A Wunda-full world? Testing the plausibility of CO$_2$ frost on Umbriel

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Umbriel and Uranus

Umbriel is one of five large (r = 584.7 km) Uranian moons. It is dark (average bond albedo ~0.1), but has a noticeable bright (~0.5) annulus inside the ~130 km diameter equatorial crater Wunda [1–3]. We hypothesize that the bright annulus, which we call “Wundafill,” represents a deposit of carbon dioxide frost.

Recent detections of CO$_2$ on the trailing hemispheres of Uranian satellites [4,5] support this hypothesis. The CO$_2$ may be produced radiolytically [6]. We test our hypothesis using a combination of thermal modeling and ballistic transport models.

The extreme obliquity of the Uranian system (~98°) makes our study fundamentally different from similar work on other planets [e.g., 7].

Ballistic Transport

When a molecule sublimates, it is launched on a ballistic trajectory with a random direction and launch angle, and with a velocity according to the Maxwell-Boltzmann probability distribution:

\[ f = 4\pi \left( \frac{\mu}{2\pi kT} \right)^{3/2} v^{-3/2} e^{-\frac{\mu}{2kT}} \]

If a molecule’s velocity exceeds Umbriel’s escape velocity of \( E = (2gr)^{0.5} = 517 \) m/s, it is lost from the system via Jeans’ escape.

Carbon Dioxide Budget

Using the temperatures and sublimation rates from our thermal model as an input for our ballistic transport model, as has been done for other planets [e.g., 7] we calculate how an initial distribution of surface CO$_2$ evolves over time.

Once CO$_2$ starts migrating, the above results change as the polar regions are rapidly depleted of CO$_2$; we expect the latitudinal band experiencing net CO$_2$ influx to narrow as the system evolves.

We also ran simulations where equatorial regions had the thermal properties of CO$_2$ ice, not regolith. These runs show sublimation rates are negligible: once Wundafill forms, it is stable throughout the age of the solar system.

Discussion

CO$_2$ frost migrates equatorward on geologically short timescales. Why does Wundafill appear in a crater, and not in a band around a low latitude? Two possibilities:

1. Wunda is a complex crater, and the flat area around the central peak is a relative cold trap.
2. Wunda is near the center of the trailing hemisphere, where CO$_2$ may be produced [5, 6].

Miranda’s escape velocity (~1.93 m/s) is too low to retain CO$_2$, but it is possible the other large Uranian moons have Wundafill-like deposits which are not yet observed. Umbriel is the only moon where we have visually observed the center of the trailing hemisphere.

We conclude Wundafill plausibly represents a CO$_2$ frost deposit. It need not be geologically young.

References