One and a Half
Age of
Space Exploration

Humanity from 2026 to 2176



From Starship to Alpha Centauri

Contents and Overview

ONE AND A HALF AGE OF SPACE EXPLORATION

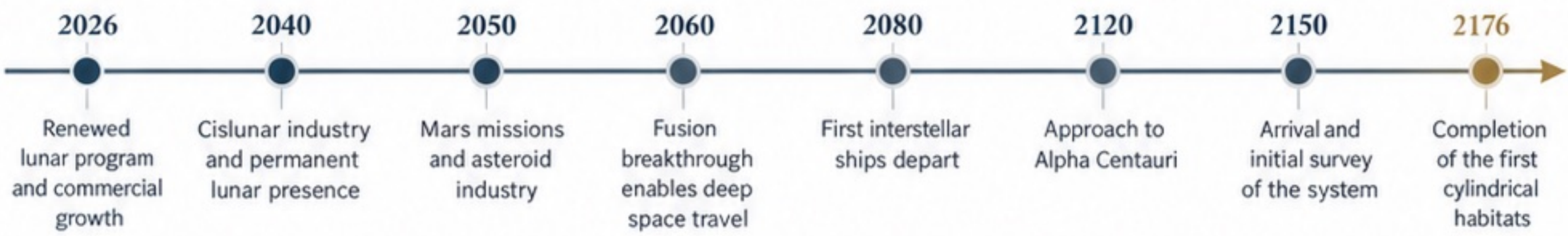
Foreword

From 2026 to 2176, humanity lives through one and a half age of space exploration. What began as a renewed return to the Moon grows into a thriving presence across the inner Solar System, the first interstellar voyages, and the establishment of a new home around Alpha Centauri. This book tells the story of a century and a half in which exploration, technology and human ambition combine to carry our species from a single planet to a multi-world future — a period that transforms space from a distant horizon into a lived human reality.



The new lunar era begins. A permanent base on the Moon, 2030s.

A Timeline: 2026 – 2176



Contents

1 **Moon Return** 6
Back to the Moon, and staying there

2 **Cislunar Industry** 24
A thriving economy beyond Earth

3 **Mars and the Belt** 46
New worlds, new resources

4 **Fusion Breakthrough** 72
A new engine for a larger future

5 **First Interstellar Ships** 96
From prototypes to departure

6 **Crossing to Alpha Centauri** 118
A generational voyage

7 **Arrival and Survey** 150
The first human look at a new home

8 **Building the Cylinder** 178
A city in space, a society for the long term

9 **A Frontier Held in Orbit** 206
Humanity's next chapter



Fusion-powered interstellar ship, 2080s. Designed for decades of continuous thrust on the voyage to Alpha Centauri.



A section cutaway of a completed cylindrical habitat, 2170s. A long-term home for thousands around Alpha Centauri.

2026–2035: Starship, Artemis and the Return to the Moon

The decade from 2026 to 2035 marks humanity's return to the Moon, enabled by a new generation of launch and in-space infrastructure. SpaceX's Starship becomes Moon-capable, NASA's Artemis missions land astronauts near the lunar south pole, and a sustained campaign begins to explore, utilize and learn from the Moon as a stepping stone to deeper space.



Fig. 1 A Starship-derived lunar lander at a south-pole base. Artemis missions establish a sustained presence near the Moon's south pole, where sunlight, water ice and scientific opportunities converge.

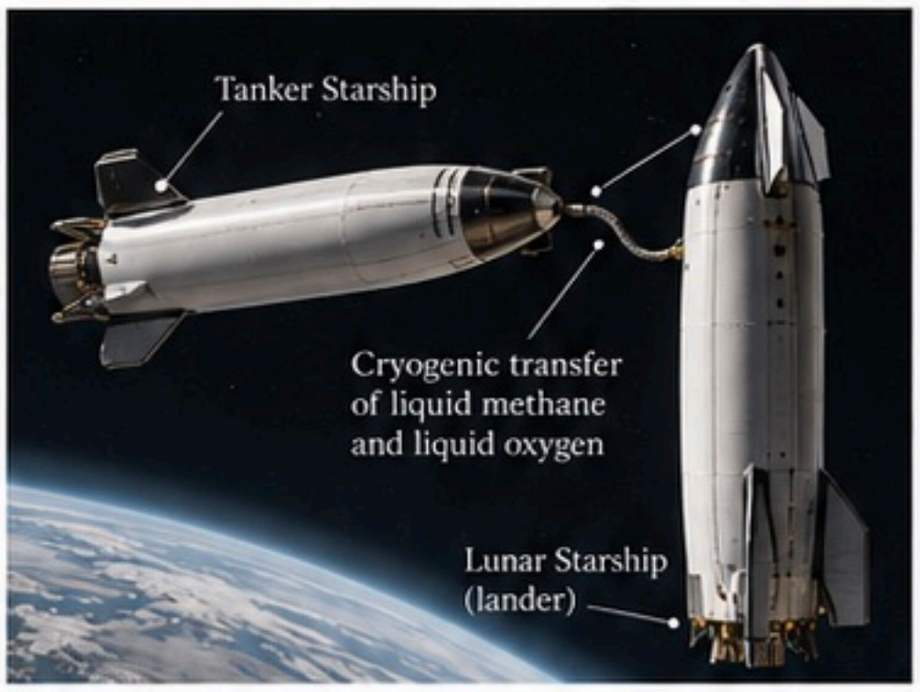


Fig. 2 Orbital refueling. Starship tankers transfer liquid methane and liquid oxygen to lunar Starships in Earth orbit, enabling the propellant needed for a round trip to the Moon and back.



Fig. 3 Lunar ISRU. Robotic systems prospect for and extract water ice from permanently shadowed regions. The ice can be processed into water, oxygen and methane to support a lasting lunar presence.

Starship becomes Moon-capable

By the late 2020s, Starship completes a series of development flights and on-orbit refueling tests, proving it can deliver large payloads to lunar orbit and support a dedicated lunar lander variant. High-cadence flights and reusable tankers make lunar missions more practical and cost-effective, opening the door to regular crew and cargo flights.

Artemis and a sustained presence

NASA's Artemis missions return astronauts to the lunar surface, focusing on the south pole. Successive landings establish increasingly capable operations, including scientific exploration, technology demonstrations and the early elements of a permanent presence, with international and commercial partners contributing hardware, research and logistical support.

A DECADE OF PROGRESS

2026
Starship development accelerates; key flight tests demonstrate core systems and reusability improvements.

2027
First orbital refueling demonstrations with Starship tankers.

2028
Starship lunar lander variant completes uncrewed tests in cis-lunar space.

2029
Artemis III: astronauts return to the Moon, landing near the south pole.

2030
Regular cargo missions deliver habitats, rovers, power systems and scientific instruments to the lunar surface.

2031
Expanded south-pole operations, including longer-duration stays and international participation.

2032
Demonstration of lunar resource utilization: extraction of water ice and production of oxygen.

2033
Larger Starship landers deliver infrastructure for sustained operations, including surface power and communications networks.

2034
Early production of methane from lunar ice demonstrated at pilot scale.

2035
A routine cadence of crew and cargo missions supports a growing lunar presence and prepares for human expeditions beyond the Moon.

THE MOON AS A STEPPING STONE TO DEEPER SPACE

2035–2050: Cislunar Industry and the First Space Economy

FROM A RETURN TO A REAL PRESENCE

Between 2035 and 2050, humanity moved from short visits to a sustained presence in the Earth–Moon system. Reusable launch vehicles drove costs down, orbital infrastructure matured, and the first real space economy took shape. Cislunar space — the region between Earth and the Moon — became a working environment, not just a destination.

REUSABLE LAUNCH UNLOCKS SCALE

By the late 2030s, fully and rapidly reusable launch systems had become operational, cutting the cost to deliver mass to low Earth orbit by an order of magnitude compared with the 2010s. Higher launch cadence and greater reliability turned space from a rare, government-led endeavor into a routine industrial activity, enabling commercial stations, lunar missions and large infrastructure projects.

ORBITAL SHIPYARDS

With lower launch costs, attention shifted to building in space. Orbital shipyards began assembling large structures — from lunar landers and habitats to power satellite components — using robotic systems and a global supply chain. Building in orbit allowed much larger and more capable spacecraft than could fit inside any rocket fairing, at lower cost and with less mass launched from Earth.

POWER SATELLITES AND NEW MARKETS

Demonstration power satellites in the 2030s proved the viability of beaming solar energy from space to Earth. By the 2040s, early commercial systems began supplying clean electricity to selected regions, showing that space infrastructure could deliver tangible benefits for people on Earth.

PROPELLANT DEPOTS

Orbital depots storing liquid oxygen, liquid hydrogen and methane became the backbone of cislunar operations. Refueling in space let missions travel farther, carry larger payloads and land more mass on the Moon at lower cost. Depots turned cislunar space into a practical transportation hub, connecting Earth, the Moon and onward to Mars.

THE MOON AS A SOURCE OF MATERIALS

Robotic and crewed missions in the 2040s began extracting water ice from permanently shadowed craters at the lunar poles. This water was refined into rocket propellant, life support supplies and industrial feedstocks. Lunar materials such as regolith also supported construction, radiation shielding and manufacturing in cislunar space.

INFRASTRUCTURE OVER FLAGS

Rather than a race for flags and footprints, the 2035–2050 era proved that lasting infrastructure mattered more. Depots, power systems, communications networks and lunar resources created enduring value, enabling scientific discovery, economic growth and a permanent human presence

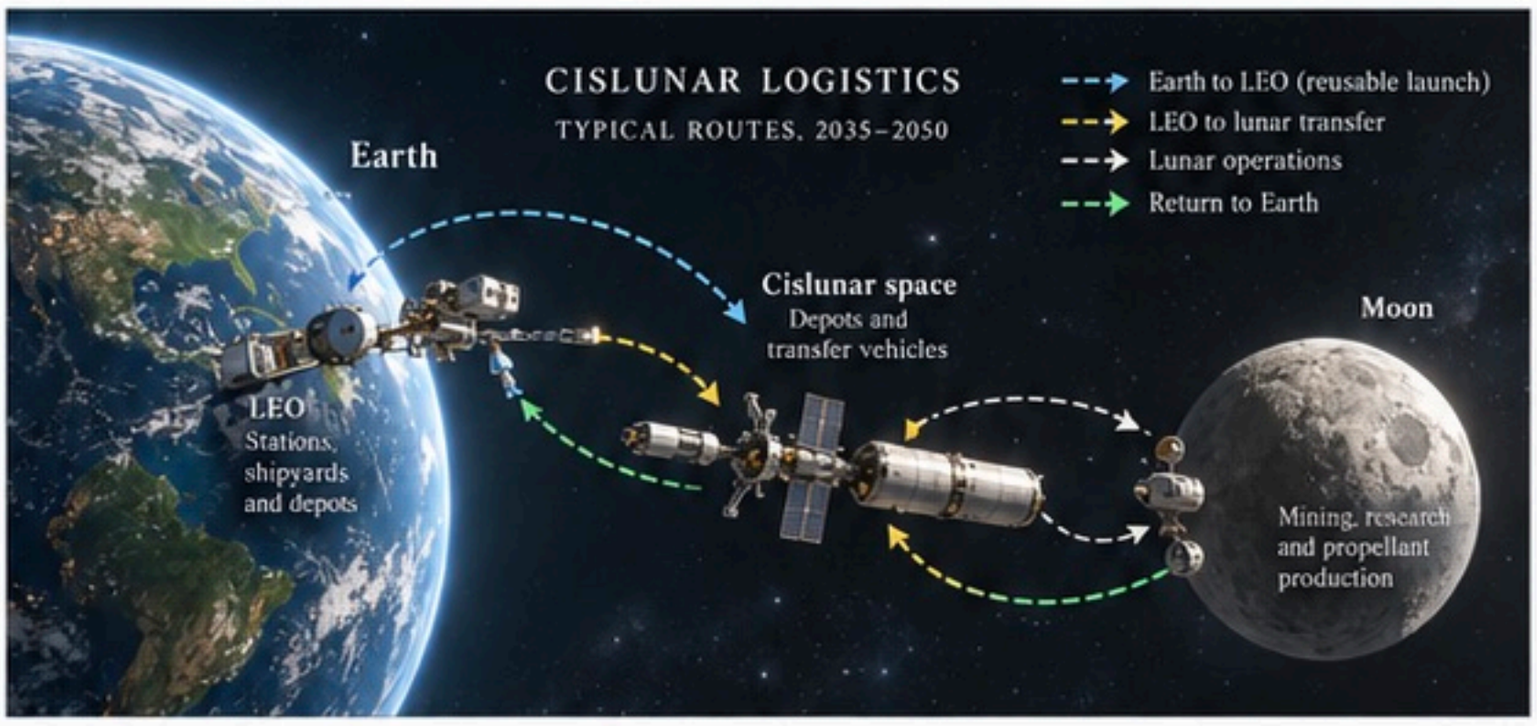


Figure 1. The Earth–Moon logistics system. *Reusable launch vehicles deliver people and cargo to Earth orbit, where depots and transfer vehicles move them to the Moon and back.*



Figure 2. An orbital shipyard in low Earth orbit. *Large lunar landers, habitats and power satellite components are assembled in space, taking advantage of low-cost launch and in-space manufacturing.*

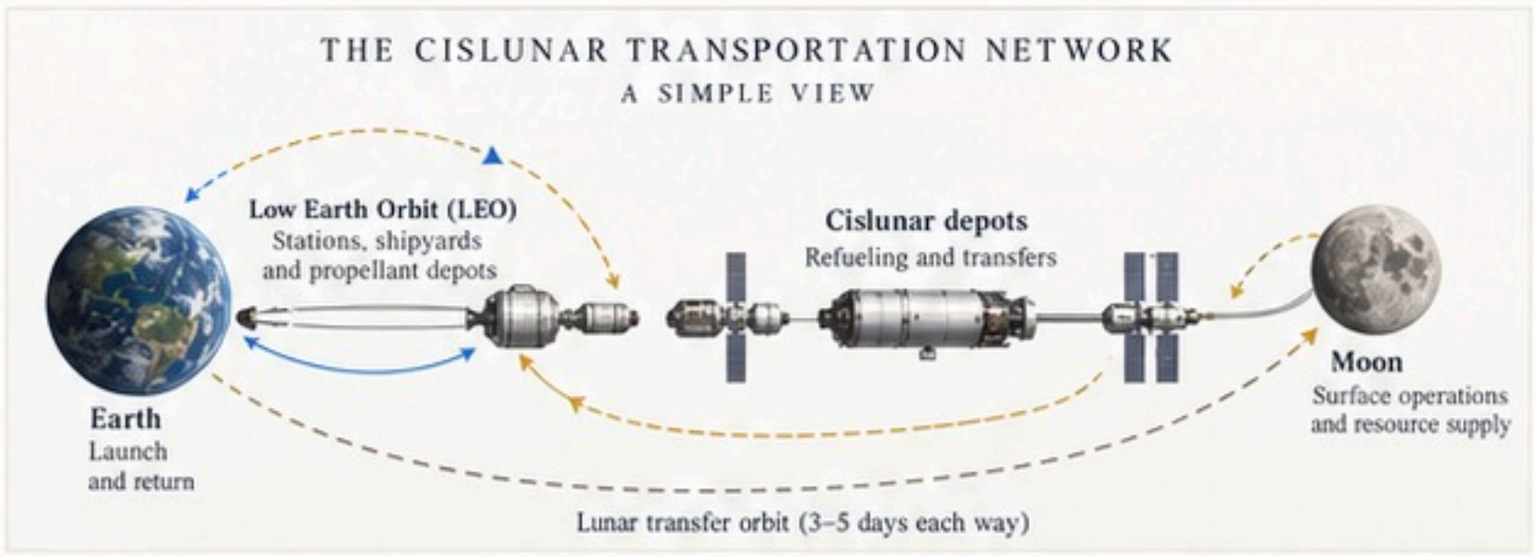


Figure 3. The cislunar transportation network. *Propellant depots and regular transfer services connect Earth, orbital infrastructure and the Moon, enabling a steady flow of people, materials and commercial cargo.*

KEY FACTS: LAUNCH COSTS AND LUNAR WATER

LAUNCH COSTS FELL BY ~10×

The cost to deliver mass to low Earth orbit dropped by about an order of magnitude between the 2010s and late 2030s, thanks to fully reusable rockets, higher flight rates and streamlined operations.

LUNAR WATER BECAME STRATEGIC

Water ice at the Moon's poles provided a local source of hydrogen and oxygen for rocket fuel, as well as life support supplies and industrial feedstock. This reduced dependence on Earth and made sustained cislunar activity economically viable.

2040–2060: Mars, the Asteroid Belt and Hard Lessons in the Outer System

HUMAN EXPANSION BEYOND CISLUNAR SPACE

The decades from 2040 to 2060 marked humanity's transition from near-Earth operations to a truly multi-planetary presence. Mars outposts took root, robotic and crewed missions unlocked the resources of the asteroid belt, and the first probes and missions to the outer system returned extraordinary science — along with hard lessons about distance, radiation and the limits *of* current technology.

Early Mars Outposts

In the 2040s, permanent robotic infrastructure was followed by the first small, long-duration human crews on Mars. The initial outposts, such as Ares Station (2044) and later Olympus Base (2051), were modest: pressurised habitats for 4–12 people, supported by local power, water extraction and in-situ resource utilisation (ISRU) plants producing oxygen, water and some rocket fuel. These early bases proved that humans could live and work on Mars for extended periods, conducting science, testing technologies and preparing for larger settlements.



Figure 1 *Astronauts conducting surface operations at Olympus Base, Mars (2051).*
Early outposts combined pressurised habitats with local resource production, allowing small crews to live and work on Mars for months at a time.

Difficult Logistics, Limited Crews

Despite rapid progress, operations beyond cislunar space remained logistically complex and expensive. Mars missions required long transit times, precise launch windows and large amounts of cargo. Crews were kept intentionally small to reduce risk and resource consumption, typically 4–6 people per mission in the 2040s and 2050s. Every kilogram mattered, and systems had to be highly reliable, as resupply was infrequent and emergency return windows were limited.

The Asteroid Belt Beckons

From the late 2040s, a series of robotic and crewed missions began prospecting metal-rich asteroids in the main belt. Advanced mapping, autonomous systems and new mining techniques identified targets rich in water, carbon and metals such as iron, nickel and platinum-group elements. By the 2050s, small crews were operating at asteroid outposts, using electric tugs and processing systems to extract and refine materials for use in space — from fuel and life support consumables to construction feedstocks.

Toward Europa and the Outer Moons

Missions to Jupiter's moon Europa and other outer system worlds began in the 2050s, combining sophisticated robotic probes with a few ambitious crewed flybys. These missions returned stunning data on icy oceans, complex chemistry and potential habitability. However, the extreme radiation environment, long travel times and high costs limited human presence to short flybys and remote operations. By 2060, the outer system remained a realm of robotic exploration, with crewed missions planned but not yet sustained.



Figure 2 *Mining tug operating at a metal-rich asteroid (2054).*
Crewed and robotic missions extracted water and metals from asteroids, providing resources for fuel, life support and construction in the inner solar system.



Figure 3 *Europa probe in Jupiter orbit (2058).*
Advanced probes mapped Europa's ice shell and analysed plumes, revealing a complex ocean environment and strengthening the case for future human missions.

Failures That Changed the Program

2043 Mars Transfer Anomaly
A crewed Mars mission was lost due to a propulsion system failure, leading to major redesigns and stricter verification.

2048 Asteroid Mining Accident
A micrometeoroid strike damaged a processing module, resulting in the loss of two crew members and temporary suspension of crewed mining operations.

2052 Europa Probe Loss
A high-radiation event caused a flagship Europa orbiter to fail, highlighting the need for better radiation shielding and hardened electronics.

2057 Outer System Crew Health Issues
A crewed Jupiter flyby mission revealed more severe-than-expected radiation and physiological effects, leading to revised mission profiles and stronger crew protection requirements.

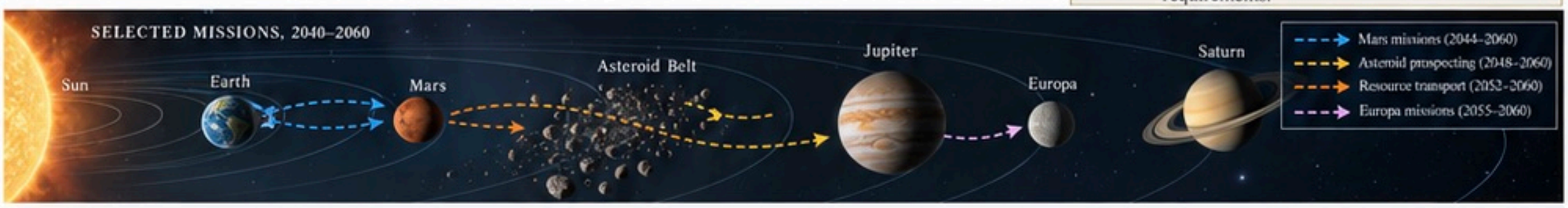


Figure 4 *Selected human and robotic missions beyond cislunar space, 2040–2060.*
Mars outposts, asteroid belt operations and missions to Europa marked humanity's expanding reach, while also revealing the technical and human challenges of the outer system.

2050–2068: The Technologies That Opened Interstellar Space

Between 2050 and 2068, a set of breakthroughs turned interstellar travel from a distant dream into a practical engineering program. None of them alone was sufficient. Together, they solved the core problems of propulsion, power, protection, sustainability, human health and autonomous operation at scales never before achieved. What followed was not a single miraculous invention, but a new generation of integrated systems, matured through two decades of relentless development and testing.

These technologies were first proven in Earth orbit and the outer Solar System, where long-duration missions validated their reliability. By the late 2060s, they had converged into a coherent architecture capable of carrying people to other stars.



FIGURE 1.1 Fusion drive orbital test stand, 2058.
An early full-scale fusion propulsion module undergoes a long-duration firing test in Earth orbit, validating plasma confinement, heat rejection and steady-state operation.

High-field superconducting magnets

By the early 2050s, new high-temperature superconductors enabled magnetic fields above 20 tesla in large, stable coils. These magnets were essential for compact fusion drives and advanced plasma confinement.

Advanced fusion pellet ignition

Robust, high-repetition fusion ignition using magnetized target fusion achieved net energy gain in the 2050s. By the 2060s it was adapted for continuous, high-throughput operation in space.

Radiation shielding

Layered composite materials, hydrogen-rich structures and active magnetic shields greatly reduced radiation exposure from fusion neutrons and cosmic rays, making long missions safe for humans.

Long-life reactors

Space-optimized fusion reactors achieved multi-decade lifetimes through self-healing materials, modular designs and in-situ maintenance, providing reliable power for propulsion, habitats and support systems.

Autonomous repair robotics

AI-guided robots could inspect, repair and replace components in harsh environments, extending the life of spacecraft and reducing the need for human extravehicular work over multi-decade missions.

Closed-loop ecology

Advanced bioregenerative life support recycled air, water and nutrients with over 99% efficiency, combining biology, material science and AI control to sustain healthy communities for generations.

Deep-space medicine

New countermeasures against radiation, bone loss, muscle atrophy and isolation enabled long-term human health, supported by AI medical systems and telemedicine.

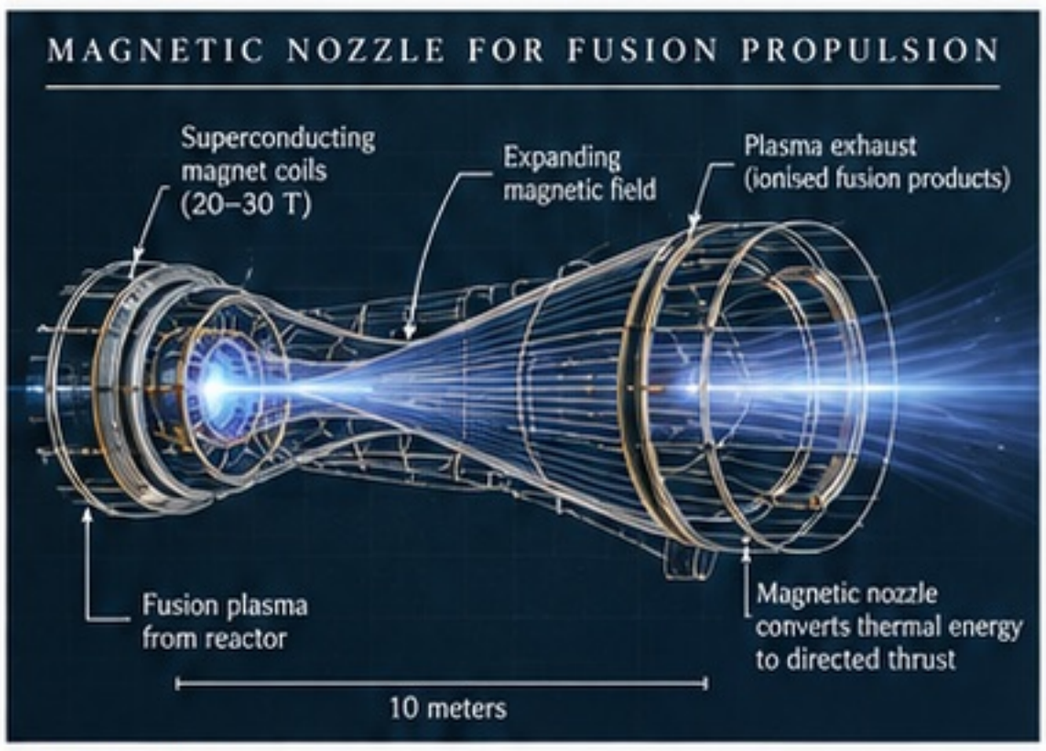


FIGURE 1.2 Blueprint of a magnetic nozzle.
Superconducting magnets shape and accelerate hot plasma from the fusion reactor, converting thermal energy into high-velocity thrust with extreme efficiency.

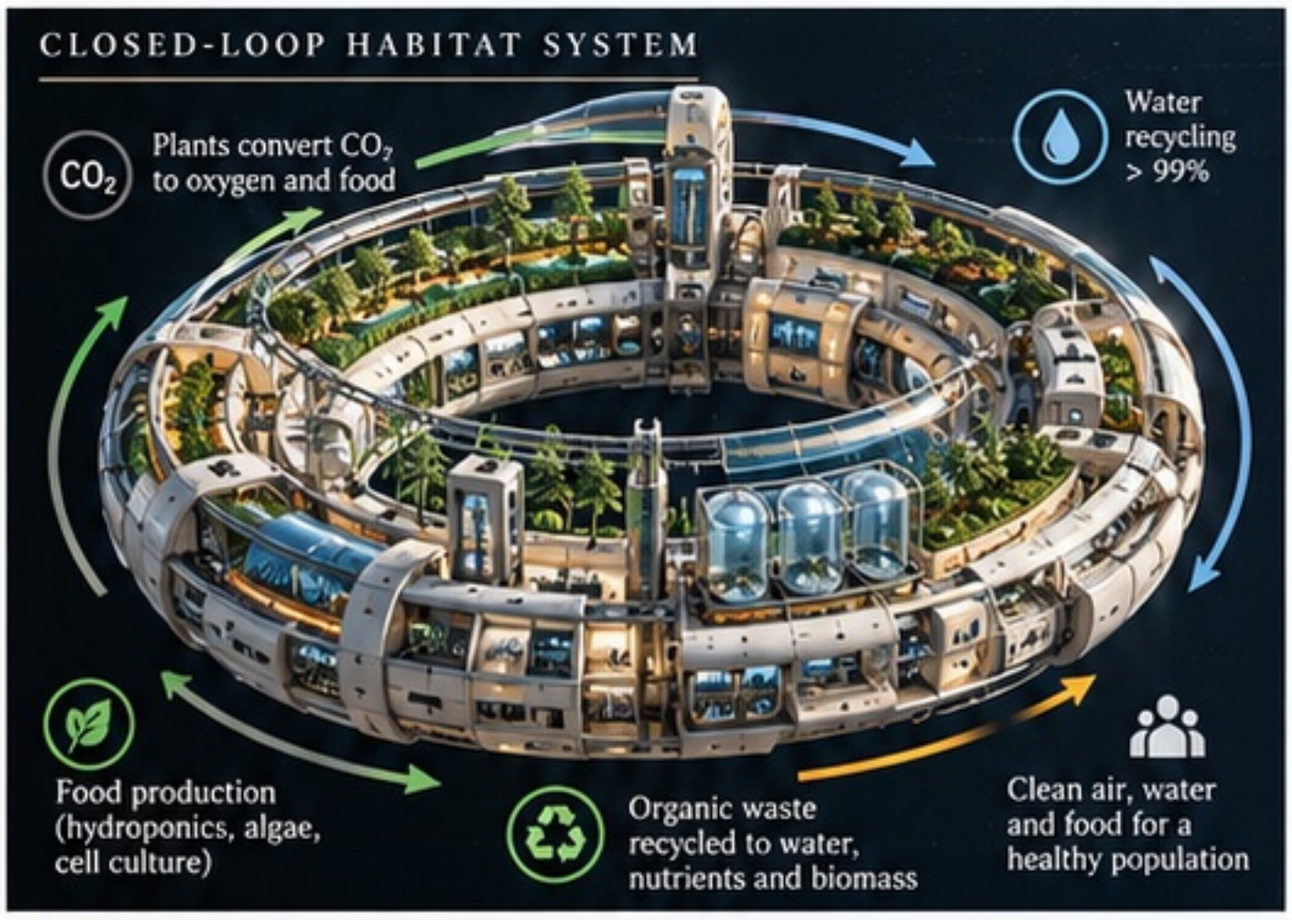


FIGURE 1.3 Closed-loop habitat diagram.
Integrated biological and physical systems recycle air, water and nutrients, creating a stable, self-sustaining environment for multi-generational missions.

THE KEY INVENTIONS, 2050–2068



High-field superconducting magnets
> 20 tesla, large stable coils



Advanced fusion pellet ignition
High-repetition net energy gain



Radiation shielding
Composite and magnetic protection



Long-life reactors
Multi-decade operation



Autonomous repair robotics
AI-guided inspection and repair



Closed-loop ecology
> 99% resource recycling



Deep-space medicine
Radiation, ageing and isolation countermeasures



AI-guided navigation
Optimal interstellar routes and real-time course correction

Interstellar travel depended on systems engineering, not one miracle invention.

2068–2079: Designing and Launching the First Interstellar Vessel

A DECADE THAT TURNED A VISION INTO A REAL SHIP

Between 2068 and 2079, humanity moved from concept studies to the first crewed interstellar vessel. What had once been speculative designs became real hardware, assembled in cislunar space, tested and, in 2077, launched toward Alpha Centauri. This was not a single breakthrough, but a decade of steady engineering, industrial growth and international cooperation that made interstellar flight possible for the first time.

Cislunar assembly: building too large for Earth

The first interstellar vessel, *Icarus*, was far larger than any rocket that could be launched from Earth. Its 2.4-kilometre length, massive fusion drive and rotating habitat were assembled in cislunar space using a combination of lunar materials, Earth-supplied components and autonomous construction systems. Building in lunar orbit allowed continuous assembly, access to water ice for propellant and shielding, and avoided the cost and risk of launching the entire ship through Earth's atmosphere.

Why the first departure happened in 2077

Early in the 2060s, a 2070 launch was considered possible. The date slipped for three main reasons: the fusion drive required longer testing to prove reliability at full power; the habitat and radiation shielding had to be redesigned after higher-than-expected galactic cosmic ray levels were measured; and large-scale cislunar infrastructure, including assembly yards and propellant production, took longer to build. By 2076 all critical systems had completed crewed tests, and a favourable Earth–target alignment opened a precise launch window in 2077.

Balancing speed, shielding and crew survival

Mission planners had to find a balance between reaching Alpha Centauri within a human lifetime and keeping the crew safe for decades in deep space. Higher speeds reduced travel time but increased engineering risk, fuel requirements and radiation exposure from high-energy particles. *Icarus* was designed for a cruise speed of about 0.06c (6% of the speed of light), a compromise that allowed robust shielding, a manageable amount of fusion fuel and a rotating habitat large enough to protect physical and mental health over a 50-year journey.

Why So Few Ships?

Extreme cost and industrial scale
Each interstellar vessel required resources equivalent to several decades of today's global space industry, including vast amounts of fusion-grade materials, precision manufacturing and cislunar infrastructure. Only one ship could be completed in the 2070s.

Fusion technology limits
Even after major progress, building a reliable, long-life fusion drive was extraordinarily complex. Each core took years to manufacture and test, with few facilities in the world capable of producing them.

Cislunar manufacturing bottlenecks
Large habitats, shielding, radiators and fuel tanks depended on lunar materials and heavy lift from Earth. Production capacity was limited, and expanding it would have required another decade or more.

Risk and incremental approach
Icarus was intentionally a single-pathfinder mission. Data from its journey would reduce risk for future ships, inform design changes and justify the immense investment needed to build more. Rather than many ships, humanity built one — and built it as well as possible.

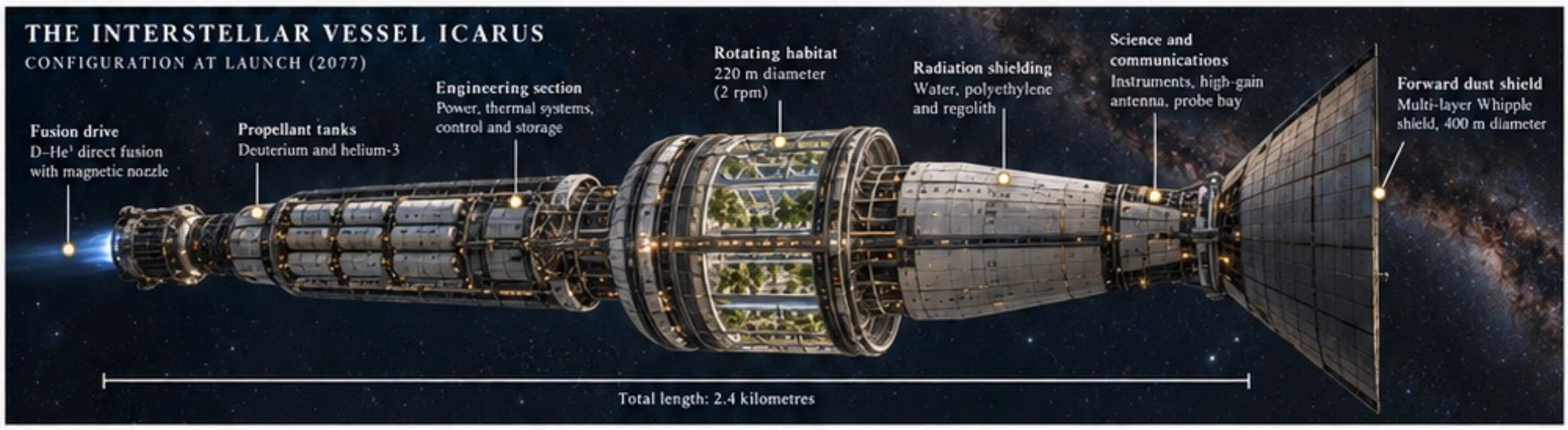




Figure 2. Departure from cislunar space, 2077.
Icarus begins its interstellar journey after final checks in lunar orbit. The ship accelerates continuously for several years before reaching cruise speed.

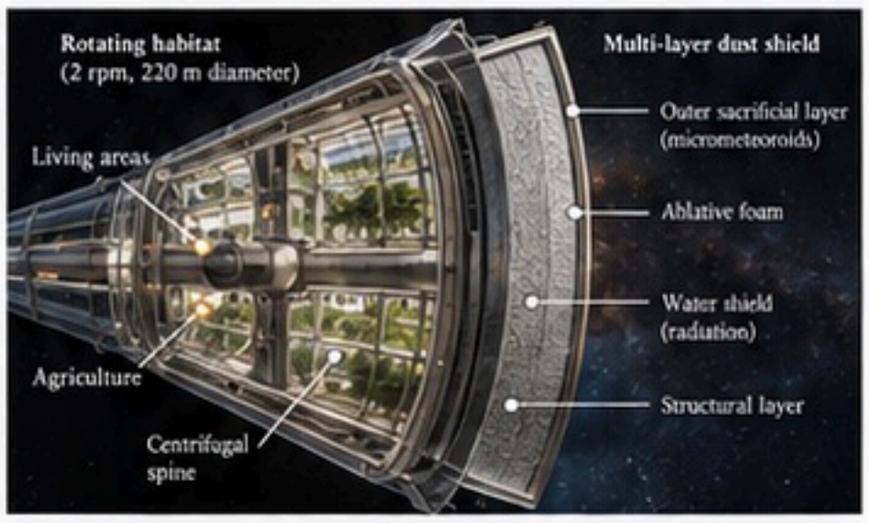


Figure 3. Cutaway of the rotating habitat and dust shield.
The habitat provides artificial gravity, living space and food production. A multi-layer shield protects the crew from interstellar dust and high-energy particles.

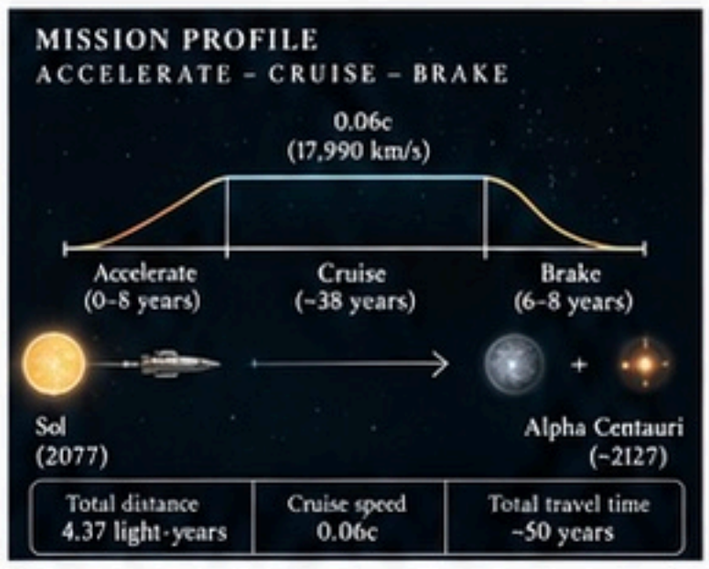


Figure 4. Mission profile to Alpha Centauri.
The ship accelerates for several years, cruises at ~0.06c for about 38 years, then decelerates on arrival for crew orbit and system operations.

2080–2120: Crossing the Interstellar Gulf

FOUR DECADES TO ANOTHER STAR

In 2080, the interstellar ships depart. What follows is a forty-year passage across 4.37 light-years of emptiness — a test of technology, organisation and human character. This is a journey measured not in days or months, but in generations, routine and quiet perseverance.



Figure 1. *An interstellar ark in cruise at 10–15% of light speed, en route to Alpha Centauri. At this speed the 4.37 light-year journey takes roughly 40 years.*

Life at 10–15% of Light Speed

The voyage to Alpha Centauri takes about 40 years at 10–15% of the speed of light (0.10–0.15 c). Life settles into a steady rhythm. People work, study, exercise, research and care for the ship. With a stable 1 g created by rotation and abundant light, food, water and green spaces, daily life is remarkably normal. Windows to the stars and a slower pace encourage a different relationship with time — one measured in seasons, projects and milestones, not news cycles.

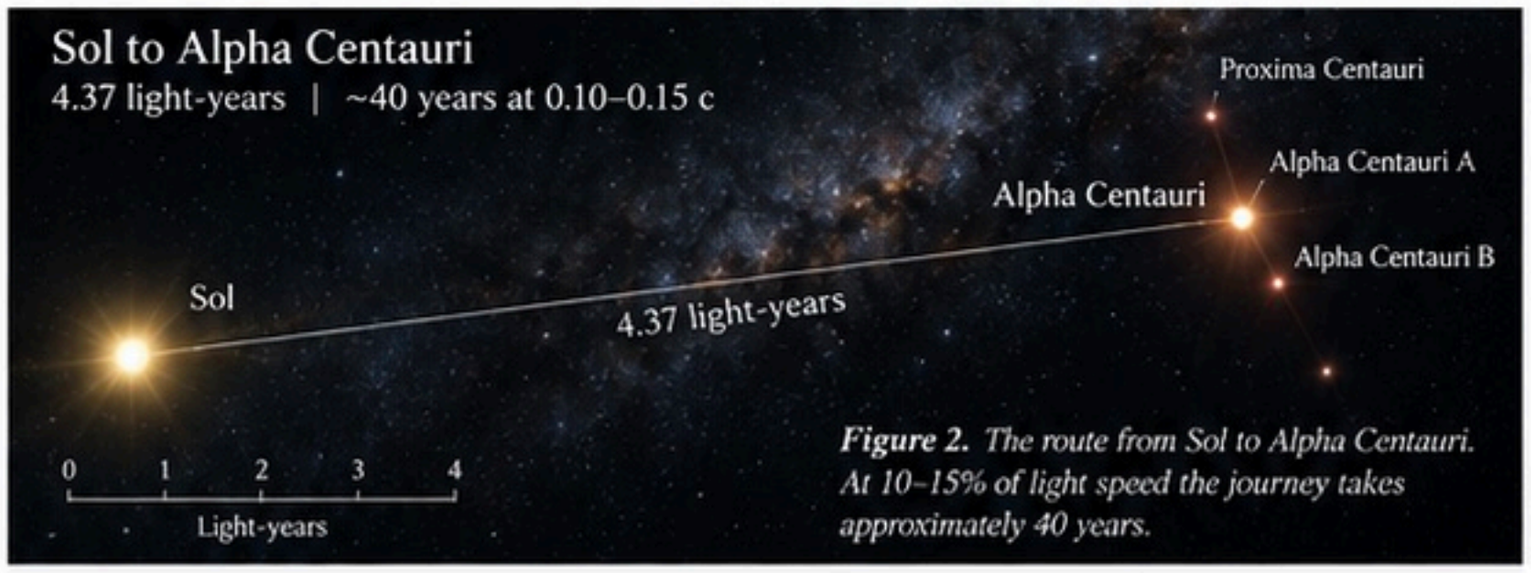


Figure 2. *The route from Sol to Alpha Centauri. At 10–15% of light speed the journey takes approximately 40 years.*

Autonomous Maintenance

The ships are designed for high autonomy. AI systems monitor every subsystem, predict failures and dispatch inspection drones. Most maintenance is routine and automated: magnetic crawlers, articulated bots and 3D printers keep the ship healthy. Humans focus on oversight, complex repairs and continual improvement.

The Dust Hazard

Even at 10% of light speed, a grain of dust can hit with the force of a high-explosive round. Multi-layer Whipple shields, vapourising front plates and electromagnetic dust deflectors reduce risk, while forward sensors detect and track larger particles. The ship's small cross-section and continuous course corrections further minimise impacts.

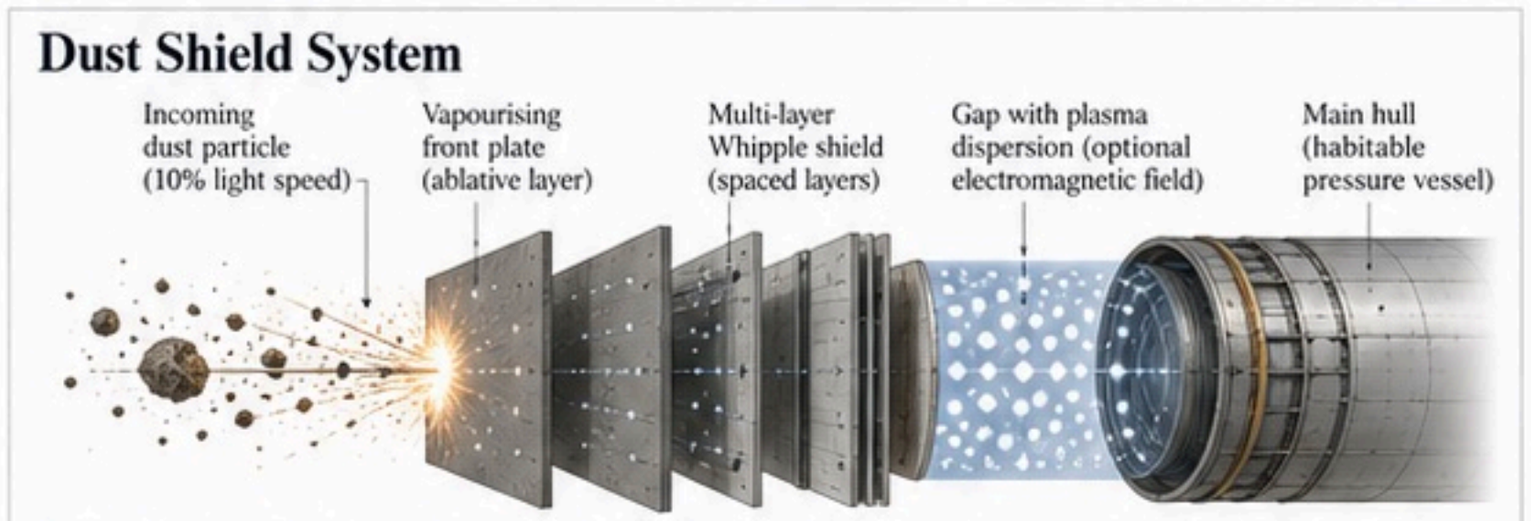


Figure 3. *Layered defences against high-velocity interstellar dust. Incoming particles are vaporised or fragmented by an ablative front plate, then stopped by spaced layers before reaching the main hull.*

Communication Delay

Radio signals to and from Earth take 4.37 years each way. Conversations become letter-like: messages are composed thoughtfully and archived for posterity. Real-time support is impossible, so the crew must be self-reliant, making decisions with local information and long-term goals.

Crew Sociology

A diverse crew of a few hundred to a thousand people forms a close, multi-generational society. Clear governance, shared purpose, meaningful work and open culture are vital. Education, the arts and scientific research flourish. While challenges arise — conflict, homesickness, different worldviews — careful selection, strong institutions and a focus on purpose help maintain a healthy and resilient community.



Figure 4. *Cutaway of the rotating habitat. Centrifugal force creates 1 g at the outer decks, while the central axis houses transit, utilities and zero-g facilities.*

Living on a Moving Frontier

- **A real home.** Stable gravity, natural light, green spaces and comfortable living quarters.
- **Purposeful days.** Work, learning, research, creativity and community life.
- **A connected society.** A few hundred to a thousand people across generations.
- **Resilience by design.** Redundant systems, strong institutions and a culture of care.
- **A new perspective.** Forty years to reflect, create and help shape humanity's next chapter.

Other Expedition Concepts

Many ideas were studied. Generation ships at slower speeds were viable but took centuries. Cryogenic crews remained too risky at scale. Self-replicating probes arrived faster but could not carry people. Directed laser sails and beamed probes showed promise, and have been used as robotic precursors, but did not yet offer the capacity, control and safety of the 2080 ships.

Robotic Precursors

Before the crewed ships, a fleet of robotic probes was sent to Alpha Centauri. These smaller, faster craft map the system, study hazards, and test navigation and communication. By the time the crews arrive, we will already know far more about our destination.

2120–2139: ARRIVAL AT ALPHA CENTAURI

DECELERATION. DISCOVERY. A FIRST LOOK AT ANOTHER WORLD.

In 2120, after 94 years in interstellar transit, the first human starship arrived at the Alpha Centauri system. The journey from the Solar System had been a generational endeavor, made possible by fusion propulsion and decades of international cooperation. Arrival was not a sudden stop, but a carefully controlled deceleration that unfolded over many months as the ship entered the star system.



Figure 1. The **first human starship** decelerates into the Alpha Centauri system in 2120. Fusion engines reduce the ship's velocity over several months, allowing a safe transition from interstellar space to bound orbits within the system.

Deceleration into the System

Beginning about six months before closest approach, the ship oriented for braking and began a long, controlled deceleration using its fusion engines. The velocity relative to Alpha Centauri was reduced from ~0.2c to a few hundred km/s, allowing a safe transition from interstellar space to bound orbits within the system. Final maneuvering placed the ship on a stable, wide orbit for exploratory operations.

Survey of Alpha Centauri A and B

From 2120 to 2125, the crew conducted detailed observations of the two Sun-like stars, Alpha Centauri A (Rigil Kentaurus) and Alpha Centauri B (Toliman), and their planetary environments. Both stars were found to be stable, mature, and broadly similar to the modern Sun, with multiple planets, asteroid belts, and complex debris structures. Several planets were identified in or near the habitable zones, but none showed the same combination of size, climate stability, and accessibility as Centauri Ac.

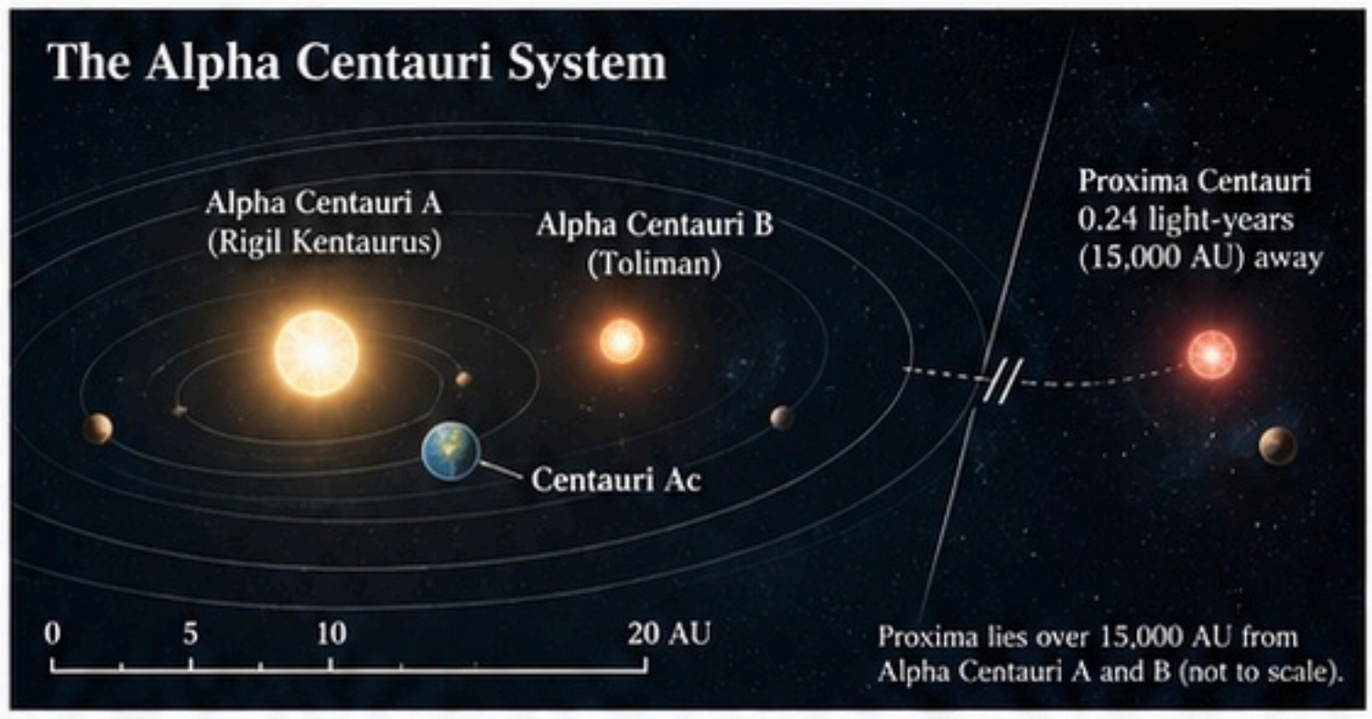


Figure 2. Map of the Alpha Centauri system. Centauri Ac orbits Alpha Centauri A within the habitable zone. Proxima Centauri and its planet Proxima b lie far beyond the A/B pair.

Distant Proxima

Proxima Centauri, a red dwarf, was surveyed in 2126. At 0.24 light-years from the A/B pair, it lies over 15,000 astronomical units away, far beyond the range of early crewed operations. Robotic probes confirmed at least one planet, Proxima b, but it was not considered a near-term destination.

First Exploration of Centauri Ac

Centauri Ac, a temperate, Earth-sized world orbiting Alpha Centauri A, became the focus of detailed study from 2126 to 2139. Remote sensing revealed a planet with liquid oceans, a breathable atmosphere, active geology, and likely abundant water and mineral resources. In 2134, robotic landers and aerial probes conducted the first close-range exploration, confirming a stable environment and no signs of indigenous intelligent life.



Figure 3. Centauri Ac from orbit. A remote survey image from 2131 showing oceans, continents, and a dynamic atmosphere. Robotic missions confirmed a temperate climate and no signs of intelligent life.

Why We Did Not Settle

Although Centauri Ac met many of the criteria for a future human home, the first mission did not establish a settlement. The crew lacked a large-scale industrial base in the system, and—critically—there was no local capacity to produce the vast quantities of high-energy propellant needed to launch a return mission. Without reliable return-launch fuel and infrastructure, a permanent settlement would have been irresponsible. The 2120–2139 mission instead established detailed knowledge, left automated facilities, and paved the way for future expeditions.

Why Orbit Came First

1. No Industrial Base

The first mission carried limited equipment. Large-scale industry was needed to build habitats, infrastructure, and fuel production facilities.

2. No Return-Launch Fuel Capacity

A return mission to the Solar System would require vast quantities of high-energy propellant, which could not yet be produced in the system.

3. High Risk

Without local industry and fuel, a settlement would risk being permanent, with no guaranteed return for future generations in the event of major problems.

4. Knowledge First

Orbital and robotic exploration provided detailed scientific data, confirmed habitability, and identified resources to support future settlement when the necessary capability exists.

2140–2176: Building the Cylinder and Holding a Frontier in Orbit

A HABITAT FOR A CENTURY AND BEYOND

Between 2140 and 2176 humanity built the most ambitious structure in its history: a kilometer-scale cylindrical station in orbit around Alpha Centauri A. It became a permanent platform for observation, industry and settlement — a way to study and use the Centauri system while keeping the nearby potentially habitable world, Centauri Ac, largely untouched.

The project drew on global expertise. Engineers from space agencies brought experience in large space structures; the fusion and propulsion industries supplied high-power systems; mining, manufacturing and robotics firms provided autonomous construction capabilities; and biologists, agronomists and planetary scientists shaped the station's long-term mission. No single nation built it — it was a truly international effort. Designs, materials and crews came from across Earth, reflecting a shared belief that the Centauri system should benefit all humanity.

Local resources were limited. Alpha Centauri A offers abundant energy but relatively little easily accessible solid material. Most of the cylinder's mass — specialised alloys, electronics, glass, life-support equipment and machinery — was therefore imported from Earth and the inner solar system. What local resources existed, such as small asteroids and minor bodies, supplemented the supply but could not provide everything. High levels of automation were essential.

Construction relied primarily on robotic assembly. Materials and pre-fabricated modules arrived from Earth, were processed, inspected and assembled by autonomous systems, with human crews supervising, maintaining and gradually moving in. The cylinder was built in stages over three and a half decades, allowing systems to be tested and expanded while remaining operational.

Rotating at around 2–3 rpm, the cylinder provides near-Earth gravity through spin. Its sealed interior houses cities, farms, industrial zones and research facilities. Enclosed agriculture supplies a significant share of food, using advanced hydroponics, aeroponics and carefully managed ecosystems.

From its stable orbit, the cylinder is an unrivalled observatory. It monitors Alpha Centauri A and B, studies stellar activity, maps the system's bodies and conducts long-term observations of Centauri Ac without landing. Sensitive instruments are shielded from planetary contamination, helping to preserve Ac's environment for future generations.

The cylinder is a greater achievement than any single landing because it created a permanent human presence, a diverse economy and a platform for discovery that can endure for centuries. It changed humanity from a species that visits other star systems to one that lives and works within them.



FIGURE 1 *Construction of the Centauri cylinder, 2158.* Prefabricated modules arrive from Earth and are assembled by autonomous systems in orbit around Alpha Centauri A.



FIGURE 2 Cross-section of the finished cylinder. Length ~20 km, diameter ~4 km (illustrative). The habitat provides gravity through rotation and includes residential, agricultural, industrial and research zones.



FIGURE 3 Interior view of the completed habitat. Enclosed agriculture, residential areas and research facilities provide a stable, Earth-like environment for a growing population.

2140 – 2176: KEY MILESTONES

2140 — Project approved; first construction materials depart Earth

2147 — Robotic assembly systems arrive at Alpha Centauri

2152 — Initial truss and rotation ring completed

2158 — First habitat modules installed; early life-support tests begin

2165 — Agriculture, power and industrial systems expanded; small crew arrives

2172 — Major sections completed; population increases

2176 — Cylinder declared fully operational

2130–2150: Why Orbit Came First

SURVEY, CAUTION AND PLANETARY PROTECTION

Although Alpha Centauri Ac was the first potentially habitable world reached by humanity, no one set foot on its surface in 2130. Instead, the first crews remained in orbit, establishing a long-term station and a fleet of robotic landers and probes. This cautious approach was not a delay, but a deliberate strategy based on practical, ethical and scientific reasons.

No return-launch capability

In 2130 there was no local production of fusion fuel or large-scale industry on Centauri Ac. A landing would have required bringing all the fuel needed for the return journey from Earth. This was technically possible for a small crew, but extremely risky, expensive and inflexible. Maintaining a permanent orbital base allowed a safe presence without committing to an irreversible descent.

A world not yet understood

Centauri Ac showed many promising signs, but remained largely unknown. Its climate, geology, radiation environment and potential biological ecosystems needed detailed study. A year on the ground would reveal far more than any simulation, potentially exposing the crew to unforessen hazards. Robotic missions could survey multiple sites in parallel, gathering data before humans landed.

Protecting a possible biosphere

If Centauri Ac harboured native life, even simple microorganisms, human visitors could have irreversibly contaminated its environment. To preserve the scientific value of the planet, strict planetary protection protocols required decades of robotic investigation and careful site selection before any human surface mission.



FIGURE 1 Uncrewed lander descending to Centauri Ac, 2132.
Robotic missions mapped the climate, geology and potential biosignatures at multiple sites, providing essential data before any human landing.

Small initial crews and high-value science

The first interstellar vessels carried only limited crew numbers, carefully selected for long-duration missions. Their primary role was to establish and operate the orbital station, deploy and manage robotic probes, and conduct detailed remote observations. Orbit provided the best balance of safety, scientific return and operational flexibility, allowing humanity to learn, prepare and build local capabilities before committing to a permanent presence on the surface.

By the 2130s, the consensus was clear: orbit first. This approach maximised scientific discovery, minimised risk to both the crew and the planet, and laid the foundation for future landings when local resources, infrastructure and knowledge made a sustainable presence possible.

FOUR REASONS ORBIT CAME FIRST



1 No return-launch fuel
There was no local production of fusion fuel. A return to orbit had to be guaranteed, making immediate landing too risky and expensive.



2 No mature local industry
Centauri Ac had no industry, mining or infrastructure. Everything needed for a surface mission had to be brought from Earth.



3 Risk of contamination
The planet might harbour native life. Strict planetary protection required decades of robotic study before humans could land.



4 Limited crew and higher value in orbit
Tnitial crews were small. Orbit allowed safe operation, continuous science and the ability to support multiple robotic missions.

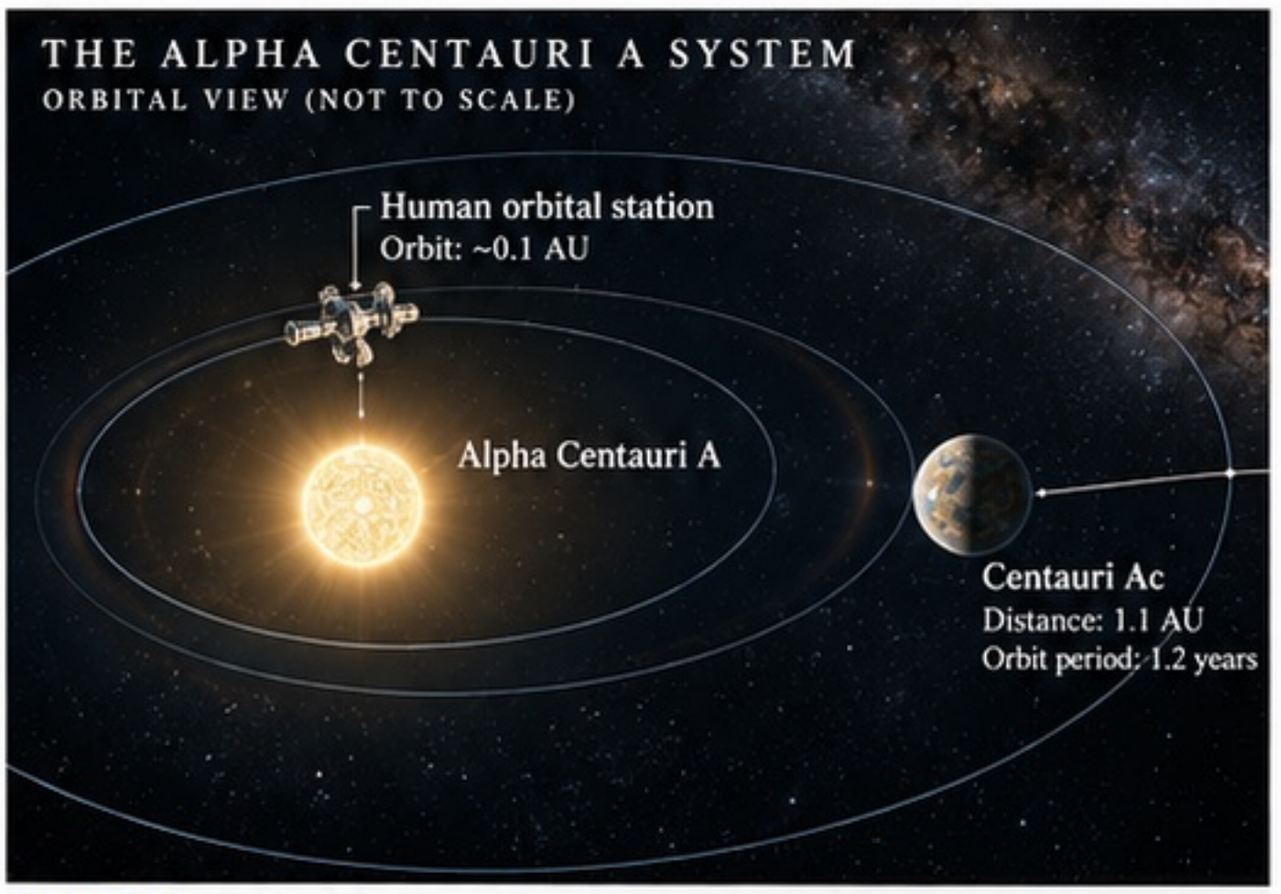


FIGURE 2 Orbit of the human station and position of Centauri Ac.
The initial station was placed in a close orbit around Alpha Centauri A, providing a stable base for observation, communication and robotic missions. Centauri Ac orbits the star at about 1.1 AU, with an orbital period of 1.2 years.

2150–2176: Life Inside the First Great Cylinder

A THRIVING COMMUNITY AROUND ALPHA CENTAURI A

By the 2150s, the cylinder was no longer a construction site, but a home. What had begun as an engineering project became a living, breathing community: a city in space that combined the best of Earth's places — clean air, green landscapes, thriving towns and opportunities for a new generation. Life inside the cylinder proved that a large, self-sustaining human settlement beyond Earth was not only possible, but desirable.



FIGURE 1 Canal-side residential district, 2165. Homes, shops and cafes line one of the central waterways, with parks and agricultural terraces on tihe outer levels of the cylinder.

Homes with a view

People live in a variety of housing, from apartments along the central canals to terraced homes overlooking parks and farmland. Large windows, open spaces and access to nature are central to the design. Every neighbourhood is within a short walk or transit ride of schools, medical centres, shops and green areas.

Food, water and a healthy environment

Hydroponic farms, greenhouses and algae facilities provide fresh food year-round. A closed-loop system recycles water, nutrients and air with over 99% efficiency. Trees, plants and water features keep the air clean and create a pleasant, Earth-like environment.

Education, healthcare and opportunity

Children grow up in a place designed for the long term, with schools, universities and research centres. Hospitals offer advanced medical care supported by AI systems and telemedicine from Earth and other settlements. People work in science, engineering, agriculture, education, the arts and many other fields, building a diverse and resilient society.

A community with a shared purpose

The cylinder is governed by a representative council elected by its residents, working with the broader Alpha Centauri administration. People from many cultures live and work together, sharing a commitment to a stable, peaceful and sustainable future. Festivals, sports, art and community events bring people together, creating a strong sense of belonging — not just a place to live, but a new chapter for humanity.

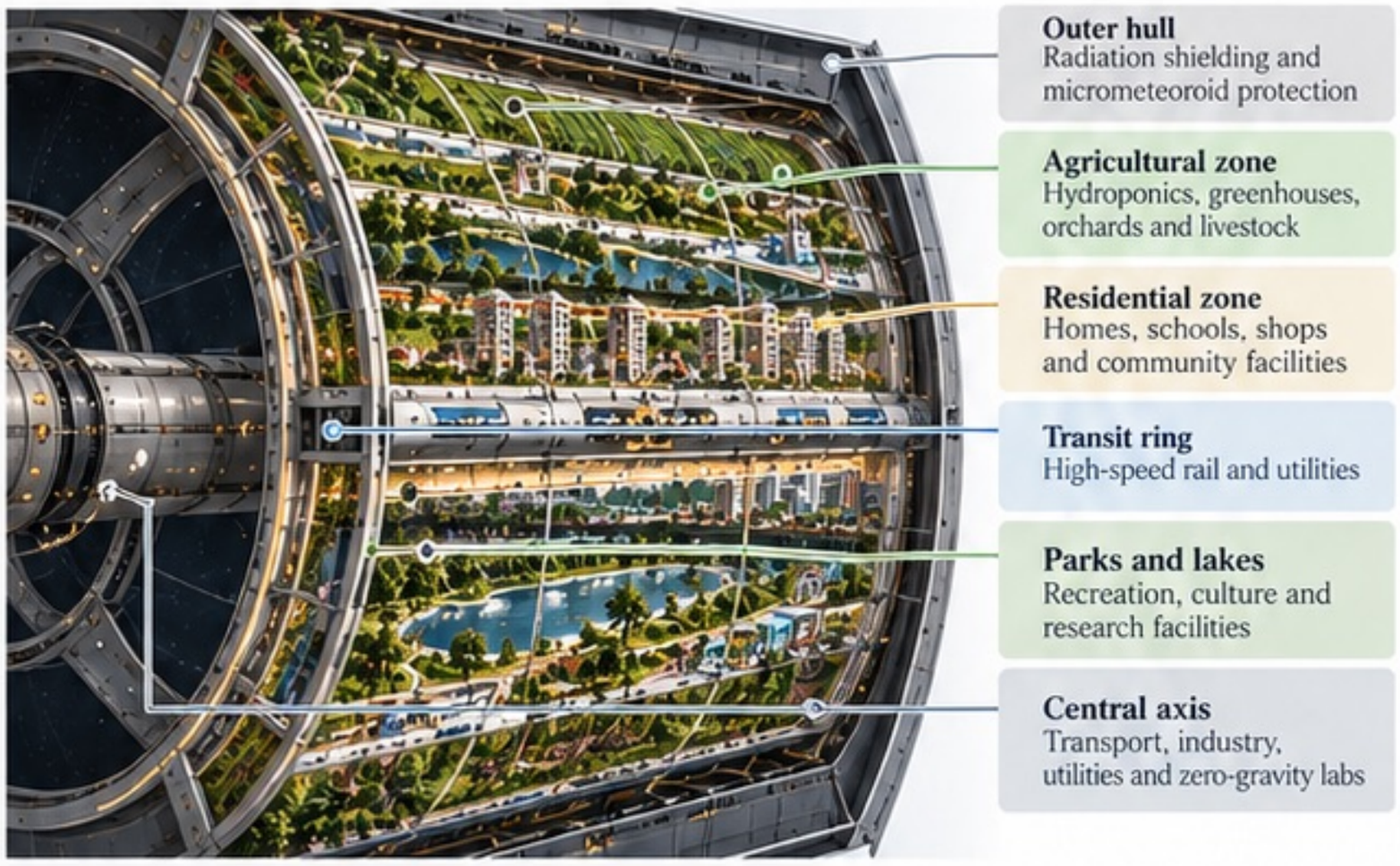


FIGURE 2 Cross-section of the cylinder. Rotation creates artificial gravity at the outer levels, allowing farms, cities, parks and transport systems to coexist in a stable, Earth-like environment.

THE CYLINDER AT A GLANCE, 2176

Population	Spin rate	Food production	Water recycling	Green space	Schools	Hospitals	Governance
1.2 million	2.3 rpm	120%	> 99%	40%	12,000	6	Elected council
and growing	0.8 g at the outer level	of total demand (20% reserve)	closed loop system	parks, lakes and ecosystems	students (primary to university)	major medical centres plus local clinics	with representation from all districts

2060–2176: Other Frontiers Beyond Centauri

A WIDER HUMAN PRESENCE THROUGHOUT THE SOLAR SYSTEM

Alpha Centauri was humanity's flagship program, but it was never the only frontier. Between 2060 and 2176, exploration and settlement across the Solar System expanded rapidly, transforming the Moon and Mars into thriving worlds and pushing robotic probes to the icy oceans and distant reaches beyond Neptune. These missions advanced science, developed technologies for interstellar travel, and broadened humanity's perspective on its place in the cosmos.

From mining asteroids to searching for life beneath ice, each destination contributed to a more resilient, multi-world civilisation. Together with the journey to Alpha Centauri, they marked a new era in which humanity explored both near and far — a Solar System alive with opportunity.

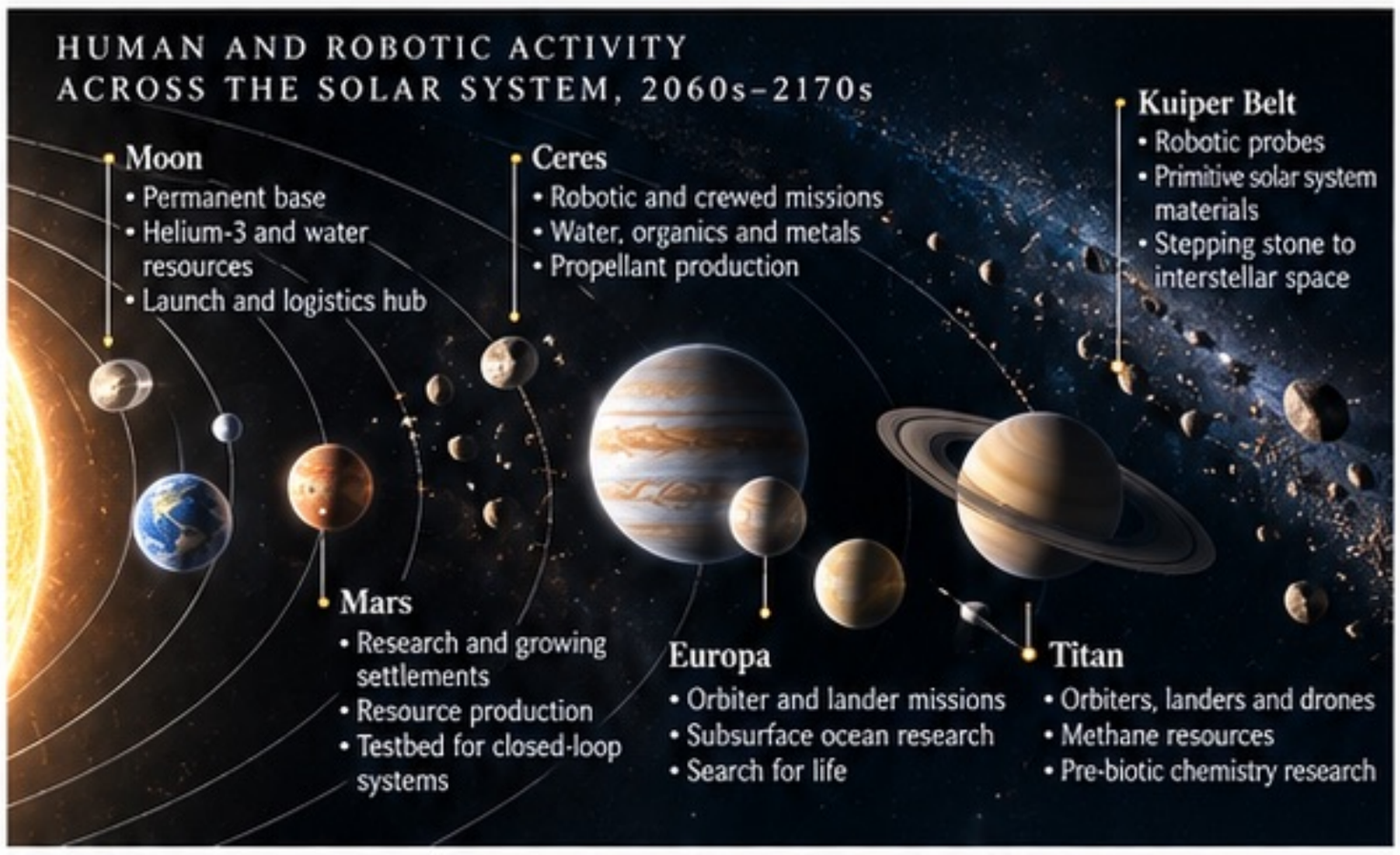


Figure 1. *Human and robotic activity across the Solar System, 2060s–2170s. Multiple destinations, each advancing science, resources and technology for a larger future. Alpha Centauri was the flagship, but part of a broader exploration effort.*



Figure 2. Europa research orbiter, 2073. *Equipped with high-resolution ice-penetrating radar and spectrometers, the mission mapped the moon's surface and searched for evidence of a broaurface ocean and potential life.*



Figure 3. Titan atmospheric and surface mission, 2128. *A long-duration probe descended through Titan's dense atmosphere, studying its methane cycle and organic chemistry. The mission included a surface lander and aerial drone, operating for several years.*

SELECTED OUTER-SOLAR-SYSTEM EXPEDITIONS, 2060–2176

● Successful mission ● Partial success ● Failed mission

2063	**Lunar Expansion Program**	Permanent base established; major increase in lunar resource production.
2068	**Mars Settlement Phase 1**	First self-sustaining settlement and industrial operations.
2071	**Ceres Pathfinder**	Robotic probe confirms water ice and valuable organics; enables later mining missions.
2073	**Europa Orbiter**	Detailed mapping of ice shell; evidence for subsurface ocean; multiple follow-on missions.
2078	**Jupiter System Probe**	Studies Europa, Ganymede and Callisto; tests advanced radiation shielding.
2084	**Titan Explorer**	Orbiter and atmospheric probe; first long-duration surface mission.
2092	**Enceladus Lander**	Confirms active plumes; detects complex organic molecules.
2107	**Uranus Orbiter**	Studies icy giant and its moons; advances deep-space power systems.
2124	**Neptune and Triton Mission**	Robotic orbiter; maps surface activity and atmospheric dynamics.
2141	**Kuiper Belt Survey**	Fleet of probes studies multiple objects; finds new dwarf planets and primordial materials.
2159	**Interstellar Precursor Probe**	Communications lost after 2 years; partial data returned.
2170	**Kuiper Belt Extended Mission**	Success. Long-duration probes continue to transmit data beyond 2176.

2050–2176: Missions That Failed, and Why They Mattered

SETBACKS THAT BUILT A STRONGER SPACE AGE

Not every mission succeeded. Between 2050 and 2176, humanity faced serious setbacks — lost craft, damaged equipment, crew health crises and technical failures. Each was a reminder of the risks of exploration beyond Earth, but also an opportunity to learn. These failures forced improvements in design, operations, safety protocols and international cooperation, making later missions safer, more reliable and ultimately more ambitious.

In a complex, multi-decade endeavour, failure was not the opposite of progress. It was part of it. The lessons learned from these missions directly shaped the technologies, industry standards and organisational culture that enabled the successful arrival and settlement of Alpha Centauri.



FIGURE 1 The Ares-3 Mars transfer vehicle after the coolant loop failure, 2054. *The mission was lost, but the investigation led to major improvements in thermal management and fault-tolerant design.*

Key Setbacks

2054 — Mars Transfer Anomaly (Ares-3)

A coolant loop failure during the Mars transfer phase led to a loss of attitude control. The uncrewed Ares-3 mission was lost. The investigation revealed a design flaw in redundant thermal valves and inadequate fault detection software.

2061 — Asteroid Mining Accident (Prospector-7)

An automated mining vessel suffered a structural failure during high-speed rotation, breaking apart and losing a multi-billion-credit payload. The accident highlighted the risks of operating autonomous systems in harsh, unpredictable environments and led to stricter testing and real-time structural health monitoring.

2083 — Outer-System Crew Health Failure (Orion Station)

A crew of six on a Jupiter-orbit outpost experienced severe radiation-related health effects after an unexpected solar particle event. Despite emergency sheltering, shielding levels were insufficient. Two crew members later died, and the mission was cut short. The incident transformed radiation standards, storm forecasting and medical protocols for long-duration missions.

2094 — Fusion Test Setback (Helios-1)

A high-power test of a next-generation fusion reactor ended in a containment failure, damaging the facility and setting back the program by several years. No lives were lost, but the event exposed weaknesses in plasma confinement modelling and emergency shutdown systems.

2120 — Early Centauri Cargo Loss (Pathfinder-1)

The first uncrewed cargo mission to Alpha Centauri suffered a guidance software error shortly after mid-course correction, placing the ship on an unrecoverable trajectory. The loss delayed early settlement plans but provided critical data for navigation, autonomous control and deep-space communication reliability.

MAJOR FAILURES AND LESSONS LEARNED

YEAR	MISSION	WHAT HAPPENED	KEY LESSONS
2054	**Ares-3** (Mars transfer)	Coolant loop failure; loss of attitude control; mission lost.	Improved thermal redundancy, fault detection and autonomous safe mode systems.
2061	**Prospector-7** (asteroid mining)	Structural failure during rotation; vessel destroyed; payload lost.	Stricter structural testing, real-time health monitoring and autonomous shutdown protocols.
2083	**Orion Station** (outer system)	Severe radiation exposure from solar particle event; 2 crew deaths; mission terminated.	Enhanced shielding standards, improved space weather forecasting and medical countermeasures.
2094	**Helios-1** (fusion test)	Containment failure during high-power test; facility damaged; program delayed.	Better plasma modelling, hardened containment systems and multi-layer safety interlocks.
2120	**Pathfinder-1** (Centauri cargo)	Guidance software error after mid-course correction; ship lost.	Upgraded navigation verification, redundant AI systems and deep-space communication protocols.

HOW FAILURES LED TO STRONGER STANDARDS

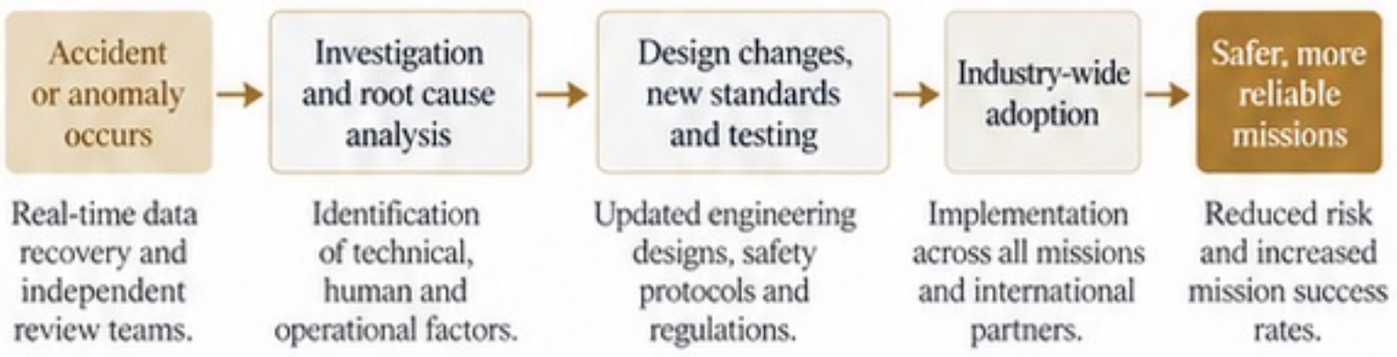




FIGURE 2 Mission control analysis of the Pathfinder-1 trajectory, 2120. *A software error during a mid-course correction placed the uncrewed cargo ship on an unrecoverable path. The incident led to major upgrades in navigation verification and autonomous control systems.*

The Centauri Roadmap: Distances, Delays and Routes

CHARTING HUMANITY'S FIRST INTERSTELLAR JOURNEY

Alpha Centauri was humanity's first interstellar target because it is close, well studied and offers a potentially habitable world. At 4.37 light-years, it is the nearest star system to the Sun, containing the binary stars Alpha Centauri A and B, and the red dwarf Proxima Centauri. Decades of robotic observations mapped its planets in detail, revealing Centauri Ac — an Earth-like world in the temperate zone of Alpha Centauri A. Its proximity, scientific value and the presence of a likely habitable planet made it the natural destination for humanity's first interstellar voyage.

What 4.37 light-years means

A light-year is the distance light travels in one year: 9.46 trillion kilometres. The gap to Alpha Centauri is 4.37 light-years, or 41.3 trillion kilometres. For *Icarus*, cruising at 0.06c (about 17,990 km/s), the voyage took 73 years of ship time. From an operational perspective, it meant the ship had to be completely self-sufficient, with no resupply, and designed for generations to live, work and maintain the vessel during the journey.

Route planning and evolution

Early concepts in the 2020s and 2030s focused on a direct course to the Alpha Centauri system. As more was learned about stellar environments, planetary orbits and interstellar medium conditions, route planning became increasingly sophisticated. By the 2050s, navigation models incorporated detailed data on interstellar dust, magnetic fields and potential radiation hazards, allowing a safer and more energy-efficient path. On arrival, the approach slowed for system operations, with a much shorter local transfer — just a few light-hours — from Alpha Centauri A to Centauri Ac.

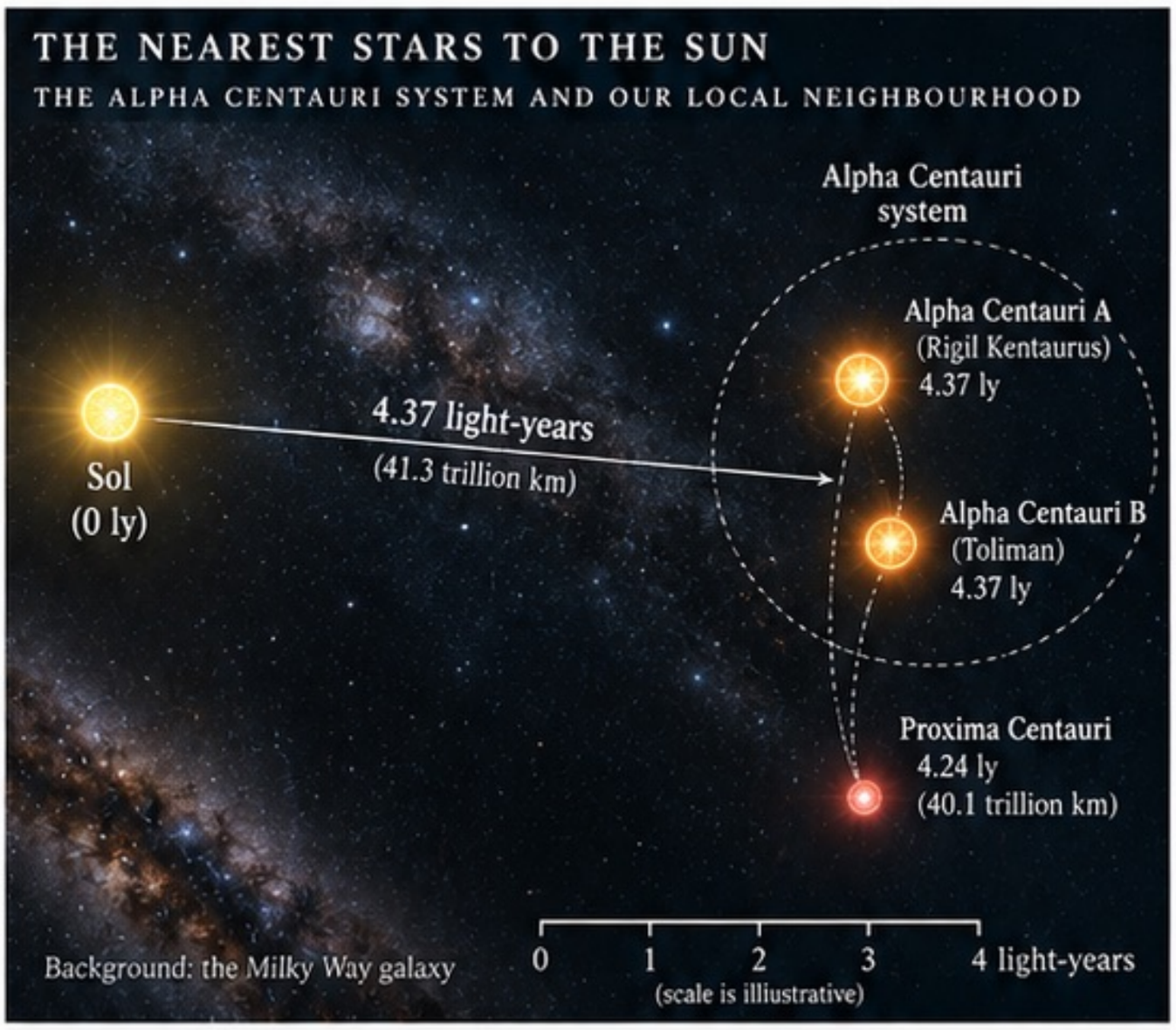


FIGURE 1 The Sun and the Alpha Centauri system. Alpha Centauri A and B are a gravitationally bound pair at 4.37 light-years from the Sun. Proxima Centauri, a red dwarf, lies slightly closer at 4.24 light-years but does not host a suitable habitable planet.

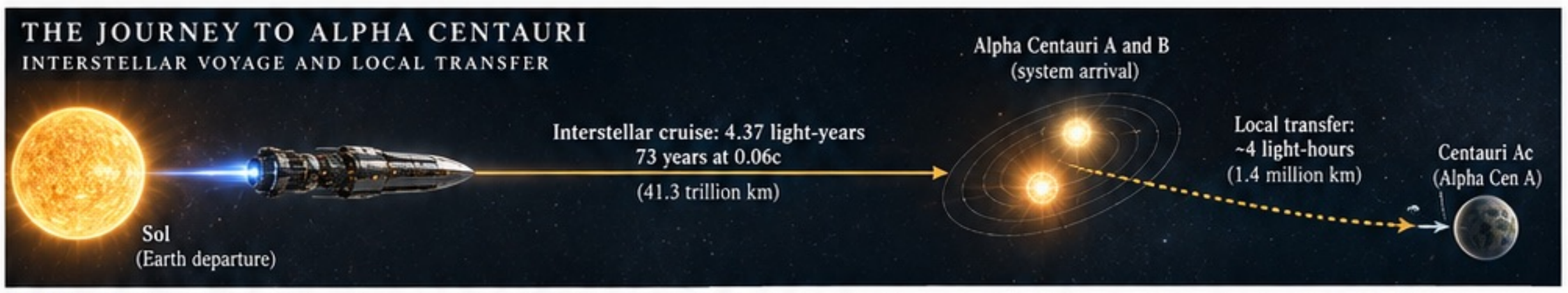


FIGURE 2 Route to Alpha Centauri. *Icarus* travelled 4.37 light-years from the Sun to the Alpha Centauri system, then completed a short local transfer of about four light-hours to reach Centauri Ac, orbiting Alpha Centauri A.



FIGURE 3 Communications delay. *Radio signals travel at the speed of light, so a message takes 4.37 years to reach Alpha Centauri and 8.74 years for a reply. Real-time communication is not possible, spacecraft must operate autonomously.*



FIGURE 4 Propulsion eras. Each generation of propulsion dramatically increased reach and capability, culminating in fusion-driven vessels able to reach Alpha Centauri within a human lifetime.

Keeping the Frontier Supplied

CARGO, MAINTENANCE AND LONG-DISTANCE LOGISTICS

The Centauri system was not a self-sufficient world. The orbital society around Alpha Centauri A survived and grew through a carefully managed flow of people, materials and knowledge from across the Solar System. Keeping the frontier supplied required long planning cycles, high-reliability transport and an economy designed for scarcity. Cargo convoys, not a constant stream of ships, carried the equipment, spare parts and specialised goods that the cylinder could not produce for itself.

Rare but vital cargo convoys

Large fusion cargo ships departed Earth on a schedule of roughly one every 8–12 years, depending on demand and industrial capacity. Each convoy carried tens of thousands of tonnes of goods, focusing on items that could not be made locally and on high-value equipment for expansion and maintenance. Because each ship represented a vast investment, they were built for extreme reliability and redundancy, with backup systems and autonomous operation throughout the journey.

Modular by design

Everything on the cylinder was designed for maintainability. Habitats, power systems, life-support units, vehicles and scientific equipment used standardised, modular components that could be replaced with the tools and facilities available in orbit. When possible, entire modules were swapped out rather than repaired in place, reducing risk and crew time.

Local recycling and reuse

To reduce dependence on Earth, the cylinder relied on extensive recycling. Metals, water, nutrients, plastics and glass were recovered and reprocessed with over 95% efficiency. This closed-loop approach minimised the mass that had to be shipped from home and turned waste into a long-term resource.

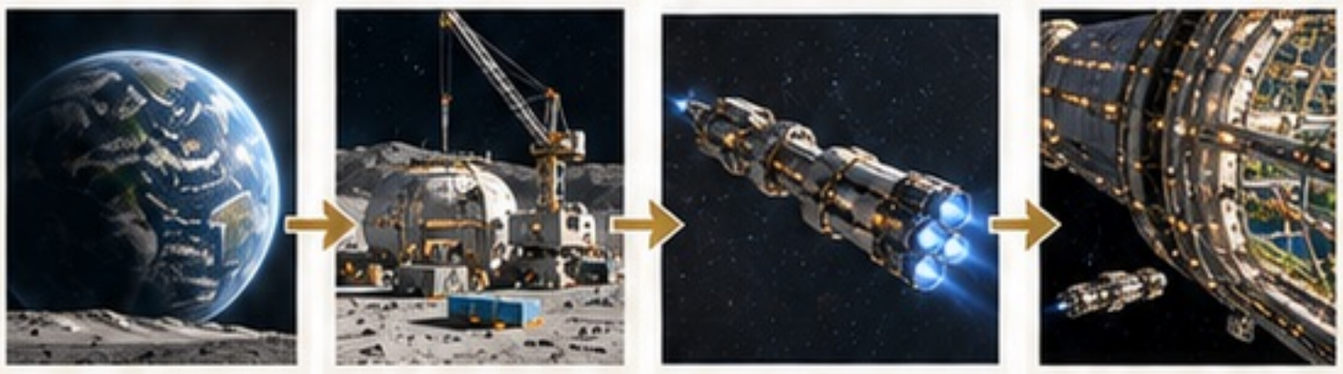
A deliberate, gradual expansion

The small number of ships and long travel times meant that growth at Alpha Centauri was gradual. New habitats, research facilities and industrial zones were added over decades as cargo arrived. This steady pace allowed the community to integrate new infrastructure safely, train people and avoid overextending its resources.



Figure 1 *A cargo fusion freighter approaches the Centauri cylinder, 2170s.*
Each ship carries essential supplies, replacement modules and specialised equipment for the orbital society.

THE INTERSTELLAR SUPPLY CHAIN



EARTH
High-value goods, specialised machines and scientific equipment.

CISLUNAR INDUSTRY
Bulk materials, modular components and assembled habitat systems.

INTERSTELLAR ROUTE
Fusion cargo ships operate on 30–40 year round trips with autonomous systems and minimal crew.

CENTAURI ORBIT
Supplies are received, inspected and integrated into the cylinder's industrial and habitat systems.

Figure 2 *The supply chain from Earth to Alpha Centauri.*
A global network of industry, assembly and interstellar transport keeps the orbital society supplied.

WHAT COULD BE MADE LOCALLY?

PRODUCED AT CENTAURI



Food and biomass
Hydroponics, algae and cell culture.



Common materials
Recycled metals, glass, plastics and composites.



Simple components
Structural parts, brackets, pipes and standard tooling.



Life-support consumables
Water, oxygen and chemicals from recycled sources.



Routine maintenance
Repair and refurbishment using local facilities and recycled materials.

IMPORTED FROM SOLAR SYSTEM



Advanced electronics
Radiation-hardened computers, sensors and AI hardware.



Specialised machinery
Precision manufacturing tools, robotics and scientific instruments.



Fusion systems
Reactor components, magnetic coils and high-performance materials.



Large structural modules
Habitat sections, rotation systems and major infrastructure.



Medical and biological supplies
Specialised pharmaceuticals, genetic resources and research materials.

KEY FACTS: SUPPLY AND LOGISTICS

Convoy cadence
One large cargo ship every 8–12 years depending on demand and industrial capacity.

Travel time
30–40 years one way.
60–80 years for a round trip.

Typical cargo mass
20,000–50,000 tonnes per ship, focused on high-value and irreplaceable goods.

Number of ships
Only a few interstellar cargo ships existed at any time due to their extreme cost and the long time each ship was away from Earth.

Design philosophy
Highly reliable, autonomous operation with modular components and extensive spares.

Local self-sufficiency
Over 95% recycling of water, air, nutrients, metals and plastics, reducing the need for imports and enabling long-term growth.

2176: A Frontier Held in Orbit

A NEW CHAPTER FOR HUMANITY

By 2176, humanity has transformed from a single-planet species into a multi-world civilization. What began a century and a half ago as a renewed return to the Moon has grown into a sustainable human presence across the inner Solar System, a mature space economy, successful interstellar travel and a permanent home around another star.

The cylindrical habitat around Alpha Centauri A stands as a milestone for human ingenuity — a thriving community, built, supplied and maintained across a distance of 4.37 light-years. It is both a destination and a beginning: a demonstration that humans can live and work far from Earth, and a platform for the next generation to explore the Alpha Centauri system.

The nearest exoplanet, Alpha Centauri A b, remains under close study. Robotic missions and long-term observation have revealed a complex and intriguing world, but it is not yet inhabited. Its climate, geology and potential for habitability continue to be investigated by orbiters, landers and autonomous research systems.

In 2176, humanity stands at a new threshold — with a secure presence in space, a home around another star, and the knowledge that this is not the end, but the foundation for centuries of further exploration.



The completed cylindrical habitat in orbit around Alpha Centauri A, 2176.
A permanent home for thousands, sustained across 4.37 light-years, and a platform for the next chapter of exploration.

A CENTURY AND A HALF OF PROGRESS: 2026 – 2176

2026 — Renewed lunar program and commercial growth

2040 — Cislunar industry and permanent lunar presence

2050 — Mars missions and asteroid industry

2060 — Fusion breakthrough enables deep space travel

2077 — First interstellar ship departs for Alpha Centauri

2140 — Construction of the cylinder begins in orbit

2170 — Arrival and initial survey of the system

2176 — Cylinder completed and a frontier held in orbit

HUMANITY IN SPACE — AT A GLANCE (2176)



The Moon
- Permanent bases with thousands of people
- Science, resource production and launch support
- Gateway to the Solar System



Mars
- Multiple settlements, growing population
- Local industry, research and exploration
- Preparation for future expansion



Cislunar Industry
- Mature economy and regular transport
- Manufacturing, fuel production and space services
- Supports lunar, Martian and interstellar missions



Asteroid Resources
- Active mining and processing across the main belt and near-Earth asteroids
- Supplies water, metals and fusion fuel
- Integrated with cislunar and interplanetary supply chains



Alpha Centauri
- Completed cylindrical habitat around Alpha Centauri A
- Thousands of residents, self-sustaining systems
- Ongoing exploration of the Alpha Centauri system



Alpha Centauri A b
- Closely studied, not yet occupied
- Robotic orbiters, landers and long-term observation
- Climate, geology and habitability under investigation



The lunar base, 2030s. Still a vital part of the space economy in 2176.



A Martian settlement, 2150s. A growing community on a second home.



Asteroid mining, 2060s. Resources that power a larger future.



Alpha Centauri A b. A promising world still under study in 2176.