Out into the Dark: Removing Space Debris from the Geostationary Orbit

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Abstract

During the first decades of placing space objects in the Geostationary Orbit, satellite owners and operators abandoned space objects at their end-of-life, or just freed the slot by removing their satellites with the last kilograms of fuel. Also rocket stages that propelled geostationary satellites were abandoned therein. Due to orbital perturbations at about 36,000 km, objects that do not have station-keeping systems can drift into the slots of neighboring satellites and disturb their operation. Space debris objects at this altitude take at least one million years to naturally de-orbit and re-enter the Earth's atmosphere. The accumulation of space debris objects that permanently cross the Geostationary Orbit is a growing hazard to operational satellites. Researchers at the IADC who published a set of Space Debris Mitigation Guidelines in 2002, identified the Geostationary Orbit as a 'protected region'. One Mitigation Guideline recommends to re-orbit space objects that are reaching their end-of-life outside of this protected area. A growing number of States and international organizations reflect the IADC Mitigation Guidelines in national legislation, recommendations and standards. However, there is still an increase of large space debris objects in this area. Since it is not realistic to wait (up to one million years) for the natural deorbiting of these space objects, remediation measures need to be initiated, such as debris removal with external systems. This article describes the State practice of re-orbiting and proposes a strategy for debris removal to maintain a sustainable access and use of the Geostationary Orbit.

Keywords: Space law, IADC, remediation, active space debris removal, Geostationary Orbit, GEO region, space debris mitigation guidelines, re-orbit guideline, Outer Space Treaty, Liability Convention.

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1. Introduction

The Geostationary orbit is a circular orbit, parallel to the equator, at about 36,000 km altitude. Space objects launched into this orbit to move from West to East, complete an orbit around the Earth each 24 hours, obtaining a harmonized speed with the Earth rotation. Geostationary satellites have an almost permanent position above a point over the terrestrial equator,[1] making this orbit of great value for telecommunications, meteorology and other uses.[2]
In 1964, the first satellite to reach the Geostationary Orbit was the US Syncom-3.[3] The United States was followed by Canada, the USSR and also international organizations as INTELSAT, NATO, ESA. Giving the high value of this orbit, many countries of all economic and technological levels have invested resources to launch and operate geostationary satellites.
In order to avoid electromagnetic harmful interference, satellite operators coordinate, through the International Telecommunication Union (ITU), the positioning of satellites which need to have a separation from the neighboring satellites in their high-speed movement. At the end of 2018, there were 529[4] operational satellites in this orbit. Unfortunately, in this area there is also space debris.[5] At the great altitude of the Geostationary Orbit, it results difficult to find in the darkness all the space debris objects that may collide with operational satellites. The surveillance of space debris in this area is therefore mainly for objects larger than one meter-cross section.[6] At the end of 2018, more than 1,000 space debris objects were reported to reside in this area.[7] These objects are mainly old satellites that ran out of fuel and were

1 Due to natural factors, like the solar radiation pressure, the Moon and Sun attraction, satellites do not keep a permanent position in their orbital path, so propulsion systems are needed to correct their movement.

2 *Cf*. ESA's Annual Space Environment Report, July 17, 2019, Figure 2.10, 22, https://www.sdo.esoc.esa.int/environment_report/Space_Environment_Report_latest.pdf.

3 See "The Father of Satcom", *Aviation Week & Space Technology* (AW & ST) (Mar. 24, 2014), 54, https://aviationweek.com/awin/harold-rosen-clinches-lifetime-achievement-award.

4 See ESA/ESOC, *Classification of Geosynchronous Objects*, Issue 21, 2019 (reporting objects of 2018), 216.

5 "Space debris are all man-made objects including fragments and elements thereof, in Earth orbit or re-entering the atmosphere, that are not functional". Inter-Agency Space Debris Coordination Committee, *Space Debris Mitigation Guidelines*, Oct. 15, 2002 (revised in 2007), IADC-02-01, 5, https://www.iadc-home.org/documents_public/view/id/82#u.

6 Sporadically, smaller objects are observed and classified, such as objects that are intentionally released during normal operations, and also parts that result from fragmentation events. See ESA/ESOC, Classification, Issue 21, *supra* 4, 7.

7 ESA/ESOC, Classification, Issue 21, *supra* 4, 216. It can be expected that the number of space debris objects in this area, smaller than 1 meter-cross-section, is in the order of several thousand or even millions.

abandoned, satellites that malfunctioned, and rocket motors that propelled the satellites into this orbit.

2. To Mitigate and to Remediate

When researchers of space agencies noted that the growth of space debris was exponential, they proposed measures to mitigate the creation of space debris and instituted in 1993 the Inter-Agency Space Debris Committee (IADC). The IADC defines 'mitigation' as the "[…] implementation of some debris mitigation measures today [as] a prudent and necessary step towards preserving the space environment for future generations".[8]
The IADC decided to start with the protection of two areas around our planet, the Low Earth Orbit (LEO) region and the Geosynchronous region (GEO) region. For this last region, the IADC did not only decide to propose measures to protect satellites in the geostationary line, but to include an adjacent area around it, in order to increase the safety of satellites moving to their slots, to protect space traffic of operational satellites that are not exactly positioned in the geostationary line,[9] and also to protect those that change the slot during their operational life.[10] The GEO protected region is 200 km above and below the geostationary line, plus 15° of latitude North and South, projected from the center of the Earth.[11]
The IADC issued in 2002 the 'Space Debris Mitigation Guidelines',[12] a list of comprehensive recommendations to mitigate space debris in the protected regions. The Committee on the Peaceful Uses of Outer Space (COPUOS) of United Nations (UN) produced its own set of guidelines,[13] largely based on the IADC Guidelines. In 2007, the COPUOS Space Debris Mitigation Guidelines were endorsed by the UN General Assembly in a Resolution.[14]
Due to the high altitude of geostationary satellites, one of the Space Debris Mitigation Guidelines recommends to 're-orbit' satellites approaching their

8 See IADC Space Debris Mitigation Guidelines, *supra* 5, 4.
9 Satellites with a slightly inclined or eccentric orbit. See ESA/ESOC, Classification, Issue 21, *supra* 4, 7.
10 See Richard Abbot and Timothy Wallace, "Decision Support in Space Situational Awareness", in *Lincoln Laboratory Journal* 16, no. 2 (2007).
11 See IADC Space Debris Mitigation Guidelines, *supra* 5, 6.
12 IADC Space Debris Mitigation Guidelines, *supra* 5.
13 UN, *Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space* [COPUOS Space Debris Mitigation Guidelines], Report of the Committee on the Peaceful Uses of Outer Space, UN Doc. A/62/20, June 15, 2007, 47-50 [Annex], http://www.unoosa.org/pdf/gadocs/A_62_20E.pdf.
14 UNGA Resolution, *International Cooperation in the Peaceful Uses of Outer Space*, UN Doc. A/RES/62/217, Dec. 22, 2007, [paragraphs 26 - 28], https://undocs.org/A/RES/62/217.

end-of-life (re-orbit guideline) into disposal orbits (graveyard orbits). Such orbits should not intersect the GEO region for at least 100 years.[15]

Oltrogge *et al.* note that "[w]hile the consequences of collision between two Boeing 702-class spacecraft [similar to the 42 m wingspan of a Boeing 737 aircraft] are not fully known, it is fairly apparent that such an event could cause irreparable damage to the "prime real estate" known as the geosynchronous arc. Even for a 'low' 800 m/s relative velocity […] collision of two satellites that are not designed to be materially robust in a collision, it's easy to envision a large debris field generated by such a collision event."[16]

There is no precise prediction of the critical point in the GEO region when the presence of space debris will heavily disrupt satellite operations, but it is obvious that measures are needed now to avoid it.

The only solution to prevent such a risk is to apply remediation measures against this kind of pollution. The IADC defined 'space debris environment remediation' as the "[…] efforts to manage the existing space debris population through active space debris removal with emphasis on densely populated orbit regions".[17] Active space debris removal would be accomplished using external systems to transfer non-functional geostationary satellites and rocket bodies into graveyard orbits.[18]

In LEO, space objects for on-orbit servicing or refurbishing have already been captured.[19] Also experiments to demonstrate other technologies have been performed by different countries.[20] In 2018 and 2019, experiments in orbit

15 See ESA's Annual Space Environment Report of 2019, *supra* 2, 72.
Taking into consideration that the gravitational pull of the Earth will also cause re-orbited satellites (in conformity with the IADC Guidelines) to re-enter the GEO region at some time in the future, the international community should start developing strategy and technologies to relocate such space debris objects (for example, by re-boosting, segmentation for recycling).

16 D. Oltrogge, S. Alfano, C. Law, A. Cacioni and T.S. Kelso, "A Comprehensive Assessment of Collision Likelihood in Geosynchronous Earth Orbit", in *Acta Astronautica* 147 (2018), 341, https://www.sciencedirect.com/science/article/pii/S0094576517315011.

17 IADC, *Key Definitions of the Inter-Agency Space Debris Coordination Committee (IADC)*, IADC-13-02, Apr. 2013.

18 For example, "[…] tethering, tugging, beaming with an electrostatic tractor […], docking with a nozzle […]". Rada Popova and Volker Schaus, "The Legal Framework for Space Debris Remediation as a Tool for Sustainability in Outer Space", *Aerospace* 5(2), 55, 2018, 8, https://doi.org/10.3390/aerospace5020055. *Cf.* IAA, *Space Debris Environment Remediation*, eds. Heiner Klinkrad & Nicholas L. Johnson, 2013.

19 See the refurbishing of the US Hubble Space Telescope in "Timeline", *ESA/Hubble Space Telescope*, https://www.spacetelescope.org/about/history/timeline/.

20 See the first experimental on-orbit servicing (by Japan) in NASA, *On-Orbit Satellite Servicing Study Project Report*, Oct. 2010, 22, http://ssco.gsfc.nasa.gov/images/NASA_Satellite%20Servicing_Project_Report_0511.pdf.

were performed in LEO to capture space objects simulating space debris.[21] For late 2019, a US private company plans the first on-orbit servicing of a geostationary satellite.[22]

For those space objects that cannot be serviced or refurbished, these experimental and operational activities may offer hardware and procedures that can be used for active space removal from the GEO region.

3. Using Own Propulsion Systems: The Re-orbit Guideline

In 1977, the governmental organization INTELSAT transferred for the first time a satellite into an orbit 50 km above the geostationary line.[23] The satellite used its own propulsion system with the last fuel it had onboard. Thereafter, INTELSAT transferred other satellites by increasing their altitude to the disposal orbit.

In 1977, researcher Luboš Perek suggested to systematically remove all space objects reaching end-of-life from the Geostationary Orbit.[24] When the IADC defined parameters for the GEO protected region, the requirements for re-orbiting became clearer. The IADC recommended in its 2002 Guidelines that "[s]pacecraft that have terminated their mission should be maneuvered far enough away from GEO so as not to cause interference with space systems still in geostationary orbit".[25] Furthermore, the International Standardization Organization (ISO) published more precise standards[26] that assist the space

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The US also performed an experimental on-orbit servicing mission with its 'Orbital Express'. See Dornheim, "Express Service", *AW & ST* (June 5, 2006), 48.

See also "China announces success in technology to refuel satellites in orbit", *Space Daily* (July 6, 2016), http://www.spacedaily.com/reports/China_announces_success_in_technology_to_refuel_satellites_in_orbit_999.html.

21 See "RemoveDEBRIS", in *Surrey Space Center*, https://www.surrey.ac.uk/surrey-space-centre/missions/removedebris.

22 The orbit of the 18-years-old US Intelsat-901 satellite will be raised outside the protected region to obtain propellant from the US 'Mission Extension Vehicle' (MEV-1), launched on Oct. 9, 2019. See Graham Warwick, "How Northrop Grumman's MEV Will Extend GEO Satellites' Lives", *AW & ST* (July 1-14, 2019), 54-56. See also Caleb Henry, "Northrop Grumman's satellite servicer MEV-1, Eutelsat satellite, launch on ILS Proton", *Space News*, Oct. 9, 2019, https://spacenews.com/northrop-grummans-satellite-servicer-mev-1-eutelsat-satellite-launch-on-ils-proton/.

23 Nicholas Johnson, "Protecting the GEO Environment: Policies and Practices", in *Space Policy* 15, no. 3 (1999), 3.

24 See Luboš Perek, "Physics, Uses and Regulations of GSO", *28th IAF Congress*, Prague, Czechoslovakia, IAF-SL-77-44 (1977).

25 5.3.1 Geosynchronous Region, IADC Space Debris Mitigation Guidelines, *supra* 5, 9.

26 ISO, *Disposal of Satellites Operating at Geosynchronous Altitude*, ISO Standard, ISO 26872:2010, TC20/SC14, ISO/DIS 26872, published in (2010), abstract available at: http://www.iso.org/iso/iso_catalogue/catalogue_tc/catalogue_detail.htm?csnumber=43853; ISO, *Estimating the Mass of Remaining Usable Propellant*, ISO Standard, ISO 23339:2010, published in 2010, abstract available at: http://www.iso.+org/iso/iso_

actors to re-orbit their satellites in conformity with this particular IADC Guideline.

Several countries have adopted national legislation that obligate licensed/authorized satellite operators to apply the re-orbiting guideline.[27] Codes of conduct, statements of States and recommendations of international organizations also address the transfer of satellites in accordance to the re-orbit guideline.[28]

As a matter of practice, since the drafting of the re-orbiting guideline, a growing number of States and international organizations have been re-orbiting their satellites into graveyard orbits. During the last 20 years, from about 300 satellites that reached their end-of-life, about 180 satellites were re-orbited in conformity with the re-orbit guideline.[29] And this practice is growing. During the last years, more than 80% of satellites that approached their end-of-life have annually been transferred into graveyard orbits in conformity with the re-orbit guideline.[30] These numbers do not only show the specific measures of States and international organizations, but also their conscious decision to accept loss of profit by burning the last kilograms of fuel to decommission healthy satellites. This is an indicator of the growing concern of States and international organizations to keep this area operational.

4. Performing Active Space Debris Removal: Sates that Could Take the First Step

Unfortunately, even after the re-orbit guideline was published, non-functional satellites are still populating this valuable area in outer space, which concern

catalogue/catalogue_tc/catalogue_detail.htm?csnumber=tallo55368; and ISO, Space Debris Mitigation Requirements, ISO Standard, ISO 24113:2019, (published in 2011, last revised in 2019), abstract available at: https://www.iso.org/standard/72383.html.

27 As example, see the United States, US 47CFR25, § 25.283 End-of-life disposal in *Code of Federal Regulations*, US Government Printing Office, Title 47 - Telecommunication, http://www.ecfr.gov/cgi-bin/text-idx?SID=f0e96087ff1ac46ccb6ac590e4969acb&mc=true&tpl=/ecfrbrowse/Title47/47cfr25_main_02.tpl. Other countries that have adopted national legislation with explicit or implicit reference to the re-orbit guideline are Austria, Belgium, Canada, China, Denmark, Finland, France, Germany, Japan, New Zealand, Ukraine, and the United Kingdom.

28 For example, see ITU, *Environmental Protection of the Geostationary-Satellite Orbit, Recommendation ITU-R S.1003*-2, (Question ITU-R 34/4) (1993-2003-2010), 1, Recommendation 3, https://www.itu.int/dms_pubrec/itu-r/rec/s/R-REC-S.1003-2-201012-I!!PDF-E.pdf.

29 See ESA's Annual Space Environment Report, Figure 6.15 (a) Absolute clearance near GEO_{IADC}, *supra* 2, 74.

30 See ESA's Annual Space Environment Report, Figure 6.15 (a) Absolute clearance near GEO_{IADC}, *supra* 2, 77, last paragraph.

operators of other satellites, and increase the risk of electromagnetic harmful interference[31] and of collision.[32]

Although there is a large number of States which have polluted the Geostationary Orbit and its adjacent region since the first Syncom satellites, the re-orbiting practice of the last 20 years also shows which States have left, intentionally or un-intentionally, non-functional satellites in the GEO region. In a snapshot from 1999 to 2018, the United States and the Russian Federation appear as the most prominent to use this area and to leave the largest number of non-functional satellites behind.[33] China has not such a prominent impact. It becomes evident that the historic conduct of the United States and the Russian Federation is the most critical to keep the GEO region operational. These States could therefore start the active removal of their own space debris. The United States has done research for the removal of space debris and has captured space objects in orbit.[34] The Russian Federation has also experience in proximity, rendezvous, docking and refurbishing operations of space objects,[35] and considers measures for active removal of space debris.[36]

5. The Problem of the Rocket Bodies

Rockets bodies (upper stages and apogee kick motors) bring satellites into the GEO region. Unfortunately, after separation from the satellite, many of the

31 "[E] that a satellite drifting in GSO after the end of its life may block RF [Radio Frequency] links of active satellites". ITU, Environmental Protection, *supra* 28, 1.

32 See Oltrogge *et al. supra* 16. See also Raymond LeClair and Ramaswamy Sridharan, "Probability of Collision in the Geostationary Orbit", in *Proceedings of the Space Control Conference*, MIT (2001), 7, http://adsbit.harvard.edu//full/2001ESASP.473..463L/0000469.000.html.

33 See Summary sections of ESA/ESOC, *Classification of Geosynchronous Objects*, Issues 1 to 21, (reporting objects from 1998 to 2018). Taking into account the strong involvement of the United States since the inception of the Intelsat system, this country is considered here as the State with jurisdiction and control over the space segment. See *FCC Report to Congress as Required by the Orbit Act, Eighteenth Report*, IB Docket No. 17-50, June 8, 2017, 2, footnote 5, https://www.fcc.gov/reports-research/reports/report-congress-required-orbit-act/eighteenth-orbit-act-report. *Cf.* Francis Lyall and Paul Larsen, *Space Law, A Treatise,* 2nd ed. (London/New York: Routledge Pub., 2018), 325. Exceptions are the Intelsat satellites whose ownership was transferred in orbit to another State.

34 See *supra* 19, on the refurbishing of the Hubble Space Telescope.

35 See four-minute video of a rescue operation: "Salyut-7: The Story of the Greatest Ever Operation", posted Feb. 12, 2017, https://www.youtube.com/watch?v=0wxpX8uBIyc.

36 It has been reported that in 2014 the Russian Federation "[…] announced $ 10 million funding for the best space removal technology". Anastasia Medvedeva, *Space Debris Remediation: An International Relations Approach,* LLM dissertation, Diplomatic Academy of Vienna (2015), Master of Science dissertation, 40, available in internet.

rocket bodies are dumped in this valuable area.[37] It has been reported that there are about 252 upper stages residing or crossing for long periods the GEO region.[38]

Again, since 1966, the Russian Federation and the United States have abandoned most rocket bodies.[39] They represent a couple of thousand tons of hardware[40] and increase the collision risk with operational satellites in the GEO region. There are also another 130 rocket bodies that cross the GEO region.[41] Some of these rockets are called ‘dark horses’, moving in high elliptical orbits.[42]

6. Suggestions of Remediation Guidelines

National Legislation demonstrates the interest of States to follow the Space Debris Mitigation Guidelines. State practice over time shows a developing opinio iuris in the specific case of the re-orbit guideline to protect the GEO region. Such opinio iuris and State practice are on their way to crystalize into a norm of customary law, that will be legally binding for all members of the international community.[43] Such re-orbit State practice, which can be objectively measured, is also on its way to become a standard of care.[44]

With the crystallization of a norm of customary law and/or the recognition of the existence of a standard of care, a State which fails to follow such norm or standard and its abandoned satellite or rocket body produces damage to an operational satellite of another States, can be considered to be at ‘fault’.[45]

37 The IADC Guidelines recommend the detaching of motors before they reach the GEO region. See 5.3.1 Geosynchronous Region, IADC Space Debris Mitigation Guidelines, *supra* 5, 9.

38 See ESA/ESOC, Classification, Issue 21, *supra* 4, 216.

39 See ESA/ESOC, Classification, Issue 21, *supra* 4, 11-49. Upper stages are in italics. Apogee kick motors are marked as AKM and as IABS (Integrated Apogee Boost System).

40 See ESA’s Annual Report of 2019, Figure 3.7 (a) Mass histogram of rocket bodies in GEO, *supra* 2, 41.

41 See ESA/ESOC, Classification, Issue 21, *supra* 4, 216.

42 See Oltrogge *et al. supra* 16, 339-401.

43 First remark on evolving *opinio iuris* and State practice of the re-orbiting practice of geostationary satellites to transform into a norm of customary law in Martha Mejía-Kaiser, “Taking Garbage Outside: The Geostationary Orbit and Graveyard Orbits”, in *Proceedings of the IISL Colloquium on the Law of Outer Space*, IAC-06.E6.5.14. (2006), http://ssrn.com/author=3412227.

44 First remark that the State practice of re-orbiting is on its way to transform into a standard of care in Martha Mejía-Kaiser, “Informal Regulations and Practices in the Field of Space Debris Mitigation”, in *Air and Space Law* 34, no. 1 (2009), 32-33, http://ssrn.com/author=3412227.

45 See Martha Mejía-Kaiser, “ESA’s Choice of Futures: Envisat Removal or First Liability Case”, in *Proceedings of the IISL Colloquium on the Law of Outer Space*, IAC-12.E7.5.11 (2012), http://ssrn.com/author=3412227.

Such a conduct will trigger the application of the Liability Convention,[46] to enable compensation to the injured State.

Although the re-orbit guideline is followed by a growing number of States, the increasing pollution of outer space calls for a set of Space Debris Remediation Guidelines. The IADC could be the forum where such guidelines could be established.

Taking into account the IADC defined ‘remediation’ as the active space debris removal, the seed for the guidelines for remediation should consider three evolving phases of this activity: experimental, operational and commercial. The recommendations could elaborate on technical and operational procedures for safe rendezvous, proximity, docking, capturing, targeting with laser or other means, standards for the architecture of satellites and rocket bodies to allow safe capturing,[47] and standards on the configuration of capturing techniques to reduce the dispersion of fragments during successful active removal or in case of collision. These recommendations should consider the active removal of space objects when fully passivated,[48] as well as space debris objects with suspected energies on board.

6.1. Legal Issues

There are no legal obstacles for the execution of active space debris removal of own space objects. Article I of the Outer Space Treaty[49] provides that States are free to explore and use outer space. The word ‘explore’ could well

46 Article III of the Liability Convention stipulates: “In the event of damage being caused elsewhere than on the surface of the Earth to a space object of one launching State or to persons or property on board such a space object by a space object of another launching State, the later shall be liable only if the damage is due to its fault or the fault of persons for whom it is responsible”. *Convention on International Liability for Damage Caused by Space Objects* (Liability Convention), Mar. 29, 1972, entered into force Sep. 1, 1972; 24 UST 2389; TIAS 7762; 961 UNTS 187.

47 In 2016, the US agency DARPA established the ‘Consortium for Execution of Rendezvous and Servicing Operations’ (CONFERS) to develop standards for safe on-orbit rendezvous for servicing operations. See “DARPA Creating Industry/ Government Group for Safe Operation of Space Robotics”, DARPA, Nov. 29, 2016, https://www.darpa.mil/news-events/2016-11-29. Many of these standards will be able to be used also for active removal of space debris.

48 States performing active removal of own objects that were insufficiently re-orbited and still reside in the GEO region need to verify if the target space object was duly passivated. Passivation is “[…] the elimination of all stored energy on a space system. Typical passivation measures include […] discharging batteries […] before shutting-off the space object.” 3.4.1 Passivation, IADC Space Debris Mitigation Guidelines, *supra* 5, 6.

49 *Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies* (Outer Space Treaty), Jan. 27, 1967, entered into force Oct. 10, 1967; 18 UST 2410; TIAS 6347; 610 UNTS 205.

include the exploration of materials, techniques, procedures. Since the beginning of the space era, testing of space systems and procedures is constantly undertaken in outer space by space actors.
According to Article VI of the Outer Space Treaty, States will be responsible for the active space debris removal of their governmental agencies and non-governmental entities and should be performed in accordance with the Outer Space Treaty. When an active removal is performed by non-governmental entities, the involved States have the primary responsibility to authorize and continuously supervise their activities. Article I of the Outer Space Treaty gives also a framework that active space debris removal is performed "[…] in accordance with international law […]."
Following the stipulations of Article IX of the Outer Space Treaty, and given the hazards of active space debris removal, States and international organizations engaged in active space debris removal need to inform in advance the international community about such intentions, allowing space actors to get aware of these hazards and become prepared for any incident or accident. Such information should include: location (parameters of the orbit), starting time of the operation and projected time of duration, degree of hazard of the operation, and any other relevant information. States then need to perform the active space debris removal "[…] with due regard to the corresponding interests of all other States […]", and conduct the active removal "[…] so as to avoid [the] harmful contamination […]" of outer space.
After a space debris removal operation or in case of an accident, space actors should follow Article XI of the Outer Space Treaty, by informing about the end of the operation or the time of the accident, on the success or failure of the operation (for instance, the space object could not be captured), the assessed number of detached fragments and of their orbits, the type of accident (if collision and detaching of fragments, if explosion of space objects involved in the operation), the degree of hazard, and other relevant information. Only in the situations where forensics show that there is solid evidence that the involved actors performed the operation negligently or with intention to cause the accident, States that suffered damage may invoke Article III of the Liability Convention and request compensation.[50]

6.2. The Experimental Phase

In the experimental phase, after successful tests with space objects simulating space debris, the United States, the Russian Federation and other States could test the active removal of their own space debris, either individually or through bilateral or multilateral cooperation (for example, in the framework of ESA).

50 Liability Convention, *supra* 46.

Experimental missions could start with decommissioned satellites and rocket bodies that were insufficiently re-orbited, that were duly passivated,[51] and that briefly intrude in each revolution of their orbits into the GEO region. Recommendation to States with jurisdiction and control[52] over such space debris need to take into account any other threats that would need extra measures during the operation (for example, if the space object is rapidly tumbling).

6.3. The Operational Phase

For the operational phase, it could be recommended to establish a list with a ranking of the collision risk of space debris objects in the GEO region. Such ranking could take into account the stored kinetic energy, trajectories (for example, gravity well[53] passage), and the mass and size of the space debris objects. This list could help to set priorities for active removal and plot actions ahead in time.[54]

Although it will take time to notice a remedial effect of active space debris removal in the GEO region, during the operational phase the first target should be to freeze the number of space debris objects. For such purpose, a number of space debris objects to be removed per year could be set. For LEO, researchers have estimated that there is a need of active removal of 10 space objects per year to keep these orbits stable.[55] Considering the yearly numbers of satellites at end-of-life and rocket bodies arriving in the GEO region, and the number of satellites re-orbited in accordance with the Space Debris

51 In order to reduce the explosion danger.

52 Art. VIII, Outer Space Treaty, *supra* 49.

53 The 'liberation points' are gravity wells in the Geostationary Orbit located at 105.3° W and 75.1° E, where space objects tend to naturally 'fall' into, making this a busy location for space traffic in this orbit.
The US Telstar 401 satellite may serve as an example of a liberating space debris object. When it malfunctioned in 1997, it drifted in an inclined orbit which crossed the Geostationary Orbit. During each revolution it posed a collision hazard to more than 20 satellites positioned around the liberation point at 105.3° W. See "Sudden Telstar 401 failure Might have a Precedent", *Space News*, Sep. 29, 2003, 4. See the current position of the Telstar 401 in *Real Time Satellite Tracking*, accessed Sep. 18, 2019, http://www.n2yo.com/?s=22927.

54 Such a ranking has been established for the Low Earth Orbit. See Carsten Wiedemann *et al.* "Space Debris Mitigation Measures and Cost Issues", IAC-11.E7.6.-E3.5.2. (2011), 5. See also Darren McKnight, "Are we Asking the right question about space debris?", in *Room: The Space Journal Magazine*, 14(4), 2017, https://room.eu.com/article/are-we-asking-the-right-questions-about-space-debris.

55 See Benjamin Bastida and Holger Krag, "Analyzing the criteria for a stable environment", in *Advances in the Astronautical Sciences*, AAS 11-411, Aug. 2011, 12, https://www.researchgate.net/publication/266556917_Analyzing_the_criteria_for_a_stable_environment/link/55eff17908ae0af8ee1b4762/download.

Mitigation Guidelines in the last 10 years,[56] this author has observed that there is an average increase of 9 space debris per year (5 satellites and 4 rocket bodies). Perhaps this could be a target number of active removals per year to freeze the space debris population in the GEO region.

In this phase, States with the technical means and know-how for active removal should yearly engage to remove a space debris object under their jurisdiction and control. States that lack such technical means and expertise to actively remove their own space debris, could contract the active removal services of States with such capabilities.

In the specific case of rocket bodies contracted to bring satellites of other States in the Geostationary Orbit, the States that provided the service and the States that contracted the service could jointly arrange for the active removal of the rocket bodies.

With the experience gained, these States would be able to increase the number of space objects to be removed per year.

6.4. The Commercial Phase

Already during the operational phase, States with the technical means and experience may offer active removal services to States that wish to contribute to clear the GEO region with the removal of their own space debris. It has been estimated that the first commercial operations will start just after 3.5 years of testing.[57]

A real commercial activity would take some more years, when different active removal entities create a competitive market. It seems likely that active removal as a new commercial activity would rapidly expand if other areas develop. This was the case with satellite remote sensing imagery for civil purposes, which went from the experimental to the operational, and finally to the commercial phase as a result of the arrival of new data communication technology: the internet.

It can be foreseen that new space activities, such as the refurbishing of satellites, repairing and resurrecting non-functional space objects, recycling of space debris,[58] may be a stimulus for active space removal. In a new commercial environment, perhaps a model similar to the Nairobi Wreck Convention could help to coordinate this activity.[59]

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56 See ESA/ESOC, *Classification of Geosynchronous Objects*, Issues 11 to 21, reporting objects from 2008 to 2018, Summary.

57 See Frank Morring, "Changing the Game, Canadian Robotics May Stretch Commercial Satellite Lifetimes", *AW & ST* (Mar. 21, 2011), 24.

58 See Martha Mejía-Kaiser, "Scavenging of Space Objects for Recycling", in *Proceedings of the International Conference on Recent Developments in Space Law-Opportunities & Challenges*, Bangalore, India, May 7, 2016, Springer Publishers (2017), http://ssrn.com/author=3412227.

59 A detailed description of this suggested scheme and a proposal for an international convention is in Martha Mejía-Kaiser, "Removal of Hazardous Space Debris", in

7. Final Considerations

There is no provision in the space treaties that forbids the generation of space debris, nor a provision that obligates States to avoid the dumping of space objects in the (IADC declared) GEO 'protected' region. Although the COPUOS Space Debris Mitigation Guidelines are not legally binding and recommend that "[m]ember States and international organizations should voluntarily take measures […]",[60] they avoid to use the word 'protect' for the GEO region. States have no interest to adopt an international treaty that prohibits the generation of space debris and space technology is not in a state to completely avoid it.

The implementation of Space Debris Mitigation Guidelines in the national legislation in several countries is a step in the right direction, but it is still insufficient to avoid the evolving hazards to keep the GEO region usable.

Given the lack of technical and legal means to avoid the pollution of the GEO region, and the fact that space debris stays for a long time at this altitude, active space debris removal appears as the only possibility to remedy the detrimental effects to this orbital area and to prevent it transforming into a graveyard region. The United States and the Russian Federation mostly use this area and also account for most of its pollution. These States would therefore need to initiate the active space removal of their space debris objects. It is in their own interest to maintain this area operational, which serves as the basis for large revenue generating space activities for both.

States and international organizations need to be aware that the recognition of a standard of care, based on the re-orbiting practice, can make them liable, if they fail to re-orbit their satellites and rocket motors outside the GEO region and cause damage to other States. This exposure should serve as an incentive to perform active removal of their space debris.[61]

There is need to start with the drafting of recommendations for active space debris removal. The IADC or another similar forum could take the lead.

Of course, States need to maintain also the Low Earth Orbits operational. If the Low Earth Orbits are infested with space debris, launched geostationary satellites may not reach the Geostationary Orbit when passing through a

Space Safety Regulations and Standards, ed. J. Pelton and R. Jakhu, Elsevier/Butterworth-Heineman (2010), Chapter 27, 371-382 and Draft International Convention on the Removal of Hazardous Space Debris, in Appendix 4, 449-458. The system is based on the *International Convention on the Removal of Wrecks*, 2007, Nairobi, May 18, 2007, entered into force Apr. 14, 2015; International Maritime Organization, IMO LEG/CONF.16/19, May 23, 2007.

60 COPUOS Space Debris Mitigation Guidelines, para. 3. Application, *supra* 13.

61 On the possibility that ESA could be at fault if its satellite Envisat collides and causes damage to operational satellites of other States, see: Mejía-Kaiser, ESA's Choice of Futures, *supra* 45. After the publication of this paper, ESA commissioned studies to de-orbit Envisat.

mine field. States need to act in a responsible way and to have a broad vision of the hazards if they authorize national space activities that they neither continuously supervise nor control.

States that have generated space debris have the responsibility to perform or arrange their active removal. If these States fail to act, no satellite will be saved from being hit by space debris. The sensors of the meteorological satellites will be blinded, the telecommunication satellites will be silenced. Will we be on time to avoid the critical point? Will the international community be able to avoid that the GEO region becomes a dark region?