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CATALOGUE OF ASTROMETRIC POSITIONS OF JUPITER`S OUTER SATELLITES ON PHOTOGRAPHIC OBSERVATIONS IN MAO NAS OF UKRAINE IN 1987-1993

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ABSTRACT. The catalog of 33 topocentric positions of Jupiter's moons J6, J7, J8 has been created on photographic observations made in MAO NASU in 1987-1993. Positions are referred to the system of TYCHO-2 using the program package LINUX/MIDAS/ROMAFOT. The comparison of observed positions was made online with their theoretical data of IMCCE (www.imcce.fr/sat).

Key words: catalogues – planets and satellites; Jupiter; positional astrometry.

1. Introduction

Outer satellites of Jupiter J6 (Himalia), J7 (Elara) и J8 (Pasiphae) were discovered at the beginning of the XX century. They make a compact group of small moons with dimensions of several kilometers. Himalia, the largest of them has 170 km in diameter.

Outer moons rotate along highly elongated elliptical orbits at considerable angles to the equatorial plane of Jupiter. Some of them orbit Jupiter in the same direction (J7). The other part moves in the opposite direction, and such satellites are called retrograde. They are J6 and J8.

Because of the small dimensions, the outer satellites can only be observed with the help of large aperture telescopes. In addition, observations should be made in the most favorable periods of visibility. For photographic observations, the most favorable conditions emerged in 1986-1989. In these years, the maximum magnitude was expected for faint satellites, J6 ~ 14.6^m, J7~ 16.5^m, and J8 ~ 17.1^m.

The first photographic observations of outer moons of the Jupiter started in MAO NAS of Ukraine in September 1987 with double wide-angle astrograph (DWA).

Telescope parameters allowed us to obtain the images of most bright satellite only, J6 (Himalia). To observe J7 (Elara) and J8 (Pasiphae), more powerful telescopes are required with better resolution and more suitable location, remote from large settlements. These requirements were met by the telescopes of the southern observatories of Uzbekistan. They are the Zeiss double astrograph DAZ of Kitab latitude station and Zeiss reflector Z600 on the Mount Maidanak. Their technical parameters see in Table 1.

At these telescopes in 1987-1989, 4 series of observations were performed. After the processing of observations using the classical method, the catalog of 28 topocentric positions of three faint moons J6,J7,J8 was obtained. Positions were referred to the system of PPM (1950.0) (Izhakevich et al., 1991;1994).

The comparison of calculated positions with their ephemeris data was made by astronomers of Tomsk university L.E.Bykova and V.F.Jurga (Bordovytsina et al.,1978). The internal accuracy of the reduction estimated as unit weight RMS error was 0.44″ for DWA and 0.34″ for DAZ on both coordinates. For Z600 this value was 0.24″ to 0.34″ on right ascension and 0.15″ to 0.28″ on declination.

2. Observations

In the framework of Ukrainian virtual observatory project (UkrVO, JDA – Joint Digital Archive) (Vavilova, 2012a; Vavilova, 2012b; Vavilova, 2016, Vavilova, 2017) it was found expedient to make a revision of MAO NASU plate collection in its part containing the Solar System (SS) bodies observations. The main goal was to find plates never processed or with SS objects' images on the stellar fields of other observational programs. The objects of the most interest were the Jupiter moons. We found several plates of FON project made on DWA and thus extended the existing observational series to 1993,(see Fig. 1). The total number of plates involved into the processing is 33.

Table 1. The some parameters of telescopes

TELESCOPE, (Marsden's list):	DWA (083)	DAZ (186)	Z600 (188)
SPESIFICATIONS:			
Lens diameter (m)	0.4	0.4	
Diameter mirror (m)			0.6
Focal length (m)	2.0	3.0	7.5
Field of view (degr.)	8.5 x 8.5	5.5 x 5.5	0.5 x 0.5
Plate size (cm)	30 x 30	30 x 30	9 x 9
Scale value (arcsec/cm)	103. 3	68. 8	27. 5
Scale value (arcsec/px)	2.47	1.45	0.57

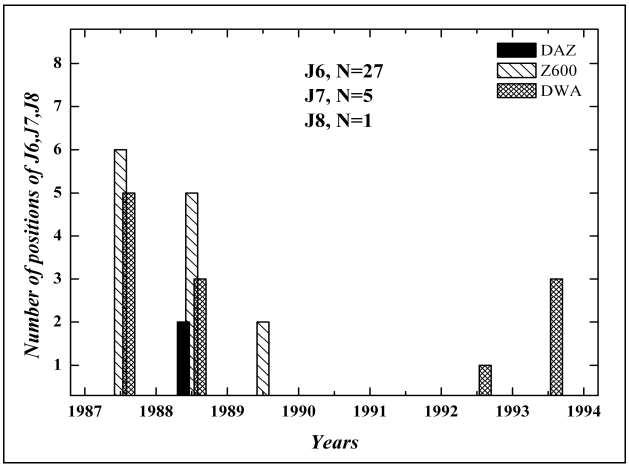

Figure 1: The distribution of J6, J7, J8 observations by years.

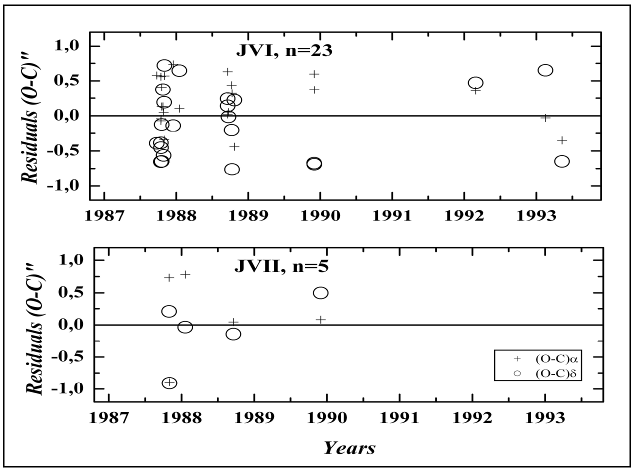

Figure 2: The dispersion of $(O\text{-}C)_i$ values for J6 and J7 over the total observational period.

The special attention was paid to re-checking of observational moments. The registration of start and finish of the exposure was made with the star chronometers. Further, their readings were referred to the time signals «Six points». After the revision of the corrections for the chronometer rate, UTC moments were calculated. The exposure time depended on moon brightness and could vary from 5 to 35 minutes. It is necessary to trace the object for a considerable time to fix its projection at the same point on the plate to obtain the images of faint moving objects like J7, J8. We calculated in advance the time intervals through which it was necessary to shift the telescope or the plate in the cassette holder at each coordinate separately (Metcalf's method). The guiding of the telescope was carried out manually by two observers. All the observations were made on the plates with the ORWO-ZU1 emulsion. To attenuate the brightness of the Jupiter on DWA we used the neutral filters.

3. Reduction

The processing of photographic observation can be divided into several steps. The first step is the plate digitizing to obtain its image in tif and fit formats. The preliminary image processing gives the rectangular coordinates ***x,y*** of all objects on the plate followed by the cross-identification with the objects in the reference catalogs (***α, δ)*** (Andruk et al., 2005; 2012; 2015). The connection between two coordinate systems can be presented in the form of infinite power series. In our case, the parameters of DWA and DAZ telescopes allowed us to restrict the model to a polynomial of the 6th degree. For plates of Z600 telescope the linear reduction model appeared to be optimal. The plate digitizing was carried out using Epson Expression 10000XL (EE) commercial scanner with resolution 1200 dpi. The reference catalog is TYCHO-2.

As a result of the reduction, a catalog was obtained the catalog of topocentric positions of Jupiter outer moons (see Table 2).

Table 2 shows the catalog of topocentric positions of Jupiter outer moons. The following columns are presented in the table: 1 – year, month, day, moment UTC in fractions of a day; 2,3 – Equatorial coordinates; 4 – values $(O\text{-}C)_i$ as a result of comparison of observations with theory DE431; 5 – the number of TYCHO-2 reference stars; 6 – indexes of plates in observational logs, identifiers of telescopes (DW -DWA, DZ –DAZ, Z –Z600); 7 – durations of exposure time in minutes of time; 8 – initials of the observer (Iv-Ivanov G., L-Ledovskaia (Kulyk) I., M-Major S., S-Sereda E., Sh-Shatokhina S., Ya-Yatsenko A., Yi-Yizhakevych O.). The last column contains some notes about the data character. Here, "1" means that average values of several reductions are presented, "2" shows the new result obtained from the first processed plate, "3" denotes positions with (O-C) exceeding 1 arcsec. Fig. 2. shows the dispersion of $(O\text{-}C)_i$ values for J6 and J7 over the total observational period.

The special attention was paid to the observations which in classical processing were successful, but their new reduction failed. For such problematic observation, we carefully tried to find the suitable reduction model. Various variants of the dimensions of the field of view and the number of reference stars on them were considered as well as the search of optimal criteria for noise level determination and noise misidentifications elimination. The bold font is used to highlight the plates for which the result is obtained as an average for several reductions. Nevertheless, on three plates (Z600, № 435,488,489), we failed to detect the images of satellites with the help of our program. One of them occurred to be half-overexposed. On the next one, the satellite J7 image almost merges with the image of the brighter star. The algorithm of the program failed to divide these two images and shifted to the brighter one. The image of the J8 moon on the third plate is so faint, that possibly «dive» in the noise too. In the previous successful classic method, the center of the satellite image was well estimated by eye even if it was the slight densifying of the emulsion. The program algorithm does not elaborate the limiting cases of recognition or too close neighborhood of the much brighter star. In those cases, the classical method with manual measurements became more successful.

Tables 3 and 4 present the statistical information of the reductions J6, J7 and J8 moons, which have $(O\text{-}C)_i$ better than 1 arcsec.

Table 2. Catalog of topocentric positions of Jupiter's outer moons J6, J7, J8 over the observational period 1987 – 1993.

DATE Year M Day UTC	RA.J2000 (h, m, s)	Dec.J2000 (°, ', ")	(O-C)al	(O-C)dl (arcsec)	N	Pl/Tel	exp min	Obs	mark
J6 (Himalia), 27 positions, 26plates, 23nights									
1987 09 23.080157	01 48 51.293	10 09 50.556	0.578	-0.392	1248	3179/DW	43	Yi	
1987 10 13.855550	01 37 48.101	09 07 47.401	0.559	-0.386	13	188/Z	5	M,L	
1987 10 13.918820	01 37 45.776	09 07 33.886	-0.071	-0.653	12	188/Z	5	M,L	
1987 10 14.903508	01 37 10.850	09 04 07.690	-0.042	-0.454	30	194/Z	10	M	
1987 10 17.955626	**01 35 21.918**	**08 53 17.694**	**0.132**	**-0.648**	**1560**	**3184/DW**	**25**	**Yi**	**1**
1987 10 17.982636	01 35 20.954	08 53 12.425	0.406	-0.123	1546	3185/DW	30	Yi	
1987 10 24.811301	01 31 16.864	08 28 27.629	0.133	0.374	38	235/Z	10	L,Sh	
1987 10 27.912917	**01 29 27.804**	**08 17 10.806**	**0.045**	**-0.563**	**1586**	**3208/DW**	**35**	**Yi**	**1**
1987 10 30.823393	01 27 47.528	08 06 42.720	-0.342	0.192	32	247/Z	10	L,Sh	
1987 10 31.811926	01 27 14.134	08 03 11.553	0.570	0.720	24	251/Z	10	L,Sh	
1987 12 15.767233	**01 12 34.796**	**06 19 32.367**	**0.737**	**-0.139**	**454**	**3219/DW**	**20**	**Yi**	**1,2**
1988 01 15.702904	01 18 45.201	06 47 09.531	1.634	0.493	624	3241/DW	30	Yi	3
1988 01 15.702968	01 18 45.099	06 47 09.698	0.070	0.667	1183	**3242**/DW	30	Yi	
1988 09 17.974690	04 16 10.784	20 03 50.657	0.020	0.140	515	0007/DZ	25	Sh,M	
1988 09 17.999275	04 16 10.857	20 03 49.843	0.630	0.243	631	0008/DZ	30	Sh,M	
1988 09 21.936897	04 16 12.562	20 01 01.671	0.522	1.829	34	323/Z	10	L,Sh	3
1988 09 21.947818	04 16 12.514	20 00 59.358	0.053	-0.016	5	324/Z	10	L,Sh	
1988 10 07.963328	04 14 17.707	19 46 09.057	0.438	-0.204	5	367/Z	9	L,Yi	
1988 10 09.825040	04 13 52.482	19 44 10.923	0.319	-0.763	4	386/Z	10	L,S	
1988 10 10.982953	04 13 35.375	19 42 57.744	-1.170	-0.233	51	402/Z	30	S,Yi	3
1988 10 22.032875	**04 10 13.862**	**19 31 07.712**	**-0.442**	**0.223**	**586**	**3297/DW**	**30**	**Sh**	**2**
1989 11 29.888139	06 45 16.710	23 18 30.458	0.598	-0.674	26	482/Z	12	L,Yi	
1989 11 30.880801	06 44 49.645	23 18 43.649	0.369	-0.689	528	487/Z	13	L,Yi	
1992 02 26.928932	10 50 57.194	08 33 13.638	0.358	0.472	1573	1956/DW	8	Ya	2
1993 02 16.043639	12 52 09.761	-03 37 02.540	-0.030	0.652	1391	2129/DW	22	Ya	2
1993 04 22.852408	12 29 40.928	-01 00 52.034	-1.060	0.217	1340	2196/DW	22	Iv	3
1993 05 10.832786	12 25 00.696	-00 42 21.360	-0.350	-0.648	1307	2207/DW	22	Yi	2
J7 (Elara), 5positions, 5plates, 5nights									
1987 10 29.822543	01 31 10.281	08 03 44.492	0.731	0.208	10	241/Z	30	L,Sh	
1987 10 31.830303	01 29 57.455	07 58 16.858	-0.895	-0.910	6	252/Z	30	L,Sh	
1988 01 18.581767	01 19 58.395	06 53 56.632	0.780	-0.035	17	265/Z	8	L	2
1988 09 17.999275	04 15 20.299	20 17 44.843	0.045	-0.140	288	008/DZ	30	Sh	
1989 11 29.920220	06 43 08.874	22 56 56.371	0.080	0.498	20	483/Z	30	L,Yi	
J8 (Pasiphae),1 position.									
1989 12 07.786099	06 39 33.759	23 21 29.889	0.579	0.080	29	492/Z	31	L,Yi	

Table 3. Results of the J6 reduction.

Tele- -scope	n	O-Cα, O-Cδ"	Sd	Exp. min	Rmsα, Rmsδ	N star
DWA	10	+0.15 -0.05	0.38 0.52	8 – 43	0.09 0.08	454- -586
DAZ	2	+0.32 +0.19	0.43 0.07	25-30	0.11 0.10	515- -631
Z600	11	+0.24 -0.23	0.31 0.49	5-13	0.26 0.26	4- -528
Σ	**23**	**+0.21** **-0.12**	**0.34** **0.49**		**0.16** **0.17**	

Table 4. Results of the J7, J8 reduction.

Tele- scope	n	O-Cα, O-Cδ	Sd	Exp. min	Rmsα, Rmsδ	N star
DAZ	1	+0.04 -0.14		30	0.08 0.08	288
Z600	4	+0.17 -0.06	0.78 0.61	30	0.27 0.20	6- -20
Σ	**5**	**+0.15** **-0.08**	**0.68** **0.53**		**0.16** **0.17**	
J8 Z600	1	+0.58 +0.08	0.78 0.61	31	0.10 0.05	29

4. Brief summary

Thus, a catalog of 33 topocentric positions of outer Jupiter satellites was obtained by the method developed and proposed by GAO NASU (Andruk et al., 2005; 2012; 2015).

The catalog contains the coordinates of the satellites for the period from 1987 to 1993 and covers the orbit of Jupiter in the range from 1.5 to 12.8 hours on a right ascension.

The internal accuracy of the reduction of observations in the TYCHO2 star catalog system is much higher than the analogous values of the previous reduction in the PPM catalog.

This can be explained by the fact that, firstly, the reduction of a faint objects was performed on the basis of much brighter reference stars, and secondly, this may be the result of inaccuracy of manual guiding following the poorly visible object (Metcalf's method). Comparing our results with the similar research of other authors for the same period (Nakamura, 1991; Rocher, 1996; Shelus, 1991) we can state that the quality of our observations is not inferior in accuracy to the results of foreign colleagues.

Especially it should be noted that initially our programs were designed for processing photographic plates obtained with wide-angle astrographs, having one exposure and dense sharp images of motionless objects. Images of satellites do not meet these conditions. The use of these programs to determine the topocentric coordinates of the bodies of the Solar System became possible after the corresponding adjustment of the software package in order to treat poorly delineated images without strong central blackening. Nevertheless, when we had to process digitized plates with faint moving objects, such as the outer satellites of Jupiter, we found some flaws in the algorithm of our programs. The most serious are two ones, a problem of isolating a faint image of the object from the background noise and the problem of attenuation the neighboring bright star. The improvement of algorithms and programs will make it possible in the future to process any photographic observations of objects having a visible motion and not related to stellar fields.

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