

# 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 deriving 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 0.2m robotic telescope ZimSMART 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 through photometry, light curves and reflectance spectroscopy observations.

## 1. INTRODUCTION

The Astronomical Institute of the University of Bern (AIUB) has been studying the small-size space debris environment in high-altitude orbit for almost 20 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) Acquiring statistical orbit information on small-size objects in support of statistical environment models
- 2) Extending the catalogues of "known" space objects towards smaller sizes
- 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 to 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 through 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 (top), ZimSMART 0.18-m (bottom left), and ZimSMART-2 0.3-m telescope (bottom right)

## 2. OPTICAL SURVEYS FOR SMALL DEBRIS IN HIGH-ALTITUDE ORBITS

More than 15 years ago ESA started an observation program to survey high-altitude regions – in particular the geostationary ring (GEO), the geostationary transfer orbits (GTO) and the medium Earth orbits of the navigation satellite constellations (MEO) – for un-cataloged small-size debris. The primary aims were to perform statistical surveys in support of the European environment model MASTER and to extend the orbit catalogue of known objects to smaller size objects. The AIUB is implementing and operating this observation program on behalf of ESA at the ESA 1-meter Space Debris Telescope (ESASDT) in Tenerife, Canary Islands, Spain.

During the past 11 years the ESASDT was dedicated to debris surveys for about 110 nights every year. The debris surveys are highly successful and resulted in the detection of a large population of small-size objects in these high-altitude regions. Figure 2 shows the distribution of magnitudes of all detections from the 2008 campaign (GEO and GTO surveys combined). The indicated object sizes were derived by assuming Lambertian spheres and a Bond albedo of 0.08. The bars denoted “uncorrelated” represent the previously unknown population of debris object predominantly in the size range from 10 to 60cm.

Among the most notable results of these surveys is the discovery of GEO debris clouds in the orbital element space. Some distinct clouds in the  $(\Omega, i)$ -space can be seen in the data from all years (see Figure 3).

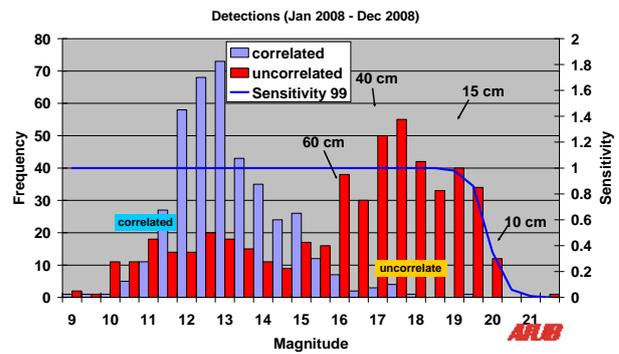


Figure 2: Magnitude distribution for the detections of a typical GEO/GTO survey. The solid line indicates the system sensitivity (scale at right-hand side) as determined from independent calibration measurements.

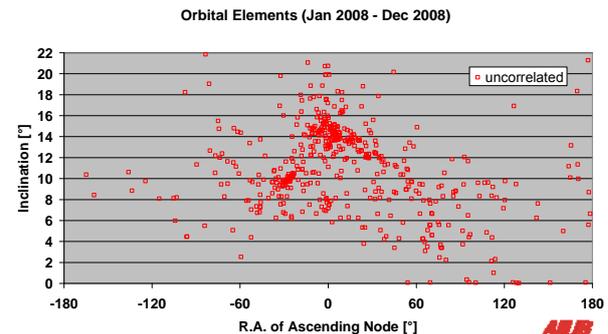


Figure 3: Inclination versus right ascension of ascending node (orientation of orbital plane) for the detections of the 2008 surveys

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

One of the major objectives of space debris research is to understand the nature and sources of the small-size debris in order to help devising efficient space debris mitigation measures. 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 semi-major axes with values close to the nominal GEO value, but eccentricities ranging from 0.13 to 0.49 [1]. 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) [2], [3]. The idea is that these high area-to-mass ratio (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 2012 contains 1218 uncorrelated small-size objects in GEO, GTO and GEO-like orbits for which 6-parameter orbits were determined. For 354 objects the AMR could be determined (Figure 4). The catalogue contains a significant population of objects with AMR larger than  $1 \text{ m}^2/\text{kg}$  (note that the AMR of an intact spacecraft is of the order of  $0.02 \text{ m}^2/\text{kg}$ , 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 5, 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.

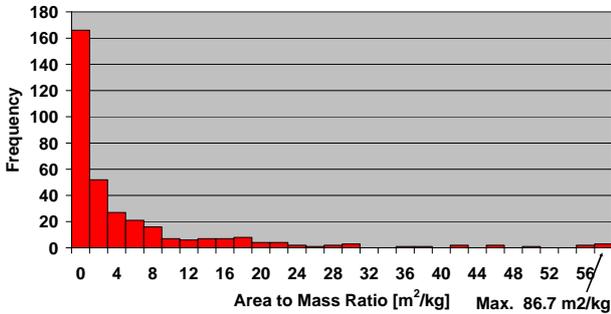


Figure 4: Distribution of the area-to-mass ratio of 274 uncorrelated objects in the AIUB/ESA catalogue.

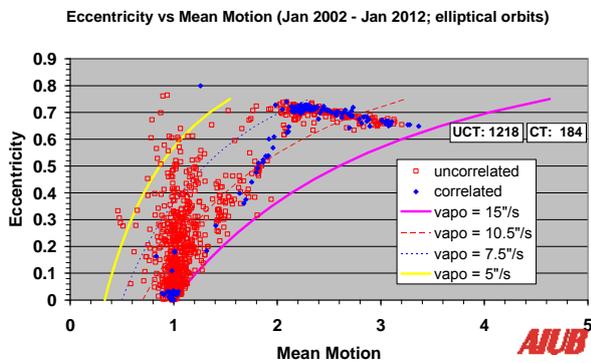


Figure 5: Eccentricity as a function of the mean motion of objects in the high AMR catalogue. ('UCT' and 'CT' denote the number of correlated and uncorrelated objects, respectively.)

The orbits of the objects in the high AMR catalogue are maintained by tasking the ZIMLAT and the ESASDT (if available) to acquire follow-up observations on a regular basis (Figure 6). Additional support is provided by the Keldysh Institute of Applied Mathematics (KIAM) in Moscow and the International Scientific Optical Network (ISON) in the framework of a scientific collaboration with the AIUB.

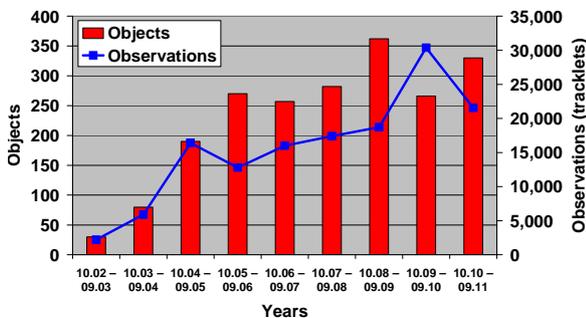


Figure 6: Number of observed objects and number of observations (tracklets) from AIUB's ZIMLAT telescope in support of the AIUB/ESA catalogue.

#### 4. CHARACTERIZATION OF INDIVIDUAL OBJECTS

Most of the small-size objects in the AIUB/ESA catalogue are likely breakup fragments or pieces which detached from intact objects due to material degradation. In order to design efficient and cost effective mitigation measures 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. AIUB uses different observation techniques like light curves, color photometry and spectroscopy to physically characterize objects.

Light curves are obtained with ZIMLAT and should allow to infer shapes and rotation states (spin rate and spin axis) of debris objects. An example of a light curve of a fast rotating high AMR object is given in Figure 7. Similar observation may be used to assess the attitude control mode of a spacecraft (e.g. after a contingency). Figure 8 shows a light curve of an abandoned GEO spacecraft which is clearly in a tumbling attitude mode.

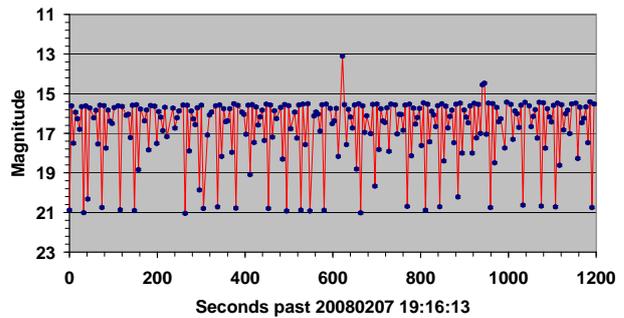


Figure 7: Light curve of object E06321D (AMR =  $2.5 m^2/kg$ ).

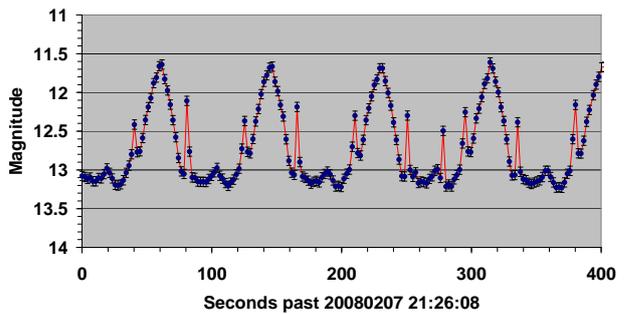


Figure 8: Light curve of an abandoned spacecraft in GEO.

Spectroscopic observations may be used to determine the surface material of objects by comparing the measured reflection spectra with spectra of known materials taken in the laboratory. Figure 9 shows reflectance spectra of 'gold' Kapton multi-layer insulation material (top, lab measurement) and of a high AMR space debris object (bottom). The "knee" at about 500nm is typical for this material and was not seen in any lab spectra of other materials used on spacecraft.

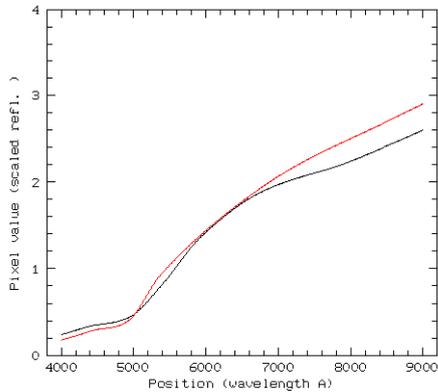
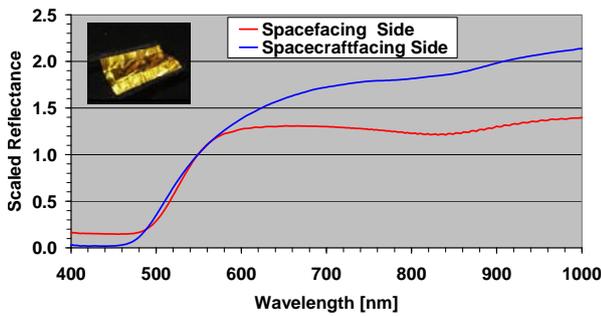


Figure 9: Reflectance spectra of 'gold' Kapton multi-layer insulation material (top, lab measurement) and of a high AMR space debris object (bottom).

## 5. CATALOGUE FROM THE ZIMSMART TELESCOPES

ZimSMART and ZimSMART-2 are fully robotic wide field telescopes with 0.2m and 0.3m aperture, respectively. They are used to perform GEO and MEO surveys during each clear night. The observations from these sensors are used to build-up and maintain AIUB-internal orbit catalogue of objects (operational spacecraft and debris) in these regions.

In the following we present the results from survey data stemming from 139 nights during the test period from June 9, 2008 to June 5, 2010. 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  $4^\circ \times 16^\circ$  with the larger extension in the declination direction. All observations were correlated with the USSTRATCOM and the AIUB internal catalogue [5]. 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 10. Correlated objects are in blue, uncorrelated objects in red, respectively (USSTRATCOM catalogue). The distribution of objects by orbit categories for the correlated and uncorrelated objects of the ZimSMART survey is given in Figure 11. GEO objects have been subdivided into station keeping objects (longitude drift  $dl \leq 0.01^\circ$ ) and drifting objects (longitude drift  $dl > 0.01^\circ$ ). Note that a considerable number of GTO and MEO objects was observed although the survey scenario was designed for GEO.

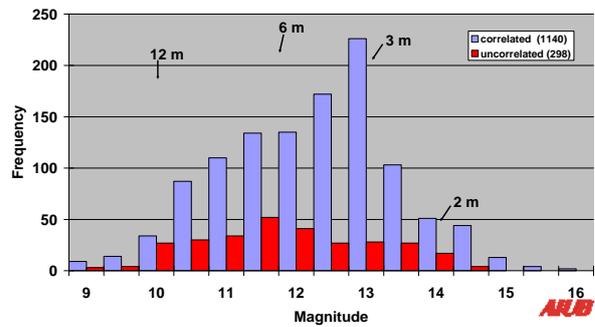


Figure 10: Magnitude histogram for the objects discovered with the ZimSMART survey. Correlated objects are in blue, uncorrelated objects in red, respectively (USSTRATCOM catalogue).

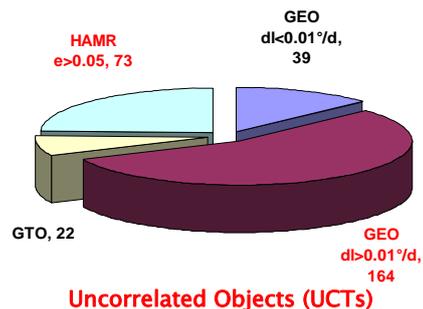
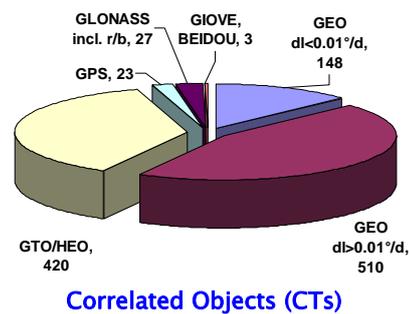


Figure 11: Distribution of objects by orbit categories for the correlated (top) and uncorrelated (bottom) objects of the ZimSMART test survey. GEO objects have been subdivided into station keeping objects (longitude drift  $dl \leq 0.01^\circ$ ) and drifting objects (longitude drift  $dl > 0.01^\circ$ ).

## 6. CONCLUSIONS

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. AIUB has been pursuing this objective for almost 20 years by acquiring observations with its own telescope at the Zimmerwald observatory, by conducting the ESA space debris surveys at the ESA telescope in Tenerife, and by devising new observation and data processing techniques.

The regular surveys for large- and small-size objects in high-altitude orbits provide information on the population of artificial objects in the near-Earth environment, which serves as input data of statistical environment models, in particular the ESA MASTER model. Such models, in turn, are instrumental for statistical risk analysis, e.g. for mis-

sion 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.

A fully robotic, small-aperture, wide field sensor ZimSMART was developed to automatically survey the GEO, GTO and MEO region for objects larger than about 1m (operational and debris objects). The sensor is operating every clear night and provides data for the AIUB-internal orbit catalogue of objects in these regions.

## 7. ACKNOWLEDEMENTS

Part of this work is performed under ESA contracts. Support in the form of observations from the ISON network to maintain the orbits is provided by the Keldysh Institute of Applied Mathematics (KIAM) in the framework of scientific collaboration with the AIUB.

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