Mem. S.A.It. Vol. 92, 144

Memorie della

Ceres: a new astrobiological target for the future missions

M.C. De Sanctis[1], E. Ammannito[2], M. Raponi[1], M. Ciarniello[1], F.G. Carrozzo[1], A. Frigeri[1] and the VIR Dawn Team

[1] Istituto Nazionale di Astrofisica –Istituto di Astrofisica e Planetologia Spaziali – INAF Rome, Italy.
[2] Agenzia Spaziale Italiana, Rome, Italy. e-mail: mariacristina.desanctis@inaf.it

Abstract. Ceres, the largest body in the main belt, has been the subject of extensive telescopic observation since its discovery on January 1, 1801. The arrival of Dawn mission at Ceres allowed to understand better this intriguing body. Chemical and physical data obtained by the Dawn mission enable measurements of key parameters constraining the habitability of this dwarf planet. The data indicate that Ceres underwent to a protracted history of reactions between liquid water and rock, including also organics. In this paper we review the main discoveries that indicate the astrobiological importance of Ceres.

Key words. Ceres, organics, astrobiology

1. Introduction

Ceres large mean radius and small bulk density, respectively 470 km and 2162 kg m^{-3} (Russell et al. 2016), are intermediate between Europa (1560 km and 3014 kg m^{-3}) and Enceladus (252 km and 1611 kg m^{-3}), and similar to those of many icy satellites in the solar system. Thanks to the Dawn mission observations (Russell et al. 2016), it has been recognized that Ceres is more akin to icy satellites than to rocky bodies, and was likely formed in the outer part of our solar system.
The Dawn data show that the crust is composed of an intimate mixture of rock and ice (Ermakov et al. 2017). The surface is cratered but very large craters are absent, indicating relaxation, presence of ice in the crust (Fu et al. (2017); Bland et al. (2016)). The surface is mainly composed of a dark and spectrally neutral component (carbon, magnetite), Mg-phyllosilicates, ammoniated clays, carbonates and salts. The observed species suggest endogenous, long term global-scale aqueous alteration (de Sanctis et al. (2015); Ammannito et al. (2016)). The surface is uniform in composition at large scale but shows important variations at local scale. Ceres also has mountains, like the extremely young Ahuna Mons [Fig. 1], that are likely cryovolcanic construct(s) (Ruesch et al. 2016), that are a strong indication of on-going geological activity. The internal structure (Ermakov et al. 2017) as well as the mineralogy (de Sanctis et al. (2015); de Sanctis et al. (2016); Ammannito et al. (2016)) indicate that Ceres experienced extensive water-related processes and chemical differentiation: it hosted a deep ocean during at

least part of its history and there are indications of present fluid circulation and liquid reservoires (De Sanctis et al. (2020); Raymond et al. (2020)).

2. Key observational evidence defining the habitability

In this section, we report observational evidence derived by the available data and models of Ceres, for each of the “ingredients” defining the habitability of a planetary body.

2.1. Water and early ocean

Gravity and topography data indicate Ceres' interior structure consist of a rocky mantle with a density of 2400 kg m^{-3} and a water-rich, 40-km thick crust with a density of 1300 kg m^{-3} . The low crustal density should imply a large fraction of water ice (that have been about 40% water ice) and void space by volume (Bland et al. 2016). Several observations and models indicate that the crust contains salts and/or clathrates (Bland et al. (2016); Fu et al. (2017)) consistent with simulations of the freezing of Ceres' early ocean (Castillo-Rogez et al. 2018). The globally distributed hydrated silicate material found on Ceres' surface (Ammannito et al. 2016) requires formation in warm and abundant liquid (Castillo-Rogez et al. 2018).

Water ice has been detected in relatively small areas of Ceres' surface (Combe et al. (2016); Raponi et al. (2018)), and since ice is not stable on Ceres' surface except in the polar regions, these ice patches must represent relatively recent exposures. Landslides and lobate flows are evident on Ceres surface and indicate the presence of water ice in immediate subsurface as reported by GRaND instrument, indicating the presence of a global subsurface water ice table few decimeters beneath the surface at latitudes greater than 45º (Prettyman et al. 2017).

2.2. Composition

Dawn observations demonstrate that Ceres' material has been processed by liquid water in an early global ocean (de Sanctis et al. (2015); Ammannito et al. (2016); Prettyman et al. (2017)), resulting in minerals that are the results of the aqueous alteration. The spectral data acquired by VIR spectrometer indicate the presence of ammonium-bearing phyllosilicates, magnesium-bearing phyllosilicates, carbonates, and a dark, spectrally featureless component whose nature is not fully constrained (de Sanctis et al. 2015). Ammonium and sodium salts and carbonates have been also detected in bright localized areas, called faculae (de Sanctis et al. (2016); Carrozzo et al. (2018)). The minerals present in the faculae material are likely originated in liquid brine reservoirs (de Sanctis et al. (2016); De Sanctis et al. (2020); Quick et al. (2019)). These fluids underwent freezing and desiccation near the surface (Quick et al. (2019); De Sanctis et al. (2020)) as suggested by the compositional gradient observed across the Cerealia Facula dome (Raponi et al. (2019); De Sanctis et al. (2020); fig.2), where hydrated sodium chloride has been detected. The distribution of the minerals and the hydration of the sodium salts indicate an extremely recent exposure on the surface by ascending fluids. These minerals provide detailed insight into the chemistry of past and current liquid water inside Ceres.

2.3. Carbon and Organics

Ceres' carbon is mainly in the form of carbonates and organics. (Marchi et al. 2019) have inferred an abundance of 20 wt.% carbon, in amorphous form, in Ceres' regolith. Abundant aliphatic organics have been detected at specific locations, in particular in Ernutet Crater (De Sanctis et al. 2017). Their intimate association with specific minerals suggests these organic compounds formed in Ceres' interior. The abundance of aliphatic have been estimated to be at a level of a few percents on average, using kerogen as analogue (De Sanctis et al. 2017) and up to about 25% in case of asphaltite as analogue (De Sanctis et al. 2017). Considering typical insoluble organic material found in carbonaceous chondrites, the abundance rise at a level of several 10s% (Kaplan et al. 2018). The estimated abundances of

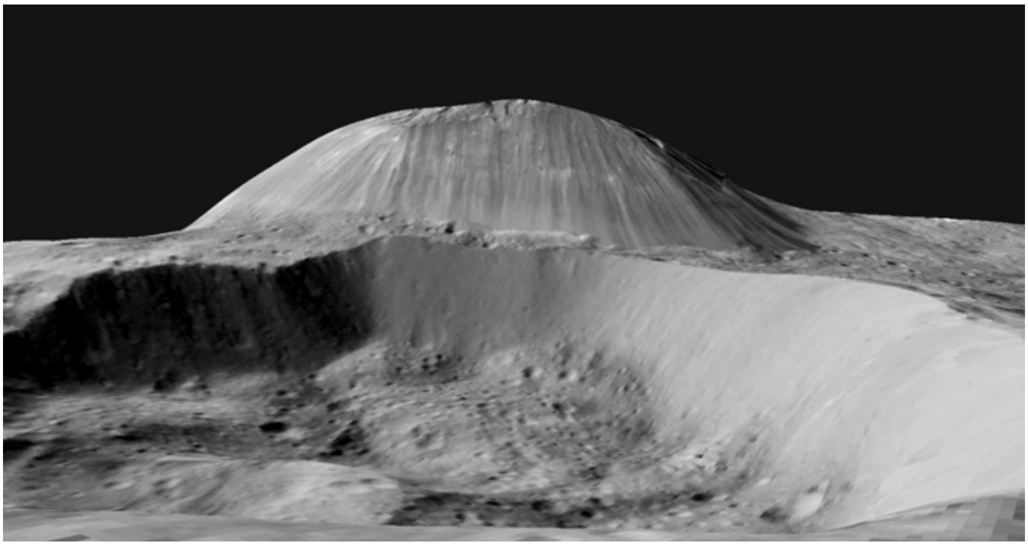

Fig. 1. Ceres' mountain Auhna Mons, which has been interpreted to be a cryovolcano (NASA/JPL-Caltech/UCLA/MPS/DLR/IDA/PSI).

those compounds are much larger with respect the aliphatic material found in Carbonaceous Chondrites.

2.4. *Evidence for recent and/or on going activity*

Several observations have indicated an active geology, likely driven by volatiles and salts (i.e., brines). The most evident expressions of recent (or on-going) activity are indicated by features such as the Occator crater faculae and Occator dome as well as Ahuna mons, and the water emission detected by Herschel (Ruesch et al. (2016), Küppers et al. (2014)). The bright spots, or faculae observed in Occator mainly consist of sodium carbonates and chloride salts, which may represent the residue of crystallized brines extruded onto the crater floor from depth. Moreover, the discovery of hydrated sodium chloride and hydrated sodium carbonate on the faculae suggest a very short exposure to the surface, because these species are very sensitive to space weathering and dehydrates in a extremely short time scale: this material of aqueous origin seems to be exposed essentially at the geological present time. These minerals suggest that the faculae were created when briny fluids originating from a cryomagma chamber beneath Occator erupted onto Ceres' surface, followed by flash freezing of carbonate, salts and ice particles, particle fallback, and sublimation of any residual water ice.

The observed mineralogy implies Ceres' material went through a phase of advanced aqueous alteration (de Sanctis et al. (2015), de Sanctis et al. (2016)). The global distribution of material suggests alteration in an early ocean, developed soon after the accretion. However, there are several evidences that remnant liquid reservoirs inside Ceres are still present today.

3. Conclusions

Several recent and ongoing studies have suggested that Ceres could have favourable conditions for the developing of life. This is mainly due to the clear identification of aqueously altered products, endogenic activity and circulation of salty fluids, including the evidence of bioessential elements in liquid water. Nevertheless, remains the problem about the long-term supply of chemical energy gradients. These can be sourced by endogenic, such

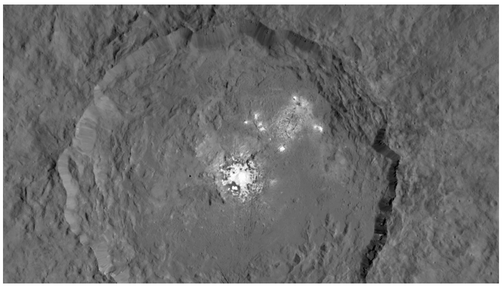

Fig. 2. Occator Crater: The bright faculae are visible inside the crater. (NASA/JPL-Caltech/UCLA/MPS/DLR/IDA/PSI)

as hydrothermal systems, and exogenic, such as heat released by impacts or solar radiation processes. However, it is difficult to asses if these sources can be sufficient to sustain protracted energy and large thermodynamic gradients. However, if the origin of life starts with an aqueous alteration of precursor organics, it is not excluded that an origin of life on Ceres may have happened.

Acknowledgements. The instrument VIR on Dawn mission has been founded by ASI (Agenzia Spaziale Italiana, grant: I/004/12/2) and INAF (Istituto Nazionale di Astrofisica).

References

Ammannito, E., DeSanctis, M. C., Ciarniello, M., et al. 2016, Science, 353, aaf4279

Bland, M. T., Raymond, C. A., Schenk, P. M., et al. 2016, Nature Geoscience, 9, 538

Carrozzo, F. G., De Sanctis, M. C., Raponi, A., et al. 2018, Science Advances, 4, e1701645

Castillo-Rogez, J., Neveu, M., McSween, H. Y., et al. 2018, Meteoritics & Planetary Science, 53, 1820

Combe, J.-P., McCord, T. B., Tosi, F., et al. 2016, Science, 353, aaf3010

De Sanctis, M. C., Ammannito, E., McSween, H. Y., et al. 2017, Science, 355, 719

De Sanctis, M. C., Ammannito, E., Raponi, A., et al. 2020, Nature Astronomy, 4, 786

de Sanctis, M. C., Ammannito, E., Raponi, A., et al. 2015, Nature, 528, 241

de Sanctis, M. C., Raponi, A., Ammannito, E., et al. 2016, Nature, 536, 54

Ermakov, A. I., Fu, R. R., Castillo-Rogez, J. C., et al. 2017, Journal of Geophysical Research (Planets), 122, 2267

Fu, R. R., Ermakov, A. I., Marchi, S., et al. 2017, Earth and Planetary Science Letters, 476, 153

Kaplan, H. H., Milliken, R. E., & Alexander, C. M. O. 2018, Geophys. Res. Lett., 45, 5274

Küppers, M., O'Rourke, L., Bockelée-Morvan, D., et al. 2014, Nature, 505, 525

Marchi, S., Raponi, A., Prettyman, T. H., et al. 2019, Nature Astronomy, 3, 140

Prettyman, T. H., Yamashita, N., Toplis, M. J., et al. 2017, Science, 355, 55

Quick, L. C., Buczkowski, D. L., Ruesch, O., et al. 2019, Icarus, 320, 119

Raponi, A., De Sanctis, M. C., Carrozzo, F. G., et al. 2019, Icarus, 320, 83

Raponi, A., De Sanctis, M. C., Frigeri, A., et al. 2018, Science Advances, 4, eaao3757

Raymond, C. A., Ermakov, A. I., Castillo-Rogez, J. C., et al. 2020, Nature Astronomy, 4, 741

Ruesch, O., Platz, T., Schenk, P., et al. 2016, Science, 353, aaf4286

Russell, C. T., Raymond, C. A., Ammannito, E., et al. 2016, Science, 353, 1008