AGILE Observations of GRB 220101A: A "New Year's Burst" with an Exceptionally Huge Energy Release

A. Ursi[1] , M. Romani[2] , G. Piano[1] , F. Verrecchia[3,4] , F. Longo[5] , C. Pittori[3,4] , M. Tavani[1,6] , A. Bulgarelli[7] ,
M. Cardillo[1] , C. Casentini[1,8] , P. W. Cattaneo[9] , E. Costa[1] , M. Feroci[1] , V. Fioretti[7] , L. Foffano[1] , F. Lucarelli[3,4] ,
M. Marisaldi[7,10] , A. Morselli[8] , L. Pacciani[1] , N. Parmiggiani[7] , P. Tempesta[11] , A. Trois[12] , and S. Vercellone[13]

[1] INAF/IAPS, via del Fosso del Cavaliere 100, I-00133 Roma (RM), Italy; alessandro.ursi@inaf.it
[2] Osservatorio Astronomico di Brera, Via Brera 28, I-20121 Milano (MI), Italy
[3] SSDC/ASI, via del Politecnico snc, I-00133 Roma (RM), Italy
[4] INAF/OAR, via Frascati 33, I-00078 Monte Porzio Catone (RM), Italy
[5] Dipartimento di Fisica, Università di Trieste and INFN, via Valerio 2, I-34127 Trieste (TR), Italy
[6] Università degli Studi di Roma Tor Vergata, via della Ricerca Scientifica 1, I-00133 Roma (RM), Italy
[7] INAF/OAS, via Gobetti 101, I-40129 Bologna (BO), Italy
[8] INFN Sezione di Roma 2, via della Ricerca Scientifica 1, I-00133 Roma (RM), Italy
[9] INFN Sezione di Pavia, via U. Bassi 6, I-27100 Pavia (PV), Italy
[10] Birkeland Centre for Space Science, Department of Physics and Technology, University of Bergen, Norway
[11] Telespazio SpA, Centro Spaziale del Fucino 23, Piana del Fucino, Via Cintarella, I-67050, Ortucchio (AQ), Italy
[12] INAF—Osservatorio Astronomico di Cagliari, via della Scienza 5, I-09047 Selargius (CA), Italy
[13] INAF—Osservatorio Astronomico di Brera, via E. Bianchi 46, I-23807 Merate (LC), Italy

Abstract

We report the AGILE observations of GRB 220101A, which took place at the beginning of 2022 January 1 and was recognized as one of the most energetic gamma-ray bursts (GRBs) ever detected since their discovery. The AGILE satellite acquired interesting data concerning the prompt phase of this burst, providing an overall temporal and spectral description of the event in a wide energy range, from tens of kiloelectronvolts to tens of megaelectronvolts. Dividing the prompt emission into three main intervals, we notice an interesting spectral evolution, featuring a notable hardening of the spectrum in the central part of the burst. The average fluxes encountered in the different time intervals are relatively moderate, with respect to those of other remarkable bursts, and the overall fluence exhibits a quite ordinary value among the GRBs detected by MCAL. However, GRB 220101A is the second farthest event detected by AGILE, and the burst with the highest isotropic equivalent energy of the entire MCAL GRB sample, releasing $E_{\mathrm{iso}} = 2.54 \times 10^{54}$ erg and exhibiting an isotropic luminosity of $L_{\mathrm{iso}} = 2.34 \times 10^{52}$ erg s^{-1} (both in the 400 keV–10 MeV energy range). We also analyzed the first 10^6 s of the afterglow phase, using the publicly available Swift-XRT data, carrying out a theoretical analysis of the afterglow, based on the forward shock model. We notice that GRB 220101A is with high probability surrounded by a wind-like density medium, and that the energy carried by the initial shock shall be a fraction of the total E_{iso}, presumably near ~50%.

1. Introduction

Gamma-ray bursts (GRBs) are powerful transient gamma-ray emissions, releasing isotropic equivalent energies on the order of $E_{\mathrm{iso}} \gtrsim 10^{52}$ erg, and representing the most luminous events observed in the universe to date (Gehrels & Mészáros 2012). Discovered in the late 1960s (Klebesadel et al. 1973), these bursts are produced by ultra-relativistic particles, accelerated in extragalactic engines. Depending on their energy spectrum and their T_{90} duration (i.e., the time interval over which the central 90% of their cumulative counts above the background is detected, Kouveliotou et al. 1993), GRBs are conventionally divided into short GRBs ($T_{90} < 2$ s) and long GRBs ($T_{90} > 2$ s). Short GRB emissions can extend above megaelectronvolt energies during the prompt phase (e.g., GRB 090510 Ackermann et al. 2010; De Pasquale et al. 2010;

Giuliani et al. 2010) and are associated with the merger of two compact extremely massive objects, such as a neutron star-neutron star, or black hole-neutron star systems (Abbott et al. 2017; Goldstein et al. 2017). Long GRBs have softer spectra and are associated with type Ic core-collapse supernovae, possibly occurring in the presence of an evolved star companion (e.g., a neutron star, or a black hole) (Vedrenne & Atteia 2009).

GRBs release most of their energy during the prompt phase, in the few kiloelectronvolt to few megaelectronvolt energy range. Their spectrum can be usually described by means of a Band model, a smoothly joint broken power law (PL) with a well-defined peak energy (Band et al. 1993). Some bursts can show extra high-energy components, which extend the spectrum up to hundreds of megaelectronvolt to gigaelectronvolt energies, requiring additional PLs or cutoff PLs, in the spectral model (e.g., GRB 910503, GRB 930131, GRB 941017, GRB 080514B, GRB 131108A Schneid et al. 1992; Sommer et al. 1994; González et al. 2003; Giuliani et al. 2008, 2014). These high-energy components can emerge either

during the prompt phase, probably produced internally due to inverse Compton-scattered synchrotron photons of the prompt (Bošnjak et al. 2009), or during the early afterglow phases, coming as delayed emissions, probably arising from external shocks traveling in the circumburst medium (Ackermann et al. 2013).

1.1. GRB 220101A

GRB 220101A is a long GRB that occurred at 2022-01-01 05:11:13 (UT), first detected by Swift-BAT (Tohuvavohu et al. 2022; Markwardt et al. 2022), and successively revealed in the low to intermediate energy range by Swift-XRT (D'Ai et al. 2022; Osborne et al. 2022), Fermi-LAT (Arimoto et al. 2022), Swift-UVOT (Kuin et al. 2022), AGILE (Ursi et al. 2022a), Fermi-GBM (Lesage et al. 2022), and Konus-Wind (Tsvetkova et al. 2022; Tsvetkova & Konus-Wind Team 2022). The burst was promptly localized by imaging detectors onboard Swift and Fermi at coordinates R.A., decl. = $0°.09$, $31°.76$. In addition to X-ray/gamma-ray detections, a number of fast-response optical observations of the GRB have been carried out, which allowed revealing an associated optical transient with redshift $z = 4.62$ (Fu et al. 2022; Fynbo et al. 2022; Perley 2022; Tomasella et al. 2022). Such an intermediate value of z led to a preliminary estimate of the associated isotropic equivalent energy equal to $E_{iso} \sim 3.6 \cdot 10^{54}$ erg, making GRB 220101A one of the most energetic events in the history of GRBs (Atteia 2022; Ruffini et al. 2022a). Depending on the energy range, the event duration was reported up to ~ 280 s, with a prompt phase exhibiting a bright and complex multipeaked time profile, consisting of different episodes.

In this paper, we focus on the properties of this remarkable GRB, which is the event with the highest associated E_{iso} detected by AGILE, to date. Such a huge reconstructed isotropic energy release is largely ascribed to the huge luminosity distance of $\sim 46,483$ Mpc associated with its estimated redshift. We analyze the AGILE scientific ratemeter (RM) data, which cover about 4 orders of magnitude in energy, to reconstruct the GRB time profile and to study its spectral evolution. We also analyzed the Swift-XRT data concerning the afterglow emission, to model the progenitor circumburst density profile and characterize the scenario in which the shock propagated.

Our results are in general agreement with the preliminary results reported in various Gamma-ray Coordinates Network (GCN) circulars delivered by Swift, Fermi, and Konus-Wind, and provide information on the temporal and spectral properties of GRB 220101A.

2. AGILE Satellite

AGILE (Astrorivelatore Gamma ad Immagini LEggero) is a satellite of the Italian Space Agency (ASI), launched in 2007 and devoted to high-energy astrophysics (Tavani et al. 2009). It consists of an imaging gamma-ray silicon tracker (30 MeV– 50 GeV), a coded mask X-ray imager SuperAGILE (SA; 18–60 keV), an all-sky Mini-CALorimeter (MCAL, 0.4–100 MeV), and an Anti-Coincidence system (AC, 50–200 keV). The silicon tracker, MCAL, and AC detectors form the so-called Gamma-Ray Imaging Detector (GRID; Barbiellini et al. 2001; Prest et al. 2003). The AGILE satellite orbits at ~ 500 km altitude, in a low-earth, quasi-equatorial orbit. Due to a failure of its reaction wheel that occurred in

2009, AGILE currently spins about its Sun-pointing axis, with a frequency of ~ 7 minute^{-1}, monitoring about 80% of the available sky with its imaging detectors. The AGILE data are downloaded to the ground station at each passage over the ASI Ground Station in Malindi, Kenya, and then processed at the AGILE data center at ASI-SSDC (Pittori & The Agile-SSDC Team 2019), delivering scientific alerts for high-energy transients within 20 minutes to 2 hr from the onboard acquisition. In this work, we carry out an analysis of the AGILE MCAL and AGILE scientific RM data, illustrated in detail in the following sections.

2.1. AGILE MCAL

MCAL is a non-imaging, all-sky scintillation detector (Labanti et al. 2009). It consists of 30 CsI(Tl) bars, providing a total on-axis geometrical area of 1400 cm^2 and an effective area of ~ 300 cm^2 at 1 MeV. MCAL is a triggered instrument, whose trigger logic works on different timescales (0.293, 1, 16, 64, 256, 1024 , and 8192 ms): this allows for the detection of both short-duration and long-duration high-energy transients, such as GRBs (Galli et al. 2013; Ursi et al. 2022b), or terrestrial gamma-ray flashes (Marisaldi et al. 2014; Maiorana et al. 2020, 2020), and to carry out searches for possible gamma-ray signatures associated with other astrophysical events, such as gravitational wave events (Verrecchia et al. 2017; Ursi et al. 2019, 2022c). Given its energy range, MCAL is mostly focused on the detection of hard-spectrum bursts: in particular, between 2007 and 2020, the AGILE MCAL detected more than 500 GRBs, most of which exhibited a non-negligible spectral component above 1 MeV (Ursi et al. 2022b).[14]

The AGILE team has developed automatic pipelines to perform a quick analysis of MCAL data, once the satellite telemetry is downloaded at the Malindi ground station (Parmiggiani et al. 2021). An offline algorithm carries out blind searches for impulsive transients and delivers prompt communication to the AGILE team, whenever a gamma-ray transient is identified. Moreover, in case of a GRB detection, an automatic GCN notice is promptly delivered to the scientific community.[15] The AGILE pipelines also perform fast follow-up of external alerts from other space missions or facilities (e.g., Swift, IceCube, LIGO-Virgo), allowing for a prompt reaction from the AGILE team in the multiwavelength/ multimessenger context (Bulgarelli 2019a, 2019b).

2.2. AGILE Scientific RMs

Data acquired by the GRID, SA, MCAL, and AC detectors are continuously stored in telemetry, with a time resolution of 0.512 s (for SA) and 1.024 s (for GRID, MCAL, and AC). Such data streams, called scientific RM data, are independent of any onboard trigger and provide continuous monitoring of the X-ray/gamma-ray background in all the detectors. Although aimed at monitoring the background variation through the orbital phases, the AGILE RM data clearly reveal high-energy transients, such as GRBs (Ursi et al. 2022b), soft gamma repeaters (SGRs; e.g., Tavani et al. 2021), and solar flares (e.g., Ursi et al. 2020a), and can serve as independent detectors as well. In particular, the SA and AC RMs, sensitive in the hard X-ray energy range, detected more than 700 GRBs between

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[14] https://www.ssdc.asi.it/mcal2grbcat/
[15] https://gcn.gsfc.nasa.gov/agile_mcal.html

2007 and 2020, whereas the MCAL RMs detected more than 500 events. Despite the coarse time resolution, the MCAL RM data are acquired in 11 energy channels, covering an energy range from $\sim$200 keV to more than $\sim$180 MeV, which allows for the reconstruction of a preliminary energy spectrum of the detected events. In particular, the joint usage of SuperAGILE and MCAL RM data allow having 12 energy spectral channels, whose energy ranges are CH0 [18–60 keV], CH1 [175–350 keV], CH2 [350–700 keV], CH3 [0.7–1.4 MeV], CH4 [1.4–2.8 MeV], CH5 [2.8–5.6 MeV], CH6 [5.6–11.2 MeV], CH7 [11.2–22.4 MeV], CH8 [22.4–44.8 MeV], CH9 [44.8–89.6 MeV], CH10 [89.6–179.2 MeV], and CH11 [>179.2 MeV]. The AC data are not calibrated in energy and are therefore not used for spectral analysis. The last channel CH11 is affected by large errors in the reconstructed count rate and it is therefore rejected. MCAL CH1 is considered only for the MCAL RM data, that are integrated onboard with a fixed 1.024 s time resolution; on the other hand, when dealing with MCAL triggered data, which are typically rebinned and analyzed on millisecond to tens of millisecond timescales, we only consider the 0.4–100 MeV energy range, which offers more reliable reconstructed energetics. The AGILE RM data are routinely calibrated, comparing the detected GRBs and SGR bursts with the fluxes and spectra reported for the same events by other space missions.

3. Prompt Phase of GRB 220101A

The AGILE satellite detected the GRB 220101A at $T_0 = $ 2022-01-01 05:11:13 UT (hereafter called T_0). The prompt phase of the event was clearly visible in the SA, AC, and MCAL scientific RM data. In addition, the event triggered an MCAL photon-by-photon onboard data acquisition, with a 4 μs time resolution, which lasted $\sim$ 34 s and covered the time interval from $T_0 + 8.43$ s and $T_0 + 42.71$ s. In particular, the triggered logic was the 64 ms MCAL timescale.

GRB 220101A took place during the commissioning phase of the Imaging X-ray Polarimetry Explorer space mission, launched 2021 December 9, which employed a large amount of available telemetry at the ASI ground station in Malindi. As a consequence, the number of served passages to download the AGILE data was largely reduced. The AGILE satellite was therefore operating in a non-optimized, reduced onboard configuration, designed to save onboard mass memory throughout more consequent orbits. This translated into the nonavailability of SA and GRID imaging data, and into a non-optimized onboard MCAL trigger logic, which prevented the full acquisition of the GRB with high time resolution. From this perspective, given the relatively large time duration of the event, the AGILE RM data are fundamental to providing an overall picture of the burst, both for the study of the light-curve time profile and spectral properties. Moreover, the partial MCAL data acquisition allows focusing on the transition between a first softer stage of the burst prompt and the onset of a larger flux, higher-energy emission.

3.1. Satellite Attitude

As the AGILE satellite spins about its Sun-pointing axis and as GRB 220101A exhibits a rather long duration, it is important to evaluate how the AGILE boresight changed during the occurrence of the burst. This evaluation is fundamental for

Figure 1. SuperAGILE 40° field of view (blue shaded region) in galactic coordinates, in the time interval from T_0 to $T_0 + 109$ s. The dashed lines represent the contours at the transitions between subsequent time *intervals A*, *B*, and *C* (reported on the left side). The localization region of GRB 220101A ($l = 111°.79$, $b = −30°.14$, indicated by the star) lies within the field of view for most of the prompt phase, with the best on-axis configuration ($\sim$0°.7) reached $T_0 + 49$ s.

what concerns the SA detector, whose detection capabilities are reliable only if the source falls inside its field of view. Also, it allows for the retrieval of the corresponding MCAL response matrices needed to perform spectral analysis. Figure 1 reports the SA 40° field of view between T_0 and $T_0 + 109$ s: it can be noticed that the GRB 220101A localization region was inside the field of view for most of its duration, reaching the most on-axis configuration (0°.7) at $T_0 + 49$ s. As a consequence, for times $< T_0 − 12$ s and $> T_0 + 135$ s, we do not consider the SA data, as the source was observed under a too large off-axis angle, preventing any reliable reconstruction of the count rate and flux.

3.2. Temporal Characteristics

The temporal profile of GRB 220101A varies with respect to energy, from $\sim$20 keV to $\sim$50 MeV, with the bulk emission occurring during the central time interval. The overall light curve consists of an initial slow flux enhancement, mostly dominated by X-ray/soft gamma-ray emission, followed by a central brighter multipeaked emission lasting $\sim$25 s and characterized by the peak emission in the megaelectronvolt range. Finally, a dim broad emission lasting more than $\sim$50 s, fades to an undetectable level and sets off the end of the prompt phase. The first three panels of Figure 2 show the SA, AC Top, and MCAL RM light curves, centered at T_0, with 0.512 s (for SA) and 1.024 s (for AC and MCAL) time resolution. The light curves show a rather long and complex multipeaked profile. As MCAL is the detector offering the best energy coverage for the burst spectrum, we divide the light curve into three time intervals, on the basis of the GRB shape in the MCAL energy range: *interval-A* (from T_0 to $T_0 + 33$ s, displayed in yellow), *interval-B* (from $T_0 + 33$ s to $T_0 + 58$ s, displayed in red), and *interval-C* (from $T_0 + 58$ s to $T_0 + 109$ s, displayed in violet), reported in detail in Table 1. As pointed out in Section 3.1, we excluded all SA data acquired before $T_0 − 12$ s and after $T_0 + 135$ s, as the source localization region was outside the detector field of view. The fourth panel in the figure reports the MCAL triggered acquisition, which covers a part of *interval-A* and a part of *interval-B*, hereby called *interval-a1* and *interval-b1*. Although partial, this acquisition allows focusing with better quality data on the transition between *interval-A* and *interval-B*, when the flux increases by more than a factor of 2, especially in the megaelectronvolt to tens of megaelectronvolt

Figure 2. Light curves of the prompt phase of GRB 220101A, acquired by AGILE (and associated $\pm1\sigma$ error bars): the first three panels display the SuperAGILE, Anti-Coincidence, and MCAL scientific RM data, acquired in the related energy ranges. The fourth panel shows the partial MCAL high time resolution trigger issued on board, covering the time interval between $T_0 + 8.43$ s and $T_0 + 42.71$ s. Finally, the bottom panel reports the GRID RM data in the highest-energy regime, integrated into the entire available sky inside the detector field of view. We excluded the SuperAGILE and GRID data acquired before $T_0 - 12$ s and after $T_0 + 135$ s, as the source localization region was outside the detectors' field of view. We divide the light curves into three intervals: A (from T_0 to $T_0 + 33$ s, yellow region), B (from $T_0 + 33$ s to $T_0 + 58$ s, red region), and C (from $T_0 + 58$ s to $T_0 + 109$ s, violet region). The corresponding parts of intervals A and B covered by the MCAL trigger acquisition are referred to as *interval-a1* and *interval-b1*.

Table 1
Properties of the Time Intervals of GRB 220101A

Scientific RMs Data			
Interval	Duration	Time Start	Time Stop
A	33.0 s	T_0	$T_0 + 33.0$ s
B	25.0 s	$T_0 + 33.0$ s	$T_0 + 58.0$ s
C	51.0 s	$T_0 + 58.0$ s	$T_0 + 109.0$ s
MCAL Triggered Data Acquisition			
Interval	Duration	Time Start	Time Stop
a1	24.6 s	$T_0 + 8.4$ s	$T_0 + 33.0$ s
b1	9.7 s	$T_0 + 33.0$ s	$T_0 + 42.7$ s

Note. Upper block: details of the three time *intervals A*, *B*, and *C* of GRB 220101A, as detected by the AGILE scientific RMs. Bottom block: details of the two time *intervals a1* and *b1*, covered by the partial AGILE MCAL triggered data acquisition.

range. For completeness, the bottom panel of Figure 2 reports also the GRID RM data. As illustrated in Section 2, the silicon tracker detector was not operational at the time GRB 220101A took place: as a consequence, the only available GRID data are those of the associated RMs, evaluated on the entire available

portion of the sky inside the detector's field of view (i.e., $\sim50°$ with respect to the AGILE boresight). Similarly to SA, we excluded data acquired before $T_0 - 12$ s and after $T_0 + 135$ s, as the source was outside the tracker field of view, and the corresponding fluxes could not be properly reconstructed. Although these data refer to a large portion of the sky and are mostly populated by background noise, a rebinning of the GRID RM light curve with 3.720 s time resolution allows for the identification of a possible emission at $T_0 + 40$ s, when the source was only $\sim5°$ off-axis. This event has a signal-to-noise ratio equal to 1.4 and a false alarm rate equal to 2.0×10^{-4} Hz (considering 5.5 hr of data): we therefore point out the possibility that this spike could represent the signature of a high-energy emission (i.e., >50 MeV) taking place during *interval-B*.

The initial emission episodes of GRB 220101A, occurring at about $T_0 - 50$ s, and reported in the Swift-BAT (Tohuvavohu et al. 2022), Fermi GBM (Lesage et al. 2022), and Konus-Wind (Tsvetkova et al. 2022) light curves, have not been detected by AGILE, as for those times the source was outside the SA detector field of view. Nevertheless, since no significant emission was detected in the MCAL light curve (which is not affected by field-of-view issues), we can infer that such initial episodes shall be dominated by X-ray emission.

Figure 3. SuperAGILE (first panel, CH0) and MCAL (other panels, CHs1-11) RM light curves of the prompt phase of GRB 220101A (and associated $\pm 1\sigma$ error bars), with a 1.024 s time resolution, and divided into 12 spectral energy channels. The SuperAGILE light curve is rescaled on the basis of the associated effective area. The red line indicates the average background rate, estimated immediately before and after the reported time interval. Dashed lines divide the light curve into the A, B, and C time intervals. A significant contribution can be noticed up to CH7 (11.2–22.4 MeV), with a higher flux in *interval-B*.

Similarly, no X-ray reflaring episodes are detected after $T_0 + 109$ s, as the source was outside the SA field of view.

GRB 220101A exhibited different durations, depending on the energy range. Adopting the algorithm illustrated in (Koshut et al. 1996), we calculated the corresponding T_{50} and T_{90} time durations, as seen by AGILE (i.e., the time over which the central 50% or 90% of the fluence is received, respectively). In particular, the event lasted $T_{50} = 19.0 \pm 0.5$ s and $T_{90} = 42.0 \pm 0.5$ s in the SA range, $T_{50} = 18.5 \pm 1.0$ s and $T_{90} = 44.5 \pm 1.0$ s and in the AC range, and $T_{50} = 16.5 \pm 1.0$ s and $T_{90} = 65.5 \pm 1.0$ s in the MCAL range.

3.3. Spectral Analysis

We performed spectral analysis of the prompt phase of GRB 220101A, taking advantage of both the AGILE RM data and the partial MCAL triggered data acquisition. Figure 3 shows the GRB 220101A light curve in the 12 spectral channels provided by both the SuperAGILE and MCAL RM data. In this plot, we rebinned the SuperAGILE light curve to 1.024 s, to be consistent with the MCAL bin width, and

rescaled it on the basis of the associated effective area, which significantly changes throughout the burst duration. A significant contribution can be noticed up to CH7 (11.2–22.4 MeV), especially in *interval-B*, where the flux reaches its maximum in the MCAL energy range. For the spectral analysis, we only considered the first eight channels of the MCAL RM data, as the background-subtracted fluxes reconstructed above ~50 MeV are affected by very low statistics and are not reliable.

Despite the coarse time resolution of the RM light curves and the limited number of available spectral channels, the AGILE data can be used to provide a preliminary picture of the overall behavior of GRB 220101A and to point out some of the most salient points of its spectral evolution. The spectral fits were carried out using the XSPEC software package (version 12.12.0) (Arnaud 1996). For each interval, we tested more spectral models, such as the PL, Band model, and cutoff power law (CPL), and selected the one minimizing the Bayesian information criterion. The statistics and χ^2 adopted to estimate the goodness of the spectral fits are severely affected by the low number of available spectral channels, but allow for providing reliable modeling to calculate the corresponding flux in each time interval.

Spectra obtained for GRB 220101A in the different time intervals are shown in Figure 4, together with the best-fit model and 1σ confidence region (lines and shaded regions). The main spectral parameters adopted for the best fits are reported in Table 2, together with fit statistics, and related fluences, evaluated in the 18 keV–10 MeV energy range and time-integrated on the corresponding time intervals. Hereafter, we briefly recap the most important points of the light-curve behavior and the spectral evolution, throughout the different time intervals:

1. *Interval-A*: $[T_0, T_0 + 33$ s$]$. Duration: 33 s. This interval features the onset of the main episode of the prompt phase. In the SA X-ray energy range, the light curve exhibits a slow rise, terminating with a sequence of emission spikes, and a peak emission flux reached $T_0 + 29$ s, equal to $f_{p,A}^{SA} = (2.3 \pm 0.2) \times 10^{-7}$ erg cm^{-2} s^{-1}. On the other hand, in the MCAL lowest-energy channels (175–1000 keV), it shows an initial *hump* between T_0 and $T_0 + 16$ s. The overall spectrum can be described by a Band model, with low-energy photon index $\alpha \sim -1$, high-energy photon index $\beta \sim -2.4$, and peak energy $E_{p,A} \sim 280$ keV. A trial fit of this spectrum by means of a PL or a CPL model ends up with a $\chi^2_{\rm red} \geqslant 2$ and is therefore rejected. The related flux in this interval, estimated in the 18 keV–10 MeV energy range, is equal to $f_A = (1.19 \pm 0.12) \times 10^{-6}$ erg cm^{-2} s^{-1}, resulting in a corresponding fluence $F_A = (3.93 \pm 0.39) \times 10^{-5}$ erg cm^{-2} (both 90% confidence level). In this interval, there is no evidence of significant emission above ~20 MeV.

2. *Interval-B*: $[T_0 + 33$ s, $T_0 + 58$ s$]$. Duration: 25 s. For the entire duration of the interval, the light curve shows a sequence of spikes in the X-ray range. For that concerning the MCAL band, the event shows a sharp first peak, clearly visible from CH1–CH6 (from 175 keV– 11.2 MeV), followed by a second longer and more spread emission episode. This interval represents the core emission of the burst and it can be clearly observed up to MCAL CH8 (i.e., 22.4–44.8 MeV). The related

Figure 4. Energy spectra of GRB 220101A, obtained from the SuperAGILE and MCAL RM data. The spectra are time integrated on the overall duration of the event (first panel, gray color), and in the subsequent different time *intervals A* (yellow), *B* (red), and *C* (violet). The best-fit models and related 1σ confidence regions are illustrated with lines and shaded areas, and reported in the legend.

integrated spectrum can be modeled with a Band function with a low-energy spectral index $\alpha \sim -0.3$, a rather flat high-energy spectral index $\beta \sim -2.2$, and peak energy $E_{p,B} \sim 170$ keV. A fit of this spectrum with either a single PL or a CPL model produces a $\chi^2_{\rm red} > 2$ and is considered not reliable. In this interval, the flux in the 18 keV–10 MeV energy range is $f_B = (3.07 \pm 0.31) \times 10^{-6}$ erg cm^{-2} s^{-1}, resulting in a corresponding fluence $F_B \sim (7.68 \pm 0.77) \times 10^{-5}$ erg cm^{-2} (both 90% confidence level). The overall flux in this interval is therefore more than twice that of *interval-A*, with the peak flux of the entire burst encountered from $T_0 + 38$ s to $T_0 + 46$ s, equal to $f_{p,B} = (2.00 \pm 0.20) \times 10^{-6}$ erg cm^{-2} s^{-1}. The corresponding time-integrated fluence results $F_{p,B} = (1.60 \pm 0.16) \times 10^{-5}$ erg cm^{-2} and constitutes the release of about 12% of the overall GRB fluence. In this interval, the right-hand side of the spectrum looks flatter, and exhibits a non-negligible emission up to ~ 50 MeV. Considering a possible high-energy emission (>50 MeV) occurring at about $T_0 + 49$ s, potentially revealed in GRID RM data, and considering the typical spectral behavior often encountered in other remarkable bursts (e.g., GRB 090926A, GRB 130427A, GRB190114C), we investigated the possible existence of an additive spectral component, arising within this interval, and extending the spectrum up to the highest energies. From our data in the 18 keV–50 MeV energy range, there is no clear evidence of such an extra high-

energy component. Nevertheless, *interval-B* might be fitted by means of a Band model plus an additive PL with a photon index of ~ 1.35, although resulting in a less reliable $\chi^2_{\rm red}$ with respect to the one obtained for a simple Band model. We report the main spectral parameters of such fit in Table 2.

3. *Interval-C*: $[T_0 + 58$ s, $T_0 + 109$ s$]$. Duration: 51 s. This interval features the end of the prompt phase, with the light curve decaying in intensity and exhibiting some last spiking both in the SA X-ray and in the MCAL high-energy range. Due to the low intensity, the spectrum is affected by large errors in the reconstructed flux. Nevertheless, we could fit this interval with a CPL, with photon index ~ 1.8 and a cutoff energy $E_{c,C} \sim 690$ keV, limiting the bulk of the emission spectrum to a synchrotron component in the sub-megaelectronvolt domain. Another fit can be carried out by means of a single PL model with a photon index of 2.8, although resulting in a worse $\chi^2_{\rm red} = 0.15$, with respect to the CPL model. The related flux in this interval, within an 18 keV–10 MeV energy range, is $f_C = (1.50 \pm 0.15) \times 10^{-7}$ erg cm^{-2} s^{-1}, resulting in a corresponding fluence $F_C \sim (7.67 \pm 0.77) \times 10^{-6}$ erg cm^{-2}. The overall flux in *interval-C* decays by more than one order of magnitude with respect to the former interval, setting off the end of the prompt phase. This interval is particularly relevant, as it features the end of the kiloelectronvolt-megaelectronvolt prompt emission, where high-energy GRBs (e.g., GRB 130427A, GRB 190114C) typically exhibit no

Table 2
AGILE RMs and AGILE MCAL Spectral Analysis of GRB 220101A

| Interv | Δt (s) | Band | | | CPL | | PL | $\chi^2_{\rm red}$(dof) | Fluence (erg cm^{-2}) |
		α	β	E_p (keV)	ph. ind.	E_p (keV)	ph. ind.		(18 keV–10 MeV)
ABC	109.0	$-0.57^{+1.38}_{-0.62}$	$-2.17^{+0.21}_{-0.35}$	$213.89^{+543.66}_{-184.41}$	...	...	...	0.39 (4)	$(1.36 \pm 0.14) \times 10^{-4}$
A	33.0	$-0.98^{+0.39}_{-0.38}$	$-2.37^{+0.13}_{-0.27}$	$279.68^{+462.32}_{-79.08}$	...	...	...	0.40 (4)	$(3.93 \pm 0.39) \times 10^{-5}$
B	25.0	$-0.29^{+0.43}_{-0.61}$	$-2.19^{+0.10}_{-0.14}$	$166.81^{+288.17}_{-143.35}$	...	...	...	0.42 (7)	$(7.68 \pm 0.77) \times 10^{-5}$
		$-0.79^{+4.05}_{-6.65}$	$-2.26^{+0.07}_{-0.73}$	$151.49^{+978.64}_{-135.63}$	...	...	$1.35^{+1.29}_{-0.30}$	0.20 (6)	$(8.05 \pm 0.80) \times 10^{-5}$
C	51.0	...	...	...	$1.85^{+0.77}_{-2.15}$	$688.30^{+692.42}_{-456.39}$	...	1.01 (3)	$(7.67 \pm 0.77) \times 10^{-6}$
		...	...	...	...	...	$2.81^{+0.84}_{-0.54}$	0.15 (4)	$(4.01 \pm 0.40) \times 10^{-6}$
a1	24.6	...	...	...	...	...	$2.51^{+0.84}_{-0.54}$	0.96 (86)	$(7.60 \pm 0.76) \times 10^{-6}$
b1	9.7	...	...	...	...	...	$2.25^{+0.26}_{-0.21}$	1.05 (86)	$(9.55 \pm 0.96) \times 10^{-6}$

Note. Best fits of GRB 220101A obtained for *intervals A*, *B*, and *C* from the SuperAGILE and MCAL RM data, and for *intervals a1* and *b1* from the MCAL data. For each interval, we report the related spectral parameters, reduced chi-square $\chi^2_{\rm red}$ and number of degrees of freedom (dof), as well as fluences evaluated in the 18 keV–10 MeV energy range, and integrated into the corresponding time interval. Adopted models involve Band functions, PLs, or CPLs.

Figure 5. GRB 220101A energy flux in the SuperAGILE (blue) and MCAL (red) energy ranges, evaluated by considering the best-fit spectra for *intervals A* (yellow region), *B* (red region), and *C* (violet region), respectively. Swift-XRT flux data (green) are also reported.

noticeable spectral evolution above a megaelectronvolt to tens of megaelectronvolts, and are well described by a single PL with photon index $\sim$2 (Piron 2016). We notice that there could be some hints of approximately megaelectronvolt emission above the corresponding cut-off energy $E_{c,C}$, but the very low-flux and limited count statistics prevent a reliable fit with an extra PL component, resulting in $\chi^2_{\rm red} > 2$. If a high-energy component is present and emerges in the final stages of the prompt phase, it shall mostly involve energies $\gtrsim$50 MeV or exhibit rather faint fluxes on the order of $\lesssim$4–5 $\times$ 10^{-7} erg cm^{-2} s^{-1}.

In the bottom block of Table 2, we report also the best fits obtained for *intervals a1* and *b1*, from the analysis of the MCAL data. These intervals occur in between *interval-A* and *interval-B*, when the event doubles its flux and the overall spectrum becomes harder, enhancing the emission in the megaelectronvolt to tens of megaelectronvolts regime. *Interval-A* and *interval-B* can be described by Band models with peak energies ranging between 150 and 270 keV. As a consequence, the adopted Band functions would appear as simple PLs in the MCAL detector energy range, whose lower limit is set at

400 keV. For that concerning *interval-a1*, we obtain a good best fit using a PL with photon index $\sim$2.5. On the other hand, *interval-b1* exhibits a flatter behavior and requires a higher photon index of $\sim$2.2, compatible with the Band β index obtained for *interval-B* in the AGILE RMs.

The overall fluxes encountered in the different time intervals are relatively moderate, if compared with other remarkable bursts (e.g., GRB 130427A). Between T_0 and $T_0 + 109$ s, GRB 220101A exhibited a total average energy flux on the order of $\sim$10^{-6} erg cm^{-2} s^{-1}. A fluence of $\sim$10^{-4} erg cm^{-2} is obtained when integrating such flux over a relatively long time interval, mostly ascribed to time dilation effects due to the non-negligible redshift value. Figure 5 shows the energy flux during the prompt emission, as detected by SA (blue) and MCAL (red), within 18–60 keV and 0.2–180 MeV, respectively. Moreover, we report the publicly available Swift-XRT data[16] (green), in the 0.3–10 keV energy range, which cover both the prompt and the extended emission phase for times greater than 109 s. It is interesting to note that for *intervals A* and *B*, the flux above $\sim$200 keV is dominant, whereas in the latter *interval-C*,

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16 https://www.swift.ac.uk/xrt_curves/0

Figure 6. Fluence distribution of the 258 bursts of the second MCAL GRB catalog. Fluences are evaluated in the 400 keV–10 MeV energy range. It can be noticed that GRB 220101A (red dashed line) is placed within the first quartile of GRB fluences among the bursts detected by MCAL. For comparison, fluences of other remarkable bursts are reported with colored dashed lines.

it fades revealing the X-ray flux in the kiloelectronvolt range, which persists up to very late times, setting the onset of the afterglow phase.

3.4. Energetics

The overall prompt emission of GRB 220101A, evaluated from T_0 to $T_0 + 109$ s, can be fitted with a Band model, resulting in a flux of $f = (1.55 \pm 0.16) \times 10^{-6}$ erg cm^{-2} s^{-1}. The corresponding fluence, integrated on the total 109 s time duration, is equal to $F = (1.69 \pm 0.17) \times 10^{-4}$ erg cm^{-2}: such value is a rather typical value among the brightest GRBs detected by MCAL (Ursi et al. 2022b), and places GRB 220101A within the first quartile of GRB fluences in the MCAL burst catalog, as shown in Figure 6. Considering the 400 keV–10 MeV energy range, which is more suitable for MCAL analysis, the burst exhibits a flux f[0.4−10 MeV] = $(6.34 \pm 0.64) \times 10^{-7}$ erg cm^{-2} s^{-1} and a fluence F[0.4−10 MeV] = $(6.91 \pm 0.69) \times 10^{-5}$ erg cm^{-2}. Assuming the redshift $z = 4.62$ (Fu et al. 2022; Fynbo et al. 2022; Perley 2022; Tomasella et al. 2022) and a standard cosmological model provided by Planck Collaboration et al. (2014) (i.e., $H_0 = 67.3$ km s^{-1} Mpc^{-1}, $\Omega_M = 0.315$, and $\Omega_\Lambda = 0.685$), we end up with an isotropic energy release and a peak luminosity in the rest frame equal to $E_{\rm iso} = 2.54 \times 10^{54}$ erg and $L_{\rm iso} = 2.34 \times 10^{52}$ erg s^{-1}, respectively. This represents the highest value of $E_{\rm iso}$ encountered among the GRBs collected by AGILE to date. The left panel of Figure 7 shows the reconstructed equivalent isotropic energy with respect to redshift, for 32 GRBs detected by the AGILE MCAL for which a redshift was provided by X-ray or optical observations of their afterglows. The $E_{\rm iso}$ is evaluated in the 400 keV–10 MeV energy range. For eight GRBs, we fitted the corresponding GRB spectrum with a Band model with a peak energy >400 keV, whereas in the remaining 24 cases, we fitted the spectrum with a simple PL, corresponding to the right-hand side of the corresponding Band, or CPL model, describing the burst spectrum. In all these cases, the 400 keV–10 MeV energy range allows us to investigate these spectra in the MCAL data, and to provide a consistent description of the energetics of the burst sample. In the figure, the dashed and dashed–dotted lines represent the average MCAL upper limit fluences, corresponding to the onboard trigger thresholds for the detection of long (blue dots) and short (magenta dots) GRBs, respectively. It can be noticed that, even in the relatively

high-energy range considered for this analysis, GRB 220101A (red star) is the event with the highest $E_{\rm iso}$ among the MCAL GRBs, even higher than other remarkable bursts, such as GRB 090709A (blue star), GRB 130427A (orange star), and GRB 190114C (magenta star). The right panel of Figure 7 shows the GRB fluence, evaluated in the 400 keV–10 MeV energy range, for the same 32 bursts detected by MCAL. We notice that GRB 220101A is the second farthest event detected by AGILE, whereas it does not exhibit a particularly large fluence, which has a quite standard value among the GRBs detected by MCAL. As a consequence, the major cause of its very large reconstructed isotropic energy release is ascribed to the large distance at which the event occurred.

4. Afterglow of GRB 220101A

We carried out a theoretical analysis of the afterglow emission, based on the forward shock model, consisting of the production of photons via synchrotron and inverse Compton (IC) mechanisms, due to the interaction of the expanding shock with particles of the surrounding medium. The shock expansion, as shown in Blandford & McKee (1976), can be adiabatic, if the shock expands maintaining a constant internal energy, or radiative, if there is a high efficiency in converting the shock internal energy into radiated energy. The latter evolution type can be verified in the prompt, or in the early stages of the GRB afterglow emission, which correspond to phases during which the outflow produced by the GRB progenitor has a large amount of energy and the system can radiate very efficiently. At later stages of the afterglow, the photon production rate decreases. In the following treatment, we analyze the afterglow emission considering the adiabatic evolution, cross checking our prediction using Swift-XRT data.

Table 3 reports the parameters adopted for our analysis. It can be noticed that the very high $E_{\rm iso} = 3.64 \times 10^{54}$ erg (as reported by Atteia 2022; Tsvetkova et al. 2022; Ruffini et al. 2022b) strongly limits the initial value of the critical frequencies ν_m and ν_c, which depend on the evolution type and the external density profile, as shown in Table 4. The ν_m and ν_c are the synchrotron frequencies evaluated for two peculiar electron Lorentz factors, denoted as γ_m and γ_c: the former corresponds to the minimum value from which the electron distribution is defined, whereas the latter is the Lorentz factor of an electron that could radiate with energy equal to $m_e c^2$. These electron Lorentz factors are not fixed for each GRB: γ_m and γ_c, and consequently the associated synchrotron frequencies ν_m and ν_c, show a temporal behavior that depends on the shock evolution and by the environment in which the shock propagates. The main consequence is that the aforementioned critical frequencies could cross different detector bands at different times, due to their temporal dependency. In the homogeneous scenario, the XRT band (0.3–10 keV) is initially placed between those frequencies. The predicted light curve (blue line in Figure 8(a)) has only one temporal break, whose nature is related to the crossing of the ν_m in the XRT band. After this break, the light curve behaves as a PL, persisting for the entire afterglow emission. In Figure 8, the reported T_0 is the Swift $T_0 = 2022$-01-01 05:10:11 (UT). This behavior is compatible with the XRT data until $\sim 4 \times 10^4$ s where a new temporal break occurs. The prediction model improves if we adopt a wind-like scenario. The expected light curve (orange line in Figure 8(a)) shows a break either at early times, when the break frequency ν_m crosses the observed frequency ν, and

Figure 7. Left: reconstructed isotropic energy, in the 400 keV–10 MeV energy range, plotted with respect to redshift, for 32 GRBs detected by the AGILE MCAL. The dotted–dashed magenta and dashed blue lines represent average MCAL upper limit fluences, necessary to trigger on short (magenta dots) and long (blue dots) GRBs, respectively. Stars represent some remarkable GRBs that exhibited either high fluences or high redshift values. It can be noticed that GRB 220101A (red star) has the second-highest redshift in the MCAL GRB sample, as well as the highest E_{iso} among the MCAL detected bursts, for which a redshift was available. Right: MCAL GRB fluence, evaluated in the 400 keV–10 MeV energy range, plotted with respect to redshift, for the same events. GRB 220101A fluence is placed within the first quartile among MCAL GRBs.

Table 3
Parameters for Homogeneous and Wind-like Scenarios

E_{iso}	Scen.	E_{53}	p	Γ_0	$\epsilon_{e;-1}$	$\epsilon_{B;-3}$	n_0	A_*
100%	hom.	36.4	2.20	1500	4	60	0.08	...
	wind	36.4	2.15	700	5.5	0.05	...	16
75%	hom.	27.3	2.10	200	3	60	0.5	...
	wind	27.3	2.10	200	3.55	55	...	9
45%	hom.	17.0	2.30	200	0.4	6	0.8	...
	wind	15.0	2.20	200	0.55	0.05	...	16
25%	hom.	11.0	2.30	150	7.0	60	0.8	...
	wind	10.0	2.20	150	7.5	50	...	16

Note. Parameters of GRB 220101A for a progenitor evolving in a homogeneous, or a wind-like scenario. For each case, we considered different fractions of the total E_{iso}, that are converted into kinetic energy of the shock.

Table 4
Critical Frequencies in the Adiabatic Evolution

Scenario	ν_m	ν_c
Homogeneous	$E_{iso}^{1/2}, t^{-3/2}$	$E_{iso}^{-1/2}, t^{-1/2}$
Wind-like	$E_{iso}^{1/2}, t^{-3/2}$	$E_{iso}^{1/2}, t^{1/2}$

Note. Dependencies of the ν_m and ν_c critical frequencies on the isotropic energy and on the time after the trigger time, for a GRB progenitor evolving in a homogeneous or wind-like circumburst density profile.

at later times, when the break frequency ν_c crosses the observed frequency ν. This behavior is similar to that of GRB 190114C, reported by MAGIC Collaboration et al. (2019), Ajello et al. (2020), and Ursi et al. (2020b). It is important to notice that the forward shock model is useful for the study of the pure afterglow emission; the prompt phase of GRB 220101A lasted for a very long time interval (~100 s) and this implies that the model used for this analysis becomes physically relevant after

100 s since the Swift T_0. Although in Figure 8(a) there are temporal breaks for $t \leqslant 100$ s, when the afterglow is not present yet, a discussion on the nature of these breaks is useful for the comprehension of how the forward shock model predicts the various temporal breaks.

The lack of a late temporal break for the homogeneous scenario is linked to the temporal evolution of the ν_c, as well as to the dependency on the E_{iso}. We can notice from Table 4 that ν_c decreases with time, and for higher values of E_{iso}, the ν_c exhibits a lower initial value: this latter effect makes the ν_c lie from the beginning in the lower part of the spectrum with respect to the XRT band. As a consequence, if at early times the ν_c already lies below the XRT band, this critical frequency would not be able to cross the detector band. On the other hand, in the wind-like scenario, this transition may occur, as ν_c increases with time at a velocity that is lower than the decreasing of ν_m. This could explain why the crossing of ν_m generally takes place at early times, while the crossing of ν_c takes place at late times.

4.1. Parameter Discussion

The equipartition parameters ϵ_e and ϵ_B, respectively, represent the fraction of energy of the electron population and of the magnetic field, with respect to the energy of the shock. As shown in Table 3, the best fit obtained for 100% of E_{iso} exhibits a very large Γ_0 initial shock Lorentz factor, with respect to the typical values characterizing other remarkable and intrinsically more energetic GRBs (e.g., GRB 190114C, whose afterglow was modeled with a $\Gamma_0 \lesssim 700$, or even with a $\Gamma_0 \lesssim 450$ (MAGIC Collaboration et al. 2019; Derishev & Piran 2021). A Lorentz factor of 1500 would therefore make it difficult to explain a high efficiency capable of converting kinetic energy into radiation, as well as the presence of an intense magnetic field. As a consequence, we hypothesized that not all of the energy released by the GRB progenitor is

Figure 8. Expected afterglow light curves for the homogeneous (blue line) and wind-like (orange line) scenarios, considering (a) the entire E_{iso}, (b) 25% of the E_{iso}, (c) 45% of the E_{iso}, and (d) 75% of the E_{iso}. Green squares represent the Swift-XRT data. Here, T_0 is the Swift $T_0 = $ 2022-01-01 05:10:11 UT.

converted into shock kinetic energy: we assume that only a fraction of E_{iso} is relevant to the origin of a primary shock, which then interacts with the external medium, producing the observed emission. In order to evaluate this, we carried out some tests by adopting 25%, 45%, and 75% of the total E_{iso}, whose light curves are reported in panels (b), (c), and (d) of Figure 8. The analyzed cases are for:

1. 25% of the E_{iso}, Figure 8(b). In this case, the predicted light curve for a homogeneous scenario (s = 0) has two near temporal breaks at very early times, due to the crossing of ν_m and of ν_c, respectively. The first break, as previously pointed out, is situated at $t < 100$ s, when the afterglow emission has still not emerged. The second one occurs within the valid region, but it seems not compatible with the early XRT data. Successively, the light curve evolves as a PL with good agreement with the XRT trend, up to $\sim 4 \times 10^4$ s, after which the XRT data diverge from the model slope. The discussion of the wind-like scenario (s = 2) is similar: however, in this case, it shows only one break due to the transition of ν_m over the XRT band, consistent with the XRT data.
2. 45% of the E_{iso}, Figure 8(c). Also in this case, the homogeneous scenario foresees the existence of an early break regarding the early transition of ν_c, which does not lie within the valid region. As a consequence, we only treated the wind-like scenario, which does not imply an early break (the transition of ν_m occurs a few milliseconds after the trigger time, in the inconsistent region).
3. 75% of the E_{iso}, Figure 8(d). The obtained fit is similar to that for 25% of E_{iso}, although exhibiting different light-curve shapes and different temporal breaks.

From this test, we notice that the cases adopting 25% and 75% of the E_{iso} are in agreement with the XRT data until 4×10^4 s; however, after this break, the temporal slopes of the expected light curves do not follow the trend of the observed light curves. On the other hand, the cases adopting 100% and 45% of the E_{iso} show good compatibility with the observed data, either before and after the break time. Moreover, both these best fits exhibit a $\Gamma_0 > 100$, which is typically required to

have an optically thin medium, allowing the gamma-ray emissions to escape the system (Piran 1999). However, as already pointed out in this section, the very large value of Γ_0 resulting from the case with 100% of E_{iso} makes us rule out this best fit as possible modeling for the burst afterglow. We therefore consider the case with 45% of E_{iso} as the best configuration to describe the shock. From a physical point of view, this means that the progenitor of GRB 220101A released a large amount of energy, and that only a considerable fraction of it is actually converted into kinetic energy, necessary for the forward shock expansion and for the beginning of the afterglow phase. This does not exclude that multiple shocks may be generated, although the primary one carries out the major part of the event energy, producing most of the detected emission. Moreover, in both configurations, the wind-like density profile is the scenario providing the better fits for the Swift-XRT data of the afterglow emission; the slope before and after the late break is compatible with the observed ones and the position of the temporal break is consistent with the observed data. We can conclude that the GRB 220101A evolved with high probability in a wind-like density medium, and that the energy carried away by the shock is almost half of the entire E_{iso} released by the event.

We cross checked the results obtained from our analysis with the optical emission in the R band, considering the preliminary fluxes reported in various GCN circulars by optical observatories, such as those of Xinglong (Fu et al. 2022), Tautenburg (Nicuesa Guelbenzu et al. 2022a, 2022b), LCO (Strausbaugh & Cucchiara 2022a, 2022b, 2022c), DFOT (Panchal et al. 2022; Ror et al. 2022), CAHA (Caballero-Garcia et al. 2022), and SAO RAS (Moskvitin et al. 2022). As shown in Figure 9, we notice that the optical fluxes show a good agreement with the model previously obtained by considering 45% of the total E_{iso}, and an expansion shock evolving in a wind-like scenario (s = 2).

5. Conclusions

GRB 220101A represents a record burst, exhibiting one of the largest isotropic energy releases ever observed from a GRB ($E_{iso} \sim 3.64 \times 10^{54}$ erg, as reported by Atteia 2022, Tsvetkova

Figure 9. Predicted light curves in the homogeneous (blue line) and wind-like (orange line) scenario, considering 45% of the total burst $E_{\rm iso}$, and the optical data (red points) retrieved from public GCN circulars (reported in the legend).

et al. 2022). Taking advantage of the SuperAGILE, Anti-Coincidence, and MCAL data, acquired by the onboard scientific RMs, the AGILE satellite provides a broadband overall description of the evolution of this GRB, from a few tens of kiloelectronvolts to tens of megaelectronvolts, high-lighting some peculiar features of its temporal and spectral behavior. The event lasted more than 100 s and its localization region was fully inside the AGILE field of view for most of its duration. We divided the prompt emission into three main intervals: the onset of the burst dominated by X-ray/soft gamma-ray emission, a central interval where the burst reaches its peak flux (especially in the megaelectronvolt energy range), and a final interval with a fading low-flux emission, setting off the end of the prompt phase. The average fluxes encountered in the different time intervals are relatively ordinary, with respect to those observed in other remarkable GRBs, exhibiting values around $\sim 10^{-6}$ erg cm^{-2} s^{-1}. The central interval between $T_0 + 38$ s and $T_0 + 46$ s features the burst peak emission, where about 12% of the overall fluence is released. The central and final intervals of the GRB prompt might feature an additive PL component, extending the spectrum to several tens of megaelectronvolts, although our data do not allow us to carry out a detailed analysis, due to the low statistics. Nevertheless, a good fit in the 18 keV–50 MeV range does not require extra components beyond single Band or CPL models.

The analysis of the afterglow of GRB 220101A, carried out using the public Swift-XRT data and adopting the forward shock model, reveals that the surrounding environment in which the event took place is mainly compatible with a wind-like density profile. The progenitor of GRB 220101A is therefore likely a massive star that provided a wind-like environment for its circumburst medium density. The best fit for this modeling is obtained considering that only a fraction ($\sim 45\%$) of the entire $E_{\rm iso}$ is converted into kinetic energy, necessary for the expansion of the forward shock. Such a model also shows a very good agreement with the optical data retrieved from the preliminary analysis of ground observatories, reported in public GCN circulars.

In the 400 keV–10 MeV energy range, GRB 220101A does not exhibit a particularly remarkable fluence, whose value ranks within the first quartile among the fluences of the GRBs detected by MCAL. However, this event has the second-highest redshift among the MCAL bursts, and due to the huge distance of the progenitor, it exhibits a reconstructed equivalent isotropic energy equal to $E_{\rm iso} = 2.54 \times 10^{54}$ erg (0.4–10 MeV), becoming the most energetic event of the entire MCAL GRB sample collected to date.

ORCID iDs

A. Ursi ⓘ https://orcid.org/0000-0002-7253-9721
M. Romani ⓘ https://orcid.org/0000-0002-4724-7153
G. Piano ⓘ https://orcid.org/0000-0002-9332-5319
F. Verrecchia ⓘ https://orcid.org/0000-0003-3455-5082
F. Longo ⓘ https://orcid.org/0000-0003-2501-2270
C. Pittori ⓘ https://orcid.org/0000-0001-6661-9779
M. Tavani ⓘ https://orcid.org/0000-0003-2893-1459
A. Bulgarelli ⓘ https://orcid.org/0000-0001-6347-0649
M. Cardillo ⓘ https://orcid.org/0000-0001-8877-3996
C. Casentini ⓘ https://orcid.org/0000-0001-8100-0579
P. W. Cattaneo ⓘ https://orcid.org/0000-0001-6877-6882
E. Costa ⓘ https://orcid.org/0000-0003-4925-8523
M. Feroci ⓘ https://orcid.org/0000-0002-7617-3421
V. Fioretti ⓘ https://orcid.org/0000-0002-6082-5384
L. Foffano ⓘ https://orcid.org/0000-0002-0709-9707
F. Lucarelli ⓘ https://orcid.org/0000-0002-6311-764X
M. Marisaldi ⓘ https://orcid.org/0000-0002-4000-3789
A. Morselli ⓘ https://orcid.org/0000-0002-7704-9553
L. Pacciani ⓘ https://orcid.org/0000-0001-6897-5996
N. Parmiggiani ⓘ https://orcid.org/0000-0002-4535-5329
A. Trois ⓘ https://orcid.org/0000-0002-3180-6002
S. Vercellone ⓘ https://orcid.org/0000-0003-1163-1396

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