# Build-up and maintenance of a catalogue of GEO objects with ZimSMART and ZimSMART 2

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The geostationary ring (GEO) is a highly populated orbit region. Within the scope of safe operations and collision avoidance it becomes increasingly important to create and maintain a comprehensive catalogue of GEO orbits. Such a catalogue should be complete down to a threshold size of hazardous objects and accurate enough to allow reasonable conjunction analysis. The Astronomical Institute of the University of Berne (AIUB) with the **Zim**merwald **Sm**all **A**perture **R**obotic **T**elescope (ZimSMART and ZimSMART 2, resp.), located 10 km South of Berne (Switzerland), regularly surveys the GEO region. The aim of these surveys is a homogeneous coverage of a given region around the celestial equator without a priori information from any object catalogue. Furthermore the object catalogue shall be established and maintained with a pure "survey only" approach, i. e. without tasked (follow-up) observations.
In this paper the build-up and maintenance of a catalogue of GEO objects with ZimSMART observations is discussed. The object identification is performed in three steps: first, each tracklet (a set of at least three observations belonging together) is correlated with the official USSTRATCOM catalogue of Two-Line Element sets (TLE) and the internal catalogue of the AIUB. In a second step the uncorrelated tracklets are analysed whether or not some of them in fact stem from the same object. Tracklets for which at least another associated tracklet could be found are called object candidates and the others remain single. In a third step the object candidates are compared via their orbital parameters to the single tracklets from previous nights and to those objects which are neither part of the USSTRATCOM catalogue nor part of the internal catalogue. At the end of the correlation process the object candidates which could not be associated with object tracklets of previous nights, are added to the AIUB internal catalogue.
Between June 9$^{th}$, 2008 and June 7$^{th}$, 2010 there were 139 nights of observations with a total number of 28494 tracklets. Performing every correlation step a total number of 24164 tracklets could be correlated, which equates to 85.2 %. We could identify 1104 objects of the USSTRATCOM catalogue and 795 which were not part of it. The latter are most likely not all unique objects due to difficulties to connect short orbit arcs with long gaps in between.

## I. Introduction

The observation facility of the AIUB is located in Zimmerwald, 10 km South of Berne (Switzerland). It consists of the **Zim**merwald **L**aser and **A**strometric **T**elescope (ZIMLAT, est. 1996) and the telescopes ZimSMART and ZimSMART 2, each decribed below.

Although we keep the telescopes in an experimental state we also perform routine observations.

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### I.I ZimSMART

The **Zim**merwald **Sm**all **A**perture **R**obotic **T**elescope (see Fig. 1(a)) was installed in 2006. It has a primary mirror with a diameter of 18 cm and a focal length of 500 mm. The mounted camera is a FLI09000 with a PL09000 chip of KODAK. It has a size of 3056 × 3056 pixel. The field of view is $4°6' \times 4°6'$. The angular resolution is about 4.8 ″/pixel. The readout time is about 9 s, which is also the minimum gap time between two exposures.

ZimSMART was operating between June 2008 and August 2009 and is operating again since April

(a) ZimSMART (b) ZimSMART 2

Figure 1: The telescopes located at Zimmerwald, which we used for the analysis presented in this paper

2010. In the second period the camera was exchanged with the one mounted on ZimSMART 2 (see next section) before. It is a FLI 16803 with a PL16803 chip again of KODAK. The chip has a size of $4096 \times 4096$ pixel, which results in an angular resolution of about $3.6\,''$/pixel. For this camera the readout time is 16 s. The limiting magnitude is about 15 mag.

## I.II ZimSMART 2

Between September 2009 and February 2010 the ZimSMART was replaced by a new telescope, called ZimSMART 2 (see Fig. 1(b)).

Its primary mirror has a diameter of 30 cm and a focal length of 1080 mm. The field of view is $2° \times 2°$. Again, the camera was the FLI 16803 with a PL16803 chip of KODAK with $4096 \times 4096$ pixel and a read-out time of 16 s. The angular resolution is about $1.8\,''$/pixel and the limiting magnitude is again 15 mag.

## I.III Surveys

The purpose of ZimSMART and ZimSMART 2 is to perform survey observations around the geostationary ring. Those are executed by scanning declination stripes with fixed right ascension. In the geostationary ring an object moves with $15°\,\mathrm{h}^{-1}$ with respect to the celestial background. Thus, the observation of one declination stripe is followed by another one shifted 15° in Eastern direction (Fig. 2 a) and b)). In case of a perfect geostationary object with 0° inclination and no eccentricity, which can be found in a frame of the first stripe it will be found again in the second stripe one hour after detection in the first stripe. In reality one cannot expect to find an object at the same position on the frames of the second stripe.

In the Figures 2 c) and d) there can be found an example: First one object is found in the lowermost frame of the stripe (red dot). In this case the object has a high inclination, it is observed one hour later in the uppermost frame of the second stripe. Additionally, the position on the second stripe is shifted to right. This means that the distance in right ascension is indeed smaller than 15°, but alongtrack the object has moved about 15°.

The observed objects fall into three categories:

1. GEO (geostationary objects): semi-major axis larger than 30 000 km and numerical eccentricity smaller than 0.1 and area-to-mass-ratio smaller than $0.5\,\mathrm{m}^2/\mathrm{kg}$
2. eGEO (eccentric geostationary objects): semi-major axis larger than 30 000 km and numerical eccentricity equal to or larger than 0.1 or area-to-mass-ratio equal to or larger than $0.5\,\mathrm{m}^2/\mathrm{kg}$
3. GTO (geostationary transfer objects): semi-major axis smaller than 30 000 km

Performing observations in this manner it is almost ensured that one observes an object at twice

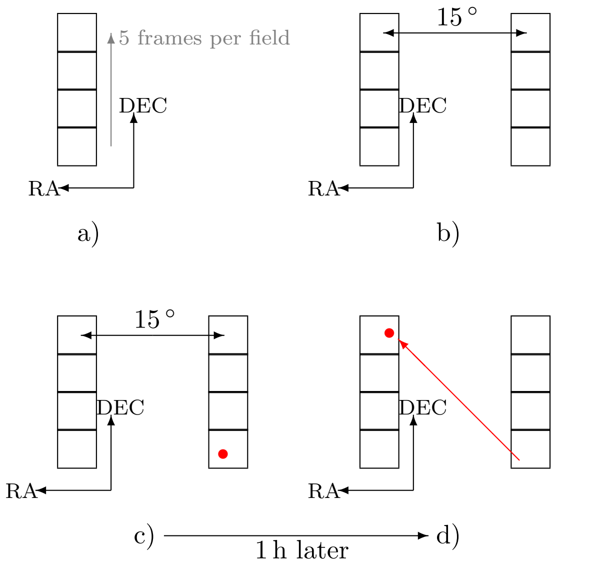


Figure 2: Scanning mode (sketch), one square represents the field of view

a night to allow a first orbit determination. But there are three critical cases to focus on:

1. The object is slower so it is one hour later *not yet* in the field of view of the second stripe or is currently moving out of the frame. This corresponds to a semi-major axis larger than 42 164 km or an object with an eccentric orbit near its apogee.

2. The object is faster so it is one hour later *not anymore* in the field of view of the second stripe or again moving out. This corresponds to a semi-major axis smaller than 42 164 km or an object with an eccentric orbit near its perigee.

3. The object has moved out of the frame in Northern or Southern direction. This corresponds to an object with an inclinded orbit.

Per frame of the survey there are five images taken. If the same object is on at least three images a tracklet will be produced. It contains information about abserving epochs, position in right ascension and declination and apparent magnitude.

## II. Object identification process

Performing sky surveys in our manner, we do not know, which objects we may have observed. Thus, the object identification has to be performed after connecting single observations to tracklets. We correlate all tracklets of one night with the USSTRATCOM catalogue and an internal AIUB catalogue. To avoid testing every catalogue object with every tracklet we use several filters. For the objects of the USSTRATCOM catalogue we use different filter methods than for our internal catalogue.

### II.I The tool COROBS

The first step to indentify objects is to correlate every tracklet with the USSTRATCOM catalogue and the internal AIUB catalogue. This first correlation step is using the tool COROBS, developed by C. Früh. For further details, the complete process is described in [Frü 09]. Both catalogues are in TLE format. Out of the TLEs there are computed the positions and current velocities at the observing epochs. The computed values are compared to those of the tracklets.

According to the deviation of the measured positions and velocities from the computed ones the tracklet correlation is classified into different categories.

The parameters, after which the categories are defined, were estimated empirically. So, a tracklet could be associated to an object, because all criteria were fulfilled, but did not belong to this object. In the end an orbit determination was not successful. An additional investigation was about the frequency of those wrongly filtered tracklets.

### II.II Correlation via positions and velocities

For objects of the USSTRATCOM catalogue there are two categories: The first category represents a very good correlation between the previous orbit and the new tracklets. The second category consists of tracklets which did not fulfil the correlation criteria.

Tracklets which fulfil the criteria are combined with older ones and stored in the database. For the further analyses they were not used, because we do not possess any orbits of these objects. So, we cannot apply the filtering method with orbital elements (see next section) to them.

### II.III Correlation with orbital elements in addition

The objects of our internal AIUB catalogue are treated differently. First of all there are three categories the tracklets can fall in after beeing processed by COROBS.

The first category represents again a good correlation between the previous orbit and the new tracklets. Those tracklets are combined with the older ones.

The second category consists of tracklets which did not fulfil the correlation criteria optimally. In these cases the temporal gaps between the previous orbit and the new tracklet is large. Though, even an orbit determination might be problematic.

Tracklets in the last category are only listed for further information of the user. An orbit determination will fail in every case.

After this first step the leftover tracklets are tested pairwise whether or not some of them belong together. Therefore a circular orbit is determined using the CelMech tool "ORBDET" [Beut 05]. If the RMS of this orbit is smaller than $2''$, we state that the tracklets belong together. Those tracklets, for which at least one matching tracklet could be found are called object candidates; the others remain single. Operating this way has the advantage that the further analysis is computationally less extensive because there are less tracklets to investigate.

The third step performs an investigation of orbital elements. Although we know that this method is not perfect we found out that it is often the only possibility for object correlation due to uncertain TLEs computed out of orbit of only one night.

First the orbits of the objects in the internal AIUB catalogue are compared to the already merged tracklets of the current night. Within only one night an orbit determination is often only possible for combined tracklets.

Nevertheless we also try to determine orbits of the leftover single tracklets and compare them to those of the objects in the internal catalogue. So the number of tracklets of earlier nights can be reduced by combining them with tracklets of the current night, no matter if combined or single ones.

We do not use all elements for comparison, in fact we chose three. For the comparison if the tracklets of earlier nights with the combined tracklets we chose the inclination $i$, the daily movement of the ascending node $\dot{\Omega}$ and the eccentricity $\varepsilon$. The $\dot{\Omega}$ is not a true time derivative but more like $\frac{\Delta\Omega}{\Delta t}$. For simplicity we used the other notation.

For the tracklets from earlier nights and the single tracklets of the current night as well as for the single tracklets from earlier nights and the combined tracklets we used the inclination and the daily movement of the ascending node. For the single tracklets of earlier nights and the current night we only focused on the inclination. Table 1 summarises the parameters which we used for each individual part of this step of the correlation process.

| Analysis step | Element(s) |
|---|---|
| Objects and object candidates | $i,\ \dot{\Omega},\ \varepsilon$ |
| Objects and single tracklets | $i,\ \dot{\Omega}$ |
| single tracklets and object candidates | $i,\ \dot{\Omega}$ |
| single tracklets only | $i$ |

Table 1: Analysed parameters for the correlation via orbital elements

We made a difference between the cases if the tracklets of earlier nights only consist of one night or more than one. The reason therefore is that the more nights were integrated into an orbit determination the more accurate the elements were.

After this filtering process an orbit determination is performed. Tracklets only are correlated when it was successful. Therefore we use the CelMech tool "SATORB" (see again [Beut 05]).

## III. Results

Between the June 9$^{\text{th}}$, 2008 and June 5$^{\text{th}}$, 2010 there were 139 nights with observation.

They split into 104 nights with ZimSMART between June 9$^{\text{th}}$ and August 5$^{\text{th}}$, 2009 and between April 23$^{\text{th}}$, 2010 and June 5$^{\text{th}}$, 2010. The other 35 nights with ZimSMART 2 were between September 8$^{\text{th}}$, 2009 and February 7$^{\text{th}}$, 2010. Because of technical problems there were no observations most of February and in March 2010.

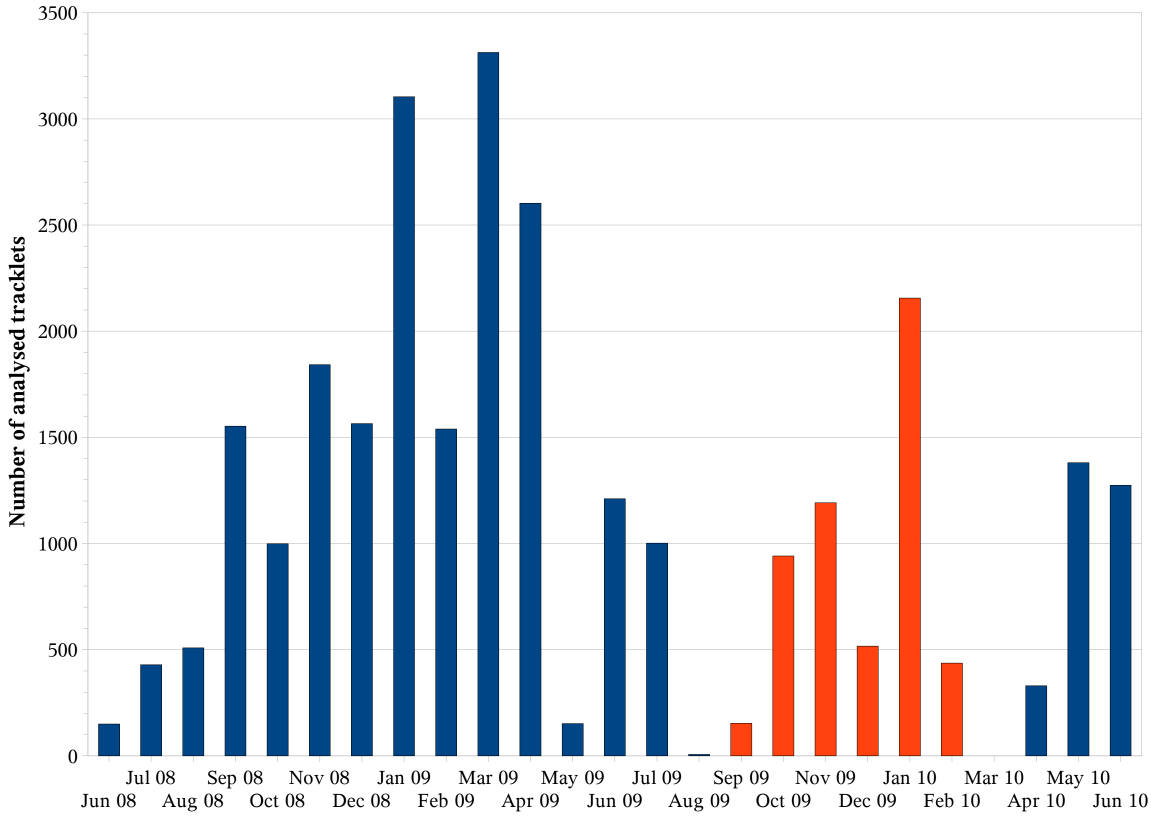


Figure 3: Distribution of tracklets per month between June 2008 and June 2010; ZimSMART observations are in blue, ZimSMART 2 observation are in red

III.I ZimSMART

Within the 104 nights of observations there were 23098 tracklets created, from which 22964 tracklets could be analysed. The other 134 tracklets only consisted of one or two observations due to an insufficient connecting process before the correlation. Both the correlation via positions and velocities and in addition via orbital elements need at least three observations per tracklets for suitable results. In Figure 3 one can see the monthwise distribution of the analysed tracklets plotted with blue bars.

After the correlation via positions and velocities there remained 3016 tracklets uncorrelated, which equates to approximately 13.1 % of all analysed tracklets. After the complete correlation process only 1116 tracklets (≈ 4.9 %) remained single. This means, during the correlation via orbit parameter there could be 2084 tracklets connected to objects of the AIUB internal catalogue. In the end about 95.1 % of the analysed tracklets could be either associated to catalogued objects or combined to new ones.

The analysis concerning wrongly filtered tracklets of the correlation with COROBS was performed for the preliminary uncatalogued objects. In total 3485 tracklets could be associated, where 121 were filtered, although they did not belong to these objects. This equates to approximately 3.4 %.

ZimSMART 2 With ZimSMART 2 we could observe in 35 nights between September 2009 and February 2010. Within these nights 5396 tracklets, from which each could be processed. So there were no tracklets with only one or two observations. The red bars in Figure 3 show the monthwise distribution of the tracklets in this period.

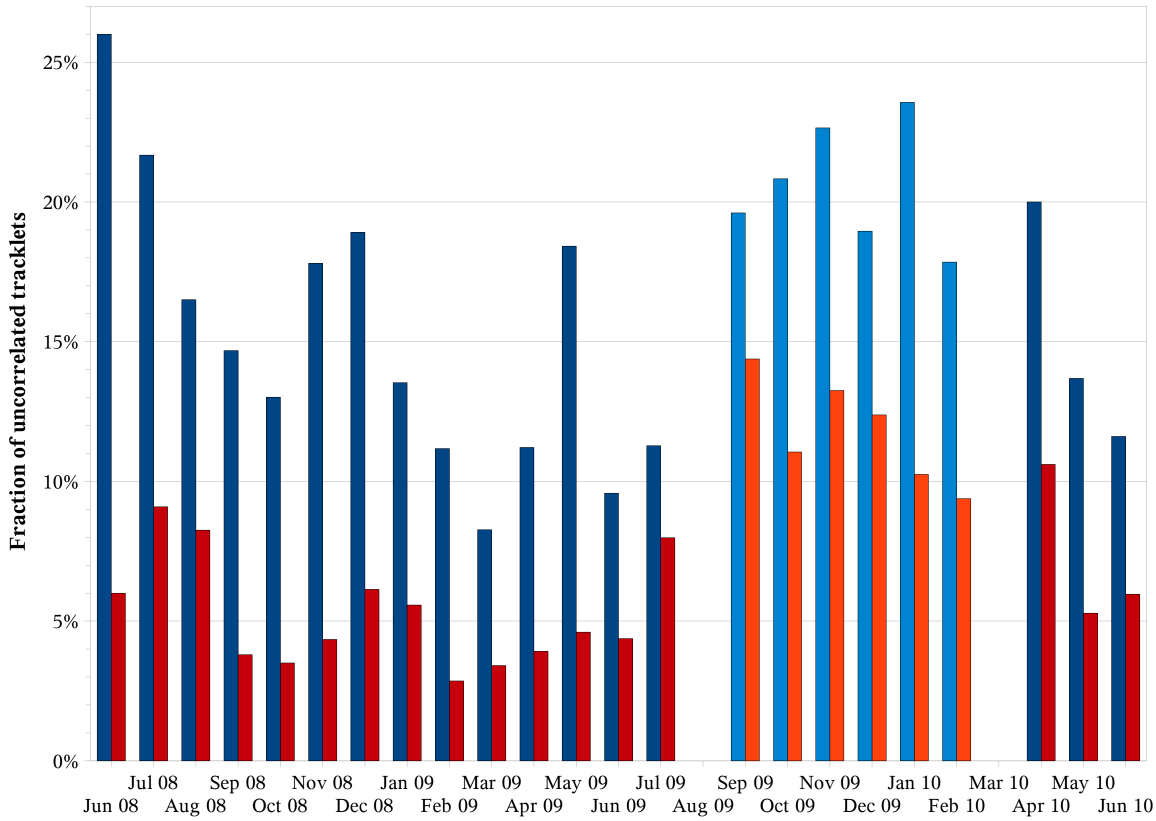


Figure 4: Fraction of uncorrelated tracklets after the correlation via positions and velocities (blue colors) and after the complete process (red colors); the period of ZimSMART 2 is plotted in lighter colors

| | Number of nights | Analysed tracklets | uncorrelated tracklets after correlation via positions and velocities | | uncorrelated tracklets after correlation via orbit parameter in addition | | wrongly filtered tracklets | |
|---|---|---|---|---|---|---|---|---|
| ZimSMART | 104 | 22964 | 3016 | (13.1 %) | 932 | (4.1 %) | 121 | (3.4 %) |
| ZimSMART 2 | 35 | 5396 | 1180 | (21.9 %) | 610 | (11.3 %) | 4 | (0.6 %) |
| **total** | **139** | **28360** | **4196** | (14.8 %) | **1542** | (5.4 %) | **125** | (2.9 %) |

Table 2: Results of the complete correlation process in the period between June 2008 and June 2010

After the correlation via positions and velocities there remained 1180 tracklets uncorrelated, which equates to approximately 21.9 % of all tracklets. After the complete correlation process there were still 610 tracklets ($\approx$ 11.3 %) which were uncorrelated or combined to new objects. So, in the end 88.7 % of the tracklets could be associated to known objects or combined to new objects. The fractions differ significantly from the values of ZimSMART. Figure 4 shows the monthly distribution of uncorrelated tracklets after the correlation via positions and velocities and after the complete process. As one can see, the fraction of uncorrelated tracklets is higher for ZimSMART 2 than for ZimSMART.

Again an analysis concerning wrongly filtered tracklets was performed for the objects which were neither in the USSTRATCOM catalogue nor in the AIUB intenal catalogue. In total 708 tracklets were associated to these objects and 4 of them were associated by mistake ($\approx 0.6\,\%$). This result is much better than for ZimSMART, maybe due to a smaller number of tracklets.

Considering the whole period between June 2008 and June 2010 there were 28494 tracklets from which 28360 were analysed for 139 nights of observations. The correlation via positions and velocities led to 4196 uncorrelated tracklets ($\approx 14.8\,\%$). After the complete correlation process 1726 tracklets ($\approx 6.1\,\%$) remained uncorrelated and uncombined. This means, on the other side, that 93.9 % of all analysed tracklets could be either associated to already catalogued objects or stored as new detections.

Taking a closer look on the uncorrelated tracklets after the complete correlation process, one can see that the longer the gap between the observations is the more tracklets remain uncorrelated. Especially after the gaps of August 2009 and March 2010 the fraction of uncorrelated tracklets is higher than the average. The reasons are the increasing uncertainties in propagating the orbits which makes it hardly possible to correlate tracklets after a certain amount of time.

The analysis of wrongly filtered tracklets led to 125 tracklets, which equates to approximately 2.9 % of the analysed tracklets. In Table 2, one can see a summary of the analysis, firstly seperated by the operating telescope, secondly the total numbers.

We could identify 1104 objects of the USSTRATCOM catalogue and 30 objects of the AIUB internal catalogue. Furthermore we could identify 765 objects which were not catalogued before. Some of them may not belong to different objects due to difficulties to connect short orbit arcs with long gaps in between. Because of the chosen observation scenario the majority of observed objects is GEO–like (see Figure 5).

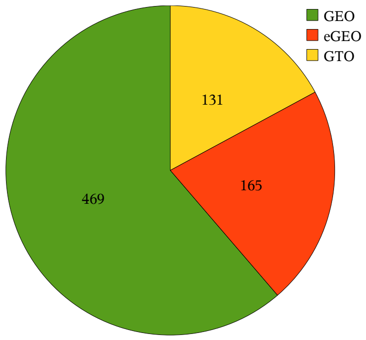


Figure 5: Number of preliminary uncatalogued GEO–, eGEO– and GTO–objects

## IV. Conclusion

In this paper we wanted to analyse the possibilty of building up and maintaining a catalogue of GEO objects. With the chosen observation scenario it is more likely to observe GEO–like objects than eGEO– and GTO–like. Nevertheless it is possible to observe also eGEO– and GTO–like objects for a longer time span, but only with tasked follow-up observations. That means an object is detected in the first night and from the second night on it has to be observed with another telescope where follow-ups are possible.

Although a correlation process via positions and velocities alone is successful with 85.2 % correlated tracklets, an additional correlation via orbital elements increases the fraction of correlated tracklets to 95.1 %. If there are long time gaps between observations as well as for newly detected objects, a correlation via orbital elements is often the only possibility.

## V. Aknowlegdements

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## VI. References

[Beut 05] G. Beutler. *Methods of Celestial Mechanics*. Springer-Verlag, Heidelberg, 2005.

[Frü 09] C. Früh *et al.* “Catalogue Correlation of Space Debris Objects”. In: *Proceedings of the Fifth European Conference on Space Debris*, 2009.