Environmental Sustainability of Large Satellite Constellations in Low Earth Orbit

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ISTI Day(s) 2020

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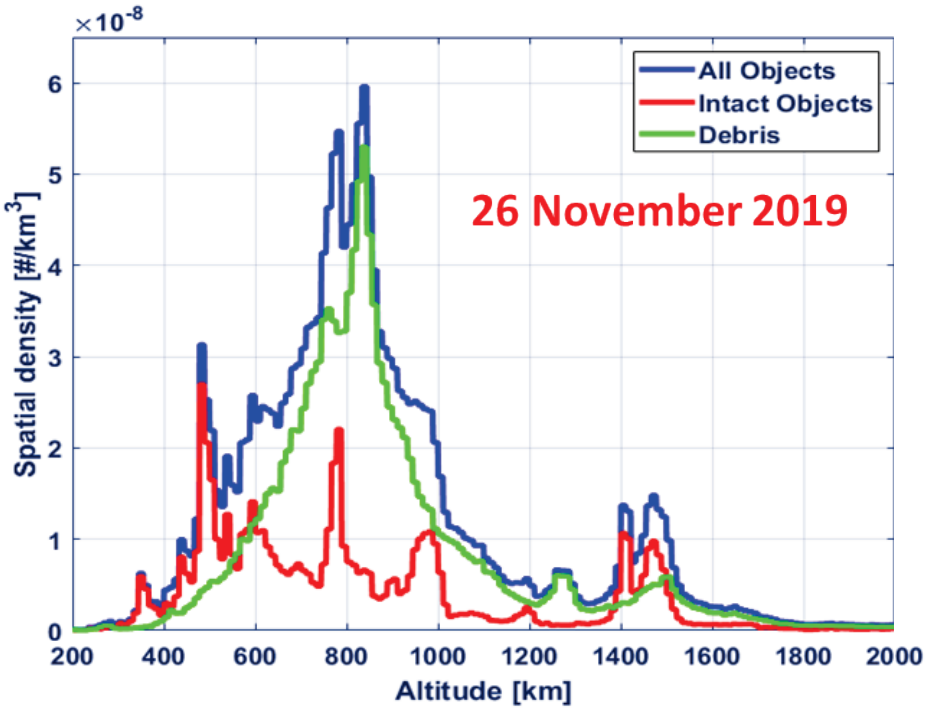
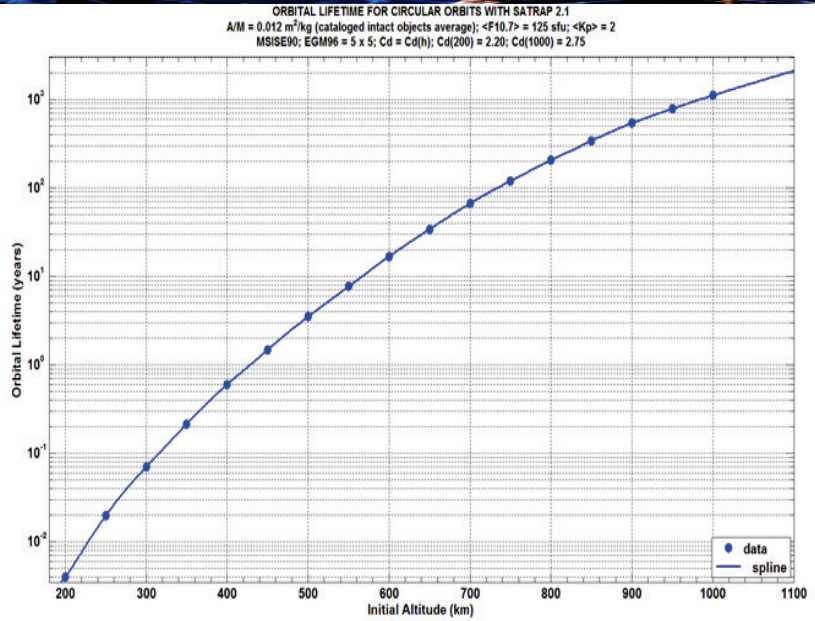
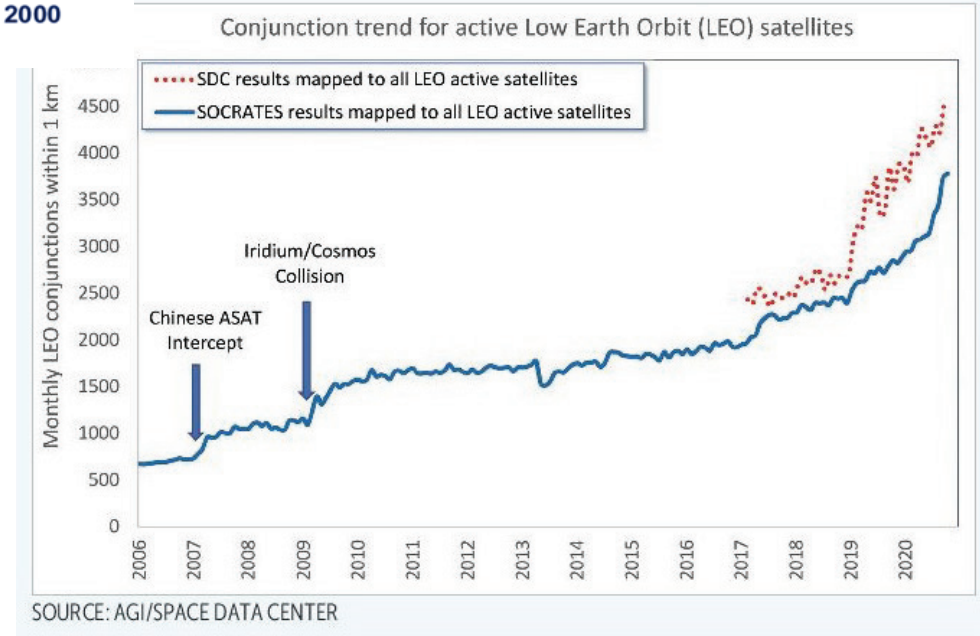
Info: http://isti.cnr.it/research/isti-day

The current situation in orbit

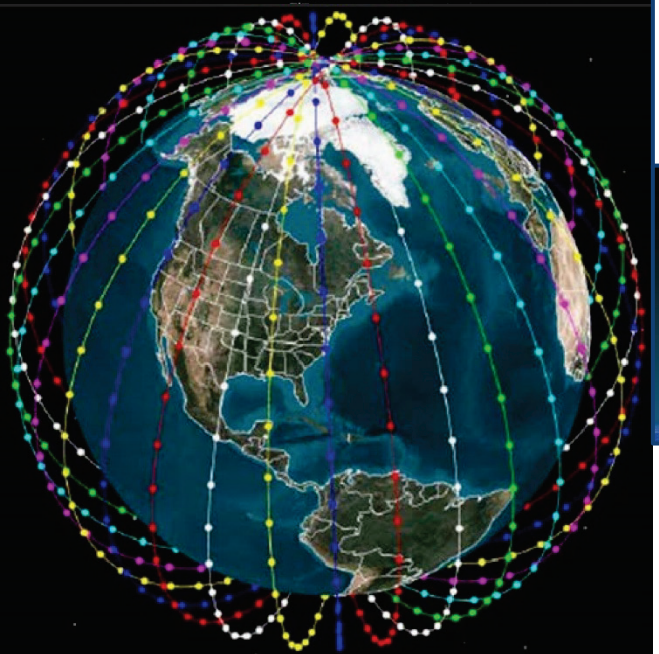


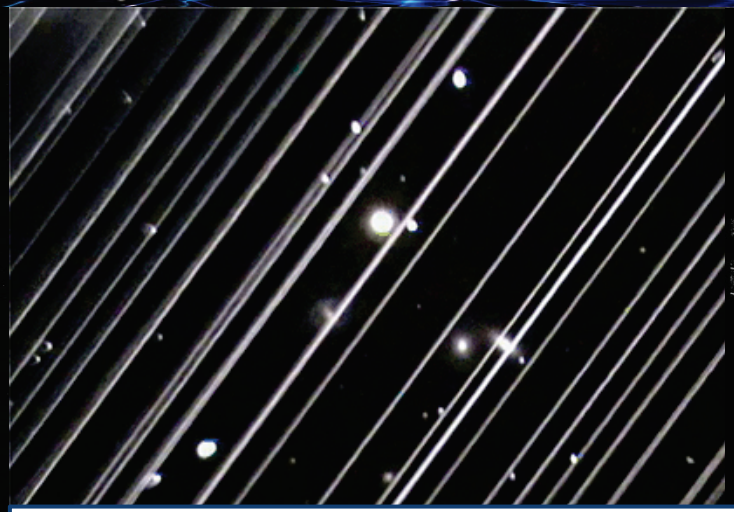


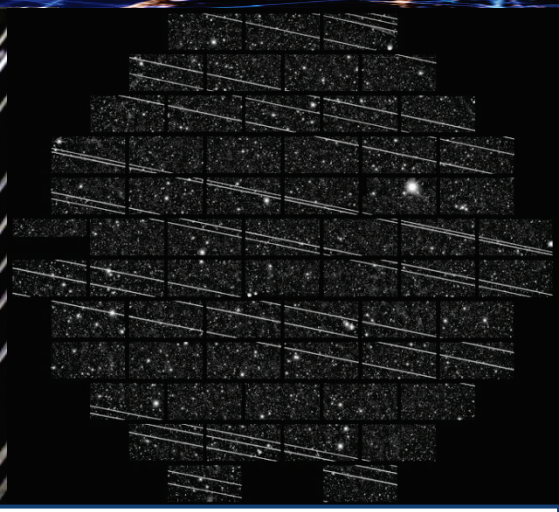
- Currently 27,000 objects > 7 cm are tracked by the US Space Command around the Earth
- About 10,000 satellites have been launched so far, of which ~6500 still in orbit and ~3000 currently active, but during the next 10 to 15 years more than 50,000 new satellites are expected, most at less than 1000 km in altitude
- Above 600 km the average residual lifetimes of inert satellites and rocket bodies are typically higher than 20 years



Megaconstellations







- The current plans envisaging the deployment of very large constellations in low Earth orbit (LEO), some consisting of thousands of spacecraft, raised a growing concern regarding the long-term sustainability of the near-Earth space environment with the present-day guidelines
- Assessing the impact of megaconstellations has been identified as a priority, in order to evaluate if additional, and more stringent, mitigation measures might be needed to preserve the long-term access and utilization of LEO
- For this purpose, during the last few years we have developed some approaches for the assessment of the environment criticality of megaconstellations

Planned large constellations in LEO

ORBITS OF NEW CONSTELLATIONS IN LEO

Mean altitudes and inclinations currently considered for new constellations, or sub-constellations, consisting of more than 80 satellites in nearly circular LEO orbits

Study Case	Altitude (km)	Inclination (°)
	335.9	42
	340.8	48
	345.6	53
	550	53
	600	97.7
1	800	98.6
2	1000	99.5
	1056	54
3	1110	53.8
	1130	74
4	1200	87.9
	1275	81
5	1325	70
6	1400	90

A satellite failing at the operational altitude of its own constellation, will typically re-enter in the Earth's atmosphere in less than 25 years, then being naturally compliant with the IADC and ISO mitigation guidelines

1. *Typical natural lifetime of intact satellites < 20 years*

- Being this study focused on the adverse long-term effects on the debris environment, only altitudes between 800 km and 1400 km were considered
- Then, detailed simulations were carried out for the combinations of altitude and inclination of cases 1-6

2. *Typical natural lifetime of intact satellites > 100 years*

A failed satellite belonging to this group will remain in orbit for a much longer time, perhaps contributing to the long-term increase of orbital debris

Evaluating the impact of large constellations

COLLISION RATE INCREASE

- This study addressed the potential long-term detrimental effects on the LEO debris environment of constellation satellites either lost, abandoned or non-maneuverable close to their operational altitudes, i.e. before the implementation of an appropriate end-of-life disposal

- For this purpose, we had previously defined a simple criticality index, named collision rate percentage increase

Additional average collision rate among the new lost, abandoned or non-maneuverable constellation satellites: CR_{0-0}

Additional average collision rate between the new lost, abandoned or non-maneuverable constellation satellites and the pre-existing background of cataloged objects: CR_{0-B}

$$CRI[\%] = \frac{100(CR_{0-0} + CR_{0-B})}{CR_{B-B}}$$

Current overall collision rate in LEO among the background cataloged objects: CR_{B-B}

Current average collision rate in LEO among the background (B) objects greater than ~ 10 cm*

*Pardini, C. and Anselmo, L. (2014) Review of past on-orbit collisions among cataloged objects and examination of the catastrophic fragmentation concept. Acta Astronautica 100:30–39, DOI: 10.1016/j.actaastro.2014.03.013

$$CR_{B-B} \approx 0.2\ year^{-1}$$

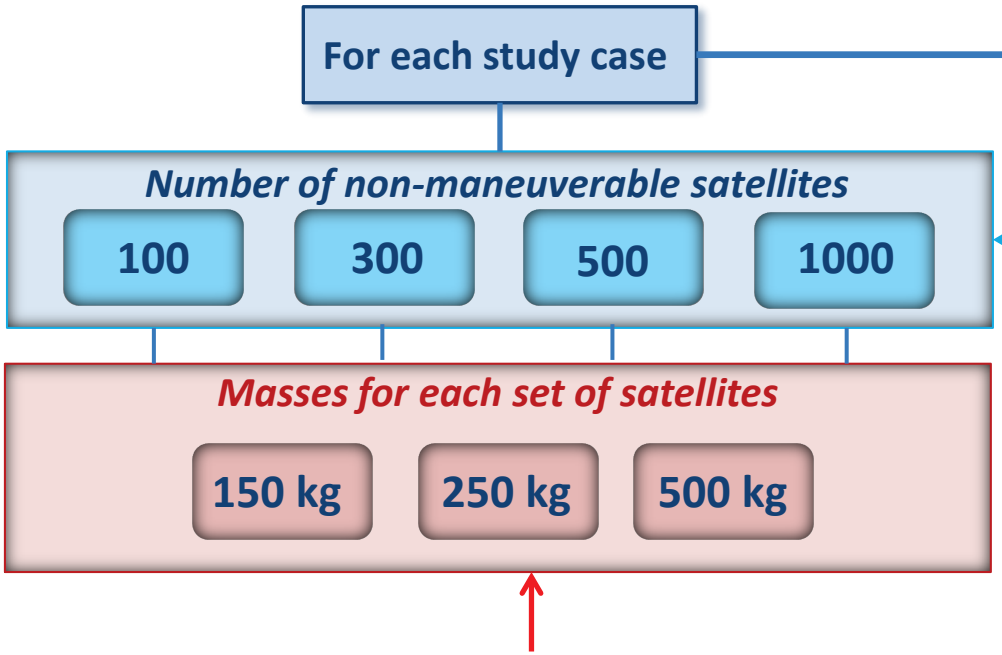
This value of CR_{B-B} was still considered a good estimate of the current (September 2019) collision rate among non-maneuverable cataloged objects in LEO

Simulation setup

SET OF FAILED CONSTELLATION SATELLITES

- Six study cases were analyzed in detail, being representative of all combinations of heights and inclinations relevant to assess the long-term negative effects on the orbital debris environment

Study Case	Altitude (km)	Inclination (°)
1	800	98.6
2	1000	99.5
3	1110	53.8
4	1200	87.9
5	1325	70
6	1400	90



- Four sets of failed constellation satellites, each comprising 100, 300, 500 and 1000 non-maneuverable spacecraft, were generated

- For each set of satellites, three different spacecraft masses, 150 kg, 250 kg and 500 kg, *well representative of the range currently considered for the new systems, either under deployment or planned*, were assumed

Moreover

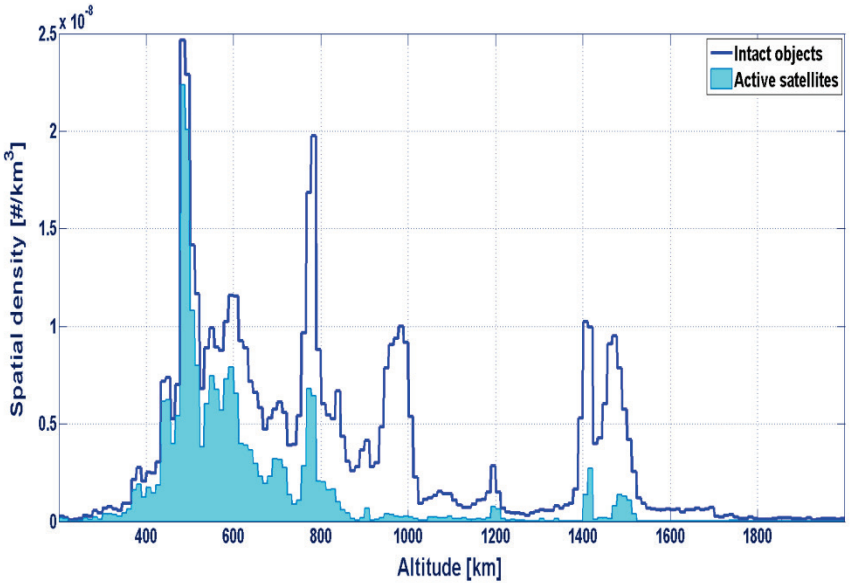
- Two radius vector dispersion intervals were specifically considered: $\Delta r = 15$ km and $\Delta r = 50$ km
- An even distribution of the nodes for the simulated non-maneuverable constellation satellites was adopted

Simulation setup

COLLISION RATE ESTIMATE

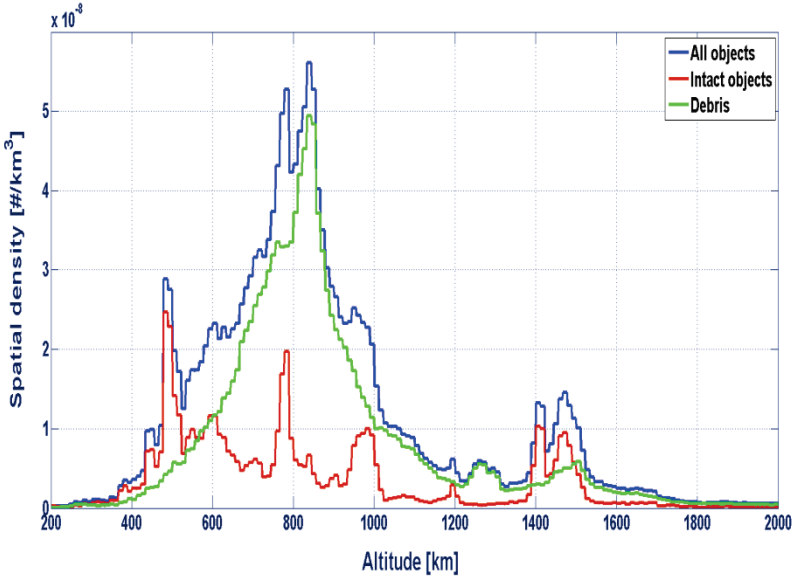
- The collision rates CR_{0-0} and CR_{0-B}, were estimated using the ISTI-CNR Space Debris Impact Risk Analysis Tool (SDIRAT), coupled with ad hoc post-processing routines to obtain the desired output as a function of the number of non-maneuverable constellation satellites, of the spacecraft mass, and of the dispersion interval of the radius vector

- As input populations, SDIRAT used
  - The cataloged objects, as of 5 September 2019
  - The simulated sets of failed constellation satellites, generated with an external routine according to the study cases considered



Spatial density in LEO of intact objects and active satellites (5 September 2019)

Spatial density in LEO of cataloged objects, intact objects and debris (5 September 2019)

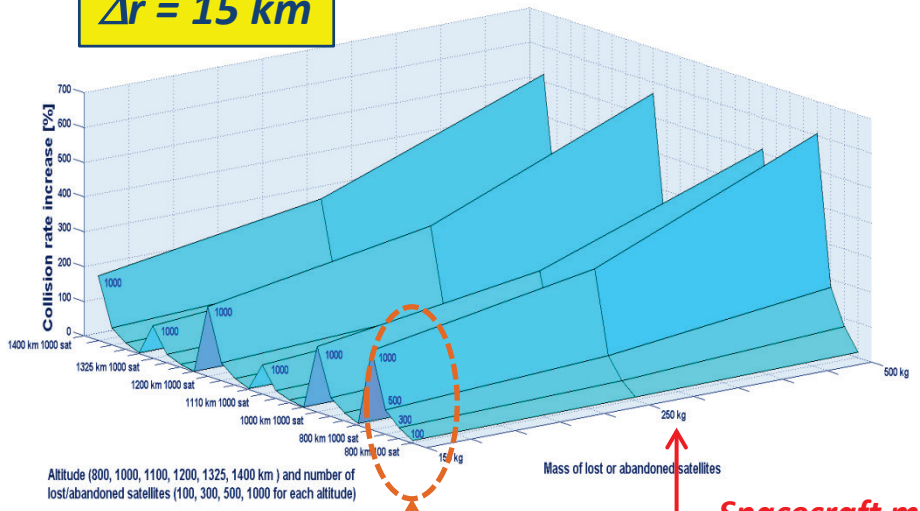


Criticality assessment

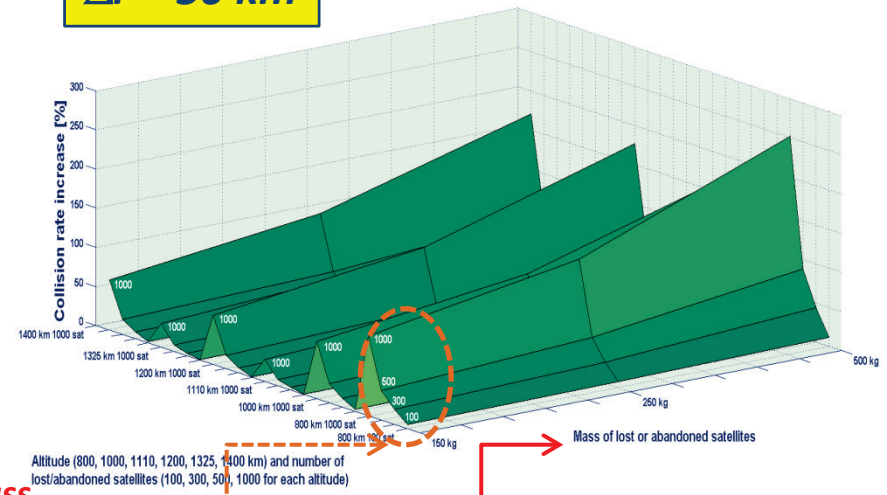
- The collision rate percentage increase *CRI* was evaluated for a total of 144 cases

Percentage increase of the collision rate in LEO for the six constellations considered, as a function of the number and mass of the lost, abandoned or non-maneuverable satellites

Δr = 15 km



Δr = 50 km



Spacecraft mass
M: 150 kg, 250 kg, 500 kg

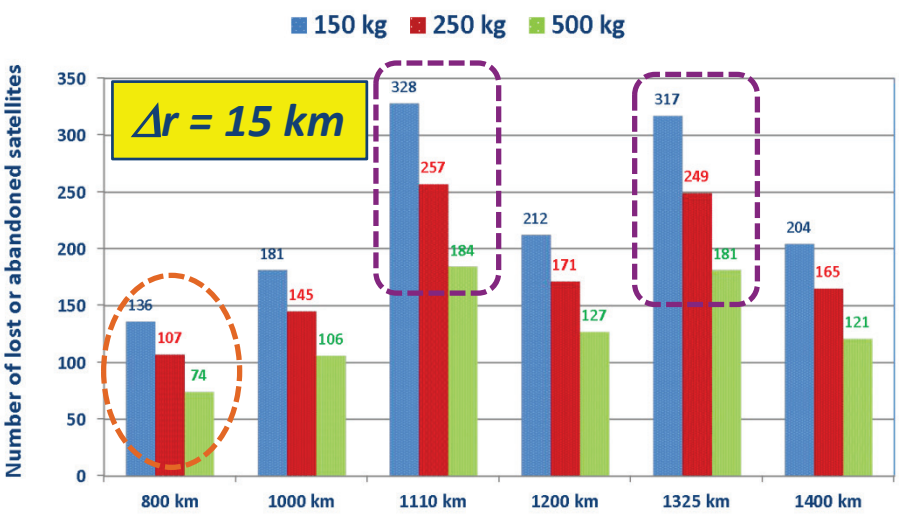
Number of satellites
N: 100, 300, 500, 1000

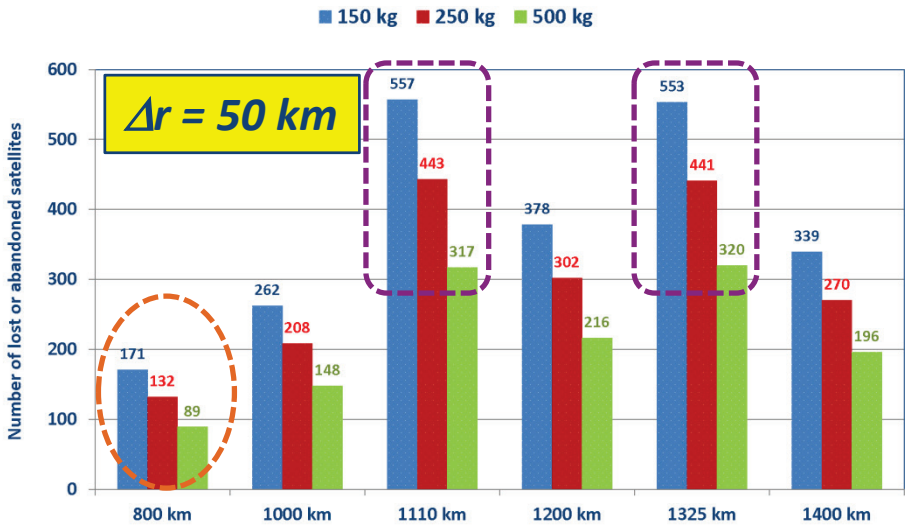
- As expected, the criticality index *CRI* increases with the number of satellites and spacecraft mass, both leading to a growth of the collisional cross-section
- Moreover, a greater spatial dilution of the satellites, i.e. a larger value of Δr, or placing the constellation in a region of space with a lower orbital debris background, e.g. at 1110 km or at 1325 km, lead to a significantly smaller value of *CRI* for a given spacecraft mass and number of non-maneuverable satellites

Main results

- **BUT, how many abandoned satellites of a single constellation would be sufficient to increase, for instance, the total collision rate in LEO by 10%?**

Number of lost, abandoned or non-maneuverable satellites able to increase by 10% the total collision rate in LEO among cataloged objects, as a function of the constellation and spacecraft mass





- **In the regions of space already most crowded with debris, as around the height of 800 km, about 100 more non-maneuverable satellites in the considered mass range would be sufficient to increase the current collision rate in LEO by ~10%, while a number between 500 and 1000 would increase it by ~100%**
- **In the less crowded LEO regions, as around 1110 km and 1325 km, a number of abandoned satellites between approximately 200 and 500 would instead be needed to boost the overall collision rate by ~10%**

Conclusions

- If a collision rate increase by 10% in LEO is considered as an impassable ceiling for a constellation, and a satellite post-mission disposal success rate of 90% is assumed, the following applies
  - No more than about 1000 constellation satellites could be deployed over the years at the height of 800 km
  - In much less crowded regions the overall deployment might not exceed a number of satellites between 2000 and 5000

- Taking into account approximately 6000 new satellites between 800 km and 1400 km, a long-term increase of the total collision rate in LEO by ~20-30% might be expected, assuming an immediate spacecraft de-orbiting at the end-of-life with a success probability of 90%
- A greater number of satellites, as well as a reduced probability of successful disposal, would hit the environment even more negatively
- Moreover, if the many disposed satellites were not de-orbited immediately, or in a short time, the collision rate in LEO would further grow, at least in the medium term, unless the satellites do not continue to be controlled and maneuverable until they re-enter the atmosphere
- The amount of this growth will depend on the number and mass of the spacecraft involved, as well as on the disposal orbits and strategies adopted
- However, 1000 satellites with a mass of 250 kg and elliptical disposal orbits of 300 km × 1000 km might increase, for a few years, the collision rate in LEO among cataloged objects by a further ~30%