The Space Framework™

Giovanni N. D'Aloisio[*]
Dipartimento di Scienze e Tecnologie Aerospaziali (DAER), Politecnico di Milano, Via La Masa 34, 20156 Milano, Italy

The *Space Framework*™ is an open-architecture concept for the integration of Solar System resources into the terrestrial economy, aiming to accelerate the transition to a space-oriented civilization while enhancing safety and sustainability in spaceflight.

The architecture rests on three pillars: a fleet of multipurpose interplanetary spacecraft (*Kvant*™, baseline capacity 10 crew + 150 t cargo or 150 passengers), a family of modular space stations (*Redstar*™, 6,400 m^3 habitable volume per unit), and an ISRU-enabled closed-loop propulsion chain (*Skyraker*™, XSLR™ engine, $I_{sp,vac} = 465$ s) that enables propellant harvesting at any destination with water or ice. A wind-driven amphibious foiling platform (*Lazarus-T*™) extends the ISRU survey capability to Titan's hydrocarbon seas. Incremental atmospheric and propulsion demonstrators (*Ikarus-X*™, *Ikarus-Y*™, *Ikarus-Z*™) de-risk the *Kvant*™ vehicle concept before its orbital debut.

In parallel with technological development, the *Space Framework*™ identifies critical governance gaps — the inadequacy of the 1967 Outer Space Treaty in a multi-actor environment, the unresolved legal status of space resources, and the fragile political consensus around station succession — and proposes a structured commercialization roadmap leading from *Skyraker*™ to *Ikarus-Y*™/Z™ to a first *Redstar*™ station built on salvaged ISS Integrated Truss Structure hardware.

Contents

[*]E-mail: giovanninicola.daloisio@mail.polimi.it — Website: https://nikitodos.github.io/ — LinkedIn: Giovanni Nicola D'Aloisio.

I. Why Building a Space Plan?

In recent years, the weight of space activities on the world economy has grown substantially and is expected to continue doing so. The latest industrial revolution has highlighted the importance of preserving the world and its ecosystems for generations to come, by moving toward circular economies. New branches of science have emerged and new market dynamics have established themselves, but humanity is increasingly challenged to maintain its activities with more advanced technologies, greater energy demands, and more efficient, effective and clean materials. Space offers answers to all three constraints.

Fig. 1 An ARRM option was to deploy a container large enough to capture a free-flying asteroid.

Fig. 2 Shoemaker-Levy 9 and Jupiter, before and after the impact.

A. Jupiter and Shoemaker-Levy 9 and the Need for Space Safety

At the beginning of the 1990s one of the most spectacular collisions ever documented occurred: that between Jupiter and comet Shoemaker-Levy 9. Discovered on 25 March 1993, it had been captured between the second half of the 1960s and the early 1970s by Jupiter, and tidal forces had caused it to break up into 21 fragments.

An extensive observational campaign was started involving numerous observers on Earth and probes in space to record the event. Between 16 and 22 July 1994, the fragments of the comet fell in a veritable bombardment. The dark spots formed on the planet were observable from Earth for several months before being reabsorbed by the giant's atmosphere. The event contributed significantly to scientific knowledge, having enabled measurements of the deep layers of the Jovian atmosphere, and underlined the role of Jupiter in reducing space debris in the inner Solar System.

Spectroscopic observations showed that ammonia NH_3 and carbon disulphide CS_2 remained in the atmosphere for at least fourteen months after the event. In the major impact points, temperatures increased in a region ranging from 15,000 to 20,000 km, but dropped to normal values within a week of the event.

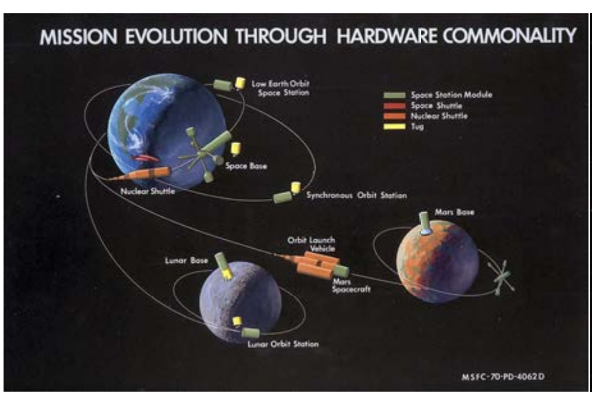

Fig. 3 Integrated Program Plan "Maximum Rate" Traffic Model (1970).

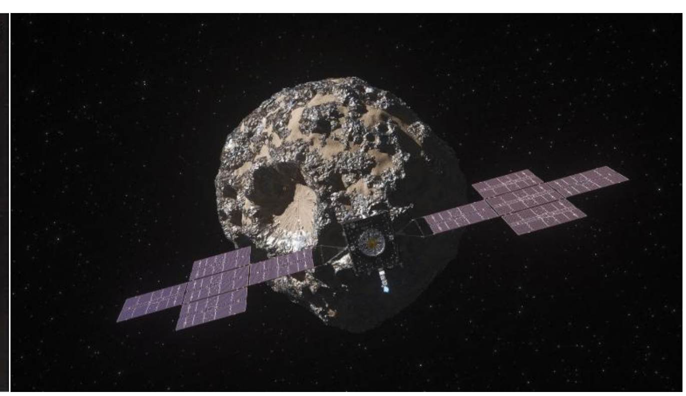

Fig. 4 *Psyche* orbits a metal-rich asteroid in the main asteroid belt to investigate its composition.

B. An Interplanetary Industry Beyond Planetary Defence

There are similar objects in circumterrestrial space: Near-Earth Objects (NEOs), which are as interesting as they are potentially dangerous for the Earth. The largest fragments of Shoemaker-Levy 9 were destroyed only at a pressure of 2.5 bar, and were described as more prominent than Jupiter's Great Red Spot.

Metal-rich near-Earth asteroids represent a small fraction of the NEA population. From near-infrared spectroscopic data of NEAs 6178 (1986 DA) and 2016 ED85, it was determined that these objects were likely transported to near-Earth space via the 5:2 mean motion resonance with Jupiter [1]. It was estimated that the amounts of Fe, Ni, Co, and the platinum group metals present in 1986 DA could exceed worldwide reserves. The first probe directly aimed at a metallic asteroid, 16 Psyche, was launched in October 2023.

Since NASA's DART spacecraft intentionally slammed into the asteroid moonlet Dimorphos on 26 September 2022 – altering its orbit by 33 minutes – the investigation team has been examining the implications of how this planetary defence technique could be used in the future [2, 3].

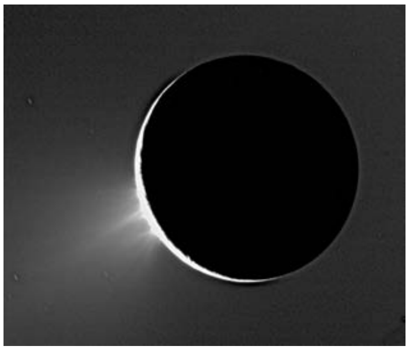

Fig. 5 ***Cassini*** **images of Saturn's moon Enceladus, backlit by the Sun, reveal fountain-like jets of icy material erupting from the south polar region. Credits: NASA/JPL/Space Science Institute. [8]**

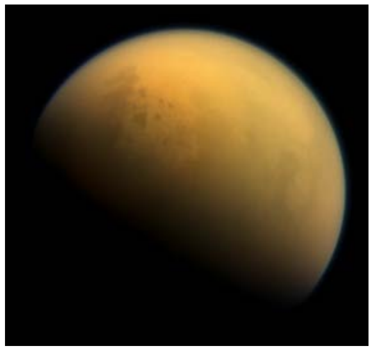

Fig. 6 Natural-color near-infrared view of Titan showing hydrocarbon seas and lakes near the north pole (upper left). Credits: NASA/JPL-Caltech/Space Science Institute. [9]

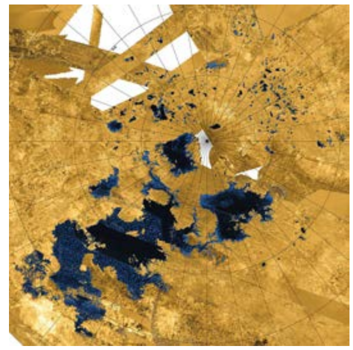

Fig. 7 ***Cassini*** **SAR mosaic of Titan's north pole, showing hydrocarbon seas, lakes, and drainage networks. Kraken Mare is at lower left. Credits: NASA/JPL-Caltech/Space Science Institute. [10]**

C. The Legacy and Challenges of Space Exploration

When one reads documents connected with the 1969–1971 Integrated Program Plan (IPP), it is often difficult to decide whether to laugh or to cry. The IPP, a product of George Mueller's Office of Manned Space Flight, began to evolve as early as 1965, but did not take on the grandiose form NASA Administrator Thomas Paine stubbornly advocated to President Richard Nixon until May 1969. Nixon's Office of Management and Budget had made it clear that NASA should expect rapidly declining annual budgets, not rapidly growing ones. Nixon interpreted Paine's stubborn advocacy of the ambitious IPP as a clumsy effort at bureaucratic empire building, not as a real proposal for a bold space program.

Here are some of the main research areas that are experiencing the greatest slowdowns:

- Engineering of In-Situ Resource Utilisation (ISRU), for the establishment of bases on other celestial bodies;
- Consolidation of knowledge on cryogenics and space revival for long-duration flights;
- Deepening of the effects of long permanence in space on the physical and psychological state of living beings;
- Direct search for evidence of extraterrestrial life, in the Solar System and on the closest stars;
- Astrophysics, particle physics and materials experiments in space;
- Testing of terrestrial technologies in space and certification of industrial products.

Lunar-derived propellants (LDPs) will be essential to reducing launch mass requirements from Earth and developing a reusable lunar transportation system [20]. Deposits of icy regolith found within permanently shadowed craters at the lunar poles can supply the feedstock material to produce liquid oxygen (LO_2) and hydrogen (LH_2) propellant needed by surface-based lunar landing vehicles (LLVs). Megawatt-class fission power systems will be essential for providing continuous power to processing plants, evolving settlements, and other activities on the Moon and in orbit [7].

D. Assessing the Limitations of the Outer Space Treaty

The primary source for international law in space is a drastically outdated document from 1967 called the Outer Space Treaty (OST), designed for an environment far simpler than the current field. That document was signed by the United States, the USSR, and sixty other nations on 27 January 1967, and it basically bans placing nuclear weapons and weapons of mass destruction into orbit. It says nothing of Earth-to-space or space-to-space arms, nor does it speak to kinetic weapons or the many subtler forms of attack developed since its drafting [4].

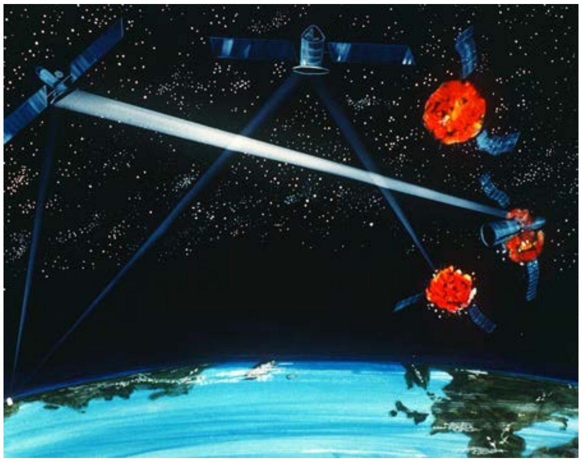

Fig. 8 An artist's concept of a ground/space-based hybrid laser weapon, 1984. Credit: NASA/USAF.

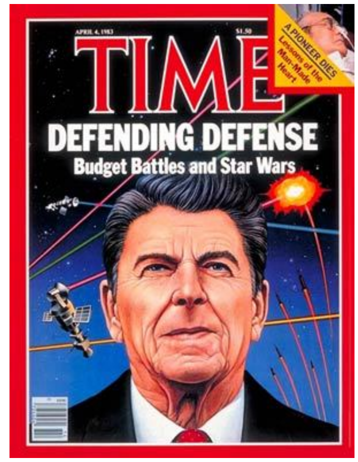

Fig. 9 Defending Defense: Budget Battles and Star Wars. *Time*, 4 April 1983. [6]

Direct kinetic attacks on space assets, and the resultant debris, could create a cascading effect that would wreck the satellites we depend on. The new military doctrine embraced by U. S. Space Force inaugurates space as a distinct war-fighting domain — a position that opposes the fundamental purpose of the OST, which was to define and preserve space as a place of peace. Both China and Russia have proposed drafts of space arms-control treaties that would theoretically ban all types of weapons in space, but they lack means of verification and their implicit allowance of direct-ascent ASAT weapons makes them deeply insufficient. The U.N. Committee on the Peaceful Uses of Outer Space says that any new binding treaty in the current geopolitical environment is impossible. Scholars have recently proposed a Conference of the Parties (COP) mechanism for the OST, drawing on the model used in environmental law to add binding definitions to existing frameworks without requiring ratification [5]. The *Space Framework*™ endorses this approach and proposes the additional establishment of a *Space Navigation Code* — a practical compendium of operational rules analogous to the International Regulations for Preventing Collisions at Sea (COLREGs) — to govern traffic, proximity operations, debris mitigation, and ISRU priority rights.

II. Transport Systems and Overall Architecture

This framework consists of a fleet of space stations and spacecraft for interplanetary crew and cargo transportation, called *Redstar*™ and *Kvant*™, respectively. Several facilities on Earth are planned to be built, for the collection, sorting and reconditioning of waste materials, design, construction, testing and launch of new orbital infrastructures, and assistance, management and administration of the Framework. The first *Kvant*™ spacecraft and *Redstar*™ space stations should be built on Earth, but after a couple of years the orbital segment should already be able to replicate autonomously.

A *Redstar*™ space station is identified by the abbreviation RDST-X-Y, with X a number representing the planet by distance from the Sun and Y a letter indicating the order of assembly at that body. A *Kvant*™ is similarly identified as KVN-XXY, where XX are the last two digits of the year and Y indicates the order of registration in that year.

A. Project Ikarus™and the Kvant™ Multipurpose Spacecraft

Kvant™ is a multipurpose spacecraft for interplanetary travel; its baseline design specifications are:

- **Crew capacity:** 10 persons (nominal mission crew);
- **Payload:** from 15 to 150 t of cargo, or alternatively up to 150 passengers in full passenger configuration;
- **Module count:** 9 pressurized modules connected by corridors;

- **Propulsion:** *Skyraker*™ ISRU chain (XSLR™ chemical engine + ICER™ electric propulsor; see Section II.C);
- **Power:** solar electric primary; modular Advanced Stirling Radioisotope Generators (ASRG) for deep-space and shadow operations [21]; X-RAYJAR™ inertial-fusion reactor as long-term option (Section II.D);
- **Navigation:** inertial reference unit, multiple star trackers, analogue sun sensors, Doppler radar and lidar for terminal approach; X-ray Pulsar Navigation (XNAV, see SEXTANT/NICER architecture [22]) in deep space;
- **Avionics:** triple-redundant Unix-like flight management system with QUEST quaternion estimator.

It is designed to perform long-duration crewed or autonomous spaceflights to any destination in the Solar System and to work on large orbital infrastructures, like an *enhanced Space Shuttle*.

A fleet of 6 units is expected: *Ranger*, *Aquila*, *Altair*, *Hydra*, *Lyra*, *Lazarus*. The first five names are inspired by constellations of the Northern sky; *Lazarus* takes its name from the New Testament figure raised from the dead, signifying the vehicle's capacity for full reusability and revival. The name *Kvant*™ itself honours the *Kvant-1* module of the Soviet space station Mir (launched 1987), in tribute to the international scientific cooperation that Mir embodied — the same spirit of collaboration that the *Space Framework*™ aims to extend throughout the Solar System.

The core module cannot be removed; it contains the bridge, the crew quarters, the electrical equipment, the propellant and life-support tanks, three parachutes and the Electric Power Subsystem. The other modules can be used as cargo holds or passenger bridges. The primary superstructure can be removed to perform the appropriate fittings between cargo and passenger configurations. Structural materials follow consolidated aerospace practice: Ti-6Al-4V alloys, CFRP laminates and similar, plus an integrated thermal protection system. At least two airlocks are included, compatible with the *NASA Docking System*, allowing both spacecraft-to-spacecraft berthing and extra-vehicular activity.

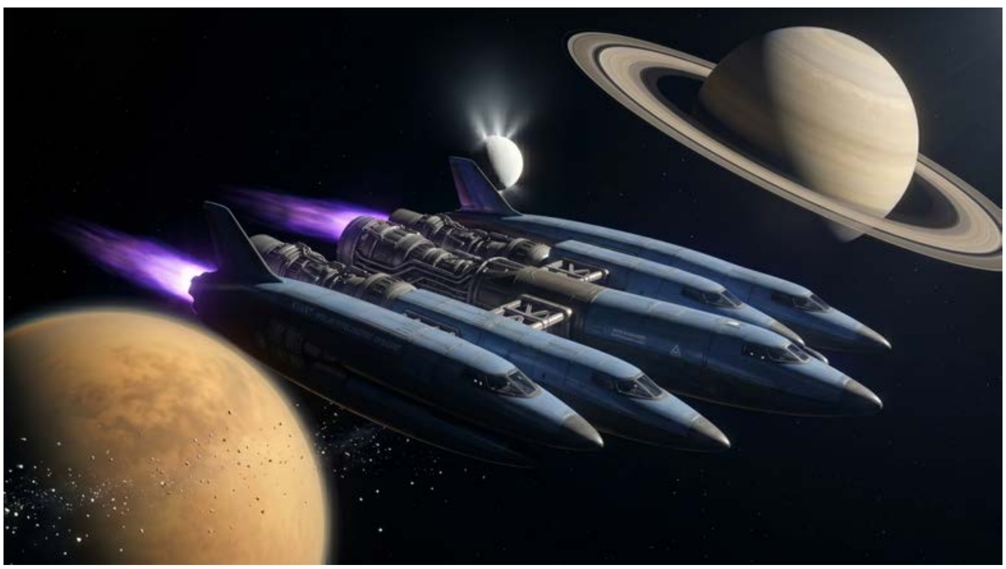

Fig. 10 An artist's concept of *Kvant*™ between *Enceladus* and *Titan*. Renders by G.N. D'Aloisio, 2026.

Project Ikarus™ began in 2019, with the design of *Ikarus-X*™ (Fig. 11), to test mid-air propulsion transition and gain experience in attitude and control [12]. The second vehicle, *Ikarus-Y*™ (Fig. 12), serves as a structural and propulsive testbed on which to assess the feasibility of the *Kvant*™ concept, including its *Skyraker* hybrid propulsion system in low atmosphere. Finally, *Ikarus-Z*™ will be the last iteration of the series before the full orbital *Kvant*™. More details on each vehicle are provided in the companion reports [13–15] and Figures 10, 11, 12.

B. Lazarus-T™: Wind-Driven Amphibious Explorer for Titan Resource Utilisation

Lazarus-T™ is a wind-driven amphibious foiling platform for the robotic exploration and long-range resource assessment of Titan's hydrocarbon seas. It is a direct derivative of the *Lazarus* Class-Moth sailing dinghy (presented at MUVE Yacht Projects 2025, Salone Nautico di Venezia, May–June 2025, by UniPV Sailing Team), adapted for operation in liquid methane at $T \approx 90$–94 K under Titan's dense nitrogen atmosphere ($\rho_{\text{atm}} \approx 5.28\,\text{kg/m}^3$, $g = 1.352\,\text{m/s}^2$) [29–31].

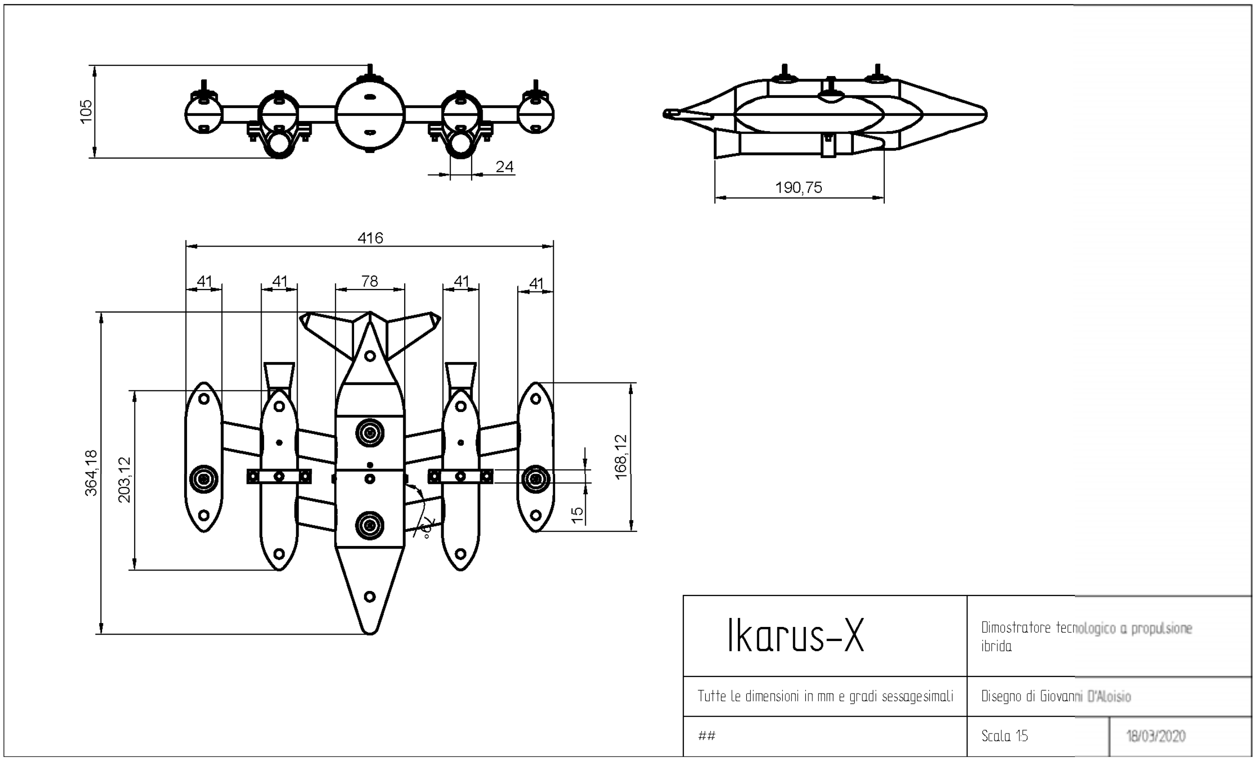

Fig. 11 ***Ikarus-X*™, the first aircraft of the *Ikarus*™ series. Propellers not included in this layout.**

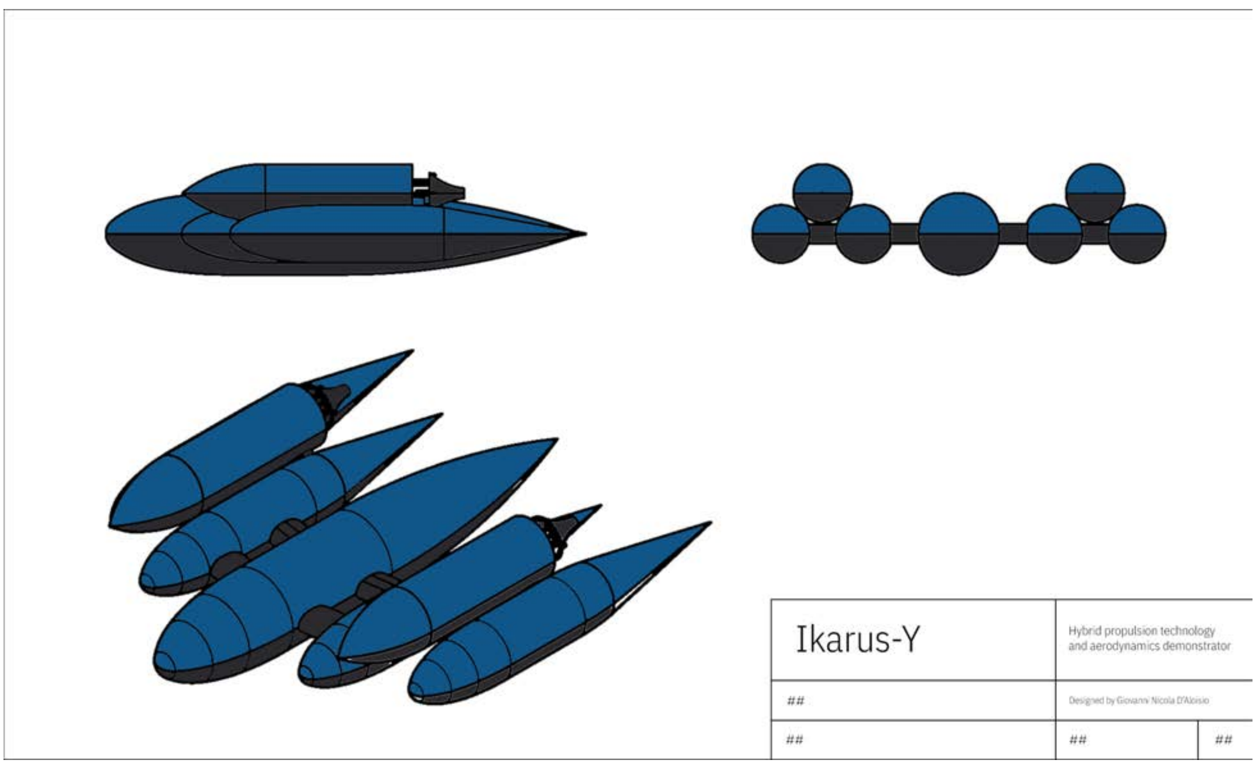

Fig. 12 ***Ikarus-Y*™. The *Skyraker*™ propulsion units are visible between the lateral modules of the aircraft.**

Resource utilisation role within the Space Framework™. A key constraint identified in the *Space Framework™* architecture is energy supply for outer Solar System operations. The propulsion energy for *Kvant™* spacecraft beyond Jupiter is provided by the *Skyraker™* ISRU chain (WTP → SEA → XSLR/ICER; see Section II.C), which requires water or hydrogen feedstock. Titan's atmosphere and seas provide both: methane for hydrocarbon synthesis, atmospheric N_2, and — critically — subsurface or polar water ice as a hydrogen source [29]. Nixon et al. (arXiv:2606.06608, submitted to *Acta Astronautica*, June 2026) identify methane and oxygen (from crustal water) as readily obtainable ISRU propellants on Titan, directly enabling long-duration outer Solar System missions.

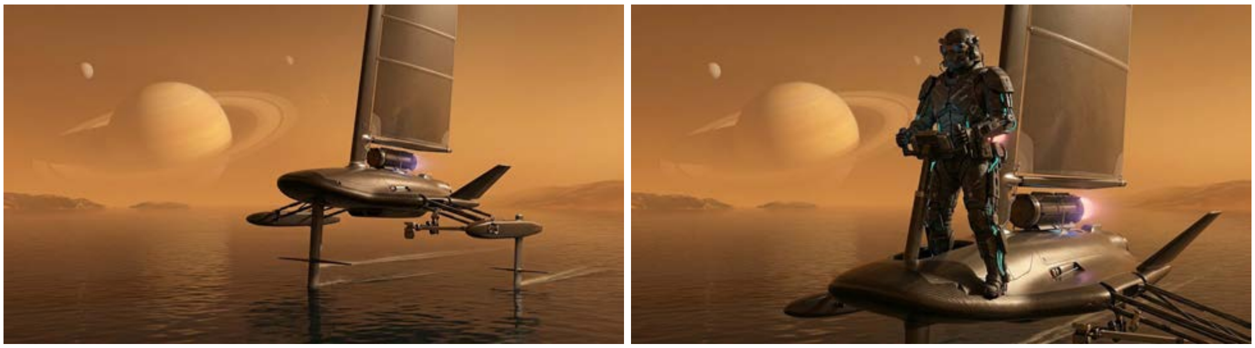

Fig. 13 ***Left:*** ***Lazarus-T™*** **autonomous cargo/science configuration, foiling on Titan's Kraken Mare with retractable amas deployed.** ***Right:*** **Crewed configuration with pressurised suit operator. Saturn and Hyperion are visible in the hazy background. Renders by G.N. D'Aloisio, 2026.**

Lazarus-T™ makes this ISRU accessible at scale by providing:

1) **Sea-surface sampling:** continuous chemical composition mapping of Kraken Mare, Ligeia Mare, and Punga Mare (> 1,000 km range per mission vs. the ~175 km baseline range of NASA *Dragonfly* [32]);
2) **Shoreline ISRU survey:** amphibious landing capability to sample ice-organic interface zones — candidate feedstock sites for a *Skyraker™*-derived ISRU plant;
3) **Atmospheric profiling:** meteorological instruments on retractable amas measure wind fields, aerosol chemistry, and boundary-layer fluxes needed to design future energy infrastructure.

Key performance parameters (from [31]). The hydrofoil lift equation gives a foil take-off speed of $V_{\text{foil}} \approx 2.45$ m/s in liquid methane ($\rho_{\text{LCH}_4} = 449.7\,\text{kg/m}^3$ at 92 K), using the *Lazarus* heritage foil geometry ($A_{\text{foil}} = 0.08\,\text{m}^2$, $C_L = 1.0$). The foil Reynolds number $\text{Re} \approx 8.4 \times 10^5$ falls in the well-characterised turbulent regime. A $4\,\text{m}^2$ rigid wing-sail generates $F_{\text{drive}} = 15.83$ N at the nominal 1 m/s Titan wind, exceeding the 2.16 N foil drag by a factor of 7.4. A Kraken Mare crossing (≈1,170 km) is achievable in ≈9 days at conservative average transit speed.

Power and propulsion. *Lazarus-T™* uses a $4\,\text{m}^2$ rigid wing-sail for primary propulsion (zero electrical power consumed by locomotion), with an MMRTG or ASRG providing ~70–140 W exclusively for science and avionics.

Development status. *Lazarus-T™* is at concept level (TRL 1–2). Full technical analysis is provided in the companion paper [31].

C. Skyraker™ Propulsion System

Skyraker™ is the ISRU-enabled hybrid propulsion subsystem of *Kvant™*. It features a closed-loop propulsion chain composed of four integrated elements:

$$\underbrace{\text{Water source}}_{\text{ocean / ice / plume}} \xrightarrow{\text{WTP}} \underbrace{\text{H}_2\text{O}}_{\text{distilled}} \xrightarrow{\text{SEA}} \underbrace{\text{H}_2 + \text{O}_2}_{\text{propellant}} \xrightarrow{\text{XSLR / ICER}} \underbrace{\Delta v}_{\text{thrust}} \tag{1}$$

where WTP is the Water Treatment Plant (filtration and demineralisation), SEA is the Solar-Electric Alkaline electrolyser, XSLR™ is the chemical rocket engine and ICER™ is the electric thruster. Together these four components constitute the *Skyraker™* system.

The chemical propulsion element of the chain is the **XSLR™** (*eXperimental aeroSpike Liquid Rocket*), a LO_2/LH_2 expander-cycle engine with a linear aerospike nozzle derived from the Rocketdyne XRS-2200 geometry (20 cells, $\varepsilon = 58$, $p_c = 50$ bar). The aerospike nozzle provides altitude-compensating thrust, making XSLR™ mission-enabling at destinations with significant atmospheric pressure such as Titan's methane seas (p_a = 146.7 kPa): at these conditions a conventional bell nozzle delivers $I_{sp} \approx 57$ s, while the aerospike auto-matches the effective expansion ratio to achieve $I_{sp} \approx 405$ s and a mass ratio of 1.90 for a 2,550 m/s ΔV — physically impossible for any bell-nozzle vehicle [14].

The final XSLR™ architecture is a parallel full-expander dual-loop augmented by a hybrid electric expander cycle (EEC), designated **Config. D+**: $I_{sp,vac}$ = 465 s; throttle 5:1 (12–100 % rated power level); $T_{turb} \leq 700$ K; startup battery 36 kg (22 kN class). At 220 kN, a turbogenerator with bypass heat exchangers resolves the battery mass bottleneck (35 kg bootstrap vs. 618 kg worst-case battery-only alternative). The complete thermodynamic analysis is documented in [14].

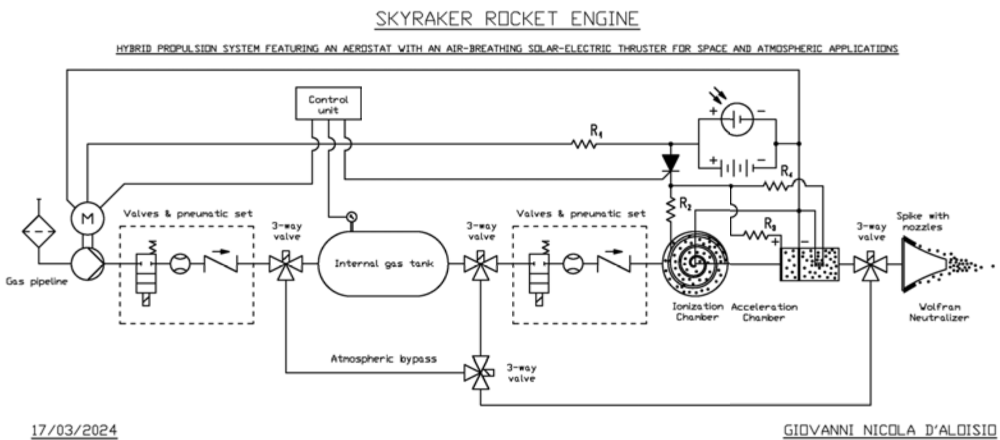

Fig. 14 Schematic flow diagram of a *Skyraker*™ propulsion system, showing the ISRU chain from water source to thrust output.

The electric complement of *Skyraker*™ is the **ICER**™ (*Ion Cruise and Exospheric Rocket*), a microwave air plasma thruster (2.45 GHz) [16] providing high-I_{sp} cruise and RCS capability, using either electrolysis-produced H_2 or ingested atmospheric gas. For planetary environments with significant atmosphere (Mars, Titan, Europa), ICER™ operates in *Air-Breathing Electric Propulsion* (ABEP) mode, eliminating onboard propellant for low-altitude orbit maintenance. Design is also underway for a thruster based on magnetic reconnection of plasmoids [17].

D. X-RAYJAR™ Energy System (Future Development)

Note on development status: X-RAYJAR™ is proposed as a **long-term conceptual technology** within the *Space Framework*™. It is not part of the baseline architecture for Redstar-1™ or the first-generation *Kvant*™ vehicles, which rely on solar-electric propulsion and ASRG technology [21]. Instead, X-RAYJAR™ is envisioned as a potential high-power energy source for future *Redstar*™ stations operating beyond Saturn and for advanced interstellar *Kvant*™ vehicles.

X-RAYJAR™ (*X-Ray Junction for Advanced Reactions*) is a conceptual pulsed inertial-fusion power system intended to investigate alternative approaches to compact space-based energy generation. The concept is based on repetitive laser-driven micro-fusion events occurring within a sealed reaction chamber, where fusion energy is converted into electricity through advanced thermal and direct energy conversion systems. The underlying plasma physics draws on the theory of compact degenerate matter as described in [18].

Future developments may investigate whether transient ultra-high-density plasma states, approaching partially electron-degenerate conditions for extremely short timescales, could improve plasma confinement, reduce radiative losses, and increase the overall energy conversion efficiency. Such plasma regimes remain speculative and have not yet been experimentally demonstrated as practical energy-generation mechanisms.

A second conceptual architecture, designated X-RAYJAR™ Mark II, investigates laser-driven reactions in lithium deuteride (LiD) crystals doped with hydrogen isotopes through ion implantation. This concept is motivated by experimental studies reporting X-ray-induced nuclear reactions involving lithium and deuterium [19]. Although these experiments demonstrate the occurrence of nuclear processes under laboratory conditions, the observed reaction rates are many orders of magnitude below those required for practical power generation. Consequently, Mark II should be regarded as an exploratory research direction rather than a mature energy technology.

The X-RAYJAR™program is intended as a research roadmap for post-2050 deep-space power systems rather than a near-term engineering proposal.

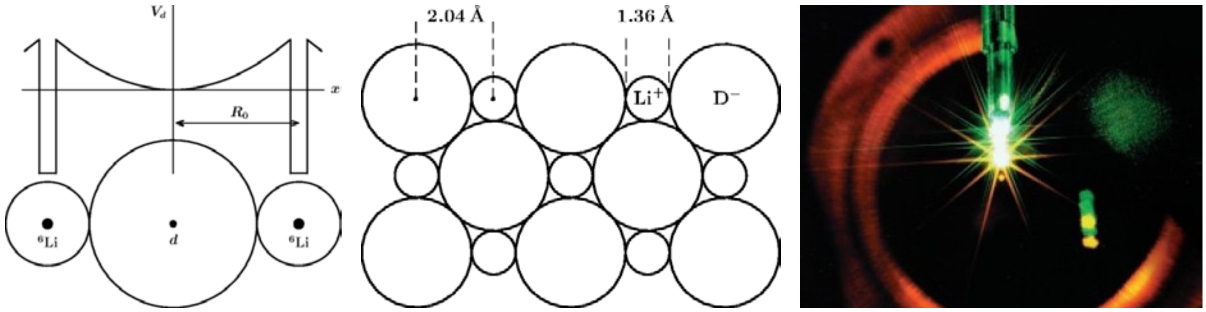

Fig. 15 Background concepts underlying the proposed X-RAYJAR™ architecture. Left: calculated potential-energy landscape for a deuteron between neighbouring ^{6}Li atoms in a lithium deuteride (LiD) crystal. Centre: schematic representation of the LiD crystal lattice. Right: inertial confinement fusion target implosion at the Nova laser facility, shown as an example of laser-driven plasma compression (for illustrative purposes only; does not represent a demonstrated implementation).

E. Redstar™ Space Stations

Redstar™ (*Research and Exploration Development Station for Space Technology Advancements and Research*) is a multipurpose orbiting infrastructure inspired by the architecture of *Skylab* and *Space Station Freedom*, and by the wet-workshop philosophy originally proposed by Wernher von Braun [11] for converting spent propellant stages into habitation volumes. Each *Redstar*™ is made up of three sections:

- **Innovate**™ (*Innovative Nexus for Navigation, Observation, Verification, and Advanced Technological Exploration*): four flexible pressurized modules connected through as many nodes/airlocks/docking compartments, forming a square. Used as a multipurpose orbiting laboratory, each module is divided into several floors according to the *Skylab* multi-floor arrangement, providing far more comfortable working volume in micro-gravity.
- **Luxe**™ (*Living Units for Xenial Exploration*): four flexible modules connected in the same way. This section is the outpost's guest living area, designed for commercial and research purposes.
- **Infras**™ (*Interplanetary Navigation and Functional Resource Assembly System*): nine rigid modules containing the electrical equipment, the navigation and command systems and the food supplies. A depressurized lattice structure houses the photovoltaic panels, the main antennas, the spare parts, the propellant tanks, depressurized hangars, four robotic arms and the solar electric propulsion system.

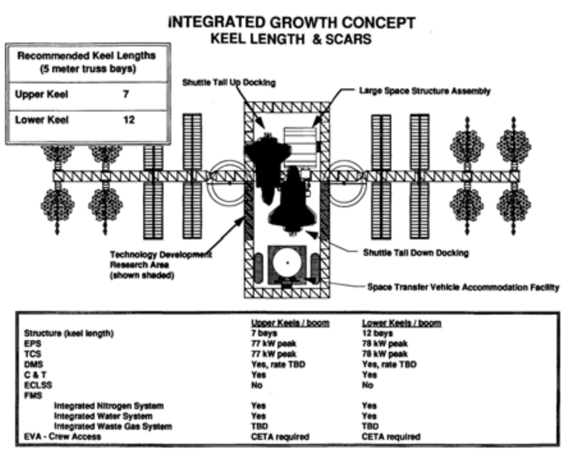

Fig. 16 Diagram from the "Space Station Evolution — Beyond the Baseline" symposium (6–8 Feb. 1990, League City, Texas) [28].

Fig. 17 Artist's concept of Space Station Freedom in its dual-keel configuration (1986) [27]. The modular dual-keel architecture directly influenced *Redstar*™.

Each pressurized rigid module has an estimated diameter of at least 8 m and an average internal length of at least 16 m, for a total of 6,400 m^3 of habitable volume — more than 8 times that of the International Space Station [25, 28]. Each *Kvant*™ in cargo configuration is capable of transporting four modules at a time; consequently about a dozen flights are sufficient for the completion of a full *Redstar*™ unit. At that point the station would be populated by at least 50 people plus an emergency *Kvant*™ vehicle.

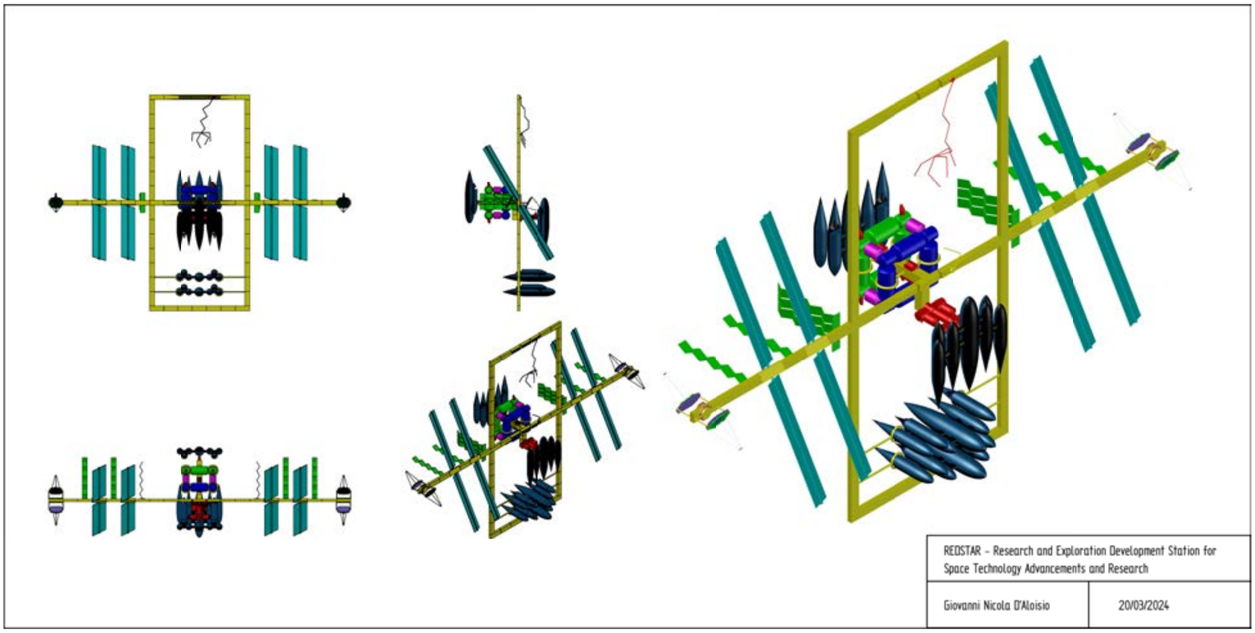

Fig. 18 Preliminary design of *Redstar*™. The *Innovate*™ and *Luxe*™ sections are visible behind the yellow Integrated Truss Structure, and the *Infras*™ section (red) in front of it. The large dark vehicles are *Kvant*™ spacecraft docked at the station.

Redstar-1 Concept. *Redstar-1*™ is the first planned instantiation of the *Redstar*™ architecture. Rather than constructing the full truss structure from scratch, *Redstar-1*™ leverages still-operational hardware segments of the *International Space Station* (ISS) Integrated Truss Structure (ITS) as its primary backbone, following the planned end of ISS operations, currently targeted no earlier than 2030 but subject to ongoing political review [34].

As an additional structural element, the *Redstar*™ architecture draws on the engineering heritage of the cancelled NASA Exploration Upper Stage (EUS), which was formally cancelled in February 2026 [35]. The EUS — before its cancellation a 4-RL10C-3 powered LO_2/LH_2 upper stage with an 8.4 m diameter tank, a 10% beryllium housing, and a dry mass of approximately 14,000 kg [23, 24] — offers a structural architecture well suited to deep-space habitation module development, given its large diameter, proven cryogenic material selection (Al-Li alloys, CFRP stiffeners), and thermal management heritage. In its *Redstar*™ adaptation, the EUS structural envelope becomes the basis for the Infras™ rigid module geometry: the 8.4 m barrel diameter provides significantly more internal volume per unit length than the 4.2 m ISS module standard while remaining within the fairing envelope of heavy-lift commercial launch vehicles. The wet-workshop approach — already proven on *Skylab*, whose orbital workshop derived from an S-IVB Saturn stage [11] — is thereby extended to the post-SLS era.

The *Redstar-1*™ assembly concept is as follows:

- **Backbone (ITS reuse):** Key ITS truss segments still within structural limits are rescued from deorbit by a *Kvant*™ or a commercial tug and transferred to the *Redstar-1*™ target orbit. This requires a formal agreement between ESA and NASA on ISS asset disposition, to be pursued through existing bilateral frameworks prior to ISS deorbit.
- **Habitation modules (commercial and EUS-heritage):** Pressurised volumes will be procured from commercial providers in the expandable or hybrid rigid-expandable category — candidates include Sierra Space LIFE® modules, Nanoracks/Voyager *Starlab*, and spacecraft expandable module technology in the Bigelow/Sierra Space heritage — consistent with the wet-workshop lineage described above. Following the NASA Ignition initiative

(March 2026 [36]),* *Redstar-1*™ is aligned with the proposed government-owned core module around which commercial modules dock and detach to form free-flying stations.

- **Communications (TDRS heritage, LINK-class servicing):** *Redstar-1*™ will require high-bandwidth relay communications. NASA is retiring the TDRSS constellation by the mid-2030s [37]. The *Space Framework*™ proposes that one or more retiring TDRS units be repositioned to co-orbit with *Redstar-1*™, using in-orbit servicing technology demonstrated by Katalyst Space Technologies' *LINK* spacecraft, launched June 2026 to raise the orbit of NASA's Neil Gehrels Swift Observatory [39], or to use the existing satellites from the Galileo constellation. NASA's Project NEXUS (Ka-band TDRSS commercial replacement, BAA issued April 2026, proposals submitted June 2026, Phase 1 awards expected September 2026) provides a complementary path [38].
- **Navigation:** *Redstar*™ stations in deep Solar System orbits (beyond lunar distance) will employ X-ray pulsar navigation (XNAV), following the SEXTANT/NICER architecture demonstrated on ISS by NASA GSFC [22], to maintain autonomous orbital knowledge without reliance on Earth-based tracking.
- **Target orbit:** To be determined in a future trade study.

Political pathway: Acquisition of the ITS from NASA requires ESA (or a European-led consortium) to formally request ISS asset transfer rights under the existing multilateral coordination framework (the 1988 IGA and its subsequent MOUs). A comparable negotiation to that for the Canadarm2/SPDM contribution by CSA is legally plausible, though it requires early political engagement — recommended no later than 2028.

III. Perspectives on Human Evolution Enabled by the Space Framework

The *Space Framework*™ serves as the cornerstone of an entire space economy, providing fertile ground for the emergence of innovative technologies and lifestyles. The following challenges, inspired by the goals articulated in NASA's Moon to Mars Architecture Definition Document [33] and elaborated here in the context of the *Space Framework*™ vision, represent the defining objectives of the present century:

- Ability to perform advanced orbital operations in a robotized or supervised manner;
- Definition of new jobs, such as space miners, planetary scientists, space forces, etc.;
- Establishment of interplanetary governmental organizations for the preservation of Peace in the Solar System;
- Occupation of every body of the Solar System in a way functional to the needs of terrestrial species;
- Definition of new building materials for the construction of new extraterrestrial cities;
- Drafting of a *Space Navigation Code*, of *urban development plans* for preventing the creation of space debris and of international conventions to regulate the relations between nations;
- Obtaining full independence of space vehicles and extraterrestrial nations from terrestrial consumables.

The *Space Framework*™ does not merely articulate these aspirations — it maps each of them to a concrete architectural element. Autonomous orbital operations (point 1) are enabled by the QUEST-based avionics and XNAV navigation of *Kvant*™. New professional roles (point 2) emerge naturally from ISRU-enabled outpost operations at each *Redstar*™ station. Interplanetary governance (point 3) is the subject of the *Space Navigation Code* proposed in Section I.D. Systematic Solar System occupation (point 4) is made feasible by the ISRU chain of *Skyraker*™, which removes the propellant bottleneck at every destination with water or ice. New construction materials and habitat concepts (points 5–6) are explored through the EUS-heritage and wet-workshop lineage of *Redstar*™ (Section II.E). Full ISRU independence (point 7) is the explicit design goal of the *Skyraker*™ chain at each destination, from the lunar poles to Titan's hydrocarbon seas.

The *Space Framework*™ facilitates international discourse on these and other topics, fostering collaboration on a global scale. Distinguishing itself from ongoing space programs like Artemis [33] and commercial ventures, the EU-led *Space Framework*™ represents one of the few research-originated, open-architecture European space framework concepts, designed to be independent of any single national space agency and open to international participation.

IV. Supportability and Commercialisation Roadmap

An ambitious endeavour like the *Space Framework*™ is contingent upon substantial and sustained funding. In 1970, a comparable initiative — the traffic model developed as part of the Integrated Program Plan in the United States [26] — was projected to require an annual budget of $9 billion in 1970 dollars (approximately $67 billion in 2022 dollars). This model aimed to estimate the maximum flow of space traffic that could be handled by the planned Space Transportation

*Not to be confused with *TEF Ignition*, the entrepreneurship programme of Tech Europe Foundation.

System. The complexity of such a plan necessitates meticulous consideration of numerous variables, particularly concerning cosmic risks (space debris, high-energy particle beams, asteroids, and comets) and human factors.

The *Space Framework*™ involves stakeholders potentially encompassing all UN member states, transcending the interests of scientists and researchers to encompass legal, economic, and individual concerns. It is an opportunity to foster job creation, alleviate physically demanding occupations, surmount ideological barriers, and galvanize societal development. It offers a paradigm shift in viewing Earth not as the ultimate origin and destination but as the cradle of human exploration and infinite possibilities.

The NASA Ignition initiative [36] has substantially altered the landscape for future low-Earth-orbit infrastructure. NASA's proposal to build a government-owned core module to which commercial modules would dock, combined with the cancellation of SLS Block 1B and the EUS [35], creates both challenges and opportunities for the *Space Framework*™. The Ignition architecture is conceptually aligned with *Redstar-1*™ (Section II.E): a government-anchored backbone to which commercial and international partner modules are attached. In June 2026 the GAO recommended NASA to document the decision factors for the ISS-to-commercial-station transition, noticing that a gap in human presence in LEO is a real risk if commercial stations are not ready before the 2030 ISS deorbit target [34]. The *Space Framework*™ is a complementary European-led option in precisely this context.

V. Concluding Remarks

The *Space Framework*™ presents a technically grounded, incrementally structured model for a sustainable space economy. Its adaptable architecture lends itself to further refinements, refurbishments, and periodic updates, serving as a foundational platform for enabling human exploration into interstellar space. The envisioned future includes the development of advanced technologies, propelled by the collective efforts of the international scientific community.

Crucially, the *Space Framework*™ is not simply an engineering exercise. By embedding a legal reform agenda, a commercialisation roadmap, and a clear political strategy for the ISS succession — aligned with and informed by developments such as the NASA Ignition initiative [36] — it aims to be deployable, not merely elegant.

Robert Goddard famously remarked: "every vision is a joke until the first man accomplishes it; once realised, it becomes commonplace". Let the *Space Framework*™ stand as a beacon, embodying humanity's relentless pursuit of the extraordinary.

References

[1] J.A. Sanchez et al., *Spectroscopic Characterization of Near-Earth Asteroids 1986 DA and 2016 ED85*, Planet. Sci. J. **2**, 205 (2021). DOI: 10.3847/PSJ/ac235f.

[2] D.G. Andrews et al., *Defining a successful commercial asteroid mining program*, Acta Astronautica **108**, 106–118 (2015). DOI: 10.1016/j.actaastro.2014.10.034.

[3] S.D. Ross, *Near-Earth Asteroid Mining*, Caltech Control and Dynamical Systems, December 2001.

[4] R. Riederer, *Ad Astra*, Harper's, November 2021. `https://harpers.org/archive/2021/11/ad-astra-the-coming-battle-over-space/`

[5] E. Sandler, *Governing Outer Space: A Conference of the Parties for the Outer Space Treaty*, Belfer Center for Science and International Affairs, Harvard Kennedy School, December 2025. `https://www.belfercenter.org/publication/governing-outer-space`

[6] TIME Magazine, "Defending Defense: Budget Battles and Star Wars," cover story, April 4, 1983. Available: https://content.time.com/time/covers/0,16641,19830404,00.html Accessed: Jun. 26, 2026.

[7] S.K. Borowski et al., *Commercial and Human Settlement of the Moon and Cislunar Space*, NASA, 19 August 2019.

[8] NASA, "Fountains of Enceladus," NASA Science Photojournal. Available: https://science.nasa.gov/photojournal/fountains-of-enceladus/. Accessed: Jun. 26, 2026.

[9] NASA Jet Propulsion Laboratory, "Lakes Through the Haze," JPL Image Gallery. Available: https://www.jpl.nasa.gov/images/pia17179-lakes-through-the-haze/. Accessed: Jun. 26, 2026.

[10] NASA, "Titan's North," NASA Science Photojournal. Available: https://science.nasa.gov/photojournal/titans-north/. Accessed: Jun. 26, 2026.

[11] W. von Braun, *Manned Mars Landing Presentation to the Space Task Group*, 4 August 1969.

[12] G.N. D'Aloisio, *Ikarus-X: Hybrid Propulsion Technology Demonstrator*, Space Framework™ Technical Report, first English edition, 23 February 2024.

[13] G.N. D'Aloisio, *Ikarus-Y: Structural and Propulsive Demonstrator for the Space Framework™*, Space Framework™ Design Study, June 2026.

[14] G.N. D'Aloisio, *XSLR Aerospike Hybrid Expander Architecture, Thermodynamic Analysis, and Multi-Mission Scaling Study*, Space Framework™ Design Study, v3.0, June 2026.

[15] G.N. D'Aloisio, *Skyraker/XSLR Testbed and Development Roadmap*, Space Framework™ Design Study, v2.0, June 2026.

[16] D. Ye, J. Li, J. Tang, "Jet propulsion by microwave air plasma in the atmosphere," *AIP Advances* **10**, 055002 (2020). DOI: 10.1063/5.0005814.

[17] F. Ebrahimi, "An Alfvénic reconnecting plasmoid thruster," J. Plasma Phys. **86**(6), 905860614 (2020). DOI: 10.1017/S0022377820001476.

[18] S.L. Shapiro and S.A. Teukolsky, *Black Holes, White Dwarfs, and Neutron Stars: The Physics of Compact Objects*, Wiley, 1983.

[19] V.B. Belyaev, M.B. Miller, J. Otto, and S.A. Rakityansky, "Nuclear fusion induced by x rays in a crystal," Phys. Rev. C **93**, 034622, 28 March 2016. DOI: 10.1103/PhysRevC.93.034622.

[20] C. C. Allen, R. V. Morris, and D. S. McKay, *Oxygen Extraction from Lunar Soils and Pyroclastic Glass*, Journal of Geophysical Research, 101, pp. 26,085-26,095, November 1996.

[21] P.C. Schmitz, L.S. Mason, and N.A. Schifer, *Modular Stirling Radioisotope Generator*, NASA/TM–2016-218911, April 2016 (AIAA-2015-3809).

[22] J.W. Mitchell et al., "SEXTANT — Station Explorer for X-ray Timing and Navigation Technology," AIAA Space 2015 Conference and Exposition, 2015. DOI: 10.2514/6.2015-4470.

[23] B. Donahue, S. Sigmon, D. Cooper, "The NASA SLS Development and Mission Opportunities," *AIAA Propulsion and Energy Forum*, 2018 Joint Propulsion Conference, DOI: 10.2514/6.2018-4639.

[24] D. Hernandez, "Thermal Development of a COTS Camera for the Exploration Upper Stage (EUS)," TFAWS 2019, paper TFAWS19-PT-10, August 2019.

[25] *Space Station Freedom: A Foothold On The Future*, NASA-NP-107/10-88, 1990.

[26] *Integrated Program Plan "Maximum Rate" Traffic Model (1970)*. `https://www.wired.com/2012/04/integrated-program-plan-maximum-rate-traffic-model-1970/`

[27] NASA, Marshall Space Flight Center, "Dual Keel Space Station," Image ID 9801776, `https://web.archive.org/web/20160402115437/https://mix.msfc.nasa.gov/IMAGES/HIGH/9801776.jpg`

[28] NASA, Johnson Space Center, "Space Station Freedom Integrated Research and Development Growth," in *Beyond the Baseline: Proceedings of the Space Station Evolution Symposium*, vol. 1, part 1, League City, TX, Feb. 6–8, 1990. Available: `https://ntrs.nasa.gov/citations/20030063196`

[29] C.A. Nixon, Y. Lu, J.E. Ruliffson, *Titan's Resources and their Utilization*, arXiv:2606.06608 [astro-ph.EP], submitted to *Acta Astronautica*, 4 June 2026.

[30] A. Coustenis, F. W. Taylor, *Titan: Exploring an Earthlike World*. World Scientific. pp. 154–155. ISBN 978-981-281-161-5. OCLC 144226016.

[31] G.N. D'Aloisio, *Lazarus-T™: A Wind-Driven Amphibious Foiling Platform for the Exploration of Titan's Hydrocarbon Seas*, Space Framework™ Internal Report v1.1, June 2026.

[32] R.D. Lorenz et al., *Dragonfly: A Rotorcraft Lander Concept for Scientific Exploration at Titan*, Johns Hopkins APL Technical Digest, vol. 34, no. 3, 2018.

[33] NASA, Exploration Systems Development Mission Directorate, "Moon to Mars Architecture Definition Document," ESDMD-001, Revision C, NASA Headquarters, Washington, D.C., December 12, 2025. Available: `https://ntrs.nasa.gov/citations/20250010956`

[34] U.S. Government Accountability Office, *NASA Faces Impending Decisions for Replacing International Space Station with Commercial Stations*, GAO-26-107805, 17 June 2026. `https://www.gao.gov/products/gao-26-107805`

[35] NASA / SpaceNews, *NASA revises plans for future Artemis missions, cancels upgrades to SLS*, 27 February 2026. `https://spacenews.com/nasa-revises-plans-for-future-artemis-missions-cancels-upgrades-to-sls/`

[36] NASA, *Ignition: NASA Announces Programmatic Changes to Lunar, LEO and Nuclear Development*, 24 March 2026. `https://www.nasa.gov/ignition/`

[37] NASA, *Tracking and Data Relay Satellite (TDRS) Generations of Spacecraft*, `https://www.nasa.gov/missions/tdrs/`, 2024.

[38] NASA SCaN, *Project NEXUS: Commercial Ka-Band Satellite Relay Service*, BAA issued April 2026; proposals submitted June 2026.

[39] NASA Science, *Rocket Integration Complete for Katalyst-NASA Swift Boost Mission*, 10 June 2026. `https://science.nasa.gov/blogs/swift/2026/06/10/rocket-integration-complete-for-katalyst-nasa-swift-boost/`

A. Declaration of First Use — Common-Law Trademark Notice

This Appendix constitutes a dated public declaration establishing prior art and first use in publication for the trademarks listed below, as a common-law trademark protection measure. It is an integral part of this document.

DECLARATION OF FIRST USE IN PUBLICATION

I, **Giovanni Nicola D'Aloisio**, citizen of Italy, MSc student at the Dipartimento di Scienze e Tecnologie Aerospaziali (DAER), Politecnico di Milano, hereby declare and state as follows:

1) I am the sole creator, author, and first user of the following project names, system designations, and associated concepts (collectively, "the Marks"), all of which I hereby assert as common-law trademarks under the principle of first use in publication:

Mark	**Description of first use / class of goods/services**
Space Framework™	Interplanetary transport and resource-utilisation architecture concept; technical publication and design study.
Kvant™	Multipurpose interplanetary spacecraft concept (name adopted in tribute to the Mir Kvant-1 module, 1987).
Redstar™	Multipurpose orbital space station architecture.
Skyraker™	ISRU-enabled hybrid propulsion subsystem (SEA + WTP + XSLR™ + ICER™).
Ikarus™	Series of propulsion and structural demonstrator vehicles (Ikarus-X™, -Y™, -YA™, -Z™).
X-RAYJAR™	Inertial-confinement nuclear fusion reactor concept for deep-space power.
Lazarus-T™	Wind-driven amphibious foiling platform for Titan sea exploration.
Lazarus™	Foiling moth sailing dinghy (UniPV Sailing Team, 2025); heritage vehicle for Lazarus-T™.
Innovate™	Orbiting laboratory module section of *Redstar*™.
Luxe™	Commercial habitation module section of *Redstar*™.
Infras™	Navigation and resource assembly section of *Redstar*™.

2) The Marks were first used publicly as follows:
   - *Space Framework*™, *Kvant*™, *Redstar*™, *Skyraker*™, *Ikarus*™, *X-RAYJAR*™: first use in publication in the document *The Space Framework*™, archived at `https://nikitodos.github.io/` and submitted to the author's GitHub repository, beginning no later than 2023.
   - *Ikarus-X*™: first use in the document *Ikarus-X: Hybrid Propulsion Technology Demonstrator* [12], 23 February 2024.
   - *Lazarus*™ (sailing dinghy): first use at the Salone Nautico di Venezia, May 2025, UniPV Sailing Team.
   - *Lazarus-T*™: first use in the document *Lazarus-T™: A Wind-Driven Amphibious Foiling Platform for the Exploration of Titan's Hydrocarbon Seas* [31], June 24th, 2026.
   - All remaining Marks: first use in the present document, *The Space Framework*™, June 24th, 2026.
3) These declarations are made in good faith and to the best of my knowledge. The Marks are used exclusively in connection with scientific publications, technical design studies, and educational material, all of which are non-commercial in nature under CC BY-NC-ND 4.0 licensing as stated in the header of this document.
4) This declaration does not constitute legal advice, and I acknowledge that common-law trademark protection is limited to jurisdictions in which it is recognised (primarily those based on use rather than registration). Registration of these Marks with the European Union Intellectual Property Office (EUIPO) under a Nice Classification appropriate to scientific publication and aerospace engineering services is under consideration for a future filing date.
5) This document is intended to create an authenticated, dated, and publicly archived record of first use, which constitutes the primary basis for common-law trademark priority.

Signed: Giovanni Nicola D'Aloisio
Location and Date: Milano (MI), Italia, June 24th, 2026
ORCID: 0000-0002-2323-1288

This declaration is archived as part of the document The Space Framework™ *(D'Aloisio, 2026) and is replicated in the companion document* Ikarus-Y: Structural and Propulsive Demonstrator for the Space Framework™ *(D'Aloisio, 2026). Copies are deposited with: (a) the author's public repository at* `https://nikitodos.github.io/`*; (b) any preprint or conference submission archive at the time of submission.*