VARIATIONS IN THE AMOUNT OF WATER ICE ON CERES' SURFACE SUGGEST A SEASONAL WATER CYCLE

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Introduction: Exposed water ice was discovered by the Dawn Visible and Infrared Mapping Spectrometer (VIR) [1] in Juling crater on Ceres [2, 3], situated in a mid-latitude in the southern hemisphere (35° S, 168° E). Clear water ice absorption bands at 1.25, 1.5, 2.0 and 3.0 μm were observed by VIR. In particular, water ice was detected on the northern shadowed crater wall, characterized by an almost vertical rocky cliff. The crater wall is lightened by secondary light coming from the adjacent illuminated regions. The crater floor shows evidence of the flow of ice and rock, similarly to Earth's rock-glacier [4].
This crater has been observed by VIR two times during the Low Altitude Mapping Orbit (L1, L2), and three times during a phase devoted to Juling's observation: Extended Juling Orbit (E1, E2, E3).

Results: The repeated observations of this crater permitted a detailed analysis of the water ice behavior. Analyzing all the acquisitions, we discovered changes in the spectra of the ice-rich wall. Water bands were detected in all the observations on the northern wall of Juling, but VIR observed variations of the water ice features in terms of band depths and overall spectral shapes [2]. In particular, the 2.0-μm water ice absorption that is the most prominent band and least affected by instrumental errors, was examined for understanding the ice trend.

In E1 and L1 observations, the crater wall was observed under the same conditions in terms of illumination and viewing geometry, permitting a direct comparison of the measured spectra. The other observations have been compared by means of dedicated modeling: the average spectra over the area of interest have been modeled as the sum of the light reflected from region outside the crater wall illumiated directly by the sun, and the region of the crater wall which is illuminated by secondary light coming from the crater floor. This has been discussed in [5].

According to the modeled spectra, the total area was covered by 9.1 ±0.3% of water ice in the first observation, and 13.7 ±0.9 % in the last observation [2], suggesting a net increase of water ice on the crater wall.

Discussion: The observed increasing abundance of water ice on the crater wall can be explained by different processes: (1) sub-surface displacement of brine or liquid water, which, percolating through clay layers, freezes when exposed to the shadowed cold surface; (2) exposure of ice present behind a regolith layer by falls, or (3) water vapor condensed in the cold wall, which is triggered by solar radiation and/or solar energetic particle events [6,7]. In fact, the changes in heliocentric distance, coupled with the varying season, result in a net increase in solar flux and a retreat of shadow on the floor.

Water vapor was observed by the Herschel telescope [6]; the linear trend shown in [2] can support the solar flux as main responsible of the observed increase.

The water ice abundance on the wall is probably not constantly increasing over a longer time range. More likely, we are observing only part of a seasonal cycle of water sublimation and condensation, in which the observed increase should be followed by a decrease. The orbital parameters of Ceres could justify such a cyclical trend: after the period covered by the observations, Ceres approaches the summer-solstice, close to perihelion, where the temperature of the shadowed area increases, possibly triggering also the sublimation of water ice previously accumulated on the cold wall, or sublimating pristine water ice with higher rate than its exposure.

References:

[1] M. C. De Sanctis et al., *Space Sci. Rev*. **163**, 329–369 (2011).
[2] Raponi et al., *SCIENCE ADV*, (2018).
[3] Combe et al., *Icarus*, (2018).
[4] B. E. Schmidt et al., *Nature Geoscience* **10**, 338–343 (2017).
[5] A. Raponi, *EPSC2017*-821 (2017).
[6] M. Kuppers et al., *Nature* **505**, 525-527 (2014).
[7] M. N. Villarreal et al., *The Astrophysical Journal Letters* **838**, article id. L8, 5 pp. (2017).

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