Software Tool for the Design and Computation of Mission End-of-Life Disposal

HTTP://REDSHIFT-H2020.EU/

Agenda

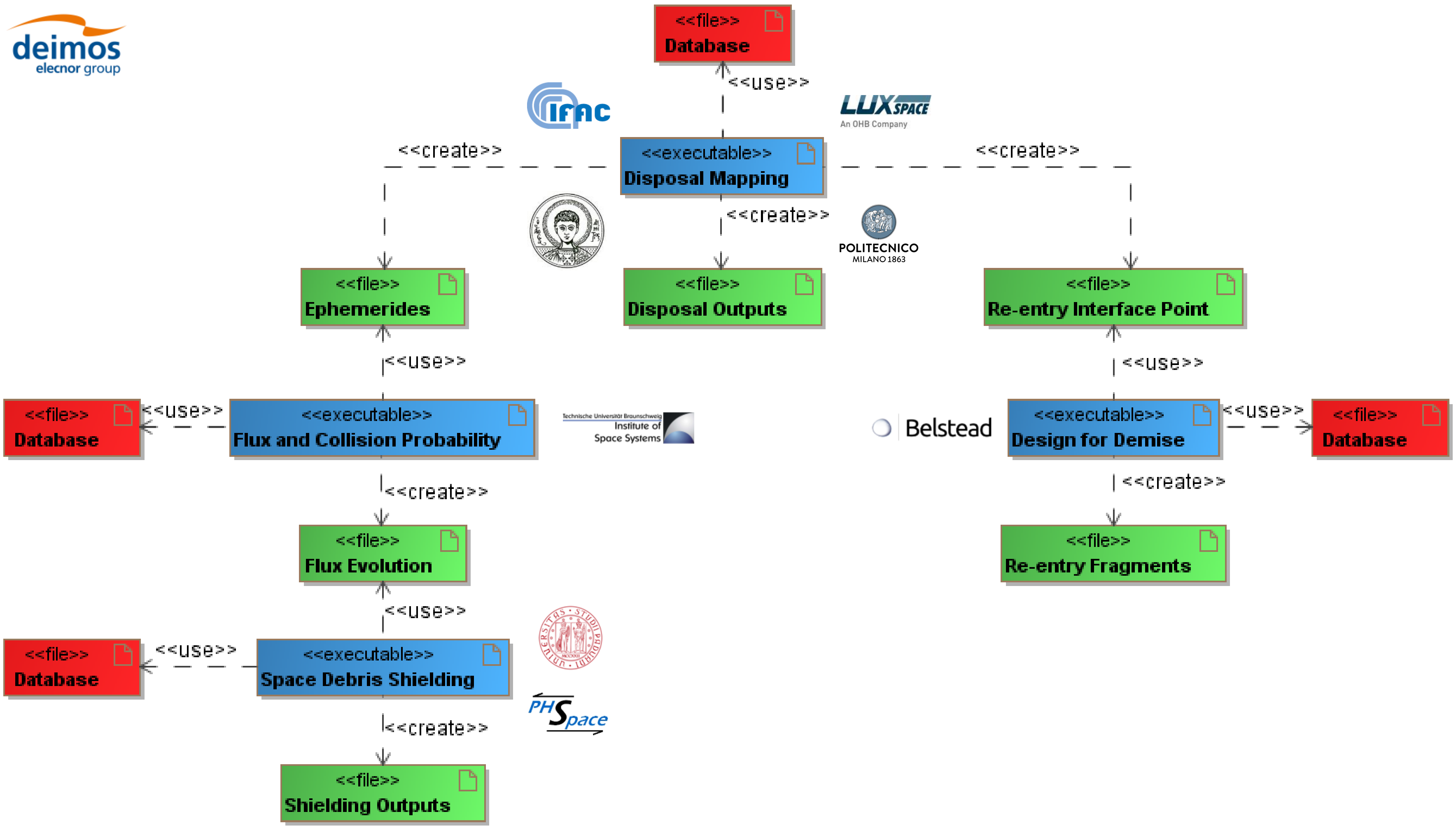
- Tool Overview
- Tool Modules
  - Disposal Mapping
  - Design for Demise
  - Flux and Collision Probability

Comprehensive SW tool implementing the holistic vision of the project.

Tool for spacecraft manufacturers and operators, space agencies and research institution to design the EoL of any Earth-based mission and to study the interaction with the space debris environment.

It is the aim of the ReDSHIFT tool to contribute in a proactive way to the mitigation of space debris problem via passive EoL mitigation.

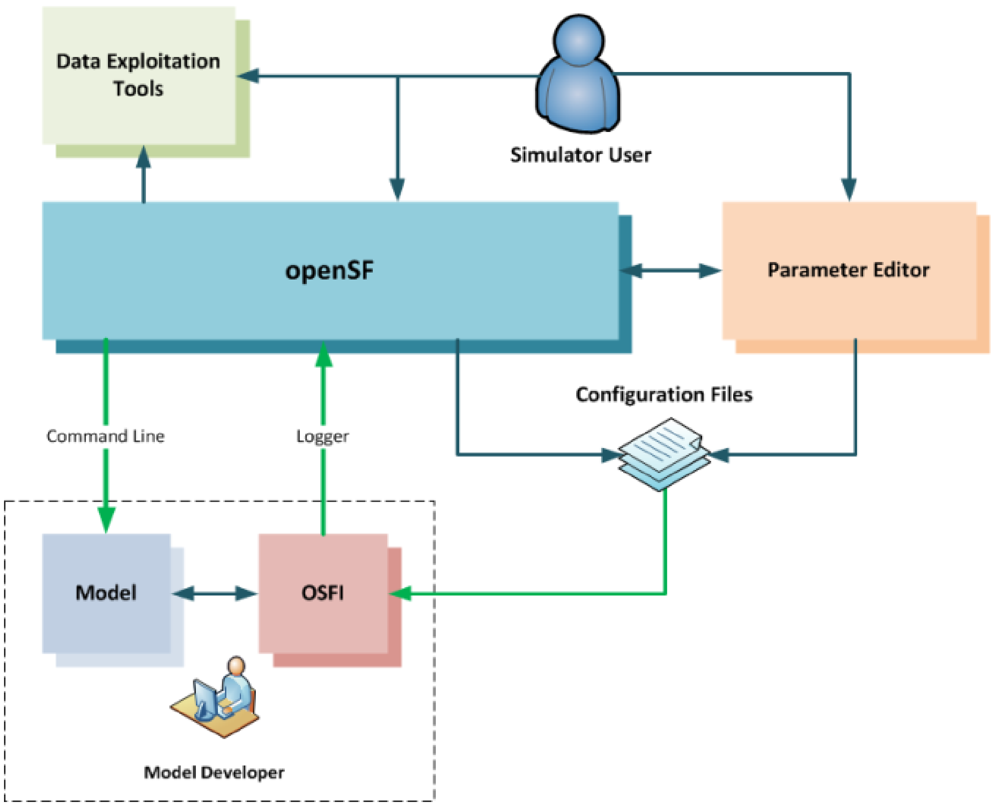
SW Processing Chain



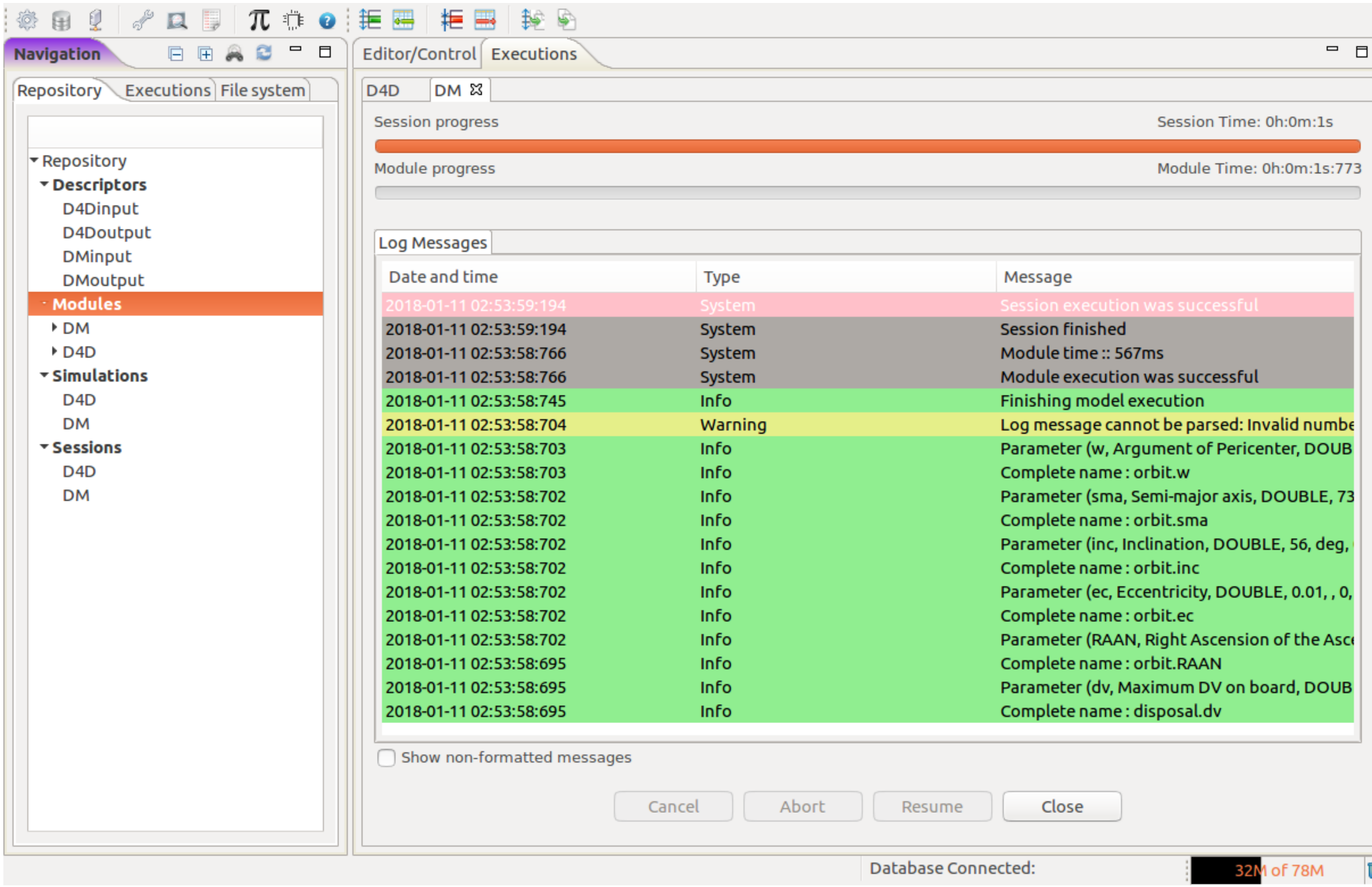
Two different user interfaces

- Desktop, based on ESA openSF, distributed within the consortium partners, highly configurable for easy upgrades
- Web, users' access control, public access to S/C operators, space agencies and research institution

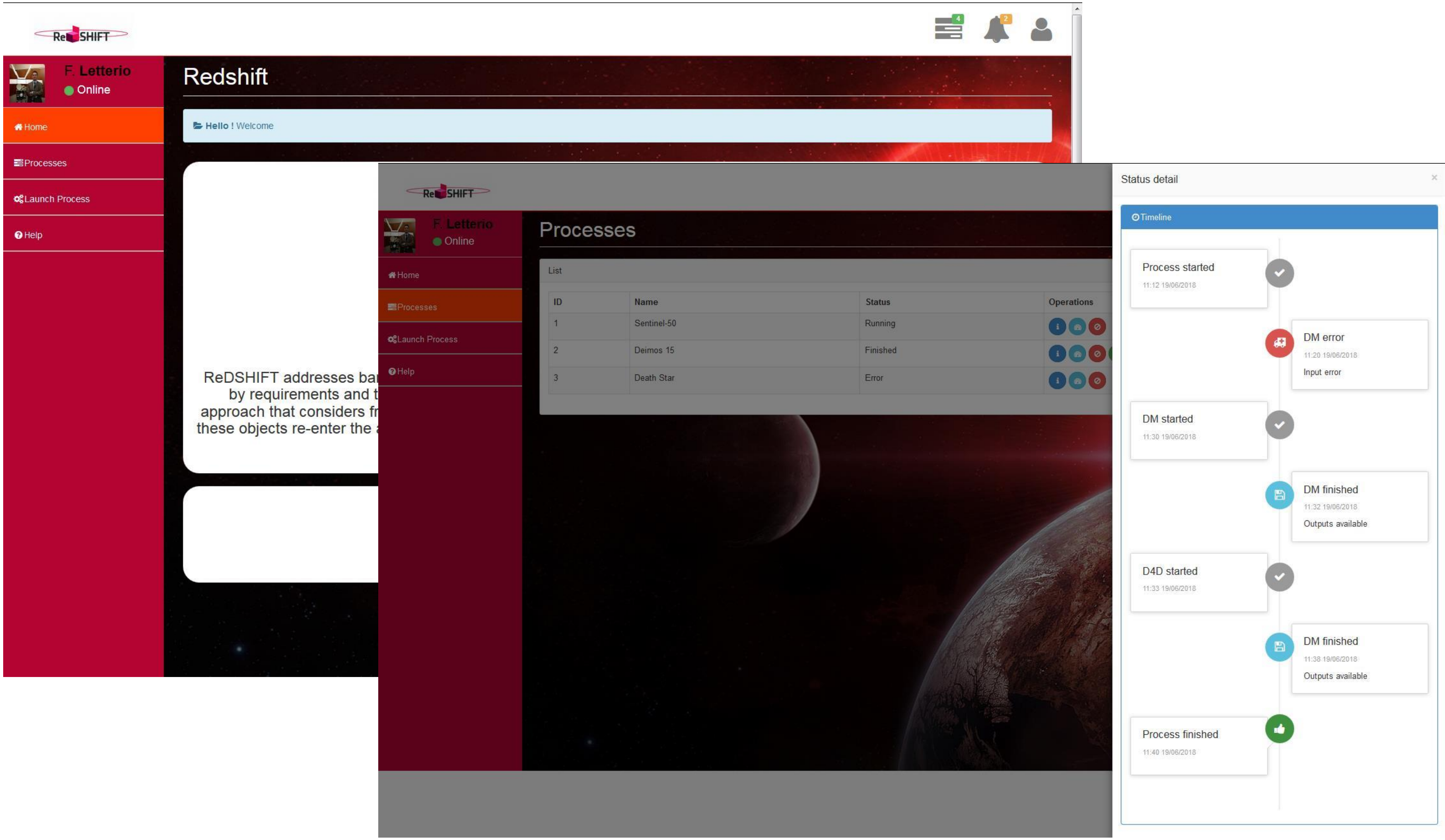
ReDSHIFT SW Tool Desktop



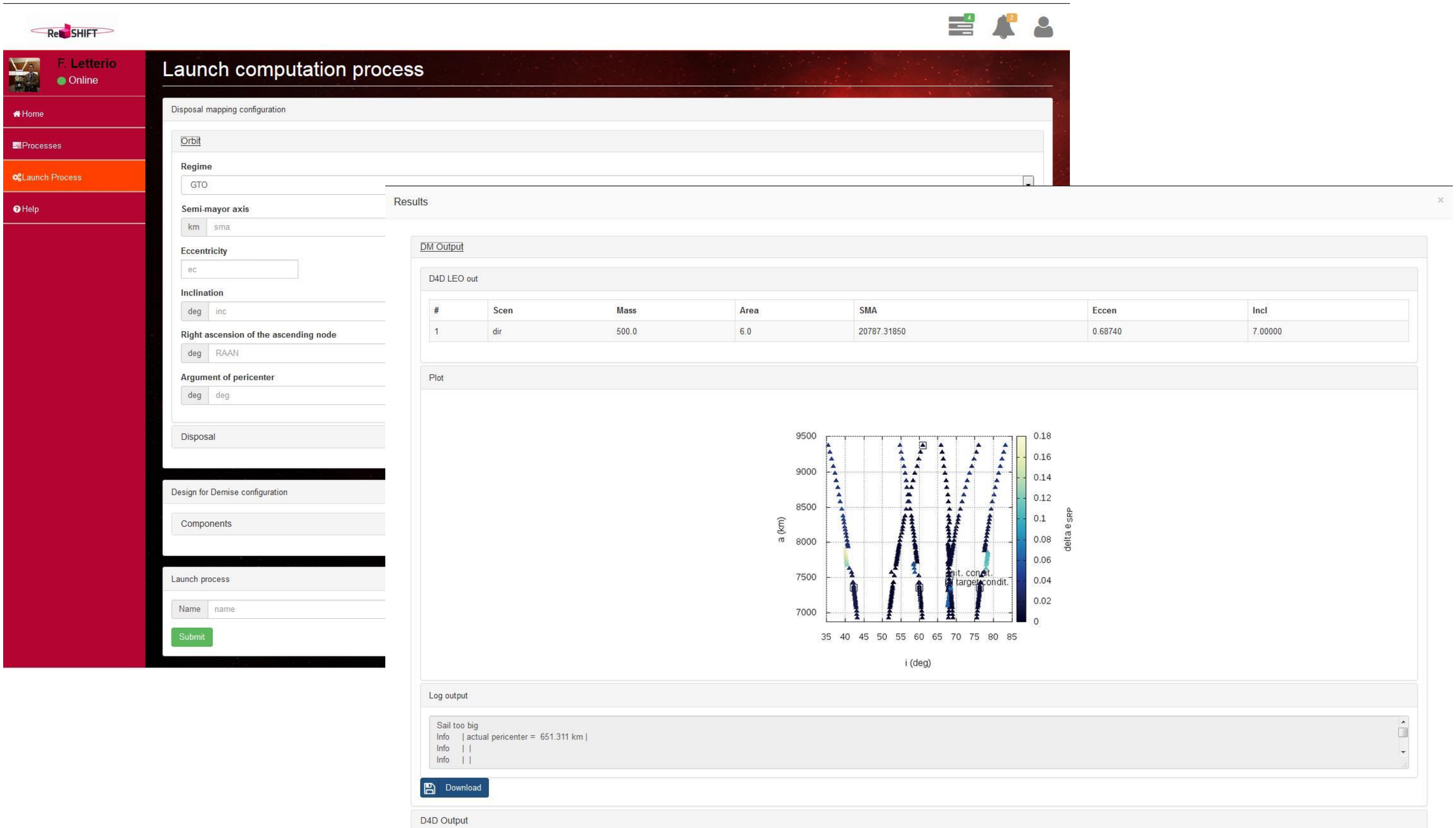
ReDSHIFT SW Tool Desktop



ReDSHIFT SW Tool Web



ReDSHIFT SW Tool Web



The module aims at assessing the best EoL disposal strategy for a given orbital configuration.

The results are based on the extensive dynamical mapping performed on the circumterrestrial space from LEO to GEO, highlighing the main dynamical perturbations to be exploited.

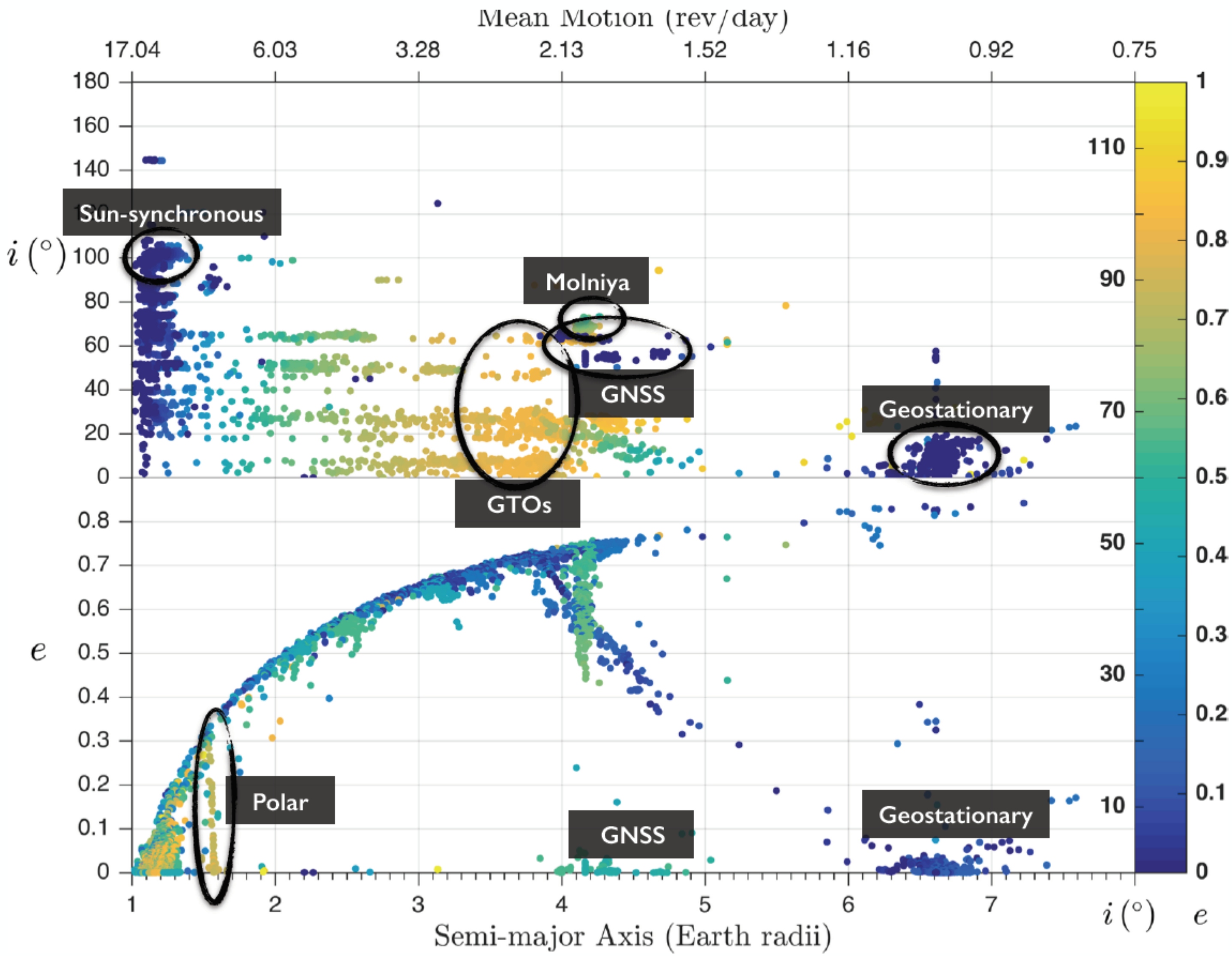
The SW provides the ΔV budget required to reach a deorbiting corridor which can facilitate a re-entry.

A hybrid approach maneuver + sail can be envisaged.

In case a reentry is not feasible, the most stable and/or less expensive graveyard orbit is selected.

Specific plots to visualize the outcome are generated.

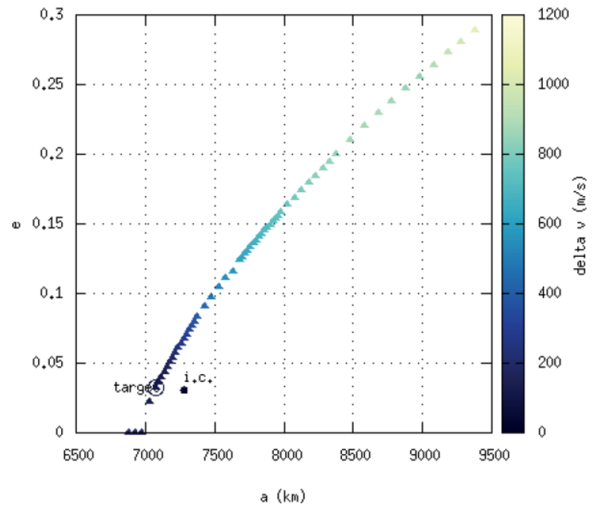
Disposal Mapping Overview



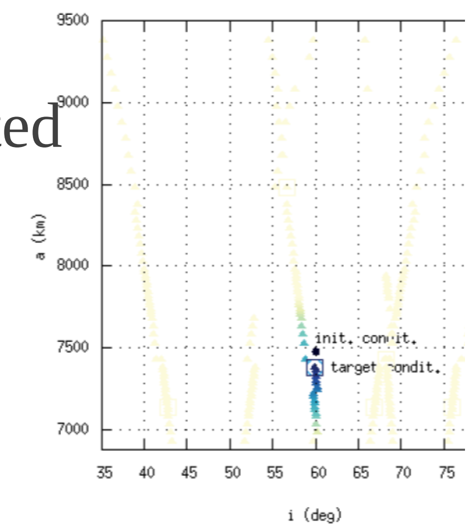
Disposal Mapping Overview

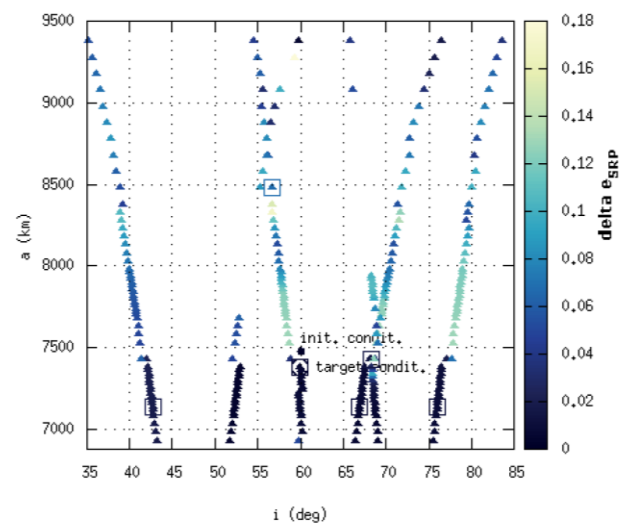
Parameter	Description
sma	Semi-major axis
ec	Eccentricity
inc	Inclination
RAAN	Right Ascension of the Ascending Node
w	Argument of Pericenter
dv	Maximum DV on board
SAIL	Solar sail presence
tor	Re-entry time: 10 or 25 years
epoch	Epoch: 1 → 22.74/12/2018, 2 → 21.28/06/2020
mass	Satellite mass

Given initial conditions, re-entry is assessed considering drag with or without sail (user input)



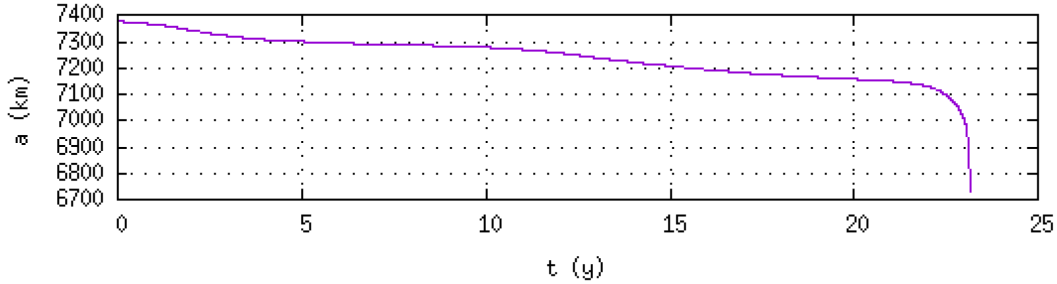
Research of resonant a, e, i conditions that can be targeted to take advantage of other perturbations

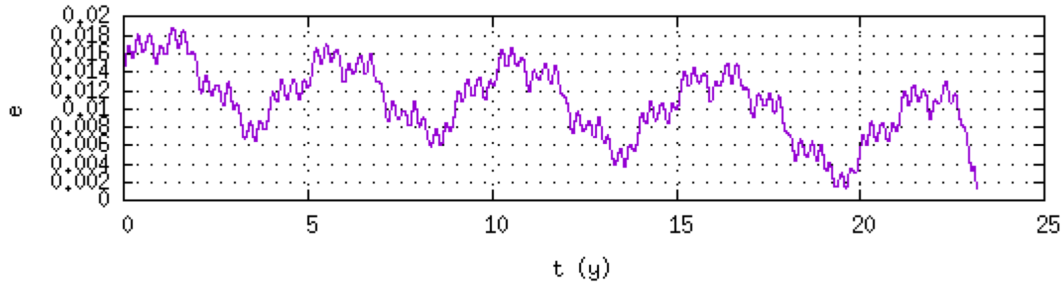


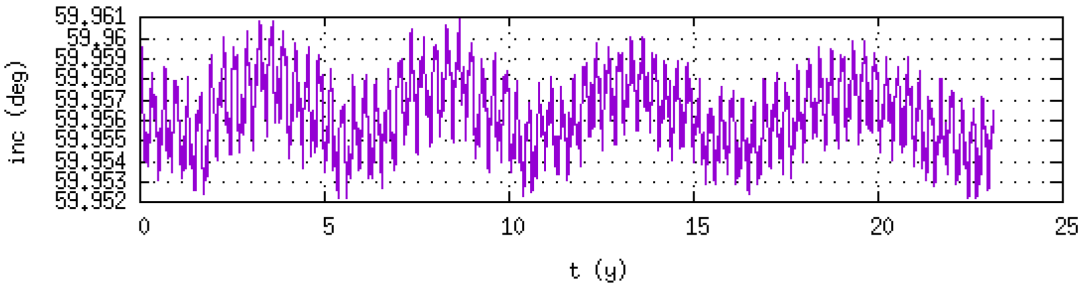


LEO Regime

If the ΔV provided by the user is lower than the one required to target any of the reentry solutions, then a propagation is performed and the corresponding ephemerides are computed







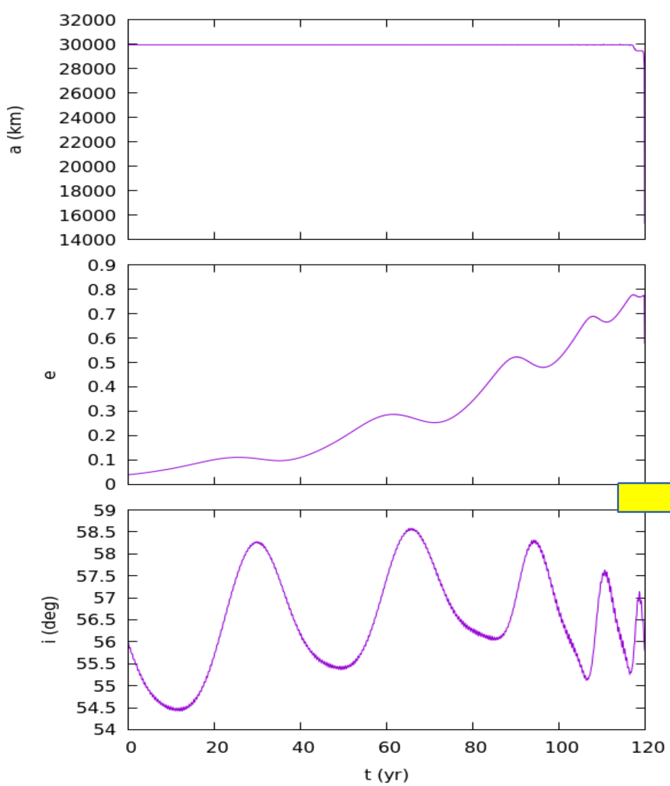
The conditions at 120 km (interface point) required by the D4D module are computed

MEO Regime – Example for a Galileo Orbit

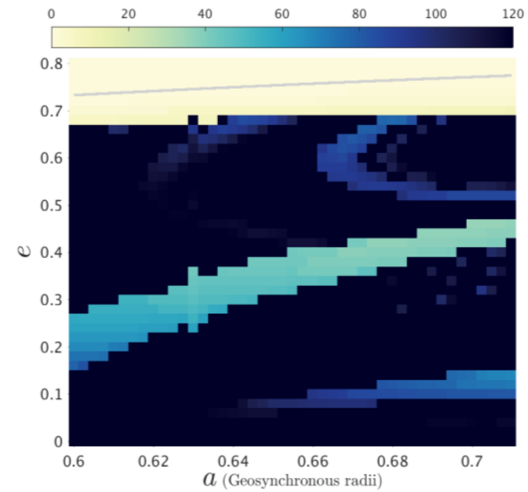
Epoch	A/m
22.74/12/2018	0.015

a(km)	e	i (deg)	Ω(deg)	ω(deg)
29601.31	0.0001	56.00	282.8	196.5

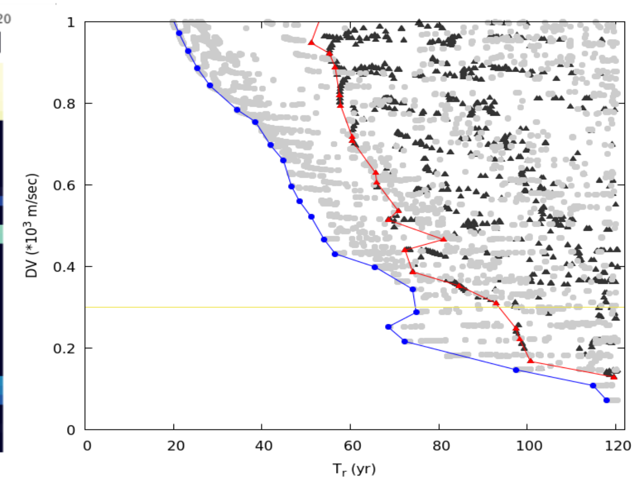
ΔV-optimal reentry solution



Dynamical map



Disposal solutions for various Ω,ω



Reentry Optimal Solutions

	a(km)	e	ΔV(m/s)	ΔT(h)	t_{life}(yr)	Method
ΔV-optimal:	29936.56	0.0400	72.7	7.31	119.93	Hohmann
T -optimal:	29936.56	0.1400	252.9	7.86	68.50	Hohmann

Reentry conditions (at 120km)

e	inc	Apogee Alt	Perigee Alt.
0.576	55.800	17729.54km	112.90km

Flight path angle (at 120 km): -1.6200 deg

Speed (at 120 km): 9836.1970 m/s

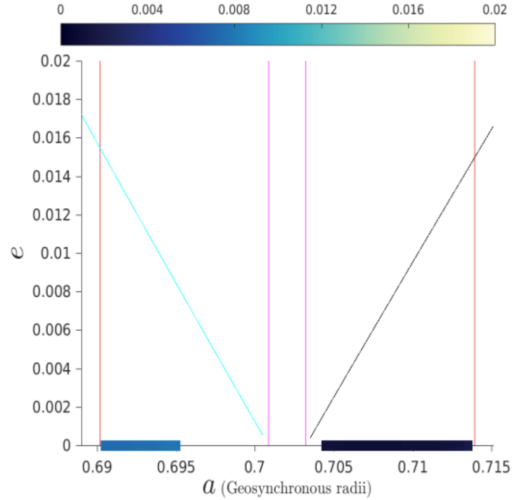
Continues to orbit

MEO Regime – Example for a Galileo Orbit

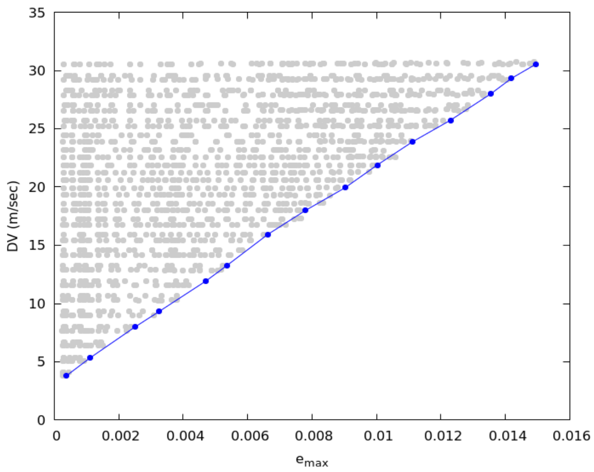
Epoch	A/m
22.74/12/2018	0.015

a(km)	e	i (deg)	Ω(deg)	ω(deg)
29601.31	0.0001	56.00	282.8	196.5

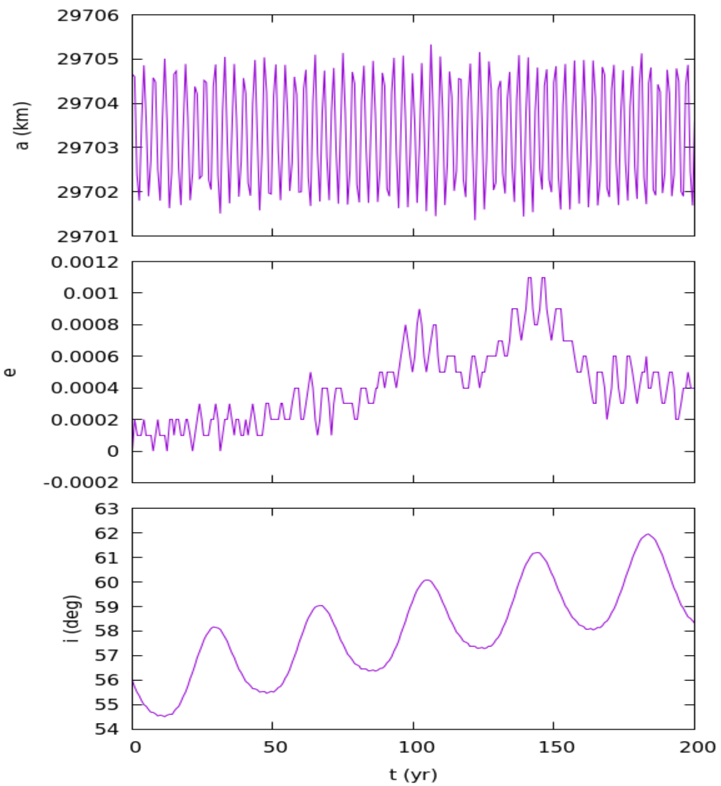
Dynamical map



Disposal solutions for various Ω,ω



ΔV-optimal graveyards solution

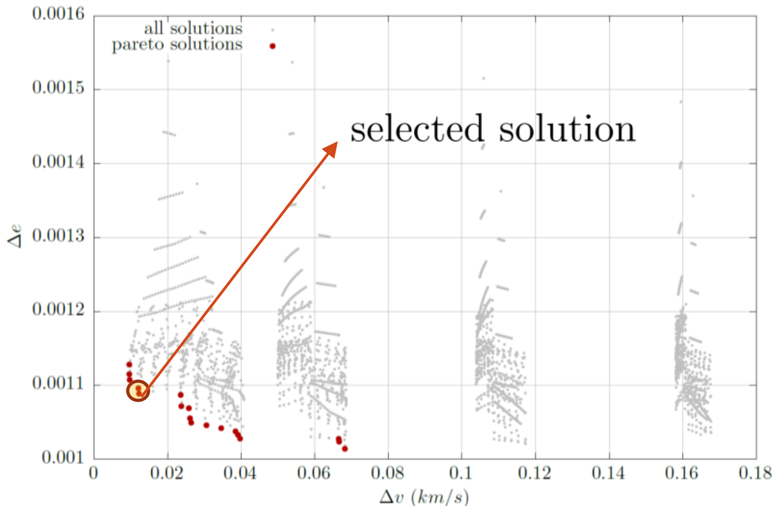


Graveyards Optimal Solutions (200yr)

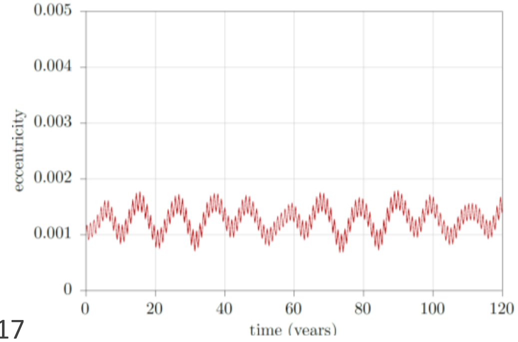
	a(km)	e	ΔV(m/s)	ΔT(h)	e_{max}	Method
ΔV-optimal:	29704.66	0.00	6.4	7.06	0.00114	Hohmann

Graveyard design example

$$a = R_{GEO},\ e = 0.001,\ i = 0^\circ,\ \Omega = 0^\circ,\ \omega = 0^\circ$$

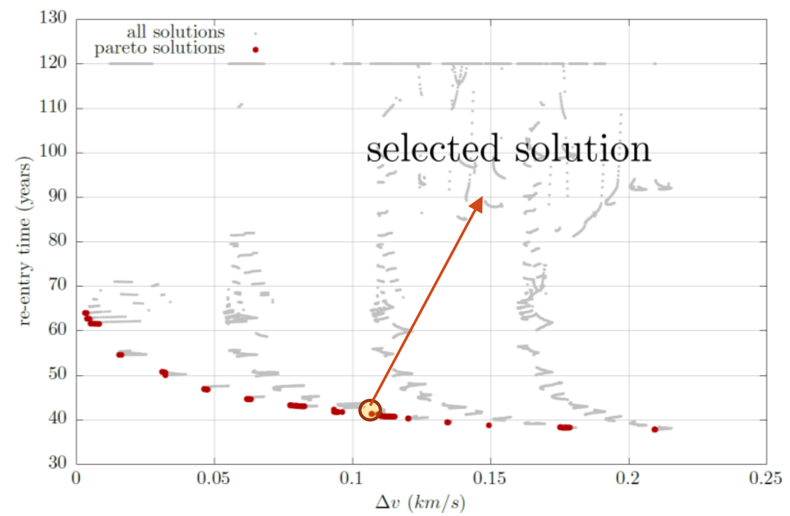


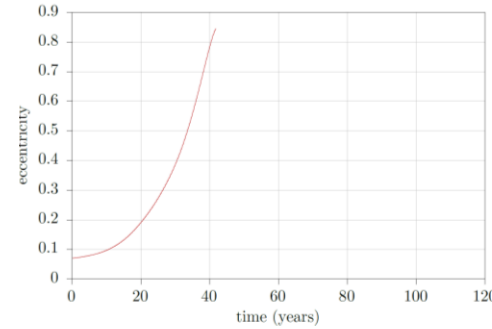
orbital evolution of selected solution



Re-entry design example

$$a = R_{GEO},\ e = 0.001,\ i = 70^\circ,\ \Omega = 0^\circ,\ \omega = 0^\circ$$





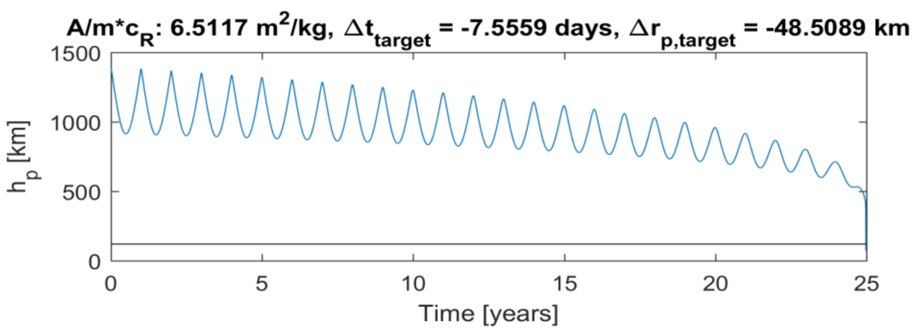
- Gkolias, Colombo, IAC 2017

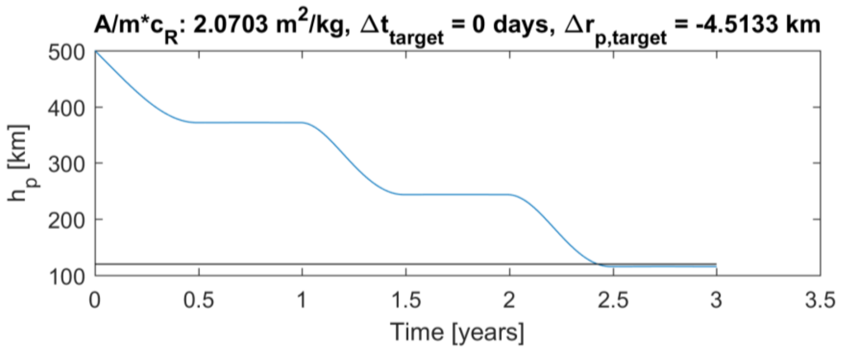
Passive Sail

Given a desired deorbiting time find the required area-to-mass ratio times c_R for passive sail approach

Zero-finding method used on a model that considers drag + SRP + J_2

If the passive approach is unfeasible: given the desired deorbiting time find the required area-to-mass ratio times c_R for a sail that modulates its attitude approx. once every six months





Sample of output:

Conditions at 120 km:

a = 6490.4993189786 km, e = 0.0000073637, i = 0.2617878165 rad

Om = -1142.6490131839 rad, om = 2049.2036034114 rad

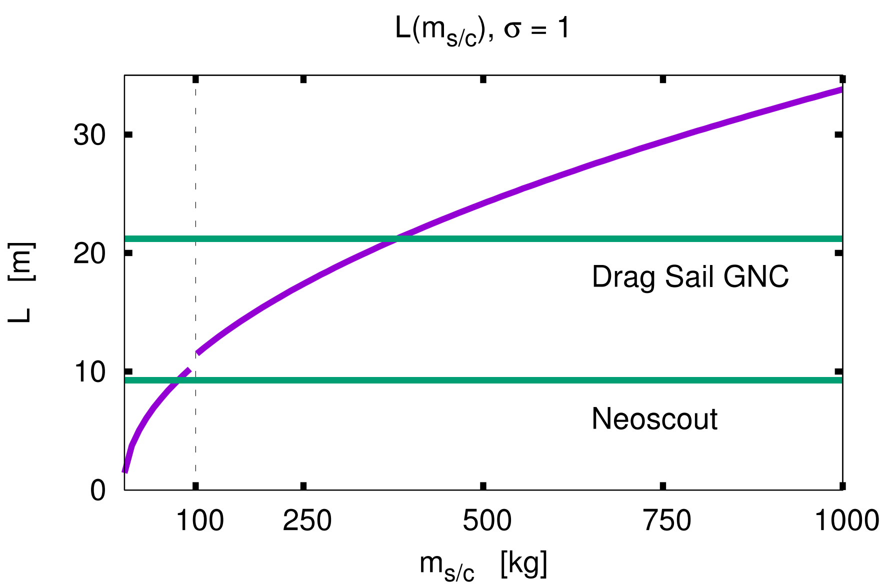
Sail Design

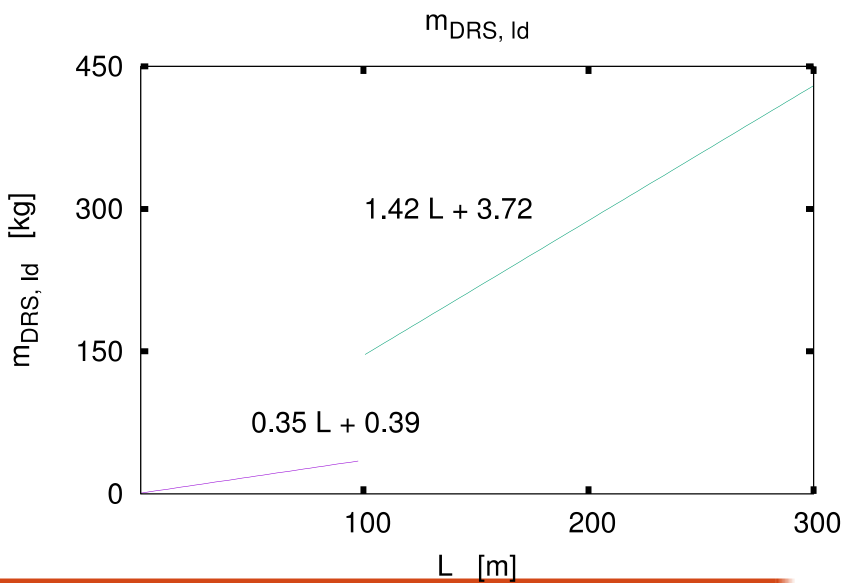
If either passive and/or modulating sail approach is possible: check feasibility according to technological boundaries. Given $m_{s/c}$ mass of the s/c and $s = Ac_R / m$ provided by the module.

$m_{s/c} \Rightarrow L(m_{s/c})$ Side length of the sail

Sample of output: Feasible sail design

- Area of the sail: 0.46477 m^2
- Mass of the sail: 0.62861 kg
- Area-to-mass ratio: 0.00831 m^2/kg
- Percentage membrane: 0.04000 (%)
- Percentage boom: : 0.88000 (%)
- Percentage empty: 0.08000 (%)





Rationale

- Provide a quick, initial assessment of vehicle demise and on-ground casualty areas
- Enable the holistic investigation of novel disposal techniques within the ReDSHIFT framework
- Identify components likely to pose a casualty risk and provide focus design-for-demise effort
- Simplified two-stage, database driven approach suitable for evaluating large numbers of scenarios in a web context

Inputs

- Spacecraft model - mass, tumble average projected area, catalogue of key components
- Component model - instance count, mass, reference length, aspect, primary material
- Orbit at entry - semi-major axis, eccentricity, inclination

Parameter	Description
name	Component name
count	Number of component instances on the vehicle
mass	Component mass
length	Component length
aspect	Component aspect
material	Primary material (ALUMINIUM, STEEL, TITANIUM, COPPER)

Algorithms

Interpolated, database driven, two stage analysis

Stage 1 - Parent vehicle re-entry to fragmentation

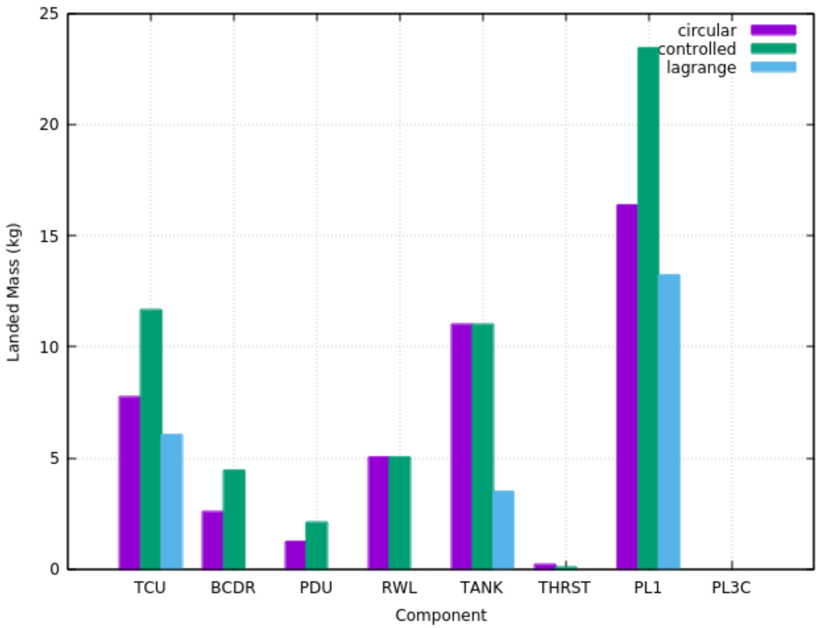
- Database derived from position independent, 3dof propagation to fragmentation of parent vehicle
- Break-up criterion - thermo-mechanical in nature, product of dynamic pressure and heat load equivalent to that experienced by circular entry at 78km
- Output - vehicle altitude, speed, flight path angle at fragmentation

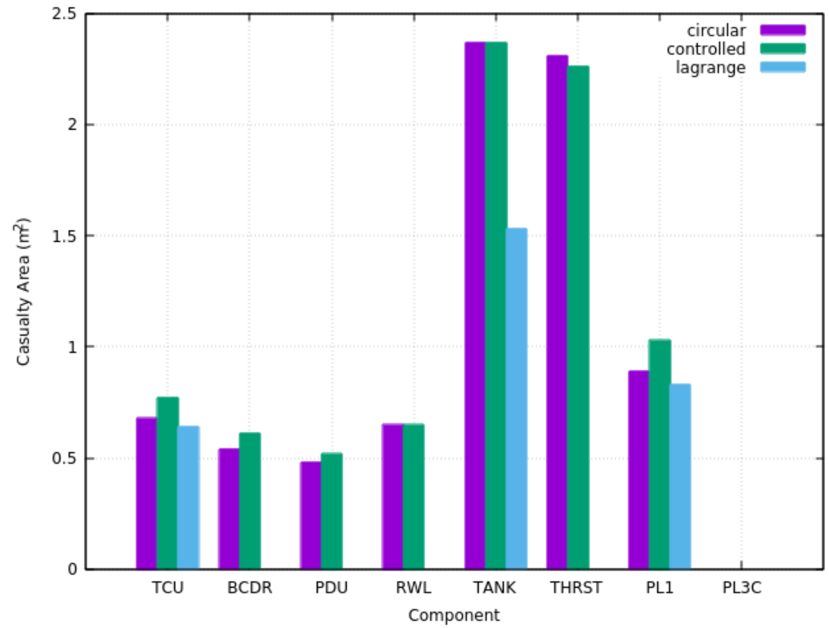
Stage 2 - Fragmentation to component demise or landfall

- Database derived from 3dof propagation to demise or impact
- Solid, cylindrical components with characteristic length and aspect
- SAM aerothermal heating models used
- Early / expected / late release assessment (+/-20% expected release altitude)
- Output - expected demise altitude, landed mass and area, qualitative demise expectation (demise / survive / uncertain)

Output

Scenario	Object	Count	Material	Outcome	FragMass	FragArea	TotMass	TotalArea	HighOutcome	NomOutcome	LowOutcome
scen1	TCU	1	ALUMINIUM	Uncertain	7.74	0.68	7.74	0.68	Uncertain	Uncertain	Survive
scen1	BCDR	1	ALUMINIUM	Uncertain	2.59	0.54	2.59	0.54	Uncertain	Uncertain	Uncertain
scen1	PDU	1	ALUMINIUM	Uncertain	1.25	0.48	1.25	0.48	Uncertain	Uncertain	Survive
scen1	RWL	1	STEEL	Survive	5.04	0.65	5.04	0.65	Survive	Survive	Survive
scen1	TANK	2	TITANIUM	Survive	5.5	1.18	11	2.37	Survive	Survive	Survive
scen1	THRST	6	STEEL	Uncertain	0.03	0.38	0.2	2.31	Uncertain	Uncertain	Uncertain
scen1	PL1	1	ALUMINIUM	Uncertain	16.37	0.89	16.37	0.89	Uncertain	Survive	Survive
scen1	PL3C	4	ALUMINIUM	Demise	0	0	0	0	Demise	Demise	Uncertain
scen1	**TOTAL**	**17**					**44.19**	**7.92**			





Environment Projection Model: Flux and Collision Probability Calculation

2 version of the model developed by two different project partners

Environment Projection
Lightweight_LUCA
TUBS

Outputs

- Annual Flux
- Collision Probability

Inputs

- Target orbit
- Object characteristics (mass, geometry)
- Configuration parameters of the collision algorithm
  Orbit trace or CUBE algorithm
- Scenario Selection (results of all scenarios available as data sets)

Flux extrapolation for small object sizes
Needed for dimensioning of the shielding (see other WP and model)

Example Output format

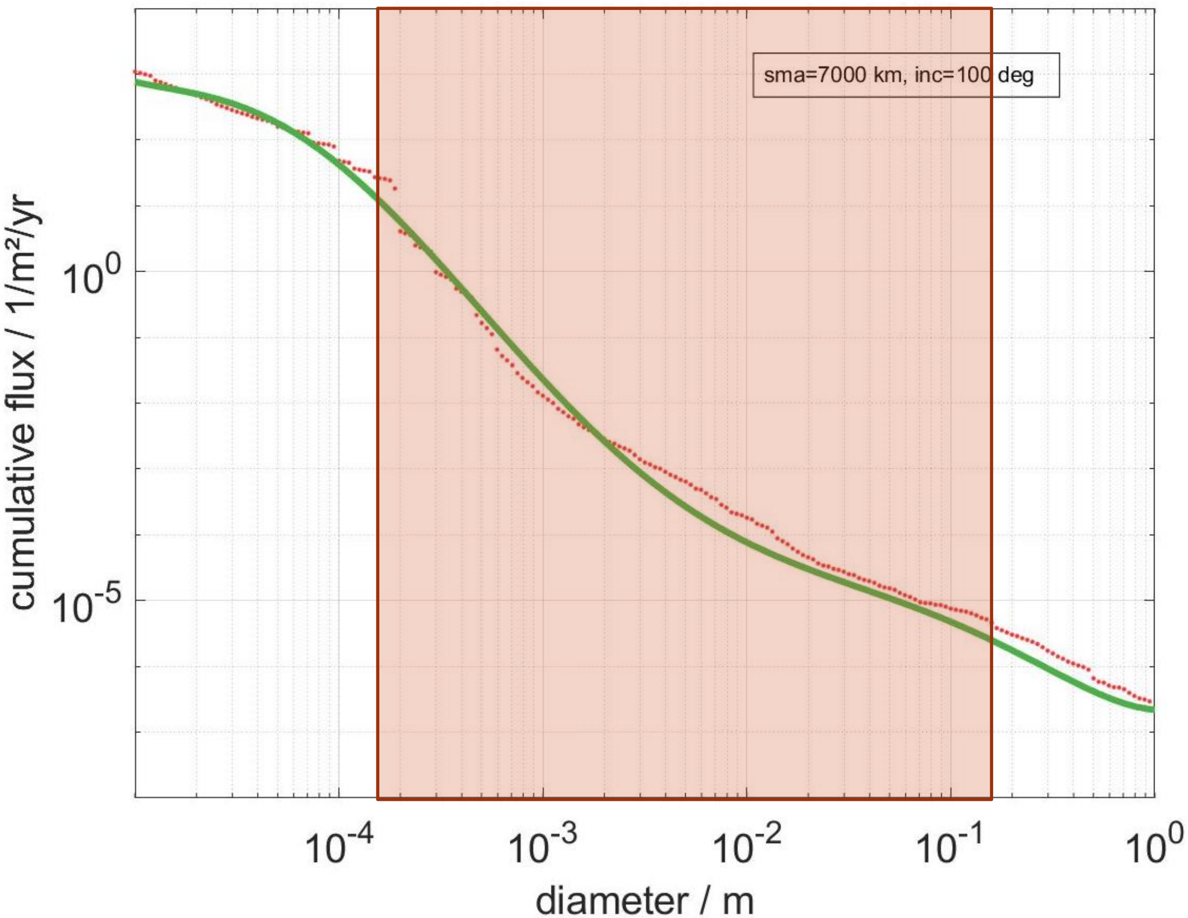
```
#  --- Generated by LUCA2
#|------------------------------------- flux on 210207663 -------|
#  year total_flux  flux >1mm  flux >1cm  flux>10cm  coll_prob |
#_[-]__[1/m^2/a]__[1/m^2/a]___[1/m^2/a]___[1/m^2/a]____[]______|
2020   0.1903E-01 0.1903E-01 0.4062E-04 0.2900E-05 0.1926E-04
2021   0.1794E-01 0.1794E-01 0.3828E-04 0.2733E-05 0.1835E-04
2022   0.1825E-01 0.1825E-01 0.3895E-04 0.2782E-05 0.1932E-04
2023   0.1986E-01 0.1986E-01 0.4239E-04 0.3027E-05 0.2168E-04
2024   0.2096E-01 0.2096E-01 0.4472E-04 0.3194E-05 0.2350E-04
2025   0.1928E-01 0.1928E-01 0.4114E-04 0.2938E-05 0.1969E-04
```

Environment Projection Model: Flux and Collision Probability Calculation

Parameter	Description
scensel	Scenario Selection
simbegin	Simulation begin
simduration	Simulation duration
data	Path to database annual results
nghost	Number of ghost objects
id[1]	Identifier
mass[1]	Mass
dia[1]	Diameter
mToA[1]	Mass to Area Ratio
sma[1]	Semi-major axis
ecc[1]	Eccentricity
inc[1]	Inclination
raan[1]	Right Ascension of the Ascending Node
aop[1]	Argument of Pericenter
man[1]	Mean Anomanly
collisionRadius	Collision Radius
numberCascadingCycles	Number of cascading cycles
maxDistance	Maximum distance between objects

Flux extrapolation

- Performed flux evaluation on the current MASTER 2013 population
- Parameter variation
  SMA: 6600-9200 km; 100 km steps
  INC: 0-100 deg; 10 deg steps
- Output data points used as input for a multivariant polynominal regression
- Approx. function for the flux
- $flux = f(d, a, i)$



Coming Soon

http://redshift-h2020.eu/

Thank you

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