PRESENTING BACARDI'S SUB-CATALOGUE OF DRIFTING OBJECTS CLOSE TO THE GEOSTATIONARY RING

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ABSTRACT

Since the beginning of its operational phase in 2017, observations with the Small Aperture Robotic Telescope Network (SMARTnet) have primarily focused on observations of Resident Space Objects in the geostationary ring, including geosynchronous objects and Resident Space Objects in so-called graveyard orbits. Those latter Resident Space Objects are uncontrolled and are potential candidates for fragmentation events and pose a threat for the geostationary ring as a whole.

After two network extensions with telescope stations in Australia (2019) and Chile (2024), almost the entire geostationary ring is now within the observational reach of the SMARTnet stations. Drifters may be observable throughout their drifting period, i. e., the time after which a Resident Space Object is again above the same longitude. We therefore launched a study to investigate the number of drifters in the Backbone Catalouge of Relational Debris Information (BACARDI) database.

In terms of orbital regions as defined by the European Space Agency, we focused on Resident Space Objects that spend some time in the geostationary ring, deliberately excluding Resident Space Objects of the Geostationary Orbit themselves. One particular focus was put on orbits with a perigee below the geostationary ring, an apogee above it, and an inclination lower than $15°$. These Resident Space Objects are crossing the geostationary ring regularly and pose a threat to active satellites. Tracklets were selected that represent Resident Space Objects in these regions. The filter process happened against the publicly available Two Line Element set catalogue.

Additionally, we present a number of tracklets from the BACARDI database that are associated with Resident Space Objects in those regions but do not have a counterpart in the Two Line Elements catalogue. These Resident Space Objects shall be observed from every available telescope station in order to determine orbit updates. It is imperative not to lose track of them again, for they still pose a threat to the space environment.

Keywords: GEO region; Resident Space Objects; SMARTnet.

1. INTRODUCTION

The Small Aperture Robotic Telescope Network (SMARTnet) was founded jointly (see [1]) by the German Aerospace Center (DLR) and the Astronomical Institute of the University of Bern (AIUB). This network consists of globally distributed telescopes, operated by DLR, AIUB, and external partners.

The scope of SMARTnet is observing Resident Space Objects (RSOs) in orbits around the Earth. In this study, we focused on two sub-groups of GEO RSOs, namely RSOs in the protected zone of the GEO as defined by the Inter-Agency Space Debris Coordination Committee (IADC). The limits may be found in [2].

The intentions are two-fold: on one hand, orbits in the database Backbone Catalogue of Relational Debris Information (BACARDI, [3]) are updated frequently to provide data products for applications such as observation planning, manoeuvre detection, and others. On the other hand, there are RSOs detected without representation in a publicly available catalogue. Those RSOs pose a threat as satellite operators may not be aware of them and may not include them in their consideration about manoeuvres. In this regard, SMARTnet is improving the insight of the RSO population.

Here, we focused on a subset of SMARTnet telescope stations that are located on three different continents. Those were the DLR-operated stations SMART-01-SUTH near Sutherland, South Africa, and SMART-02-KENT at Mt. Kent, Australia, together with the AIUB-operated observatory at Zimmerwald, Switzerland. Fig. 1 shows their geographical locations. Furthermore, the observation limits of $15°$ in elevation and a selection of geosynchronous RSOs are displayed. The symbols show which RSOs are observable from two stations (green dots), from a single station (orange dots), and invisible for the entire network (red dots). As drifters may be included, the figure is a snapshot for an arbitrary epoch. Tab. 1 lists the key properties of the used sensors. They are taken from [1] for GSOC's telescopes and from [4, 5] for AIUB's telescopes.

These telescopes cover a broad variety of applications in

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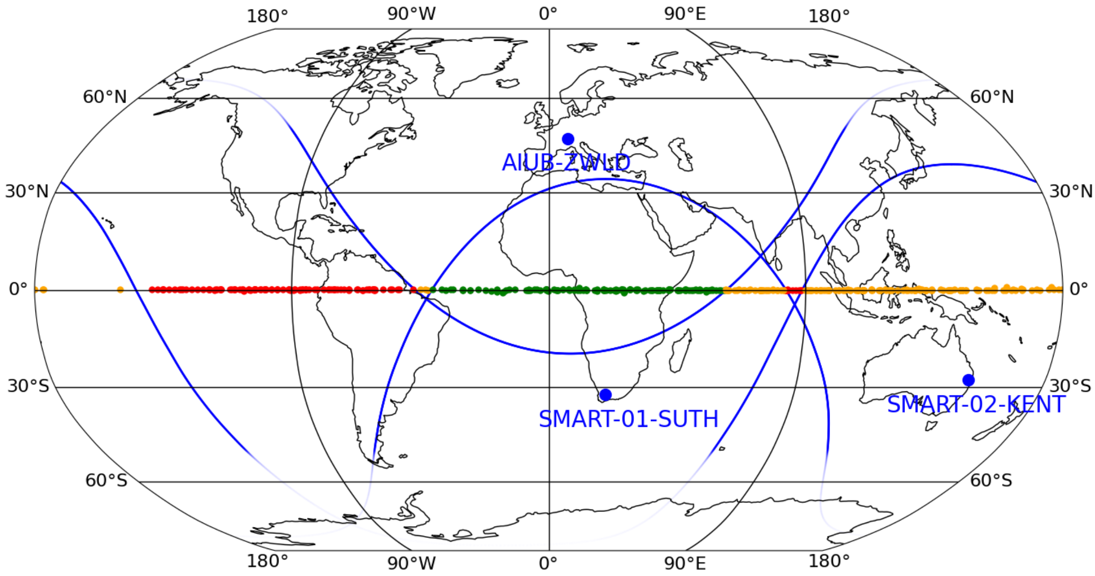

Figure 1. Locations of the telescope stations of SMARTnet in 2023. The dots represent geosynchronous RSOs, the colour code is described in the text.

Table 1. Specifications of the contributing Sensors

Station	Sensor	Main mirror	Focal length	Field of view
SMART-01-SUTH	SMART-01-A-SUTH SMART-01-B-SUTH	50.8 cm 20.3 cm	3454 mm 590 mm	$0.61^\circ \times 0.61^\circ$ $3.4^\circ \times 3.4^\circ$
SMART-02-KENT	SMART-02-B-KENT	25.4 cm	902 mm	$2.3^\circ \times 2.3^\circ$
AIUB-ZWLD	ZimSMART ZimTWIN-1	20.3 cm 40 cm	590 mm 960 mm	$3.6^\circ \times 3.6^\circ$ $2.14^\circ \times 2.14^\circ$

the field of RSO observations: from the search for previously undetected RSOs via blind survey and orbit determination with trueness and precision based on the optics to monitoring orbital evolution of fragmentation events.

2. OBJECTIVE

This study was performed in order to deduce how many RSOs of the BACARDI database are drifting inside, diving into, or crossing the geostationary ring.

Drifting and librating RSOs are taken from [6], where 868 such RSOs are listed. The list of drifting RSOs is from 2019, while the data is from 2023, and might therefore be outdated. However, conclusions regarding observations of the drifter population will still hold. The orbital data of the drifting RSOs is recent, only the list itself will most likely not be complete. We took the same sub-classes as stated in [6], leading to the following numbers: 696 drifters, 112 RSOs with libration around the eastern stable point, 41 RSOs around the western stable point, and 19 RSOs around both stable points. Due to the telescope stations's locations, we expect a small number of RSOs librating around the western stable point (geographical longitude: $105°$W) to be observed. The telescope station SMART-02-KENT cannot observe the western stable point. The number of observed RSOs around the eastern stable point (geographical longitude: $75°$E) should be higher, as both SMART-01-SUTH and SMART-02-KENT can observe those.

When looking at diving RSOs, they fall into two categories:
1. apogee higher than GEO_{IADC}, perigee inside GEO_{IADC}
2. apogee inside GEO_{IADC}, perigee lower than GEO_{IADC}

That means, they may spend a fraction of their orbital period inside the IADC protected zone of the geostationary ring (GEO_{IADC}) and pose a threat to active satellites. Into this category fall RSOs that are between $35\,586\,\mathrm{km}$ and $35\,986\,\mathrm{km}$ above ground, as well as at an declination between $-15°$ and $+15°$. At their perigee or apogee, the velocity differs from a satellite on a GEO orbit, which may lead to a collision.

The last group we looked at were RSOs that cross the IADC protected GEO region. Their orbits have an apogee higher than GEO and a perigee lower than GEO. They also pose a threat to active satellites, because their relative velocities differ from those of GEO RSOs.

Here again, the same conditions for perigee distance, apogee distance, and inclination have to hold for an RSO to cross the IADC protected zone of the geostationary ring.

The tracklets were filtered against a publicly available RSO catalogue. We use Two Line Elements sets (TLE) provided by space-track.org ([7]). In case there was a counterpart in the catalogue, the corresponding orbital elements could be extracted and determined whether the tracklet belongs to an RSO of the aforementiond categories.

In cases without a representation, a first orbit determination was performed. Due to the short time span covered by a single tracklet, the resulting orbital elements have to be treated carefully as they may carry large uncertainties.

2.1. Dataset

We used tracklets of all five telescopes mentioned in Tab. 1. In total, 38228 tracklets were analyzed, beginning with 2023-01-01 until 2023-05-31. The temporal distribution is shown in Fig. 2. Tracklets are shown locationwise for the sake of clarity. Due to meteorological and technical interruptions, there are gaps when no telescope could acquire observations. That was the case for 26 days in the given interval.

In particular, looking at the telescope stations SMART-01-SUTH printed in blue and AIUB-ZWLD printed in green, the advantage of telescope stations being on either hemisphere becomes clear. Although there are days without observations for each single station (78 for SMART-01-SUTH, 81 for AIUB-ZWLD), these numbers are nearly halved for both at the same time (42 in the given interval). Limited observation time can be balanced, and declining weather conditions may only be faced by one telescope station, leading to successful observations by another.

2.2. Analysis Method

The filter results of the tracklets against the publicly available TLE catalogue were taken as the ground truth. These filter results could have been taken from the RSO database BACARDI or achieved with a stand-alone filter solution. The procedure used in this study is called pseudo-probability method and is described in [8]. The measurements are checked against calculated positions and velocities to determine a Mahalanobis-like distance and consequently a pseudo-probability value to show a likelihood for a match. The difference between the pseudo-probability method and method of the Mahalanobis distance is the missing covariance matrix, which is not available for TLE data.

The advantage of BACARDI is the subsequent automatic orbit determination process. With the stand-alone solution, orbits have to be determined in a subsequent process, potentially triggered manually.

Afterwards, the identified RSOs are investigated whether they belong to one of the ESA categories or satisfy our definitions of diving and crossing RSOs.

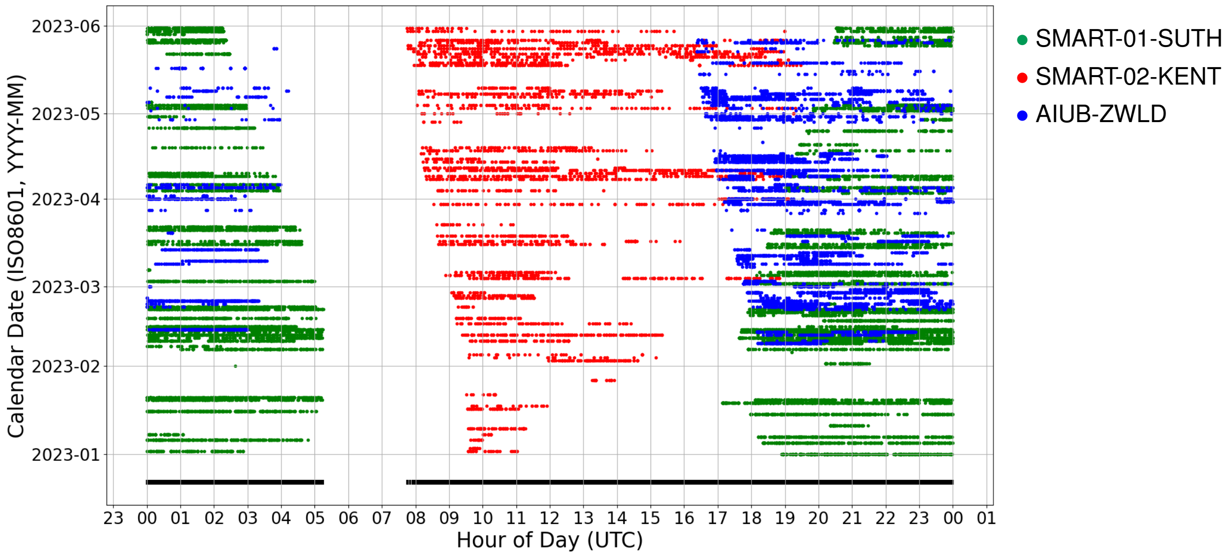

Figure 2. Temporal distribution of the analyzed tracklets. The horizontal axis represents the tracklet epoch, while the vertical axis stands for the corresponding calendar date.

There will also be tracklets that do not have a representation in the TLE catalogue. Those are analyzed separately in terms of performing an initial orbit determination. Due to the short arc length, orbits carry large uncertainties. For evaluation regarding orbital regions and presumed transit through the geostationary ring, they can however give hints.

Within the set of 38228 tracklets, there were 7968 tracklets that could not be associated to any catalogued RSO. However, that does not mean that there were 7968 different RSOs detected, multiple observations of RSOs are possible and even likely. These tracklets stem from all contributing sensors, there is no bias towards a specific sensor configuration. This study did not incorporate an analysis regarding how many tracklets belong together. This can be done within BACARDI together with an orbit determination.

The number of measurements is not correlated with the possibility of association to a catalogue RSO. There are almost as many tracklets with three measurements as there are with at least seven. Fig. 3 shows the distribution of said number of measurements.

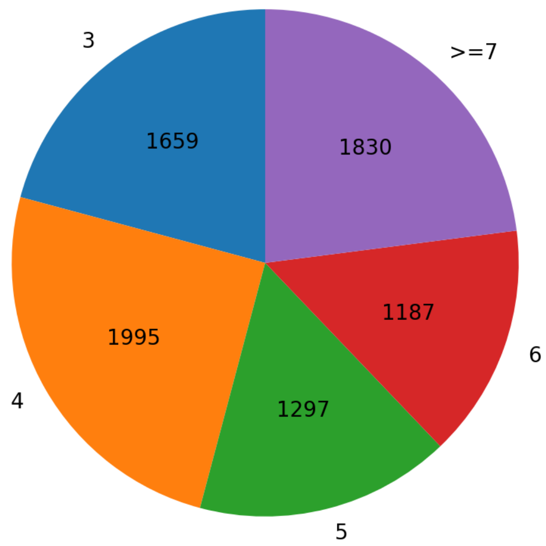

Figure 3. Distribution of unassociated tracklets with respect to number of measurements. The numbers outside the pie chart represent the number of measurements per tracklet.

3. RESULTS

Based on ESA's classification publication, we have observed 272 out of 696 drifters, 14 out of 41 RSOs librating around the western stable point, 104 out of 112 RSOs librating around the eastern stable point, and 17 out of 19 RSOs librating around both stable points. As expected due to the limited coverage of the geostationary ring, the fraction of observed librating RSOs around the western stable point is lower. Based on the categories imposed by DLR in this study, we could observe 122 more RSOs that cross the IADC protected GEO region and 103 more RSOs that dive into it.

With the aforementioned analysis method, a number of conclusions can be drawn. First of all, there are a lot of RSOs that spend a significant amount of time in the IADC protected region for the geostationary ring. Fig. 4 shows the distribution of hours spent in GEO for a period of 24 hours. Here, RSOs are considered when they spend at least one minute inside the protected region, but less then 24 hours (in mathematical terms: $[1\,\mathrm{min}, 1439\,\mathrm{min}]$ as the step size was one minute). There are about 193 RSOs that spend three hours or less in the IADC protected GEO region.

104 of them fall into the category of crossing RSOs as defined above. Their apogee is above the GEO region while their perigee is below. Spending a small portion of the day inside the IADC protected GEO region could mean high relative velocities and therefore a large threat for collisions.

On the other hand, without dedicated and thorough observation strategies, RSOs may not be observed regularly. The observation strategies of the telescope stations were not coordinated. Tracklets were taken from a period where each telescope station performed its own survey and follow-up strategies, respectively. With the five months we analyzed, there were 60 RSOs with one tracklet, i. e., one successful observation series, and 221 RSOs in total with five tracklets or less. In terms of one-time orbit update, one tracklet might be enough, but for catalogue maintenance, those numbers are too scarce for a successful catalogue maintenance. A valid conclusion may be that once such an RSO is identified, it must be scheduled for regular observations. Fig. 5 shows the distribution of tracklets and how many RSOs had that many tracklets associated to them.

With the unassociated tracklets, the analysis had to be different. The corresponding RSOs and their orbits are unknown. Simultaneously, an orbit determination is nearly impossible due to the short arc represented by the measurements in the tracklets. We chose a method to get deliberately very rough estimations and performed a circular orbit determination for each tracklet.

In Fig. 6, the number of tracklets per radius bin are presented. There are two peaks visible. The one between $40\,000\,\mathrm{km}$ and $42\,500\,\mathrm{km}$ mostly represents geostationary and geosynchronous orbits, while the other peak (between $25\,000\,\mathrm{km}$ and $27\,500\,\mathrm{km}$) incorporates a multitude of orbits. They might represent true circular orbits of RSOs in the Medium Earth Orbit region (MEO) and elliptical orbits observed near the perigee and spuriously forced onto a circular orbit during the orbit determination process, respectively. The angular velocities derived from the measurements in the tracklets are in agreement with a circular orbit with the displayed radius. A distinction between the orbit types cannot be made at this stage.

4. SUMMARY

In the presented study, we analyzed five months of tracklet data of the telescope network SMARTnet regarding drifters. The categories of drifters were taken from ESA's Classification of Geosynchronous Objects. Furthermore, we added two categories with RSOs spending some amount of time in the IADC protected GEO region. Those RSOs were not in ESA's list of 2019 but might have been added later.

We analyzed 38228 tracklets from three different telescope stations and could identify RSOs in each of ESA's categories. Due to a region above the Eastern Pacific Ocean that was not covered by the network, a significant number of RSO that drift through the geostationary ring (424 of 696 RSOs) or librate around the western stable point (27 of 41 RSOs) remained unobserved. The sucess rate of the other categories is higher: 104 of 112 RSOs librating around the eastern stable point were observed as were 17 of 19 RSOs librating around both stable points. Additionally, we could file 225 RSOs into DLR's added categories.

However, regarding the number of tracklets per RSO, we found that without dedicated observation strategies a catalogue maintenance of those RSOs could be challenging or even impossible, when 60 RSOs had only one tracklet each associated to them in the entire analysis period. Our conclusion is to observe those sets of RSOs on a regular basis.

We also looked into the time period the RSOs spend inside the IADC protected GEO region and found that there are 193 RSOs spending three hours or less in the protected region. While this may sound small, the relative velocities must not be ignored. Thus, those RSOs pose a threat to active satellites in terms of collision risk.

At last, we performed a circular orbit determination with the unassociated tracklets to identify the orbital regions of those measurements. On one hand, due to the short-arc nature of the tracklets, there is no use in trying to compute a six-parameter orbit, hence the circular approach. On the other hand, not all RSOs will be located on a (even approximate) circular orbit, and the resulting radii are only rough guesses. A tracklet-tracklet association and a more reliable orbit determination can be performed within BACARDI and was not part of this study.

In the end, we found possible improvements for future observation strategies to improve the insight of the RSO population in and near the geostationary ring. At least regular scheduling should be considered to observe these RSOs and for timely orbit updates. Furthermore, to compensate for varying visibilities, observation schedules of

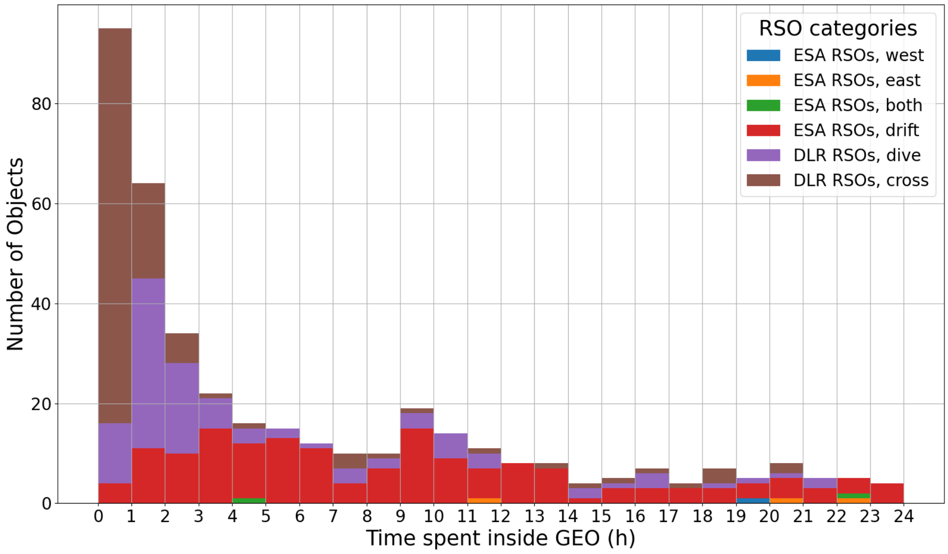

Figure 4. Time in hours the RSOs spend in the IADC protected GEO region.

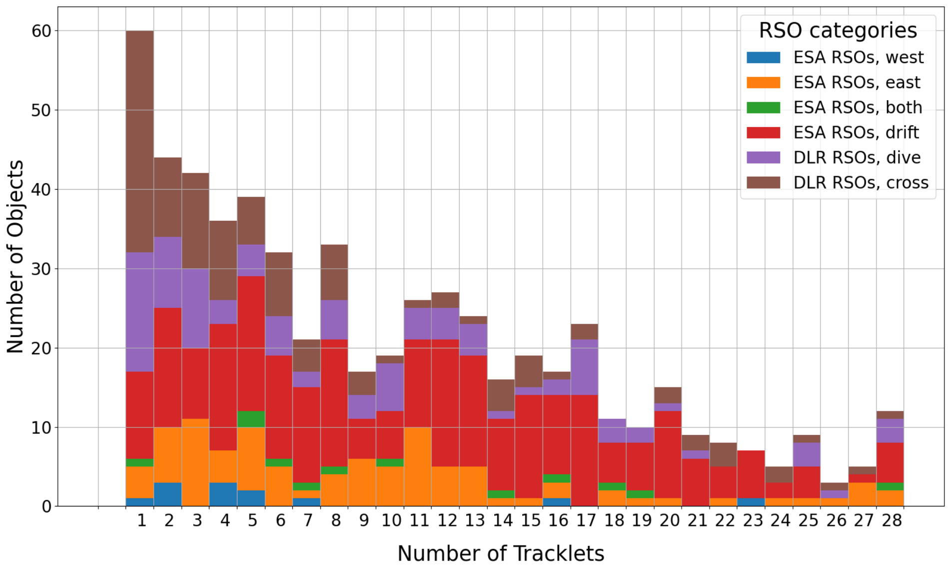

Figure 5. Number of RSOs with the number of associated tracklets.

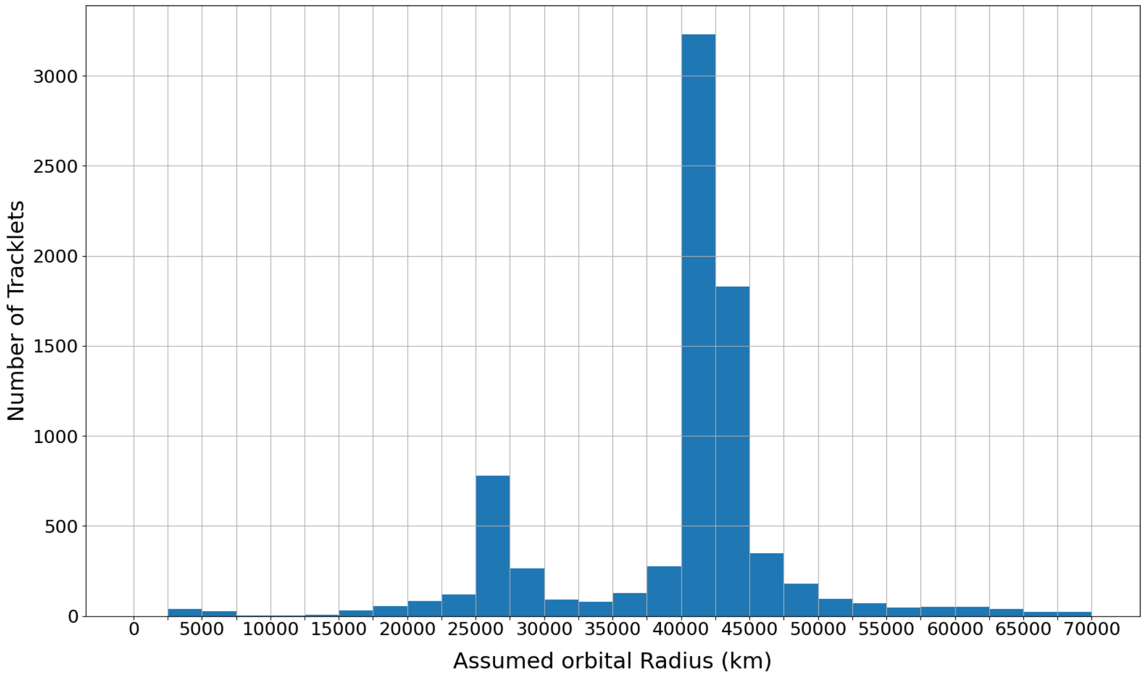

Figure 6. Results of circular orbit determination. Number of tracklets per radius bin.

the involved telescope stations should be coordinated. Also regarding the previously unassociated RSOs, coordinated observations are advised to achieve a first reliable orbit and to schedule timely follow-up observations. Depending on applied observation strategies in general, a free-of-charge tracklet exchange may also lead to a reliable orbit for given objects, even when coordinated observations are not possible. The free-of-charge exchange of observational data in general represents a base principle of SMARTnet [9, 10].

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