BEHAVIOR AND STABILITY OF GROUND ICE ON CERES: INITIAL CLUES FROM DAWN.

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Introduction: Before the Dawn spacecraft arrived at Ceres, detections of water vapor by the Herschel telescope [1] were used to calculate production rates of water vapor in the cerean atmosphere ($6\ \mathrm{kg\ s^{-1}}$). The observations of [1] are consistent with models of the historical evolution of Ceres [2] and recent observations of surface geomorphology by the Dawn spacecraft [3] suggest a crust with a substantial fraction of water ice. Modeling the transport and fate of water ice on Ceres, therefore, is key in understanding the current conditions observed by the Dawn spacecraft.

We build on the work of [4], incorporating an accurate pole-vector determination from Dawn data, to explore ground ice stability and retreat rates. We model surface and subsurface temperatures on Ceres by balancing surface insolation, thermal emission and conduction to the subsurface. We estimate ice loss rates for both surface ice and ice covered with a low-thermal-inertia sublimation lag, and convert this value to vapor production rate for different locations on Ceres. Sublimation lag thickens with time reducing total sublimation and vapor production [5-7]. Here, we discuss the additional (and potentially important) effect of regolith collapse when ground ice that exceeds the pore-filling volume is removed, causing sublimation lag thickness to increase more slowly than expected. We also report on sublimation rates from observed bright spots on Ceres' surface, assuming an icy composition, and show that such sublimation can match the observed water vapor production reported by [1].

Observations: Dawn observations indicate a lack of large high-albedo regions, indicating that extremely clean surface ice is not present in significant amounts (i.e., as a surface polar deposit). Dawn observations also show the presence of small-scale high-albedo spots (Fig. 1). The most prominent of these bright spots is in Occator crater (Fig. 2), though they occur across the surface of Ceres.

We model sublimation from these bright spots assuming they have an icy composition. Elsewhere on Ceres, ice is likely to be buried by regolith. We simulate the evolution of this buried ice using a surface albedo of 0.09 and a thermal inertia of $15\ \mathrm{J\ m^{-2}\ K^{-1}\ s^{-1/2}}$, unless otherwise noted.

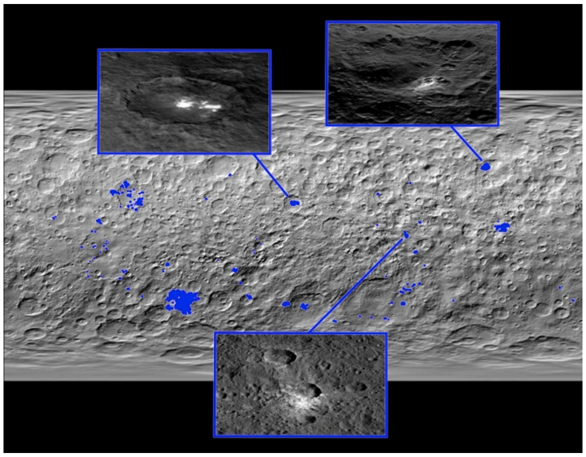

Fig. 1 Figure showing the relative locations of the bright spots on Ceres, indicated by blue areas on the albedo map. Credit: NASA/JPL-Caltech/UCLA/MPS/DLR/IDA, perspective views of Occator and Oxo craters: [8].

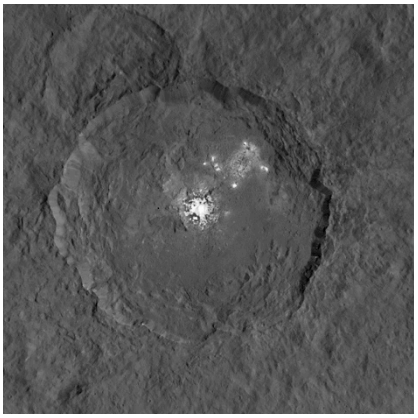

Fig. 2 Image of the bright spots on the 92-km-diameter Occator crater on Ceres (20°N, 239°E). Credit: NASA/JPL-Caltech/UCLA/MPS/DLR/IDA

Modeling and preliminary results: We use a model based on [5] to calculate the annual average temperatures and convert mass flux of the sublimated material through a granular medium. Fig. 3 shows the typical surface temperatures over the course of a Ceres year at the equator and poles according to our model.

In the case where pore-filling ice (50% ice by volume) extends to the surface, average loss rates range from almost zero (mm/Gyr) at the poles to several decimeters per year at the equator. These loss rates are suppressed by 2-3 orders of magnitude when ice is covered by even a few centimeters of dry sublimation lag [7]. Assuming negligible internal heat flux, we model the retreat of ice as a function of latitude and estimate the outgassing of water molecules expected from buried ice at all latitudes as a function of time. We find this global sublimation of buried ice (Fig. 4), cannot reproduce the results of [1]. Similar modeling by [9] agrees with this conclusion, unless the ice content of the outer layer is well above 50%.

Ground ice on Ceres could exceed the available regolith pore space in some areas. In the case where we have dirty ice rather than icy dirt, the insulating regolith cover will also thicken with time, albeit much more slowly. This effect would lead to thinner regolith covers and so could significantly increase vapor production rates in the present day.

Surface ice at Occator and other bright spots: We next modeled whether or not the bright spots could be a source of water vapor consistent with [1]. We use a thermal inertia more typical for ice (2100 J m^{-2} K^{-1} $s^{-1/2}$), and an albedo three times the Ceres average (0.27). Our models show that, given an icy composition, some of the most prominent of these bright spots in Occator crater (20°N) have loses of ~2cm/yr (Fig. 5). During some seasons, peak sublimation rates approach 2 kg s^{-1} from each square kilometer. Suggestively, the area and sublimation rates of the Occator bright spots match the observed vapor production rates of [1].

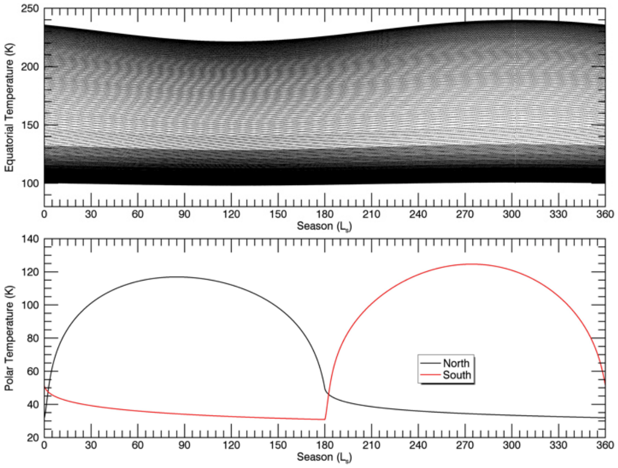

Fig. 3 Model results showing the temperature as it varies with season at the equator and poles of Ceres.

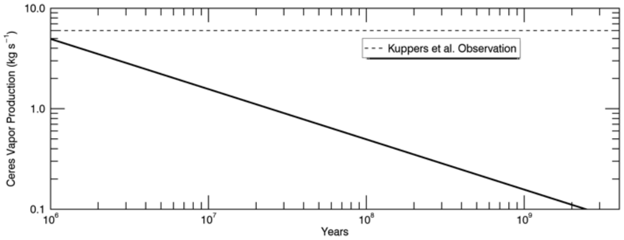

Fig. 4 Calculation of the vapor production on Ceres over time, given a fixed initial amount of pore-filling ice. The dotted line shows vapor production observation [1].

Our vapor production varies diurnally and seasonally, consistent with [1]. With the high sublimation rate (~2cm/yr), these bright spots would not be stable over long periods of time. Continued monitoring by Dawn over the coming months in the low-altitude mapping orbit will be able to test for changes.

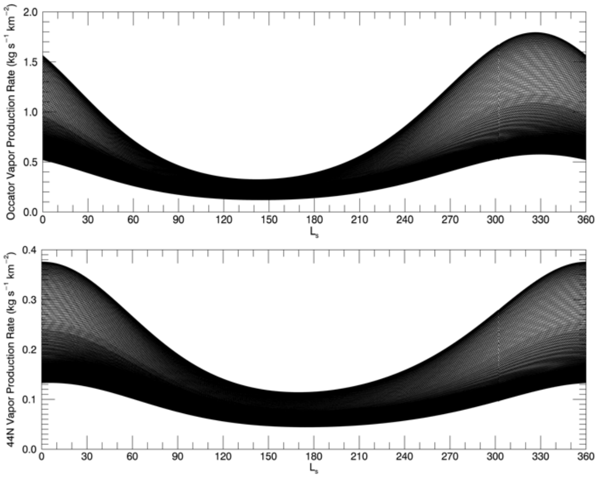

Fig. 5 Calculations of vapor production rates at Occator crater (20°N) and at a bright spot located at 44°N as a function of season (curve width is due to diurnal variation). Note the decrease in vapor production rate with increase in latitude.

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