DRAMA 3.0.0: A one stop shop for the verification of space debris mitigation requirements

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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 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**

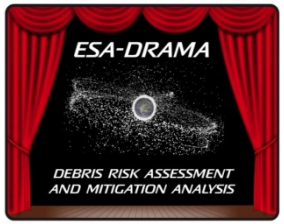
- ESA's methods and implementation have been available since the European code of conduct (2004) and are evolving (e.g. 2014 ECSS adoption)
  - DRAMA (Debris Risk Assessment and Mitigation Analysis)
  - MASTER (Meteoroid and Space Debris Terrestrial Environment Reference)

SDM Tools: DRAMA & MASTER

- Target mission designers (engineers & operators)
  - **Phase 0 / A (catch risks early)**
  - Phase B/C/D/E (support design decisions and operations)
  - Phase F (Enable the interpretation of surveillance data)
- Support a large user base:
  - Platforms: MacOS (10.4 <), Linux (SuSE 11 <), Windows (7 <)
  - Technical support contact
  - a *Procedural user* vis-à-vis a *creative user*
  - Ease integration and compatibility with other tools
- Maintain Legacy code and square it with new developments
  - Legacy models FORTRAN 90, GUI java, GNUPLOT layer
  - New models C++, java, python, 3D-bindings

The DRAMA software tool suite

*"The **aim of DRAMA is** to support the objectives of the ESA Space Debris Mitigation Requirements by **enabling satellite programs** in Europe **to assess their compliance** with the recommendations contained in that document."*



ARES
Assessment of Risk Event Statistics:
Analyze requirements for collision avoidance manoeuvres expected for a mission.

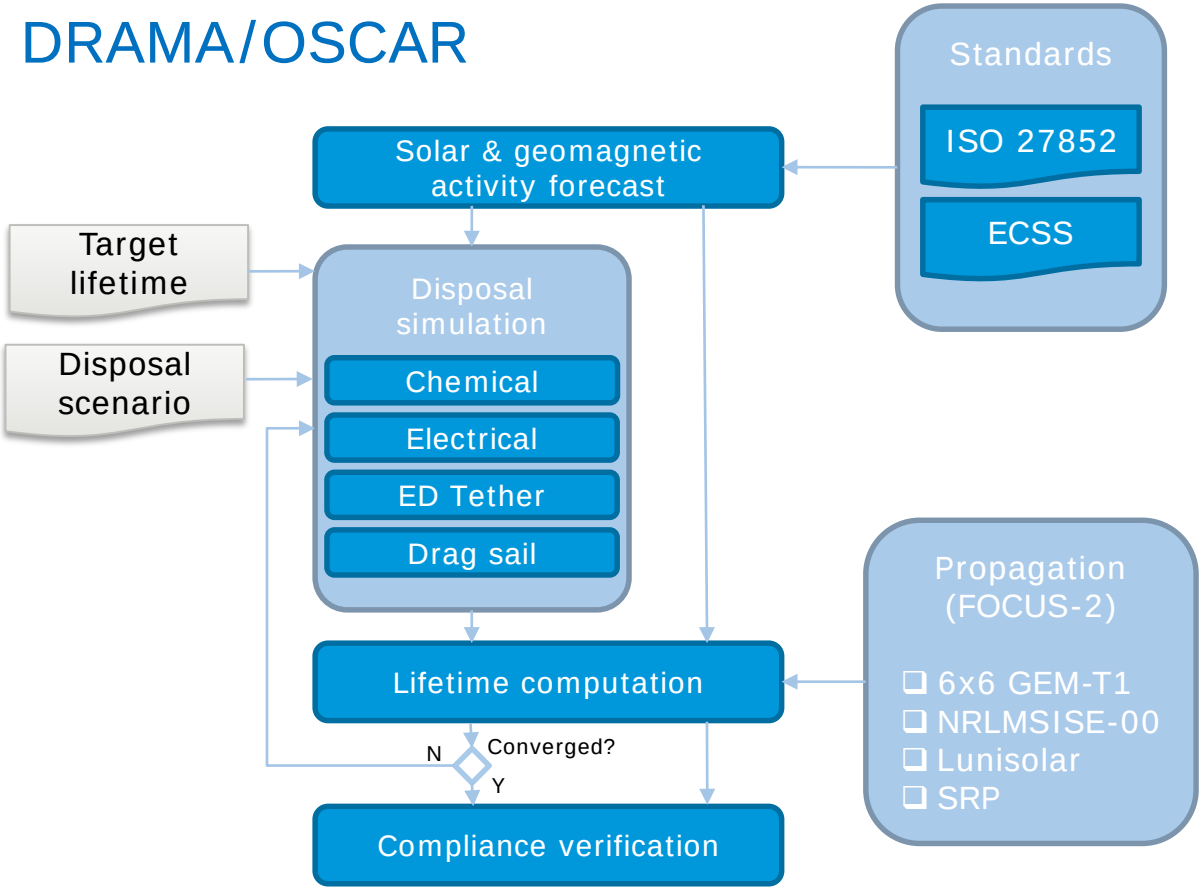
MIDAS
MASTER (-based) Impact Flux and Damage Assessment Software:
Modeling of the collision flux and damage statistics for a mission.

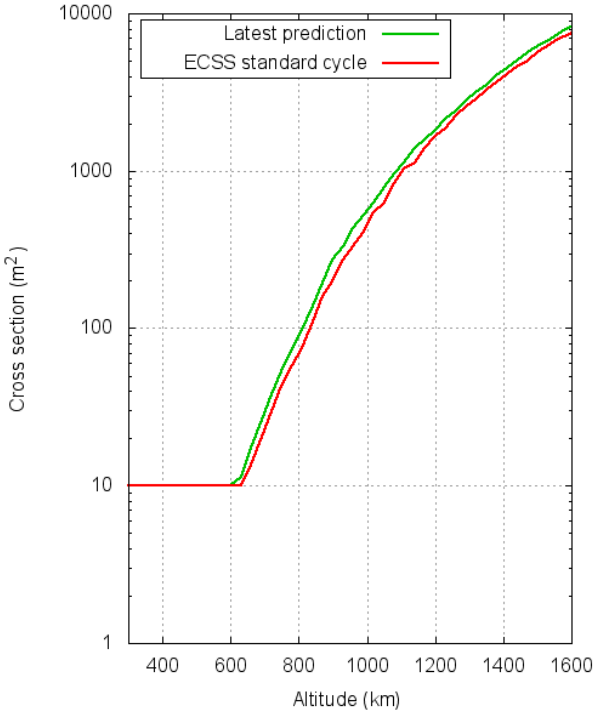
OSCAR
Orbital Spacecraft Active Removal:
Analyze disposal scenarios and assess compliance with mitigation requirements.

CROC
Compute projected cross-sectional areas of complex bodies

SARA
Spacecraft Entry Survival Analysis Module (SESAM): Modeling the re-entry.
Spacecraft Entry Risk Analysis Module (SERAM): Assessing on-ground risks of objects surviving re-entry.

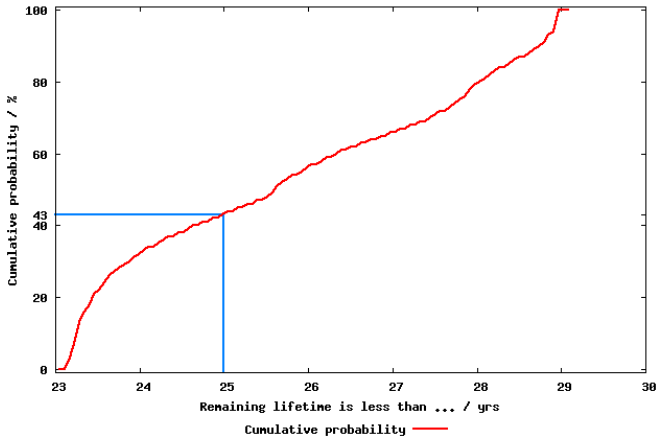
DRAMA/OSCAR

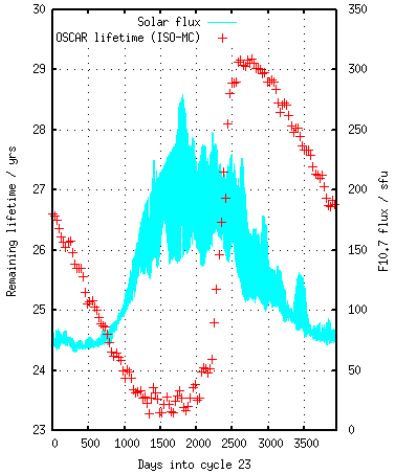

Standards
ISO 27852
ECSS
Solar & geomagnetic activity forecast
Target lifetime
Disposal scenario
Disposal simulation
Chemical
Electrical
ED Tether
Drag sail
Lifetime computation
N
Converged?
Y
Compliance verification
Propagation (FOCUS-2)
6x6 GEM-T1
NRLMSISE-00
Lunisolar
SRP


Latest prediction
ECSS standard cycle
Cross section (m²)
Altitude (km)
10000
1000
100
10
1
400
600
800
1000
1200
1400
1600

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

- DRAMA 2 -> 3 Changes:
    - Essentially under the hood in propagator improvements
    - Stochastic nature of the problem dealt with separately
    - Lagrange point orbits not (directly) addressed

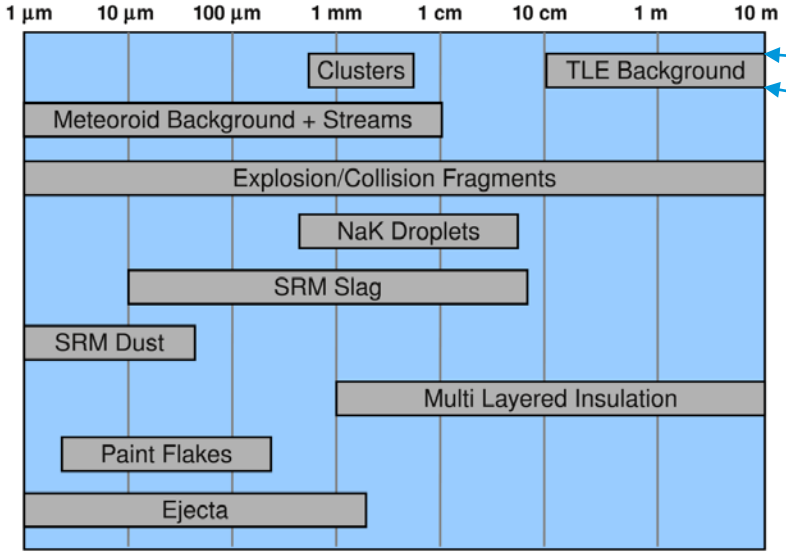
DRAMA/ MIDAS & ARES

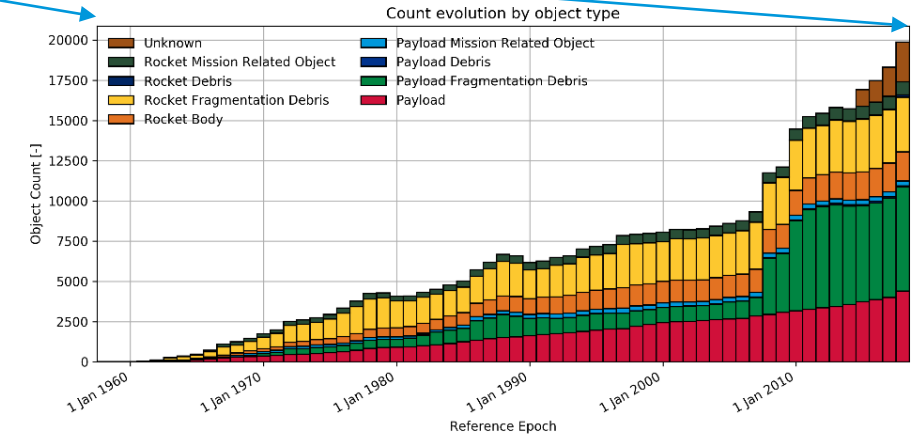
- "**During the design** of a spacecraft an **assessment** shall be made of the risk that a **space debris or meteoroid impact will cause the spacecraft to break-up** before its end of life."

- "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**."

- The MIDAS and ARES tools are based on the **MASTER environment model**

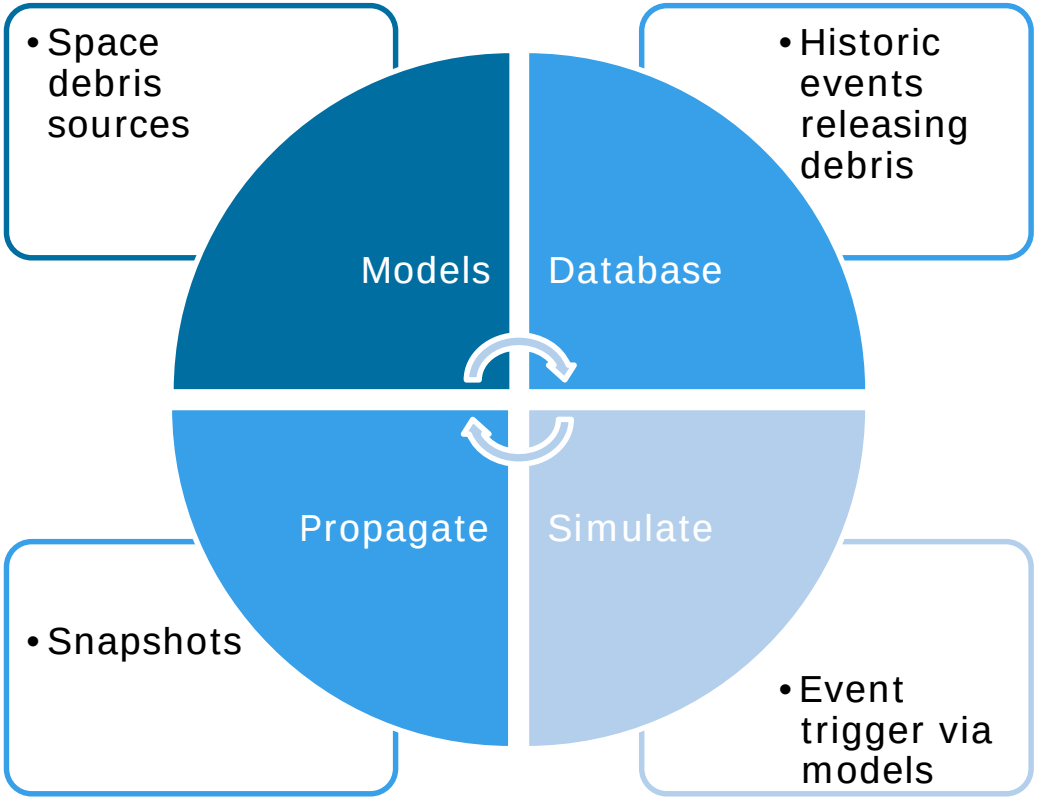
MASTER





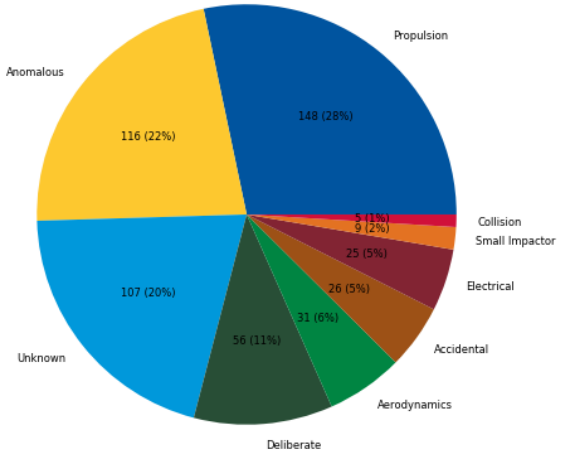
- Collision Avoidance
- Shielding
- An uncertainty gap

MASTER



MASTER 2009

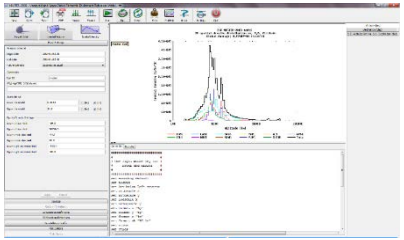
https://sdup.esoc.esa.int



MASTER

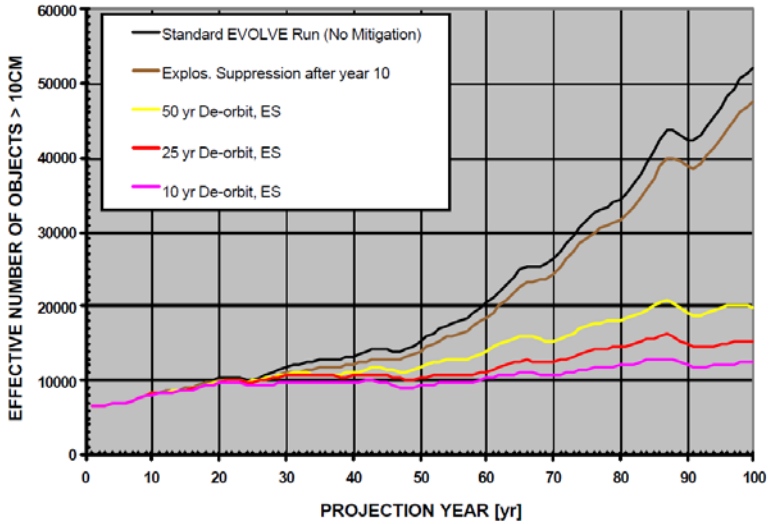
- MASTER-2009 -> MASTER-8:
  - Model updates (NaK, An Grün meteorided)
  - Flux (meteoroids only) up to lunar altitudes and Lagrange points
  - Condensed population files instead of individual sources
  - Deriving uncertainties from the validation process (four dedicated radar and eight dedicated optical campaigns added)
  - Single **future scenario** including uncertainties (down to 1 µm)

- Yearly updateable reference population
- FORTRAN API access layer & GUI (java):

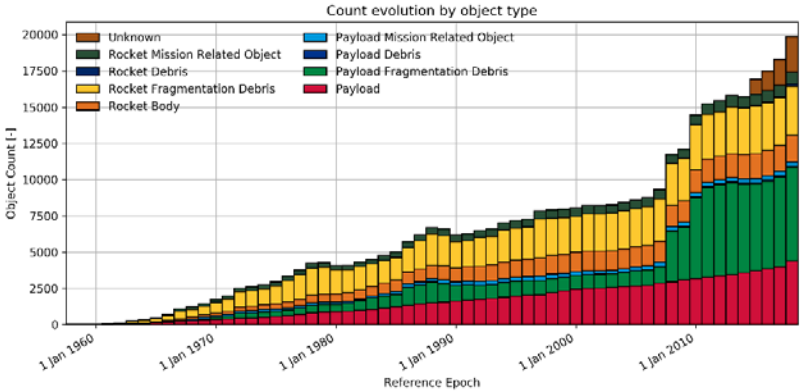


MASTER/ Future prediction

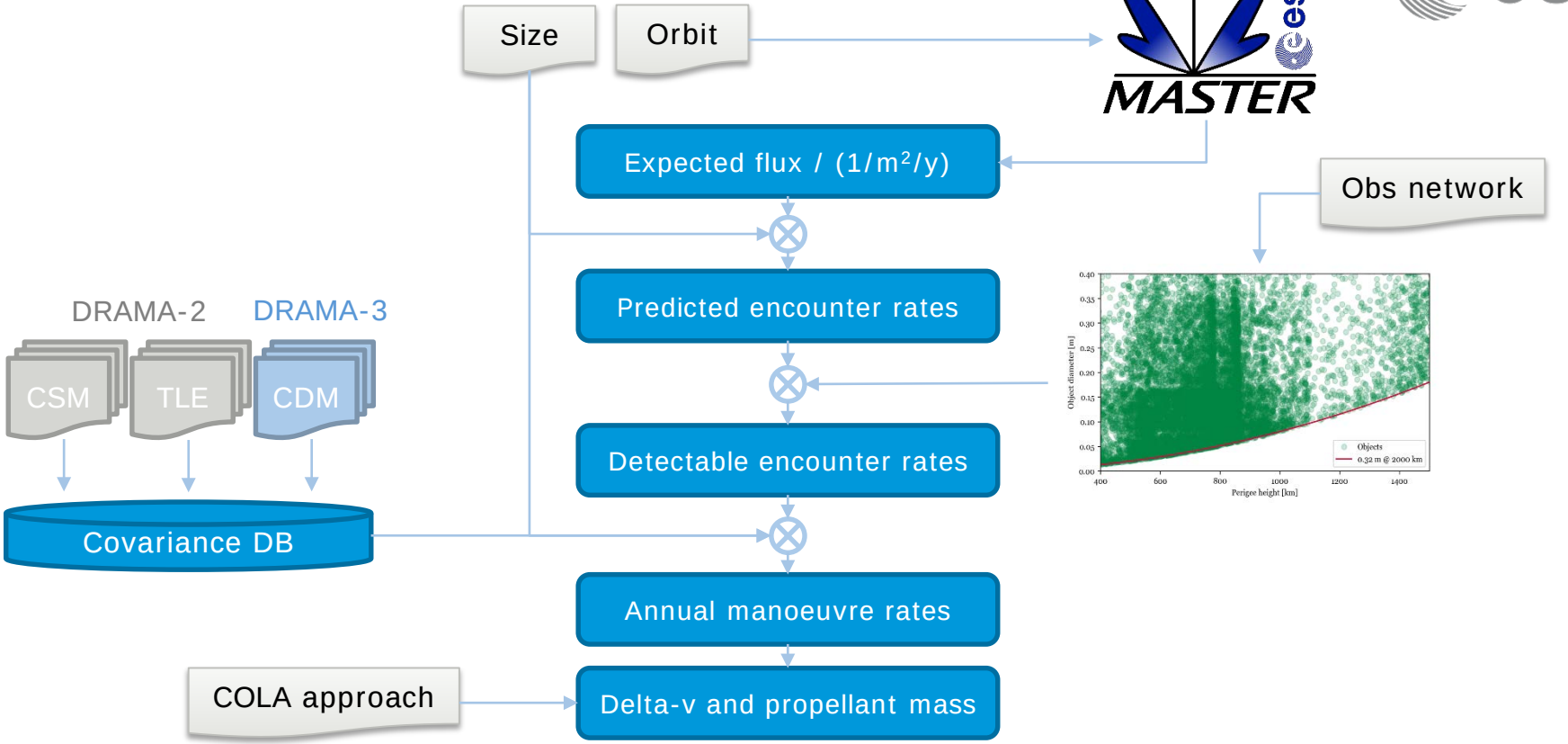
Prediction in 2001



Observation in 2017

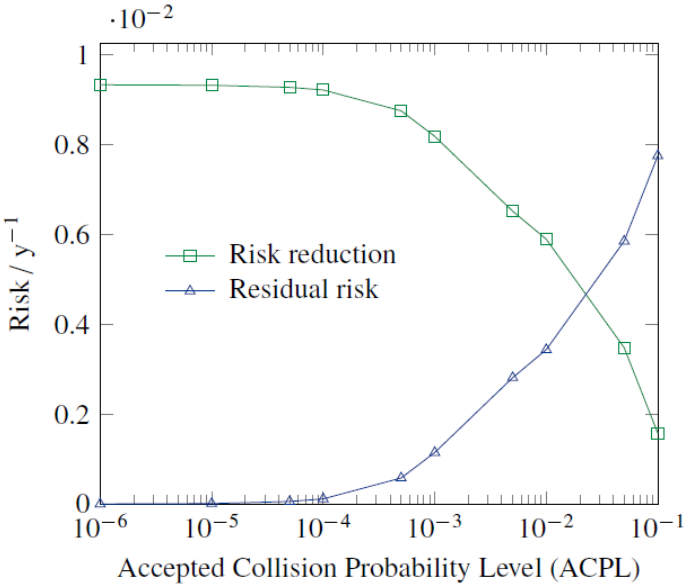


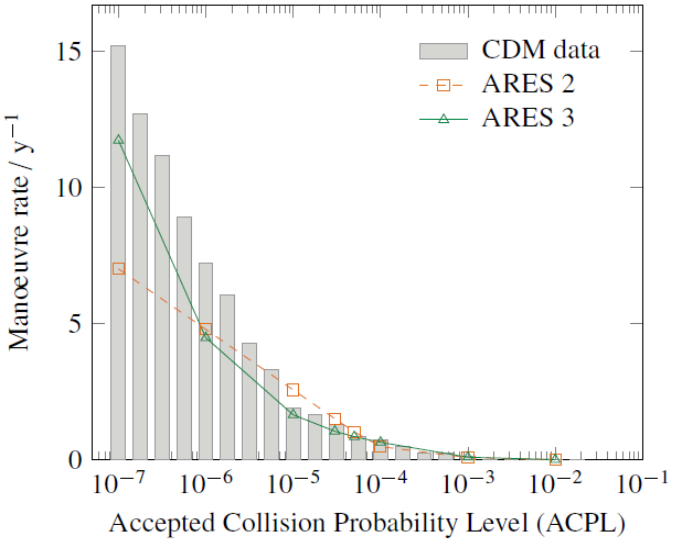
DRAMA/ARES


Size
Orbit
MASTER
Expected flux / (1/m²/y)
Obs network
Predicted encounter rates
DRAMA-2
DRAMA-3
CSM
TLE
CDM
Covariance DB
Detectable encounter rates
Annual manoeuvre rates
COLA approach
Delta-v and propellant mass
Object diameter [m]
Perigee height [km]
Objects
0.32 m @ 2000 km

DRAMA/ARES

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



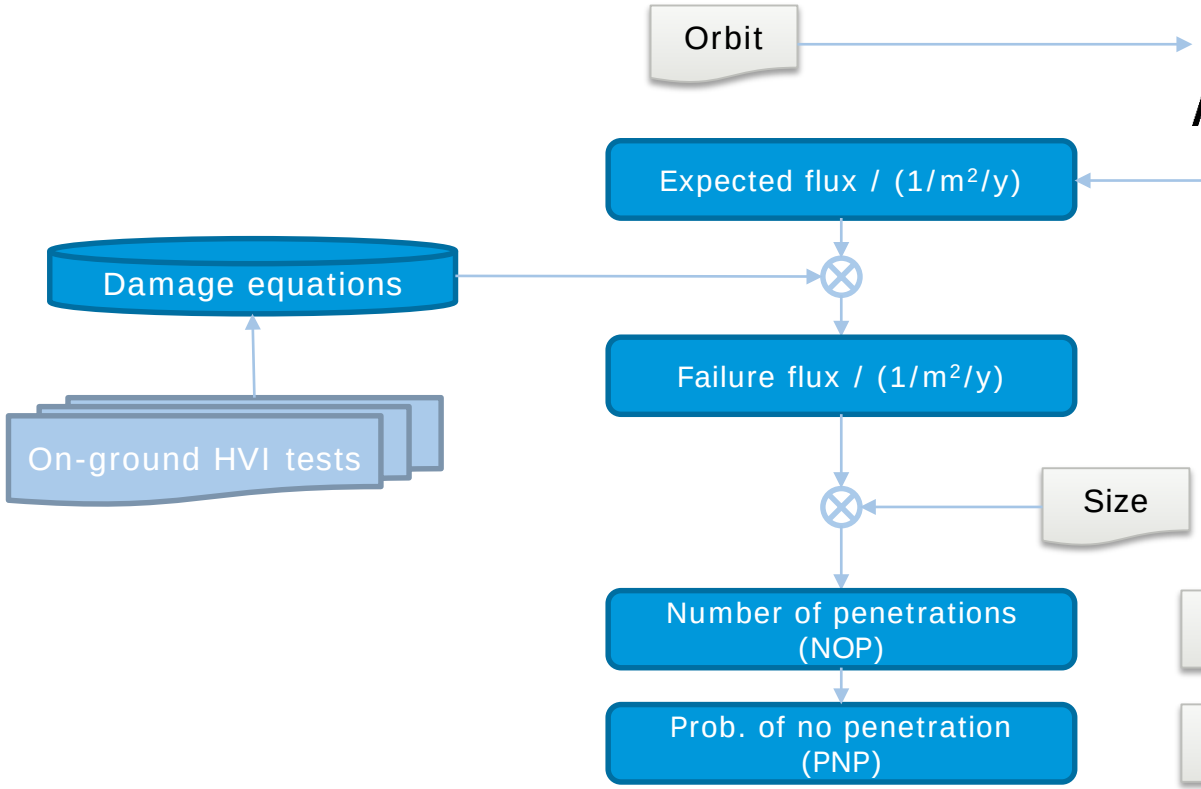


DRAMA/ARES

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

- DRAMA 2 -> 3 Changes:
  - Under the hood in chaser covariance assessment
  - Adapted detectability equations in view of commercial SST
  - MASTER-8 integration
  - Operational/Decay orbits can be propagated

DRAMA/MIDAS



Poisson statistics

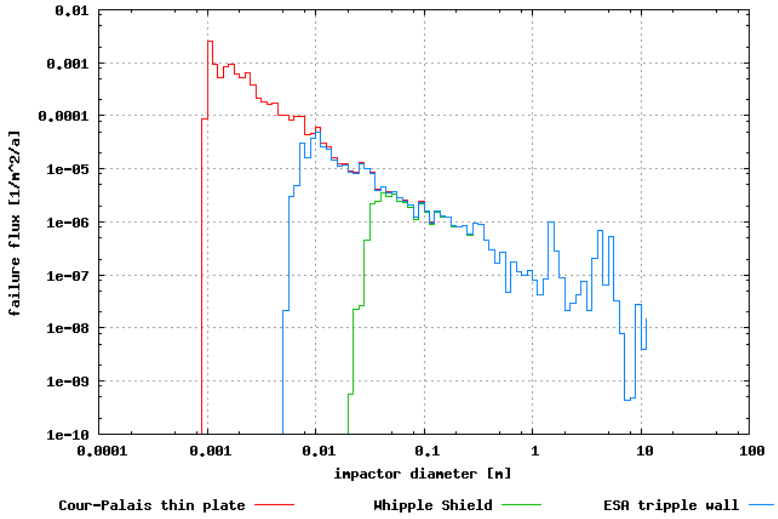
$$NOP = f \cdot A \cdot \Delta t$$

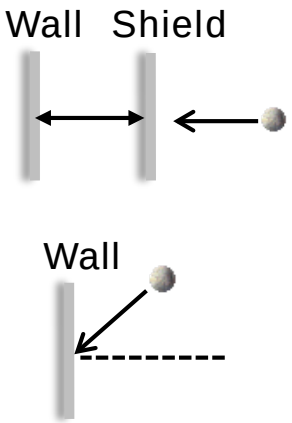
$$PNP = 1 - (1 - e^{-NOP})$$

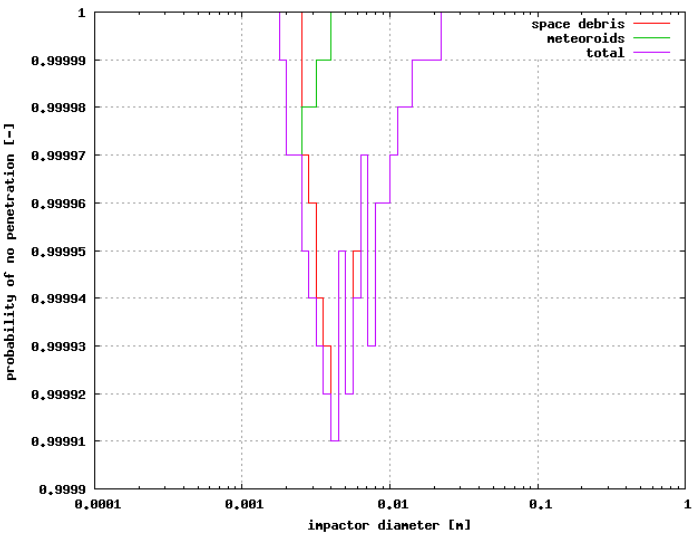
DRAMA/MIDAS

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

- Damage analysis for up to ten oriented surfaces



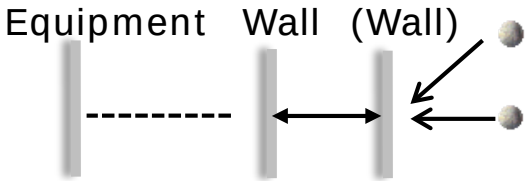




DRAMA/MIDAS

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

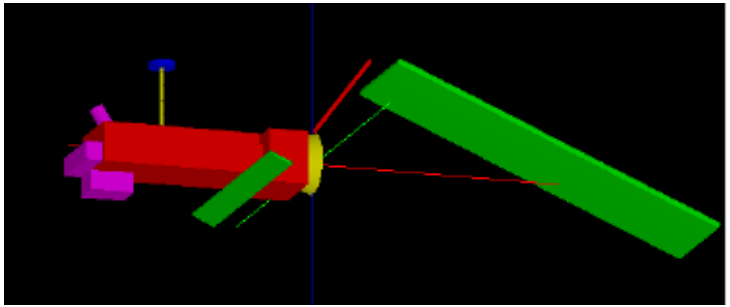
- DRAMA 2 -> 3 Changes:
  - MASTER-8 integration
  - Operational/Decay orbits can be propagated
  - Addition of the SRL Ballistic Limit Equations

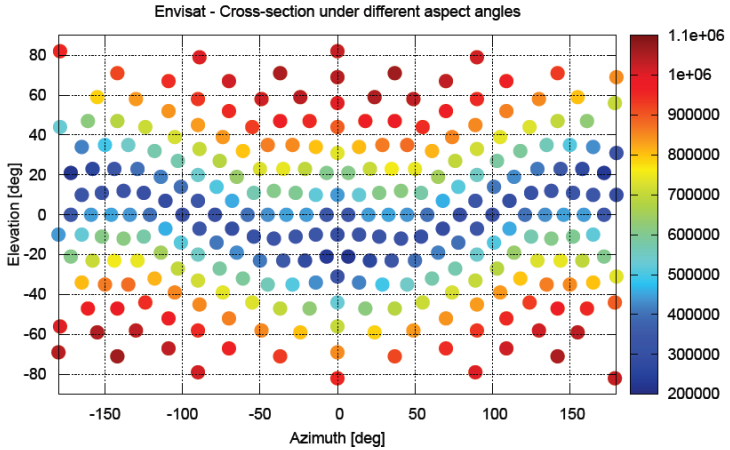


DRAMA/CROC

- **CROC tool:** Graphical *design of a 3D model* of a satellite from a set of basic shapes:
- Computation of the **cross-section** under different assumptions:
  - User-defined aspect angle
  - User-defined aspect angle and rotation axis
  - Randomly tumbling satellite

- DRAMA 2 -> 3 Changes:
  - Usability enhancements





DRAMA/SARA

- “The space system shall be designed and operated such that the re-entry **casualty risk** does not exceed $\mathbf{10^{-4}}$ 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 paradigm breaks the conservative approach

DRAMA/SARA

SESAM tool

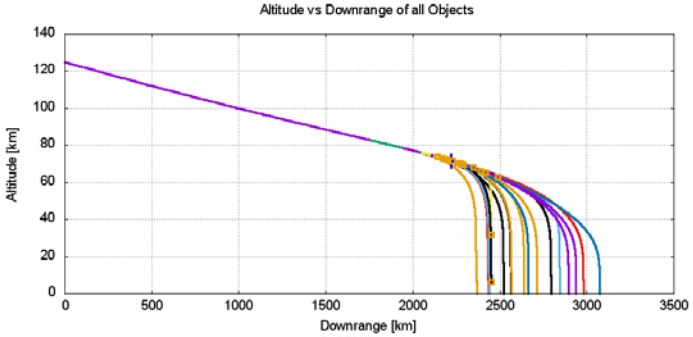
- Model the re-entry of a space system
- Physics based release pre-defined primitives
- Simplified aerothermal analysis & propagation
- Database of material thermal characteristics

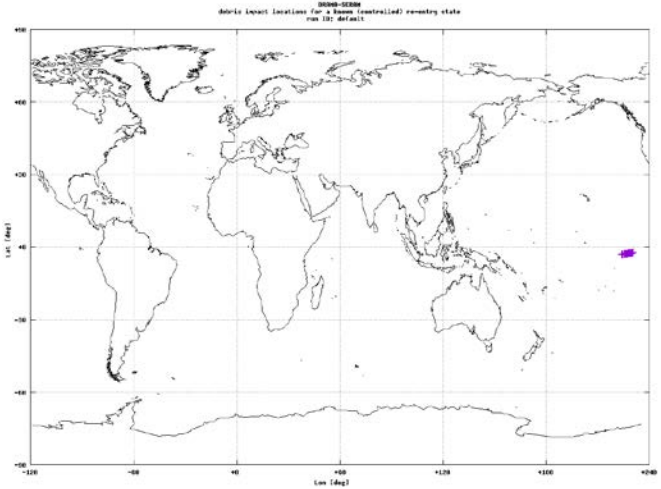
SERAM tool

- Assess on-ground risk of surviving objects
- Debris footprint
- World population model
- Casualty expectation

Additional stochastic module

- Parameter variations
- Calculation of impact zones

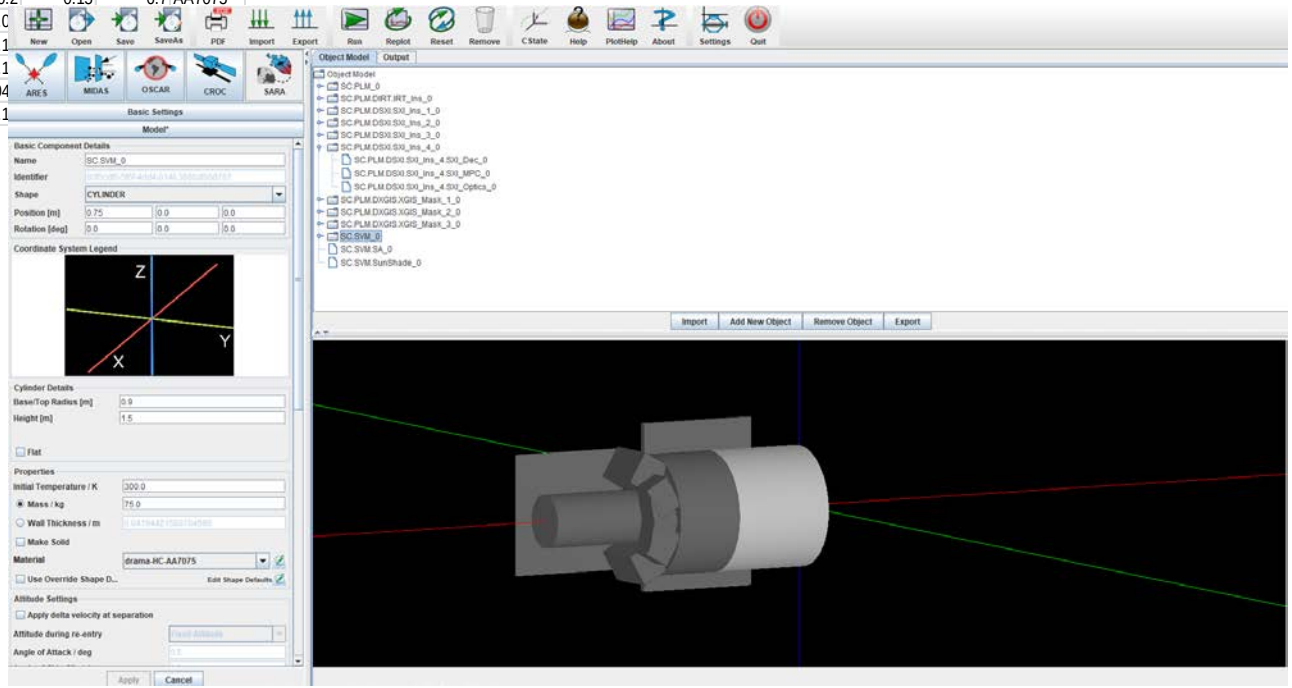




DRAMA/SARA Changes

Surviving components

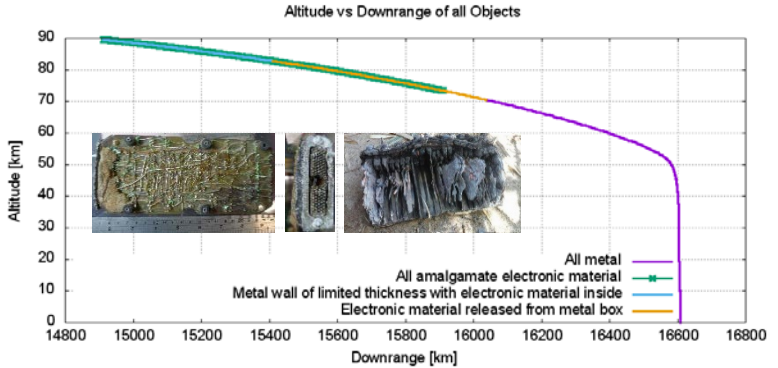
Name	Shape [-]	No. [-]	Width/Diam [m]	Length [m]	Heigth [m]	Mass [kg]	Material [-]
TCU	Box	1	0.52	0.38	0.27	33	AA7075
Batt	Box	1	0.54	0.4	0.21	50	Batlit
TRU	Box	1	0.2	0.2	0.15	6.7	AA7075
RWL	Cylinder	2	0.31	0.0			
STRE	Box	4	0.2	0.1			
STRE	Box	2	0.2	0.1			
Tank	Sphere	1	0.45	0.04			
Thrsts	Cylinder	12	0.032	0.1			



DRAMA/SARA Changes

- Simple method changes which can have large effects:
  - Continuous heating (along the entire trajectory, radiative)
  - Nested-ness (local-global heating, shielding)
  - Material models (metal and composites materials)

- Support for user defined detailed aerothermodynamics
- Explosions
- Estimation of the fall out zone integrated
- UNPPP population model integrated
- Model guidelines



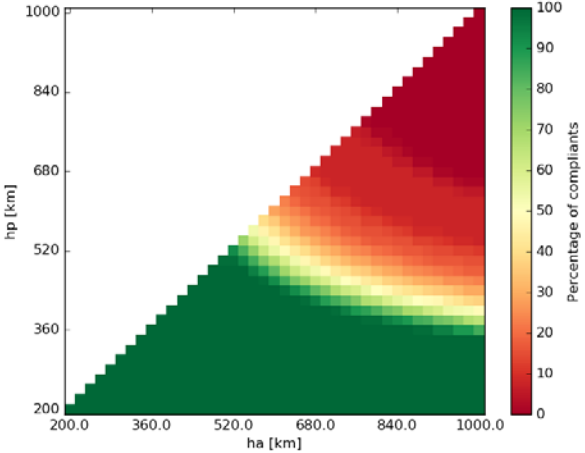
DRAMA/pyDRAMA

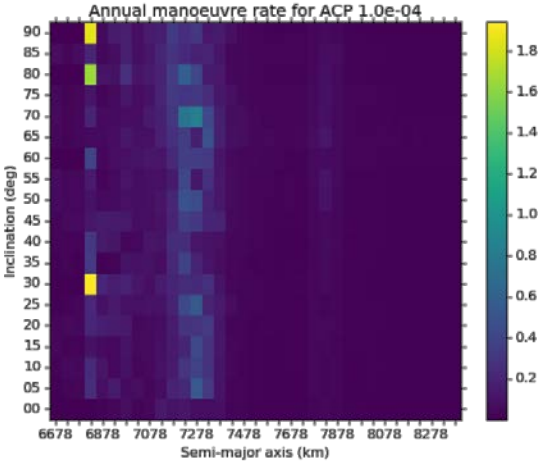
- A user survey pointed out the needs of a *Procedural* vis-à-vis a *creative user*
- DRAMA is a suite but tools are not connected
- How to support without drawning in support work? -> Python encapsulation

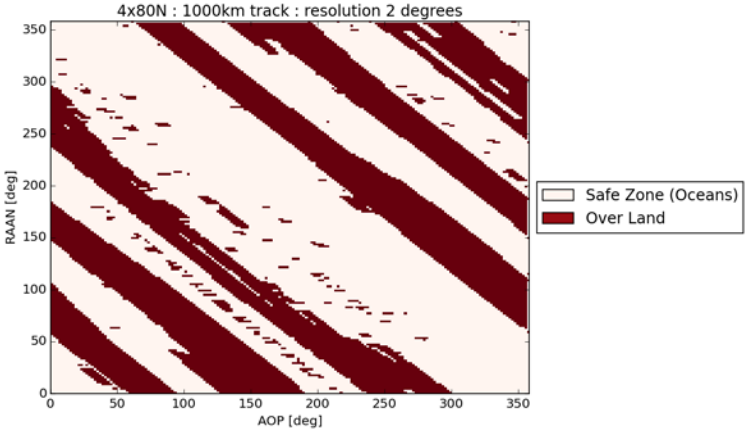
```
In [1]: from drama import oscar

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/pyDRAMA

- Basic Python 3, no additional libraries delivered.
- All tools comes as package with configuration generation and output parsers
- Basic stochastic module making use of the multiprocessing package
- The user can mix and match







Conclusions

- MASTER8 has been upgraded to
  - Include extensive new validation data to provide a global reference for the space debris environment (1958 to 2055)
  - Include a FORTRAN API for tool integration
- DRAMA3 has been upgraded to:
  - Integrate with MASTER8
  - Capture the evolution in SDM requirements (ARES & MIDAS)
  - Capture the scientific and engineering shifts w.r.t. re-entry (SARA)
  - Include some FORTRAN API and python bindings for tool integration
- Release Q1 2019, https://sdup.esoc.esa.int , free and worldwide
- Future: Open Source (permissive, referenced, central governed master)

Not updated: The logo