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Past and future mutual events of the Natural Planetary Satellites: need of a network of observation

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Abstract. The transit of the Earth and the Sun in the equatorial plane of the planets makes possible the occurrence of mutual eclipses and occultations between the planetary satellites. The observations of such events are very fruitful because of the accuracy of the data obtained. Such events occur only during the equinox time of the planets i.e. every 6 years for Jupiter (..., 1997, 2003, 2009, ...), every 15 years for Saturn (..., 1995, 2010,...) and every 42 years for Uranus (..., 2007,...). Since these events are rare and occur at any time during a short period of a few months, a worldwide network of observers is very important. We will explain the specific nature of these observations and encourage the observers to join the network, mainly for the exceptional Uranian occurrence in 2007.

Introduction

Since 1973, the mutual events are extensively observed during the favourable periods. The observations are easy for the Galilean satellites because of their brightness but are more difficult for the Saturnian or the Uranian satellites which are fainter. More, for Uranus, such events happen very rare. So, in order to obtain as many observations as possible, we need to use a network of observers well equipped with telescopes and receivers able to provide useful data.

1. The observations of the natural planetary satellites

The natural planetary satellites are as small solar systems. Such systems are very interesting to be studied, showing many dynamical effects due to the perturbations by the oblateness of the planet, by the other satellites and by the Sun and the other planets. More, some tidal effects are now possible to be put into evidence if a sufficient number of accurate observations are available.

For that purpose, we need to make regularly observations which are of two kinds:

- first, the direct astrometric observations (figure 1, at left). The satellites are bright points in a field with stars. These stars allow to make a classical astrometric reduction since they could be found in an astrometric catalogue. Such observations have been made in the past with photographic plates and are now performed using CCD cameras. However, such a method has its limit in the astrometric accuracy as indicated in the table n1. A description of this type of observation is provided by Pascu (1977).

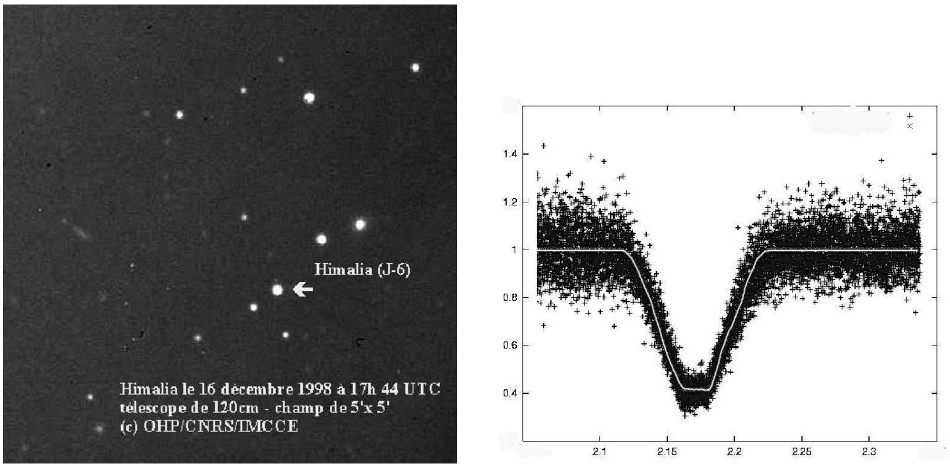

Figure 1. *Left:* Astrometry through image. *Right:* Astrometry through photometry.

- second, the photometric observations of some events such as eclipses or occultations. The main phenomena are eclipses of the satellites by the planet itself occurring, in the case of the Galilean satellites, for each revolution of the satellites. Unfortunately, the shadow of Jupiter is not well known because of the thick atmosphere that decreases the accuracy of the observations (cf. table 1). However, the mutual events between the satellites themselves are much more accurate as they have no atmosphere. The analysis and the fit of the photometric light curve provide the distance between the satellites with an accuracy in kilometers and not in arcsec that is more interesting for distant objects (cf. table 2). Many results have been obtained: published catalogues of observations of the events of the Galilean satellites (Arlot et al. 2006) and of the Saturnain satellites (Thuillot et al. 2001) and astrometric data deduced from these events (Kaas et al. 1999, Vasundhara et al. 2003).

With the photometric observation, the direct astrometric measurement is replaced by a photometric measurement against time (figure 1, at right). It is a light curve which includes physical properties of the surface of the body and dynamical parameters of the motion of both satellites.

Table 1. Accuracy depending on the kind of observation: case of Jupiter

Kind of observation	Accuracy (mas)	Accuracy (mas)
Eclipses by Jupiter	150	450
Old photographic plates	100	300
Transit circle	60	180
Plates newly reduced	50	150
CCD observations	40	120
Mutual events	15	45

Table 2. Accuracy depending on the kind of observation: case of Uranus

Kind of observation	Accuracy (mas)	Accuracy (mas)
CCD observations	40	400
Mutual events	6	60

2. The occurrence of the mutual phenomena

As shown in figure 2, the mutual events (eclipses when a satellite passes through the shadow of another satellites and occultations when a satellite goes behind another satellite for a terrestrial observer) occur when the Earth and the Sun pass through the equatorial plane of the planet which is, in the case of Jupiter, Saturn and Uranus, the orbital plane of the main satellites.

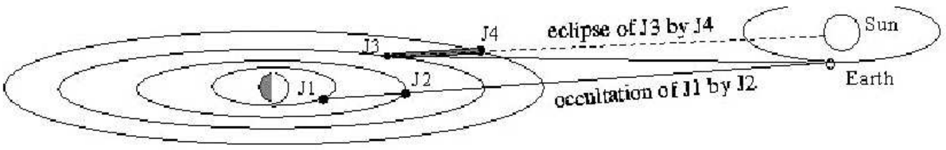

Figure 2. Configuration of the satellites for mutual events

Figure 3 shows, as example, the jovicentric declinations of the Earth and the Sun in 2003 and in 2009: mutual events occur when these declinations become zero.

Note that the occurrence is much more favourable when it occurs during the opposition of the planet in order to make the observations possible. For Saturn, this planetocentric declination becomes zero every 15 years, e.g. in 1995 and 2010. For Uranus, it will occur only every 42 years, e.g. in 2007-2008: we should make a special effort for this rare occurrence.

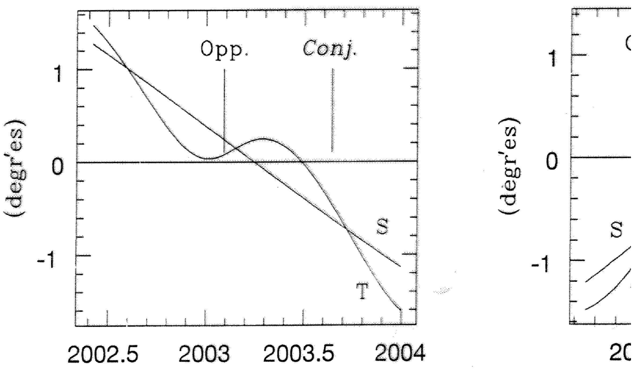

Figure 3. *Jovicentric declinations of the Sun and the Earth. Left:* 2003. *Right:* 2009.

3. The observations of the mutual events

Even the observation of the mutual events seems to be easy, many precautions had to be taken in order to get a useful observation. First of all, the telescope and the receiver must be adapted to the event: the size of the telescope must be chosen depending on the magnitudes of the satellites. If the Galilean satellites have a magnitude around 5 and need small telescopes, the Saturnian ones have a magnitude from 10 to 15 and the Uranian ones from 14 to 16 needing even larger telescopes, at least with a one meter aperture. Don't forget that the photometric observation has to be sampled with time: one point every second of time is necessary depending on the duration of the event. For a long event (more than 20 minutes), one point every 5 seconds of time is sufficient but for events less than 10 minutes, one point every second of time may be necessary. Second, one must remind that each point of the light curve may be referred to UTC within less than 0.1 second of time: the velocity of the satellites being around 10 km/s, an accuracy of the timing of 0.1 second of time may lead to an astrometric accuracy of 1 km! Third, the filter must be chosen depending on the sky background. For satellites far from the planet, a R filter may be used. For satellites close to the planet, a specific filter which will darken the planet is very useful. Don't forget that a narrow filter will imply a larger telescope!

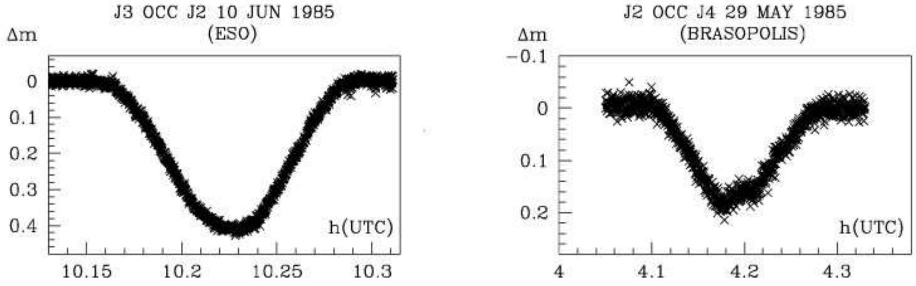

Figure 4. *Left:* Light-curve with a good signal/noise ratio. *Right:* Light-curve with asymetry.

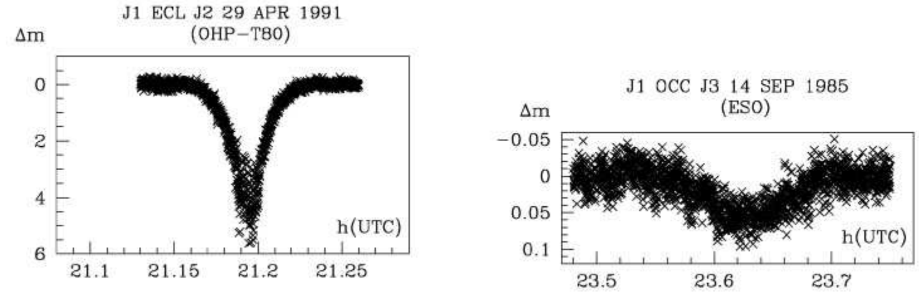

Figure 5. *Left:* Deep event (6 magnitudes). *Right:* Faint event (0.05 magnitude.

The events may show a large magnitude drop or a faint one. The light curves may be noisy or not. The figures 4 and 5 show several examples of light curves: figure 4, at left, a light curve without noise, at right, a non symmetrical light curve providing information on the surface of the occulted satellite.

Figure 5, at left, shows a deep total event, the magnitude drop being large and figure 5, at right, a very faint event, its magnitude of being less than one tenth of a magnitude. The main problem encountered by the observers is that it is not possible to choose the time of the event. At that time, for a given site of observation, the satellites may be low above the horizon or the sky may be cloudy. A large network of sites of observation may allow to have at least one site where the observation could be done in good conditions. However, since the observation is made in relative photometry, it is possible to obtain valuable data even under difficult conditions. Figure 6 shows the light curve recorded during an event made when the satellites are low above the horizon, during twilight and through slight clouds! Since a CCD target was used, it was possible afterwards to determinate the photometric variation of several zones of the field. Figure 6, at left, shows the raw signal of the eclipsed satellite and, at right, the signal from the background. The twilight leads to an exponential variation but after subtracting the sky background from the signal of the eclipsed satellite, the light curve shows the magnitude drop due to the mutual eclipse (figure 7, at right), the signal from another satellite not eclipsed, supposed to be constant during the short time of the event. After, subtracting the sky background from the signal received from a reference satellite not affected by any event, we get the flux from the reference satellite which not constant due to the clouds (figure 7, at left). Dividing the signal of the eclipsed satellite by the one of the not eclipsed satellite leads to the light curve of figure 8 which has been then correctly reduced. This shows the interest of a two-dimensional target such CCD's for the observation of the mutual events. If you use a single-channel photometric receiver, be careful to record from time to time, the sky background around the involved satellite (attention to the planet implying a gradient in the background of the satellite) and a reference object such as another satellite or a star (preferably a solar-type star).

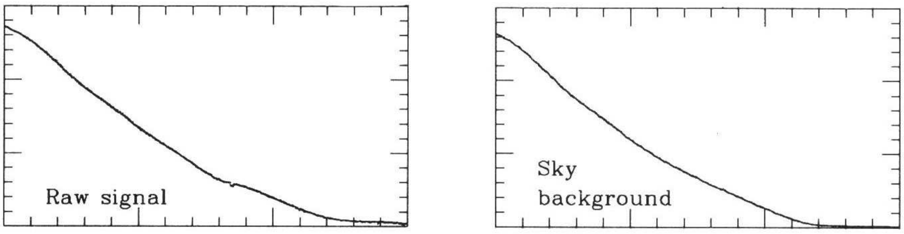

Figure 6. *Left:* Raw signal of the event with the sky background dominating. *Right:* The sky background during the event (twilight).

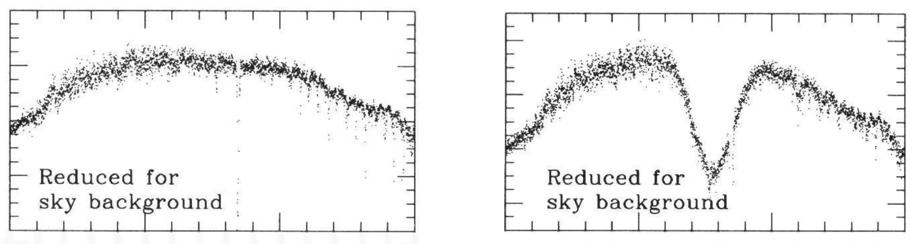

Figure 7. After elimination of the sky background. *Left:* Reference object. *Right:* Eclipsed satellite.

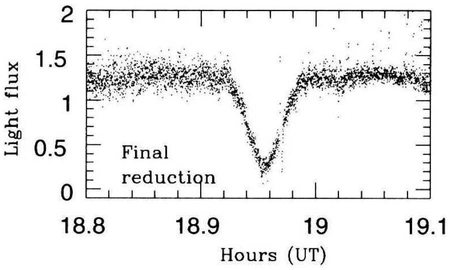

Figure 8. Reduced light-curve.

4. The infrared observations

Another source of information is the infrared observation. The distribution of the emission from the surface of the satellite is very different in the visible light (solar spectrum showing the shape of the satellite) and in infrared light (thermal emission). In the infrared light, hot spots, if any, will be dominating. This is the case of Io, the first satellite of Jupiter. For a given level of radiance, the solar reflected light is dominating below 2 micrometers and the thermal emission is dominating after 10 micrometers. Between 2 and 10 micrometers, only hot spots may be seen. The challenge was to observe an occultation of Io by another satellite in this spectral band: the modeling of such an event is shown by figure 9 at left, and the observational result at right. It is possible to measure the flux and temperature of the hot spot (hotter than previously supposed) together with its position on the satellite thanks to the other observations in the solar spectrum of the same occultation.

5. The network of observers

All these observations need a network of observers for several reasons: - the events occur at any time: the observers must have the objects observable (at least above the horizon) so the observing sites should be distributed all over the Earth; - the meteorological conditions may be different from a site to another, even for very close sites so higher the number of sites is, larger will be the number of possible observations; - each site has not several receivers working at different wavelengths (solar spectrum and infrared wavelengths) so the sites equipped

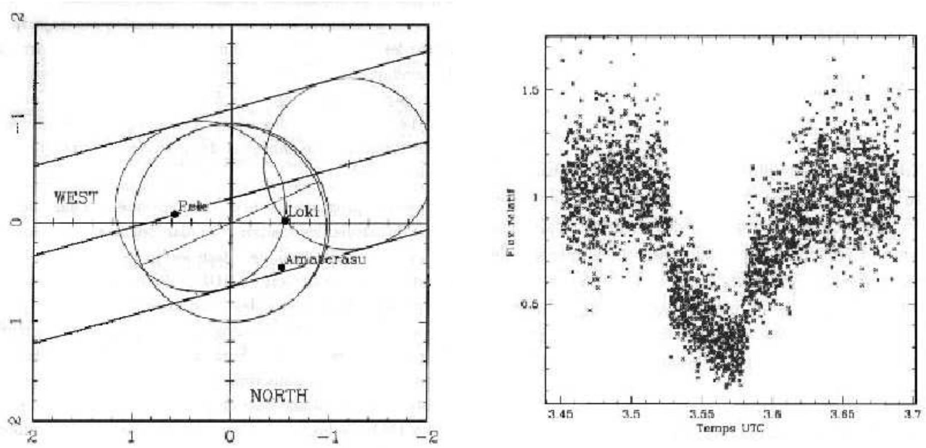

Figure 9. *Left:* Occultation of Io by Europe. *Right:* Observation of the occultation at 2 micrometers.

with different materials are welcomed. Most of the observing sites are in the northern hemisphere (Europe, Asia, North America, Hawaii) that is penalizing when the declination of the observed objects is negative. A few site will be available in South America and Australia. Table 3 shows the results obtained for past campaigns. For the Uranian campaign, the faintness of the satellites will require larger telescopes. We call for new observers joining our network.

Table 3. Past campaigns of observation of the mutual events of the Galilean satellites

	1985	1991	1997	2003
sites of observations	28	36	42	34
number of observations	166	401	255	271
observed events	64	115	122	104

6. The case of the Uranian satellites in 2007

In 2007-2008, taking the opportunity of the equinox on Uranus, we could observe mutual events and eclipses by the planet of the satellites. Figure 10, at left, shows the major satellites of Uranus and, at right, shows the fainter satellites Miranda and Puck in the infrared wavelength, not visible so easily in the visible light.

The V-magnitude of the satellites are as follows:
Ariel: magnitude 14.4
Umbriel: magnitude 14.8
Titania: magnitude 13.8
Oberon: magnitude 14.2
Miranda: magnitude 16.5

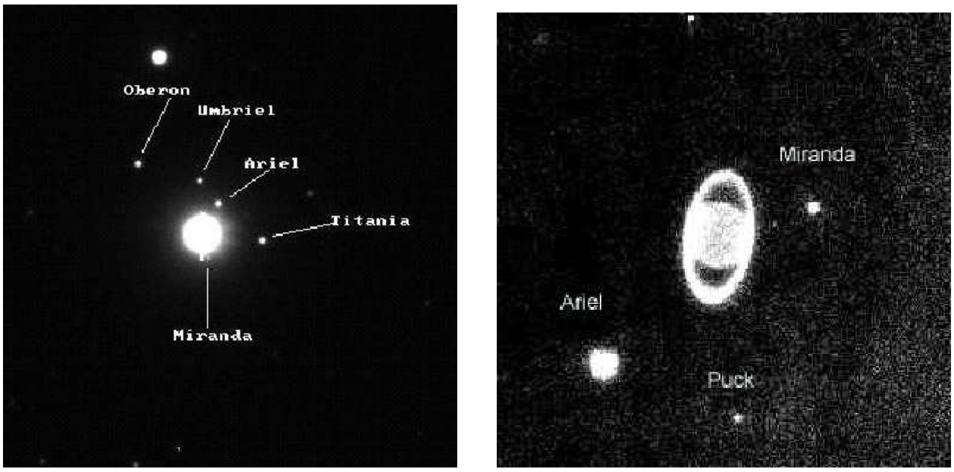

Figure 10. *Left:* The main satellites of Uranus in visible light. *Right:* The fainter satellites of Uranus in infrared wavelengths.

Puck: magnitude 20

This is the high difference in magnitude between the satellites and the planet Uranus (V-magnitude 5.7) which makes difficult the observations. We encourage to observe the events involving the fainter satellites Miranda and Puck in the infrared wavelengths. The list of the observable events has been published (Arlot et al. 2006) and is available together with technical information concerning the observation on the web site of IMCCE at the address: http://www.imcce.fr/pheura07 Note that from a given site, for example Antalya, 16 events are easily observable and more are possibly observable.

7. The scientific goals of the observation of the mutual events

The observation of the mutual events provide valuable information for several goals:

- The study of dynamics of systems of natural satellites: they are small solar systems allowing to understand formation and evolution of such kinds of systems. For that purpose we need accurate astrometric observations in order to be able to build confident models of the motion.
- The making of models including all gravitational effects and dissipation of energy: this needs a high astrometric accuracy of the observations in order to quantify all physical and dynamical parameters and measure accelerations. Figure 11 shows the effect of the tides on the motion of a satellite, effect that we intend to measure through accurate astrometric observations. Table 4 shows the preliminary results obtained for the accelerations of the Galilean satellites of Jupiter.
- The analysis of infrared observations may help us to know better the surface of the satellites (temperature, albedo,...) together with other types of observations, especially from the space probes.

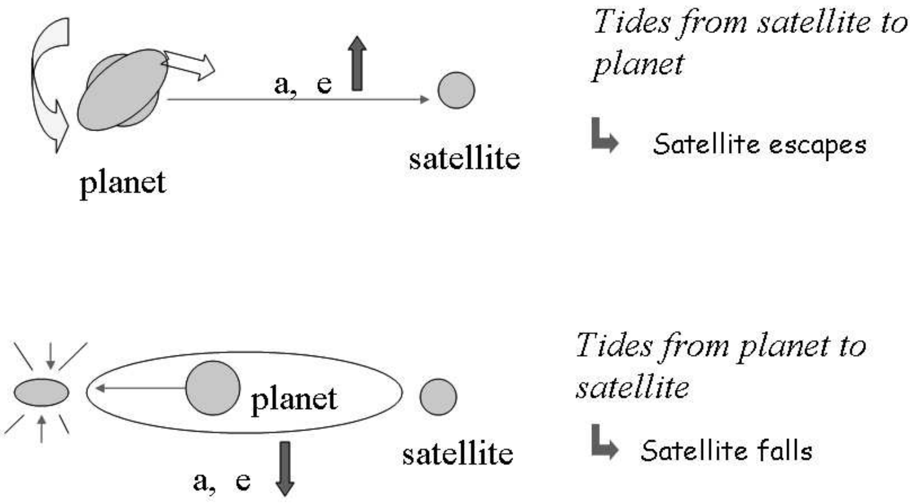

Figure 11. The consequences of the tides on the motion of a Galilean satellite.

Table 4. The tidal effects through the measure of the accelerations

	n'1/n1	n'2/n2	n'3/n3
De Sitter (1928)	+33 + / − 5	+27 + / − 7	−15 + / − 6
Greenberg (1986)	+32 + / − 8	−16 + / − 4.5	−16 + / − 4.5
Goldstein (1996)	+70 + / − 75	+56 + / − 57	+28 + / − 20
Vasundhara et al (1996)	+22.7 + / − 7.9	−6.1 + / − 9.3	+10.6 + / − 10.6
Aksnes et al (2001)	+54.7 + / − 16.9	+27.4 + / − 8.4	−27.4 + / − 8.4

Conclusion

Mutual phenomena of the Uranian satellites are rare and difficult to observe due to the large distance from Earth (and then due to the faint magnitude of the objects).A large network of observers will be welcome to facilitate the observation of as many observations as possible. Information on the next campaign could be found on the web site: http://www.imcce.fr/pheura07 Contact by e-mail: arlot@imcce.fr A Workshop will be held in Paris on November 16-18, 2006 for discussion and organization of the observations: Web site of the workshop: http://paris2006.imcce.fr

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