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LONG-TERM DYNAMICS OF HIGH AREA-TO-MASS RATIO SPACE DEBRIS IN GEO

Abstract

The motion of high area-to-mass ratio (HAMR) objects in high-Earth orbits has been studied extensively since the discovery of this debris population in near GEO orbits by Schildknecht and colleagues (2004). Anselmo and Pardini have made several numerical studies of this problem, mapping out the dynamics of these objects over long time spans with all relevant perturbations included. The major perturbations acting on high altitude space debris are solar radiation pressure (SRP), anomalies of the Earth gravitational field, and third-body gravitational interactions induced by the Sun and the Moon. In the framework of orbit propagation, the evolution of space debris objects over long time-scales remains a challenge. While numerical integration of high fidelity debris and force models is technically conceivable, it becomes practically unusable due to the large amount of computer time required for accurate predictions. Averaging methods have proven to be among the most powerful instruments in the analytical study of dynamical systems. Applying these techniques to the dynamics of debris allows for a qualitative analysis of the object's orbital evolution, and reveals the essential dependence of the evolution on the system parameters in a more satisfactory way than does a numerical solution of the non-averaged equations.

We explore a new averaged model for the evolution of HAMR objects, explicitly given in terms of the eccentricity and angular momentum vectors. This new formulation provides predictions of the secular evolution of their orbits that compare well with non-averaged numerical integrations over many decades. The geometry of the Earth-Moon-Sun system, and in particular the lunar nodal precession, was found to have a significant effect on the long-term dynamics of HAMR orbits. The dynamical configuration of the Earth-Moon-Sun system is known to repeat itself closely after a period of time equal in length to the classical Saros cycle of 18.6 years. When the nodal period of the joint SRP and J2 system in the equatorial frame is near resonant with the Saros, the long-term inclination and eccentricity evolutions exhibit complex behavior.

In this paper, we will present the force models for each perturbation, discuss their fundamental predictions, and make comparisons with simulated and observed HAMR orbit dynamics. The extent to which the qualitative properties of the orbit persist with increasing area-to-mass will be investigated. We show that many of the extreme dynamical behaviors reported for these objects are due to the coupling between SRP, J2, luni-solar perturbations, and the Saros phenomenon.