THE RESULTS OF PHOTOGRAPHIC OBSERVATIONS OF GALILEAN SATELLITES WITH 26-INCH REFRACTOR AT PULKOVO.

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Abstract.

Photographic observations of the Galilean satellites of Jupiter have been made in Pulkovo with 26-inch refractor during two periods 1976-1981 and 1986-1993. The internal mean square errors of jovicentric coordinates and mutual distances is equal to 0.10 arcsec. The external errors are equal to 0.08 and 0.17 arcsec in AR and Decl. The systematic errors were analysed. The errors of the theory G-5 of J.E. Arlot do not exceed 0.1 arcsec.

Systematic observations of the Galilean satellites of Jupiter were carried out at Pulkovo using the 26-inch long-focus refractor in two periods: 1976-81 and 1986-93. 289 photographic plates with nearly 2500 exposures were obtained. Each plate contains two diurnal trails and ten images of Jupiter and its satellites. The high-contrast ORWO WO-3 plates were used. Exposure times of about 30-60 sec were chosen. No filters were used to reduce the planet brightness. The measurements were made with the help of a measuring machine Ascorecord. The scale-trail technique was used for astrometric reduction (Kisselev, 1989, Pascu, 1980).

In this paper, we consider the results of observations made in 1976-1981. The jovicentric coordinates of the satellites and their relative (mutual) coordinates were analysed by comparison with corresponding theoretical coordinates derived from the modern theory of Galilean satellites G-5, developed by J.E.Arlot (1982). The values (O-C) for jovicentric and mutual coordi-

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TABLE 1. The mean (O-C) and m.s.e. in jovicentric coordinates(arcseconds)

S/J	$(O-C)_x$	$(O-C)_y$	E_x	E_y	IE_x	IE_y	N
1	-0.029	-0.062	0.100	0.116	0.090	0.090	102
2	-0.021	-0.039	0.107	0.166	0.090	0.100	113
3	-0.029	-0.044	0.116	0.187	0.090	0.100	114
4	-0.012	0.000	0.149	0.229	0.100	0.110	92

TABLE 2. The mean (O-C) and m.s.e. in mutual coordinates (arcseconds)

S/S	$(O-C)_x$	$(O-C)_y$	E_x	E_y	N
1-2	-0.011	-0.026	0.075	0.131	95
1-3	+0.008	-0.014	0.074	0.121	93
1-4	-0.029	-0.081	0.087	0.192	73
2-3	+0.008	-0.012	0.076	0.188	102
2-4	-0.002	-0.041	0.098	0.164	82
3-4	-0.022	-0.035	0.088	0.224	81

nates of satellites were used for analysis of the precision of observations, theory of motion, the phase effect of Jupiter and orbital phase effect of satellites, the errors of scale and orientation and the remaining refraction effects.

1. The precision of observations.

The mean square error (m.s.e.) of one observation was calculated from the deviation of the observed and theoretical relative coordinates in the whole 6-years period. The mean square error of one observation and the mean values (O-C) are presented in tables 1 and 2. The internal errors do not exceed 0.1 arcsec, but the external errors reach 0.2 arcsec for the 3rd and 4th satellites in Y-coordinate and depend on the distances between the satellites (table 3). Table 3 shows that the scale-trail method provide a high precision of relative coordinates (0.05 arcsec) if the X-coordinates do not exceed 100 arcsec.

The m.s.e. in the relative coordinates of each satellite with respect to the "mean satellite" are 0.062 and 0.107 arcsec (in X and Y).

TABLE 3. The dependence of m.s.e. on X-coordinates (arcseconds)

X	E_x	E_y	N
O" - 20"	0.053	0.046	27
20 - 100"	0.050	0.049	118
100 - 1000"	0.083	0.170	425

2. The systematic errors of observations and reduction

The phase correction reduction model for Jupiter was computed on the basis of orthotropic law of light reflection with the coefficient 0.5 in X and Y-coordinates. This coefficient has been obtained by the analysis of the (O-C) near the satellite elongations.

The geometrical scale of 26-inch refractor was found to be 19.8078 ± 0.0006 arcsec/1 mm. Hence, the error of coordinates depending on the scale, for mutual distances up to 1000 arcsec, is not over 0.05 arcsec. This conclusion is confirmed by the high precision of coordinate X for all satellites in tables 1-2. The most considerable error in scale-trail method is the inaccuracy of orientation and effect of remaining refraction. These errors were investigated in detail using two trails on the photographs. The value of systematic orientation error in our case attained 0.018 degree leading to errors in relative Y-coordinate of about ± 0.22 arcsec for X-distances up to 600 arcsec (maximum for the 4^{th} satellite). Thus, the errors of Y-coordinate increase with the distances of X-coordinates. The analysis of observational errors depending on zenith distances, hour angles and seasons have demonstrated small influence of these conditions. The total effect does not exceed ± 0.1 arcsec.

3. The precision of the theory of motion of Galilean satellites

The (O-C) of the satellite positions in their jovicentric orbits made possible to estimate the precision of the theory of motion of the satellites. The distribution of (O-C) on the jovicentric longitudes does not show any systematic deviations for the 1^{st} and 2^{nd} satellites. There is a small trend in $(O\text{-}C)_y$ for the 3^{rd} satellite and appreciable wave in $(O\text{-}C)_x$ for the 4^{th} satellite with maximum amplitude 0.1arcsec near the conjunctions. This wave may be conditioned by the error of longitude of the 4^{th} satellite and also orbital phase effects of satellite. These two errors cannot be determined separately in this investigation. The error of longitude of the 4^{th} satellite may be obtained from the solution of the system of equations

$$V_xT + XM = (O - C)_x \tag{1}$$

where T is the unknown correction of longitude (the time argument), M is the unknown correction of scale, V_x is the X-velocity of the motion of the 4^{th} satellite. From (1) we have obtained:

$$T = 0.354 \pm 0.141 \text{ min}$$

$$M = 0.00005 \pm 0.00004 \tag{2}$$

$$E_o = \pm 0.146 \text{ arcsec}$$

Thus we may estimate the errors of theory of motion, because the other errors are known from our investigations:

$$E_{cx} = 0.082, \qquad E_{cy} = 0.132 \text{ arcsec.} \tag{3}$$

Thus the precision of the theory G-5, as derived by their comparison with the observations of 26-inch refractor, is close to 0.1 arcsec; in other words, its accuracy is within observational errors.

4. The determination of coordinates of Jupiter by the measurements of satellites and stars of FK5 catalogue.

A by-product of this work was the determination of the positions of Jupiter by the satellites and fundamental stars which were measured on the photographs with Galilean satellites. In this case, the images of the planets were not measured. The positions of the FK5 stars and theoretical distances of satellites to Jupiter and the method scale-trail were used. The precision of this technique is higher than usual photographic one. The error of one position of the planet is 0.15 arcsec. In conclusion, the results of this work may be used in future observations of satellites of planets with CCD and 26-inch refractor, this year, in Pulkovo. The author thanks Dr.N.I.Glebova (Institute of Theoretical Astronomy) for computing theoretical coordinates of Galilean Satellites.

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