Frequency characterization of orbits in the LEO region

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Abstract

As part of the deep dynamical analysis carried out within the H2020 ReDSHIFT project, we present a characterization of the orbital elements of low-altitude objects in terms of their periodic components. Considering a representative sample of possible initial orbital conditions in the Low Earth Orbit (LEO) region, we propagated the dynamics of the objects over a suitable time span. The dynamical model includes the effects of geopotential up to degree and order 5, solar radiation pressure (SRP) and atmospheric drag. Lunisolar perturbations were expressly removed from the model in order to account specifically for the role of geopotential and SRP. Moreover, we considered different values of the area-to-mass ratio of the object. Then, we decomposed the resulting quasi-periodic series in their spectral components by a numerical computation of Fourier transform, accounting for the finite duration of the signals. The aim of this spectral analysis is to clearly link each frequency signature to the dynamical effect which originates it in order to build a frequency chart of the LEO region. Indeed, the detailed analysis of the principal spectral components turns out to be a powerful tool to enable a better understanding of the relative importance of each specific gravititational and non-gravitational perturbation in the LEO region as a function of the initial semi-major axis, eccentricity and inclination of the debris. Ultimately, the analysis will be used, together with the cartography of the LEO phase space, to identify the most suitable perturbations to be exploited to facilitate the passive dynamical de-orbiting of spacecraft at the end of life.

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.

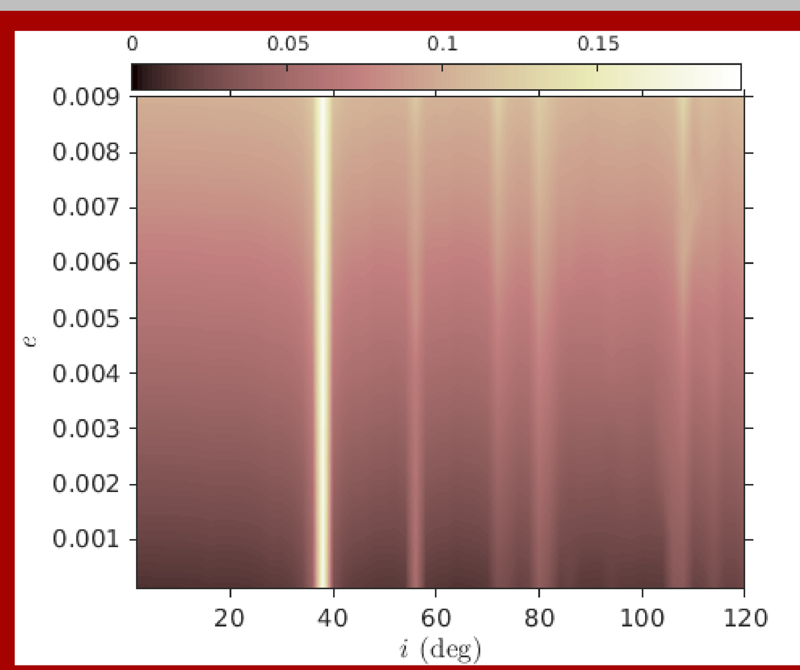
Dynamical model:	5×5 geopotential	SRP (cannonball model)
	Lunisolar perturbations	Atmosferic drag (Jacchia-Roberts)

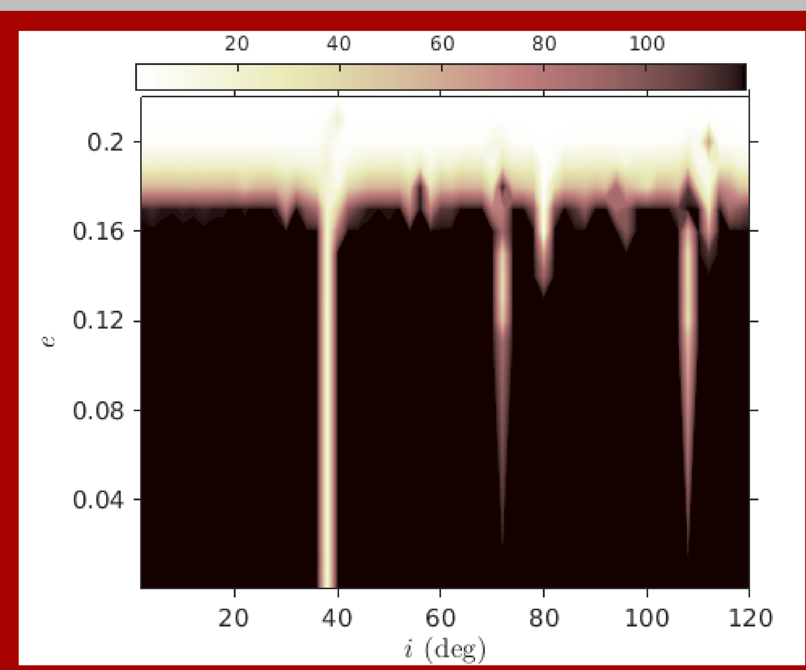
→ we want to investigate expressly the effects due to geopotential and SRP.

Grid of the initial conditions included in the frequency analysis:

A/m (m^2/kg)	h (km)	Δh (km)	e	i (°)	Δi (°)	Ω (°)	ω (°)
0.012	$[1000 \div 1300]$	50	0.02	$[2 \div 120]$	0.5	0	0, 90
	$[1320 \div 1600]$	20					
	$[1700 \div 2200]$	100					
1.0	$[1600 \div 3000]$	100	0.001	$[2 \div 120]$	0.5	0	0, 90

Maximum eccentricity & Lifetime



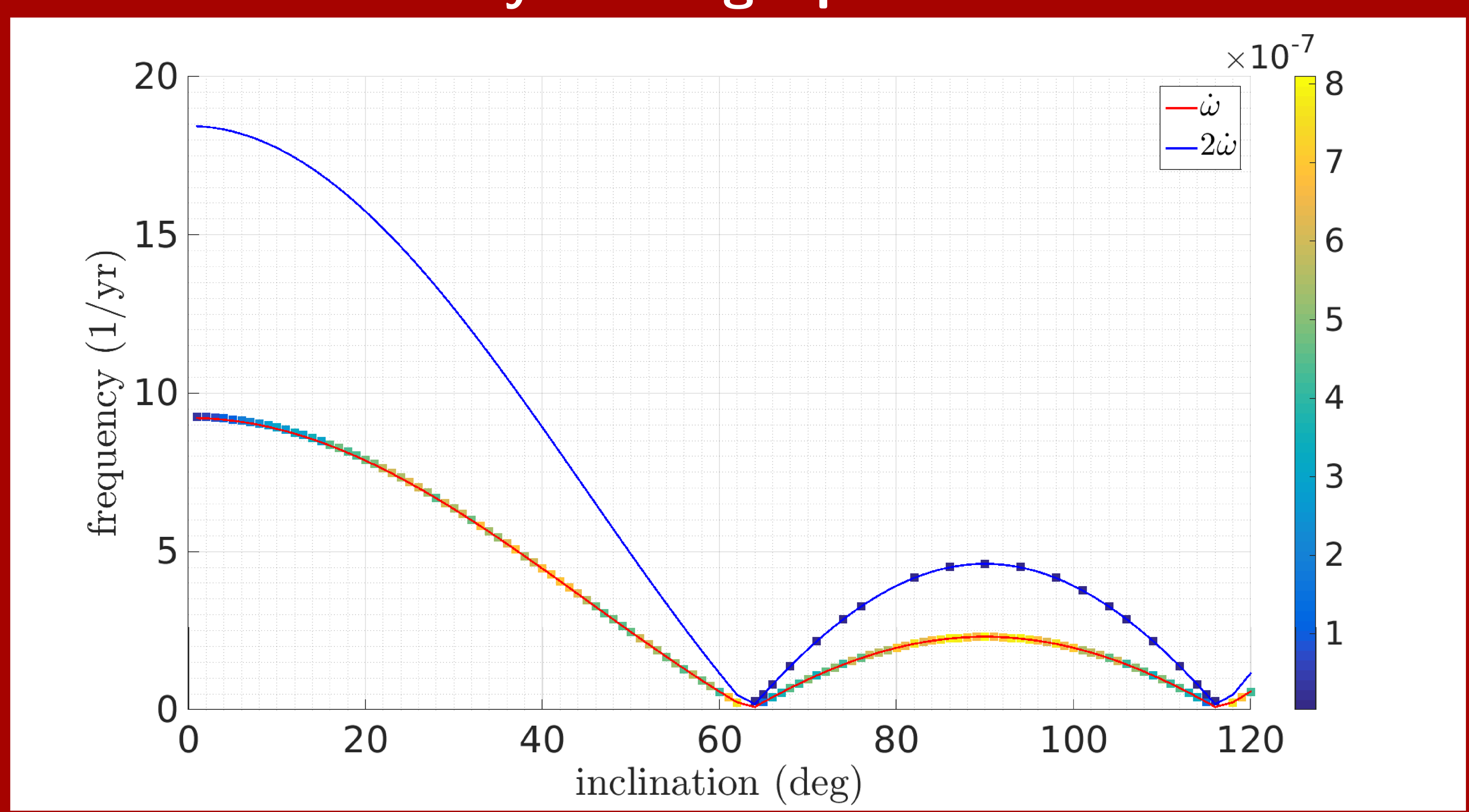


Initial orbit: $a = R_e + 2200$ km, $\Omega = \omega = 0°$ and $A/m = 1$ m^2/kg.

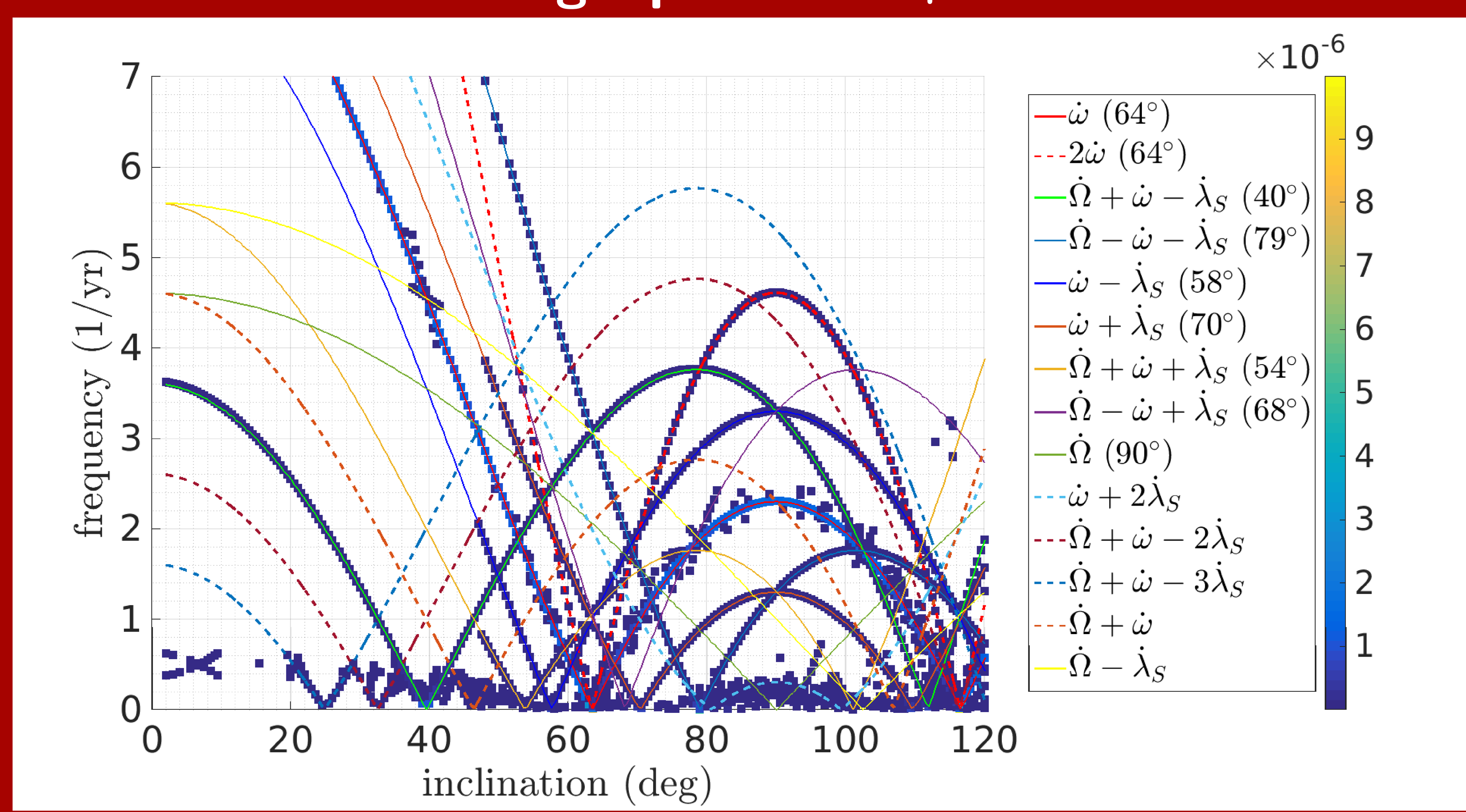
Bright "corridors": at resonant values of i a sudden increase of e due to SRP is able to ensure natural reentry in some tens of years or less (see E.M. Alessi et al. presentation).

Identification of the main frequency components

only 5×5 geopotential



5×5 geopotential + SRP



Initial orbit: $a = R_E + 1600$ km, $e = 0.02$, $\Omega = \omega = 0°$ and $A/m = 0.012$ m^2/kg.

Resonances

We assume that the rate of e can be written as:

$$\frac{de}{dt} = A \sin\psi\,.$$

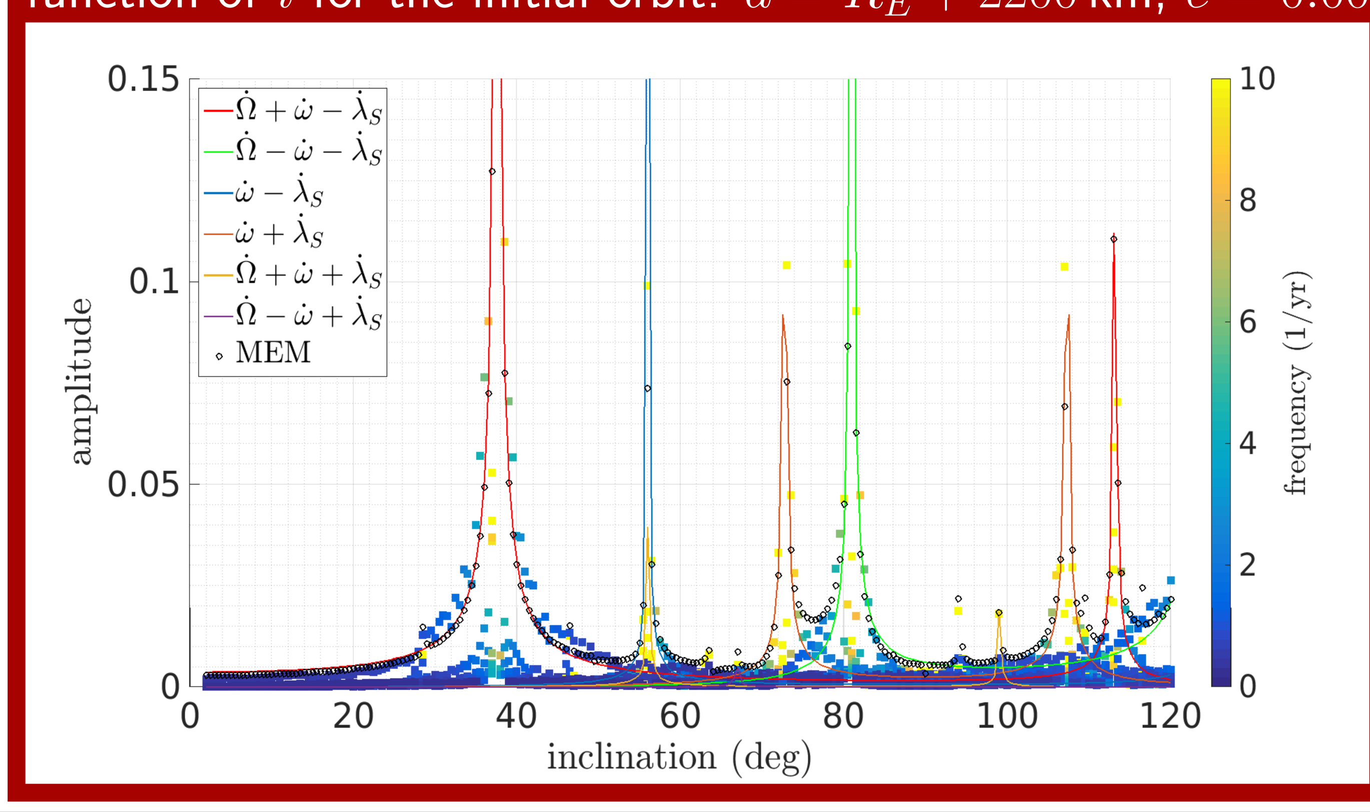
→ resonance condition: $\dot\psi \simeq 0$

- Perturbation induced by geopotential: $\psi = \omega$;
- Perturbations induced by SRP for $h \in [1600 : 3000]$ km:

ψ	i at singularity
$\Omega + \omega - \lambda_S$	$39.5° - 34.0°$
$\Omega - \omega - \lambda_S$	$79.0° - 84.5°$
$\omega - \lambda_S$	$57.5° - 53.5°$
$\omega + \lambda_S$	$70.5° - 77.5°$
$\Omega + \omega + \lambda_S$	$53.5° - 60.5°$
$\Omega - \omega + \lambda_S$	$68.0° - 64.5°$

Analysis of the results

Comparison between theoretical amplitude, computed amplitude and maximum eccentricity as a function of i for the initial orbit: $a = R_E + 2200$ km, $e = 0.001$, $\Omega = \omega = 0°$ and $A/m = 1$ m^2/kg.



Theoretical amplitude:

$$\Delta e = 2 \left| \frac{A}{\dot\psi} \cos\psi \right|$$

Assumption: the rate of Ω and ω is due mainly to J_2 perturbation, given (a, e):

$$\dot\omega(i) = \frac{3}{4}\frac{J_2 R_e^2 n}{a^2(1-e^2)^2}(5\cos^2 i - 1)$$

$$\dot\Omega(i) = -\frac{3}{2}\frac{J_2 R_e^2 n}{a^2(1-e^2)^2}\cos i$$

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