Five reasons why Cubesats deserve more attention: law and science overview

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FIVE REASONS WHY CUBESATS DESERVE MORE ATTENTION: LAW AND SCIENCE OVERVIEW

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The beginning of the Space Age was marked by the launch of Sputnik 1, an 87kg satellite, carrying a single radio transmitter, that, according to most of the literature, would fit into the small (micro) satellites category. As time went by, satellites grew in size and mass, in purpose and complexity. In parallel to this, a series of satellites, named OSCAR, were built and put into orbit by non-State actors. Such space objects are most popular nowadays. The study of the OSCAR series offers understanding on the behavior of small low complexity satellites in the space environment, such as cubesats, into outer space for, at least, five good reasons that will be detailed in this paper.

1. Introduction

The first Brazilian microsatellite, the Digital Orbiting Voice Encoder (DOVE) small satellite, the 17th of the Orbiting Satellite Carrying Amateur Radio (OSCAR) series was launched in 1990, with five other small "brothers" of this series, free riding a big Spot-2 satellite launch. The mission (voice messages of world peace), the size (22,6 X 22,6 X 22,3 cm), the shape (8 cubes) and the mass (12,92 kg) of DOVE, as shown in Figure 1, would perfectly fit into the microsatellite classification, as most of the literature/NASA advocates [2].

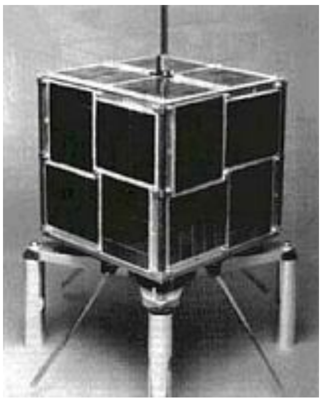

Figure 1: DOVE/OSCAR-17 [1].

NASA’s Classification [2]
Minisatellite, 100 tp 180 kg
Microsatellite, 10 to 100 kg
Nanosatellite, 1 to 10 kg
Picosatellite, 0.01 to 1 kg
Femtosatellite, 0.001 to 0.01 kg

Moreover, the fact that this space object was totally and independently made by a natural person, Prof. Júnior Torres de Castro, is remarkable. In an era when space activities were, predominantly, conducted by States, having a professor to launch into Earth Orbit its own satellite was quite an accomplishment. Another relevant aspect of such advent is the piggyback launch, a concept very familiar to cubesat missions nowadays.

DOVE was not the only cubesat launched before the 2000’s. As mentioned, it belonged to the OSCAR series. OSCAR-1 (Figure 2) was launched in 1961, only four years after the launch of Sputnik-1. Although, there is nothing in it that resembles to a cubesat, OSCAR was built and launched as piggyback rider by non-State actors. It was the first radio amateur satellite in history.

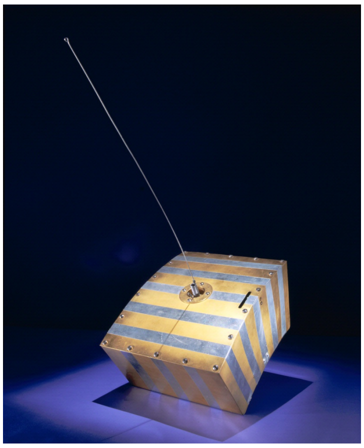

Figure 2: OSCAR-1 [3]

The OSCAR series satellites are mostly classified as microsatellites, as Table 1 describes, and many of them, after decades, are still in orbit.

Table 1: The OSCAR satellites series in Figures.

Description	Quantity
Launched Satellites	94
Microsatellites (up to 100 kg)	89
In Orbit Satellites	75
Decayed Satellites	19
Satellites in Orbit for more than 25 years	28
Objects registered at UNOOSA	71

Recently, the picture began to change dramatically: cubesats grew in number, purposes, and importance, due to a variety of reasons, congregating unusual space actors, such as Universities, in the space arena. Figure 3 shows the number of cubesat launches per year, since 2002.

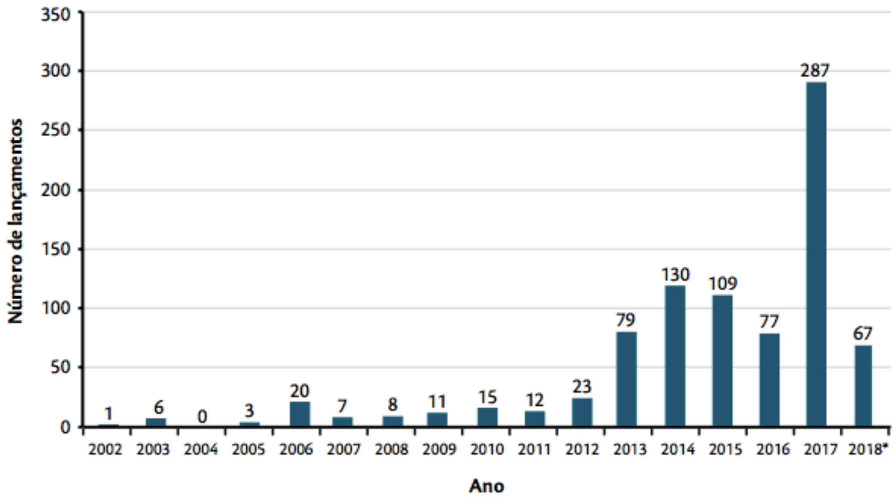

Figure 3: Cubesat Launches, per year, since 2002 [4].

Notwithstanding, most cubesats have environmental impact in outer space with no provisions for their avoidance or removal. This includes damage or destruction by interference, contamination, collision or other types of damage of 1) a single natural resource that is *res communis omnium*; 2) a useful object in orbit; 3) an orbit niche; 4) a whole orbit; 5) damage or interference in ground activities (by risk of re-entry, fall, impact on the soil, on humans, on human facilities, on air, maritime, and even terrestrial traffic); 6) damage or disuse of activities (communication, sensing, meteorology etc.) and even their objects.

Despite their small sizes, light mass and short lives, they are considered, by the Treaties and Conventions of Space Law, space objects, subject to the rigor of a law drafted during the Cold War times.

There are, at least, five reasons why cubesats deserve a closer look that goes way beyond their position into outer space.

2. Reason # 1

There is a growing number of space objects being launched in all Earth orbits since 1957. The European Space Agency's (ESA) Space Debris Office published Figure 4, below, which shows the count evolution by object since the launch of Sputink-1. Not all objects are still operational, though.

The 1967 Outer Space Treaty (OST), or Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and the Other Celestial Bodies, claims, in its Article I, that the exploration and use of outer space shall be carried out for the benefit and interest of all, on a basis of equality and in accordance with international law. Does the unreasonable occupancy of the outer space with defunct objects that, additionally, pose risk to operational ones, goes against such enforcement?

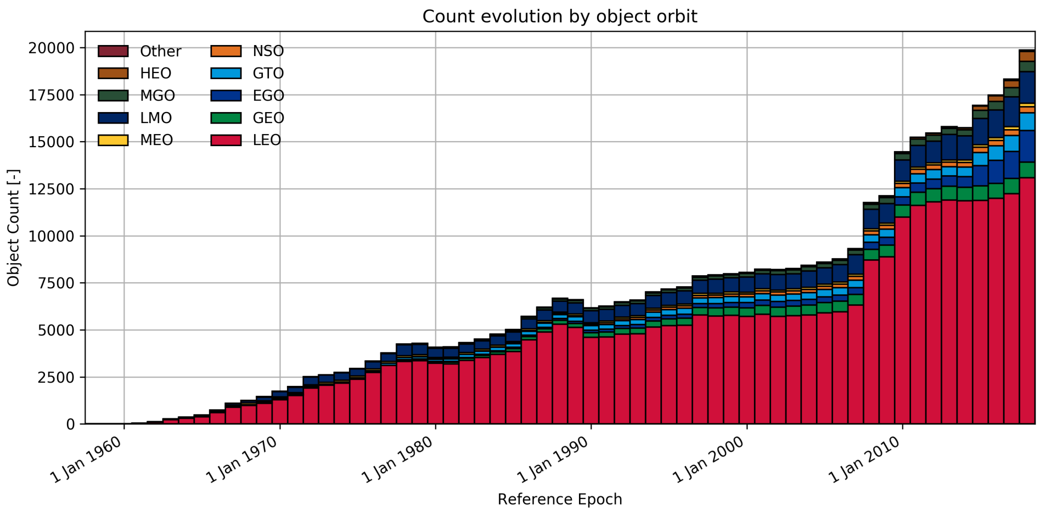

Figure 4: Count Evolution by Object Orbit [5].

Article II OST states that the outer space, the Moon and the celestial bodies are not subject to national appropriation by claim of sovereignty, by means of use or occupation, or by any other means. Is the misuse of orbits by non-functional objects a kind of national appropriation by occupation? According to ESA, of the 8,650 satellites launched since 1957, only 1,800 are still operational. Table 2 draws other figures to attention.

Table 2: Adapted from ESA [6].

Description	Number
Rocket launches since the start of the space age (1957)	About 5400 (excluding failures)
Satellites these rocket launches have placed into Earth orbit	About 8650
Of these, satellites still in space	About 4700
Number of these still functioning	About 1800
Number of debris objects regularly tracked by Space Surveillance Networks and maintained in their catalogue	About 21 000
Estimated number of break-ups, explosions, collisions, or anomalous events resulting in fragmentation	More than 500
Total mass of all space objects in Earth orbit	More than 8100 tons
Number of debris objects estimated by statistical models to be in orbit	29,000 objects >10 cm, 750,000 objects from 1 cm to 10 cm; 166 million objects from 1 mm to 1 cm

3. Reason # 2

There is a variety of Earth orbits that are useful for humankind activities in outer space, in special, for the allocation of satellites. The most popular ones are the Low Earth Orbits (LEO), where many Earth Observations satellites and the International Space Station (ISS) are; the Medium Earth Orbit (MEO), where the Global Positioning System (GPS) satellites are; the High Earth Orbit (HEO), where many weather satellites are allocated and the Geostationary Orbit (GEO), useful for telecommunication satellites. Figure 5 presents those Earth Orbits.

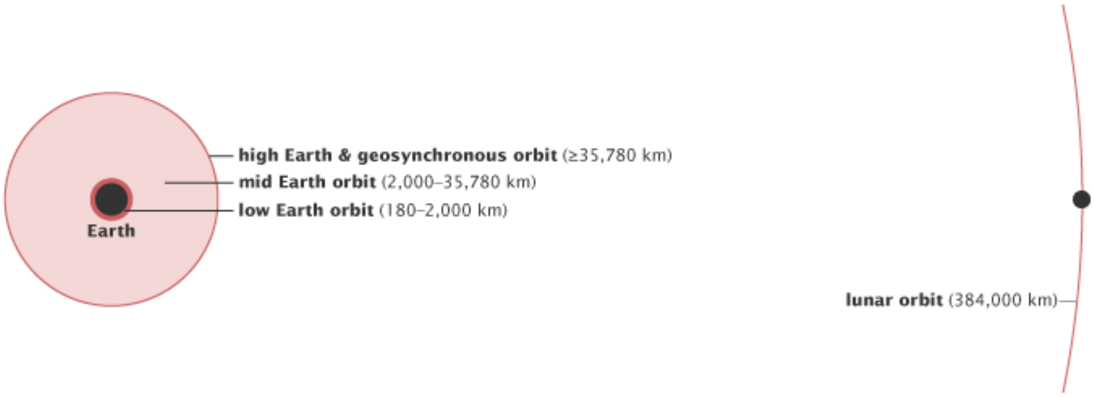

Figure 5: Earth Orbits (NASA illustration by Robert Simmon) [7]

It is unequivocal, as Figure 4 illustrates, that the number of space object is crescent in all Earth orbits. However, the most impactful figure belongs to LEO, in red. Figures 4 takes into consideration all types of object, which means high and low complexity satellites.

The Union of Concerned Scientists says LEO “contains roughly half of today’s active satellites and half of the known space debris”, and:

> In LEO, space debris travels at roughly 17,000 mph—some 30 times faster than a passenger jet. Because of its enormous speed, even small pieces of debris can cause severe damage to a satellite in a collision. Satellites cannot be shielded against collisions with debris larger than about an inch in size. An object 4 inches in size could completely destroy a satellite in a head-on collision, which could produce thousands of additional pieces of deadly space debris [8].

4. Reason # 3

Into these disputed orbits, the cubesats are normally placed. “The Cubesat standard was created by California Polytechnic State University, San Luis Obispo and Stanford University's Space Systems Development Lab in 1999 to facilitate access to space for university students” [9].

The access to space provided by the cubesat programs also validates the provisions of Article I OST that claims that the benefits of space exploration shall be in the interest of all countries irrespective of their degree of economic and scientific development, because, as technology went cheaper and faster, governmental and non –governmental entities, such as start-up companies and universities, were able to develop their own space projects and get a ride into outer space. Yet, the problems arising from the densification of space activities, which may represent a threat to its long-term sustainability grew worse. “[T]hreats include on-orbit crowding, radio-frequency interference, and the chances of an incident in space sparking or escalating geopolitical tensions on Earth” [10]. Cubesats usually have no maneuver capability to avoid potential collisions, are travelling a very high speed that vary according to their altitude, they may reenter, but, as the OSCAR series teaches us, they may stay in orbit for decades without any provision for removal, despite the ongoing attempt by the scientific and technical community in the development of ways to remove space debris [11].

Legal concerns surround the space debris removal because, according to Article VIII OST, the State that registers a space object detains jurisdiction and control over it. Any possible removal shall require that State of registry authorization, recalling that not all non-operational space objects are useless. One may contain strategic and even top secret information.

5. Reason # 4

Space technology became cheaper and faster, within the reach of many. Currently, it is possible to buy a cubesat kit on the Internet for less than USD 10,000 [12]. Nevertheless, reliability, which is "the probability that an item will continue to perform its intended function without failure for a specified period of time under stated conditions" [13], also decreased. Due to cubesats' low complexity and low reliability, they tend to stay operational for a very short period of time and soon they become space debris.

Langer & Bouwmeester (2016) assert that most of cubesats are lost in their first operational phase, mainly "due to poor system level functional testing":

> The overall reliability of CubeSats is strongly dominated by so-called dead-on-arrival (DOA) cases, where the satellite was ejected from its deployer and subsequently never achieved a detectable functional state. Due to these DOA cases after a successful deployment, the overall reliability thus drops instantly to a value between 87.09% and 75.62% (95% confidence interval). With a reliability value between 73.24% and 58.94% (95% confidence interval) after 100 days in orbit, infant mortality is the dominant effect [14].

Cubesat failures and short lives may undoubtedly increase the already crescent amount space debris, and, thus, give rise to a legal concern: the State responsibility over all space activities, whether such activities are carried out by governmental or non-governmental entities, and liability for any damage their space objects may cause on Earth, to an aircraft in flight and elsewhere.

6. Reason # 5

There is an unfamiliarity in the cubesat community about the international laws governing the space activities, it was noted in the Report on the third United Nations/Austria/European Space Agency Symposium on Small Satellite Programmes for Sustainable Development: "Implementing small satellite programmes: technical, managerial, regulatory and legal issues", held in Austria in 2011 [15].

Article VI OST states that State Parties to the Treaty bear international responsibility for national activities in outer space, whether such activities are carried on by governmental agencies or by non-governmental entities, and for assuring that such activities are carried out in conformity with the provisions of the Treaty, the last being subject to the appropriate Stare authorization and continuous supervision, which includes start-up companies, universities and any other entity. It is worth recalling that all five Space Law Treaties and Conventions are State-oriented, and communication among those vary space actors is basilar.

Article VII deals with liability, which implies in damage caused by space objects of its nationals to third State, no matter the size of such object (cubesat, microsatellite, including), in air space and in outer space. Article VII was further elaborated to become the 1972 Liability Convention, or Convention on International Liability for Damage caused by Space Objects. This Convention establishes a strict system of compensation based on the place of the incident: absolute liability for damage caused by a space object on the surface of the Earth or to aircraft in flight (Article II), and fault liability for damage being caused elsewhere than on the surface of the Earth or to aircraft in flight (Article III).

The same scheme is valid for cubesat missions. The context in which such legislation was drafted explains its harshness: “The aim of the LIAB was – by establishing effective procedures and international rules for victims to represented by their State – to ensure the continuation of outer space activities, despite their potential danger” [16].

5. Conclusions

This article aimed at listing five reasons why cubesats deserve more attention from experts. In a dialogue that involved both Law and Science, it was possible to see that cubesats initiative are as old as the space debris concerns, but it grew worse as more and more actors came into play. A case study was presented to show that it is not all true that cubesats stay in orbit for a short period of time. Many are in space for over 25 years. Also, this work reminded that non-operational objects unduly occupy useful and limited resources, which is contrary to provisions of the law.

Cubesat initiatives are excellent sources of technological development at the same time as they allow the equal access to space foreseen by the outdated Space Law framework. However, the severity of the Law also calls for more responsibility from States and their nationals. Raising awareness of the cubesat community about the current legal regime is just one small but necessary step.

The inhospitable and harsh environment of outer space requires a set of tests and a level of complexity that cubesats are not yet ready for. Increasing the reliability of cubesats (another step) may reduce the failure rate, unfortunately that may increase not only the cost but also the time of each mission. There may come a time when a decision must be taken for the safety of all and for the space environment own good.

Since the geopolitical moment does not favor a new Treaty based on consensus, the adoption of national legislations (one more step) that both foster cubesat initiatives and safeguards State from incidents is instrumental.

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References

[1] Gunters's Space Page, DOVE (DOVE-OSCAR 17, DO 17), https://space.skyrocket.de/doc_sdat/dove.htm, (accessed 27/08/2018).

[2] National Aeronautics and Space Administration (NASA), What are SmallSats and CubeSats? https://www.nasa.gov/content/what-are-smallsats-and-cubesats, (acessed 18/08/2018).

[3] Smithsonian National Air and Space Museum. Communications Satellite, Oscar 1, https://airandspace.si.edu/collection-objects/communications-satellite-oscar-i, (accessed 27/08/2018).

[4] Centro de Gestão e Estudos Estratégicos (CGEE), Resumo Executivo: CubeSats, https://www.cgee.org.br/documents/10195/734063/CGEE_resumoexecutivo_CubeSats_Web.pdf, (accessed 18/08/2018).

[5] European Space Agency (ESA), Space Debris: Analysis and Prediction, https://www.esa.int/Our_Activities/Operations/Space_Debris/Analysis_and_prediction, (accessed 27/08/2018).

[6] European Space Agency (ESA). Space Debris by Numbers, https://www.esa.int/Our_Activities/Operations/Space_Debris/Space_debris_by_the_numbers, (accessed 30/10/2018).

[7] National Aeronautics and Space Administration (NASA), Catalog of Earth Orbits, https://earthobservatory.nasa.gov/Features/OrbitsCatalog, (accessed 30/10/2018).

[8] Union of Concerned Scientists. The Growth of Space Debris Since 1957. https://www.ucsusa.org/nuclear-weapons/space-weapons/growth-of-space-debris#.W9ikChNKjC8, (accessed 30/10/2018).

[9] Cubesat. The Cubesat Program. http://www.cubesat.org/about/, (accessed 30/10/2018).

[10] Secure World Foundation. Handbook for New Space Actors in Space. https://swfound.org/handbook/download-the-handbook/, (accessed 30/10/2018).

[11] Gizmodo Brasil. Missão britânica finalmente começa a testar sistema com rede e arpão para coleta de lixo especial, https://gizmodo.uol.com.br/missao-britanica-coleta-lixo-espacial/, (accessed 30/10/2018).

[12] Cubesat Shop. Pumpkin Cubesat Kits, https://www.cubesatshop.com/product/pumpkin-cubesat-kits/, (accessed 30/10/2018).

[13] Weibull. About Reliability Definition, https://www.weibull.com/basics/reliability.htm, (accessed 30/10/2018).

[14] M. Langer, J. Bouwmeester, Reliability of CubeSats – Statistical Data, Developers' Beliefs and the Way Forward, https://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=3397&context=smallsat, (accessed 30/10/2018).

[15] United Nations Office for Outer Space Affairs (UNOOSA). Report on the third United Nations/Austria/European Space Agency Symposium on Small Satellite Programmes for Sustainable Development: "Implementing small satellite programmes: technical, managerial, regulatory and legal issues", http://www.unoosa.org/pdf/reports/ac105/AC105_1005E.pdf, (accessed 30/10/2018).

[16] L. J. Smith; A. Kerrest. Preamble. In: HOBE, Stephan; SCHMIDT-TEDD, Bernhard; SCHROGL, Kai-Uwe (eds.). Cologne Commentary on Space Law, v. II, Cologne, Heymanns, p. 101, 2013.