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## Ongoing Activities in the Field of Space Debris Modeling

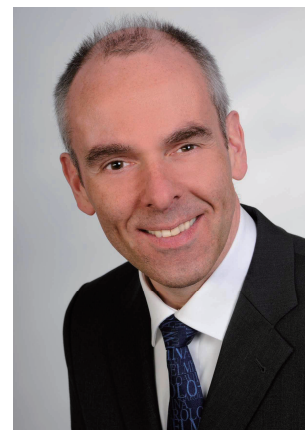
**Carsten Wiedemann**  
**Braunschweig University of Technology, Germany**

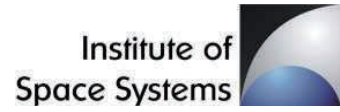
A significant amount of the larger orbital objects is continuously tracked by sensors. The existence of smaller objects is known from sporadic measurement campaigns. But their orbits cannot be tracked. The number and the orbital distribution of small objects must be described by statistical models. These models must have the capability to reproduce the sporadically obtained measured data. Especially in the millimeter and centimeter range there are large uncertainties due to missing data. Currently there are about 700,000 man-made objects larger than one centimeter on all Earth orbits. The number of objects larger than one millimeter is estimated to be 200 million. The number of objects in the sub-millimeter range is several trillions. The most dangerous objects exist between one and ten centimeters in diameter. They are too small to be tracked and too big for protective measures. It is important to identify the main risk factors for the most important orbits. For these orbits it is useful to implement regulations on the mitigation of space debris. The highest spatial object density exists at altitudes near 900 km. (Only in the micrometer size range, the highest density is found near 1000 km.) This can be shown by simulations. Below 900 km, the orbital lifetime of objects decreases due to the atmospheric drag, leading to a reduction in spatial object density towards lower altitudes. Above 900 km altitude, space activities decrease because less debris is produced there. Important tasks in the field of updating the existing model are the consideration of new fragmentation events, the review of historic events, and the validation of the new population with measurement data.

### **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 modeling of the space debris environment. One important research project was the development and upgrading of the ESA MASTER (Meteoroid and Space Debris Terrestrial Environment Reference) model.





## Ongoing Activities in the Field of Space Debris Modeling

Dr.-Ing. Carsten Wiedemann, Prof. Dr.-Ing. Enrico Stoll

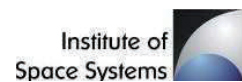
### Space Debris Research in Braunschweig

Meteoroid and Space Debris  
Terrestrial Environment  
Reference

Program for Radar and  
Optical Observation  
Forecasting



Carsten Wiedemann - Space Debris



## Overview

### Introduction

#### Current Status

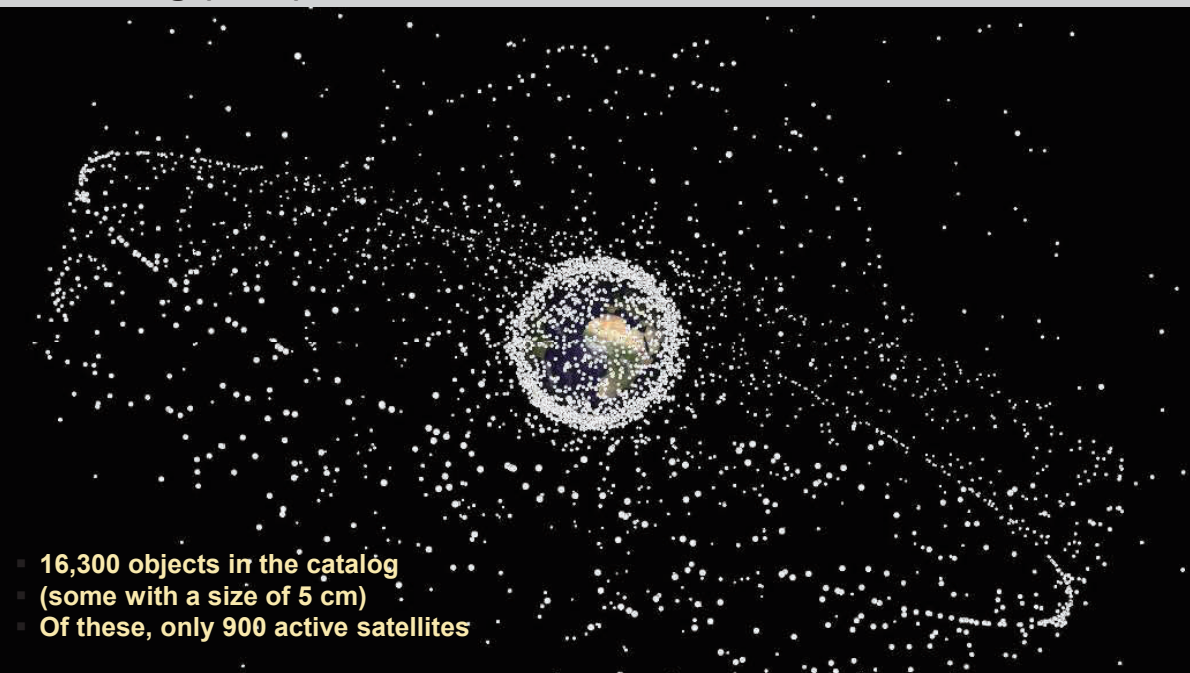
- Space debris sources
- Object distribution
- Particle flux on different orbits
- Long-term simulation

#### Ongoing Activities

- Model update
- Investigation of mitigation measures
- Review of sensor data
- Establishing a new population

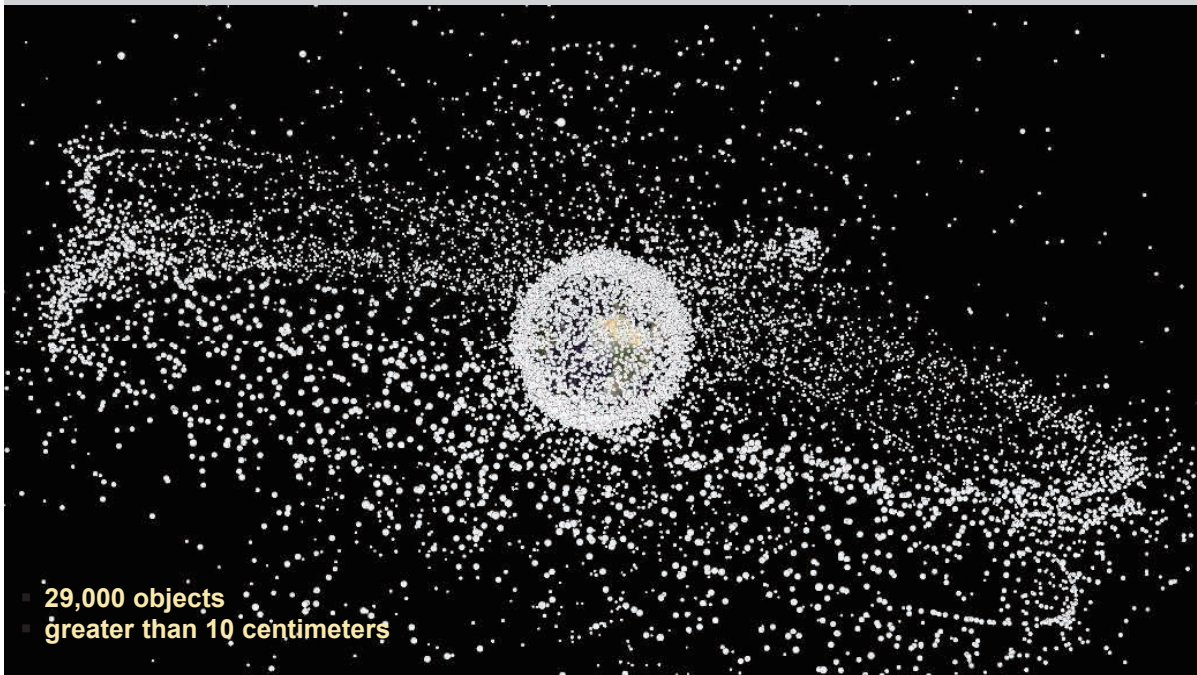
#### Summary

## Catalog (2009)





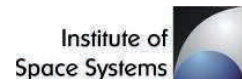
### Objects greater than 10 cm



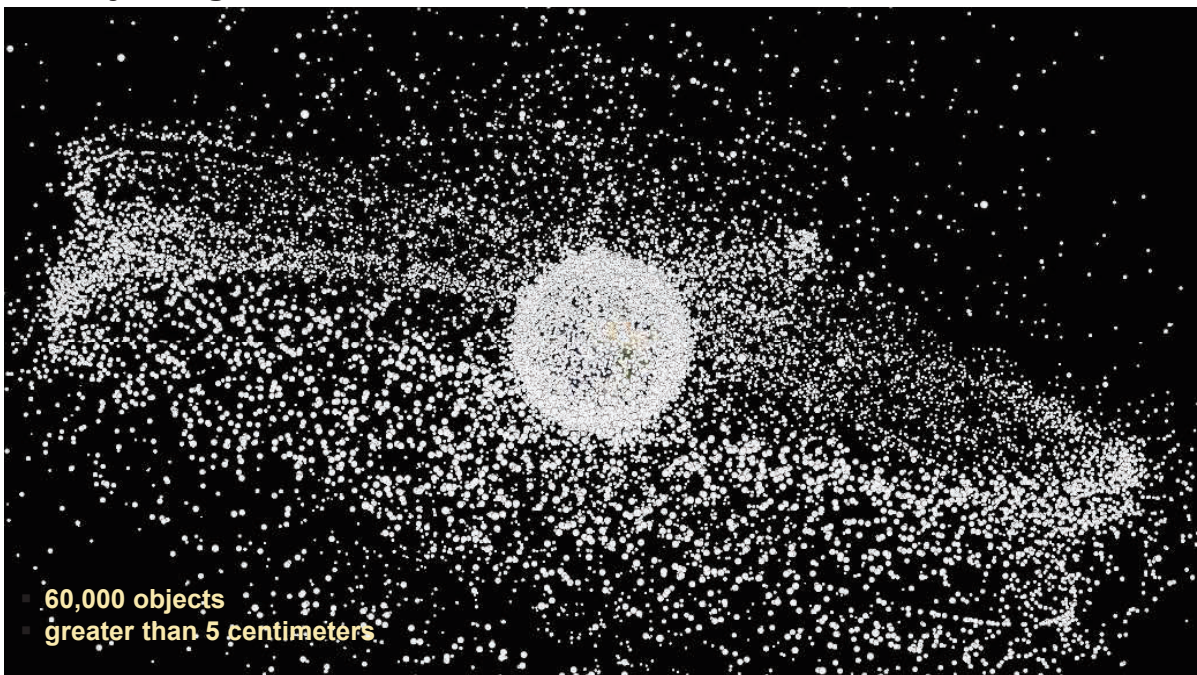
29,000 objects  
greater than 10 centimeters



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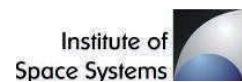
### Objects greater than 5 cm



60,000 objects  
greater than 5 centimeters

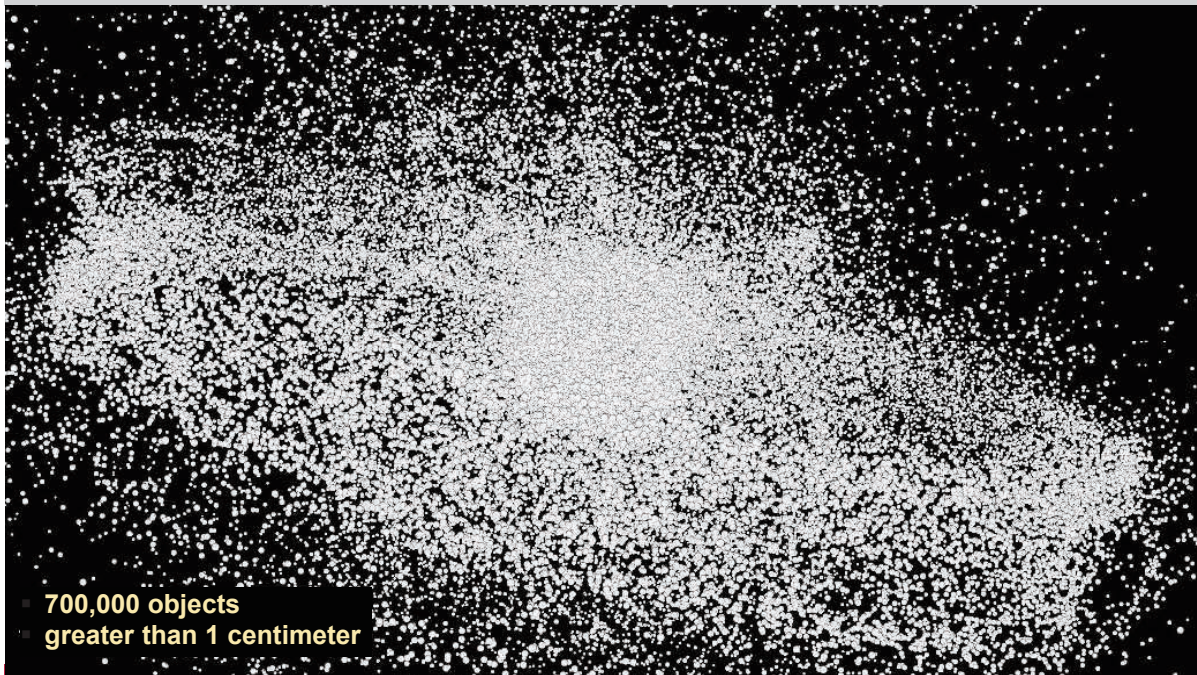


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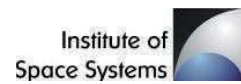
## Objects greater than 1 cm



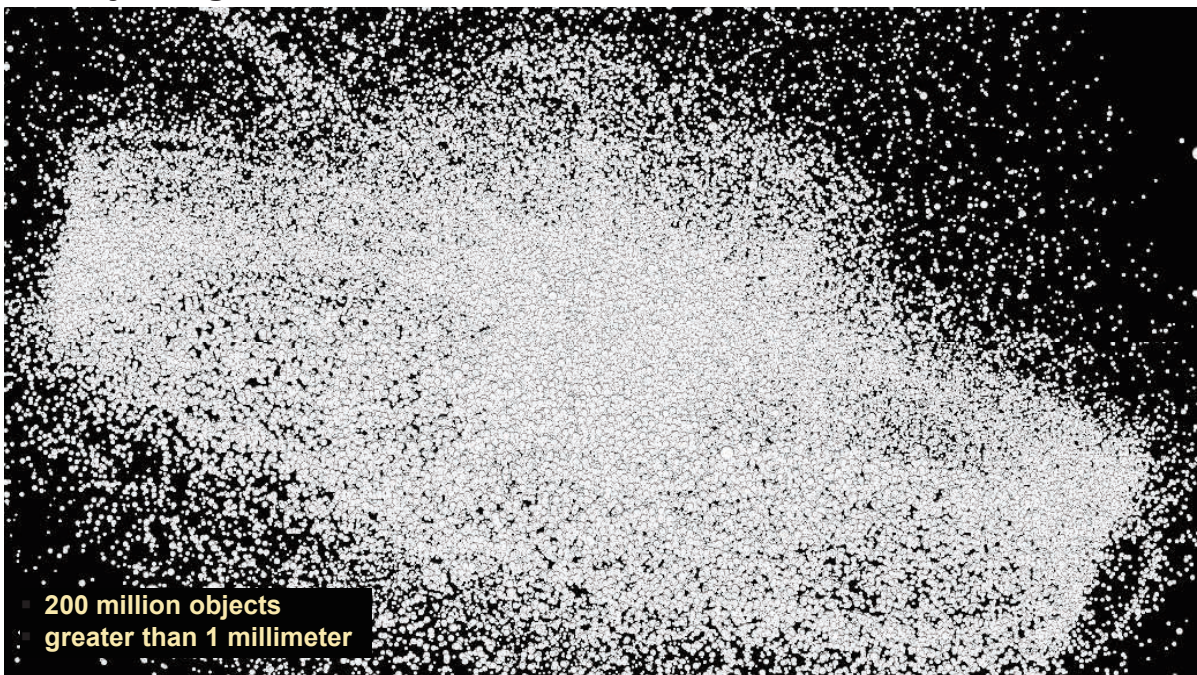
**700,000 objects  
greater than 1 centimeter**



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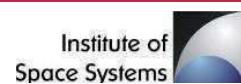
## Objects greater than 1 mm



**200 million objects  
greater than 1 millimeter**

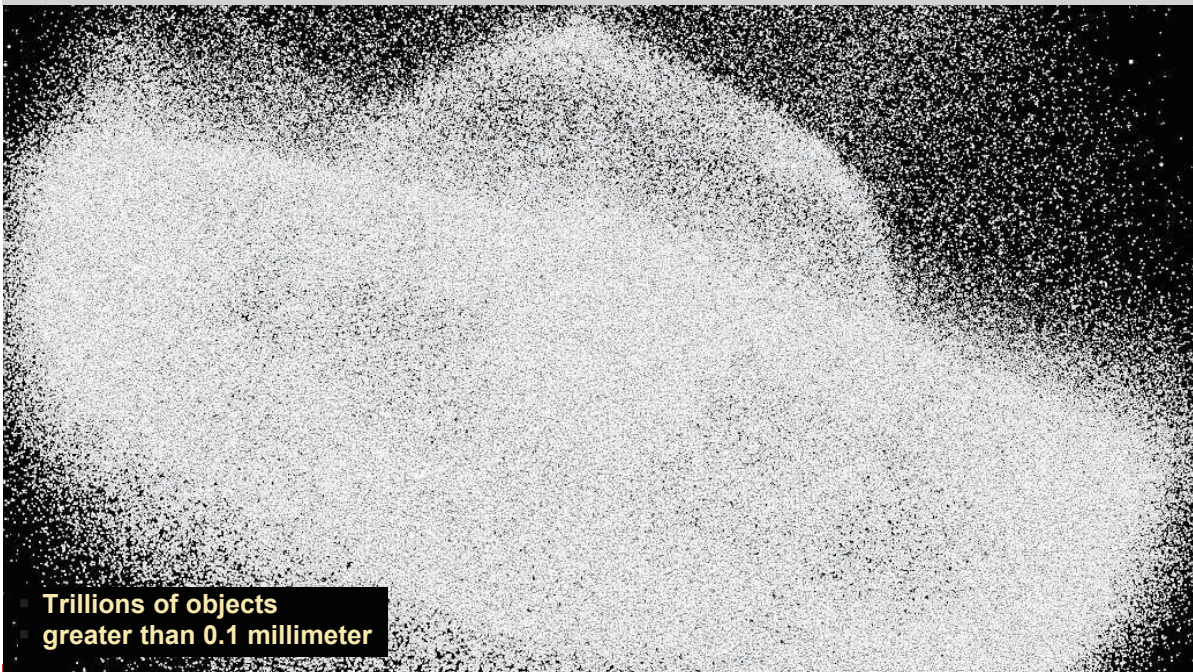


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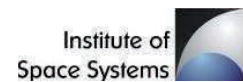




## Objects greater than one tenth of a millimeter



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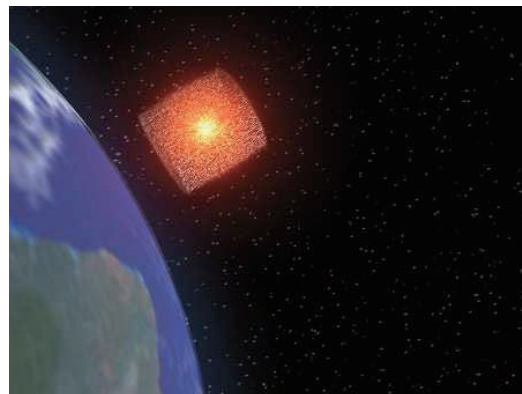


## Fragmentations

Is space debris a problem ?

### Generation of space debris

- Most significant contribution: Explosion fragments
- 234 explosions of satellites and rocket bodies
- Common reason: unintentional self-ignition of residual fuel

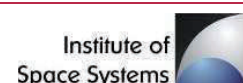


### High velocity impacts on satellite surfaces

- High relative velocities of about 10 km/s
- Twelve times the energy of dynamite
- Centimeter object: energy of a hand grenade



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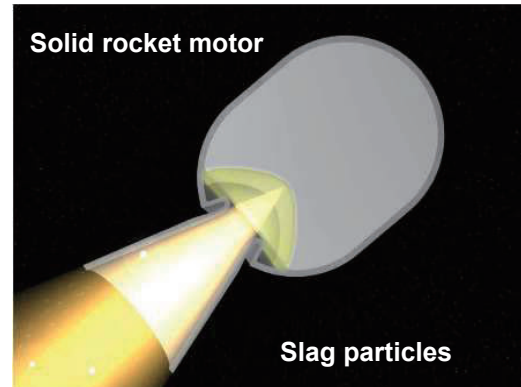


## Solid Rocket Motor Slag

New contributions to the space debris environment

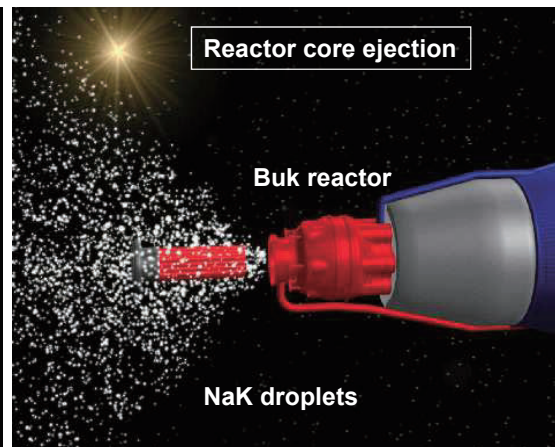
### Solid Rocket Motor Slag

- 1,965 orbital transfer maneuvers
- Most maneuvers occurred at altitudes between 200 – 800 km and at 36,000 km
- Composition: mainly aluminum oxide
- Size of slag particles: up to 6 cm



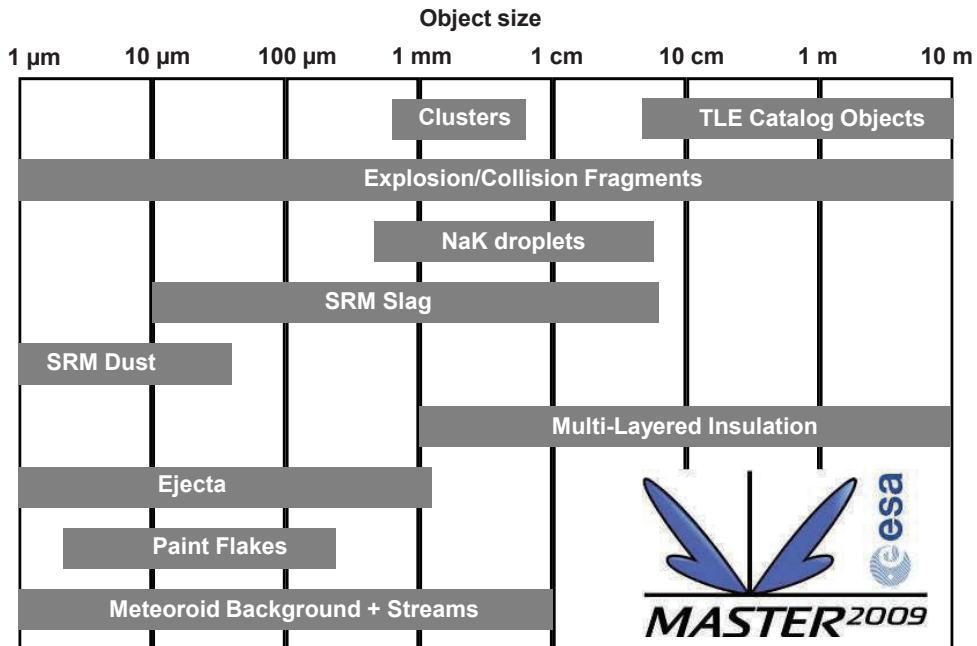
## Liquid Metal Droplets

RORSAT: Nuclear reactors in space

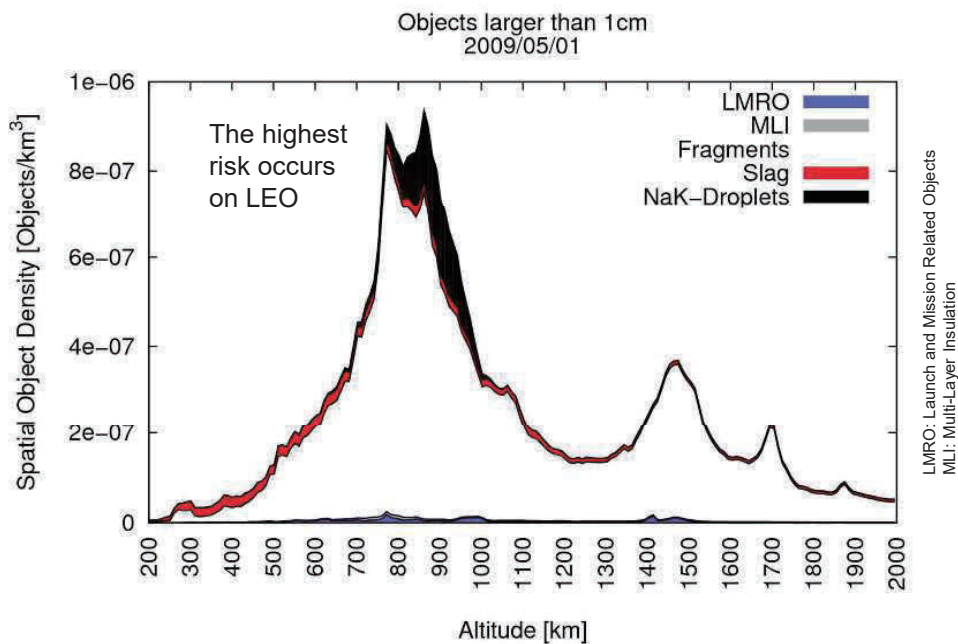


It is assumed that the release of reactor coolant is an **uncontrolled, unintentional by-product** of the core ejection process. A total of **16 core ejections events** have taken place.

## Size Range of Space Debris Sources



## Spatial Density (2009)

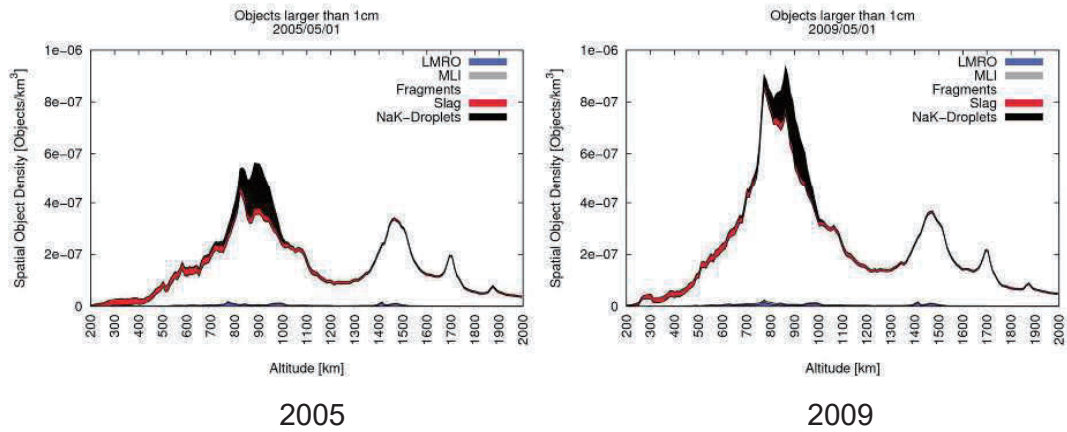




## Spatial Density (> 1 cm)

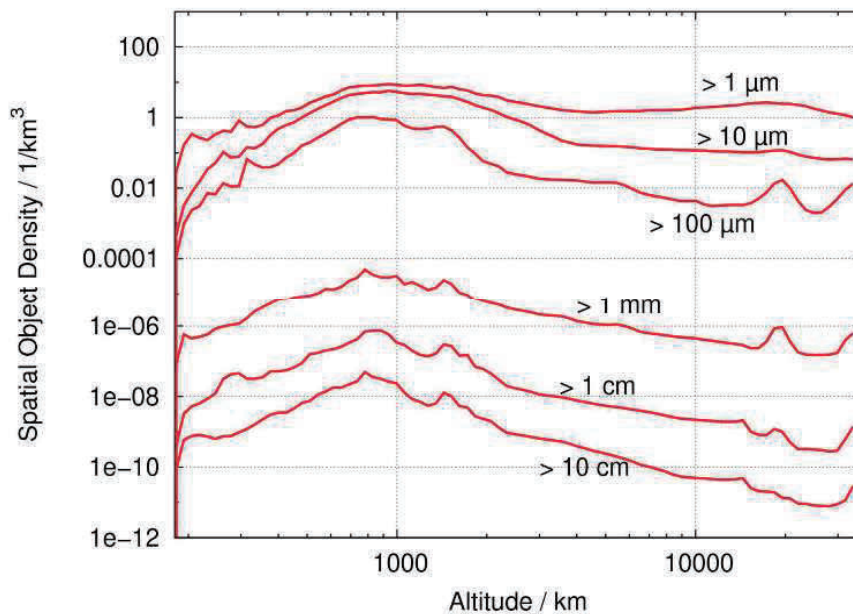
Significant increase in the fragments as a result of two events:

- FengYun-1C (2007)
- Cosmos/Iridium (2009)

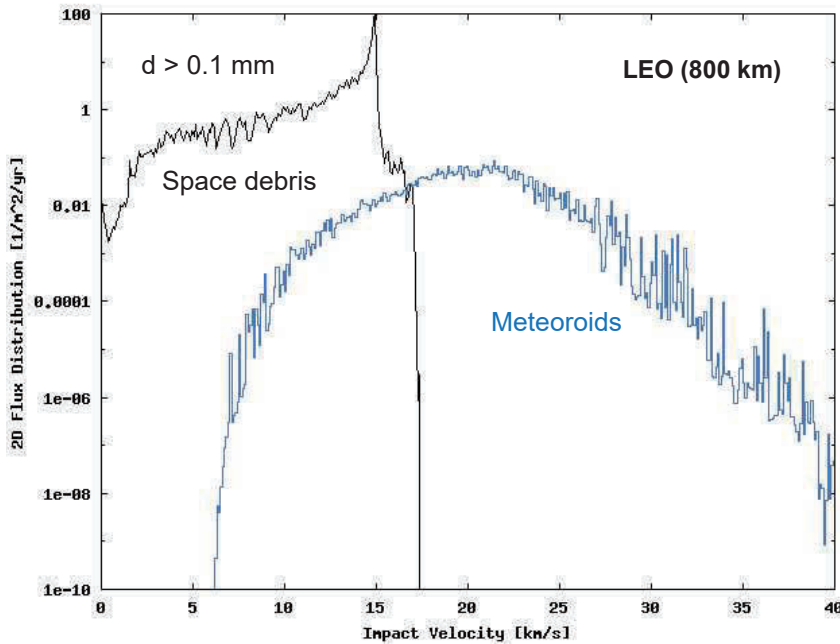


Spatial density of debris larger than one centimeter according to MASTER-2009

## Spatial Density Distribution



### Impact Velocity Distribution on LEO

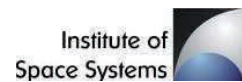


Space debris exceeds meteoroids by two orders of magnitude. Mainly head-on collisions can be expected (twice orbital velocity).

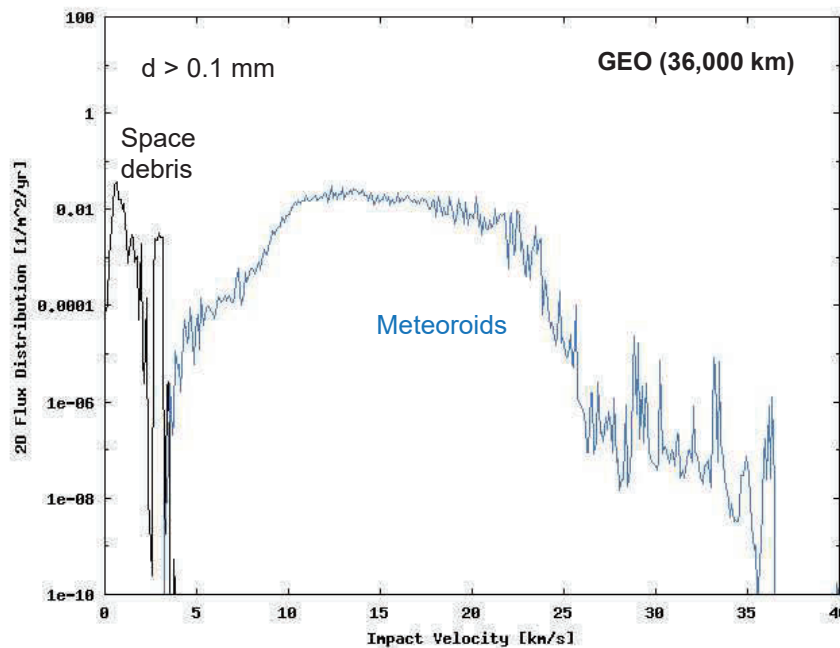
Impact velocity distribution for objects greater than 0.1 mm for the leading surface of an Earth-oriented satellite according to MASTER-2009 (May 1, 2009).



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### Impact Velocity Distribution on GEO

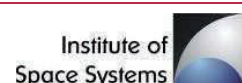


Meteoroids dominate due to the lack of space debris.

Impact velocity distribution for objects greater than 0.1 mm for the leading surface of an Earth-oriented satellite according to MASTER-2009 (May 1, 2009).



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## ESA's Space Debris Model MASTER (1)

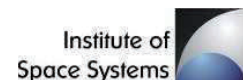
### Meteoroid and Space Debris Terrestrial Environment Reference Model (MASTER)



Institute of Space Systems  
TU Braunschweig



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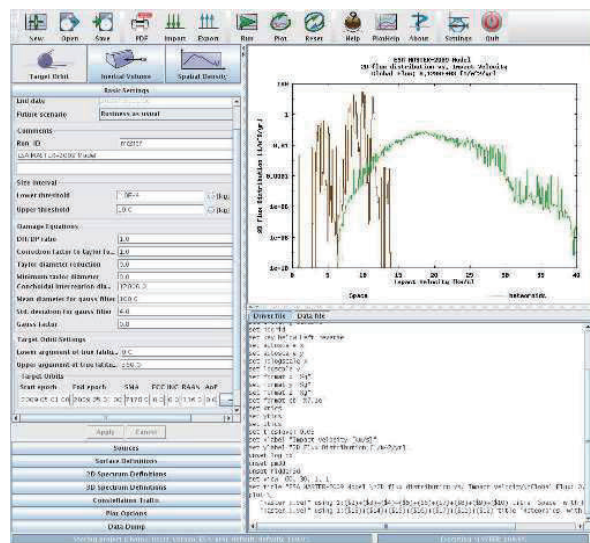
## ESA-MASTER Space Debris Model (2)



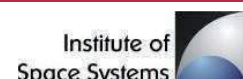
### Space Debris Model MASTER

- Necessity: only partial measurement data for small size population
- Population generation: simulation of all events, propagation of object clouds
- Validation: radar measurements, impacts on S/C hardware

→ Realistic depiction of the space debris environment down to 1µm object size

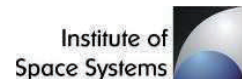
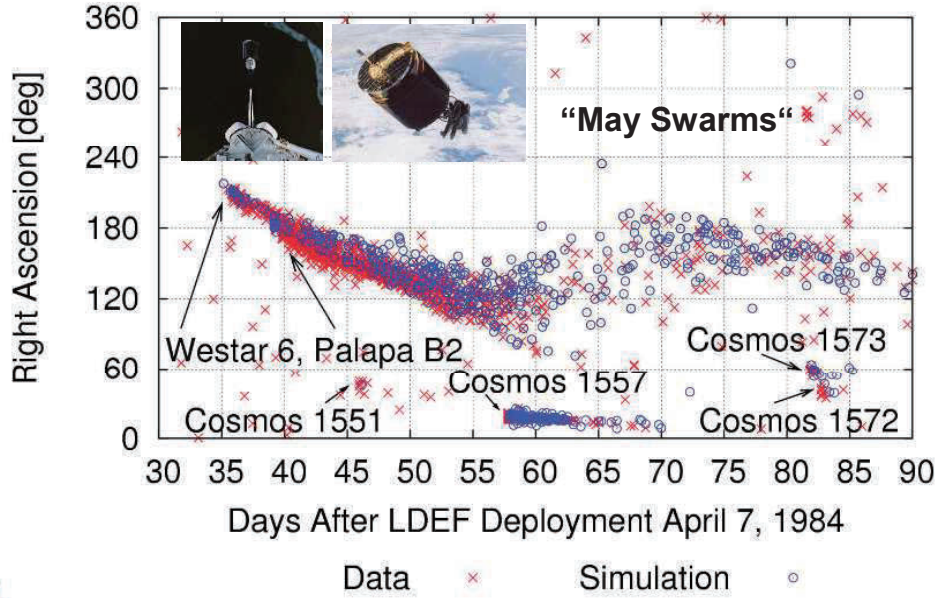


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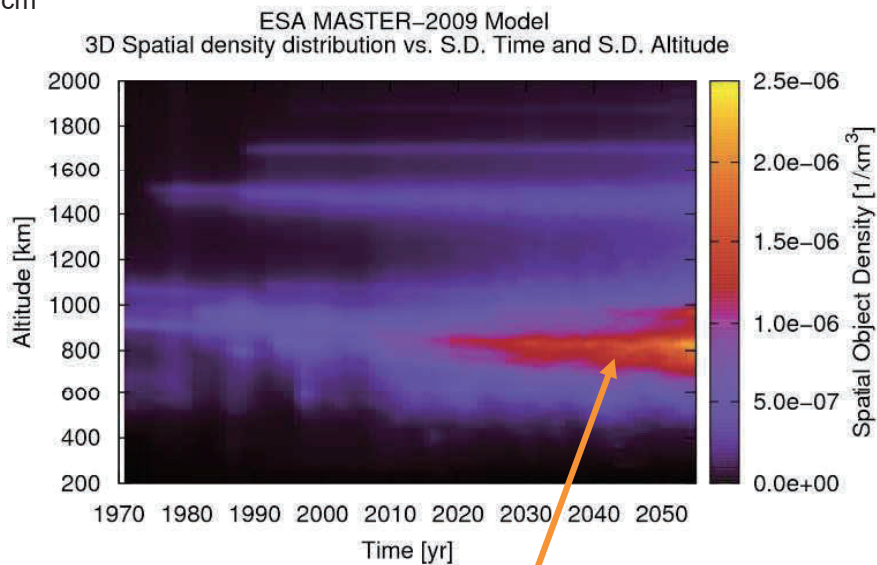
# Validation (Example)

### Event Simulation for IDE South Face

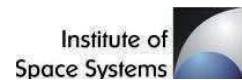


# Long-term Simulation of the Space Debris Environment

d > 1 cm

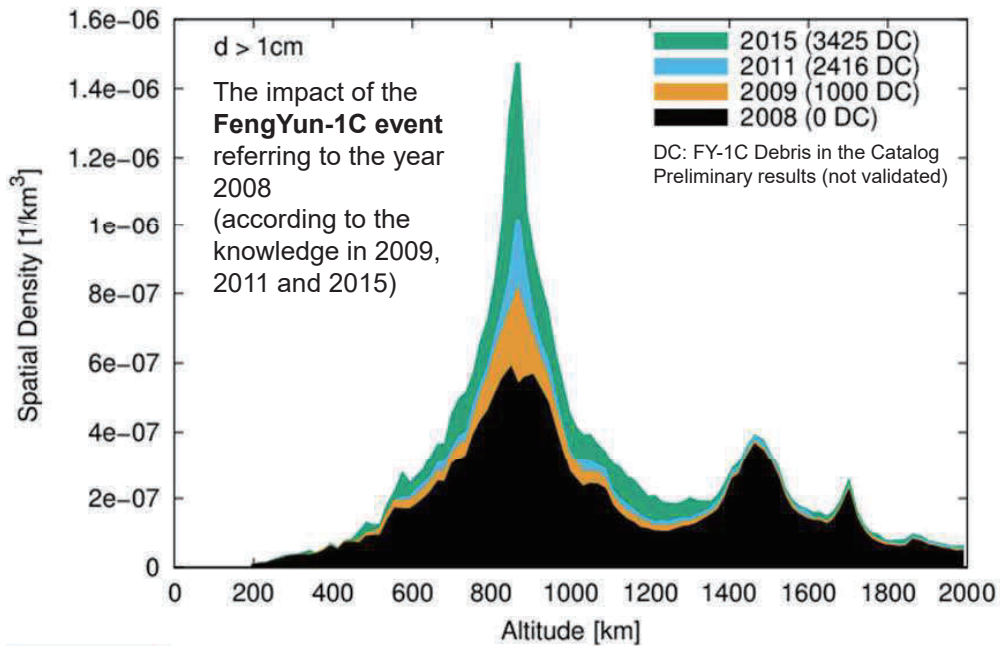


Increasing risk for Earth observation satellites

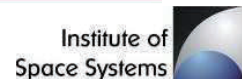




### Model Update (Example)



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### Long-term Projection of the Space Debris Environment

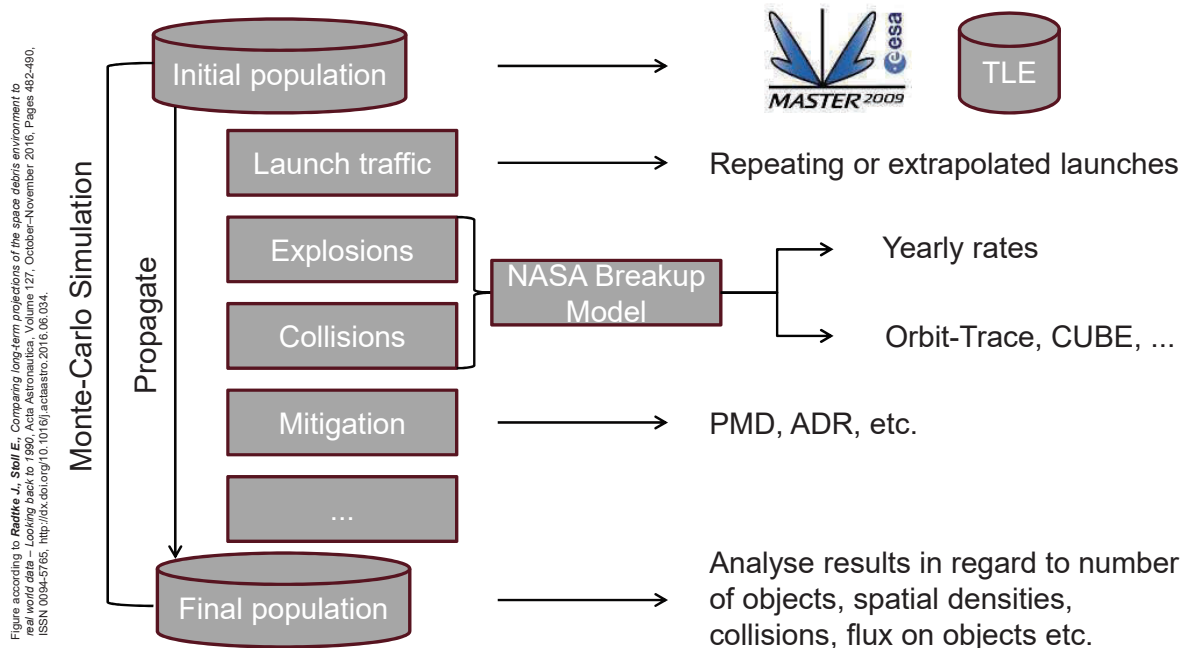
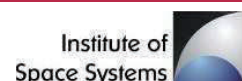
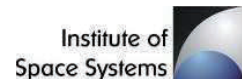
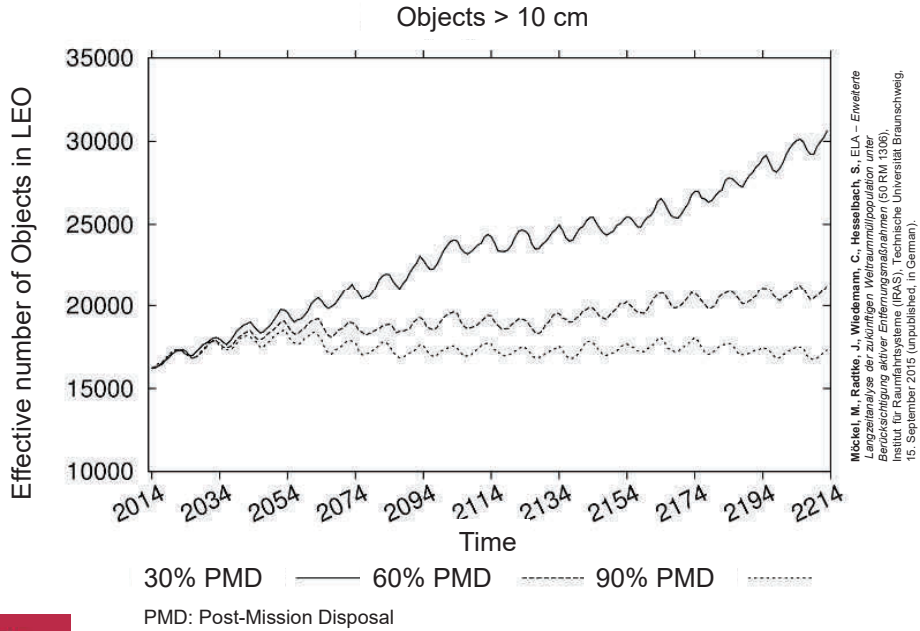


Figure according to Radtke, J., Stoff, E., Comparing long-term projections of the space debris environment to real world data - Looking back to 1990, Acta Astronautica, Volume 127, October–November 2016, Pages 482–490, ISSN 0094-5765, <http://dx.doi.org/10.1016/j.actaastro.2016.06.034>.

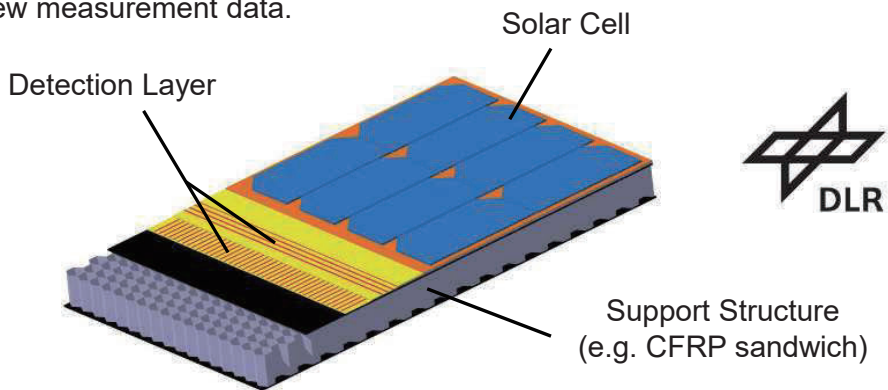


## Investigation of Mitigation Measures



## Sensors for Small Particle Impacts

The validation of the debris population requires new measurement data.

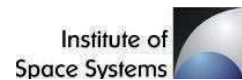


**SOLID: Solar Generator based Impact Detector**

DLR owns Patent in GER and USA  
 Qualified on Ground by HVI-tests  
 Flight Qualification on Satellite in 2017

Used with permission: Bauer, W., Space Debris Detection using Solar Panels, German Aerospace Center (DLR), Institute of Space Systems

Bauer, W., Romberg, O., Putzar, R., *Experimental verification of innovative debris detector*, Acta Astronautica, DOI 10.1016/j.actaastro.2015.07.008.



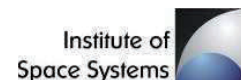


## Versioning scheme

Software	Reference population	Reference date
MASTER'95	March 30, 1995 ( $\pm 10$ yrs)	March 30, 1995
MASTER'97	December 31, 1996 ( $\pm 10$ yrs)	December 31, 1996
MASTER'99	August 1, 1999 ( $\pm 10$ yrs)	August 1, 1999
MASTER-2001	1960 – 2050 (continuous)	May 1, 2001
MASTER-2005	1957 – 2055 (continuous)	May 1, 2005
MASTER-2009	1957 – 2055 (continuous)	May 1, 2009
MASTER	<i>TBD</i>	<i>TBD</i>

Starting at the next release:

- No reference epoch in name → “MASTER”
- **More frequent population updates for the user**



## Summary

### Modeling of Space Debris

- Realistic depiction of the space debris environment down to 1  $\mu\text{m}$  object size is possible.
- Particle impacts can be described as high-resolution object flux with respect to oriented surfaces.

### Model Update

- New events have to be considered.
- Some historic events have to be reviewed.
- The results have to be validated with measurement data.

### Conclusion

- The LEO population of space debris is increasing.
- In the future, the LEO population may become instable.

