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How hydrothermal vents affect water on Ceres

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Abstract

We numerically model hydrothermal vents in Occator crater, to explore their effects on the water distribution in Ceres' exosphere and surface. Although *Dawn* did not detect active vents on Ceres, it returned evidence that such vents were intermittently active in the recent past. We find that such vents partially explain the observed exospheric water distribution [1], and, while seemingly implausible, are nevertheless consistent with Ceres' northern excess of surface hydrogen [2].

1. Introduction

The Herschel Space Observatory (HSO) detected evidence of discrete surface regions injecting water into Ceres' exosphere [1]. Known surface ice deposits cannot sublime sufficient water to explain these observations [3,4 *c.f.* 5]. Thus, another source of exospheric water is required. *Dawn* later observed significant evidence for intermittently active hydrothermal vents in Occator crater. The floor of Occator contains numerous bright spots, thought to be recently emplaced by hydrothermal eruptions of subsurface brines [6-10]. Such subsurface brines may have been formed/emplaced by residual impact heating [11] or cryomagmatic plumes [12].

Dawn's GRaND instrument found a global asymmetry in the distribution of hydrogen in Ceres' near-surface, with relatively more water present at northern latitudes [2]. Here we explore the possibility that these observations are linked; that the hydrothermal activity in Occator crater produced a plume substantial enough to produce the observed exosphere [1] and surface water asymmetry [2].

2. Methods and Results

Given the low flux producing the cerean exosphere (~6 kg/s [1]) hydrothermal vents on Ceres are likely sufficiently rarified that continuum fluid mechanics breaks down. To study fluid flows in this transitional regime, we use numerical Direct Simulation Monte Carlo (DSMC) methods to compute the fluid flow statistically [1,13]. Our PLANET DSMC code [14-15] allows particles to adsorb/desorb onto/from the surface, using a temperature-dependent residence time model [14-17], and moves them subject to the non-inertial forces of the rotating reference frame.

We ran our initial simulations without collisions (free molecular flow), consistent with previous studies of Ceres' exospheric dynamics [18]. Collisions affect the gas flow only in a small region near the source of the vent. Thus, neglecting collisions provides a study of how the post-collisional ejection velocities of the water molecules affect their behavior. Here we summarize our initial results, focusing on how a hydrothermal vent in Occator crater ejecting 6 kg/s of water at 200K [1] vertically at 485 m/s (the most probable molecular speed) from a ~250K reservoir [11-12] would influence water observations on Ceres.

2.1 Exospheric Water Absorption

HSO detected two peaks in the water absorption from Ceres' continuum emission, near sub-observer longitudes of ~220º (coincident with Occator) and ~110º [1]. Because ballistic motion on the rotating Ceres moves ejected water westward in the exosphere, it is plausible that hydrothermal activity in Occator crater produced these absorptions. To test this, we compute the average gas flowfield around Ceres from an Occator vent, and project the resulting gas density onto the disk of Ceres to compute the average column density of water between Ceres and the observer. We find that the hydrothermal vent in Occator matched the absorption profile near 220º (fig. 1), suggesting that hydrothermal activity could form the observed exosphere.

A single steady hydrothermal vent in Occator cannot, however, fit the absorption peak centered on ~110º suggesting that a second source of activity was present on the surface [1]. Alternatively, nonsteady vent flow may also cause this absorption. HSO observations began with the detection of this absorption, which dampened to ~half its value one rotation later (consistent with Ceres' ~7 hr exosphere decay timescale [18,19]). Thus, if the Occator vent's water flux were significantly greater *prior* to the start of the observations, the absorption at ~110º could be due to unsteady flow from Occator that decayed away one rotation later.

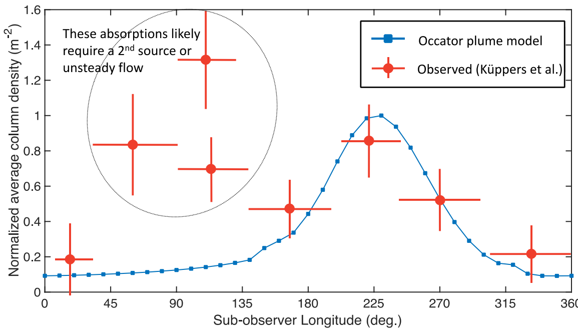

Figure 1: The average column density of water projected onto the disk of Ceres, from a plume in Occator Crater. Model normalized to peak at unity.

2.2 North/South Asymmetry

The total northern excess of water-equivalent hydrogen (WEH) detected by GRaND is ~2.5%, but is less in the low latitudes and grows to ~10% more hydrogen near the northern pole than the southern pole [2]. To explore the effects of a plume in Occator on this water distribution, we assume that the amount of time water molecules contact the surface is a linear proxy for the amount of WEH that eventually resides in the surface. We compute the net duration of time water molecules ejected from an Occator plume contact the surface, and compare with observed trends. Our simulations reveal that similar amounts of water reach the northern and southern low-latitudes (0-30º), but Occator's northern location leads to ~10% more water in contact with both the northern mid- (30-60º) and high-latitudes (60-90º) relative to their southern counterparts. Fitting the latitudinal trend to a linear dependence on surface temperature (fig. 2), we find general agreement with Ceres' measured difference in northern/southern WEH [2], but with deviations from this trend at low- and mid-latitudes, and potential longitudinal dependences that require further study.

The similarity in observed and modeled trends (fig.2) suggests that an Occator vent must source a sizeable, if not dominant fraction of the global WEH detected by GRaND, to explain the observed asymmetry. This would require Occator to have emitted ~1,000 - 10,000 km^3 of water (we assume a global average of ~20% wt. of water in Ceres' upper ~0.5 m, and that ~1-10 % of the emitted water permanently remains in the surface). If the source brines were a residual melt pool from the Occator-forming impact, this volume likely exceeds the total volume of the water reservoir [11]. Nevertheless, this likely represents a fraction of the total volume of a subsurface cryomagmatic brine reservoir ~90 km in diameter [12]. Thus, while perhaps unlikely that hydrothermal vents are responsible for Ceres' north/south WEH asymmetry [2], the volume of potential reservoirs and similarity in modeled and observed latitudinal trends suggest that it is nevertheless plausible, and begs further study.

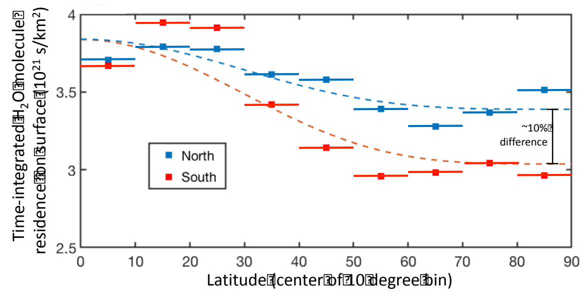

Figure 2: Latitudinal dependence of water contacting the surface: model (squares) and fit (dashed lines).

Acknowledgements

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References

[1] Küppers, M. *et al.*: Nature 505, 525 – 527, 2014
[2] Prettyman, T. *et al.*: Science 355, 55 – 59, 2017
[3] Küppers, M.: JGR: Planets 124, 205 – 208, 2019
[4] Landis, M.E. *et al.*: JGR:Planets 124, 61 – 75, 2019
[5] Raponi, A. *et al.*: Sci. Adv. 4: eaao3757 (6pp.), 2018
[6] Vu, T. *et al.*: P&SS 141, 73 – 77, 2017
[7] Palomba, E. *et al.*: Icarus 320, 202 – 212, 2019
[8] Raponi, A. *et al*.: Icarus 320, 83 – 96, 2019
[9] Schenk, P. *et al.*: Icarus 320, 159 – 187, 2019
[10] Thomas, E. *et al.*: Icarus 320, 150 – 158, 2019
[11] Bowling, T. *et al.*: Icarus 320, 110 – 118, 2019
[12] Quick, L. *et al.*: Icarus 320, 119 – 135, 2019
[13] Bird, G.A.: Molec. Gas Dyn. and Direct Sim. of Gas Flows, Oxford Science Pub. – Oxford, UK, 1994
[14] Stewart, B. *et al.*: Icarus 215, 1 – 16, 2011
[15] Prem, P. *et al.*: Icarus 255, 148 – 158, 2015
[16] Frenkel, Z.: Zeitschrift für Physik, 26, 117 – 138, 1924
[17] Langmuir, I.: Phys. Rev. 8, 149-176, 1916
[18] Schorghofer, N. *et al.*: ApJ 850:85 (7pp.), 2017
[19] Steckloff, J.K. *et al.*: 50th LPSC, #1066, 2019