AGILE Highlights

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with contributions from Carlotta Pittori (INAF OAR & SSDC) & Marco Tavani (INAF IASF Roma)

AGILE: a *first of its kind*

- *First* among the **small missions program** in 1998.
- *First* HE mission to have a **hard X-ray monitor on board**
- *First* HE mission with a **ground segment** allowing fast ToOs
- *First* evidence of **hadronic cosmic-ray acceleration in SNRs**
- For the *first time*, a γ-ray mission devoted to the observations of the sky became an asset in the **study of terrestrial γ-ray flashes**
- AGILE discovered, for the *first time*, flux **variability in the Crab Nebula**, previously considered to be a "standard candle" in the energy range (0.1–10) GeV

The roaring Crab

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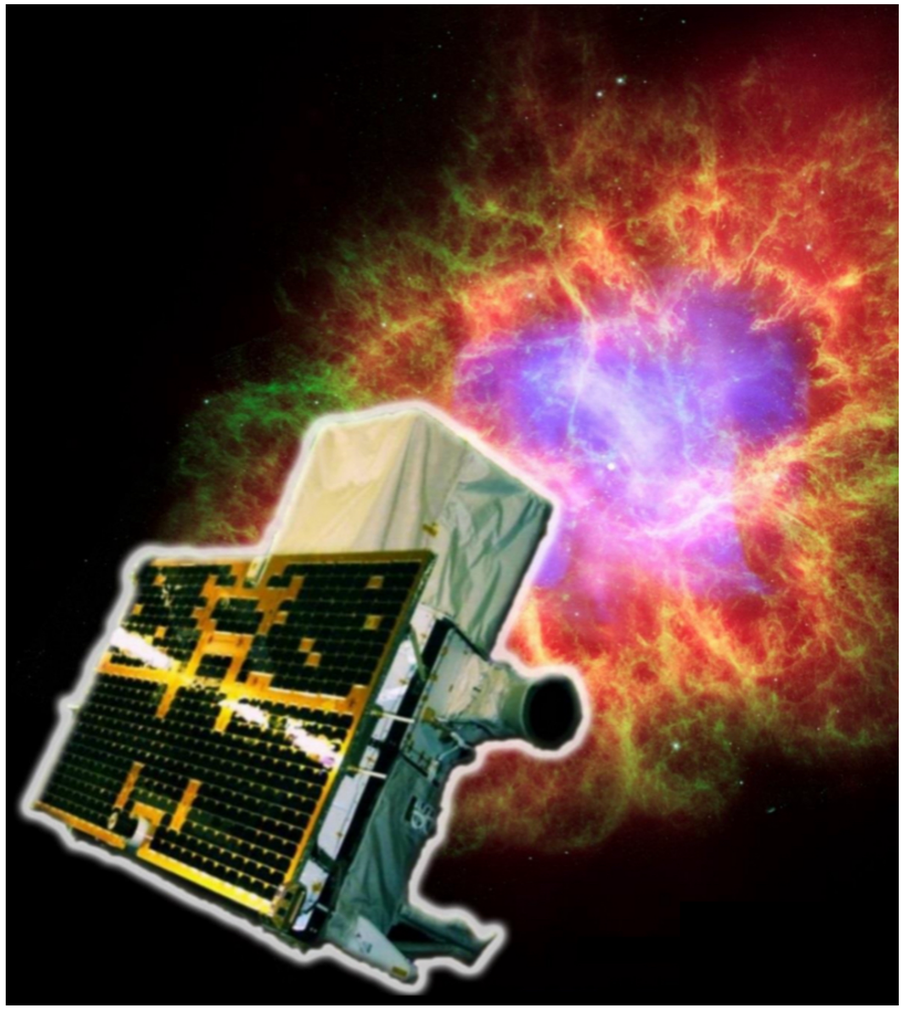
DI ASTROFISICA



AGILE detection of enhanced gamma-ray emission from the Crab Nebula region

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*on **22 Sep 2010; 14:45 UT***
Distributed as an Instant Email Notice Transients
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Subjects: Pulsar

Referred to by ATel #: 2856, 2858, 2861, 2866, 2867, 2868, 2872, 2879, 2882, 2889, 2893, 2903, 2921, 2967, 2968, 2994, 3058, 3276, 3283, 4239, 8544

𝕏 Post

AGILE is detecting an increased gamma-ray flux from a source positionally consistent with the Crab Nebula.

Integrating during the period 2010-09-19 00:10 UT to 2010-09-21 00:10 UT the AGILE-GRID detected enhanced gamma-ray emission above 100 MeV from a source at Galactic coordinates (l,b) = (184.6, -6.0) +/- 0.4 (stat.) +/- 0.1 (syst.) deg, and flux F > 500 e-8 ph/cm2/sec above 100 MeV, corresponding to an excess with significance above 4.4 sigma with respect to the average flux from the Crab nebula (F = (220 +/- 15)e-8 ph/cm^2/sec, Pittori et al., 2009, A&A, 506, 1563).

We strongly encourage multifrequency observations of the Crab Nebula region.

REPORTS

Discovery of Powerful Gamma-Ray Flares from the Crab Nebula

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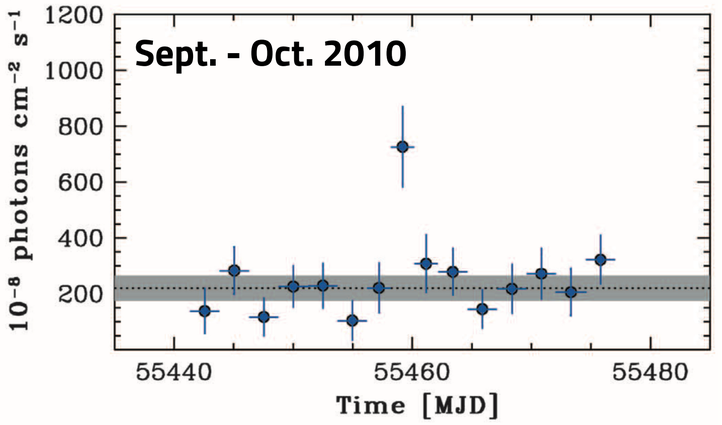
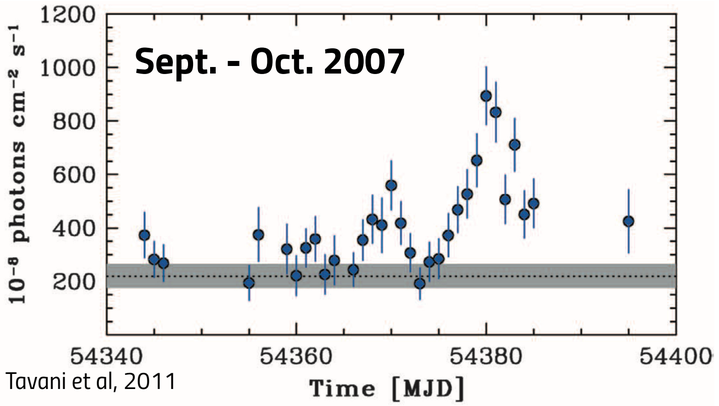
The well-known Crab Nebula is at the center of the SN1054 supernova remnant. It consists of a rotationally powered pulsar interacting with a surrounding nebula through a relativistic particle wind. The emissions originating from the pulsar and nebula have been considered to be essentially stable. Here, we report the detection of strong gamma-ray (100 mega–electron volts to 10 giga–electron volts) flares observed by the AGILE satellite in September 2010 and October 2007. In both cases, the total gamma-ray flux increased by a factor of three compared with the non-flaring flux. The flare luminosity and short time scale favor an origin near the pulsar, and we discuss Chandra Observatory x-ray and Hubble Space Telescope optical follow-up observations of the nebula. Our observations challenge standard models of nebular emission and require power-law acceleration by shock-driven plasma wave turbulence within an approximately 1-day time scale.

The roaring Crab





Tavani et al, 2011

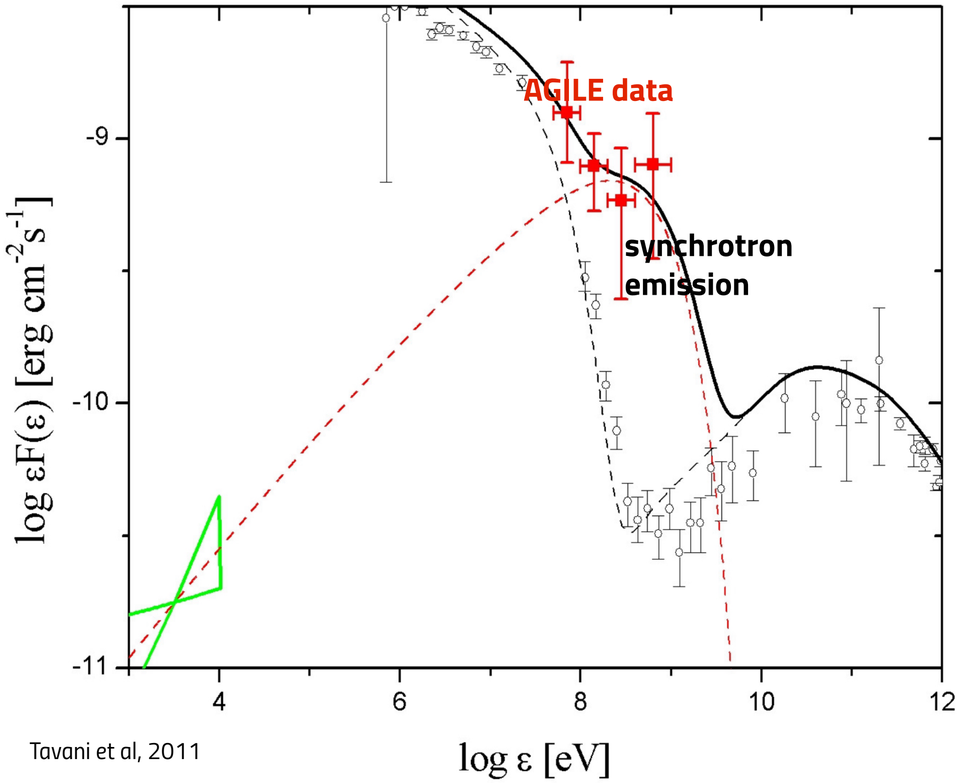
A few months after the launch.

Lesson learnt: expect the unexpected!

$$F_\gamma^{steady} = (2.2 \pm 0.1) \times 10^{-6} ph\, cm^{-2} s^{-1}$$

$$F_\gamma^{2010} = (7.2 \pm 1.4) \times 10^{-6} ph\, cm^{-2} s^{-1}$$

$$F_\gamma^{2007} = (8.9 \pm 1.1) \times 10^{-6} ph\, cm^{-2} s^{-1}$$



Tavani et al, 2011

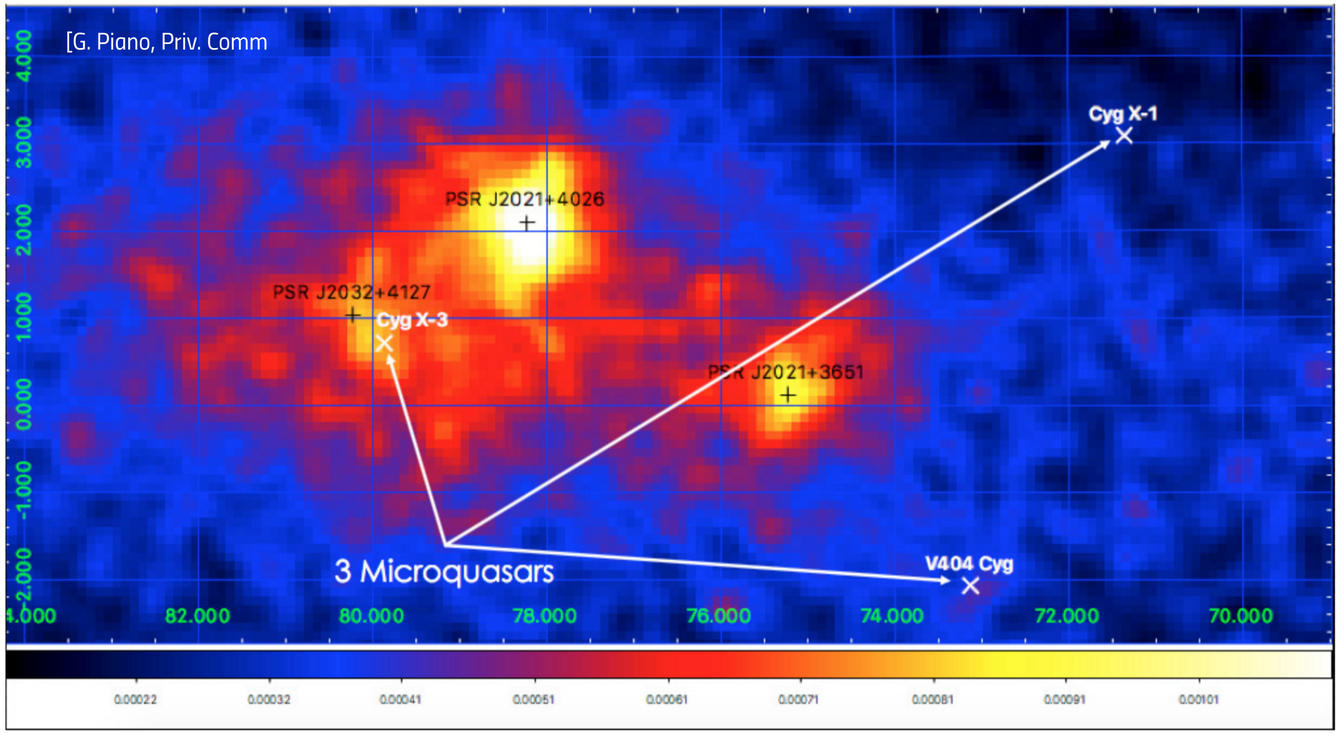
No enhancement was detected at other energies, indicating that the flaring episode happened only in the γ-ray band.

No variations were detected in the pulsar emission, leaving out any interpretation in terms of magnetospheric origin near the Crab pulsar.

The Bruno Rossi Prize

2013 January 8th
221 AAS Meeting, Long Beach (California).

The Cygnus region



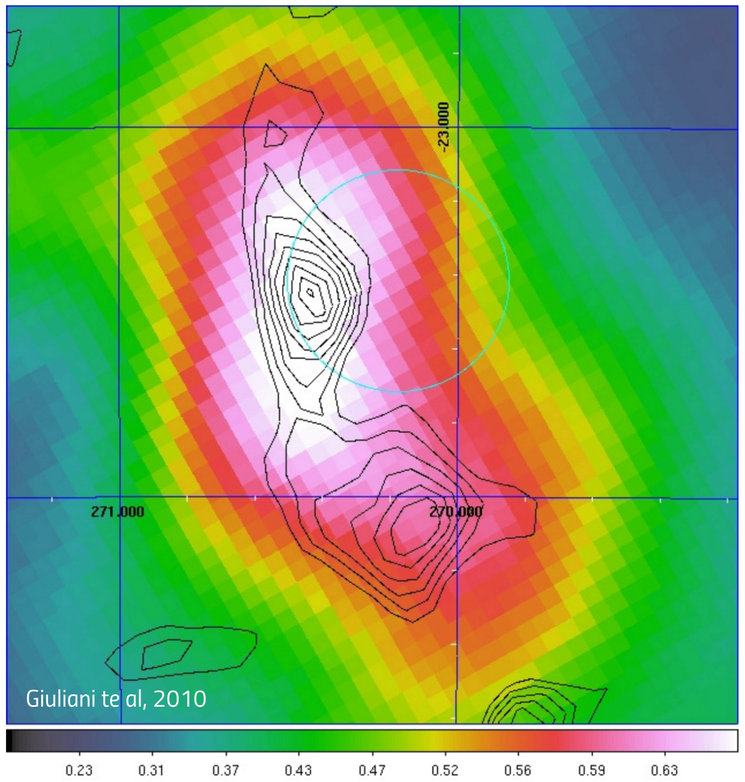
This region is shining both above **a few hundred GeV** [see the H.E.S.S. Galactic Plane Survey] and in the **TeV–PeV energy band** [as reported in the first LHAASO catalog].

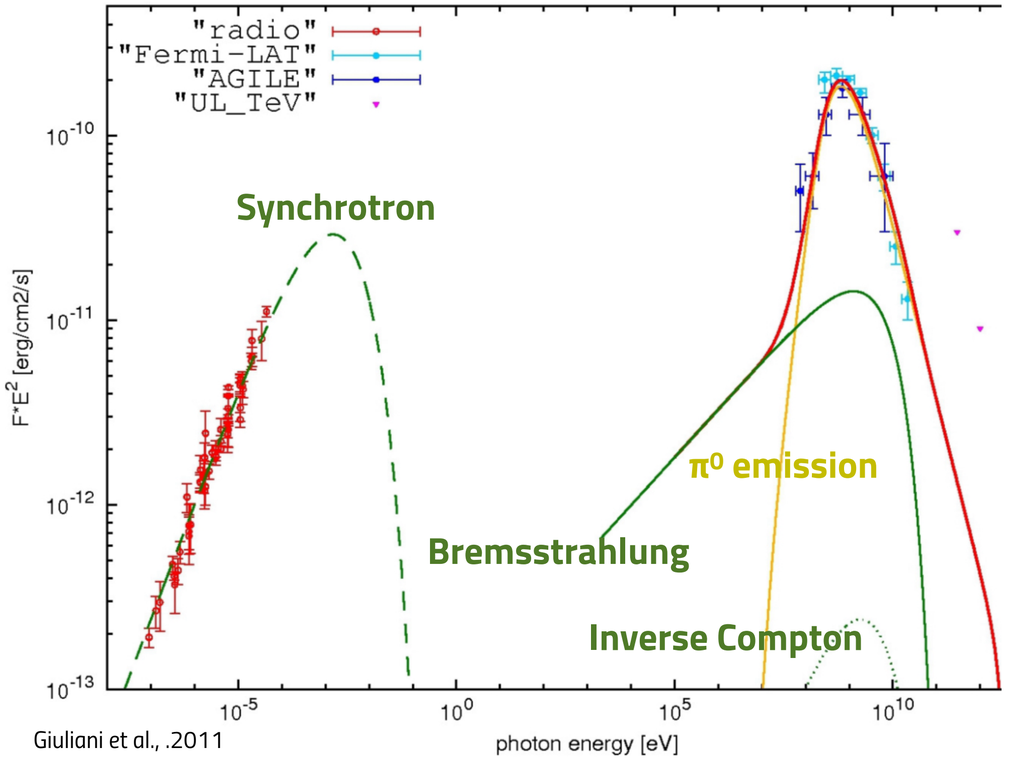
3 (persistent) pulsars: PSR J2021+3651, PSR J2021+4026, and PSR J2032+4127.

3 (variable) μ-QSOs: Cygnus X-1 (extreme particle acceleration on 1-day timescales). **Cygnus X-3** (typical flare has a γ-ray flux of about one order of magnitude larger than its steady flux) and **V404 Cygni** (γ-ray flare after more than a quarter of a century of quiescence, coincident with outbursts in other energy bands).

1 Be-type star with a black hole companion in MWC 656.

W28 & W44: the hadron factories

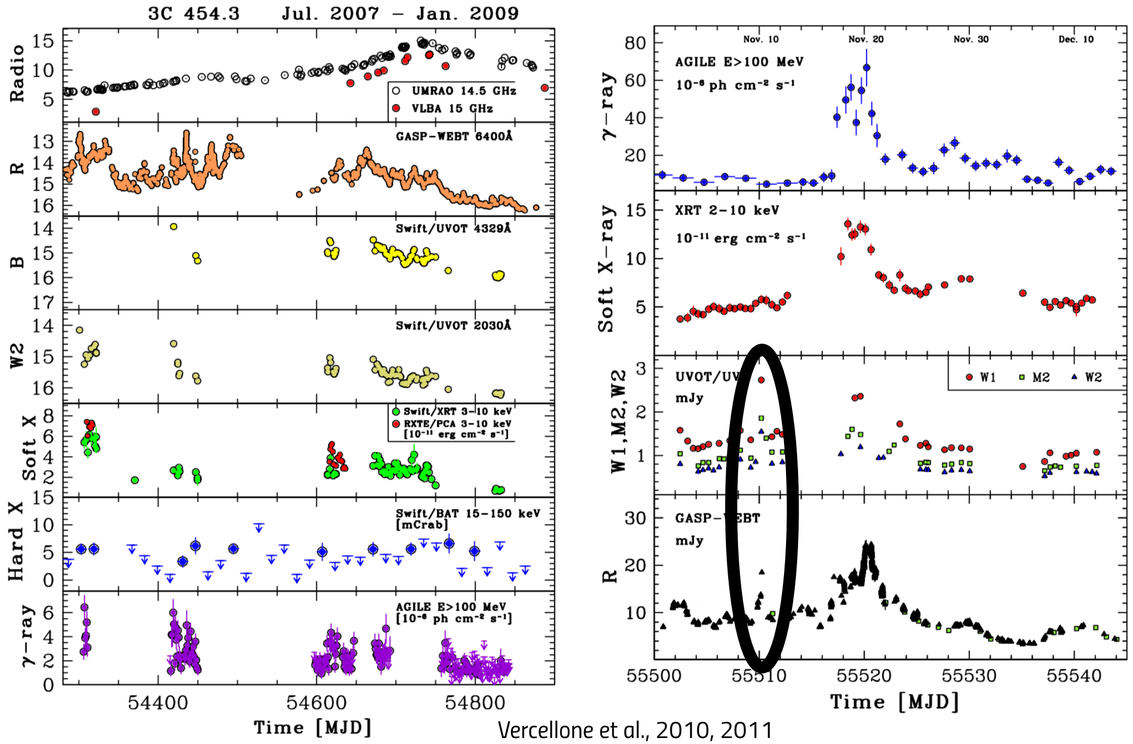




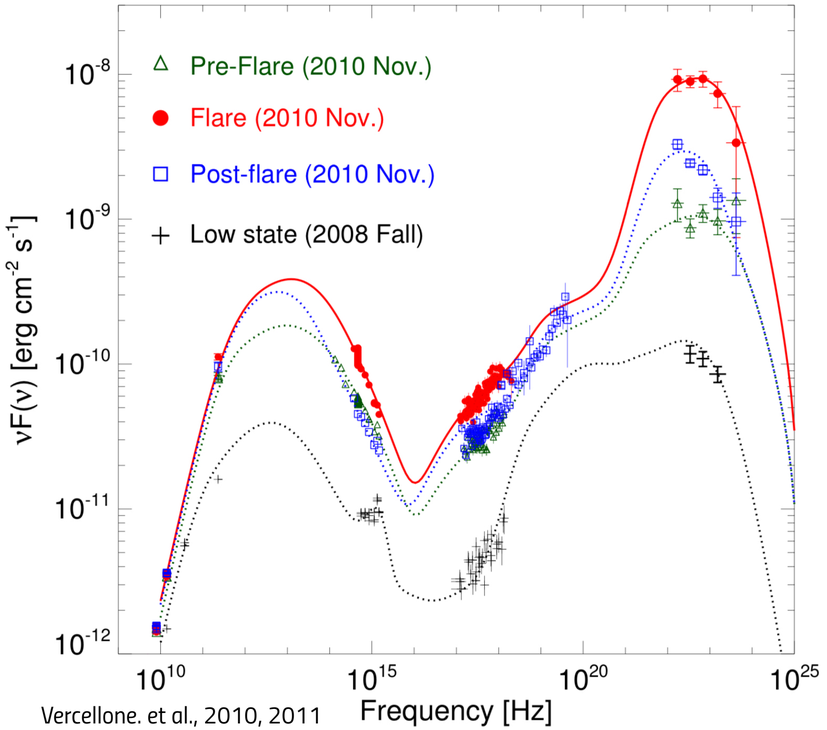
Left: W28 data (E > 400 GeV, Gaussian-smoothed map) accumulated during the "pointing mode" with the superimposed ^{12}CO contours (black lines) and the position of W28 (cyan circle). We model the observed data in terms of **hadronic-induced interaction with the two molecular clouds adjacent to the SNR.**

Right: W44 data show the first evidence of **hadronic cosmic-ray acceleration in the 50–100 MeV energy range.** The multi-wavelength SED of W44 shows observations from radio up to TeV.

3C 454.3: the *Crazy Diamond*



Vercellone et al., 2010, 2011



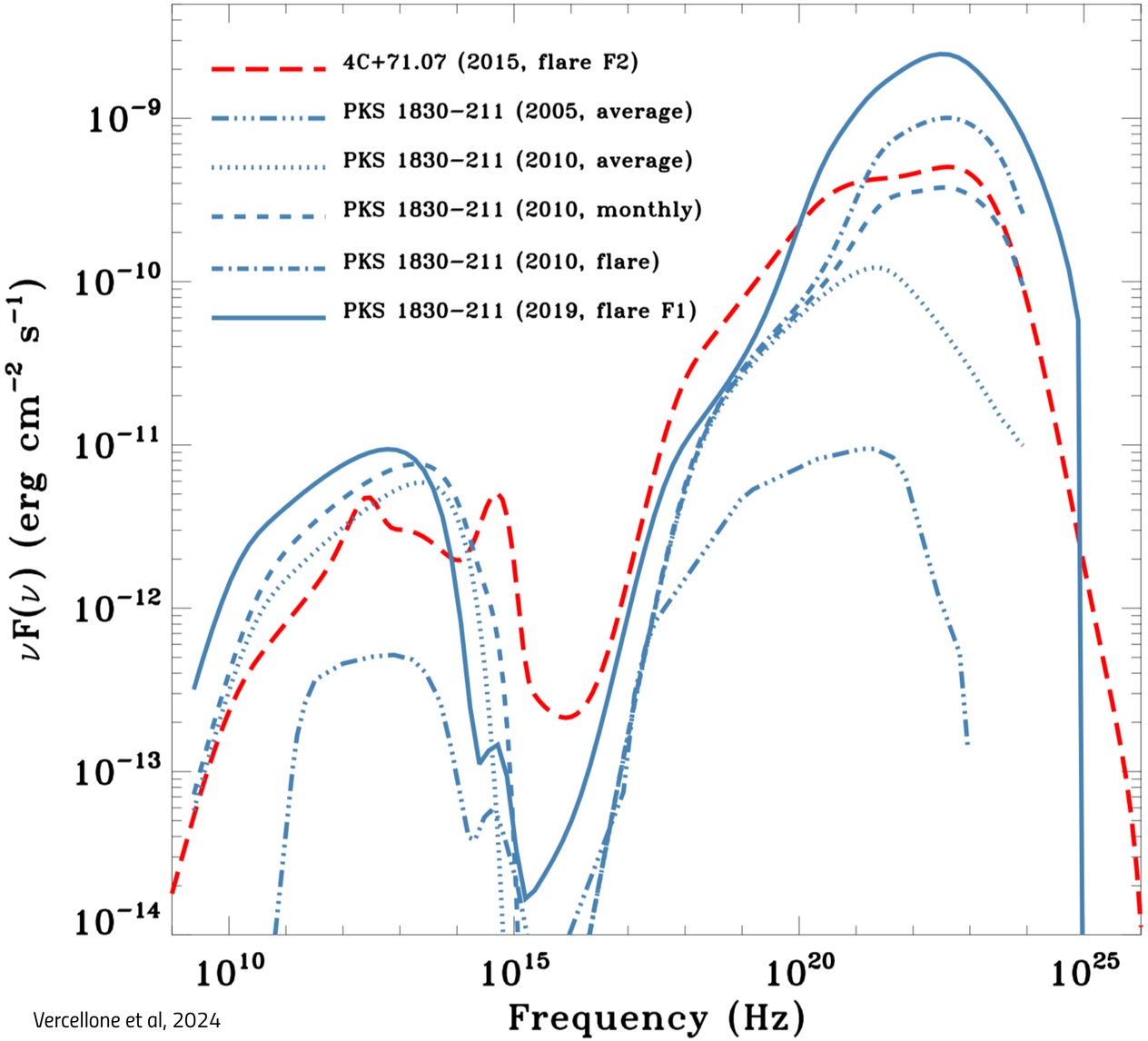
Vercellone. et al., 2010, 2011

The different behavior of the light curves at different wavelengths could be interpreted in terms of a **change of the jet geometry between 2007 and 2008.**

The **γ-ray orphan optical flare** may challenge the model of a uniform external photon field responsible for the high-energy emission.

SED: **emerging of the disc emission in the quiescent state** and a Compton dominance of about 20 during flares.

Distant sources: 4C +71.07 & PKS 1830-211



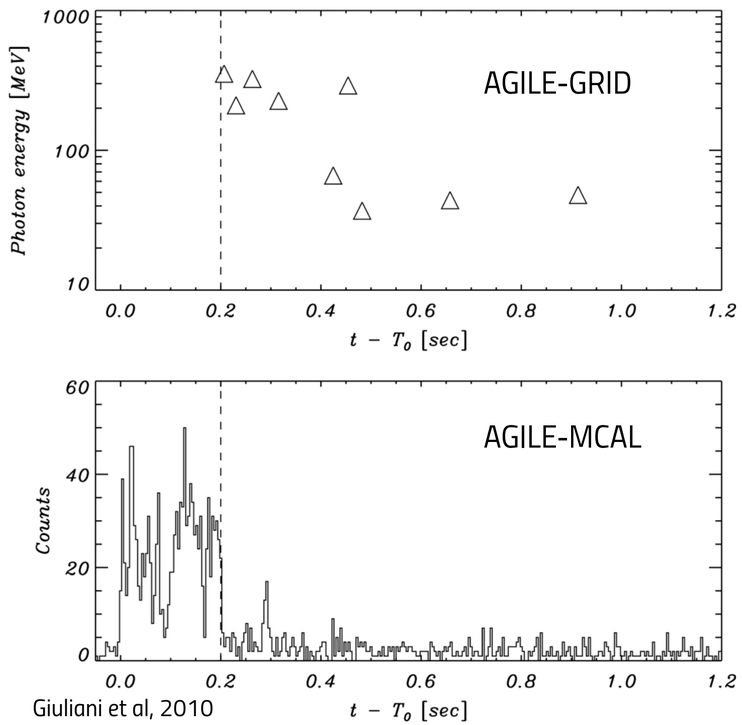
Vercellone et al, 2024

During the flaring states, both sources are within a factor of about 10 in flux.

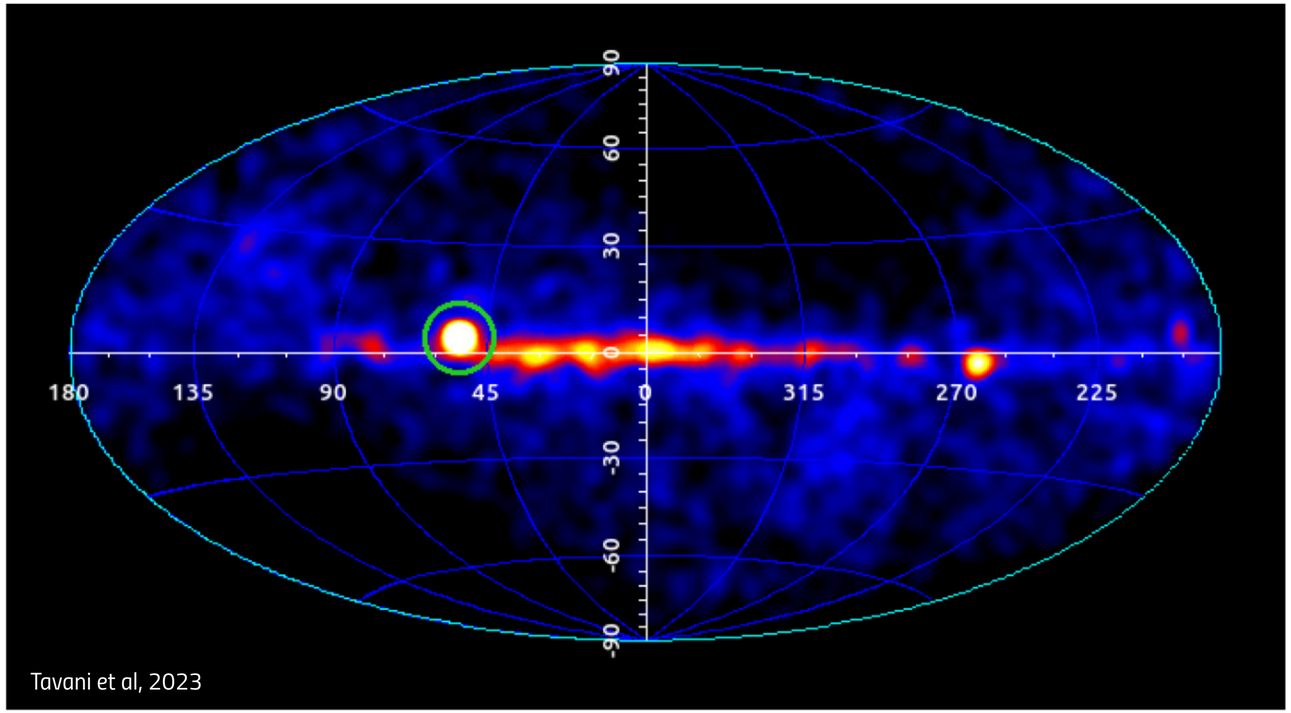
A notable difference between the flaring and the average state of **PKS 1830–211** is the value of the Compton dominance (CD). During the 2005 **average state**, the CD is of the order of **CD~20**, rising to 100 in 2010 and topping at **CD>200 in 2019**.

Such high CD values may challenge the canonical one-component emission model, requiring alternative models to explain this remarkable SED, such as the “mirror model” or “jet-cloud interaction model”.

GRBs: delayed emission and the BOAT



Giuliani et al, 2010

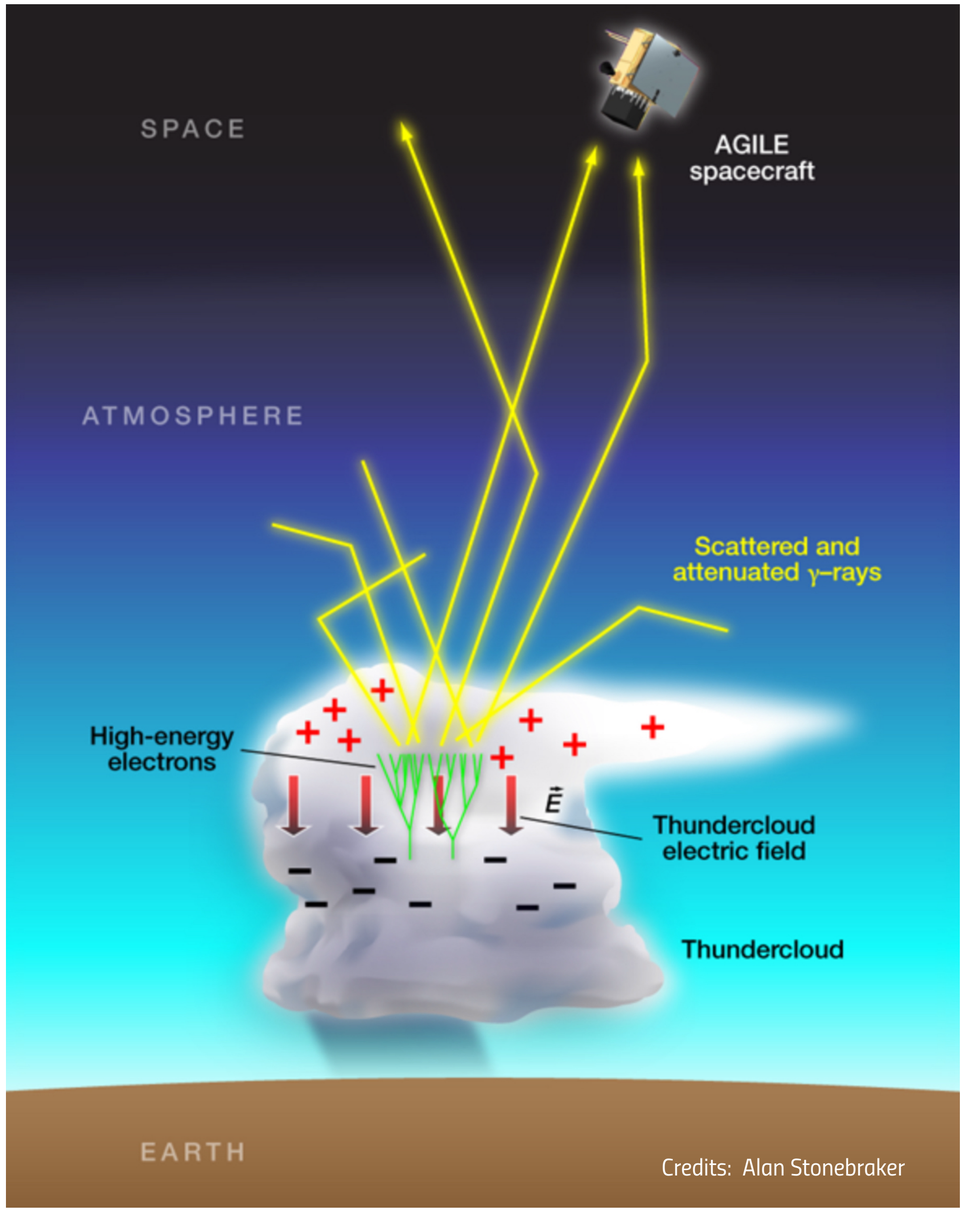


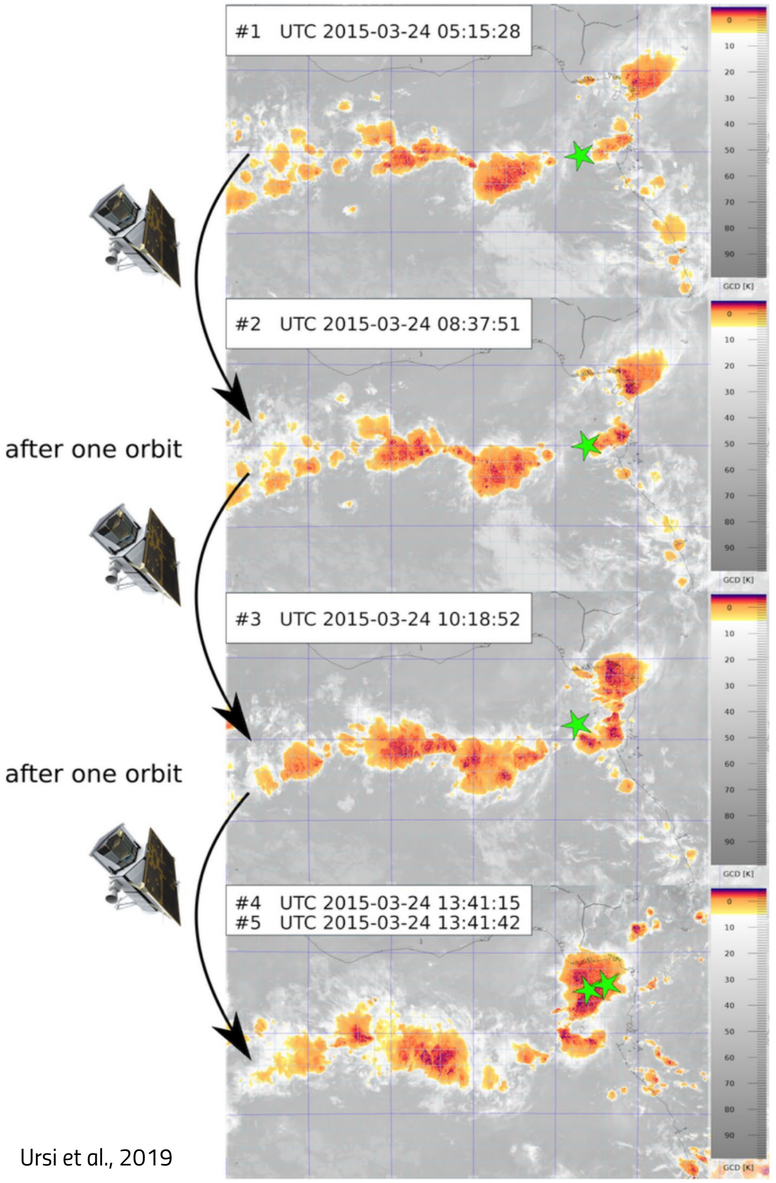
Tavani et al, 2023

Left: GRB 090510 is the first case of a short GRB with delayed γ-ray emission. The AGILE Collaboration reported a **delay of 0.2 s between the AGILE-GRID data with respect to the AGILE-MCAL ones.** The short GRB 090510 is now considered a reference for potential electromagnetic γ-ray emission that could be associated with a gravitational wave event.

Right: GRB 221009A (the BOAT). The BOAT clearly outshines all other γ-ray sources active at that time. **The high-energy emission has been observed with an almost-continuous time coverage, from ~200 s up to ~20 ks after the GRB onset.** The AGILE data suggest a dramatic transition between prompt and afterglow emission with a peculiar phase of coexistence of MeV and GeV emissions with very different spectral properties.

Terrestrial gamma-ray flashes





Ursi et al., 2019

The AGILE MCAL detected **more than 2000 TGFs.**

A new onboard trigger configuration enhanced the TGF **detection rate up to more than 50 TGFs/month.**

AGILE detected a large number of **multiple TGFs from the same active storm.**

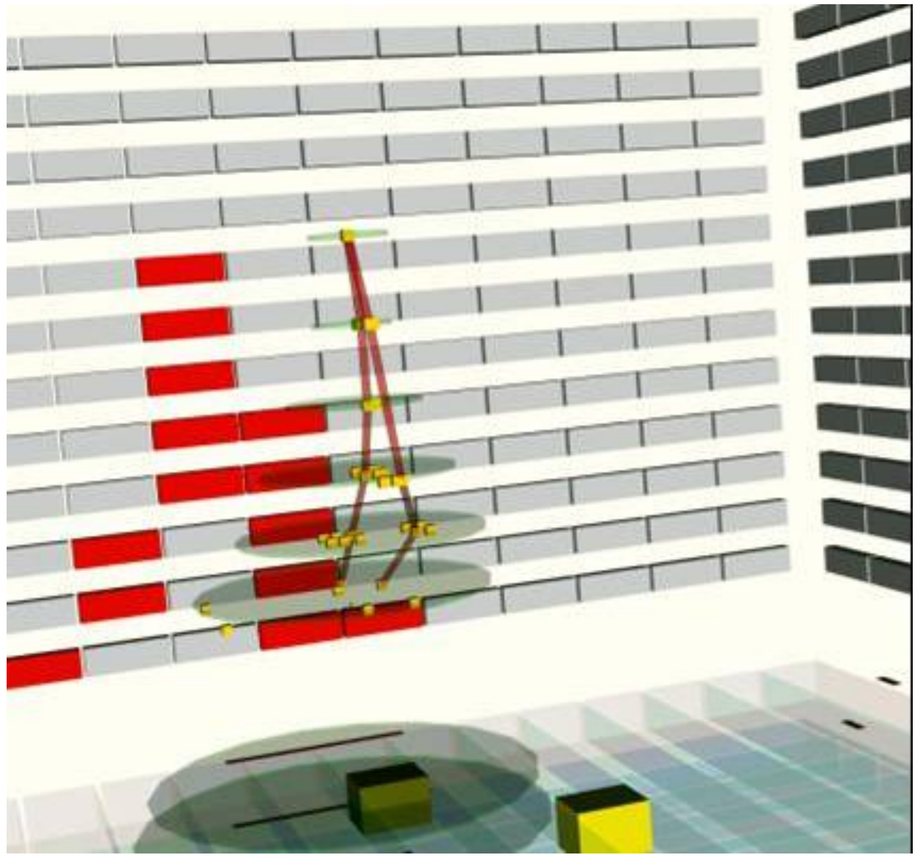
The AGILE legacy

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

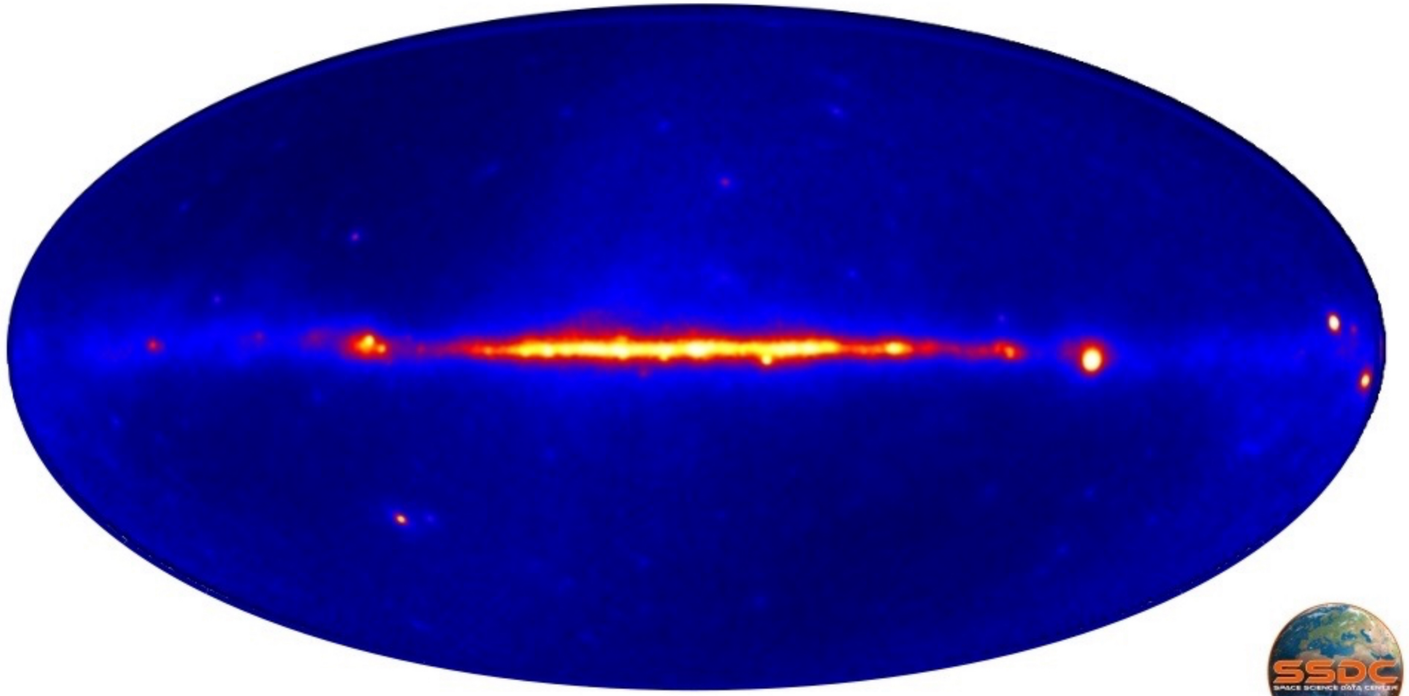
Vercellone et al., 2024, Universe, 10, 153. https://doi.org/10.3390/universe10040153

The AGILE catalogs cover both celestial (including GRBs and solar flares) and terrestrial events (TGFs). This shows the **AGILE versatility,** which, thanks to the information collected by its detectors, could detect steady, flaring, and transient events from **20 keV up to 30 GeV.**

From dawn to dusk



Credits AGILE Collaboration



Credits AGILE Collaboration

Launch date: 23 April, 2007 - Re-entry date: 14 February, 2024
Science observations ended on 18 January, 2024
Planned Nominal Phase: 2 + 2 extended years
Elapsed: **16 years and 10 months** in orbit (6.141 days)

Thank you !

Credits AGILE Collaboration