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CHAOTIC BEHAVIOR OF HIGH AND ECCENTRIC EARTH ORBITS—THE CASE OF ESA'S INTEGRAL SPACE OBSERVATORY

Abstract

ESA's successful Integral mission relies on a high-altitude and highly eccentric orbit—9,000 km periapsis, 153,000 km apoapsis—that guarantees long periods of uninterrupted observation with almost uniform background. However, this orbit design causes important variations in the strength and origin of the perturbations undergone by the satellite along its orbital path, who vary periodically from prevalent Earth-related perturbations to dominant third-body effects. Furthermore, the 72-hour orbit of Integral, while guaranteeing continuous, optimal coverage from the ground stations, introduces a 9:1 resonance with the motion of the Moon.

The uneven distribution of the perturbations is a feature of high-eccentricity orbits that commonly results in high sensitivity of the orbit propagation with respect to the initial conditions. This behavior has been confirmed in practice for Integral, for which highly accurate numerical propagation tools are used to check the predicted atmospheric reentry time of Integral. This may vary from just a few years to about a century, depending on the chosen initial state. On the other hand, this chaotic behavior is basically reproduced when using lower-accuracy tools, as the mean-elements propagator HEOSAT. Moreover, the stability characteristics of the semi-analytical integration, as well as its fast performance, allowed us to carry out a dense parametric study that showed that the changes in the predicted lifetime of Integral occur abruptly. These facts suggests that rather than the exact time of the ephemeris, or the number of figures preserved along the numerical integration, the sensitivity is related to a resonant-type dynamics.

We dig into the origin of this apparently chaotic behavior, and find that the Integral mission design sets the orbit in a region of phase space close to a separatrix. Numerical simulations using the semi-analytical propagator show that the orbit of Integral crosses repeatedly this resonance line, which is in fact a diffuse region mainly driven by the motion of the Moon's right ascension of the ascending node.