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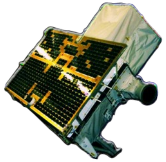


AGILE Satellite
Bruno Rossi Prize 2012

AGILE results and interpretation of the exceptional long gamma-ray burst GRB 221009A

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

TeVPA 2023

TeVPA2023 conference – Naples (Italy) – 12/09/2023

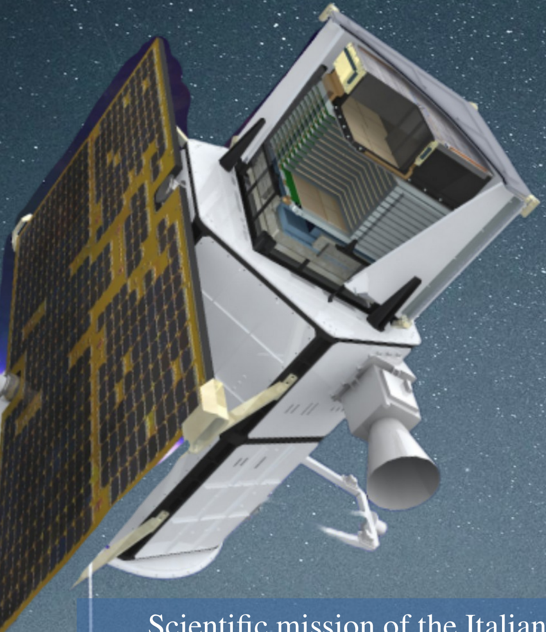
Overview

- The AGILE satellite
- GRB 221009A: AGILE observations
- GRB 221009A: AGILE interpretation

AGILE satellite

more than 16 years of operations in space

Bruno Rossi Prize 2012
Marco Tavani and the **AGILE team**



Scientific mission of the Italian Space Agency (ASI),
with programmatic and technical support of INAF and INFN.

Current operation status

Fully operational, nominal status, and active in:

- **Gamma-ray astrophysics**
  - Persistent and variable sources
  - Transient sources (GRBs, gamma-ray counterparts of GWs, neutrinos, FRBs)
- **Solar physics** (flares from the Sun)
- **Terrestrial physics** and **space weather** (TGFs)

Actively involved in the hunt for high-energy **electromagnetic counterparts of gravitational waves** during the current LIGO-Virgo-Kagra O4 observing run, started in May, 2023.

Probable satellite reentry in 2024?

AGILE satellite

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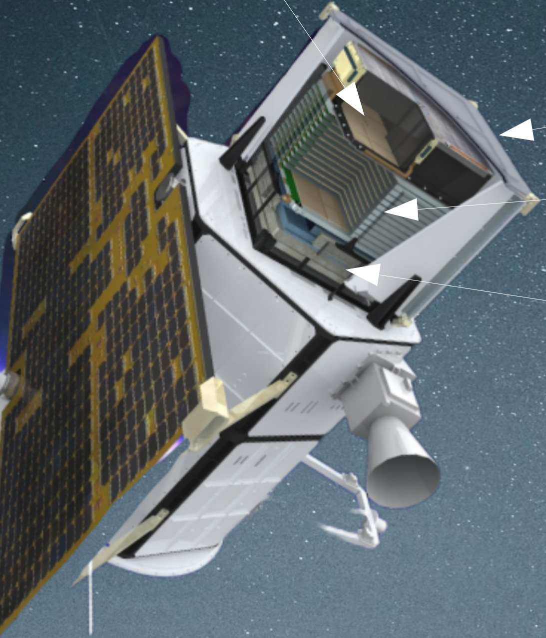


SuperAgile (SA)
[18 – 60 keV]

Anti-Coincidence (AC)
[50 – 200 keV]

Silicon Tracker
[0.03 – 50 GeV]

MiniCalorimeter (MCAL)
[0.35 – 100 MeV]

GRID
Gamma-ray imaging detector

Large field of view of ~60°
for the ɣ-ray sky monitoring

Continuous monitoring of
the sky!

Spinning observation mode
~200 passes/day

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

Scientific results

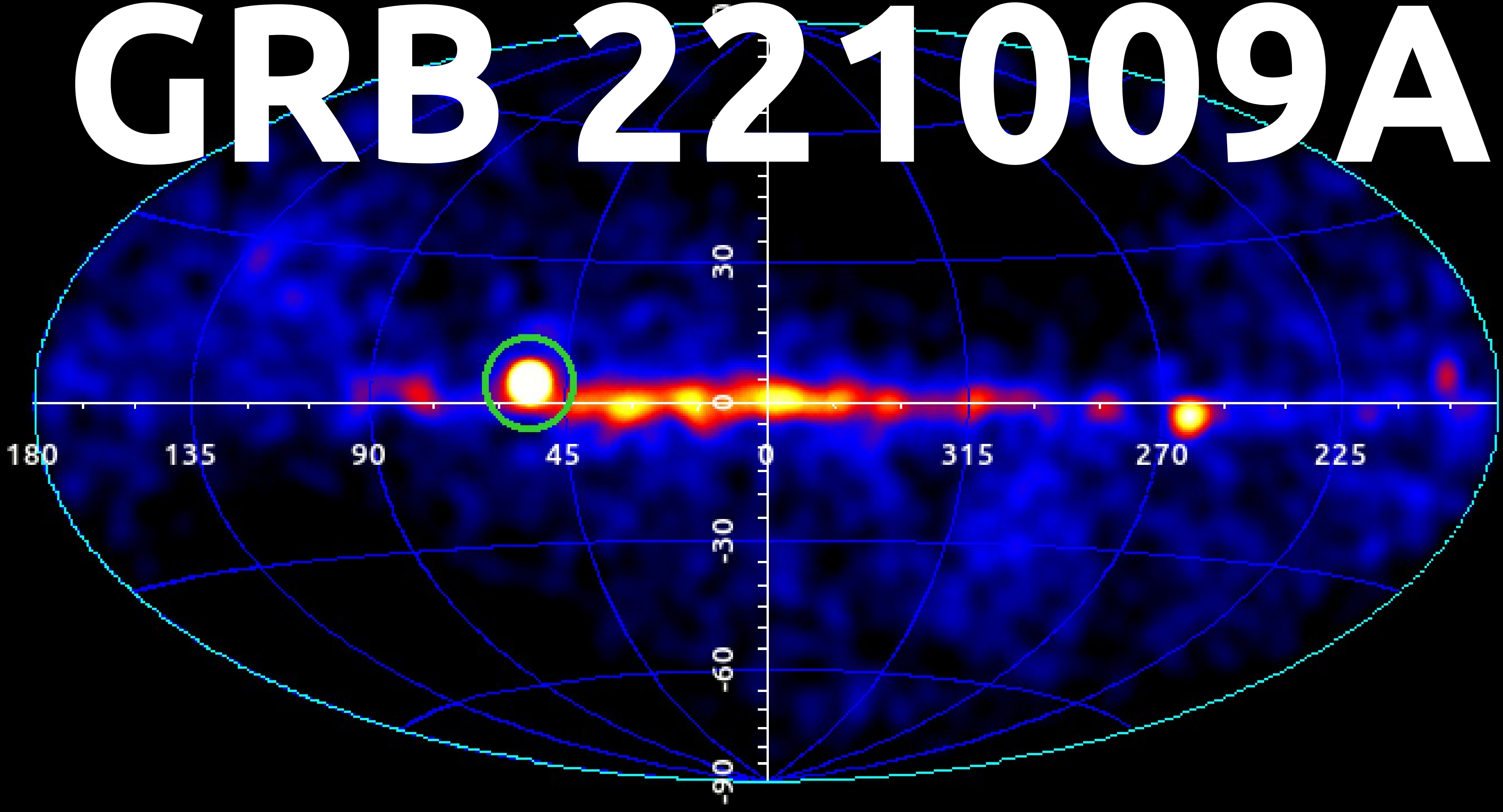
NASA-ADS counting >800 bibliographic references in ADS,
of which >160 refereed articles

- Fruitful monitoring of the gamma-ray sky: >230 ATel and >200 GCN

Latest AGILE results on GRBs

- **AGILE MCAL second GRB catalog**: comprehensive catalog of all GRB detected by MCAL from 2007 to 2020 (Ursi et al., ApJ 925, 2022)
- **GRB 190114C**: First GRB event detected at very high-energies by MAGIC participation to the multi-frequency paper [MAGIC Collaboration, Nature, 2019]
- **GRB 190114C**: dedicated analysis of the prompt phase with AGILE and Konus-Wind data [Ursi et al., ApJ, 2020]
- **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]

GRB 221009A



AGILE gamma-ray sky during the GRB 221009A event

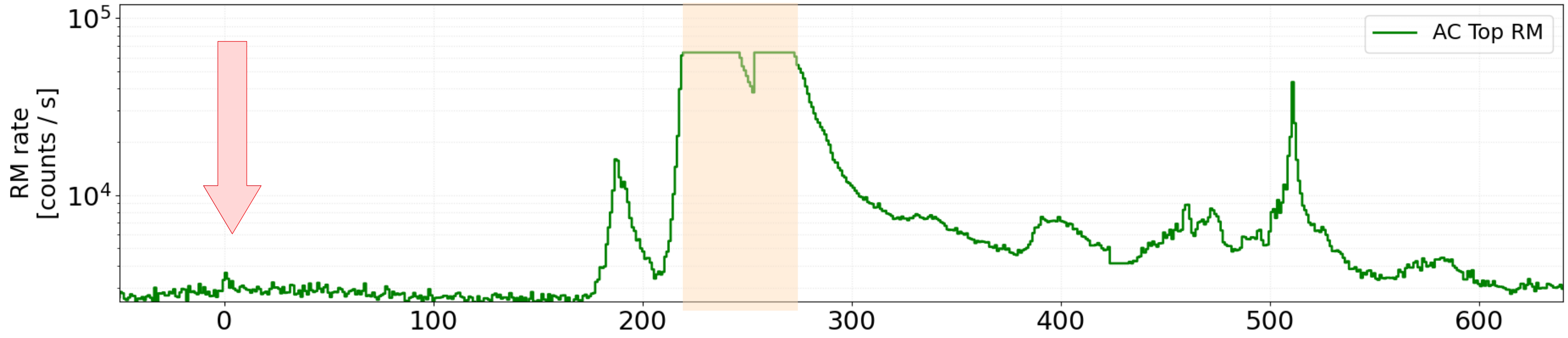
AGILE observations of GRB 221009A

Results published in Tavani+2023, submitted

- 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
- AGILE was affected by **saturation** during the brightest phases of the GRB between [220, 270 s]

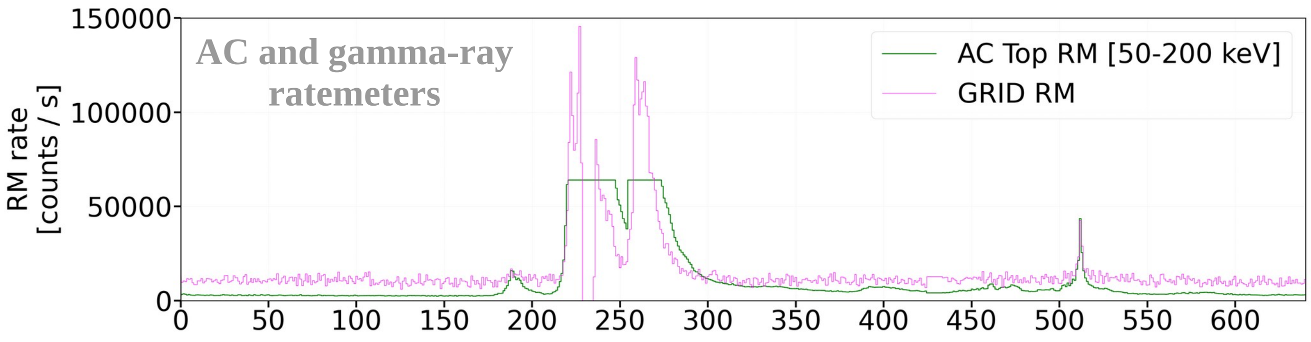
The initial event triggering at T_0 turned out to be a weak precursor to the brightest part of the GRB that occurred after 200-300 s.

Anti-coincidence rate meters



AGILE observations of GRB 221009A

Results published in Tavani+2023, submitted



- When the AC saturates, it introduces a veto on the GRID ratemeters
- We excluded those time intervals from the current analysis

AGILE observations of GRB 221009A

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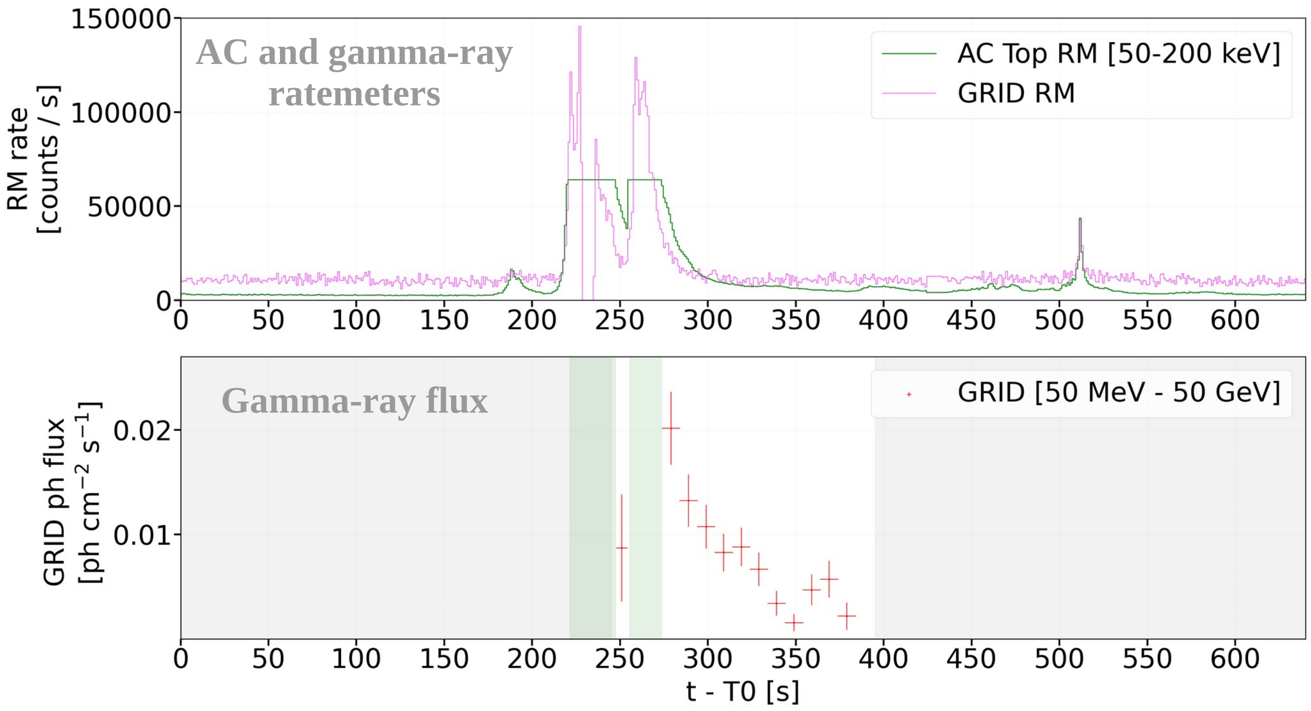

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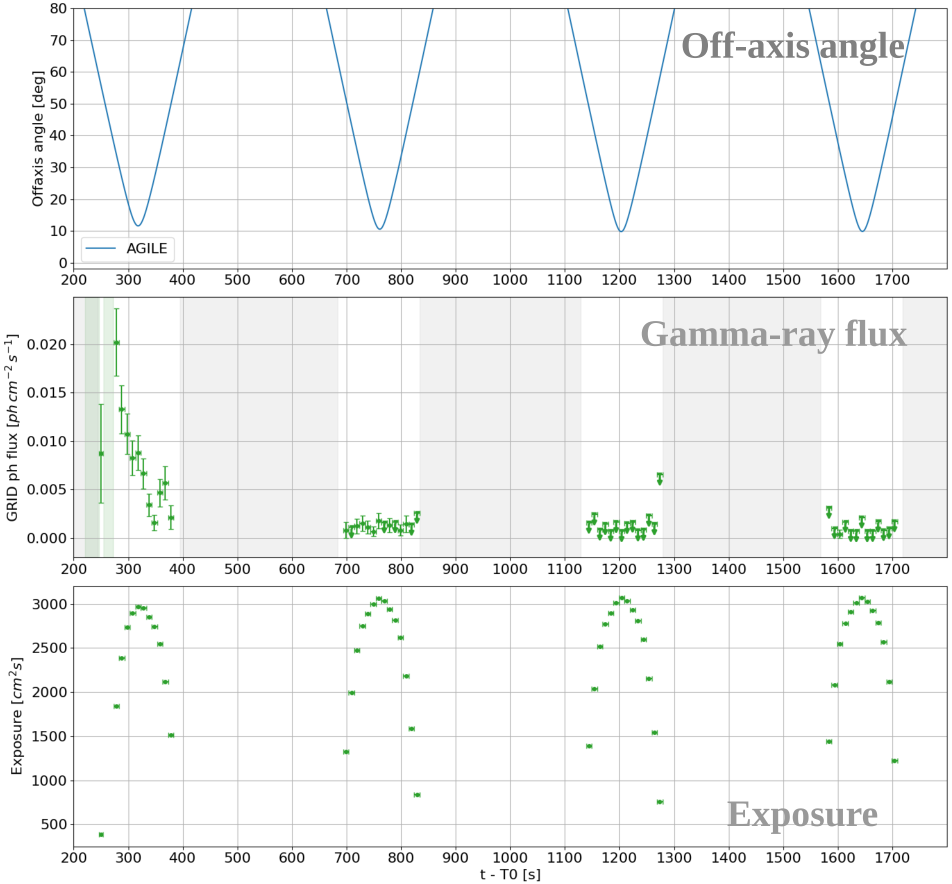
AGILE observations of GRB 221009A

Results published in Tavani+2023, submitted

- 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!



AGILE observations of GRB 221009A

Results published in Tavani+2023, submitted

We defined **6 main time windows**:

a) **[155; 211] s** → first intense **hard X-ray emission** peaking at ~180 s.

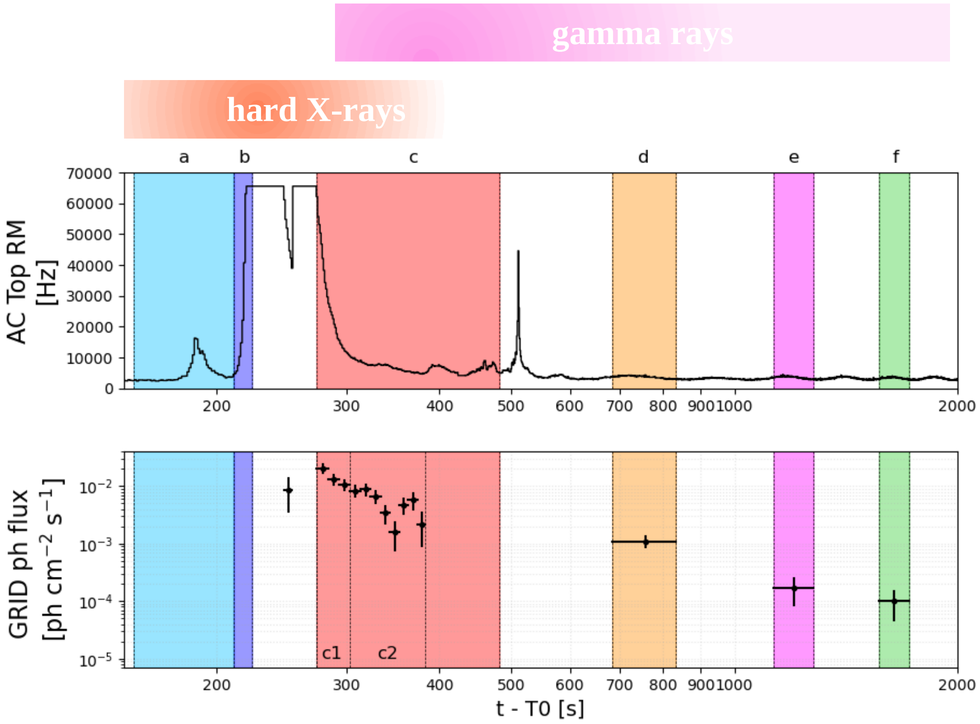
b) **[211; 223] s** → rapid **hard X-ray** flux increase to extremely large values that eventually saturated all ratemeters.

c) **[273; 482] s** → **hard X-ray emission** and 1st very intense **γ-ray** episode.

d) **[684: 834] s** → 2nd GRID **γ-ray** exposure.

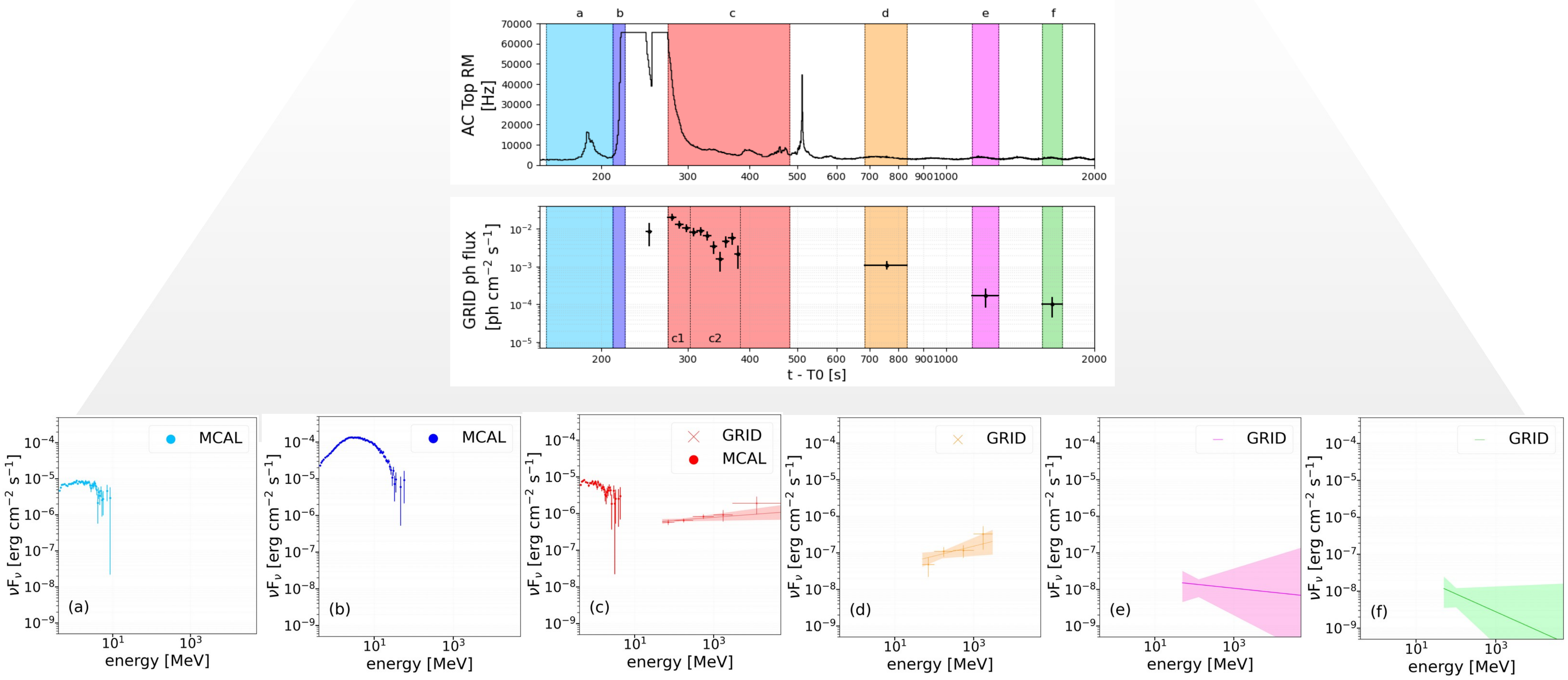
e) **[1129; 1279] s** → 3rd GRID **γ-ray** exposure.

f) **[1569; 1719] s** → 4th GRID **γ-ray** exposure.



Spectral evolution

Results published in
Tavani+2023, submitted



Spectral evolution

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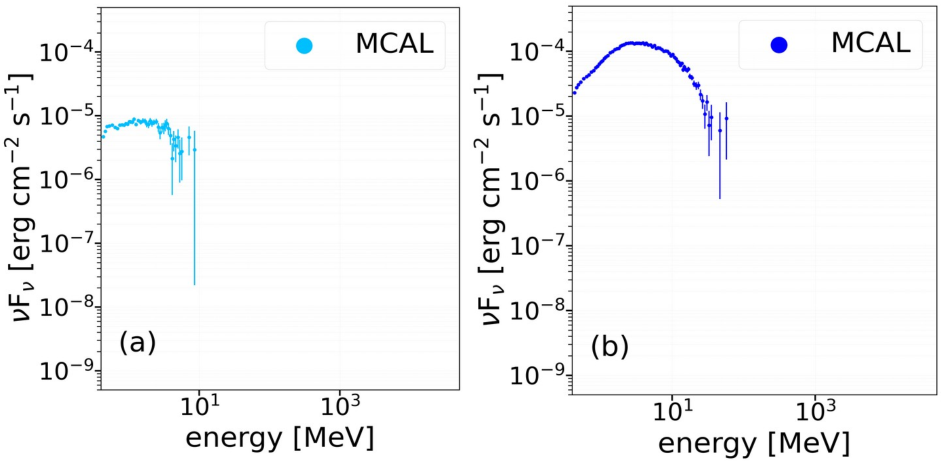
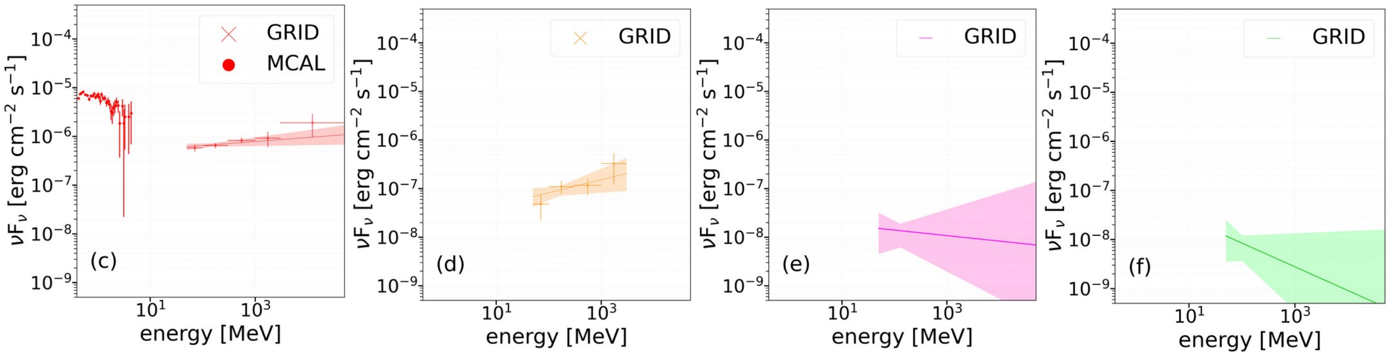


- MCAL spectrum shows a very rapid and rising hard X-ray flux
- low-energy spectral index is $\sim$1.
- The emission peaks at $E_{peak} \simeq 3$ MeV



Spectral evolution

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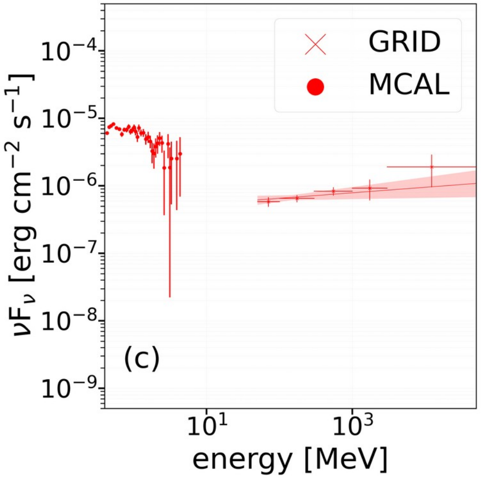
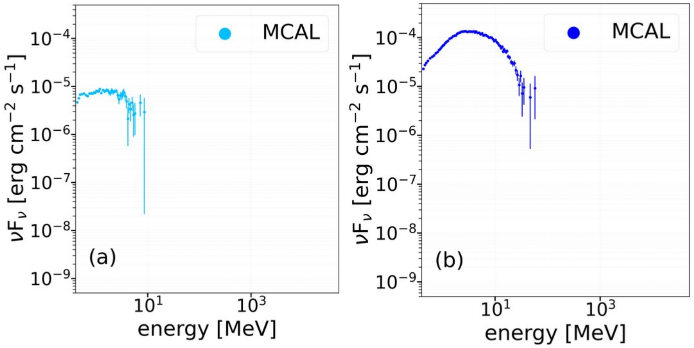
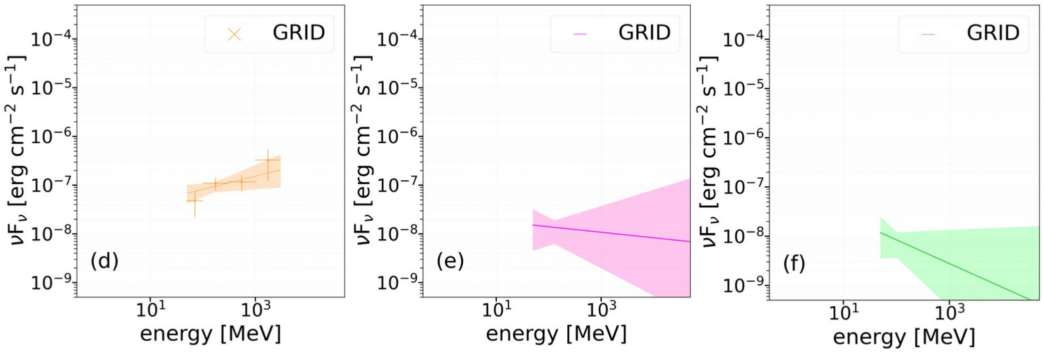


- Prominent hard gamma-ray emission produced with a spectrum quite different from the decaying MeV component
- Prompt emission is supplemented by an additional GeV component that we attribute to inverse Compton emission
- The beginning of the GRB afterglow





Spectral evolution

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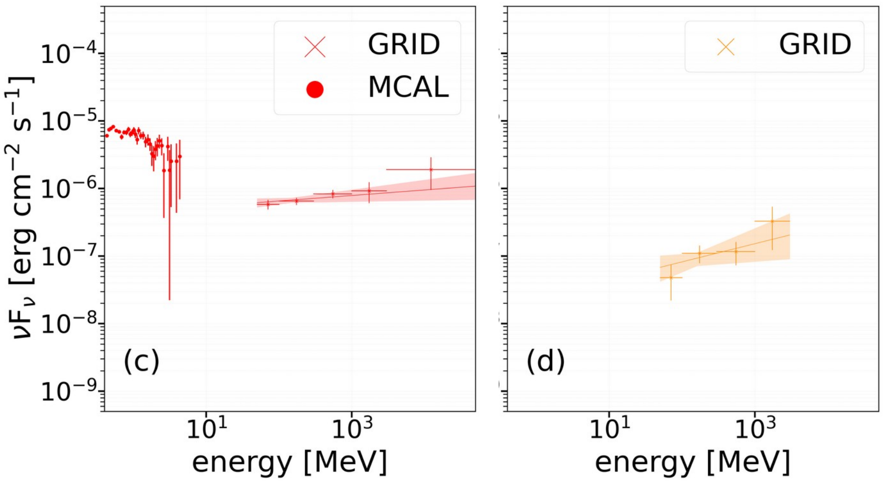
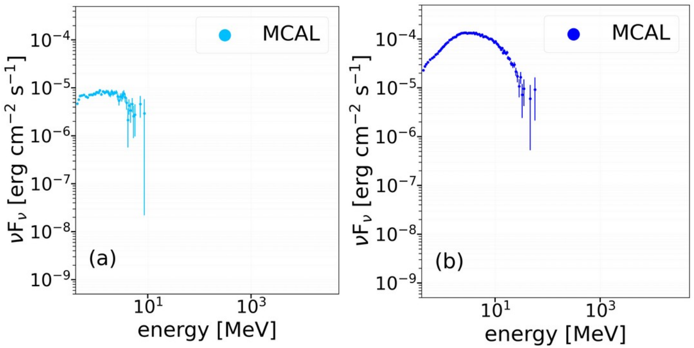
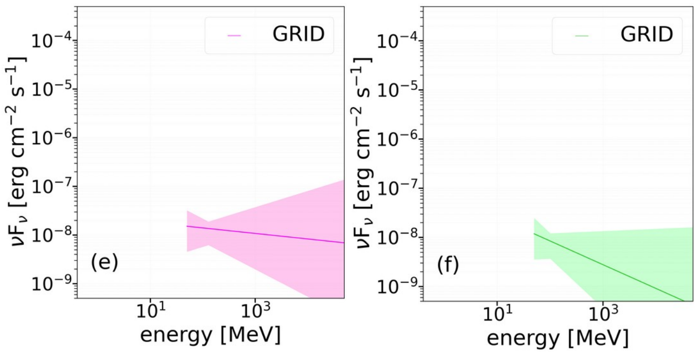


- Spectral **hardening** in the GeV range as the overall flux decreases in the early phases of the afterglow





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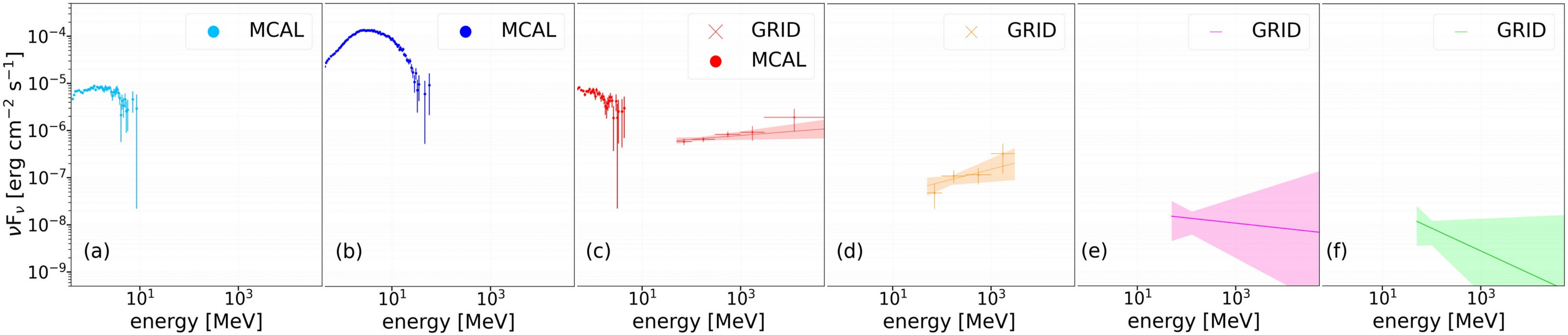
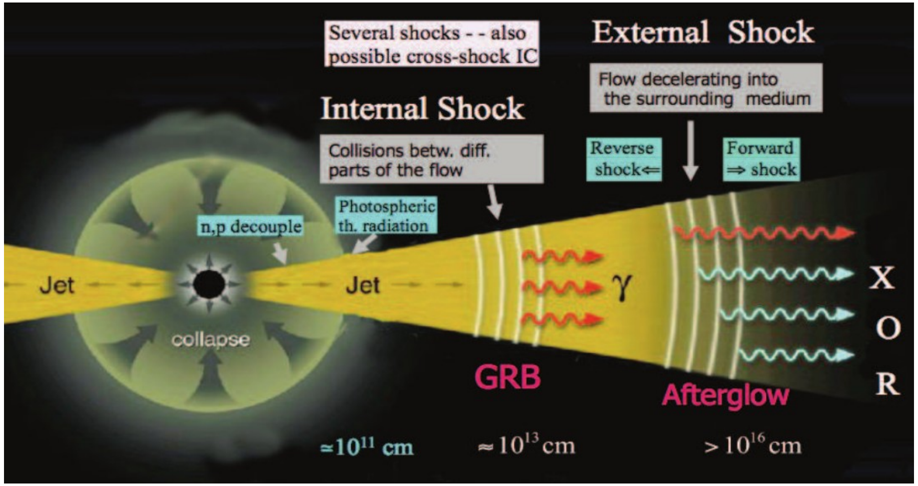


Relativistic fireball model



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

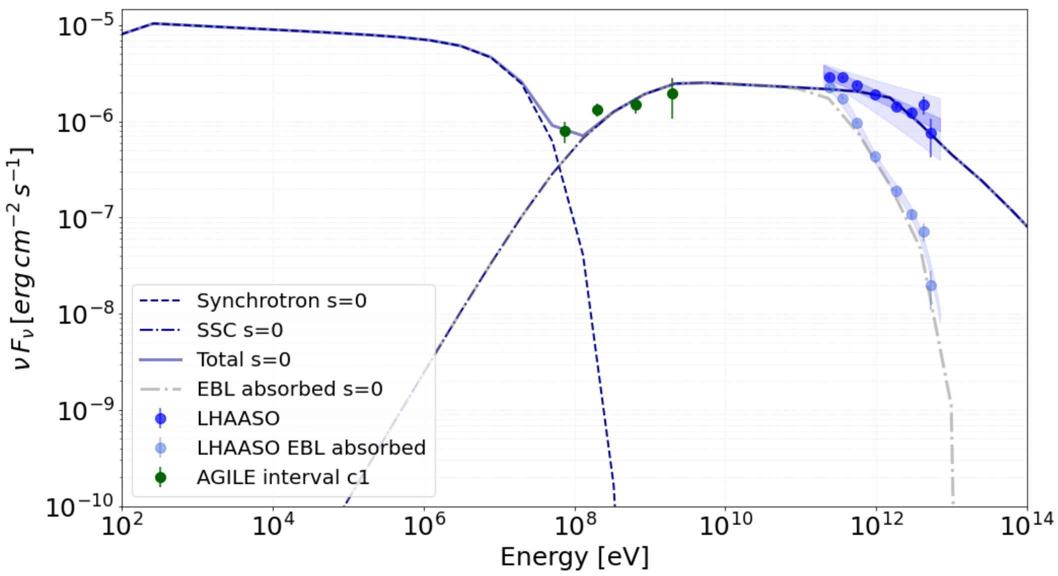
- GRB afterglow emission due to **synchrotron** and **Inverse Compton** (IC) radiation produced by relativistic fireballs expanding in the surrounding medium (e.g. Sari et al. 1998; Sari & Esin 2001).
- External shock model describing the adiabatic expansion of a relativistic blast wave in a medium with **density** $n(r) = A\, r^{-s}$
- The shock front is expanding with bulk Lorentz factor Γ(r), accelerating e^- and e^+ over a power-law energy distribution $N(\gamma) = N_0\, \gamma^{-p}$
- A homogeneous magnetic field is assumed to be co-spatial with the accelerating particles
- The evolution of the blast waves is described as a function of time t after the initial event occurring at $T^* = T_0 + 226$ s (here we assume, for simplicity, the same reference time adopted in Cao et al. 2023).

How do AGILE data constrain the modeling?

Results being published
Foffano+

- We show here the GRB evolution in a reasonable scenario in a constant density medium s = 0
- A complete set of MWL information is essential for a comprehensive quantitative treatment of GRB 221009A (e.g., GRB 190114C [MAGIC+19])
- The AGILE-GRID data and LHAASO data are well described by IC emission of the afterglow of GRB 221009A in the considered time interval.
- A comprehensive exploration of the model fully applied to the data will be addressed in an upcoming publication [Foffano+ , in preparation]

Energy [erg]	Gamma_0	s	n_0 / A*	p	ee	eb	Event	time_start [s]	time_end [s]
1.5e+55	700	0	0.65	2.08	0.05	0.002	GRB221009A	22	100



Conclusions

- GRB 221009A was extraordinary but also a very complex event
- AGILE obtained good data during the most important emission phases of GRB 221009A
- AGILE data useful to constrain the Inverse Compton emission at gamma rays
- Dramatic transition between prompt and afterglow emission with a phase of coexistence of MeV and GeV emissions

  → maybe two different emitting regions,

    - An inner and probably optically thick region,
    - An optically thin and relativistically expanding region

Thank you!