Spring 2022

Improving Asteroid Remote Sensing by Examining Past Martian Methods

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Major: Geographic Information Science and Technology

Thesis Title: Improving Asteroid Remote Sensing by Examining Past Martian Methods

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IMPROVING ASTEROID REMOTE SENSING BY

EXAMINING PAST MARTIAN METHODS

A Thesis Submitted to the
Graduate Faculty
of Jacksonville State University
in Partial Fulfillment of the
Requirements for the Degree of
Master of Science
with a major in
Geographic Information Science and Technology

By

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May 6th, 2022

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Abstract

Deep Space Remote Sensing is an ever-evolving field. The very first missions into deep space were explorations that utilized trial and error, as humanity faced a new frontier of unknowns. Over these 70 years of deep space exploration, much attention has been given to our three nearest celestial neighbors: the Moon, Venus, and Mars. Mars, in particular, has been the target of much observation and study due to it being a target for future colonization. Meanwhile, the areas beyond Mars have had comparatively less focus. Asteroids and objects beyond Mars offer many new horizons for humanity to study. By using what we have learned from Martian observation and utilizing technologies that have proved their mettle in these endeavors, it can be possible to improve future missions beyond the "Red Planet."

This research will encompass a great deal of philosophy and data and offer a deep dive into the history and development of asteroid remote sensing. Research will also be done into Martian probes, which have enjoyed almost 70 years of development compared to a mere two decades for asteroid remote sensing, and how Mars Orbiters may offer insights into further ventures into the Asteroid Belt and beyond. The goal of this research is to bring a better understanding to how asteroid and planetary remote sensing could evolve by looking at the hardware, processes, and techniques used by Martian missions, and applying them to Asteroid and outer planet missions.

Acknowledgements

I would like to take this opportunity to thank the people who have supported me during the voyage to complete this thesis. First, I would like to acknowledge Dr. M. Sean Chenoweth, my thesis advisor, for his support both academic and personal, and for being an incredible fountain of knowledge. I would also like to thank the members of my thesis committee. Dr. Saideh Gharehchahi, for assisting me in advancing my knowledge, and fostering the growth of my passion for the field of Remote Sensing. Additionally, Dr. Vicki Tinnon-Brock for the fantastic support and for providing valuable advice in times when it was needed most.

I would also like to thank Mx. Madeline Miles for their patience, assistance, and friendship during the creation of this thesis. Thanks for being the Spock to my Kirk. I would be remiss to discount the contributions of Ezio, Reid, and Monty.

Lastly, I would like to pay homage to something that has inspired me to study space and all its oddities: Star Trek. From my youth to my return to college in my 30’s, Star Trek has inspired me to keep looking beyond for answers, but also to be content with the questions I am left with. To all who read this: Live Long and Prosper and remember that “Infinite Diversity exists through Infinite Combinations.”

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Abbreviation Key

NASA	National Aeronautics and Space Administration
MRO	Mars Reconnaissance Orbiter
MGS	Mars Global Surveyor
JPL	Jet Propulsion Laboratory
RGB	Red, Green, Blue Light Wavelengths
NIR	Near Infrared Wavelength
IR	Infrared Wavelength
Perilune	Distance closest to the Moon
HAMO	High Altitude Mapping Orbit
LAMO	Low Altitude Mapping Orbit

Table 1. Abbreviation Key.

I. INTRODUCTION

Deep Space Remote Sensing is a field that is relatively old, but thanks to the advancement of camera and delivery vehicles, new opportunities for discovery and scientific advancement abound. It is only logical, thanks to proximity and less harsh conditions than our actual closest neighbor, Venus, that Mars is the most widely accepted target for future manned planetary missions. According to NASA's active mission list, as of 2021, there are eight orbiters actively surveying various Martian processes. (Greicius, 2015) But Mars, despite being a focus in both the media and the scientific community, is but a step for humanity on our pathway to the stars. Beyond Mars is one of the most expansive and diverse areas in our entire solar system: the Asteroid Belt. Very few missions have been launched to study this unique region of space, but the ones that have revealed that what we know now is but the tip of the proverbial iceberg for humanity. One mission in particular, Dawn, was launched in 2007 with the goal of collecting data on the two largest non-planetary bodies in the solar system: Ceres and Vesta. The data collected from this mission provided insights into not only the Ceres and Vesta itself, but the possible origins of our solar system (Springer, 2016).

Spawned from the data collected and analyzed from these orbiters, Martian and Asteroid remote sensing is a unique field of study, yet despite existing in separate spheres, intersect in a multitude of ways. Given that humanity has yet to reach both Mars and the Asteroid Belt with manned missions, scientists are at a disadvantage due to the inability to collect on-site data. The only tools left to a Planetary Cartographer is the data sent back from Orbital Platforms and Rovers. While this may be seen as a detriment to some, the creation and advancement of orbital platforms such as DAWN, the MRO, and the MGS have provided valuable data with which to study celestial geomorphological formations.

- Research will be done to analyze the payload of selected probes and how they assisted in completing their assigned mission.
- Additional research will be done into analyzing deep space remote sensing methods, predominantly focused on the DAWN mission, as well as data from the Mars Global Surveyor.
- Analysis of data from both Mars and Vesta will be conducted, with a focus on the quality of the data.
- These will be compared and contrasted against one another for the purpose of understanding how data collection methods from Martian missions, which have been occurring since the 1960's, can improve future missions to asteroids.

II. LITERATURE REVIEW

Planetary Cartography is not a new field of study, but it suffers from a lack of streamlined data management and standardized practices. The most important key to streamlining the field of Planetary Cartography lies in the ability for data collectors and mappers to have efficient, consistent, and standardized platforms on which the data may not only be available, but distributed (Oberst, 2017). As maps are the single greatest way to communicate spatial data, the need for easy access and simple manipulation of the data is paramount. It is also important to note that mapping of Planetary bodies uses many of the same processes and workflows seen in terrestrial cartography, and therefore existing infrastructure supporting those systems can be used as models for extra-terrestrial data mapping (Oberst, 2017).

The process of managing cartographic data of planetary bodies begins with the sensor itself. While there have been very few probes sent to or beyond the Asteroid Belt in comparison to the number of probes used to study inner solar system planets, each of these probes has employed different technologies to fulfill the mission on which they were dispatched (Siddiq, 2018).

Historical Context

When first approaching the subject of Planetary Cartography regarding deep space, it is important to look back at the path blazed through the past 60 years by the space agencies that have spearheaded the effort to explore deep space. While humanity has been launching objects into space since the late 1950's, it was not until 1991 during the *Galileo* mission that a spacecraft first approached an asteroid at a close enough distance for observation. Furthermore, it was not until 2001 that an unmanned spacecraft entered orbit, and proceeded to land upon an asteroid (Farquhar, 2001). In contrast, the first probe to successfully reach Mars occurred in 1964 when the JPL engineered *Mariner 4* made a successful flyby of Mars. This also marked the very first time a mission sent back imagery of another planet. The proximity of Mars to Earth has allowed for faster development and deployment of missions compared to objects further into the solar system, which may take years to reach, even after the launch of the mission.

Compared to Mars, the study of asteroids and comets is in its relative infancy. But it is still equally important to lend attention to these celestial bodies, as their existence may provide clues to the early days of our solar system, and possibly provide valuable resources to future deep-space missions. Perhaps the most well-known and comprehensive mission to visit an asteroid can be seen in the case of the Dawn mission. Launched on September 27th, 2007, DAWN was the first mission to visit the largest celestial bodies in the Asteroid Belt, Ceres and Vesta. After spending four years in transit, Dawn reached Vesta, and two years later, Ceres. The Dawn mission had three goals: to help decipher clues about the early days of our solar system, to help establish what building blocks were used during this time, and to define the differences in how Vesta and Ceres both formed and evolved over time (Siddiq, 2018).

Data Collection Methods

Deep Space Sensors vary from mission to mission. Due to changing mission goals, the equipment used on various deep space probes is as varied as the objects they are sent to study. What is perhaps the current benchmark for space probe sensors is the

Framing Camera used on the DAWN space probe as it collected data from asteroids/proto-planets Ceres and Vesta.

The DAWN Framing Camera was a German contribution to the project and featured a series of cameras that were made to measure the RGB, NIR, and IR bands. Additionally, another camera was specifically crafted to assist in mapping the topography of Vesta and Ceres. A camera for navigation was also installed. For redundancy, two of these cameras were mounted onto the spacecraft, and each was given a re-closable door apparatus to protect the camera while in transit. Each of these cameras weighed only 5.5 kg (12.1254 lbs.).

The cameras on the DAWN spacecraft were some of the most complete mapping payloads to leave our orbit and could help to define future mapping and astrological studies of non-planetary bodies (Russell, 2012).

To further investigate the field of data collection, it is also necessary to look at other sensors aboard other spacecraft that have had orbital remote sensing in mind as their primary goal. As Mars has set many benchmarks for planetary remote sensing, looking into the most well-known and successful Mars missions can add valuable insights into future missions beyond the red planet.

Learning from Mars Missions to Better Outfit Future Deep Space Ventures

By studying the past sensors and payloads of deep space exploration craft, it would be possible to ascertain the methods and hardware that was the most effective at achieving the assigned mission. While many spacecrafts use highly specialized sensors tailor-made to fit their respective missions, it may be possible to find sensors used by other, more versatile spacecraft that may have fit the mission profile just as well, if not better.

Due to the variety of spacecraft created by many different countries, the hardware used on each deep space probe has been varied and unique. It is for this reason that a standardized space probe would be a boon to future space programs. This would assist in reducing construction costs, create more rapid concept-to-launch times, and allow for training of crew personnel to take less time.

The History of Deep Space Remote Sensing

Deep Space is defined as any space that exists beyond the direct influence of Earth and the Moon. This description is, in itself, a very large classification. The percentage of space that is inside the realm of Earth and the Moon is vastly smaller, by astronomical proportions, than the area that lays without. The exploration and education on Deep Space areas are heavily reliant upon probes, utilizing a variety of scientific instruments to help Earth-based scientists to gain a better understanding of these vast expanses. The imagery and visual information we receive all fall under the umbrella of Remote Sensing. Remote Sensing is defined as the collection of information via indirect means, typically describing information gathered without direct, physical human interaction. Remote Sensing is a science almost as old as humanity itself, as humans have been observing stars and faraway objects using a variety of instruments since the invention of the first telescopes and aerial data collection methods. When coupled with deep space exploration, Remote Sensing, when specifically applied to planets and celestial bodies, can be described as Planetary Cartography. While Planetary Cartography is not a new field, it is thanks to advancements in the last 70 years of space exploration that it has become a pathway that helps pave the way for future ventures beyond our own planetary sphere into the reaches of deep space. Methods of Deep Space Remote Sensing and Planetary Cartography are varied and exist in multitudes, and to assist in understanding on how we may better improve upon existing methods, we must first examine the history and milestones that have brought the field of Deep Space Remote Sensing to where it is today.

Luna 1

The very first object to be launched into space with the intent to collect data on other planetary bodies was the Soviet-made Luna 1 space probe. Launched in January 1959, Luna 1 was the first satellite to successfully reach a celestial object outside of Earth's orbit and holds the distinction of being the very first manmade object to achieve escape velocity, which enabled it to leave Earth's gravitational field. While it contained no equipment to capture imagery of the Moon, it instead collected data ranging using a Geiger counter, micrometeorite detector, and a magnetometer. This mission was the first step into space exploration for mankind and led to revelations on the nature of interplanetary space, including the discovery of solar winds, discoveries about radiation around both the Earth and the Moon, and the interaction of gasses in outer space (Balint, 2002).

Following the success of the Soviet Luna Program, and the escalation of the Cold War into a new theater beyond our own planet thanks to other successes of the USSR's space program, the United States space program, known as NASA (National Aeronautics and Space Administration), started work on its very own probe to explore the Moon. This culminated in the creation of the Lunar Orbiter 1 space probe. Launched on August 10th, 1966, Lunar Orbiter 1 had the distinction of making the very first footprint into the new ground that was Planetary Remote Sensing: it was the very first spacecraft to give humanity a glimpse of the Earth from the Moon.

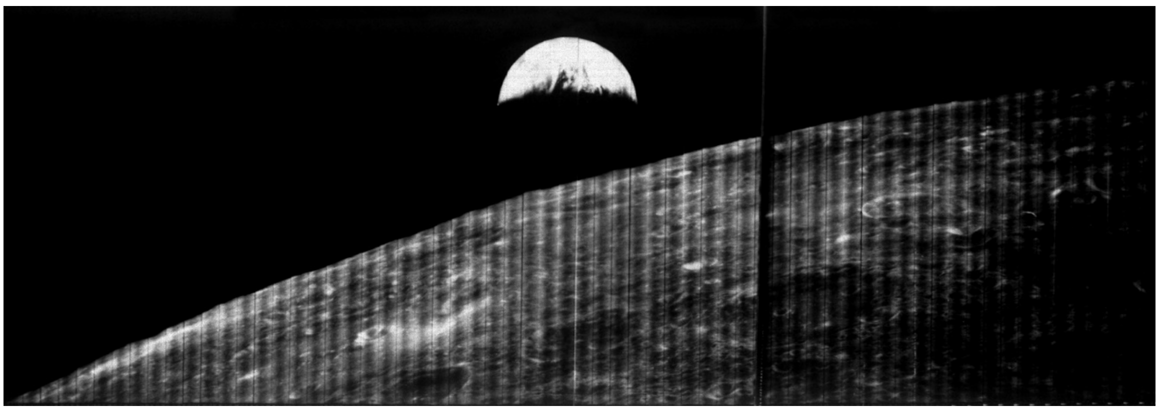

Figure 1. The Earth from the Moon, 1966.

Orbiting at a distance 46 miles above the Moon's surface (the orbiter's perilune), Lunar Orbiter 1, utilizing a massive 145-pound camera rig built by Eastman-Kodak, used two separate cameras: the first a narrow angle camera with a 3-foot resolution camera, and the second a wide-angle lens with a 25 foot resolution. Using 70mm film, the Eastman-Kodak camera rig took pictures in a series of 1, 2, 4, 8, and 16 images at a time. These were highly advanced sensor packages at the time and were designed from cameras that had previously been used on United States Military surveillance satellites. The images taken by Lunar Orbiter 1 were then developed onboard the spacecraft from the 70mm film used to obtain them, and then beamed back to Earth via radio signal, which were then converted into imagery. These raster images were 2.67 x 65 mm in size and were created using GRE (Ground Reconstruction Equipment). Lunar Orbiter I is also notable for having been the very first spacecraft to help survey the surface of the Moon to assess landing sites for the Apollo program (Mignard, 1979).

In the field of Remote Sensing, NASA'S Lunar Orbiter 1 opened the door to a vast array of new possibilities for humanity's understanding of not only Earth, but other objects within our Solar System. For the first time, humanity was able to visualize regions of space that could previously only be seen from its own home.

The Venera Program

After the success of Lunar missions by both the USSR and NASA space programs, the next logical step for exploration lay with our nearest planetary neighbors: Venus. The exploration of Venus and its surface is a story of short-lived excursions. Venus is hostile to both equipment and organic material as it is the single hottest planet in our solar system. While Mercury is almost 10 million miles closer to the sun than Venus, the atmosphere of Venus, which is rich in carbon dioxide and sulfuric acid, has created a highly toxic, incredibly hot greenhouse effect (Bertaux, 2007).

Due to this greenhouse effect, the surface of Venus provided engineering challenges for the scientists of the USSR, as the surface of Venus exists at a density of 180 Earth atmospheres, and a temperature that averages at around 1000 C. The Soviets, who developed the Venera probe in secret under the codename "Heavy Sputnik," attempted to take readings from the surface of Venus multiple times, but it was not until Venera 7 that one of their spacecraft would reach the surface. The circumstance of Venera 7 reaching the surface of Venus was a turbulent affair, as the parachute that assisted in its descent collapsed in on itself and the spacecraft plummeted to the ground. While it was assumed that the probe would be destroyed, it continued to transmit atmospheric data back to Earth for 23 minutes before eventually succumbing to the harsh Venusian conditions (Avduevskij, 2007).

The breakthrough success of the Venera program came from Venera 9. Venera 9, launched on June 8th, 1975, and reached Venus in October of the same year, and was the first of the Soviet probes to reach the surface both intact and operational. On October 22nd, 1975, Venera 9 set a milestone in the field of Deep Space Remote Sensing: Venera 9 successfully transmitted imagery from the surface of Venus back to Earth. While not a complete success, due in part to the inability for the Venera 9's camera to open to its complete 360-degree view, the camera still returned a 170-degree field of view that showed the surface of Venus for the first time.

Figure 2. Venera 1 First Image from Venus (NASA Goddard Spaceflight Center, 1975)

The Venera camera was much different than many of its predecessors, as this camera was instead modeled of a Panoramic Telephotometer that resembled a television camera more than typical photography cameras. It recorded imagery in a 128 x 512, 6-bit resolution, and was able to record live images of the surface of Venus (Ksanfomality, 2013). Venera was active for another four months before the Soviet scientists lost contact with it, but it would not be the last Venera probe to be sent to Venus, as the program was active for another nine years following the success of Venera 9. Each subsequent mission would attempt to replicate the successes of this landing and provide imagery of increasing clarity over the near decade the program would remain active. (Siddiqi, 2018)

Venera paved the way for future planetary missions. Venus, the most inhospitable of planets in our solar system due to its corrosive atmosphere and incredibly hot surface temperatures, provided engineering challenges that were overcome over the course of the program's history, and helped pave the way for future expeditions to other celestial objects.

The Probes of Mars

While the Moon and Venus were an early focus of the Soviet and United States Space Programs, the focus of each organization eventually turned to objects further beyond. Mars has been one of the single most studied planets in our solar system. While Venus has been observed by probes sent from Earth a total of 42 times throughout the existence of human space exploration, Mars holds the record for the greatest number of missions sent to study a celestial body in deep space. Mars is a current target for human settlement thanks to the upcoming Artemis mission, and as such has undergone a great deal of observation throughout the course of the past few decades.

I. **Mariner 4**

When dealing with the fields of Remote Sensing and Mars, the very first intersection between these two fields occurred with Mariner 4, launched on November 28th, 1965, from Cape Canaveral. Mariner 4 made an eight-and-a-half-month journey from Earth and conducted the very first successful flyby of the planet while collecting imagery of Mars. This imagery was the first of its kind, and the very first images taken of a planet that was not Earth. This imagery was taken with a 200 x 200-pixel, 6-bit camera, from a height of 17,000 km from the surface of Mars (Leighton, 1966). The images were then sent back to Earth. This data was transmitted twice to ensure maximum coverage and accuracy. The success of Mariner 4 would inspire future missions to the “Red Planet,” and it would only be one short decade before the next phase of Martian exploration would begin.

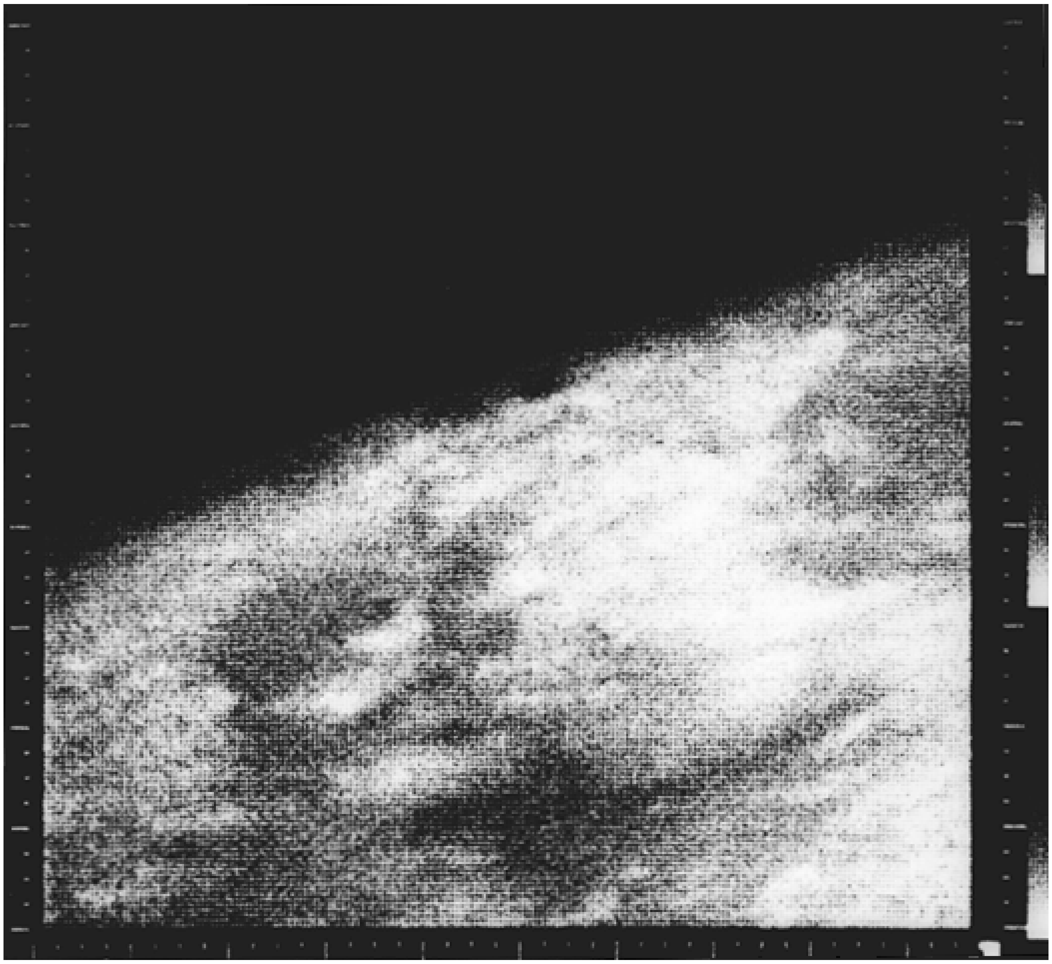

Figure 3. Mariner 4 First Mars Image, 1965.

II. Viking 1

Following the continuing successes of the Mariner missions, it was then decided that NASA would attempt to send a lander to Mars. This culminated in a mission that would do something previously not done prior in the history of Mars exploration: a probe that was both an Orbiter and a Lander would be deployed to gather data. Launched on August 20th, 1975, Viking 1 ventured to Mars and reached its destination on June 19th, 1976. While the intention for Viking 1 was to detach the orbiter a few days prior to arrival, the landing site had proven to be more hazardous than previously thought. The discovery of this issue was thanks in large part to the deployment of the camera package that was stored within the Viking 1 Orbiter. The Orbiter imagery package, a two-camera system that, like Venera, was based on television cameras of the time, was called the Visual Imaging Subsystem. The Visual Imaging Subsystem consisted of a camera with a focal length of 475 mm and sported a 7-bit 1182 x 1056-pixel image format. Additionally, the camera took a photo of an area every 8.96 seconds. This slow camera time and large focal length meant that the resolution of the imagery provided by Viking 1 would be lower than that of many space probes of the time, clocking in at only 100 m resolution on average (Wellman, 1976).

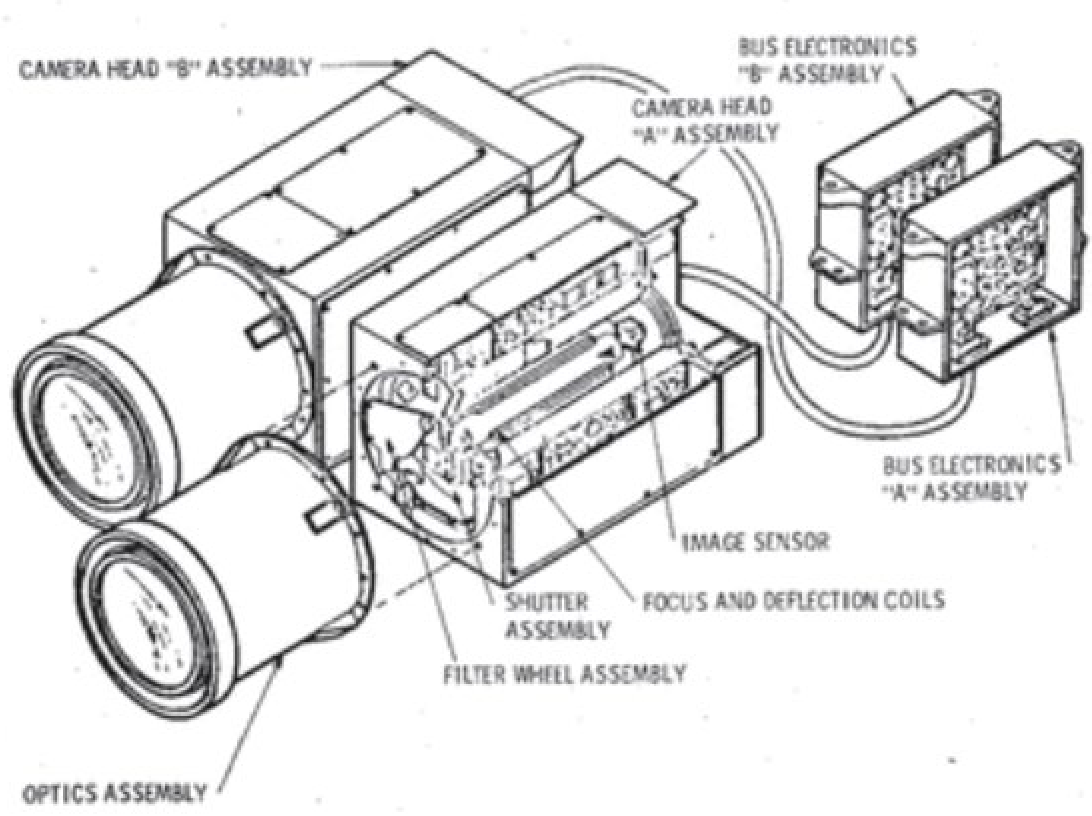

Figure 4. Viking Orbiter Camera (Wellman et al., 1976).

Despite this lower resolution, scientists back on Earth were able to assist in finding a new location with which to land the Viking Lander. Once a new site was chosen, the Lander was detached from the Orbiter and sent to the Martian surface. On July 20th, 1976, the Viking Lander safely descended from orbit and came to rest on a plan named Chryse Planitia.

It was at this location that the very first image taken of the surface of Mars from the surface of Mars was taken. Viking 1's onboard camera package was quite advanced for its time, as instead of following previously utilized photographic methods, it instead was composed of 12 silicon photodiodes. This camera package scanned an area and scanned it into the lander's memory to then be sent back to Earth for analysis. These photodiodes utilized six different light bands (Red, Green, Blue, NIR, and two IR frequencies), and thus captured the very first image of the Martian surface (Wellman, 1976).

Viking 1 operated well beyond it's expected operational life, as did the lander, but paved the way for future Martian missions.

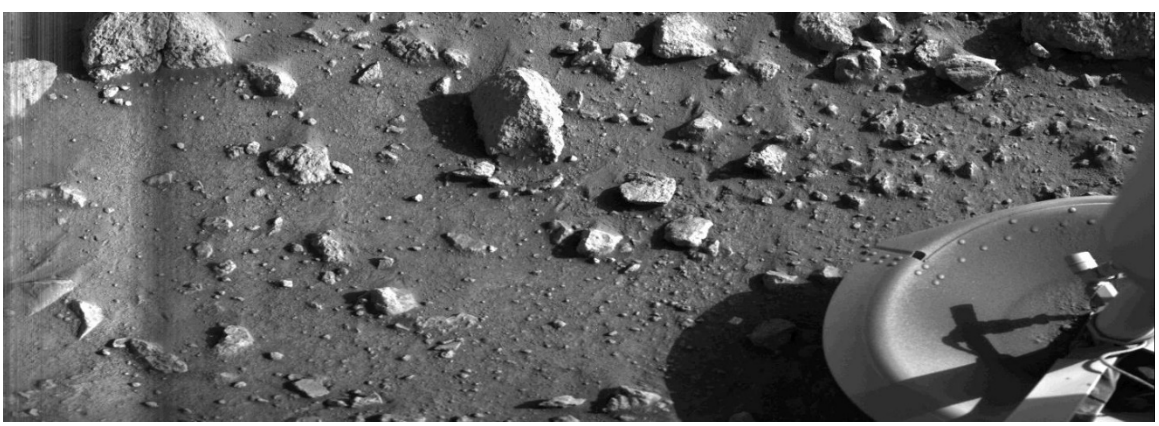

Figure 5. First Image of Mars from Viking 1 Lander.

It is at this point that the examination of current missions must be done. Mars has proven to be one of the most successful targets for surveying and testing new deep space technologies. From the employment of multiple orbiters for the purpose of understanding weather and surface conditions, to the use of robotic rovers to survey geologic processes, to the eventual use of helicopter-like drones to gather imagery and atmospheric conditions, the techniques used on Mars have been the standard for how we develop technologies to explore areas further into our solar system.

Chapter 3- The DAWN Mission and Asteroid Exploration Philosophy

With the history and importance of past milestones in the field of deep space exploration established, it is possible to analyze methods that may assist in ventures to bodies that may be overlooked due to their considerable distance from Earth or perceived lack of current scientific importance. Many of the locations previously discussed were done so about locations that were within proximity to Earth, or within the Inner Solar System. While areas within these limits are naturally expected to be the first targets for manned exploration, areas beyond the Moon and Mars hold keys to many more mysteries of our solar system, and perhaps hold the answers to questions we have not yet begun to ask. Discoveries from missions that have been launched into deep space continue to provide reasons to continue such programs.

The most logical target for exploration into the history and development of our solar system lies within the Asteroid Belt. Existing between Mars and Jupiter, the Asteroid Belt consists of leftovers from the formation of our solar system. While it encompasses a large circumstellar region between Mars and Jupiter, it has a comparatively small mass when weighed against other celestial heavyweights. The entire mass of the Asteroid Belt equates to only 4% of the mass of Earth's Moon. Yet within this region are a variety of stellar bodies ranging from small asteroids no larger than the size of a city bus to objects large enough to be classified as dwarf planets. Of the objects in the Asteroid Belt, four objects stand apart from the rest: 1-Ceres, 4-Vesta, 2-Pellas, and 10-Hygiea (Clark, N.D.). Of these objects, Ceres is the largest, itself accounting for 25% of the Asteroid Belt's total mass. Vesta is the second largest object in the Asteroid Belt. While not a dwarf planet like Ceres, it holds the distinction of being the largest known

Asteroid in our solar system (Frigeri, 2019). It is these two objects that have provided proof to the point that further exploration is necessary beyond the reaches of Earth and Mars. While there have been probes launched to search the far reaches of our solar system, most famously Voyager and Cassini, they pale in number compared to missions launched to Mars and the Moon.

This bias toward missions that only target areas within Earth's nearest stellar neighborhood is something that should be remedied. It stands to reason that this would be the case. As with any spatial movement of persons and goods, understanding what is nearest to one's location is of utmost importance. It assists in establishing safer and more efficient modes of travel. It is why the upcoming Artemis mission, which has an eventual goal of sending humans to Mars, has a component that includes the use of the moon as a jumping-off point to send humans into deep space. It is only logical that missions will need to be undertaken to Earth's closest stellar neighbors before any other destinations can be reached. But this focus on what is nearest to us also excludes chances to understand much of what may make our "stellar neighborhood" what it is.

To add some perspective to the argument that we must begin to look further beyond our immediate goals: there have been nine total missions to areas beyond the Asteroid Belt. As of the date of this thesis, only one mission has been launched with the express intent of studying an object in the asteroid belt (Salmon, 2021). To put this in perspective, there have been over 100 objects sent to the moon over the course of the past 70 years of space exploration. 49 separate objects have been sent to Mars. Forty-two spacecraft have been sent to Venus. This shows a remarkable bias toward nearby objects compared to missions to explore outer solar system objects. Again, this is only logical, but the vast ratio of objects that have explored the Moon, Mars, and Venus compared to those exploring beyond is cause for examination.

Why might this occur? What is preventing this exploration of deep space objects? Why has only one mission been dispatched to the Asteroid Belt? It is the belief of the author that these two circumstances may be the cause for this occurrence.

1. **Mission Time**: The average time for a mission to the Asteroid Belt and beyond is measured in years, not months as can be the case when an object goes into transit between Earth and Mars or Venus. This is no surprise, as the distances when exploring beyond Mars get greater and greater with more distance between objects occurring as you travel beyond. For reference, the distance between Earth and Jupiter is 555 million km with Mars and the entirety of the Asteroid Belt in between. The distance from Jupiter to Saturn, the next planet in our solar system, is 450 million km, almost 80% of the distance from Earth to Jupiter. These distances present challenges to ensure that any probe launched beyond is both able to survive the transit, as well as ensure that the equipment is both powered and functional upon arrival. The number of unknowns increases as more time is factored into the mission, and the chance for something to go wrong increases, especially since space is an area of relative unknowns when going beyond Mars.
2. **Cost**: As of statistics gathered from NASA, the average cost to launch and sustain an unmanned mission to deep space is approximately 300 million USD (Bushnell, 2021). This is a vast amount of money to both design and launch an object into deep space when it has no immediate monetary benefit. Costs this high make it difficult for projects to come to fruition. Most satellites cost upwards of

> 1.5 million USD each year to keep running. This figure typically only accounts for Earth-orbiting satellites, but the comparison can only be inflated when looking at missions that require a full team of scientists and engineers to ensure success, especially over a span of years between any surveying being done. The costs are exceedingly prohibitive to ensure proper exploration of deep space objects that are not current targets for manned exploration.

With this possible explanation in place, what can a future scientist wishing to explore a niche part of the solar system hope to do? There are many different avenues that can be taken, but to first understand the nuances of exploring an asteroid or deep space object, looking at one of the most recent missions to explore past-Mars objects can provide some valuable insights.

Of the missions launched to study outer solar system objects, the Dawn Mission is one that merits further examination. The Dawn Mission was a watershed mission in the field of remote sensing. For hundreds of years, we have known that the Asteroid Belt was home to celestial bodies that were far larger than even some of the traditional planets in our solar system. Dawn was launched with the intention of observing two such objects: 1 Ceres and 4 Vesta, the largest and second largest objects within the Asteroid Belt, respectively. These objects had once been classified as planets during the early days of modern astronomy, as they were almost indistinguishable from planet and star to Earth-based observers. But during the early 1900's, a new class of celestial body was added: asteroid, which means "star-like." Ceres and Vesta have been known to mankind for hundreds of years, even prior to this classification, but had not been the target of any probes or missions until the early 2000s. Greenlit by NASA in 2003, the Dawn probe was assembled by JPL and scientists at UCLA for $446 million USD. The original allotted budget for this mission was $300 million USD, but the addition of many new instruments and sensors inflated the cost well over its original projections (Springer, 2016).

Figure 6. Dawn Mission Artwork.

The Dawn mission was launched on September 27th, 2007, from Cape Canaveral, Florida, USA. Dawn was special for a variety of reasons that will be explored, but the first of which was highlighted as the probe made its way to its destination. Dawn employed a new type of thrust technology using Xenon to create ionic propulsion. This allowed Dawn to reach far distances much faster than previous deep space probes, and as such cut down the mission timeframe (Brophy, 2003). Most missions to study deep space can be measured in a length of five years and beyond, as the distances a probe must travel are much greater than one heading to Mars or the Moon. While this was still the case for Dawn, the use of this new thruster technology, along with the masterful use of both the Earth and Mars to slingshot itself at faster and faster speeds toward its destination, allowed for a much smaller temporal span.

Dawn’s first target was the asteroid 4-Vesta. The probe arrived at Vesta on July 16th, 2011, after four years in transit. It was here that a man-made object began the very first Asteroid survey mission. Vesta, being the second largest object in the Asteroid Belt, proved to be a great test for the equipment carried within Dawn.

Dawn proved to be an investment well spent, as its propulsion system was not the only advanced piece of equipment carried onboard. In the field of deep space remote sensing, it is difficult to find a better piece of imagery equipment than the Dawn Framing Camera. Mounted within the Dawn spacecraft were two different cameras that had specialized covers to protect them during transit. Each camera, weighing in around 5.5 kg, was specialized to capture a multitude of spectral bands ranging from Red/Green/Blue to NIR, IR, and UV, which occurred between the wavelengths of 0.3-5 microns. Labeled as FC1 and FC2, each camera was identical in its construction, and allowed for unprecedented coverage of any surface it happened to be surveying. The lens also featured a filter wheel mounted lens to allow for different bands to be directly observed. The resolution of this camera was 12m per pixel (Sierks, 2011). While not all imagery from Dawn was of this resolution due to the orbital altitude of the probe, it still allowed for a level of clarity in its imagery that rivaled the quality of many current Earth-observing satellites.

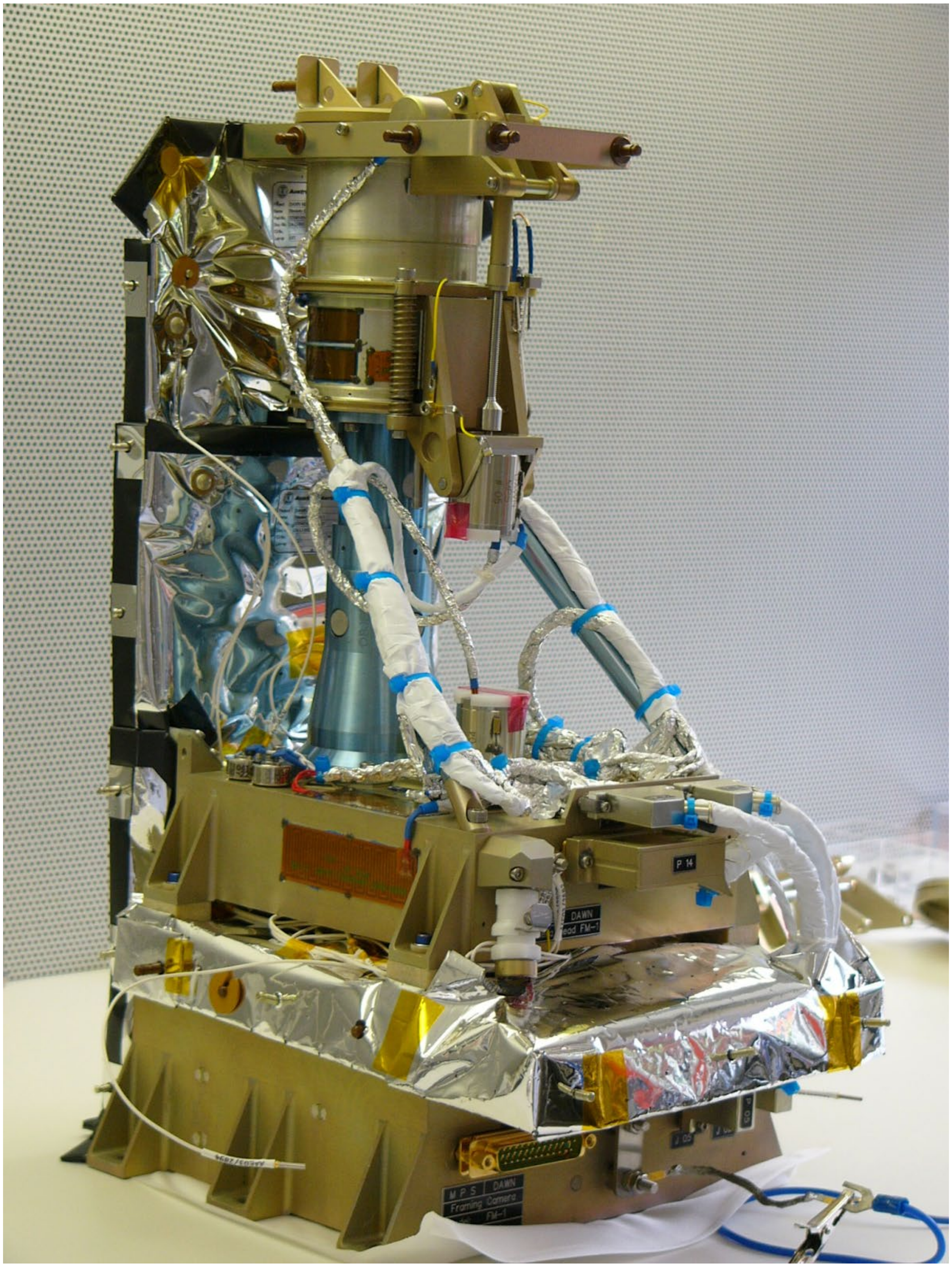

Figure 7. The Dawn Framing Camera prior to Installation. (NASA/JPL)

The images from Dawn were then stored on a CCD drive, which then processed the transmissions of the data back to Earth. This camera served a multitude of purposes beyond mere observation: many of the goals of the Dawn mission revolved around studying the geomorphological and topographical features of Vesta and Ceres. It has long been theorized that objects within the Asteroid Belt are either remnants from the creation of the solar system, or even objects that have been caught by the gravitational pull of our sun and now reside within it. The Dawn framing camera hoped to provide imagery that would allow earth-based scientists and geomorphologists a chance to being to learn more about the formation of celestial bodies by studying objects that either did not have the chance to form into full-sized planets, or had this process interrupted (as is now known to be the case with Vesta). When Dawn completed its survey of Vesta, it marked the very first time that humans were able to map an asteroid nearly completely. This allowed for a variety of innovative studies to begin, many of which revolved around the peculiar shape of Vesta and the oddity of many of its geomorphological features.

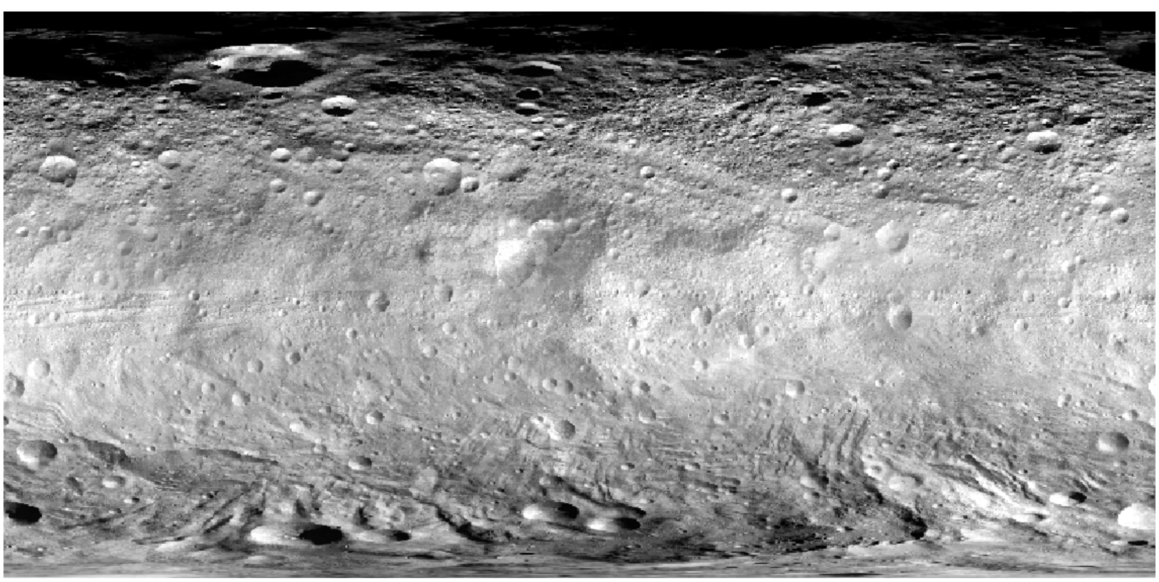

Figure 8. Vesta Mosaic from the Dawn Framing Camera.

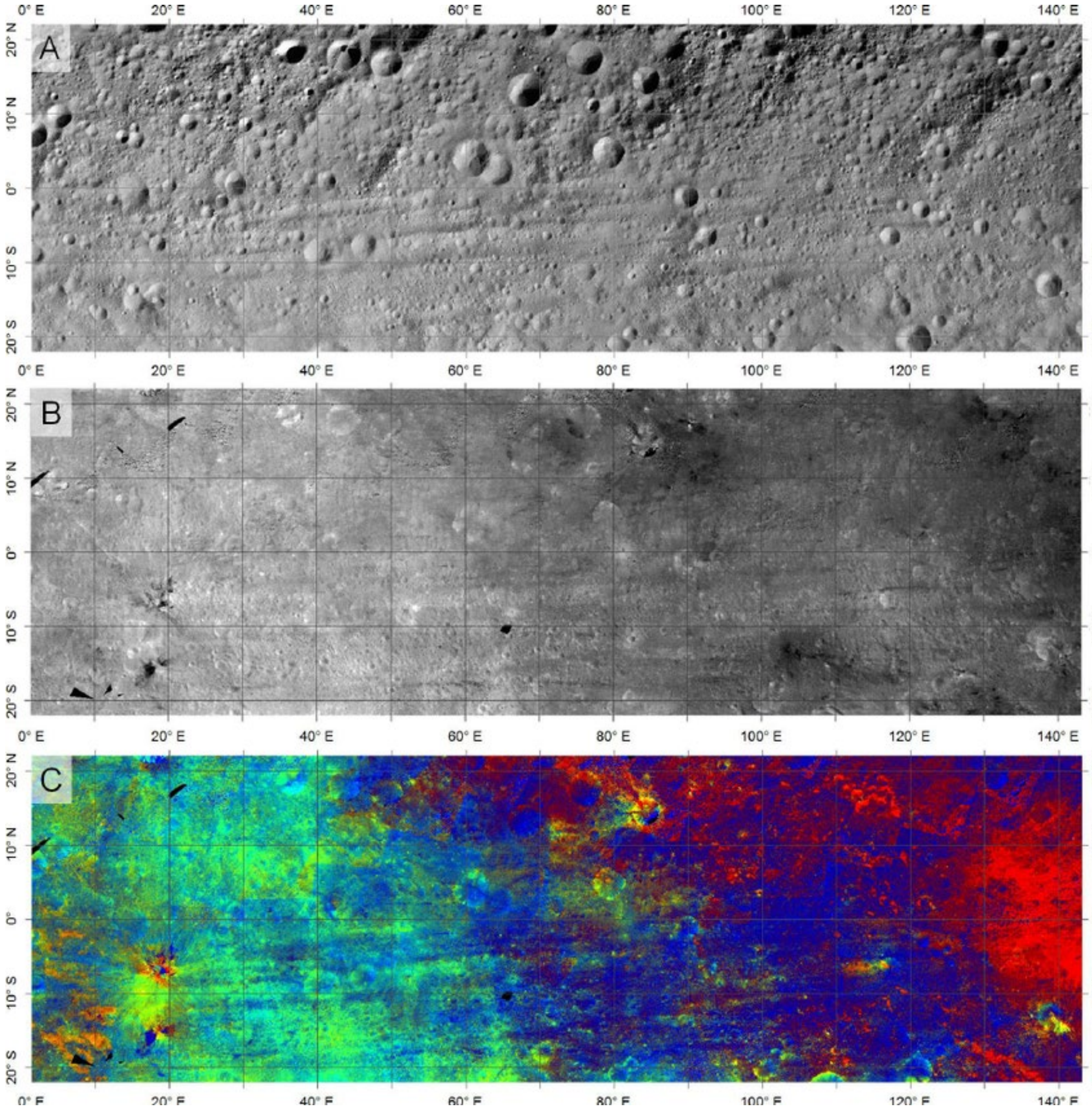

Figure 9. Imagery of a 20° Slice of Vesta's Equatorial Region. A) HAMO Imagery, B) NIR Imagery, C) Colorized IR Imagery (NASA/JPL)

The survey of Vesta was a success in all regards and from every standpoint and proved that Dawn's equipment had been successful in helping to fulfill its mission. Even when looking at the astounding cost of the probe during its development, it can be argued that it more than made up for it.

The question now is: how can this assist future remote sensing specialists when attempting to survey asteroids in the future? What can be learned?

Chapter 4- Stepping Stones from Mars to the Belt

It is difficult to discuss deep space remote sensing without discussing the successes of the Martian missions. Mars has enjoyed a multitude of scientific equipment being deployed to its surface. Thanks to this bevy of scientific instruments being tested and refined over the many years of Martian exploration, it is possible to look at Martian exploration efforts and begin to find methods that may be able to be applied to Asteroid Exploration.

To examine the successes of Martian missions that involve remote sensing as a primary mission profile, we must first focus upon missions that have been launched to this exact end. Of all the equipment sent to observe Mars and map it's surface topography, the Mars Reconnaissance Orbiter holds what is widely believed to be the most powerful sensor package ever sent into deep space. The sensor, known as HiRISE, rivals the accuracy of many Earth-observing satellites. At a weight of 65 kg, this 40 million USD piece of equipment is one of the largest objects in Martian orbit. This size and price tag is justified, however, as the imagery that HiRISE is capable of capturing is some of the absolute best in the solar system. Sporting an astounding spectral resolution of 30 cm per pixel, HiRISE delivers imagery that is unparalleled in the field of deep space remote sensing. Much of this can be attributed to the fact that HiRISE has the largest optical sensor of any object sent to Mars, an aperture reflecting telescope with a width of 0.5 meters (19.7 in). (Ebben, 2007)

Figure 10. The HiRISE Camera During Construction. (NASA/JPL)

Imagery from HiRISE is also used to study Martian Gullies, which are areas of interest for geomorphologists. These areas are comparable to areas on Vesta where channels seemed to have formed. While the circumstances of their formation are no doubt different, the methods and equipment used to study Mars can be applied to other bodies as well.

To see the difference between the best sensors sent to Mars in comparison to the current benchmark for asteroid remote sensing (Dawn), we can compare images taken from both. This comparison would then make it possible to understand how equipment used on Mars may be of use to Asteroid remote sensing missions. For this comparison, images from the HiRISE camera will be used for Martian imagery, and images of Vesta's equatorial region from the Dawn framing camera will be used to provide a baseline for asteroid remote sensing packages.

Figure 11. HiRISE Imagery Slice of Martian Surface (NASA/JPL/UArizona.)

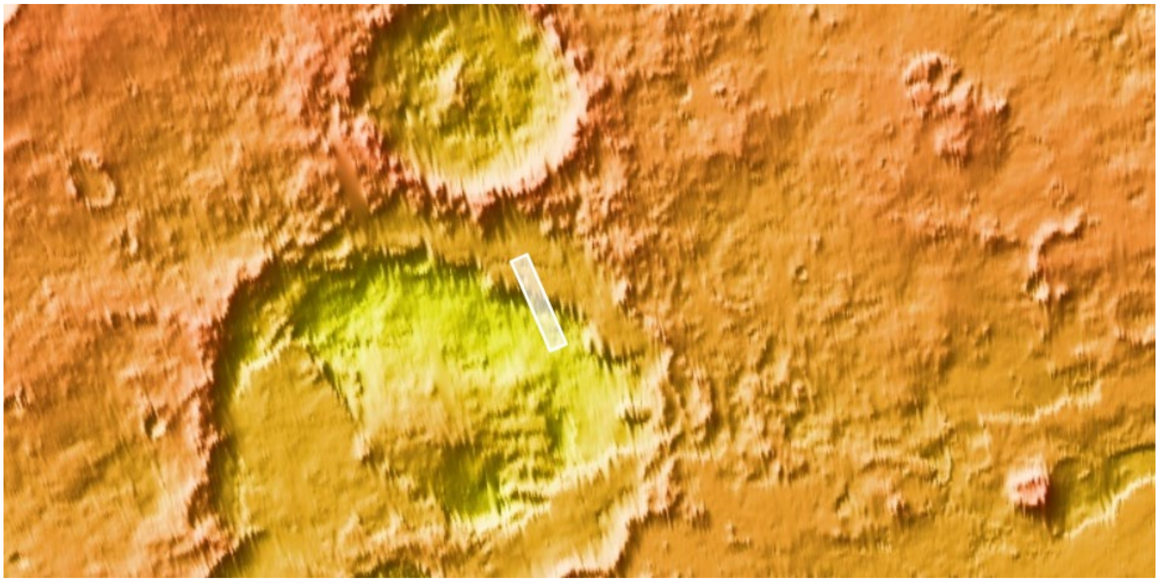

Figure 12. HiRISE Imagery of Martian Surface (NASA/JPL/UArizona.)

Figures 11 and 12 are images taken from the HiRISE camera on March 1st, 2022, and is a section currently being studied by scientists at the University of Arizona. This image is a selected slice of a larger area being looked at to help figure out mass wasting processes in Mars past. This image captures features from the northern Martian hemisphere. These features make for easy analysis as we compare it against the image of Vesta in Figure 13.

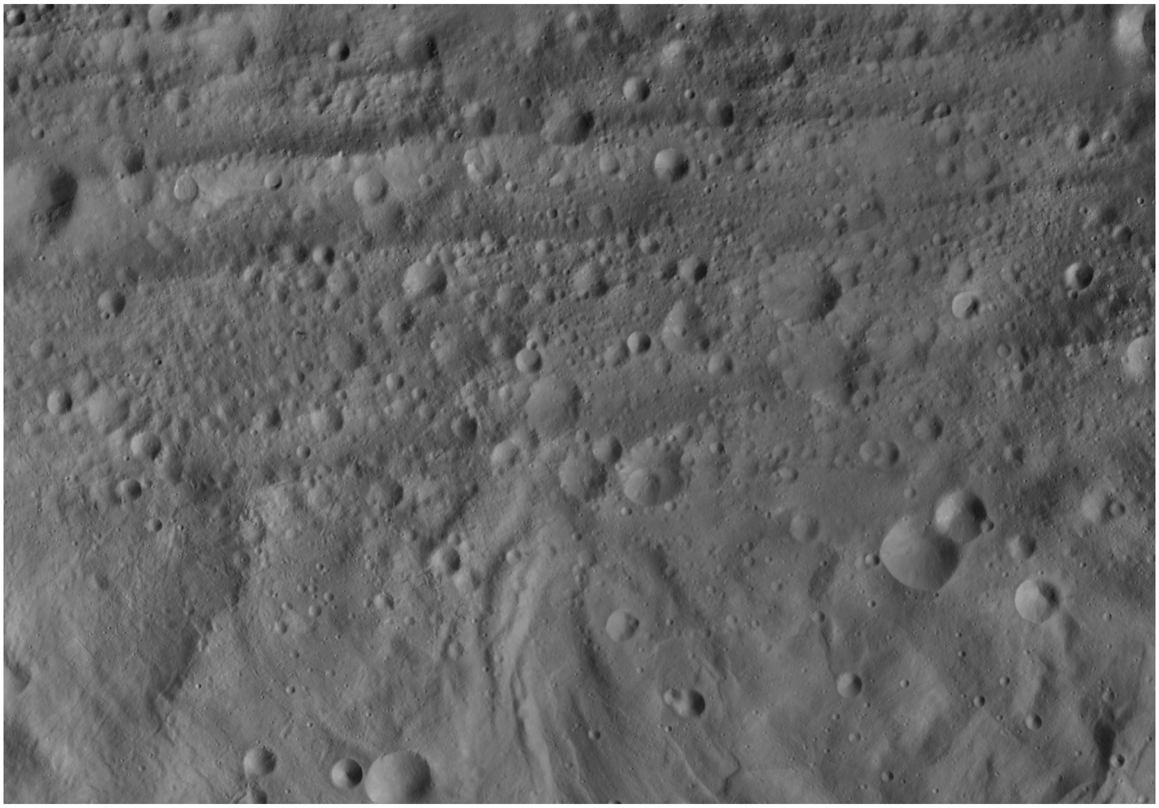

Figure 13. Surface of Vesta, Dawn Framing Camera. (NASA/JPL)

This image, taken by the DAWN probe, is one of the most dynamic images taken from the surface of Vesta. Within this image, a variety of features can be seen, ranging from craters to valley-like formations that make up a portion of the equatorial region of the asteroid named “Domna.” These formations are believed to have been formed from a collision with another object during Vesta’s formation, which resulted in the asteroid's “potato-like” shape.

The methodology used to assist in the assessment of these images will be looking for the following details:

- Accuracy
- Clarity

- lack of interference
- consistency of temporal resolution
- number of bands
- relevance of the data
- Completeness
- ease of access/availability of the data

These images will be examined using ERDAS Imagine (ver. 2022).

1. Vesta

To begin the analysis of imagery from Vesta to ascertain its viability compared to the Martian imagery, a Digital Terrain Model was acquired from the NASA Astrogeology Annex. Before examination can occur, looking at the criteria for the usefulness and accessibility of the data must occur.

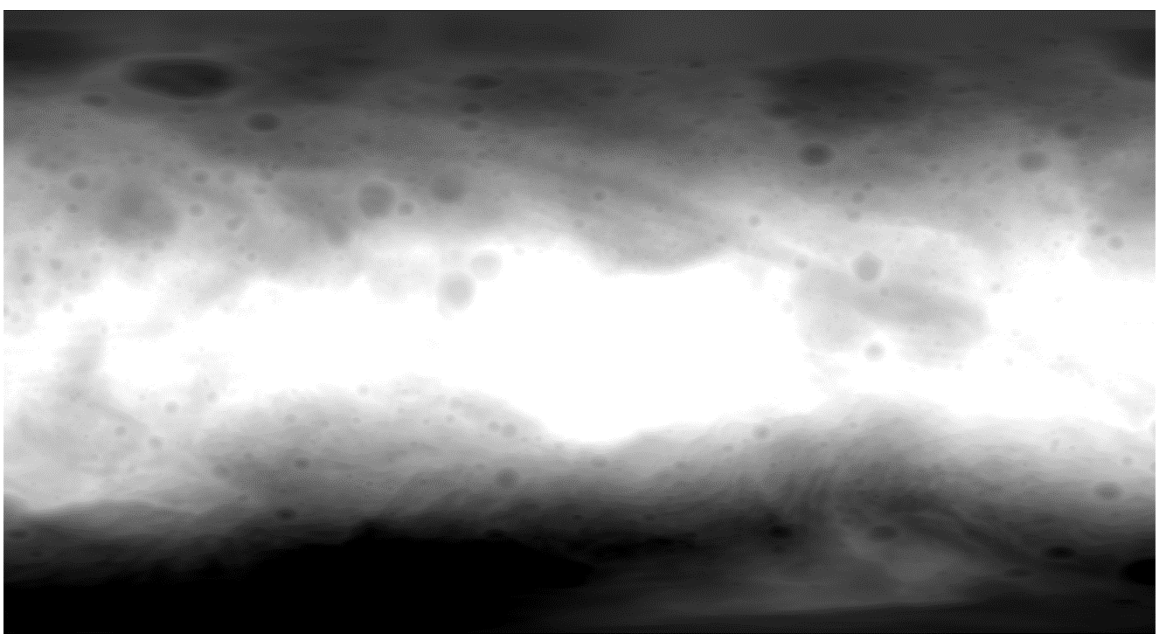

Figure 14. Raw Orthomosaic Image of Vesta taken by Dawn Spacecraft.

1) Accuracy- this data is a HAMO image that was taken at a resolution of 92m per pixel. This Digital Terrain Model has a coverage percentage of 95% of Vesta's surface.
2) Clarity- the resolution of this data means that any close observation will prove difficult.
3) Lack of Interference- Vesta has no known atmosphere, so no known atmospheric interference is present.
4) Consistency of Temporal Resolution- This image is a mosaic collected over the course of Dawn's mission to explore Vesta. There has been no imagery collected of Vesta since Dawn, so no temporal analysis is possible.
5) Number of Bands- This image consists of only a single layer, and is not separated into any distinct bands. This makes any other spectral analysis impossible. Data exists of Vesta that can have spectral analysis performed, but this DTM exists as a single layer.
6) Relevance of Data- This data will provide useful insights in the capability of the Dawn Framing Camera.
7) Completeness- This data encompasses 95% of the surface of Vesta. Much of the remaining 5% exists around the poles.

8) Ease of Access- This data was easily acquired and was found from the Astropedia Annex following a mere Google Search. It is difficult to obtain data more easily than this.

When assessing this data, testing the viability of several spatial analysis tools is necessary. For this Vesta data, given the low resolution of the DTM image, some analyses will not only be difficult to conduct, but may also provide skewed results due to the large amounts of area included in a single pixel.

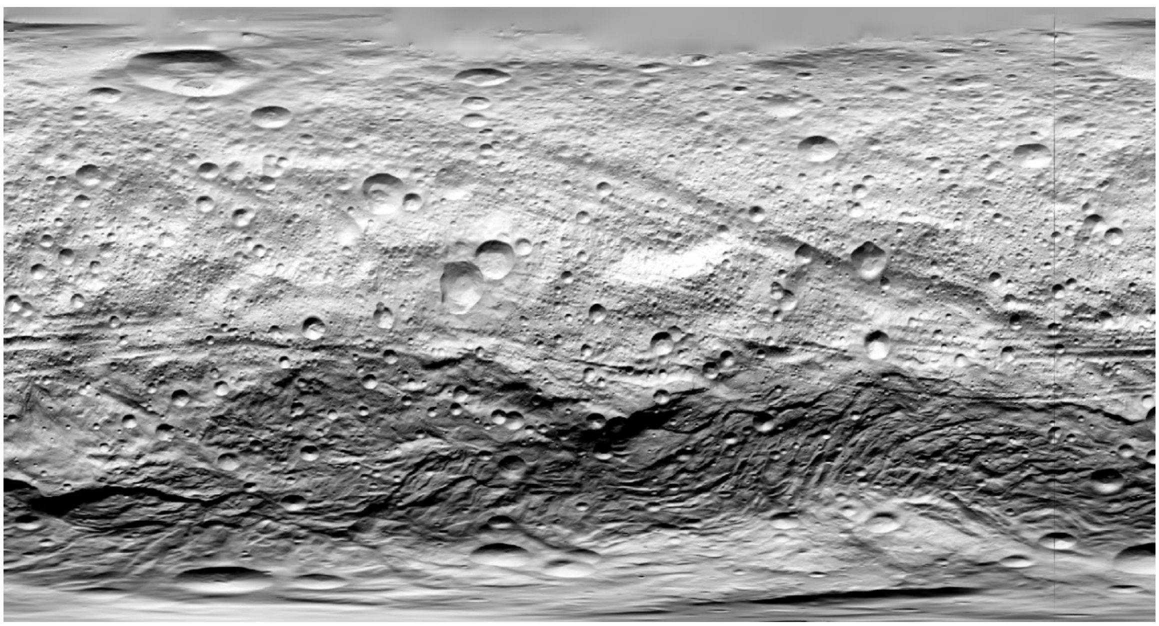

Figure 15. Shaded relief of Vesta taken by Dawn Spacecraft.

This image is the result of conducting a Shaded Relief analysis of the Vesta DTM image. This image clarifies and refines many of the land features that were collected from the DTM and allows for visibility of landforms and surface features. This image has made it incredibly easy to see not only the craters upon the surface of Vesta, but the large parallel formations that run along its equatorial region.

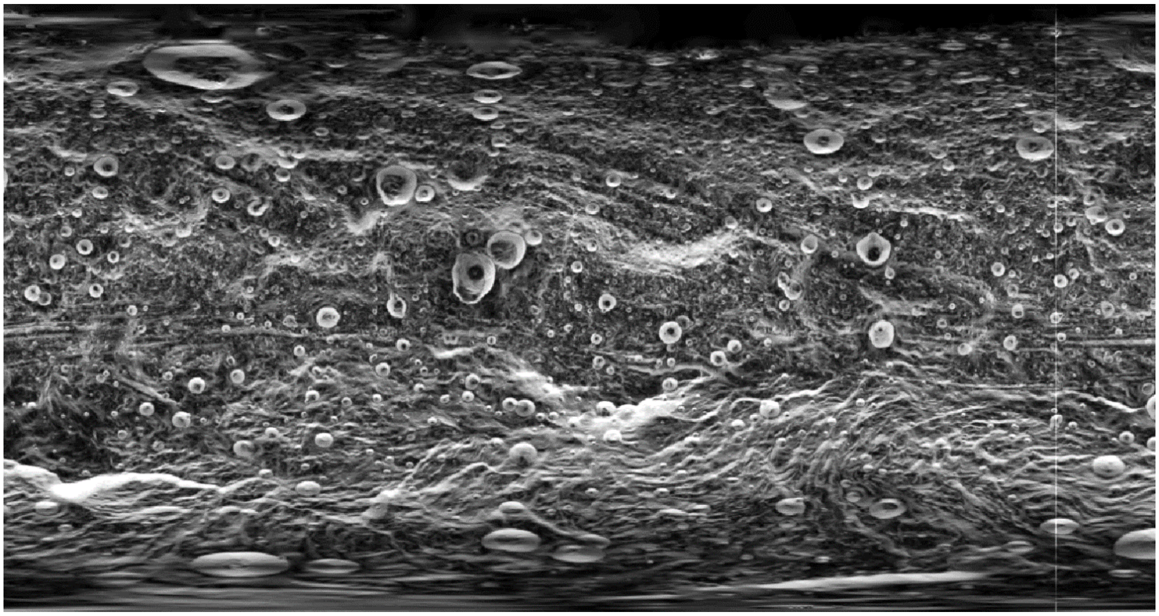

Figure 16. Slope analysis of Vesta taken by Dawn Spacecraft. Brighter shades are steeper slopes.

The image in Figure 16 is an image that was analyzed to understand slope severity. In the image, we can see in areas of brighter color, the slope is at a more severe angle, where areas of dark coloration indicate flatter areas with less severe slopes. Images like this can be useful for a variety of reasons: like the mission of Luna 1 40 years prior to this, images like this can be useful for capturing areas where spacecraft can land upon the surface of Vesta. Additionally, this information can also be useful for understanding the patterns behind geologic formations, and perhaps even understanding the size and age of a crater, including the force of the impact.

2) Mars HiRISE Data

To understand the viability of the Martian gully data, it is necessary to examine data from the HiRISE imaging camera. HiRISE, considered to be the benchmark for deep space remote sensing technology thus far, imagery from this sensor has assisted scientists in a multitude of ways, and in a multitude of disciplines.

1) Accuracy- this includes both a HAMO and LAMO image that has a resolution of 11.4 inches.
2) Clarity- the resolution of this data means that close observation will not only be possible but may be quite easy to analyze.
3) Lack of Interference- While Mars does have an atmosphere, there is very little interference in the image.
4) Consistency of Temporal Resolution- Mars is constantly being surveyed. This image is from an area that has seen coverage earlier in 2022.
5) Number of Bands- This image consists five distinct bands that range from R, G, B, NR, and IR.
6) Relevance of Data- This data will provide useful insights in the capability of the HiRISE camera.
7) Completeness- This data encompasses only a single study area but is a complete mosaic.
8) Ease of Access- This data was easily acquired and was found from the Astropedia Annex following a mere Google Search. It is difficult to obtain data more easily than this.

Chapter 5: The VEGeTA Concept

This thesis can wax philosophical all the author wishes, but it is necessary for the first step toward a standardized process to be taken. It is for this reason that a mock-up of a concept must be the first step toward helping space exploration. The VEGTA concept is named for the model it proposes:

Variable **E**xploratory **Ge**o-Planetary **T**ransmission **A**rray, or VEGeTA.

This concept aims to produce an object that is modular and variable in the equipment that can be equipped with it to conduct its exploratory function. It will be a geo cartographic satellite that will explore and map stellar objects from HAMO and LAMO, providing an unparalleled look at objects that get very little current attention. In addition, this concept will provide an array that will be capable of transmitting data back to Earth to be collected, cataloged, and analyzed by specialists.

After charting the progress of the space program and exploring the various sensors and techniques used by past missions, it is possible to create a concept for a satellite that incorporates many of the best parts of those missions. By using existing systems and hardware, the cost to develop and specially manufacture each piece of equipment can be lowered, perhaps even to a rate that would allow for easy mass production.

The concept for this satellite will need to be variable in its loadout. This means that the satellite will be modular. Additionally, it is necessary to address four unique systems that will act as a basis for further development. These will be referred to as Necessary Systems, and will be as follows:

2. Propulsion- This will be a system that will act as the satellites method of movement. This is an integral system, as it controls the distance traveled, and is necessary for course corrections or outright changes during flight. This will also cover the power systems for the satellite.
3. Navigation- The VEGeTA satellite must have a standardized method of navigating itself to destinations, as well as allowing for proper ways to geo-reference it's position.
4. Sensor Package- This must be a modular, customizable area to store payloads of various kinds. This will be the location for the camera packages, as well as any other sensors that are chosen for the missions utilizing this vehicle.
5. Transmitter- The need to send collected data back to Earth is paramount to the success of any successful deep space exploration mission.

The VEGeTA satellite will be an amalgamation of parts that have proven their mettle in their respective missions. Among these parts, the cost of construction will also be considered. This may come at the cost of quality in some areas but will instead favor functionality and producibility. For this concept, it must be noted that the author is not an engineer, and many of the nuances of space exploration may be lost upon this model. But the four main systems will be the focus, as they are where much of the money to create these systems are allocated.

The image in Table __ show the details of what the components that the VEGeTA satellite will consist of.

System	Equipment	Cost/Weight (If Applicable)
Propulsion	2x NSTAR Xenon Ion Thruster Unit, 4x Hydrazine Corrective Thrust Units	425 kg (Thrusters and Fuel)
Navigation	Rear and Front Framing Cameras	5.5 kg
Sensor Package	Rear and Front Framing Cameras	5.5 kg
Transmitter	DSN Connected 1.5m High Gain Dish	Varied

Table 2. VEGeTA technical specifications estimated by the author.

1) Propulsion

This satellite will use technology similar to the Dawn spacecraft. This will consist of two NSTAR Xenon Ion Thrusters. The fuel capabilities of this will vary due to fuel load. The concept model will use Dawn's specifications, so it will come standard with a 425 kg fuel payload. These will be placed at the rear of the spacecraft. See Figure ___. Propulsion will be complimented by four Hydrazine attitude correction nozzles. These use fuel at a faster rate than the NSTAR engines but will only be used for course corrections while on-mission. Thus, they will need less fuel to operate and require less resource allocation within the body of the spacecraft.

2) Navigation

This satellite will use techniques utilized by many spacecrafts in the past. Navigation will be done using technology connected to the Framing Camera. This system will reference its location against the location of stars within the camera's view. This works much like navigation in the Age of Sail, measuring the location and movement of stars and celestial bodies to determine its location in space.

3) Sensor Package

VEGeTA's Sensor Package will be a customizable system. As the satellite is meant to be modular by design, this will be a hot-swappable piece of equipment that will be adjusted for mission profile. For the purposes of this concept model, this will come with a Framing Camera that will take the best features of both the Dawn and MRO payloads, while being designed with a dual mount like the Dawn FC. It will be equipped with a camera that is smaller than the HiRISE camera to save space, but also incorporate some of the technologies that made it so successful. The lens width will be two feet wide, as compared to HiRISE's one meter size. Additionally, this camera will only measure bands in the R, G, B and NIR wavelengths. Any additional bands will need to be covered by the SA-IN system nodes. This will save on both processing power and camera size, as fewer light wavelengths will need to be observed and recorded.

Taking from DAWN's techniques, it will also have a second camera on the rear of the spacecraft. This will allow for a redundant system should the main Framing Camera be damaged or rendered unusable. Additionally, this will allow for navigation while the main Framing Camera is in use for observation of mission targets.

	VEGeTA Specifications
Camera Size	15 kg, 24 in. Lens Width
Cost	Variable
Bands	R, G, B, NIR, IR
Focal Length	150 mm
Resolution at HAMO	12 Meters/pixel
Resolution at LAMO	5 Meters/pixel

Table 3. VEGeTA Camera Specifications.

4) Transmitter

This system will be modeled after the systems installed on the Dawn spacecraft but will instead be miniaturized and complimented by a radio transmission system. The Dawn spacecraft utilized a 1.5-meter-wide high gain dish antenna. VEGeTA will instead use an internally installed dish for transmission and signal reception, and utilize hull mounted exterior antennae for signal reception during mission execution.

5) The SA-IN System

Along with the customary systems listed above, the VEGeTA satellite will also incorporate a modular six-node payload delivery system. This is the system that will operate as the main draw for standardization practices. The VEGeTA satellite will come with a standard equipment package, as outlined with the four previous components. The customizable part of this satellite will be the SA-IN System (Substitutable Apparatus-Indention Nodes). These will be nodes connected to the main body of the spacecraft that will allow for variable mission profiles. The intention for the addition of six indention nodes is to allow for the release of multiple data collection equipment. These may take the form of additional smaller satellites to collect synchronous data from multiple angles of the celestial body, specialized cameras to augment the visual capabilities of the VEGeTA Framing Camera, or even additional navigation packages or fuel pods. The SA-IN system will be the differentiating factor that separates VEGeTA from other satellite systems, allowing it to fit multiple mission profiles.

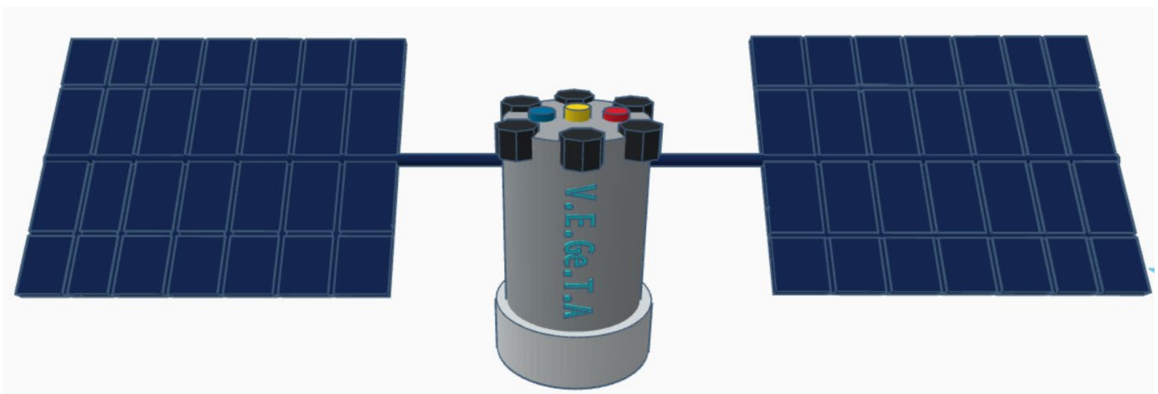

Figure 17. VEGeTA Satellite Side Profile.

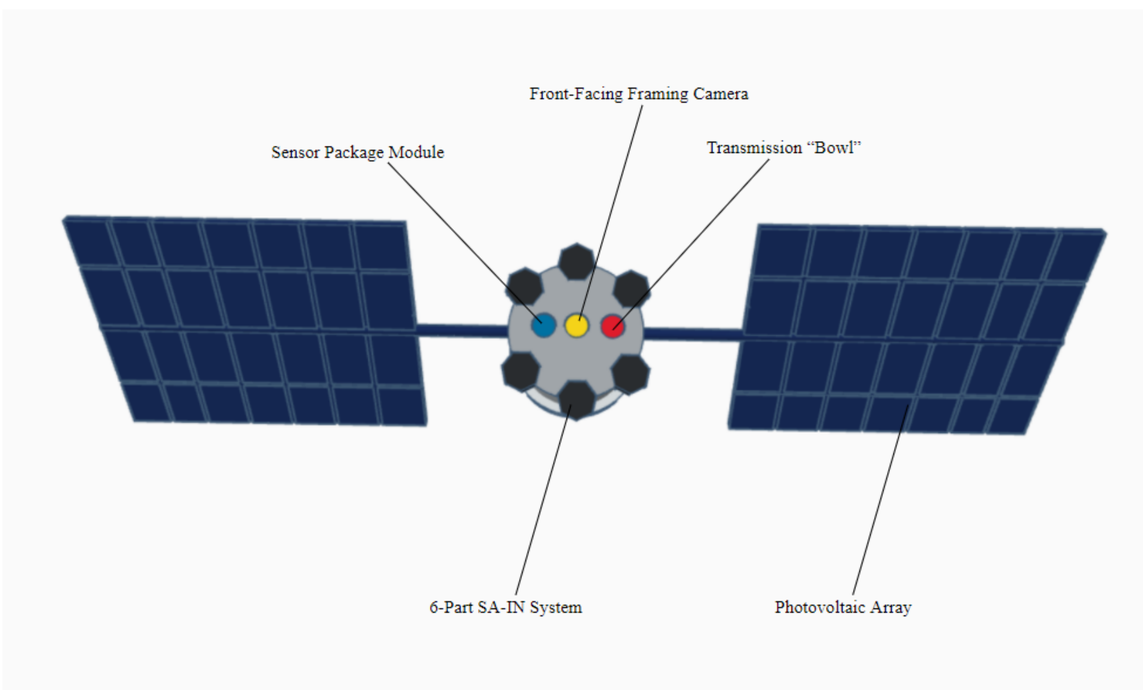

Figure 18. Front View of VEGeTA

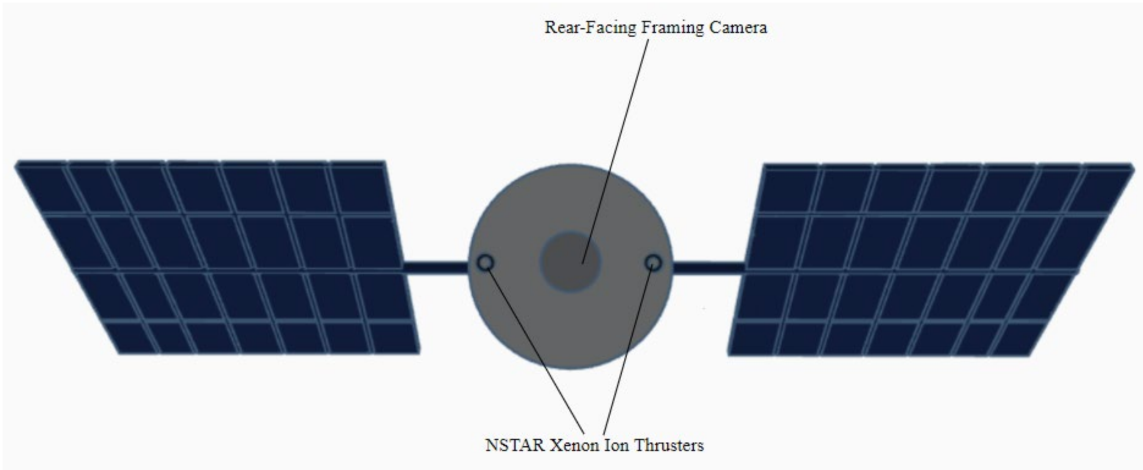

Figure 19. Rear View of VEGeTA.

Chapter 6: Results

To truly understand the differences between remote sensing methods of planetary Mars and asteroid Vesta an important step is comparing imagery from the two and charting the ease of use and results.

As the mapping of Vesta in its entirety is done from HAMO, the accuracy of imagery is reduced due to the limitations imposed when mapping an entire celestial body as opposed to a small portion of it. For this reason, imagery taken at LAMO is needed to properly compare images to Martian surveyed data. The image in Figure ___ is of the Domna Region of Vesta. This region was chosen for its diversity of geologic features, as many of the horizontal lines that make up parts of Vesta's equatorial region are on full display.

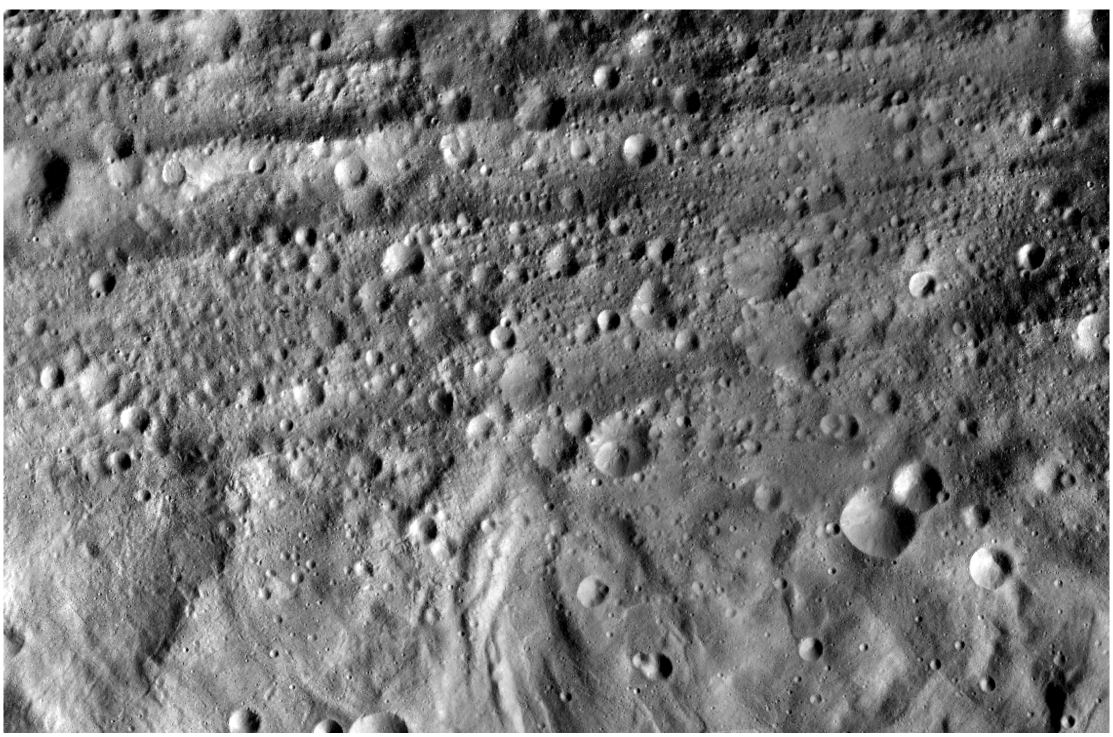

Figure 20. Domna region of Vesta.

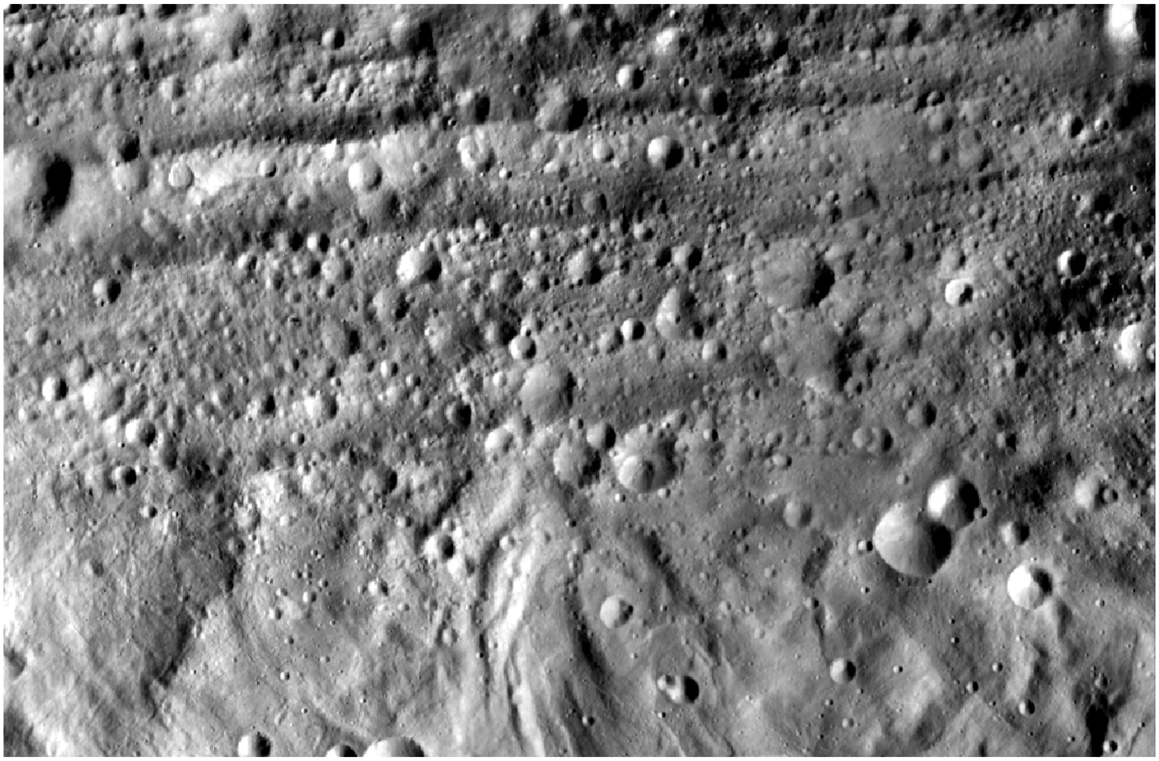

Figure 21. Domna region noise reduction.

The first step to handling this data is to perform a Noise Reduction. Noise Reduction smooths and refines many of the pixels in this image for easier manipulation and interpretation.

Following this, it is important to try and find ways to interpret the data. Since it is difficult to discern the actual topography of an area from just a cursory visual examination, the very first step in this process is to try to decide what is being seen, exactly.

This is an image of the Domna Region of Vesta when using a Slope tool to measure the depth and angle. This image, which shows areas of light and dark color, shows the angle of the slopes. The darker the value, the more extreme the slope:

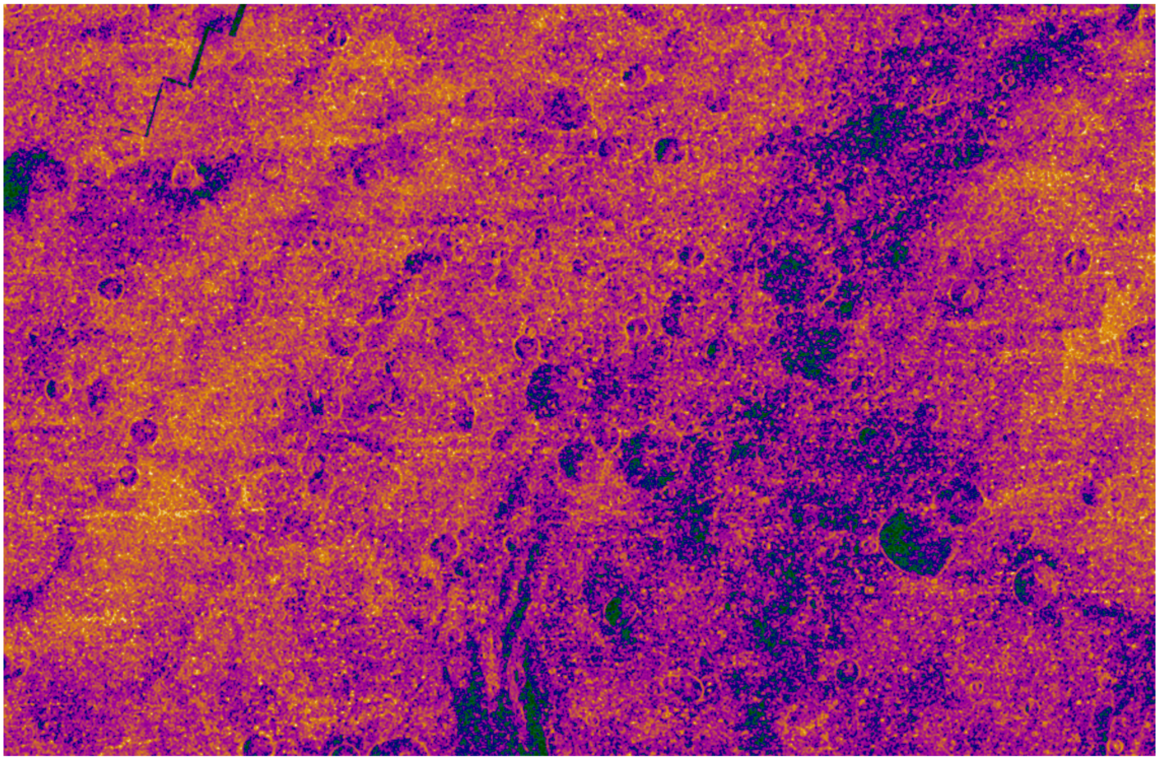

Figure 22. Slope analysis of Domna region .

Using the images obtained from Dawn, we are able to get a view of the topography of Vesta. Vesta is dynamic in its topography, especially around the equatorial region, which is where the Domna Region is located. From this image, we can also extract some statistics which help show just how dynamic and varied the surface of Vesta truly is. Table 4 shows the variance in the slope characteristics of the Domna region.

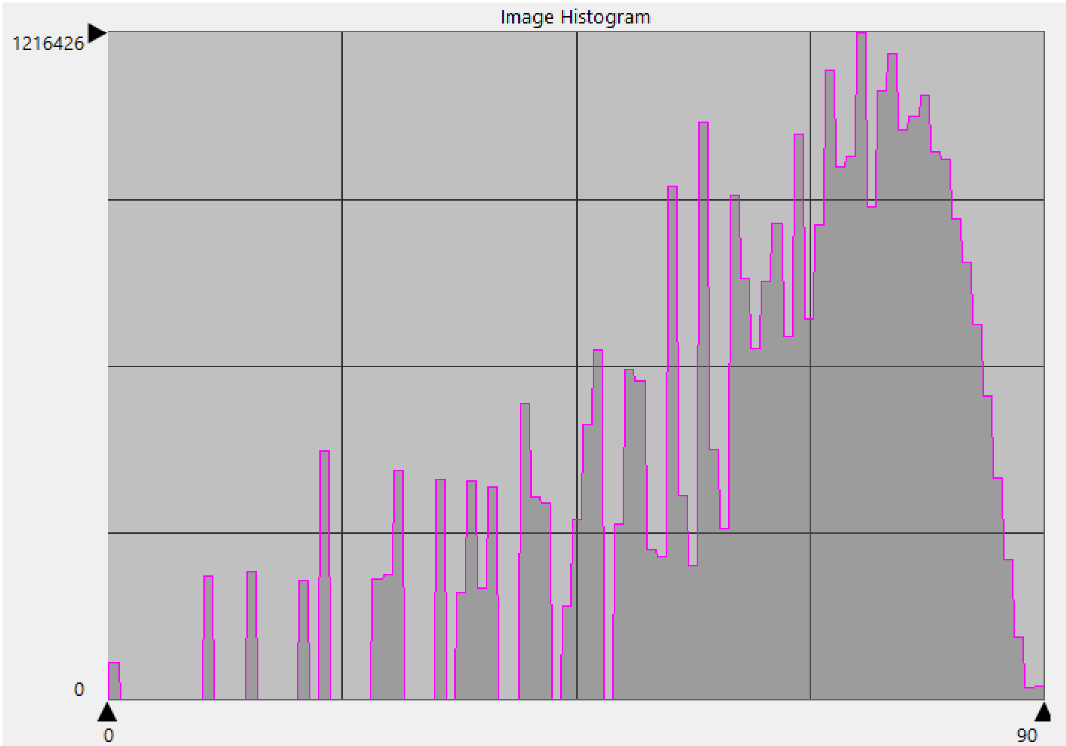

Table 4. Domna region slope analysis of the raw data.

These statistics can be further refined to show the average slope through the Domna image:

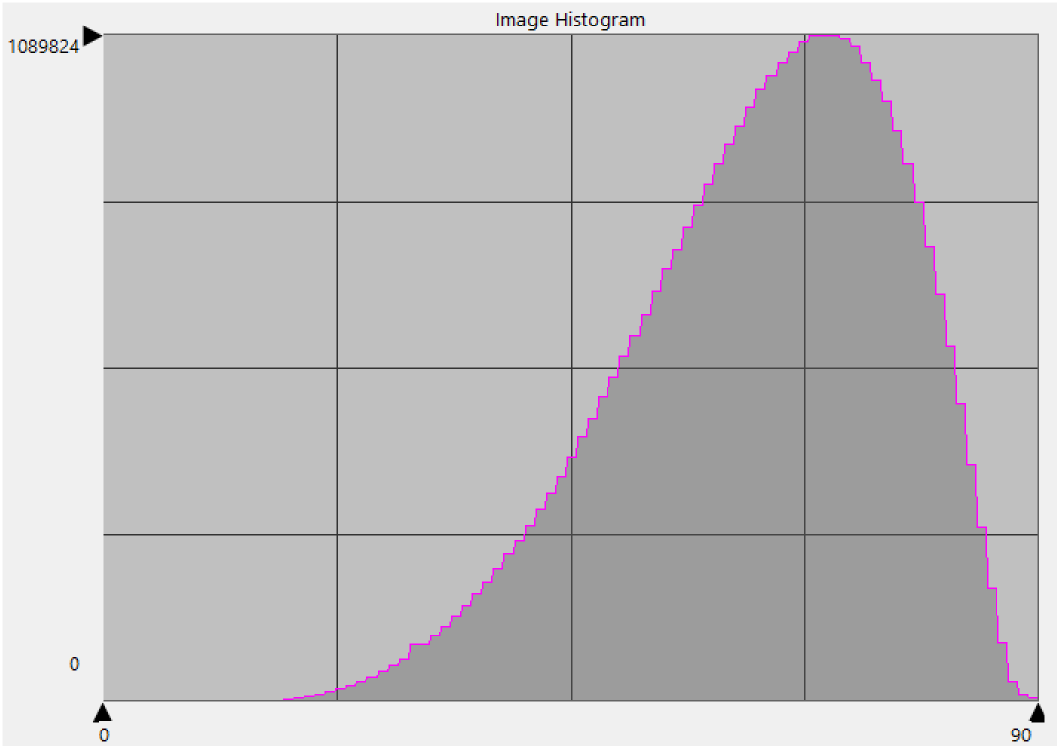

Table 5. Domna region slope analysis..

This analysis, while solely done on a single equatorial region of Vesta, shows that the slopes of Domna average at 61.75 degrees.

Following this analysis, to provide a better look at the surface features, a simple inversion of the brightness values can be done. This allows the viewer to see the features in a new way, and in this case, they bring out the depth of the craters and the ridges much more clearly:

Figure 23. Brightness inversion of Domna region.

These images show that even the simplest of images, when provided a spatial resolution of high enough quality, can provide fantastic insights into planetary bodies.

While the images of Vesta are a fantastic use of the Dawn Framing Camera, it is also important to understand that Mars has received much more in-depth equipment employed into its orbit.

The Mars Reconnaissance Orbiter utilizes the previously mentioned HiRISE camera. This camera is the pinnacle of deep space cameras, and this can be seen by taking an image captured by the MRO and observing just how in-depth the image can be.

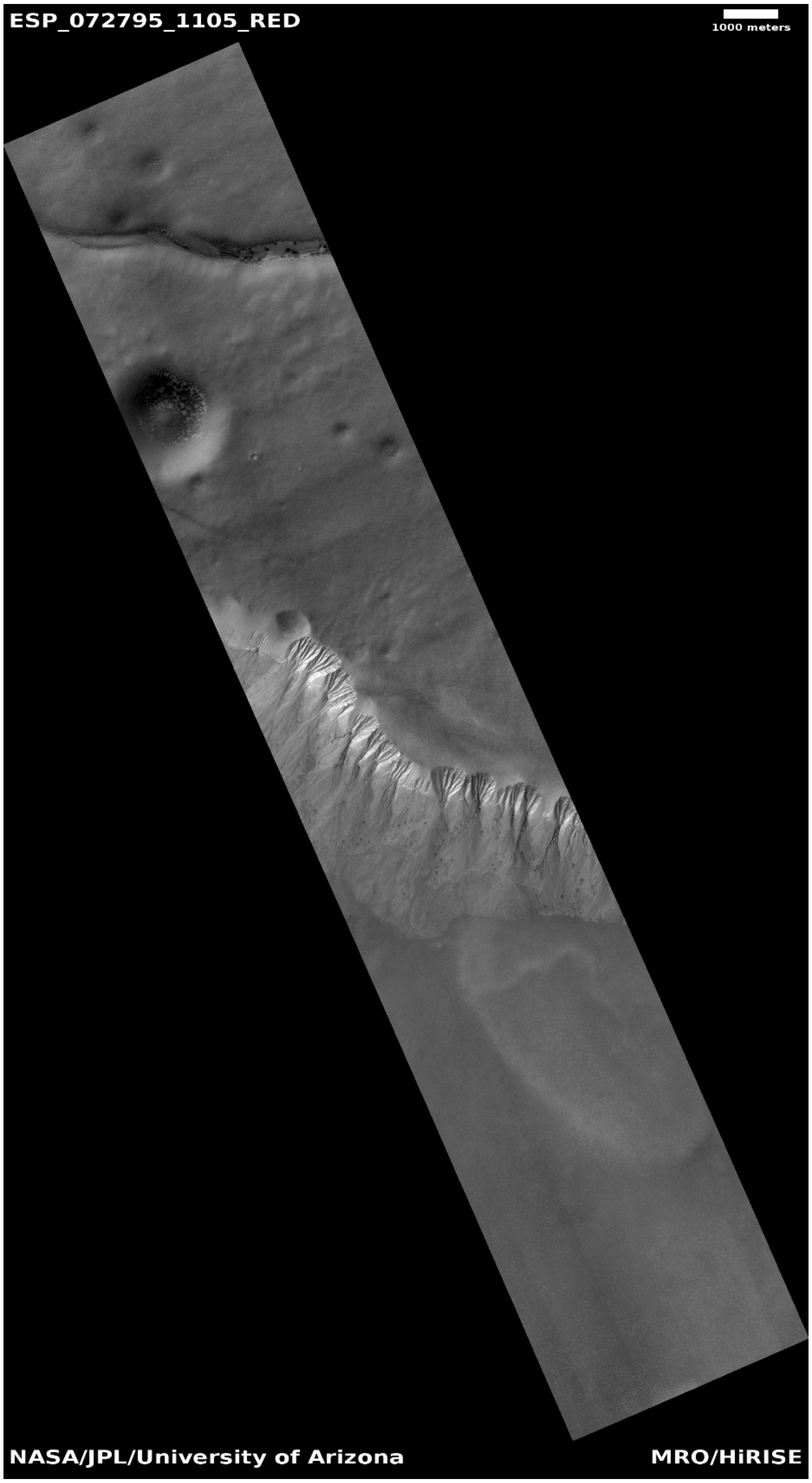

Figure 24. HiRISE imagery of Martian.

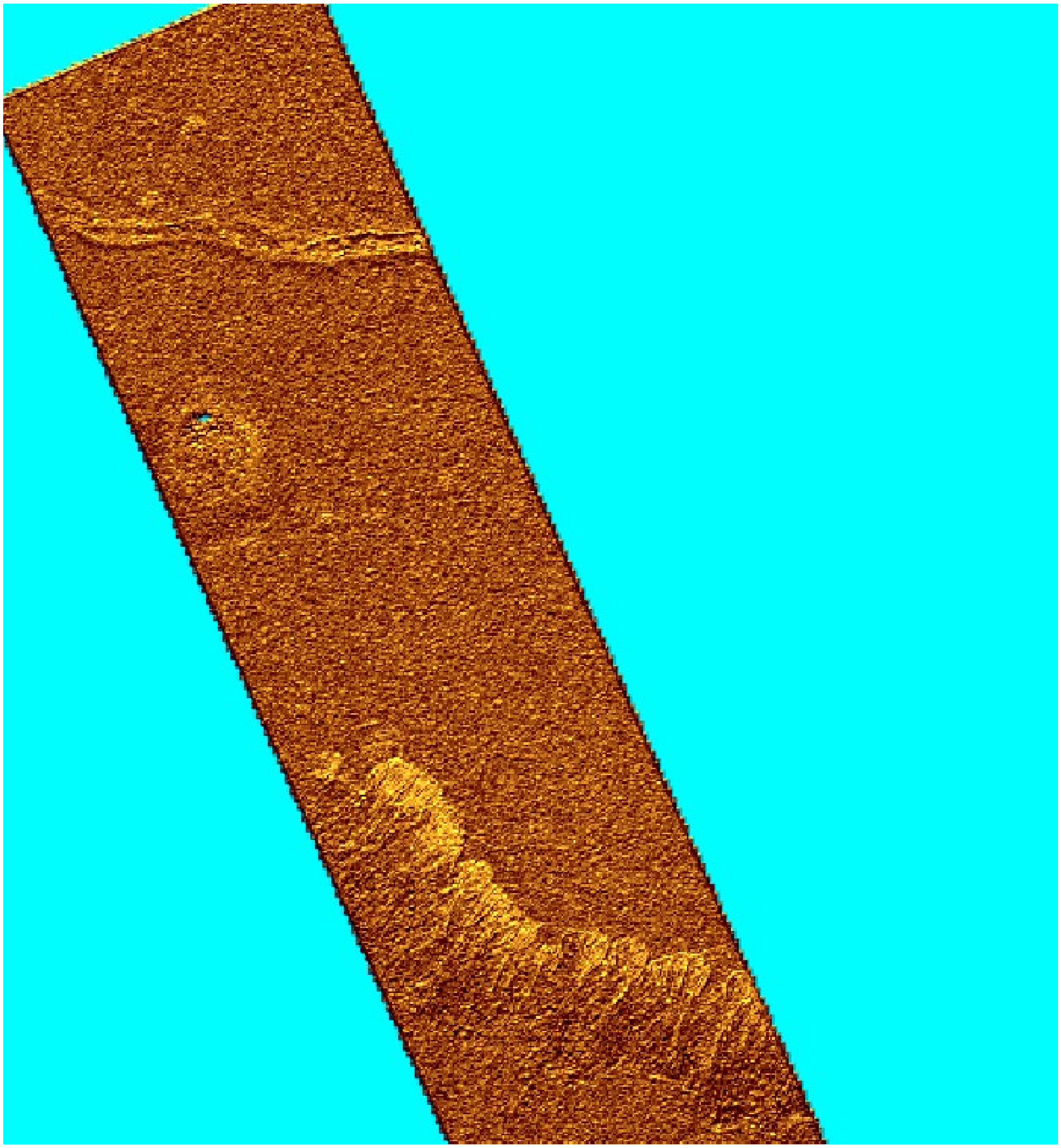

Figure 25. Slope analysis of Martian landscape.

These images from HiRISE highlight a drastic change between the images from Vesta compared to the images of Mars. The HiRISE camera has a noticeable edge, as the spatial resolution of the HiRISE camera at LAMO is 30 cm. Compared to the Dawn Framing Camera, which was a much larger 115 feet per pixel.

Chapter 7: Discussion

Throughout the course of this study, examinations on a multitude of satellites have been conducted, as well as looking at imagery from the absolute best satellites to orbit two separate celestial bodies: HiRISE for Mars, and Dawn Framing Camera for Vesta.

It was clear through the analysis of these two cameras that the HiRISE camera is by far the superior piece of remote sensing technology. The disparity between the capabilities of the two sensors is remarkable, despite the two of them being constructed around the same time. Much of this can be attributed to the budget of the two projects, with the HiRISE camera being a part of the Mars Reconnaissance Orbiter project with a budget of 720 million USD. To contrast, Dawn was nearly 300 million USD less.

This disparity can also be attributed to the fact that HiRISE was launched as a part of a mission that would help humanity understand a planet that may eventually be hosted to manned exploration. Mars has been a target for manned space exploration for many decades, and thanks to the Artemis mission, is expected to be a reality within the next two decades. For this reason, data that is as accurate and complete as possible is necessary. For this reason, the MRO is meant to operate as long as can be achieved, and as such, the equipment is meant for longevity and reliability.

Dawn, however, is a highly specialized probe meant to fulfill an observation mission that also has a defined beginning and end date. Dawn was launched with the mission of providing an understanding of both Ceres and Vesta, as well as attempting to understand the geologic makeup of both celestial bodies. Dawn’s Framing Camera is one of the most advanced sent beyond Mars, and achieved the goal of the Dawn mission, opening the door to many geomorphologists and astronomers to better understand the Asteroids in the Belt.

Table 6 highlights the differences between the Dawn and HiRISE probes.

	Dawn	HiRISE
Camera Size	5.5. kg	65 kg
Cost	24 million USD	40 million USD
Bands	7 Bands	14 Bands
Focal Length	150 mm	12 m
Resolution at HAMO	21 meters/pixel	1.3 meters/pixel
Resolution at LAMO	12 meters/pixel	30 cm/pixel

Table 6. Dawn FC and HiRISE Camera Comparison.

Highlighting these differences, we see that Martian remote sensing has enjoyed a much better litany of instruments, led by the HiRISE sensor in both quality and effectiveness.

The question we aim to answer through all of the prior analysis is this: how can the equipment used for Martian observation improve remote sensing techniques of Asteroids and other deep space objects? How could it even be improved upon after the success of the Dawn mission?

To answer this question, we must weigh the data collected against one another. Looking at CHART ABOVE, we can see that HiRISE enjoys a technological advantage over the Dawn Framing Camera. When considering the end goal of each mission, this comes as no surprise. But does this mean that research missions into deep space need not be equipped with such advanced sensor packages?

The answer to that question may lie somewhere between yes and no, as the most prohibitive barrier to more extensive deep space exploration lies in the cost of building and launching each satellite/probe. Each probe that has been discussed prior to this has cost hundreds of millions of dollars, and many of which (including Dawn) have gone over budget while trying to build the sensor platforms.

It is at this point that I believe the philosophy on the construction and launching of probes used for deep space remote sensing must be changed. The past seventy years of space exploration have brought many advancements to the field of remote sensing, but it has come at a literal astronomical cost.

1. The Prohibitive Cost of Space Exploration

The solution to the high cost of space exploration may come with one of the most basic tenets of streamlining manufacturing: standardized manufacturing. While each mission has been specially designed to fulfill the specific goals put forth by the mission profile, this means that exploration is limited to that single mission profile. This can be mitigated by having other equipment present around the same celestial body, as often happens with Mars, but when dealing with bodies that have not had any other exploration beyond the first, it can often prove limiting. This is often the case with areas in the Asteroid Belt and beyond. Since the mission to Vesta and Ceres, each of these bodies has not been visited since, nor does any space agency currently have any plans to return. It is possible that a passing-by probe could conduct a flyby, taking pictures as it moves past on its mission to its destination. But there are currently no guarantees. This also goes for many of the Outer Planets and the moons and objects that revolve around them. This veritable bounty of information about our Solar System sits unexplored, or waiting decades in between missions.

This is coupled by the fact that after the end of the Space Race in the 1960's and 1970's, budgets for space exploration have been cut in many countries. For reference, the budget for NASA in the 1960's enjoyed being almost 4-5% of the entire US budget. In 1965, NASA had a budget of 5 Billion USD, which accounted for 4.31% of US Government spending. When adjusted for inflation in 2020, this would come out to almost 5 Trillion dollars. In 2020 the budget of NASA was 22.629 billion USD, which only accounted for 0.48% of US Budgetary Spending (Steinberg, 2011).

These figures require some historical context, as the 1960s was one of the most pitched periods of the Cold War. This era in US space exploration was less focused on the exploration aspect, but rather the race against the Soviet Union's rapid advancements. The Cold War ended decades ago, and once the Apollo program ended, trips to the moon did not occur, and funding to NASA started to decline year after year. This slowed the advancement of space technologies considerably. Where previously NASA had been a large, proud part of the American cultural zeitgeist, the goal of reaching beyond the Moon that once seemed well within reach, was stalled. While NASA's Artemis mission has re-kindled the goal of reaching other planets, specifically Mars, space exploration has slowed since the 1960's. This has meant that missions must have very specific goals and parameters, but also that many of the instruments are outsourced to other areas in the private sector as the government simply cannot cover the costs of researching and constructing a piece of equipment alone. This is not an inherent negative. International cooperation is key to ensuring success of missions with various profiles, but this still presents an obstacle and adds more moving parts to an already complicated project.

2. A Standardized Solution, and a new Philosophical Approach

To remove much of the cost of space exploration, the idea of standardization must be entertained. I theorize that it is possible to construct a probe that can be both cheap yet still fulfill the mission parameters that need to be met when exploring deep space objects.

Additionally, the world's approach to space exploration has provided so many advances and discoveries about our solar system. Yet at this time, there are still untold mysteries yet to even be discovered. Untold answers to the past and future of not only our own planet, but our solar system and our place in our stellar neighborhood.

It should then be proposed that we take a more "scattershot" approach to space exploration than simply choosing one object to explore at a time. Perhaps the idea of a massive array of probes, mass produced to cut costs and using smaller, less specialized instruments to explore many different corners of our solar system at once. A spread of satellites, exploring various bodies at a time, would allow for humanity to instead gain a first look at a location, and then choose which mission profile best fits future explorations. This would also serve to assist humanity in returning to places where we have not been in recent years, including Ceres, Vesta, and even other Inner Planet locations like the moons of Mars and Venus.

Chapter 8: Conclusion

This thesis has given a detailed exploration of the disparity between Martian and Asteroid remote sensing and provided opportunities to both bridge that gap and create new opportunities for deep space exploration. The Dawn Framing Camera and HiRISE are fantastic pieces of equipment that have added to humanity's body of knowledge about the Solar System. While they fulfill a variety of function, it should be possible to create a system that can be standardized for use with future mission.

The VEGeTA Space Probe, coupled with the SA-IN system, would provide a highly customizable framework for the standardization of future deep space missions. It is argued that the selection of locations for highly specialized missions does assist in growing humanity's knowledge, a wider breadth of exploration must be reached for. The cost of space exploration has been prohibitive due to the decreased government spending upon space programs since the 1970's. While space enthusiasts have found alternative ways to explore our universe, we must remember that "necessity if the mother of all invention," and find ways to decrease these costs to allow for more and greater knowledge so that humanity may reach to the stars with more confidence and safety.

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