

# Galaxies with supermassive binary black holes: (I) a possible model for the centers of core galaxies

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Received: 20 August 2013 / Accepted: 5 November 2013  
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**Abstract** The dynamics of galactic systems with central binary black holes is studied. The model is a modification from the restricted three body problem, in which a galactic potential is added as an external potential. Considering the case with an equal mass binary black holes, the conditions of existence of equilibrium points, including Lagrange Points and additional new equilibrium points, i.e. Jiang-Yeh Points, are investigated. A critical mass is discovered to be fundamentally important. That is, Jiang-Yeh Points exist if and only if the galactic mass is larger than the critical mass. The stability analysis is performed for all equilibrium points. The results that Jiang-Yeh Points are unstable could lead to the core formation in the centers of galaxies.

**Keywords** Galactic dynamics · Stellar dynamics

## 1 Introduction

A modification of the restricted three body problem was first studied in Chermnykh (1987). The angular velocity variation of the system was considered and the stability of solutions near equilibrium points was investigated. Extending from the work of Chermnykh (1987), Papadakis (2004) studied the symmetric motions near the three collinear equilibrium points, Papadakis (2005a) investigated the stability of the periodic orbits and explored the network of the orbital

families, Papadakis (2005b) provided the analytic determination of the initial conditions of the long- and short-period Trojan families around the equilibrium points of the Sun–Jupiter system.

Then, Jiang and Yeh (2006) and Yeh and Jiang (2006) investigated the existence of new equilibrium points of a system with binary masses and a disk as a modification of the restricted three body problem, which was hereafter called Chermnykh-like problem for convenience (Jiang and Yeh 2006; Yeh and Jiang 2006). Moreover, Kushvah (2008a, 2008b, 2009) studied the linear stability of equilibrium points of the generalized photo-gravitational problem. The trajectories and Lyapunov characteristic exponents are also calculated and studied in Kushvah (2011a, 2011b).

Furthermore, the recent rapid development of the discoveries of extra-solar planetary systems has triggered many interesting theoretical work (see Jiang and Ip 2001; Ji et al. 2002; Jiang et al. 2003; Jiang and Yeh 2003, 2004a, 2004b, 2004c, 2007, 2009, 2011), statistics work (see Jiang et al. 2006, 2007, 2009, 2010), and also the following-up observational work (Jiang et al. 2013) in this field. In fact, some results of the Chermnykh-like problem could have important applications on the dynamical problems of planetary systems (Papadakis 2005b; Kushvah 2011a).

On the other hand, the dynamical evolution of galaxies is another field that Chermnykh-like problems could be used as theoretical models. It is now generally believed that nearly every galaxy hosts a supermassive black hole at the center. It is also believed that most massive elliptical galaxies were formed by merging of existing galaxies. Thus, it is possible that many luminous elliptical galaxies might host binary black holes. The orbital motion of stars near the binary black hole at the centers of galaxies is a dynamical system that Chermnykh-like problems could act as a good model. The possible orbits of these stars would be related with the den-

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