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Mercury's Uneven Ice Deposits: Implications from Craters that Lack Observable Water Ice

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Abstract

The presence of water ice in Mercury's polar regions raises compelling scientific questions about its origin and age. Here we present evidence that Mercury's ice deposits are unevenly distributed and that there are sizable, thermal cold traps near Mercury's poles that lack water ice. This suggests that Mercury's water ice was not emplaced by a steady process but rather by an episodic event, such as by a large impact.

1. Introduction

Earth-based radar observations [5] and MESSENGER measurements [2] have provided multiple lines of evidence that Mercury's polar deposits are dominantly composed of water ice. In this study, we focus on the distribution of the ice, which can provide constraints on the origin and age of the deposits. Studies of both the north [3] and south [1] poles have shown large permanently shadowed regions that lack radar-bright signals. Being permanently shadowed is necessary but not the only condition required for ice on Mercury to be stable. The permanently shadowed region also has to have a thermal environment with sustained temperatures low enough to maintain water ice.

Conversely, regions can also lack radar-bright signals because of the limited viewing geometry of the Earth-based radar observations. Each Earth-based radar observation has portions of the polar region that were located in "radar-shadow" – locations that the radar could not view due to being obstructed by Mercury's topography. Thus, the lack of radar-bright signals could be due to viewing limitations rather than a lack of water ice and perhaps these cold traps do have ice.

Here we focus on a region of Mercury's north pole (Fig. 1), where previous studies have indicated sizable permanently shadowed regions that lack extensive radar-bright signal. Does this region really lack water ice deposits?

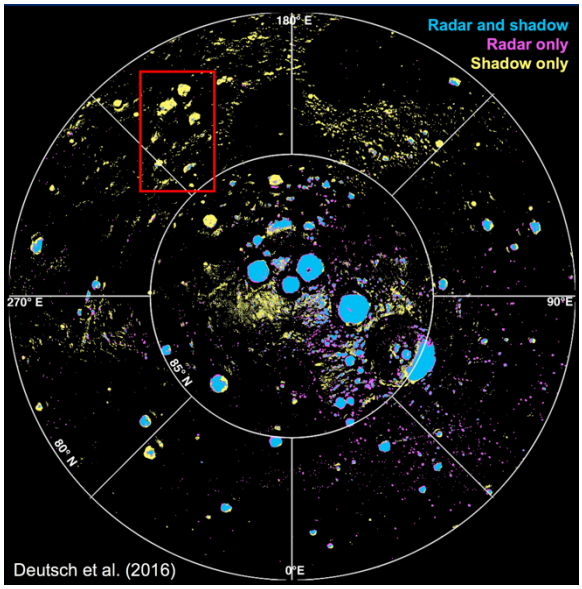

Figure 1: Region of study (outlined in red) near Mercury's north pole, which has sizable regions of permanent shadow [3] that lack extensive radar-bright signals (yellow).

2. Region, Datasets, and Results

The study region (Fig. 1) is located between 81°–85°N and 210°–230°E. The thermal modeling results [7] of this area show sizable permanently shadowed regions that are conducive to the long-term stability of water ice. We investigated three aspects of this area:

1) Individual Arecibo radar observations and the associated radar visibility;
2) MESSENGER Mercury Laser Altimeter (MLA) surface reflectance measurements;
3) MESSENGER Mercury Dual Imaging System (MDIS) images of the permanently shadowed surfaces.

Analysis and comparisons of these datasets indicate that Arecibo radar viewing conditions were highly favorable to detect water ice in this region, if ice were

present; an example of one Arecibo observation opportunity is shown in Fig. 2. MLA measurements and MDIS images both show that permanently shadowed regions in this area have low-reflectance surfaces, despite lacking extensive radar-bright signals.

3. Summary and Conclusions

We conclude that multiple Arecibo radar viewing opportunities were highly favorable to detect ice in this region of Mercury and that the lack of detection by Arecibo suggests that these permanently shadowed regions do not have extensive water ice deposits. However, these permanently shadowed regions have low-reflectance surfaces, interpreted to be volatile, complex organic compounds that concentrated on the surface as water ice sublimated to space [6. 7].

How would low-reflectance surfaces form in regions that lack water ice? We conclude that this resulted because: 1) water ice and other volatiles were initially delivered to these locations, 2) low-reflectance sublimation lag deposits began to form, but 3) the amount of water ice was low, such that it was all lost before a sufficiently thick (~10 cm) lag deposit could be formed to insulate any remaining water ice beneath it. This implies that the emplacement of Mercury's ice was uneven across the polar regions, and that the total ice abundance may be on the lower end of the range estimated for Mercury's polar deposits – conclusions which may support a recent, large impact event as the source of Mercury's water ice, such as potentially delivered by the Hokusai impactor [4].

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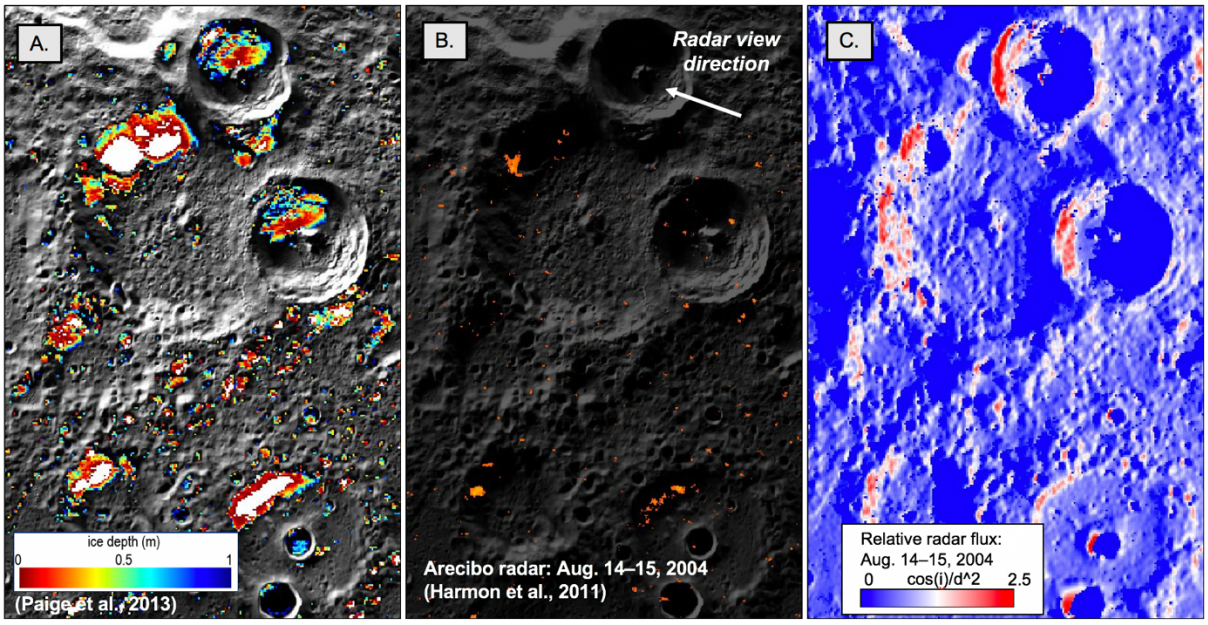

Figure 2: Maps of the region identified in Fig. 1: **A.** Depth at which water ice is stable. **B.** Arecibo radar observation. **C.** Radar visibility at the time of the Arecibo observation; high relative radar flux indicates favorable viewing conditions.