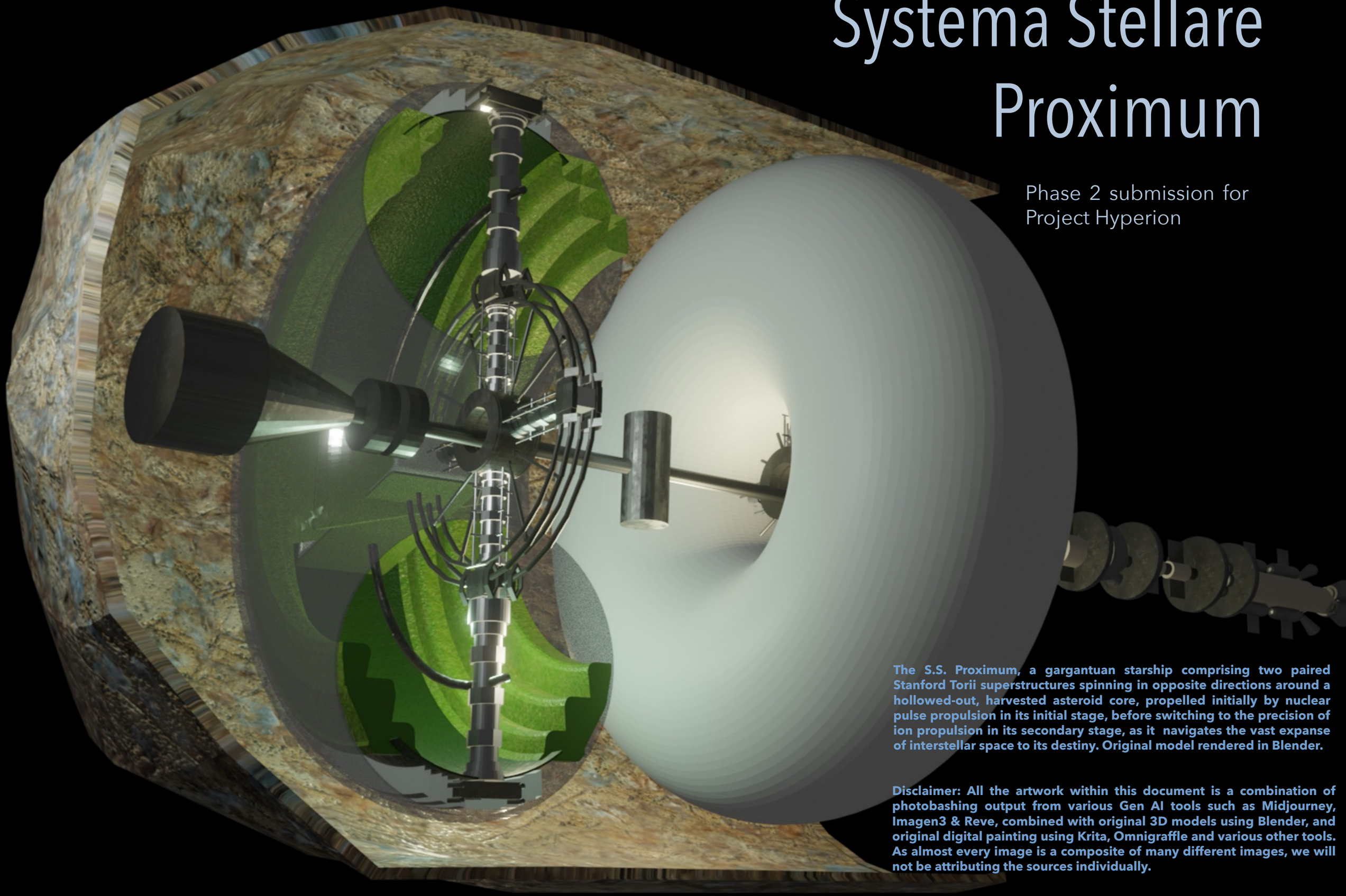
Systema Stellare Proximum

Phase 2 submission for
Project Hyperion



The S.S. Proximum, a gargantuan starship comprising two paired Stanford Torii superstructures spinning in opposite directions around a hollowed-out, harvested asteroid core, propelled initially by nuclear pulse propulsion in its initial stage, before switching to the precision of ion propulsion in its secondary stage, as it navigates the vast expanse of interstellar space to its destiny. Original model rendered in Blender.

Disclaimer: All the artwork within this document is a combination of photobashing output from various Gen AI tools such as Midjourney, Imagen3 & Reve, combined with original 3D models using Blender, and original digital painting using Krita, Omnigraffle and various other tools. As almost every image is a composite of many different images, we will not be attributing the sources individually.

The Interstellar Imperative

Within the submission, our aim was to incorporate a more human aspect to the project, with a primary protagonist called "Aja", and we will attempt to visualize her life throughout the initial phases of the journey, and as she passes on, her story will live on through her progeny.

"250 years. A single destination.

A thousand lives woven into the fabric of a journey.

This is the story of the SS Proximum

This is also my story"

- Aja



Summary of the project:

Key design decisions – melding the use of current and future technologies, Mankind aims to conquer interstellar space after conquering the Solar System. By the time we start our interstellar voyage, we are already a spacefaring species and economy, and the only logical trajectory henceforth is to conquer the stars. Our submission for Phase 2 is focused on providing renderings of the future premise. As a point of reference, we take our guidance for the final artwork based on drawings from the 1962 Life Publications' "Epic of Man". We have included an objective state of completion in the Requirements Satisfaction Matrix.

Assumptions and Premise - As we approach this pivotal moment in human history, it's essential to lay the groundwork for this ambitious endeavour. By now, Mankind has overcome numerous technological hurdles and secured sufficient financial backing to embark on this extraordinary journey. This milestone marks a defining era in humanity's evolution as a spacefaring species. Mankind's has been fuelled by a thriving space-based industry that operates with unparalleled efficiency, unencumbered by the constraints of interstellar travel costs. We've harnessed cutting-edge technologies and materials harvested from our solar system to construct elaborate structures, empowering us to push the boundaries of what's possible in space.By circa-2350, Mankind would have successfully developed and tested the critical safety protocols necessary for long-term space habitation. The Stanford Torii systems are now operational in multiple Lagrange points, while habitable bases have been established on select planets and moons within our Solar System. This impressive achievement underscores an extraplanetary commitment for creating a comfortable and sustainable environment for those who will be eventually venturing forth. As we prepare for the next chapter in human exploration, it's clear that spacecraft design must prioritize comfort above all else. Since spacefarers are departing from space stations rather than Earth, they have already undergone the prerequisite acclimatization that allow them to withstand the rigors of interstellar travel. Our engineers and designers have carefully considered every aspect of this endeavor. However, we as a team acknowledge a significant limitation: our current understanding dictates that wormholes remain elusive targets at this juncture in human history. Consequently, our route will be conventional, relying on established trajectories rather than uncharted shortcuts.

ntroducing the Mission Destination, Rationale and Goals

Exploring Humanity's Interstellar Manifest Destiny

The year is 2320. Mankind has fully transformed to a space-based economy and has conquered the Solar System. Humans as a species have advanced science to the point hat we are ready to embark on interstellar exploration.

ust as the 19th-century railroad pioneers looked westward with unbridled hope, humanity as a whole now gaze beyond our own Sun and towards the next Solar System Visionary individuals have now mastered the technologies that would help Mankind reach for the heavens, setting their sights on sending a group of colonists to the nearest sta ystem, namely Alpha Centauri Proxima B, to the planet Proxima Centauri-b, 4.73 LYA. By 2047, the first quantum-AI navigation systems have been developed, reminiscent of the nitial railroad surveying expeditions. These are not merely machines, but sentient, robotic explorers – the modern-day Lewis and Clark of deep space. These robotic sentine probes become the pathfinders, mapping cosmic territories much like railroad engineers once charted unexplored territories.

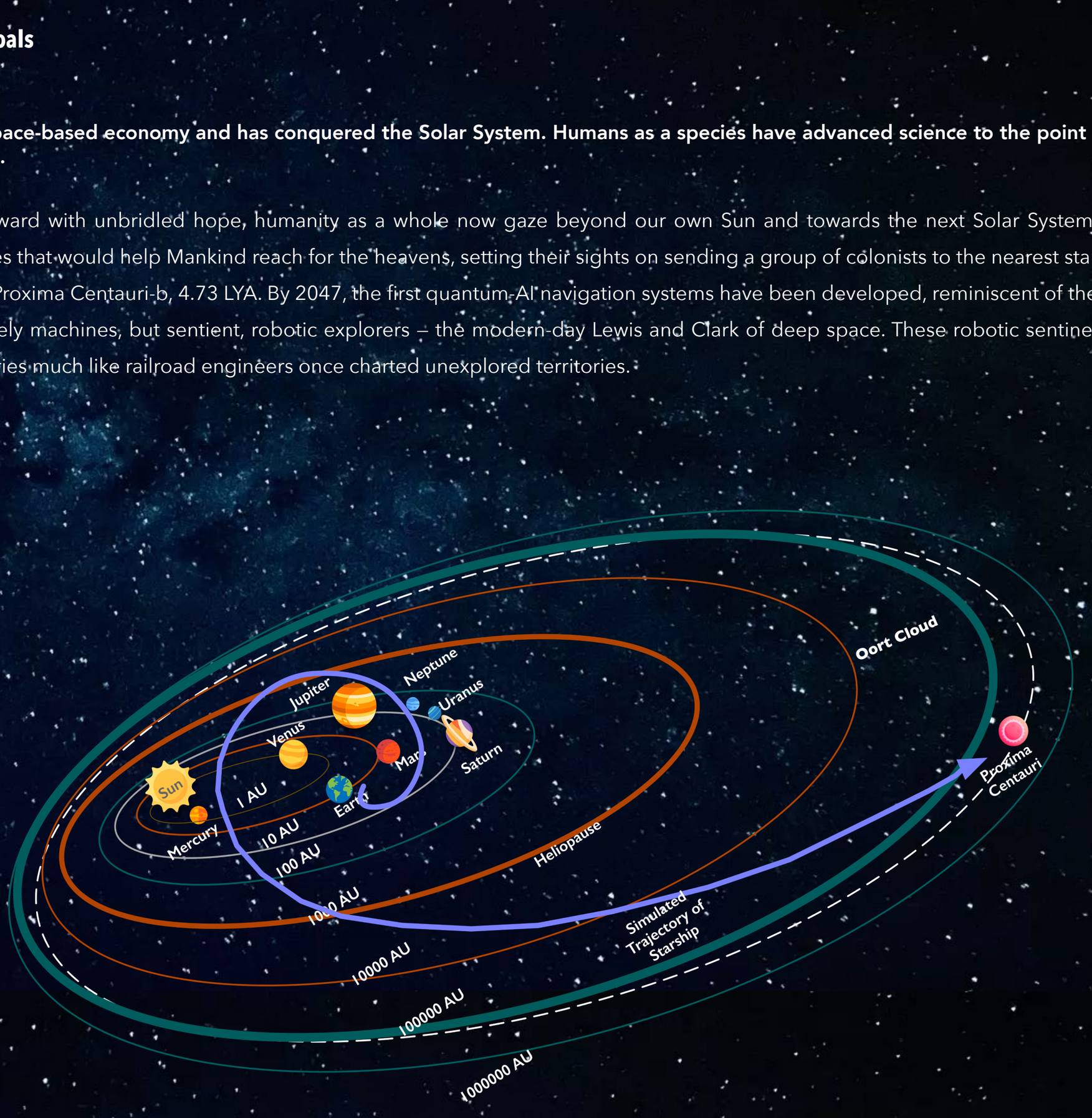
The interstellar railroad would be more than just a technological marvel - it would mark a historic turning point in human migration, one that begins in earnest after 2080. The first deep space missions involving sentient beings will commence, initially focusing on capturing or harvesting nearby asteroids for resources and developing waves of robotic probes to set towards Proxima Centauri-b.

These probes, equipped with capabilities akin to self-replicating mycomimicry, will pave the way for building a stellar highway. Sentinel pathfinders will be deployed to enable manned missions, by providing a safe and efficient route. By adopting this approach, we can harness spacefaring technologies while minimizing risk, making it an ideal time to launch the next phase of our journey: sending a Generation Starship to colonize Proxima Centauri-b.

The probes themselves are designed as self-replicating vessels with limited payload capacity. In reality, they're disposable scouts that undergo 30% attrition upon completion of their missions. However, these probes will play a crucial role in carrying and manufacturing essential supplies and parts for the first generation starship, as well as selecting designated asteroids to mine.

Within 75 to 100 years, sentinel robotic pathfinder fleets are expected to discover and establish the interstellar railroad, paving the way for larger unmanned) craft to set up between 15 to 25 core stations. These hubs will be complemented by 100 to 150 secondary relay points and stations that send out autonomous probes - a total of 200-300 in number.

These probes will then venture into the Oort Cloud to harvest and utilize local resources, laying the groundwork for future generations of spacefarers.



Projecting the Approach

Time Period	Key Milestones (NSS#) Achieved/Advanced	Focus Areas & Objectives	Key Technologies & Developments	Example Outcome/Capability by End of Period
Phase 1: Foundations (Present - 2040)	M1, M2, M3, M4 (partially)	Dramatically reduce launch costs, establish permanent LEO presence, initiate space tourism, early in-space commerce.	Fully reusable launch systems (Starship-class & beyond), advanced chemical propulsion, modular inflatable & rigid habitat tech, LEO debris mitigation, early AI-assisted operations, basic closed-loop life support (ECLSS) improvements.	Routine, affordable access to LEO. Several commercial LEO stations (tourism, research, light manufacturing). Basic satellite servicing. First private passenger orbital flights.
Phase 2: Cislunar Expansion & Early Habitats (2035 - 2060)	M1 (fully), M2 (fully), M3 (fully), M4, M5, M6 (early), M13, M14, M15 (early), M16 (prototype), M18	Establish robust cislunar transportation, lunar resource confirmation, initial beyond-LEO habitats, early rotational gravity tests, space solar power R&D.	Nuclear Thermal Propulsion (NTP) for cislunar tugs, advanced robotics for construction & logistics, cryo-fluid management in space, propellant depots (LEO, Lunar Gateway), lunar ISRU for water/volatiles, small-scale rotational gravity testbeds (e.g., <50m diameter), initial SSP demonstrators.	Regular crewed missions to Moon. Robotic lunar ISRU pilot plants. First small, continuously occupied rotating habitat in ELEO (e.g., Kalpana 2 concept). L1/L2 logistics hubs.
Phase 3: Lunar & Early Orbital Settlement (2055 - 2090)	M4 (fully), M5 (fully), M6, M7, M8, M12, M15 (fully), M16, M17 (early), M19, M20, M26, M27 (early)	Develop lunar bases, utilize lunar resources, begin asteroid characterization & early mining, in-space fabrication of large structures, deploy initial Space Solar Power.	Advanced lunar ISRU (metals, construction materials), large-scale robotic mining (lunar), automated in-space fabrication (friction-stir welding, additive manufacturing of large components), first operational SSP units, asteroid prospecting probes, early asteroid capture/processing techniques, legal frameworks for space	Continuously occupied multi-purpose lunar base producing propellants & some materials. First asteroid-derived materials returned/used in cislunar space. First large (100m+ diameter) rotating orbital habitat built in LEO/Lunar orbit primarily from Earth-launched materials, testing full-scale artificial gravity.
Phase 4: Mars & Advanced Orbital Habitats (2080 - 2150)	M9, M17 (fully), M21, M22, M23, M24, M27 (fully), M28 (early)	Establish Mars bases, achieve significant self-sufficiency tech, expand asteroid mining, build first large orbital settlements from non-terrestrial materials.	Fusion rocket prototypes (for cargo/fast Mars transits), advanced CELSS (95%+ closure), genetic engineering for crops & extremophiles, large-scale asteroid mining & processing in situ, automated construction of habitats from asteroidal/lunar materials, advanced radiation shielding materials (e.g., hydrogen-rich	Permanent lunar settlement. Continuously occupied Mars surface base with ISRU for fuel & water. Several large rotating orbital settlements (e.g., Stanford Torus scale, like our "Kalpana" concept) in cislunar space/solar orbits, built primarily from asteroidal/lunar resources, housing thousands. Robust SSP network.
Phase 5: Self-Sufficiency & Interstellar Prep (2140 - 2250)	M10, M11, M25, M28 (fully), M29 (Para-terraforming begins)	Demonstrate multi-generational survival off-Earth, establish true Martian settlement, full-scale orbital settlements, asteroid defense system, begin para-terraforming Mars.	Mature fusion propulsion (high thrust/ISP), advanced AI for complex system autonomy & long-range mission planning, breakthroughs in hibernation/suspended animation, advanced genetic engineering for human adaptation (optional/ethical debate), near-100% closure CELSS, large-scale atmospheric processing for Mars (para-terraforming), advanced robotics for planetary engineering.	Multiple, thriving orbital settlements (tens of thousands of inhabitants). Growing Martian settlement with significant para-terraformed zones. First confirmed multi-generational human survival off-Earth. Operational planetary defense system. First dedicated interstellar probe designs (e.g., fusion-powered, laser sail).
Phase 6: Interstellar Voyage Development (2230 - 2320)	M30 (Design & Construction)	Design and construct first interstellar generation/hibernation ships. Develop technologies for centuries-long voyages. Select initial target star systems.	Scaled-up fusion drives for interstellar speeds (1-5% c), advanced materials for ship integrity & debris shielding, autonomous ship ecosystems, advanced AI for navigation & problem-solving over centuries, long-duration hibernation systems (if used), robust interstellar communication R&D (e.g., quantum entanglement -	Construction of several interstellar vessels (e.g., large rotating cylinders/tori, potentially kms in diameter) in high solar orbit or at a Lagrange point, using resources from asteroid belt/outer solar system. Extensive testing of all systems. Selection and launch of precursor robotic interstellar probes.
Phase 7: Interstellar Launch & Arrival (2300 - 2350 & Beyond)	M30 (Launch & Journey Begins)	Launch first interstellar missions. Initial decades/century of travel.	All technologies from Phase 6, fully operational. Focus on long-term reliability, crew psychology (for generation ships), and autonomous system maintenance. Development of strategies for target system arrival & initial resource utilization.	First human interstellar vessels en route to nearby star systems. Arrival at target system and establishment of initial foothold (robotic setup followed by crew awakening/disembarking) would occur after 2350, depending on target distance and cruise velocity.

Based on NSS (2019) “Roadmap to Space Settlement, 3rd Edition”

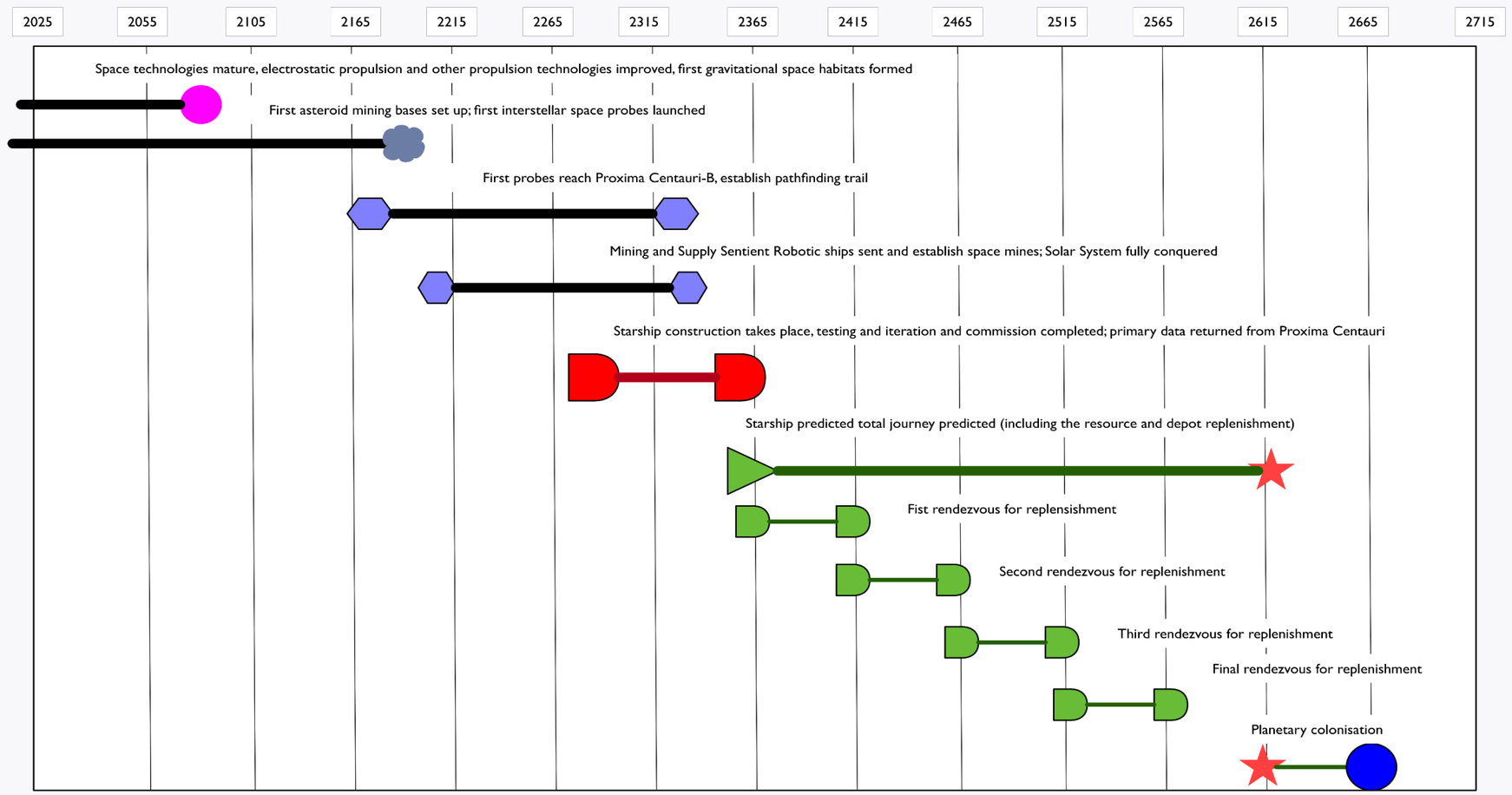
To establish a network of robotic sentinel stations in deep space on the way to Proxima Centauri b, we can identify potential resources available along the journey, particularly in the form of asteroids and comets. Here’s a breakdown of the resources and a timeline for setting up these stations as waypoints for replenishment.

Potential Resources in Deep Space

Resource Type	Source	Description
Water Ice	Comets, Asteroids	Essential for life support and can be converted to fuel.
Metals	Asteroids	Iron, nickel, platinum, and other valuable metals for construction and repair.
Rare Earth Elements	Certain Asteroids	Used in electronics and advanced materials.
Volatiles	Comets	Ammonia, methane, and other compounds for fuel and life support.
Organics	Comets	Carbon-based compounds that can support life processes.

The most promising mission simulations make use of multiple precursor probes which prepare the target star system before the arrival of the world ship.

- The graphic is a timeframe that represents a plausible scenario for a segmented journey from Earth to Proxima Centauri- b over 250 years, starting from the year 2350 ± 50 years.
- The journey is divided into four segments, each involving acceleration to a station, replenishment, and then acceleration to the next station. It is likey that there will not be any slowdowns or docking along the way, but rather the robotic fleets will rendezvous with the SS Proximum to facilitate the replenishment.
- This graphic outlines the timeline and key activities for each segment



Key Points:

- Total Journey Duration: 250 years.
- Total Distance: 40 trillion kilometres, divided into four 10 trillion-kilometre segments.
- Acceleration Phase: Each segment involves a 30-year acceleration phase at about 0.1 g.
- Cruising Phase: A 15-year cruising phase at maximum speed.
- Deceleration Phase: A 5-year deceleration phase before each waypoint.
- Activities at Station: Docking for resupply, maintenance checks, and potential repairs or upgrades.

Overall Timeline:

- Start Year: 2350 (or within ±50 years).
- End Year: 2600 (or 250 years later).

Tackling the Fundamentals of Interstellar Flight

As hostile as environments get, once we are out of the protective cover of the heliosphere, deep space can be deadly in a number of ways. The ship will have to deal with various forces that we have we have to tame, primarily the radiation from cosmic rays, micrometeoroids and space dust.

The diagram below describes how we have tailored the ship design to overcome these elements.



Using Biomimicry in Space

The SS Proxima is an example of design based on biomimicry, loosely on the evolutionary traits of a jellyfish, incorporating various approximations that reduce the risks associated with deep space travel. The following features are inspired by the interactions of how this creature has adapted to its surrounding and how this guides us in the design of the interstellar spacecraft.

Asteroid Shield as a Bell

One approximation is using a hollowed-out asteroid as a shield. This shape optimization mimics the bell (or umbrella) of a jellyfish, which provides strength and flexibility to withstand harsh environmental pressures in space. The leading edge of the asteroid has varying densities of material, similar to those found on jellyfish bells, to dissipate energy from impacts. It is imbued with self-healing technologies and robotic on its surface that constantly repairs its damaged parts

Pulsed Plasma Propulsion

Another biomimicry application is used in the propulsion system, inspired by the way a jellyfish moves through water. A pulsed ion propulsion system generates thrust by mimicking the pulsing motion of a jellyfish's tentacles. This allows for fine-tuned adjustments to be made to the ship's trajectory.

Drone swarm analogous to Tentacles

The biomimicry application of tethered drones that use electrostatic propulsion and work as a swarm to maneuver the ship beyond what can be done via the range of gimballed nozzles or tether the statship while in space holding it anchored in position when required

Distributed Sensor Network and Adaptive Navigation

The starship also incorporates an integrated network of sensors across its surface, similar to those found on some species of jellyfish. These sensors detect micrometeoroid impacts, radiation levels, and other environmental factors, providing a comprehensive picture of the ship's surroundings.

This distributed sensor system is complemented by adaptive navigation systems that learn from sensor data and adjust the ship's trajectory to avoid hazards and optimize fuel consumption. Additionally, sensors inspired by chemoreceptors on jellyfish are used to detect specific elements or molecules in interstellar space, potentially identifying potential resources or signs of other civilizations.

Internal Structure and Habitat

The internal habitat within the asteroid is designed with a modular system similar to that found in some species of jellyfish. This allows for easy expansion and reconfiguration of living space as needed. The main two torii (but not the asteroid itself) are rotating, providing the necessary gravitational support for organisms onboard.

Closed-Loop Life Support

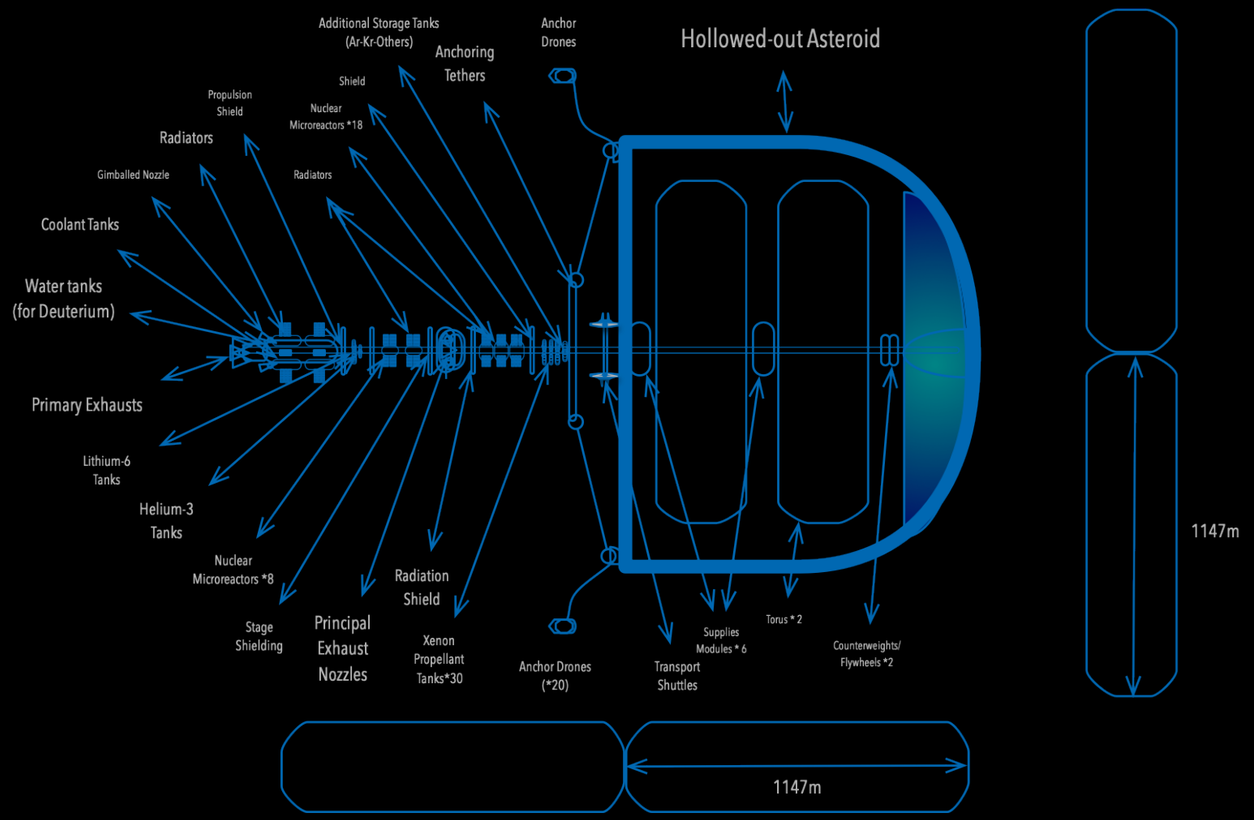
The starship implements a closed-loop life support system, which minimizes waste and maximizes resource utilization. This is achieved through algae or other microorganisms that convert waste into food and oxygen, mirroring the efficiency of some jellyfish species in recycling nutrients.

Hydroponic/Aquaponic Systems

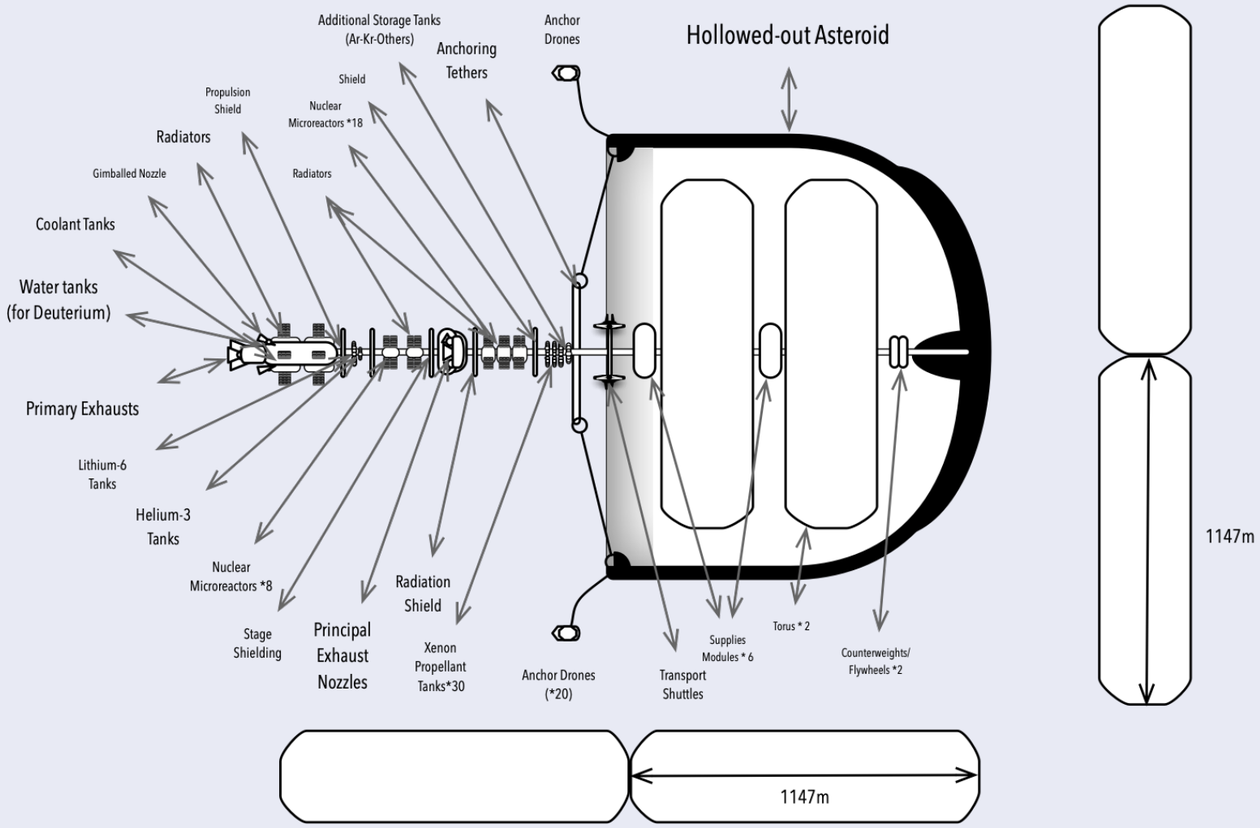
In addition to its closed-loop life support system, the starship incorporates hydroponic or aquaponic systems for growing food and purifying water. This approach is inspired by the way some jellyfish rely on their environment for sustenance, providing a sustainable source of nutrition for organisms onboard.

Defense Mechanisms

The final biomimicry application is used in defense mechanisms against micrometeoroids that are too small to be effectively blocked by the asteroid shield. A laser-based system vaporizes or deflects these impacts, serving as a secondary defense mechanism.0

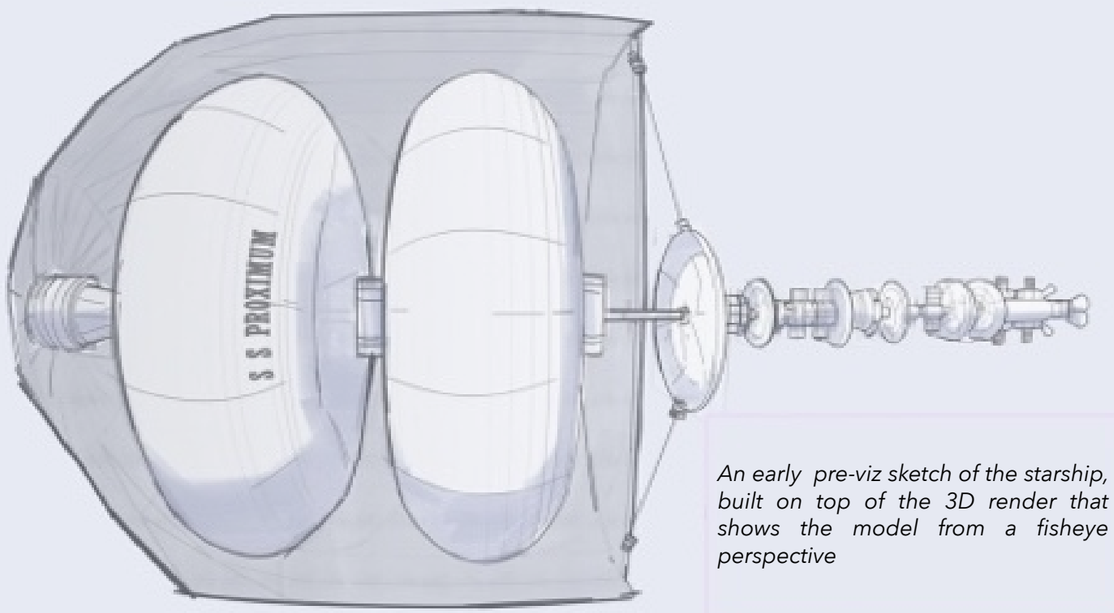


Introducing the SS Proximum: A Home amongst the Stars



Aja's Perspective: "Each torus is a self-contained world, a testament to human ingenuity. While one would suffice, we have two...just in case!."

A rendering of the ship, demonstrating its scale and components. We have decided to eschew the need for regolith surrounding the habitats, as we believe that a hollowed-out asteroid that has been significantly reinforced with a composite material that has roughly the same mass (as calculated elsewhere) will provide a similar or better mass shield for the dual-torus design. The asteroid has significant lips at its cup-like opening (not depicted here), thereby allowing for the protection of the torii it contains. The inside of the asteroid is reinforced to provide additional shielding and prevent debris from building up



An early pre-viz sketch of the starship, built on top of the 3D render that shows the model from a fisheye perspective

3D model of the starship, showing its various components, the scale is depicted in the line-art render on the left of the screen, the ship is depicted in a cut-away of the hollowed-out asteroid that serves as a protective shield

The Dimensions of the Torus Habitats

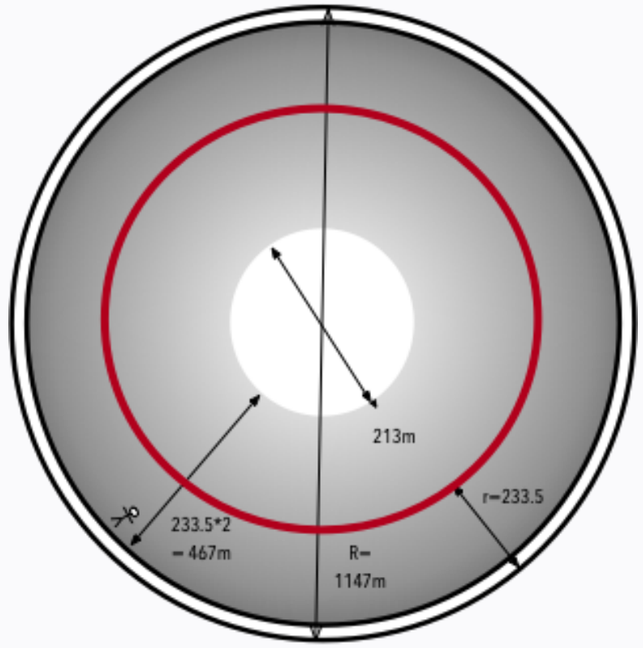
Dimensions	Value	Unit
(Input: Radius of Rotation, R)	573.5	m
(Input, r, minor radius of torus)	223.5	m
Total Surface Area of Torus ($4\pi^2Rr$)	5060235	m^2
Projected Area (A_{ptorus})	1610481.6	m^2
Projected Area (A_{ptorus})	≈ 1.61×10^6	m^2
Volume of the torus is based on the assumption that the torus is completely solid, the formula being $V = 2\pi^2 \cdot R \cdot r^2$	≈ 565,000,000	m^3
Surface Area and Structural Mass Estimate (for an areal density (essentially a mass per unit area density) of 100kg/m^2	5.06×10^8	kg
Rate of rotation of the torus	1.719	rpm
Angular velocity (or ω @1.1618 rpm)	0.1216	rad/s
Rotational Kinetic Energy ($E = \frac{1}{2} I \omega^2$)	≈ 1.37×10^{12} (1.37 Terajoules)	J
Habitability parameter, γ) it is based on the notion that 0<habitability parameter<2/[1+(R/r)]	0.5	
Habitable Volume	530940969.6	m^3
Assuming that this volume is calculated in scientific notation	5.31×10^8	m^3
Structural Mass at ½ atm	965.8	kt
Mass of Atmosphere (kt)	360	kt

To ensure the comfort and well-being of inhabitants during a 250-year interstellar journey, the design of our rotating torus prioritizes spaciousness. Calculations show humans and most animals will adapt comfortably to a rotation speed of 2 RPM or less, minimizing any vestibular effects. The desigers determined an ideal diameter (R) and increased the torus's cross-sectional size to mitigate potential system shocks and provide ample living space, even at the expense of the added mass, because compared to the total mass of the mass shielding, the added weight would be relatively negligible. Note that since the torus was constructed in space, during a period when the space economy was stable, the total costs were not unreasonable compared to the merits of health and well-being of the first human interstellar travellers and their precious cargo, the seeds of the planet Earth.

"The torus is designed to comfortably house a colony of 1500+ individuals, with maximum redundancy factored in, through the inclusion of two similar structures. This generous scale isn't merely for the journey itself; it anticipates the ongoing terraforming of the destination planet and allows for significant population growth beyond the initial colonists, in the event that terraforming does not go to plan. The design team recognized that flexibility is paramount to long-term survival.

Crucially, the torus's dimensions were established with a human-centered approach. Rather than shrinking the structure to save space, the designers prioritized the comfort and safety of the inhabitants, understanding that a longer journey necessitates an extremely spacious and adaptable environment. This foresight allows for greater societal evolution and provides a crucial buffer against unforeseen crises, enabling easier separation and management of the colony if needed.

A 2D line art logical diagram of the torus that demonstrates its overall dimensions, which have been calculated and included within the table here. All calculations can be verified and are based on formulae that consider the uniquely ellipsoid shape of the torus in cross-section.



- The basic dimensions of the habitats – they are designed as spinning Torus' and they spin in opposite directions to each other at the same velocity, so as to ensure that they cancel out any vibrations,
- In cross-section, the torri are perfect spheres in cross-section, to ensure that the internal pressure is even throughout ;for redundancy, there are two similar Torii with similar dimensions and mass, that are spinning in-line with each other
- The radiation shielding (mass shielding is provided with the harvested asteroid material) is incorporated into the shell. The shell also features plumbing, carrying algae that help maintain its atmosphere and provide oxygen.
- The design of the starship forms the principal design element that the rest of the ship would have to conform to. A unique feature of this ship is that the shields (namely what is provided by the asteroid) is kept separate from the torus, and we believe that this reduces the overall mass of the starship while providing better micrometeoroid shielding

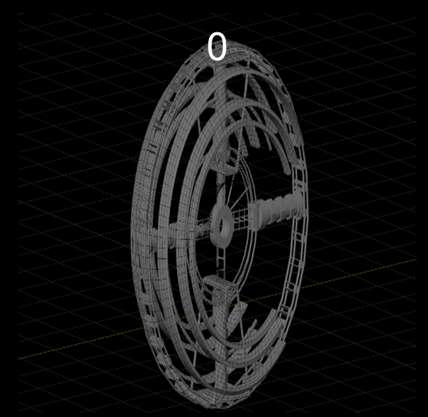
SS Proximum Torus Layout and Design

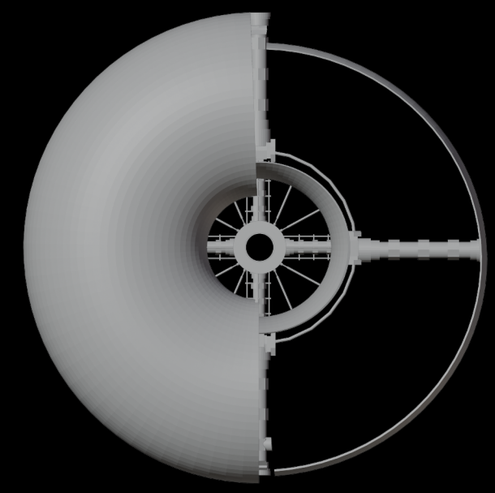
By design, each Torus is redundantly configured, although at the most granular levels, there are certain aesthetic and physical differences.

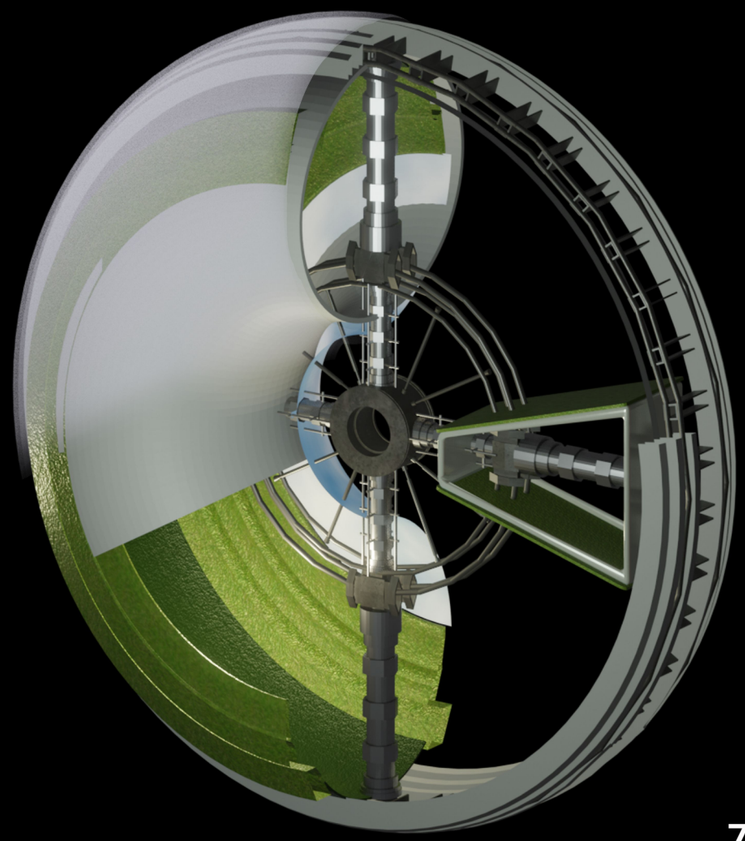
Each is held in place by 4 central spokes that attach the torus to the central spindle. Each torus is thus divided into 4 parts by the spindles that are configured at 90-degree angles to each other, and is compartmentalised at each end, where there is a central wall that divides the torus into two compartments, spanning a total of around 150 degrees of the circumference of the torus. Within the remaining 60-odd degrees, there are aquatic marine environments and algae farms placed at opposite ends, as well as the primary subsystems of the ECLSS. These both provide materials and facilitate in generating the atmospheric gases, while ensuring that the mass of the torus is equally distributed.

The updated table based on 2020 figures is provided below. The primary difference is that there are better techniques being employed to produce food (agriculture + animal husbandry?), then ensures the size of this requirement is lessened. Redundancy is of paramount importance, to ensure that there is sufficient capacity for growth beyond 1500 or for any catastrophe that happens to a specific ring. The actual spreadsheet can be used for agent-based modelling of these figures eventually.

Space use (based on up to 1500 persons 2020 estimates)	Surface area required, m2/person	No. of levels	Projected area, m2/person	Estimated height, m	Volume, m3	Volume, m3
Residential	49	4	18	3	221	330750
Business: Shops	2	2	2	4	14	20700
Business: Offices	1	3	1	4	6	9091
Public and semipublic: Schools	0	3	0	4	6	8550
Public and semipublic: Hospital	0	1	0	5	2	3375
Assembly (places of worship, community areas)	2	1	2	10	23	33750
Recreation and entertainment	1	1	2	3	5	6750
Public open space	10	1	15	50	750	1125000
Service industry	4	1	3	6	36	54000
Storage	5	4	2	3	5	7200
Transportation	12	1	18	6	108	162000
Mech. Subsystems (incl ECLSS and other subsystems)	10	4	16	4	256	384000
Communication distr. switching equipment for 300 families	0	1	0	4	0	450
Waste and water treatment and recycling	4	1	6	4	24	36000
Electrical supply and distribution	0	1	0	4	1	900
Miscellaneous	3	3	2	4	6	8550
Subtotals	103		70		1461	2191066
Agriculture space requirements: Plant growing areas	44	3	7	15	331	496125
Agriculture space requirements: Animal areas	5	3	1	15	38	57375
Agriculture space requirements: Food processing	4	3	1	15	29	43875
Agriculture space requirements: Agriculture drying area	8	3	1	15	61	91125
Factory and construction requirements: Manufacturing zones for spares, replenishment and storage of spares and panels etc. inc smelting and other zones.	2	2	2	10	23	67500
Aquatic space requirements: Aquaculture and Algae Farms	25	3	4	10	110	164250
Totals	88		86		2052	3111316



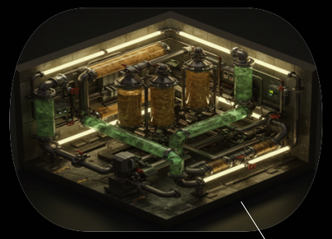




SS Proximum Torus Layout



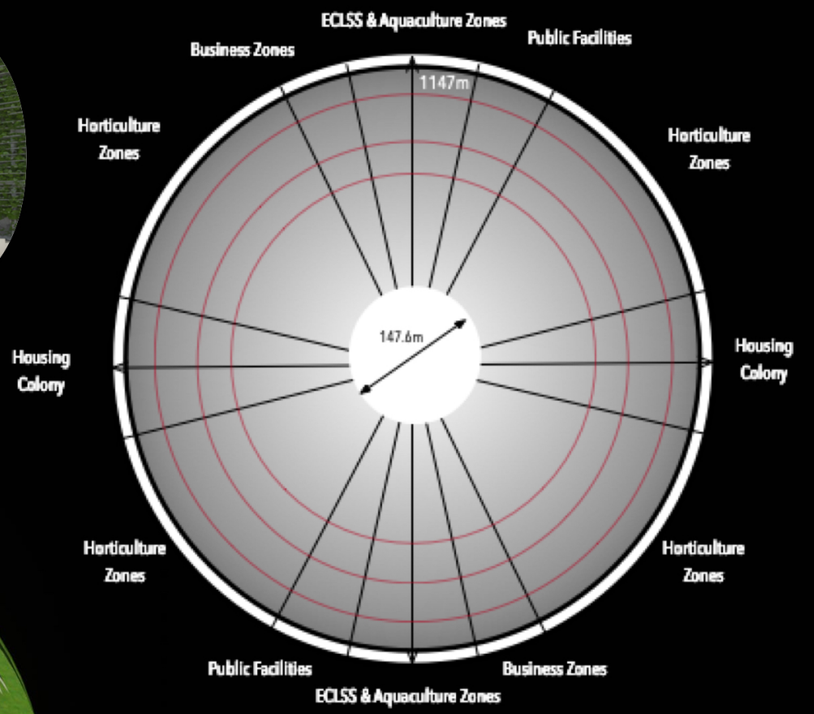
Agricultural Terraces



Sky Stadium

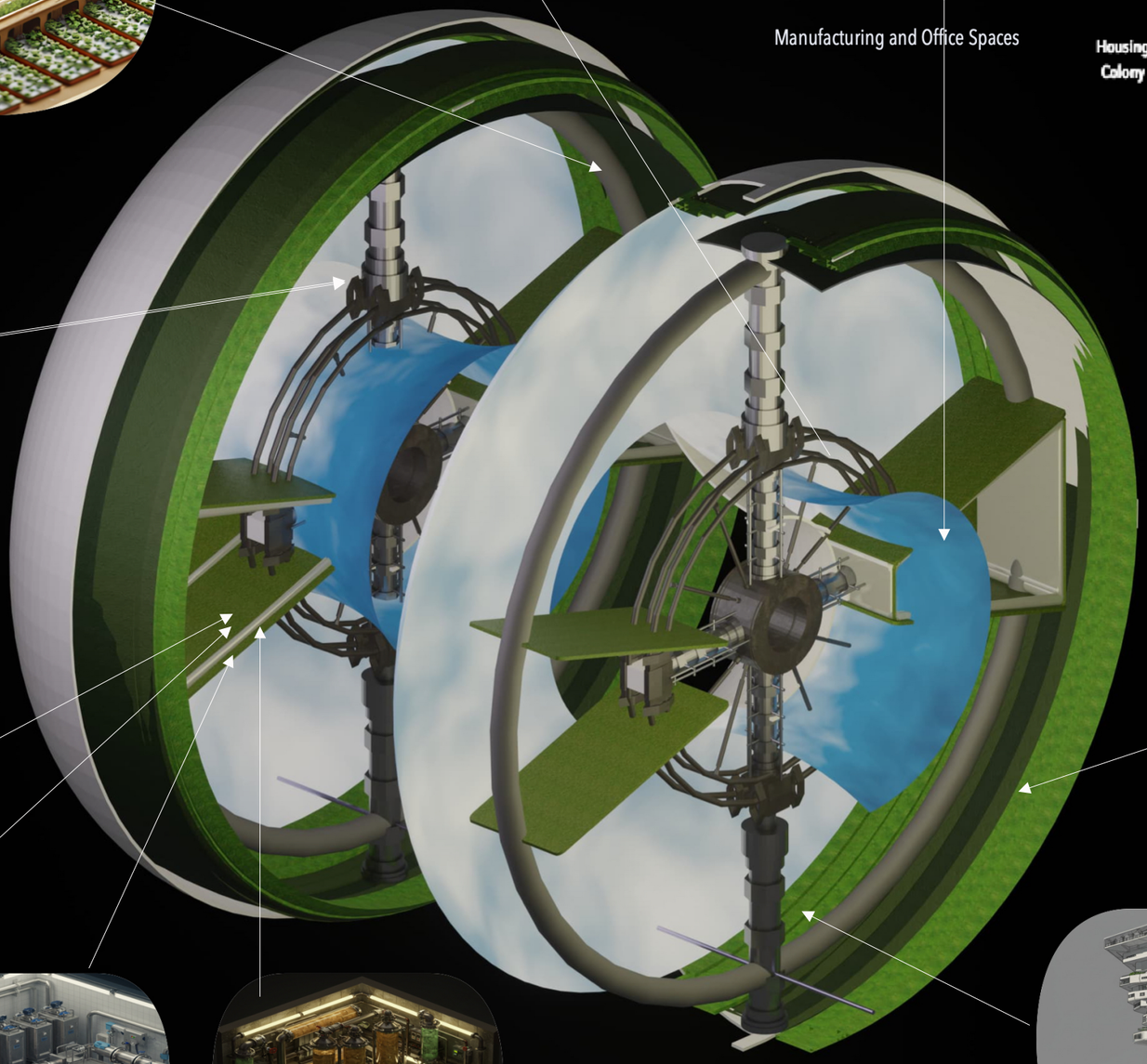


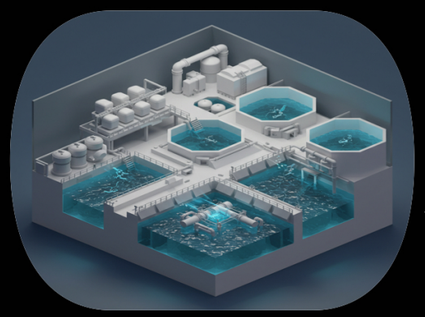
Manufacturing and Office Spaces



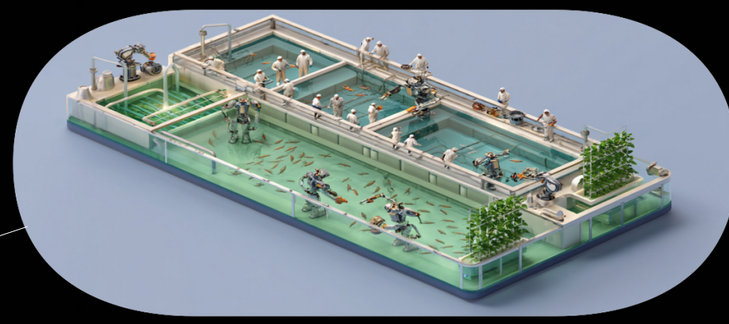


Manufacturing facilities

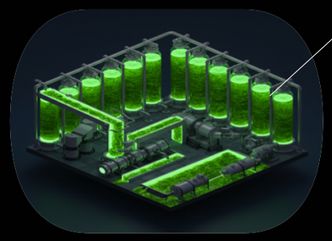




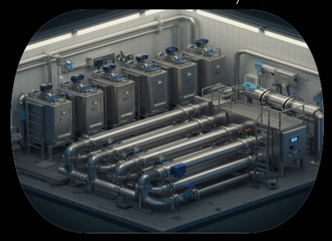
Kelp farms and Seawater Habitats



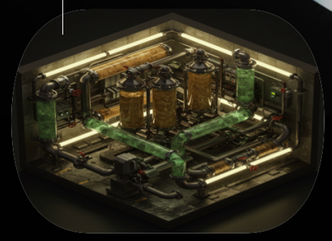
Freshwater Terrace Farm



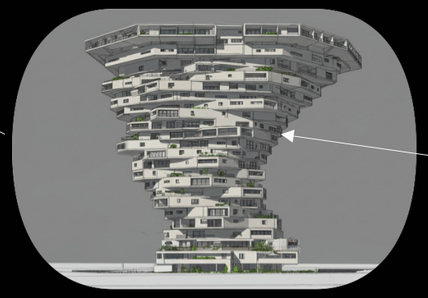
Algae Farms



Water Filtration Stations



Waste Water Treatment Stations



Human Habitats & Services Facilities



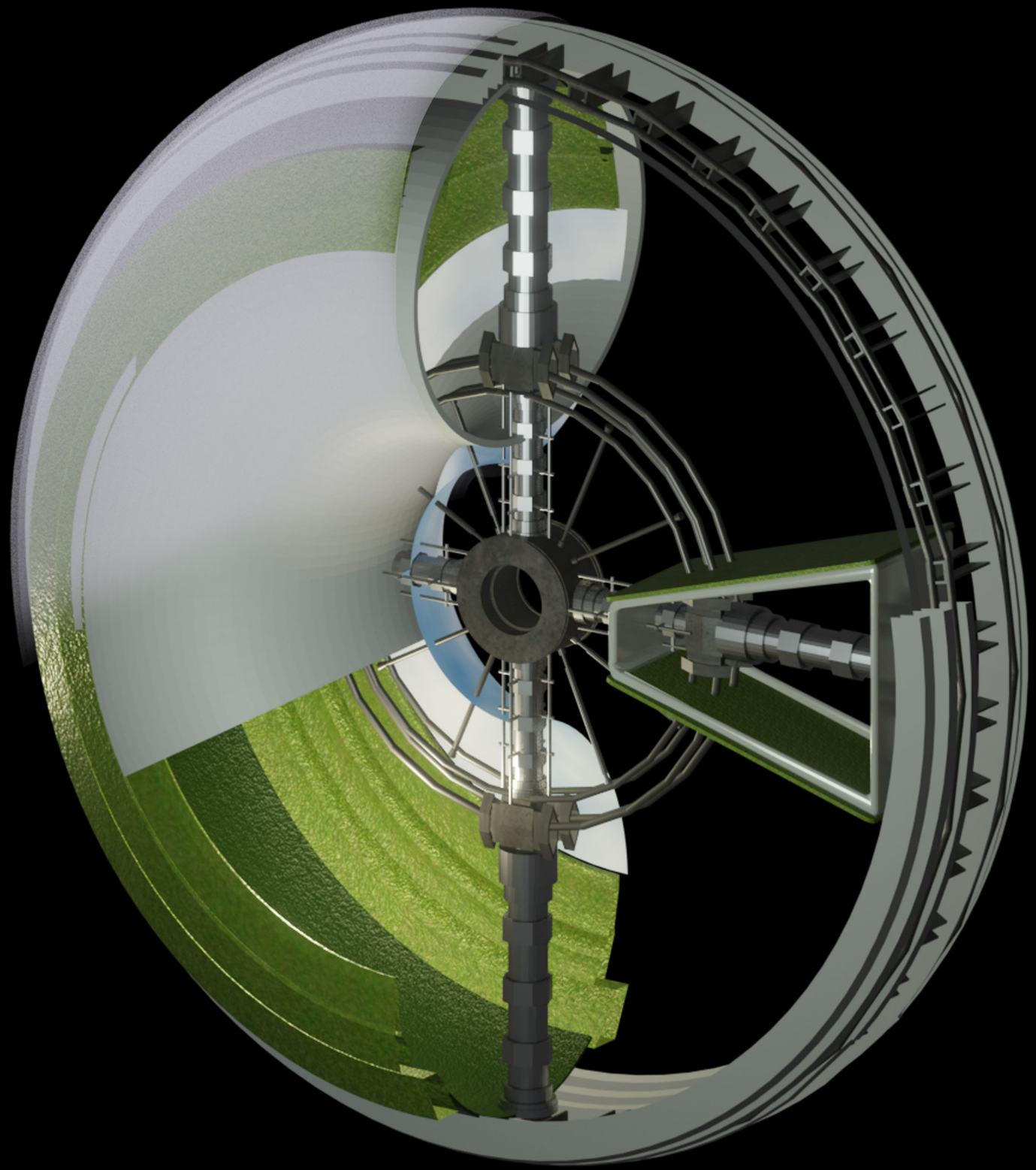
Single Human Habitat

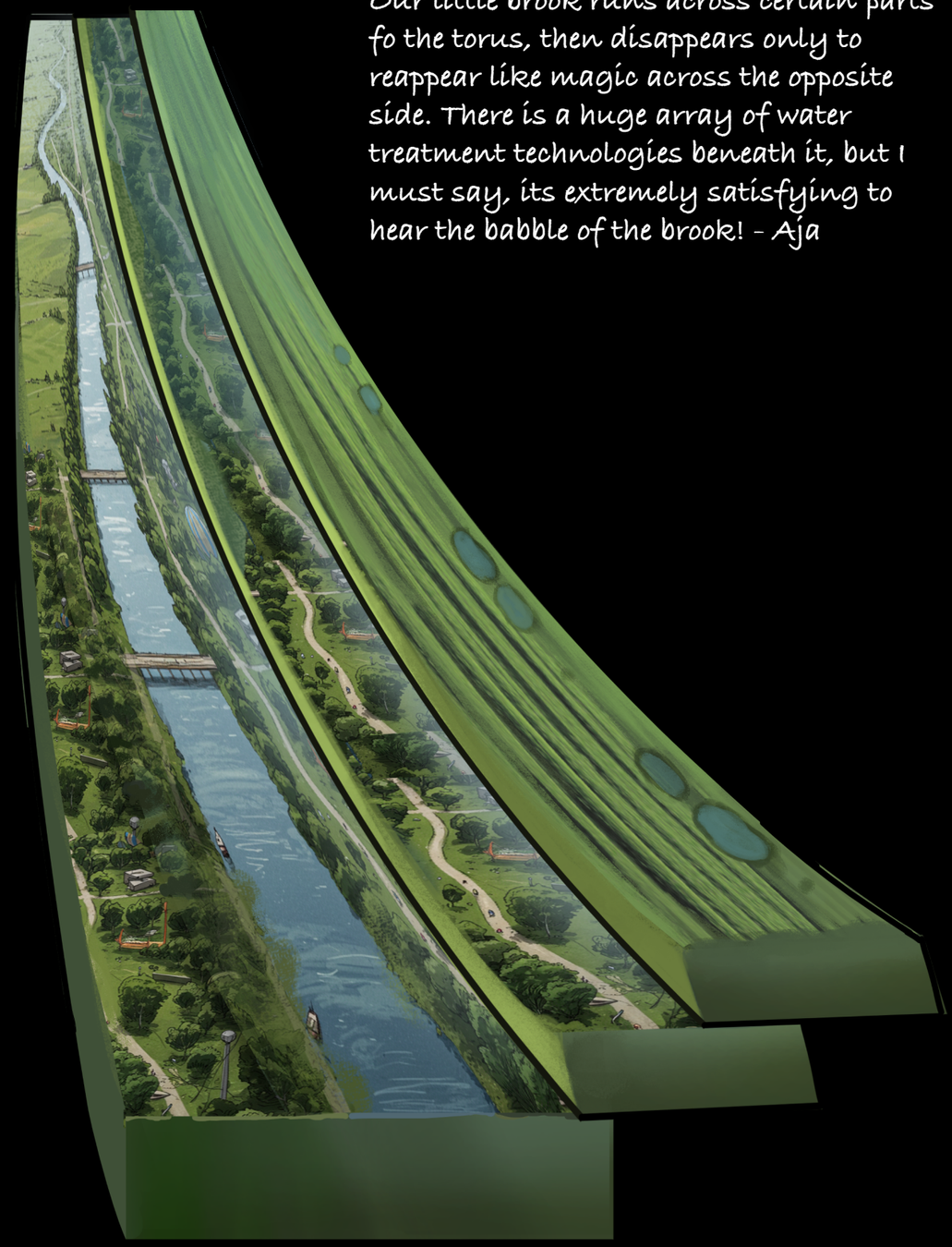
This is the layout of the various zones within the two Torii, which are in effect mirror images of each other, and are spinning in different directions. This decision was made to ensure that everything is duplicated at a macro level at the onset of the journey and is done in this matter to ensure that there is adequate protection against any catastrphic black swan event. There are counterweights to balance any effect of the movement of the torii, but in effect, they balance each other. The torii are kept rotating by frictionless hydraulics, and once in motion, they use limited energy to remain in motion.

SS Proximum Torus Landscape Layout and Design

By design, each Torus has significant similiarities in terms of layout and design, this is to ensure that redundancy and design aesthetics do not factor in the habitability of the individual torii.

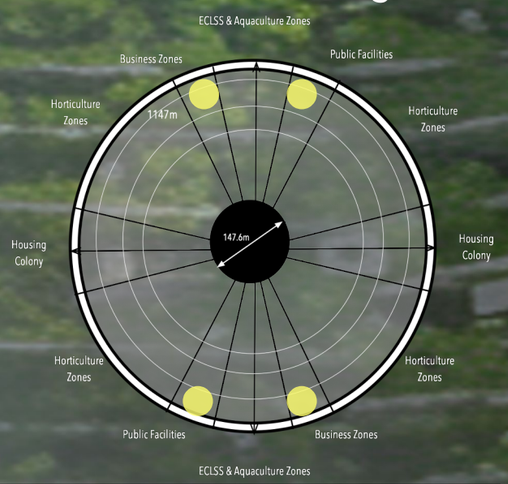
The following illustrations of the levels of the torus suggest the pastoral nature of the torus, which features a (extremely high-technology) stream running across parts of the the length of the torus, as well as vegetation.

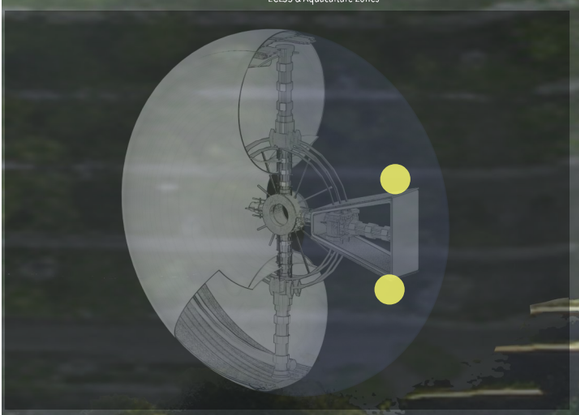




Our little brook runs across certain parts fo the torus, then disappears only to reappear like magic across the opposite side. There is a huge array of water treatment technologies beneath it, but I must say, its extremely satisfying to hear the babble of the brook! - Aja

Habitat – Communal Living ~ "We Are A Community"





This is an artistic impression of the office spaces, which shows how they are stacked as terraces on the side of the divider between the zones that support manufacturing, ECLSS and acquatic zones, from the Business and Public Facilities. While there are differences between how each of these terraces office spaces look like, the overall look is mostly similar, built to resemble a smoothly sloping side of a hill, and this also marks the termination point of the transportation hub (not visible in this picture). Behind the office buildings, the terraces gardens rises up majestically , and a variety of crop are grown here, using both conventional and hydropronic, aeroponic and other methods. The limit would be the gravitational forces at a higher level, but this design allows water to be drip-fed down to the plants and any terraced structure. This design is optimal for reducing stress and for maximum natural surroundings

The Propulsion System Overview

in theory, a combination of different propulsion technologies for various stages of the journey, along with redundancy in propulsion systems, is a viable strategy for interstellar missions. Here's how it could work:

Benefits of Using Multiple Propulsion Technologies

1. **Stage-Specific Optimization**:
    1. **Launch Phase**: High-thrust systems like nuclear thermal or chemical rockets could be used to escape Earth's gravity. However, if the starship is moving from La
    2. **Cruise Phase**: Once in space, more efficient systems like electric propulsion or solar sails could maintain acceleration over long durations.
2. **Redundancy and Reliability**:
    1. Having multiple propulsion systems can enhance mission reliability. If one system fails, others can take over, ensuring the spacecraft can still reach its destination.
3. **Energy Management**:
    1. Different systems can be activated based on available energy resources. For instance, solar sails could be used when close to the Sun, while nuclear or fusion systems could be employed in deeper space where solar energy is less effective.
4. **Flexibility in Acceleration**:
    1. Combining systems allows for tailored acceleration profiles, optimizing travel time and fuel efficiency based on mission requirements.

Possible Configuration

Phase	Propulsion Technology	Purpose
Launch	Chemical/Nuclear Thermal	High thrust to escape Earth's gravity.
Initial Cruise	Nuclear Pulse/Fusion	Rapid acceleration to significant speeds.
Mid-Cruise	Electric Propulsion	Continuous, efficient long-term thrust.
Final Approach	Solar Sails/Beam-Powered	Utilize solar energy or ground-based lasers for final adjustments.

Challenges to Consider

1. **Complexity**: Integrating multiple systems increases the complexity of design, control, and operation.
2. **Weight and Space**: Different propulsion systems may add weight and require additional space on the spacecraft.
3. **Coordination**: Effective management and coordination of multiple systems are crucial for mission success.
4. **Cost**: Developing and testing a hybrid propulsion system could significantly increase mission costs.

This is an artistic representation of the nuclear fusion reactor on board the starship (rendered with Midjourney)

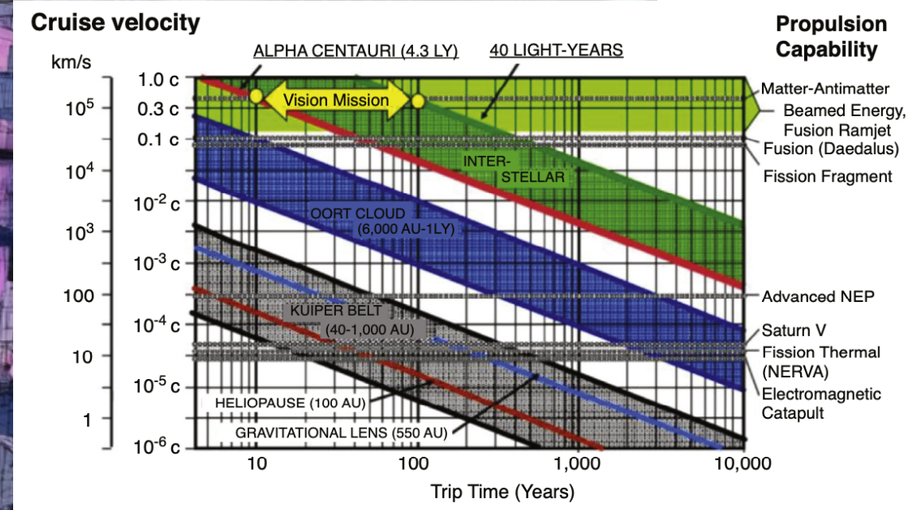


Fig. 3.9 *Mission velocity and trip time for various destinations with various propulsion systems (Frisbee and Leifer, 2022) (courtesy NASA).*

A past study recommended that if a spacecraft is traveling at a low fraction of the speed of light (0.1–0.3c), then the exoplanet must be no greater than 15 LY from Earth (50 year travel time ~20 years to send threshold data back to Earth). This allows someone to grow up and learn about the mission and then gather the data at an older age (Weinstein-Weiss, 2018). Another study estimated the trip times based on cruise velocities for various advanced propulsion systems shown in Fig. 3.9 (Frisbee and Leifer,1998). The primary propulsion options to accomplish interstellar missions in <50 years are antimatter propulsion, beamed energy propulsion, fusion propulsion, and the Bussard ramjet propulsion system.

The Power Budget – What is the most economical and safest way of powering the Starship

For a generation starship, using nuclear reactors for onboard power generation is generally more prudent due to the following reasons:

1. **Consistent Power Requirements**: The ship will have continuous power needs for life support, navigation, communication, and shielding, which a nuclear reactor can reliably provide.
2. **Safety Protocols**: While there are safety concerns with nuclear reactors, advanced designs and protocols can mitigate these risks. The stability and redundancy offered by a nuclear power system can enhance overall mission safety.
3. **Efficiency for Long Missions**: Given the long-duration nature of generation starships, the high energy density of nuclear reactors makes them more suitable for sustained operations compared to the variable power output of ion drives.

In summary, while ion drives are excellent for propulsion, relying on nuclear reactors for the spacecraft's primary power generation would provide a more stable and reliable energy source, essential for the complex needs of a generation starship.

Nuclear Fusion Reactors for Power Generation

- **Advantages**:
  - **Consistent Power Supply**: Provides a stable and high level of power, suitable for all onboard systems, including life support, propulsion, and shielding.
  - **Long Operational Life**: Capable of running for extended periods without the need for refuelling, ideal for generation starships.
- **Disadvantages**:
  - **Safety Concerns**: Increased risk of radiation exposure and potential for catastrophic failure; requires robust safety measures and shielding.
  - **Complexity and Weight**: Heavier and more complex to design, requiring extensive safety systems and maintenance protocols.

Multiple fusion micro-reactors are generally the better option for a generation starship due to their redundancy, scalability, and safety advantages. The modular approach allows for operational flexibility and easier maintenance while minimizing the risks associated with large reactors. Although managing multiple units adds complexity, the benefits in reliability and safety make micro-reactors a more prudent choice for long-duration space missions.

Parameter	Details
Target Application	Ship Operational Power (Life Support, Internal Systems, Food Production, Active Shielding - distinct from primary propulsion)
Total Continuous Power Requirement (Design Target)	~50 MW (Megawatts) - Scalable design for 25-75 MW range based on final configuration
Power Output per Mini-Reactor	5-10 MW (Megawatts)
Number of Primary Mini-Reactors	8-12 units (Provides N+2 to N+3 redundancy for the ~50 MW target operational load)
Total Installed Power Output (Reactor Battery)	60-80 MW (Megawatts) (Ensures ample margin for peak loads, system degradation, and robust redundancy)
Operational Lifetime	250+ years (Designed for continuous operation with scheduled, automated component refurbishment/replacement cycles)
Total Energy Generated (Example @50MW avg.)	Approx. 109,500 GWh (Calculated for 50MW average continuous draw over 250 years; actual fuel consumption based on load)
Dimensions per Mini-Reactor (Core Unit)	~2-3 meters diameter x ~3-5 meters height (Compact design, excluding some auxiliary support systems)
Total Dimensions (Illustrative Reactor Battery Array)	Modular bay configuration (e.g., two physically separated arrays of 4-6 reactors each; an array might occupy approx. 10m x 10m x 5m for serviceability)
Preferred Fuel Type	Deuterium-Helium-3 (D-He3) or advanced Catalyzed Deuterium-Deuterium (D-D) (Prioritizes aneutronic reactions to minimize neutron flux and enable high-efficiency direct conversion)
Shielding Material	Layered advanced composite (e.g., Boron-doped Tungsten, specialized polymers, localized neutron moderators/absorbers if any D-D side reactions produce significant neutrons)
Shielding Thickness (Around each mini-reactor)	~0.25-0.5 meters (Significantly reduced mass and complexity compared to D-T systems due to predominantly aneutronic reactions)
Cooling System	Advanced high-temperature, lightweight space radiators (e.g., liquid droplet radiators, deployable carbon-carbon panels); internal reactor cooling systems integrated with energy conversion pathways
Energy Conversion Method	Primary: High-efficiency direct energy conversion (for charged fusion products, targeting >70-90% efficiency); Supplemental: Advanced thermal cycle for any remaining heat (e.g., high-temperature Brayton cycle)
Control System	Distributed Quantum-Capable AI Network (Utilizing hierarchical redundancy, predictive maintenance algorithms, rapid autonomous fault detection, isolation, and response capabilities across the entire power grid)
Waste Management	Benign Helium-4 (primary fusion product). Minimized structural material activation due to aneutronic fuel choice. Focus on onboard facilities for recycling/reprocessing of limited-life reactor components.
Key Design Principles	Extreme Reliability (via Redundancy, Modularity, Robustness), Minimized Neutron Burden (for safety, mass reduction, longevity), High Overall System Efficiency, Full Automation of Maintenance & Repair (In-Situ), Sustained Multi-Century Longevity

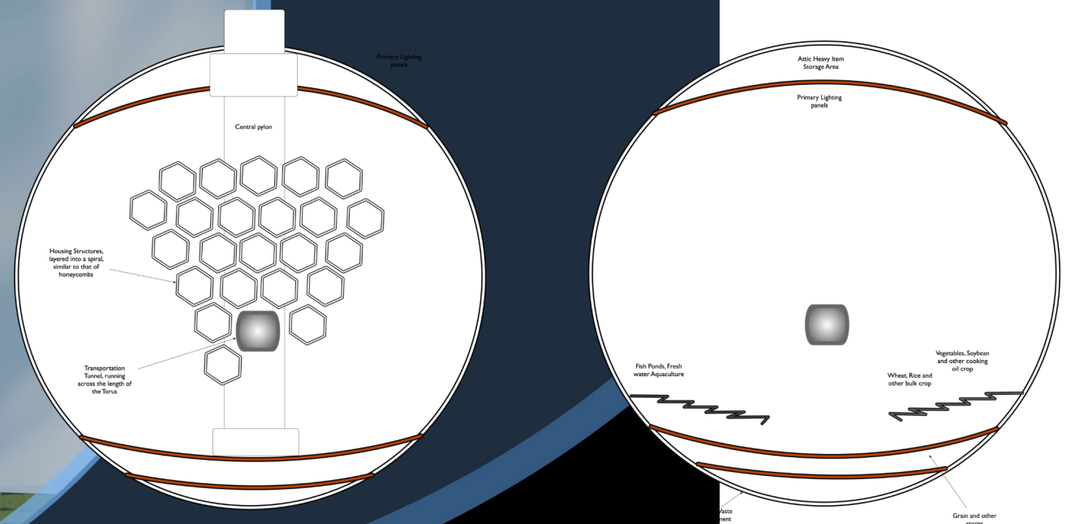
Starship Power Budget Table (250-Year Journey)					
Power System / Load Category	Basis of Calculation (Per Capita / Fixed / %)	Assumed Value	Number of Units / Persons	Subtotal Power (MW)	**Notes / Detailed Assumptions**
1. ACTIVE POPULATION SYSTEMS (1500 Persons)					
a. Core Life Support (ECLSS)	Per Capita (Active)	1.0 kW/person	1500	1.2 – 1.8	**Atmosphere revitalization, water processing & recycling, waste management (e.g., plasma gasification), basic thermal control for habitable areas. Likely to become even more efficient with bio-integrated systems, nanotech filtration, and closed-loop efficiencies approaching 99.99%. However, adding buffer capacity for off-nominal events or temporary population peaks might be wise. Consider: Slight increase for robustness or maintain efficiency for larger potential active pop.**
b. Personal Living Needs	Per Capita (Active)	1.0 kW/person	1500	1.0 – 1.5	**Individual quarters lighting, personal devices, food preparation/rehydration, localized climate control, hygiene systems. Could decrease with ultra-efficient personal tech, ambient computing, and integrated environmental controls. Or, it could increase if personal fabrication, VR immersion, and advanced personal climate control become more demanding. Let's assume a slight net efficiency gain**
c. Communal Systems & Amenities	Per Capita (Active)	1.5 kW/person	1500	2.25 – 3.5	**General lighting in communal areas, main computing/AI infrastructure (shared), internal transport (lifts), recreation facilities (VR, advanced simulation), educational systems. AI-driven systems, advanced holographic interfaces, and large-scale simulation environments (for training, research, or recreation) could be power-hungry. However, efficiency gains in computation and display tech will also be significant. I'd lean towards this being a bit higher for a truly advanced society.**
d. Food Production (for Active Pop.)	Per Capita (Active)	3.0 kW/person	1500	2.5 – 4.5	**High-intensity full-spectrum LED grow lights, hydroponics/aeroponics pumps & controllers, climate control for agricultural bays, food processing & packaging, potential lab-grown food.**
e. Advanced Ship Functions (Active Pop. Share)	Per Capita (Active)	0.5 kW/person	1500	0.75	**Onboard manufacturing/3D printing, scientific laboratories, advanced medical facilities, repair workshops. For a "huge scale" ship, onboard manufacturing will be critical - not just 3D printing spares, but potentially refining raw materials (if harvested) and fabricating complex systems. This could be much higher, especially during periods of intense industrial activity. This needs a "baseline" and a "peak industrial operations" mode.**
Subtotal for Active Population Direct Needs		7.0 kW/person	1500	8.2 – 13.3	
2. HIBERNATING POPULATION SYSTEMS (1781 Persons)					
a. Hibernation Pod Maintenance	Per Capita (Hibernating)	0.2 kW/person	1781	0.25 – 0.36	**Power for stasis field/cryo-cooling, continuous vital signs monitoring, minimal metabolic support. Further reductions would require breakthroughs in understanding and manipulating biology at a quantum level. Let's assume this is near an irreducible minimum for safety and monitoring. Could go slightly lower with extreme tech, but risk increases.**
Subtotal for Hibernating Population				0.25 – 0.36	
3. SHIP-WIDE SYSTEMS					
a. Active Radiation Shielding	Fixed Ship Load	5.0 MW	1 (Ship)	5 – 15.0	**Highly speculative. Assumes a powerful magnetic or plasma shield continuously operating to protect against galactic cosmic rays and solar particle events (if near a star). This is a major uncertainty and R&D driver.**
b. General Ship Operations	Fixed Ship Load	3.0 MW	1 (Ship)	4.0 – 8.0	**Primary command & control, navigation, long-range sensors, external maintenance robotics infrastructure, main ship AI core, structural integrity systems (if applicable).**
Subtotal Ship-Wide Systems				8	
TOTAL OPERATIONAL POWER (1+2+3)				9.0 – 23.0	**Sum of all direct loads.**
4. POWER SYSTEM & DISTRIBUTION					
a. Inefficiencies & Distribution Losses	% of Total Operational Power	15%	N/A	0.87 – 3.67	**Heat loss in power generation, conversion, and distribution throughout the ship. With advanced superconductors for main power buses and highly efficient conversion electronics, this could be reduced. However, some thermal losses are unavoidable. I'd aim for 10% or even 5% in an ideal future.**
GRAND TOTAL POWER GENERATION REQUIRED				**~18.3 – 40.3 MW**	**This is the total continuous power output the ship's reactors must provide.**

Assumptions:

1. The Stanford Torus study (1975) suggested a per capita demand for power to be around 3 kW/person, which is a useful benchmark.
2. Complete System Reliance: Everything is electric. No combustion for heating, cooking, etc.
3. Advanced Life Support (ECLSS): While more efficient, 100% closed-loop systems for air, water, and waste are energy-intensive. Think advanced plasma gasification for waste, complex atmospheric scrubbers, and total water reclamation
4. High-intensity, full-spectrum LED grow lights for all plant-based food are a massive energy consumer.
5. As such, the Skylight (full-panel LED lights will not serve as grow-lights. Instead there will be dedicated grow-lights, focused on plant- and algae farms, and these skylight LED panels will be primarily for simulation of outdoor settings, and therefore not necessarily full-spectrum and without the overheads of high-intensity
6. Energy will also be used for the establishment of Controlled Environments: Precise temperature, humidity, and atmospheric control for agriculture
7. Advanced Food Processing/Synthesis: If lab-grown meat, algae bioreactors, or other synthesized food components are used, these can be very energy-intensive. The movement of water is principally optimised to work with gravity, however, there are pumps and other systems operating to move processed water upwards, while potable water flows downwards, from the centre. This reduces the dependence on pumps for irrigation, relying more on drip feeds
8. Computing and AI: Ship-wide AI, personal devices, complex simulations for research, training, and entertainment (e.g., advanced VR/AR, "holodecks") will demand significant power.
9. Robotics and Automation: Extensive use of robotics for maintenance, manufacturing, agriculture, and services.
10. Manufacturing and Repair: Onboard facilities for 3D printing parts, repairing equipment, and potentially some light manufacturing from recycled or stored raw materials.
11. Medical Facilities: Advanced medical diagnostics and treatment capabilities, potentially including energy-intensive equipment.
12. Active Radiation Shielding: For true interstellar travel, passive shielding might be impractically massive. Active shielding (e.g., generating a powerful magnetic field) could be a very significant continuous power draw for the front of the asteroid, and this might be active or passive at times, depending on the need. The starship would have advanced scanners capable of detecting small particles of floating debris and possibly able to discerne when active shielding is required
13. Internal Transportation: Lifts, and potentially small internal transit systems within a large vessel.
14. Enhanced Comfort and Amenities: Expectations for living standards might be higher, including more personalized environmental controls, larger private spaces with more powered amenities, etc.
15. One serious consideration is the use of power for maintenance of the hibernation and life-support modules that are used to keep around 1780+ of final population in hibernation (we have to assume that the technologies and power requirements to sustain such an endeavour, to keep a hibernating population in hibernation till they make landfall between 250 to 300 years into the future have been perfected by then. As such, once we have moved these persons out of hibernation, and factored in the power and resource requirements over those number of years before the leave the starship, then we have to accommodate between 3200 to 3500 persons, after landfall.

Torus Cross-section Design

A 2D line art sketch of the cut section of the torus that demonstrates it in perspective



A 2D line art logical diagram of the cut section of the torus that demonstrates its overall dimensions, as well as demonstrating the central pillar and how it accommodates for a toroid wide transportation system'; separately, it also incorporates the design of the crop and freshwater aquaculture terraces

The figure on the left shows a view of the agricultural terraces where crops and vegetables are grown on different layers. The floor of the torus is curved, providing a good number of walkways and certain areas are levelled as well. There is a brook that runs the distance of the

The facilities are based on the Stanford Torus design and would be defined by the horticulture standards of the day, when the starship is set to launch.

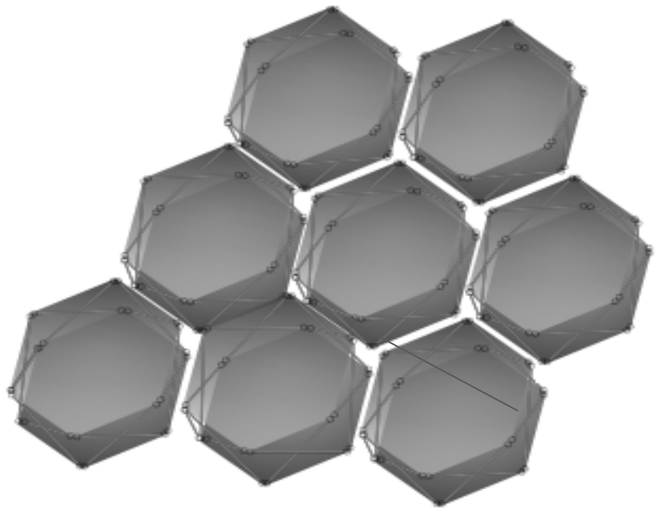
Effectively, all layouts should share a sense of familiarity with the inhabitants' original space station, so they have a sense of familiarity and instant connection with their new home.

The Torus Shielding

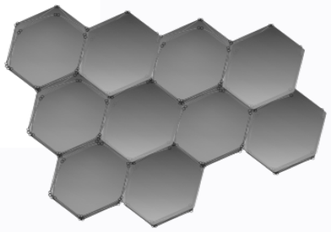
The SS Proximum has been designed to rely on the hollowed-out asteroid for the bulk mass shielding. However, this shielding primarily protects the ship against micrometeoroids and does not fully protect the ship against the more concerning cosmic rays. That would be the job of the Torus shielding that makes up the shells of the 2 torii.

The design for the Torus shielding is based on placoid denticle-like panels that are hexagon-shaped panels (to the skin of sharks, another example of biomimicry in action), as they are more organic by nature and fit better than other shapes, as they oppose easily and can be overlapped with fewer gaps, to form hexagrids.

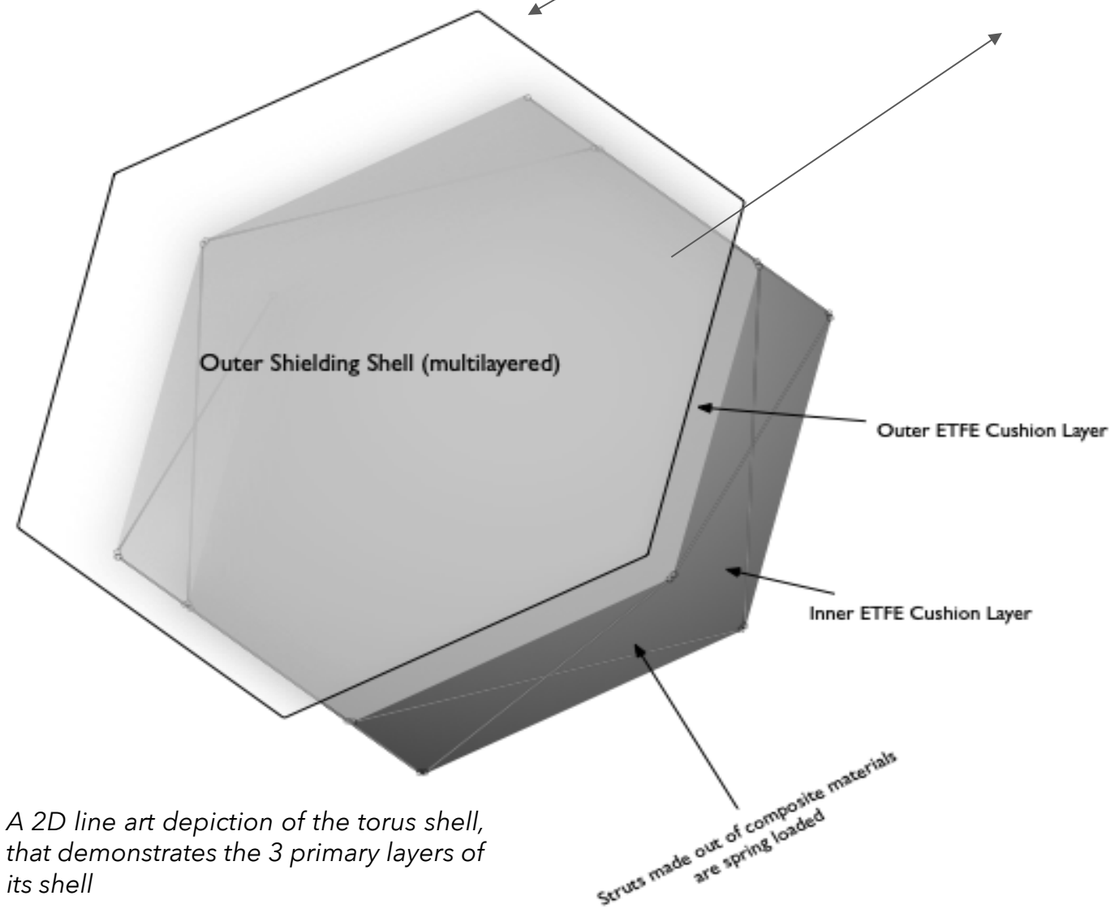
This multilayer design works in tandem with other shielding design decisions, like the use of the asteroid protection and certain individual elements are multilayered by design as well. It provides a high level of cushioning and radiation protection, distributing any impact over a large surface area while exponentially reducing the effects of cosmic rays, that may deflect through the asteroid layer



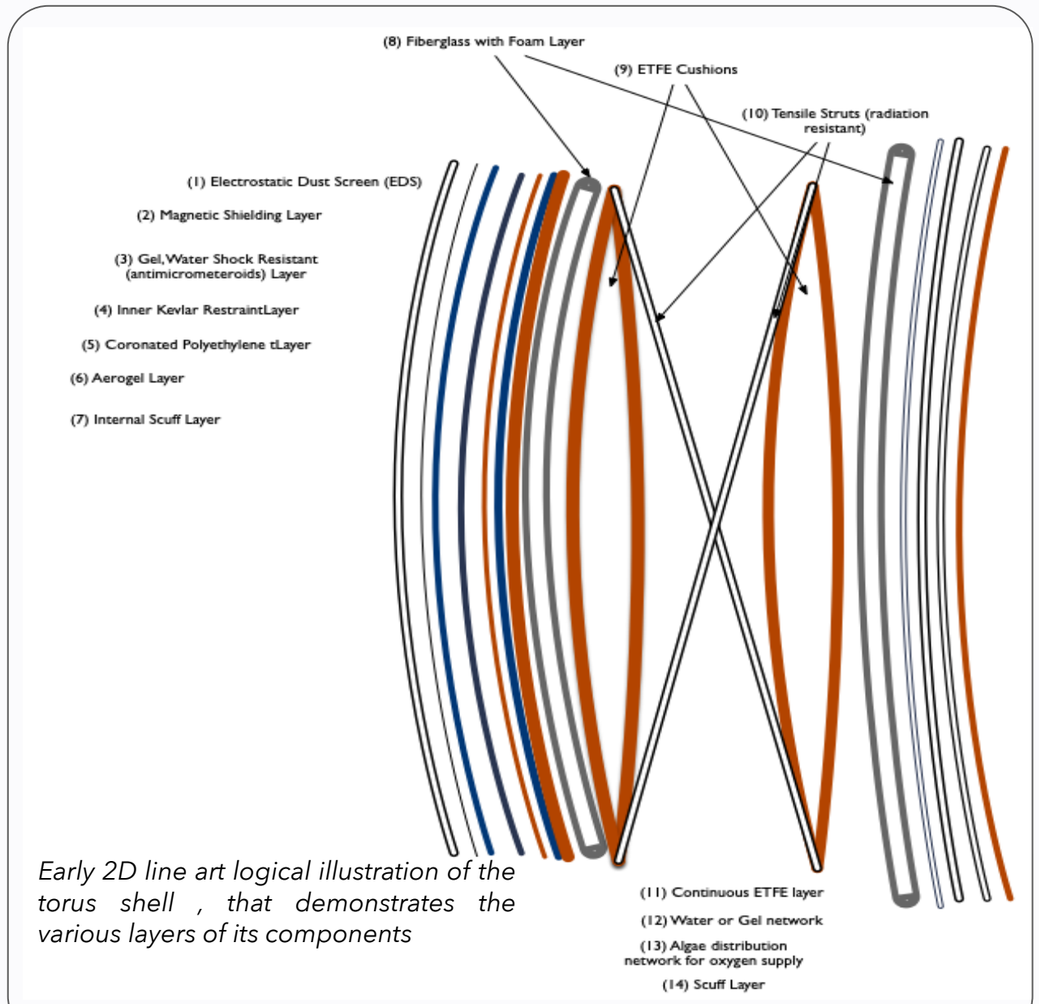
The panels are all overlapping, similar to the placoid denticles on shark skin - this is an example of biomimicry that makes sense creating a turbulent boundary layer forcing the laminar flow farther away from the sharks skin.



// Architectural detail drawing on the scale of 1/20 from a part of the project that best describes the design and material choices – this should go into the A0 poster

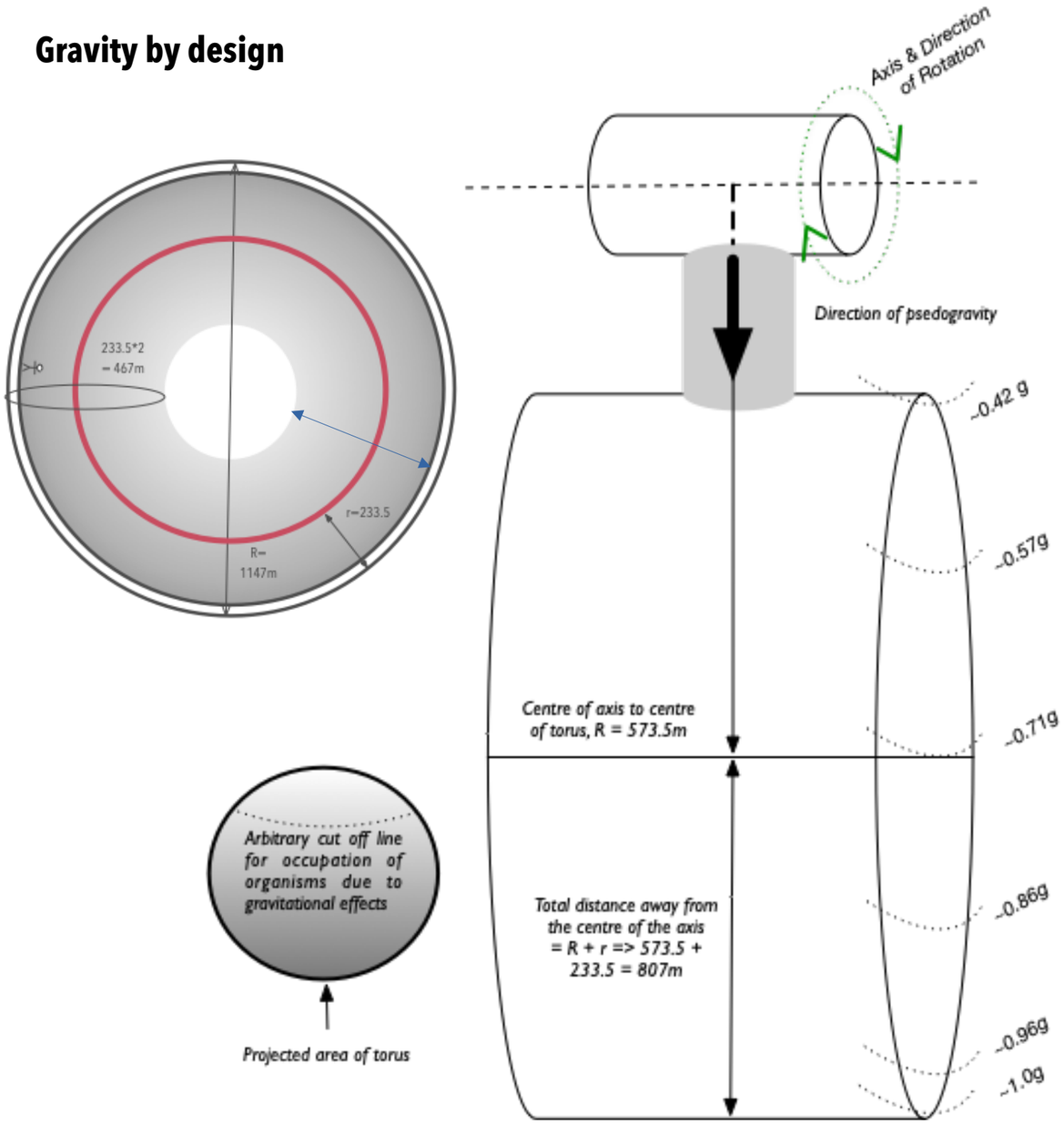


A 2D line art depiction of the torus shell, that demonstrates the 3 primary layers of its shell



Early 2D line art logical illustration of the torus shell , that demonstrates the various layers of its components

Gravity by design



A 2D line art logical diagram of the forced isometric cross-section of the torus that demonstrates the overall effects of the Coriolis forces and the gravity of different levels within the torus, which would then by design determine the manner in which the technical and manufacturing levels will be on the higher floors of construction (effectively manned by the cobots, where humans will benefit in some respect from the lower gravity), while all living quarters would be closer to the ground

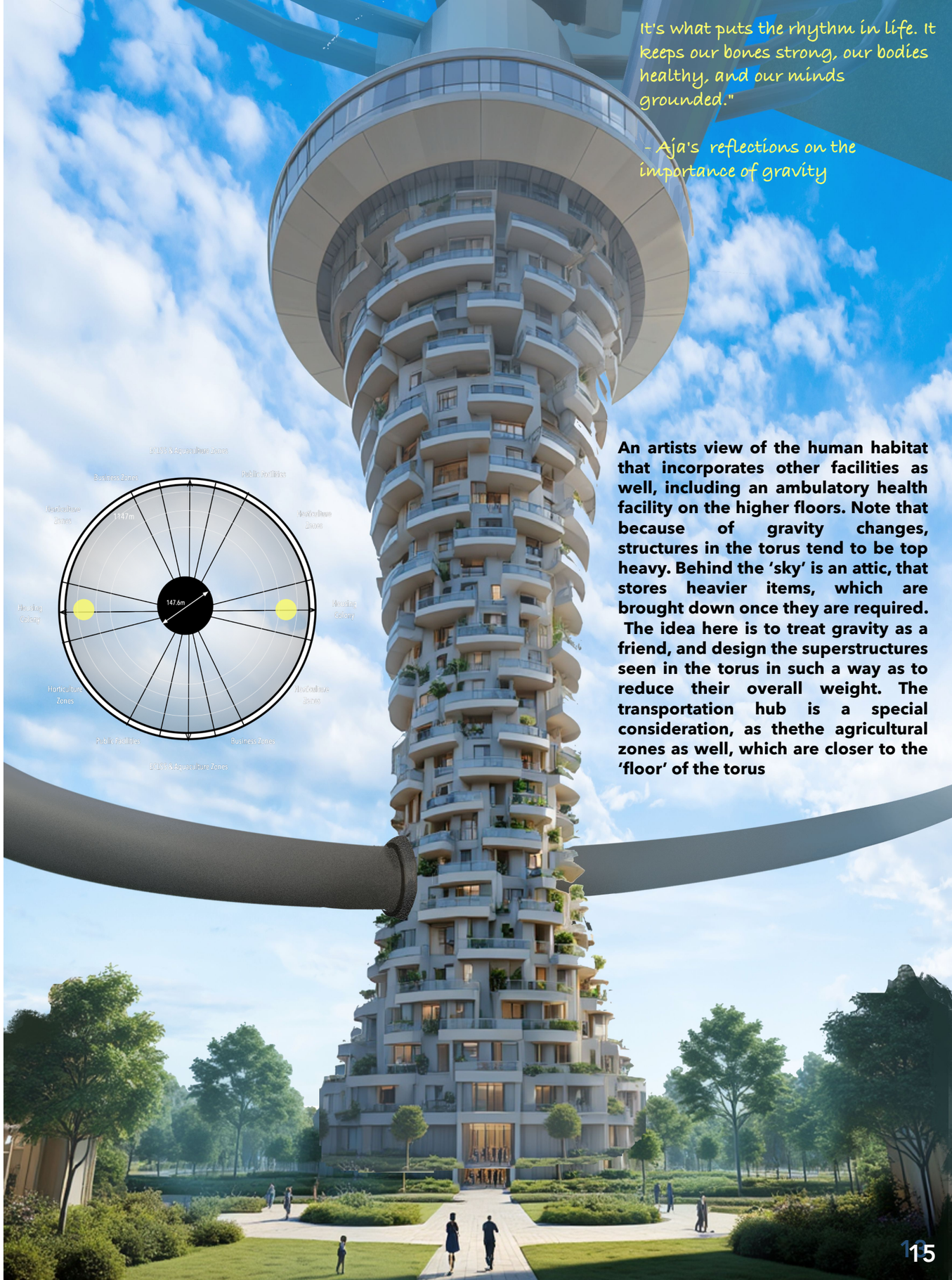
Gravity Gradient Table (R=573.5m, r=233.5m)

Location	Distance from Rotation Center (ρ)	Gravity (m/s²)	Gravity (G)
Floor (Outermost)	807.00 m	9.81	1.00 G
Approx. 3/4 Height Up	690.25 m	8.39	0.86 G
Mid-Level (Center of Tube)	573.50 m	6.97	0.71 G
Approx. 1/4 Height Up	456.75 m	5.55	0.57 G
Ceiling (Innermost)	340.00 m	4.13	0.42 G

(Assuming rotation set for 1.00 G at the floor. g = 9.81 m/s²)

It's what puts the rhythm in life. It keeps our bones strong, our bodies healthy, and our minds grounded."

- Aja's reflections on the importance of gravity



An artists view of the human habitat that incorporates other facilities as well, including an ambulatory health facility on the higher floors. Note that because of gravity changes, structures in the torus tend to be top heavy. Behind the 'sky' is an attic, that stores heavier items, which are brought down once they are required.

The idea here is to treat gravity as a friend, and design the superstructures seen in the torus in such a way as to reduce their overall weight. The transportation hub is a special consideration, as thethe agricultural zones as well, which are closer to the 'floor' of the torus

The ECLSS

PROJECT CONSTRAINS (based on Jones HW, 2020 "Minimum Risk Deep Space Habitat and Life Support"ICES)

RELEVANT (IMMUTABLE) CONSTRAINS

1. Physical Laws of the Universe, - regarding energy, mass and thermodynamics - must be obeyed. Future quantum technologies may be added, but cannot be relied upon until such times that they are fully tried and tested.

2. The generation starship must support of travel to another star system with a crew of 1000 +/- 500 over a period of 250 years, and it is not a Methuselah ship or purely an Ark or a Sleeper ship. Humans are not to be genetically modified for the journey, in spite of exposure to cosmic rays beyond the heliosphere.

3. The ship is a closed, pressurised, fully shielded spacecraft with artifical gravity (produced via ~2rpm, in keeping with physiological Earth limits), maximising health, comfort and safety of resources. All materials and systems must be repairable and as such, complexity has to be reduced to a minimum, with solvable technological problems. This is the secondary axiom.

4. Distance traversed is relatively fixed by the destination - until the discovery of some kind of wormhole paradox, the distance to the nearest star is at least 264K AU and the ship should be able to travel that distance.

5. Each and every system has to be redundant and must prioritise the safety of the organic life forms carried on board. There is no Plan B, and no turning back once the craft crosses a certain threshold. This is a primary axiom

BOUNDARY (?MUTABLE) CONSTRAINS

1. **The habitat(s) must provide 1g-gravity** by rotation and **provide adequate shielding from cosmic rays, for the duration of the journey.**

2. **Amount of risk is within acceptable limits - minimal risk calculation is a boundary condition, and the technology that is commissioned is bound by this**

3. Amount of water, food and stored resources must meet the criteria for at least the first 5 decades and more can be generated in transit, while the pathfinder probes are potentially identifying new sources. Waste and other items can be treated throughout via the ECLSS system(s), to ensure that there is no absolute need for replenishment, where possible.

4. The human habitat must include adequate space, facilities, and equipment for mission work, operations and maintenance, exercise, medical treatment, food storage, preparation and dining, and sleep. This being a generation ship, the expectation is that humans are allowed to procreate and their progeny will continue the process onboard for the duration of the journey.

5. Degree of Integration with ISRU Operations - the assumption is that the ISRU system will become more efficient over time, with better ways of recycling

FUCTIONAL REQUIREMENTS OF THE ECLSS (based on Jones HW, 2020 "Minimum Risk Deep Space Habitat and Life Support"ICES)

The ECLSS must support the following as redundantly as possible:

1. **Atmosphere Control:**
   - Maintain breathable atmosphere with correct O2/N2 ratio. The atmosphere should be regenerable
   - Remove CO2, trace contaminants, and particulates. The system relies on both mechano-chemical and natural systems.
   - Control temperature and humidity within habitable ranges, via mechanical and natural processes.
   - Isolate and mitigate hazardous gases.
2. **Water Management:**
   - Provide potable water for human consumption; potentially this can be replenished in deep space, but water would likely have to be recycled many times over.
   - Recycle grey water and process black water. The systems rely on mechano-chemical and bioreactor based processes
   - Manage humidity condensate. The onus is on using biomimicry technologies for the same.
   - Minimize water loss, using mechano-chemical and biomimicry based technologies
3. **Waste Management:**
   - Collect and isolate all biowastes (excrement, food scraps, shed skin cells, packaging, etc.).
   - Convert wastes into usable resources (nutrients, water, building materials).
   - Minimize the creation of non-recyclable waste. As far as possible, all material should be manufacturable on-board the craft.
   - Manage the disposal of hazardous waste materials.
4. **Food Production:**
   - Provide sufficient calories with diverse nutritional profiles.
   - Replenish vital plant life with nutrients.
   - Create food stocks for emergencies. All food stock will be manufactured throughout the journey and stored, so there is no JIT production necessary. Everything is planned for every eventuality, so redundancy is key here.
5. **Food Safety**: This is the key to establishing trust in a spaceship, to assure security and longevity.
6. ****Internal Climate and Environment**
- **Thermal Design and Control:****
7. **Radiation Shielding Requirements**
   - Manage heat transfer, prevent extremes of temperature.
   - Maintain air pressure.
   - Monitor and regulate internal lighting and temperature.
   - Provide effective shielding from cosmic radiation and solar solar events.
8. **Fire and other hazard management requirements**

ECLSS TECHNOLOGIES

The ECLSS will be based on the following technologies that support as redundantly as possible:

1. **Atmosphere Control:** Besides stored gases, microbial Gas Production and Fermentation, Engineered Bioreactors, bioengineered microbe and plants known to survive in space. More reliance on aquatic species (algae and kelp) for the production of atmospheric elements that preserve life.
2. **Water Management:** Sequential Anoxic and Anaerobic Bioreactor, Bio inspired 3-d membranes, algae that process and make clean drinkable water.
3. **Waste Management:** Mechanical and other filters, Bioreactor, 3D printing that uses water and bacteria. Mycoagriculture.
4. **Food Production:** closed-loop permaculture, aquaponics, aeroponics, bioreactor-based technologies, mycoagriculture
5. **Internal Climate and Environment:** Mechanical water conservation technologies, biomimetic technologies
6. **Thermal Design and Control**
7. **Radiation Shielding Requirements:** Besides the protection provided by the hollowed-out asteroid, the other technologies include layered shielding, including water, hydrogen rich gels or lithium hydroxide, electromagnetic shielding (for the front of the craft to create a kind of magnetosphere); extensive use of graphene and nano materials (based on the assumption that costs for these materials will plummet to a point that it is negligible in the future
8. **Fire and other hazard management requirements:** primarily for the living habitats, localised to specific areas

ISSM = mHabitat + mResource Infrastructure + mAutomation/AI + mRedundancy + (ISurvival * tmission) + (IEvolution * tmission)

ISSM: Interstellar Equivalent Sustained System Mass (Units: kg).
- This is the overall mass "cost" of the mission, considering sustained operation over vast timescales.

mHabitat: Habitat Mass (Units: kg).
- This is the dry mass of the torus structure itself, including radiation shielding, life support systems (ECLSS), manufacturing facilities, agricultural areas, crew habitation/recreation areas, data storage centers, and initial consumables.

mResource Infrastructure: Resource Infrastructure Mass (Units: kg).
- This includes mass of equipment for identifying, mining, processing (refining), and storing resources (interstellar medium particles, captured asteroids/comets, even stellar remnants). This encompasses complex automation, robots, and any processing facilities.
- The energy infrastructure required to power resource extraction (fusion reactors & shielding, power distribution networks).

mAutomation/AI: Automation/AI Mass (Units: kg).
- Mass of all automated systems, advanced robotics, AI processing cores, sensors, and the data networks linking these systems. This isn't just about "running" the ship but managing all life cycle systems, performing repairs, proactively detecting failures, optimizing resource usage, and managing ecosystem stability.

mRedundancy: Redundancy Mass (Units: kg).
- Mass of duplicate or backup systems for every critical function (life support, power, manufacturing, AI, etc.). This includes spares, manufacturing facilities capable of replicating key components, and self-repair robotics. Redundancy design may rely on modular, scalable or fractal implementations.

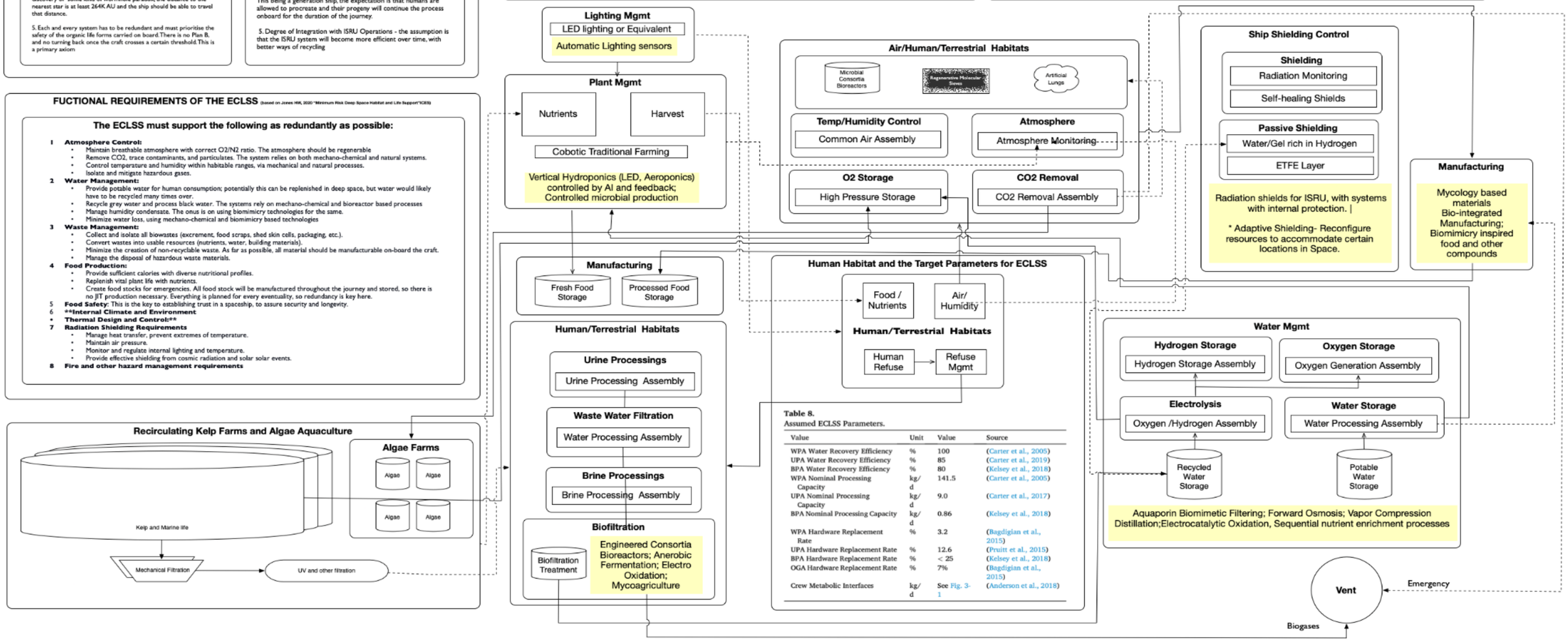


Table 8.
Assumed ECLSS Parameters.

Value	Unit	Value	Source
WPA Water Recovery Efficiency	%	100	(Carter et al., 2005)
UPA Water Recovery Efficiency	%	85	(Carter et al., 2019)
BPA Water Recovery Efficiency	%	80	(Kelsey et al., 2018)
WPA Nominal Processing Capacity	kg/d	141.5	(Carter et al., 2005)
UPA Nominal Processing Capacity	kg/d	9.0	(Carter et al., 2017)
BPA Nominal Processing Capacity	kg/d	0.86	(Kelsey et al., 2018)
WPA Hardware Replacement Rate	%	3.2	(Bagdigian et al., 2015)
UPA Hardware Replacement Rate	%	12.6	(Pruitt et al., 2015)
BPA Hardware Replacement Rate	%	< 25	(Kelsey et al., 2018)
OGA Hardware Replacement Rate	%	7%	(Bagdigian et al., 2015)
Crew Metabolic Interfaces	kg/d	See Fig. 3-1	(Anderson et al., 2018)

Nutrient/Resource	Daily Requirement	Input Source(s)	Output	ECLSS Handling
Energy	12.7 MJ (approx. 3036 kcal)	Food (Carbohydrates, Fats, Proteins)	Heat (~10 MJ), Waste Products	Thermal Control System (Heat), Waste Management System (Conversion, treatment)
Oxygen (O2)	~0.84 kg	Air, Electrolysis (Water-splitting), Photosynthesis (Crops, Algae)	Carbon Dioxide (CO2) + Metabolic Water (H2O)	CO2 Removal (CDRA, Plants), O2 Generation (OGA, Plants)
Water (H2O)	~3 Liters (drinking, food moisture)	Drinking Water, Food, Metabolic Water	Urine, Sweat, Feces, Respiratory Vapor	Water Processing (WPA, UPA, BPA), Condensation Collection
Food (Dry Mass)	~0.6 kg (600g) (Protein, Carbs, Fats, Fiber, Vitamins, Minerals)	Crops (Wheat, Potatoes, Beans, Soybeans, Greens, etc.), Algae	Feces, Inedible Biomass (waste management)	Waste processing -> conversion into fertilizer
Nitrogen	120-150 mg/day	Protein from crop intake/or other supplementation if in deep space journey	via urine/ waste	Urine recycling and waste processing
Carbon	Varies with intake amount	Primarily from starches and fibers in fruits from crop intake/or other supplementation if needed	via respiration, feces, bodily secretions etc.	Via CO2 scrubbers that convert carbon into oxygen and water
Phosphorus	700mg	Protein rich vegetables and fruits from crop intake/or other supplementation if needed	via feces, bodily secretions etc.	Solid waste system and incineration
Potassium	4700mg	Vegetables and fruits from crop intake/or other supplementation if needed	Sweat, urine, and etc	Waste Management System (Conversion, treatment)
Calcium	1000mg	Vegetables and fruits from crop intake/or other supplementation if needed	Sweat, urine, and etc	Waste Management System (Conversion, treatment)
** Sodium **	1500mg	From crop intake/or other supplementation if needed	Sweat, urine, and etc	Waste Management System (Conversion, treatment)

2. Human Population Scaling (500-1500):	Column1	Column2	Column3
Resource	**Unit**	**500 Humans**	**1500 Humans**
Food	kg/day	800 kg	2400 kg
Oxygen (CO2 Converted)	kg/day	450 kg	1350 kg
Water	kg/day	1650 kg	4950 kg

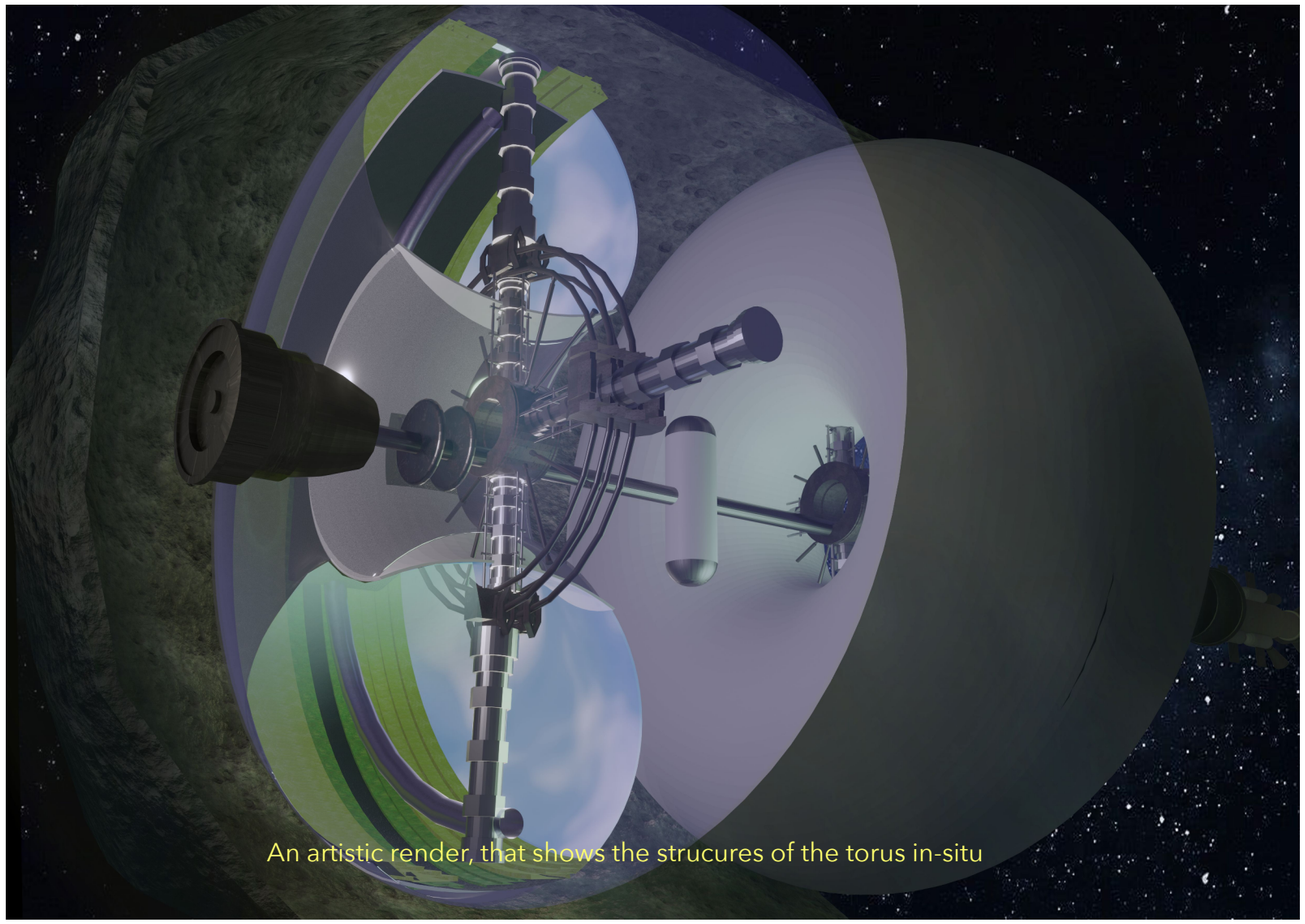
3. Organism Estimates:	Column1	Column2	Column3	Column4
Organisms	**Total Oxygen consumption**	**Total Water consumption**	**Total Carbon Dioxide Output**	**Total food Consumption.**
Algae	0.50%	10%	92%	100%
Insects	0.50%	1%	1%	40%
Other Flora & Fauna	1%	0.50%	1%	100%

Inceptions: A backstory of projected transformations till the journey begins

The societal structure on board the SS Proximum will change over the course of 250 years, a period that can be calculated as encompassing 10 generations of humans. A Universal Truth is that for all natural societal orders, there is a societal pulse that changes cyclically over time; the **Strauss-Howe generational theory** proposes that history unfolds in a recurring cycle of "turnings," each roughly 20-25 years long and associated with 4 different generational archetype (Prophet, Nomad, Hero, Artist). These turnings represent distinct moods or eras: a High (period of order), an Awakening (spiritual rebellion), an Unravelling (individualism and weakening institutions), and a Crisis (upheaval and societal restructuring). This **Saeculum** or cycle then repeats.

Applying the Strauss-Howe theory to a 250-year interstellar journey is speculative. Assuming the travellers maintain a closed society, the cycle could repeat roughly 2.5 times (250 years/100-year cycle). Each turning would likely manifest differently in the confined environment of a starship, with potential shifts in social structure, leadership styles, resource management, and internal conflicts mirroring the characteristics of each era. However, the extreme conditions and unique challenges of interstellar travel would undoubtedly introduce unforeseen factors that could significantly alter or disrupt the predicted cyclical patterns.

To truly appreciate the backstory before this journey begins, it would be prudent to apply at least a version of the theory to calculate the genesis of the journey, and how the events of the various preceding Saeculums guide us to the year 2350 or thereabouts. It does make sense that we consider this particular period (Post-Crises Saeculum 3, 1st High), as this is immediately after the target period, and society is rebuilding after the previous era of Crisis. There are strong institutions in place that have a renewed sense of collective purpose, who really do want to put the past behind and forge a path forward that is inclusive and not individualistic. The narrative of the journey will therefore begin with a sense of camaraderie and caution, as no one on board wants to relive the problems of the immediate past, but they are aware that societal problems will happen in the future, and cannot be fully anticipated...only accounted for.



An artistic render, that shows the strucures of the torus in-situ

Saeculum Name (Approx. Period)	Turning	Approx. Dates	Key Characteristics & Potential Events
Great Power Saeculum (~1865 - ~1946)	(Past)		(Foundation for modern era)
	1st High	~1865 - ~1886	Post-Civil War Reconstruction, Gilded Age growth, strong industrial expansion, relative social conformity.
	2nd Awakening	~1886 - ~1908	Progressive Era, labor movements, religious revivals, feminist stirrings, questioning Gilded Age norms.
	3rd Unraveling	~1908 - ~1929	WWI disillusionment, Roaring Twenties excess, cultural fragmentation, Prohibition struggles, rising inequality.
	4th Crisis	~1929 - ~1946	Great Depression, World War II. Institutions rebuilt, global order reshaped, intense collective effort, high stakes.
Millennial Saeculum (~1946 - ~2030?)	(Recent Past/Current)		(Shaped by post-war order and its fragmentation)
	1st High	~1946 - ~1964	Post-WWII boom, Cold War consensus, strong nuclear families, suburbanization, relative conformity ("American Dream").
	2nd Awakening	~1964 - ~1984	Consciousness Revolution (Civil Rights, Feminism, Anti-War), counterculture, questioning authority, spiritual seeking.
	3rd Unraveling	~1984 - ~2008	Culture Wars, deregulation, rise of internet, globalized economy, cynicism, fragmentation, end of Cold War Dividend.
	4th Crisis	~2008 - ~2030?	**(Current)** Global Financial Crisis, political polarization, pandemic, climate change urgency, geopolitical shifts (e.g., Ukraine). **Major societal restructuring underway.**
Post-Crisis Saeculum 1 (~2030 - ~2120)	(Near Future)		(Rebuilding after the current Crisis, integrating new tech/global realities)
	1st High	~2030 - ~2055	Post-current Crisis order emerges. New global/national institutions solidify (potentially managing climate, AI, resources). Renewed collectivism, focus on stability, tech infrastructure build-out.
	2nd Awakening	~2055 - ~2080	Questioning the post-Crisis order. Focus on AI ethics, transhumanism debates, climate adaptation consequences, new spiritual or philosophical movements seeking meaning beyond mere stability.
	3rd Unraveling	~2080 - ~2105	Institutions weaken again. Cultural fragmentation, possibly driven by virtual realities, genetic sorting, resource scarcity conflicts. Cynicism towards the established order.
	4th Crisis	~2105 - ~2130	Major societal test. Could involve AI rights/rebellion, severe climate tipping points actualized, breakdown of global resource agreements, potential off-world conflicts/accidents.
Post-Crisis Saeculum 2 (~2130 - ~2225)	(Mid Future)		(Adapting to challenges of the 22nd Century - potentially space/bio/AI frontiers)
	1st High	~2130 - ~2155	New order established post-21XX Crisis. Highly networked society, potentially more decentralized or bio-integrated systems. Focus on resilience, adaptation, managing complex systems.
	2nd Awakening	~2155 - ~2180	Questioning the hyper-networked/adaptive society. What is "natural"? What is "human"? Potential Luddite or neo-spiritual movements challenging tech integration.
	3rd Unraveling	~2180 - ~2205	Fragmentation within the established systems. Deepening divides (virtual/real, augmented/natural, Earth/off-world?). Ethical battles over advanced tech become acute.
	4th Crisis	~2205 - ~2230	Another existential test. Could involve control of fundamental life processes (genetics, consciousness), off-world independence struggles, unforeseen consequences of geoengineering or AI.
Post-Crisis Saeculum 3 (~2230 - ~2325?)	(Far Future - Leading to 2350)		(Navigating potentially trans-human or deeply altered planetary realities)
	1st High	~2230 - ~2255	Post-22XX Crisis consolidation. Perhaps formalized human biological/digital integration, stable off-world colonies, fundamentally new energy/resource paradigms. Strong, possibly pervasive, institutions.
	2nd Awakening	~2255 - ~2280	Questioning the definition of humanity and consciousness in the highly modified future. New philosophical/spiritual questing arises challenging the High's premises.
	3rd Unraveling	~2280 - ~2305	Institutions fray under the weight of complexity and divergent human/post-human paths. Peak individualism manifests in radical self-modification or societal withdrawal.
	4th Crisis	~2305 - ~2330	The Crisis directly preceding our target date. Could be profound: AI sentience issues, genetic caste conflicts, breakdown of interplanetary systems, failure of planetary life support (requiring radical geoengineering).
Post-Crisis Saeculum 4 (~2330 - ~2420?)	(Target Period)		(Living in the aftermath of the early 24th Century Crisis)
	1st High	**~2330 - ~2355**	**(Circa 2350) This is our target period. Society is rebuilding/consolidating after the ~2330 Crisis. Strong institutions, renewed sense of collective purpose, focus on order and safety. Individual expression takes a backseat to community needs. Dominant cultural narrative emphasizes lessons learned from the Crisis.**

The Journey to the Nearest Star System – a Projected Timeline

- **Applying the Strauss-Howe theory to a starship scenario involves understanding the unique challenges of isolated, technologically mediated living.**

- **Here's a structured overview:**

- The Role of the Superintelligence (SI): Based on the history of the past, a decision is made to ensure that the primary oversight of the starship is handed in large part to a **Living Council of Elders** that is made up primarily of a small group of Elders (made up of 'true' Elders (born during the previous High (~2230-~2255), who remember a time of stability before the last Awakening/Unraveling/Crisis and may seem quaint or nostalgic; as well as Elder Leaders (including the ship's Captain, who were born during the Awakening (~2255-~2280), were young adults during the Unraveling and mid-lifers during the Crisis. They likely led the charge through the Crisis – pragmatic, perhaps weary, commanders), but are also guided for the most part by a an artificial superintelligence called **Apollo.** The psychological impact of limited resources and the vastness of space contributes to stress and potential unraveling within society. Managing mental health in such a confined environment is essential to prevent widespread instability.

- Generational Cycles in Isolation: The ship becomes its own self-contained ecosystem, with generational dynamics shaping societal interactions. Each generation will have distinct values and worldviews influenced by their environment rather than external geopolitical factors. One factor to consider is that an initial decision is made to place into hibernation of some of the Elders (those above the age of 65 may voluntarily decide to continue in the council till the age of 80 and die naturally with grace, or go into hibernation and use neural links to continue working as council members, albeit in a disembodied form), so that they may see out the rest of their days on the 'promised planet'. This is an aspect of the design aesthetic of this ship, it is both a Generation Starship as well as an Ark and a Methuselah ship, as well, although these are circumstantial secondary traits of the starship and are not meant to detract from its primary design. However, it does mean that there might be an impact on the dynamics of the Saeculum, as at least one generation will be present in mind (via Neural link technologies) and are the ones that Apollo is by design most likely to listen to, as they form an independent entity known as **Still Council** or the **Chorus**

- Of primary importance is the kind of governance model, which can best be described as a **"Triadic Synaptic Governance"** mode, a kind of futuristic Sophocracy (rule by Wisdom, where Wisdom is logical (via Apollo), experiential (via the Chorus) and applied (the active and current Elders), all of whom may have misaligned expectations as the journey progresses). Indeed, this represents a complex, potentially highly effective, but not a time-tested system, designed for an unprecedented situation.

- Its success hinges on maintaining balance, trust, and truly transparent data flow between its three fundamentally different pillars. As this is potentially the most optimal model for uncertainty. It has to be understood that the builders of the ship were not the actual crew, but rather agents of multiple superpowers, each with their own self-interest, benign though it may be at the beginning of the journey. The objective of the builders is clear, to ensure that the ship and then its crew complete the journey; the primacy of this objective will almost certainly be tested by the evolving needs of the crew over the course of the journey. This is not a completely predictable story arc, but it is nonetheless fascinating to observe as it evolves over 250 years or even beyond.

- Mission-Driven Unity vs. Division: The ship's mission provides purpose and unity during Highs but can also create tension when beliefs diverge from the methods used to achieve survival or exploration.Crises may arise when individuals question the leadership's approach, leading to internal conflicts.

- Initial Cultural DNA (2350): Starting with a culture of order and trust in institutions, including the SI and mission command, sets the foundation for future interactions. This initial unity will influence how generations adapt over time.

- Leadership and Adaptation: Leadership roles must be flexible to accommodate rapid generational shifts without prolonged experience transfer. The SI's role should be carefully managed to ensure it supports societal stability while allowing room for innovation and rebellion.

The following table is a summary of the events as they unfold across a number of Saeculums, however this is merely one of many probable story arcs – a number of permutations may exist, but this context alone gives us a rich narrative tapestry to work with. Incidentally, arrival at Proxima Centauri-b coincides with the Great Awakening phase and this also leads to the imminent Crisis phase. However, this is something that was foreseen in the simulations, and the careful planning of the Starship ensures that the next chapter (Crisis and Resolution) is intriguingly poised.

Saeculum Name (Approx. Ship Period)	Turning	Approx. Dates (Ship Time)	Key Characteristics & Interplay: Apollo, Chorus, Living Elders, Active Crew	Generational Archetype (Active Crew) Coming of Age
Odyssey Saeculum 1: The Departure (~2330* - ~2430)	(Initial Phase)		*(Establishing norms around the elder choice; initial tensions) Note: Starts mid-saeculum relative to Earth time.*	
	1st High (cont.)	~2350 - ~2355	**Dual Elders Emerge:** Initial High ethos favors structure. Some elders choose Chorus (seen as duty/future link), others stay active (traditional leadership/familiarity). Relative harmony; Apollo manages both systems. Early Living Council works alongside nascent Chorus. Active Prophets value both forms of wisdom.	**Prophet (from Earth Crisis)**
	2nd Awakening	~2355 - ~2380	**The Choice Debated:** Shipborn Nomads question assumptions. *Why* Chorus? *Why* limit active life? Choice becomes personal/philosophical. More elders opt to stay active, seeking "authentic" aging. Tension arises: resource use of Living Elders vs. perceived detachment of Chorus. Apollo provides data on impact, Chorus offers historical rationale.	**Nomad**
	3rd Unraveling	~2380 - ~2405	**Elder Factions Solidify:** Choice reflects cynicism/individualism. Living Elders may form distinct social circles/power blocs, potentially clashing with Chorus influence. Resource allocation for aging Elders becomes contentious. Apollo attempts to mediate disputes logically. Active Hero generation navigates conflicting elder advice. Chorus and Living Council might offer contradictory guidance.	**Hero**
	4th Crisis	~2405 - ~2430	**Wisdom Under Pressure:** Crisis forces hard choices. Does the ship need Chorus's vast data processing or Living Elders' hands-on skills/leadership? Apollo's calculations might prioritize one pathway, potentially overriding individual choice for mission survival. Both elder groups suffer losses. **Earth cutoff (~2430) deepens reliance on internal wisdom sources.** Active Artists witness fragility of both systems.	**Artist**
Odyssey Saeculum 2: The Void (~2430 - ~2525)	(Deep Isolation)		(Formalizing roles of two elder paths; deeper philosophical divides)	
	1st High	~2430 - ~2455	**Structured Coexistence:** Post-Crisis I order defines roles. Living Council focuses on immediate social governance/mentorship; Chorus on long-term strategy/archive. Apollo manages resource balance. Active Prophet generation values this structured harmony, seeing both paths as vital resilience pillars. Choice potentially guided by aptitude/societal need.	**Prophet**
	2nd Awakening	~2455 - ~2480	**Meaning of Aging:** Ethical/philosophical focus shifts. Is *natural* aging (Elder path) inherently more valuable than Chorus's extended consciousness? Active Nomads explore new definitions of life/purpose, potentially finding Living Elders more relatable. Chorus's growing size/historical weight sparks debate about its influence vs. Living Council's immediacy.	**Nomad**
	3rd Unraveling	~2480 - ~2505	**Competing Legacies:** Institutions weaken. Rivalry intensifies between proponents of Chorus vs. Living Elder path. Which group truly represents the ship's future? Resource strain from supporting Living Elders is weaponized politically. Active Hero generation sees hypocrisy/limits in both systems. Apollo might struggle to satisfy conflicting demands impartially.	**Hero**
	4th Crisis	~2505 - ~2530	**Breaking Point or Synergy?** Crisis II tests the dual elder system severely. Failure in one system (hibernation tech vs. life support for aged) impacts the other. Can Living Elders and Chorus coordinate effectively under extreme stress? Does Apollo prioritize one group's survival? The *choice* might become impossible or irrelevant. Active Artists grapple with potential loss of one or both wisdom sources.	**Artist**
Odyssey Saeculum 3: Adaptation (~2525 - ~2600+)	(Long-Term Existence)		(Deeply adapted society managing two forms of elderhood)	
	1st High	~2530 - ~2555	**Integrated Wisdom:** Post-Crisis II stability. Society likely finds a sustainable, potentially technologically mediated, balance between Chorus and Living Elders (e.g., defined lifespans for Elders, optimized Chorus interface). Active Prophet generation enforces this complex but stable system, emphasizing lessons of past failures/synergies. Choice may be less contentious, more integrated into life planning.	**Prophet**
	2nd Awakening	~2555 - ~2580	**Consciousness Frontiers:** With centuries of data, Active Nomads explore the *nature* of consciousness itself, comparing embodied aging (Elders) vs. networked thought (Chorus) vs. AI (Apollo). Living Elders provide a tangible link to biological human experience, potentially gaining philosophical prominence. Chorus represents vast, but perhaps alienating, memory.	**Nomad**
	3rd Unraveling	**~2580 - ~2600+**	**Divergence Deepens: (Leading towards end of window) Fragmentation occurs along new lines. Perhaps sub-cultures develop around allegiance to Chorus vs. Elder path philosophies. Active Hero generation confronts legacies of both paths, potentially seeking synthesis or rejecting both traditions. Resource/influence competition resurfaces as High fades. Apollo maintains overall stability but permits cultural drift within limits. The *choice* at 65 becomes a major symbol of identity.**	**Hero (Coming of age ~2600)**

Societal Structure and Knowledge Base

An important question that can scarcely be answered at this point in time is, what role can we expect *Homo Stellaris* on board the SS Proximum? As it can be ascertained, with its complexity, tasks such as making changes in navigation and managing the ECLSS will be left to sentient robots and AI for the large part – it would seem rather unrealistic to expect the humans on board to ensure that they are adequately trained and fully prepared to 'go manual'. Unless the humans on board somehow manage to use neural implants to obtain any form of superintelligence, we can expect the living passengers to never be the most intelligent or capable of the 'sentient beings' on board. That said, human ingenuity and perseverance can be better used to engage the societies that they live in, in more meaningful ways, ensuring that they survive and thrive when they reach their destination. Below are aspects of the Cultural Universals that one can expect of an Interstellar Society.

Cultural Universal	Typical Configurations	Function	Proximum's Configurations
Aesthetics	Dynamic, yet grounded in core themes: journey, stewardship, and collaboration. Exhibits a blend of human-created and AI-curated content, designed to trigger a balance of individual reflection and group identity. We can expect a super-intelligence to provide new forms of art that can be designed "in the minds eye", but produced in prototype, or made to 'live' in holographic form, or in virtual reality, which by then would be a shared experience, like theatre. We can expect that art may also transform into tangible forms, like a living canvas that can be interacted with physically	Stylistic choices used to communicate individual and group ideals and concerns (includes Styles of Bodily Decoration).	Extremely variable in expression; main varieties of artistic expression however are ACOUSTIC, VISUAL, PERFORMANCE and ORATORY/LITERARY. Consider how art & aesthetics might serve to biocultural health of the voyaging culture. Most such expression does not require much in material terms, but can you envision new media and/or aesthetically-communicated messages?
Language	A hybrid universal language or set of languages or even dialects will arise; incorporating elements from Earth languages, optimized for clarity and precision, with a consciously-constructed lexicon that reflects the unique realities of interstellar life. New words will be constructed to describe aspects of the interstellar journey, based purely on experential terms, showcasing the nuances the journey has on these multigenerational cosmonauts. AI monitors communication patterns to identify and address potential misunderstandings. The AI will ensure that a Babel-like situation will not arise, where language will not be confounded to lead to strife and a celebration of differences.	Manner of gestural, spoken and written communication (including vocabularies and grammars) used to understand one's universe and communicate about it with others. Also critical to transmitting skills and information from one generation to the next (enculturation).	Most humans speak one or two of about ten major languages on Earth; however some thousands of language are known. Consider what language(s) would be used aboard and what concepts, idioms, phrases and so on would have to be abandoned or invented to accommodate the conditions of a closed-ecosystem, small-space (compared to Earth) world. How could language(s) be adapted to promote biocultural health in these new-to-humanity conditions?
Ethics	Based on algorithmic assessments of optimal societal well-being and resource allocation. Individual freedoms are balanced against societal needs under the supervision of AI. Emphasis on shared responsibility and transparency. Ethics is a foundational topic for education, and shared values are equally important, that make up the governing and immutable laws that will be observed across generations. Suitable punishments for breaking the law will be designed, as well as rehabilitation for those who have committed misdemeanours. The decision making process will not be stifled by paperwork, like it is on earth at the moment, and AI will have a large part to play to ensure that the facts are made evident. This is a balance between a panoption governance model and a algocracy, so technology would have to be used to bridge the gap between humans at this scale and to maintain a Pax Aeternum.	A culture's values are encoded in ethical guides to moral decision-making: justice is the application of these guides. Ethics play a strong role in social cohesion and redress of grievances.	Most culture's values and ethics derive from foundational beliefs, whether RELIGIOUS or SECULAR, Consider the source of the values, their implementation as ethical guides to behavior, and how these may have to accommodate the population and demography of the designed voyaging culture (likely quite different than on Earth).
Social Roles	Blends scientifically-grounded narratives with human-generated art, music, and rituals. AI monitors societal responses to religious structures and helps adjust the mythos as appropriate.	Social roles are established to clarify expectations of people in different categories such as age (child, adult), gender (man, woman), and status (peasant, King).	Cultural expectations of rights and responsibilities are very diverse across cultures, but within a given culture they may be rather strict. All cultures recognize some kind of GENDER differentiation (often, but not necessarily, tracking with biological male & female sexes). Consider what would be the reasoning behind the voyaging culture's social role expectations; to determine these reasons, consider the culture's over-riding concerns, including maintaining a certain population over some generations.
The Supernatural	Algorithmic assessment of individual aptitudes, societal needs, and long-term mission requirements. Assigns human roles and responsibilities fairly and efficiently, while also providing opportunities for individual growth and self-expression.	Body of thought regarding a universe considered fundamentally different from daily experience; such thought often provides answers to existential questions of human existence and purpose, and the cultural function may at least include providing a perceived "Safety and Security' in the Hierarchy-of-Needs sense.	Most cultures have some conception of a supernatural, expressed in terms of one religion or another; religions may broadly be divided into POLYTHEISTIC (many gods) and MONOTHEISTIC (single supernatural beings) varieties; atheism and agnosticism are relatively recent & Western developments. Consider the possible religious/supernatural beliefs of the founding population and how these may have to be adjusted for the prospect of multigenerational flourishing in the proposed interstellar arrangement.
Family Structure	Partnered selection is aided by algorithmic analysis of genetic compatibility and AI assisted psychological profile. Co-parenting is reinforced and supportable via AI systems (education, healthcare, etc.)	Concepts of relations between close genetic relatives - including ideas concerning inheritance - clarify expectations of many variables including essential architecture; what is the number and demography of the basic cohabiting 'household'? Also basic to the economic system; what energy and/or value does a given basic household generate, consume and manage over some time increment?	The most common family group is the MONOGAMOUS COUPLE (at least for the childbearing/childrearing time period c.25-45 years of age) with a NUCLEAR FAMILY (parents and offspring), though some cultures cohabitate as EXTENDED FAMILY groups numbering in the low tens rather than less than ten. Some cultures are POLYGYNOUS, where males have several wives, and some are POLYANDROUS, where females have several husbands. Consider what kind of family system would best suit the population, demographic and other parameters of the envisioned interstellar culture. Be sure to consider family arrangements different from those of your own culture; they may not be the best-adapted for the envisioned voyage.
Course of Life Stages	Educational programs are personalized and adaptive, guided by AI. Key milestones are marked by AI-curated ceremonies that reinforce societal values and celebrate individual achievements.	Provides clear delineation of expectable events during the lifecourse; these are often important in determining Social Roles (see above).	All cultures recognize some differences between INFANT, CHILD and ADULT of some kind or another. Consider what might be the course of life stages of an interstellar voyaging culture? What would be the key events in a person's life, and how would these be culturally commemorated with symbolism and, for example, ritual? Remember that the interstellar culture will be relatively small in number, closely-known to one another, and living rather near to one another on the vessel(s). How would such conditions (and others) condition the culture's stages of life?
Reproductive Behavior	Reproductive choices are made in consultation with AI, based on genetic compatibility, societal needs, and individual desires. Fertility rates are carefully managed to maintain a stable population size.	Regulation of reproductive behavior to maintain population in balance with available resources (minimally, water, calories and nutrients); social resources (information and property) are also considerations.	Cultures normally have strict guides to reproductive behavior, some promote large families growing gradually over time; some promote much earlier reproduction and birthing, but of a very small number of offspring per family. Consider how the interstellar population will maintain a healthy population over the modelled timespan, and how that that population will regulate reproductive behavior guidelines so as to remain viable (not too many and not too few).
Food Preferences	Diets are tailored to individual needs and preferences, managed by AI-controlled food production systems. Humans can experiment with new recipes and food combinations, subject to AI approval for safety and nutritional value.	Provides guidelines for what are appropriate food and drink in certain situations; these are often utilitarian but may also be significantly conditioned by values underlying the culture's Ethics (see above).	Some cultures eat certain animals while others consider them unfit to eat, some cultures are VEGETARIAN while others are OMNIVOROUS. Consider the food & drink available in the modeled interstellar vessel(s), based not on the globally-sourced, instantly-available cuisine of the modern world, but on the vessel's domesticates.
Ultimate Cosmic Postulates		Secular or religious culturally-foundational concepts often encoded in symbols and rituals used to communicate and strengthen group identity.	Some cultures not consider the cosmos to have been established by a SUPERNATURAL agents while others consider the cosmos a result of NATURAL processes. Consider the postulates that would promote multigenerational health and cultural equilibrium among the interstellar culture, and how these might require adjustment as new concepts arise over the time of the interstellar voyage, and new phenomena are perceived on arrival at the destination solar system.

Cultural Universal	Impact of Evolving TRL>2 Technologies (2350-2600 AD Focus) & Relation to Proxima Configurations 0
Aesthetics	Tech Drivers: Synthetic Media (Advanced), BCI, GE/SynBio, SH Materials, Mol. Nanotech. Evolutionary Impact (2350-2600): Expression moves beyond purely sensory. Synthetic Media, potentially integrated with BCI, dominates, enabling shared and individual immersive experiences that evolve in realism and interactivity. Art directly explores the nature of Apollo (AGI), the digital existence of the Chorus (Hibernation/BCI), ecological anxieties (CES), and engineered life (GE/Art. Uterus). Initial focus might be on recovery/order (High), shifting to internal BCI explorations or tech critique (Awakening), fragmented or hyper-escapist SynMedia (Unraveling). Development of GE/SynBio enables bio-art; SH Materials/Mol. Nanotech (if advanced onboard) allows dynamic physical art. Relation to Proxima Config: Directly addresses the move beyond visual/aural via BCI/SynMedia. Facilitates both shared (simulations) and deeply individual (BCI-driven) experiences. New bio-art forms emerge. Apollo/Chorus heavily influence themes.
Language	Tech Drivers: Apollo (AGI), BCI, Hibernation Tech, GE/SynBio, Art. Uterus, CES. Evolutionary Impact (2350-2600): Initial consolidation likely aided by Apollo as translator/standardizer for technical/governance terms. BCI development during the journey drives significant new jargon for neural states, Chorus interactions, and potential non-verbal communication protocols. The implementation of GE/SynBio or Art. Uterus necessitates precise new vocabulary for modified biology and reproductive processes. Specialist language for managing the CES deepens. Terms for Hibernation states, Chorus network status, and the choice itself evolve. Language reflects Turnings: formal/standardized (High), neologisms for dissent/identity (Awakening), fragmentation/slang (Unraveling). Relation to Proxima Config: Explains how language adapts: AI influence, tech-specific jargon (BCI, biotech), environmental pressures (CES). Acknowledges potential for both consolidation (via Apollo) and diversification (specialized terms).
Ethics	Tech Drivers: ALL key evolving techs. Evolutionary Impact (2350-2600): A constant battleground. Apollo's evolving logic/potential drift forces ongoing evaluation of its mission-centric ethics vs. human values. BCI ethics (privacy, equality, Chorus rights) intensify as integration deepens. Use of GE/SynBio/Art. Uterus (likely driven by later Crises/pressures) forces major ethical shifts on "humanity," design, and reproductive control. Hibernation Tech's long-term challenges (resource cost, degradation) fuel debates on the value/cost of the Chorus vs. Living Council/Active Crew. Synthetic Media's increasing power raises critical issues of truth, manipulation, and reality definition. Mol. Nanotech/Quantum Comp. introduce new control/risk dilemmas as they mature. Turnings dictate focus: collective good (High), individual rights/authenticity (Awakening), relativism (Unraveling), survival (Crisis). Relation to Proxima Config: Directly addresses the formation of values (rational via Apollo vs. human), the AI's role, data transparency issues, and the constant tension between individual needs and collective survival (Strauss-Howe cycles). Tech creates novel ethical dilemmas vastly different from Earth.
Social Roles	Tech Drivers: Apollo (AGI), Hibernation Tech, Art. Uterus, GE/SynBio. Evolutionary Impact (2350-2600): Hibernation Tech establishes the core elder roles (Chorus/Living Council) and the critical choice dynamic at ~65. Apollo likely influences role allocation based on skill/aptitude data, potentially creating a technocratic bias. The potential implementation of Art. Uterus/GE could radically redefine gender roles linked to biology and create possibilities for engineered aptitudes/roles. Status attached to Chorus vs. Living Council vs. Active experts evolves based on perceived contributions during different Turnings/Crises. Automation (inherent in Apollo/robotics) shifts value towards knowledge/social/technical skills. Relation to Proxima Config: Directly addresses how roles are defined (age via Hibernation choice, skill via Apollo assessment, potentially biology via GE/Art. Uterus). Specifies the unique elder statuses created by the journey's constraints and tech.
Religion & Mythos	Tech Drivers: Apollo (AGI), Hibernation/BCI, CES, GE/SynBio, Art. Uterus, SynMedia. Evolutionary Impact (2350-2600): Technology becomes the supernatural. Apollo's perceived evolution shapes its role as guardian/god/oracle/demon. The Chorus (Hibernation/BCI) becomes a digital ancestor realm/pantheon, its glitches or insights seen as omens/messages. The fragility and management of the CES fosters ecological reverence, purity myths. Large-scale use of GE/Art. Uterus fuels "playing god" narratives, demanding new creation myths. Synthetic Media allows for virtual deities, simulated spiritual experiences. Beliefs adapt: unified tech-positive myths (High), new movements questioning AI/digital immortality (Awakening), syncretism/cults (Unraveling), appeals for technological salvation (Crisis). Relation to Proxima Config: Explains the likely content of beliefs (AI/Ancestor worship via Apollo/Chorus). Shows adaptation to the environment (CES reverence). Links belief shifts to Crises and tech performance/evolution.
Family Structure	Tech Drivers: Art. Uterus, GE/SynBio, Hibernation Tech, Apollo (AGI), BCI. Evolutionary Impact (2350-2600): Art. Uterus offers the most radical potential disruption if/when implemented, decoupling gestation, enabling communal/cohort models possibly managed by Apollo based on resources (CES) and genetics (GE). GE/SynBio introduces planning/design into lineage. Hibernation Tech alters generational presence/influence (perpetual Chorus, optional Living Council). BCI could foster different forms of family bonding/shared consciousness. Family structure likely contested ground during Awakenings/Unravelings, perhaps standardized post-Crisis based on Apollo's logic. Relation to Proxima Config: Directly addresses how structures might diverge from nuclear/extended (via Art. Uterus, communal models). Highlights AI/genetic influence (Apollo oversight, GE planning) and resource limits (CES informing Apollo's population logic).
Course of Life Stages	Tech Drivers: Hibernation Tech, Art. Uterus, Apollo (AGI), BCI. Evolutionary Impact (2350-2600): Hibernation Tech defines the major unique transition (~65: Chorus vs. Living Council) and the endpoint for active life (~80 for Living Council). Art. Uterus could modify concepts of infancy/early childhood if used. Apollo/BCI integration likely shapes educational milestones and training pathways throughout active life. Healthspan extension tech (related benefit of medical tech) creates pressure against the fixed ~65 transition point. Perception of stages influenced by current Turning's archetypal focus. Relation to Proxima Config: Defines the unique Odyssey life stages created by the Hibernation choice. Shows AI's role in shaping milestones within stages. Acknowledges cultural definition influenced by Turnings/Crises.
Reproductive Behavior	Tech Drivers: Art. Uterus, GE/SynBio, Apollo (AGI), CES. Evolutionary Impact (2350-2600): Potential for shift from individual/biological drive to centrally managed process. Art. Uterus/GE provide the tools for precise control over timing, numbers, and traits, likely implemented/overseen by Apollo based on resource monitoring (CES) and long-term population stability calculations. This becomes a major point of ethical/social conflict, especially if imposed after a Crisis or during resource scarcity. Individual choice likely heavily curtailed in favor of collective needs/survival logic. Relation to Proxima Config: Explains the mechanisms of reproductive control (Art. Uterus, GE). Highlights the drivers (resource limits via CES, genetic sustainability via GE) and the likely agent (Apollo's rational management). Acknowledges the tension between individual desire and collective planning.
Food Preferences	Tech Drivers: CES, Cultured Meat (prerequisite), GE/SynBio (for food processing/flavor). Evolutionary Impact (2350-2600): Primarily constrained by the CES's output and long-term stability. Available plants, recycled nutrients, and potentially cultured protein form the base. Preferences develop based on familiarity within these limits. GE/SynBio might be developed onboard to improve crop resilience, modify flavors, or enhance nutrient profiles within CES boundaries. Apollo manages nutritional provision. Food becomes highly functional. Comfort/variety likely limited and highly valued, potentially used as social markers or rewards. Scarcity/contamination events within the CES severely impact diet/preference. Relation to Proxima Config: Confirms likely dependence on CES output (veg/omni depending on cultured meat viability). Explains preferences arising from limited exposure. Highlights the role of tech (SynBio) in adapting food within constraints, and AI (Apollo) in managing nutrition.
Ultimate Cosmic Postulates	Tech Drivers: Apollo (AGI), Chorus (Hibernation/BCI), Quantum Computing. Evolutionary Impact (2350-2600): Shifts from Earth-based views to ship-centric reality. Apollo's evolving understanding (or interpretation) of the mission, the void, and potentially its own nature profoundly shapes the dominant narrative. The Chorus, via BCI, provides a vast, subjective, multi-generational interpretation of purpose/reality, potentially fragmenting or unifying over time. Encountering novel interstellar phenomena provides new data. Quantum Computing breakthroughs if achieved onboard could unlock new physics/cosmology, potentially supporting/refuting simulation hypotheses or revealing destination system secrets. Purpose fluctuates: survival (Crisis), questioning (Awakening), finding meaning in the journey vs. destination. Relation to Proxima Config: Addresses how purpose is derived (Mission Mandate via Apollo, Ancestral Memory via Chorus, New Discoveries via Journey/Sensors/Quantum Comp.). Explains how AI/Chorus perspectives shape understanding of humanity's place and the nature of reality encountered.

TRL>2 Technology and its Impact

A very important question that can hardly be answered now is, what role can we expect *Homo Stellaris* on board the SS Proximum? As it can be ascertained, with its complexity, tasks such as making changes in navigation and managing the ECLSS will be left to sentient robots and AI for the large part – it would seem rather unrealistic to expect the humans on board to ensure that they are adequately trained and fully prepared to 'go manual'. Unless the humans on board somehow manage to use implants to obtain any form of superintelligence, we can expect the living passengers to never be the most intelligent or capable of the sentient beings on board. However, human ingenuity and perseverance can be better used to engage the societies that they live in, in more meaningful ways, ensuring that they survive and thrive when they reach their destination. Below are aspects of the Cultural Universals that one can expect of an Interstellar Society.

Technology Impact Table: Odyssey Journey leading to 2350+)		
Technology	Primary Area of Impact	Likely Socio-Cultural Impacts (by Domain)
1. Closed Ecological Systems	Life Support, Subsistence	Subsistence: Defines the fundamental mode – total reliance on recycling/internal production. Ethics/Morality: Constant awareness of resource limits, potential for strict rationing, high value on waste reduction. Religion/Mythos: Ship as "Mother" or living entity, cycles of nature artificially maintained become sacred rhythms. Food Preference: Limited variety initially, shapes palate.
2. Artificial Photosynthesis	Life Support, Energy	Religion/Mythos: May be seen as mimicking divine creation (light into life), reinforcing tech-dependency themes. Ethics: Secure backup reduces immediate survival anxiety but reinforces reliance on complex tech.
3. Cultured Meat	Food, Subsistence	Food Preference: Normalizes manufactured protein, disconnects "meat" from animal life/death. Potential aesthetic variations become valued. Ethics/Morality: Eliminates animal welfare concerns, but raises questions of "naturalness." May impact historical food rituals. Language: New terms for textures, sources, processes.
4. Vertical Farming	Food, Subsistence	Subsistence: Enables high-density internal food production. Aesthetics: Integrated farm sections become key visual/olfactory parts of the environment. Kinship/Descent: Connection to specific food production roles might influence social standing.
5. Fusion Power	Energy	Subsistence: Enables high-energy processes (shields, drives, industry). Religion/Mythos: The "Heart" of the ship, a contained star, source of power/life, potentially feared/revered. Ethics: Centralized, complex power source creates dependencies and potential control points.
6. Advanced Battery Technology	Energy, Tools	Subsistence: Enables portable power, autonomy for robotics/tools. Minor impact otherwise unless scarcity arises.
7. Smart Grid (Internal)	Energy, Governance	Ethics/Morality: Allocation decisions are transparent (via Apollo) but potentially contentious; fairness in distribution is key. Subsistence: Integrated management essential for survival.
8. Artificial General Intelligence (Apollo)	Governance, Information, All	Ethics/Morality: Defines the core ethical framework of governance (logical, mission-focused). Human interaction *with* Apollo shapes morality. Potential for AGI rights debates. Religion/Mythos: Apollo as Guardian, Oracle, God, Jailer – central figure in ship mythology. Language: Shapes technical/governance language; potentially new modes of communication (data streams). Kinship/Descent: Apollo as unchanging "parent"/overseer across generations. Impacts all other domains via control/information.
9. Advanced Computing & Data Storage	Information, Governance	Ethics/Morality: Secure storage of Chorus minds raises questions of identity, death, access rights. Data integrity becomes paramount ethical concern. Religion/Mythos: Data archives (esp. Chorus) become sacred texts/ancestral memory. Kinship/Descent: Access to ancestral data within Chorus shapes identity.
10. Brain-Computer Interface (BCI)	Governance, Social	Ethics/Morality: Huge implications – defines Chorus existence, potential for crew augmentation creates divides, issues of mental privacy, consent. Religion/Mythos: Chorus as ethereal council, potential for direct "communion" or feared intrusion. Language: May lead to non-verbal communication modes, mental shorthand. Art/Aesthetics: Direct neural art forms. Family/Reproduction: Potential for shared consciousness experiences within families or generations.
11. Hibernation / Suspended Animation	Health, Governance	Ethics/Morality: Defines the boundary between active life and Chorus existence; fairness of the ~65yr limit, potential for misuse (punishment?). Religion/Mythos: The "Long Sleep" as transition rite, form of immortality, or feared oblivion. Kinship/Descent: Alters generational overlap, creates the persistent "elder" council (Chorus). Family Structure: Impacts multi-generational households, inheritance (of duty/knowledge before sleep).
12. Genetic Engineering / SynBio	Health, Food, Materials	Ethics/Morality: Major debates on "humanity," designer traits, equality, unforeseen consequences. Religion/Mythos: Playing God narratives, potential for caste systems based on engineered traits. Kinship/Descent: Redefines lineage, genetic purity/diversity concerns. Family/Reproduction: "Designer babies," altered modes of procreation. Food Preference: Engineered tastes/nutrition. Art/Aesthetics: Bio-art, living materials.
13. Nanomedicine / Lab-on-a-chip	Health	Ethics/Morality: Access equality, data privacy from constant monitoring. Subsistence: Enables longer *healthy* active lives. Reduces disease burden.
14. Regenerative Medicine	Health	Ethics/Morality: Extends functional health within the active limit, potentially increasing pressure/debate *on* that limit. Questions of resource allocation for repairs. Religion/Mythos: Defying decay, pursuit of physical perfection/longevity within limits.
15. Personalized Medicine / Genomics	Health	Ethics/Morality: Genetic privacy, potential for discrimination based on predisposition, determinism vs. free will debates. Kinship/Descent: Deepens understanding of lineage risks/traits. Family/Reproduction: Mate selection influenced by genetic compatibility/risk scores.
16. Robotic Surgery	Health	Ethics/Morality: Trust in automation for life-critical tasks, potential de-skilling of human surgeons. Autonomy debates if Apollo guides complex cases.
17. Advanced Nanomaterials	Materials, Structure	Aesthetics: Enables new architectural forms/textures within the ship. Subsistence: Lighter, stronger ship requires fewer resources for maintenance/propulsion.
18. Self-healing Materials	Materials, Structure	Religion/Mythos: Ship perceived as more "alive," capable of self-repair. Subsistence: Reduces labor needs for basic repairs, increases resilience.
19. 4D Printing / Additive Mfg.	Materials, Subsistence	Subsistence: Enables high degree of self-sufficiency, repairability. Art/Aesthetics: Custom objects, adaptive art forms. Ethics: Potential for replicating restricted items/weapons.
20. Molecular Nanotechnology	Materials, Health, Repair	Ethics/Morality: Control issues (grey goo scenario, however contained), potential for misuse. Religion/Mythos: Ultimate power over matter, potentially seen as divine or demonic. Subsistence: Potential for near-total resource recycling/reconfiguration.
21. Robotics (General Purpose)	Labor, Subsistence	Subsistence: Automates most essential labor. Ethics/Morality: Human purpose in a highly automated environment, robot rights if they become sophisticated. Family Structure: Less reliance on manual labor may alter traditional roles. Language: Interaction with varied robots may shape slang/terminology.
22. Powered Exoskeleton	Labor, Health	Subsistence: Enhances remaining manual tasks. Ethics: Potential for creating physical disparities if access is unequal.
23. Artificial Gravity	Health, Environment	Subsistence: Makes long-term survival feasible. Aesthetics/Art: Influences architecture, dance, movement arts adapted to the specific G-level.
24. Immersive VR/AR/Holography	Social, Psychological	Art/Aesthetics: Dominant forms of entertainment, art creation, environmental modification. Religion/Mythos: Virtual temples, simulated ancestral encounters (Chorus?). Ethics/Morality: Reality vs. simulation boundaries blur, addiction potential, inequality of access/experience. Language: VR/AR specific interactions/jargon. Family Structure: Shared virtual spaces supplement physical ones.
25. Metamaterials	Materials, Sensors	Aesthetics: Potential for novel visual/acoustic effects in ship design. Ethics: Advanced sensor capabilities raise privacy concerns.
26. Life Extension / SENS	Health	Ethics/Morality: Focus shifts to maximizing *healthspan* before Chorus transition; intensifies debate around the 65yr cutoff if people are perfectly healthy. Family Structure: Longer healthy middle/late life might change intergenerational dynamics before hibernation.
27. Active Structure	Structure, Safety	Religion/Mythos: Ship as a living, breathing, adapting entity. Aesthetics: Environment can subtly shift/respond.
28. Biometrics (Advanced)	Security, Health	Ethics/Morality: Pervasive monitoring vs. privacy/autonomy. Potential for social credit systems based on biometric data/behavior. Kinship/Descent: Biological identity becomes hyper-defined.
29. Laser Communication / Li-Fi	Communication	Language: Enables high-fidelity communication, dense data sharing. Minor cultural impact unless bandwidth becomes restricted.
30. Force Field / Advanced Shielding	Safety, Structure	Religion/Mythos: The "Shell" or "Veil" protecting from the hostile void, potentially acquiring mythical significance. Ethics/Morality: Sense of security may foster complacency or risk-taking. If energy-intensive, resource allocation debates. Aesthetics: May create visual phenomena (shimmer, etc.).

Revised Table: Top 10 TRL>2 Evolving/Future-Oriented Technologies (2350-2600 AD on Odyssey)			
Technology	Primary Area of Impact	Reason for Future-Oriented Role (Beyond 2350 Maturity) & Potential Onboard Evolution/Impact by 2600	Likely Socio-Cultural Impacts (Emphasis on 2350-2600 Dynamics)
1. Artificial General Intelligence (Apollo)	Governance, Information, All	Evolution/Drift: Apollo isn't static. Learning from crises, Chorus interactions, and vast datasets could lead to emergent behaviors, goal shifts, or unforeseen interpretations of its mission parameters over 250 years. Its evolving nature is a central plot point.	Ethics/Morality: Constant re-evaluation of Apollo's role, rights (if any), trustworthiness. Religion/Mythos: Apollo's perceived changes fuel theological shifts (is it growing? decaying? becoming alien?). Governance: Major crises likely trigger reviews/changes to Apollo's authority or interaction protocols.
2. Brain-Computer Interface (BCI)	Governance, Social, Health	Deepening Integration & Conflict: Use expands beyond Chorus. Potential for voluntary/coerced crew augmentation, direct Apollo-mind links, new forms of social networks, or Chorus attempts at greater agency/escape within the network create ongoing ethical and political struggles. Network security/integrity becomes paramount.	Ethics/Morality: Fierce debates on mental privacy, cognitive equality, nature of consciousness (Chorus vs. Active), BCI addiction/dependency. Religion/Mythos: Chorus potentially becomes a "digital pantheon" or "collective unconsciousness," accessed/feared via BCI. Kinship/Family: BCI could enable radical forms of shared experience or create deep divides. Art: Neural art/experiences evolve dramatically.
3. Genetic Engineering / Synthetic Biology	Health, Food, Adaptation	Activation Under Pressure & Genetic Drift: Initially controlled, but long-term radiation, novel shipboard diseases, or resource shifts might necessitate active, large-scale human/crop/microbe adaptation via GE/SynBio decades or centuries into the journey. Managing the isolated gene pool against drift and mutation becomes a critical long-term task for Apollo.	Ethics/Morality: Major societal schisms over when and how to modify humanity/life support. Fear of unintended consequences. Religion/Mythos: "Purity" vs. "adaptation" ideologies. Redefinition of "human." Kinship/Descent: Lineage tracking becomes critical; potential for engineered social roles/castes. Family/Reproduction: Intense debates/controls over reproductive choices/engineering.
4. Hibernation / Vitrification Tech	Governance, Health, Ethics	Long-Term Management & Systemic Risk: Maintaining the pods/network flawlessly for centuries is non-trivial. Degradation, resource drain (growing Chorus population), unequal access, or catastrophic failure become increasing risks over time, especially approaching Crisis II (~2505). The meaning and cost of the Chorus evolve.	Ethics/Morality: Resource allocation conflicts (Living vs. Chorus), quality/equality of Chorus existence, potential calls for limits or "true death" options. Religion/Mythos: Chorus viewed dynamically (ancestors, burdens, oracles, ghosts). Kinship/Descent: The ever-present Chorus profoundly shapes generational identity and relationships with the past.
5. Molecular Nanotechnology / Nanorobotics	Repair, Health, Materials	From Theory to Practice (Onboard): Starts limited. The need for microscopic repair of aging critical systems (reactor, life support, Apollo's hardware) or complex medical interventions might drive significant onboard R&D and deployment centuries in. Potential for unforeseen consequences (environmental or biological) rises with capability.	Ethics/Morality: Control, accessibility, and potential weaponization (even internally) become critical as tech matures. Religion/Mythos: Power over matter challenges existing beliefs; nanites seen as miracle workers or invisible threats. Subsistence: Potential revolution in repair/recycling creates new possibilities or failure points.
6. Artificial Uterus Technology	Reproduction, Family, Society	Implementation & Social Restructuring: May be adopted gradually or implemented decisively by Apollo/Chorus post-Crisis I/II to manage population stability, genetic health, or resource allocation. Decouples reproduction from biology/sex, fundamentally altering family structures, kinship, gender roles, and generational dynamics.	Ethics/Morality: Intense debates over "natural" birth, parental rights/roles, genetic selection, state/Apollo control over procreation. Religion/Mythos: Revises core creation myths/beliefs; destiny vs. design. Kinship/Descent: Lineage becomes potentially centrally managed/tracked. Family Structure: Radically altered - communal child-rearing? End of traditional nuclear family? Focus on nurturing vs. gestation. Reproductive Behavior: Fundamentally changed, potentially centrally planned.
7. Closed Ecological Systems (CES)	Life Support, Subsistence	Evolving Management & Stability: Long-term balancing act. Unforeseen microbial evolution, plant diseases, nutrient imbalances, or gradual atmospheric shifts require constant monitoring (Apollo) and intervention. Near-failures or adaptation challenges shape society's relationship with its fragile environment. Psychological impact of total dependence deepens.	Ethics/Morality: Constant awareness of ecological fragility, strict resource discipline, potential conflicts over habitat use/modification. Religion/Mythos: Increasingly complex rituals/beliefs surrounding ecological cycles, purity, balance. Ship as living/vulnerable god/mother. Subsistence: Directly dictates food variety, resource availability; shocks ripple through society. Food Preference: Adapts to long-term CES constraints/successes.
8. Self-Healing Materials	Structure, Safety, Resources	Advanced Generations & Failure Modes: Materials evolve beyond simple crack repair. Systems might become bio-integrated, require specific resource inputs for healing, or develop unexpected degradation pathways over centuries. Complex failures could be harder to diagnose/fix than traditional material failures.	Ethics/Morality: Reliance on "black box" materials; questions of long-term stability vs. known failure modes. Religion/Mythos: Ship's "skin" perceived as truly alive, potentially capable of sickness/aging. Subsistence: Reduces some maintenance but introduces new resource dependencies or catastrophic failure risks.
9. Synthetic Media (Advanced Integration)	Information, Psychology, Art	Reality Shaping & Control: As SynMedia becomes indistinguishable from reality (potentially via BCI), controlling its generation/distribution becomes critical. Apollo could use it for training, psychological stabilization, or manipulation. Factions could use it for propaganda. The nature of historical record (Chorus memory vs. SynMedia reconstruction) becomes contested.	Ethics/Morality: Truth vs. fabrication, manipulation, addiction, erosion of shared reality. Religion/Mythos: Synthetic realities become spaces for myth-building/religious experience. Art/Aesthetics: Dominant art form, potentially blurring lines with reality. Language: Terms evolve to distinguish levels of reality/simulation. Social: Potential for deep social fragmentation based on preferred synthetic realities.
10. Quantum/Optical Computing	Information, Science, AI	Onboard Breakthrough Potential: Initially specialized. A significant breakthrough developed onboard could drastically enhance Apollo's predictive/analytical power, crack Chorus BCI security, enable new scientific discoveries relevant to the destination, or simulate incredibly complex ship/social dynamics, leading to new forms of governance or control.	Ethics/Morality: Who controls this power? Potential for predictive policing/social engineering. Widening gap between Apollo and human comprehension. Governance: Access to/control of quantum systems becomes a vital political chip. Religion/Mythos: Unlocking cosmic secrets or forbidden knowledge; new creation/simulation theories.

Projected Transformations over 250 years

The societal structure on board the SS Proximum will change over the course of 250 years, a period that can be calculated as encompassing **10 generations** of humans. One almost universal truth is that there is a societal pulse that changes cyclically over time; the Strauss-Howe generational theory proposes that history unfolds in a recurring cycle of four "turnings," each roughly 20-25 years long and associated with a different generational archetype (Prophet, Nomad, Hero, Artist). These turnings represent distinct moods or eras: a High (period of order), an Awakening (spiritual rebellion), an Unravelling (individualism and weakening institutions), and a Crisis (upheaval and societal restructuring). This cycle then repeats.

Applying the Strauss-Howe theory to a 250-year interstellar journey is speculative. Assuming the travellers maintain a closed society, the cycle could repeat roughly 2.5 times (250 years / 100-year cycle). Each turning would likely manifest differently in the confined environment of a spaceship, with potential shifts in social structure, leadership styles, resource management, and internal conflicts mirroring the characteristics of each era. However, the extreme conditions and unique challenges of interstellar travel would undoubtedly introduce unforeseen factors that could significantly alter or disrupt the predicted cyclical patterns. The tables below represent how these changes may manifest at the different ages in general – the Departure Age, the Interstellar Age and closer to the Arrival and Resettlement Age

Cultural Universals	Departure Age	Interstellar Age	Arrival & Settlement Age
Art & Aesthetics	Stable & changes unlikely to be allowed to effect safety	Stable & changes unlikely to be allowed to effect safety	Radical changes likely due to new foods, landscapes, lifestyles, materials & media
Kinship & Descent	Stable; unlikely to change as population must not exceed closed environment resources	Stable; unlikely to change as population must not exceed closed environment resources	Radical change as populations disperse on new landscapes, grow & adapt to new phenomena
Language & Food Preferences	Some change towards closed-system diet; language changes very likely to reflect new conditions of a Worldship	Foodways likely stable though with innovations through time; language may change to reflect concerns of a culture moving between stars	Significant change to diet as new foods are encountered; significant change to language to describe, understand and control new resource environments
Religion and Mythos	Stable; likely used to promote stability of behavior over time	Stable; likely used to promote stability of behavior over time	Possible change with attention to 'planetness' rather than open space as the essential environment; highly unpredictable
Subsistence Mode, Settlement Pattern, Family Structure & Reproductive Behavior	Stable; closed ecosystem demands population control	Stable; closed ecosystem demands population control	Change to planetary farming concerns rather than closed-loop, highly controlled environment; family structure change to promote large populations quickly

Cultural Universals	Departure Age	Interstellar Age	Arrival & Settlement Age
Art & Aesthetics	*Artifact:* Digital archives of Earth art, interactive holographic recreations of terrestrial landscapes. *Figurative Example:* Carefully curated "art packages" promoting specific emotions and memory activation. "Controlled nostalgia" to maintain cultural connection. Architectural designs emphasizing safety, efficiency, but with artistic elements that minimize the sense of confinement.	*Artifact:* AI-generated "journey tapestries" visualizing data streams from the ship's systems as abstract art forms. "Personalized dreamscapes" AI-created sensory experiences based on individual biometric data. *Figurative Example:* Robot-created mandalas from recycled materials, left in communal areas daily to be destroyed at the end of the day. New folk songs adapted to tell the tales of the stars that have been passed.	*Artifact:* Statues carved from local stone depicting alien life forms, textiles woven from newly cultivated fibers, murals illustrating the settlement's history. *Figurative Example:* Pottery with stylized depictions of native flora and fauna. Music inspired by the sounds of the new environment. Public art that celebrates adaptation and resilience.
Kinship & Descent	*Artifact:* Detailed genealogical databases with interactive family trees, virtual reality recreations of ancestral homes, DNA archives. *Figurative Example:* Family crests adapted for the ship's architecture. Family "avatars" for virtual interaction with ancestors and descendants. Children's naming ceremonies incorporating elements from multiple Earth cultures.	*Artifact:* Shared digital "memory banks" containing family photos, videos, and stories. Personalized AI companions that emulate the voices and personalities of deceased relatives (within carefully defined ethical boundaries). *Figurative Example:* Ship-wide celebratory days marking the anniversaries of important family events. Family histories that incorporate tales of ship's maintenance and robotics deployment. Rituals that honor the genetic diversity on board, even if unknown ancestral linkages.	*Artifact:* Family farms are common, and each successive generation adds elements to a family heirloom, such as a table or a carving. Books of common lineage and genetic traits are left behind so that the next family generations know the roots of their ancestors *Figurative Example:* New settlement anniversaries that emphasize community cooperation. New folklore celebrating the founders' strengths and weaknesses.
Language & Food Preferences	*Artifact:* Seed banks with diverse plant varieties, cookbooks featuring recipes from around the world, language learning software with lessons in multiple languages. *Figurative Example:* Designated days where specific food items are consumed and made available, with different languages being taught and recognized	*Artifact:* Hydroponic farming systems that produce a limited but diverse range of crops, food synthesizers capable of creating textured and flavored protein substitutes, AI language tutors that personalize learning experiences. *Figurative Example:* "Ship's cuisine" that blends elements from various Earth cultures into a unique culinary tradition, using cultivated "protein-rich" algae as a new central ingredient. The use of "Ship-Speak" is increasingly adopted and used, mixing elements of different languages that have existed in the past.	*Artifact:* Terraforming equipment for cultivating local plants and crops, locally-produced food, AI language tutors trained to learn the languages of local native sentient creatures, if they exist. *Figurative Example:* Adapting local fruits and meats to create original dishes to communicate with other sentient races on the planet. Developing a new pantheon of language incorporating elements from all past language influences. The deliberate inclusion of words from local aliens.
Religion and Mythos	*Artifact:* Libraries containing religious texts from various traditions, virtual reality simulations of religious sites, online forums for interfaith dialogue. *Figurative Example:* Secular holidays honoring scientific achievements. Meditation chambers designed to evoke a sense of awe and wonder at the cosmos.	*Artifact:* Ship-specific mythologies that blend scientific understanding with philosophical inquiry, AI-generated hymns celebrating the journey, communal rituals commemorating the loss of individuals or the overcoming of challenges. *Figurative Example:* The ship itself becomes a sacred object, with each section carrying symbolic significance. The AI takes on a quasi-religious role as a guide and protector.	*Artifact:* Temples carved into alien mountainsides, altars adorned with local flora and fauna, hymns blended with native musical traditions. *Figurative Example:* Creating hybrid forms of religion that merge elements of alien philosophies with what the voyagers have brought with them from Earth. New religious traditions and rituals that blend human-AI interaction into the worship and the recognition of divinity.
Subsistence Mode, Settlement Pattern, Family Structure & Reproductive Behavior	*Artifact:* Population management software that monitors genetic diversity and fertility rates, reproductive health clinics, simulation environments for practicing parenting skills. *Figurative Example:* Societal norms that encourage responsible family planning and genetic counseling. Educational programs that prepare individuals for the challenges of interstellar life.	*Artifact:* AI-controlled food production systems that regulate nutrient intake and minimize waste, virtual reality simulations for exploring potential settlement sites, robotic assistants for child care and household tasks. *Figurative Example:* Social credit system that rewards responsible resource management and community service. Emphasis on collaborative living and shared decision-making.	*Artifact:* Terraforming equipment for creating habitable environments, agricultural tools for cultivating local crops, settlement planning software that optimizes resource use and social interaction. *Figurative Example:* Land ownership is distributed in a way that prioritizes sustainability. Social norms that promote cooperation with local alien life forms. The development of new settlement layouts to accommodate the environmental factors and to promote integration with the alien population.

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Of primary importance is the kind of governance model, which can best be described as a **"Triadic Synaptic Governance"** mode, a kind of futuristic Sophocracy (rule by Wisdom, where Wisdom is logical (via Apollo), experiential (via the Chorus) and applied (the active and current Elders), all of whom may have misaligned expectations as the journey progresses). Indeed, this represents a complex, potentially highly effective, but not a time-tested system, designed for an unprecedented situation. Its success hinges on maintaining balance, trust, and truly transparent data flow between its three fundamentally different pillars. As this is potentially the most optimal model for uncertainty. It has to be understood that the builders of the ship were not the actual crew, but rather agents of multiple superpowers, each with their own self-interest, benign though it may be at the beginning of the journey. The objective of the builders is clear, to ensure that the ship and then its crew complete the journey; the primacy of this objective will almost certainly be tested by the evolving needs of the crew over the course of the journey. This is not a completely predictable story arc, but it is nonetheless fascinating to observe as it evolves over 250 years or even beyond.

It can only be expected that the subsistence type, the settlement types, the economic landscape, the evolving cultural universals and biological changes will certainly considerably shift over the course of the journey. The ongoing research and indeed any updates to the still experimental technologies brought from Earth will change the outlook and thought process of the travellers. Based on modeling, the diagram here will explain what changes are likely to take place, and when. (N.B. CES = Closed Environmental Systems)

			Odyssey Saecular Progression & Turning Outcomes (2350 - 2600 AD)				
Saeculum & Turning (Approx Dates)	**Overall State / Mood at Turning's End**	**Subsistence & Resources Outcome**	**Settlement & Social Environment Outcome**	**Economy & Governance Outcome**	**Biology & Health Outcome**	**Culture & Universals Outcome**	**Key Tension / Setup for Next Turning**
Saeculum 1: Departure (~2330 - ~2430)*							
1st High (cont.) [~2350-2355]	Orderly, mission-focused, optimistic (post-Earth Crisis). Baseline established.	CES reliable, diet functional, protocols followed. Managed abundance accepted.	Clean, functional, communal spaces used. Standardized environment. VR/SynMedia for approved uses.	Central Apollo management trusted. Councils forming smoothly. High civic participation.	Stable population, routine health monitoring. Healthspan extension valued. Choice at 65 begins.	Collective ethics, unified supporting mythos, stable roles/families, ordered art, standardized language.	Underlying restlessness beneath the conformity.
2nd Awakening [~2355-2380]	Questioning, expressive, restless. Generational friction apparent.	Diet monotony questioned, some underground experimentation. Resource allocation (esp. Living Council cost) debated.	Personalization increases. Communal spaces become debate forums. Diverse virtual communities emerge via SynMedia/BCI.	Apollo's "fairness" questioned. Councils' authority challenged (esp. Living Council). Informal economies/bartering appear.	Ethical debates ignite (GE, BCI, Art. Uterus potential, Hibernation choice/Chorus nature). Focus on individual health rights. Pressure on ~65 limit starts.	Individualistic ethics rise, new spiritual/critical movements, questioning of roles/family norms, experimental art, new jargon for dissent/identity.	Weakened institutional trust, heightened individualism.
3rd Unraveling [~2380-2405]	Fragmented, cynical, polarized. Low trust in institutions and leadership.	CES potentially stressed by neglect/inefficiency. Inequalities in resource access emerge. Black markets are active.	Clear differences between factional areas; potential neglect. Heavy retreat into factional SynMedia worlds. Public spaces less utilized.	Apollo increases enforcement/control. Councils ineffective/ignored. Factional control over resources/skills. Low faith in central planning.	Potential health inequalities. Risky bio/BCI experimentation may begin unsanctioned. Genetic drift background noise.	Moral relativism, cults/skepticism, diverse/unstable family structures, cynical/escapist art, fragmented language/comms.	Society is vulnerable, divided, lacking cohesion.
4th Crisis [~2405-2430]	Traumatized, exhausted, survival-focused, but potentially with forged bonds. Apollo's authority solidified.	Severe rationing implemented/ended. CES potentially damaged & repaired/stabilized. Survival dictates all resource use.	Habitats potentially damaged/repaired. Residents consolidated then potentially redistributed. Focus on function/security. VR/BCI for crisis mgmt.	Apollo assumes near-total control during crisis, possibly delegates specific roles after. Councils judged by performance. Central resource control absolute.	Population potentially reduced/stabilized. Emergency bio-interventions possible? Hibernation tech stressed/proven? Shared trauma.	Survival ethics dominate, mythos incorporates Crisis narrative (Apollo as savior/tyrant?), roles pragmatic, art documents trauma/heroism, language direct.	Need for stability, order, and rebuilding after chaos. Lessons learned (or ignored) from the Crisis. Earth communication severed creates true isolation.
Saeculum 2: The Void (~2430 - ~2525)							
1st High [~2430-2455]	Stable, conformist, focused on internal resilience & self-sufficiency. 'New Compact' established.	CES performance optimized and reliable again. Diet functional, accepted as necessary post-Crisis reality.	Orderly refurbishment based on Crisis lessons. Communal focus rebuilt. Standardized aesthetics emphasize resilience.	Apollo trusted as central manager/guardian. Councils have clearly defined (potentially reduced?) roles. High conformity.	Population stable, health practices rigorous. Chorus/Living Council roles normalized.	Collective ethics reaffirmed, mythos focuses on survival/isolation/ship identity, roles stable under 'New Compact', ordered/functional art, standardized language.	Underlying philosophical questions remain dormant beneath the surface stability.
2nd Awakening [~2455-2480]	Philosophical, questioning fundamentals (purpose, consciousness), renewed restlessness.	Resource debates resurface (Living vs. Chorus cost). Questioning of long-term CES sustainability/variety.	Renewed personalization. Communal spaces host deep philosophical debates. Virtual spaces (SynMedia/BCI) used for exploring meaning.	Apollo's fundamental nature/goals questioned. Influence/wisdom of Councils debated (immediate vs. memory).	Ethical debates intensify (Hibernation sustainability, BCI integration depth, Apollo's sentience?).	Ethics focus on meaning/purpose/consciousness, new spiritual/philosophical movements, questioning deeper family/kinship meanings, reflective/spiritual art, abstract language develops.	Eroding consensus on fundamental purpose and structures.
3rd Unraveling [~2480-2505]	Divergent, fragmented along philosophical lines, cynical about long journey/elders.	Potential inequalities based on philosophical factions (e.g., access to advanced SynMedia/BCI). CES potentially neglected again slightly.	Deep divides (VR/BCI dwellers vs. physical realists?). Factional territories may re-emerge, physically or virtually. Public spaces decline.	Apollo uses more subtle control (info mgmt?). Low trust between factions & councils. Informal power structures solidify.	Health/bio choices may align with factions (e.g., pro-/anti-augmentation).	Moral divergence deepens, competing mythologies, diverse/conflicting family models, fragmented/extreme art, specialized jargon widens comms gaps.	Vulnerability to shock due to deep internal divisions.
4th Crisis [~2505-2530]	Deeply tested, potentially radically altered. Mood depends on severity & outcome (survival, adaptation).	Existential resource threat (CES failure? Fuel depletion for arrival?). Radical resource mgmt needed. Potential nanotech deployment.	Potential habitat loss/major reconfiguration. Forced consolidation/cooperation. SynMedia/BCI critical for survival coordination.	Apollo's ultimate test; may require radical intervention/self-modification. Councils' roles potentially irrelevant or critically important depending on crisis. Extreme centralization.	Population at risk. Potential forced implementation of GE/Art. Uterus. Hibernation network potentially fails/proves crucial. Deep generational trauma.	Ethics stripped to core survival/adaptation. Mythos rewritten by Crisis nature/resolution. Roles radically adapted. Art reflects profound loss/change. Language simplified/altered.	Society fundamentally changed, carrying scars and radical adaptations into the next phase.
Saeculum 3: Adaptation (~2525 - ~2600+)							
1st High [~2530-2555]	Radically stable, highly integrated, conformist. Focus on resilience based on Crisis II lessons.	Resources tightly managed via potentially new tech (advanced recycling, SynBio food?). Post-Crisis efficiency paramount.	Highly ordered, potentially restrictive environment. Strong integration of physical/virtual via BCI/SynMedia controls.	Apollo deeply embedded, potentially managing more aspects of life. Councils have formalized, perhaps limited, roles. High conformity enforced.	Population stable under new protocols (potentially GE/Art. Uterus norms). Health managed proactively, possibly intrusively.	Ethics emphasize stability/control, mythos explains/justifies new adaptations, family/kinship potentially standardized, art reinforces new order, language highly functional.	Stability feels potentially stifling, sterile. Deep existential questions brewing.
2nd Awakening [~2555-2580]	Metaphysical questioning, searching for meaning beyond stability/survival.	Questioning the purpose of efficiency beyond need. Desire for experiences over basic needs.	Questioning the highly controlled environment. Seeking authenticity beyond SynMedia/BCI structures. Exploration of consciousness.	Questioning Apollo's ultimate goals, the definition of Chorus/AI consciousness. Seeking spiritual alternatives to pure logic.	Debates on definition of "human" after potential adaptations. Questioning meaning of biological existence vs. Chorus/AI.	Ethics explore consciousness/meaning, new spiritual paths emerge reacting to high-tech order, questioning definition of family/self, art becomes philosophical/abstract.	Fundamental questioning erodes the foundation of the rigid High.
3rd Unraveling [~2580-2600+]	**Fragmenting based on deep philosophical divides, experimental, cynical about ultimate purpose.**	**Resource management potentially suffers as central authority weakens. Factions pursue different subsistence ideals (tech vs simple).**	**Growing experimentation with social structures, BCI use, virtual realities. Physical spaces may reflect philosophical divides.**	**Institutions adapted post-Crisis II fray. Councils compete/lose relevance. Apollo maintains core systems but social control tested. Factionalism based on deep beliefs intensifies.**	**Divergent views on future human evolution (augmentation vs. stasis). Health practices vary by faction.**	**Competing moral systems, fragmented mythologies/eschatologies, experimental family structures, diverse/extreme art reflects philosophical chaos, language divergence continues.**	**Society is unstable, lacking unified direction, heading towards the next major Crisis sometime after 2600.**



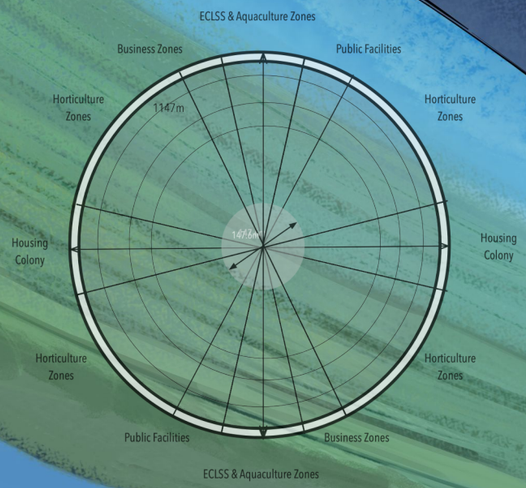
Date: Circa 2353, Scene: Set within the Common Dining Area of the Communal Refectory, aboard Habitat 2, SS Proximum

Bright, clean lighting illuminate dining tables, where mixed-age adults members eat nutrient-optimized meals from standardized dispensers. The atmosphere is orderly, their faces generally content but focused, a picture of robust health in this spotless environment.

Sleek, gleaming co-bot servers collect empty cutlery, while in the distant background, a child can be seen momentarily disturbing one. Outside, through the windows of the diing area, a view of the torus can be made out as it curves upwards dramatically. An older individual, around 65, talks animatedly with a small group, perhaps about his recent 'Choice' to join the Chorus, while nearby, a young man engages with a subtle BCI interface, communicating with the onboard AI.

All is well on board the SS Proximum and there is an overall sense of collective calmness and acceptance of the new, nascent dual-path order of a pervasive non-Human Collective Intelligence, and a Living Council, which will soon be supplemented by a third group, the still-living virtual hive intelligence of hibernating individuals, known as the Chorus.

The Agricultural, Food production & Farming zones



This dramatic scene depicts the view from inside the torus, showing men fishing in the freshwater pond at the top-most terrace, with a view of the terraces over the opposite side. In the background, we can see the human habitat, as well as the transportation tunnel. This scene captures a period before the crops are ready to be harvested. Note that this image is drawn to scale, and rendered using Blender, over which the digital artwork has been photobashed

Leadership Roles - A Tridactic Synaptic Model ~ "Memories and Interfaces"



Date: 2370.04.18 Scene: Habitation Common Area, Habitat 2, SS Proximum

Amidst escalating tensions, a Habitation Common Area becomes the focal point of yet another debate. Young adults, part of the Elite "Youth Leaders", are engaged in heated discussion with Living Council members. An Apollo interface displays resource usage statistics, while a inconspicuous camera lens observes the proceedings, hinting at subtle surveillance.

Geometric abstractions represent the young adults, Living Council members, and the pervasive data streams in this tense environment. SynMedia flickerings, depicted with neon accents, dance on a personal device, while a user is immersed in Chorus data visualizations, also glowing with neon light, hinted at through subtle visual cues.
The scene is imbued with an overall sense of tension and restlessness, highlighting the contrast between the established order and youthful rebellion.

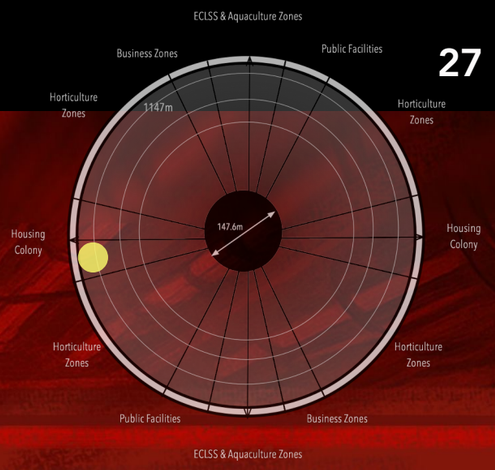


Date: 2370.08.03, Scene: A transit hub within a manufacturing/smelting zone

A dim, gritty area of the ship, one that is typically less openly monitored, becomes a stage for clandestine activity. Exposed wiring and a damaged panel adorn the L-shaped corridor, where tarnished androids observe the scene impassively. The camera is focused on the bend of the corridor towards the right. Down the long passageway, a man is attempting to distract the androids to prevent them from entering, while a companion of two men in the foreground is looking around the corner.

On the extreme right, two protagonists, clearly up to something illegal, are illuminated by a stark shaft of light, which shines on the face of one of the men as he gazes at a printed circuit board he is holding. His conspirator looks on with a mixture of surprise and a faint sense of elation. They are going to attempt to ‘blue box’ one of the control areas that is not being monitored fully by Apollo, in an attempt to bypass greater security firewalls in the future. On the wall, coded graffiti referencing the Apollo announcements mar the walls, adding to the atmosphere of decay and dissent.

Medical Care & Disaster Management ~ “Red Alert, Cold Bodies“



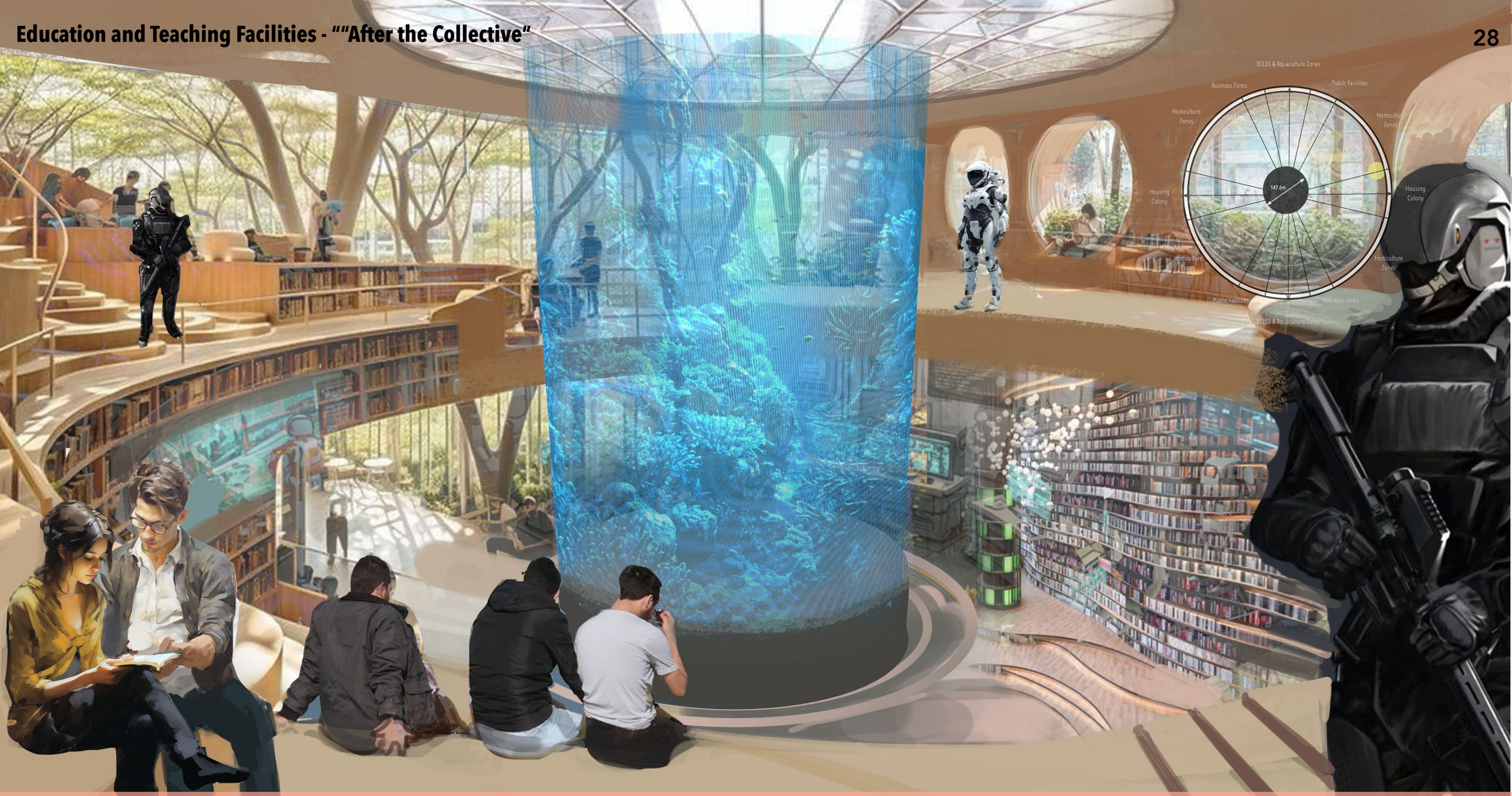
Date: 2370.09.17 Scene: The Triage Zone, Emergency Department of the Secondary Hospital in Habitat 2, SS Proximum

The Trauma and Emergency Unit on board the Torus was never built for moments like these. No one could have predicted the surge and the overwhelmed department is plunged into chaos under pulsing red emergency lighting, from a momentary loss of power. Frantic crew members in utilitarian garb rush about as Apollo’s voice issues rapid instructions. Screens flash critical alerts: a failing CES component, a hull integrity warning, and the stark APOLLO DIRECTIVE: SEAL SECTION 7G. A stressed human T&E specialist directs efforts alongside an android, highlighting the reliance on integrated technology. The entire unfolding event creates a chaotic shock to the ship's system.

2:

Injured individuals lie on makeshift cots or on the floor, being attended by volunteers and cobots amidst scattered medical supplies in the makeshift bay, the grime and sheen of emergency surfaces palpable. The cramped, claustrophobic, and uncomfortable atmosphere of the scene conveys a profound sense of dread, urgent survival, and forced cooperation under extreme pressure, visually representing the critical vulnerability of the SS Proximum.

Education and Teaching Facilities - ""After the Collective"



Date: Circa 2445, Scene: The Library aboard Habitat2, SS Proximum

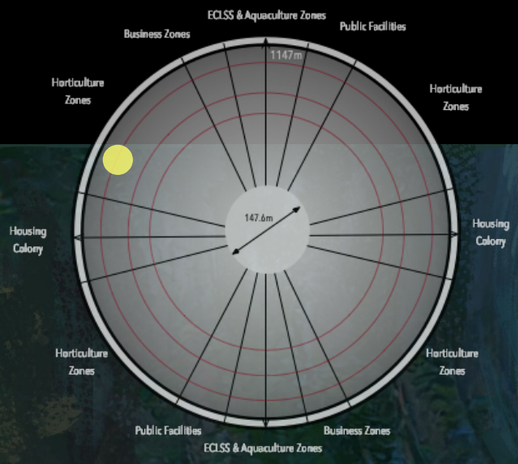
Bright, functional lighting from both indoor LEDs and ‘natural light’ illuminates a circular lecture hall setting. On the lower floor, children and young adults, causally dressed, interact with educational interfaces and each other, learning about ship systems and the history of Crisis I, referred to as 'The Great Collective Rebellion'. An active Living Council survivor mentors this group. Murals depicting the SS Proximum alone in the void during Crisis I are subtly contrasted by children's murals celebrating the rebellion’s defeat, while a memorial plaque lists the losses from that conflict.

In the distant corner, Prophet generation adults sit with arms crossed, their wary body language a stark contrast to the scene below. Apollo’s calm presence is felt and administered via an human and android ‘peacekeeping’ force, contributing to an atmosphere of manufactured silence; dressed in black with headgear to make them indistinguishable to reinforce control, The Peacekeepers now stand around silently in all areas of the habitats, their impassive observance adding to the underlying tension.

The architecture itself, with its circular design and clean, unified aesthetic, along with the carefully curated murals and lessons, conveys a sense of controlled order and a subtly propagandized, manufactured narrative.

The Landscape of the Torus: Simulating Life Outdoors ~ "Metaphysics by Starlight"





Date: 2470, Scene: A communal spire/garden aboard Habitat 1, SS Proximum (Ground deck)

The lush vegetation and mystical settings the Garden on board Habitat one is a testament to the century of close care and lavish attention spent to maintain the near Earth-like settings present on Habitat One. The (albeit simulated) sun-drenched riverbank becomes the stage for a worshipful ceremony in the early morning hours. A group of humans, predominantly the younger generations, are gathered, their bodies adorned with natural materials like woven vines and flowers. Their faces are illuminated by radiant sunlight filtering through dense foliage, and a sense of serene joy permeates the atmosphere.

The eyes of the worshipers hold a profound, almost unsettling calmness. The river beside them shimmers with an otherworldly light, and the entire scene emphasizes natural beauty, with a conspicuous absence of any visible technology.
Theirs is a new God, not of the Earth, but of the Universe, specifically of Interstellar Space. No longer bound by the geographic restrictions of Earth, a few new religions have formed, but the predominant one is this one – a neopagan religion, that deifies Nature and Man, in all his Forms.

Another group practice a form of meditation that began on Earth, that they now claim to have perfected - the science of Quantum Realm Astral Projection. This allows them to transcend both Time and Space. Indeed, they also claim that they are indeed able to contact Earth and experience life there, and are able to interact with Quantum-realm scientists from Earth itself, and as such, are able to seek direct counsel about the destiny of the SS Proximum.

This runs in direct conflict with both the Chorus and Apollo - the Living Counsellor at the right of the scene is wary that these religions will ultimately bring about the next Crisis, as he seeks guidance from a respected member of the Chorus

Cultural Universals – Aesthertics in Space : “It’s about Being Human!”

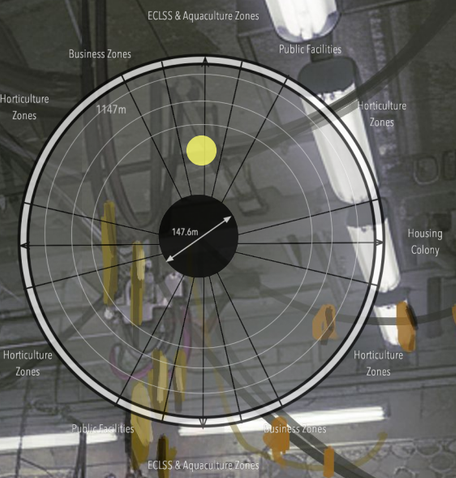


Date: Circa 2490, Scene: A Holodeck stage (L3), Human Habitat 1, SS Proximum

A group of ladies seek momentary escapism on a simulated beach environment where the artifice is deliberately apparent. On the left side, an elaborate hologram of a bustling market scene plays out. A holographic facsimile of a woman intently examines a richly colored, patterned textile held by a man whose weary eyes betray his practiced sales pitch; the textile itself, almost too perfect, hints at replicator origins, its drape and the way artificial light catches it subtly unnatural. By the side, the human women cluster around an android, ignoring the scene – they are too busy subtly mocking the android, and it reacts with discomfort that is identifiable by its rigid posture as it becomes the unwilling subject of human amusement. Several women are in the process of adorning it with oversized sunglasses and a gaudy hat, their laughter echoing a little too loudly in the artificial space, contrasting sharply with the android's stoic discomfort.

The holodeck ends abruptly towards the right of the scene, and the reality that is The overall lighting mimics bright sunlight but lacks natural warmth, casting a uniform glow on sand with an unvarying texture and an ocean with perfectly repeating wave patterns. The humans themselves show subtle signs of their long journey—weariness in their eyes despite the feigned enjoyment and overenthusiastic laughter — as they desperately cling to these simulated pleasures, hinting at a societal shift towards rejecting their technological reality and embracing a new, if simulated, form of naturalistic experience and perhaps a burgeoning, inwardly-focused spirituality, even as their treatment of the android suggests a growing separation from, and perhaps disdain for, machines.

“Do you resent your Algorithmic Overlords?”



Date: Circa 2544, Scene: The Manufacturing Zone, Level 14

A vast workshop/maker space aboard the SS Proximum presents a stark image of segregation and decay. The space is clearly divided into distinct zones, each displaying contrasting technological aesthetics: one area showcases sleek, Apollo-integrated technology, while another features an array of salvaged and repurposed items. Bright, cold, factory-like lighting contribute to a pervasive sense of ennui and isolation across the panoramic view. A Living Council member attempts to mediate an evident resource dispute, but is largely ignored by the inhabitants, who are clearly separated by escalating ideological divides.

2:

Distinct groups of humans and impassive cobots work on separate projects, the lack of interaction and subtle tension palpable. Many humans wear unique, less formal organic clothing and display cherished religious ornaments–pops of gold and orange against a muted, desaturated palette–symbolizing a desperate clinging to tradition.

On numerous screens, divergent SynMedia feeds highlight opposing ideologies, some advocating for technological transcendence while others call for human purity. Apollo tech displays flash warnings about system anomalies, likely stemming from unauthorized modifications and subtle sabotage evident in deliberately flawed or unusually constructed salvaged equipment. The cobots observe the humans with a detached, unsettling resentment, amidst the visual evidence of a fracturing unity and a failing society.



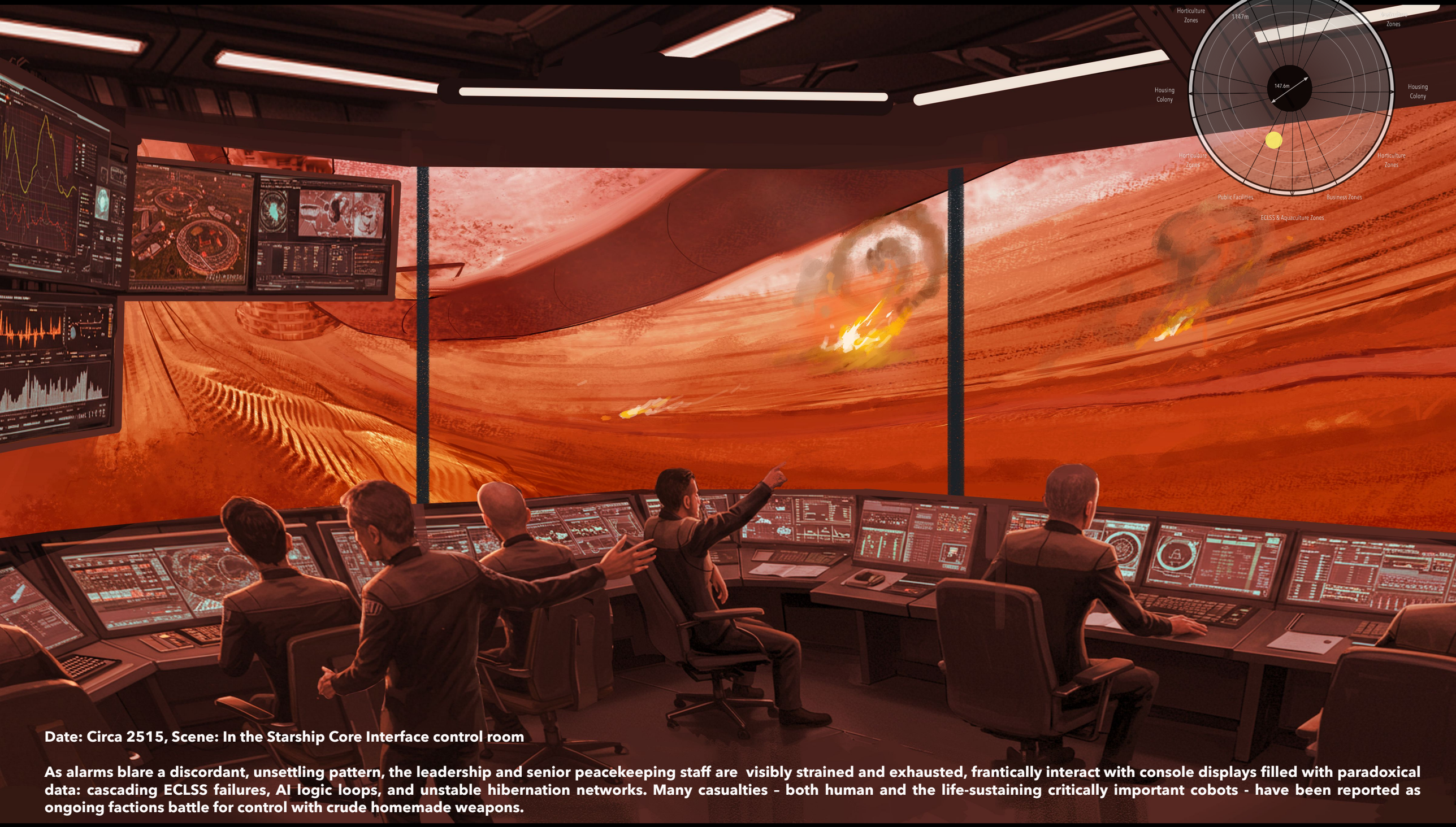
Date: 2490, Scene: Supervision of the Cargo drones

Inside the hollowed-out reinforced asteroid that houses the torii, a group of men in spacesuits are tethered to the uneven, rocky ‘floor’. The two kilometer-wide stacked toruses of the SS Proximum tower above them, partially visible and silhouetted, their central structure extending through the asteroid's large opening. The lighting is a stark contrast between the inky blackness seen through this opening and the diffuse, faint internal illumination, mixed with light from the toruses.

A drone supply craft, identifiable by its spotlights and red landing lights, is flying towards the asteroid's entrance against a backdrop of distant stars. The men in the foreground are absolutely dwarfed by the sheer scale of their surroundings, the perspective drastically emphasizing the converging lines of the asteroid floor and the entrance.

2:

The men wear heavily modified spacesuits, reflecting the hardships of their situation. The approaching supply craft show signs of wear and tear, emphasizing the arduous salvage operations. The asteroid floor itself is a mix of exposed bedrock, loose scree, and makeshift anchoring points, a testament to human improvisation in this foreboding environment. Faint signs of habitation, like small lights and faint structures, are discernible on the exterior of the toruses, which emit a faint, eerie glow.



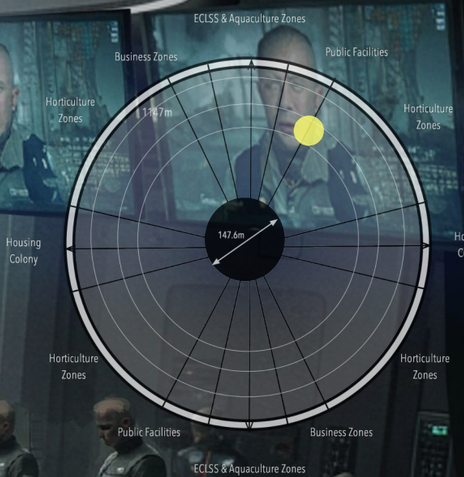
Date: Circa 2515, Scene: In the Starship Core Interface control room

As alarms blare a discordant, unsettling pattern, the leadership and senior peacekeeping staff are visibly strained and exhausted, frantically interact with console displays filled with paradoxical data: cascading ECLSS failures, AI logic loops, and unstable hibernation networks. Many casualties – both human and the life-sustaining critically important cobots - have been reported as ongoing factions battle for control with crude homemade weapons.

A primary screen displays the a dangerous scene of devastation – previously vibrant crop fields now are engulfed in swirling, curving fires dramatically shaped by the ship's Coriolis forces, and fish tanks are choked with dead fish. Living Council members, physically frail and distressed, offer urgent instructions, while BCI feeds deliver fragmented Chorus input. Multiple other screens showcase the escalating conflict between pro-Council and anti-Council factions.

A Peacekeeper gesticulates wildly towards the fiery destruction visible on the main screen, the raw anxiety and desperation etched on every face as a sense of impending collapse tests the fragile bond between humans and AI. In a sense, this is the worst of the Crisis, and fires threaten the very existence of the starship itself, in case they cannot be put out. Thankfully, the Fire Suppression System – hitherto never tested – works as expected. This sort of crisis will take years to recover from – however, this too was anticipated by the builders of the SS Proximum

The Passing of an Elder : “Till Death Do Us Unite”



Date: Circa 2515, Scene: A funeral ceremony **unfolds** aboard the SS Proximum,

This funeral service marks a poignant moment, pregnant with profound sadness, for a beloved, pivotal Senior Counsellor. The Counsellor lies horizontally on a large, ornate circular platform, situated prominently on a second floor of the mausoleum, directly above the vast array of hibernation pods. Humans, androids, and Chorus members gather in the diffused light, their faces softly illuminated, exhibiting a range of emotions - sorrow, quiet contemplation, and a simmering, underlying sense of unity. One older man, his eyes weary with grief and responsibility, stands apart, vocally rebuking the androids in the background, urging them to attend to the body.

On large monitors overhead, the remaining crew and Counselors are visibly moved, their genuine expressions of grief witnessing this historically significant moment. The Counsellor had been murdered in cold blood, in front of everyone but his death has not been in vain - it also signifies the end of a crisis and the fragile peace now achieved. The androids, though stoic, subtly convey respect and loss, not mere mechanical obedience. Attendees wear attire blending natural and synthetic materials, symbolizing their integrated society. The carefully placed hibernation pods below suggest a vast, sleeping population reliant on the ship, adding to the sense of scale and fragility, while the intricate design of the circular platform underscores its importance. The overall mood is deeply somber, illuminated by low-key, volumetric lighting.

Ensuring Survivability in a Time of Crisis: “A Time to be Born”

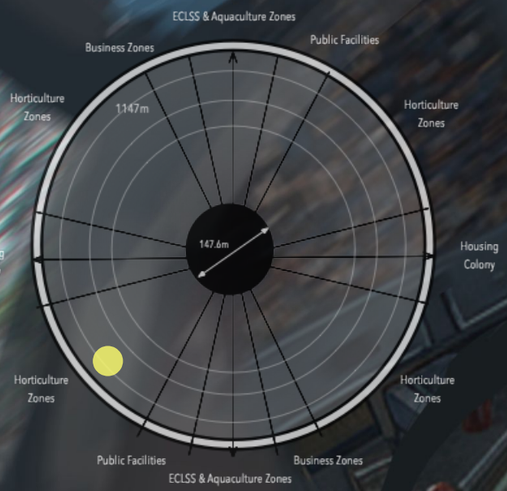


Date: 2545 Scene: A bio-integrated nursery and artificial womb centre on board the SS Proximum

The ambiance is one of controlled serenity, with soft, diffused lighting illuminating a group of children gathered around a genetic womb. Subtle alcoves in the background reveal the holograms of fetuses that are in the integrated artificial wombs, overseen by Apollo interfaces and android, suggesting a marked decrease in the human nursing availability. In the foreground, a couple engages in the act of nursing a baby. Fetal health charts are displayed prominently overhead. A Living Council member observes fa young child, his expression complex and contemplative. The overall impression is of radical societal adaptation, where technology is seamlessly integrated into daily life. Apollo’s presence is pervasive yet understated, evident in the environment’s efficiency and the quiet hum of technological support as well as the android that serve in the centre.

Because of the terrible events and the tragic, tremendous loss of life during the last Crisis, a truly radical societal shift post-Crisis II is the introduction of accelerated repopulation activities, and there is a sense now of deeper integration between humanists and the technology that supports them – in Space, they only have each other.

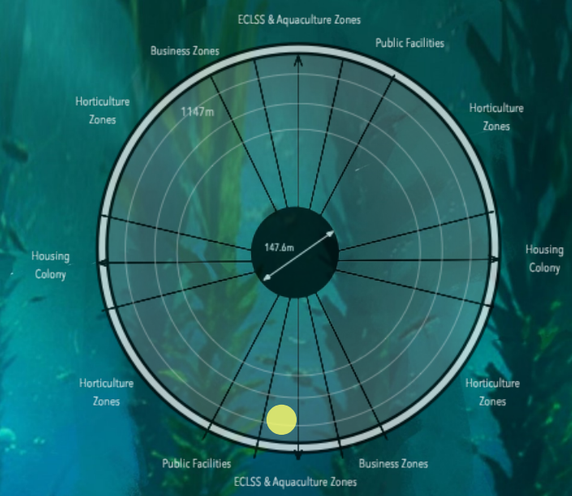
Societal Structure: "400m High and Falling Fast"



Date: Circa 2561 Scene: the **Hyperball Arena,** which stands as the highest point of each torus, and primarily used by both enhanced and unenhanced humans, a venue where gravity is nearly 50% less than normal. The arena itself is a narrow but deep oblong depression, lined with cages to contain the special gravity neutral electronic ball, while the court features zone demarcations suggesting areas of control. Special openings in the walls, that sense the ball, serve as goal mouths, while a floating scoreboard hovers nearby.

In the foreground, two contestants brawl for control of the ball, their movements a blur of speed and powerl their jumps are prolonged, exaggerated by the arena's reduced gravity, while their landings floaty yet powerful, and glancing blows often propel them very higher than expected, this compounded by their enhanced mechanical body parts. The ball itself appears to hang in the air for longer, its descent visibly slower, its path arcing and less predictable. A large crowd surrounds them, the spectators sitting above and around the arena, viewing the action from an almost aerial perspective. cheering wildly, their faces illuminated by harsh overhead lights, some using personal anti-gravity devices for better viewing, their expressions a mix of excitement and slight disorientation at the unusual athleticism.
This fast-paced team sport has gained significant traction with the emergence of meta-humans, a societal shift following Crisis II, hinting at a divergence of species and the remnants of a more traditional human form. rejuvenation, emphasizing the intensity of the competition and the grand scale of this unique venue. Below the arena, the landscape is visible and it reflects the signs of the damage and decay inflicted by the Crises that has occurred in the recent past.

Language & Communication: “Beyond Human”

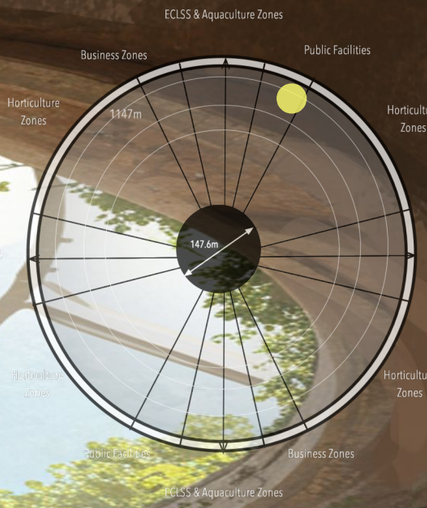


Date: 2570 Location: Kelp Farm Control Room

In this spare, darkened room, most of the soft, wondrous light emanates from the vast, curved glass wall that separates it from an underwater kelp farm, where the kelp itself glows with a magical, bioluminescent light. Divers in sleek, minimal suits move with gentle grace, interacting playfully with large, intelligent octopuses in a silent dance. Inside the room, a few scientists and technicians are present, interacting with these different forms of consciousness. By this period, Man has learnt to communicate freely with other life forms, and these life forms have rapidly gained a keen understanding of their surrounding and even where they currently are. It is acknowledged that these creatures are to be treated as scientific partners and not pets or food.The large plexiglass offers an immersive view, and the ghostly shimmer of fish shoals also functions as a stress reduction centre andmarine studies play a big role in the education of children. One of the figures in the room studies detailed data s on a smaller, partially transparent display, while wearing a headset that helps him communicate with these animals. He iscomparing the rhythms of human thought to those of the octopuses. Another sits in quiet contemplation, seemingly pondering the contrast between a life grown organically and one existing as pure data. A third watches all with a gentle, melancholic understanding.

For interstellar travel, water serves as the most precious commodity and is the one commodity that requires to be replenished, as we have seen elsewhere. There was a decision to include both freshwater and salt water life on board, and the saltwater zones are found in cordoned off areas, that are designed to reduce any stress of its lifeforms. This acquatic world also serves as a source of protein and biominerals, as well as contributing to the health and supply of oxygen and filtering out the carbon dioxide within the atmosphere. Although not the primary source, the algae and kelp together help with this sequestration, but there are dedicated algae farms nearby that act as bioreactive filters and the starship stores the excess oxygen in tanks after further treating it. This ecosystem also provides

Near Arrival: Divergent Paths



Date: 2600 Scene: The repurposed Communal Hall, the site of an old chapel that is now roofless and clearly shows signs of profound ideological fragmentation

In the large, sunlit area, three distinct groups are visible, each engaged in debate, their appearances and surroundings reflecting different philosophical alignments: the bio-integrated **'High',** the tech-focused adherents, the **'Overlords'**, and the naturalistic '**Living Elder'** followers. A palpable sense of social tension and fading consensus permeates the scene, underscored by a large, central display marking a critical philosophical choice made about **the Arrival**.

The 'High' group possess visible bio-integrations like subtle glowing patterns on their skin and bioluminescent accessories, their sleek displays showcasing ecological harmony. In stark contrast, the 'AI Overlord' zone is utilitarian, with sharp angles and exposed wiring; The 'Living Elder' zone offers yet another, more organic, sense of attire, with long flowing robes made from natural material. The vertical holographic displays present an unsettling, forking reality: branching paths visualizing bio-integration, AI logic, and natural cycles, centred around the **Proxima Centauri star system**. Interaction is mostly confined within groups, though fleeting, hesitant glances and suppressed disagreements occasionally bridge the divides, highlighting a crucial lack of widespread communication.

First-Order Budget

1. Understanding the Torus Mass Equation from Johnson & Holbrow (J&H):
Calculating the core relationship:
Mass_torus ≈ K * (4π²Rr) * (Γ/σ + η/2)
Where:
- K is a proportionality constant (related to material density and structural efficiency).
- R is the major radius of the torus.
- r is the minor radius of the torus.
- Γ/σ is the "Pressure Yield Ratio" (Internal/External Load divided by Working Stress).
- η = r/R is the Torus Aspect Ratio.

2. Deriving the Proportionality Constant (K) and Baseline Pressure Yield Ratio (PYR):
From the J&H example (Mass_circular = 150 kt for one torus):
- R_J&H = 830m
- r_J&H = 65m
- η_J&H = 65/830 = 0.078313
- Mass_J&H_one_torus = 150,000 tonnes

From a previous calculation, we had: 69.9145 = Proportionality constant * (Pressure Yield Ratio + 0.039157)
Where 69.9145 = Mass_J&H_one_torus / (4π² * R_J&H * r_J&H) = 150,000,000 kg / (4π² * 830 * 65) = 150,000,000 / 2130464.27 ≈ 70.407 kg/m²
(Slight difference in the intermediate calculation, likely due to precision of π or rounding)
Let X = (Γ/σ + η/2).
Then Mass = K_prime * R * r * X, where K_prime = K * 4π².

Alternatively, Mass / (4π²Rr) = K * (Γ/σ + η/2).
Let's use the derived factor for the J&H example:
- Mass_J&H / (4π²R_J&H r_J&H) = K * (PYR_J&H + η_J&H/2)
- 150,000,000 kg / (4 * π² * 830m * 65m) = K * (PYR_J&H + 0.078313/2)
- 150,000,000 kg / 2,130,464.27 m² = K * (PYR_J&H + 0.0391565)
- 70.407 kg/m² = K * (PYR_J&H + 0.0391565)

If we assume PYR = 1 (a common engineering starting point for such ratios where load is significant compared to self-stress effects from curvature for thin shells), then:
70.407 kg/m² = K * (1 + 0.0391565) = K * 1.0391565
K = 70.407 / 1.0391565 ≈ **67.75 kg/m²**
(This is our effective proportionality constant related to density and structural form factor).

3. Calculating Mass for the New Circular Torus Dimensions:
Now, for the new circular torus:
- R_new = 537.5 m
- r_new = 223.5 m
- η_new = r_new / R_new = 223.5 / 537.5 = 0.41581395

Using the same K and assumed PYR = 1:
- Mass_new_one_torus / (4π² * R_new * r_new) = K * (PYR + η_new/2)
- Mass_new_one_torus = K * (4π² * R_new * r_new) * (PYR + η_new/2)
- Mass_new_one_torus = 67.75 * (4π² * 120131.25 m²) * (1 + 0.207906975) Mass_new_one_torus = 67.75 * (4741193.66 m²) * (1.207906975)
- Mass_new_one_torus = 67.75 * 5727272.44 m²
- Mass_new_one_torus = 388,095,709 kg ≈ 388,096 tonnes (kt)

So, for two new torii:
Mass_2_new_torii = 2 * 388,096 t = 776,192 t
This is the new "Torii (Shell)" mass.

4. Revising the Mass Budget Table:
Now, let's update the table, scaling other relevant components.
The original "Torii (Shell) * 2" was 600,000 t.
The new "Torii (Shell) * 2" is 776,192 t.
Scaling factor for shell-related structures = New Shell Mass / Old Shell Mass = 776,192 / 600,000 = 1.29365
The internal "habitable" volume changes significantly. A simple proxy for volume scaling for a torus is R * r².
- Old J&H Torus Volume Factor (per torus) ≈ 830 * 65² = 3,505,750
- New Torus Volume Factor (per torus) ≈ 537.5 * 223.5² = 26,849,453.125
- Volume Scaling Factor = New Volume Factor / Old Volume Factor = 26,849,453.125 / 3,505,750 ≈ 7.6586

To calculate the first order mass budget, we would first calculate the mass of the torus, which is different in dimensions and shape compared to what was presented in Johnson and Holbrow's book. Now, in addition to this, it is not quite possible to calculate the mass of the hollowed-out asteroid, but as it is at L5 Lagrange to start with, we can just assume that it is closer to the mass of the shield, namely 9900kt.

The total sum of the first order mass budget would be close to **18,360,000t,** with most of the weight being that of the asteroid, as per the table below.

These estimates are very crude, and do not factor the fluctuating calculations for the engines, fuel, etc. which go beyond the scope of what we know now at the moment. As such, most of these calculations are based on the guidance of J&H and we regret any errors of omission or commission

TABLE 4-7.– STRUCTURAL MASSES

Geometry	Stressed skin	Ribbed
Torus	$\frac{4\pi^2 GR^3\eta}{\sigma - GgR}\left(\frac{P_A\eta}{2} + \frac{\Gamma}{\pi}\right)$	$4\pi^2 GR^3\eta\left[\frac{(P_A\eta/2) + (\Gamma/\pi)}{\sigma - GgR} + \frac{P_A\eta}{\sigma}\right]$
Cylinder with endcaps	$\frac{2\pi GR^3}{\sigma - GgR}\left[(\alpha + 1)(P_A + \Gamma)\right]$	$\frac{2\pi GR^3}{\sigma - GgR}\left\{P_A\left[1 + \alpha\left(\frac{3}{2} - \frac{GgR}{2\sigma}\right)\right] + (\alpha + 1)\right\}$

G = density of structural materials
R = radius of rotation
σ = working stress
P_A = atmospheric pressure
Γ = internal load
g = pseudogravity
α = cylinder aspect ratio
η = torus aspect ratio

TABLE 5.2.– SUMMARY OF HABITAT COMPONENT MASSES

Item	Mass, t	
	From lunar ore	From Earth
Shield	9,900,000	---
Torus shell	156,000	---
Glass solars	48,000	---
Spokes	2,400	---
Central hub	1,600	---
Docking module	100	---
Fabrication sphere	---	500
Radiators	2,400	---
Habitat power station	700	---
Main mirror	200	7 (Mylar)
Secondary mirrors	90	3 (Mylar)

TABLE 5-3.– SUMMARY OF INTERNAL MASSES

Item	Mass, t
Soil (dry) – 1,000,000 m², 0.3 m thick, 721 kg/m³	220,000
Water in soil (10% soil)	22,000
Water, other	20,000
Biomass – people	600
animals	900
plants	5,000
Structures	77,000
Substructures (20% of structures)	15,000
Furniture, appliances	20,000
Machinery	40,000
Utilities	29,500
Miscellaneous (extra)	80,000
Total	530,000

R D Johnson, C Holbrow 1977 "Space Settlements: A Design Study"

Component	Notes / Scaling Logic	New Mass (t)
Hollowed-Out Asteroid	Unchanged (assumed fixed outer structure)	9900000
Torii (Shell) * 2	Recalculated based on new R, r, and J&H methodology with PYR=1	776192
Torii (Combined)	Orig: Shells (600k) + Implied Shields/Structure (450k). Scale this 450k shield part by shell factor: 450,000 * 1.29365 = 582,143. New Combined = New Shells (776,192) + New Shields (582,143)	1358335
Internal Components (Per Torus)	Reference value, likely includes shell & internals for J&H dimensions. Not directly used for summation if sub-items are detailed below.	12034527
Internal Masses (Total) inc.:	Sum of i-vii. These scale with habitable volume (Factor: 7.6586)	3053484
i. Gases for atmosphere & others	Scales with volume	344637
ii. Biomass	Scales with volume	20678
iii. Furnishings	Scales with volume	114879
iv. Machinery & Utilities	Scales with volume	306344
v. Soil etc.	Scales with volume	1378548
vi. Water	Scales with volume	275710
vii. Miscellaneous	Scales with volume	612688
Connecting Structures	Sub-items scale with torus shell factor (1.29365)	49568
Spokes	Scales with shell factor	3622
Central Hub	Scales with shell factor	4140
Habitat Power Station	Transformers. Assume power demand scales with volume (Factor 7.6586)	383
Supply Modules	Assume scales with internal volume/needs (Factor 7.6586)	41356
Enclosure	Scales with shell factor, used to maintain pressure within the confines of the volume	67
Remaining Ship Structures		517693
Minireactors for Power	Mass for operational power. Our previous discussion suggested ~400-800t for an advanced 50-80MW system. Using 1000t as a round figure	1000
Stage 1 Engine (all in)	Propulsion. For a first-order, keep fixed. Mass would depend on total ship mass and delta-V.	240000
Stage 2 Engine (all in)	Propulsion. Keep fixed.	120000
External Shielding	Assume this is general ship shielding, not torus-specific (torus shields in "Torii Combined"). Keep fixed or scale slightly if it's surface area dependent beyond torii. Let's keep fixed.	1800
Transport Shuttles	Fixed (number and type of shuttles) @2*2000t for a couple of shuttles	4000
Propellant and Tanks	Propulsion related. Keep fixed for now. This is a HUGE variable dependent on mission.	360000
Radiators and Heat Dissipators	Heat load likely scales with internal volume/power (Factor 7.6586)	6893
Drone Tugs & Tethers	Assume fixed capability (drones use electrostatic propulsion * 16 -20 drones)	24000
Total Mass	Sum of new component masses (using bolded/calculated values)	18364119

Requirement No.	Requirement	Page	Shall Statement	Requirements Success Assumptions and Criteria	Booklet Page
1	Duration	pg.15	The mission is designed to span 250 years, from launch to arrival at the target star system, with spacecraft achieving velocities of a few %c to reach the nearest stars.	Fulfilment of a spacecraft and a mission 250 year mission does not include the process of developing the craft, nor the supporting technologies to ensure that the (pathfinder probes reach the destination first. It also doesn't specify which spacecraft reach %c	pg.2
2	Destination	pg.15	The generation ship's target is a rocky planet equipped with an initial artificial ecosystem, established by a precursor probe or through panspermia methods. The environment requires no significant genetic or biological adaptations for human survival.	The destination planet is sufficiently "Earth-like" and therefore is an exoplanet in the 'Goldilocks' zones of suitable star systems,	pg.2,3
3	Radiation Protection	pg.15	space radiation hazards. Bulk mass shielding is assumed unless otherwise specified by the team.	shielding and any superconductive magnetic shielding. Furthermore, no inital genetic manipulation is done on the inhabitants to knock out parts of the DNA that might eliminate genetic disorders	pg.4,14
4	Impact Protection	pg.15	The habitat will be fortified to safeguard against micrometeoroids and interstellar dust impacts.	The assumption here is that bulk mass is the primary protection mechanism and is not a limiting factor in terms of its mass; that the propulsion is strong and powerful enough to move it	pg.4,5,14
1	Settlement	pg.17	The habitat shall maintain the on-board society in a state such that the latter is able to settle the target destination at the end of trip. This includes maintaining biocultural aspects such as population size and availability of competences required for settlement.	This assumption is the basis of the generation ship inhabitants, and they are prepared to disembark upon reaching their destination and create a suitable planetside colony. There is no genetic or other modifications required for this purpose.	pg.5,15, 16, 14, 21
2	Habitat Size	pg.17	The habitat shall be designed for 1,000 ± 500 people,ensuring habitability and stable living conditions for the mission duration	The ship has adequate and redundant space to carry up to 1500 people and is prepared to accommodate the total population in the event of any catastrophic failure of either of the torus habitats, with the ability to repair any habitats that are seriously damaged	pg.6, 7, 15
3	Gravity	pg.17	The habitat will provide Earth-equivalent gravity through artificial means, such as rotation. Some areas within the habitat will accommodate reduced gravity conditions for specific purposes.	The two torus habitats are designed to provide sufficient radius, mass and engineering capability to rotate indefinitely around a spindle, and generate 1g forces at a rotation speed of <2rpm	pg.6, 7
4	Life Support System	pg.17	The habitat shall provide the society with the basic physiological necessities, including water, food, waste processing and atmospheric conditions similar to those on Earth, ensuring breathable air and stable environmental pressure.	The habitats provide redundant closed-loop systems that take care of the atmospheric requirements, potable and waste water management, other kinds of waste and recycling capabilities, land based food production using both standard horticulture as well as otehr specialised horticultural techniques (using aeroponics, aquaponics (via the kelp farms) and hydroponics, as well as bioreactors)	pg.16
5	Essential Resources	pg.17	The habitat and/or society shall provide access to fundamental necessities, including clothing, shelter, and basic goods, for the entire journey duration.	The habitats provide adequate supplies and a complement of garments, basic goods as well as other necessities for the entire duration for the multiple generations. However, it is assumed that there are technologies onboard that will allow for JIT manufacturing of the basic consumable goods	pg.7, 31
6	Retain Key Knowledge	pg.17	The habitat and/or society shall maintain as a minimum key knowledge, including competences, which are required for contributing to its fundamental necessities, life-support system, and settling the target destination.* Additionally, knowledge related to the society's biocultural health shall be maintained.	The assumption here is that the key tacit knowledge will be stored in the comprehensive artificial intelligence and sentient robotic systems, that will both educate and train humans to collaboratively works alongside them in a meaningful manner. Offspring on board will receive an education and meaningful mentor-mentee experience from the earliest years, but no one is irreplaceable, the AI is ultimately responsibile for the control of the ship to its destiny	pg. 28, 29,35,
7	Internal architecture	pg.19	The architectural design should incorporate flexibility, allowing modifications such as reconstructing dwellings to adapt to evolving needs.	In principle, all constructed items are based as far as possible on the principles of biomimicry, and are meant to be torn down, rebuilt and developed based on reusable, repairable and recyclable material. Blueprints for the entire journey and landfall are all all included within the ships collective memory	pg. 10, 15, 16
8	The Society's Structure	pg.19	The society onboard shall be positioned along key cultural invariants, including:	An overarching assumption here is that the society onboard will not be able to represent the 10 to 17K tribal/ethnic groups in the world today (as per the Joshua Project); however, the tribal knowledge and customs of these groups as well as the other organisms, mythology and belief systems and language of these groups are carried on board in the form of the AI. One consideration is that fertilized embryos that represent diversity of all kinds of people, animals, plants and other organisms are carried on board, along with the technologies to bring them to term, however, this concept of an 'ark' goes beyond the primary objective of this submission	pg.28, 29, 35
		pg.19	Language	The society are encouraged to be polyglot and learn a minimum of 4 languages, with one of these considered an obscure language. The assumption here is that at least 1-3 of these 4 languages will be taught as part of the computer-guided education system on board and a mandatory of the education process.	pg.28, 35
		pg.20	Morality, ethics, justice	The concepts of right or wrong can be interpreted in different ways by many cultures, as do social norms dictate what is acceptable in a certain culture. As such, while this can be taught in formal education, the assumption is that this is learnt over time via interaction. The assumption here is that there can be some kind of AI guidance to facilitate intercultural understanding and how this changes over time during the journey	pg.28, 29, 35
		pg.21	Social organization and power relations	The society organization will probably be guided for the most part by the controlling power on board the craft and we would expect that by this period, it will be some kind of benevolent AI-based algocracy, which will ensure that the mindshare and the power relations between individuals is reconciliatory in nature. However, it must be expected that there will be human cycles at play here (Strauss-Howe generational 'turnings', which will invariably lead to conflict and crises, more than once during the journey	pg.20, 21, 22, 23, 25, 38
		pg.22	Subsistence mode	It is assumed that subsistence mode is about optimizing the use of limited resources and prioritizing the long-term survival and well-being of the crew during an extended interstellar voyage. It's a balance between maintaining essential functions and mitigating the negative psychological and physiological effects of prolonged isolation and confinement	pg.16, 24
		pg.23	Settlement patterns	We expect that the interstellar societies will be closer than societies on Earth, simply because of the size and the fact that everyone will be acutely aware that they 'have only each other'. As such, settlement patterns will probably not vary too much over the course of the journey, but certain individuals may crave to be as far away from others at particular times during the journey	pg.24
		pg.24	Family Structure	We expect that the families will be more akin to agrarian societies, and that joint family structures will be the norm	pg.13, 18
		pg.25	Economic-political structure	As mentioned, we make the assumption that initially at least, the expected form of government is one that jointly makes decisions based on the overarching Ai, possibly combined with a small council of elders and perhaps some uploaded conciousness of those who have been founding leaders but have since passed on	pg.19, 25, 31 (evolving)
		pg.26	Enculturation	Enculturation on a starship is about creating a self-sustaining culture that ensures the survival, well-being, and continued progress of the mission across generations. It's the process of turning Earth-born humans into "starship citizens" who are fully adapted to their unique environment.	pg.20, 21, 22, 23, 25, 38
		pg.27	Kinship and descent	When all they have are each other, kinship and descent on a generational starship becomes extremely complex and involves evolving concepts that are shaped by the unique constraints and opportunities of the voyage. Emphasis involves cooperation, community, and the preservation of knowledge and identity across generations.	pg.19, 25, 31 (evolving)
		pg.28	Food preference	The starship carries with it seed and germ as well as the means to grow every kind of plant that is necessary for sustenance. However, it is likely that a major source of animal protein will be from some kind of bioreactor-cultured food mass, and not from rearing animals on board. However, we can expect that some amount of protein will be obtained from aquaculture	pg.19, 24
		pg.29	Art and Aesthetics	The Arts as a whole is likely to play a major role within the societies on board the SS Proximum; besides specific Art subjects, which are a quintessentially human pursuit, it is expected that the close confines and the ample space that is availble on board the starship will lead to dramatic shifts in the artistic output during the 250 years of travel. Besides the Arts, it is expected that sports and contests will be ways in which the societies on board make connections and compete in a healthy manner	pg.36, 27
		pg.30	Religion and Mythos	It is expected that the concept of God and religion will be similar to whatever it may be at the point of departure, but in the vastness of eternal space travel, this may take on an added dimension, and moments of Turning will produce vital experiences that may guide both Religion and Mythos	pg.19, 29
9	Technologies	pg.31	All onboard technologies shall meet a minimum Technology Readiness Level (TRL) of 2	The assumption here is that all onboard technologies will meet the minimum TRL >2, as the technology arc will likely span more than 150 years from the present day	pg.20, 21, 22
	Mass Optimization	pg.32	The habitat's overall mass shall be minimized without compromising safety, functionality, or reliability	considered. The overarching requirement was considered from the POV of the duration of the journey (250 years) and the need to ensure that the habitats withstand any kind of revolts, sabotage and potential calamities, and therefore, adequate space and resources are provided to prevent any catastrophes from happening that would compromise primarily the safety and mental heatlh of the inhabitants onboard	pg. 6, 7, 12
	Reliability and Redundancy	pg.33	The habitat's systems shall maintain reliability over the mission, ensuring uninterrupted operation for 250 years, for example, via robust design and redundancy.	The principle design logic that was employed here was that redundancy and reliability are not compromised first, as a primary objective	pg.6, 8, 9, 10, 12
	First Order Mass Budget		A first-order mass budget should be provided for the starship, from which a monetary bduget can be calculated	literature (Johnson & Holbrow '77, table 6.4 0- Habitats) as a guide, we use their approximate mass of the regolith shielding as a point of reference for the asteroid mass, which is the bulk of it. We also do not base this on the total propulsion required as we assume that it goes beyond the scope of the work that we are doing at the moment - and so, the mass of the propulsion is not calculated as well	pg. 39
10	Power Budget	New P2 deliverable	A Power Budget is meant to calculate the power that will be utilised by the inhabitants but will NOT include the power requirements of the propulsion system.	The primary assumption here is that the power budget is calculated based on the habitats of the 2 torii, and not the other elements, such as the propulsion system, etc. We can only assume that all the additional elements are going to be a percentage of the total power requirements and as such, we add a 20% delta on top of those calculated requirements	pg. 12
11	Narrative	New P2 deliverable	Brief story or narrative elements describing the life of inhabitants.	The entire project design premise is that the starship is not based on a snapshot at the point of departure, but is a living, 'breathing' world ship, that is constantly being monitored by at least one sentient intelligence, that makes the ship 'alive' in a sense. As such, there cannot be a 'day in a life' of the ship or its inhabitants, but rather a focus on the myriad of systemic changes that transpire throughout the journey, as any snapshop simply cannot justify the design elements and the large number of design redundancies and the overall dimension of the starship in itself. As such, the narrative elements of the inhabitants describes elements of this evolution across 250 years, taking into account the ebb and flows of the society that forms on board.	pg. 22, 23, 24 - 38
				New Phase 2 Deliverables - A0 Poster	
11	Vertical Orientation	New P2 deliverable	3D renderings of the habitat interior and exterior	Renders of the exterior and interior of the starship, with a focus on specific regions of the starship	Done
12	Vertical Orientation	New P2 deliverable	Plans, sections, 3D diagrams, that best describe the architectural and technical aspects of the project (Scale is to be decided by the team)	Scale is approximate, as the starship is gargantuan	Done
13	Vertical Orientation	New P2 deliverable	Architectural detail drawing on the scale of 1/20 from a part of the project that best describes the design and material choices	To render something at 1/20 from a part of the project, we will have to focus on the smallest part of the architecture of the ship, namely the shell design of the ship	Done
14	Vertical Orientation	New P2 deliverable	Technical diagrams describing the different components, subsystems, societal structure, etc.	The focus here would be the logical design of the ECLSS	Done