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

V. B. Kuznetsov, Yu. A. Chernetenko

Institute of Applied Astronomy of the Russian Academy of Sciences, St. Petersburg, Russia

vb.kuznetsov@iaaras.ru, cya@iaaras.ru

INTRODUCTION

At nearest years, the asteroid (16) Psyche will have considerable interest for the world science society. As particularly, the automatic mission "Psyche" was launched NASA in October 2023. The start of investigations will be expected in 2029 and before it the new information about this large asteroid with effective diameter near 222 km is expected from other sources. The main specialty of science interest is assumption that asteroid is metallic and may be a naked kernel of protoplanet. This assumption is based on the relatively high volume density and properties of surface that received from spectroscopic and radiolocating observations (Shepard et al., 2017). Some researchers have apprehension that high volume density of Psyche near 4 g/cm³ is not enough for the metallic meteorites and Psyche may have metallic-stone structure, and it is parent body for the mezoderites (Viikinkoski et al., 2018). The assumption about ferrovulcanic activity on Psyche was suggested recently as an alternative mechanism that can explain the present observational data (Johnson et al., 2020). Ferrovulcanism would be possible to cover stone mantle by metallic layer as result of last eruption of molten iron. This theory is good to agree with relatively low volume density and availability of the metals on the surface, particularly as iron and nickel.

At last ten years a some means of mass of asteroid (16) Psyche was received. They are presented in Table 1 in 10^{-11} units mass of Sun (the fifth column). This table shows good agreement in the means of mass that are obtained by dynamical method with using of asteroids as test participles. The mass values and theirs errors in planetary theories have more dispersion. Because we suppose that with growing number of asteroid observations improvement of Psyche mass and masses of other asteroids of the taxonomic class M by classification of Tholen (Tholen, 1989) is actual.

Table 1. Mass of (16) Psyche

№	Authors	Perturbed body	Number of perturbed bodies	Mass, 10^{-11} M_{Sun}
1	B. 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)	planets and spacecrafts	–	1.567±0.106
6	DE440 (2021)	–	–	1.198
7	Vernazza et al. (2021)	asteroids	–	1.137±0.146
8	Siltala & Granvik (2021)	asteroids	10	1.117±0.039

DYNAMICAL MODEL

The integration of equations of motion and equations of variations are produced by Everhart method. The equations of motion involve the perturbations from all planets on the base of 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. Also, the equations of motion involve relativity terms from the Sun. The system of normal equations is solved using the Least Square Method with respect to orbital elements of perturbed asteroids and improved mass.

USED OBSERVATIONS

In our investigations, we are employ observations of Minor Planet Center (http://www.minorplanetcenter.net/iau/mpc.html) and Gaia catalog. Gaia observations were taken from "Focus Product Release". This release contains observations of 156792 asteroids for 66 months from 2014 to 2020 years (https://www.cosmos.esa.int/web/gaia/focused-product-release).

The real structure of MPC observations was combined from observations with different quality and accuracy (photographic, CCD terrestrial and cosmic). In such case, the important problem is choice of weights. In this project, we use two schemes for assigning weights. At first, weight scheme of Ephemerides of Minor Planets (EMP, 2017) was used: "The observations made before 1901 were assigned weight equal 1/16, the observations made in interval from 1901 to 1950 were assigned weight 1/9, the observations made during the time interval from 1951 to 1995 were assigned weight equal to 1/4, and at last observations starting from 1996 were considered as having unit weight." As second, the weight scheme proposed in (Veres et al., 2017) was used. This latter is based on a detailed analysis of observations of individual observatories, based on the results of which weights are assigned. For Gaia observations, the algorithm of weight calculation was used in accordance with description of "Focus Product Release".

SELECTION OF TEST PARTICIPLES

The preliminary selection of test particles is done on the base of our catalogue of asteroid approaches. Then, perturbing mass value and its error is obtained for each test asteroids. The corresponding list is then sorted with respect to the perturbing mass error. For the next step, we select test particles with minimal perturbing mass errors. Our aim is to ensure that the mass values obtained on the last step are as statistical as possible. In that way, the number of test particles that used for mass estimation of each perturbing asteroid is estimated particularly. These numbers are represented in table 2 (the third column) for each perturbing asteroid.

THE RESULTS

After discussion of results that were obtained with different weight systems for MPC observations, we concluded that the obtained mass values are practically independent of the adopted weight system, but corresponding errors are less for Veres' system (Veres et al., 2017). Later, the results of solutions with this weight system are presented.

Table 2 shows the number of asteroid and his name (the first and second columns), then the total number of test asteroids, N_{total} and number of asteroids with Gaia observations, N_{Gaia} (the third and fourth columns). The fifth column shows the values of mass of Psyche and 16 asteroids of the taxonomic class M that we obtained, in mass of the Sun. The presented mass values are at least twice as large as their errors. The Table 2 (the sixth column) shows diameters of asteroids from JPL web-site (https://ssd.jpl.nasa.gov/tools/sbdb_lookup.html) (SBDL). This allows one to calculate the densities of asteroids (the last column of table 2). The density error is estimated using the formula (Carry, 2012):

$$\frac{\delta\rho}{\rho} = \sqrt{\left(\frac{\delta M}{M}\right)^2 + \left(\frac{\delta D}{D}\right)^2},$$

where ρ is density, M – mass, D – diameter of asteroid, $\delta\rho$, δM and δD are their errors.

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/cm³, that correspond to density of stony-iron meteorites. The hypothesis about homogeneity of asteroid structure is being disputable.

Only two asteroids we assessed, (441) and (739), have average density near or more than iron density. The middle densities of asteroids (55) and (83) more far from density 5.32 g/cm³ (Krasinsky et al., 2002) that has been estimated for asteroids of with the taxonomic class M. Future improvement of masses and diameters of these and other asteroids is necessary to reduce their errors and draw correct conclusions about density.

Table 2. Masses of asteroids of the taxonomic class M

№	Name	N_{total}	N_{Gaia}	Mass, M_{Sun}	Diameter, km	Density, g/cm³
16	Psyche	36	23	$(1.187 \pm 0.009)\ 10^{-11}$	222 ± 4.00	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

SUMMARY

1. The obvious conclusion is that the using observations of FPR Gaia allows rising the accuracy of the obtained mass values. This is due both to an increase in the total number of observations and the greater accuracy and weight of these observations than the MPC. The contribution of Gaia observations is maximal, when these cover a close approach with the perturbing body.
2. We give preference to (Veres et al., 2017) weight model for the positional observations. Although the obtained mass values are close for both models of weights.
3. The obtained mass value of Psyche is in good agreement with results of other researches that used asteroid observations. The middle density of Psyche is near to 4 g/cm³, which corresponds to density of stony-iron meteorites. The hypothesis about homogeneity of asteroid structure is being disputable.
4. In addition to the mass of Psyche, the masses of sixteen asteroids of the taxonomic class M were obtained. The asteroids (441) and (739) have middle density near or more than iron density. The middle densities of asteroids (55) and (83) more far from density 5.32 g/cm³ that had been estimated for asteroids with the taxonomic class M. The future improvement of the masses and diameters of these and other asteroids is necessary to reduce their errors and obtain correct conclusion about their densities.
5. And another obvious conclusion: the problem of evaluation of asteroid densities is strong connected with large dispersion in evaluation of their volumes. The inflated values of volumes are produced to low values of density for asteroids of the taxonomic class M and vice versa. Therefore, the future refinement of asteroids sizes will assist in minimization of error in values of density.

ACKNOWLEDGEMENTS

This work has made use of data from the European Space Agency (ESA) mission Gaia https://www.cosmos.esa.int/gaia, processed by the Gaia Data Processing and Analysis Consortium https://www.cosmos.esa.int/web/gaia/dpac/consortium (DPAC). Funding for the DPAC has been provided by national institutions, in particular the institutions participating in the Gaia Multilateral Agreement.

This research has made use of data and/or services provided by the International Astronomical Union's Minor Planet Center http://www.minorplanetcenter.net/iau/mpc.html.

REFERENCES

1. Shepard, M. K., Richardson, J., Taylor, P. A., et al. 2017, Icarus, v. 281, p. 388.
2. Viikinkoski, M., Vernazza, P., Hanuš, J., le Coroller, H., Tazhenova, K., Carry, B., et al. 2018, Astronomy & Astrophysics, v. 619, L3.
3. Johnson, B. C., Sori, M. M., Evans, A. J., et al. 2020, A. J., NatAs, v. 4, p. 41.
4. Tholen, D. J., 1989, "Asteroid taxonomic classifications", Asteroids II. Tucson: University of Arizona Press, pp. 1139–1150.
5. Carry, B., 2012, Planet. Space Sci., v. 73, p. 98.
6. Baer, J., Chesley, S. R., 2017, AJ., v. 154, p. 76.
7. Elkins-Tanton, L. T., et al. 2020, Journal of Geophysical Research: Planets, v. 125 (3), p. 23.
8. Fienga, A., Avdellidou, Ch., Hanuš, J., 2020, Monthly Notices of the Royal Astronomical Society, v. 492 (1), pp. 589–602.
9. Pitjeva, E., Pavlov, D., Aksim, D., Kan, M., 2021, in Proceedings IAU Symposium, v. 364, pp. 220–225 https://iaaras.ru/en/dept/ephemeris/epm/2021/.
10. Park, R. S., Folkner, W. M.,Williams, J. G., Boggs, D.H., 2021, The Astronomical Journal, v. 161, p. 105.
11. Vernazza, P., Ferrais, M., Jorda, L., et al. 2021, A&A, v. 654, pp. A56.
12. Siltala, L., Granvik, M., 2021, ApJ, v. 909, pp. L14.
13. Vereš, P., Farnocchia, D., Chesley, S. R., Chamberlin, A., 2017, Icarus, v. 296 (1), pp. 139–149.
14. Krasinsky, G. A., Pitjeva, E. V., Vasilyev, M. V., Yagudina, E. I., 2002, Icarus, v. 158, pp. 98–105.
15. EMP, 2017, Ephemerides of Minor Planets for 2018, IAA RAS, p. 20.

ВАК 2024 MODERN ASTRONOMY: FROM THE EARLY UNIVERSE TO EXOPLANETS AND BLACK HOLES

300 years Russian Academy of Sciences

ВАК – 2024
25 – 31 августа
Нижний Архыз