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New optics of the 1.25 m telescope AZT-11 of the Crimean Astrophysical Observatory

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ABSTRACT

The AZT-11 telescope was put into operation in 1981. Over 40 years, the telescope primary mirror has been repeatedly recoated with aluminium. As a result, the mirror surface quality has substantially degraded, causing an increase in instrumental polarization among other adverse effects. Taking into account the parameters of the original telescope system (F = 16 m), which are poorly fit to modern light detectors, as well as the availability of a CO-115 sitall blank of appropriate size, a new optical system was designed and manufactured. We present data on the new optical system and discuss challenges during its development and manufacture, as well as the techniques and methods employed.

Key words: telescope, optical system, modernization

1 Introduction

In the mid-1950s, when a photographic plate was the principal detector in astronomy, Prof. V.B. Nikonov, Head of the Department of Stellar Physics, had the idea of creating a telescope equipped with a photometer and a spectrophotometer. After consultations with the department staff, the following basic requirements for the new telescope were formulated: high optical resolving power, ease of operation, high pointing accuracy, the ability to switch rapidly between observing modes, and full automation. As a result, the design bureau of the Leningrad Optical and Mechanical Association (LOMO) developed a telescope designated as AZT-11.

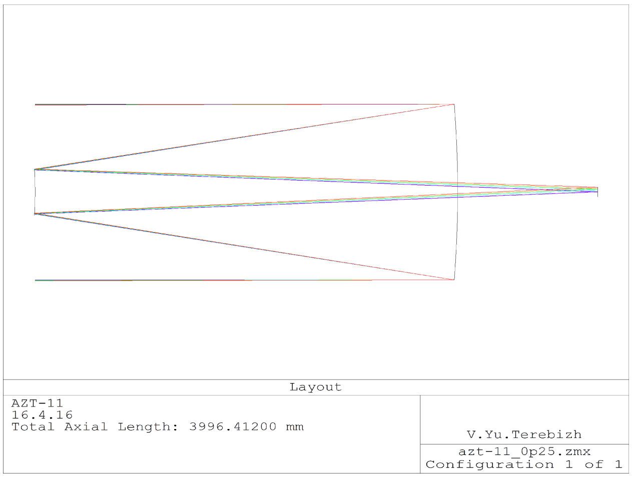


Fig. 1. Standard (nominal) optical design of the AZT-11 telescope.

The AZT-11 reflector with an aperture of $D = 1.25$ m was manufactured by LOMO and commissioned in 1981. The optical design of the telescope (Fig. 1) is a Ritchey–Chrétien system comprising two hyperbolic mirrors with eccentricities defined by first-order parameters and equivalent focal length F. The principal characteristics of the standard optical system are listed in Table 1.

Table 1. Principal characteristics of the standard optical system of AZT-11.

Aperture diameter	1250 mm
Equivalent focal length	15984.1 mm, $f/12.8$
Field of view diameter	15′ (70 mm)
Image scale	77.5 μm/″
Squared eccentricity of the primary mirror	1.04180
Diameter of the secondary mirror	350 mm
Squared eccentricity of the secondary mirror	3.17908
Mirror separation	3001.4 mm
Image offset behind the primary mirror vertex	995.0 mm
Total length of the optical system	3996.4 mm

A classical two-mirror system comprising a parabolic primary mirror and a hyperbolic secondary mirror provides subarcsecond image quality over a field of only a few arcminutes (Maksutov, 1946; Mikhel'son, 1976; Terebizh, 2019). Hyperbolization of the primary mirror in the Ritchey–Chrétien system extends the field of view to approximately 15′. This is shown for the telescope under consideration in Fig. 2.

Concurrently with the telescope, LOMO developed the attached instrumentation: a photometer and a spectrophotometer. Over 20 years passed between the telescope order

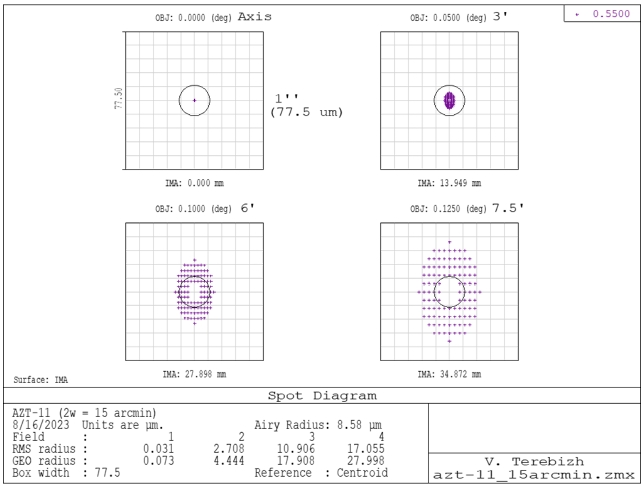


Fig. 2. Images of a point source within a 15′ field of view for the standard optical system of AZT-11. Circles indicate the diffraction Airy disk; the side of each square corresponds to 1″.

and its commissioning, resulting in the fact that both instruments had become technologically obsolete. In 1982, a five-channel photopolarimeter designed by V. Piirola (1975) was installed at the Cassegrain focus and served as the standard instrument for more than 40 years. In 2005, taking into account the range of scientific tasks solved by the Department of Stellar Physics, a CCD photometer was installed at the Nasmyth focus. Given the large focal length of AZT-11, a focal reducer is placed in front of the photometer.

2 Problem formulation

The necessity of creating a new optical system for the AZT-11 telescope arose primarily from the fact that after nearly half a century of operation, the mirror surfaces had undergone significant degradation, leading to a substantial increase in instrumental polarization. The restoration of large aspheric surfaces is an extremely challenging task, and in this case it would be unreasonable to solve it since the nominal optical system does not fit modern detectors: the equivalent focal length of the telescope, 16 m, is too long.

There was a blank of sitall CO-115 of appropriate size that remained since the 1980s at CrAO RAS. This allowed considering the manufacture of a new optical design for AZT-11.

The principal requirements for the new optical design were as follows:

1) to achieve the focal length $F \sim 12$ m ($\sim 58\ \mu$m/″ scale);
2) to preserve a flat field of view with a diameter of 2w $\sim 15'$;
3) to ensure observations in the U band (0.34–0.38 μm);
4) to perform calculation accounting for the available sitall blank for the primary mirror and other types of glass for manufacturing the remaining optical elements of the system;
5) to significantly simplify the optical elements (with regard to the shape and steepness of the optical surfaces), taking into account the capabilities of the optical and mechanical workshops of CrAO RAS;
6) to match the new optical system to the existing mechanical structure of the telescope.

In addition, it was necessary to design and then manufacture auxiliary optical systems. This requirement arises from the need to employ the so-called compensator for controlling aspheric surfaces during their manufacture. Indeed, a sphere generates the diffraction image of a point source located at its center, which is required for controlling; whereas in case of the aspheric surface, an auxiliary optical system – a compensator – must be attached to it, having precisely the same magnitude of aberration but of opposite sign as the aspheric surface tested.

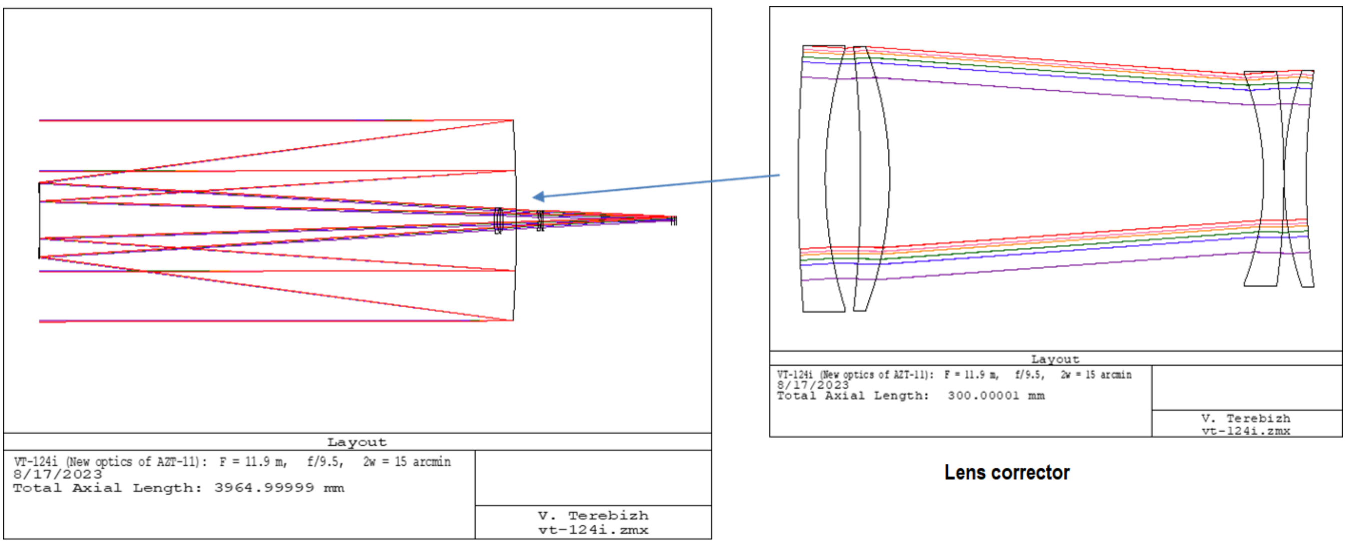


Fig. 3. Optical layout of the VT-124i system (left) and its four-lens corrector (right).

3 Principal results

As a result of discussions of the scientific tasks that are planned to be resolved with AZT-11 and after numerous calculations and searching for the optimal optical system of the telescope, the VT-124i layout was chosen. The optical layout of the new telescope system, VT-124i, comprises two mirrors – primary and secondary – and a four-lens corrector located near the vertex of the primary mirror (Fig. 3).

The principal merit of this layout is the simplicity of optical surfaces. The only aspheric surface is the primary mirror, which is a paraboloid of moderate focal ratio $f/3.8$. A unique feature is the spherical shape of the secondary mirror surface at $f/6.7$. It is well known that controlling convex aspheric surfaces requires sophisticated means and complex auxiliary optics; in this case, the problem of controlling is radically simplified. The four-lens corrector with all spherical surfaces is compact: the maximum lens diameter is 157 mm, the corrector length is 300 mm, and all lenses are made of the basic K8 glass.

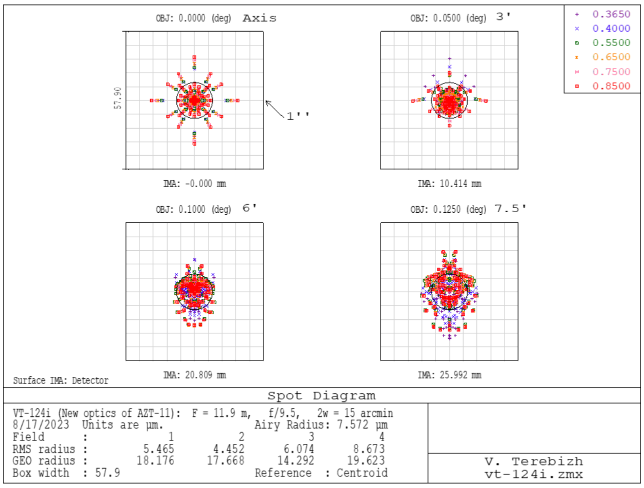


Fig. 4. Images of a point source within a 15′ field of view for the VT-124i optical system. Notation as in Fig. 2.

In the new optical system, the effective focal length of the telescope has been reduced to ~ 12 m (previously 16 m), the corresponding focal ratio is $f/9.5$ (previously $f/13$), and the image scale is 57.9 μm/″ (previously 77.5 μm/″). The integral geometric characteristics of the layout are more than satisfactory: the mirror separation is 2970 mm against a nominal value of 3001 mm, the focus offset is 995 mm at the same nominal value. The 31 mm difference in mirror separation falls within the range of the standard adjustment of the secondary mirror. Preserving focus offset means that the position of the attached equipment for observations remains unchanged.

In the optical calculations, image quality was optimized within the spectral range $\lambda\lambda$ 0.365–0.85 μm; however, a broader wavelength range is accessible for observations, particularly in the long-wavelength domain. As shown from comparison of Figs. 2 and 4, the computed image quality of VT-124i within the field of the same angular size of 15′ exceeds the nominal one, approaching the diffraction limit. The root-mean-square diameter of the images of a point source is $D_{\rm rms} < 17.4$ μm (0.30″), and the diameter of a circle that includes 80% of energy is $D_{80} < 31.2$ μm (0.54″). Finally, the image distortion in integrated light does not exceed 0.2%.

Once the new optical layout had been approved, manufacture started. All optical elements of the new system – two mirrors, four lenses of the corrector, and three lenses of the compensator – were manufactured at CrAO by opticians Ya.N. Chernykh and V.N. Skiruta. The components of the new secondary mirror cell and baffles for the primary and secondary mirrors were manufactured in the mechanical workshops of CrAO by mechanics V.N. Zubko, L.T. Mushchinkin, and A.N. Stepanov, with the active participation of chief engineer A.V. Dolgopolov.

The main challenges were associated with the manufacture of the 125 cm paraboloidal primary mirror. As noted above, an appropriate aberration compensator is used for the constant controlling of the surface shape during the manufacture process. For decades, the Offner compensator was employed in international practice; however, following the fault in the manufacture of the Hubble Space Telescope, it became apparent that the use of this compensator had led to analogous errors in numerous other projects. Therefore, a new-type compensator (Terebizh, 2014) was employed for controlling the primary mirror, which allows one to perform preliminary verification of the manufacture and assembly quality of its own optical components and then to install the compensator into the control layout for the mirror surface (Fig. 5) with the required accuracy using optical methods.

To control the manufacture of the primary mirror, a three-lens compensator was designed; according to this design, an unequal-arm laser interferometer was developed for controlling in a horizontal layout, with the mirror tested being on the tool faceplate, rotated 90 degrees relative to the faceplate rotation axis (Fig. 6).

The null-corrector lenses were also manufactured and tested in the optical workshop, and the cell with the adjustment system for precise null-corrector positioning was manufactured in the mechanical workshop of CrAO.

The interferometer design employs a stabilized He-Ne gas laser at wavelength $\lambda = 632.8$ nm and a long coherence length, which enables acquisition of high-contrast interference patterns with a well-defined system of interference bands. A point light source is formed in the interferometer using a lens system and a micro-objective. The light then falls on a beam-splitter plate; part of this light is deviated onto the mirror tested, while the remaining part passes to the reference mirror. Being reflected from both mirrors, it is collected at the centers of mirror curvature. When these images are superimposed, an interference pattern is formed. The null-corrector allows one to use a reference wavefront from a precise spherical mirror.

In the final stage, when approaching calculated parameters, the current state was controlled after each polishing session. The surface quality achieved is illustrated by the interferogram shown in Fig. 7.

The secondary mirror (SM) in its new cell is installed at the central hole, which allows eliminating the need for thermally compensated radial supports (Fig. 8). The thickness of the SM was chosen to ensure rigidity and to eliminate the need for edge supports. This led to a reduction in cell weight and manufacture effort. The SM cell design enables

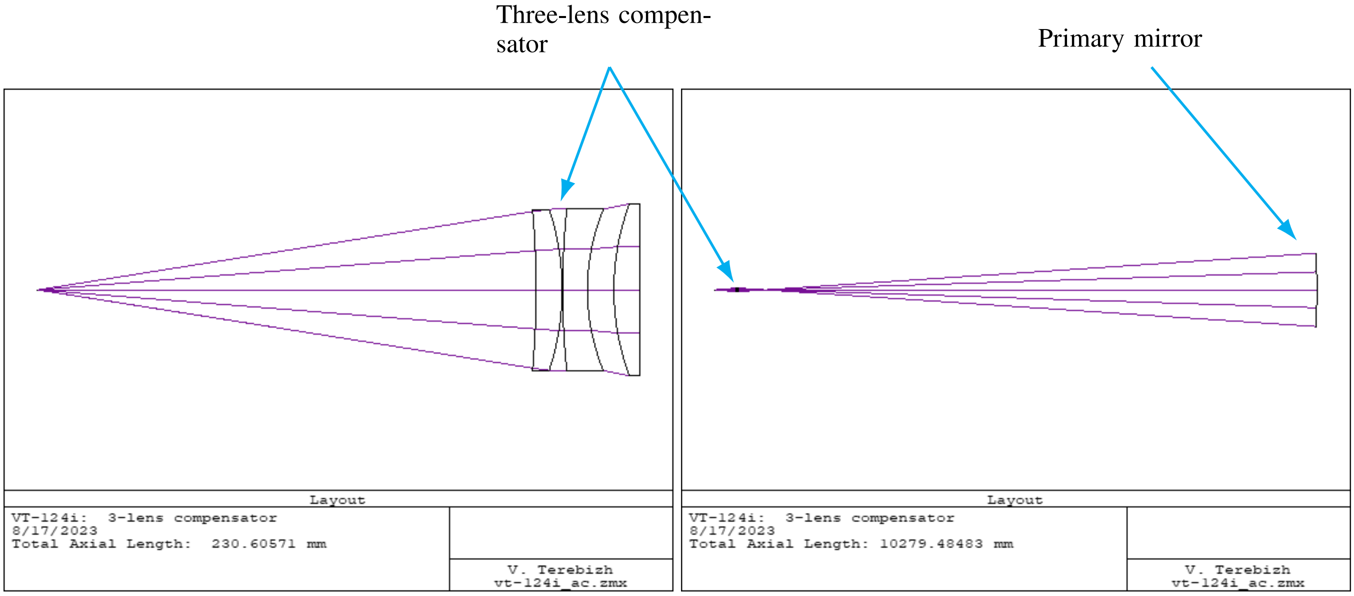


Fig. 5. Layout for the preliminary verification of the manufacture and assembly of the three-lens compensator (left) and its installation into the control layout for the primary mirror surface (right).

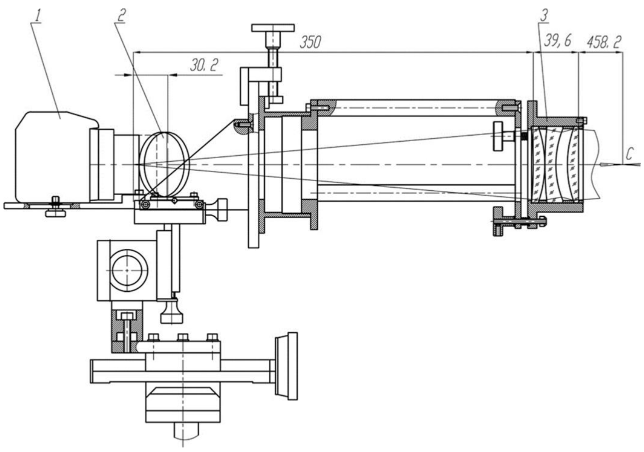


Fig. 6. Unequal-arm laser interferometer for controlling the manufacture of the telescope primary mirror. 1 – digital camera for interferogram recording, 2 – beam-splitter plate, 3 – three-lens null-corrector in a cell with the adjustment system, C – curvature center of the mirror tested.

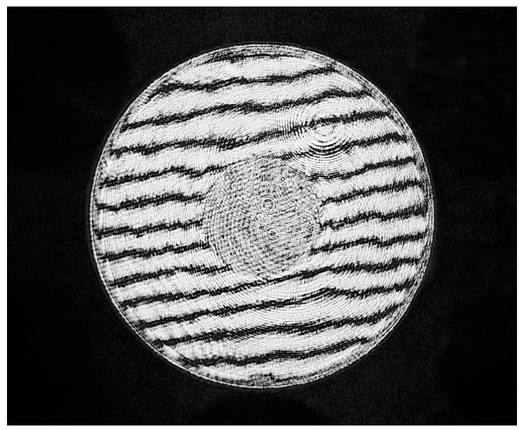


Fig. 7. Interferogram of the 125 cm paraboloidal primary mirror.

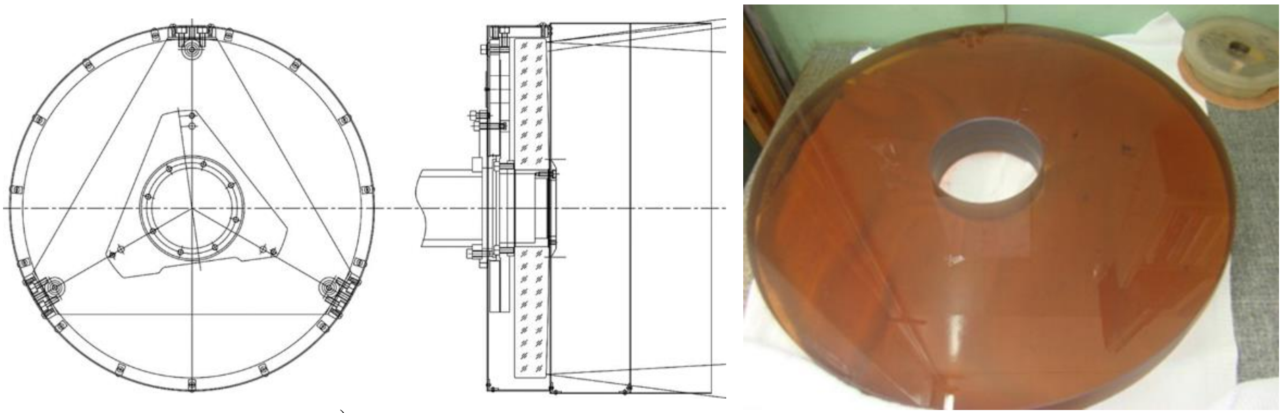
adjustment movements: lateral displacement and tilt of the mirror.

The four-lens corrector node of the AZT-11 telescope consists of two cells of two lens groups assembled together, along with the corrector's support bracket that allows it to be mounted on the primary mirror baffle support bracket (Fig. 9).

To perform alignment, the corrector adjustments along the telescope axis are provided for the corrector to be precisely aligned relative to the primary mirror along the telescope axis, as well as transverse displacements of the telescope axis and tilt of the corrector. For convenience of alignment, all corrector adjustment movements are accessible from the back side of the primary mirror cell, from outside the telescope. To facilitate installation of the corrector into the telescope, guide rails with fluoroplastic plates were mounted on the primary mirror baffle support tube. After final corrector alignment, stops with locking screws are provided on the new primary mirror baffle flange to additionally fix the corrector position.

The final adjustment of the telescope optical system was performed in the autocollimating design using a full-aperture flat mirror (Fig. 10).

Figure 11 presents interferograms of the AZT-11 telescope optical system assembled, demonstrating the optical quality achieved. The distortions of bands on the interferograms are primarily associated with air flows distorting the wavefront. The combined analysis of the interferograms was



a) b)

Fig. 8. Secondary mirror node: a) a layout of mirror mounting in a cell, b) secondary mirror prior to coating.

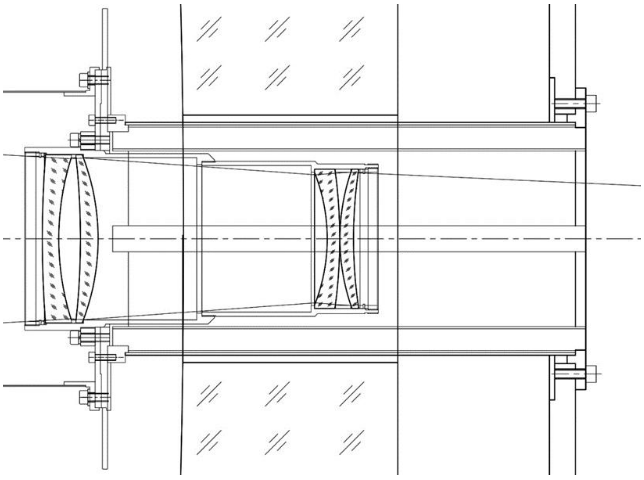


Fig. 9. Mounting the four-lens corrector in the central hole of the primary mirror.

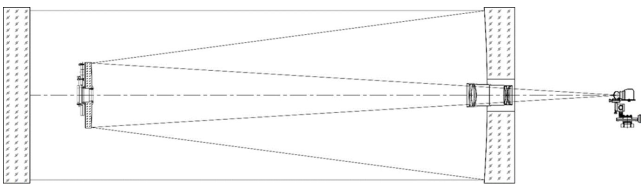


Fig. 10. Autocollimating control layout for the VT-124i optical system with a full-aperture flat mirror. From left to right: 1300 mm flat mirror, secondary mirror, primary mirror, four-lens corrector, laser interferometer.

performed using a large number of frames in order to exclude these errors.

The change of the primary mirror material to sitall CO-115 (the original mirror was made of LK-5 glass according to the LOMO drawing) gave rise to the necessity to recalculate thermal compensators, which compensate for the difference in linear expansion coefficients of the material for the primary mirror and its cell. A thermal compensator structurally consists of several tubes made of materials with different linear expansion coefficients. The calculations showed that for the sitall CO-115 mirror, one of the compensator tubes needed to be replaced with a material having a higher linear expansion coefficient. Polyamide was chosen as its physical properties meet the requirements for the thermal compensator structure. The correct functioning of the thermal compensator was confirmed experimentally. The thermal compensator calculations and manufacture were carried out by A.V. Dolgopolov.

The weight of the original primary mirror was 670 kg, while that of the new mirror is 620 kg. Due to the 50-kg difference in weight, calibration of the 12 radial and 18 frontal support nodes required. Appropriate stands and facilities were designed and manufactured for this purpose.

During system assembling, a flat mirror was installed in place of the secondary mirror; after mounting on the telescope, the interferometer was installed in the central hole of the primary mirror, and the system was aligned. The flat mirror was then replaced by the secondary mirror, and the image corrector was installed in the central hole.

By mid-September 2023, all work on the replacement of the telescope optical system had been completed and first light was obtained. For test observations, a region in Cygnus previously observed with the AZT-11 standard system was selected. A comparison of observations acquired with the standard and new optical systems under similar weather conditions (Fig. 12) demonstrated a gain in limiting stellar magnitude of approximately 1.5 mag. Under good seeing conditions, images are better than $1''$, confirming that the system manufacture and alignment were carried out with high precision.

Observations of polarization standards showed that the degree of instrumental polarization, with the exception of the I band, does not exceed the error limits in its determination and is less than 0.1%. In the I band, the degree of polarization is approximately 0.15%. Six months of observations have demonstrated the stability of instrumental polarization parameters.

4 Conclusions

The first observations with the new optical system of AZT-11 have demonstrated its high efficiency: in addition to the gain

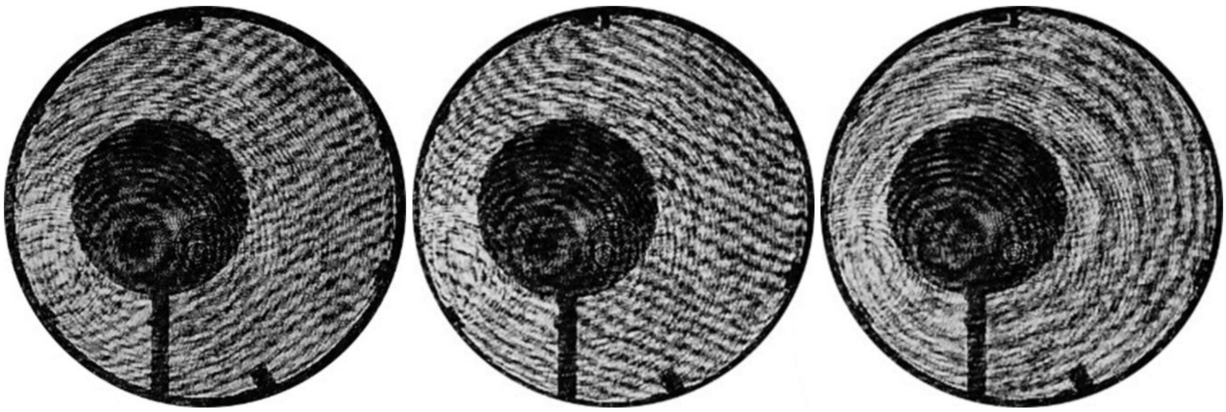


Fig. 11. Interferograms of the AZT-11 telescope optical system assembled with the four-lens corrector.

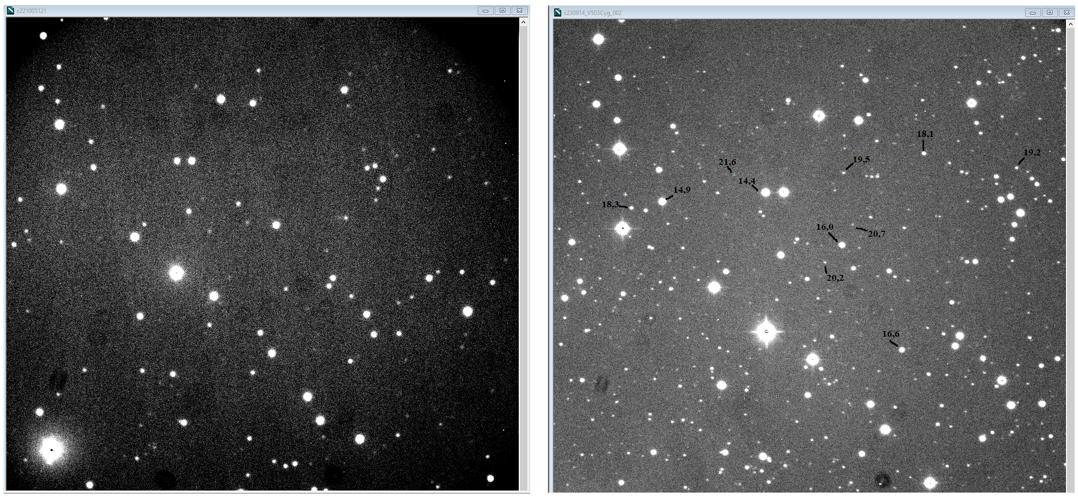


Fig. 12. Comparison of observations acquired with the standard and new optical systems of AZT-11. Left: image of the region around V503 Cyg obtained on 05.10.2022 with the standard system. Right: image obtained with the new optical system on 14.09.2023 under analogous observing conditions (R_c band, exposure time 180 s). Magnitudes of selected objects are labeled on the image.

in limiting magnitude, consistently improved image quality has been achieved, enhancing the precision of observations. The magnitude of instrumental linear polarization will enable the detection of weaker variability effects.

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- chief research scientist Dr. V.Yu. Terebizh for the optical system calculation;
- chief project engineer A.V. Dolgopolov for the design, supervision of the mechanical assembly, and supervision of the optical alignment of the telescope;
- Head of the optical workshops N.M. Steshenko for overall supervision of the work.

For the direct manufacture of the system components:

- optical workshop: leading engineer Ya.N. Chernykh, grade-5 optician V.N. Skiruta, grade-5 optician S.D. Trofimenko, grade-4 grinder N.A. Aksimentyeva, grade-4 grinder R.L. Semyonova, grade-3 grinder V.V. Aksimentyev, category-1 technician A.N. Ryaboshapko, engineer E.N. Karakozova, engineer N.V. But, and category-2 engineer I.V. Bondar;
- mechanical workshop: grade-6 machine operator A.P. Cheprasov, grade-5 machine operator A.N. Stepanov, grade-6 machine operator V.A. Zubko, grade-6 machine operator L.T. Mushchinkin, and leading engineer I.V. Kharchenko.

References

Maksutov D.D., 1946. Astronomical optics. M.: Gostekhizdat. (In Russ.)

Mikhel'son N.N., 1976. Optical telescopes. M.: Nauka. (In Russ.)

Piirola V., 1975. Ann. Acad. Sci. Fennicae, Ser. A VI – Physica, vol. 418.

Terebizh V.Yu., 2014. Mon. Not. Roy. Astron. Soc., vol. 440, pp. 1824–1827.

Terebizh V.Yu., 2019. Survey Telescope Optics. Bellingham, WA: SPIE Press.