COLOR INDICES OF SELECTED OBJECTS SITUATED ON THE MEO AND GEO ORBITS OBTAINED BY TWO TELESCOPES OBSERVATIONS

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Abstract

In the presented paper we are investigating the color indices of targets situated at the geostationary orbits. To get the color indices we performed five nights of observations at the Astronomical and Geophysical Observatory FMPI CU, Modra during the summer and fall 2012 and during the winter 2013. The main targets were stable spacecrafts and rocket bodies. In three cases we also observed fragments of the Titan 3C rocket body which fragmented on GEO in 1993. Two types of observations were used. During one station observations the measurements were performed by the 0.6-meter Zeiss telescope with 3.29-meter focal length and with Johnson/Cousin BVRI filters. For two simultaneous observations the 0.6-meter Zeiss telescope and 0.28-meter Celestron EdgeHD telescope equipped with Johnson/Cousin R filter were used. We calculated astrometric positions of selected targets by our own package Sateph and by using the public catalogue.

1 Introducion

It is almost a decade since the new population of space debris with high area-to-mass ratio (HAMR) has been discovered [1]. This type of population is specific by the orbits with mean motions close to one revolution per day and with high eccentricities. Its origin, as well the mechanism of creation weren't sufficiently described until today. Our recent knowledge indicates that these objects could be created in the GEO belt and under the influence of perturbations, mostly by the solar radiation, they migrate to the more eccentric orbits with higher inclinations [2].

Except dynamical evolution, also the physical properties such as colors and color indices can help us understand this population in more detail. By comparing the optical properties of HAMR targets with other known objects, one can extrapolate their surface physical properties. For this purpose the laboratory [3] or the optical measurements can be used [4], [5].

In our presented work we are discussing the color indices of objects which are characteristic for the GEO belt, the HAMR objects, most likely area of their origin. We present the single telescope observations as well two telescopes simultaneous observations performed at the Astronomical and Geophysical Observatory FMPI CU, Modra, Slovak Republic (AGO). During the measurements we used our 0.6-meter Zeiss telescope with 3.29-meter focal length and with Johnson/Cousin BVRI filters (see Figure 1, on the left) and smaller 0.28-meter Celestron EdgeHD telescope equipped with Johnson/Cousin R filter (see Figure 1, on the right).

Figure 1. Two telescopes situated at the Astronomical and Geophysical Observatory FMPI CU, Modra which were used for the observation campaign. The 0.6-m Zeiss telescope with 3.29-m focal length and with Johnson/Cousin BVRI filters (on the left) and the 0.28-m Celestron EdgeHD telescope with 2.8-m focal length and with Johnson/Cousin R (on the right).

2 One telescope observations

Several optically stable nights were used for our observation campaign. We performed single station observations in 19th of August, 16th and 19th of October and 14th of November 2012. We chose objects observable with 0.6-m telescope in B filter. Using the 5 seconds exposure time this means approximately limiting magnitude of +14 in B filter. To obtain the object's ephemeris we used orbital elements from the public catalogue and our own package Sateph, the tool using the analytical model SGP4 [6]. Sidereal tracking was turned off during the measurements, so the stars appeared as a streaks and GEO objects as points or a very short streaks. For one object from ten to twelve images were taken for each filter B, V, R and I. Due the

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readout time of CCD camera, this corresponds to about 30 minutes of observations per one object.

During the observation night we also observed several standard star fields for each filter. In that case the sidereal tracking was on. We used the Landolt standard stars to perform the conversion from instrumental into the apparent magnitudes [7]. After observations, the standard image calibration was performed by the Image reduction and Analysis Facility (IRAF). We subtracted the master bias, dark and flat field images from the raw images. For that purpose the IRAF package *dbphot* was used kindly provided to us by Dr. Patrick Seitzer from the University of Michigan.

After the image reduction procedure, the instrumental magnitudes for every filter of every object were measured and converted into to the apparent magnitudes. As the last step, the observed apparent magnitudes were corrected by the phase angle. In that case we got for every object its absolute magnitudes in different filters. The measured magnitudes with their calculated errors are plotted in *Figure 2* and *Figure 3* for SL-12 R/B and debris fragment from Titan 3C R/B respectively.

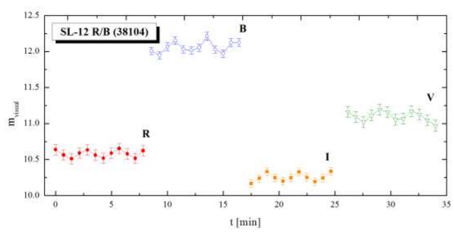

Figure 2. The magnitudes of the SL-12 R/B for B, V, R, I filter (y axis) as a function of time (x axis) obtained during single telescope observations.

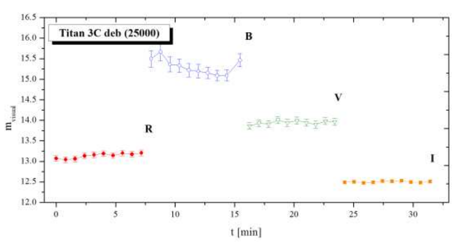

Figure 3. The magnitudes of the Titan 3C R/B debris for B, V, R, I f ilter (y axis) as a f unction of time (x axis) obtained during single telescope observations.

In total, 14 GEO objects and one object on more eccentric orbit () were observed during four nights of single telescope observations. One object, SL-12 R/B 38104 was observed twice, in 19th of August and also in 14th of November. There were three different types of Astra spacecrafts observed, five satellites in total. Except the SL-12 R/B 38104, also two others SL-12 R/Bs were observed, the 11567 and 11684. The rocket bodies Titan 3C R/Bs 7324 and 10002, Titan 4C R/Bs 27712 and Atlas were observed as well. Except the intact targets, we measured the magnitudes of fragments from Titan 3C R/B 1968-081E, which fragmented in the GEO ring in 1992 [8]. There were three fragments observed in total.

For every of these objects we obtained magnitudes in B, V, R and I filters. The exceptions were two debris fragments from Titan 3C R/B which were too faint to be observed in B filter. To calculate the color indices the averaged value of magnitudes for given filter was used.

3 Simultaneous observations

Also we performed test simultaneous observation in 7th of February 2013. The snapshots were taken every minute by both telescopes at the same time. The used exposure time was five seconds and the sidereal tracking was turned off. To achieve the synchronization between both observers, the radio controlling clocks were used. For the 0.6-m telescope we were taking images using filters R, B, V and I. There were six images taken per each filter per object. During the exact time, we took images of the same object with the small 0.29-m telescope, but only in the R filter.

In final, we obtained color indices B-R, V-R, and I-R as a function of time. We subtracted indices B-R and V-R to obtain the color index B-V. There are an examples plotted in *Figure 4* and *Figure 5* for SL-12 R/B (38104) and Ekran 13 (15219). The magnitudes obtained for R filter by the 0.28-m telescope as a function of time are shown in the upper plot of *Figure 4* and *Figure 5*. On the lower plot of *Figure 4* and *Figure 5*, the color indices are plotted as a function of time.

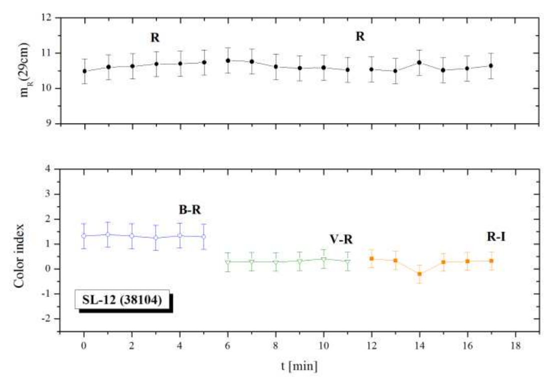

Figure 4. T he color indices obtained during two telescopes simultaneous observations (figures below) and the light cur ve for R f ilter obtained by 0.28-m telescope (above) of SL-12 R/B 38104. The x axis represents the time since first image expos ure. The y axis represents the indices V-R, B-R, I-R and the R magnitudes obtained by 0.28-m telescope.

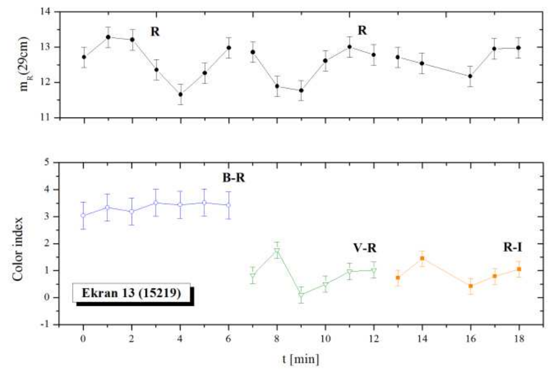

Figure 5. The color indices obtained during two telescopes simultaneous observations (figures below) and the light curve for R filter obtained by 0.28-m telescope (above) of spacecraft Ekran 13(15219). The x axis represents the time since first image exposure. The y axis represents the indices V-R, B-R, I-R and the R magnitudes obtained by 0.28-m telescope.

There were four objects in total simultaneously observed by two telescopes, the Astra 1M (33436), Astra 2C (26853), Ekran 13 (15219) and SL-12 R/B (38104).

4 Results

The color indices obtained by the single telescope observations and by the simultaneous observations, R-I versus V-R and B-V versus B-R, are plotted in *Figure 6* and *Figure 7*. The values have average error of 0.18 of magnitude for B-V and B-R indices and error of 0.13 of magnitude for R-I and V-R indices. These errors are results of combination of the error caused by signal to noise ratio for given object in given filter and the observation conditions during the measurement night.

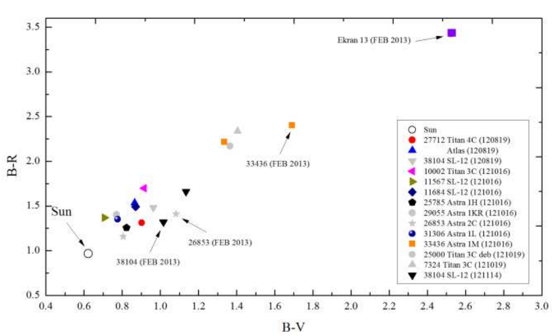

Figure 6. The color indices B-V versus B-R obtained during the single telescope observations (nights 2012/08/19, 2012/10/16, 2012/10/19, 2012/11/14) and during the simultaneous observations (night 2013/02/07, on plots referred as FEB 2013). For comparison the color indices for Sun are also plotted in figures.

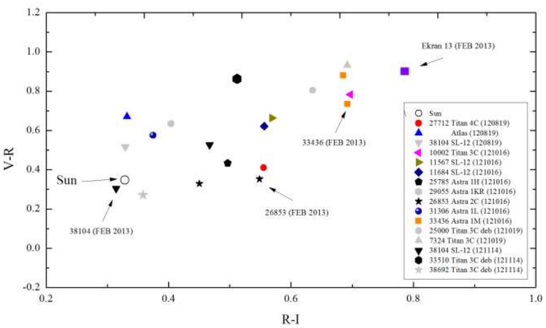

Figure 7. The color indices R-I versus V-R obtained during the single telescope observations (nights 2012/08/19, 2012/10/16, 2012/10/19, 2012/11/14) and and during the simultaneous observations (night 2013/02/07, on plots referred as FEB 2013). For comparison the color indices for Sun are also plotted in figures.

5 Discussion

There are several groups clearly distinguish in the *Figure 6* and *Figure 7*. There are Astra spacecrafts, SL-12 rocket bodies, Titan 3C rocket bodies and the debris (25000 and 33510). Some objects are separated from the groups, such as Astra 1M and recently catalogued Titan 3C debris fragment 38692. There are also several objects which are one of their kind such as Titan 4C R/B (27712), Atlas R/B and Ekran 13 (15219). All mentioned groups and targets are discussed further in following sections.

The Astra 1M (33436) was observed twice, during the single telescope measurements in 16th of October 2012 and also during the two simultaneous telescopes measurements in 7th of February 2013. Obtained color indices during both observations are very close to each other. It is important to point out, that observed Astra spacecrafts have different manufactures. The Astra 1M was built and launched as the last one and unlike the other four Astra spacecrafts (Astra 1H, Astra 2C, Astra 1KR, and Astra 1L) its bus is covered by copper multilayer insulation (MLI). By using laboratory measurements [3] we can see that this type of material has relatively high B-V and B-R indices comparing to the Sun or to the other in space used materials.

Another interesting targets are Titan 3C rocket bodies (7324 and 10002) and fragments (25000, 33510 and 38692). The fragments 33510 and 38692 are plotted only in *Figure 7*, while there were too faint to be observed in B filter with the 0.6-m telescope. To get the magnitudes in V filter we used the stacking images procedure to improve the signal to noise ratio for these targets. In *Figure 7* the Titan 3C R/Bs 7324 and 10005 and the fragments 25000 and 33510 are very close to each other. Interesting case is the fragment 38692 which is having the smallest V-R index from observed targets.

According to laboratory measurements [3] this index is close to the materials like aluminum and aluminized Kapton.

The SL-12 R/B 38104 was observed in three different nights, two times by the one telescope and once by the two telescopes simultaneously. This rocket body is on the geocentric Earth orbit since beginning of 2012, which makes it the youngest object we observed. From every observation we performed for this target, we got very similar results in its color indices.

The SL-12 R/Bs 11567 and 11684 have slightly different color indices. We expected that results, because these targets are the same type of objects and also spent the same time on the orbit, while they were launched in same period of time.

The most extreme color indices were measured for the Ekran 13 (15219). These values will be further investigated and other simultaneous observations will be performed for this target.

6 Conclusions

In the paper we are presenting results from the photometric measurements of GEO type of objects performed at the Astronomical and Geophysical Observatory FMPI CU, Modra. We performed observations during five nights in total. In first four nights the 0.6-meter Zeiss telescope was used to obtain the targets brightness in B, V, R and I filters. In fifth night, in the 7th of February 2013 we used two telescopes for simultaneous observations, the 0.6-meter Zeiss telescope equipped with Johnson/Cousin BVRI filters and the smaller 0.28-meter Celestron EdgeHD telescope equipped with Johnson/Cousin R filter.

During our data processing we performed several calibration steps. First we applied image reduction procedure on raw images. We calculated the photometric equation coefficients using standard stars to get the conversion between instrumental and apparent magnitude. For some objects we also did corrections of the apparent magnitudes for a phase angle.

For 17 objects in total we measured and calculated the color indices (*Figure 6* and *Figure 7*). They were functional and non-functional spacecrafts, rocket bodies and fragmentation debris. The SL-12 R/B 38104 was observed three nights and the Astra 1M (33436) was observed two nights. The color indices were calculated from the mean values of measured magnitudes for given filter for given object. During the simultaneous observations we obtained directly the color indices B-R, V-R and R-I as a function of time.

The measured color indices help us better understand and characterized the GEO region. In the future simultaneous observations we will continue to measure the color indices for another targets such as fragmentation debris from Titan 3C R/B 1968-081E and from Ekran 2 1977-092A and also HAMR type of objects which are reachable by our system.

Acknowledgement

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