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How is water vapour released from Ceres?

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Abstract

Remote observations from ground and space and in-situ exploration by the Dawn spacecraft have revealed a transient water exosphere around dwarf planet (1) Ceres, demonstrating that water ice is ubiquitous in the outer asteroid belt. However, no clear conclusion has been reached about the process that drives the release of water vapour from the surface or subsurface of Ceres. We will summarize the available evidence and estimate the contribution from various suggested processes.

1. Introduction

Indirect evidence through its shape and density pointed to Ceres being differentiated into a silicate core and an icy mantel [1]. The first tentative detection of water vapour from Ceres was reported in 1992 based on IUE observations [2], and a clear signal was observed on 3 out of 4 occasions by Herschel [3]. However, not all observations resulted in water detection (see Fig. 1).

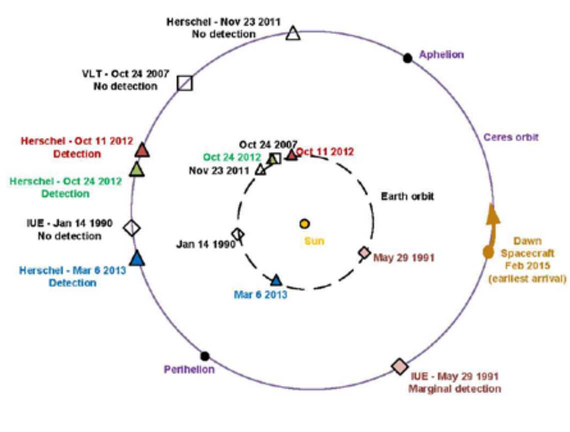

Figure 1: Observations of water vapour at Ceres before arrival of the DAWN spacecraft. Filled symbols are detections, empty symbols represent non-detections. Figure taken from [3].

The rendezvous of the Dawn spacecraft with Ceres observed the exosphere indirectly through bursts of energetic electrons, indicating the presence of a bow shock caused by an exosphere [4]. The Dawn observations confirmed the transient nature of the atmosphere. Furthermore, Dawn detected water ice on and below Ceres' surface. Now, with the Dawn mission coming to its end, it is timely to review our knowledge about water on Ceres and the mechanism of water vapour release.

2. Properties of water on Ceres

The process(es) responsible for water vapour release from Ceres need to be consistent with the following observations:

1. Near-Infrared spectra of the surface show evidence for water ice at a single near-equatorial location [5]. Water ice is more abundant in shadowed polar regions [6], but the detectable amount of surface ice is too low to explain the observed water vapour.

2. A water-rich subsurface layer is very close to the surface in polar regions and at depths of several dm or 1 meter in equatorial latitudes [7].

3. When water vapour from Ceres is detected, the production rate is typically a few times 10^{26} s^{-1} [2,3,4].

4. The expansion velocity of the water vapour is ~400-700 m/s and the thermal velocity ~700 m/s, although a larger velocity > 1 km/s was observed on one occasion [3].

5. The water vapour does not originate from polar regions and is emitted from localized sources [3].

6. The occurrence of a transient exosphere observed by DAWN is correlated with solar proton events [4].

3. Possible mechanisms for water vapour release from Ceres

Here we review the mechanisms that were suggested for water vapour release from Ceres and evaluate them based on the observational results from the previous section:

A) **Water from the interior of Ceres**

As water ice is expected in the interior of Ceres, ice could sublimate far below the surface and diffuse through a porous subsurface layer [8]. However, the estimated production rate is ~2 orders of magnitude lower than the observed one, and as most of the water vapour is predicted to come from polar regions, it is not consistent with observations 5 and 6.

B) Cryovolcanism

Cryovolcanism is a process that may create water vapour with the observed properties (observations 3 and 4) and was suggested as an option [3]. However, no evidence for cryovolcanoes was found on Ceres by DAWN, and the process is inconsistent with observation 6.

C) Evaporation from recent large impact

A large recent impact could create temporary water activity by evaporation of the icy impactor and a newly created fresh crater. However, the process cannot explain the existence of more than one water source (observation 5) and the non-detection of a large crater with water ice at the surface.

D) Water ice sublimation

A straightforward way of creating water vapour is the mechanism of cometary activity: Sublimation of ice from either the surface or from just below it. While the mechanism is consistent with most observed properties of water vapour (observations 4-5), the observed amount of water ice is insufficient to explain the production rate. However, it is currently unknown how much water ice may be “hidden” from observations in an intimate ice-dust mixture on the surface, and impacts of small meteorites may locally remove the surface layer and thereby increase sublimation.

If sublimation is the dominant process, a separate explanation of observation (6) needs to be found.

E) Sputtering of ice by high energetic solar protons

This process, suggested by [4], is the only one that can explain observation 6. However, sputtering efficiencies appear too low to explain the observed production rates [9]. Also, the observed expansion velocities are on the low side for sputtered water. A more detailed investigation of the interaction of solar energetic particles with the surface and subsurface layer is needed to fully evaluate this process.

4. Conclusions

No known process can explain all observations. The most promising ones are (sub)surface sublimation and sputtering by high energetic protons, or a combination of both. We will present our detailed study of both processes to better evaluate what causes the water vapour leaving Ceres.

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