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Orbital debris: What are the best near-term actions to take? A view from the field☆

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ABSTRACT

The geostationary Earth orbit (GEO) satellite belt[1] is a unique location above the earth affording a continuous line-of-sight to satellite uplink and downlink stations. The volume defined by this belt is large, but available slots are limited. During the last fifty years of the space age, this volume has become more crowded, as humankind has launched more and more satellites into this particular orbital regime, and satellites that suffered incapacitating anomalies and space debris have remained in the belt. The latter pose a hazard since they are uncontrolled, and the only way for satellite operators to avoid collisions with space objects is to maneuver. Knowing when and where to maneuver requires space situational awareness (SSA), but this is just one aspect needed to maintain safety of flight in this very valuable orbital regime.

This paper reports on, from the point of view of an SSA practitioner, what the key issues and dangers surrounding the current situation in the GEO belt are, and what the best possible set of near-term actions could be, involving international cooperation (through bodies such as the United Nations Committee On the Peaceful Uses of Outer Space (UN COPUOS)), data sharing between actors in the space arena, public and private sector SSA efforts, and nascent research efforts into active space debris removal. Where should limited available resources be applied to affect the best possible outcome?

1. Key issues and dangers in GEO

Operating in the geostationary Earth orbit (GEO) orbital regime entails operating in a harsh environment (including such factors as being in a vacuum, and having to deal with natural and artificial hazards such as increased radiation and charged particles, orbital debris, space weathering, *etc.*), at long distances that generally preclude making repairs to orbiting systems. But a slot at GEO is a valued, finite resource, and there is competition between countries and companies to utilize the GEO orbit. Below are described the major issues and hazards that are part of operating in the GEO orbit.

1.1. Space debris near GEO

The year 1963 saw the dawn of the commercial satellite era with the launch of the first GEO satellite, Syncom 2. Geosynchronous satellite communications have since provided many benefits to mankind. However, “as a result of past activities in space, a massive amount of space debris – non-functional and uncontrolled objects – has been left in Earth orbit which poses a serious challenge to the sustainability of outer space”[1]. Fig. 1 illustrates the concentrations of tracked, man-made objects in Earth orbit, with a concentration of objects evident in the neighborhood of the GEO ring.

One source of larger debris in the GEO ring is the population of non-functioning payloads and upper stages that were placed into the GEO ring, but were unable of being disposed into orbits higher than GEO (as is the current practice) upon their end of life [3]. These objects are trapped in one or both of the two gravitational wells (“pinch points”) caused by the gravitational anomalies (more specifically, perturbations related to the tesseral components of the

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[1] In this work we will refer to the geostationary *ring* as the altitude at which the orbital period exactly matches the rotation of the earth, with zero eccentricity and zero inclination, such that the object appears exactly fixed in the sky from an earth-based observer. Similarly, the geosynchronous *belt*, as, similarly to the geostationary ring, that volume where the orbital period is almost synchronous with the rotation period of the earth, and the inclination and eccentricity are not constrained to being zero. Though this implies an unlimited region for geosynchronous objects, the limitation of launch geometries and perturbations constrain the geosynchronous objects to a "band" around the Earth.

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2468-8967/

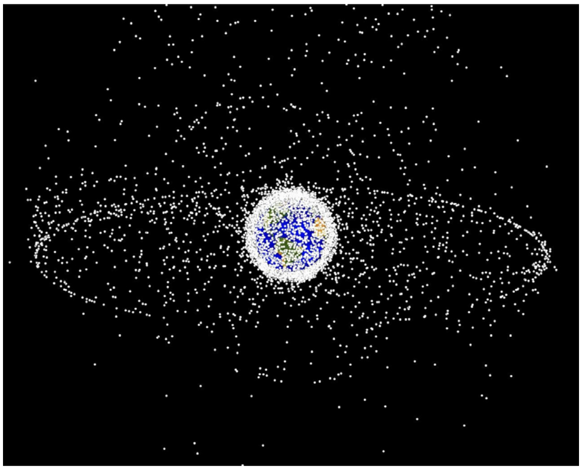

Fig. 1. Computer generated images of objects in Earth orbit that are currently being tracked. Approximately 95% of the objects in this illustration are orbital debris, i.e., not functional satellites. The dots represent the current location of each item. The orbital debris dots are scaled according to the image size of the graphic to optimize their visibility and are not scaled to Earth. This image was generated from a distant oblique vantage point to provide a good view of the object population in the geosynchronous region (around 35,785 km altitude). Note that the larger population of objects over the northern hemisphere is due mostly to Russian objects in high-inclination, high-eccentricity orbits. Image and caption courtesy of the NASA Orbital Debris Program Office [2].

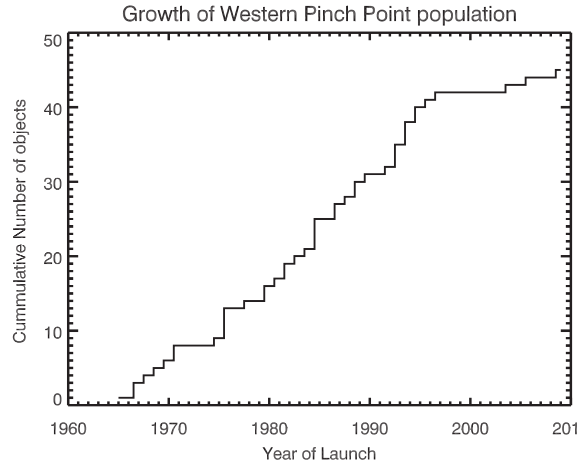

Fig. 2. Shows the cumulative growth of the number of defunct satellites that orbit about the western pinch point (the geo-potential well at 105° W).

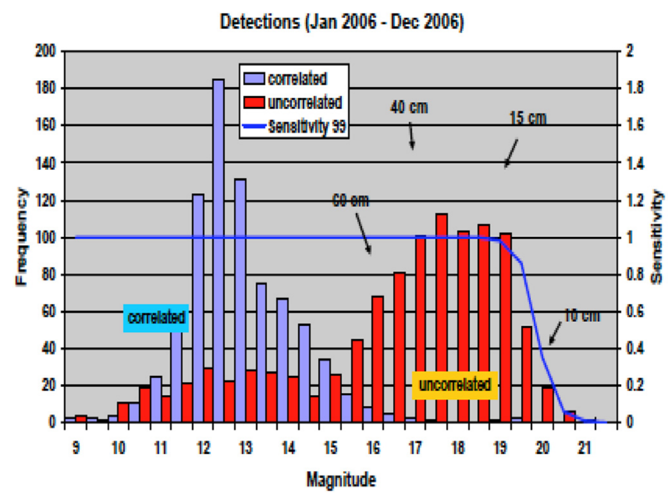

Fig. 3. Shows the distribution of objects that can be correlated (in blue) with the public catalog, as well as a new population of faint objects that are not found in the catalog (in red). The right-hand distribution of uncorrelated objects contains the high area-to-mass (HAMR) objects [15]. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 1
The oblateness of the earth causes the existence of two stable gravitation wells [6], which 'trap' non-station-kept objects in the geostationary ring. The trapped objects are mostly old payloads [7].

Characteristic	75° East well	105° West well	Trapped in both wells
Payload: Radugas (29), Gorizonts (9), Ekrans (8), etc.	83	39	15
Rocket body: Largely Proton-K Fourth Stages	17	0	3
Debris: 2006 Feng Yun and 1978 Ekran 2	2	0	0
Total	102	39	18

spherical harmonic expansion of the Earth gravitational model) of the Earth at the Equator [4]. Objects that are trapped in one (or both) of the wells oscillate back and forth, passing through the wells, the period and amplitude of the oscillations being dependent on the specific orbital geometry. The objects thus trapped are primarily defunct payloads, including the first commercial GEO communications satellite, Intelsat-1 F1 ("Early Bird") [5]. Table 1 summarizes the trapped object population. Fig. 2 shows, for the western pinch point (105° W), the cumulative growth of trapped objects.

The trapped objects represent a variety of ages (~45 years) and sizes (up to a factor of 30 in size difference), as well as a number of manufacturers and launching states. As may be seen in Fig. 2, the trend has been for fewer objects to become trapped over the years, as operators follow improved "best practices" [8]. However, the trapped objects will remain in GEO, and constitute a continuing threat to operational spacecraft.

Besides the larger (greater than a few square meters in cross sectional area) tracked objects found in the public domain catalog [9], observational campaigns estimate ~500 unknown, uncatalogued debris objects brighter than 18.5 visual magnitudes (about 29 cm in size assuming an albedo of 8%) in the geostationary ring [10]. This figure does not include high area-to-mass (HAMR) objects drifting through the GEO ring, nor does it include large station-kept satellites not included in the public catalog.

In addition to the objects enumerated above that exist in, or drift above or below the GEO belt, there is another class of objects shown in Fig. 3 that are also of concern. These objects[2] have high area-to-mass ratios, and their orbital elements can change on time-scales of weeks to months by solar radiation pressure, which causes them to periodically pass through the GEO belt [11–14], as may be seen in Fig. 4.

1.2. Orbital congestion and interference

The GEO ring has a relatively high density of active and defunct satellites, and this orbital congestion can give rise to interference between satellites (both spatial interference and radio-frequency interference) (Fig. 5).

1.3. Space weathering and satellite aging

A modern communications satellite is a complex system involving numerous subsystems that have finite lifetimes due to me-

[2] High Area to Mass Ratio (HAMR) objects are defined by their dynamical properties. It is not known with any certainty what materials constitute these objects, but common spacecraft construction materials (thin aluminum plates, solar panel covers, thermal blankets, multi-layer insulation and similar) can have area to mass ratios that fit within the observed ranges. See the references for details.