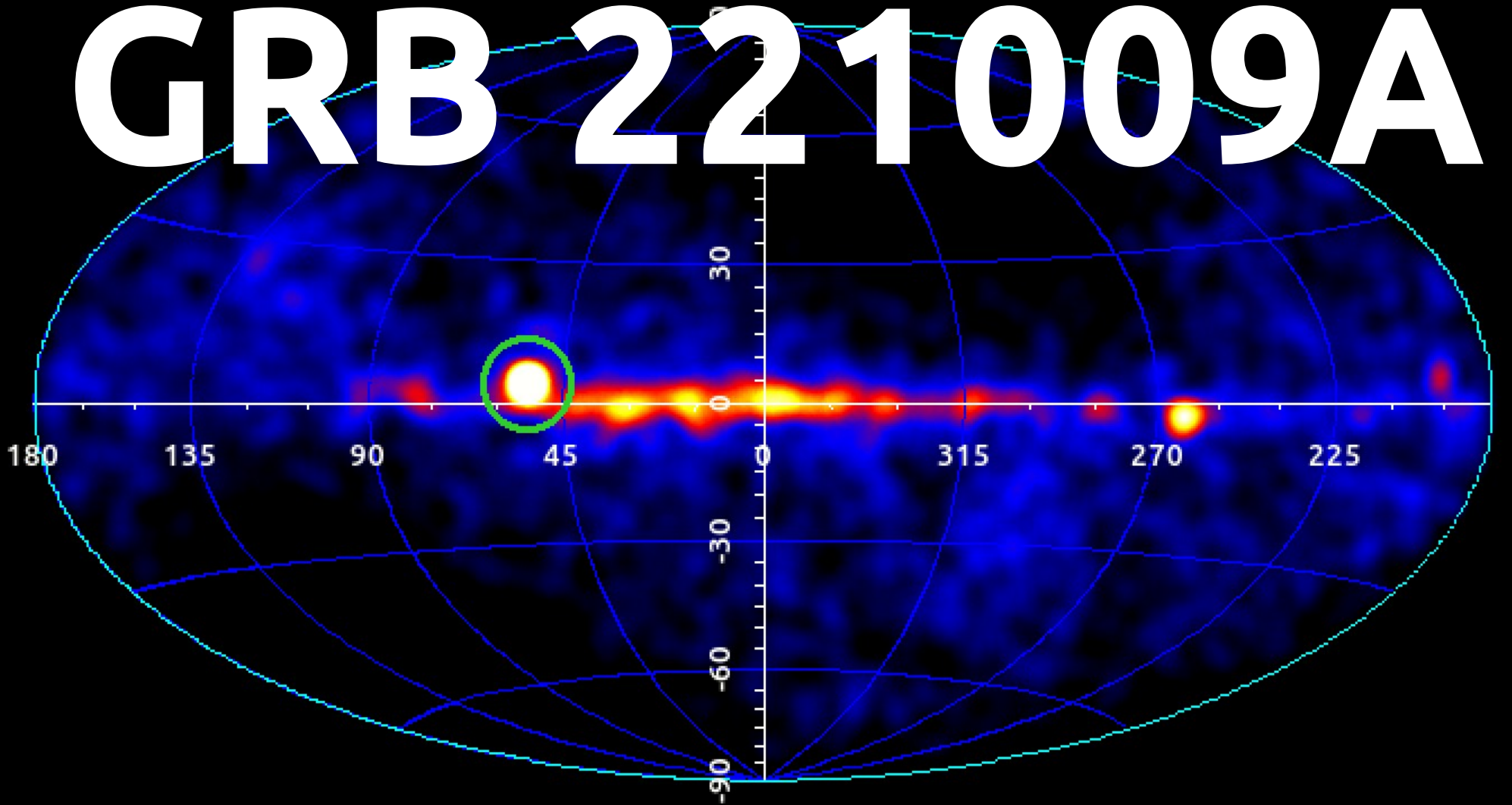
AGILE perspective of GRB 221009A: theoretical implications of MeV-GeV-TeV coexistence in a multi-wavelength context

Foffano L., Piano G., and Tavani M., on behalf of the AGILE Team

GRB 221009A



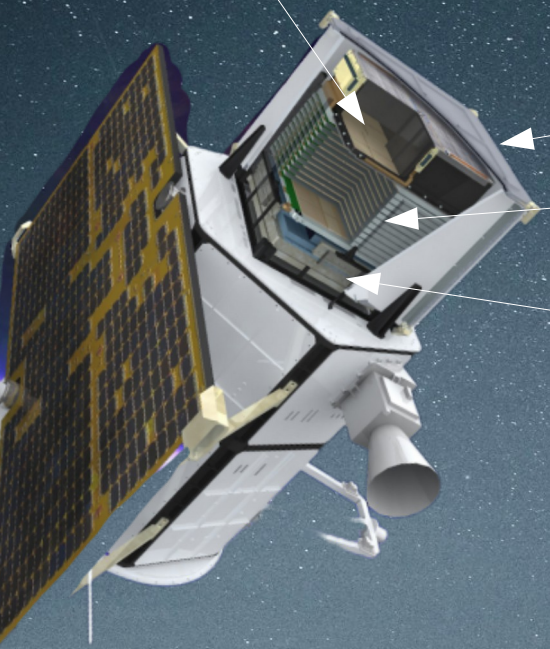
AGILE gamma-ray sky during the GRB 221009A event

AGILE satellite 2007-2024

more than 16 years of operations in space

Bruno Rossi Prize 2012
Marco Tavani and the AGILE team

SuperAgile (SA)
[18 – 60 keV]



Anti-Coincidence (AC)
[50 – 200 keV]

Silicon Tracker
[0.03 – 50 GeV]

MiniCalorimeter (MCAL)
[0.35 – 100 MeV]

Gamma-ray imaging detector
GRID

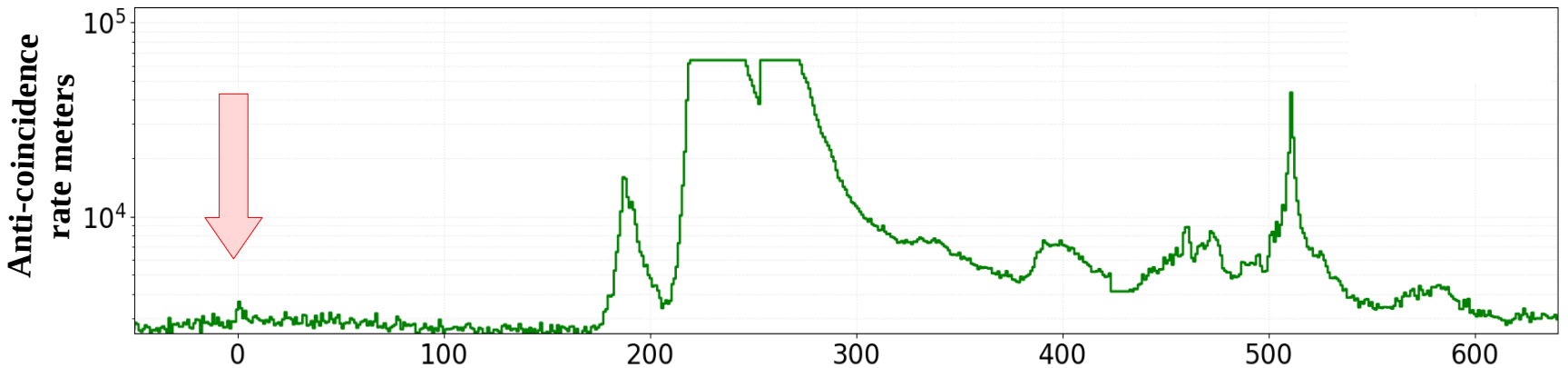
Large field of view of ~100° for the ɣ-ray sky monitoring

Continuous monitoring of the sky!

Spinning observation mode
~1 revolution / 420s

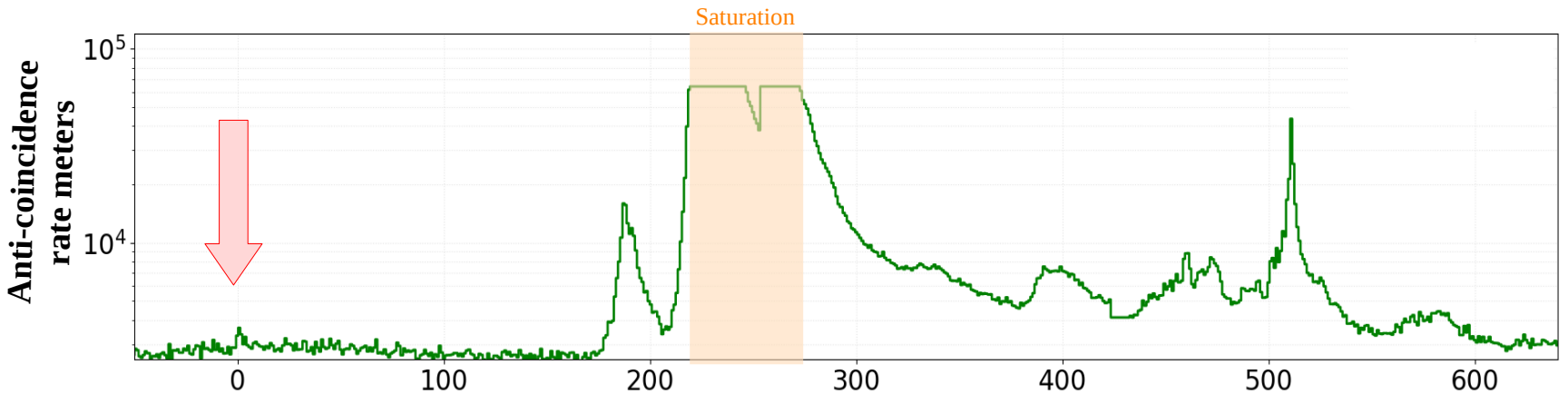
Unique combination of 2 co-aligned X-ray and ɣ-ray imaging detectors

AGILE observations of GRB 221009A



- AGILE triggered GRB 221109A on the weak precursor at T_0 of *Fermi*-GBM on October 9, 2022, T_0 =13:16:59.99 UT
- The brightest phase of the GRB occurred ~220 seconds after the first precursor at T_0.
- AGILE was affected by **saturation** during the brightest phases of the GRB between ~ [220, 270 s]

AGILE observations of GRB 221009A



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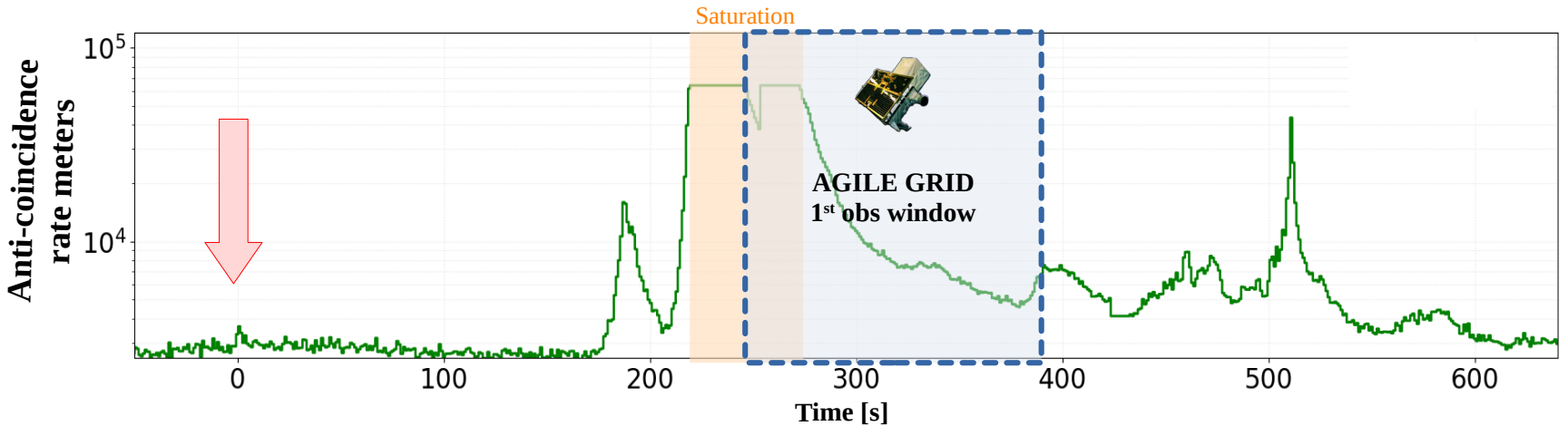

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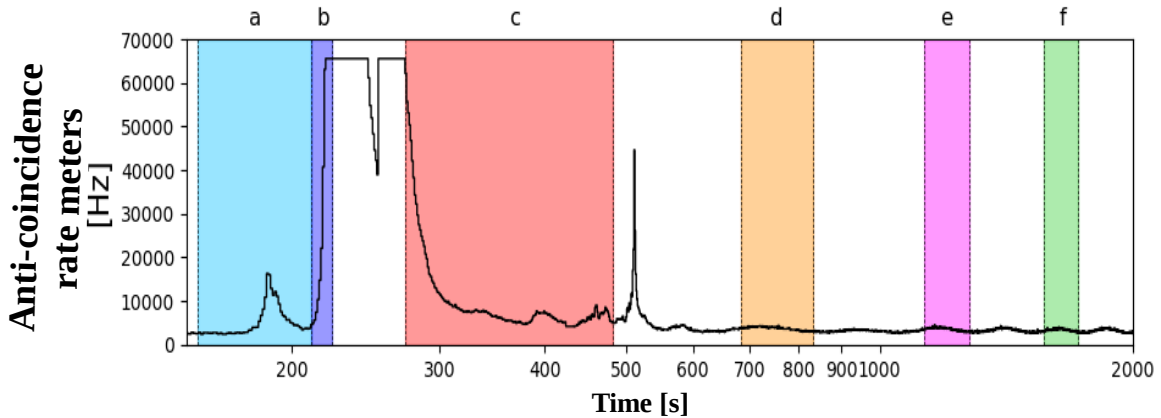
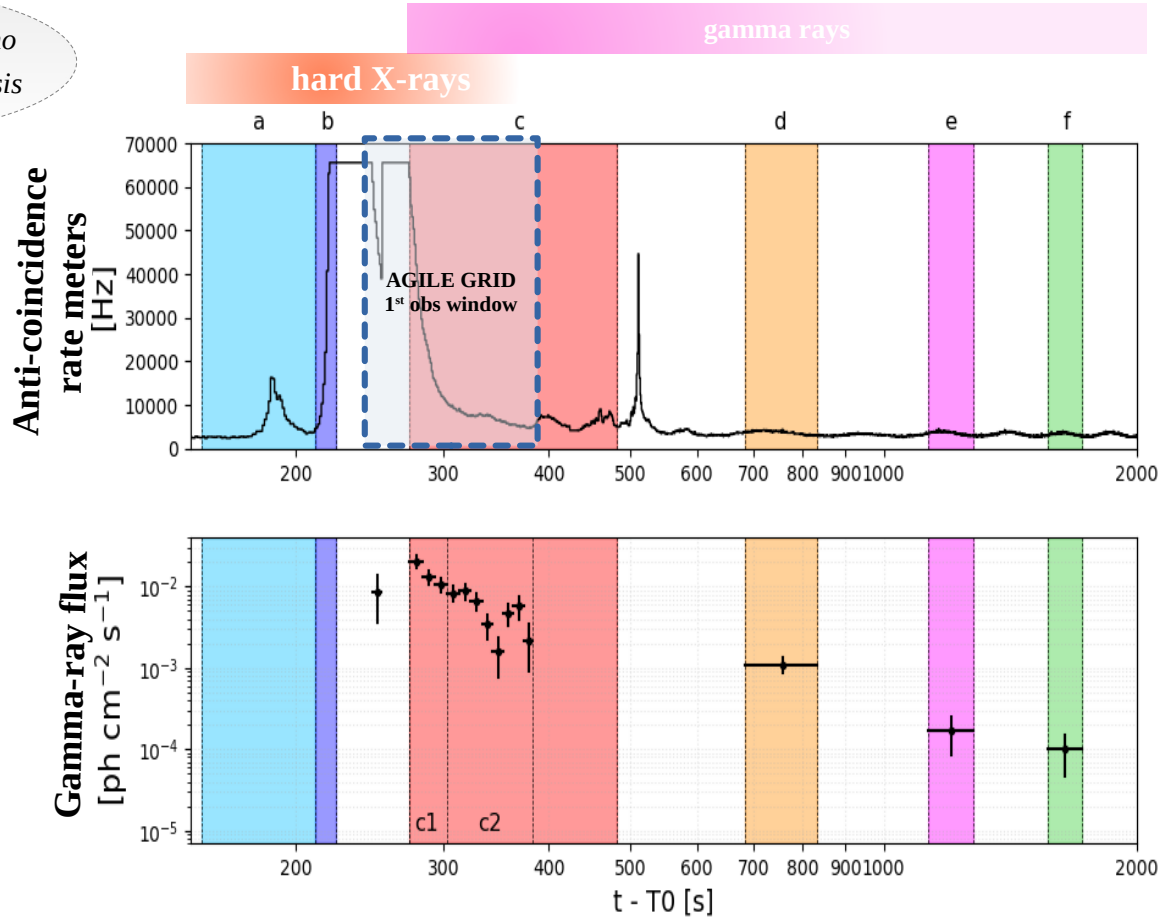


Analysis reporting spectral evolution of AGILE MCAL and AGILE GRID over 6 main time windows

AGILE observations of GRB 221009A

See poster by Giovanni Piano for more details on the analysis



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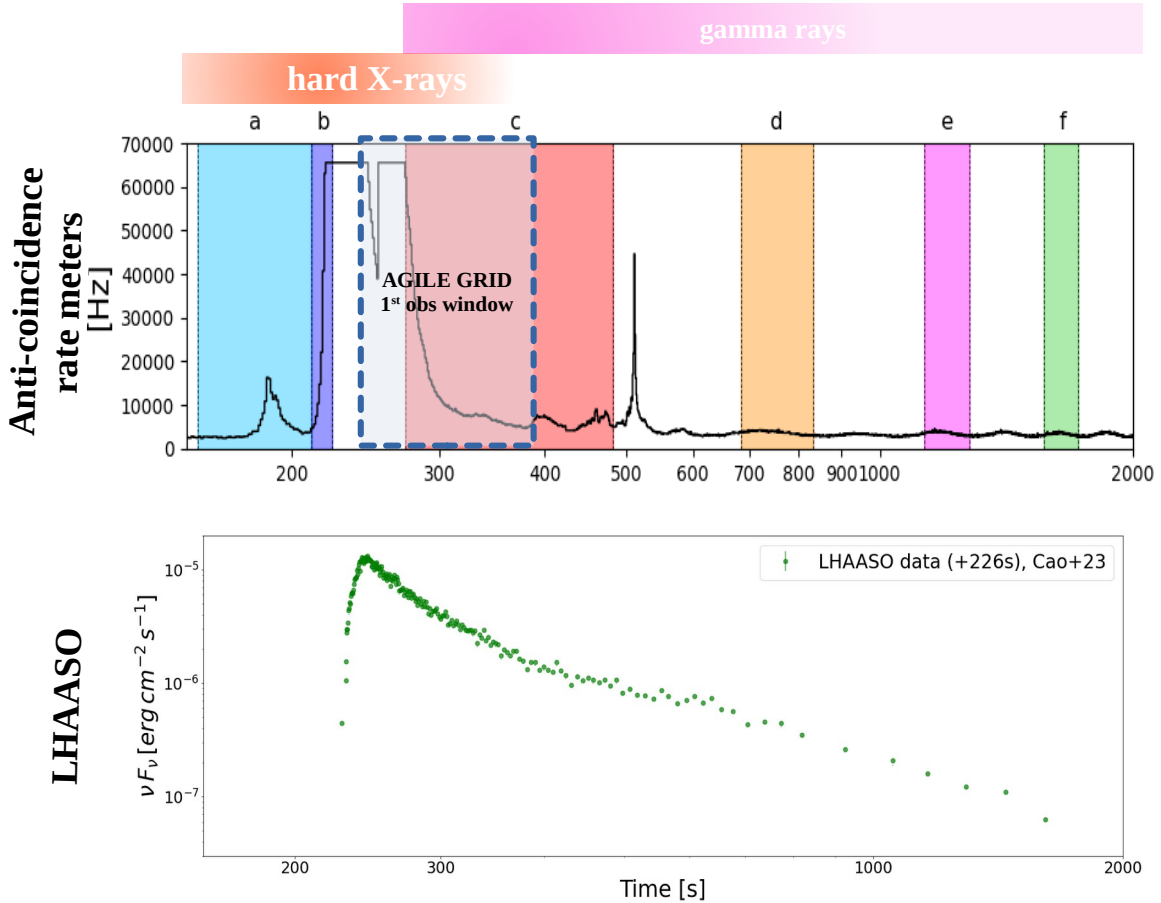

Spectral evolution

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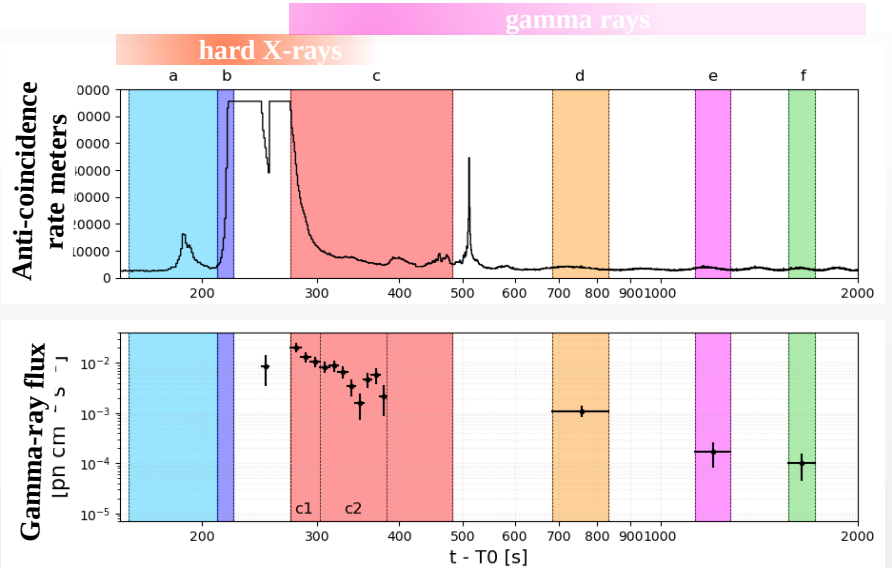
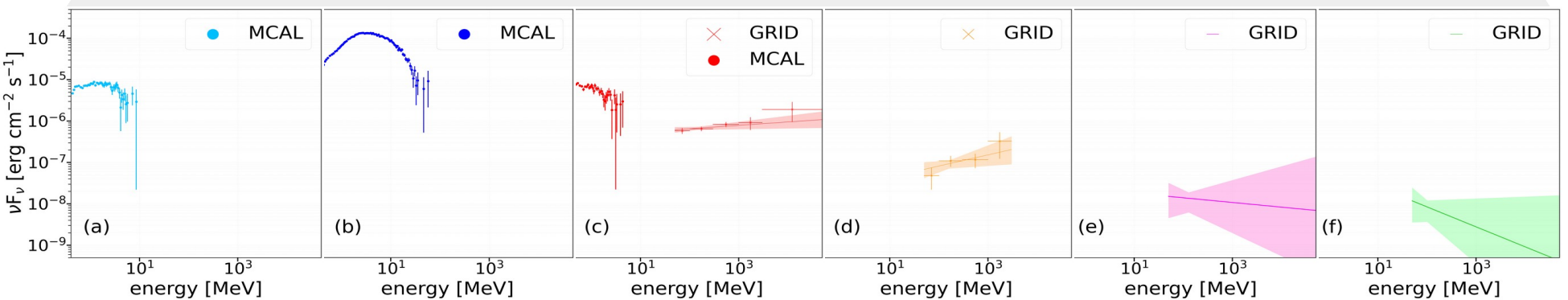
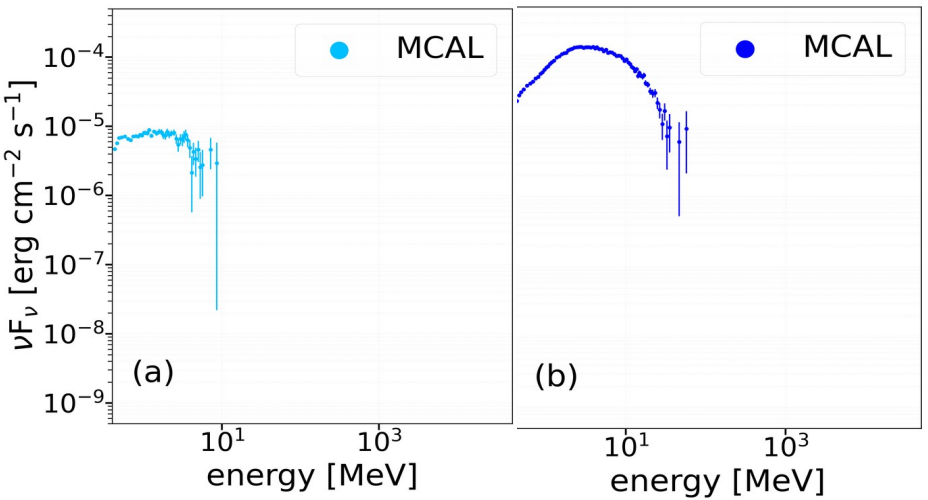




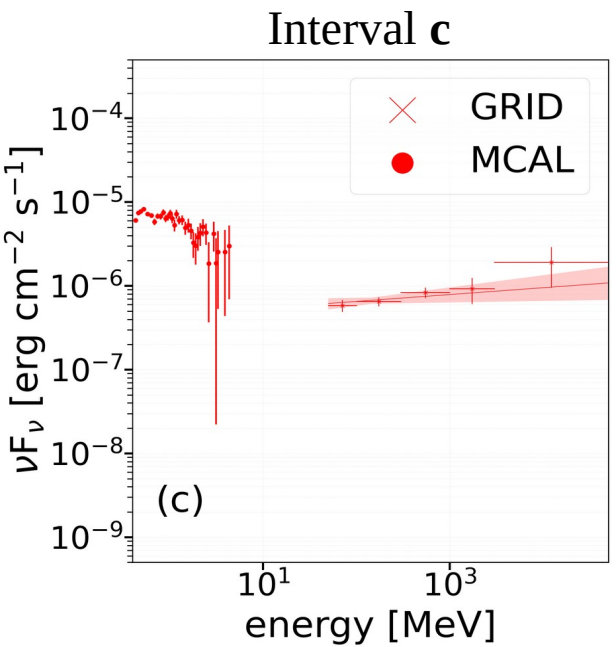
Spectral evolution

Intervals **a** and **b**



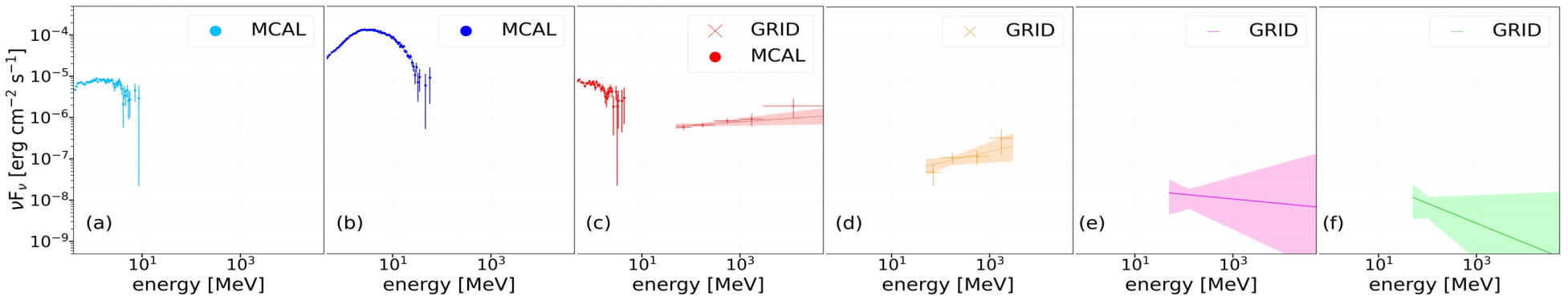
- MCAL shows a very rapid and rising hard X-ray flux
- Emission peaks at $E_{peak} \simeq 3$ MeV
- Low-energy spectral index is ~ 1
- Interpreted as **prompt emission** contribution in a **optically thick environment**

Spectral evolution



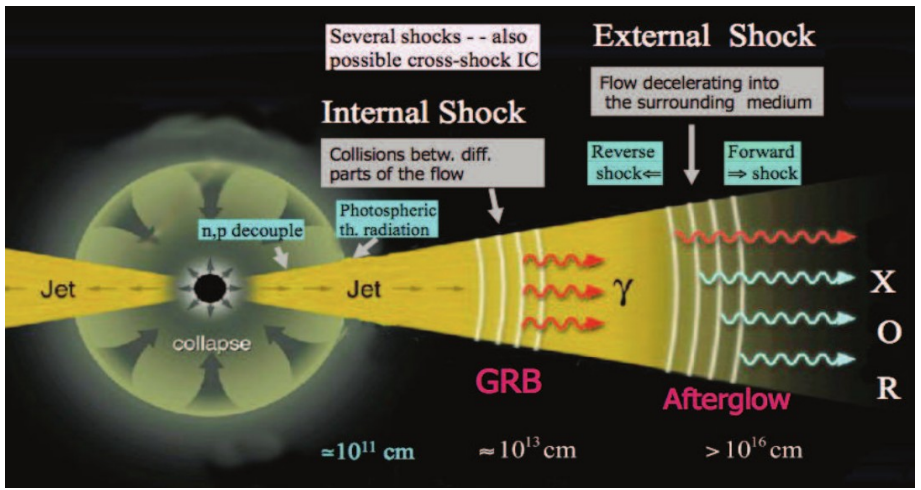
- Prominent hard GeV gamma-ray emission produced with a spectrum **very** different from the decaying MeV component
- **Co-existence** of the MeV prompt emission and an additional GeV-TeV component, which we attribute to inverse Compton afterglow emission
- Together with the TeV spectrum, it provides invaluable information

Spectral evolution



Spectral **hardening** in the GeV range as the overall flux decreases in the early phases of the afterglow

Relativistic fireball model



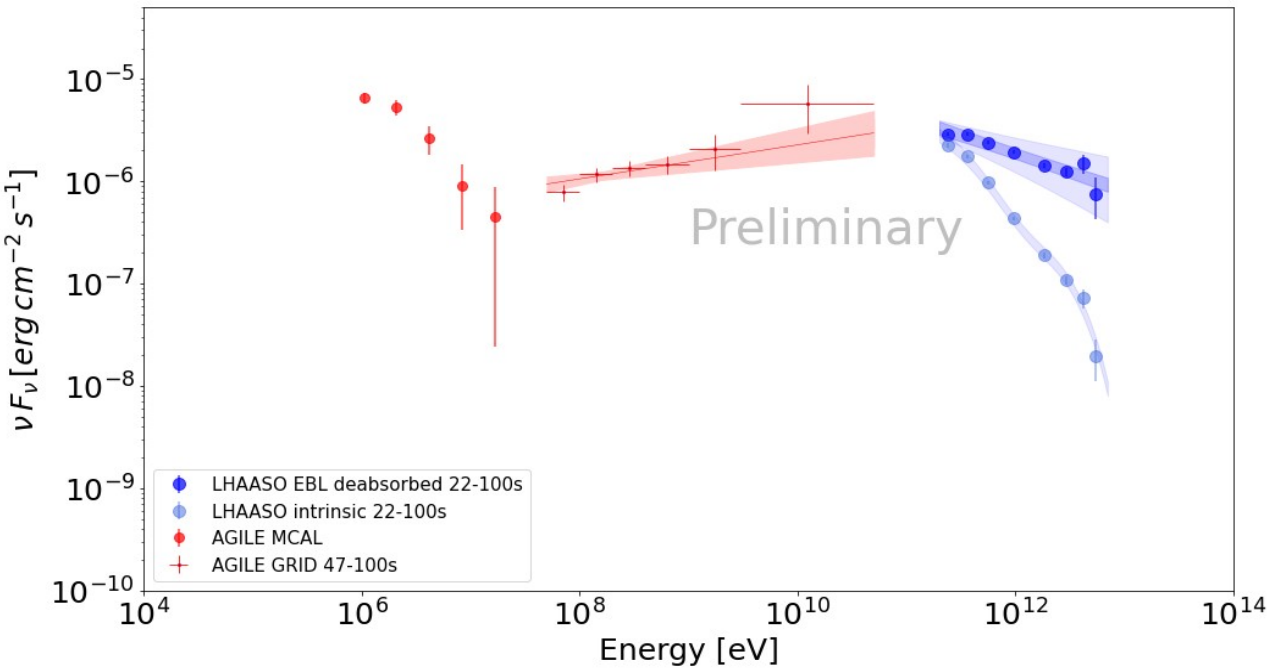
Extracted from P. Mészáros, M.J. Rees, Gamma-ray burst, 2014

- GRB afterglow emission due to **synchrotron** and **inverse Compton** radiation produced by relativistic fireballs expanding in the surrounding medium (e.g. Sari et al. 1998; Sari & Esin 2001)
- External shock model describing the adiabatic expansion of a relativistic blast wave in a medium with **density** $n(r) = A\, r^{-s}$
- Shock front expanding with bulk Lorentz factor Γ(r), accelerating e^- e^+ over a power-law energy distribution $N(\gamma) = N_0\, \gamma^{-p}$
- Homogeneous magnetic field assumed to be co-spatial with the accelerating particles
- Developing a new software for the modeling of spectral evolution of GRBs [L.Foffano+, in preparation]

How do AGILE data constrain the modeling?

Paper in preparation:
L.Foffano+2024

AGILE MCAL, AGILE GRID, and LHAASO data

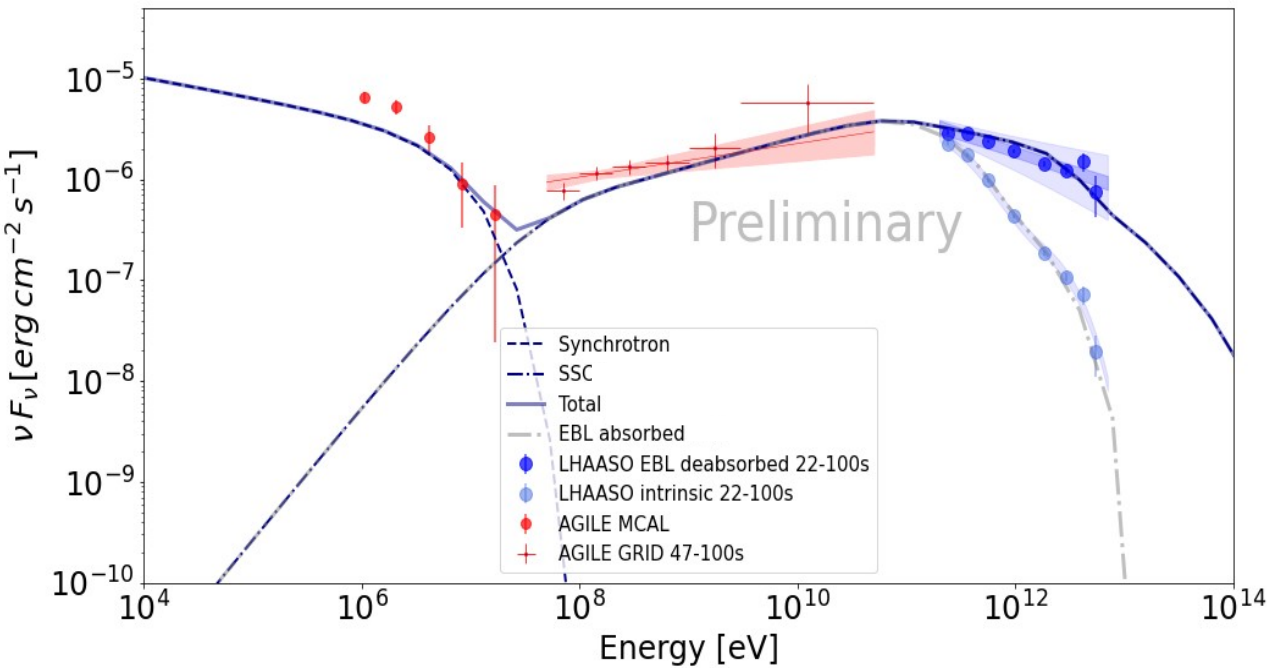


New analysis of the AGILE GRID gamma-ray data, simultaneous to LHAASO data sets

How do AGILE data constrain the modeling?

Paper in preparation:
L.Foffano+2024

E_0 [erg]	Γ_0	s	n_0 / A*	p	ε_e	ε_b	Event	T_{start} [s]	T_{end} [s]	γ_{max}
8e+55	500	0	1.0	2.4	0.012	0.0001	GRB221009A	22	100	2.0e+06



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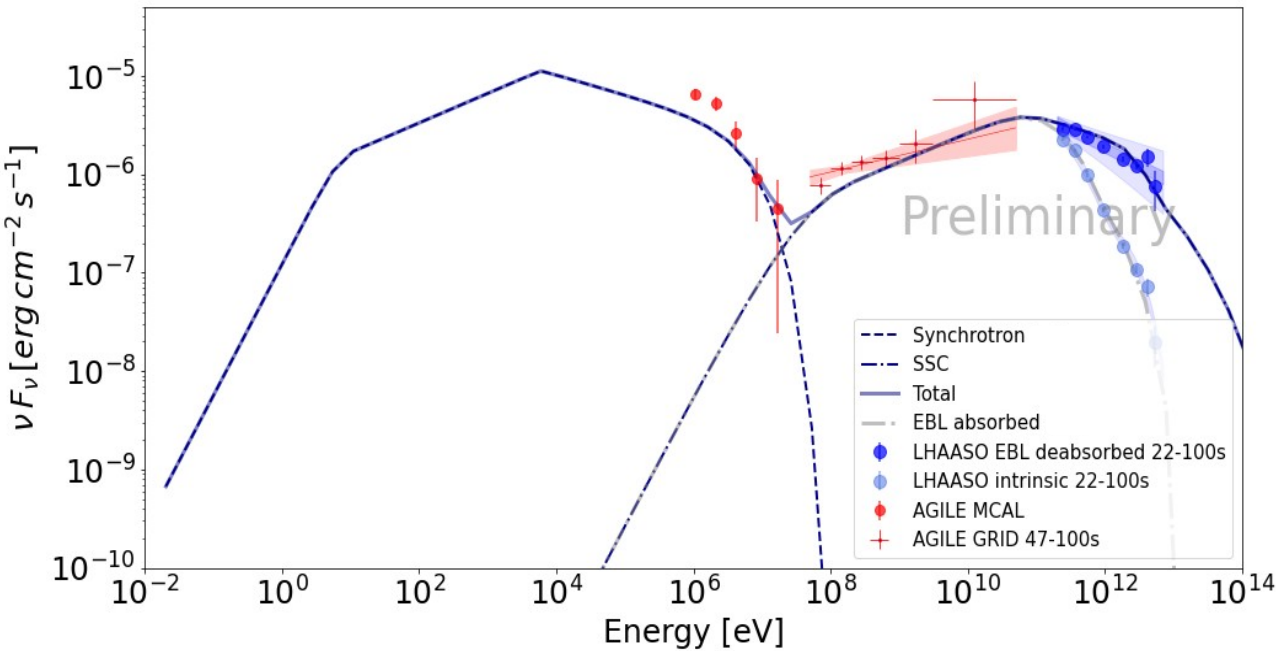

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Interpretation of GRB 221009A

Take home message from AGILE

New publications coming soon!

Wow! GRB 221009A was extraordinary and very complex

AGILE fireworks!

AGILE obtained **excellent data** during the most important emission phases of GRB 221009A:

- excellent agreement of GeV AGILE spectral data with LHAASO spectral data
- **crucial insights for the theoretical interpretation** of this exceptional event
- useful to constrain both the synchrotron and the inverse Compton emission at gamma rays

Co-existence of MeV and GeV emission:

AGILE detected the **co-existence** of the MeV emission with the GeV-TeV afterglow emission.

This suggests the presence of two distinct emitting regions: an inner, likely optically thick region, and an optically thin, relativistically expanding region.

We must be ready! Great opportunities for CTA!

Prompt response of gamma-ray observatories to transients is crucial to provide essential information to the interpretation of these extreme events.

Thank you!

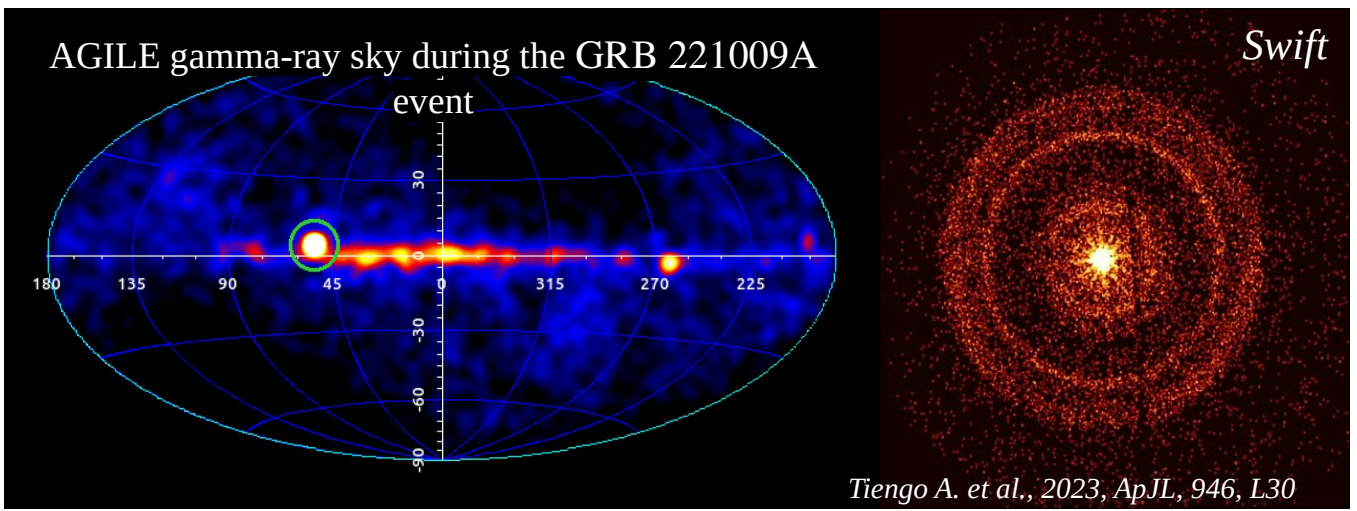
Backup

GRB 221009A

- Redshift z = 0.15095 ± 0.00005 ~ 750 Mpc
- Fluence: >0.05 erg/cm^2
- Brightest-of-all-time (BOAT)

  → Main burst caused saturation in many instruments, including AGILE

- ✔ Detected in gamma rays keV/MeV/GeV
- ✔ Detected by LHAASO at TeV energies
- ✗ Not detected by IACTs (full moon)
- ✗ No associated neutrinos



AGILE observations of GRB 221009A

- AGILE detectors recorded the most intense part of the GRB 221009A activity with no Earth occultations and good exposure
- Good time intervals are dominant and provide crucial scientific value!