IMPACT-DRIVEN PRODUCTION OF CERES' SURFACE ICE PATCHES AND THEIR EXOSPHERIC CONTRIBUTION: M.E. Landis[1], S. Byrne[1], J.-P. Combe[2], S. Marchi[3], J. Castillo-Rogez[4], H.G. Sizemore[5], N. Schörghofer[5], T.H. Prettyman[5], P.O. Hayne[6], C.A. Raymond[4], C.T. Russell[7], [1]Lunar and Planetary Laboratory, University of Arizona (mlandis@lpl.arizona.edu), Tucson, AZ, [2]Bear Fight Institute, Winthrop, WA, [3]Southwest Research Institute, Boulder, CO, [4]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, [5]Planetary Science Institute, Tucson, AZ, [6]University of Colorado, Boulder, CO [7]Institute of Geophysics and Planetary Physics, Department of Earth and Space Sciences, University of California, Los Angeles, CA.

Introduction: Detections Ceres' transient exosphere [1-4] suggest a currently active water vapor production process. Subsequent efforts to explain the timing and mass of the exosphere [5-7] rely on some amount of exposed or near surface water ice from which to derive vapor. Ceres has several exposed water ice patches detected in spectra from the VIR instrument poleward of 30° latitude [8] that could be potential water vapor sources. Here, we model the current production of water vapor from sublimation of these patches and, in combination with the rates from sublimation from buried ground ice [6,9,10], give an estimated expected background water vapor contribution to the exosphere as Ceres approaches perihelion.

Some water ice patches are associated with craters (e.g. Oxo and Juling craters) and small impacts have been shown to expose shallow subsurface ice on Mars [11]. Assuming the current asteroid derived impact cratering rate for Ceres [12] and the distribution of the buried water ice consistent with the Gamma Ray and Neutron Detector (GRaND) results [10], we use a Monte Carlo approach to estimate the number of ice exposing impacts, and therefore plan-view area, of water ice exposed both during the duration of the Dawn mission at Ceres and within the last kyr. This insight into the long-term water ice patch exposure rate provides context for currently observed water ice on Ceres.

Sublimation from currently exposed water ice patches: To date, nine surface water ice exposures have been identified [13], four of which are in impact craters that are resolved in the global Low Altitude Mapping Orbit (LAMO) digital terrain model (DTM) [14] and two that likely lie within craters ~250m in diameter. The remaining three are associated with sloped terrains or landslides. With the LAMO DTM, it is possible to derive slopes and azimuths for these features and model their temperatures (Table 1). We used the code of [6] with a modification to include realistic (non-conic section) crater rim heights to determine the currently exposed water ice patches' outgassing rates.

An albedo of 0.135 (the albedo of ice within Oxo crater, [15]) and thermal inertia of 2100 SI units was assumed for the ice within these craters. Areas reported in [13] were used where the water ice patch was resolved. Where it was not, an estimated area based on the number of bright pixels was used. The amount of vapor production reported here is best interpreted as an order of magnitude estimate, as the actual albedos likely vary from those at Oxo.

The total amount of vapor produced from these nine patches is shown in Figure 1. Most of the nine individual patches produce much less than 2×10^{-4} kg/s

Table 1 Location, slope, azimuth, and area of spots reported in [13] organized by ID letter assigned therein.

ID	Lat	Lon	Slope	Azimuth	Area (km^2)
A (Oxo)	41.33	0.28	17.75	326.4	6.8
B	61.24	-138.70	16.84	348.6	1.4
C (Messor)	69.82	114.40	15.95	332.6	3.3
D (Juling)	-35.02	168.70	47.94	189.5	3.2
E	61.48	51.57	39.10	44.97	0.01
F	29.60	155.07	18.01	322.2	0.041
G (Ezinu)	42.17	-160.53	8.26	35.61	0.047
H	44.61	32.49	18.62	25.95	0.005
I	-47.98	265.55	10.92	213.2	0.028

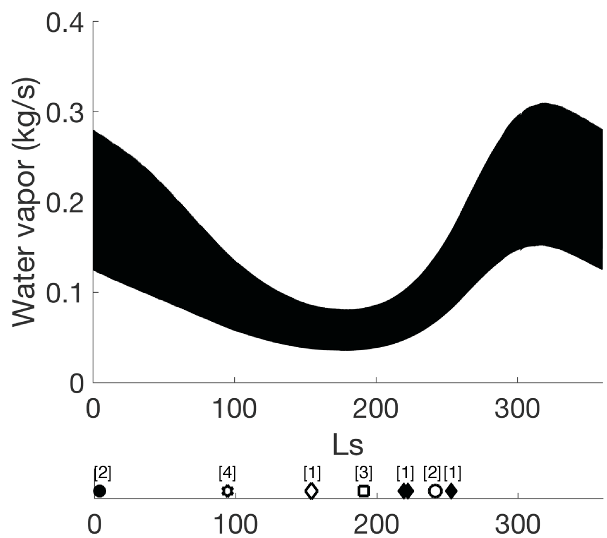

Figure 1 Vapor production from the nine exposed surface ice patches identified in [13] over one Ceres year. Detections (open symbols)/non-detections (filled in) of an exosphere from [1-4] shown at the L_s of observation for reference.

of vapor. Most of the vapor produced comes from Oxo and Juling craters (both at a maximum of ~0.2 kg/s). The width of the curve in Figure 1 shows the diurnal variations in the amount of vapor produced. Ceres perihelion occurs at solar longitude (L_s) 302 and previous detections (and non-detections) of exospheres are shown at their respective L_s (Figure 1).

During the period of maximum vapor production slightly after perihelion (delayed from perihelion due to the local slopes of many of the patches), at most ~0.3 kg/s of water vapor can be expected to come from the exposed surface ice. This is greater than or equal to the amount of water vapor produced as a background from a buried ice table (depending on the parameters assumed for the overlying regolith [6,9,10]) of ~0.003-0.3 kg/s, and gives a total of at most ~0.6 kg/s of water vapor with significant seasonal variability (an order of magnitude below the ~6 kg/s vapor production rate reported in [1]).

Ice-exposing impact rate: With a potentially large contribution of exposed surface ice to Ceres' background exosphere level, understanding the rate at which ice exposures can be generated by impacts is an important next step.

We use a Monte Carlo simulation to generate populations of impact craters with a size-frequency distribution based on [12]. We set a lower limit on the diameter of 5 m, which assuming a 0.2 depth/diameter (d/D) ratio for the final crater will access material ~1 m below the surface. This will give an over-estimate of the number of ice exposing impacts compared to assuming a 0.1D excavation depth, but is appropriate in this case because we want to include craters that may not have icy ejecta but could still have an icy interior. Hydrogen enrichment, a possible interpretation of which is a buried ice table, within 1 m of the surface occurs poleward of ~40° latitude on Ceres [10]. For an impact to be considered "ice-exposing" in our Monte Carlo simulation, it must be >5 m in diameter and occur at ≥40° latitude.

We ran 10,000 simulations and report 95% confidence interval uncertainties for a three-year period for Ceres (approximately the length of time the Dawn mission has been in orbit). In three years, the model predicts 3557±95 new ice exposing impacts. The maximum crater diameter for those ice exposing impacts is 69.3±10.2 m. The LAMO resolution is ~35 m/pixel and so the maximum crater diameter is ~2 LAMO pixels, and is likely unresolvable. However, the total number of ice exposing impacts would add ~0.255±0.014 km^2 (plan view) of exposed surface ice that would be undetectable by Dawn. This area is about double the surface area from small, unresolved ice exposures reported by [13], and could substantially add to the vapor produced from known ice patches, depending on latitudinal distribution. This additional area would have diurnal and seasonal variations similar to those shown in Figure 1.

Running the same simulation now for 1 kyr (still using 10,000 simulations and reporting 95% confidence levels), the number of ice exposing craters is $1.18x10^6 ± 1.71x10^3$, the maximum icy crater diameter is 544.1±66.7m, and the plan-view area exposed is 90.1±0.9472 km^2.

Could a single impact in the last kyr fully explain the vapor production reported in [1]? The sublimation vapor model results of [6] suggest that the exposure of a 1km^2 ice patch could result in a ~6kg/s vapor production rate [1]. The largest crater in the last kyr is most likely to be ~575 m in diameter (plan view area of 1.04 km^2) and applying the 0.2 d/D assumption, it would access the upper 115 m of material on Ceres. To be consistent with GRaND results [10], any ice table near the equator must be buried >1 m. However, there is ample geomorphological evidence of substantial subsurface water ice near equator [16]. We cannot rule out that a ~575 m crater could expose ice near Ceres' equator, although for how long an order of magnitude ~1kg/s vapor production rate can be sustained is the topic of future work.

The next step in this Monte Carlo approach is to understand how long a crater will produce significant water vapor, especially when the water ice patch has developed an optically thick sublimation lag. We are currently modeling this and will combine these results with the crater production rate at all sizes to compare with the multiple exosphere detections over the last ~25 years [1-4].

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