Effects of Mitigation Measures on the Space Debris Environment

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Overview

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- Space debris environment
  - Particle flux on satellites
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  - Penetration of satellite walls
- Instability of the LEO Population
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  - De-orbiting of stages and satellites
  - Cost and benefit analysis
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- Summary

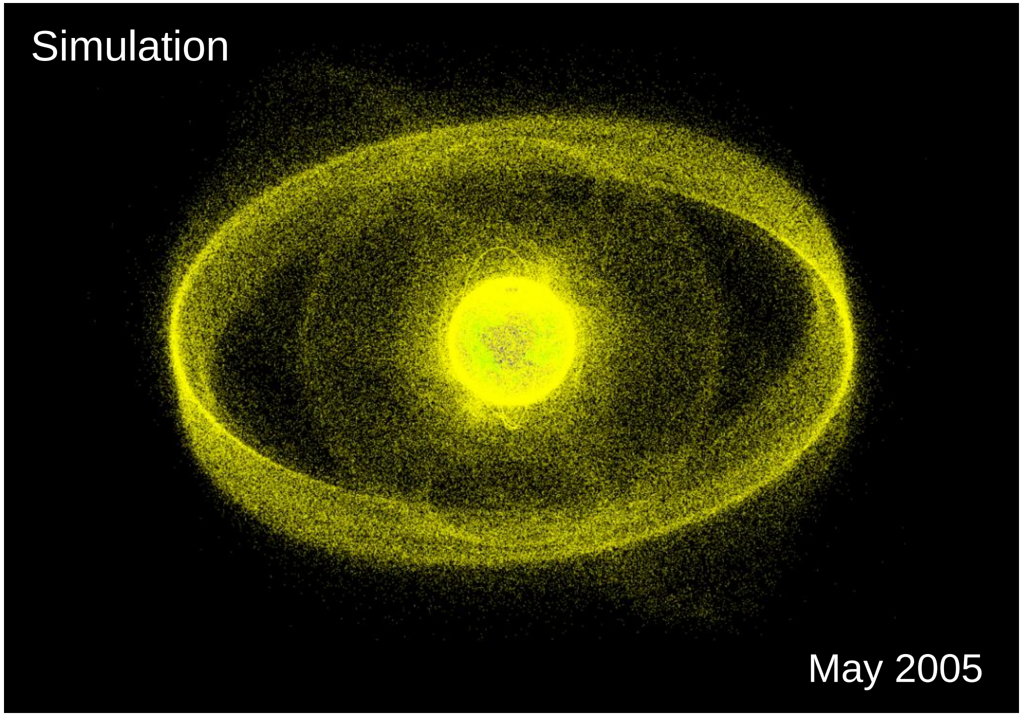
Meteoroid and Space Debris Terrestrial Environment Reference Model (MASTER)

MASTER 2005

Space Debris Model MASTER

- Necessity: Limited amount of measurement data in the small size regime.
- Population generation: Simulation of all events, propagation of object clouds.
- Validation: Radar measurements, impacts on SC Hardware.

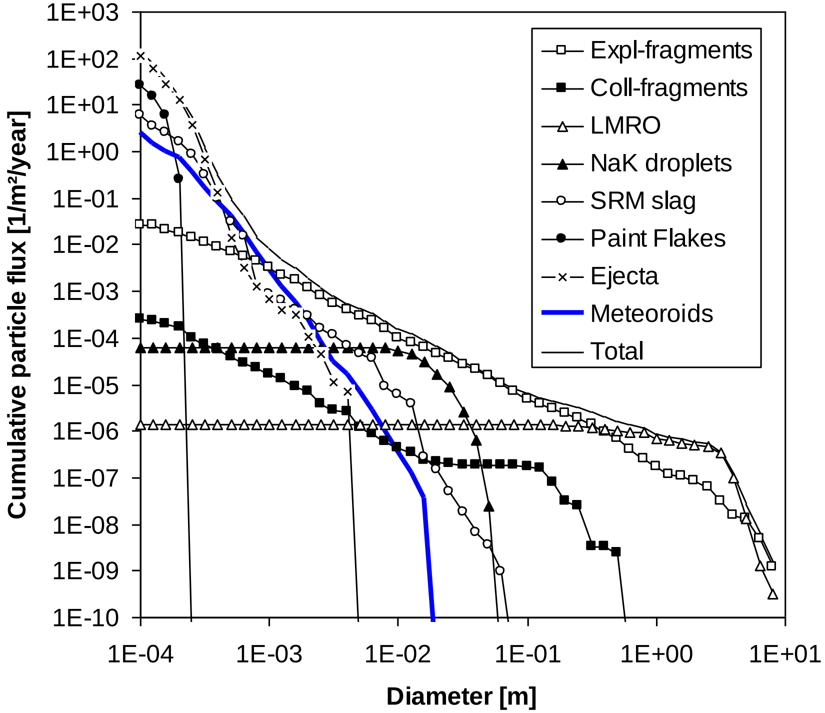
→ Realistic description of the space debris environment down to 1µm particle size.



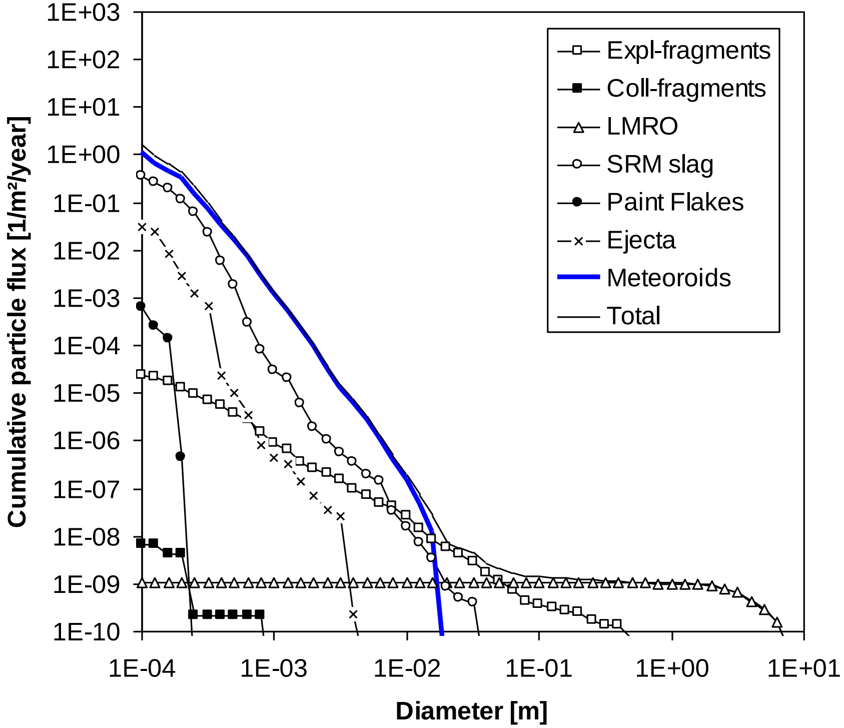
600,000 objects larger than 1 cm
150 million objects larger than 1 mm

Particle Flux on Satellites

LEO (900 km)

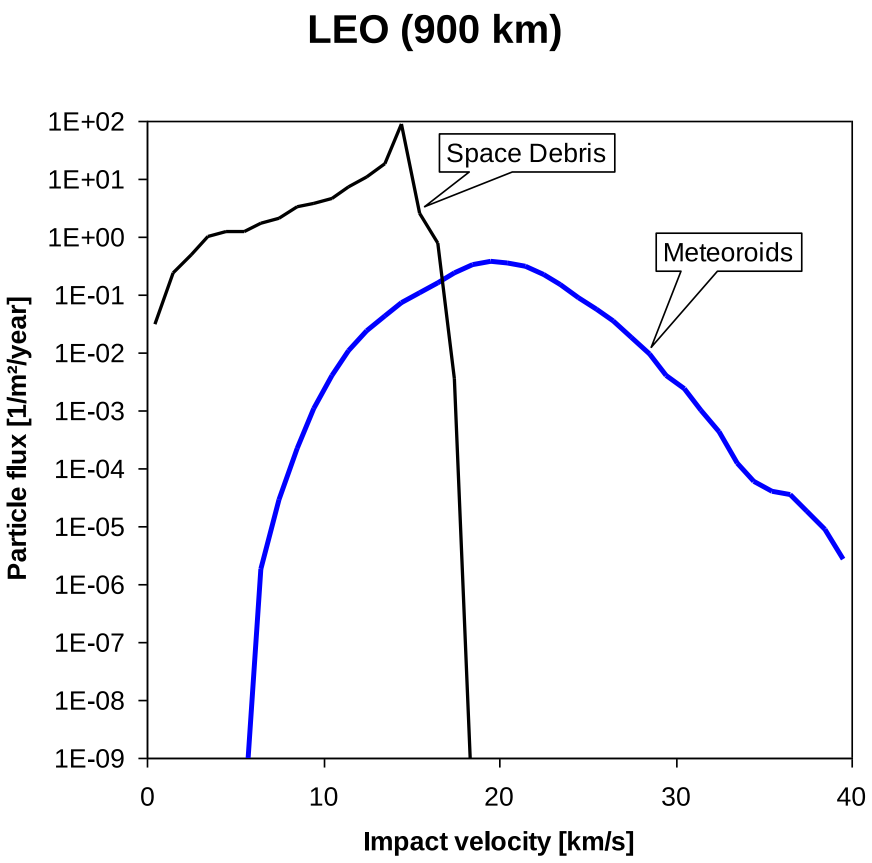


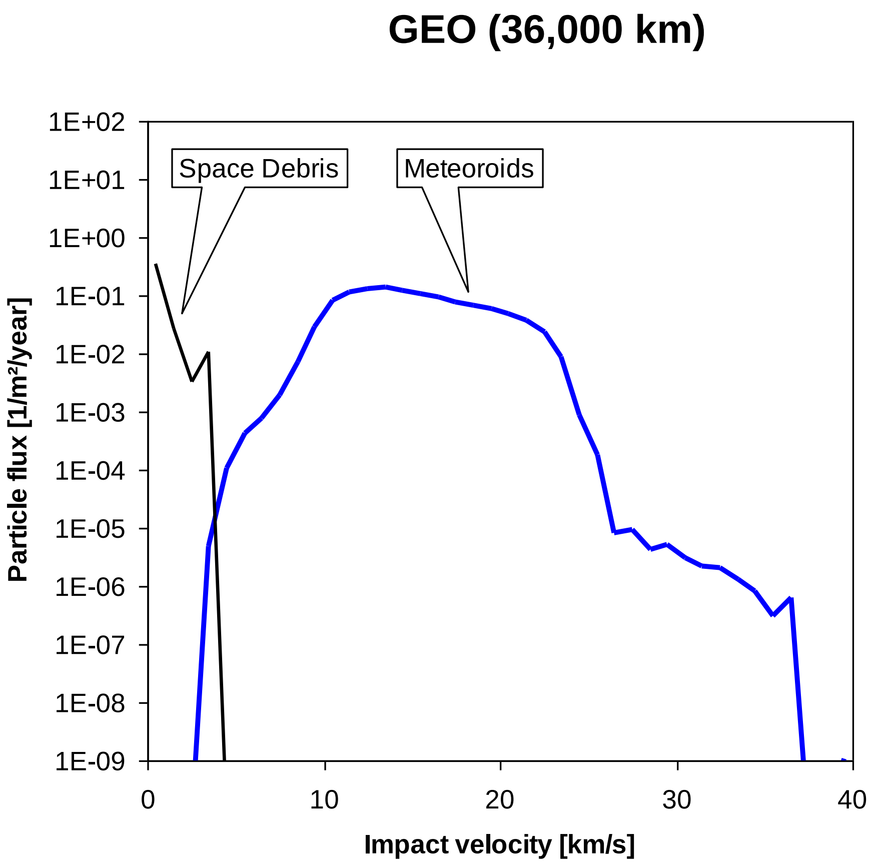
GEO (36,000 km)



Cumulative flux of impacting particles greater than 100 microns versus diameter on the front surface of an earth-oriented satellite according to MASTER-2005 (1 May 2005).

Impact Velocity of Particles





Flux of impacting particles greater than 100 microns versus impact velocity on the front surface of an earth-oriented satellite according to MASTER-2005 (1 May 2005).

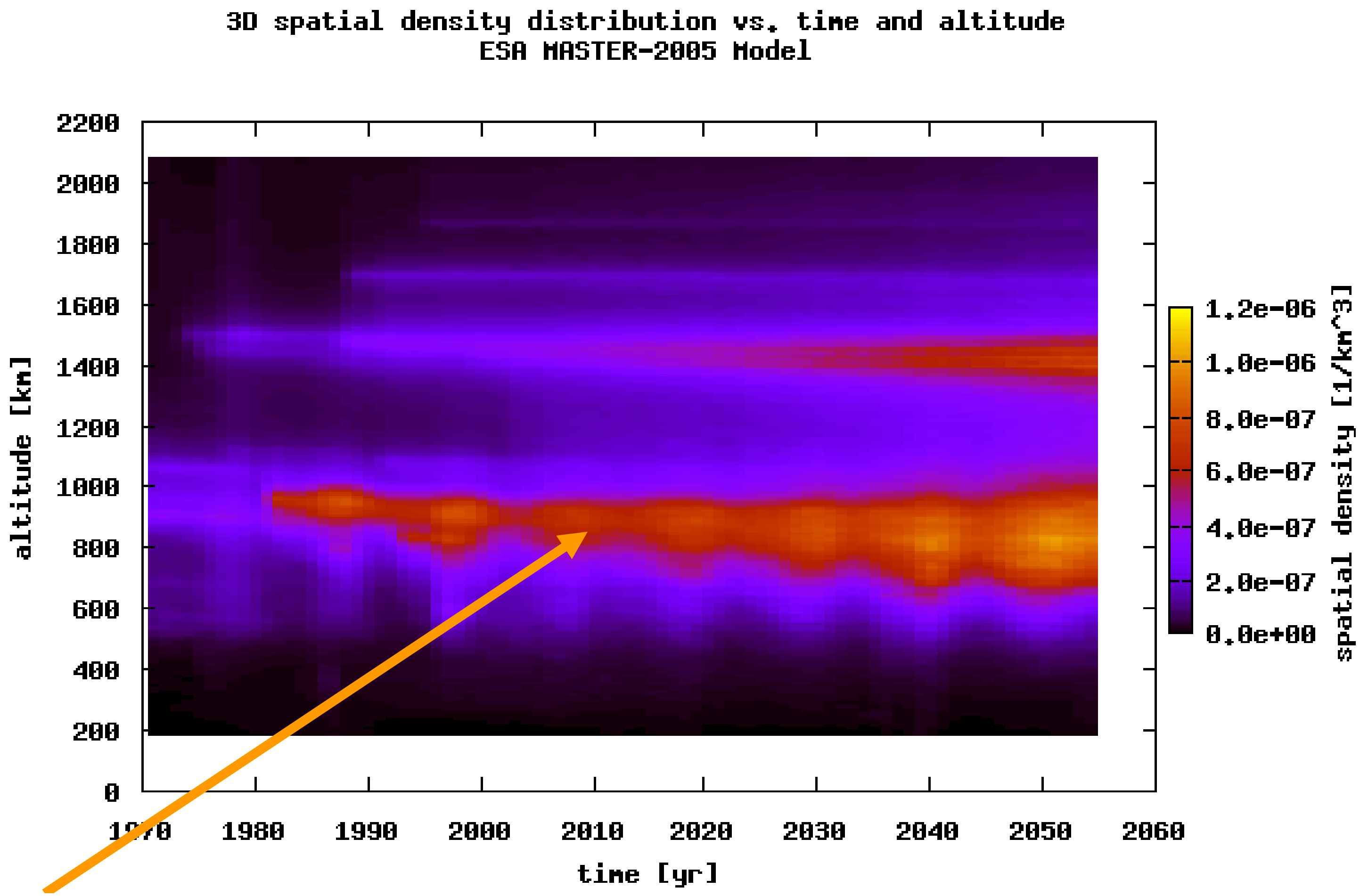
Penetrations of Satellite Walls

Satellite wall **LEO (900 km)**	Number of impacts (> 100 µm)	Number of penetrations			
		Wall (t = 0.8mm)	Honeycomb (ts=tb=0.4mm) (s = 1cm)	Honeycomb (ts=tb=0.4mm) (s = 3cm)	Honeycomb (ts=tb=0.4mm) (s = 5cm)
Fragments	3	2	1	1	1
Ejecta	27,126	1,663	55	4	1
SRM-slag	1,004	154	29	3	1
Paint flakes	4,866	1,005	0	0	0
Meteoroids	391	71	23	7	4
Total	**33,390**	**2,895**	**108**	**15**	**7**

Satellite wall **GEO (36,000 km)**	Number of impacts (> 100 µm)	Number of penetrations			
		Wall (t = 0.8mm)	Honeycomb (ts=tb=0.4mm) (s = 1cm)	Honeycomb (ts=tb=0.4mm) (s = 3cm)	Honeycomb (ts=tb=0.4mm) (s = 5cm)
Fragments	0	0	0	0	0
Ejecta	4	0	0	0	0
SRM-slag	64	0	0	0	0
Paint flakes	0	0	0	0	0
Meteoroids	500	105	20	5	3
Total	**568**	**105**	**20**	**5**	**3**

Front surface: 20 m², mission: 7 years, altitude: 900 km

Instability of the LEO Population



Increasing threat for the orbits used by Earth Observation Satellites

Implementation of Mitigation Measures

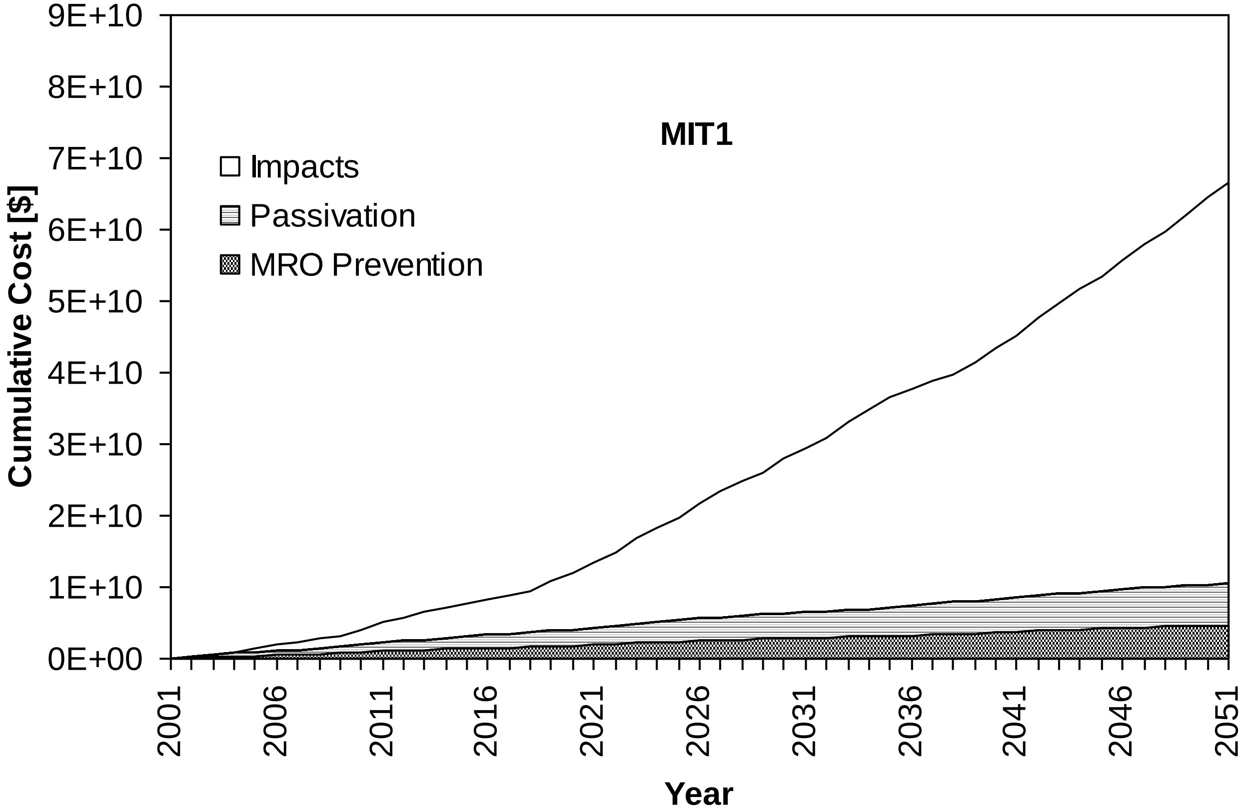
A cost estimation is combined with results of simulations of the future space debris environment to evaluate the cost and benefit of mitigation measures.

(The analysis is performed by an upgraded version of the long-term debris environment model LUCA.)

MIT	MIT1	MIT2	MIT4	MIT5
MRO Prevention	X	X	X	X
Passivation	X	X	X	X
Slag Prevention	-	X	X	X
GEO Re-Orbit	-	-	X	X
De-Orbit (25 y)	-	-	X	X
LEO Disposal	-	-	-	X

Parameters of the selected mitigation scenarios.

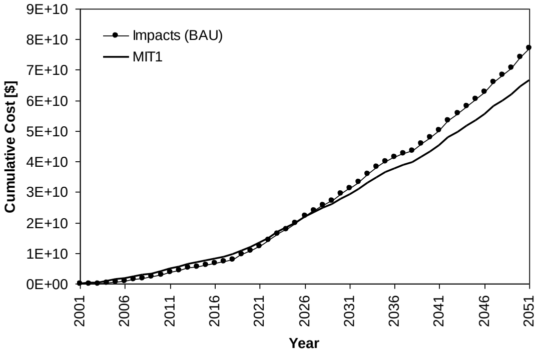
Damage Cost of Particle Impacts



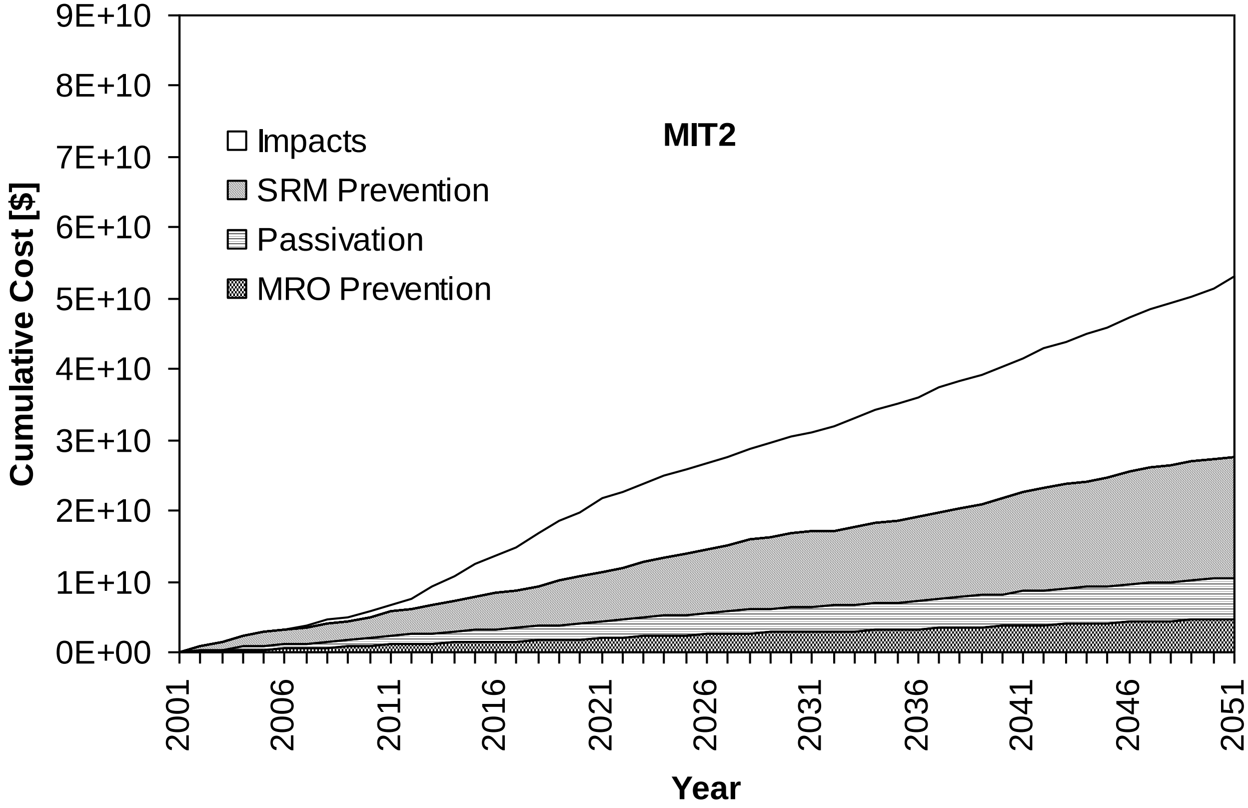
In the mitigation scenario MIT1 the cost of debris impacts represents the highest share.

The expenses for MRO prevention and passivation are low.

There is a small cost increase after the implementation of the mitigation measures in the year 2001. The break-even point is reached in 2025. After this point there is a small cost saving due to the reduced number of generated fragments in this scenario.

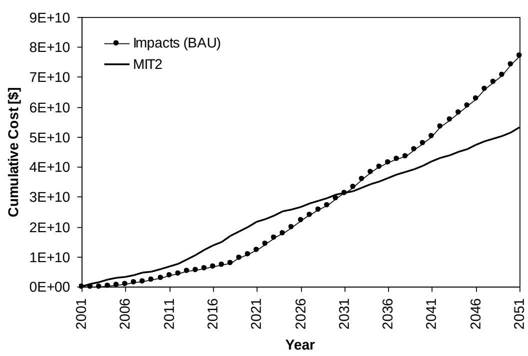


Mitigation of small Particle Impacts



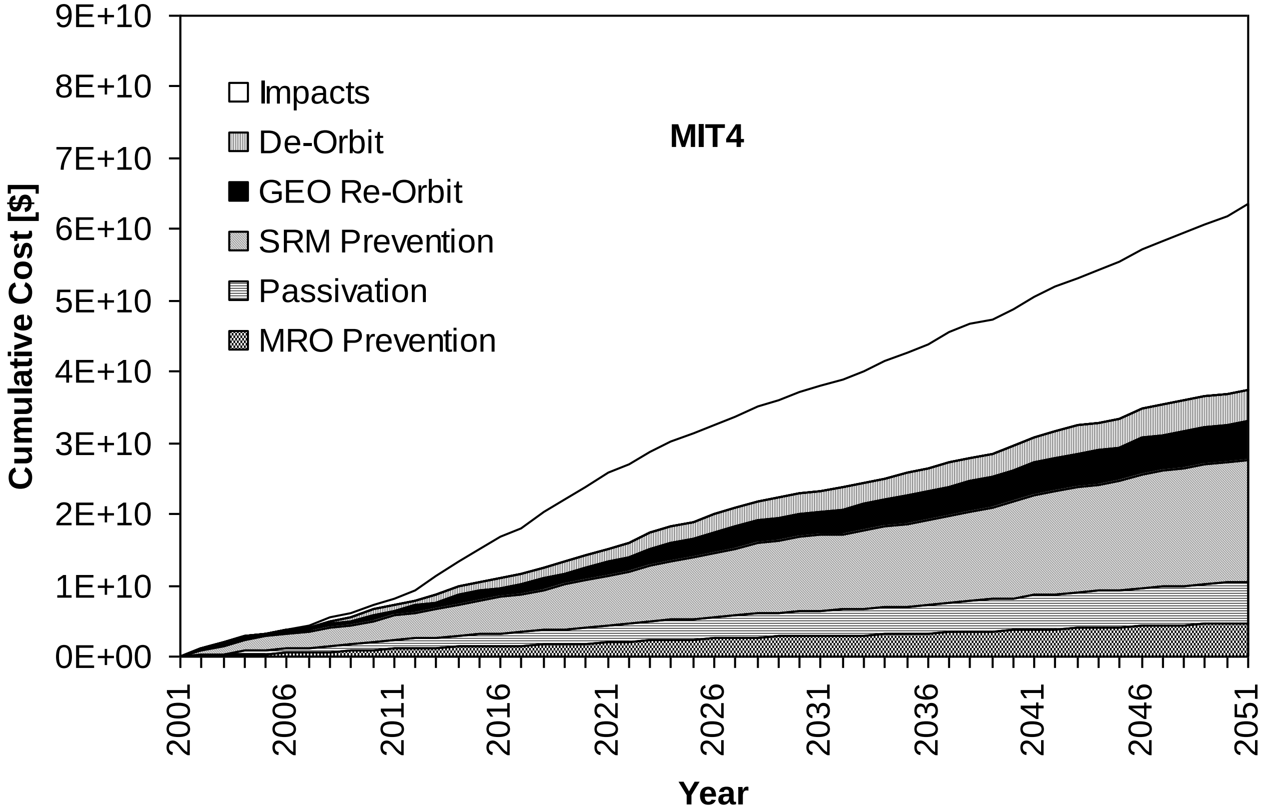
In the mitigation scenario MIT2 the sum of mitigation measures represent the highest cost share.

The cost development of MIT2 is very different from the BAU scenario.

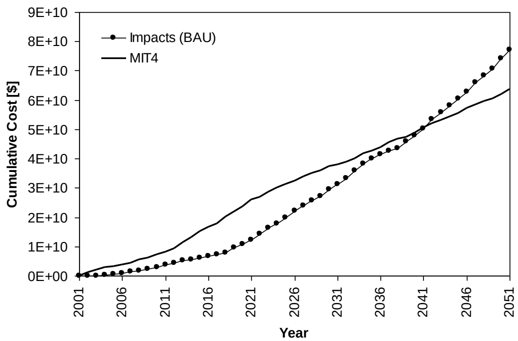


There is a significant cost increase after the implementation of the mitigation measures in the year 2001. The break-even point is reached in 2031. After this point there is a considerable cost saving due to the reduced number of generated slag particles in this scenario.

De-Orbiting of Stages and Satellites

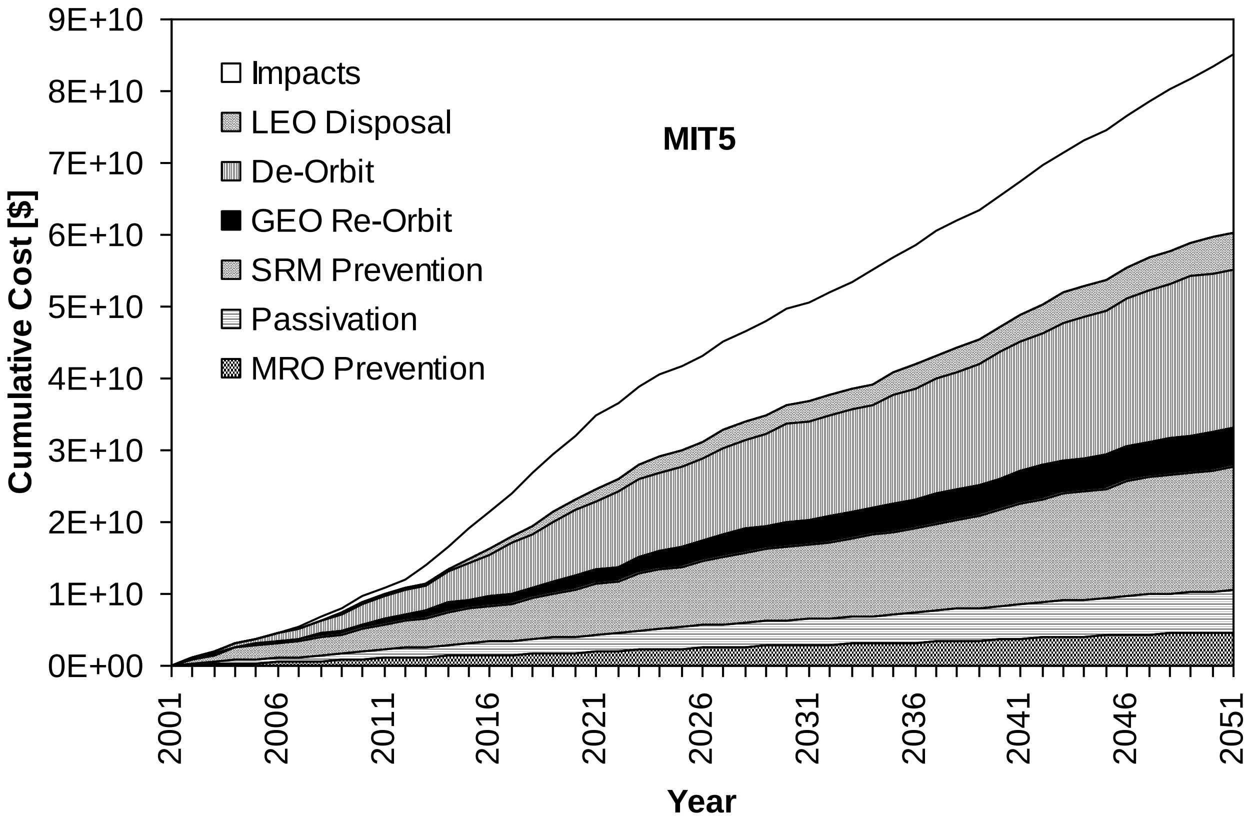


The de-orbiting maneuvers are executed using cheap solid rocket motors.



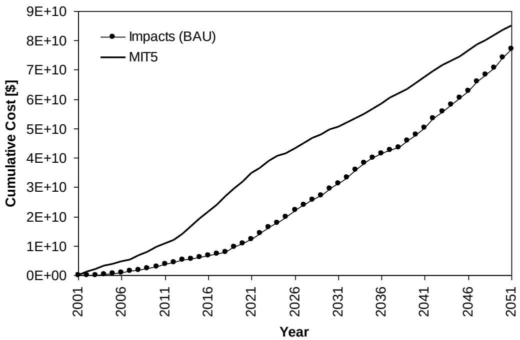
There is a significant cost increase after the implementation of the mitigation measures in the year 2001. The break-even point is reached in 2041. After this point there is a considerable cost saving due to the reduced number of generated slag particles in this scenario.

LEO Disposal

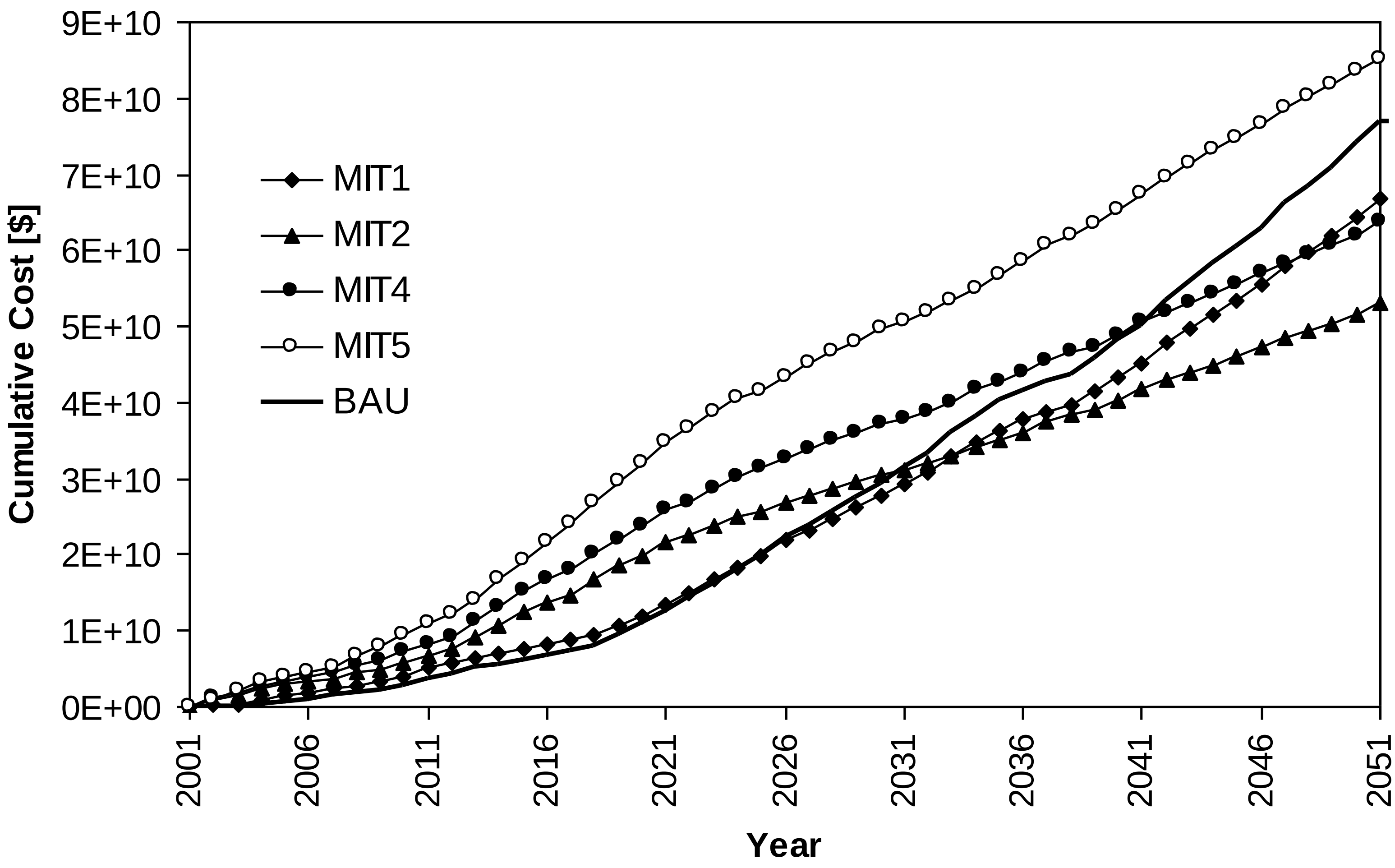


The de-orbiting maneuvers are executed using expensive liquid propellant systems.

There is a considerable cost increase after the implementation of the mitigation measures in the year 2001. The break-even point is not reached till 2051.

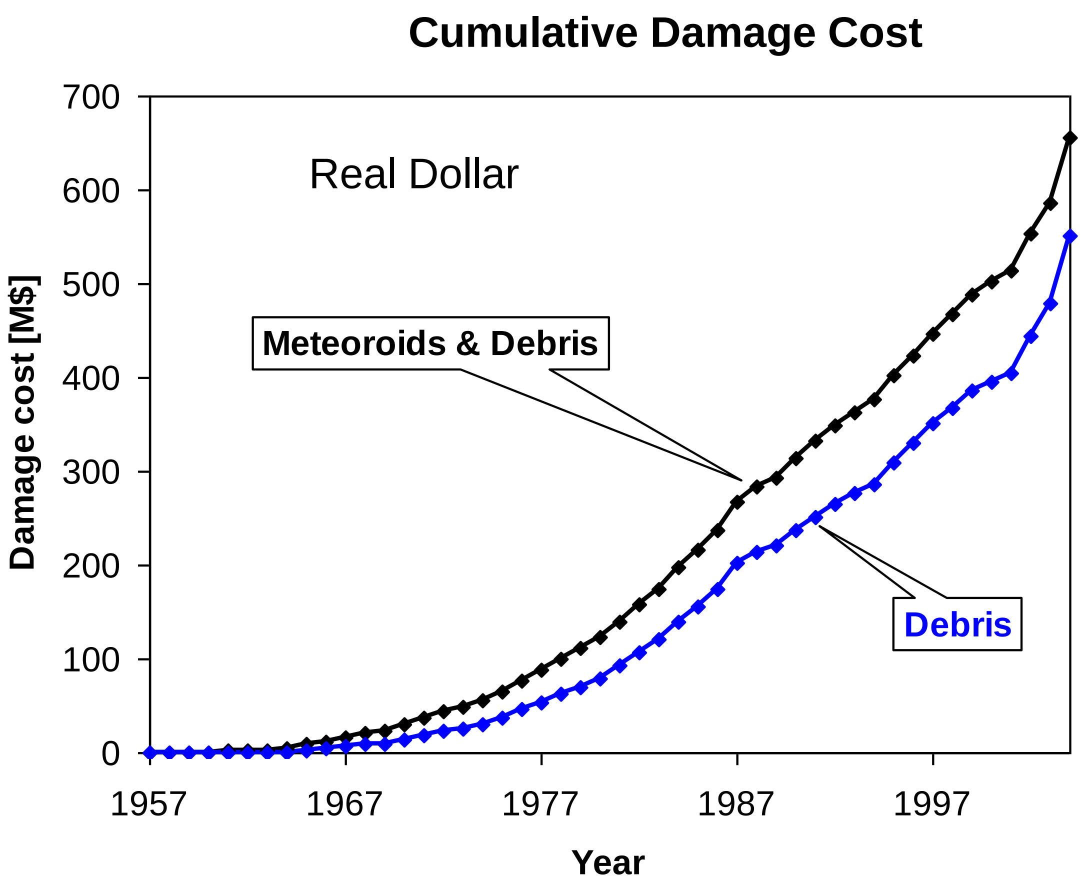


Cost and Benefit Analysis



Comparison of the cumulative cost over time of MIT1, MIT2, MIT4, and MIT5 with the BAU scenario (cost in FY02$).

Historical Damages on Satellites



Simulation
Very complex, because it was necessary to perform a risk analysis for 3893 single satellites (incl. subsystem distribution, failure probability, cost estimation).

Damage Cost up to 2004:
- Damages altogether: 650 M$
- Damages from Space Debris only: 550 M$

Summary

- The general trend of the historical evolution of the space debris environment has been an ever increasing number of space debris objects.

- The most important mitigation measure is the de-orbiting of spent satellites and upper stages on LEO, to prevent an instable population.
  - Reduction of the orbital lifetime to 25 years.
  - Active removal of larger objects, e. g. by robotic systems.

- The suppression of the release of small particles can also be a cost effective mitigation measure.