The complex of SAO RAS optical instruments as an instrument for studying transient sources in the Universe

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Abstract Technical facilities of Special Astrophysical Observatory of Russian Academy of Sciences (SAO RAS) and its application for studying transient sources are described. The astrophysical task related to transient sources is briefly described. Future prospects are outlined.

Keywords: Astronomical Optical Facilities, Transient Sources, Gamma-Ray Burst Afterglow

1. Introduction

The epoch of studying optical transients in Russia in 1997, when researchers of SAO RAS first succeeded in detecting a gamma-ray burst (GRB) afterglow and its identification with a host galaxy (the famous object GRB 970508).

2. Optical Facilities of SAO RAS

Optical telescopes of SAO RAS – both available and being designed ones – are a rather powerful instrument for the wide-range studying of transients sources appearing in the night sky. The observational complexes created for solution of astrophysical tasks with the basic SAO's instruments – the Big Azimuthal Telescope (BTA) with the 6-meter mirror and the 1-meter reflector Zeiss-1000 – can solve rather efficiently both the tasks of detection of such quick-changing sources and on-line determination of their most important characteristics.

From a set of scientific equipment of the SAO RAS's optical telescopes we turn our attention to the variants which are adequate to the assigned task of on-line study of transient sources. Hereinafter, from the whole variety of transient sources we will mean the variable sources of the so-called "distant space". This will allow us neglecting their motion, though at present the fulfilled reconstruction of the Zeiss-1000 telescope control system makes it possible to guide fast-moving objects of the near space.

2 variants of observations with the BTA optical telescope can be attributed to such equipment – the prime-focus optical reducers SCORPIO [1,2] and the complex for analyzing microsecond variability MANIA [3]. These complexes are installed in the telescope's prime focus in accordance with the BTA operation schedule and can be used at this time only.

The focal reducer SCORPIO are equipped with registration systems based on charge-coupled devices (CCDs), which makes them applicable in investigation of slow variations of transient characteristics. Such type of observations includes photometry in wide-, middle- and narrow-band filters, spectroscopy with long slit, photo- and spectropolatimetry. Technical parameters of the used systems restrict the temporal resolution of the investigations by tens of seconds. As is shown by statistics of exploitation of focal reducers with BTA, as a rule, their percentage is from 50 to 60% of calendar time (generally, practically all moonless and partly moon time).

On the other hand, the temporal resolution of the multimode panoramic photospectropolarimeter – the MANIA complex – is up to 10^{-6} sec, but it is used at BTA during 15-25 nights per year. This reduces considerably the probability of its application in the study of transient sources.

The instrument facilities of the BTA telescope can be added due to application of the attached implements of the 1-meter telescope Zeiss-1000 – the UBVRI photometer with a CCD system and a large-aperture spectrograph UAGS also equipped with a CCD camera. The temporal resolution of these systems is identical to that of above-mentioned BTA focal reducers – the tens of seconds. Of course, the threshold of magnitude in these observational methods is smaller, and the study of faint objects (especially, their spectroscopy) with a small telescope will be not-too-effective. On the other hand, the field of view of a photometer of the 1-meter telescope can be extended to 10 arc minutes due to usage of a large-format CCD camera; besides, the utilization of the instrument is not too strong, which makes it possible to use it in the search of transients in the case of low precision of their coordinates.

3. Studying of transient sources

The matched operation of the 6-m and 1-m telescopes permits expecting an effective solution of the problem of detection and studying transient sources. A rather good example of such coordinated operation of the SAO's telescopes can be the story of studying of one of the first gamma-ray bursts detected and investigated with our telescopes – GRB 970508. Figure 1 shows the source of optical afterglow of this event obtained first with the 1-meter telescope in the search mode, and then its image was obtained with BTA several days later (in the inset).

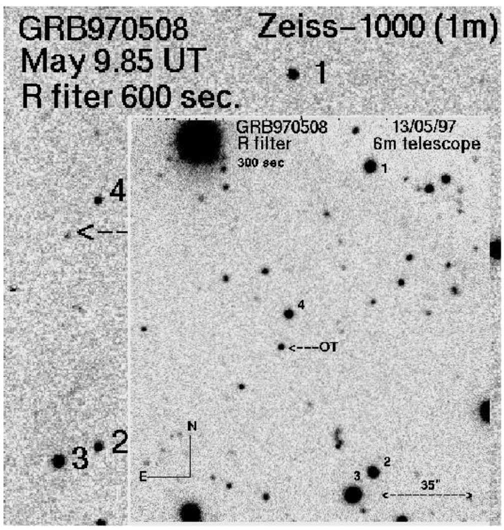

Fig. 1. *Images of optical afterglow of the gamma-ray burst GRB 970508 obtained with the 1-meter telescope Zeiss-1000 at the moment of discovery and with the BTA telescope 5 days later (in the inset). Both images were obtained in the R_c band.*

The next Figure 2 presents a result of joint photometry of this transient source fulfilled at both telescopes: the brightest phase was studied at the 1-me telescope, the fainter stages were accessible, naturally, only for BTA [4].

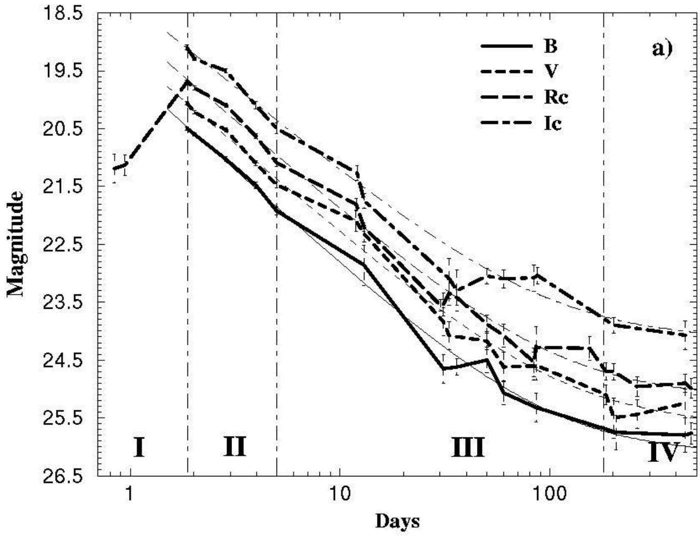

Fig.2. *The combined light curve of the source GRB 970508 in the B, V, Rc, Ic bands obtained from data of the 1-m telescope Zeiss-1000 and the BTa telescope [4].*

Later on, the work on identification and studying the nature of gamma-ray bursts has been fulfilled (up to the present time) in a wide international collaboration. The participants of the program, beside the SAO team, are the researchers from Spain (the 10.4-m GTC, the 4.2-m Calar Alto, etc.), France (the submm Observatory at Plateau de Bure), New Zealand, India (the 2.34-m VBT Kavalur, the 2.01-m HCT IAO, the 1.04-m ST Naini Tal).

Another example of the study of transient sources fulfilled with optical telescopes of SAO RAS is the joint program of a SAO RAS and ASC FIAN team on investigation of synchronous variability of a sample of blazars carried out at the 1-m SAO's optical telescope and the 22-m radio telescope of Crimean Astronomical Observatory. This program was started in 2002 and it includes a sample of almost 15 BL Lac type objects. In the course of the program some indications to a possible synchronism of variability of optical brightness and radio flux were detected. For example, in Figure 3 from [5] in data for a famous object AO0235+164 one can see both coinciding peaks of brightness and their total mismatch. Along with it, some indications to the presence of an intra-day variability in objects of this type were detected.

At present, the software was elaborated in SAO which provides the on-line translation of alerts about gamma-ray bursts and other transients discovered by the space missions Swift, Fermi, MAXI, INTEGRAL, etc., and with ground-based facilities. When there is an alert, an observer sees a dialog box in the monitor which, in case of the positive decision, permits to start immediate pointing to the object's coordinates. So, the reaction time of the complex is reduced to minimum.

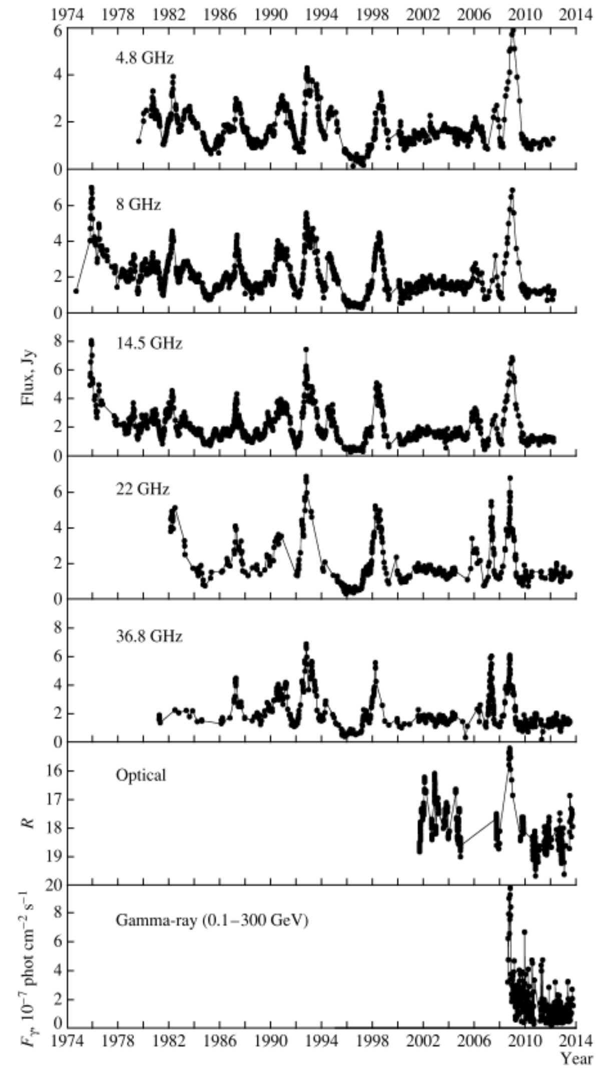

Fig. 3. *The results of the long-term monitoring of variability in radio, optical and gamma-ray ranges (the lowest diagrams) of the famous BL Lac type object AO0235+164 from data of paper [5].*

Beside external sources of data about transient events, SAO RAS has its own wide-field system for detection of optical events – Mini-Mega-TORTORA [6]. Its feature is the presence of a wide field of view (about 900 sq. degrees), the subsecond temporal resolution and a possibility of fast transition to the study of a detected transient by means of multi-color photometry and polarimetry. Mini-Mega-TORTORA is oriented to early detection of optical flares whose localization in unknown in advance, their on-line classification and transfer of coordinate information to other SAO RAS's telescopes.

4. Future prospects

In the nearest future SAO plans to manufacture and put into operation in the Northern Caucasus a modern wide-field telescope with a 4-meter class mirror designed to operation in optical and near infrared ranges within the field of view up to 2 degrees. Its optics should be made of astrositall with application of methods of adaptive optics and adaptation of the wave front. Such solutions will permit the new telescope to overcome BTA in investigation methods where the quality of image built by optics is crucial. The information capacity of the new instrument in which it is planned to introduce mosaic detectors of emission of the size up to 20K×20K elements will considerably overcome the BTA facilities too.

The plans include also the equipment of Nasmith focuses of this telescope with such high-technology complexes as a panoramic spectrograph with a minute field of view, a multi-object spectrograph for several hundreds of simultaneously-studies objects, and others.

The main tasks of the new instrument will be the study of transient sources along with deep spectral surveys of the sky, the search for distant supernovae. It is planned to create such an instrument in 2017-2025.

A much cheaper and more realistic project also promoted by our specialists is the creation of a row of small telescopes of diameter 0.5 m equipped with large-size registration systems based on CCDs. With their fields of view of order of 1 degree, such systems will allow us fulfilling a mass photometry of relatively bright objects of the 15-17 st. magnitude, spectral and polarization study and, if required, getting involved to the system of studying transients.

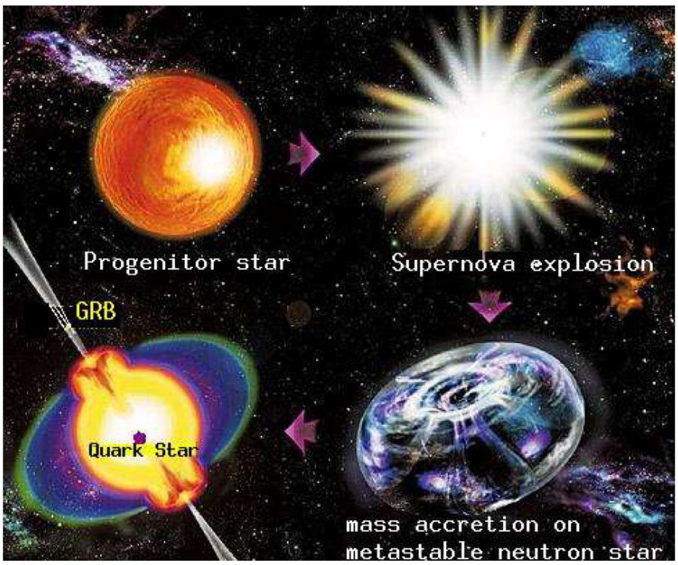

Fig. 4. *(from [7]) A schematic representation of the last stages of the evolution of a massive star (M > 8 Msun) leading to the delayed conversion of a pure hadronic star to a quark star (hybrid or strange star) and to the emission of a neutrino burst and possibly to a gamma-ray burst. Clockwise from the upper left corner of the figure: (i) nuclear burning stage of the progenitor star; (ii) supernova explosion and birth of a pure hadronic star ("neutron star"); (iii) mass accretion on the metastable hadronic star; (iv) conversion process of the hadronic star to a quark star (second "explosion") neutrino burst and gamma-ray burst.*

Now quark-gluon plasma is a new direction both in the high energy physics and in the study of compact objects of the type of neutron star and collapsars (candidates in BH of stellar mass). The phase transition in the quark-gluon state is related with the mechanism itself of core-collapse supernovae explosion (the energy of such a transition can be a source of cosmic gamma-ray bursts). Signals of transition of matter to pure quark-gluon plasma can be neutrinos that are observed with modern detectors, including our ones, e.g. Baksan Underground Scintillation Telescope (BUST). Now the equipment of the gravitational detectors LIGO/VIRGO is also customized for signals of such a transition.

Participation of astronomers in programs of the study of localization boxes of neutrino (and, possibly, gravitational) events is already being discussed in detail (e.g., see https://wikispaces.psu.edu/display/AMON). SAO RAS, with all its telescopes (+ other telescopes in the Northern Caucasus) can join this new international program of synchronous observations of astrophysical objects related with collapse of massive star nuclei (see Fig.4).

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