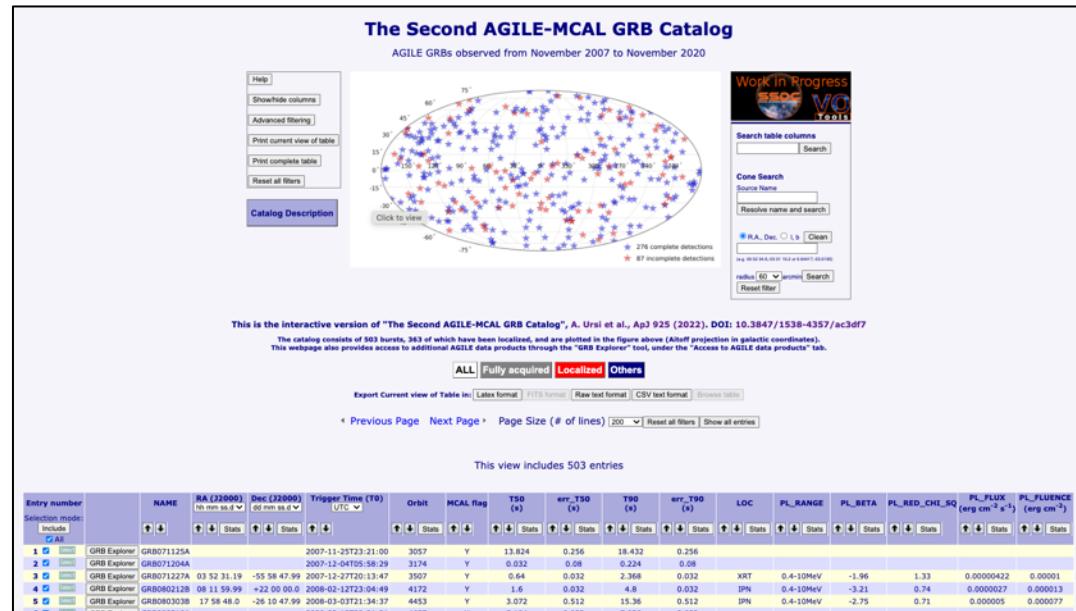
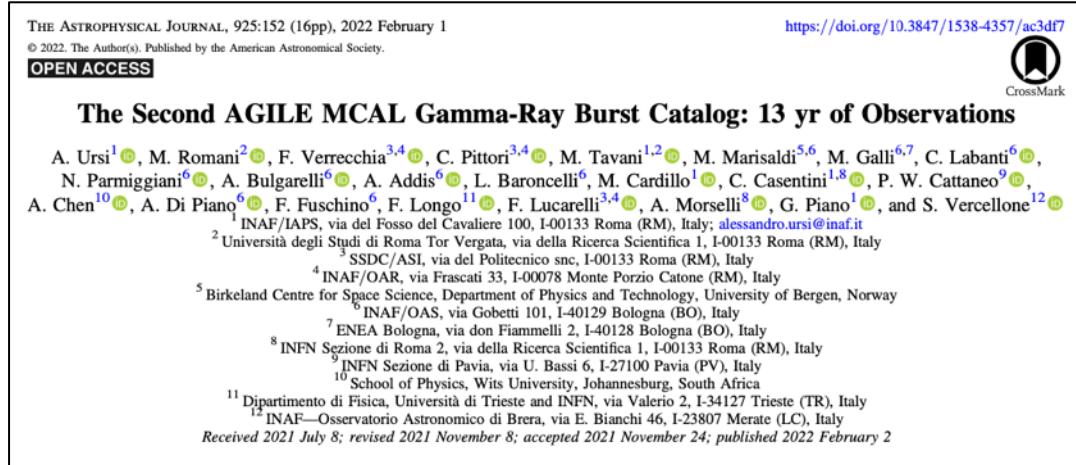
Parmiggiani, N. et. al.: "The RTApipe framework for the gamma-ray real-time analysis software development", Astronomy and Computing. Volume 39, 2022, <https://doi.org/10.1016/j.ascom.2022.100570>

Parmiggiani, N. et. al.: "The AGILE real-time analysis software system to detect short-transient events in the multi-messenger", Astronomy and Computing. Volume 44, 2023, [https://doi.org/10.1016/j.ascom.2023.100726 \(just published!\)](https://doi.org/10.1016/j.ascom.2023.100726)

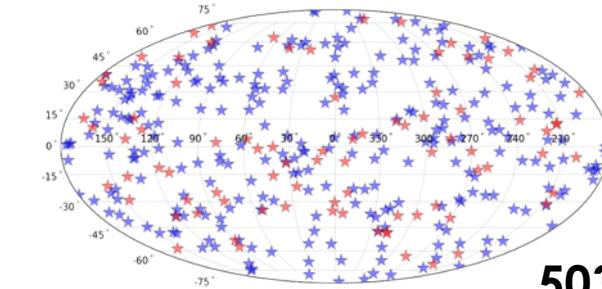
# **Updates on AGILE and GRBs**

# AGILE MCAL second GRB catalog

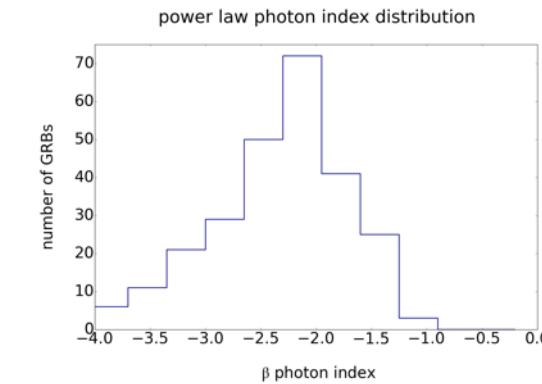
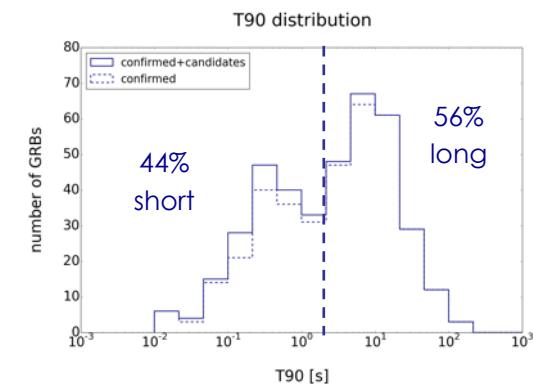
- Comprehensive catalog of all GRB detected by MCAL from 2007 to 2020 (*Ursi et al., ApJ 925, 2022*)



SSDC interactive web page <https://www.sscdc.asi.it/mcal2grbcatalog/>



503 GRBs



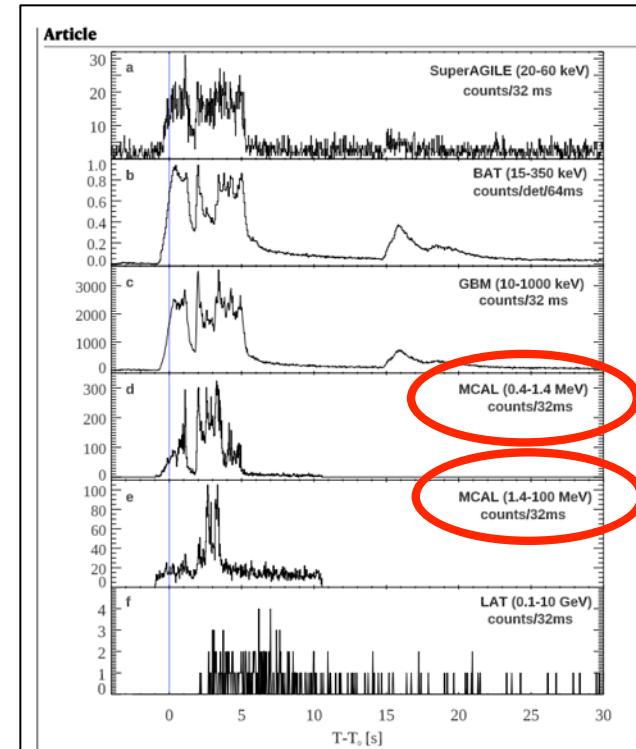
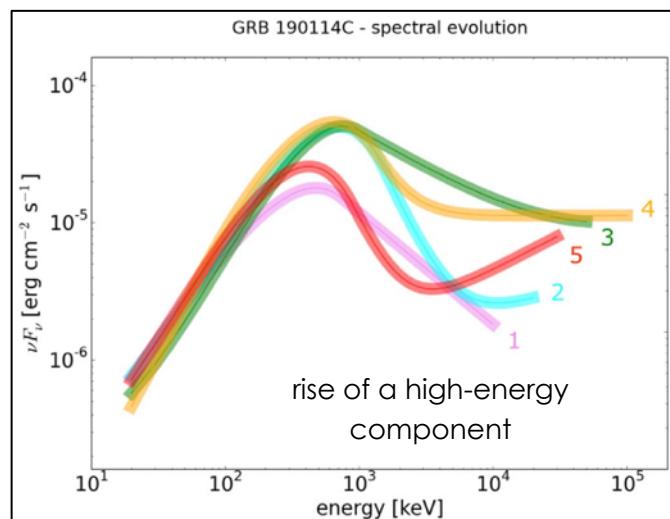
Spectra  
 mostly fittable  
 with power-laws  
 (high-energy tail  
 of the spectra  
 in MCAL band)

# 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]

The screenshot shows the **nature** journal website. The article title is "Observation of inverse Compton emission from a long gamma-ray burst". It was published on 20 November 2019. The authors listed are MAGIC Collaboration, P. Veres, ... D. R. Young. The article has 10k accesses, 91 citations, and 821 Altmetric metrics. The abstract discusses long-duration gamma-ray bursts originating from ultra-relativistic jets.



THE ASTROPHYSICAL JOURNAL, 904:133 (17pp), 2020 December 1  
© 2020. The American Astronomical Society. All rights reserved.  
<https://doi.org/10.3847/1538-4357/abc2d4>

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

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

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<sup>6</sup> Birkeland Centre for Space Science, Department of Physics and Technology, University of Bergen, Norway

# **Update on AGILE and GW**

# AGILE and GW

- AGILE **unique** combination of two co-aligned X-ray and  $\gamma$ -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  $\sim (1-2) 10^{-8}$  erg cm $^{-2}$  s $^{-1}$  in 100 sec.**
- Also two non-imaging detectors ( $4\pi$ ): 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) detected up to now.**

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



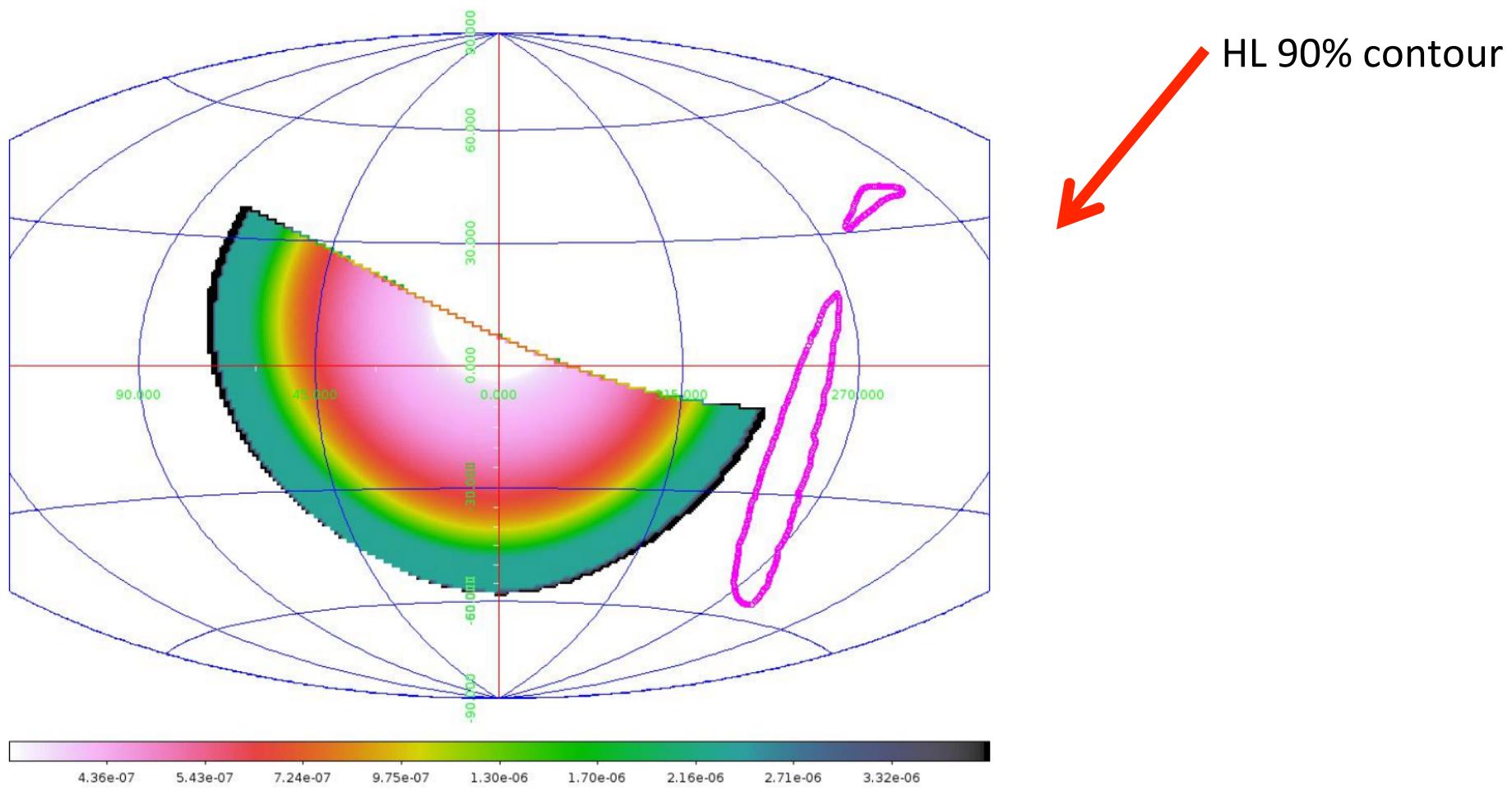
A Decade of AGILE | Published: 05 November 2019

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 P Maura Pilia, Carlotta Pittori, Alessandro Ursi the AGILE Team

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

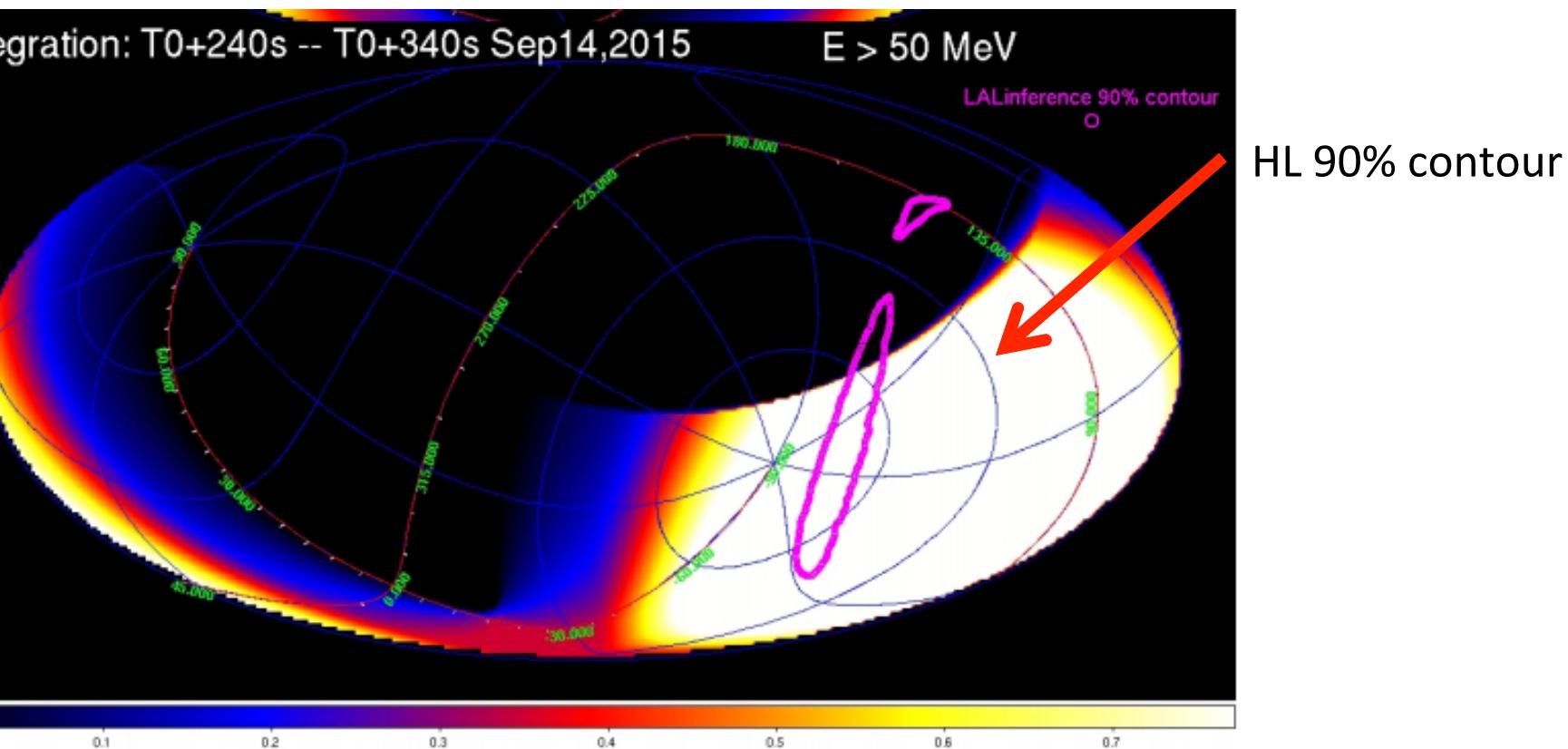
# GW 150914 first GW event AGILE exposure at T0: outside of the FoV



(M Tavani et al., ApJL 825, 2017)

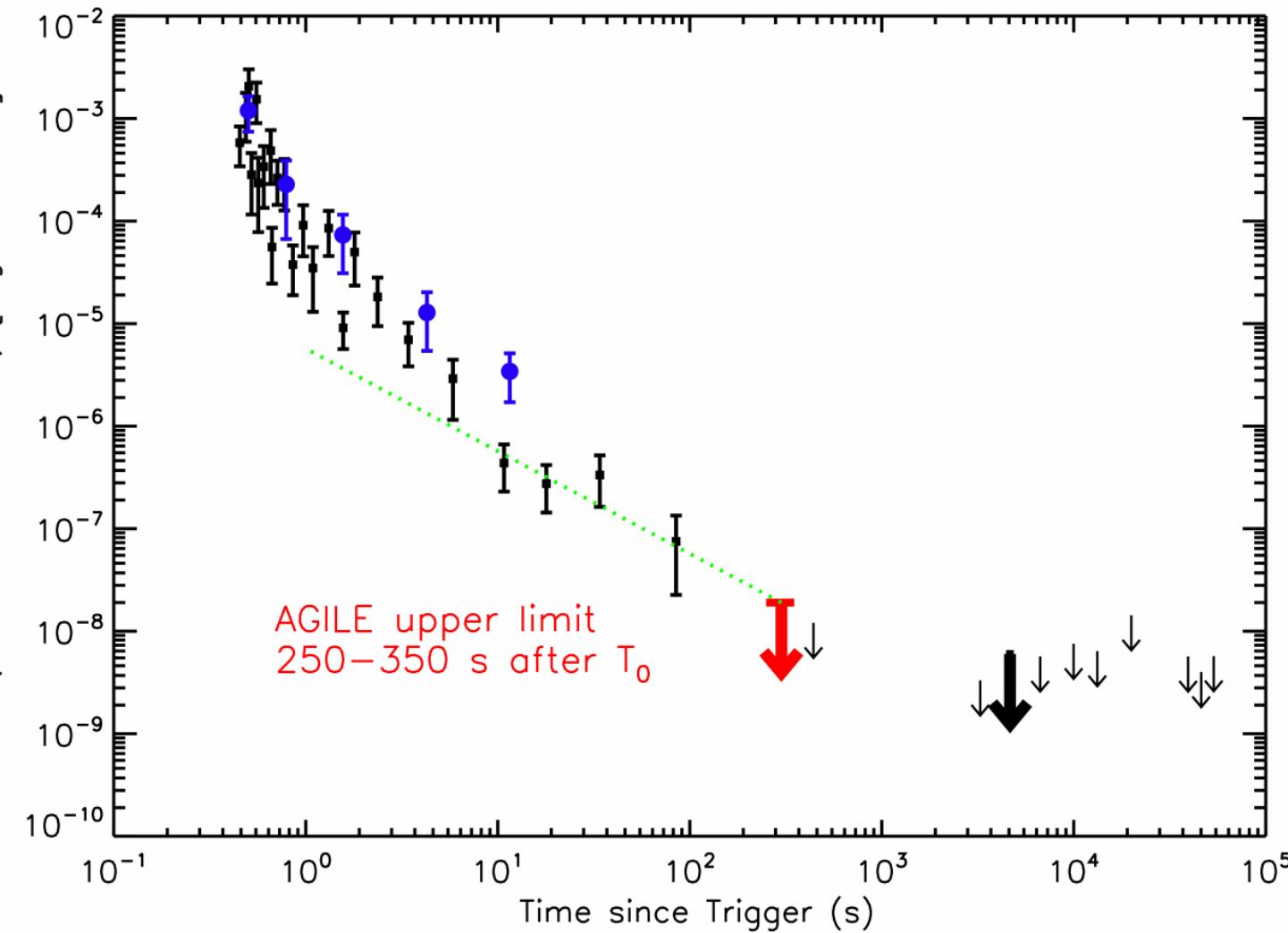
# GW 150914 first GW event

## AGILE exposure at T0+~300 s:inside the FoV (for ~75%)



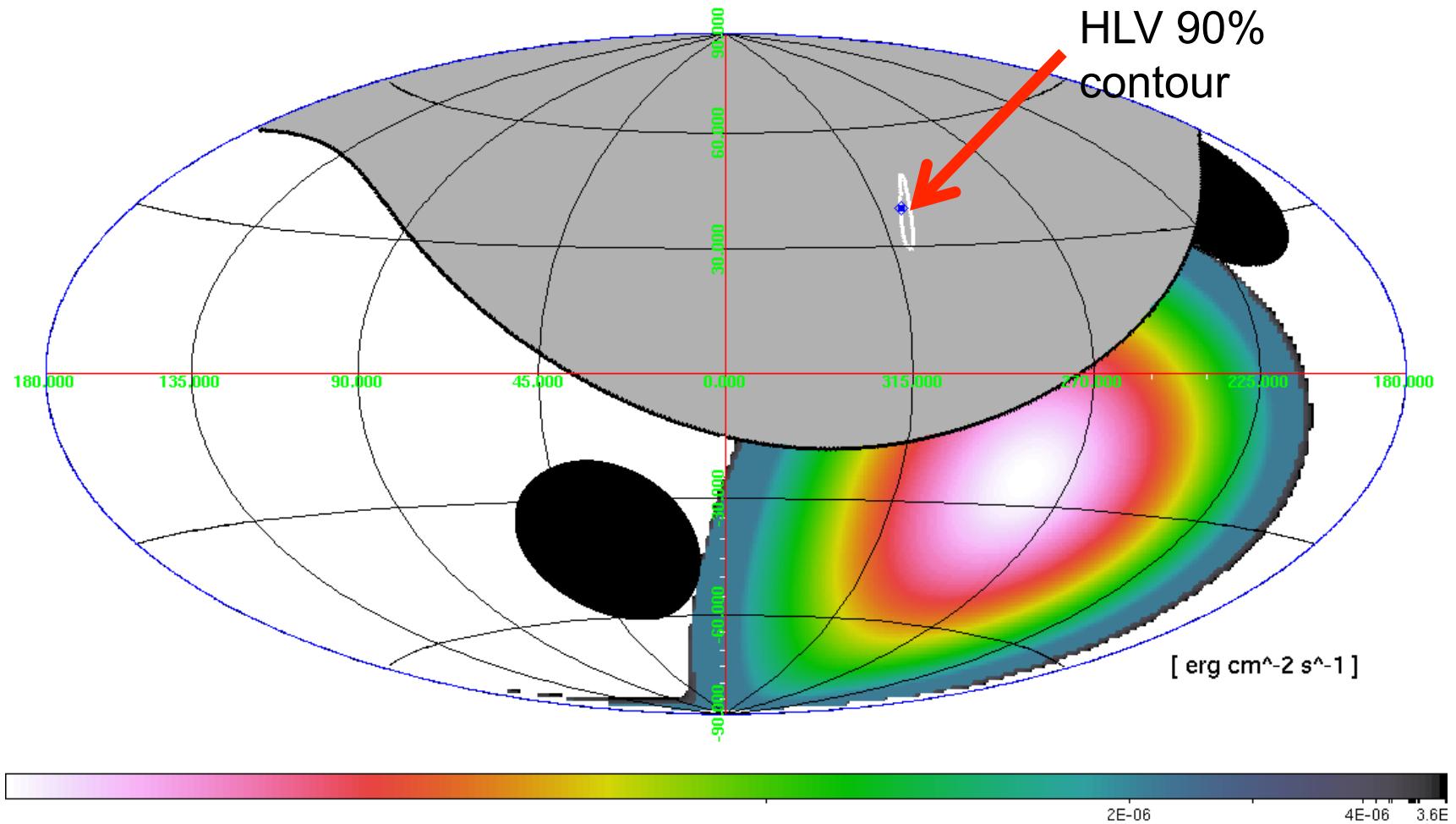
(M Tavani et al., ApJL 825, 2017)

# GW 150914 first GW event AGILE Upper limits

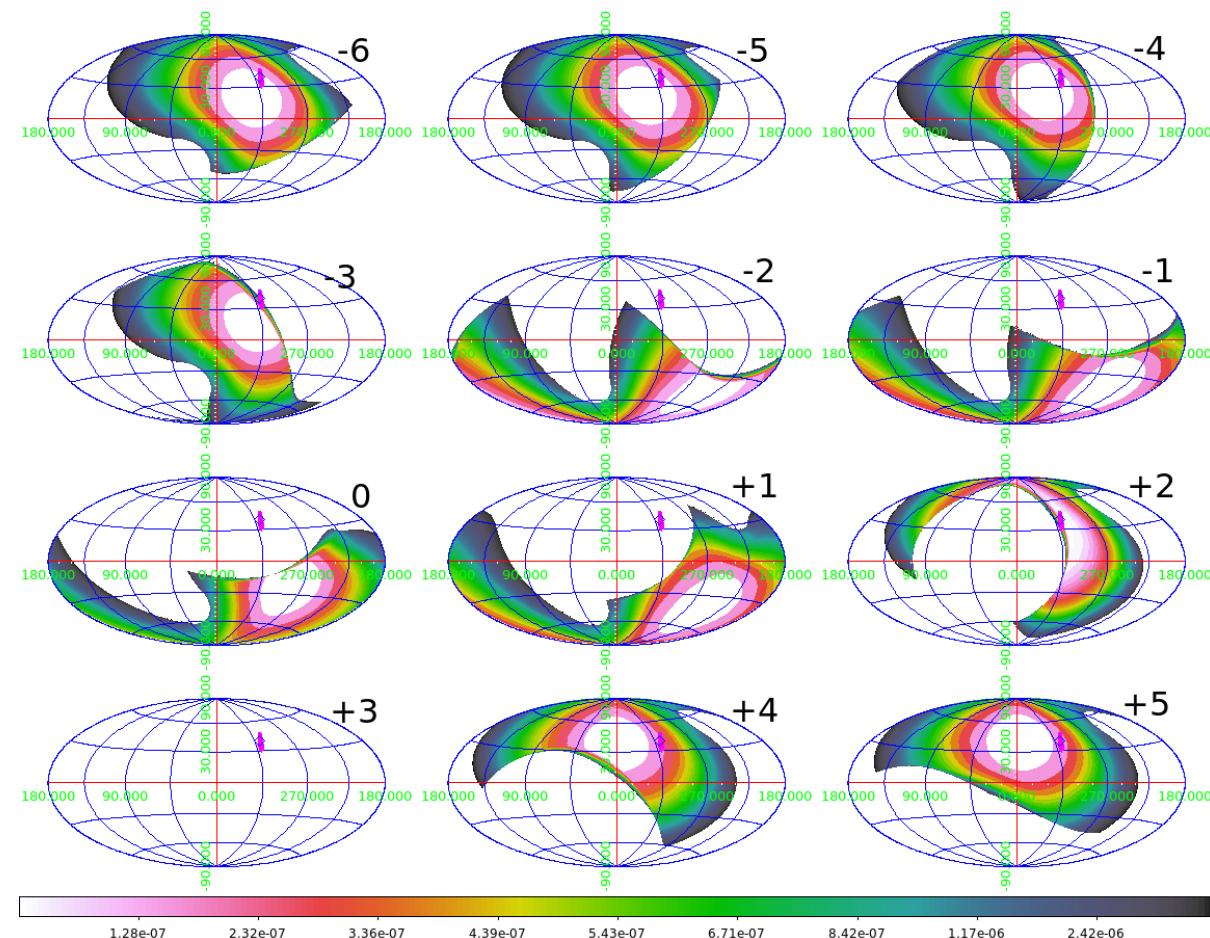


(M Tavani et al., ApJL 825, 2017)

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



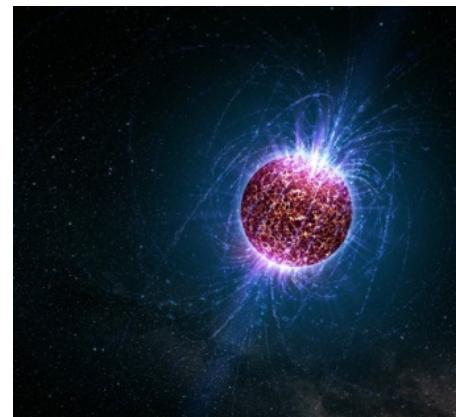
# AGILE-GRID precursor/delayed emission search: short time scales (150s within -/+1 hr)



Evaluation of GRID  $2\sigma$  upper limits Pre/Post  $T_0$  (F. Verrecchia et al., ApJL 850, 2017)

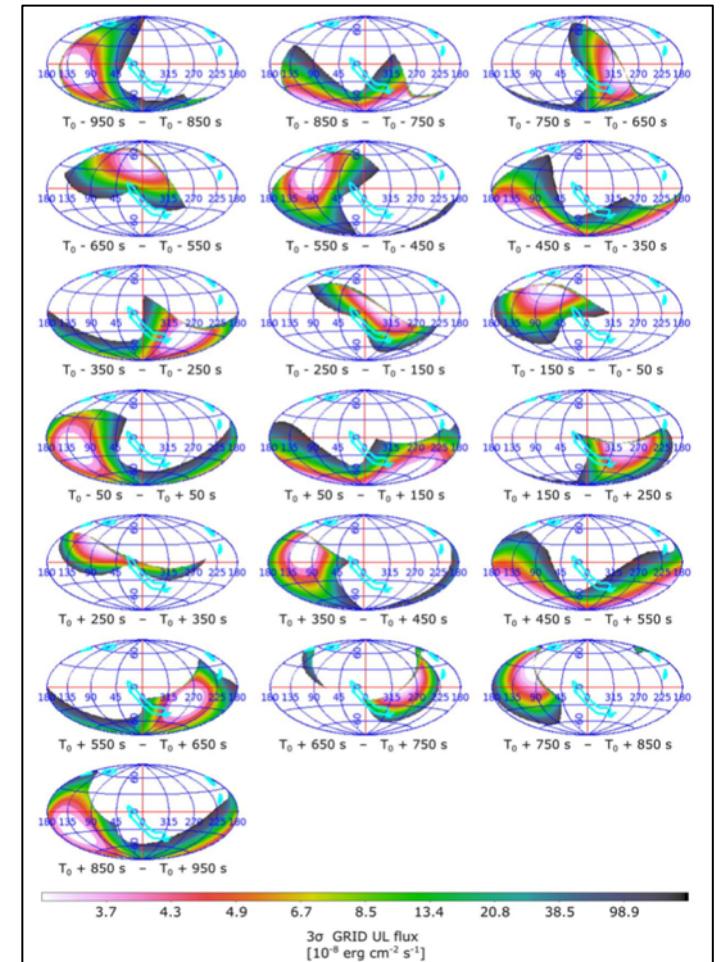
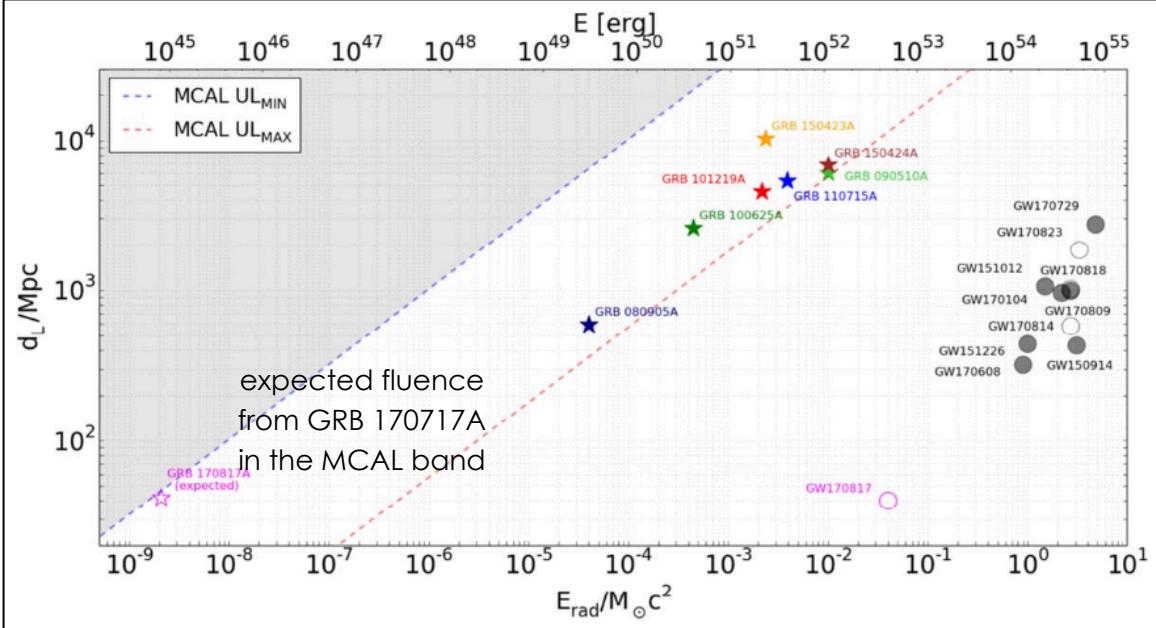
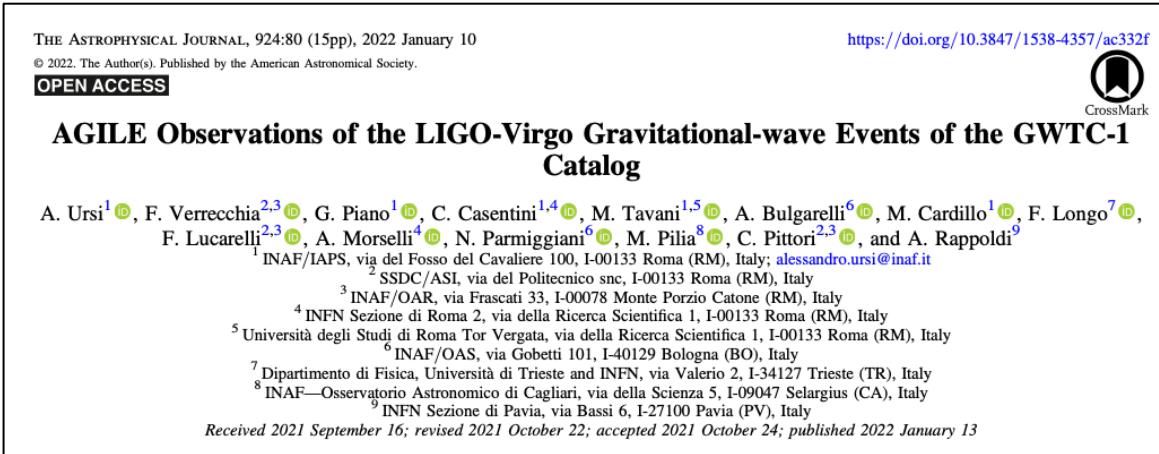
# NS-NS merger GW170817-GRB170817A

- AGILE and GW170817: first  $\gamma$ -ray instrument with exposure on the localization region starting at  $\sim T_0 + 930$  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 observations of GWTC-1 catalog events

- detailed analysis of AGILE MCAL and GRID data in correspondence of LIGO-Virgo GW events [Ursi et al., ApJ, 2022]



GRID exposure to error box of  
GW170729

# AGILE and LIGO-Virgo-Kagra 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 high probability to have an electromagnetic counterpart.

The LVK GW event **S230529ay** has been identified as a significant GW compact binary merger candidate with high probability (73%) to be composed by a **MassGap** merger, which has a high probability to have an electromagnetic counterpart. The event should contain a NS with high probability (98%).

AGILE results from the fast follow-up of GW S230518h and GW S230529ay were published in the [GCN Circular #33893](#) and [#33894](#) respectively, reporting the **AGILE/MCAL flux upper limits in the 0.4 - 1 MeV energy range**, for 1 s integration time from the GW trigger time (T0), at different celestial positions within the accessible Localization Region (LR).

The detection of a **short pulse** in the same energy band with  **$S/N \sim 5.7$  at  $T0+10.77$  s** was also reported by AGILE for **S230518h**. Updated analysis *in progress* (soft band  $E < 1.4$  MeV).

## CONCLUSION: THE AGILE ALL SKY SCANNING GOES ON

- Enhanced detection capabilities for transients: especially for **GW and neutrino follow-up, short and long GRBs detection, FRBs.**
- Fully integrated in a network of multi-frequency and multi-messenger observers from ground and space.
- AGILE unique contribution also for **Terrestrial Gamma-ray Flashes and Solar Flares.**
- Automatic pipelines plus human vetting: on-duty 7dd/7 - 24h/24 since the start of the Ligo-Virgo-Kagra **O4 GW run** in May 2023.