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Condensed CO_2 on the Uranian Moons: Erosion Timescales from Sublimation, Sputtering, and Implications for Internal Source.

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IRTF/SpeX [1-3] and recent JWST observations [4] support possibly mm-thick CO_2 ice deposits on the classical Uranian moons. The high obliquity of the Uranian system implies extreme seasons on these icy moons. The winter hemispheres endure ~ 20+ years of darkness with their surface temperature plummeting to ~20 K [5]. Solid CO_2 is thermally stable over these frigid polar zones but is altered and eroded by the charged particles in Uranus' magnetosphere that impact the moons' surface. Laboratory irradiation [6] shows that charged particles dissociate CO_2 mostly into CO and O_2. At 25 K, a single 100 keV proton ejects ~15-20 molecules from the ice, and the sputtered flux is dominated by CO and O_2. Every intact CO_2 molecule in the sputtered ejecta is accompanied by ~10 CO and ~3 O_2 molecules [6].

Figure 1: CO_2 ice on the surface of the Uranian icy moons could be eroded by the impinging magnetospheric ions to generate CO/O_2-rich bound exospheres. Laboratory irradiations [6] reveal that CO_2 ice is readily sputtered by 100 keV protons at 50 K with yields reaching as high as ~ 2500 per ion. The sputtered flux is dominated by CO and O_2, rather than intact CO_2. The sputtering yield is drastically reduced (~ 100×) at 25 K, since the radiolytic byproducts CO and O_2 are 'thermally stable' and thus retained more effectively in the ice at colder temperatures. See [6] for additional details on the Instrumentation and experimental conditions.

Seasonal transition dramatically alters erosion dynamics. At spring equinox, the winter hemispheres emerge into sunlight, which warms their surfaces to release volatile CO and O_2 first, followed by CO_2. This process triggers transient pressure spikes in their exospheres [7]. Sublimation rates rise exponentially with temperature, but CO_2 sputtering, also temperature-dependent, may be an equally significant yet understudied erosion mechanism contributing to the moons' exospheres. At 50 K, the same 100 keV proton ejects ~ 2500 molecules [$CO:O_2:CO_2$ 1000:250:1] – two orders of magnitude above the 25 K yield (Figure 1, from [6]). Together, solar forcing and sputtering may accelerate CO_2 loss from the summer hemispheres, potentially creating day-night exosphere asymmetries. CO, O_2 and CO_2 molecules from the sunlit sides migrate via ballistic hops, trapping at cold locations in the winter pole or even at the shadowed equatorial canyons [8]. Measurements of the velocity distributions of the sputtered species are needed to constrain escape fractions at various moons.

Adding new measurements of CO_2 radiolysis and sputtering by keV electrons, we refine the dependence of CO_2 sputtering yield on projectile stopping power. By combining these with Voyager 2 charged particle fluxes [9, 10], we report on estimates of survival time of mm-thick CO_2 deposits against charged particle sputtering and discuss whether an endogenic source is needed to replenish the CO_2 abundance at the surface of these moons. Geological markings on the young terrains of

Ariel and Miranda (fault canyons, spreading grooves, coronae) support resurfacing from the interior [11, 12].

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