IMPROVEMENT OF THE ORBITS OF ASTEROIDS AND THE MASS OF (1) CERES

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ABSTRACT

We present the results of work concerning the exploitation of the observations of asteroids made by Hipparcos, in addition to ground-based observations, to determine the mass of (1) Ceres from its perturbations on the orbits of 4 asteroids. The value obtained, $(4.785 \pm 0.039)\ 10^{-10} M_\odot$, is in good agreement with most recent results obtained by other authors and shows that the value of the mass of Ceres recommended by the IAU should be decreased. A second work in progress, concerning the improvement of the orbital data of all the asteroids observed by Hipparcos, is also presented. We show that the addition of the Hipparcos data to the ground-based observations leads to a high improvement of the accuracy of the orbital elements of these asteroids, mostly for the inclination and the longitude of the node.

Key words: minor planets: (1) Ceres; masses; ephemerides.

1. INTRODUCTION

48 minor planets were observed by Hipparcos from 1989 to 1993. The data obtained have very good accuracy (about 0.01 arcsec), and their use presents a great interest for many applications, in particular for the improvement of the accuracy of the orbital data of these asteroids. Another application is the determination of the masses of large asteroids which have induced gravitational perturbations on the orbits of the 48 asteroids observed by Hipparcos. For both applications, since the time interval spanned by the Hipparcos data is relatively short, these data have in most cases to be used in addition to ground-based data of the studied minor planets.

2. DETERMINATION OF THE MASS OF (1) CERES

2.1. Current Situation of Mass Determinations

Large asteroids induce non-negligable and, sometimes, strong gravitational perturbations on the orbits of a great number of solar system objects (main belt asteroids, planets). For example, the recent ephemerides DE403 from Jet Propulsion Laboratory (USA) takes into account the gravitational perturbations of 300 minor planets, with estimates of their masses (Standish et al. 1995).

The masses of large asteroids are rather poorly known. About ten masses only have been determined, and, in most cases, with low accuracy. Ceres is the biggest of all asteroids. Its mass is about 50 per cent of the total mass of the main asteroid belt. For this reason, a very good knowledge of this mass is necessary. It is not currently the case, although many attempts have been made since the last 30 years to determine this mass. For our part, we are involved in the determination of the mass of Ceres for a few years, and we have published three preceding determinations of this mass (Viateau & Rapaport 1994, 1995, Viateau 1995).

2.2. Method

Before 1992, all the determinations of the masses of asteroids used their gravitational perturbations on the orbit of only one asteroid. In this case, the correlations between the mass of the perturbing asteroid and the orbital elements of the perturbed asteroid can induce a bias on the value obtained for the mass of the perturbing asteroid.

There are 2 main solutions to reduce this bias:

(1) the first solution is to use several asteroids perturbed by Ceres. In this case, the correlations between the parameters are smaller, and the individual bias are averaged. To our knowledge, the first authors who used this method are Sitarski & Todorovic-Juchniewicz (1992).

(2) The second solution is to improve the accuracy of the orbital data of the perturbed asteroids, because the accuracy of the value found for the mass is linked with the quality of the orbit determined for the perturbed object. The observations made by Hipparcos are very useful for this, because their use can strongly improve the orbital data of the perturbed asteroids.

We applied these two solutions: we made separate determinations of the mass of Ceres from its perturbations on the orbits of 4 asteroids strongly perturbed by Ceres in the past: (2) Pallas, (203) Pompeja, (324) Bamberga and (348) May. Then, we calculated the

Table 1. Values of the mass of Ceres obtained with each of the 4 perturbed asteroids.

Perturbed asteroid	Mass ($10^{-10} M_\odot$)	
(2) Pallas	5.121	± 0.090
(203) Pompeja	4.655	± 0.049
(324) Bamberga	4.845	± 0.120
(348) May	4.952	± 0.144

weighted mean of the values obtained for the mass of Ceres. We used a great number of ground-based observations of the perturbed asteroids. Among them, Pallas and Bamberga were observed by Hipparcos. Thus, we added the Hipparcos data of these 2 asteroids. All the observations were given weights corresponding to their estimated accuracy. Since the effect of the perturbation of Ceres grows with time, the observations used span a very long time interval, from the epoch of the discovery of the minor planets to the current epoch. The integration of the motion of the 4 studied minor planets took into account, as a standard procedure, the perturbations of 7 large asteroids, which are (2) Pallas, (4) Vesta, (10) Hygiea, (11) Parthenope, (52) Europa and (704) Interamnia, with masses taken from literature when possible, or deduced from their mean diameter and an estimation of their mean density, if not, as made and detailed in Viateau & Rapaport (1997).

2.3. Result

Table 1 gives the values of the mass of Ceres obtained with each of the 4 perturbed asteroids. The weighted mean of these values gives the result $(4.785 \pm 0.039)\ 10^{-10} M_\odot$, with a standard deviation which is smaller than the one of all other determinations of the mass of Ceres made until now (see Table 2). Then, the most important result of this work is to show, in agreement with the majority of other authors, that the value of the mass of Ceres recommended by the International Astronomical Union, which is $5.0\ 10^{-10} M_\odot$, is certainly too high by about 5 per cent. This fall has non-negligable consequences on the calculation of the orbits of Mars and of many asteroids.

2.4. Perspectives

This result can yet be improved. Several other asteroids are good candidates to determine the mass of Ceres: (4) Vesta, (5) Astrea, (32) Pomona, (91) Aegina, (534) Nassovia, ... At least 2 of them ((4) Vesta and (5) Astrea) were observed by Hipparcos. We plan soon to test the introduction of these objects in our determination.

Moreover, these asteroids and the four ones we used are included since 1995 in an observing programme by the CCD meridian circles of Bordeaux (France) and Sao Paulo (Brazil), as part of a collaboration between the two observatories (see also Réquième et al. 1997). The observations made, especially in the case of (348) May, are expected to contribute strongly to a better knowledge of the mass of Ceres.

3. MINOR PLANETS ORBITS IMPROVEMENT

The Hipparcos data can also be used to improve the orbits of the 48 asteroids observed by Hipparcos. We have begun a collaboration on this subject with Daniel Hestroffer (ESA-ESTEC). The aim of this work is to improve the orbital elements of these asteroids using the observations made by Hipparcos in addition to all the available ground-based observations of these asteroids.

3.1. Asteroid (2) Pallas

We will consider the case of (2) Pallas. The observations made by Hipparcos enable us to see what is the accuracy of the orbits determined using only ground-based data.

Two years ago, we published new orbital elements of Pallas, determined using only ground-based observations (Viateau & Rapaport 1995). At the same time, other orbital elements of Pallas were published in the *Ephemerides of Minor Planets for 1996* (Batrakov 1995), which is the publication in which all the orbits of asteroids are given each year. It is interesting to compare the accuracy of the two orbits.

The Hipparcos data give only one coordinate, which is named λ, and which is the abscissa of the projected position of the asteroid on a reference great circle. Figures 1 and 2 represent the residuals $\lambda_o - \lambda_c$ obtained with each of the two orbits. The dispersion of the residuals corresponds to the precision of the calculated orbit of Pallas, and not to the precision of the observations, which is about 0.01 arcsec. These graphs show that our orbit has good precision, about 0.06 arcsec, while the precision of the orbit of Pallas currently given in the *Ephemerides of Minor Planets* is about 0.14 arcsec.

We will show in Section 3.2 that the use of the observations of Pallas made by Hipparcos can yet improve strongly our orbital elements of this asteroid.

3.2. Effect of the Hipparcos Data on the Orbits of Pallas and Bamberga

In the work presented in Section 2 concerning the determination of the mass of Ceres, we determined at the same time new orbital elements for Pallas and Bamberga.

Table 3 shows the ratio:

$$\frac{\sigma_p \text{ (using ground} - \text{based data)}}{\sigma_p \text{ (using ground} - \text{based} + \text{Hipparcos data)}}$$

where σ_p is the standard deviation obtained on each orbital element p of Pallas and Bamberga.

We can see that for most elements, the standard deviations are divided at least by 2. The greatest

Table 2. The current status of Ceres mass determination.

Mass (10^{-10} M$\odot$)		perturbed bodies	Author
6.7	± 0.4	(2) Pallas	Schubart (1970)
5.1		(4) Vesta	Schubart (1971)
5.9	± 0.3	(2) Pallas	Schubart (1974)
4.99	± 0.09	"	Landgraf (1984)
5.0		"	Goffin (1985)
5.21	± 0.3	"	Landgraf (1988)
5.0	± 0.2	Mars	Standish & Hellings (1989)
4.9	± 0.15	(2) Pallas	Schubart (1991)
4.7	± 0.3	(203) Pompeja	Goffin (1991)
4.796	± 0.085	(203) & (348)	Sitarski & Todorovic-Juchniewicz (1992)
4.80	± 0.22	(348) May	Williams (1992)
5.1	± 0.2	(2) Pallas	Viateau & Rapaport (1994)
4.85	± 0.06	6 asteroids	Bowell et al. (1994)
4.92	± 0.07	4 asteroids	Muinonen et al. (1994)
5.0	± 0.2	(2) Pallas	Viateau & Rapaport (1995)
4.67	± 0.09	5 asteroids	Carpino & Knezevic (1995)
4.88	± 0.45	(4) Vesta	Hilton et al. (1995)
4.26	± 0.09	5 asteroids	Kuzmanoski (1995)
4.64		DE403 solution	Standish et al. (1995)
4.78	± 0.06	(2) & (203)	Viateau (1995)
4.71	± 0.05	7 asteroids	Carpino & Knezevic (1996)
4.785	± 0.039	4 asteroids	this work

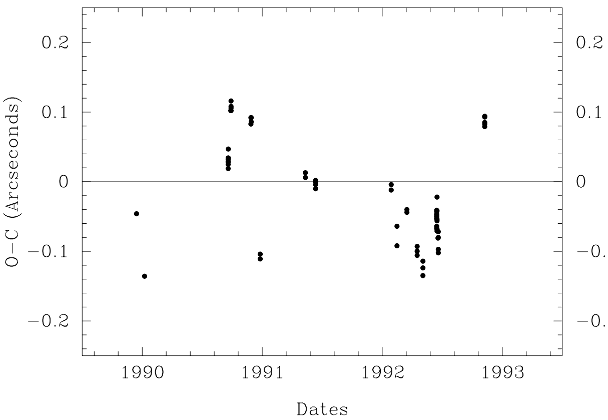

Figure 1. Residuals in $\lambda_o - \lambda_c$ of the Hipparcos data of Pallas with the orbital elements published in the Ephemerides of Minor Planets for 1996.

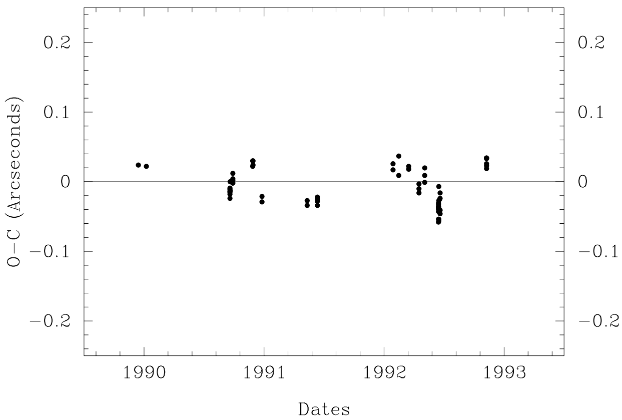

Figure 2. Residuals in $\lambda_o - \lambda_c$ of the Hipparcos data of Pallas with the orbital elements published in Viateau & Rapaport (1995).

improvement is obtained for the inclination and the node of the orbit, which are determined with very good accuracy by the Hipparcos observations.

We hope to have similar results when we will determine the orbital elements of all the asteroids observed by Hipparcos.

Table 3. Improvement factor of the standard deviations of the orbital elements of Pallas and Bamberga obtained with the Hipparcos data.

	a	e	i	Ω	ω	M
(2) Pallas	1.12	1.7	4.7	2.2	3.2	3.5
(324) Bamberga	1.13	2.5	6.4	4.7	3.1	2.5

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