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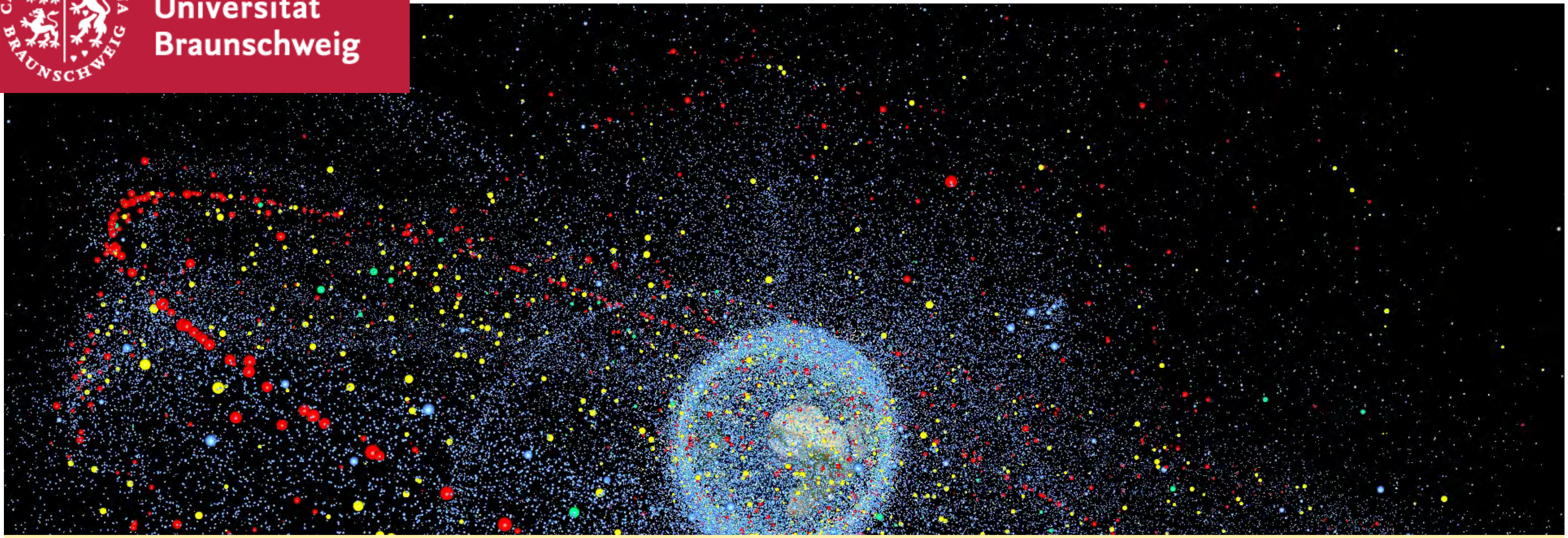
Institute of Space Systems



Mega Constellations and Space Debris
- Impact on the Environment and the Constellation Itself -

DGLR Workshop: Neue Märkte! Neue Konzepte? November 4th 2016, Berlin

Jonas Radtke, Christopher Kebschull, Enrico Stoll

Overview

- Impact on the environment
  - Simulation set-up
  - Results
  - Summary

- Impact on a constellation
  - Baseline definition
  - Collision probabilities and collision avoidance
  - Variations of the baseline definition

- Summary and conclusion

What is the impact of one Mega-Constellation on the Space Debris Environment?

Definition of long-term scenarios

- Perform long-term term simulations of the space debris environment, with
  - repeated background launch traffic (8-year cycle from 2005 to 2012)
  - 90% post-mission disposal for background objects,
  - No collision avoidance for background.

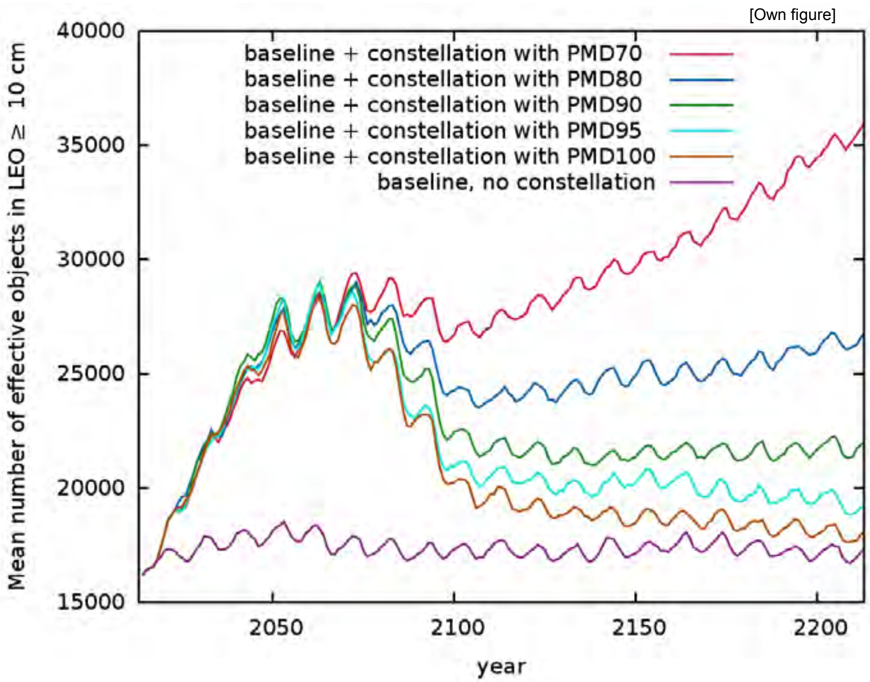
- Define an arbitrary "Mega-Constellation"; include it in the simulation.

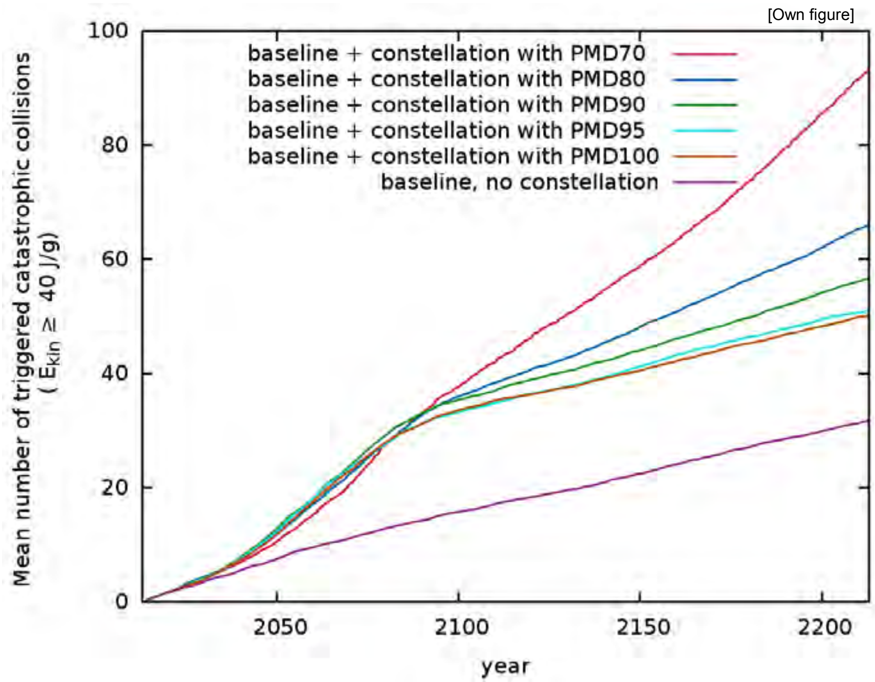
- Vary constellation parameters, such as:
  - Post-mission disposal success rate,
  - Remaining lifetime of disposal orbit,
  - Shape of disposal orbit, etc.

Constellation	**1080 satellites 1100km altitude 20 orbital planes 85° inclination**
Mission	Jan 2021 to Jan 2071
Satellite	200 kg mass 1m² effective cross-section 5 years of mission lifetime
Constellation build-up	2018 - 2020 20 launches per year 18 satellites per launch
Constellation maintenance	2021-2071 18 objects per launch 12 launches per year
Mitigation behaviour	Launcher stages directly re-entry No mission-related objects

➢ "European mini-campaign on Mega-Constellations" [1].

Results: Impact of post-mission disposal success rate

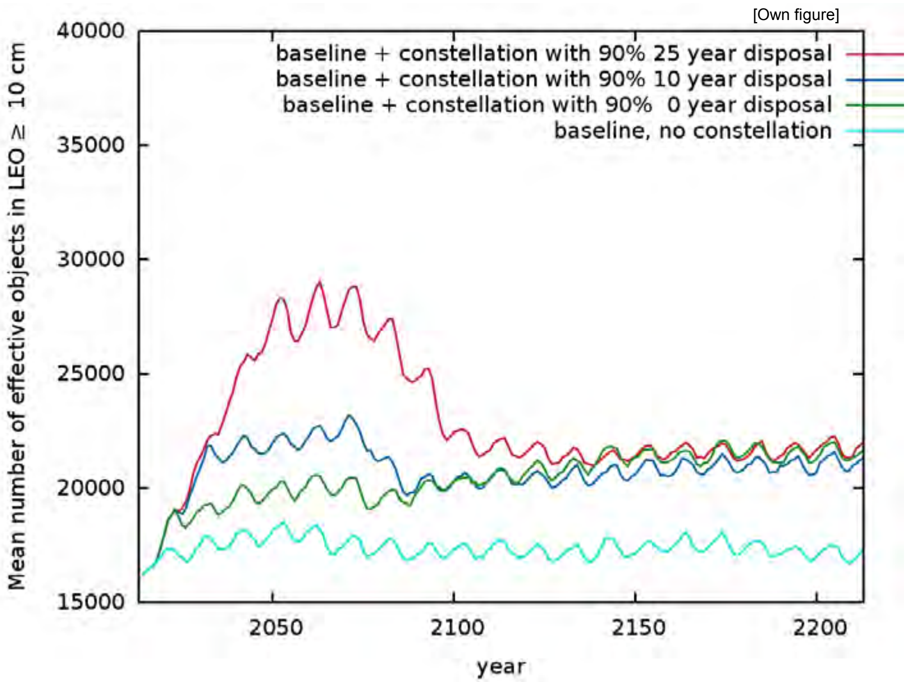


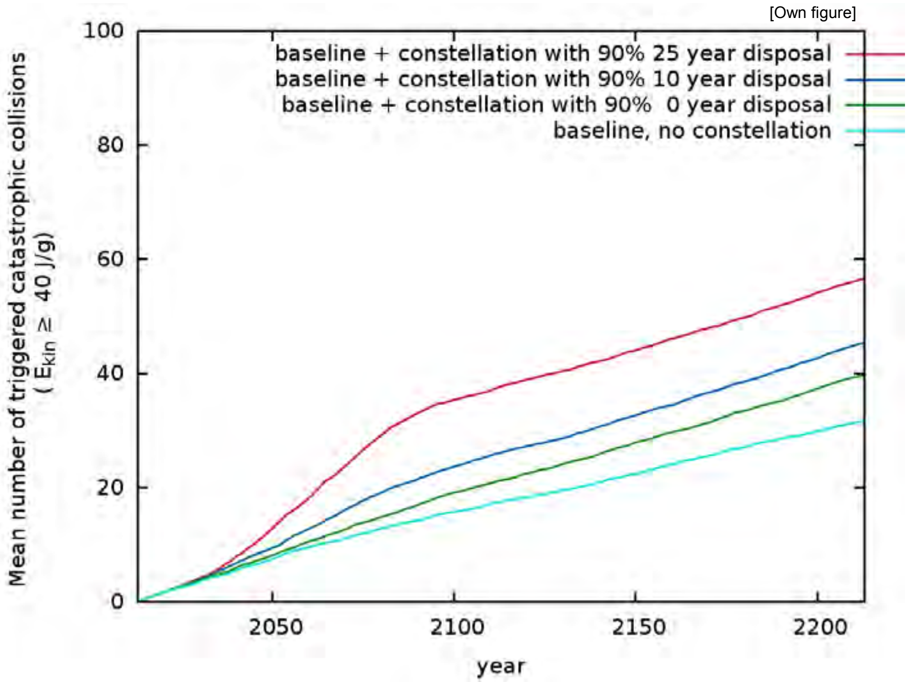


→ Driving factor on the **long-term** is the number of objects left in the environment.

* Results from LUCA only, [1] shows combined results.

Results: Impact of post mission disposal rem. lifetime





→ Driving factor on the **medium-term** is the lifetime of the disposal orbit.

* Results from LUCA only, [1] shows combined results.

Impact on the space debris environment: Main findings

- The impact on the **long-term is governed by the number of objects left** in the space-debris environment. On the mean, at least 90% disposal success are needed for no long-term impact.
- The impact on **the short- and medium-term are governed by the lifetime** of disposal orbits.
- For the overall environment it is most important that constellation objects are removed from the environment.
- **But:** Opposite effect of PMD on the short term: Less collisions with lower PMD in the background population.
- **Though:** With a reliable and strict space-debris mitigation plan, the space debris environment can sustain large constellations of satellites (with limits not determined).

What is the impact of the Space Debris Environment on a Mega-Constellation?

Baseline description: OneWeb constellation (1)

One Web Space Debris Mitigation Plan:

- Data sharing agreement in place with USSTRATCOM/JSpOC to decrease orbit determination uncertainties.
- Collision avoidance foreseen from the active phase (from injection to end-of-disposal), with the aim to be able to keep the satellites active during the complete orbital lifetime.
- An orbital lifetime after end-of-mission (EOM) of 5 years.
- A success rate for the end-of-life (EOL) disposal of ≥ 90%.
- All satellites will be equipped with a grapple fixture to allow future active debris removal operations.

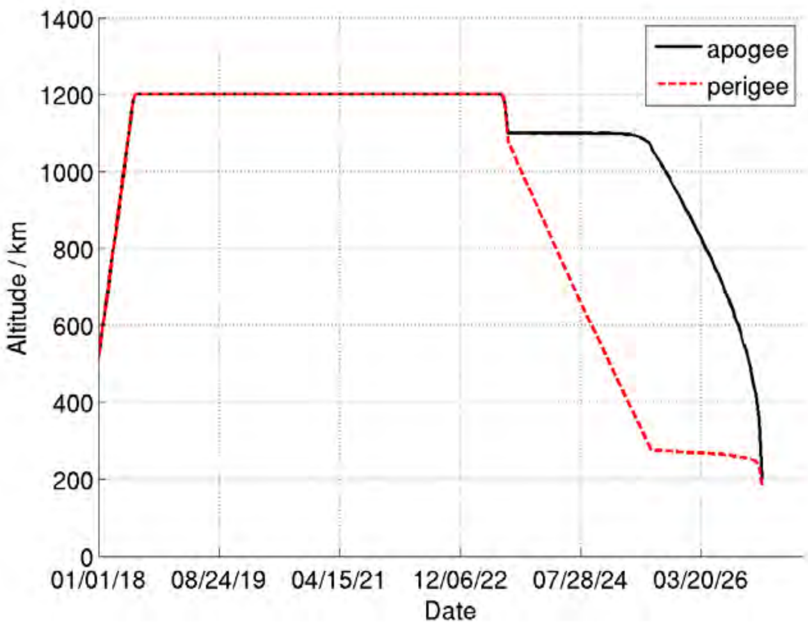
Used <u>OneWeb constellation as example only because they share most details</u>, not because they appear to be exceptionally critical.

Lindsay, M. (2016). OneWeb - Overview. Presentation held during the 53rd Session of the Scientific and Technical Subcommittee of the UNCOPOUS, February 2016.

Baseline description: OneWeb constellation (2)

Mission orbit:

1. Release at 500 km and 6 months <u>active</u> spiraling to final altitude of 1200 km at 87.9° inclination.
2. <u>Active</u> mission for 5 years at nominal orbit.
3. <u>Active</u> disposal to 1100x275 km orbit taking 2 years using the electrical engine in two steps: First, lowering the orbit to a circular 1100x1100 km orbit followed by an eccentric disposal to the final orbit.
4. <u>Passive</u> re-entering of the object.



Jonas Radtke, Christopher Kebschull, Enrico Stoll, Interactions of the space debris environment with mega constellations—Using the example of the OneWeb constellation, Acta Astronautica, Volume 131, February 2017, Pages 55-68, ISSN 0094-5765, http://dx.doi.org/10.1016/j.actaastro.2016.11.021.

→ Perform flux analysis, calculate collision probabilities and expected avoidance manoeuvres,
→ Scale results for complete constellation.

Baseline: Collision probabilities and coll. avoid. manoeuvres

	$P_{1200km, 720, 3cm}$ / %
Phase 1	4.11
Phase 2	13.45
Phase 3	15.15
Phase 4	7.24
Total	**34.69**

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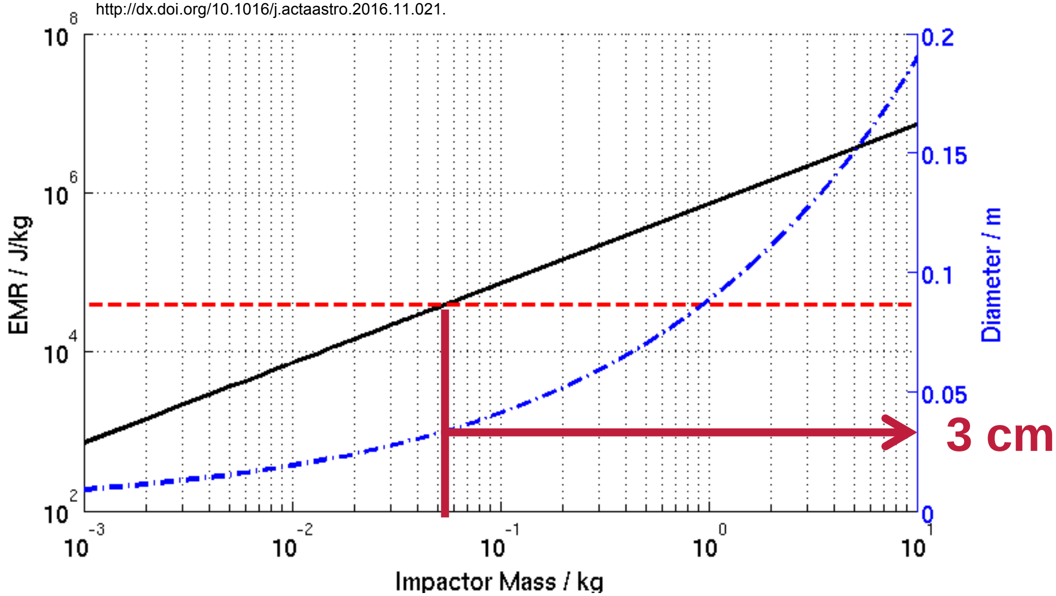
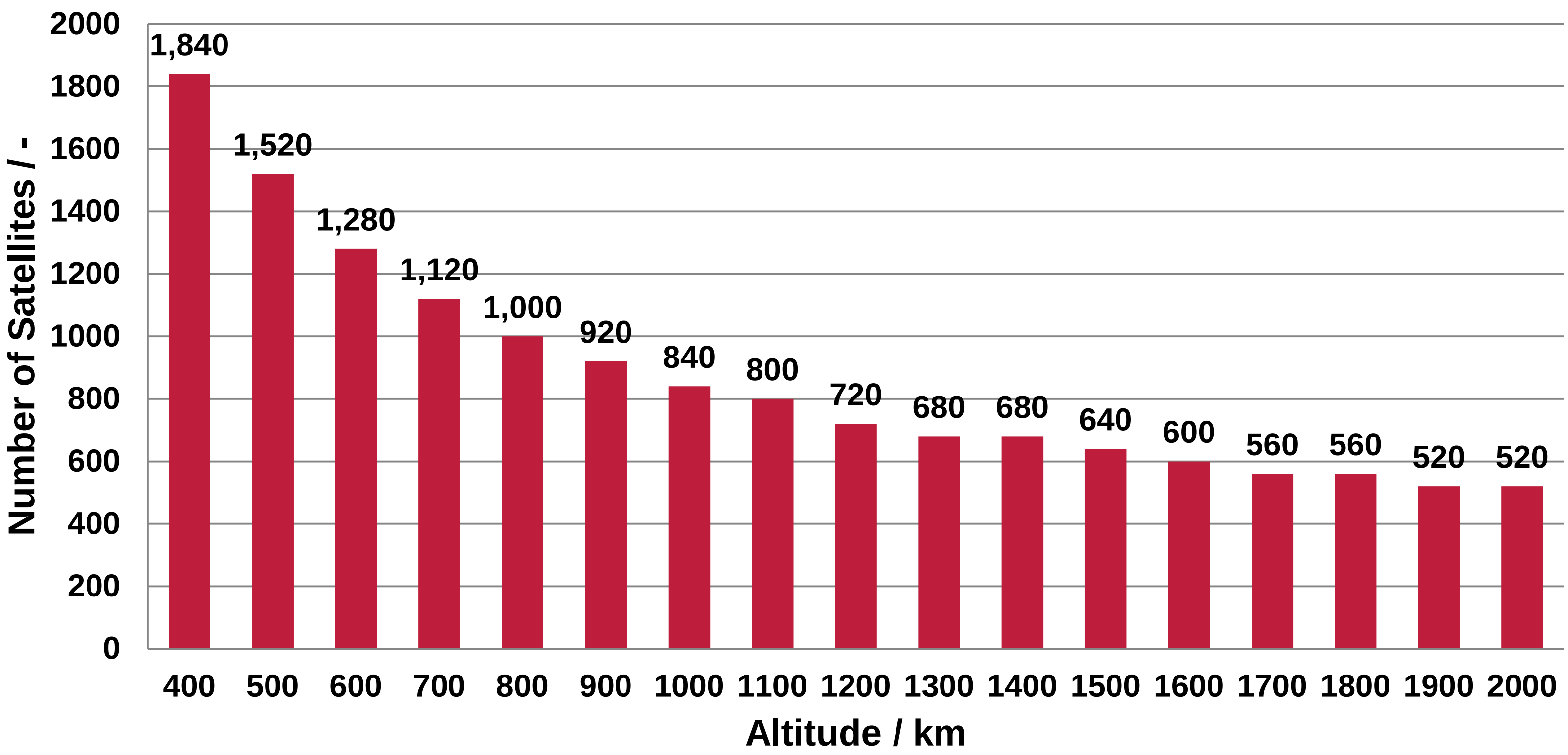


→ More than 200 collision avoidance manoeuvres during phases 1 – 3.

→ Highest collision probabilities / time (and number of avoidance manoeuvres) during active disposal and spiral-up.

*Numbers state probabilities to collide at least once.

Varying the constellation parameters: Operational altitude



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- Assuming same bandwidth and availability, identical satellite bus etc.
- Keeping the grazing angle constant.

Operational altitude variation: Collision probabilities

OneWeb

	$P_{800km,\ 1000,\ 3cm}$ / %	$P_{1200km,\ 720,\ 3cm}$ / %	$P_{1400km,\ 680,\ 3cm}$ / %
Phase 1	2.64	4.11	9.47
Phase 2	62.11	13.45	25.8
Phase 3	9.67	15.15	13.03
Phase 4	8.71	7.24	5.36
Total	**69.35**	**34.69**	**45.28**

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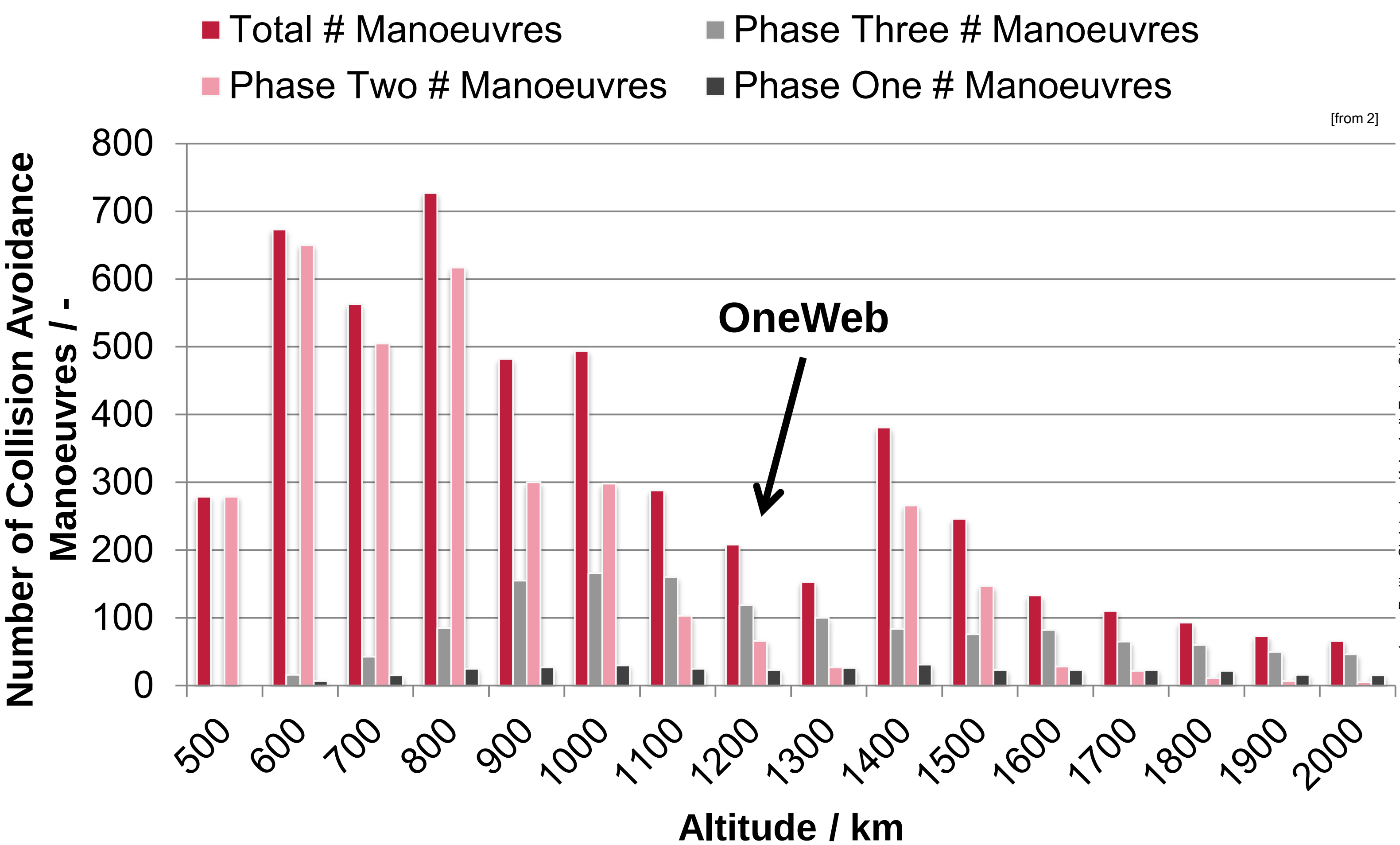
*Numbers state probabilities to collide at least once.

Operational altitude variation: Coll. Avoidance manoeuvres



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Operational lifetime and PMD rate variation

So far:

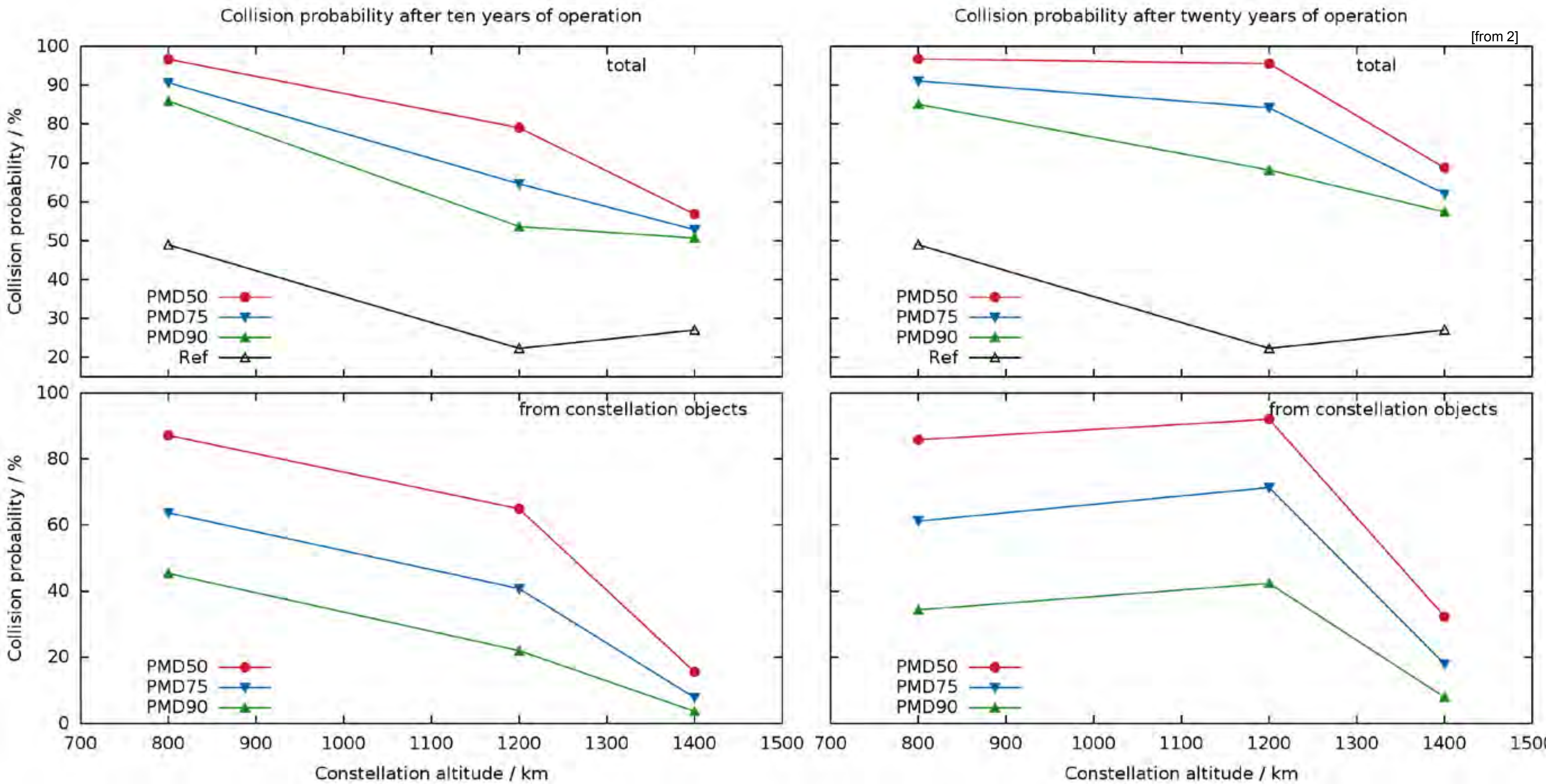
- Considered OneWeb baseline case,
- Varied the operational altitude (and number of needed satellites).

Next step:

- Investigate the impact of
  - Constellation‘s operational lifetime → 10 years and 20 years,
  - Impact of post-mission disposal success rate during that time → 50%, 70%, 90%.

Operational lifetime and PMD rate variation: Coll. probabilities

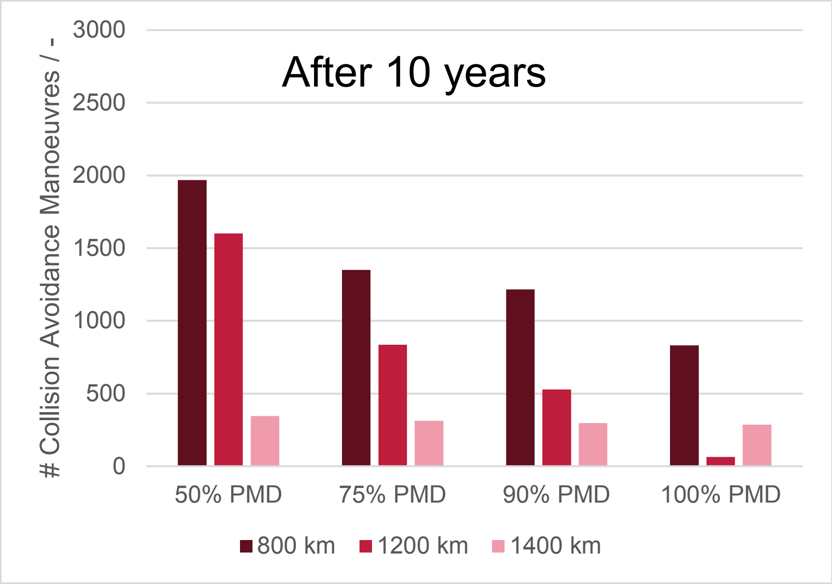
All figures: Jonas Radtke, Christopher Kebschull, Enrico Stoll, Interactions of the space debris environment with Mega constellations— Using the example of the OneWeb constellation, Acta Astronautica, Volume 131, February 2017, Pages 55-68, ISSN 0094-5765, http://dx.doi.org/10.1016/j.actaastro.2016.11.021.

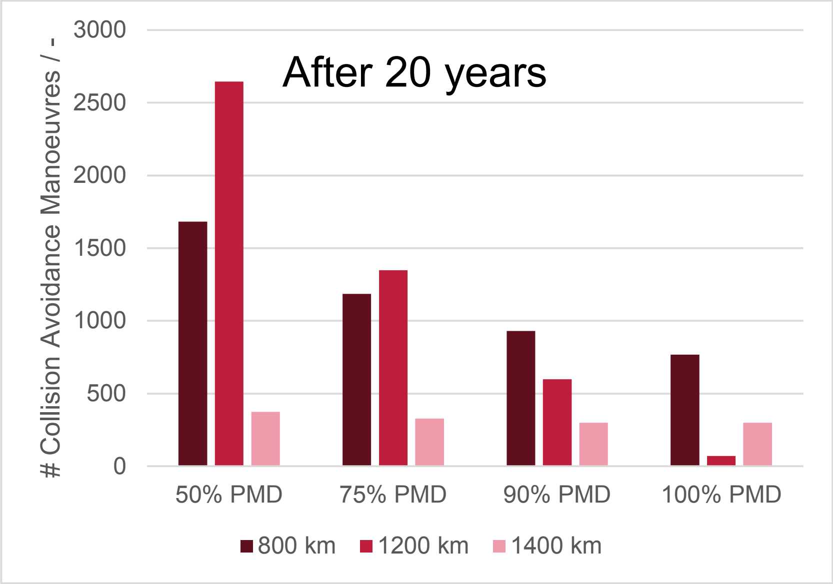


*Results always valid for last generation of satellites of the constellation.

Operational lifetime and PMD rate variation: Avoid. manoeuvres

Both figures: Jonas Radtke, Christopher Kebschull, Enrico Stoll, Interactions of the space debris environment with Mega constellations— Using the example of the OneWeb constellation, Acta Astronautica, Volume 131, February 2017, Pages 55-68, ISSN 0094-5765, http://dx.doi.org/10.1016/j.actaastro.2016.11.021.





→ High PMD rates especially of importance for altitudes without significant contribution of drag.

→ Lifetime and shape of disposal orbit of less interest for the constellation.

Summary and conclusion (1)

Impact of a constellation on the space debris environment:

- The impact on the **long-term is governed by the number of objects left** in the space-debris environment. On the mean, at least 90% disposal success are needed for no long-term impact.

- The impact on **the short- and medium-term are governed by the lifetime** of disposal orbits.

- If a strict debris mitigation plan is implemented, the space debris environment can sustain a Mega-Constellation (up to a threshold not determined).

Summary and conclusion (2)

Impact of the space debris environment on a Mega-Constellation:

- Objects need to be able to perform collision avoidance, else catastrophic collisions become almost unavoidable after time.
- The altitude chosen by OneWeb turns out to be an ideal case in regards to space debris impact, for the first generation of satellites.
- Given the low impact of drag in high altitudes, a high post-mission disposal success is crucial for a constellation. From a constellation's point of view though, little changes in the orbit suffice.
- Especially at altitude between ~1000 km and 1400 km, where the drag does not support orbital clearing and the volume available is still comparably small, a high success rate of end-of-life disposal is even more important.

References and further reading

[1] B. Bastida Virgili, J.C. Dolado, H.G. Lewis, J. Radtke, H. Krag, B. Revelin, C. Cazaux, C. Colombo, R. Crowther, M. Metz, **Risk to space sustainability from large constellations of satellites**, Acta Astronautica, Volume 126, September–October 2016, Pages 154-162, ISSN 0094-5765, http://dx.doi.org/10.1016/j.actaastro.2016.03.034.

[2] Jonas Radtke, Christopher Kebschull, Enrico Stoll, **Interactions of the space debris environment with Mega constellations— Using the example of the OneWeb constellation**, Acta Astronautica, Volume 131, February 2017, Pages 55-68, ISSN 0094-5765, http://dx.doi.org/10.1016/j.actaastro.2016.11.021.
Freely available (until Jan 12th 2017): https://authors.elsevier.com/a/1U5gL_29e7zq6p

[3] B. Bastida Virgili, H. Krag, H. Lewis, J. Radtke, A. Rossi, **Mega-constellations, small satellites and their impact on the space debris environment,** 27/09/2016, 67th IAC, Guadalajara, Mexico.

Upcoming:
ESA Contract (4000115454-15-F-MOS): “Impact risk in LEO as a result of the increase of nano and micro satellites”, Final presentation TBD.

Thank you for your attention.

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