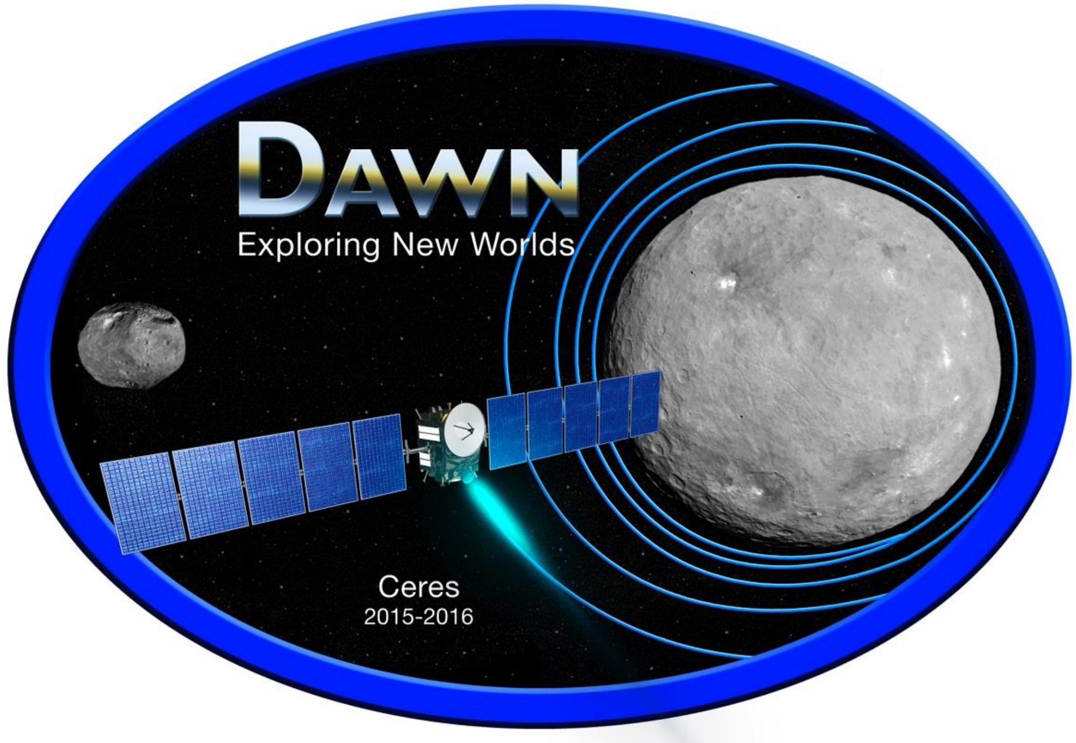



# Dawn at Ceres

C.T. Russell, Dawn Principal Investigator

National Academy of Science

Committee on Astrobiology and Planetary Sciences

2101 Constitution Ave, N.W.

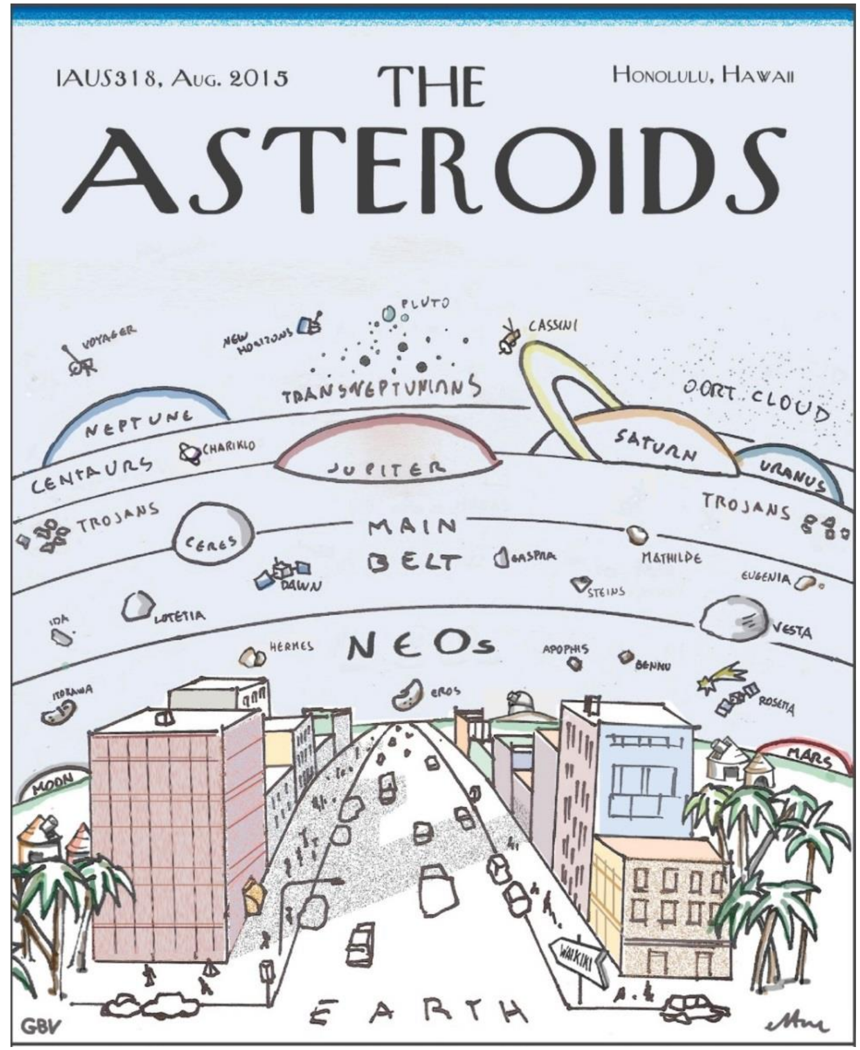
Washington, D.C.

Thursday, March 31, 2016

9:30-10:30AM

# Our Solar System Historical Archive: The Asteroids

- If we want to understand the nature of the building blocks of the solar system we have to turn to the asteroids
- The larger planets are too evolved to retain much information on the nature of the starting material.
- The asteroids and the samples they send to us, the meteorites, have retained much information on the geochemistry of the early days of the solar system



# In the Beginning

- Over 4.5 billion years ago in a cloud of cold gas and dust, the solar nebula was believed to have formed and to begin accreting protoplanets.
- It is also believed that a supernova occurred nearby and seeded the solar nebula with short-lived radionuclides such as $^{26}Al$, and $^{56}Fe$.
- Protoplanets accreting at the time trapped the heat inside, which led to melting and differentiation.
- Bodies farther out from the protosun are thought to have begun accreting later when there was less primordial heat from the radionuclides.

# Asteroid Belt Evolution Paradigm

- Vesta was formed with trapped radionuclides that helped melt the rock and drive off the primordial water. Ceres was formed later, farther from the Sun. The radioactivity had largely decayed by this time.
- When Jupiter formed, the main belt was stirred by its passage around the outer edge of the belt. This changed the asteroid belt from a region of accretion to comminution. Vesta and Ceres may have survived because they were the largest bodies in this region.
- Material from collisions was scattered toward the Earth falling as meteorites. These have been used by scientists to understand the evolution of the solar system.

Early solar nebula by W. Hartmann

- In the 16th, 17th, and 18th centuries, scientists had a strong suspicion that there was a planet between Mars and Jupiter. As the 19th century dawned, on January 1, 1801, Giuseppe Piazzi discovered Ceres, the long expected planet. But more planets followed, too many more.

# Early Dawn: Two Hundred Years Later

- 1992 – NASA announces the Discovery mission program of PI-led planetary missions. Discovery Workshop held. Dawn science team formed.
- 1994 – Proposed Diana to Moon and active asteroid with TRW. Not selected.
- 1996 – Proposal MBAR to Vesta, Lutetia, Glasenappia with CTA. Not selected.
- 1998 – Proposal MBAR to Vesta, Lutetia with Orbital. Not selected.
- 2000 – Proposal Dawn to Vesta, Ceres with Orbital. Selected for Step 1.


DAWN

A Journey to the Beginning of the Solar System

Title Page: "A cocoon nebula, perhaps the primordial solar nebula", a painting by William K. Hartmann, depicts the first rays of the newborn sun shining on its shroud of dust at the dawn of planetary formation. Superimposed on this are images from the HST of Vesta and Ceres and a drawing of the spacecraft. Dawn determines how these two minor planets, formed at the earliest moments of the solar system, evolved in such entirely different manners, one apparently dry, hot and differentiated and the other wet, cold and primitive.

RESTRICTION ON USE AND DISCLOSURE OF PROPOSAL INFORMATION

The information contained in this proposal constitutes information that is confidential or privileged. It is furnished to the Government in confidence with the understanding that it will not, without permission of the offeror, be used or disclosed for other than evaluation purposes; provided, however, that in the event a contract is awarded on the basis of this proposal, the Government shall have the right to use and disclose this information to the extent provided in the contract. This restriction does not limit the Government's right to use or disclose this information, if obtained from another source without restriction.

UCLA JPL Orbital DLR

A Proposal Submitted by the

Regents of the University of California

to the

National Aeronautics and Space Administration

in Response to AO 00-OSS-02

August 18, 2000

Principal Investigator: C. T. Russell

# Dawn is Selected for Development

- In 2001, we were selected to enter a Step 2 competition for developing the next Discovery mission.
- In September, we were ready for the site visit, scheduled for September 12, and we were just outside Dulles, VA, practicing our presentation on September 11 when the 9/11 terrorist attacks struck.
- We looked at the TV screens in awe, cancelled the site visit, and drove across the country back to LA as there were no planes flying.
- The site visit was rescheduled and we were selected, and started to prepare the mission in 2002.
- Budget delays, descopes, two cancellations, and two reinstatements later, we made it to the Cape.

# 200 Years after the Discovery of Vesta: Our Discovery Mission at the Cape

- 2007 – Orbital assembles, tests, and ships Dawn to the Cape for July launch. This is the second-to-last opportunity before Ceres moves out of position. An afternoon launch in July is almost impossible. Boat and plane needed for mid-Atlantic telemetry both have trouble. Fortunately, second stage does not get fueled or there would be no mission today.
- Spacecraft does not get launched in June/July opportunity.
- Spacecraft and third stage are disassembled and reassembled in September.

Cape Canaveral Air Force Station

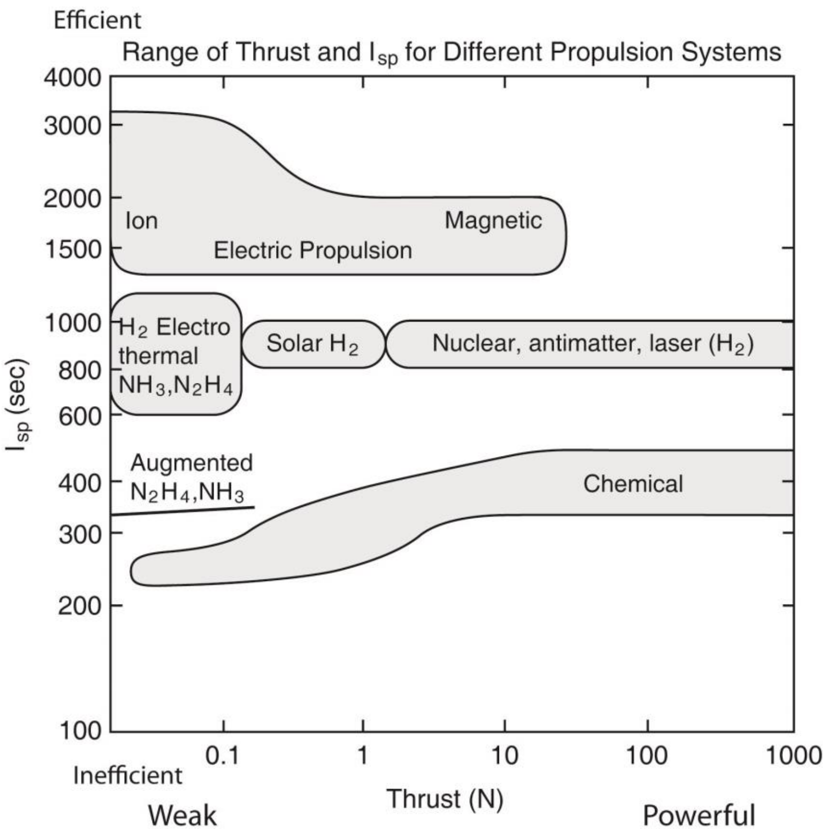
# Beautiful Dawn Launch: On a Beautiful Dawn in Florida

September 27, 2007

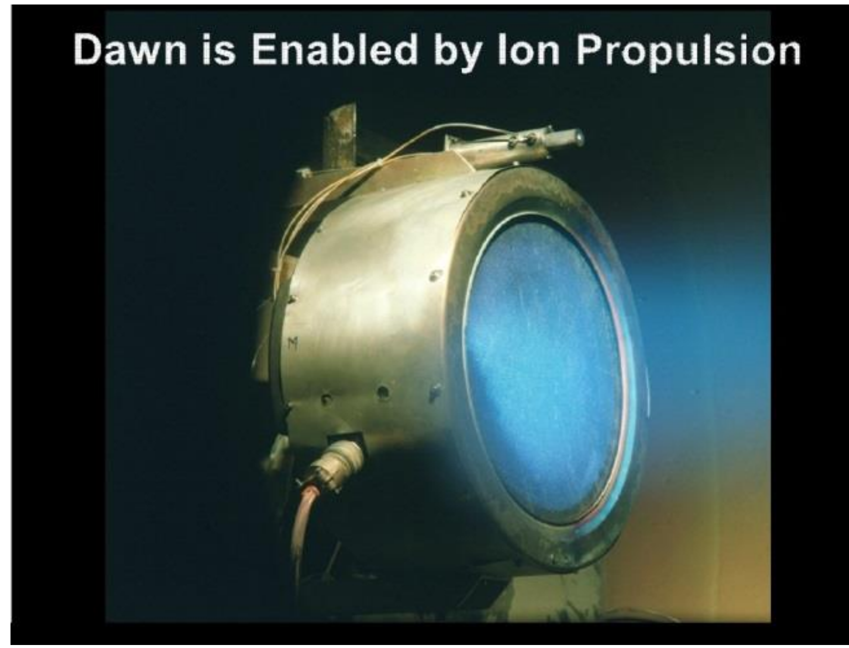
# The Mission

- Dawn's top-level objective is to explore backwards through time to understand the origin and evolution of the solar system.
- To do this, it interviews the two oldest witnesses to these events that we believe have been intact since the earliest days of the solar system.
- We first visited Vesta to verify that it was as predicted from its meteorites.
- We then visited Ceres to find out what was behind its secrecy.
- To do this, we needed a new type of scientific spacecraft, powered by solar electric propulsion using xenon as fuel.
- For the cost of a Discovery mission, there was no other way to do this.

# Rocket Science

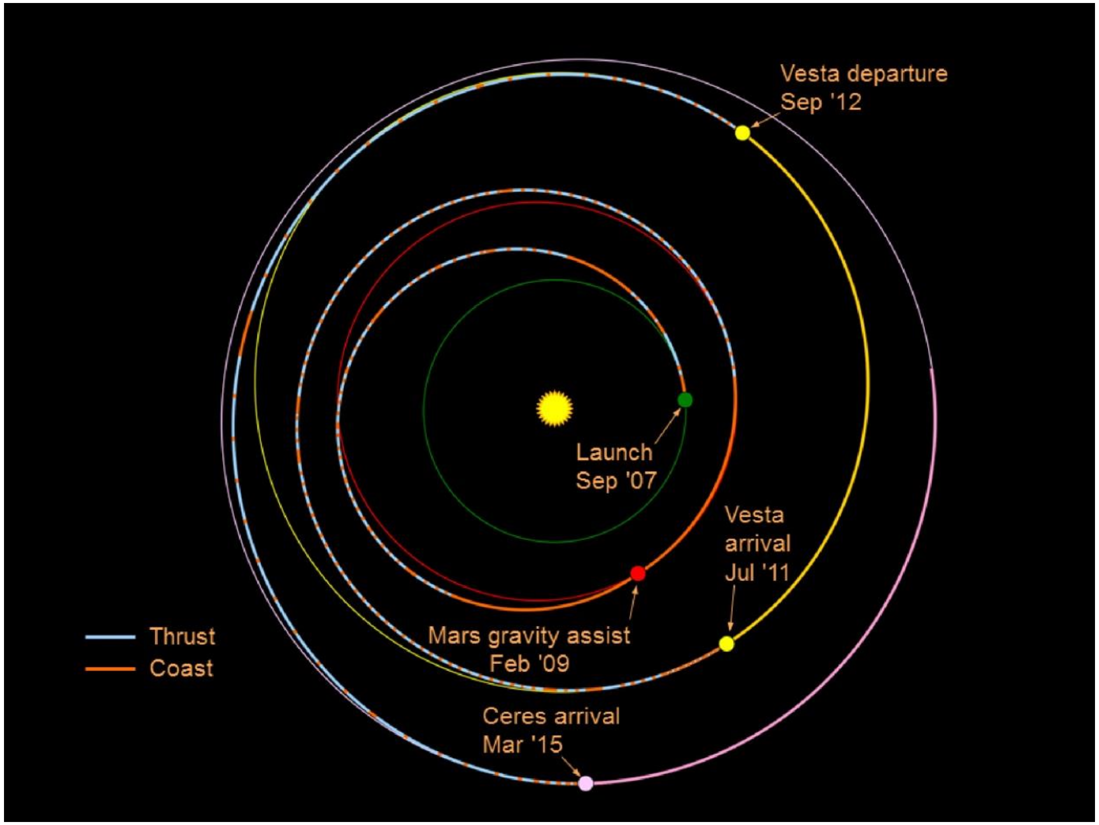



- If a spacecraft carries propellant, it is best to fire it at as high a speed as possible.
- If a spacecraft is lifting off a planet, it needs a powerful engine.
- If it is cruising for a long time in space, a weak efficient engine is very useful.



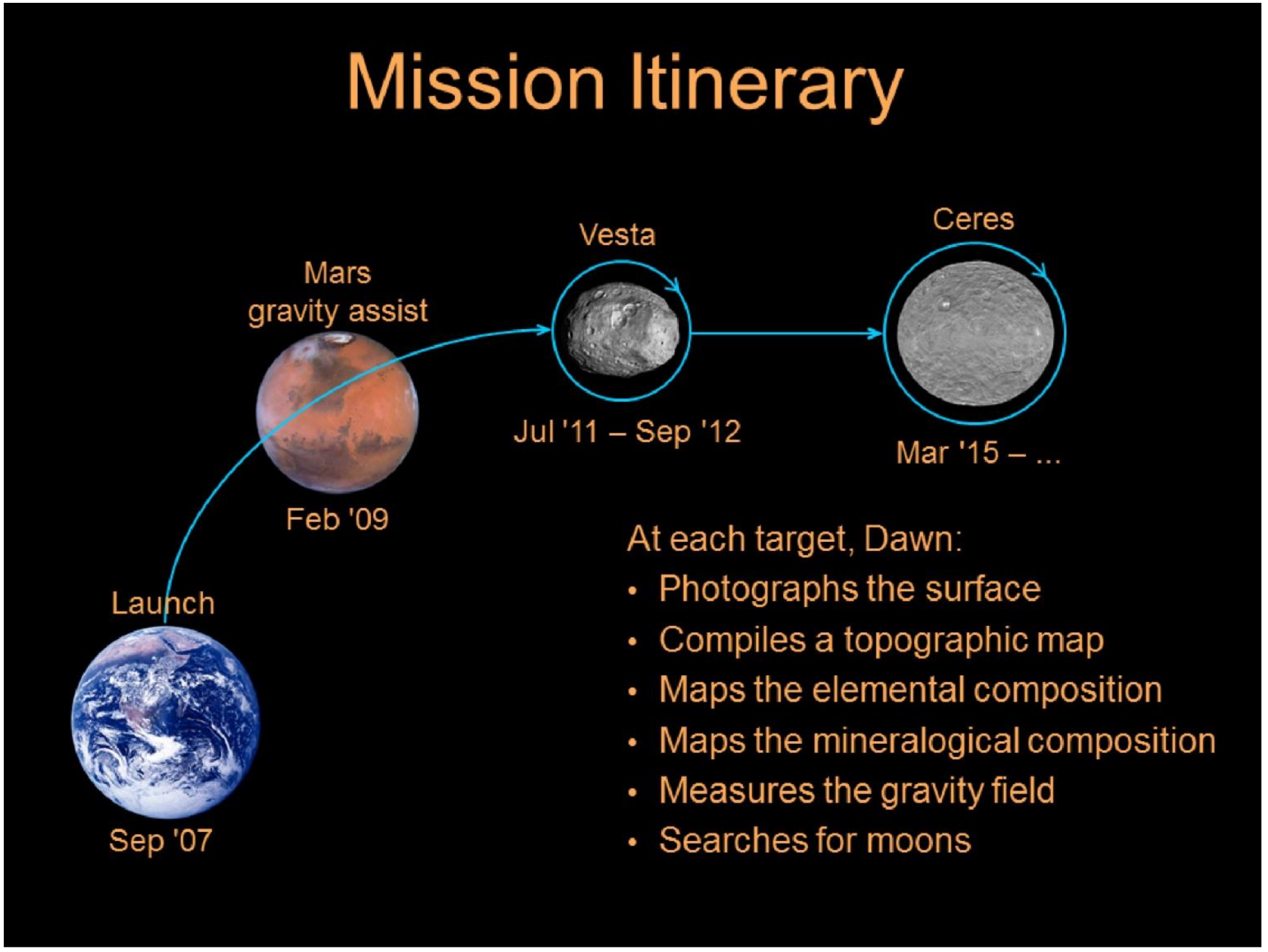

- Dawn uses the most efficient possible ion engine.
- It carries large solar panels so it has power even far from the Sun.
- The ion engine moves the spacecraft from the Earth to Vesta; into Vesta and out; to Ceres and into orbit.
- The ion engines allow Dawn to optimize its exploration strategy.

# Dawn's Interplanetary Journey



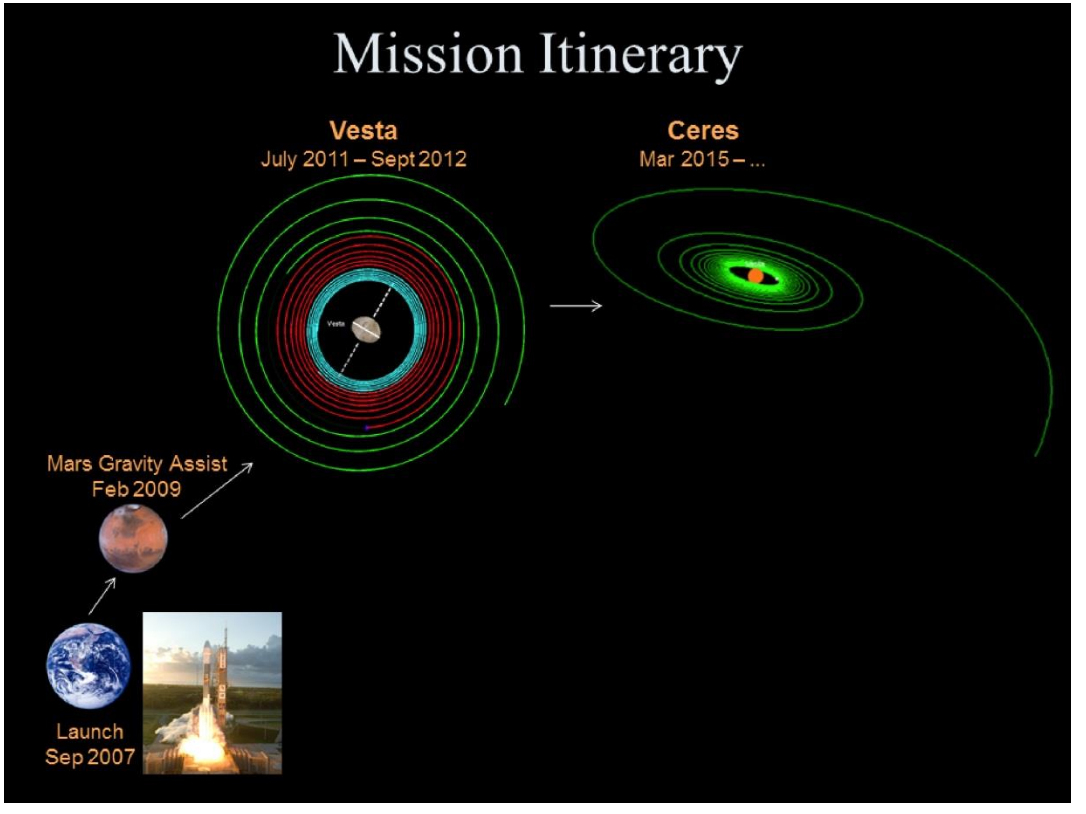

- This slide shows Dawn's interplanetary journey with blue coloring for periods when it was thrusting.
- The spacecraft has now used over 400 kg of Xe, changing its speed by 11 km/s which it uses to move outward in the Sun's gravitational well and to move into and out of the gravitational wells of Vesta and Ceres.

# What Dawn Does



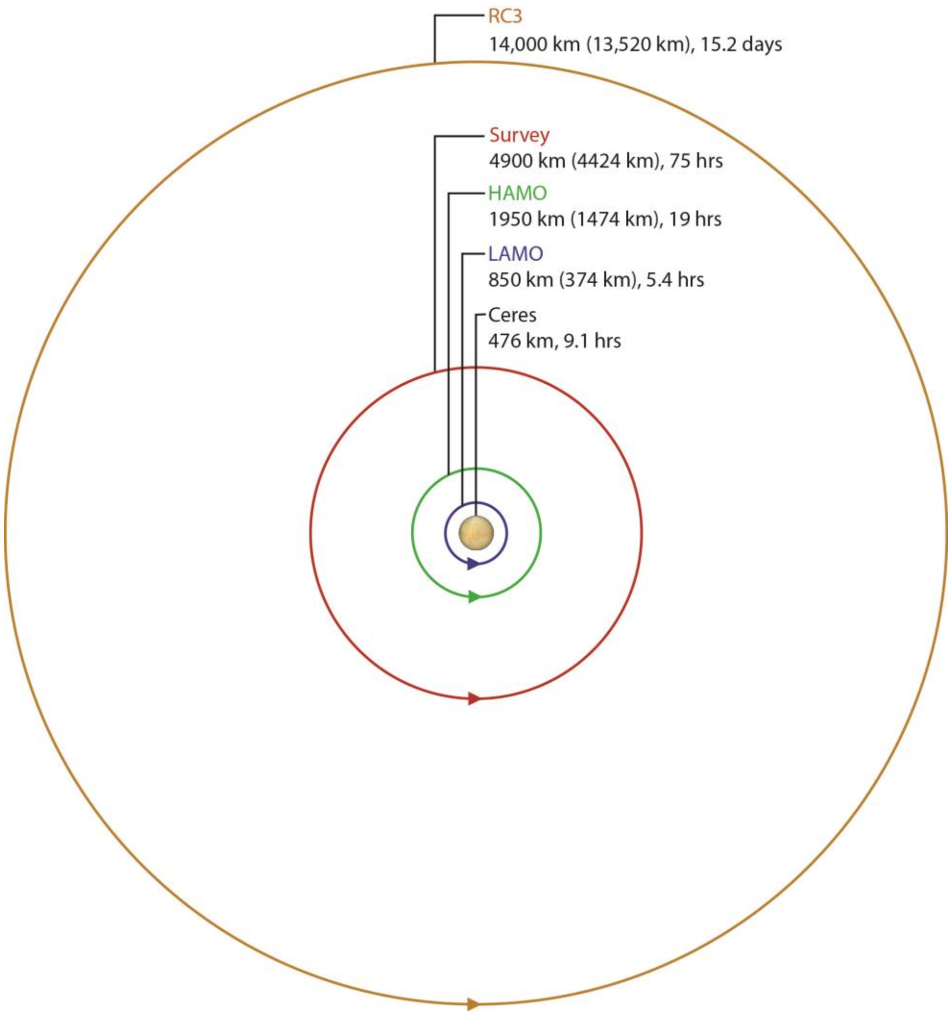

- Unlike most missions of initial planetary reconnaissance, Dawn stops at its target and orbits the body.

# Descent into the Gravitational Well




- When Dawn arrived at Vesta and Ceres, it slowed down, matched speed with the bodies, and descended to three main observational altitudes called Survey, High Altitude Mapping Orbit, and then Low Altitude Mapping Orbit.
- Dawn is the only spacecraft to have orbited two extra terrestrial bodies and was the first to visit a dwarf planet.

# How We Map: Rotational Characterization, Survey, High and Low Altitude



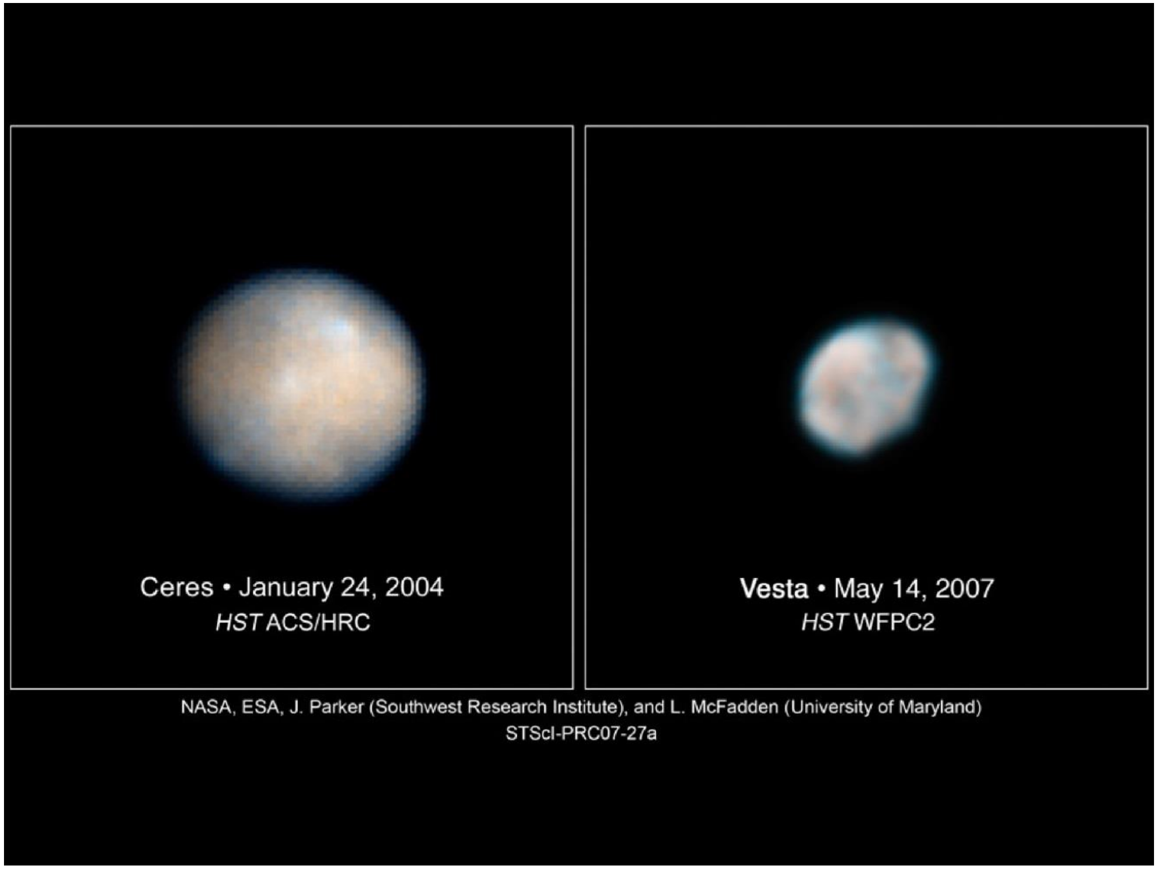

- We map from circular orbits with nadir pointing so that all instruments see the surface.
- The orbits chosen both enable the navigation to proceed for the next mapping cycle but also to prepare the science observations for the next orbital elevation.
- The Survey orbit is optimized for the visible and infrared mapping spectrometer.
- HAMO is optimized for the camera and stereo photography.
- LAMO is optimized for the Gamma Ray and Neutron Detector and gravity.
- The same plan was used for Vesta and Ceres.
- We will concentrate on Ceres results today.

# Dawn’s Payload

- Two redundant framing cameras (1024 x 1024 pixels, and 7 color filters plus clear) provided by Germany (MPS and DLR).
- A visible and infrared mapping spectrometer (UV to 5 microns) provided by Italy (INAF and ASI).
- A Gamma Ray and Neutron Detector built by LANL and operated by PSI.
- A Radio Science Package provides gravity information.
- Topographic model derived from off-nadir imaging.

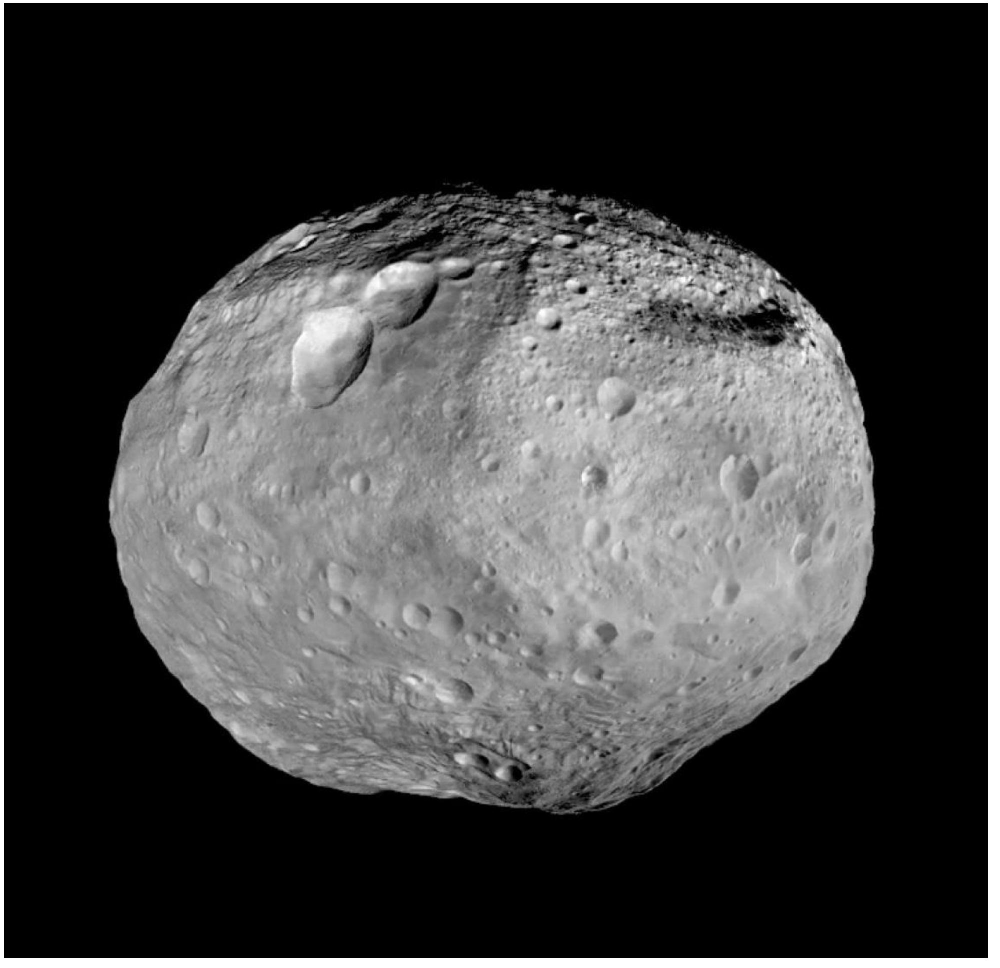


# Pre-Dawn Knowledge of Vesta and Ceres: HST Images



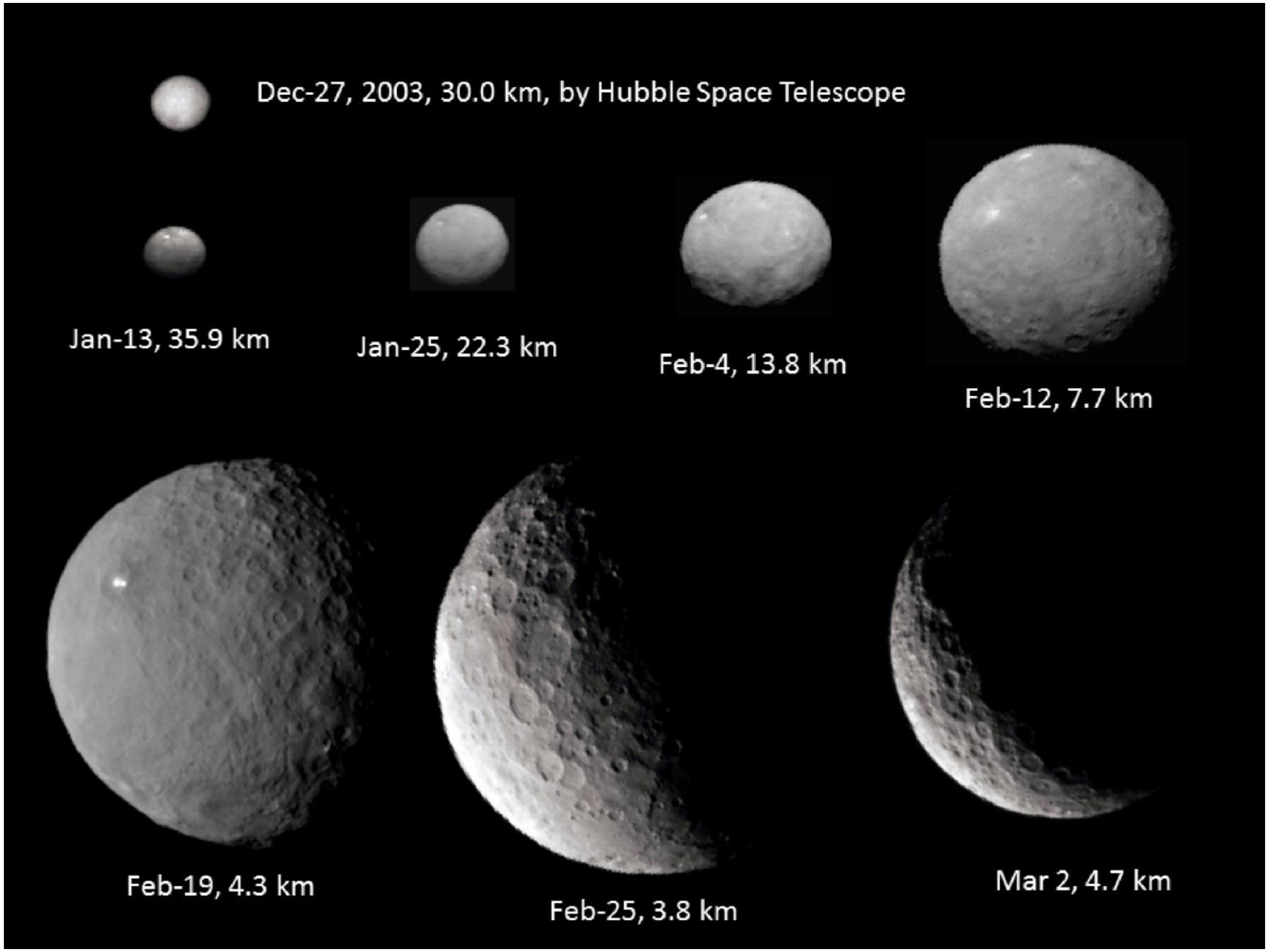

- Meteorites from Vesta had informed us about the crust of Vesta, but we had no meteorites from Ceres.

# Vesta



- Vesta had revealed its geochemistry through its meteorites sent to Earth, but the surface was a surprise.
- We will not spend time on Vesta today.

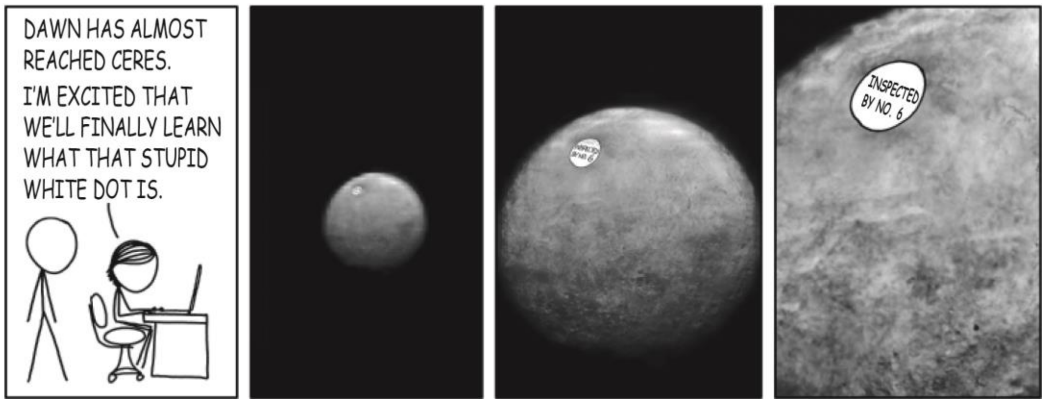
# Ceres Reveals (?) Itself




- As Dawn approaches Ceres, an unexpected feature was seen. A bright spot!

# The Public Helps the Science Team

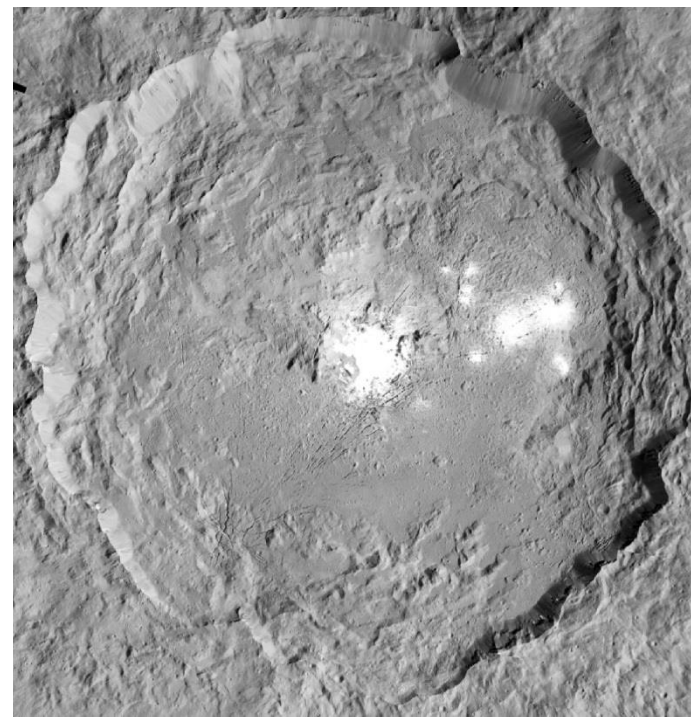
Cartoons online




- Despite all this help, we are still puzzled by the bright spots.

Mail-in solutions from the public

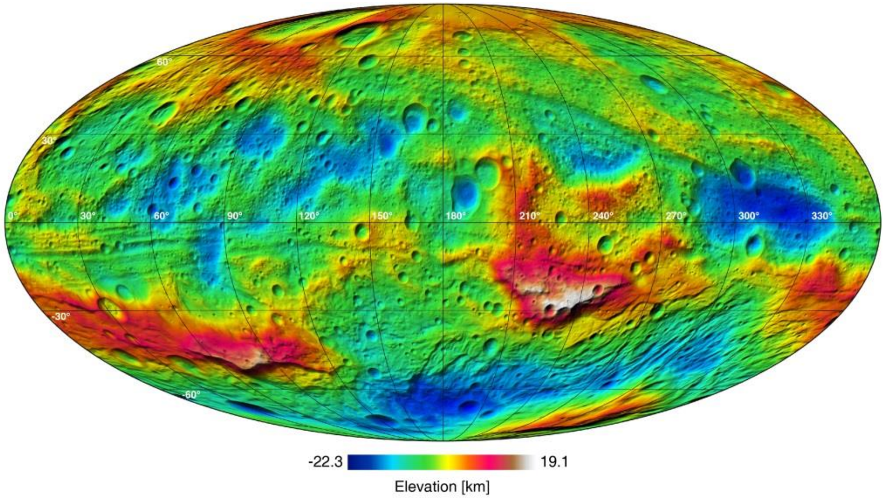

Dropped flour bag



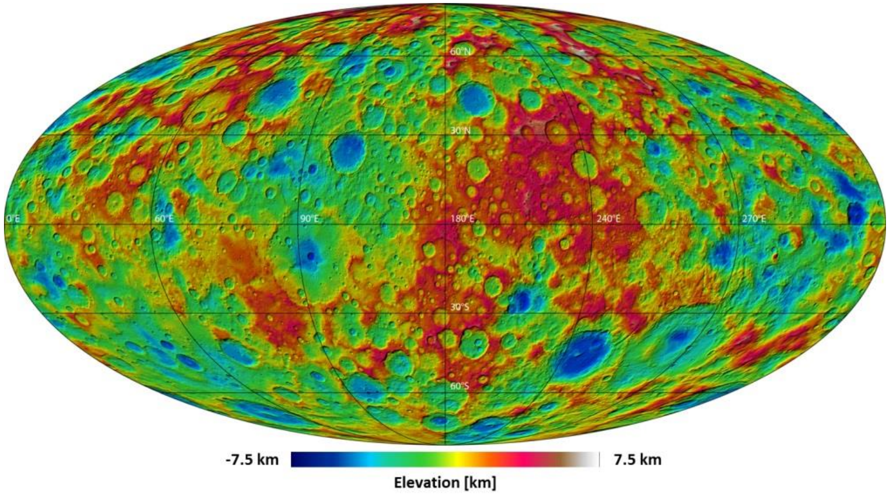
Cosmic Powder Drop at Occator?

# The First Surprise at Ceres: The Topography

- We expected an icy crust, but at the temperature of Ceres and under its gravitational field, there should be little topographic relief. However, the topographic relief is nearly half of that on Vesta.
- A second surprise is the crater distribution. Vesta was scoured by large impacts, but Ceres does not show obvious scars of large impacts. The impactors should have been similar at each.
- The implication of this is that Ceres' interior is much different than that of Vesta.



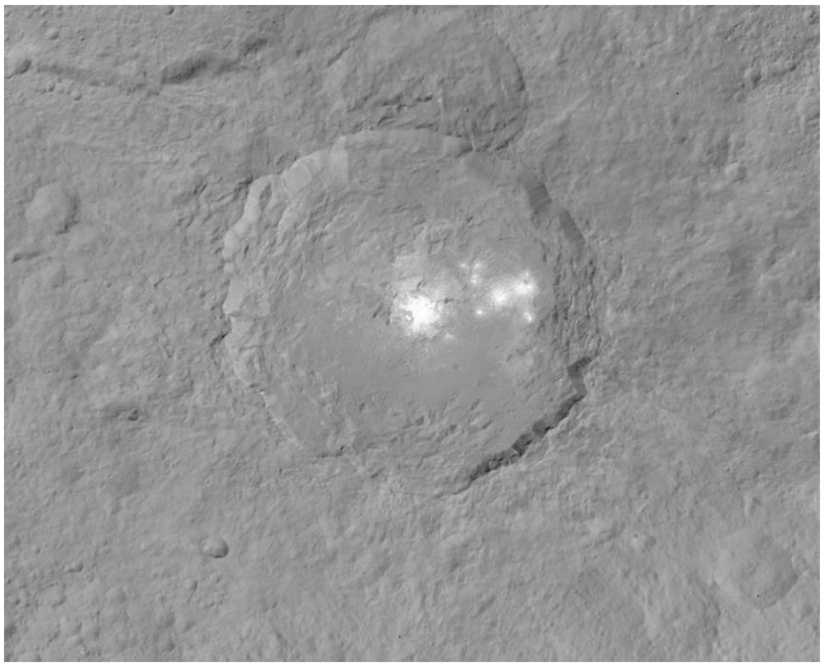

Vesta




Ceres

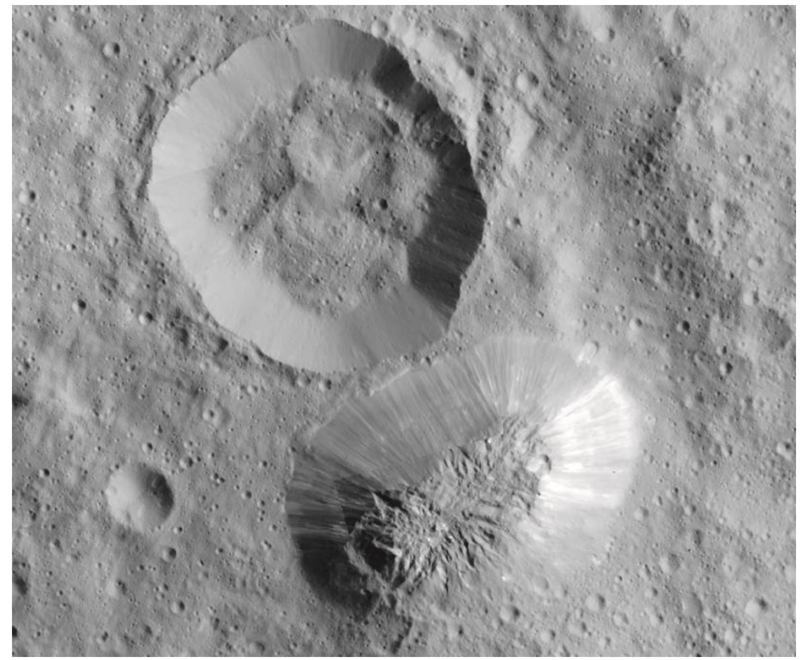
# Intriguing Features on the Surface

Occator



- Occator crater has bright material on its floor. It seems to have come out of the interior of Ceres. It may be a salt that was deposited by brine.

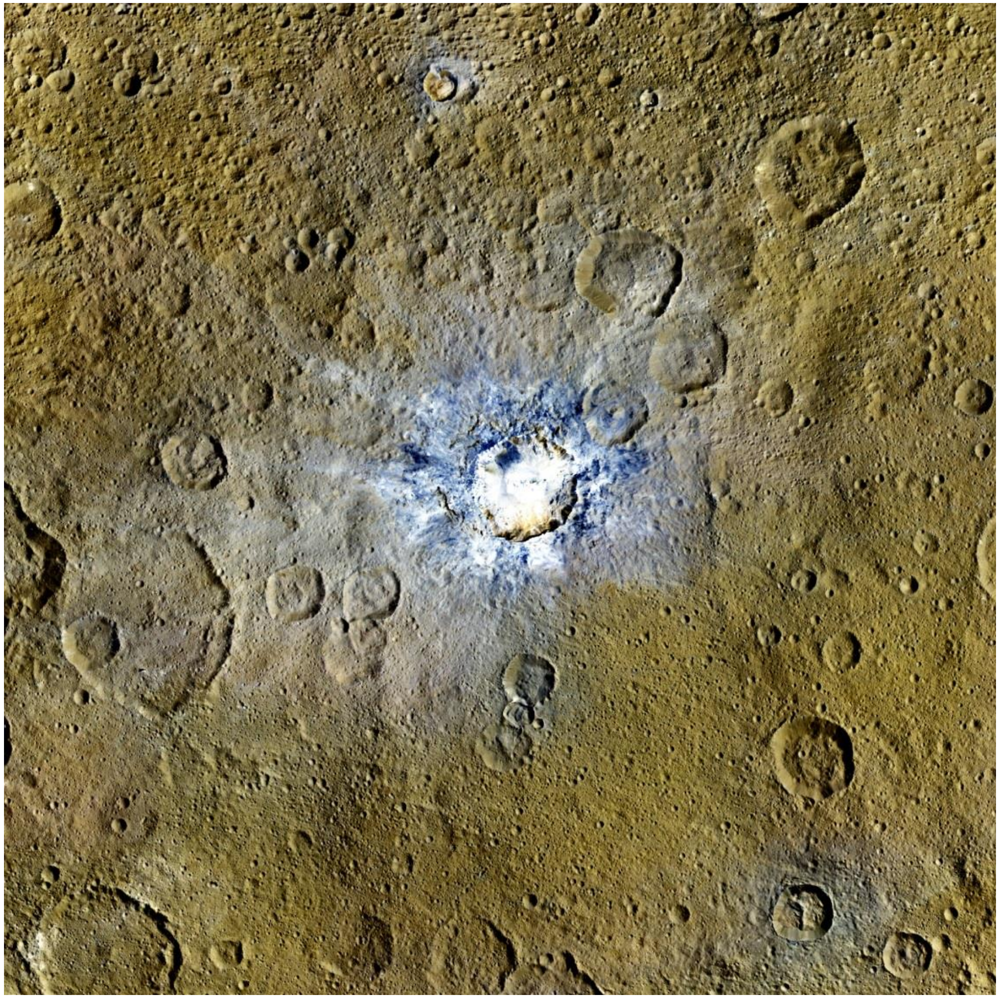
Ahuna Mons



- Ahuna mons is an apparently young mountain. It may be supported by water ice. Some of Pluto’s mountains resemble Ahuna Mons.

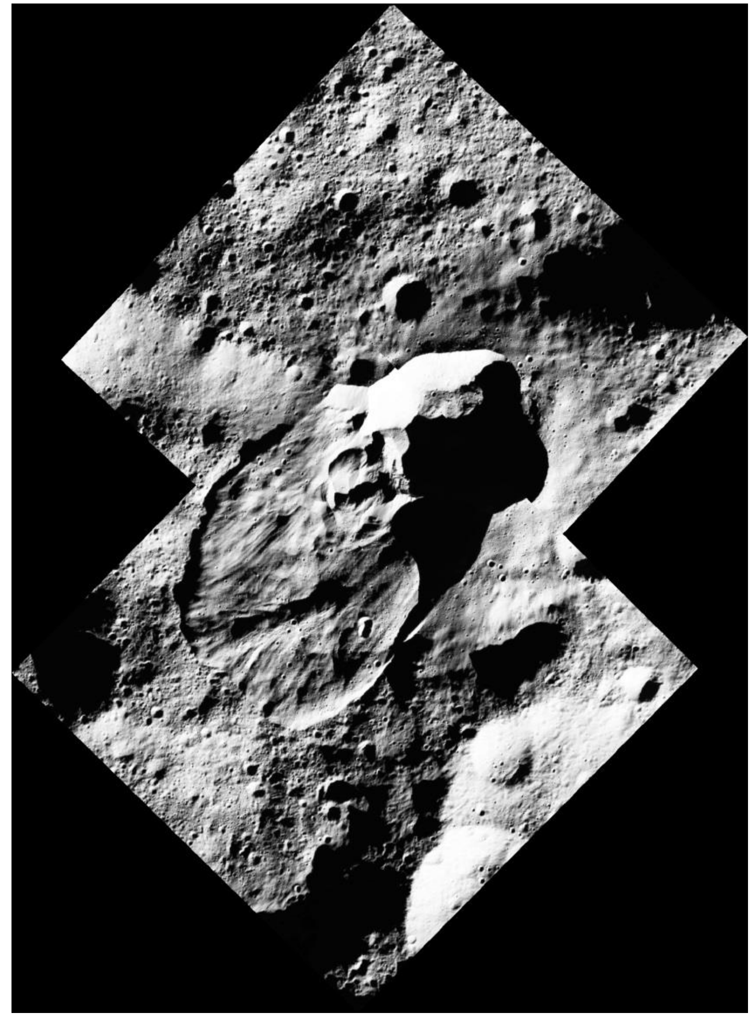
# Haulani Crater

- Haulani crater is young with no impact craters on its floor.
- Its brightness contrasts with its drab surroundings.
- It has a central peak and an extensive ray system.

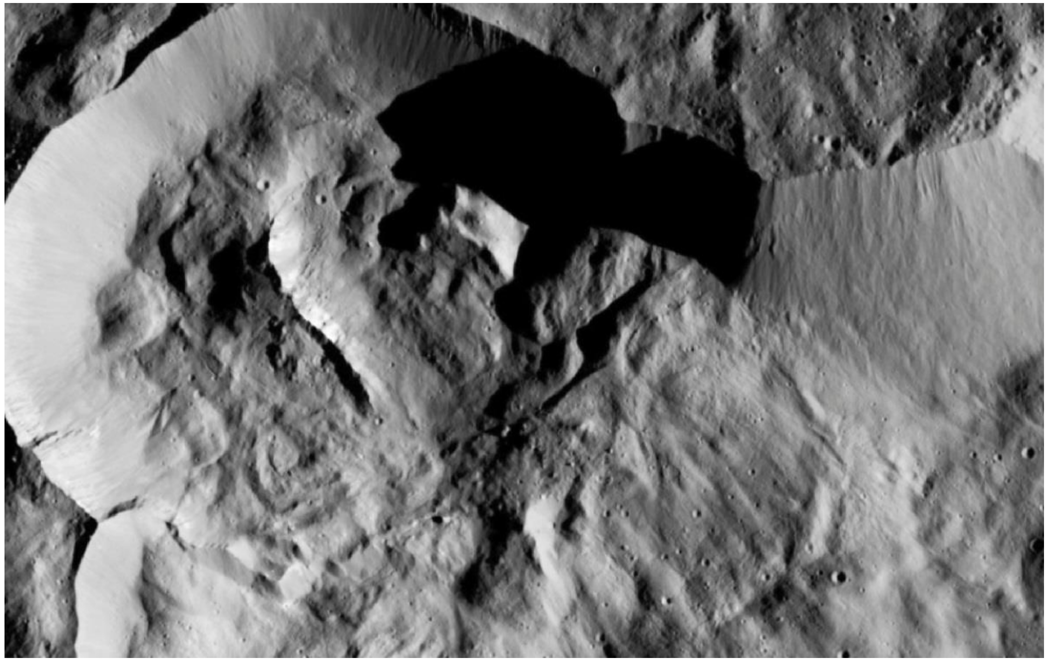


# Flows on Ceres

- Ice, even at the temperature of Ceres' surface, relaxes over time. This relaxation has not occurred.
- Rock, on the other hand, is rigid, but as shown here, we do see flows.
- The bright crater wall shows the direction of the Sun. This helps your eye interpret the edges of the flow.
- Ice is too weak and rock is too rigid. What is the 'goldilocks' solution that is just right?



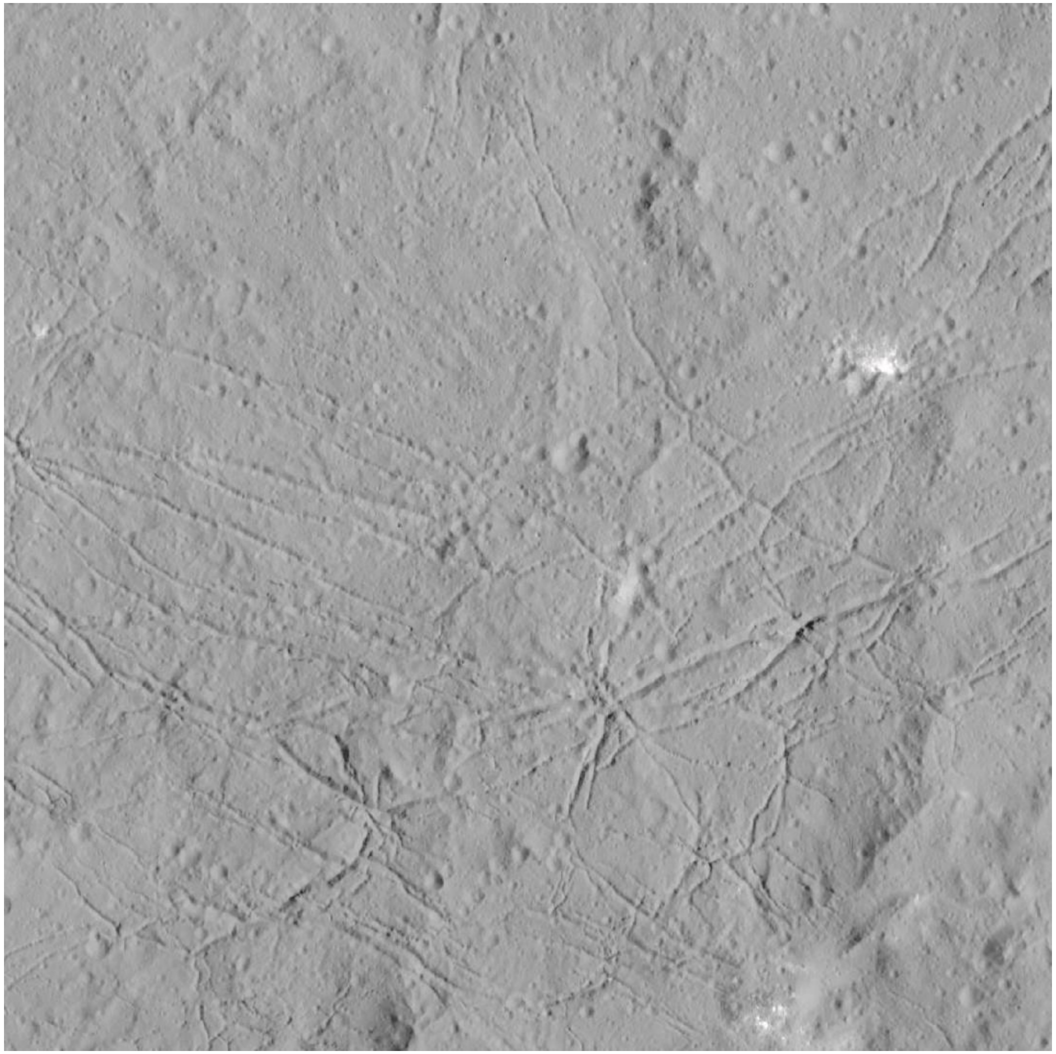
# The Goldilocks Solution: Rock-Ice Mixture



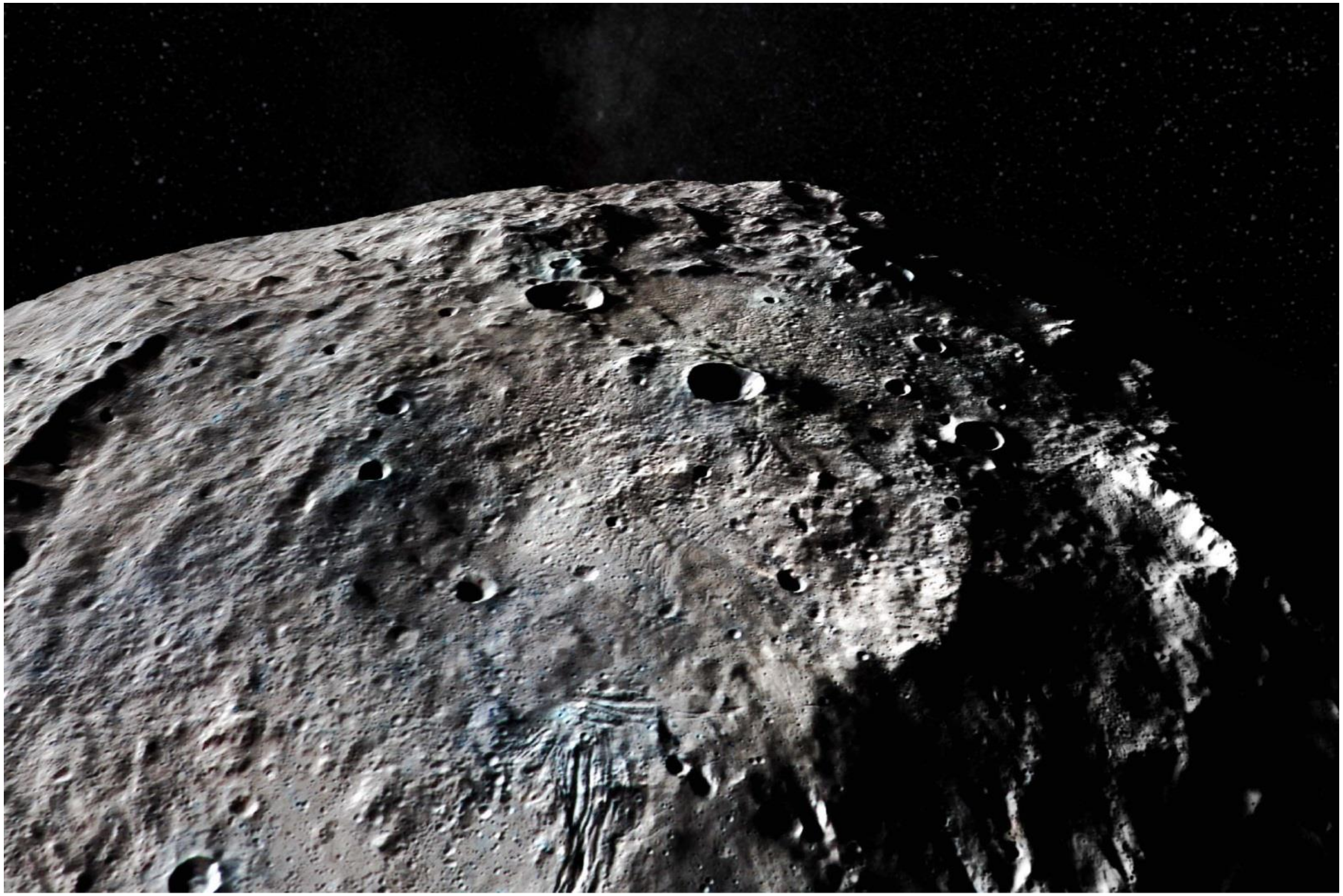
- We have much evidence for flows all over Ceres.
- Many flows seem triggered by impact and were simultaneous with the impact; others seem to have occurred after the impact coming out of the floor of the crater at a later date.
- We believe that the crust is made of a mixture of rock and ice.
- This rigid rock-ice layer is thick enough to support large craters up to perhaps 200-km diameter.
- Beneath this hard rock-ice layer is a weaker zone of the material, but warmer so it has less strength.

# Crater Floors

- Crater floors on Ceres are varied and interesting.
- In addition to flows, there can be both peaks and pits in the centers of the crater.
- The craters sometimes are heavily cracked or fractured, as this one with many different directions of the fractures.

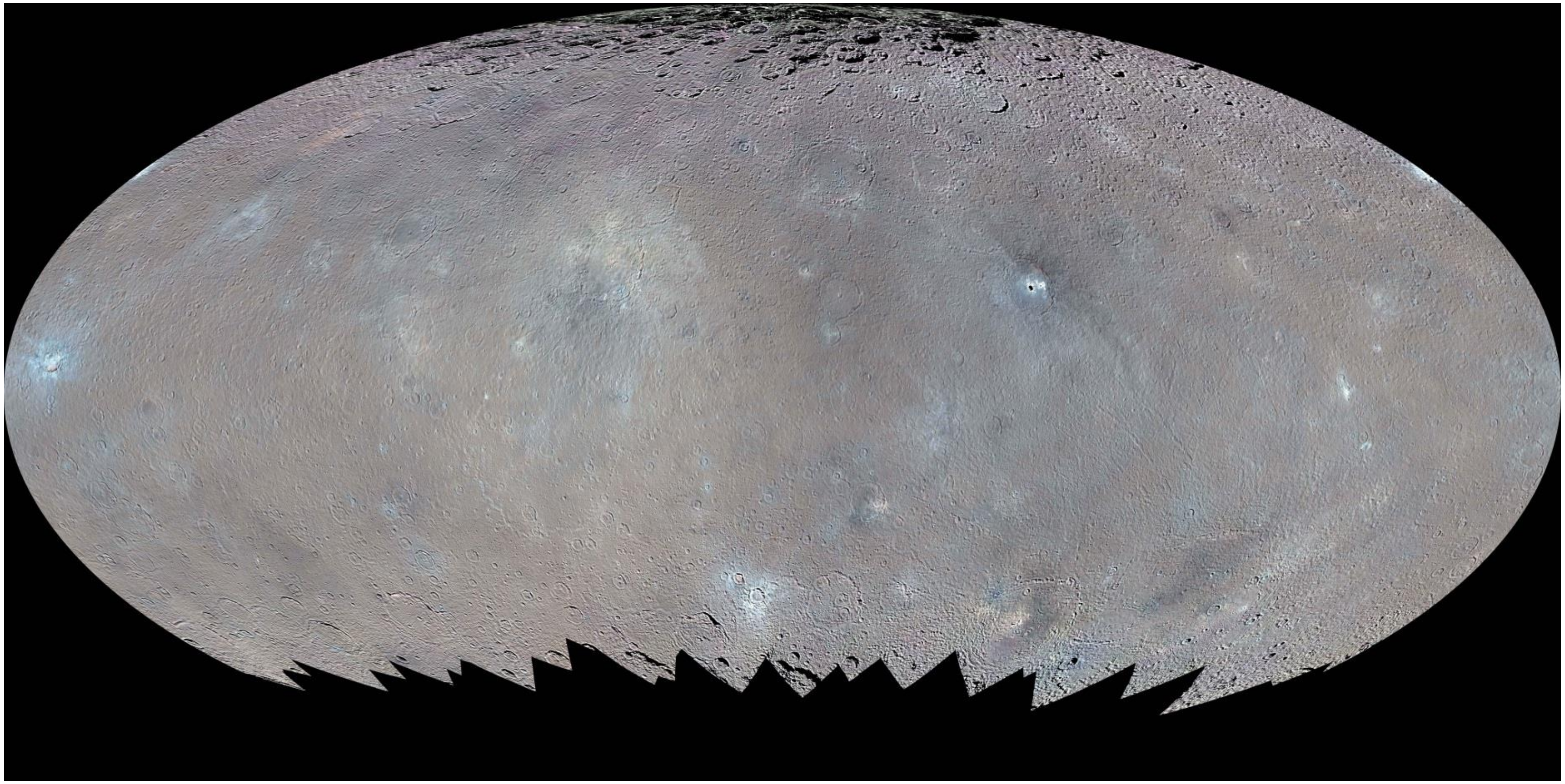


# Complex Terrain: Yalode Crater



- There is terrain that defies explanation, such as this structure in Yalode crater.

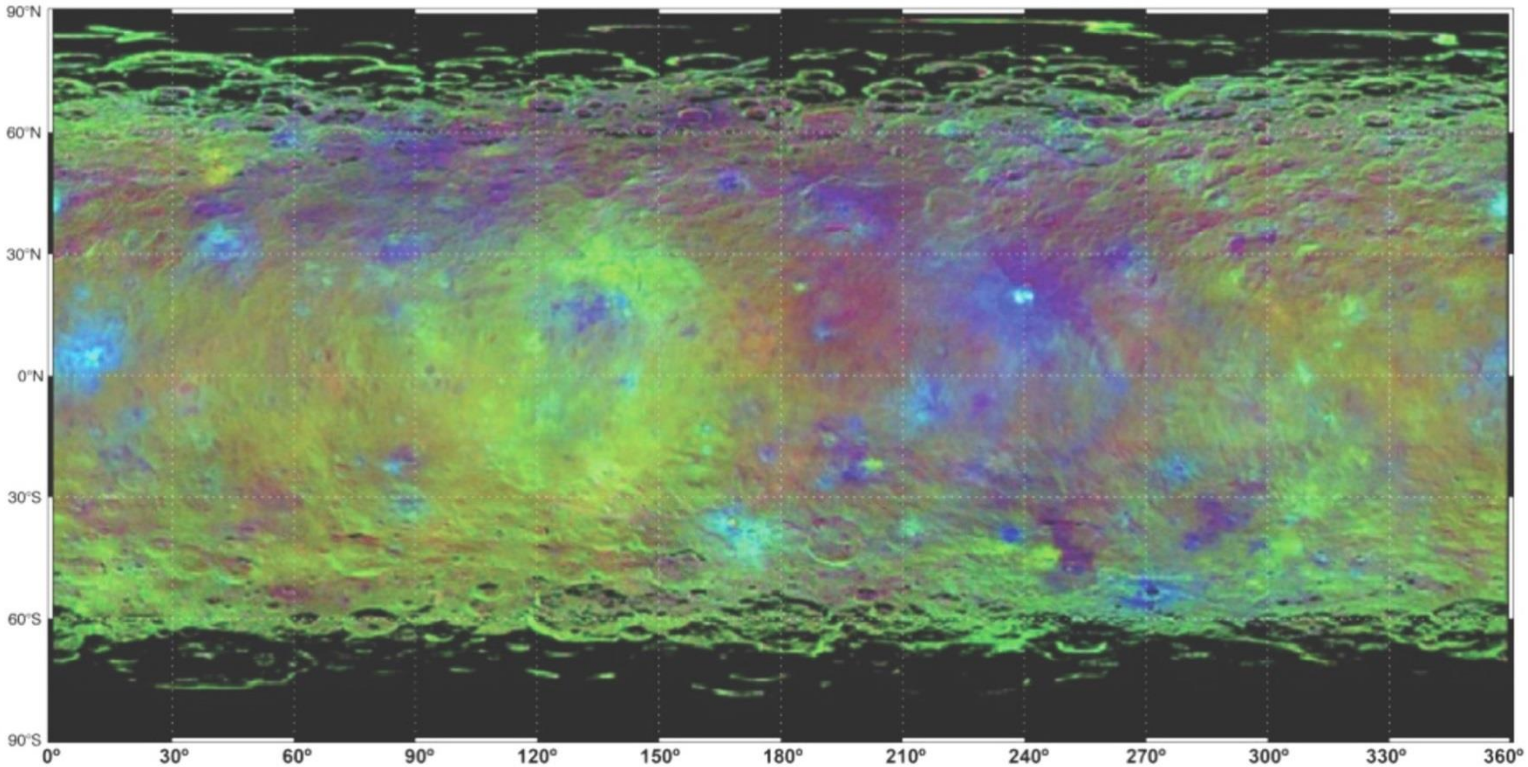
# Diversity of the Surface: Natural Color



T. Roatsch et al.

- It is difficult to reconstruct the color of the surface as the eye would see it, but one member of our team has tried in this mosaic in “natural” color.

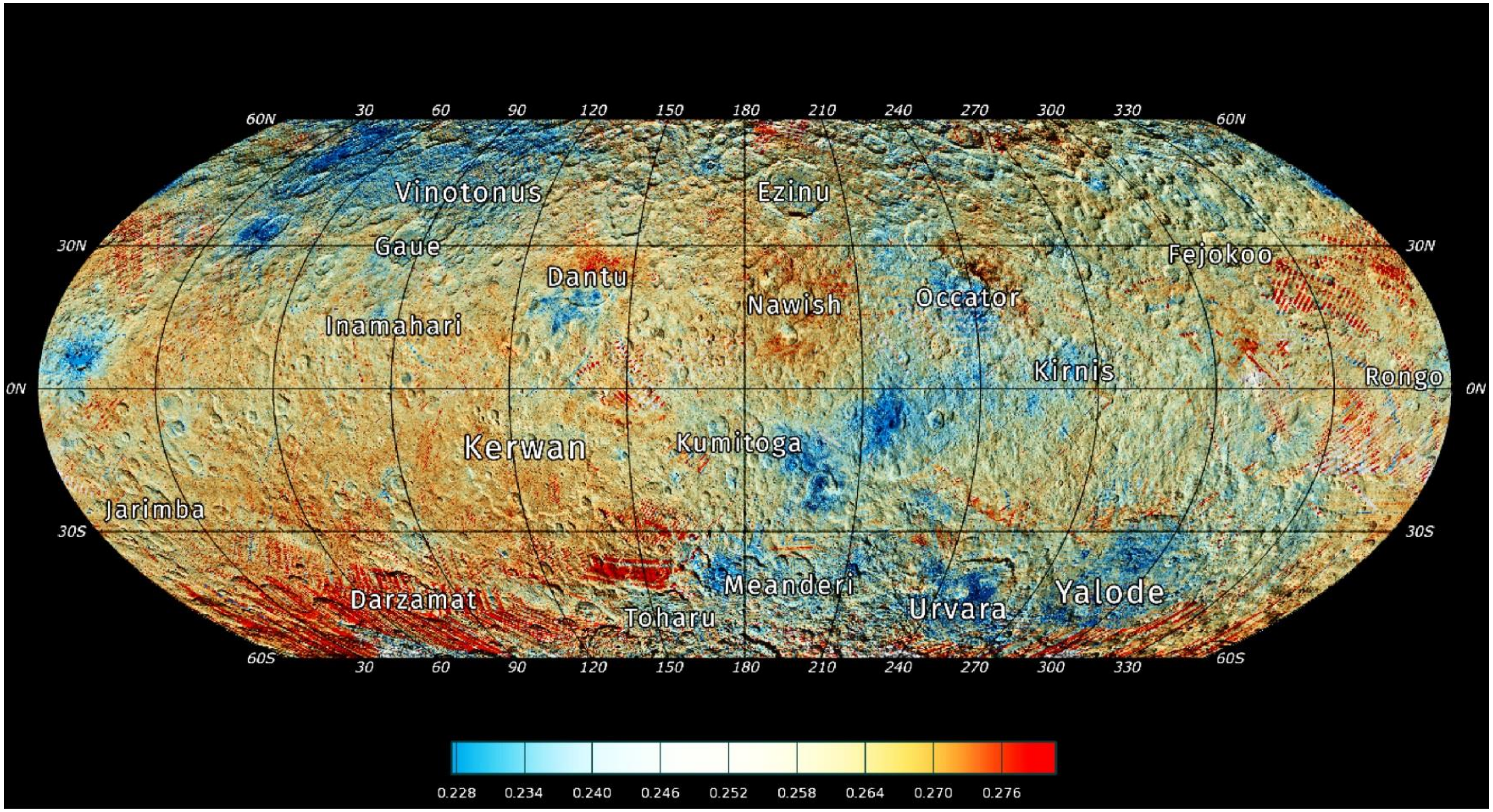
# Diversity of the Surface: Albedo




J.-Y. Li

- The surface of Ceres has a similar chemical composition everywhere, but the concentration of minerals vary as does the surface color.
- We can assign colors to different parameters to demonstrate the variability of the surface.
- Here we show the varying reflectivity of the surface to visible light. The greener the color, the more reflectivity it has.

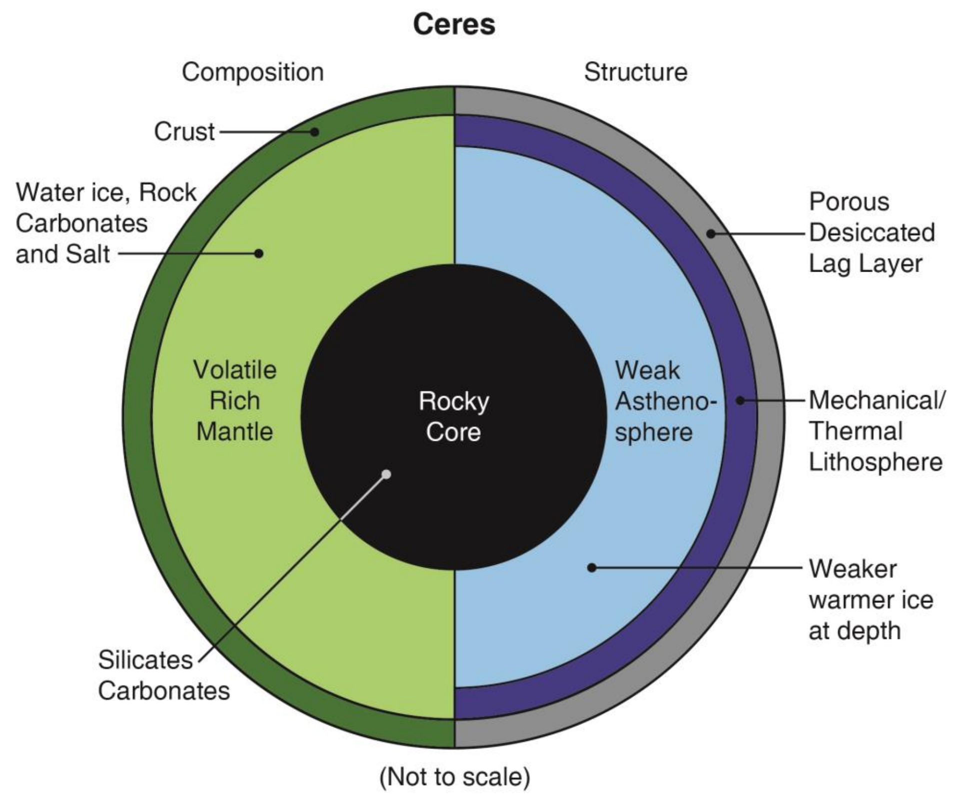
# Diversity of the Surface: VIR 2.7µm Absorption Band Depth



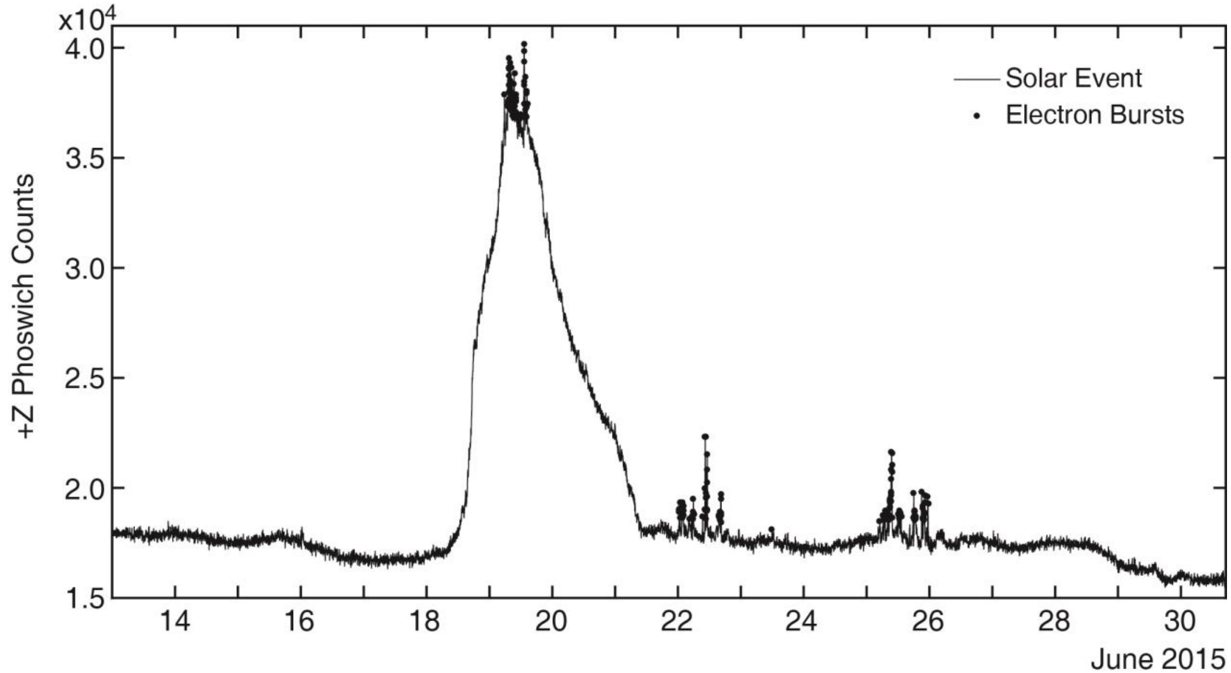

- VIR spectrometer determines the mineral composition of the surface by examining the depth of absorption bands in the near infrared.
- Here we see evidence for differing amounts of phyllosilicates across the surface. The team consensus is that the phyllosilicates were created in Ceres and were not transported to Ceres from some other location.

# What May Be Beneath the Surface

- The outer surface of Ceres, exposed to the vacuum of space, is a desiccated, clay-like lag material.
- Beneath that layer is the rigid rock-ice material or lithosphere.
- This material also contains carbonates, silicates, sulfates and brine.
- This is equivalent to Earth’s upper mantle.
- The temperature rises with depth, and the material weakens.
- This is equivalent to the Earth’s asthenosphere.
- At the center lies a dry rocky core.

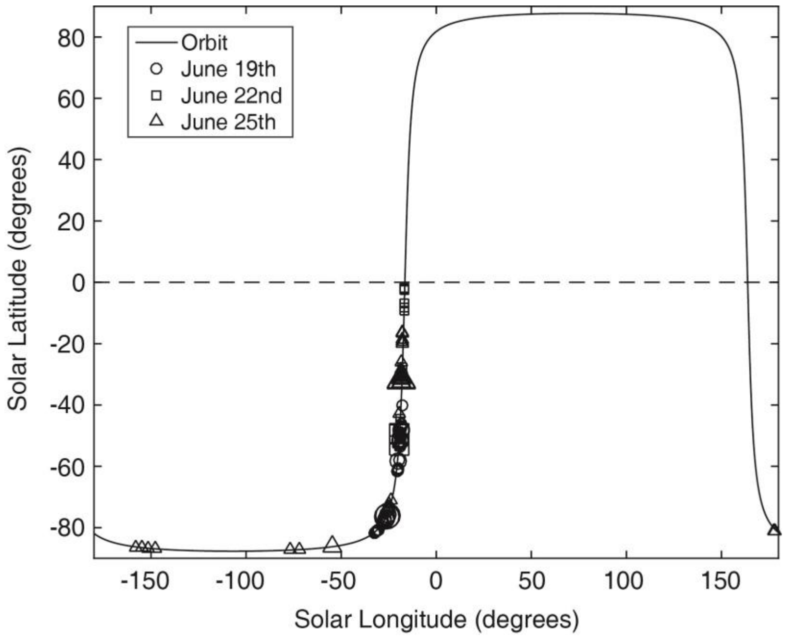


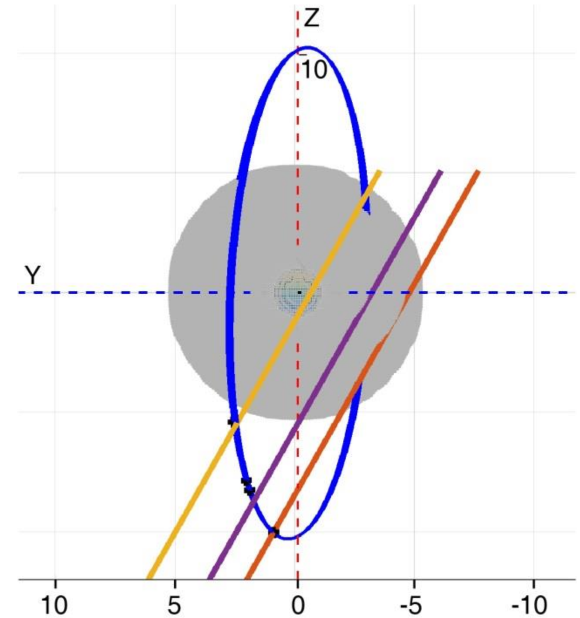
# The Biggest Surprise: Ceres Can Accelerate Electrons

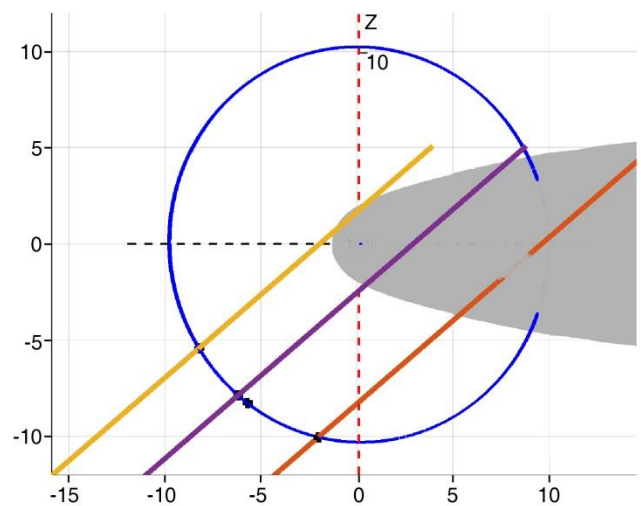



- The Gamma Ray and Neutron Detector (GRaND) can detect electrons with energies tens to hundreds of electron volts.
- In June 2015, a solar proton event occurred in the solar wind and GRaND began to see electron bursts every orbit for a week.
- The detector was pointed at Ceres all the time so the electrons were coming from the general direction of Ceres.

# The Source of the Electrons




- The electrons were seen in the same location on each orbit but in solar coordinates not planetary.
- Ceres was interacting with the solar wind but only for a week.
- We believe that the solar event liberated gases from the surface that became ionized and formed a bow shock which in turn accelerated the electrons back along the field to the Dawn spacecraft.


Flight Over Ceres
NASA
Jet Propulsion Laboratory
California Institute of Technology