Russian optical telescopes: facilities for follow-up observations of sources of gamma-ray bursts and supernovae, identification of neutrino and gravitational-wave signals

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Abstract New challenges for the ground-based astronomy (mainly, for the Russian one) are discussed. All instrumental facilities – both current and prospective – of Special Astrophysical Observatory are briefly described. Some proposals on alert events observational strategy for Russian telescopes are presented.

Keywords: Ground-Based Astronomy, Alert Events, Gamma-Ray Bursts, Astronomical Instrumentation.

1. Introduction

The first years of the 21-st century in the modern astronomy were marked, among other things, by detection of astrophysical signals of a principally new type. They include neutrino events, fast radio bursts and, finally, gravitational-wave signals. The statement about the beginning of era of so-called Multimessenger Astronomy has become a commonplace already. The main challenge of the modern astronomy is to reliably detect these signals, to identify them as soon as possible in other, already “classical” ranges and to understand the physical nature of phenomena generating these signals. We give a brief description of available facilities of optical telescopes of Special Astrophysical Observatory of RAS and other Russian observatories, which are able to solve such tasks. The details of promising projects developed in SAO are presented. An important aspect of the problem is the fulfilling the earliest possible observations with equipment installed in the telescope focuses in the standby mode – spectrographs, cameras for direct imaging and high temporal resolution systems. The systems monitoring the celestial hemisphere in SAO are themselves capable to generate the alert signals for subsequent studying. The available experience of scientific integration obtained by us during recent decades in the process of studying optical afterglow of gamma-ray bursts permits us to hope for successful implementation of scientific tasks of this kind.

2. New challenges for the ground-based astronomy at the early XXI century

2.1. Gamma-ray bursts

Strictly speaking, the era of studying powerful bursts of emission in the gamma-ray range (Gamma Ray Burst – GRB) started almost 50 years ago, when, within the framework of the USA space program of monitoring nuclear explosion, in 1967 the data about first events of this kind were obtained. Three years later the astronomical community was informed about discovery of the burst GRB700822 registered by three Vela satellites simultaneously.

The next 25 years were dedicated to the intense study, the building of different model of burst origin, attempts to identify them in spite of big errors in coordinates. Only 1997 – the first year of operation of the BeppoSAX mission, which permitted to considerably enhance precision of burst location – was successful in the first optical identification (February 28), determination of distance to the gamma-ray burst (May 8) and, finally, discovery of a burst at a cosmological distance of $z=3.42$ (December 14).

This was the beginning of a new era in the research. Of course, the detailed picture of the gamma-ray burst phenomenon is not built yet, in spite of the subsequent 20 years. But it became indisputable that this phenomenon is accompanied by enormous energy release never met by researchers before. The launch of new missions – HETE-2, SWIFT, INTEGRAL – in combination with quasi-simultaneous ground-based research using robotic systems and the largest telescopes made it possible to get new data shedding light to nature of the phenomenon, to establish relation between the bursts and supernovae explosions and, finally, to determine that gamma-ray burst are the most distant objects in the Universe for today. A remarkable review of the gamma-ray burst problem is presented in [1].

2.2. Gravitational-Wave Signals

In the field of gravitational-wave astronomy we are now approximately in the situation similar to that with gamma-ray burst research before operation of BeppoSAX: the researchers have already learnt to register them, but their position precision is still far for that necessary for reliable identification.

The era of direct registration of gravitational waves has begun right in front of our eyes, when at 9:15 on 14 September 2015 two detectors of gravitational waves built in the framework of the LIGO collaboration in Hanford and Livingston (USA) have got signals with a time lag of 7 milliseconds between them, as was predicted theoretically. It was denominated as GW150914. The theoretical apparatus developed long ago has permitted to explain the observed picture as the merging of two black holes of 36 and 29 Solar masses, the arising black hole is to have mass equal to 62 masses of the Sun. Energy released in the process of merging during tenths of a second is equivalent to about 3 Solar masses. Distance to the system where this phenomenon occurred is estimated as 1.3 billion light years. Since this event was detected only by two installations, there is no question of precise localization of the system – the GW150914 error box is about one thousand square degrees. There are some theoretical problems also: first of all, it is difficult to explain how a pair system of massive black holes could origin and live till our days.

By now, several other responses of gravitational-wave detectors were registered, which are already interpreted as a more acceptable scenario, when neutron stars are merging, but not black holes. Apparently, the situation will become clearer with a better localization of source of gravitational waves, when several other similar detectors will come into operation. This will enable to get error boxes of several degrees and minutes, which will considerably accelerate their subsequent identification.

2.3. Neutrino Astronomy

As before, the neutrino astronomy counts the "caught" neutrinos by units, which also does not facilitate the further identification of their sources. It can be said that by now there is only one event (of course, beside generation of neutrinos in the interior of the Sun), which gave a noticeable signal. This is our nearest explosion of a supernova in the Large Magellanic Cloud galaxy at a distance of only 50 kpc from us, which is quite a small distance on an intergalactic scale.

The progress in construction of new neutrino telescopes is enormous, but, nevertheless, for the present the researchers can reliably get a significant neutrino signal only within a sphere of approximately identical size. Astrophysicists are inspired optimism that we will surely know when a supernova will explode in our Galaxy by getting neutrino signals from many underground, underwater and under-ice installations. We are separated from the most recent such explosion already by more than 400 years, so, it is time to fulfill the statistical law of supernovae burst rate.

The researchers are not only waiting for a supernova in our Galaxy, but also create more and more powerful installations with the hope to detect supernovae events in other galaxies also. The international neutrino observatories ANTARES, SuperKAMIOKANDE and especially ICECUBE keep enhancing their precision parameters achieving error boxes of several degrees. This allows us to hope for success in identification of such events due to joint efforts of the whole astronomical community. Baksan Neutrino Observatory can also give alert signals for optical identification, but, due to specific character of such investigations, this information is most often useful for observatories of the southern hemisphere, and we can only hope for targeting from, first of all, the ICECUBE installation operating at the southern pole of the Earth.

2.4. Fast Radio Bursts

The phenomenon of fast radio bursts (FRB), as well as sources of gravitational waves, is a discovery of the new century already. During several years (before 2013) the powerful millisecond pulses of radio emission (the flux of more than 1 Jy during less than 10 milliseconds) were considered to be of the terrestrial origin, but the experiment with the 64m radio telescope in Parks (Australia) has shown their not only extraterrestrial, but extragalactic nature. Due to the measured lag in the arrival of a pulse at different wavelengths, it is possible to estimate distance to a FRB source, which is hundreds and thousands megaparsecs (now the list includes more than 20 such bursts).

The fact that FRBs are still counted by unites is a consequence of small field of view of large radio telescopes. Allowing for their sizes, the expected number of fast radio bursts in the sky can be from 1000 to 10000 per day. Creation of new telescopes with large field of view equipped with multichannel radiometers will permit increasing their number many times, simultaneously enhancing their coordinate precision. So, in this field also, the united effort of astrophysicists-observers will be needed soon to identify such events quickly.

Speaking about a possible interpretation of such phenomenon, a good suggestion can be from the fact that the expected rate of fast radio bursts (about 0.001 per galaxy per year) coincides (or close with accuracy of one order) with the core-collapse supernovae explosion rate, which is about 0.01 per galaxy per year.

3. What Should Be Observed and with What Equipment?

As the multiyear experience of astrophysical research shows, the most complete information about phenomena under study is obtained from combination of data in the maximum wide spectral range. For all enumerated types of phenomena this means a required demand of optical identification.

So, the rate of expected events:

1. Gamma-ray bursts – 2-3 per week.
2. Gravitational events – several ones during recent 2 years.
3. Neutrino events – several ones per year.
4. Fast radio burst – less than 10 per year so far.

Apparently, we cannot hope for radical increase of the event number in the nearest years (maybe, except FRBs). The author still remembers enthusiasm among the researchers of gamma-ray bursts about multiple increasing of events after new missions HETE-2 and SWIFT were launched. Alas! The nature does not indulge us… So, the most probably, we will have to be satisfied with rare alerts, seeking to get maximum information about each event as soon as possible with available observational facilities in the so-called Target-of-Opportunity (ToO) mode.

What can the Russian ground-based astronomy answer to indicated challenges? At present, its armory includes mainly the long-time optical telescopes with nowadays-modest fields of view often with not too high-tech equipment.

Fig1. *General view of the complex MiniMegaTORTORA created jointly by a team of SAO RAS headed by G.M. Beskin, and specialists of OOO "Parallaks" (Kazan) with the financial support of Kazan (Privolzhsky) Federal University.*

So, at present, to study transient events in Russian observatories, the following research complexes in the shared-use mode are proposed (items 1-3 refer to SAO RAS):

1. The 6m telescope BTA equipped with complexes for spectroscopy and photometry with the field of view of 6 angular minutes, the method of fast photopolarimetry in a small field, but with a possibility of analysis at milliseconds times and better;

2. the 1m telescope Zeiss-1000 equipped with a CCD photometer with a set of wide-band filters with the field of view of 7′ and a low-resolution spectrograph with low penetrating power for such tasks;
3. a multi-channel wide-angle complex of subsecond temporal resolution MiniMegaTORTORA having the field of view of 900 sq.degrees and the limit stellar magnitude about 11.5 during exposure of 0.1 sec. The general view of the complex is presented in Fig1.
4. the 2m Russian-Ukrainian telescope Zeiss-2000 of the Terskol Branch of Institute of Astronomy of RAS equipped with a CCD photometer with the field of view of 11′ and a moderate-resolution spectrograph;
5. the 2.6m Shajn telescope of the Crimean Astrophysical Observatory equipped with CCD photometers with the fields of view of 9′ and 20′.

Observational time of these telescopes is allocated by the Russian Telescope Time Allocation Committee, and the details description of instruments is given in Circulars of the Committee [2]. Beside these telescopes in Russia there are a number of optical telescopes of the class of 1-2 m, which are under the authority of scientific and educational organizations.

Among promising projects of the nearest future useful for solution of the indicated tasks, we can mark out a complex of small telescopes of 0.5 m diameter with field of view of several degrees (the perspective view of the site area is shown in Fig2, now the construction of the first telescope with the observing hut-outhouse is being carried out), a photopolarimeter of the 1m telescope and a fast photopolarimeter of “hot reserve” of the Nasmith-1 focus of the 6m telescope. These projects are being conducted in SAO RAS and are close to their implementation.

Fig2. *The design view of a complex of small 0.5m telescopes after completion of construction. The authors of the project are a team of SAO RAS researchers headed by S.N. Fabrika and G.G. Valyavin, OOO “Parallaks” (Kazan). Financial support is from a grant of Russian Scientific foundation №14-50-00043.*

4. The project of a survey wide-field telescope

Among new infrastructure projects, which are urgent for successful operation in the framework of alert programs, one should mark out a project of a large-aperture telescope of the 4m class equipped with gigapixel mosaic detectors.

Since there is no proper project we give here a brief description of initial technical requirements of such a telescope.

The main tasks for the instrument are supposed to be the study of transient sources: gamma-ray bursts, supernovae explosions, neutrino events, fast radio bursts, the fulfilling of deep surveys with a set of medium-band filters for studying samples of active galactic nuclei, massive identification of sources, which will be detected by the cosmic mission SRG, the mapping of the Galaxy plane in emission lines of ionized gas, the surveys of the sky in polarized light, etc.

The main characteristics of the telescope:

- altazimuth mounting;
- the optical scheme – quasi- Ritchey-Chrétiens;
- diameter of the main mirror – about 3.5 (4) m;
- the mirror material – sitall CO-115M (Zerodur);
- focuses – Cassegrain, 2(4) Nasmiths;
- the operational spectral range: 0.35 – 1.7 (2.5) microns;
- angular resolution – not worse than 0″.5;
- the operational field – 2º (it is desirable up to 3 º).

An important feature of the project is the system of adaptive optics, a system of adaptation of wave front in a small field. Among other things, the effective operation of the telescope supposes introduction of technology of high-performance reflecting coatings with the reflectance factor up to 97% in a wide range.

The supposed equipment: in the Cassegrain focus – a mosaic of 20k×20k el (optics) and 8k×8k (IR) for photometry in wide fields; in the Nasmith focus it is supposed to install an integral field spectrograph and a scanning Fabry-Perot interferometer; the creation of a multi-object spectrograph for 300-500 objects is also possible.

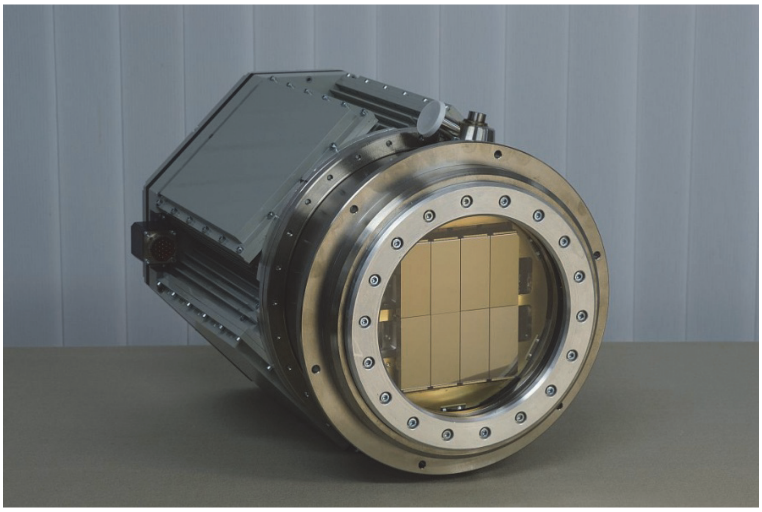

Fig3*. A prototype of the large-format mosaic detector created in SAO RAS by the Advanced Design Laboratory under the direction of Cand.Sc.(Engineering) S.V. Markelov.*

Among possible prototypes of such an instrument there is the 4.1-m telescope VISTA operating in the European Southern Observatory. The time of its creation is estimated as 2018-2023. The cost will about 3.5-4 billion roubles based on current prices.

Among technical facilities already available in SAO RAS one can mark out the available groundwork for creation of large-format mosaic detectors of optical emission. One of specimens of such systems is shown in Fig3.

5. Methodology for studying alert events

We consider the space missions Swift, Fermi, INTEGRAL, Lomonosov and others as a source of alert information. The alerts from the MiniMegaTORTORA system are quite possible. In addition to that we also aim at the search for optical components of source of neutrinos and gravitational waves (GW events) detected with neutrino observatories and with detectors of LIGO (Laser Interferometer Gravitational-wave Observatory) and Virgo.

The fulfilling of research is a part of the program carried out by an international observational collaboration including the observatories обсерваторий Calar Alto (Spain, 2.2 and 3.5 m for direct imaging and spectroscopy), La Palma (Spain, the telescopes of the 1-2m class for photometry, the 4.2m and 10.4m GTC for photometry and spectroscopy), Nainital (India, the 1.0m and 1.3m optical telescopes for direct imaging), Campo-Imperatore (MAO RAS, Italy), AZT-24 for photometry in the near IR.

Execution of work supposes 3 stages of the research involving different telescopes and instruments:

Stage 1: identification and improvement of coordinates with the 1m and 2m telescopes in the photometric mode, for very rough error boxes – identification with MiniMegaTORTORA, which results in prompt transfer of coordinate information to BTA and other large telescopes.

Stage 2: the study: photometry in the BVRcIc bands with the 1-2m telescopes up to R~22, BTA – the spectroscopy of objects brighter than R~22 in the range 350-950 nm for determination of red shift of a source and obtaining absorptions in the line of sight, resolution depends on the source brightness, the fast photometry and polarimetry with complexes of fast variability in the first minutes and hours after a burst, then – the photometry with the deep limit up to R~25.

A CRITICAL MOMENT: photopolarimetry for determination of the collapse geometry, the polarization value is expected to be of order of 10%.

Stage 3: Photometry and low-resolution spectroscopy with BTA and GTC of different phases of the source evolution – the appearance of the secondary maximum brightness, spectral peculiarities of supernovae.

Unfortunately, this strategy is good for identification of sources with good error boxes, which are gamma-ray bursts now. Her our advantage is a fast reaction to alerts of different types and our geographical position. In case of sources of othe types the coordinate precision is not sufficient yet; the telescopes with large fields and good limit are necessary.

6. Conclusion

1. For reliable identification of transients (from gamma-ray, radio, neutrino and gravitational sources) the coordinated optical observations are necessary.

2. In whole, equipment of SAO and other Russian observatories is ready to observations of transient sources of a new class.

3. The successful realization of the projects demands a wide international cooperation and implementation of plans for development of instrument basis, what we are going to do all together.

References

[1] Vedrenne G. and Atteia J.-L., Gamma-Ray Bursts The Brightest Explosions in the Universe, Praxis Publishing Ltd., Chichester, UK, 2009

[2] The web-resource www.sao.ru/hq/Komitet/circ.html