MULTYCOLOR PHOTOMETRY AND SPECTROPHOTOMETRY SPACE DEBRIS OBJECTS

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Abstract

At the present, more then 2000 non-functional artificial space objects are situated at the orbits with the heights more than 10 000 km. Duration of the natural de-orbiting for these objects comprises more than thousand years. Destruction of these objects caused by the natural and intrinsic constructional factors can lead to the catastrophic pollution of these practically important and unique orbits. In the present situation it is especially important to develop methods for detection of surface and construction changes of the space objects and to determine the most probable scenarios of their evolution. Earlier works are concentrated on the detection of the malfunction of uncontrolled satellites, often caused by its destruction during the launching and injection interval. The purpose of recent studies is to detect evolutionary arising processes. Original data for the solution of this task will be use from high-accuracy spectrophotometrical measurements of the surface-scattered radiation of the spacecrafts and there debris. The data include an orbital parameters as well as the angular and temporal distributions of the radiation in visual band. These parameters are used to the imitation modeling of the monitored light curves and the phase-positional dependencies of the space object of known or assumed construction. It is known, that uncontrolled satellites are in the rotation modus. Observations with the high temporal resolution allow a detailed investigation of an irradiated surface in order to reveal components of the rotational spectrum, including those close or coinciding with the eigenfrequencies of the object. Achievement of the high photometric accuracy and temporal resolution in the project will be allowed due to the methods of statistic photometry, approved by investigation of other fast-happening astrophysical objects, like flaring stars. The developed methods and equipment allow to obtain light curves of the mobile space bodies with the hight time resolution from 5 ms without the dead time with an error not bigger that 1% with the telescope of moderate size. For the solution of project tasks, we will use the experimental data obtained by authors during observations with the astronomic telescopes of Sayan observatory ISZF SB RAS starting from the 80-th years of 20th century and continuing till the present time. Different types of space objects situated near the geostationary orbit have been selected for the investigation. Those are mainly spacecrafts launched at different years, boosters and other elements of the launching and injection equipment. The observations were performed for the typical representatives of different satellite families with known geometric characteristics. Observations of these objects may be used for their further analysis by the methods of computers simulation.

Observatory and the acquisition hardware

The study of the optical propertes and orbits of the small sized debris on GEO was started at Sayan mounting observatory (operated by ISTP SB RAS) at 2007 year. At present UBVRI photometry and low resolution spectroscopy are put into practice. The observation setup consist of an upgraded AZT 14 telescope and 1.7 meters Richey-Chretien telescope (fig.1). Cassegrenian telescope AZT14 with 0.5 meter parabolic mirror was supply with three lens prime focues corrector is assure FOV 1.3x1.3 degre with CCD system PL 4301. A limiting star magnitude 19@ 30 second have been ensure in good weather condition and air mass near a two. The AZT 33 IR is a special astronomical Richey-Chretien telescope with 1.7 meter primary mirror and 30 meters focal length in Cassegrenian focus [1] The main feature of the equipment is the focal reducer with UBRI Cousine-Jonson glass filters. It responds fairly well to the requirements listed anywere to study the sattelites optical propertis. The performances of the focal reducer which accepts the image of f/20, 170 cm Richi-Cretien AZT 33 telescope and transfer it onto CCD (1Kx1K, 16 mkm pixel size devise, named ISD 017, produced by plant " Electron" , St-Petersburg) are suitable for finding and detection of small-sized debris with magnitude less than 18, and poor determined orbital parameters. For finding a brighter debris and spacecrafts an axillaries 30 cm telescope mounted on the main optical system structure have been applied. A low dispersion difractic spectrometer (LDDS) has been used to study of the space objects reflected spectra. A LDDS had been established on the main cassegrenian focus and provide a linear dispertions 1A/px and 4A/px with changeable gratings on the spectral band 0.4 - 0.9 mkm.The main feature of the spectrometers is possibility to simultaneos registration of the spectra and imiges on the spectrometer slit. This give an opportunity for tracking and guiding of a moving object during an exposition time. Additonally, the control system of the both telescopes and their mechanical drivers, electronic and software units enable an object tracking along an ephemeredes and make possible to detect the small-sized objects. The objects were detected on the AZT 14 focal plane are processed to the objects indetificaion and initial orbits

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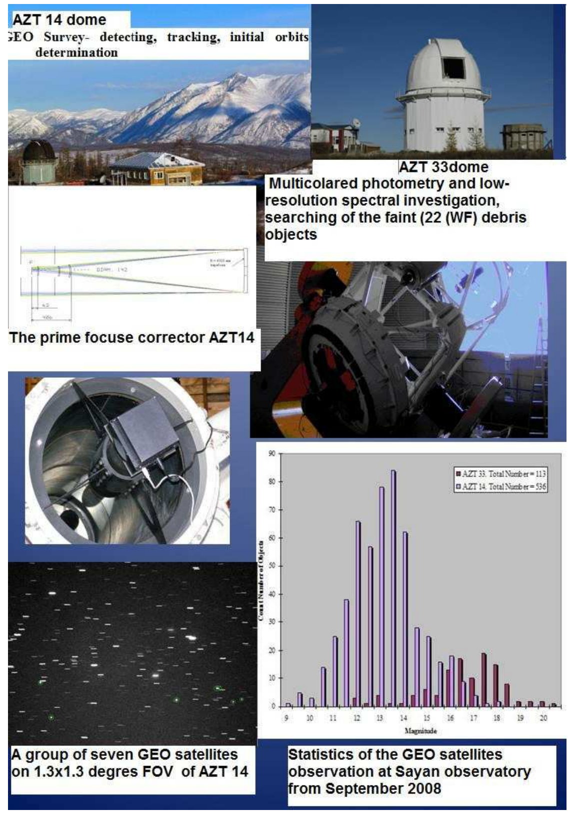
determination and than hand down to AZT 33 system for spectrophometrical mesurements.

Methodics of the debris optical properties registration

Ephemeridal support of the observations includes the dynamic catalog of the debris objects KIAM, [2](V.Agapov et al. 2009) which is represented by database table, containing orbital characteristics. A graphic user interface enables an effective planning of the observation time. A choice of an object is determined by the following factors: (1) height over the horizon, (2) extent of the object illumination by sunlight (phase), (3) an absence of the earth shadow and moon background. Conditions of object visibility are reflected on the graphic interface (Fig.2). The regions of trajectories, that are well illuminated by sun (phase angles < 60 degres) are shown, the horizon line and the shadowed regions of the flight are marked. The software package SATRADANA [3] had been imported to the telescope control system. The individuale programs of the package may be used for orbit improvement and prediction. Calculation of ephemerides is performed in the given time interval (dark part of the day) with the time spacing 1 min., which is enough for the objects that are moving with the speeds about several arcsec/s. Ephemeride parameters are saved and used for the planning of observations, as well as for the revealing and programm tracking of objects along the ephemerides. To monitor a space object, an ephemerid point is selected, which responds to the optimal vision conditions. Guidance routine enables calculation of the coordinates of the visible position of objects and tuning of the telescope to the calculated position with 1`` precision. Refraction and errors of the telescope polar axis installation are taken into the calculation. Pointing of the telescope towards the ephemerid point is performed in advance (few seconds) before the object passing. Guidance routine controls time remaining before the object appearance and puts on the telescope engine in a given time to enable the object guiding. Object guiding is performed via delivery of its current angle speed along the houre angle and declination on the telescope mechanucs.

Investigations of model scenarios of destruction of geostationary SC allow to calculate the debris orbits and to determine their time evolution. Models point out the existence of 2 points of intersection of parental body orbit and debris one, corresponding to parental body argument of latitude at the moment of destruction. A region of debris



movement occupies a belt of variable width in a projection onto sky. The width of the belt in the debris pinch region is 40-60 arc minutes in declination. Relative speed of movement of debris in the pinch point is up to about 15 arcsec\ sec and lies in the interval 0.2 to 10 arcsec\ sec and 0.2-20 arcsec\ sec in hour angle and declination angle accordingly. For observation with a 1.5 m diameter telescope in a “stare mode” these values of speed of objects mean, that only the 18 -18.5 magnitude objects can be detected. More fainter objects must be detected in tracking mode. Multi-color photometric measurements of small sized debris also have to be carried out only in the tracking mode. Under a 60 second exposition, the 1.5 meter telescope can detect objects of 20 magnitude at zenith angle about 2 with a signal/noise ratio = 5. This magnitude is almost equal to brightening of diffuse sphere with diameter of 10 cm at the 36000 km distance. For achievement of limiting magnitudes for detecting, the measurements of the color indexes and dynamic characteristics of a movement of a debris objects, it is necessary to keep a telescope tracking motion with high accuracy. The requirements imposed on the telescope structures, drivers and control system hold a point image of debris object under an ephemerides motion. In a stare and objects tracking modes a field of view are crossed by stars. Following mentioned above estimations of a limiting magnitude with 1.5 meter telescope it can be determined, that the tracks of a stars brighter than 18.5 magnitudes will be recorded. The average amount of a stars brighter than 18.5 mag. is about 200 in a field of view during a typical exposition time. It should be expected, that approximately half of a field will be star track occupied. To recognize and to measure precisely the photometric parameters of a point like objects superimposed on extremely non-uniform background, a complex of sophisticated algorithms becomes a necessity.

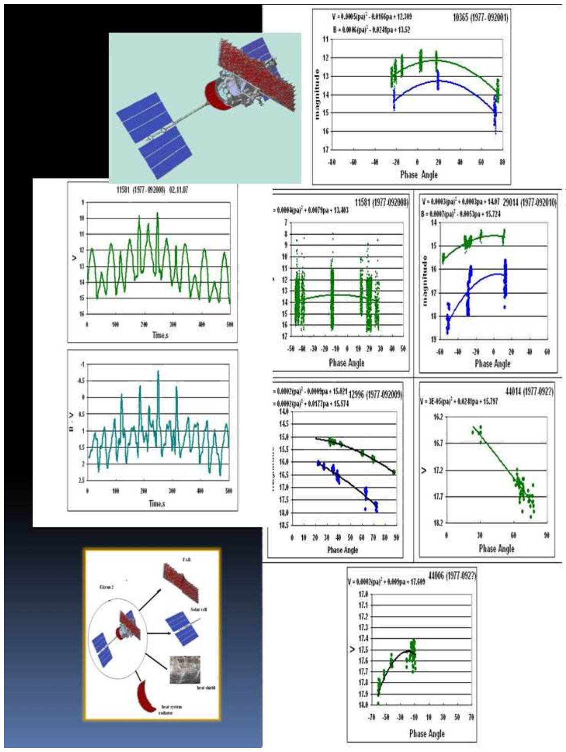
Originally, photometric measurements were made for all revealed objects by registration of image series. Stars from the field, in which the observed object was situated, were used as reference. Analysis of this data demonstrated, that errors during the image calibration often exceed amplitude of the observed differences of object shine. Therefore, in the posterior observations, standard fields close to the program object were used for the calibration (A.Landolt, 2001) (B.Warner 2006). A hallmark for the standard field selection was difference of the air mass, which should not have exceeded 0.2-0.3. In these conditions together with typical fluctuations in transparency (about 10%) an error of the brighteness estimation did not exceed 0.02-0.03 magnitudes. Measurement of the instrumental magnitudes of a moving object represents a more sophisticated task, which is not yet completely solved. In the present work, instrumental magnitudes were determined with a method of aperture photometry. Previous applications of this method revealed, that during measurements of the objects with 16-17 magnitudes errors appear, that are connected with passing of stars over 'signal' background apertures. However, during relatively short expositions with duration determined by conditions of brightnes change period registration the errors have the same order of magnitude with those caused by statistical light nature and transparency fluctuations. In practice, in the magnitudes range of observed objects, the method of aperture photometry appears to be even more precise then method of the star image profile approximation with a point spread function.

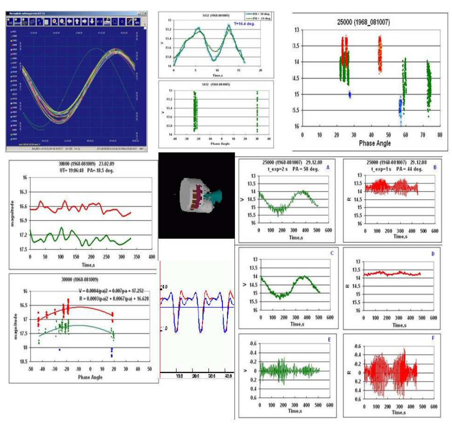
Direct acquisition of photometric information with high temporal resolution (0.5-1 s) for the objects weaker than 17 star value is not possible. Measurement of these objects s is performed using 'long' (5 s and more) expositions. Revelation of the periodic component in the brightness of these objects will be performed using statistical methods of latent periodicity analysis (S. Veniaminov et al 2005). For the construction of a light curves of these objects, a method of superimposed periods obtained with shortest possible exposition must be used. The exposition length must be determined from the conditions of object revelation in the image, with minimally acceptable signal to noise ratio.

Results of the multi-colour photometric measurements of the debris objects.

The time serias of the frames at BVR filters were obtained. A time resolution in a serias had been definded by the exposure time in the given filter. An ordinary situation it was equel from 1 to 3 seconds for R and V filters and 5-10 seconds for B filter as a compromise between a signal to noise ratio and a periods of a brightening variaton was marked. The procedure was repiated at different phase angles during to objects visibility. The observable debris objects have various mean brightness in the range from 14 up to 18.5 magnitude and various colors (B-V) and a dynamic of the brightness variation. A photometrical accuracy can be estimated from a some qualitatively reasons and was no more than 0.05 magnitudes. It is important to note that all objects which were observed have a strong variability. The variability amplitudes are depend on a phase angle. A row data can not reveal existent any phase dependences of the faint objects brightness. The new data processing, making with more careful calibration procedures don't confirm this claims. To approximate the data averaging on the time intervals more than main periods one can obtain Significant phase dependences for all observed objects. Linear parts of the polynomial function approximation (magnitude per degree) are cited in the figures 2 and 3. There are significantly different a phase coefficient in the B and V filters for any samples of the small sized objects. It will subject for future stage of this work.

The individual light curves of the Ekran 2 satellite and debris objects under investigation are presented in Fig.2 and 3. There are considerable differences in the light curves variability due to objects rotation or (and) trembling. The form of a light curve and distinction of amplitudes speaks conditions of illumination and distinctions in albedo, indicatrix and geometry of the surfaces. To obtain color indexes one must use curves differences in the adjacent filters. The row data was fitted a spline before get differences. The photometrical properties of the debris objects being observed in the Ekran 2 and Transtage IV tube are summarized in a figures 2 and 3.





Figures 2 and 3. Phase dependenses for Ekran 2 and Transtage IV debris.

Low resolution spectra of space debris

It was established in multicolor debris observations that their colors are demonstrated the short periods fluctuations. An example of its is demonstrated on left panel on fig.2. We had conducted an analisys of the different methods for simultaniosly measurements in spectral bands and consentrated on classic difraction grating spectrometers.

Low-resolution spectrometer at advanced telescope AZT 33 was applied to spectrophotometrical study of an object irradiation . At the figures below one can see example of spectra of three different GEO objects labeled on FOV frame. With a custom CCD camera spectra and slit imagers can be obtained simultaneously, The spectra presented below were obtained with expose time 2.5 s . The hardware for spectral investigation one can see at bottom left picture.

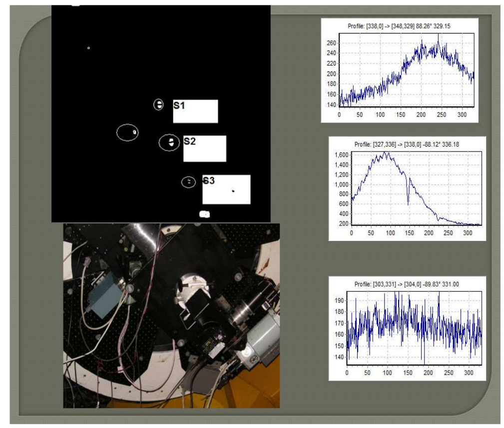


Figure 4. Hardware for low resolution spectroscopy and examples of the row spectra space debris objects

Summary

An advanced telescope AZT 33 were applied to small sized debris detection, orbit determination and photometrical measurements. The equipment and methods for multicolor photometry of a small sized movie debris were developed. The equipment and software of the telescope control system allow, by the use a predicted orbit to make precision tracking of object and it is reliable to detect mobile objects of 22 magnitude.

From the results of multicolor photometrical observations and a light curves analyses of the non active geostationary spacecraft and faint debris objects it is possible to deduce any conclusions about an objects suspect of destruction on the base of orbits analyses. The fragments in close neighborhood to an orbit of the Ekran 2 were investigated. Attempt of an identification of the 7 debris objects with the Ekran 2 design by using B-V color index were made. Amongst the Ekran 2 families objects there are objects 11581 that have the appearance of solar panels. Its light curver have been demonstated two bell-like details, approximately identical duration, but distinguished on amplitude on 1.5-2 magnitudes. At the specific moments at the top of a smaller magnitudes detail a short mirror flashe with an amplitudes of 8 magnitudes and strong bluring effect have been observed. This kind of the light curver behaviour are typical to solar panels one (N. Anfimov et. al. 2002). Notably that no mirror flash and bluring effects being detected for Ekran 2 parental body. The other objects are allocated along a "tube" of trajectories near Ekran 2 parental body does not demonstrated any sign of mirrors effect. There are much reddening objects in comparison with average color of space objects with entirely diffuse indicatrix. The experimental equipment at Sayan mounting observatory of Institute of Solar Terrestrial physics provides the opportunity of a detection of moved objects up to 22 (R) magnitudes in the tracking mode. For measuring of a spectral brightness the CCD photometer has been used. Commonly used UBVRI filters are located in gear (worm)-driven filter wheel. In the multicolor photometrical mode, which is more adequately for faint objects, the measurements are executed consequently with expose time choosing by observer. For simultaneous measurements in different spectral bands low dispersion slit specrtrometer with custom CCD device was commissioned.

Referenses

[1] S.F. Kamus,V.I. Tergoev, P.G. Papushev 2002 Wide – band astronomical telescope ; Optical Jornal of Russia", vol. 69, №9, 2002 г.

[2] V.Agapov et al. 2009 Classification and caracterisation of GEO population based on the results oft the jbservation. This issure

[3]Yurasov, V.S. Long-Term Prediction of Space Objects Motion in GEO. Proceedings of The Third U.S.-Russian Space Surveillance Workshop. 20-23 October, 1998, Washington, DC.

[4]N. Anfimov, R. Kopyatkevich, Yu. Koluka, G. Mishin , P. Papushev, 2001 Remote diagnostics of performances and technical status of a spacecrafts with the help of telescope. Nea-Earth astronomy XXI century, Moscow , GEOS, 2001

[5] Yu. Karavaev, R. Kopyatkevich, M.Mishina, G. Mishin, N. Sakva, O. Yurysheva Astrophotometrical observation of artificial satellites and study of the technical status of parental bodies of space debris at geostationary ring Proceeding of the Fourth European Conference on Space Debris, 18-20 April 2005, ESA/ESOC, Darmstadt, Germany.