One million (paper) satellites

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The occupation of orbits by large constellations of satellites has been given substantial attention over the past few years. About 4,500 Starlink and 630 OneWeb satellites are on orbit as of July 2023 (*1*), but this is only the beginning. Recent filings for radio spectrum with the International Telecommunication Union (ITU) suggest that a dramatic increase in satellite numbers is possible, much more than the tens of thousands often reported. By treating orbital space as an unlimited resource, humanity is creating serious safety and long-term sustainability challenges to the use of low Earth orbit (LEO), including science conducted from space and the ground. The ITU filings are the warning, and also part of the solution. There is urgent need for the ITU and its Member States to adopt meaningful controls.

Constellations much larger than SpaceX's Starlink have been filed, including a 337,320-satellite constellation named Cinnamon-937 that was filed at the ITU by the Government of Rwanda in September 2021. Media reports linked the filings to a French company named E-Space, founded by American entrepreneur Greg Wyler (*2*). In June 2023, the French government made a new filing for E-Space, a 116,640-satellite constellation named Semaphore-C; as a result, the actual extent of E-Space satellite constellations is unclear, though the numbers remain substantial (*3*).

Filing with the ITU occurs because satellites require access to radiofrequency spectrum to communicate with ground stations and carry out mission operations, such as providing communication services or returning Earth observation data for analysis. The filings are made by national governments on behalf of private satellite companies and government agencies, under rules and procedures set out in the ITU's Constitution, Convention, and Radio Regulations (*4,5*). Different bands within the radiofrequency spectrum are used for different applications, such as fixed or mobile satellite services, and their associated filing types vary. Some operate on a first come first served basis, while others leave satellite operators to coordinate among themselves. In all cases, the ITU requires nations to submit information on behalf of operators about their proposed satellite networks to enable coordination with existing systems. That information is examined here.

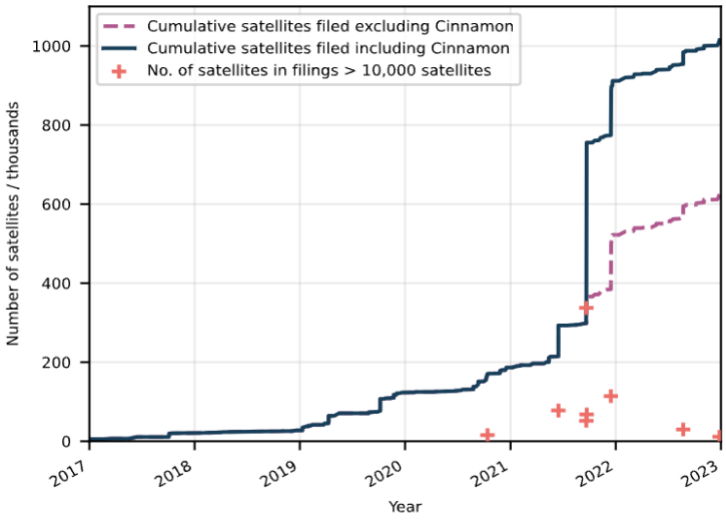

Figure 1. Cumulative growth in the number of satellites filed in the ITU's 'As Received' database from 1 January 2017 to 31 December 2022. The blue line represents the total cumulative number of satellites filed, with all constellations of ten or more

Using the ITU's 'as received' database, we extract filings for constellations with ten or more satellites, finding that more than 300 constellations representing over one million satellites were filed between 1 January 2017 and 31 December 2022. This is over 115 times the number of operational satellites currently in orbit. Moreover, among these 300 constellations there are more than 90 that comprise over 1,000 satellites each. Twenty-three have over 5,000 satellites, and eight have over 10,000 satellites. The largest single filing is Cinnamon-937 with 337,320 satellites. For all these numbers, we have attempted to exclude repeated filings for the same satellites. Figure 1 shows the cumulative number of satellites filed over the examined period, with most of these satellites destined for LEO.

Most of the proposed constellations were filed by China (circa 65) and the United States (circa 45); however, very large (>10,000 satellite) constellations have also been filed by Rwanda, Germany, Spain, Norway, France, and Solomon Islands. The 'operating agencies' for the 20 largest constellations come from nine nations and include well-established satellite companies, start-ups, and government agencies.

The growth of objects in LEO has consequences. The environment already contains considerable mass from thousands of operational satellites and tens of thousands of pieces of tracked debris, including defunct satellites and abandoned rocket bodies. It is estimated that there are millions of pieces of smaller, untracked and potentially dangerous debris (*6*). The addition of hundreds of thousands of new satellites would greatly increase the complexity of operations and the risk of on-orbit collisions. Moreover, reentries from medium-to-large satellites and the rocket

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bodies used for launches would pose a growing risk to people on the ground, at sea and in aircraft (*7*). Light reflecting off satellites would continue to disrupt astronomy through streaks and glints, while radio astronomy would become further limited by transmissions and electronics noise (*8*).

Most likely, many of the filed satellites will never be launched. There are many reasons why satellite projects do not come to fruition, including funding problems, withdrawals of political support, and engineering issues. In some cases, large filings could be a calculated move by governments or companies: applying for more satellites than they intend to launch, possibly with a view to attracting investors or selling the rights to spectrum. In other cases, a company might engage in 'spectrum warehousing' by acquiring spectrum rights that it hopes to use later, as technology develops, customer demand increases, or additional investors are found.

There are past examples of over-filing for satellites. In the 1980s and 1990s, a company called Tongasat, operating on behalf of the Government of Tonga, filed for geosynchronous orbit (GSO) slots and began leasing them to foreign satellite companies (*9*). Cases of possible over-filing have also occurred in LEO, including in 2015 when large filings were submitted for OneWeb, SpaceX, Thales Alenia Space, Telesat, and KleoConnect within months of each other (*10*).

Regardless of the reason, over filing hampers our ability to identify and address potentially catastrophic problems in a timely manner. The challenge is further complicated by other industry practices. Some companies split their satellite constellation across multiple filings with the ITU. For example, SpaceX's Starlink Gen2 constellation was submitted across approximately 22 filings. This presents a challenge to the ITU's efforts to protect GSO satellites against harmful radio interference from satellites in LEO, including through limits on equivalent power-flux density (EPFD), a measure of transmission power. It was already difficult for the ITU to accurately model EPFD emissions from non-GSO satellites and evaluate compliance with EPFD limits under Article 22 of the Radio Regulations; splitting constellations across multiple filings only exacerbates the problem (*11*). The ITU has identified that one reason why operators split filings is to obtain favourable EPFD results that would otherwise exceed ITU EPFD limits if they were submitted as a single constellation (*12*). While it advises against this practice, the ITU has not yet prohibited or taken steps to disincentivize it.

In several cases, companies have had several nations file for the same constellation. Three nations – Norway, Germany, and the United States – submitted filings for SpaceX, while three others – the United Kingdom, France, and Mexico – submitted filings for OneWeb. It is not clear why Rwanda submitted filings for E-Space, registered in France, though Greg Wyler's previous links to the nation provide a possible explanation (*13*). Papua New Guinea has submitted filings for the US company Omnispace, and Solomon Islands has submitted filings for the Australian company Fleet Space.

Different nations will have different policies concerning ITU filings, including the fees charged, the degree of scrutiny applied, and the transparency (or obfuscation) provided with respect to the companies involved. Companies likely consider these policies when deciding where to file, creating the possibility of flags of convenience. In the maritime domain, flag-of-convenience nations provide shipping companies with registrations for their vessels, as is required by international law, but do so with minimal regulation and lax enforcement. Unsurprisingly, these ships have poor safety records. At the same time, we do not assume or intend to imply that nations such as Rwanda, Papua New Guinea, and Solomon Islands are acting in bad faith. The accessibility of the ITU's processes for securing radio frequency spectrum offers nations a way into this fast-growing high-tech sector.

CHANGING THE RULES

If over-filing is a problem, there is a solution available. The ITU is an effective law-making body through which its 193 Member States can readily create or update rules that then bind them all. By ratifying the ITU Convention and Constitution, nations agree to further law-making at Plenipotentiary Conferences held every four years, and at World Radio Conferences (WRCs) held every three to six years, where ITU Member States review and revise the Radio Regulations. They do so through a consensus-based process that further ensures that no nation is bound without its consent. This ability to create new rules without requiring a new and lengthy round of treaty ratifications is unusual in international relations though not unique, with the International Maritime Organization also able to adopt new, widely applicable rules with some regularity.

The ITU does not have enforcement powers as such; it relies on national regulators to ensure compliance. The ITU's primary responsibility, and those of the Member States, acting together, is to keep the rules abreast of new technological developments.

Due diligence rules were first established at the 1997 WRC (WRC-97) in part to reduce speculative filings. These require governments to submit information such as the planned spacecraft manufacturer and launch provider to the ITU, but they do not apply to all spectrum bands. Separately, in 1997, the ITU Council introduced a cost recovery scheme that eventually had the effect of partially curbing speculative filings in GSO, though proposals for fees used explicitly to discourage over-filing were rejected by Member States (*14*). At the most recent WRC, WRC-19, the first rules to address the over-filing of constellations were adopted, including a 'milestones' approach whereby operators must launch specific portions of their constellation within certain time periods after the initial filing. National regulators are implementing these rules: For example, Amazon's Project Kuiper license from the US Federal Communications Commission requires that they have at least half of their satellite constellation in orbit and operating by July 2026 or they risk losing some spectrum rights. However, at least in terms of deterring speculative filings, the milestones approach does not appear to have been particularly effective, with our data showing that filings for over 900,000 satellites have been made since it was adopted.

Agenda items for WRC-23 to begin in late November 2023 show an awareness of the challenges presented by large satellite constellations and could lead to progressive changes to the Radio Regulations; in other words, up-to-date rules. Post-milestones reporting is being explored, which would require nations to report significant satellite failures so that the ITU has accurate data. Technical solutions are being developed to accurately model aggregate EPFD produced by all non-GSO satellites, and these will help the ITU evaluate whether constellations are complying with EPFD limits. Consideration is also being given to limiting the allowed altitude deviations of non-GSO satellites to facilitate regulatory control and prevent interference. Other sustainability issues, such as orbital congestion and light and radio pollution from satellites, might indirectly benefit if these updates were made (*11*).

Although the ITU is paying attention to at least some of the issues emerging with respect to large constellations, the rapid growth in the cumulative number of satellites being filed remains a concern. Better rules will have to be adopted, either at WRC-23 or at the next World Radio Conference in 2026/27. These might include some kind of limits on the number of satellites in individual constellations, or in certain highly desirable orbits. Other options include higher fees for large filings or bonds that are repaid after satellites are deorbited. The possibility of flags of convenience should also be addressed, along with the possibility that larger constellation operators may be filing for speculative reasons. The agenda for that next conference will be adopted at WRC-23, making negotiations over the next few months critically important.

Satellite constellations offer great benefits to society, but their unchecked proliferation threatens everyone's interests, including astronomers, scientists that rely on Earth imaging satellites, and all other space users. It is time for the ITU and its Member States to step up: their authority over radio spectrum makes them uniquely able to manage LEO, a finite resource that belongs – and should remain accessible – to all humankind.

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