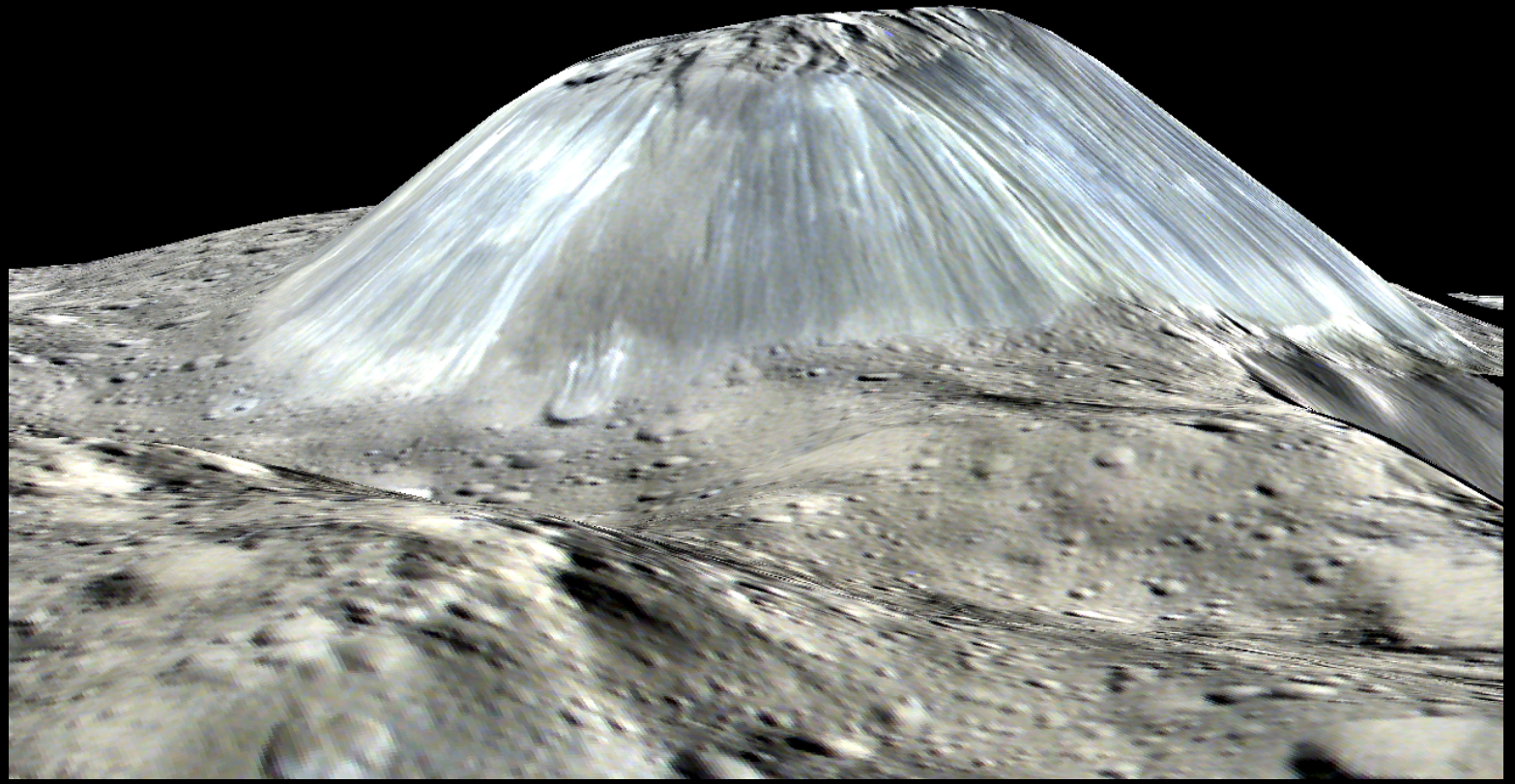
Latest results on Ceres from Dawn: ingredients for life?



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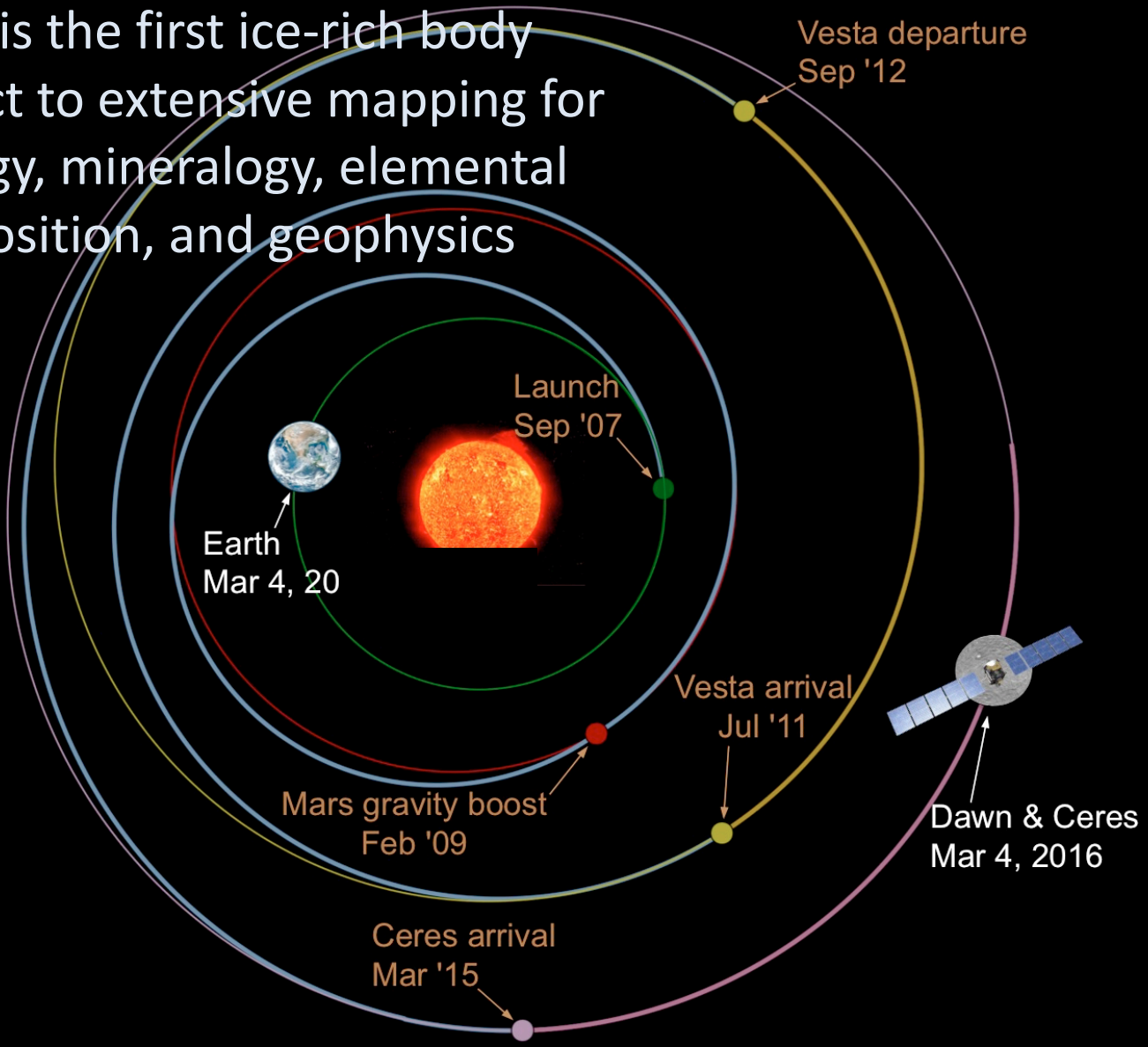
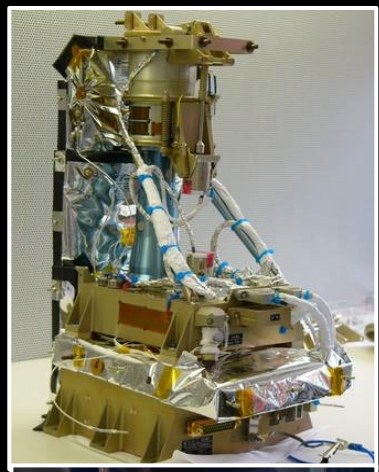
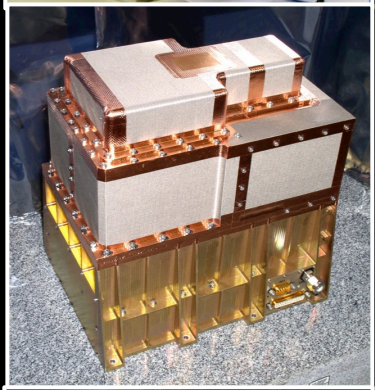
Road Map to Vesta and Ceres

Ceres is the first ice-rich body subject to extensive mapping for geology, mineralogy, elemental composition, and geophysics

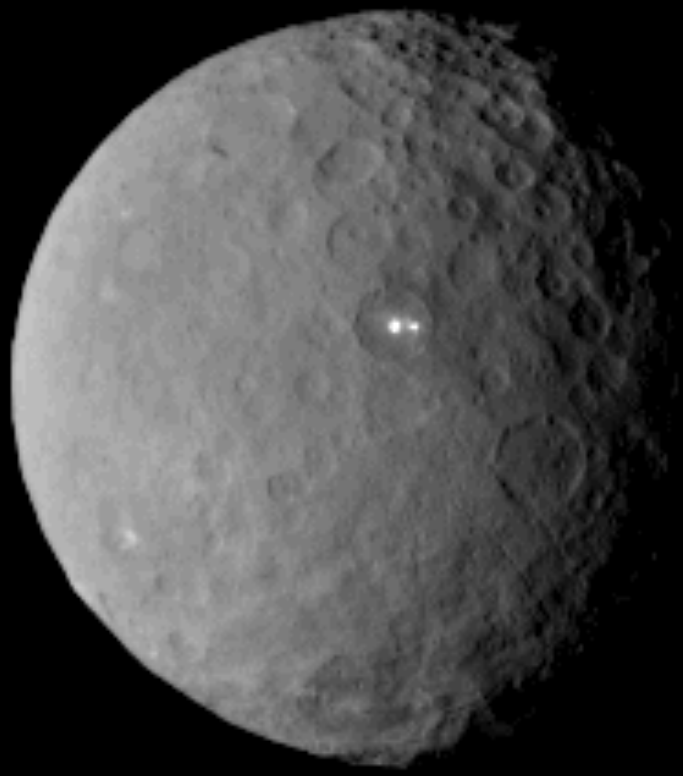






Ceres - The Basics

- 482 x 482 x 446 km
- mean radius 470 km
- Rotation period 9.074 hr
- Ceres' surface reflects <10% of incident sunlight
- Average surface temperature 110-155K-Maximum at equator-subsolar point ~230-240 K
- Density 2.162 kg m^{-3}
- Ceres as a whole is ~50 vol.% water
- Early models suggested Ceres could have a 50-100 km thick ice shell



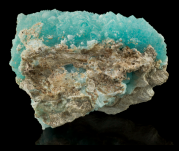
Pre-Dawn Ceres

ρ = 2.2 g/cm^3

D ~ 963km equ
x 891km pol

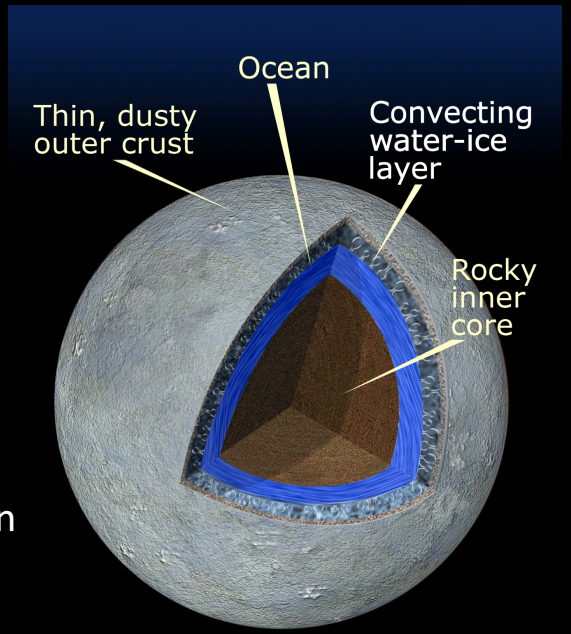
Rot+shape ➔ differentiated, icy mantle & rocky core (Thomas et al. 2005)

Dark, flat spectrum similar to carbonaceous chondrites? (Larson et al. 1979)



Phyllosilicates, carbonates, magnesite, brucite… (Lebofsky et al. 1981, King et al. 1992, Rivkin et al. 2006, Milliken & Rivkin 2009)

Thermal models suggested icy outer shell, possible interior ocean. (McCord & Sotin 2005, Castillo-Rogez & McCord 2010)



Predictions of near-surface ice stability
&
Possible polar frosts (Fanale & Salvail 1989)

Sporadic water emission (Felman et al,1992, Kuppers et al.,2014)

What is “habitability” ?

- Habitability has been defined as the potential of an environment (past or present) to support life of any kind.
- In its astrobiology roadmap, NASA has defined the principal habitability criteria as "**extended regions of liquid water,conditions favorable for the assembly of complex organic molecules, and energy sources to sustain metabolism**".

What makes a planet “habitable”?

- ? the presence, persistence, and chemical activity of liquid water
- ? the presence of thermodynamic disequilibria providing suitable energy
- ? environmental factors that bear on the stability of covalent and hydrogen bonds in biomolecules (e.g., solar input, subsurface heating, temperature, pH, salinity, irradiation)
- ? the presence of bio-essential elements, principally C, H, N, O, P, S, and a variety of metals

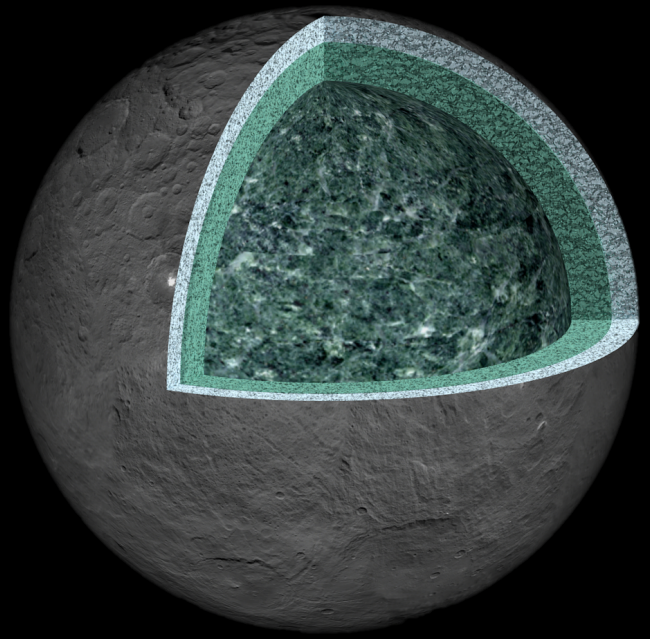
from NASA Astrobiology Strategy 2015

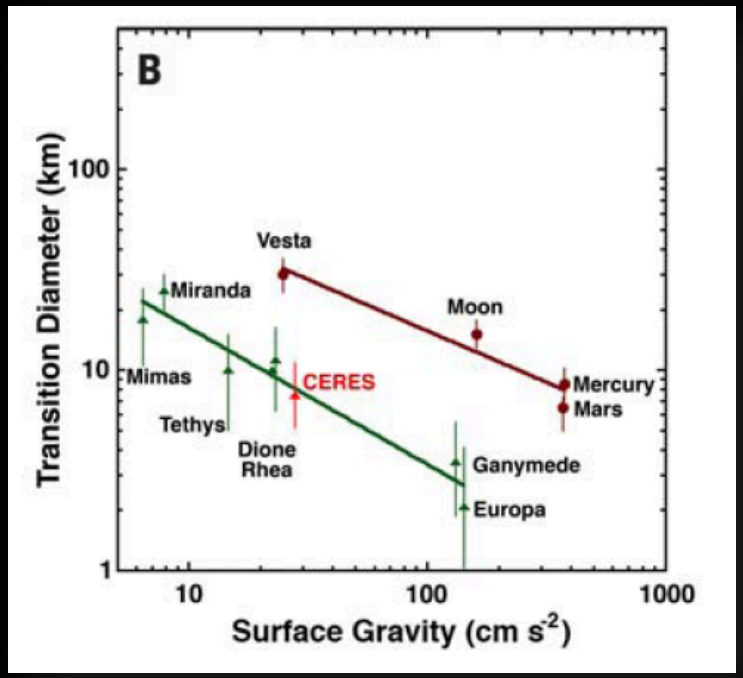
A past global ocean

Ceres appears to have a strong ~40-km thick crust of density ~1250 kg/m3 (Ermakov et al., JGR, 2017)

Core/mantle of hydrated silicate (with possible dehydrated center)

Crater shapes compatible with those observed on « icy » bodies (Heisinger et al, 2016)

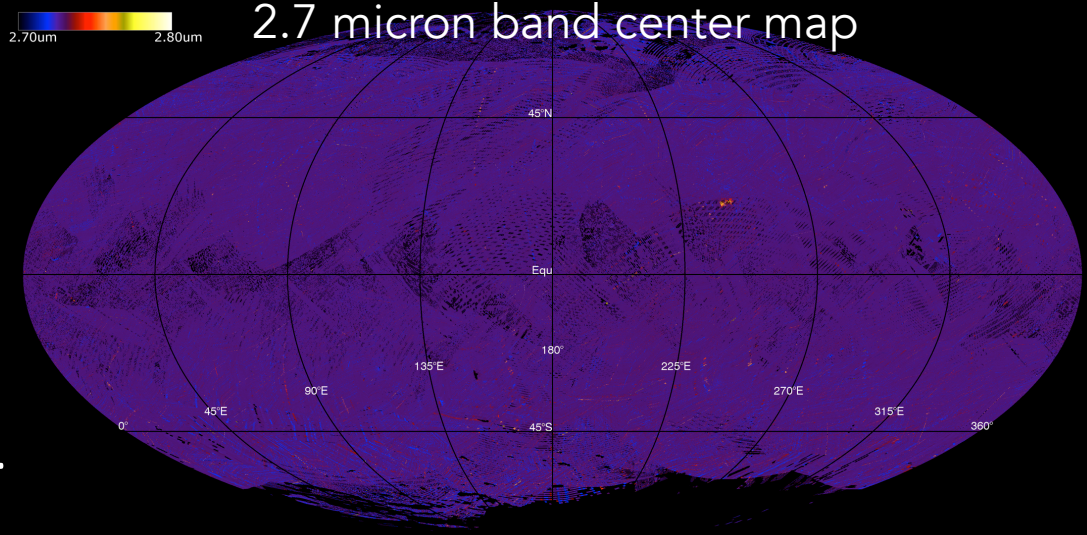


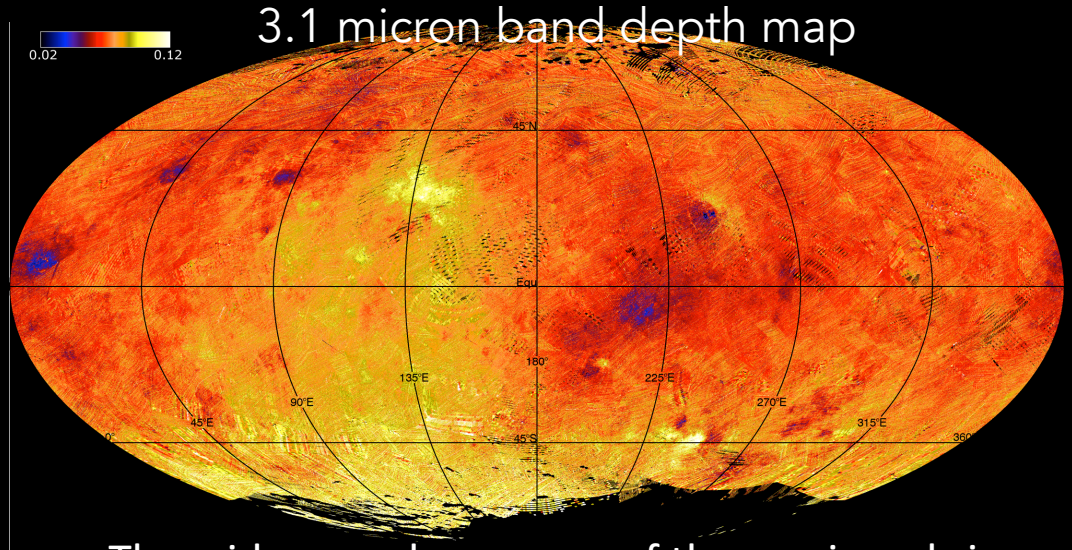


Hydrothermal alteration products on the surface

Band Center maps at 2.7 and 3.1 show ubiquitous presence of phyllosilicates. Band centers and shapes indicate Mg- phyllosilicate and NH4-clays (De Sanctis et al., Nature, 2015)

Band depth maps show local variations in proportions of NH4-rich and Mg-rich clays.





The widespread presence of these minerals is a strong indication of a global and extensive aqueous alteration.
(Ammannito et al., Science, 2016)

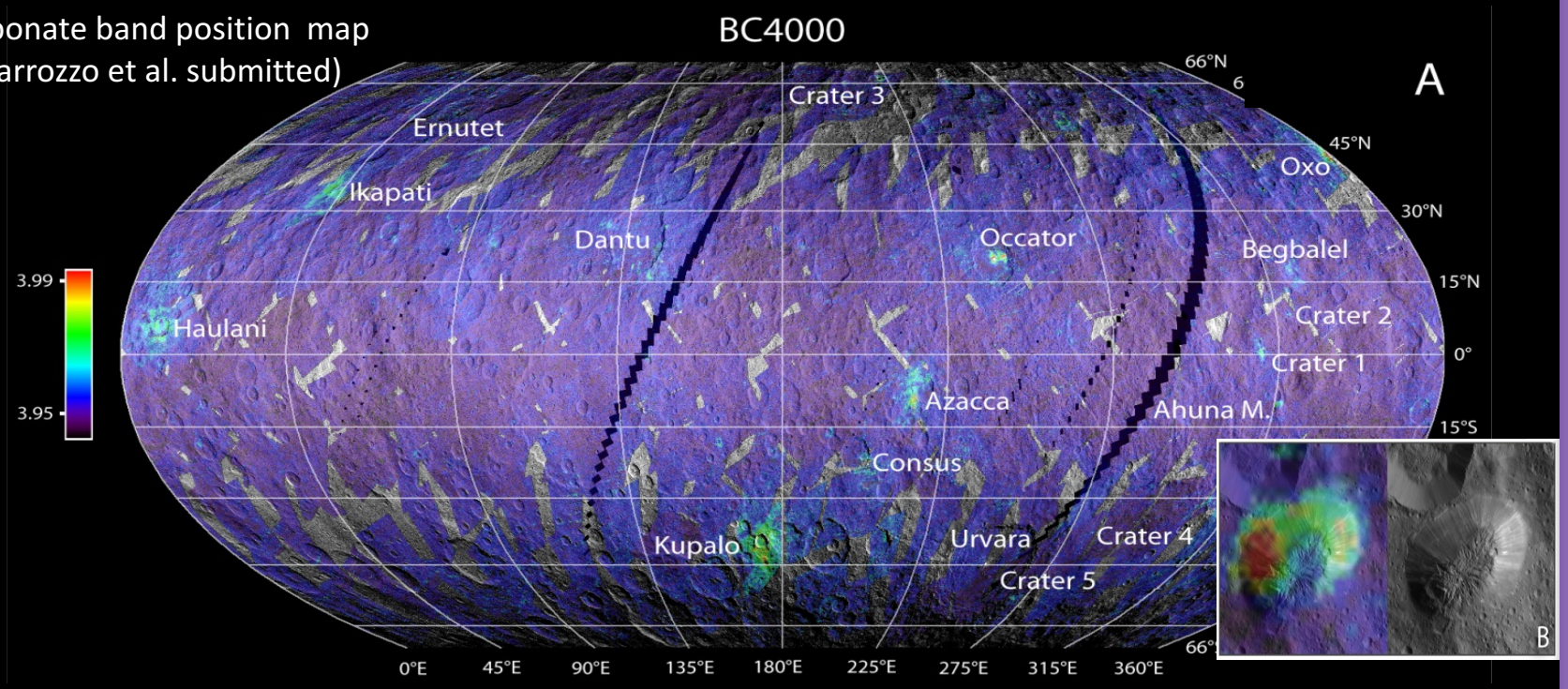
water : a past global ocean

Ceres Carbonates

Carbonate found everywhere on Ceres surface

Two main kind of carbonate found: Na Carbonates and Mg, Ca carbonates (De Sanctis et al., Nature,2016)

Carbonate band position map (Carrozzo et al. submitted)

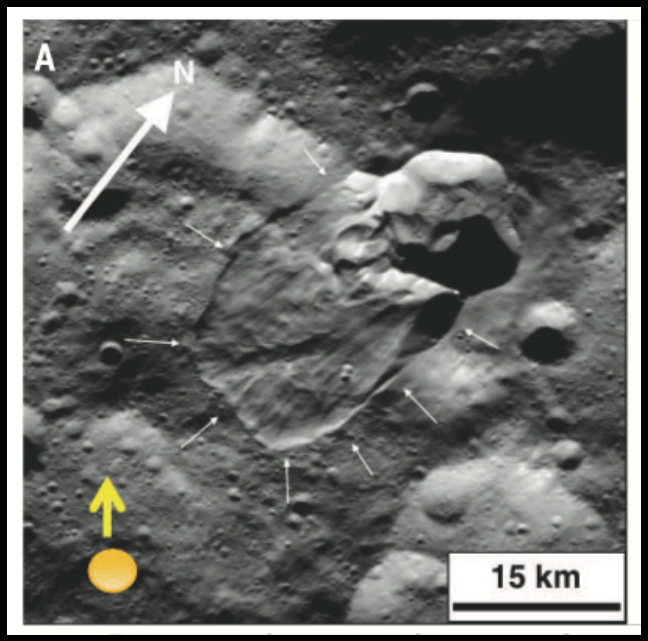


The widespread presence of Ca, Mg carbonates is a strong indication of a global and extensive aqueous alteration

water: a past global ocean

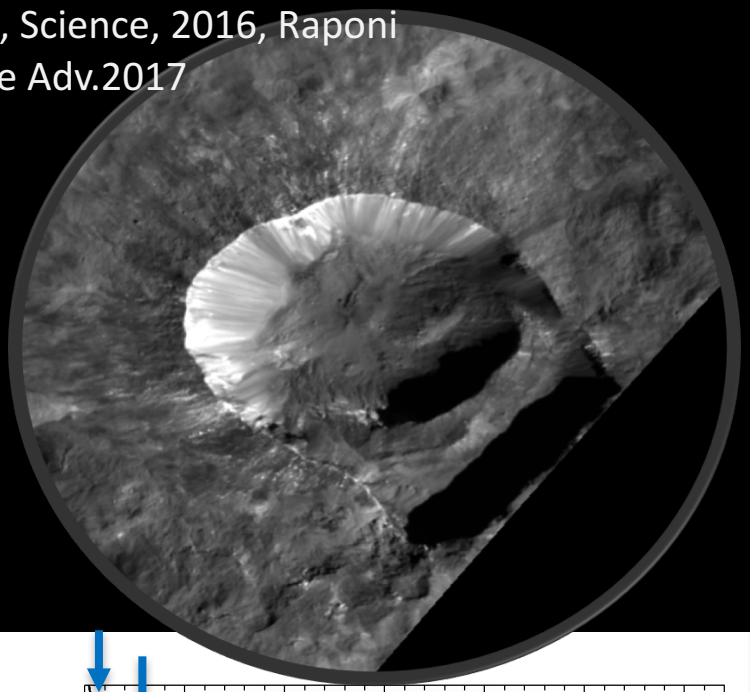
Water: present ice/liquid

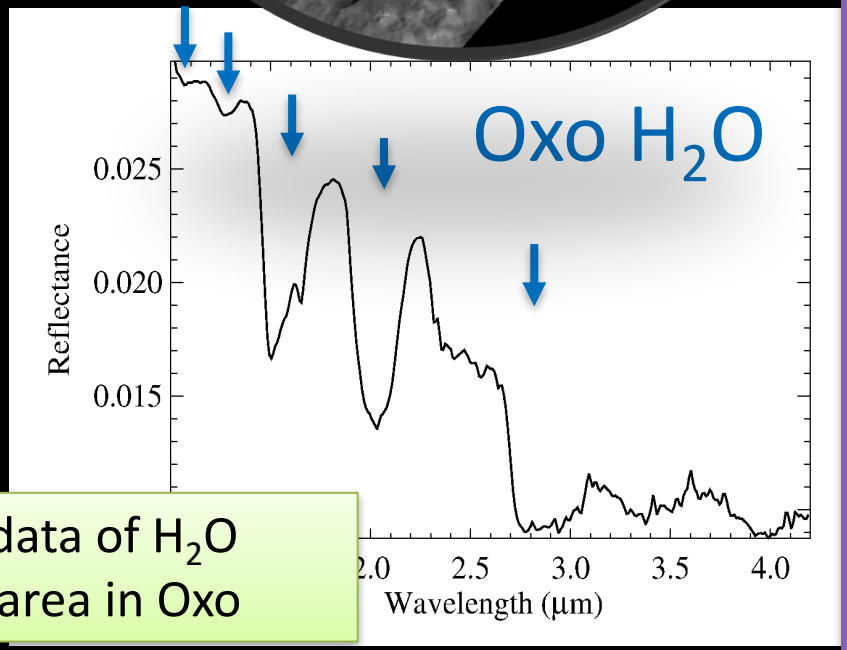
Direct evidence of water ice on the surface and flow features



Buczkowski et al., Science, 2016; Schmidt et al., Nature Geo. 2017

Combe et al., Science, 2016, Raponi et al., Science Adv.2017

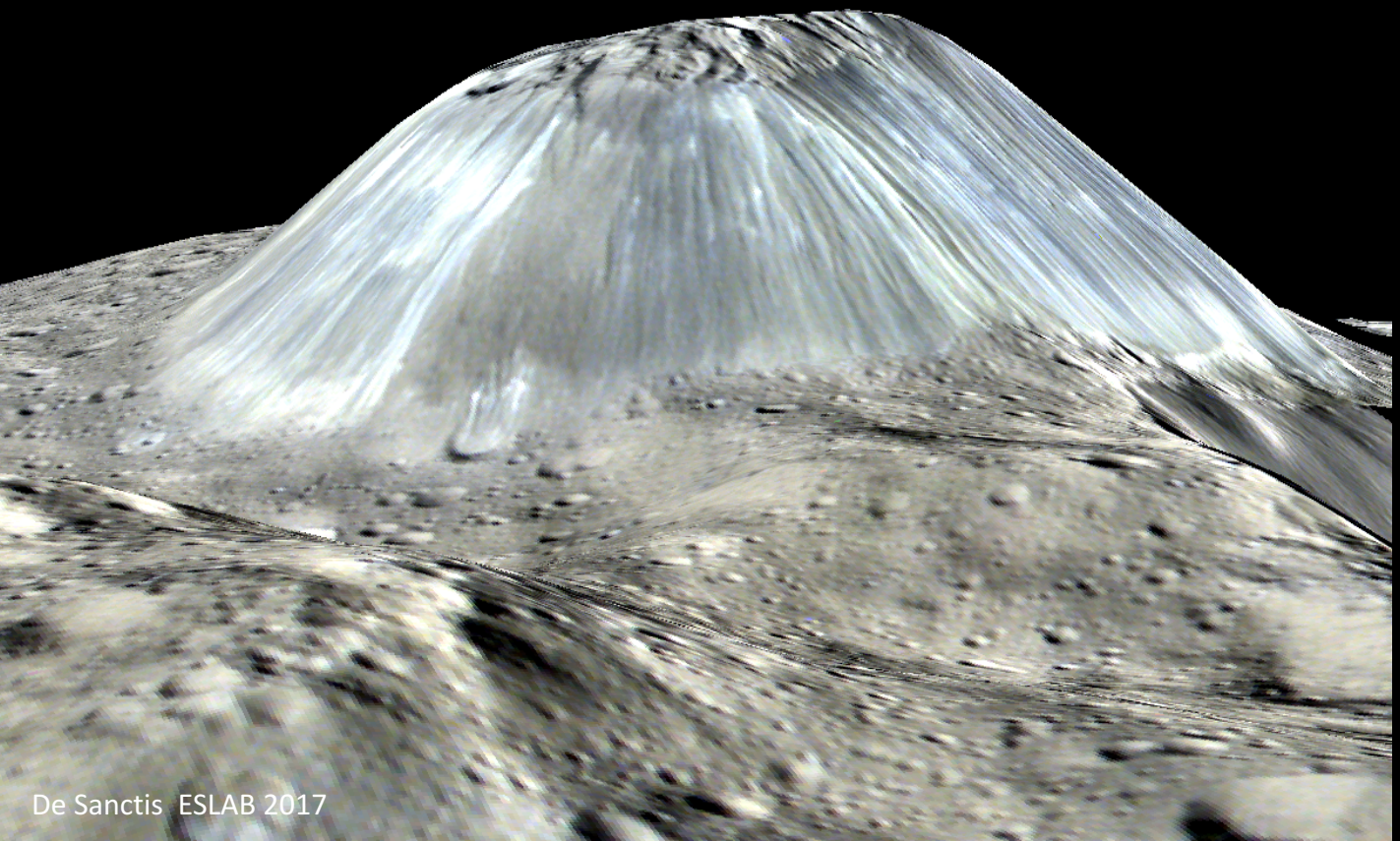




VIR data of H_2O rich area in Oxo

Ahuna Mons: cryo-volcano

The emplacement of 4-km high Ahuna Mons requires a partially molten source (Ruesch et al., Science, 2016), indicating a few % brine in at depth



Bright streaks are rich in Na-carbonate (Zambon et al., GRL, 2017)

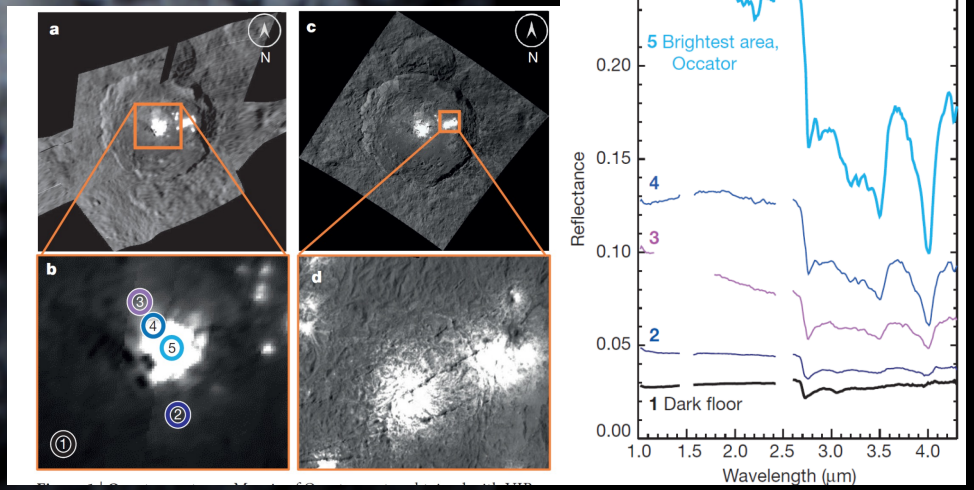
Water: present ice/liquid

Occator Bright Spots

Smooth dome with what looks like expansion fractures.

Evidence for sodium carbonates (De Sanctis et al., Nature,2016) and NH4 salts (De Sanctis et al., 2016, Raponi et al., 2017). Al-phyllosilicates over the dome with Na-carbonate

Suggests liquid transport & evaporation from a brine reservoire (De Sanctis et al, 2016).



De Sanctis et al. 2016

Water: present ice/liquid

De Sanctis ESLAB 2017

Ceres: presence, persistence, and chemical activity of liquid water ?

water

- ✓ Gravity and shape data indicate partial differentiation (Park et al., 2016, Fu et al. 2017) consistent with models of early ocean (Zolotov, 2009; Castillo-Rogez and McCord, 2010)
- ✓ Ice-rich regolith, altered chondritic elemental composition and low Fe measured by GRaND (Prettyman et al., 2016) indicate extensive water-rock fractionation and volatile mobility
- ✓ Presence of pervasive phyllosilicates and carbonates (De Sanctis et al., 2015; Ammannito et al., 2016, Carrozzo et al., 2017) indicates global aqueous alteration and recent transport to surface (mobility)
- ✓ Flow features (Buczkowski et al., Science, 2016; Schmidt et al., 2017) and ice variations (Raponi et al. 2017)
- ✓ Cryo-volcanic constructs and Faculae formation via eruptions-Ahuna Mons, Occator bright dome indicate transport to the surface (Ruesh et al., 2016, De Sanctis et al., 2016, Quik et al., 2017, Zolotov et al., 2017)

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Many evidences of past persistent global ocean and modern/present fluids

water

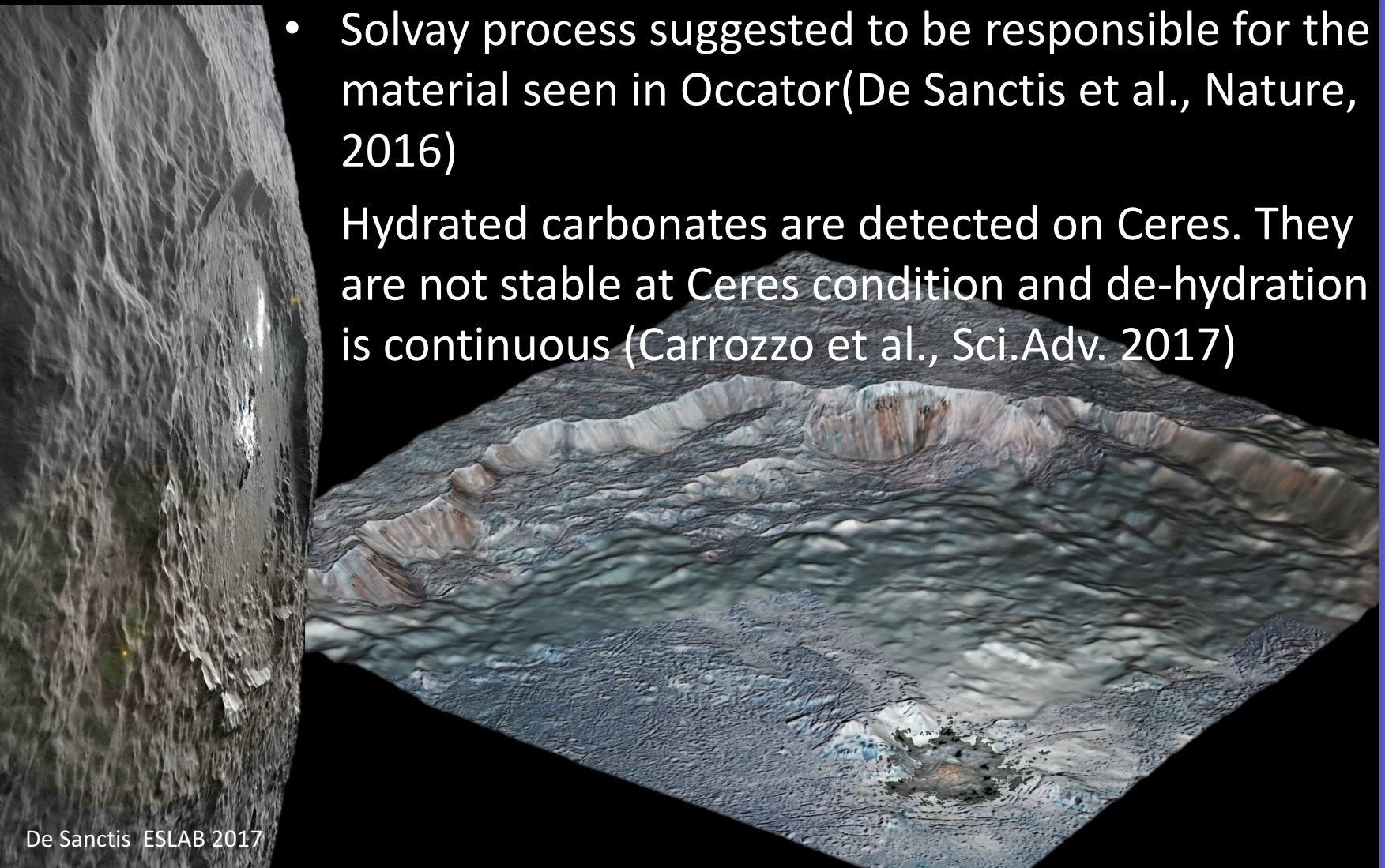
Energy

Energy sources for molecular transformations on Earth and other terrestrial bodies include **high-energy discharge, UV radiation, heat, radiation bombardment, hydrothermal energy, and serpentinization.**

Ceres has many of these different kind of energy avaible including "serpentinization"

Chemical reactions

Ceres shows places where chemical reactions happened/happens



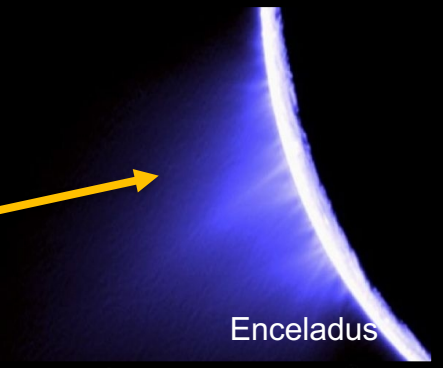
- Solvay process suggested to be responsible for the material seen in Occator(De Sanctis et al., Nature, 2016)

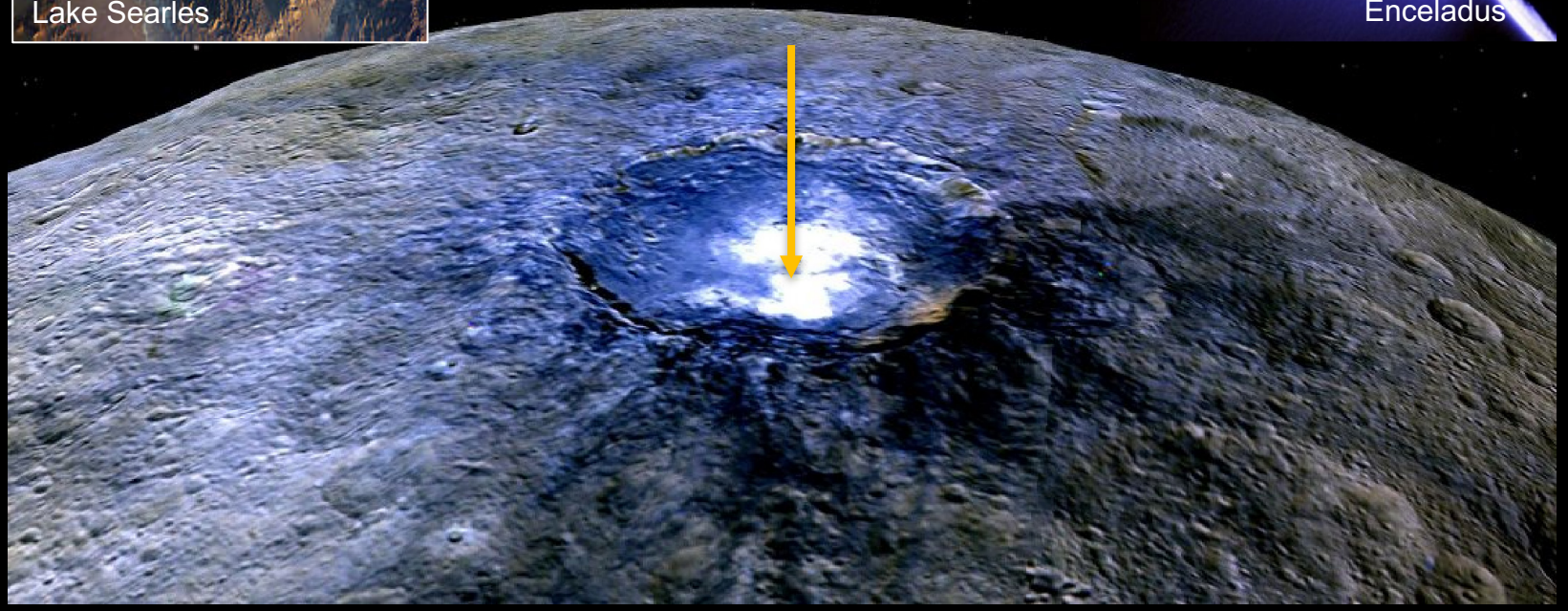
  Hydrated carbonates are detected on Ceres. They are not stable at Ceres condition and de-hydration is continuous (Carrozzo et al., Sci.Adv. 2017)

thermodynamic disequilibria and energy

Dawn revealed Ceres to be a chemically active world

Sodium carbonates
Ammonium Salts
De Sanctis et al., Nature (2016)





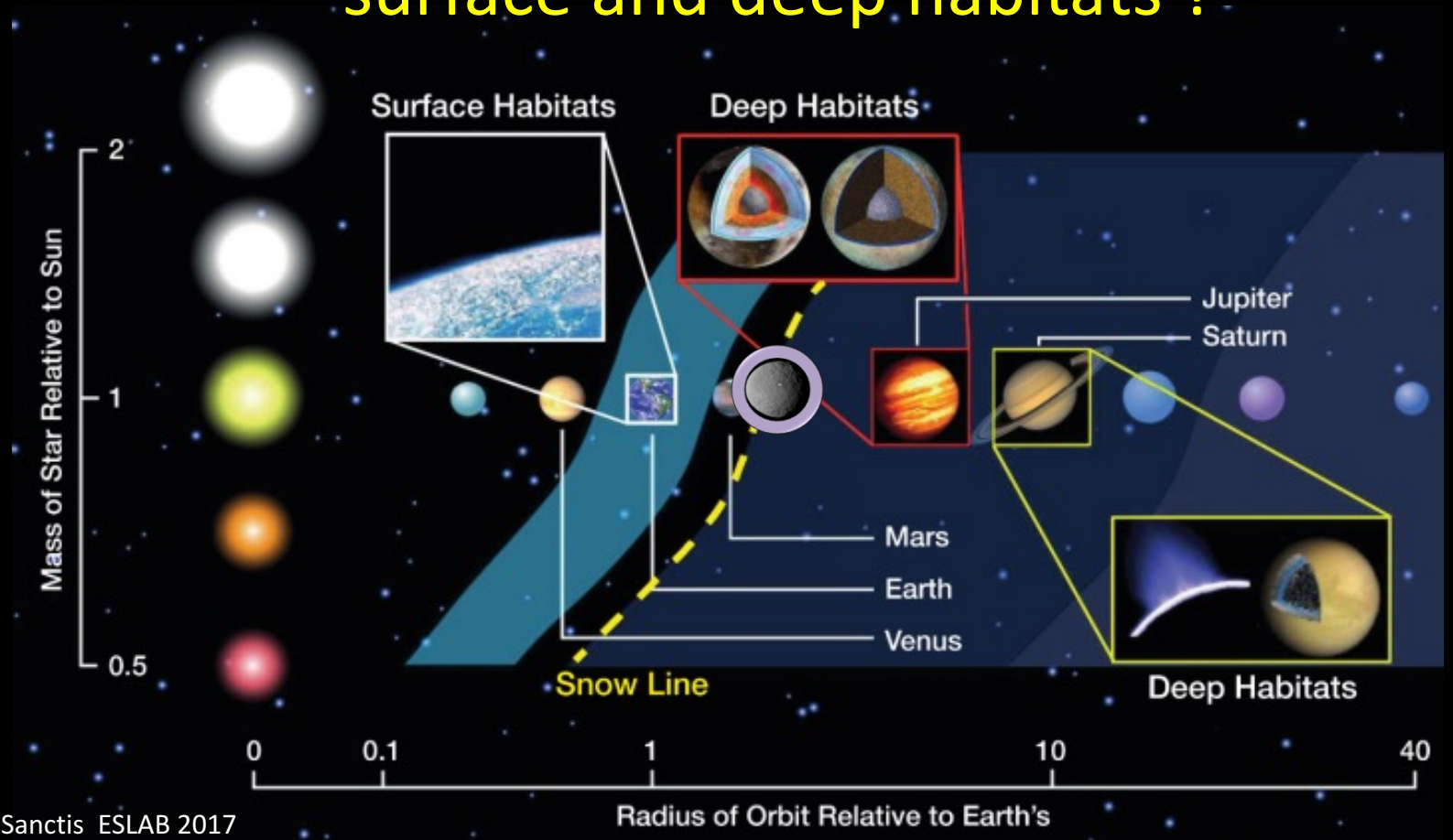
Below the strong crustal layer is a denser rocky mantle with a weak upper layer with pore space filled with residual brines that controls the global shape (*Fu et al., EPSL, 2017*)

thermodynamic disequilibria and energy

Ceres: Energy and temperature

- Surface average temperature of 130-160K, max at equator of 240 K
- Energy source: Sun irradiation and long lived radioisotopes

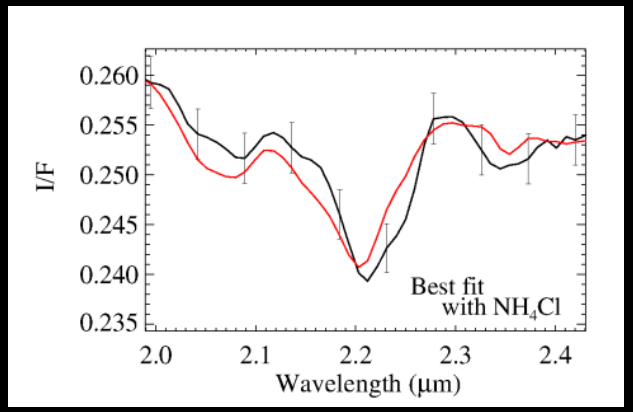
surface and deep habitats ?

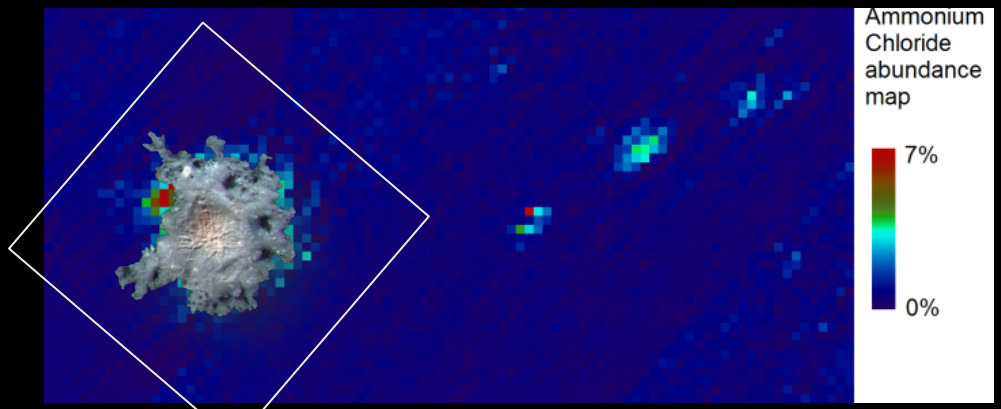


Ceres:
Ph and salinity

- Alkaline water inferred by the chemistry of the surface and salty fluids (De Sanctis et al., Nature, 2016)
- The detection of sodium carbonate provides key constraints on the composition of fluids that were/are alkaline (De Sanctis et al., Nature, 2016, Castillo et al., 2017)

The presence of several salts has been modeled and some of them detected: NH4Cl (Raponi et al., 2017)





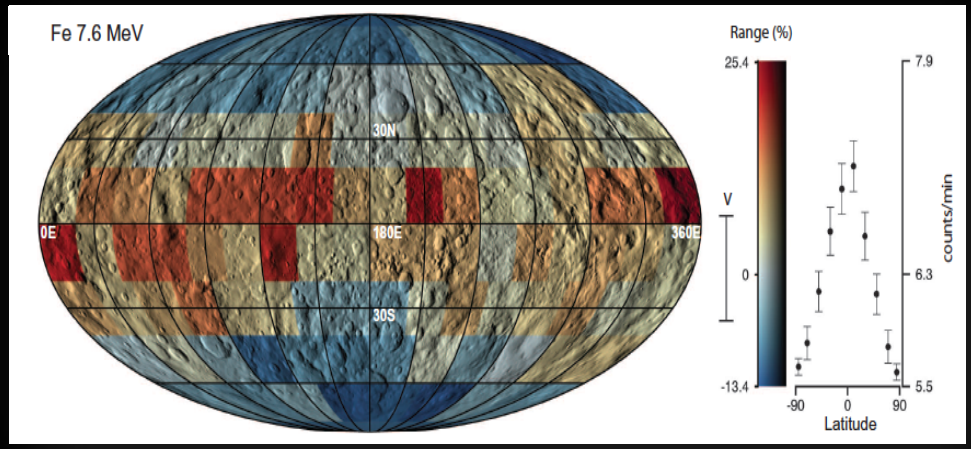
Environment

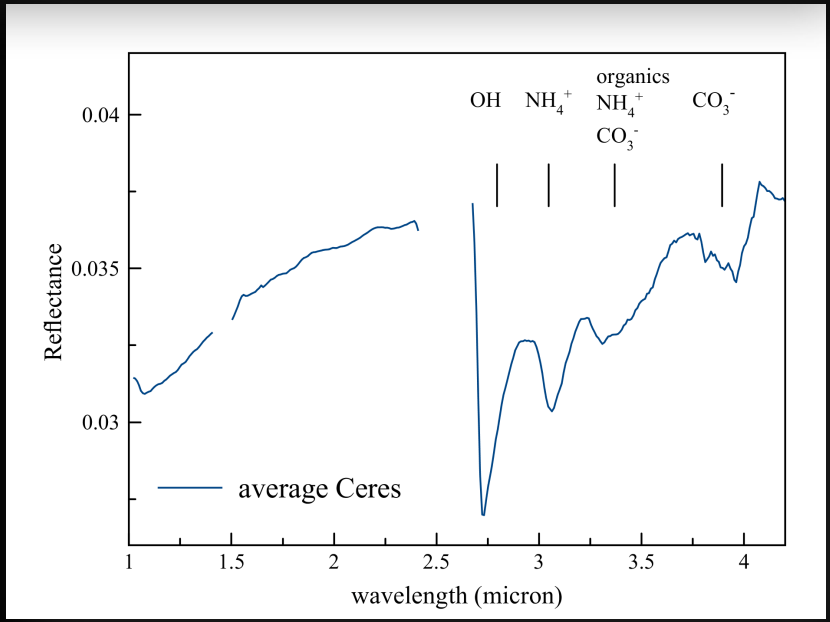
Dawn revealed Ceres to have a very rich chemistry

Bio-essential elements are C, H, N, O, P, S, and a variety of metals

C,H,N,O have been detected in high abundance and in several different chemical formulas.

Also metals measured (De Sanctis et al. 2015,2016, Prettyman et al.,2016).

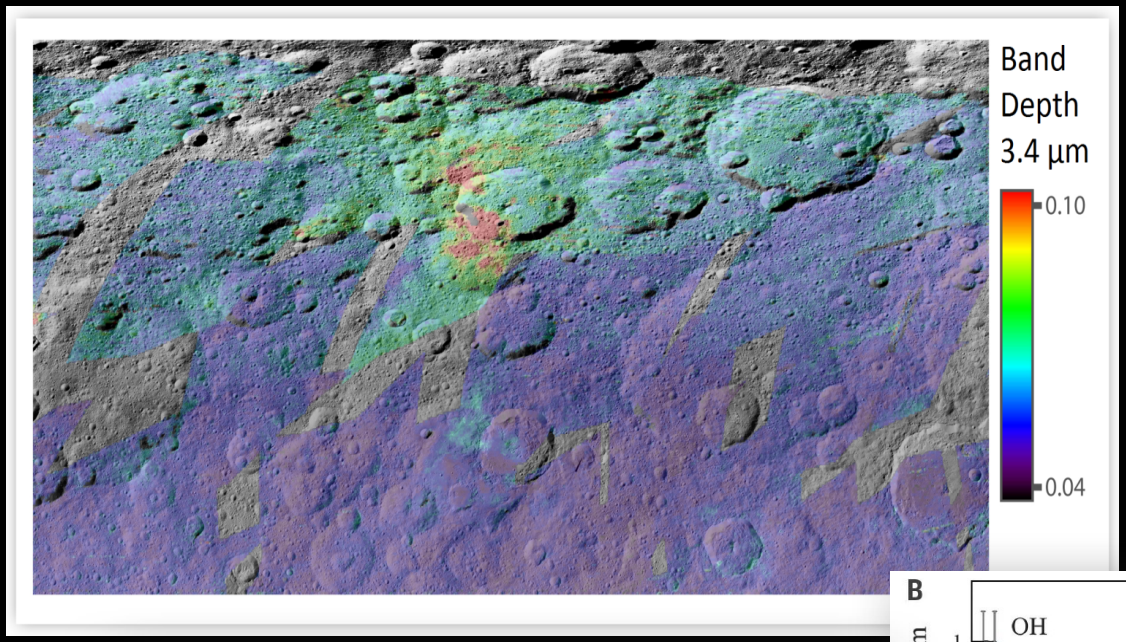




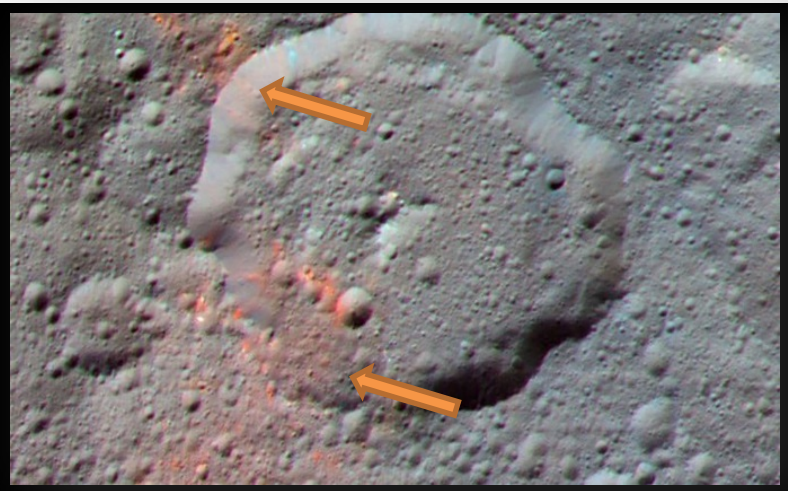
bio-essential elements

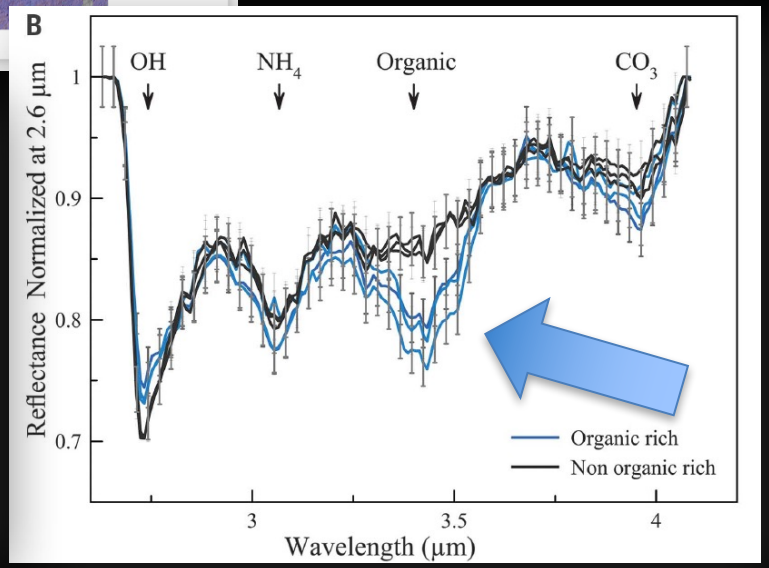
Dawn detects prebiotically relevant chemistry: Organics

De Sanctis et al., Science 2017



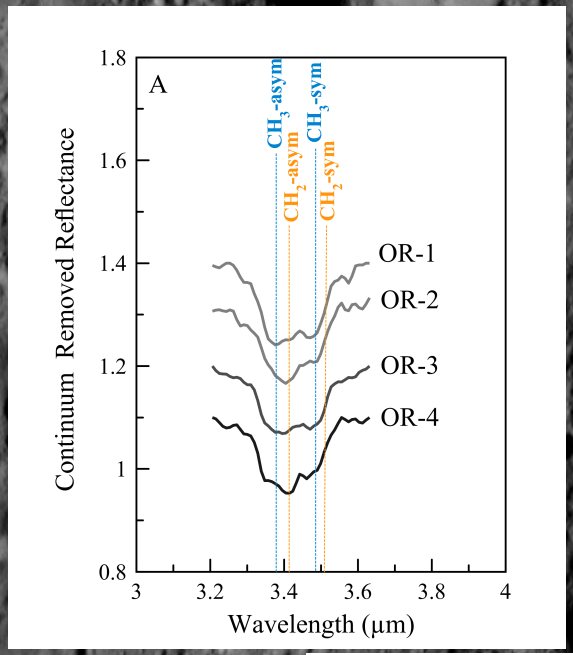
Organic molecules detected on a large portion of the surface





bio-essential elements

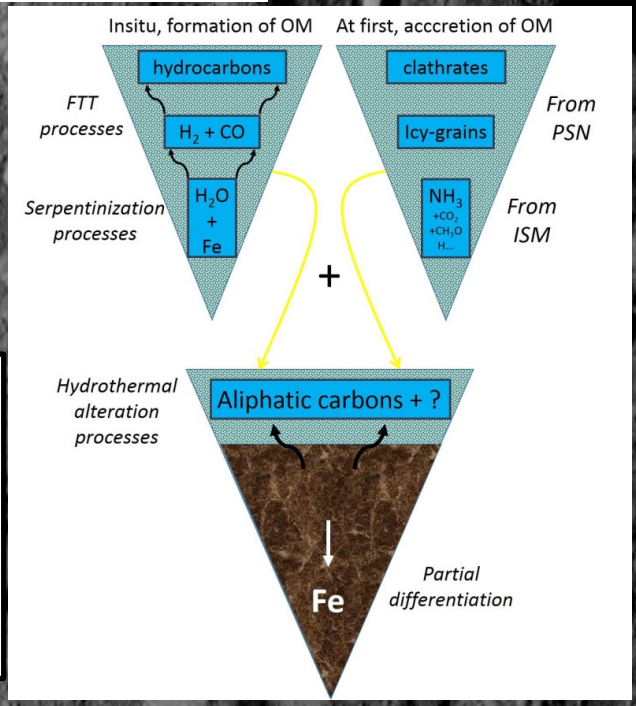
Organics on Ceres



De Sanctis et al., Science 2017

Ceres organics characteristics:

- Aliphatic chain with absence or low abundance of OH, COOH groups
- Aromatic carbons are possible, as well as nitrogen compounds (amines, imines, nitriles)
- Average Ceres spectrum compatible with 1-2% of organics



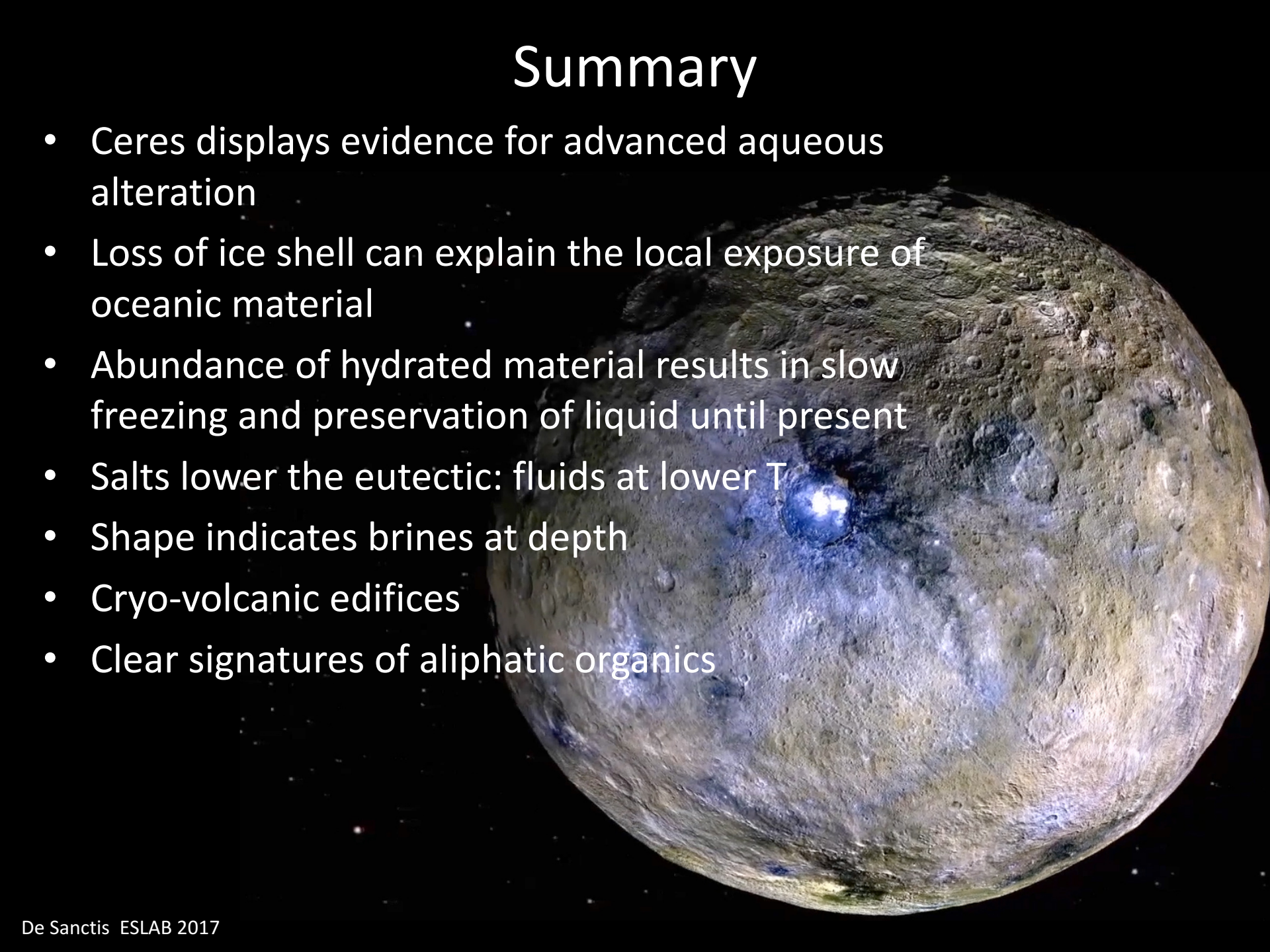
Organics can be formed on Ceres with different pathways

Vinogradoff et al., submitted

bio-essential elements

Summary

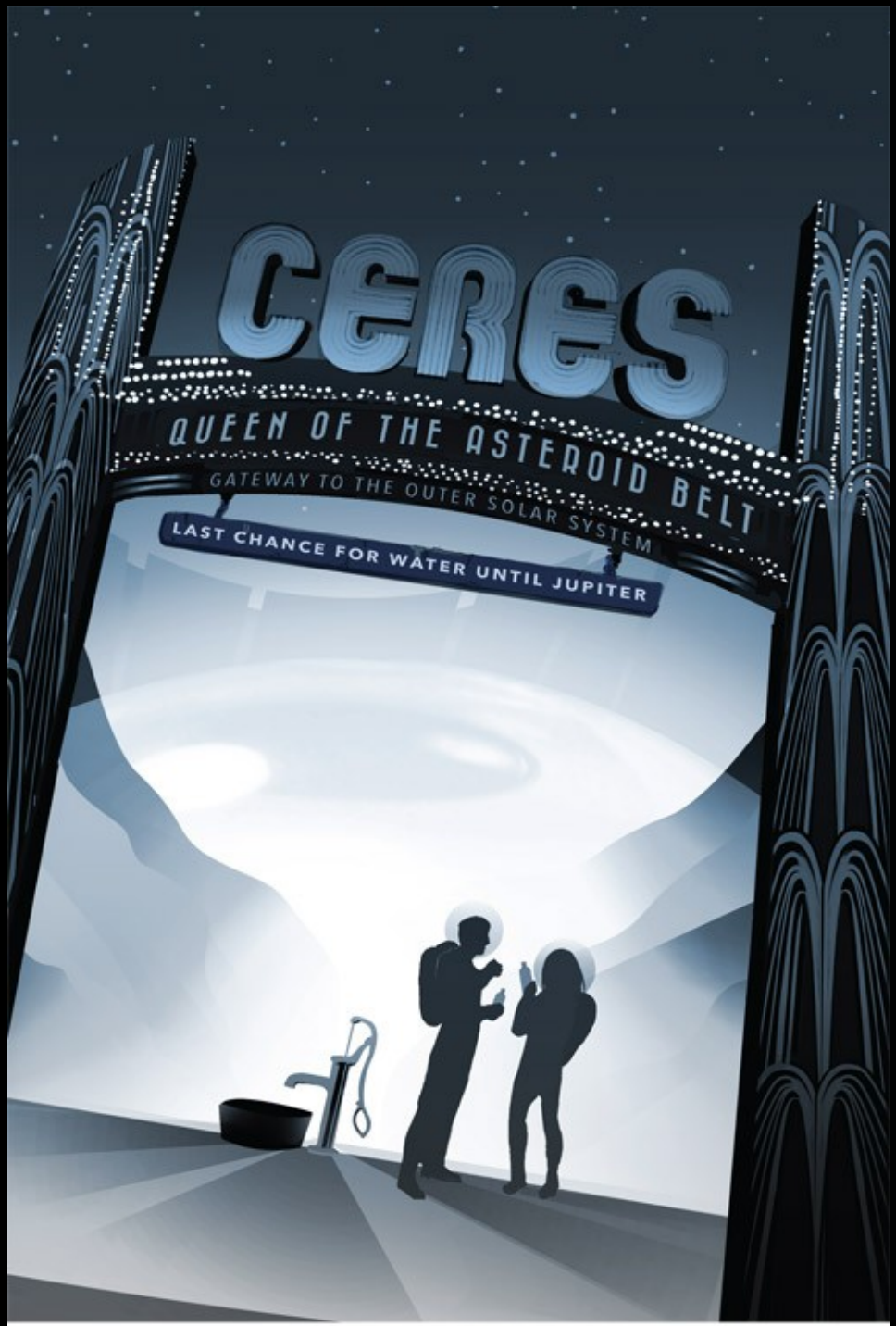
- Ceres displays evidence for advanced aqueous alteration
- Loss of ice shell can explain the local exposure of oceanic material
- Abundance of hydrated material results in slow freezing and preservation of liquid until present
- Salts lower the eutectic: fluids at lower T
- Shape indicates brines at depth
- Cryo-volcanic edifices
- Clear signatures of aliphatic organics



Ceres' Past and Current Habitability?

Ceres shows most of the key elements considered essential for life

Thanks!


CERES
QUEEN OF THE ASTEROID BELT
GATEWAY TO THE OUTER SOLAR SYSTEM
LAST CHANCE FOR WATER UNTIL JUPITER