Space Debris Mitigation: Methods (and implementation) MASTER8, DRAMA3 & ESTIMATE

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25/10/2018

SDM Objectives

- Spaceflight shall be compatible with the **sustainable use of outer space**
- The **proliferation of space debris** shall be **constrained**

- Avoiding the intentional release of space debris into Earth orbit;
- Avoiding break-ups in Earth orbit;
- Removing spacecraft and launch vehicle stages from protected orbital regions;
- Minimise the risk of collision with other space objects;

- Reducing the risks of re-entry to people, property and the Earth's environment.

SDM Standards

Mitigation Requirements

2002 — Inter–Agency Space Debris Coordination Committee
IADC Space Debris Mitigation Guidelines

2004 — asi agenzia spaziale italiana, BNSC British National Space Centre, cnes Centre National d'Etudes Spatiales, DLR, esa European Space Agency / Agence spatiale européenne
European Code of Conduct for Space Debris Mitigation

2008 — **Requirements on Space Debris Mitigation for ESA Projects** (esa European Space Agency / Agence spatiale européenne)

2014 — **Space Debris Mitigation Policy for Agency Projects** (esa European Space Agency / Agence spatiale européenne)

extended until 2022 in 2018

Implementation Standards

2011 (2018?) — ISO TC20/SC14 N **24113:2011** (ISO)
Space Systems — Space Debris Mitigation

2012 (adopted) — **ECSS-U-AS-10C**
EUROPEAN COOPERATION ECSS FOR SPACE STANDARDIZATION

Handbook as support document

2015 — **ESA Space Debris Mitigation Compliance Verification Guidelines** (esa European Space Agency / Agence spatiale européenne)

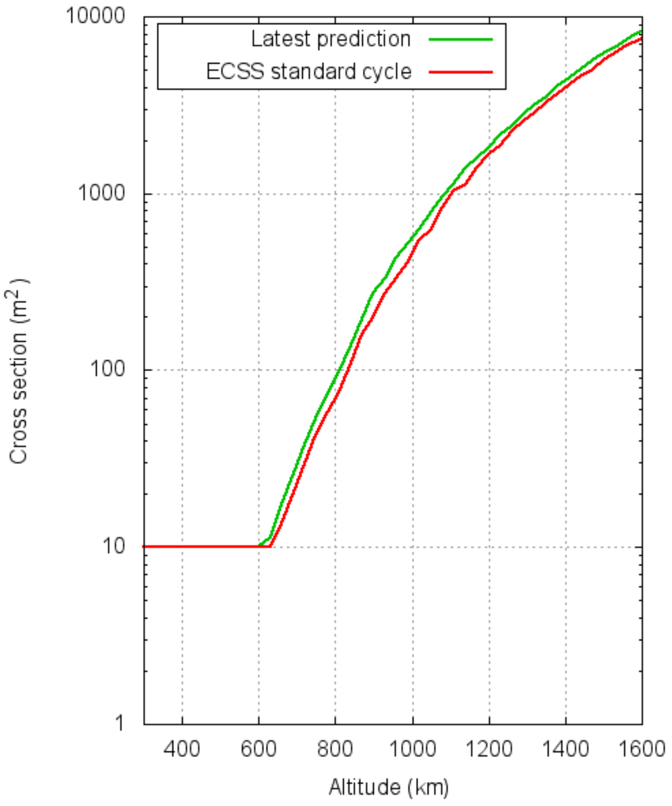
SDM Methods

- SDM Standards remain fairly top-level (currently):
  - **World-wide levelled playing field** to meet the same objectives
  - **Detailed standards exists where the state of the art allows it**
  - **Methods** have been developed by the individual **risk takers**
  - Methods tend to produce the **same trend** but **different values**
- ESA's methods and implementation have been available since the European code of conduct (2004) and are evolving (e.g. 2014 adoption and handbook)
  - DRAMA & MASTER (https://sdup.esoc.esa.int)
  - Complemented with dedicated testing and simulations

- How do we evolve with the state of the art and minimise differences?

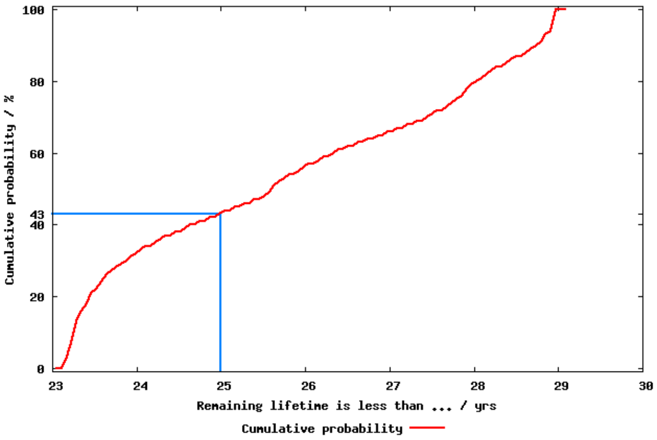
DRAMA/OSCAR

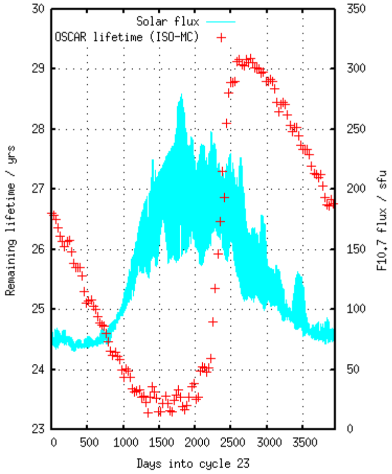
- **OSCAR method:** Analysis of different *disposal options*
- Widely-accepted (and standardised!) **methods for future projection** of solar and geomagnetic activity
- Disposal methods:
  - Chemical propulsion
  - Electric propulsion
  - Electrodynamic tethers
  - Drag augmentation systems



DRAMA/OSCAR

- The requirement is to reduce the orbit lifetime below a *target* or avoid a region for a *target* amount of years.
    - A single baseline method for an inherently stochastic process driven by mission parameters

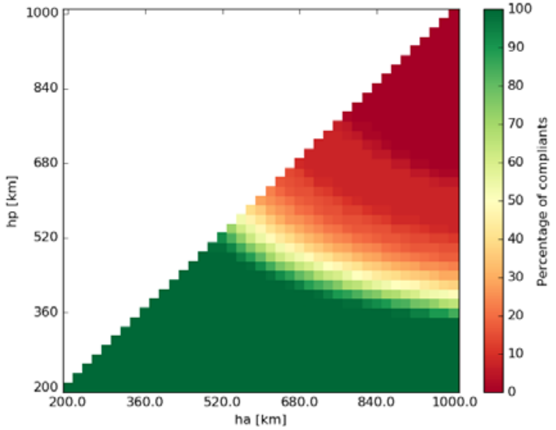


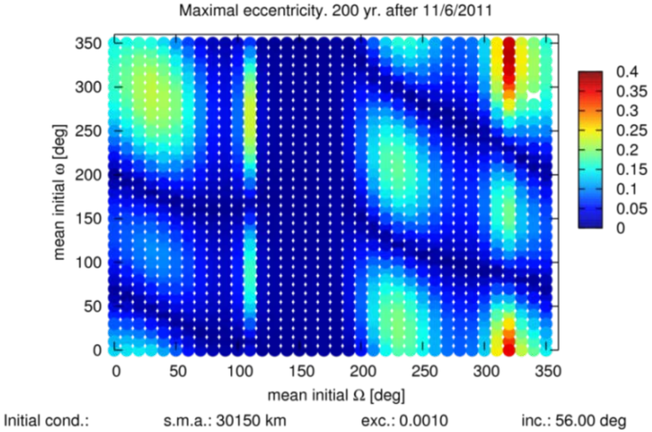


outliers: n_L =0 n_U =7

DRAMA/OSCAR

- The requirement is to reduce the orbit lifetime below a *target* or avoid a region for a *target* amount of years.
    - A single baseline method for an inherently stochastic process driven by mission parameters
    - The shift is towards finding mission orbits compatible with SDM





DRAMA/OSCAR

- The requirement is to reduce the orbit lifetime below a *target* or avoid a region for a *target* amount of years.
  - The shift is towards finding mission orbits compatible with SDM
  - The method and implementation updates to account for this as well

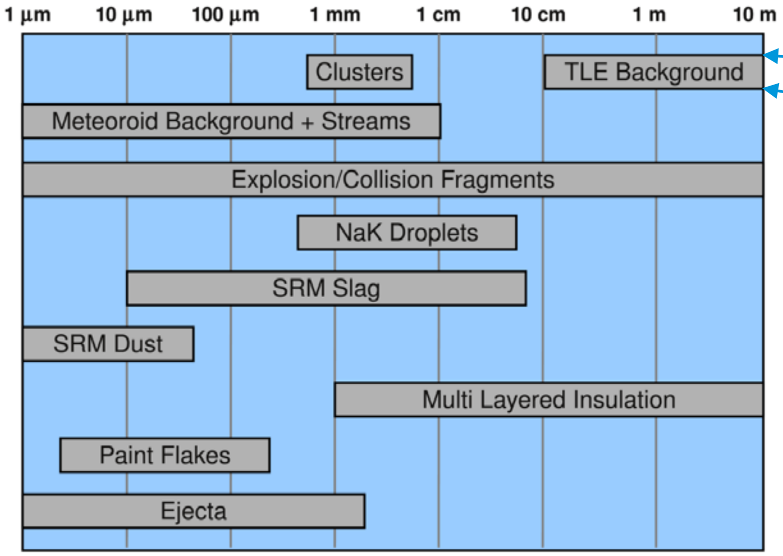
```
In [1]: from drama import oscar

In [8]: from drama.monte_carlo import Gaussian

In [9]: config_mc = oscar.get_default_config()
        config_mc['sma'] = Gaussian(mu=6700, sigma=2.5)
        results_mc = oscar.run_monte_carlo(config_mc, confidence_level=95)
        print('Monte Carlo campaign ended after {} simulations, with status = {}'.format(len(res
        print('Mean lifetime = {} years'.format(results_mc['mean']))

Monte Carlo campaign ended after 45 simulations, with status = OK
Mean lifetime = 0.3851111111111111 years
```

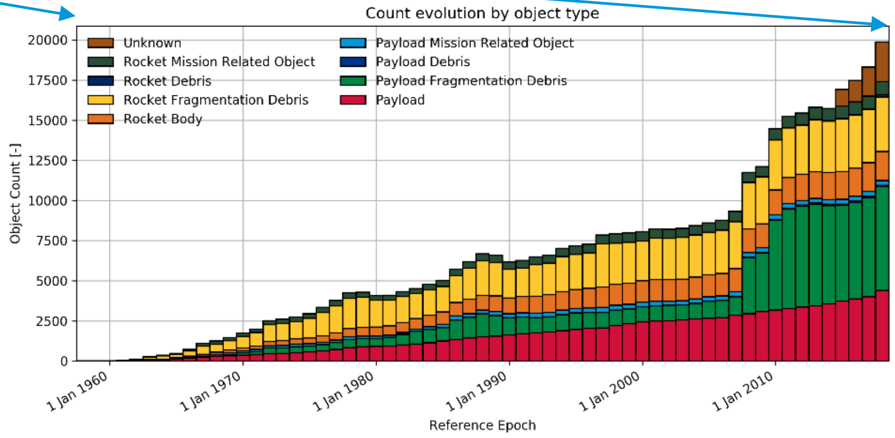
DRAMA/ MIDAS & ARES

- “During the design of a spacecraft an assessment shall be made of the risk that a space debris or meteoroid impact will cause the spacecraft to break-up before its end of life.”
- “For a spacecraft with the capability to actively manage collision risk, if the risk of collision with other space objects is assessed to be above the corresponding risk threshold set by an approving agent then collision avoidance manoeuvres shall be conducted to reduce the risk of collision below the threshold.”

- **MIDAS tool:** Modelling the *collision flux* and *damage statistics* for a mission
- **ARES tool:** assessment of the *annual collision risk* and *manoeuvre rate*
- Both based on the **MASTER environment model**

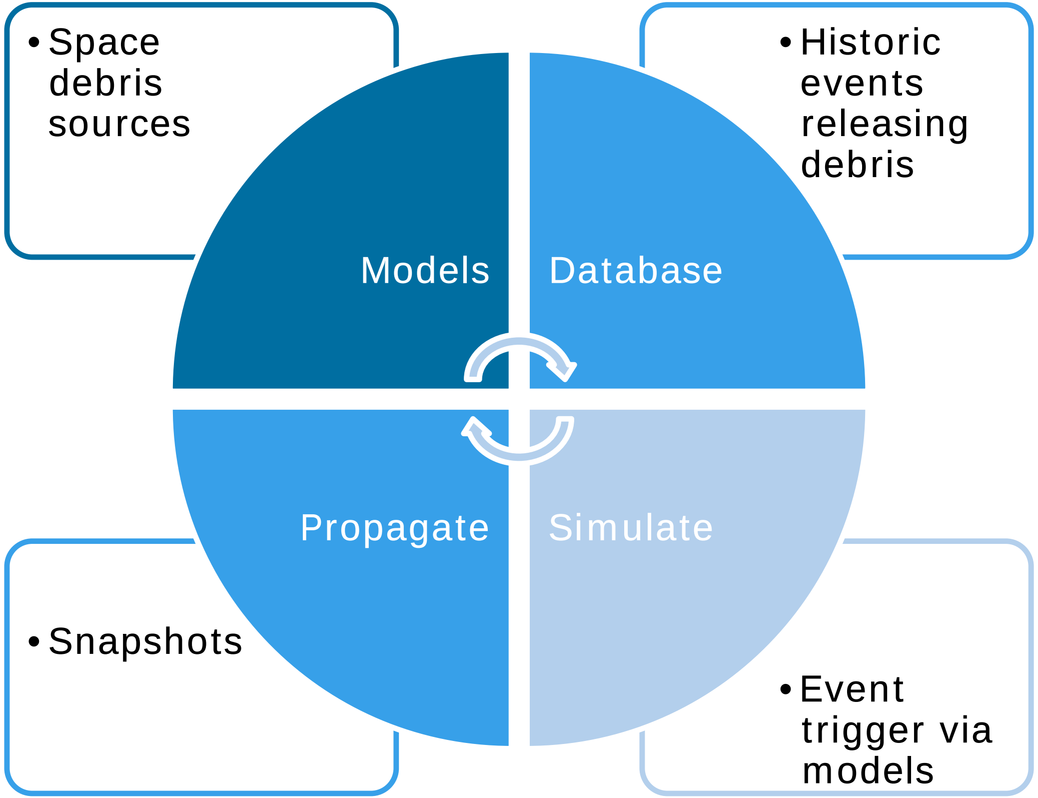
MASTER





- Collision Avoidance
- Shielding
- An uncertainty gap

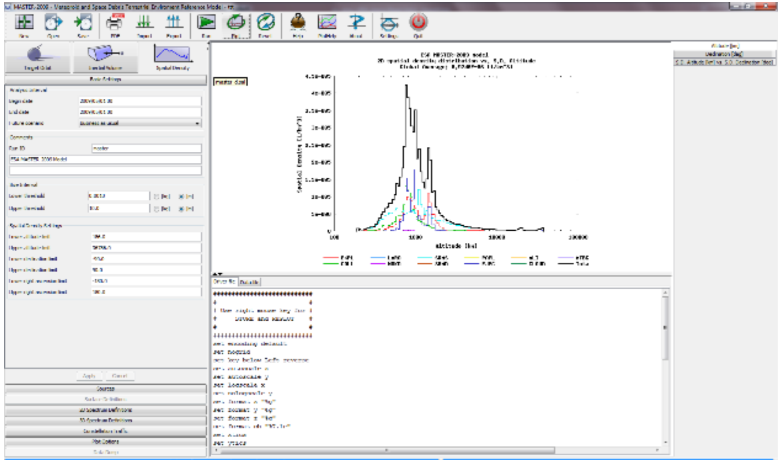
MASTER



https://sdup.esoc.esa.int

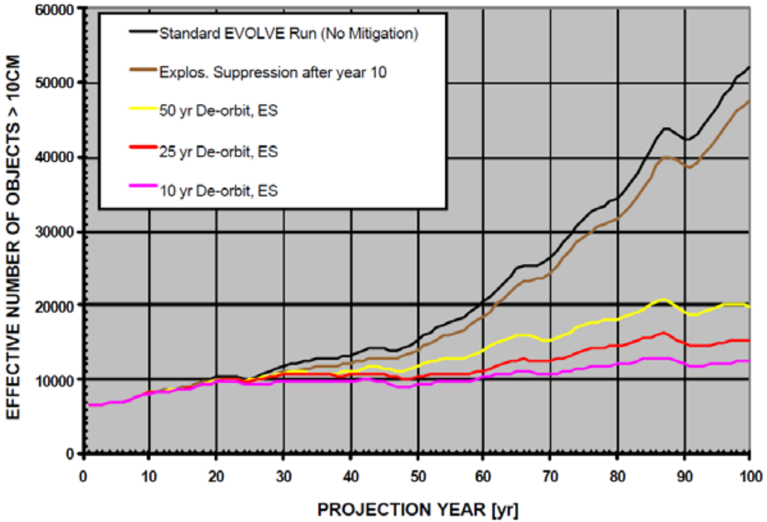
MASTER

- MASTER-2009 to MASTER-8:
  - Model updates
  - Deriving uncertainties from the validation process
- Yearly updateable reference population
- FORTRAN API access layer & GUI:

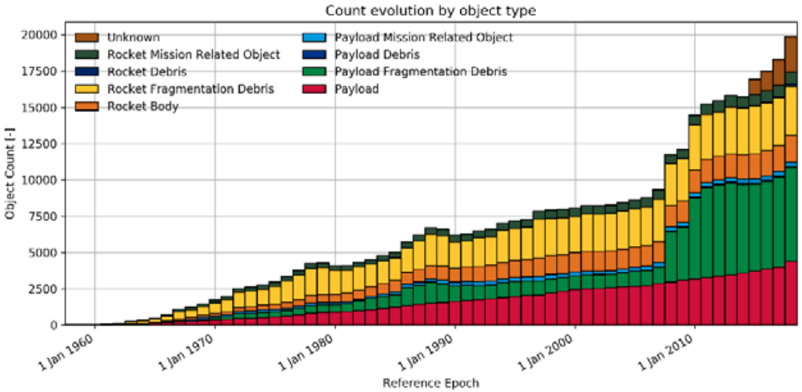


MASTER/ Future prediction

Prediction in 2001



Observation in 2017



MASTER/ Future prediction

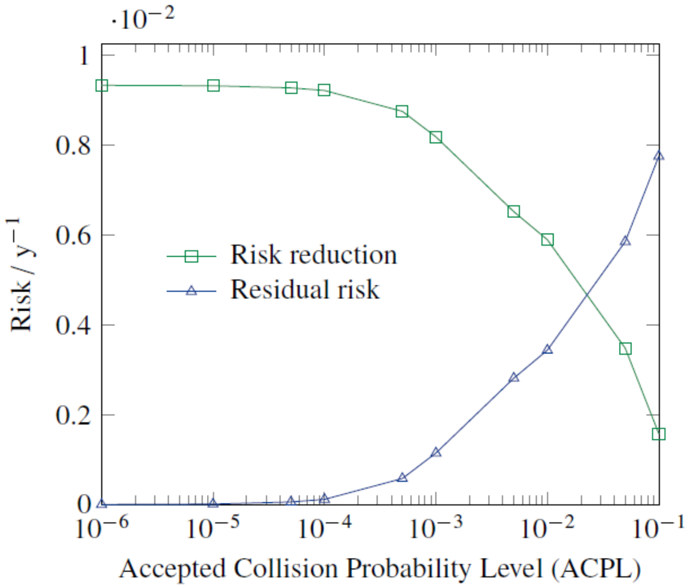
- Cumulative number of impacts in SSO (800 km, i = 98 deg) / $m^{-2}y^{-1}$

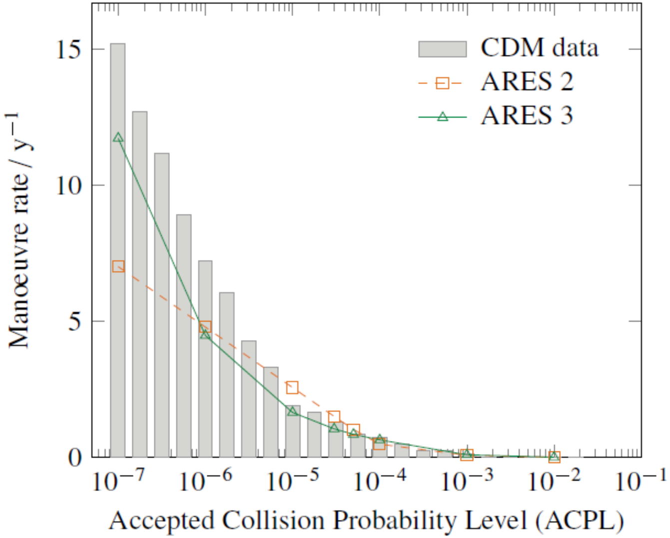
Diameter	M2005	M2009		M8	
		Flux	ΔM2005	Flux	ΔM2005
0.001 m	1.30e-2	1.79e-2	+38%	1.49e-2	+15%
0.002 m	2.63e-3	4.09e-3	+56%	3.76e-3	+43%
0.005 m	5.63e-4	8.12e-4	+44%	9.48e-4	+68%
0.01 m	1.97e-4	2.76e-4	+40%	3.36e-4	+71%
0.05 m	2.26e-5	2.22e-5	-2%	4.12e-5	+82%
0.1 m	8.93e-6	1.41e-5	+58%	2.29e-5	+156%

Epoch: May 1, 2016

DRAMA/ ARES

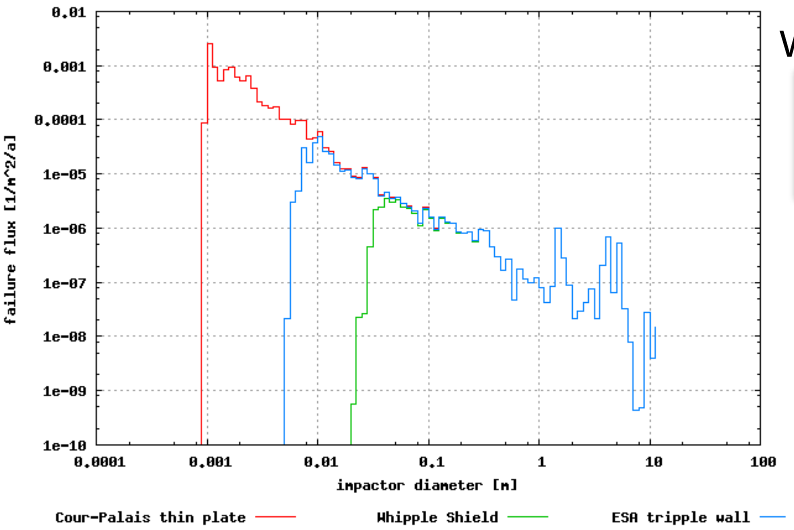
- An assessment is performed and what is “acceptable” is (currently) decided on orbit and mission basis

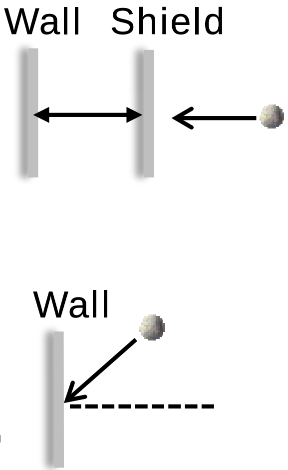


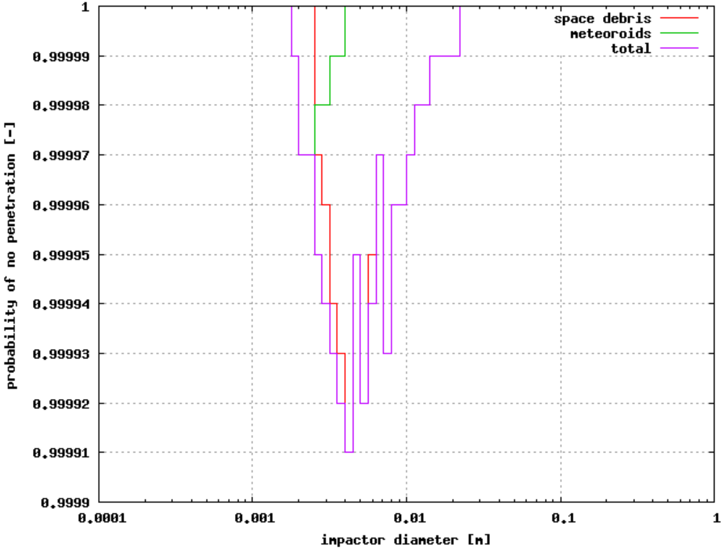


DRAMA/ MIDAS

- An assessment is performed and what is “acceptable” is (currently) decided on orbit and mission basis







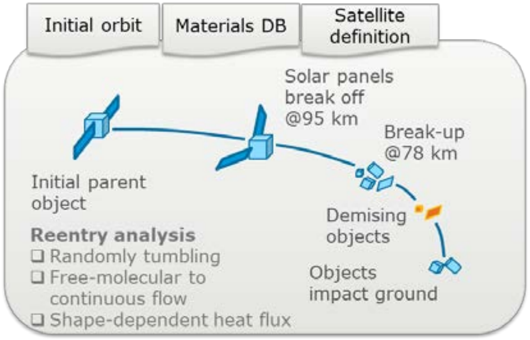
DRAMA/ SARA

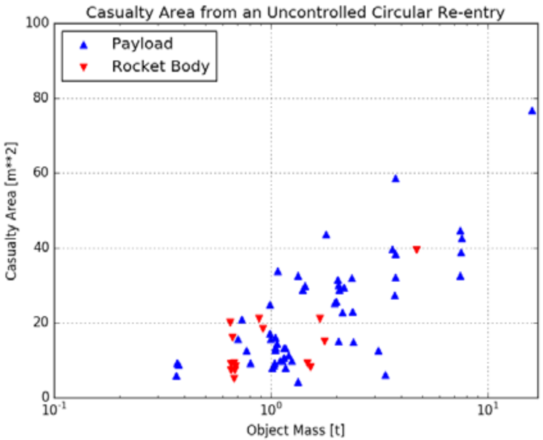
- “The space system shall be designed and operated such that the re-entry casualty risk does not exceed 10^{-4} for all re-entry events.”
    - “The re-entry casualty risk analysis shall be performed with the ESA tool DRAMA.”
    - “The use of tools other than the ESA tool DRAMA for the re-entry casualty risk analysis shall be approved by the ESA relevant Authority specified in the Space Debris Mitigation Policy for Agency Projects.”

- Tool = process = methodology = standard
    - The acceptable risk is captured by the methodology
    - The design for demise pardigm breaks the conservative approach

DRAMA/ SARA (w.r.t. v2)

- Simple method changes can have large effects:
  - Continuous heating ↓
  - Nested-ness ↑
  - Material models ✥

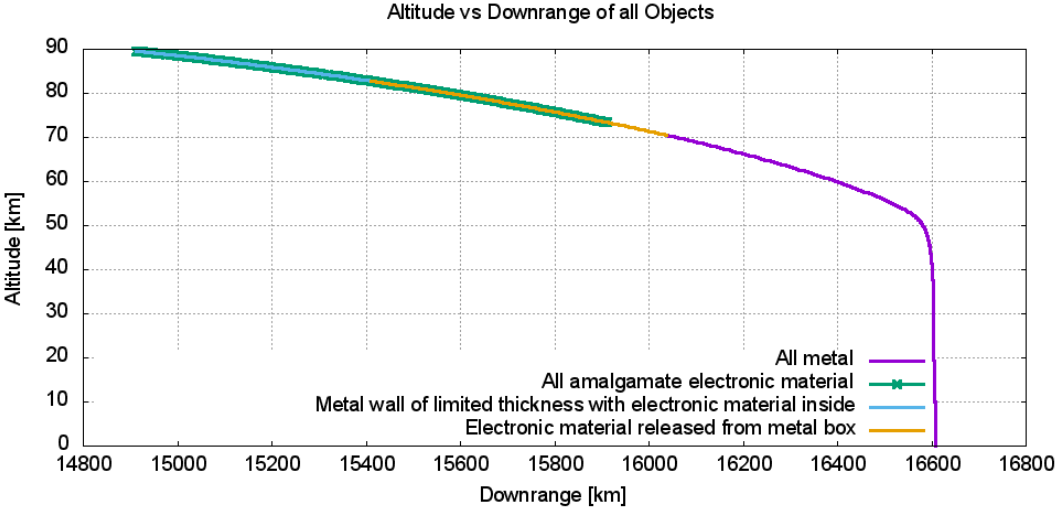


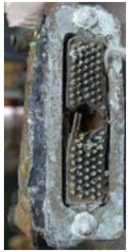


DRAMA/ SARA (in v3)

- E.g. spacecraft modelling :
  - Dependent on aerothermodynamics (can be default or overwritten)
  - To be tackled by guidelines in absence of ground truth

- E.g. Aerothermodynamics
  - Local versus global per size
  - Tumbling mode




DRAMA/ SARA (in v3)

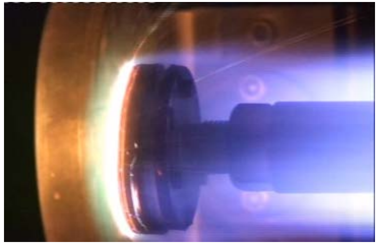
- While the research is active and incompatibilities exist, how to assure that we converge instead of diverge?
  - Community approach?
  - Open source/data approach?

- ~~Object- or spacecraft oriented, low- or high-fidelity or CFD~~
- But verification versus design tools/tests?
  - A verification tool should not contradict rigours testing or analysis.
  - A subsystem/mechanism qualified for demise can feed back into a component library?
  - Probabilistic versus baseline can already be covered.

ESTIMATE

- The behaviour of materials in the re-entry environment drives the casualty risk, however test data is relatively rare but there is hope.
- European Space maTerIal deMisability dATabasE:
  - Measurement data from Plasma Wind Tunnels
  - Characterised material parameters.

- Currently available:
  - CHARacterisation of DEMisable Materials [DLR, HTG, ÖGI]
  - Characterisation of Demisable Materials [FGE, BRL, VKI, IRS, AAC]



ESTIMATE

- https://estimate.sdo.esoc.esa.int

- Inclusion of additional finished and currently running projects. There is no limitation for non-ESA projects.

- The desire is to create a transparent case of reference scenarios:
    - The definition of material properties for re-entry break-up software with uncertainties.
    - The inclusion of more complex structural tests for rebuilding exercises.

- A community of experts standardise at least this part of re-entry risk?

SDM Roadmap

- The vision is clear: sustainable use of outer space
- The objectives are clear:
  - Avoiding the intentional release of space debris into Earth orbit;
  - Avoiding break-ups in Earth orbit;
  - Removing objects from protected orbital regions;
  - Minimise the risk of collision with other space objects;
  - Reducing the risks of re-entry.

- The implementation can be standardised in certain parts, and more flexible procedures are available where not (with healthy debates assured).