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Determination of the mass of asteroid (16) Psyche and masses of other asteroids of the taxonomic class M by the dynamic method

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Abstract. We use the dynamical method of estimation of the mass of perturbing asteroid by its gravitation influence on test asteroids. The positional observations of test asteroids from Minor Planet Center database and Focus Product Release of Gaia cosmic telescope are employed. The calculation of coordinates of perturbing planets is based on the ephemeris DE440. The set of test asteroids is used for estimation of perturbing mass. This set was collected by error of the mass of the perturbing asteroid for each test object. The number of test asteroids was selected particularly for each estimated mass. For the mass of asteroid (16) Psyche a value equal to $(1.1868 \pm 0.0092)\ 10^{-11}\ M_{\odot}$ was obtained. The masses of sixteen asteroids with numbers 55, 69, 75, 77, 83, 92, 97, 110, 129, 135, 201, 325, 441, 498, 516, and 739, that are from the taxonomic class M were estimated also. The estimated masses more than twice exceed their errors.

Keywords: planetary systems: minor planets; asteroids: general; individual: (16) Psyche

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1 Introduction

In the coming years, the asteroid (16) Psyche will be of considerable interest to the world scientific community. In particular, the automatic mission "Psyche" was launched by National Aeronautics and Space Administration (NASA) in October 2023. Investigations are expected to begin in 2029 and until then, new information about this large asteroid with an effective diameter of about 222 km is expected from other sources. The main scientific interest is the suggestion that the asteroid is metallic and may be a naked core of protoplanet.

Over the past ten years, a range of mass values has been obtained for the asteroid (16) Psyche (Table 1). They show good agreement of the masses obtained by the dynamical method using asteroids as test particles. The values of mass and their errors in the planetary theories have a larger dispersion. We assume that with the increasing number of asteroid observations, it is relevant to clarify the mass of Psyche and the masses of other asteroids of taxonomic class M according to Tholen (1989) classification. We use the dynamic (astrometric) method of determination of the masses of asteroids. This method involves using gravitational perturbations that a more massive body put on one or more less massive bodies.

Table 1. Mass of (16) Psyche.

№	Authors	Perturbed body	Number of perturbed bodies	Mass $10^{-11}\,M_\odot$
1	Carry (2012)	–	–	1.368 ± 0.372
2	Baer & Chesley (2017)	asteroids	3	1.150 ± 0.035
3	Elkins-Tanton et al. (2020)	–	3	1.15 ± 0.35
4	Fienga et al. (2020)	planets and spacecrafts	–	1.077 ± 0.192
5	Pitjeva et al. (2021)[1]	planets and spacecrafts	–	1.567 ± 0.106
6	Park et al. (2021)	–	–	1.198
7	Vernazza et al. (2021)	asteroids	–	1.137 ± 0.146
8	Siltala & Granvik (2021)	asteroids	10	1.117 ± 0.039
9	Farnocchia et al. (2024)	asteroids	38	1.206 ± 0.013

[1] https://iaaras.ru/en/dept/ephemeris/epm/2021/

2 Calculation

Integration of the equations of motion and the variational equations is performed by the Everhart's method. The equations of motion include the perturbations from all planets, taken from ephemeris DE 440 (Park et al. 2021), dwarf planets Pluto and Ceres and 14 asteroids with numbers: 2, 3, 4, 10, 15, 31, 48, 52, 65, 87, 88, 451, 511, 704. The system of normal equations is solved by the least-squares method with respect to the orbital elements of the perturbed asteroids and the refined mass value. We employ observations from Minor Planet Center[1] and Gaia catalog. Gaia observations were taken from "Focus Product Release". This release contains observations of 156792 asteroids over 66 months from 2014 to 2020[2]. We use two schemes to assign weights: weight scheme of Ephemerides of Minor Planets[3] and the weight scheme proposed in Vereš et al. (2017). The latter is based on detailed analyses of observations from individual observatories, from which weights are assigned. For Gaia observations, a weight calculation algorithm was used as described in the FPR. The preliminary selection of test particles is based on our catalogue of asteroid approaches. Thus, the number of test particles used to estimate the mass of each perturbing asteroid is estimated in a particular way. In that way, the number of test particles that used for mass estimation of each perturbing asteroid is estimated particularly. These numbers are presented in Table 2 (the third column) for each perturbing asteroid.

3 Results

After discussing the results of using different weight systems for MPC observations, we concluded that the obtained mass values are practically independent of the adopted weight system, but the corresponding errors are smaller for Vereš system (Vereš et al. 2017). The results of solutions with this weight system will be presented later.

Table 2 shows the number of asteroid and its name, then the total number of test asteroids, N_{total} and number of asteroids with Gaia observations, N_{Gaia}. The fifth column shows the values of mass of Psyche and 16 asteroids of the taxonomic class M that we obtained. The presented mass values are at least twice as large as their errors. The Table 2 (the sixth column) shows diameters of asteroids from Jet Propulsion Laboratory (JPL)[4] and obtained densities of asteroids (the last column). The density error is estimated using the formula from Carry (2012).

The obtained value of Psyche mass and its error confirms the results of other researches that used asteroid observations. The average density of Psyche turned out to be close to 4 g/cm^3, that correspond to density of stony–iron meteorites. Only two asteroids we assessed, (441) and (739), have average density of about or more than iron density and mean densities of asteroids (55) and (83) more are far from iron density.

[1] http://www.minorplanetcenter.net/iau/mpc.html
[2] https://www.cosmos.esa.int/web/gaia/focused-product-release
[3] https://iaaras.ru/en/about/issues/emp/
[4] https://ssd.jpl.nasa.gov/tools/sbdb_lookup.html

Table 2. Masses of asteroids of the taxonomic class M.

№ Name	N_{total}	N_{Gaia}	Mass $M_{\odot}$	Diameter km	Density g/cm^3
16 Psyche	36	23	$(1.187 \pm 0.009)\ 10^{-11}$	222 ± 4.0	3.89 ± 0.22
55 Pandora	21	17	$(1.702 \pm 0.757)\ 10^{-13}$	84.79 ± 2.50	1.06 ± 0.48
69 Hesperia	5	4	$(2.951 \pm 0.226)\ 10^{-12}$	138.13 ± 4.70	4.25 ± 0.54
75 Eurydike	18	10	$(1.682 \pm 0.430)\ 10^{-13}$	62.38 ± 1.60	2.63 ± 0.70
77 Frigga	15	11	$(3.553 \pm 1.100)\ 10^{-13}$	61.39 ± 0.18	5.83 ± 1.81
83 Beatrix	30	20	$(4.491 \pm 0.689)\ 10^{-13}$	110.50 ± 0.83	1.26 ± 0.20
92 Undina	5	3	$(3.186 \pm 0.141)\ 10^{-12}$	126.42 ± 3.40	5.99 ± 0.55
97 Klotho	8	6	$(1.049 \pm 0.133)\ 10^{-12}$	100.72 ± 0.64	3.90 ± 0.50
110 Lydia	31	21	$(7.339 \pm 0.071)\ 10^{-13}$	86.09 ± 2.00	4.36 ± 0.31
129 Antigone	10	8	$(2.123 \pm 0.169)\ 10^{-12}$	113.00 ± 5.00	5.59 ± 0.87
135 Hertha	51	38	$(4.859 \pm 0.504)\ 10^{-13}$	79.24 ± 2.00	3.71 ± 0.48
201 Penelope	36	21	$(4.361 \pm 0.345)\ 10^{-13}$	85.88 ± 3.14	2.62 ± 0.35
325 Heidelberga	4	2	$(6.133 \pm 2.131)\ 10^{-13}$	75.72 ± 1.70	5.36 ± 1.90
441 Bathilde	17	14	$(7.386 \pm 1.087)\ 10^{-13}$	65.13 ± 1.07	10.15 ± 1.57
498 Tokio	7	4	$(5.099 \pm 1.647)\ 10^{-13}$	81.83 ± 2.30	3.53 ± 1.18
516 Amherstia	5	3	$(3.161 \pm 1.183)\ 10^{-13}$	65.14 ± 0.38	4.34 ± 1.63
739 Mandeville	3	2	$(2.402 \pm 0.201)\ 10^{-12}$	104.52 ± 1.62	7.99 ± 0.76

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