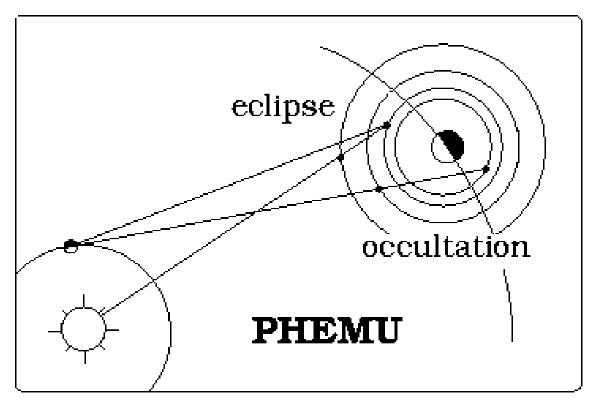
Institut de mécanique céleste et de calcul des éphémérides
77 avenue Denfert-Rochereau, F-75014 Paris, France
Observatoire de Paris - CNRS



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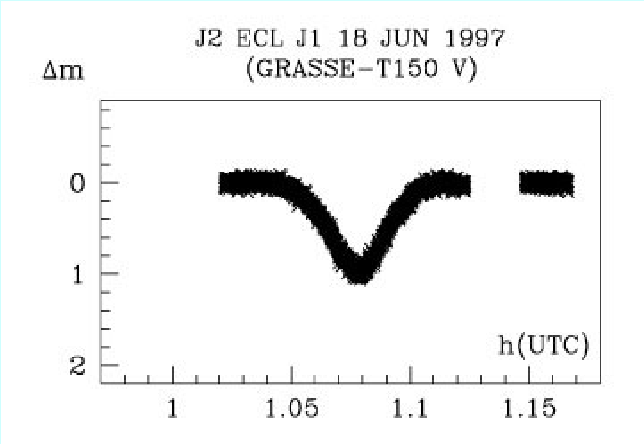
EXAMPLES OF LIGHT CURVES OBTAINED DURING THE PAST CAMPAIGNS OF OBSERVATION

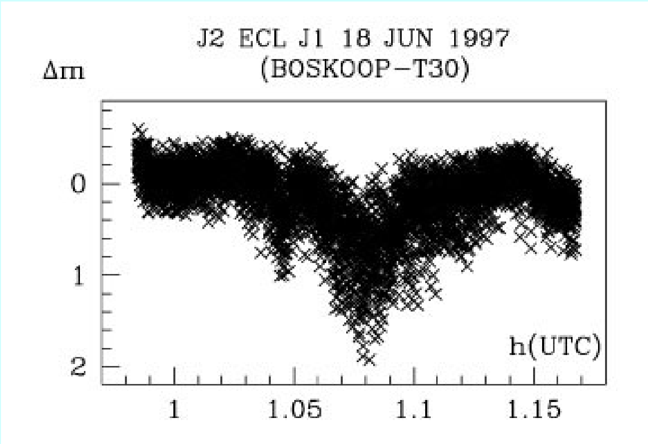
J.-E. Arlot
Institut de mécanique céleste, UMR 8028 du CNRS, 77 avenue Denfert-Rochereau, F-75014 Paris

1. Introduction

In order to make aware the observers of what type of data they are going to obtain, we propose to have a look to some light curves obtained during the former campaigns of observations. We will analyse what was obtained depending on the receptor or on the observational conditions. We will see how to determinate if the observation is worth being used latter for theoretical purpose.
First let see some light curves: the light curve at left is that you should get from an observation of a mutual event. The light curve at right is that you should not get!



The light curve presents a good signal/noise ratio The integration time is small due to the large size of the telescope (150cm) but may be increased with a smaller telescope.



The light curve presents a bad signal/noise ratio due to the agitation of the image in a too small diaphragm and the integration time for each point is too small. Light clouds may also be present at the time of the observation

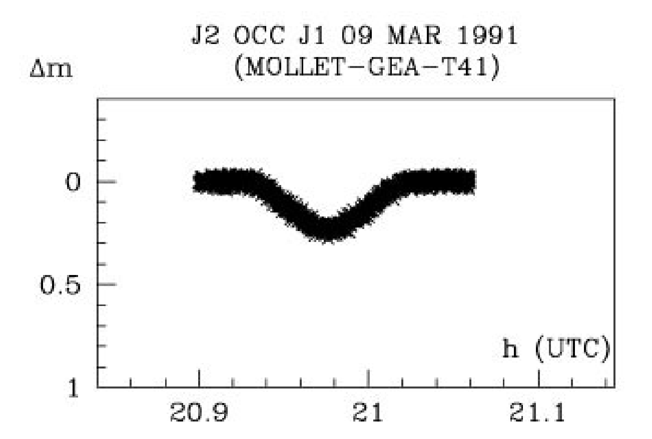
How to be sure to get the good one? We will show you how to have a good use of the receptor and a good adaptation to the local atmospheric and meteorological conditions.

2. Deep light curves (non grazing events)

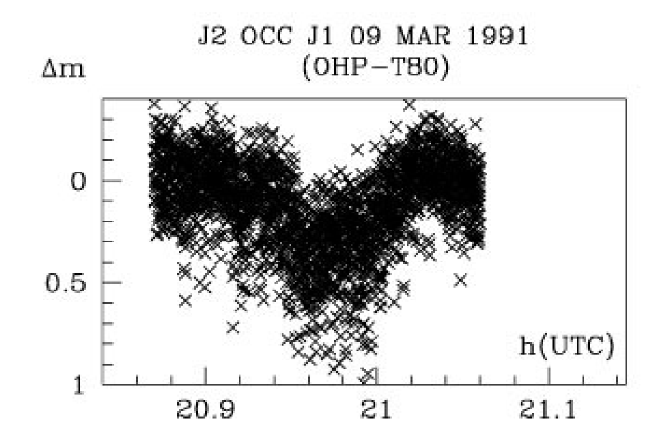
Each event is associated to a specific magnitude drop which may vary from 0 (grazing event not observable) to 1 (total event, for example total eclipse of a satellite by another). In fact, the light curve provides the flux received from the only concerned satellite when it is possible, and from two or more satellites either for the occultations (we observed the two concerned satellites together) or for eclipses (in case of the proximity of a satellite to the eclipsed satellite). In the tables, we calculated the magnitude drop considering that we observe only one satellite for the eclipses and two satellites for the occultation. The result is that each light curve is characterized by its magnitude drop, more than by the nature of the event (occultation or eclipse). We may make a classification leading to consider that an event, the magnitude drop of which is less than 0.1 (10% extinction) is grazing. Let us first consider the non grazing events which are easier to observe, to reduce and to analyse.

a) The signal/noise ratio and the integrating time of each point of the light curve

The examples of light curves presented here, show that the noise of the light curve may be very different from an observation to another. How to optimize the observation and to reduce the noise? The noise depends of several parameters:
-observational conditions: the light measured inside a diaphragm may vary because of the bad seeing of the images (scattered light out of a too small diaphragm) leading to a bad signal/noise ratio. In that case, the solution is to increase the size of the diaphragm.
-measurement of the light flux: the light is measured inside a too large diaphragm and the sky background is too high (and it may vary, reducing the signal/noise ratio). In this case, decrease the size of the diaphragm.
-integrating time: the light flux is integrated during a too short time and the scintillation due to the atmosphere will lead to a large variation of the light flux from one point to another point of the light curve. In this case, increase the integrating time but be careful to keep enough points in the light curve in order to have a good fit during the reduction.



Lightcurve of small amplitude well recorded with a small telescope and a good integrating time



Same with a bad signal/noise ratio due to a too short integrating time in spite of the use of a larger telescope

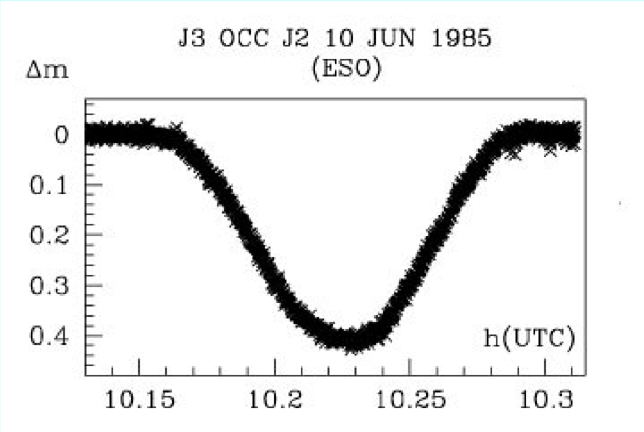
The example above shows what to do and what to avoid. The left curves have been made using a similar sampling of 0.4 second but with a smaller integrating time at right. The dead time between two recordings was too long.
The results are as follows:

	Mollet GEA T41	OHP T80
Time of the minimum	20h 58m 36s +/- 7s	20h 58m 23s +/- 53s
Magnitude drop	0.226 +/- 0.018	0.382 +/- 0.204

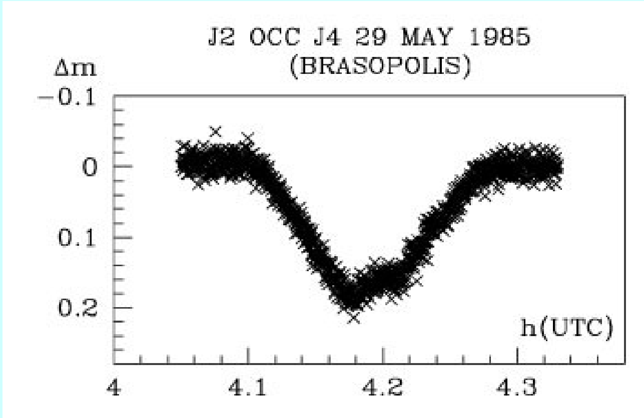
The results are coherent but the bad light curve has larger errors. So, be careful when choosing the integrating time…

2- *The shape of the light curves*

Each light curve contains many informations. The shape of the light curve is one of these informations. Since the disks of the satellites are not uniform, the shape of the light curves is not symmetrical. Only in some cases, the disks are sufficiently uniform to lead to symmetrical light curves. The examples presented here, show that the light curves may be not symetrical or may present a flat bottom (mainly in case of annular events).

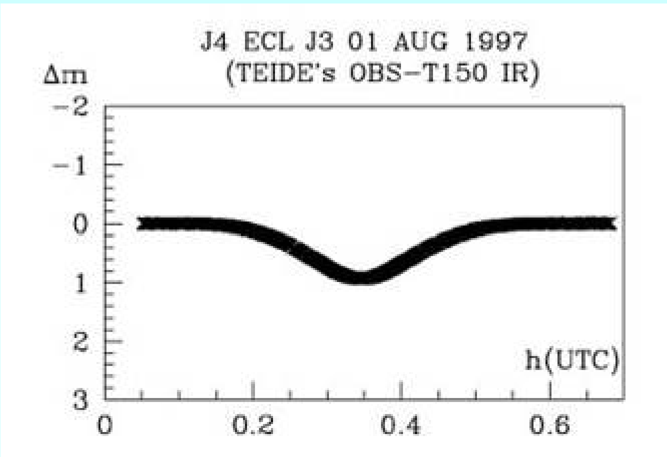


Non-symetrical lightcurve due to the phase defect..

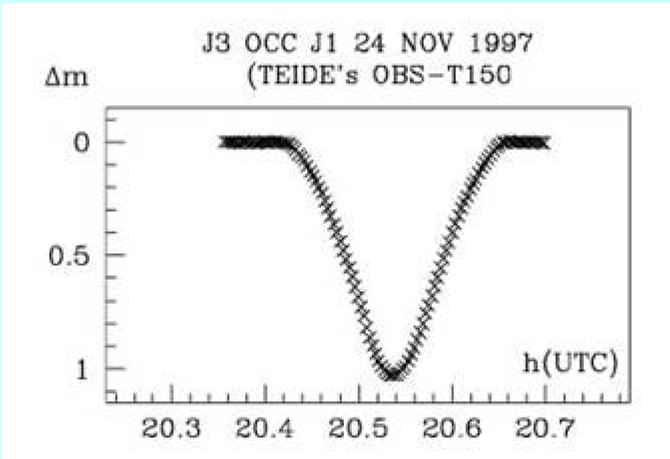


Non-symetrical lightcurve due to surface effects.

Below, good lightcurves: the light curve from an eclipse and one from an occultation. The edge are sharper for an occultation because of the penumbra in case of an eclipse. Be careful: start the observation well in advance in order to be sure to get the beginning of the light curve especially in case of an eclipse.



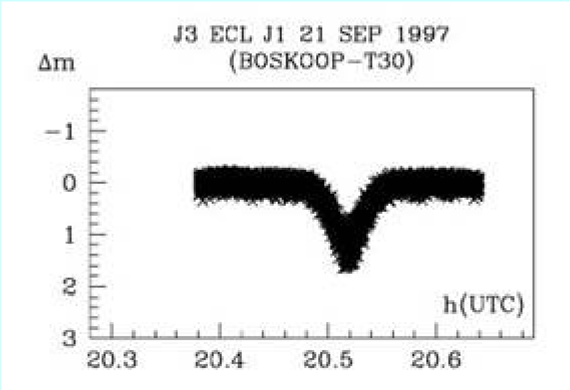
The beginning and the end of an eclipse is smoother than for an occultation

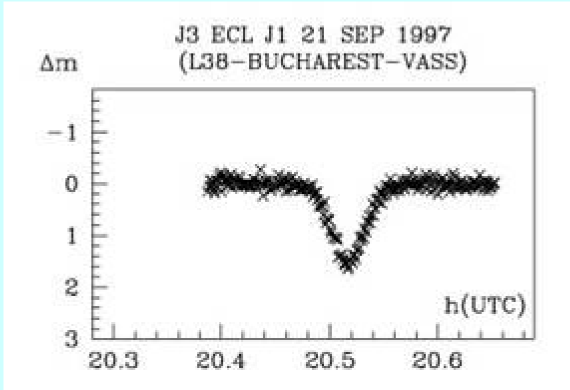


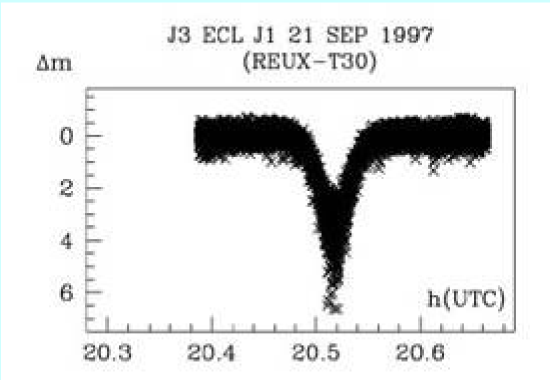
The beginning and the end of an occultation is sharper than for an eclipse

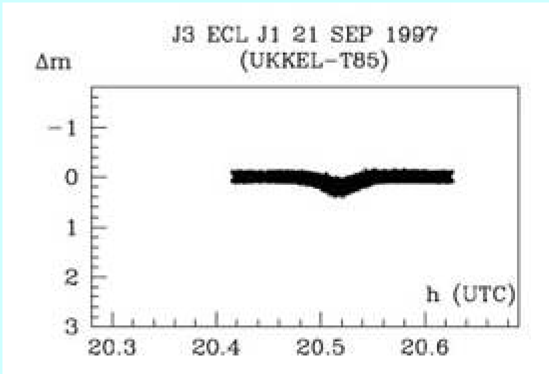
3- *The calibration of the magnitude drop*

A light curve is, in fact, a series of timings, each one associated to a light flux level. The unit for the dates is the time and should be carefully referred to Universal Time. For example, seconds of time starting from a given date in UTC. The unit for the light flux is very important and should be carefully calibrated. In fact, we need to know the flux received from the satellite(s) for each point of the light curve. The scale should be in light flux assuming that no light from the satellite(s) corresponds to a zero flux. The calibration should be relative and it is necessary to provide the flux of the sky background and the flux of the satellite(s) before and after the event. However, comparing several observations of the same event leads to some inconsistencies: the magnitude drop of the same event may be very different. In this case, the photometric calibration has not been done carefully and the receptor may be not well calibrated. The examples provided below show such inconsistencies. Note that the raw data are provided in flux units (0 to 1) since the reduced light curves are provided in magnitude units (0 to ∝).

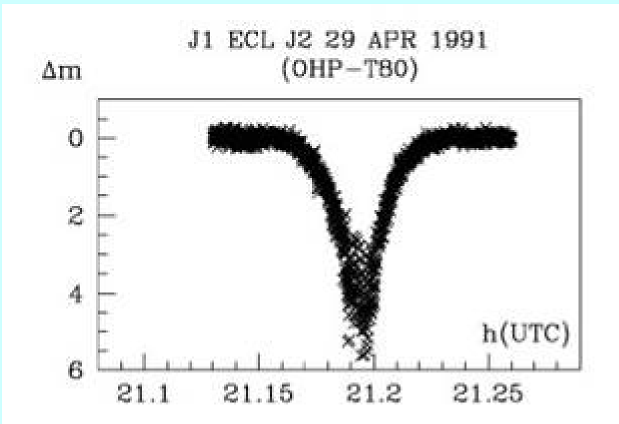








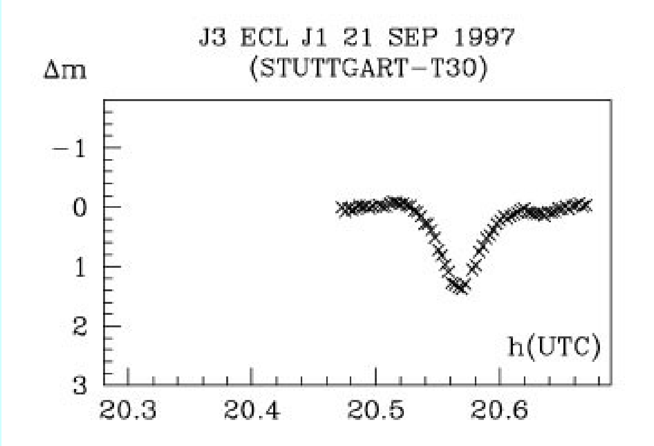
The four lightcurves above concern the same event: unfortunately, if the timings are coherent, the magnitude drops are completely different... This is due to a bad calibartion of the photometry of the observation. The flux zero and the sky background were not noted.
Below an example of a total eclipse: the flux becomes zero and the magnitude drop, measured in magnitudes is very large.



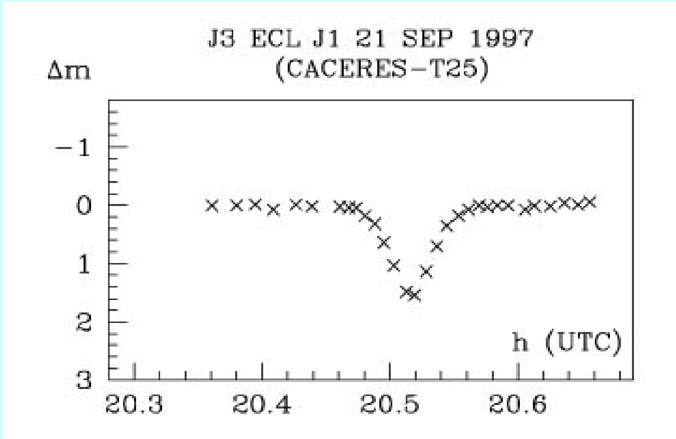
Total eclipse: the magnitude drop increases dramatically

4- *The calibration in time*

Each point of the light curve should be referred to UTC through radio signal, GPS or internal clock verified just before and just after the event. This is not so easy and you should avoid the example below. All observational sites measured the maximum of the event at the same time except one site the timing of which is different from the other of several minutes of time. The observation will be useless.



For this event, the maximum appears to be at 20.57 hours UTC

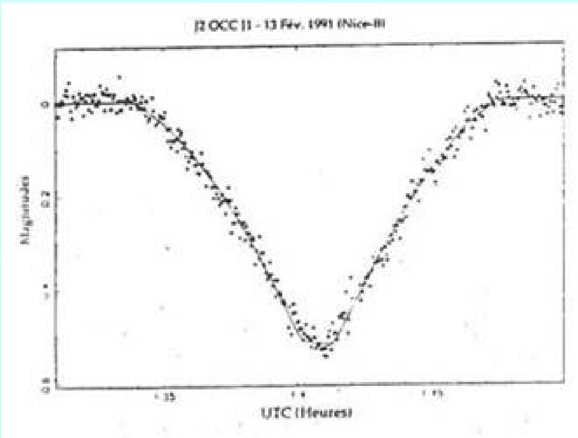


The maximum of the same event appears to be at 20.52 hours UTC

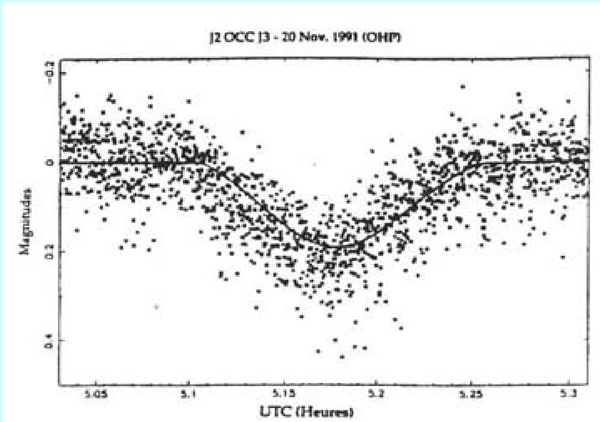
One of those two observations has a wrong timing: a third observation is needed to state which one is to be rejected.

5- *The fit of the light curves: the sampling of each light curve*

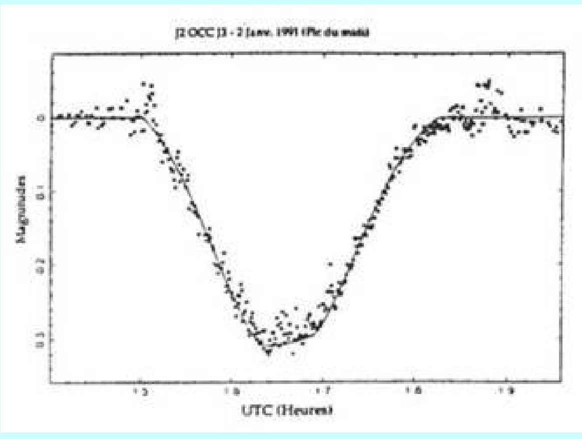
The goal of the reduction is to fit the light curves to a model in order to transform the photometric data into astrometric relative positions. It is necessary to avoid a too small sampling of the light curve in order to get enough points for the fit. The examples below show several attempts of fit of some light curves.



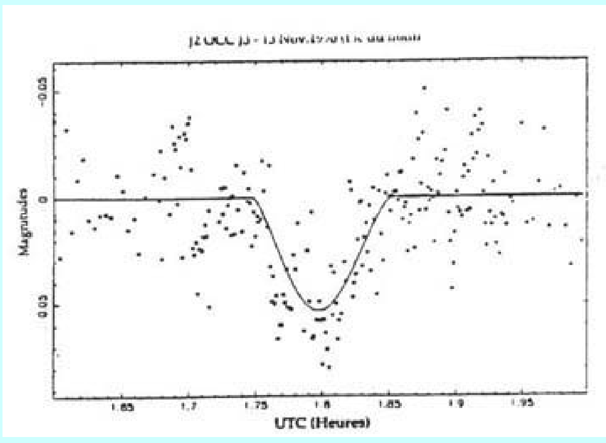
Symetrical deep lightcurve with the fit



Other symetrical light curve with a worst signal/noise ratio and its fit



Non-symetrical lightcurve well fitted by the theoretical model.

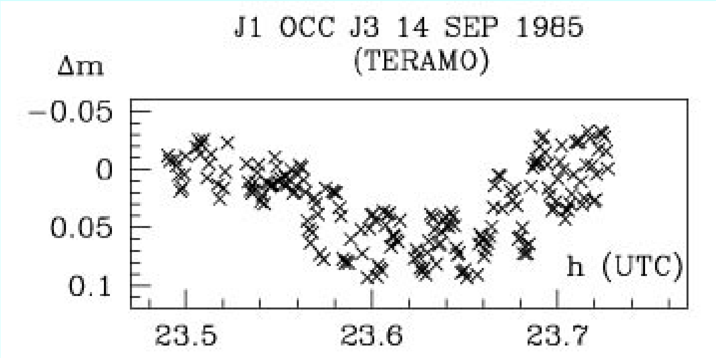


Grazing event with the fit based upon the theoretical model.

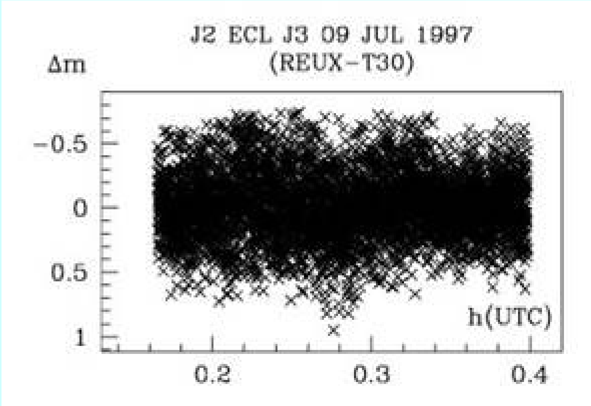
b) The faint light curves

The signal/noise ratio

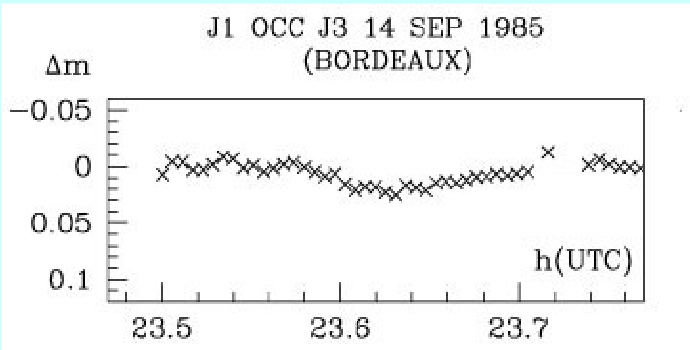
Grazing events with a small magnitude drop may be interesting too. All the problems shown above have to be solved imperatively. If not, the light curves will not be useful. The examples below show the same problems than for deep light curves. However, they may be solved and good light curves may be produced.



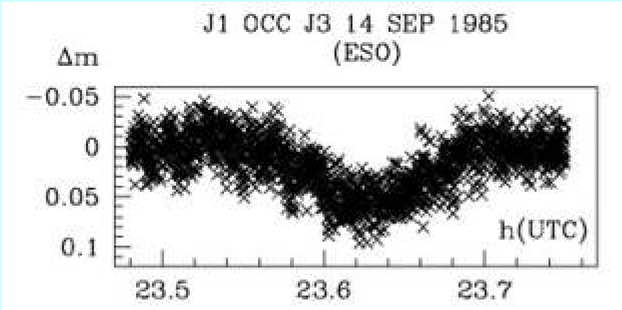
Grazing event: poor signal/noise ratio: however,the observation is sufficient to detect the event.



Grazing event: the magnitude drop is very small and difficult to measure because of the too small signal/noise ratio.



Grazing event: not enough point to have a good determination of the shape of the lightcurve.

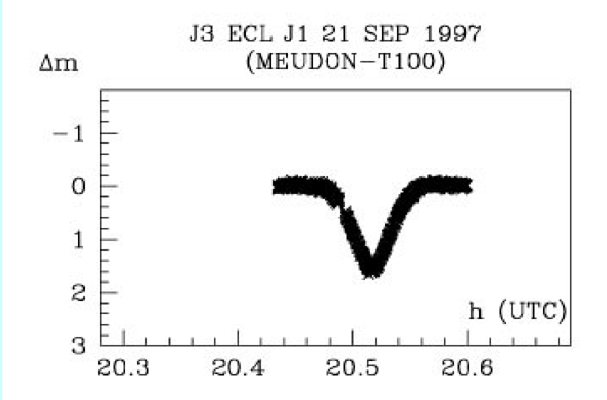


Grazing event: the magnitude drop is very small but easy to measure because of the good enough signal/noise ratio.

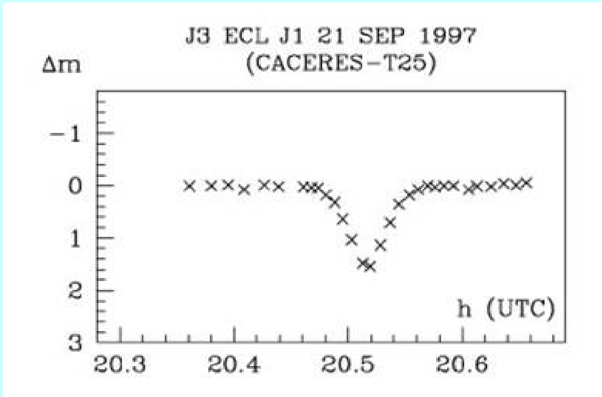
c) The influence of the receptors

1- *Sampling of the light curve*

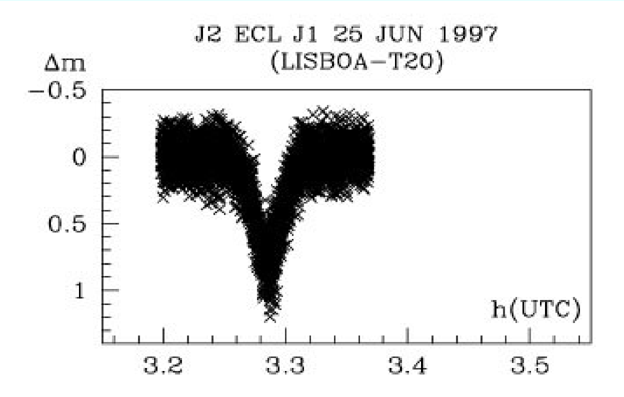
The choice of the sampling of the light curve depends on the receptor. We have to determine the acquisition of the receptor: start of the integrating time, end, reading of the measured light flux, start of the next measurement, and so on... The dead time dedicated to the reading of the measured light flux may be as small as possible. The examples below show the light curves obtained with several sampling. Note that the sampling may be reduced afterwards by software.



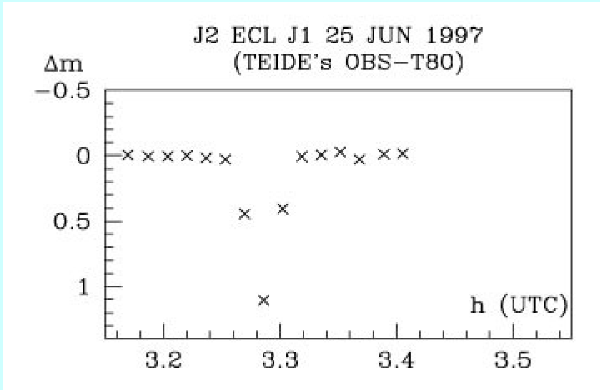
Lightcurve with a sufficient sampling in order to fit a model to the lightcurve.



The sampling is poor but allows a fit of a model to the lightcurve.



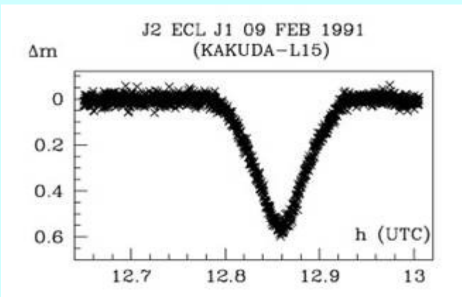
Too large sampling, unuseful. The number of points may be decreased numerically by sum of successive points.



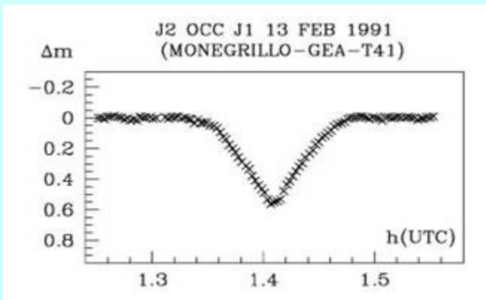
Too poor sampling: the lightcurve is not well-defined.

2- *Which receptor is the best?*

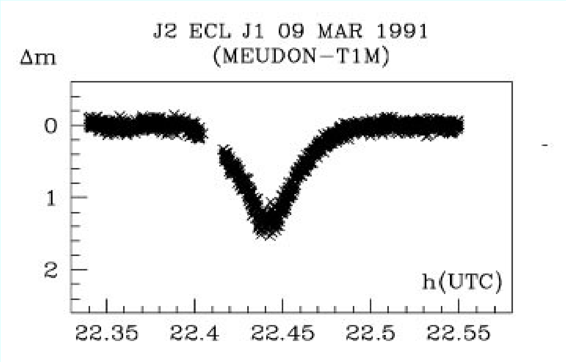
In fact, any fast photometric receptor may be used for the observation of the mutual events. Fast means that it will be possible to get enough points for the light curve. The sampling of the light curve will depend on the duration of the event. The examples below show the influence of the number of recorded points depending on the duration of the events.
Another necessity during a photometric observation is to record reference objects for comparison. We will see in the next paragraph that the two-dimensional receptors are very efficient for that.
We show several examples of light curves made either with a single channel photometer or with a CCD receptor. We show also observations made with other types of receptors, even visual observations for comparison.
In any case, the use of a two-dimensional CCD receptor is the best way to succeed.



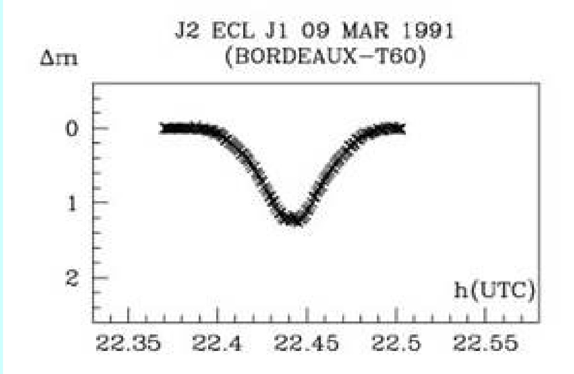
Hamamatsu R647 1P21 photoelectric photometer 15cm refractor, 1 point per second



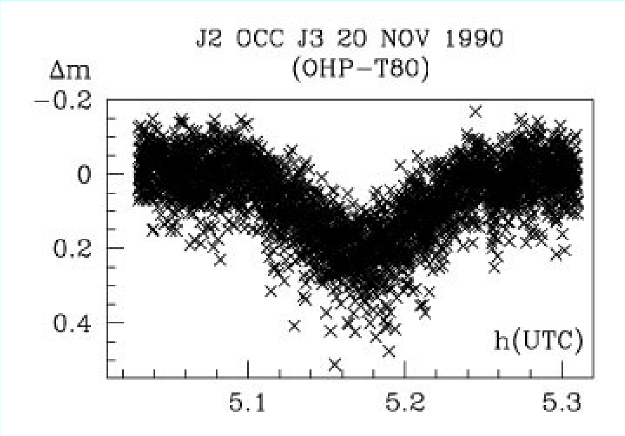
Optec photodiode SSP13 photoelectric photometer 41 cm reflector, 1 pt per 10 seconds



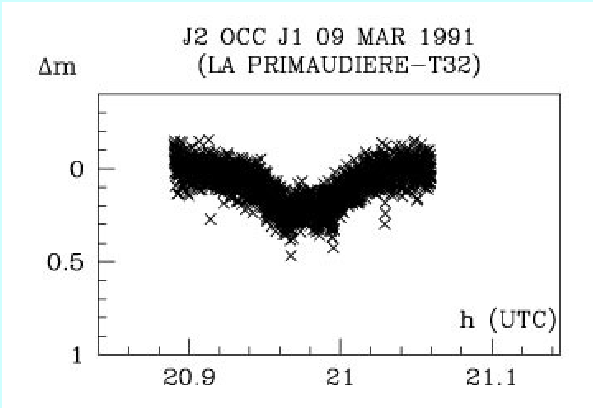
Video Imaintel CCD camera + VCR
1m reflector, 10 points per second



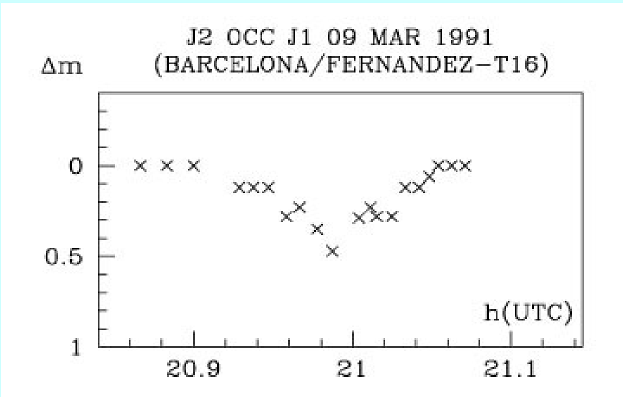
Cooled CCD receptor with TH7852 target
60 cm reflector, 1 point per 1.5 second



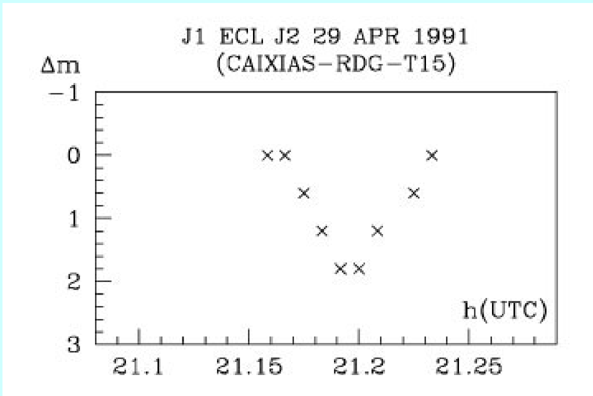
Intensified uncooled video camera (S20 cathode) + VCR 80 cm telescope, 10 points per second



Video camera + VCR 32 cm telescope: 10 points per second



Visual observation with a 16 cm reflector using the Argelander method to estimate the light flux: the maximum of the magnitude drop is well defined but the magnitude drop itself is not.

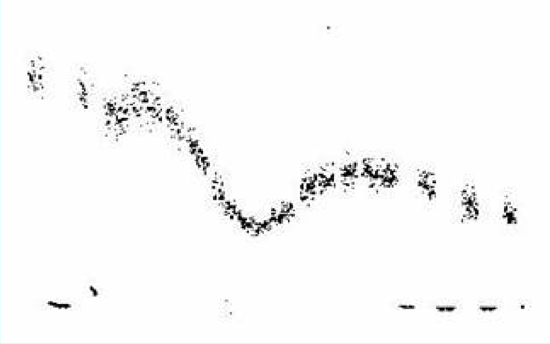


Photographic technique with a 15 cm reflector: the photometric measurement is possible only for long events: 1 point per minute

d) The influence of the transparency of the sky

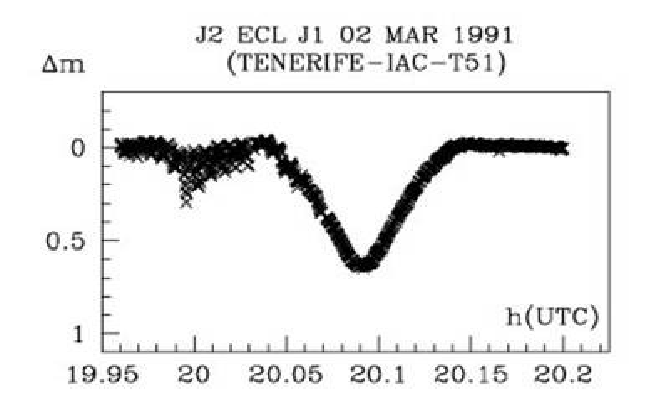
1- *The light curves recorded with bad meteorological conditions*

Since we do not choose the time of the observation, clouds may arrive during the observations. Several cases may occur. The best case is the transit a "small" cloud, occulting a small part of the light curve which may be interpolated (this happens also when interrupting the observation to record the sky background or a reference object). A progressive absorption will lead to a light curve needing to be recalibrated assuming that the light level of the satellite is the same before and after the event. A model of the absorption has to be fitted and substracted from the observation. Examples are provided below.



The absorption of the atmosphere increases during the event:
- the satellite is supposed to be stable before and after the event
- the sky background has been recorded to be sure of its stability

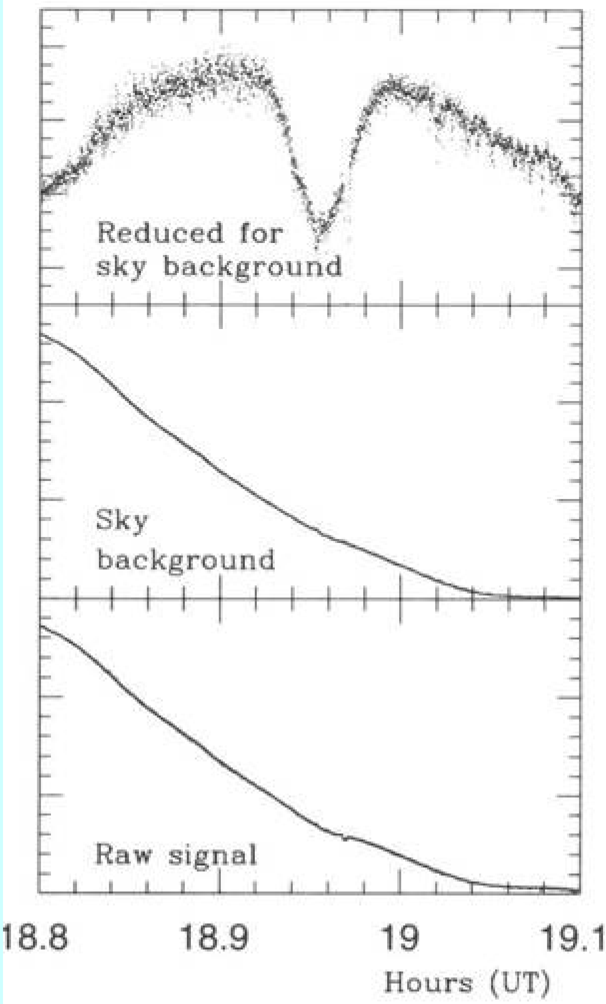
The lightcurve has been recalibrated thanks to the recording at left



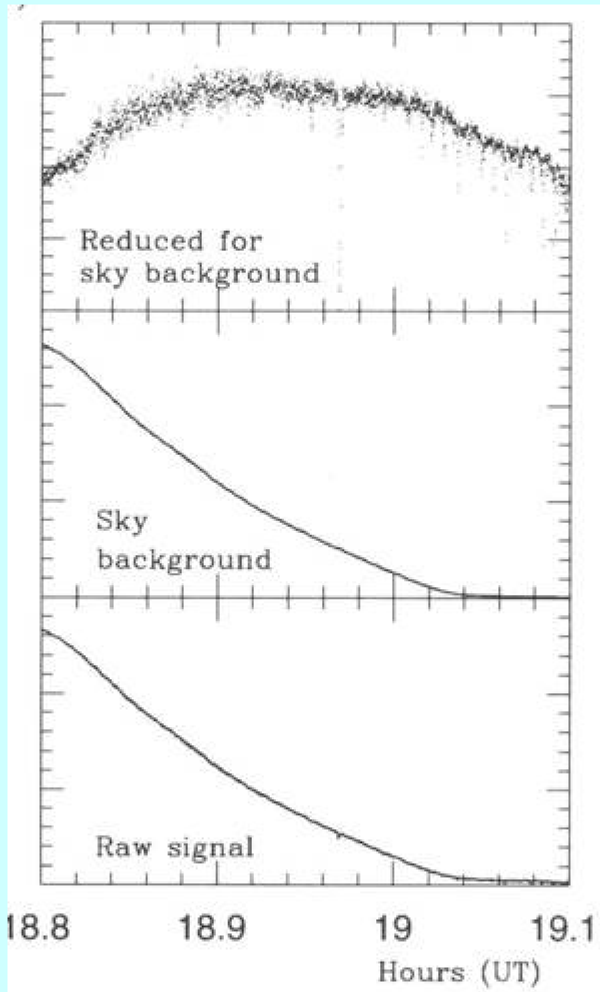
Case of a lightcurve made with some light clouds disappearing after the beginning of the event

2- *The use of the two-dimensional receptors to compensate the bad meteorological conditions.*

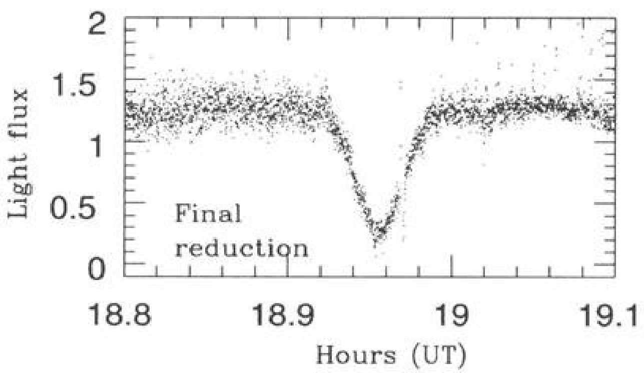
The use of a two-dimensional receptor is a powerful tool in order to make observations with bad meteorological observations and during twilight. The next example (J-1 eclipses J-2 on April 22, 1991, Meudon observatory) shows what we are able to do in such cases: at left the recording of the eclipsed satellite without and with the background (it was twilight) and at right the same with a reference object (light clouds were passing over the site). The combination of these measurement allows to get a good lightcurve of the event.



Eclipsed satellite

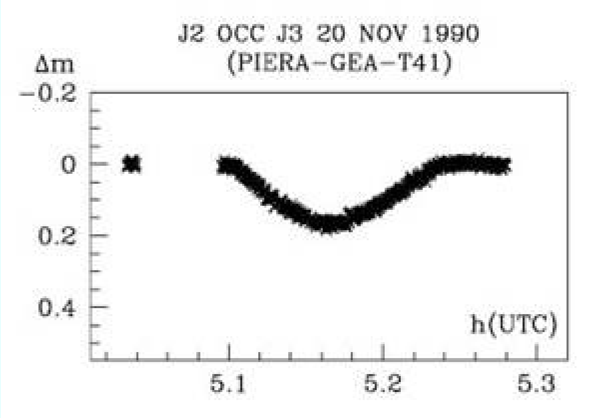


Reference satellite

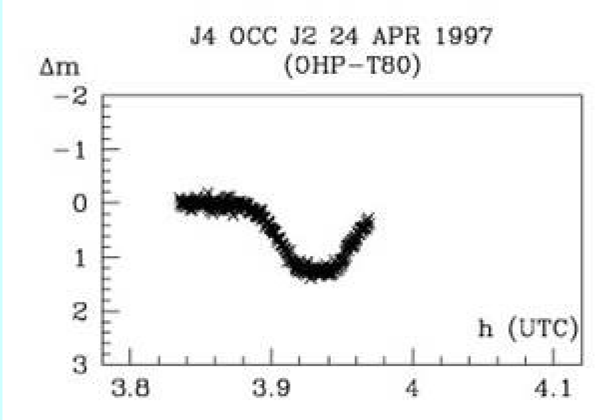


e) Some problems occurring during the observation

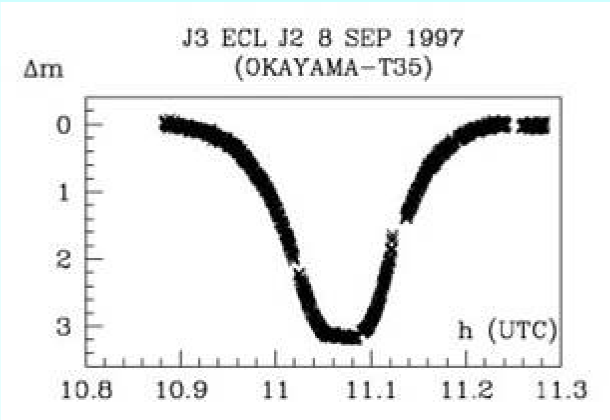
The light curves below show an interruption during the event. In fact this may occur for several reasons: some problems in the receptor and recording system; a stop of the guiding of the telescope needing to find again the occulted or eclipsed satellite ... If the interruption is short, the light curve will be useful. if only the maximum of the event is recorded, the calibration will not be possible except if the satellite outside the time of the event is recorded. However, such a partial observation should not be rejected but kept in order to check the time scale for the light curve of the same event made in another observational site.
In some case, the interruption is made intentionnally in order to record the sky background, or the reference satellite. This has to made when the recording is made only for the occulted or eclipsed satellite without a simultaneous reference and only in case of very long event (more than half an hour) in order to measure the absorption or the sky background if they are changing rapidly (twilight, fog, ...).



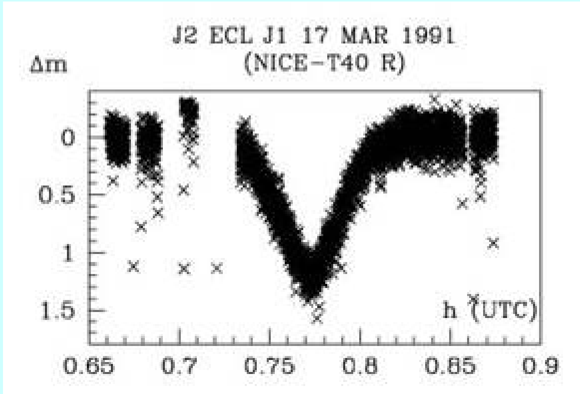
The lightcurve has been interrupted before the beginning of the event: be careful to start the recording of the event sufficiently in adavnce!



The lightcurve has been interrupted too soon and it will be difficult to determinate the end of the event..



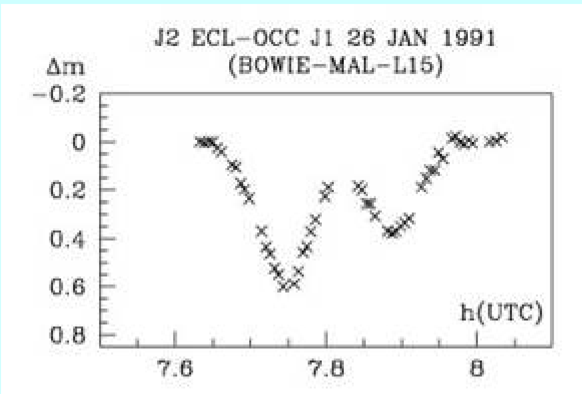
This observation has been interrupted for technical reason; however, the fit of the lightcurve will be possible after eliminating the wrong points.



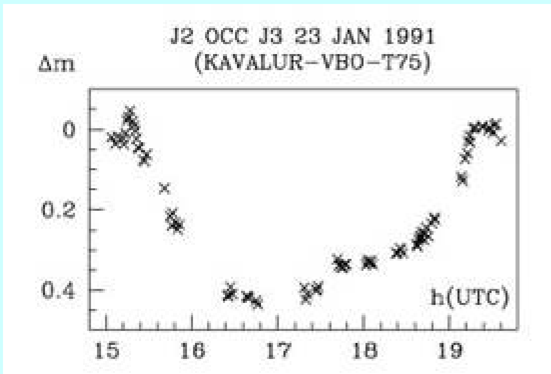
Numerous interruptions for the measurement of references and background: be carefull of the beginning of the event which may occur sooner than predicted.

f) Some very specific lightcurves

The light curves presented below are rare and will be difficult to reduce and to fit to a model.



Double event: the occultation starts before the end of the eclipse



Very long event (more than 4 hours): it is difficult to keep a good photometric accuracy during so much time.

g) The problems related to the sky background

We have seen above how to deal with the changing sky background and the changing transparency of the sky. The closeness of the bright planet may impose a sky background with a high gradient from one side of the image to the other side. It is then necessary to fit a two or three-dimension second order polynomial on the background (after removing all the objects of the image).

8) Filters

We did not indicate the influence of the filters used for the observation. In fact, a red filter will eliminate a part of the sky background. Some specific filter are able to eliminate the light from Jupiter for events occurring near the limb of the planet but think that a narrow filter will decrease the level of the measured light flux. Fortunately, the Galilean satellites are bright. The observation in the infrared wavelengths are interesting too, but the observation is much more difficult and the observers have to know all about the infrared observations.

9) Conclusion

In conclusion, during the observation of the mutual events of the Galilean satellites, everything can happen. The examples given above should help you to analyse your first observations and, if necessary, to improve the observational technique that you use. A good use of your telescope and of your receptor will allow you to get fine observations. The observation itself is not difficult: the Galilean satellites have a magnitude of about 5 to 6.