

Can photometric data help to maintain a catalogue of small-sized space objects?

Preliminary results of small-sized GEO debris observations

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Abstract

Specific programs were conducted for metric and photometric observations of space debris with the 1.7 meter telescope at the Sayan observatory. The methods of light curve photometry for analysis of the optical properties of small sized debris objects at GTO and GEO had been applied. The results of multi color (BVR) observations in visible wavelengths: phase dependence of magnitude, color indexes distribution, and light curves of the small-sized objects had been investigated.

The family of objects with average magnitudes of 15- 18.5 (V), moving in orbits, which group around the orbit of the object with international number 77092A (Ekran 2), had been studied closely. Data had been obtained about the objects' irradiation spectrum, angle distribution, and rotational dynamics. These data have yielded information for preliminary identification of the Ekran 2 event.

Modern and future calls for the problem of space surveillance for cataloging of small-sized objects in the near-earth space have been discussed. By a preliminary estimate, the photometric information can be used for small-sized objects' identification and cataloguing.

Background

The modern catalogues of artificial space objects are constructed only on the basis of the data for position in space (the metric data or the coordinate information). However, today we face a problem of prediction of small-sized space debris positions. On short time intervals the orbital characteristics of these objects vary so considerably, that correlation between their orbital elements is very low. In the future we plan to follow these objects continuously with the help of wide-field optical systems for a high-speed sky survey. However, it does not solve the problem of their cataloguing.

In the 1990s a method has been proposed for identification of non-active geostationary satellites from metric data (A.S. Sochilina, 1990). On the basis of this method the evolution of the long term orbital elements had been studied. (A.S. Sochilina, R.I.Kiladze, K.V.Grigoriev, A.N.Vershkov, 1999.) In this work indications had been obtained that orbits of some non-active spacecraft and space vehicles are spontaneously changed. It was a direct indication of the source of GEO debris objects.

The experimental works performed at the end of the 1990s (T. Schildkneht, et al., 2001), (J. Africano, P. Kervin, K. Hamado et al., 2002,) concerned the statistical estimations of a quantity of small-sized debris on geostationary orbits. A large amount of small sized GEO and GTO objects fainter than 16 magnitude were found. In subsequent studies the measurement of their positions and the determination of their orbits were performed. Taken together with newly developed methods of orbit determination, which include characteristic fluctuations due to the solar irradiation pressure, these works obtain ephemerides essential for the long-term guidance of the objects and for the measurement of their photometric characteristics.

In action orbital parameters are not sufficient for cataloging small sized objects. The orbital elements are significantly changed due to non-gravitational factors. Besides the orbital

parameters, the additional, more stable attributes are necessary, which will allow identifying the debris objects. For example, one can use their optical characteristics. Measurement of the optical characteristics is one of the more difficult tasks of experimental astrophysics.

The optical characteristic data should be carefully calibrated and standardized. Only in this case classical photometric data can be effectively used for recognition and identification of the artificial space objects.

Methodical approaches and observational techniques

The main task of the present work is to demonstrate feasibility of the photometric methods for identification of the observable debris objects with their parental body. The AZT 33 IR telescope, which is located at the Sayan mountain observatory of the Institute of Solar Terrestrial physics, is used for the investigation. The AZT 33 IR is a special astronomical Richey-Chretien telescope with a 1.7 meter primary mirror and a 30 meters focal length in the Cassegrain focus (S. Kamus et.al., 2004). The optical system is established on a fork type equatorial mount. The control system of the telescope, its mechanical drive, and electronic and software units enable tracking an object along an ephemeris, and make it possible to detect small-sized objects.

The main feature of the equipment is the focal reducer (FR). The optical scheme FR and its mounting in the Cassegrain focus of the AZT 33 are sketched in Fig.1. It responds fairly well to the requirements listed above. The performance of the FR, which accepts the image of the $f/20$, 170 cm Richey-Chretien AZT 33 telescope, and transfers it onto the CCD (1Kx1K, 16 μm pixel size device, named ISD 017, produced by plant “ Electron”, St-Petersburg) is suitable for finding and detecting small-sized debris with a magnitude less than 18, and poorly determined orbital parameters. For finding brighter debris and spacecraft an auxiliary 30 cm telescope mounted on the main optical structure has been used.

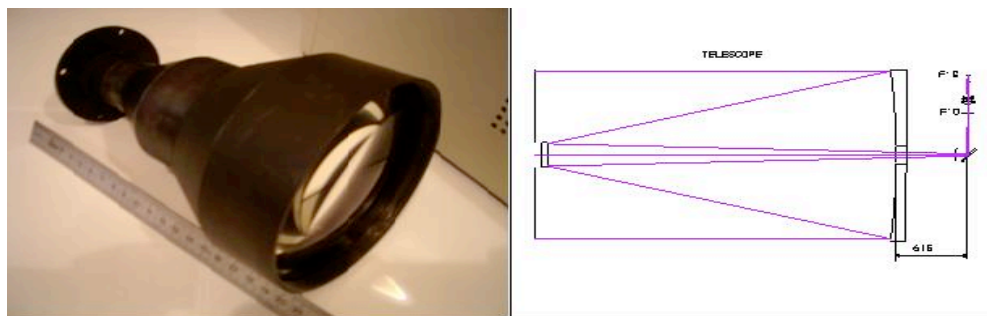


Fig. 1. Optical scheme of telescope with a focal reducer. Focal reducer design.

This experimental equipment provides the opportunity for detection of moving objects up to 22 (R) magnitude in the tracking mode. For measuring spectral brightness the CCD photometer has been used. Commonly used UBVRI filters and a low dispersion grism are located in a worm-driven filter wheel. In the multicolor photometric mode, which is more adequate for faint objects, the measurements are executed consecutively with exposure times chosen by the observer.

Several features of the telescope and its control system are very suitable for observing small-sized objects. Ephemerides in support of the observations includes the dynamic catalog of the debris objects by KIAM, (V.Agapov et al. 2007), which is represented by a database table, containing orbital characteristics. A graphic observation interface enables effective

planning of the observation time. The choice of an object is determined by the following factors: (1) height over the horizon, (2) extent of the object illumination by sunlight (phase), and (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 the Sun (phase angles < 60 degrees) are shown, the horizon line and the shadowed regions of the flight are marked.

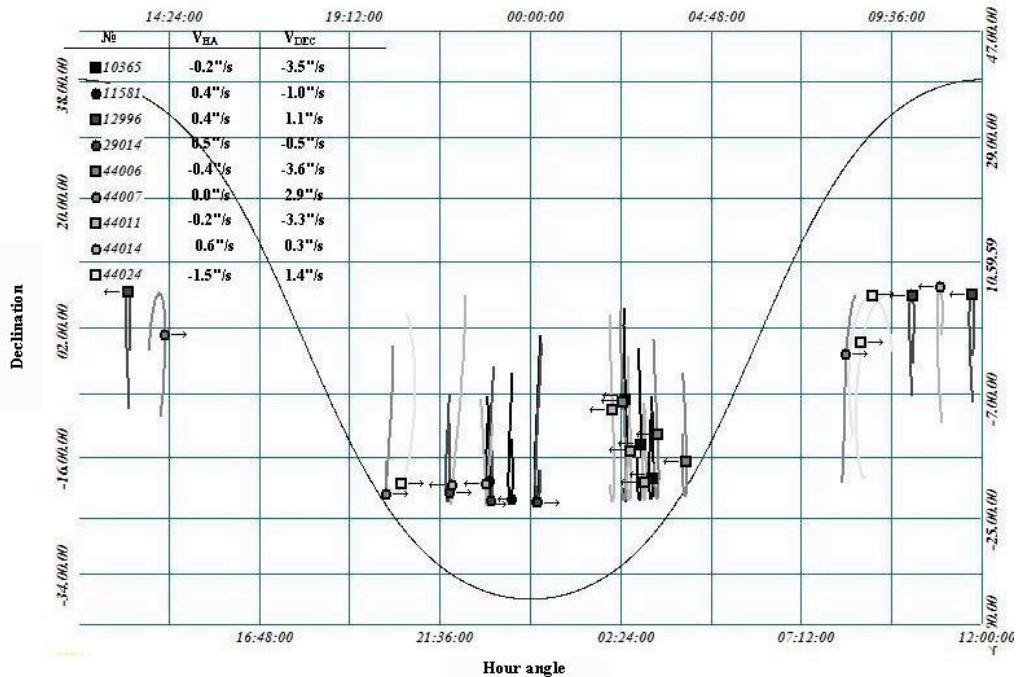


Fig.2 A block of the telescope AZT33 graphical users interface. A trajectory of a debris satellite is plotted.

The software package SATRADANA (V.Yurasov, 2007; V.Yurasov et al. 1995) had been imported to the telescope control system. The individual 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 of 1 min., which is enough for objects that are moving with speeds of about several arcsec/s. Ephemerides parameters are saved and used for the planning of observations, as well as for discovering and tracking of objects along the ephemerides. To monitor a space object, an ephemeris point is selected, which responds to the optimal vision conditions. Guidance routine enables calculation of the coordinates of the visible position of objects and turning of the telescope to the calculated position with 1'' precision. Refraction and errors of the telescope polar axis installation are included in the calculation. Pointing the telescope towards the ephemeris point is performed in advance (few seconds), before the object passing. Guidance routine controls the time remaining before the object's appearance and turns on the telescope guidance in time to enable the object guiding. Object guiding is performed via delivery of its current angle speed along the hour angle and declination of the telescope mechanics.

Investigations of model scenarios of the destruction of geostationary SC allows calculating the debris orbits and determining their time evolution. Models point out the existence of 2 points of intersection of the parental body orbit and the debris orbits, corresponding to a parental body argument of latitude at the moment of destruction. The 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. The relative speed of movement of the debris in the pinch point is up to about 15 arcsec/sec and lies in the

interval of 0.2 to 10 arcsec/sec in hour angle and 0.2-20 arcsec/sec in declination angle, respectively. For observations with a 1.5 m diameter telescope in a “stare mode”, these values of the speed of the objects mean, that only the 18 -18.5 magnitude objects can be detected. 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. With a 60 second exposure, the 1.5 meter telescope can detect objects of 20th magnitude at air mass about 2 with a signal/noise ratio = 5. This magnitude is equal to brightness of a diffuse sphere with a diameter of 10 cm at the 36000 km distance. For the achievement of the limiting magnitudes for detecting, the measurements of the color indexes, and the dynamic characteristics of the movement of debris objects, it is necessary to keep a telescope tracking with high accuracy. The requirements imposed on the telescope structures, drives, and control system are hold a point image of a debris object under ephemerides motion. In stare and tracking modes the field of view is crossed by stars. Following the above mentioned estimations of a limiting magnitude with a 1.5 meter telescope, it can be determined, that the tracks of stars brighter than 18.5 magnitudes will be recorded. The average numbers of stars brighter than 18.5 mag. is about 200 in a field of view during a typical exposure 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 point like objects superimposed on an extremely non-uniform background, a complex of sophisticated algorithms becomes a necessity.

Originally, photometric measurements were made for all known objects by registration of an image series. Stars from the field, in which the observed object was situated, were used as reference stars. Analysis of these data demonstrated, that errors during the image calibration often exceed the amplitude of the observed differences of object brightness. 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 the 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 brightness 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 the ‘signal’ background apertures. However, during relatively short exposures, with the duration determined by the conditions of brightness variations, the errors have the same order of magnitude as those caused by the statistical nature of light and transparency fluctuations. In practice, in the magnitude range of observed objects, the method of aperture photometry appears to be even more precise than the 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 fainter than 17th magnitude is not possible. Measurement of these objects is performed using ‘long’ (5 s and more) exposures. Determinations of the periodic component in the brightness of these objects will be performed using statistical methods of latent periodicity analysis. For the construction of light curves of these objects, a method of superimposed periods obtained with the shortest possible exposure must be used. The exposure length must be determined from the conditions of object appearance in the image, with minimally acceptable signal to noise ratio.

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

Observations of space debris in the geostationary rings have been performed in the Sayan observatory ISZF in January-October 2007. The total number of the observation nights equaled 81. Two unknown faint objects had been discovered. The brightness range of the

dependences of the faint object's brightness. The new data processing, made with more careful calibration procedures does not confirm this claim. To approximate the data averaging on the time intervals of more than the main periods, one can obtain significant phase dependences for all observed objects. Linear parts of the polynomial function approximation (K- magnitude per degree) are cited in the table 1. There is a significantly different phase coefficient in the B and V filters for any sample of the small sized objects. It will be the subject for a future stage of this work.

№	V	B-V	K	Period	Amplitude
10365	12.2 ^m – 14.0 ^m	1.1 ^m	V: 0.017 B: 0.024	135 s	1 ^m
11581	13.2 ^m - 14.4 ^m	from 1.5 ^m	V: 0.012	536 s	up to 3.5 ^m
	flash: up to 8 ^m	to -1.5 ^m		67-79 s;	A1: up to 5.5 ^m A2: up to 3.5 ^m flash: up to 8.4 ^m
29014	14 ^m - 15.2 ^m	from 1.1 ^m to 2.6 ^m	V: 0.024 B: 0.034	26 s, 52 s	V: 0.2-0.3 ^m B: 0.2-1.4 ^m
12996	14.6 ^m – 16.4 ^m	from 1.2 ^m to 1.9 ^m	V: 0.026 B: 0.030	18.5 s	V: 0.2 ^m B: 0.2-0.7 ^m
44014	16.5 ^m – 17.8 ^m	-	V: 0.027	-	0.1-0.4 ^m
44006	17.3 ^m – 18 ^m	1.0 ^m	V: 0.014 B: 0.007	-	0.2 ^m

Table 1. In the table are listed the object number in the KIAM database; the magnitude in Bessel V filter; Color indexes (B-V); K - the phase coefficient in magnitudes per degree; periods and amplitudes of a brightness fluctuation in objects.

The individual light curves of the Ekran 2 satellite and debris objects under investigation are presented in Fig 4. There are considerable differences in the variability of the light curves due to the objects' rotations. The form of a light curve and the distinction of amplitudes indicates conditions of illumination and the distinctions in albedo, indexes, and the geometry of the surfaces. To obtain color indexes one must use different curves in the adjacent filters. The row of data was fit to a spline before obtaining differences.

Consider in more detail the changes of brightness and the scattered radiation spectra of these debris objects. The object 11581 is on the average, brighter than any other, but it has strong variability in magnitudes and color indexes (see figure 5). The basic period consists of 2 bell-like details, approximately identical in duration, but distinguished in amplitude by 1.5-2 magnitudes. The basic period is 66 ± 3 sec. The precise period, with a duration of about 500 seconds, may be determined. At specific moments at the top of smaller magnitudes, short mirror flashes are observed. The amplitudes of the mirror flash can achieve an upward jump of 8 magnitudes.

On the average the spectrum of an object, determined by the help of a color index, is shifted to a long-wave range with respect to the Sun spectrum. However, in short duration intervals at the moments of "flashes", it is shifted to the blue, short-wave area with an average length of a wave of 0.43 microns reliably marked. It is necessary to note, that mirror flashes always are observed only on the second half-cycle, namely only at one side of rotating object. Mirror flashes are observed on a light curve of an object in a wide range of corners. Other observed debris objects do not indicate mirror components of the reflected radiation. The amplitude of changes of magnitude in debris, 29014, 12996, 44014 and 44006, does not

exceed 0.2 magnitudes and the characteristic time of changes makes the period about 20 sec. The most remarkable feature of these debris, as shown in a separate series of observations, are the distinction of the amplitudes of the variability of brightness in filters B and V and the essential reddening of objects in comparison with the average color of space objects in a diffuse part of indexes. Only for object 44006 the color index appeared identical to the color of the parent object, the Ekran 2 (№ 10365).

The observation of the Ekran 2 object which has been carried out in filters at various phase angles, shows stable changes of brightness with an amplitude of about 1 magnitudes and a period of 135 seconds. At mean brightness, depending on phase angles, object 10365 is not observed with mirror flashes and blueing. The phase dependences can be fit by a cosine function with a maximum at an opposition region.

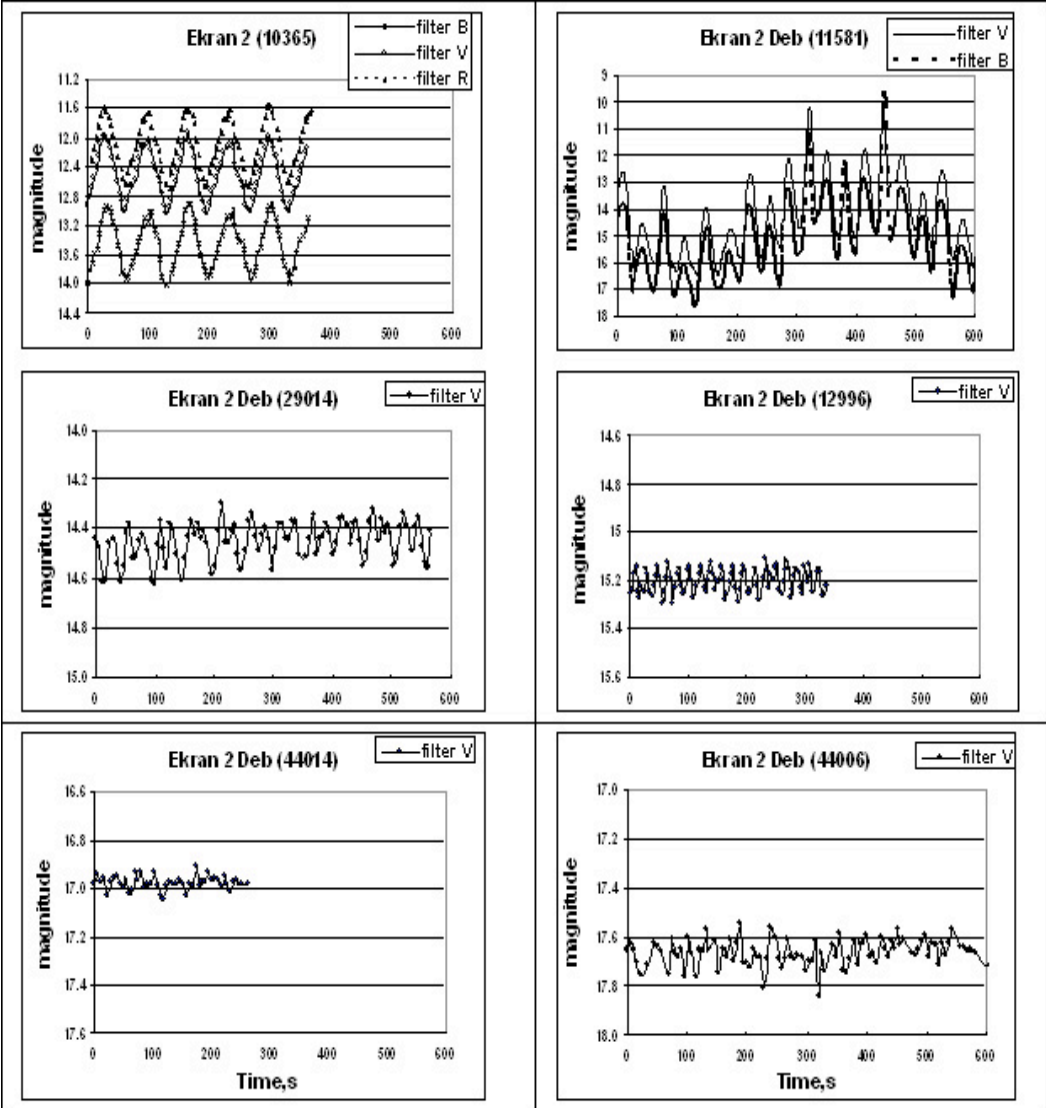


Fig. 4. Examples of debris objects' light curves (row data, calibrated with the help of Landolt stars)

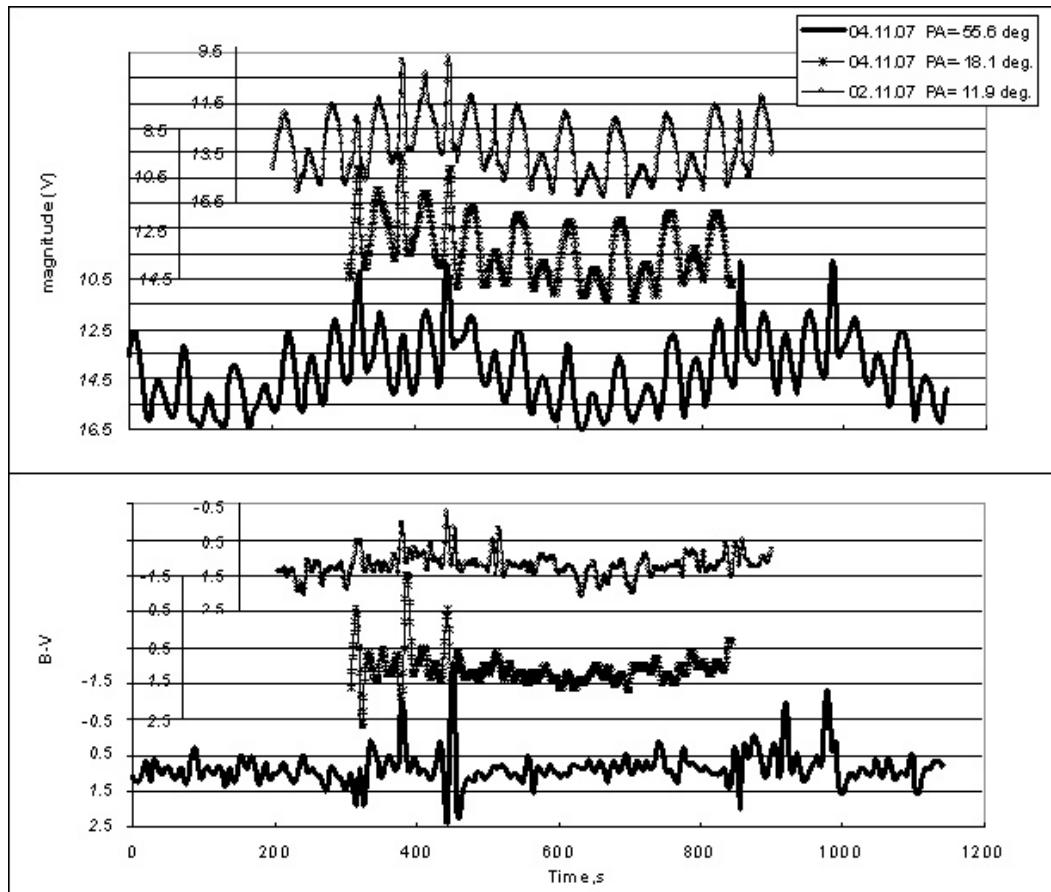


Fig. 5. The light curves for the 11581 object from Ekran 2 family. At the top panel – a light curve in the V filter, the lower panel represents dependences of B-V color index versus time.

Summary

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

From the results of multicolor photometric observations and light curve analyses of the non-active geostationary spacecraft and faint debris, it is possible to deduce conclusions about an objects' source. The fragments in a close neighborhood of an orbit of the Ekran 2 were investigated. An attempt of identification of the 7 debris objects with the Ekran 2 design, by using B-V color index, were made. Among the Ekran 2 family there is object 11581 that has the appearance of solar panels. Its light curve has demonstrated two bell-like details, with approximately identical duration, but distinguished in amplitude by 1.5-2 magnitudes. At specific moments at the top of smaller magnitudes short mirror flashes with an amplitude of 8 magnitudes and strong blueing effect have been observed. This kind of light curve behaviour is typical of solar panels (N. Anfimov et. al., 2001). Notably, no mirror flash and blueing effects have been detected for the Ekran 2 parent body. The other objects are allocated along a "tube" of trajectories near the Ekran 2 parent body and do not demonstrate any sign of mirror effects. There is much reddening of objects in comparison with average color of space objects with entirely diffuse indexes. They can be identified with other

elements of a spacecraft, namely thermal radiator external surface, a bit of heat shield material, etc. Mathematical simulation of observational data is needed to resolve Ekran 2 events in more detail.

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