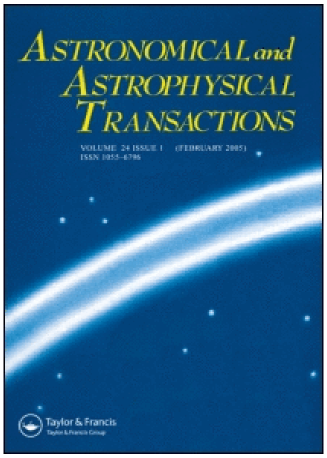

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ELECTROPHOTOMETRY OF ARTIFICIAL CELESTIAL BODIES: EQUIPMENT PROBLEMS, OBSERVATION AND INTERPRETATION OF THE RESULTS

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Artificial celestial bodies (ACBs), during their 50 years of existence, have become full members of space in the same way as their older colleagues: stars, planets, comets and so on. Similar to all natural celestial bodies they can be investigated by astronomical and astrophysical methods. One of the methods for investigating ACBs is photometric observations. Work on the realization of photometrical observations of ACBs has been carried out in many astronomical observatories and institutions. In particular, several instruments for this kind of observation at the Lviv Astronomical Observatory and the Zvenigorod Astronomical Observatory have been constructed. The importance of observations on ACBs by photometric methods is considered in this paper. A description of the equipment used for such observations and the obtained results are given in this paper too.

Keywords: Artificial celestial bodies; Space debris; Photometry

1 INTRODUCTION

The appearance of the first artificial satellites of the Earth was the first real step on the journey of mankind to the stars. However, it was only in the 1980s that launching multitask apparatuses (investigation of the near-Earth space, observations of celestial bodies in the spectral regions inaccessible from Earth, television, communications, etc.) was obviously invading space with ‘debris’ (McKnight, 1997).

The quantity of objects and debris in space is increasing. The near-Earth space is populated with spacecrafts, artificial satellites and different remains of space objects (Rykhlova, 1998). Very often, during satellite destruction the presence of large parts can present a serious danger for people when re-entering the Earth’s atmosphere. Taking into account that in the near-Earth space there are many various artificial celestial bodies (ACBs) (the international

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catalogue contains more than 10,000 of the largest artificial space objects), it is obvious that regular observations of all these objects and a search for unknown objects become necessary.

The problem of 'space debris' is considered in different ways in various countries. The countries launching most of the satellites should be interested in solving this problem (USA, Russia and Western Europe). On the other hand, celestial objects do not select the place on Earth where they fall. That is why the monitoring of the near-Earth space is a very important and necessary task, which can be solved only through the cooperation of different countries.

Observations of the ACBs have been conducted since the moment that they appeared in the sky in 1957. The most informative types of observation are positional and provide orbital data of the object. At the beginning of the 'satellite era' (from 1957 to the 1980s), such observations were realized by photographic methods. Now very good results can be obtained with charge-coupled device matrices (Kovalchuk *et al.*, 2000).

However, orbital data do not provide complete information about the physical state of the satellite, and photometric observations must be made. Variations in the light curves (the result of photometric observations) of ACBs had already been noted in the light curve of the second satellite. It is quite evident that the light curves change because different parts of the satellite reflect sunlight in various ways.

As has been mentioned by many workers (see for example Bagrov and Smirnov (1989)), the specifics of the movement and of the light changes of the ACBs require special methods and equipment for ACBs observations, but the importance of monitoring the sky justifies all costs for creating such equipment.

2 PROBLEMS OF PHOTOMETRIC OBSERVATIONS

Photometric observations of the ACBs are aimed at solving two tasks: identification of the observed object comparing the received data with those from different data banks and catalogues; determination of the shape, dimensions and some other characteristics of the object's appearance (Bagrov and Smirnov, 1986).

Realization of photometric observations of the ACB is not a simple task, because the ACB changes both its luminosity and its position in the sky very quickly. Two principles provide the basis for photometric observations of ACBs: the first is photometry of stars, and the second is the other type of ACB observations (*i.e.* positional observations). Unification of these methods resulted in a very special method for carrying out the photometry of ACBs.

Methods of observations should meet some requirement, namely the duration of the observed satellite pass should be as long as possible, the standard stars should be observed in the same time interval and in the same area of sky that the ACB, and the data for the initial corrections (subtraction of the sky background, reduction in all light curves to one distance, and taking into account atmospheric absorption) must be noted.

For observation of ACBs (especially low-orbit objects, *i.e.* orbit altitudes from 300 km to several thousand kilometres), one must construct a special instrument, and it should be placed on a special mounting. The most precise and suitable is four-axis mounting, which allows one to guide the object over one axis.

3 THE CONSTRUCTION OF PHOTOMETRIC EQUIPMENT

A schematic diagram of the electrophotometer for observation of ACBs (the whole family of such photometers were constructed at the Lviv Astronomical Observatory (LvAO) (Blagodyr *et al.*, 1996) on the basis of different optics and different guiding mountings) is shown in Figure 1. The photometer consists of two mechanically connected electropho-

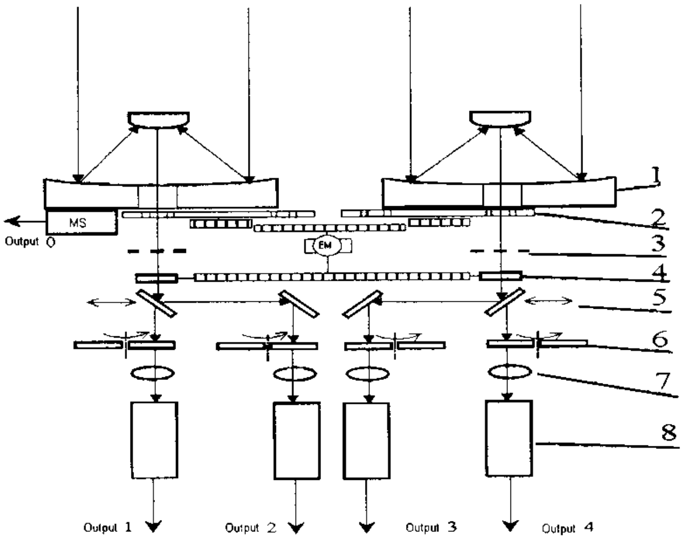

FIGURE 1 Schematic diagram of the LvAO electrophotometer: 1, 34 cm optical objectives with a Cassegrain system; 2, twin diaphragms; 3, black–white modulator; 4, filters on the ring mount; 5, Fabry lenses; 6, photomultipliers; MS, modulator sensor; EM, electromotor.

tometers which have two 34 cm optical objectives with a Cassegrain system 1, twin diaphragms 2 with black–white modulators 3 and position sensors 2a for dividing the object light plus background signal from background signal, and filters on the ring mount 4. Two photomultipliers 6 with Fabry lenses 5 act as the light receivers. The signals from the photomultipliers are transfered to the 'system of selection and the operating processing block', which consists of a pulse amplifier with a discriminator and interface block which connects the system with the parallel port of computer. The timing of each packet of information (the capacity of which is regulated by the position sensor and the time of integration) is realized through the signal from the quartz clock to the interface block. The computer in real time makes the initial corrections of the signals and display the results on the monitor with simultaneous recording to a file. The equipment is set on the four-axis mounting from the LD-2.

As the main optics in Zvenigord Astronomical Observatory (ZAO) equipment a 10 cm objective with a SIM-ICCD-05 television camera is used. The sensitivity of this camera is quite high (2×10^{-5} lux) in a wide spectral range (380–650 nm), which allows one to use it as a main receiver for the photometric observation of low-orbit ACBs in integral light. The real time television signal is transmitted through a special video card to the computer where the initial correction is made and then the signal is recorded to a file. This system has a sensitivity of magnitude near 12 (Masumy *et al.*, 2000). The mounting from the LD-3 is used as the guiding mount.

4 EXPERIMENTAL RESULTS AND THEIR ANALYSIS

As mentioned above, the photometric light curves of the ACB could be the basis for determining the object shape. This task is the inverse photometric problem. Solving it is connected with some problems of both mathematical (*e.g.* the reflection of sunlight by the satellite surface) and practical (obtaining and analysing light curves) character. To obtain a single solution, one should have some preliminary information about the object: about its appearance, its orbit position, etc. However, the results from other types of observation (polarimetric or spectral) could be used as additional information too. This could reduce the necessary quantity of experimental data (the light curves) for analysis of the state of the ACB.

During decades the LvAO and ZAO staff carried out photometric observations of ACBs. A data bank of the resulting light curves was created. From these data it could be concluded that the light curves could be divided into three types: monotonic (smooth) curves (Fig. 2(a)), quasisinusoidal curves (Fig. 2(b)) and curves with a flash of light (Fig. 2(c)).

Generally speaking, the first type of light curve results from observation of a steady-condition object. The second type of light curve could be obtained as a result of observing a free tumbling rocket-like object. The flash on the third type of light curve is a result of the reflection from the mirror-like details on the object. Since the presence of the flash already gives some information about the object, such a light curve is easier to interpret than the first two types.

The first (and in general the simplest) step making an analysis of the light curves with a flash is to determine the reflecting plane orientation. Mutual location of the satellite, observer and Sun is not a very difficult geometric task.

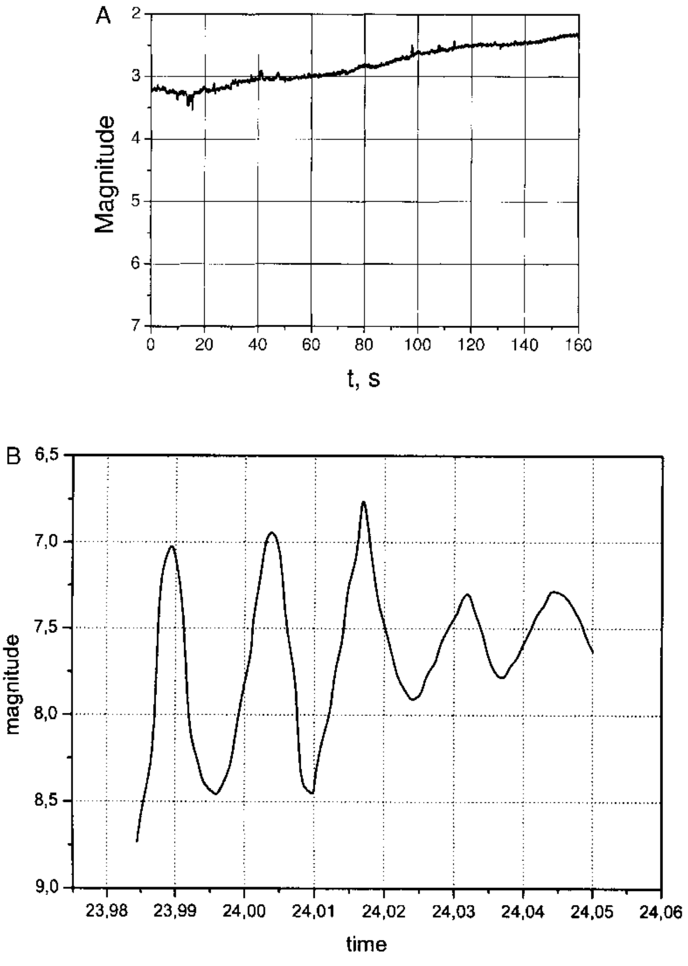

FIGURE 2 Light curves of different satellites: (a) smooth curve (Topex); (b) quasisinusoidal curve (7402902); (c) curve with a flash of light (Topex).

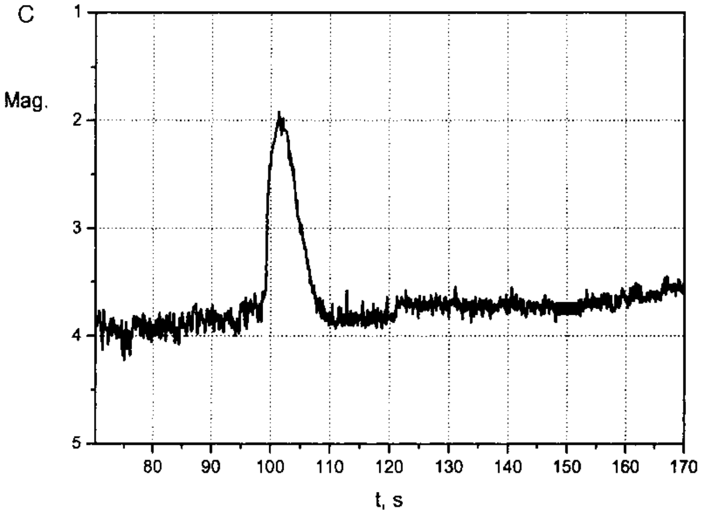

FIGURE 2 (*continued*)

For the object with a known shape the contribution of different reflecting details to the light curve could be monitored. As an example, one could look at the light curves of Ajisai (8606101). This is a spherical object with many mirrors and corner reflectors on its surface (it was launched for laser ranging); that is why the light curves have many flashes (Fig. 3). The second object that is of some interest is Topex (9205201). Most of its light curves are smooth (Fig. 2(a)), but sometimes on the light curve there is a flash, a reflection from the solar panel (Fig. 2(c) or Fig. 4). As the flash passes, the position of the solar panel can be easily found using the methods described by Yepishev (1983).

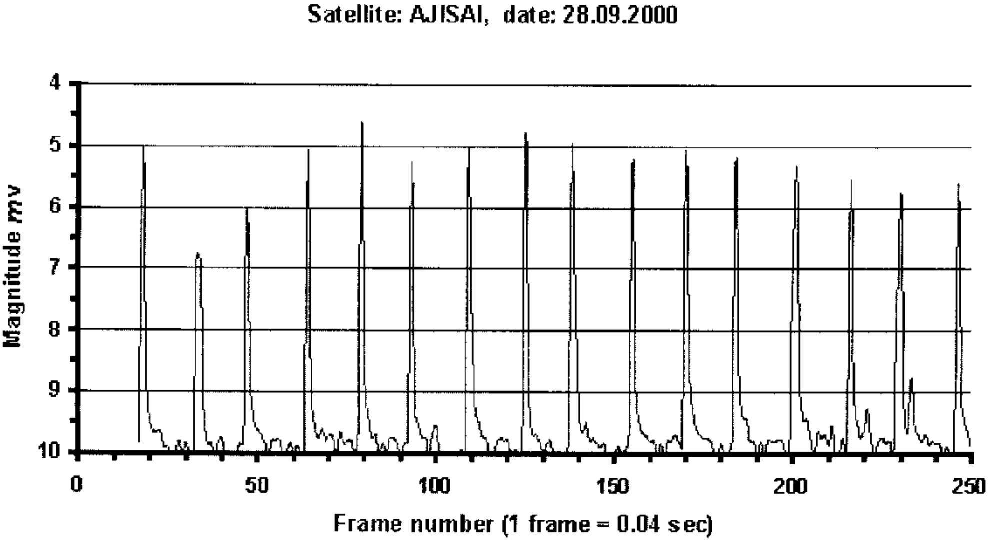
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FIGURE 3 Light curve of Ajisai obtained at ZAO.

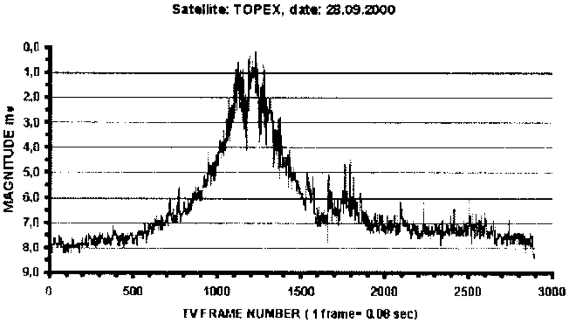

FIGURE 4 Light curve of the satellite Topex received at ZAO.

5 CONCLUSIONS

To summarize, photometric observations are very important tasks requiring special equipment as at LvAO or ZAO.

The results of electrophotometry of ACBs from LvAO and television photometry from ZAO are in good agreement. The obtained data confirm and supplement each other. That increases the quantity of data in the data bank and allows one to make more accurate light-curve analysis.

Comparison of the observed results with the exterior of satellites could provide methods for solving the inverse problem of photometry, namely determination of the object's shape. In general, the inverse problem without additional information is very difficult to solve. So other types of observation (polarimetric, spectral, etc.) can give the necessary additional data. This indicates the way to modernize and develop equipment.

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