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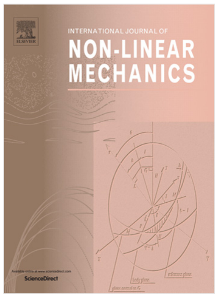

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Correlating the escape dynamics and the role of the normally hyperbolic invariant manifolds in a binary system of dwarf spheroidal galaxies

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Abstract

We elucidate the escape properties of stars moving in the combined gravitational field of a binary system of two interacting dwarf spheroidal galaxies. A galaxy model of three degrees of freedom is adopted for describing the dynamical properties of the Hamiltonian system. All the numerical values of the involved parameters are chosen having in mind the real binary system of the dwarf spheroidal galaxies NGC 147 and NGC 185. We distinguish between bounded (regular, sticky or chaotic) and escaping motion by classifying initial conditions of orbits in several types of two dimensional planes, considering only unbounded motion for several energy levels. We analyze the orbital structure of all types of two dimensional planes of initial conditions by locating the basins of escape and also by measuring the corresponding escape time of the orbits. Furthermore, the properties of the normally hyperbolic invariant manifolds (NHIMs), located in the vicinity of the index-1 saddle points L_1, L_2, and L_3, are also investigated. These manifolds are of great importance, as they control the flow of stars (between the two galaxies and toward the exterior region) over the different saddle points. In addition, bifurcation diagrams of the Lyapunov periodic orbits as well as restrictions of the Poincaré map to the NHIMs are presented for revealing the dynamics in the neighbourhood of the saddle points. Comparison between the current outcomes and previous related results is also made.

Keywords: methods: numerical – galaxies: dwarf – galaxies: kinematics and dynamics

1. Introduction

When we study a system of classical mechanics, then the index-1 saddles of the effective potential play a prominent role for the whole dynamics. They are the extremal points where the potential goes down along one direction only and goes up along all the other directions. For energies which are not too high over the saddle energy the escape from the inner potential holes to the outside regions or the transitions between various inner potential holes runs over these saddles. Usually we find some invariant subsets of the dynamics over the saddles and these sets are dynamically unstable in transverse directions, they are known as normally hyperbolic invariant manifolds (usual abbreviation NHIMs). General information on the NHIMs can be found in [48]. The states sitting over the potential saddles are also known under the name transition states (for their properties and connections to the NHIMs see [44–46]). If the saddle has index-1 and correspondingly the invariant subset has codimension 2 then the stable and the unstable manifolds of these NHIMs are of codimension 1 and they form impenetrable boundaries in the phase space and they delimit and channel the flow over the saddle. Generally, trajectories approach the saddle region along the stable manifolds and leave it again along the unstable manifolds of the NHIM. The projection of these stable and unstable manifolds from the phase space into the position space confines the saddle flow in the position space. As a consequence a major part of the study of any escape processes consists in the detailed investigation of the dynamics over the index-1 saddles of the effective potential. The saddle points of the effective potential in the rotating frame are also known as Lagrange points.

The most important periodic orbits within the NHIMs are the Lyapunov orbits over the saddle [22]. Therefore an important part of the investigation of the saddle dynamics consists of the study of the Lyapunov orbits and in particular of their development and bifurcation scenario as a function of the total energy. Also important for the global scenario are the most important periodic orbits growing out of the potential wells. For increasing values of the energy the orbits coming out of the potential minima frequently interact with the orbits coming from the saddles

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