

Visual timinigs of four 2015 mutual eclipses of Galileian satellites compared with the ephemerides

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Abstract

The nodes of the orbits of the satellites of Jupiter each 6 years are aligned with the axis Sun-Jupiter and mutual eclipses and occultations (PHEMU) occur in series, and their observations help to improve the ephemerides, influenced -on the long period- by many bodies interactions, relativistic corrections and internal mass distributions. The visual observations made in Rome of Ganymedes eclipsed on 20 and 27 Feb and Europa eclipsed on 26 February and 8 May 2015 are compared with the ephemerides. They have 10s accuracy in time, and 0.1 magnitudes in photometry, with a luminosity scale “brighter than”, “equal to”, “dimmer than” relative to uneclipsed satellites. The paper is structured in 1. Introduction to the mutual phenomena as geometrical consequence of orbital momentum conservations. 2. Visual observations with 3" telescopes and lack of scotopic vision under city lights. 3. The results of 20, 26 and 27 Feb and 8 May eclipses with relative photometry 4. Accuracy on timing and magnitude of the center of the eclipse; comparison with four ephemerides: IMCCE, BAA (computed by Jean Meeus), Belgian Observatory ephemerides, and Occult 4; 5. Conclusions. Significant departures from the ephemerides have been found either in time, 1min, and magnitudes, 0.5mag.

Introduction: the mutual eclipses of Jupiter's satellites

When the line of sight Sun-Jupiter includes the nodes of the equatorial plane of Jupiter and of the orbits of its satellites, the mutual phenomena occur: it happens each 6 years and their observations contribute to the definition of orbital parameters (the theory of the grand satellites of Jupiter, the internal distribution of their masses [1]), and to the physical

parameters of the satellites, like the albedo and the transient atmosphere (e.g. The ejecta from the volcanoes of Io) when present [2, 3]. The eclipses between satellites are better observable than the superpositions (occultations) between them; the angular resolution of the telescope does not allow a significant accuracy in the determination of the superposition, while an eclipse with Jupiter not in opposition is well visible even with small telescopes as it is shown in the following.

2. Visual observations with small telescopes under city lights

A tabletop telescope of 3" is larger than the first galileian telescope [4] used in the discovery of the Jupiter's satellites. But the conditions of the urban skies are nowadays much worse than in 1610 and the scotopic vision of our eyes cannot often take place. This reduces the limiting magnitude for visual observations at these telescopes at $mv=7\div7.5$, not only because the sky is bright, but also because the eye uses only the cones as detectors. So a mutual eclipse between the satellites of Jupiter can easily be a temporary disparition of the eclipsed one if observed with a small telescope. The eclipsed satellite can experience a magnitude drop from 0.1 mag to some magnitudes (about 1 in the case of Europa's eclipse of 8 May 2015). For the smaller magnitude drops the method of Argelander can take advantage of the uneclipsed satellites: their visual magnitudes when Jupiter is at mean opposition are **I**, Io, 4.8; **II**, Europa, 5.2; **III**, Ganymedes, 4.5; and **IV**, Callisto, 5.5 [5]. For larger magnitudes drops the arbitrary scale $A>B$, $A=B$ and $A<B$ is better than trying to evaluate the drop, due to the rapidity of the phenomenon (usually about 5 minutes) and the difficulty to find opportune reference stars.

3. Observations from Rome

The events and their ephemerides were furnished by IOTA/ES [6] section and BAA [7] through the Planoccult mailing list. The observation of superpositions and eclipses in 2015 has been made with 3 different telescopes: a refractor of 3" at 30x, a Newton of 3" at 20x – 58x and a Schmidt-Cassegrain of 8" at 81x, all without tracking motor. The superpositions have been observed: they do not issue a sharp timing. Only with the larger telescope of 8" the difference in magnitude between the satellites was evident, either because of the larger limiting magnitude, either due to the longer focal length which determines a large separation between the satellites and Jupiter.

The eclipses observed have been on 20, 26, 27 february 2015 and 8 may 2015: two of Ganymedes, the brightest satellite, and two of Europa, the third one in order of luminosity.

On 20 February Ganymedes was closer to Jupiter than Io and its brightness changed as in the table, because it was eclipsed by Io: G>I stands for Ganymedes is brighter than Io etc.

Observations 20 February 2015	IMCCE ephemerides	BAA ephemerides	Occult 4
00:34:55 UT G>I	Begin	Begin	Begin
00:36:35 UT G=I	00h 34min 55s UT	00h 36 min 45 s	00h34min55s UT
00:38:00 UT G<I	End	End	End
00:39:00 UT G<I	00h 43min 25s UT	00h 41 min 43 s	00h43min07s UT
00:40:00 UT G<I	center of the eclipse	center of the eclipse	center of the eclipse
00:41:54 UT G=I	00h 38 min 10 s	00h 39 min 14 s	00h 39 min 01 s
00:42:30 UT G>I	Duration: 8 min 30 s	Duration: 4 m 58 s	Duration: 8 m 12 s
00:43:00 UT G>I	Delta mag =	Duration of annular	
00:43:25 UT G>I	0.835 mag	phase: 2 m 44 s	
Data as orange lozenges in fig.1.		Delta mag = 0.62 mag	Delta mag = 0.6 mag

Ganymedes went dimmer than Io for 2 minutes, and the center of the eclipse estimated is around 00:39:05 UT+/-10s (fig. 1), in better agreement with BAA ephemerides and Occult4, as well

as the duration of the phase from $G<I$ to $G=I$ was 2 min 54 s.

On 26 of February the first satellite next to Jupiter was Europa and it was eclipsed by Callisto; observed with the Schmidt-Cassegrain 8". Ganymedes shined the brightest and external. Callisto appeared equal to Io.

Observations 26 February 2015	IMCCE ephemerides	BAA ephemerides	Occult 4
22:46:50 UT E starts to dim 22:48:19 UT E is dim 22:49:50 UT E is dimmest 22:51:57 UT E is recovering 22:52:21 UT E as the beginning	Begin: 22h43min54sUT End: 22h52min 47s UT center of the eclipse 22h 48 min 20 s UT Duration: 8 min 53 s Delta mag = 0.947 mag	Not computed because only the penumbra of Callisto passed over Europa. From Belgian Almanac maximum at 22:48 Delta mag= 0.8 mag	Begin: 22h43min59s UT End: 22h52min33s UT maximum eclipse 22h 48 min 16 s Duration: 8 min 34 s Delta mag = 0.6 mag

The eclipse at maximum was perceived around 22:49:50 UT, a time after than IMCCE, BAA and Occult4 ephemerides.

On 27 of February Io eclipses Ganymedes: observations with Refractor 3" at 30x.

Observations 27 February 2015	IMCCE ephemerides	BAA ephemerides	Occult 4
03:32:58 UT G not the brightest 03:34:00-10 UT $G<I$ 03:34:40 UT $G\geq C$ 03:34:56 UT G almost = Io 03:34:15 UT G= Io; G > Callisto 03:35:20-30 UT G<Io; G= Callisto 03:36:20-45 UT $G<Io$; G=C 03:37:20 UT $G>C$; G<I 03:38:00-48 UT G=I 03:39:45-55 UT G>Io start brighter 03:40:10 UT G>Io more bright	Begin [UT] 03h 31min 11s End [UT] 03h 40min 40s center of the eclipse [UT] 00h 35 min 50 s Duration: 8 min 29 s Delta mag= 0.968mag	Begin [UT] 03h 33 min 06 s End [UT] 03h 38 min 54 s center of the eclipse [UT] 03h 36 min 00 s Duration: 5 min 48s Duration of the annular phase: 3 m 14 s Delta mag= 0.69 mag	Begin [UT] 03h 31m 13 s End [UT] 03h 40m 22 s Max [UT] 03 h 35 m 47s UT Delta mag= 0.7 mag

The eclipse was shallower than 20 February's one, the center was observed around 03:36:00+/-10s. Europa appeared to be the fainter object, but it was closer to Jupiter. The luminosities of Io and Ganymedes were correctly evaluated brighter than Europa and Callisto with the 3" telescopes.

The magnitude drop predicted by Jean Meeus (BAA ephemerides) and his timing is closer to the observations.

On May 8 Europa was eclipsed by Io and observed from indoor with a Newton 3" f=350 mm at 58x.

Observations 8 May 2015	IMCCE ephemerides	BAA ephemerides	Occult 4
21:21:20 UT E is fainter	Begin 21h 21min 26s UT	Begin 21h 22min35s UT	Begin 21:21:29UT
21:22:11 UT E is more faint	End 21h 26min 53s UT	End 21h 25 min 39sUT	End 21:26:49UT
21:23:14 UT E is much more faint	center of the eclipse 21h 24 min 10 s UT	center of the eclipse 21h 24 min 09 s UT	Max 21:24:09UT
21:23:45 UT E almost disappeared	Duration: 5 min 27 s	Duration:3min04 s	
21:24:24 UT E at deepest	Delta mag = 0.57	Duration of the annular phase: 0m 56s	Delta mag = 1.0 mag
21:24:40 UT E starts to recover	mag	Delta mag = 0.88 mag	
21:25:48 UT E brightening			
21:26:18 UT E brightness restored			

Europa already appeared as the faintest satellite, but in the maximum eclipse it almost disappeared at 21:24:20 UT +/-10s a timing in agreement with all ephemerides. A larger Delta Mag than the ephemerides is estimated by the observations because Europa disappeared at the center eclipse [8].

4. Accuracy of timing and photometry; comparison with the ephemerides

The timing has been taken using UTC synchronized audio-records [8], the same method used for occultations [9] or solar

eclipses. The phrases are timed to the nearest second, but since the records do not contain sharp events the general accuracy is within $\pm 15 \div 20$ s. The average between symmetrical events (like the first G=I and the second G=I) help to find the center of the eclipse; with two independent determinations of the center of the eclipse we have estimated the error on its determination of ± 10 s.

The photometry of the satellites of Jupiter is within ± 0.1 magnitudes, since the difference in luminosity between Ganymedes, Io, Europa and Callisto has been always noticed, even when their order is not known before. The data in the tables have not been converted into magnitudes, because in the case of deep eclipses the complete disappearance of the eclipsed satellite made impossible the estimate. The method of Argelander can be used only with large magnification $> 50\times$ and large opening $> 3''$ for eclipses of Ganymedes, which experience gradual dimmings down to the luminosity of Callisto. For Europa at the minimum of the 8 may eclipse its luminosity was much fainter than the others, making unaccurate the estimate. For the eclipses of the satellite Io the Argelander method could work too, since other two satellites are dimmer than it.

A clear result of these four observations is that for 8 may the flux drop of Europa was > 1 mag, and the more accurate ephemerides was Occult 4.

The eclipse of February 27 observed with a Schmidt-Cassegrain 8" telescope was noticed shallower than Feb 20 (though observed with a smaller instrument), so the predicted flux drop of IMCCE ephemerides seems too large and all others ephemerides predict similar flux drops for both eclipses, contrarily to my observations.

Finally the timing of the eclipse of 26 february shows the

beginning and the maximum eclipse almost two minutes later than ephemerides.

The calculated timing accuracy is consistent to the accuracy in the magnitudes estimate: as an example in the case of 20 February is predicted a magnitude drop of 0.6-0.83 magnitudes in 4 min 15 s; this corresponds with an average drop of 0.14-0.2 magnitudes per minute, in 10 seconds from 0.02 to 0.03 magnitudes: this figure is at the limit of visual observations possibilities [12].

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5. Discussion and conclusions

Among the mutual events between Galileian satellites, with small telescopes, no tracking and urban city lights, the eclipses give the possibility to determine visually the center of the eclipse within ± 10 seconds and to check the predicted amount of Delta Magnitudes within 0.1 mag.

The ephemerides published by IOTA/ES (IMCCE) and BAA have been used as comparison to our observations: in the 8 May eclipse of Europa the Delta Magnitude seem to be larger than IMCCE and BAA, as well as the center of the 20 February eclipse of Ganymede was more in agreement with BAA ephemerides, within the errorbars evaluated. A video of such events (see figure 1 of Alex Pratt) would allow accuracies down to ± 0.1 s, but our visual observations can be successfully repeated with simple instruments by young students as introductory experiences with UTC synchronized audio-records [8] of astrometry in the solar system, for the next 2020 PHEMU series.



Fig. 1 The light curve of the mutual phenomenon of Ganymede (blue) eclipsed by Io (yellow) on 20 February 2015. Measurements made by Alex Pratt (York); the orange lozenges are the visual observations presented in this paper, in good agreement with the CCD data either in time and magnitude.

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