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Motion of the asteroid (13206) 1997GC22 and the mass of (16) Psyche

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Abstract. From the perturbing effects of the asteroid (16) Psyche on the motion of the asteroid (13206) 1997GC22 the mass of (16) Psyche is determined. A close approach between these two asteroids at 0.00376 AU, and at a relative velocity of 0.74 km s^{-1}, occured in July 1974. The value of (3.38 ± 0.28) 10^{-11} $M_{\odot}$ has been found for the mass of (16) Psyche, which yields a density of (6.98 ± 0.58) g cm^{-3}. These values are very different from those obtained by other authors, but the mass is much closer to the value based on the IRAS estimation of (16) Psyche diameter and its M-type taxonomical classification.

Key words. celestial mechanics – minor planets, asteroids – methods: numerical

1. Introduction

It is well known that the gravitational influences of the large main–belt asteroids in the motions of both other asteroids and some major planets, can not be neglected. The achieved accuracy in the measuring of the positions of the solar system bodies requires including of large asteroids as perturbing bodies in the dynamical model of the solar system. Thus, in the construction of DE403 (Standish 1995) and DE405 (Standish 1998) ephemerides, 300 asteroids were included, with the masses determined by different methods.

Since the first successful attempt (Hertz 1966) to determine an asteroid mass by the most frequently used dynamical method, the masses of nearly 30 asteroids have been estimated in the same way. Summary of almost all estimations of asteroid masses until 2001 is given by Krasinsky et al. (2001). Generally, the asteroids with mass determined by dynamical method belong to C or S types, with the exception of (16) Psyche, which has been classified as M type asteroid.

The first determination of the mass of (16) Psyche, based on close encounter with asteroid (94) Aurora, was made by Viateau (2000). In this case, the values of $(8.7 \pm 2.6) \times 10^{-12}$ $M_{\odot}$ for the mass and (1.8 ± 0.6) g cm^{-3} for the density were calculated. However, Krasinsky et al. (2001), from close encounters with three asteroids ((263) Dresda, (2819) Ensor, (2589) Daniel), found a weighted mean value of (1.27 ± 0.18) × 10^{-10} $M_{\odot}$. These results are very different with respect to the mass based on the IRAS data. Using the mean diameter of Psyche given by IRAS (264 ± 4) km and the mean density of 5.3 g cm^{-3} for an asteroid of M-type (Standish 2000; Krasinsky et al. 2001), one gets an estimated value of 2.5×10^{-11} $M_{\odot}$.

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2. Procedure of mass determination

In a list of asteroid close encounters we compiled, we have found the close encounter which occured between asteroid (16) Psyche and asteroid (13206) 1997GC22. These two asteroids approached each other on July 17, 1974, at the minimum distance of 0.00376 AU. The relative velocity at that moment was 0.74 km s^{-1}, while the angle of deflection of the perturbed asteroid was 5.3 arcsec. These kinematical parameters revealed that this close encounter should be suitable for mass determination of (16) Psyche. For the analysis of the motion of (13206) 1997GC22 we used the observational data, as well as initial orbital elements, which can be found at the public database AstDys (see http://hamilton.dm.unipi.it/astdys).

There are 127 available observations which cover the time span 1960–2002, but with an uneven distribution. Thus, 123 postencounter observations cover the time span 1995–2002, while only four preencounter positions of the perturbed body were observed in 1960, during a very short 9-day interval. During the process of calculation of the perturbed orbit, only two of postencounter observations were discarded. Both coordinates (right ascension and declination) were discarded if one of them gave a residual above 3σ. Calculated RMS of orbital residuals is 0.69 arcsec.

The numerical integration of the differential equations of motion is carried out by Addams-Bashforth-Moulton

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Table 1. Masses of perturbing asteroids included in the dynamical model.

Asteroid	Mass $10^{-10}\ M_{\odot}$
(1) Ceres	4.76
(2) Pallas	1.08
(4) Vesta	1.35
(10) Hygiea	0.47

predictor-corrector method, implemented by Moshier (1992). In the dynamical model we have included all major planets plus four largest asteroids (their masses as used are given in Table 1), as well as (16) Psyche as a perturbing body.

Bearing in mind that some other asteroids could perturb the motion of (13206) 1997GC22 during the interval of time considered, the close encounters between this asteroid and all asteroids larger than 200 km in diameter were searched. Also, gravitational effects of these asteroids on motion of (13206) 1997GC22 were analysed. It was found that only perturbing effects of (1) Ceres were 2.4 arcsec in right ascension and 0.6 arcsec in declination, as a result of two close encounters: in 1964 (at distance of 0.188 AU) and 1975 (at 0.067 AU). Perturbing effects of all other asteroids were found to be negligible.

The mass determination of (16) Psyche was performed by means of the classical least-squares method, widely used by many authors. According to this method, as it is well known, correction ΔM of the mass of the perturbing asteroid is computed along with the corrections $\Delta E = (\Delta E_1, ..., \Delta E_6)$ of six osculating elements of the perturbed asteroid. These corrections are solutions of the system of linear equations:

$$P\Delta E + Q\Delta M = R\,, \qquad (1)$$

where P is the matrix depending on the partial derivatives $\frac{\partial c_i}{\partial E_k}$ of the coordinates c_i (right ascensions and declinations) of the perturbed asteroid with respect to osculating elements $E = (E_1, ..., E_6)$, Q is the matrix depending on the partial derivatives $\frac{\partial c_i}{\partial M}$ of the coordinates of the perturbed body with respect to the perturbing mass M, and R is the matrix depending on (O–C) residuals in coordinates of the perturbed body. Elements of matrices P, Q and R have to be computed for each epoch of observation. This technique, applied when Keplerian orbital elements are used, gives a correlation matrix with a very strong correlation between the mass of the perturbing body and the mean motion (or the semimajor axis) of the perturbed one (such that the absolute value is very close to 1). If initial position and velocity are used instead, correlation coefficients do not exhibit any undesired characteristic.

3. Results and discussion

Firstly, we have computed variations of the mutual distance between (16) Psyche and (13206) 1997GC22 for the period 1960–2002, covered by observations. During this period only one close encounter has occured, as can be seen in Fig. 1. Note that the distance changed very slowly around the epoch of the minimum, so that these asteroids were at a distance smaller than 0.01 AU from June 25 to August 7, 1974.

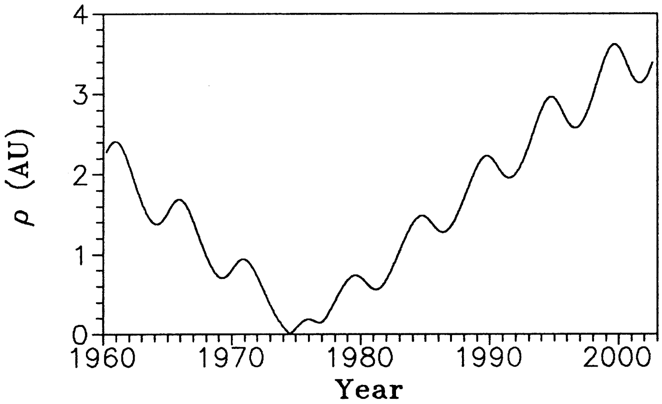

Fig. 1. Mutual distance between (16) Psyche and (13206) 1997GC22 from 1960 to 2002.

Table 2. Orbital elements of (16) Psyche and their standard deviations (in degrees), for the epoch JD 2437000.5.

Elements	Values	σ
M_0	300.508561	0.000149
ω	216.709926	0.000685
φ	5.571441	0.000013
i	2.020701	0.000014
Ω	164.051773	0.000661
n	0.205185900	0.000000043

Calculation of the mass of (16) Psyche was done by means of initial osculating elements of the perturbed asteroid for two epochs: JD 2452500.5 used for backward integration and JD 2437000.5 used for forward integration. In both cases, the numerical procedure has been initialized by an assumed value of $1.0\times10^{-11}\ M_{\odot}$ for the mass of (16) Psyche. Integrating backwards and using Eqs. (1), coefficients of ΔM (partial derivates $\frac{\partial c_i}{\partial M}$) at the moments of postencounter observations are practicaly 0, as well as the coefficients computed at the moments of preencounter observations in forward integration. Bearing in mind the number of preencounter (4) and postencounter (121) observations, different results were expected for the mass and its formal error. However, differences between obtained values were negligible.

The same method has been applied on both, the Keplerian orbital elements and the position and velocity vectors, for both above mentioned two initial epochs. Obtained values for mass and its formal error were identical.

The final values of orbital elements (mean anomaly M_0, argument of perihelion ω, angle of eccentricity φ, longitude of node Ω, inclination i and mean motion n) of asteroid (13206) 1997GC22 and their standard deviations derived for epoch JD 2437000.5 are given in Table 2. Some higher values of standard deviations of argument of perihelion ω and longitude of node Ω could perhaps be explained as a consequence of the afore mentioned unsuitable distribution of observations.

Table 3. Correlation coefficients for Keplerian orbital elements of (13206) 1997GC22 and mass of (16) Psyche.

	M_0	ω	φ	i	Ω	n	M_P
M_0	1.000	–0.250	0.079	–0.091	0.047	–0.775	–0.767
ω		1.000	–0.018	–0.232	–0.975	0.215	0.223
φ			1.000	–0.056	0.026	–0.477	–0.450
i				1.000	0.260	0.120	0.121
Ω					1.000	–0.060	–0.060
n						1.000	0.995
M_P							1.000

Table 4. Correlation coefficients for initial position and velocity of (13206) 1997GC22 and mass of (16) Psyche.

	x_0	y_0	z_0	$\dot{x}_0$	$\dot{y}_0$	$\dot{z}_0$	M_P
x_0	1.000	0.936	0.566	–0.970	0.939	0.720	0.069
y_0		1.000	0.415	–0.878	0.955	0.715	–0.106
z_0			1.000	–0.524	0.548	0.568	–0.077
$\dot{x}_0$				1.000	–0.926	–0.699	–0.152
$\dot{y}_0$					1.000	0.695	–0.124
$\dot{z}_0$						1.000	–0.201
M_P							1.000

Correlation coefficients between parameters are given in the Table 3 (using Keplerian orbital elements) and Table 4 (using initial position and velocity vectors).

The final value obtained for the mass of (16) Psyche is $(3.38\pm0.28)\times10^{-11}\,M_\odot$. Its mean density, based on IRAS diameter of 264 km, is thus (6.98 ± 0.58) g cm^{-3}. As can be seen, the value obtained in this work is much closer to the one estimated from the taxonomic type and IRAS data,than those previously available.

This result should be quite reliable, because the perturbing effects of (16) Psyche on the motion of asteroid (13206) 1997GC22 were very large. The differences in right ascensions and declinations, as inferred from the two forward integrations, with and without (16) Psyche in the dynamical model, can be as large 47 arcsec in right ascension (shown in Fig. 2), and 12 arcsec in declination (shown in Fig. 3).

In this sense, very different results for the mass of (16) Psyche, found by Viateau (2000) and Krasinsky et al. (2001), could be explained by the small corresponding effects on motions of perturbed asteroids used in their determinations.

4. Conclusion

The values for the mass $(3.38\pm0.28)\times10^{-11}\,M_\odot$ and density of (16) Psyche (6.98 ± 0.58) g cm^{-3} obtained from the close encounter used in this analysis is the first successfull attempt based on a dynamical method, leading to the conclusion that composition of an asteroid is metallic. The mass of Psyche $(2.5\pm0.1)\times10^{-11}\,M_\odot$ based on its taxonomic type is about 26% smaller. For still better determination of the mass and density of (16) Psyche from this close approach one needs new observations at more oppositions and more precise determination of the orbit of the asteroid (13206) 1997GC22. Of course, one can expect that other asteroid close encounters with (16) Psyche will become available in the future.

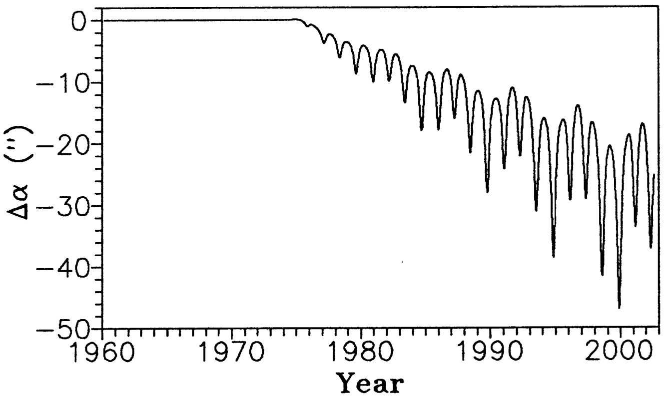

Fig. 2. Differences of the geocentric right ascensions of the perturbed body (13206) 1997GC22, taking into account the gravitational effects of the perturbing body (16) Psyche.

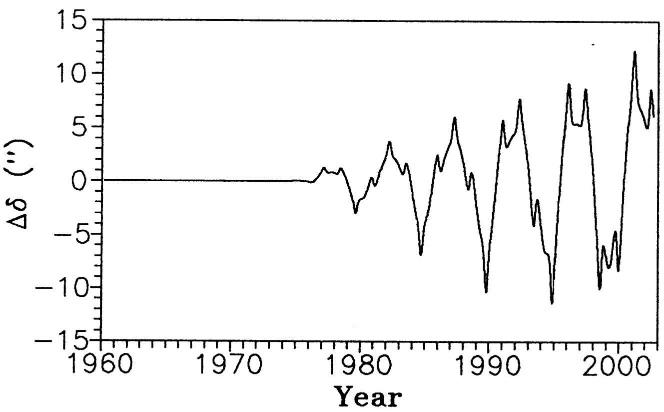

Fig. 3. Same as Fig. 2, but for declinations.

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