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A FEW SHELLS, A FEW OPERATORS: WHERE LOW EARTH ORBIT IS CROWDED IN AN ALTITUDE-INCLINATION MAP OF 16,620 ACTIVE SATELLITES

Abstract: Orbital congestion is usually described by counting satellites at each altitude. Altitude alone, however, cannot show how the population is organised, because satellites at one altitude may fly in very different orbital planes. Using the CelesTrak catalogue of active satellites retrieved on 28 September 2026 (16,620 objects), we computed each satellite's mean altitude from its mean motion with Kepler's third law and mapped the population on two axes at once, altitude in 50 km bands and inclination in 5 degree bands. Crowding is extremely concentrated. 70.3% of active satellites fly between 450 and 600 km, and the single band 450-500 km holds 9,899 satellites (59.6% of the catalogue), 93.7% of them Starlink. The three densest altitude-inclination cells are all in this band: 50-55 degrees (4,425 satellites, 99.7% Starlink), 40-45 degrees (3,266, 99.4% Starlink) and 95-100 degrees (1,886, 73.7% Starlink). Most of the next-largest concentrations are also single-operator shells: Amazon Kuiper holds 369 of 612 satellites at 600-650 km, OneWeb 648 of 720 at 1,150-1,250 km, and Qianfan 198 of 244 at 1,050-1,100 km. Without these four constellations, no 50 km band holds more than 646 active satellites. The snapshot was taken while SpaceX was moving about 4,400 Starlink satellites from roughly 550 km to 480 km during 2026, so the location of the main peak is itself a recent and changing decision. In the current catalogue, crowding in low Earth orbit is a property of a few shells built by a few operators, and it should be described on altitude and inclination together, with the date of the catalogue.

Keywords: orbital congestion; low Earth orbit; satellite constellations; Starlink; Kepler's third law; CelesTrak

Introduction. The number of active satellites has grown sharply in recent years, driven mainly by large communication constellations in low Earth orbit (LEO) [1, 2]. Concern about this growth goes back to the observation that collisions between orbiting objects can produce fragments which cause further collisions, a cascade first described by Kessler and Cour-Palais [3]. How crowded a region of space is therefore matters beyond the number of satellites in it.

Most popular descriptions of congestion count satellites by altitude. Large constellations, however, are built as shells: many satellites at one altitude and one inclination, spread over several orbital planes [4]. Two populations at the same altitude but at different inclinations are different shells, often run by different operators, while one operator's shell appears as a single dense spot when altitude and inclination are plotted together. A two-dimensional map therefore

shows how the population is organised and who fills each part of it, which a one-dimensional altitude count cannot. It does not, by itself, show where satellites approach each other; that requires conjunction analysis, which is outside the scope of this study.

The timing of this study also matters. In January 2026 SpaceX announced that about 4,400 Starlink satellites would be lowered from roughly 550 km to about 480 km over the course of 2026, stating that debris and planned constellations are less dense below 500 km [5]. A catalogue taken in September 2026 therefore captures the constellation part-way through a deliberate move.

This study asks a narrow question that can be answered from public data: which combinations of altitude and inclination are crowded in the current catalogue of active satellites, and how much of that crowding belongs to single operators?

Materials and Methods. Data. We used the CelesTrak "active" group of general perturbations (GP) element sets, retrieved on 28 September 2026 at 01:09 UTC from <https://celestrak.org/NORAD/elements/gp.php?GROUP=active&FORMAT=csv> [6]. The file lists 16,620 objects. Their element-set epochs range from 31 August to 27 September 2026, with one predicted epoch dated 29 September. For each object the file gives the name, the international designator (which contains the launch year), mean motion (revolutions per day), eccentricity and inclination. All 16,620 records were complete and none were excluded. "Active" here follows CelesTrak's classification of operational satellites; a few long-lived passive objects, such as the calibration sphere CALSPHERE 1 launched in 1964, are included in that list.

Altitude. For each satellite, the orbital period is $T = 86,400 / n$ seconds, where n is the mean motion in revolutions per day. Kepler's third law gives the semi-major axis $a = (\mu T^2 / 4\pi^2)^{1/3}$, with $\mu = 398,600.4418 \text{ km}^3/\text{s}^2$ [7]. Mean altitude is a minus 6,378.137 km, Earth's equatorial radius. Two simplifications should be noted. First, GP mean motion is a mean element defined for the SGP4 model, and converting it directly ignores the correction for Earth's oblateness; for low orbits this changes altitude by about one to two kilometres, which can move a satellite across a band edge but does not change the pattern. Second, altitude is measured above the equatorial radius, so over the poles a satellite is about 21 km higher above the surface than stated. Because 16,570 of the 16,620 objects have eccentricity below 0.1, mean altitude is a good description of where almost all of them fly.

Bands and operators. Satellites were grouped into altitude bands of 50 km (band k covers 50k to 50k + 50 km) and inclination bands of 5 degrees. Operators of the four largest constellations were identified from object names (names containing STARLINK, ONEWEB, KUIPER or QIANFAN). Identification by name is reliable for these constellations but not for every smaller satellite, which is why all other objects are grouped as "other".

Launch year. The launch year was read from the first four characters of the international designator. Because the catalogue contains only satellites that are still active, counts by launch year show how many satellites from each year are in a band today. They do not show when a satellite entered that band, which matters here because many Starlink satellites were launched to higher orbits and later lowered.

Results. Altitude alone. Figure 1 shows the population below 2,000 km (15,806 satellites) by altitude and constellation, and Table 1 lists the most crowded 50 km bands. The band 450-500 km contains 9,899 satellites, 59.6% of all active satellites, and 93.7% of them are Starlink. Together, the three bands from 450 to 600 km hold 11,681 satellites, 70.3% of the catalogue. Other bands are also dominated by one constellation: 600-650 km by Amazon Kuiper (369 of

612), 1,050-1,100 km by Qianfan (198 of 244), and 1,150-1,250 km by OneWeb (648 of 720). The geostationary band at 35,750-35,800 km holds 554 satellites from many operators.

Table 1 - The ten most crowded 50 km altitude bands, with the share of the largest constellation in each

Band, km	Satellites	Largest constellation	Its satellites	Its share
450-500	9,899	Starlink	9,277	93.7%
500-550	944	Starlink	294	31.1%
550-600	838	Starlink	337	40.2%
350-400	817	Starlink	709	86.8%
600-650	612	Amazon Kuiper	369	60.3%
35,750-35,800	554	none	0	0.0%
400-450	480	Starlink	250	52.1%
1,150-1,200	383	OneWeb	315	82.2%
1,200-1,250	337	OneWeb	333	98.8%
1,050-1,100	244	Qianfan	198	81.1%

Altitude and inclination together. Figure 2 shows the population on both axes. Crowding is concentrated in a few cells rather than spread across the band. The three densest cells are all at 450-500 km: inclination 50-55 degrees (4,425 satellites, 4,410 Starlink), 40-45 degrees (3,266, 3,246 Starlink) and 95-100 degrees (1,886, 1,390 Starlink). No other cell below 2,000 km holds more than 550 satellites. The next dense cells are also single-operator shells: 600-650 km at 50-55 degrees (381 satellites, 369 Kuiper), 1,050-1,100 km at 85-90 degrees (Qianfan) and 1,150-1,250 km at 85-90 degrees (OneWeb). The 95-100 degree cells correspond to the sun-synchronous corridor used by Earth-observation satellites; across all altitudes below 2,000 km, the 96-99 degree range holds 3,615 satellites, of which 1,530 are Starlink. Sixteen objects fly on retrograde orbits with inclinations above 100 degrees, up to 142 degrees; Figure 2 extends to 145 degrees to include them.

Removing the large constellations. When Starlink satellites are excluded, the most crowded bands are 500-550 km (650 satellites), 450-500 km (622), 600-650 km (612) and the geostationary band (554). When all four large constellations are excluded, the largest band holds 646 satellites (500-550 km), and the 600-650 km band drops from 612 to 243. The largest band without Starlink is about fifteen times smaller than the 450-500 km band with it.

Launch year of satellites now in the main band. Of the 9,899 satellites now in the 450-500 km band, 118 were launched before 2021 (the oldest in 1990), 491 in 2021, 1,323 in 2022, 1,547 in 2023, 1,568 in 2024, 2,943 in 2025 and 1,909 in 2026 up to 27 September (Figure 3). Because many Starlink satellites launched in 2021-2025 first operated near 550 km and were lowered in 2026 [5], these counts describe the age of the satellites in the band, not when the band filled.

Discussion. The result reframes what "congested low Earth orbit" means in the current catalogue. At the level of the whole population, crowding is not a general property of LEO. It is a property of a small number of shells, each defined jointly by altitude and inclination and each filled mostly by one operator: one very large Starlink shell system at 450-500 km, and smaller shells of Kuiper, Qianfan and OneWeb higher up. Outside these shells the distribution of active satellites is much flatter.

This matters for how congestion is measured. An altitude histogram alone shows one very tall peak at 450-500 km, but it cannot show that most satellites in the peak sit in two inclination bands, 40-45 and 50-55 degrees, arranged as organised shells. The altitude-inclination map shows this directly and makes clear which operator is responsible for each dense region. It also shows that the sun-synchronous corridor at 95-100 degrees is the one dense cell shared by a large constellation and many independent operators, which makes it the natural place to begin a study of crossing traffic.

The map also depends strongly on the date of the catalogue. The peak at 450-500 km is the result of SpaceX's 2026 decision to lower thousands of satellites from about 550 km [5], a move the company presented as a safety measure because debris and planned constellations are less dense below 500 km. The same method applied to a catalogue from early 2026 would place the Starlink peak higher. Any statement about where orbit is crowded should therefore carry the date of the catalogue it describes, and repeated snapshots of the same shells over time would turn this map into a record of how operators move.

Limitations. The catalogue lists active satellites only; it does not include debris, rocket bodies or inactive satellites, which contribute strongly to collision risk [2]. Mean altitude from GP mean motion ignores the oblateness correction and is measured above the equatorial radius, so individual altitudes carry an uncertainty of a few kilometres; mean altitude is also not a good description of the 50 objects with eccentricity above 0.1. Operators were identified by name, which is reliable for the four large constellations but not for all other satellites. Counts by launch year describe satellites still active today and do not show when they reached their present altitude. Finally, the study describes where satellites are, not how often they approach each other; conjunction analysis would be the next step.

Conclusion. In the CelesTrak catalogue of 28 September 2026, 70.3% of active satellites fly between 450 and 600 km, and the three densest altitude-inclination cells are all in the 450-500 km band and are filled mostly by Starlink. Most of the other dense regions are also single-operator shells, of Amazon Kuiper, Qianfan and OneWeb, and without these four constellations no altitude band holds more than 646 active satellites. Crowding in the current catalogue is therefore concentrated, dated and largely built by a few operators, and it should be measured on altitude and inclination together.

Data availability. The catalogue is publicly available from CelesTrak at the address given in Materials and Methods. The analysis code is available from the authors on request.

Conflict of interest. The authors declare no conflict of interest.

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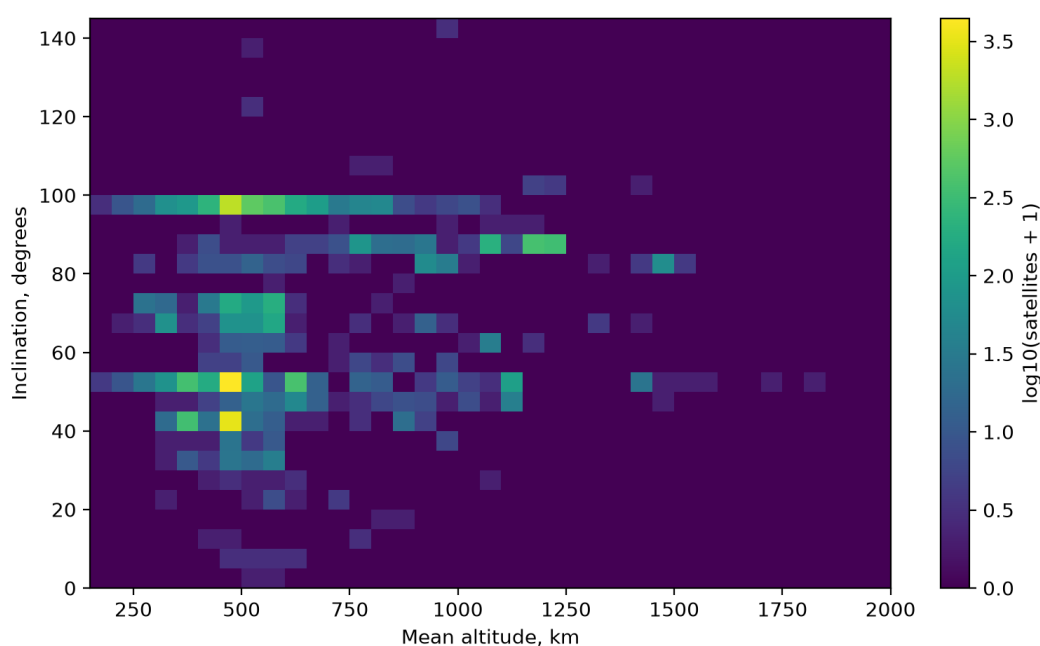
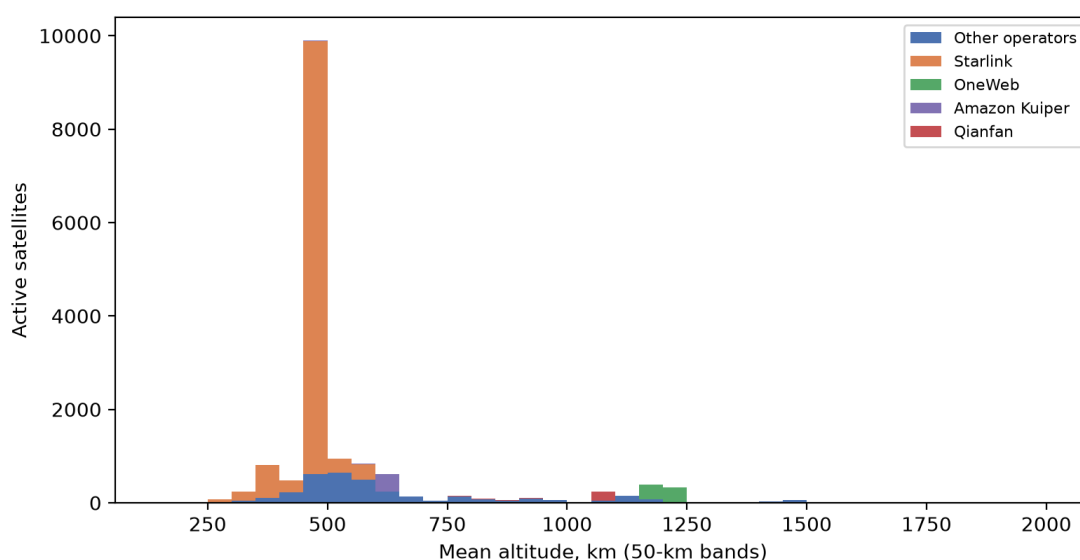
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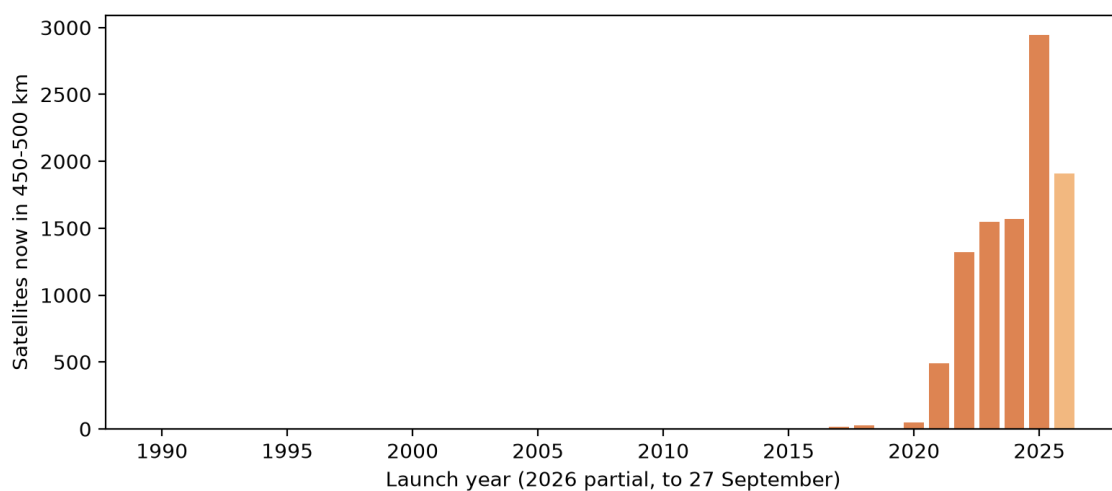


Figure captions:

Figure 1. Active satellites below 2,000 km by mean altitude (50 km bands), coloured by constellation. CelesTrak catalogue, 28 September 2026.

Figure 2. Number of active satellites in each altitude-inclination cell (50 km by 5 degrees), below 2,000 km and up to 145 degrees inclination, on a logarithmic colour scale.

Figure 3. Satellites now in the 450-500 km band by launch year. The 2026 bar covers launches to 27 September only.

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