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Post eclipse thermal response of Uranian satellites with SINFONI: a status report

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Abstract. We report on the status of a project to measure eclipse-induced changes in surface temperature on the major Uranian satellites. Such measurements enable a uniquely direct determination of the thermal inertia, a measure of the resistance to changes in surface temperature. Thermal inertia is a very sensitive indicator for the presence or absence of powdered materials and tenuous atmospheres. Two different telescopes and observation techniques are used: The post-eclipse temperature variation of the H_2O-ice component will be determined from analyzing observations of temperature-dependent H_2O absorption features in the near-IR (observations taken in 2007 with SINFONI at VLT). Variations of the disk-integrated thermal emission during and after eclipse events will be observed in the thermal infrared (Q band) using T-ReCS on Gemini South in July 2008.
The thermal inertia of objects beyond Saturn's orbit is generally unknown, with the sole exception of Pluto. The eclipse events of the Uranian satellites in 2007–2008 represent an extremely rare opportunity - occurring only at Uranus equinoxes, i.e. every 42 years – to determine their thermal inertia. Our results will be crucial for improving thermal models used for the analysis of radiometric data of bodies in the outer Solar System, such as other icy satellites and Kuiper belt objects. This project is part of an international campaign aimed at coordinating observations of Uranus at the epoch of the equinox.

1. Introduction

The occurence of the Uranus equinox at December 7th, 2008 - the first after the 1986 fly-by of Voyager 2 - triggered intense observational activity coordinated by an international network [1] (Hammel 2006; Thuillot 2006) with the purposes of observing the mutual events of the uranian satellites, i.e. eclipses, occultations and transits between satellites or between satellites and the planet, the ring system edge, and the long therm behaviour of

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[1] http://pds-rings.seti.org/urpx/, http://www.imcce.fr/paris2006/

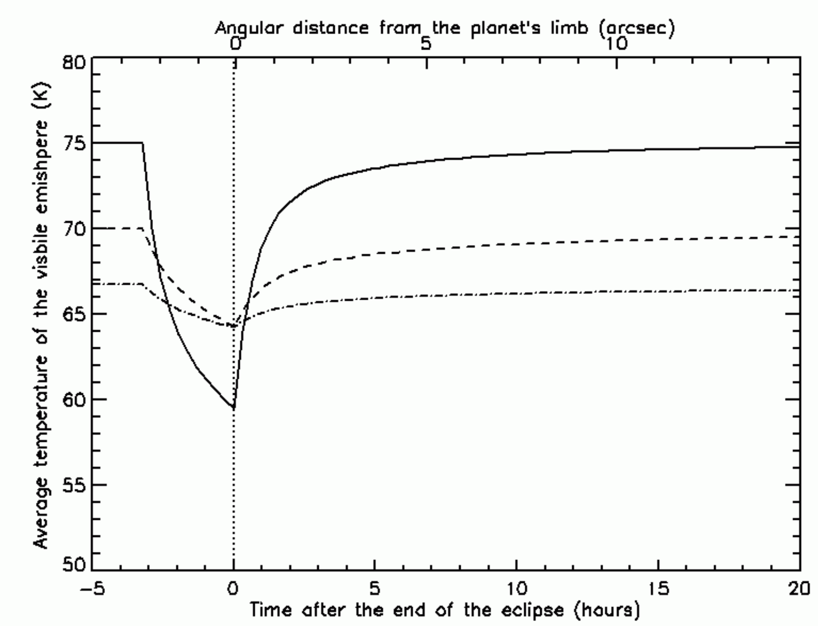

Fig. 1. Expected variation of the surface temperature for Oberon during an enclipse and after its end for three values of the thermal inertia, Γ, respectivelly 10 $\mathrm{Jm^{-2}sec^{-0.5}K^{-1}}$, full–line, which is typical of large MBA, 40 $\mathrm{Jm^{-2}sec^{-0.5}K^{-1}}$, dashed–line, which is appropriate for our moons and Pluto (Lellouch et al. 2000) and 100 $\mathrm{Jm^{-2}sec^{-0.5}K^{-1}}$, dash–dotted–line, which is appropriate for the NEA. It is assumed $t = 0$ when Oberon emerges from the umbra, and that the eclipse begins at $t = -4$ hours.

Uranus atmosphere with the change of season. Due to the peculiar tilt of Uranus, mutual events for the Uranian satellites can be observed just near the epoch of equinoxes (Arlot, Lainey, Thuillot 2006). The eclipses of the satellites behind the planet are also of particular interest becouse they allow to study the effect of changing insolation over their surfaces.

Observations of the thermal response of a planetary surface to changing insolation, by diurnal rotation or eclipses, provide a means of determining the surface thermal inertia, Γ. Thermal inertia is defined as $\Gamma = \sqrt{\rho \kappa C}$, where ρ is the density, C the specific heat capacity, and κ is the thermal conductivity; it is a measure of the resistance of a material to temperature changes. It is a sensitive indicator for the degree of compaction of the material at the surface of a body, as well as for the presence (or absence) of a layer of loose material covering the surface. It was shown (Morrison & Cruikshank 1973) that κ and hence Γ is sensitive to the presence of a tiny atmosphere. The major moons of Uranus are ice-rock conglomerates. They appear to be composed of about 50% water ice, 20% carbon- and nitrogen-based materials, and 30% rocky. Their surfaces, almost uniformly dark gray in color, display varying degrees of geologic history. Very ancient, heavily cratered surfaces are apparent on some of the moons, while others show strong evidence of internal geologic activity. The spin periods of all these satellites are synchronized with the orbital period, with the possible exception of Oberon. These four major satellites have a low inclination relative to the equatorial plane of Uranus which displays the unusually large obliquity of 89° w.r.t. the ecliptic, leading to very pronounced seasons over the Uranian year. Currently, the sub-solar point on Uranus is close to the equator, leading to a gradual heating up of the hemisphere which was in obscurity for some four decades. For the largest moons, such as Titania, this may have produced a tenuous atmosphere through sublimation. In addition understanding how thermal inertia correlates with the variety of the surface make-ups displayed by the major Uranian moons will improve our comprehension of the physics of ice in the outer Solar System. This may be also important to improve thermal models of other icy satellites and Kuiper-belt objects: the current lack of knowledge on their typical thermal inertia is the major source of uncertainty in determining their diameter and albedo from thermal-infrared observations. We recall that in the outer Solar System beyond Saturn, the thermal inertia is known only for a small set of objects among them Pluto.

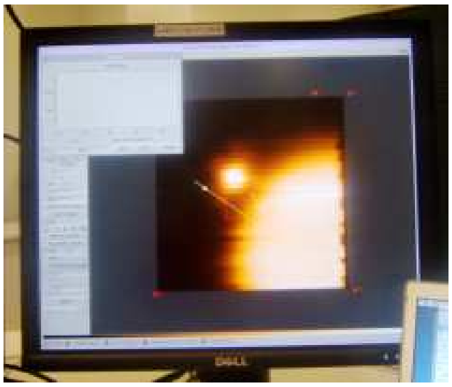

Fig. 2. Oberon emerging from the shadow of Uranus in the night of October 6th, 2007 as seen at VLT/Yepun with the SINFONI integral field spectrograph. The picture has been taken in the first minutes after the emersion.

2. Our approved observational proposals

From Earth it is not possible to observe the diurnal variations of insolation produced by the satellites rotation, the phase angle being too small ($< 3°$). Satellite–satellite eclipses are too short to be observed with current instruments. Only Planet - Satellite eclipses could be used to determine the thermal inertia. Hence, we proposed to follow-up the brightest Uranian satellites Oberon, Titania, Umbriel and Miranda as they emerged from the Uranus shadow with the VLT and the GEMINI telescopes. The observational methods proposed are complementary in that: the VLT measurements are based on IR thermometry of water ices (Grundy et al. 1999) while GEMINI ones on near–IR radiometry. Water ice thermometry is based on the fact that the strength and wavelength of water ice features in J, H and K bands change as a function of $T_{\rm ice}$, in particular in the H and K bands. The observation of water ice features in J, H and K spectra has been demonstrated by Grundy et al. (1999) and Grundy et al. (2006) for all of the largest Uranian satellites. Hence VLT measures will monitor the thermal response of water ice while GEMINI that of the whole body. In the following we summarize on the VLT proposal for which data taking is concluded, the GEMINI being scheduled for the 2008 [2].

3. VLT observations and current status

Altougth planet–satellite eclipses are quite frequent, at the equinox the number of events observable from an earth observable site is limited by severall constrains. Nevertheless, we succeded in scheduling the observation of eclipses lom enough to produce a significant decrease in surface temperature. Simulations using our sophisticated thermophysical models, like the one in Fig. 1, (Mueller 2007; Delbó 2007; Delbó et al. 2007) shows that the surface temperature rises from the minimum temperature at the end of eclipse, $T_{\rm min}$, at the equilibrium temperature, $T_{\rm eq}$, within few hours, most of the variation occuring within the first hour or so. About ten or more temperature samples have to be obtained to properly model the temperature rise, with an accuracy in the temperature determination better than 10% and a resolution $\Delta\lambda/\lambda \approx 500$. So a satellite must be observed as soon as possible following its emergence from the Uranus shadow and for at least two hours. This forces us to

[2] Talk held January 2008.

observe the satellites very near to the Uranus limb and rings, asking for adaptive optics (AO) in order to asses proper separation. An accurate rejection of the Uranus diffused light is also an issue. Furthermore, events characterized by a long occultation of the satellite by the planet after its emergence from the shadow are of little use and were discarded. Also care was taken to consider only eclipses ending at night and with Uranus remaining above the telescope limit elevation, (30° for VLT), for at least two hours. All of this limited the number of useful events to only a few.

We observe the Uranians satellites for all of the VLT useful events during observing period P80, concentrated in 7 nights between October 5th and November 2nd 2007, with the SINFONI integral field spectrograph (Eisenhauer et al. 2003; Bonnet et al. 2004) at VLT/Yepun. Having not a bright guide star within 30 arcsec from Uranus, we closed the AO on Uranus itself. This is nearly at the limit of the AO guide on extended objects, nevertheless the AO performs general well even with poor seeiing (we have had seeing between 0.3 arcsec and 2 arcsec), observing Uranus within 7° from the Moon and near the 30° limit of elevation. The AO allowed also us to well separate near satellites not partecipating the eclipse at angular distances of about 1 arcsec from the target satellites.

SINFONI allowed us to observe H and K at the same time and J separatelly with $\Delta\lambda/\lambda \approx 1500$. Being less sensitive to $T_{\rm ice}$ variations to save time we observe J only one or twice per night per satellite. In addition we observe the full disk of Uranus, in H, K and J as at least one or two satellites far from Uranus each night. Such satellites are observed both as a refence standard and to provide spectra of satellites at equilibrium temperatures. Solar analogs have been acquired at the begin, the mid and the end of each observing run at airmasses craddling the Uranus airmasses.

Fig. 2 is a snapshot of the first event: Oberon emerging from the Uranus shadow, October 6th, 2006. The image is the integration of the spectrum over H and K. The field of view was 3×3 arcsec with a resolution of 0.1 arcsec/pixel. In K uranus is not observable, due to the strong absoption from atmospheric CH_4, so that it does not represents an important contaminant. The plane of the rings is at the bottom of the figure, since rings are very narrow, they are quite weak and do not represents an important contaminant. The exposure time is 6 minutes divided in 3 dithered exposures.

The program produced more than 20 GBytes of data currently under reduction by using the standard SINFONI pipeline (Modigliani et al. 2006).

4. Final remarks

An international collaboration has been organized to study the post-eclipse thermal responses of Uranian satellites in the framework of 2007 Uranus equinox by using two different methods. The collaboration applied successfully for VLT and GEMINI time. VLT observations are completed, preliminary results allows a mild optimism, but data analysis is still in progress. If successful this program will provide information on thermal inertia of uranian satellites, as, perhaps, they ice/rock mixing ratio

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