Surface Mineralogy of Ceres: Implications for Origin and Evolution

M.C. De Sanctis, E. Ammannito, A. Raponi, M. Ciarniello, G. Carrozzo, F. Tosi, **L.A. McFadden**, H.Y. McSween, C.A. Raymond, C.T. Russell and

The Dawn team

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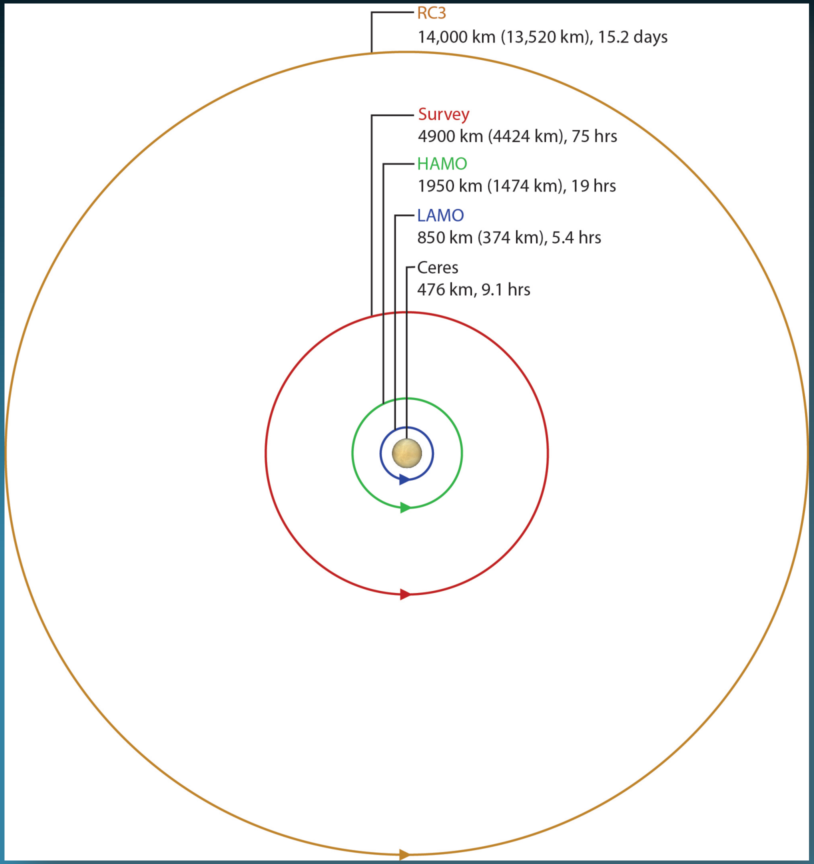
UCLA JPL Jet Propulsion Laboratory California Institute of Technology Orbital ATK iaps asi agenzia spaziale italiana DLR INAF MPS

Dawn's Orbit Plan at Ceres:

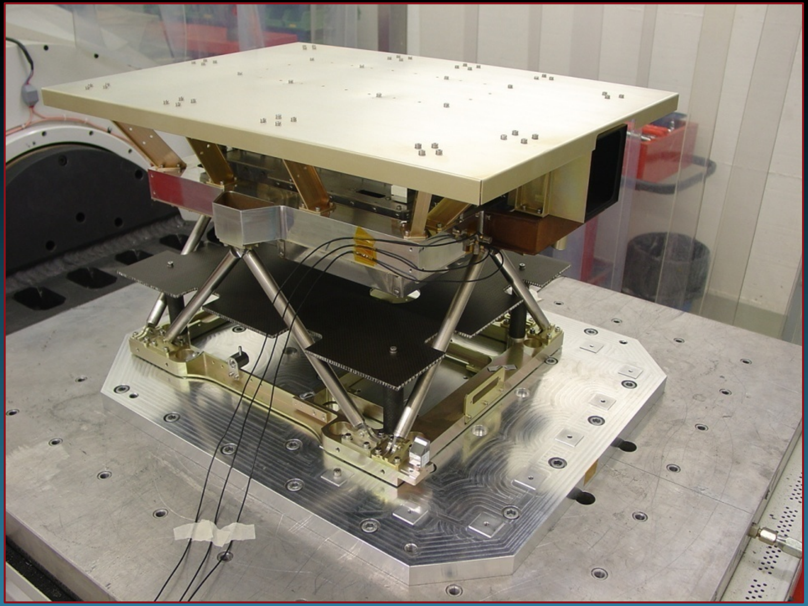
Approach, Rotational Characterization 3, Survey, HAMO, LAMO



- Acquired data on Approach at increasing resolution.
- RC3: resolution ~3km/px
- Survey mapped most of the surface: resolution ~1.1 km/px
- HAMO completed last week:resolution ~360m/px

VIR Mapping Spectrometer

- VIR, the Visible InfraRed Mapping Spectrometer, is an Italian instrument, contributed to Dawn by ASI and INAF
- VIR is a rebuild of the VIRTIS-M on board ESA's Rosetta and VEX missions
- VIR is an imaging spectrometer coupling high spectral and spatial resolution in Visible (0.25-1 μm) and IR (0.95-5 μm).



	VISIBLE	IR
Spectral Range (μm)	0.25-1.0	0.95-5.0
Spectral Resolution (λ/Δλ)	125-500	100 -500
Spectral channel	432	432
Spatial Resolution (mrad)	0.250	0.250
Field of view (mrad)	64	64

Ceres VIR results

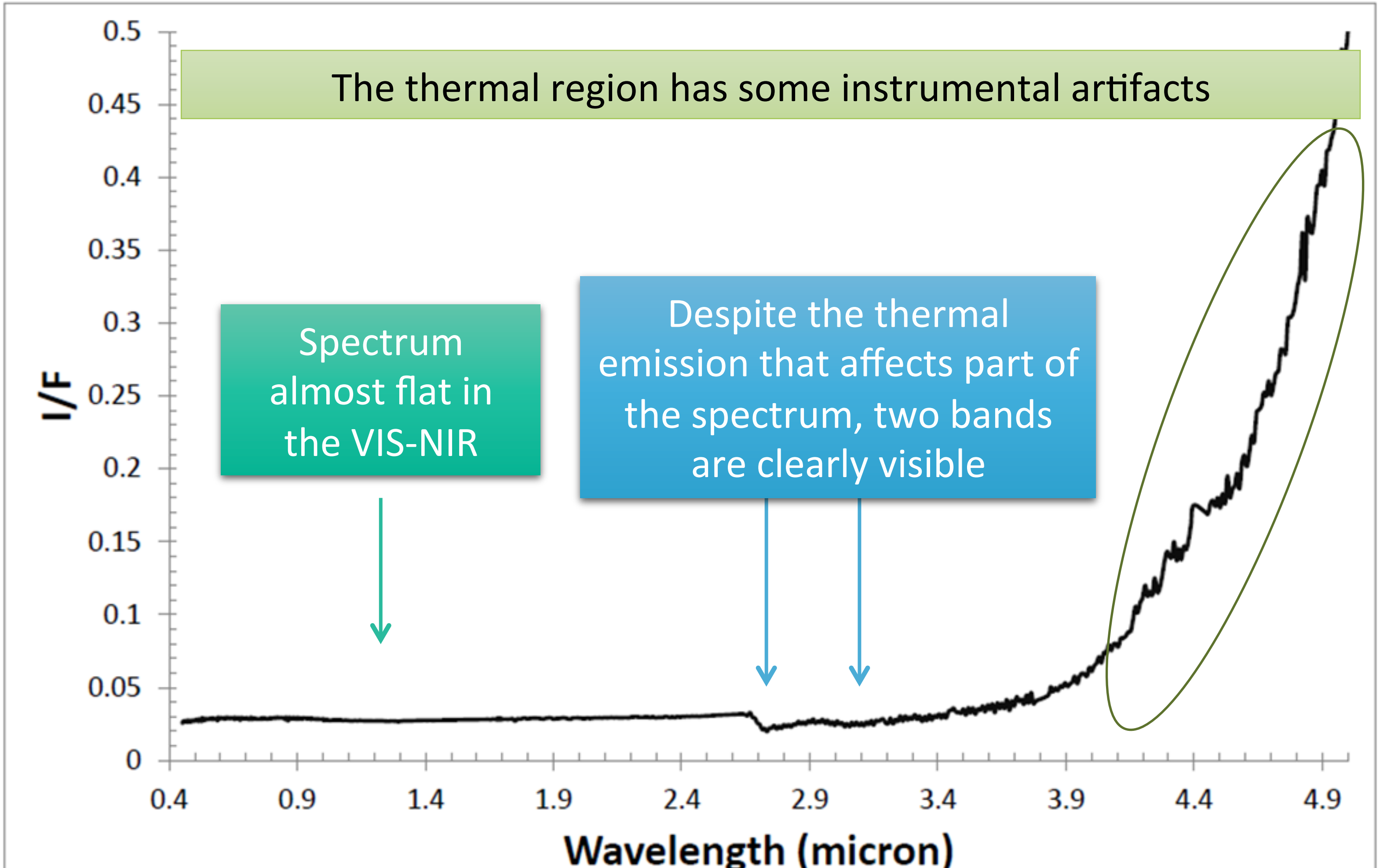
- VIR's large spectral range measures both reflectance and emission spectra
- We focus on global spectral properties, its composition and implications for its origin
- ~ 2500 spectra acquired during early mission phases, under standard viewing geometry (incidence angle 30°, emission angle 0°) are presented and analyzed
- There are no large spectral differences in spatial regime and the surface is mostly homogenous at the VIR pixel resolution of 3-360 m/px

Spectral imaging at increasing spatial resolution

VIS IR thermal IR

Tosi et al.

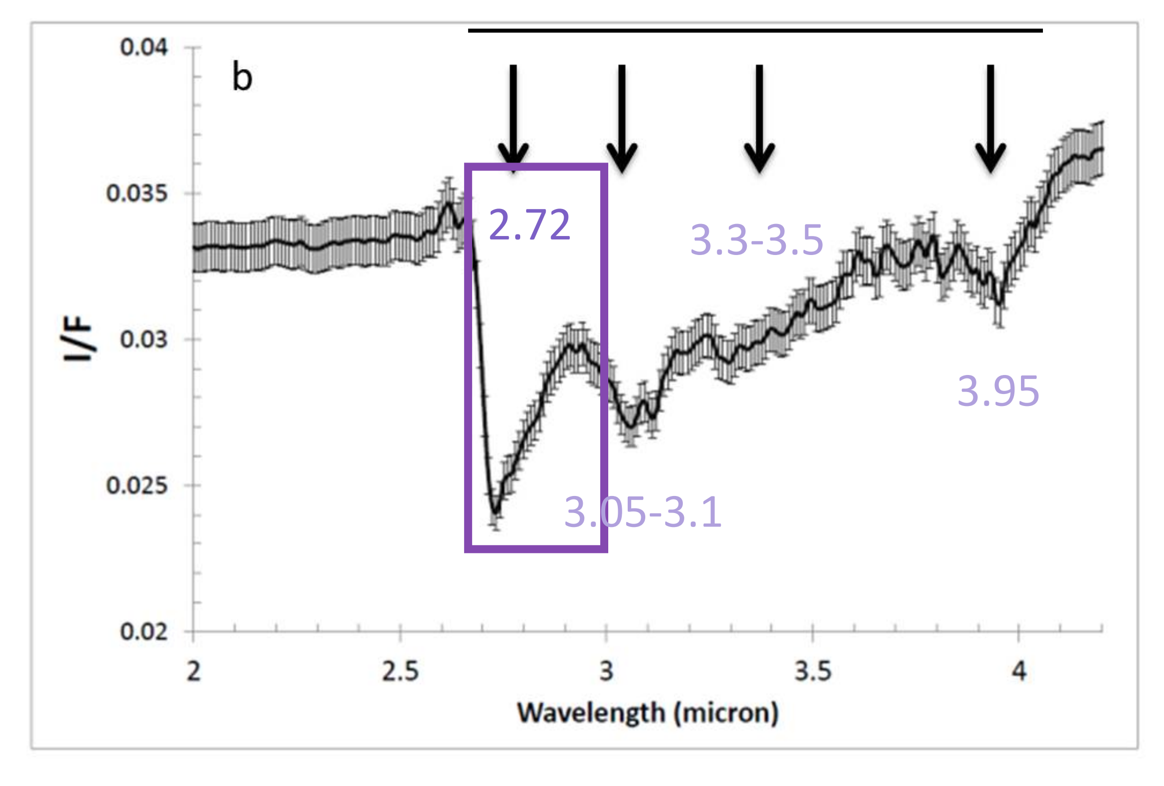
Global spectrum of Ceres



De Sanctis et al., Nature, under review

SPECTROSCOPICALLY ACTIVE 3 µM REGION WITH THERMAL CORRECTION

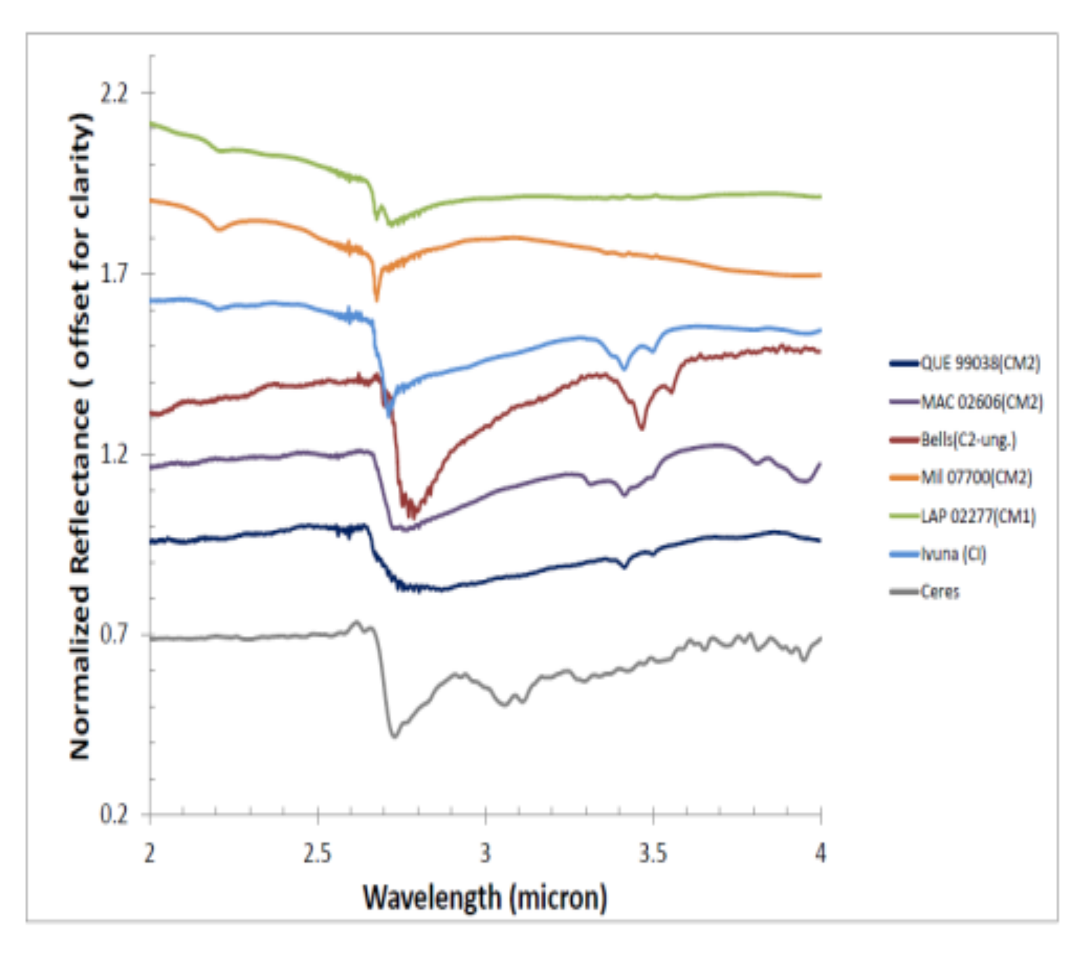
- The thermally-corrected reflectance spectrum of Ceres shows that the 2.6-4.2 µm wavelength region is characterized by a broad asymmetric feature, due to H_2O/OH bearing materials.
- Within this broad absorption feature there are several distinct absorptions bands at 2.72, 3.05-3.1, 3.3-3.5, and 3.95 µm.



The 2.72 µm band was not observed before Dawn

De Sanctis et al., Nature, under review

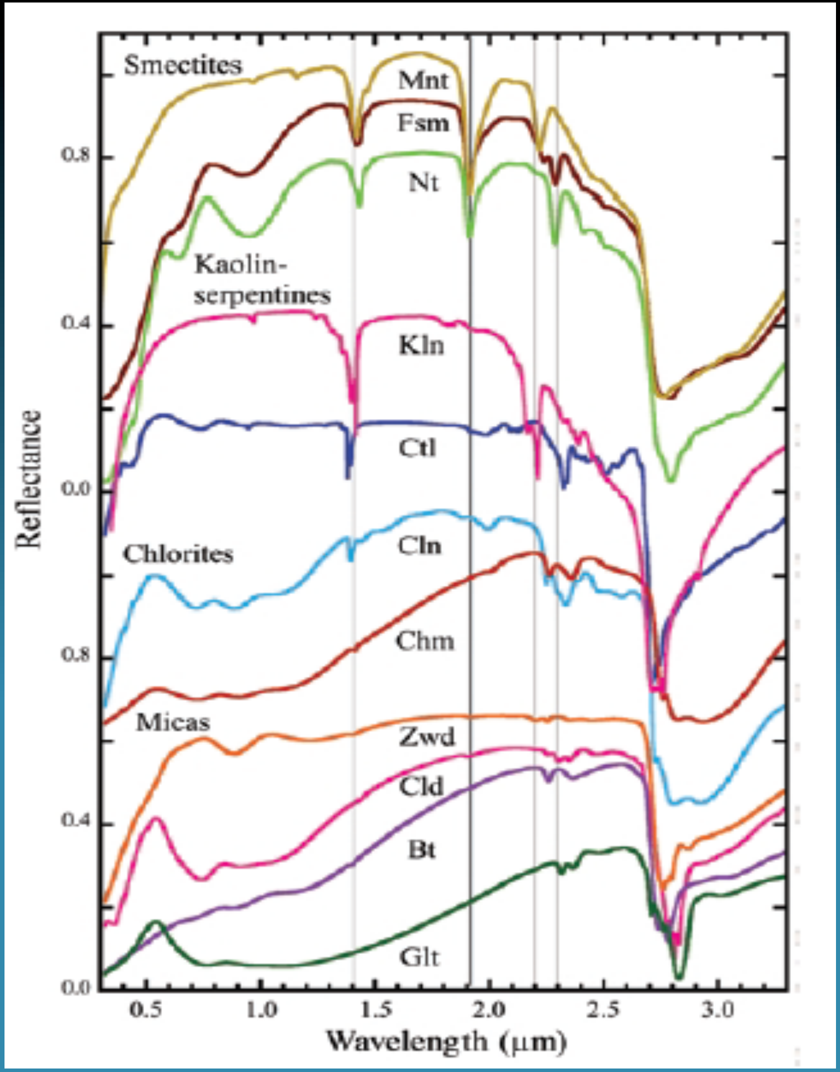
Comparison with Carbonaceous Chondrites



- Spectra of CI and CM carbonaceous chondrites measured under anhydrous conditions, share the prominent 2.7 µm OH absorption band, suggesting some mineralogical similarity
- However, these carbonaceous chondrites have significant spectral differences compared to Ceres at other wavelengths.

2.7 μm band in terrestrial phyllosilicates

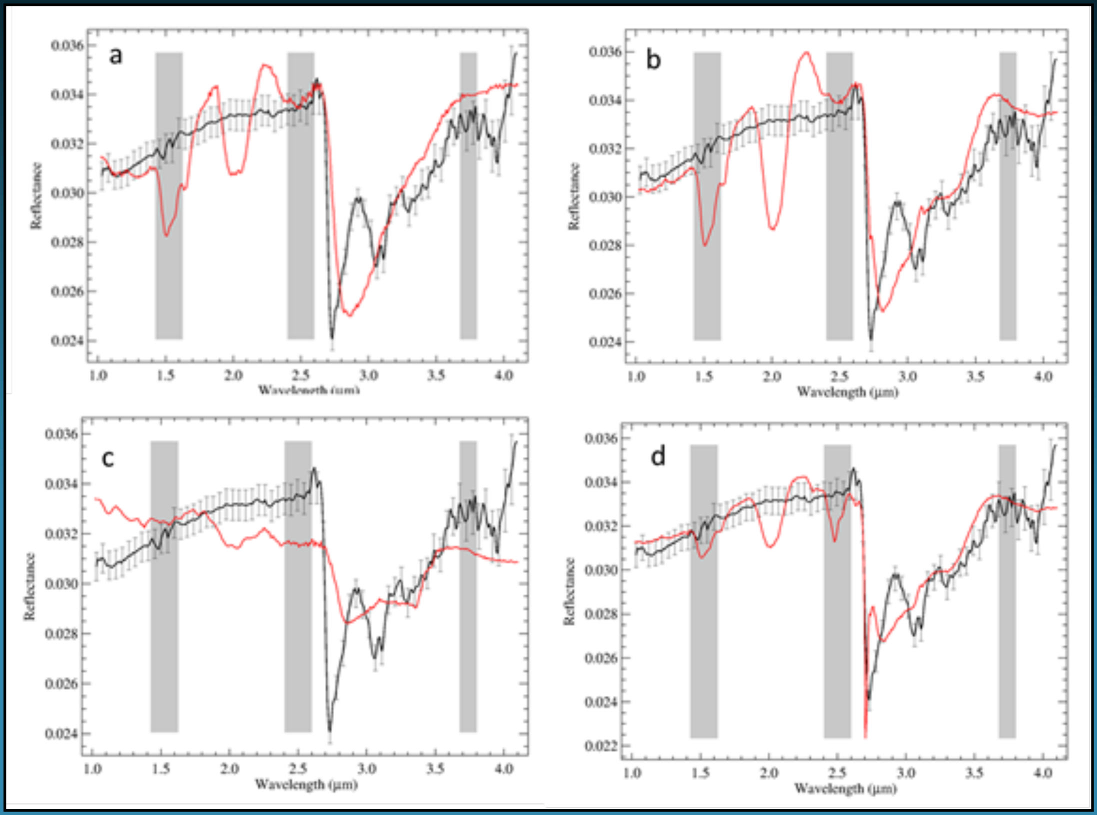
- VIR observations show a strong and narrow absorption in Ceres centered at 2.72-2.73 μm.
- This characteristic absorption feature is distinctive for *OH-bearing minerals*
- H_2O bearing minerals have a broader band that is a poor match for Ceres' spectrum.
- OH-stretching vibrations occur in the 2.7-2.85 μm range for phyllosilicates with band centers at different wavelengths for different species.



Bishop et al., 2008

Fits with water ice and CC

Water ice is not present at global scale

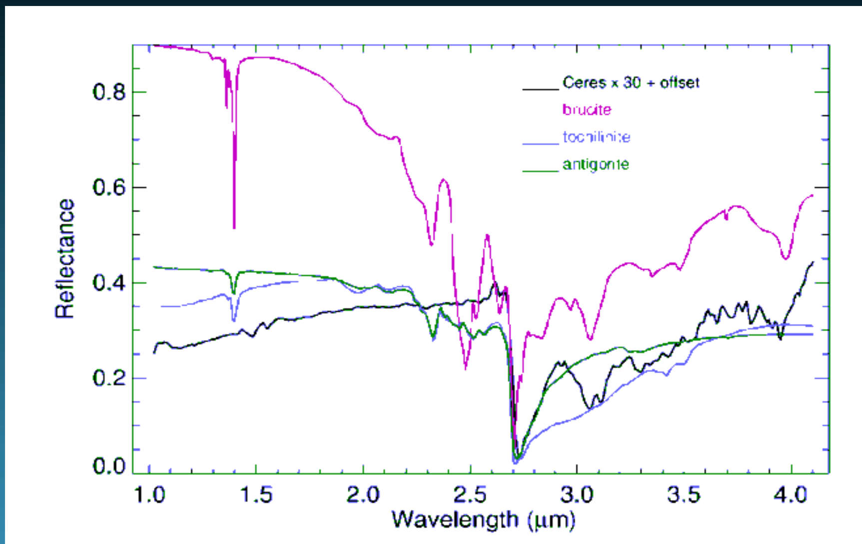


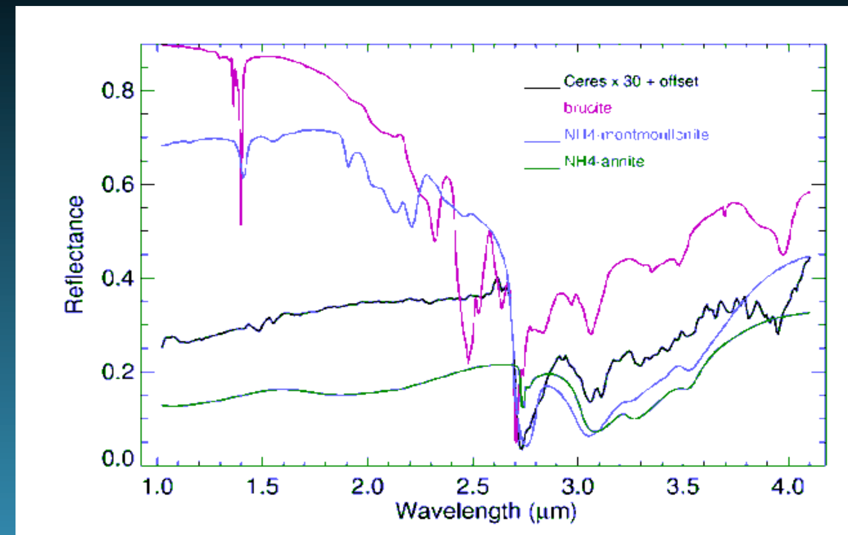
- a) water ice and Ivuna CI chondrite (heated at 500 ºC);
- b) water ice and MAC 87300 CM chondrite;
- c) water ice (1%) and Murchison CM chondrite(99%) ;
- d) water ice, Ivuna CI chondrite (heated at 500 ºC), and brucite.

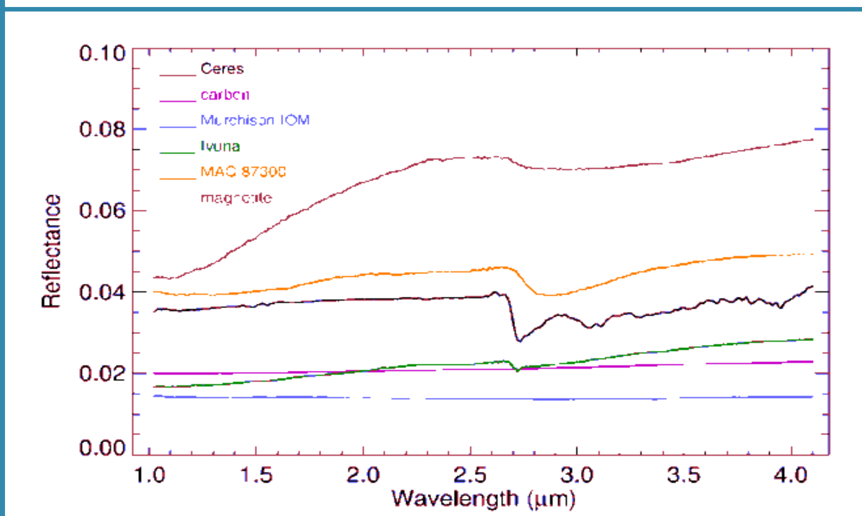
De Sanctis et al., Nature, under review

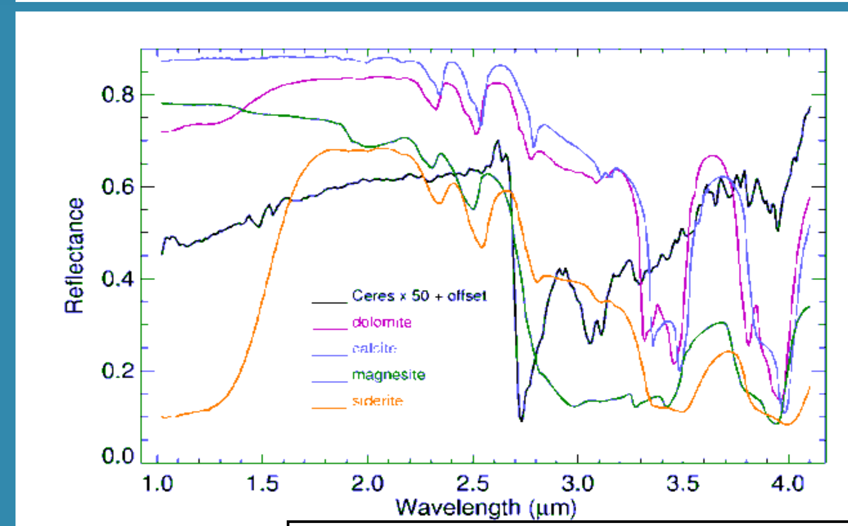
Spectral fitting/linear mixing

- Using combinations of end-members and radiative transfer equations in a particulate medium, Hapke model (2012), possible compositions are examined.







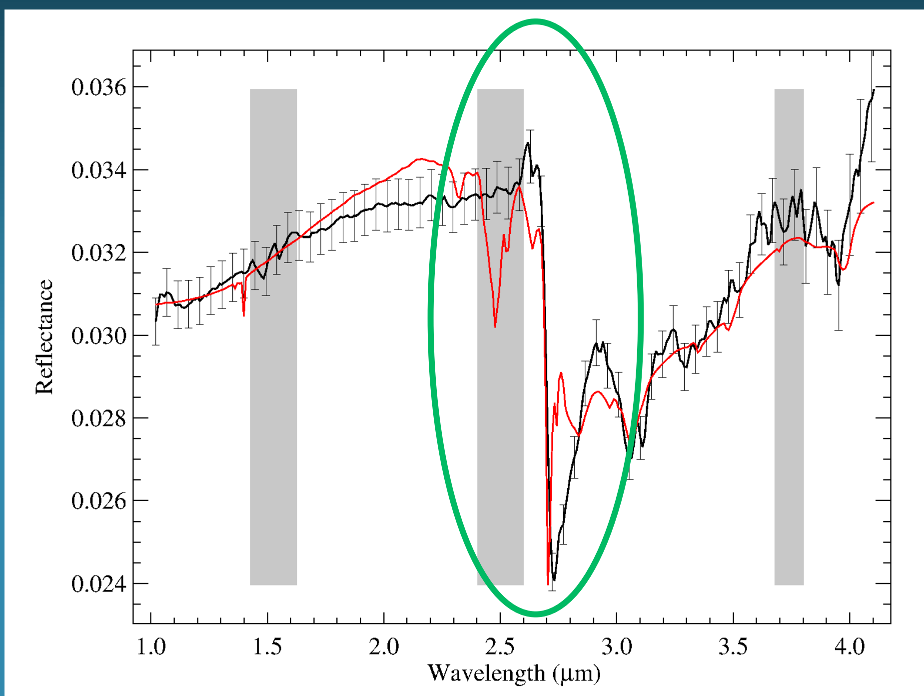


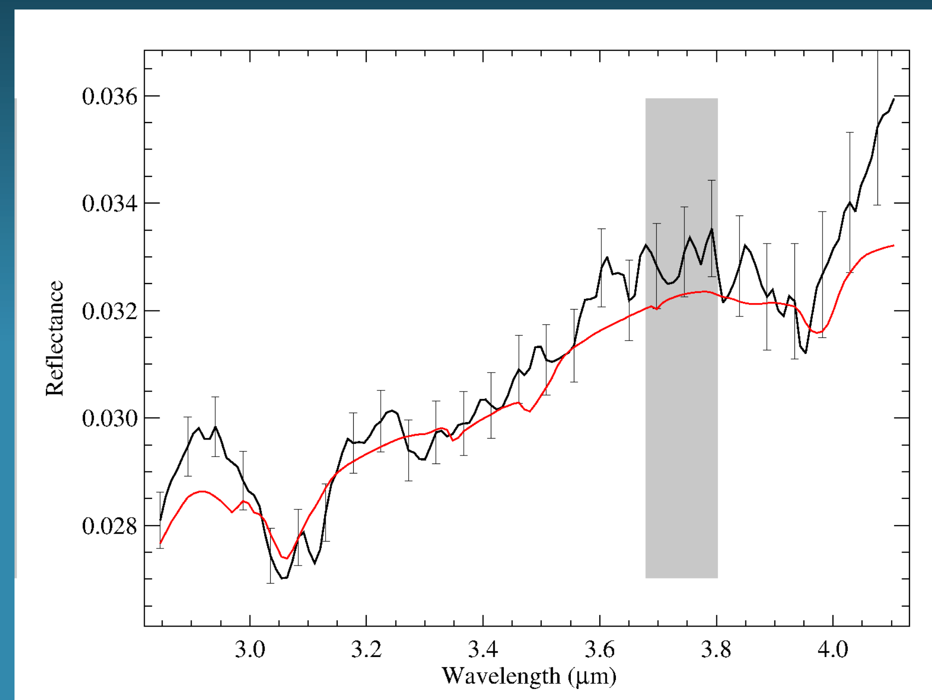
De Sanctis et al., Nature, under review

3.1 micron band: Brucite on Ceres ?

- Spectral fitting model (red curve) using brucite, Mg-carbonates, dark component and cronstedtite

- Precludes the presence of brucite

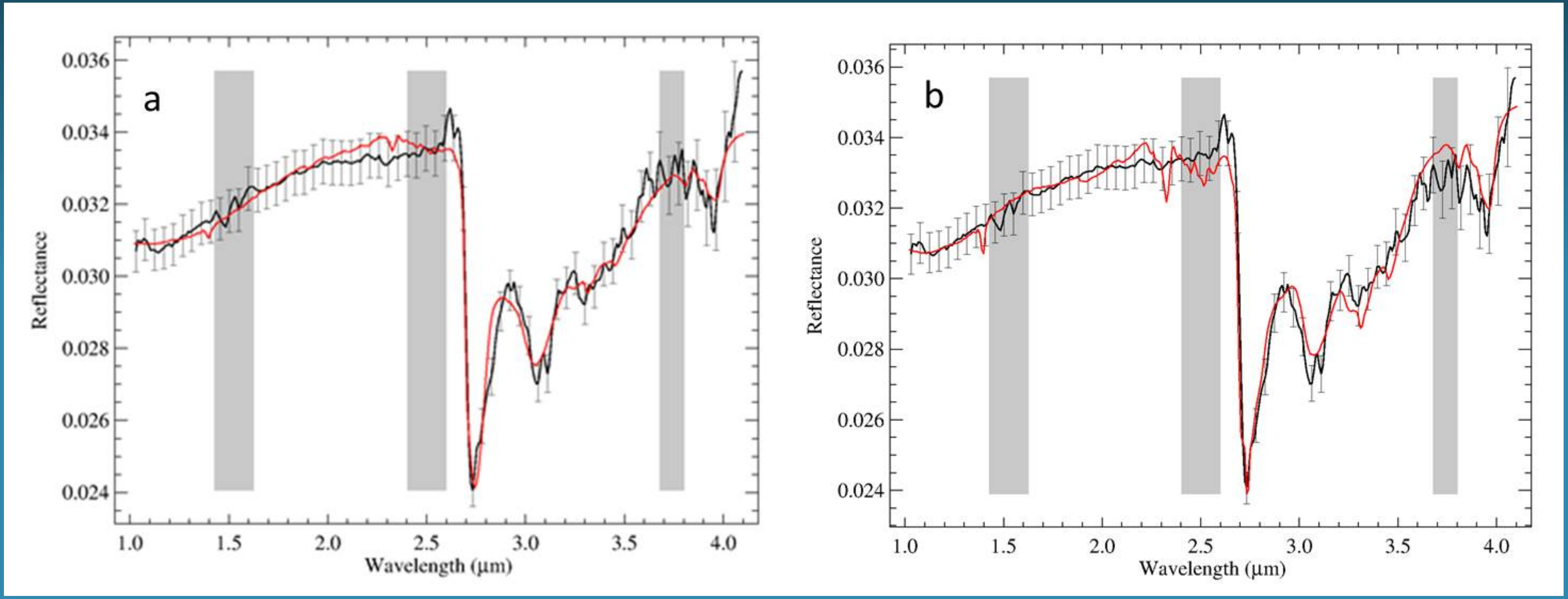




De Sanctis et al., Nature, under review

Best fit with Ammonium-bearing species

- NH_4-montmorillonite, antigorite, Mg-carbonates, and dark component
- NH_4-annite, antigorite, Mg-carbonates, and dark component



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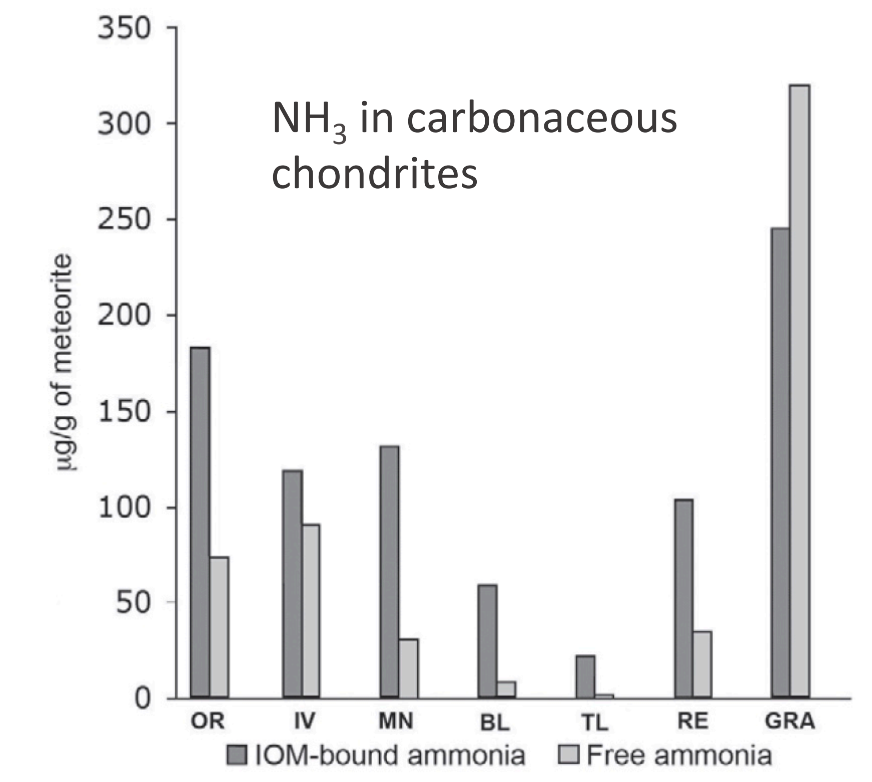
Whence the ammonia?



Pizzarello and Williams, 2015

- Organic compounds containing ammonia have been found in CM/CI chondrites.

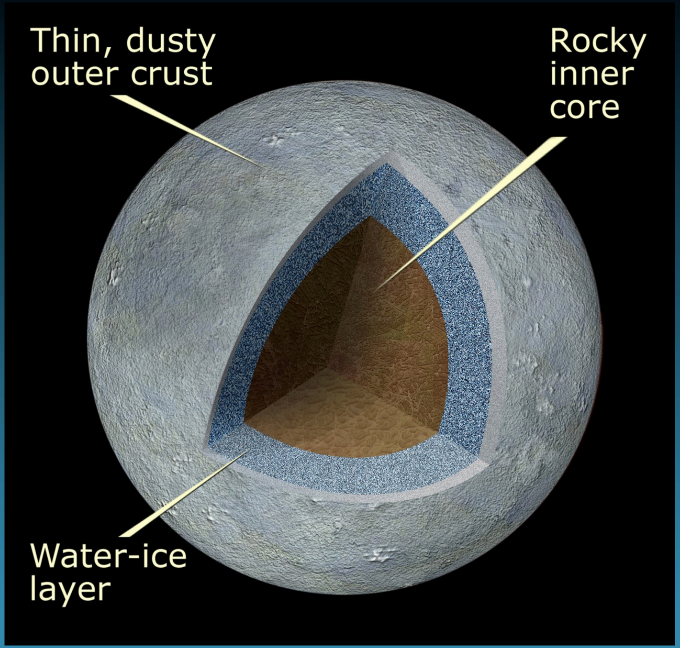
This NH_3 is released during hydrothermal heating experiments at temperatures of ~300^{o} C (Pizzarello and Williams, 2015).

- These are the same conditions under which clay minerals can form, and smectite clay, especially montmorillonite, readily accommodates the ammonium ion (NH_4^+) (Giese, 2001).

Implications: presence of ammoniated clays

Evolution - ice melt

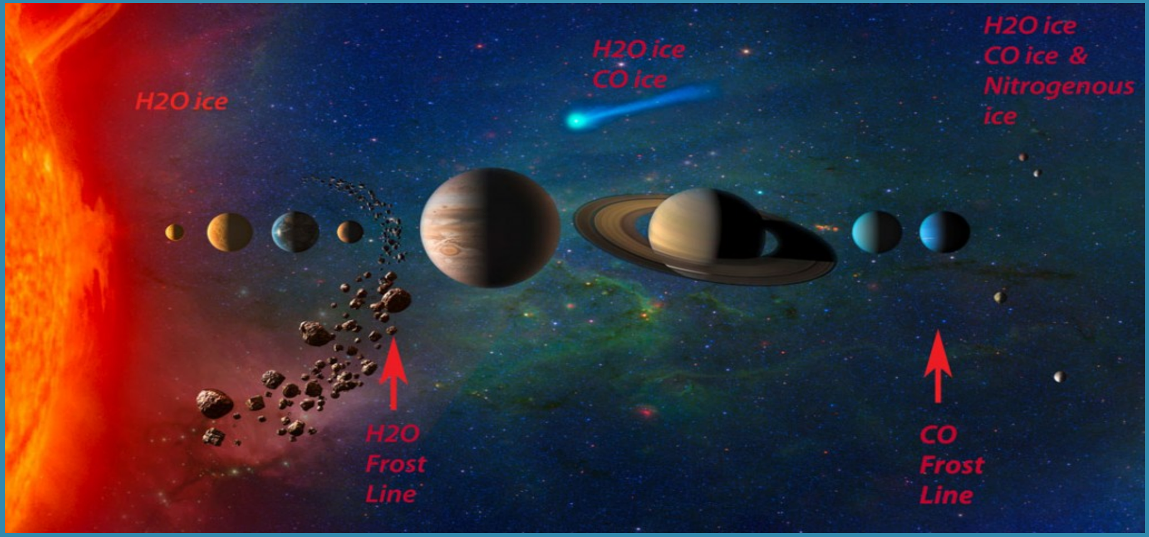
- Ammonia lowers the melting temperature of water ice
- With implications for the evolution, history and internal structure
- Liquid water could have been present (McCord & Sotin, 2005)



We still do not completely know what is inside, but the crust seems composed by clays, ammoniated-clays and carbonates

Implication: Source of Ammonia

- Ammonia ice has been observed on large trans-Neptunian objects, such as Orcus (a=39 AU) and Charon (a moon of Pluto at 40 AU) (De Meo et al., 2015; Barucci et al., 2008).
- The ammoniated organics could have formed in interstellar space or in parent bodies; alternatively, they could have formed in the nebula by UV irradiation of N_2 or NH_3 ices (Clark et al., 2009).
- *The location of the N_2/NH_3 frost-line* might be inferred from the presence of N_2 ice on Triton, Pluto and TNOs, in the *vicinity of Neptune at 30 AU*.



Walsh et al., 2012

Ceres' origin

- It is difficult to think that Ceres completely accreted from the material present only at its current position.
- It is possible that *Ceres grew close to its present position* by accreting pebble-sized objects, some of which could *have drifted inward from larger heliocentric distances where ammonia was stable*. That material may contain ammonia-bearing organic matter, originally formed by irradiation of N_2 ices condensed near the orbit of Neptune. But why do we see this only at Ceres?
- Or *Ceres may have formed further out in the solar system*, presumably in the trans-Neptunian disk, before subsequently implanted in the main belt. The implantation of Ceres in the main belt could have taken place during a migratory phase of the giant planets, either during their growth in the proto-planetary disk or at a later time as a result of an orbital instability.
- *In both cases Ceres should have incorporated material from the outer solar system*

Aknowledgements

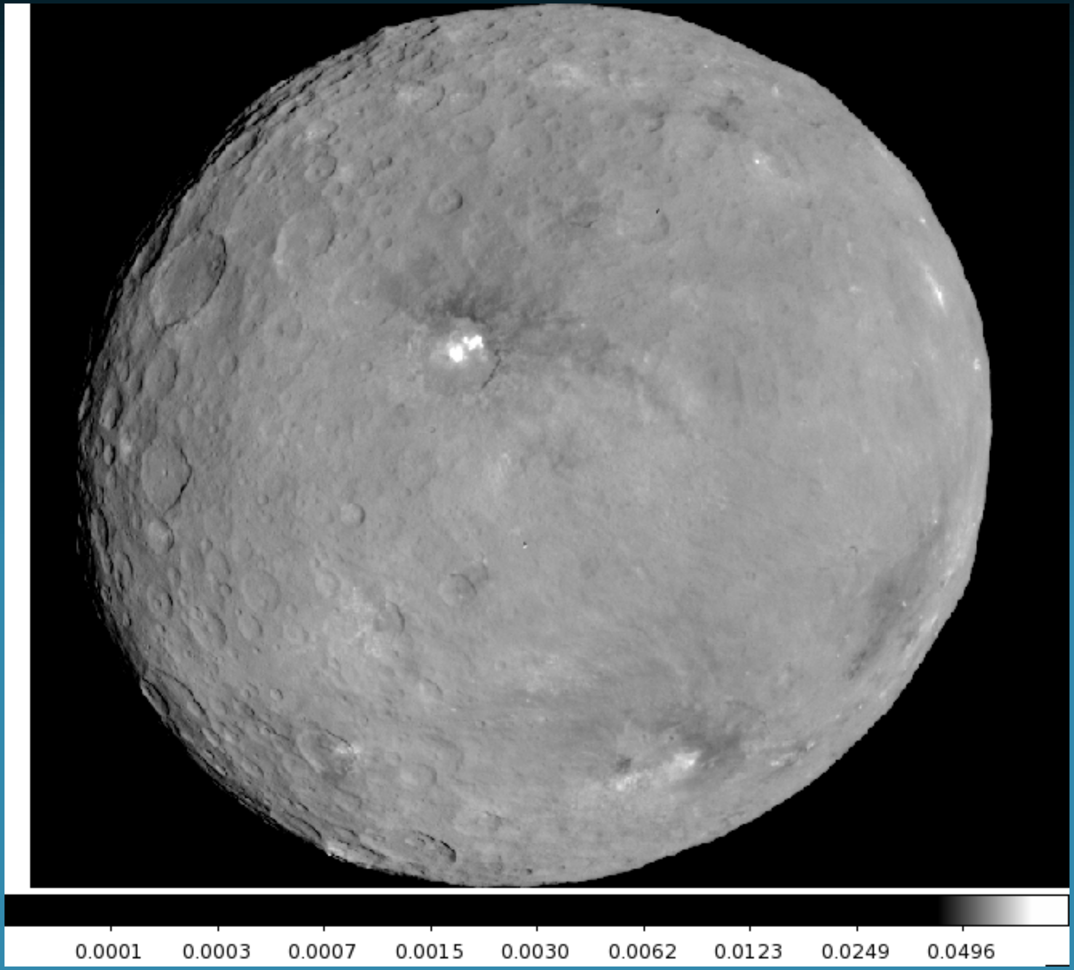
- VIR team who worked hard to plan, acquire, calibrate and interpret the data presented here.
  - photometric properties (Ciarniello et al., Longobardo et al.)
  - composition (Raponi et al.)
  - distribution of minerals (Ammannito et al.)
  - spectral units (Zambon et al.)
  - surface temperatures (Tosi et al.)
  - ice thermal stability (Formisano et al.)
- Dawn's operations and navigation teams for successfully operating the spacecraft to get these wonderful data.
- VIR was funded and coordinated by the Italian Space Agency and built by SELEX ES, with the scientific leadership of the Institute for Space Astrophysics and Planetology, Italian National Institute for Astrophysics, Italy, and is operated by the Institute for Space Astrophysics and Planetology, Rome, Italy.

Back-up

Things to know about Ceres

- Bulk Density: 2100 kg/m^3 give some comparisons
- Albedo: 0.09 Li et al. Is higher than carbonaceous chondrite meteorite albedos (0.02-??)
- Surface Temperature: 215 K (Dotto et al. 2000)
- General spectral reflectance characteristics
  - 0.4-1.0 µm range, flat and featureless.
  - Strong absorption edge shortward of 0.45µm
- Mineral absorption features

Things to know about Ceres:
It's round, hydrostatic equilibrium, in tact



VIR image of the crater Occator with bright spots

We acquired spectra of the Occator bright spots and we are working on the data.