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Study of the Yarkovsky diurnal effect on planetary satellites: Application to the satellites of Mars

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Abstract

We study here the perturbation caused by the Yarkovsky diurnal effect on the long-term evolution of Phobos' and Deimos' orbits. In particular, the past evolution of the Mars satellites is still not completely understood. While tidal effects may have played the most important role in the past evolution of their orbits, it is still important to verify that all relevant perturbations required to compute accurately the moon orbits have been considered. Moreover, due to their proximity to the sun, Mars moons are expected to be the most concerned of planetary moons by Yarkovsky effect.

1. Introduction

The Yarkovsky effect is a result of a force acting on a rotating body in space caused by the anisotropic emission of thermal photons (basically re-emitted from the Sun), which carries momentum. It is usually considered in relation to meteoroids or small asteroids (about 10 cm to 10 km in diameter), as well as artificial satellites of the Earth since its influence is most significant for objects in this size range and not too far from the Sun. The induced force affects the orbital motion of these bodies. To our knowledge the effect on small planetary satellites has never been studied.

2. Main problem

We consider the system composed of a main central body (the Sun), Mars and one of its satellites.

We used the Yarkovsky diurnal force for spherical bodies that was given by D. Vokrouhlicky 1998 [1], (equation 1).

$$\begin{cases} f_X = -\dfrac{4\alpha}{9}\Phi\sin\theta_0\dfrac{1+\kappa_1\Theta}{1+2\kappa_1\Theta+\kappa_2\Theta^2} \\[2ex] f_Y = -\dfrac{4\alpha}{9}\Phi\sin\theta_0\dfrac{\kappa_3\Theta}{1+2\kappa_1\Theta+\kappa_2\Theta^2} \\[2ex] f_Z = -\dfrac{4\alpha}{9}\Phi\cos\theta_0\dfrac{\sqrt{2}R'}{\sqrt{2}R'+\Theta} \end{cases} \qquad (1)$$

This latter's system of axes is defined such as the Z axis corresponds to the body's rotation axis and the X axis is oriented towards the Sun in the (XZ) plane as shown in the Figure 1.

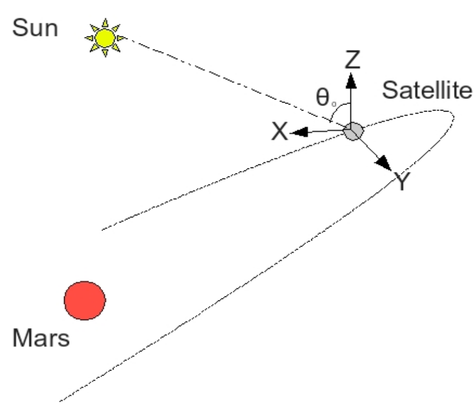

Figure 1: The coordinate system in which the Yarkovsky diurnal force is considered.

After performing the proper rotations we developed Gauss equations in Fourier series using the Bessel function [2]. Then we obtained a general analytical formulation providing the secular variations of the semi-major axis and eccentricity associated to the Yarkovsky diurnal perturbation (equations 2 and 3).

$$\left.\frac{da_s}{dt}\right|_{secular} = -\frac{\alpha}{9n_s}\frac{a_s}{a_{\odot}^{9/2}}\Lambda\Phi'\Theta' \times \left(\frac{7}{8}\cos 2i - \cos i + \frac{21}{8}\right) + O(e^2, a^2) \tag{2}$$

$$\left.\frac{de_s}{dt}\right|_{secular} = -\frac{\alpha}{9n_s}\frac{1}{a_{\odot}^{9/2}}\Lambda\Phi'\Theta' \times \left(-\frac{1}{2}\cos i + \frac{21}{16}\right) e_s + O(e^2, a^2) \tag{3}$$

where α, Λ, ϕ' and Θ' represent the satellite's properties. n_s, a_s, e_s and i are the satellite's respectively mean motion, semi-major axis, eccentricity and its inclination to ecliptic plane. Since the axis system was centred on Mars to obtain these equations, $a_{\odot}$ is the sun's semi-major axis viewed from Mars. Table 1 shows the secular variations of the semi-major axis and the eccentricity caused by Yarkovsky effect on Deimos and Phobos.

Table 1: Semi-major axis and eccentricity secular variations caused by Yarkovsky effect

	Deimos	Phobos
da/dt (au.Myr^{-1})	-4.28×10^{-13}	-4.51×10^{-14}
de/dt (Myr^{-1})	-2.05×10^{-13}	-4.28×10^{-12}

6. Summary and Conclusions

We have obtained analytically the secular terms induced by the diurnal Yarkovsky effect. We used numerical simulations with initial conditions from the ephemeris of Lainey et al. 2007 [3] to check the accuracy of our analytical developments. We conclude that the Yarkovsky diurnal effect has provided only a very limited effect on the past evolution of the Mars moons. Our formulation can be easily applied to any other planetary system or asteroid systems.

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