AWARE: Alert Watcher and Astronomical Rapid Exploration

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Аннотация The previous LIGO/Virgo/Kagra (LVK) O3 run has demonstrated the importance of rapid follow-up observations of binary-neutron star (BNS) and neutron star – black hole mergers (NSBH) electromagnetic counterparts such as short gamma-ray bursts (GRBs) and kilonovae (KNe). However, the localization of LVK events typically spans a few hundred square degrees on the celestial sphere. It is essential to observe the localization contour as much as possible in order to find the fast-decaying optical sources. The issue is that one needs telescope network and automatic scheduler to observe the localization area. In this paper, we discuss two main follow-up tactics: target observations for narrow-field and mosaic scanning for wide-field telescopes. We describe the automatic schedule software AWARE that provides both LVK alert receiving and observation scheduler. The processed alert messages are almost immediately sent to the subscribers via Telegram bot. The asynchronous implementation of AWARE allows scheduler thread in the concurrent mode to create observation plots and plans as a final product. The generated products are adapted for usage in observational systems, for instance, KDS, FORTE or CHAOS. We are attempting to exploit the AWARE with IKI GRB Follow-up Network (GRB-IKI-FuN) in the LVK O4 run.

Keywords: software: development · software: public release · methods: observational · neutron star mergers · gamma-ray bursts.

Introduction

The observation and following study of the electromagnetic counterparts to gravitational-wave events registered by the LIGO [20], Virgo [6] and KAGRA [19] as the LVK collaboration [1,2] is a crucial objective in the modern multi-channel astronomy era. A gravitational signal is emitted from coalescing binary systems (CBS) such as binary neutron star mergers, neutron star – black hole mergers, and binary neutron star (BBH) mergers. The presence of an NS in a CBS gives a rise to electromagnetic transients: a short GRB and a KN. Up to the moment, there is a single LIGO/Virgo event that known to be accompanied with

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electromagnetic counterparts – GW170817 [5,3,4] associated with a short GRB 170817A [15,26,23] and later flared up kilonova AT2017gfo [12]. Altough, there is a short GRB 190425A, which is tentatively connected with a gravitational-wave event S190425. Continuous multi-channel observation will allow to shed more light on processes in forming the KNe from CBSs [22,14,28]. The major problem that astronomers are challenging now is the sky localization uncertainty of the GW events. The entire sky box area estimated only by the LVK detectors is up to a thousand squared degrees. However, the refined error box may be reduced with space gamma- and X-ray instruments to a few dozens squared degrees, if the electromagnetic counterpart has already found. Still, observations of such localization regions remains difficult, but it is a significant goal for the astronomers.

The attempts to create a generic observation planner were made, for example, in [10,18,16,21]. The SALT scheduling system [10] is a queue-scheduled system and requires the proposal to start observations of the specified targets. It creates the minimal observation blocks that must be scheduled. [18] describes the `PIPT` tool for uploading the proposals. Authors [18] shows different features of `PIPT`: exposure calculator based on the simulated spectra, visibility and slew toolkits. The scheduler used in the [17], accounts for the Moon separation and phase, seeing, zenith distance, and sky transparency at the site location. Also, [25] indicates that the scheduling algorithm is designed for operation in the telescope network. [16] proposes the `OPS` for optimizing the observation plan of the targets and determining the best observation and exposure times. [21] are positioning the `astroplan`[3] as a logical branch of the `astropy` package family, specifically, for planning the optical observations. The `astroplan` API provides classes and methods for setting the observation location, plotting the airmass of targets as seen by the observer. It has features important for planning the observations: setting the constraints (e.g. on Sun altitude, and the Moon separation), grouping targets in blocks and perform ranging by airmass (lowest targets have greater score). Also `astroplan` supports the calculation of the time of the transition between targets (accounts for filter changes, telescope slews and CCD read-out time). In contrast, [24] designed the scheduler `gwemopt`[4] for observing the LVK sky error boxes with the network of optical telescopes. [24] demonstrate multiple algorithms for planning the observations with `gwemopt`. The main idea is to re-grid the sky localization region into tiles of a size of the telescope FOV and scan the tiles in the probability maximization order [24]. Like the SALT planner, `gwemopt` also creates observation blocks, based on the visibility of targets and exposure. Inside blocks, those targets at high altitudes have a higher priority, than targets at lower altitude. However, the lower altitude, the faster a target will disappear. Hence, a low target *may be* to not observed with such ordering within the block. A tile ordering as computed by `gwemopt` accounts for slewing time of a telescope, what is significant, but the order as deduced from [24] is probably not optimal in terms of slew transitions between sky fields, reaching several degrees.

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[3] `https://github.com/astropy/astroplan`

[4] `https://github.com/skyportal/gwemopt`

While, the article [24] does not provide information on target observations of galaxies inside LVK sky boxes, it seems that the latest versions of `gwemopt` support it. Later [11] proposed extended algorithms to `gwemopt` providing the overlapping algorithm to already existing ones. This extension aimed at solving the problem, where some of unique sky tiles assigned to several telescopes could be not observed due to various factors, e.g. weather.

`AWARE`[5] is a lightweight Python double-threaded application for receiving and re-transmitting alerts on LVK events as well as high energy astrophysical transient sources (GRBs). Besides that, AWARE provides optimal scheduling for the observations of these astronomical phenomena with a network of telescopes. Alert messages are distributed by the Gamma-ray Coordinate Network (GCN)[6] Confluent Kafka[7] Cluster operated at NASA. Once alert messages were received by the AWARE Confluent Kafka Consumer, they almost immediately sent to the Telegram-bot[8] subscribers in human-readable form. Later on, AWARE creates the telescope-specific observational plan, depending on the event type.

In this paper, we discuss different methods of observations best suitable for both narrow-field and wide-field telescopes in Section 1. We provide an overview of AWARE's architecture and implementation (Section 2), data system and operation (Section 3), and algorithms used in observational planning (Section **??**). In the last section we summarize our results and make conclusions, and generate ideas on future enhancement of AWARE.

1 Optical observations

1.1 Observation tactics

Localization area of astrophysical events spans orders of magnitudes: from a few squared arcseconds for gamma-ray bursts (in optical or soft X-ray bands) up to several hundred squared degrees for gravitational wave events and gamma-ray bursts detected in hard X-rays or in gamma-rays; and depends on the detector sensitivity in the corresponding band. In the first case, when localization region does not exceed a few squared degrees, it is observed, as a rule, even with a regular telescope with a narrow field of view in a series of observations. However, in order to cover the gravitational-wave sky map error box, a network of optical telescopes is involved. In this scenario the observational planning should account for each telescope target visibility at its location, as well as distribution of targets or sky fields between the telescopes for better efficiency. Depending on an FOV of telescopes being used, we can define two main observation tactics: target observations of galaxies (probable hosts of optical transients) inside the error box, and scanning the error box by tiles of a size of an FOV. The third tactic of observations can be defined as a combination of the previous two.

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[5] `https://github.com/mickolaua/aware-repo`

[6] `https://gcn.nasa.gov`

[7] `https://confluent.io`

[8] `https://telegram.org`

Target observations Since the BNS and NSBH events are typically happened in dwarf elliptic galaxies, it is possible to perform target observation of theses galaxies to find optical transients. Fortunately, there is a special catalog GLADE+[9] [13], containing $N \sim 23$ million galaxies. The mean sky density of the GLADE+ galaxies is can be calculated as $\rho = N/A_{sky} \approx 561$ deg^{-2}, where $A_{sky} \approx 41309$ deg^2 is the total sky area. Although, the sky density per square degree is large, it can be reduced to a few galaxies per FOV on average, when taking into account a typical FOV of a telescope 0.25×0.25 deg^2, constraint on the gravitational event distance, and catalog completeness, target observations of GLADE+ galaxies could be performed with ordinary telescopes. Moreover, the first detect optical transient related to the BNS merger occurred on the outskirts of the dwarf elliptic galaxy. Let us estimate a maximal performance of target observations, assuming the sky error box area $A \approx 300$ deg^2, FOV $= 0.0625$ deg^2, galaxy density $\rho = 1$ deg^{-2}, and single exposure time 120 s. Thus, the sky error box would be observed 10 hours with only one telescope. Using network of five telescopes could reduce the observation time to 2 hours if there is no common targets distributed between the telescopes.

Mosaic scanning Another convenient way to observe LVK events in optical band is to perform mosaic scanning of sky tiles of a size of the telescope FOV. Let us assume an average wide-field telescope has an $FOV \approx 5$ deg^2, then a localization region with area $A \approx 300$ deg^2 would be covered in only 60 exposures, 120 s each, i.e. a whole region in two hours (actually more, due to hardware limitations). As can be seen, a single wide-field telescopes has a performance compared with 5 narrow-field instruments. However, a typical narrow-field telescope reaches deeper limiting magnitudes due to large aperture, so can detect faint transients.

Combined observations In a more realistic scenario for a large collaboration or network could be the presence of both types of instruments being available, narrow-field and wide-field telescopes. This approach assumes starting from mosaic observations of high-probable area of a sky error box first, and after it, carry out target observations of GLADE+ galaxies closer to periphery of the sky error box contour. Such order is preferable because a typical wide-field telescope is able to cover more area during the night, than a narrow field instrument. In turn, on behalf of GRB-IKI-FuN collaboration we among other groups have an access to small aperture (less than 1 meter) wide-field and large aperture narrow-field telescopes. We find this tactics more applicable in O4 run of LVK, rather than just target observations in previous run.

The Fig.1 illustrates these methods of observations in a schematic way.

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[9] `https://glade.elte.hu`

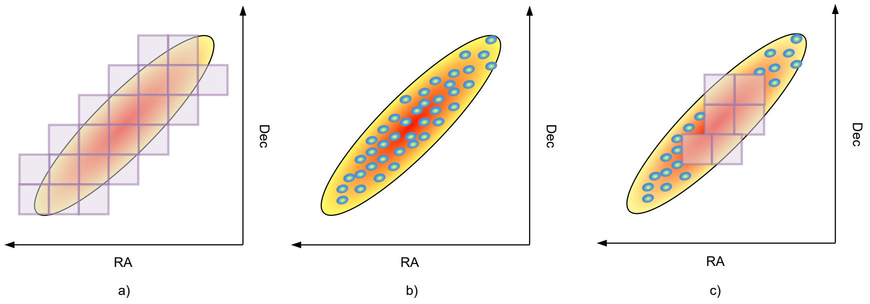

Рис. 1. The schematic big picture of observation tactics: a) mosaic scanning, b) target observations, and c) combined observations. The vertical axis is R.A. and horizontal one is Dec (both in arbitrary units). The highlighted quasi-elliptical contour represents a localization region: the redder the color, the higher the probability to find an LVK event there. The purple squares in the a) and c) cases indicate sky tiles to be observed with a wide-field telescope. The small blue ellipses in the b) and c) represents GLADE+ galaxies.

2 Application design

As mentioned earlier, AWARE is a double-threaded asynchronous Python application: the alert parser and scheduler is ran in the first thread, while the second thread is a Telegram bot that in concurrent mode send alert messages in human-readable form, observing plots and plans to subscribers. For faster development process and easier deployment we decided to make monolithic application, i.e. solution, which is self-contained and independent from other programs. The diagram of the processing flow of the application is presented in the Fig.2.

The application configuration is stored in form of YAML file. Specially for AWARE we designed `CfgOption` class, which allows to set a proper option name, default value and type. A `CfgOption` object finds the full caller module name (a module, where an option is defined) and transforms this name in order to retrieve a value from a nested dictionary, what is raw YAML configuration really is. By default, the `aware.yaml` will be loaded if placed in the working folder, otherwise a person should set the environmental variable `AWARE_CONFIG_FILE` to the path to the actual configuration file. However, the configuration file is not necessary to utilize the AWARE.

2.1 Alert processing

The `AWARE` connects to the GCN Kafka Cluster for alert messages via Confluent client for Python (packages `gcn_kafka`[10] and `confluent_kafka`[11]). Note, it is required to obtain GCN credentials to be able to receive messages. For security

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[10] https://github.com/nasa-gcn/gcn-kafka-python

[11] https://github.com/confluentinc/confluent-kafka-python

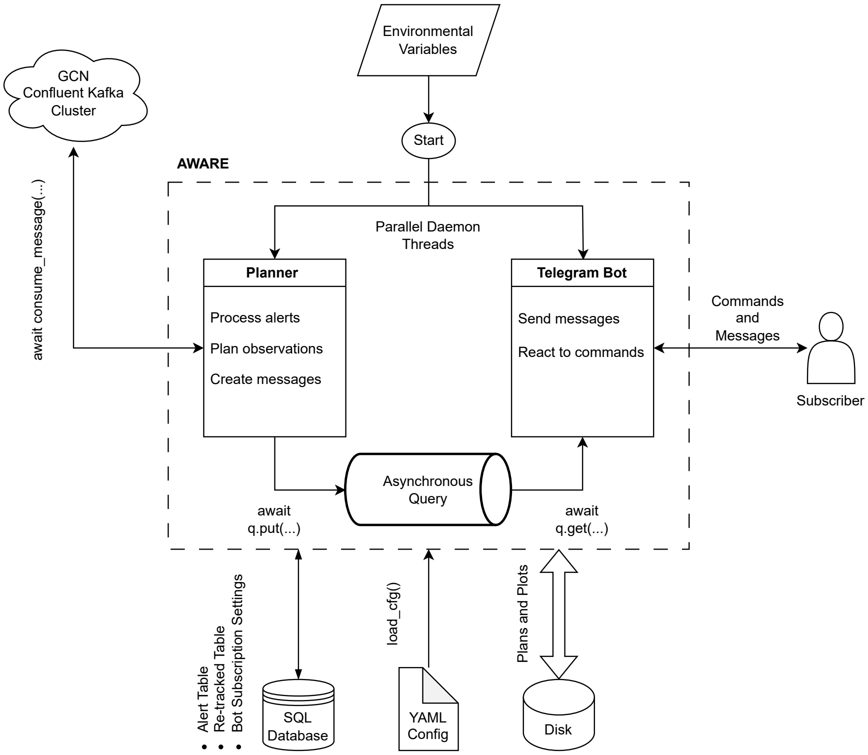

Рис. 2. The processing flow of the monolithic application "AWARE". On startup planner and bot threads are started in daemon mode. The planner thread communicates with GCN via TCP and with bot thread via asynchronous query. This thread dumps data to the database and on disk. The bot thread reads data from the query and sends human-readable messages, observational plots and plans to subscribers.

reasons credentials are passed via environment variables `GCN_KAFKA_CLIENT_ID` and `GCN_KAFKA_CLIENT_SECRET`. Altough, the GCN continues support of socket connection for receiving alert messages, this practice considered outdated and not secure. This is the reason, why `pyGCN`[12] client was not chosen as a candidate solution for consuming alerts. The `AWARE` provides a special object `ConsumerLoop` for consuming alert messages asynchronously, which is important for not blocking the execution threads. In comparison, `Hop Client`[13] as a part of SCiMMA [9,8], provides only synchronous interface. A raw stream of alert messages should be parsed and processed to extract necessary information events. The GCN provides three types of the data format: text messages, binary messages and VOEvents. Actually, there is a fourth type that seems is only supported by LVK at the

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[12] `https://github.com/nasa-gcn/pygcn`

[13] `https://github.com/scimma/hop-client`

moment is JSON structures, which are validated against specified schemes. Since, at the moment of writing, VOEvents are most supported among astronomers we decided to support only it. Migration to more convenient JSON in the future could be possible with only rewriting some parts of the parsing functions.

Parsing Thus, AWARE is receiving alert messages in form of VOEvents [29,27] – basically, XML files with a special header, and parse them. When alert message has received, the application tries to find a suitable `AlertParser` from the registry, that matches a special attribute `id` of the parser with alert topic, for example, `gcn.classic.voevent.LVC_PRELIMINARY`. The Python package `lxml`[14] (v4.9.2) used in AWARE provides convenient interface and great performance for XML tree parsing. Due to VOEvent headers are different from ones of common XML files, we temporarily replace them before parsing, but saving original headers. This is implemented with a code from `voevent-parse`[15] package, which provides the convenient interface for representation of VOEvent trees as objects with attributes, using `lxml.objectify` underneath. After parsing, the parameters of the event: a name, a trigger date and time, skymap, coordinates of the localization barycenter and it uncertainties, etc are retrieved and assigned to a `TargetInfo` object. A certain set of parameters of the event assigned to the `TargetInfo` is dumped to the database (more detailes in Section 3. LVK skymaps are altready represented as HEALPix multi-ordered maps (MOC) [21], but for some other instruments, for instance, Fermi GBM or Swift XRT conic MOCs are created based on the localization center coordinates and error radius with `mocpy`[16] [7].

Event crossmatching While receiving new alert messages, it is important to establish relationship with events already stored in the AWARE database. It allows to reveal if the event contained in a new message is actually coincident with an already stored event under different name. We do not want to create and send observational data for such events, when they provide a larger localization error box. To solve this problem, the event from a new message is cross-matched against the SQL database. The crossmatching is performed with a nearest-neighbor algorithm in both time and sky coordinates. A pair of events are matched in the coordinate space using their MOCs: if intersection of MOCs is not empty, then the events are matched. The events with a trigger date difference bellow several minutes are considered matching in time. Mathematically speaking, the crossmatching conditions are expressed by the inequalities (1):

$$matching = \begin{cases} M_1 \cap M_2 \neq \{0\} \\ |T_1 - T_2| < \mathit{\Delta} T \end{cases} \tag{1}$$

where, M_1, M_2 are MOCs of the events, T_1, T_2 are alert trigger dates, and $\mathit{\Delta} T$ is the trigger date matching uncertainty. Typically, $\mathit{\Delta} T$ should be at least

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[14] `https://lxml.de`

[15] `https://github.com/timstaley/voevent-parse`

[16] `https://github.com/cds-astro/mocpy/`

a minute, because different instruments could trigger to a different phase of the event due to various energy range sensitivity of their detectors, especially if the event spectrum is soften/harden over time. We estimate performance of the cross-matching as a few seconds for a database containing about 500 rows.

2.2 Planning observations

`AWARE` provides a special class `aware.site.Site` that defines a telescope inherited from `astroplan.observer.Observer`, but has more attributes, for instance, default exposure time and number of frames, field of view, observation plan file format, default limiting exposure, aperture size, short and full name. This information is used to create observation plans. We implemented a special factory function `aware.planning.program.create_observation_program` to generate observational plans in given formats. At the moment of writing there are two formats available: a simple `.txt` ASCII table, and `.list` for automatic schedulers `KDS`, `FORTE` or `CHAOS`. Mentioned file formats can be described by expressions 2 (first row corresponds to `.txt`, and second for `.list` formats, respectively):

$$\begin{array}{lcl} \texttt{hh:mm:ss.s} \pm \texttt{dd:mm:ss.s T.TxN F} & & \\ \texttt{Jhhmmss.ss} \pm \texttt{ddmmss.ss} & = & \texttt{O hhmmss.ss} \pm \texttt{ddmmss.ss m.mm NxT.T[*F]} \end{array} \tag{2}$$

where, `hh:mm:ss.s` is the RA in hours, `dd:mm:ss.s` is the Dec in degrees, `T.T` is the single exposure time (s), `N` is the number of exposures, `F` is the filter name. Additionally, there are fields unique for `.list` format: `Jhhmmss.ss±ddmmss.ss` is the target name, `O` is the target type (fixed or moving), `m.mm` is the estimate magnitude of a target, and squared brackets indicate an optional field (filter can be omitted).

The planning process started as soon as processed alert message has sent to Telegram bot subscribers. Let us consider the planning process, which is slightly different for GRBs and LVK events below.

Planning of GRBs Alert messages on GRBs sent by such observatories as Fermi, Swift, INTEGRAL, etc. provide approximately circular sky error region in the sky according to the Gaussian 2D probability distribution to find event inside the region. For these events, the planner creates the visibility plot for the center of the localization region, if the target could be observable by a telescope at the nearest observational window[17] within 24 hours from current date, calculated using `astroplan` methods. In addition, in the current implementation of `AWARE`

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[17] The nearest observational window is defined by two times, when the Sun altitude is below a certain value, specified for each telescope. Commonly, these correspond to the Sun rise, and the Sun set at the telescope location. However, for some of locations, for example at the Mondy observatory, the Sun could never cross-horizon for a few month in year. This is the reason of setting Sun altitude constraints for an instrument separately.

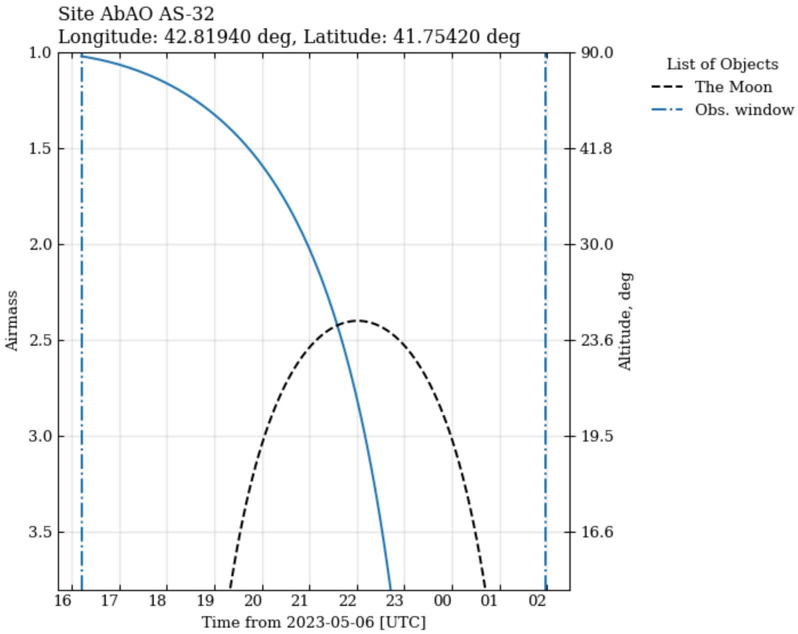

Рис. 3. Visibility plot for Swift BAT Trigger 1167288 (GRB 230506C) calculated for AbAO AS-32 telescope. The blue solid line is airmass of the target, black dash line is the Moon, and blue dash-dot lines denote the observational window borders. Left and right vertical axis are airmass and corresponding altitude (deg), respectively. Horizontal axis is UTC time.

we assume that telescope must observe GRB localization in a single scan, i.e. localization area must be less than 90% of the FOV[18]. Finally, the constraint is put on airmass $X = \sec Z$, where Z is zenith angle, $X \geq 3.5$ or $Alt = 90° - Z \geq 16.6°$ for a target/sky field to be considered observable. Thus, the observation plan file will contain only one target. The example of planning products: the visibility plot, and the target list (in two formats) for GRB 230506C generated for Abastumani Observatory (AbAO) presented in the Fig.3, and List.1.1, respectively.

Planning of LVK events At the first step, the 90% (by default) cumulative probability contours are calculated using Python package `ligo.skymap`, which has a lot of functionality to work with HEALpix skymap files. Secondly, for each telescope in the list of specified telescopes planner applies different observational tactics depending on the FOV, as was stated in Section . If a telescope has the $FOV \leq 45''$ target observation plan is computed, otherwise, for a wide-field telescope the plan for mosaic scanning is created.

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[18] 10% is accounted for possible edge artifacts or abberations.

Листинг 1.1. The examples of planning files for GRB 230506C for different formats.

```
# Output of .txt file
ra dec exp filter
10:13:14.9 +48:12:13 120.0x3 R

# Output of .list file
J101314.90+481213.00 = F 101314.90 +481213.00 0.00 3x120.0*R
```

Target planning The reduced GLADE+ catalog is loaded, which contains only RA, Dec, B_{mag}, and d_L fields. The catalog is cross-matched in coordinate space against 90% cumulative probability volume, which depth is defined by distance constraint $d_{L,GLADE+} \in [\hat{d_L} - \sigma_{d_L}, \hat{d_L} + 2\sigma_{d_L}]$, where $d_{L,GLADE+}$ are photometric distances of GLADE+ galaxies, $\hat{d_L}$ is a mean photometric distance (estimation) to the event and σ_{d_L} – is the standard deviation error of d_L. These borders were found to be more relevant than $\pm 1\sigma$ by considering the GLADE+ completeness.

In the second case, the HEALPix localization map is re-projected in such way that each pixel has the size of the telescope FOV. The scanning order is defined by the probability gradient: from most probable to least probable pixel, but without significant field re-directions. Actually, the mosaic planning is performed first and all the fields on the skymap, that should be observed are painted with zeros to prevent including GLADE+ galaxies inside them to the target observation plan. Wherein, for each telescope based on its location and observation time, the planner selects only those GLADE+ galaxies (target observations) or field centers (mosaic scanning) that can be observed by the telescope. For this purpose, we use `astroplan` package to calculate nearest observational window (i.e. night). The example, demonstrating the concept of the observational window on visibility plot is depicted in the Fig.3.

We implemented a special class for planning observation of LIGO/Virgo skymaps `aware.planning.planner.SkymapPlanner`

We implemented suitable classes located in module `aware.planning.distributor` for distribution of targets (or sky fields) between telescopes.

Also, if an observational window is not located within 24 hr from current date, a target/sky field is meant to be unobserved.

Finally, the AWARE planner creates human-readable messages using `TargetInfo` objects and send it via Telegram bot. There are actually two types of message: `TelegramAlertMessage` and `TelegramDataPackage`. First one contains only text information about event name, trigger date, origin, and first mention. Also, `TelegramAlertMessage` includes other experiment-based parameters of the event. Such messages are put to the query firstly, so the Telegram subscribers are notified on the event as soon as possible. `TelegramDataPackage` messages, stores the telescope parameters, generated visibility and skymap plots, and observational plans in telescope-specific format. They are put to the message query only if the observational plots and plans could be created. The example localization coverage plot is shown in the Fig.4.

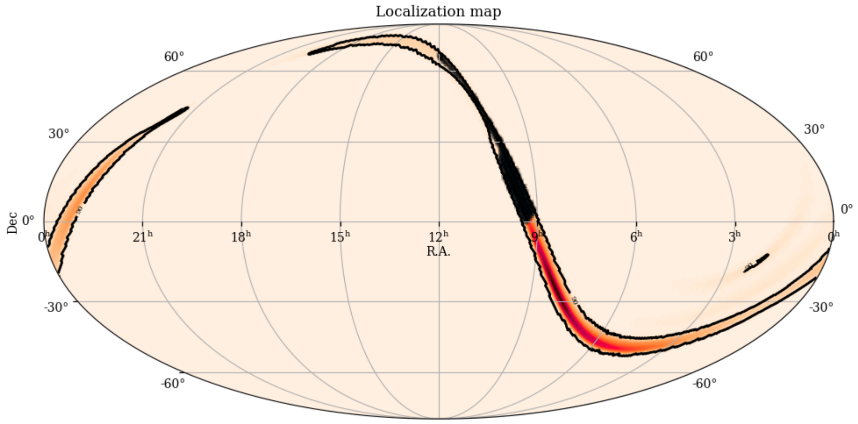

Рис. 4. The sky error box coverage map for LVK S230528A, drawn for AbAO AS-32 telescope. The black solid line traces 90% probability contours on the sphere. The contours filled with yellow and red color: the more reddish, the higher probabilty. The black highlighted area is the telescope coverage.

Note, the coverage in the Fig.4 is total area that the telescope can observe, it does not mean this sky region will be observed.

Target sorting algorithm The algorithm for sorting the targets in optimal observational order implemented in `AWARE` represents a slightly modified nearest-neighbor method. The first target to observe is chosen the one with a highest airmass (or lowest altitude) on average during the night. It is possible using the `astroplan.Observer.altaz` object for construction of the airmass-time $X_i(T_{obs})$ curves, where $i = 1 \dots n$ – is a target index, and n – is the number of targets. Secondly, for each subsequent target, a closest neighbor is selected in the circle of a radius of several arcminutes (defined in config-file). The radius is selected in such a way to decrease sharp transitions from one target to another, because a regular mounting can not rotate the telescope fast and stabilize it at the same time. Hereafter, the algorithms repeats step #2 while list of sorted targets is being updated.

2.3 User interaction

A user (or subscriber) receiving alert messages and observational data via interacting with bot. We have chosen `aiogram`[19] (v2.25.1) package as an asynchronous

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[19] `https://aiogram.dev`

Telegram client, which has a wide spectrum of features to create bots: message handlers, state machine, different text rendering, keyboards, middleware support and etc. Since `aiogram` state machine a bit complicated to create dialogues using keyboards, the package `aiogram_dialog` [20] (v2.0.0b18) was found to be more convenient for that role. To subscribe to the bot, a user must send it the command `/sub`. The dialogue is implemented as a state machine under the hood, which corresponding transition diagram is shown in the Fig.5.

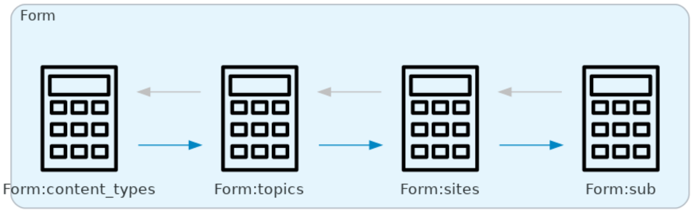

Рис. 5. The Telegram subscription dialogue transition diagram. The state are denoted with windows with buttons. Bright blue arrows shows the forward direction of the dialogue (from start to finish. Faint gray arrows represent backwards direction (when user wants to return to the previous form).

The dialogue is started from a state `content_types`, where a user has to choose which kind of content should be received: alert messages, observational data or both. The next state is where the user selects the types (topics in Kafka terminology) of alert messages, that will be sent to the person. At further state, it is possible to choose the telescope names for which one wants to receive observational data or just skip this form for not obtaining the observational planning. Finally, the user should approve the decision to subscribe or cancel the dialogue. Note, at each step excluding the first one, the person can switch back to the previous form, e.g., when some of alert types must be checked or unchecked.

Despite, the `/sub` command, the Telegram bot has a set of auxiliary commands that a user may find helpful: `/status` – shows the current status of the bot (processing, idle), `/findchart` – displays the $15' \times 15'$ finding chart image of the DSS2 field centered on the target (see Fig.6), `/telescopes` – list of available telescopes, `/mysettings` – current subscription plan, and `/unsub` – unsubscribe from the bot messages (e.g., when you want to change subscription plan).

Currently, the bot is running only in long-polling mode. Communication between the planner and the bot is established via asynchronous query from the Python standard library. Note, the environmental variable `AWARE_TG_API_TOKEN` that stores the Telegram bot token granted from `BotFather`[21] must be set before running the `AWARE`. Also, the application can be executed with disabled Telegram

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[20] `https://github.com/aiogram/aiogram`

[21] `https://t.me/botfather`

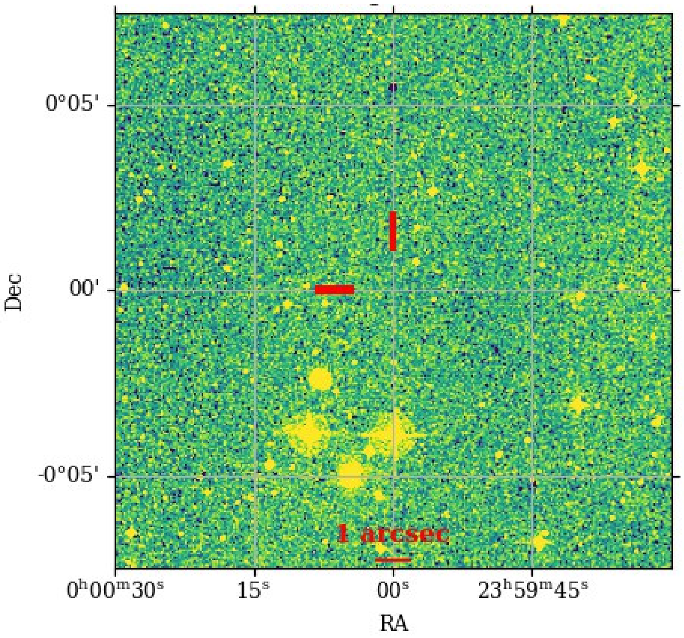

Рис. 6. The DSS2 finding chart plot of the artificial target at 00h 00m 00s 00d 00m 00s. The red crosshair is pointed at the target coordinates.

bot in the case someone wants only planning features or they want to connect the planner with other service or GUI.

3 Data Storage

The `AWARE` generates not so much data, only observational plots and plans are created and stored inside the working direction, which path is specified in the configuration file. Typically, for a single event there is a up to several megabytes of disk volume is consumed. Thus, it does not require special disk partitioning, nor large cloud storage to store data. Since that, we deployed the `AWARE` instance on a regular server PC in our department.

On the startup, the `AWARE` creates two sub-folders inside the current working directory: products and cache. The products sub-folder is a root folder for further tree that stores the observational data split by telescope. All downloaded skymap files are located inside the cache folder. The complete folder tree is shown in the Fig.7.

The application also creates a SQL database on startup (if it is not exist yet), which is necessary for its operation. All incoming alert messages, excluding re-tracked ones, are stored in the database. The main reasons for that are a possibility to cross-match alert events for localization updates and to store

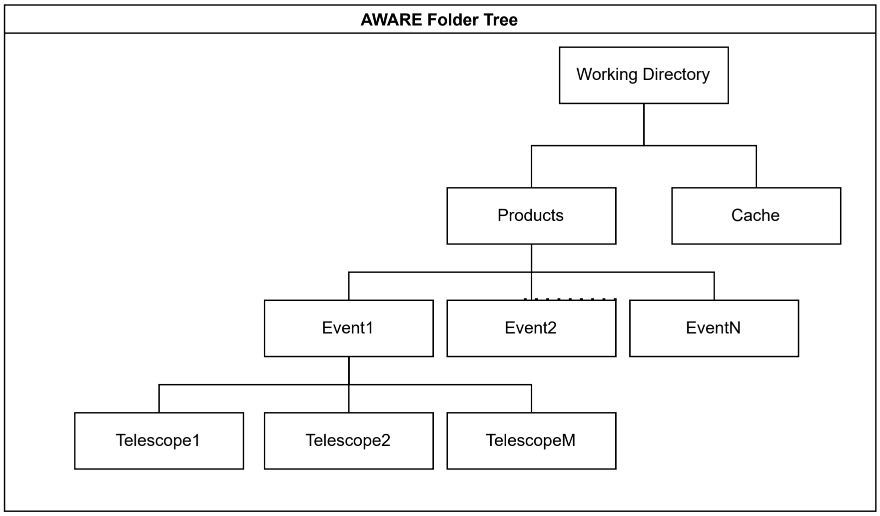

Рис. 7. The working directory tree. The event data is placed in separate sub-folders in the `products` directory. Also, the event sub-folder holds a separate folder for observational data per each telescope used. The downloaded HEALPix localization files are stored in the `cache` folder.

subscription settings of the users. The SQL database contains the given tables: `alert` for storing alerts and cross-matching the events for localization updates and user notification, `reject_alert` to store re-tracked events, and `settings` for storing subscription setting of the users. The entity relationship diagram of these three tables are illustrated in the Fig.8.

We rely on `sqlalchemy` package for querying the database in the objected-oriented style. Upon this, `sqlalchemy` provides API for most used database engines such as PostgresSQL, MySQL or SQLite. Since SQLite does not support login session, `sqlcipher3` package is applied to get access to the previously AES-512 encrypted database. The keyphrase is stored in the environment variable `AWARE_SQL_KEYPHRASE`. The reason behind it is to achieve secure storage of sensible data, in our case identifiers of the Telegram bot subscribers, and their subscriptions. We encourage users to not use SQLite in the production, and use e.g. PostgresSQL or MySQL, which are more advanced and reliable.

4 Conclusions

4.1 Results

Thus, in this paper we overviewed the own lightweight open-source project `AWARE` for receiving alerts on LVK events and GRBs. Compared with other ones, `AWARE` provides an automatic three-in-one solution for receiving alert messages on LVK events and GRBs, scheduling optical observations of their sky error

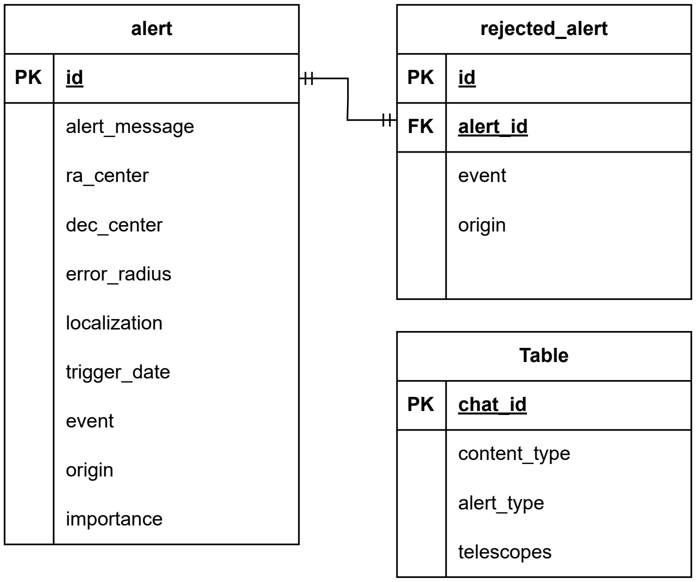

Рис. 8. Entity relationship diagram of the AWARE SQL database. Tables `alert` and `rejected_alert` are linked with one-to-one relationship in order to obtain rejected alert by parent id. The `settings` table remains isolated.

boxes, and notify users via Telegram in near real-time. The scheduler performs distribution of GLADE+ galaxies and sky tiles for further observations with network of telescopes without intersection. The asynchronous implementation helps to perform these task together. A deploy process of `AWARE` is simple, we installed it on the laboratory server, configured and set it in the production mode. During work, `AWARE` reacted to several Swift and Fermi GBM gamma-ray bursts, and the LVK events since O4 start, including: S230518h, S230527bv, S230528a, S230528bt, S230529p, and S230529ay. The scheduler reacted only to S230518h and S230528a, since other ones were not classified as CBS having an NS by LVK pipelines. We encourage the developers who interested in the observing and studying the optical transients, contribute to the project.

4.2 Future plans

We are planning to continue the development and further support the `AWARE` project in future. There are many features we want to add/change, for instance:

- custom telescope plugins provided as JSON-files from outside
- migrate from SQLite to Postgres SQL for the database
- improve stability of the application, especially, when power cuts
- add parsers for alert message from all instruments we interested

- account for the Moon separation in the observation scheduling

We found it convenient to use observation constraints and blocks provided by `astroplan` package API in the next versions of `AWARE`. Visibility plots will contain the Moon separation drawn each two hours in the future releases. Probably, the GCN will force everyone to migrate from VOEvents to AVRO messages in near future, and we should adapt to this change. Currently, we are not considering split the `AWARE` into three parts maintained separately: an alert parser, a scheduler and a bot, however, one can suppose it.

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Data Availability

The `AWARE` is an open source[22] project licensed under GPLv2 license. We are glad to ask researchers to cite this article and insert the URL of the code repository in the footnote if your work has made use of `AWARE`.

5 Замечания рецензентов v1.0

5.1 Ответы рецензенту №1

Замечание №1 "Мне кажется, что в такой форме статья не подходит для конференции. Она явно написана для какой-то другой (стиль цитирования, например)"

Ответ: действительно, изначально был использован стиль другого журнала (MNRAS). Стиль рукописи изменен в соотвествии с требованиями конференции.

Замечание №2 "Аннотации так не пишут - тут одни аббревиатуры"

Ответ: Данные аббревиатуры расшифрованы в аннотации, а их использование широко распространенно в данной области астрономии.

Замечание №3 "Статья есть, по сути, описание одного продукта. Непонятно, кто его сделал - на github нет информации об авторах. Научная статья - это сравнение продуктов, например. А описание одного продукта - это производственная документация"

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[22] Source code is available here: `https://github.com/mickolaua/aware-repo`

Ответ:Продукт является уникальным и необходимым в данной задаче (планирование наблюдений распределенной сетью телескопов). Тем более, что продукт её решает и это решение (алгоритмы, архитектура) представляет собой научный результат. Наблюдение оптических транзиентов осуществляется по планам наблюдений полученным нашим приложением. Ведущий разработчик приложения - Н.С. Панков, первый автор данной статьи. Действительно, на гитхабе не указана подробная информация об авторстве, но платформа не требует этого.

Замечание №4 "Описание IT-составляющей продукта чисто перечислительное. Что используется. Описание же астрономической составляющей типа: 'Actually, the mosaic planning is performed first and all the fields on the skymap, that should be observed are painted with zeros to prevent including GLADE+ galaxies inside them to the target observation plan.' оценить не представляется возможным"

Ответ: действительно, не все детали реализации представляется возможным оценить, на этот случай будут приготовлены примеры работы имплементированных алгоритмов.

Замечание №5 "Английский язык должен быть проверен. E.g. ' in this paper we overviewed a an open-source software project AWARE'"

Ответ: Постарались исправить все видимые грамматические и смысловые ошибки.

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