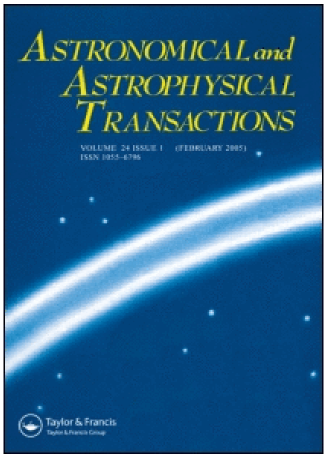

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OBSERVATIONS OF ARTIFICIAL EARTH SATELLITES AT ODESSA OBSERVATORY

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A historical review of the contribution of Odessa University Observatory to the development of satellite photometry is presented.

KEY WORDS **Satellites, photometry, history of electrophotometry**

Observations of artificial Earth satellites (AES) at the Astronomical Observatory of Odessa State University started in 1957 according to the IGY program. The Observatory Director, Corresponding Member of the Academy of Sciences of the UkrSSR Professor V. P. Tsessevich took up realizing them with great energy and enthusiasm.

On the base of AO OSU, two stations were organized by the Astronomical Council: the station of AES visual-optical observations No. 1036 and the station of AES photographic observations No. 1073. Let us consider in brief the contributions made at these two stations to the given project.

The first head of the visual-optic observational stations was V. M. Nechaev. At the beginning, the stations were equipped with standard instruments consisting of a complete set of AT-1 tubes, in a year or so these were equipped with more convenient TZK-1 tubes. Efficient determinations of precise AES positions were carried out, and V. P. Tsessevich was the first to begin photometric observations of AES light variations. General approaches were developed as well as methods of visual estimates of AES light, adequate instructions were compiled and disseminated to stations, large series of visual AES light observations were arranged and made at different stations of Astrocouncil of the USSR Academy of Sciences. The processing of the first results showed a high informativity of photometric observations for obtaining data on AES behaviour on orbit, variations in parameters of its rotation, enabled to relate them to parameters of the upper Earth's atmosphere and to the influence of space factors. Theoretical fundamentals of determinations of AES orientation from photometric data were developed by V. P. Tsessevich and V. M. Grigorevsky (Tsessevich *et al.*, 1958; Tsessevich, 1959; Grigorevsky, 1959a, b; Grigorevsky, 1960; Grigorevsky and Leikin, 1960), for the first time the theoretical curve of AES brightness variations was determined dependent on the rotational axis orientation of AES (Karetnikov and Grigorevsky, 1960), investigations were carried out on the Earth's upper atmosphere density and its relation to solar activity (Grigorevsky, 1963). Odessa observatory took part in an expedition for observations of the opening of the AES EHO-2. Observations were obtained in the cities of Ufa, Kirov, Siktivkar, Nariyan-Mar and Norilsk. Curves of EHO-2 brightness variations obtained by V. G. Karetnikov in Ufa and O. E. Mandel in Kirov, allowed to determine the period of rotation of EHO-2.

Significant is also the contribution of the stations of visual-optical AES observations to training astronomical personnel - all the astronomy Chair students acquired their first practical skills in astronomical observations at this station. At different time the station was taken charge of by V. M. Nechaev, Yu. S. Romanov, V. A. Pozigun, V. V. Panchuk, V. A. Depenchuk, V. M. Grigorevsky, A. V. Dobrovolsky, N. I. Koshkin and others.

At the station of photographic observations No. 1073 regular photographic AES observations were made for their precise position determination. Yu. D. Russo was in charge of this station over all these years, from 1957 through 1964. According to the task assigned by Astrocouncil of the USSR Academy of Sciences a quadruple installation for photographic AES observations on the base of NAFA-3c/25 cameras was developed and manufactured, subsequently this was introduced at stations of photographic AES observations in Kiev, Kharkov, L'vov and Odessa. One of the most important stages of the station work was taking photographs of scattering a sodium cloud released by the second Soviet space rocket. In addition to the photographs taken in Alma-Ata, these observations allowed to determine the spreading rate of the cloud. Some AES photos were used by V. P. Tsessevich for photographic photometry of AES light variation, thereby the station contributed to photometric satellite investigation.

Of important was the assignment given by the Astrocouncil of USSR Academy of Sciences to the station and aimed at developing methods of photographic AES observations from the board of ships and those of processing the results obtained. This investigational work of significance was carried out by Yu. D. Russo, N. S. Komarov and V. A. Pozigun. Tens of AES photos were taken on board the ships of the Black Sea steamship line in Odessa, the bending of satellite tracking due to microvibrations of the ship at its mooring was studied, mathematical methods of satellite tracking correction were developed.

Dwelling upon the work of Odessa station of photographic AES observations, one more undertaking should be mentioned - V. A. Smirnov and Yu. D. Russo made a good start in our country by carrying out spectral satellite observations (Smirnov and Russo, 1969). Photometric errors made in measuring "Ekho-2" satellite and stellar spectrograms were investigated as well as the law of reciprocity by means of an "artificial meteor" device specially designed for spectrophotometric calibration of short exposure images (Smirnov and Russo, 1965). Unfortunately, further works on photographic AES spectrophotometry were discontinued.

Since 1969, upon the suggestion of the Deputy Chairman of the Astrocouncil of the USSR Academy of Sciences A. G. Masevich, Odessa Observatory has been engaged in developing an electrophotometer for registration of AES light variation, electrophotometric methods of satellite observations, and in introducing these methods V. P. Tsessevich charged Yu. A. Medvedev and V. N. Ivanov with this important mission. Developed and manufactured were several types of electrophotometers for registering AES light variations, developed were methods of electrophotometric observations which were introduced at AES observational stations of the USSR Academy of Sciences. For the first time, at the Observatory there appeared an economic-contractual satellite project joint with the organization engaged in space investigations. As a result of fulfilling it, a two-channel electrophotometer for registering AES light variation as designed on a compensating circuit was developed, manufactured and introduced; the method of AES observations and the processing of the results were developed and introduced as well. In 1970 the scientific research sector of satellite observations was established.

In parallel to the economic-contractual works, the Observatory rendered engineering assistance to the Laboratory of space studies, Uzhgorod University, where an analogous two-channel compensating electrophotometer was produced and tested by the laboratory collaborator Ya. M. Motrunich with participation of Odessa observatory researchers V. N. Ivanov and Yu. A. Medvedev. Eventually, the above electrophotometer was mounted in the guide of the AFU-75 camera (Ivanov and Medvedev, 1971). Thus, the foundation was laid to electrophotometric satellite investigations in Uzhgorod University, and it shared its experience with L'vov observatory.

Performing economic-contractual works on satellite theme resulted in material-scientific base establishment for further advanced progress in AES photometry development in virtue of photoelectric satellite observations. For this purpose, works were continued on designing new types of electrophotometers for observations of AES light variations. On base developing first in Russia electrophotometer for recording AES light variation (Medvedev and Sorokin, 1964), a non-heavy mini-electrophotometer, with a TZK tube as a tracking system, was developed, designed and successfully tested (Grigorevsky *et al.*, 1971). Observational results compared with the data given by R. Wandeburg and K. Kissel (1971) have shown measurements taken on miniphotometers to be in good agreement with the data obtained on a 61-cm telescope. In developing highly reliable compact circuits of electrometric amplifiers in Odessa observatory, first for satellite electrophotometry the transistor amplifiers with field-effect transistors were used instead of electrophotometer tubes in the input. The experience in designing such electrometric amplifiers was afterwards applied in stellar electrophotometry (Ivanov and Kovalev, 1975).

Subsequent modernization of photometers for AES observations led to developing a single-channel photometer on counting photoelectron basis with a jumping diaphragm attached for measuring intensity of the sky background. Its design in contrast to a two-channel photometer proved to be notably simplified, dimensions and weight decreased, this being rather important for the tracking system, reliability and stability of the apparatus increased. The system of counting photoelectrons permitted to immediately obtain information in digital form, to drastically cut the time needed for storing, to pass over to automated data medium, in consequence the informativity of AES light curve strongly increased, enabled us to automate and accelerate the process of reduction the photometric data obtained (Ivanov *et al.*, 1976). Final choice of the given type of photometer and its operation conditions was made after detailed investigating different methods of registering a light curve and various types of photometers. V. N. Ivanov set observations by using three types of photometers: two-channel-compensating photometer with direct current amplifier (DCA), modulation photometer with a narrow band amplifier of alternating current (made by GOI and transferred to AO OSU for testing) and single-channel photometer with counting photoelectrons and recording data on the perforated tape. Synchronous observations of stars and some artificial Earth satellites were carried out. The analysis of the obtained material has shown the results to be close in accuracy and penetrating power at certain advantages and drawbacks of various methods and types of photometers used. However, the single-channel photometer with single electron operation conditions proved to be more simplified, more reliable, more technological, somewhat more informative with further wider modernization capacity (Ivanov, 1982).

Further development of photometric investigations promoted to set the task of designing a satellite photometer for multicolour AES photometry. The specificity of this engineering development as compared to that of a stellar photometer, wherein all the problems were solved successfully long ago, lies in the artificial Earth satellite being able to change its light within a short time by several stellar magnitudes. Therefore the registration, in consecutive order, of AES light in different filters, though of interest, gives scanty information. Simultaneous measurements in different filters are needed, only then these curves can be consistent with each other. With this in view at the observatory department of space investigations the design was developed of a photometer with quasi-simultaneous registration of AES light in different filters from single feeding optics, the specificity of fast AES light variations being taken into account. The filters are placed on a fast-rotating disk, the light flux is registered with a single photometric channel, information is recorded in different memory cells depending upon the filter number.

High-precision (as compared to visual and photographic observations) photometric material available enabled us to advance investigations on AES behaviour on orbit (characteristics of AES rotation around mass center, orientation of axis rotation and variation in these parameters with time) and those on photometric properties depending upon shape and coating materials. From 1970 to 1976, V. M. Grigorevsky took charge of these investigations, and since 1977 Yu. A. Medvedev has taken charge of them. At that period, in the Observatory, apart from economic-contractual research works relevant to the engineering development of photometric apparatus for observing AES, those on interpretation of photometric observations were started.

Economic-contractual works at the Odessa observatory promoted to introducing the results in other organizations and establishing a new direction: photometric AES observations. Since 1977 the sector of AES observations in Odessa observatory has been transformed into the department of Space studies.

The task of increasing informativity of AES light curve the demanded to investigate factors influencing the accuracy of the light values obtained. The analysis was made of atmosphere turbulence effect on AES photometry in order to estimate amplitude fluctuations of the registered signal due to the distribution of radiation in the turbulent atmosphere. The method of noise component calculation, integral light curves, taking account of statistic apparatus effect, was suggested (Korobko *et al.*, 1988). Carrying out photometric AES observations and solving questions of interpretation of the data obtained contributed to: formulating and solving problems related to the determination of conditions for AES visibly and elimination of background source effects on results of AES photometric observations. Earth shadow model and its location relative to the observer were calculated (Paltsev, 1990). For parameters of AES transit across regions shadowed by the Earth, equations were derived which describe models of surfaces restricting these regions and taking into account their form dependencies on the Earth's orbital motion (Korobko *et al.*, 1990a). Methods were developed to take account of influences of background radiation from extra-atmospheric sources (stars, planets, interstellar and galactic formations, other satellites, etc.) upon AES photometric observational results (Korobko *et al.*, 1990b). By now plentiful photometric material has been gained which is used for studying dynamics of AES motion around mass center (Kolesnik, 1990), etc.

To interpret AES photometric observations, a method of the mathematical and physical modeling of satellites of complicated form for different conditions of reciprocal shadowing the AES design has been developed and introduced. Model light variation as determined by conditions of observations and dynamics well displays respective variation in AES light and permits to optimize methods of obtaining data on AES dynamic motion from photometric observations (Koshkin *et al.*, 1988).

The analysis of the combined effects related to illumination of artificial Earth satellites by the Sun, the character of glares reflected to the Earth's surface by the AES elemental design led to making a laboratory television set. It enabled us to obtain on the monitor a photometric screen image of a light spot from the satellite onto the Earth's surface in the form of a semi-tone pattern or photometric curves with a photometry step set across the light spot area – that is equidensities of the light spot. The model rotation in a special mechanical system allows to see the dynamics of brightness distribution in the light spot and to model the AES light curve for any screen point as corresponding to a certain observational point on the Earth's surface as well as to synchronous AES observations from different points (Chaichuk *et al.*, 1988; Chaichuk, 1990).

At the Department of Space studies Odessa Observatory, works on engineering developed and refinement of apparatus, methods, and procedures of AES observations, processing results and interpreting data are continued. The apparatus complex for AES observations consisting of a tracking system KT-50, electrophotometer and device for recording data on the automated data medium was produced and certified for quality and acceptance by attestation. Over 25 invention certificates were granted for new engineering developments.

In 1974, the Observatory first participated in works on laser-detection and ranging of high orbital AES with the orbital altitude as high as 25-50 thousand km. Jointly with the customer-organization, a laser range unit was mounted on the base of a powerful optical quantum oscillator (OQO) GOS-1001 and a telescope-reflector AZT-3. Large dimensions and weight of the apparatus caused the OQO being installed in the Coude telescope focus, developing methods of adjusting optical system of the Coude telescope and the guide, methods of searching and space object setting, and tracking it throughout the detection and ranging process. Several runs of laser detection of high orbital AES observations were carried out.

At present the Observatory makes contribution to the works on complex state scientific-technical program for laser range AES investigations. With this in view, at the Observatory station, in settlement Kryzhanovka, complex of pavilions for laser and photometric AES observations has been built. This station of Odessa Observatory is a part of the network of laser detection and ranging of AES observations in the Ukraine. Works on organizing photometric observations of high orbital and geostationary satellites are under way.

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