NONGRAVITATIONAL FORCES AND METEOROID STREAMS

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(Received July 8, 1994)

Abstract. The action of the solar electromagnetic radiation on the moving interplanetary dust particles in its more complete form than the special case known as the Poynting–Robertson effect is theoretically discussed in application to meteoroid stream of comet Encke.

Normal and transversal components of the perturbing nongravitational force are used due to the action of the solar electromagnetic radiation. It is shown that the normal component of the force is negligible. However, transversal component is very important: it can probably completely explain all the observed meteoroid streams situated along the orbit of comet Encke (and, possibly, some asteroids) as the product of the comet Encke alone. Much shorter time is required for producing such a meteoroid stream than is a general conception.

If the idea about the significance of the transversal component of the nongravitational force (may be, not produced by electromagnetic radiation) is correct, it may have important consequences for our understanding of ageing of comets, global evolution of the cometary (and, partially, asteroidal) system, and, of course, for a long-term evolution of small interplanetary particles.

Keywords: interplanetary dust particles, nongravitational forces, Poynting–Robertson effect, orbital evolution, meteoroid streams, comets

1. Introduction

One of the most important forces influencing the long-term orbital evolution of small interplanetary dust particles is the Poynting–Robertson effect (P–R effect). The P–R effect is a nongravitational effect induced by electromagnetic radiation on a moving small dust particle, e.g., of spherical shape (Klačka 1994b discusses another example). In this paper the influence of the solar electromagnetic radiation on interplanetary dust particles is studied. However, the correct and complete interaction between a moving small dust particle and the incident electromagnetic radiation is somewhat more complicated than it would correspond to the P–R effect (Klačka, 1994a; Klačka and Kocifaj, 1994; Klačka, 1994b). The aim of this paper is to point out on the possible importance of terms in equation of motion which do not occur in the P–R effect.

2. Electromagnetic Radiation and Equation of Motion for Dust Particle

The effect of the solar electromagnetic radiation on a moving small interplanetary dust particle is given by the equation of motion in the form
\[ \frac{\mathbf{dv}}{dt} = \frac{\beta \mu}{r^2} \left\{ \left( 1 - \frac{\mathbf{v} \cdot \mathbf{S}}{c} \right) \frac{\mathbf{S}}{c} - \frac{\mathbf{v}}{c} + \alpha_T \mathbf{e}_T + \alpha_N \mathbf{e}_N \right\}, \]

where \( \alpha_T \) and \( \alpha_N \) are dimensionless constants, independent on radius vector \( \mathbf{r} = r \mathbf{S} \) and velocity \( \mathbf{v} \) in the first approximation; they are given by the process of interaction between dust particle and incident electromagnetic radiation (for more details, that such terms exist in Equation (1), see Kláčka 1994a, Kláčka and Kocifaj 1994, Kláčka 1994b). \( \beta \) is the ratio of the radiation force to the gravitation force, \( \mu/r^2 \) represents magnitude of the solar gravitational acceleration acting on the particle.

As it is seen from Equation (1), the term containing \( \alpha_N \) corresponds to the existence of normal acceleration (normal to the instantaneous orbital plane) and it changes the inclination of the particle's orbit. The term containing \( \alpha_T \) causes additional acceleration \( (\alpha_T > 0) \) or deceleration \( (\alpha_T < 0) \) in comparison to the particle's orbital motion. In the case of \( \alpha_T = \alpha_N = 0 \), the Equation (1) is reduced to the P–R effect.

### 3. Secular Changes of Orbital Elements

On the basis of Equation (1) we can now calculate secular changes of orbital elements for a particle moving in gravitational and electromagnetic fields of the Sun (see also Kláčka 1994c).

If we consider \( \alpha_T = 0 \), one finally obtains

\[ \frac{di}{dt} = \alpha_N \beta \frac{\sqrt{\mu}}{a^{3/2}} X \cos \omega, \]

\[ \frac{d\Omega}{dt} = \alpha_N \beta \frac{\sqrt{\mu}}{a^{3/2}} X \frac{\sin \omega}{\sin i}, \]

\[ \frac{d\omega}{dt} = -\alpha_N \beta \frac{\sqrt{\mu}}{a^{3/2}} X \frac{\cos i}{\sin i} \sin \omega, \]

where

\[ X = \frac{1}{e} \left\{ 1 - \frac{2}{\pi} \frac{1}{\sqrt{1 - e^2}} \left( \arctg \sqrt{\frac{1 - e}{1 + e}} + \arctg \sqrt{\frac{1 + e}{1 - e}} \right) \right\}. \]