October 2, 2024

Orbital lifetime of space debris and chaos

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Forewords

Switch to Space 4

- I promise there will be no equations ☹
- But several nice pictures and animations ☺
- Substantial research effort 2014-2022 and results discussed today have been shaped from collaborations with Prof. Aaron Rosengren (UCSD), Prof. Christos Efthymiopulos (UPadova), Prof. Ioannis Gkolias (UThessaloniki) and Dr. Edoardo Legnaro (UGenova). They all are acknowledged.

Today's presentation

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- In the previous talk, orbital lifetime was addressed for low-Earth orbits (LEOs)
  - In LEOs, there is a natural sink mechanism: DRAG.
  - Above the LEO shell, there is no more *a priori* sink mechanism:

Question: is the orbital lifetime infinite?

- This talk is about the dynamics of resident space objects in medium Earth orbits (MEOs) in the long-term:
  - Orbital altitude between LEO and geosyncrhonous orbits,
  - Host of navigation satellites: BeiDou, GPS, GLONASS, Galileo, Molniya,
  - Orbital period is roughly12 hours,
  - Decades or centuries: 10^3, 10^4 orbital revolutions,
  - Non-cooperant objects (= debris). The environment and forces govern the motions,
  - Small and slow effects have time to build up: resonances,
  - Resonances goes with chaos.

Today’s presentation

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Take-home message:

Resonant and chaotic dynamics in MEOs shape the orbital lifetime by creating chaotic paths leading to re-entry Earth corrdiors.

Ingredient #1: chaos

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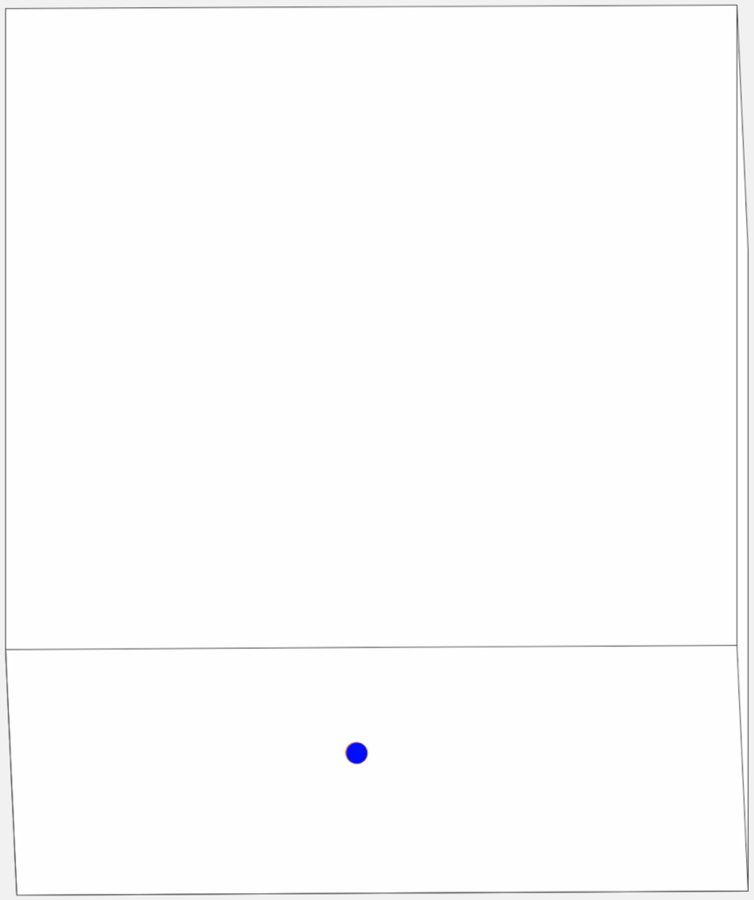
Lorenz system: sensitivity to initial conditions



Credit: André de Souza Mendes

- E. Lorenz: father of modern chaos theory (1961).

- Chaos: Systems exhibit a great sensitivity to initial conditions.

implications: small changes produce large effects.

- Chaos precludes the possibility of making accurate predictions in the long term.

- Determinism doesn't imply the possibility of long-term prediction: profound consequences and ramifications in many fields.

- Chaos found in many systems at different scales: plasma physics, fluid dynamics, planetary systems.

Ingredient #2: Resonances and chaos

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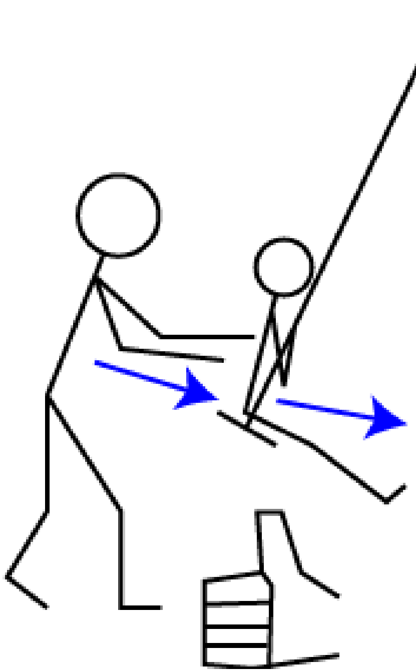
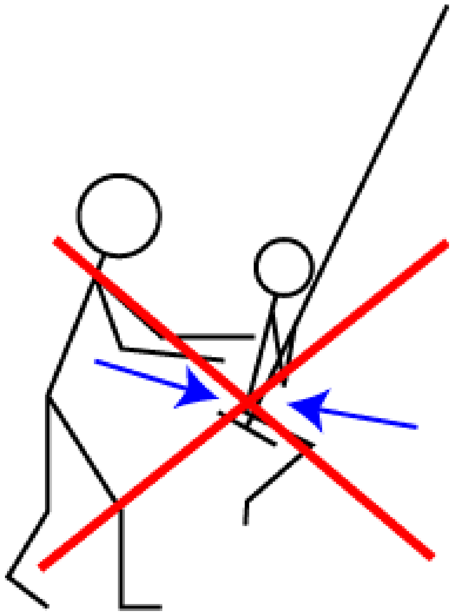
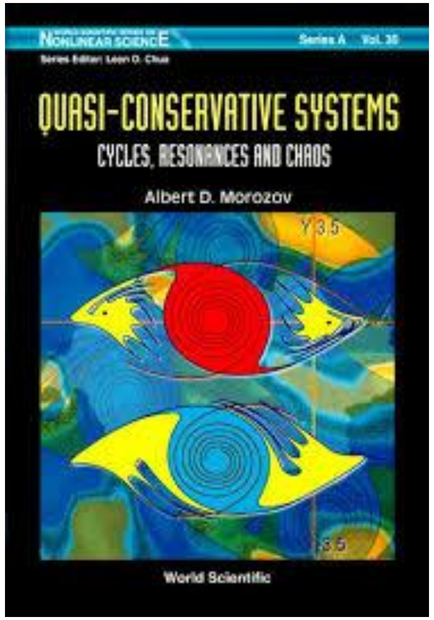
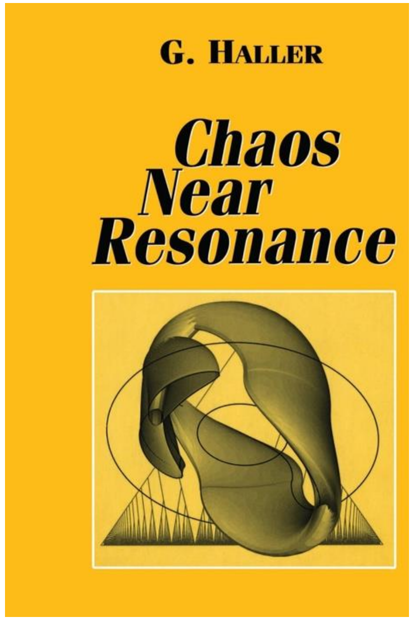




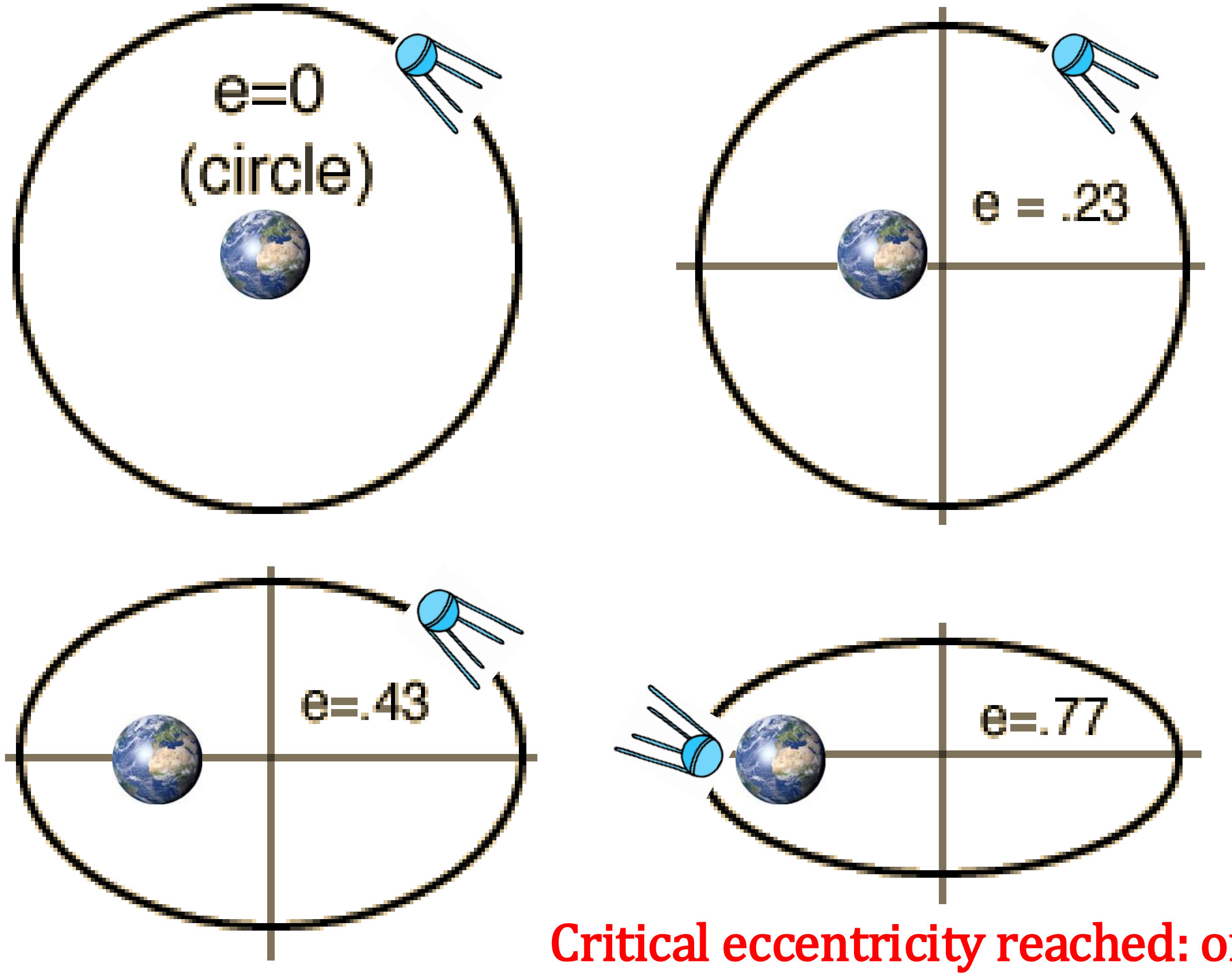




Resonances: some frequencies are commensurate

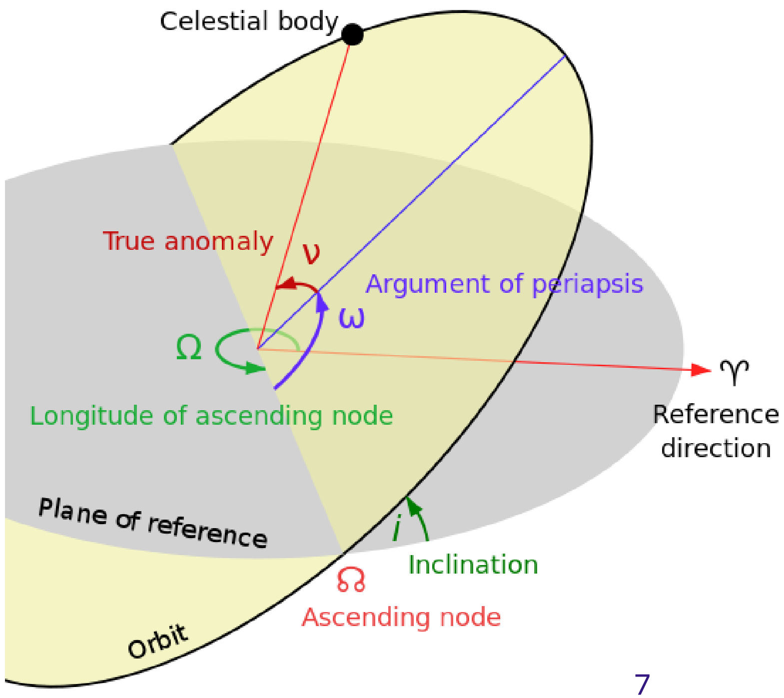
Resonances lead to chaos

Ingredient #3: Ellipses and lifetime



Critical eccentricity reached: orbital crash

Besides the shape, 3 parameters describe the orientation of the ellipse in space.



MEOs and resonances

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Earth J2 term + Moon + Sun

Development of the perturbations + Averaging

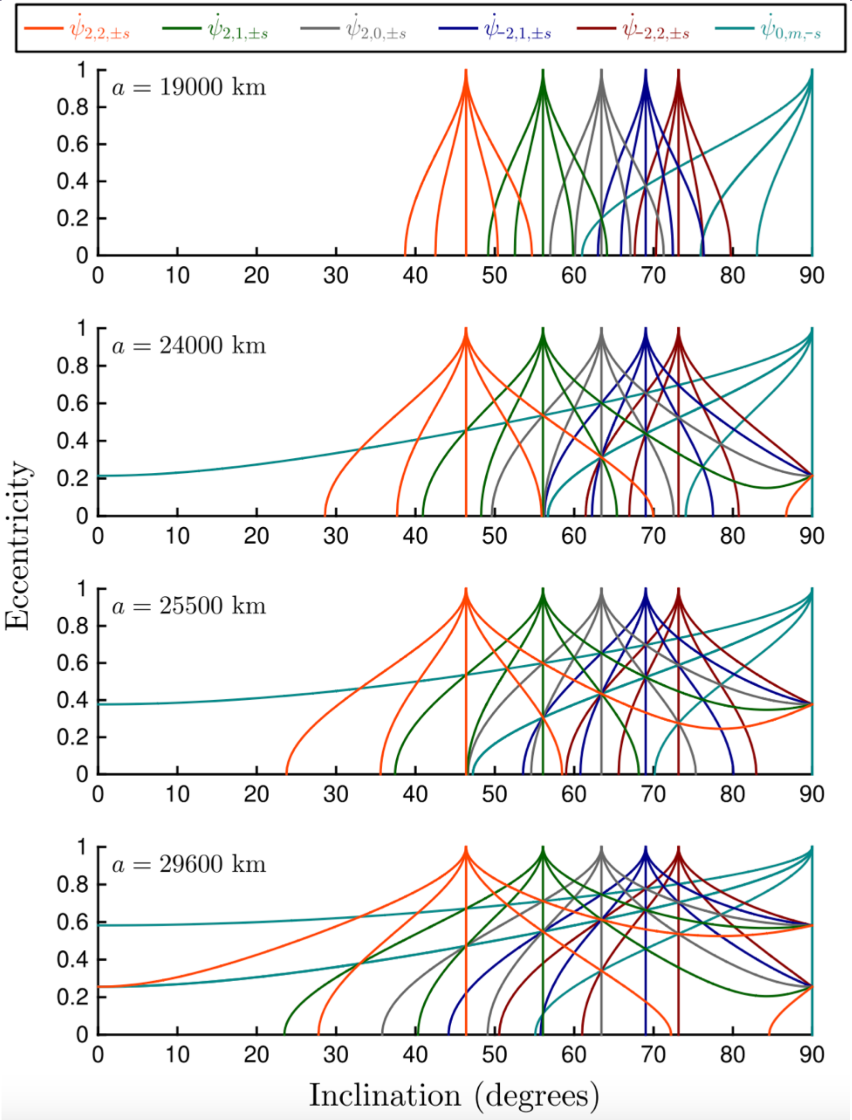
Treatment of the dynamics within an Hamiltonian framework.

MEOs are full of resonances with the Moon and the Sun, they are called lunisolar resonances:

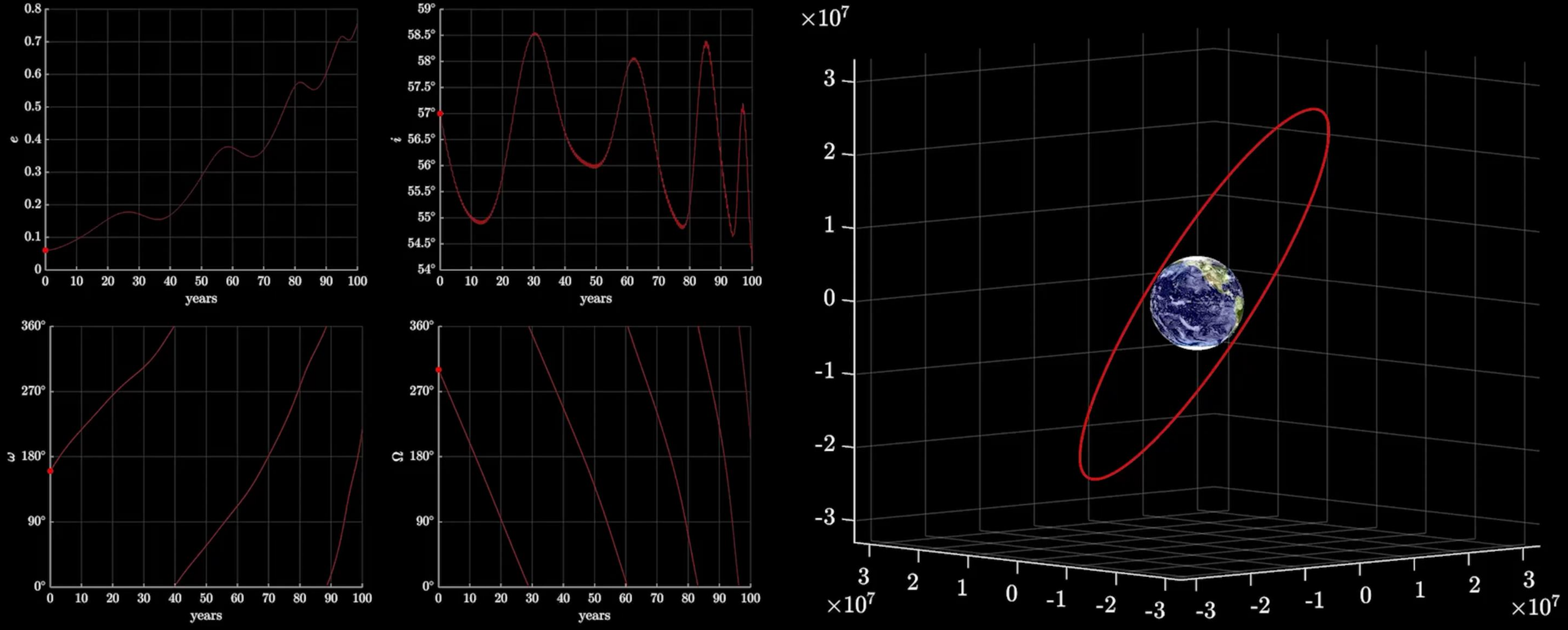
$$k_1\omega + k_2\Omega + k_3\Omega_{\text{Moon}} \simeq 0$$

They cover densely the MEOs shell when we scan the region

Manifestation of those resonances: growth of the eccentricity and sensitivity to initial conditions.



time: 0.00 years



Sensitivity to initial conditions in MEOs

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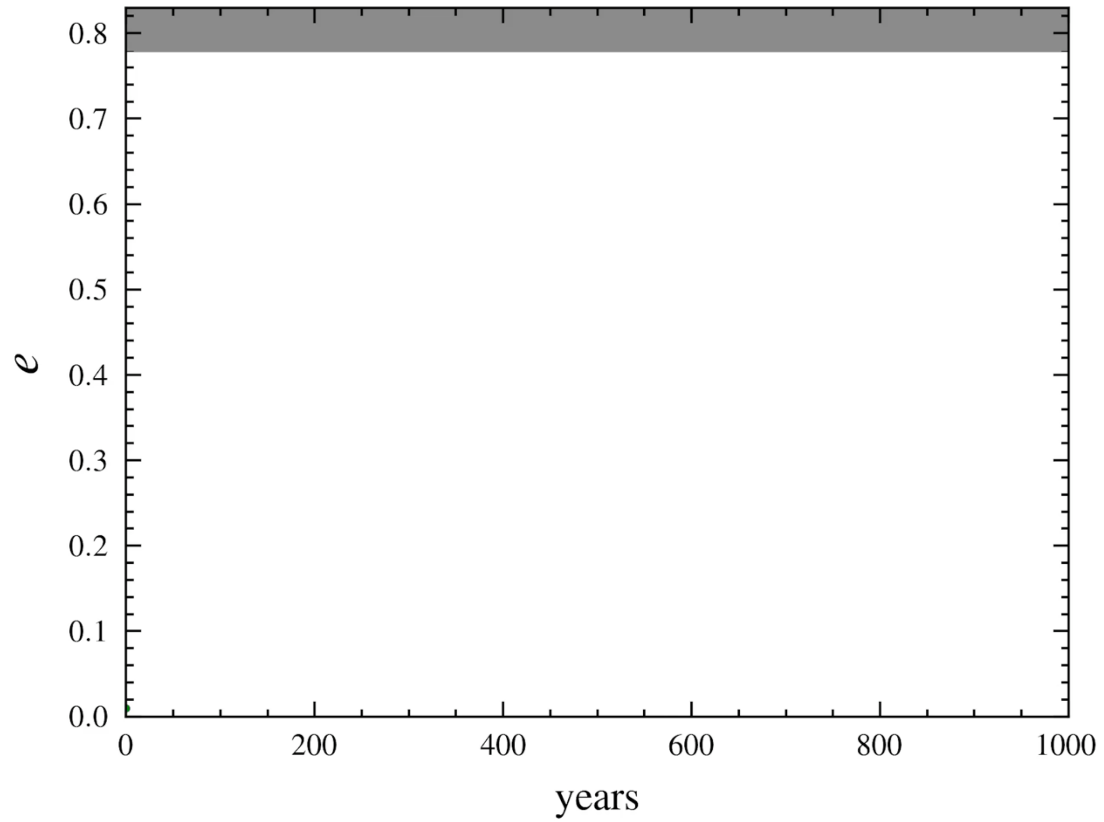
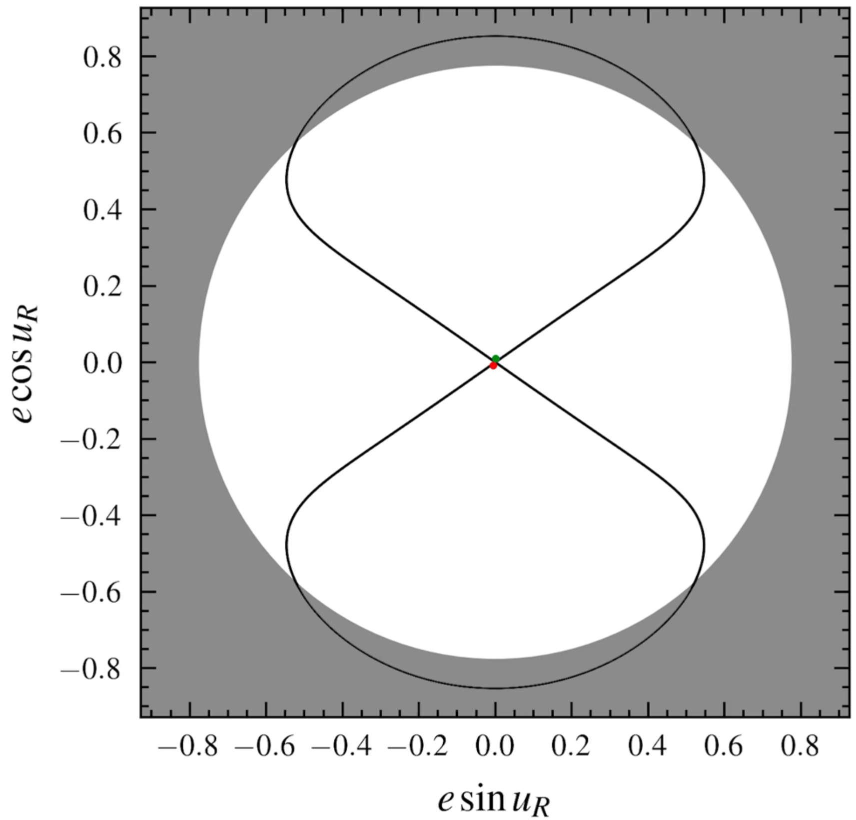
Galileo like objects

a = 29600 km, e = 0.01, i = 57°

$\omega = 0, \Omega = 5.13$ lifetime: 167y
$\omega = 0, \Omega = 0.0125$ lifetime: 485y
$\omega = 0, \Omega = 0.0123$ lifetime: 977y





Models and characterisations

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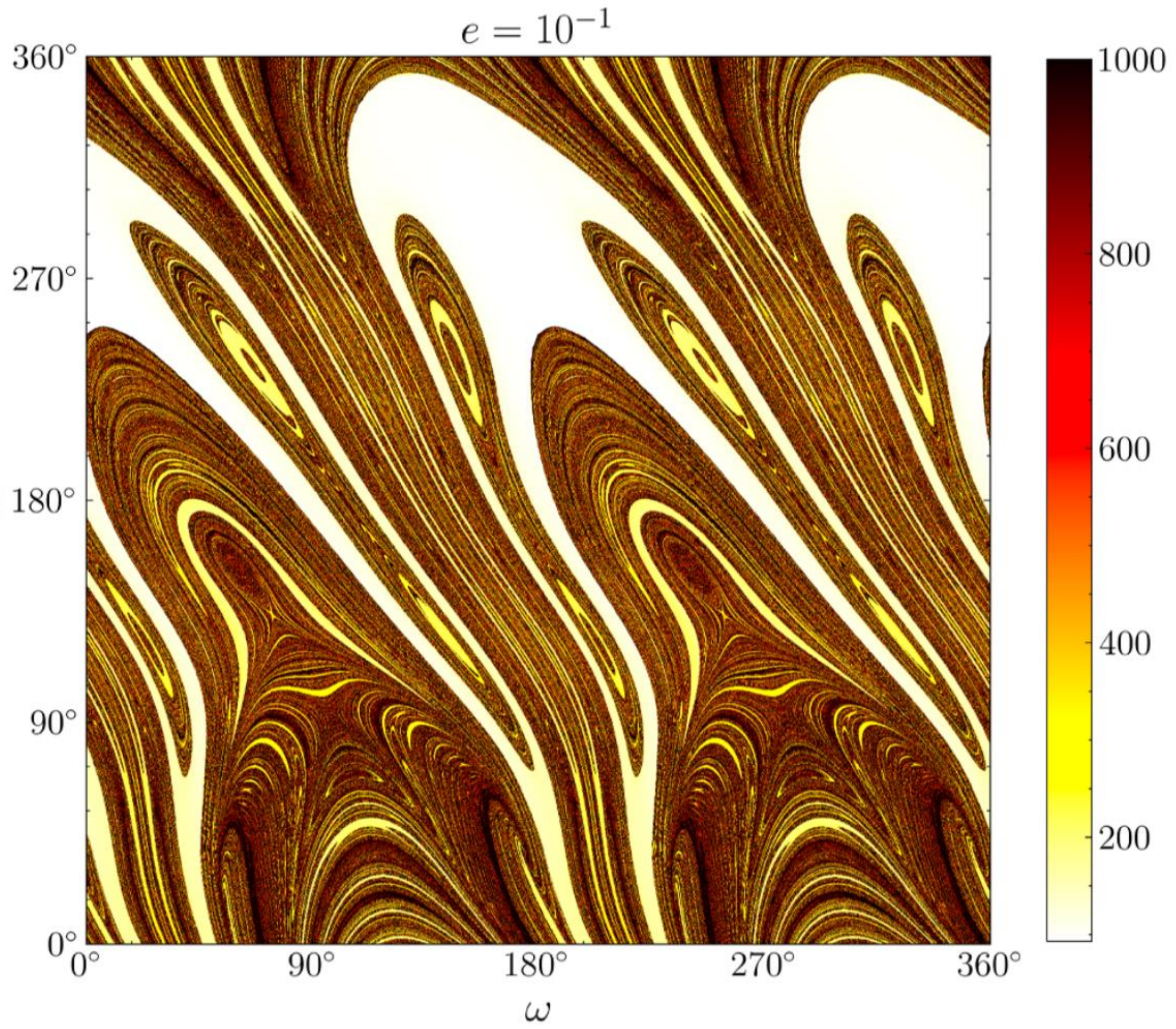
- We provided the precise mechanisms behind the eccentricity growth.
- We provided analytical models useful to make lifetime predictions in accordance with numerical results.
- We provided set of models and tools to produce efficiently an atlas of stability maps, focusing on:
    - 1. chaos detection,
    - 2. orbital lifetime.
- Clear evidences that lifetimes are dictated by the chaotic structures.



Final words

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- A deep and deeper understanding of the long-term dynamics could inspire end-of-life disposal strategies:
  - Large transport mediated by resonances and chaos, ruling the orbital lifetime.
  - Reciproqual idea: set of tools to find very stable orbits for graveyards.

- The various orbital habitats are complex with a great variety of orbits, far from idealised Keplerian ellipses:
  - Dynamical system theory and nonlinear sciences are precious tools.

- (The results shown today have been published in several papers, see e.g., Daquin et al. 16, Daquin et al. 22, Legnaro et al. 23.)

Advertisments

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1. UNamur part of the UNIVERSEH alliance (European Space University),

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UNIVERSEH

2. New course designed on Astrodynamics (Master 1), first cohort this year, next semester,

3. AND most importantly, some exciting news shall be annouced very soon, stay tunned!

Thank you for your attention

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