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Author: Ms. Lei Peng
Beihang University, China

Dr. Yuying Liang
ISAS, JAXA, China
Ms. Qingfang Xiao
Beihang University (BUAA), China

SEPARATRIX OF BOUNDED ORBITS AND ESCAPING MANIFOLDS IN HYPERBOLIC RESTRICTED THREE-BODY PROBLEM

Abstract

With the growing number of bolide events observed, e.g., the 2013 Chelyabinsk meteor, and the near-Earth asteroids (NEAs) discovered, the threats of the NEAs have been drawing more and more attention as potential hazard to lives on the Earth. Many approaches have been proposed including solar sail gravitational tractor (Gong et. al., 2009) and kinetic impact (DART, 2022). However, these strategies are designed and conducted on the estimation that the NEAs are approaching the Earth at a low elliptical velocity while preliminary analysis shows that a large number of the NEAs flyby the Earth at hyperbolic velocity. The motion of the defense spacecraft can be described as the dynamics of massless particle in the framework of hyperbolic restricted three-body problem (HR3BP) for the Earth and high-speed NEA system.

Previous literatures showed instructive conclusions on the global flow (Cors and Llibre, 1995), equilibrium points (Barrabés et al. 2017), zero velocity curve (Luk'yanov, 2010) but many important questions remained opened or not clarified well including: 1) separatrix of boundness and escape in the extended phase space; 2) transfer trajectories under limited time constraint. In this paper, we focus on these questions and particularly on the escaping manifolds and bounded orbits associated with the secondary, which generates fast transfers from the Earth and long-term parking orbit around the NEA.

In CR3BP/ER3BP, the manifold tubes of (quasi-)periodic orbits around equilibrium points separate non- and transit trajectories and the escaping occurs only if the zero-velocity curve (ZVC) breaks at neck region. However, in time-varying HR3BP, dynamical structures like ZVC does not exist and the manifold tubes are not inherited (Luk'yanov, 2010). Thus, we turn to its Hamiltonian, which parameterizes the boundary at different Jacobi energy (Alvarez et al. 2006). The gradient of Hamiltonian on the Poincare section at the singular point is generated in the extended phase space and time flow. The shrink and expand of the Hamiltonian imply the exchange of boundness and escaping, then its extreme solutions are produced by optimization numerically. The solution set provides geometric criterion of separatrix for bounded orbits and escaping manifolds, but it does not guarantee continuous evolution in the time flow. Furthermore, the aforementioned literatures regard the time flow as infinite, which satisfies the scope of astronomy but hardly fits the engineering requirement. Contrarily, in this paper, the solution segments are characterized by their initial and final epoch, which indicates the time constraint of the Earth-NEA transfers.