COLOR PHOTOMETRY AND LIGHT CURVE OBSERVATIONS OF SPACE DEBRIS IN GEO

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ABSTRACT

The ESA debris surveys at high altitudes revealed a significant population of small-size debris in GEO and GEO-like orbits. For a sub-set of the discovered objects high area-to-mass ratios were determined. The nature and the origin of most of this debris are currently unknown. There are several ways to identify possible progenitors or parent objects. Studies of the dynamical properties of the objects are one way; another possibility is to acquire more information on the sizes, shapes and possibly the material of the debris pieces. Non-resolving observation techniques like color photometry, light curves, and spectrometry are the only ground-based optical methods applicable for objects at the given distances.

Objects are searched for and discovered by performing dedicated survey campaigns with the ESA 1-meter telescope (ESASDT) in Tenerife, Canary Islands. Observations are then shared in a network of observing sites, which acquire further observations allowing to determine and maintain orbits and to provide ephemerides to other observation techniques and partners, especially in the context of the Inter-Agency Space Debris coordination Committee (IADC).

Currently these ephemerides are in particular used to acquire light curves and color photometry observations with AIUB's 1-meter ZIMLAT telescope in Zimmerwald, Switzerland. Color observations may help inferring the material type of the debris and thus may provide information on the potential parent objects of the debris. Light curves are used to estimate rotation or tumbling rates. Finally empirical characteristics of light curves may help to identify object classes or even individual objects and thus may provide crucial information when trying to correlate new observations with the existing catalogue of objects.

Multi-color observations of small-size space debris including high area-to-mass ratio debris were obtained with ZIMLAT. We will discuss the techniques used to obtain colors for objects with considerable brightness variations over short time intervals.

Light curves of a variety of space debris were obtained over different time spans. Some debris objects show distinct signatures and periods in their light curves. These features seem to be stable over long time intervals and may thus be used to identify the objects. Other objects show highly variable light curves with strongly changing amplitudes and periods, indicating complex shapes and scattering properties.

1. INTRODUCTION

The objective of space debris surveys is to establish an inventory of debris objects for a specific region in space. Ideally these objects would be characterized by their orbits and as much physical parameters as possible. The physical properties of interest are in particular the size and shape, and the type of material. All this information is required to develop models of the space debris environment. Such models eventually may provide debris fluxes to assess the collision risk for specific missions.

During the last decades it became obvious that the mitigation of space debris is a key issue to prevent uncontrolled growth of the debris population, and thus to allow for future space operations in certain orbital regions. The most sensitive regions are certainly some unique high-altitude regions like the geostationary orbit region (GEO) where no natural clean-up mechanism or 'sinks' exists. The development of efficient and cost-effective mitigation measures, on the other hand, require a detailed understanding of the current debris population, and most importantly the identification of the major sources and release mechanism of space debris.

Optical surveys primarily provide statistical information on the environment including a rough characterization of the orbits (either circular or 6-parameter orbits) and information on the brightness (magnitude) of the objects. The conversion of the magnitudes to physical sizes, however, requires detailed knowledge of the surface properties and the shapes of the objects (albedo, amount of specular v.s. diffuse reflection, color, etc.). A detailed analysis of these properties requires observations of individual objects with large aperture telescopes having small fields of view, e.g. to obtain light

curves, color photometry, or spectra. Tracking of individual objects with such telescopes, in turn, is only possible if precise ephemerides, or in other words, a catalogue of precise orbits is available. Some other physical characteristics like the area-to-mass ratio (AMR) can only be derived by monitoring the orbits over long time intervals.
The ESA optical debris surveys revealed several populations of small-size debris in high altitude regions. Among them are debris with moderate AMR values in the 'classical' GEO and geostationary transfer orbit (GTO) regions but also a remarkable population of high AMR objects in GEO-like orbits [1], [2]. Although there are speculations that these objects could be pieces of multi-layer insulation blankets, there is no observational proof for the nature and the potential parent objects of these objects.
For a subset of the objects discovered by the ESA surveys the orbits are maintained over a longer time span using follow-up observations from the 1 meter telescope ZIMLAT of the Astronomical Institute of the University of Bern (AIUB), which is located in Zimmerwald. Additional observations are provided by the International Scientific Optical Network (ISON) led by the Keldysh Institute of Applied Mathematics KIAM ([3]). These orbits are then used to provide ephemerides to acquire color photometry and light curves observations with the ZIMLAT telescope.

2. COLOR PHOTOMETRY

Photometric observations of several high AMR objects in the Johnson-Cousins BVRI bands were acquired with ZIMLAT. The method consisted of taking full frames and using reference stars in the field of view to calibrate the instrumental magnitudes (so-called relative photometry). Series of consecutive exposures in the three different filters were acquired (V, R, I, V,… sequences). The exposure times were of the order of a few seconds (limited by the apparent motion of the objects) and the time interval between two consecutive exposures was about 15 seconds. Unfortunately, it turned out that the magnitude of the observed objects was changing considerably within 15 seconds (see next section). We thus decided to form color-indices V-I and R-I of consecutive observations and to average them. Figure 1 and Figure 2 show individual color indices V-I and R-I and their average values for the observations of the high AMR objects EGEO33 and EGEO45. The scatter in the figures is dominated by the intrinsic brightness variations of the objects as the accuracy of a single photometric measurement is of the order of 0.05 mag for both objects.
The color indices for solar type stars are (V-I) ~ 0.6 mag and (R-I) ~ 0.35 mag, respectively [4]; Cousins system). EGEO33 thus seems to be blue while EGEO45 has a more white-like color. Such color indices will have to be compared with reflection spectra from known materials. It became, however, obvious that it is very difficult to obtain accurate color information of these objects unless simultaneous measurements in several color bands are available.

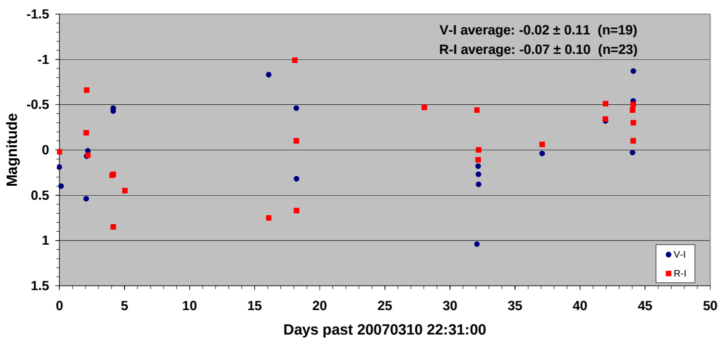

Figure 1: V–I and V–R color indices of object EGEO33 (AMR = 5.4 m^2kg^{-1}).

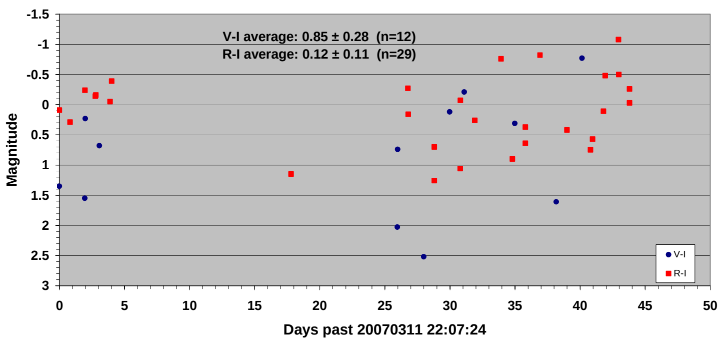

Figure 2: V–I and V–R color indices of object EGEO45 (AMR = 17 m^2kg^{-1}).

3. BRIGHTNESS VARIATIONS

Each follow-up observation acquired for the maintenance of the orbits also yields a measurement of the brightness of the object at this epoch. Most of the high AMR objects show significant brightness variations with an rms value of 0.1 to 1.5 magnitudes (Figure 1). The average brightness variation (rms) of this object class is 0.6 magnitudes. If the objects with extreme AMR values would be simple sheet-like pieces of e.g. foil we would expect them to show the largest magnitude variations. This is not the case and no significant correlation between the magnitude variation and the AMR value was found (Figure 2).

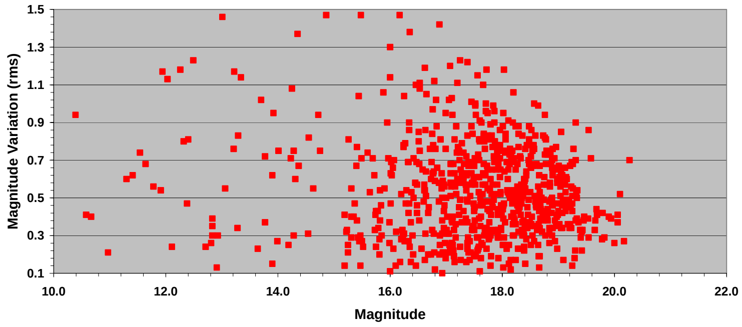

Figure 3: Brightness variations (rms) of 217 high AMR objects as a function of the average brightness.

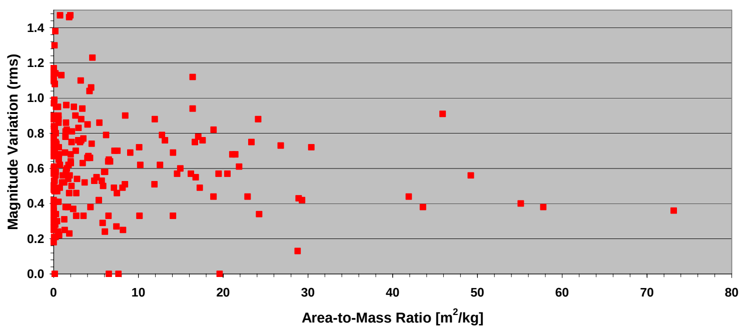

Figure 4: Brightness variations (rms) of 217 high AMR objects as a function of the AMR.

4. LIGHT CURVES

In order to gain more information on the shape and the attitude motion of the high AMR objects light curves were observed with the ZIMLAT telescope. Light curves are sequences of brightness measurements over time, where the temporal resolution of the observations has to be adapted to the temporal variations of the object's brightness. Most of the objects turned out to have brightness variations with frequencies of a few millihertz up to a few tenths of a hertz, which would correspond to tumbling or rotation rates of the order of a tenth to many rotations per minute.

In order to properly sample such frequencies one measurement every few seconds is required. As a consequence the maximum integration time is also limited to a few seconds and in most cases to even shorter times because of the finite readout time of the detector. Technically the required high temporal sampling is achieved by reading small subframes of a classical CCD detector. More precisely there is a full frame acquired first, the object to be measured is identified on this frame and a small subframe centered at the object's position. During the actual measurement of the light curve the subframes are continuously read out, automatically processed and the resulting centroid coordinates used to actively track the object in the subframe. Active tracking is mandatory even when rather precise ephemerides are available.

A set of full frames with reference stars is observed immediately after the light curve measurements. These reference stars are then used to calibrate the photometric system. Only a relative calibration is performed, i.e. no extinction curve is applied. This is a valid approach as the reference fields are chosen such that their elevation is very similar to the elevation of the object during the light curve observations.

Most high AMR objects are fainter than 17 mag and were therefore observed in 'white light' or 'open', i.e. without passband filters. In other cases a standard Johnson-Cousins BVRI filter set was used.

Observations

The main objective of this work was to compile a first inventory of light curves for different object types. Of particular interest were the high AMR objects, and here especially the question if these objects would show specific characteristics in their light curves compared to ‘normal type’ debris with low AMR. Furthermore we posed the question if large and small objects show different light curves. In general there was also an interest to see if any kind of taxonomic classes could be distinguished.

Light curves of a small number of GEO debris with low AMR were observed over several months. All off them repeatedly showed flat light curves over time spans of 15 to 20 minutes, with one exception. Figure 5 shows the light curve of the bright GEO debris object 95013 (AMR = 0.03 m^2kg^{-1}) on the left, and the light curve of the smaller GEO debris 90070 (AMR = 0.01 m^2kg^{-1}) on the right. A light curve of the exceptional object 95311 is given in Figure 6. This objects was brightening by four magnitudes, corresponding to a factor of 40, over a time span of five minutes.

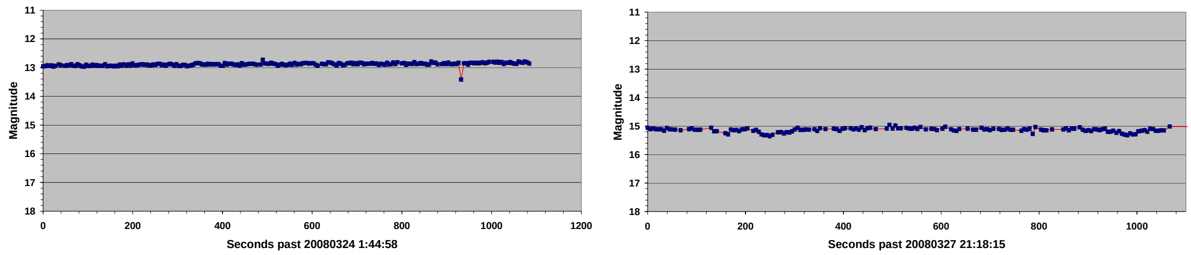

Figure 5: Left: light curve of the bright GEO debris object 95013 (AMR = 0.03 m^2kg^{-1}). Right: light curve of the GEO debris object 90070 (AMR = 0.01 m^2kg^{-1}).

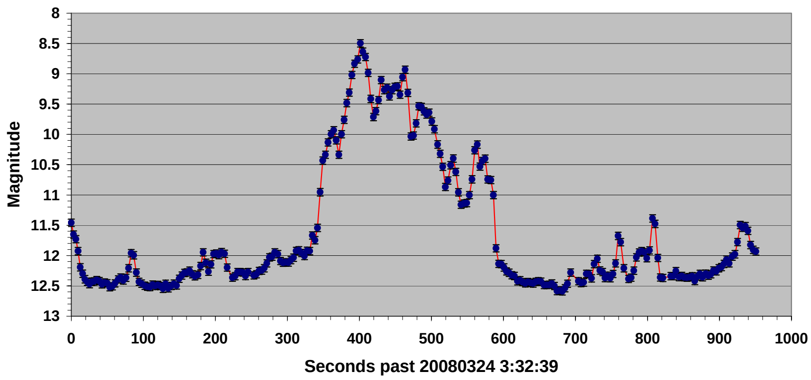

Figure 6: Light curve of the exceptionally bright GEO debris object 95311 (AMR = 0.02 m^2kg^{-1}).

High AMR objects show very different light curves. They are all characterized by more or less pronounced quasi-periodic signals. Both, the frequencies and the amplitudes of these signals seem to generally depend on the objects brightness and AMR. Bright objects with a small AMR show periods of several minutes while most of the faint objects with AMR significantly larger than 1 m^2kg^{-1} show periods smaller then the sampling period, which leads to typical beat frequencies in the observed light curve. Very large amplitudes up to 8 magnitudes (peak-to-peak) are preferentially found among bright objects with low AMR. These are only very general trends and individual cases differ significantly. Moreover, it has to be noted that one and the same object may show significantly different light curves over time. This behavior is most pronounced for bright objects with large amplitudes.

Figure 7 shows light curves of the same bright object 95046 with an AMR of 1.9 m^2kg^{-1}. Note the huge brightness variations in the top figure and the significantly different signature in the bottom figure. The primary period is of the order of one to two minutes in both cases.

A series of light curves of faint objects is given in Figure 8. In three of these cases the original signal has been clearly undersampled, i.e. the main periods were shorter than the sampling period, which was between 4.5 and 6.5 seconds.

A second approach to obtain color indices consisted in the acquisition of consecutive light curves in different filters. Figure 9 and Figure 10 show light curves in the V and the R band for the objects EGEO45 and EGEO33, respectively. The measurements for EGEO45 seem to indicate a V–R color index of the order of 0.5mag, while the observations of EGEO33 are consistent with V–R=0mag. These vales are consistent with the ones obtained in the previous section (Figure 1 and Figure 2).

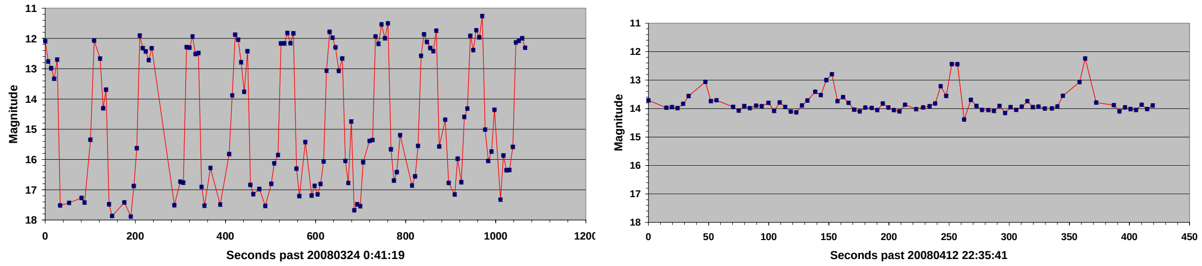

Figure 7: Two light curves of the high AMR object 95046 (AMR = 1.9 m^2kg^{-1}).

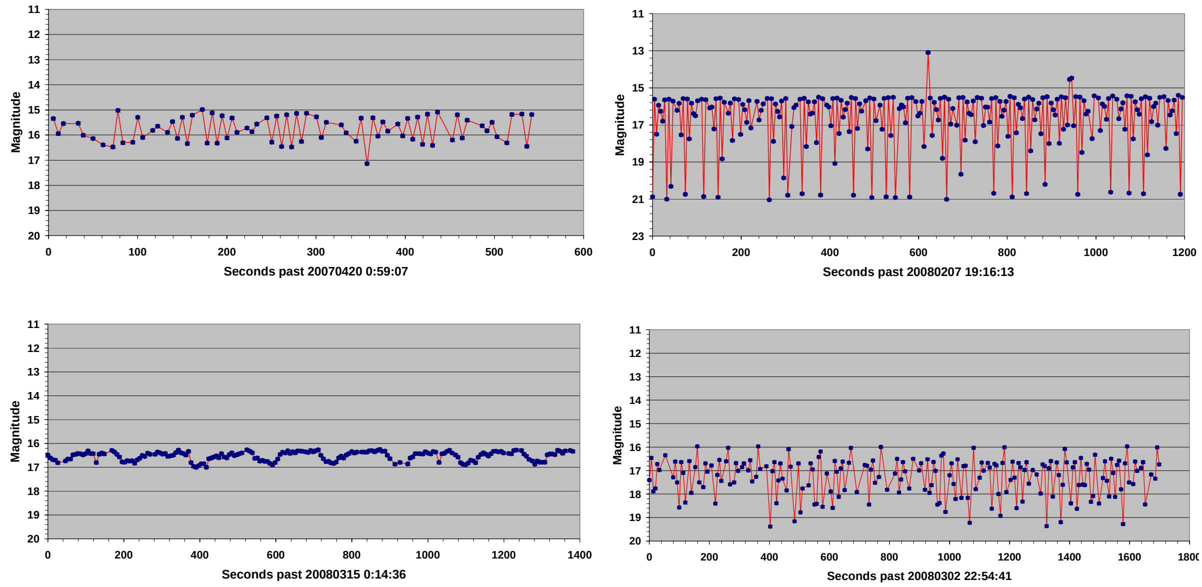

Figure 8: Light curves of faint high AMR objects. Top: two light curves of object E06321D (AMR = 2.6 m^2kg^{-1}; 5.5 s and 4.5 s sampling period); note the beats. Bottom left: E07337C (AMR = 1.9 m^2kg^{-1}; 6.5 s sampling period. Bottom right: E07287A (AMR = 0.5 m^2kg^{-1}; 6.5 s sampling period).

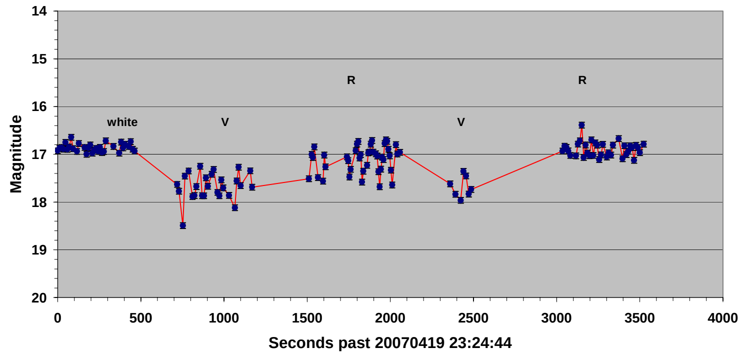

Figure 9: Consecutive light curves of objects EGEO45 (AMR = 17 m^2kg^{-1}) in different filter bands.

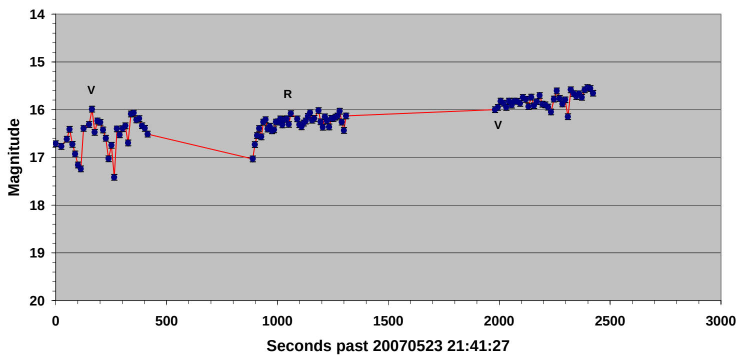

Figure 10: Consecutive light curves of objects EGEO33 (AMR = 4.6 m^2kg^{-1}) in different filter bands.

5. SUMMARY AND CONCLUSIONS

The nature and the possible parent objects of the high AMR objects discovered by the ESA surveys are still unknown. Multi-color Johnson-Cousins VRI photometry and light curve observations of high AMR objects were acquired with AIUB's 1 meter ZIMLAT telescope. The color measurements may give a first indication about the material of the objects, while the light curves give some information on the attitude motion and the shape of the objects.
The average magnitude variation (rms) of the high AMR objects is 0.6 magnitudes. No correlation of the brightness variation and the average brightness or the AMR could be identified.
Classical color measurements turned out to be difficult because of the strong intrinsic brightness variations of these objects. We therefore additionally performed consecutive light curve observations in different colors. Both methods provided consistent results. Color indices for two high AMR objects were derived. EGEO33 has as V–I = –0.02 ± 0.11, and is thus rather blue and EGEO45 has V–I = 0.85 ± 0.28, which corresponds to a white or grey object.
The light curve measurements show a vide variety of signatures. Most 'classical' low AMR GEO debris objects have flat or slowly varying light curves. High AMR objects, on the other hand, show all variations with periods of a few minutes and shorter. The dominant period in the light curves of most faint high AMR objects turned out to be even shorter than the sampling period, which was 4.5 to 6.5 seconds.
No specific classes of light curves were identified. There seems to be a general trend that bright objects with moderate AMR show larger brightness variations with longer periods than faint objects with high AMR. Light curves of individual objects, however, may show large deviations from this trend, and they may look significantly different from one observation epoch to the other.

6. ACKNOWLEDGMENTS

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7. REFERENCES

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