
ZENITH
STATION

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Executive Summary

Our designed rotating space settlement begins its journey through the sending of a "seed package" on **163693 Atira**, a 41 trillion kg S-type asteroid located in the Goldilocks zone. Over the course of six years, the settlement will be constructed by using the **four robotic self-replicating "spiders"** and the tools included in the capsule. After the specified time period, only finishing touches that are not structurally related to the spaceship remain to be dealt with by the initial crew of 1,012 people (12 at first, 1,000 soon after) that will arrive on the asteroid. Implementing a substantial amount of original ideas into this plan was a key component we've made sure to integrate: **a highly detailed and modified Blender rendition of the settlement** (a modular cross-section elliptical torus with a cylinder in the middle), along with the plan of leaving 163693 Atira to place the spaceship into the L1 Mars-Sun Lagrange Point, are just some of the details we succeeded in including.

The 20,000-person **citizen selection process** will not be conducted through the usual interrogatory methods that are too uncertain to be trusted and will instead place the candidates in an unknown, challenging setting designed to reveal their true moral and physical values.

The settlement's **radiation shielding** will be composed of a hybrid system using 7-meter-deep polymer water tanks (placed in the torus' hull) and several radiation-resisting materials. The thermal one will possess an incorporated multilayered insulator made out of glass fabric and Mylar (a stretched polyester), along with an active system consisting of both heating and cooling systems.

We will achieve the generation of **artificial gravit**y through powerful magnetic field-inducing electromagnets rather than engines. Such a unique configuration will sustain the torus' rotation for extended periods of time and allow for stable zero-gravity conditions within the cylinder.

Obtaining energy will be done by placing **solar panels** on the exterior of the settlement (with integrated Inverted Metamorphic Multi-Junction (IMM) cells and a photonic crystal cooling system) and piezoelectric materials consisting of lead zirconate titanate (PZT) and polyvinylidene fluoride (PVDF) embedded within the pavement structure.

We have also chosen to extensively explore certain modern and pressing topics, such as **space debris**, **asteroid mining**, and **special scenarios** (i.e., the Carrington Event), while comprehensively detailing apparently usual subjects like transportation and communications.

1. Introduction

We have chosen to name our space settlement **Zenith Station** due to the center point of our mission: the never-ending quest of development, discovery, and the spread of life beyond Earth. The term "Zenith" refers to the highest point, the summit of achievement and desire. It represents our ambition to push the frontiers of space exploration, achieving new heights of human creativity and determination. Just as ancient explorers set sail beyond the known horizon, we travel into space, intending to establish a self-sustaining, independent community among the stars. With **Zenith Station**, we stand at the summit of possibility, ready to go on a journey that will push the boundaries of human powers.

2. Citizen Selection

Criteria by which a person will be taken into consideration (the "ECLP" selection process we've designed):

Educational Background / Occupation: we assign a specific number of positions that need to be filled on the settlement, and we need to select field experts according to those needs.	**Community involvement**: this attests to the presence of several character traits.
Lack of criminal record: to reduce the safety hazard risks as much as possible.	**Passing the medical and psychological tests**, which are described below.

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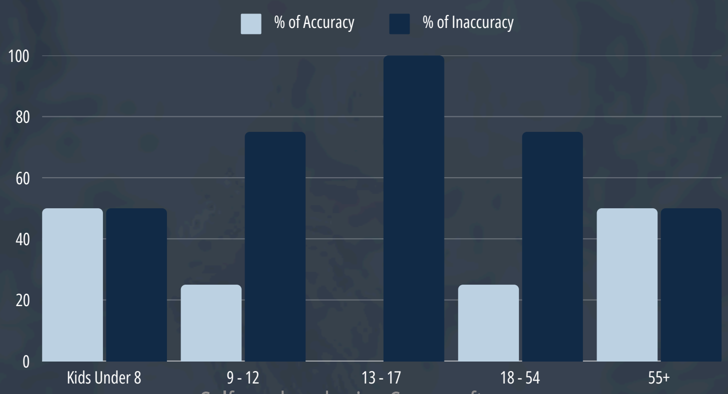
Psychological test:

In order to prepare for a longer-lasting crewed space mission, the Russian Federal Space Agency conducted, along with the RAS Institute of Biomedical Problems, a psychosocial isolation experiment named Mars500 that replicated the key characteristics and constraints of a Mars mission for an international crew of six well-trained people aged 25 to 40 [Ушаков et al., 2014]. The results were gathered in 2011, after 520 days of confinement, and the harsh conditions that were imposed could clearly be seen in the deprecating outcome, which described the team's exacerbating mental state, as shown in the poor decision-making, overall performance, psychoemotional state, sleep phase structure, communicative behavior, and biochemical and mental health indicators.

Notably, the Mars500 experiment also revealed significant sleep disturbances: some participants reported chronic sleep deprivation, which resulted in decreased concentration and more errors [PubMed, 2014]. Additionally, the crew displayed signs of the "third-quarter phenomenon", in which their mood and motivation sharply declined during the middle phase of the isolation period. Additionally, the study showed a consistent decrease in activity levels, with crew members sleeping for almost 700 more hours by the end of the mission than they did at the beginning. Furthermore, the enforced communication lag, which mimicked the circumstances of a Mars expedition, increased interpersonal conflicts and raised psychological strain [ResearchGate, 2014].

If just over a year and a half can cause such severe psychological trauma, for an individual to live their whole life on a space settlement that drastically limits any contemporary lifestyle would be difficult to achieve. To minimize the risks and ensure society's thrivingness, we created a specific psychological test that will be given to every candidate.



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To begin explaining, even the most accurate and renowned tests that have by now been standardized do not take into account the complexity of the human mind and the fact that many individuals who strongly desire to become a citizens of the spacecraft are willing to lie their way into obtaining so, a few of them even doing so unknowingly. Along with the fact that the questions' right answers are too easy to predict (for example: "Have you had any nervous outbreaks recently?" - the correct answer is clearly "No.", this causes any standard test to lose its entire credibility.

The next issue to discuss is, even if a person is willing to tell nothing but the truth, it would be hard for any individual to asses their exact attitude given a dangerous or trauma-inducing event that might happen in an extreme but possible case on a space settlement, not to mention the mental toughness required just to successfully get by on a day to day basis.

Our solution for these two problems goes accordingly: we will exclude the entire interrogatory part from the test and instead require every candidate to take part in an eliminatory probe in which they enter unprepared to what is about to happen, such that the true moral values of everyone are able to emerge to the surface. Each person will be placed in a challenging setting that presents many difficulties and will be individually evaluated by a committee in order to assess the existence of each desired moral (e.g., ability to remain calm, work in a team, contribute, share, adapt, commit, and be selfless when necessary) and physical (e.g., high level of resistance in front of starvation/dehydration and lowered/higher temperatures) value.

Medical Test

It is essential for each candidate to go through a baseline physical examination, followed by more rigorous procedures such as cardiovascular, respiratory, neurological, and musculoskeletal assessments, blood and urine tests, a detailed review of the medical history, endocrine and hormone tests, and an assessment of the immunization status. Candidates will also undergo behavioral and cognitive assessments as part of their health evaluations to determine their ability to handle prolonged isolation and stress, similar to NASA's Selection of Astronauts procedures, which include psychiatric and neuropsychological testing. Through these examinations, all participants are guaranteed to meet the rigorous physical and mental requirements necessary for space residence.

What happens next?

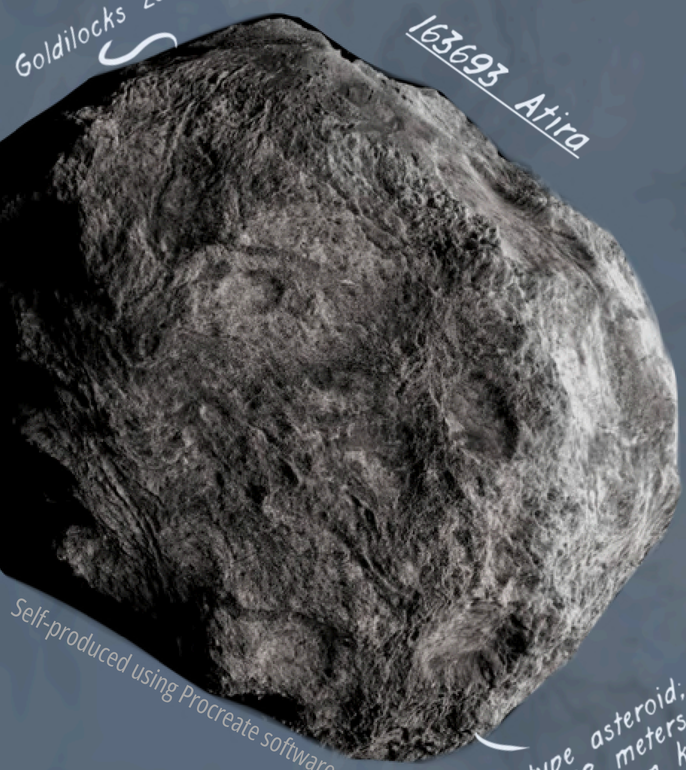
If a person passes the "ECLP" selection process, they will need to start the preparation for the space-specific conditions, including being educated on certain areas such as radiation exposure, microgravity effects, psychological challenges, nutrition, and space hazards, following complete emergency medical training. Training plans will be based on current astronaut conditioning regimens, such as extended restricted habitat simulations, hypobaric chamber exposure, and parabolic flight training. This guarantees that prior to their deployment, candidates are both physically and psychologically prepared for the demands of space life.

Clarifications:

1. We will also bring the children of the accepted candidates onto the settlement, as we put great faith in the selection process and believe their parents raised them in the spirit of the values they hold.
2. We will not consider age to be a disqualifying factor in the citizen selection process, as it is unrelated to the capacity of an individual to contribute to society. However, we will still ensure the colony's statistics (as a whole) regarding birth rate will not be affected.

3.1. Settlement From Asteroid

STRUCTURE



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"It is possible even with existing technology". That was Gerard K. O'Neill's statement regarding the practicability of living in space. He said it in 1974, and fast forward almost 50 years, and we still don't have a settlement on a planet or in space. The main reason? Just like he put it, "The challenge is to bring the goal of space colonization into economic feasibility." And while the technology advanced greatly, it certainly didn't get any cheaper. Apart from this, the risk of such a major operation going wrong in any of its many steps is just one more factor to take into consideration when thinking about whether such a colossal amount of money should be invested.

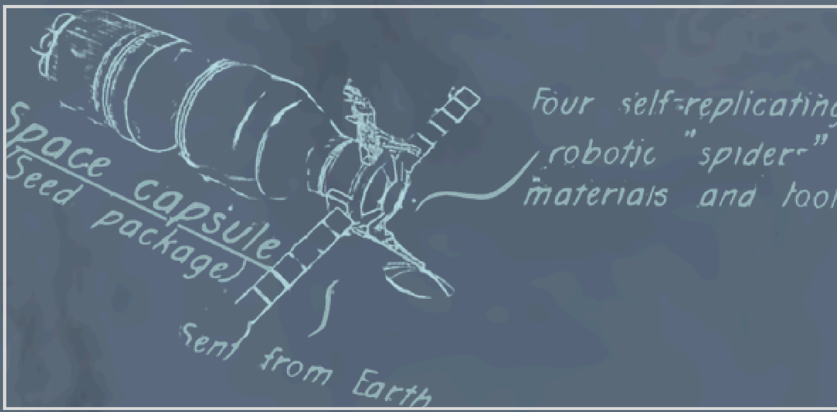
Everything begins with a "seed package" that is sent in the Goldilocks zone (habitable zone with temperatures of 0-100 °C) to the 163693 Atira asteroid, an S-type asteroid (84.9% oxides, 11.1% free metal, and 4% volatiles) with a mean radius of 1928 meters and a mass of 41 trillion kilograms.

The capsule sent contains some materials and tools, along with four robotic workers. That's it. With just that group of four automated "spiders," we are able to replicate them using the many state-of-the-art circuit board modules included in the package and the in-situ asteroid materials with which we build the other parts of the spiders, including their framework, connectors, covers, and legs.

Once the replication process is done and thousands of "spiders" and many more mechanical automata are ready to go, they will start mining the asteroid, with the final goal of restructuring it to resemble the enclosed substructure of a space settlement with a large inventory of supplies.

Mining and Processing:

To start off, small robotic devices will deliver regolith dust, pebbles, and grains to the base station, with an impact crusher further breaking up the small stones into grains and separating the metal, silicate, and ice fragments. To break down bigger rocks, mechanical tools will employ jackhammer chisels, while slabs and monoliths could require blasting and digging. Additionally, the majority of the unbound ferromagnetic metal grains (nickel, cobalt, and iron) from the silicate and carbonaceous grains will be extracted by magnetic beneficiation. The paramagnetic metals (zirconium, titanium, platinum, and magnesium) could also be extracted with more complexity and stronger magnetic fields. These metals will be divided, listed, and stored [Jensen, 2023].



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The materials will be processed using Fresnel lenses and mirror systems, which concentrate the sunlight. Most of the free volatiles will be released from the regolith grains as a result of lowtemperature solar heating. For oxides, a common melt temperature of approximately 1200 °C is frequently used. Gases including water (100°C), hydrogen sulfide (-60°C), carbon dioxide (-78°C), methane (-161°C), oxygen (-183°C), carbon monoxide (-191°C), nitrogen (-196°C), hydrogen (-253°C), and helium (-269°C) will condense when the temperature is gradually lowered.

Regolith grains will be melted in a solar furnace in order to form tiles of ceramic and anhydrous glass (an astonishingly high tensile strength type of glass that, according to researchers, can replace structural metals for a range of space engineering purposes as it possesses tensile strength of 13,800 MPa and a bending strength of about 100 MPa, higher than those of the metals [Jensen, 2023]). One possibility is casting, which may make use of a few molds brought along for the reorganization mission. Rapid cooling of the anhydrous oxide strips is going to be employed to create sturdy laminate plies, which will be stacked and pressure sintered as they cool. These will offer the structural strength needed in our structure and be almost as robust as the individual plies.

Materials:

The main difference between an ordinary asteroid mining mission and this asteroid restructuring plan is that now we are focusing on using bulk oxide material instead of just the metals or water found in situ, which was previously considered waste despite composing over 80% of the asteroid. With this, we can create rods and tiles with which we build trusses, panels, and siding.

Glass may be utilized in structures such as windows, bricks, slabs, and beams. Columns, beams, blocks, shells, slabs, and cylinders are among the feasible building materials. These materials can also be used to create finished items like electrical insulators, flooring, sinks, and pipelines. High-strength glass fiber can also be used to make cables.

Glass structures may be strengthened with asteroidal nickel-iron steel, improving their ability to withstand numerous types of compression and tension, but with the increased tensile strength provided by the anhydrous, vacuum-produced glass, this may not be required. Basalt sheets may be used as panels and should ideally be produced using continuous strip casting [Jensen, 2023]. This technique is used on Earth (melting the feedstock constantly, extruding the molten stock, and creating a cooling material sheet where the molten material moves downhill using gravity, after which it hardens and lengthens) and will need to be modified due to the asteroid's low gravity and vacuum. The molten material may flow if the continuous casting equipment is rotated to create some gravity.

Why 163693 Atira?

Out of all 22,122 asteroids listed in the JPL Small Body Database (from the Apollo, Aten, Atira, and Amor classes), Dr. Jensen, in his study "Autonomous Restructuring of Asteroids into Rotating Space Stations" [Jensen, 2023], has chosen 163693 Atira after a careful selection process in which he took into account their orbits and inclination (to be Earth-like: a semimajor axis less than 1.5 AU, an inclination lower than 26°, an eccentricity smaller than 0.4, a perihelion exceeding 0.4 AU, and an aphelion less than 2.2 AU), their rotation speed and size (the magnitude parameter must be greater than 20, the rotational period higher than 3 hours, and the diameter between 0.45 km and 5.0 km). To choose from the remaining 87 asteroids, he computed the ROI (Return on Investment: travel cost over the estimated value of the asteroid) for each of them and found 163693 Atira to be the best option.

Colonizing the Settlement:

Once the framework of the settlement is ready, possessing radiation protection and Earth-like gravity, an initial crew of 12 people will be brought to the rotating settlement to inspect the automated work done by the "spiders" and automata, after which a larger crew of 1,000 people will arrive to employ the surplus materials to provide heating, energy, air, cooling, and light to the structure, along with the other required finishing touches. Subsequently, the population will gradually start getting there in spacecraft with a capacity of 100 people (detailed in the "Transportation" section), thus slowly colonizing the settlement.

Departure:

Our mission will not end at the 163693 Atira asteroid. We had in mind the idea of leaving its orbit and heading for a more resourceful place in our solar system, but a concerning thought about disrupting the nearby orbits occurred to us. Atira's moon's orbit would enlarge due to the sudden decrease in the asteroid's mass, and then it would move even more, being attracted by the settlement at takeoff. However, because this would not actually endanger our spacecraft, we will let the moon stabilize its new orbit by itself, and we will confidently head towards our final destination.

Note: This restructuring plan is viable for many asteroids, but we kept the choice of 163693 Atira for its proximity to Earth, which reduces the cost and time of bringing future settlement citizens to the spacecraft.

Construction phases:

Seeing as the construction of our settlement will be done exclusively in outer space, it is necessary to assemble it gradually, beginning with the central cylinder and expanding outward. Therefore, every single element will be divided into sections, which will be welded together as they are assembled, ensuring an airtight seal once the entire structure is ready to be inhabited. It is important to mention that every part of the settlement will already have the appropriate shielding incorporated when it is assembled.

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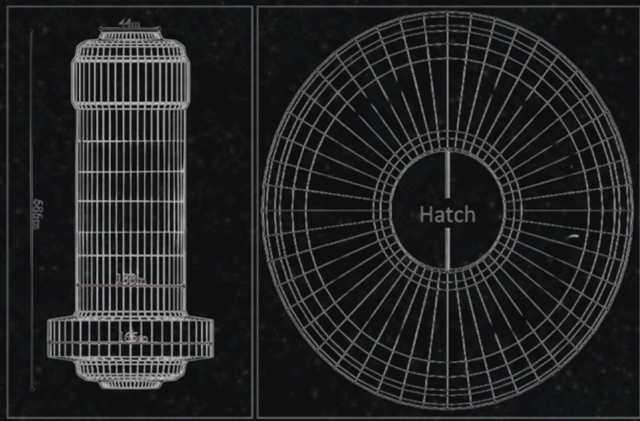
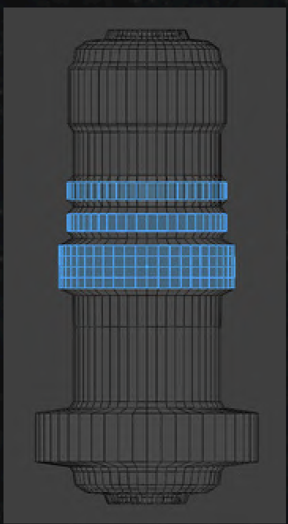


Phase One - The Central Cylinder

The main hub is made up of several rings that will be superposed, while two similarly circular structures will close the open ends of the newly formed tube, thus forming the main hub. The front structure of the cylinder will have a hatch that allows the station to connect to another space station module if it is seen as necessary in the future of the colony. The central cylinder will not rotate, so it will permanently stay in 0G.



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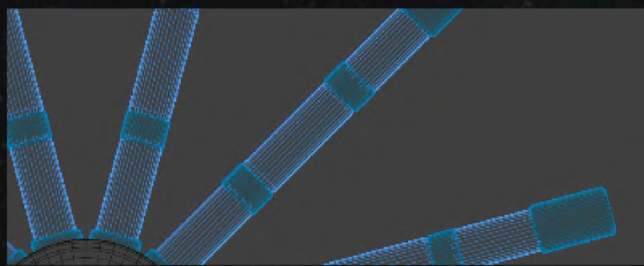
Phase Two – The Rotating Rings

In the middle of the cylinder, on its outside, a permanently rotating ring will be placed. Working on an electromagnetic field, the ring will rotate only the torus, thus allowing the cylinder to be in 0G while the torus has a gravity similar to that on Earth. A second and a third ring will be placed next to the main one, with the second one starting its rotation only when people pass from the torus into the cylinder or vice versa (detailed in the "Transportation“ and “Artificial Gravity” sections).



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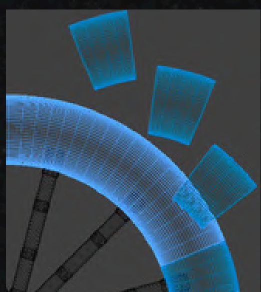
Phase Three – The Connecting Tubes

On the main permanently rotating ring, we will attach 12 resistant tubes oriented perpendicularly to the surface of the ring, each comprised of three smaller cylindrical structures, which will be added sequentially. They will connect the cylinder with the torus.

Phase Four - The Elliptical Torus

In a comparable manner to the assembly of the cylinder, the torus will be split into 24 smaller elliptical modules, and each module will have very resistant retractable walls at both of its ends, which can be closed or opened on demand. After all the rough elements are put into place, the inner section of the torus will be removed, with the remaining materials being repurposed further down the process, so it can be replaced with our large glass special panels (which form the ceiling of the torus).



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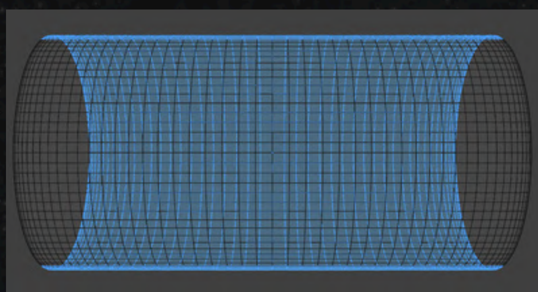

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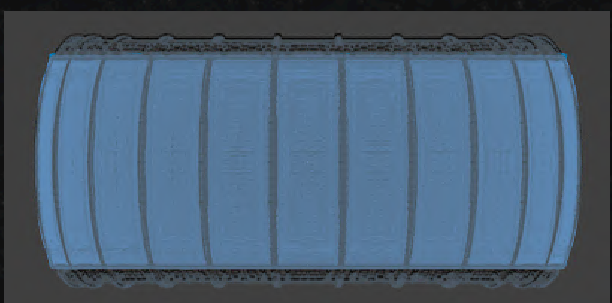

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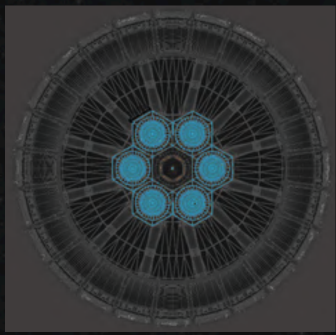
Phase Five – The Solar Panels & Escape Pods

Along the outer structure of the torus, we will place solar panels, which provide us with an important source of energy. On the outer structure of the torus, we will also place the escape pods (detailed in the "Safety" section).

Phase Six – Thrusters

The thrusters will be placed in a honeycomb shape at one end of the cylinder, each thruster being hexagonal. We chose this structure because it will allow us to expand this area in the future: if we attach more and more module space settlements identical to the main one, we will implicitly need greater propulsion power. Thus, thruster modules will be added as the number of additional settlements docked to the main settlement increases. To move the spaceship laterally, we will attach eight smaller thrusters along the outer structure of the torus.



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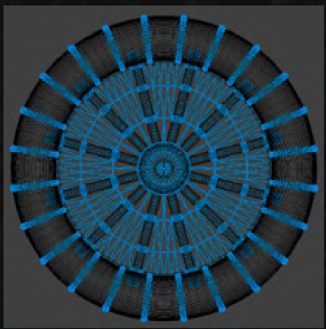

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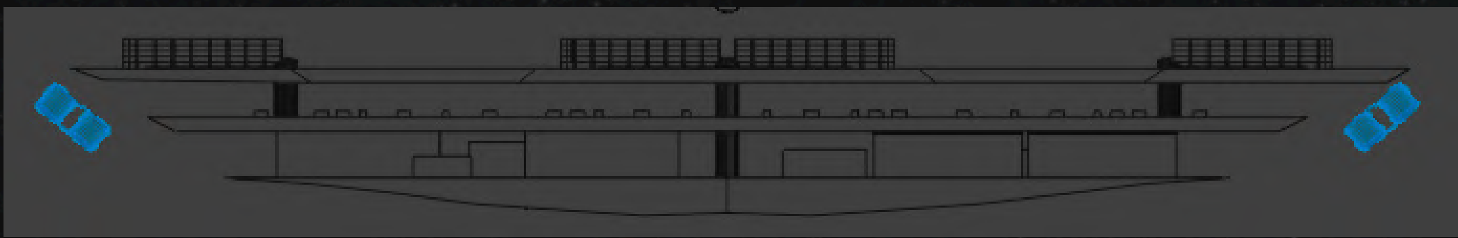
Phase Seven-Reinforcements

Each of our main elements will be reinforced along their seams using large steel structures that act not only towards the improvement of the overall structural integrity but also as a means of heat dissipation, seeing as there are not many ways for the heat to escape in the near vacuum of space.

The Phase Eight - Interior Structure

Once every major element is in place, we can begin building the structures that will support the three floors into which the torus will be divided, parallel to the axis of rotation. The outermost floor will contain the bulk of our industrial facilities. The middle floor contains our transportation network, which provides easy access to any area of the torus, as well as tunnels that pass through the floor to reach the escape pods. On the top floor, we will place the residential, educational, and recreational areas.



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Phase Nine – Ensuring Habitability

The last phase of our process consists of making life both possible and pleasant on the station. Firstly, a mixture of gases meant to replicate Earth's atmosphere will be slowly released into the entire volume of the living space. Secondly, a thorough test for any leaks or errors during construction will commence, ensuring the lowest possible number of risks are taken when we finally allow the members of our program to step on their future home. Finally, the living spaces will be adorned with plants, all the light fixtures will be installed, and all the buildings will be fully furnished and ready for people to inhabit.

Expansion Plan:

As the settlement gains its footing and becomes one of the cornerstones of humanity's outward expansion into space, the eventual necessity for enlargement is not something we can dismiss. While the torus does provide plenty of room for extra residential complexes, crowding the settlement may put excessive pressure on the limited food production. This, coupled with increasing demand from aspiring colonists on Earth, may provide the incentive to begin the construction of a second torus. It would ideally be of identical size to the first and placed on an extended central cylinder, rotating in the opposite direction so as to assure greater stability for the station as a whole. All the additional structures for making the expansion plan work were mentioned in the lines above.

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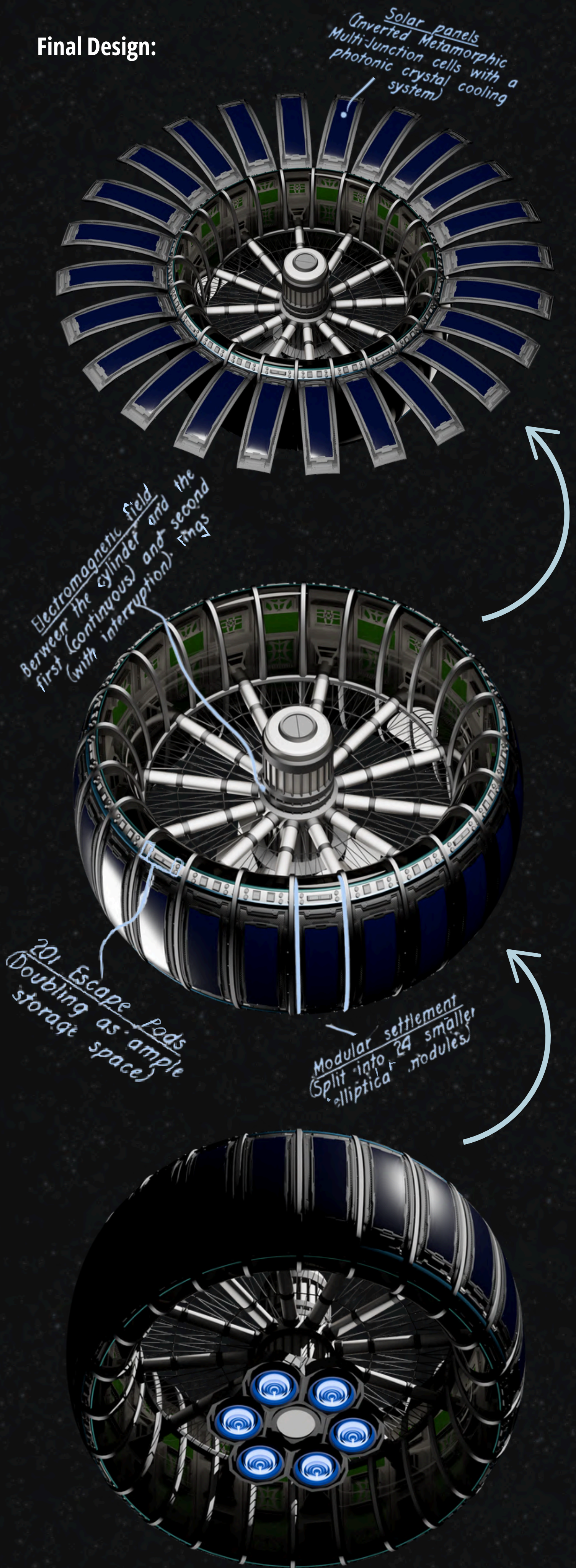
Final Design:



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Engineering Zenith Station in orbit:

Rather than being launched as a prefabricated building, Zenith Station will be manufactured in orbit using resources mined from Atira. This necessitates the development of a Space Assembly Factory (SAF), an extensively automated orbital construction machine able to process raw asteroid material and to assemble the station's modular components in microgravity. This method consists of electromagnetic stabilization, self-replicating robots, and precise welding in a vacuum. The fundamental difficulty for the SAF is to assemble huge, pressurized, and structurally durable modules in an environment without gravity, air pressure, or typical building methods.

A. Assembly process

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Phase	Steps
Matertial proccesing	Metal extraction from Atira's regolith. Electromagnetic separation for iron, nickel, cobalt. Silicats are melt by solar funaces into construction panels. Structural components fabricated by 3D printing
Modular assembly	Components are trasnported to magnetic stable zones. Airtigh seals are created by electron beam wielding. An AI-driven laser corrects positioning.
Final integration	Modules are moved to the rotating torus Gyroscopic stabilizers match spin velocity. Atmosphere regulation, power grids and artifical gravity are installed on the space settlement

B. Challenges and Solutions

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Challenge	Solution
Modules float unpredictably which causes misalignment.	Electromagnetic docking arms & AI-guided robotic manipulators help secure components before welding.
A 1 cm misalignment can cause structural failure.	Lidar-guided docking, polymer infusion, and real-time stress monitoring ensure sub-millimeter accuracy.
Radiation causes material decay, and impact with debris can puncture hulls.	Regolith-infused composites absorb radiation; multi-layer Whipple shielding deflects impacts.

3.2. Shielding

The space environment presents numerous challenges for human habitation, with one of the most significant being radiation exposure. The Lagrangian Point L1 between Mars and the Sun experiences high levels of solar and cosmic radiation. A study analyzing particle flux data from various spacecraft (such as MAVEN, Mars Odyssey, and the Radiation Assessment Detector on the Mars Science Laboratory) has revealed that energetic protons in the 0.05–5 MeV range increase by a factor of 2.5–4 during the solar maximum of cycle 24, while 300–500 keV protons at 90% cumulative probability (CP) were higher in solar cycle 23 by a factor of 1.7–3.2 compared to cycles 24 and 25. The 145–440 MeV proton flux, representing low-energy galactic cosmic rays, varies within a factor of 1.8 at both 50% and 90% CPs. Given these findings, implementing effective radiation shielding is critical to ensure the habitability of a settlement at Mars-Sun L1, where the lack of a global magnetic field and significant atmosphere makes shielding even more essential compared to near-Earth environments.

Radiation Shielding Methods

The most common way of attenuating radiation effects is passive shielding, which consists of building layers of radiation-resistant materials around the settlement walls. Another method is using water: the radiation resistance of water has long been acknowledged due to its extraordinary features. It is a strong shield against numerous types of radiation, especially ionizing radiation found in space habitats, because of its high density and hydrogen concentration. Water can act as a radiation shield by absorbing and dispersing radiation rays, which lessens their damaging impact on beings. This characteristic has prompted water-based shielding systems in spacecraft and habitats, essential for preserving the health and safety of astronauts and other occupants subjected to space travel. The third method is magnetic shielding, which involves creating a protective magnetic field around the spacecraft. This field deflects charged particles, like solar wind and cosmic rays, away from the protected area, reducing the risks posed by space radiation and enhancing the safety of missions. Although magnetic shielding has the highest protection rate, it would be impractical as it consumes too much energy. Also, this technology still needs to be appropriately developed in today's age, so it is unstable and can quickly fail.

Selected Shielding Approach:

Considering the efficiency and feasibility of different shielding methods, the settlement at L1 will employ a hybrid shielding system combining water and passive shielding materials. Water will serve as the primary radiation shield, forming a 7-meter-thick layer in the hull of the settlement.Considering the efficiency and feasibility of different shielding methods, the settlement at L1 will employ a hybrid shielding system combining water and passive shielding materials. Water will serve as the primary radiation shield, forming a 7-meter-thick layer in the hull of the settlement.

Unshielded deep space radiation levels are estimated at 1000 mSv/year, based on deep-space exposure models for long-duration missions. Using the radiation attenuation equation:

$$I = I_0 e^{\frac{-x}{\Lambda}}$$

where:

- $I_0 = 1000 mSv/year$
- $x = 7 meters$ (water thickness),
- $\Lambda = 1.6 meters$ (attenuation length for cosmic rays in water)

we calculate:

$$I = 1000 e^{\frac{-7}{1.6}} = 1000 e^{-4.375} \approx 12.5 mSv/year$$

Thus, a 7-meter-thick water shield reduces deep-space radiation by ~98.7%, lowering exposure from 1000 mSv/year to ~12.6 mSv/year, which is comparable to natural background radiation on Earth.

Effectiveness of 7 m of Water:

- Low-Energy Protons (0.05–5 MeV): These protons have very short ranges in water (a 5 MeV proton is stopped in roughly 0.3 mm of water). Even a thin layer will stop them almost entirely; thus, 7 m of water provides nearly 100% attenuation.
- Intermediate Protons (300–500 keV): These particles have even shorter ranges and are also absorbed almost entirely.
- High-Energy Protons (145–440 MeV): A 150 MeV proton has a range of roughly 15 cm in water, while a 400 MeV proton travels about 40–45 cm. A 7 m thick shield provides roughly 15–45 times the stopping distance for these particles, ensuring almost complete absorption.

This thickness is designed to reduce radiation levels to those found in high-altitude locations on Earth, such as Quito, Ecuador. Additionally, passive shielding materials will reinforce protection in cases where water levels drop. The layered passive shield consists of:

- Boron compounds (such as sodium tetraborate or boron carbide) to absorb neutron radiation and slow down charged particles.
- T-10 glass fabric (composed of aluminum, silicon, and boron oxides) for further attenuation.
- Nickel as the final layer, providing a dense barrier against high-energy radiation.

Thermal Insulation:
The great temperature fluctuations in space, from -270°C to over 250°C, call for both passive and active thermal control strategies. By means of a 20-layer composite of aluminized Mylar, glass fabric, and aerogels, which reduces heat transport, passive thermal protection is obtained. Additionally, ultra-light silica aerogels tucked inside the hull's construction can offer remarkable insulation, by lowering thermal conductivity. Phase-change materials, or PCMs, such as paraffin-based compounds, also absorb and release heat during phase transitions, stabilizing interior temperatures. Variable emissivity coatings, such as vanadium oxide (VO_2) coatings, which dynamically change heat radiation qualities, therefore providing effective temperature control, are another vital component.

Also quite important is active thermal regulation. Excess heat from cryogenic radiators and heat pipes loaded with liquid ammonia flows to high-efficiency radiators, where it is dissipated into space. Smart thermal sensors driven by artificial intelligence enhance this system by constantly monitoring and adjusting heating and cooling activities. These all-around solutions guarantee ideal temperature stability for all onboard systems and occupants.

Impact Shielding:
We use a multi-layered Whipple Shield able to reduce hypervelocity hits considering the hazard presented by micrometeoroids and orbital garbage. There are three basic levels to the Whipple Shield. Comprising a titanium-aluminum composite, which fractures incoming missiles upon impact, the first layer (that of the outer bumper) is designed to distribute kinetic energy. Kevlar, Zylon (PBO fiber), and Nextel ceramic fabric make up the second layer, intermediate filling. Ensuring structural integrity, the last layer (pressure containment) is a reinforced carbon-carbon (RCC) inner wall.

We combine self-healing shielding materials to improve impact resistance even more. Epoxy-based healing agents included in microencapsulated polymer composites independently fix damage caused by impact. Aluminum-titanium oxide and other metal-oxide coatings allow automatic mending of micro-cracks through atomic diffusion, so preserving the lifetime and potency of the shield.

Maintaining structural integrity hinges on real-time damage monitoring. Continuous stress level assessment and microfracture detection before propagation are achieved by embedded fiber-optic strain sensors Moreover, early indications of material fatigue given by carbon nanotube-based stress sensors enable proactive maintenance and repairs as necessary.

3.3. Engines & Thrusters

Launching the settlement
We have decided to employ a Hall-effect thruster for our space settlement. Hall thrusters are a type of ion thruster that employs electric and magnetic fields to ionize gases such us xenon to propel the ions out to develop thrust. Instead of a grid, it utilizes an electron plasma to develop a negative charge at its open end. They are extremely long-lasting, with runs lasting up to 1.330 hours, which makes them suitable for deep space missions. Hall thrusters utilize electricity drawn from solar panels to expel plasma(gas cloud made of charged particles). This allows the spacecraft to achieve a speed of up to 24.85 miles per second. In contrast to that, a vintage chemical rocket only manages 3.106 miles per second. Researchers are in the process of installing a new type of Hall thruster called the X3 Ion thruster. It is the most efficient and powerful type of Hall thruster to date, having established several records for thrust, maximum power output, and current operating achieved by a Hall thruster to date in a recent test.

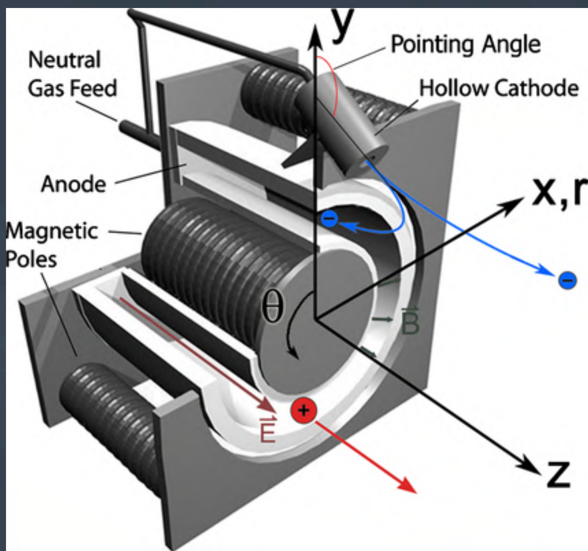

Image Credit.

The X3 Ion thrusters have a magnetic field created by a set of magnetic coils arranged in a nested or concentric manner, offering a more complex magnetic field geometry than the standard Hall thrusters. Traditional Hall thrusters operate between one and six kilowatts, thus producing low thrust. X3 is capable of reaching from six to 100 or 200 kilowatts (because of the nested configuration of the magnetic field), thus generating higher thrust and therefore having a higher acceleration. This aspect is crucial for us because we will have to take off from the asteroid, the X3 Ion thruster being able to depart. The magnetic field keeps the electrons in check as they move around, forming an electric current.

A radial magnetic field is created when a voltage is supplied between the cathode and anode and the gas is injected via tiny holes in the anode. High-energy electrons ionize the gas atoms as they enter the thruster. The electric field then accelerates these ions, providing propulsion. Because the magnetic field predominantly impacts electrons, most can circulate near the thruster's exit.


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Even if the development of this type of thruster is still ongoing, the results so far show that the end of this research is near, X3 Ion Thrusters promise to be the means by which we will be able to travel more safely and quickly to Mars and beyond. Therefore, we will use them on our settlement.

The optimal propellants that can be used to power Hall thrusters are Xenon and Krypton (the use of Argon, Neon, or Helium would imply significant structural changes to the settlement or drastic drops in efficiency). We will choose to employ Xenon, considering the small space it requires for storage and its high performance results.

Launching the smaller spaceships:

Even if X3 Ion Thrusters can launch the settlement from the surface of 163693 Atira because of its weak gravity, they can not do the same thing in the case of launching spaceships from the Earth's surface. Thereby, we will send the people to the settlement with smaller spaceships (detailed in the "Transportation" and "Safety" sections) equipped with chemical rocket engines. This type of thruster generates a high level of thrust, which is crucial for overcoming Earth's gravitational pull and achieving escape velocity [*Types of Chemical Rocket Engines*, n.d.]. As such, we have decided to use a liquid rocket engine, which offers better fuel efficiency by delivuering greater thrust per unit weight of propellant burned. In a liquid rocket, liquid hydrogen and liquid oxygen are injected into a combustion chamber and burned together. At high temperatures and pressures, combustion creates a large amount of exhaust gas. The hot exhaust is accelerated by passing it through a nozzle. Thus, thrust is produced, as demonstrated by Newton's third law of motion. However, to improve the efficiency of this type of engine, we'll launch the spaceships using the "air-breathing" method (detailed in the "Transportation" section).

Calculations for Thrusters:

Exhaust velocity is found by multiplying the specific impulse of the X3 Ion Thruster by Earth's gravitational acceleration.

$$v_e = I_{sp} \cdot g_0 = 3000 \times 9.81 = 29430 \text{ m/s}$$

Using the Tsiolkovsky Rocket Equation, we determine the **final mass** after expelling fuel.

$$m_f = \frac{m_0}{e^{\Delta V / v_e}} = \frac{1 \times 10^8}{e^{2/29430}} = \frac{1 \times 10^8}{1.00007} = 99,993,204 \text{ kg}$$

Fuel mass is the difference between initial and final mass after fuel burn.

$$m_{\text{fuel}} = 1 \times 10^8 - 99,993,204 = 6.8 \text{ tons of Xenon}$$

Acceleration is obtained by dividing the required velocity change by the total escape time.

$$a = \frac{\Delta V}{t} = \frac{2}{86400} = 2.31 \times 10^{-5} \text{ m/s}^2$$

Thrust is determined using Newton's Second Law, multiplying mass by acceleration. $F = (1 \times 10^8) \times (2.31 \times 10^{-5}) = 2314.8 \text{ N}(2.31 \text{ kN})$

The thrust of each X3 thruster is found by dividing total required thrust by number of thrusters.

$$T_{\text{thruster}} = \frac{F_{\text{required}}}{N_{\text{thrusters}}} = \frac{2314.8}{6} = 385.8 \text{ N}$$

Optimized thruster design requires only 6 thrusters for the entire ship.

Total power is calculated by multiplying the number of thrusters by power consumption per thruster. $P_{\text{total}} = N_{\text{thrusters}} \times P_{\text{thruster}} = 6 \times 21.92 = 131.52 \text{ MW}$

Power output per square meter of IMM solar panels is computed by multiplying efficiency by solar flux. $P_{\text{IMM}} = 0.333 \times 589 = 196.3 \text{ W/m}^2$

Required solar panel area is total power demand divided by power generated per square meter. $A_{\text{solar}} = \frac{P_{\text{total}}}{P_{\text{IMM}}} = \frac{131.5 \times 10^6}{196.3} = 670,570 \text{ m}^2$

Solar radiation pressure force is determined by dividing absorbed solar power by the speed of light.

$$F_{SRP} = \frac{P_{\odot} A}{c} = \frac{(589)(1.03 \times 10^6)}{3 \times 10^8} = 2.02 \text{ N}$$

where A is the total surface of our settlement, P is the solar flux

Number of X3 thrusters for station-keeping is found by dividing required force by thrust per optimized thruster.

$$N_{\text{thrusters,station}} = \frac{F_{\text{station}}}{T_{\text{thruster}}} = \frac{2.02}{385.8} = 0.0052$$

Only ~0.0052 thrusters are needed for station-keeping, meaning a single thruster is more than enough for this purpose.

Total power required for station-keeping is ~21.92MW since only one thruster is used.

$$P_{\text{station,total}} = 1 \times 21.92 = 21.92 \text{ MW}$$

Formula for calculating **yearly Xenon usage.**

$$m_{\text{Xenon,year}} = \frac{F}{v_e} \times t$$

$$m_{\text{Xenon,year}} = \frac{2.02}{29430} \times 31,536,000 = 2164.55 \text{ kg} = 2.16 \text{ tons per year}$$

4. Orbiting Location

Once all the citizens board the now-finished settlement on the 163693 Atira asteroid, a key turning point already arrives, raising the question: Where should we start heading? To answer this question, it is essential to return to the main reason we had for choosing the passive and ingenious method of building the spacecraft, which is that Dr. Jensen's paper clearly improves the economic aspects of such a space mission, bringing feasibility into a reachable state.

Additionally, to keep on track with the idea of an achievable plan, it is important to acknowledge the scientific uncertainties regarding human hibernation, a phenomenon that could, if working ideally, drastically reduce resource consumption (i.e., water, food, and oxygen) along with better preserving the muscle mass and bone structure of the involved individuals. Unfortunately, even the most optimistic studies only announce the first unperfected, rough testing of long spaceflight hibernation no sooner than a decade later [Pultarova, 2023], indicating a future life-saving solution but a current too big of a risk to take (it has also been determined by analyzing the correlation between energy expenditure and body mass in hibernating animals that the difference in terms of energy saved for people who would artificially hibernate and for those who wouldn't would be negligible [McRae, 2022]).

Keeping our mission launch date in the near future (no later than early 2035) and accounting for the issues of human hibernation that were discussed above greatly limit our potential orbiting locations. To maximize the settlement's efficiency (i.e., amount of energy and fuel consumed during travel, solar energy gathered, total journey duration), we will choose to orbit Mars, or more specifically, place the settlement in the L1 Mars-Sun Lagrange Point. As for the benefits brought by selecting this orbiting location, the water from the buried ice found In-Situ could be extracted, exponentially reducing the cost of producing it via a chemical process. The "Mars Express" orbiter recently discovered certain areas near the Medusae Fossae Formation, containing water buried at over 3 kilometers in height [Cooper, 2024]. Additional In-Situ-Resource-Utilization possibilities offered by Mars involve the processing and collection of gases (carbon, nitrogen, hydrogen, and oxygen) and minerals (iron, titanium, nickel, aluminum, sulfur, chlorine, and calcium). The close proximity to the Main Asteroid Belt will also facilitate a constant income of resources (detailed in the "Asteroid Mining" section). The L1 Lagrange Point provides continuous solar energy to be collected, a position from which to monitor space debris, greatly reduces fuel output, offers us a natural advantage for radiation shielding, and allows us to position the settlement such that we maximize the natural light coming directly through its window. Being so close to a planet like Mars enables easier dropping of resupply packages from Earth (in the rare case they're needed) and facilitates an area where the escape pods can bring the citizens in a dangerous and unprobable emergency (detailed in the "Safety" section).

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The equilibrium conditions at the L1 Mars-Sun Lagrange Point

$$F_{\text{sun}} = \frac{GM_{\text{sun}}m}{R^2}, \quad F_{\text{mars}} = \frac{GM_{\text{mars}}m}{d^2}, \quad F_c = m\omega^2 R, \quad \omega^2 = \frac{GM_{\text{sun}}}{a^3},$$

$$F_{\text{sun}} - F_{\text{mars}} = F_c,$$

$$\frac{GM_{\text{sun}}}{R^2} - \frac{GM_{\text{mars}}}{d^2} = \frac{GM_{\text{sun}}}{a^3}R,$$

$$\frac{1}{(a-d)^2} \approx \frac{1}{a^2}\left(1 + \frac{2d}{a}\right),$$

$$\frac{GM_{\text{sun}}}{(a-d)^2} \approx \frac{GM_{\text{sun}}}{a^2}\left(1 + \frac{2d}{a}\right),$$

$$\frac{GM_{\text{sun}}}{a^2}\left(1 + \frac{2d}{a}\right) - \frac{GM_{\text{mars}}}{d^2} = \frac{GM_{\text{sun}}}{a^3}(a-d),$$

$$GM_{\text{sun}}a + 2GM_{\text{sun}}d - GM_{\text{mars}}\frac{a^3}{d^2} = GM_{\text{sun}}(a-d),$$

$$2GM_{\text{sun}}d - GM_{\text{mars}}\frac{a^3}{d^2} = -GM_{\text{sun}}d, \quad d^3 = \frac{M_{\text{mars}}a^3}{3M_{\text{sun}}},$$

$$3GM_{\text{sun}}d = GM_{\text{mars}}\frac{a^3}{d^2}, \quad d \approx a\left(\frac{M_{\text{mars}}}{3M_{\text{sun}}}\right)^{1/3}$$

Final Result

$$\begin{aligned} d &\approx (2.279 \times 10^{11})\left(\frac{6.417 \times 10^{23}}{3 \times 1.989 \times 10^{30}}\right)^{1/3} \\ &= (2.279 \times 10^{11})\left(\frac{6.417}{5.967} \times 10^{-7}\right)^{1/3} \\ &= (2.279 \times 10^{11})(1.0756 \times 10^{-7})^{1/3} \\ &= (2.279 \times 10^{11})(4.78 \times 10^{-3}) \\ &= 1.089 \times 10^{9}\ \text{m} \\ &\approx 1.08 \times 10^{9}\ \text{m} = 1,080,000\ \text{km} \end{aligned}$$

Explanation

The calculation finds the Mars-Sun L1 point by balancing gravitational forces with centripetal acceleration. Newton's law expresses the forces, and the equation is solved for d, the position where they match the required orbit. A first-order approximation simplifies the expression,yielding $d \approx 1.08 \times 10^9$ as the L1 distance from Mars.

5.1. Artificial Gravity

LIFE SUPPORT

Lack of gravity can cause muscle atrophy, bone density loss, cardiovascular issues, fluid redistribution, vision changes, immune system suppression, psychological effects, altered sleep patterns, and altered metabolism in astronauts [Warmflash, 2023]. Therefore, we should supply artificial gravity to make living possible for the settlement's residents.

Our Method of Creating Artificial Gravity

We have decided that the generation of artificial gravity will be made possible through rotation. To do this, electromagnets will be used to revolve the torus rather than engines. Thus, centripetal force exerts an outward force that mimics gravity. Multiple things, such as radius and velocity, will determine the strength of the force.

Electromagnets work by creating a powerful magnetic field (between the ring that supports the torus and the portion of the cylinder on which it is positioned) as current flows through their coils. The ring rotates as a result of interactions between this magnetic field and its ferromagnetic substance [Electromagnets, n.d.]. In this instance, a unique configuration of electromagnets will be used to support and rotate the torus. The magnets will sustain the rotating motion for a considerable amount of time since there are no friction forces between the cylinder and the torus. As the torus rotates independently of the cylinder, stable and controlled zero-gravity (0G) conditions may be created and maintained inside the cylinder thanks to the precise control over rotation that electromagnets provide. Once the torus starts its motion, electromagnets will just keep it in place.

The Coriolis Effect

The Coriolis effect is an astonishing phenomenon that occurs when an object is in motion within a reference frame that is itself rotating, such as the rotation of the Earth [Rotating Space Station Dynamics, n.d.]. In our context, where the settlement is designed to create artificial gravity by spinning, the Coriolis effect becomes relevant. When the spacecraft is rotating, objects inside it take curved paths instead of moving in straight lines. This can be disorienting and even lead to motion sickness among the spacecraft's occupants.

The good news is that it will be easy for us to handle this problem. It is significant to note that humans usually cannot detect the Coriolis effect at rotational speeds below two revolutions per minute (2 rpm). Therefore, by adjusting our spacecraft's radius appropriately, we can mitigate the impact of this effect.

The residential area will be located approximately 515 meters from the torus' center. Thus, we determined a rotational period of 45.548 seconds, translating into 1.317 rotations per minute (rpm), and an angular velocity of 0.137 rad/s.f.

5.2. Energy

Long-term survival and success of space living depend on energy. The estimated energy demand for the settlement can be calculated using:

$$E_{total} = P_{avg} \times N \times t$$

where E_{total} is the total energy required in watt-hours (Wh), P_{avg} is the average power consumption per person in watts (W), N is the number of residents, and t is the operational time in hours.
Assuming, for instance, an average daily energy use per person of roughly 2.5 kW, similar to present Earth-based household consumption, a community with 20,000 people would demand:

$$E_{total} = 2.5 \times 10^3 \times 20000 \times 24 \approx 1.8GWh$$ per day

Solar Power Collection

Zenith Station mostly runs on solar energy. However, the lower solar flux near Mars' L1 point affects its efficiency. Sunlight's intensity at Mars's L1 point is much lower than Earth's solar constant of 1361 W/m^2, around 593 W/m^2, so solar panels will only get 43% of the solar energy accessible at Earth's orbit.
The power received by the solar panels is given by:

$$P_{solar} = S \times A \times \eta$$

where S is the solar flux at Mars' L1 (593 W/m^2), A represents the total surface area of the solar panels, and η is their efficiency. Zenith Station will use Inverted Metamorphic Multi-Junction (IMM) solar cells, with 33.3% efficiency, instead of conventional silicon-based cells at 20% in order to offset the reduced solar flux. The settlement will also use solar concentrators, including movable mirrors, to focus and magnify sunlight, guaranteeing enough power output for long-term viability.

Thermal Considerations

Solar panels in space experience temperature fluctuations from -150°C to +120°C which affects their efficiency. The efficiency drop due to overheating follows:

$$\eta_T = \eta_0 \times (1 - \alpha (T - T_{ref}))$$

where α is the temperature coefficient, typically -0,3%/°C, and T_{ref} is the reference temperature at which η_0 it is measured. To mitigate overheating, photonic crystal cooling coatings will be applied, which reflect infrared radiation and minimize heat absorption.

Piezoelectric Energy Harvesting

Piezoelectric materials included in pavements and transportation systems can transform mechanical strain into electrical power. The given output power P_{piezo} comes from:

$$P_{piezo} = \frac{1}{2} k x^2 f$$

k is the piezoelectric stiffness constant (N/m), x is the deformation displacement (m), and f is the frequency of foot traffic (Hz).
Embedded beneath high-foot-traffic areas will be piezoelectric materials such as polyvinylidene fluoride (PVDF) and lead zirconate titanate (PZT). Pressure-induced stress created by settlers walking over these surfaces produces electrical charge that is stored in supercapacitors. With 20,000 people's constant foot circulation, this low-maintenance, passive energy-generating approach could augment the main power sources.

Energy Storage and Distribution

For constant availability, energy produced by solar panels and piezoelectric harvesting systems needs to be stored effectively. Lithium-ion batteries, modeled by: $E_{battery} = CV$

where C is the battery capacity in ampere-hours (Ah) and V is the nominal voltage (V), will serve as the primary storage method. Assuming a battery capacity of 10,000 Ah and a voltage of 400 V, each battery would store 4 MWh of energy.
Flywheel energy storage systems (FESS), which save extra energy as spinning kinetic energy, will be included in the settlement to improve energy retention and stability. This approach runs with low energy losses over time and guarantees quick discharge as needed.
Additionally looked at for short-term energy buffering are superconducting magnetic energy storage (SMES) systems. This method achieves almost instantaneous response times for grid stability by depending on superconducting coils that store energy in a magnetic field.

Power Distribution and Efficiency

High-voltage direct current (HVDC) networks will be used to effectively move energy across the settlement, minimizing transmission losses. HVDC greatly lowers resistive losses over long distances, unlike alternating current (AC) systems. Smart-grid technology and power converters will dynamically distribute energy where demand is greatest, therefore maximizing general efficiency.

The colony will keep a very strong and self-sustaining energy network able to support long-term human habitation by means of the integration of solar power, piezoelectric energy harvesting, sophisticated storage technologies, and an efficient power distribution system.

5.3. Lighting

Natural Lighting through the Glass Ceiling

Except in rare alignments when Mars blocks direct lighting, orienting the habitation near the Mars-Sun L1 Lagrange Point (~226 million miles from the Sun) guarantees constant solar exposure. For best use of natural lighting:

- Specialized glass panels enabling sunlight to pass while preserving thermal insulation and pressure stability will make up the torus ceiling.
- Automated shutters will control light intensity; they will close during artificial "night" and open during "day."
- To offset the less solar intensity at Mars L1, solar reflectors will focus sunlight onto the glass ceiling.

The inverse-square law controls the declining sunshine intensity with distance:

Self-produced using Procreate and Blender software

$$I = \frac{P}{4\pi r^2}$$

where:

- I = light intensity (W/m^2),
- P = power of the Sun ($3.826 \times 10^{26} W$),
- r = distance from the Sun ($2.26 \times 10^{11} m$)

Substituting the values: $I_{MarsL1} = \frac{3.828 \times 10^{26} W}{4\pi \left(2.26 \times 10^{11}\right)^2} \approx 593 W/m^2$

The settlement gets only ~43% of Earth's solar flux compared to 1,366 W/m^2, hence it requires adjustable mirrors to concentrate sunlight onto the glass ceiling and keep a reasonable degree of natural illumination.

LED Illumination for Nighttime and Shadowed Areas

High-efficiency LEDs will illuminate dark areas and at night since sunlight will not be equally distributed. These LEDs will have an adjustable control system to change brightness all through the day. The luminous efficacy of an LED is $\eta = \frac{\phi_v}{P}$

where:

- ϕ_v = luminous flux (lumens)
- P = electrical power input (W)

For IMM solar cells with 33.3% efficiency generating 10 kW/m^2, LEDs with 150 lm/W efficiency can provide adequate illumination with minimal power consumption.

Day-Night Cycle and Circadian Synchronization

Lighting will follow a 24-hour programmed cycle split into Earth's natural cycle:

- Sunrise (06:30–08:00) simulating dawn by progressively raising LED brightness.
- Day (08:00 – 20:00): LEDs for non-sunlight-receiving locations running full brightness
- Sunset (20:00–21:30) uses slow fading to simulate dusk.
- During the night (21:30–06:30), dim red lighting (600–650 nm) is employed for necessary operations. Otherwise, LEDs turn off in most locations to encourage sleep

Based on melatonin suppression, which blue light (430–490 nm controls), nighttime circadian-friendly lighting use of warmer LED tones lessens disturbance of sleep.

The melatonin suppression index (MSI) is: $MSI = \frac{E_{\lambda,blue}}{E_{\lambda,total}}$

where:

- $E_{\lambda,blue}$ = blue-light irradiance,
- $E_{\lambda,total}$ = total irradiance.

By setting MSI < 0.2 after 20:00, melatonin regulation is preserved, ensuring a healthy sleep cycle.

5.4. Atmosphere

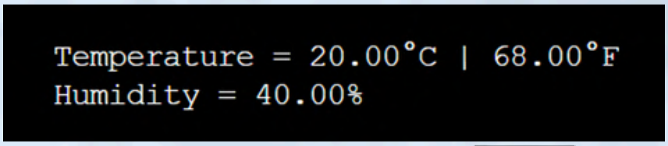
Composition of Earth's Atmosphere: Our settlement will simulate Earth's atmosphere, which is composed of 78.08% nitrogen, 20.95% oxygen, 0.93% argon, 0.04% carbon dioxide and trace amounts of other gases [Atmosphere, n.d.]. As a result of the settlement being on Mars' orbit, which contains about 95% carbon dioxide, 3% nitrogen and 1.6% argon, the gases we require are simple to come by [Dobrijevic et al., 2023]. Due to the anticipated enormous amount of carbon dioxide, we may also use it to produce the necessary amount of oxygen. The oxygen needed will be provided by the settlement's many plants and by growing phytoplankton in artificial lakes, consuming carbon dioxide, and producing oxygen during photosynthesis. We can also obtain oxygen by extracting it from carbon dioxide through electrolysis, being reduced to oxygen and carbon monoxide, which, although a poisonous gas, can be used in pyrometallurgy to reduce metals from ores. Carbon monoxide strips oxygen off metal oxides, turning them into pure metal and producing carbon dioxide. The resulting carbon dioxide can be once again electrolyzed to extract oxygen.

- **Pressure:** We aim to recreate Earth's atmosphere as accurately as possible. Therefore, the settlement's atmospheric pressure will be 1 atm, or 1,01325 bar, and will be monitored at all times.
- **Temperature:** The range of comfortable room temperature falls between 20 and 22 °C, while the optimal sleep temperature is around 18 °C; thus, we will keep the temperature at a constant and permanent 20 °C.
- **Humidity:** The ideal humidity is between 30% and 50%. Because we want to simulate Earth's humidity, we will have it be 40% to increase comfortability.
- **Air Circulation:** For astronauts or settlers to live in a habitable and healthy environment, air circulation in a space settlement is crucial. In order to distribute oxygen, remove carbon dioxide, regulate temperature and humidity, and stop the building of pollutants, proper air circulation is essential. To purge the air of particles, dust, and other pollutants, we will use air filtration equipment. HEPA filters and similar technology can be useful. Air circulation requires careful planning, monitoring, and maintenance to create a sustainable and comfortable living environment.

SENSOR PROCESSING:

With its numerous advantages, the Arduino (as an example) has revolutionized the world of electronics and embedded systems. Because of its open-source nature and user-friendly interface, it has opened up electronics and programming, allowing individuals and companies to create without requiring substantial technical skills. The adaptability of the Arduino allows it to control applications in a wide range of sectors, from smart home automation to medical equipment, making technology more accessible and flexible in real-world situations [What Is Arduino?, n.d.].

That very adaptability enables the development of custom-built sensors and control systems to monitor life support systems, radiation levels, and ambient variables, ensuring the settlers' safety. Additionally, the ease of programming of the Arduino allows for rapid prototyping and changes to adapt to the ever-changing demands of space. With that in mind, our team has decided to create and test out an Arduino sensor station that detects and displays the humidity, temperature, carbon monoxide level, heat index, and carbon dioxide, simulating the life support sensors aboard the spacecraft.



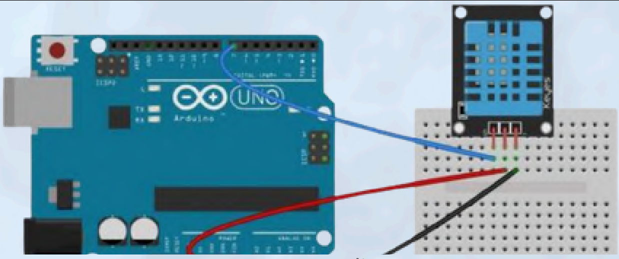


Image Credit

```
#include <dht.h>
#define outPin 8

dht DHT;

void setup() {
  Serial.begin(9600);
}

void loop() {
  int readData = DHT.read11(outPin);

  float t = DHT.temperature;
  float h = DHT.humidity;

  Serial.print("Temperature = ");
  Serial.print(t);
  Serial.print("°C | ");
  Serial.print((t*9.0)/5.0+32.0);
  Serial.println("°F ");
  Serial.print("Humidity = ");
  Serial.print(h);
  Serial.println("% ");
  Serial.println("");

  delay(2000);
}
```

Code written using the Arduino IDE software

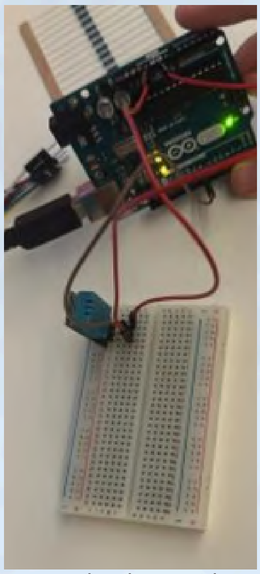


Image taken by us with our own Arduino sensor station

5.5. Storage LIFE SUPPORT

Maintaining a largely self-sufficient space settlement is quite a tall order, particularly considering all the materials required to sustain the human inhabitants. Thus, well-organized storage is paramount to the settlement's well-functioning.

Image created using ChatGPT (AI)

Water and basic food will be stored in special containers placed in each escape pod from each module of the torus, where they will remain accessible and in close proximity to the settlers at all times, including in case of emergency (when the citizens would take off with the escape pods - detailed in the "Safety" section). We will also place a separate water storage tank in the cylinder, as we need an established water source to run the farming area. Rations of food will be distributed weekly by the underground EMU trains going around the torus and will be stored in each household for the duration of the week using similar technologies and methods to those on Earth. Water will be distributed throughout the torus and cylinder through a system of pipes.

Extensive gas stores will also be required for keeping the atmospheres within the pressurized sections topped off, as leaks are inevitable, for providing fuel for the fusion reactors, namely tritium, and deuterium, and for having xenon reserves to set the settlement in motion when needed. Transportation of the gases throughout the station will be realized mainly through pipelines running the length of the cylinder and around the torus, while transfer between the cylinder, where the gases will be stored in vacuum c, and they will be stored in each household for the duration of the week using technologies and methods similar chambers for better preserving, and the torus is achievable by moving the gases in parallel with the flow of people as is detailed in the "Transportation" section. Any pipelines, however, will be well insulated and isolated from the rest of the settlement's systems, particularly the ones designated to deuterium as it is highly flammable.

Other solid matter consisting of various devices, jigs, parts, industrial products, and other solid resources collected from asteroids or from Mars will be stored in the 0G storage area from the cylinder, their transportation being assured by robots placed on a grid system that coalesces into central hubs where materials can be picked up by the high-speed rail traveling along the cylinders length, from where they can be prepared for transfer to the torus or taken directly to the industrial section for use or processing. The energy will be stored in large lithium-ion batteries.

5.6. Water LIFE SUPPORT

Water assumes unparalleled importance in a space settlement, where every resource is finite and critical for survival. Water forms the cornerstone of life support systems, providing oxygen via electrolysis and acting as a radiation shield against space's deadly rays.

WATER OBTAINMENT

One of the methods of obtaining water would be using molecular sieve technology known as the Water Vapor Adsorption Reactor. The WAVAR would provide a dependable water source by extracting water from the atmosphere of Mars efficiently and reliably by adsorption in a bed of type 3A zeolite molecular sieve. The water vapors in the Martian atmosphere come into contact with the zeolite 3A, which absorbs the water vapor until it is nearly saturated. Then, the material is heated within a sealed chamber utilizing microwave radiation, which releases the water vapors, which flow to a condenser where they are frozen and liquefied. The collected water will go through further purification processes to remove any impurities, ensuring it is safe for drinking or supporting various life supports.

Another method would be optical mining, a breakthrough technology for harvesting valuable resources such as water from asteroids. Optical mining simultaneously excavates carbonaceous chondrite asteroid surfaces and pushes water and other volatiles out of the excavated material into an enclosing, inflated bag without needing unfeasible and expensive robots [Optical Mining, n.d.]. First, the desired asteroid is enclosed in a containment bag. Then, the mining process begins by concentrating the Sun's rays through a parabolic reflector onto the asteroid, which is fractured into pieces, realizing the water inside. The water is collected in cryobags, frozen, and stored for future use. This process of extracting water from the CI/CM Chondrite asteroids found in the Main Asteroid Belt by heating the regolith with solar concentrator mirrors is also detailed in the "Asteroid Mining" section.

WATER RECYCLING

The first water purification system that came to mind was *reverse osmosis*. This process uses a semipermeable membrane to remove any of the impurities from greywater. This method would seem perfect for our wastewater sources, as the membrane allows all of the water molecules to pass through while blocking larger molecules and ions, but it is not an efficient water purification system. First of all, reverse osmosis can waste between 3 and 20 times the water it produces, making it highly ineffective for our space settlement as water is undoubtedly the most valuable resource. Another disadvantage of this system is that, aside from removing bad contaminants, it also removes healthy minerals such as calcium, magnesium, and potassium. As such, the pH of the treated water is decreased, making it more corrosive for plumbing systems, and it can strip lead and copper. As such the water purification system we choose to implement consists of six phases: pH adjustment, coagulation, flocculation, sedimentation, filtration, and disinfection.

***pH adjustment*:** The first step in the purification would be the adjustment of the pH, as the wastewater is never pure, being acidic or alkaline. As such, acidic water will be treated with soda ash or sodium hydroxide. Alkaline water does not pose a problem, facilitating the next purification stages.

***Coagulation*:** During this phase, chemicals are added to the water, causing particles to form. Aluminum sulfate and ferric sulfate are some of the most commonly used coagulants. They are injected into the water at a high-turbulence location. These compounds produce sticky particles known as floc. Floc attracts dirt particles, becoming heavy enough to sink to the bottom of the storage tank in which it sits.

***Flocculation*:** It works by bringing together suspended fine particles in water and causing them to form larger, heavier aggregates called flocs. It requires the addition of coagulants like aluminum or ferric chloride, which neutralize the electric charges on these suspended particles, causing them to draw closer together.Then, flocculants, long-chain polymers, are injected to generate bridges between these particles, allowing them to connect more easily. The flocculants diffuse uniformly throughout the water during gentle mixing or agitation, allowing particles to collide and cling to one another. These aggregates expand in size as the process progresses, finally settling at the bottom of a basin or tank due to gravity.

***Sedimentation*:** The water enters a sedimentation basin or tank after being coagulated and flocculated to aid in the production of larger flocs. The water flow is greatly reduced in this settling chamber, allowing the heavier flocs to settle to the bottom gradually. As the particles fall, they form a sediment layer known as sludge. The clarified water, which is now almost free of these settling particles, flows softly across the top of the basin.

***Filtration*:** During this step, water travels through a physical barrier made up of various filter media, such as sand and activated carbon. As such, we shall use a rapid sand filtration system that utilizes a bed of very fine sand to constantly remove suspended particles and microorganisms from water Water is injected into the top of a filter bed, which is usually several feet deep and housed within a filter tank. Because of the porous shape of the sand grains, suspended particles are physically caught and maintained as water percolates downward through the sand. As the filter bed accumulates confined particles, it must be backwashed on a regular basis to restore its filtration capacity. Water runs upward during backwashing to loosen and eliminate accumulated contaminants.

Disinfection: It is the process of eliminating or reducing harmful germs from water. Chlorination and ultraviolet (UV) rays are two methods for accomplishing this. To do this, we have chosen to use UV radiation, which uses UV light to corrupt the DNA of any surviving microorganisms and prevent them from reproducing. We will add fluoride to the water to adjust the pH. This prevents corrosion in the pipes and ensures that the disinfectants accomplish their job of keeping the water clean as it flows through the pipes.

Researchers in a new study led by Aiping Liu at Zhejiang Sci-Tech University and Hao Bai at Zhejiang University devised a tree-inspired water transport system that employs capillary pressures to move filthy water upward through a hierarchically constructed aerogel, where it can later be transformed into steam by solar energy to produce fresh, clean water [*Aiping Liu's Research Works | Zhejiang Sci-Tech University (ZSTU) and Other Places*, n.d.].

The new technology comprises two primary components: a long, porous, ultralight aerogel that transports water and a carbon nanotube layer on top that absorbs sunlight and converts the water into steam. A glass container houses the system. Water rises through the pores of the aerogel due to capillary forces induced by water-molecule attachment to the inner surface of the pores. When the water manages to reach the top, the solar-heated carbon nanotube layer converts it to steam, leaving behind any pollutants. The steam condenses on the walls of the surrounding glass container, generating water droplets that travel down to the container's bottom and accumulate in a reservoir. The researchers demonstrated gains in these areas with the novel aerogel design, reaching upward flow performance of 10 cm in the very first 5 minutes and 28 cm just after 3 hours. The device is also suitable for clean water, ocean, sewage, and sandy groundwater.

Furthermore, the carbon heat collector possesses a conversion energy rate of up to 85%. The meticulous design of the aerogel's architecture was crucial to the advancements. To create the material, the researchers placed the aerogel materials into a copper tube, which was then exposed to a temperature gradient with the cold end of the tube at -90 degrees Celsius. This resulted in the formation of ice crystals in a certain pattern within the aerogel along the temperature gradient. The resultant aerogel had a structure with micro-sized holes, radially aligned channels, molecular meshes, and wrinkled inner surfaces after freeze-drying the tube. All of these microscopic structures contributed to the aerogel's excellent performance. [*Aiping Liu's Research Works*, n.d.].

WATER MANAGEMENT

A study made by the Philadelphia Government shows that the average American uses about 384.22 L of water per day. The distribution of the usage is shown in the following table:

Activity	Quantity	Unit
Hygiene(washing face, brushing teeth, etc.)	9.4	L
Toilet	11 x 6-8	L x flushes per day
Shower	7.6	L/minute
Clothes washer	64.8	L/load
Dishwasher	23.2	L/load
Drinking	3	L
Bath(full tub)	136.27	L

By replacing the need for baths with shorter showers we can eliminate the 136 liters needed for filling the tub, thus cutting down the daily water usage per person to an average of 247.9 L per day. We can estimate that to 260L for safety and comfort reasons. The final consumption looks like this: 260L x 20,000 residents = 5,200,000 L/day

There will be no water waste because all of the toilets, sinks, showers, bathtubs, and other fixtures have semi-closed loops. The maximum amount of water loss the residents may produce is 1 L/resident/day, which equates to a total of 20,000 L/day for all the residents, given that we cannot achieve 100% efficiency in the drinking water recirculation system and that there is 0.5 L/resident/day of accidental water loss (for example, spilled water). Water recovery will be done once a month, hence 30 x 20,000 = 60,000 L of water could be lost during this time. In order for the people to not notice a decline in water supply, an additional 600,000 L of water must always be present in the storage reservoir. So, for the residential area we would need 5,800,000 L of water.

WATER DISTRIBUTION

On the torus, water will be stored in the escape pods. Inside them, there are storage basins, from which a row of pipes distributes water throughout the torus when needed. Since the spacecraft is equipped with recycling systems, this process will only occur when the remaining water level is low enough. A monitoring system allows this process to be automated without needing any personnel. Furthermore, in an emergency where the water purification system ceases operation, additional water can be taken from the seven meter laver stands as part of the radiation shield.

5.7. Agriculture & Food

A recent NASA study called PESTO shows that plants grow 10% taller in microgravity than they would in 1G, so we decided to put the farming area in the cylinder [Station Science 101: Plant Research - NASA, 2023].
The diversity of the plants we cultivate will increase along with the population; therefore, in order to adapt to the shifting demands of society, we transported most of the Global Seed Vault from Norway, the largest collection of agricultural biodiversity, which is made up of millions of brown particles originating from more than 930,000 different types of food crops [Svalbard Global Seed Vault - Crop Trust, 2023].

Considering all the advantages presented below, we have chosen the aeroponic system for our space settlement.

- Due to being suspended in the air, the roots benefit from maximum exposure to oxygen which allows the plants to develop faster than in other mediums.
- Given the fact that the available space is limited (on a space settlement), the usage of an aeroponic system would be the best solution. As such, its design allows plants to be stacked upon one another saving up vital space.
- It requires minimal maintenance, the only important task being the constant monitoring of the root chamber [28 Advantages and Disadvantages of Aeroponics and Hydroponics, 2019].
- Fewer resources are needed for a productive crop. By eliminating the soil, plants require less water and fewer nutrients to finish a full growing cycle [A Deep Look at Aeroponics - Trees.com, 2022].

TYPES OF AEROPONIC SYSTEMS

- **Low-pressure Aeroponics:** The roots are suspended in the air or partly in the nutrient solution. The roots are heavily sprayed and even reach down into the nutrient reservoir. Even though the LPA is the most commonly used aeroponic system due to its lower initial cost and effectiveness, it has a higher water usage than other aeroponic systems.
- **High-pressure Aeroponics:** The HPA has the roots completely held up in the air. It must run at a high pressure to dissolve water into tiny water droplets less than 50 microns. By using a fine droplet size, it creates more oxygen for the root chamber than the LPA, making it more efficient. The HPA is regarded as having the lowest usage of water and nutrient compared to the other hydroponic systems. Also, the HPA systems can run without power for periods of time, which makes them vital in case of a power outage on the space settlement. [C., 2022].

As such, we decided that the HPA system would be the best choice for our space settlement. Its low water consumption and the ability to speed up plant growth make it the most efficient aeroponic system available.

LIGHTING

For the lighting, we shall use an LED-based system as they can concentrate the energy at the various wavelengths of the spectrum to stimulate plant growth. As they produce little heat compared to other light bulbs, we can place the LEDs closer to the plants in a small space. The best LEDs for horticultural lighting are the Phytofy LEDs which are a cutting-edge technology designed specifically for space agriculture by Osram, a global high-tech lighting company in close collaboration with NASA. The Phytofy LED lighting system distinguishes itself through its customized spectra that are tailored to the needs of different plant species. This allows us to optimize plant growth by adjusting the light spectrum to mimic natural sunlight or enhance growth phases. As LEDs are inherently energy-efficient, the Phytofy LEDs can provide the necessary light for plant development while keeping energy consumption minimal.

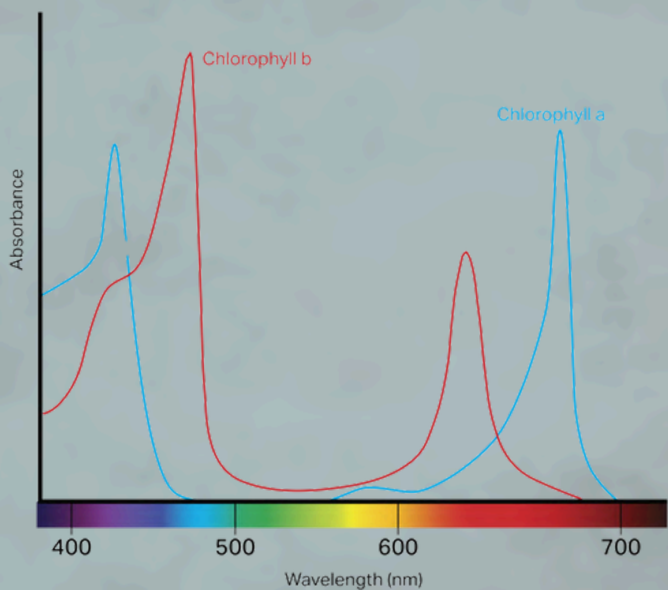


Image Credit

The agricultural environment requires strict control over factors such as temperature, humidity, and light. As such, the Phytofy LEDs can be incorporated into a closed-loop, automated system that maintains optimal lighting conditions for plant growth. Through the optimization of light spectra, the aforementioned LEDs can lead to higher crop yields, which is essential for sustaining the population in the space settlement

MICROBIAL-BASED FOOD PRODUCTION SYSTEMS

As a complementary source of food for the citizens, we have chosen the following plan presented by Llorente et al. in their study entitled "Harnessing bioengineered microbes as a versatile platform for space nutrition" (2022).

Microorganisms require fewer inputs, double their biomass faster, are widely utilized to make food additives, are generally more receptive to bioengineering interventions and are regarded as a potential sustainable food source. A promising option for transformation into a microbial food production system is Saccharomyces cerevisiae, a food-grade microbe, more precisely a yeast that has been used in the food industry for thousands of years. Yeast cells have a macronutrient profile which is similar to the one of soy flour, with 40.4% protein, 34.6% carbs, 1.5% fats, and 13 kJ per gram of dry cell weight, this aspect giving them the potential to become a significant component of a human's daily diet. They also contain all necessary amino acids that humans cannot synthesize and must get from food sources, like histidine, methionine, isoleucine, leucine, threonine, valine, etc. Microgravity circumstances do not appear to have a substantial impact on its development or survivability, S. cerevisiae grows very quickly, doubling in 90 minutes under ideal conditions, and is highly genetically adjustable [Llorente et al., 2022].

The main resources needed to synthesize S. cerevisiae are carbon dioxide (CO2) and nitrogen (N2). CO2 can be procured from the atmosphere of Mars, as it is found in large quantities. Nitrogen will be procured both from Mars' atmosphere and human urine, which has a high urea concentration (~10 g/L), a nitrogen source that is easily assimilated. This way, we will provide a recycling system in which almost nothing is lost.

There are several techniques for producing microbial food directly on CO2 once it is available and can be conveniently gathered and delivered into a bioreactor. We will employ electrochemical CO2reduction with hydrogen to produce methanol, a liquid one-carbon (C1) source. The demand for sugars as a carbon and energy source is S. cerevisiae's main restriction as a food-production system. A solution to this limitation would be the C1 assimilation that may theoretically be engineered directly in S. cerevisiae, eliminating the need for autotrophic partners (like cyanobacteria). With today's synthetic biology capabilities, it is possible to suggest engineering numerous features for S. cerevisiae's nutritional and sensory enhancement to repurpose it for creating edible microbial biomass. To support the preservation of a balanced diet and allow for the customization of food to personal preferences, a collection of yeast strains created for optimal nutrition and a diversity of textures, scents, tastes, and colors would be beneficial. Selected yeast strains cultivated in microbial bioreactors on one-carbon sources might rapidly yield edible biomass for human use [Llorente et al., 2022].

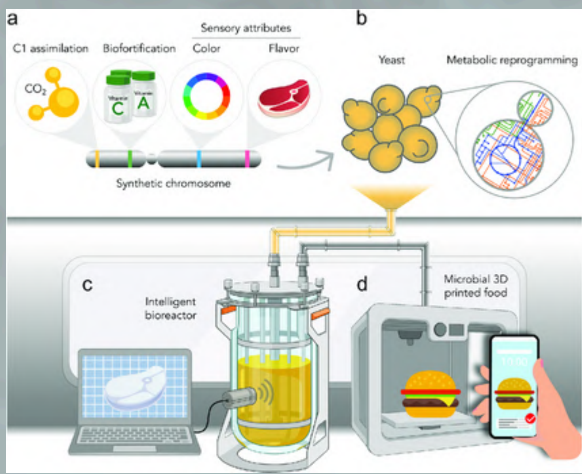


Image Credit

3D food printing technologies enable the production of more complex food regarding sensory qualities and creating aesthetically beautiful personalized meals. Because the entire edible microbial biomass harvested from bioreactors may be used for printing food, this technology could allow for maximal food output with the lowest waste [Llorente et al., 2022].

DIET (REQUIREMENTS & CHOICES)

A nutritious diet is essential as it protects against a wide range of chronic diseases. It needs to include consuming a variety of foods and consuming less salt, saturated fat, sugar, and industrially generated trans-fats. Thus, we have provided a list of values for daily intake levels of nutrients:

Nutrient	Quantity per day
Energy	8,700 kilojoules
Protein	50 grams
Fat	70 grams
Saturated Fatty Acids	24 grams
Carbohydrates	310 grams
Sugars	90 grams
Sodium	2.3 grams
Dietary Fibre	30 grams

At first, the balanced diet for the colony will consist of five different plant species (to obtain the first crop as fast as possible, we will apply seed germination to every chosen type of plant) (See Fig d.1 for nutritional values).

1. Soybeans (Glycine max):

High-source plant-based proteins with versatility in processing (possibility of oil, milk, and flour production). Up to 50% of the energy used by soybeans is wasted on recycling harmful compounds that are produced by the Rubisco enzyme, taking up oxygen molecules rather than carbon dioxide. To improve this situation, scientists at the University of Essex [RIPE, 2018] created a model crop in which they overexpressed the H-protein involved in photorespiration, discovering that crop production can be boosted with values between 27% and 47% this way. Additionally, research [Lü & Tian, 2022] has created an effective and targeted CRISPR/Cas9 method to use stable transformation to introduce heritable mutations in soybeans. The researchers targeted phytoene desaturase genes, used half-seed explants, and built constructs that targeted both homologous soybean PDS genes. Most transgenic plants showed evidence of mutation efficiencies ranging from 75 to 100%, thus improving the nutritional values of the soybeans.

2. Sweet Potatoes (Ipomoea batatas):

High in dietary fiber, vitamins C and A, and many complex carbohydrates. Using CRISPR-Cas9, we can [How CRISPR Could Make Sweet Potatoes Bigger and More Nutritious, n.d.] enhance the traits of sweet potato plants by focusing on two gene sets: the genes for beta carotene hydroxylase and cell wall invertase inhibitors. We can increase the amount of beta-carotene in sweet potatoes by turning them into orange-fleshed ones. To raise the iron content and treat iron deficiency anemia, we can work on cassava and other staple food crops like yams.

3. Quinoa (Chenopodium quinoa):

Complete protein source containing all of the necessary vitamins, minerals, iron, and amino acids. A study [Pinto et al., 2021] has shown, using DEA and multi-product analysis, that quinoa production efficiency increases under water stress, so we'll apply this concept.

4. Broccoli (Brassica oleracea var. italica):

rich in dietary fiber, folate, and vitamins K and C. According to the latest research [Zhao et al., 2023], hypocotyl explants are excellent for Agrobacterium-mediated transgenic and CRISPR/Cas9 gene editing in broccoli. Hygromycin B proved beneficial for resistant broccoli sprouts, with genotype 19B42 having the greatest transformation rate of 26.96%.

5. Algae:

By implementing the [Field, 2021] circular method that maximizes sustainability and produces an algae pigment filled with protein, vitamins, phytonutrients, minerals, antioxidants, and Omega-3 fatty acids, we can improve the taste of the colony's diet and also reduce the number of items required to consume, by simply being able to add the powder on top of the other served plants.

Following the stabilization of the food resource, each citizen will have an individual diet established with a nutritionist. The food rations returned to each citizen will be recalculated.

Rancid food: When food is exposed to air for an extended period of time, it becomes rancid, a process known as oxidation. In fact, many usual components, especially lipids (oils and fats), react with oxygen. Heat or ultraviolet light can hasten the process. Smaller molecules such as ketones, aldehydes, and fatty acids are formed during oxidation, giving rancid foods their distinctive rank, pungent, and metallic odor. While antioxidants operate in a variety of ways, they can generally negate many of the processes that promote rancidity and extend the flavor and the food's nutritional value. This is where an AI tool comes in handy. Once the machine recognized general chemical patterns, such as how different compounds react with one another, we fine-tuned it by teaching it some more complex chemistry. Our team used a database of nearly 1,100 combinations already published in the scholarly literature for this stage. At this stage, the AI could anticipate the effect of any combination of two or three antioxidants in less than a second. 90% of the time, its forecast matched the effect stated in the literature. As such, AI models are an essential tool in developing antioxidant combinations and assisting scientists in finding better ways to preserve food [Garcia, n.d.].

5.8. Recycling LIFE SUPPORT

In our space settlement recycling will play a major role in the management of resources, as a circular economy model based around recycling in which input and output are kept to a minimum is mandated by the high costs of resource acquirement. Additionally, more easily recycled resources such as metal and glass will be favored over harder to recycle ones like plastics. Most waste falls into two categories, organic and inorganic. Typically, organic waste can be recycled through biological processes while inorganic waste can be recycled through melting and recasting. The recycling of water doesn't fall within the scope of this section, being already detailed in the "Water" section.

Organic Waste: For most waste materials of organic origin such as food waste, manure and scraps from the agricultural industry, composting represents a cheap and effective method of recycling. With the use of various microorganisms, the organic waste is transformed into stable and safe compounds that can be used to replenish the nutrients crucial for plant growth and agriculture. Plastics are markedly resilient materials, being processed to a point where microorganisms have a hard time decomposing them. Pyrolysis is one of the most promising methods of plastic recycling and our method of choice, consisting of subjecting the shredded waste material to temperatures of 400-800 ℃ in an oxygen-free environment [Kabeyi & Olanrewaju, 2023]. This mainly produces pyrolysis oil, a liquid mix of various compounds that can be later converted into fuel or into a large range of high-value polymers.

Inorganic Waste: Glass and various metals, such as iron, steel and aluminum pose little challenge in being recycled. Through the use of furnaces, these materials can be easily melted down and recast without losing their respective strengths and qualities. Batteries and other electronic components would probably have to be recycled, despite the high costs and complexities of the process, due to the difficult to obtain elements found within such as lithium and cobalt. Lithium-ion batteries, for example, require a lengthy multi-step process, including discharge, disassembly and mechanical and metallurgical processing, before the valuable metals can be extracted, all the while chemical, electrical and thermal factors add additional risk throughout the recycling process. Various composite or ceramic construction materials such as concrete, brick and other masonry are easily ground up and reused for construction in the form of aggregates and fill. On Earth medical waste is usually discarded off and destroyed thoroughly due to the various pathogens usually present, however radiation treatment through the simple exposure to the interplanetary medium may open up this category of waste to recycling. Textiles come in two main varieties, natural and synthetic. Natural textiles, after sorting by color and material, can be shredded and respun for later weaving and knitting without much trouble, while synthetic textiles are granulated and melted down, before being cast into new polyester fibers ready for reuse [How Are Textiles Recycled? - London Recycles, 2020].

5.9. Death Protocol LIFE SUPPORT

Regarding the death of a citizen, we shall enact a standard death protocol that will follow how the deceased's body will be dealt with. After the corpse is collected, the necessary religious ceremonies are performed. If the family requires this, the body will enter the first stage of the composting process. As such, we have decided that it is futile to implement a conventional cemetery as it represents a waste of soil, energy, and space that are indispensable for the function of the settlement. Also, we cannot dispose of the body in space, as it could eventually collide with a satellite or another ship [Stirone, 2021]. With that in mind, we implemented the "Body Back" for the burial, which uses a process called promession developed by biologist Susanne Wiigh-Mäsak, who founded Promessa in 2001 [Raj, 2015].

Promession is a method of corpse disposal where a body is turned into a powder (crystallized body particles), much like cremation. Promession uses a freeze-drying technique to lower the body's carbon content rather than flames, intense heat, or high pressure [Fortino, 2021]. The body would be frozen on Earth using liquid nitrogen during the promession procedure. However, in space, a robotic arm would suspend the body outside the spaceship encased in a bag, exposing it to a temperature of -200 degrees Celsius. The body will be left outside in the frigid void for over an hour until it becomes brittle; at this point, the arm would vibrate, shattering the body into ash-like fragments. This method could reduce a 200-pound astronaut to a 50-pound mass the size of a suitcase. The remaining mass will be placed in an urn and given to the deceased's family (if they request it). If the families request it, ceremonies commemorating the departed will be held. When there are too many urns in the space settlement, the ashes will be extracted from the urns and placed on a spaceship bound for Mars, where they will be spread across its surface.

6. Safety

Even if we provide the required circumstances for the settlement's inhabitants, there are still threats to the community; thus, it is crucial that everyone living there is entirely protected. Internal and external factors may lead to unfortunate events. Therefore, we are taking into consideration all types of emergencies.

External Threat: The chance of collision with an asteroid, comet, space debris, or any other space body is quite small, but not zero. In order to minimize the risks of collisions (which can turn into real catastrophes), we have incorporated some security systems and measures, as described below:

1. The spaceship will be equipped with state-of-the-art sensors that, when they detect any object that could endanger the settlement's safety, will notify the command center, and immediately the procedures will be carried out to move the spaceship from the object's trajectory, thus avoiding the collision.

2. In an unlikely maximum emergency scenario in which it is found that the spacecraft cannot alter its trajectory in time to avoid collision with a space body, people will be redirected to the escape pods located on the first floor of each module, taking off as quickly as possible and heading for the Mars bases, where they will await further orders (if the spacecraft can be repaired in a convenient time, the people will remain at the Mars bases and then, after all the repairs are done, return to the settlement, or leave for Earth if the settlement is found to be completely destroyed).

The Escape Pods: After completing their mission to bring the future citizens to the settlement built on 163693 Atira, the small spacecrafts will attach to the outside of the torus and cylinder, becoming the escape pods that will always be prepared to evacuate the citizens from the mother spaceship, taking them to the surface of Mars or to Earth. There will be 201 escape pods (192 on the outside of the torus—eight on each module—and 9 on the outside of the cylinder), each with a capacity of 100 people. They will have individual thermal and radiation shielding, a pseudo-atmosphere, and an appropriate pressure level for the people's comfort. As we said in the "Storage" section, on the escape pods there will already be food and water resources capable of supporting life for a long period of time. Each escape pod will be equipped with medical kits, sports equipment (since people will have to stay longer in microgravity), and a sealed container with all kinds of seeds (in case people have to stay on Mars until the settlement is repaired, they will have to replant new seeds to restore agriculture upon returning to it). During the construction of the settlement on Atira, a series of "spider robots" will be sent to Mars to build bases that will serve as units for collecting resources from the surface of the planet but also as shelter in the scenario in which the citizens are evacuated from the settlement and settled on Mars until its repair. The major problem with a long stay on Mars will be the low gravity (3.721 m/s^2) that can affect people's health. Hence, the bases will be equipped with human centrifuges, which will recreate the feeling of 1G by exposing people to controlled rotating forces. Thus, residents will be expected to use these centrifuges often, ideally once a month, along with following a daily workout.

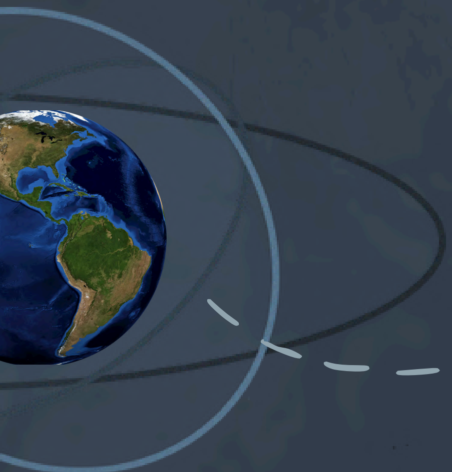
Internal Threat: For internal problems that would endanger the safety of citizens, such as fires, floods, failure of vital systems, etc., we will incorporate fire extinguishing systems, underground emergency lines (for police, rescue, and firefighters), surveillance cameras, alarm systems, and evacuation of water in case of flooding (water collects in specially arranged underground basins).

A study investigated the utilization of honey bees as biomonitoring instruments to detect pollution in urban settings. It used bees to track harmful contaminants while were foraging for pollen, nectar, and water. European honey bees have long served as sentinel species to keep track of illnesses and chemicals. The results imply that honey bees might be helpful instruments to keep an eye on pollution in urban environments [Murcia-Morales et al., 2020]. Therefore, it would be a great idea to host beehives across the whole spacecraft and especially in the industrial zone to detect hazardous contaminants, thus being able to maintain the well-being of the people. We will place bee habitats in every module of the spacecraft, in enclosed spaces to prevent bees from escaping into other areas, along with compact flowering plants, providing a source of nectar and pollen for the bees

7. Transportation

1. The Journey to Mars

1.1 The transfer of people from Earth to the settlement: In order to be able to bring people from Earth to the spaceship built from the 163693 Atira asteroid most efficiently, using as little fuel as possible, we decided to use the air-breathing method to leave Earth's atmosphere and then the slingshot maneuver, using Earth's gravity to increase the speed of the spaceships, thus reaching the settlement. The smaller spaceships with which the people will be transported will become the escape pods from the settlement. Because we will have to take 18,988 people from Earth and the maximum capacity of a small spacecraft is 100 people, we will have a total of 190 spacecraft arriving with the citizens on board. The crew (1012 people, so 11 more small spaceships are added to the 190) that will arrive before the citizens to make the finishing touches will be transported just like the rest of the people, the whole process being described in the lines below. Also, they will bring from Earth resources that cannot be produced immediately in space, such as seeds for agriculture and initial food.

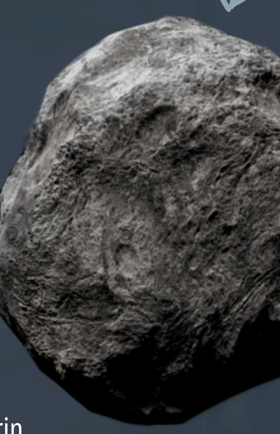


a. From Earth to Earth orbit (LEO): "Travelling from Earth's surface to its orbit is one of the most energy- intensive steps of going anywhere else"— Shuttle Flight Engineer Don Petit, January 2012. This is caused by the colossal weight of the fuel (liquid oxygen is often found in its composition, which is by far the heaviest component), which not only reduces the payload capacity but also slows down the spaceship's acceleration upon take-off. Nevertheless, as we know, we are surrounded by air that contains oxygen, but how could we capitalize on this advantage? The air-breathing technique could be the answer to the above question. The term "air-breathing" refers to a vehicle utilizing oxygen from the air instead of the heavy liquid oxygen carried in its tanks for at least some of a flight.

Self-produced using Canva software

Jones and Donaldson observed in 1987 that air-breathing aircraft that ascend directly from Earth to orbit require at least 56% of take-off weight to be hydrogen fuel; otherwise, sufficient kinetic and potential energy will be unavailable to place the vehicle in Earth's orbit. Aside from the fuel mass percentage, the vehicle must have a distinct relationship between propellant efficiency and the thrust-to-drag ratio. They determined that for a straight ascent to Earth's orbit, the hydrogen fuel fraction of the space vehicle, i.e., what remains when oxygen is not taken on board at take-off, was more essential than the propellant fraction. They discovered that liquid hydrogen fuel must account for at least 57% of the vehicle's take-off mass, but this is only possible if liquid oxygen is created in flight using innovative cryogenic air liquefaction and oxygen separation technologies. Using this method, we would be able to transport a greater number of people with a single spacecraft and reduce the launch costs and the delta-v value (reaching LEO from the Earth's surface will take about 9 km/second). It should be noted that once they arrive on the settlement, the air-breathing engines of the small spacecrafts will be replaced with X3 ion thrusters so that they can move later in outer space.

b. From LEO to 163693 Atira: To reach the settlement with the smaller spacecraft from LEO, the delta-v value would be approximately 4,77 km/second. Also, to reduce fuel consumption and mission costs, as we mentioned before, we will use the slingshot maneuver [Cain, 2017] to reach the settlement. With the help of 163693 Atira's gravitational field, we will be able to decelerate them (reversibility of orbits). Because 163693 Atira is a near-Earth object (NEO), the probability of radically changing its position relative to the Earth is minimal, so we do not have to consider the scenario in which the spaceships should change their route to reach the settlement's new location.



1.2 The way to Mars: "Mars is there, waiting to be reached"— Buzz Aldrin.
All passengers arrived at the settlement safely. Now, everyone is waiting for the takeoff to Mars. The departure period was set in advance, considering it should be 26 months after the last "perfect" alignment of the Earth with Mars (the distance "d" between the two planets is the smallest possible). Also, we chose the period when Mars is closer to the Sun.

As described in the "Engines and Thrusters" section, we chose X3 Ion Thrusters due to their increased efficiency compared to the classic chemical rockets and their new technology that allows us both to successfully take-off from the asteroid and to leave the Earth's gravitational field without being slowed down or, worse, to be drawn back. It should be mentioned that before departure we will take from the Moon the water required for the travel period. To better describe the journey to the final destination, we relied on the essay written by Dr. John Burk and Dr. Tor Ole Odden in which the trip to Mars initiated with the help of ion thrusters is described in detail [Burk et al., 2020]. They started by comparing the feasibility of a conventional rocket with that of an ion-drive spaceship. They even chose a specific ship for the two categories: the Big Falcon Rocket represents the conventional rocket, and the spacecraft from the movie "The Martian," called "Hermes," represents the ion drive. We will obviously focus on the sequences of the study in which the journey of Hermes to Mars is described.

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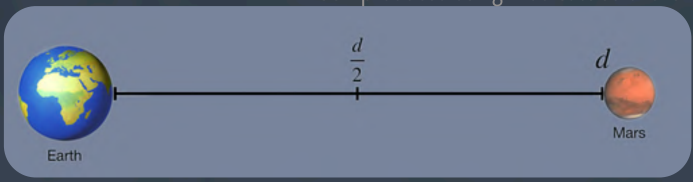


The description of the journey to Mars begins after the take-off of the settlement from the asteroid (the takeoff will not require a large amount of thrust because the gravitational field of Atira is not very strong). After the spacecraft reaches the speed necessary to escape the Earth's gravitational field, a constant acceleration of 2 m/s^2 will be established. This acceleration will be maintained until approximately halfway through the journey because, at some point (d_{turn}), the settlement will pivot and realign itself so that its ion engine switches from accelerating to decelerating. Our problem is that we need to know when this will happen. If the d_{turn} occurs too soon, the settlement will decelerate to the point the direction of Earth, thus "turning around" and never reaching where it begins to accelerate in Mars. If the d_{turn} occurs too late, the spaceship will still move as it comes to Mars.

Our goal will next be to discover the minimal number of dturn so that the settlement arrives at Mars with a velocity of roughly 0 m/s. Thanks to the simulations made in Python by Dr. John Burk and Dr. Tor Ole Odden, we discovered that the sweet spot is a turnaround at approximately 59.4% of the travel, the settlement reaching its destination with a speed of 0.05 m/s. Thus, the journey will last approximately six months, and once the final destination is reached, the settlement's activity will increase, and the first extraterrestrial society will begin to develop.

2. Transportation in the Torus

Since the size of the torus will be significant, implicitly, the distances that the citizens will have to travel to reach its various areas will be considerable. That said, there is no doubt that we will need some means of transportation. We consider that they must not pollute nor require parking lots or wide streets laid out on the floor inhabited by citizens. For these reasons, cars, motorcycles, and buses are out of the question. In the end, here are the conclusions we reached:

2.1 Public Transportation: It will be carried out using Electric Multiple Unit (EMU) trains that will be located on the second floor of the torus [Redding, 2023]. There will be four railways: two for the transportation of citizens and two for emergency services (one for each direction), where only the police, firefighters, and paramedics will have access (detailed in the “Institutions“ chapter). Since there will be two directions of traffic, by default, there must be separate platforms for each direction. Thus, we will place bridges over the tracks so citizens can cross, reaching the desired platform. We will now dwell on the concept of EMU trains to describe it briefly and to observe the advantages of choosing such a means of transport.

Electric Multiple Unit Trains (EMU): It is a multi-unit train made up of self-propelled electric vehicles. The vehicles that comprise a complete EMU set are typically split into four types based on distinct functions: the power car (which carries the necessary equipment to draw power from electrified infrastructure), the motor car(which carries the traction motor), the driving car (which is similar to a cab car and contains a driver's cab for controlling the train-in our case, the driver will be replaced with a state-of-the-art AI system; an EMU consists of two driving cars, one at each end of the train), and the trailer car (=the passenger car).

They are semi-permanently connected and are intended to function as a single integrated unit. EMU is ideal for frequent stops since its electric traction equipment is spread throughout the train, allowing for quick acceleration and deceleration. Additionally, EMUs as a means of public transportation in our settlement have an environmentally friendly character (because they are powered by electricity and not by diesel motors), efficient long-term maintenance (the higher initial upfront cost of establishing specialized tracks for EMUs is offset by substantially reduced maintenance rates), quiet and smooth operation [G, 2017].

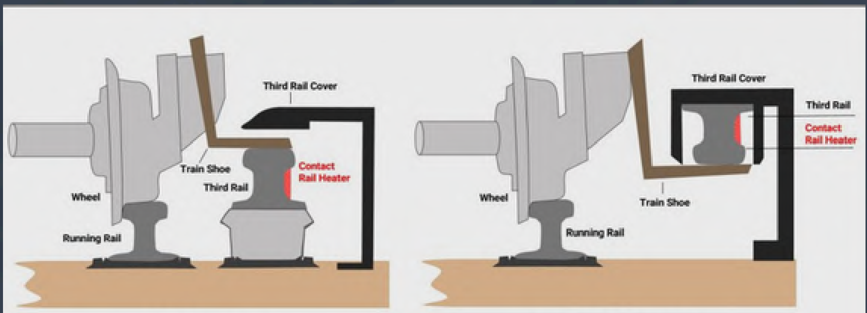


Image Credit

Third Rail: The use of electricity to operate the EMU trains inherently implies rails specially designed to support such a mechanism. Thus, we discovered that third rails are the most suitable for putting electric trains into operation. It supplies electric power to a railway train via a continuous rigid conductor laid beside or between railway rails (we chose to place it beside). It is often employed in a mass transport or rapid transit system with alignments in its own corridors that are totally or nearly fully isolated from the outside environment. Third rail systems provide direct current (DC) power. Metal contact blocks known as "shoes" (=contact shoes/pickup shoes) on the trains make contact with the conductor rail. In our case, the contact will be with the bottom of the third rail (this type of connection is called bottom running). The traction current flows back to the producing station through the running rails. To decrease resistance in the electric circuit, the conductor rail is usually composed of high-conductivity steel, and the running rails must be electrically connected using wire bonds or other mechanisms [Third Rail |, n.d.].

The presence of an electric rail makes falling a person into the tracks exceedingly perilous. To avoid any accident, we will place automatic gates that will open only when the train has arrived at the station, thus wholly separating the area of the tracks from the platform where the citizens will wait.

Image Credit

The stations where citizens will wait for the EMU train will also be on the second floor, so we had to design a way as simple and efficient as possible by which citizens can reach the stations from any area of residential or industrial floor. Thus, we have decided to place elevators along the torus that can be accessed from any module or floor of the settlement (detailed in the "Division" section). The police, paramedics, and firefighters will use separate elevators located directly in the institutions where they work in order to reach the emergency site in the shortest possible time.

2.2 Individual Transportation: In addition to public transport, citizens will be able to travel by other eco-friendly methods: by bicycle, skateboards, rollers, or electric scooters.

3. Transportation in Cylinder

It will also be done by making use of the Electric Multiple Unit trains, except that each seat will be equipped with thick safety belts so that the passengers do not levitate during the transport (since the cylinder is in 0G). There will be two tracks, one for each direction.

4. The transfer between the torus and the cylinder

Because the torus provides gravity but the cylinder does not, the transfer between them requires a particular method to assure citizens' safety and rapid transportation. Thus, we devised a four-step plan that requires the additional two rings we put on one side of the main rotating rings and the circular elevators placed in the tubes that connect the torus to the cylinder. The whole process will be controlled by a state-of-the-art AI system. The plan of transportation from the torus to the cylinder will look like this:

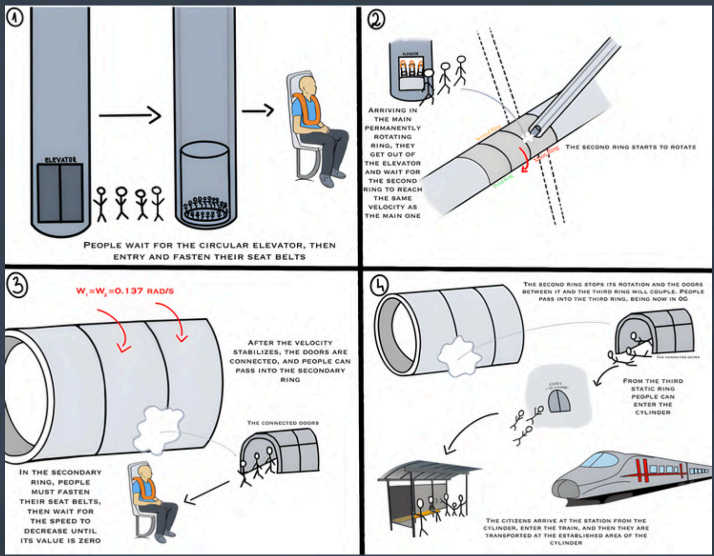
Since the 12 connecting and supporting tubes will cross the entire thickness of the torus, their base being in its basement, people will be able to call the circular elevators on whatever floor they are on. However, it should be mentioned that all visits in the cylinder will be scheduled in advance and usually only be done in groups, with citizens not being allowed to walk unaccompanied by an official staff in the 0G area. After getting into the elevators, people must fasten their seat belts, as gravity will change its value on the way to the cylinder.

Once the elevators have reached the main permanently rotating ring, which functions on electromagnets and supports the torus, people will exit the elevators and wait for the door to the secondary ring to open. This will happen when the second pass ring reaches the same speed as the ring supporting the torus (0.137 rad/s), coupling with it.

People enter the secondary ring (which also functions on electromagnets; however, when it is not in operation, for saving energy, it will be attached to the cylinder by some retractable metal structures, the electromagnetic field being turned off), where other seats equipped with safety belts are placed. Once everyone is seated and secured with the belts, the speed of the ring will decrease until it stops completely, thus entering 0G.

Since both the permanent rotating ring and the second one that rotates periodically will work on electromagnets, the transfer to the cylinder will not be possible directly from inside them, thus requiring the construction of a third static ring, included in the structure of the cylinder. After the second rotating ring stops, its coupling with the third ring will take place. The citizens pass through the open doors in the last ring, and from there they can enter the cylinder. Arriving at a station, they will be greeted by an EMU train and taken to their final destination.

To go back to the torus, the same plan will occur, but in reverse.



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8. Industry

Following the settlement's self-sustainability requirements, a well-developed and diversified industry sector will be implemented in order to provide the plethora of processed goods needed throughout the settlement. As products will be handled in bulk, most industrial activity will take place within the torus, reducing transportation demands.

First and foremost, an efficient food processing industry will be needed to meet the basic needs of the citizenry. The relative resource scarcity to which the settlement is subject dictates a maximized extraction of calories and nutrients from the raw agricultural output. Thus, the degree to which the food is processed will be kept to a minimum, as even basic processes such as cooking, freezing or pasteurization may easily break down the often complex and delicate molecular structures of most nutrients, reducing overall nutritional value [Processed Foods and Health, 2023]. Additionally, the limited food diversity entails fortifying certain items with vitamins and minerals such as calcium, vitamin D or iodine.

Metals will represent the fundamental construction material for most of the settlement and as such, the metallurgical industry will play an important role in its construction and maintenance. From the underlying support structure, to buildings and transportation systems, a number of parts and elements will require constant replacement on top of the initial fabrication and assembly. For convenience, most of the infrastructure left behind from the settlement's first phases of construction could be reused and recycled in the metallurgical industry.

Another cornerstone of industry is the chemical and pharmaceutical sector. A wide range of non-naturally occurring substances are employed in daily life, among these certain medications, soaps, detergents, fertilizers and polymers such as plastics and synthetic fibers. All of these will have to be synthesized in-house mainly from the limited selection of raw materials provided by the agricultural industry and extracted from Mars and from asteroids.

Miscellaneous non-metallurgical manufacturing, comprising textiles, furniture and other day-to-day items constitutes the final major segment of the settlement's internal industry. Bioplastics [Gibbens, 2021] represent our material of choice regarding this area of production, as they possess regular plastic's unique combination of durability, flexibility and light-weight as well as profiting from a straightforward production process, based on easily acquirable plant matter.

While the harsh conditions of outer space mostly represent hurdles to be overcome, they present us with numerous opportunities for specialized manufacturing. Crystals, for one, grow to much larger sizes while maintaining close to perfect shape and achieving greater overall quality. Optical cables, for example, have been proven in a study conducted on the ISS [Guzman, 2023] to perform up to 100 times better when produced in micro-gravity. Furthermore, the occurrence of defects becomes virtually impossible when casting objects, a process also rendered almost effortless in space through the clever use of mirror-focused solar energy and rapid cooling through exposure to the vacuum.

9. Asteroid Mining

The idea of asteroid mining, first mentioned in "Edison's Conquest of Mars" as a science fiction scenario, has since progressed and entered a stage of feasibility, with the first practical attempt to enable this plan being made in 2012 by a company named Planetary Resources.

By choosing the L1 Mars-Sun Lagrange Point, we placed our settlement in the immediate proximity of the Main Asteroid Belt, which will play a major role in resource collection and production. Understandably, we will not travel to the asteroids with our settlement but will instead use several transit vehicles that accommodate a crew of about ten people (depending on the asteroid size, mission complexity, and duration time) and multiple expertized robots and automata for this type of mission. These vehicles will dock to the torus through hatches on the industry level's wall, unloading materials in an airlock and processing them in factories. Because the overall mission time for a single asteroid would range between a few months and about three years, the crew will need a station base from which they will conduct their daily activities and where they will sleep. Some of its areas will be dedicated to producing the required life support systems, where they will grow a large portion of their food, some of which (non-perishable) will be necessary to bring from the settlement until the fresh one produced on-site is ready to harvest (in about a month and a half from planting the seeds).

The long exposure to microgravity and radiation creates health concerns for the crew, so constant health monitoring will be necessary, along with providing several pieces of exercise equipment, such as the ARED (Advanced Resistive Exercise Device) device being used on the ISS or the HIFIm (High Frequency Impulse for Microgravity) device invented in 2021 and heavily funded by the UK SpaceAgency, that is able to cut the required exercise time for astronauts to keep up muscle mass and bone density from 2 hours to just 30 minutes [Blake, 2021], [International Space Station Advanced Resistive Exercise Device (ARED), 2021]. Additionally, researchers from Beth Israel Deaconess Medical Center have demonstrated the ability of resveratrol, a naturally occurring compound found in grapes and blueberries, to preserve muscle function and reduce muscular atrophy, so we will add this supplement to the crew's meals.

Such a base could be inflatable, similar to the structure proposed for "Mars Base 10" in 2012, which could be briefly described as a conical, rigid body that lands on the ground and deploys an inflating toruslike structure made up of bladder, shielding, and restraining materials, which are initially stored in the MB10 module's blunt body of fewer than 30 tons and packed in a star folding pattern or the Miura-ori folding pattern as they are best at decreasing the storage volume.

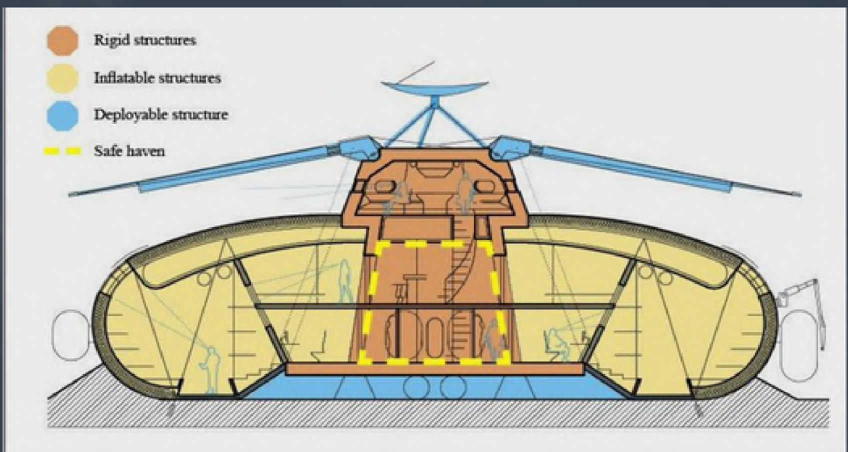


Image credit

The air bladder is made of various materials, including Ethylene Vinyl Alcohol (EVOH), Polyvinylidene Chloride (PVDC), Polyamide (PA-NYLON), Polyethylene (PE), and Polyurethane (PU). The internal pressure reaches 100,00 Pa after only 4 seconds of inflation, and the structure has a mild, 1-5 degrees roof-like slope on top to decrease the risk of debris or dust. It would require protection against space-debris impact, which could be provided by thermally cured thermosets consisting of a thermoset polymer resin-impregnated fibrous substructure [Inflatable Structures for Mars Base 10 - Strathprints, n.d.].

The asteroids can be classified into four main categories, each of which has its own subtypes with very different mineral distributions:

• Chondrites (Enstatite: EH / Ordinary: H Fe, L Fe, LL Metal / Carbonaceous: CI, CM, CR, CO, CV, CK) - Stony accumulations of chondrules and silicates. Chondrules, which are embedded in the meteorite, are basically single, approximately spherical grains of olivine/pyroxene that were flash-heated

• Achondrites (HED Howardites / Eucrites / Diogenite) - Stony accumulations of silicates without chondrules

• Iron (HEX Hexahydrite, OCT Octahedrite, ATA Ataxites) - an alloy of nickel and metallic iron that resembles stainless steel

• Stony Irons (PAL Pallasites, MES Mesosiderites) - an alloy of nickel and metallic iron with olivine crystals

So choosing what asteroid to mine is essential, considering the overall mission longevity and the range of different resources needed for our settlement, many of which are findable on specific subtypes. The asteroids can be studied by spectroscopy in order to characterize their surface composition. With a far greater spectral resolution than was previously attainable with filter photometry, spectra of substantially fainter asteroids may now be obtained using CCD spectrographs, which have been developed during the past two decades, and with the help of the M4AST project —a database of over 2,700 asteroids from the Main Asteroid Belt and other Near-Earth Objects, providing a unique framework for spectral data from telescopic observations of asteroids from sources including the Centre d'Observation à Distance en Astronomie à Meudon (CODAM), SMASSI, and S3OS2—, along with previous missions that have had close encounters with several asteroids from the Main Asteroid belt, we can improve our knowledge on their minerals, grain size, and modal abundances [Popescu et al., 2012].

Once a crew arrives at an asteroid, it will start the mining mission, as opposed to the rather known idea of the "complete capture of an asteroid and transportation of the entire asteroid back to a processing station," discussed, among many others, by Dr. Philip Metzger in 2013. This idea has been dismissed by many renowned scientists for economic reasons and for the major limitations imposed by the asteroid's size, whose diameter should not exceed 10 meters.

The anchoring method used will be essential, as this kind of mission has never been tested, so there still remains an element of uncertainty. While many ideas have been rejected (mainly different kinds of harpoons and nets), there is one particular study released in early 2021 that seems very promising, based on the cross-drilling geometric force closure of an ultrasonic drill that is actuated by piezoelectric ceramic and ideal for drilling on a weak gravitational asteroid's surface due to its low power consumption, low drilling pressure, and wide temperature range. The influencing components of the anchoring force are simulated using the EDEM program, which is based on the discrete element method. By combining this idea with the other more traditional methods, we could obtain the desired anchoring force for such a spacecraft [Wang et al., 2021].

To make mining easier and faster, we will make use of the state-of the-art technology implemented in the Scar-e robot (along with those used in the "Settlement from Asteroid" section), developed by Asteroid Mining Corporation (AMC) in collaboration with Tohoku University, that can drill an asteroid in orbit to extract iron, nickel, and platinum, as well as grab onto an asteroid to keep it from floating away [Asteroid-mining May Be Possible With Scar-e Robot, 2023].

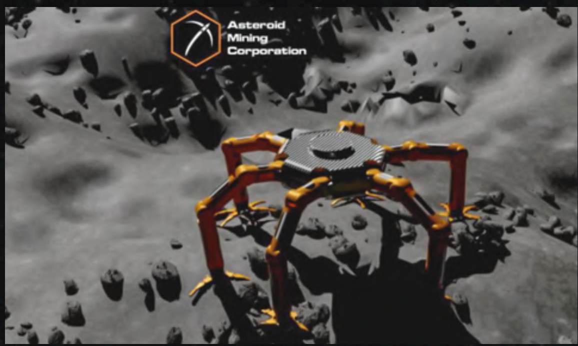


Image Credit

But not every asteroid is suitable for a mining mission, as several requirements are needed to assure the viability of the plan, according to data gathered by John K. Strickland:

Orbital period	Diameter	Maximum distance from Sun	Delta-v	Spin type	Rotational speed	3D geometry
< 3-5 years	> 300m for easier landing	< 1.5 AU for the availability of solar based energy	< 5 km/sec	Either tumbling or along a main axis	< 1-2 rph	To provide secur[e] landing areas an[d] accessibility to sol[ar] radiation

Additionally, we created a chart showing from what type of asteroid we will collect each essential resource, with the exception of water, oxygen, and hydrogen, which we will treat separately as they are more complex to collect/produce:

Nitrogen	Sulfur	Phosphate	Carbon	Iron	Nickel, Cobalt	Silicon	Germanium	Aluminum	Magnesium	Titanium	Plastics
CI/CM Chondrite	CI Chondrite	CI Chondrite	CI/CM Chondrite	PAL Stony Iron	Iron asteroids, MES Stony Iron	Ordinary Chondrite, HED Achondrite	Iron asteroids	CM/CO/CV/CK Chondrite	PAL Stony Iron	HED Achondrite	From carbon

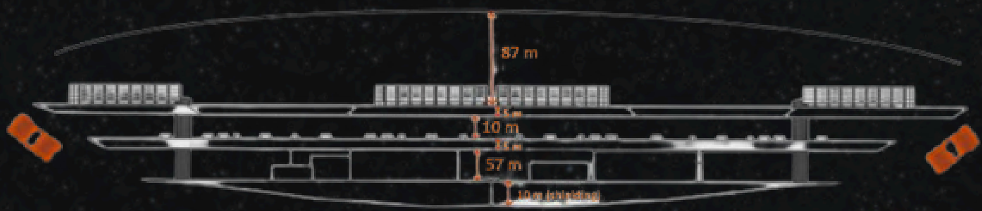
Obtaining water (CI/CM Chondrite): We will obtain it by heating the regolith with solar concentrator mirrors: water will result in gaseous form from ice, sulfates (partial reaction), hydroxides, and hydroxyl (partial reaction) at temperatures of about 500° K and from sulfates (complete reaction), hydroxyl (complete reaction), and organics at temperatures of about 1000° K. The water can be recovered after condensation, while the other gases (SO2, CO2, etc.) won't condense and can be restored later instead. We dismissed the possibility of obtaining water from the gases CO2 and H2, as gaseous hydrogen is difficult to obtain as a raw material.

Obtaining oxygen/hydrogen (data gathered by John K. Strickland): 1. We can obtain them, just like on the ISS, by the Polymer Electrolyte Membrane (PEM) water electrolysis at 50-100 kPa and 70° C. 2. Oxygen can also be obtained from CO2 by solid oxide electrolysis at 150 kPa and 850° C (also resulting in carbon monoxide), or it can be directly produced from the regolith by a carbothermal reaction at 1850° C if the above methods are impossible to realize due to the lack of necessary resources.

10. DIVISION

1. Torus: Because Earth-like gravity can be found on the torus, people will live there, carrying out all their activities. To significantly increase the available floor space, for better structure and greater delimitation of the areas dedicated to distinct fields and activities, we decided to divide the torus into three floors that citizens can access through the circular elevators* spread along it.

Distances between floors



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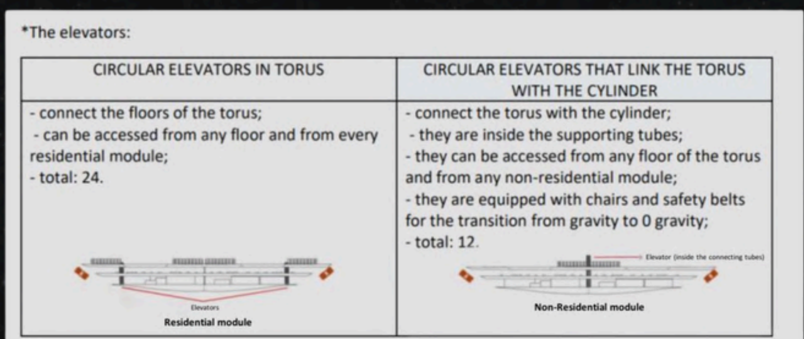
Since each floor will correspond to a different radius, gravity will also have distinct values on each level. However, this aspect will not be a problem since we have established the settlement dimensions so that the gravity oscillates between 1G and 1.15G, values that do not affect human health.

a. The Industrial Area (First Floor): The industrial zone represents a space inherent to the functioning of society since goods are manufactured, garbage is recycled, and essential foods are produced/processed here. Thus, this floor will be dedicated to factories belonging to various industries, but also to laboratories where scientists will work every day in order to permanently improve life on the settlement and to be able to carry out the indispensable research within the space missions (the bioreactors, with the help of which we will produce the meat, will also be in these laboratories). On this floor, we will also place selective containers in which the various types of waste produced during the various activities carried out in any district of the settlement will be brought. Then, the selected waste will be distributed to the factories where it was produced, where it will undergo recycling processes. At the same time, here we will place the nuclear reactors, through which we will obtain some of the necessary energy and the lithium-ion batteries in which we will store the energy.

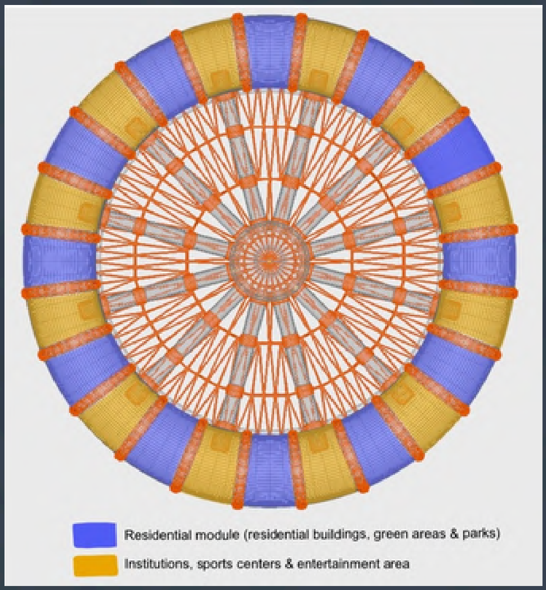
b. The Public Transportation Area (Second Floor): The second floor is intended for public and emergency (used only by the authorities) transport lines. Beside the lines, there will be stations where citizens can wait for EMU trains and bridges connecting the platforms corresponding to each direction. The access hatches to the escape pods will also be found on this floor.


*The elevators:

CIRCULAR ELEVATORS IN TORUS	CIRCULAR ELEVATORS THAT LINK THE TORUS WITH THE CYLINDER
- connect the floors of the torus; - can be accessed from any floor and from every residential module; - total: 24.	- connect the torus with the cylinder; - they are inside the supporting tubes; - they can be accessed from any floor of the torus and from any non-residential module; - they are equipped with chairs and safety belts for the transition from gravity to 0 gravity; - total: 12.
Elevators Residential module	Elevator (inside the connecting tubes) Non-Residential module

Self-produced using Procreate and Blender software

c. The Living Area (Third Floor): Since our settlement is modular (divided into 24 modules), in the residential area we have decided to use this aspect to organize the space where the citizens will spend their lives in the most structured and efficient way. Thus, interspersed, there will be 12 modules in which the residential buildings are located (in the middle and on the two sides of the module), alongside green areas and parks for children, and the other 12 modules in which the institutions (government, schools, universities, police, fire stations, hospitals, offices, and local banks) are located, alongside sports centers and entertainment areas. Streets for pedestrian traffic can be found along the entire floor.



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2. Cylinder: It is the main component of the settlement, as it supports the torus. Because this is a gravityfree zone, we decided to place the main agricultural area here, an EMU train line that will ensure fast transport of people and resources from one end of the cylinder to the other, a docking area for spaceships that will come with a part of resources (mainly with the water required for maintaining the agricultural area) brought from Mars or asteroids, and some storage chambers. We also decided to place the settlement's central control panel here, from which we will monitor its internal and external activities. It will be managed by astronauts, who will work a significant amount of time there, thus being exposed to the dangers brought by microgravity. However, the existence of a person on board the spaceship is essential, so astronauts will rotate the task, being obligated to go to the gym every day after work to avoid becoming victims of microgravity's repercussions.

11.1. Government INSTITUTIONS

The political science of the last two decades shows a constant decrease in the number of people who vote rationally, with the majority choosing the political leader wrongly based on cognitive biases, blind following of favored parties, and misinformation (as Achen and Bartels mention in their study entitled "Democracy for Realists"). Another contemporary American political philosopher, Jason Brennan, argues in his book "Against Democracy" that voting should be limited to knowledgeable citizens and, therefore, democracy should be reduced to improve policymaking. However, we note that the problem is not limited to the irrational and ignorant vote of the citizens; on the opposite side lies the lack of competent candidates that run for high positions. Most of the time, the most intelligent and intellectual people choose not to involve themselves in politics.

To solve those issues, we will utilize an adapted system of government for our settlement, based on the form of "boule," formerly used in Ancient Greek democracy. Instead of a sole leader, we will form a council of 88 people (symbolic number on our settlement) named "Vero" ("truth" in the universal language Esperanto), which will exercise executive function and regulatory powers, among other essential political duties. The 88 people from the council will be rechosen every two years by a computerized randomized selection, with every citizen having the right to be a council member just once in his life. This way, we will ensure that more people can contribute with their ideas and opinions while also being given a chance to improve the settlement’s living conditions if the majority of the council approves. The citizens selected to be a part of "Vero" will need to abandon their current job for those two years to be able to focus more on helping and improving the settlement with the opportunity provided by this council. Also, before entering it, a basic instruction made by the members of the former council for the new board will be necessary.

Every citizen, including the members of "Vero," will need to respect a new code of laws named "Justeco" ("justice" in the universal language Esperanto), which will establish the rights, liberties, and obligations of the population without encouraging or permitting any discrimination. To avoid situations in which council members could modify/add/remove certain laws from "Justeco" to satisfy their own purposes, we have decided that any proposal from the council for any kind of change in the code of laws should be subject to a vote made by citizens not involved in "Vero." This code will also specify the allowed behavior and the appropiate sanctions for breaking the law.

We should note that "Justeco" is based on the supremacy of the law and equality between everyone, so noone, not even those from "Vero," will be forgiven without a sanction if they break any law. The code of laws will be displayed on an official tablet in the council room, the citizens being able to check them on the official website of the council. All the information will be recorded in a secure database so that in the event of a system failure, nothing is lost. Some of the jobs from the settlement don't require a large amount of work from the person who occupies it (for example, a legal case may not appear very often, so the lawyers, prosecutors, and judges will rarely have to work). In "Justeco," we implemented a law stating that if a person doesn't get to perform a set amount of hours per week (different for each job, calculated by its 42 difficulty, physical and mental work put in, and other essential factors), then the person will need to bring a contribution to the community in another way until that number of hours is reached.

11.2 Education INSTITUTIONS

We chose the brightest and most committed teachers during the citizen recruitment phase who were aware of the enormous responsibility they bore: they were to serve as the primary source of general information on the settlement, act as mentors for the kids, and be in charge of the future development of the young adults, forming them not only career-wise but also as individuals. Life on the spaceship offers us new possibilities and an opportunity to restructure and improve the educational process. Therefore, we will focus on the principle of early education, while education specialists will fully redesign the curriculum to match the new life conditions.

Stage 1 (three years):
Three-year-old children will enter groups of mixed ages (from three to six years old) to help them integrate better into future society. Their education will focus on subjects such as Universe Science, Mental Health and Self-Awareness, Resource Management, Environmental Care, and "Terra," a subject about Earth and the history of humanity. Also, they will learn the basics of reading, writing, and calculating and start their English studies.

Stage 2 (five years):
The new curriculum will deepen the subjects introduced in S1 and present new ones. Among others, there will be: astronomy and cosmology, Computer science, Civics on spaceships, and Space settlement studies. In addition, children will visit different settlement areas, such as the 0G agriculture zone. The purpose of these visits is for them to acknowledge their importance as citizens of the spaceship and future professionals. This is also where the SUAP program (an acronym for Skill, Utility, Applicability, and Preference) will be introduced. It determines the best job or field for each student based on a series of skill tests, their wishes, and the spaceship's life conditions.

Stage 3 (four years):
According to the SUAP results, each student's curriculum will be personalized, allowing them to gather only helpful information for their future job. Of course, students will be able to attend optional classes based on their interests. Moreover, school-organized spacewalks will occur so students can perform scientific experiments, observe space, and understand citizens' dependence on the spaceship. After completing this stage, students who do not want to pursue higher education will have the opportunity to start working. In contrast, those who want to continue their studies will enter university and have access to the education needed for specific jobs updated to the new lifestyle.

Considering the population size, speaking the same language will be an essential factor for our spaceship's unity and good functioning. As the citizen selection process does not include a linguistic criterion, we will have brilliant English professors to teach this language to non-English speakers. In the meantime, citizens will utilize a highly accurate AI translation technology, for example, the new SeamlessM4T introduced by Meta [Mauran, 2023].

Self-produced using Canva software

11.3. Entertainment

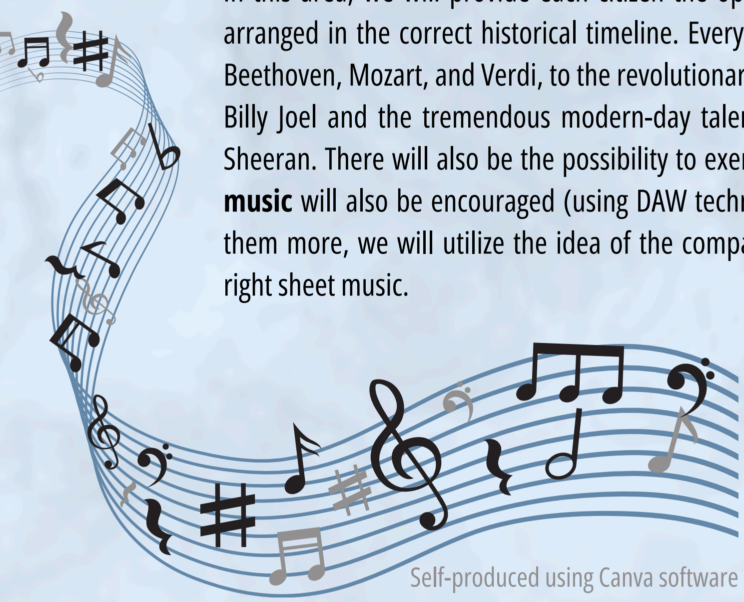
Keeping every citizen's sanity at a high level is our priority. A functional space settlement that can provide the necessary conditions for surviving is insufficient. Enjoyable activities can cause the brain's endorphins, which are naturally occurring "feel-good" chemicals, to be released. Lowering stress and anxiety levels can encourage relaxation and general well-being. Below, we listed only worth-mentioning or unique activities that we were able to include in our settlement. (We did not list the usual activities from Earth that we added in the settlement, as they are similar to what the people already know, like watching a movie at cinemas, eating at restaurants, reading e-books).

The Museum of Memories

We created "The Museum of Memories", a place to display the essence of humankind and its definitory inventions. Many generations of citizens who have never seen anything from Earth will be born, and this will assure, along with the "Terra" subject, that humanity will not forget its origins and history. The museum will be divided into multiple sections, as described below:

Music

In this area, we will provide each citizen the opportunity to listen to the most remarkable musical pieces of all time, all arranged in the correct historical timeline. Every song will be available, from the definitory composers like Chopin, Bach, Beethoven, Mozart, and Verdi, to the revolutionary Michael Jackson, Queen, Pink Floyd, The Beatles, Elvis Presley, ABBA, and Billy Joel and the tremendous modern-day talents like Eminem, Taylor Swift, Ariana Grande, Justin Bieber, Sia, and Ed Sheeran. There will also be the possibility to exercise and play every invented instrument, but the idea of **digital-created music** will also be encouraged (using DAW technology). To make future composers' work more accessible and encourage them more, we will utilize the idea of the company "Frettable" (link), which can transform an instrument's audio into its right sheet music.



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Art:

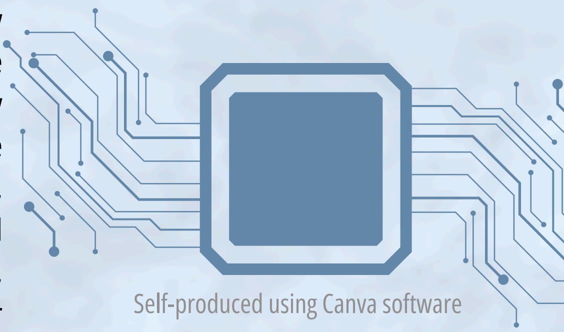
Here, we succeeded in collecting the work of the most accomplished artists, like Leonardo da Vinci, Vincent van Gogh, Pablo Picasso, Claude Monet, and Rembrandt, and exposed all of them to the citizens to watch, admire, and understand their specific style and vision of the world. We will also offer the population the means to create their own pieces in painting, sculpture, or digital form, as online art exhibitions will be organized to encourage amateurs and be space efficient.

Gaming:

In this zone, we were able to create a gaming hub in which we placed all types of games we could find, from the irreplaceable retro arcade machines and board games to the newly cherished video games that changed our perspective, like "The Legend of Zelda", "Grand Theft Auto", "The Last of Us", the "Uncharted" collection and "Super Mario Bros". Additionally, we built dedicated spaces for the games everyone used to play outside on a sunny day, like "Hide and Seek" and "Red light, Green light".

Technology:

From the beginning, it was clear to us that many essential objects and inventions of humanity could not be placed into one of the three categories listed above. To solve this issue, we created another area entitled "Technology" that explores this subject. It will contain many revolutionary items displayed as **tactile holograms**, arranged on a timeline, from the Printing Press (1450), which enabled a way for literacy to expand, the Electric Light (1879), which helped power many social changes, the Automobile (1885), which increased everyone's mobility to the Mobile Phone (1973), that was invented in the more recent years, allowing us to communicate more efficiently. This area will help future generations better understand human evolution.



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Physical Activity

Numerous advantages of physical activity for both physical and mental health are well known. These include better sleep and general quality of life, as well as increased brain health, cognitive performance, and a decreased risk of anxiety and depression.

Taking this into consideration, on our spaceship, we implemented two sports centers, each with a capacity of 1 000 persons. They will support the usual sports (football, basketball, tennis, etc) and also include "endless pools", by which we managed to save much space and water, as they enable you to swim against the water current, making it seem infinite because you can never reach the end, even though you are swimming hundreds of meters and the pool only occupies a few. Inside the complex, there will be high-capacity gyms. There, citizens who spend time in microgravity or null gravity conditions will be able to train in strength and endurance exercises to counteract the effects of muscle atrophy and bone density loss that can occur.

Adding a traditional skiing slope in the settlement was impossible, as it is hard to deal with the constantly needed snow and the immense size it covers. The company "Neveplast" succeeded in solving this problem by creating an "extremely smooth" material "with a coefficient of friction equal to snow." This revolutionary low-cost invention is light, with a similar feel to the snow, being able to be placed on any surface (even grass), thus transforming it into a suitable one for skiing and snowboarding. This eliminates the necessity of having snow while also being easy to add or remove from a surface if the used space is required for something else. We will use this invention in our settlement to enable our citizens the possibility of skiing and snowboarding.

Image Credit

Public Parks

"*In every walk with nature, one receives far more than he seeks*" – John Muir.

We will build public parks and other green spaces around the Torus to allow citizens to spend time in nature, maintain a healthy mind, and find a worry-free and relaxing recreational space. At night, theater plays with hologram backgrounds could take place in parks, as well as movie projections.

0G entertainment

Some null gravity chambers placed in the central cylinder and low gravity chambers placed in the tori will be used for entertainment purposes so that citizens can take the best advantage of the conditions they find themselves in. Some of the available activities are:

Sports in Zero Gravity: Basketball, soccer, or other games (spaceship life development will surely leave its pattern, and new sports will be invented) can be adapted to zero-gravity environments. The dynamics of these sports would be dramatically different and captivating to watch.

Zero Gravity Dance Parties: Choreography and movements would take on an entirely new dimension without the constraints of gravity. This would also be an opportunity for artists to create music specially designed for a zero-gravity environment.

Art and Sculpture Exhibitions: Artists could create sculptures and installations using three-dimensional space in ways that are not possible on Earth.

Virtual Reality: VR technology can offer users a fully immersive experience, making access possible in any environment or time desired.

In addition, entertainment spacewalks will be possible, allowing citizens to observe celestial events better.

Spacewalks offer unique perspectives of the Cosmos. Accordingly, those who are interested can capture photographs and videos that may contribute to scientific research.

Safety precautions like trained employees and security cables will be used, as microgravity may have malignant effects on health. People who spend considerable time in these conditions will need to follow strict exercise routines to maintain their bodies unaffected.

Viewing the stars

"*Look up at the stars and not down at your feet. Try to make sense of what you see and wonder about what makes the universe exist. Be curious.*" – Stephen Hawking.

We designed our tori from the settlement to have ceilings made out of glass. This choice was made not just for letting the natural light spread around the torus easier, thus using much less energy for the artificial lighting, but also for a beloved activity that everyone on Earth used to enjoy. For many of us, viewing the stars became one of the daily pleasures we could take advantage of. We can receive hope and happiness by watching these distant light sources, so including such a precious activity in our settlement was essential. We will place a performant telescope that the citizens will be able to utilize at any moment of the day to admire the universe.

11.4. Police

As a symbol of governance and the embodiment of the principles of justice, law enforcement agencies function as indispensable institutions in any advanced society, diligently upholding order through the lawful exercise of their officially sanctioned authority to arrest and employ force as necessary.

Placement & Divisions: Three police stations will be strategically positioned on the residential base of the torus, each overseeing eight sections of the torus's floors and effectively demarcating distinct jurisdictional zones. The primary police station, situated within the accommodation segment of the torus, will also house the Administrative Division.

Digital Rights and Privacy Protocols: Clearly defined guidelines and protocols will be established for balancing security and individual privacy rights within the settlement’s closed environment.

Security force: To ensure the well-being of our residents, we will create a dedicated task force with the mission of reinstating order and security within the space colony. A specialized team comprising extensively trained personnel will be prepared to address unique contingencies, including catastrophic events such as an asteroid impact.

Smart policing drones will patrol our spaceship's public places to ensure real-time surveillance and response to criminal activity. At the same time, road cameras will be installed every 100 meters and use 360-degree sensors for optimal monitoring.

11.5. Healthcare

A robust medical infrastructure is necessary to manage the health issues that astronauts and settlers may have. The productivity and happiness of a colony's people determine its viability and sustainability.

To fit all our inhabitants comfortably, our settlement will have two large hospitals that include all essential departments: cardiology, neurology, radiology, surgery, oncology, urology, emergency units, and many others. Those will also include an intensive care unit (ICU) and pharmacies where medical supplies are accessible for people with prescriptions. Additionally, at every two modules, there will be small clinics intended to provide first aid and to treat minor health problems. Here are just some examples of the innovations we want to achieve on the settlement:

<u>Cancer-killing molecule:</u> Curing cancer has always been the target in world medicine. It would save countless lives and alleviate immeasurable suffering for patients and their families. Additionally, it holds the potential to unlock new frontiers in medical research, as cancer is interconnected with various aspects of biology and genetics. A recent study has led to the creation of a molecule that could induce selfdestruction in blood cancer cells, offering potential as a new cancer treatment. This process is called B-cell lymphoma (DLBCL) therapy. The researchers designed this molecule to activate genes controlling cell death in cancer cells, and it managed to effectively kill lymphoma cells in lab tests without significant side effects [Drug Turns on Self-Destruct Genes in Cancer Cells, 2023].

<u>Solving liver issues:</u> NIHR-supported researchers have developed a novel technique to grow "mini bile ducts" in a lab and successfully used them to repair damaged human donor livers. This breakthrough can benefit patients with malfunctioning livers, often caused by bile duct issues. The shortage of liver donors and the challenges in organ storage make such innovations crucial. Researchers have shown that damaged livers can be repaired using lab-grown cholangiocyte organoids. Finding liver donors in a small community like the one on our settlement can be a severe problem [Human Liver Repaired Using Cells Grown in a Laboratory for the First Time, n.d.]. This breakthrough can solve our issue, increasing the number of suitable livers for transplantation, potentially saving more lives.

Upon boarding the settlement, each citizen will receive a high-performance smartwatch that they must wear at all times containing all relevant personal information. Through this gadget, citizens can communicate with the authorities, reporting any problem in real time; they can receive warnings and indications during an emergency, and their position on the settlement can be easily located, the paramedics, police or firefighters knowing where to go if a citizen needs help. Also, through the smartwatch, they can check information about the rations they still have available, the date when the next batch of rations will be delivered, and their own legal situation (how many points they have – detailed in the "Economy“ section).

<u>Image created using Midjourney (AI)</u>

12. Economy

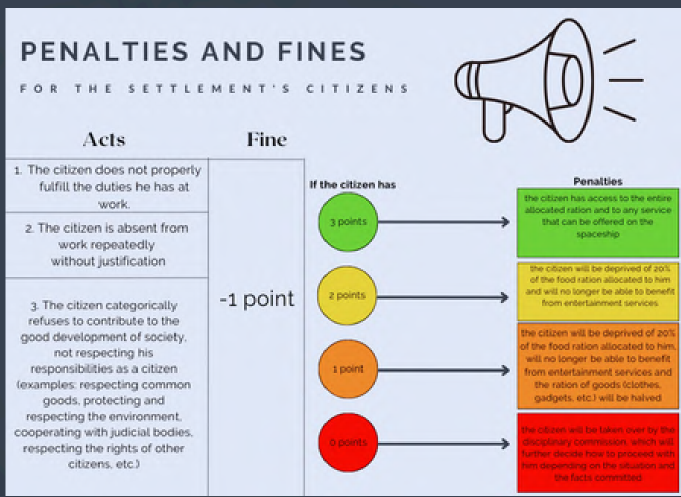
An economy, when stripped down to its core integral features, represents a space in which the production, distribution, trade and consumption of goods take place, facilitated through various systems and mechanisms [Kenton, 2023]. Those systems and mechanisms are usually tuned as such in pursuit of a certain goal, such as maximizing freedom of the individual or minimizing inequality. For us, that goal is maintaining a well-functioning and independent space settlement hosting a prosperous society.

Given the constant precariousness of outer space, order and cooperation are prioritized, assuring that the settlement runs like clockwork at all times. Thus, personal economic liberty is cast aside in favor of government-provided rations tailored to each according to their need. Furthermore, punishments, usually in the form of ration cuts or restricted access to entertainment or other public facilities, will be levied following any low to medium level disruptions of the settlement's public order, namely unjustified absence from work, poor execution of personal job duties or not respecting public goods or the environment. Additionally, individuals with multiple misdemeanors will be denied access to any government positions.

We will put this in practice through a points system, wherein each citizen starts off with 3 points. Any of the above-mentioned misconduct will land you a one-point reduction, with each level having its own corresponding punishment, detailed in the attached diagram:

Points will only be regained, one by one, through maintaining a clean record for a certain number of months. The points system will no longer be valid in the case of a citizen that commits an abominable act. He will automatically be tried in court and will bear the taken measures.

In accordance with the relative scarcity of basic resources and especially commodities we take for granted on Earth, the settlement's economy will have as its core principles needs-based rationing and maximized reuse and recycling of materials.



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Food rations will be adjusted for every citizen based on gender, work demands and medical conditions by digitalized nutritionists and will be picked up together with similarly tailored hygiene supplies from local banks where they are accounted for in a digital database. Water and electricity are delivered directly to homes and their rationing will mainly take into account the number of residents and their respective ages. Clothing will be handed out regularly in shorter intervals for children and teens and longer ones for adults, with the provided uniforms being mandated by schools and the workplace, in order to foster a sense of belonging, community and responsibility.

We have decided to ensure product longevity and efficient recycling of personal items with the following process. Any items with perceived damage will be taken by their owners for assessment, from where they are either taken in for repairs, if possible, or deemed unsalvageable and sent to recycling plants. Owners will be given replacements, however repeated damage reports for the same object will be subject to investigation and potentially punishment in the form of confiscation.

While we admit some of these measures fall on the more draconic side, we place our trust in the selection process to provide a rational populace with well-established moral values that is able to adapt to the imposed conditions and understand their necessity.

13. Communications

Approximately 73 seconds after liftoff, the Space Shuttle Challenger from NASA's STS-51-L mission disintegrated, causing its entire crew of seven people to die and marking the program's immediate suspension and one tragedy the world will never forget. This happened due to one of the solid rocket boosters' O-ring seals malfunctioning from the unusually low temperatures at the launch site. Following the disaster, NASA reevaluated its entire procedures and safety protocols, assuring such a major mistake would never happen again.

The $200 billion that was put into the program wasn't enough to prevent the catastrophe from happening, as the technology from 1986 didn't allow for a proper and detailed review to take place before the crew's departure. But the most astonishing part refers to realizing there was no way for the mission controllers and engineers on the ground to obtain telemetry data and real-time video from the shuttle as it was ascending, as otherwise, they may have detected the O-ring issue and aborted the mission in time.

Implementing a well-thought and executed system of communication for our settlement will make a difference in such disturbing cases, provide the citizens with an easy way of contacting each other, and establish a stable connection with Earth and all of the mining missions.

External communication: For securing a constant transmission with Earth, we will utilize NASA's pioneering Deep Space Optical Communications (DSOC) system initiated in October 2023 as part of a six-launch mission, started in 2013 and set to end in 2024, which focuses on enabling improved and higher data rates from space. Each of them (LLCD, LCRD, TBIRD, ILLUMA-T, DSOC, O2O) is specialized in a particular niche, and the one we've chosen is the only one that aims to show transmission of data at distances up to 390 million kilometers (240 million miles), being capable of sustaining communication from as far away as Earth (to Mars), 1,000 times farther than any previous optical communications test [X, 2023]. Two ground telescopes from Earth (the Hale Telescope at Caltech's Palomar Observatory in San Diego County, California, and the one at the Optical Communications Telescope Laboratory at JPL's Table Mountain site in Wrightwood, California) have been modified to interface with the flight laser transmitter for DSOC's needs [Deep Space Optical Communications (DSOC) - NASA, 2023]. A JPL “cryogenically cooled superconducting nanowire photon-counting array receiver” is integrated into the Hale Telescope. In order to precisely target the returning laser beam back toward Earth, the transmitter will act as a pointing reference, or beacon, sending a modified laser signal to the DSOC's flight transceiver, which will be attached to the exterior of the settlement [Murphy, 2023].

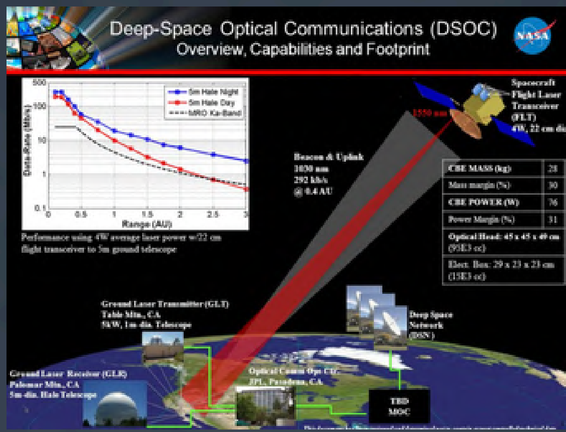


Image Credit

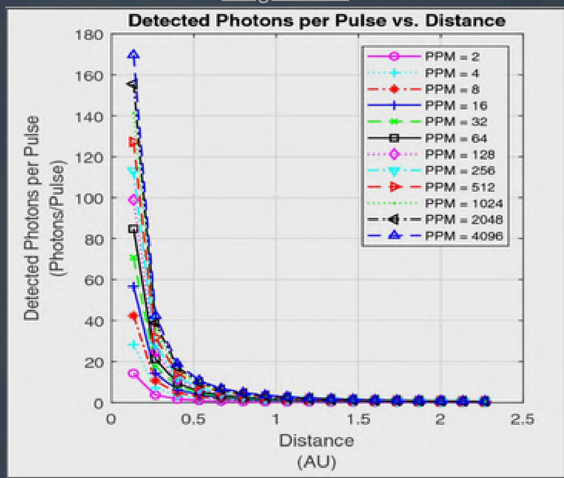


Image Credit

Internal communication: For the general, day-to-day use throughout the settlement, we will implement a traditional system of Radio Frequency, which will benefit everyone with a trusted technology that provides the needed wide coverage. For high-bandwidth applications where the advantages of fast data transfer rates and low latency are essential, such as scientific data transfer or telemedicine, we will establish a system of optical communication, possessing laser transmitters and large-aperture telescopes and sensitive optical detectors as receivers, in addition to accurate tracking systems for reliable connections. We will also incorporate strong security protocols, emergency protocols, maintenance, testing, and redundancy to guarantee continuous and dependable communication for the settlement’s citizens.

14. Space Debris

It all started with the first interaction with space- 1957: the launch of Sputnik I produced the first man-made orbital debris- the rocket stage that launched the artificial satellite and the satellite itself. 1960: Space exploration intensifies, and the launch of anti-satellites (ASAT) for testing and the explosion of old spaceships produced even more space debris. 1961: The upper stage of the Thor-Ablestar rocket exploded, and this caused the tripling of the number of space junk. 2009: A derelict Russian spacecraft collided with and destroyed a functional Iridium commercial satellite from the US. The collision added almost 2,300 pieces of big, trackable debris to the catalog of space junk and many smaller bits. And the list is expanding even today.

Our planet is now surrounded by over 4500 satellites, including communication satellites, GPS rings, weather equipment, and much more. As time passes, the orbit will just get more and more crowded because humanity plans to continue launching satellites by the thousands, but not to take them back after it is established that they are no longer functional.

What is Space Debris and what are the dangers posed by it?

Space ("orbital") debris is any man-made object in Earth's orbit that no longer serves a functional purpose. Nonfunctional spacecraft, abandoned launch vehicle stages, mission-related junk, and fragmentation debris are examples of such debris [10 Things: What's That Space Rock? - NASA Science, n.d.].
A recent report done by ESA shows that there are currently around 30,000 distinct pieces of space debris greater than 10 cm in size, with more than half of them littering low Earth's orbit. Moreover, it is estimated that there are 131 million small space debris (smaller than 10 centimeters) that are not trackable [List of Space Debris Producing Events, 2024].

Fortunately, at this time, space junk does not pose a significant risk to our exploration endeavors; nonetheless, only satellites are directly affected by their presence since they must perform periodic maneuvers to avoid colliding with space debris. However, the dangers are not far away. Don Kessler and Burton Cour-Palais of NASA produced an influential article in 1978 that predicted the Kessler Syndrome: the point at which the population of orbital debris would develop predominantly through collisions rather than new launch activities. The debris issue received increased attention due to their efforts and intensive space activity, and thus an alarm signal was raised regarding the future of space exploration.

Nowadays, several missions have been conceived through which we can physically clean space (RemoveDEBRIS; ClearSpace-1; Astroscale: COSMIC; LaserBROOM etc.). Nonetheless, these missions are only concerned with cleaning up trackable massive debris, but not making as many efforts in removing the rest of 131 million untrackable small space debris that can reach up to 28,16352 km/h speeds, fast enough to destroy a satellite or spacecraft. Even if the majority of new space debris is generated by large chunks, small space debris poses the greatest threat due to the fact that it is not known when a satellite or a spacecraft will be hit by such debris, and therefore maneuvers cannot be made to avoid the collision. **So, what do we have to do in this case...?**

Removing the Small Space Debris:

Taking advantage of already being in space and having the latest and most efficient research technologies on board, we dared to hope that we would find a solution that could actually be implemented. Searching through numerous studies about cleaning the space debris, we initially found a material that seemed to be promising since it was used on a very small scale on the International Space Station (ISS) for 18 months to capture cosmic particles for study: *silica aerogel*.

What is Aerogel, and how will we obtain it?

Aerogel represents a silicon-based solid with a porous structure that contains more than 99% free space. Glass, another silicon-based material, is 1,000 times denser than aerogel. This exotic substance possesses several odd qualities, including exceptional thermal insulation, survival in stressful conditions, and an excellent ability to absorb hypervelocity dust (when a high-velocity particle collides with an aerogel, it buries itself in the material, leaving a narrow cone-shaped track as it slows and comes to a rest) [Todd, n.d.].

A silica precursor is the primary substance required to produce silica aerogels. We will utilize silicon dioxide (SiO_2) because we can find significant quantities on Mars as silicate minerals in its regolith. The silica precursor is dissolved in a solvent to form a gel containing a three-dimensional network of silica particles suspended in liquid. Alcohol (e.g., ethanol or isopropanol) is a common solvent. The gel is then allowed to age for a set length of time, during which structural changes occur that determine the ultimate qualities of the aerogel. Drying is a crucial stage. The solvent in the gel is carefully replaced with a supercritical fluid (typically carbon dioxide) while preserving the pressure and temperature parameters required to prevent the gel structure from collapsing. Freeze-drying is the process of freezing the gel and then removing the solvent through sublimation. Following drying, the aerogel will be subjected to other treatments, such as solvent extraction and thermal annealing, to optimize its characteristics even more.

Using aerogel cushions seems promising so far, but how could we make this project happen on a much larger scale? What would be the exact process of catching small space debris? Moreover, how many pieces would catch such a panel?

With these questions in mind, we tried to find some answers. So, while browsing through various studies, we came across a Master Thesis written and published in 2023 by Patricia Carceller Suarez for obtaining the degree of "Master of Science" at Delft University of Technology. This thesis is called "Mitigation of Small Space Debris," and in 109 pages it deals in detail with the subject presented in the title. We could find the majority of the answers to our questions in this work, so our cleaning plan will integrate some of the information and technical data found in it.

In order to be able to find the exact values within the plan, Patricia's study was based on an event that has already happened, namely the Kosmos 1408 anti-satellite weapon test, held in November 2021. The focus was on simulating the break-up event and determining how many fragments could be caught for a population of 10,000 fragments during seven days. The best coordinate systems and reference frames for the study were determined to be the Earth-Central Inertial (ECI) frame to describe the movement of the spacecraft and the Local Vertical Local Horizontal (LVLH) frame to describe the position of the debris relative to the spacecraft. Also, Keplerian elements (=the set of six independent constants that define an orbit) were used for spacecraft orbit simulations and debris, and Cartesian coordinates (horizontal x-axis and vertical y-axis) were used for debris motion relative to the spacecraft. Those aspects ensured that the relative motion of the spacecraft and debris bits was accurately represented [Patricia, 2023].

The data creation and simulation process was thoroughly detailed, as were the challenges that Central Processing Unit (CPU) time posed to the simulation, resulting in the elimination of perturbations. The smallest possible passing distance between the catcher space shuttle and the object was established at 20 m to help set a limit while still allowing for determining the adequate size of such an approach by experimenting with different radii for the catcher spacecraft. The results showed that the best size was the largest possible: a radius of 100 meters.

It was discovered that the mission's launch time has no effect on the amount of debris caught. It is noted, however, that several deployments with various deployment periods and positioning the spaceship perpendicular to the direction of movement would result in an increase of the number of trapped fragments [Patricia, 2023].

Moving on to the number of debris captured by a spacecraft consisting in a flat and circular surface with a radius of 100 m made out of aerogel, the results show that for a population of 10,000 fragments, the yield ranges between 11.68% and 12.51% of fragments caught, depending on the aforementioned factors. Possible injection inaccuracies in altitude or inclination can lead to catching less than 1% of small debris, so we must be highly accurate when stabilizing the spacecraft's position in orbit.

Although the passive catching method is feasible because it does not require any maneuvers, a velocity loss would occur over time due to the repeating hits of the debris pieces [Patricia, 2023]. This would imply adjustments required to re-orbit the spacecraft in the proper orientation. Furthermore, the spacecraft could be re-positioned to another orbit where a fragmentation event has just occurred or is likely to occur. Similarly, a maneuver would be required to avert a collision if the spacecraft were to find itself on a collision course with another spacecraft. That being said, sufficient delta-v would need to be available to perform the required maneuver, and we can know the exact delta-v value by solving the following equation:

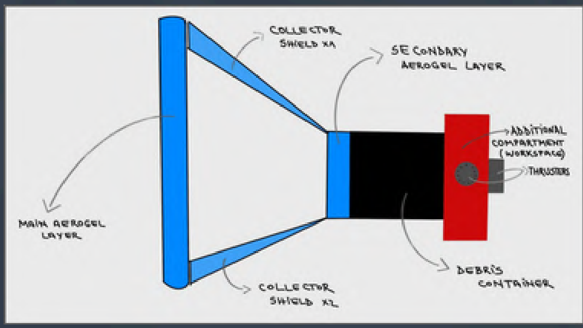
$$\Delta V^2 = V_1^2 + V_2^2 - 2V_1V_2 \cdot cos(\Delta i)$$

where V_1 = initial velocity; V_2 = final velocity; Δi = inclination of the spaceship.

Last but not least, it was determined that, while the overall sizes and hence momentum of the pieces are often small, there is a chance of one or two fragments with a considerable momentum to be caught. Simulations made by P. C. Suarez discovered momentum values ranging from a low of 0.01 kg*m/s to a maximum of 526 kg*m/s. This factor was crucial in the design of the spaceships involved in the debris cleanup.

The spaceships: The spacecraft we will send in the cleaning mission will have the design suggested by Patricia in her work, and additionally we will place a compartment that will serve as a workspace. To minimize the risk of human casualties, the mission will involve only robots. Since we cannot expose the aerogel panels to the journey between Mars and Earth, we had to find a solution by which the aerogel is placed in the panels only when the spaceships reach the Earth's orbit, in the predetermined place. But how can we do this? Patricia's work does not give any indication regarding this aspect, so we decided to contact and ask her this question via email. Patricia was very kind and answered. We have attached our conversation below.

We will follow her first suggestion and prepare the aerogel directly in the spaceships, when they have reached their predetermined destination. This process will take place in the laboratory from the additional compartment and will be undertaken by programmed robots. The waste containers will be the only mobile components, being replaced by new containers sent in advance from the settlement when they are full. The full containers will return to the settlement, where the waste brought will enter the recycling processes.



Self-produced using Procrate software

<u>Note</u>: The aerogel panels will not be changed whenever the exchange of waste containers occurs, so they will work until they show the first defects (they will be periodically controlled by the robots who will send the analysis data to the settlement, where the researchers will make the decision to continue/stop their operation).

Final aspects: Our plan based on Patricia's study refers to cleaning space debris smaller than 10 cm in size, an activity that has never been taken into account on Earth due to several aspects (costs, the lack of the necessary technology). However, Earth will have the critical task of collecting the rest of the large space debris through the current developing missions, together (our settlement and Earth), to be able to clean the orbit and annihilate the evolution of the Kessler effect.

Since man also reached the Moon and left debris there too, we will soon have to develop missions to clean its orbit, but this will happen only after the success of the current mission. We put our trust in the sustainability of future satellite launches, those being done <u>ONLY</u> if the launched object will be recovered after its defection without abandoning it in space.

15. Special Scenarios

Contact with Earth will be permanent, and will be accomplished using a laser system, as described in the "Communications" section. It is important for keeping updated on the latest news from the planet and primarily for advances in science. Scientists and engineers from both our settlement and Earth will be in constant touch and work together to constantly develop and improve all aspects linked to the colony. Naturally, everybody will have access to the information transmitted from Terra.

SCENARIO 1. CATACLYSMS. CARRINGTON EVENT: In case of a cataclysm threatening life on Earth (biological catastrophe, nuclear war, runaway global warming), we see it as our responsibility to ensure that humanity will survive through us. In the scenario depicted above, people surviving the cataclysm might find themselves on a new and strange Earth that can no longer sustain life (as a consequence of extreme climate, supervolcanic eruption, ocean acidification, resource depletion, etc), or as damaged that it would be most difficult to regain the former state of development. Should that occur and in the limit of science and our possibilities, we will intervene in the attempt to help. Hence, life on the settlement will suffer immediate and significant changes, starting with reestablishing its very goal.

We will no longer only seek to sustain a prosperous and improved society and to insure its expansion, but we will focus on making Earth habitable again. This will trigger the emergence of new jobs and a rise in the work effort demand. Thus, more teens will choose to not follow higher education and start work after completing Stage 3. In the 2020 EGU general assembly it was stated that "the probability of occurrence in the next decade of an extreme event of a magnitude comparable or larger than the well-known Carrington event of 1859 is estimated to be between 0.46% and 1.88%" [Serra et al., 2020]. The consequences of such an event could be disruption of power grids, damage to satellites, as well as economic, transportation and healthcare impacts. On these terms, we will provide assistance as regarding the following actions:

- Behaving as a communication relay to help mitigate disruptions in global communication, allowing emergency services, governments, and organizations to coordinate their response efforts more effectively;
- Assuring emergency power generation, either by implementing SBSPs (according to an ESA article, “the biggest challenge to the economic feasibility of Space-Based Solar Power has historically been the high cost of space launch to orbit”. Launching from space is far less expensive and brings multiple advantages, thus making SBSP production possible and convenient), or by using our advanced solar arrays to provide emergency power to critical infrastructure on Earth, helping to stabilize power grids and prevent prolonged blackouts in key areas;
- Giving our scientific expertise and transferring technologies (advanced energy storage, radiation shielding, space weather prediction systems)

SCENARIO 2. INTERSTELLAR TRAVEL: As humanity evolves and advancements in science seem to grow exponentially, it is legitimate to consider space colonization and interstellar travel as intrinsic. Thus we have developed an expansion scheme that would allow us to further explore the cosmos and find a new place for mankind to settle in and thrive, as although asteroid-provided resources reach huge quantities, they are still exhaustible. As of the present state of scientific progress, the realization of interstellar travel remains unattained. Consequently, the formulation of a viable blueprint, encompassing the subsequent notions, is contingent upon future advancements in scientific understanding and technological capabilities.

The selection of a suitable celestial location for interstellar travel and space colonization is crucial, and this process will be executed by specialized personnel who carefully examine various factors such as mission feasibility, distance, potential habitability, and scientific interest. This deliberation will be fortified by empirical data obtained through the utilization of interstellar probes, with particular emphasis on nanocrafts.

Starchips (centimeter-sized nanocrafts) are an interstellar spacecraft designed for the Breakthrough Starshot program, and will be constructed and regularly sent to space, providing data as imaging and spectroscopy information, ISM studies, magnetic fields, and cosmic rays measurements [Breakthrough Initiatives, n.d.]. Solar sails, which leverage the momentum of photons emitted by the Sun, will be used to periodically launch nano crafts in space using our Mars-based laser propulsion infrastructure, powered by solar energy, following the project's pattern [Society, 2022].

A laser light sail propulsion system can be built from asteroid and Martian resources, using advanced 3D printing and manufacturing technology, and assembled in space, potentially through robotic or autonomous systems. This could involve constructing a large array of laser emitters capable of focusing on the light sail, powered by Mars-based solar arrays. The laser's power demand is approximately equivalent to that needed for launching the space shuttle into orbit, conferring us a significant advantage [Williams, 2023].

Starships are distinguished by whether the ship carries its own reaction mass or not. **"Slowboats"** carry a huge amount of equipment to initiate operations in a new solar system and its hold of radiation shielding, unlike laser-propelled ships, which depend on external sources, such as lasers, for accelerated travel. The advantages of laser-driven ships include the ability to reach cruising speeds of a few percent of C in 6 weeks instead of 100 years [Chung, 2022].

Interstellar traveling will require massive amounts of energy and mass, so it will be necessary to have some kind of energy source comparable to controlled fusion power. **Fusion power plants** are being developed to create practical fusion propellant for interstellar travel, but it still faces limitations such as technical complexity, fuel availability, and heat management.

The Magnetic Fusion Plasma Drive (MFPD) is an innovative approach harnessing controlled nuclear fusion reactions to produce both thrust and potential electric power. The resulting plasma from these fusion reactions is carefully confined and manipulated through the use of magnetic fields, assuring controlled energy release and precise directionality.

16. Housing

"Housing is absolutely essential to human flourishing. Without stable shelter, it all falls apart." -Matthew Desmond

Home. The word that makes us all think of a private and intimate place where we can find comfort and spend quality time with our loved ones. Starting from this idea, we had no choice but to offer each citizen a home that would make him feel that this is where he belongs. Thus, we decided to organize the residential areas in apartment buildings, as they can host a more significant population while requiring a smaller space.

These blocks will contain the following:

1. **Apartments with two bedrooms**, intended for couples who will have a child in the future or for families who already have a child:

Self-produced using Autodesk software

2. **Apartments with three bedrooms**, intended for families with two children:

Self-produced using Autodesk software

Access to the blocks will be based on digital cards that correspond to each block in the torus. Thus, we will ensure the safety and comfort of citizens.

3. **Houses with two bedrooms**, for a couple that will have a child in the future or for a family that already has a child. The projects show the two connected duplexes.

4. **Houses with three bedrooms**, intended for families with two children. The projects show the two connected duplexes.

Self-produced using Autodesk software

Shaping our passion for Space Exploration

Our path towards designing Zenith Station, was marked by numerous events: participating in ISDC (2023 and 2024), where we expanded our knowledge about the latest space technologies; meeting the only Romanian cosmonaut, Dumitru Prunariu, who talked to us about his spaceflight experience (at an Octo Bucharest Rotary Club reunion).

We are truly grateful to the organizers for their contribution in our journey to discover the wonders of outer space exploration through designing our space settlement.

Romanian Youth Space Conference (2022)

Attending **ISDC** (2023)

Our team at **ISDC** (2023)

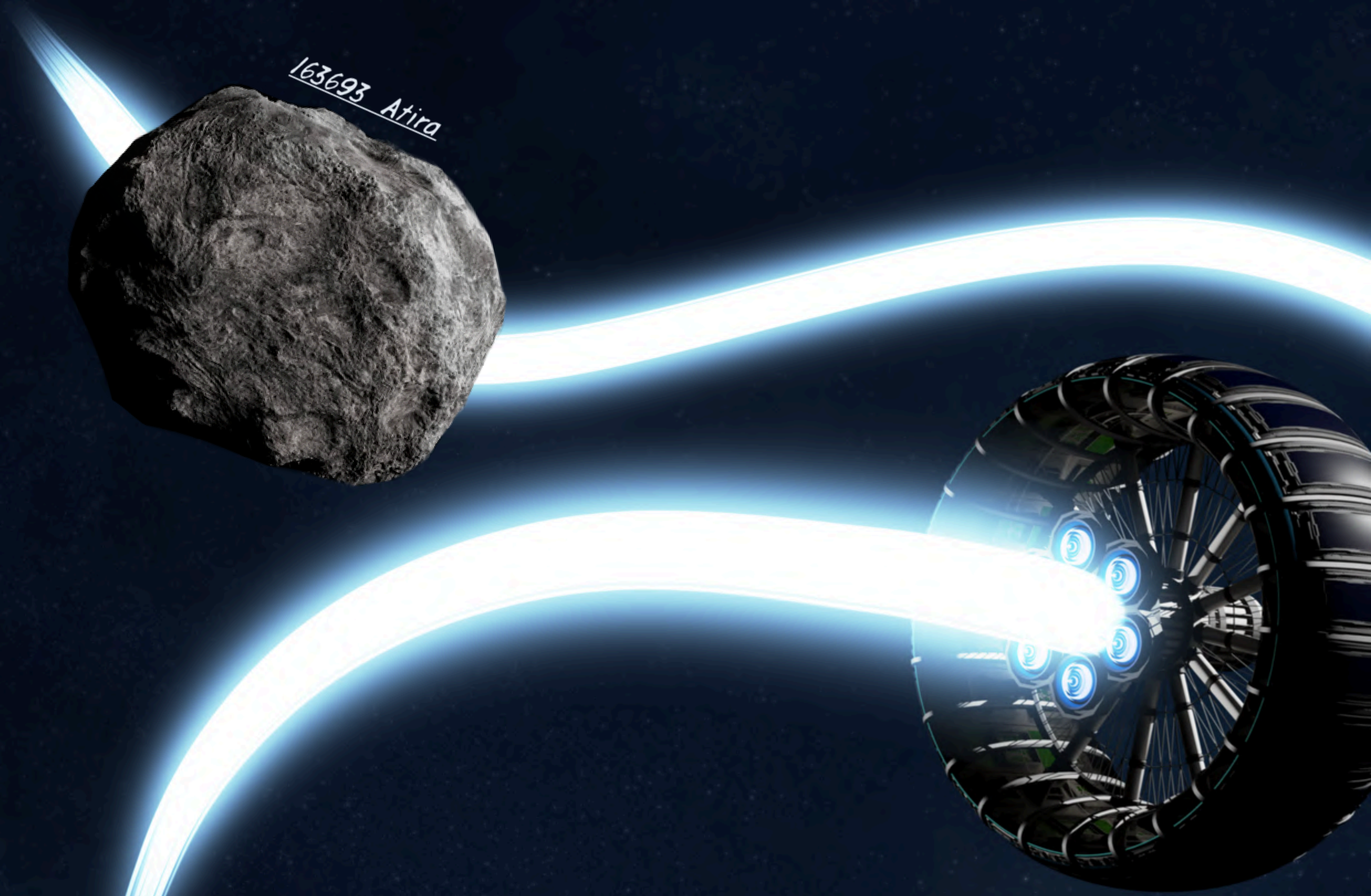
Attending **ISDC** (2024)

Doing an internship at **CERN** (2024)

Attending the science summer school at Magurele, Romania **(MSchiTech 2024)**

Award Ceremony at **CERN** (2024)

Meeting with **Dumitru Prunariu**, the only Romanian cosmonaut



So here we are. Now, only the future lies in front of us. Humanity will continue not just to exist, but to strive, even in the most unfavorable scenario, thanks to the settlement we've created, to the civilization we've built together. Our wish is clear: we hope to be able to read history books about events that have not yet happened. There is much progress to be made and many stories to come.

ZENITH STATION

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