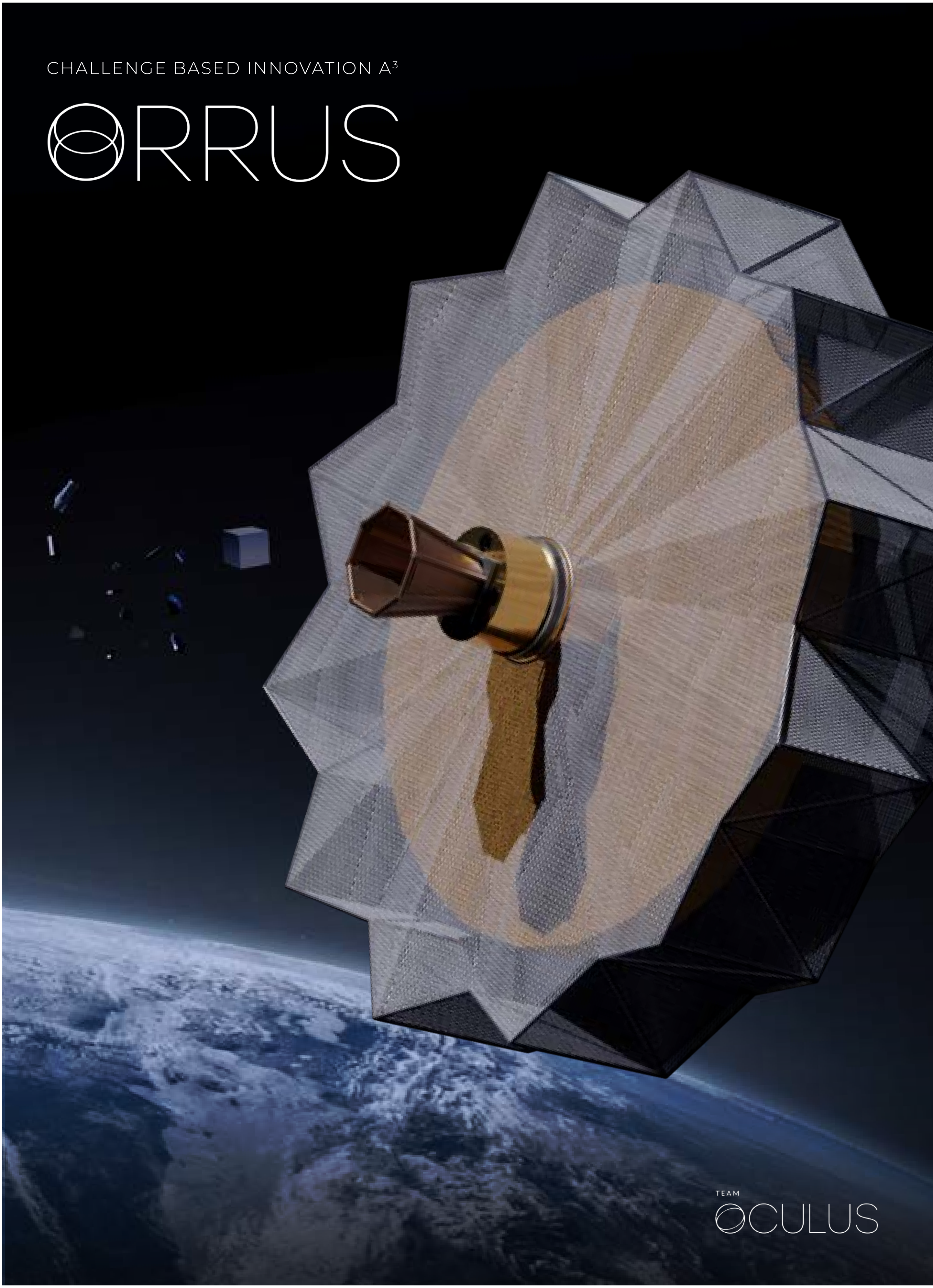
CHALLENGE BASED INNOVATION A^3

ORRUS



TEAM OCULUS

Abstract

The Low Earth Orbit (LEO) is a limited resource that is currently being exploited due to expanding global investment into space exploration and decreasing satellite launch costs. The quantity of satellites in LEO has grown rapidly in the past 10 years, and there is a significant number of orbital debris from rocket launches and collisions. With LEO being a desirable orbit, the growing number of satellites and space debris presents a risk for space activities, with potential to cause cascading collisions in the future.

To address this threat and ensure the sustainable use of space for generations to come, we propose a systematic approach that transforms satellite manufacturing practices, remediates space debris, and regulates space use. Our system is composed of 5 parts: (1) the International Coalition of Space Programs, (2) the ORRUS space mission, (3) the Shared Space Infrastructure, (4) the Orbital Resource Depository, and (5) the Orbitariums - immersive exhibitions on Earth that raise awareness.

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Contents

TEAM OCULUS

Liza Karimova

User Experience Design

Liza joins the team with 6 years of experience designing and building custom residential architecture. Originally from Russia, Liza went to UC Berkeley to complete her B.A. Her passion for experimentation, problem-solving and new technology has lead her to pursue a career in Product Design, which debuted with her M.S. at Pace University.

Liza enjoys acrylic and oil painting, cooking and eating creative dishes, reading Sci-Fi novels, traveling, and sketching architectural projects.

Nishant Doshi

User Experience Design

During his pursuit of a Bachelor's in Computer Engineering in India, Nishant discovered his passion for User Experience Design while volunteering as a Graphic Designer for his college's IEEE student branch. He's now on the path to further hone his craft with a Master's in Human-Centered Design in the bustling city of New York.

Beyond his design journey, Nishant is a dedicated FC Barcelona fan who enjoys strumming his guitar to '80s rock ballads and playing FIFA in his free time.

Lauren DeMaio

Computer Science

Lauren is currently in her final year of undergraduate study at Pace University, pursuing a BS degree in Computer Science with a minor in Italian Studies. Prior to her studies at Pace, Lauren was a Jazz and Contemporary trainee at the Joffrey Ballet School in NYC.

She loves to push both her creative and logical passions in life, and is always searching for new ways to overlap the two

Priyanka Kadam

User Experience Design

Priyanka's journey, saturated in Visual and Communication Design, now advances with her Master's in Human-Centered Design. Driven by her passion for design and problem-solving, she combines empathy and artistic finesse into User Experience Design, creating designs that go beyond mere functionality.

Beyond the world of design, Priyanka finds joy in long drives and indulging her sweet tooth. She's also an avid outdoor enthusiast, always ready for an adventure.

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Responsible Consumption and Production

The Challenge

Challenge Based Innovation (CBI) A3 is a project-based initiative launched by Design Factory Melbourne that focuses on the development of creative solutions that integrate technologies from CERN, the European Organization for Nuclear Research, and ATTRACT Academy, an innovative project funded by the European Union. The objective is to conduct a thorough exploration of a problem space in line with the 2030 United Nations' Sustainable Development Goal number 12 (UN SDG 12), which is titled "Responsible Consumption & Production".

The aim of the program is to design a solution that addresses a specific problem at a local level for each collaborating Design Factory. Our Design Factory is in New York City (NYC Design Factory at Pace University 2024).

This project focuses on the problem of making the consumption of our orbital resources more responsible and satellite production more sustainable. It addresses UN SDG target 12.5, to "Substantially Reduce Waste Generation", and target 12.6, to "Encourage Companies to Adopt Sustainable Practices and Sustainability Reporting" [25]. Our solution contributes to these targets in a collaborative way on a global scale.

NASA estimated in the year 2021 that there are 500,000 pieces of small debris measuring 1cm to 10cm in LEO [19]. Our solution is based on this assumption, and we use this number as a guiding metric to quantify our impact.

Solution Summary

As we gaze into the vast expanse of space, it's easy to imagine it as boundless, but the truth is far more complex. Our continued exploration of space has led to the proliferation of satellites, driven by advancing technology and our deepening interest in understanding the cosmos. Satellites are not only becoming smaller and more affordable but also more numerous, reflecting the growing global investment in space activities. However, with this expansion comes a critical challenge: the risk of space becoming an overcrowded graveyard of defunct satellites and debris from past missions.

To address this looming threat and ensure the sustainable use of space for future generations, we propose the establishment of the International Coalition of Space Programs (ICSP). The role of this coalition is to bring together nations, space agencies, and private entities with a shared commitment to responsible space utilization and preservation. It creates a market for trading access to rocket launch pads, and collects fees whenever access is transferred. It uses these funds to launch the ORRUS space missions, construct the Orbital Resource Depository [ORD] and a Shared Space Infrastructure [SSI], and open immersive exhibits on Earth called the Orbitariums.

At the forefront of this initiative are the ORRUS space missions that serve as the orbital recovery, recycling & utilization system. The purpose of these missions is to collect, process and store decommissioned nanosatellites and other small debris. Deep technology from CERN and ATTRACT is adapted to characterize, disassemble and sort through debris components. By targeting smaller debris and nanosatellites, ORRUS not only mitigates collision risks for active satellites and spacecraft but also unlocks the potential for recycling and repurposing these materials. This dual focus on debris removal and resource utilization aligns with the UN SDG 12 principles of responsible consumption and production, transforming what could be seen as a threat into an opportunity for innovation and responsible administration of space.

Through the economic and political efforts of the ICSP, and the technological power of ORRUS space missions, we envision a future where space waste is turned into valuable resources. Sustainable space practices are supported by a shared space infrastructure and an orbital depository that provide servicing and maintenance for satellites. Satellites no longer become waste, space missions do not generate debris, and space manufacturing makes use of the resources available in our orbits.

ORRUS ring and satellite prototype (below) and sketches (above).

The Problem of Space Debris

According to NASA's projections, the amount of space debris is expected to grow tenfold in the next decade [19]. With currently 500,000 pieces of small debris on LEO [18], that is no small number. This congestion, along with the increasing number of satellites and space objects, aggressively escalates the probability of collisions.

The potential for debris collisions, which can generate more debris, is of high concern. Every collision creates thousands of new fragments, which can then collide with each other, potentially triggering what is called the Kessler Syndrome [8, 28]. The term was coined by Donald Kessler in the 1970's, when cascading collisions first came to NASA's attention. The Kessler Syndrome revolves around the concept that, once space debris reaches a critical mass in LEO, unstoppable cascading collisions will begin, rendering LEO unusable. Kessler predicted that it would take 30 to 40 years for this to occur, and some researchers think that we have already reached the threshold [8, 28].

The cause of space debris

Space debris is in large part caused by the sheer number of commercial satellites and rocket launches used for telecommunications. In 2023, commercially launched rockets were responsible for 65% of all global launch attempts [11], the majority of which were used for communications [24]. SpaceX alone had 98 launch attempts that year, which is equal to 90% of all US launches [11]. These numbers are driven by the general population's growing need for data, influenced by industrialization and population growth.

Additionally, LEO is an extremely desirable orbit. Companies such as SpaceX want to place their satellites closer to Earth to minimize latency and reduce their launch costs. Because satellites at that altitude can only access a small part of Earth's surface area at a time, a large quantity of satellites is needed to achieve global coverage - hence the proliferation of mega- constellations of satellites [34].

The cost of space debris

Currently, telecommunications companies spend hundreds of millions of dollars per year on collision avoidance maneuvers for their satellites [9]. This cost is not representative of the amount of valuable mission time and data that they loose when performing these operations. Even prior to the start of the mission, Launch Collision Avoidance (COLA) can cause costly delays, and insurance premiums related to orbital debris are difficult to estimate [19, 13]. These financial setbacks make space operations cost-prohibitive to many players, such as research scientists that need microgravity to research and develop breakthrough drugs, and developing countries that need weather satellites to predict natural disasters.

"...satellites in LEO by 2029 will face potential collision with more than 16,000 pieces of orbital debris of 1 mm or larger each year" - Williamson [26]

Why are nanosatellites an issue?

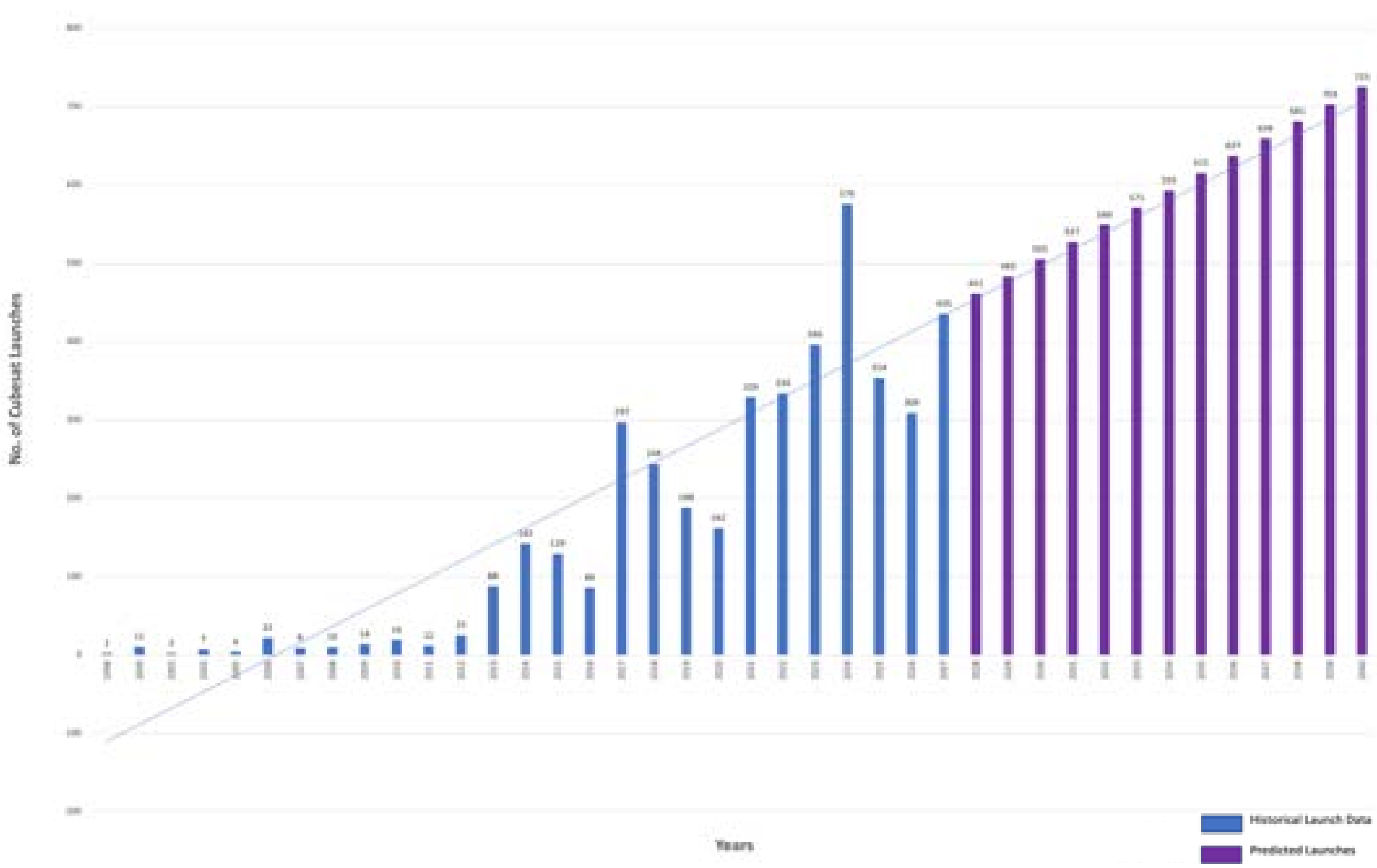
One of the main sources for small debris is decommissioned nanosatellites and cubesats. Nanosatellites (nanosats) and cubeSats, small and cheap to produce, have become popular for scientific and commercial space missions. These small satellites are often launched in large quantities, which results in the congestion of low Earth orbit (LEO) and increases the risk of collision with other objects or debris [5, 11, 17]. Approximately 500 nanosatellites are launched into LEO every year [10]. Their operational lifespan typically ranges from 1 to 5 years, and it takes on average 5 years for them to burn up in the Earth's atmosphere [19,27]. This means that they quickly become non-functional debris, contributing to the accumulation of space debris [2].

SpaceX, the leading launcher of nanosatellites, has gained regulatory approval to launch 12,000 in the next 5 years [23], with plans to launch over 40,000 satellites in the future. The satellites have an average lifespan of 5 years, which means that there will be a turnover of 2,400 decommissioned nanosatellites every year in LEO, awaiting their re-entry [25]. This is equal to 2,500 kg of mass that presents potential collision risks and cannot be controlled, which could instead be repurposed into valuable materials.

Unlike larger satellites, nanosats and CubeSats typically have limited maneuvering capabilities, making it difficult to avoid potential collisions with other objects or debris [2]. In the unfortunate event of a collision, these small satellites can fragment into numerous pieces, leading to further debris creation and scattering across different orbital paths. Their concentration in specific orbits, such as sun-synchronous or communication constellations, also heightens localized congestion and collision risks.

The trend towards using nanosats and CubeSats for space missions has its benefits, but it also poses significant challenges in terms of space debris and sustainability. To manage the debris generated by nanosatellites and CubeSats, tailored strategies are required due to their small size and distributed nature. Advancements in debris tracking, collision avoidance, and debris removal technologies are necessary to mitigate the risks of space debris. International cooperation and standards are crucial for establishing sustainable practices for deploying and managing these small satellites.

Historical and projected growth of nanosatellite launches per year

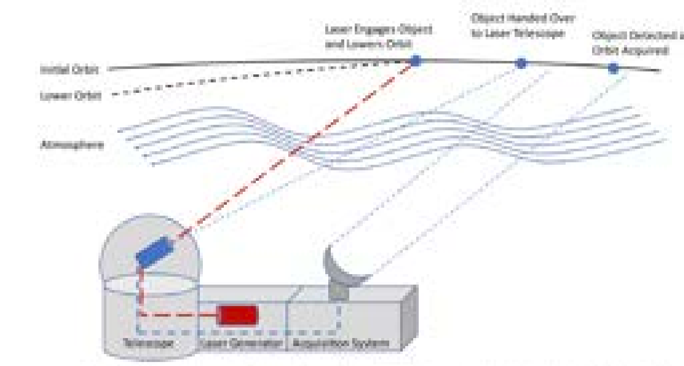


A linear regression model was applied to the historical data of nanosatellite launches [10] to forecast launches up to the year 2040.

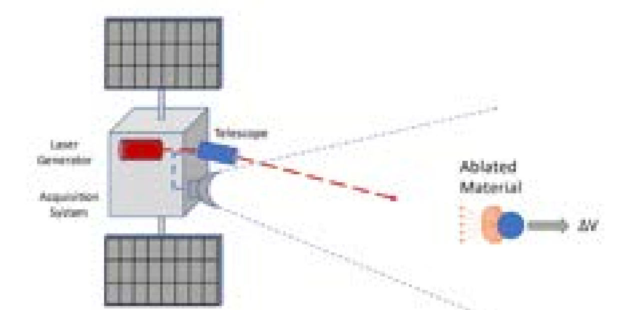
Current Solutions

Today, the general guidelines for satellites that have reached their end of life or end of mission is for them to stay in LEO until they reach natural decay - in other words, until Earth's gravity pulls them into Earth's atmosphere, where they burn up [26]. This is an example of a passive debris remediation method, that takes on average 5 years for nanosatellites [26]. The problem with this approach is that satellite re-entry releases harmful metals and oxides into our atmosphere, damaging the ozone layer [29]. Larger satellites also re-enter Earth's atmosphere, but do not completely burn up, and are instead directed to Point Nemo - a location in the pacific ocean [30]. This practice is harmful to our environment, as we are essentially placing space waste into our oceans with no plans for future remediation.

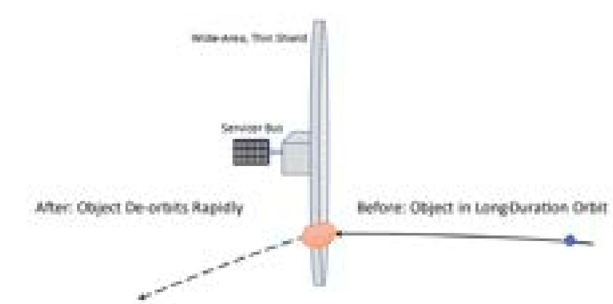
Proposed active debris remediation methods are also based either on satellite re-entry into the Earth's atmosphere, or nudging the debris farther into more distant orbits - which only delays the problem. Three of the most promising solutions for small debris, presented by NASA in their 'Cost & Benefit Analysis of Orbital Debris Remediation', cost between $300 to $90,000 per kg of debris remediated [31]. The solutions are a ground-based laser, a space-based laser, and a space sweeper. The cost of these solutions is calculated based on technology and launch mass. It is projected that to research and develop such a system would also take, on average, 5-10 years. To summarize, the upfront costs and long timelines associated with debris remediation make it difficult to secure funding, creating a catch-22 situation [5].



Notional concept of a ground-based laser facility for imparting impulses to orbital debris. The telescope that focuses the laser may require advanced adaptive optics to correct for atmospheric distortions to the beam. The system costs $300/kg



A space-based laser functions similarly to a ground-based laser; however, it requires much less powerful lasers and does not need adaptive optics to correct for atmospheric distortions to the beam. The system costs $300/kg



Sweeper concepts generally use a large pad of material to collide with small debris, thereby reducing the velocity of the debris such that it deorbits rapidly. The system costs $90,000/kg

Are there laws for debris remediation?

For many years, scientists have been arguing for Earth's orbits to be seen as a global commons worthy of protection from the United Nations [35], pushing for the licensing of space launches. Yet, no international binding laws around space launches and use exist.

The United Nations, which can advise the activities of only its member states, has created several non-binding space laws. The first law, called 'The Outer Space Treaty' from 1966 states that outer space "shall be free for exploration and use by all states without discrimination of any kind" and that "there shall be free access to all areas of celestial bodies" [36]. This treaty has not been updated since it was written - and the issue is that it has transformed space orbits into a tragedy of the commons. In other words, because of the lack of ownership, our orbits have become overexploited, with no one taking responsibility or providing stewardship. There are bodies that coordinate space activities, such as the International Telecommunication Union (ITU), but they do not regulate or enforce policies around satellite launches and operations.

It has proven difficult to establish international space laws. NASA created the Artemis Accords in 2020, where multiple nations signed a non-binding agreement on what regulations should be followed in space [37]. Although a step in the right direction, the non-binding nature of these agreements, and the lack of signatures from big players such as Russia and China, has limited their effectiveness.

Regarding policies around space debris, the Federal Communications Committee (FCC, USA) and the European Space Agency have put forth regulations for standard practices around decommissioned satellite disposal. Since 2022, the FCC has enforced a 5-year time limit for LEO satellites disposal at their end of life [38]. This is a significant change from the previous rules, where LEO satellites were given 25 years to re-enter Earth's atmosphere.

The FCC and ESA are also recommending that companies to design their satellites to limit the deliberate release of debris, improve spacecraft reliability, choose spacecraft materials that reduce the likelihood of fragmentation, shield spacecraft from small debris strikes, and employ self-disposal methods [2]. However, most of these strategies are extremely costly and time-consuming, with more research needed. In addition, there are no strict rules for implementation.

"Because of its lack of regulation, space junk is an example of a "tragedy of the commons," where many interests have access to a common resource, and it may become depleted and unusable to everyone, because no interest can stop another from overexploiting the resource." - PBS News

The signing of the Outer Space Treaty. United Nations, 1966

Space Manufacturing takes off in 2030

The Future

As the space industry becomes increasingly important to countries' economies and strategic interests, the pressure to address these issues will intensify. Space manufacturing is expected to take off in 2030, and projected to be worth 4.6 billion [13]. Multiple startups, such as Varda Space Industries, have already successfully manufactured revolutionary drugs on board it's spacecraft - spearheading space manufacturing for the healthcare industry [9]. This rapidly growing sector, with applications in many different industries, adds to the urgency of space safety [12]. The future of the space economy depends on the successful space regulations.

The Opportunity

The issue of space debris is multifaceted, with factors such as collision avoidance maneuver cost, public demand for data consumption, and space industry growth all contributing the to it's rapid growth. That is why space debris needs to be addressed at all stages, starting with data consumption by the general public and rocket and satellite production, and ending with rocket and satellite disposal. In the future, more conscious and responsible data needs could help reduce the number of launches and satellites in orbit. Modular and reusable satellite production practices could lead to better remediation opportunities, reducing the amount of space debris and recycling materials already in orbit.

Projections for 2030 & Beyond

Designing for the future requires speculation on what the next few decades will bring. In this case, we imagine a future where human wants and needs take precedence over environmental concerns. The consequences of prioritizing progress above all else would be far-reaching.

Social

We speculate that people will continue to be largely indifferent to the issue of space debris, prioritizing their immediate wants and needs. The concept of "out of sight, out of mind" prevails, with many individuals unaware of the potential consequences of space debris on future generations. Space sustainability is not a widely discussed topic, and it is not in the interest of satellite companies to raise awareness around this issue.

Technological

Advancements in technology lead to greater space use, which lead to even more debris generation. While some efforts are made to develop space debris removal technologies, they lack support and funding because their return on investment is many years out. Focus remains on short-term gains rather than long-term sustainability. Technology also plays an ever greater part in human lives, with brain-computer interfaces and AI assistants becoming ubiquitous.

Economic

The space economy grows as human desires are prioritized, with industries catering to immediate human wants. Space debris removal and sustainability efforts are seen as costly and time-consuming, taking a back seat to more profitable ventures. Space manufacturing becomes a booming business for the health, electronics and hospitality industries.

Environmental

The constant stream of decommissioned satellites burning up in Earth's atmosphere at their end of life raises greenhouse gases to dangerous levels. The significant presence of metals in the air becomes alarming. Point Nemo in the Pacific Ocean is overloaded with defunct satellites, which pollutes the oceans.

Legal

Without strong political support, legal frameworks for space debris removal and sustainability are weak and unenforceable. Companies launching satellites face minimal consequences for contributing to space debris, as the focus remains on economic growth. Legal battles arise as collisions and damage occur due to space debris, but the root causes are not adequately addressed.

Political

Governments prioritize economic growth and short-term gains, neglecting the need for space regulations. International cooperation is limited, with each country focusing on its own interests. The lack of cooperation between nations leads to geopolitical tensions, and monopolies form over commercial space use.

Ethical

Individual desires are prioritized over collective environmental responsibility. The lack of ethical consideration for future generations results in a short-sighted approach to space exploration. The benefits of space exploration are enjoyed by a select few, while the negative consequences of space debris are felt by all.

The Future of Space

Source: New Space Economy

How might we make space exploration safe & accessible for all while making use of existing resources & stabilizing the growth of space debris?

Solution System

Our proposed solution to the challenges of space debris and the increasing demand for sustainable space exploration is a comprehensive five-part system:

1. International Coalition of Space Programs (ICSP)

We propose the formation of an international coalition that brings together various space programs from different countries. This coalition fosters collaboration and the sharing of resources, knowledge, and technologies related to space exploration and debris remediation. It collects funding and enables the ORRUS space missions, the construction of the ORD and SSI, and the operation of the Orbitariums.

2. ORRUS Space Missions

ORRUS, the "Orbital Recovery, Recycling & Utilization System", is a series of dedicated space missions that focus on the remediation of space debris. Each mission is launched over the course of several years. Each ORRUS is composed of a debris processing unit and a perimeter ring truss with a storage bag that unfolds around it. ORRUS employs advanced technologies and methods to capture decommissioned nanosatellties and small space debris. It processes the collected debris and stores it in the storage bag for use in future space projects. Once the storage bag is full, the processing unit detaches and travels to a new perimeter ring truss with a storage bag.

3. Orbital Resource Depository (ORD)

The role of the ORD is to collect the storage bags that ORRUS leaves behind, and bring them to a central location. From there, it processes the satellite scraps into new materials for building public space projects. It maintains a comprehensive database of all materials that it stores.

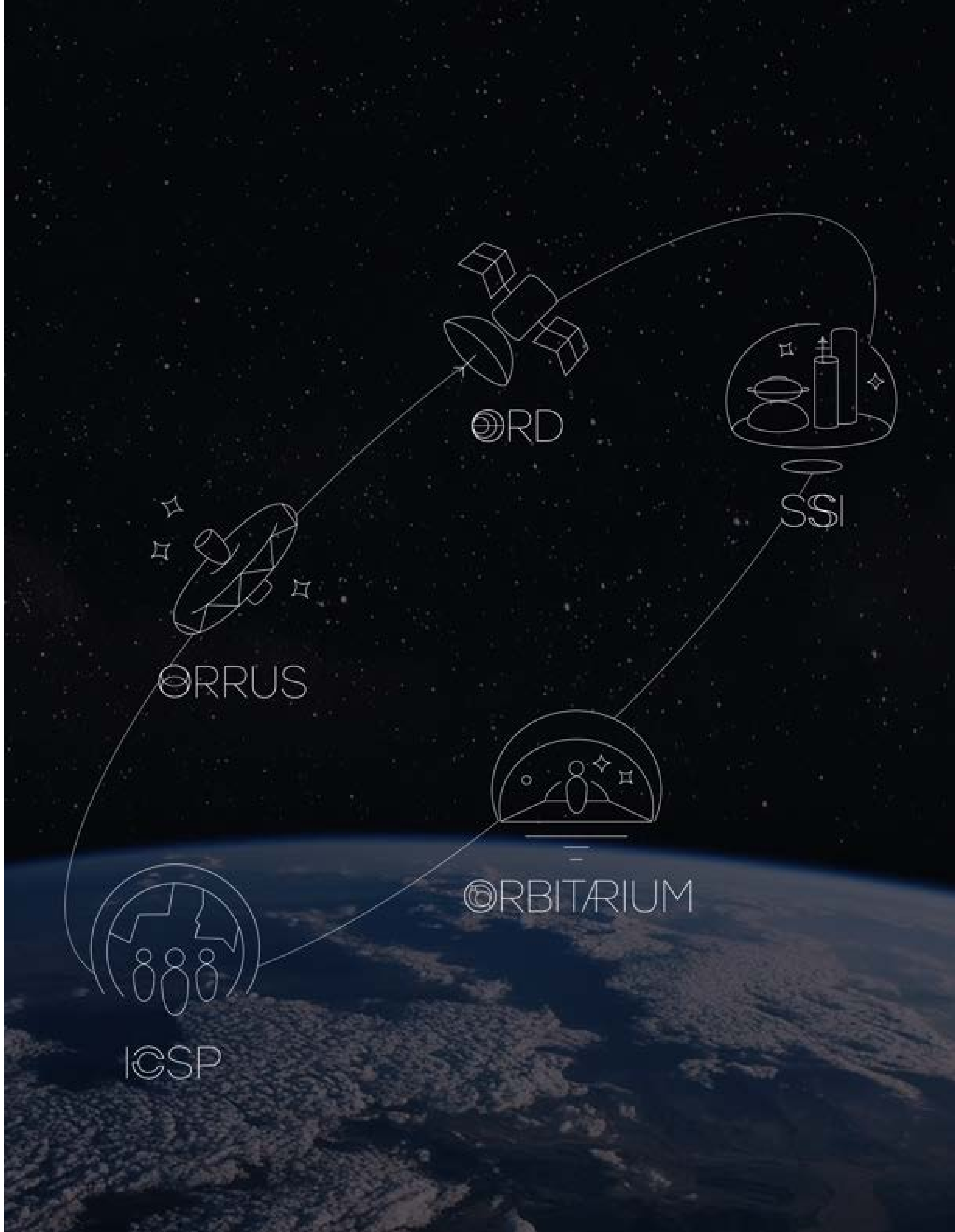
4. Shared Space Infrastructure (SSI)

The SSI supports ORRUS missions and makes it possible to service satellites and perform maintenance easily in space. It is regulated by the members of the ICSP, and is instrumental for transforming satellite manufacturing practices and preventing space waste.

5. Orbitarium - Immersive Exhibitions

It can be challenging to grasp the problem of space debris from the surface of the planet. To address this gap, Orbitarium Immersive Exhibitions are established on Earth to raise awareness about space sustainability, and educate civilians about it's challenges and impact. Visuals of satellites and debris moving in real-time in our orbits, with alerts for collision risks, show the sheer quantity of objects in space, and the dangers that this presents. The exhibitions also highlight the resources that have become available for public projects thanks to the ORRUS missions, emphasizing that what was once considered as waste is now a valuable resource in the deserted vacuum of space.

This five-part system of ORRUS aims to address the pressing issues of space debris, resource utilization, and the need for sustainable collaboration in space exploration. By uniting diverse space programs, employing specialized missions, efficiently managing resources, and engaging the public, we believe space exploration can become more accessible, environmentally friendly, and beneficial to all stakeholders and the mankind.



The Coalition of Space Programs creates a market for trading access to space launch pads

International Coalition of Space Programs

The International Coalition of Space Programs (ICSP) is the central component of our proposed solution, aiming to regulate access to orbits and manage space infrastructure. The first priority of the ICSP is to collect funding for debris remediating missions through space launches. It does this by creating a market where access to rocket launch pads can be tracked, traded and sold. Each rocket launch pad is allocated with a set number of launches per year. This provides a framework for countries to share launch pads and regulate their usage. The ICPS collects a fee every time access to a rocket launch pad is transferred. With many countries competing for launch pad access, this venture is expected to quickly generate revenue to fund various initiatives.

Once the initial funds are secured, the ICSP begins to address the issue of space debris in LEO by launching a dedicated space mission, ORRUS. Each year, and additional ORRUS mission and ORRUS debris storage bag is launched.

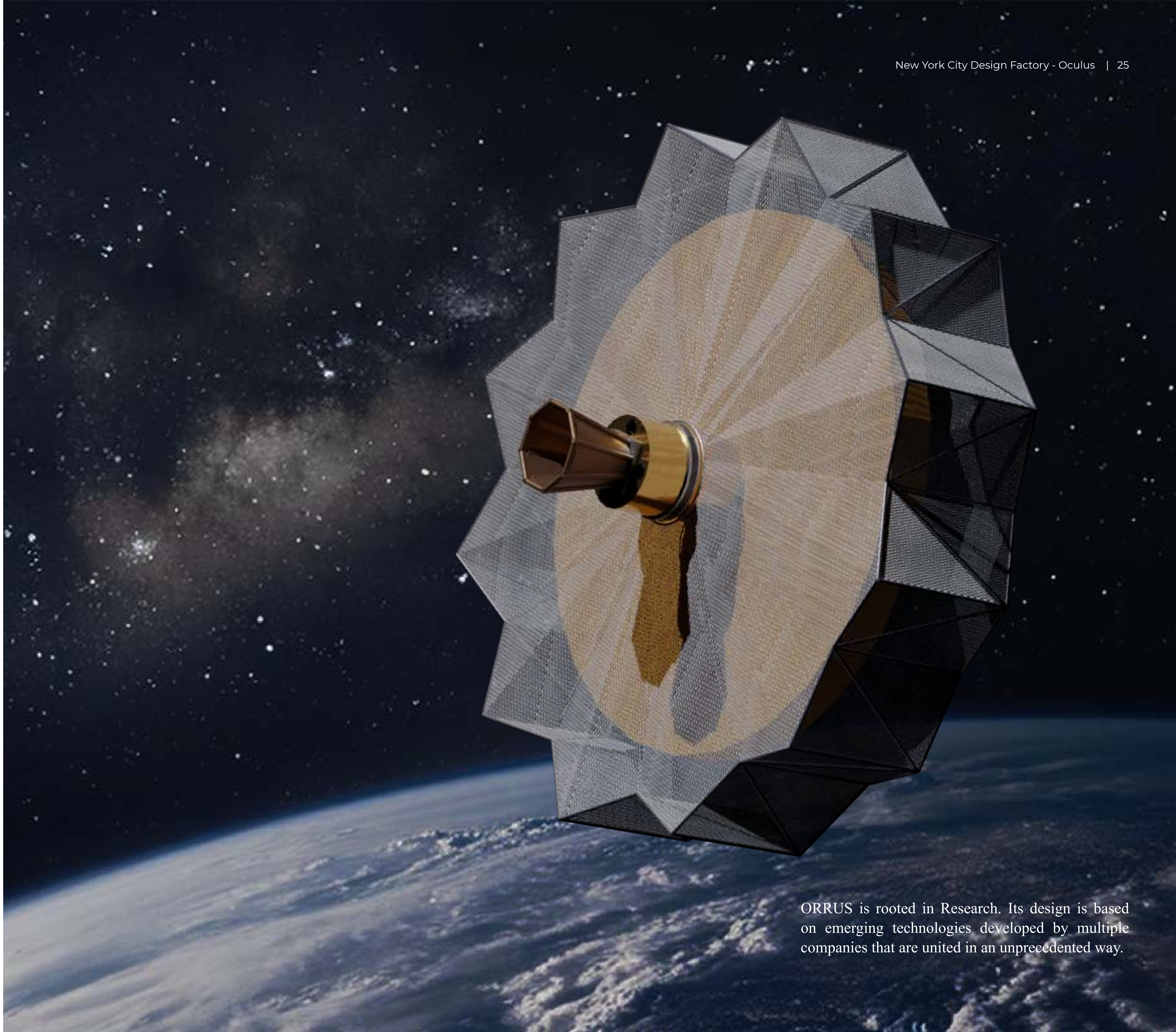
To support the ORRUS missions, the ICSP constructs an Orbital Resource Depository (ORD) to collect and process ORRUS debris storage bags while keeping track of the resources obtained from space. This initiative is supported by the development of a shared space infrastructure (SSI), which optimizes resource utilization and reduces the burden on individual space programs.

Furthermore, the ICSP bridges the gap between space exploration and the general public awareness of the space debris problem by inaugurating immersive exhibitions on Earth. These exhibitions, called the Orbitariums, provide educational and captivating experiences that foster a deeper understanding of space exploration and its challenges.

Through these multifaceted initiatives, the ICSP strives to regulate space activities, promote sustainability, and secure funding for projects that pave the way for responsible and collaborative space exploration.

ORRUS Space Missions

The ORRUS space missions are designed to address the issue of space debris by collecting, processing and storing small debris objects. The physical system consists of a central satellite and a surrounding perimeter ring truss structure.



ORRUS is rooted in Research. Its design is based on emerging technologies developed by multiple companies that are united in an unprecedented way.

Deployment of the ORRUS ring in LEO orbit

THE ORRUS RING

Design

The ring is a deployable structure that unfolds around the central satellite. It stores processed debris and protects it from potential impacts upon unforeseen collisions. The design of the perimeter ring truss is based on the Northrop Grumman AstroMesh deployable mesh antenna structure [31]. It is made of metal tubes, ties, and AstroMesh fabric. The choice of a perimeter ring truss for the ORRUS mission offers the advantages of lightness and stiffness while providing exceptional structural efficiency. The ring is able to protect the space debris within thanks to it's ability to dissipate energy across it's large surface. This means that when objects collide with ORRUS, their energy does not puncture the ring fabric, but is instead absorbed by the surface in tension. With a ring diameter of 3 meters, the storage system of ORRUS can hold up to 500 nanosatellites, as shown in the diagram on the right.

Dimensions

The ring diameter is 3 meters, and the height of the deployed ring is 0.6m. This provides the ring with the capability to hold an inflatable bag in it's interior to store over 500 of 10x10x10cm objects.

Mass

The total mass of the ORRUS ring is based on the mass of the 12m diameter AstroMesh ring, which is 57kg [32]. The total surface area of the 12m diameter ring is approximately 113.1 meters squared. The reflector mass-to-area ratio is 0.37 meters squared per kilogram for diameter increases [33]. The diameter increase from a 3m diameter (with total area of 7.07 meters squared) to a 12m diameter ring is 106.03 meters squared. Thus, the total mass-to-area difference is approximately 40kg. If we subtract that from the total mass of the 12m diameter ring, which is 57kg, we end up with a mass of 17kg for the 3m diameter ring. We believe that this is a generous estimate, given that a similar prototype of a 3.6m diameter perimeter ring truss had the mass of 6.6kg [32].

THE ORRUS SATELLITE

Design

The role of the central satellite is to collect and process space debris. It is attached to the center of the perimeter ring truss, where it stores debris after processing it. It is able to detach itself from the ring. The satellite is made up of multiple compartments: a disassembly chamber, a sorting chamber, a metal processing unit, a fuel storage tank, a propulsion mechanism, and various sensors, detectors and controls and navigations systems.

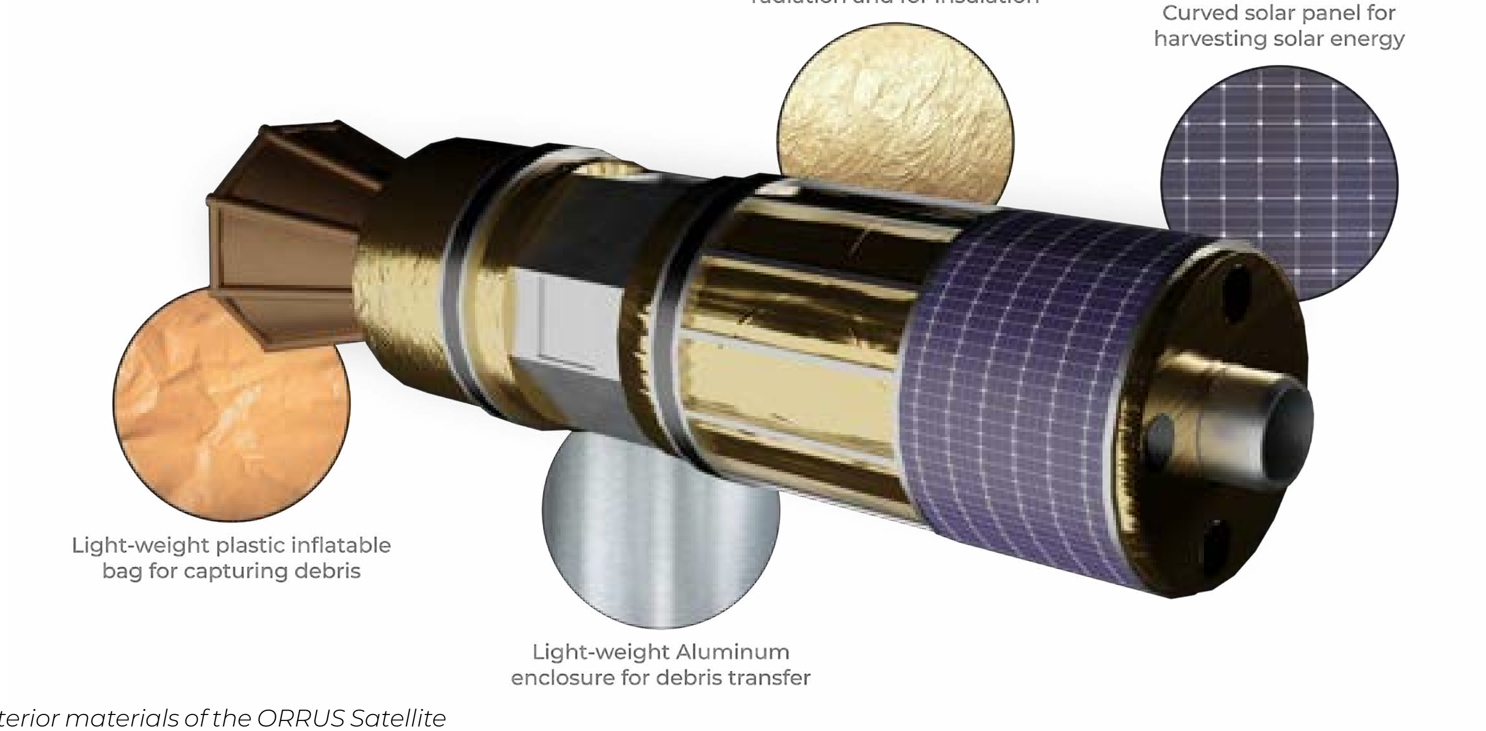
Kapton film protects the exterior of the satellite from radiation and temperature changes, and a wrap-around solar panel converts solar energy into electricity. Star Trackers detect debris, and DPSS lasers on the front slow down the debris. An inflatable capture bag, developed by TransAstra and NASA, directs debris to the interior. VISIR2 and Medipix3 technologies identify the type of the debris on the exterior, and characterize materials inside the satellite. Inside, the CERNBot arms disassembles the debris.

Dimensions

The ORRUS satellite is 0.4m in diameter, and 1.2m long. The total volume of the satellite is 0.15 cubic meters. The size of the satellite is determined by the dimensions of the MicroSpace Foundry [30], Neumann Drive, CernBot, and other technologies, as well as debris size.

Mass

Given that a 10x10x10cm object, with a corresponding volume of 0.001 meters squared has a mass of 1kg, it can be inferred that with a volume of 0.15 cubic meters, the ORRUS satellite has a mass of 150kg. This number is consistent with the average mass of satellites of the same size.



Exterior materials of the ORRUS Satellite

MISSION STEPS

ORRUS collects decommissioned nanosatellites as it's first target. After the ring deploys in space, ORRUS utilizes star trackers to detect a nanosatellite. It then uses DPSS lasers to slow it down before performing identification. This process involves VISIR2, a camera capable of capturing images in both visible and infrared light, depending on the lighting conditions. The data from these images is processed using Medipix3 technology. This helps ORRUS ascertain that is has found a nanosatellite that has been decomissioned and that is ready for collection.

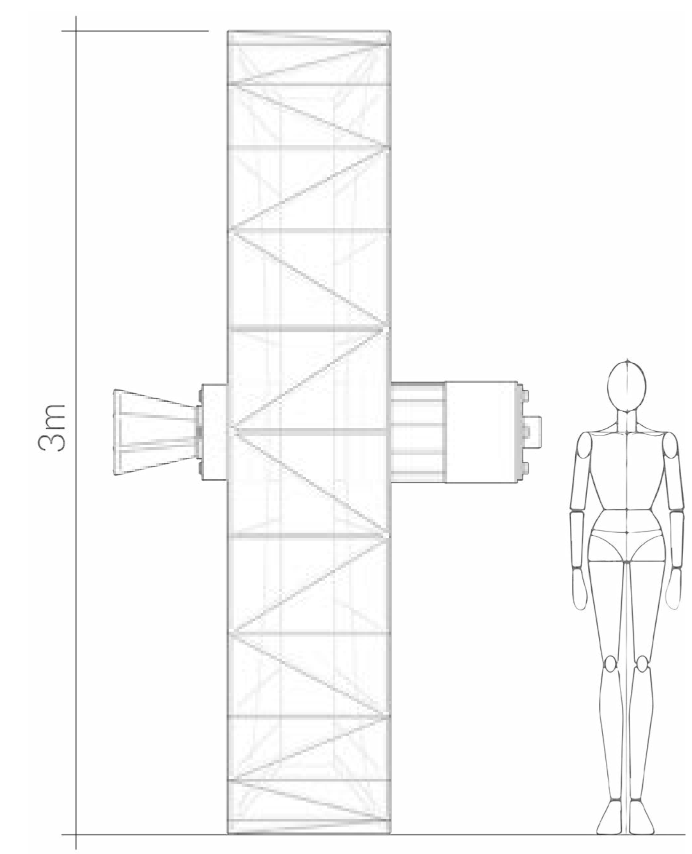
As a next step, ORRUS employs an innovative collection method that involves an inflatable capture bag, developed by TransAstra & NASA. After the nanosatellite enters the interior of ORRUS, the sorting process begins. The CERNbot robotic arm is used to disassemble the nanosatellite into individual components, and VISIR2 and Medipix3 are used once more to characterize the components by material.

The aluminum frame and screws of the nanosatellties are processed into fuel using a MicroSpace Foundry by CisLunar Industries and a converted into propulsion using the Neumann drive by Neumann Space. This fuel is essential for the continuation of the ORRUS mission. The remaining materials are carefully stored in an inflatable storage bag, which is protected by the perimeter ring truss structure. Once the storage bag is filled to capacity, the ORRUS satellite detaches and travels to a new ORRUS storage bag.

ESTIMATED COST

The total mass of the ORRUS satellite and ring is 160 kg (about half the weight of a large motorcycle). Based on the total mass, the estimated launch cost for one ORRUS mission is $80,000. This number is based on NASA's approximate estimate of $500/kg for launch costs aboard the SpaceX Starship [2].

Assuming a collection rate of 500 nanosatellites per year, this results in a cost of approximately $160 per piece of debris removed. This cost is significantly lower than NASA's cheapest proposed solutions for small debris remediation, potentially making ORRUS an efficient and cost-effective solution [2].



ORRUS satellite scale reference

Integrated Technology

EX-Fusion

Diode-pumped solid-state laser (DPSS)

To tackle the fast-paced small debris traveling at a speed of 7km/s, ORRUS intermittently aims lasers at the debris, opposing the direction of its travel. The laser slows down the debris, allowing for easier capture and preventing possible damages to ORRUS.

ATTRACT

VISIR2

Inside ORRUS, a camera that uses both visible light and short wave infrared light (SWIR) characterizes the debris parts by type of material. It provides information on the composition of the debris, based on how it's components reflect light.

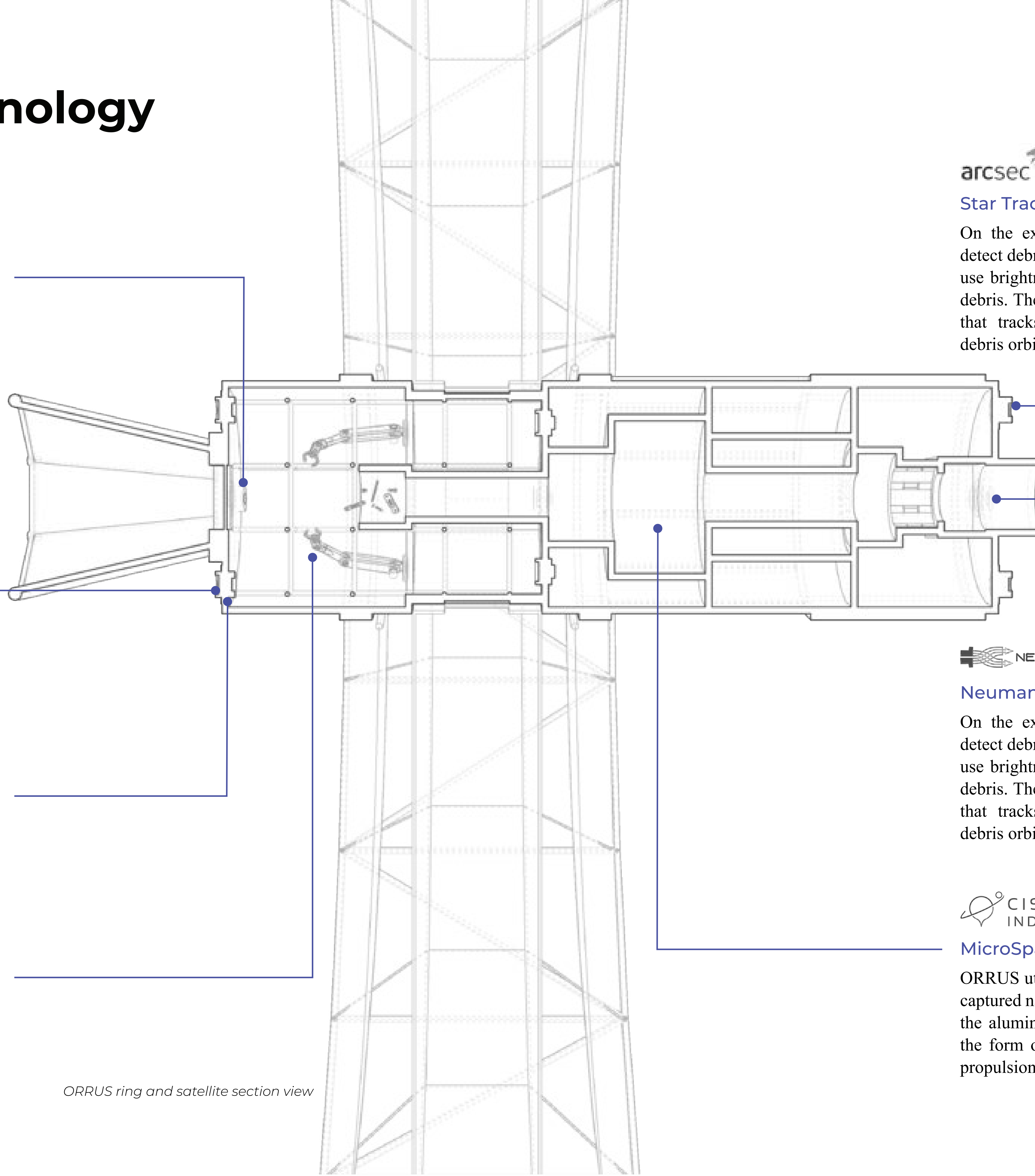
CERN

Medipix3

Medipix3 is a Complementary Metal-Oxide-Semiconductor (CMOS) pixel detector readout chip that can be connected with VISIR2 to process the captured images at a much faster speed - an estimated 3 seconds by 2030. The color imaging and high-resolution capabilities of Medipix3 allow to identify the type, size, and composition of the debris.

CERNBot

Robotic arms called CERNbot, which can work together or independently, to disassemble collected nanosatellites and other debris. They work together with VISIR2 and Medipix3 to separate aluminum from the rest of the materials.



ORRUS ring and satellite section view

arcsec

Star Trackers

On the exterior, ORRUS utilizes star trackers to detect debris. This is done via optical sensors, which use brightness information to determine the size of debris. The debris is detected using the same sensor that tracks ORRUS's altitude, ensuring accurate debris orbit calculations.

NEUMANN SPACE

Neumann Drive

On the exterior, ORRUS utilizes star trackers to detect debris. This is done via optical sensors, which use brightness information to determine the size of debris. The debris is detected using the same sensor that tracks ORRUS's altitude, ensuring accurate debris orbit calculations.

CISLUNAR INDUSTRIES

MicroSpace Foundry (MSF)

ORRUS utilizes MSF to recycle the aluminum from captured nanosatellites and space debris. It processes the aluminum into standardized metal feedstock in the form of propellant rods, that are then used for propulsion via the Neumann Drive.

Future Orbital Resource Depository

Orbital Resource Depository

Within our proposed framework, the Orbital Resource Depository (ORD), serves as a central point for the systematic aggregation, storage, and processing of resources procured from space debris. It is concentrated specifically on small space debris and nanosatellites obtained through the ORRUS missions. The ORD is funded, constructed and maintained by the ICSP.

One of the main roles of the ORD is to collect debris storage bags that ORRUS satellites leave behind in shielded perimeter ring trusses. It brings the rings to a central location, where it extracts the storage bags from the rings and processes their contents using advanced technological systems. The recovered materials are converted into resources that can be used for public space projects and shared space infrastructure (SSI).

Another essential responsibility of the ORD is to maintain a resource database that catalogs all debris collected. This comprehensive dataset facilitates data transparency and the sharing of space resources between nations. This step is also instrumental in ascertaining potential secondary applications for the materials, thereby optimizing the utilization of space-derived resources.

The ORD is crucial to our solution, as it provides a structured and systematic approach to managing resources obtained from space. By centralizing the collection, storage, and processing of these resources, the ORD promotes efficient utilization, sustainability, and waste reduction.

Shared Space Infrastructure

The Shared Space Infrastructure (SSI) is a necessary initiative for space sustainability. It encompasses the phased development of an adaptable platform for maintenance services performed in space. The role of the SSI is to support ORRUS missions and the ORD, service satellites, and provide support to the developing sector of Space Manufacturing. It is constructed and funded by the ICSP.

The SSI plays a crucial role in supporting the ORRUS mission and the ORD by aiding with servicing and maintenance. This includes regular inspections, repairs, and upgrades to optimize the functionality and durability of these essential components. The SSI's involvement is vital for ensuring the long-term sustainability and effectiveness of critical orbital resources.

Another key function of the SSI is to provide crucial in-space satellite services, such as refueling, maintenance and repair. These services have the ability to enhance the longevity and overall performance of satellites, ultimately increasing their life span and preventing them from turning into space debris. In this way, the SSI is instrumental in paving the way forward for reusable satellites, that can be repaired and re-used for multiple missions. This marks a significant departure from traditional satellite manufacturing practices.

Lastly, the SSI provides support to the developing sector of Space Manufacturing. Countries share resources and missions, which makes projects in various industries financially feasible, benefitting all of humanity. As a shared platform, SSI is crucial to international collaboration, space sustainability and innovation.

SSI

Shared Space Infrastructure supports ORRUS missions and ORD operations

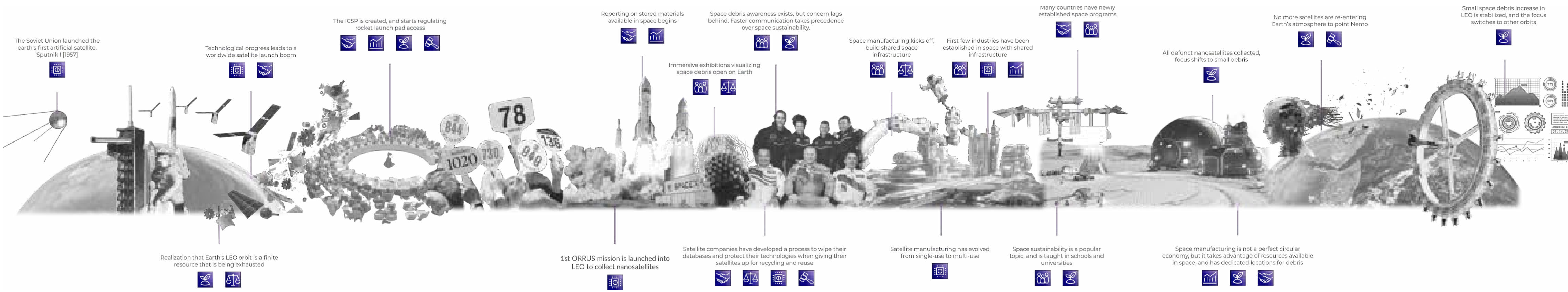
The Orbitariums: Immersive Exhibitions

The Orbitariums are a series of immersive exhibitions created with the intention of educating visitors about the critical issue of space waste and inspiring behavioral change around data consumption. They function as a vital link between the world of space exploration and the public.

Inside the exhibitions, real-time visuals display the quantity of objects in Earth's orbits in an effort to make the problem of space debris easier to grasp from the Earth's surface. Commercial satellites and satellites used for telecommunications are differentiated to demonstrate that the main source of objects are satellites used for public data consumption. The relationship between data usage and orbital sustainability is highlighted in an effort to influence behavioral change surrounding data usage demands and practices.

Further in the exhibition space, real-time potential collision alerts appear on the displays, demonstrating to the public the frequency of collision avoidance maneuvers that satellite companies need to perform. The goal of displaying the real-time visuals is to raise awareness about space debris through data transparency and data visualization. Once there is awareness around of the number of threats that constantly need to be dodged, the urgency of the problem that the space industry is facing comes into perspective.

In addition to accurately depicting objects and potential collisions in our orbits, the Orbitariums showcase the debris materials that have been recycled into resources by the ORD. This underscores the fact that objects that were once a threat can be transformed into valuable resources, thanks to the impact of the ORRUS missions and ORD operations. The goal of this display is to create accountability for the ICSP and other players, fostering a sense of responsibility around the preservation of our orbits, and elevating LEO to become a global commons.



Implementation Roadmap

The proposed timeline for the rollout of ORRUS solution system spans several decades and can be broken down into key phases.

The initial phase involves the establishment of the ICSP and the collection of funding, which is crucial for the subsequent steps. By 2025, it is expected that the ICSP will be fully operational and will have a steady source of funds to use on space projects.

The year 2030 marks a significant milestone with the launch of the first ORRUS space mission aimed at collecting decommissioned nanosatellites. Simultaneously, Orbitarium exhibitions are inaugurated to educate the public and raise awareness about the importance of space sustainability.

By 2035, all nanosatellites are collected. The focus shifts to the construction of the ORD and the SSI, designed to support the ORRUS space missions and emerging space manufacturing industries. This phase involves significant collaboration and development to ensure the successful establishment of these elements.

Moving forward to 2040 and beyond, ORD and SSI help satellite manufacturing practices evolve and move towards recycling and reuse. Space sustainability becomes a major topic of discussion for the general public. The reduced number of small debris in Earth's orbits leads to lower satellite operational costs, which makes space more accessible to all and helps dismantle monopolies around commercial space use.

The long-term goal, by 2050, is to have successfully collected and remediated a significant portion of small debris in LEO, allowing subsequent ORRUS missions to focus their efforts on other orbits. This carefully planned timeline reflects a comprehensive and gradual strategy to address the complex challenges posed by space debris and to foster sustainable space exploration.

2025 | 2030 | 2040 | 2050

ICSP

- LEO is recognized as a finite resource that is being overexploited
- The ICSP (International Coalition of Space Programs) is created to make access to space equitable and space use sustainable
- It is backed by major players because it offers financial incentives to those that help enforce new space launch regulations

- The ICSP creates a market where access to rocket launch pads can be traded
- Each time access to a launch pad is transferred, the ICSP collects a fee

- The ICSP has gathered enough funds to finance the first LEO debris cleaning mission, called ORRUS

- The ICSP establishes satellite collection laws for decommissioned nanosatellites

- The ICSP has successfully funded and launched 3 ORRUS missions
- The ICSP works to raise funding for SSI (shared space infrastructure) and ORD (orbital resource depository)

- The ICSP has successfully funded the construction of the ORD facility in space

- The ICSP regulates the ORD facility
- The ICSP helps reform satellite manufacturing standards from single-use to multi-use
- The ICSP creates new regulations for SSI use and operations

- The ICSP establishes and enforces international laws in space
- The ICSP switches focus to other orbits

ORRUS

- The first ORRUS satellite and ring is launched
- It starts collecting nanosatellites, processing aluminum into fuel for VAT propulsion, and storing the rest of the materials for future recycling

- 3 ORRUS satellites have been launched, and an additional 12 rings that hold debris have been sent to space
- 15 rings now hold 500kg of debris each
- All existing defunct nano-satellites have been collected
- ORRUS starts collecting small debris

- ORRUS focuses solely on small debris
- ORRUS satellites and rings are launched as needed to address small debris growth in LEO

- small debris increase in LEO has been stabilized
- ORRUS continues collecting small debris indefinitely
- ORRUS starts focusing on other orbits

ORD

- First data regarding stored materials from nano-satellite collection becomes available
- The data is recorded and made publicly available

- First data regarding stored materials from small debris collection becomes available
- This data is recorded and made publicly available

- The ORD facility is built, and it begins collecting ORRUS rings and processing materials for use in SSI projects

- The ORD is an important depository for resources for building public SSI projects

- The ORD is an important depository for resources that are used by many space manufacturing industries

SSI

- SSI is gradually built in space
- It helps support and maintain ORRUS and ORD
- It also provides satellite refueling and maintenance services, which help evolve satellite manufacturing practices

- SSI becomes an integral part of emerging space industries, such as healthcare and semiconductors

- SSI enables many new players to gain access to space and provides a foundation for new space industries

- Private space infrastructure becomes tied into SSI

ORBITARIUM

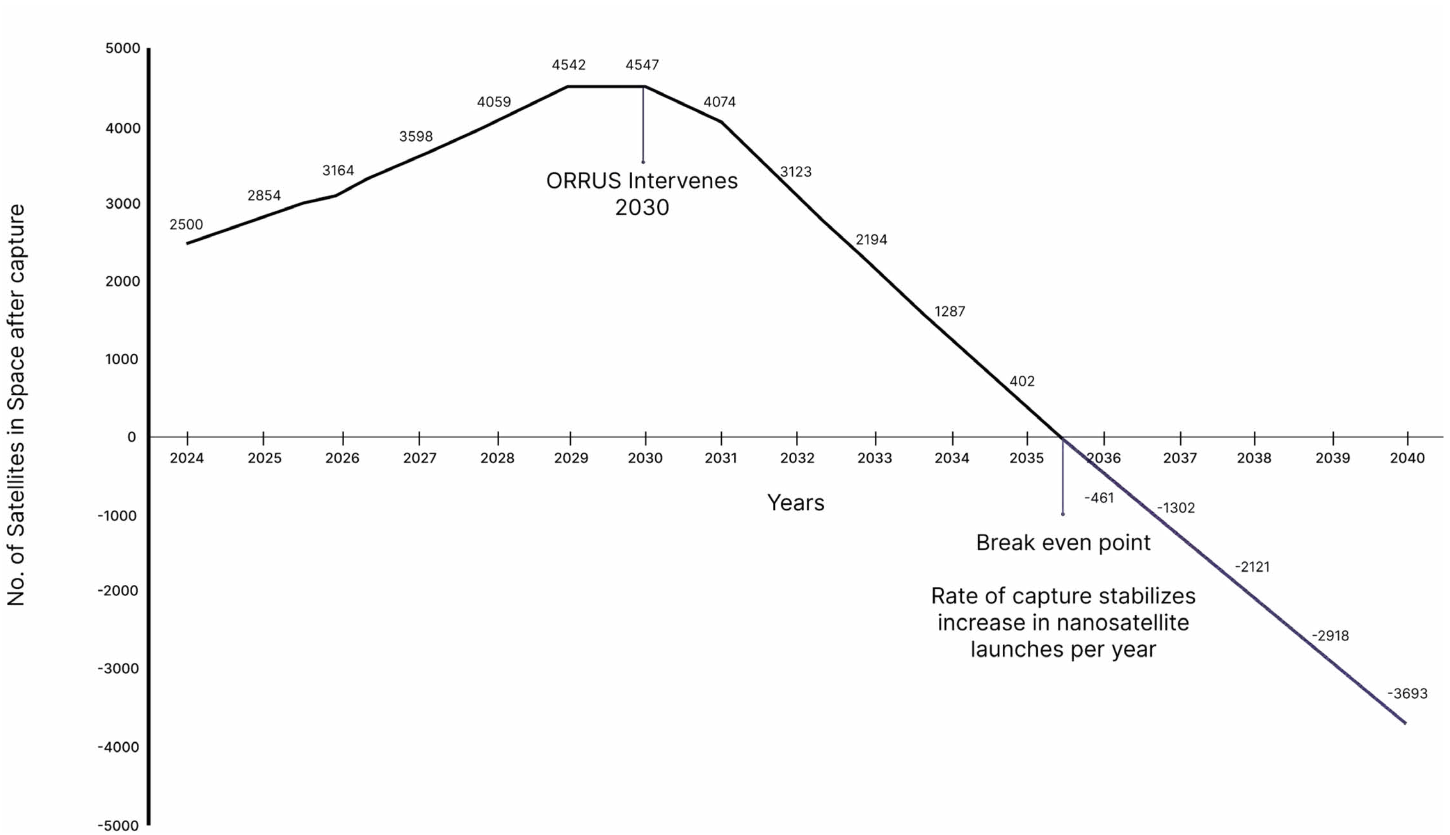
- Orbitarium's immersive exhibitions visualizing space debris open on Earth with the goal to raise awareness about space sustainability and how data usage affects it
- The installations also inform what resources are available in space from nanosatellite and debris recycling

- The Orbitariums have helped raise awareness, and space sustainability is now part of school and university curriculums

- Citizens of Earth are more conscious of their data and internet usage, because they realize that it utilizes finite resources

Value Proposition

Impact of ORRUS over the years - Reaching breakeven point in 2035



As demonstrated earlier on page 10, a linear regression model was applied to the historical data of nanosatellite launches from [10] to forecast launches up to the year 2040.

This data was used to quantify the impact of the ORRUS missions for removing decommissioned nanosatellites from the LEO orbit.

By 2035, it is expected that 3 ORRUS missions will be active in LEO. With each mission collecting 500 nanosatellties per year, a total of 7,500 nanosatellites will be collected by 2035. As shown on the graph, this is 100% of all decomissioned nanosatellites.

Following that, 17 more ORRUS missions will be launched, with the goal of capturing other small debris in the LEO. With this fleet, ORRUS will collect 30% of current small debris by the year 2050, equivalent to 150 tons of waste.

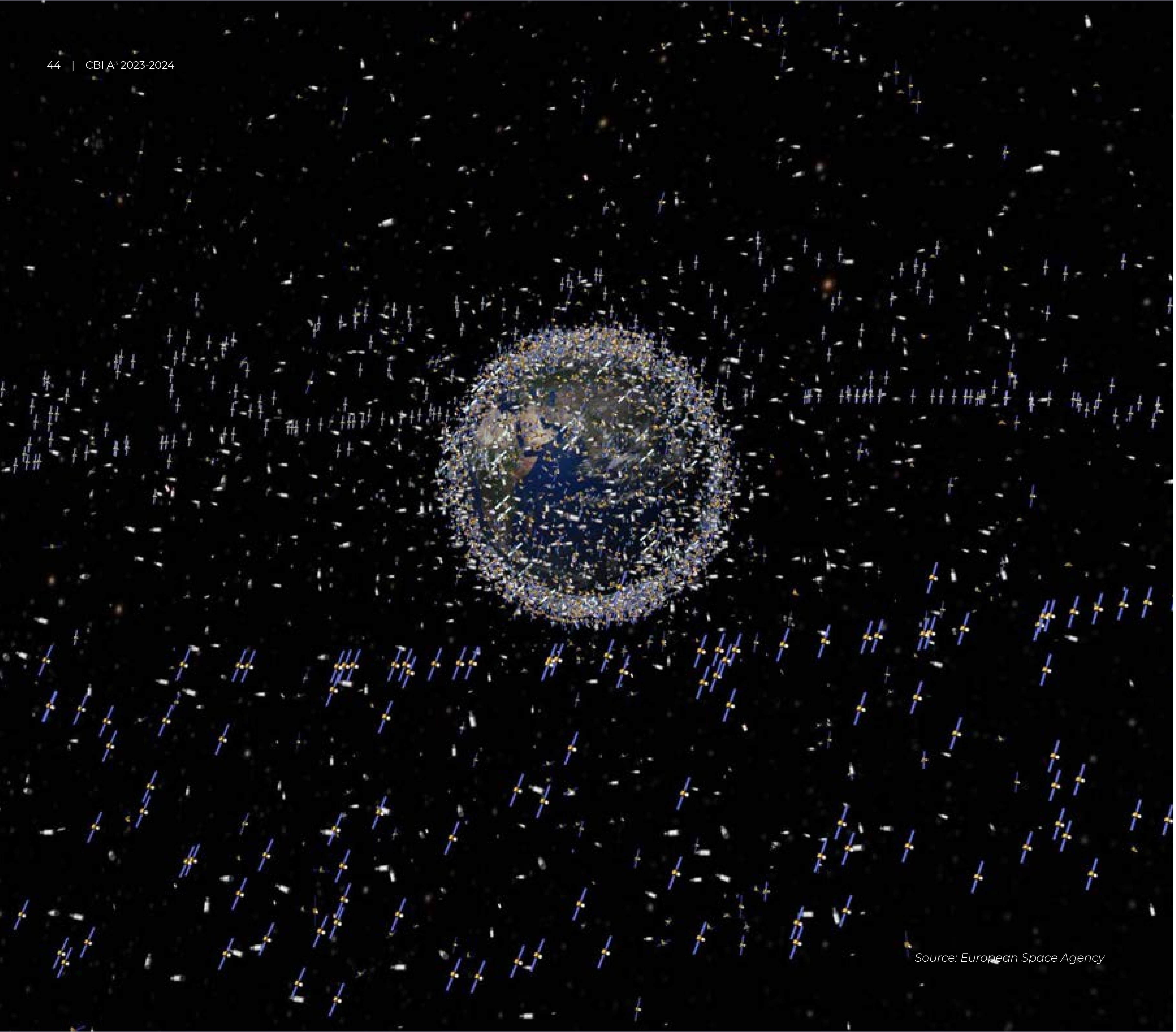
There are three main aspects to our solution that set it apart from our competitors.

Firstly, we aim to address the root cause of the problem with behavioral change. Our system provides funding and infrastructure that is needed to not only clean our orbits, but also change our satellite manufacturing practices to not produce any more debris.

Secondly, we adopt a realistic approach, given the scale of the problem. We realize that we cannot clean LEO of all small debris in the next few decades, but we can remove all decommissioned nanosatellites, and collect a substantial amount of small debris.

Thirdly, our solution is rooted in research. Our system is based on the work of multiple companies, that have developed real products. We are using their emerging technologies and combining them in unprecedented ways.

Source: European Space Agency



Source: European Space Agency

Conclusion

As demonstrated, the issue of space debris in LEO poses a significant threat to current and future space activities. The proliferation of nanosatellites and cubesats, driven by their small size, low cost, and versatility, has resulted in a congested and hazardous space environment. The increasing number of these small satellites, coupled with the presence of larger debris, heightens the risk of collisions and the potential for cascading impacts - coined as the term 'Kessler Syndrome'.

We believe that a systematic approach, such as the one outlined in the paper, is the key to solving this problem. We need to transform satellite manufacturing practices, remediate space debris, and regulate space use through international cooperation, advanced technologies, and public engagement. It is necessary to foster innovation, environmental responsibility, and the collective commitment to preserving the space environment to ensure the sustainable use of space for generations to come.

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