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Ready for O4 II: GRANDMA observations of *Swift* GRBs over eight weeks in spring 2022

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ABSTRACT

Aims. We present a campaign designed to train the Global Rapid Advanced Network Devoted to the Multi-messenger Addicts (GRANDMA) network and its infrastructure to follow up on transient alerts and detect their early afterglows. In preparation for O4 II campaign, we focused on gamma-ray burst (GRB) alerts since they are expected to serve as the electromagnetic counterpart of gravitational-wave events. Our goal was to improve our response to the alerts and to start prompt observations as soon as possible, so that we may better prepare the GRANDMA network for the fourth observational run of LIGO-Virgo-Kagra (launched at the end of May 2023) and future missions such as SM.

Methods. We set up a dedicated infrastructure and organized a rota of follow-up advocates (FAs) to guarantee round-the-clock assistance to our telescope teams, with an aim to receive, manage, and send out observational plans to our partner telescopes. To ensure a large number of observations, we focused on *Swift* GRBs whose localization errors were generally smaller than the GRANDMA telescopes' field of view. This allowed us to bypass the transient identification process and focus on the reaction time and efficiency of the network.

Results. During the 'Ready for O4 II' phase, 11 *Swift*/INTEGRAL GRB triggers were selected. Of these, nine fields had been observed and three afterglows had been detected (GRB 220403B, GRB 220427A, GRB 220514A) with 17 GRANDMA telescopes and 17 amateur astronomers from the citizen science project Kilonova-Catcher. Here, we highlight the GRB 220427A analysis, where our long-term follow-up of the host galaxy allowed us to obtain a photometric redshift of $z = 0.82 \pm 0.09$ and its lightcurve evolution, as well as to fit the decay slope of the afterglows and study the properties of the host galaxy.

Conclusions. During this eight-week-long GRB follow-up campaign, we successfully fulfilled our goal of training telescope teams for O4 and improving the associated technical toolkits. For seven of the GRB alerts, our network was able to start the first observations less than one hour after the GRB trigger time. We also characterized the network efficiency to observe GRB afterglow given the resulting time delay and limiting magnitude, and to its light curve evolution based on the observation of GRB 220427A.

Key words. methods: data analysis – telescopes – gamma-ray burst: general

1. Introduction

The detection and successful electromagnetic characterization of GW170817 by the International Gravitational-Wave Observatory Network (IGWN; Abbott et al. 2017a,b) have boosted the importance of dedicated multi-messenger efforts in time-domain astronomy. In particular, the identification and follow-up studies of GRB170817A by *Fermi*-GBM (Goldstein et al. 2017) and INTEGRAL (Savchenko et al. 2017) have corroborated the long-predicted connection between binary neutron stars (hereafter, BNS) and short gamma-ray bursts (sGRBs; see e.g., Alexander et al. 2017; Haggard et al. 2017; Hallinan et al. 2017, amongst others). Our current efforts are focused on characterizing the electromagnetic emissions associated with gravitational waves (GWs) produced by compact binaries across various wavelengths. This is done to comprehensively investigate the complete range of astrophysical information related to a compact binary coalescence.The kilonova emission from such sources (e.g., Andreoni et al. 2017; Arcavi et al. 2017; Hu et al. 2017) is widely studied to constrain the neutron star equation of

[†] Deceased.

state (EOS; Bauswein et al. 2017; Margalit & Metzger 2017; Coughlin et al. 2018, 2019, 2020b), the Hubble constant (e.g., Abbott et al. 2017a; Hotokezaka et al. 2019; Coughlin et al. 2020a,c), and studies of *r*-process nucleosynthesis (Perego et al. 2021). In this context, the Global Rapid Advanced Network Devoted to the Multi-messenger Addicts (GRANDMA; Antier et al. 2020a,b) collaboration's primary goal is to follow-up GW alerts provided by the IGWN with telescopes distributed worldwide in order to achieve as short a response time as possible. GRANDMA brings together telescopes located in both hemispheres with the objective of coordinating them all as a single facility to respond to GW (or other transient) alerts. Coordinated observations can be achieved thanks to a common scheduler that automatically sends coordinated observation plans to individual telescopes. A centralized data cloud coupled with a database allows for the storage of images that are uploaded by telescope teams within GRANDMA's network. The images provided by the team will then be processed by tools used within the collaboration (see Sect. 4.3). GRANDMA has performed an intensive follow-up of GW alerts during the O3 LIGO-Virgo run and demonstrated an efficient response time: less than 90 min of latency for 50% of the alerts, with a record of 15 min (Antier et al. 2020a,b). After the end of O3 in March 2020, GRANDMA has continued on its path, increasing in size through the introduction of a number of new groups. In order to facilitate both software and educational advancement, multiple observation campaigns were conducted, typically on an annual basis. These campaigns served a dual purpose. They prepared and trained the collaboration, which included both telescope teams and infrastructure development, while also allowing for the creation of novel tools within the context of SkyPortal[1] (Coughlin et al. 2023). The ultimate aim was to be well-prepared for O4, which commenced at the start of May 2023 with a planned duration of 18 months. The first GRANDMA "training campaign" took place from April to September 2021, dedicated to the follow-up of transient candidates detected by the Zwicky Transient Facility (ZTF) and processed by the Fink broker (Aivazyan et al. 2022; Möller et al. 2021; Bellm et al. 2014). This work presented the first integration of amateur astronomers, through the citizen science program named "Kilonova-Catcher" initiated by GRANDMA. Lastly, follow-up observations dedicated to GRB 221009A were performed with data from the prompt emission 30 days after the GRB alerts (Kann et al. 2023). In this paper, we present the results of a "training GRANDMA campaign" over a duration of eight weeks. We followed the GRB observed by *Swift* due to its small localization error, which is consistent with GRANDMA telescopes' field of view. Besides preparing our network for O4, we tested our capability to identify and characterize GRB afterglows, in the framework of the forth-coming mission SM (Wei et al. 2016). GRANDMA was able to observe 9 of the 11 GRBs detected by *Swift*/INTEGRAL during the campaign period, corresponding to a success of ~82% with three afterglow detections. We present, in more detail, the observation and detection of an afterglow, GRB 220427A, which was observed at very early times and followed up until it was host-galaxy dominated. The current study demonstrates the effectiveness of GRANDMA in swiftly initiating observations upon the detection of a transient alert, while also promptly observing their optical counterparts. This is crucial to ensuring that no gravitational wave (GW) event with expected electromagnetic (EM) observations is missed. The article is structured as follows: Sect. 3 details the existing GRANDMA network, Sect. 4 outlines the infrastructure established for the GRB campaign, while Sects. 5 and 6 present the outcomes of our campaign, and Sect. 7 summarizes our conclusions.

[1] https://skyportal.io/

2. Motivations

For its second campaign between the third and fourth observational runs of the IGWN, the GRANDMA collaboration performed a GRB follow-up campaign lasting eight weeks from March 19 to May 14, 2022. The 'Ready for O4 II' campaign was designed to measure and improve the reaction of the teams belonging to the network, as well as their performance in following up on fast transients. Special attention was given to the new teams (e.g., Pico Dos Dias and SOAR Observatories) in the collaboration. The list and description of the teams who joined the collaboration for this run are presented in Appendix A.

Given this objective, we chose to focus on *Swift* GRBs. This provided us the opportunity to easily quantify the reaction time and efficiency of the network as the *Swift* typical localization errors are generally smaller than the GRANDMA telescopes' field of view. This aided the complication of the transient identification process in large localization errors that have been previously tested and used during the GRANDMA O3 follow-up (Antier et al. 2020a,b). Also, at the end of the campaign, on May 14, 2022, the detection of a long GRB by INTEGRAL was observed by GRANDMA telescopes.

The campaign had several objectives. Primarily, it aimed to gauge the effectiveness of the network by analyzing the response time to the detection of optical/NIR afterglows. The goal was to trigger observations among the telescope teams in our collaboration as early as possible and with the best time sampling achievable, while also extending the observations for as long as the source remains detectable. This approach allowed for a comprehensive analysis of the geometry and physical characteristics of the observed GRBs. A second key goal was to utilize the network for identifying kilonova or supernova counterparts. Additionally, the campaign sought to identify any long-term emissions, such as supernovae or other components distinct from the afterglow. Lastly, it aimed to discover and characterize the host galaxy by determining the spectroscopic redshift, especially in the case of a bright host. This task necessitated revisiting the field, potentially employing various filters, at later time points, typically after ~1 month.

The above scientific objectives have been designed to stress the GRANDMA system in various ways to serve as a pathfinder for the O4 run. Among the technical and practical objectives of this campaign, we can specifically mention the desire to optimize and harmonize image collection, processing, and data reduction with pipelines built within the collaboration through Skyportal (Coughlin et al. 2023). Finally, we aim to improve the overall expertise in time-domain astronomy and the tools of the collaboration dedicated to enabling rapid decision making which is essential for transient follow-up. We also wanted to ensure our capacity of person power and technical investment for GRB programs, for example, as done by the Space-based multi-band astronomical Variable Objects Monitor (SM) mission.

3. GRANDMA and Kilonova-Catcher

The GRANDMA consortium is a world-wide network of 18 observatories and 26 telescopes, 42 institutions, and groups from 18 countries. These facilities make available large amounts of observing time that can be allocated for photometric and/or spectroscopic follow-up of transients. The network has access to wide field-of-view telescopes (FoV $> 1\,\mathrm{deg}^2$) located on three continents, and remote and robotic telescopes with narrower fields-of-view[2]. To complement this telescope network, GRANDMA has initiated a citizen science project called Kilonova-Catcher[3] (Antier et al. 2020b; Aivazyan et al. 2022; Kann et al. 2023, KNC). This program allows any interested amateur astronomer to connect to the GRANDMA alert system to perform follow-up observations of promising multi-messenger transient sources. At present, 110 amateur astronomers all around the world are connected to the KNC web interface to receive alerts and customized observation plans as well as subscribe to our mailing list.

4. Interface and communication for addicts of the rapid follow-up in multi-messenger era (ICARE) pipeline

4.1. GRANDMA infrastructure

For this campaign, we set up dedicated infrastructure to receive, manage, and send observational plans to our partner telescopes. The full code is accessible in the gwemopt library[4] and it inherits the same protocol as described in Antier et al. (2020a). We enabled the reception of GCN-notice[5] alerts from *Swift* (i.e., those named "*Swift*/BAT alert" or "*Swift*/BAT position," which correspond to packet_type 97 and packet_type 61, respectively), along with *Swift*-XRT ("Flight *Swift*/XRT Position," packet_type 67). There were no BAT-GUANO[6] triggers included in this campaign. We recorded the date and time of the GRB discovery, the coordinates and their error, the sky localization and distance from the Sun and Moon, the probability that the alert was astrophysical, and the signal-to-noise ratio (S/N) of the source in the 2D gamma-ray image. Using these data, we calculated a score of interest, with points for whether: (1) the probability of being astrophysical is 1; (2) the moon illumination is below 0.7 and the Moon and Sun distance from the source is more than 20 deg, plus (1); and 3) $S/N_{\mathrm{image}} > 6.5$, plus (1) and (2).

We then created a VO event dedicated to each telescope and broadcast via an IP address. The event (described in the Appendix B.1) contains the name of the GRB, trigger ID, trigger time, event status, internal pack number, long and short classification, the h_{ratio} of the GRB (if available), GRANDMA telescope receiver, and the coordinates in J2000 with the error. The astronomical teams are consistently listening to our IP address and they receive an initial GRANDMA notice within a few seconds, when the *Swift* coordinates are available, followed (if needed) by a second "update" GRANDMA notice when *Swift*-XRT coordinates are available (typically within a few tens of minutes). In case of a GRB follow-up, the same coordinates are transmitted to all astronomical teams, but the code allows us to send multiple targets and a dedicated list per telescope receiver. In this way, telescope teams belonging to our collaboration are requested to carry out the relevant observations.

For each GRB, our software also automatically creates a repository on our owncloud platform[7] where the information about the GRB is stored, such as: folders containing information like the observability map, logbooks for campaign members to follow up on and detail the progress of the GRB observations, folders to upload stacked images and photometric data, and so on. We have implemented redundancy and automated restart to prevent any hardware interruption.

During the entire period of the campaign, we did not report any problem with the hardware and observation plans were automatically sent to the astronomical teams successfully. In Table 1, we give the latency performance of our infrastructure per *Swift* GRB.

Table 1. Delay of GRANDMA notice delivery compared to the trigger time.

Name	Trigger time (UTC)	BAT pos. delay (s)	TCA receiver delay (s)
GRB220319A	2022-03-19T17:40:33	19	<1
GRB220325A	2022-03-25T17:16:23	13	9
GRB220403B	2022-04-03T20:42:39	18	1
GRB220404A	2022-04-04T11:54:30	53	<1
GRB220408A	2022-04-08T05:46:04	12	<1
GRB220412A	2022-04-12T06:36:50	54	<1
GRB220412B	2022-04-12T17:06:48	13	<1
GRB220427A	2022-04-27T21:00:34	25	<1
GRB220430A	2022-04-30T13:53:15	275	2
GRB220501A	2022-05-01T-19:51:50	21	70

Notes. The delay is calculated from the telescope receiver and takes into account the delay of transmission from *Swift* in sending the position of the GRB, the delay of treatment by the GRANDMA infrastructure, and the delay of transmission.

4.2. GRANDMA follow-up organization

In the case of an alert, as with any GRANDMA campaign, a rota of follow-up advocates (FA) was organized to guarantee round-the-clock assistance to our telescope teams. The FAs were needed to guarantee that everything ran smoothly day after day during a campaign and to notify teams of the GRB alerts received through GCN via the dedicated communication channel. As soon as a GRB alert was received, FAs would alert the teams within minutes post the alert, validating whether or not a given alert should be followed. It is also the role of the FAs to ensure that the dedicated owncloud repository for a given alert was done correctly (OwnCloud[8]). As soon as the observation plans for each alert were sent to the observers, the FA filled out a logbook reporting whether a telescope was able to observe and to check whether the images had been correctly uploaded for further analysis. The FAs must keep the teams up-to-date about all circulars published about a given alert (reported via GCN), to decide whether or not to halt the observations. In the case of a counterpart discovery by external telescopes and reported via GCN, the FA had the responsibility to submit a request for a new observation plan to follow up on this transient. The FA is in charge of informing the teams of the magnitudes and filters used to trigger the GRANDMA telescopes suitable for the follow-up to help characterize possible light curves. In the case of a counterpart discovery by GRANDMA telescopes, the FA was responsibility for triggering our spectroscopic facilities after checking if the transient magnitude was suitable for spectroscopy. When the observation cycle for a particular GRB was complete, the FAs that received the alert during their shift reported the

2 https://grandma.ijclab.in2p3.fr/
3 http://kilonovacatcher.in2p3.fr/
4 https://github.com/skyportal/gwemopt/tree/main/gwemopt
5 https://GCN.gsfc.nasa.gov/
6 https://www.swift.psu.edu/guano/
7 https://grandma-owncloud.lal.in2p3.fr/
8 https://owncloud.com/

observations and their characteristics by sending out a GCN on behalf of GRANDMA.

The campaign presented in this paper was organized on four shifts per day: 04:00–10:00, 10:00–16:00, 16:00–22:00, and 22:00–4:00 (UTC). The FAs were organized in weekly teams led by an experienced weekly coordinator (senior scientist) who was also responsible for training FAs, pairing the beginners with more experienced FAs, and supervising the full duration of the shift. There are between four and eight FAs over a full week and each one is assigned to a particular slot once a day, starting and ending every Thursday (ending at about 16:30 Paris time).

We also trained the telescope teams to familiarize them with their role during the campaign and make sure they have access to all tools. As the major challenge of GRANDMA is to coordinate dozens of teams having different instruments all over the world, the training was aimed at helping bring all observational teams to the same level and perform "smooth observations" altogether. The telescope teams are composed of at least one observer, and one photometry expert, that operates one (or more) telescopes, upon which several instruments can be mounted. In case of a transient alert, the FA on shift will warn the telescope teams about it. The telescopes teams then must respond immediately as to whether or not they will be able to perform an observation of the given alert. In the case of a positive reply, the teams will then provide images with a header containing standardized fields in as short a time as possible. The data will be then analyzed and their photometric results will be posted in the GCN. All the documentation available for telescope teams and follow-up advocates is available on a dedicated page[9].

4.3. Photometry

The process of uniformly analyzing the diverse set of images taken by different telescopes within our network was done by two dedicated photometric pipelines: STDPipe[10] (Karpov 2021) and MUPHOTEN[11] (Duverne et al. 2022; Kann et al. 2023). These software stacks were the same as those used during our previous "ready for O4 campaign-I" which is described in Sect. 4 of Aivazyan et al. (2022).

These pipelines follow slightly different approaches. STDPipe is a ready-to-use set of scripts pre-configured for processing the data from selected instruments. MUPHOTEN is a library of both low- and high-level routines for creation of custom pipelines for the data from arbitrary telescopes and varying complexity of the analysis (e.g., taking into account the spatial dependence of photometric zero point or colour term, using custom noise models, advanced filtering of detected transient candidates, and so on). In our analysis, they were configured to perform similar steps – object detection, astrometric and photometric calibration, image subtraction using Pan-STARRS or telescope-specific templates, and transient detection and photometry on difference image – on the data pre-processed by an instrument-specific code to perform bias, dark subtraction, and flat-fielding on the telescope side. As shown in Aivazyan et al. (2022), the results of both pipelines are typically identical within measurement errors and provide an important cross-check on potential processing errors.

In the case of GRBs, the positions of the transient are known prior to our observations with the accuracy of (at least) 2–3 arcsec due to promptly downlinked data from XRT. In case of events with optical afterglows, the position is further improved by the detections from *Swift* onboard Ultraviolet and Optical telescope (UT) or ground-based rapid response robotic telescopes, down to typically sub-arcsecond accuracy. The latter was true for all events where we had a clear detection of transients in our images. Therefore, we did not specifically perform any transient detection on our images; instead, we concentrated solely on the forced photometry at the published event position or different images, contingent upon the level of congestion in the field. In cases where the object was not detectable, we derived the upper limits as described below.

In MUPHOTEN, they are computed as global properties of the whole studied image. The default method outlined in Duverne et al. (2022) calculates the success rate of recovering PS1 objects within 0.2 mag intervals and selects the faintest interval where more than 10% of PS1 objects in the field of view (FoV) are detected in the image. In the case of images where there is a high detection rate up until the limit of the Pan-STARRS catalog, an alternative method defines the upper limit as the magnitude of the faintest source detected with a S/N of about 5. For STDPipe, we followed a simpler approach and assumed the 5σ upper limit to be the flux equal to five times the background noise inside the aperture placed at the transient position. It corresponds to the stellar magnitude of a point source that may be detected with a given S/N. We note that both these definitions are not sensitive to the exact transient position, thus, they may be employed for setting upper limits in cases of non-detections.

STDPipe also contains a suite of routines that facilitate the proper detection and (to some extent) filtering of transients in the images, both before and after the template subtraction. While they have not been used during the GRB-focused run reported here, we plan to fully employ them for the task of transient detections in our data to be acquired during O4.

5. Report summary of GRANDMA observations of GRBs

In this section, we present the observation for the GRBs followed during the campaign. From ten selected *Swift* and one INTEGRAL GRB alerts, we successfully detected three afterglows. We highlight them in Sect. 5.1: GRB 220403B, GRB 220427A, and GRB 220514A. Observations for two GRBs: GRB 220404A and GRB 220412B, were triggered but led to no observations as the targets were too close to the Sun and the Moon, respectively. For six other GRBs, observations were made but no afterglow was detected by our telescopes (their upper limits are reported in this section).

5.1. Non-detections

GRB 220319A. The first alert received in the "2022 ReadyforO4 Campaign II" on March 19, 2022 at 17:40:33 UT (Page et al. 2022). The first observation occurred about 14 min (Bizouard et al. 2022) after the initial *Swift* alert thanks to amateur telescopes from the Kilonova-Catcher program. A further follow-up was performed with ALi-50 telescope and nine amateur telescopes until ~11 s after the GRB trigger, reporting a limiting magnitude of ~20 (*B*, *R* and Clear bands). None of these observations detected an afterglow: the values are consistent

[9] https://grandma.ijclab.in2p3.fr/preparation-of-the-grb-campaign/
[10] STDPipe is available at https://gitlab.in2p3.fr/icare/stdpipe
[11] MUPHOTEN is available at https://gitlab.in2p3.fr/icare/MUPHOTEN

with observations made outside GRANDMA (Lipunov et al. 2022b; Belkin et al. 2022; Strausbaugh & Cucchiara 2022a; de Ugarte Postigo & Clavero Jimenez 2022; Hosokawa et al. 2022).

GRB 220325A. The *Swift* Alert Telescope (BAT) detected the GRB 220325A on March 25, 2022, at 17:16:23 UT (Ferro et al. 2022), and GRANDMA observations started 4.28 s after the BAT trigger time with the SNOVA telescope (Andrade et al. 2022). A further follow-up was obtained (in r'-, R- and i-band) with SNOVA, KAO, C2PU, and NOWT telescopes up to ~10 s after the GRB trigger with a limiting magnitude up to 21.2 mag, but no optical counterpart was detected (Lipunov et al. 2022c; Gupta et al. 2022; Strausbaugh & Cucchiara 2022b; Nicuesa Guelbenzu et al. 2022; Kuin & Ferro 2022).

GRB 220408A. Detected by *Swift* on April 8, 2022 at 05:46:04 UT and the first image was obtained ~38 min after the trigger from an amateur astronomer in the V-band with a limiting magnitude of 17.7 without detection. Further observations were achieved with four GRANDMA telescopes, SRO, Xinglong-TNT, ALi-50, and MOSS, along with two amateur astronomers (T19 and HAO) up to ~19 s after the *Swift* trigger (Beradze et al. 2022a). None of these observations provided a detection of the afterglow, with the most constraining limiting magnitude achieved being 21.4 mag without a filter (Oates & Caputo 2022; Hu et al. 2022b; Strausbaugh & Cucchiara 2022c; Zhu et al. 2022; Watson et al. 2022a).

GRB 220412A. On April 12, 2022 at 06:36:50 UT, the *Swift* triggered and located GRB 220412A which was classified as long with a duration of $T_{90} = 41.66 \pm 7.00$ s (Klingler et al. 2022b). GRANDMA observed GRB 220412A with three telescopes and two amateur astronomers between ~5.6 and ~22 s after the *Swift* trigger (Beradze et al. 2022b). The observations were contaminated by the moon and only provided upper limits in the L, R, V, and I bands, reporting a limiting magnitude up to 20.8 in the R band (Watson et al. 2022d,c,b).

GRB 220430A. Detected on the April 30, 2022 at 13:53:15 UT by *Swift* (Ambrosi et al. 2022). GRANDMA observed GRB 220430A with four telescopes, SNOVA, Makes-T60, HAO, and MOSS, between ~34 min and ~6.3 s after the *Swift* trigger (Dornic et al. 2022). None of these observations provided detection of the afterglow with the most constraining limiting magnitude achieved being 21.0 mag without a filter (Groot et al. 2022; Pankov et al. 2022; Hu et al. 2022c; Swain et al. 2022; Jiang et al. 2022a,b).

GRB 220501A. On May 1, 2022 at 19:51:51 UT, *Swift* triggered and located GRB 220501A (D'Ai et al. 2022). GRB 220501A was observed by one amateur astronomer starting about ~30 min after the trigger. We did not detect any optical counterpart to a limiting magnitude of 16.0 in r'-band (Hu et al. 2022a).

5.2. Afterglow detections

GRB 220403B. The *Swift*-Burst Alert Telescope (BAT) observed and detected GRB 220403B (trigger = 1101053), on April 3, 2022, at 20:42:42 UT. The BAT light curve showed a single-peak structure with a duration of 30 s, and a rate of about 2800 counts s^{-1} (15–350 keV; Klingler et al. 2022a). The 1 s peak photon flux measured at 1.06 s in the 15–150 keV band was 2.7 ± 0.3 ph cm^{-2} s^{-1}: all the quoted errors are at the 90% confidence level (Lien et al. 2022).

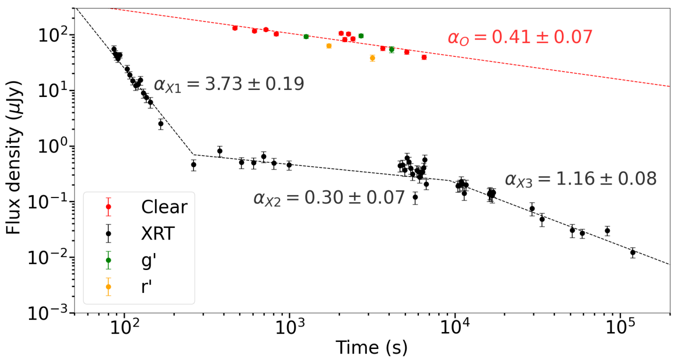

Fig. 1. Optical and X-ray light curve of GRB 220403B. The dashed line shows the best power law fit for both optical and X-ray light curves.

The first GRANDMA observation started eight minutes after the BAT alert (Song et al. 2022). The follow-up was performed with four GRANDMA telescopes up to ~1 day after. The afterglow was clearly detected within the first hour in the g' and r'-band and observations without a filter. The light curve without a filter can be fit by a power law decay with an index of $\alpha_O = 0.41 \pm 0.07$ (where $f_\nu \propto t^{-\alpha}\nu^{-\beta}$). We fit (as shown in Fig. 1) the X-ray light curve observed by *Swift*/XRT with a broken power law with two breaks. The obtained break times are $t_{b1} = 263 \pm 2$ s and $t_{b2} = 9571 \pm 1667$ s, with a decay index of $\alpha_{X1} = 3.73 \pm 0.19$, $\alpha_{X2} = 0.30 \pm 0.07$, and $\alpha_{X3} = 1.16 \pm 0.08$, respectively. The optical data obtained fall in between the two breaks observed in X-rays and the shallow decay observed in optical is coincident with a plateau phase in X-ray. These plateaus are common in X-ray and optical and have already been observed in other GRBs (e.g., Knust et al. (2017)). They can be interpreted in a variety of ways: late energy injection in the forward shock due to a wide spread of the gamma factors (e.g., Granot & Kumar 2006), high latitude emission produced at large angles with respect to the jet axis leading to a long-lasting X-ray plateau for an on-axis observer (e.g., Oganesyan et al. 2020; Ascenzi et al. 2020), a structured jet seen slightly off-axis (e.g., Beniamini et al. 2020), the signature of a long-lived reverse shock due to a tail of low Lorentz factor material (e.g., Uhm & Beloborodov 2007; Genet et al. 2007; Uhm et al. 2012), evidence for a leftover GRB central engine being a millisecond magnetar (e.g., Tang et al. 2019; Zhao et al. 2020), or emission due to a continued accretion of fall-back gas onto the newborn neutron star or black hole (e.g., Kumar et al. 2008b,a). We note in the spectral domain that our color data point toward a spectral index $\beta_O \sim -1.4$. Although we have not corrected the data for optical extinction, all galactic extinction models predict a lower extinction in the r' compared to the g' band (e.g., Schlafly & Finkbeiner 2011). Thus, our measurement can be understood as an upper limit: $\beta_O < -1.4$. This value is highly unusual and not compatible with the expectations from the standard fireball model. Even if the injection frequency was located in the r' band, this would lead to a measure of $\beta_O \sim -0.3$ at best. However, he data we have on hand are too scarce to investigate further this steep spectral index. No host galaxy is visible in our latest image with a limiting magnitude of 20.9 (in B and g-band).

GRB 220427A. The GRANDMA system received the *Swift* notice and transmitted the observation request to the whole network in about one minute. Early on, the GRB had limited observability from terrestrial observatories and was limited to observatories near Australia and southern Africa. Within the GRANDMA network, only the telescopes located at

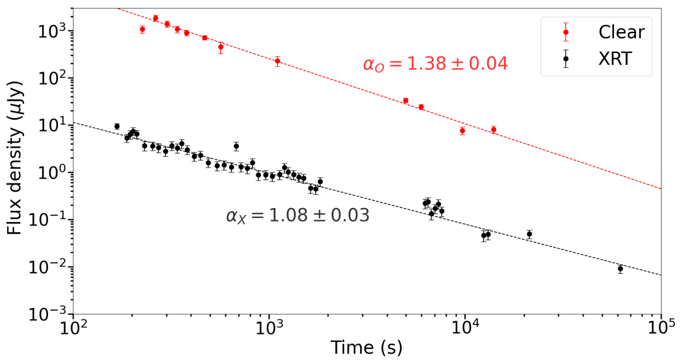

Fig. 2. Optical and X-ray light curve of GRB 220427A. The dashed line shows the best power law fit for both optical and X-ray light curves.

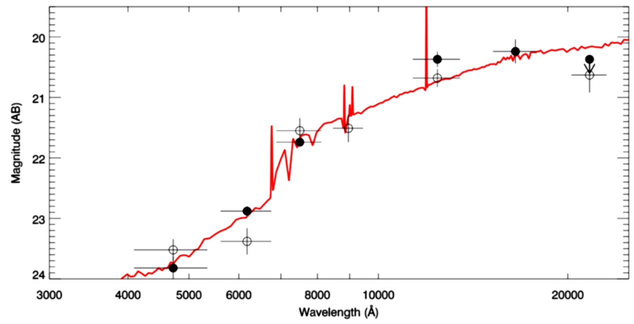

Fig. 3. Spectral energy distribution fit to the host galaxy photometry of GRB 220427A.

La Réunion could observe at early times. The TAROT/TRE robotic telescope, automatically triggered by the alert, started the observation of the *Swift* localization without a filter in the beam about 196 s after the GRB trigger. Preliminary analysis of the TAROT/TRE images rapidly confirmed the detection of an optical afterglow. Further detection of the afterglow had been obtained by Les Makes/T60 telescope starting about 1.4 h after the GRB trigger.

The light curve elution derived from our optical data, presented in Fig. 2, can be fit by a power law decay with a decay index of $\alpha_O = 1.38 \pm 0.04$. The X-ray light curve, as observed by *Swift*/XRT, elves as a power law with a decay of $\alpha_X = 1.08 \pm 0.03$. From the X-rays, we also have the spectral slope, which corresponds to a $\beta_X = 1.02 + / - 0.15$ (where $F = \nu^{-\beta}$). This corresponds to a standard fireball model with a wind density profile in the external medium, at a pre-break time, with the cooling break located between the optical and X-rays and an electron slope of $p \simeq 2.2$ (Granot & Sari 2002).

The host galaxy of GRB 220427A was observed using GROND at the MPG 2.2 m telescope at ESO's La Silla observatory (Greiner et al. 2008) on May 27, 2022 in 7 bands ($grizJHK_S$). The observation included integration of ~3600 s in each of the bands. We corrected the resulting photometry of galactic extinction using the (Schlegel et al. 1998) and the (Schlafly & Finkbeiner 2011) corrections. The spectral energy distribution was used to determine a photometric redshift by fitting it with galaxy models at varying redshifts using LePhare (Arnouts & Ilbert 2011). The best fit was obtained for a redshift of $z = 0.82 \pm 0.09$ (see Fig. 3). Using this redshift, we performed a further SED fit with CIGALE (Boquien et al. 2019), which delivered similar host galaxy properties to the ones obtained with LePhare. The results obtained with CIGALE are given in Table 2. Input parameters for the SED fitting with CIGALE are presented in Table 3. We have adopted a delayed star formation rate (SFR $\propto t/\tau_0^2 \cdot e^{-t/\tau_0}$), on top of which a possible recent burst of star formation is enabled. The recent burst and the AGN contributions are not required to reproduce the obtained SED behavior and removing both contributions marginally changes the estimated parameters presented in Table 2. The inferred parameters are compatible with what one could expect from a long GRB host galaxy (e.g., Hunt et al. 2014; Perley et al. 2016; Palmerio et al. 2019; Schneider et al. 2022).

GRB 220514A. GRB 220514A was detected by INTEGRAL (Bissaldi & Meegan 2022). The preliminary analysis showed a light curve with multiple peaks in the 50−300 keV range and a duration of around 66 s, making it a long GRB. The on ground-calculated position for GRB220514A is RA = 147.6670 deg, and Dec +13.1472 deg (Bissaldi & Meegan 2022). From $T0 - 2.8$ s to $T0+64.8$ s, the time-averaged spectrum was best fit using a band function with Epeak = 139 ± 21 keV and an alpha value of −1.25 ± 0.06. The 1 s peak photon flux starting at $T0 + 28.9$ s was found to be in the 10−1000 keV band range and is 16.6 ± 0.5 ph s^{-1} cm^{-2} (Bissaldi & Meegan 2022).

The first observations of the GRANDMA telescope network were obtained by TNT 1.57 h after the trigger time, which detected an afterglow in r'-band with mag 18.9 ± 0.1, compatible with other telescopes reported outside of GRANDMA (Gopalakrishnan et al. 2022; Murata et al. 2022; Zheng & Filippenko 2022; de Wet et al. 2022; Lipunov et al. 2022a). Further detections were made by MOSS and CAHA/CAFOS in Clear and i'-band respectively (Yan et al. 2022; see Table B.1). Other observations by AbAO-T70, KNC-HAO, FRAM, and KNC-T21 were performed, resulting in upper limits. Due to the lack of multiple detections in any band, no slope could be fit for this GRB using the GRANDMA data.

6. Results and summary of the campaign

This eight-week-long GRB follow-up campaign fulfilled its goal of training telescope teams for O4 as well as the improvement of the associated technical toolkits. One of the main goals was to stress the GRANDMA system in various ways in a similar way to what is expected from O4 and to simulate a real GW follow-up.

In this way, GRANDMA's infrastructure has evolved greatly since the first campaign (Aivazyan et al. 2022). The GRANDMA system has been able to ingest and distribute the *Swift* alerts to the network in real-time with a delay compatible with the detection of early afterglows. The online system harmonized the image collection and optimized the data reduction, which represents meticulous and time-consuming work for this kind of campaign, covering numerous observations with very different telescopes. This campaign further allowed testing and standardizing of the two data analysis pipelines (*STDpipe* and *MUphoten*) used by the collaboration.

As presented in Fig. 4, of the 11 triggers selected, nine fields have been observed, and three afterglows were detected. The network was not able to perform any observations for two of these 11 GRBs due to the localization of the source near the Sun and/or the Moon. For seven of them, the first observation occurred less than one hour after the BAT trigger. The fastest image achieved thanks to the TAROT robotic telescope system, was performed 196 s after the GRB 220427A BAT trigger. On the KNC side, the fastest observation was performed 14 min after the GRB 220319A BAT trigger, highlighting the effectiveness of the KNC system, the willingness of amateurs to

Table 2. Summary of SED fitting results.

$\log_{10}(M_\star)$ $[M_\odot]$	$\log_{10}$(SFR) $[M_\odot\,\mathrm{yr}^{-1}]$	A_V mag	Z	t_{mass} Myr	δ	f_{agn}	f_{burst}
$10.62^{+0.18}_{-0.32}$	$1.89^{+0.31}_{-\mathrm{nan}}$	1.32 ± 0.51	$0.004^{+0.007}_{-0.004}$	802 ± 668	-0.60 ± 0.30	$0.03^{+0.06}_{-0.03}$	$0.08^{+0.08}_{-0.08}$

Note. (1) stellar mass in log scale, (2) SFR in log scale, (3) amount of dust attenuation in the V band, (4) metallicity, (5) age weighted by stellar mass, (6) attenuation curve slope for stellar continuum, (7) AGN fraction, (8) mass fraction of the late burst population.

Table 3. Input parameters for SED fitting with CIGALE.

Parameter	Symbol	Range
Delayed star formation history + recent burst		
Age of the main stellar population	t_0	200, 500, 1000, 2000, 3000 Myr
E-folding time of the main stellar population model	τ	200, 500, 1000, 2000, 3000, 5000, 7000, 10 000 Myr
Mass fraction of the late burst population	f_{burst}	0.0, 0.1, 0.2
Age of the late burst	t_{b}	20.0, 50.0, 100.0, 200.0
E-folding time of the late starburst population	τ_{b}	50.0
Metallicity [(a)]	Z	0.0001, 0.008, 0.02
Dust attenuation		
Color excess for nebular emission[(b)]	$E(B-V)_{\mathrm{lines}}$	0.01, 0.25, 0.5, 0.75, 1.0, 1.25, 1.5, 1.75, 2.0, 2.25, 2.5, 2.75, 3.0
Ratio of color excess	$\frac{E(B-V)_{\mathrm{stars}}}{E(B-V)_{\mathrm{lines}}}$	0.44
Attenuation curve slope for stellar continuum	δ	−1, −0.7, −0.4, −0.1, 0.2, 0.5, 0.7
AGN[(c)]		
Slope of the power law	α	2.0
AGN fraction	f_{agn}	0.0, 0.1, 0.2
Redshift	z	0.8159

Notes. [(a)] $Z = 0.02$ is the solar metallicity. [(b)] $E(B-V)_{lines}$ is the color excess between the B and V bands applied on the nebular emission lines. [(c)] Parameters of the dale2014 model Boquien et al. (2019).

contribute, and their ability to provide scientifically valuable data. A total of 17 professional telescopes and 17 amateur astronomers' participated in the "Ready for 04 II campaign," providing good-quality images from which upper limits were computed (see Table B.2).

The time sampling of the observation of GRB 220427A allowed us to study the light curve evolution and fit the decay slope of the afterglow. The long-term follow-up allowed us to identify and study the properties of the host galaxy, which exhibits typical properties for a long GRB host galaxy. The efficiency of the network to observe GRB afterglow is illustrated in Fig. 5. It presents a selection of one observation per telescope (gathered in Table B.2) that was performed during the campaign, and compares its delay and limiting magnitude to an archived sample of an observed afterglow light curve. Figure 5 highlights the performances of the observation performed during the campaign. All selected observations would have been able to detect a significant fraction of optically bright archived afterglows in the sample.

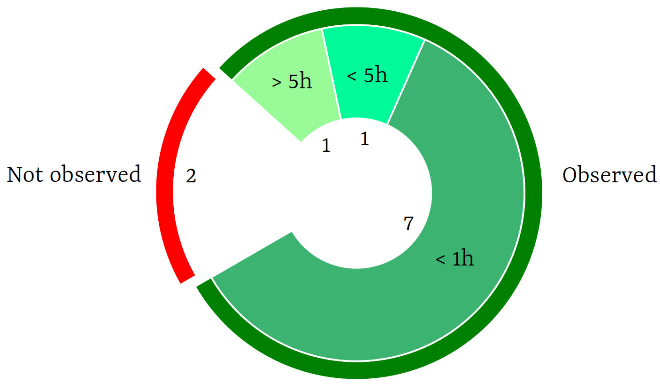

Fig. 4. Overall performance of the GRB follow-up conducted by GRANDMA telescopes.

7. Conclusions

In this paper, we describe GRANDMA's "Ready for O4 II," a campaign designed to train the network of telescopes as well as to test new tools for MM purposes. The campaign observed and searched for afterglows of *Swift* GRBs over an eight-week period. This campaign was essential to improve GRANDMA's network and system in preparation for the IGWN O4 run, as the follow-up of GW alerts is very challenging and the campaign will greatly enhance the chances of efficiently observing an electromagnetic counterpart during future follow-ups.

Here, we stressed the challenge of coordinating such a large network as GRANDMA both in terms of infrastructure and human resources. We presented developments performed at the interface and communication levels as well as in the image collection, processing, and data reduction to uniformize and authorize the follow-up results. This also provided important practice for the collaboration to become accustomed to using the reduction pipelines, STDPIPE and MUPHOTEN. From the follow-up

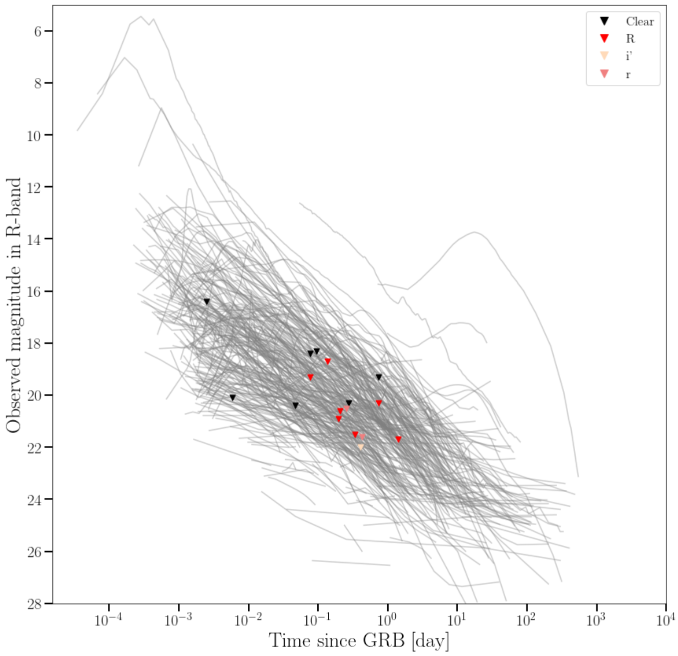

Fig. 5. Selected achieved upper limits of observation performed during the campaign (gathered in Table B.2) compared to a sample of observed afterglow light curve in *R* band.

of 11 selected *Swift*/INTEGRAL GRB alerts, we successfully observed nine GRBs, representing 82% of the total triggers, and detected three afterglows (GRB 220403B, GRB 220427A, GRB 220514A), over an eight-week-long campaign.

Our response to the GRB alerts was less than an hour for eight of them, meaning that our teams were able to start observations within less than one hour after the initial time of the trigger. For GRB 220427A, we presented the detection of the host galaxy and the study of its properties including its redshift. Altogether, the observations presented in this work show the capacity of the network to contribute meaningfully to multi-messenger follow-up and the importance of this work in tackling the challenges posed by the transient sky in the coming years.

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Appendix A: New telescopes to the GRANDMA collaboration

The GRANDMA consortium is a worldwide network telescopes and groups from 18 countries. These facilities make available large amounts of observing time that can be allocated for photometric and/or spectroscopic follow-up of transients located on three continents. New telescopes have joined the network since 2021, during the ready-for-O4 campaign as described in Aivazyan et al. (2022).

Below, we describe the new astronomical teams (arranged in alphabetic order) that have contributed to this work.

C2PU: C2PU-Omicron – C2PU is an astronomical research facility located at the Calern site of *Observatoire de la Côte d'Azur* (OCA), in south-eastern France. The coordinates are 43° 45′ 13.2″ N, 6° 55′ 22.7″ E, 1270 m (above MSL). The median value of the seeing at Calern is 1.09″ @ $\lambda = 500$ nm (GDIMM measurements over 3.5 years; see Aristidi et al. 2019). The sky background is less than ideal since the site is located within 30 km from large cities (Cannes, Antibes, Nice). Sky Quality Meter (SQM) background measurements yield values around Vmag=21 per squared arc-second. The C2PU facility is geared with two 1.04 meter telescopes on equatorial yoke mounts, nicknamed “Epsilon” and “Omicron”. Only Omicron has a wide field mode suitable to participate to the GRANDMA follow-up campaigns. This wide-field mode directly uses the focus of the parabolic primary mirror, through a three-lens Wynne coma corrector. The resulting aperture ratio is $F/3.2$. With a QHY600 camera, the FoV is $37.6' \times 25.2'$ and the plate scale is 0.47″/pix in 2×2 binning mode, and 0.24″/pix in 1×1 binning mode. SDSS filters g', r', and i' are available for this configuration. The Omicron telescope is in the wide field mode for approximately 40% of time, running GAIA photometric alerts follow-up observations or LSB (low surface-brightness) imaging experiments. GRANDMA alerts can be considered as ToO and can be inserted within these observation programs. Data are analyzed by a custom pipeline using GAIA-DR3 catalog for astrometric calibration and SDSS or Pan-STARRS catalogs for photometric calibrations.

GMG – The 2.4-meter telescope is located in Gao-Mei-Gu (GMG) village, Lijiang, Yunnan Province, China. The camera called YFOSC has a set of UBVRI (Johnson) filter system and a set of ugriz (sloan) filter system, and one can perform the photometric observation. A spectrograph with mid or low spectral resolution is also part of the camera, such that we can perform spectral observations. The telescope can execute target-of-opportunity (ToO) observations. When a trigger is received, a duty member can immediately respond to the trigger where checking target coordinates and telescope conditions is quickly performed. Then, the ToO observation can begin. After the ToO observation, the duty member can access the data catalog and perform preliminary data reduction. GRB observation has been carried out by the telescope since 2010 (as an example, see Mao et al. 2012). The telescope members have joined large international collaborations for GRB observations, GW electromagnetic counterpart and neutrino counterpart searching, and other transient observations.

OPD – The National Laboratory of Astrophysics (LNA) is a research unit of the Brazilian Ministry of Science, Technology and Innovations (MCTI) that manages the telescopes of the Pico dos Dias Observatory (OPD). Located in Brazópolis-MG, OPD has provided two telescopes for the GRANDMA campaign collaboration: a) The Perkin-Elmer 1.6m Telescope (code OPD-1.60m), with Richey-Chrétien optical design and can be used for photometry, polarimetry and spectroscopy equipped with $UBVR_CI_C$ filters; b) The Boller & Chivens 0.6 m Telescope (code OPD-60) used for photometry and polarimetry, equipped with $UBVR_CI_C$ and J, H filters.

KAO – The Kottamia Astronomical Observatory (KAO) is operated by the National Institute of Astronomy and Geophysics (NRAIG) in Egypt. It is located at 29.9341° N, 31.8277° E, 476 meters (amsl) and is used for scientific observations (Azzam et al. 2010). KAO telescope has a 1.88-meter primary mirror, equipped with 2kx2k CCD camera covering 8.3 x 8.3 arcmin and with two sets of filters, the SDSS- u'g'r'i'z' and Johnson Cousins-UBVRI (Azzam et al. 2020). The KAO team is from NRIAG and accesses the telescope via time proposals. For ToO observations, our team is allowed to request the telescope duty on-site observer to observe a GRB counterpart that has a well-defined *Swift* position once the trigger is received. Time is allocated for the detected GRB counterpart until it fades. Data reduction and photometry are performed by IRAF and/or Astropy packages using the comparison stars obtained from USNO-B1.0, SDSS, and Pan-STARRS catalogs.

MOSS, OWL and HAO – The Oukaimeden observatory (Benkhaldoun et al. 2005) is located 75 km from the city of Marrakesh. The site, located at an altitude of 2750 m, is part of the High Atlas mountain range. It houses several telescopes and other observational instruments (Benkhaldoun 2018). Among these telescopes, three took part in the observation campaigns of the GRANDMA project:

- MOSS (Moroccan Oukaimeden Sky Survey), is operated within the framework of cooperation between France, Switzerland, and Morocco. It consists of a Newton-type telescope (0.5m $F/3$, FOV 1d 23min x 55 min, 3 sigma limit mag 20.8, max 21.5).
- Optical Wide-field patroL Network (OWL), is operated within the framework of a cooperation between the Korean Astronomy and Space Institute (KASI), and Morocco. The telescope aperture size of the mirror is 0.5m with Ritchey-Chretien configuration, and its field of view is 1.1 deg x 1.1 deg on the CCD sensor. The optical tube assembly was manufactured by Officina Stellare. The alt-az type telescope mount was developed for the OWL-Net exclusively. Its maximum slewing speed is 20 deg/sec, and its acceleration performance is 20 deg/sec. The pointing accuracy is $5arcsec$, and the tracking accuracy is $2arcsec/10minutes$. Although on-tracking is also available, it is just for experimental use. The system is also equipped with a filter wheel that holds Johnson B, V, R, and I filters.
- HAO (High Atlas Observatory) is operated within the framework of cooperation with an association of Moroccan astrophotographers. The telescope used for GRANDMA observations is of the Ritchy Chretien type (CDK 0.318 m $F/8$, FOV 26 sec x 18 sec, 3 sigma limit mag 20.4 in R filter).

We incorporate GRANDMA program targets into the operations of the Oukaimeden Observatory based on instrument and observer availability, ensuring no conflicts with previously scheduled programs. This decision is reached in collaboration with our partner teams to maintain program coordination.

SOAR – SOAR is located at 2,700 m, in Cerro Pachón, Chile. It has both optical and near-infrared instruments with a FoV covering a few arcminutes. Observations are seeing-limited (typically seeing about 0.″8). The observations in May were performed using the TripleSpec instrument, a spectrometer that covers the entire 0.9-2.5 micron region simultaneously. TripleSpec also has a 2′×2′Slit View detector operating at the J band, which can also provide scientific data. For GRANDMA, the team also collected broad-band K filter images taken with the Spartan NIR Camera.

UBAI-AZT-22 – The AZT-22 telescope of Maidanak Observatory can be used for conducting observations in GRANDMA under the responsibility of the UBAI team. AZT-22 is a 1.5-meter Ritchey-Chrétien telescope and was installed in the late 1980s. The commissioning of the telescope was carried out during 1990-1994 (Sergeev et al. (2014)). The primary mirror, in combination with interchangeable secondary convex hyperbolic mirrors, gives two systems with different image scales with an aperture ratio of 1:7.7 (short focus) and with an aperture ratio of 1:17 (long focus). The main working optical system of AZT-22 is a "short focus" with a length of 11550 mm. The CCD camera SNUCAM (Seoul National University CAMera) was provided by Seoul National University and installed on AZT-22 in August 2006. It is a camera system with an active array of 4096 by 4096 with a physical pixel size of 15 microns (0.268 arcsec). SNUCAM CCD uses UBVRI Bessell filter set (Im et al. 2010). The FOV of the telescope with SNUCAM CCD is 18.1'x18.1'. The camera has been cryogenically cooled with a CryoTiger closed-cycle refrigeration system. The temperature of the camera was set to -108°C as recommended by the spectral instruments.

Appendix B: Observations from the GRANDMA program

Specific time allocation for this campaign – During the GRB campaign, special agreements were made with partners to allow possibilities for observation. First, the observation time of AbAO telescopes is divided between three groups of AbAO observers. In the case of ToO observations (GW sources, Lacertids, GRBs, comets, asteroids, etc.), as a rule, we give the telescope to the appropriate group. Since part of the Georgian GRANDMA team has been observing GRBs since 2012 in collaboration with A.S. Pozanenko Group (Space Research Institute RAS), a special agreement was made to obtain the data for this campaign.

The allocation time for the TRT network for the GRB campain was activated using the Target of opportunity time for our submission proposal which is called every three months.

In FRAM collaboration, there was a long-lasting GRB observations program outside GRANDMA that is activated automatically upon receiving a trigger over the GCN network and governs the observations of prompt and early afterglow phases of GRBs for up to 2 hours after the trigger. No events have been observed under this program during Spring 2022 campaign due to unfavorable weather conditions at the sites, or sky positions of the triggers. However, later time observations of GRB220514A have been triggered manually.

Since being installed, GRB follow-up has been the primary program of VIRT (Neff et al. 2004). As such, this program is carried out independently of GRANDMA (Gokuldass et al. 2021). Over the course of the GRANDMA GRB campaign, though, EO informed GRANDMA of VIRT responses to GRB triggers, and infrastructure was added to monitor the GRANDMA-based alerts systems.

We obtained some time allocation for observing with WIRCAM mounted on CFHT in 2022A under the name of GRANDMA for 3h time. This time was granted to observe short gamma-ray bursts that may be associated with kilonova and compact binary coalescences.

The data acquired for the afterglow detections under these observations and part of the GRANDMA campaign are reported here.

Table B.1. Summary of the afterglow observations detected by GRANDMA.

Source	Obs date	Time	δt (h)	Exposure	Filter	Magnitude	Telescope/ Observer
GRB220403B	2022-04-03	20:50:23	0.13	5 x 20 s	Clear	18.61 ± 0.06	BJP/ALi-50
GRB220403B	2022-04-03	20:52:16	0.17	5 x 20 s	Clear	18.73 ± 0.07	BJP/ALi-50
GRB220403B	2022-04-03	20:54:10	0.2	5 x 20 s	Clear	18.67 ± 0.06	BJP/ALi-50
GRB220403B	2022-04-03	20:56:03	0.23	5 x 20 s	Clear	18.87 ± 0.08	BJP/ALi-50
GRB220403B	2022-04-03	21:03:36	0.35	20 x 20 s	g'	18.98 ± 0.08	BJP/ALi-50
GRB220403B	2022-04-03	21:11:29	0.48	20 x 20 s	r'	19.40 ± 0.10	BJP/ALi-50
GRB220403B	2022-04-03	21:16:52	0.57	5 x 20 s	Clear	18.84 ± 0.08	BJP/ALi-50
GRB220403B	2022-04-03	21:18:44	0.6	5 x 20 s	Clear	19.11 ± 0.10	BJP/ALi-50
GRB220403B	2022-04-03	21:20:37	0.63	5 x 20 s	Clear	18.86 ± 0.08	BJP/ALi-50
GRB220403B	2022-04-03	21:22:31	0.67	5 x 20 s	Clear	19.09 ± 0.09	BJP/ALi-50
GRB220403B	2022-04-03	21:27:38	0.75	20 x 20 s	g'	18.95 ± 0.08	BJP/ALi-50
GRB220403B	2022-04-03	21:35:29	0.88	20 x 20 s	r'	19.94 ± 0.15	BJP/ALi-50
GRB220403B	2022-04-03	21:43:42	1.02	20 x 20 s	Clear	19.52 ± 0.09	BJP/ALi-50
GRB220403B	2022-04-03	21:51:40	1.15	20 x 20 s	g'	19.56 ± 0.15	BJP/ALi-50
GRB220403B	2022-04-03	21:59:33	1.28	20 x 20 s	r'	> 19.6	BJP/ALi-50
GRB220403B	2022-04-03	22:07:47	1.42	20 x 20 s	Clear	19.68 ± 0.10	BJP/ALi-50
GRB220403B	2022-04-03	22:11:35	1.48	20 x 20 s	r'	20.11 ± 0.12	BJP/ALi-50
GRB220403B	2022-04-03	22:15:44	1.55	20 x 20 s	g'	> 19.6	BJP/ALi-50
GRB220403B	2022-04-03	22:23:38	1.68	20 x 20 s	r'	> 19.8	BJP/ALi-50
GRB220403B	2022-04-03	22:31:51	1.81	20 x 20 s	Clear	19.91 ± 0.11	BJP/ALi-50
GRB220403B	2022-04-04	13:44:06	17.67	15 x 300 s	Clear	> 21	SNOVA
GRB220403B	2022-04-04	20:40:18	23.97	300 s	R	22.22 ± 0.12	UBAI/AZT-22
GRB220403B	2022-04-04	21:25:43	24.72	24 x 32 s	B	> 21.0	KNC-T-CAT
GRB220403B	2022-04-04	21:25:43	24.72	24 x 32 s	G	> 21.1	KNC-T-CAT
GRB220403B	2022-04-04	21:25:43	24.72	24 x 32 s	R	> 20.9	KNC-T-CAT
GRB 220427A	2022-04-27	21:04:04	0.05833	30 s	Clear	16.32 ± 0.22	TAROT/TRE
GRB 220427A	2022-04-27	21:04:43	0.06916	30 s	Clear	15.74 ± 0.18	TAROT/TRE
GRB 220427A	2022-04-27	21:05:21	0.07972	30 s	Clear	16.04 ± 0.18	TAROT/TRE
GRB 220427A	2022-04-27	21:05:59	0.09028	30 s	Clear	16.33 ± 0.19	TAROT/TRE
GRB 220427A	2022-04-27	21:06:37	0.10083	30 s	Clear	16.51 ± 0.16	TAROT/TRE
GRB 220427A	2022-04-27	21:07:36	0.11722	30 s	Clear	16.77 ± 0.11	TAROT/TRE
GRB 220427A	2022-04-27	21:09:15	0.14472	30 s	Clear	17.26 ± 0.35	TAROT/TRE
GRB 220427A	2022-04-27	21:17:26	0.28111	30 s	Clear	18.0 ± 0.3	TAROT/TRE
GRB 220427A	2022-04-27	22:08:04	1.1250	15 × 120 s	Clear	20.09 ± 0.12	Les Makes/T60
GRB 220427A	2022-04-27	22:38:32	1.6327	15 × 120 s	Clear	20.44 ± 0.14	Les Makes/T60
GRB 220427A	2022-04-27	23:41:31	2.6825	15 × 120 s	Clear	21.69 ± 0.22	Les Makes/T60
GRB 220427A	2022-04-27	00:52:03	3.8581	15 × 120 s	Clear	21.64 ± 0.21	Les Makes/T60
GRB220514A	2022-05-14	13:58:35	1.57	3 x 300 s	r'	18.9 ± 0.1	Xinglong-TNT
GRB220514A	2022-05-14	20:04:11	7.66	9 x 60 s	R	> 17.3	Abastumani/T70
GRB220514A	2022-05-14	20:21:43	7.95	45 x 60 s	Clear	19.9 ± 0.25	MOSS
GRB220514A	2022-05-14	20:38:27	8.23	15 x 120 s	R	>19.7	KNC-HAO
GRB220514A	2022-05-14	20:40:25	8.50	15 x 120 s	Clear	> 19	FRAM-CTA-N
GRB220514A	2022-05-14	21:59:16	9.58	10 x 150 s	i'	20.3 ± 0.1	2.2m CAHA/CAFOS
GRB220514A	2022-05-15	03:27:54	15.06	17 x 180 s	Rc	> 19.6	KNC-iT21

Note: δt is the delay between the beginning of the observation and the public detection discovery. In this table, only detection magnitudes of each observational epoch are reported. Magnitudes are given in the AB system (calibrated using PS1 or USNOB1) and are not correct for Galactic extinction with calibration.

Table B.2. Selection of one observation per telescope.

Telescope	Source	δt(h)	Limiting magnitude	Filter
BJP/ALi-50	GRB220403B	0.14	20.1	Clear
SNOVA	GRB220430A	17.74	19.3	Clear
NOWT	GRB220325A	4.72	20.9	*R*
KAO	GRB220325A	8.11	21.5	*R*
C2PU-Omicron	GRB220325A	10.16	21.6	r'
UBAI/AZT-22	GRB220412A	33.9	21.7	*R*
TRT-SRO	GRB220408A	1.82	19.3	*R*
Xinglong-TNT	GRB220408A	4.95	20.6	*R*
MOSS	GRB220430A	6.59	20.3	Clear
GMG-2.4	GRB220412A	6.06	20.5	r'
VIRT	GRB220412A	17.59	20.3	*R*
Les Makes/T60	GRB220427A	1.13	20.4	Clear
TAROT/TRE	GRB220427A	0.06	16.4	Clear
Abatsumani/T70	GRB220430A	3.22	18.7	*R*
OWL	GRB220514A	1.82	18.4	Clear
FRAM-CTA-N	GRB220514A	2.28	18.3	Clear
2.2mCAHA	GRB220514A	9.61	22.0	i'

Note: The images were provided during the campaign and allowed us to provide an upper limit. Here, we present 17 telescopes that provide good-quality images, resulting in upper limits.