GALILEO DISPOSAL ORBIT STRATEGY: RESONANCES, CHAOS, AND STABILITY

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Abstract: *Recent studies have shown that the Global Navigation Satellite Systems exist in a background of complex resonant phenomena and chaotic motion. Woven throughout the eccentricity and inclination phase space is an exceedingly complicated web-like structure of lunisolar secular resonances, which become particularly dense near the inclinations of the navigation satellite orbits. As in all cases in the Solar System, chaos emerges from the overlapping of neighboring resonances. The precarious state of the four navigation constellations, perched on the threshold of instability, makes it understandable why all past efforts to define stable graveyard orbits, especially in the case of Galileo, were bound to fail; the region is far too complex to allow of an adoption of the simple geosynchronous disposal strategy. Here we will apply our recent results on the stunningly rich dynamical structure of the navigation satellite orbit region toward the design of disposal strategies for the Galileo constellation. We will identify long-term stable regions, suitable for robust graveyards, as well as dynamical pathways that lead to large, chaotic variations in eccentricity, which can be used for post-mission deorbiting of constellation satellites.*

Keywords: *Medium-Earth Orbits, Chaos, Resonances, Fast Lyapunov Indicators, Stability Maps.*

1. Extended Abstract

The complexity of the dynamical environment occupied by the Earth's navigation satellites is now becoming clearer [1, 2]. Resonant phenomena are widespread within the medium-Earth orbit (MEO) region as a whole, but particularly so amongst the highly inclined orbits of the navigation satellite systems, and a clear picture of the nature of these resonances is of considerable interest for the design of disposal strategies [3]. This concerns particularly the question as to whether suitable stable orbits exist such that satellites in these graveyards will not interfere with the constellations, or whether strong instabilities exist, whose destabilizing effects manifest themselves on decadal to centennial timescales, that can be exploited to permanently clear this region of space from any future collision hazard. The process of dynamical clearing of resonant orbits is a new paradigm in post-mission disposal, but has not been hitherto rigorously investigated. Our recent work has shown that the occurrence and nature of the resonances driving the dynamics of MEOs depend chiefly on the frequencies of nodal and apsidal precession and the rate of regression of the Moon's nodes [1, 2]. Lunisolar secular resonances, defined by specific linear combinations of these frequencies, interact to produce a dense stochastic web in eccentricity-inclination phase space (Figs. 1 and 2).

The motions with initial conditions in the overlapping regions can be both chaotic and regular, depending on the initial orientation angles, while the motions with initial conditions in the non-overlapping regions are generally regular. We will present an atlas of Fast Lyapunov Indicator (FLI) and Lyapunov time maps, such as those in Fig. 2, showing the geometrical organization and coexistence of chaotic and regular motion. We will also study how the chaotic layers change when varying the initial orientation angles, with the purpose of defining stable orbits for graveyards or highly unstable orbits for faster re-entry and destruction within the Earths atmosphere.

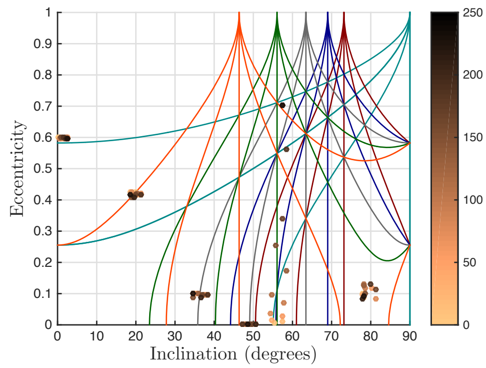
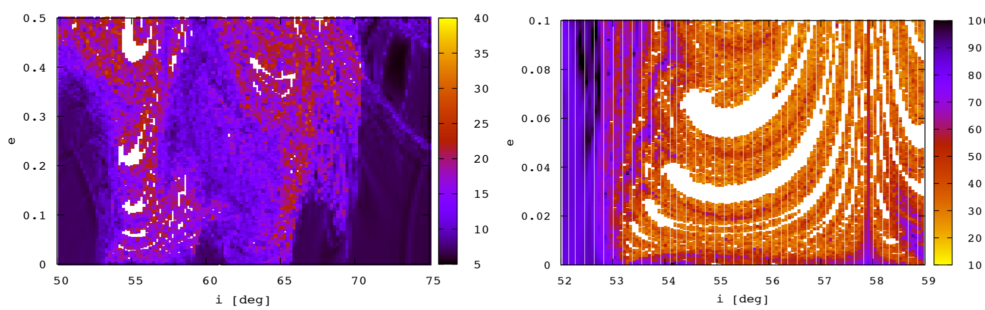


Figure 1. Dynamical evolution (over 250 years) of five orbits with initial inclinations and eccentricities in non-overlapping resonance regions and of one Galileo-like orbit ($i_0 = 56°$), superimposed on the background of lunisolar resonant curves. Adapted from [1], to which we refer for more details.



(a) FLI stability map. (b) Map of Lyapunov-time (in years).

Figure 2. Stability maps for distinguishing between regular, resonant, or chaotic motions [2].

2. References

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