How do we know that we have samples of Vesta here on Earth?

By Professor Lucy McFadden, Dawn Co-Investigator

Our understanding that we have samples/fragments from the asteroid named 4 Vesta comes from almost 40 years of scientific research. In 1968, or the late 60's, as those from the flower child generation like to say, a professor at MIT was applying a research and analysis technique that he used in his doctoral dissertation, to other bodies in the solar system. It is very exciting when there is a combination of theory and observational technique that can be applied to any field of research. Tom McCord was measuring the reflected sunlight from the Moon, planets and asteroids in the late 60s. He took advantage of photoelectric multiplier tubes that could quantify the number of photons that were reflected from an object as observed through a telescope through different filters that allowed discrete wavelengths of light to pass through them. McCord had made similar measurements on different regions of the Moon and discovered that those that looked different to the eye, were actually reflecting the spectral signature of the minerals making up the surface. Eventually, he and his colleagues also realized that different spectral signatures reflected the degree to which the material had been exposed to space, a concept called spectral maturity.

It was a landmark day, when McCord and his student, Torrence Johnson, looked at the reflected light signature of Vesta. It was like none they had seen before, having a strong absorption band at 0.9 µm, a second band between 0.5-0.6 µm, and a strong UV absorption. They called in their colleague John Adams, to help them interpret it. Using theory developed by Roger Burns, also at MIT, they were able to demonstrate the nature of the photon interactions with the electronic structure of low calcium pyroxene that dominates the surface mineralogy of Vesta. The relationship to basaltic achondrite meteorites was recognized immediately.

The spectral reflectivity (0.30 to 1.10 microns) of several asteroids has been measured for the first time. The reflection spectrum for Vesta contains a strong absorption band centered near 0.9 micron and a weaker absorption feature between 0.5 and 0.6 micron. The reflectivity decreases strongly in the ultraviolet. The reflection spectrum for the asteroid Pallas and probably for Ceres does not contain the 0.9-micron band. Vesta shows the strongest and best-defined absorption bands yet seen in the reflection spectrum for the solid surface of an object in the solar system. The strong 0.9-micron band arises from electronic absorptions in ferrous iron on the M2 site of a magnesian pyroxene. Comparison with laboratory measurements on meteorites and Apollo 11 samples indicates that the surface of Vesta has a composition very similar to that of certain basaltic achondrites.

Basaltic achondrites are special meteorites, only 1 in 7 meteorites are basaltic achondrites, which refers to the fact that they have been heated to the melting point of rock, had the heavier elements separate out, and that the chondrules, or spherical drops of material from the early solar nebula, have melted and mixed with the rest of the rock. Basaltic achondrites, have no chondrules, and they are basaltic in composition, which

refers to the percentage of silica in the rock (basalts have <52% silica). Among the meteorites, the spectral signatures of basaltic achondrites are unique. (Note that Vesta is an HED parent body or analogue).

McCord, Johnson and Adams recognized that they were learning something significant about Vesta, and they submitted their paper to Science magazine, because it would be of interest to a wide scientific audience. As this research team studied more asteroids with reflectance spectroscopy, they were surprised that they found no other asteroids with similar spectral features.

There was a puzzle that we couldn't explain. If Vesta were the only asteroid with the spectral signature of the eucrite meteorites, how did fragments of Vesta get to Earth? Until 1985, the dynamicists were certain that there was no mechanism to get fragments of Vesta to Earth. First of all, Vesta is large and is intact, so there shouldn't be many fragments floating around. Secondly, dynamically, the orbits of the main belt asteroids have been the same since the formation of the solar system, 4.56 billion years ago.

In the early 1980's, Jack Wisdom was studying the dynamics of the solar system. In a series of papers he outlined a mechanism where perturbations within the asteroid belt, bring material into a dynamical resonance that then sends fragments into an earth-crossing orbit. This we get meteorites on Earth from the asteroid belt.
http://swiss.csail.mit.edu/users/wisdom/

At about the same time, his colleague, Rick Binzel, was carrying on a tradition of spectral reflectance measurements at MIT, and observing smaller and fainter asteroids, using the technique that Tom McCord pioneered. Binzel and Xu, found more Vesta-like asteroids, which they called Vestoids. When they plotted the location of these meteorites with respect to their orbital elements, low and behold, a string of Vestoids, is found going from Vesta, inward to the 3:1 Kirkwood gap, and observational evidence was found to support the dynamical theory that Jack Wisdom proposed. This is a very satisfying moment for scientists. The papers were written and published in Science and Nature.

So let's recap.
1. The spectral signature of Vesta is the same as the eucrite meteorites.
2. A dynamical mechanism is found to deliver fragments from an asteroid into an orbit that intersects the Earth.
3. Small asteroids with the spectral signature of Vesta are found and their location traces a path from Vesta to the 3:1 Kirkwood gap.

There are two more chapters to finish off the story.

Lightcurve measurements also indicate that there are spots on Vesta that are regional in nature.
Mike Gaffey observed Vesta as it rotates on its axis in the course of a Vesta day. He observed changes in the spectral reflectance that indicates compositional changes.

When the Hubble Space Telescope trained its eyes on Vesta in 1994, an irregularity in its shape was seen. That irregularity is equivalent to a basin that is 285 km ? wide and 8 km deep. You might say that this is the smoking gun.

It now appears that a giant chunk of Vesta was removed, by what must have been a near-cataclysmic event.

So we are confident that when we study the HED meteorites, we are learning something about Vesta. That information is very important, but they are just pieces. What is Vesta like on a global scale and as observed with cameras and spectrometers that can distinguish regional and spatial differences and morphology and topography?

These are important questions that we pose while we await the return of data from Vesta.

Are there meteorites from Ceres?
We don't think so, but it is time to revisit that question, now that we have recently studied Ceres with state of the art instrumentation.