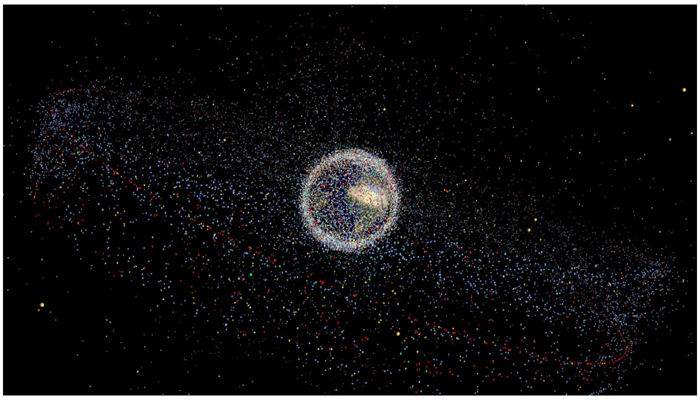
A07

Modelling the Space Debris Environment

Carsten Wiedemann and Enrico Stoll (TU Braunschweig)

The development of the new MASTER model has just been completed at the Institute of Space Systems of the TU Braunschweig. The most important changes in the population are presented here. MASTER stands for "Meteoroid and Space Debris Terrestrial Environment Reference". The development is carried out on behalf of the European Space Agency ESA. The model considers numerous different sources of space debris. As part of the update, the contributions of the individual sources have been scientifically revised. This revision includes to a lesser extent the introduction of new sources that were not previously known. Far more important, however, is the addition of further events to already considered sources that were not known in the past. In addition, events that have occurred since 2009, when the last version of the MASTER model was published, must be added. Furthermore, the revision includes the complete creation of the historical particle population on Earth orbits. This also means that the new population may differ in some areas from previous versions of the model. An update of the model is required at regular intervals. Past forecasts must then also be adapted to the current state of knowledge. In individual cases, some historical events must also be checked in detail. This is particularly necessary if current measurements indicate that a relatively recent event released considerably more debris than originally measured. Examples of particle flux analyses for typical satellites are presented.



Biography

Carsten Wiedemann

Dr.-Ing. Carsten Wiedemann is a permanently employed senior scientist at the Institute of Space Systems at the Technische Universität Braunschweig (Germany). His tasks include the following positions: quality manager of the institute, team head of the space debris group, organization and presentation of lectures, supervision of student research projects, and scientific project work. He is member of the DLR delegation at the Inter-Agency Space Debris Coordination Committee (IADC). His field of research is the modeling of the space debris environment. One important research project was the development and upgrading of the ESA MASTER model.

Technische Universität Braunschweig
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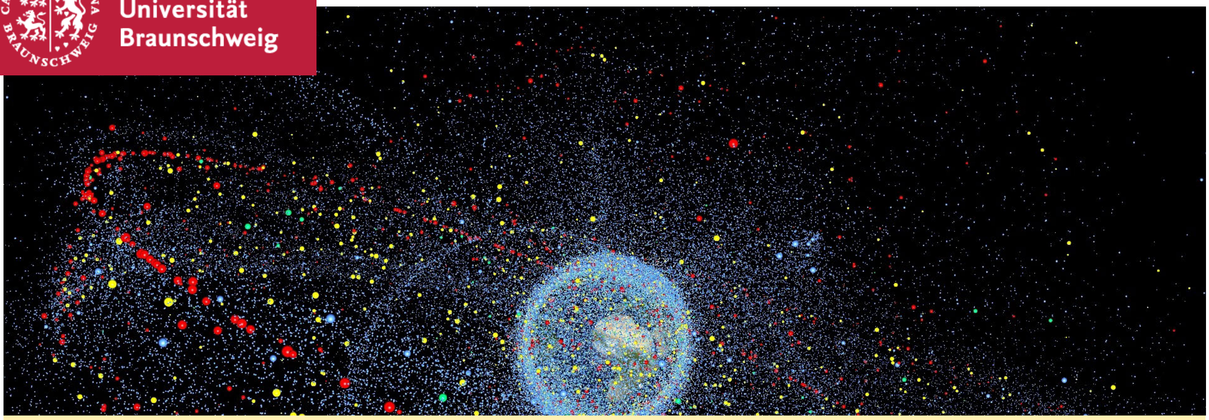

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Introduction

The development of the new MASTER model has just been completed at the Institute of Space Systems of the TU Braunschweig. The most important changes in the population are presented here.

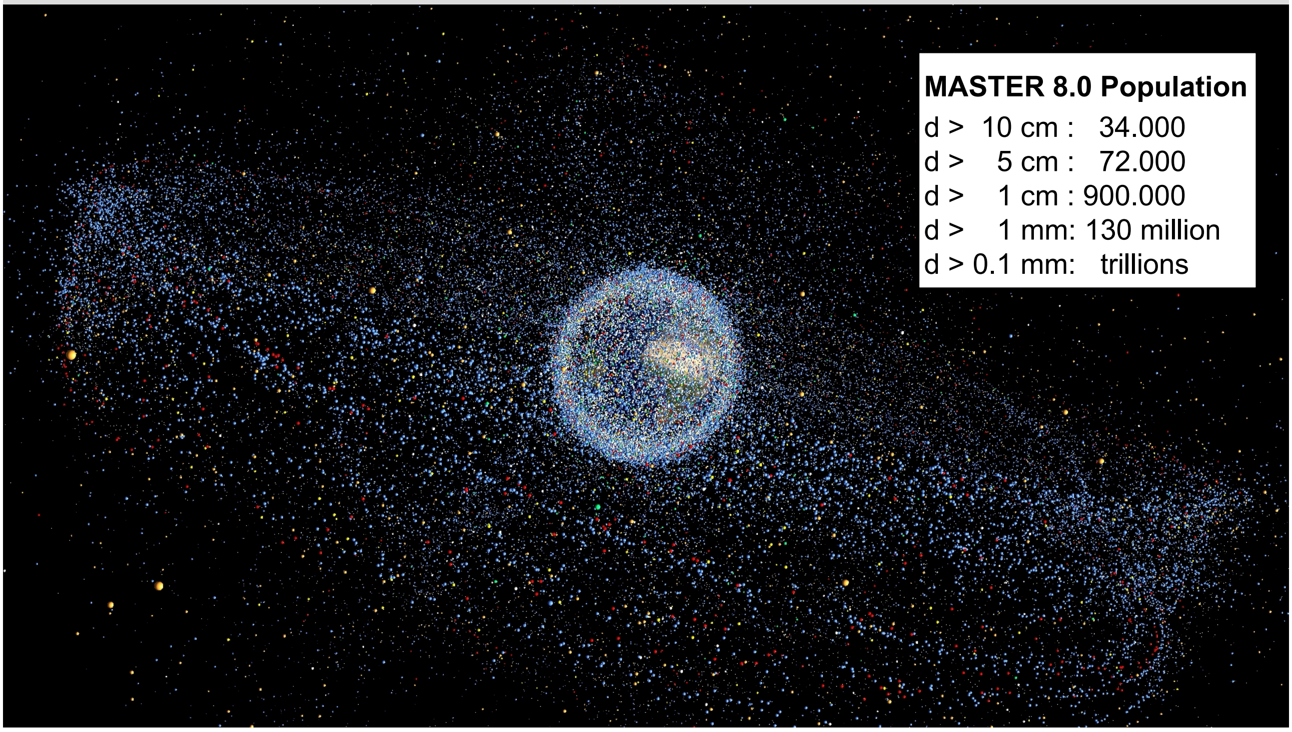
- As part of the update, the contributions of the individual sources have been scientifically revised.
- In addition, events that have occurred since 2009, when the last version of the MASTER model was published, must be added.
- Furthermore, the revision includes the complete creation of the historical particle population on Earth orbits.

This also means that the new population may differ in some areas from previous versions of the model.

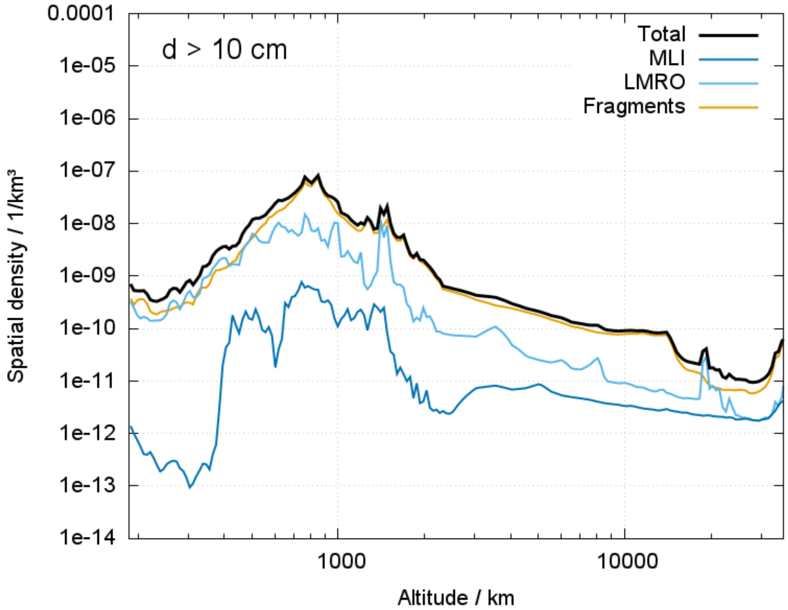
Examples of particle flux analyses for typical satellites are presented.

A simplified cost model for the assessment of mitigation measures, the post-mission disposal (PMD) maneuvers is presented. PMD maneuvers are used for de-orbiting of low-earth orbit (LEO) spacecraft at the end of the operational lifetime.

Object Numbers on all Orbits (LEO to GEO)

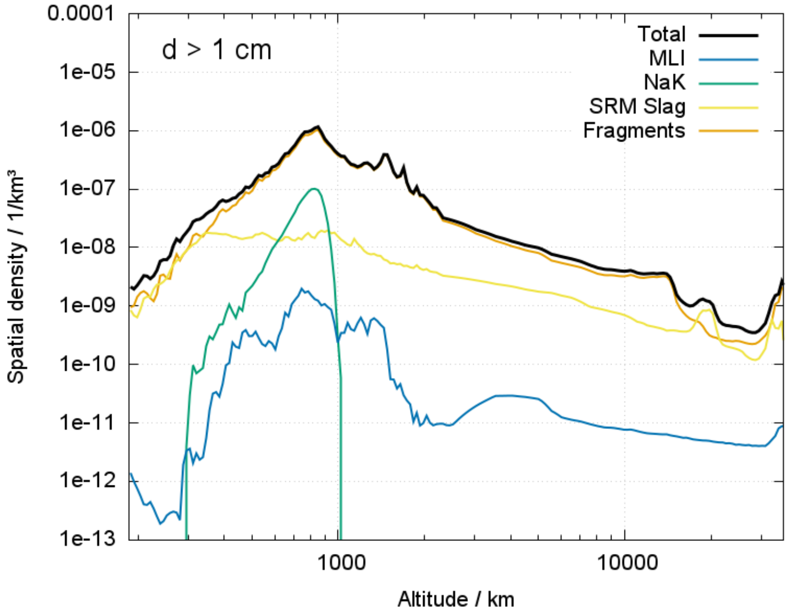


The 10 cm Population



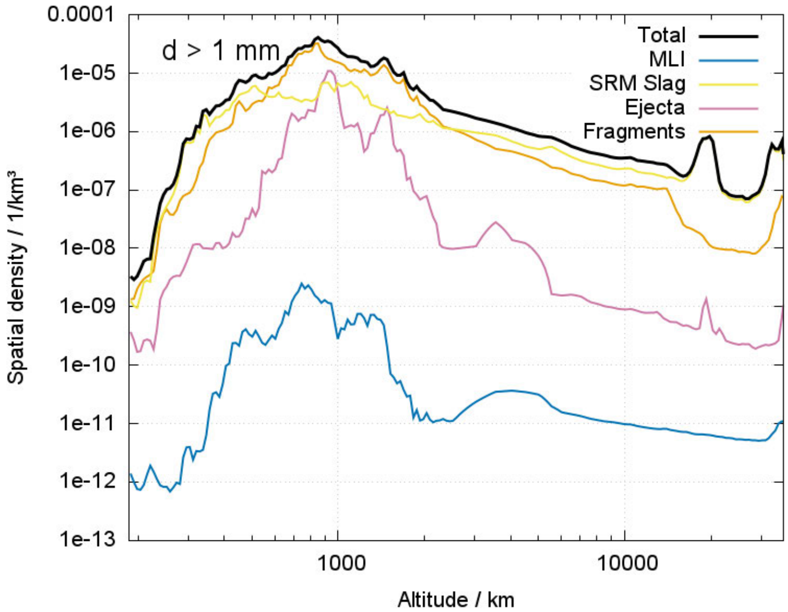
Spatial density of objects larger than 10 cm on earth orbits in the year 2016 (validated).

The 1 cm Population



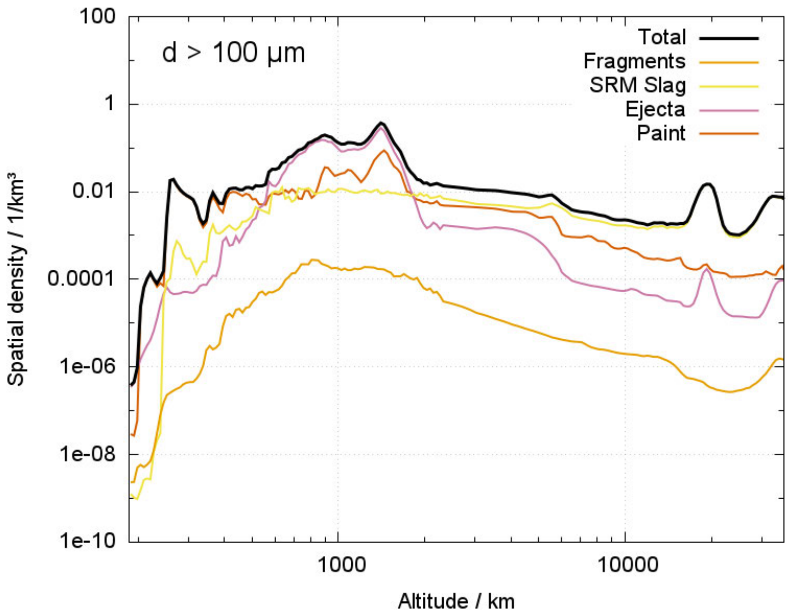
Spatial density of objects larger than 1 cm on earth orbits in the year 2016 (validated).

The 1 mm Population



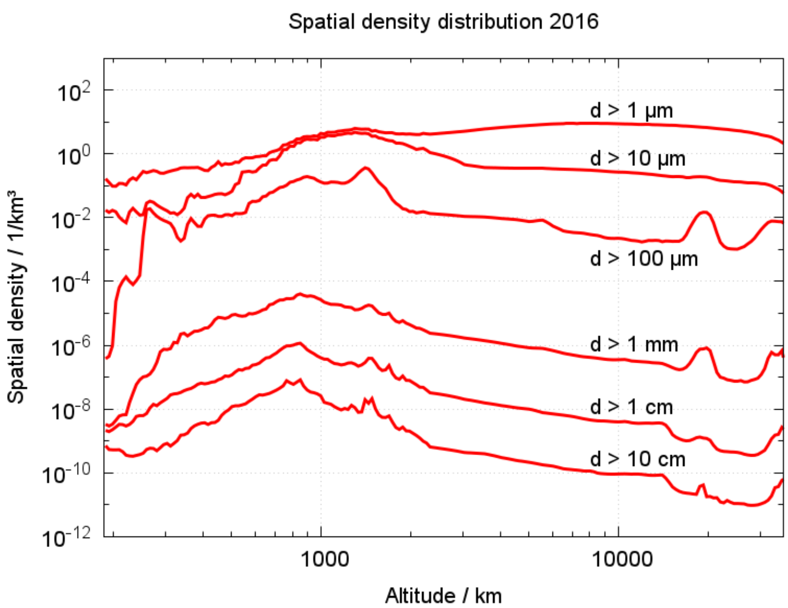
Spatial density of objects larger than 1 mm on earth orbits in the year 2016 (validated).

The 100 µm Population



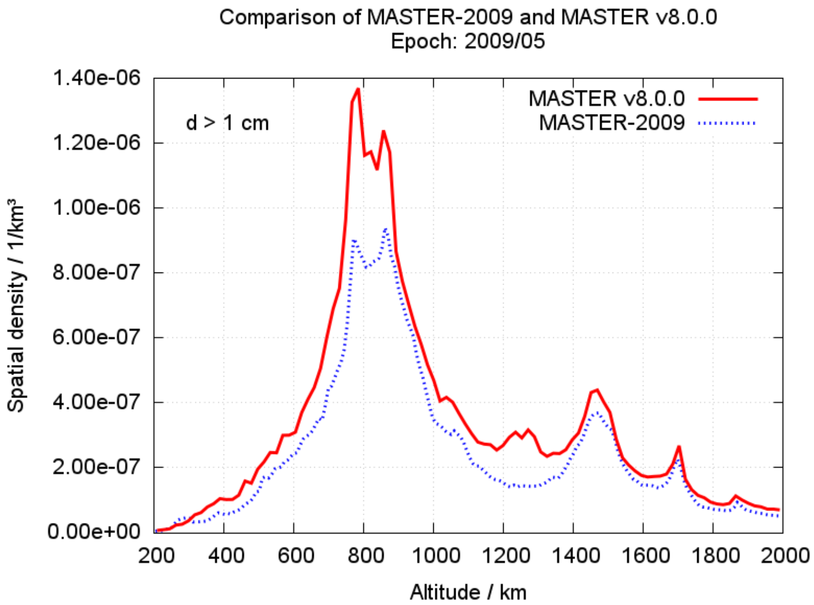
Spatial density of objects larger than 100 µm on earth orbits in the year 2016 (validated).

Comparison: All Size Classes



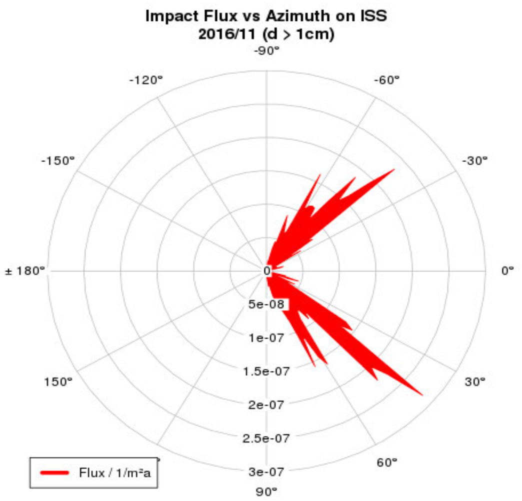
Comparison of spatial densities for all considered debris size classes in the year 2016 (validated)

Comparison: MASTER-Versions



Comparison of the spatial density of objects larger than 1cm, calculated using the new MASTER model, to the results for the previous version (1.Mai 2009).

Particle Flux Sources: Example LEO

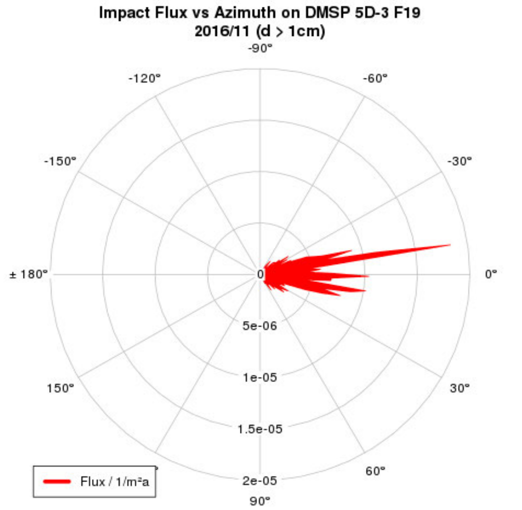


Directional debris flux as azimuth distribution for objects greater than 1 cm per square meter cross-sectional area and per year on a LEO target object at about 400 km altitude according to the new MASTER model

Flux	[1/m²/a]		
Diameter	Man-Made	Meteroids	Total
d > 1cm	5.65E-06	4.37E-06	1.00E-05
d > 1mm	2.68E-04	1.48E-03	1.75E-03
Time	**[a]**		
Diameter	Man-Maide	Meteroids	Total
d > 1cm	177,022	228,833	99,800
d > 1mm	3,728	677	572

Particle flux of man-made debris and natural meteroids as well as average time between two subsequent impacts in years on one square meter cross-sectional area for the LEO example

Particle Flux Sources: Example SSO (900km)

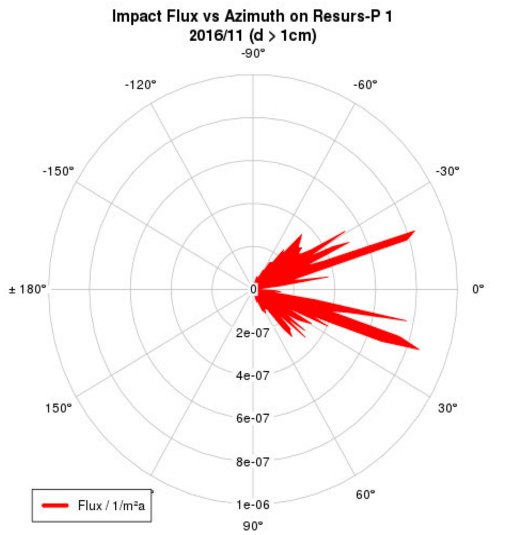


Flux	[1/m²/a]		
Diameter	Man-Made	Meteoroids	Total
d > 1cm	2.34E-04	4.42E-06	2.39E-04
d > 1mm	9.77E-03	1.49E-03	1.13E-02
Time	**[a]**		
Diameter	Man-Made	Meteoroids	Total
d > 1cm	4,268	226,296	4,189
d > 1mm	102	669	89

Directional debris flux as azimuth distribution for objects greater than 1 cm per square meter cross-sectional area and per year on a LEO target object at about 900 km altitude according to the new MASTER model

Particle flux of man-made debris and natural meteoroids as well as average time between two subsequent impacts in years on one square meter cross-sectional area for the SSO (900 km) example

Particle Flux Sources: Example SSO (460km)

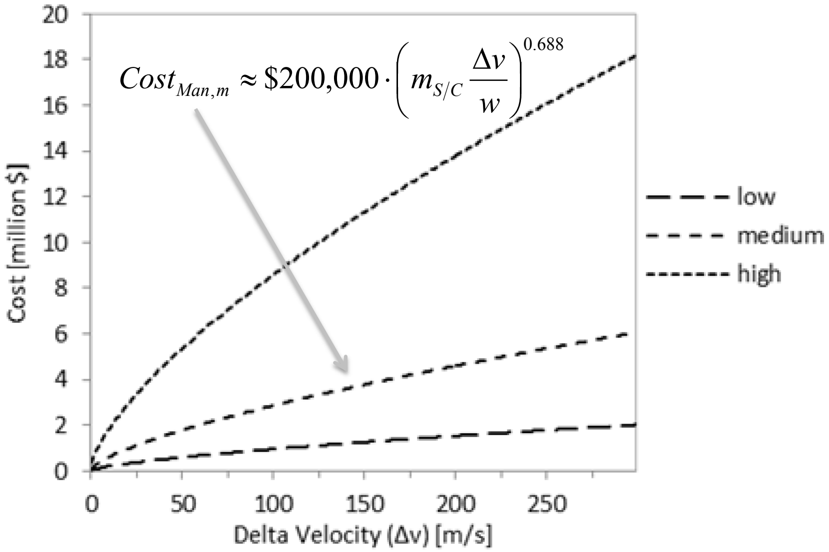


Flux	[1/m²/a]		
Diameter	Man-Made	Meteoroids	Total
d > 1cm	1.91E-05	4.26E-06	2.34E-05
d > 1mm	1.77E-03	1.44E-03	3.21E-03
Time	**[a]**		
Diameter	Man-Made	Meteoroids	Total
d > 1cm	52,329	234,522	42,790
d > 1mm	567	693	312

Directional debris flux as azimuth distribution for objects greater than 1 cm per square meter cross-sectional area and per year on a LEO target object at about 460 km altitude according to the new MASTER model

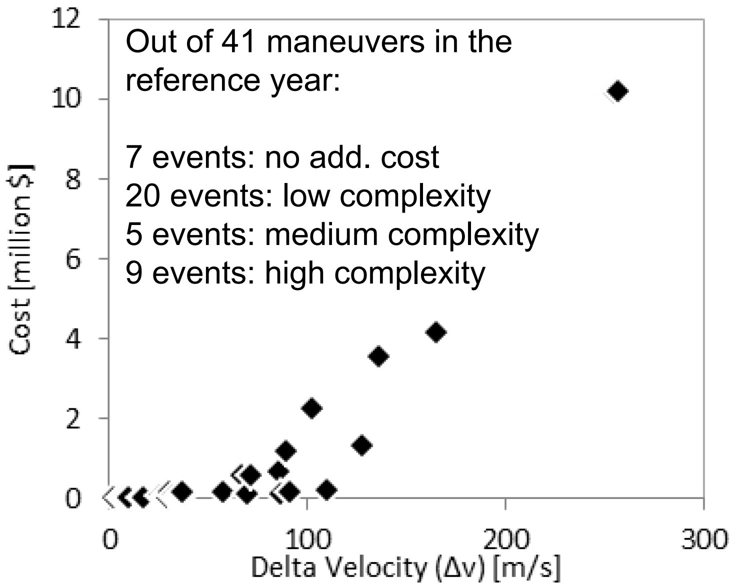
Particle flux of man-made debris and natural meteoroids as well as average time between two subsequent impacts in years on one square meter cross-sectional area for the SSO (460 km) example

Cost Model for Post Mission Disposal Maneuvers



Representative cost models for propulsion systems considering a combination of TFU and development costs (in US $ of 2017).

PMD Maneuver Cost (25-Years Rule)



Individual costs for all 41 PMD maneuvers of the exemplary reference year to comply with the 25-years rule (in US $ of 2017).

Conclusion

- The validated population forms the basis for the risk analysis of the new MASTER model.
- The population has been simplified in an appropriate way to visualize the main accumulations of space debris on specific orbits.
- An important partial result of the now completed investigations is that the FengYun-1C event, which occurred at an altitude of about 850 km in 2007, had to be re-evaluated.
- According to the current state of knowledge, the number of centimeter objects at these altitudes can be estimated to be about 50 % higher than assumed in the last version of the MASTER model.
- A cost formula is presented with which orbit maneuvers can be calculated. The cost estimation depends on the mass of the object to be maneuvered and the velocity requirement.

Acknowledgements

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