Modern brines at Ceres: hints from VIR imaging spectrometer on Dawn mission, M.C. De Sanctis[1], E. Ammannito[2], M. Ciarniello[1], A. Raponi[1], F.G. Carrozzo[1], A. Frigeri[1], M. Formisano[1], B. Rousseau[1], M. Ferrari[1], S. De Angelis[1], S. Fonte[1], , M. Giardino[1], B.L. Ehlmann[3,4], S. Marchi[1,5], C.A. Raymond[3,4], C.T. Russell[6]

[1]Istituto di Astrofisica e Planetologia Spaziali, INAF, Via del Fosso del Cavaliere 100, 00133 Roma, Italy; [2]Agenzia Spaziale Italiana, ASI, via del Politecnico, 00133 Roma, Italy; [3]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA; [4]Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA, USA; [5]SWRI, 1050 Walnut Street, Boulder, CO 80302, USA; [6]Earth Planetary and Space Sciences, University of California, Los Angeles, CA, USA.

Introduction: Ceres, the largest body in the main belt and the closest dwarf planet to the Sun has been the subject of extensive observation by the Dawn mission [1]. Since telescopic observation was known that Ceres is constituted by a large amount of water. The Dawn data show that Ceres overall density is 2.16 g/cm^3 but the crust is composed of an intimate mixture of rock and ice, with a much lower density of ~1.25 g/cm^3, implying a great quantity of water in the crust ([1,2]).

The surface is cratered but very large craters are absent, indicating efficient relaxation [3]. Ceres has mountains, like the geologically recent Ahuna Mons, that are likely of cryovolcanic origin [4]. The crater distribution [3] and morphological features [5] support the inference that Ceres' crust is a mixture of ice, rock and salt hydrates that is periodically mobilized to produce extrusive features such as Ahuna Mons, as well as flow features and bright deposits.

After Dawn mission results, it became clear that Ceres is an ocean-world, but the physical status of the water (ice vs liquid) has been extensively debated [6]. Here we will review the indicators for the presence of modern brines inferred primarily by the VIR spectrometer on board of Dawn.

VIR/Dawn Discoveries: VIR spectrometer [7] extensively observed the surface of Ceres. The surface mineralogy indicates that Ceres experienced extensive water-related processes and chemical differentiation. The surface is mainly composed of a dark and spectrally neutral material (carbon, magnetite), Mg-phyllosilicates, ammoniated clays, carbonates and salts [8,9]. The observed species suggest endogenous, global-scale aqueous alteration [8,9] indicating the presence of a global ocean in the past of dwarf planet history [6].

Water ice has been identified in several small locations [10] and ice abundance variation over a short timescale (few months) has been observed in one crater (Juling crater [11]). It must be recalled that water ice is not stable at Ceres surface and most of these water ice exposures have been found in shadowed areas, where the temperatures are much lower with respect to the average surface as suggested by numerical models (e.g. [15]). Nevertheless, the reason for the observed variation in the ice abundance in Juling is still to be understood and suggest a sort of "water cycle" at Ceres.

The surface shows important variations in the abundance and presence of different species, including the presence of salts. Sodium carbonates have been identified in several bright areas on the surface, notably in Occator crater's bright material (faculae) (Fig. 1) [12,13]. Also hydrous sodium carbonate has been identified in the vicinity of the water ice deposits [13] indicating close relationship between water and salts.

In the Occator faculae, sodium carbonate constitutes most of the bright material but it is not the only component. Recently, by investigating the IR spectra of the central part of Occator large facula (fig. 1), brines constituted by NaCl·2H2O (hydrohalite), NH4Cl (ammonium chloride), and Na2CO3 (natrite) have been identified[14].

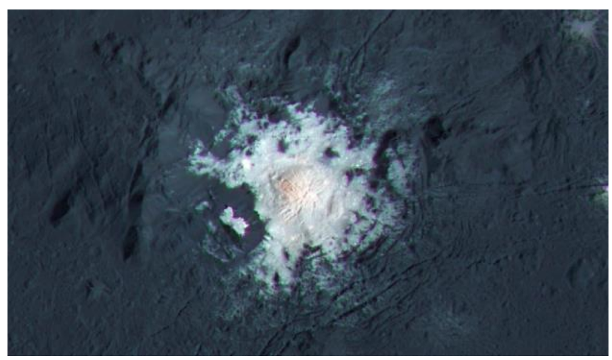

Fig. 1 The dome of Cerealia facula in Occator crater. The bright material is mainly sodium carbonate. Image Credit: NASA, JPL-Caltech, UCLA, MPS/DLR/IDA

The formation of the Occator central pit and tholus, and the emplacement of the bright material, has been extensively debated. Among the different hypothesis, the are two major scenarios: the first one involves the formation and extrusion of liquid salty water induced by the heat released by the Occator impact without pre-existing circulation of fluids at depth; the second considers the presence of pre-existing fluids that extrude onto the surface, facilitated by the fractures and conduits formed consequently to the impact.

Both the hypothesis require circulation of fluids at depth, able to extrude onto the surface, but the origins of those fluids (induced by external factors or by endogenic processes) and consequent implications, are different.

The facula shows concentric and radial fractures within the Cerealia tholus, which are the expression of the uplift stress. These extensional fractures represent the preferable conduits where fluids can escape towards the surface. The VIR data acquired on Occator bright material indicate that the hydrous salt is mainly on top of the Ceralia tholus in proximity of the fractures. Moreover, the presence of hydroalite, being very unstable at the Ceres surface and dehydrating in halite (NaCl) in a very short time (tens of years), suggests a very recent or continuous emplacement, implying that brines would still be able to extrude onto the surface[14].

The extremely recent emplacement is mainly consistent with the scenario of an endogenic process of circulation of salty aqueous solutions able to extrude onto the surface if the conditions are favorable (as the presence of fractures). The distribution of different species present on the faculae suggests that this material was produced inside Ceres, in modern brine-fed hydrothermal systems that recently brought this material to the surface.
Moreover, a long-term preservation of deep brines is possible if the crust is rich in clathrate hydrates as suggested by the model of Castillo-Rogez et al. 2019 [16] and by the lack of convection modes in the subsurface of Ceres [17].

Conclusions: Together with other observations by Dawn mission, such as the presence of cryo-volcanos , fluid landslides, geomorphological features, the VIR/Dawn discoveries suggest the presence of modern brines circulating inside Ceres and able to extrude onto the surface.

Many of the minerals observed on Ceres have been also detected in the plumes originating from the subsurface ocean of Enceladus (e.g. [18]), supporting the fascinating hypothesis of a residual ocean also in Ceres. Ceres is very appealing in terms of habitability, given also the discovery of aliphatic organics [15] and the likely existence of carbon globally present on the surface [16]. As such, the dwarf planet is a privileged target for the search of life in the solar system, showing clear signs of fluids circulation in the recent past or even at present, and the presence of aqueous alteration products, water ice and organic material.

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Dawn data are archived in NASA's Planetary Data System; VIR spectral data may be obtained at http://sbn.psi.edu/pds/resource/dwncvir.html

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