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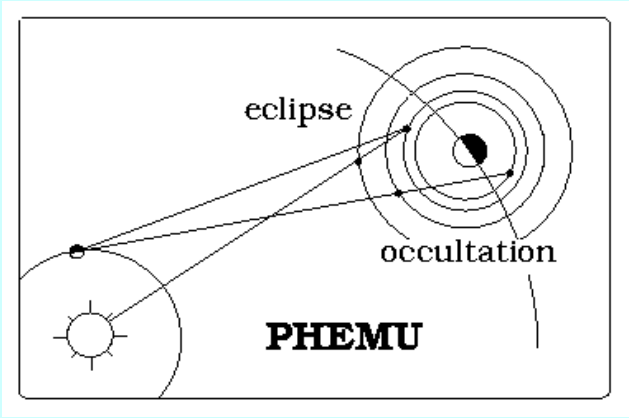

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THE VISUAL OBSERVATION OF THE MUTUAL PHENOMENA

IMCCE, UMR 8028 of the CNRS

1. Introduction

The IMCCE organizes campaigns of observation of the mutual phenomena of the Galilean satellites of Jupiter. These phenomena occur only every six years and are of a high astrometric interest. The Galilean satellites, which are known since 1610, aroused numerous observations and numerous theoretical works. The spatial investigation boosted the interest of these works. In 1973 the Pioneer probe, in 1980-81 Voyager probes, then in 1995 by the space probe Galileo, made enormously progress our knowledge of the Galilean system. A particular effort had been supplied from 1968 better to know the movements of the Galilean satellites and so to prepare these spatial missions. For that purpose, photographic observations made from the ground with instruments with long focus had been used. Together with former photometric observations of eclipses and former photographic observations, they allowed to obtain a theory of the movements of the Galilean satellites giving their position with an accuracy of 400 km (or 0.1" geocentric).

The precision of the ephemerides of the Galilean satellites can be improved on one hand by progress in the mathematical formulation of the dynamic model of the movement - it is a current work at present to the IMCCE - and on the other hand by the increase of the number of precise observations which are used to fit the theory. The observations of the mutual phenomena, which are particularly precise, can allow this progress. In 1973 and 1979 some observations of these phenomena had been obtained: it allowed to appreciate the interest of it. In 1985 , 1991, 1997, 2003, real international campaigns of coordinated observations took place. To pursue this effort justified by the value of the obtained results, a new campaign is going to take place in 2009 with for purpose to have a good coverage in longitude, increasing so the number of observable different phenomena. More than about fifty phenomena are observable from most of the sites of observation and one will refer to files and software available on the server of the IMCCE (http://www.imcce.fr/phemu09) to obtain dates, nature and visibility of the phenomena.

The object of the present note is to describe the mutual phenomena that every amateur using an instrument of small aperture, can observe; it is also to indicate the procedures and the precautions to be taken for those that will wish to make visual observations and to communicate us their data of observation so that they are exploitable. It is especially for the visual observers of variable stars that we address.

2. Description of the mutual phenomena

The four Galilean satellites are in orbits in almost the same plane around Jupiter. During their rotation, it happens (generally for each revolution) that these satellites pass behind the planet or in the shadow of this one. A ground observer can then see the satellite disappearing behind Jupiter, either going out next to the planet. These are the classic phenomena of occultation and eclipse by the planet itself or its shadow. Similar phenomena, between satellites, can also occur, but in a rare way. Every six years, we see the orbits of Galilean satellites " by the edge ". The Earth and the Sun pass in the plane of orbits: it is then that the mutual phenomena can occur (cf. Technical note PHEMU n°1).
In fact, this corresponds to two satellites on a line with the Sun or the Earth, as it is about an mutual eclipse or about a mutual occultation. In the first case, a satellite enters into the shadow produced by another satellite, and in the second case, a satellite passes behind another satellite with regard to a ground observer.

3. What does one observe during these phenomena?

Before a mutual occultation one can observe the approach of both concerned satellites. Then, from a moment which depends on the power of resolution of the used instrument of observation, both satellites merged in a single spot the luminosity of which is going to decrease quickly, to pass by a minimum and to return to the initial value before both satellites part again. During a mutual eclipse, the darkened satellite will be observed only. As first the brightness will vary by way of a minimum which can moreover be much deeper than in the case of an occultation where the occulting satellite never disappears, of course.
The duration of this variation of brightness is of the order of some minutes generally but it can reach one hour or two, exceptionally more. The amplitude of this variation depends on relative positions of satellites and their radii; one can so observe partial, annular or total phenomena. Generally the observations of mutual eclipses are easier to observe, because the variation of brightness is often more important than in the case of the occultations where one observes always two satellites simultaneously.
It is the observation of this variation of brightness that supplies the interesting information. The useful datum for the astrometry is the shape of the curve of light and the date corresponding at the minimum of distance between both satellites which is close to the date of the minimum of light. This date is calculable by the theory and depends on relative positions of these celestial bodies. The distance between the prediction and the observation will be used to correct the theoretical model. Furthermore, the atmosphere being almost non-existent around the Galilean satellites, the interpretation of the shape of the observed curves of light do not present the difficulties met during the observations of eclipses by the planet. In these, indeed, the precision is strongly degraded by the refraction of the light during its transit in the atmosphere of Jupiter. It is the reason for which the observations of the mutual phenomena are astrometrically very interesting.
One can moreover refer to the other technical notes PHEMU to have more details concerning the observation of the mutual phenomena or to look at papers published on these observations (cf. Technical note n°8).

4. Interest of the visual observations

Why to make visual observations, when the other techniques can provide a much superior precision? Besides the educational interest got by such observations and their spectacular aspect, the visual observation can be made in difficult conditions, when the other techniques are often impracticable: so, the phenomena occurring during twilight, either very low on the horizon, or very near Jupiter, or finally with a poor quality sky (variable absorption), are observable visually without too much difficulty. A visual observation can also allow to raise an ambiguity by comparison to another doubtful observation of the same phenomenon, made on another site. The previous campaigns showed than the precision of the visual observations have a honorable level, as the table below shows it which gives a comparison of the precision obtained for various types of observation. All this can only encourage the amateur astronomers to make these observations with an indispensable particular care to obtain usable results.

PRECISION ASTROMETRIQUE DES OBSERVATIONS DES SATELLITES GALILEENS

Observations	Type	Instrument		Erreur individuelle ('') géocentrique	km
Eclipses	visuelles		d<40cm	0,250	1000
Eclipses	photométriques visuelles		d<40cm	0,200	800
Astrographe	photographiques	f=3,4m	d<40cm	0,190	760
Eclipses	photométriques photoél.		d<60cm	0,150	600
Astrographe	photographiques	f=5,2m	d<40cm	0,130	520
Héliomètre	visuelles	f=2,5m	d<40cm	0,120	500
Astrographe	photographiques	f=6m	d<40cm	0,100	400
Astrographe	photographiques	f=10m	d<60cm	0,060	240
Phén. mutuels	visuelles en site urbain		d<40cm	0,055	220
Appulses	images numériques	f=20m	d=1m	0,030	120
Phén. mutuels	images numériques en site urbain	f=20m	d=1m	0,015	60
Phén. mutuels	photométrie photoél. en site urbain		d=40cm	0,012	48
Phén. mutuels	photométrie photoél. en site moyen		d=80cm	0,010	40
Phén. mutuels	photométrie photoél. en site exceptionnel		d=1m	0,002	8

5. Technique of observation

It is the recording of the variation of brightness, properly noted in Universal Time, that is the complete datum of the observation. To obtain it, the astronomers use photoelectric photometres or CCD receptors, material who begin moreover to spread among the amateurs. We shall content however here to describe the technique of visual observation, the other technical note PHEMU available on the server of the IMCCE describes the other techniques of observation (photoelectric, CCD, video...). The amateurs can also obtain a detailed documentation with the photoelectric section of their association.
The object of the visual observation by the amateurs is so to note with a good precision (of the order of some seconds) when the brightness decreases, when it is stable and when it increases, these moments being expressed in Universal Time. This can be realized, even by a little experimented observer, and allows then to determine the moment of the beginning of the fall of brightness, that of the end of the ascent and that of the minimum of brightness. However, such observations will not generally present a sufficient precision to be able to be used afterward by the astronomers improving the dynamic models. To obtain useful precise data is however possible for trained observer: a more experimented observer will use a comparison method of brightness, such as that used by the observers of variable stars, and who allows better to describe this variation of brightness. It is a question then of estimating the brightness of the satellite, occulted or eclipsed, compared with the brightness of a nearby satellite. The ideal is to be able to have, as for the estimations of brightness of variable stars, two marks of brightness (satellites or stars), the one more brilliant than the variable object and the other one weaker. In the neighborhood of Jupiter one should mostly content with estimating the brightness by means of a single mark: another Galilean satellite.
The curve of light serving simply for determining characteristic instants, it is not necessary to know the absolute magnitude of the used marks of brightness. One will estimate simply the differences of brightness in "degrees", according to Argelander's method (cf. Dumont and Figer 1973). One will find in the Technical Note n°6 examples of light curves observed during the last campaigns: some of them were observed visually. The scale of the ordinates is increased in arbitrary degrees. The zero of the scale is the brightness of the satellite - reference, and we put on a graph the distance in degrees between the occulted or eclipsed satellite and the reference, according to time. One often notices, for the fast phenomena, that the variation of brightness is very fast near the central moment of an eclipse: more than a half-magnitude per minute. In these conditions, it is important to make visual estimations fast. One has in fact only some seconds to decide on the value of estimation, while classically a visual estimation of brightness of variable star takes around thirty seconds from the moment the object is pointed (and sometimes much more for the novice variable observers).
The satellites of Jupiter being very bright in the telescope, one can advise to put slightly out of focus to facilitate the estimations of brightness. One will have particularly advantage to do it in the case of the occultations where it is a question of estimating the global brightness of both satellites and it's better not to separate visually and also not to use a too strong magnifying-power. On the other hand, a stronger magnifying-power is advised in the case of eclipses to increase the visible distance between the eclipsed satellite and the eclipsing satellite (reference of brightness) if this last one is too close. Also, one will increase so the visible distance with the planet Jupiter if this one is too close, because the luminosity is annoying for the estimations of brightness.

6. Reduction of the measures

The reduction of the data will be made numerically. You can try yourself to determine the moment of the minimum of brightness. For that purpose, one uses generally the graphic method assuming that the light curve is symmetric. If the quality of the observations justifies it, one can use numerical methods more elaborated as Kwee and Van Woerden's method (1956). However, these methods are not reliable because a light curve of a mutual phenomenon is not always symmetric. We prefer so that you send us raw data in the form of a list of measures, all the timings corresponding to a value of brightness. Only this type of data - and provided that the measures are referred to the Universal Time within less than one second of time - will allow to obtain after reduction an interesting precision.

7. The precautions to be taken

These observations of mutual phenomena, should be realized by taking certain number of indispensable precautions in order to get useful results.

A) *To make a good study of the prediction of the phenomenon* (cf. the predictions on the server http://www.imcce.fr/phemu09 of the IMCCE as well as the configurations of satellites) to prepare the observation: Jupiter in particular can bother enormously the estimation of brightness of satellites, due to its nearness. Some predicted phenomena occur in front of the planet, and are so only curiosities. The duration and the magnitude of the phenomenon are important to know, the observer should not be surprised by what he is observing (note that events the magnitude of which is less than 10 % are very difficult to observe).
It is also necessary to know the predicted beginning of the phenomenon and its the duration, beeing aware that the defects of ephemerides can cause differences from 1 to 5 minutes of time with the observations: please , do not so wonder of an advance or a delay of the phenomenon with regard to the prediction, and begin your observations enough early!

B) *To know the configuration of satellites not to make a mistake about satellite* (it already arrived!). It is necessary indeed to know how to identify one or several interesting satellites (attention to the inverted fields), but also it is important not to be bothered by the possible approach of a third satellite or by the disappearance behind or in the shadow of Jupiter of the satellite chosen as reference of brightness... An interactive software allowing to get the configurations of the satellites is available on the internet server of IMCCE.

C) *Have a tape recorder*. It is necessary to be able to record all which takes place during the observation: the comments of the observer, the sound tops giving the clock and the estimations of brightness with the moment of the estimation. Without tape recorder, the presence of an assistant which notes all these data scrupulously is indispensable.

D) *Foresee a precise timing.*
It is not useless to remind that only an observation referred well with the Universal Time (UTC) will be exploitable. One can for example have a quartz watch, noting before and after the observation the difference with UTC. An assistant announces the time to the nearest second, gives a top which is recorded, and takes notes, in particular the estimations of corresponding brightness at the announced moment. The Universal Time is available either by phone, or by means of a receiver radio getting a broadcasting station of Universal Time (3170 , 4525 , 75, 50 , 77.5 kHz) or by GPS. Once again, let us insist on the fact that an observation not referred within one second of time to the Universal Time presents no interest.

E) *Practice, before the period of the mutual phenomena, to observe the eclipses of satellites by Jupiter* (what constitutes a good preparation), or very fast variable stars (RZ case, CY Aqr...). Please , send us the data so obtained.

F) *Prepare a procedure written of all that is to make before, during and after the observation of the phenomenon*, and to follow it conscientiously.

8. The writing of a report

To be able to be useful an observation should be accompanied with a certain number of information. We propose so to the amateurs interested to draft a short report of every observation of mutual phenomenon giving the following information:

- Name of the observer and address;
- Place of the observation and its geographic coordinates;
- Type of observed phenomenon;
- Date (day, month);
- Instrument used (aperture, focal length, refractor or reflector, used magnifying power, please , indicate also if you have to put slightly out of focus);
- Estimated quality of the observation (sure, doubtful,...);
- Quality of the sky, stability of the images, weather conditions (mist, cloudy passages, cirrus...);
- Presence of the Moon, twilight...;
- Height of Jupiter on the horizon.

One will find in appendix a model of report to be reproduced for every visual observation.

Also give the results of the observation:
- List of the estimated values of brightness and the precise dates corresponding to the nearest second of Universal Time;
- If A and B are references and V is the variable object, the estimations of brightness will be under the form A (3) V (to indicate that the reference A is brighter with 3 degrees) or, if one uses two references, under the form A (2) V (5) B (for V fainter than A of 2 degrees and more brilliant than B of 5 degrees). Do not omit to give the identification of references used (to see in appendix n°1 for more details).

9. Conclusion

We have just described a technique for the visual observation of the mutual phenomena of the Galilean satellites which may be difficult and should be made only by experienced visual observers. The other methods using a more consequent material are applicable by amateurs and are described in the other technical notes PHEMU: for example the use of a TV camera and the recording on VCR.
Finally, please , send us your first observations or your preliminary observations quickly: we can then advise you to improve possibly the used procedure. Please , do not hesitate to contact us in order to require further information:
- at IMCCE , Campaign PHEMU09, 77 avenue Denfert-Rochereau, F-75014 Paris, (or by e-mail in: phemu@imcce.fr),

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APPENDIX.

REPORT OF VISUAL OBSERVATION

(To send back after every observation to the IMCCE, PHEMU09 , 77 ave. Denfert-Rochereau, F-75014 Paris)

PHENOMENON OBSERVED:

NAMES OF THE OBSERVERS:
ADDRESS:
PLACE OF THE OBSERVATION:
Geographic coordinates: (longitude: hr m s; latitude: ° ' "; height = m).

WEATHER CONDITIONS (mist, cloudy?):
Quality of the sky (stable, transparent?):
Stability of the images:
Height on the horizon at the time of the observation:
Twilight? Moon?

INSTRUMENT USED:
Refractor or reflector?
Aperture:
Focal length:
Used magnifying power:
Out of focus?

Used CLOCK (references?):
Scale of time used (UTC, Legal Time...):

ESTIMATION of the quality of the observation
(Sure, doubtful...):
Estimation in magnitude of your personal "degree" used for the comparisons of brightness:

COMMENTS:
Join the list of the estimations of brightness made with the timing of each of them.
Indicate reference celestial bodies used with their visual magnitude in the date of the observation.