February 2015

AEROSPACE AMERICA

Remembering AIAA's Jim Harford/page 4

$AVE BILLION$ ON YOUR FLEET

Stop wasting time and parts on no fault found Page 28

USAF's Otto on ISR planes/24

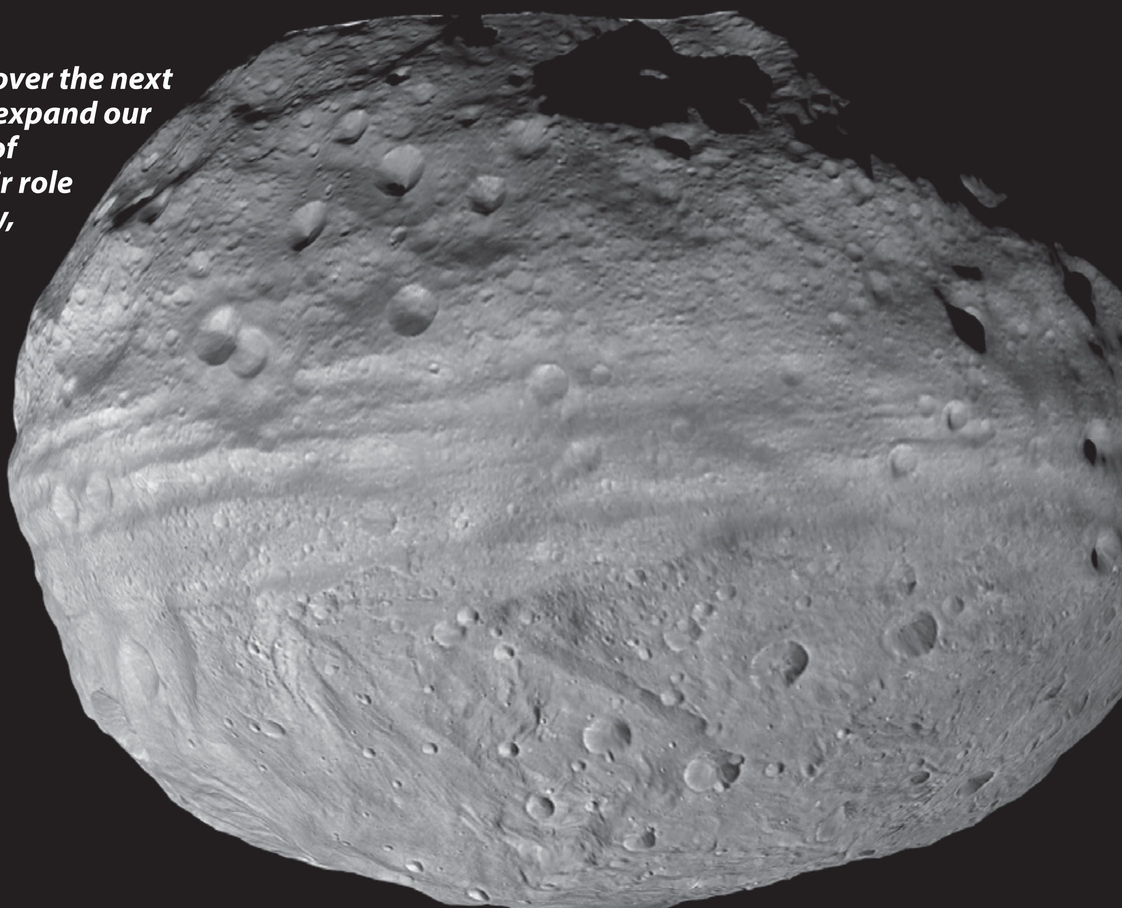
Small sats, big plans/40

A PUBLICATION OF THE AMERICAN INSTITUTE OF AERONAUTICS AND ASTRONAUTICS

NASA

Asteroids in the crosshairs

Space missions over the next 10 years aim to expand our understanding of asteroids — their role in Earth's history, the potential treasure they hold, how we might avert a catastrophic collision. Astronaut Tom Jones looks at plans to pry secrets from asteroids, including Ceres in March.



Vesta, the third largest object in the asteroid belt, was photographed in 2011 by the Dawn spacecraft. Dawn departed Vesta in September 2012 and is set to rendezvous with the largest asteroid in the solar system, Ceres, in March.

They hold mineral wealth estimated to be in the trillions of dollars. They preserve the environmental and chemical conditions prevailing at the dawn of the solar system. It's likely they delivered the water that filled the young Earth's oceans. Only in the last 50 years did we learn that these orbital orphans have repeatedly altered the evolutionary course of life on Earth — and absent action we take in space, will do so again.

They are the asteroids, and for the next decade they will come under intense scrutiny. Three exploration craft will venture to asteroids by 2024, testing anchoring and sampling techniques, gathering ancient or even pre-solar organic material, prospecting for potential space resources, and demonstrating how we might nudge a future rogue asteroid from a collision course with Earth.

NASA's Science Mission Directorate is currently running two robotic exploration missions to asteroids. They are Dawn, which is deep into a decade-long mission to the main asteroid belt between the orbits of Mars and Jupiter, and the Origins Spectral Interpretation Resource Identification Security Regolith Explorer, or OSIRIS-REx, slated for launch in 2016.

Vesta revealed

Dawn conducted an intense, 14-month scrutiny of main belt asteroid 4 Vesta. Before it left Vesta in September 2012, the ion-propelled probe revealed the asteroid as a complex mini-world, its rough, varied terrain more similar to the Moon, Mercury and the outer planet satellites than the battered, inactive surfaces of most asteroids.

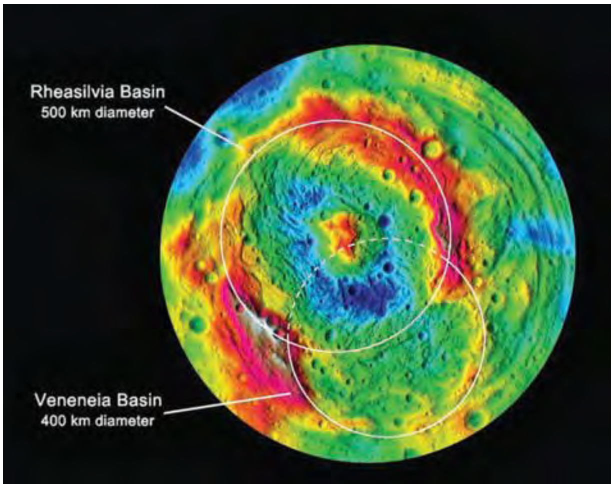
As seen in a geologic map released by Dawn's science team in November, the most prominent feature on Vesta is a giant impact basin, Rheasilvia, 500 kilometers across and 19 kilometers deep. Rheasilvia dominates the entire southern hemisphere; the impact that formed it excavated 1 percent of Vesta's volume and ejected large fragments into solar orbit, while carpeting Vesta's surface with debris. The survival of these fragments from the collision, up to 10 kilometers across and compositionally linked to Vesta, indicates the impact occurred as late as 1 billion years ago.

Dawn's orbital gravity data and detailed mapping of Vesta's impact basins suggest that the asteroid, which is 525 kilometers in diameter, has a crust about 10 kilometers thick, a rocky mantle (like Earth's) and a nickel-iron core about 220 kilometers across. Vesta underwent intense early heating and was large enough to have differentiated: Molten, dense metals sank to the core, while lighter silicate minerals separated into mantle and crust.

Dawn's cameras revealed localized, pitted terrain where dark material seems to have been freshly exposed at the surface. Dawn's instruments identified the material as water-bearing silicate minerals, like those found in carbonaceous chondrite meteorites. Dawn also spotted sinuous gullies on the walls of several young craters, ending in fan-shaped deposits on the crater floors. Could the water and gullies be related?

Chris Russell, the mission's principal investigator, told me in an email exchange that evidence for water erosion on Vesta's airless surface is the mission's most surprising discovery:

"Because we expected that Vesta had once been almost completely melted, and because it is very small, [we thought] it would be very dry. But when we looked at several of the more recent large craters, we found evidence for gullies with interconnecting networks that looked like they had once carried flowing water down the crater walls. There were the expected deposits of material at the end of the gullies, as you might have on earth at the end of a river — like a delta. There was evidence on the crater floors of the floor once being wet."



A topographic map of the asteroid Vesta generated with data from the Dawn spacecraft shows two large impact basins in the southern hemisphere. Rheasilvia, the largest impact basin, was formed about 1 billion years ago, and Veneneia is at least 2 billion years old. In the map, red indicates higher areas and blue lower areas.

The fresh-looking gullies, says Russell, suggest that even today one might find ice under the surface, like terrestrial permafrost, releasing meltwater when a small asteroid strikes the surface. To be sure, water flowing on a once-molten, airless asteroid is a controversial proposition that Dawn scientists are still debating.

Vesta was once thought to be a rare protoplanet — the building blocks for larger worlds like Earth — that survived the chaotic formation of the early solar system and 4.5 billion years of subsequent collisions. But Dawn's revelation of Vesta's multiple giant impacts, prominent shock-induced grooves and debris deposits suggest that it is probably a composite body — blasted, shattered and then reassembled to include fragments of colliding asteroids.

Russell admits that "our early ideas about Vesta were too simplistic." He says a "sophisticated process" appears to drive formation and evolution of small planets. "Perhaps then the biggest surprise was how much Vesta resembled her larger brothers and sisters, including Earth."

On to Ceres

The Dawn team is now intent on a rendezvous with the solar system's largest asteroid, the 950-kilometer-diameter dwarf planet 1 Ceres, in March. By mid-March, Dawn will be some 75,000 kilometers from Ceres, and its framing camera is already seeing Ceres more clearly than the best Hubble images.

Ceres is thought to be composed of rock and ice with a rocky core. Hydrated minerals and frost have been detected on its surface by Earth-based telescopes. Lucy McFadden, a physical scientist at Goddard Space Flight Center and a Dawn co-investigator, tells me that Ceres's water-rich composition could mean lots of surprises: "Will we see traces of recent liquid water flows, as on Vesta? Will eruptions from the wa-

NASA

OSIRIS-REx, shown in an artist's rendering, will extend an arm to collect up to 2 kilograms of regolith from the near-Earth asteroid Bennu and return the sample to Earth.

ter-rich mantle have resurfaced parts of Ceres?"

She hopes that Dawn will be able to map surface vents that might be the source of water vapor detected by the Herschel space telescope in early 2014. "We would like to find those sources, but it won't be easy. Other spacecraft have had a big challenge identifying the source of vapor jets streaming from a comet's surface," she says.

The past few months of Dawn's approach to Ceres have been anything but routine. On Sept. 11, the spacecraft sustained a pair of radiation-induced single event upsets that shut down its ion engines and affected attitude control. For 95 hours, Dawn was unable to thrust toward its Ceres rendezvous, but the team recovered the spacecraft from safe mode, redesigned its capture trajectory and resumed thrusting.

Marc Rayman, Dawn's chief engineer and mission director, tells me via email that "the team did an outstanding job with a very challenging situation. We resolved both [anomalies] and returned to routine ion thrusting in four days. The mission is, to a large extent, entirely unaffected. That's part of the beauty of ion propulsion."

Following a looping approach toward Ceres after its March capture, Dawn should reach its initial, 13,500-kilometer mapping orbit by April 23. Rayman said Dawn's systems are healthy and ready for action at Ceres, but — and this is a significant "but" — two of Dawn's four reaction wheels have failed; these provide the primary means to point the spacecraft.

"For many missions, losing two could have dire consequences, but we have been able to devise plans that will allow us to complete all Ceres objectives regardless of the health of the wheels. That is, we are not even dependent on the two remaining wheels. We have what I like to call a zero-reaction-wheel plan," says Rayman.

Chris Russell, the Dawn principal investigator, is eager to dig into Ceres's mysteries: "We have very little knowledge of what to expect. There are no meteorites that came from Ceres to guide our thinking. Everything will be a surprise.... [The] moons of Saturn can help our thinking process, but none is a good analog for Ceres."

Timely experience

Japan launched its Hayabusa 2 probe on Dec. 3. Its target is near-Earth asteroid 1999 JU3, a dark, C-type object, thought to be similar to carbonaceous chondrite meteorites; it appears to harbor water-bearing silicate minerals. In 2018, after mapping the asteroid, the probe, whose name in Japanese means falcon, will deliver four small landers and fire a penetrator to gouge a crater and expose fresh bedrock.

Samples will be collected by touching down briefly at three locations, firing tantalum bullets into the surface to blast debris upward into separate collection chambers. Hayabusa 2 will depart the asteroid in 2019 and a re-entry capsule will deliver the samples to Earth in 2020.

NASA meanwhile is pressing ahead on its own asteroid sample return mission, OSIRIS-REx, slated for launch in September 2016. The mission is designed to explore the 500-meter-diameter near-Earth asteroid Bennu. A dark, possibly water-bearing asteroid, Bennu's spectral similarity to carbonaceous chondrite meteorites suggests it may preserve grains that predate the solar system's formation. After a mapping phase in 2018, OSIRIS-REx will descend for a touch-and-go landing using its pogo-stick-like sampler arm. When the arm's sampler head touches the surface, a jet of pure nitrogen will fluidize and push at least 60 grams of regolith into the sample chamber. Surface contact pads on the arm's exterior will also collect fine-grained material at touchdown to supplement up to three gas-driven sampling attempts.

OSIRIS-REx could gather up to 2 kilograms of the asteroid for return in 2023. NASA and the Japan Aerospace Exploration Agency have agreed to exchange samples from their respective missions, enhancing the study of these two objects, which may have formed in different regions of the asteroid belt.

Results from these ambitious asteroid missions will open a promising frontier in our space exploration future. Dawn, Hayabusa 2 and OSIRIS-REx should teach us how to identify water-rich objects in the inner solar system, boosting prospects for eventual use of that invaluable resource. Extensive robotic operations around asteroids will improve our chances of warding off a rogue Earth-impactor and pave the way for complex astronaut operations on small bodies like the Martian moons Phobos and Deimos.

Tom Jones
Skywalking1@gmail.com
www.AstronautTomJones.com