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The surface and thermal history of Orcus

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Abstract

Orcus is a 1000km diameter intermediate-size Plutino with a water ice-rich surface that should theoretically be too small and too hot to have retained its pristine volatile content (CO, CH_4, N_2) on its surface [5]. However, repeated spectroscopic observations show an intriguing shallow absorption feature around 2.2 microns that is difficult to interpret. The presence of methane and ammonia cannot be completely ruled out although their presence is difficult to explain. Another intriguing property is the unambiguous presence of water ice in its crystalline state [1,2,3], evidenced by an absorption feature at 1.65 microns in various H-band spectra. In this work, we review the spectral and surface properties currently known for Orcus and will try to put them in perspective. We further study and discuss the thermal history of the interior of this object, using a new 3D thermal evolution code [4] to describe how the crystalline water ice can be produced and being eventually supplied to the surface in the recent past.

1. Spectral properties

Orcus has a neutral (2%/100nm), featureless spectrum in the visible (300-900nm) range. Water ice was always detected in the Near Infrared (NIR) spectra [2, 3 and references therein], and in its crystalline state for the most recent, higher SNR data.

The presence of crystalline water ice is difficult to understand as it is sensitive to solar and cosmic rays irradiation. Pristine crystalline ice should be destroyed over a timescale much smaller compared to the age of Orcus, e.g. should not be observable today. In this work , we will investigate how crystalline water ice can be produced in the interior of Orcus and possibly survive over 4.5 billion years.

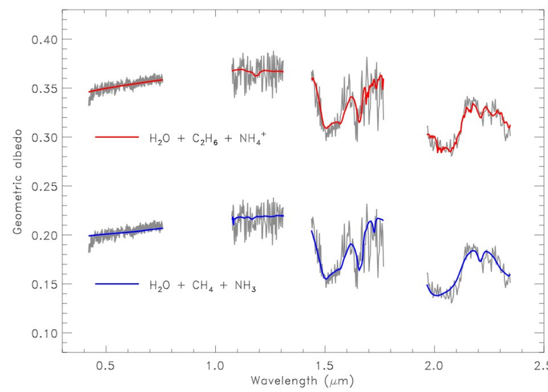

Figure 1 : reflectance spectra of Orcus from Keck+LRIS and Gemini+NIRI. Tentative composition models are super-imposed. Top spectrum has been shifted by +0.15 albedo units for clarity.

Fig. 1 show the shallow absorption feature that is observed at 2.2 microns in our Gemini+NIRI data (UT 2005-02-22). Such a feature is also reported by [1] and [3]. Tentative Hapke modeling using intimate mixtures of various species show that the best fit to our data is obtained from 1) crystalline and amorphous water ice + methane + ammonia (pure or diluted) and 2) crystalline water ice + ethane + ammonium (see Fig. 1). Ethane and ammonium can be irradiation products of methane and ammonia resp. However, we do not claim direct detection of this species. A detailed discussion on these radiative transfer models and their limitations can be found in [2]. If methane, ammonia and their irradiation products happen to be present as traces on the surface of Orcus, it could mean that fresh and irradiated sources are currently present, (and in the case of CH_4, that volatiles can survive at the surface of such an object): the related chemical and physical processes should be investigated. This can only be done from significantly higher SNR spectral data coupled with focused laboratory studies.

These NIR spectral properties resemble very much those of Pluto's satellite Charon and Plutino (208996) 2003 AZ_{84}.

2. Thermal history

With the use of a full 3D thermal evolution model developed by A. Guilbert-Lepoutre [4], we investigated the temperature evolution of the interior of Orcus over the age of the Solar System under the effect of short lived (^{26}Al, ^{60}Fe, ^{53}Mn) and long lived (^{40}K, ^{232}Th, ^{235}U, ^{238}U) radiogenic elements. Orbit, size, albedo, density, porosity and formation delay are taken into account. From the bulk density and an assumed residual porosity of 10%, we ran the simulations on a body constituted by mass fractions of 77% of dust and 23% of water ice, the dust being homogeneously distributed within the ice matrix.

We will discuss our results in details. The main result is that even under the effect of the long-lived radiogenic elements only, most of the volume of the object is crystallized: only a thin layer of amorphous water ice is left at the surface of the body (see Fig. 2). In all cases, we obtained a melted core, an effect that is strengthened if ammonia is initially present in the object.

This liquid water+ammonia phase could reach the surface through cracks in the ice matrix (if not directly present in sub-surface layers in the most extreme of our simulations)

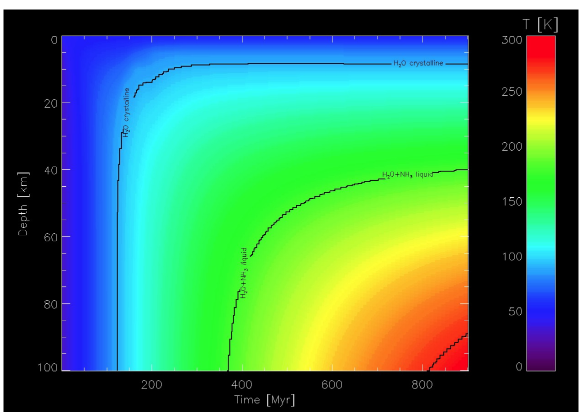

Figure 2: Depth [km] of the crystalline water ice front and liquid water and ammonia phase as a function of time

The possible existence of a liquid phase in intermediate to large water-bearing Kuiper Belt objects could be of astrobiology interest.

Our results suggest that the thermal history of Orcus is compatible with a past cryovolcanic event, that could explain the presence of crystalline water ice (and maybe ammonia) on its surface, although we cannot precisely date such an event. Cryovolcanism can be even more efficient in the presence of methane. The surviving of crystalline water ice, methane and ammonia on the surface of such an object is still an open question.

Acknowledgements

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