La missione Dawn: all'alba del sistema solare

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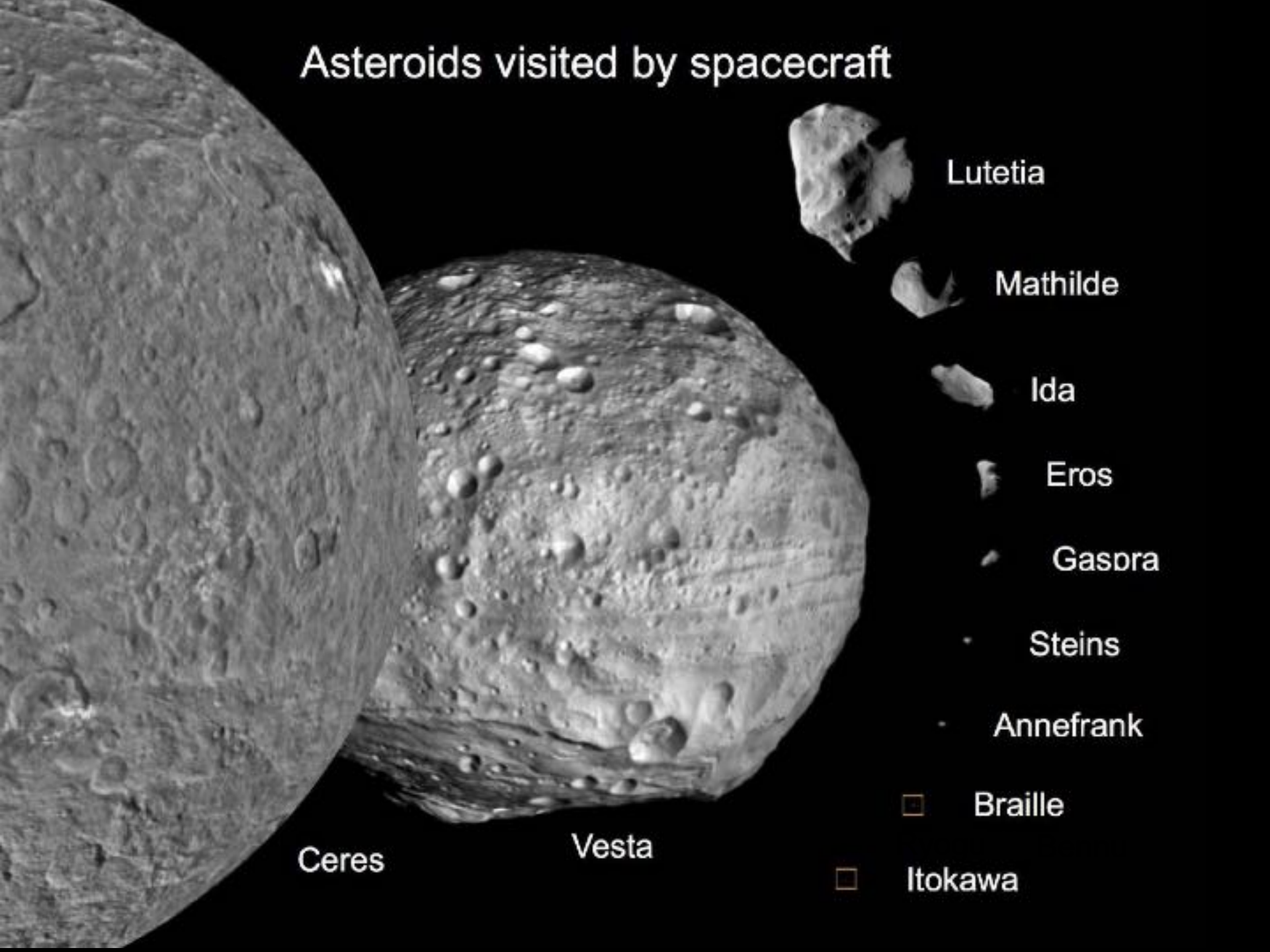
Annibale de Gasparis WS
Osservatorio di Napoli, 7-11-2019

Gli asteroidi della fascia principale

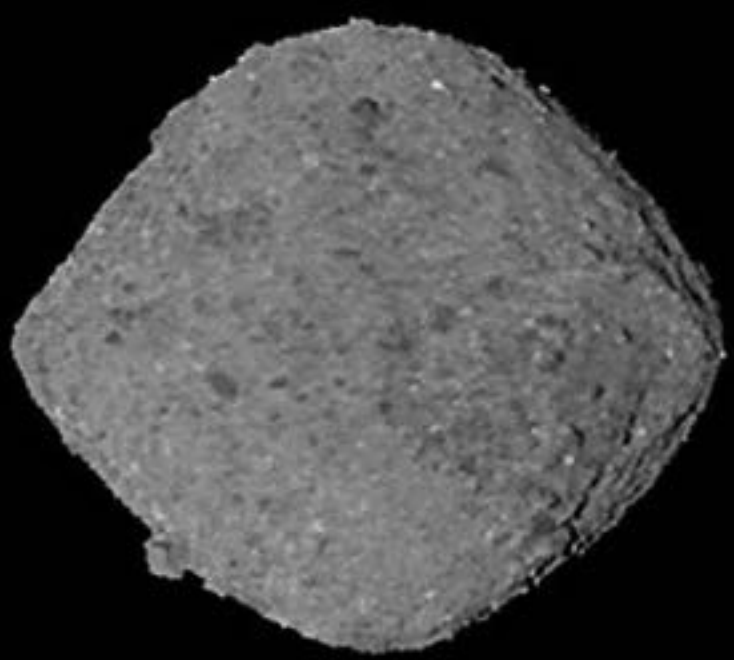
Il contributo italiano allo studio degli asteroidi ha origini lontane nel tempo come testimonia questo workshop

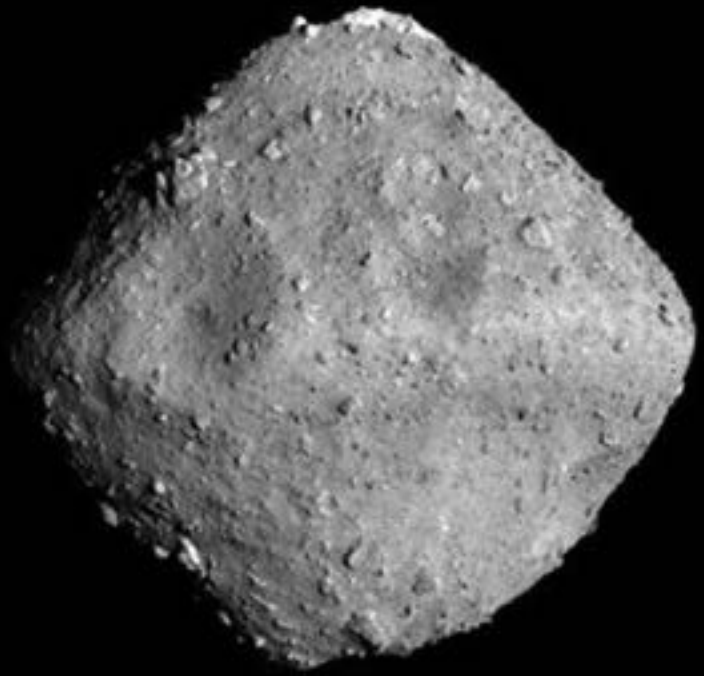
Gli asteroidi ci offrono una finestra sui processi che hanno caratterizzato il sistema solare nelle sue fasi iniziali

La diversità racchiusa nella zona compresa tra Marte e Giove ci indica quanto questi processi siano stati complessi


Asteroids visited by spacecraft
Lutetia
Mathilde
Ida
Eros
Gaspra
Steins
Annefrank
Braille
Itokawa
Vesta
Ceres

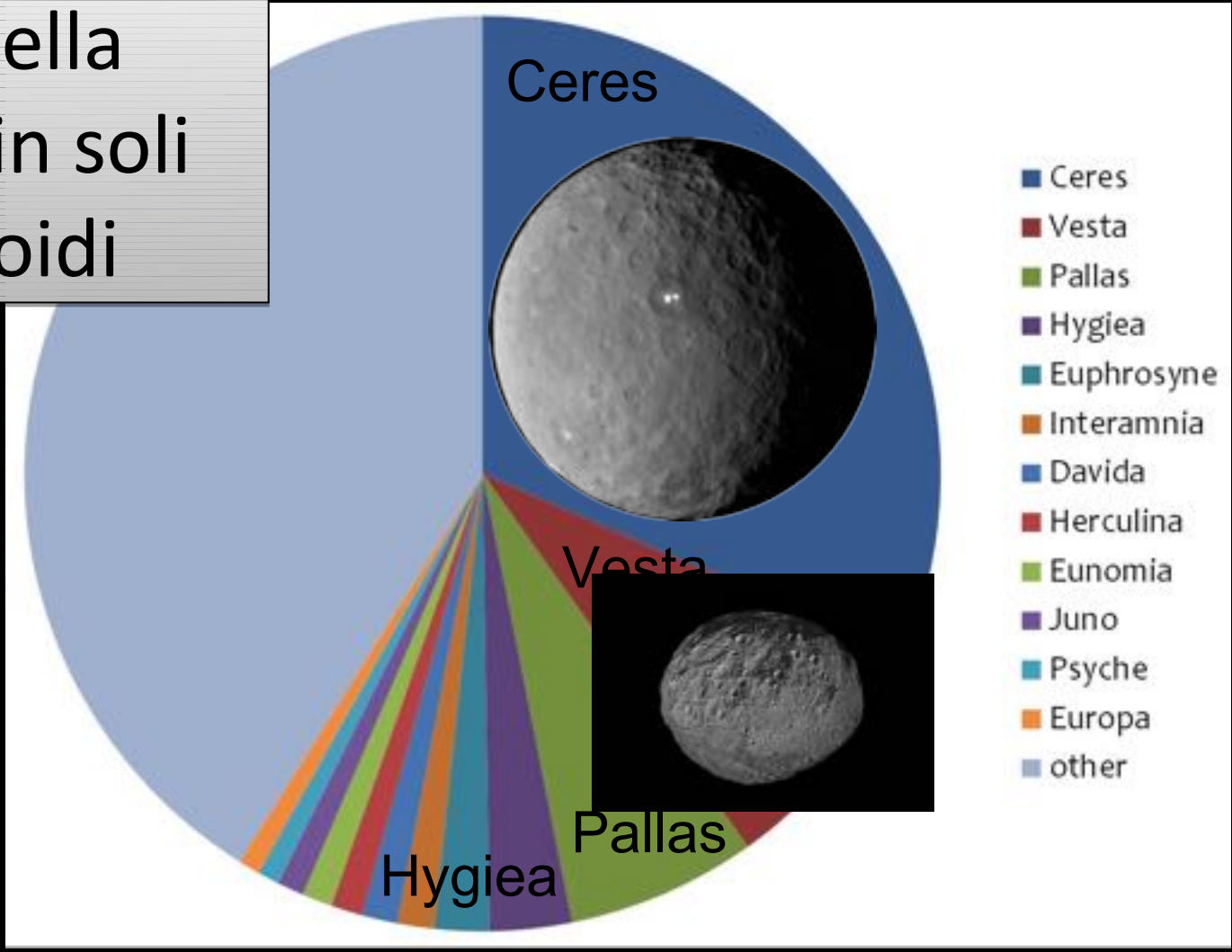
Ryogu e Bennu





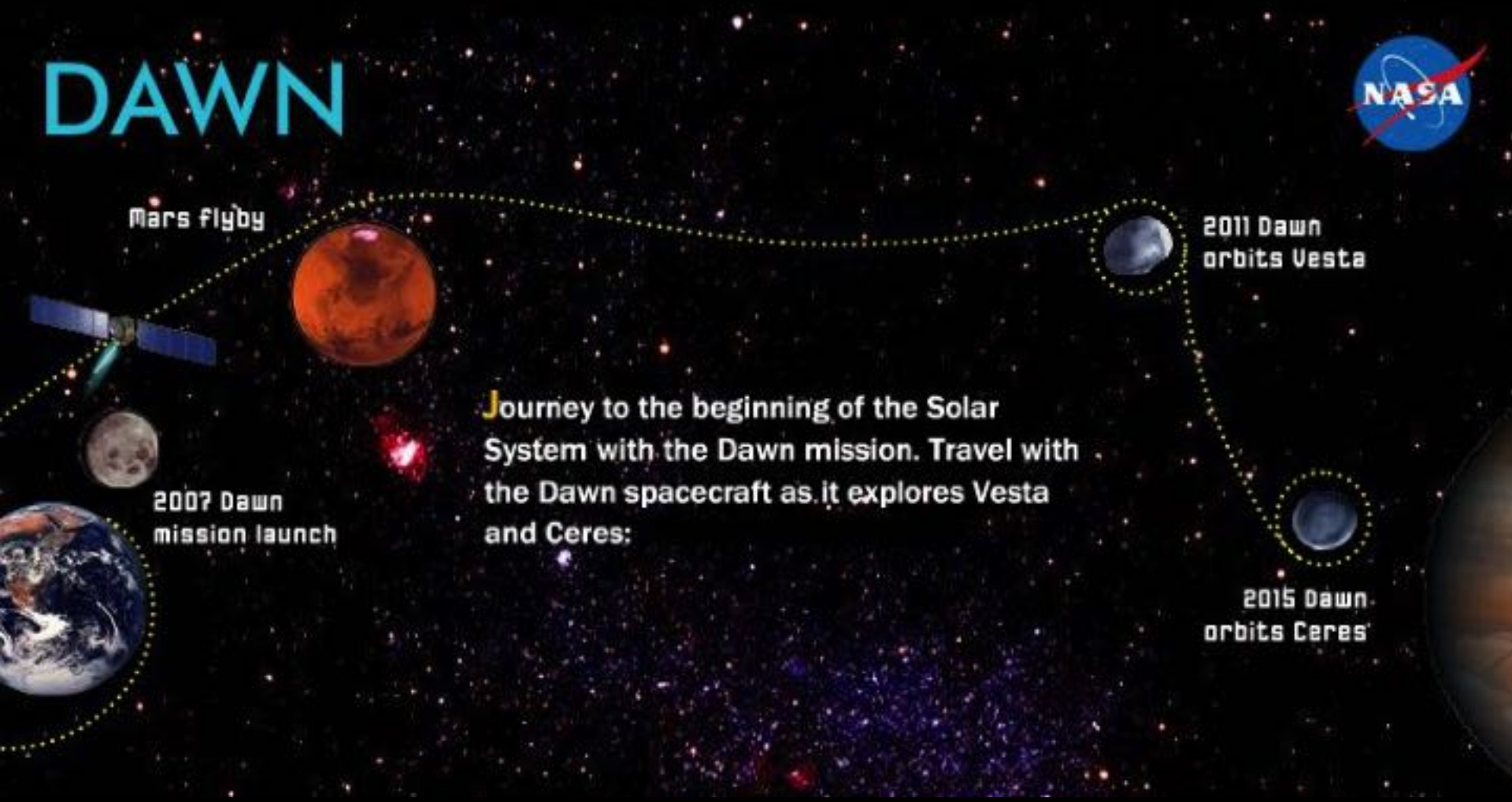
Massa della cintura principale

Metà della massa in soli 4 asteroidi



Missione Dawn

Dawn: un viaggio nello spazio e nel tempo



Dawn: un viaggio nello spazio e nel tempo

Spazio	Tempo
• da Vesta a Cerere: attraverso la **snow-line** • Vesta: basaltico e differenziato—Prototipo dei planetesimi dei pianeti terrestri • Cerere: idrato/ghiacciato e differenziato – Prototipo dei planetesimi dei pianeti esterni	• Vesta e Cerere: Fossili del sistema solare • Vesta: il più antico oggetto/pianeta del sistema solare • Cerere: ruolo dell'acqua nel sistema solare primordiale • Cronologia e tipologia dei processi di formazione del sistema solare

DAWN

NASA

UCLA - Overall management

JPL - Mission operations

asi agenzia spaziale italiana

INAF

- Visible-Infrared Mapping Spectrometer

MPS

DLR

- Framing camera

Planetary Science Institute EST. 1972

Los Alamos NATIONAL LABORATORY EST. 1943

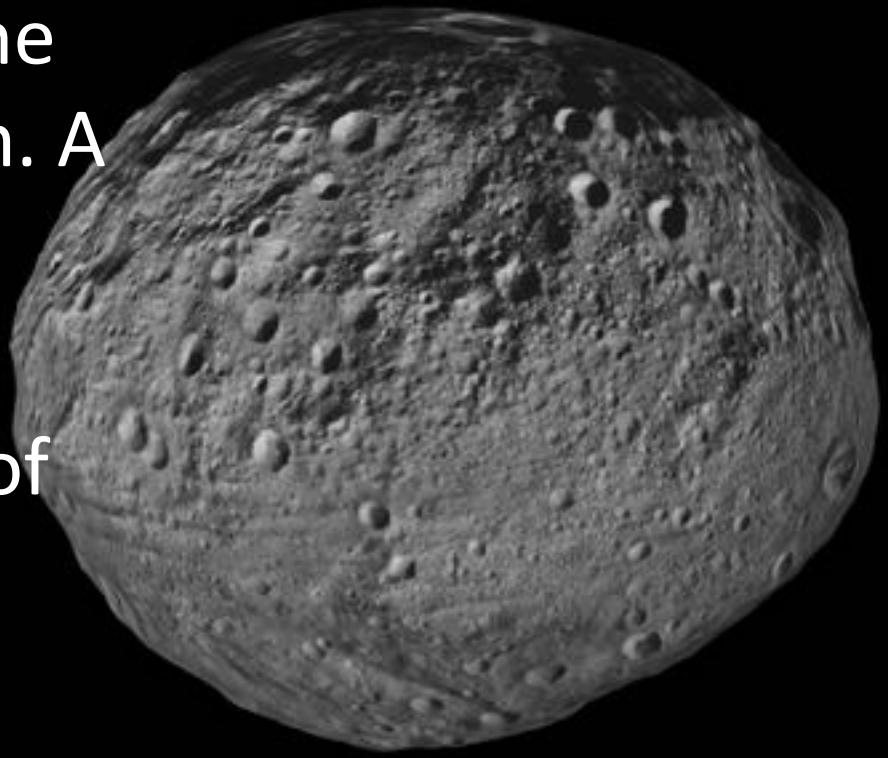
- Gamma Ray and Neutron Detector

Dawn a Vesta

COSA ABBIAMO SCOPERTO E QUALI SONO LE IMPLICAZIONI

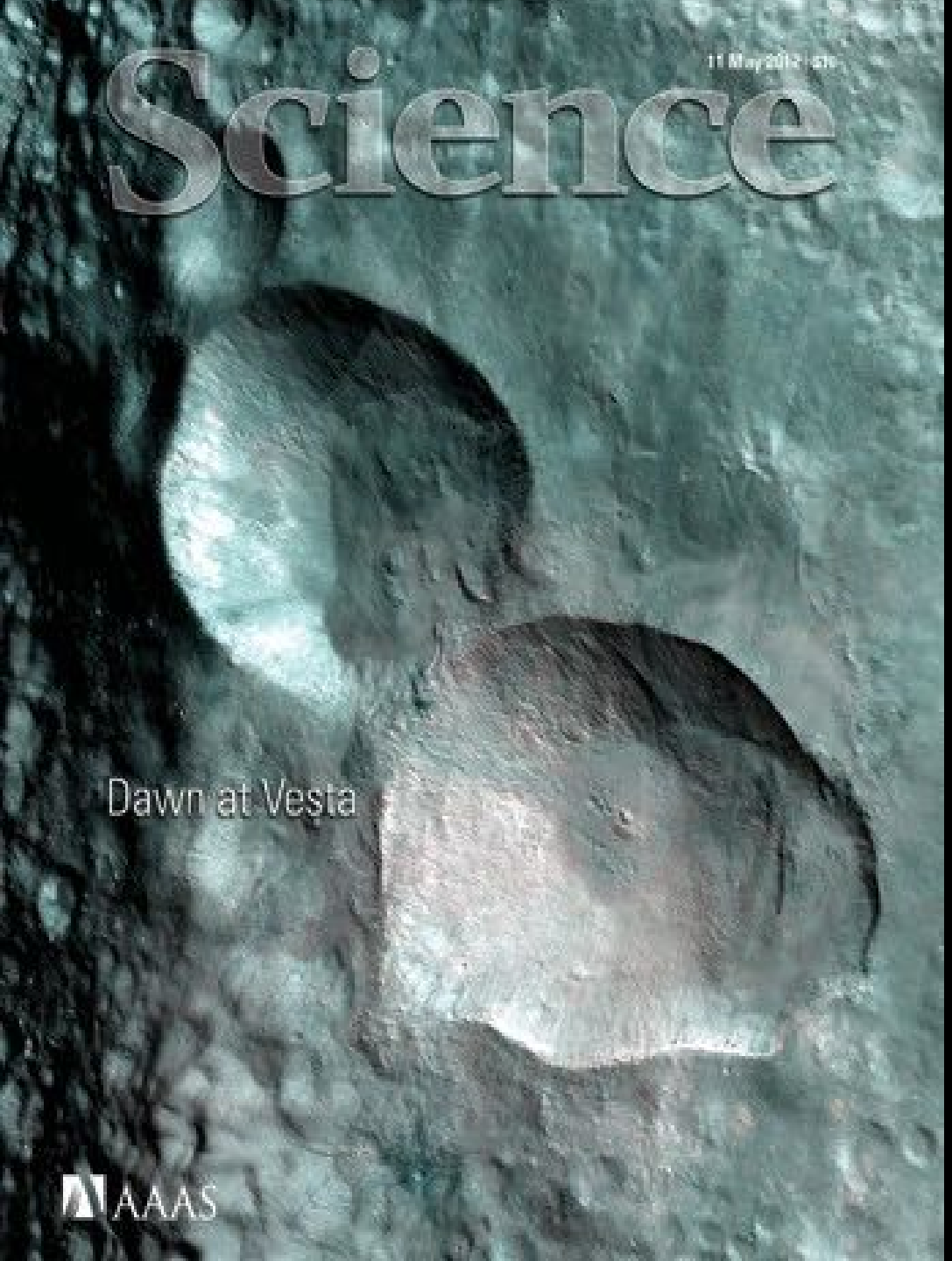
Why Vesta

- Vesta formed early, within 1 to 2 million years of the birth of the solar system. A relict of the primordial solar system
- Is Vesta the progenitor of the HED meteorites ?
- Is Vesta fully differentiated ?
- Is it completely dry ?



Vesta VIR data

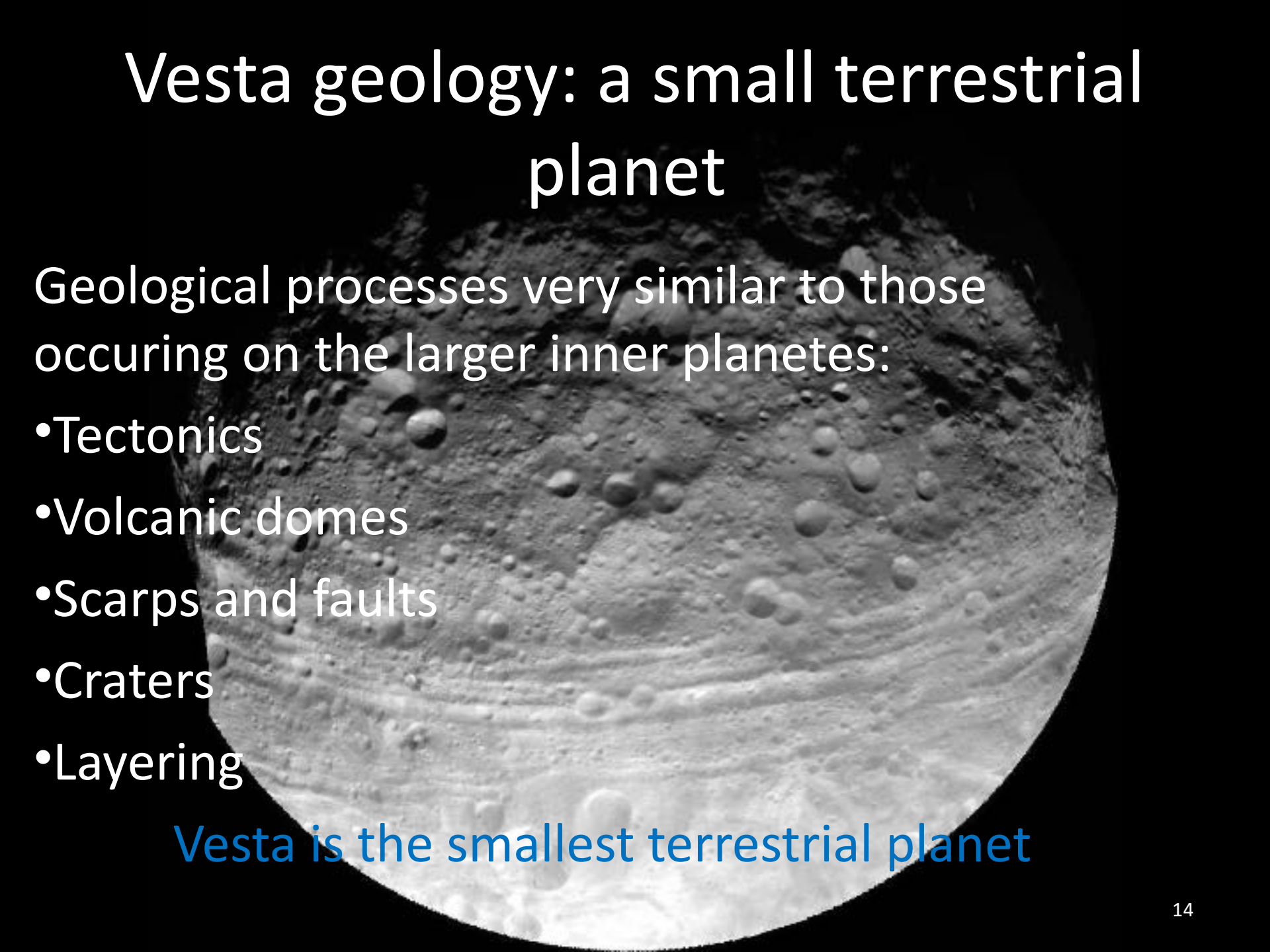
- VIR is the imaging spectrometer onbaord of Dawn specacraft. It is provided by ASI and INAF under the leadership of IAPS-INAF
- Spectral range 0.25-5.1 micron
- 864 spectral channels
- Spatial resolution from 1.3 km to 70 m
- >20.000.000 spectra



DAWN: A WINDOW ON THE PRIMORDIAL SOLAR SYSTEM

- Spectral diversity correlated with topography: Vesta is a small differentiated planet

Vesta geology: a small terrestrial planet



Geological processes very similar to those occuring on the larger inner planetes:

- Tectonics
- Volcanic domes
- Scarps and faults
- Craters
- Layering

Vesta is the smallest terrestrial planet

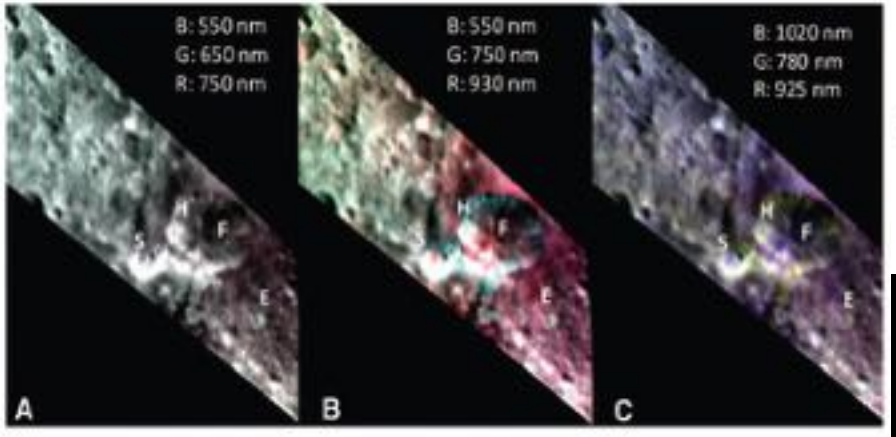
Spectral diversity

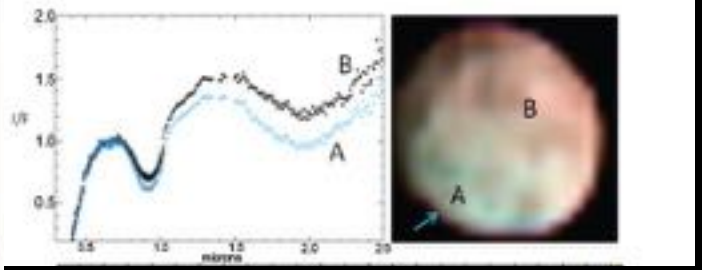
Spectroscopic Characterization of Mineralogy and Its Diversity Across Vesta

M. C. De Sanctis,[1*] E. Ammannito,[1] M. T. Capria,[1] F. Tosi,[1] F. Capaccioni,[1] F. Zambon,[1] F. Carraro,[1] S. Fonte,[1] A. Frigeri,[1] R. Jaumann,[2] G. Magni,[1] S. Marchi,[3] T. B. McCord,[4] L. A. McFadden,[5] H. Y. McSween,[6] D. W. Mittlefehldt,[7] A. Nathues,[8] E. Palomba,[1] C. M. Pieters,[9] C. A. Raymond,[10] C. T. Russell,[11] M. J. Toplis,[12] D. Turrini[1]

The mineralogy of Vesta, based on data obtained by the Dawn spacecraft's visible and infrared spectrometer, is consistent with howardite-eucrite-diogenite meteorites. There are considerable regional and local variations across the asteroid: Spectrally distinct regions include the south-polar Rheasilvia basin, which displays a higher diogenitic component, and equatorial regions, which show a higher eucritic component. The lithologic distribution indicates a deeper diogenitic crust, exposed after excavation by the impact that formed Rheasilvia, and an upper eucritic crust. Evidence for mineralogical stratigraphic layering is observed on crater walls and in ejecta. This is broadly consistent with magma-ocean models, but spectral variability highlights local variations, which suggests that the crust can be a complex assemblage of eucritic basalts and pyroxene cumulates. Overall, Vesta mineralogy indicates a complex magmatic evolution that led to a differentiated crust and mantle.

- VIR mostra che Vesta ha una composizione eterogenea e legata alla stratigrafia.
- La distribuzione delle litologie indica una composizione differente tra la crosta e gli strati più profondi, consistenti con alcuni modelli di formazione.

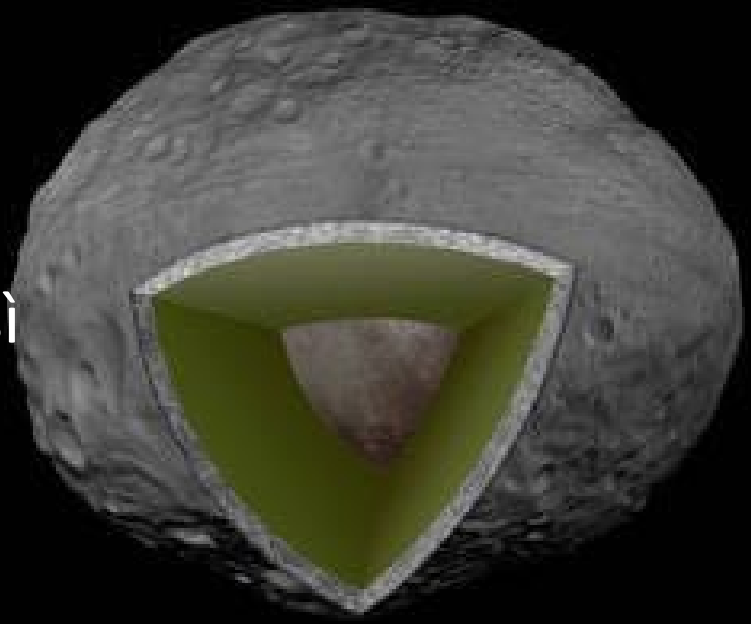




De Sanctis et al., Science, Vol. 336, 6082, pp. 697- (2012)
Pieters et al., Nature, Vol. 491, 7422, pp. 79-82 (2012)

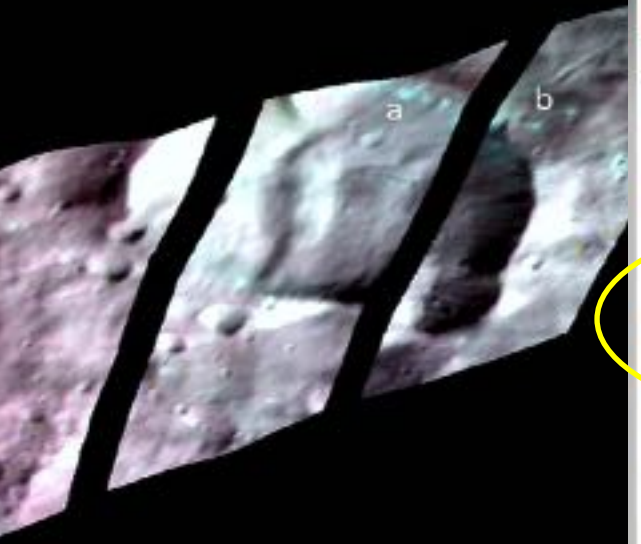
Vesta è un piccolo pianeta formatosi agli albori del sistema solare

- Vesta è differenziato con una crosta, un mantello ed un nucleo di ferro (si evince dalla mineraologia e dalla struttura interna).
- La differenziazione di oggetti così piccoli (D=500km) implica l'abbondanza di sorgenti di energia molto efficaci: ^{26}Al e ^{60}Fe
- **Solo i planetesimi più antichi sono riusciti a differenziarsi**



Russell et al., Science, Vol. 336, 6082, pp. 684- (2012).
Jaumann et al, ., Science, Vol. 336, 6082, pp. 687- (2012).

Vesta is differentiated -Vesta's mysterious olivine



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日本語要約

Olivine in an unexpected location on Vesta's surface

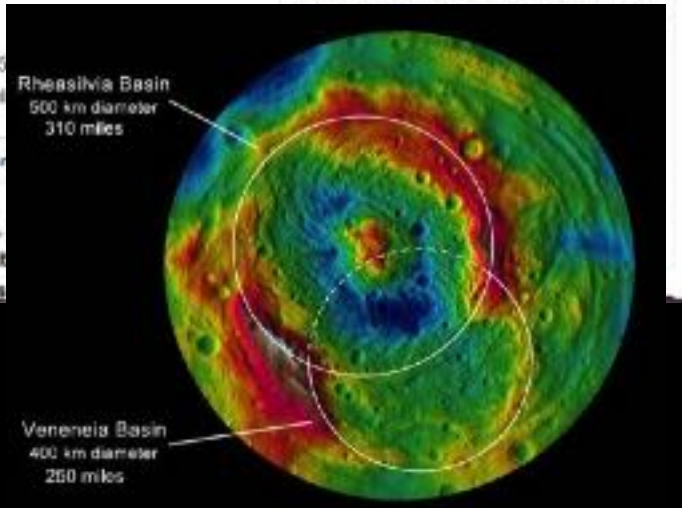
E. Ammannito, M. C. De Sanctis, E. Palomba, A. Longobardo, D. W. Mittlefehldt, H. Y. McSween, S. Marchi, M. T. Capria, F. Capaccioni, A. Frigeri, C. M. Pieters, O. Ruesch, F. Tosi, F. Zambon, F. Carraro, S. Fonte, H. Hiesinger, G. Magni, L. A. McFadden, C. A. Raymond, C. T. Russell & J. M. Sunshine

Affiliations | Contributions | Corresponding authors

Nature 504, 122–125 (05 December 2013) | doi:10.1038/nature12660
Received 10 April 2013 | Accepted 13 September 2013 | Published online

Editor's summary

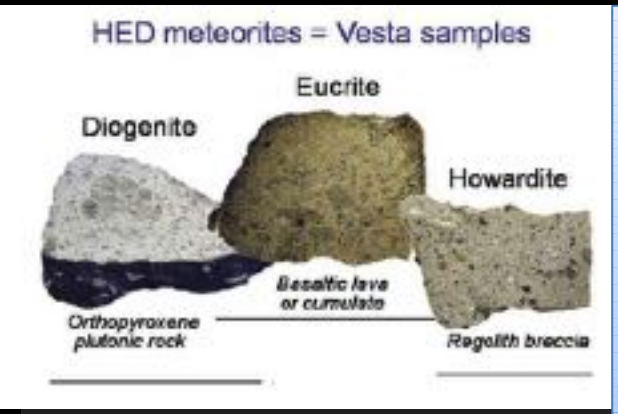
Between July 2011 and September 2012, NASA's Dawn spacecraft was in orbit around the asteroid Vesta. In this paper, Dawn's Visible and Infrared Mapping Spectrometer (VIR) team presents a surprising finding — the signature of olivine on the asteroid's surface. Olivine is a major component of the mantle of differentiated bodies, including Earth. Vesta is a large asteroid, large enough to have differentiated into an Earth-like layered structure and the expectation was that olivine would be found within Vesta's deep, south-pole



Olivina è un minerale che tipicamente si forma nel mantello della terra-Indica che Vesta ha avuto una evoluzione simil terrestre

Ammannito et al., Nature, Volume 504, Issue 7478, pp. 122-125 (2013).

Vesta: a fossil of the solar system

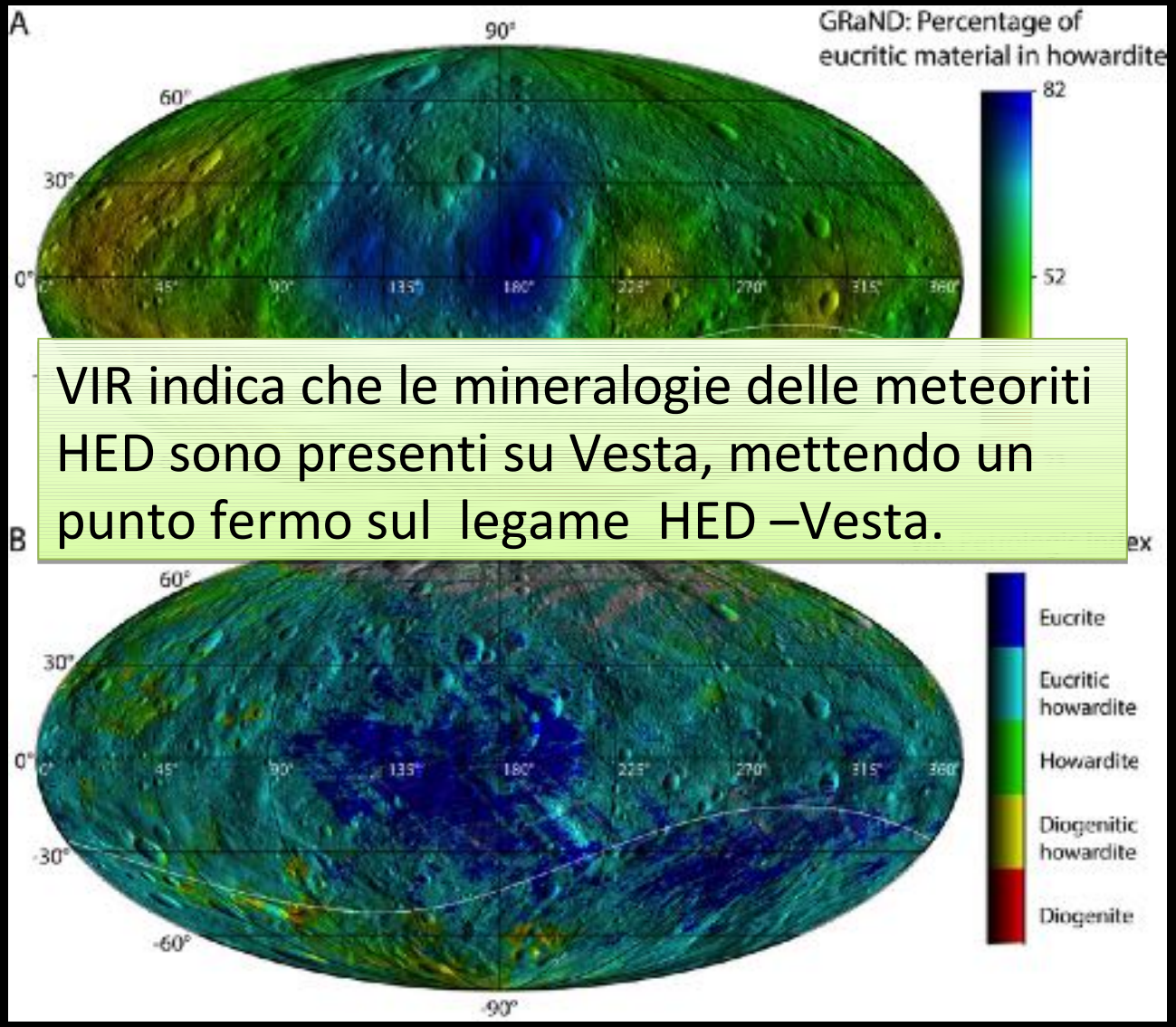


Chronology of the early Solar System from the radiometric ages of meteorites (Scott, 2007)

- CAIs (the most ancient) appeared 4.568 Ga ago
- **HEDs appear to have formed about 2.5 Myr later when the Al26 was abundant**
- Meteorites associated with other parent bodies date to even more recent times

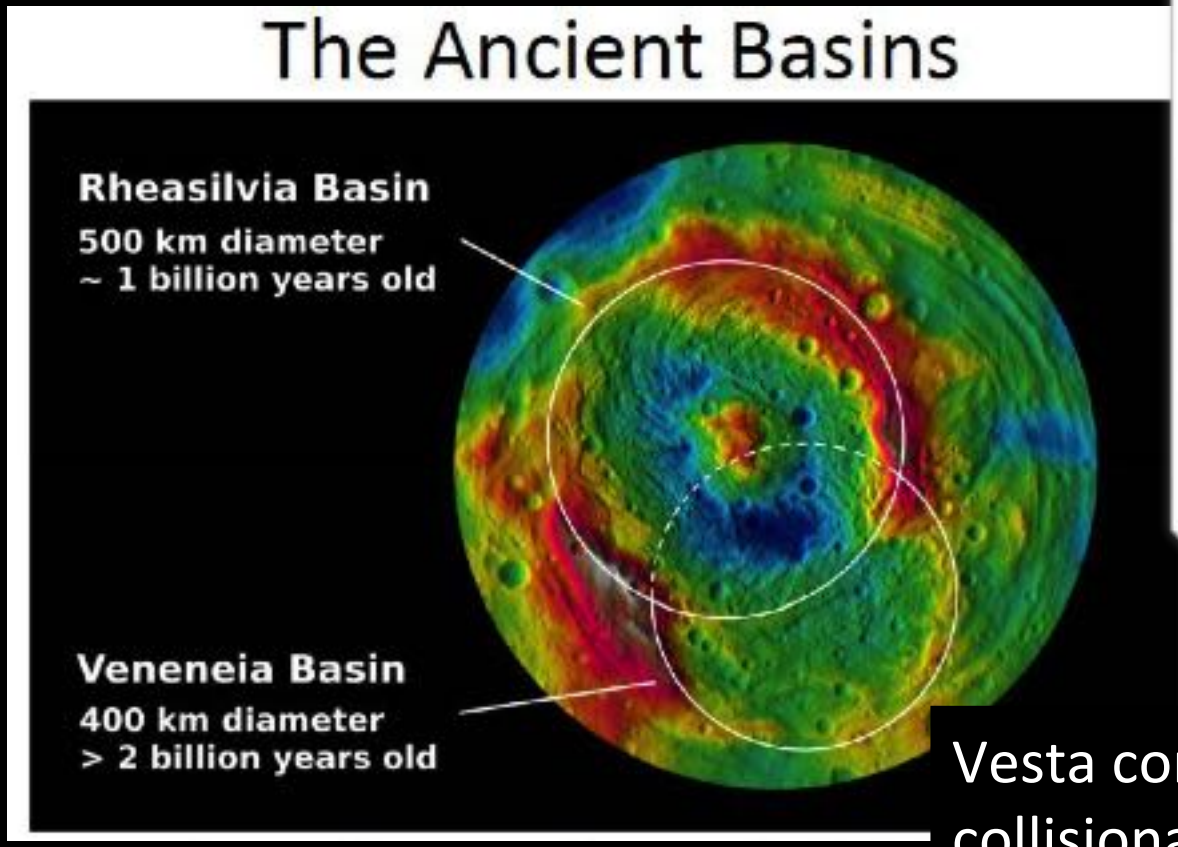
Based on neutron absorption measurements by GRaND
(Prettyman et al. 2013)

Based on visible/ near-infrared spectroscopy by VIR
(DeSanctis et al. 2013)



VIR indica che le mineralogie delle meteoriti HED sono presenti su Vesta, mettendo un punto fermo sul legame HED –Vesta.

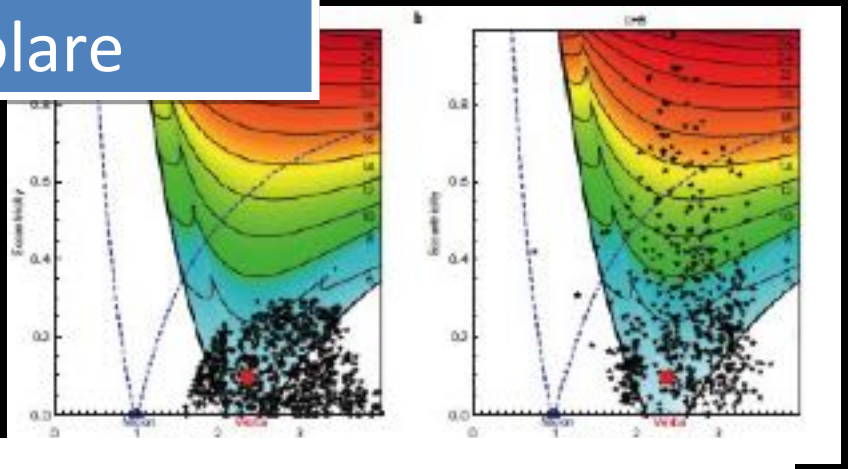
Collisions and Chronology of the solar system

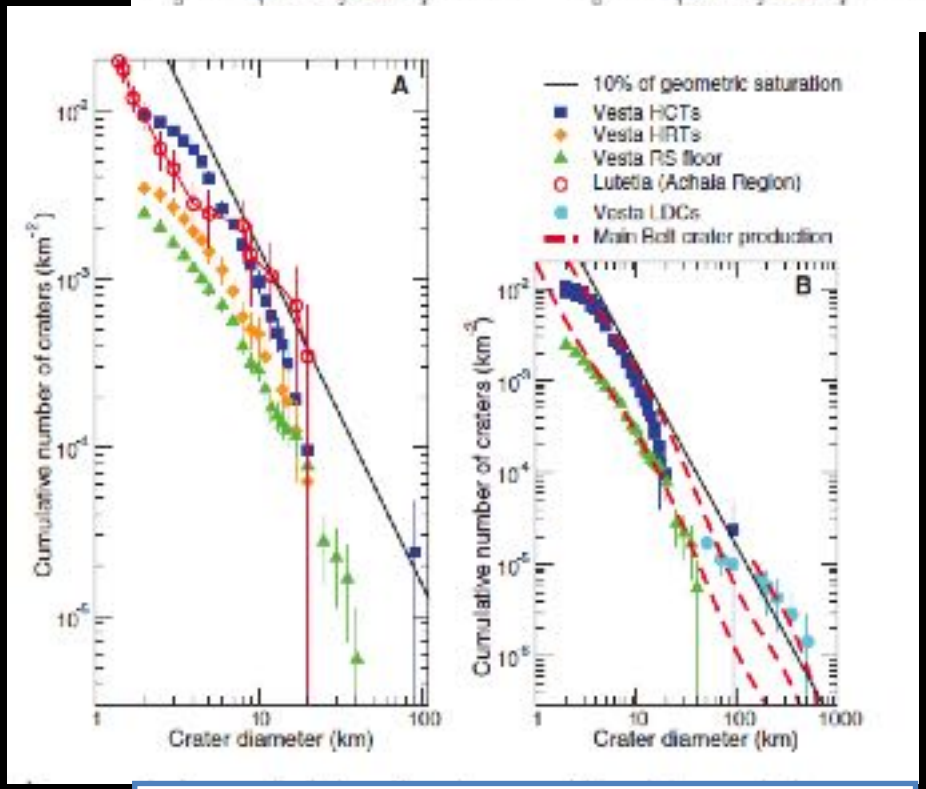


Vesta compositions, structure and collisional hystory gives us clues of the evolution of the Solar system

Storia collisionale del sistema solare

- Gli impatti sono eventi frequenti ma ci sono state epoche remote in cui le collisioni furono molto più violente e frequenti
- Lo studio della superficie di Vesta, insieme alle datazioni delle HED, ci indicano che il «late heavy bombardment» è stato un fenomeno globale che ha interessato tutto il sistema solare dalla fascia degli asteroidi ai pianeti terrestri.

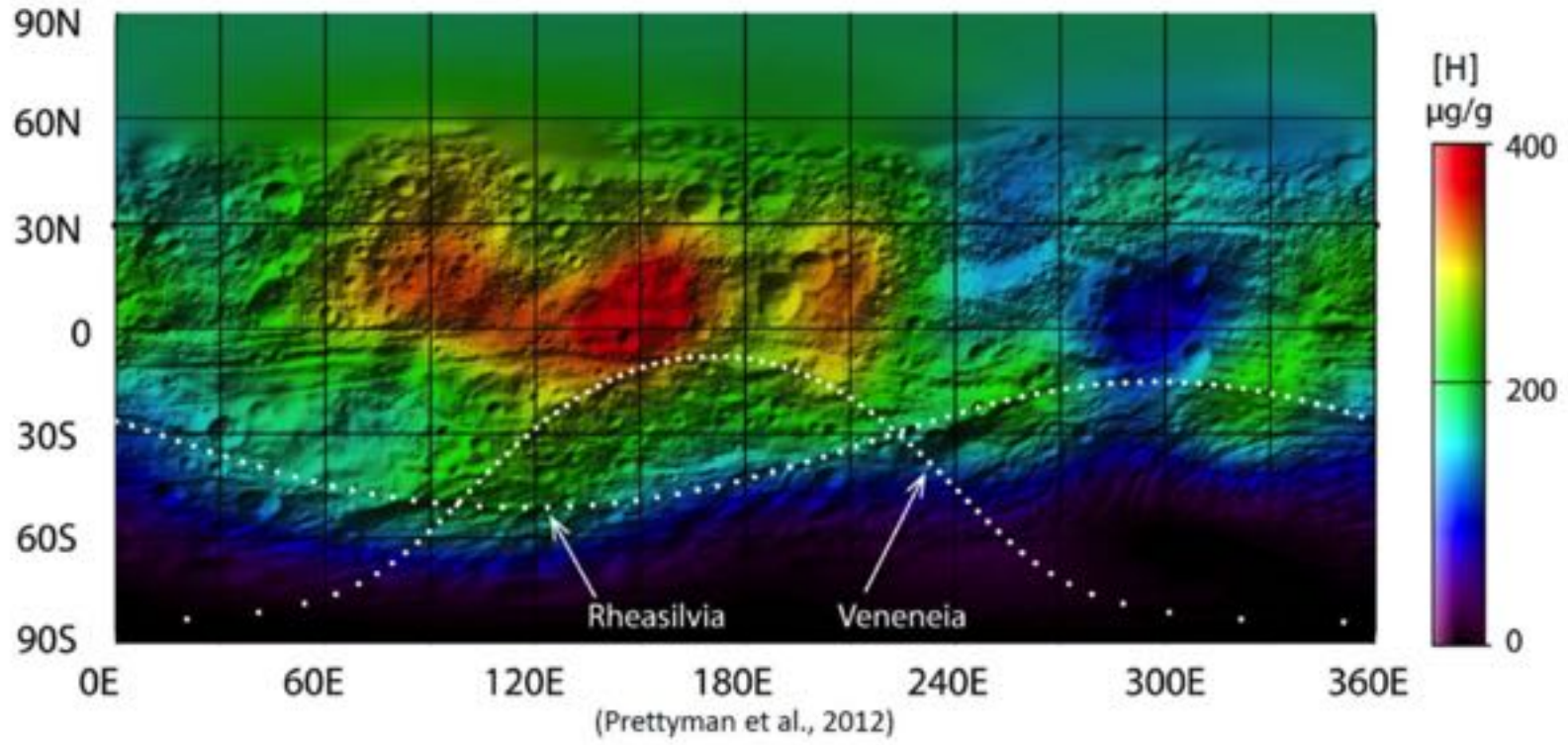




Marchi et al., Nature Geoscience, 6, 4, 303-307 (2013).
Marchi et al., Science, 336, 6082, pp. 690-(2012)

Fasi primordiali: Idrogeno e OH

Global Distribution of Hydrogen



(Prettyman et al., 2012)

- Abundances are far in excess of that expected from solar wind (<100 ppm).
- Highest H abundances are in association with more ancient, lower albedo regions on Vesta in equatorial regions where water-ice is not stable.
- 400 µg/g in low albedo deposits consistent with CC-abundances in howardites. Evidence indicates delivery of H by accumulation of exogenic CC.

volatili su Vesta

Pitted Terrain on Vesta and Implications for the Presence of Volatiles

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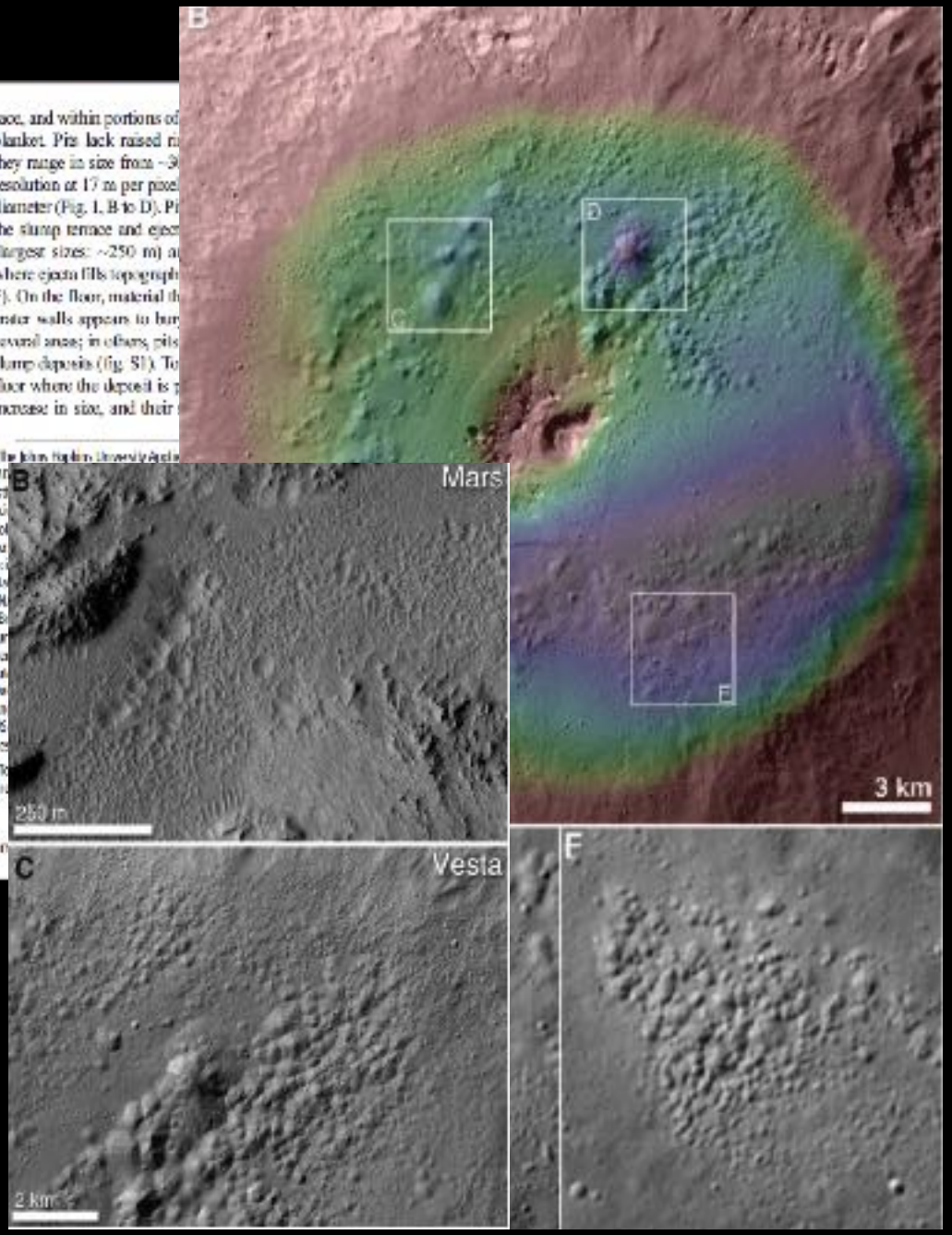
We investigated the origin of unusual pitted terrain on asteroid Vesta, revealed in images from the Dawn spacecraft. Pitted terrain is characterized by irregular rimless depressions found in and around several impact craters, with a distinct morphology not observed on other airless bodies. Similar terrain is associated with numerous martian craters, where pits are thought to form through degassing of volatile-bearing material heated by the impact. Pitted terrain on Vesta may have formed in a similar manner, which indicates that portions of the surface contain a relatively large volatile component. Exogenic materials, such as water-rich carbonaceous chondrites, may be the source of volatiles, suggesting that impactor materials are preserved locally in relatively high abundance on Vesta and that impactor composition has played an important role in shaping the asteroid's geology.

In July 2011, the Dawn spacecraft entered into orbit around Vesta, the second-most massive asteroid in the solar system. After initial Survey and High-Altitude orbits, Dawn spiraled down to its ~210-km Low-Altitude Mapping Orbit (LAMO) (*1*), allowing for acquisition of Framing Camera (FC) images (*2*) at pixel scales of <20 m, as well as high-resolution views of Vesta's geology. LAMO clear-filter images cover >70% of the surface (latitudes above ~55°N were in shadow). In this data set, we identified terrain with a distinct pitted morphology. Here, we describe this terrain and its implications for the presence and origin of volatiles on Vesta.

The most widespread occurrence of pitted terrain is associated with Marcia crater (~70-km diameter; Fig. 1A). Marcia is among the most recent large impacts on Vesta; using the methods of Marchi *et al.* (*3*), we estimate its age to be ~70 million years. Pitted terrain is found on otherwise smooth deposits located on the crater floor surrounding a small central peak, atop a slump ter-



- Impatti con oggetti ricchi in acqua possono essere all'origine dei volatili su Vesta

Denevi et al., Science, Vol. 338, 6104, pp. 246- (2012)

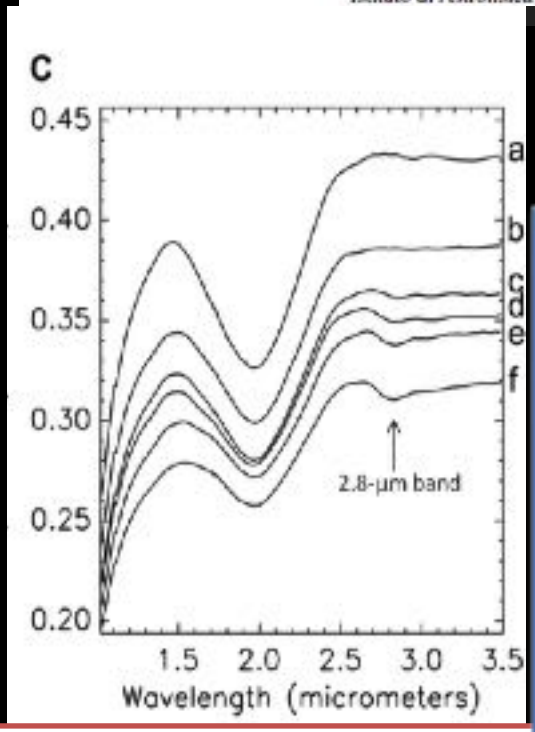
Scoperta dei materiali idrati su Vesta

OH band detected by VIR on Vesta

The Astrophysical Journal Letters, 758:L36 (5pp), 2012 October 20

DETECTION OF WIDESPREAD HYDRATED MATERIALS ON VESTA BY THE VIR IMAGING SPECTROMETER ON BOARD THE *DAWN* MISSION

M. C. De Sanctis[1], J.-Ph. Combe[2], E. Ammannito[1], E. Palomba[1], A. Longobardo[1], T. B. McCord[2], S. Marchi[3], F. Capaccioni[1], M. T. Capria[1], D. W. M[illegible]
S. Fonte[1], A. Frigeri[1]
[1] Istituto di Astrofisica e



LETTER

doi:10.1038/nature11561

Dark material on Vesta from the infall of carbonaceous volatile-rich material

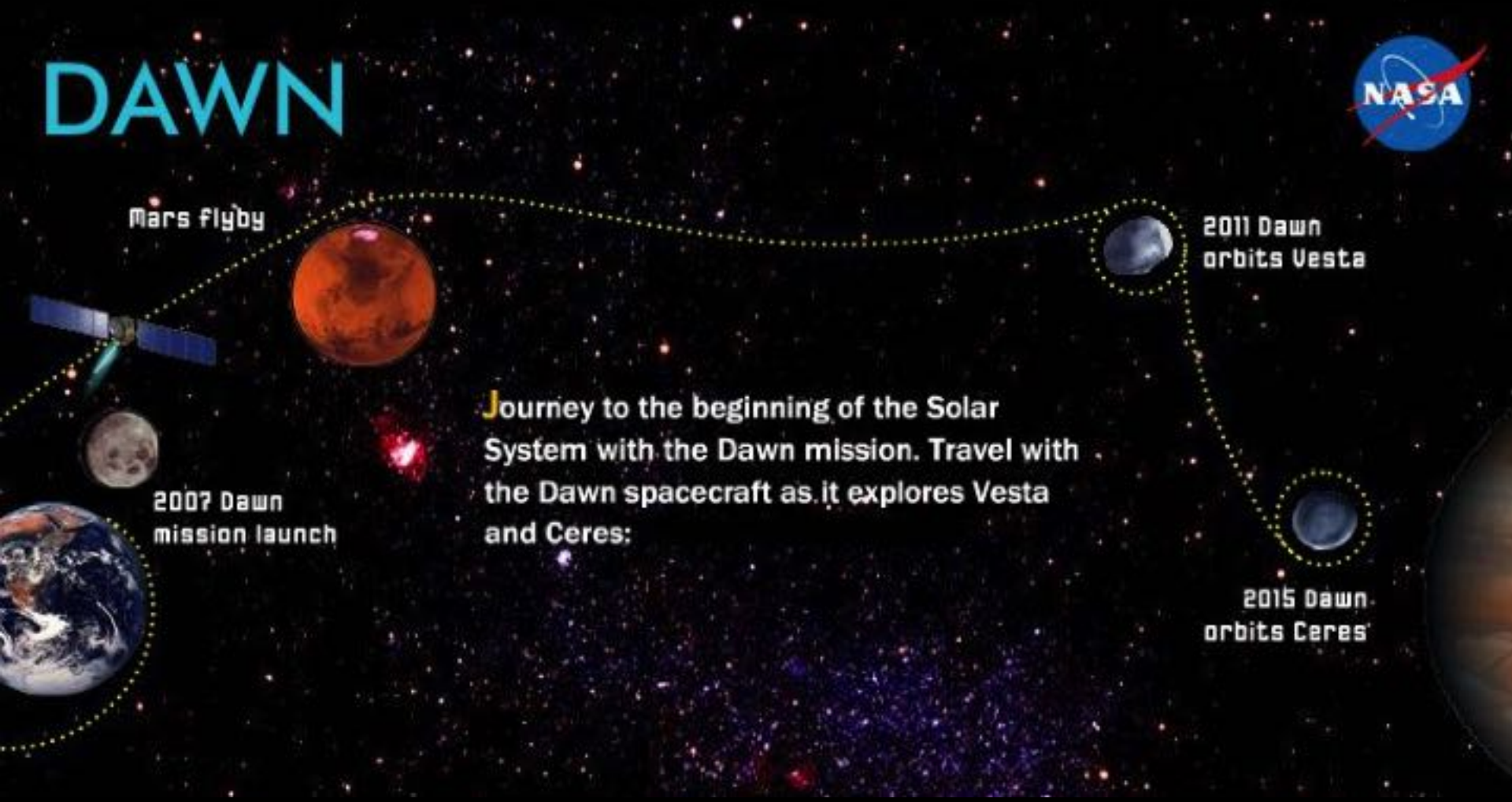
La distribuzione di OH su Vesta indica un processo primordiale diverso da quello lunare.

Questo stesso processo può essere il responsabile del trasporto di acqua e di materiali organici sia nella fascia principale che sui pianeti terrestri.

I dati di VIR possono fornire osservazioni chiave per capire il processo di trasporto dell'acqua sulla Terra.

De Sanctis et al., ApJ Lett., 758, L36, 2012
McCord et al., Nature, Vol. 491, 7422, pp. 83-86 (2012)

Dawn: verso Cerere

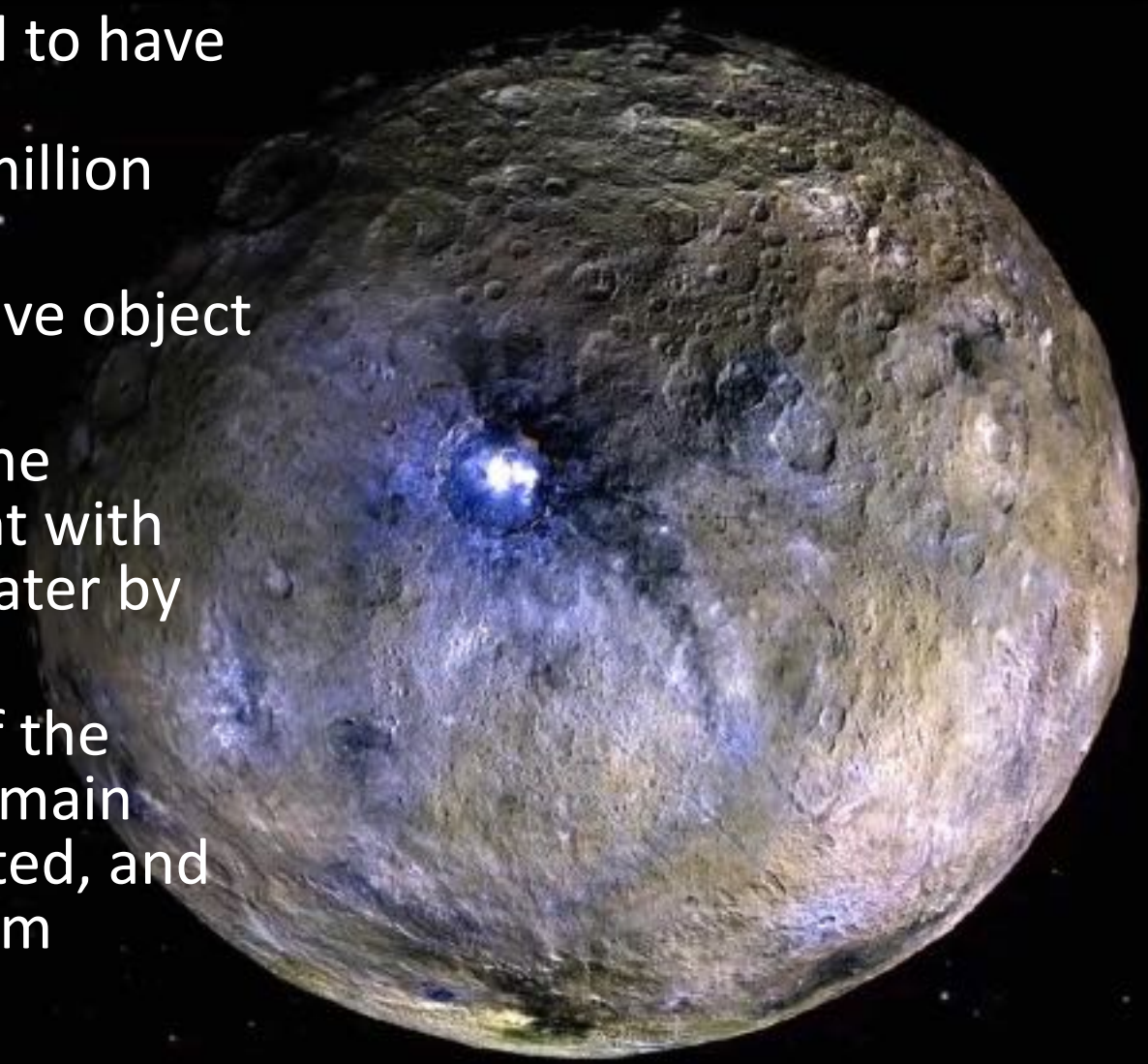


Dawn a Cerere

COSA ABBIAMO SCOPERTO E QUALI SONO LE IMPLICAZIONI

Why Ceres ? Water, water, water

- Ceres is is expected to have formed in the first approximately 10 million years.
- It is the most massive object pof the belt
- Its is WATER rich: the density is consistent with Ceres being 25% water by mass
- Today only some of the largest asteroids remain relatively undisrupted, and Ceres is one of them

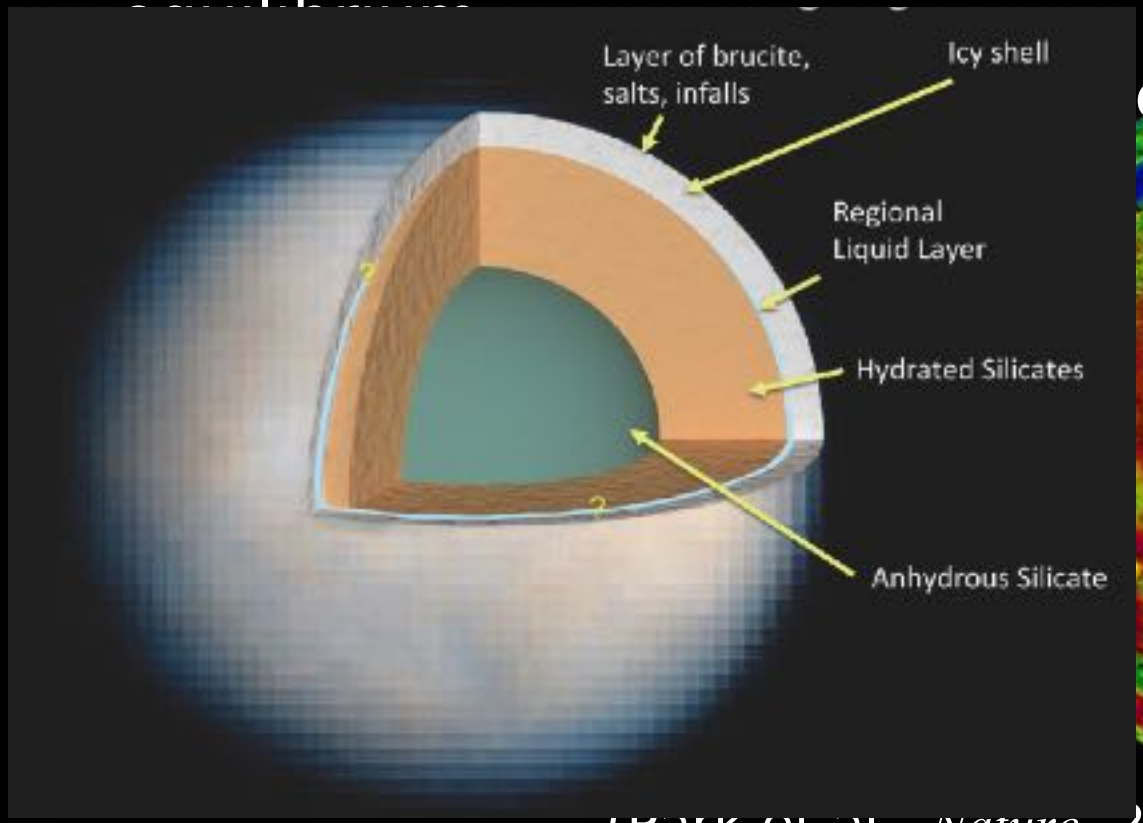


Dawn at Ceres: a dwarf planet made of rocks and ice

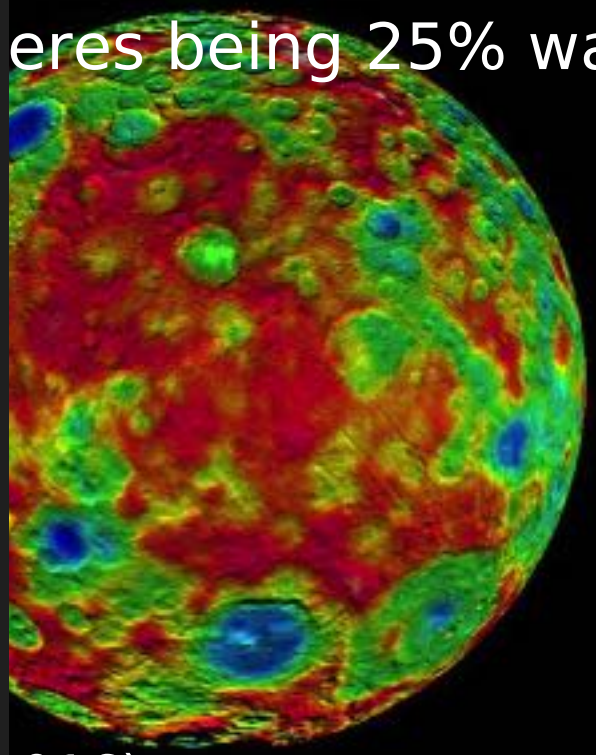
- Ceres is water and silicate rich
- Ceres (has) had an ocean
- Minerals like those in the Enceladous plume
- Ceres has mons and subsurface fluids: ongoing geological activity
- Ceres shows organics on the surface

Ceres is water and silicate rich: Properties of the outer shell

- Ceres has +7.2 to -6.4 km of topography relative to geoid
- Gravity data indicate Ceres is close to hydrostatic

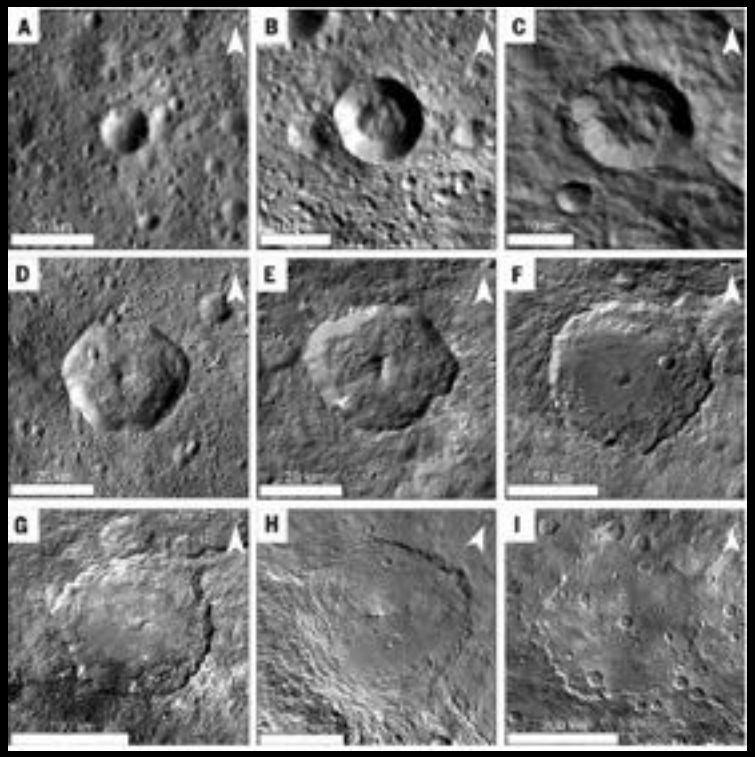


eres being 25% water



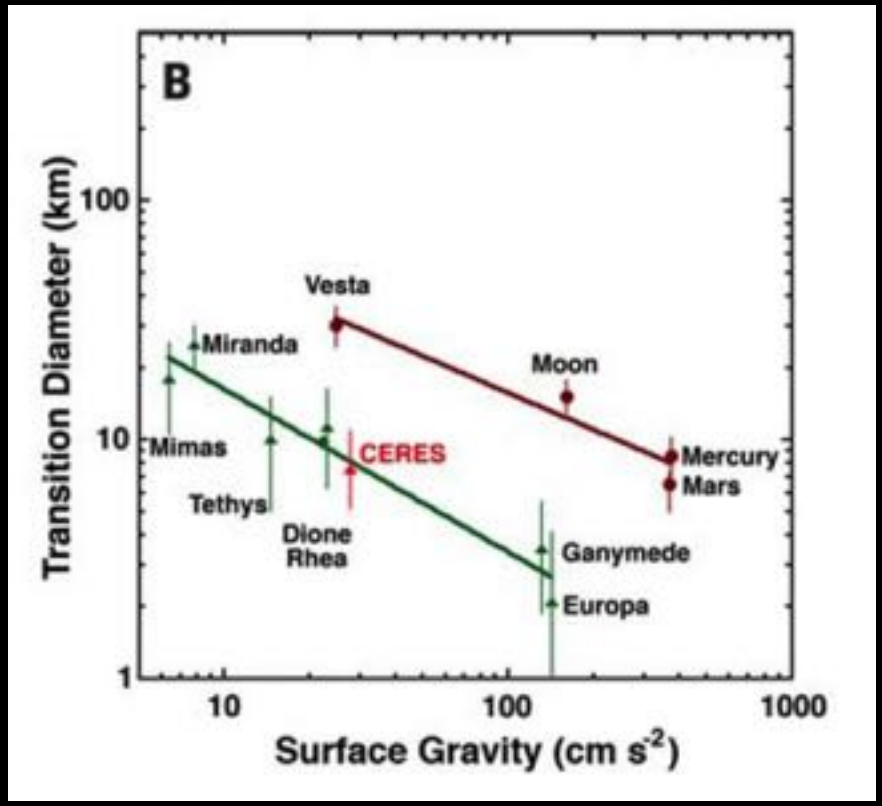
(Park et al., *Nature*, 2016)

Ceres is water and silicate rich: rheology



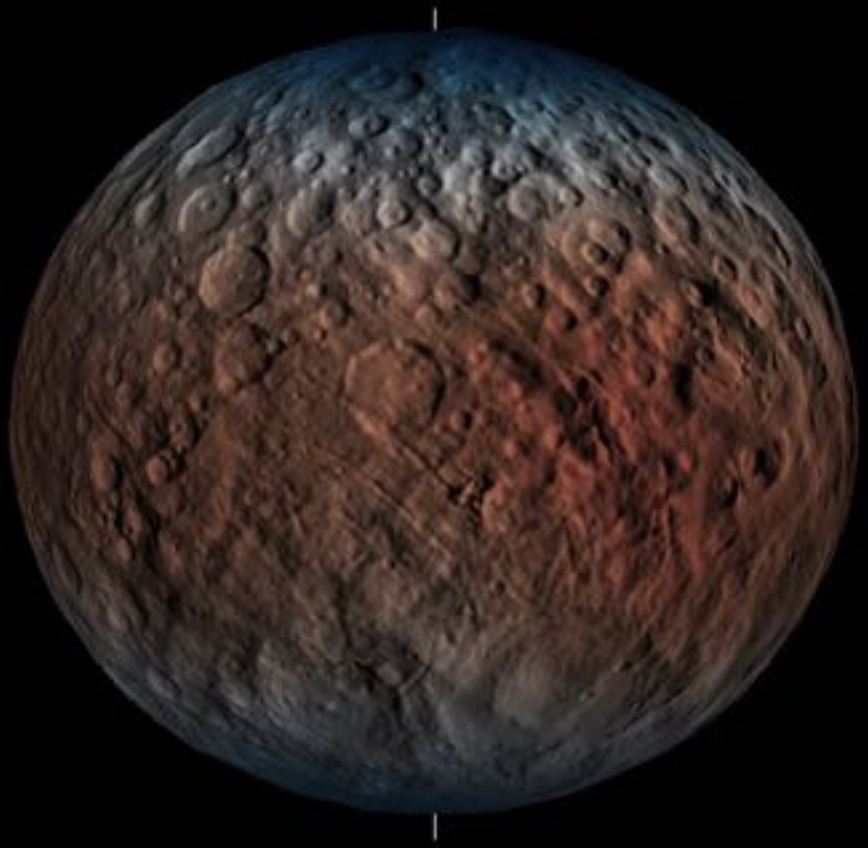
Transition compatible with those observed on « icy » bodies

Transition observed from simple to complex craters



(Hiesinger et al., *Science*, 2016)

Ceres is water and silicate rich: Hydrogen/water ice



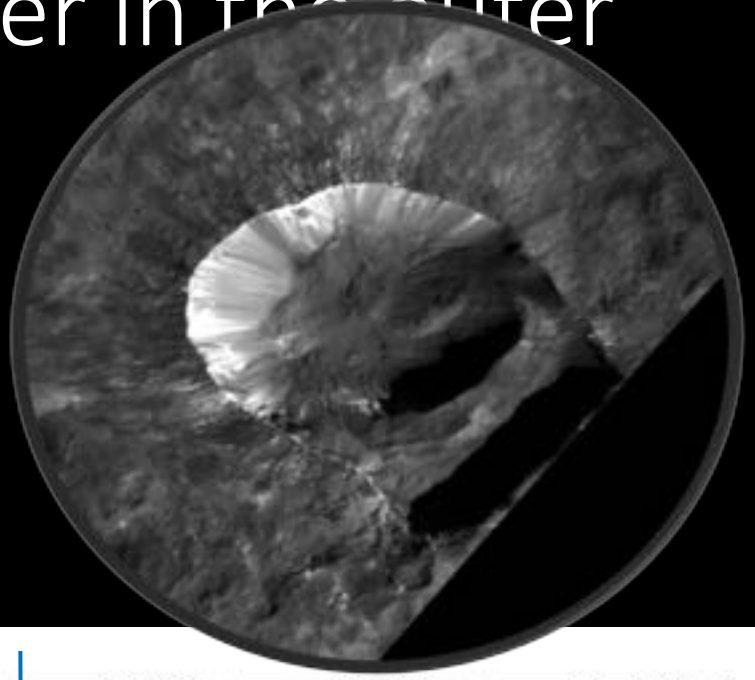
Neutron counts drop towards the poles

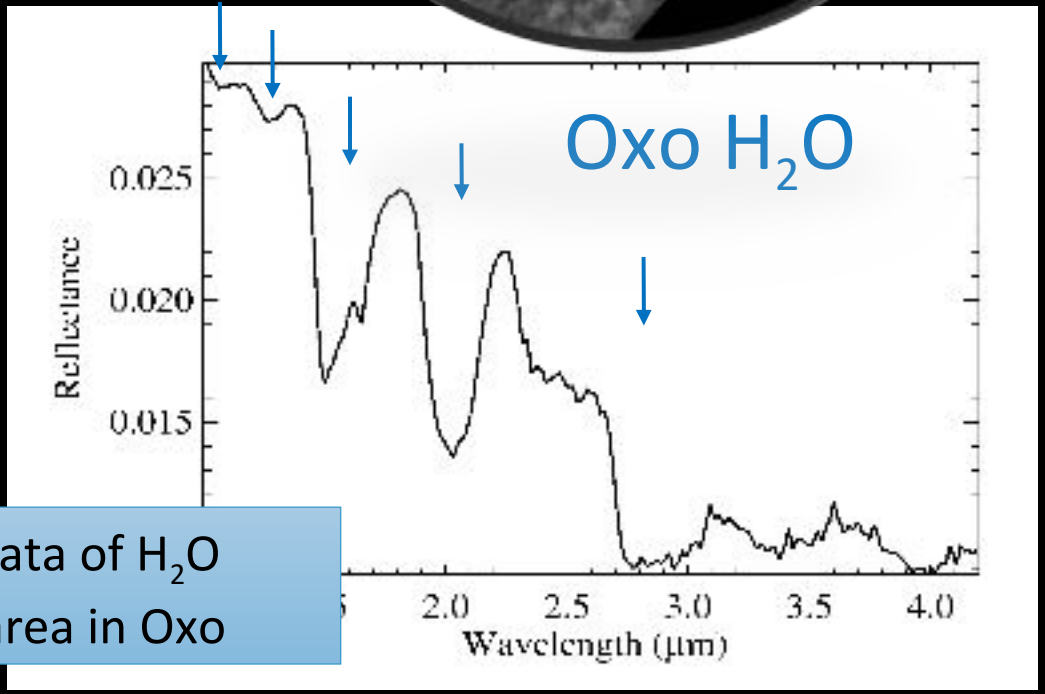
Evidence for water ice at high latitudes
(at depth <1m)

(Prettyman et al., Science, 2016)

Direct evidence for water in the outer shell

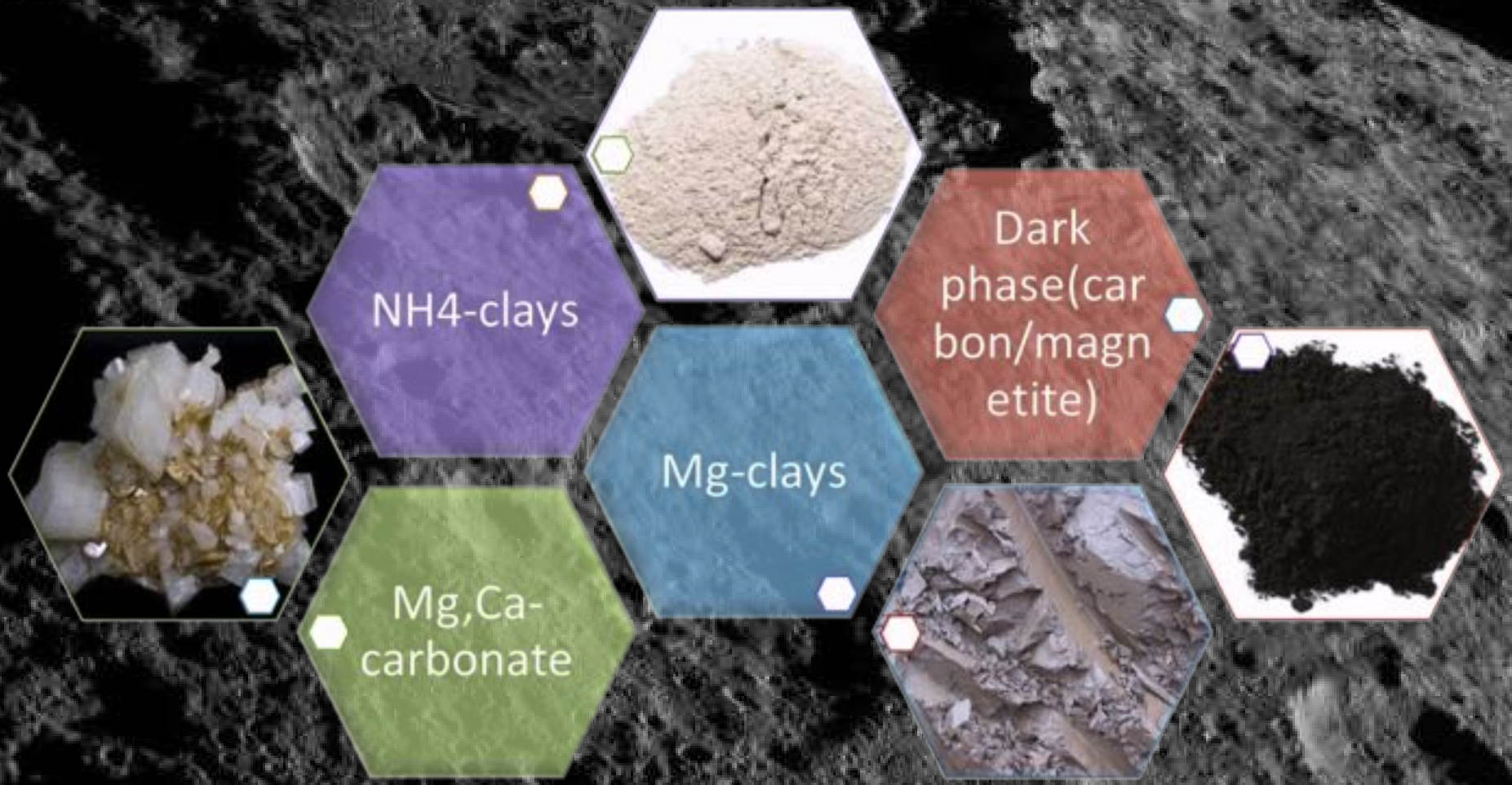
- Reflectance spectra VIR reveal the presence of **exposed surficial H_2O on Ceres** (Combe et al., Science, 2016).
- There are other locations where water ice is exposed on the surface

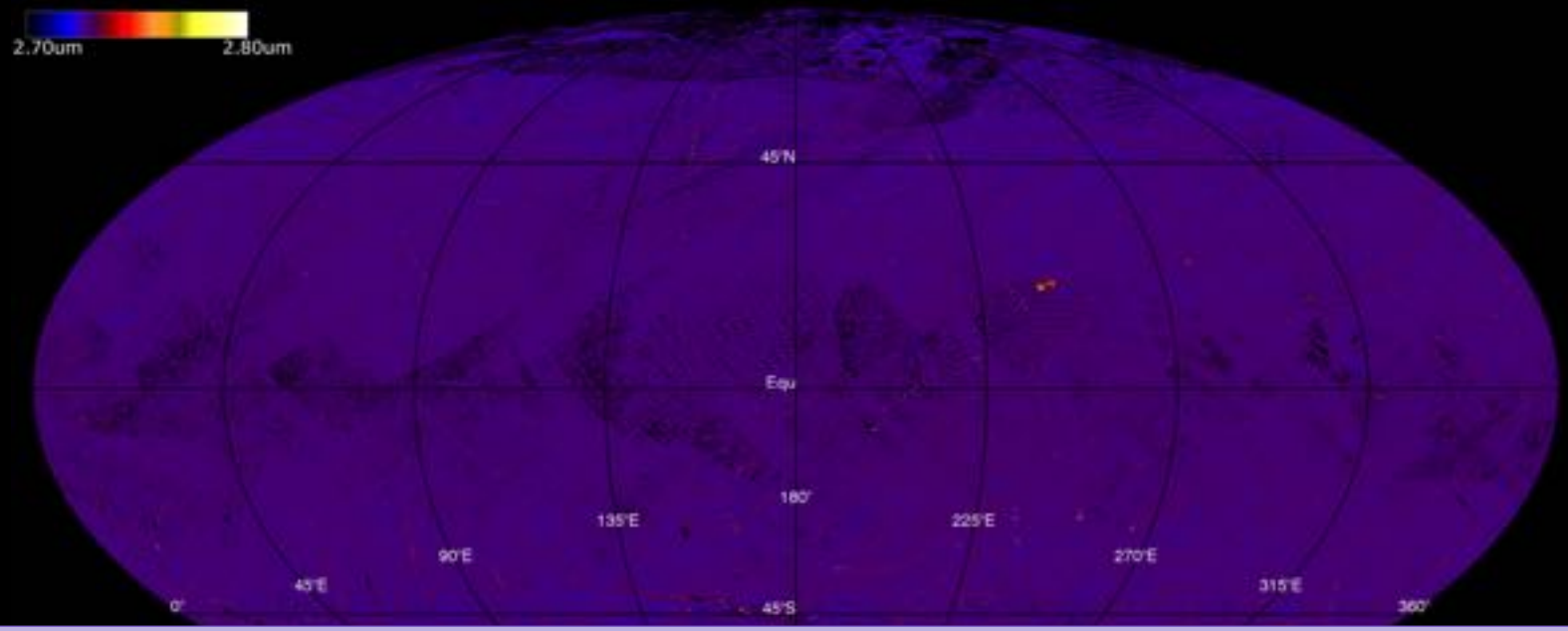




VIR data of H_2O rich area in Oxo

Ceres (has) had an ocean: Mineralogy of the surface dominated by aqueous alteration products



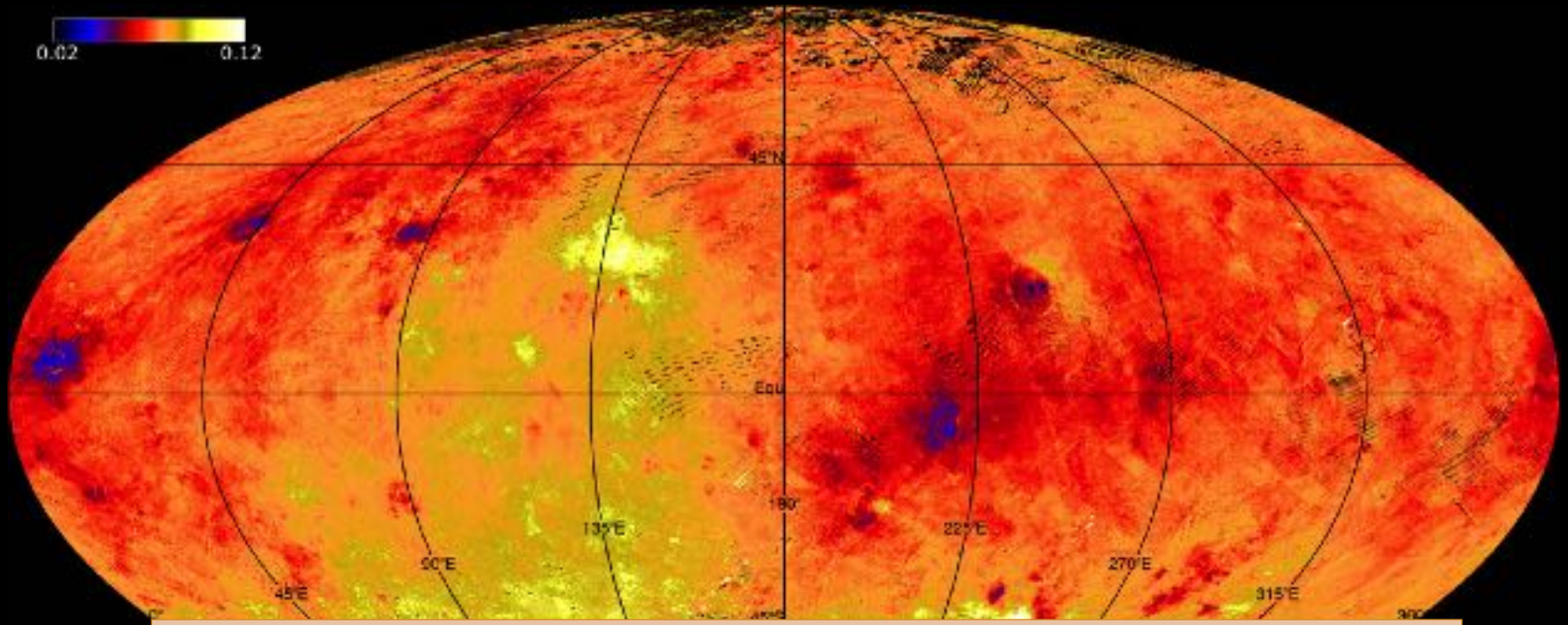


- The 2.7µm band is ubiquitous
- The position of the 2.7 µm absorption is mostly uniform → composition of phyllosilicates is uniform
- The value of 2.727±0.005 µm is indicative of Mg- phases, like Mg-serpentine or Mg-smectite

Ammannito et al., Science, 2016

Ceres (has) had an ocean:

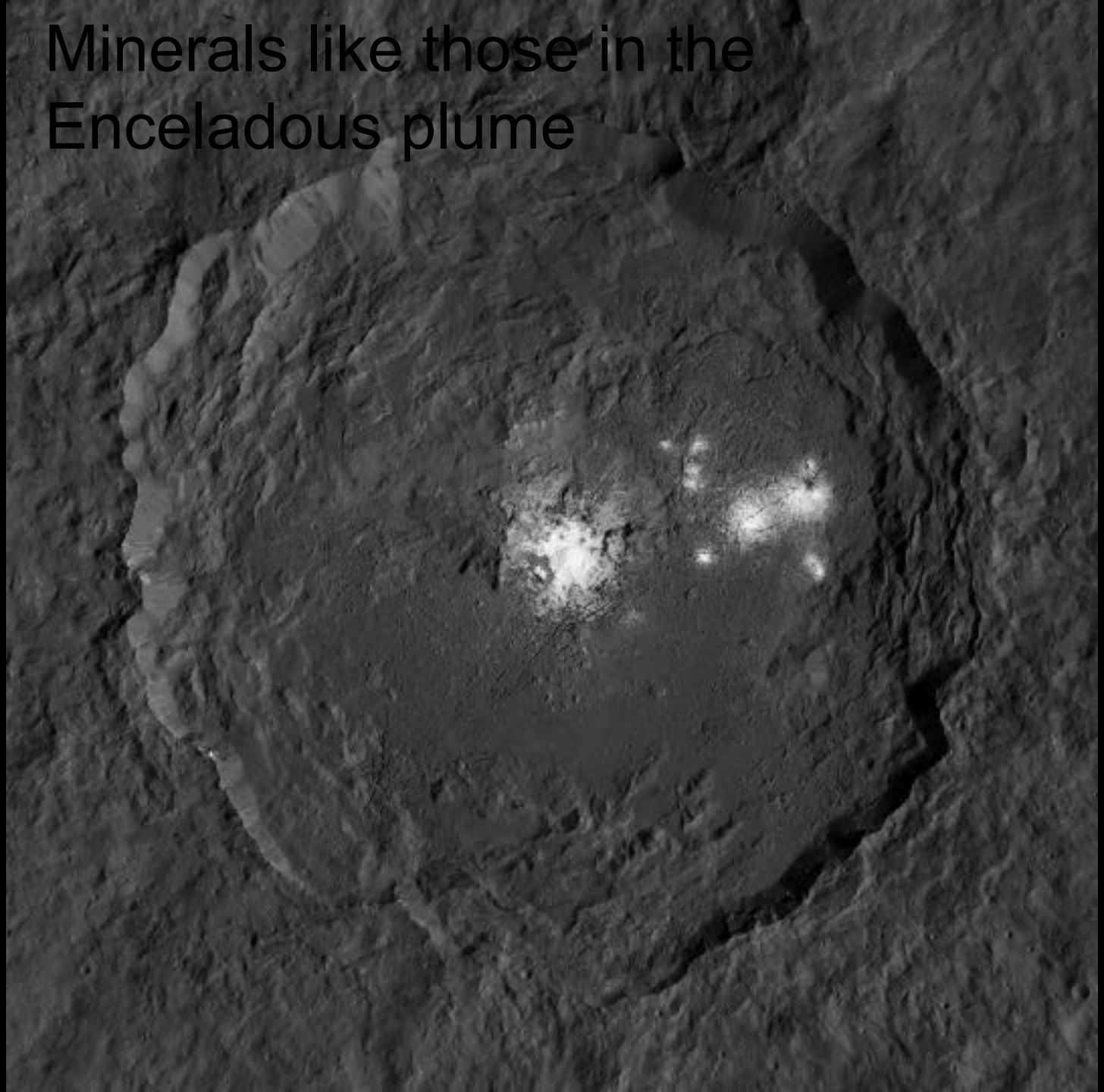
Ammoniated clays band depth



Ammoniated clays are also ubiquitous. The widespread presence of these two types of minerals is a strong indication of a global and extensive aqueous alteration.

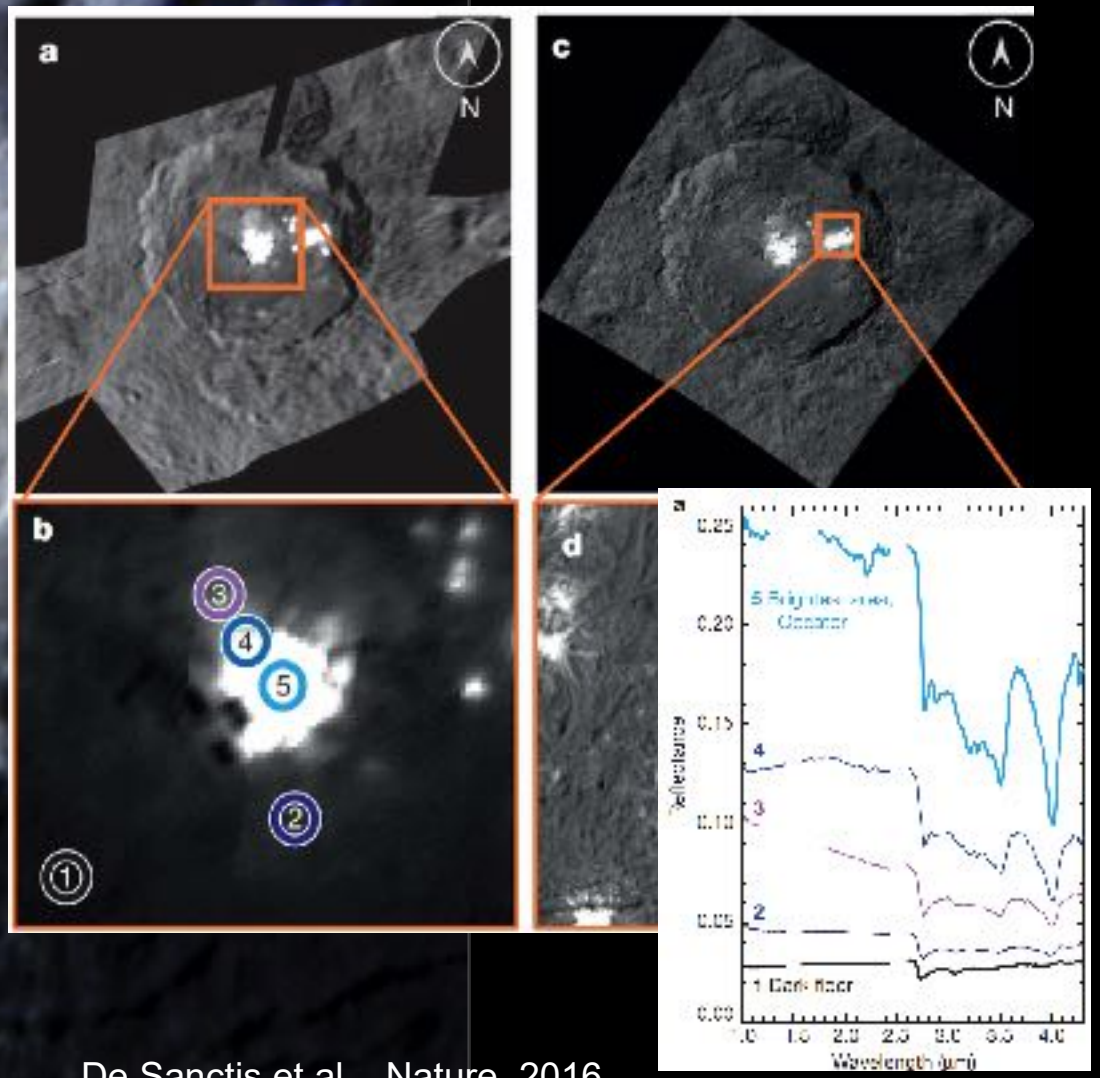
Ammannito et al., Science, 2016

Minerals like those in the Enceladous plume



Bright Spots

Evidence for sodium carbonates (De Sanctis et al., Nature,2016) and NH4 salts (De Sanctis et al., 2016, Raponi et al., 2017).

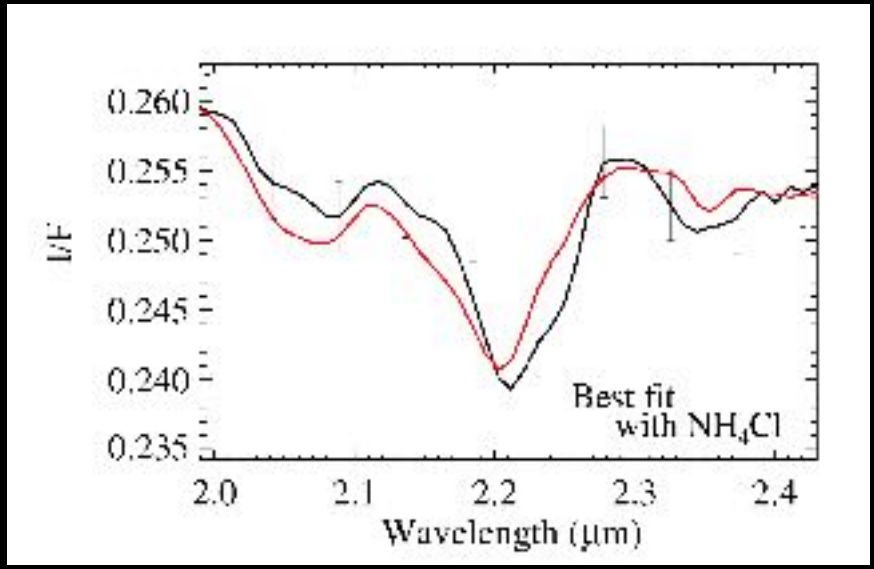


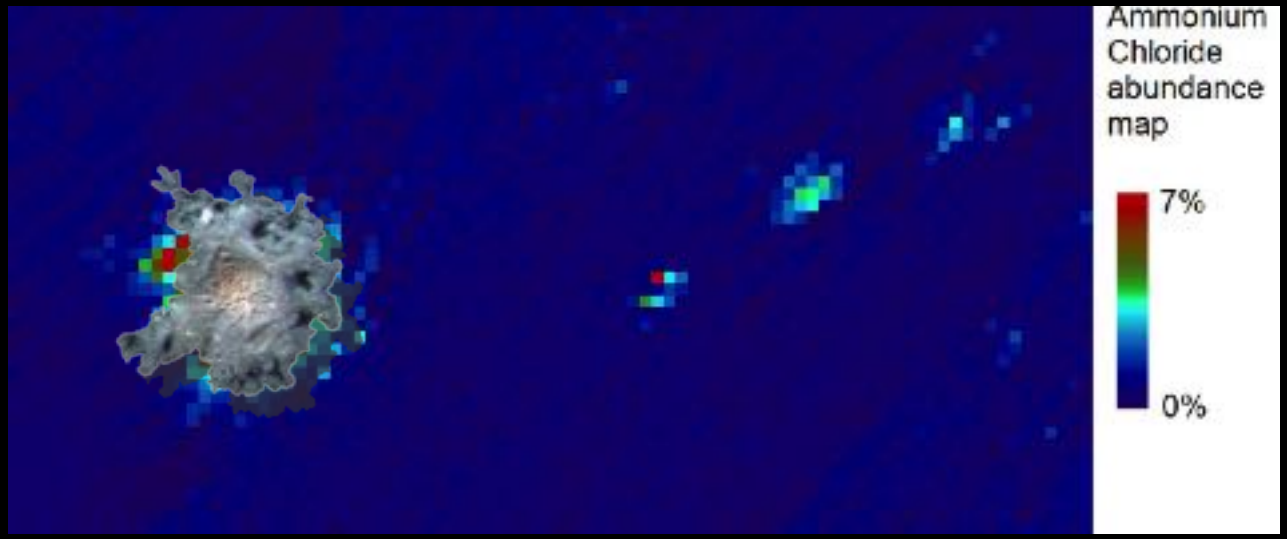
Suggests liquid transport & evaporation from a brine reservoir.

De Sanctis et al. , Nature, 2016

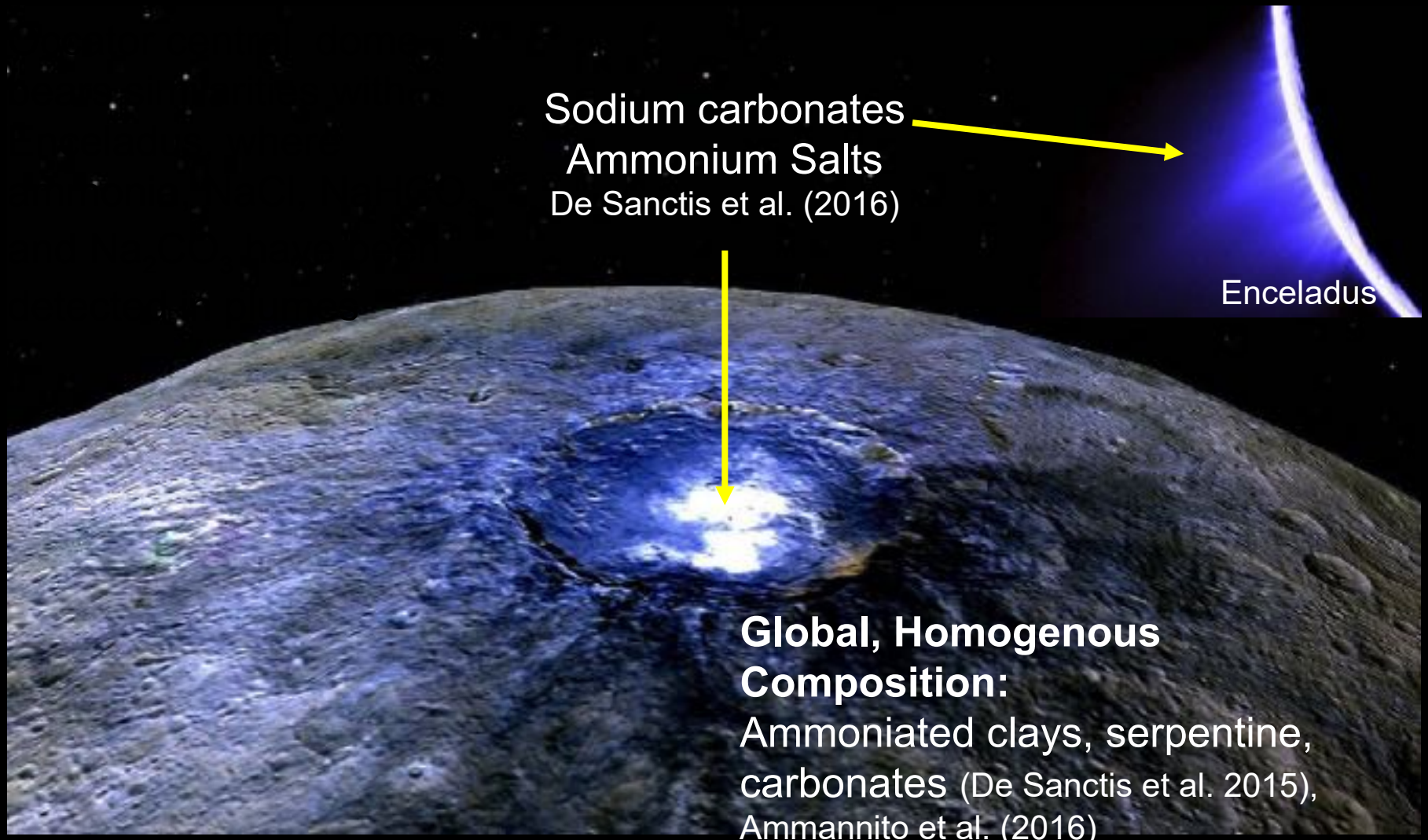
Ceres: liquid brines – low eutectic ?

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





Ceres' Surface Shows Evidence for Mineralogy Formed at Depth

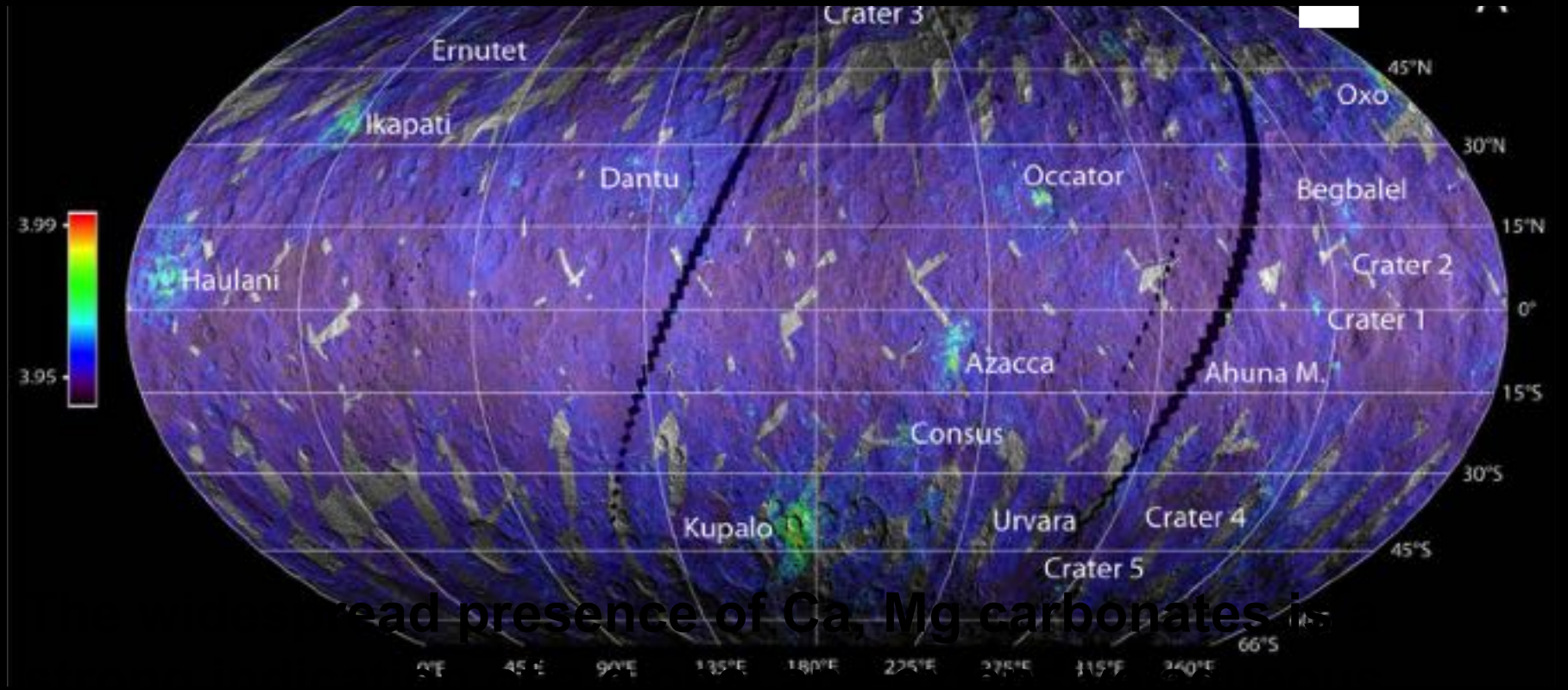


Ceres Carbonates

Carbonate found everywhere on Ceres surface

Two main kind of carbonate found: Mg, Ca carbonates (De Sanctis et al., Nature, 2016; Carrozzo et al., 2018) and Na Carbonates locally

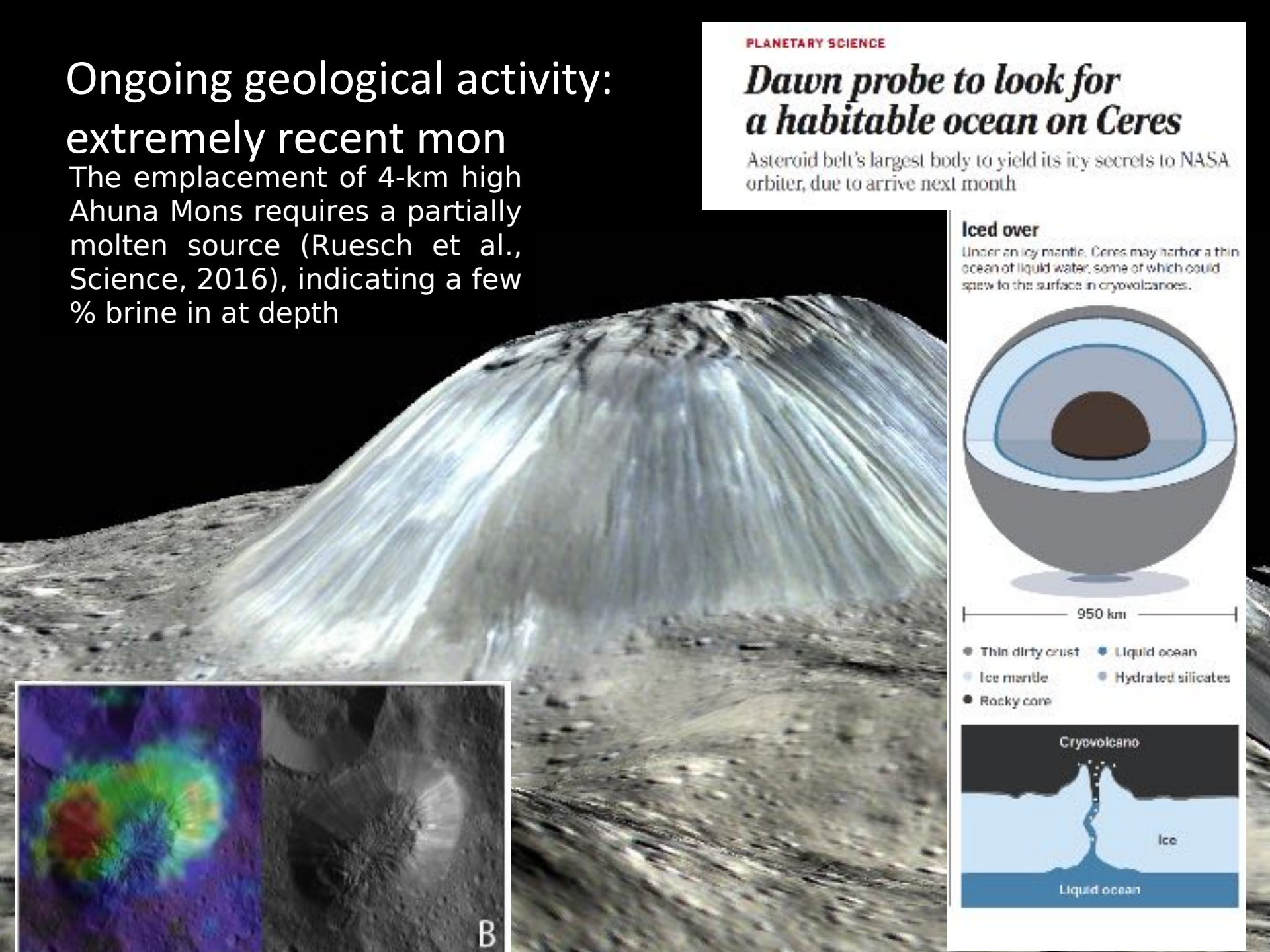
Carbonate band position map (Carrozzo et al. Science ADV, 2018)



ead presence of Ca, Mg carbonates is

Ongoing geological activity: extremely recent mon

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

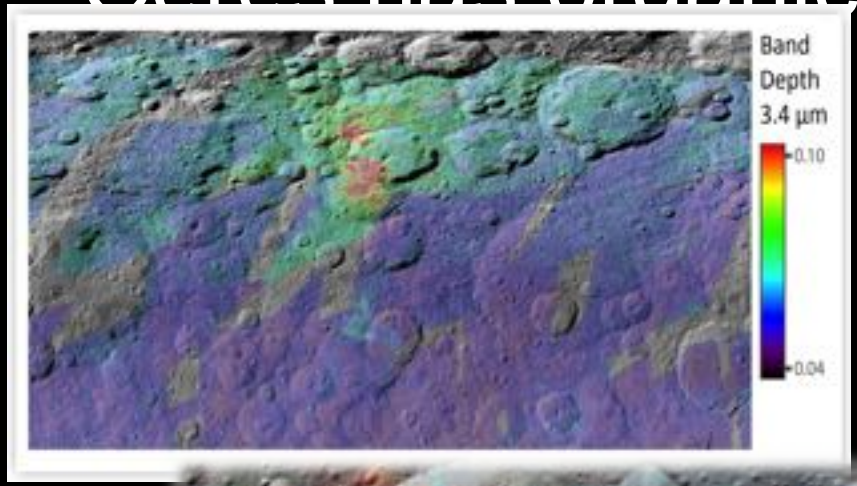


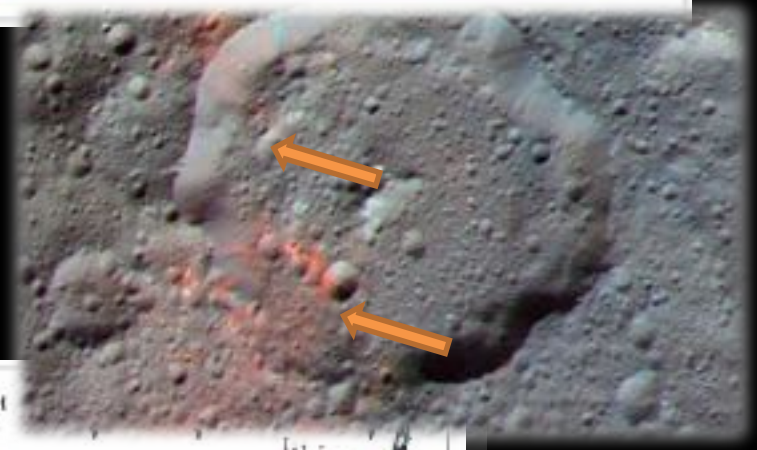
PLANETARY SCIENCE

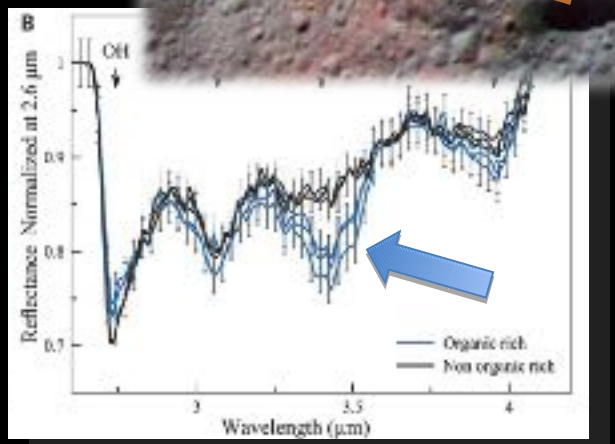
Dawn probe to look for a habitable ocean on Ceres

Asteroid belt's largest body to yield its icy secrets to NASA orbiter, due to arrive next month

Ceres has organics







Organic molecules detected on a large portion of the surface

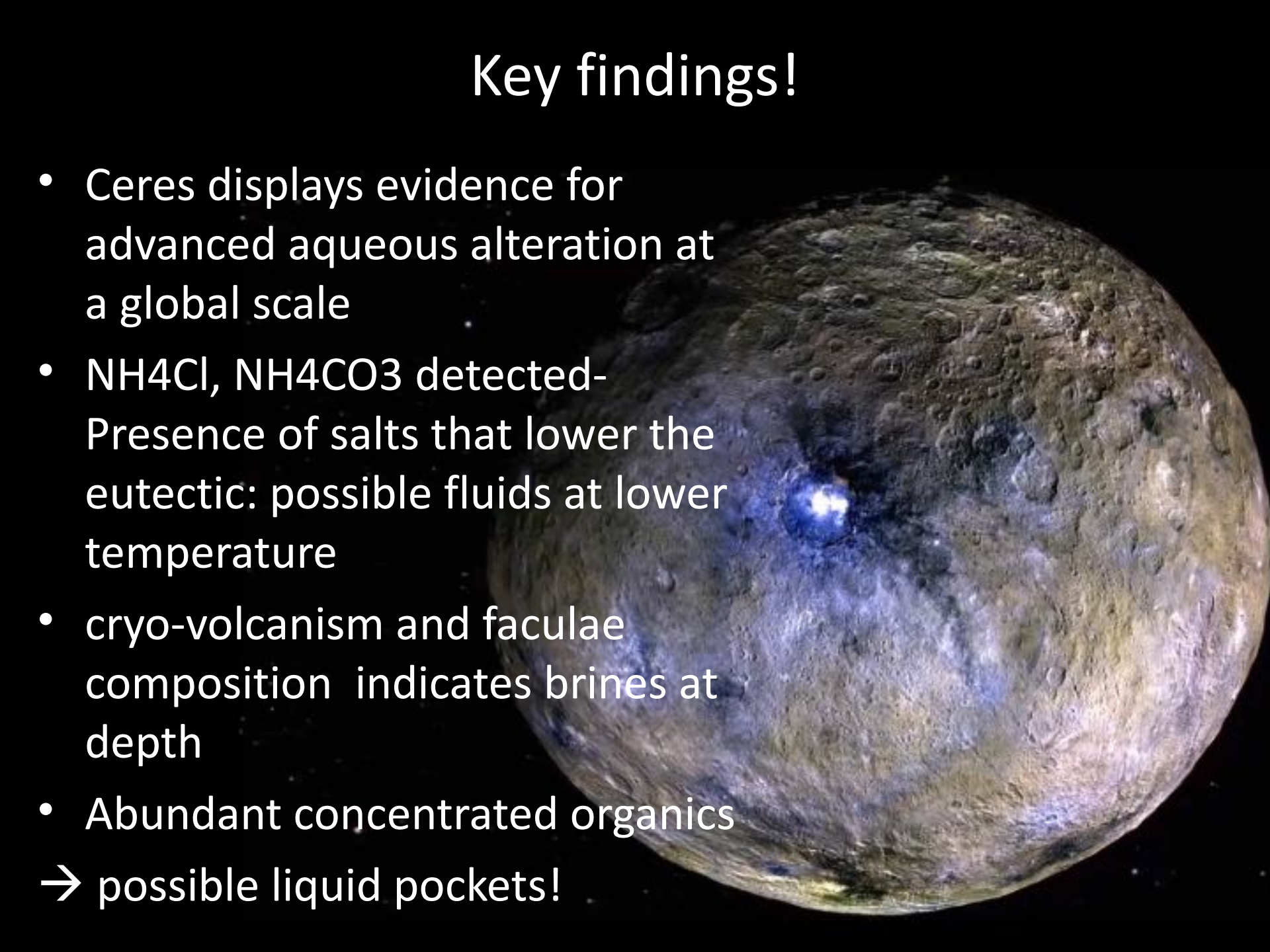
- Potential analog for Europa, at least in terms of chemistry
- Playground for exobiological studies
- Assuming clues for a deep ocean are confirmed
  - Is the ocean a habitable environment (T, pH, redox)
  - Are the building blocks of life present (CHNOPS) - Yes
  - Is there an energy source available for life? - Yes
- Are biomaterials present?

De Sanctis et al., Science 2017

Key findings!

- Ceres displays evidence for advanced aqueous alteration at a global scale
- NH_4Cl, NH_4CO_3 detected- Presence of salts that lower the eutectic: possible fluids at lower temperature
- cryo-volcanism and faculae composition indicates brines at depth
- Abundant concentrated organics

→ possible liquid pockets!



Dawn in the context of the SS

- Many unexpected discoveries and confirmations of previous studies
- The Dawn results open new scenarios in the formation and differentiation processes in the early solar system

- Formation in situ is not consistent with observed mixing of dry and wet asteroids in the main belt.
- Ceres and Vesta could not form in the same timeframe
- Dawn results indicate that asteroid belt material evolved in two reservoirs separated by Jupiter, with water rich materials found in the inner SS migrated from the outer SS, triggered by the end of giant planet growth and/or planetary migration ~3-4 My after CAIs

Esplorazione di nuovi mondi: una storia iniziata in Italia

- 1801 -Piazzi a Palermo scopre Cerere, il primo asteroide
- 2000-VIR fa parte del payload di Dawn
- 2006 Cerere viene definito pianeta nano
- **2015 Dawn arriva a Cerere !**

Special thanks

- Questa missione è stata fortemente voluta dalla

"Signora della Planetologia Italiana"

Angioletta Coradini

Voglio ricordare anche questo nuovo premio edito dal SSERVI NASA dal 2017:

- Named in honor of planetary

scientist Angioletta Coradini

- To be awarded to a

mid-career scientist for broad, lasting accomplishments related to SSERVI

fields of interest