THE ORIGIN OF VESTA'S ASYMMETRIC DISTRIBUTION OF HYDROGEN SIGNATURES AND HYDRATED MINERALS. J. K. Steckloff [1,2], D. Goldstein[1], P. Varghese[1], L. Trafton[3], [1]University of Texas at Austin, Department of Aerospace Engineering and Engineering Mechanics, 2617 Wichita St., Austin, TX 78712, USA (steckloff@utexas.edu) [2]Planetary Science Institute, 1700 East Fort Lowell, Suite 106, Tucson, AZ 85719, USA [3]University of Texas at Austin, Department of Astronomy, RLM 16.326, Austin, TX 78712, USA

Introduction: The *Dawn* mission to Vesta found evidence of aqueous alteration on its surface. The *Dawn* VIR instrument detected terrains rich in OH groups[1] that coincide with terrains that the GRaND instrument found to be rich in hydrogen[2].These terrains are thought to be the result of water: hydrated minerals[1] and/or subsurface water[2]. Although Vesta has no permanently shadowed regions[3], the Vestan subsurface is cool enough to store water ice for billions of years [3,4].

Other large, airless bodies in the inner solar system show similar evidence of water. Water ice has been found in permanently shadowed craters on Mercury[5-9], the Moon[10-15], and Ceres[16,17] in latitudinal trends that suggest water's distribution of water on these bodies is largely controlled by solar insolation flux. In stark contrast, Vesta's hydrated and H-rich terrains are localized, but do not follow latitudinal trends[1,2]. This enigmatic distribution has been attributed to stochastic delivery of these hydrated materials by carbon-rich impactors[18]. Nevertheless, Vesta and Ceres experience the same impactor population, suggesting that, if Vesta's hydrated mineral distribution is solely due to impacts, similar patterns should be seen Ceres.

We instead propose that Vesta's non-latitudinal distribution is the direct result of its smaller size, which precludes the retention of a bound H_2O exosphere. Exospheres facilitate water migration about the surface, distributing water both longitudinally as the body rotates, and latitudinally as the water migrates toward the poles over diurnal timescales[19,20]. Such exospheres can form following large, water-rich impacts[19-21], impacts into water-bearing surface terrains, or from the direct sublimation of surface water ice.

Bodies Capable of H_2O Exospheres. To form an H_2O exosphere, a body must be warm enough for ice to sublimate during the day, and large enough to prevent the escape of the resulting water vapor. From kinetic-molecular theory, one may describe the expected time that a typical water molecule resides in a condensed ice phase, prior to sublimating to gas as[22,23]:

$$\tau_{res} = \tau_0 e^{\frac{u_0}{k_B T}}$$

where τ_0 is the oscillation period of a molecule on the surface perpendicular to the surface, u_0 is the molecular binding energy, k_B is Boltzmann's constant, and T is the surface temperature. For a water molecule in an ice lattice, these values are τ_0 = 5.0 x 10^{-13} s and u_0 = 6.64±0.02 x 10^{-20} J for unannealed H_2O ice and u_0 = 7.00±0.07 x 10^{-20} J for annealed H_2O ice[24]. Each airless solar system body has a unique residence time determined by its peak blackbody temperature over the course of a rotation:

$$T_{peak} = \left[\left(\frac{1-A}{\varepsilon\sigma}\right)\left(\frac{L_{solar}}{4\pi r^2}\right)\right]^{\frac{1}{4}}$$

where A is the surface's bond albedo, L_{solar} is the solar luminosity, r is the heliocentric distance, ε is surface's the emissivity, and σ is the Stefan-Boltzmann constant. The emissivity (ε) of typical geologic materials are close to unity. To form an H_2O exosphere, an airless body's residence time must be significantly shorter than the length of a day, otherwise water would condense into a permanent, high-albedo frost layer. There are only four large airless bodies in the inner solar system for which this condition is met, allowing H_2O exospheres to form: Mercury, the Moon, Ceres, and Vesta (see fig. 1).

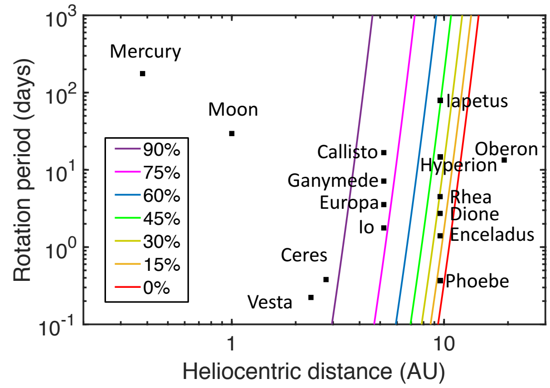

Figure 1: The rotation periods of airless bodies, plotted with residence time of water ice as a function of albedo.

Bodies Large Enough to Retain Exospheres Additionally, a body must be sufficiently large to gravitationally retain water vapor, to prevent rapid ballistic escape of exospheric H_2O. One can compute the mean-magnitude thermal speed of a water molecule on the illuminated side by balancing solar heating with radiative heat loss (averaged over the illuminated side of the body):

$$v_{th} = \sqrt{\frac{8k_B T_{avg}}{\pi m}}$$

$$T_{avg} = \left[\left(\frac{1-A}{2\varepsilon\sigma}\right)\left(\frac{L_{solar}}{4\pi r^2}\right)\right]^{\frac{1}{4}}$$

where T_{avg} is the average temperature on the illuminated side of the body, and m is the mass of a water molecule. Comparing this to the surface escape speed we find that Mercury and the Moon can clearly retain these water molecules, while Ceres and Vesta have thermal speeds comparable to their surface escape speeds.

	Mercury	Moon	Ceres	Vesta
Avg. Surf. Temp. (K)	469-577	318-324	190-206	194-215
Avg. H_2O speed (m/s)	743-824	611-617	473-492	478-503
v_{esc} (m/s)	4,250	2,380	510	360

Table 1: H_2O speeds and surface escape speeds.

Refining this approach, we compute the thermal speed of a water molecule as a function of angular distance from the subsolar point for both Ceres and Vesta. Since H_2O condenses into surface frost on the night side of these bodies and sublimates at the dawn terminator[20,21], we also compute the minimum speed needed to reach various points across the illuminated surface of the body from the dawn terminator at the equator.

For Ceres, we find that the thermal velocity of a water molecule is usually less than the surface escape speed, except for a region within ~40 degrees of the subsolar point. Additionally, the thermal speed at/near the dawn terminator is sufficient to send water molecules anywhere across the illuminated side of Ceres, with any molecules that land near the subsolar point have a high probability of escaping. Nevertheless, this escape hatch is small enough that Ceres should be able to retain an H_2O exosphere for many diurnal cycles (fig. 2).

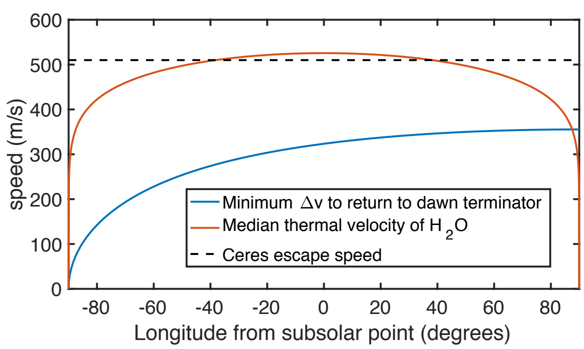

Figure 2: The thermal speed of water on Ceres, and minimum speed to hop from dawn terminator at 2.7 AU.

Unlike Ceres, on Vesta the thermal speed of H_2O upon leaving the surface is always greater than the surface escape speed, except for a thin ribbon along the terminator, leading to rapid ballistic escape of any water molecules. Confounding this loss, the thermal speed near the terminator is sufficient to send water molecules anywhere on Vesta's surface. Thus, any water molecules not directly ejected from the surface would likely make a few ballistic hops from the dawn terminator before striking a surface sufficiently warm to eject it. As a result, Vesta cannot retain an H_2O exosphere (fig. 3).

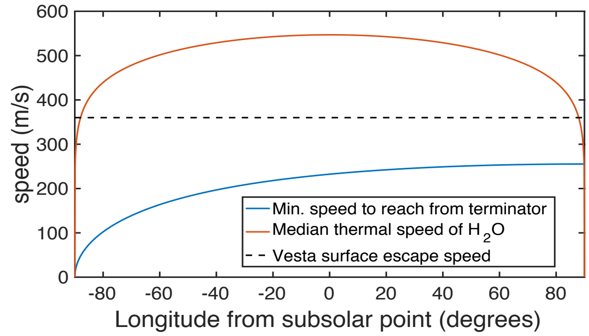

Figure 3: The thermal speed of water on Vesta, and minimum speed to hop from dawn terminator.

Conclusions: Given that Vesta and Ceres experience the same impactor population, the mechanism causing Vesta to lack a latitudinal trend in its water/hydrated mineral distribution is likely intrinsic. Vesta, like Mercury, the Moon, and Ceres, is warm enough to form an H_2O exosphere, but is too small to retain it. This precludes exospheric dynamics from smoothing Vesta's water into the expected latitudinal trend. Instead, water and hydrated minerals on Vesta are either directly delivered to the surface as impact ejecta, or form from impact-delivered water directly striking Vesta's surface, producing an asymmetric distribution of these features, in lower concentrations than are found on Ceres[1,2,17].

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