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Predictions and observations of events and configurations occurring during the Uranian equinox

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Abstract

The occurrence of the Earth and Sun transits through the equatorial plane of Uranus will bring us the opportunity for observations only possible at that time: mutual events of the satellites, search for new faint satellites and measurement of the thickness of the rings.

The predictions of the mutual events need a theoretical model of the motion of the satellites. The calculated occurrences of the occultations and eclipses highly depend on the model since these predictions are very sensitive to the relative positions of the satellites. A difference of 0.05 arcsec in latitude may make an event inexistent and the accuracy of the theoretical models is around 0.1 arcsec.

In order to be sure of the occurrence of each event, we made the predictions using three theoretical models: the first one is GUST86 made by Laskar and Jacobson in 1986, the second is GUST06 based on the former model fitted by Emelianov on new observations and the third one is LA06 based on a brand new theory with an accuracy 10 times better than GUST and fitted on recent observations made since 1950.

This comparison shows that some events predicted with one model are not predicted using another one. We try to select the events which will occur surely in order to help the observers to catch the best phenomena.

The search for new satellites and the measurement of the thickness of the rings are planned by means of observations at the time of the transit of the Earth in the ring plane.

Keywords: Celestial mechanics; Uranian satellites; Mutual occultations; Eclipses; Ephemerides

1. Introduction

The Uranian ring plane crossing time provides an opportunity to make rare observations of events occurring only every 42 years since the Earth and the Sun will cross Uranus' equatorial plane. Since we succeeded in the past in observing the same events occurring near Saturn and Jupiter, it appears that we should encourage the observations of the events near Uranus in spite of difficulties due to the faintness of the Uranian satellites and this proximity to the planet.

2. The equinox: an opportunity for the observation of rare events

(1) *The case of Jupiter*: Since 1973, the mutual events of the Galilean satellites, occurring during the Jovian equinox, are observed worldwide (Aksnes and Franklin, 1990; Arlot, 2002; Arlot et al., 2006a, b). The equinox on Jupiter takes place every 6 years allowing mutual occultations and eclipses to be seen from the Earth since the satellites are orbiting in the same plane, mainly the equatorial plane of Jupiter. At the time of the equinox, the Sun (and the Earth) are on this plane allowing the events to be seen for a terrestrial observer. The magnitude of the satellites (from 4 to 6 magnitude) allows observations even with small telescopes. All the past observations provided us the experience of the

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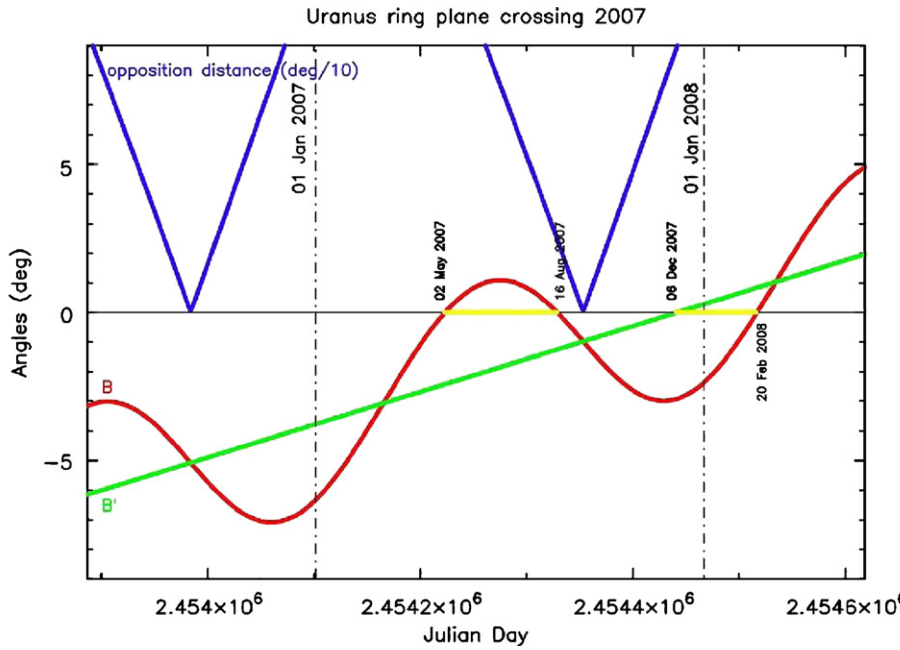

Fig. 1. Evolution of B, sub-Earth uranocentric latitude (in degrees), B′, Sun sub-latitude (in degrees).

making of observations and their reduction. The high astrometric accuracy allowing to determine very precise relative positions of the satellites at the time of the event, associated to the possibility of analyzing the surfaces of the satellites made these observations very popular among the astronomers interested in the study of the Galilean satellites. Moreover, after 30 years of observations, the data allowed us to determine very faint effects in the motion of the satellites such as an acceleration, signature of the internal structure of the satellites. The occurrence of 2003 made numerous observations possible and we will take benefit of the one of 2009 for a new campaign of observation. The jovicentric declinations of the Sun and the Earth become zero in 2003 and 2009, at the time when the Earth and the Sun cross the equatorial plane of the planet. Fortunately, these crossings occur near the time of the opposition of Jupiter making the observations easier.

(2) *The case of Saturn*: Since the orbital period of Saturn is near 30 years, the equinox occurs every 15 years. The last observational occurrences were in 1980 and in 1995 (Aksnes and Dourneau, 1994; Aksnes et al., 1984; Arlot and Thuillot, 1993; Thuillot et al., 2001) and the next one will be in 2009. The seven main satellites are implied in these events (Iapetus has a too large inclination of 18°, since the others have an inclination near 1°). Examples of light curves obtained during this occurrence are presented in Fig. 2. Comments will be given in Section 6.

(3) *The case of Uranus*: The long orbital period of Uranus (84 years) makes the equinox occurring only every 42 years. During the last occurrence, in 1965, no observation of the mutual events was possible because of the faintness of the satellites (magnitude 14–16) and of the poor accuracy of the ephemerides. The 2007–2008 occurrence will allow the observations either thanks to adaptive optics permitting observations near the planet or thanks to infrared detectors making the planet darker. Fig. 1 shows the uranocentric declination of the Sun and the Earth.

3. The interest of the mutual events

(1) *What is a mutual event*? Because of the configuration of the system Sun–Earth–planet, the satellites will occult and eclipse each other during a period of about 1 year, depending on the relative inclinations and of the size of the different satellites. Smaller satellites will show less events than larger ones.

The eclipses do not depend on the terrestrial observer: a satellite will enter the shadow cone of another satellite. When observing the eclipsed satellite, one will record the flux from the satellite vs. time. In case of a total eclipse, the remaining flux will become near zero.

In contrast, the occultations depend on the observers because one must have the observer and two satellites on a same line. The occulted satellite will disappear behind the occulting satellite. As before, recording the flux of both satellites together, an observer will see the flux first decreasing then increasing as for the eclipse.

Examples of light curves are given in Fig. 2. Comments are given in Section 6.

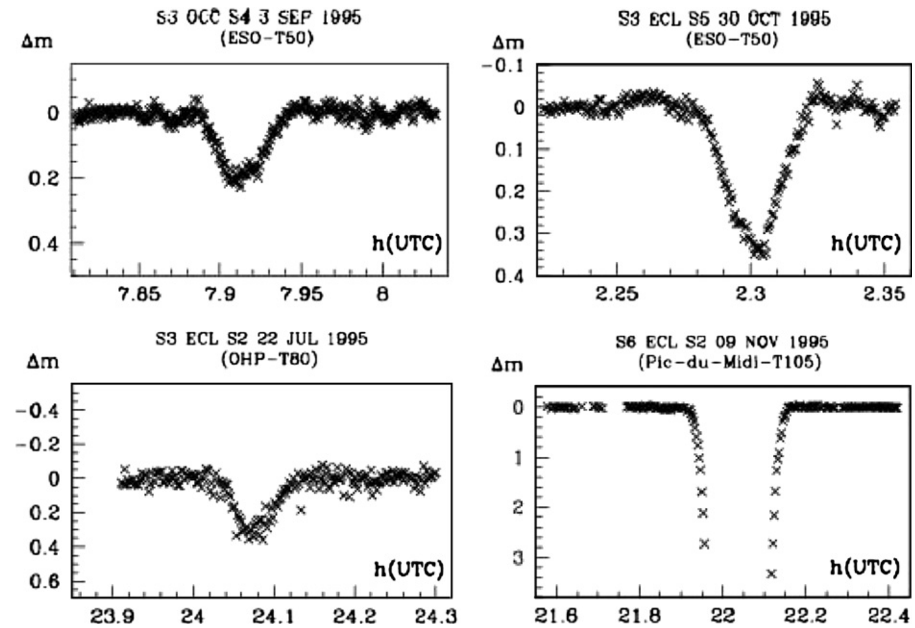

Fig. 2. Examples of light-curves obtained with the Saturnian satellites.

Table 1
Accuracy of the Galilean satellites observations

Type of observations	Accuracy	
	mas	km
Eclipses by Jupiter	150	450
Photographic plates	100	300
Automatic transit circle	60	180
Digitized plates	40	120
CCD observations	40	120
Mutual events	10	30

Table 2
Accuracy of the Uranian satellites observations

Type of observations	Accuracy	
	mas	km
CCD observations	40	400
Mutual events	5	50

(2) *The accuracy of the observation of mutual events*: The observation of a mutual event is a photometric observation which provides information on the flux of the satellites and on their positions. In order to be able to determine such very accurate positions from the mutual event, one must be very careful to be sure that each image is referred to UTC within less than 0.1 s of time. A reference object with a constant flux must be recorded in order to get an accurate photometry of the observation. Our experience of these observations makes possible the comparison of their accuracy with direct astrometric measurements as provided in Table 1 for the Galilean satellites and in Table 2 for the Uranian satellites (provided in mas—milliarcsec—and km—kilometer).

4. The different theoretical models

We used three ephemerides: GUST86 (Laskar and Jacobson, 1987) fitted on observations made from 1911 to 1986, GUST2006 (Emelianov, 2006) based on the same theoretical model and fitted on observations made from 1911 to 2005 and LA06 (Arlot et al., 2006a, b) based on a N-body code including Uranian gravity field and solar perturbations and fitted on observations made from 1948 to 2005. The internal accuracy of these models is about 80 km for GUST86 and GUST2006, and 10 m for LA06. The external accuracy is much more larger and the comparison of the ephemerides issued from these models leads to a maximum difference of 500 km.

5. The predictions of the events

The prediction of the mutual events is very sensitive to the accuracy of the ephemerides. We must know as accurately as possible the relative inclinations of the orbits of the satellites. Table 3 shows the sizes of the satellites (apparent angles and km). The ephemerides uncertainty (500 km) must be compared to the sizes of the satellites, showing the maximum uncertainty for the prediction of grazing events. In order to make a line observer–satellite–satellite for the occultations or Sun–satellite–satellite for the eclipses to have an event, the accuracy depends on the size of the satellite and of the accuracy of the ephemeris. Two effects modify the predictions: a shift in longitude

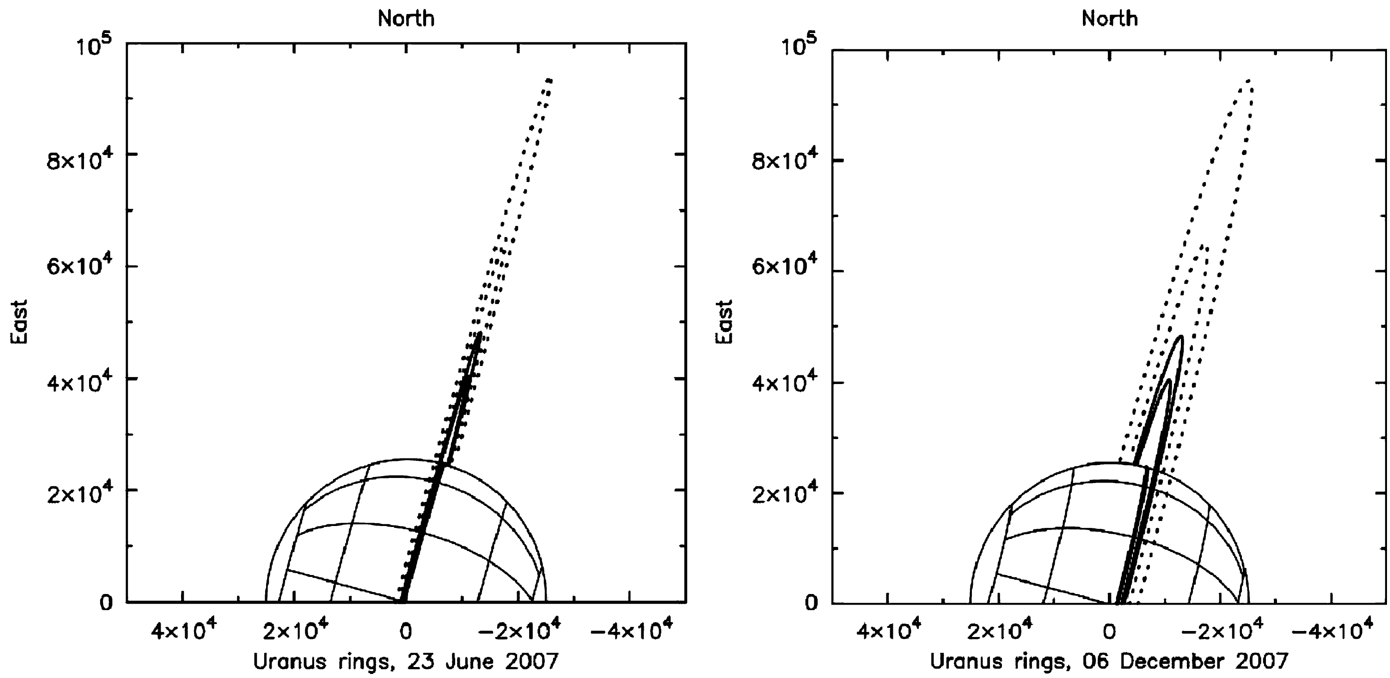

Fig. 3. Aspect of Uranus rings at two different dates: left—23 June 2007, ring opening of 1°.08, and right—06 December 2007 during the Sun RPX, with a ring opening of 2°.93. Each field is about 7.1 × 7.1 arcsec. The thick curves delineate the limits of the main rings, while the dotted lines show the faint dusty ring R1 and R2 recently discovered by HST (Showalter and Lissauer, 2001; de Pater et al., 2006), regions where more rings and more small unknown satellites could be present.

Table 3
The diameters, magnitudes and albedoes

Satellite	km	mas	R-magnitude	R-albedo
Miranda	480	48	14.4	0.310
Ariel	1162	116	14.8	0.374
Umbriel	1169	117	13.8	0.185
Titania	1578	158	14.2	0.234
Oberon	1522	152	16.5	0.230

which makes the event to take place latter or earlier and a shift in latitude which increase or decrease the magnitude drop. For grazing events (those with a small magnitude drop), an event may be predicted using an ephemeris and may be not existing using another ephemeris. We used several ephemerides for the predictions of the events, allowing to understand more precisely the real accuracy of the predictions.

The differences in the prediction of some events are provided in Table 4.

6. The observations

(1) *The difficulties to make observations*: The observations of the events between the Uranian moons and by the rings are much more difficult than for the Jovian and the Uranian systems. The greater distance from the Earth brings two difficulties: the satellites are fainter and the field is smaller. Then, the bright planet close to the satellites will make difficult the observation of fainter objects. The solution is in the use of a K-filter (methane band) where the planet Uranus is very dark, contrarily to the satellites. The events are occurring at a distance smaller than 10 arcsec from the limb of the planet. For observations very near the limb of the planet, the adaptive optics may be very useful.

The two-dimensional photometry is absolutely necessary in order to eliminate problems due to twilight or semi-transparent clouds during the events. The phenomena occur at given dates and it is not possible to anticipate or postpone the observations. However, our experience shows that it is possible to make observations even with not good meteorological conditions since we make relative photometry. Figs. 4–6 show an example of observation (Galilean satellites) under bad conditions. Fig. 4 shows the raw light curves of the eclipsed satellite, the sky background rapidly varying due to the twilight and the difference showing the event unfortunately disturbed by clouds. Fig. 5 shows the same light curves for a reference object with a constant flux during the event. By dividing the eclipsed satellite by the reference object, we obtain the light curve in Fig. 6. The signal level is in arbitrary unit.

(2) *The mutual events*: Most of the observations should be made with a K-filter as explained above, but, for some occultations allowing to detect hypothetical hot spots on the surface of the satellites, the observations should be preferably made at the L band. For all the events, they consist in the acquisition of a series of successive images (one every 2–10 s of time) during the occurrence

Table 4
Differences in the predictions of some events in 2007 using several models

Event	Date	Maximum of the events		Impact parameter	
		GUST86 vs GUST2006 (s)	GUST06 vs LA06 (s)	GUST86 vs GUST2006 (mas)	GUST06 vs LA06 (mas)
1 occ 2	April 24	+97	+4	0	+6
1 occ 3	May 3	+96	+127	−1	−26
1 occ 4	May 3	+30	+47	0	+4
1 occ 5	May 23	−217	+497	−30	+30
2 occ 3	April 30	+133	+7	0	−17
2 occ 4	May 4	+61	+64	−1	+22
2 occ 5	August 20	+137	+143	0	−10
3 occ 4	May 3	+51	+119	+1	+1
3 occ 5	July 12	−145	−244	0	+8
4 occ 5	May 11	−83	−177	−37	−21

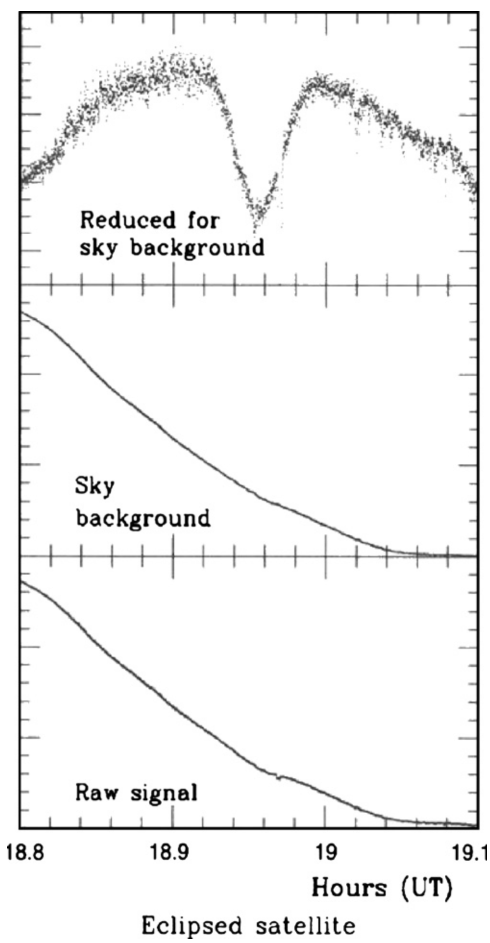

Fig. 4. Raw recorded light curves of the eclipsed satellite.

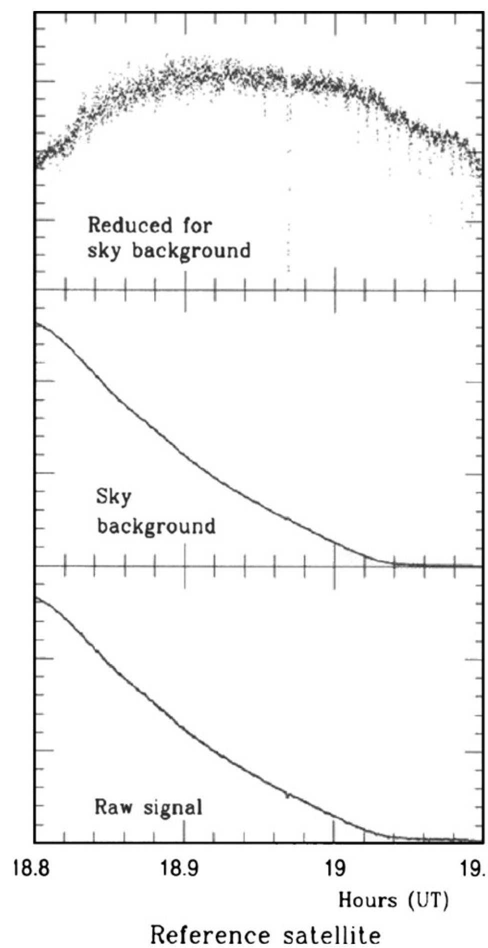

Fig. 5. Raw recorded light curves of the reference object.

of the phenomena (from 5 to 30 min) with an integration time depending on the size of the telescope. The need of large telescopes comes from the faintness of the satellites (14–16 magnitude), the necessity of short exposures allowing to get a good sample of the event (the photometric signal has fast variations) and of the vicinity of the planet Uranus (from 2 to 10 arcsec). We need to select the best events to be observed, the occurrence of which being sure. The timing of each image must be very precise in UTC to be able to link the observations with those made in other sites situated at other longitudes and able to catch events not observable from the first observing site.

(3) *The search for new satellites and thickness of the rings*: Fig. 1 shows the evolution of the planetocentric declinations of the Sun and the Earth, the one of the

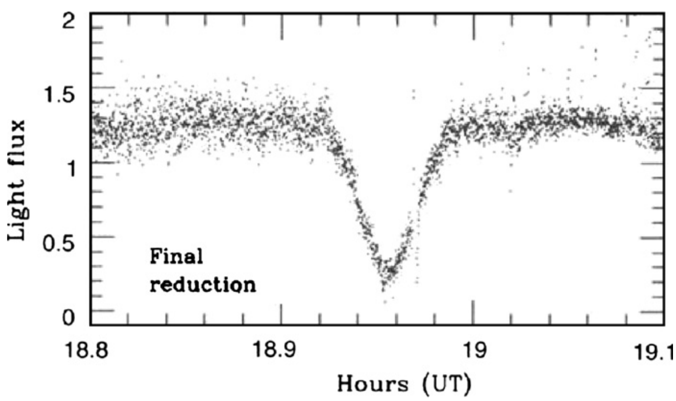

Fig. 6. Final reduced light curve of the eclipse.

Sun being a strait line since the one of the Earth is a curve describing the motion of the Earth around the Sun. Several dates are worth to be quoted (Fig. 3) as follows:

- On May 2, 2007 around 17 h UTC, the first (on a total of three) ring plane crossing of the Earth will occur allowing to measure the rings photometric thickness. This event will not be favorable, too close to the conjunction Uranus–Sun.
- On August 16, 2007, around 9 h UTC, the second ring plane crossing of the Earth will occur. Same observations could be made. It is possible to detect new satellites and to measure positions of the faintest known satellites thanks to the disappearance of the rings. This event is especially favorable, close to the opposition Uranus–Sun and it is the first priority.
- On December 6, 2007, around 20 h UTC, the Sun will cross the equatorial plane of Uranus. The observations of small shepherd satellites of the rings (Fig. 3) will be possible (this is the second priority).
- On February 10, 2008, the third ring plane crossing of the Earth will occur but not observable because too close to the conjunction Uranus–Sun.

These observations should be made at the K spectral band 2.2 μm, where the methane absorption darkens the large disk of the planet Uranus (3.5 arcsec in diameter) down to a magnitude of 15.5 per square arcsec to be related to the magnitude of the main satellites (from 14 to 16 magnitude) and of the faintest (magnitude 20).

(4) *The observational network*: In order to be able to observe the maximum of events, we need to organize a worldwide network of observatories. We must be able to have:

- observatories situated at several different longitudes in order to have Uranus above the horizon from at least one site at every time of the day;
- several observatories in the same area in order to avoid meteorological problems. A small cloud in front of Uranus at the time of an event will prevent the observations but another observatory, even within a few kilometers, may be able to observe. Table 5 provides the list of observatories where observations should be made. We provide in this table the number of observable events, calculated using two criteria: (1) events occurring with the Sun at less than -8° below the horizon, Uranus at more than 15° above and the events occurring at more than one Uranian radius from the limb of the planet; (2) events occurring with the Sun at less than -10° below the horizon, Uranus at more than 25° above and the events occurring at more than two Uranian radii from the limb of the planet.

Table 5
The possible observational network

Site	Telescope aperture (m)	Wavelength	Number of observable events	
			(1)	(2)
SALT, South Africa	10	I or R	33	21
Subaru, Mauna Kea	8.3	K	25	22
VLT, Paranal	8	K + AO	31	14
Galileo, Canarian I	3.6	K	24	13
CFHT, Mauna Kea	3.6	K	25	22
NTT, La Silla	3.5	K + AO	32	16
IRTF, Mauna Kea	3	K	25	22
Yunnan, China	2.4, 1.2, 1	I or R	30	15
VBO, India	2.3, 1	I	30	17
Girawali, India	2	I	29	19
Hanle, India	2	I or R	26	15
Faulkes, Siding Spring	2	I	27	21
Faulkes, North	2	I	25	23
Pic Terskol, Ukraine	2, 0.6	V, R or I	30	18
Asiago, Italy	1.8	V, R or I	32	19
Itajuba, Brazil	1.6	V + coron.	23	15
Pic du Midi, France	1	V, R or I	25	15
Catania, Italy	1	V, R or I	33	20
OHP, France	0.8	V, R or I	26	16
Uccle, Belgium	0.8	V	29	14
Munich, Germany	0.8	V, R or I	30	16
Saint-Veran, France	0.6	V	29	16
Belgrade, Serbia	0.6	V	30	19
Sabadell, Spain	0.5	V or K	25	15

7. The scientific goals

When using the opportunity of the ring plane crossing, long exposures for measuring the rings thickness are possible. These long exposures will also bring into evidence faint satellites, already known or not yet discovered, as well as transient bodies caused by dusty aggregates. It will be necessary to make such observations several times in order to be able to determinate the motion of these objects.

The results of the observation of the occultations and eclipses will allow to get a good photometry of the surfaces and to get relative positions at the time of the events. These relative positions will be accurate to a few kilometers (10 km correspond to 1 mas geocentric). This analysis has been made for the Galilean satellites providing accurate astrometric positions (Emelianov and Gilbert, 2006; Kaas et al., 1999; Vasundhara et al., 2003) and allowing to fit the theoretical models (Lainey et al., 2004). Such an accuracy, even on few observations will allow to understand the dynamics of the satellites by fitting the theoretical models of their motions, to measure the inclinations of their orbits on the Uranian equator and to determinate the precession of the polar axis of Uranus.

8. Conclusion

Mutual events of the Galilean and Saturnian satellites are observed since 1973, but we now have a new challenge: the mutual events of the Uranian satellites more difficult to observe, very rare (every 42 years) but such observations allow to reach a photometric and astrometric accuracy only reachable with space probes, not from ground-based observations made outside the time of the Uranian equinox.

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