A European campaign of observation of the phenomena of the first eight Saturnian satellites in 1995

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Starting from July 1992, the apparent inclination of the orbital plane of the satellites of Saturn has begun to be small enough to induce phenomena. This configuration occurs every 15 years and gives opportunity to observe eclipses and occultations of the first eight Saturnian satellites by the planet. Moreover, in 1995 and 1996 the Earth and Sun will pass through the plane of the rings and we will observe mutual events of the Saturnian satellites; the satellites will eclipse and occult one another. We have computed the whole set of these phenomena. The observation of this type of event gives the opportunity to get astrometric measurements with a very high precision and will permit us to improve our knowledge of the dynamical motion of these satellites. Furthermore these observations are an interesting method for physical investigations concerning the atmosphere of Titan, and they can be used for a photometric study of the surface properties. An international campaign of observation will be organized by the Bureau des Longitudes for that goal.

1 Introduction

Powerful groundbased technique for exploring different problems related to their dynamics and physics. Every 15 years the Saturnian satellites presents a particular configuration which gives the opportunity to observe mutual events. They occur when the planetocentric declinations of the Earth and the Sun become zero. Since Iapetus has an inclination on the Saturnian equator very different from the other satellites, this satellite is not implied in the mutual events. Table 1 shows the main photometric data concerning the seven first Saturnian satellites and the number of phenomena where each satellite is eclipsed or occulted by another and for light flux drop greater than 0.1. The calculations of the predictions of these events were made using Dourneau's ephemerides (Dourneau 1987). The results previously obtained by analyzing similar phenomena involving the Galilean satellites of Jupiter show the interest of such observations. Campaigns of observation of the mutual events of the Galilean satellites , which occur every six years, have been recently organized (Arlot et al. 1990, Arlot et al. 1992, Franklin et al. 1991). The results obtained have shown that, with the help of a photometric-astrometric model, measurements of the surface characteristics and very accurate astrometric data can be deduced from them (Mallama 1991, Mallama 1992, Descamps et al. 1992) works may be carried out for studying the Saturnian satellites and they can lead to a better knowledge of these satellites. They will be also be useful for preparing the next space projects to the Saturnian system, particularly

Table 1: Data concerning the Saturnian system and number of phenomena where the satellite is eclipsed or occulted

Satellite	Eclipsed	Occulted	Magnitude V_0 (mag)	Geometric albedo p^a	Limb darkening k^b
1 Mimas	64	11	12.5	0.77	0.65
2 Enceladus	23	21	11.7	1.04	0.78
3 Tethys	13	12	10.2	0.80	0.63
4 Dione	7	12	10.4	0.55	0.54
5 Rhea	6	6	9.7	0.65	0.53
6 Titan	6	2	8.3	0.20	-

[a] From Voyager clear filter data ($\lambda \sim 0.47\mu$) (Buratti et al. 1982 , Buratti 1983)
[b] From Buratti 1984

the Cassini mission.

The Bureau des Longitudes will organize a campaign to observe the Saturnian phenomena and the mutual events and we call for observers. A listing of predicted eclipses and occultations by Saturn and mutual events has been published by Arlot and Thuillot (1993). An international workshop will held at Bucharest, Romania, on September 19, 20 and 21, 1994. The installation of an anonymous ftp site is in progress for further workshop information. Ephemeris of the Solar System bodies will be also available into ftp.bdl.fr.

2 Issues in the dynamical study of the Saturnian satellites

The system of the first eight satellites of Saturn has been the subject of recent astrometric and dynamical works. Since the works of Struve and Woltjer, different theories have been developped to model the motion of these satellites and to study the resonances (Sinclair 1977, Taylor 1984, Rapaport 1978, Harper et al. 1988). Analysis of adjustements of theory to old and modern observations led to new orbital elements and ephemerides (Dourneau 1987 , Taylor and Shen 1988). Recent works gave an estimate of the precision of the moderne ephemerides. In his analysis of 21,794 observations spanning 1886-1985, Dourneau (1993) gives a RMS (root-mean-square) of the residuals close to 0.20 arcsec. (about 1200 km at Saturn's mean opposition distance) for the first six Saturnian satellites, 0.55 arcsec. (3300km) for Hyperion, and 0.25 arcsec. (1500km) for Iapetus. By comparing with the 0.05 arcsec. accurac (about 200km) of the ephemerides of the Galilean satellites of Jupiter (Arlot 1982, Lieske 1980), we see that the dynamical model of the Saturnian satellites needs improvements. A theoretical effort has been recently made with a new approach to the dynamical prolem: by means of the development of a general theory of the motion of the

Saturnian system (Duriez and Vienne 1991, Vienne and Duriez 1991, 1992). New periodic terms appeared and important results could be next obtained by the analysis of new accurate observations.

Observation of mutual phenomena will be an opportunity to get very accurate measurements of positions of the Saturnian satellites. Similar observations of the Galilean satellites led to an accuracy better than 100 km on the position measurement. Contrarily to the photographic observations, the accuracy derived from the timming of a photometric observation does not depend on the distance from the observer to the system of satellites. Therefore an accuracy close to the high accuracy of the observations of the Galilean satellites can be obtained for the Saturnian system. The timing of a closest approach during a mutual event may usually be made with an accuracy of 10 to 30 sec of time depending on the photometric accuracy of the lightcurve. The maximum relative velocity between two satellites may reach 15 km/sec for inner satellites and 5 km/sec for the others. Therefore, the astrometric accuracy of the measurement of the relative positions deduced from a mutual event is most of time of 200 km (0".03).

3 Planetologic interest of observing mutual events

In order to reduce the observations of mutual events, we have recently developped a photometric -astrometric model based upon the behavior of the solar light scattered by surfaces. This model was successfully applied to a set of observations of mutual phenomena of Galilean satellites (Descamps 1992, Descamps 1994, Descamps et al. 1992). Light scattering by atmosphereless bodies is well represented by laws such as the Hapke law (Hapke 1986) or the Minnaert law. The optical properties contain information on chemical composition and surface microstructure. A lunar-like law of surface optical scattering were found for Dione and Rhea but others are somewhat more complex, involving a significant component of Lambert-like scattering (Buratti et al. 1982).

The major drawback for ground-based observations is due to the scattered light from the rings and plane in the case of the closer satellites such as Mimas, Dione, Tethys and Enceladus which induces a serious hindrance to accurate photometry. Another limitation results from the coverage in phase angle which is always limited to a little more than 6°. Thus, up to the Voyager imaging observations in 1980-1981, it was difficult enough to measure the surge in brightness near the opposition or surface roughness of Saturnian satellites. For instance, Franz et al. (1975) found a significant opposition surge for Dione and Tethys whereas Verbiscer and Veverka (1989), from Voyager observations of Rhea, have derived only a slight opposition surge.

However, several extensive photometric studies of Saturn's satellites have been published since 1971 and global photometric data of the Saturnian satellites are presently available and well known. They are reported in the Table 1. The limb darkening parameter of the Minnaert's law, k, would approach 0.5 for a dark surface in which single scattering dominates and for an ideal Lambert surface, k=1 at all phase angles. The determinations of k were made from disk-resolved scans of Voyager images at relatively high phase angles for Mimas, Enceladus and Tethys, respectively at 16.8°, 13.4° and 9.9° . These results may not be considered as entirely reliable estimates because according to the laboratory and theoretical works of Goguen (1981), Minnaert's function is regarded as inadequate except when the phase angle is near 0°.

Although Minnaert's model is useful in understanding differences at low phase angles

Table 2: Hapke photometric parameters

Satellite	Single scattering albedo $\tilde{\omega_0}$	Asymmetry factor g	Macroscopic roughness $\bar{\theta}(^\circ)$	Source
Mimas	0.93	-0.30	30	Buratti 1985
	0.95	-0.21	30	Verbiscer and Veverka 1992
Enceladus	0.99	-0.35	30	Buratti 1985
Rhea[a]	0.86	-0.29	13	Verbiscer and Veverka 1989
Rhea[b]	0.89	-0.32	13	Verbiscer and Veverka 1989

[a] Disk-integrated data
[b] Disk-resolved data

among the satellites in their scattering properties, they cannot be directly related to the physical properties of the surfaces.

The characterization of satellite's light scattering properties in terms of Hapke parameters makes it possible to discuss these properties in the context of the satellite's geology and surficial microstructure. So far only a few Saturnian satellites have been studied with the help of the Hapke model. Classical methods of study require disk-resolved or/and disk-integrated observations such as those obtained from spacecraft like Voyager. Unfortunately, the Voyager data sets are most complete for only Enceladus, Mimas and Rhea. In general phase angle coverage extends to $30-40^\circ$, with a few points at higher phase angles ($\sim 100^\circ$). For example, observations of Enceladus extend only to $\alpha \simeq 40^\circ$, they are not suited to detect the possible influence of large-scale roughness. The situation is better for Mimas and Rhea ($\alpha = 1.8^\circ - 135^\circ$). Hapke model results for Mimas, Enceladus and Rhea are summarized in Table 2. The discrepancy between results on Mimas may arise from the assumption made by Verbiscer and Veverka (1992) on the Mimas' opposition surge considered as identical to that of Rhea due to lack of data at low phase angles.

Accordingly, since estimations of macroscopic roughness become trustworthy when data are available at $\alpha \geq 40^\circ$, these results need at least to be confirmed by other observations.

From this point of view, mutual phenomena observations are particurlarly interesting. Indeed, our approach succeeds in estimating not only macroscopic roughness and single-scattering albedo but also opposition surge parameters in the context of the Hapke model. During a phenomenon the photometric effect of the macroscopic roughness dominates especially at the beginning and at the end, that is, where shadows are prominent in areas near the limb or the terminator. This effect induces an asymmetry in the shape of the light curve and provides therefore constraints on the determination of the macroscopic roughness.

Thus the upcomming mutual events will provide an ideal opportunity to obtain near-opposition data with minimal scattered light from the broad ring system wich will appear edge-on in 1995. They are also an excellent Earthbased approach for measuring limb darkening on objects that are too distant for Earthbased disk-resolved study. Moreover, mutual events observation allow a regional analysis namely leading side/trailing side differences by acting as a disk-resolved scan..

Finally, a lot of information relating to the surface properties in terms of Hapke parameters and limb darkening of the major Saturnian satellites might result from their mutual phenomena observation. These determinations would allow to discuss or comment precedently published results not confirmed yet.

4 Observation of the phenomena

In the past, several campaigns of observation of mutual events of the Galilean satellites took place and succeeded in obtaining a large amount of useful data. However, the Galilean satellites have a magnitude of about 5 and are easy to observe, even with a small telescope. The Saturnian satellites are much more difficult to observe because of their magnitudes, which are given in Table 1. The main difficulty arises from the proximity of the planetary disk because of the brightness of the rings,except during the transit of the Earth in their plane. This will lead us to select instruments and sites particularly adapted to these observations. We have also to note that some events are very difficult to observe because the magnitude difference between some satellites is too large (events involving Titan and Hyperion for instance imply a light flux drop never larger than 0.001). Events occurring near Saturn will be observed only with very good seeing. Photoelectric photometers as well as CCD could be used but preliminary tests have to be made by observing the Saturnian satellites before the date of the events in order to estimate the Signal/noise ratio. Antiblooming CCD will be preferable for the observations of satellites near the planet but one has to be careful to avoid a saturated image of the observed satellite in order to have a good photometric measurement. Tests have also to be made to know exactly the time resolution of the photometric measurements. One measure per second of time is at least necessary. If possible light flux measurements of each separated satellite before and after the phenomena are necessary for the calibration of the lightcurves.

5 Conclusion

New data of high accuracy are expected from the next series of phenomena, eclipses by Saturn and its rings and especially mutual events of the Saturnian satellites in order to improve the dynamical model of the motions as well as our knowledge of the photometric characteristics. These data would also be helpful to the preparation of the next spacecraft missions to the Saturnian system. Further details on these events or on their topocentric conditions of observation can be obtained on request from the authors.

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