Investigation of non-gravitational effect influence on a few potentially hazardous asteroids

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Abstract. Observations of potentially hazardous asteroids 2014 JO25, (418094) 2007 WV4, (276033) 2002 AJ129 were carried out at MTM-500M and ZA-320M telescopes of the Central Astronomical Observatory of the Russian Academy of Sciences at Pulkovo. Solar radiation pressure was taken into account to study the evolution of their orbits. Deviations in the orbital motion were calculated for different numerical values of albedo of these objects. The results of non-gravitational effect influence on the orbits of these near-Earth asteroids were obtained.

1. Introduction

As is known, potentially hazardous asteroids are the objects having the minimum orbital intersection distances with the Earth less than 0.5 AU and quite large sizes to make significant damages during the impact. Although they aren’t dangerous today, their resonant returns after close encounters can cause a collision in future. This means that continuous monitoring of celestial objects with subsequent calculations and modeling are necessary to prevent such cases.

Observations of potentially hazardous near-Earth asteroids 2014 JO25, (418094) 2007 WV4, (276033) 2002 AJ129 were performed at MTM-500M and ZA-320M telescopes of the Central Astronomical Observatory of the Russian Academy of Sciences at Pulkovo. All these objects belong to the Apollo group. 2014 JO25 made a close flyby of the Earth on the 19th of April, 2017, and its maximal approach to the planet was 1.8 million kilometers. This asteroid has a peanut shape with the largest dimension of about 870 meters [1], which is quite significant. Despite the collision with the Earth is highly improbable, its next close approach will be in 2091. (418094) 2007 WV4 safely passed the Earth on the 1st of June, 2017. It is worthy of note that the rate of approaching was more than 83 thousand kilometers per hour. Next time this asteroid will have the close encounter in 2151. (276033) 2002 AJ129 with the maximum cross-section of 1.2 kilometers [3] had the closest approach to the Earth on the 4th of February, 2018. The minimum distance to the planet was 4.2 million kilometers, that is 10 times higher the distance between the Earth and the Moon. In 2172, its future approach will be within 1.8 lunar distances.

The Everhart numerical integration of motion equations [4] provided quantitative estimates characterizing the deviations caused by radiation pressure. The method developed in [4] allows one to compare two motion models — the restricted and the photogravitational restricted three-body problem. The first model associated only with gravity which acts on an asteroid as a material point. The second
model imply solar radiation pressure besides the gravity. Here an asteroid is considered as an extended spherical body. Thus, a comparison of these models result in the orbital deviations of one asteroid relative to another. In addition, calculations were made for three different values of albedo: the real one, the albedo of a bright body and of an absolutely white body. Although a paint coating of asteroids looks still a bit futuristic, it is important to understand whether this estimation method is useful. The displacement along the heliocentric radius-vector ∆r, the displacement along the orbit ∆l and the total displacement ∆d were calculated in accordance with the method [4].

2. Results
The initial data for all asteroids was taken on the epoch 2458200.5 (2018-Mar-23.0).

For 2014 JO25 the semi-major axis a is 2.068019, the eccentricity e is 0.885689, the absolute magnitude in the V band H, is 17.8 [5]. The diameter D obtained from Arecibo radar observations [1] is 0.87 km.

For (418094) 2007 WV4 the semi-major axis a is 1.486395, the eccentricity e is 0.441073, the absolute magnitude in the V band H, is 19.6, the diameter D is 0.89 km [2].

For (276033) 2002 AJ129 the semi-major axis a is 1.370442, the eccentricity e is 0.914896, the absolute magnitude in the V band H, is 18.7 [6]. The diameter D discovered by the Near-Earth Asteroid Tracking (NEAT) project [3] is 1.2 km.

Using the formula \( \lg D = 3.122 - 0.5\lg \delta - 0.2H, \) [7], which links an absolute magnitude and a diameter, one can derived a geometric albedo \( \delta \) (whiteness of a surface) of the object. Therefore, the albedo of 2014 JO25, (418094) 2007 WV4, (276033) 2002 AJ129 are 0.18, 0.03 and 0.04 respectively. The optical coefficient that is also necessary for calculation the deviations under radiation pressure can be found from \( k = 1 + 4\delta/9 \) [8]. Consequently, one can achieve 1.07, 1.01 and 1.02 for the abovementioned objects respectively.

Since the densities of these objects have not yet been accurately determined, one can use the Tholen’s classification instead. For example, it was determined that 2014 JO25 is attributed to the S spectral type (siliceous) [9], thus the corresponding density to this class is about 2.71 g/cm\(^3\) [10]. The spectral type for (418094) 2007 WV4 hasn’t been identified, but it was registered that the object is dark enough [11], so one can assume that this asteroid is carbonaceous (C class) with the corresponding density 1.38 g/cm\(^3\) [10]. For (276033) 2002 AJ129 there is no data at all, therefore one can use the mean density 2 g/cm\(^3\), which is accepted for many asteroids.

For correct comparison, calculations for all these objects are presented for the same short time interval. However, deviations in the orbital motion can be estimated for any period of time, including future close approaches. Nevertheless, it was found earlier [4], that the character of ∆r, ∆l and ∆d changing is non-linear over time. In this way, the expected increase of displacement values is significantly non-proportional to time.

The firsts results were obtained for the real values of albedo.

Table 1. Orbital displacements of the asteroids with their real albedos (0.18, 0.03 and 0.04 respectively) in the next 20 years.

| Asteroid          | ∆r   | ∆l   | ∆d   |
|-------------------|------|------|------|
| 2014 JO25         | 151.6 km | 201.4 km | 226.2 km |
| (418094) 2007 WV4 | 14.4 km  | 46.7 km  | 46.7 km  |
| (276033) 2002 AJ129 | 192.4 km | 276.6 km | 337 km  |
The second results were carried out from the assumption, that the asteroids were much brighter, for example, by means of light color covering. The model albedo 0.8 is close to the surface reflectance of white chalk or paper.

**Table 2.** Orbital displacements of the asteroids with the model albedo $\delta = 0.8$ and the optical coefficient $k = 1.36$ in the next 20 years.

| Asteroid          | $\Delta r$ | $\Delta l$ | $\Delta d$ |
|-------------------|------------|------------|------------|
| 2014 JO25         | 192.7 km   | 256 km     | 287.6 km   |
| (418094) 2007 WV4 | 19.4 km    | 62.9 km    | 62.9 km    |
| (276033) 2002 AJ129 | 257.4 km | 370 km     | 450.7 km   |

The third results were found from the assumption, that the asteroids are the absolutely white bodies.

**Table 3.** Orbital displacements of the asteroids with the model albedo $\delta = 1.0$ and the optical coefficient $k = 1.44$ in the next 20 years.

| Asteroid          | $\Delta r$ | $\Delta l$ | $\Delta d$ |
|-------------------|------------|------------|------------|
| 2014 JO25         | 204.1 km   | 271 km     | 304.5 km   |
| (418094) 2007 WV4 | 20.5 km    | 66.6 km    | 66.6 km    |
| (276033) 2002 AJ129 | 272.4 km | 391.6 km   | 477 km     |

3. Conclusion

It is obvious from the Tables 1-3 that the deviations grow with increasing of the surface reflectance of the asteroids. 2014 JO25 has the similar diameter to (418094) 2007 WV4, but the spectral class and the surface reflectivity are different, so the obtained results are not similar. Estimates obtained for (276033) 2002 AJ129 exceed them since the asteroid is bigger and the mean density was assumed. Furthermore, (418094) 2007 WV4 and (276033) 2002 AJ129 are very dark objects having the similar low albedo and the high solar absorptivity, and 2014 JO25 is much brighter them. The maximum values of $\Delta l$ are achieved when the changes of $\Delta r$ are minimal. Therefore, the maximum values of $\Delta l$, as a rule, are close to the values of $\Delta d$. Summarizing the results, one can compare the size and the surface reflectivity of the objects in relation to the solar radiation pressure influence.

Monitoring of hazardous objects is very important for the accumulation of reliable statistical data and precise prediction. However, the most problem is that the physical data such as mass or density of an asteroid is often inaccessible, since there haven’t been any radar observations yet.

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