ASTRONOMY EQUIPMENT AND LIGHT RECEIVERS OF THE SHAMAKHY ASTROPHYSICAL OBSERVATORY

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Introduction

The emergence of the cosmic period in human history (the second half of the 1950s) gave a strong stimul to the development of new ideas, technical means and methods of space research, in other words, the development of instruments and methods of near-earth and terrestrial astronomy. It also accelerated the technical reconstruction of existing observatories. In the areas with favorable astroclimates of some countries new observatories and large telescopes have been built. The Shamakhi Astrophysical Observatory (ShAO) was established in 1959 on the basis of the Astrophysics Laboratory under the Institute of Physics of the Azerbaijan Academy of Sciences since 1953 (later the Astrophysics Sector) and was included in the structure of the Azerbaijan Academy of Sciences as an independent research institute.

The observatory has been equipped with astronomical instruments and light receivers since its establishment. In 1957, the first Chromosphere-Photosphere Solar Telescope, was built at the Pirgulu Astronomical Station and solar patrol observations began. In 1959, a 200 mm photoelectric telescope was put into operation, which solved the problem of studying the astroclimate of the area. In the following years, Horizontal Solar Telescope (1962), AST-452 Telescope (1964), AZT-8 Telescope (1970), and Zeiss-600 Telescope (1980) were put into operation. The purchase of the 2-meter telescope manufactured by Carl Zeiss company from German Democratic Republic and its expluation in September 1966 is of special importance in equipping the observatory.

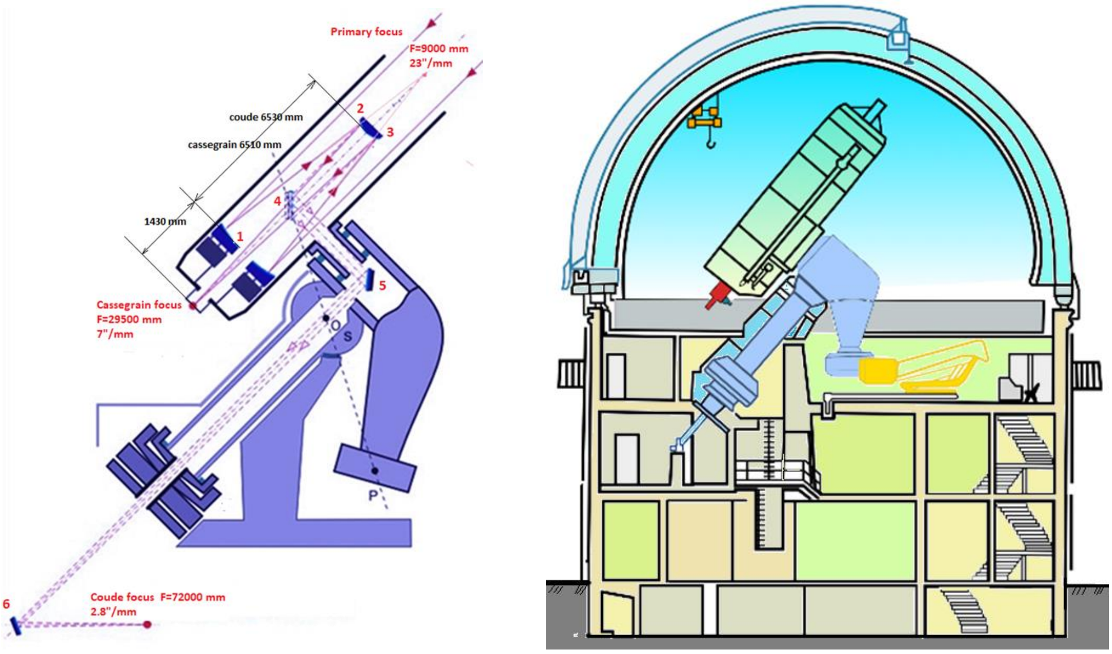
2-meter telescope and its devices

The Zeiss-2000 Telescope is the second of five such telescopes reflector of which is manufactured by Carl Zeiss Jena (Germany). It was brought to the observatory in 1964 and put into operation in 1966. Geographical coordinates are: $\lambda = 48° 35' 50''$ E, $\varphi = 40° 46' 51''$ N. The telescope was built at an altitude of 1460 m above sea level. The main mirror is parabolic, with a diameter of 2080 mm and a focal length of 9000 mm. On the opposite sides of the main tube of the 2-meter telescope diametrically opposite 1 pair of seekers (lens diameter - 110 mm, focal length - 1130 mm, field of view -1 °) and 1 pair of guide telescopes (lens diameter - 300 mm, focal length - 7500 mm, field of view - 15') fastened. The outer layer of the dome and the building is covered with aluminum plates for thermal insulation.

General view of the 2-meter telescope. Left image from the outside, right image from the inside.

The 2-meter telescope combines 3 different optical systems and is mainly designed for the spectral observations [2]:

1. **Primary focus.** Focal length is F = 9 m, focal ratio is f/4.5, useful field of view is 6'x6', designed for obtaining spectra of weak objects. With the help of correction lenses it is possible to increase the useful field of view to 21'45″ x 21'45″ and is designed for the direct photography of celestial bodies. The scale on the focal plane is 23″/ mm.
2. **Cassegrain focus.** Effective focal length is F = 29.5 m, focal ratio is f/14.75, size of view field 7'x7 ', scale on the focal plane is 7″/mm.
3. **Coude focus.** Effective focal length is F = 72 m, focal ratio is f/36, size of view field 3'x3', scale on the focal plane is 2.8″/mm.

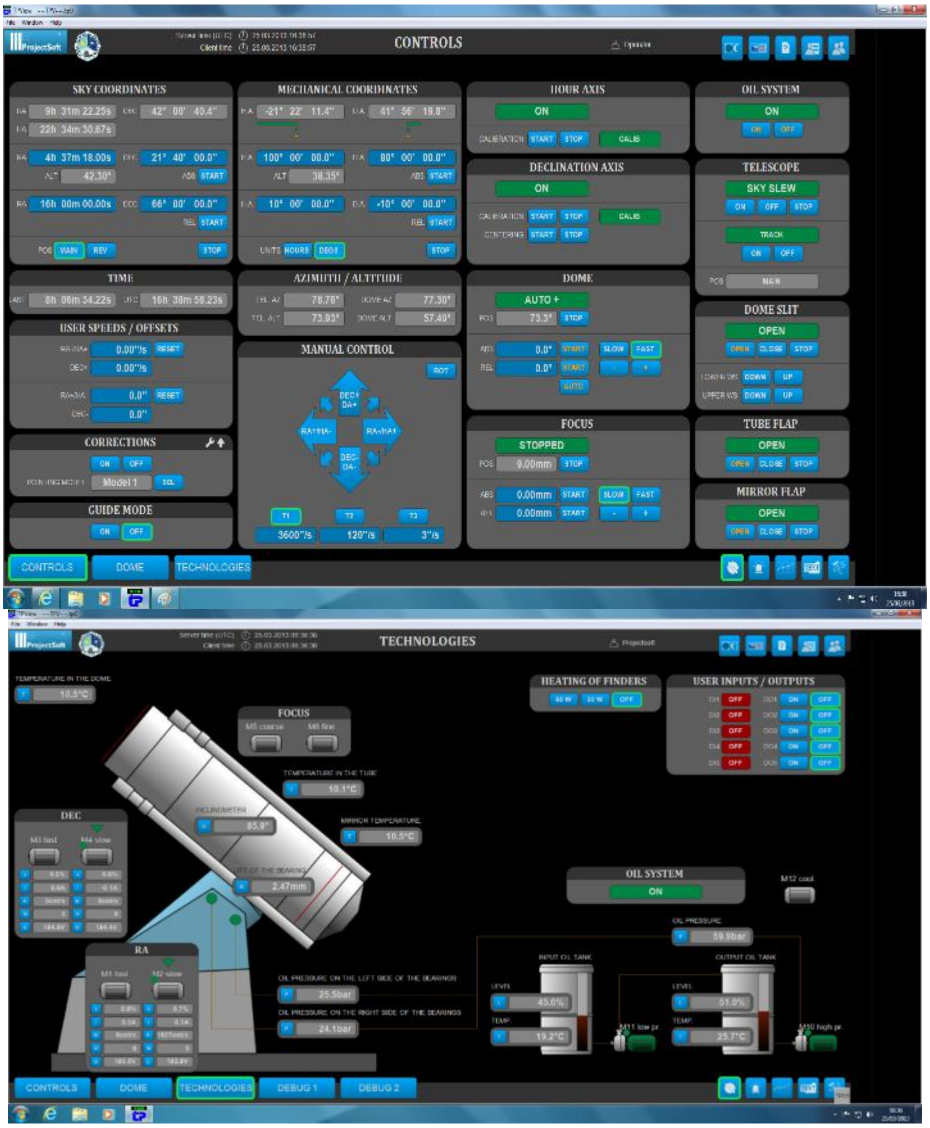


Optical scheme of the 2-meter telescope. 1 – primary parabolic mirror: effective diameter is D = 2 m, focal length is F = 9 m; 2,3 - cassegrain and coude hyperbolic mirrors: diameter is d = 580 mm, focal length is f_{cass} = -3600 mm, f_{coude} = -2850 mm; 4 flat mirror with size- 620x400 mm; 5 flat mirror with diameter d = 520 mm; 6 flat mirror with diameter d = 50 mm., S is the center of gravity, P counterweight

From the beginning, the telescope was mainly used for spectroscopy. In the past, Kodak and ZU photoplate were used as light receivers to obtain spectra. In 1998, electronic detectors began to be used. From 1998 to 2014, Russian-made nitrogen-cooled 530x580 CCDs were used for spectral observations, and then CCDs produced by Alta Apogee began to be used for the photometric observations.

Modernization of the 2-meter telescope

Within the framework of strengthening the material and technical base of the observatory by the decrees signed by the President of the Republic of Azerbaijan in September 2008 and July 2009, the hydraulic and electrical systems of the 2-meter telescope were reconstructed in 2012-2013 by the Czech company ProjectSoft [3] and the control system was automated [4]. The conventional industrial control system of Siemens company was used to control the telescope. The integrated control program works directly on the programed logic controller (PLC). All calculations are performed on the single processor, which ensures the most reliable control. The telescope is controlled and visualized by PC. In addition, the telescope can be controlled remotely using the standard TCP/IP protocol.The correction system (model) was installed on the controller to eliminate mechanical errors when the telescope was aimed at the object. The system includes calculation of precession and refraction, correction of aberration and nutation, etc. All this increased the speed and accuracy of the telescope's orientation to new coordinates. For example, the telescope's orientation accuracy has been reduced from the original 300 to the current 6 arcsec. Equipping the telescope with a control system that meets the modern requirements of terrestrial astronomy and new light receivers allows the Observatory to successfully participate in international cooperation in astronomical research.



General view control panel of the telescope.

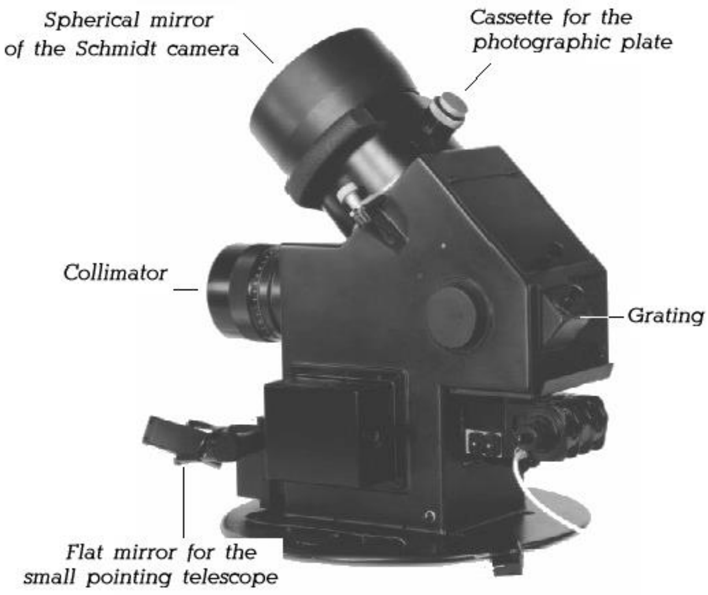
Optical devices of 2-meter telescope

Historical spectrographs:

Primary spectrograph. The primary focus is considered for the photographic and spectral observations of weak celestial bodies.

1. Cassette device for direct photography. When the concealer is used, the useful viewing area is 21′45″x21′ 45″.

2. 3-chamber 232 spectrograph used to obtain spectra of weak objects with small resolution with dispersion diffraction 137; 86; 79; 46; 29 Å/mm grating

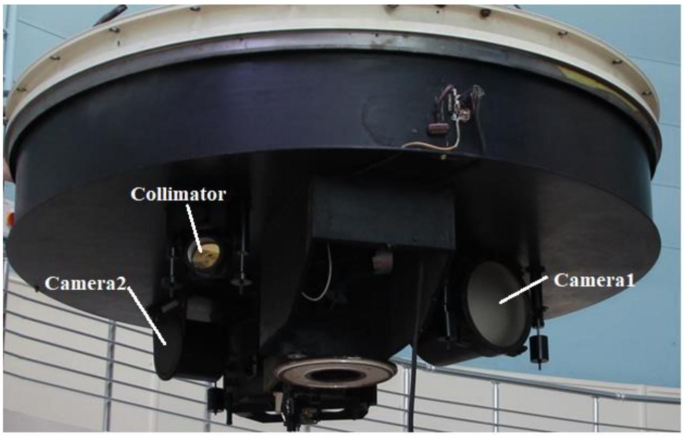


General view of the main focus spectrograph.

Optical characteristics of the spectrograph:
Collimator mirror - diameter - 75 mm, focal length - 337 mm
Diffraction Grating - size - 80x110 mm, Grating constant - 650 mm^{-1}
Schmidt camera 1 - diameter - 125 mm, focal length - 150 mm
Dispersion - 33÷100 Å / mm
The linear dimension of the spectrum - 50 mm
Schmidt camera 2 - diameter - 125 mm, focal length - 75 mm
Dispersion - 67÷200 Å/mm
The size of the photographic plate - 11x50 mm
Schmidt camera 3 - diameter - 125 mm, focal length - 45 mm
Dispersion - 133÷400 Å/mm
The linear dimension of the spectrum - 50 mm.

Since the cameras have an internal focus, it is not possible to use modern light receivers (CCD matrices).

There are 3 spectrographs of Cassegren focus (standard diffraction grating spectrograph, universal diffraction grating spectrograph, 2x2 prism spectrograph) and a cassette device for photography. Standart spectrograph of Cassegren focus 10; 15; 25; 30; 37.5 is a spectrograph with two Schmidt camera diffraction grids with a dispersion of 75 Å/mm. Optical characteristics of the spectrograph:
Collimator - aperture 1:14.5; out of axis type
Grating - 139x150 mm
Dispersions - 10 ÷ 30 Å/mm
Schmidt camera 1- diameter 366 mm, focal length 540 mm
The format of the photoplate is 19.5x126 mm
Schmidt camera 2 - diameter 234 mm, focal length 220 mm
Dispersions - 37.5÷75 Å/mm
The format of the photoplate is 12.5x60 mm



General view of the cassegrain spectrograph.

Coude focus has 3 Schmidt camera diffraction grating spectrograph. Optical characteristics of the spectrograph are as follows:
Collimator - focus out of axis type, f = 5400 mm, diameter d = 150 mm.
Camera 1 - Spherical mirror, focus - f = 350 mm, diameter - d = 352 mm, corrector diameter - 226.6 mm, dispersion - 16; 24 Å/mm.
Camera 2 - Spherical mirror, focus - f = 700 mm, diameter - d = 550 mm, corrector diameter - 268.9 mm, dispersion - 8; 12 Å/mm.
Camera 3 - Spherical mirror, focus - f = 1400 mm, diameter - d = 800 mm, corrector diameter - 226 mm, dispersion - 4; 6 Å/mm.
Note:
1. The Cassegrain Echelle Spectrograph was developed in 2004 on the basis of UAGS (Universal Astro Grating Spectrograph)
2. 2x2 prism spectrograph and 2 th UAGS has been modernized and adapted with a modern light receiver (2x2 prism spectrograph + CCD FLI, UAGS + Camera Canon + CCD Andor) and is currently in use.
3. On the basis of the 3-camera classical kude spectrograph "Coude- echelle spectrometer" with a resolution of R=30000 (1998) and "Universal coude-eschele spectrograph with a resolution of R=100 000 ÷ 500 000" were created.

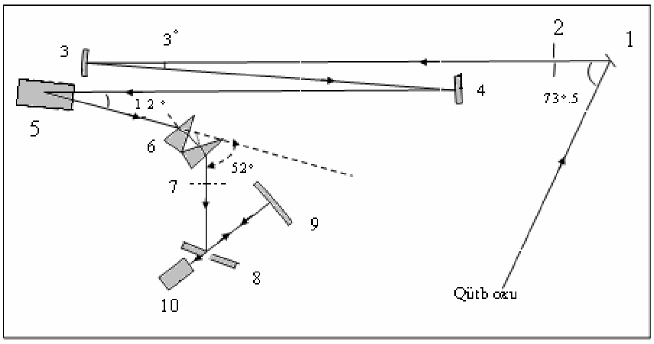
Modern devices of 2-meter telescope

After the commissioning of a 2-meter telescope at the Shamakhy Astrophysical Observatory since 1966, wide opportunities have opened up for spectral observations. The telescope was equipped with prism and diffraction spectrographs with different resolutions.

Spectral observations were made in both the Coude and Cassegrain focus of the telescope, which are considered to have a high resolution of various celestial bodies for their period. Even Kodak photoplate were used as light receivers. At that time, these photoplate were considered sensitive light receivers. They are no longer in production. Nowadays, multichannel CCDs have been used as light detectors for several decades, but their size is much smaller than the size of the spectrum obtained in the focal plane of classical spectrographs. If we apply CCDs to classical spectrographs as a light detector, we will record a very small part of the spectrum, and the information content of the spectrograph will be very low. The resolution and accuracy of measurements obtained with classical spectrographs do not meet the requirements of modern astrophysics. The combined use of Eshel spectrographs and CCDs as a detector fully meets modern requirements. Therefore, they have become widely used in astrophysics. Such systems have been used in many of the world's leading observatories since the late 1980s and early 1990s. The installation of such systems on the 2-meter SAR telescope has been planned since 1992. However, the failure of the telescope significantly delayed the implementation of these systems. After the restart of the 2-meter telescope in 1998, in 2003, echelle spectrographs + CCD systems were gradually installed at the Coude and Cassegrain focus. These echelle spectrographs are based on the optical details of classical spectrographs at a low cost. From 1998 to 2020, more than 10,000 spectra of various celestial bodies were captured at the Coude and Cassegrain focus.

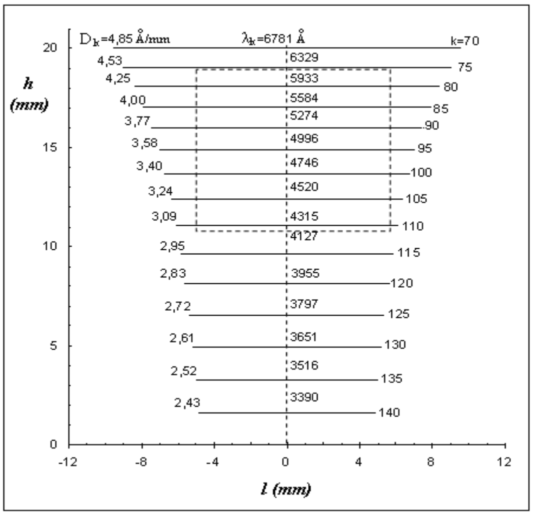
Coude echelle spectrometer

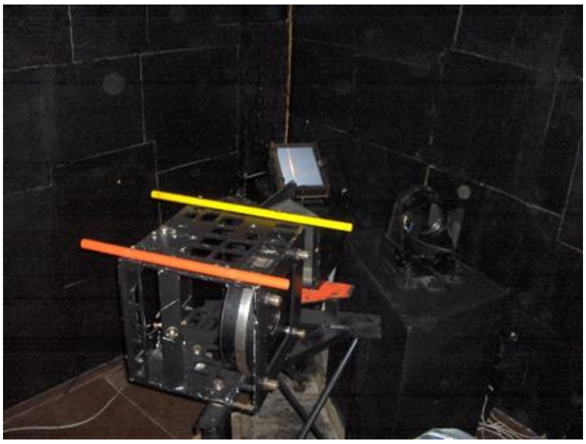
It was installed and commissioned in 1998 [5,6]. The kude echelle spectrometer is based on the classical coude spectrograph and does not violate the functions of the classical coude spectrograph.



Optical layout of the echelle spectrograph Coude. R = 30000. 1, 4 - flat mirrors,
2 - slit, 3 - collimator, 5 - echelle of gratings, 6 - cross disperser-prism, 7 - Schmidt corrector,
8 - flat mirror with a central hole, 9 - camera, 10 - CCD.

Optical characteristics of the Coude-Eschelle spectrometer:
Resolution - R=λ/Δλ=30000
Collimator - f = 5400 mm, d = 150 mm
Camera - f = 350 mm, d = 352 mm
Echelle grating - blaze angle γ = 63.5 °, line density 37.5 gr / mm, size 200 x 300 mm.
Cross disperser - 2 quartz prisms, refractive (peak) angle 45 °
Light receiver - CCD camera with a size of 530x580 pixel, 1 pix = 18x24 mic., cooling liquid nitrogen.



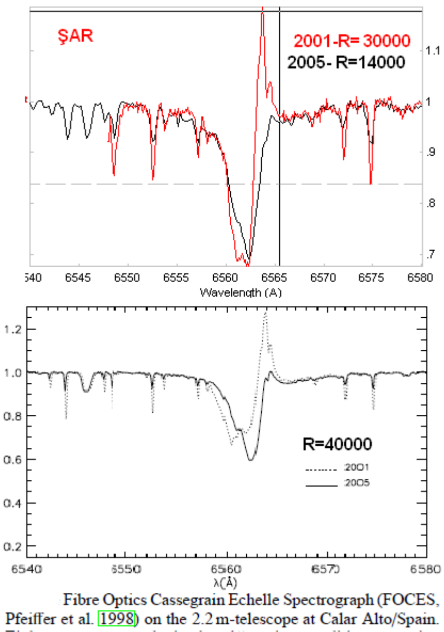


Left- format of echelle- spectra on the focal surface of the camera. h - distance between orders,
l- is the length of echelle orders, k- is the number of orders, D_k -is the dispersion in the center of theorder,
λ_k- is the central wavelength of the orders. Rectangular dotted line CCD format.
Right -General view of the coude echelle spectrograph.

The systematic measurement error of the equivalent width does not exceed 2% in the less strong lines of the spectra obtained with a good signal/noise ratio (S/N≥100). The measurement accuracy of the beam velocities determined for telluric lines is around 0.5 km/s. At very strong and wide emission and very weak absorption lines, it is around 2 km/s.

Observations on the echelle spectrometer installed in the coude focus of the 2-meter telescope of the Shamakhy Astrophysical Observatory showed that the spectrometer fully meets the modern requirements of stellar spectroscopy. With the help of this spectrometer up to 1,000 qualitative spectra of stars and comets have been obtained. Using the spectra obtained in this spectrometer, it is possible to study the fine structure of the spectral lines of the stellar and interstellar medium. Spectral observations at the observatory were carried out by this spectrograph for 4 years from 1998 to 2001.

Echelle spectrum of the star α Cyg

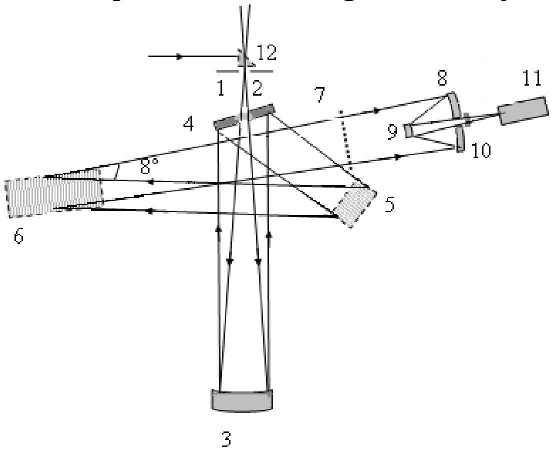


Comparison with the literature data of the Hα region
in the spectra of the star α Cyg

Cassegrain echelle spectrometer.

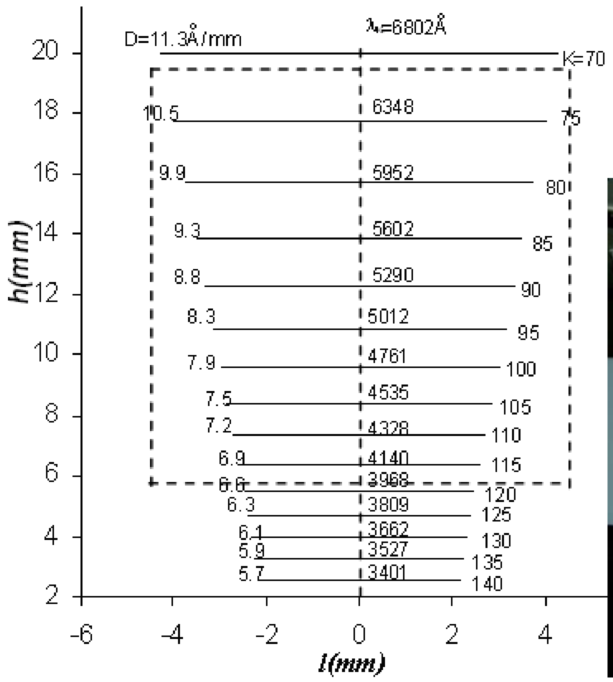
The echele-spectrometer of the Cassegrain focus was developed in 2003 on the basis UAGS (Universal Astro Grating Spectrograph) spectrograph of the peroduced in Germany [7,8]. The spectra obtained with the echelle spectrometer and preliminary research results indicate that the echelle spectrometer, made for the Cassegrain focus of a 2-meter telescope, fully meets the requirements for modern light detectors. The echelle spectra obtained with the spectrometer are of good quality and provide photometric and positional accuracy sufficient for astronomical tasks. In conclusion, we present the main characteristics of the manufactured echelle spectrometer:

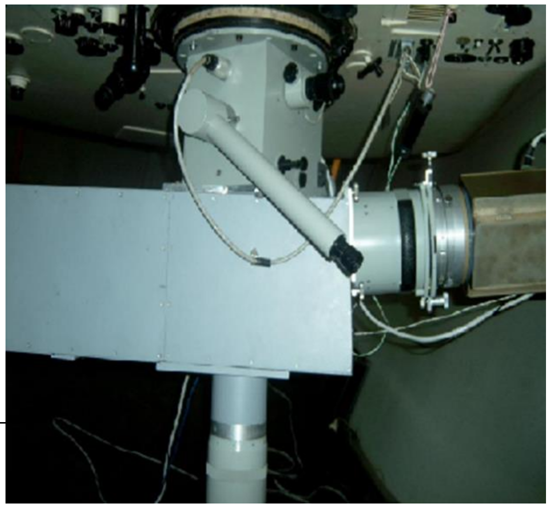
The resolving power is R = 13 600, which is quite acceptable for this type of receivers. The spectrometer operates in 70-140 orders. Dispersion in the red region ~ 10.5 Å/mm, in the blue region of the spectrum ~ 6 Å/mm. The accuracy of measuring radial velocities in the red region is < ± 2 km / s, the accuracy of measuring the equivalent widths is < 4%. One of the important properties of the echelle spectrometer is its good stability.



The optical layout of Cassegrain Echelle spectrograph. 1 - slit, 2 - collimator lens, 3 - collimator mirror, 4 - flat mirror, 5 - cross dif. grating, 6 -echelle, 7 – Shmidt corrector, 8,9,10 – Cassegrain camera, 11 - CCD camera, 12 - calibration prism.

Optical characteristics of the spectrograph:
Resolution - $R=\lambda/\Delta\lambda=13600$
Collimator mirror - f = 1100 mm, d = 75 mm
Echelle Grating - blaze angle $\gamma=63.5°$, density of lines 37.5 gr/mm, size 100 x 200 mm
Cross disperser - blaze angle $\gamma = 4$ °, density of lines 325.5 gr/mm, size 100x100 mm.
Schmidt cassegrain camera - f = 150 mm, d = 105 mm, distance from the back surface to the focus 13 mm.
Light receiver - CCD, size 530x580 pixels, 1 pixel = 18x24mic, cooling - liquid nitrogen.

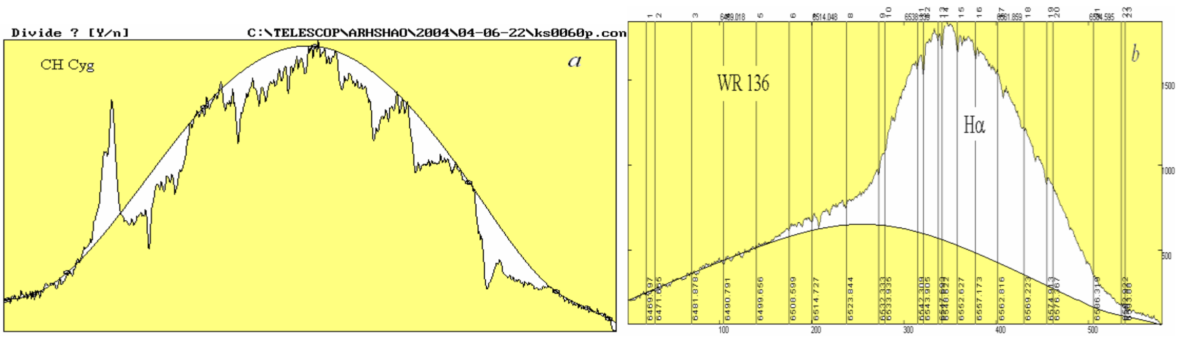




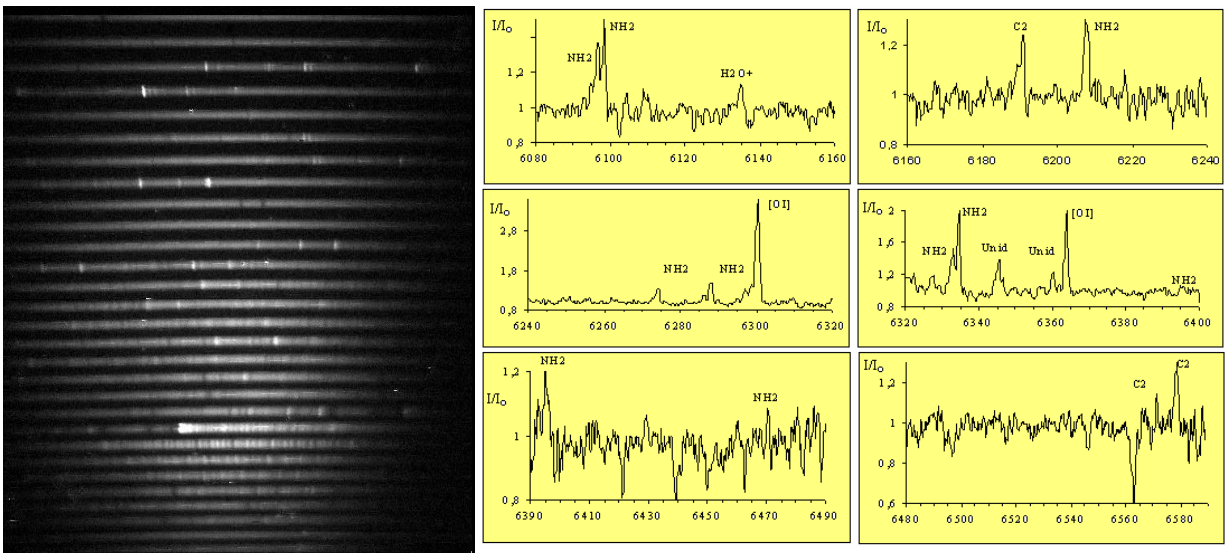
Formt of the echelle spectrum

General view of the spectrograph with Kassegren echelle

Examples of spectra obtained by cassegren echelle spectrography:



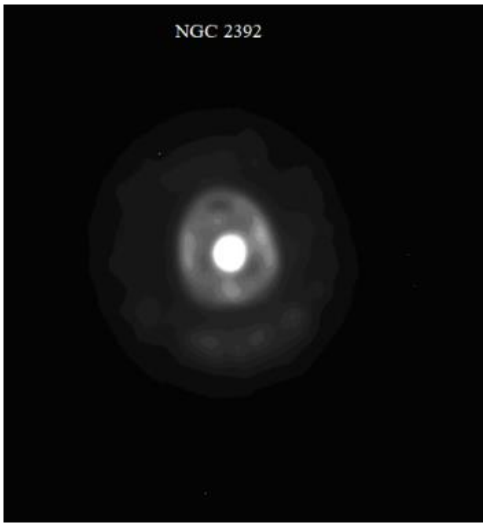
Hα regions of the CH Cyg and WR 136 stars

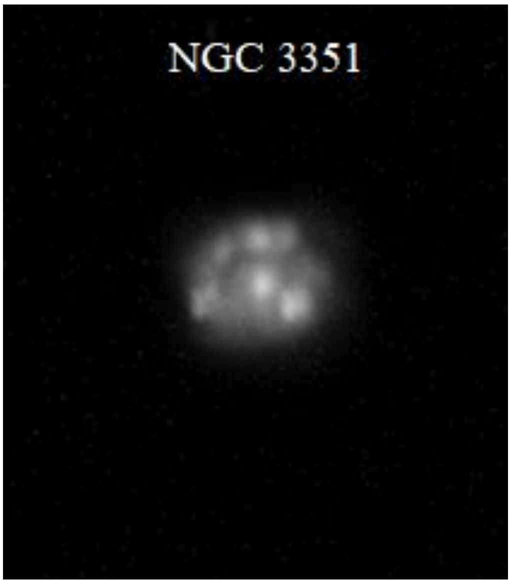


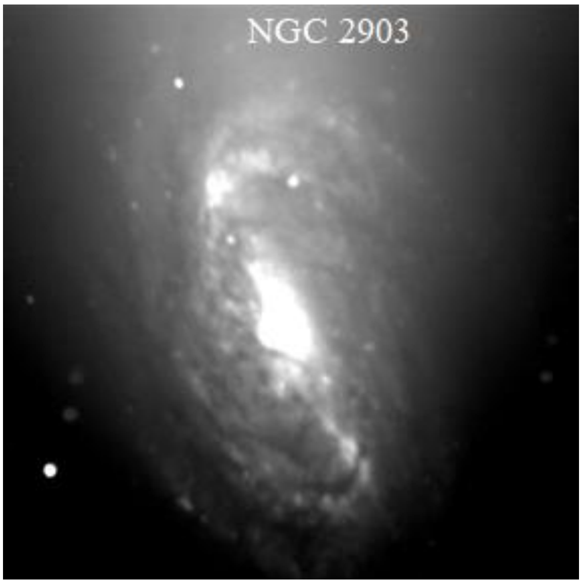
The echelle spectrum of comet C2004Q2, January 15, 2005

Standard cassette device + CCD.

In 2007, the standard cassette device was adapted to a CCD for photometric observations in the cassegrain focus of a 2-meter telescope.
Light receiver - Apogee Alta CCD, size 3056 x3056 pixels. 1 pixel = 12x12 microns.
Useful fields - 4′ x 4′





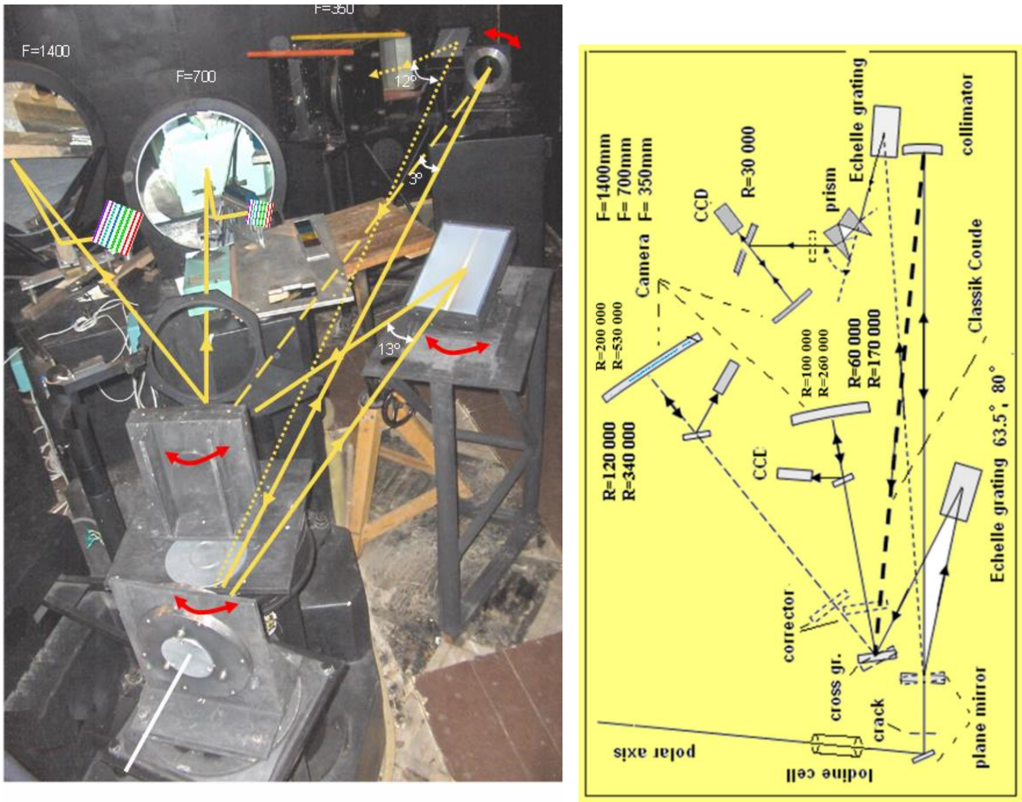


Examples of images captured with a cassette device

Universal kude-eschele spectrograph with very high resolution.

It was developed in 2009 on the basis of the classical coude spectrograph [9]. The echelle grating was applied without touching the optical-mechanical details of the classical coude spectrograph.
The main advantage of the spectrograph is that it is possible to double the resolution using two separate (alternating) cameras, and in a short time the spectrograph can be transformed from a echelle into a classic variant. The new echelle spectrograph retains the 2nd (F-700 mm) and 3rd (F=1400mm) cameras of the classic kude spectrograph. The parabolic collimator mirror has been replaced by a spherical mirror with the same focal length. The echelle grating can be used in two variants: a single grating with a blaze angle of 63.5^o and a mosaic variant with a blaze angle of 80^o. This allows to increase the resolution of the spectral spectrograph by 2.8 times.

In the new modification of the spectrometer, the path of optical light is as follows: slit - spherical collimator mirror - flat mirror with central aperture - echelle grating - cross grating - Schmidt camera - flat mirror to remove the focus from the optical axis - CCD.



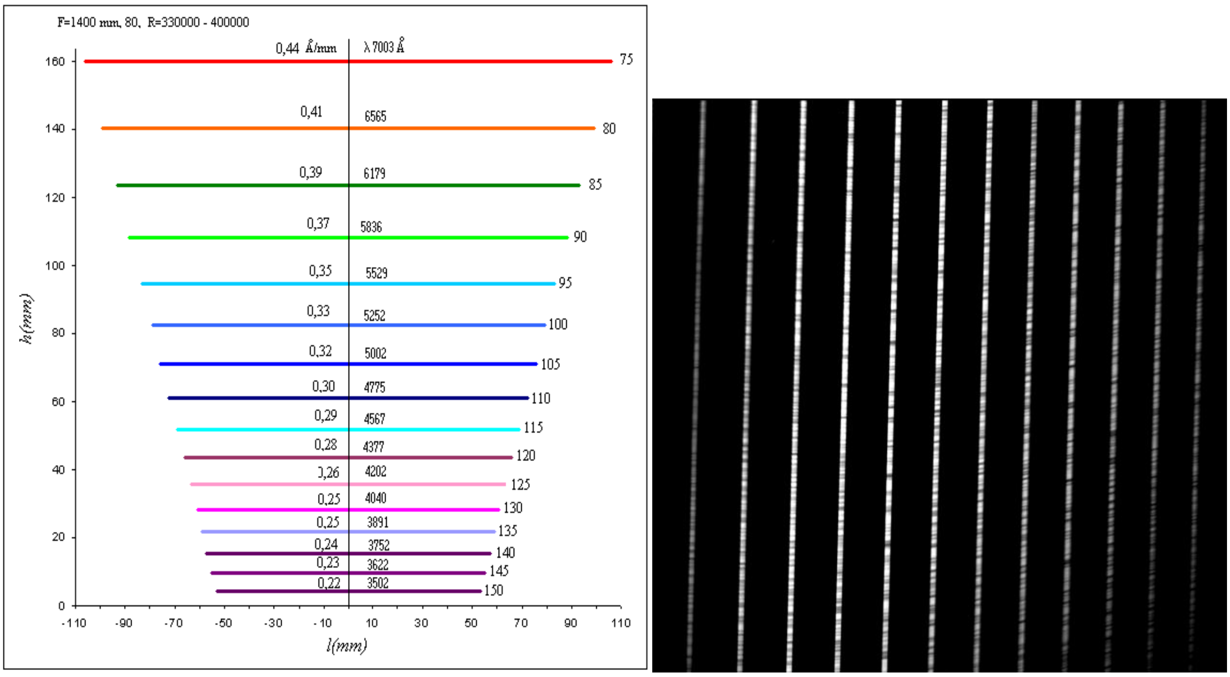
General view and optical scheme of the Universal Coude echelle-spectrograph with very high-resolution**.**

Optical characteristics of the echelle spectrograph:

Collimator - d = 150 mm, f = 5400 mm
Camera I - d = 350 mm, f = 352mm
Camera II - d = 550 mm, f = 700 mm
Camera III - d = 800 mm, f = 1400 mm
Echelle grating 1- γ = 63.5 °, N = 37.5 gr/mm.
Eshele grating 2 mosaics - γ = 80 °, N = 37.5 gr/mm.

The resolution *$R=2f_{kam}tg\gamma/2pix$. 1pix=15 mic.:*

1. Echelle grating -1, γ = 63.5 °, N = 37.5 gr/mm
   a) Camera II, F = 700 mm, R = 93,000
   b) Camera III, F = 1400 mm, R = 186,000
2. Echelle grating 2- mosaic, γ = 80 °, N = 37.5 cartoon/mm
   a) Camera II, F = 700 mm, R = 265,000
   b) Camera III, F = 1400 mm, R = 530,000

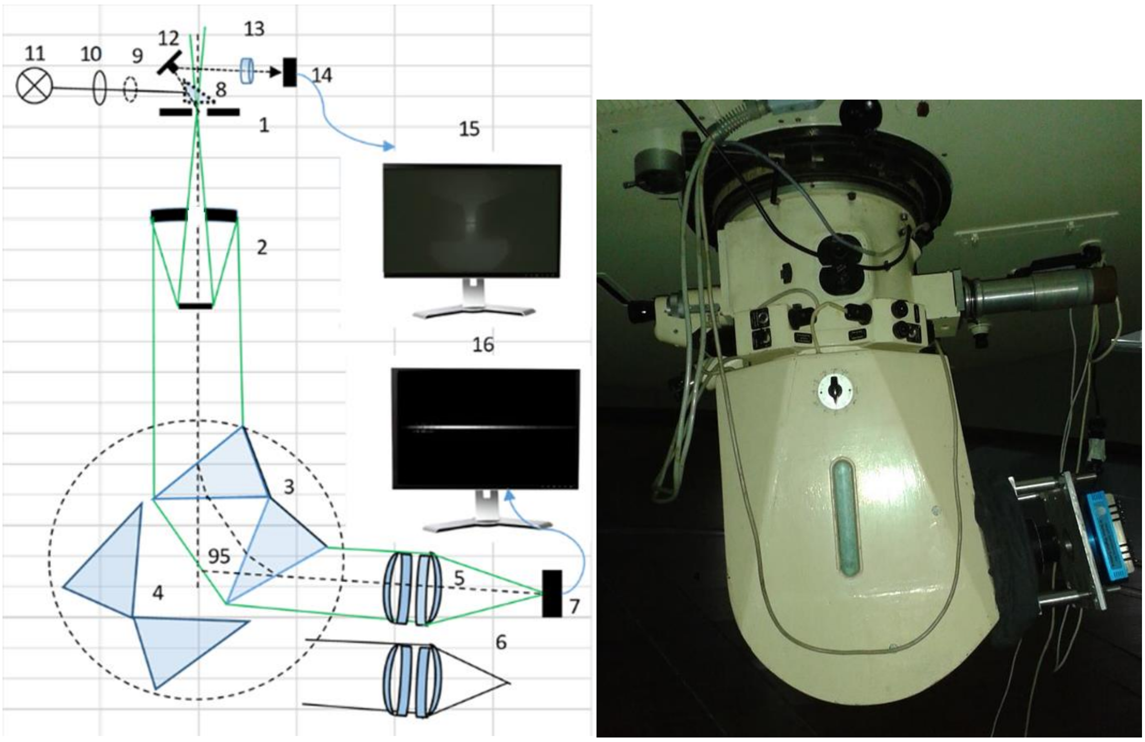


The output format of the universal Coude Echelle spectrograph R= 530000

2x2 prism spectrograph with CCD matrix of Cassegrain focus of the 2 m telescope of ShAO [10]

In 2013, the 2x2 prism spectrograph of the Cassegrain focus of the 2-meter telescope was upgraded using a CCD as a light receiver. This spectrograph is used to obtain low-resolution spectra of faint celestial bodies (galaxy, comet, asteroid, etc.).

In this spectrograph, it is possible to obtain the spectra of weak stars and galaxies in the wavelength range λλ3800÷9000ÅÅ, with inverse variances of 94 Å/mm near Hγ, 150 Å/mm near Hβ and 420 Å / mm near Hα. Spectral resolution in the region of the lines Hγ, Hβ and Hα, in dependence of the application of binnin1 or binning 2 during receiving of the spectrum is 1.7 A and 3.4 Å, 2.7 Å and 5.3 Å; 7.6 Å and 15.3 Å, respectively. During the observation process, the image is transferred to the observation room - a monitor for guiding.



Optical layot of the 2x2 prism spectrograph. 1 – slit, 2 - collimator (d = 45 mm, f = 650 mm), 3, 4 - disperser- two-prism system F2 and UBK-7, 5, 6 - camera - f = 137.5 mm and f = 82.5 mm, 7 – CCD, 8 - prism for calibration lamp, 9 – filters, 10 – condenser, 11 - calibration lamp, 12 - flat mirror, 13 - lens for guiding CCD, 14 –CCD for guiding, 15 - monitor

Optical characteristics of the spectrograph:

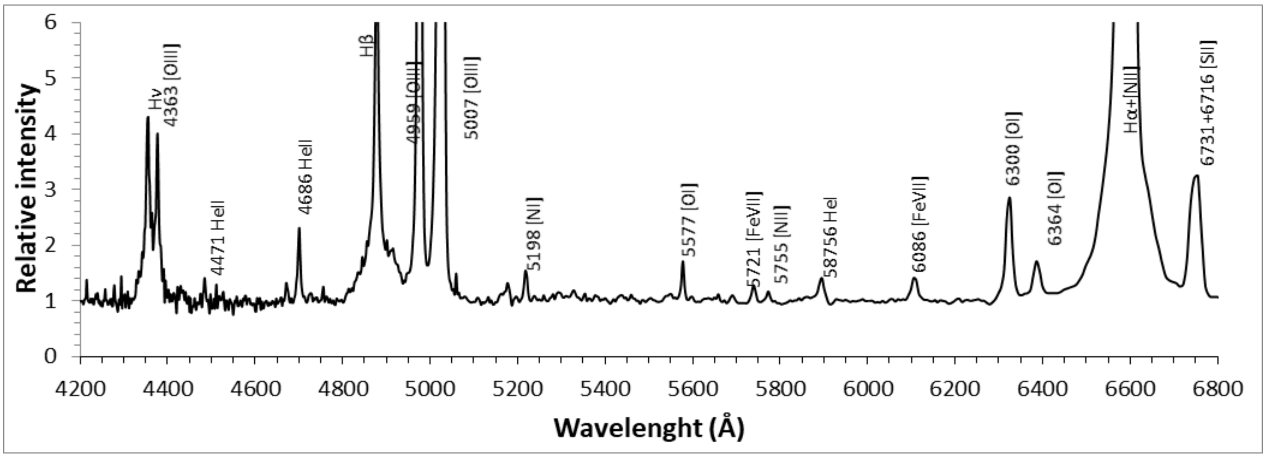
Collimator - d = 45 mm, f = 650 mm.
Camera 1 - d = 55 mm, f = 137.5 mm
Camera 2 - d = 55 mm, f = 82.5 mm
Light receiver- CCD (FLI), 4096x4096 pixels, 1 pixel = 9 microns.

The resolution of a spectrograph depends on several factors, including the resolution of the light receiver. If bining = 1 is taken, then the width of the inlet is 0.085 mm, if bining = 2 then 0.17mm.

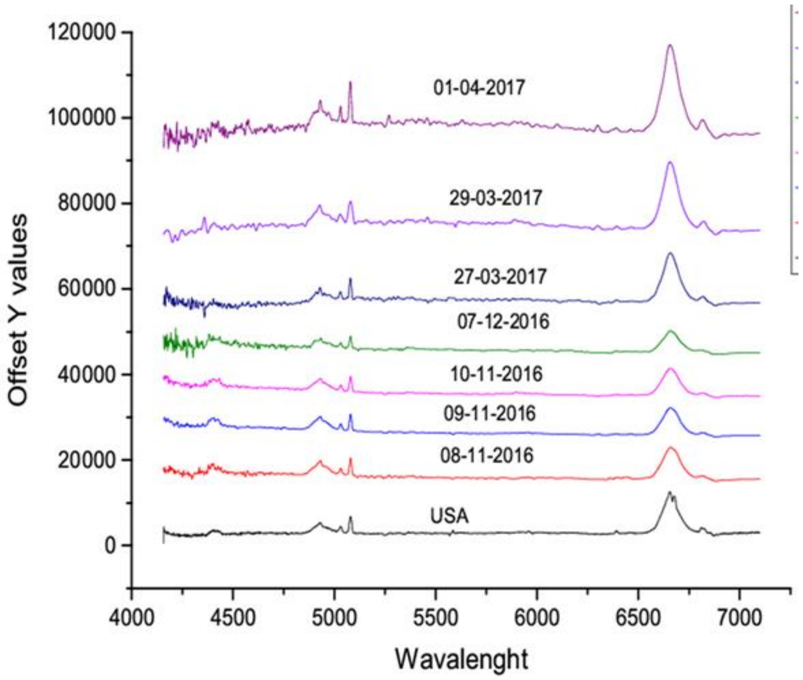
The table shows resolution and dispersion for spectrograph at selected lines.

λ	D Å/mm	Δλ (Å)	
		1pix=0.009mm	1 pix=0.018mm
Hγ	94	1.7	3.4
Hβ	148	2.7	5.3
NaI (D1,D2)	290	5.2	10.4
Hα	420	7.6	15.1

Examples of spectra obtained in a spectrograph



Spectrum of NGC 4151. The dispersion at the line Hγ is 94 A/mm.



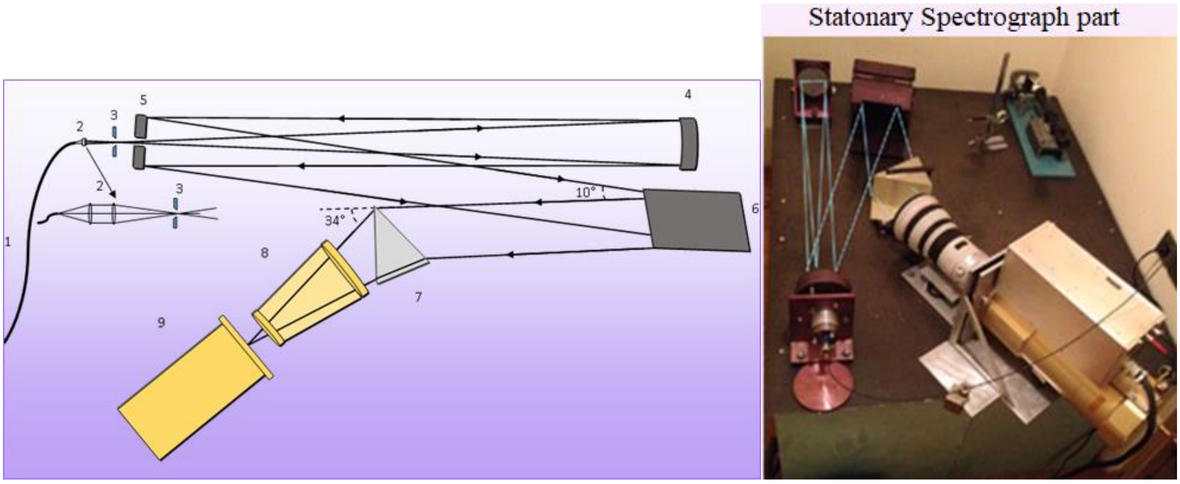
Spectrum of the galaxy NGC 2617 [11,12,13]. The dispersion at the line Hγ is 94 A/mm.

High resolution Shamakhy Fiber Echelle Spectrograph- SHAFES.

Designed for the Cassegrain focus of the 2-meter telescope. It is very important to equip telescopes with high-resolution spectrographs to solve modern astrophysical problems, as well as to join international projects (grants). One of the most advanced methods of improving the characteristics of spectrographs is the development of echelle- spectrographs with optical fiber (Fiber) input, which can be applied in practical astrophysics. The spectrograph was developed in 2015 and put into operation in 2016.

The spectrograph consists of 2 main blocks: a heavy stationary part in a separate room under the dome and a light hanging part attached to a telescope in the focus of Cassegrain. The blocks are connected by an optical fiber with a diameter of 200 microns and a length of 20 meters.

1. **Stationary Part.**



Optical circuit of the echelle spectrograph. Fiber *1* with a diameter of 200 μm and a length of 20 m, lens group *2*, entrance slit *3*, collimator *4*, plane mirror *5* with an aperture 10 mm in diameter, echelle grating *6*, cross-dispersion prism *7*, Canon objective *8*, and CCD camera *9* are indicated.

Optical characteristics of the stationary part of SHAFES:

1- Optical fiber - diameter 200 microns, length 20 meters. Numerical aperture N = 0.25

2- Lens system to match the output of the optical fiber with the focal ratio of the collimator, focal ratio 1:10

3- Entrance slit - the normal width of the slit is 75 microns in bining 1x1, 150 microns in bining 2x2. The slit can be easily rotated around the optical axis.

4- Collimator, focal ratio 1:10, f = 1000 mm, d = 100 mm. The presence of a 10 mm hole in the middle of the mirror allows you to place the exponometer on the back of the mirror.

5- Plane mirror, d = 100 mm, rotated about 5 °.

6- Echelle grating. The characteristics of this grating are as follows: size of 200 × 300 mm, 37.5 grooves/mm, and blazing angle of 64°. The grating is mounted at an angle of 26° to the horizontal plane for autocollimating operation. Its working surface faces downward in order to prevent the accumulation of dust on it. The echelle was rotated 5 ° perpendicular to the dispersion to send a beam of light dispersed vertically from the cage to the cross disperser.

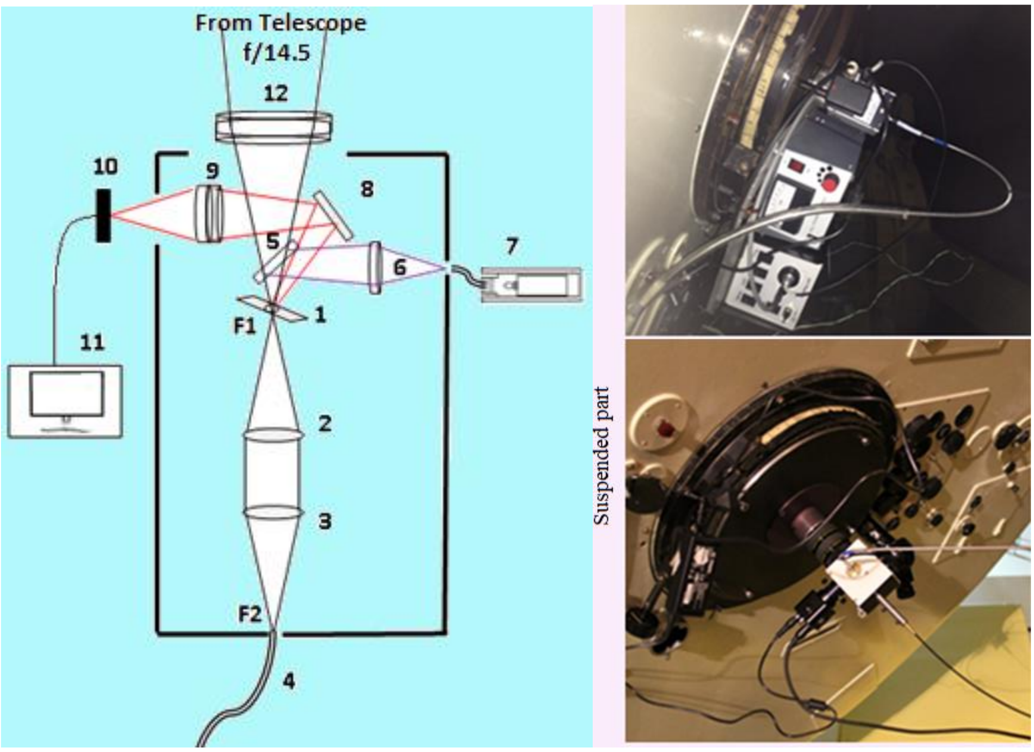
7- The cross-dispersion prism with a refraction angle of 45° was fabricated from dense flint glass. This element provides horizontal light dispersion needed to separate echelle orders. Its refraction index is 1.6444 in the red spectral region (dense flint) and 1.6852 in the violet region. This corresponds to a deflection angle of ~34°.

8- Canon lens objective 8 has an effective focal length of 400 mm and aperture F/2.8.

9- CCD camera cooled with liquid nitrogen, size 4096x4096 pixels, 1 pix = 15x15mic.

- All details are assembled on a solid table and each detail is provided with adjustment elements.
- The spectrograph is covered with a well-insulated cover.
- The room temperature is kept stable by a temperature sensor.
- A small computer cooler is placed in front of the CCD to prevent sweating.

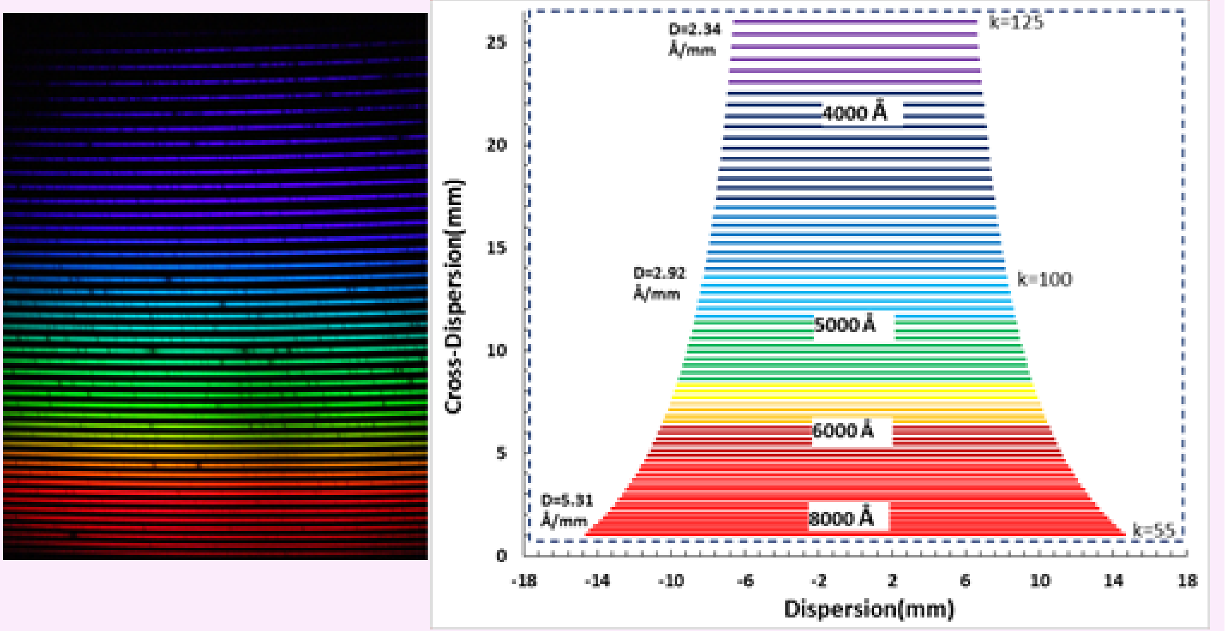
2. **Suspended part.**



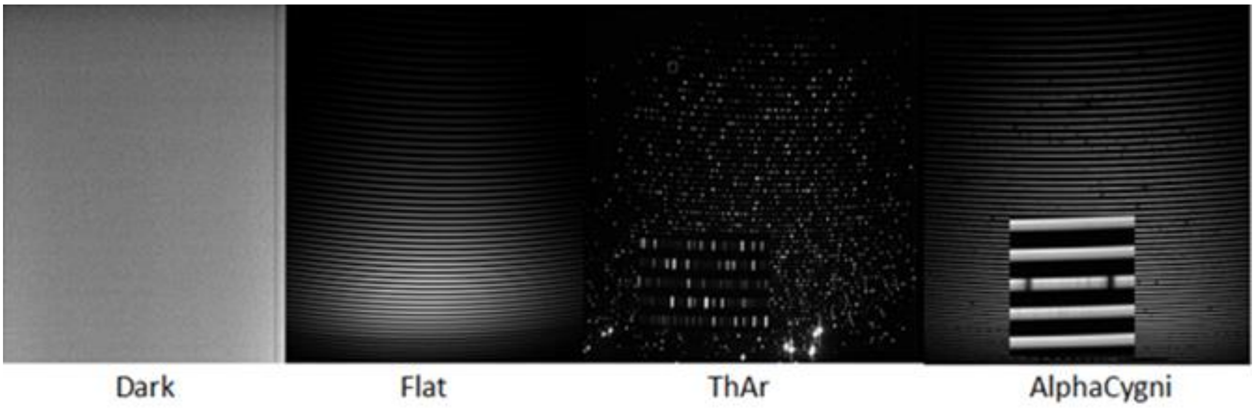
Schematic diagram of the suspended spectrograph part. Input aperture *1*, collimating lenses *2*, focusing lenses *3*, fiber *4*, movable diagonal mirror *5*, lens group *6*, calibration lamps *7*, diagonal mirror *8*, lens group *9*, television camera *10*, monitor *11*, and focal reducer *12* are indicated.

The suspended part features optical elements for matching the stellar image scale with the fiber size, the adjustment assembly with sources of continuous and discrete spectra, and monitoring aids for checking the object position at the fiber input. Figure 2 shows the schematic diagram of the suspended (prefiber) spectrograph part mounted at the Cassegrain focus. Movable mirror 5 for calibration lamps of continuous and discrete spectra, the fiber positioning system, and guiding television camera 10 are installed in this part. The observed image is formed in focal plane F1, where input aperture 1 is positioned. The relative aperture at the Cassegrain focus of the 2-m telescope is F/14.5. The beam from the 2-m mirror is collimated using one or two focal reducers 12 with relative aperture F/9 or F/6 beyond the focal plane by lens group 2 and in focal plane F2, where the input fiber part is located, by lens group 3. Input aperture 1 with a diameter of 200 μm is positioned on a reflective plate. Its linear size is 2.2″ and 3.5″ for focal reducers F/9 and F/6, respectively. Since typical images of stars are no smaller than 3″, the circuit with focal reducer F/6 was chosen to be the baseline design. The image of the studied star enters the fiber via aperture 1, and the field reflection from the aperture edges is guided to field viewing camera 10, which is also focused at the front surface of the aperture plate by plane mirror 8 and focusing lens 9. The image from the field viewing camera is used for guiding and is transmitted to monitor 11, which is installed in the observation room.

Artificial light sources 7 are mounted at the Cassegrain focus and used for wavelength calibration (hollow- cathode lamp filled with a mixture of gases) and to produce a flat field (halogen lamp). Light beams from these sources are focused and guided to the input aperture by a short fiber section, lenses 6, and mirror 5. The suspended part of the spectrograph is 50 × 50 × 100 mm in size and has a mass of ~1 kg.



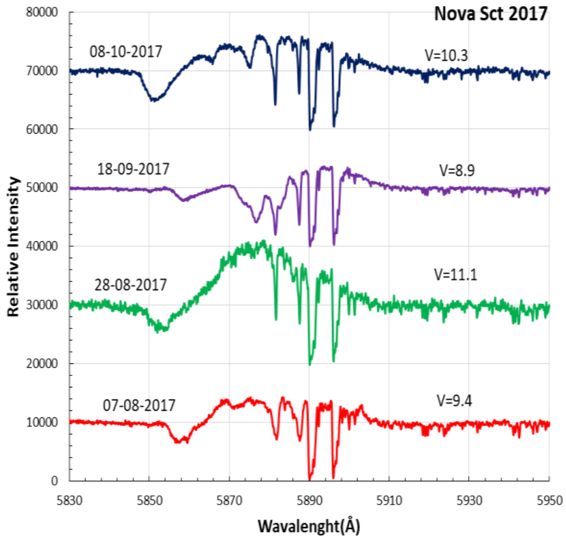
The output format of the Shamakhy Fibre Echelle Spectrograph.

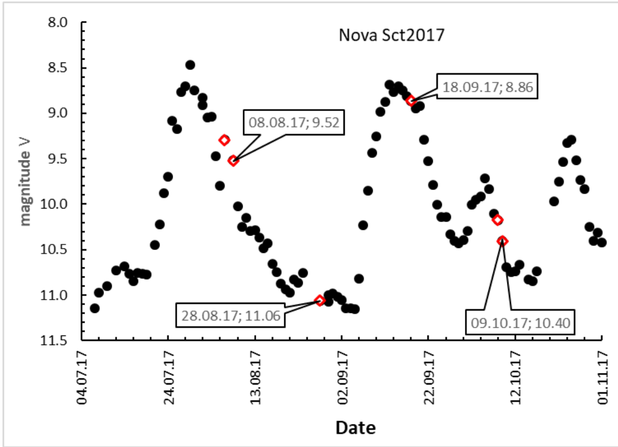


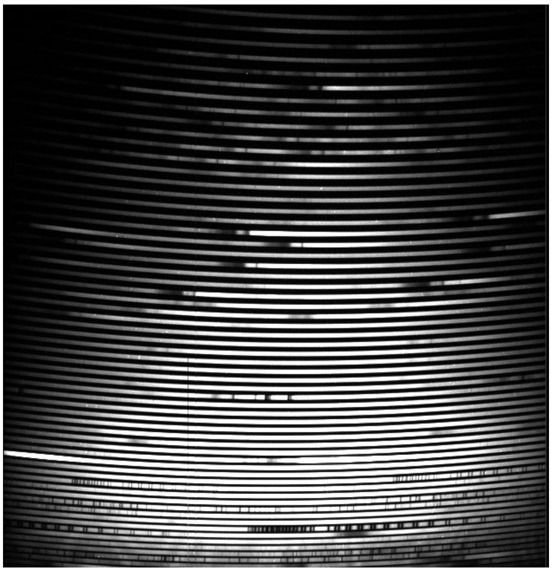
Fragments of different types of images: dark, flat, ThAr, and α Cyg.

The penetrating power of the spectrograph.

Test observations demonstrate that the spectrograph is capable of measuring spectra of 8^m and 11^m stars with a signal-to-noise ratio of S/N = 150–200 at λ = 580 nm with a 1-h exposure, a 2–3″ image, and resolution R = 55000 and 27500, respectively.







Fragments from the spectrum of Nova Sct 2017

The importance and advantages of this spectrograph are as follows:

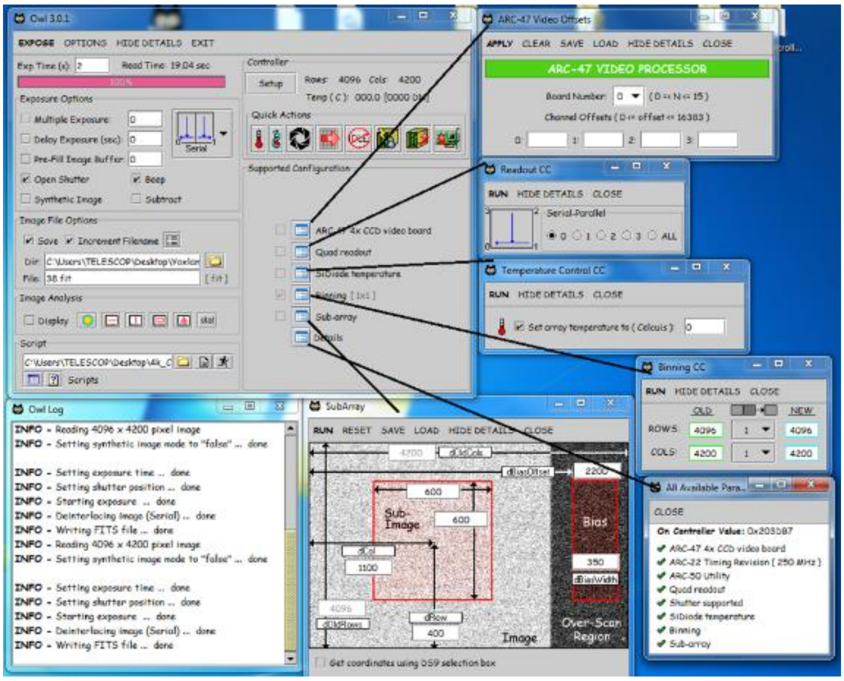
- Allows to obtain high-resolution spectra of celestial bodies in the cassegren focus of the telescope. The spectrograph operates in two modes ($\Delta\lambda/\lambda$ = 55000 and 27500) and can easily switch from one mode to another in a few seconds.
- Due to the fact that the spectrograph is stationary and closed, as well as the light of the object under study and calibration lamps are transmitted to the same channel, there are no instrumental shifts and the measurement accuracy of spectral parameters is high (error for radial velocity 50-100 m/s, equivalent width 1-5%)
- The spectrograph uses a large CCD camera cooled with liquid nitrogen with a size of 4000 x 4000 pixels as a light receiver, and as a result it is possible to obtain a very wide wavelength range of the spectrum (λ9000-3600 Å) at the same time in -1 frame.
- During the spectrograph observation, the process of tracking a star in a 2-meter telescope is automated and the image is transmitted directly to the monitor in the observation room.

CCD Camera 4096x4096 pixel.

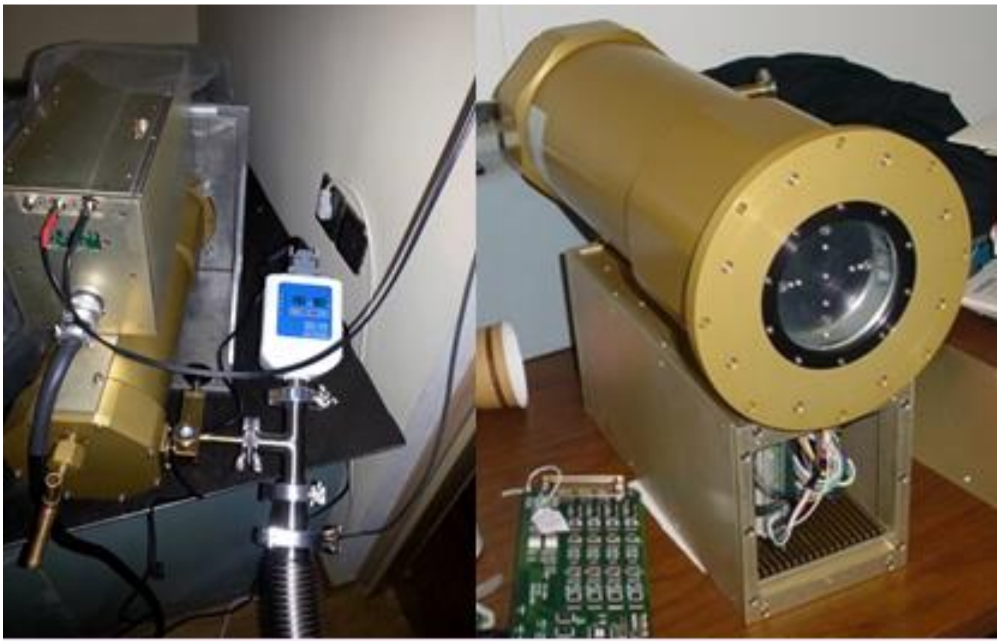
The STA4150A CCD camera produced by Semiconductor Technology Associates was used as a photodetector. The camera is a 4096 × 4096 image array cooled by liquid nitrogen with pixels 15 μm in size. The CCD sensor is cooled to the certain temperature, which may be chosen within the interval from –110°C to –145°C, and the selected temperature is controlled with accuracy of ±0.1°C. The recommended temperature for the actual observations is –120°C. The cooling system has a volume of 3 L and remains operational for at least 24 h between nitrogen refills. The CCD camera has an antireflective coating, and its quantum efficiency is maximized in the 300–800 nm range. Figure shows the wavelength dependence of the quantum efficiency of STA4150A. It follows from these data provided by the manufacturer that the quantum efficiency exceeds 70% in the 300–800 nm range. It should be noted that this photodetector has high quantum efficiency in the near UV range (as high as 90% at 400 nm). The high linearity of the output signal, which is maintained through to the level of 65000 counts, also sholud be noted

Key parameters of STA4150A are as follows: 4096 × 4096 pixels, 15 × 15 μm pixel size, 61.44 × 61.44 mm photosensitive area size, and 300-900 nm operating range. The full-frame readout time is 6.5, 19, and 40.7 s in the fast (FST), medium (MED), and slow (SLW) modes. The gain and the readout noise (RON) are 1.27 e–/ADU and 3.74 (SLW), 2.24 e–/ADU and 4.8 (MED), and 2.0 e–/ADU and 7.3 (FST). The measured dark current is 4 e– pix–1 h–1. A 15-m-long fiber cable is used to control the camera and transfer data to a PC.

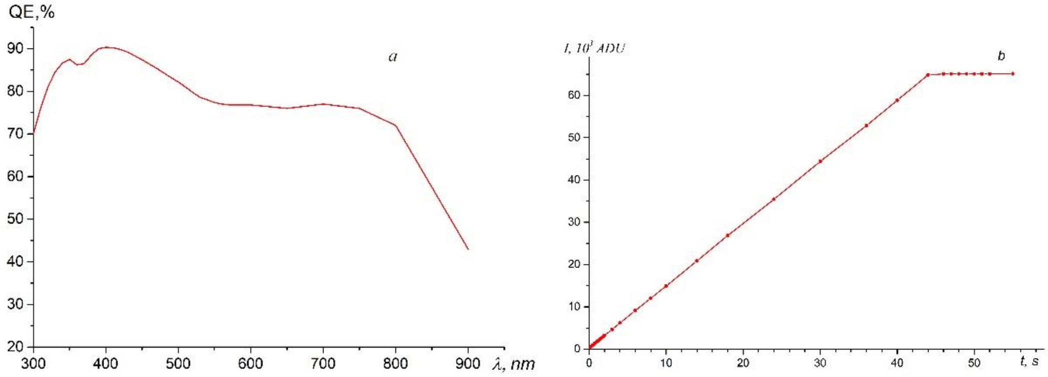
CCD control (chip cooling temperature, exposure transfer), image acquisition and conversion, chip format selection, binning are performed by Owl 3.0.1 program. Images are taken in .fit (Flexible Image Transport) format.



General view of Owl 3.0.1 programm.



General view of 4x4 k CCD camera



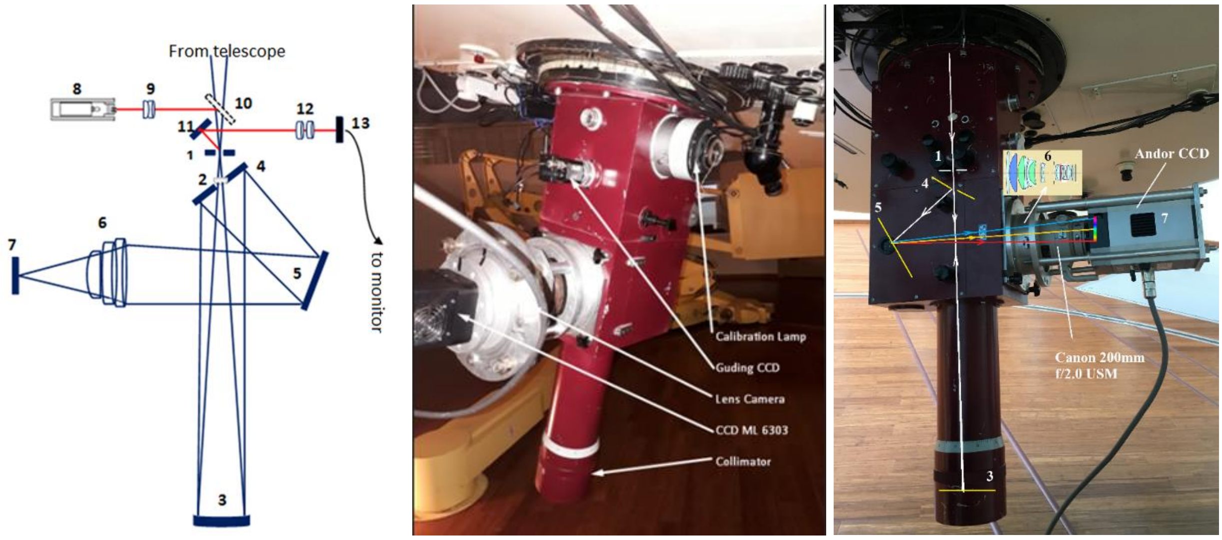
(a) Wavelength dependence of the quantum efficiency of the CCD sensor at T = –120°C.
(b) Linearity of the CCD response.

Universal Spectrograph with Variable Diffraction Cage + CCD.

This observational complex was designed for spectral observations at the Cassegrain focus of a 2-meter telescope. It is developed on the basis of the UAGS (Universal AstroGrating Spectrograph) spectrograph. In the classical version, such spectrographs used photographic plates as light receivers. CCD-matrices have been used as light receivers in astronomy (both spectral and photographic observations) for several decades. Due to the large size of CCDs, it is not possible to use them as a light receiver in the internal foci of the spectrograph. The UAGS kit includes 3 cameras, two of which are internal and one is Schmidt-Kassegen camera with external focus. The external focus is only 13 mm from the rear surface of the camera. The chip of professional CCD cameras is mainly located at a depth of 20 ÷ 30 mm from the opposite surface. Therefore, it is not possible to use CCD cameras in such spectrographs. This system uses 2 cameras - Uranium-9 250 mm f/2.5 and Canon EF 200mm f/2.0.

With the help of medium and small telescopes, which dominate the world's observatories, it is impossible to observe faint astrophysical objects of great scientific importance at critical stages of stellar evolution on high-resolution spectrographs.

Universal spectrographs of the UAGS type with a low resolution in combination with CCDs are indispensable for medium-sized telescopes in the spectral study of faint astrophysical objects (galaxies, quasars, symbiotic stars, such as Ae-Be Herbig, etc.).



Universal diffraction grating spectrograph. 1- entrance slit-telescope focal plane; 2- lens for collimator; 3-collimator; 4-Flat mirror; 5-grating; 6-spectrograph lens camera; 7-CCD camera; 8-calibration lamps; 9-calibration lens; 10-movable mirror; 11-flat mirror for guiding; 12-guiding lens; 13-Guiding detector

Optical characteristics of the spectrograph:

Collimator - focal length f = 1100 mm, diameter d = 75 mm.

Camera 1 - Uranus-9, f = 250mm, aperture f / 2.5, efficiency factor 0.65, Optical system - lens 4 7 elements in the group, angle of view 64º [14],

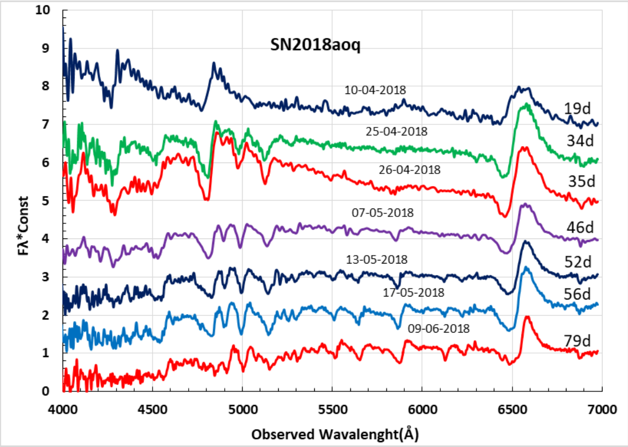
CCD - FLI ML 6303, 2048 x 3056 pixels, 1 pixel = 9 mic.

Spectral region - λλ4000÷7000Å, Dispersion - 115Å / mm, 60Å / mm

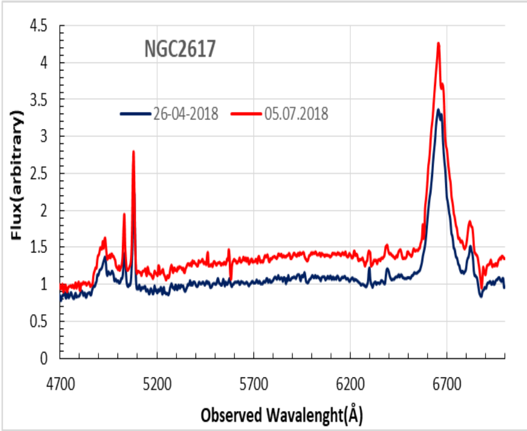
Camera 2- Canon EF 200mm f / 2.0 L IS USM, efficiency factor 0.90, Optical system - lens 12 17 elements in the group, Fluorite lens - 1 piece, UD (ultra dispersion) - 2 pieces, angle, of view -12º [15].

CCD - Andor CCD camera, iKon L 936, BEX2 - DD, 2048x2048 pixels, Spectrograph + The new version of the CCD system can work in a wide range of wavelengths, in different spectral resolution modes using separate diffraction grids. The variance in the wavelength range λλ 3800-8000 Å is 144 mm / mm, 75Å / mm, the variance in the wavelength range λ 3800-5300 Å is 25 Å/mm, and the variance in the wavelength range λ 5000-8000 Å is 30 Å/mm.

Examples of spectra obtained in UAGS + Uranium-9 + CCD FLI system:



Spectrum of the extreme new star SN 2018aoq [16]



Spectrum of the galaxy NGC2617

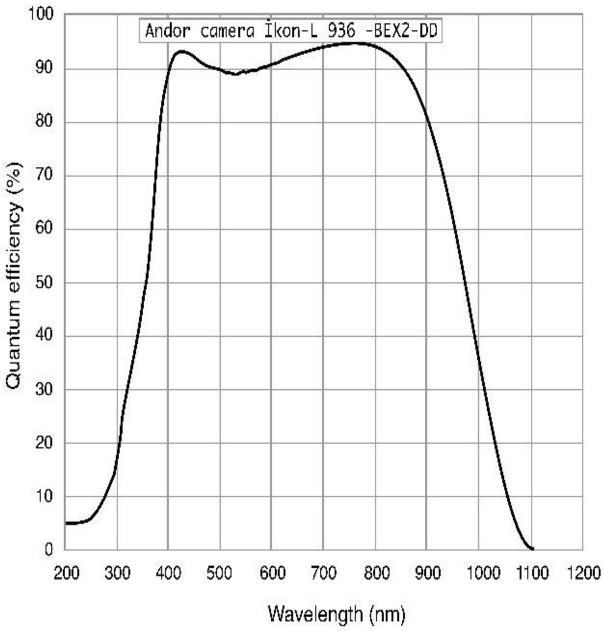
Universal Spectrograph with Variable Diffraction Grating

light receiver- Andor CCD camera.

Characteristics of the Andor CCD camera:

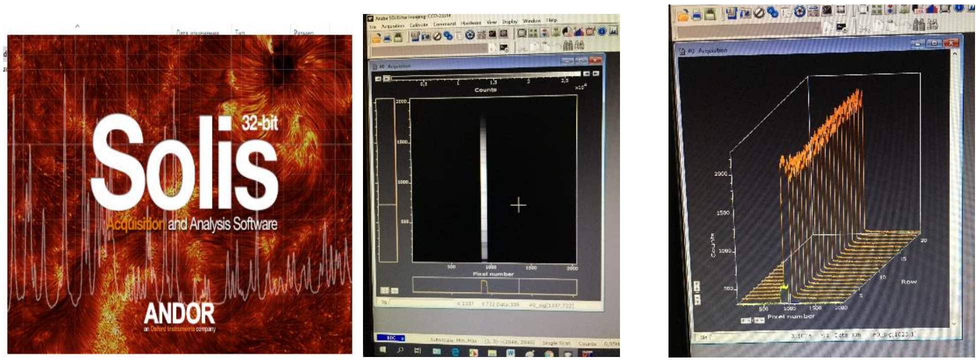
- Type - iKon L 936
- Fringe Suppression Technology - BEX2 - DD
- Size– 2048x2048, 1 pixel = 13.5 mic. 27.6x27.6 mm
- RON (Read out noise) - 2.9 e-
- Dark current -80 ºC, - 0.006 e- / pixel / sec
- 5-stage peltier cooling, with air -80 ºC, with air + water -100 ºC

Andor CCD camera + Canon EF 200mm f / 2.0



Andor camera iKon-L 936-BEX2-DD, Quantum efficiency

Andor (icon L-936-BEX2-DD) CCD camera control (exposure, cooling mode selection, chip format, etc.) is performed by the software Solis.

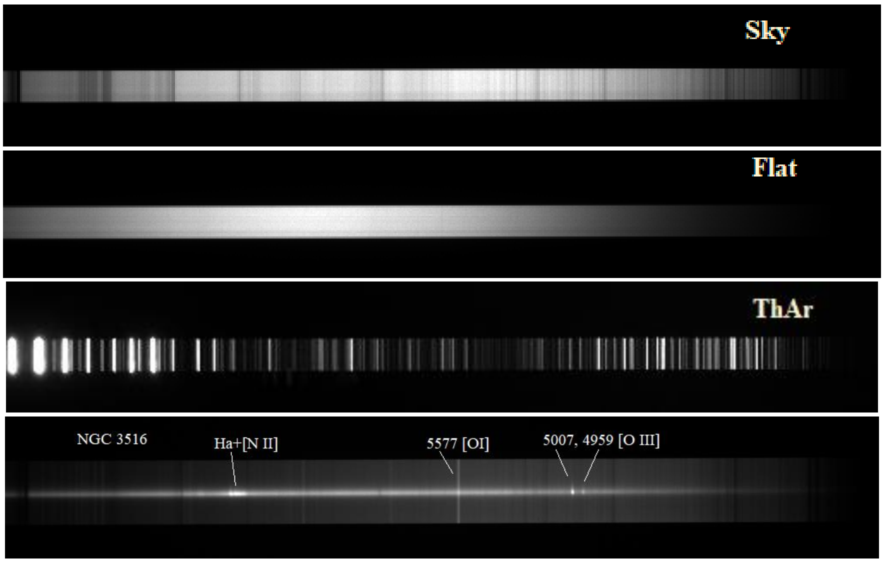


General view of the Solis program

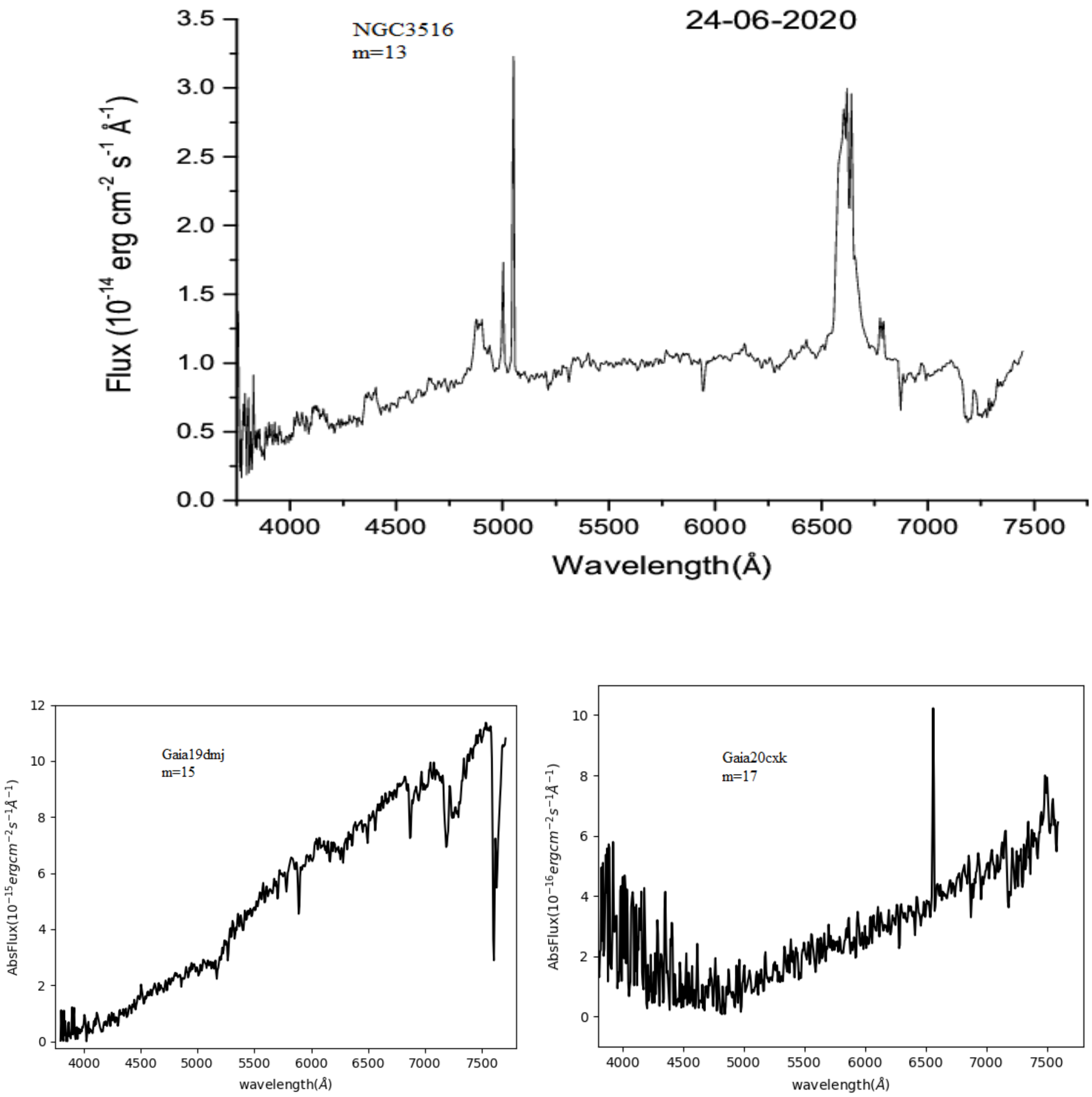
The main advantages of the new spectrograph + CCD system are:

- The Canon lens is completely free of color aberrations thanks to ultra-low dispersion and fluorite lenses, so the entire spectral region is in focus at the same time.
- In the process of observation, it is possible to switch to different spectral resolution modes in a short time by changing the diffraction grating.
- Andor (ikonL-936-BEX2-DD) CCD camera has a 5-layer electronic cooling system. The chip can be cooled to -80 ºC by air and -100 ºC by using air + water.
- The Andor (icon L-936-BEX2-DD) CCD camera has a smooth sensitivity curve over a very wide wavelength range (λ4000 ÷8000 Å) and is above 90%.
- The spectrum is completely free of hot pixels and fringes.

Examples of spectra obtained in UAGS + Canon + CCD Andor system:



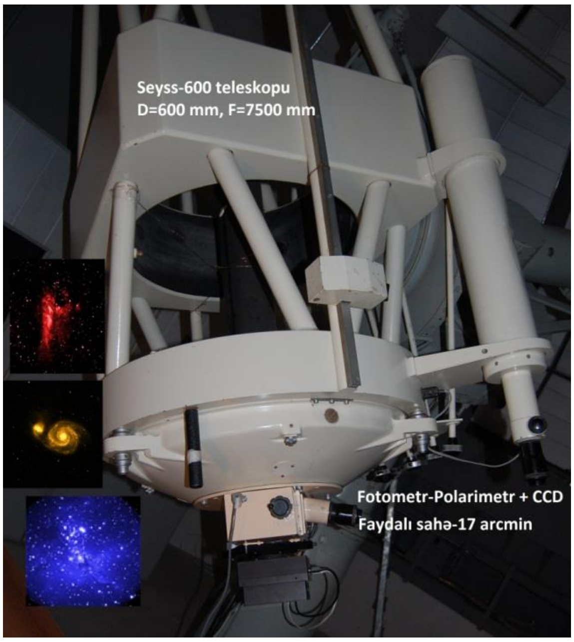
Images from different types of spectra



Spectrograms of different types objects

Zeiss-600 telescope.

Manufactured by the company Carl Zeiss JENA (Germany). It was installed and put into operation in 1982. The telescope is used for photometric studies of stars and galaxies. The telescope's optical system is the classic Kassegren system. It is a completely non-aberration mirror system consisting of a primary parabolic mirror and a convex hyperbolic cassegren mirror. The focal length of the primary mirror is F = 2400 mm, the effectiv focal length of the Cassegrain system is F = 7500 mm. The diameter of the primary mirror is D = 600 mm, the diameter of the Cassegrain mirror is d = 183 mm, the focal length is f = -1030 mm. In the focal plane of the telescope, the scale is - 27.5 ″/mm.



Zeiss-600

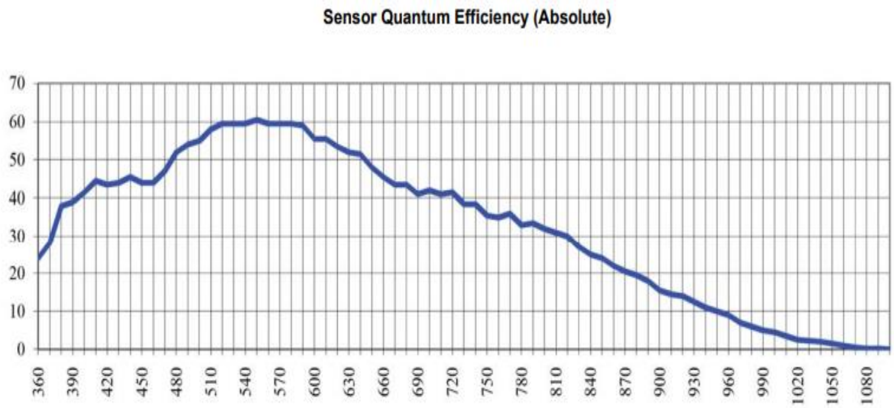
Observations at the telescope have long been carried out by electrophotometer, and now, with the financial support of the Science Development Foundation under the President of the Republic of Azerbaijan, developed in accordance with the optical system of Zeiss-600 telescope, equipped with an international photometric system filter set (B, V, Rc, R, J) multifunction photometer is carried out by means of a polarimeter (useful area 17 arcmin) [17]. The FLI CCD camera (electronic cooling) with a size of 4000x4000 pixels (1pix = 9 mic) is used as a light receiver.

In recent years, the telescope has performed CCD photometry of young stars of medium (UX Ori type) and large (Wolf-Raye type) stars and various types of galaxies, taking more than 5,000 multicolor digital images of them.

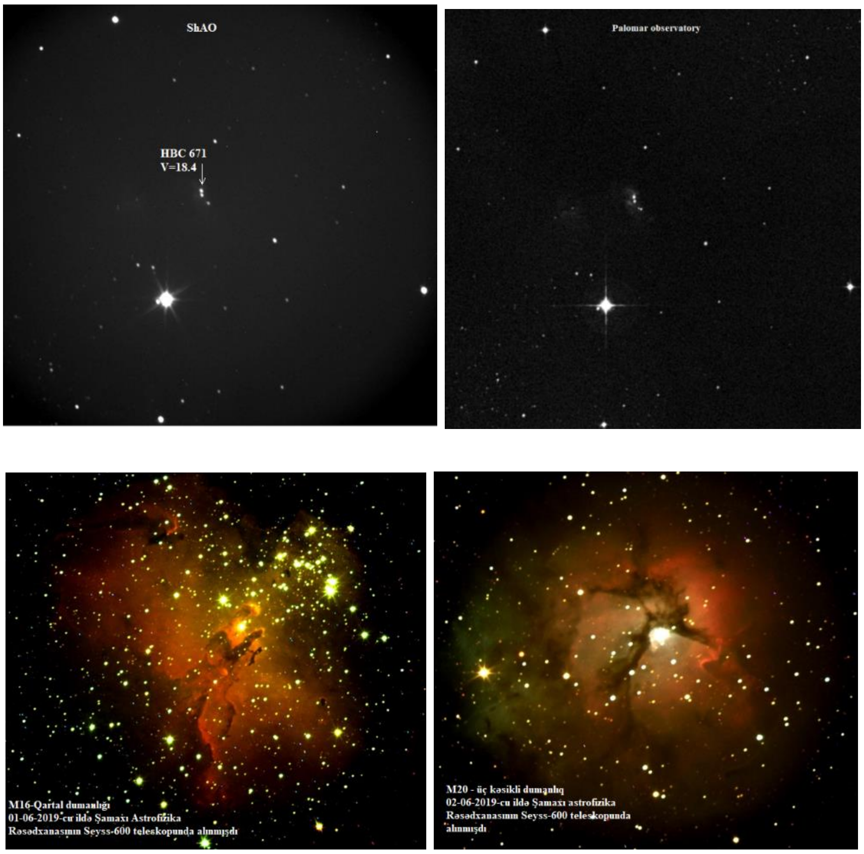
The telescope can operate in two modes of focal ratio f/12.5 and f/8. Using a focal length reducer, the telescope's light output can be increased 1.6 times. This allows photometric observations of celestial bodies up to 19 m in size in the telescope. The focal reducer can be easily inserted into the optical axis and removed from the optical axis by means of a special drill during the observation process.

CCD FLI 4096x4096 pix.

Chip - KAF -10803, size - 4096x4096 pix, 1 pix = 9x9 microns.



CCD FLI 4096x4096 pixel, Quantum efficiency CCD FLI



Examples from the pictures taken at the Seiss-600 telescope

Telescope "AZT-8"

The telescope was developed by the Leningrad Optical-Mechanical Association. The telescope was installed in 1970. The telescope has two mirrors and the Cassegrain optical system. The primary mirror is parabolic and has a diameter of 700 mm and a focal length of 2820 mm. The focal length of the first Cassegrain system is 11200 mm and the relative aperture is F/16 and the field of view is 40 ', the scale is 18 ″/mm. The focal length of the second Cassegrain system is 28000 mm, the field of view is 18 ', the scale is 7 ″/mm, and the relative aperture is F/40. The telescope is equipped with a 5-filter CCD photometer for photometric observations of stars and galaxies (field of view 8 arcmin.), And an ASP-21 spectrograph with a dispersion of 30 Å / mm to obtain the spectrum of bright stars. The telescope was actively used in photoelectric photometry, polarimetric and spectrophotometric observations of celestial bodies.

Modernization of the AZT-8 telescope can solve a wide range of astronomical problems as:

- regular acquisition of echelle spectra with medium resolution of bright stars
- observations of space objects of artificial origin (space debris);
- Observation of gamma rays after ignition;
- Danger of the asteroids approaching the Earth.

Meniscus telescope AST-452

The AST-452 meniscus telescope is a Maksutov mirror-lens telescope. Designed for photographic observation and installed in 1964. The optical design is a classic meniscus optical system. developed by D.D. Maksutov. Since the telescope is very compact and enclosed, the image is very high quality. The telescope was manufactured at the Kazan Optical and Mechanical Plant. The telescope is equipped with a meniscus and field bending lens and objective prisms with refraction angles of 15° and 35° 40'. Since they are made of ultraviolet glass, spectral and photometric observations can be carried out in the near ultraviolet (3400 Å) region. The diameter of the aperture (meniscus lens) is 350 mm, the diameter of the mirror is 490 mm, the focal length of the telescope is 1200 mm. The scale on the focal surface of the telescope is 2.86′/mm. The focal ratio is f/3.4. The telescope can work in 2 focus: primary and Newtonian. The field of view in the primary focus is 4° 14', the linear size of the field is 90 mm, and in the Newton focus it is 2° 52' and 60 mm, respectively.

The telescope is indispensable for the spectral classification and photometry of star clusters, as well as for the search for new and supernova stars, comets and asteroids.

AZT-8

AST-452

Azimuth Coelostat Plant ASQ-5 (Horisontal solar telescope)

The telescope was installed in 1963. İt is used for the spectral and photometric investigation of the Sun. The diameter of its coelostat secondary and primary mirrors is 440 mm, the diameter of Newtonian mirror is 200 mm, the Newtonian focal 3 length is 17 500 mm, and equivalent focus distance in the Cassegrain system is 60 540 mm. The telescope was equipped with two cameras for the direct photography in primary and Cassegrain focus as well. The Newtonian focus is used for the spectral and magnetic observations. The telescope was equipped with ASP-20 spectrograph working inautocollimated regime (focal length is 7000 mm). Rating of 150-200 square mm ruled area and 600 lines mm. Dispersion in the second working order is 1.12 Å/mm and spectral field is 360 Å, diameter of the image is 160 mm is used for the obtaining of spectrograms of solar flares, for visual observations of the magnetic fields of sunspots, studies on the development and dynamics of coronal prominences and spicules, fine structure of the solar spectral lines.

Horisontal solar telescope

Chromosphere photospheric telescope AFR-3

İt was installed in 1957. This telescope was used for the solar patrol more than 35 years, the diameter of the photospheric tube objective is 200 mm and the equivalent focal length is 9 000 mm the diameter of the chromospheric tube is 130 mm and the focal lengths are 6 000 and 2 000 mm the diameter of an image is 100 m. with the help of the polarization interference filter (band width is 0.5A) the chromospheric patrol and patrol of other active formations on the Sun were carried out. With the help of photospheric tube the solar photosphere was observed.


Chromosphere photospheric telescope AFR-3

Auxiliary devices for the telescopes

1. **Turbomolecular Vacuum Pump CDK 180.**
   The functional units for generating high and ultra-high vacuums are completely mounted in a housing. The individual components are perfectly matched to one another. The SST turbomolecular pump is equipped with dry-running, solid-lubricated hybrid rolling bearings (ceramic balls) which prevent the vacuum being contaminated by greases, oils or their decomposition products. This means that the design excludes residual hydrocarbon gas spectra. CDK turbomolecular pump systems are compact and dry running. The automatic shut-off system stops the backing pump when the required final vacuum is reached. Ultimate pressure 5×10^{-7} mbar

Turbomolecular Vacuum Pump CDK 180

2. **Liquid Nitrogen Plant LNP-20.** Compact nitrogen liquefiers LNP from a well-known American manufacturer - Cryomech Inc. (USA) for the production of liquid nitrogen from atmospheric air. Liquid nitrogen production rate ≥ 20 liter/day (0.8 liter/hour).
   Liquid nitrogen generators operate in automatic mode, do not require constant operator presence and are very reliable in operation. The production of liquid nitrogen requires only air and electricity. Nitrogen gas is produced by compressing, purifying and further separating air on a nitrogen membrane. After separation on a membrane or PSA unit, nitrogen with a purity of 98% (optionally 99% or 99.99%) enters the Dewar vessel, where it condenses at a pressure close to atmospheric on a cold heat exchanger of a cryogenic refrigerator. Liquid nitrogen is withdrawn from the Dewar through a flexible cryogenic hose when the liquid nitrogen supply valve is opened.

Liquid Nitrogen Plant LNP-20.

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