**THE PERMANENTLY SHADOWED CRATERS OF CERES AS SEEN BY THE DAWN SPACECRAFT.**

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**Introduction:** Ceres, Earth's Moon, and Mercury have a very small spin axis tilt and craters near the rotational poles can thus experience permanent shadow, where, due to low temperature, ices can accumulate [1]. On Mercury, the cold traps are filled with water ice. The content of the cold traps on the Moon is ambiguous. For Ceres, the Dawn spacecraft provides the first opportunity to explore permanently shadowed regions (PSRs), that have been studied theoretically [2]. Moreover, Ceres' gravity is strong enough to hold on to various molecular species, so that water molecules undergo ballistic hops that can transport $H_2O$ from any part of the surface to the cold traps. Here, orbital images of the northern polar region are used to determine the size of the cold traps, and modeling is utilized to estimate how much ice may have accumulated in them.

**Methods:** Soon after the northern summer solstice in late July 2015, Dawn entered its High Altitude Mapping Orbit (HAMO). For a preliminary analysis, Framing Camera (FC) images [3] from the first HAMO cycle (18–27 Aug 2015) are used, with a resolution of 138 m/px. The images were map-projected using the ISIS software from USGS, and then stacked to identify areas that are shadowed in all images [4]. Current registration errors may cause the persistent shadows to underestimate the real permanent shadows. On the other hand, the limited temporal sampling may lead to an overestimate. Additional pertinent FC images are available and will be analyzed.

To quantify transport in the water exosphere, a Monte-Carlo model of ballistic hops at thermal speeds is used [5,6]. Hop distance and time of flight are calculated for non-uniform gravity and a rotating sphere. Surface temperature is obtained from a thermal model.

**Results:** *Mapping of PSRs in the northern hemisphere.* Figure 1 shows the polar region with white patches that indicate the minimum extent of shadows determined from 51 images. The white areas are upper bounds, but given the local time coverage and the proximity to solstice, they should be good approximations of the extent of the PSRs. It is mostly polefacing crater walls and parts of crater floors that remain continuously shadowed. Poleward of 80°N, 3.7% of the area is always observed shadowed. This corresponds to 790 km$^2$ or 0.06% of the hemisphere. This proportion is comparable to the Moon, where about 0.08% of the global area is permanently shadowed [7].

*Exosphere model.* The thermal speed of water molecules is comparable to Ceres' escape speed, and hop lengths are comparable to the size of Ceres. For the estimated cold-trapping area, mirrored on the south pole, 0.07% of the water molecules that are generated on the surface end up in the cold traps over a Cererean year. This is significantly less than on the lunar surface, where an estimated 11% get cold-trapped. Many molecules are lost due to gravitational escape. Even the small axis tilt causes a seasonal effect, where water molecules seasonally reside near the cold pole, before being released again, so a "dusting" of frost can be expected around the winter pole.

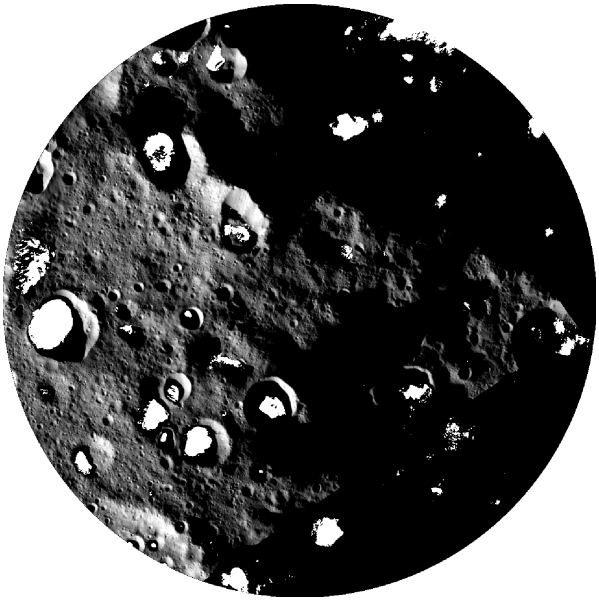

Figure 1: Minimum shadows (white) in the north polar region. In this polar stereographic projection, latitudes are above 80°N, and the north pole is at the center. The background shows a single image, while the minimum shadows are obtained from 51 images with a range of local times. These images are from near summer solstice, so the white areas represent the extent of permanent shadow.

*Water supply.* The source of the ice in the cold traps of Mercury and the Moon is not known, and could be infall or solar-wind generated. For Ceres, the retreating subsurface ice layer is another potential source for coldtrapped water. Assuming (arbitrarily) that the outer layer has 40% ice, it was estimated that 0.02 kg/s of $H_2O$ is currently output as a direct result of the globally retreating ice [8]. With a trapping area of 790 $km^2$ at each pole, this amounts to 0.3 m of ice in the last Gyr. Herschel observations suggest an output of 6 kg/s [9]; in this case 80m of ice would have accumulated over the last Gyr alone. This rate is higher than the estimated Lyman-α space weathering erosion rate of ~0.1 m/Gyr [10]. Depending on the actual supply rate and the actual space weathering erosion rate, ice deposits may be present in the cold traps.

**Discussion:** Cold traps are effectively defined by peak temperatures below 120K. Due to Ceres' large distance from the sun, even briefly illuminated areas might remain below this temperature. In this case, cold-trapped ice may be briefly visible, and we are studying the images with this possibility in mind.

No comparable shadow geometry has been present in the southern polar region since the arrival of the Dawn spacecraft at Ceres, and the southern solstice will occur only in Dec 2017, long after the end of the nominal mission. An extension of the mission into southern fall would provide better constraints on the area in permanent shadow at southern latitudes. It would also allow acquiring more long-exposure and losslessly compressed images to observe areas that do not receive direct sunlight with scattered light, and possibly observe bright deposits.

The seasonal frost cap around the colder pole may, for the assumed supply rate, accumulate to a thickness on the order of nanometers. Its presence and sudden disappearance may lead to observable consequences.

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