OBSERVING THE GEOSTATIONARY RING

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Abstract- **Based on orbital data contained in the DISCOS database, the situation in the geostationary ring is analysed. In January 2007, from 1121 known objects populating the geostationary region, 354 are controlled within their allocated longitude slots, 448 are drifting above, below or through GEO, and 147 are in a libration orbit. For 165 objects there is no orbital information available. In the last ten years from 1997 to 2006, 152 spacecraft reached their end of life; 56 were reorbited in compliance with the Inter-Agency Space Debris Coordination Committee (IADC) recommendation, 54 were reorbited below the minimum recommended altitude, and 42 were abandoned or lost without any end-of-life disposal manoeuvre. Apart from these catalogued objects, the ESA 1-m telescope has observed many smaller debris (down to about 15 cm) in this orbital region representing a non-negligable collision risk for geostationary spacecraft.**

I. INTRODUCTION

The geostationary ring is a valuable resource currently populated by more than 350 operational satellites. Unlike in low Earth orbit there is no atmospheric drag which will remove abandoned objects over time. Therefore, it is the responsibility of the spacecraft operators to keep this unique orbital region clean. Already in 1977, Perek [6] proposed that spacecraft should be systematically removed from their geostationary orbit (GEO) at end-of-mission. In the same year INTELSAT sent for the first time in space history an aging satellite into a GEO graveyard orbit.

Since then a number of guidelines and recommendations for end-of-mission disposal were issued by national and international institutions as described by Johnson [4] and in a United Nations Committee for the Peaceful Uses of Outer Space report [11]. In 1995 the International Academy of Astronautics [9] recommended to reorbit "geostationary satellites at end-of-life to disposal orbits with a minimum altitude increase 300-400 km above GEO depending on spacecraft characteristics". At the same time, space agencies like NASA, JAXA, Roskosmos, CNES and ESA developed guidelines. All recommended an altitude increase of more than 200 km above GEO. Finally in 1997, an international consensus was found within the Inter-Agency Space Debris Coordination Committee [10]. The recommended minimum altitude increase (in km) is given as

$$\Delta H = 235 + 1000 \cdot C_R \cdot A/m \qquad (1)$$

where C_R is the solar radiation pressure coefficient (usually with a value between 1 and 2), A is the average cross-sectional area in square metres and m is the mass of the satellite in kg.

In view of these guidelines and recommendations one would expect that the geostationary ring is a well protected and unlittered space. However only about one third of all satellites follow the internationally agreed recommendations. Two out of three satellites are reboosted into an orbit so low above GEO that they will sooner or later interfere with geostationary satellites, or they are completely abandoned without any end-of-life disposal manoeuvre.

In this paper an updated survey of the reorbiting practices in the geostationary ring during the last ten years (1997-2006) is given. Also the significant population of uncatalogued objects as small as 10-15 cm, which was detected by ESA's 1 meter telescope at Teneriffe [2, 8] is shortly discussed. The large number of other objects (mostly upper stages in geostationary transfer orbits) that pass through GEO and also represent a hazard are not considered in this analysis.

II. ORBITAL DATA ANALYSIS

The basic source of information are the NASA Two-Line Elements (TLE). They are copied into ESA's DISCOS Database (Database and Information System Characterising Objects in Space) every day by ESOC's Mission Analysis Section. Geostationary objects are selected from the DISCOS Database according to the following criteria:

- eccentricity smaller than 0.1,
- mean motion between 0.9 and 1.1 revolution per sidereal day, corresponding approximatively to a radius of 42164 ± 2800 km,
- inclination lower than 30°.

911 objects met these criteria as of 31 December 2006. Their orbital histories were analysed in order to classify them according to different categories. Six different types of categories are defined [7]:

- C1: objects under longitude and inclination control (E-W as well as N-S control) - the longitude is nearly constant and the inclination is smaller than 0.3°,
- C2: objects under longitude control (only E-W control) - the longitude is nearly constant but the inclination is higher than 0.3°,
- D: objects in a drift orbit,
- L1: objects in a libration orbit around the Eastern stable point (longitude 75° East),
- L2: objects in a libration orbit around the Western stable point (longitude 105° West),
- L3: objects in a libration orbit around both stable points.

III. CURRENT SITUATION IN GEO

Next to the 911 objects which fulfill the orbital criteria above, there are 210 more objects also known to be in this orbital region although no orbital elements are available in DISCOS. Thus, the total number of known objects in the geostationary region is 1121. They were classified as follows:

- 354 are controlled (238 under longitude and inclination control),
- 448 are in a drift orbit,
- 147 are in a libration orbit,
- 97 are uncontrolled with no orbital elements available,
- 68 are uncatalogued objects which can be associated to a launch,
- 7 could not be classified (they were recently launched and are en route to their longitude slot or they had a recent manoeuvre).

Figure 1 illustrates the percentage of the various categories. In the annual report "Classification of Geosynchronous Objects" by Arregui and Jehn [1] the status of all the individual objects can be found. In this paper we confine ourselves to some statistical data.

Figure 2 shows the number of objects under control (bottom bars), in drift orbit or in libration orbit (top bars) according to the launch year. Most of the satellites launched before 1990 are meanwhile either in a drift orbit or in a libration orbit. Up to 10 objects were abandoned in such libration orbits every year.

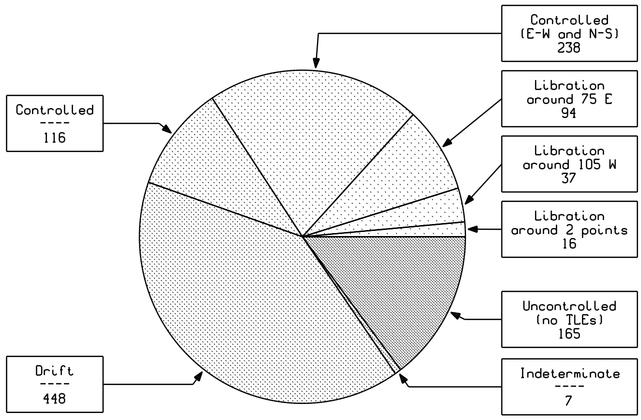

Fig. 1: Number of objects in each category. The 116 controlled objects consist of 71 objects in class C2 (only East-West station keeping) and 45 objects which TLEs are not available.

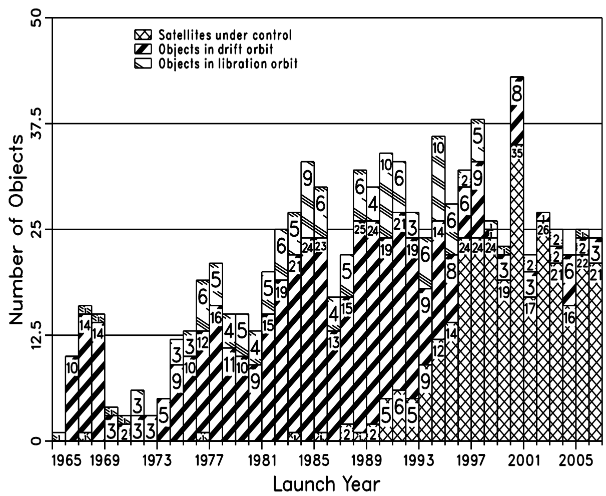

Fig. 2: Number of objects in each category according to the launch year.

Figure 3 shows the distribution of the longitude of the 309 satellites under control for which the orbital position is known. A concentration of satellites over Europe and also over the United States can be observed. Except for a small "hole" around 200° East, the congestion of the geostationary ring becomes evident.

Figure 4 illustrates the distribution of the objects in drift orbit. Each vertical line represents one object. The horizontal axis gives the semi-major axis mean deviation from the geostationary altitude, which is inversely proportional to the mean drift rate of the object. The vertical axis gives the perigee and apogee mean deviation from the geostationary altitude. The altitude of the object varies between these two values. It can be seen that if the eccentricity is large, the object will go through the geostationary altitude. According to the IADC recommendation, a satellite should be reorbited at its end-of-life to a graveyard orbit with a perigee altitude which is about 260 km above the GEO ring, see (1). All lines which cross the region of 200 km around GEO represent objects entering into the protected zone around GEO.

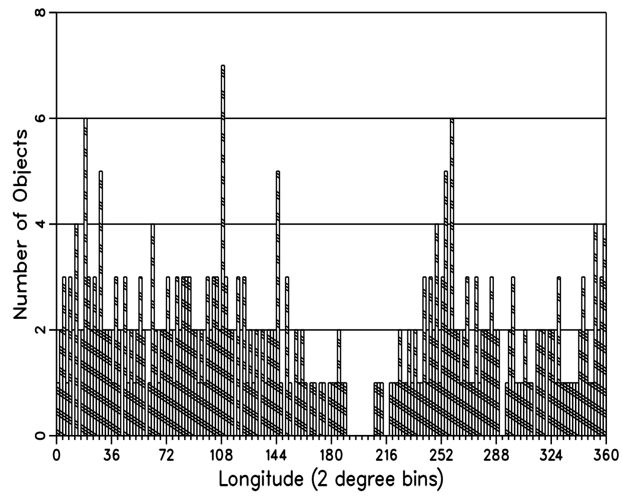

Fig. 3: Distribution of the longitude of the 309 satellites under control (with updated TLEs) in 2-degree bins.

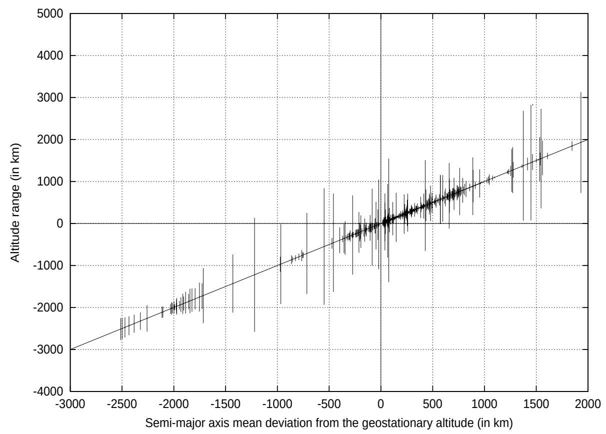

Fig. 4: Distribution and altitude range of objects in drift orbit.

Figure 5 illustrates the number of objects in a libration orbit that pass through a given longitude. The 110 objects classified as librating around the Eastern stable point (category L1) or around both stable points (category L3) are counted in the interval 72.5°-77.5°, because they all go through 75° E longitude. 53 objects (37 in category L2 and 16 in category L3) librate through the Western stable point at 105° W, whereas only a few librating satellites pass through 0 or 180° E.

IV. Reorbiting statistics in the years 1997 to 2006

In total 152 satellites reached end-of-life during the last ten years. According to the orbital data in the DISCOS database, 42 of these were abandoned without any reorbiting manoeuvre. 26 were abandoned in the Eastern hemisphere (mainly Russian spacecraft) and are now librating around the Eastern libration point L_1 at 75° E over India. The libration period is between 2 years (Luch 1-1) and nearly 5 years (Kosmos 2224). 13 were abandoned in the Western hemisphere and are now librating around the Western libration point L_2 at 105° W. Three spacecraft were abandoned in orbits librating around L_1 and L_2 crossing nearly all longitudes during a libration period of around 10 years.

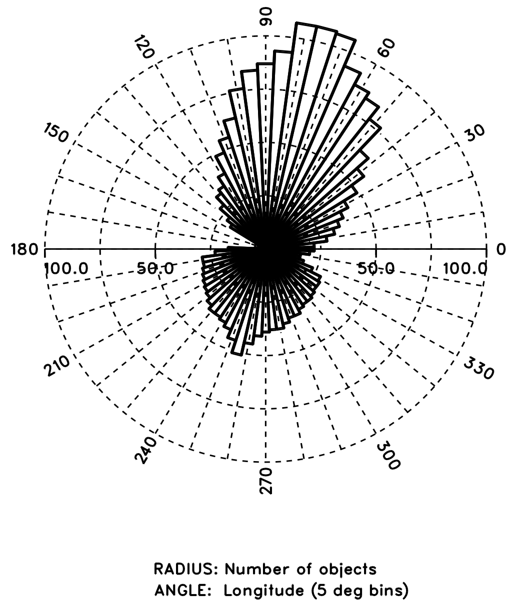

Fig. 5: Number of objects in libration orbit in 5-deg bins of geographic longitude (objects with updated TLEs only).

54 GEO spacecraft performed an end-of-life manoeuvre where the perigee was not raised above GEO + 260 km, which is the approximate reorbiting altitude calculated with (1) for typical GEO spacecraft. Some spacecraft operators reserve only a minimum amount of propellant to free their own orbital slot. The reorbited satellites will then drift slightly above the geostationary ring in a region which is declared "protected" because it is the area where GEO satellites are drifting during station acquisition or during relocation manoeuvres.

Table 1: Reorbiting practices from 1997 to 2006

	Left around			Graveyard orbit		
	L_1	L_2	L_1/L_2	low	IADC	Total
1997	1	2	-	6	6	15
1998	7	3	-	6	6	22
1999	5	1	-	4	5	15
2000	3	1	2	2	3	11
2001	5	1	-	6	2	14
2002	1	1	-	5	4	11
2003	-	1	-	7	8	16
2004	2	1	-	5	5	13
2005	1	1	1	6	10	19
2006	1	1	-	7	7	16
Total	26	13	3	54	56	152

Only 56 GEO spacecraft were reorbited in compliance with the IADC recommendations. 9 of them were Intelsat satellites, 7 Japanese, 5 Russian, 11 US American and 24 belonging to other countries, including five Eutelsat satel-

lites. Table 1 summaries the reorbiting practices during the last ten years. Table 2 shows the owners of the spacecraft which reached end-of-life. There are some general trends to be seen: Whereas some countries like Japan or organisations like Intelsat and Eutelsat tend to comply with the general reorbit recommendations, other nations like China and Russia still have difficulties in taking measures to preserve the geostationary ring.

Table 2: Reorbiting practices from 1997 to 2006 - distribution by country.

	Left around	Graveyard orbit	
	L_1 and/or L_2	low	acc. to IADC
China	4	2	-
Intelsat	1	3	9
Japan	-	4	7
Russia	28	5	5
USA	7	16	11
Other	2	24	24
Total	42	54	56

Not only old GEO spacecraft end up close to the geostationary ring, also some countries place rocket upper stages around GEO. In 2006 a Proton-K fourth stage (06022D) was left in a -420 x 15 km GEO crossing orbit. It is now drifting 2.6°/day eastward. China placed the apogee kick motor (06053C) of Fengyun 2D in a -195 x 710 km GEO crossing orbit. It is now drifting 3.3°/day westward crossing the geostationary altitude twice a day. The crossing of these rocket bodies of the GEO protected zone is a clear noncompliance with the IADC guidelines.

V. ESA observations of the geosynchronous orbits

The ESA 1-m telescope is used since 1999 to search for debris at geostationary altitude. The sensitivity of the telescope is limited to objects brighter than visual magnitude of 20 or 21 under good observation conditions [2]. Visual magnitude of 20 corresponds to an object of about 10 cm assuming an albedo of 0.08.

Table 3 gives an overview of all the GEO and GTO campaigns until end of 2006. In a "good" year more than 10 000 square degrees of the sky were scanned with up to 80 000 frames. During up to nearly 100 nights up to 700 observation hours were logged (on average 6 hours per night). The terms "correlated" and "uncorrelated" refer to detections for which a corresponding catalogue object could or could not be identified, respectively. The identification procedure, or "correlation procedure", is based on comparing the observed orbital elements and the observed position of the object at the observation epoch with the corresponding data from the catalogue. We used the unclassified part of the USSTRATCOM catalogue as our reference (actually data from the ESA DISCOS database was used). By "detection" we denote the detection of an object within a single 30- or 15-minute observation series. Some of these detections actually refer to the same object, i.e. we have incidentally observed some of the objects multiple times. The column "Catalog objects" gives the number of detected catalogued objects.

Table 3: Observation statistics for the ESA 1-m telescope

Year	Scanned Area Frames / deg^2	Observations days / h	Detections cor. / uncor.	Catalog objects
1999	5400 / 895	13 / 49	180 / 348	56
2001	65000 / 11200	82 / 548	2023 / 1587	448
2002	81800 / 13700	96 / 691	1738 / 1676	392
2003	66000 / 10600	88 / 559	1121 / 1195	337
2004	49500 / 7800	70 / 417	599 / 896	266
2005	59500 / 8800	85 / 495	708 / 922	443
2006	70000 / 9800	95 / 580	tbd	tbd

It is very important to point out that all surveys in Table 3 suffer from observational biases depending on observation epochs and pointing directions at these epochs ("what we see depends on where and when and how we look"). The numbers given in Table 3 could therefore be misleading, e.g. when simply taking the ratio of uncorrelated to correlated detections as a measure to estimate the total number of debris objects.

Figure 6 shows the brightness distribution of all detected objects between 2001 and July 2006. As it can be expected, most objects with a visual magnitude fainter than 15 are not contained in the USSTRATCOM catalogue. The roll-off of the distribution beginning at magnitude 18 is due to the sensitivity limit of the 1-m telescope.

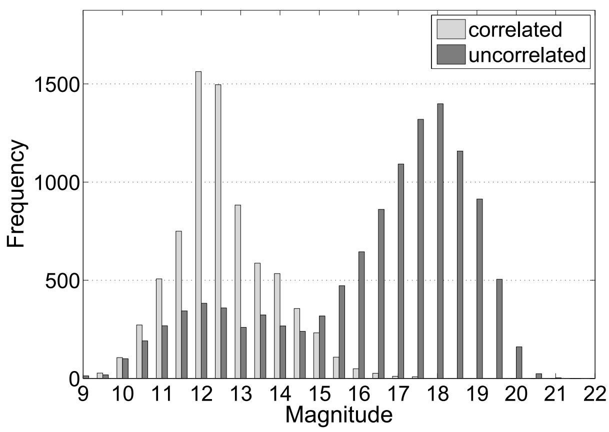

Fig. 6: Visual magnitude of objects detected with the ESA 1-m telescope between 2001 and July 2006.

Another hitherto unknown debris source was discovered by the ESA 1-m telescope [8]. Figure 7 shows a large number of objects with a mean motion of about 1 rev/day and eccentricities of up to 0.55. Liou and Weaver [5] speculate that these objects may be similar to the thermal blankets or Multi-Layer Insulation which are known to rip off from LEO satellites. Due to their very large area-to-mass ratios they can build up considerable eccentricities in a few months.

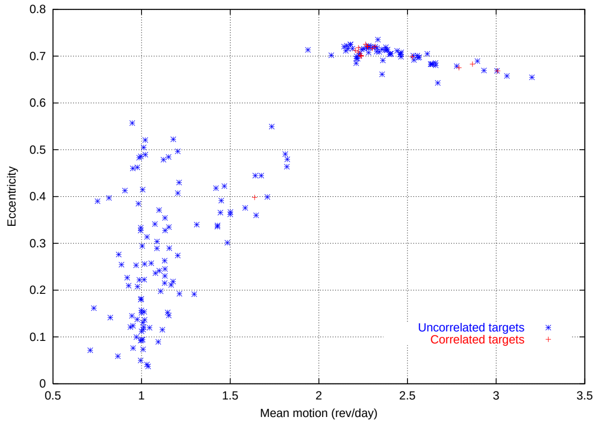

Fig. 7: Eccentricity versus mean motion of objects detected with the ESA 1-m telescope between August 2002 and July 2003.

VI. CONCLUSIONS

Analysis of orbital data of 911 objects in or near the geostationary orbit revealed that 147 satellites and rocket stages were abandoned at geostationary altitude and are now librating through all longitudes of the geostationary ring. 448 objects are drifting, mostly above GEO, but many of them intrude into the protected GEO region daily. These abandoned objects pose a collision risk to the active GEO spacecraft. Therefore the reorbiting of GEO spacecraft at end-of-life is recommended since nearly 30 years.

In 1997 the Inter-Agency Space Debris Coordination Committee issued a world-wide accepted recommendation to reorbit GEO spacecraft by at least 235 km plus a term depending on the spacecraft characteristics, see (1). However, this recommendation is only followed in about one third of all cases. During the last ten years, from 1997 to 2006, only 56 out of 152 spacecraft were properly reorbited. 54 were put in a disposal orbit with a perigee below the IADC recommended value. And 42 GEO spacecraft were completely abandoned without any end-of-life manoeuvre. However, there is a trend of improvement to be seen: whereas from 1997 to 2001, the precentage of abandoned satellites was 40 % (31 out of 77) it dropped to 15 % (11 out of 75) in the last 5 years.

Finally, the observations made with the ESA 1-m telescope reveal that the situation in the geostationary ring is even more critical than what analysis of the catalogued objects tells us. We are just about to discover the full scope of the debris problem in GEO, which was previously thought to be much less compelling than the debris problem in LEO.

ACKNOWLEDGMENT

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