

Quasi-satellites and mini-moons

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In recent decades, there has been a rapid development of means and methods of astronomical observations. This has led to more than just an increase in the number of discovered asteroids. Previously unknown types of their dynamic behavior were revealed. As one of the most unexpected events, we can consider the discovery of asteroids that combine motion around the Sun with a long stay in the vicinity of one of the planets. Depending on whether the asteroid crosses the Hill sphere of the planet or not, such objects are divided into two classes: quasi-satellites [Kog90] and mini-moons [BJa14].

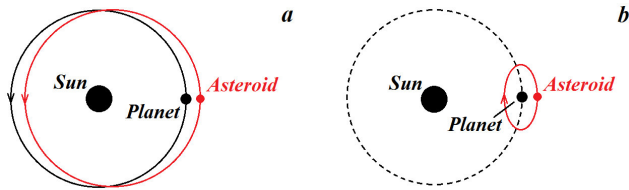


Figure 1: The orbital motion of a quasi-satellite and its host planet. Panel **a**: a Sun-centered reference frame that preserves the orientation in the absolute space. The quasi-satellite and the planet move around the Sun with the same orbital period in elliptic and in circular orbits respectively. Panel **b**: a Sun-centered frame rotating with the mean orbital motion of the planet

A quasi-satellite is an object that moves in the vicinity of a planet at a distance significantly less than the distance from this planet to the host star, and at the same time always remains outside its Hill sphere. The quasi-satellite mode of orbital motion is realized at 1:1 resonance of the mean motions of this object and the planet and, under certain conditions, it can transform into other modes of resonant motions (typically, into a horseshoe mode). In the quasi-satellite mode the asteroid's motion is weakly perturbed heliocentric (Fig. 1). This makes it possible to apply perturbation theory for analytical studies of quasi-satellite motions [MI97, Nam99, NCM99, Sid+14].

To date, eight asteroids are known to be quasi-satellites of the Earth: (164207) 2004GU₉, (277810) 2006FV₃₅, 2013LX₂₈, 2014OL₃₃₉, (469219) Kamoʻoalewa, 2020PP₁, 2022YG, 2023FW₁₃. We discuss the qualitative properties of the dynamics of these quasi-satellites using simple models: the restricted circular three-body problem "Sun-Earth-asteroid", averaged taking into account 1:1 mean motions resonance, and its modification, where the influence of other planets on the motion of the asteroid is added.

The objects, called mini-moons, orbit the planet several times in orbits that substantially intersect the Hill sphere. It is known that the Earth's mini-moons were asteroids 2006RH₁₂₀ and 2020CD₃. The motion of mini-moons is perturbed significantly more than the motion of quasi-satellites. Strong disturbances make it difficult to study the dynamics of mini-moons using analytical methods. A number of important results about the possible number of mini-moons near the Earth and the duration of stay of objects in the mini-moon regime were obtained using numerical calculations.

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