Investigation of radiation pressure influence on the asteroids that subsequently have fallen to the Earth

A Martyusheva

1The Central Astronomical Observatory of the Russian Academy of Sciences, Pulkovskoe chaussee 65, Saint-Petersburg, 196140, Russia

E-mail: alex.mart13@gmail.com

Abstract. The deviations in orbital motion of the asteroid-meteoroid 2008 TC3 and the asteroid, which subsequently became the Chelyabinsk meteorite, under radiation pressure influence were calculated. These celestial objects are of special interest for investigation, since due to the close encounters with the Earth their orbits had dramatically changed, which resulted in their downfall. Calculations were made for several values of albedo of the asteroids in order to compare the extent of deviations. Obtained results allowed estimating the effect of solar radiation pressure depending on changes of surface reflectance of the objects.

1. Introduction

Identification of potentially hazardous Near-Earth asteroids remains an urgent problem. As part of the model problem for the asteroid-meteoroid 2008 TC3 and the asteroid, which subsequently became the Chelyabinsk meteorite, the values of deviations in their orbital motion under the influence of solar radiation pressure were calculated. These asteroids are of particular interest for the study, since due to the close encounters with the Earth their orbits had changed significantly, which in turn, led to their downfall.

The asteroid 2008 TC3 met with the Earth on the 7th of October 2008. This asteroid was discovered in Mount Lemmon Observatory (Arizona, USA) on the day before the collision with the Earth. Observation data, passed to the Minor Planet Center, allowed a calculation of preliminary orbit the asteroid before the anticipated collision. During the fall it collapsed in the atmosphere above the Nubian Desert in Sudan, some fragments reached the Earth's surface. All fragments were collectively named after the railway station Almahata Sitta where the bolide was noticed. Therefore, the fall of this asteroid was the first predicted fall of a celestial body.

The Chelyabinsk meteorite fell to the Earth on the 15th of February 2013 as a result of braking in the atmosphere of a small asteroid. The meteorite fall was accompanied by shock waves spread over the territory of the Chelyabinsk region and other regions of Russia and Kazakhstan. Fragments of the asteroid were found in the Chelyabinsk region. The major fragment was reached out of Chebarkul Lake.

Estimation of radiation pressure influence on the motion of the asteroid 2008 TC3 and the Chelyabinsk meteorite was produced by means of specially developed model [1] based on numerical integration of motion equations by Everhart method. The three-body system was chosen for this
problem which splits into two different models: the restricted and the photogravitational restricted planar circular three-body problem. In first model only gravity affects on an asteroid. In second one, an asteroid is considered as an extended spherical body (of finite radius and definite density) so that gravity and radiation pressure influence on it. Comparison of these two problems gives us the deviations in motions of asteroids, caused by solar radiation pressure. The motion is defined in heliocentric rectangular coordinates. The initial orbits of the asteroids are elliptical. Calculations for each of the asteroids were made with three different values of albedo: the real albedo, albedo of a bright body (increased reflectance) and of an absolutely white body (the maximal reflectance). Thus, one can compare the deviations due to the radiation pressure influence.

The displacement along the heliocentric radius-vector $\Delta r$, the displacement along the orbit $\Delta l$ and the total displacement $\Delta d$ were also calculated for each object.

2. Results

It is important to note that calculations were made for the model asteroids with the parameters of real objects (2008 TC3 and the Chelyabinsk meteorite) on the assumption as if these asteroids did not fall to the Earth and continued their movement in space.

The orbital and physical parameters of the asteroid 2008 TC3, used for taking into account the solar radiation pressure, were taken on the epoch 2454746.5 (2008-Oct-07.0):

$e = 0.312065$ — eccentricity [2],
$a = 1.308201$ AU — semi-major axis [2],
$H_V = 30.4$ — absolute magnitude [2],
$D = 4.8$ m — diameter [3],
$\rho = 2330$ kg/m$^3$ — density [4],
$\delta = 0.05$ — albedo in the band $V$, derived from the asteroid’s absolute magnitude and its diameter by using the formula $\lg D = 3.122 - 0.5\lg \delta - 0.2H_V$ [5],

$k = 1.02$ — optical coefficient for an extended spherical diffusely-reflecting body, derived from [6]:

$$k = \alpha + \rho + 13\delta/9, \quad (1)$$

where $\rho$ — is the mirror reflection ($\rho = 0$ for a natural body) and $\alpha = 1 - \delta$ — is the absorption coefficient.

Within the next 20 years, the maximum deviations of the asteroid 2008 TC3, caused by the radiation pressure, would have amounted:

**Table 1.** The maximum deviations of 2008 TC3 in the next 20 years.

| Deviation | $\delta = 0.05$, $k = 1.02$ | $\delta = 0.80$ (bright body), $k = 1.36$ | $\delta = 1.0$ (absolutely white body), $k = 1.44$ |
|-----------|--------------------------|--------------------------------|---------------------------------|
| $\Delta r$ | $782.2 \pm 0.1$ km | $1042.9 \pm 0.1$ km | $1104.3 \pm 0.1$ km |
| $\Delta l$ | $3293.3 \pm 0.1$ km | $4391.0 \pm 0.1$ km | $4649.3 \pm 0.1$ km |
| $\Delta d$ | $3293.4 \pm 0.1$ km | $4391.2 \pm 0.1$ km | $4649.5 \pm 0.1$ km |

The orbital and physical parameters of the Chelyabinsk meteorite, used for taking into account the solar radiation pressure, were taken on the epoch 2456338.5 (2013-Feb-15.0):

$e = 0.51$ — eccentricity [7],
$a = 1.69$ AU — semi-major axis [7],
$D = 18$ m — diameter [8],
$\rho = 3600$ kg/m$^3$ — density [8],
\[ \delta = 0.21 \] — albedo [9],
\[ k = 1.09 \] — optical coefficient, derived from (1).

Within the next 20 years, the maximum deviations of the asteroid, which subsequently became the Chelyabinsk meteorite, would have amounted:

**Table 2.** The maximum deviations of the Chelyabinsk meteorite in the next 20 years.

| Deviation | \( \delta = 0.21 \), \( k = 1.09 \) | \( \delta = 0.80 \) (bright body), \( k = 1.36 \) | \( \delta = 1.0 \) (absolutely white body), \( k = 1.44 \) |
|-----------|-------------------------------|---------------------------------|---------------------------------|
| \( \Delta r \) | \( 379.6 \pm 0.1 \) km | \( 473.7 \pm 0.1 \) km | \( 501.5 \pm 0.1 \) km |
| \( \Delta l \) | \( 1104.9 \pm 0.1 \) km | \( 1378.6 \pm 0.1 \) km | \( 1459.7 \pm 0.1 \) km |
| \( \Delta d \) | \( 1109.1 \pm 0.1 \) km | \( 1383.8 \pm 0.1 \) km | \( 1465.2 \pm 0.1 \) km |

3. Conclusion

The studies revealed that the asteroid 2008 TC3, which became the meteorite, was formed in a collision of three different asteroids [9]. Nysa-Polina asteroid family consists of three types of asteroids: the relatively rare B-type, the siliceous S-type and the transitional X-type. The fragments of Sudanese meteorite have spectral characteristics that are common to all three types of asteroids. This fact could mean that 2008 TC3 was presumably formed in a collision of an asteroid of S-type with an object of B-type, followed by another collision with an asteroid of X-type.

In case of the Chelyabinsk meteorite, it has been found by the group of scientists that about 10 million years ago a parent asteroid survived the collision in outer space, whereupon its trajectory had intercrossed with the Earth [10].

During the evolution small asteroids come under the impact of such non-gravitational effects, which can significantly change their orbits in a relatively short period of time by virtue of low mass of objects. Therefore, the effect of radiation pressure on the orbital motion of an asteroid should be taken into account in calculation of close encounters with the Earth. These calculations allowed estimating the possible effect of radiation pressure on asteroids by changing their albedo. It should be noted that these deviations are quite significant and should be considered at future calculations. Solar radiation pressure is the important disturbing factor especially in case of closeness of asteroid orbits to resonance zones with Jupiter and the Earth at large time intervals.

References

[1] Martyusheva A. A., Petrov N. A., Polyakhova E. N. Vestnik of SPbU, Vol.2 (60), Issue 1, pp. 135-147, 2015.
[2] http://ssd.jpl.nasa.gov/sbdb.cgi?sstr=2008%20TC3;old=0;orb=0;cov=0;log=0;cad=0#elem
[3] Aleshkina E. Y., Kupriyanov V. V., Devyatkin A. V. Vereshchagina I. A., Slesarenko V. Yu., L'vov V. N., Tsekmyster S. D. Solar System Research, Vol. 45, No. 1, pp. 36-44, 2011.
[4] Jenniskens P., Shaddad M. H., Numan D., Elsir S., Kudoda A. M., Zolensky M. E. et al. Nature. Vol. 458, pp. 485-488, 2009.
[5] Vinogradova, T. A., Zhelезнov N. B., Kuznetsov V. B., Chernetenko Yu. A., Shor V. A. Tr. Inst. Prikl. Astron. Ross. Akad. Nauk, Issue 9, 2003.
[6] Polyakhova E. N., Shmyrov A. S. Vestnik of SPbU, Vol. 2, Issue 8, pp. 87–104, 1994.
[7] Zuluaga J. I., Ferrin I. arXiv:1302.5377, 2013.
[8] http://neo.jpl.nasa.gov/news/fireball_130301.html
[9] Gayon-Markt J., Delbo M., Morbidelli A., Marchi S. arXiv:1206.3042, 2012.
[10] Antipin N. A. (Ed.) Materials All-Russian Scientific Conference «The Chelyabinsk meteorite — one year on the Earth», p. 410, 2014.
[11] Ozawa S., Miyahara M., Ohtani E., Koroleva O. N., Ito Y., Litasov K. D., Pokhilenko N. P. Scientific Reports, Vol. 4, 2014.