# Autonomous Orbital Bioreactors:

## Biotechnology as the Foundation for the Materials Space Economy

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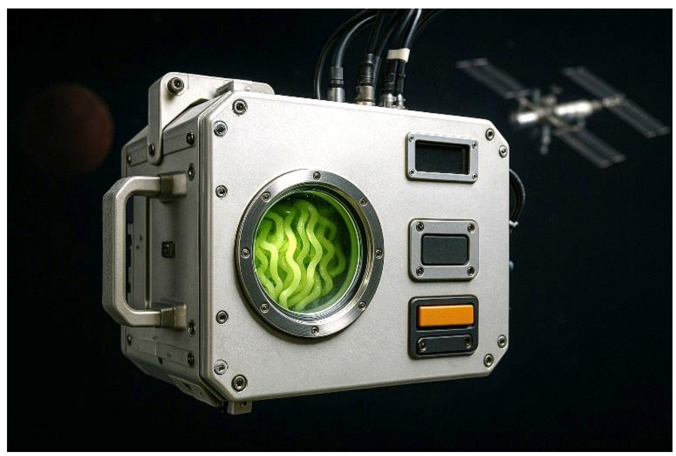
### Introduction

A new industrial revolution is about to begin off Earth. As launch costs plummet and commercial space stations multiply, manufacturing is moving into orbit and will become a key enabler of next-generation space transport infrastructure. Just as the first satellites created a space-based information economy, orbital manufacturing will power the new materials space economy.

Biotechnology has an essential role to play in this "bits-to-atoms" transition — and European biotechnology must not be a passenger in this shift.

### Program Vision

We will build the enabling technology for this new materials space economy: **self-driving bioreactors** that can operate, regulate, and adapt to conditions in orbit— without human hands. This technology breaks all previous paradigms of both space and terrestrial bioproduction and advances biotechnology toward its next viable frontier: continuous, autonomous biomanufacturing in orbit.



### Why Now

- **The ISS is nearing retirement (by 2030).** Beyond that, commercial activities in orbit will accelerate, driven by US players (e.g., SpaceX, Axiom, Vast) and emerging European counterparts (e.g., Alatyr, Isar Aerospace) that are democratizing access to orbit.
- **We need "Exhibit A" for the materials-based space economy.** To spin the flywheel of orbital infrastructure development, we must demonstrate practical, automated production of useful materials in orbit. Bioreactors designed for autonomous operation are the missing activating technology to unlock biotech's participation in this new industrial phase.
- **A convergence of mature technologies is now possible.** Advances in biotechnology, synthetic biology, sensing, physics-based and AI modeling mean that living systems can be designed and optimized digitally. This convergence enables a near-term leap: digital-to-biological automation as the core of space bioproduction.

## The Gap / The Opportunity

Microgravity enhances biological processes—protein crystallization, tissue growth, molecular assembly, and even product titers—offering **superior performance, purity, and yield** compared to Earth-based production. Yet today, space biomanufacturing remains **fragmented, small-scale, and manually operated.** The result: limited throughput, low data density, and sparse biological insight from each mission.

Historically, the field has faced three major blockers:

1. High launch costs,
2. Lack of reliable, flight-proven hardware platforms, and
3. Dependence on human intervention aboard crewed missions.

As launch costs continue to fall and commercial stations multiply, the remaining blockers are (2) and (3):

- The absence of **standardized, designed-for-orbit bioreactor hardware**, and
- The lack of **automation systems** which eliminate the need for human operation.

The **Autonomous Orbital Bioreactors program** directly targets these two remaining obstacles. We will design, build and test bioreactors that are:

- **Flight-proven and interoperable**, optimized for mass, volume, power, microgravity and sterility constraints in orbit; and
- **Intelligent and autonomous**, using in-situ, multimodal sensing to detect process and cellular conditions, integrated with feedback control systems that self-adjust the process to within optimal operating windows.

Solving automation for orbit will also deliver **dual-use breakthroughs** for terrestrial biomanufacturing. In both domains, we face the same pressures: high reliability, constrained human oversight, and the need for adaptive control of complex biological systems. The challenge of autonomy in space is therefore both **an elegant proving ground** and a **commercial accelerant** for intelligent bioproduction on Earth.

## The Program

Through the **Autonomous Orbital Bioreactors program** (€30M, 3 years), we will:

- Design interoperable, fully autonomous bioreactor hardware and data systems.
- Demonstrate autonomous, self-regulating bioproduction in microgravity.
- Galvanize a European ecosystem by converging advanced biotech, sensor platforms, orbital payload integrators, and AI/ physics-based modeling for the next phase of the space economy.

The program will progress through three phases:

| Year | End of Year Demo | Yield Milestone | Continuous Operation Milestone | Other Activities |
|---|---|---|---|---|
| 1 | Bench-scale demonstration of a fully-autonomous bioreactor intended for orbit | 5x yield relative to previous demo OR 0.5 g/L/day minimum titers | ≥ 60* days | |
| 2 | Payload scale demonstration of a fully-autonomous bioreactor intended for orbit | 10x yield relative to previous demo OR<br>1 g/L/day minimum titers | ≥ 100* days | In-orbit validation of crucial subsystems (if it affects design choices)* |
| 3 | Fully-autonomous bioreactor in orbit | 10x yield relative to previous demo OR<br>1 g/L/day minimum titers | ≥ 100* days | Teams can plan for multiple runs (more than 1 mission) to achieve this goal |

Our goal is to achieve **at least a 10× improvement in product yield** and **establish benchmarks in continuous bioreactor operation for >100 days** compared to previous space bioproduction experiments—establishing reference systems for future orbital factories. To achieve this goal, we aim to fund 3-6 multi-partner performer teams (1.5M Euros initial funding for year 1) who have the capabilities to advance the state-of-the-art in bioreactor design and automation and apply novel approaches to achieve our program metrics.

## Impact

If successful, this program will:

- Deliver multiple flight-ready prototypes for the next generation of autonomous, space-ready bioproduction platforms.
- Stimulate company formation to commercialize these platforms for both space and Earth applications.
- Position Europe as a global leader in the emerging materials space economy.
- Catalyze further commercial activity in low-Earth orbit (LEO) centered on materials and industrial production.

## Call to Action

SPRIND has the mandate to catalyze frontier technology development for Germany and Europe. The **Autonomous Orbital Bioreactors program** is such a frontier—where space, biotech, and automation intersect. There's a **generational window of opportunity** to mobilize global scientific talent and engage private capital already seeking early positions in the **materials-based space economy**. With the ISS decommissioning on the horizon, interest in orbital manufacturing is surging. The time to build this capability in Europe is now—and automation is the key unlock to make it happen.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