Exploiting SRP and impulsive maneuvers for LEO disposal design

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Introduction

As part of the deep dynamical analysis carried out within the H2020 ReDSHIFT project, we performed an extensive study of the dynamics of the Low Earth Orbit (LEO) region by propagating a fine grid of initial orbits. Starting from this detailed cartography of the LEO phase space, we analyze here the possible strategies to guide the disposal of spacecraft at the end-of-life. In particular, we investigate the use of impulsive maneuvers and solar sails to target the unstable orbits where dynamical perturbations, as solar radiation pressure (SRP) or atmospheric drag, can assist the reentry. This strategy was included in a software suite developed within ReDSHIFT to help the spacecraft operator in designing a space debris compliant mission.

LEO orbits propagation

Fast Orbit Propagator (FOP): accurate, long-term orbit predictor.
FOP integrates singly-averaged equations of motion for a set of orbital elements. The numerical integrator is a multi-step, variable step-size and order.

Dynamical model:	5×5 geopotential	SRP (cannonball model)
	Lunisolar perturbations	Atmosferic drag (Jacchia-Roberts)

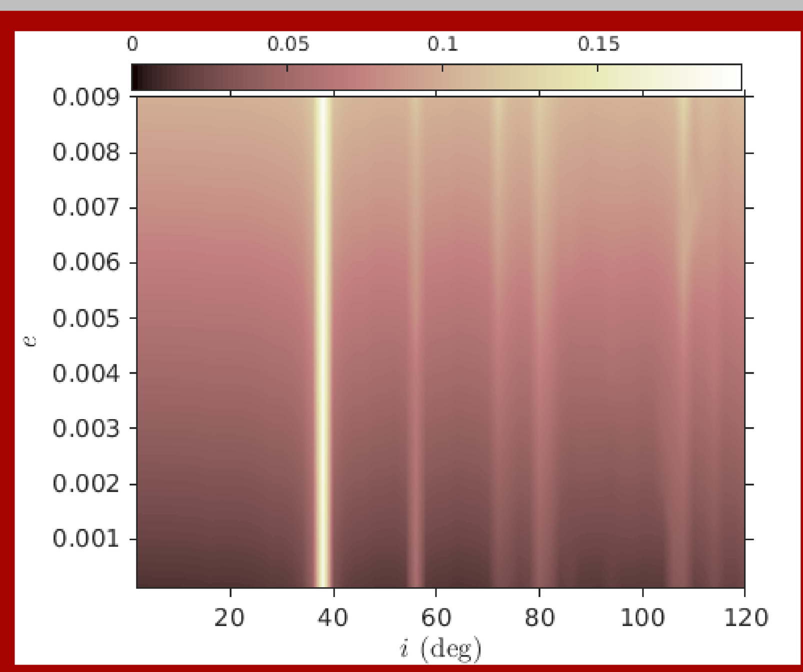
Grid of the initial conditions considered for propagation:

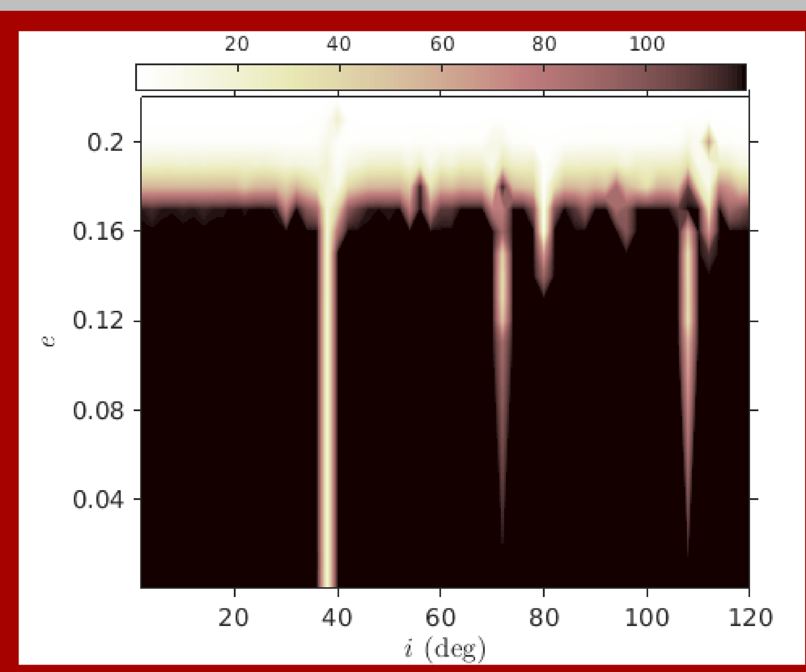
h (km)	Δh (km)	e	i (°)	Δi (°)	Ω (°)	ω (°)
$[500 \div 700]$	50	$[0 \div 0.27]$	$[2 \div 120]$	2	0, 90, 180, 270	0, 90, 180, 270
$[720 \div 1000]$	20					
$[1050 \div 1300]$	50					
$[1320 \div 1600]$	20					
$[1650 \div 2000]$	50					
$[2100 \div 3000]$	100					

Two possible values of A/m:

- $A/m = 0.012\,\mathrm{m^2/kg}$, a reference value for typical intact object in LEO;
- $A/m = 1\,\mathrm{m^2/kg}$, representative value for an object equipped with an area augmentation device (e.g. solar sail).

Maximum eccentricity & Lifetime





Initial orbit: $a = R_e + 2200\,\mathrm{km}$, $\Omega = \omega = 0°$ and $A/m = 1\,\mathrm{m^2/kg}$.

Bright "corridors": at resonant values of i a sudden increase of e due to SRP is able to ensure natural reentry in some tens of years or less [see Alessi, Schettino, Rossi, Valsecchi, MNRAS 473,2408 (2018)].

Determination of the possible target orbits

Given $\Delta \boldsymbol{v} = (\Delta v_r, \Delta v_t, \Delta v_h)$, the Gauss planetary equations allow to find the possible displacements in (a, e, i):

$$\Delta a = 2\frac{e \sin f}{n\sqrt{1-e^2}}\,\Delta v_r + 2\,\frac{(1+e\cos f)}{n\sqrt{1-e^2}}\,\Delta v_t$$

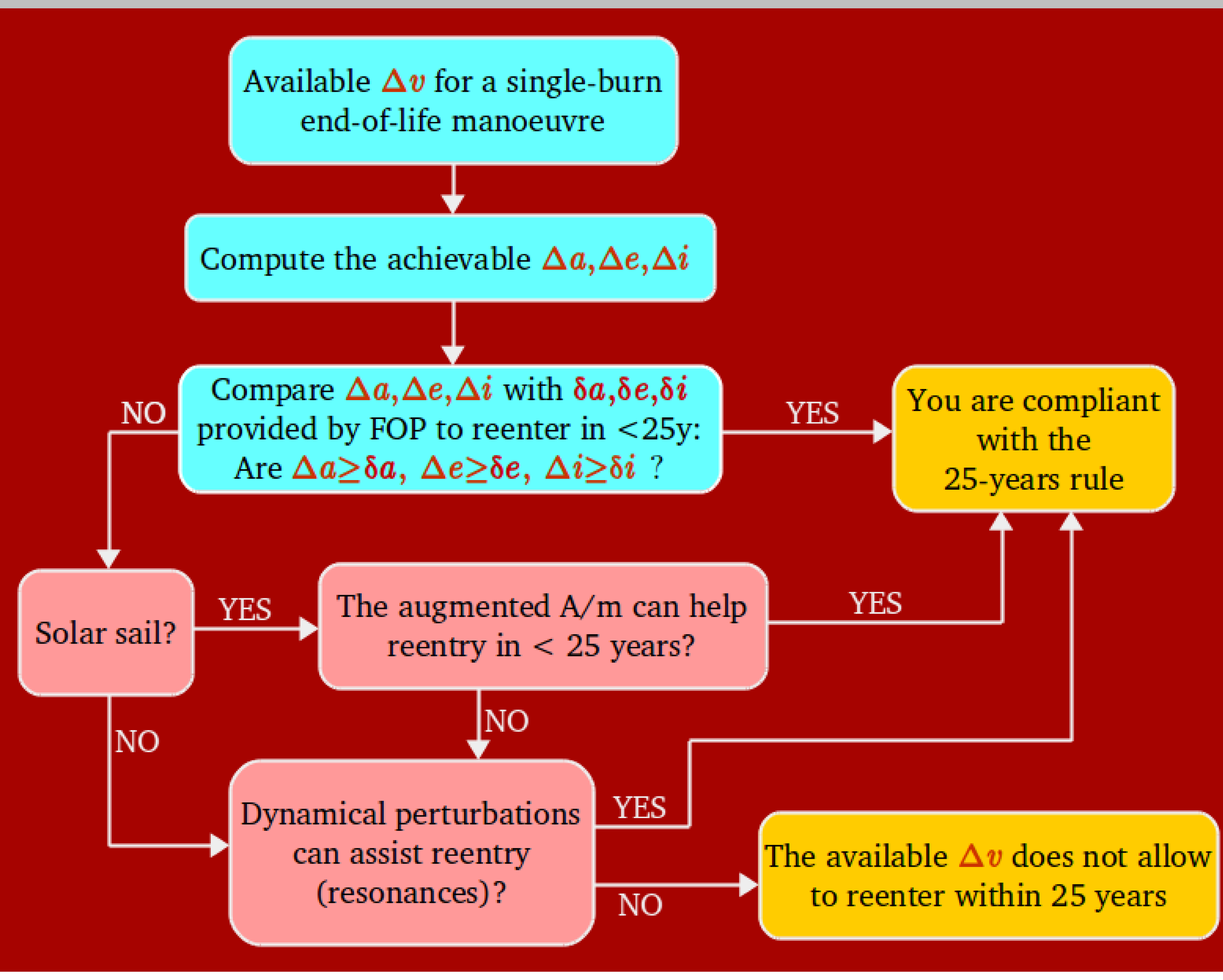
$$\Delta e = \frac{\sqrt{1-e^2}\sin f}{na}\,\Delta v_r + \sqrt{1-e^2}\,\frac{\cos f + \cos E}{na}\,\Delta v_t$$

$$\Delta i = \frac{r}{h}\cos u\,\Delta v_h\,,$$

where f is the true anomaly, E the eccentric anomaly, u the argument of latitude, r the radius, h the angular momentum, n the mean motion.

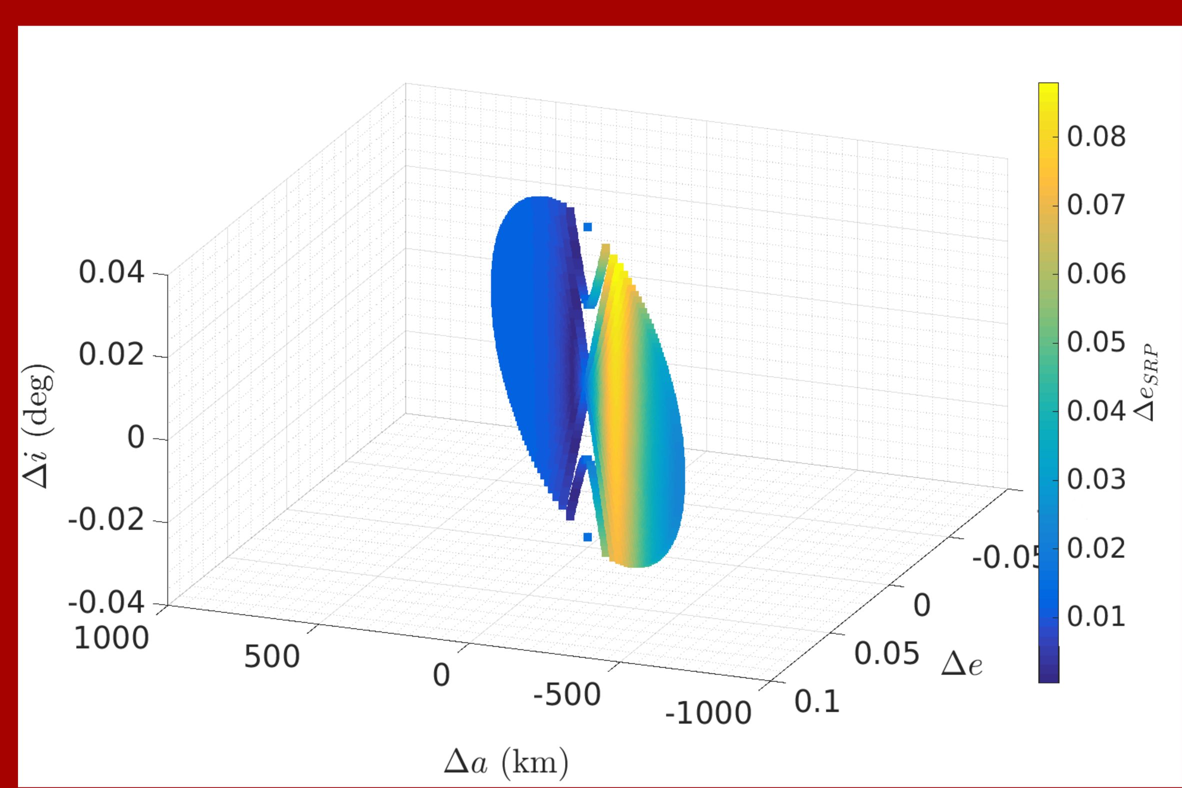
On the other side, for each initial orbit of the grid, the detailed cartography of the LEO region allows to identify the displacements $\delta a, \delta e, \delta i$ to reach a target orbit compliant with the 25-years rule.

Disposal strategy



Example of disposal design with sail

Initial orbit	Target orbit
a=7900 km, e=0.001, Ω=ω=0°, Δv=0.06 km/s, i=10°	δa=-133.3 km, δe=0.017, δi=0°. Δv is not enough to reenter in 25 years
a=7900 km, e=0.001, Ω=ω=0°, Δv=0.06 km/s, i=40°	δa=-8 km, δe=0.001, δi=0°, with Δv=0.004 km/s where SRP assists reentry: Δe_{SRP}=0.106, deorbiting in < 8 years
a=8170 km, e=0.01, Ω=90°, ω=0°, Δv=0.26 km/s, i=10°	δa=-532.0 km, δe=0.066, δi=0°. Δv is enough to reenter in 25 years
a=8170 km, e=0.01, Ω=90°, ω=0°, Δv=0.26 km/s, i=40°	δa=-236.4 km, δe=0.08, δi=0.16°, with Δv=0.104 km/s where SRP assists reentry: Δe_{SRP}=0.081, deorbiting in < 11 years



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