ABOUT SCIENTIFIC SCHOOLS AT THE NIKOLAEV ASTRONOMICAL OBSERVATORY IN THE FIELDS OF POSITIONAL ASTRONOMY AND ASTRONOMICAL INSTRUMENTATION

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The Nikolaev Astronomical Observatory (NAO) was founded in 1821. In the initial "naval" time of its growth the observatory also carried out some works of an astronomical character. Later on, and especially in the last decades there have been finally formed two main directions of scientific activity at the NAO, as position determination for celestial bodies and astronomical instrumentation.

POSITION DETERMINATION OF CELESTIAL BODIES

Regular determinations for positions of stars at the Meridian Circle made by Ertel have begun in Mykolaiv in 1832 by the first director of the Observatory Karl Knorre. Obviously, they were the first meridian observations in Russian Empire. Another Meridian Circle was set up in Derpt since 1821, but to the best of our knowledge there have not been made any position observations with it.

The Meridian Circle in Mykolaiv unlike to the Derpt one and to the Meridian Circle, placed in Pulkovo in 1839, had a significant difference. Knorre has equipped it with the mobile mercury horizon, which has also allowed him to observe stars in reflecting light from mercury [8]. The use of this original method has allowed K. Knorre to achieve high accuracy coordinates of reference stars for made by him the fifth sheet of the stellar map of the Berlin Academy of Sciences. Using this sheet in 1845 a minor planet called Astraea (5) has been discovered, and in 1847 – a minor planet called Flora (7). Owing to these discoveries Knorre found fame as a highly qualified astronomer.

The second contribution to the positional astronomy was the work of Ivan Kortazzi for compilation of the catalogue of positions for 5954 stars of the equatorial zone [10]. This work has come to the history of astronomy as "Nikolaev zone". It is interesting to note that Kortazzi has observed at his Meridian Circle ($D = 108$ mm, $F = 1300$ mm) the stars up to 9.5 magnitude, but at present at the analogous telescope in Mykolaiv one can see in the equator the stars only up to 7.5 magnitude. It follows that from the last 100 years the transparency of the Earth atmosphere be worse approximately 5 times.

After transition of the Nikolaev Observatory to the Pulkovo Observatory the new domes for the transit telescope, made by Freiberg–Kondratiev ($D = 108$ mm, $F = 1300$ mm), and for the Vertical Circle, made by Repsold ($D = 108$ mm, $F = 1400$ mm), at the NAO have been built. There have been made extensive observations by absolute method and have been compiled the Nik1915, Nik25, Nik30, Nik50, Nik60 catalogues using these observations and original methods of investigation and taking into consideration the instrumental errors. In 1955 at the Meridian Circle ($D = 150$ mm, $F = 2160$ mm), made by Repsold, which was brought from Pulkovo, the Nikolaev Observatory took part in all significant international works of the astrometrical character, as in the compilation of the catalogues such as the AGK3R, Southern Reference Stars, Catalogue of Faint Stars (KCS), Bright Stars Catalogue, High Light Catalogues, observations of the stars of the equatorial and ecliptic zones.

A great attention was paid to the groundwork of the new methods for determination of the elements of installation and parameters of the instruments. So, for example, it was shown that the azimuth of the transit instrument is more precisely determined from the combination of zenith stars observations with the stars at zenith distances of $\approx \pm 60°$ [13], but is not precisely determined from the near-polar stars, as it had been written in all textbooks. If this method one can use in the observatories with the high geographical latitudes, as for example in Pulkovo, where zenith stars in the low culmination transit the meridian at zenith distances of 60°, then the azimuth after the reduction of right ascensions for zenith stars will also be an "absolute". It will allow to solve the problem of absolute determinations of right ascensions of stars without using the day-time observations of stars.

The determination of right ascensions of the stars at high geographical latitudes during the polar night belong to the number of fundamental works, the idea and authority of which belongs to G. M. Petrov [14]. In such places the night continues for several months, and every 24 hour series one can makes on average practically in the similar conditions that is very important for the accuracy of the observations. High position of the celestial pole is also a great potential. The observations during the polar night were carried out in the Western Spitsbergen Island during the three nights of 1974–1977. The Nik(Spz)75 catalogue of absolute right ascensions has surpassed all expectations [16]. Later on, it was used for construction of the FK5 fundamental catalogue.

One can also recognize regular observations of the Sun and major planets in the conditions of the Northern Caucasus and Transcaucasus as the first in the history of astronomy, where the 10-years series of the high mountain observations have been made at the Pulkovo transit instrument of Ertel [1, 6].

It is also worth to recognize such works, as:

- processing of the nearly 30-years (1965–1992) series of the high accuracy photoelectric observations of stars at the time service of the NAO for the research of the Earth polar motion using the space Hipparcos catalogue;
- processing of the 37-years (1961–1998) series of the photographic observations of the Solar System bodies (minor planets, Mars, Galilean satellites of Jupiter and selected Saturn's satellites) at the Zone Astrograph ($D = 160$ mm, $F = 2046$ mm) with the aim to improve the theory of their motion, also the link of the stellar and dynamical reference frames; the photographic observations of the minor planets were estimated in the MPC Database very high [`http://cfa-www.harvard.edu/iau/special/residuals.txt`];
- observations of the celestial objects (extragalactic radio sources, stars in the selected fields and other objects), of the Solar System bodies (selected minor planets, near-Earth asteroids, objects of the near-Earth space) at the Axial Meridian Circle (AMC), Multi-Channel Telescope MCT (former one astrograph) of the NAO.

In particular, from 1996 till 1998 during the 169 nights at the AMC more than 120 thousands of CCD observations of the stars brighter than 15 magnitude, which are arranged around the 190 extragalactic radio sources were obtained. There were compiled three catalogues based on these observations in 2000. The most complete catalogue of positions for 15 thousands of stars in the declination zone from −20 to +70 degrees was used as a reference one for improvement of positions of the extragalactic radio sources.

ASTRONOMICAL INSTRUMENTATION

The works for improvement of astronomical instrumentation have been carried out at the Nikolaev Observatory since the first director K. Knorre.

In the second part of the 20th century there have been made a lot of works for modernization of meridian instruments in the observatory. First of all it should be recognized the works to equip the instruments with photoelectric methods of registration of the star transits [3, 7, 9], to equip the transit instrument with vacuum tubes to meridian marks [15], with a slit filter for observations of the Sun [12], with a device for determinations of the personal errors in observations of major planets, with a device for determination in the automatic mode the azimuth of the photoelectric transit instrument [4], and also complexes for taking into account the out dome and in dome refraction [18].

The astronomical instrumentation works have reached the great effect in the end of the 20th century during the active search of more perfect optical and mechanical solutions for the construction of the astrometrical instruments, the introduction of the new register devices based on charge coupled devices (CCD), and also for introduction of the telescope computer control, *i.e.*, at the complete automation of the observations and their processing. At present, the observations at the NAO are made with three telescopes – the Axial Meridian Circle (AMC), Multi-Channel Telescope (MCT), and Fast Robotic Telescope (FRT)

Axial Meridian Circle (G. I. Pinigin is a head of the project)

In 1995 at the NAO a new telescope was put into operation. It was the AMC telescope of the original horizontal design, using of which the influence of the weight deformations was significantly decreased. It has allowed to determine the coordinates of the celestial objects in relative to the fixed long focus collimator (meridian mark). The construction of the AMC, the process of its creation, the results of the research and observations are good enough presented [17]. At present the AMC is equipped with contemporary register detectors using the CCDs and computer control [19]. Later we shall recognize some distinguishing peculiarities of the AMC.

The principal components of the current AMC:

- horizontal tube ($D = 180$ mm, $F = 2480$ mm) is connected with the ocular CCD micrometer and pentag and can be rotated along the axis. The testing of the stellar micrometer of the AMC with the universal

CCD camera (UCC) designed at the NAO has shown its high properties, such as the limiting magnitude of 16^m, the inner register accuracy of $\pm 0.02'' \div \pm 0.04''$;

- autocollimator ($D = 180$ mm, $F = 12360$ mm) in the prime vertical is set up to the AMC pentag. Autocollimator micrometer equipped with TV CCD camera has mean error of artificial mark reading about $\pm 0.02''$;
- AMC place is based on the special foundation and located in two pavilions. There is a separate control and observers' room (cabin);
- computer control system (CCS) includes control and master PC computers. Control computer is situated in a separate cabin nearby the AMC telescope pavilion. Master computer is set up in a auxiliary room at a distance of about 200 m. During the observations both computers are connected in local network with an access to the Internet, which has been made at the NAO since 1995. CCS provides observations with the AMC in automatic and manual modes; determination of the telescope parameters and the testing of some parts; making observations at the different modes of the CCS; processing; viewing and storage of observational data.

Real parameters of the current AMC system:

- horizontal flexure is negligible and not more than $0.03''$;
- collimation variation is $0.026''/10^\circ$ C;
- evaluation of the systematic errors of the AMC, which has been made using reference stars from the high accuracy Hipparcos catalogue in the declination zone from –5 to +70 degrees, has shown their substantially low level about $0.02'' \div 0.03''$;
- the stability of the instrumental system of the AMC during three years of observations was high, as the deviations of separate values of the instrumental system from the mean values do not exceed $0.02''$.

Observations at the AMC in 1996–1998 have shown its reliability (hard to repair faults and failures do not take place), good enough speed (a possibility to observe up to 7000 objects per hour), and in the whole, a great effectiveness and vast opportunities to participate in the modern astronomical programs. Taking into consideration the unique properties of the AMC it was included to the list of the science objects, which are national property of Ukraine by the Decree of Government in 1999.

Regular observations have begun under the new program at the modernized AMC since 2003, as:

- observations of the long strips in astrometric reference fields ($1^\circ \times 7.5^\circ$) along the ecliptic zone with the aim to create a compiled catalogue of star positions;
- observations of the selected minor planets (asteroids), bright radio sources;
- adoption of the artificial satellites observations at low and high orbits using the different modes of CCD camera.

Current observations have shown such results:

- the limiting magnitude up to 16^m;
- mean error of a single star observation in the range of $7^m \div 14^m$ is about $\pm 0.085''$, and in the range of $14.5^m \div 16.0^m$ is about $\pm 0.17''$ in both coordinates.

Fast Robotic Telescope (A. V. Shulga is a head of the project)

In 2000 at the NAO a construction of the Fast Robotic Telescope (FRT, $D = 300$ mm, $F = 1500$ mm) with mirror objective and CCD detectors has been begun. FRT is intended for observations of stars, Solar System bodies and objects of natural and artificial origin in the near-Earth space [2].

FRT was made at the base of the parallactic mounting telescope and has such an equipment:

- basic tube of the telescope (Maksutov design, $D = 300$ mm, $F = 1500$ mm) is equipped with the UCC camera (1040×1160, pixel size 16×16 mkm, FOV $40' \times 40'$);
- the tube of the satellite camera with a small field, three-lens refractor ($D = 300$ mm, $F = 500$ mm) is equipped with high sensitivity $1/2''$ TV-CCD camera (FOV – $30' \times 30'$, 25 frames frequency per second);
- the tube of the satellite camera with a large field, six-lens refractor ($D = 100$ mm, $F = 250$ mm) is equipped with high sensitivity $1/2''$ TV-CCD camera with a mode of STAT LIGHT (FOV – $2^\circ 30' \times 2^\circ 30'$, frequency of frames is from 1 to 25 per second);

- two coordinates drive with the use of digital detectors of rotation angle (estimated speed of rotation is up to $2°30'$ per second, the accuracy of position is $\pm 0.1''$);
- time service of 1 ms;
- software control.

FRT can work in three modes:

- tracking mode with a day drive mode of the telescope (astrograph mode);
- observations in drift scan mode at the fixed mounting (meridian circle mode);
- tracking of the objects in the near-Earth orbits with inclination of $\pm 90°$ (satellite camera mode).

Test observations with the FRT (December 2003 – May 2004) have shown such results:

- the limiting magnitude:
  - basic tube of the telescope up to 17.5^m ($\tau = 60$ s);
  - tube of the satellite camera with a small field up to 14^m ($\tau = 0.04$ s);
  - tube of the satellite camera with a large field 10^m ($\tau = 0.1$ s),
- mean error position of a single star observation:
  - in the range of $7^m \div 14.5^m$ is about $\pm 0.06''$;
  - in the range of $14.5^m \div 17.5^m$ is about $\pm 0.11''$ in both coordinates.

The FRT has come to work in a semi-automatic mode by the research programs of the near-Earth space in June 2004.

Multi-Channel Telescope

Previous Zone Astrograph was substantially modernized (Multi-Channel Telescope (MCT), $D = 160$ mm, $F = 2046$ mm) and equipped with devices of the CCD cameras UCC for observation of the objects in the near-Earth space and Solar System [5]:

- basic tube ($D = 160$ mm, $f/12.7$) with the UCC camera;
- photometry tube ($D = 100$ mm, $f/16.5$), with high sensitivity $1/2''$ TV-CCD camera;
- satellite tube ($D = 100$ mm, $f/2.5$) with high sensitivity $1/2''$ TV-CCD camera.

Such results were obtained using the observations with MCT:

- the limiting magnitude:
  - basic tube of the telescope up to 15^m ;
  - the tube of the satellite camera with a small field up to 14^m ;
  - the tube of the satellite camera with a large field 10^m ,
- mean error position of a single star observation:
  - for the range of $7^m \div 13.5^m$ is about $\pm 0.20''$;
  - for the range of $13.5^m \div 15^m$ is about $\pm 0.50''$ in both coordinates.

The equipping of three small-sized telescopes at the NAO with CCD cameras allow them to use with a great effect iveness, for the purposes of determination of stars positions, the Solar System bodies, and also for observations and research the objects in the near-Earth space at low, high, and geostationary orbits.

Register devices (A. N. Kovalchuk is a designer)

The working out and development of the original CCD cameras for astrometry research have begun at the NAO since 1993. There have been made four variants of CCD in different modifications, which were installed into: AMC, MCT, FRT at the NAO and the Meridian Axial Circle of the Main Astronomical Observatory [11]. At present, all these cameras are used for regular observations. The universal CCD camera made in a last modification is UCC camera. Matrix ISD017AP made by "Electron–Optronic" (St.-Petersburg) with the best properties was used as a basis of UCC camera [19].

Basic characteristics of the UCC, obtained from the observations, meet with the estimate ones and with the world level, and for some parameters, such as multifunctioness this one exceed even industrial models of foreign companies.

The perspective step to the development of image registration is to improve the industrial model S2C ("Electron–Optronic", St.-Petersburg), *i.e.*, to equip it with a module of external synchronization of frames, introduction a drift-scan mode, that will be extend substantially functional properties of the CCD camera and also the sphere of astronomical investigations.

CONCLUSION

In the whole, more than half a million determinations of stars positions also including the contemporary ones using CCD methods, and tens of thousands of observations for the Sun, the Moon, major and minor planets during entire activity at the NAO have also been made. More than 35 catalogues of celestial bodies positions have been made on these observations.

All observations made by the absolute methods were used for construction of the FK3, FK4, and FK5 international fundamental catalogues of stars positions. Differential observations of the Sun, the Moon, the Solar System bodies have been used for improvement in the planets' motion.

About nine thousands of photographic plates have been collected in the "glass" library of the NAO, but the last years the expansion of CCD observations is going on. Now the general volume of the digital database at the NAO is about 90 GB.

The achievements of the NAO in the fields of positional astronomy and astronomical instrumentation are the consequence of tireless activity of the astronomers of Mykolaiv school by active collaboration with native and international astronomical observatories and institutes. At present, NAO scientific public intends to continue further the traditions, which have been established in the observatory during the long history of its existence.

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