A DETERMINATION OF THE MASS OF (704) INTERAMNIA FROM OBSERVATIONS OF (993) MOULTONA

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Abstract. On 1973 November 23, there was a close approach ($0.013 AU$) between (704) Interamnia as the fifth largest minor planet, and (993) Moultona. It was made an attempt to determine the mass of Interamnia from its perturbations on the motion of Moultona, using 82 right ascensions, 72 declinations, and of 1 observation the portion normal to the apparent motion, from altogether 95 observations from 22 oppositions 1923 January to 1991 February with a mean error of 0."51. For the mass of Interamnia was obtained a result of $0.37 \pm 0.17 \cdot 10^{-10}$ solar masses. Although its uncertainty, this result gives an independent information about the mass of Interamnia besides the estimation from the diameter and the suspected density, considering the uncertainty of these parameters.

Key words: Minor Planets, Mass Determination, Masses of Minor Planets, Astronomical Constants

The masses of the principal planets are nowadays known with high precision, but considering the minor planets, the situation is much worse. Minor planets have no observable satellites and their perturbations on the motion of other objects usually are not detectable. Currently, only for the four largest minor planets, Ceres, Pallas, Vesta and Hygiea, have been obtained results for their masses from their gravitational attraction (table 1). The masses of the asteroids can be determined from their mutual perturbations. There exist resonances in cases of perturbations by the largest asteroids, but in general we have occasional close encounters, which lead to erratic changes in the orbits of minor planets and which can be used to calculate the mass of the perturbing asteroid. However, there are not many possibilities of further mass determinations. In all the cases of close encounters found by M.Hoffmann (1988), only the computation of the mass of Hispania from observations of Olbersia let expect significant results during the next decade; already in the second favorable case, the formal mean error of the result for the mass of Elisabetha calculated from the currently available observations of Euphemia, is one magnitude larger than the expected mass.

The fifth largest minor planet, Interamnia, had a close encounter with Moultona in November 1973. This encounter, whose characteristics are given in table 2, produced perturbations of about 0."5 until the end of the century, and thus makes possible to calculate the mass of Interamnia. An earlier investigation using observations until 1982 did not gave a significant result but indicated that after more observations, during ten years, this would become possible.

1. The observations

Since the discovery of Moultona in 1923, 110 observations from 22 oppositions have been published. They are all photographic. Some of them, which originally have been published only approximately, were remeasured for this work and its continuation. The observation from 1928 was remeasured by L.Kohoutek, those from 1931, 1960 and 1964 were remeasured by E.Bowell, the two last observations from 1943 by T.Lehmann and the last one from 1977 by A.J.Noymer.

S. Ferraz-Mello (ed.), Chaos, Resonance and Collective Dynamical Phenomena in the Solar System, 179–182.

Table I
The current status of direct mass determinations of minor planets.

object	mass m.e. (in 10^{-10})		perturbed object	observations	author
Ceres	6.7	± 0.2	Pallas	1803-1968	Schubart (1970)
	5.9	± 0.15	"	1802-1970	Schubart (1974)
	4.99	± 0.09	"	1802-1983	Landgraf (1984)
	5.0		"	1802-1983	Goffin (1985)
	5.21	± 0.07	"	1802-1987	Landgraf (1988)
	4.9		"	1802-1989	Schubart (1991)
	5.1		Vesta		Schubart (1972)
	4.74	± 0.04	Pompeja	1879-1990	Goffin (1991)
	5.0	± 0.07	Mars		Standish,Hellings (1989)
Pallas	1.3	± 0.2	Ceres	1802-1970	Schubart (1974)
	1.14	± 0.11	"	1801-1970	Schubart (1975)
	1.08	± 0.11	"		Schubart (1979)
	1.4	± 0.07	Mars		Standish,Hellings (1989)
Vesta	1.17	± 0.10	Arete	1879-1962	Hertz (1966)
	1.20	± 0.12	"	1879-1962	Hertz (1968)
	1.38	± 0.06	"		Schubart (1979)
	1.33		"		Goffin (1991)
	1.5	± 0.08	Mars		Standish,Hellings (1989)
Hygiea	0.47	± 0.23	Academia	1914-1978	Scholl *et al.* (1987)
	0.21	± 0.13	"		Goffin (1991)
Interamnia	0.32	± 0.20	Moultona	1923-1991	presented at the meeting
	0.37	± 0.17	"	1923-1991	this paper
Hispania	0.05	± 0.04	Olbersia	1933-1991	

Table II
Encounter between Interamnia and Moultona.

Encounter conditions are given in ecliptical coordinates. The perturbations are referred to an assumed mass of $0.3 10^{-10}$.

t	1973 Nov. 23.41 ET		r	2.96	AU	$d\mu$	-1"62	/century
Δ	0.01313AU	Δ/Δ_{Tiss} 71.85	v	+5.70	km/s	$d\phi$	-0"003	
Δ_x	-0.0012 AU		v_x	-0.96	km/s	$d\pi$	-0"202	
Δ_y	-0.0122 AU		v_y	+2.15	km/s	$d\Omega$	-0"079	
Δ_z	+0.0048 AU		v_z	+5.19	km/s	di	-0"000	

2. Basic assumptions and details of the calculations

The basic assumptions and details of the calculations are almost the same as explained on the author's earlier publication (1988). The motion of the two asteroids and the partials for the equations of conditions for the improvement of the orbital elements of Moultona and the mass of Interamnia were integrated with a step size of 2.4 days. The positions of Mercury to Neptune were read from a file generated by

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using the theory by the ITA, Leningrad, but rotated to the dynamical equinox; this agrees very close with the FK_5 system. The integration of the motion of Moultona was started with the elements obtained during the earlier investigation (*MPC* 8137) which are already referred to the FK_5 system. The elements for Interamnia, taken from the *EMP*, were corrected by 0."8 in mean anomaly in order to have a better representation of the encounter in the FK_5 system.

The observations of 1923 have been reduced to the FK_4 system; after this, all observations were transformed to the FK_5 system. Observations with more than approximately 1."2(2μ) and 1."8(3μ) residuals have been weighted down ($p = 0.4$) or eliminated, respectively. For this, it was considered the residual referred to the neighbouring observations, if there were no obvious systematic errors. The weight was changed one class lower, or the coordinate was eliminated, if the residual of the other coordinate exceeded 2."4(4μ) or 5", respectively, in order to exclude correlated errors, time errors, measured plate grain, etc. An exception was the last declination of the discovery opposition (the right ascension has an error of 1'); it is likely that the asteroid was measured and since a time error would affect only minutely the declination, it was used. The observations from La Silla and Cerro Tololo from 1989 are of very good quality and thus have got the weight 4; those from Nauchnij and Nanking are apparently of lower quality and thus received 0.4 as maximal weight. The observations from Klet, from 1987, and the right ascensions from Mt.Palomar, from 1986, were completely excluded because of their systematic errors. Because of the known error of the Lowell and Mt.Palomar declinations, these have got lower weight or were omitted. For the two last observations of 1943, the observation times are uncertain. Because of this, the equations of conditions and the residuals have been transformed to the coordinates normal and parallel to the topocentric motion, and the part along the motion was omitted from the second observation. Of the 95 observations, weights of $\geq 1/0.4$ were attributed to 54/28 right ascensions and 29/42 declinations. The result presented at the meeting (table 1) was based on 46/20 right ascensions and 34/21 declinations from 88 observations (still without those of 1928,1987,1988 and some of 1991).

3. Results and conclusions

The results are given in table 3. The result for the mass of Interamnia, $0.37 \pm 0.17 \cdot 10^{-10}$, is formally only of little significance. From experience we know that, after a sufficient discussion of the weights attributed to the observations, the parameters calculated from astrometric observations, in almost all cases, are better than 2μ. Thus, the result means that the mass of Interamnia is very probably less than $0.7 \cdot 10^{-10}$. From photometry, we can guess the diameter of Interamnia to be 338 km (E.Bowell 1979). If we assume an uncertainty of 15% for this, and a density between 2.2 to 3.5, then we can expect a mass of $0.15..0.55 \cdot 10^{-10}$. Our direct mass determination, although their little significance, is in good agreement with this estimation; however, it is an independent result of approximately the same weight, and a confirmation using a totally different method, which after a few years more of observations of Moultona let expect more significant results.

Table III

Improved orbital elements of Moultona and mass of Interamnia

Given are the osculating elements referred to standard Schwarzschild coordinates in the FK_5 system, and the correlation coefficients between them and the mass of Interamnia.

Epoch	2448200.5000 = 1990 Nov 5.0 TDB			(B1950)		
M	35.3546704	± 0.0002342	P	.275470602	Q	-.961307130
a	2.862974981	± 0.000000052		.893101164		.256745260
e	0.04848397	± 0.00000014		.355649065		.099852260
ω	183.9561357	± 0.0004318				
i	1.7716905	± 0.0000206				
Ω	250.0556512	± 0.0004892				
	$m_I = 0.374 \pm 0.174 \cdot 10^{-10}$					

	(M)	(a)	(e)	(ω)	(Ω)	(i)	(m_I)
(M)	1.000000	.211072	.189389	-.472958	-.038193	-.042682	.188448
(a)	.211072	1.000000	-.220104	-.117991	-.008320	-.007174	.956914
(e)	.189389	-.220104	1.000000	-.081317	.001210	.010441	-.156365
(ω)	-.472958	-.117991	-.081317	1.000000	-.861861	-.297462	-.103435
(Ω)	-.038193	-.008320	.001210	-.861861	1.000000	.362104	-.008351
(i)	-.042682	-.007174	.010441	-.297462	.362104	1.000000	.006490
(m_I)	.188448	.956914	-.156365	-.103435	-.008351	.006490	1.000000

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