NUCLEAR ASTEROID MINING

8/4/2020

INTRODUCTION

Every day the Earth is bombarded with about 100 tons of dust and sand-sized particles from space. About once a year a car-sized "meteoroid" hits the Earth' atmosphere and creates a fireball before hitting the Earth's surface as a "meteorite." Every 2,000 years, a meteoroid of the size of a football field hits Earth and causes significant damage. Once every few million years the Earth is hit by a meteoroid that can cause mass extinctions.

The Earth asteroids could be a location for a "Noah's Ark" preserving a copy of life as it exists on Earth for any need for reproduction against the possible calamity of mass extinction caused by astral impacts, earthquakes, volcanism or global epidemics. They share the same importance as the moon and Mars as candidates for human bases.

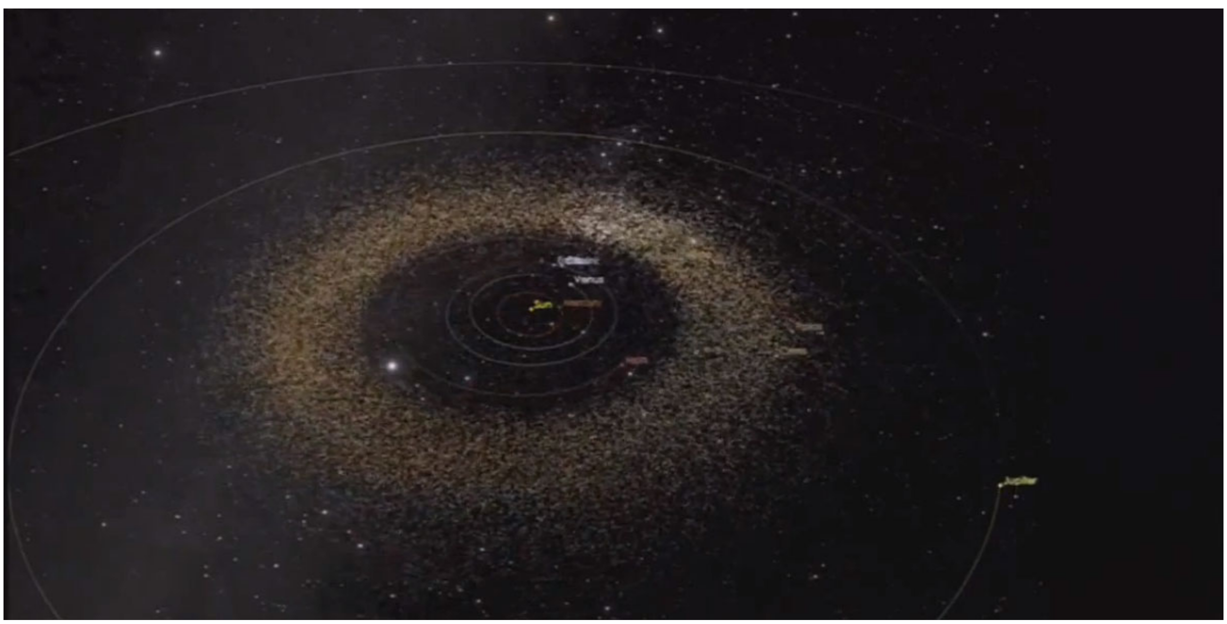

Figure 1. Thousands of asteroids populate the Asteroid Belt between Mars and Jupiter in the solar system.

About 1 percent of the 100×10^9 asteroids in the solar system could be modified into human settlements. In between the orbits of Mars and Jupiter, the solar radiation intensity is $1/10^{th}$ what the Earth receives. This is sufficient for plant growth. "Experimental cultures and a vast array of intrinsic and cultural freedoms become manifest. [1]"

The asteroids resource base in water and minerals is crucial for the future human exploration of space for food growing, rocket fuel, and construction and radiation shielding materials for future human habitation of space and the spread of life in the known universe. In the short term, they can expand the Earth's resource base in minerals and rare metals, some to use in space and some to bring down to Earth. In the long term they would prepare for eventual bases on the moon and mars as well as the asteroids as Noah's Arks for life on Earth. They shall develop the technologies that would also be used to protect life on Earth from potential mass-extinction stellar comets and asteroid assailants by nudging them away from their Earth-impact orbits. Two companies, Planetary Resources and Deep Space Industries, have announced plans to mine the resources of water and minerals in the asteroids.

NATURE OF ASTEROIDS

The asteroids are bodies of primordial material left over from the formation of the Solar System that never had a chance to aggregate to form an inner rocky planet in the solar system such as Earth, Mars, Venus and Mercury. They are scattered throughout the solar system with some of them orbiting close to the sun and some others are found out beyond the orbit of Neptune.

Jupiter, as a large gaseous planet with a large gravitational attractive force, herds a large number of them into the Main Asteroid Belt between Mars and Jupiter. It may be that the gravitational effect of Jupiter prevented them from aggregating into a planet. On the other hand, the strong gravitational pull from Jupiter attracts some of these asteroids to impact Jupiter itself and hence protects the Earth from being impacted by them. The infrequent impacts, that would cause mass extinctions, gave a large enough longevity factor for life to evolve on Earth.

Thousands of asteroids that do not belong to the Main Asteroid Belt have been discovered that pass near the Earth's orbit around the sun about 1,000 of them discovered per year.

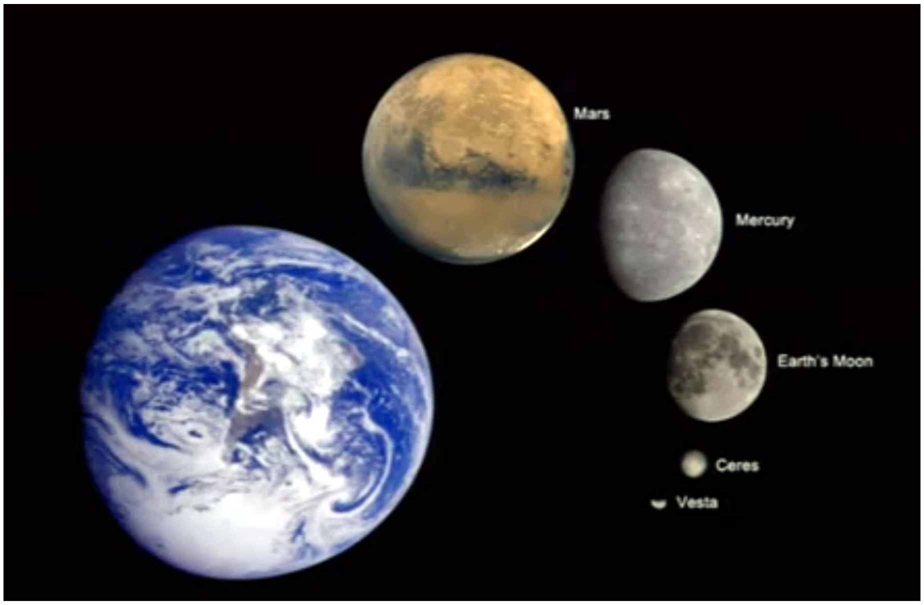

Figure 2. Vesta and Ceres asteroids relative sizes compared with the solid rocky planetary bodies. Ceres is largest known asteroid and Vestas has been visited by a NASA space probe.

MAIN ASTEROID BELT

The Main Asteroid Belt consists of millions of asteroids residing in a toroidal region between the orbits of Mars and Jupiter. While these asteroids are important for understanding the early history of the solar system they are not as easy to energetically reach as the Near-Earth-Asteroids.

NEAR-EARTH ASTEROIDS

Millions of asteroids orbit near mars and Jupiter's orbits. Sometimes, the gravitational perturbations kick some of these asteroids closer to the sun, creating the class of asteroids designated as Near Earth Asteroids. Near-Earth Asteroids are generally defined as that population of asteroids which spends at least part of each orbit between 0.983 and 1.3 Astronomical Units (AUs) from the sun.

The Astronomical Unit (AU) is the Earth's distance from the sun at about 150 million kms or 93 million miles. These asteroids were previously part of the Main Asteroid Belt population or were once active comets.

As of 1960, only 20 Near-Earth Asteroids had been identified. The number grew to 134 by 1990 and by 2013 nearly 9,000 Near-Earth Asteroids are known to exist, and the number increases at the rate of 1,000 year. Astronomers believe the number may actually exceed one million.

Of the asteroids currently observed, 981 of these objects are larger than one kilometer in diameter. The majority of the remaining known Near-Earth Asteroids are believed to be between 100 m and 1 km in diameter. Those smaller than 100 meters in diameter are about 2,800.

POTENTIALLY HAZARDOUS ASTEROIDS

The potentially hazardous asteroids are about 150 m or 500 feet or larger, at about the size of the Statue of Liberty. They approach the earth's orbit within 7.5 million kilometers or about 4.6 million miles.

In comparison, Mars and Earth at their closest approach would be 53 million kms of 33 million miles apart.

ASTEROIDS CATEGORIES

Near-Earth-Orbit asteroids are categorized into three groups based on their distances from the sun: the Atens, Apollos, and Amors groups. Some near-Earth asteroids spend nearly all of their time outside the Earth's orbit, while otherstellar objects, known as the Earth-crossers, have orbits that intersect the Earth's orbit from below or above.

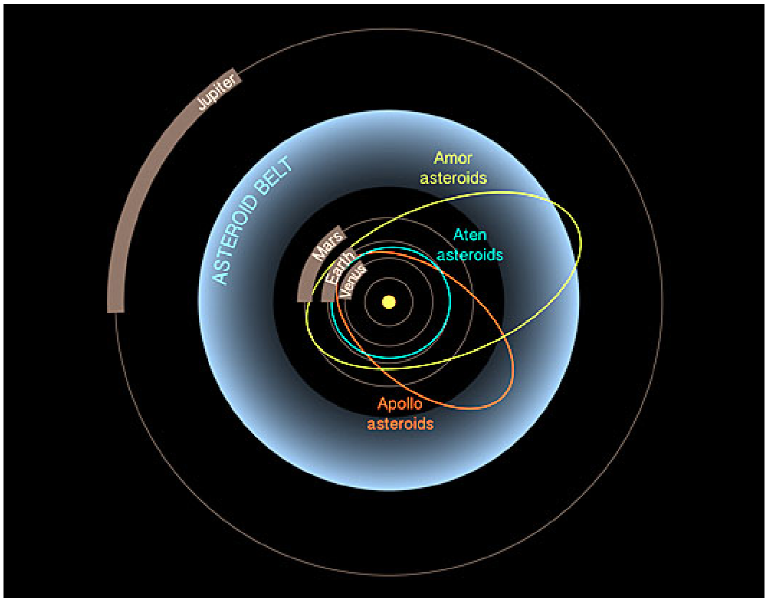

Figure 3. Asteroid categories: Atens, Apollos and Amors groups.

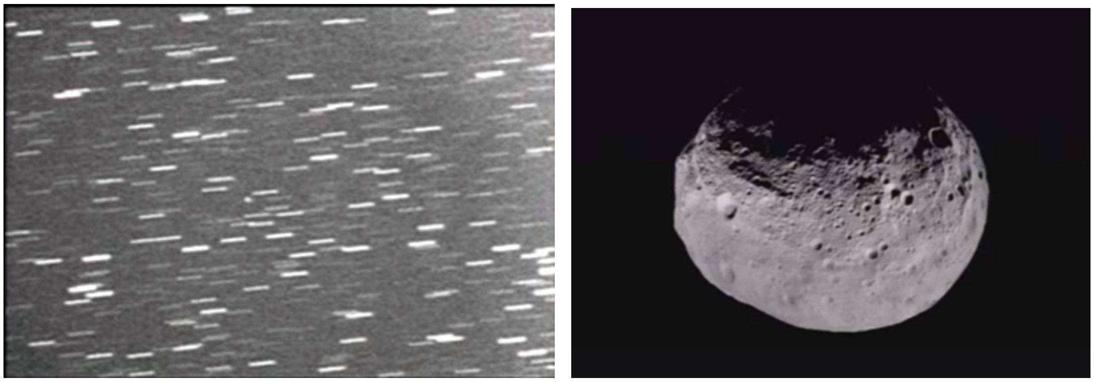

Figure 4. Asteroid seen as a dot against the star background (left) and Vesta asteroid (right). Source: NASA.

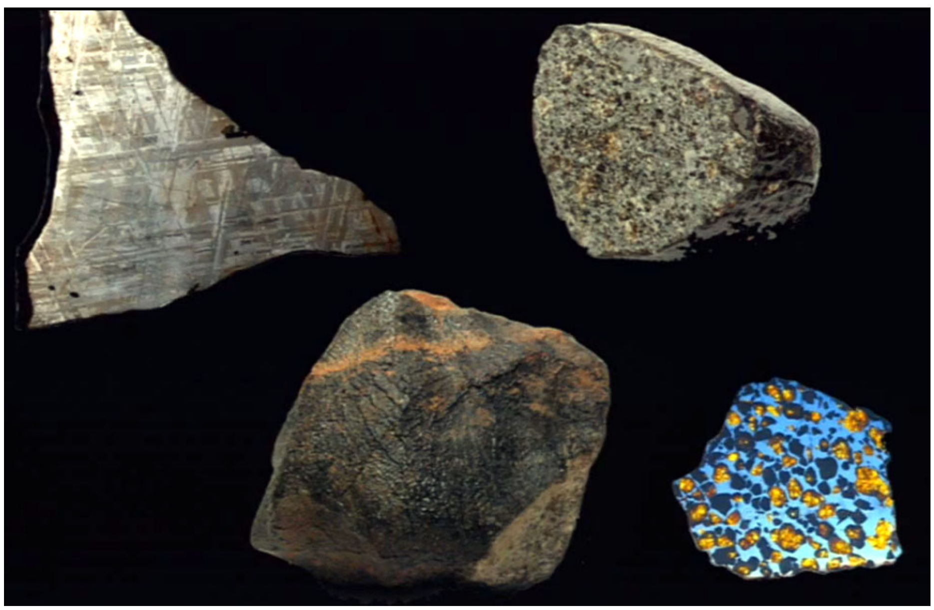

Figure 5. Asteroid samples found on Earth: silicaceous, carbonaceous, iron and palacite with inclusions of perodite meteorites.

PLATINUM GROUP METALS PGMs

About 75 percent of the Near Earth Asteroids (NEAs) are rich in water and about 10 percent are rich in the Platinum Group Metals (PGMs) elements and even gold. Because of the process of formation of the Earth, most of these elements have migrated to the core region and only a remnant of them is available near the earth's surface. They are hard to mine with 350 mt of ore and five months of processing time are needed to produce a single kg of Pt. All the platinum mined on Earth would fill a cube 6 m on the side. Yet ¼ of all manufactured goods require or require PGMs in their manufacture in the high end electronics, transportation, energy and medicine.

The PGMs are rare on Earth but abundant in space. On Earth they are 1,000 times less abundant than the Rare Earth Elements. Without the Earths active Geology, PGMs in space are a common as Sn (tin) or Pb. A single platinum-rich 500 meter wide asteroid contains about 174 times the yearly world output of platinum, and 1.5 times the known world-reserves of platinum group metals.

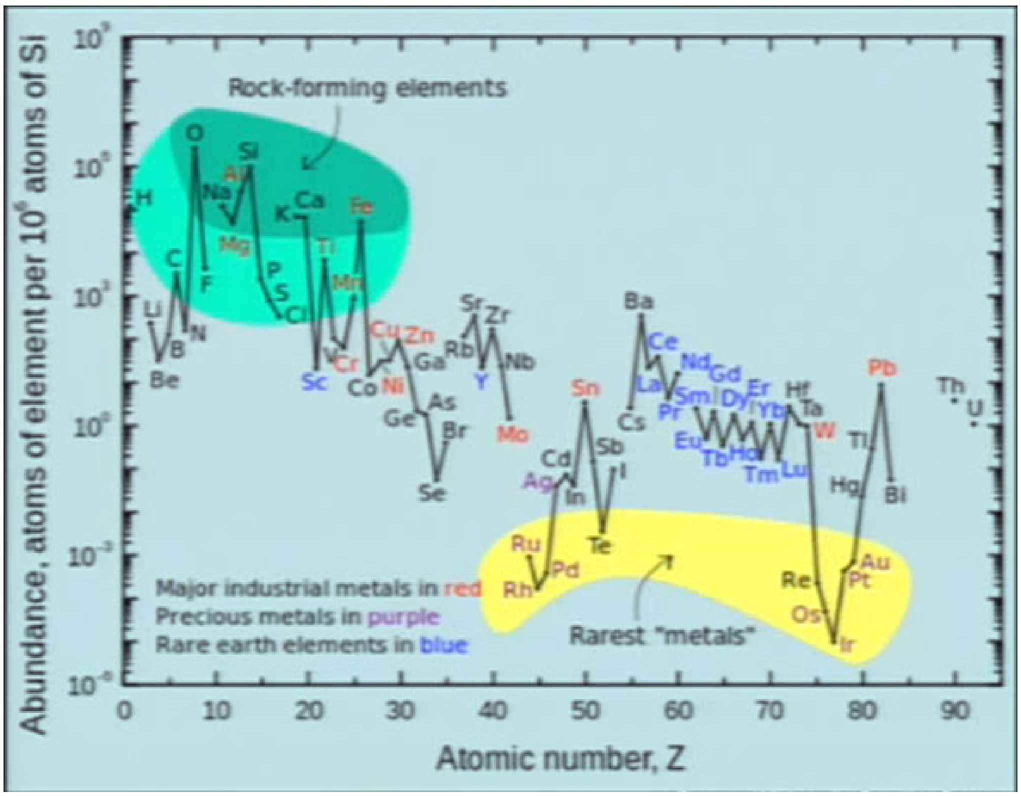

Figure 6. Relative asteroid elemental abundance relative to the Earth's crust.

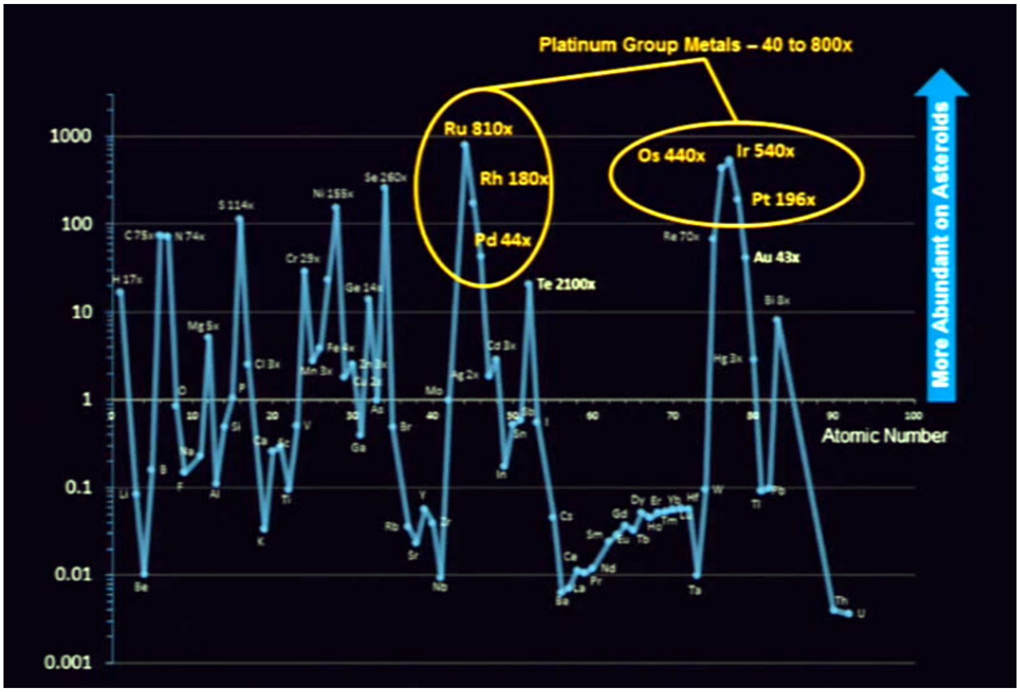

Figure 7. Platinum Group elements abundance relative to Si in the Earth's crust. Source: USGS.

About 18 percent of the known asteroids are easier to reach energy-wise than the moon and 58 percent are easier to return resources from them than from the moon. This has to do with the fact that the moon has a substantial gravity, and the asteroids have a much lower gravity so that they are easier to settle on and then leave. Some of the light elements of interest include volatiles such as NH_3 and H_2O as well as C. Some asteroids are rich in construction metals such as Fe, Ni and Co. Some are rich in PGMs such as Pt, Pd, Rh, Ir, Ru and Os.

Table 1. Asteroid types.

Type	Composition
C-Type, Carbonaceous	70 percent, silicates 20 percent, water, ice 10 percent, oxides
S-Type, Stony	45 percent, Fe silicate 40 percent Mg silicate 5 percent, unknown
M-Type, Metallic	60 percent, Fe 30 percent Nickel 5 percent Pt group metals

Table 2. Composition of Carbonaceous C-type asteroids.

	Composition
H_2O	Up to 20 percent
Metals	Up to 30 percent Ferrous metals: Fe, Ni, Co Platinum group metals: Pt, Pd, Ir, Ru, Rh, Os
Volatiles	C, CO, N, S, Cl, F
Organics	Up to 6 percent organic polymers Tar Sands
Silicates	35-50 percent

Table 3. Annual production of Platinum Group Metals.

Element	Annual production [mt]
Pt	192
Pd	207
Ru	36
Rh	23
Ir	4
Os	1
Total	463

WATER RESOURCE OF ASTEROIDS

In space, water is as much a valuable resource as it is on Earth. By dissociating water using Nuclear or Solar Energies, hydrogen as a propellant and oxygen as an oxidizer can be used as chemical rocket fuel. Even more important the future astronauts will need oxygen for breathing and water to grow plant and animal food supplies. Hydrogen and oxygen can also be used to produce electrical power in fuel cells with the recombination product being again water:

$$2H_2O \xrightleftharpoons{electricity,heat} 2H_2 + O_2 \tag{1}$$

Water would be needed to shield the astronauts against radiation in the radiation-harsh space environment. Water being a solvent, it would be used for the processing of other minerals for living enclosures as well as for transportation systems.

The lifting into deep space of 1 liter of water costs \$50,000. It is estimated that one single 500 m diameter water-rich asteroid would provide the equivalent of \$5 trillion of water for use in space. The goal is to be able to access \$100 per liter of water in space instead of \$50,000 per liter if launched from Earth.

It is estimated that a single water-rich 500-meter-wide asteroid contains 80 times more water than the largest supertanker could carry on earth and could provide more than 200 times the rocket fuel required to launch all the rockets ever launched in human history.

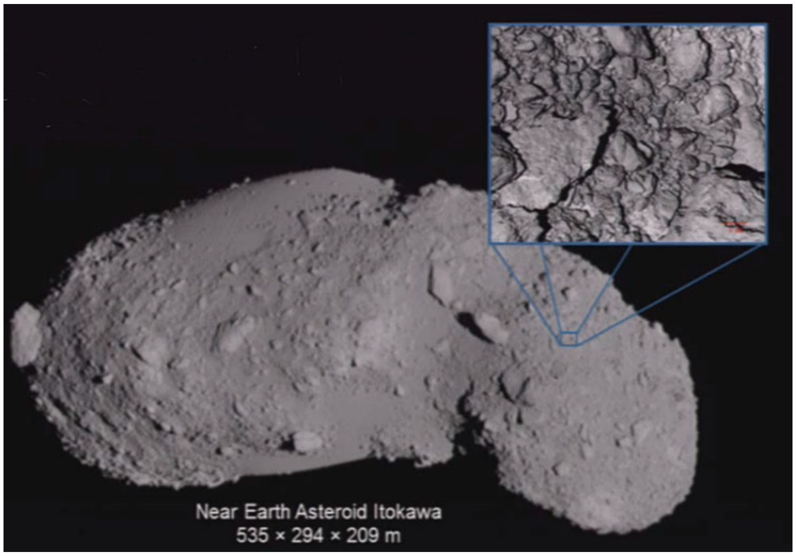

Figure 8. Itokawa is a water-rich Near Earth Asteroid (NEA). Fine material accumulated near its center and bulky material sticks to its surface. Source: NASA.

OTHER ASTEROID RESOURCES

The Asteroids also contain more common metallic elements such as iron, nickel, and cobalt, that could be used in space construction. Volatiles such as nitrogen, CO, CO_2, and methane, exist in quantities sufficient to warrant extraction and possible utilization.

ARKYD SPACECRAFT ROAD MAP

The Arkyd spacecraft are contemplated by the Planetary Resources Company for an evolutionary approach to asteroids mining.
Arkyd 100 series: Would develop core technologies in low-Earth-orbit as a commercial space telescope.

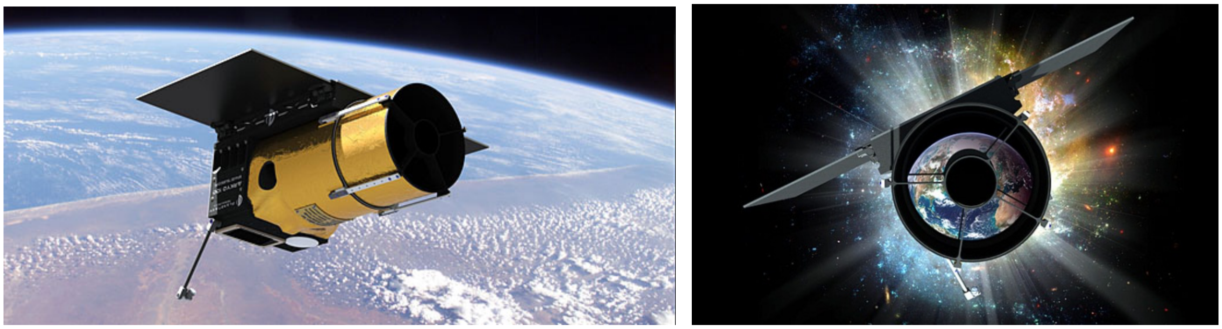

Figure 9. Arkyd series 100, Leo space telescope. Source: Planetary Resources.

Arkyd 200 series: Would initiate initial visits to Earth-crossing asteroids and would demonstrate propulsion and communication systems and would impact asteroids for characterization of their compositions and properties.

Figure 10. Arkyd Sseries 200 Interceptor. Source: Planetary Resources.

Arkyd 300 series: These would involve swarm expeditions to multiple Near Earth Asteroids (NEAs) using laser communications with touch-down and mining claims.

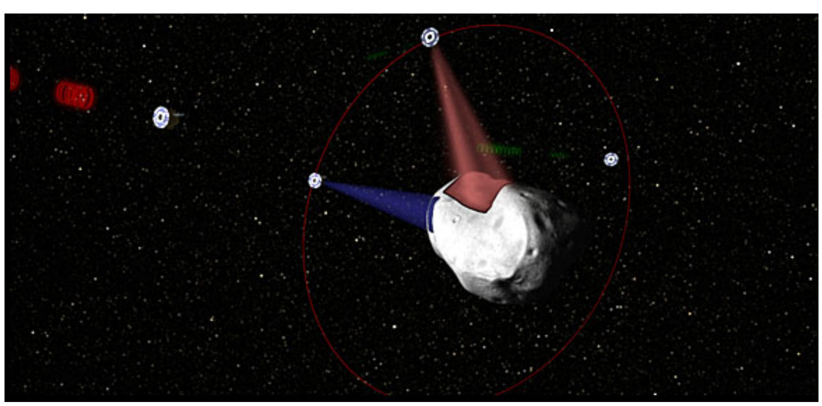

Figure 11. Arkyd series 300 Rendezvous prospector. Source: Planetary Resources.

DEEP SPACE INDUSTRIES

The Deep Space Industries Company is planning to launch a first fleet of asteroid-hunting robotic spacecraft that are laptop-size. Designated as “FireFlies” they will be sent on one-way missions, lasting two to six months, to scout out potential asteroids for harvesting. The 55-pound probes will do flybys of smaller asteroids taking up to 100 photographs as they pass in order to distinguish loose rubble piles from solid bodies made of valuable minerals like nickel, iron or platinum.

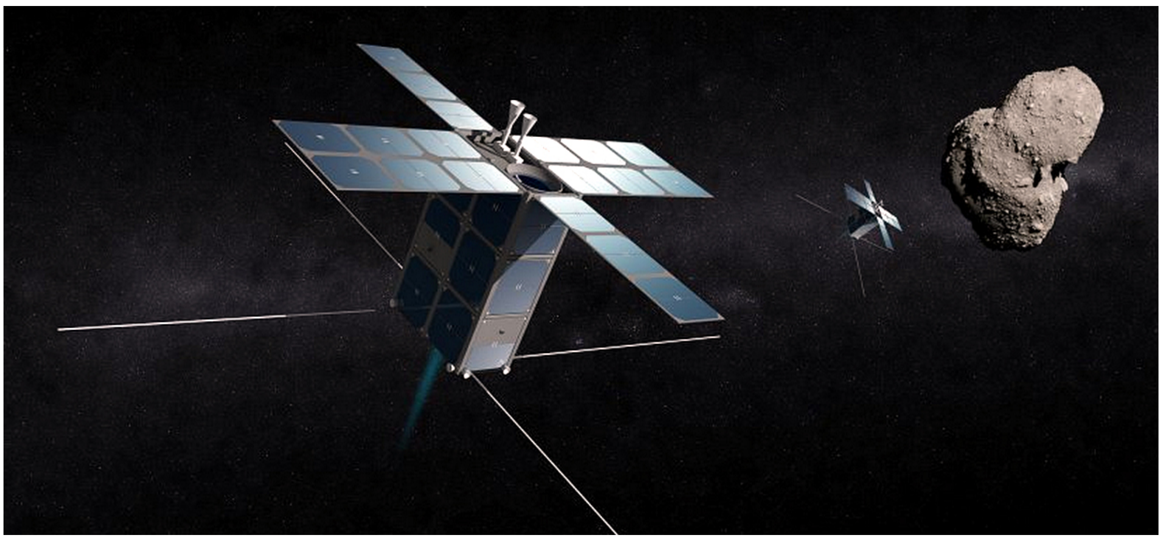

Figure 12. Firefly robotic probe. Source: Deep Space Industries.

It will cost $20 million to get the first fleet of FireFlies built and sent into space, hitching rides on the launch of larger communication satellites. Slightly larger spacecraft designates as Dragonflies will follow out on 2-3 years missions and bring back asteroid samples so that scientists back home can analyze their composition.

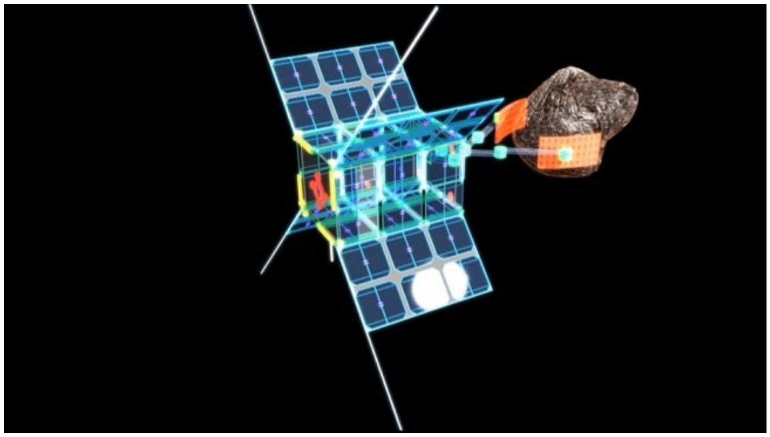

Figure 13, Dragonfly Asteroid mining conceptualization. Source: Deep Space Industries.

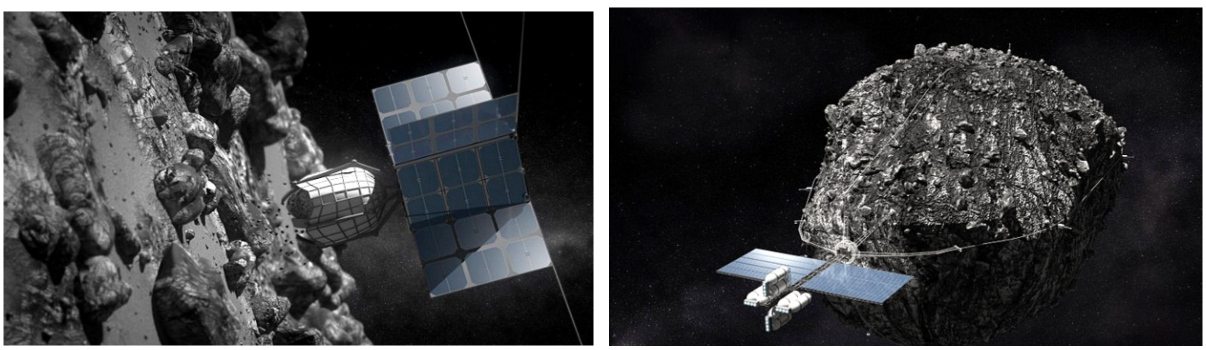

Figure 14. Asteroid material bagging and Harvester devices. Source: Deep Space Industries.

Larger harvesting vehicles would be used to "bag" and drag back smaller asteroids, 10 to 23 feet in diameter, to high Earth orbit.

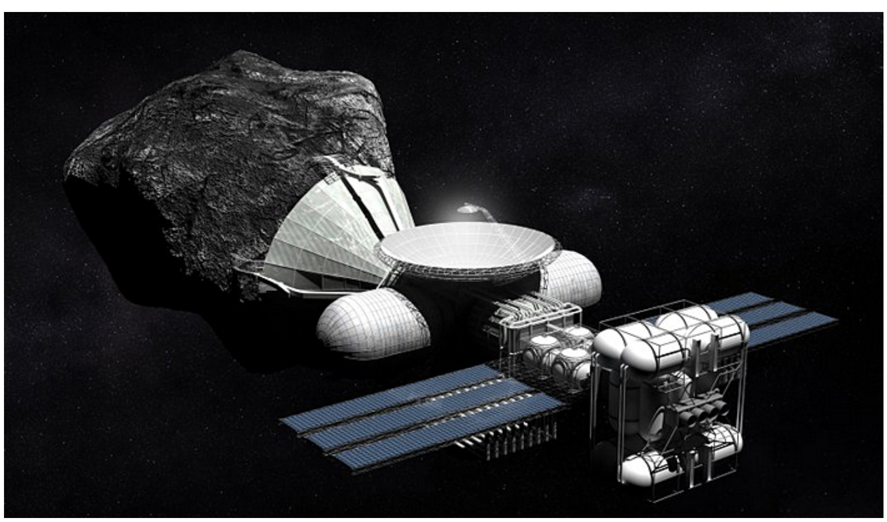

Figure 15. Fuel Processorn spaceship. Source: Space industries.

The Deep Space Company suggests a refrigerator-sized Three Dimensional Printer designated as the Microgravity Foundry that can take crushed asteroid material and “print” metal parts and tools.

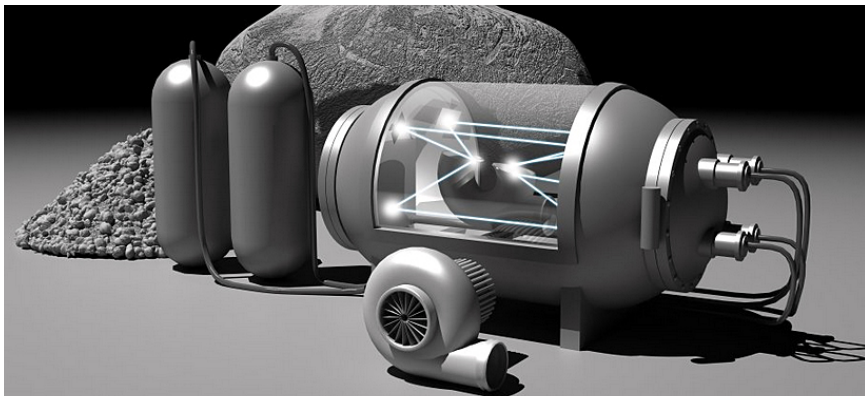

Figure 16. Three Dimensional Printer Micro Gravity Foundry. Source: Space Industries.

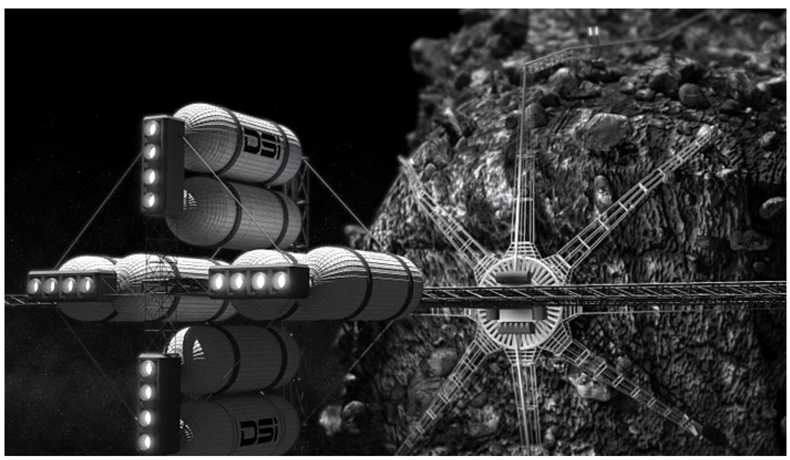

Figure 17 Space habitats and factories. Source: Deep Space Industries.

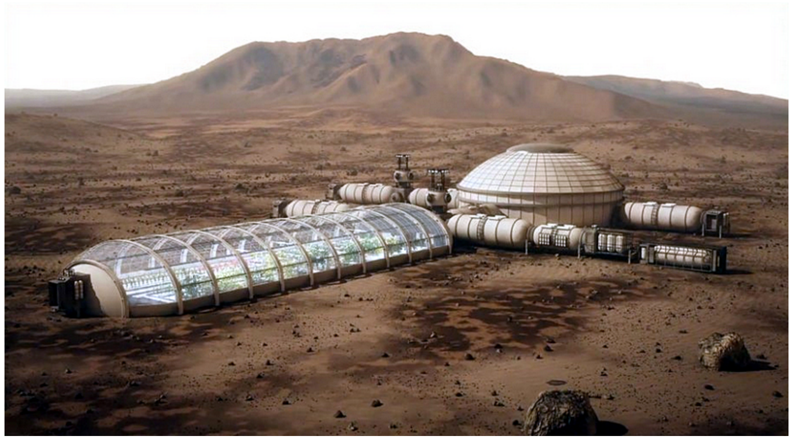

Figure 18. Space settlement on Mars. Source: Deep Space Industries.

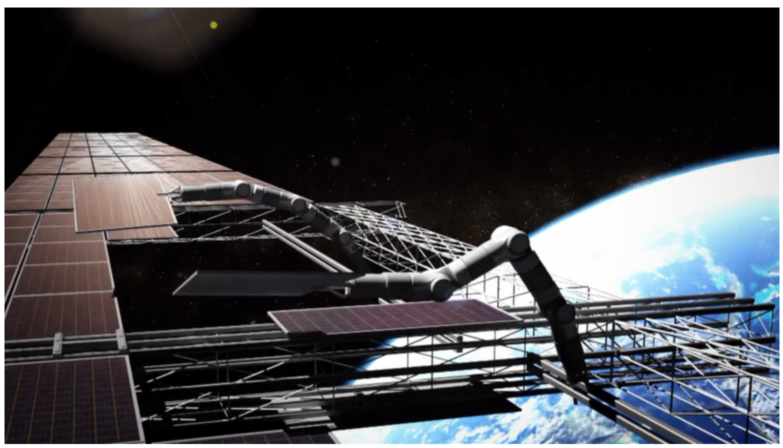

Figure 19. Solar arrays for power production. Source: Deep Space Industries.

NUCLEAR SPACE REACTORS

A Heat Pipe Operated Mars Exploration Reactor (HOMER) providing between 50 and 250 kWe has been proposed for life support, operations, in-situ propellant production, scientific experiments, high-intensity lamps for plant growth and other activities on a Mars mission. Similar designs with higher power output can be used in space manufacturing applications.

This is crucial, since a solar array providing the same power would require a surface area of several football fields. In addition, day and night, geographical sunlight issues, seasonal variations and dust storm environments would not affect a fission reactor system.

The rotating drums around the circumference achieve power level control. These consist of a neutron absorbing side and a neutron scattering and reflecting side, allowing power control without the need for terrestrial used control rods. Moving parts are also eliminated by the use of heat pipes transferring heat for rejection by radiation to space without the use of pumps and moving parts.

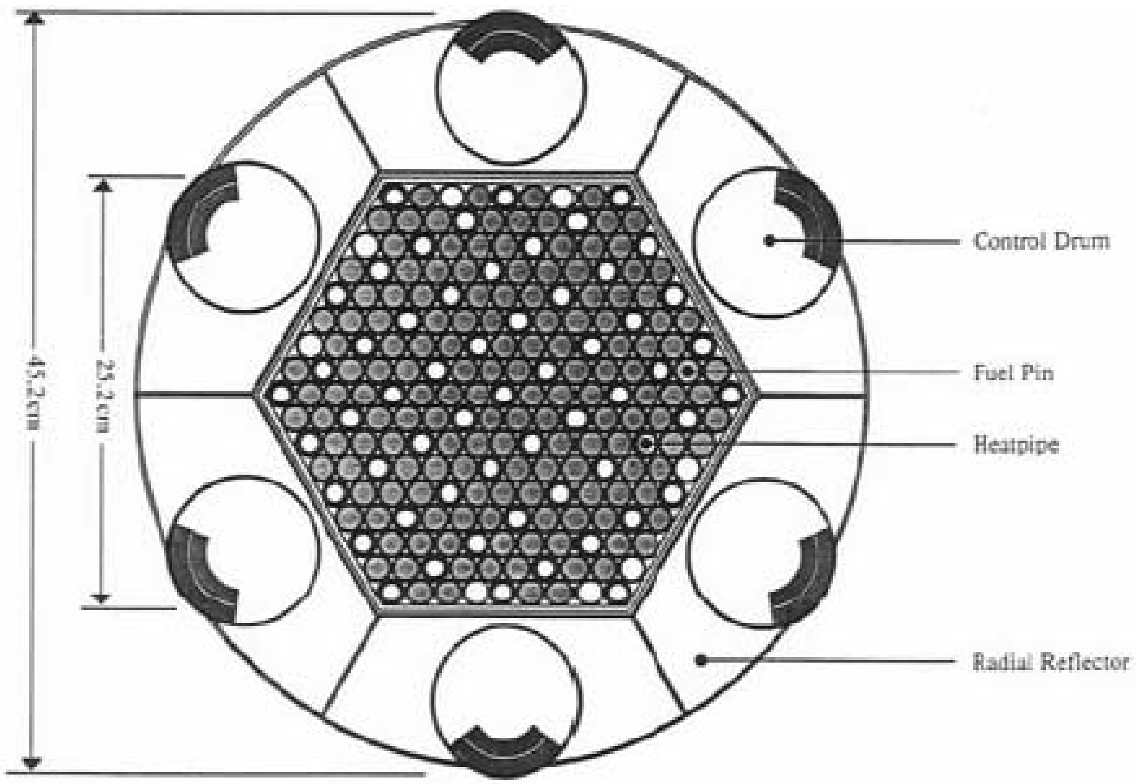

Figure 20. Cross Section of heat pipe space reactor of 125 kWth power, showing the peripheral control drums.

The core contains stainless steel clad uranium dioxide fuel. The fuel pins are structurally and thermally bonded to a sodium heat pipe. Heat is conducted from the fuel pins to the heat pipes which carry the heat to the power conversion system.

The core design is compatible with different types of power conversion cycles: thermoelectric, thermionic, Brayton, Stirling, Rankine or Alkaline Metal Thermal to Electric Converter (AMTEC) using high pressure Na vapor.

SHIELDING AGAINST SPACE RADIATION

Space is a harsh radiation environment. Astronauts cannot be totally shielded from this potentially harmful radiation. Shielding provided by the typically-available structural aluminum skin on a spacecraft around 5 mm in thickness, is significant, but it provides very little reduction in the number of energetic ionizing particles.

In mining the asteroids, materials from the asteroids proper can be used for shielding purposes including both the water, iron and the Platinum Group Metals.

The shielding itself produces secondary particles and radiation such as neutrons and other energetic particles which pose an additional hazard. The amount of aluminum shielding required to eliminate the currently-perceived risk from these heavy ions would produce a spacecraft so heavy that it could never be launched. And, even if this were done, astronauts working outside the spacecraft would still be exposed to space radiation, especially if a solar event occurred.

The long term effects of radiation are measured in terms of the effective dose previously known as the dose equivalent unit. In the conventional system of units the effective dose unit is the radiation equivalent man or rem unit;

$$1 \text{ rem (radiation equivalent man)} = 1 \text{ Q.rad } [\frac{\text{ergs}}{\text{gm}}] \tag{2}$$

where Q : radiation quality factor.

The quality factor accounts for the long term or chronic effects of different types of radiation on living tissue.

In the Système International (SI) system of units, the Sievert unit is used for the effective dose or dose equivalent, where:

$$1 \text{ Sv (Sievert)} = 100 \text{ rem} \tag{3}$$

The following relationship is recommended:

$$1 \text{ rem} = 1 \text{ cSv} = 1 \text{ centiSievert} \tag{4}$$

The six months effective dose rate (dose equivalent rate) for astronauts in the International Space Station (ISS) is shown in Fig. 21 to be around 0.45 [mSv/day]. In a space mission to Mars, it would be three times as much at about 1.3 [mSv/day]. It is clear that special consideration must be given to the shielding and location of the dwellings of any space mission to Mars or for a lunar base.

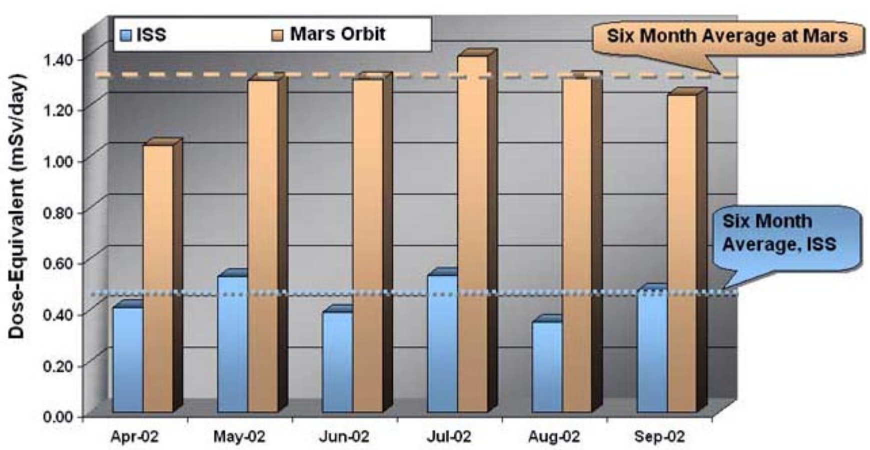

Figure 21. Comparison of effective dose rate or dose equivalent rate for a six-months mission in the International Space Station (ISS) and in a Mars orbit.

Hydrogen rich compounds such as polyethelyne and water are much more effective than aluminum as shielding materials and are being considered for spacecraft use. In fact, water, which must be on board for consumption anyway may have a secondary use as shielding in the future.

Estimating the risk in any given situation including orbital inclination and altitude if in Earth orbit, and the type of shielding, current state of the solar wind is the real challenge. NASA's plan is reduce the uncertainty of long-term risk to 300 percent.

The overall uncertainty in the risk to humans due to ionizing radiation in space can be attributed to three broad categories:

1. Uncertainty in the characterization of the radiation itself in terms of energy and types and possible interactions.
2. Uncertainty in the effects of shielding which would produce a great variety of secondary particles which are in themselves a hazard too.
3. The most significant uncertainty in estimating the risk lies in the response of cells and tissues to the radiation environment that they encounter.

Electromagnetic waves exist as photons and vary according to their energy which is proportional to their frequency, ranging from low frequency, non-ionizing radio waves, up through the visible light frequencies, and then even higher to x-rays and gamma rays.

It is interesting that the energy of light photons is just below that required to ionize molecules. At energies just above the visible part of the electromagnetic spectrum, ultraviolet photons are able to remove electrons from some of the most easily ionized types of molecules such as those found in and around human cells. Fortunately, these "electromagnetic" types of ionizing radiation are not a great threat to humans in space. This is true because they can either be stopped with thin shields or, as in the case of x-rays and gamma rays, their intensity is fairly low in most volumes of space where humans desire to explore. Some have claimed that low frequency electromagnetic fields from power lines are responsible for increased cancer risk but this has not been proved. This leaves the highly energetic particles which can pass through shielding materials as the most obvious threat to humans in space.

LANGRAGIAN POINTS ZERO-GRAVITY MANUFACTURING

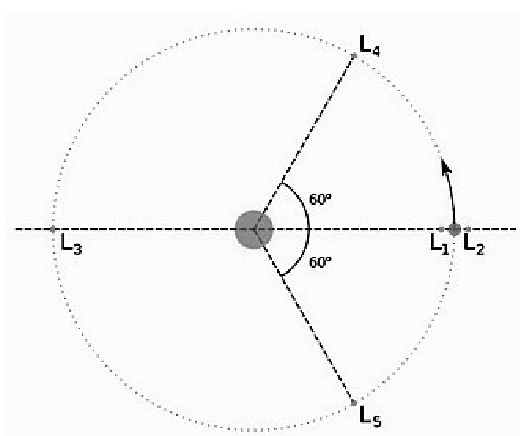

Figure 22. Lagrangian points around planets.

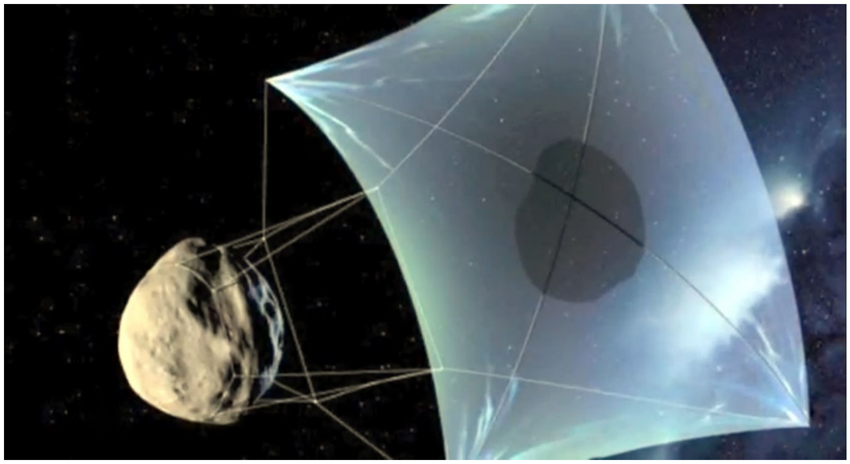

Figure 23. Solar sail tug for asteroids grabbing.

As the gravitational field of the Earth interacts with the gravitational field of the sun there are locations along the Earth's orbit with zero gravity where other bodies can hang out without getting shoved around too much by any celestial bodies. These spots are called the Lagrangian points: L1-L5. While there are five of them, only two are stable, and they are perpetually located 60 degrees in front of the Earth and 60 degrees behind the Earth in its orbit. A zero-gravity space manufacturing station can be built at these points.

Every planet in the solar system has these same stable points, and there are asteroids referred to as Trojans along the orbits of Mars, Jupiter, and Neptune. They are hard to see from Earth since one cannot look 60 degrees ahead or behind the Earth's orbit without getting a telescope glared with sunlight. The Wide-Field Infrared Survey Explorer was launched by NASA in December 2009 and it discovered that the Earth has company in the form of the 2010 TK7 1,000 foot (200-300 m) wide Trojan asteroid at the Lagrangian point L4 preceding the Earth in its orbit that the Earth is going to keep on chasing around the sun for eternity. It travels above and below the plane of the Earth's orbit and poses no immediate hazard as it is expected to remain stable for the next 10,000 years at 80 million km from Earth, coming no closer than 25 million km.

ASTEROID EXPLORATION MISSIONS

The Deep Impact mission at Comet 9P/Tempel was sent by NASA in 2005. Two near-Earth asteroids have been visited by robotic spacecraft launched by NASA. The asteroid 433 Eros was visited by NASA's NEAR mission, and the asteroid 25143 Itokawa by Japan's Hayabusa mission.

NASA is planning the OSIRIS-REx mission to visit the carbonaceous asteroid 1999 RQ36 in 2019. The Large Scale Synoptic Telescope (LSST) is keeping a watch on near-Earth-orbit asteroids. NASA is exploring the best asteroids for a potential human asteroid mission by 2025.

DISCUSSION

To visit and eventually habitate the asteroids, humanity needs to develop a multitude of new engineering, scientific and technological skills including:

1. Development of nuclear and Photovoltaic power sources,
2. Energy conversion systems,
3. Zero-gravity manufacturing processes,
4. Survival in harsh cosmic space radiation environments
5. Fail-safe autonomous robotic systems,
6. Long distance laser communications,
7. Complex systems engineering,
8. Instrumentation and data interpretation systems,
9. Anticipatory control systems,
10. Non-aqueous microgravity mining and manufacturing methodologies at the Lagrange points.

A "Noah's Ark" global effort is needed in preserving a copy of life as it exists on Earth for any need for reproduction against the possible calamity of mass extinction caused by astral impacts, earthquakes, volcanism or global epidemics. In addition to the Earth's moon and mars, the Earth asteroids could be a location for such a "Noah's Ark."

REFERENCE

1. Richard Obousy, "Nuclear Propulsion for Solar System Domination," Discovery News, April 30, 2013.