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Masses of asteroids 10 Hygiea and 152 Atala obtained by the dynamical method

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The masses of asteroids 10 Hygiea, 152 Atala were determined using observations of perturbed asteroids (PA) starting from 1900. PA were considered as test particles. Calculations were fulfilled using two independent programs (A and B), however models of motion and the observations were the same. PA were selected in accordance with the error of the mass value of perturbing asteroids found from perturbations of only one test particle. Gravitational perturbations from all major planets and Pluto were taken into account in the equations of motion of the asteroids. The coordinates of the perturbing bodies were calculated using DE405. Relativistic perturbations from the Sun and perturbations from Ceres, Pallas, Vesta (CPV), or from 307 asteroids were also included into the model. The erroneous observations were excluded in accordance with the criterion 3σ (program A) or by application of the robust regression (program B). The final mass values were obtained by common solution using observations of all selected PA for each perturbing asteroids. The LSM was used to fit conditional equations. Two variants were considered: a) all observations were supposed to have equal weights and b) weight $1/\sqrt{2}$ was fixed for observations before 1950, whereas for all other observations the unit weight was fixed.

Table 1 gives the numbers of PA for 10 Hygiea (the first column) and values of its mass (the 4th and 5th columns) obtained when taking into account the perturbations from Ceres, Pallas and Vesta (CPV), apart from all other perturbations, or from 307 asteroids. Comparison of values in these columns shows the appreciable influence of the different sets of perturbing bodies on the mass values obtained from perturbations of some asteroids (20, 111, 1287, 1965, 13266). The estimations of contribution of Yarkovsky effect into the mass values of 10 Hygiea were obtained for some PA.

For asteroid 152 Atala mass value $(1.34 \pm 0.27) 10^{-11} M_{\text{Sun}}$ was obtained using observations of PA: 651, 250, 264. Taking into account its diameter (287 km) the mean density is equal to 2.8 g cm^{-3} .

Table 1. Mass values of asteroid 10 Hygiea (D = 429 km)

Number of PA	D (km)	σ_m ($10^{-11} M_{\text{Sun}}$)	Mass of Hygiea ($10^{-11} M_{\text{Sun}}$)	
			CPV	307 asteroids
3946	13.5	0.16	4.06	4.05
11215	8.5	0.26	4.28	4.42
113976	4.5	0.27	3.39	3.39
24433	10.3	0.38	3.26	3.28
6143	10.7	0.44	5.43	5.43
15187	6.5	0.54	3.25	3.52
20	151.0	0.54	3.08	1.32
48499	5.4	0.58	5.35	5.59
10380	6.5	0.68	5.26	5.31
13266	6.5	0.72	6.24	5.64
357	110.0	0.73	5.51	5.16
5941	9.8	0.76	6.37	6.52
111	139.0	0.77	7.05	9.44
382	60.6	0.77	2.58	2.61
1965	14.8	0.78	2.41	1.76
465	76.6	0.83	5.44	5.33
983	77.3	0.84	4.53	4.55
1780	31.7	0.87	3.58	3.46
4094	8.1	0.87	5.16	5.17
1287	27.0	0.94	7.47	8.65

Table 2 gives the mass of asteroid 10 Hygiea found from common solution in which the mass of Hygiea and corrections to the orbit elements of all used PA were determined. The mass of Hygiea is found to be close to $(4.0 \pm 0.1) 10^{-11} M_{\text{Sun}}$ (mean density is equal to 2.0 g cm^{-3}). This estimation is in agreement with other values in range $(2.5 \pm 0.4 - 5.01 \pm 0.41) 10^{-11} M_{\text{Sun}}$.

Table 2. The mass values of asteroid 10 Hygiea from common solutions

Mass of Hygiea (in $10^{-11} M_{\text{Sun}}$)	Number of PA used	Perturbations from:	Program	Weights of observations
4.17 ± 0.09	20	CPV	A	$1/\sqrt{2}; 1$
4.15 ± 0.10	16 (without 20, 111, 357, 1287 with D > 100 km)	307 asteroids	A	$1/\sqrt{2}; 1$
4.03 ± 0.10	8 ($\sigma_m < 0.6 \times 10^{-11}$)	307 asteroids	A	$1/\sqrt{2}; 1$
3.89 ± 0.34	20	CPV	B	1; 1
3.96 ± 0.26	20	CPV	B	$1/\sqrt{2}; 1$