Radiation pressure influence on the motion of hazardous asteroids

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Abstract. The deviations under radiation pressure influence were calculated for three asteroids 308635 (2005 YU55), 367943 Duende (2012 DA14) and 357439 (2004 BL86) that had a close encounter with the Earth. Calculations were made for different values of the assumed albedo of the asteroids. Deviations in orbital motion of the asteroids before the next close encounter with the Earth are also presented.

1. Introduction

In recent decades, investigation and identification of potentially hazardous Near Earth Asteroids are one of the most important problems in astronomy. For hazard level evaluation firstly it is necessary to determine the orbit of an object. During the orbit modeling it is important to consider all possible factors influencing on its variation, including radiation pressure. Although radiation effects in motion of asteroids, as known, are small, at relatively large time intervals they can cause significant changes in parameters of orbital motion. By changing albedo of the asteroid's reflecting surface, in the future one can change its orbit.

The deviations in orbital motion of hazardous asteroids 308635 (2005 YU55), 367943 Duende (2012 DA14) and 357439 (2004 BL86) under radiation pressure influence were calculated. Estimation of radiation pressure effect was produced by means of specially developed program based on numerical integration of motion equations by Everhart method [1].

The five-body system the Sun — Jupiter — an asteroid (a material point; only gravity affects on it) — an asteroid (a spherical body having a finite radius, a certain density and optical coefficient; radiation pressure and gravity affect on it) — the Earth was selected to solve this problem. The system splits into four independent models of three bodies of different configuration and allows revealing the Earth influence on the asteroid motion, which is important in connection with the asteroid and comet hazard. The comparison of these models allows one to calculate the deviation of asteroid positions relative to each other, caused by radiation pressure influence. The work [1] is devoted to a detailed description of the model.

Each of asteroids, selected for investigation, had a close encounter with the Earth that is of particular interest. Three values were calculated for each asteroid: the displacement along the
heliocentric radius-vector $\Delta r$, the displacement along the orbit $\Delta l$ and the total displacement $\Delta d$. As a comparison calculations were made in case of increased reflectivity of asteroids using the bright coating of surface and also in case of absolutely white body.

2. Results

The orbital and physical parameters of the asteroid 367943 Duende (2012 DA14), used for taking into account the solar radiation pressure, are following:

- $e = 0.089428$ — eccentricity [2],
- $a = 0.910316$ AU — semi-major axis [2],
- $H_V = 21.0$ — absolute magnitude [2],
- $D = 40$ m — diameter [3],
- $\rho = 2330$ kg/m$^3$ — silicon density under normal conditions (L-class asteroid),

Hence $\delta = 0.28$ — albedo in the band $V$, derived from the asteroid’s absolute magnitude and its diameter by using the formula [4]

$$\lg D = 3.122 - 0.5 \lg \delta - 0.2 H_V$$

In general, the optical model of asteroid surface is based on the assumption of predominance of diffuse nature of reemission, and the continuity condition for solar energy flux is: $\alpha + \rho + \delta = 1$, where $\alpha$ is the absorption coefficient, $\rho + \delta$ is the reflection coefficient composed of the mirror reflection $\rho$ and the diffuse reflection $\delta$. The optical coefficient for the diffuse reemission is: $k = \alpha + \rho + 13\delta/9$ [5]. For a natural body it was accepted that there is no mirror reflection ($\rho = 0$), and the diffuse reflectance $\delta$ is the geometric albedo of an asteroid. Thus, for extended spherical diffusely reflecting body the optical coefficient is: $\alpha = 1 - \delta$, $k = \alpha + 13\delta/9 = 1 + 4\delta/9$.

Therefore $k = 1.12$ — optical coefficient.

In the next 20 years the maximum deviations of 2012 DA14, caused by radiation pressure for different values of the assumed albedo are summarised in Table 1:

**Table 1. The maximum deviations of 2012 DA14 in the next 20 years.**

| Deviation | $\delta = 0.28$ | $\delta = 0.80$ (bright body) | $\delta = 1.0$ (absolutely white body) |
|-----------|-----------------|-------------------------------|---------------------------------------|
| $\Delta r$ | $21.8 \pm 0.1$ km | $26.5 \pm 0.1$ km | $28 \pm 0.1$ km |
| $\Delta l$ | $270.4 \pm 0.1$ km | $328.4 \pm 0.1$ km | $347.7 \pm 0.1$ km |
| $\Delta d$ | $270.6 \pm 0.1$ km | $328.6 \pm 0.1$ km | $348 \pm 0.1$ km |

The orbital and physical parameters of the asteroid 308635 (2005 YU55), used for taking into account the solar radiation pressure, are following:

- $e = 0.430609$ — eccentricity [6],
- $a = 1.157390$ AU — semi-major axis [6],
- $H_V = 21.9$ — absolute magnitude [6],
- $D = 400$ m — diameter [7],
- $m = 10^{11}$ kg — mass [8],
- $\rho = 3.0$ g/cm$^3$ — density,

Hence $\delta = 0.02$ — albedo, derived from (1),

$$k = 1.00(8)$$ — optical coefficient.

In the next 20 years the maximum deviations of 2005 YU55, caused by radiation pressure for different values of the assumed albedo are summarised in Table 2:
Table 2. The maximum deviations of 2005 YU55 in the next 20 years.

| Deviation | \(\delta = 0.02\) | \(\delta = 0.80\) (bright body) | \(\delta = 1.0\) (absolutely white body) |
|-----------|--------------------|----------------------------------|-------------------------------------|
| \(\Delta r\) | 16.6 ± 0.1 km | 22.4 ± 0.1 km | 23.7 ± 0.1 km |
| \(\Delta l\) | 47.2 ± 0.1 km | 63.6 ± 0.1 km | 67.3 ± 0.1 km |
| \(\Delta d\) | 49.3 ± 0.1 km | 66.4 ± 0.1 km | 70.3 ± 0.1 km |

The orbital and physical parameters of the asteroid 357439 (2004 BL86), used for taking into account the solar radiation pressure, are following:

- \(e = 0.403073\) — eccentricity [9],
- \(a = 1.502202\) AU — semi-major axis [9],
- \(H_V = 19.3\) — absolute magnitude [9],
- \(D = 325\) m — diameter [10],
- \(\rho = 1.6\) g/cm\(^3\) — density [11],

Hence \(\delta = 0.32\) — albedo, derived from (1),

\(k = 1.14\) — optical coefficient.

In the next 20 years the maximum deviations of 2004 BL86, caused by radiation pressure for different values of the assumed albedo are summarised in Table 3:

Table 3. The maximum deviations of 2004 BL86 in the next 20 years.

| Deviation | \(\delta = 0.32\) | \(\delta = 0.80\) (bright body) | \(\delta = 1.0\) (absolutely white body) |
|-----------|--------------------|----------------------------------|-------------------------------------|
| \(\Delta r\) | 32.2 ± 0.1 km | 38.4 ± 0.1 km | 40.6 ± 0.1 km |
| \(\Delta l\) | 109.4 ± 0.1 km | 130.5 ± 0.1 km | 138.2 ± 0.1 km |
| \(\Delta d\) | 109.8 ± 0.1 km | 130.9 ± 0.1 km | 138.6 ± 0.1 km |

3. Conclusion

These results allowed one to estimate the possible effect on asteroids by changing their albedo. Before the next encounter of asteroids 308635 (2005 YU55), 367943 Duende (2012 DA14) and 357439 (2004 BL86) with the Earth (using the bright coating of surface) possible total deviation under radiation pressure influence will be approximately 199.2 ± 0.1 km (2075 year), 509 ± 0.1 km (2046 year), 79 ± 0.1 km (2027 year), respectively. Thus, changes in orbital motions of the asteroids under the influence of such non-gravitational effect as radiation pressure can be significant enough to affect the risk assessment of objects’ collision during close encounters with the Earth.

References

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