OBSERVATIONS OF THE MUTUAL PHENOMENA OF THE GALILEAN MOONS IN 2009

N.Koshkin[1], E.Korobeynikova[1], L.Shakun[1], N.Dorokhov[1], D.L.Doan[2], T.N.Manh[2], T.N.Minh[2], S.Udovichenko[1], Y.Bondarenko[1], V.Kashuba[1], A.Klabukova[1]

[1] Astronomical Observatory of I.I.Mechnikov Odessa National University, Odessa, Ukraine
[2] Astronomical Observatory of Vietnam National University, Hanoi, Vietnam

ABSTRACT. The instrumental and ephemeris preparation for the photometric observations of the mutual phenomena in the system of planetary satellites was conducted within the PHEMU09 project. Several reliable light curves and more than two tens of preparatory photometric observations of various mutual phenomena in the Jovian system were obtained. The observation data were processed, and the moments of the greatest phases of the phenomena were defined. The difference of moments of the observed greatest phases of the phenomena and the ephemerides, computed by the theory of V. Lainey, is about 0.02÷0.5 minutes. To construct an improved theory of motion of the Jovian moons, the observations are to be used for the concluding processing in the IMCCE (Institute de Mécanique et de calcul des éphémérides, France) that coordinates the PHEMU09 campaign.

Introduction

The Galilean satellites (moons), known since 1610, induced numerous observations and theoretical researches. The motion of these quickly rotating moons is perturbed by the Sun, Jupiter's flattening, interaction between them, and also by the adjacent planet Saturn. The Galilean moons can be reckoned as a small model of the Solar system where weak gravitational and nongravitational effects, as well as problems related to resonances and not yet considered in other cases, are studied.

In 2009, the PHEMU09 campaign for observations of the mutual phenomena (eclipses and occultations) of the Galilean satellites was launched on the initiative of the IMCCE (Institute de Mécanique et de calcul des éphémérides, France, http://www.imcce.fr/phemu09/). These phenomena occur only once per six years when the Earth and the Sun cross the orbital planes of the Galilean moons, and are especially valuable for the astrometry of natural satellites system. Since the mentioned moons became a target of space missions, they have aroused keener practical interest. The studies, made by Pioneer, Voyager and then Galileo probes, advanced our knowledge of the Jovian system greatly. In 1968, to prepare the mentioned missions, a specific research was commenced, and photographic observations from the Earth were carried out using long-focus instruments. The above, together with the early photographic observations and photometric observations of eclipses by the planet, permitted to construct a theory of motion of the Galilean moons, describing their position to within 400 km (or 0.1" of geocentric arc). Unfortunately, those observations have some systematic errors, and therefore, it is extremely important to develop various types of observations on an up-to-date level of accuracy standards.

Large number of accurate observations, from the one hand, and a progress in mathematical formulation of dynamic model, from the other hand, are necessary to improve the theory of motion of the Galilean moons. Such a progress can be ensured by especially precise photometric observations of the mutual phenomena in the satellites system. In 1973 and 1979 some data of observations of those phenomena were obtained, and that made possible to estimate their potentials. In 1985, 1991, 1997 and 2003, several international campaigns of coordinated observations took place. In 2009 ephemerides of more than 50 phenomena were computed for different locations [3].

Mutual phenomena can occur when the orbits of the Galilean moons are visible edgewise, and when in so doing the Sun passes through their orbital planes. Practically, it means that two moons are aligned with the Sun or the Earth, and that causes either a mutual eclipse or a mutual occultation. As it can be seen by a terrestrial observer, in the first case, a satellite enters the shadow produced by another satellite; in the second case, a satellite passes behind another satellite. When a mutual occultation occurs, it is possible to observe the approaching of the involved satellites when two images merge into one spot. The brightness is to reduce rapidly, reach the minimum and return to its initial value as the satellites part again. Throughout a mutual eclipse, only a decrease in the satellite brightness is observed, and in so doing the involved satellites can be observed separately.

The duration of such brightness variations is from several minutes to one hour or longer. The amplitude of variations depends on the relative positions of the satellites and on their radii; partial, annular or total phenomena can be observed.

The observation of brightness variations provides extensive information. The shape of the light curve and the moment of brightness minimum that conforms to the minimum distance between the satellites are the most valuable data for astrometry. Those moments are pre-computed by the theory and depend on relative positions and shapes of those gravitating bodies. The difference between the predicted and the observed moments is used to correct the theoretical model of the system of natural satellites [6].

Types and methods of observation of the Galilean moons

Observations of positions of the satellites. The photographic observations of the Galilean moons started in 1880-1890. Only short-focus refractors were used at that time. During 1920-1930, the abstract researches on the theory of motion of the Galilean moons, as well as their observations, were interrupted as it seemed very hard to improve the ephemerides. However, when electronic calculators appeared in 1960s, the study of the dynamics of the Galilean moons recommenced. The photographic observations were carried out all over again, but this time with long-focus telescopes and better photographic emulsions.

The appearance of CCD detectors with the improved sensitivity, comparing to emulsions, made the photographic plates useless. The only problem was the small size of CCD detectors, providing too small field of view. But that was solved when new star catalogues appeared, making possible to calibrate any field, even a very small one. Such calibration allows of using of any instrument, so there is no more requirement of either the field of view of high quality or the stability of the sky during the nighttime. The excessive brightness of the Galilean moons, complicating the simultaneous presence of satellites and comparison stars in a frame, still remains the only problem for their observation.

The resultant accuracy of the measured positions of the Jovian satellites for different types of observations is shown in Table 1. It is obvious that the photometry of mutual phenomena yields the best results in determining the geocentric position of the satellites with a minimum error, even under the city sky conditions.

Time scale for the observations. Since the observations are carried out to be used in the dynamic models of motion directly, all data should be referred to a certain time scale to link all observations together. Note, for example, the moon Io has an orbital velocity of 17.2 km/s; thus, an error of 0.1 second of time corresponds to an error of about 17.2 km/s in space. As the intrinsic accuracy of the theory of motion of the satellites is about one kilometer, it is evident that a timing accuracy better than 0.1 second is necessary. That means that each photometric measurement compiling a light curve should be dated in the UTC time scale with an error less than 0.1 second.

As a rule, the ephemerides of phenomena in the Solar system are computed in the Terrestrial Time (TT) scale. The most stable time standard is the International Atomic Time (TAI); the Terrestrial Time is offset from TAI by a constant value: TT=TAI+32.184 s. The Universal Time Coordinated (UTC) scale, which we use every day, has been adjusted relative to TAI and TT constantly, but irregularly. Since 1972, such an adjustment has been realizing by inserting a leap second on either December 31st or June 30th of another year. Therefore, UTS is a discontinuous time scale. The correlation between TAI, TT and UTC is shown in Fig.1. It is evident that UTS is offset from TT by more than one minute of time in 2009 (TT-UTC=66.184 s). The last positive leap second was added on December 31st, 2008, and the difference between TAI and UTC as per now is 34 seconds (http://hpiers.obspm.fr/eop-pc/). Since the observations are generally planned and dated in the UTC scale, it is indispensable to take into account the scale difference indicated above.

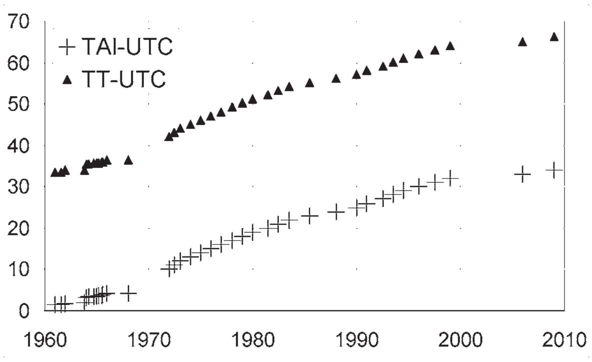


Figure 1. The difference of the null points of the TAI, TT and UTC time scales in seconds.

Photometry of the satellites with a CCD detector. The photometry with a CCD detector is efficient even for the phenomena very close to the planet. For the mentioned phenomena, to reduce the light of Jupiter, it is possible to use interference filters, such as CH4. By using a small telescope, it is possible to observe without any filter in the wavelength of the detector's sensitivity in order to gather more light. The spectral band with less light pollution is preferable for the observations carried out in a city polluted with light.

Table 1. Astrometric accuracy of observations of the Galilean satellites [2, 4]

Observations	**Type**	**Telescope**		**Individual geocentric error**	
				(")	km
Astrograph	Photographic	f=3,4 m	d<40 cm	0,190	760
Eclipses	Photoelectric photometry		d<60 cm	0,150	600
Mutual phenomena	Visual (medium quality sky)		d<40 cm	0,055	220
Astrograph	Photographic digital	f=10 m	d<60 cm	0,040	160
Mutual phenomena	Digital image (city sky)	f=20 m	d=1 m	0,015	60
Mutual phenomena	CCD photometry (city sky)		d=40 cm	0,012	48
Mutual phenomena	CCD photometry (high quality sky)		d=1 m	0,002	8

The Galilean moons are very bright and can saturate the detector. To avoid over-exposure of the image, it is necessary to decrease the telescope aperture or to use neutral density filters. To increase the number of illuminated pixels of the detector, it is possible also to defocus the image slightly.

The solar-type stars can be used for calibration. But usually, it is a satellite not involved in the phenomenon that is used as a photometric reference. It is necessary to measure the luminous flux emitted by the satellites before and after the phenomenon.

The photometric calibration. To eliminate the problem of non-uniform quantum yield for different pixels, it is necessary to have a map of the detector's sensitivity. To do that, it needs to illuminate the CCD with calibrated light; then, to divide each pixel of the image by the respective flat-filed (FF) image pixel and to multiply by its mean value. Usually, to make the above, the sky image $\mathbf{I}_{FF}(x,y)$ (several images would be better) should be obtained in the twilight at an altitude of 45° at antisolar azimuth so that the average brightness corresponds to the middle of the detector's dynamic range. Further, the dark image should be obtained for the same temperature and time of accumulation $\mathbf{I}_{tt}(x,y)$. The accounting of the flat filed (FF) and spurious counts for the image $\mathbf{I}(x,y)$ is the following:

$$\mathbf{I}^*(x,y) = (\mathbf{I}(x,y) - \mathbf{I}_{tt}(x,y)) \times \mathbf{I}_{FF\ average} / \mathbf{I}_{FF}(x,y)$$

Calculation of the luminous flux emitted by the object. It is necessary to properly take into account the brightness of the sky background. If the local background near the satellite is homogeneous (for example, when the satellite is far from Jupiter), it takes only to calculate the sum of counts of pixels, located within the window centered on satellite Sat1 (the window can be either square or round). Let us denote the mentioned sum as S1 and the number of pixels within the window as N1. The same calculation is made for the bigger window. We are to get new values S2 and N2 respectively. Then, the sky background is Fon = (S2 - S1) / (N2 - N1), and the averaged flux emitted by the satellite is F = S1/N1 – Fon.

We use a comparison object for the relative photometry. If comparison object Sat2 is in the filed of the CCD camera, we can calculate its average flux F2 for each image using the same method. Then, the relative luminous flux emitted by the eclipsed or the occulted satellite Sat1 is FR = (F/F2) * FM2, where FM2 – the time-averaged flux emitted by comparison object Sat2. Such methods enable to observe mutual phenomena under difficult conditions: by closeness of Jupiter (the background by two satellites can be quite different), with variations of the sky transparency or passage of light clouds (in the process F/F2 is still constant), by observation in the twilight (the sky background changes considerably, but it is subtracted from each image).

The observations carried out using CCD television camera are processed by the similar scheme. But even stable observations, performed using such a camera and recorded on the computer, require the measurement reduction to be made. The problem is the detector's strong nonlinearity. It should be taken into account by building a calibration function with solar-type stars. Then, that function is used for the brightness reduction to restore the true light curve of the phenomenon with actual drop of the apparent magnitude.

Observations of mutual phenomena in 2009

In 2009, in Odessa, 49 various mutual phenomena of the Galilean moons in the Jovian system could be observed from May 7th to December 25th under conditions when the Sun was not less than 5° below the horizon (the twilight), and Jupiter was 10° above the horizon at the moment of phenomenon occurrence. The fragment of the phenomena ephemerides for the dates of observations carried out in Odessa is given in Table 2.

Table 2. Ephemerides (TT) and conditions of observations of the mutual phenomena in the Jovian satellites system in 2009.

Year	Month	Day	Hour	Minute	Second	Phenomena	Flux drop	Duration, s	Distance to Jupiter, RJ	Impact factor	RA, h	m	sec	Declination, degrees	'	"	Azimuth, degrees	Altitude, degrees	The Sun's altitude, degrees
2009	8	15	23	54	9	1 ECL 3	0,282	359	5,5	0,556	21	38	32,8	-15	13	51,9	149,3	22,9	-24,6
2009	8	17	21	17	9	1 ECL 2	0,525	601	5,7	0,384	21	37	35	-15	18	51,1	188,7	27,8	-29,6
2009	8	17	21	5	53	1 OCC 2	0,42	762	5,8	0,109	21	37	35,2	-15	18	49,8	191,7	27,4	-29,1
2009	8	24	23	32	43	1 OCC 2	0,425	947	5,7	0,003	21	34	0,41	-15	36	59,7	145	20,8	-29
2009	8	25	0	15	49	1 ECL 2	0,468	831	5,3	0,429	21	33	59,5	-15	37	4,1	135,3	16,1	-25,1
2009	9	1	21	5	16	1 ECL 2	0,349	460	6,3	0,516	21	30	14,7	-15	55	32,4	173,9	27,4	-34,3
2009	9	1	20	3	22	1 OCC 2	0,192	713	5,9	0,573	21	30	15,9	-15	55	26,7	190,6	27	-29,9
2009	9	8	23	44	2	1 ECL 2	0,561	449	6,5	0,344	21	27	11,2	-16	10	10	128,4	11,2	-32,8
2009	9	8	22	27	33	1 OCC 2	0,195	599	5,9	0,562	21	27	12,5	-16	10	4	145,1	20,3	-37,6
2009	11	16	15	14	29	2 OCC 1	0,426	234	2,6	0,015	21	27	20,6	-16	2	51,3	187,2	27,2	-9

Table 3. List of observations of the mutual phenomena in the Jovian satellites system obtained in Odessa in 2009.

Year	Date	Time of phenomena	Observation sites (points)	Observer
2009	August 15th	23h54m UTC	p. Mayaki	S. N. Udovichenko
2009	August 17th	21h06m UTC	p. Odessa	N. I. Koshkin
2009	August 17th	21h17m UTC	p. Odessa	N. I. Koshkin
2009	August 24th	23h32m UTC	p. Mayaki	S. N. Udovichenko
2009	August 25th	00h 16m UTC	p. Mayaki	A.V. Klabukova, V. Kashuba, Y. Bondarenko
2009	September 1st	20h03m UTC	p. Odessa	N.I. Koshkin, S.M. Melikyants, S.S. Terpan
2009	September 1st	21h05m UTC	p. Odessa	N.I. Koshkin, S.M. Melikyants, S.S. Terpan
2009	September 1st	21h05m UTC	p. Mayaki	A.V. Klabukova, I. Shepelenko
2009	September 8th	22h27m UTC	p. Mayaki	A.V. Klabukova, N.I. Dorokhov
2009	September 8th	23h44m UTC	p. Mayaki	A.V. Klabukova, N.I. Dorokhov, Y. Bondarenko
2009	November 16th	15h14m UTC	p. Odessa	N.I. Koshkin, S.M. Melikyants, S.S. Terpan

Altogether, 14 observations of phenomena in the Jovian satellites system were carried out at Odessa observatory in 2009 (Table 3).

Within this project, in addition, trial photometric observations were obtained with the participation of the authors with AZT-8 at the Hissar observatory at Sanglok Mountain on October 10th, 2009, from 7h56m33s to 18h03m09s (UT); in Hanoi, Vietnam on October 28th, 2009, from 22h06m06s to 23h02m27s (UT); and with 80-sm telescope of OAO at the Mechnikov ONU on Terskol peak.

Observation point in Odessa with KT-50. The observations were carried out with telescope KT-50 with video camera. The geodesic coordinates of the observation point are the following: the longitude 30.75565E; latitude 46.47780N; altitude 86 m; X=3781186, Y=2250073, Z=4602039 in WGS84 system. KT-50 is the Maksutov telescope with the primary mirror diameter of 0.5 m and the equivalent focus length of 1.50 m [1]. To reduce the luminous flux emitted by the satellites and by Jupiter itself, the entrance pupil is diaphragmed to 0.22 m. CCD television camera WAT-902H2 Sup with Sony detector operates in the TV standard of 25 frames per second (or interlaced 50 fields per second). The camera's filed of view with the indicated focal length is 25x20 arcminutes in the sky that scales to about 2" per a pixel for the frame of 768x576 pixels. The reference to the UTC time scale is provided by receiving of GPS signals by ACE III GPS module and then by entering the pulse-per-second output straight to the video frame. The accuracy of time reference should be of 0.1 ms. The observations were performed without any filters. Under operating conditions, a 12-bit digitized frame occupies a lot of disc space so that the frame recording rate is reduced to 6.25 frames per second for the same filed exposure time of 0.02 s for the long lasting (longer than 10 minutes) observations (in fact, one frame, composed of two fields, is recorded; then, three frames are skipped, etc.).

The results of the observation of the occultation and the subsequent eclipse of satellite J2 by satellite J1 occurred on August 17th, 2009, that was carried out in Odessa are presented in Fig. 2 and 4.

Figure 3 shows the brightness variation for satellite J3 that was observed simultaneously along with the phenomena and used as a comparison object for the photometry.

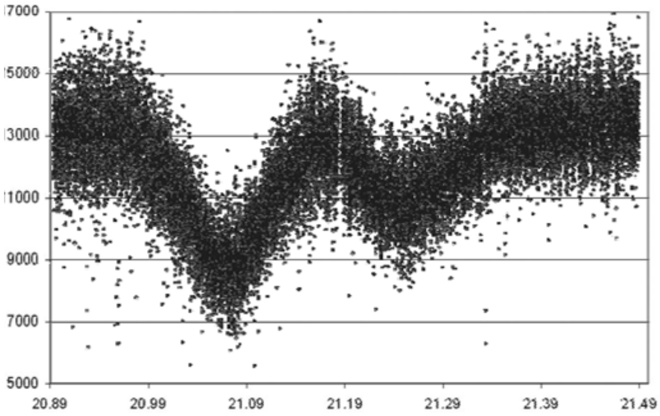


Figure 2. The light curve for the occultation and the eclipse of satellite J2 by satellite J1 on 17.08.2009. The X-axis shows time in hours (UTC). The Y-axis shows the total luminous flux emitted by two satellites in the instrumental scale.

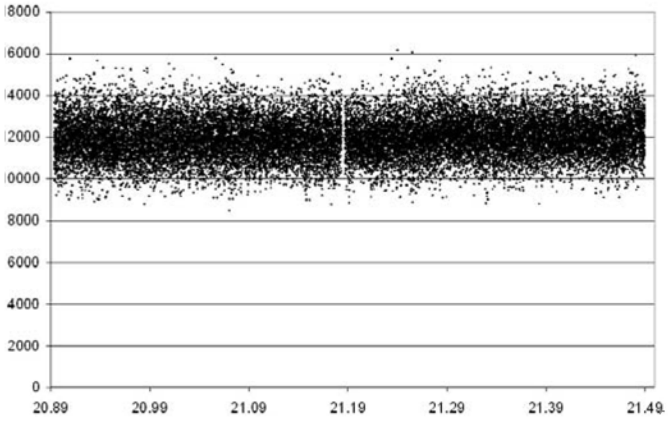


Figure 3. The light curve for comparison satellite J3 on 17.08.09. The axes are similar to Fig. 2.

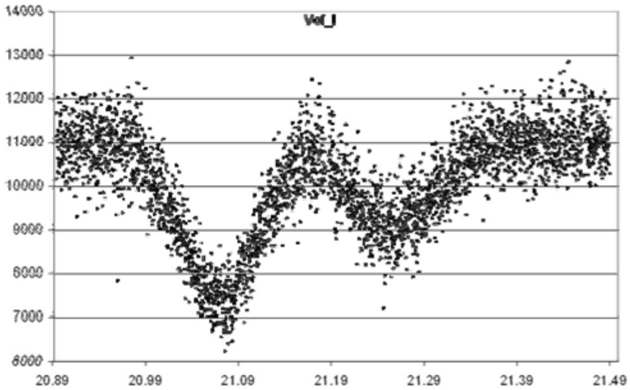


Figure 4. The light curve for the occultation and the eclipse of satellite J2 by satellite J1 on 17.08.09 on having the total luminous flux (J1+J2) pointwisely divided by flux J3 and averaged in eight counts.
The axes are similar to Fig.2.

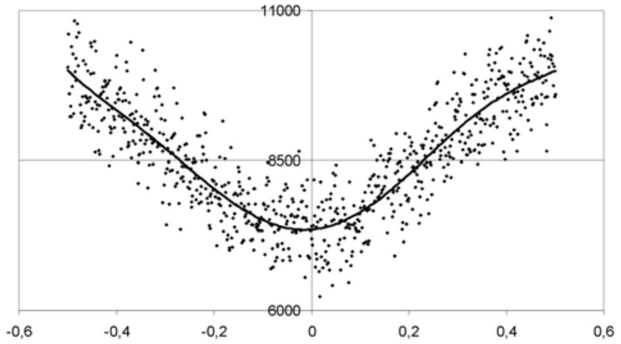


Figure 5. The part of the light curve corresponding to the maximum phase of the occultation on 17.80.2009.
The X-axis shows time normalized within the range of -0.5 – +0.5.
The curve shows the 6th degree polynomial approximation of the brightness variation.

The smoothing polynomial approximation of the light curve as it is shown in Fig. 5 for the occultation allows of determining of the moments of maximum phases of the phenomena observed:

- The occultation (J1 occ J2) 17.08.2009 at 21h04m14.5s ($21.^h07068$) ±0.5 s.
- The eclipse (J1 ecl J2) 17.08.2009 at 21h15m01.4s ($21.^h25038$) ±0.5 s.

The relative light curve as a result of the occultation observation (in instrumental scale) is shown in Fig. 6; the initial light curve for the eclipse of satellite J2 by satellite J1 that occurred an hour later is shown in Fig. 7. Both curves are compiled on September 1st, 2009, in Odessa.

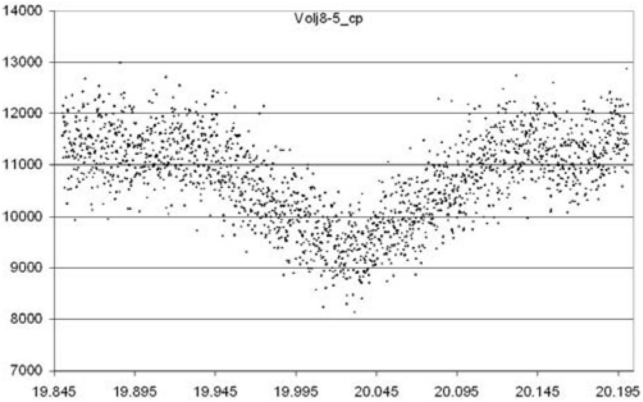


Figure 6. The relative light curve averaged in eight points for the occultation of satellite J2 by satellite J1 on 01.09.2009. The X-axis shows time in hours (UTC). The Y-axis shows the total luminous flux emitted by two satellites.

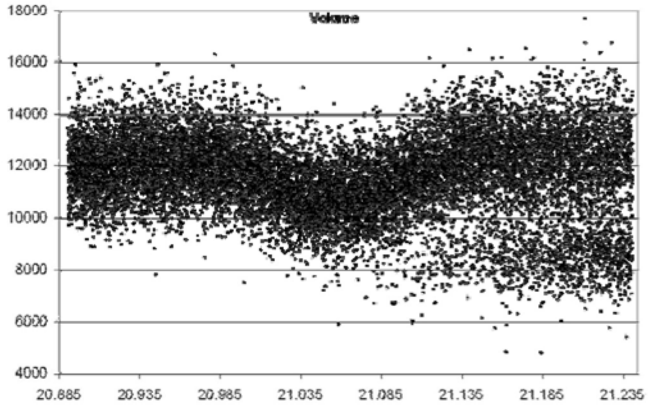


Figure 7. The light curve for the eclipse of satellite J2 by satellite J1 on 01.09.2009.
The axes are similar to Fig.6.

It should be noted that some part of the light curve is imperfect due to a wide dispersion of the points on the plot after the eclipse occurred on 01.09.2009. It can be caused by the phenomenon of eclipse itself, as well as by the processing method used. Since during this phenomenon the directions to satellites J1 and J2 are rather close at the beginning of the eclipse, their images merge into one spot in the frame, and then, by processing, they are automatically placed to the common diaphragm as a single object. But, as a result of the satellites moving away from each other with the lapse of time, their images periodically part and then merge again into one spot due to atmospheric distortions, so the program record them alternately as two objects at one moment, and as a single object at another. That leads to recurring loss of a portion of the total luminous flux and distorts the light curve for the eclipse.

The 6th degree polynomial approximation of two parts of the light curve corresponding to the minimum enables to obtain the following moments of the observed maximum phases:

Table 4. The theoretically predicted moments of the maximum phases for the gathered observations of the mutual phenomena and the respective values (O-C).

The moment of the maximum phase of the phenomenon	Theory of					
	V. Lainey V2.0|V1.1, 2004a, A&A, v. 420, p. 1171; 2004b, A&A, v. 427, p. 371.		J.-E. Arlot G-5. 1982, A&A, v.107, p.305.		D. Lieske E-5, 1998, A&AS, v.129, p.205.	
Occultation (J1 occ J2) 17.08.2009	21h04m13.5s	+ 1.0 s	21h04m48s	– 33.5 s	21h04m50s	– 35.5 s
Eclipse (J1 ecl J2) 17.08.2009	21h15m40s	– 38.5 s	21h16m00s	– 58.5 s	21h16m10s	– 68.5 s
Occultation (J1 occ J2) 01.09.2009	20h01m46s	+ 1.0 s	20h02m15s	– 28 s	20h02m22s	– 35 s
Eclipse (J1 ecl J2) 01.09.2009	21h03m40s	– 19 s	21h04m08s	– 47 s	21h04m14s	– 53 s

- The occultation (J1 occ J2) 01.09.2009 at 20h01m47.0s (20.^{h}02972) ±0.5 s.
- The eclipse (J1 ecl J2) 01.09.2009 at 21h03m20.7s (21.^{h}05574) ±0.5 s.

To preliminary define the observed moments, we compare them with the predictions of motion and approaching of the satellites, made on the basis of different theories presented in Table 4 (*http://lnfm1.sai.msu.ru/neb/nss/nssoc5hr.htm*).

The difference of moments predicted by different theories gives an idea of the characteristic value of inaccuracy that is inherent in modern theories of motion of the Galilean moons of Jupiter. The obtained discrepancy between the observed and the predicted moments is also from units to tens of seconds of time.

Observation point at Mayaki station (46.39679°N, 30.27274°E., 27 m). Telescope AZT-3 with the mirror diameter of 0.5 m is equipped with a classical astronomical CCD camera with optical photometer Sony ICX429ALL that operates in the charge storage mode with the following readout of the frame to the computer.

The light curve for the total brightness for the occultation of satellite J2 by satellite J1 on 24.08.2009 at 23.5h (UTC) is shown in Fig. 8.

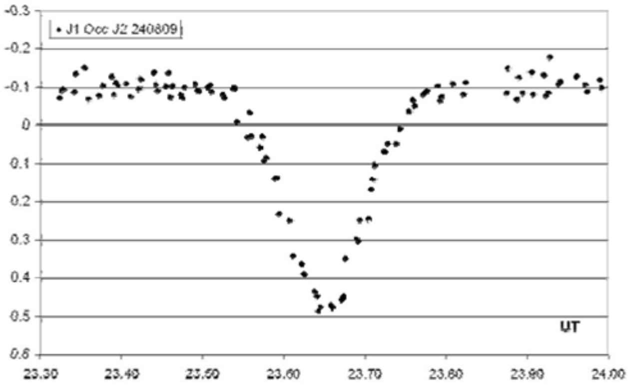


Figure 8. The light curve for the total brightness for the occultation of satellite J2 by satellite J1 on 24.08.2009. The brightness is in relative magnitude m(J1+ J2)–m(J3). The X-axis shows time in hours (UTC_hel).

The 4th degree polynomial approximation of the part of the light curve dated 24.08.2009 allows of determining of the moment of maximum phases of the phenomena observed:

24.08.2009 J1 occults J2 at 23h39m04.6s (23.^{h}65128) ±0.5 s (UTC heliocentric) or

J1 occults J2 at 23h30m49.5s (23.^{h}51376) ±0.5 s (UTC).

The prediction (by the theory of V. Lainey V2.0|V1.1) is 23h30m58.5s, and (O-C) = -9 s.

The observations of the mutual phenomena were conducted at Mayaki astronomical station using several telescopes simultaneously. In particular, with 60-sm telescope of Ricci-Chrétien type with CCD camera FLI IMG1001E, 1024x1024 pixels in 24 microns (the filed of view is 22'x22'):

2009-08-25 (J1 eclipses J2); observation start at Tstart = 0h05m42s and end at Tend = 0h28m35s. About 120 measurements are made with the time of exposure of 0.1 s and the time interval between observations dT of about 7 s.

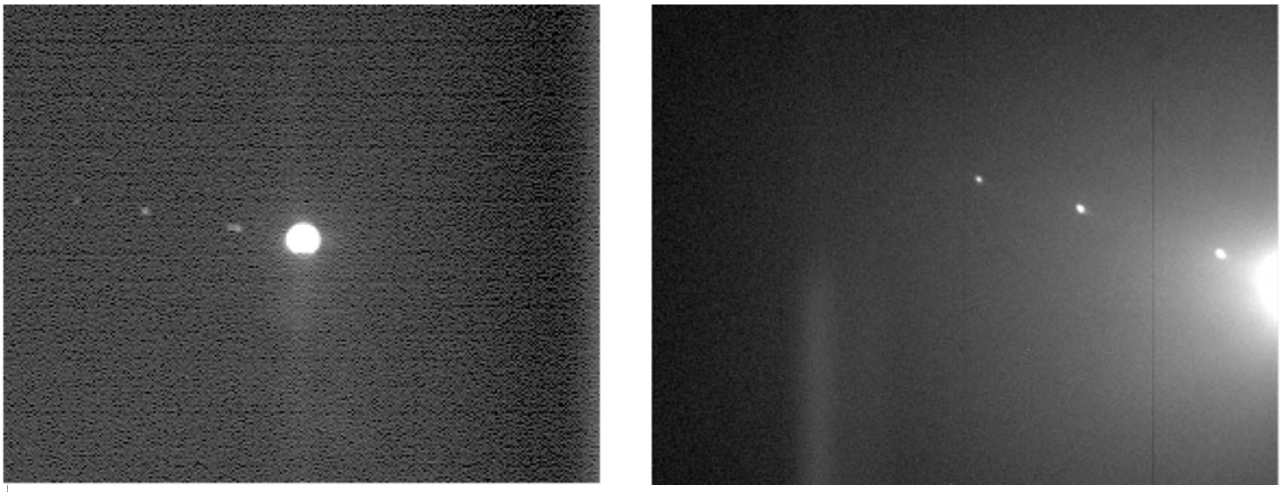
2009-09-01 (J1 eclipses J2); observation start at Tstart = 20h58m54s and end at Tend = 21h15m22s. About 130 measurements are made with the time of exposure of 0.5 s and dT of about 7.5 s.

2009-09-08 (J1 occults and then eclipses J2); observation start at Tstart = 22h06m59s and end at Tend = 23h53m15s. About 344 measurements are made with the time interval dT of 7.2 s, but with different time of exposure: 0.3 s or 0.5 s.

At the same time, numerous image records of the Jovian satellites system were obtained and subsequently undergone the photometric processing using 40-sm telescope with a video camera.

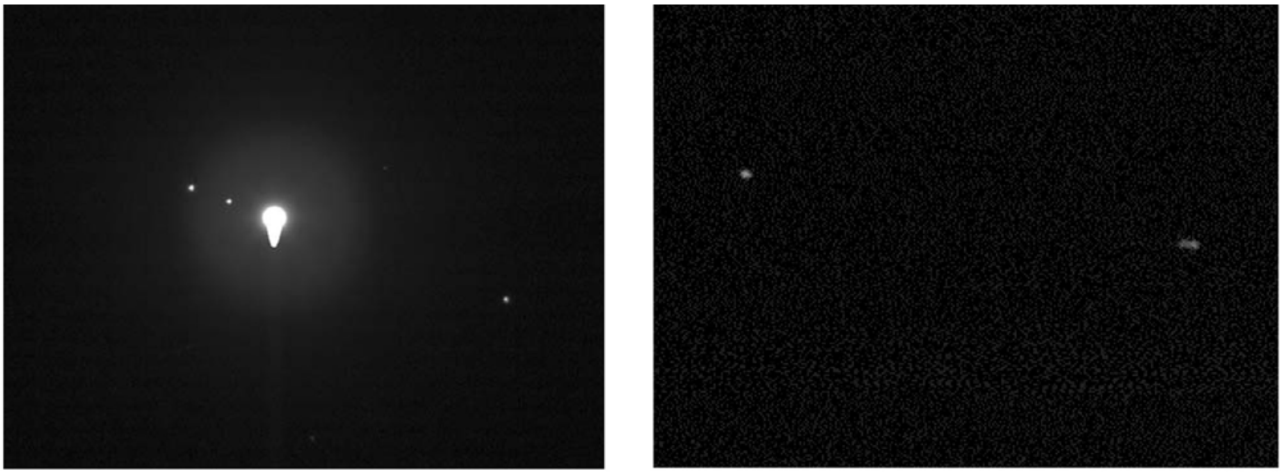
The observations conducted with all three telescopes at Mayaki station are encumbered with a number of shortcomings. First of all, it applies to the lack of calibrated reference to the UTC time scale with a sufficient accuracy for some telescopes. The measurements made with a CCD camera in the television mode are not reduced to the magnitude scale. The closeness of bright Jupiter with a narrow field of view, poor operation of mount RC-60 and, as a sequence, nonhomogeneity and fluctuations of the sky background brightness impeded the photometry and background brightness impeded the photometry and caused corruption of useful signal by a considerable noise. Nevertheless, those observations can be of use to analyze the fact of occurrence itself and the type of the observed phenomenon (appreciably less qualitative observations were processed during the previous campaign [5]).

Several examples of images of the Jovian satellites system obtained with CCD detectors of different telescopes to subsequently undergo the photometric processing are given in Fig. 9.



Mayaki, 40-cm, 09.09.2009

Mayaki, 60-cm, 08.09.2009



Gissar, 80-cm, 09.10.2009

Hanoi, 30-cm, 29.10.2009

Figure 9. The examples of images of the Jovian satellites system obtained with CCD detectors of different telescopes.

Conclusion

The methodological, instrumental and ephemeris preparation for the photometric observations of the mutual phenomena in the system of the Jovian satellites was conducted at the Astronomical Observatory of the I. I. Mechnikov Odessa National University and at the Astronomical Observatory of Vietnam National University, Hanoi.

Five reliable light curves and more than twenty preliminary photometric observations of different mutual phenomena in the Jovian system were compiled.

The observation sites are the following: observatory in Odessa, observation station in Mayaki village, observatory in Hanoi (Vietnam), observatory on Terskol peak (Russia) and the Hissar observatory at Sanglok Mountain (Central Asia).

The observations were processed and the moments of the maximum phases of the phenomena were obtained.

The comparison of the moments of the maximum phases of the phenomena, obtained as a result of the observations, with the ephemerides computed by the theory of V. Lainey and other authors shows a significant discrepancy (of about 0.5-1 minute of time).

To construct an improved dynamical theory of motion of the Jovian moons, the results of the observations were submitted for the concluding processing to the IMCCE (Institute de Mécanique et de calcul des éphémérides, France) that coordinates the PHEMU09 campaign (*http://www.imcce.fr/phemu09*).

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