ASTROMETRY AT THE RTT150 TELESCOPE WITHIN THE INTERNATIONAL COLLABORATION BETWEEN KSU (RUSSIA), TUG (TURKEY), AND NAO (UKRAINE)

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Modern astrometric projects require precise positional measurements of objects down to magnitude 20^m–22^m. For ground-based observations, this is possible by the use of astrographs with apertures 1 meter or more with precise tracking using long exposures and precise timing. The multifunctional astronomical complex RTT150 (the 1.5-m Russian–Turkish Telescope) is appropriate for such purposes.

THE RUSSIAN–TURKISH TELESCOPE RTT150

The 1.5-m telescope RTT150 was manufactured by the well-known optical-mechanical company LOMO (St.-Petersburg) and was moved after 1995 to Turkey [1, 6, 11]. In 1998 the work on the telescope's assembly and installation in Antalya has been completed and a Joint Facility of the Kazan State University (KSU), the Space Research Institute of the Russian Academy of Sciences (SRI RAS), and the Turkish National Observatory (TUG) was ready to provide for scientific research.

The optical scheme of the RTT150 telescope has a set of four optical systems ($F/3$, $F/8$, $F/16$ for the Cassegrain focus and $F/48$ for the Coude focus). In addition, the telescope is equipped with two guides – Ritchey–Chretien telescopes – with 360 mm diameter mirrors, which can be used independently. The full FOV of the Ritchey–Chretien $F/8$ variant with the corrector installation is 88 arcminutes (300 mm). For the small field ($8'\times8'$) limited by the CCD size, the corrector is not necessary.

RTT150 is equipped with three CCD cameras, which give a possibility to perform observations in stare mode and in drift scan one.

The main camera is the ANDOR CCD (2K$\times$ 2K, a pixel size is 13.5$\times$13.5 mkm, CCD scale is $0.23''$/pixel). With this CCD camera, it has been possible to obtain images of the magnitude 22^m stars with 10 minute exposures; objects down to magnitude 20^m with 5 minute exposures are registered with a good signal/noise ratio.

The other two cameras, ST-8 and AP-47 (APOGEE), are the auxiliary ones of lesser sizes and lower sensitivities. ST-8, which is completed with an AO7 device, has so far been used as a photo guider. We note that, with this device, it was possible to record images with $FWHM$ of 0.7–0.9 arcseconds in short exposures (up to 10 min). AP-47 will soon replace ST-8 as a guider and ST-8 can be attached to one of the 360 mm guide telescopes.

For longer exposure times, the new digital CCD camera DinaCam with a liquid nitrogen cooling could be used. This camera was developed at the Special Astrophysical Observatory. In addition to its extremely low noise, the camera provides several modes of charge storage: stare mode, drift scan, forward-backward and their combination. The DinaCam CCD camera is equipped with the ISD017AP CCD.

The precise automatic drive mode of the telescope along a predicted trajectory is used to take images of faint objects in long exposures with the aim to decrease distortions of images of asteroids. A possibility for precise tracking is recognized for telescope motion along the predicted trajectory, which is successfully used to correct irregularities of the general gear and to compensate the influence of differential refraction at great zenith distances.

The telescope is equipped with the computer control system developed at the KSU and SRI RAS that allows one to perform observations:

– in batch mode, when the list of objects (coordinates, moments of the start of an exposure, and exposure times) is prepared in advance and loaded into the computer control for pointing the telescope on the next target;

– via the remote terminal (PC), connected to the control PC, and (using the Internet) via local network.

The computer control software has a user-friendly interface which allows one to control the telescope both in interactive and automatic modes for performing observations in accordance with the prepared list of objects.

OBSERVATION PROGRAMS

The main task of the RTT150 telescope is the astrophysical research: observations of distant objects (quasars, galaxies and clusters of galaxies, micro-lensing objects, *etc.*), the nearby galaxies and the Milky Way objects. However, the RTT150 with its equipment for a high quality imaging allow one to use the telescope for modern astrometry. Observations of extra galactic radio sources (ERS) and stars around them have been successfully made within an international campaign for the refinement of the connection between optical and radio coordinate systems (2000–2003). Some observations have been also carried out for selected minor objects of the Solar System (2002–2003) with the aim to determine their positions.

At present, a list of the observation programs and methods is prepared for new astrometric projects. In particular, several problems concerning the research of the Solar System small bodies down to magnitude 20^m are started, such as

– determination and improvement of orbital elements of near-Earth asteroids (NEAs),

– determination of masses of selected asteroids by taking into account their gravitational perturbations on orbits of the less massive asteroids,

– participation in gathering precise positions of selected minor planets for ground-based support of the international program “GAIA Follow-Up”, and photometric observations of brief occultations of stars by asteroids.

A FOLLOW-UP PROGRAMME FOR THE SPACE ASTROMETRY PROJECT GAIA

This program relates only to the astrometric aspect of the GAIA project for the Solar System object [9, 10]. GAIA will provide many position measurements of objects of the Solar System with the unique precision. About one million small objects in our Solar System, mainly asteroids, will be observed down to magnitude 20^m. The highest precision, about 10 micro arcseconds, will be reached for stellar objects with magnitude brighter than 15^m. It will be about $200\,\mu$ as for those of magnitude 20^m. This precision will, however, be degraded for the non-stellar and fast-moving objects, such as NEAs. It could then be about several mas. GAIA will perform a wide scan of the sky and will have not generally the possibility of immediately re-observing an object just detected. The faint and eventually fast objects are then likely to be lost.

Therefore, observations on alert seems to be necessary in order to catch more data on these targets and follow-up from the ground. A follow-up program will be necessary to ensure these objects are not lost and to improve their ephemerides. Several means make it possible to organize these observations, in particular, dissemination of alarms by the Internet via mailing lists (Minor Planet Mailing List for example) or maintenance of the official page of targets. Within the Solar System Working Group of GAIA, the plans are to constitute a network for ground-based observations in order to follow-up GAIA observations with the principal aim of confirming new target detections by GAIA and to carry out any astrometric measurements necessary for the improvement of the orbital elements and the cataloguing of these objects.

Once a network has been organized, it will then be possible, during the years before GAIA launch in about 2010, to test the astrometric performances on representative targets, to set up operations of data recovery, to develop and check a procedure for astrometric reductions, and then to prepare some experiments on full-scale alarms. Particularly, it will provide many positional measurements of the Solar System objects; also numerous new objects will be detected. Some constraints imposed by the objectives of the GAIA follow-up network are available in [Thuillot W., Stavinschi M., private communication].

For the proposed network, small telescopes down to 1.5-m seem to be well suitable for follow-up task. Fast moving objects such as NEAs will require fast reactions in order to operate several telescopes after receiving an alert from the GAIA control centre. Ground based robotic or automatic telescopes would obviously be much more efficient in order to shorten the reaction time. Besides, small telescopes are able to work in appropriate locations. At present, there are already identified more than 10 telescopes which are interested in this program. In the near future, this network will be extended and a process established to make it efficient for a follow-up: identification of each limiting magnitude, determination of the individual astrometric accuracy, rules to apply for a fast reaction on alert. Also, CCD cameras on these telescopes are generally well suited for precise astrometry of fast and eventually faint objects. The telescope RTT150 could also be used for monitoring the objects down to 20^m.

CURRENT PROGRAMMES FOR COLLABORATING TELESCOPES

Within the joint project on the basis of international collaboration of KSU (Russia), TUG (Turkey) and Nikolaev Astronomical Observatory – NAO (Ukraine), it is planned to perform positional and photometric observations of the Solar System small bodies in connection with GAIA project [2]. A fundamental problem for determination and improvement of the orbits and also for studying the multiplicity and masses of the selected asteroids down to magnitude 20^m is picked out within the project framework on the base of precise observations at the 1.5-m telescope RTT150.

In addition, observations of the brighter objects (down to 18^m) will be carried out with the CCD telescopes of NAO such as AMC ($D = 190$ mm, $F = 2480$ mm, CCD scale is $1.33''$/pixel), MCT ($D = 160$ mm, $F = 2046$ mm, CCD scale is $1.61''$/pixel), FRT ($D = 300$ mm, $F = 1500$ mm, CCD scale is $2.19''$/pixel). In 2001–2003, the telescopes AMC, MCT, FRT of NAO were modernized and equipped with perfect Universal CCD cameras (UCC) and necessary software for observations to implement the whole range of possibilities for high-accuracy observations of stars and asteroids.

The joint use of telescopes with different limiting magnitudes and different CCD fields of view will allow position measurements of the Solar System's faintest star-like or slow moving bodies with the highest precision in small fields ($8'\times8'$ for RTT150), and fast-moving objects with high precision in wide fields (about $30'\times30'$ for NAO telescopes).

During the period of implementation of the project (within the next 5 years) at the collaborating telescopes, there will be observed

- about 80 asteroids down to magnitude 20^m, which will be NEAs at distances less than 0.1 AU, allowing the determination and improvement of their orbital elements,
- about 100 asteroids with encounters, allowing the inclusion of task of mass determination in a program before GAIA.

First observations of objects from the prepared list have begun in May 2004 at the RTT150. From 82 observations of three minor planets and one NEA during one night, the mean error of a single observation was evaluated using (O–C) values, to be in the range $0.02''\div0.04''$ in both coordinates. Also, mean errors in the range $0.01^m \div 0.08^m$ for a single observation were obtained using V(O–C) values. An accuracy obtained shows a high potential for such observations at the RTT150. In general, by using reference catalogues which have a high accuracy and density (TC2, UCAC, USNO-B1, *etc.*) the expected positional accuracy of the Solar System small bodies down to magnitude 20^m, including fast and non-stellar asteroids in the near-Earth space, will be about $0.02'' \div 0.1''$.

The use of contemporary ephemerides and TV CCD cameras for observations of occultation of stars by asteroids provides a new possibility to study dynamical and physical characteristics of the Solar System bodies. Such observations will not only allow to improve the accuracy of observed quantities, but will also give an opportunity to study the physical properties of the surfaces, to determine diameters, to study resolvable objects, *etc.*

Determination of an enough precise orbit of a single asteroid (in the case of NEA – its trajectory) is well known and approved. In the case of a binary asteroid, the problem is much complicated, because the rotation of the components would affect the visible motion of separate parts of the binary asteroid. That's why it is planned to pay some attention for detection of possible satellites of asteroids (detection of binarity). Here we intend to combine exposures of the direct imaging with observations of occultation of stars by asteroids and careful photometric monitoring of the assumed resolvable binaries. For improving the ephemerides, it is planned to use fast photometry of the occultations besides astrometric methods. For this purpose, RTT150 will be equipped with a fast photometer for observation of occultations.

One of the important characteristics of asteroids is their masses. It is planed to evaluate masses of some asteroids using the dynamical method, based on the analysis of perturbations of small asteroids by big ones. It is considered that such a method gives the smallest relative error. As shown by A. Fienga *et al.* [5] GAIA will allow more than 100 asteroid masses to be determined accurately.

METHODS

It is planned to use the method and experience of CCD observations that have been gained during the observational program of extragalactic radio sources (stare mode). It is possible for asteroid observations in drift scan mode to use the covered strips method [6, 7] and the combined CCD method [4, 8].

The covered strips method

The first and basic objective of the method is to get a direct image of asteroids with reference stars. With the availability of a reference catalogue of an enough density and accuracy (TC2, UCAC, USNO-B1), the task to calculate object coordinates with the RTT150 observations can be fulfilled successfully.

However, there can be lacks of reference stars in some fields of celestial sphere. In this case, the auxiliary observations at the precise meridian circle AMC NAO can be used to get additional reference stars. For the method of covered strips, a CCD detector is used in drift scan mode. The method is effective for observations of the Solar System small bodies down to magnitude 20^m by performing multiple CCD observations at the RTT150 and other telescopes within the project. Thereby, the observations of asteroids at the RTT150 are combined with the AMC observations and the data are obtained in strip-scans of an enough length with the aim to include reference stars from precise catalogues, besides asteroids [6, 7]. The use of this method for our observations in 2002–2003 has given positive results.

The combined CCD method

The use of CCD cameras in two modes (stare and drift-scan) is planned for different optical channels of the RTT150 by applying the combined CCD method [4, 8].

The combined CCD method of observations of NEAs or other small bodies is a new approach by using techniques and methods to study characteristics of a motion, which can provide a high positional accuracy. The principle of observation at the telescope with equatorial mounting, equipped with a multipurpose CCD camera is in the base of this method. The CCD camera has the possibility to record celestial objects both in stare and drift scan mode, *i.e.,* small bodies are observed in stare mode with the fixed telescope, and moving star images are obtained in drift scan mode. So, we have stellar images both for small bodies and for reference stars with the moments of observations recorded with the aid of the time service. The combined method was successfully used for observation of objects on geosynchronous Earth orbits [3].

CONCLUSIONS

Technical parameters of the RTT150 and the first observations of the selected asteroids have shown that it is possible to determine high-precise coordinates of such objects, with an accuracy in the range of 20–40 mas, which satisfies the requirements of the GAIA Follow-UP Program.

A network of the automatic telescopes, together with the narrow-field CCD and wide-field CCD, can be used for coordinated and precise observations of the Solar System bodies before GAIA is launched, or during the mission in alert mode.

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