

Article

Studies of Hot Stars and Other Observational Programs Using the 1-Meter Optical Telescope Zeiss-1000 of SAO RAS

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Abstract: Here, we briefly describe the current state of the Zeiss-1000 telescope of the Special Astrophysical Observatory of Russian Academy of Sciences (SAO RAS). Principal attention is given to research programs from recent years. The observations made according to allocated requests both by researchers from the observatory and scientists from other institutions and organizations are planned within a half-year schedule. The instrumental facilities provide a wide range of methods for studying objects of interest. They include standard photometry, moderate- and high-resolution spectroscopy, and polarimetry, along with unique “guest” methods (e.g., emission line imaging). The research programs cover different fields of astrophysics. The topic of “hot stars” and other important developments have become possible due to the introduction of new research methods at the telescope. Blazars, gamma-ray burst optical transients, massive supernovae, cataclysmic variables, magnetic stars, white dwarfs, luminous blue variables, red dwarfs, and many others are among its targets.

Keywords: telescopes: optical; methods: observational; photometry; spectroscopy; polarimetry



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1. Introduction

Identical 1-m aperture optical Ritchey–Chrétien telescopes with the English mounting EM-2 (Zeiss-1000) have been produced by Carl Zeiss JENA (the German Democratic Republic) since 1968. For the Special Astrophysical Observatory of the USSR Academy of Sciences, the tenth of its eleven manufactured Zeiss-1000 telescopes was installed in close vicinity to the 6 m optical telescope BTA—Big Telescope Azimuthal.

The Zeiss-1000 at SAO RAS is a classical reflecting optical telescope with a primary mirror of a 1 m diameter and a focal ratio of $F/13$, which provides an unvignetted field nearly $45'$ wide. Thanks to the Ritchey–Chrétien–coudé optical scheme, Zeiss-1000 telescopes are characterized by the maximum possible versatility, providing different observational techniques to be implemented. The tasks for such telescopes span from wide-field multi-target direct imaging to photometry or spectroscopy of an individual object. For spectral observations, either a Cassegrain focus equipped with an attachable instrument of a small size or a coudé focus (with a stationary device, e.g., a high-resolution spectrograph) may be in operation. This possibility is one of the EM-2 mounting’s advantages. Another one is its suitability for installation in various geographical locations. For more details on Zeiss-1000 telescopes (the optical layout, technical characteristics, locations, etc.), see [1].

The observational capabilities of SAO RAS’s Zeiss-1000 telescope and the technical characteristics of the devices and equipment used in its observations have previously been discussed [1,2]. In this paper, principal attention is given to the most important scientific

results obtained during the last four years. We would like to show that even with a 1 m optical telescope that has been operating for more than 25 years, it is possible to obtain world-class scientific results today.

The Zeiss-1000 telescope of SAO RAS saw its first light in October 1989. Starting from 1993, it has been put into regular operation with a six-month observation schedule. To date, the telescope is equipped with a set of devices for the generally accepted methods to meet different researchers' needs. Time with the telescope is allocated by the Russian Telescope Time Allocation Committee (<https://www.sao.ru/hq/Komitet/index-en.html> (accessed on 1 May 2025)). Most observations are conducted in remote mode thanks to the implementation of an automated control system a little more than 10 years ago.

The observational programs run using both standard and guest methods. They include photometry of massive supernovae (SNe), gravitational lens candidates, contact binaries, luminous bright variable (LBV) candidates, and X-ray sources in the optical range. Long-term monitoring of selected blazars and supernova impostors, as well as identification of ultrabright X-ray sources in the optical range, is carried out. Spectroscopical methods are used in monitoring active galactic nuclei (AGN) and studies of bright SNe and binary systems. They are essential in magnetic surveys of main sequence stars, in compilations of Herbig spectral atlases of bright Ae/Be stars, and in the search for and study of the variability in the magnetic fields of peculiar stars.

In Section 2, we present an outline review of the instruments and methods used in observations with SAO RAS's Zeiss-1000 telescope. More details can be found in the dedicated paper by Komarov et al. [1]. To illustrate a wide coverage of areas of astrophysical research, the results of some studies are mentioned in Section 3.

2. The Instruments and Research Methods

One standard device is the UAGS—the Universal Astronomical Grating Spectrograph—of a medium resolution. Its low weight (less than 60 kg) allows it to be used with the Cassegrain focus. Due to the wide choice of diffraction gratings (covering spectral ranges of 3700–7500, 3600–8000, 3880–6300, and 5750–7050 Å with spectral resolutions of 7.5, 6.3, 1.5, and 2.1 Å, respectively), it helps with solving different astrophysical tasks. The targets of these studies range from rather faint extragalactic objects (up to $V = 16^m$) to sufficiently bright ($V = 6^m$ – 8^m) stars. The CCD EEV 42-40 (2048×2048 px, 13.5×13.5 µm) is used as a detector.

Another standard instrument is the spectrograph for the coudé focus—the CEGS (Coudé Echelle/Grating Spectrometer [3]). It is used for high-resolution astrospectroscopy ($R = 30,000$) in a wide spectral range of 3600–9000 Å. The spectrometer is equipped with a circular polarization analyzer and replaceable diffraction echelle gratings. There are several observation modes, of high, medium, moderate, and low resolutions. The limiting magnitude in good atmospheric conditions is about 7^m for one hour of acquisition time. Studies of (long-periodic) magnetic stars is the main program.

The third standard device is the CCD photometer installed in the Cassegrain focus. It provides for direct imaging of astronomical objects in the $UBVR_cI_c$ bands of the Johnson–Cousins photometric system, as well as in white light (3600–10,000 Å). The limiting magnitudes in moderate seeing conditions (1.5–2 arcsec) are in the range of 19^m – 22^m depending on the band and the total exposure time (<https://www.sao.ru/Doc-en/Telescopes/small/CCD/> (accessed on 1 May 2025)). Currently, the device is used for photometry in follow-up observations and monitoring of various transient objects like SNe, cataclysmic variables (CVs), LBV candidates, gamma-ray burst optical transients (GRB OTs), blazars, etc.

In addition to the three main ones, there are other devices that can be used in the Cassegrain focus. They are (1) the MultiMode Photometer–Polarimeter (MMPP), provid-

ing for studies of linear/circular polarization in the polarimetric mode and for photometry with a set of broadband filters of the John–Cousins system and medium-band filters, which is applied in observations of white dwarfs (WDs), contact binaries, and exoplanets; (2) the tunable-filter photometer MaNGaL (Mapper of Narrow Galaxy Lines [4]; <https://relay.sao.ru/hq/lsvfo/devices/mangal/> (accessed on 1 May 2025), mounted onto the scanning Fabry–Perot interferometer and operating in the spectral range of 460–800 nm with a typical spectral resolution of about 1.3 nm, which allows for imaging of galactic and extragalactic nebulae in emission lines under different conditions of excitation and diagnostics of the gas ionization state; and (3) the MAGIC (Monitoring of Active Galaxies by Investigation of their Cores)—a focal reducer for several observational modes: photometry, polarimetry, and long-slit spectroscopy [5]. The latter two are the authors’ instruments. To apply either the MaNGaL or the MAGIC in observations, one should contact the representative of the SAO RAS laboratory of spectroscopy and photometry of extragalactic objects (<https://relay.sao.ru/hq/lsvfo> (accessed on 1 May 2025)).

3. Some Results of Research Programs

Here, we mention the most recent publications that obtained their results using SAO RAS’s Zeiss-1000 telescope. Some of these observations have been run in collaboration with other telescopes in the frame of monitoring campaigns or have provided ground-based support to space missions. Some of them are being conducted as long-term research programs at the Zeiss-1000 telescope only. Target-of-opportunity observations of transient events are also of great importance.

GRB OT follow-up observations yield plenty of GCN (Gamma-Ray Coordinate Network) circulars (see, e.g., [6–9]) to trigger more detailed studies. For example, one of these presents full photometric coverage and spectroscopic data for an OT of a soft GRB 201015A with a redshift $z = 0.426$ associated with a supernova through both photometric and spectroscopic observations [10].

Figure 1 demonstrates the results of the follow-up observations [11] and monitoring of the GRB 230414 optical transient using the Zeiss-1000 telescope. These data were taken on 14–18 April 2023 applying the CCD photometer. Based on the R_c -band brightness estimates, we have detected OT brightening at the early stages, as well as a change in the law of the brightness drop two days after the trigger, i.e., the detection of GRB 230414B [12] by the space observatory Swift (https://swift.gsfc.nasa.gov/archive/grb_table.html/fullview/230414B/ (accessed on 1 May 2025)).

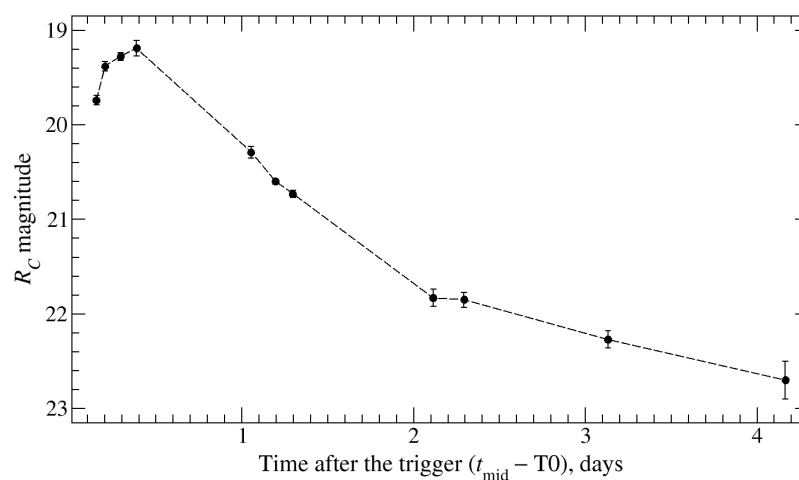


Figure 1. The light curve of the GRB 230414B OT in R_c based on photometry using SAO RAS’s Zeiss-1000.

It should be stressed that SAO RAS's Zeiss-1000 is one of the most valuable knots in the GRB network owing to the telescope's location ($+43^{\circ}39'12''$ N, $41^{\circ}26'3''$ E). The more equidistant the location of the telescopes for follow-up observations of GRB OTs is, the more detailed and informative the light curves of OTs will be, particularly those associated with SNe.

Photometric and spectroscopic observations of a new eclipsing cataclysmic variable MLSS120126:042313+212951 were carried out at the 1 m Zeiss and 6 m BTA SAO RAS telescopes, respectively [13]. An orbital period P of about 2.5 h was found based on the series of photometric data obtained over 11 months using the Zeiss-1000. It has been confirmed that the object belongs to rare CVs, which fall into the period gap of $2 \lesssim P \lesssim 3$ h. The spectroscopic data collected using SAO RAS's 6 m telescope have been used to estimate the parameters of the system. The morphology of the accretion disk interaction region has been traced out by means of Doppler tomography.

The results of optical identification of the new X-ray source SRGA J213151.5+491400, discovered by the Spectrum-Roentgen-Gamma (SRG) observatory during the ART-XC survey, follow-up X-ray and optical observations using different instruments/telescopes, and detailed studies (photometry, spectroscopy, power spectral analyses, etc.) have provided the conclusion that this object is a polar-type magnetic CV source. It is claimed to be the only polar with the occurrence of a soft X-ray component in the low state to be detected to date [14].

Multicolor photometry and medium- and low-resolution spectroscopy of the red nova V838 Mon remnant have been applied for 16 years since the 2002 outburst using different telescopes, including SAO RAS's Zeiss-1000. Archival photometry of the photographic plates of the Sonneberg and Moscow collections from 1928 to 1994 has also been used. An analysis of these observational data has confirmed that the progenitor of the V838 Mon explosion was a wide pair of B3V-type stars of reduced luminosity. The scenario of V838 Mon's evolution is a subject of ongoing discussion [15].

Photometric and spectroscopic studies of a unique B[e] star CI Cam 24 years since its outburst in 1998 have resulted in a thorough analysis of the nature of the system, along with the features of its optical emission behavior [16]. A lot of instruments and telescopes from different observatories have been used, including SAO RAS's Zeiss-1000 with the CCD photometer, the MMPP for photometry, and the UAGS spectrograph for low- and medium-resolution spectroscopy. High-resolution spectral observations of CI Cam have also involved many instruments from different observatories. Based on the results of the analysis, the classification of CI Cam's main component as a B[e] supergiant was completely ruled out due to the observed pulsation periods. CI Cam has been assumed to belong to the FS CMa-type group of objects with the B[e] phenomenon.

In long-term monitoring of the dwarf galaxy DDO 68 using the Zeiss-1000 at SAO RAS and using data from observations at SAO RAS's 6 m telescope and the 2.5 m telescope of the Caucasian Mountain Observatory of Moscow State University, along with archival data obtained using the HST and nine ground-based telescopes all over the world, six star-forming regions (or knots) in the DDO 68 "Northern Ring" have been studied [17]. One of these regions, namely Knot 3, hosts the unique, extremely metal-poor LBV DDO 68-V1. According to the photometry results, for the last eight years, Knot 3 has demonstrated brightness variations of an amplitude of up to 0.3 mag. An analysis of the light curves of the other knots has also revealed light variations, although less pronounced compared to those for Knot 3. They can naturally be explained as manifestations of the variability in the brightest supergiants being harbored in the regions under consideration. Thus, new LBVs might be found in this dwarf galaxy.

Observations of the $H\alpha$, $H\beta$, [SII] $\lambda\lambda 6716, 6731$, and [NII] $\lambda 6583$ emission lines in the galactic H II region Sh2-235 using the MaNGaL in combination with archival AKARI far-infrared data have made it possible to estimate the contribution of the front and rear walls to the total column density of neutral material in S235 and to explain the 3D structure of the region [18]. To check the calibration of the MaNGaL flux maps, long-slit spectra were obtained using SCORPIO-2 [19] at the SAO RAS 6 m BTA telescope. The MaNGaL has also been used to study the S254-258 star-forming complex. The results of tunable-filter surface photometry in the $H\alpha$, $H\beta$, [NII], [SII], and [OIII] lines, complemented by long-slit spectroscopy at the SAO RAS 6 m telescope, were used to construct maps of optical extinction and then to find the attenuation in the H II emissions by neutral material. Possible explanations for the shell-like structure of the ionized gas were proposed [20].

In polarimetric observations of BL Lac carried out in 2020–2022, a photometer-polarimeter StoP [21] and a focal reducer MAGIC were used. Multiband optical studies have revealed rapid changes in the brightness and polarization of the object occurring on a time scale of up to 1.5 h without any stable oscillation period. Owing to the significant number of observation epochs, not only intraday changes in the brightness and polarization of BL Lac but also their correlation with the long-term variability have been found. The wavelength dependence (chromatism) of the blazar polarization in the optical range presented in all observational epochs is assumed to be of an internal nature, whereas none of the models discussed can fully quantitatively describe the observation data [22].

The results of a long-term optical-to-radio study of the BL Lac object S4 0954+658 [23] include measurements from three Russian radio telescopes (SAO RAS's RATAN-600 at 1–22 GHz, the RT-32 of the Institute of Applied Astronomy of RAS (IAA RAS) at 5 and 8 GHz, and the RT-22 of the Crimean Astrophysical Observatory of RAS (CrAO RAS) at 37 GHz) and R-band photometry (using the 1 m Zeiss-1000 and 0.5 m AS-500/2 telescopes of SAO RAS, along with a few epochs of observations using *BVI* filters). To construct the multiband radio spectra for the blazar throughout the whole nearly 40-year period of historical studies, radio data collected in the CATalogs support system [24,25] (CATS, <https://www.sao.ru/cats/> (accessed on 1 May 2025)) have been used. The long-term optical light curve for this object is based on data from 670 nights from over more than 20 years of observations. A correlation between the flux variations of the blazar emission in the optical, radio, and γ -ray spectral ranges has been found, which may be evidence of the fact that the same population of photons emitted from spatially connected areas is being observed. The results suggest that the synchrotron radio waves in this AGN may be produced by relativistic protons.

In the frame of the same program of monitoring the optical variability of BL Lac objects, the multiwavelength variability (MW) of the blazar AO 0235+164 based on radio-to- γ -ray data covering a 27-year time period has been studied [26]. Measurements from different telescopes, both radio and optical, have been used, along with archive data in the submillimeter range and γ -rays. To analyze the properties of variability, fractional variability indices, discrete correlation functions, Lomb–Scargle periodograms, and structure functions have been applied. A significant correlation between all bands has been found, with time delays from 0 to 1.7 year. The relation between the time delay and frequency is described by a linear law with a negative slope of -10 d GHz^{-1} . The properties of the MW variability discovered for the low-activity period and for flaring states suggest that the mechanisms dominating the radio-to- γ -ray variations are not substantially different.

Based on studies of the radio and optical properties of the high-frequency peaker (HFP) blazar PKS 1614+051 during 2023–2024, using different methods and instruments (SAO RAS's RATAN-600, IAA RAS's RT-32, and CrAO RAS's RT-22 telescopes in radio; SAO RAS's 1 m Zeiss-1000 and 0.5 m AS-500/2 telescopes in the optical range), including

the ZTF archive data, a deep analysis of the blazar's variability has been conducted [27]. The importance of multiwavelength observations and long-term monitoring in studies of high-redshift blazars is highlighted.

Within the program of studying the variability of slow-rotating magnetic stars using the CEGS, magnetic monitoring of the Ap star HD 110066 (AX CVn) has been carried out. The expected period of the object was previously estimated to be 13.4 years [28]. Based on a series of magnetic measurements using the Zeeman spectra of the star, a much shorter period estimate, of $P = 6.4769 \pm 0.0011$ days, was derived [29]. To confirm this result, high-accuracy polarimetric data are desirable.

The results of polarimetric observations aiming to search for highly magnetized WDs among evolutionary old stars have confirmed assumptions regarding the higher frequency of the occurrence of far-evolved magnetic WDs compared to that of the population of young WDs. This fact indicates differences in the thermal evolution of the physical properties of magnetic WDs (with fields of several megagauss) and weakly magnetic WDs [30]. Based on magnetometric studies of single WDs, it has been concluded that all WDs with surface fields exceeding several tens of kilogauss are carriers of regular global fields damped at times of 10^{10} years. Magnetic fields with intensities of several kilogauss and lower lose their global structure, fragmenting into spots, which makes it difficult to detect them using the standard spectropolarimetric methods [31]. These results confirm the hypothesis of the relict origin and slow degeneracy of WD magnetic fields [32].

A project searching for exoplanets and transient processes in near and deep space has been developed. It aims to create an extensive, continuously updated survey of transient events and exoplanets for several 0.07 m optical telescopes and the Zeiss-1000 and the 6 m BTA telescopes of SAO RAS [33]. Its first results can be found in the paper cited. Currently, the project is running successfully, increasing the number of exoplanets detected.

4. Conclusions

In 2014, the Zeiss-1000 telescope of SAO RAS celebrated its 25th anniversary. The same year, the telescope was fully automated, and it became possible to make observations by using it in remote mode. Having continuously been modernized and upgraded in its hardware and software, it is still “on duty”, assisting astronomers in exploring the Universe. New instruments are being constructed, new methods are being tested, and fast photometry is one of them. In spite of their modest-size apertures, the role of small telescopes like the Zeiss-1000 in the current research is noticeable. The results of the running programs are of great interest within the frame of multiwavelength studies conducted in collaboration with other ground-based and space telescopes, either in monitoring campaigns or in optical identification programs. They are highlighting the perspective directions to be elaborated. Monitoring observations of hot stars, as well as massive supernovae, blazars, and white dwarfs, are in focus.

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