New Capabilities of One-Meter Schmidt Telescope of the Byurakan Astrophysical Observatory after Modernization

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Abstract

Within the framework of cooperation between Byurakan Astrophysical Observatory and Special Astrophysical Observatory during 2013–2015 y the 1-m Schmidt telescope of the Byurakan Astrophysical was upgraded. We completely redesigned the control system of the telescope: we replaced the actuating mechanisms, developed telescope control software, and made the guiding system. In the Special Astrophysical Observatory the 4k×4k Apogee (USA) liquid-cooled CCD was reworked and prepared. Detector was mounted in the focus of the telescope and provides 1 degree field of view with pixel-size of 0.868, and RON~11e^{-}. The detector is equipped with a turret with 5 holes for filters. The 20 intermediate-band filters (FWHM= 250A) uniformly covering the 4000–9000 AA wavelength range, five broadband filters (u, g, r, i, z SDSS), and three narrow-band filters.

During the first year of test operation of the 1-m telescope we performed pilot observations within the framework of three programs: search for young stellar objects, AGN evolution, and stellar composition of galaxy disks. We confirmed the possibility of efficiently selecting of young objects using observations performed in narrow-band Hα and [S II]filters and the intermediate-band 7500Åfilter.Three-hours long exposures with SDSS g, r, and i band filters allow us to reach the surface brightness level of 28^{m}from square arcsecond when investigating the stellar content of galaxy disks for a sample of nine galaxies. We used observations performed with the 1-m telescope in five broadband (SDSS u, g, r, i, and z) and 15 intermediate-band filters (4000–7500A) to construct a sample of quasar candidates with0.5<z<5(330objects) in about one-sq. degree SA 68 field complete down to R_{AB}=23^{m}. Spectroscopic observations of 29 objects ($19._{m}5<R<22_{m}$) carried out at the 6-m telescope of the Special Astrophysical Observatory of the Russian Academy of Sciences confirmed the quasar nature of 28 objects.

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1. Introduction

Wide field cameras as Schmidt telescopes made huge amount of astronomical surveys during last century using large photographic plates (Schmidt, 1931). The era of photographic observations, which ended in mid-1080s, left many telescopes without use. Such famous instruments as Palomar Schmidt, Barrell Schmidt, Asiago Schmidt, and Byurakan Schmidt played important part in the development of astronomy. Despite their excellent optics and mechanics their outdated control systems and obsolete observation methods rendered them noncompetitive against more modern telescopes. The 1-m Schmidt telescope of Byurakan Astrophysical Observatory of National Academy of Sciences of Armenia is one of the worlds's top five and three Schmidt telescopes in terms of the size of the mirror and the size of objective prisms, respectively, and has one of the highest aperture ratios (*f/*2.1) among the world's top instruments of its class. The telescope was made by the State Optical-Mechanical Plant named after Joint State Political Directorate (now LOMO) and installed at Byurakan Observatory in 1960 (Dobichin 1961). In mid-1960s B. E. Markarian used this telescope to undertake the first program aimed at searching for extragalactic objects with UV excess in the continuum (Markaryan 1967) via the technique of slit-less spectroscopy. In the process of the survey many new AGNs were discovered, which are now known as Markarian galaxies and are targets of comprehensive studies. It was before B. E. Markarian completed the program of the First Byurakan Survey that the task was set to extend low-dispersion spectroscopic studies to fainter magnitudes and expand the range of selected objects. This idea formed the basis of the Second Byurakan Spectroscopic Sky Survey. Observations within the framework of the survey program started in 1974 and were finished in 1991 (Markaryan & Stepanyan 1983, Stepanyan 1994). No systematic observations were performed on the telescope after the end of the Second Byurakan Sky Survey and the telescope was abandoned in mid-1990s. The lack of detectors of appropriate size and quality posed a particular problem—huge fields of view of the telescopes (e.g., 35.5×35.5 cm photographic plates were used for Palomar Schmidt) could not be filled with CCD detectors, which were too small at the time. The development of observing technologies (high quantum efficiency of detectors; their sizes, which can now be as large as 10 × 10 cm; higher than 90% transmission of the filters, and efficient broadband coatings) made it possible at the beginning of the new century to bring wide-field Schmidt telescopes back to regular operation. Control systems were replaced on the telescopes to turn them into robotic instruments for remote observations, and photographic equipment was replaced by CCD detectors. Such upgrades are rather costly and therefore not all such telescopes are currently in use. The special interest in Schmidt telescopes is due to their large field of view, high transmission (because of the small number of optical elements), low level of scattered light, and high focal ratio. Such telescopes are good for detecting low surface brightness levels, performing surface photometry of galaxies, and photometry of stars. In this paper we report the results of our efforts aimed at restoring the 1-m Schmidt telescope (100/125/213) of Byurakan Astrophysical Observatory of National Academy of Sciences of Armenia to working condition. Section 2 describes the upgrade of the control system and observational tasks that we plan to perform on this telescope; Section 3 describes the detector mounted at the focus of the telescope and its main parameters; Section 4 describes the filter properties, and Sections 5 and 6 describe the technique of observations and calibration of the data and presents the results of the first observations.

2. Observational tasks

We plan to use the telescope to perform several observing programs that take advantage either of its high aperture ratio or large field of view. The former include the program of the search for and study of young stellar objects with mass outflows (observations in narrow-band — *FWHM* = 100 A and intermediate-band — *FWHM* = 250 A filters); the program of deep surface photometry of galaxies (observations in broadband filters); study of the distribution of ionized gas in galactic disks and beyond the optical radii (observations in narrow-band — *FWHM* =100A and intermediate-band — *FWHM* = 250A — filters). The search for AGNs in selected sky areas using the technique of intermediate-band photometry is a program of the second kind. We modeled broadband and intermediate-band filter observations on the 1-m telescope. According to our estimates, we can reach the brightness levels of 28–29^{m}/ • '' with 3–5-hour exposures in *g*-SDSS, *r*-SDSS, *i*-SDSS filters. For the AGN search program we estimated the optimum number of spectral bands uniformly distributed throughout the entire optical range, the accuracy of the classification of objects and determination of their photometric redshifts, and the total observing time per field. We plan to use 20 intermediate-band filters with 250 A pass band and higher than 90% transmission in the 4000–9000 A wavelength interval. In this case, with a total of 30 exposure hours (detector DQE of about 60%) and 2seeing we can achieve a signal-to-noise ratio of *S/N* = 5 in each filter for objects with AB ~23^{m}. We believe that for the given survey depth in each filter AB = 23^{m} we can completely trace the QSO luminosity function out to z = 3.2 (*MB* = -23) and z = 5 (for objects with *MB* > -24.7).

3. Control system for the Schmidt telescope

In 2006 the work began to recommissioning the telescope and restore it to working condition. We completely upgraded the telescope control system: replaced the actuating mechanisms, developed telescope control software, made the guiding system, reworked the CCD detector and prepared it for mounting at the telescope focus. The software that we developed makes it possible to control the detector, the wheels, the movements of the telescope and the dome, and automatically focus the telescope.

The telescope control system is built from universal control modules, each responsible for a certain part of the telescope. From a hardware point of view all the modules have the same structure. Each control module is programmed and customized for a certain task before being installed on the telescope. The operator computer acts as the Master device for all of these modules. The control modules are the Slave devices that are controlled from the computer. This Master-Slave mechanism is initiated by creating a wireless network between the computer and the control modules using RF Data Modules. The system also has the option to be setup through a wired network using an RS485 interface. This option can be used in places where RF restrictions apply or where there is too much interference.

Below is the list of modules that are installed on the telescope.

1. Alpha module
2. Delta module
3. Focus module
4. Dome module
5. Guide module

Alpha and Delta modules are installed on the right ascension and the declination axis of the telescope. The semodules' operations include:

- Reading the telescope's position from a 25 bit absolute encoder
- Reading data from safety limit switches
- Controlling a Stepper motor for slow navigation and trace
- Controlling a 3 phase asynchronous motor for fast navigation
- Displaying information on a built-in LCD
- Reading the temperature and the humidity of the module's surroundings

The Focus module is installed in the optics area of the telescope pipe. The main function of this module is to read the position of the focus lens of the telescope using high precision ADC circuitry and to position the lens by driving the stepper motor.

The Dome unit is positioned on the dome wall. It obtains the dome position from an absolute encoder and sends it to the master computer. The module also controls the dome shutters and the dome rotation depending on the telescope's position and the operator's command.

The Guide module is programmed to control 2 stepper motors which are installed on the secondary optical system's guiding router. The operator uses this system to navigate the narrow field of view CCD to a guide star, after which the guiding process takes place automatically. The whole control chain is also equipped with a secondary system that goes through the whole telescope and measures the humidity and the temperatures in different areas of the building and the telescope.

4. Detector

We acquired a two-staged Peltier cooled amateur Apogee Alta 16M CCD camera (Apogee, USA)with air cooled hot Peltier junction to mount on to the telescope. The camera is equipped with a KodakKAF-16803 4096 × 4096 CCD with a pixel size of9 × 9 μm. Laboratory tests of the camera showed that it has a readout noise and gain of RON = 11.1 $e^-$and ADU = 1.487 e^-, respectively, and that the camera has sufficient linear response range for observations. The spectral response of the camera allows it to be operated practically throughout the entire optical wavelength range. Figure 1 shows the spectral response measurements that we performed in the laboratory. We redesigned the camera by replacing air cooling with liquid cooling and vacuumed the volume where the detector is located. These modification sallowed us to significantly reduce the dependence of the temperature of the detector and electronic components on the ambient temperature and decrease the working temperature of the detector down to-$40^\circ \pm 0^\circ.1$C with a coolant temperature of $+10^\circ \pm 0^\circ.1$C. We mounted a two-component post-rectifying anti reflection lens specially computed to correct the curvature of the focal plane of the 1-m telescope throughout the entire optical wavelength range. We mounted a filter turret with replaceable filter wheels(HSFW, manufactured by Optec, USA) onto the camera box, with each wheel hosting five 50-mmdiameter filters. In October 2015 a CCD camera was installed onto the standard focusing unit of the telescope and a coolant supply line was set to connect the camera to the cooling system (Minichiller, manufactured by Huber, Germany) located in the dome space of the telescope. We use a mixture of ethanol with distilled water as a coolant. As a result, the telescope equipped with

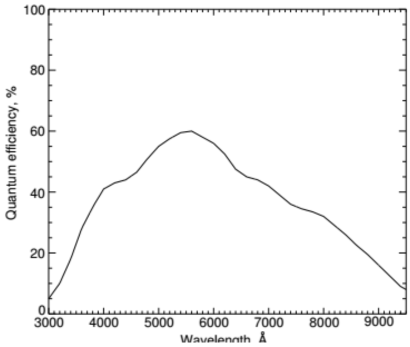

Figure 1. Spectral response of Apogee Alta 16M camera according to laboratory measurements

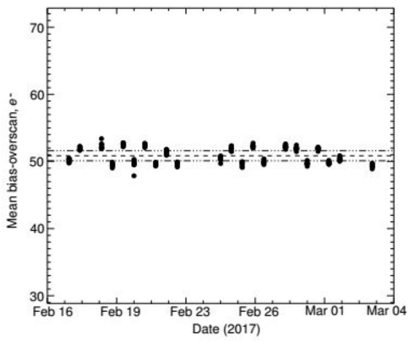

Figure 2. Measurements of the base level of bias-overscan under real conditions on the telescope at dome temperatures ranging from -18◦C to +2◦C. The dashed line shows the average level and the dashed-and-dotted lines, the average level ±0.5 ADU.

Alta 16M camera has a field of view of about 1°with a resolution of 0'' .868/pixel. We investigated the photometric stability of the detector under real observing conditions: we measured the base level with respect to which the object brightness is determined (bias-overscan) for over two weeks. The dome temperature varied from -18°C to +2°C (Fig. 2). The measurements showed that the rms deviations of the variations of the base level did not exceed 1.4 e^-, i.e., 1 ADU of the detector, without any appreciable trends.

5.Filters

In line with our scientific goals we acquired 20 intermediate-band filters (*FWHM* = 250A) uniformly covering the 4000–9000A wavelength interval, and three narrow-band filters (5000A, 6560A and 6760A, *FWHM* = 100A). The ˚ filters were manufactured by Optec (USA) using ion bombardment technology, they have high transmission (more than 90%) at the response peak, and efficiently suppress light in "blind" wavelength domains (>4D). We also acquired a set of five broadband filters (*u,g,r,i*, and *z* SDSS) manufactured by Astrodon, USA. The filters have a clear aperture of 50 mm. Figure 3 shows the results of laboratory measurements in an *F/2* convergent beam. Filters are mounted on six filter wheels, and can therefore be changed during observations. The filter turret is controlled from the same shell that is used to control the camera.

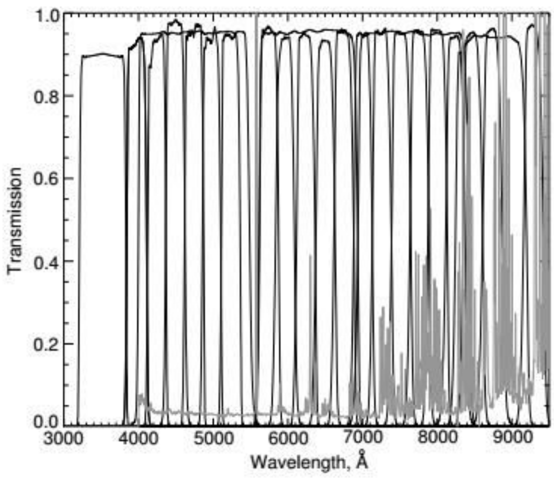

Figure 3. Results of filter measurements made in a laboratory in a converging beam with an aperture ratio of *F/2*.

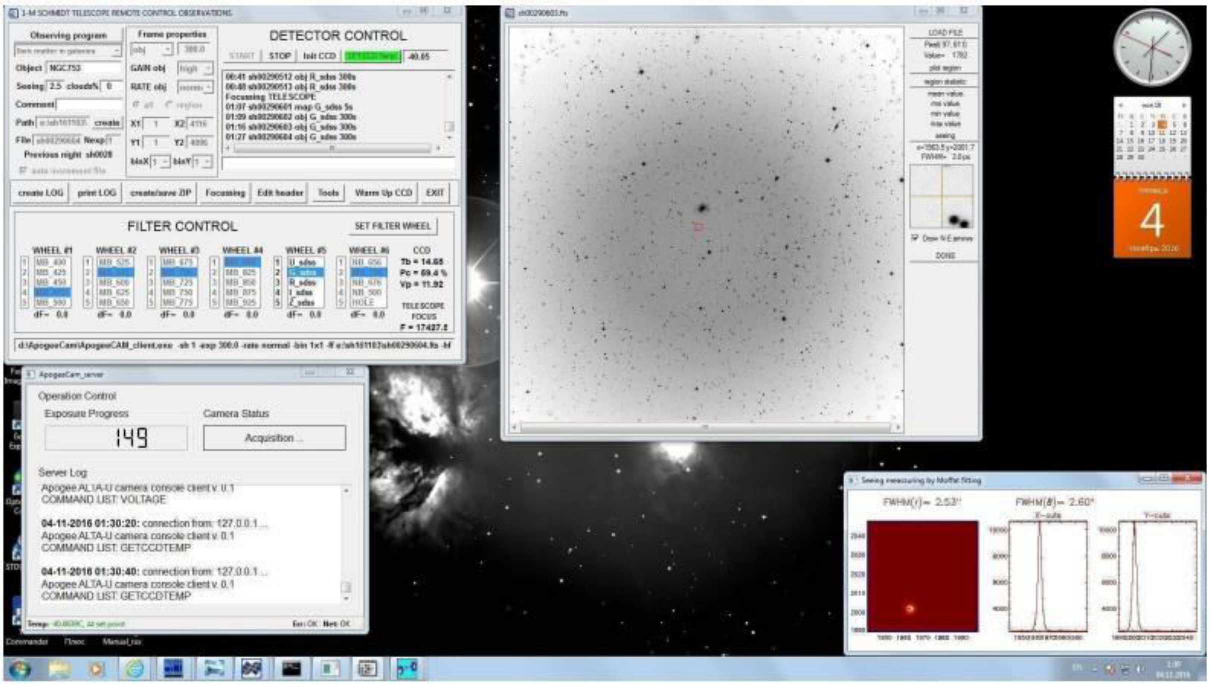

Figure 4. Screenshot of the detector control monitor during observations on the 1-m telescope.

6. Observations and data calibration

Multicolor photometry toward which we reoriented the 1-m telescope allows the observational technique to be significantly formalized, and this is the key aspect of the transition to fully automated observations. While developing the telescope control software we had in mind the possibility of future remote observations and subsequent transition to practically automatic mode of observations in accordance with a preset program. We also developed a software environment for controlling the detector, which can be used not only to control the detector state, set the exposure and image integration modes, but also to control the filter turret while interacting with the telescope control program, focus the telescope, retarget it, calibrate the data, and archive the data obtained and produce the log of observations performed during the past night (see Fig. 4).

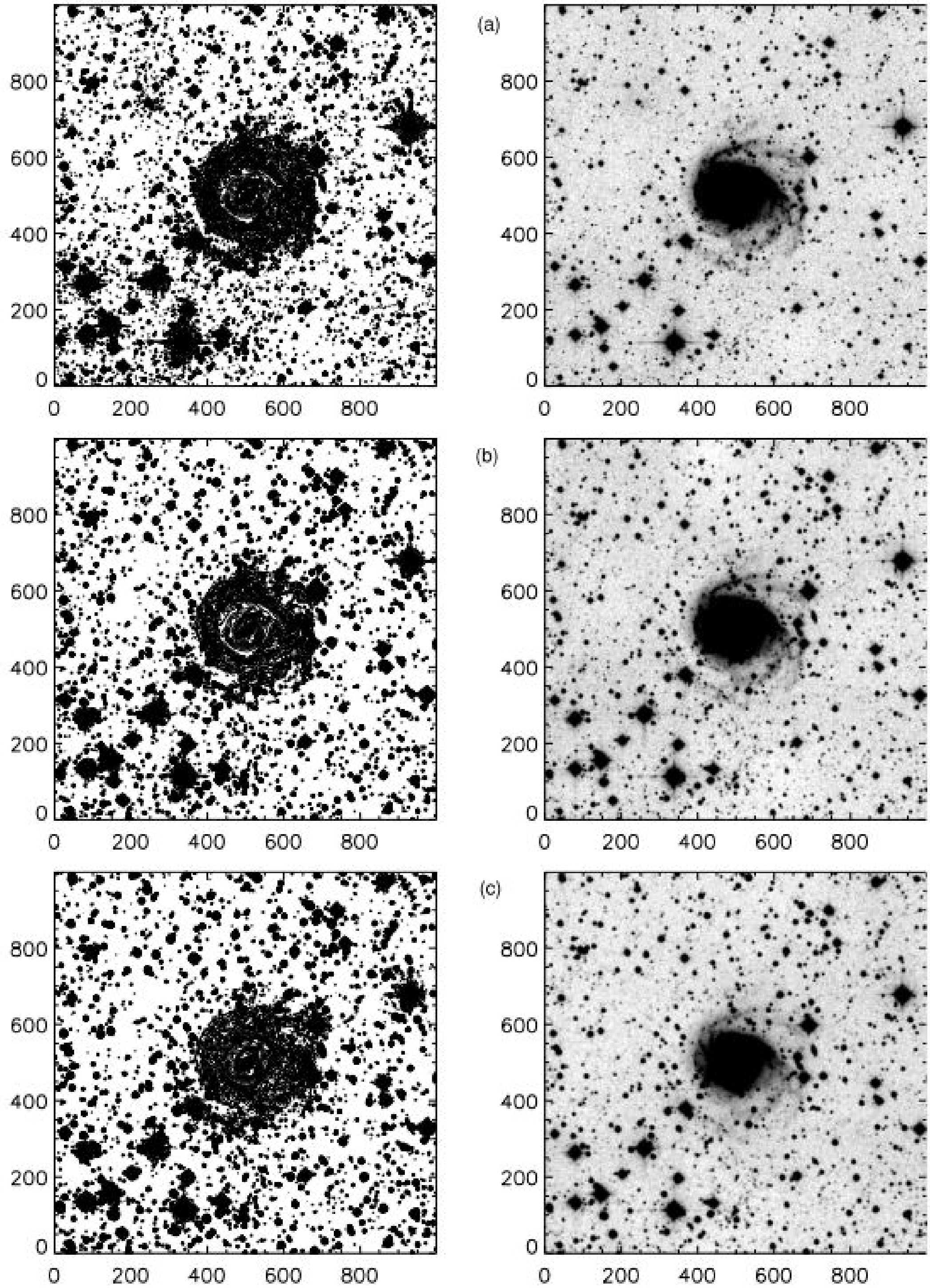

Figure 5. UGC 03685 as observed with the 1-m Schmidt telescope of Byurakan Astrophysical Observatory of the National Academy of Sciences of Republic of Armenia. Left: surface photometry contours; right: images of the object taken in *i*SDSS (a), *r*-SDSS (b), and *g*-SDSS (c) filters with 6000 s, 10 500 s, and 8100 s exposures, respectively. The outermost isophotes correspond to the levels of $26^{m}.5$/• '', $27^{m}.7$/• '', and $28^{m}.0$/• '', respectively.

Details of data reduction methods and techniques, as well as results of first observations are presented in (Dodonov 2017). In this paper we will present some images and spectral energy distributions of some interesting objects (see Fig. 5 and 6).

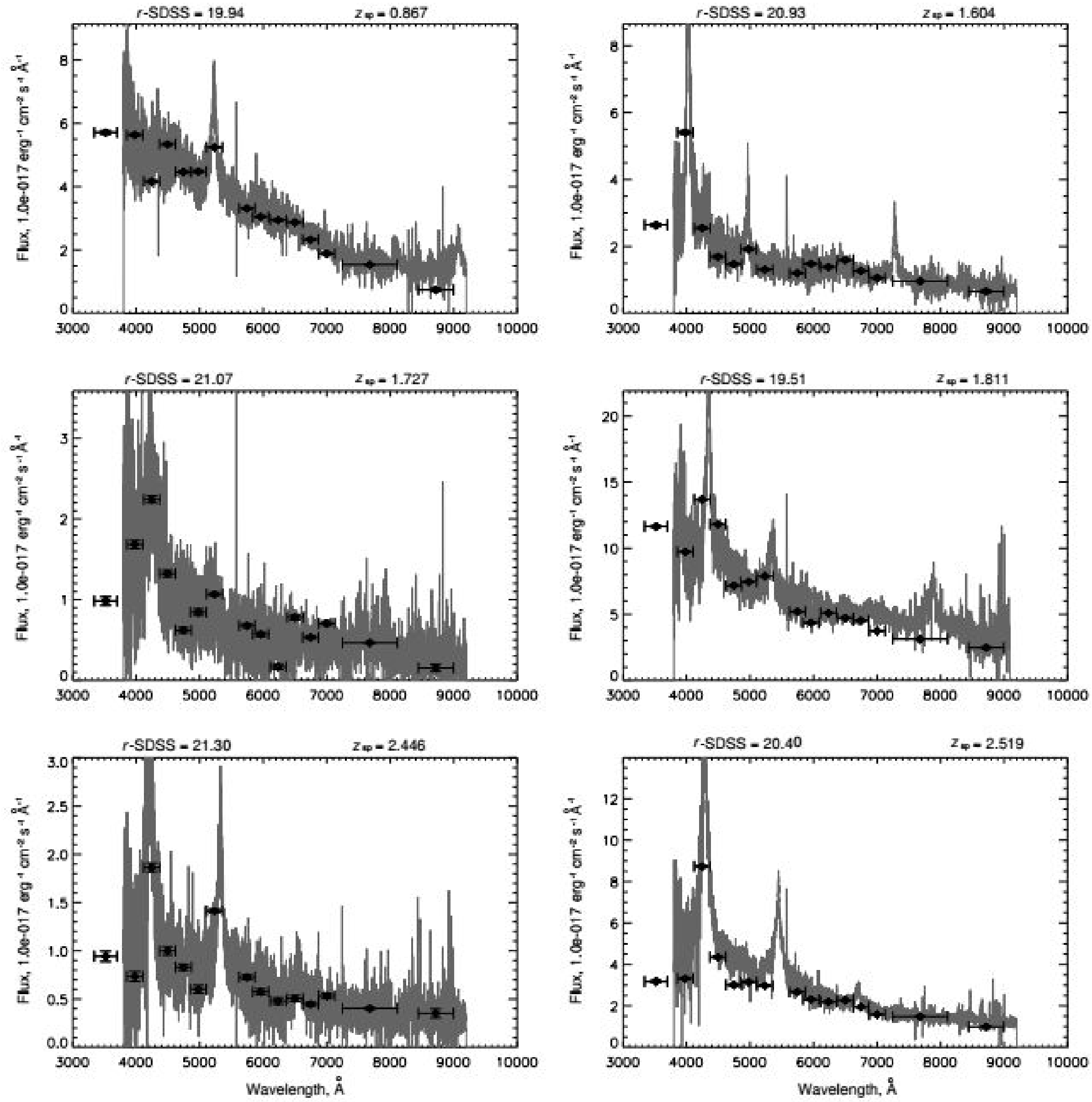

Figure 6. Spectral energy distribution in six quasars in the HS 47.5-22 field according to multicolor photometric observations made with the 1-m Schmidt telescope (the points with the error bars: the horizontal and vertical bars correspond to the filter passband and error of the photometry of the object in the given band, respectively) and the SDSS spectra of these objects (the solid line).

7. Conclusions

Returning to regular observations on the 1-mSchmidt telescope of Byurakan Observatory expands the opportunities for Russian and Armenian astronomers to tackle the key problems of modern astrophysics: study of the evolution of active objects, investigation of gamma-ray bursts at early stages of their detection, search for distant (out to z ~1)clusters of galaxies, study of the environments of giant radio galaxies, investigation of the connection of AGNs and clusters of galaxies, study of the distribution of ionized gas in galaxy disks and beyond the optical radius, and investigation of star-forming regions in the Galaxy. We hope to greatly increase the efficiency of observations on the 1-m telescope in the foreseeable future by mounting a mosaic detector at the focus to cover the entire 16° field of view of the telescope.

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