# The Interesting Main Belt Asteroid (324787) Wlodarczyk

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This paper is devoted to the orbital analysis of a dynamically interesting Main Belt asteroid (324787) Wlodarczyk discovered at the Moletai Observatory. The orbital motion of the asteroid (324787) Wlodarczyk is perturbed by massive asteroids from Main Belt asteroids and by the dwarf planet (1) Ceres.

## 1 Introduction

The asteroid (324787) Wlodarczyk was discovered on 2007 April 15 at Moletai Observatory by K. Cernis. It is one of 541128 numbered asteroids and one of 21922 named asteroids as of 2019 May 19[1].

## 2 Orbit of the (324787) Wlodarczyk

According to the JPL Small-Body Database[2], the absolute magnitude, $H$ of the (324787) Wlodarczyk is 15.2. The diameter range is derived from $H$ and assumed albedo for C and S type asteroids (0.04 and 0.20, respectively), which gives a diameter of about 6.1 to 2.7 km. The C-type asteroids are the most common type of known asteroids, compromising about 75% of them. They contain a large amount of carbon. The S-type asteroids consist mainly of iron-magnesium silicates. The 17% of asteroids are of this type.

To compute orbital elements and orbital evolution of the asteroid (324787) Wlodarczyk, we used the OrbFit software and took into account weighting and selecting observations according to the Near Earth Objects Dynamic Site (NEODyS) (Milani et al., 2005a,b) and Wlodarczyk (2015). We used the JPL DE431 ephemerides and additionally 15 perturbing asteroids and two dwarf planets: (1) Ceres and (134340) Pluto according to Farnocchia et al. (2013). The non-gravitational parameters of (324787) Wlodarczyk are not computed because of large uncertainties in orbital elements.

Tab. 1 lists computed Keplerian orbital elements of the asteroid (324787) Wlodarczyk and their uncertainties.

The computed absolute magnitude is $H = 15.314 \pm 0.402$ mag, i.e., close to the JPL estimate. The $RMS$ of the computed positions is 0.602".

[1] http://www.minorplanetcenter.org/iau/lists/ArchiveStatistics.html
[2] https://ssd.jpl.nasa.gov/sbdb.cgi#top

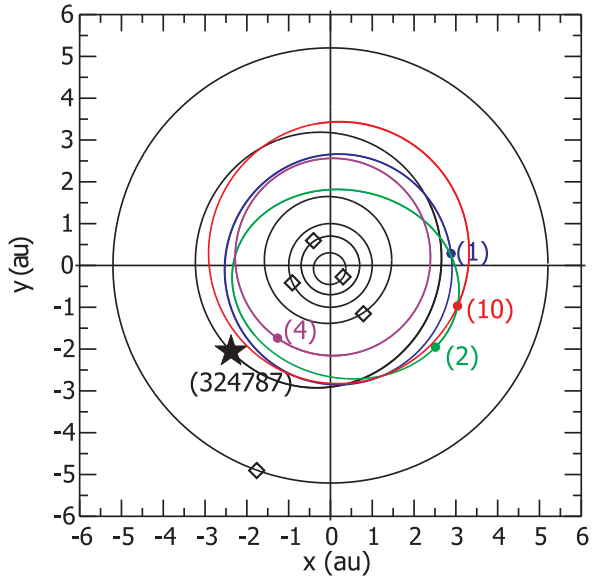


Fig. 1: The orbit of (324787) Wlodarczyk in the ecliptic plane. Positions of planets, the asteroid (324787) Wlodarczyk, dwarf planet (1) Ceres and three massive asteroids: (2) Pallas, (4) Vesta and (10) Hygiea are presented for the epoch 2007 April 15, i.e., for the date of discovery at Moletai.

## 3 Long Time Orbital Evolution of (324787) Wlodarczyk

To study orbital evolution of asteroid (324787) Wlodarczyk we first generated the Virtual Asteroids (VAs). To do this we computed orbital elements of 1001 clones (VAs) with the use of the OrbFit software v.5.0.5 and the method of (Milani et al., 2005a,b). Following this method, we computed 500 clones of both sides of the *LOV* which is a one-dimensional segment of a (curved) line in the initial conditions space. Then we propagate all the VAs 100 Myr forward and backward. Time evolutions of orbital elements of all clones are calculated by means of the software swift_rmvs developed by M. Broz[3]. This software takes into account gravitational influence of all planets (variant swift_rmvs3_f) and diurnal and seasonal variations of the Yarkovsky effect (variant swift_rmvs3_f_y). Our calculations were done for the case without Yarkovsky effect.

Tab. 2 lists the number of close approaches of (324787) Wlodarczyk into Hill radius of perturbing bodies. These close approaches cause throwing clones from Solar System model or colliding with the Sun. Other clones end their evolutions by colliding with planets: forward 10 and backward 9 clones.

Tab. 2 presents reasons for throwing clones out of the SWIFT software during 100 Myr integration. It is visible that the dominant role of perturbing (1) Ceres, (2) Pallas and (10) Hygiea. After 41 Myr forward and 47 Myr backward integrations all clones of (324787) Wlodarczyk were ejected from Solar System model as a result of entering the Hill radius.

[3] `http://sirrah.troja.mff.cuni.cz/~mira/mp/`

Tab. 1: Initial nominal orbital elements of (324787) Wlodarczyk. The angles $\omega$, $\Omega$, and $i$ refer to Equinox J2000.0. Epoch: 2007 April 15=JD2454205 TDB.

| $a$ (au) | $e$ | $i$ (deg) | $\Omega$ (deg) | $\omega$ (deg) | $M$ (deg) |
|---|---|---|---|---|---|
| Without perturbing asteroids | | | | | |
| 3.0771694989 | 0.1098268840 | 17.21300779 | 77.24031666 | 259.40184378 | 254.60169717 |
| With 15 perturbing asteroids and 2 dwarf planets | | | | | |
| 3.0771695000 | 0.1098268815 | 17.21300780 | 77.24031678 | 259.40184385 | 254.60169624 |
| $3.82 \times 10^{-8}$ | $8.45 \times 10^{-8}$ | $9.66 \times 10^{-6}$ | $3.231 \times 10^{-5}$ | $5.918 \times 10^{-5}$ | $4.943 \times 10^{-5}$ |

Tab. 2: Entry of (324787) Wlodarczyk into Hill radius of perturbing bodies.There were no approaches with Vesta.

| object | rHill(au) of object | number of events | |
|---|---|---|---|
| | | forward | backward |
| (1) Ceres | 0.00138 | 714 | 685 |
| (2) Pallas | 0.0007013 | 127 | 159 |
| (10) Hygiea | 0.0006808 | 142 | 140 |

Tab. 2 presents more detailed study of approaches inside the Hill radius of studied bodies. The Hill radius of planet is given by

$$r_{\mathrm{H}} = a(1-e)\sqrt[3]{\frac{m}{3\mathrm{M}_{\odot}}} = 0.006570\,(\mathrm{au}) \tag{1}$$

where $r_{\mathrm{H}}$ is the Hill radius of the planet, in au, $a$, $e$ are the semimajor axis and eccentricity of the orbit of the planet, $m$ is the mass of the planet, and $\mathrm{M}_{\odot}$ is mass of the Sun.

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## References

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