AGILE observations of the ultra-luminous GRB 221009A

Giovanni Piano (INAF-IAPS),
Luca Foffano (INAF-IAPS) and Marco Tavani (INAF-IAPS)
on behalf of the AGILE Team

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Summary

Intro: GRB 221009A, the brightest GRB ever detected

1. The AGILE observations
    - Technical issues: complex analysis
    - The AGILE lightcurves
    - Spectral evolution
    - Multiwavelength lightcurve

2. Modeling the afterglow
    - New analysis: AGILE simultaneous with LHAASO
    - Modeling the GeV-TeV afterglow spectra

Concluding remarks

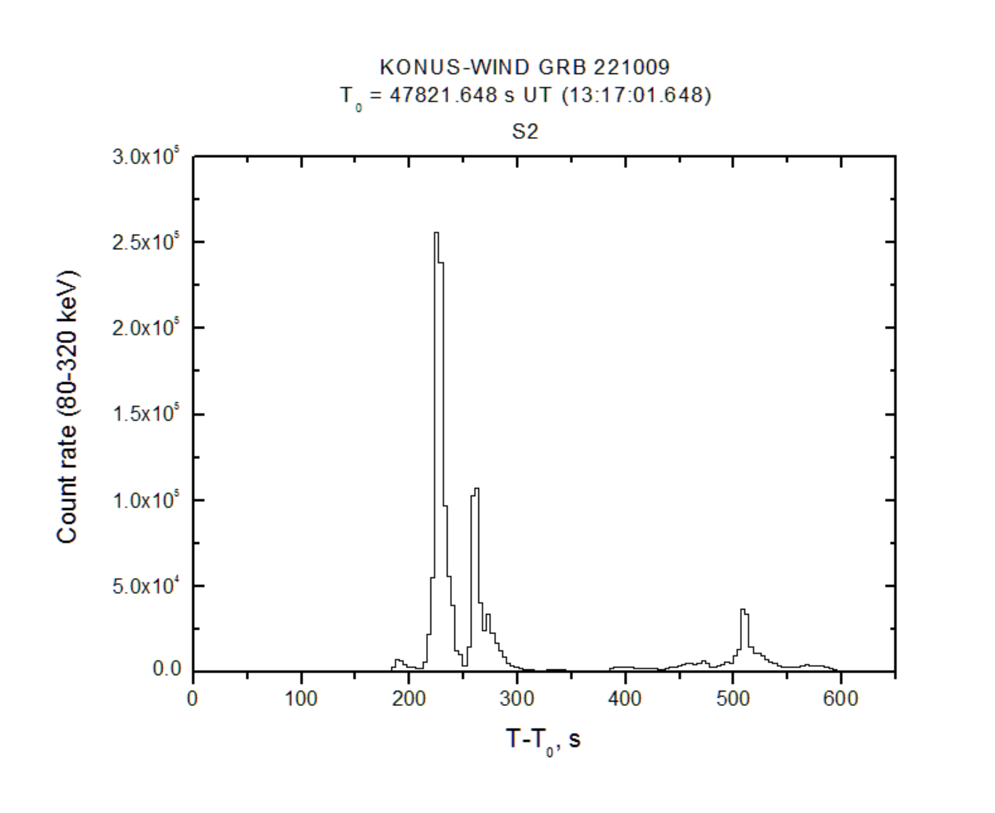
GRB 221009A: The brightest of all time (The BOAT)

October 9, 2022 Swift/BAT detects a bright transient emission, subsequently identified as a GRB

- Prompt emission detected by several satellites.
  - T_0 = 2022-10-09 UT 13:16:59.99
  - Duration: ~600 seconds → Long GRB
  - Peak flux = 3 x 10^{-2} erg cm^{-2} s^{-1} [Konus-WIND]

    ~10 times higher than GRB 230307A
  - Fluence (600 s) = 0.21 x 10^{-2} erg cm^{-2} [Konus-WIND]

    ~100 times higher than GRB 140219A
  - $E_{iso} \simeq 10^{55}$ erg [Konus-WIND]
  - $L_{iso} \simeq 10^{54}$ erg s^{-1} [Konus-WIND]
- Afterglow emission observed from radio to VHE gamma-rays (LHAASO).
- Redshift: z = 0.15 → distance ~750 Mpc



GRB 221009A coordinates

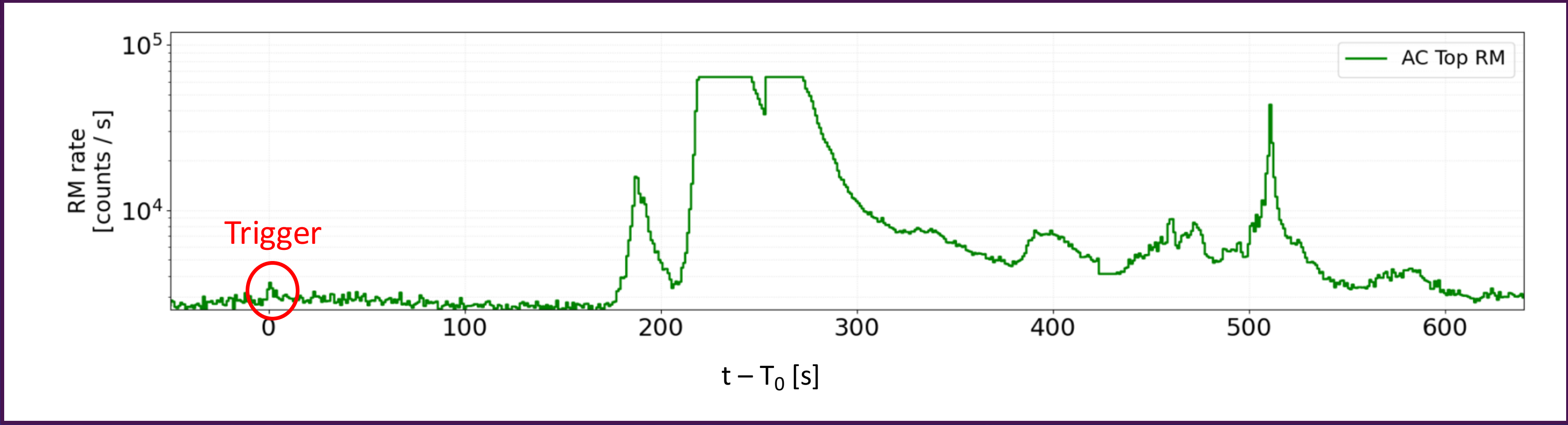
Celestial: (RA, Dec) = (288.27, 19.77)
Galactic: (l, b) = (52.96, 4.32)

GRB 221009A: AGILE observations

AGILE Mission
- launch: April 17, 2007
- Pointing: 2007-2009
- Spinning: 2009-2024
- end of the scientific activities: January 18, 2024
- re-entry the Earth's atmosphere: February 13, 2024

GRB 221009A detected by:

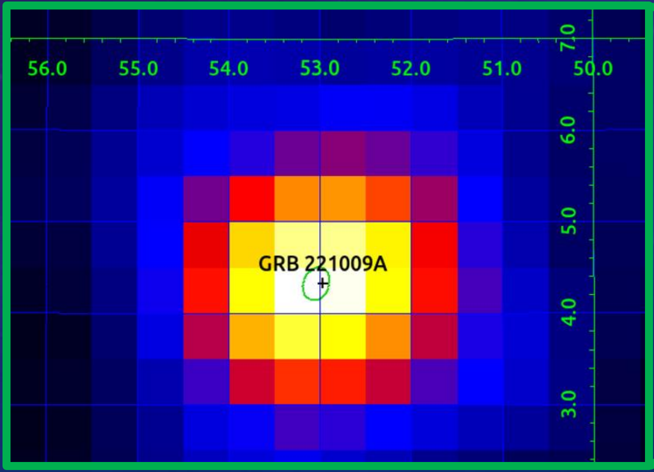
- GRID [30 MeV – 50 GeV]
- MCAL [350 keV – 10 MeV]
- Ratemeters [RM, 50-200 keV]
  - MCAL
  - Anticoincidence (AC)
  - GRID ("unvetoed")
- SuperAGILE not in observing mode

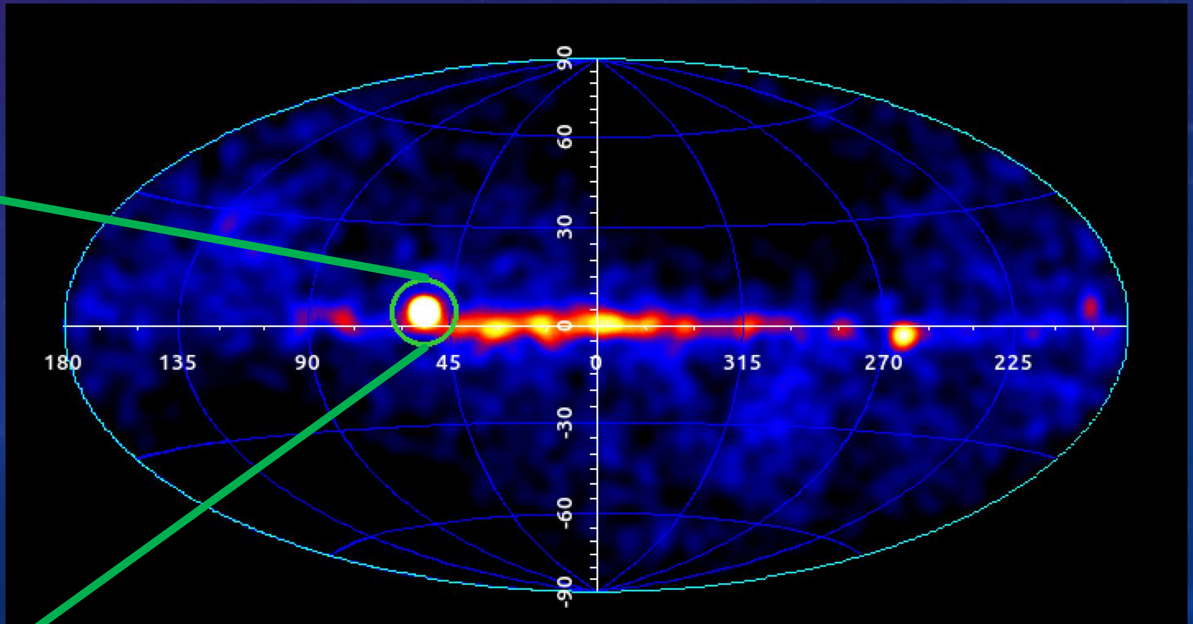


T_0 + [273, 383s]

E > 50 MeV

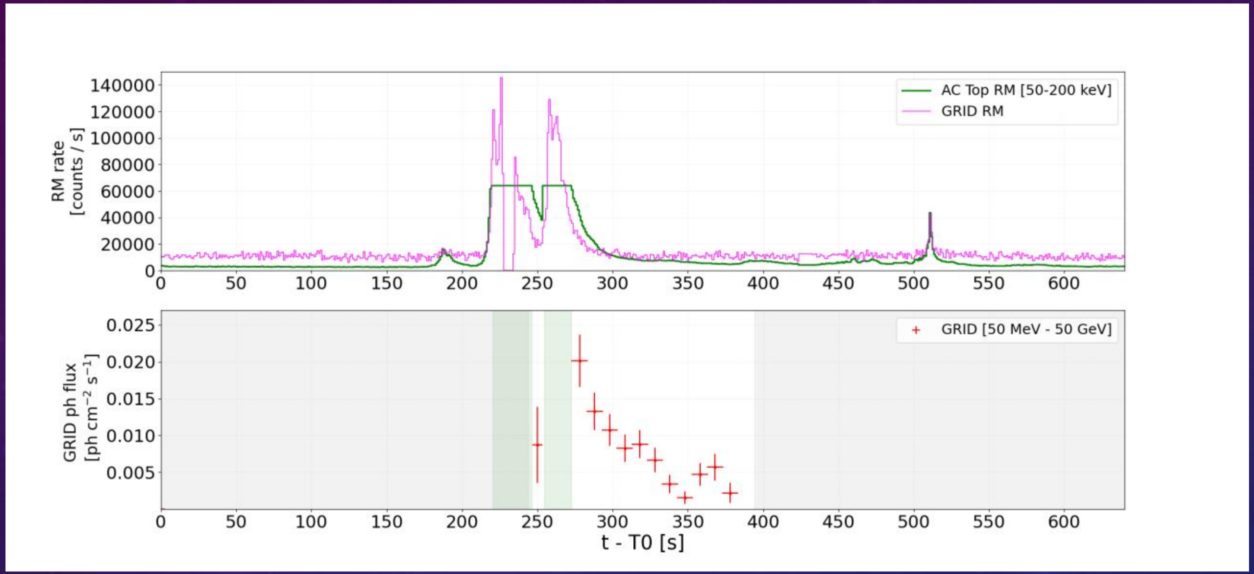
(l, b) = (53.1, 4.3) ± 0.1° (stat) ± 0.1° (syst)





GRID: skymap, E > 100 MeV, 48h-integration after T_0

GRB 221009A: saturation of the AC-Top RM



GRID: two main analysis issues due to the extraordinarily high count rate of the AC-Top panel (incoming X-rays):

1. Dead time correction (usually not required in standard analysis):

   AC-Top activation (charged particle/X-ray) → inhibition of the GRID onboard data acquisition: 5.14 μs

   → GRID livetime (exposure) correction

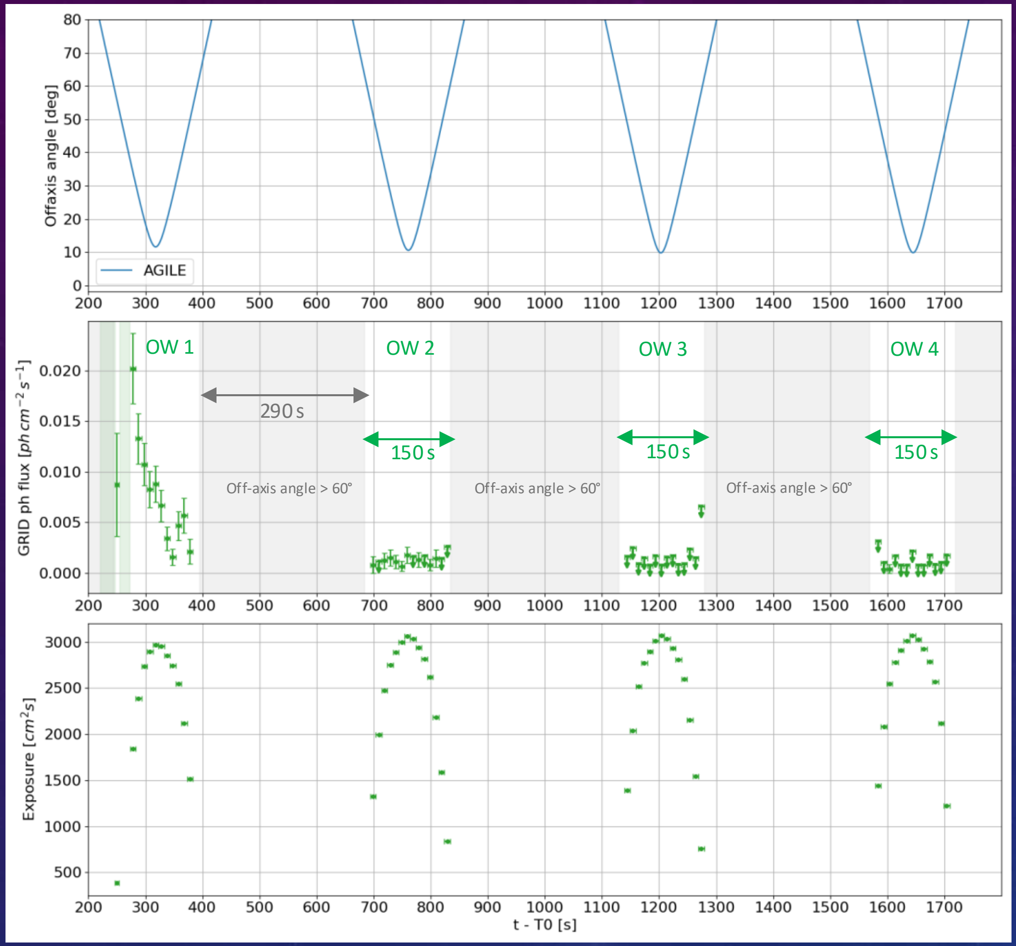
2. AC-Top RM are saturated to 65535 counts/s during two intervals: [220.4, 246.4 s] and [254.4, 272.6s] after T_0

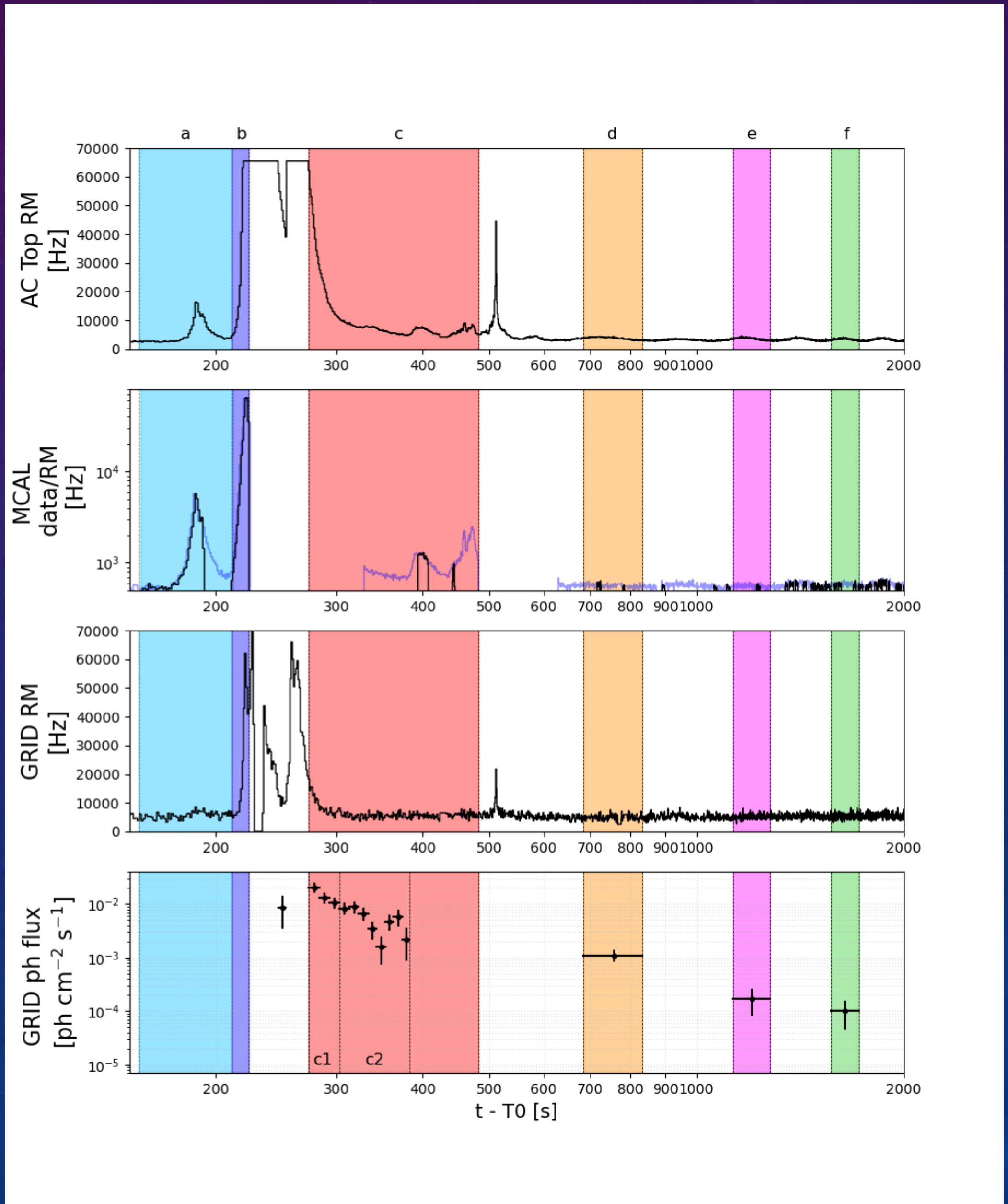
   → Both time intervals are excluded from our analysis

   (actual number of AC triggers unknown→ livetime correction would not be accurate)

GRB 221009A: The AGILE lightcurves

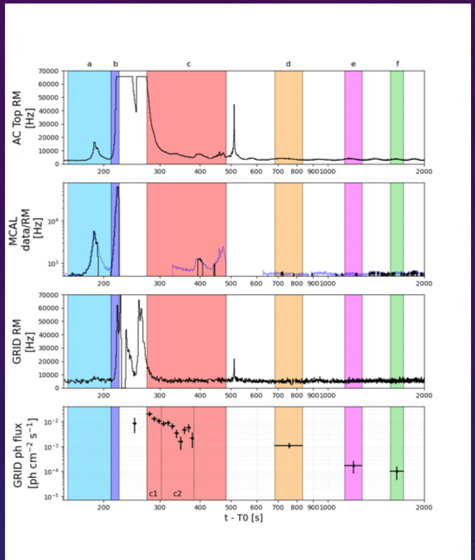
GRID Observation Windows (OWs)

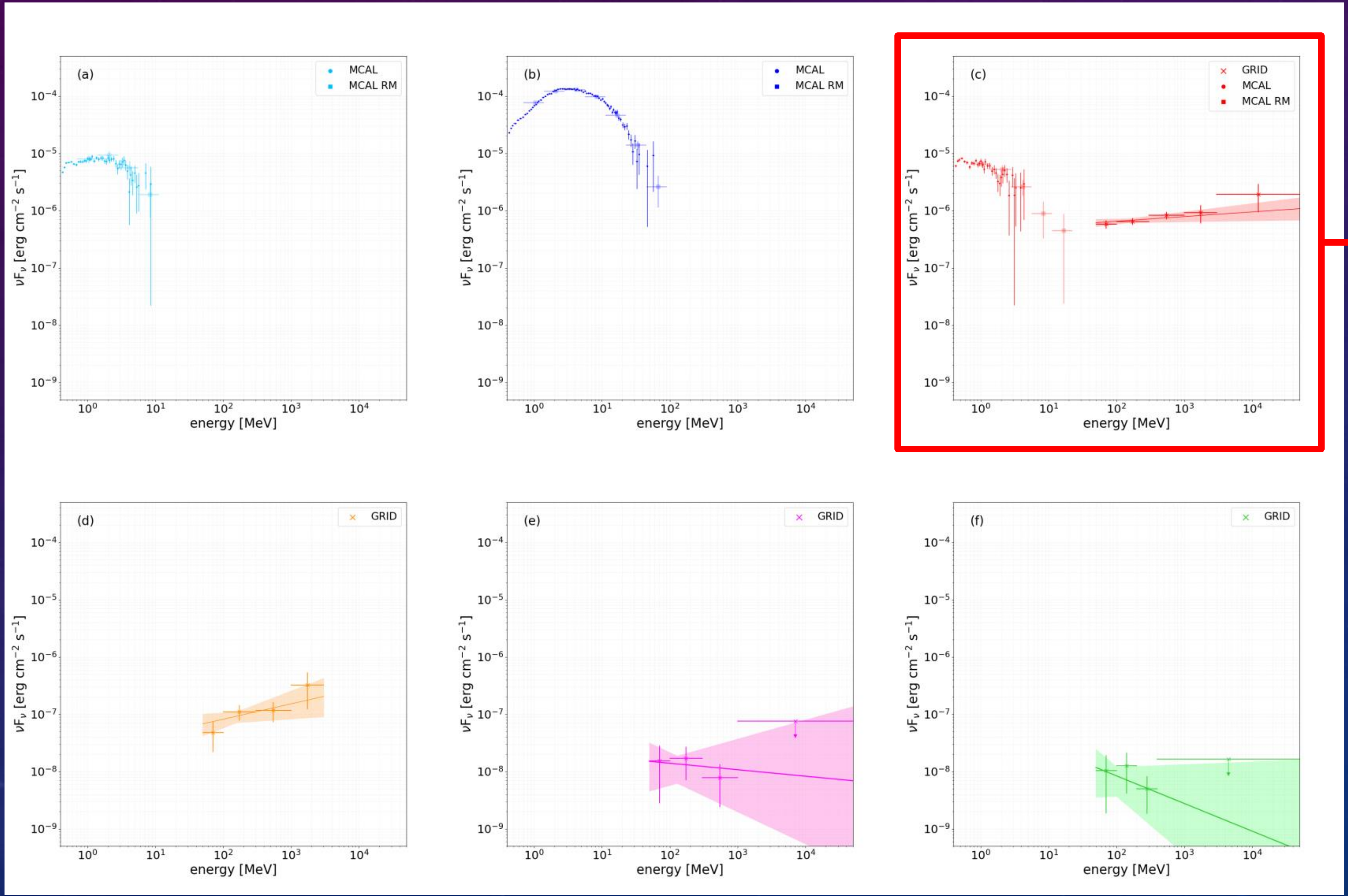




Time evolution of the GRID FoV (spinning mode): boresight-axis rotation period ~440 s

GRB 221009A: spectral evolution





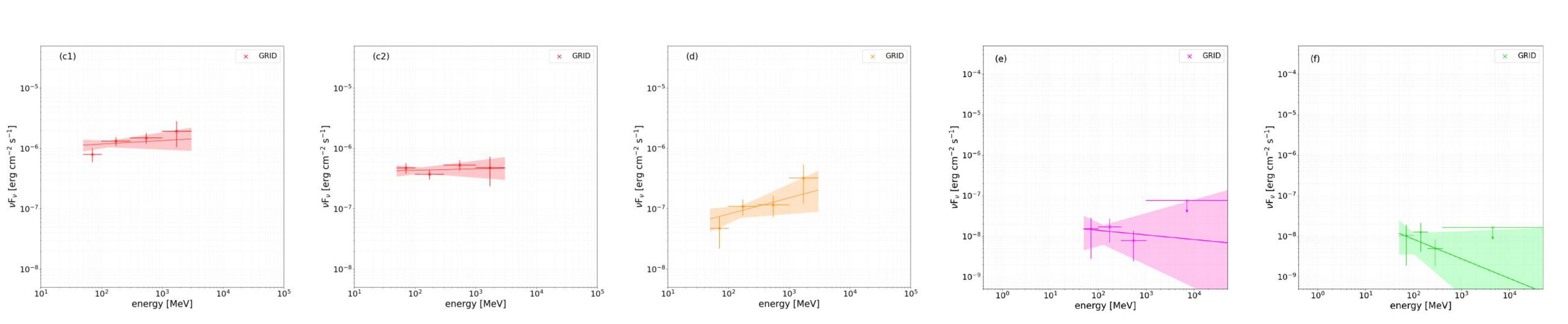
MCAL-GRID simultaneous spectra prompt + afterglow

GRID spectrum: T_0 + [273, 383s]

- Power-law fit (0.05 – 50 GeV)
- Significance: 46**σ**
- Flux = (8.4 ± 0.6) 10^{-3} ph cm^{-2} s^{-1}
- Photon index = 1.92 ± 0.06
- Associated counts: 206 ± 16

"AGILE Gamma-Ray Detection of the Exceptional GRB 221009A"
Tavani, M., Piano, G., Bulgarelli A., et al.
ApJL 956, L23 (2023)

GRB 221009A: GRID spectra



Power-law fit:

	Time interval [s, s]	photon index	flux [ph cm^{-2} s^{-1}]
c1	[273, 303]	1.9 ± 0.1	(1.5 ± 0.2) 10^{-2}
c2	[303, 383]	2.0 ± 0.1	(5.4 ± 0.6) 10^{-3}
d	[684, 834]	1.7 ± 0.2	(1.1 ± 0.2) 10^{-3}
e	[1129, 1279]	2.1 ± 0.4	(1.7 ± 0.8) 10^{-4}
f	[1569, 1719]	2.5 ± 0.5	(1.0 ± 0.5) 10^{-4}

Spectral behavior:

- hardening-softening (hints)
- $t > T_0 + 1000$ s → no HE gamma rays (E > 3 GeV) detected

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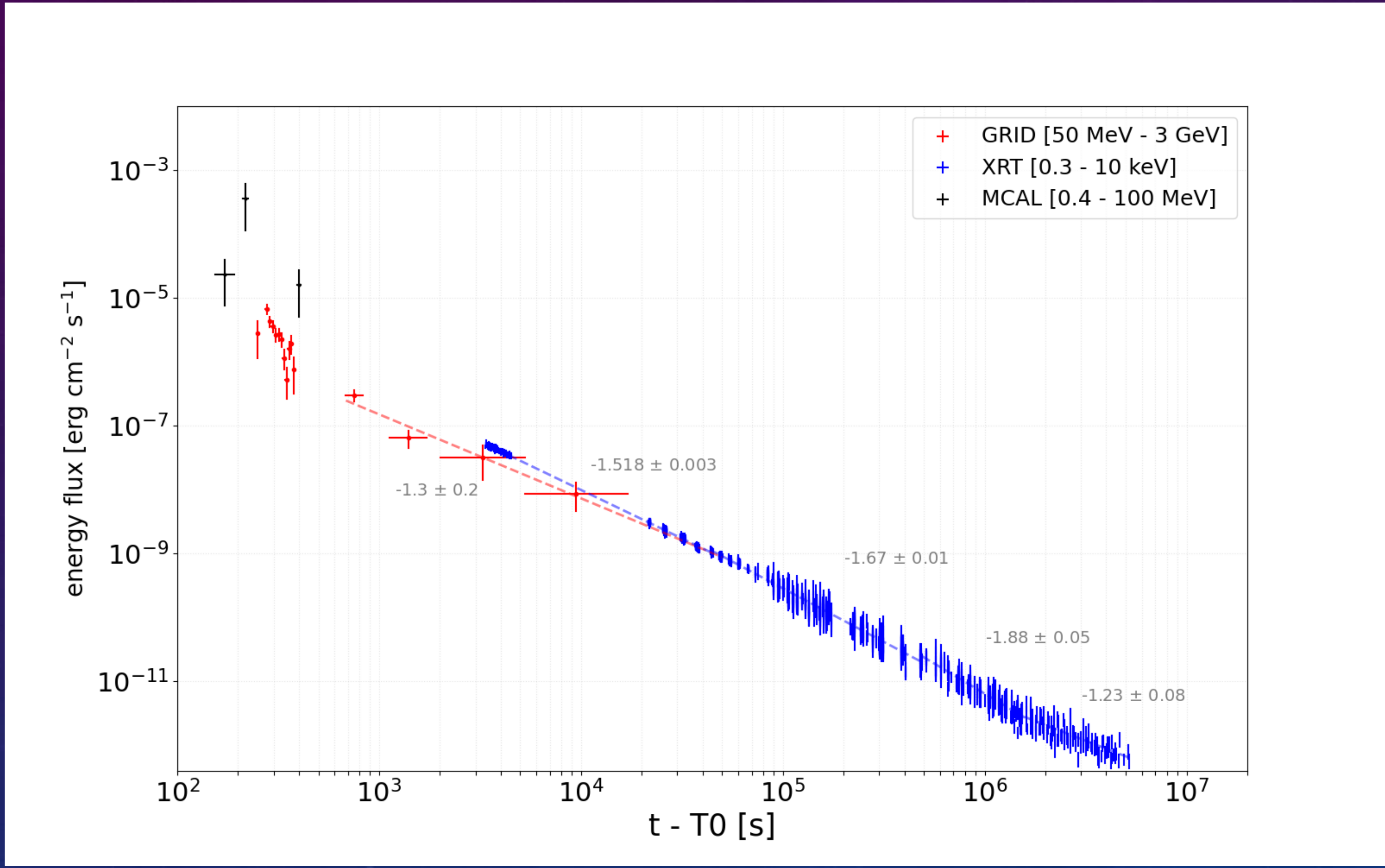
GRB 221009A: multiwavelength lightcurve



- GRID detections of the GRB: from the onset of the prompt phase up to ~20 ks after T_0.
- Spinning-modulated continuous coverage.
- Afterglow flux decay: power-law trend consistent with Swift/XRT

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ApJL 956, L23 (2023)

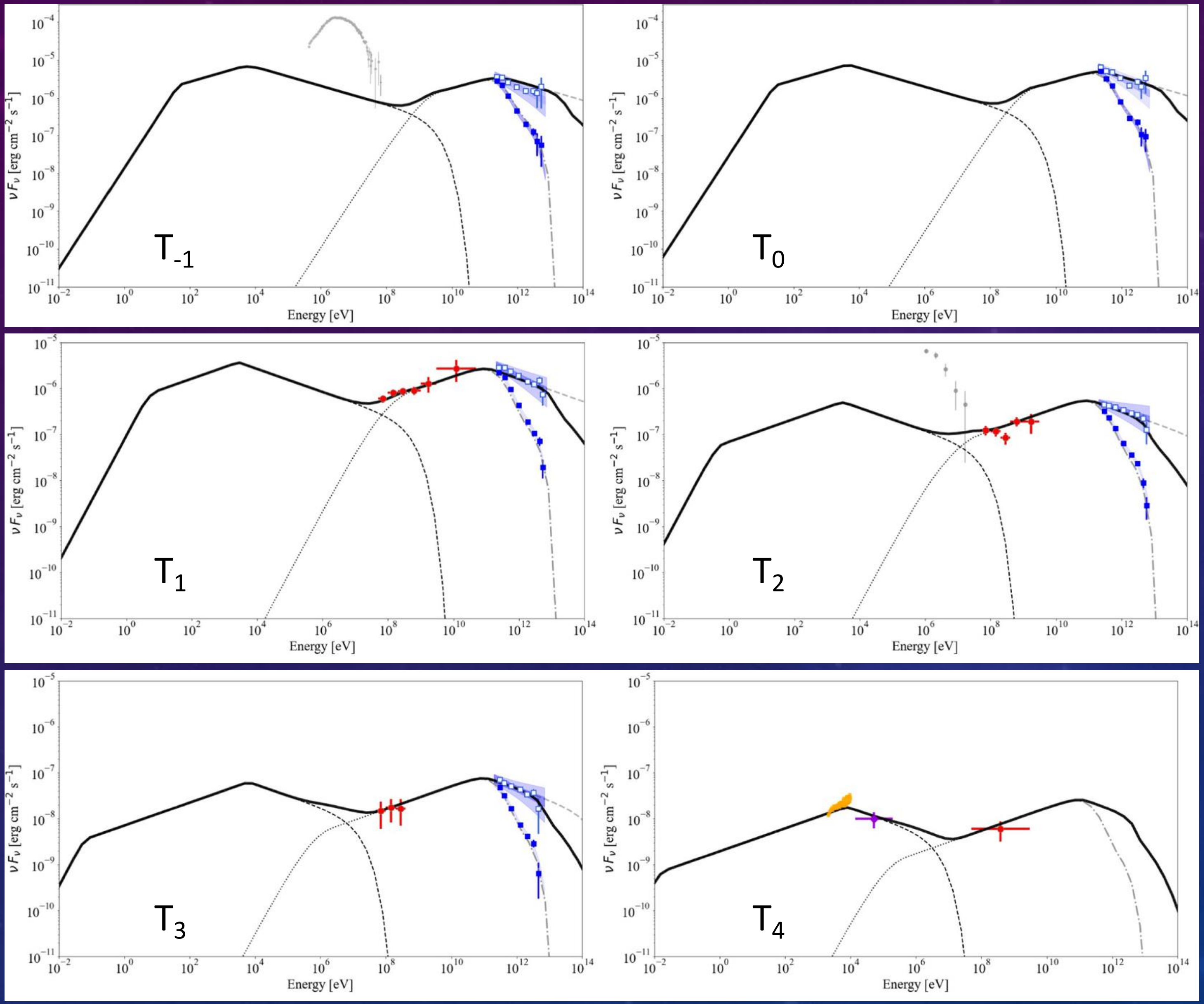
GRB 221009A: modeling the afterglow

- New specific analysis of the AGILE GeV data → simultaneous with the LHAASO TeV data (Cao+ 2023)

- Relativistic fireball model:
  - blast wave expanding in a homogeneous medium
  - adiabatic expansion → $e^{+}e^{-}$ acceleration (power-law distribution)
  - Synchrotron and inverse Compton emission from accelerated leptons

- Modeling the evolving afterglow spectrum (and lightcurves) at GeV-TeV energies

GRB 221009A: modeling the evolving spectrum



A consistent model for the the afterglow evolution

Standard adiabatic model with variable ε_e and ε_B

ε_e : fraction of the shock energy transferred to the electron kinetic energy
ε_B : fraction of the shock energy transferred to magnetic field

$$\varepsilon_e \sim t^{\,0.19 \pm 0.02}$$

$$\varepsilon_B \sim t^{\,-0.84 \pm 0.04}$$

Foffano L., Tavani M., Piano G. (2024)
"Theoretical Modeling of the Exceptional GRB 221009A Afterglow"
ApJL 973, L44 (2024)

Concluding remarks

The AGILE observations of GRB 221009A

- Complex analysis: months of teamwork, data selection/correction, non-standard data analysis
- AGILE: long-term MeV/GeV observation of the GRB (prompt/afterglow phase)
  - GRID: detection up to ~20 ks after T_0
  - MCAL: detection during the initial phase (up to T_0 + 445 s)
  - Scientific RMs: continuous monitoring
- Lightcurves and spectra
- Tavani et al., ApJL 956, L23 (2023)

Modeling the GRB afterglow

- GeV (AGILE) + TeV (LHAASO) simultaneous dataset
- Fireball model: blast wave adiabatically expanding in a homogeneous medium
- Foffano, Tavani and Piano ApJL 973, L44 (2024)

THANKS FOR YOUR ATTENTION