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Phemu 2021: Catching an Eclipse of Io by Europa Near the Horizon in Very Bright Twilight

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ABSTRACT: You should never forget that when you try to observe something, you are not sure to succeed, but if you do not try, you are sure not to succeed! This is the story of the observation of a mutual phenomenon of Jupiter's satellites, an eclipse of Io by Europa on March 16th at 4h58 UT. Nothing very original, except that this Phemu observed from the south of France took place at twilight with a very bright sky and at 4° above the horizon. Of course, we will discuss the technical aspects of this observation, such as the choice of the telescope and observation site, data reduction and analysis of timings, but not only. Indeed, we will see that the observation of this Phemu is also and above all a human story. The story of a cooperation between all the authors of this article to succeed in producing scientifically usable and useful data from this observation, showing us that it is possible to collaborate in amateur science astronomy, whatever distance is between us. So let's not forget either that if alone we go faster, together we go further!

Introduction

Year 2021 is the year of mutual events of Jupiter's moons. Mutual events occur every six years when the Earth and the Sun are crossing the common plane in which the satellites orbit, allowing the moons to eclipse and occult themselves.

And now, let's take a look at how our first attempt at this 2021 campaign went:

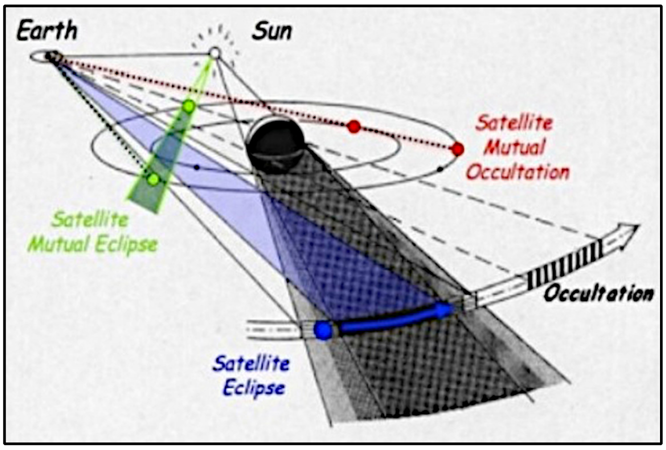

Figure 1. The principle of the phenomena of the Galilean satellites of Jupiter.

The Observation

A Lively Report by Jean-François Coliac & Franck Gourdon

Sunday March 14th - With the great software *Occult 4*, we chose the Phemu on Tuesday March 16th: delta mag 0.7 with a separation to Jupiter's limb of 70 arcsec, altitude of Jupiter 4° above the horizon, the sun at -10°. Europa is eclipsing Io with a duration of around 15 minutes. It is a beautiful Phemu with a large separation from Jupiter and large magnitude difference. This event should give us a chance of success.

Monday, March 15th - Big stress, we are waiting for the travel approval paper from *Paris Observatory* by Jean-Eudes Arlot because of Covid virus. If we do not have this paper, we are not allowed to drive by night.

20h UT: Approval received, yes! Thanks to IMCCE (Institut de mécanique céleste et de calcul des éphémérides)!
All is setup in the car: HEQ5 PRO mount (with polar finder), 200 mm f/4 Newtonian telescope, field corrector, filter wheel, Watec 910HX, video time inserter (VTI), one battery for the mount. Franck asks: "O.k. for the batteries?", "Yes, it is ok!" 2 batteries for computer and camera and a table.

We are doing a Zoom session to discuss about three possible locations:

- One at 787 metres altitude
- One at 226 metres altitude, at the observatory
- One just near the sea at 186 metres altitude

We looked at the weather website to see where there would be no clouds on early Tuesday. We decided on the road near the sea at around 186 m elevation.

21h UT: Did we forget anything? Eyepiece for pointing, finder, batteries, 220/12 V converter, cables, computer. The batteries are charging - very important! We go to bed. It is difficult to sleep.

Tuesday, March 16th

2h UT: Getting up and have a hot coffee. There is a strong wind outside. Doesn't matter, science is waiting for us!

3h 15 UT: Together we drive to the location near the sea. No cars in the streets, because of Covid, it was as if we were in the desert of Atacama...

4h 15 UT: The mount is on the ground, there are clouds in the sky. We do a quick polar alignment with the polar finder! It is very important to have a good polar alignment because the field of the Watec 910HX is very small with 900 mm focal length and shifts of the field of view with the handpad to recentre can be very bad for Tangra to keep track of the star movement. The atmosphere will surely be very turbulent, so we do not want to add another problem. Good... observing is possible. Clouds are in the sky everywhere but not on the eastern horizon!

4h 30 UT: All is setup, mount, camera, VTI. We point the finder and focus on a bright star through the clouds. The VTI is beeping: 8 satellites received on the screen, everything works well, almanac is updated.

4h 40 UT: Jupiter is there, near the horizon, we are "Go" now. Wouah - huge turbulence! Franck comments that Io and Europa are not separated. They should be, it's an eclipse. The turbulence is so high that Europa and Io are merged! We hope we could process the eclipse as an occultation. We try the V-filter, then the R-filter. Yes, it is better with R. We have more flux and less turbulence.

4h 45 UT: Jupiter is centred; we adjust the exposure. Many clouds around in the sky, Polaris is covered but the horizon shows a clear sky! We check for exposure: x2 is too bright, Jupiter is overexposed and the satellites Io/Europa at 70'' near the halo of overexposed Jupiter. We set at 1/50 sec. Io and Europa seem measurable, the satellites are not touched by the Jupiter halo. But Io and Europa are merging, the seeing is near 20'' - distance between the satellites!

Tracking is good, no shift of polar alignment. However, the wind is there.

4h 50 UT: 5 minutes before the predicted start... 3... 2... 1...zero. Ouf - there were no problems until now, hope it will continue! The image of Io/Europa is blurring. Ahh... it is awful! How are we going to get a lightcurve from this?

4h 55 UT: The eclipse of Io by Europa starts... Our breathing is stopping... we hope we will track without problems.

4h 58 UT: Minimum. We are frightened...! A small cloud near Jupiter! Ouff... fortunately it stays below the planet... yes!

5h 01 UT: Eclipse ends!

5h 07 UT: Recording stopped. All worked well.

5h 10 UT: We make a copy of the avi file.

6h 00 UT: All is stored in the car, have to go to work now... The dawn is here, the light of the Sun is arriving, and Jupiter disappears in the daylight. We could not do better than this.

16h 00 UT: Back home from work. Jean uses *Tangra* to try to do a lightcurve. Arghh... he does not succeed, the image of Io/Europa is jumping in the circle. He tries many options with *Tangra* - no success. He sends a message to get some help on Planoccult mailing list and Arnaud Leroy is answering rapidly. "Thanks for your offer to help to reduce the data, Arnaud!" He uploads the big avi file to a server at grosfichiers.com - thanks, that there is an internet!

Figure 2. Site B at 5:07 UT: the observation is over! Jupiter is visible at now 5° above the horizon in a very bright sky, but fortunately with particularly good transparency. (F. Gourdon)

Wednesday, March 17th

We are now to work on this image which shows huge turbulence:

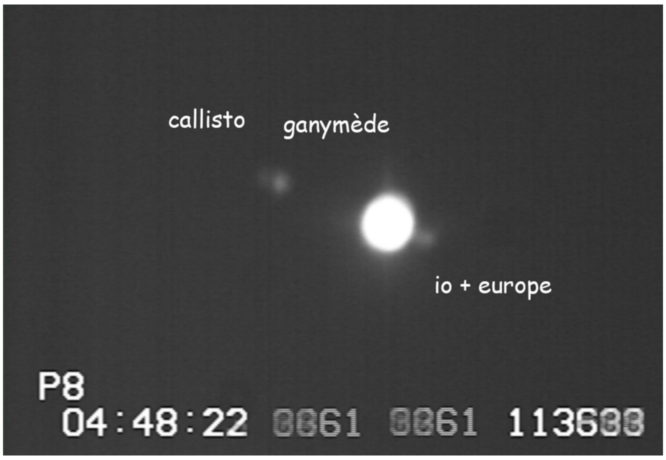

Figure 3.

Arnaud writes: "Hi Jean, I got a lightcurve!" Jean opens the file… what a beautiful lightcurve! Great Job, Arnaud! Tony George answered too, he downloads the avi file and calculates the timing of minimum with *ROTE*: 4h58m30s UT, offset O-C (observed – calculated): +9 s. The time of minimum is delayed by 9 seconds from the ephemeris. Great job, Tony, thanks!

This is how we lived this first Phemu campaign of 2021!

Behind the Scenes

But now we invite you behind the scenes to see in more detail how, all together, we united our efforts to prepare and realise this observation.

Is an Observation Possible?

IMCCE created a web page to give all predictions to catch the Phemus [1]. Moreover, the website Gemini helped to link pro-am projects [2]. But this year, there is a big problem to get lightcurves of mutual phenomena for observers in the northern hemisphere. The first Phemu begins with Jupiter very low near the horizon, around four degrees, and moreover very early in the morning. So the question is «is it possible to catch a lightcurve?» A lightcurve which can give astronomers scientifically usable data.

A Little of Photometry

Is it possible to see a signal embedded in the noise generated by the huge turbulence of the atmosphere?

At an elevation of only a few degrees, the large airmass reduces brightness a huge amount, creates strong turbulence and refracts the light of stars depending on their colour, blue being more absorbed than red. Because of this, any book of photometry tells to do photometry with a minimum elevation of around 30°. Below 30°, the data could be not usable.

Here, the first goal is to measure a «time of minimum», not really the magnitude of the satellites. It is the same kind of goal as for eclipsing binaries, for which we aim to measure the «time of minimum» and compare it with ephemerides so that we can get an offset. The measured offset will tell the astronomers that something is not known, maybe tidal effects, maybe another cause.

So, the scientific goal is possible (as we are not to measure a magnitude) if we can succeed to see the fall of magnitude on the lightcurve. This is the challenge. See a fall of magnitude, see a signal bigger than the noise.

So, let's go and prepare for it.

The first problematic parameter will be the choice of location depending on the weather.

The Preparation of the Observation

Documented by Jean-François Coliac & Franck Gourdon

We had decided to try a difficult challenge: get a lightcurve of a Phemu low on the horizon and very near dawn. By chance, we live near the sea in the south of France where the horizon can be very low.

The Choice of the Date of the Phemu with *Occult 4*

The two important parameters were:

- The delta magnitude of the fall in magnitude
- The angular distance of Io from the limb of Jupiter

If the delta magnitude is too low, we could see more noise than signal. If the angular distance is too small, the brightness of Jupiter could overexpose Io and Europa.

We use *Occult* 4 [3] to choose a good Phemu. It is important to notice that the separation displayed in *Occult 4* is the angular distance from the eclipsed satellite to the centre of the planet. So, we have to retrieve the radius to calculate the distance of the target to the limb and check the value with IMCCE ephemeris (73,9'').

We choose the Phemu on Tuesday March 16th.

- Large delta magnitude: 0.8
- Large separation from the limb of Jupiter: 70''
- Jupiter's elevation: 4°
- Sun below horizon at -10°

The other Phemu at 6h UT is too late, because the Sun is too high in the sky (Figure 4). But we see that *Occult 4* does not display the height of Jupiter and should use the IMCCE ephemeris to get the value (Figure 5).

- Time of beginning: 4h55 UT
- Time of ending: 5h01 UT

We want to start the recording five minutes earlier and end five minutes later according to the ephemeris as it gives accurate timings. Our goal was to measure a small offset between ephemeris and observation, in seconds.

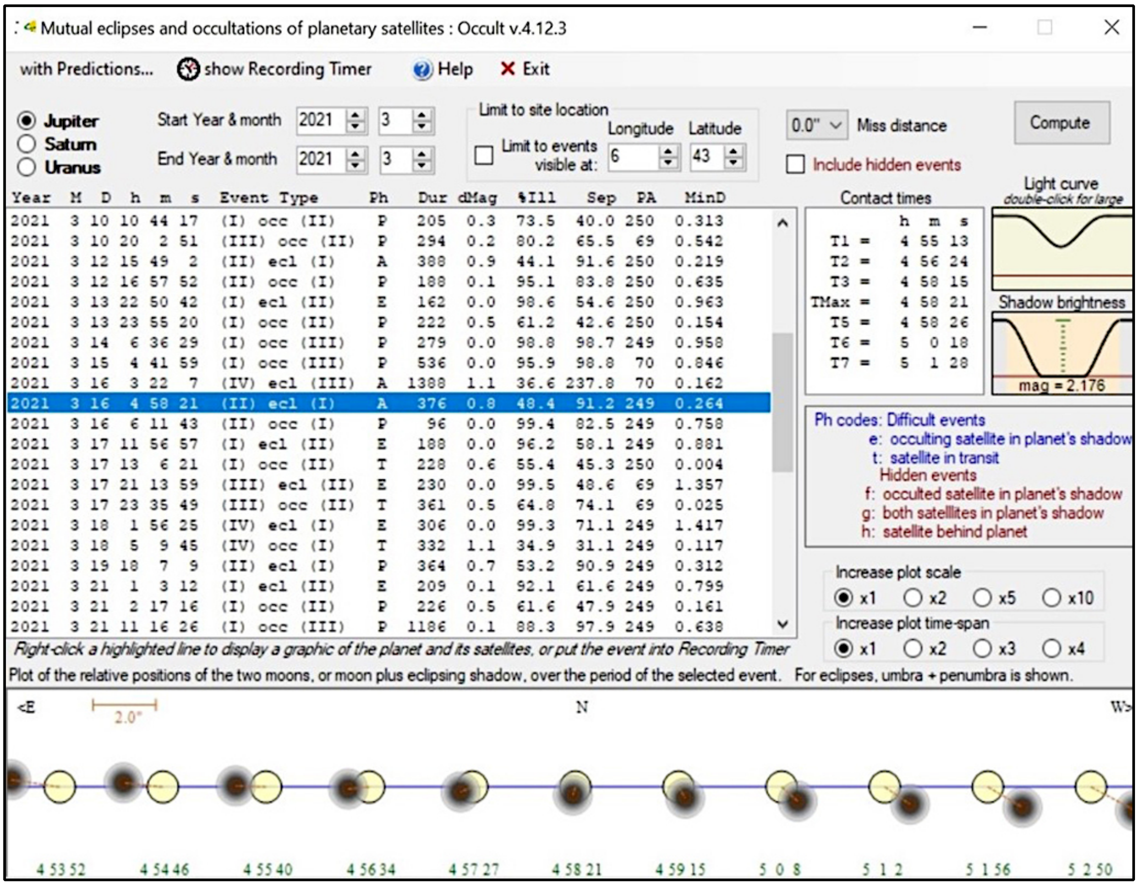

Figure 4. Screen capture of prediction for mutual events of Jupiter's satellites in March 2021. The chosen event is highlighted.

```
v5.20.11i     Planet: Jupiter CALCEPH:  (INPOP17a)
 Planet
    Observatory N: 509 - La Seyne sur Mer
        Timescale: UTC
Mean equator and equinox of J2000.  ICRF.

Mutual events of satellites:
Date  begin: h  m  s end: h  m  s    Type  Dur(m) Impact   m   Δm   limb(") dist(") Planet(º)  Sun(º) Moon phase

2021  1  7  15  9 23     15 43 47    2O1    34.4  0.369   5.1 0.328   70.18         :   20.109    9.542  0.410
2021  1  7  16 42 14     17  6 13    2E1    24.0  0.057   5.1 0.870   77.00    6.12 :    8.370   -4.412  0.406
2021  1  8   8 18 55      8 33 48    2E3    14.9  0.845   4.9 0.044  122.62    9.41 :    1.558    9.594  0.358
2021  2 12   6 18  7      6 26 59    2E1     8.9  0.055   5.1 0.896   77.86    4.54 :    0.342   -4.309  0.044
2021  2 12   6 45 22      6 52 39    2O1     7.3  0.107   5.1 0.566   76.39         :    4.798    0.469  0.045
2021  2 28   7  0  9      7 11 10    4E2    11.0  0.212   5.4 0.947   80.99   40.26 :   15.073    7.440  0.920
2021  3 14   6 34 28      6 39 34    1O3     5.1  0.903   4.7 0.016   81.35         :   18.159    7.320  0.064
2021  3 15   4 37 52      4 47 27    1O3     9.6  0.789   4.7 0.052   82.80         :    0.727  -13.624  0.118
2021  3 16   4 55  7      5  1 37    2E1     6.5  0.256   5.1 0.689   73.90   20.33 :    4.189  -10.170  0.178
2021  3 16   6 11  8      6 12 25    2O1     1.3  0.970   5.1 0.003   65.36         :   15.916    3.736  0.181
```

Figure 5. Screen capture IMCCE ephemerides which shows the altitude of Jupiter above the horizon at the observing site.

The Choice of Equipment

So, now, what kind of telescope should we use? Jean-François will bring the telescope and the Watec 910HX and a VTI. He has three different possible telescopes: Newtonian 200 mm f/4, Refractor 120 mm f/7.5, Cassegrain 200 mm f/12. We discussed about the diameter: the Cassegrain has a high focal ratio and is not suitable with a small sensor camera as the 910HX, the refractor 120 mm f/7.5 has a small diameter. Jean-François did the Phemu 2015 and used the refractor 120 mm f/7.5 but Jupiter was high in the sky. Here, with a large airmass, there is a high probability that we need more flux. So, we decide to bring the Newtonian 200 mm f/4 with field corrector.

The Analysis of the Weather

We decide to do a Zoom session to choose the good location, Monday night. Weather conditions are particularly important for observing a Phemu, but more importantly, the fact that the phenomenon takes place above your local horizon. For this reason, we had to give up the use of our observatory (OAGC), this Phemu at 4° above the horizon not being observable there.

We therefore have chosen two alternative sites with quite different characteristics, but in both cases a totally clear eastern horizon:

Figure 6. Satellite map with sites A and B and the location of the OAGC. The arrows point to the azimuth of Jupiter at the predicted time of event. Map: Google Earth

• Site A: site 8 kilometres inland located on the highest peak in the region at about 787 metres above sea level, with the direction of the Phemu above the land.

• Site B: seaside site at about 186 metres above sea level, on the steep slope of a relief facing east, with the direction of the Phemu above the sea.

For this observation at 4° above the horizon with about 11 airmass, we know that the turbulence would be very strong and hope that the transparency would be very good, and therefore the humidity low.

It's the day before the observation, and it's time for us to study the weather forecast. For this, we use the ECMRWF (European Centre for Medium-Range Weather Forecasts) model which is for our region one of the most accurate and reliable. A quick check shows us that the current forecasts are in line with what we are seeing outside (Figure 7). We can now study the forecasts provided for the Phemu time slot (from 1 hour before to 1 hour after):

• Partial cloud cover at medium altitude above our region, therefore higher than our two sites, but a clear sky to the east, which will make the Phemu visible but may pose a problem for the polar alignment of the mount.

• A strong north-westerly wind, called Mistral, with quite different values for sites A and B. For site A at altitude, we have an average wind of around 31 knots, but gusting to almost 45 knots. At the lower altitude of site B, we have an average wind of around 25 knots with gusts to 35 knots. But this site being located on the leeward side of the relief, we know that we will have a much less strong wind at this location

The good news is on the humidity side as this north-westerly wind is known to dry up the atmosphere. And indeed, the forecasts tell us a very low humidity on the two sites, around 45 %.

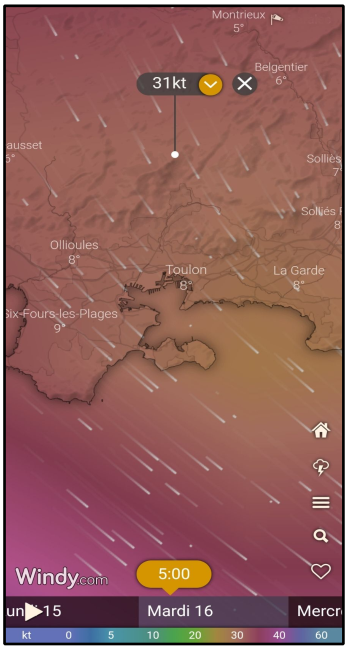

Figure 7. Screenshot of the forecast for the wind at time of event.
Forecast provided by ECMRWF and windy.com

Now all we have to do is summarize these forecasts in the form of a comparative table between the two sites for the important criteria:

		Site A	Site B
Visibility	Polaris	😐	😐
	Phemu	🙂	🙂
Seeing		☹️	🙁
Transparency		🙂	🙂
Instrument vibrations		☹️	😐

Table 1.

Therefore, the die is cast. We will try to observe this Phemu from site B!

Of course, success is not guaranteed. But it is from this location that we will have the best chance to catch this Phemu.

The Analysis of the Lightcurve by Arnaud Leroy

Jean-François tried to process the data with *Tangra* [4] and the eclipsing modelling but without success. So, he sent the message on the Planoccult mailing list, Arnaud decided to help us. Here he describes his process:

"For the analyse, I used Tangra V3. First, I tried to use the dedicated function for mutual events, but without success. The tracking of the two satellites involved in the event being not steady: the two satellites were very near of the limb of Jupiter and Jupiter was only 5° above horizon (bad seeing). For the second run, I used the classical function for asteroid occultation (Figure 8).

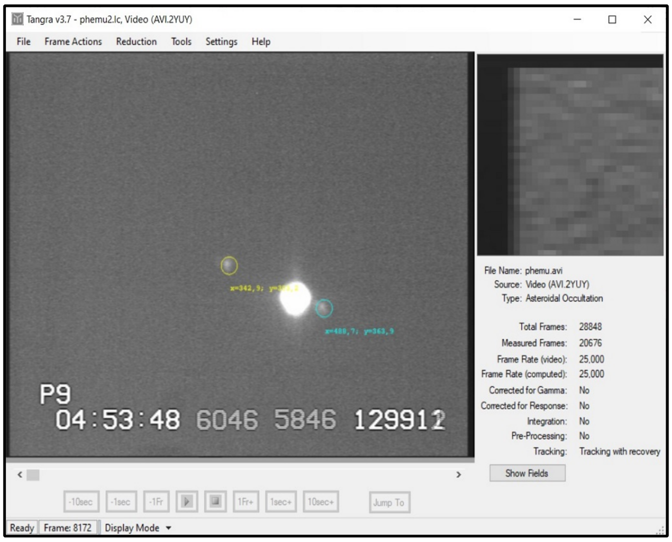

Figure 8.

Then, I adjusted the aperture of photometry measurement manually and used (III) Ganymede and (IV) Callisto (in one circle) for tracking and reference. The aperture radius was 12/35 (background). The background for (I) Io and (II) Europa was contaminated by the limb of Jupiter but I got the result!"

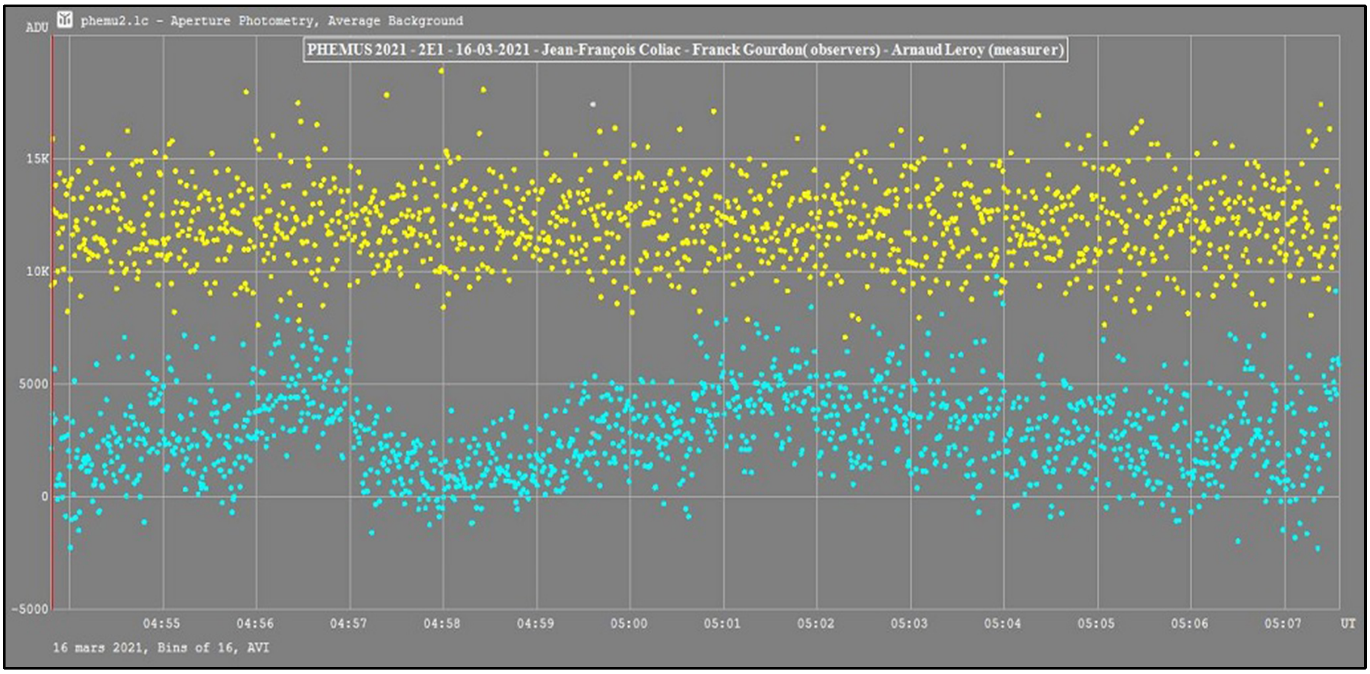

Figure 9. Light curve normalized with the reference (yellow) - binning 16 frames.

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The Analysis of the Timings by Tony George

Following the capture of the IIEI Phemu event by Jean-François & Franck, Tony saw a message on Planoccult indicating Jean-François had difficulty in getting a clean light curve using Tangra. Since he had recently completed my own difficult Phemu observation and data analysis using *PyMovie* [5], he sent an offer to Jean-François to analyse his video and send him the results of the analysis. Here is Tony's report:

"On 2021 March 16, I received the video. I used PyMovie to analyse the video. The event was Europa eclipsing Io, however, both moons were so close during the event, they could not be easily separated, so both were included in the same aperture. Also, Jupiter was so close, it too could not be excluded from the measurement aperture. However, with PyMovie we can apply some tricks to the analysis. First, I set Jupiter as a tracking aperture. The aperture was 71-pixels wide, edge-to-edge. Second, I set another 71-pixel aperture over the combination of Europa and Io. Within the second aperture, I set a 15-pixel static aperture to measure the occultation. Then, I set the PyMovie background to 'lunar' so that the bright limb of Jupiter would be excluded from the measurement.

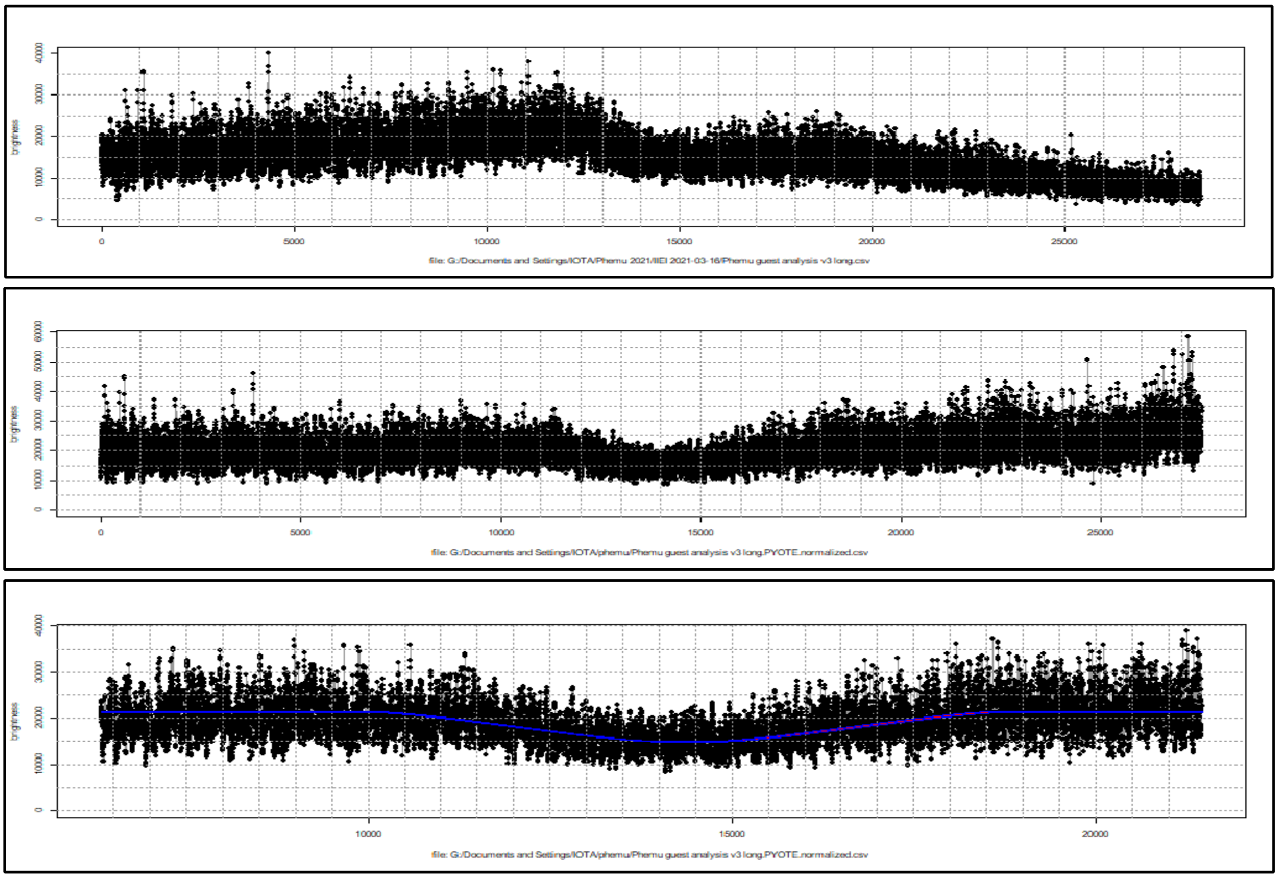
Finally, I set a 71-pixel aperture on Ganymede with a standard 'snap-to-blob' aperture that traced the actual size of the Ganymede image in the aperture. The resulting raw occultation light curve is shown in Figure 10a.

As can be seen, the light curve has a pronounced hump in it. This is due to the moons rising slowly through dense atmosphere near the horizon in the rising part of the hump and then due to increasing twilight in the decreasing part of the hump. The 'notch' in the middle of the hump is the eclipse event.

In order to better see the true shape of the event and to perform a timing analysis on it, the raw light curve was normalised to the Ganymede light curve using the program ROTE [6].

The resulting light curve resulted in a reasonably flat light curve with the event clearly visible (Figure 10b). This light curve was saved as a separate .csv file for further analysis in ROTE.

The new normalized .csv file was analyzed in ROTE using the edge-on-disk (EOD) penumbral light curve analysis methodology. While this was an eclipse and not an occultation, and while both Europa's shadow and Io's disk were both circular, experience has shown that the EOD methodology provides are very good fit to Phemu light curves and that it can provide reasonable approximate start, middle, and end times for the Phemu event to check results against predicted event times. The EOD analysis fit a smooth curve to the normalized light curve resulting in the graphic shown in Figure 10c.



Figures 10a, 10b and 10c.

The EOD analysis resulted in the following event times:

Duration (seconds) = 190.237279 (+/-) 2.493

Without camera delay and VTI offset:

D_{begin} 04:55:35.180400
D_{end} 04:58:15.179760
R_{begin} 04:58:45.411679
R_{end} 05:01:25.423039

MagDrop

Nominal = 0.39
Maximum = 0.39
Minimum = 0.38

Based on the D_{end} and R_{begin} results, the midpoint time of the event is 04:58:30 UT.

Compared with the predicted midpoint of the event, the O-C is 9 seconds. This is a very good result for such a 'tenous' observation (low altitude, onset of dawn twilight, proximity to Jupiter, and merged moons).

I congratulate the observers for getting this data in the face of such difficult conditions!"

Sending Reports and Measurements to IMCCE

The file generated by Arnaud with *Tangra* was modified to three columns: julian date, flux of target, flux of reference satellite. This file is joined to the report, indicating useful information for astronomers: latitude, longitude, altitude, telescope, camera...

As a result, we can see that it is possible to do a collaborative work in amateur science astronomy, whatever distance is between us.

Yes, astronomy is the school of... "stronger when together"...

Acknowledgements

We would like to thank Planoccult mailing list, IOTA and IMCCE for all precious advice they give on their web site and all amateurs that contribute on the web and elsewhere to share their experience and techniques. This paper was made using software *Occult*, *Tangra*, *PyMovie* and *ROTE*.

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