SUSTAINABLE SATELLITES:
AIR-BREATHING PROPULSION FOR LOW-LATENCY, ECO-FRIENDLY GLOBAL 5G CONNECTIVITY

EcoStar SysNova Campaign

A project by:

instituto de telecomunicações

INDRA

universidade de aveiro

KREIOS SPACE

Presented by Daniel Poças

18 September 2025

ECOSTAR CONSTELLATION

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01

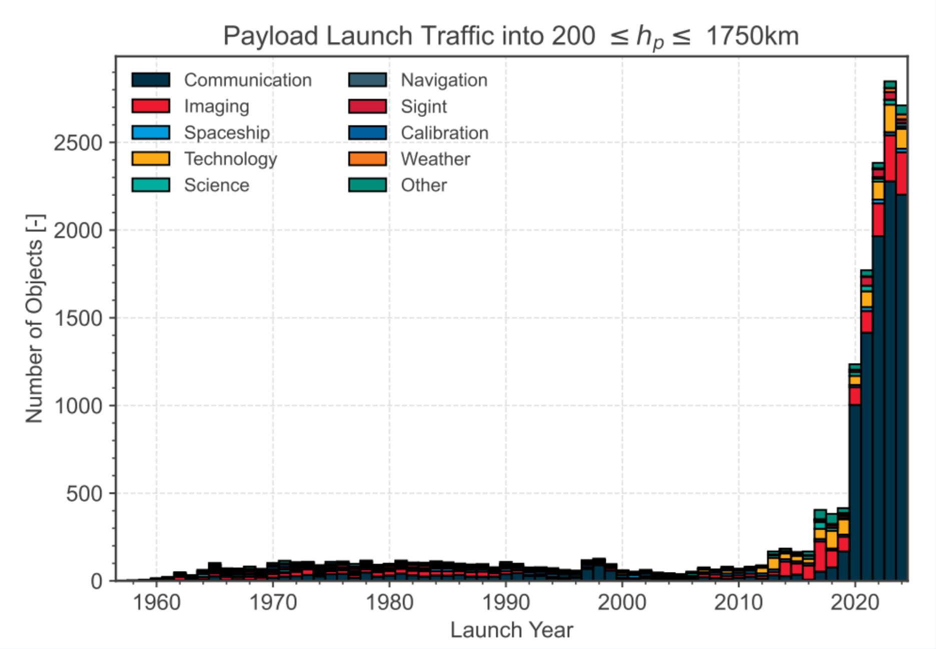
BACKGROUND

THE CHALLENGE

Highest Launch Traffic Ever

*"While the exponential growth in the number of new payloads slowed in 2024, the number of launches continued to rise, and in terms of mass and area, **launch traffic is still at the highest rate seen thus far.**"*

- ESA's 2025 Space Environment Report



HIGH MARKET DEMAND

Driver of Launch Traffic

Starlink doubled in size last year, increasing the number of internet customers it serves by 100%, growing revenue by 95%, and thus adding USD 8.18 billion in 2024.

CATEGORY	TYPE	# (KS)	AVG PER / PER MO	TOTAL (M USD)
Hardware (terminal sales)	Residential	2,825	$ 375	$ 1,059
	Roam, Mini, Land Mobility	800	$ 500	$ 400
	Business, Fixed Site	150	$ 1,000	$ 150
	Maritime	125	$ 500	$ 63
	Aviation	0.5	$ 150,000	$ 68
Customer (subscription sales)	Residential	3,475	$ 85	$ 2,500
	Roam, Mini, Land Mobility	900	$ 125	$ 652
	Business, Fixed Site	150	$ 500	$ 653
	Maritime	75	$ 780	$ 344
	Aviation	0.5	$ 25,000	$ 97
Speciality Starlink	Govt. & Enhanced Cybersecurity (incl. Starshield)			$ 2,000
	Other (Community Gateway, John Deere, accessories)			$ 200
			Starlink Revenue	**$ 8,186**

- Source: https://payloadspace.com/estimating-spacexs-2024-revenue/ [Accessed: 10-September-2025]

ENVIRONMENTAL IMPACT

- *Life-cycle environmental impact*
- *Stratospheric contamination*
- *Aluminium oxide as a major by-product*
- *Potential impacts on atmospheric chemistry and climate*
- *Large uncertainties*

REFERENCES

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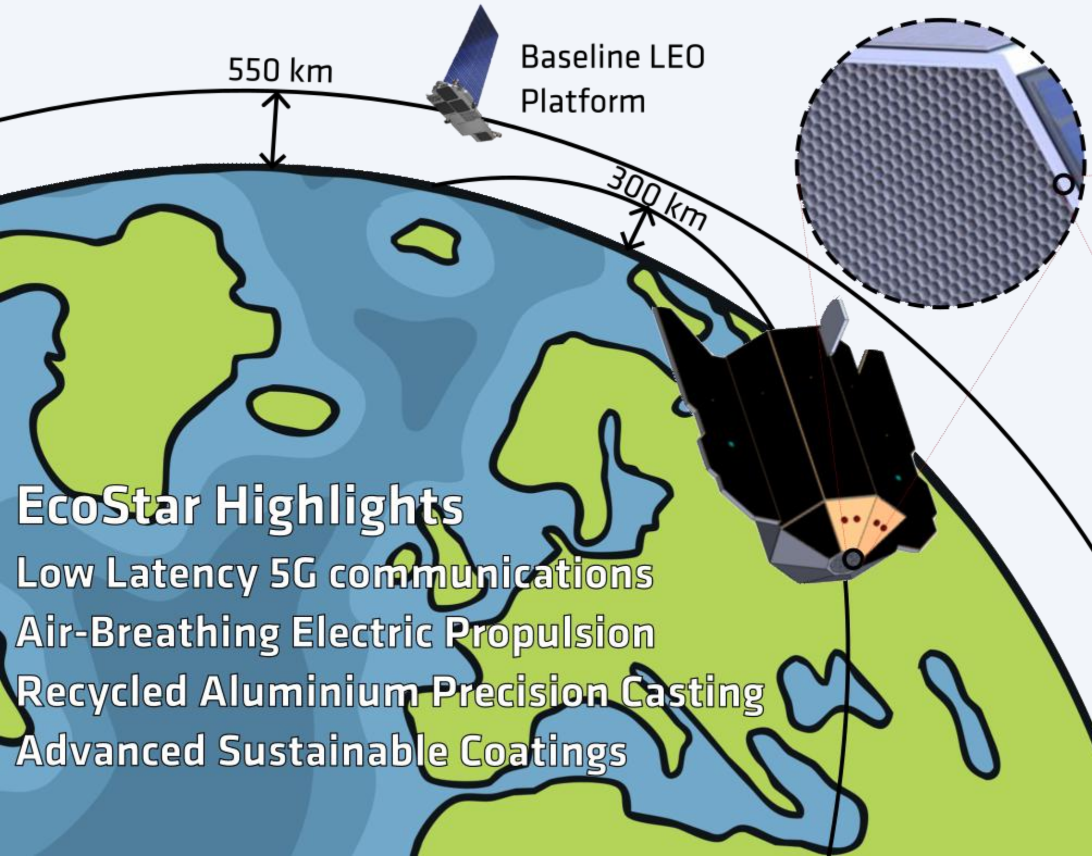
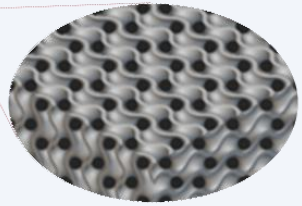
C. Maloney, R. W. Portmann, K. H. Rosenlof, and C. Bardeen, "Stratospheric loading and radiative impacts from increased Al2_2O3_33 emission caused by an anticipated increase in satellite re-entry frequency," in *Proc. AIAA SciTech Forum*, Orlando, FL, USA, Jan. 2024.

A. C. Boley and M. Byers, "Satellite mega-constellations create risks in low Earth orbit, the atmosphere and on Earth," *Sci. Rep.*, vol. 11, no. 10642, May 2021.

OUR PROPOSAL



Air Breathing Electric Propulsion (ABEP) accelerates atmospheric gases to produce thrust.



- Micro-cellular structures provide lighter and stronger mechanical parts.
- EcoStars in Very Low Earth Orbit (VLEO) for reduced launch costs and lower latency comms.
- Over 40% environmental impact reduction in key lifecycle assessment metrics.

EcoStar Highlights

Low Latency 5G communications
Air-Breathing Electric Propulsion
Recycled Aluminium Precision Casting
Advanced Sustainable Coatings

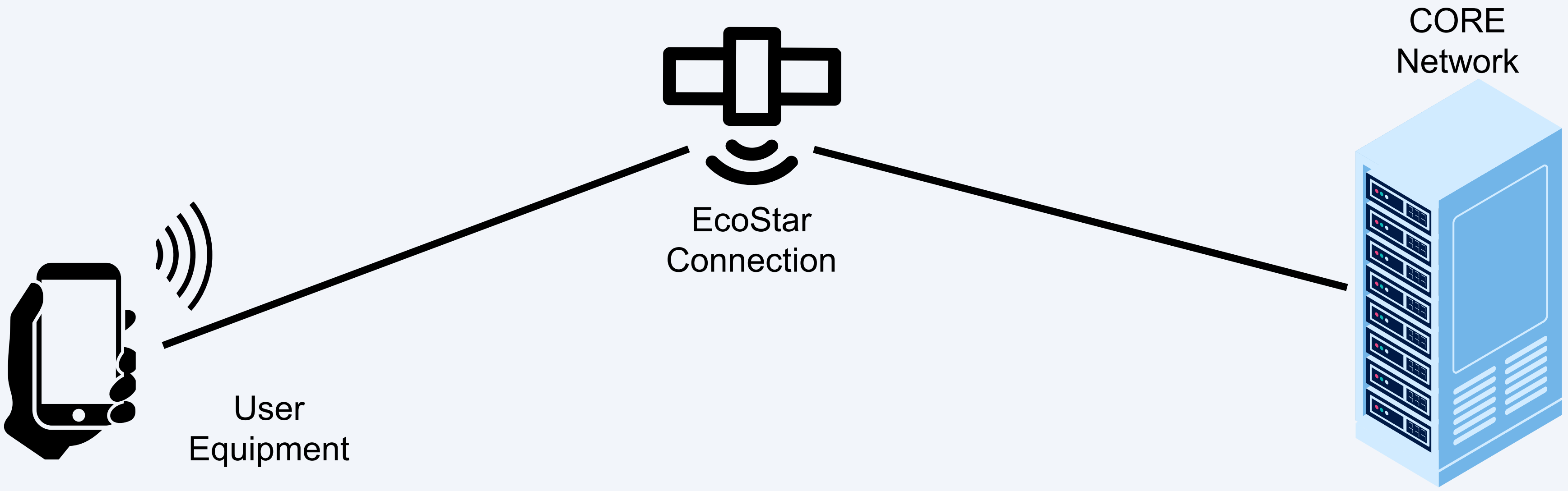
TODAY'S AGENDA

September 18, 2025

02

SYSTEM REQUIREMENTS

CHOICE: DIRECT-TO-DEVICE



> The Direct-to-Device commercial application was chosen due to the perceived higher Total Addressable Market and reduced competition, while clearing programmatic constraints.

BASELINE

Starlink's D2D Constellation

JUSTIFICATION

- Relevance
- Data availability
- Comparability

RISKS

- Payload attribution
- Incomplete data disclosure
- Constellation architecture
- Temporal effects

BASELINE PERFORMANCE

- Direct LTE connection to unmodified smartphones.
- Downlink: 4 Mbps.
- Uplink: 256 kbps.
- Continuous global coverage from 58º S up to 58º N.

SYSTEM REQUIREMENTS

SR 1. *The system shall provide direct-to-device connectivity with unmodified 3GPP-compliant mobile phones.*

SR 2. *The system shall support a user downlink throughput of at least 4 Mbps per satellite beam.*

SR 3. *The system shall support a user uplink throughput of at least 256 kbps per satellite beam.*

SR 4. *The system shall provide continuous 5G coverage up to at least*

SR 5. *The system-shall operate in Very Low Earth Orbit between 150 km and 350 km.*

SR 6. *The system shall allow seamless integration with existing 5G mobile core networks via standardized interfaces.*

SR 7. *The system shall be shown, via a lifecycle cost-benefit analysis, to achieve an Internal Rate of Return (IRR) of 10% over a 10-year analysis period starting from the beginning of the initial service phase.*

SR 8. *The system shall reduce its environmental impact of the following indicators: a. Global warming potential at 100 years minimum by 28%, targeting above 40%. b. Primary energy consumption minimum by 20%, targeting above 30 %. c. Mineral resources depletion minimum by 20%, targeting above 30 %, by maximising circular economy on Earth.*

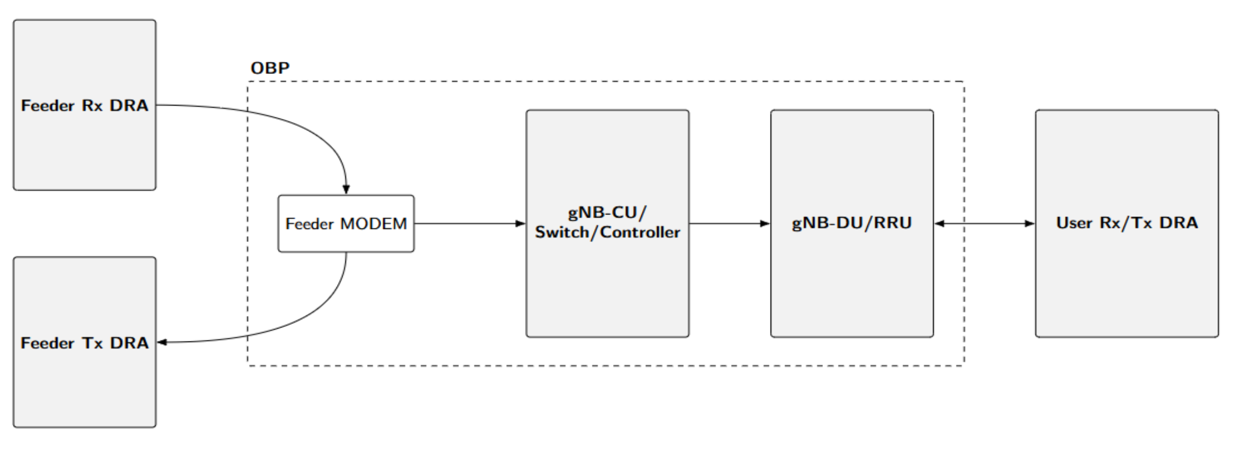
SR 9. *The system shall employ an ABEP subsystem as its primary means of drag compensation, enabling sustained operations in VLEO without reliance on consumable propellants.*

03

CONSTELLATION DESIGN

BASELINE PAYLOAD

Regenerative 5G Payload



L. Berthoud, R. Hills, A. Bacon, M. Havouzaris-Waller, K. Hayward, J.-D. Gayrard, F. Arnal, and L. Combelles, "Are very low Earth orbit (VLEO) satellites a solution for tomorrow's telecommunications needs?," *CEAS Space J.*, vol. 14, no. 4, pp. 609–623, Dec. 2022

AIR BREATHING ELECTRIC PROPULSION

Key Requirement for constellation design

ABEP 2. *The overall efficiency of each Helicon Plasma Thruster shall be greater than 15% during nominal operations at 150-300 km.*

TRADE-OFF

- Highest altitude in range yields the least drag.
- Higher altitudes reduce the number of satellites.
- Impacts in the datarate can be mitigated by increasing bandwidth.

COST MINIMIZATION

Algorithm 1: Constellation Design Procedure

Input: Latitude bounds $\pm\gamma$, minimum elevation angle θ, satellite altitude h,lower and upper bounds for total number of satellites $T_{\min}$ and $T_{\max}$

Output: Optimal constellation configuration(s) with minimum cost satisfying requirements

for $T \leftarrow T_{\min}$ **to** $T_{\max}$ **do**
  for *each feasible number of orbital planes* P **do**
    for *each feasible phasing* F **do**
      Check coverage constraints for the Walker-delta constellation $T/P/F$;
      if *constellation satisfies coverage constraints* **then**
        Record configuration (T, P, F) and associated cost;

PARAMETER	VALUE
Launch Cost	69.75M EUR
Minimum Total Satellites (T_{min})	100
Maximum Total Satellites (T_{max})	2000
Latitude Bound	58°
Minimum Elevation Angle	25°
Altitude	300 km
Propulsion Power	1 kW
Payload Power	1280 W

Walker-Delta 1368/36/1 is the least cost solution.

Walker-Delta 1023/341/279 has the least number of satellites.

04

LIFE CYCLE ASSESSMENT

OBJECTIVE

To evaluate the potential environmental impacts of the proposed EcoStar constellation and to provide a comparison with the Starlink V2 Mini constellation (baseline constellation).

- To quantify the potential environmental gains of the EcoStar constellation
- To identify environmental hotspots

Launch scenarios:

EcoStar:

- Using Falcon 9 (SpaceX) launching from Cape Canaveral (United States of America, USA)
- Using RFA One (Rocket Factory Augsburg) launching from the Shetland Islands (Scotland)

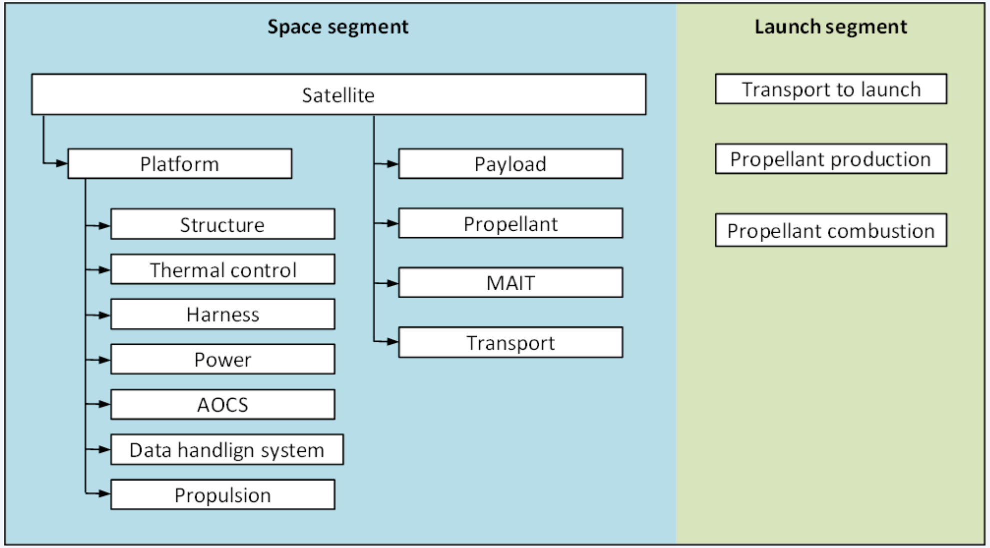
Starlink

- Using Falcon 9 (SpaceX) launching from Cape Canaveral (United States of America, USA)

Transport scenarios from the assembly site to the launch site (transport modes)

SCOPE

Boundaries & Functional Unit



Functional unit:

Provision of 5G connectivity from space with continuous coverage between latitudes of ±58◦, over the lifespan of the satellites. Since the lifespan is unknown, similar lifespans are assumed for both the Ecostar and baseline satellites.

Reference flows for the scenarios assessed:

- EcoStar launched with Falcon 9: 1368 satellites;
- EcoStar launched with RFA One: 1023 satellites;
- Starlink: 657 satellites.

DATA SOURCES

Amounts of materials and equipment

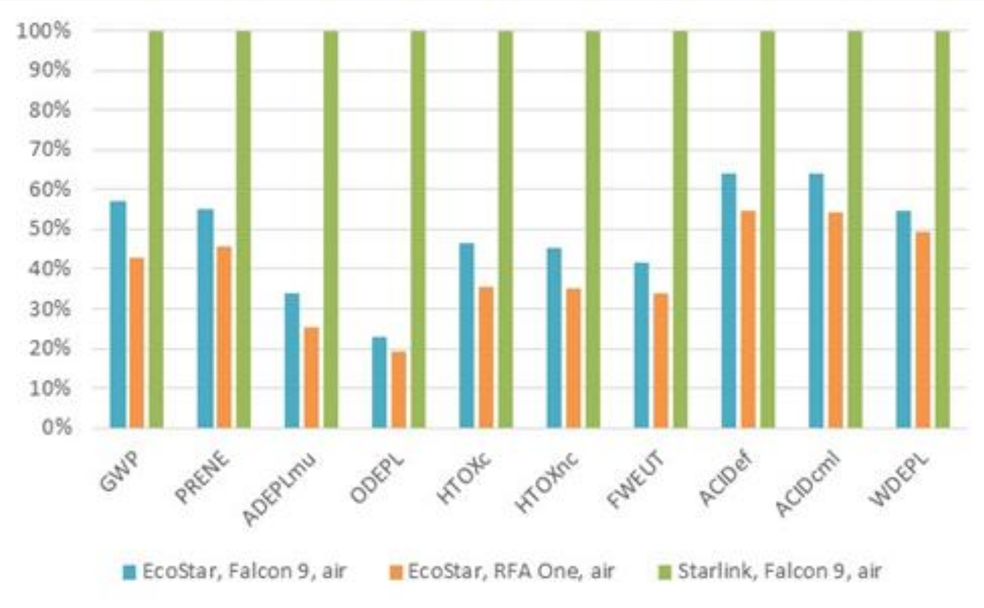
- EcoStar - estimated by the project team
- Starlink V2 Mini satellites - based on publicly available data; when information was not available at the required level of detail: data for the Microsatellite Bus MP42, developed by NanoAvionics

Impact factors

- ESA LCA Database
- Ecoinvent database

RESULTS

Comparison of EcoStar with the baseline



Total mass of the constellations:

- EcoStar launched with Falcon 9: 396 t;
- EcoStar launched with RFA One: 296 t;
- Starlink: 637 t.

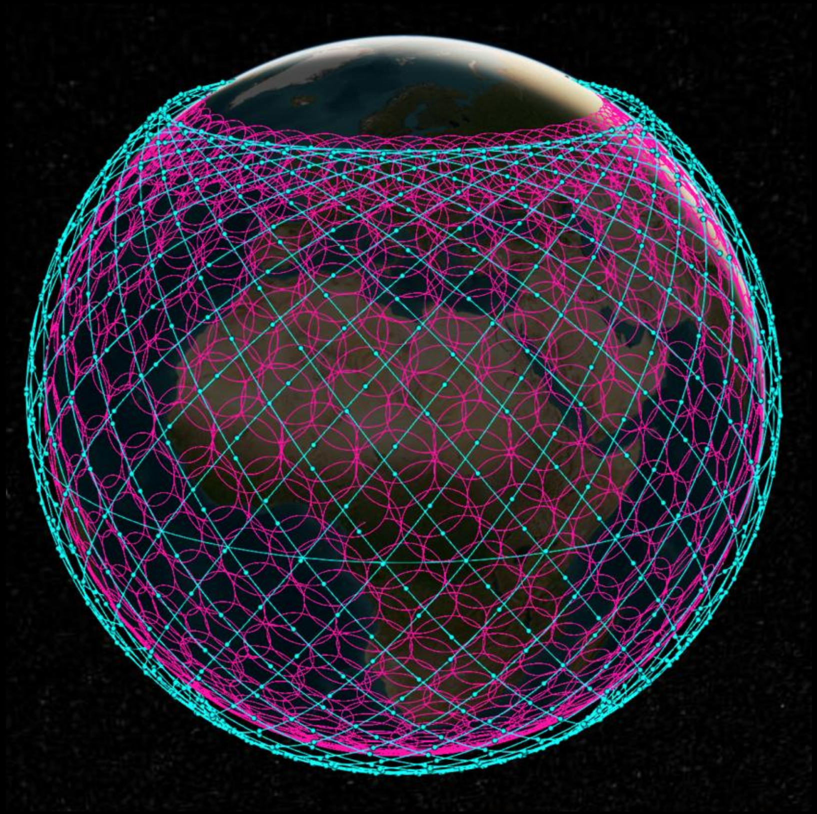
Transport from assembling site to launch site by plane (worst case, although differences between transport scenarios are small)

DISCUSSION

Reductions with EcoStar

IMPACT CATEGORY	FALCON 9	RFA ONE	MINIMUM REDUCTION REQUIREMENTS	REDUCTION TARGETS
Climate change	43%	47%	28%	40%
Primary energy consumption	45%	54%	20%	30%
Resource use - minerals and metals	66%	75%	20%	30%

DECISION



Walker-Delta 1368/36/1 with coverage representation.

KEY ECONOMIC RESULTS

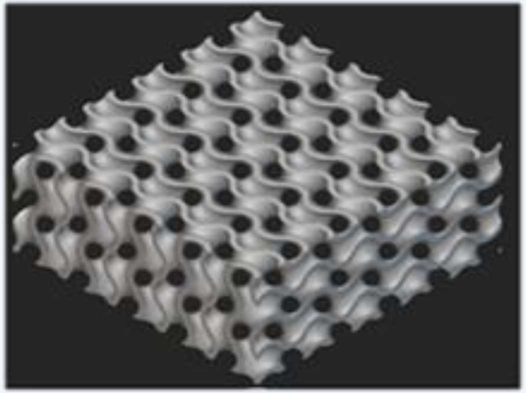
- Estimated cost to deploy constellation: 1.72×10^9 EUR
- Estimated Revenue:
  - Pessimistic (highest OPEX, smallest adoption)
    2.27×10^9 EUR (<1% IRR over 10 years)
  - Baseline
    4.01×10^9 EUR (13% IRR over 10 years)
  - Optimistic (lowest OPEX, highest adoption)
    6.29×10^9 EUR (30% IRR over 10 years)

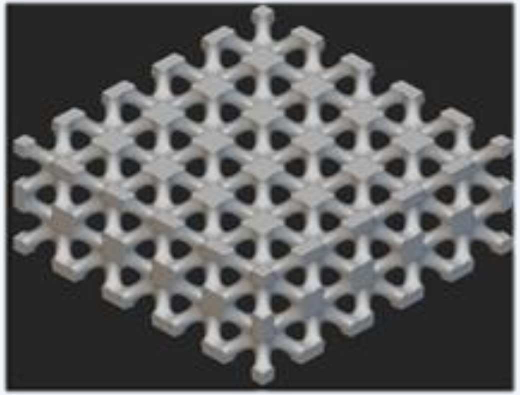
05

MATERIALS & MANUFACTURING

TPMS-BASED STRUCTURES: MANUFACTURING

Gyroid (left) and IWP (right)





TPMS-BASED STRUCTURES: TESTING

	IWP	GYROID
Structure Density [g/cm^3]	0.751 ± 0.009	0.730 ± 0.005
Mass reduction (comparison with solid)	$72.7\% \pm 0.003$	$73.5\% \pm 0.002$
1st max. compressive strength [MPa]	18.20 ± 1.39	42.39 ± 1.69
Plateau stress 20–40% [MPa]	11.08 ± 0.83	35.00 ± 2.14
Specific strength (1st max. comp. strength) [MPa.cm^3/g]	24.19 ± 1.54	58.10 ± 1.95
Specific strength (plateau stress) [MPa.cm^3/g]	14.73 ± 0.91	47.96 ± 2.68

In comparison to solid aluminium counterparts, a mass reduction of 72–74% was experimentally verified, which demonstrates strong potential for lightweighting structural satellite parts.

TPMS-BASED STRUCTURES: DISCUSSION

- **Higher strength:** IWP & Gyroid show higher maximum compressive and plateau stress than honeycomb, linked to higher density.
- **Strength:**
  - Honeycomb: 35.9 MPa (typ.), 49.8 MPa (max)
  - IWP: 24.2 MPa
  - Gyroid: 58.1 MPa

<u>→ Performance strongly depends on architecture.</u>

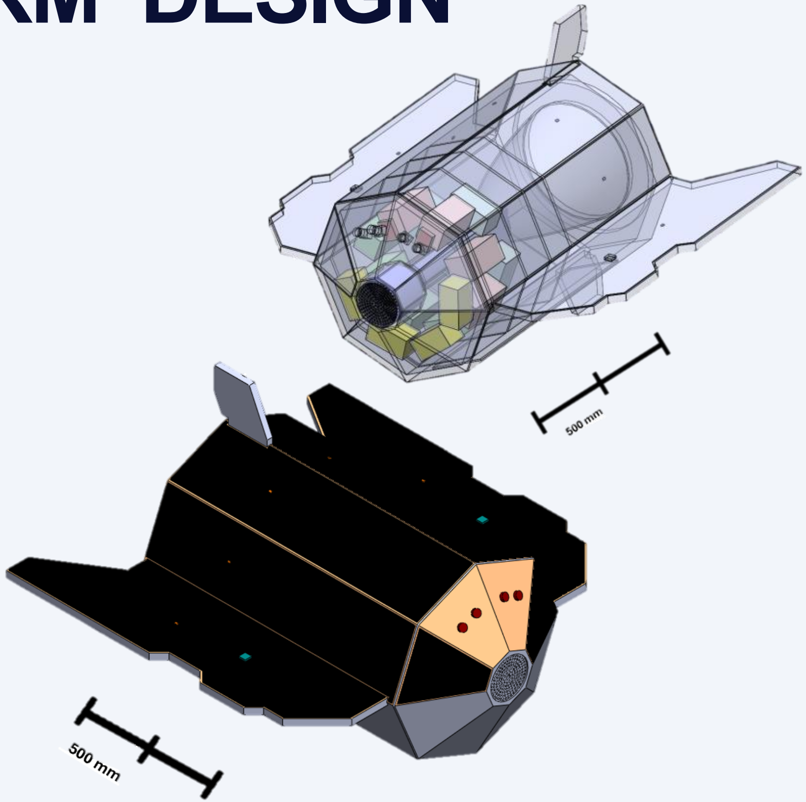
- **Tailorable properties:** Cell size, wall thickness, and geometry can be adjusted for mission-specific needs.
- **Design freedom:** TPMS structures allow energy absorption per unit mass and CAD-driven orientation optimization → unlike pre-made sandwich panels.

06

IOD PLANNING

PRELIMINARY PLATFORM DESIGN

- Baseline geometry derived from GOCE platform, scaled to fit 6.13 m² solar array surface;
- Resulting platform volume: ~1.01 m³;
- Challenging ABEP requirements.



CRITICAL TECHNOLOGIES

TRL targets

CRITICAL TECHNOLOGY	CURRENT TRL	TRL TARGET (BEFORE IOD)	TRL TARGET (AFTER IOD)
Sustainable anti-corrosion coatings	3	6	**7-8**
Regenerative 5G NTN payload	4	6	**7-8**
Air-Breathing Electric Propulsion	6	8	**9**

CONCLUSIONS

- Credible path to a **VLEO 5G D2D constellation** with 290 kg platform.
- Attractive IRR scenarios, strong market positioning vs. higher-orbit constellations.
- **Environmental gains:**
  - 43–47% climate impact (GWP)
  - 45–54% primary energy
  - 66–75% mineral resource depletion
- TPMS structures enable up to **72–74% mass reduction**, design freedom, and improved durability.

	STARLINK	ECOSTAR
RTT	15 ms	**8.6 ms**
Standard	LTE	**5G**
Environmental Impact	1	**-40% in key metrics**

THANK YOU

Presented by Daniel Poças – pocas.daniel@av.it.pt