AIUB EFFORTS TO SURVEY, TRACK, AND CHARACTERIZE SMALL-SIZE OBJECTS AT HIGH ALTITUDES

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ABSTRACT

Since more than a decade the Astronomical Institute of the University of Bern (AIUB) is investigating the small-size space debris environment in high-altitude orbit regions. Originally the efforts concentrated on statistical optical surveys with the primary goal to derive fluxes as input data for statistical environment models. It became, however, obvious that important characteristics of the debris population could not be determined by this technique. The sparse surveys did not yield orbital elements for the debris objects, and it was very difficult to assess the total number of objects for a given region.

One essential task of the space debris research is to find and understand the sources of debris, which in turn will enable to devise efficient mitigation measures – a prerequisite for the sustainable use of outer space. In order to understand the nature and eventually the origin of small-size debris objects, observations allowing to derive orbital parameters and physical characteristics like size, shape and material are required.

This paper discusses the AIUB activities to build-up and maintain an orbit catalogue of small-size debris. AIUB uses its dedicated 0.3m robotic telescope ZimSMART-2 to constantly survey the GEO, the GTO and the MEO region. The data from this telescope is fused with observations from AIUB's 1-meter ZIMLAT telescope and ESA's 1-meter telescope in Tenerife and shared with international partners. The resulting catalogue of orbital elements enables physical characterization of the debris objects trough photometry, light curve and reflectance spectroscopy observations.

1. INTRODUCTION

The Astronomical Institute of the University of Bern (AIUB) is studying the small-size space debris environment in high-altitude orbit for over 15 years. These efforts lead to a better understanding of the space debris population in the near Earth environment in terms of spatial density, of statistical orbital characteristics, as well as characteristics of individual objects. Eventually the results add to the scientific foundation for a sustainable use of the near-Earth space.

AIUB is pursuing this objective through:

1. Extending the catalogues of "known" space objects towards smaller sizes
2. Acquiring statistical orbit information on small-size objects in support of statistical environment models
3. Characterizing individual objects
4. Long-term monitoring of the environment

The extension of the catalogue to smaller sizes, or the extension of the so-called deterministic population is a prerequisite the enable active collision avoidance, but also required to allow for the characterization of individual objects. Collision avoidance is obviously of highest importance for the owner/operators of spacecraft, but in our context more importantly, the avoidance of collisions is the number one countermeasure to avoid a potentially catastrophic growth of the number of space debris in certain orbit regions.

Statistical information on the space debris population, on the other hand, is required to set up and validate statistical environment models like the ESA MASTER model. Such models are used to assess mission risks, e.g. during the mission analysis phase, and to properly design active and passive shielding measures. The same models serve as input data for studying the long-term evolution of the debris environment

Efficient and cost effective debris mitigation measures require detailed knowledge about the sources of space debris. In most cases this information can only be obtained by characterizing individual debris objects with the aim to determine their nature and to identify their progenitors. Examples are the identification of breakup events trough the analysis of debris clouds and the association of objects with the disintegration of spacecraft due to aging processes.

Long-term monitoring of the environment, finally, allows timely detection of new debris sources and the validation of the evolution models.

The observation data is primarily acquired with three telescopes at the AIUB Zimmerwald observatory located near Bern, Switzerland (see Figure 1) and the ESA 1-meter Space Debris telescope (ESASDT) at Tenerife, Canary Islands. The 1-meter Zimmerwald Laser and Astrometry Telescope (ZIMLAT) is primarily used to support the maintenance of a catalogue of small-size debris by performing follow-up observations and for the characterization of individual objects by means of light curves and color photometry. The two Zimmerwald SMall Aperture Robotic Telescopes ZimSMART and ZimSMART-2 are fully automated wide field sensors dedicated to experimental surveys of the GEO, GTO, and MEO regions.

Figure 1: ZIMLAT 1-m telescope (left), ZimSMART 0.18-m (middle), and ZimSMART-2 0.3-m telescope (right).

In the following sections we give examples for the AIUB efforts in the field of cataloguing and characterizing small-size debris with high area-to-mass ratios (AMR).

2. A CATALOGUE FROM THE ZIMSMART TELESCOPES

Between June 9, 2008 and June 5, 2010 the ZimSMART telescopes have been acquiring survey data during 139 nights. ZimSMART was operated during 104, and ZimSMART-2 on 35 nights, respectively (Figure 2). A total of 28360 tracklets consisting of 5 consecutive observations within 2 minutes were collected over this period. The surveys focused on the GEO ring and consisted of scanning 2 parallel stripes of 4°x16° with the larger extension in the declination direction. All observations were correlated with the USSTRATCOM and the AIUB internal catalogue [1]. Out of 1429 observed objects, 1131 could be associated with objects in the USSTRATCOM catalogue ("correlated objects"), and for 298 objects no counterpart in the catalogue could be found.

A magnitude histogram for the objects discovered with the ZimSMART survey is given in Figure 3. Correlated objects are in blue, uncorrelated objects in red, respectively (USSTRATCOM catalogue). The limiting magnitude of the observation system is about 14.5. The distribution of the correlated objects shows the well known peak at magnitude 13 while the 298 uncorrelated objects are rather uniformly distributed in magnitude.

A closer look at the orbital elements of the objects reveals that many of the bright uncorrelated objects are in fact objects in orbits with a semimajor axis near the nominal GEO value but considerable eccentricities, which is the typical signature for high AMR objects in near-GEO orbits [2], [3]. In Figure 4, which shows the eccentricity as a function of the mean motion for the objects ZimSMART survey, this population is the vertically dispersed cloud concentrated at a mean motion of 1 rev/day. High AMR object are normally fainter than magnitude 16 and were thus not expected to be found in large number in the ZimSMART survey. Individual objects of this class have, however, shown large brightness variations of many magnitudes in previous surveys with larger telescopes. We thus conclude that even a small-aperture telescope may discover high AMR objects when they occasionally become unusually bright. The ZimSMART GEO survey is also sensitive to the 12-hour navigation constellations (2 rev/day, circular obits) and a vide range of GTO orbits as can be seen in Figure 4.

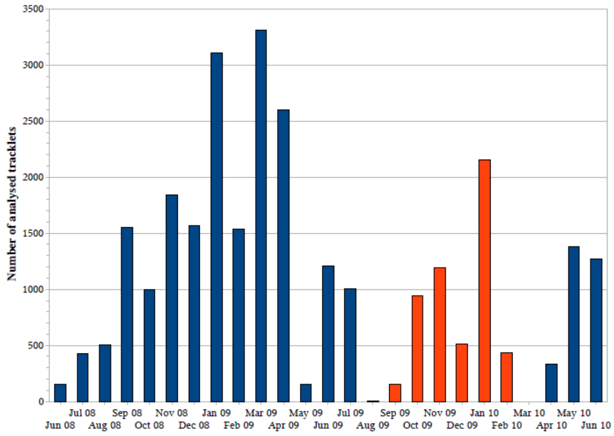

Figure 2: Monthly number of tracklets between June 2008 and June 2010; ZimSMART observations are in blue, ZimSMAR-2 observations are in red.

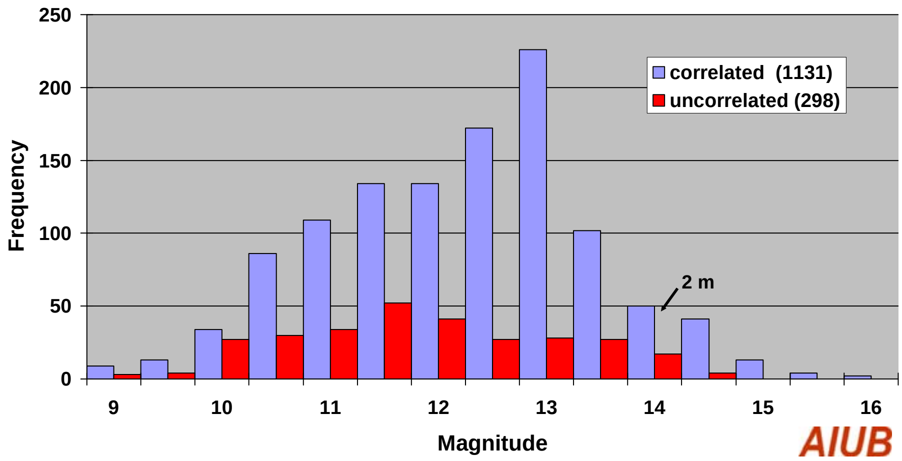

Figure 3: Magnitude histogram for the objects discovered with the ZimSMART survey. Correlated objects are in blue, uncorrelated objects in red, respectively (USSTRATCOM catalogue).

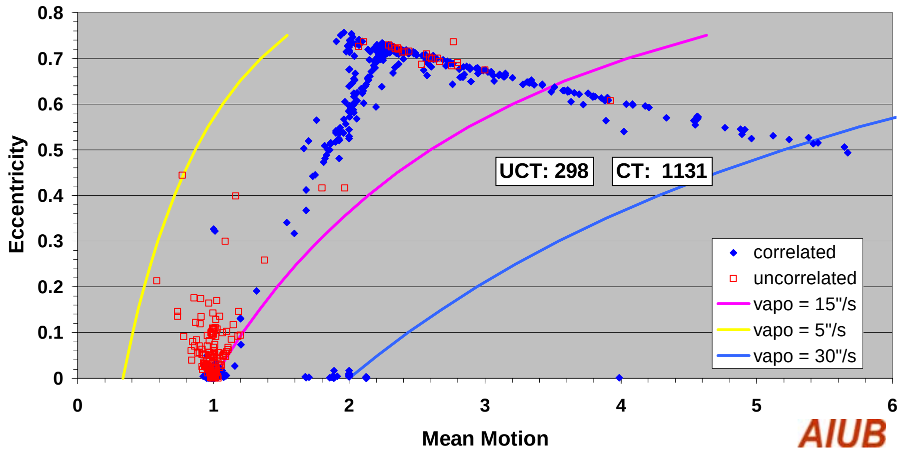

Figure 4: Eccentricity as a function of the mean motion for 1429 objects of the ZimSMART survey ('UCT' and 'CT' denote the number of correlated and uncorrelated objects, respectively, HAMR denotes high AMR).

The distribution of objects by orbit categories for the correlated and uncorrelated objects of the ZimSMART survey is given in Figure 5. GEO objects have been subdivided into station keeping objects (longitude drift d*l* ≤ 0.01°) and drifting objects (longitude drift d*l* > 0.01°).

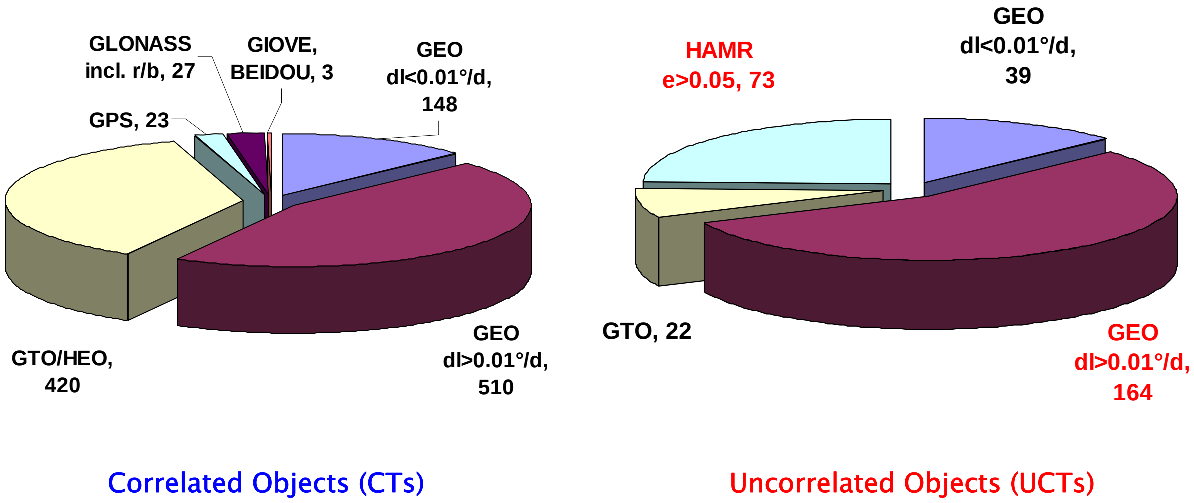

Figure 5: Distribution of objects by orbit categories for the correlated (left) and uncorrelated (right) objects of the ZimSMART survey. GEO objects have been subdivided into station keeping objects (longitude drift d*l* ≤ 0.01°) and drifting objects (longitude drift d*l* > 0.01°).

3. THE AIUB/ESA HIGH AREA-TO-MASS RATIO DEBRIS CATALOGUE

One of the major objectives of the surveys is to understand the nature and sources of the small-size debris in order to help devising efficient space debris mitigation measures. As early as 2003 it became obvious that any further investigations would require more closely observing and characterizing individual objects, which in turn is only possible if precise orbits are available. As a consequence AIUB decided to build up and maintain an internal catalogue of orbits for a subset of the objects discovered at the ESASDT. Among the first objects in this catalogue were a handful which had semimajor axes with values close to the nominal GEO value, but eccentricities ranging from 0.13 to 0.49 [2]. This was the first indication of a new population of debris objects in an orbital region where no potential parent object could be identified. Shortly thereafter it became clear that this new population consists of objects with high area-to-mass ratios (AMR) [3], [5]. The idea is that these high AMR objects – potentially pieces of multi-layer insulation material – were originally produced in GEO, but the solar radiation pressure is strongly perturbing their orbits, resulting in periodically varying eccentricities and inclinations.

The AIUB/ESA catalogue as of January 2010 contains 1057 uncorrelated small-size objects in GEO, GTO and GEO-like orbits for which 6-parameter orbits were determined. For 274 objects the AMR could be determined. As can be seen in Figure 6, there is a significant population of objects with AMR larger than 1 m^2/kg (note that the AMR of an intact spacecraft is of the order of 0.02 m^2/kg, and the one of ordinary office paper of the order of 12 m^2/kg). A closer analysis reveals that the majority of the objects with AMR larger than 1 m^2/kg are objects with a mean motion near 1 rev/day and eccentricities ranging from 0.05 to 0.8. In Figure 7, which shows the eccentricity as a function of the mean motion for the objects of the AIUB/ESA catalogue, this population is the vertically dispersed cloud concentrated at a mean motion of 1 rev/day.

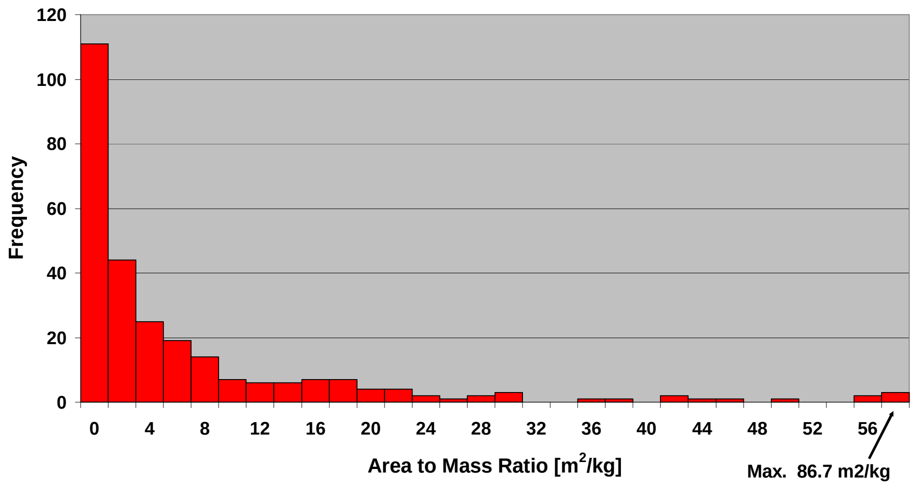

Figure 6: Distribution of the area-to-mass ratio of 274 uncorrelated objects in the AIUB/ESA catalogue.

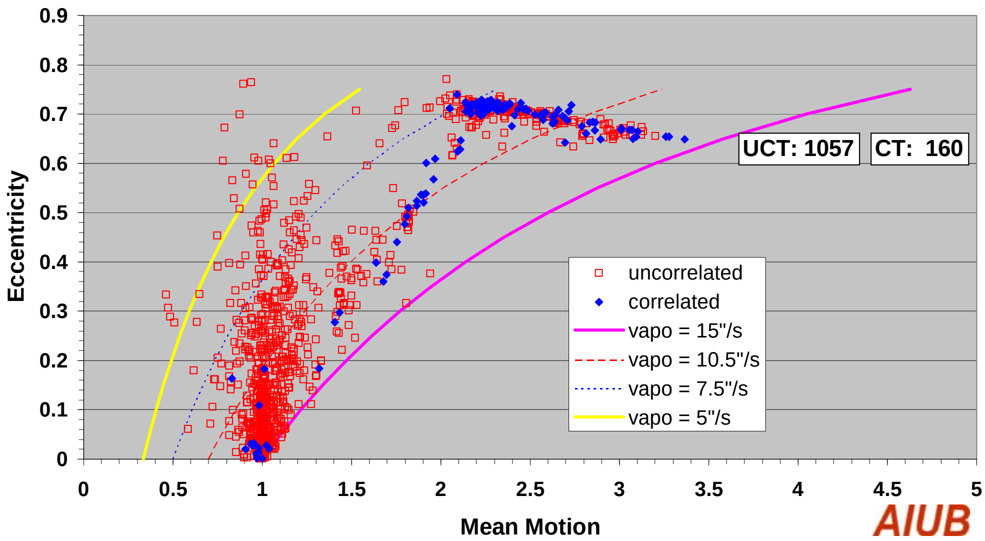

Figure 7: Eccentricity as a function of the mean motion for 1217 objects for which 6-parameter orbits were determined. ('UCT' and 'CT' denote the number of correlated and uncorrelated objects, respectively).

4. CHARACTERIZATION OF INDIVIDUAL OBJECTS

Most of the small-size objects in the AIUB/ESA catalogue are likely breakup fragment or pieces which detached from intact objects due to material degradation. In order to design an efficient and cost effective mitigation measure it is necessary to know the predominant sources and, hence, first of all to assess the nature of the observed objects.

Additional observations should, therefore, investigate the physical characteristics of the objects, in particular their sizes, shapes, attitude states, and material type. Different observation techniques like light curves, color photometry and spectroscopy were used to characterize objects. Two examples of light curves from ZIMLAT are given in Figure 8. Most likely parts of these light curves are dominated by specular reflections and it is thus not obvious how to derive a magnitude-size relation and a mean albedo for these objects. Light curves may generally be used to determine shapes and attitude motions. One conclusion from these particular light curves is that the objects are rotating or tumbling at a high rate.

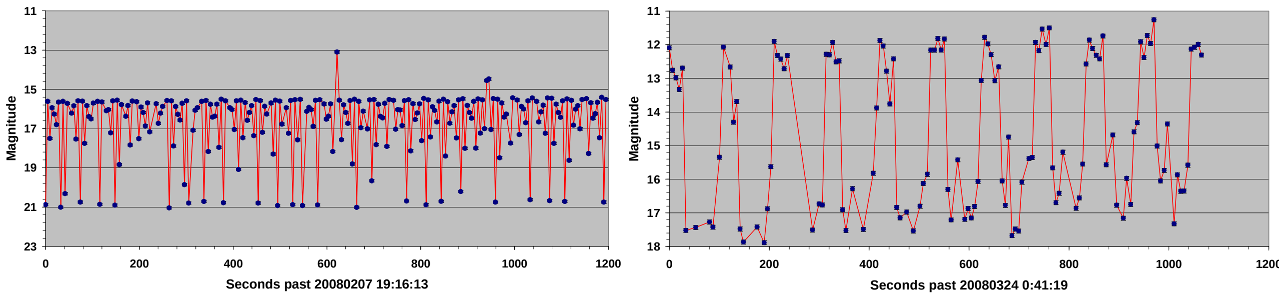

Figure 8: Light curve of object E06321D (left, AMR = 2.5 m^2/kg) and object 95046 (right, AMR = 1.9 m^2/kg).

In order to determine materials, multi-color Johnson-Cousins VRI photometry is performed with the ZIMLAT telescope. The approach to obtain color indices consisted in the acquisition of consecutive light curves in different filters. Figure 9 shows a light curve in the V and the R band for the objects EGEO45. Note that the object's brightness is changing considerably from epoch to epoch and we thus have to average the measurement in each filter. The resulting V–R color index for EGEO45 is 0.5mag. If we subtract the V-R color index of the Sun (0.35mag) from this value we end up with a V-R color index of 0.15mag for the reflectance spectrum of this object. In other words EGEO45 seems to be "white" in the wavelength range from 500 to 700 nanometers, which excludes e.g. bluish solar cell material.

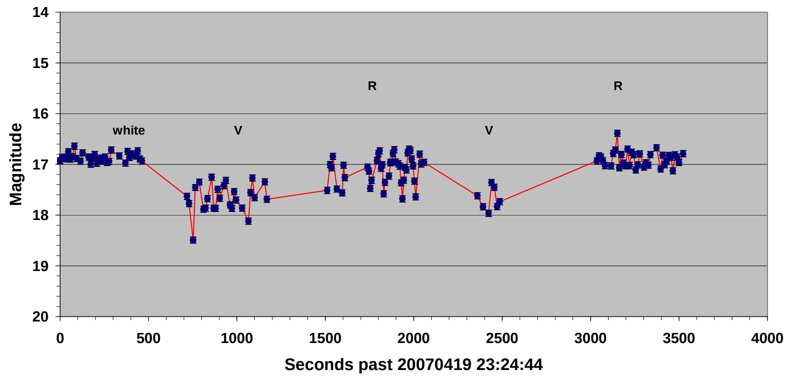

Figure 9: Consecutive light curves of objects EGEO45 (AMR = 1.7 m^2kg^{-1}) in different filter bands.

Spectroscopic observations are performed with a low-resolution spectrograph mounted at the RC-focus of the 1-meter ESASDT telescope. The aim of these observations is the quantitative measurement of the reflection properties of the target objects as a function of wavelength. The observations are rather demanding due to the faintness of the objects and the limited accuracy of the ephemerides (during the measurement the object must be tracked such that it remains within the 2-5 arcseconds wide slit of the spectrograph). The calibration and reduction of the spectra is equally challenging as we actually aim at a quantitative comparison of the measured spectrum with the spectrum of the illuminating source, in our case, the Sun (stellar spectroscopy in most cases does not require absolute calibration).

In a recent effort to characterize high AMR objects, ESA and NASA organized a joint campaign to simultaneously acquire multicolour photometry and low resolution spectra of a set of high AMR objects in GEO-like orbits. NASA used two telescopes at Cerro Tololo, one observing in the Johnson-Cousins B-filter, and the other in the R-filter [6]. The cameras of the two telescopes were synchronized to guarantee simultaneous observations in both filters. Object input data like orbits and visibilities were mutually provided by both teams. Eventually spectra of 11, and photometry of 8 high AMR could be acquired. Spectra of two objects which were observed by the ESA spectrograph and the NASA telescopes during the same night are given in Figure 10. The color indices B-R were derived from the spectra and will be compared with the ones observed by the NASA team.

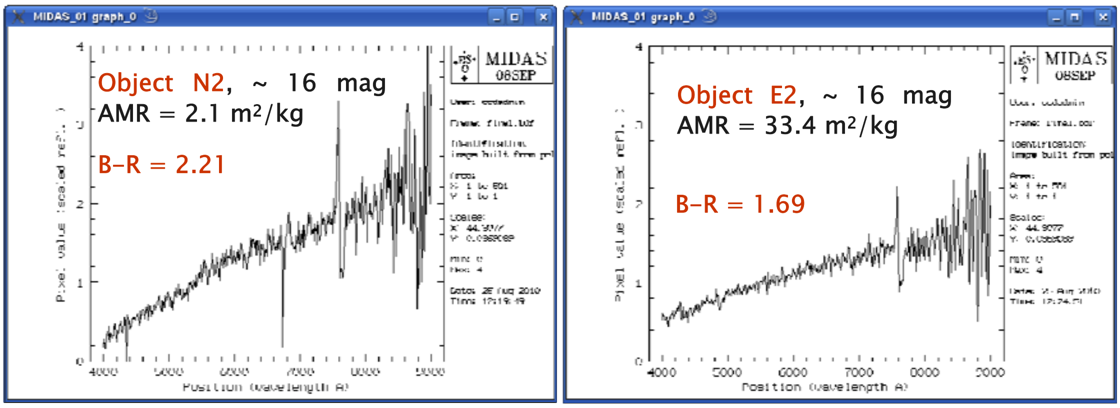

Figure 10: Spectra of two objects which were observed by the ESA spectrograph and the NASA telescopes during the same night. The color indices B-R were derived from the spectra.

5. SUMMARY AND CONCLUSIONS

AIUB performs regular surveys for large- and small-size objects in high-altitude orbits. These surveys provide statistical information on the population of artificial objects in the near Earth environment, which serves as input data of statistical environment models. Such models, in turn, are instrumental for statistical risk analysis, e.g. for mission analysis purposes, and are used as initial conditions for long-term evolution models.

The survey data together with dedicated follow-up observations are used to maintain a catalogue of large and small debris objects. A particular subset of this catalogue is known as the AIUB/ESA catalogue of high AMR objects.

The catalogue allows characterizing individual objects in order to understand the nature and sources of the small-size debris. Different observation techniques are applied to investigate the physical characteristics of the objects, in particular their sizes, shapes, attitude states, and material type. Light curves from the ZIMLAT are used to determine shapes and attitude motions. Attempts to assess the material types of the high AMR debris are done by acquiring reflection spectra from ESA's low-resolution spectrograph at the ESASDT in Tenerife. Recently ESA and NASA conducted a joint campaign to simultaneously acquire multicolour photometry and low resolution spectra.

AIUB is aiming at a better understanding of the near Earth environment in order to provide the scientific foundation for a sustainable use of near-Earth space.

6. ACKNOWLEDGMENTS

The ESA observations were acquired under ESA/ESOC contracts 21447/08/F/MOS. The collaboration with the Keldysh Institute of Applied Mathematics (KIAM) and the ISON was and is instrumental in maintaining the orbits of the targeted debris objects for the spectroscopic observations.

7. REFERENCES

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