SED

Student Experiment Documentation

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Mission: BEXUS 34

Team Name: SpiCy

Experiment Title: Stratospheric investigation on combinatory Cyanobacterial biofilms

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Change Record

Version	Date	Changed chapters	Remarks
0	2023-Aug-25	New Version	Blank Book 2023
1	2024-Jan-20	All	**PDR**
1.1	2024-Feb-09	1.3; 1.4; 2.1; 2.2; 2.3; 2.4; 2.5; 3.1; 3.3.3; 4.5; 6.1.5;	post-PDR feedback Changes are underlined with yellow color Some Editorial edits have been shifted, need a rework (i.e. table of contents)
2			
			CDR
	2024-Mar-07	1.5.2	Team picture
			Updated team member list
	2024-Apr-10	1.1	Minor changes
		1.5.3	Member Restructuration
		3.5	PE10 Mitigation Action adjusted
		6.1.2	Launch risks added
		6.1.4	Launch site requ. added
		6.1.5	Flight requirements added
	2024-Apr-14	7.1	New bacterial strains and media added, minor changes
	2024-Apr-14	Preface	Minor changes
		1.5.2	Role adjustment
		2.1	Requirements revised
		4.2.4	Thermal interfaces revised
		3.3.2	Budget Plan
		5.1	STR-002 update
		Whole doc	Page numbers
	2024-Apr-16	6.1	Dimensions updated
	2024-Apr-17	3.4; Appendix B	Full update on outreach
		1.1; 1.4;	Updated promising strains and minor changes to sc.
	2024-Apr-18		background
		7.5	Added changes in Concept
			Updates on new lessons learned
		3.5	

	2024-Apr-19	1.6	Changed some risk assessments
		3.1	Prof. Detrell´s picture added
		3.3.3	Workload Schedule and SCRUM added
		4.4	Supporters added
		4.6	Mechanical part has been revised. Pictures were added.
		6.3.1	Complete Motherboard Software/Hardware rework.
		1.5.2	updated electronic interface
		B.2.4	Changed Team Member pictures
		B.3.1	Added section website
		B.3.3	Added section posters
		C	Added section wearables
		5.1	added sensors and PROFETs
		5.2	Added verification matrix
		4.2.1	Complete verification plan
			Added mechanical interfaces
3			**IPR**
		1.3 1.5.2 2 3.1 3.2 3.3.1 3.3.2 3.3.3 3.4 3.5 4.1 4.2.1 4.3 4.4	Team list update Objective updated according to CDR remark Team members and roles Additional verification methods Requirements updated New Work Breakdown Structure Updated Gantt chart Manpower w/ all team members Expenses updated Updated sponsors list Minor additions Risk register w/ CDR remarks Setup specifications added Fixation methods specified

		4.5	Experiment dimensions update
		4.6	Mechanical design refinement
		4.7	Hardware specifications
		4.8	Thermal design rework
		4.9	Updated power budget
		5.1	Biological experiment design
		5.2	Software updates
		5.3	Verifications updated
		6.1.2	Verification plan remodel
		6.1.3	Verification results added
		6.1.4	Safety risks elaborated
		6.1.5	Electrical interfaces specified
		6.2	Added launch site requirements
		6.3	Flight requirements adjusted
		6.4	Minor changes
		B.3.2	Timeline specified
		B.4	Post flight outreach added
		C	New sticker design
			Recent outreach events added
			Oxygen sensor information
4	2024-Aug-26		**EAR, Pre-Campaign**
		1.1	Extended introduction
		1.5.3	Previous members edited
		3.1	WBS extended acc.to IPR
		3.2	Schedule update
		3.3.2	Expenses and budget update
		4.2	Gondola fixation detailed
		4.3	Minor updates
			Total mass update
		4.4	Mechanical design updates
		4.5	Cable management
			Inrush current limiter
		4.6	Thermal testing added
		4.7	Power systems elaboration

		4.8	Major software redesign
		4.9	Add. chapter: Biological exp..
		5	Testing updated
		6.1	Mass update
			Flight requ. justifications
		6.2	Timeline refined
		6.4	Added Recovery instructions
		Appendix A	Review Reports added
		Appendix B	Outreach updates
		Appendix C	MSDS
			protocol for bac. Medium
		Appendix D	Extended Gantt chart moved
		Appendix E	Assembly checklist added
5			**Final report**
	2025-Jan-03	All chapters	Figure naming update
		All chapters	Minor grammatical updates
		All chapters	Past tense
		Abstract	Results added
		1.1	Best candidates upd.
		1.4	Flight samples detailed
		1.5.2	Fig.1.5-2 added
			Roles updated
		3.3.2	Expenses finalized
		4.5	PCB design process
			Processor selection
		4.6.8	Tvac test results
		4.9	Sample prep explained
		5.1	Final verification matrix + plan
		7.2	Launch Campaign report
		7.3	Results, analysis + outlook
		7.4	No Campaign rep. input
		7.5	Summary of Lessons Learned
		8.1	Abbreviations added
		B.3.1	Poster creation

		B.3.2 C D	New logo + stickers design Biological preparation added Updated Gantt chart

Keywords: REXUS or BEXUS, SED - Student Experiment Documentation, cyanobacteria, oxygen production, human space flight, oxygen supply, SpiCy, biofilm

Please keep the change record as detailed as possible. It helps the organisers to review your SED in a shorter time as well as you to keep track of your changes throughout the programme.
When updating chapters, instead of saying chapter 1, state sections chapter 1.1. and so on for technical changes (design, numbers, status…). For linguistic changes you might write "minor changes in chapter 1/ throughout the document" etc…
We require you to additionally highlight changes you made from the last issue in a light colour (e.g. yellow) in addition to the regular version.

CONTENTS

Preface

The REXUS/BEXUS programme is realized under a bilateral Agency Agreement between the German Aerospace Center (DLR) and the Swedish National Space Agency (SNSA). The Swedish share of the payload has been made available to students from other European countries through a collaboration with the European Space Agency (ESA). EuroLaunch, a cooperation between the Esrange Space Center of SSC and the Mobile Rocket Base (MORABA) of DLR, is responsible for the campaign management and operations of the launch vehicles. Experts from DLR, SSC, ZARM and ESA provide technical support to the student teams throughout the project. REXUS and BEXUS are launched from SSC, Esrange Space Center in northern Sweden.

SpiCy (Stratospheric investigation on combinatory cyanobacterial biofilms) is an experiment developed by a team of students from the Ludwig-Maximilians-University Munich, Technical University of Munich, and University of Applied Sciences Munich in Germany. Its aim is to test the photosynthetic rate of combinatory cyanobacterial biofilms when subject to increased ionizing and non-ionizing radiation levels. SpiCy is scheduled to fly aboard BEXUS 34 as part of cycle 15 of the Swedish-German program REXUS/BEXUS.

This document contains all relevant available information regarding SpiCy; including the experiment's objectives and requirements, a breakdown of the experimental module's design, design verification procedures, a timeline, plans for pre-launch campaign activities and post-flight results. Technical documents that pertain to the design are also included for reference, as appendix sections.

ABSTRACT

SpiCy (Stratospheric investigation of combinatory cyanobacterial biofilms) is a student-led mission to investigate the behavior of combinatory cyanobacterial biofilms under increased ionizing and non-ionizing radiation levels in the stratosphere to propose new alternatives of oxygen suppliance during space travel missions.

Cyanobacteria are among the oldest and most efficient photosynthetic organisms on planet Earth. They contribute 25% of the oxygen on Earth today and were crucial in forming our atmosphere in the early stages of Earth's development through oxygenation. As they are mostly aquatic or at least, need a certain degree of humidity, heterotrophic bacteria as a biofilm coordinator to mitigate their dependency are incorporated. These biofilms are a promising candidate in a plethora of space-related research (i.e. medicinal, life). Through forming adhesive biofilms, the bacteria are more resilient to radiation, thermal shocks, mechanical tearing and dry environments.

Project SpiCy intends to capitalize on the cyanobacterial ability to produce oxygen with minimum requirements and research their viability in long-term oxygen generation for human space flight and colonization missions.

The main finding of our experiment showed that pure culture *Nostoc sp.* oxygen production dropped immediately and significantly during flight in contrast to complementary cultured *Nostoc sp.* with *E. coli*. This is a first indication towards mediation of resilience in cocultivation and complementary formation of biofilms of cyanobacteria with heterotrophic bacteria.

1 INTRODUCTION

1.1 Scientific/Technical Background

Ever since a human entered space for the first time in 1961, humanity saw the possibility of a human presence in outer space. In order to achieve this goal, there must be implementations to improve duration and sustainability of elongated manned space missions. One of the major factors limiting the duration and thus distance from earth of a mission is oxygen supply for the crew.

Oxygen supply on the ISS is achieved through electrolysis of water. 40% of this water is derived from carbon dioxide breathed out by astronauts and cosmonauts on board via Sabatier reactors as well as from excreted waste waters. Since the oxygen derived from this is not enough to establish a sufficient oxygen level, additional freshwater tanks are delivered to the space station. This process is highly consuming of resources and energy and not suitable for further travel ambitions as the distances to other planets only exacerbate these problems. Life support systems on such vehicles must use a cyclic allocation of resources to simulate a steady earth-like environment without the need to provide them with a constant external supply. New ways of sustainable oxygen production on board a spacecraft need to be explored[1].

Approximately 2.4 billion years ago the earth's atmosphere had a low concentration of oxygen, so most organisms lived anaerobically. The rising population of the first phototrophic unicellular organisms, predecessors of today´s cyanobacteria performing photosynthesis, led to the Great Oxygenation Event (GOE)[2]. This oxygenation is thought to be one of the greatest extinction events in the history of the earth since the quickly rising high atmospheric oxygen levels were toxic for most microbes living at that time. The event fundamentally changed our atmosphere from a reducing to an oxidizing environment. This important step facilitated the evolution of aerobic organisms.

In photosynthesis, sunlight is used to fixate carbon dioxide and split water into electrons and oxygen, a process referred to as photolysis. This step is one step in an electron transport chain, commonly referred to as the light reaction, designed to produce ATP, the main energy carrier in organisms. The ATP molecules obtained through the electron transport chain provide energy for the dark reaction or Calvin-Benson-Basham Cycle in which carbon dioxide and further carbon hydrogen compounds are eventually synthesized into Glucose and Saccharides (i.e. Starch), the main energy storage for plants. The oxygen production is only a byproduct of this process.

The phylum of cyanobacteria uses photosynthetic pigments (i.e., carotenoids, chlorophyll A) and thylakoid membranes to perform oxygenic photosynthesis. They inhabit nearly every environment on earth and have specialized in various forms ranging from unicellular to filamentous growth patterns and from harmless to toxin-producing species[3]. They are small, can reproduce quickly, and need only a small amount of nutrients in comparison to plants. As they are prokaryotic, genetic modification (i.e., via plasmids) is generally easier than in eukaryotes. Various other substances can be produced by using the energy provided by photosynthesis[4]. As primary producers, select species of cyanobacteria are crucial contributors to marine life cycles.

Their ability to form biofilms is highly interesting for biotechnological applications. Biofilms are a consortium of microbes that use cell communication (quorum sensing) to produce a slimy adhesive extracellular matrix (EPS). This matrix consists of a conglomerate of various proteins, lipids, polysaccharides, and DNA. This composition allows the cells to function as a community where cells take on different functions in the complex.[5] This leads to an increased resilience towards low humidity, radiation, mechanical shearing, etc. As the formation of a biofilm is highly efficient for bacteria, they form very quickly and are most known as one of the biggest problems in industrial and medical systems (i.e., hydraulics, medical equipment, …). On the contrary, biofilms also have great potential to make cyanobacteria accessible as biocatalysts[6]. This was further investigated by *M. Bozan et al* when they researched bioreactor setups working with cyanobacteria for hydrogen production [7]. Here they used heterotrophic complements *Pseudomonas taiwanesis* and *E. coli* as biofilm coordinators in photobioreactors (PBR) to amplify the biomass of the composite cyanobacterial colonies. This idea is also tested for pre-colonization of surfaces with heterotrophic bacteria followed by an increased biofilm production of the cyanobacterial follow-up[8]. The complete inner workings of biofilm formation and sustainability are yet to be researched and are not fundamentally understood.

The viability of cyanobacterial biofilms for oxygen production depends on their ability to thrive in the extreme environment of space[1]. Most prominently constant ionizing and non-ionizing radiation from natural sunlight can lead to DNA damage, reproductive cyclic arrest, and release of harmful reactive oxygen species (ROS)[9]. On BEXUS, we want to evaluate the difference in survivability and oxygen production between cyanobacterial strands and combinatory strands with heterotrophic complements compared to laboratory tests on the ground.

The best performing strains in terms of survivability during high light exposure and oxygen production were determined through ground experiments. The strains tested were members of the Nostoc genus, Chroococcidiopsis cubana PCC 7433, Tolipothrix sp. PC 7712, Synechocystis sp. PCC 6803 and Synechococcus elongatus UTEX 2973 [10]. Promising biofilm-forming heterotrophic complements are members of the Pseudomonas phylum, Bacillus subtilis, Lactobacillus plantarum and Lactobacillus fermentum. However, since some of the more promising strains like Tolipothrix sp. PC 7712 are S2 while the laboratories at LMU and ESRANGE only allow S1 strains we decided to solely cultivate S1 bacterial strains.

In our experiment, the bacteria were cultivated in an aqueous medium. In summary, cyanobacteria are a strong contender for cyclic biological oxygen production.

1.2 Mission Statement

Project SpiCy aims to investigate the viability of single-species and multi-species cyanobacterial biofilms for long-term cyclic life support systems regarding their oxygen production efficiency when stressed with constant ionising and non-ionising radiation of natural sunlight in the stratospheric environment.

1.3 Experiment Objectives

Obj. 1	Technical	Manufacturing and conduction of experiment	Primary
Obj. 2	Scientific	Measuring the photosynthesis to respiration rate of the biofilms	Primary
Obj. 3	Scientific	Analysis of the EPS-matrix composition	Secondary
Obj. 4	Scientific	Analysis of DNA, RNA and Proteins in comparison to ground levels.	Secondary

1.4 Experiment Concept

The experiment measures the oxygen concentration of different biological samples containing different biofilms and strains.

For this purpose, the system is made of different subsystems listed below:

- The biological samples are enclosed in test tubes exposed to natural sunlight. The cyanobacteria strain is Nostoc sp. Different heterotrophic bacteria were chosen for comparison. The flown samples are as follows:
    - 1x *Nostoc sp.* + *Bacillus subtilis*
    - 1x *Nostoc sp.* + *Pseudomonas taiwanensis*
    - 1x *Nostoc sp.* + *Escherichia coli (newly formed biofilm)*
    - 1x *Nostoc sp.*
    - 1x *Nostoc sp.* + *Escherichia coli* (scraped established biofilm, in the following “scraped”)
    - 1x BG11 medium only as control sample

- Temperature sensors placed inside each tube, within the electrical compartment and in the sample compartment outside the tubes measure the temperature in each compartment of the experiment.
- A UV sensor measures the UV radiation reaching the biological samples.
- Six oxygen sensors placed inside the tubes measure the dissolved oxygen concentration within each respective tube over the duration of the experiment.
- Heating elements (Kapton heaters) are wrapped around the tubes to ensure the fulfillment of the temperature requirement.

All electronic components are connected to a custom-built PCB. It features a microcontroller which houses the software architecture. All essential functionalities such as thermal control, data acquisition, and uplink/downlink communication processes are implemented here. The sensor readout component efficiently gathers and processes data from embedded sensors. Oxygen sensor and thermal sensor data points are sent to the ground station consisting of a tech stack via downlink where it is plotted and may be filtered for easy analysis. A PI controller adjusts the heater temperature to stabilize the temperature by measuring the temperature continuously and activating/deactivating the heaters one tube at a time accordingly. The top of the module consists of a translucent quartz-glass ceiling, allowing UV radiation to pass into the module. The casing of the module is built with aluminum profiles and an aluminum bottom plate to fix the module into the gondola. Styrofoam is used to thermally isolate the module on each of the non-translucent sides, as well as to separate/compartmentalize the electronics bay and the biological samples.

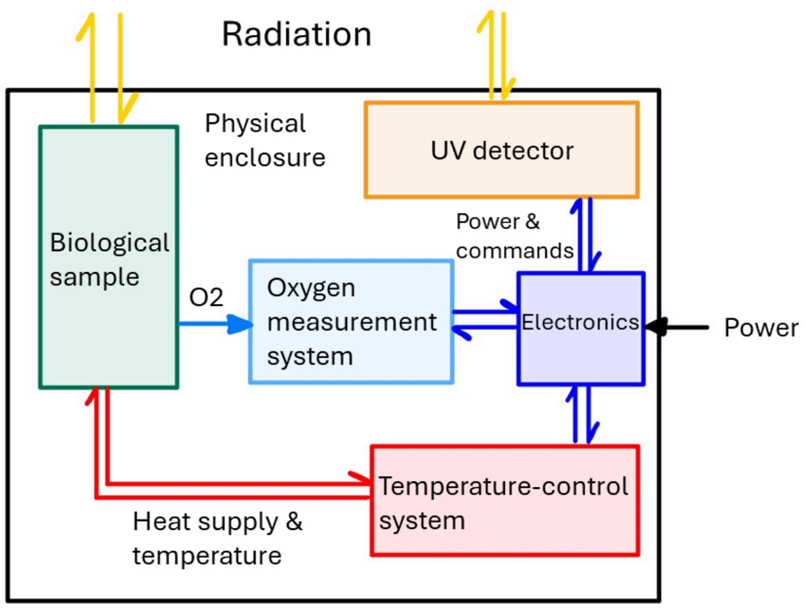

Figure 1.4-1: Outline of experiment concept

1.5 Team Details

1.5.1 Contact Point

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Contact point endorsing professor:

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1.5.2 Team Members

Fig

Fig. 1.5-1: SpiCy Team Picture

Fig. 1.5-2: SpiCy team picture with module after recovery

Project Management

Ilana Schürmeyer
Biology BSc, LMU

Date of onboarding:
2023-Jun-19

Roles:
Project Management,
Biological Research

SCRUM Master

Biology

Alexander Kubryk
Biology BSc, LMU

Date of onboarding:
2023-Jun-19

Roles:
Biological Lead
Experimental Design

Assistant Project Manager

Jacqueline Wiethaler
Biology BSc, LMU
Biological Technical Assistant

Date of onboarding:
2023-Jun-19

Roles:
Laboratory Lead,
Biological research

Mechanical Engineering

Tian Lan
MSc Aerospace Engineering, TUM

Date of onboarding:
2023-Jul-18

Roles:
Experimental Design,
CAD, Manufacturing,
Mechanical & Sealing
Solution

Runjia Zhao
MSc Aerospace Engineering, TUM

Date of onboarding:
2024-06-01

Roles:
Experimental Design,
CAD

Thermal Engineering

Pablo Martín Carrilero
MSc Aerospace Engineering, TUM

Date of onboarding:
2023-Jun-19

Roles:
Thermal Analysis, Control Engineering

SCRUM Product Owner

Systems Engineering

Sibtain Ali Thepdawala
MSc Aerospace Engineering at TUM

Date of onboarding:
2023-Dec-22

Roles:
Systems Engineering

Jayanth Narra
MSc Aerospace Engineering at TUM

Date of onboarding:
2023-Jul-18

Roles:
Systems Engineering

Electronics

Fynn Gewiese
BSc Electrical Engineering at HM

Date of onboarding:
2023-Dec-18

Roles:
Electrical Design,
Embedded Software,
Downlink Communication

Software

Elias Eggenberger
BSc Software and Design at HM

Date of onboarding:
2024-Feb-24

Roles:
Ground Station,
Data Visualisation,
SCRUM Implementation

Outreach

Eva-Maria Sontag
BA Communication Design at HM

Date of onboarding:
2023-Aug-08

Roles:
Brand Identity,
Social Media Management

Amanda Clot
BA Communication Design at HM

Date of onboarding:
2024-Feb-17

Roles:
Website Development,
Print and Apparel Design,
Event Management

1.5.3 Previous Team Members

Antonia Steinhoff
BA Communication Sciences at LMU

Time of membership:
2023-Jul-13 to 2023-Dec-17

Roles:
Social Media Appearance,
Presentations

Alexander Ens
Biology BSc at LMU

Time of membership:
2024-Dec-19 to 2024-Mar-10

Roles:
Biological Research

2 EXPERIMENT REQUIREMENTS AND CONSTRAINTS

2.1 Functional Requirements

Req. ID	**Description**	**Verification Methods**
F.1	The biofilms shall be exposed to natural sunlight.	I,T, R
F.2	The experiment shall measure the dissolved oxygen levels in the medium	A, T
F.3	The experiment shall measure the temperature inside the tubes.	A, T
F4	The experiment shall measure the temperature outside of the tubes.	A, T
F.5	The experiment shall measure the temperature of the electronic compartment.	A, T
F.6	The experiment shall measure the UV light entering the module.	A, T
F.7	The experiment shall save the recorded data of diluted oxygen.	A, T
F.8	The experiment shall save the recorded temperature data.	A, T
F.9	The experiment shall save the light transmission data.	A, T
F.10	The experiment shall have biological control samples.	I, R

2.2 Performance Requirements

Req. ID	Description	Type	Verification Methods
P.1	The Oxygen sensors shall operate with an accuracy of 0.4 mg/l ± 0.009.	Performance	R, T
P.2	The temperature shall be maintained within the range of -20 to 50°C.	Performance	T, A
P.3	The thermal sensors shall operate with an accuracy of <=1°C.	Performance	R, T
P.4	The thermal sensors shall operate with a response time of <=1 seconds.	Performance	R, T
P.5	The light sensors shall measure the incoming light with an accuracy of ± 20nm.	Performance	R, T
P.6	The Oxygen sensors shall operate with a sampling rate of <3 seconds.	Performance	R, T, A

2.3 Design Requirements

D.1	The top side of the module shall allow UV light to pass through.	Design	R, T
D.2	The tubes shall be hermetically sealed to prevent leakage.	Design	R, T
D.3	The electronics bay shall be accessible externally.	Design	I, R
D.4	The tubes inside the module shall have an exposure to natural sunlight for an elevation angle larger than 0 degrees.	Design	A
D.5	The biofilms shall cover the flat surface of the tubes.	Design	I, R
D.6	The temperature of the biofilm medium shall be maintained at 25-30°C.	Design	A, T
D.7	The temperature of the electronic compartment shall be maintained within the operational temperature range of the hardware components.	Design	A, T
D.8	The biological samples shall be S1.	Design	R
D.9	The experiment shall not interfere with other BEXUS experiments.	Design	A, R

D.10	The experiment shall withstand the loads during the flight.	Design	A, I, R, T
D.11	The experiment shall withstand pressure differences during flight as defined in the BEXUS manual.	Design	R, T
D.12	The experiment shall withstand temperature differences during flight as defined in the BEXUS manual.	Design	R, T
D.13	The experiment shall withstand the loads during the landing.	Design	A, I, R, T
D.14	The experiment shall be compatible with the BEXUS vehicle.	Design	I, R
D.15	The experiment shall provide an interface for power and LAN.	Design	I, R, T
D.16	The experiment shall be grounded with the power connector.	Design	R, T
D.17	The experiment shall work within the ambient temperature range of -60 to +30°C.	Design	R, T
D.18	The experiment shall stay within the mass budget of 8kg.	Design	T
D.19	The experiment dimensions shall not exceed 340x340x300mm.	Design	I, T
D.20	The electronic system power consumption shall operate within the BEXUS power supply range.	Design	A, R, T
D.21	The experiment shall operate within the BEXUS voltage supply range.	Design	A, R, T
D.22	The data rate shall be lower than 50 kb/s.	Design	A, T
D.23	The electronics compartment shall be accessible independently from the biological experiment.	Design	I, R
D.24	The sensor data shall be sent to the ground station in accordance to the data rate specified in D.22.	Design	A, T
D.25	The frontend shall provide a function to evaluate the collected data in the oxygen plot.	Design	A, T
D.26	The frontend shall provide a function to help evaluate the collected data in the temperature plot.	Design	A, T
D.27	The system shall store raw data in a database.	Design	A, T
D.28	The incoming data shall be live plotted on the ground station.	Design	A, T

D.29	The plot shall check for new data at least every 3 seconds.	Design	A, T
D.30	The software interface shall visualize the temperature data on the ground station.	Design	A,T
D.31	The software interface shall visualize the oxygen data on the ground station.	Design	A,T
D.32	The software of the ground station shall be structured in frontend, backend and database.	Design	R

2.4 Operational Requirements

O.1	The biosafety protocols for handling the selected biofilms before and after flight shall be followed.	Operational	I,R
O.2	The biofilms shall be cultivated inside of the Esrange laboratory.	Operational	I, R
O.3	The biofilms shall be transferred inside of the Esrange laboratory.	Operational	I, R
O.4	The experiment shall operate autonomously, without human intervention	Operational	T
O.4.1	The system shall instantly start running and continue to function when connected to power supply	Operational	T
O.4.2	The system shall instantly shut down when disconnected from power supply on retrieval	Operational	T
O.5	The tube's temperature measurements shall be shared via Downlink with the Ground Station.	Operational	A, T
O.6	The handling of bacteria shall comply with the safety regulations of the facilities they are handled in.	Operational	I, R
O.7	The handling of bacteria shall comply with the rules for international exports posed by the German war weapons control act.	Operational	I, R
O.8	The backend shall ensure continuous data processing and management in the event of receiving invalid requests.	Operational	A, T
O.9	Operational documentation detailing the backend functionality shall be maintained and made available for user reference and system explanation.	Operational	R
O.10	The plot interface shall alert if the temperature data are exceeding the tolerance range according to D.14, D.15.	Operational	A, T

O.11	The software system shall feature a fault detection system.	Operational	A, T
O.12	The system shall support retrieval and export of plotted data for further analysis and reporting.	Operational	A, T

2.5 Constraints

C.1	The laboratory shall be accessible pre-/post-flight for cultivation, sampling and pre-analysis.
C.2	The external environment post-flight may affect the retrieval of experiment setup.
C.3	The duration for recovery may delay the further analysis of secondary objectives
C.4	Low manpower during exam period may lead to delays in meeting deadlines.
C.5	Low sunshine conditions at the launch site may reduce sunlight exposure of the bacteria significantly.

3 Project Planning

3.1 Work Breakdown Structure (WBS)

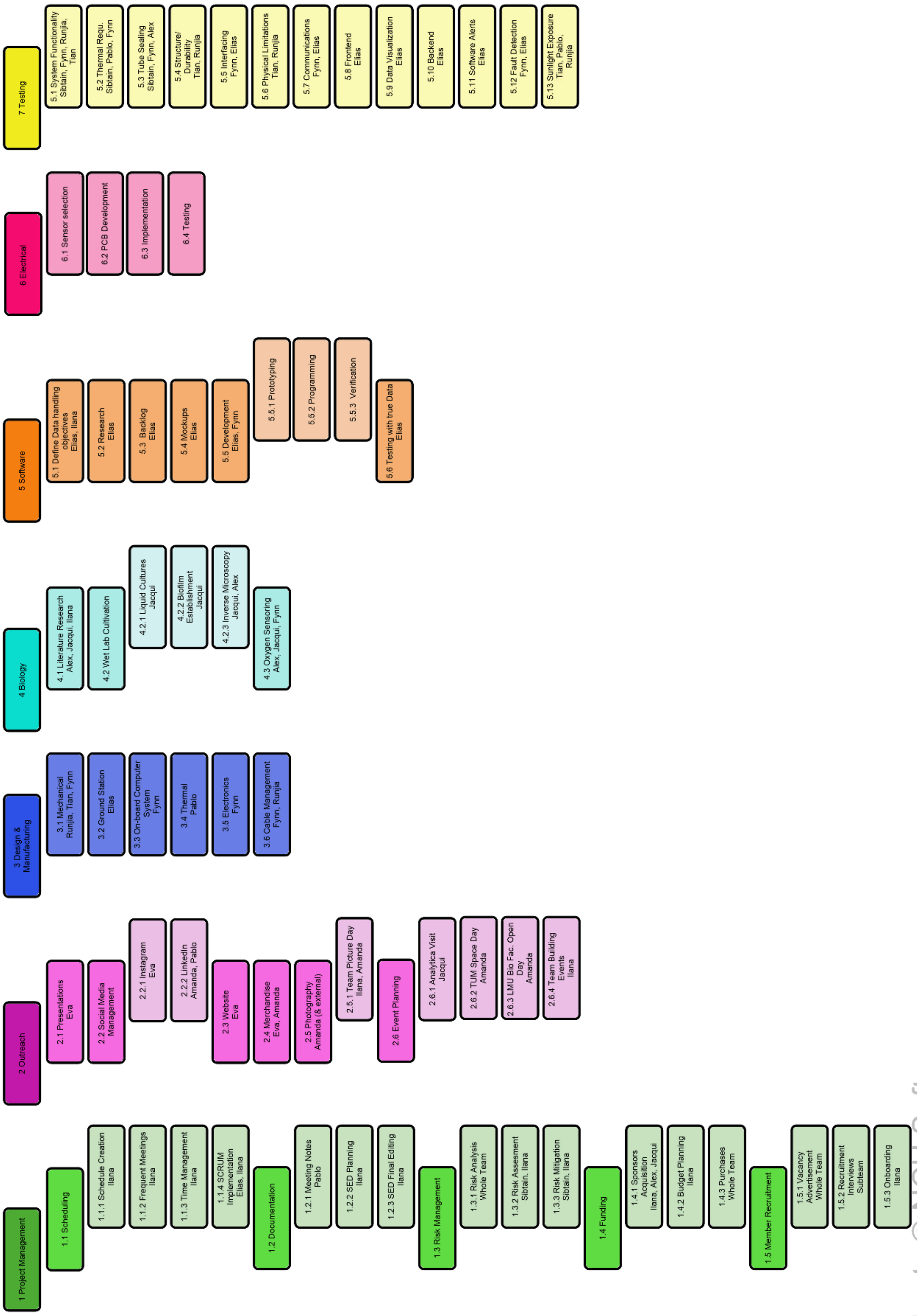


Fig. 3.1-1: Work Breakdown Structure

To increase transparency and efficiency in the workload we have adapted a SCRUM inspired work flow.

The duration for each sprint is 2 weeks with one weekly team meeting and additional subteam meetings.

3.2 Schedule

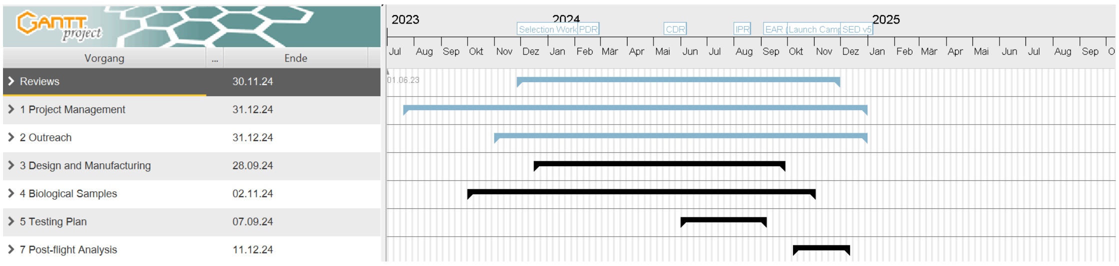


Fig. 3.2-1: Summarized Gantt Chart

Please find the extended Gantt Chart in Appendix D.

3.3 Resources

3.3.1 Manpower

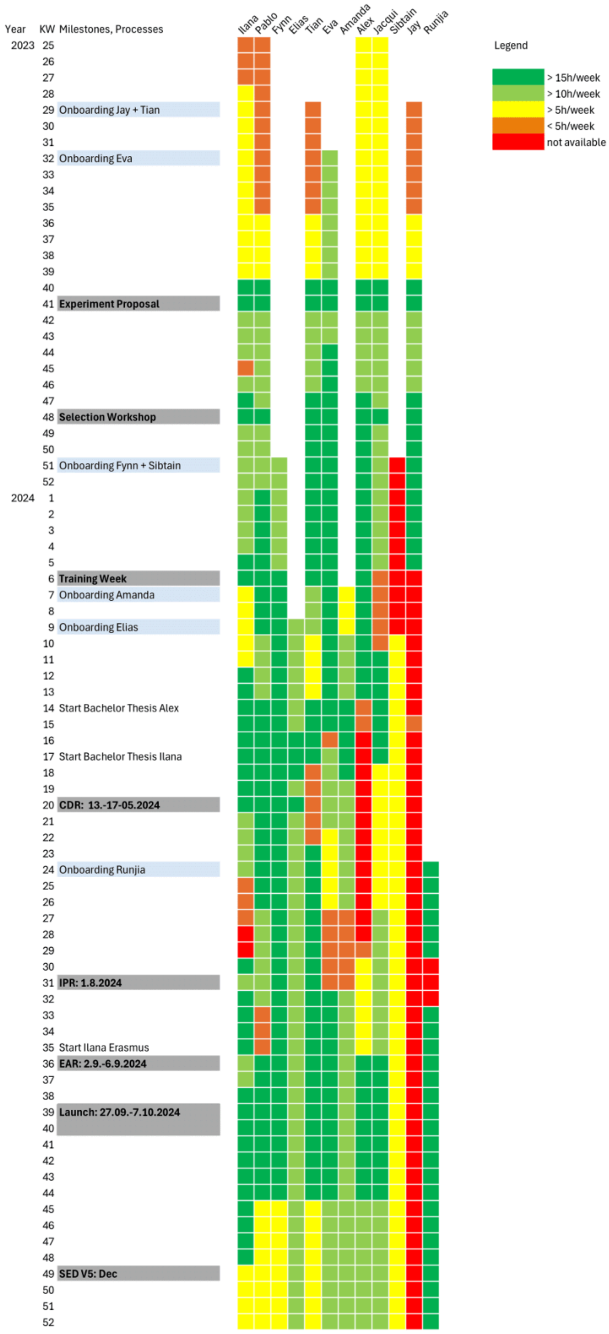


Fig. 3.3-1: Workload Estimation and Schedule for Team Members over duration of REXUS/BEXUS

3.3.2 Budget

We are working with different money sources and sponsors. In the following table we defined which parts of our expenses are covered by which sponsors and how to acquire the money.

Table 3-1: Money acquisition guide for SpiCy members

How to get money for SpiCy?

	ZARM	LMU Bio Dean	LMU Bio Lehrförderung
How much?	ca. 6000 EUR (with some wiggle room	ca. 5000 EUR	6000 EUR
What?	Module Parts	Bacteria, lab supplies, outreach	travel cost, oxygen sensors
How?	Material request form	send bill to deanery Adress: Dekanat Biologie LMU München Biozentrum Martinsried Großhaderner Str. 2 D-82152 Martinsried	send bill to deanery Adress: Theresa Neuner Dekanat Biologie LMU München Biozentrum Martinsried Großhaderner Str. 2 D-82152 Matinsried

Our expenses and budgets are tracked in the following tables.

Table 3-2: Expenses covered by DLR via ZARM

Expenses: DLR via ZARM				
Specification /Name	**Source**	**Paid by**	**Price**	**Status**
PCB v3	multiple	DLR via ZARM	90,14 €	Delivered
Electronic Components v3	Mouser	DLR via ZARM	217,49 €	Delivered
PCB v4	Multi PCB	DLR via ZARM	33,34 €	Delivered
Electronic Components v4	Mouser	DLR via ZARM	340,33 €	Delivered
test modules	Amazon	DLR via ZARM	52,75 €	Delivered
RS485 test Modul	Amazon	DLR via ZARM	5,99 €	Delivered
PyroScience Oxygen Sensor FD-OEM (6 pc.)	PyroScience	DLR via ZARM	1.000,00 €	Delivered

Atlas Oxygen Sensor	Roboshop.com	DLR via ZARM	350,00 €	Delivered
Box, cable harness and things to test	Amazon	DLR via ZARM	315,58 €	Delivered
Styrofoam / PIR side panels and insides	Hardware store and FaóamOnline	DLR via ZARM	40.77 (6.46+34.31)	Delivered
Alu profile and groove nuts for Gondola	myaluprofil.de	DLR via ZARM	42,17 €	Delivered
Microfiber Gloves	SV Artikel	DLR via ZARM	65,00 €	Delivered
Manufacturing Tools	Amazon	DLR via ZARM	213.05 €	Delivered
Caps and silicone septa	Carlroth	DLR via ZARM	128,00 €	Delivered
PCB 4.1	Aisler	DLR via ZARM	47,86 €	Delivered
Components PCB 4.1	mouser	DLR via ZARM	325,32 €	Delivered
Glue	Amazon	DLR via ZARM	81,14 €	Delivered
Hardware store 24.07.2024 (Glue, Screws, SandPaper...)	Hardware store	DLR via ZARM	56,60 €	Delivered
Quartz Glass tubes, 24 pc.	Chinese sus supplier	DLR via ZARM	215,00 €	Delivered
Amazon order 08.08.24	Amazon	DLR via ZARM	168,29 €	Delivered
Amazon order post-flight (small-scale laboratory tools)	Amazon	DLR via ZARM	272,83 €	Delivered
Replacement FD-OEM module	Pyroscience	DLR via ZARM	260,00 €	Delivered
Amazon order 22.08.24	Amazon	DLR via ZARM	32,40 €	Delivered
Amazon order 04.09.24	Amazon	DLR via ZARM	62,67 €	Delivered
Amazon order 21.09.24	Amazon	DLR via ZARM	160,96 €	Delivered
		Available	6.000,00 €	
		Sum	4.063,86 €	
		What's left?	1.936,14 €	

Table 3-3: Expenses covered by LMU Faculty of Biology

Expenses: LMU Faculty of Biology				
Specification /Name	**Source**	**Paid by**	**Price**	**Status**
Chroococcidiopsis cubana,	DSMZ	LMU Faculty of	191,53€	Delivered

Active Culture		Biology		
Oscillatoria sp.	LMU AG Jung	LMU AG Jung	0,00 €	Picked up
Anabaena cylindrica	LMU AG Stibor	LMU AG Stibor	0	Picked up
Bacillus subtilis	DSMZ	LMU Faculty of Biology	191,53€	Delivered
3x Quartz Glass plates	ProQuartz	ProQuartz, LMU Faculty of Biology	740,18€	Delivered
		Available	5.000,00 €	
		Sum	1.338,24€	
		What´s left	3.661,76 €	

Table 3-4: Expenses covered by Study Grant LMU Faculty of Biology

Expenses: LMU Faculty of Biology Studienförderungsmittel				
Specification /Name	**Source**	**Paid by**	**Price**	**Status**
Ilana CDR Travel Cost		LMU Studienförderungsmittel	800,00 €	Paid
SpiCy Stickers Vol. 2		LMU Studienförderungsmittel	106,77 €	Delivered
Sweaters		LMU Studienförderungsmittel	600,00 €	Delivered
Alex Launch Travel Cost (airplane)		LMU Studienförderungsmittel	724,07€	Paid
		Available	5.000,00 €	
		Sum	2.230,84 €	
		What´s left	2.769,16 €	

Table 3-5: Expenses covered by Verein für Förderung der Raumfahrt (VfR)

Expenses: VfR				
Specification /Name	**Source**	**Paid by**	**Price**	**Status**
Pablo Travel cost Launch Camp.	-	VfR, Team	1.300,00 €	Paid

		SpiCy		
		Available	1.300,00 €	
		Sum	1.300,00 €	
		What´s left	0 €	

3.3.3 External Support

The project is supported by many entities who have expressed their interest and support in our research and provide either material, financial, spatial, or scientific aid.

The following institutions support us:

- LMU Faculty of Biology: Monetary support, laboratory space and supplies, professional advisory, technical advisory, material for manufacturing module
- TUM ChemSPACE: Laboratory Space, Founder´s Advisory
- TUM MakerSpace: Material for the module, technical appliances for manufacturing
- Gerhard C. Starck Foundation: financial and ideational support of Ilana Schürmeyer through student scholarship
- Hochschule München Faculty of Electrical Engineering: Official meeting and storage room
- SP Bel-Art: Vacuum Chamber Sponsorship
- PyroScience: Oxygen sensing setup
- ProQuarz: Glas plates (manufacturing cost only)

The following professors support us:

- Prof. Gisela Detrell, Professorship Human Spaceflight Technology at TUM: Endorsing Professor
- Prof. Ralf Heermann, Professorship of Microbiology at Uni Mainz:

  Expert on biofilms, consultation on experiment design
- Prof. Heinrich Jung, Dean of Studies at Faculty of Biology at LMU:

  Support with sponsoring and communication within faculty
- Dr. Daniela Meilinger, Lecturer of Human Genomics at LMU:

  Academic networking support
- Dr. Frank Landgraf, Lecturer of Microbiology at LMU:

  Safety officer for biological laboratory
- Prof. Dr. Benjamin Kormann, Dean of Faculty of Electrical Engineering at HM:

  Provision of official SpiCy meeting room, connection to HM press

3.4 Outreach Approach

The foundation of our outreach approach lies in the combination of the biological and technical backbone together with the results of an in depth target group analysis. Depending on the media/platform used to communicate, this influences both our verbal and visual language (see platform description below) as we aim to engage people of various educational backgrounds and interest about scientific content on social media.

To cover all these goals, we implemented an iconic and intuitive visuality for all platforms and formats, and since we want to engage as many people as possible on instagram to raise interest in the REXUS/BEXUS programme and scientific content, we use as many barrier free tools as possible, in particular alt-texts, tags and screen reader-friendly writing.

The Outreach of Team SpiCy shall target different types of audience. The tools of choice for reaching a broad audience are the following social media platforms:

Instagram
https://www.instagram.com/spicy_bexus/

Aimed for a wider audience with an approachable, professional but also easy-to-understand mentality. Sentences shall be phrased in an easier language and the pictures shall either show the team or support the written content. The last slide is alway open for a call-to-action or a humorous slide.

Our goal is to post once a week to show progress and maintain attention, however, this schedule is temporarily changed to daily posts from 08. April until 13. April, as we have been invited to join the LMU-Takeover programme. The goal of this was to expand our effective reach and raise interest within a new target sector.

Find more details in the Appendix or our instagram channel @spicy_bexus (launched in December 2023).

Website
https://spicybexus.de/

The website shall especially provide more detailed explanations of the experiment, the project, our team, and institutions as well as a deeper insight into the scientific research behind the project. Moreover our website shall encompass an overview about all our sponsors and external supporters so it lay out an overall insight for professional interest in our project.

The website was launched in March 2024. Ever since March we've included an overview of our team-members, a page dedicated to our sponsors, partners and important people, a contact formular and details regarding our project. We update our website at least every two weeks with our latest news.

LinkedIn

LinkedIn is a platform of secondary priority for us and built for business and sponsoring connections. It shall introduce our project development, provide insights, references, attended events and connect teams and team members for further collaborations.

Additionally, lectures, exhibitions and presentations (at universities) are planned before and after the launch. SpiCy aims to contribute to scientific education due to sharing our experience and knowledge gained during this project. One of the main goals is to catch the students' attention for the REXUS/BEXUS programme and later establish a continuous academic competition team or students club within our universities. To reach that goal, SpiCy takes and will take part in various public events. The following paragraph, shall give an insight into what events we're attending:

April 13th 2024: **TUM "Space Day"**

- The Space Day as part of the international Yuri's Night takes place on April 13th at the TU Campus in Ottobrunn
- Planned for SpiCy: Talk, booth, and activities for students, families, and children
- Organized by: Prof. Gisela Detrell and Yuris Night Deutschland e.V
- Find details in the Appendix and/or our instagram channel

July 3rd 2024: **"Open Day" at LMU's Bio Faculty**

- Self-organized booth at the Open Day with educational exhibits and our project merch
- Planned for SpiCy: Provide insight into our project with a focus on the biological part and presenting the REXUS/BEXUS programme to the audience
- Open Days often attract pupils who consider studying in a certain field. Thus, we prepared ourselves and our overall outreach approach for that specific target group f.e. with a button machine with individual motives

as a playful way to get to talk to each other, stickers and real, living cyanobacteria that they could have a look at.
- Find details on our instagram channel

Furthermore, to suit the interests of our target audience, our concept of representation is translated to not only digital but also physical components such as clothing, posters, flyers, stickers, rollups and more.

See Appendix B – Outreach and Media Coverage for further details.

3.5 Risk Register

Risk ID
TC – technical/implementation
MS – mission (operational performance)
SF – safety
VE – vehicle
PE – personnel
EN – environmental
…etc.
Adapt these to the experiment and add other categories.
Consider risks to the experiment, to the vehicle, and to personnel.

Probability (P)
A. Minimum – Almost impossible to occur
B. Low – Small chance to occur
C. Medium – Reasonable chance to occur
D. High – Quite likely to occur
E. Maximum – Certain to occur, maybe more than once

Severity (S)
1. Negligible – Minimal or no impact
2. Significant – Leads to reduced experiment performance
3. Major – Leads to failure of subsystem or loss of flight data
4. Critical – Leads to experiment failure or creates minor health hazards
5. Catastrophic – Leads to termination of the REXUS and/or BEXUS program, damage to the vehicle, or injury to personnel

The rankings for probability (P) and severits (S) are combined to assess the overall risk classification, ranging from very low to very high and being coloured green, yellow, orange or red according to the SED guidelines

Table 3-6: Risk Register

ID	Risk & consequence	P	S	P x S	Mitigation Action
TC10	Temperature inside the tubes exceeds temp. Limits of 25-30°C. The Bacteria will have slowed metabolism (lower limit) or denature (upper limit).	B	3	Low	Perform thermal analysis. Temperature monitoring during flight, active heating system. Testing in a thermal vacuum chamber.
TC20	The tubes containing the bacteria and bacterial medium leak.	B	1	Very Low	absorbent material around tubes
MS10	O2 sensor fails to record data due to environmental stress.	B	3	Low	Environmental and data storage testing
TC30	Tubes melt due to sun radiation	A	3	Very Low	Selection of appropriate material, like Quartz glass.
TC40	Water hammer effect at the end of the tube at take off and landing.	B	3	Low	Selection of appropriate material to resist cavitation.
TC50	Oxygen bubbles due to faulty sealing	A	2	Very low	Tubes fully filled with liquid medium. Slightly tilted implementation of tubes in module for “controlled failure”.
TC60	Cables disconnect through vibration	A	3	Very low	Fixing the cables with adhesive material. Thermal vacuum chamber test.
TC70	Casing deteriorates by kinetic shock	A	2	Very Low	Dense styrofoam. Detailed operation instructions for the recovery team to ensure their safety in case glass shatters.
SF10	Part of experiment falls from balloon gondola over a highly populated area during flight	A	4	Very Low	Secure fixation of all experiment parts to the gondola and module by the aluminum profiles and casing.

MS20	Cyanobacteria die prior to experiment	B	3	Low	Careful handling and performance evaluation shortly prior to flight. Redundant charges of flight-ready tubes with bacteria.
MS30	Uplink/downlink fails	B	1	Very Low	Repeated software testing
VE10	Ballon power supply fails	A	3	Low	Strong Redundancy in the PowerRails -> Most shorts would only deactivate a single sensor/heater
PE10	Financial resources are not sufficient to fund the experiment.	B	2	Very Low	Acquisition of additional sponsors. Foreseeable expenses are covered.
PE20	Some team members are unavailable at launch	C	1	Very low	Proper knowledge transfer on the team through reliable communication and clear action protocol.
EN10	Biological samples leak out of the module	A	1	Very Low	Acceptable risk: sealing of the tubes and the module.
EN20	Tubes burst due to pressure difference.	B	§	Low	Acceptable risk: Redundant sealing of tubes and pressure test.

4 Experiment Description

4.1 Experiment Setup

The experiment setup will consist of a module for the biological samples for which a suitable environment will be provided with the appropriate medium and the suitable thermal conditions.

The biofilm strains will be transferred to containers (UV-translucent tubes around 50ml each) with a suitable buffered medium (BG11-derived) fixed presumably at pH=8.1. These samples consist of 3 biological replicates of the best candidate of cyanobacteria strain, cyanobacterial strains with heterotrophic complements, and multiple controls (dark control, heterotrophic bacteria only control, empty control). Oxygen sensors, suited for dissolved oxygen measurement, and NTC Thermistors are applied to the biological sample tubes and sealed on multiple levels (clamping/screwing with a silicone/rubber sealing ring and gluing). The biological setup is aligned for optimal light coverage and fixed inside the module. Kapton Heaters are deployed to maintain suitable temperature for photosynthesis and metabolic activity (25-30°C). Thermal sensors and an incoming UV-wavelength-sensor are connected to the electronics module, a custom built PCB. A PI controller adjusts the heater temperature to stabilize the temperature by measuring the temperature continuously and activating/deactivating the heaters one tube at a time accordingly. The top of the module consists of a translucent quartz-glass ceiling, allowing UV radiation to pass into the module. The casing of the module is built with aluminum profiles and an aluminum bottom plate to fix the module into the gondola. PIR insulation foam will be used to thermally isolate the module on each of the non-translucent sides, as well as to separate/compartmentalize the electronics bay and the biological samples.

Constant measurement of oxygen concentration enables high resolution of data across the different strains. Afterward, data is collected and compared to the data already collected on the ground. If possible (dependent on post-flight weather conditions and recovery time), fixation or RNAse deactivation of the samples is performed after flight to enable radiation damage analysis through RNA sequencing. The EPS matrix is stained with crystal violet and analyzed with potential HPLC analytics for changes in composition and biomass.

The parameters set in the module rely heavily on the strains tested and may be subject to change.

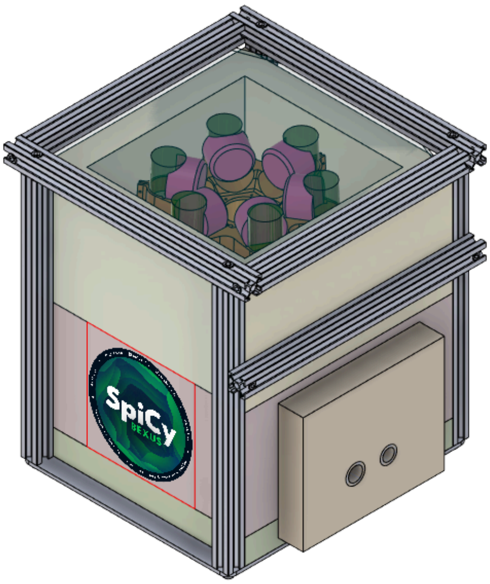


Fig. 4.1-1: Demonstration of module design

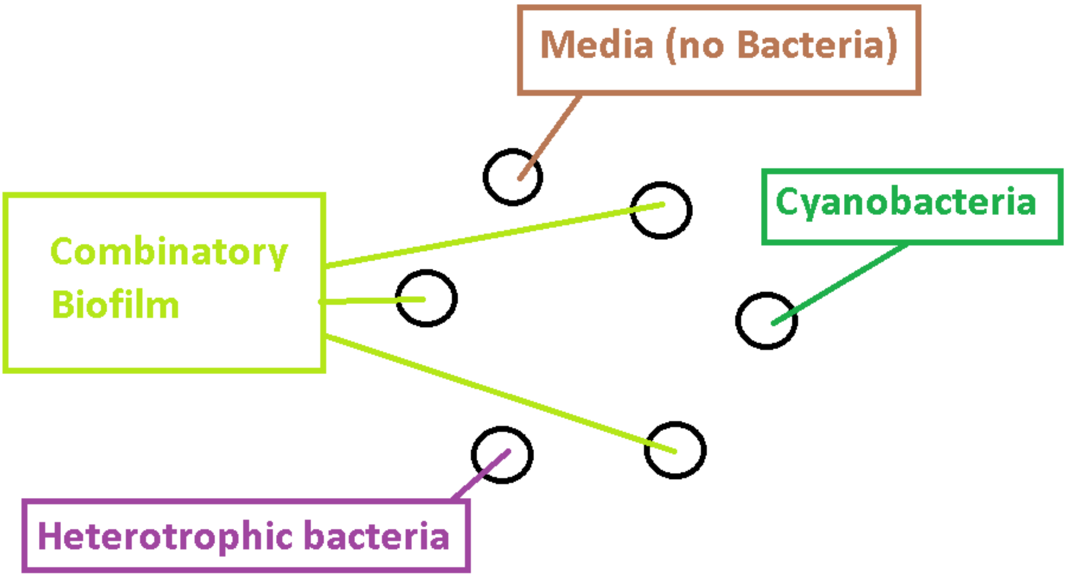


Fig. 4.1-2: Biological sample set-up

The tubes containing our experiment subjects, the combinatory biofilms, are placed in a circle alternating with the different control experimental approaches.

4.2 Experiment Interfaces

The ethernet port will be used for down and uplink data.

4.2.1 Mechanical

The mechanical interfaces will be the following:

- With the gondola: by the 4 aluminum profiles attached on the upper part, as shown in the CAD design, with 4 aluminium brackets of 20x20 to 45x45. The rest of the aluminum profiles (4) and two crossed steel hole stripes underneath fixated with 4 M5 bolts will act as a casing for the styrofoam box with the top glass lid stopping the vertical movement. The glass lid will be mounted under the aluminium profile frame on the top and glued together with the foam box below it as a damper.

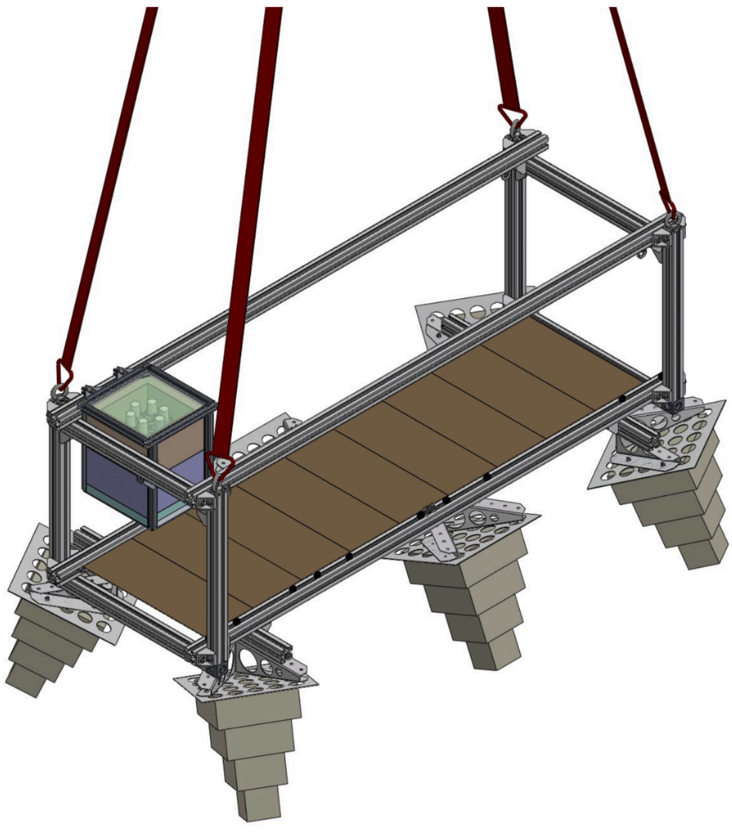


Fig. 4.2-1: Assembly of the module into the gondola

- With the environment: by the styrofoam box that is a porous material so the pressure in the inside and the outside is the same.

- With the styrofoam box: by the tubes and electronics compartment. Horizontally, it will be fixated by the aluminium profiles cage outside and high quality foam glue. Some pins go through the styrofoam box from sides and fix the position of the internal module vertically.

- With the electronics compartment and the glass tubes: by a styrofoam small compartment to allocate the electronics bay.

- With the inside of the module and the biofilms: by the glass tubes and the sealing around the oxygen and the temperature sensor.

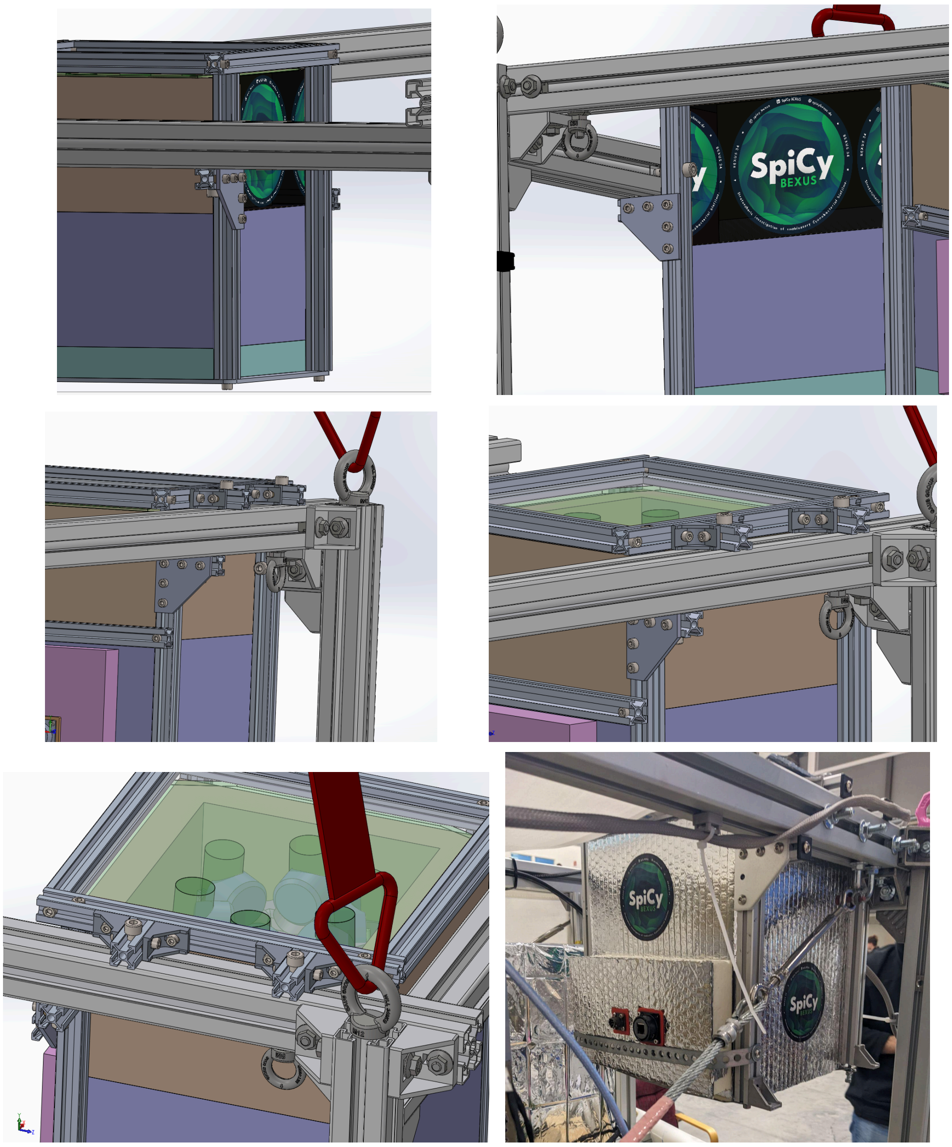


Fig. 4.2-2: Detailed illustration of the fixation on gondola.

In the upcoming Fig. 4.4-1, it can be seen how these interfaces are working in the assembly process.

4.2.2 Electrical

The electrical interfaces will be the following:

- Usb C for reprogramming and debugging
- Battery Connection
- Ethernet Port

4.2.3 Thermal

The thermal interfaces are the following:

- UV transparent Quartz glass upper boundary: radiation and conduction are the effective ways of heat exchange.
- UV transparent Quartz glass test tubes: radiation (upper part) and conduction (Kapton heater surface) are the effective ways of heat exchange.
- Styrofoam structure: conduction are the effective way of heat exchange and the interface with the outside of the experiment.

4.3 Experiment Components

Table 4-1: Experiment components

#	Component	Number of items	Cost in EUR	Sponsor	Status
1	NTC Thermistor	6	10	DLR via ZARM	Delivered
2	Oxygen Sensor	6	Ca. 6000	DLR via ZARM/LMU	Delivered
3	Quartz Glass Vials	6	TBD	DLR via ZARM	Delivered
4	Kapton Heater	6	-	DLR via ZARM	Delivered
5	PIR Foam Box	1	100	DLR via ZARM	Delivered
6	RTV Glue	1	12	DLR via ZARM	Delivered
7	Motherboard	1	300	DLR via ZARM	Delivered
8	Light Sensor	2	30	DLR via ZARM	Delivered
9	Buck Convertor	2		DLR via ZARM	Delivered

Table 4-1*: Components specification

#	Component	Specification
1	NTC Thermistor	A thermistor whose resistance changes with temperature. It is used to monitor, control and record the temperature in the tube during the flight.
2	Oxygen Sensor	FD-OEM oxygen sensor is characterized by small size and low power requirement. It is an optic-based sensor causing minimal disturbance of the tube environment.
3	Quartz Glass Vial	Quartz glass has a wide transparency range, which can extend from ultraviolet into near-mid infrared, which make it an optimal material for the study of the spatial radiant influence on bacteria.
4	Kapton heater	Kapton heaters are thin flexible metal foils that can be easily glued to curved surfaces. The tube temperature will be controlled by the heater at around 25°C.
5	PIR foam box	PIR (Polyisocyanurate) is a thermoset plastic typically produced as a foam and used as thermal insulation. PIR panels are usually laminated with aluminum foil and contain fire retardants.
6	RTV Glue	RTV stands for Room Temperature vulcanizing. It is used for the sealing of the tube to withstand the pressure difference.

7	Motherboard	Motherboard is the brain of the device. It monitors and controls all the parameters of the tubes such as temperature and oxygen density. It also powers the electronic devices and records the data for post flight analysis.
8	Light Sensor	Light sensor, which is capable of measuring both ambient and UV light, is to study the influence of the spatial radiant on the production of oxygen.
9	Buck Convertor	The motherboard requires two buck converters for power supply. One to power all LDOs which provide stable 3.3V to things like the microcontroller and SD card, the other powers the heating elements.

Table 4-2: Experiment summary table

Experiment mass (in kg):	3.86 kg
Experiment dimensions (for BEXUS) or module size (for REXUS) (in m):	290 x 290 x 319 mm (Incl. Aluprofiles)
Experiment expected COG (center of gravity) position:	145 x 145 x 200 mm

Table 4-3: Mass summary table

Rack (3D printed)	182 g
6 tubes with medium	108 g x 6 = 648 g
1 Quartz Glass lid	610 g
Aluminum Cage with fixation for the gondola	1640 g

IPR Foam Box	676 g
Cabling	100 g
Total experiment mass (in kg):	**3856 g**

4.4 Mechanical Design

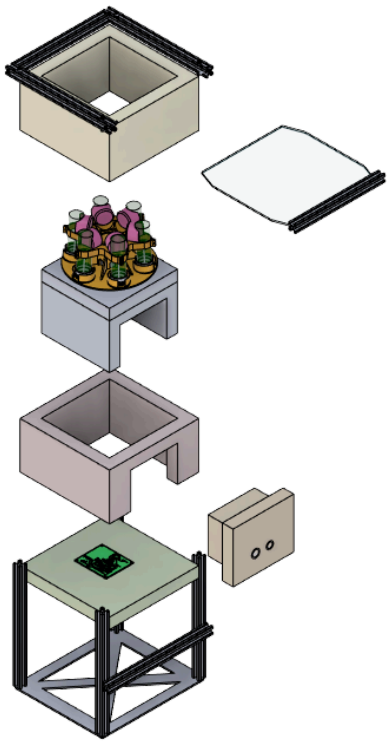


Fig. 4.4-1: Assembly view of the module design.

The mechanical part consists of 5 main components:

1. Bio experimental setup
2. Thermal control system
3. Quartz Glass Cover
4. Electronics
5. PIR Box with aluminum profile cage

Fig. 4.4-2: The assembled module design without aluminum cage.

The detailed explanation of the mechanical design is as follows:

1. Experimental setup (Biofilm Tubes Housing):

A small styrofoam container with precise dimensions securely houses biofilm tubes, each slot tailored to accommodate their diameter and length. The styrofoam's insulation properties maintain stable temperature, preventing movement and potential damage conditions for the tubes. The tubes are tilted lightly into the center to avoid the formation of big bubbles at the tube bottom which could impact the oxygen measurement accuracy.

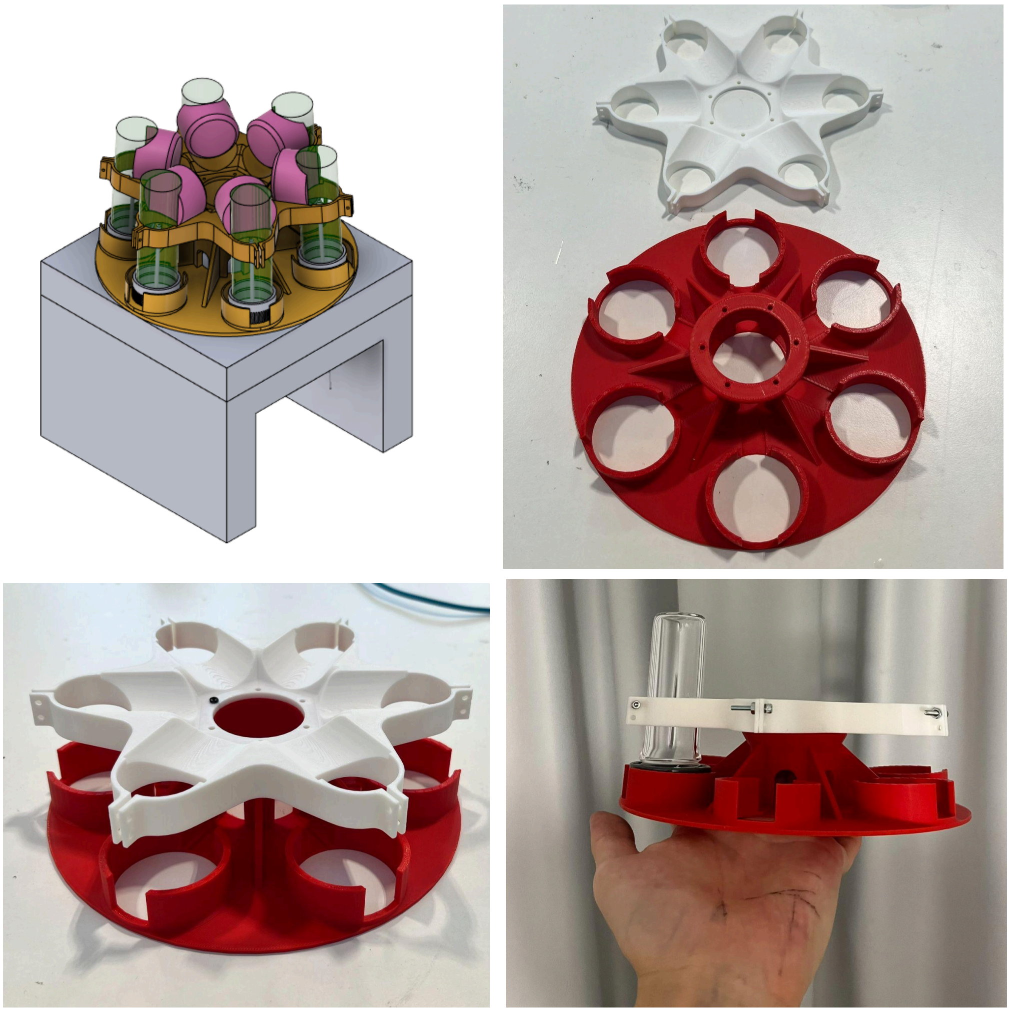


Fig. 4.4-3: Experimental setup design.

2. Thermal Control System:

The design integrates an active environmental control system (Kapton heater as heating element) to maintain suitable thermal conditions for biofilm, featuring temperature regulation for stable growth. Strategically placed sensors monitor environmental factors, providing real-time feedback to the control system (PI controller) for automatic adjustments based on the measurements from temperature probes on the inside of the tubes.

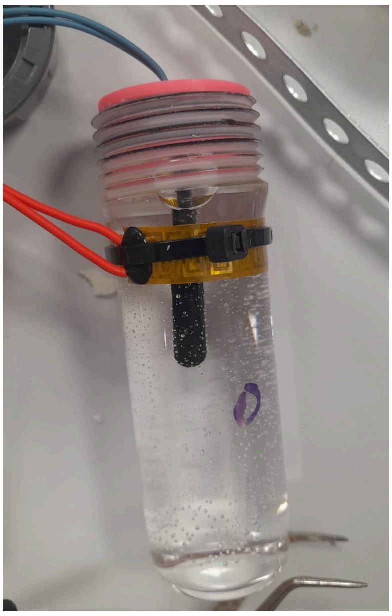


Fig. 4.4-4: Tube assembly with Kapton heater wrapped around.

3. Quartz Glass Cover:

A custom-cut Quartz Glass lid serves as a transparent protective cover for the styrofoam container, allowing sunlight penetration and visual inspection of biofilm tubes. Securely attached, it maintains a sealed, contamination-free environment. The Quartz Glass cover will be installed under the aluminum profiles and pressed and bonded together with the foam box under it. Silicone and rubber material will be used between the glass and the aluminium interface as damper and sealant.

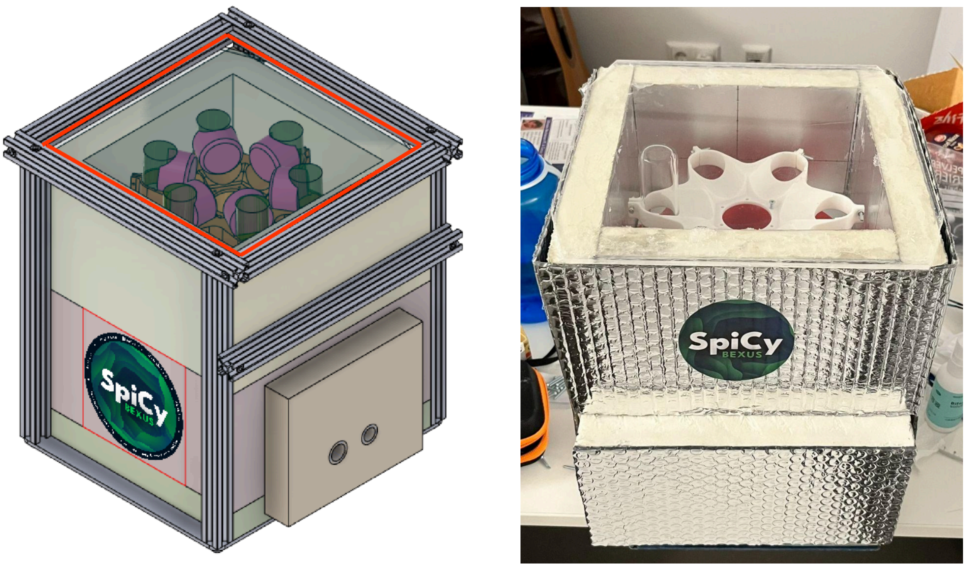


Fig. 4.4-5: Quartz glass cover (in red box).

4. Electronics Compartment:

The electronics compartment, constructed from durable materials like rigid plexiglass, surrounds the styrofoam biofilm tube housing, providing structural integrity and protection for internal electronics. Its organized interior features specific sections for different electronic components, minimizing clutter and ensuring efficient organization. An extra door was made for convenient access to the electronics compartment. The door position is fixed by one piece of steel hole stripe mounted on the side of the aluminum cage. Furthermore, the connectors for power and ethernet from the gondola are integrated on the door.

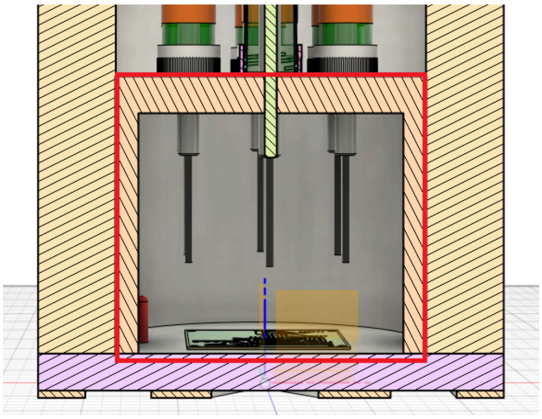


Fig. 4.4-6: Electronics compartment design (in red box).

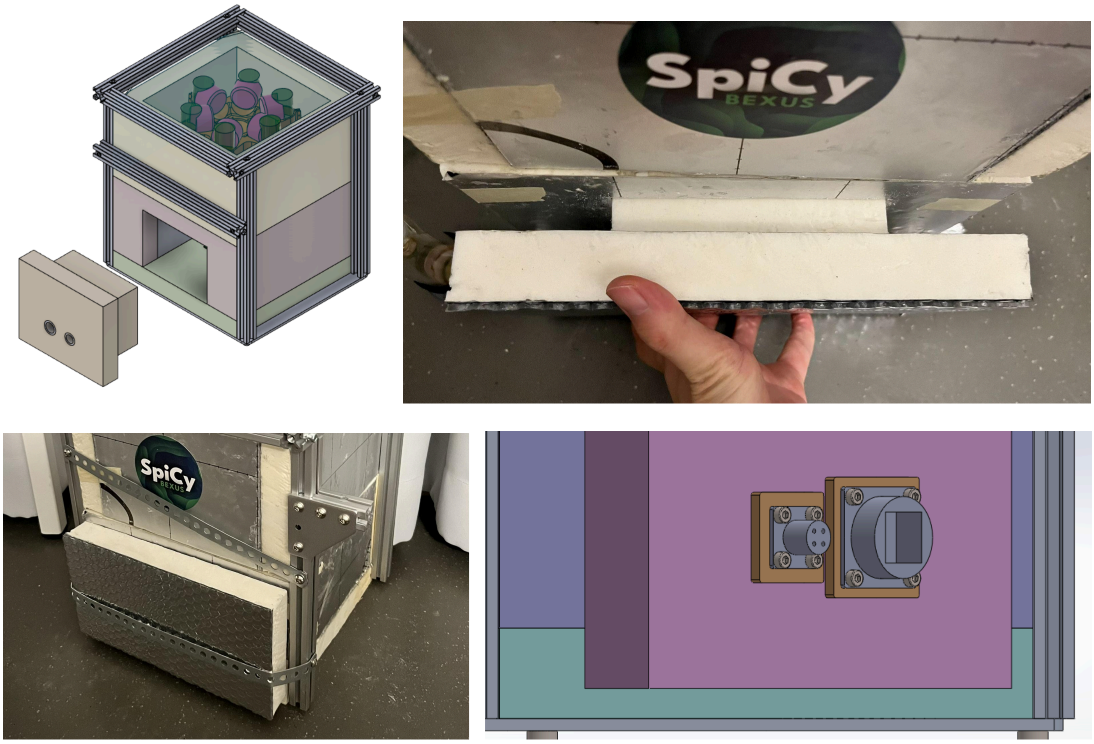


Fig. 4.4-7: Access door to the electronics compartment (top) and the steel hole stripe to fix the door position (bottom left). Power & Ethernet connectors (bottom right). The holes for the connectors are still missing in the module.

5. Box with aluminum profile cage:

An aluminum profile cage reinforces the outer box, enhancing structural integrity and providing resistance to external forces and impacts. This protective shell ensures the internal components remain secure during transportation or handling, while the compartmentalized interior organizes and stabilizes the biofilm tubes.

Fig. 4.4-8: Box with aluminum profile cage design.

6. Sealing mechanism of the tube

For the tube sealing design, a 3D-printed plug is utilized to effectively seal a glass tube, ensuring water-tightness through optimized printing settings that enhance the material's impermeability. Two rubber O-rings are strategically placed on the nuts of the plug, providing a robust sealing interface to prevent any medium leakage under pressure. The plug is securely held in place by the cap, which ensures that it remains within the tube even when subjected to internal pressure variations. The hole on the plug for the temperature sensor cables will be filled by silicone material.

This sealing mechanism is critical for preventing leakage and avoiding potential contamination within the bio module, thus maintaining the integrity of the biological environment and ensuring reliable experimental outcomes. Proven by the pressure test in a vacuum chamber, this sealing mechanism is able to seal the tube for at least 5 hours under 1 bar pressure difference.

Fig. 4.4-9: Plug with O-Rings in the tube.

Fig. 4.4-10: Water filled tube without the cap (left) and with the cap (right).

7. Integration of Components:

The 3d printed biofilm tube housing and Quartz Glass lid are seamlessly integrated, using secure fasteners or adhesive bonding for robust attachment. The electronics compartment is designed to be located directly below the biofilm tube housing, ensuring the integrity of the design and ease of operation.

8. Material Considerations:

Firstly, IPR Insulation foam is selected for its light weight and outstanding insulating properties, ideal for maintaining a controlled environment for the biofilm tubes.

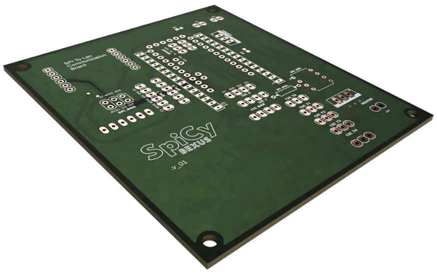
Secondly, Quartz Glass is chosen for its high UV allowance and transparency, allowing for a clear view of the biofilm tubes.

Finally, Aluminium profiles are ideal for constructing a robust and durable framework due to their lightweight and high strength. Their lightweight nature reduces the overall structure's weight, making it easier to handle and transport. Their strength ensures the framework can support biofilm tubes and other components, withstanding environmental stresses without deformation. Aluminium's corrosion resistance enhances longevity in high humidity or chemically exposed environments. Additionally, their versatility allows for flexible design options to accommodate various experimental setups.

4.5 Electronics Design

4.5.1 Hardware

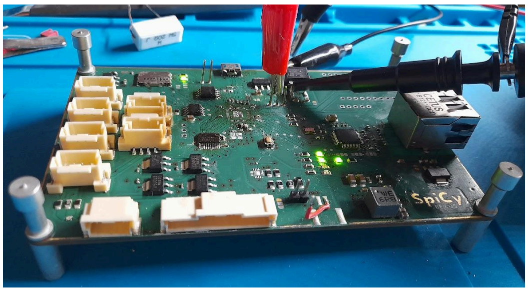
Hardware Versions



The version V1 was just a debug board for an arduino and a few sensors. This proved as not sufficient, mainly because of the limited capabilities of the arduino uno as well as space restrictions and reliability.

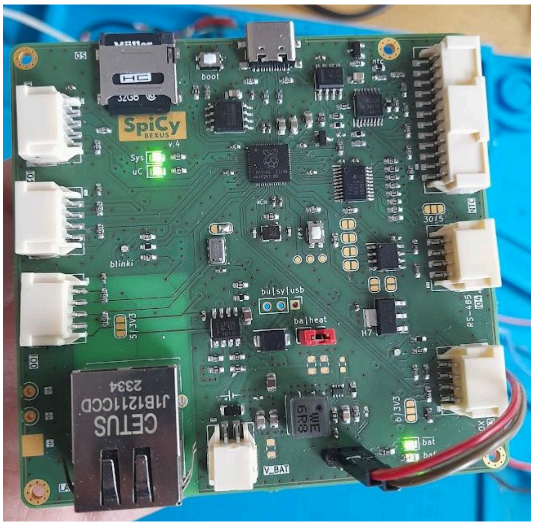
Fig. 4.5-1: SpiCy PCB V1

Second version (no picture) implemented a better Microchip AVR processor on a custom pcb, but got replaced by V3 as the RP2040 was a clear upgrade. Also a lot of sensors had changed so it made sense to start from scratch.



V3 was the first board with the RP2040, but due to a lack of soldering skills critical traces were destroyed and rendered it useless.

Fig. 4.5-2: SpiCy PCB V3



V4.0 was the first flightready hardware. It got some minor changes from V3, like different connectors for power and SD. This almost halved it´s footprint.

The heating elements also switched from *PROFET*s to normal Mosfets, as *PROFET*s don't work at low voltage.

The USB was changed from MicroUsb to Usb C.

Fig. 4.5-3: SpiCy PCB V4.0

V4.1 is the latest iteration of this project. The oxygen sensors changed and weren't I2C compatible anymore. Instead, 6x UART were required. This added a multiplexer.

Also every heating element as well as thermistor got its own connector, in V4.0 they were bundled together.

Fig. 4.5-4: Assembled Motherboard 4.1

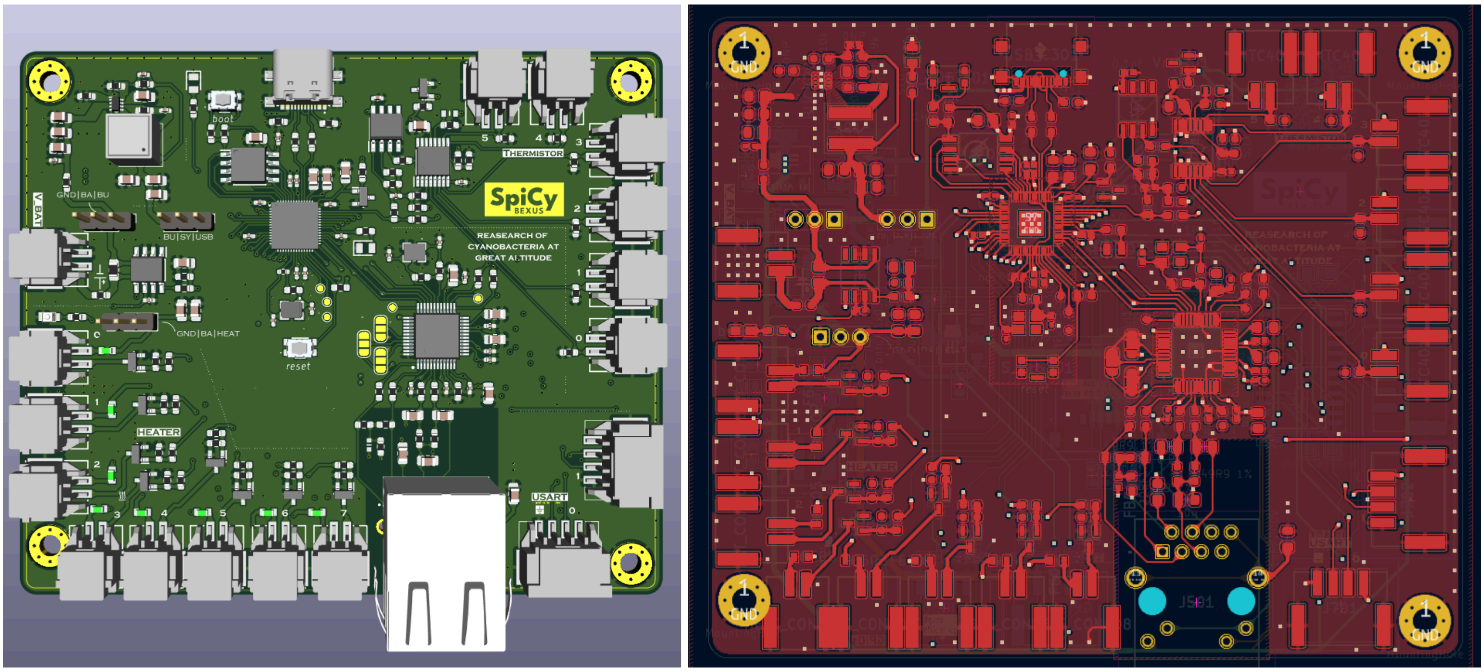


Fig. 4.5-5: V4.1 of the motherboard: [left] 3D rendering top view, [right] signal routing top layer

Processor

RP2040 is a 32-bit dual ARM Cortex-M0+ microcontroller by Raspberry Pi Ltd. It's mostly known as the processor of the Raspberry Pi Pico.

It was chosen mainly because of the dual core, the ability to multiplex the IO buses like I2C and its easy integration with the Arduino Ide.

Uplink/Downlink

A W5500 Ethernet chip manages the LAN link to the ground station. It's a Hardwired TCP/IP + MAC + PHY High Speed SPI Interface.

Heating

As the probes require active temperature control, kapton heaters are used to keep the temperature constant. They get their power from a buck converter. Battery voltage can´t be connected directly, as there's a high current whenever all heaters are turned on. Initially the plan was to compromise this issue with a high resistance heating element, but they are hard to find in the small size required. The final design settled on a buck converter to lower the voltage therefore decreasing inrush current. Looking back it would probably have been fine with a big capacitor bank.

The switching elements were Mosfets with low enough Vth to be switched via GPIOs directly.

For short safety, a PTC fuse is used for each heating element.

Temperature Probes

NTC probes are used, and with a multiplexer, it's possible to read up to six probes using just one ADC connection. The Multiplexer is connected between the NTC voltage divider and a high impedance amplifier, so it doesn't interfere with the NTC measurement. The amplifier scales the voltage drop across the voltage divider to 3.3V to optimally use the ADC range.

NTC Resistor

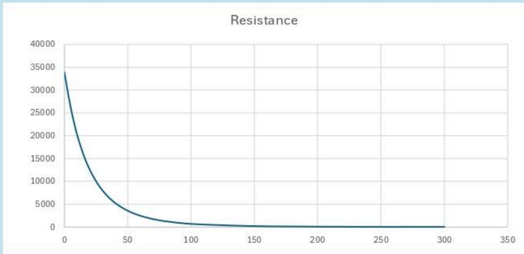
Constans:	
B-Constant	3977
R at 25°C	10000

Formulars:

$$R_T = R_N \cdot e^{B\left(\frac{1}{T} - \frac{1}{T_N}\right)}$$

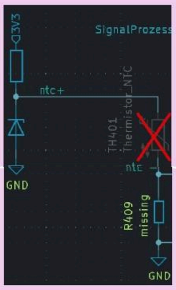
0 °C + 273,15 = 273,15 K

Temperature	Resistance
0	33900,4209
5	26093,9205
10	20271,5946
15	15886,9982
20	12554,7025
25	10000
30	8025,14518
35	6486,44088
40	5278,52005
45	4323,45404
50	3563,13194
55	2953,87922
60	2462,62387
65	2064,14174
70	1739,0614
80	1252,5298
100	684,938723
150	194,411188
200	72,0085807
250	32,2475864
300	16,6142994



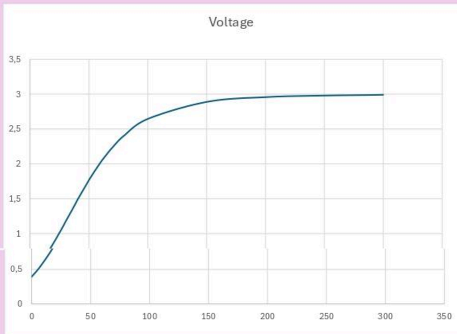
Voltage Divider

Constants:	
VCC (ntc+)	3,00
R9	5100



Temperature	Voltage
0	0,39230346
5	0,49048019
10	0,6030366
15	0,72902279
20	0,86662463
25	1,01324503
30	1,16570139
35	1,32050905
40	1,47419863
45	1,62360849
50	1,76610493
55	1,89970567
60	2,02310736
65	2,13563614
70	2,23714909
80	2,40848929
100	2,64479897
150	2,88983977
200	2,95823175
250	2,98115002
300	2,99025862

Imax [mA]	0,58632522
I at 30°C [mA]	0,2285689
d(mV)/dT at 30°C	30,7264014
mV/ADCstep	0,73242188
min Tres at 30°C	0,02383689

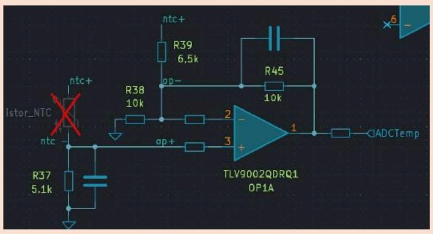


Signal Prozessing

Constans	
Gain	2
Voff	0,4
VCCoff (ntc+)	3
R1	5100
R2	10000
ADC Resul [bit]	12
ADC Vref	3

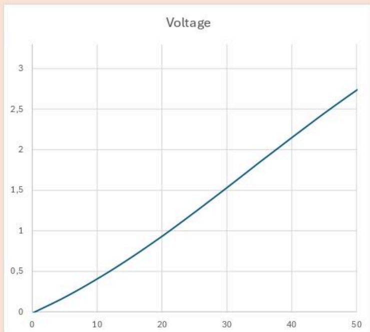
Vairables	
R3	65000
R4	10000

$$V_{out} = \left(1 + \frac{R_4}{R_2}\right)\left(\frac{v_{dd}}{1 + \frac{R_{ntc}}{R_1}} - \frac{V_{cc}}{1 + \frac{R_3}{R_2}}\right)$$

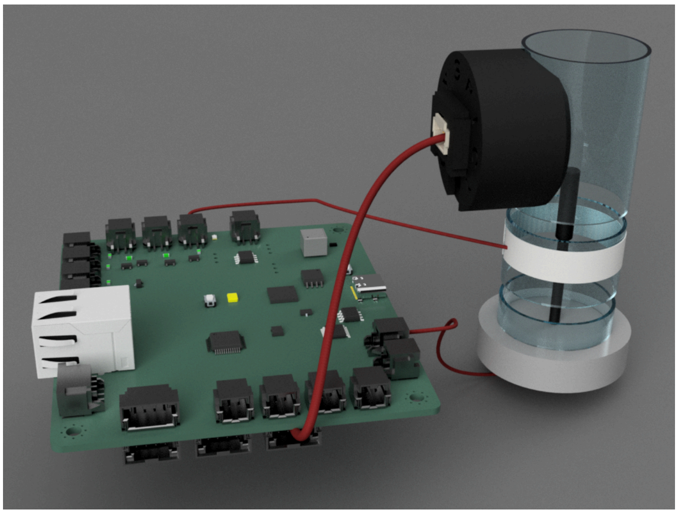


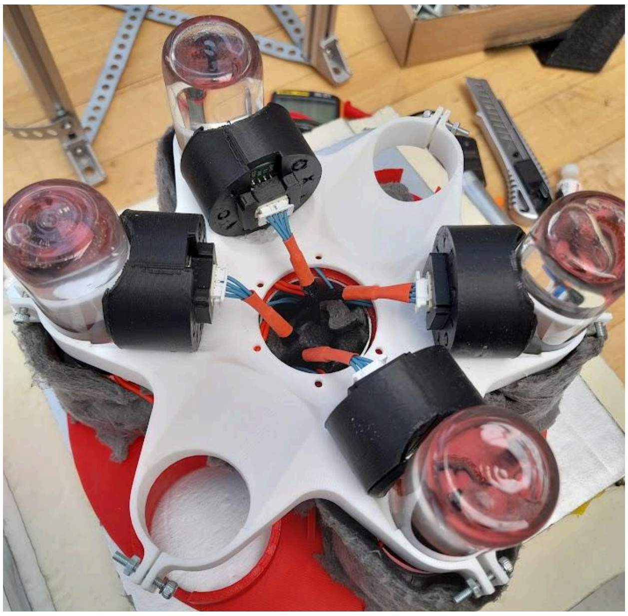
Temperature	Voltage
0	-0,01539308
5	0,18096038
10	0,40607319
15	0,65804558
20	0,93324925
25	1,22649007
30	1,53140278
35	1,84101809
40	2,14839725
45	2,44721698
50	2,73220985
55	2,99941133
60	3,24621472
65	3,47127227
70	3,67429818
80	4,01697859
100	4,48959795
150	4,97967954
200	5,1164635
250	5,16230004
300	5,18051723

Imax	0	mA
I at 30°C	0	mA
d(mV)/dT at 30°C	61,4528027	mV/°C
mV/ADCstep	0,73242188	mV
minTempResoltion at 30°C	0,01191845	°C



Oxygen Probes





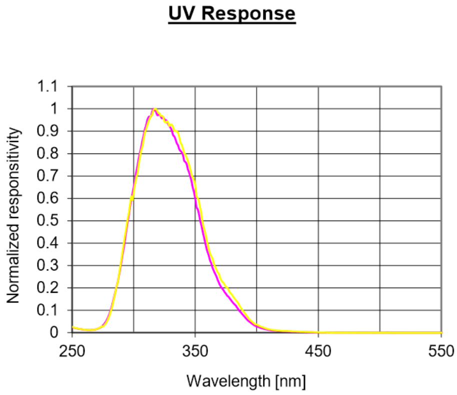
[left] Fig. 4.5-6: Rendering of single tube set-up. [right] Fig. 4.5-7: actual setup with 4 tubes installed

We are using 6 FD-OEM Modules from PyroSience. Links to them are found in the Appendix. They work via a spot glued inside of the container of your oxygen-containing medium. This spot is flashed with a UV light. The reflection of the light in the spot is measured and converted to an oxygen value.

They are easy to program via serial, offer for this project sufficient measurement ranges and accuracies and are equipped with an ambient temperature, humidity and barometer sensors each. As the used microcontroller doesn't have 6 serial IOs, an analog multiplexer is used to select the active sensor. To save on GPIO pins, the multiplexer of the NTCs is linked with the one of the oxygen probes, so if the oxygen probe 1 is selected, so is the NTC 1.

Light Sensors

The project uses the LTR-390UV light sensor board from Adafruit, which is capable of measuring both ambient and UV light.



[left] Fig.: 4.5-8: UV Sensor LTR-390UV; [right] Fig. 4.5-9: Absorption spectrum of LTR-390UV

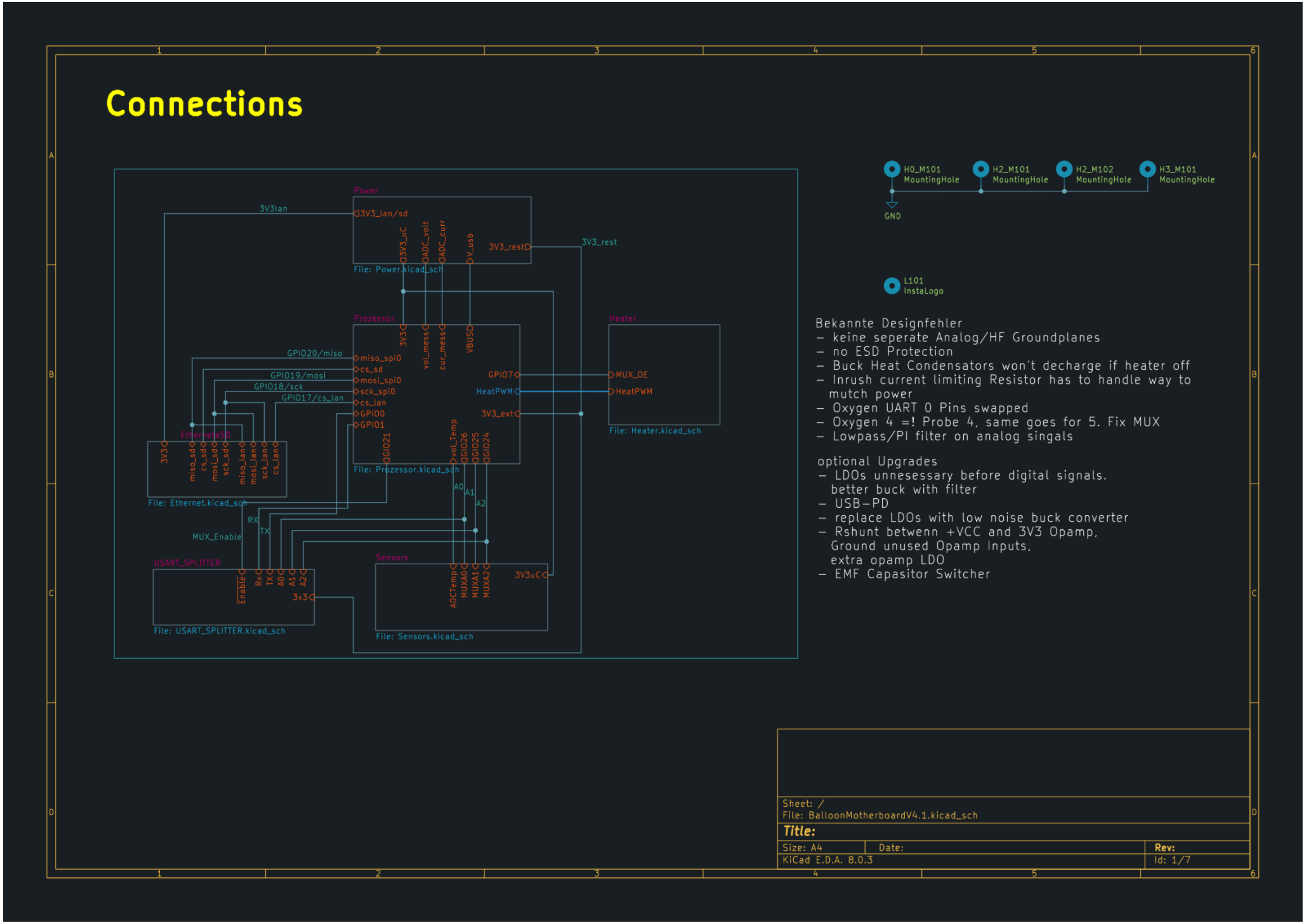
The sensor provides a raw value for each measurement, which can then be converted to LUX.

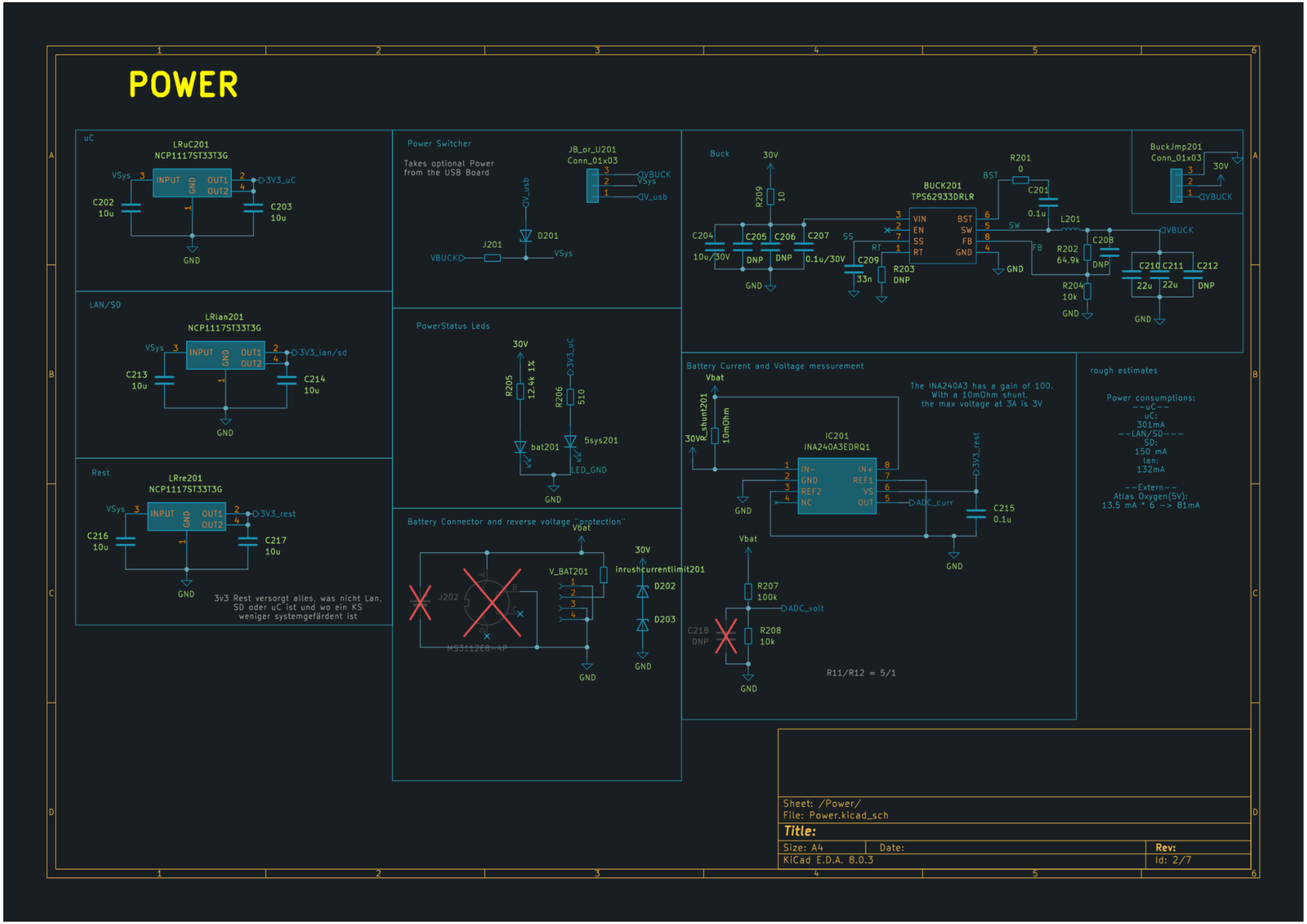
Fig. 4.5-9: Sensor placement in the module in the right corner

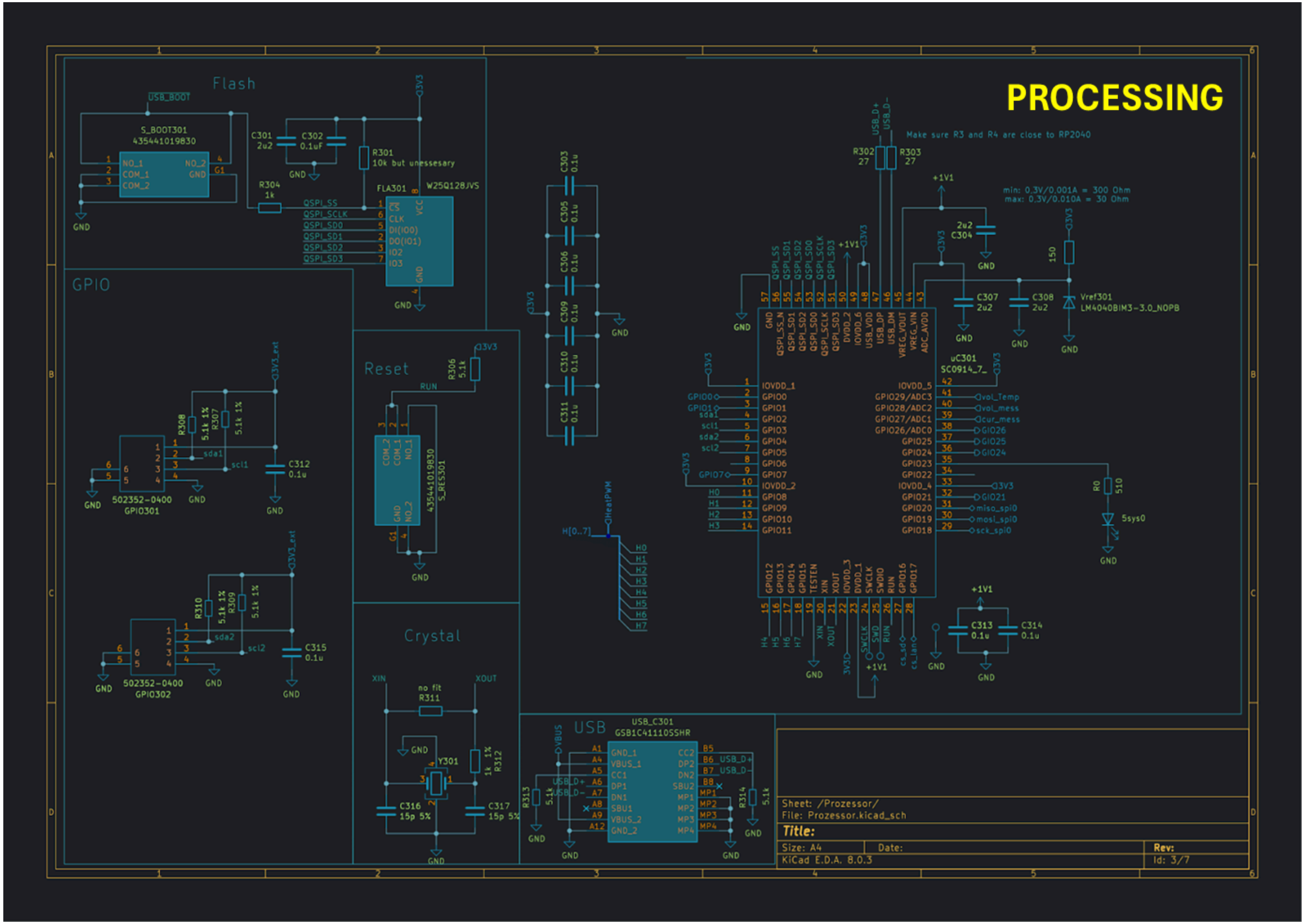
The oxygen sensors were also able to record ambient light.

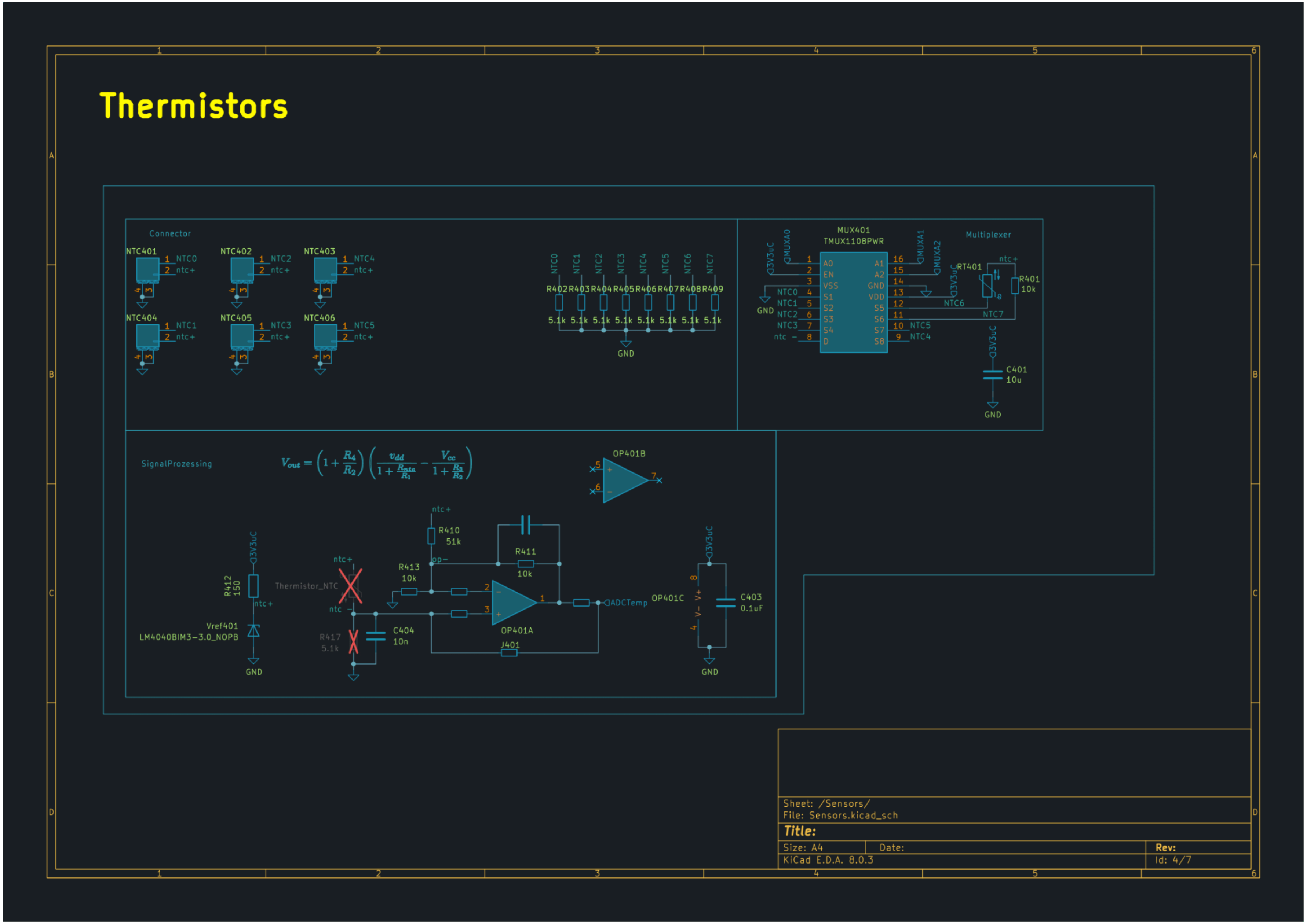
Circuit Diagrams

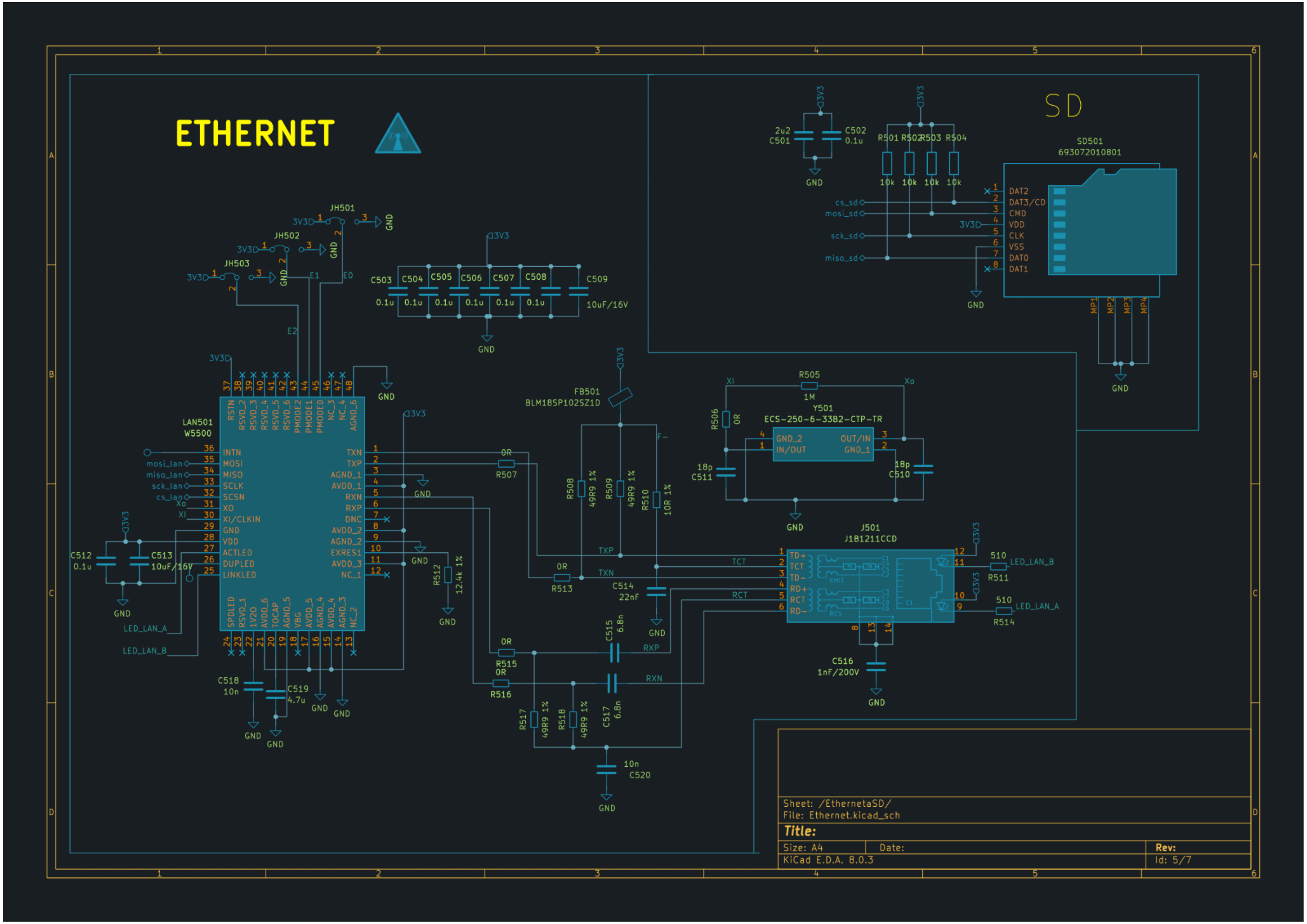
Elements crossed out with a red X are not on the board and are included only for completeness and understanding.

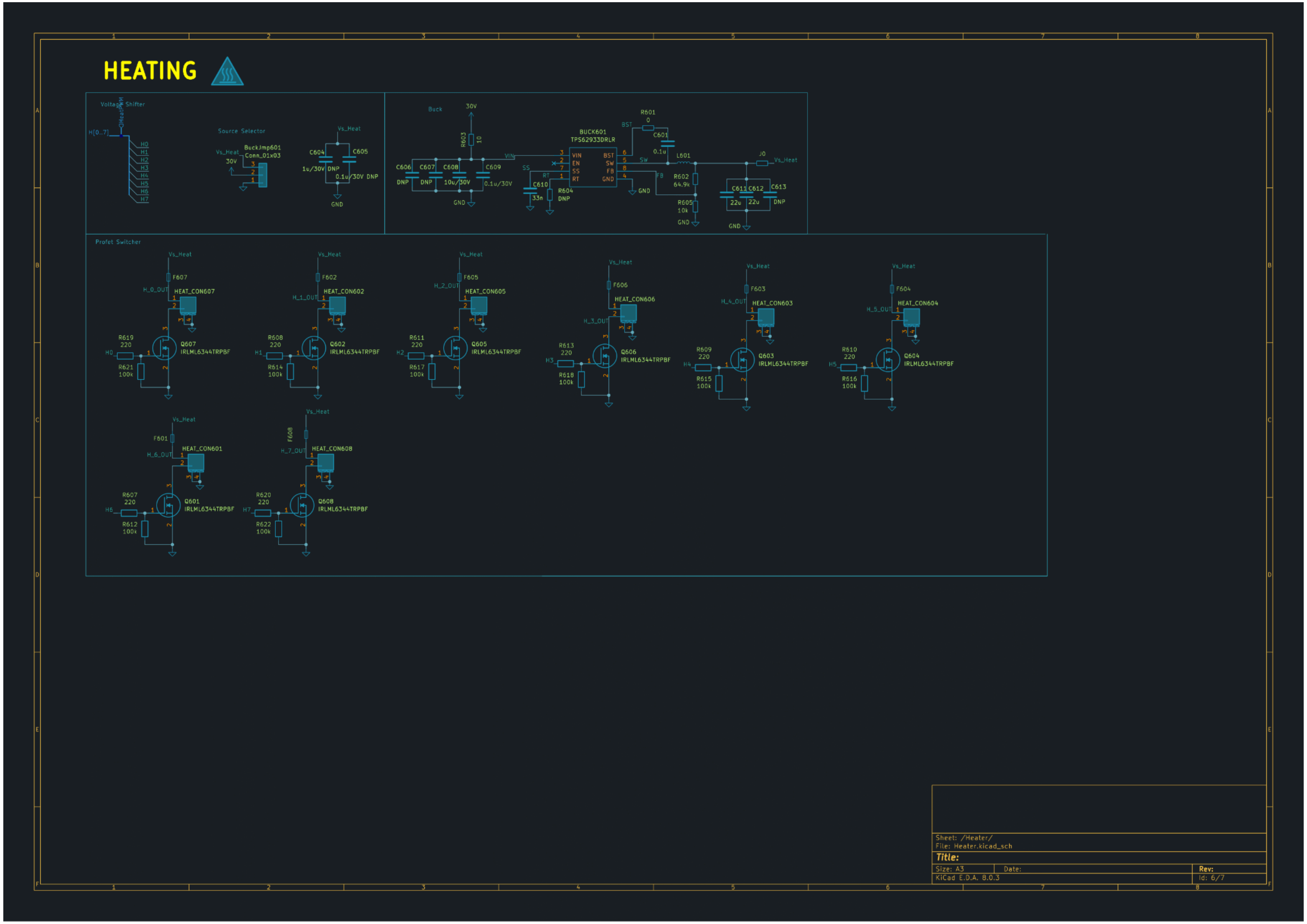


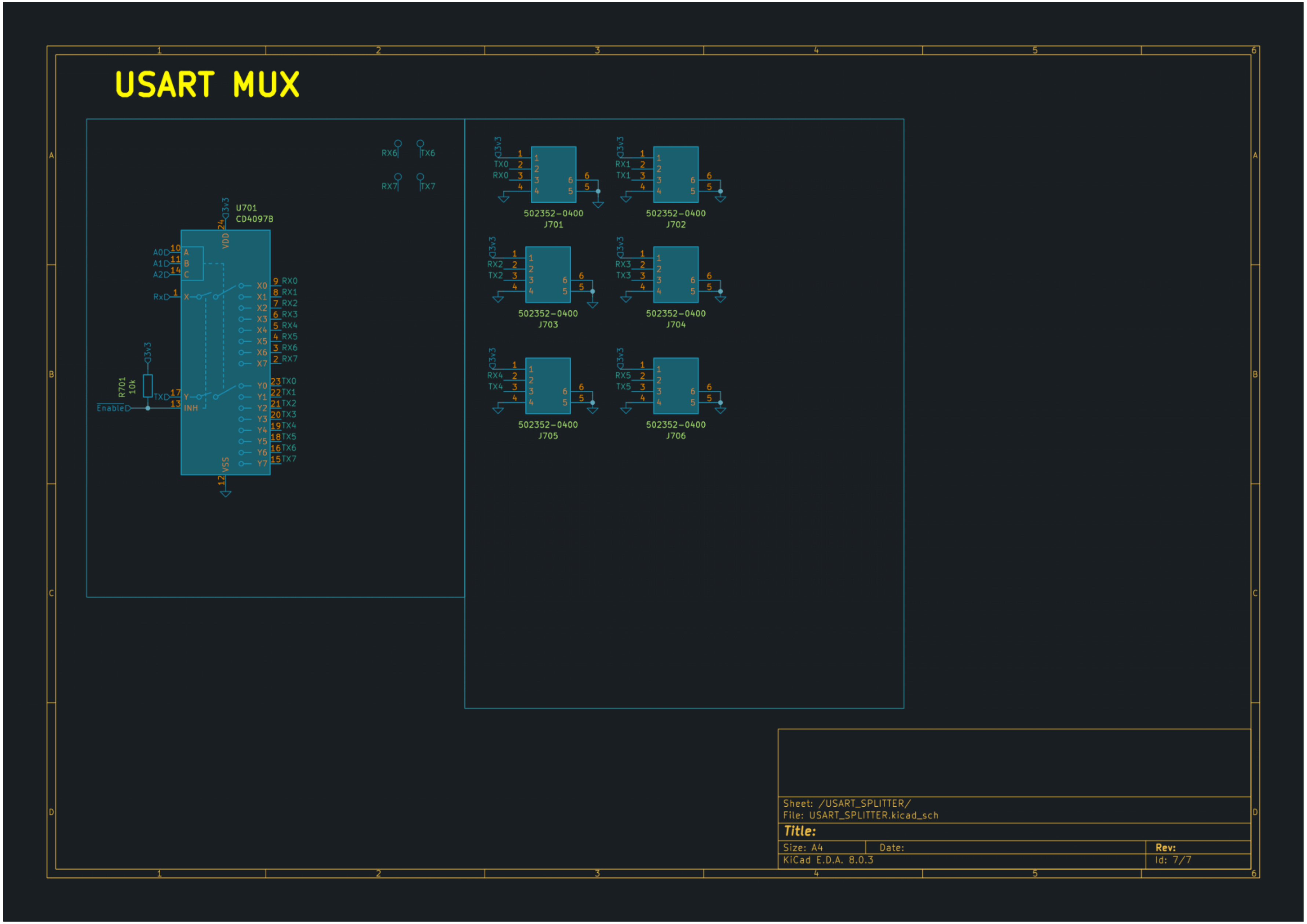

POWER
uC
LRuC201
NCP1117ST33T3G
LAN/SD
LRlan201
NCP1117ST33T3G
Rest
LRre201
NCP1117ST33T3G
3v3 Rest versorgt alles, was nicht Lan, SD oder uC ist und wo ein KS weniger systemgefärdent ist
Power Switcher
Takes optional Power from the USB Board
JB_or_U201
Conn_01x03
PowerStatus Leds
Battery Connector and reverse voltage "protection"
Buck
BUCK201
TPS62933DRLR
BuckJmp201
Conn_01x03
Battery Current and Voltage messurement
The INA240A3 has a gain of 100. With a 10mOhm shunt, the max voltage at 3A is 3V
IC201
INA240A3EDRQ1
R11/R12 = 5/1
rough estimates
Power consumptions:
--uC--
uC:
301mA
--LAN/SD---
SD:
150 mA
lan:
132mA
--Extern--
Atlas Oxygen(5V):
13.5 mA * 6 -> 81mA
Sheet: /Power/
File: Power.kicad_sch
Title:
Size: A4
Date:
Rev:
KiCad E.D.A. 8.0.3
Id: 2/7


PROCESSING
Flash
GPIO
Reset
Crystal
USB
Make sure R3 and R4 are close to RP2040
min: 0.3V/0.001A = 300 Ohm
max: 0.3V/0.010A = 30 Ohm
Sheet: /Prozessor/
File: Prozessor.kicad_sch
Title:
Size: A4
Date:
KiCad E.D.A. 8.0.3
Rev:
Id: 3/7


Thermistors
Connector
NTC401
NTC402
NTC403
NTC404
NTC405
NTC406
NTC0
NTC1
NTC2
NTC3
NTC4
NTC5
NTC6
NTC7
ntc+
R402R403R404R405R406R407R408R409
5.1k 5.1k 5.1k 5.1k 5.1k 5.1k 5.1k 5.1k
GND
Multiplexer
MUX401
TMUX1108PWR
MUXA0
MUXA1
MUXA2
3V3uC
A0
EN
VSS
S1
S2
S3
S4
D
A1
A2
GND
VDD
S5
S6
S7
S8
ntc −
RT401
R401
10k
C401
10u
SignalProzessing
$V_{out} = \left(1 + \frac{R_4}{R_2}\right)\left(\frac{v_{dd}}{1+\frac{R_{ntc}}{R_1}} - \frac{V_{cc}}{1+\frac{R_2}{R_2}}\right)$
OP401B
R410
51k
R411
10k
R413
10k
op−
R412
150
Thermistor_NTC
ntc
Vref401
LM4040BIM3-3.0_NOPB
R417
5.1k
C404
10n
OP401A
J401
ADCTemp
OP401C
V+
V−
C403
0.1uF
Sheet: /Sensors/
File: Sensors.kicad_sch
Title:
Size: A4
Date:
Rev:
KiCad E.D.A. 8.0.3
Id: 4/7


ETHERNET
SD
LAN501
W5500
SD501
693072010801
J501
J1B1211CCD
Y501
ECS-250-6-33B2-CTP-TR
FB501
BLM18SP102SZ1D
JH501
JH502
JH503
Sheet: /EthernetaSD/
File: Ethernet.kicad_sch
Title:
Size: A4
Date:
Rev:
KiCad E.D.A. 8.0.3
Id: 5/7


HEATING
Voltage Shifter
Source Selector
Buck
Profet Switcher
BUCK601
TPS62933DRLR
Sheet: /Heater/
File: Heater.kicad_sch
Title:
Size: A3
Date:
Rev:
KiCad E.D.A. 8.0.3
Id: 6/7



USART MUX
U701
CD4097B
R701
10k
502352-0400
J701
J702
J703
J704
J705
J706
Sheet: /USART_SPLITTER/
File: USART_SPLITTER.kicad_sch
Title:
Size: A4
Date:
KiCad E.D.A. 8.0.3
Rev:
Id: 7/7

Cable Harness

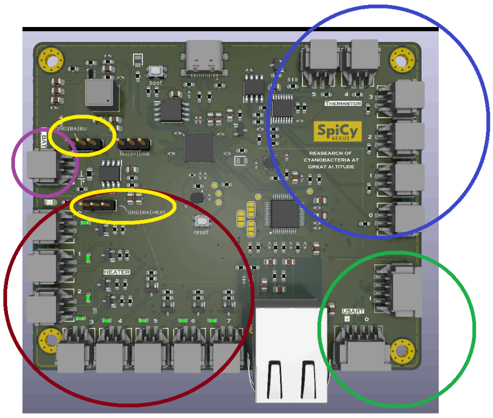


Fig. 4.5-10: PCB with indicated connector types (comp. Table. 4-4).

Table 4-4: Cabling Scheme

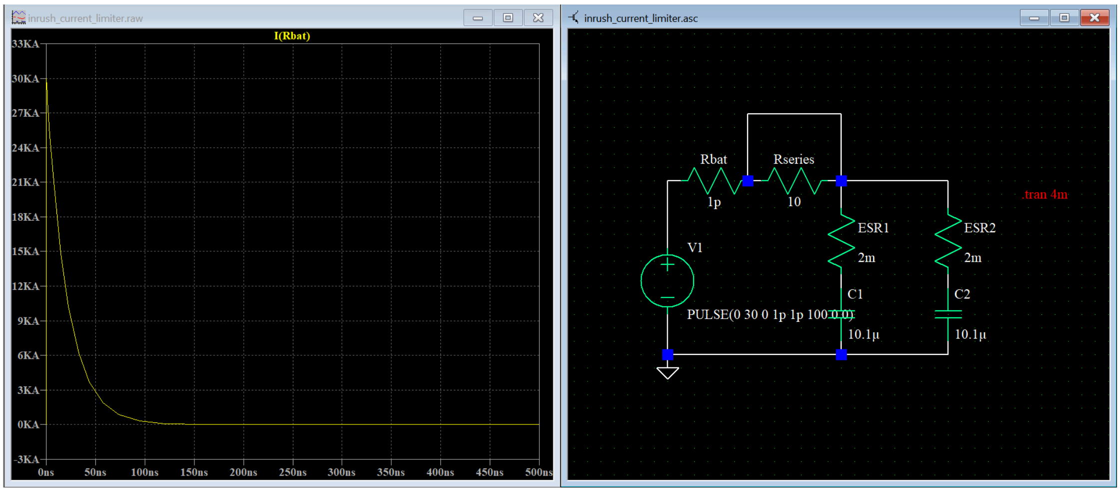
Connector on Motherboard	**Cable type**	**Length**	**Extras**
Blue: 6x NTC/Thermistors	2 x 24 AWG blue teflon wire with a duraclick connector. Blue tape at end	30 cm	One cable side glued to cap of tube.
Green: 6x USART for the oxygen sensors. At USART0 the RX/TX line is switched.	4 x 24 AWG blue teflon with two duraclick connectors. Wire bundled and red tape on end.	30 cm	USART0 cabling has green tape on the end and RX/TX switched.
Red: Heating elements	2 x 24 AWG blue teflon wire with a duraclick connector. Blue tape at end	30 cm	One cable side soldered to kapton heater.
Purple: Battery connector	2 x 24 AWG blue teflon wire with a duraclick connector and the MIL – C-26482P soldered onto	20 cm	
Yellow: connections for external buck converter. One for heating and one for the rest..	3 x 24 AWG blue teflon wire to one JST connector. The other side is soldered to the buck converter.	20 cm	On the real pcb those are JST header and not pin header.
Ethernet	Lan cable to RJF21B	20 cm	-

USB-C	USB C cable which can transfer data	-	Only used to flash firmware/debug

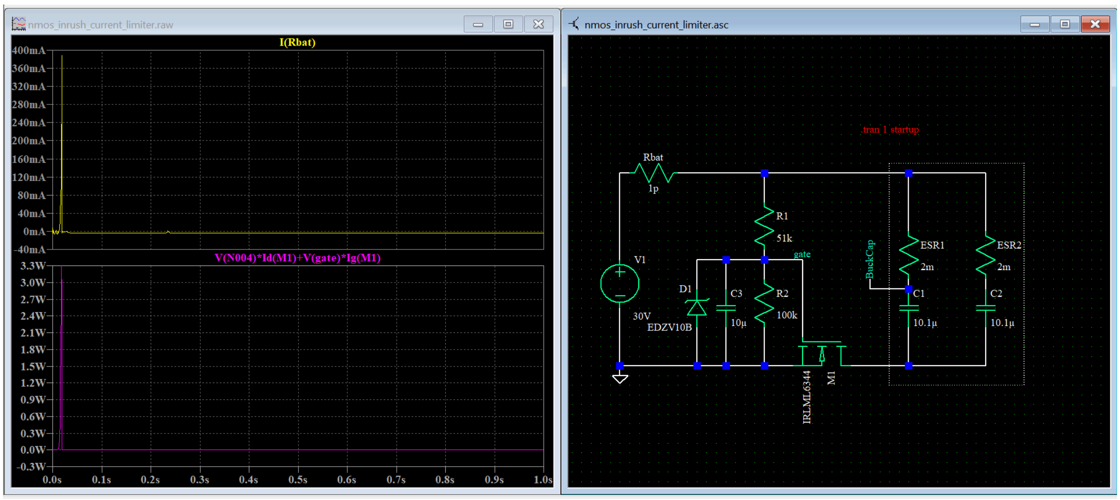
Inrush current limiter

I decided against the use of such a limiter, as it seems not to be normally implemented on BEXUS missions. The battery fuse does trigger at 5A, but is expected to need continuous current and doesn't seem to be triggering at peaks. Regardless, here are my designs:

As the input of the buck converter features quite large capacitors, there's a considerable current flowing whenever the motherboard is plugged in. And as the battery features a 5A fuse, a current limiter was planned. It would be implemented as a mosfet circuit.



Simulation without current protection. Ideal circuit-> in reality current limited by battery and wire resistance



Simulation with current protection. Capacitor limits rise of gate voltage, z-diode clamps gate voltage.

It would be implemented as an extra protection circuit between the battery and the motherboard.

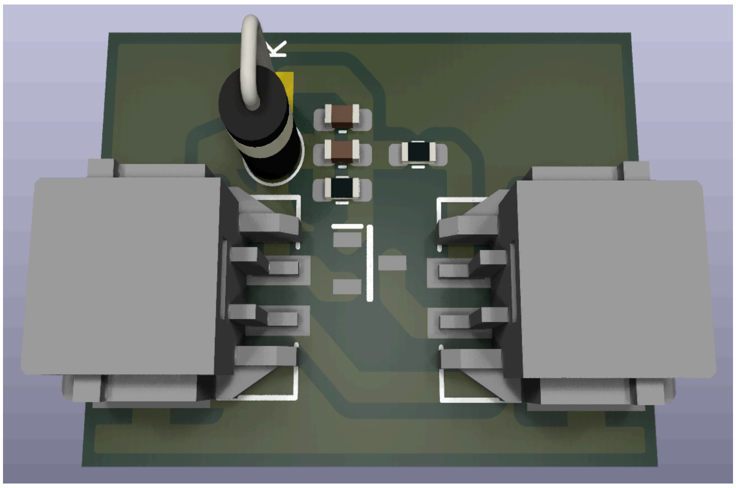


Fig. 4.5-11: Theoretical placement of inrush current limiter on PCB (not used in the end)

4.6 Thermal Design

4.6.1 Goals

The thermal design in this experiment has two primary objectives:

- Maintain the temperature of biological samples within their operating range of 25-30°C.
- Ensure that the temperature of the electronic components stays within the specified operating range for each component.

4.6.2 Boundary conditions

The experiment operates in a low-pressure environment, approximately 1% of ground-level pressure.

Initially, convection is neglected due to the low density of the air.

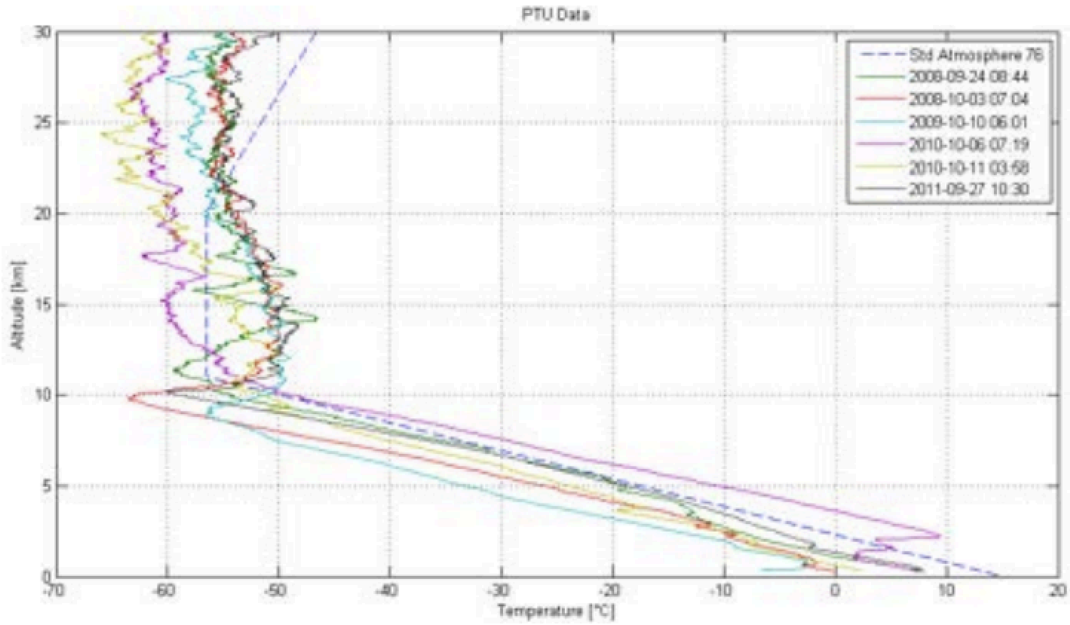


Fig. 4.6-1: Temperature of the Kiruna atmosphere on different days.

Fig. 4.6-1 illustrates the temperature profile of the Kiruna atmosphere on various days. The module must function in temperatures as low as -80°C, as stated in the BEXUS User Manual. Therefore, the cold case is defined at -80°C, and the hot case during the float phase is at -40°C.

4.6.3 Heat transfer model

To determine the appropriate thermal control system and its design, the heat flow into and out of the module must be modeled and analyzed. A schematic representation is shown in Fig. 4.6-2.

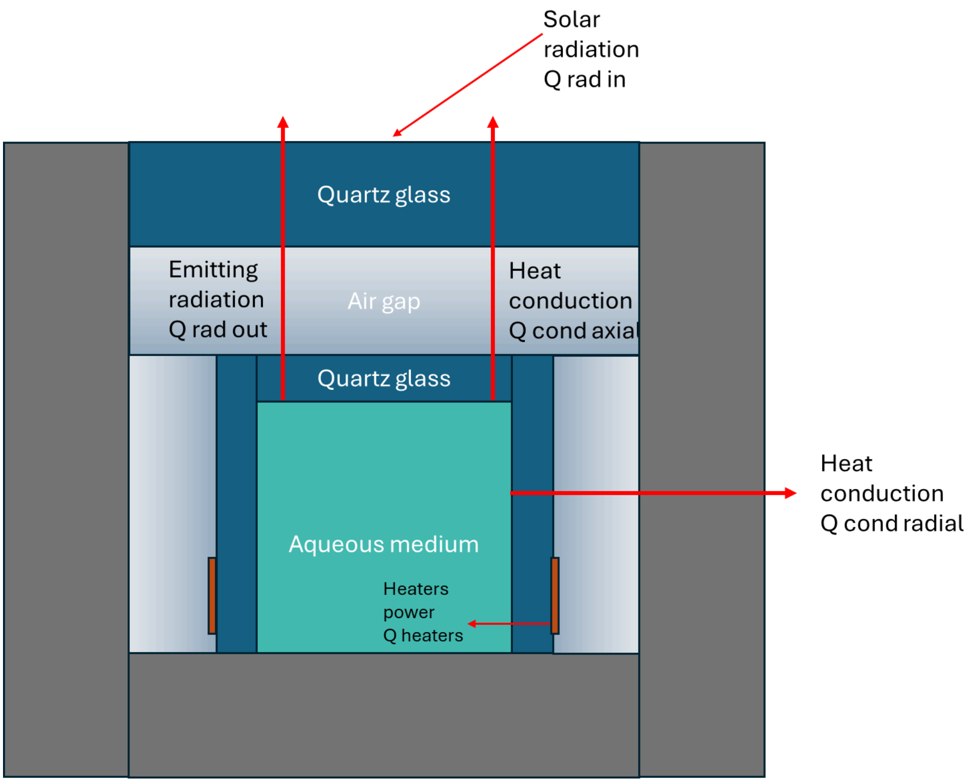


Fig. 4.6-2: Heat exchange model.

For the heat input (Q_{in},), the following sources are considered:

- Solar radiation: Solar energy entering through the transparent glass layer and the module surface. Only the solar radiation through the top is considered, as the rest of the module is covered with a non-transparent fabric.

- Albedo: Reflected solar radiation from the Earth's surface is significant for satellites but is neglected here, as the gondola's lower part and sides are covered.

- Earth IR radiation: Similar to albedo, infrared radiation is neglected because the module is shielded by the gondola's bottom plate and fabric layer.

- Air friction: Heating due to air friction is considered only during the ascent phase due to higher velocities but is relatively minor compared to solar radiation.

In this case, only solar radiation through the glass layer is included in the model.

For Q_{out}, the heat rates to be considered are the following:

- Convection of air outside the module: Heat losses due to the cooling effect of the surrounding cold air. During the float phase, low air density results in a less effective convection with a heat transfer coefficient (h) of 0.254 W/(m²·K). Fig. 4.6-3 shows the variation of this coefficient with temperature and pressure.

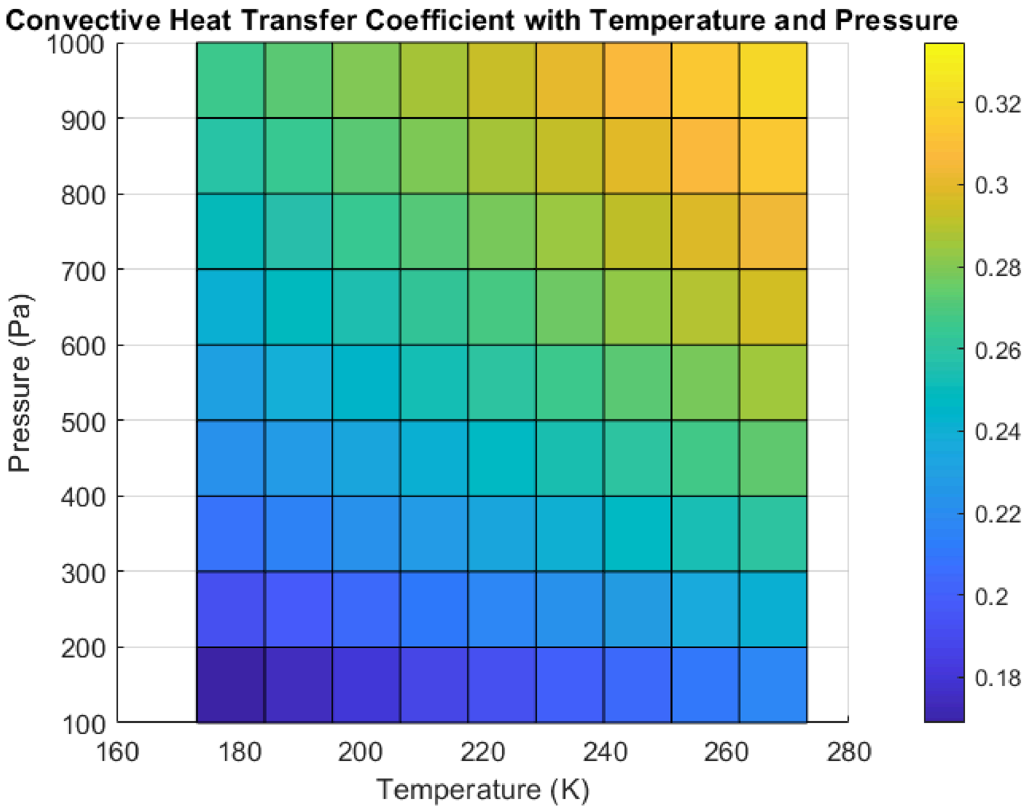


Fig. 4.6-3: Variation of the convective heat transfer coefficient with Temperature and Pressure.

In this context, convection is more relevant than for a satellite. Thus, the outer temperature of the module is assumed to equal the environmental temperature.

$$T_{\text{outer\_surface}} = T_{\infty}$$

- Radiation through the glass layer: The biological samples, at 27.5°C, emit infrared radiation through the transparent glass layer. This requires the view factor between the glass layer and the tube's flat end.

- Radiation at the module surface: When the module's surface temperature differs from the environment and there is no convection, radiation occurs. Here, the outer temperature equals the environment temperature, so there is no radiation through the styrofoam box.

- <u>Heat conduction through the glass plate (Axial)</u>: Heat loss through axial conduction from the aqueous medium to the outer environment across the glass layers is modeled using an electric circuit analogy to determine total resistance.

$$R_{cond,plate} = \frac{L}{kA}\left[\frac{K}{W}\right]$$

Fig. 4.6-4: Electric circuit analogy for heat conduction of flat plates.

- <u>Heat conduction through the styrofoam box (Radial):</u> Similar to glass conduction, but for cylindrical shells.

$$R_{cond,cyl} = \frac{\ln\left(\frac{r_2}{r_1}\right)}{2\pi Lk}\left[\frac{K}{W}\right]$$

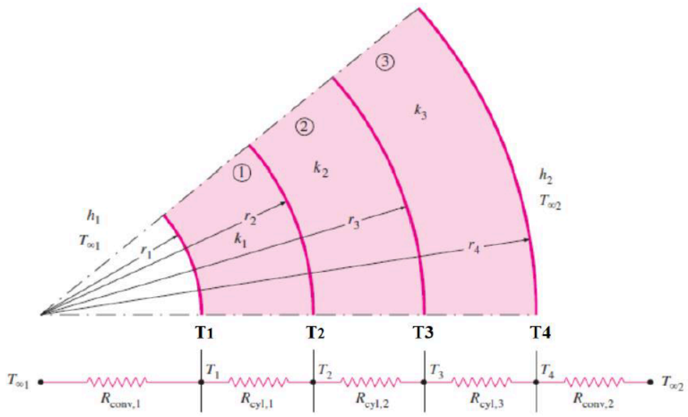


Fig. 4.6-5: Electric circuit analogy for heat conduction of cylindrical shells.

4.6.4 Equilibrium analysis

The heat transfer rates are calculated using the following equilibrium formula:

$$mc\frac{dT}{dT} = Q_{\text{heater}} + Q_{\text{solar}} - Q_{\text{out}}$$

m is the mass of the system,
c is the specific heat capacity,
$\frac{dT}{dT}$ is the rate of change of temperature with respec
Q_{heater} is the heat input from the heater,
Q_{solar} is the heat input from solar radiation,
Q_{out} is the heat loss from the system.

In the following Table 4-5, the results of the heat transfer model computed in MATLAB are displayed.

Table 4-5: Heat rate distribution

Qin	Qout	
Solar radiation	**Hot case (T_{amb} = - 40°C)**	**Cold case (T_{amb} = - 80°C)**
0.18 W	1.75 W	2.54 W

As it can be observed in the table, there is a deficit of power that must be provided in order to keep the temperature constant.

To maintain a constant temperature, an active thermal control system with Kapton heaters and a PI controller is recommended. The required power is 2.54 W per tube in the cold scenario.

Regarding the electronics, the different components have to operate in the range of temperatures specified for them. The most restrictive one is -25°C to 70°C. The approach to keep the temperature within the operating range is to cover the electronics box with insulating foam so the dissipated power remains inside the electronics box to keep it within the operating range.

Table 4-6: Component Temperature Range

Component Type	Typical Temperature Range (°C)	Component Name
Inductor	-40 to 125	74439346068
SMD Resistor	-55 to 155	435441019830
SD Card Socket	-25 to 85	693072010801
Shunt Resistor	-55 to 125	PA1206FRE7W0R001Z
Battery Connector	-40 to 105	502352-0200
Right Angle Header	-40 to 105	502352-0400
Micro SD Card Hinge	-40 to 70	502352-1210
Crystal Oscillator	-40 to 85	ABM8G-12.000MHZ-4Y-T3
Chip LED	-40 to 85	APTD2012LCGCK
Ferrite Bead	-55 to 125	BLM18SP102SZ1D
Pin Header	-40 to 105	Conn_01x03
Crystal Oscillator	-40 to 85	ECS-250-6-33B2-CTP-TR
USB Type-C Connector	-40 to 85	GSB1C41110SSHR
Ethernet Connector	-40 to 70	J1B1211CCD
Operational Amplifier	-40 to 125	LM2904AVQDRQ1
Voltage Reference	-40 to 85	LM4040BIM3-3.0_NOPB
RS-485 Transceiver	-40 to 85	MAX3485AEASA+T
Voltage Regulator	-40 to 125	MCP1826S-5002E_DB
PPTC Fuse	-40 to 85	MF-FSML100/8-2
Voltage Regulator	-40 to 85	NCP1117ST33T3G
NTC Thermistor	-40 to 125	NTCGS163JF103FT8
Rectifier Diode	-40 to 150	RBR2LB60BTBR1
Microcontroller	-40 to 85	RP2040
Status LED	-40 to 100	LTRBR37G-4R4S-0125-0
Analog Multiplexer	-40 to 125	TMUX1108PWR
Buck Converter	-40 to 85	TPS62933DRLR
Voltage Translator	-40 to 85	TXS0108EQPWRQ1

Flash Memory	-40 to 85	W25Q128JVS
Network Controller	-40 to 85	W5500
Light Sensor	-40 to 85	AS7262
Light Sensor	-40 to 85	AS72623

4.6.5 Mission envelope analysis

To compare different operation points is relevant to analyze the mission envelope and what are the different heating needs of each. In this analysis, convection is included dynamically as at the beginning the pressure is significantly higher than the one over the float phase.

The assumptions made in this chapter are the following:

- Convection outside the module is included and it will have an effect on the heat transport.
- Convection in the air gap between the glass plate and the tube is included.
- The module is not airtight and the pressure on the inside of the module is the same as outside, modifying then the heat convection coefficient.

In light of these assumptions and the provided mission in the following graph, the power required can be derived.

The mission consists of a combination of pressure and temperature points that varies from 1013.15 Pa to 101315 Pa and from 20°C to -60°C. The temperature is depicted with the blue line and the pressure is depicted with the red line.

The power that is required in each of the operating points is depicted in the green line. It varies from 0.19 to 2.09 W per tube. The most demanding conditions occur during the float phase reaching the maximum power usage.

In addition, the dependency of the heat transfer by convection with respect to the air pressure is remarkable just at the beginning and at the end of the flight. Also the heat required is linear with respect to the difference in temperature between the desired and the outside temperature. This is the case for segments where there is no change in temperature. In case of pressure change, the variation between the heating power and temperature is no longer linear as the convection heat transfer coefficient is highly nonlinear with respect to the pressure.

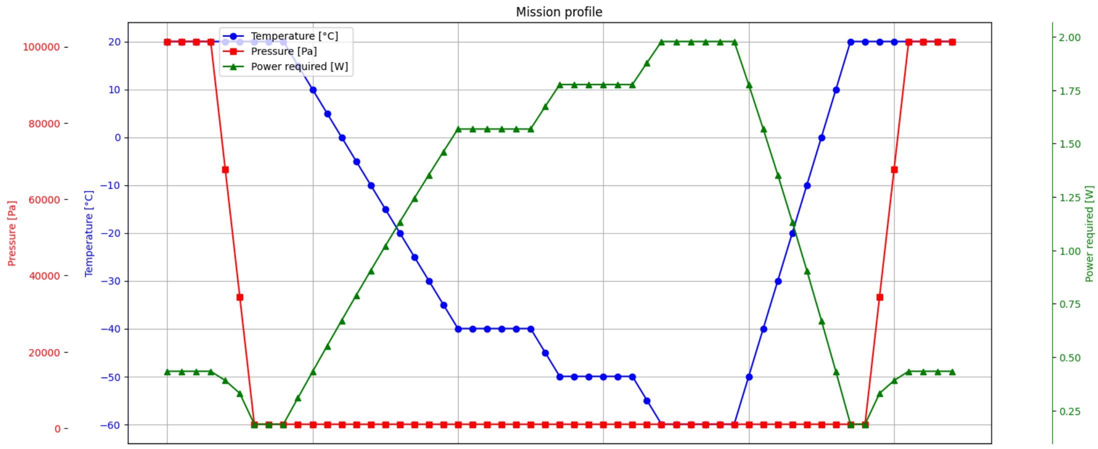


Fig. 4.6-6: Temperature distribution along the tube with the heaters around.

4.6.6 Dynamic analysis

To study heat transfer dynamics, MATLAB simulations using a FEM solver show that heating the tube's center from 27.5°C to above 30°C takes approximately 2 minutes when the heater maintains 60°C at the water interface.

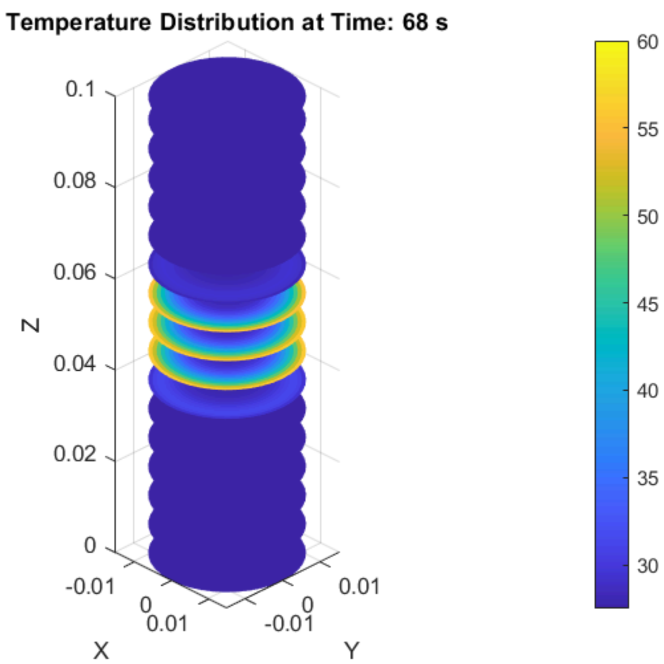


Fig. 4.6-7: Temperature distribution along the tube with the heaters around.

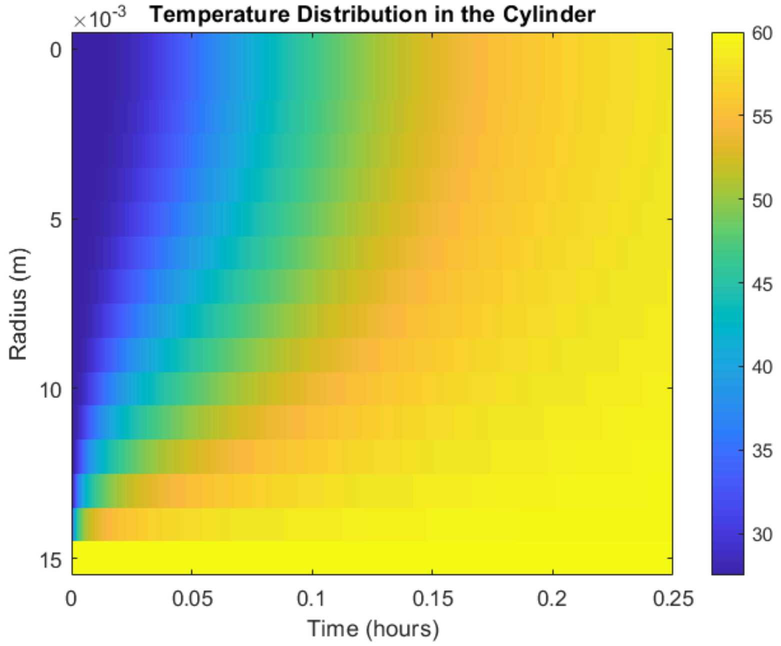


Fig. 4.6-8: Temperature radial distribution along the tube.

Moreover, to keep the temperature on the tube at a reasonable level and avoid exceeding the 30°C limit at the end of the tube, the conduction over the axial direction of the tube was computed.

In this graph it depicts the time that it takes to the end of the tube to reach 30°C while the heaters are turned on and their operating temperature is 60°C. It takes 278 seconds to reach 30°C so the heaters will operate less than this time to keep the temperature of the biological samples within the limits.

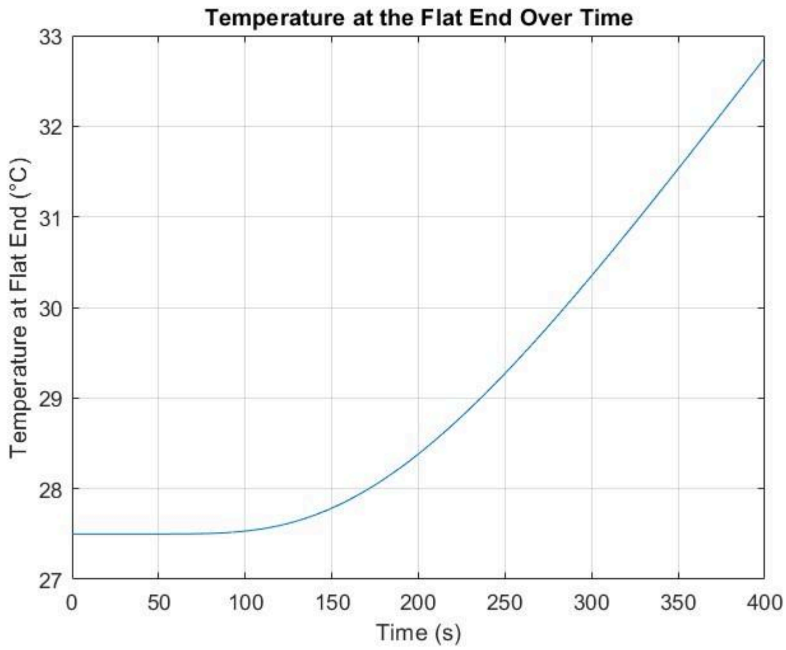


Fig. 4.6-9: Temperature axial distribution along the tube.

For convection and buoyancy analysis, the characteristic time that takes for water to travel half of the tube is computed as follows.

To analyze convection currents in water, we start with the essential properties of water: specific heat capacity (c_p), thermal expansion coefficient (β), kinematic viscosity (v), thermal diffusivity (α), and thermal conductivity (k_{water}).

- Rayleigh number (Ra)

The Rayleigh number is calculated using the formula:

$$\mathrm{Ra} = \frac{g\,\beta\,\Delta T\left(\frac{L}{2}\right)^3}{\nu\,\alpha}$$

$$\begin{aligned} g &\text{ is the acceleration due to gravity,} \\ \beta &\text{ is the thermal expansion coefficient,} \\ \Delta T &\text{ is the temperature difference,} \\ L &\text{ is the characteristic length (e.g., height of the water column),} \\ \nu &\text{ is the kinematic viscosity,} \\ \alpha &\text{ is the thermal diffusivity.} \end{aligned}$$

where g is the acceleration due to gravity, ΔT is the temperature difference, and L is the characteristic length (e.g., height of the water column). The Rayleigh number characterizes the flow regime in natural convection.

- Nusselt number (Nu)

The Nusselt number, representing the ratio of convective to conductive heat transfer, is given by:

$$\mathrm{Nu} = C \times \mathrm{Ra}^n$$

For a vertical tube, typical empirical constants are C = 0.1 and n = 1/3.

- Convective heat transfer coefficient of water (h_{water})

The convective heat transfer coefficient of water can be determined using the Nusselt number:

$$h_{\text{water}} = \frac{\text{Nu} \times k_{\text{water}}}{\frac{L}{2}}$$

This coefficient represents the heat transfer per unit area per unit temperature difference.

- Velocity of convection currents (v)

The velocity of convection currents is calculated as:

$$v = \frac{h_{\text{water}} \times \Delta T}{m \times c_p}$$

where m is the mass of water.

- Time delay (τ)

Finally, the time delay for convection currents to travel half the characteristic length L is given by:

$$\tau = \frac{\frac{L}{2}}{v}$$

With this time delay, the convective effects and delays in heat diffusion are accounted for. The result for the tube used in the experiment is 0.0073 s. The time delay is very small but it is relevant due to the different position of the temperature sensor inside the tube and the heaters.

4.6.7 PI controller

To maintain the temperature in the operational range, an active thermal control system is needed. The approach is to use a PI controller with saturation, because it reduces rise times and steady state errors, very suitable for thermal control on fluids.

In order to derive the controller, the plant, represented in the following figure as a transfer function, is needed to plot it in SIMULINK.

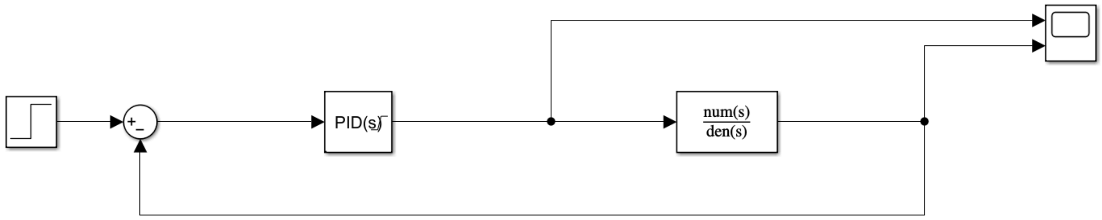


Fig. 4.6-10: Closed-loop thermal control system.

- **Transfer function:**

From the 1st law of Thermodynamics, the dynamics of heat transfer analyzed as follows:

$$mc_p \frac{dT}{dt} = \dot{Q}_{\text{heater}} + \dot{Q}_{\text{solar}} - \dot{Q}_{\text{rad,water}} - \dot{Q}_{\text{cond,glass}} - \dot{Q}_{\text{cond,box}}$$

The power of the heater is the input and the water temperature is the output.

In line with that, the heat losses are written with the temperate explicitly:

$$mc_p \frac{dT}{dt} = \dot{Q}_{\text{heater}} + \dot{Q}_{\text{solar}} - \sigma\epsilon A\left(T^4 - T_{\text{env}}^4\right) - \frac{(T - T_{\text{env}})}{R_{\text{glass}}} - \frac{(T - T_{\text{env}})}{R_{\text{box}}}$$

As the operating point is in a very narrow range of 5°C, it is reasonable to linearize the equation with respect to $\Delta T = T - T_{nom}$. T_{nom} is the operating temperature of 27.5°C.

In addition lets linearize the the terms of fourth order like this:

$$T^4 \approx T_{\text{nom}}^4 + 4T_{\text{nom}}^3 \Delta T$$

After that , the equation looks like this:

$$mc_p \frac{d(T_{nom} + \Delta T)}{dt} = \dot{Q}_{heater} + \dot{Q}_{solar} - \sigma\varepsilon A\left({T_{nom}}^4 - {T_{env}}^4\right) - \sigma\varepsilon A 4\, {T_{nom}}^3 \Delta T - \frac{(T_{nom} - T_{env})}{R_{glass}} - \frac{\Delta T}{R_{glass}} - \frac{(T_{nom} - T_{env})}{R_{box}} - \frac{\Delta T}{R_{box}}$$

Simplifying more the equation:

$$mc_p \frac{d(\Delta T)}{dt} = \dot{Q}_{heater} - \sigma\varepsilon A 4\, T_{nom}{}^3 \Delta T - \frac{\Delta T}{R_{glass}} - \frac{\Delta T}{R_{box}} + \dot{Q}_{solar} - \sigma\varepsilon A\left(T_{nom}{}^4 - T_{env}{}^4\right) - \frac{(T_{nom} - T_{env})}{R_{glass}} - \frac{(T_{nom} - T_{env})}{R_{box}}$$

Sorting by terms of ΔT, Q_{heater} and constant C, the result is the following:

$$mc_p \frac{d(\Delta T)}{dt} = \dot{Q}_{\text{heater}} + K\Delta T + C$$

Where K and C are constants.

For the transfer function, the focus is on the relation between Q_{heater} and ΔT, ignoring the offset C, as it doesn't affect the dynamics

$$mc_p \frac{d(\Delta T)}{dt} = \dot{Q}_{\text{heater}} + K\Delta T$$

Taking Laplace function in both sides, the time domain change into the frequency domain:

$$mc_p s \Delta T(s) = \dot{Q}_{\text{heater}}(s) + K\Delta T(s)$$

Rearranging the terms,

$$G(s) = \frac{\Delta T(s)}{\dot{Q}_{\text{heater}}(s)} = \frac{1}{mc_p s + K}$$

Including the time delay of the temperature sensor with respect to the heaters and the delay of the heat leaving the body of water, the transfer function is transformed by the Pade approximation:

$$G(s) = \frac{\Delta T(s)}{\dot{Q}_{heater}(s)} = \frac{\left(1 - \frac{\tau_{\text{in}} s}{2}\right)\left(1 + \frac{\tau_{\text{out}} s}{2}\right)}{\left(1 + \frac{\tau_{\text{in}} s}{2}\right)\left[mc_p s\left(1 + \frac{\tau_{\text{out}} s}{2}\right) + K\left(1 - \frac{\tau_{\text{out}} s}{2}\right)\right]}$$

The open-loop step response of the system is depicted in the following graph with a final value around 11K which is the temperature increment if 1W is applied for a long time.

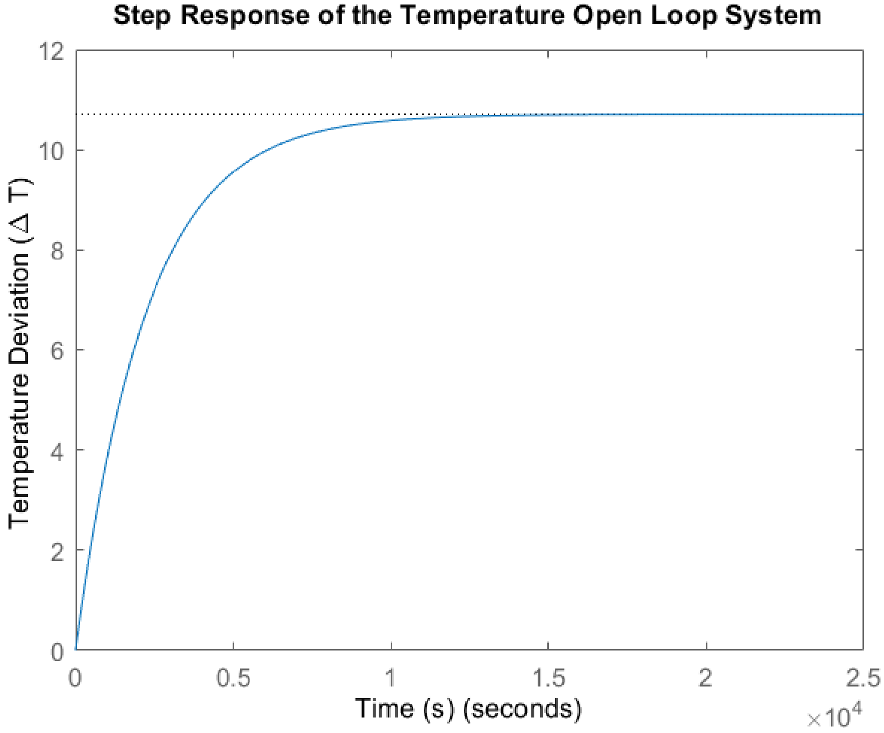


Fig. 4.6-11: Open-loop step response of the temperature control system with delay.

On the other hand, the closed-loop system has some overshoot as can be seen in Fig. 4.6-12. And it reaches the desired step response with a smaller settling time. The solution is very dependent on the values of Kp and Ki. In this case the values used are Kp = 8 and Ki = 0.0004.

Those can be derived depending on the characteristics of the system desired, the type of thermal damping or inertia in it. Also, the calibration of these parameters in TVAC is performed.

In order to have in place a functional controller the values must be realistic with the hardware used and that is the case of the simulation in Figure 4-25 and 4-26 where the power of the heaters is limited and the solution converges with the required heating and its profile.

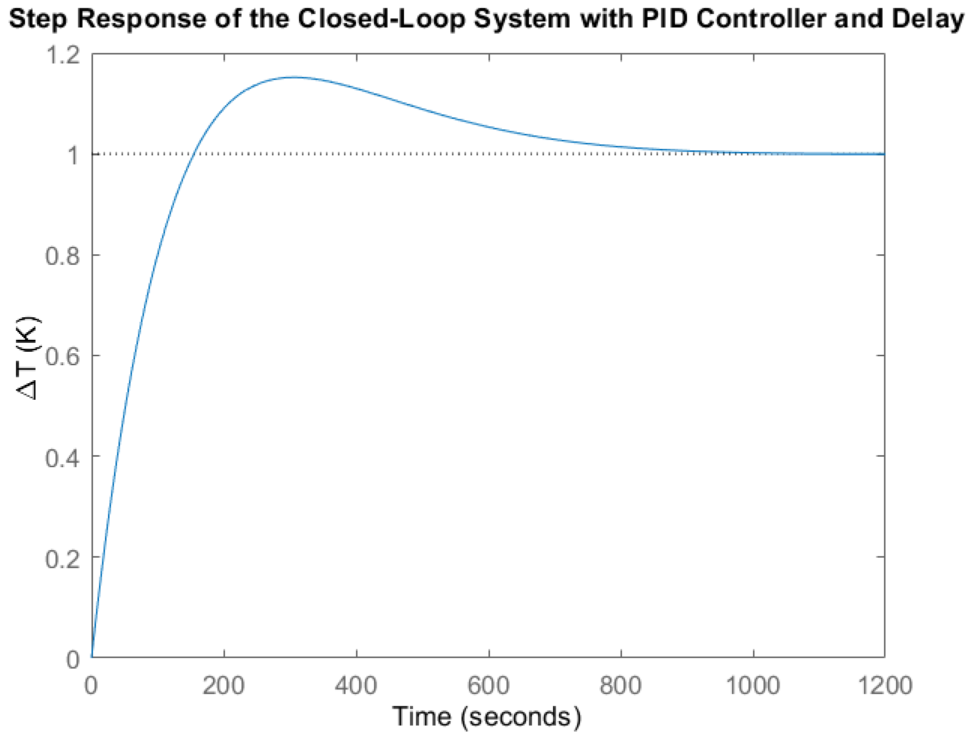


Fig. 4.6-12: Closed-loop step response of the temperature control system with delay.

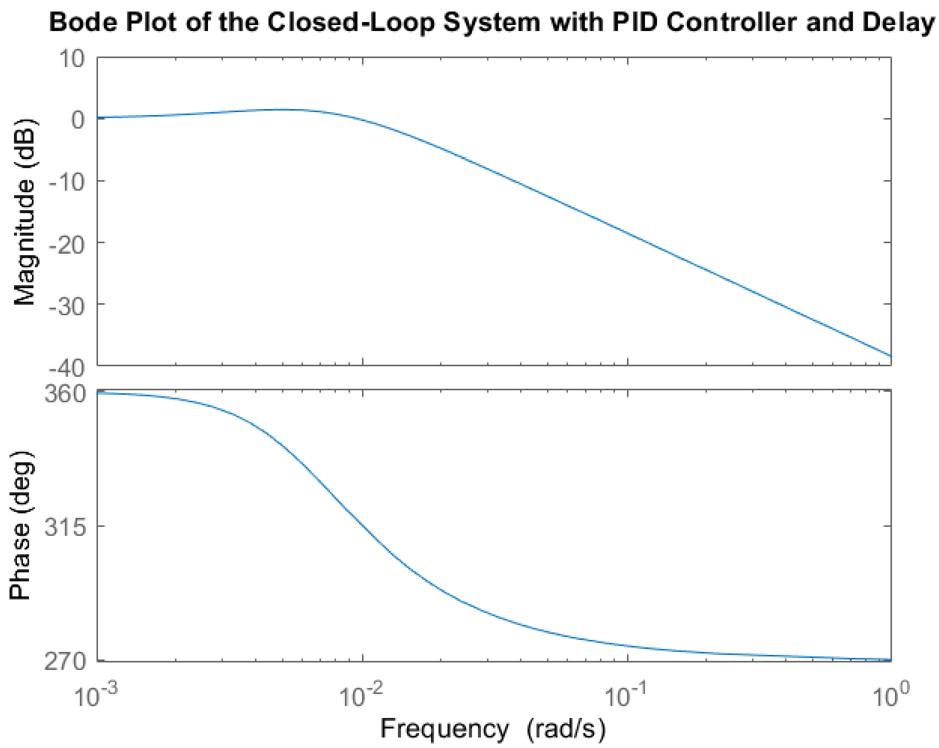


Fig. 4.6-13: Bode plot on the closed-loop system with PI controller and delay.

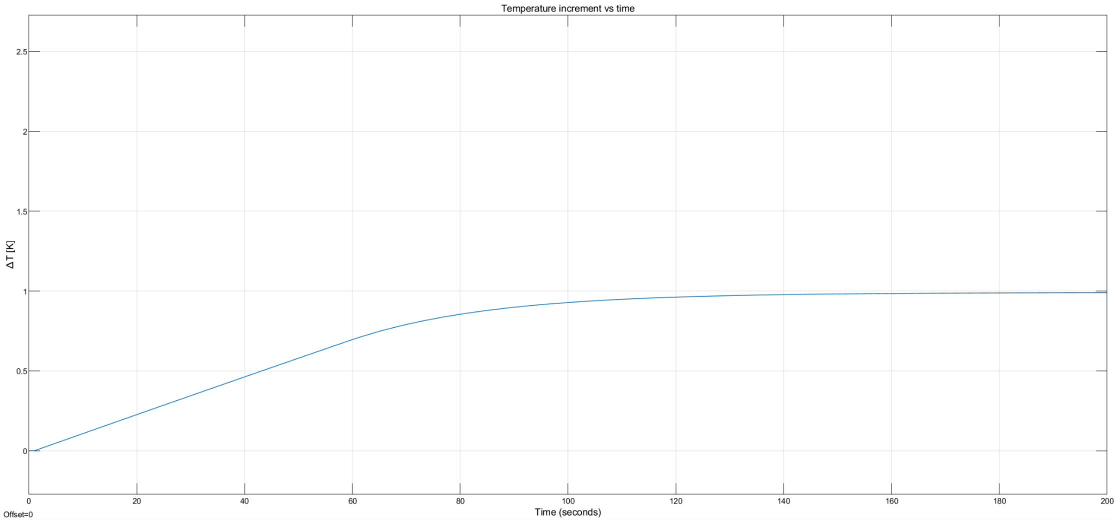


Fig. 4.6-14: Closed-loop step response of the temperature control system with delay and power limitation.

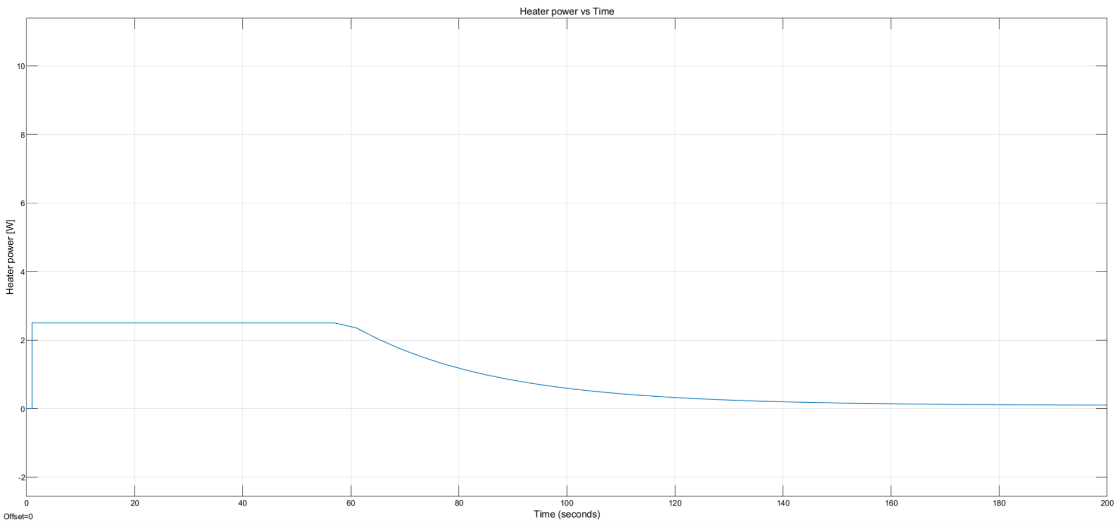


Fig. 4.6-15: Power consumption of heaters of a closed-loop system for active thermal control.

4.6.8 TVAC test

During the TVAC test, the module is exposed to the combination of temperature and pressure represented in the graph below to replicate the conditions that the module is exposed to during the actual flight. In it the pressure was reduced up to 10 mbar and -60°C. The electronics and different tubes were tested to determine their readiness to fly on the gondola.

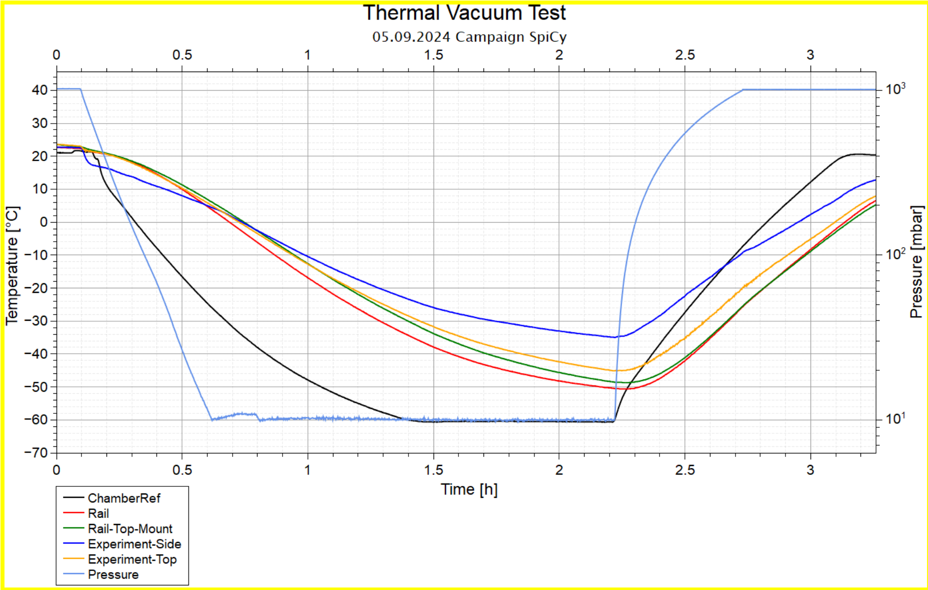


Fig. 4.6-16: TVAC testing temperature and pressure conditions.

Over the TVAC test, the temperature of the electronics compartment is displayed in the following graph and the temperature is between 25 to 40°C and falls in the required temperature range, granting an adequate operation of the module electronics.

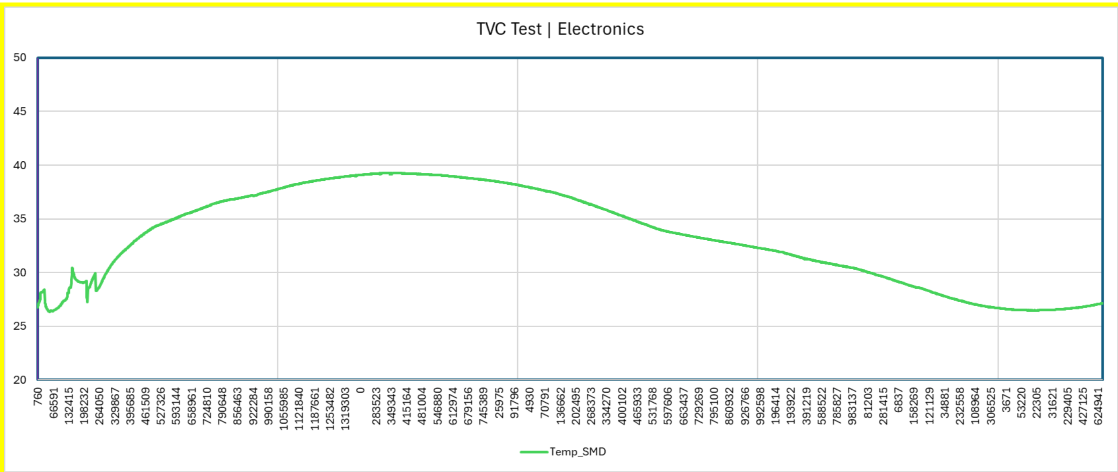


Fig. 4.6-17: Electronics temperature over TVAC test.

Regarding the glass tubes during the TVAC test, Fig. 4-42 and Fig. 4-43 display the temperature inside (blue) and the power consumption of the heater (orange). For both of them, the temperature is kept in the desired temperature range of 25° to 30°C with a power consumption similar to the one predicted for the mission envelope analysis but without the solar radiation contribution. The power required at -60°C is 2.23W. On the other hand, both glass tube graphs differ in their dynamic behaviour with broader fluctuations in the power provided to keep the temperature at 27.5°C. The PI controller has different Kp values which provides a stronger response in case of a higher Kp. Thanks to this variation of gains, the faster response is chosen to ensure the system's stability

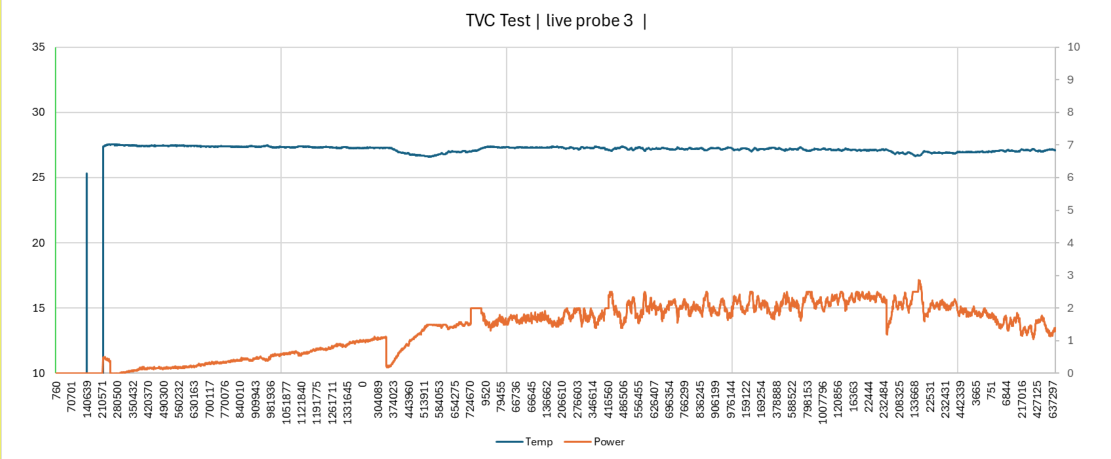


Fig. 4.6-18: Probe with Kp = 0.7047 and Ki = 0.0014 on TVAC test.

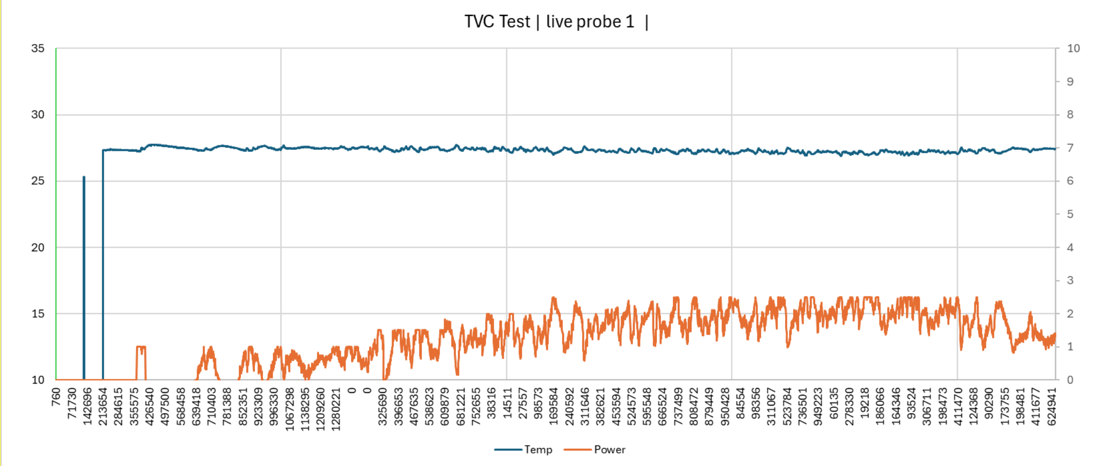


Fig. 4.6-19: Probe with Kp = 1.0011 and Ki = 0.0019 on TVAC test.

4.7 Power System

Overview

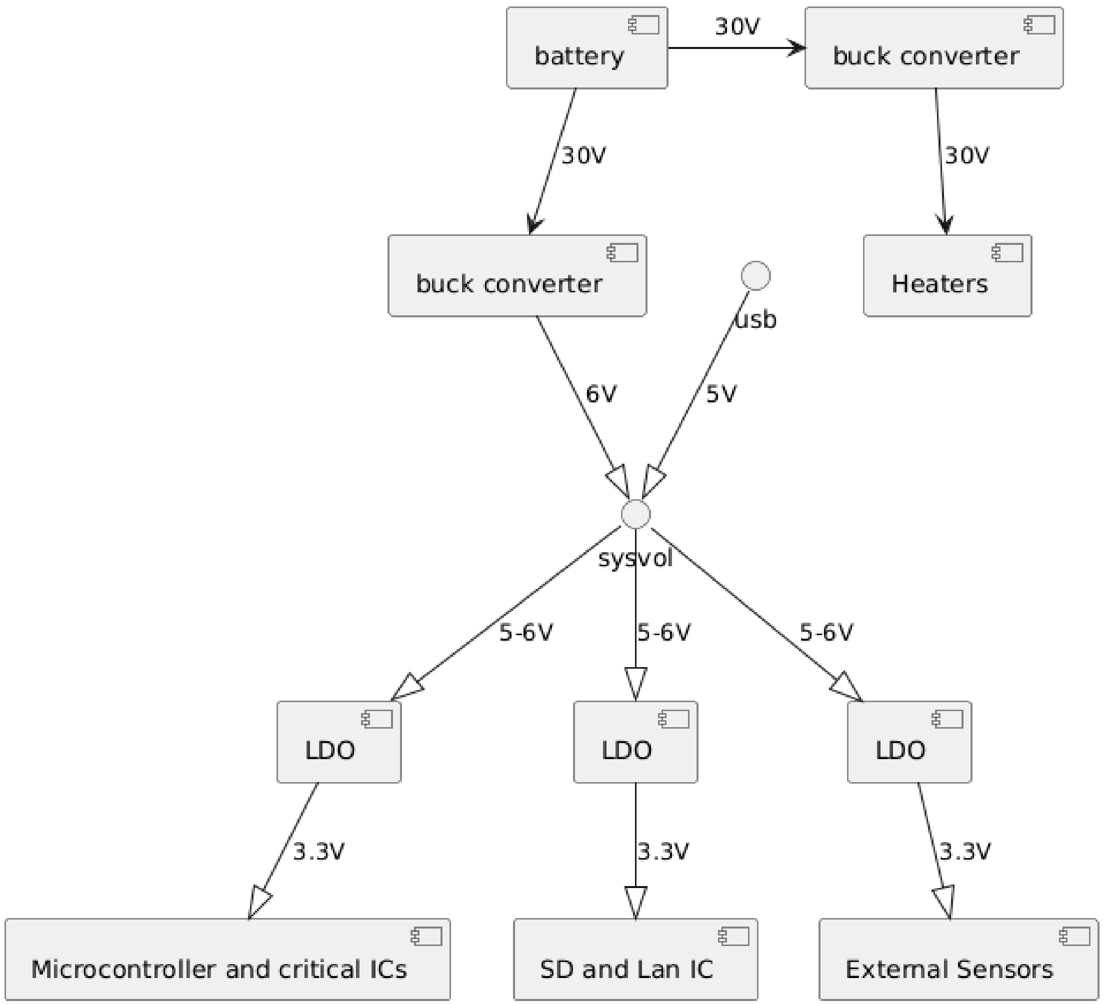


Fig. 4.7-1: Power System Flow Chart

The battery voltage is stepped down to 6V, to be linear regulated to 3.3V and 5V rails. The 3.3V rails are splitted in 3 to spread the heat (power losses) and provide redundancy. Therefore the uC can keep running even if all external sensors are shorted.

Through a shunt resistor power consumption is tracked, and the power available to the heating system will be adjusted to the power the BEXUS battery can provide minus the power consumption of the rest of the system.

Also it can detect a heater presence or failure via comparing the measured current with the expected one.

Also both buck converters are replaced with external ones to increase performance and reliability (more on that later).

Detailed Power Plan

It is read from right to left, from consumer to stabilizer to converter to provider. The power values at the consumer states how much power is used. The power values of the stabilizer/converter/provider states how much power this component draws with all following components connected and active.

All efficiency values are already implemented in the power calculations. So for example the Microcontroller consumes 0.0924W under load. But this power goes almost double into the calculation of the power the LDOuC draws, as the LEDOuC has a efficiency of 0.55 aka needs to draw almost double the power it provides.At the recommended max current draw of 1.8A from the battery, it provides ~30V * 1.8A = 54W.

Also one is able to read out the diagram, max power drawn from the battery at full load is around 35.3W. 32.6W of that power goes directly to the heaters, and will in praxis never be that high. As all testing till now was done with 15W of heating power and that should be enough already.

Fig. 4.7-2: Detailed power plan

Power provider			**Voltage converter**					**Voltage stabiliser**					**Power consumer**			
Component	Power_load	Power_idle	Component	Describtion	Efficiency	Power_load incl. Efficiency	Power_idle incl. Efficiency	Component	Describtion	Efficiency	Power_load incl. efficiency	Power_idle incl. Efficiency	Component	Description	Power_load	Power_idle
Vbatt	35,02453909	0,533953351						->					**APTD2012LSURCK**	wrong battery polarity detection LED	doesn´t matter	doesn´t matter
			LM2596S	Buck converter Vsys	0,9	2,415803842	0,533913751	**NCP1117ST33T3G**	LDO uC	0,55	0,344187818	0,314181818	**Rp2040**	Microcontroller	0,0924	0,0924
													APTD2012LCGCK	green LED + Resistor	0,0066	0,0066
													W25Q128JVS	Flash	0,0825	0,066
													TMUX1108PWR	Mux NTCs	0,0000033	
													TLV9002QDRQ1	OpAmp NTCs	0,0066	0,0066
													LM4040BIM3-3.0_NOPB	V_Ref uC	0,0006	0,0006
													LM4040BIM3-3.0_NOPB	V_Ref NTCs	0,0006	0,0006
								NCP1117ST33T3G	LDO Lan/SD	0,55	1,83	0,057704918	**W5500**	ethernet controller	0,4356	0,0429
													kigsman 8GB	micro Sd	0,495	0,0033
								NCP1117ST33T3G	LDO Extern	0,55	0	0,1086	**OXY**	All 6 Oxygen Sensor. Under load: alway just one, P_load = P_one_load + 5 * Pidle	0,0759	0,0594
													CD4097B	MUX OXY	0,00033	0,00033
														Light sensor		
			DONGKER 280W/12A	Buck converter Vheat	0,92	32,60873525	0,0000396			->			**INA240A3EDRQ1**	Heater Mosfet	0	0
														Kapton Heaters	30	0

Variables:	
VSYS[V]	6
Heater[W]	5

Buck converter

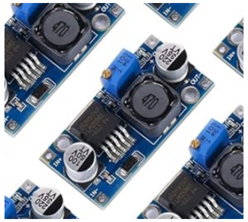
The motherboard itself needs 2 buck converters.

One converter (V_Sys) to power all LDOs, which provide stable 3.3V to things like the microcontroller and sd card.

The other one (V_Heat) provides power to the heating elements.

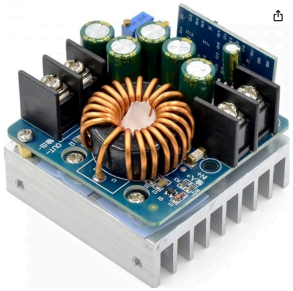
On the board these are both TPS62933DRLR buck converters, which are able to provide 3A. They were chosen because of the high output current and efficiency, but proved to be hard to solder and not reliable enough (2 shorted chips during testing).

So the jumpers connecting them to the corresponding voltages got removed and JST headers were used to connect external ones. This was anticipated and so this feature was implemented in the motherboard -> no PCB change needed.



The V_Sys voltage is now provided by a LM2596S based Buck converter module. It is a very commonly used board and features 1,25-35V input voltage as well as theoretical 3A output. It will at peak load need to provide around 3W at 3.3V -> around 0,9A, but realistically more like 1W -> 0,3A continuous current, as peak load can't happen.

Fig. 4.7-3: LM2596S based Buck converter module

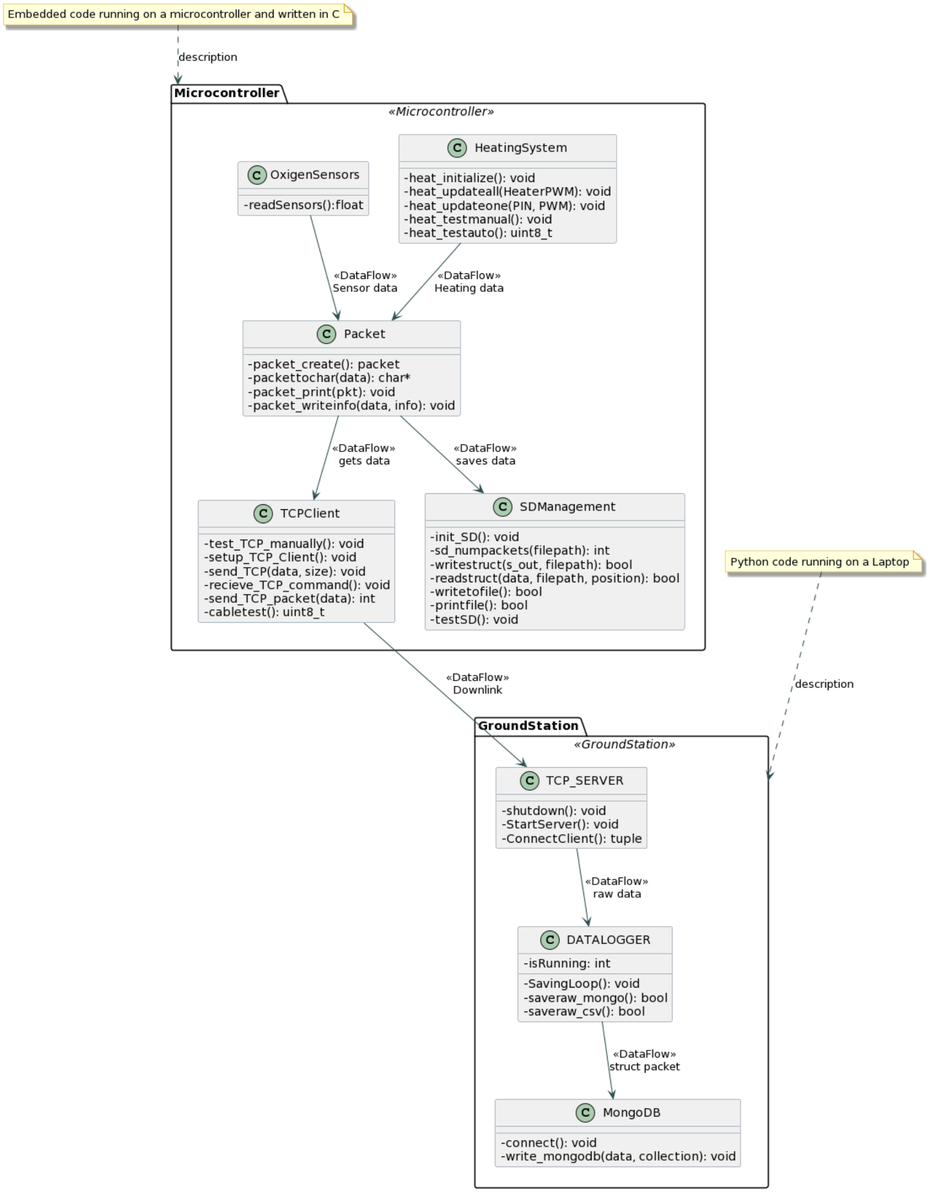


The V_Heat voltage is provided by a DONGKER SZ-BK0612 buck converter. It has a 10,5V-60V supply voltage range and can deliver up to theoretical 15A of output current. Not reachable without increasing cooling, realistically more like 12A (dependent on ambient temperature).

This is still way more power than we need for heating, which is 30W on 6x12 Ohm Kapton heaters -> 5V and ~3.8A in total. And this is the theoretical maximum to allow for some unforeseen heat spikes. In reality, heating should´t consume more power peak than 6W -> ~1.73A (1W per probe). This is still peak power consumption during ascent, the average is way lower.

Fig. 4.7-4: DONGKER SZ-BK0612 buck converter

4.8 Software Design



Overview

The embedded software architecture is implemented on the microcontroller in C++, covering essential functionalities like thermal control, sensor data acquisition and uplink/downlink communication processes. The thermal control is implemented as a PI controller, which controls the heating via PWM.

For ground station operations, the system will utilize a tech stack consisting of a Node.js backend communicating with a MongoDB database, complemented by a Web-based Localhost Application frontend.

Embedded Software

You can find all the embedded source code here.

It´s 1163 lines of comments on 3288 lines of code.

IDE/Language

All code running on the Microcontroller is written in C/C++. We are using the arduino ide with heavy dependence on the earlphilhower open source arduino core/framework for the rp2040.

Fig. 4.8-1: UML diagramm [Version of 25.3.24]

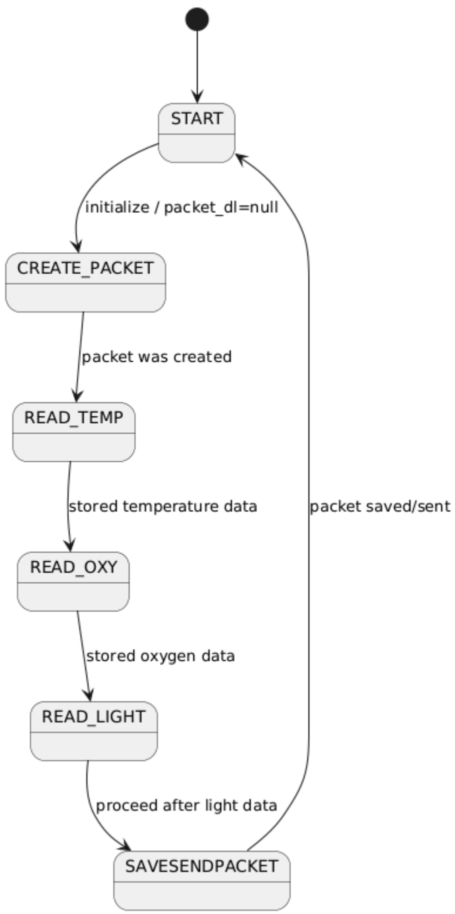


Fig. 4.8-2: State machine

Multithreading

The rp2040 has 2 cores.

First one handles all the sensor/data traffic as a state machine. It creates a packet, that's a container for data, and fills it with mostly temperature, oxygen and light sensor data. More details to the packet in the chapter Up/Downlink.

Second one is running exclusively the PI controller.

As the thermistor multiplexer is connected with the multiplexer of the oxygen sensors, the second core is paused whenever the oxygen sensors are accessed by the first core..

On the left is a simplified state machine of the first core. Of course there is also an Error state.

Also, after each state change, the controller is checking whether there are new commands available via serial or tcp.

Memory Safety

As with every C based code, memory safety must be provided.

These steps are taken to make this happen:

- Before memory is freed, the corresponding pointer is checked if it's NULL. That's because after freeing of memory the pointer is set to NULL. Prevents double freeing.
- All code is checked by cppcheck
- If possible, method parameters are const, especially strings
- For string operations, only methods with buffer_length parameters are used
- All buffer sizes are calculated by the compiler or provided by #define

Up/Downlink

The link is provided via BEXUS. Our project is using the payload as a client and the groundstation as a server. The client stays connected and will periodically send data down or receive commands from the ground station. All data from the payload will be saved in a struct named packet. It ist 472 bytes long and will be sent down every second. With additional head room of string based debug messages, the downlink rate is <5KB/s. Uploads are just the commands of 11B and if necessary a firmware file of 162KB, which needs to be uploaded in at least 6 seconds (watchdog). -> 11B/s for normal operation, 162KB/s if a firmware update should be necessary

Every packet has an individual ID and timestamp. These are followed by sensor data. Power is the voltage and current of the battery.

```
/**
 * packet used for downlink.      You, last week • got oxygensensor switching and measuring r
 * please use packet_create() and packet_destroy() for good memory management
 * */
You, 8 seconds ago | 1 author (You)
struct packet
{
    unsigned int id = 0;              // each packet has a unique id
    unsigned int timestampPacket = 0; // in ms
    float power[2] = {0};             // battery voltage in V and current consumption in A

    struct OxygenReadout oxy_measure[6];
    float light[12] = {0.0f};

    /**temperature from thermistors:
     *0-5 NTC cable
     *6 NTC SMD
     *7 fix reference value
     *8 cpu temp*/
    float thermistor[9] = {0};
    float heaterPWM[6] = {0}; // power going to heating
    float Kp[6] = {0};
    float Ki[6] = {0};
};
```

The struct OxygenReadout on the right is an extra container just for the measurements of the oxygen probes. It is included once per probe within the main packet.

```
You, last week | 1 author (You)
struct OxygenReadout
{
    int32_t error = 0;
    int32_t dphi = 0;
    int32_t umolar = 0;
    int32_t mbar = 0;
    int32_t airSat = 0;
    int32_t tempSample = 0;
    int32_t tempCase = 0;
    int32_t signalIntensity = 0;
    int32_t ambientLight = 0;
    int32_t pressure = 0;
    int32_t resistorTemp = 0;
    int32_t percentOtwo = 0;
    unsigned long timestamp_mesurement = 0;
};
```

Debug Console

There is a simple debug console implemented on the microcontroller to make prototyping easier and to have a chance to fix things during flight.

It can be accessed via USB or Ethernet. When accessed via USB, all messages (Infos up to errors) have different colors and are human readable to provide a pleasant debug experience. When used via Ethernet, every error debug message is just an error code, which needs to be looked up. Here the list of available error codes:

```
1       ERROR_SD_INI,
2       ERROR_SD_COUNT,
3       ERROR_WR_STR,
4       ERROR_SD_WRITE_OPEN,
5       ERROR_SD_PINMAP,
6       ERROR_TCP_INI,
7       ERROR_TCP_COMMAND_PARSING,
8       ERROR_TCP_PARAM_CORRUPT,
9       ERROR_TCP_COMMAND_CORRUPT,
10      ERROR_TCP_SEND_FAILED,
11      ERROR_TCP_SEND_TIMEOUT,
12      ERROR_TCP_SERVER_INVALID,
13      ERROR_TCP_TRUNCATED,
14      ERROR_TCP_TRUNCATED_2,
15      ERROR_TCP_CABLE_DISCO,
16      ERROR_TCP_NO_RESPONSE,
17      ERROR_TCP_DEBUG_MEMORY,
18      ERROR_TCP_CLIENT_CONNTECION,
19      ERROR_TCP_SEND_MULTIBLE_FAILED,
20      ERROR_HEAT_INI,
21      ERROR_LIGHT_INI,
22      ERROR_NO_NTC_CONNECTED,
23      ERROR_STATE,
24      ERROR_PACK_ID_OV,
25      ERROR_PACK_MEM_AL,
26      ERROR_PACKAGE_FREE_TWICE,
27      ERROR_OXY_INI,
28      ERROR_OXY_AUTO_AMP,
29      ERROR_OXY_SIGNAL_INT_LOW,
30      ERROR_OXY_OPTICAL_DETECTOR_SATURATED,
31      ERROR_OXY_REF_SIGNAL_LOW,
32      ERROR_OXY_REF_SIGNAL_HIGH,
33      ERROR_OXY_SAMPLE_TEMP_SENSOR,
34      ERROR_OXY_RESERVED,
35      ERROR_OXY_HIGH_HUMIDITY,
36      ERROR_OXY_CASE_TEMP_SENSOR,
37      ERROR_OXY_PRESSURE_SENSOR,
38      ERROR_OXY_HUMIDITY_SENSOR
```

Each command to the console consists of a [char]command and 4 [float] parameters. Not every command uses all parameters, but they are limited to 4 to make data recovery and integrity easier.

Here a list of currently implemented commands:

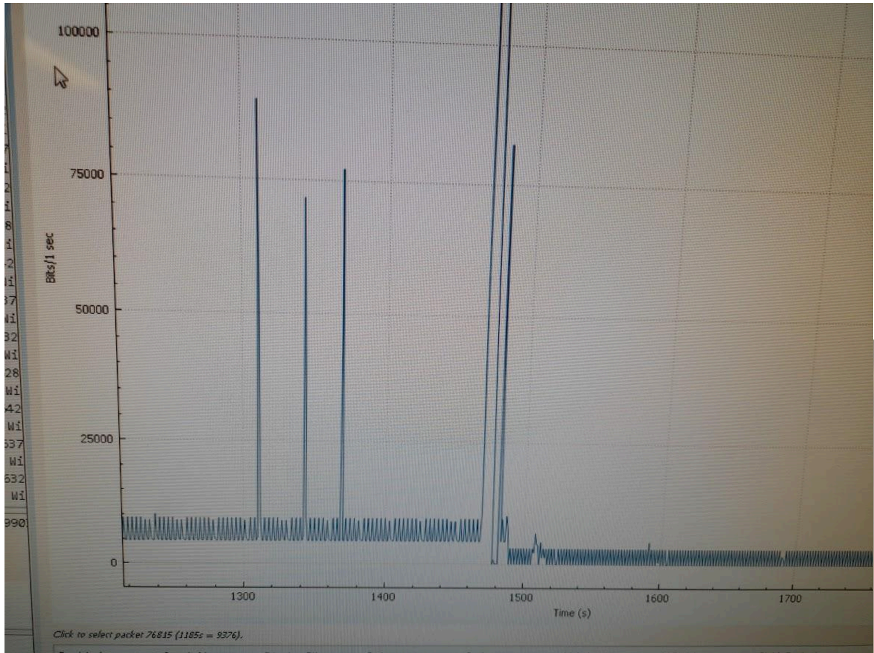
```
"/b|Returns Battery Voltage and current\n\
/s|Read out Status\n\
/l|Sets the controller in sleep for ... ms.\n\
/r|Reboots. if followed by a 1 reboots in Boot Mode\n\
/m|Read out Memory Info\n\
/h x y| set heater pin x at prozent y .if x == -1 is given\n\
        will return pwm status of all pi_controlled heaters.\n\
/i|scans for i2c devices\n\
/f|changes the analogWrite frequency. \n\
   For heater run one heating command and change then.\n\
/d|check connected peripherals\n\
/p|sends a test packet over lan\n\
/w|Sets Watchdog to ... ms. Cant be disables till reboot.\n\
/t|returns temperature value. 0-6 for external probes, 7 for uC one, -1 for all of them\n\
/x|prints barometer temperature and pressure\n\
/o|starts console to talk to PyroSience FD-OEM Oxygen Module\n\
/a|reads out light spectrometers\n\
/q|shut down microcontroller\n\
/c|[kp] [ki] [imax] [SET_TEMP_DEFAULT] sets pi controller gain values. \n\
   Set SET_TEMP_DEFAULT = -1000000.0 to deactivate PI controller\
    and be able to controller heater manually\
/u|starts an over_the_air OTA update\n"
```

Also, if using TCP, the command is sent three times to make sure the data is valid. Each parameter is sent twice, as they are less important than the command.

As one might notice, there is a command for the oxygen sensors. This opens another console, which is primarily for calibrating and testing of these sensors and will not be used in flight.

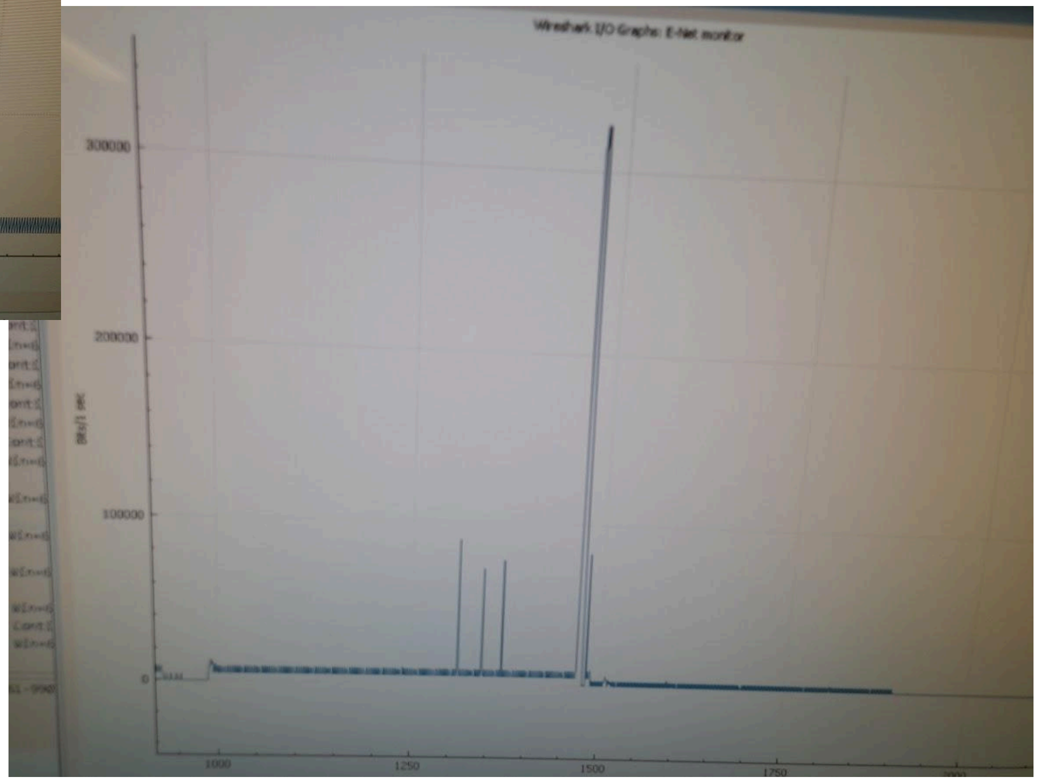
Uplink during Launch

COM tests at the Launch revealed the TCP overhead was missing in the calculations above. Also string based debugging proved to be quite huge. Especially as colour strings got sent with them. There was a parameter to disable the color, but after the FRR no firmware updates were allowed.



[left] Fig. 4.8-3: Here you can see the data traffic. The peaks are whenever /? got used for an overview of available commands -> this is a huge sting.

[right] Fig. 4.8-4: Peak was a firmware update.



NTC thermistor readout

This method reads out a NTC thermistor, with some advanced features.

It detects if there's no NTC connected and returns then -1000000.

It takes a predefined amount of ADC measurements and averages them out. Then it loops over the array of measurements and replaces every value which dividates strongly from average with the average. This removes any spikes in the measurement, like from EMI or noisy power supply. Then the average from the now spike free array is used in the calculation of the temperature.

This calculation is done via the [Steinhart-Hart equation](#).

Also there is a fixed voltage option as “ntc input”, which can provide feedback whether the amplifier is working correctly and the temperature data is valid.

```
/**
 * Reads out the temperature of one NTC thermistor.
 * Temperature range with current resistor values: 0.25 til 44.85°C
 * @param NTC Output NTC of the MUX selecting the NTC
 * @param nTimes
 dictates over how many measurement the values should be meaned. Set to 1 to just read out once.
 * @return temperature value or -1000000 if NTC is not connected/vaulty
 */
float temp_read_one(uint8_t NTC, uint8_t nTimes)
{
    /*circuit design*/
    const float VCC_NTC = 3.0;     // reference voltage for the NTC Readout
    const float R_SERIES = 5200.0; // Fixed resistor value in ohms (10kΩ)
    const float R41 = 10000.0;
    const float R43 = 51000.0;
    const float R53 = 10000.0;

    /*thermistor stats*/
    const float NTC_B_AMPHENOL = 3977.0; // Beta parameter
    const float NTC_B_SMD = 3435.0;      // Beta parameter
    const float NTC_B_FIX = 4000.0;
    const float NTC_T0 = 298.15;         // Reference temperature in Kelvin (25°C)
    const float NTC_R0 = 10000.0;        // Resistance at reference temperature (10kΩ)

    /*calculations*/
    const float R43_paral_R41 = R41 * R43 / (R41 + R43);
    const float gain = 1.0 / (R43_paral_R41 / (R43_paral_R41 + R53));
    const float R41_paral_R41 = 0.5 * R41;
    const float voffset = VCC_NTC * R41_paral_R41 / (R41_paral_R41 + R43);

    if (!temp_init)
    {
        temp_setup();
    }

    /*Connect the right one*/
    select_oxy_or_ntc(NTC);

    /* check if NTC connected*/
    if (analogRead(PIN_TEMPADC) > ADC_MAX_READ * 0.05)
    {
        // error_handler(ERROR_NO_NTC_CONNECTED);
        return -1000000;
    }

    /*Read out ADC in a buffer and calculating adc_average*/
    float adc_average = 0;
```

```
    /*Read out ADC in a buffer and calculating adc_average*/
    float adc_average = 0;
    float adc_buffer[nTimes];
    for (int i = 0; i < nTimes; i++)
    {
        float adc_redout = (float)analogRead(PIN_TEMPADC);
        adc_buffer[i] = adc_redout;
        adc_average += adc_redout;
    }
    adc_average = adc_average / nTimes;

    /*removing spikes in adc_buffer*/
    const float tolerance = 0.2;
    float voltage_adc;
    unsigned int counter_spikes_removed = 0;
    for (int i = 0; i < nTimes; i++)
    {
        if (!((1 - tolerance) * adc_average < adc_buffer[i] < adc_average * (1 + tolerance)))
        // replaces adc_buffer values which dividate from the adc_average about more than tolerance
        {
            adc_buffer[i] = adc_average;
            counter_spikes_removed++;
        }
    }
    debugf_info("spikes removed:%u from %u samples\n", counter_spikes_removed, nTimes);

    /*calculating new adc_average without spikes*/
    float filtered_adc_average = 0;
    for (int i = 0; i < nTimes; i++)
    {
        filtered_adc_average += adc_buffer[i];
    }
    filtered_adc_average = filtered_adc_average / nTimes;

    /*calculating volgae form adc value*/
    voltage_adc = (filtered_adc_average / ADC_MAX_READ) * VCC_NTC;

    /*Converts the adc voltage after the opamp circuit to the voltage on the ntc*/
    float volt_ntc = voltage_adc * (1.0 / gain) + voffset;

    /*Converts ADC value to a Resistance*/
    float resistance = (float)R_SERIES * (((float)VCC_NTC / volt_ntc) - 1);

    /*selects the right NTC_B value for each NTC type*/
    float NTC_B = NTC_B_AMPHENOL;
    switch (NTC)
    {
    case NTC_SMD:
        NTC_B = NTC_B_SMD;
        break;
    case NTC_10kfix:
        NTC_B = NTC_B_FIX;
        break;
    default:
        NTC_B = NTC_B_AMPHENOL;
        break;
    }

    /*Calculate the temperature in Kelvin using the Steinhart-Hart equation*/
    float tempK = 1.0 / (1.0 / NTC_T0 + (1.0 / NTC_B) * log(resistance / NTC_R0));

    /*Convert temperature from Kelvin to Celsius*/
    float tempC = tempK - 273.15;
    // debugf_info("VADC:%.2f VNTC:%.2f R:%.2f T:%.2f\n", voltage_adc, volt_ntc, resistance, tempC);
    return tempC;
}
```

PI Controller

Implementation of a discrete PI controller with anti windup integral part and cap on integral as well as the power level. It’s struct based and nonblocking.

```
/**
 * updates the discrete PI controller and therefore the heating power as well.
 */
void pi_update_controller(PI_CONTROLLER *pi)
{
    if (!heat_init)
    {
        heat_setup();
    }

    /*static Variables*/
    /*Variables.*/
    unsigned long time_curr = millis();
    float measured_temp = temp_read_one(pi->thermistor_pin);
    float error = pi->desired_temp - measured_temp;
    float dt = (time_curr - pi->time_last) / 1000.0f;
  // divided by 1000 because then its in s and not ms
    /*p*/
    float p = pi->kp * error;
    /*i*/
    float i = 0.5f * pi->ki * dt * (error + pi->error_last);

    /* Anti-wind-up */
    if (pi->pi_last == PID_MAX)
    // clamps integral when Controller is in positive saturation
    //  and i is still increasing (making things worse)
    {
        if (i > 0)
        {
            i = pi->i_last;
        }
    }
    else if (pi->pi_last == (-1 * PID_MAX))
    // clamps integral when Controller is in negative saturation
    //  and i is still decreasing (making things worse)
    {
        if (i < 0)
        {
            i = pi->i_last;
        }
    }
    else
    // increases i by the last value if non of the anti wind up occurs.
    {
        i = i + pi->i_last;
    }

    /*integral clamping*/
    if (i > pi->I_MAX)
    // This clamping isn´t depended on anything. Shouldn´t be needed in normal operation,
    //  but prevents exessive integral values if something gets wrong
    {
        i = pi->I_MAX;
    }
    else if (i < (-1 * pi->I_MAX))
    {
        i = (-1 * pi->I_MAX);
    }

    /*adding all up*/
    float pid = p + i;
```

```c
    /*adding all up*/
    float pid = p + i;

    /*clamping PID output*/
    if (pid > PID_MAX)
    /*This is needed as the heating power provided can´t be infinite large*/
    {
        pid = PID_MAX;
    }
    else if (pid <= -PID_MAX)
    {
        pid = -PID_MAX;
    }

    /*converting PID to dutycycle for heater*/
    float heat = (100 * pid / PID_MAX);

    /*clamping heat*/
    if (heat <= 0)
    {
        heat = 0;
    }

    heat_updateone(pi->heater_pin, heat);

    pi->time_last = millis();
    pi->i_last = i;
    pi->error_last = error;
    pi->pi_last = pid;
    pi->heat = heat;
    // debugf_status("updating PIN_HEAT:%u with PIN_NTC:%u ", heater, thermistor);
    // debugf_info("SET_TEMP_DEFAULT:%.2f°C measure_temp:%.2f°C p:%.2f i:%.2f heat:%.2f%%\n", desired_temp, measured_temp, p, i, heat);
}
```

This pi controller will run with a frequency of 1Hz, as the temperature of the water takes at least a minute to change by a reasonable amount.

Thermal Testing

Getting a numerical approximation for the system response function

As described in the function documentation, this function waits till the probe cools down to a set temperature and then will set the heater to 100% for a preprogrammed time. It’s non blocking and will record results as step response on the sd card.

```c
/**
 * records a transfer function with specified values.
 * First cooles Probes down to T_START.
 * Then waits and records till TIME_TILL_STOP
 * @return 0 is still recording 1 if done
 */
uint8_t pi_record_transfer_function(uint8_t Heater, uint8_t NTC, float T_START, float TIME_TILL_STOP)
{
    enum pi_sweep_states
    {
        INIT, // writes header and infos on the sd card
        COOLING,
        RECORD_STEP
    };

    /*static variables*/
    static enum pi_sweep_states pi_state = INIT;
    static char sd_filepath[100];
    static unsigned long timestamp_transfer_function = millis() + TIME_TILL_STOP;
    static unsigned long timestamp_last_update = millis() + 1000;
    static uint8_t done = 0;

    if (millis() > timestamp_last_update)
    /*limits frequency*/
    {
        timestamp_last_update = millis() + PI_T;

        if (millis() < timestamp_transfer_function)
        // test if finished with all cycles
        {
            /*measure temperature*/
            float temp_measure = temp_read_one(NTC);

            /*writes current temp to SD card*/
            char str_buff[300];
            if (pi_state != INIT)
            {
                snprintf(str_buff, 300, "%u,%f,%f", millis(), temp_measure, get_current());
                sd_writetofile(str_buff, sd_filepath);
            }

            /*prints status every status_delay s*/
            const unsigned long status_delay = 60 * 1000;
            unsigned long timestamp_status = millis() + status_delay;
            if (millis() > timestamp_status)
            {
                timestamp_status = millis() + status_delay;
                debugf_status("pi_step_response[%u][%u][%f] Testing PID for: [%u]min\n", nMOTHERBOARD_BOOTUPS, Heater, temp_measure, (millis() - timestamp_transfer_function - TIME_TILL_STOP) / 1000.0 / 60.0);
            }

```

```
            switch (pi_state)
            {
            case INIT:
            {
                debugf_status("pi_step_response[%u][%u] state: Initialising\n", nMOTHERBOARD_BOOTUPS, Heater);

                /*creating file path from bootups and heater*/
                snprintf(sd_filepath, 99, "temp_step_respons[%lu][%.2f].csv", nMOTHERBOARD_BOOTUPS, HEAT_VOLTAGE * HEAT_CURRENT);

                /*creating header*/
                snprintf(str_buff, 300, "Timestamp,Temperatur,Power");
                sd_writetofile(str_buff, sd_filepath);

                debugf_status("pi_step_response[%u][%u] state: COOLING\n", nMOTHERBOARD_BOOTUPS, Heater);
                pi_state = COOLING;
                break;
            }
            case COOLING:
                /*cools probe down till TEMP_COOL*/
                {
                    heat_updateone(Heater, 0.0);
                    if (temp_measure < T_START)
                    {
                        debugf_status("pi_step_response[%u][%u] state: RECORD_STEP\n", nMOTHERBOARD_BOOTUPS, Heater);
                        pi_state = RECORD_STEP;
                        timestamp_transfer_function = millis() + TIME_TILL_STOP;
                    }
                    break;
                }
            case RECORD_STEP:
                /*switches on a PI controller with preprogrammed values for TIME_TILL_STOP*/
                {
                    heat_updateone(Heater, 100.0);
                    break;
                }
            default:
                break;
            }
        }
        else
        {
            if (!done)
            /*limits "done" print state*/
            {
                debugf_status("pi_step_response[%u][%u] state: Done\n", nMOTHERBOARD_BOOTUPS, Heater);
                heat_updateone(Heater, 0.0);
                done = 1;
            }
        }
    }
    return done;
}
```

The step response function can now be numerically approximated. This is done by this python script.

```python
#tool to numerical aproximate a PT1 tranfer function
import numpy as np
from scipy.optimize import fsolve

# Define the function based on the given points
def equations(vars, x1, y1, x2, y2, x3, y3):
    a, x0, t1 = vars
    eq1 = y1 - (a - a * np.exp(-(x1 + x0) / t1))
    eq2 = y2 - (a - a * np.exp(-(x2 + x0) / t1))
    eq3 = y3 - (a - a * np.exp(-(x3 + x0) / t1))
    return [eq1, eq2, eq3]

# Initial guesses for a, x0, t1
initial_guess = [35.416269564093575, 575938.9233337401, 1981412.601652126]

# Points (x1, y1), (x2, y2), (x3, y3)
x1, y1 = 3317342, 25.017115
x2, y2 = 7032671, 28.60647
x3, y3 = 14361460, 30.30401

# Solve the system of equations
solution = fsolve(equations, initial_guess, args=(x1, y1, x2, y2, x3, y3))
a, x0, t1 = solution

print(f"a = {a}, x0 = {x0}, t1 = {t1}")
```

The estimated values are based on guesses with help of online plotting tools (mainly GeoGebra).

Figure below is an example graph with the numerical approximation in red and the real recording in blue:

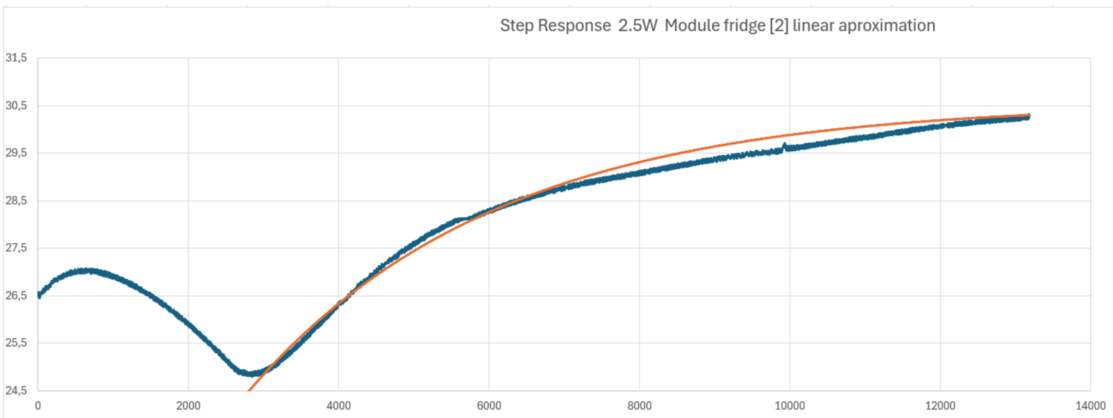


Fig. 4.8-5: Example of step response

If you now divide the numerical approximation of the step function by 3, you get the transfer function of the system.

PI_controller_sweep

This function records the performance of a few PI controllers with preprogrammed gains for a set time. It is useful to finetune controller values.

Also with Kp=1 and Ki = 0, it's able to record a step function.

It's struct based and non-blocking. For more details take a look at the code here.

This is the cycle it goes through:

- cools down to specified temperature
- engages a pi controller with programmed values
- when temp hits a specified temperature, it waits for a specified duration
- cooling down again

It then repeats this cycle for nCycles with different PI gain values

In praxis, the temperature curves it produces looks like this:

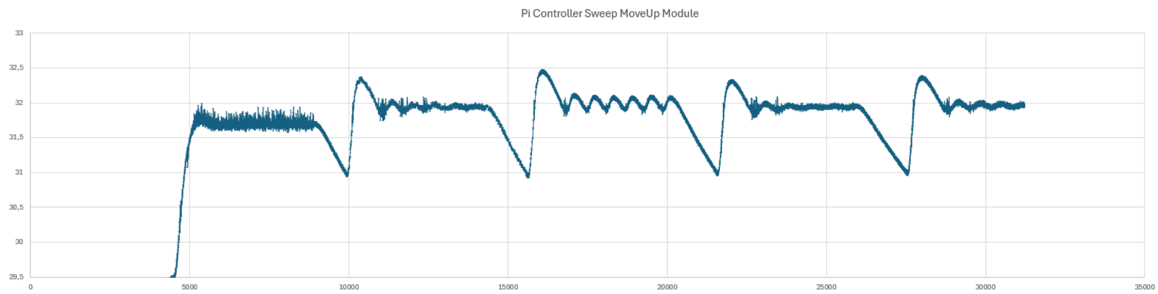


Fig. 4.8-6: Example of PID cycle

OTA updates

Over-the-air updates through an Ethernet connection are implemented in this system. Here's how the process works:

1. **Firmware Compilation**: The firmware is first compiled on a local machine (ground station).
2. **Mainboard waiting**: The mainboard receives a command through the tcp server, so it's waiting to receive the new firmware.
3. **Firmware Transmission**: The compiled firmware is then transmitted to the mainboard via the TCP server.
4. **Saving the Firmware**: Once received, the firmware is saved as a LittleFS file on the mainboard.
5. **Comparing sizes:** With the waiting command the mainboard received the filesize of the firmware. This is now compared to the filesize of the uploaded one. This ensures data integrity at a basic level.
6. **Loading into Arduino OTA Buffer**: The saved firmware file is then loaded into the Arduino OTA buffer.
7. **System Reset and Boot**: Finally, the microcontroller needs to be reseted, and it boots up with the newly updated firmware. If no reset occurs, it can be reflashed to replace the previous version

Groundstation

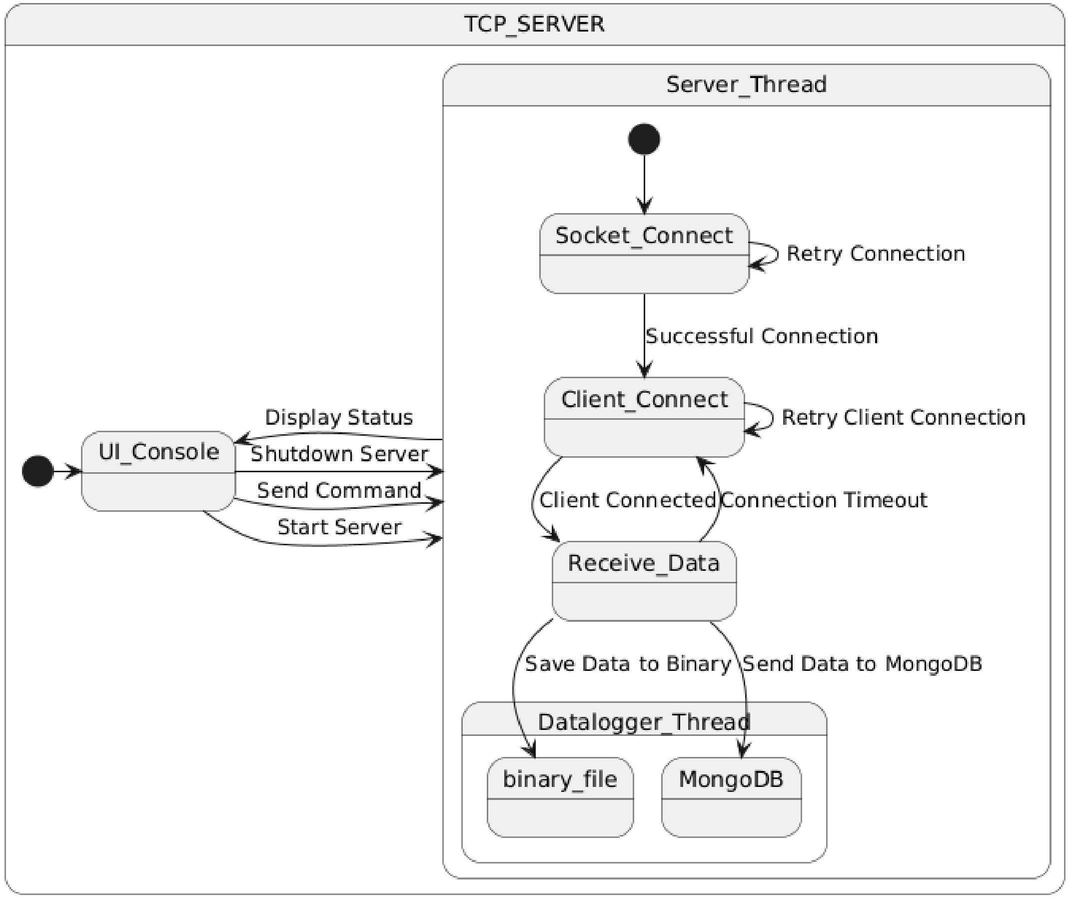


Fig. 4.8-7: UML diagram of the TCP_Server

TCP Server (Python Groundstation)

You can find the code here.

A video of it running here.

This server handles the communication to the motherboard. It's written in python and is based on the library socket. Also the final version is compiled in a .exe.

It has a console with the following features:

- Displaying network infos
- Displaying infos about running threads
- Starting Server
- Closing Server
- Displaying status updates, like what is running, if data is received and when what kind (packet, error or debug message
- Sending commands

The Server itself connects a socket and a client and receives data from the client.

If that data is a packet it gets saved to a binary file and sent to MongoDB. If it's an error or debug message it gets printed on the console as text

Data Storage & Plotting

1. Purpose:

The ground station's purpose is to visualize incoming sensor data and assist in evaluating experiment results.

2. Design:

The design will be structured around a REST-based application system, with separate handling of data and plotting responsibilities allocated to the frontend and backend, respectively (Figure 4.8 - 1).

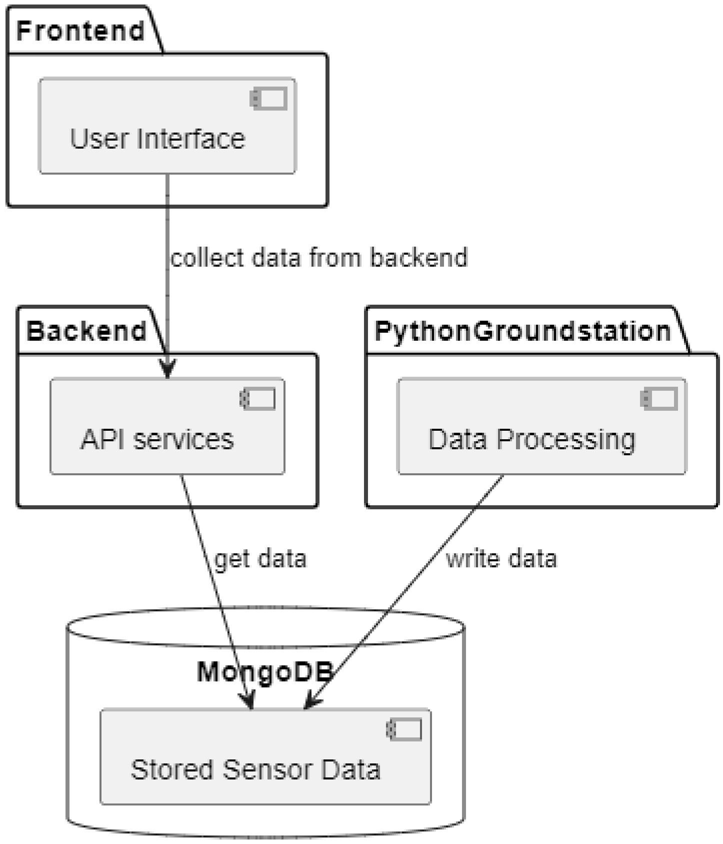


Fig. 4.8-8: Groundstation Software Design

Backend Functions and Design:

The backend consists of two main functions. One of them is to provide the frontend with all measured data existing in the database (Figure 4.8-2), while the other is to retrieve the new data of one sensor since the last call (Figure 4.8-3).

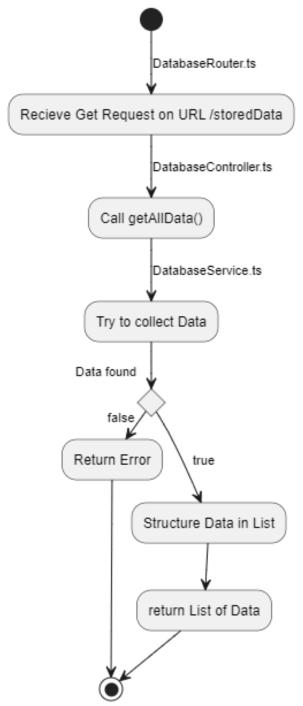


Fig. 4.8-9: Endpoint GET /storedData_latest/:sensorname/:id

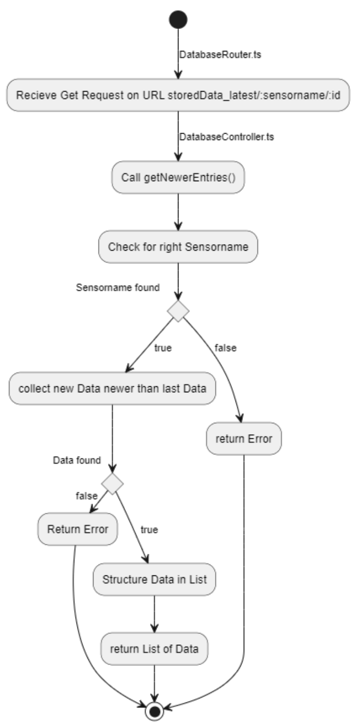


Fig. 4.8-10: GET /storedData_latest/Sensor1/6602a19c2d76cc5bcd9ede51

Frontend functions and design:

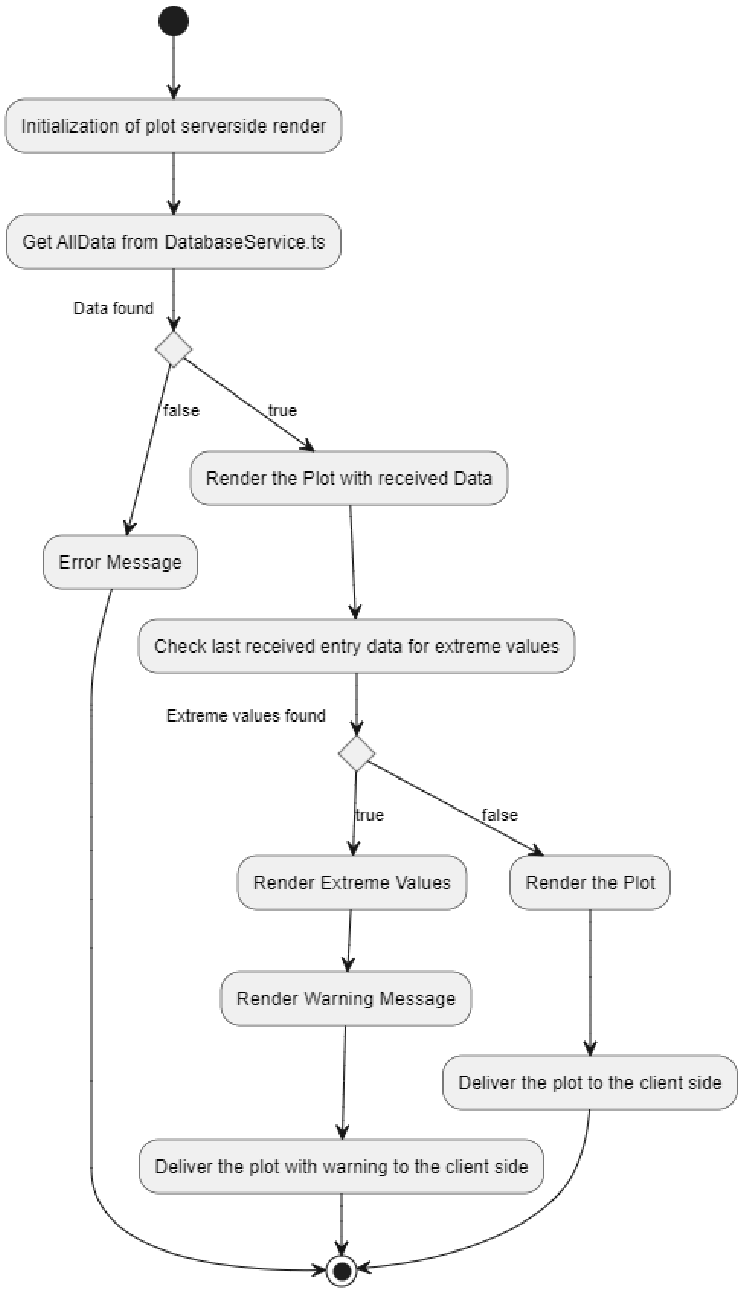


Fig. 4.8-11: Frontend Design

3. Implementation:

The software is stored and managed in a GitHub repository for development and documentation purposes. Development is conducted using the VSCode editor.
https://github.com/EggiEl/SpiCy-BEXUS

4.9 Biological Experiment Design

Biofilms composed of cyanobacteria and heterotrophic complements are cultivated and sealed in tubes with oxygen sensors. The test tubes are exposed to natural sunlight in the stratosphere to observe their behavior, especially UV-B radiation. Stressed cyanobacteria produce less oxygen as they have to halt their metabolism to avert radiation damages or die off quickly. We expect a positive impact of biofilm structures formed together with heterotrophic bacteria in this stress response, with higher oxygen production compared to a single species biofilm.

<u>Cultivation and growth:</u>

Cyanobacteria were grown in natural light conditions at room temperature for 2-3 weeks in BG11 medium or BG11+ medium (*C. cubana* +). Heterotrophic bacteria were incubated for 2 days at 30°C (*E. coli*) and 37°C (*B. subtilis*, *P. taiwanesis*) in M9 medium (see protocol and comparable commercial datasheet in appendix).

Cyanobacterial growth was monitored with photometric measurement of Chlorophyll A.

Cyanobacteria and heterotrophic complements were paired together in small well plates to observe their survival and biofilm formation qualities and cultivated for 3 weeks under natural light conditions at room temperature.

A detailed biological laboratory plan can be found in appendix C.

The following images were taken 3 weeks after joint cultivation with an inverted microscope (40x) to control cyanobacterial growth with different added heterotrophic complementary bacteria.

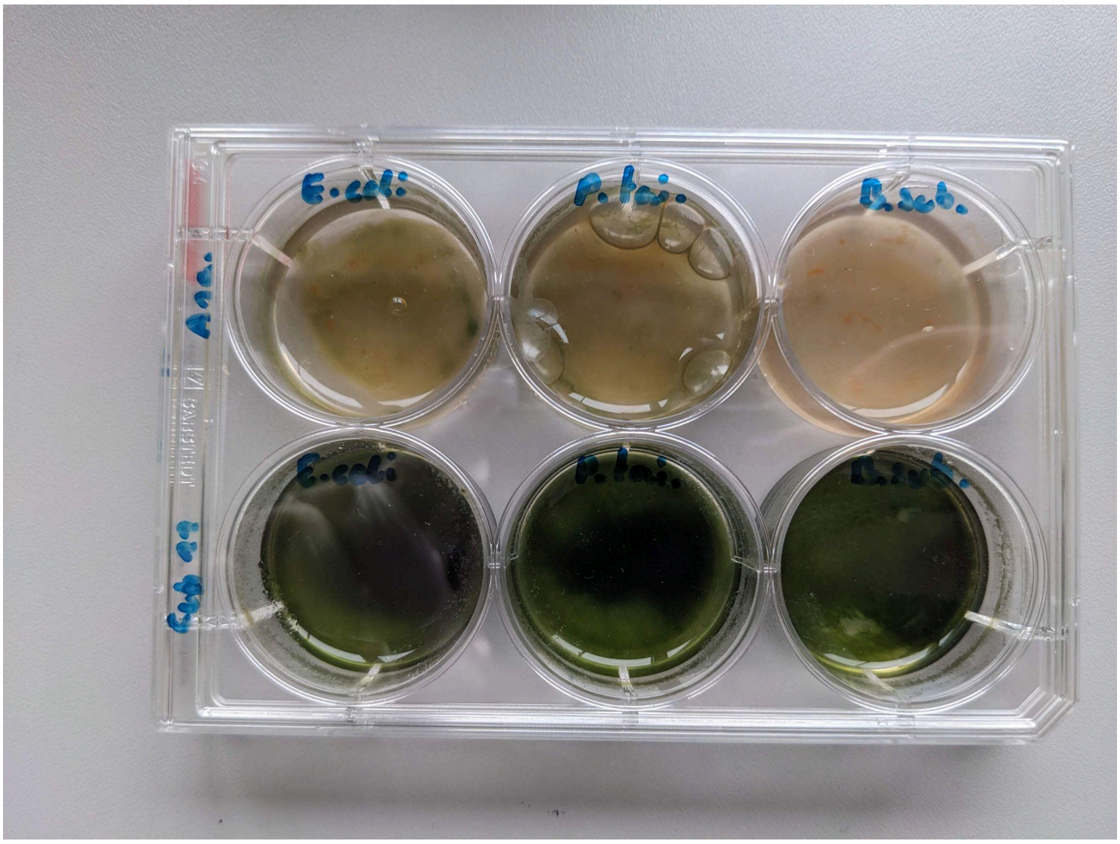


Fig. 4.9-1: Exemplary first cultivation of Biofilms. *Anabaena cylindrica* (top row) and *Chroococcidiopsis cubana* (bottom row) show varying response to co-cultivation (5ml volume) with heterotrophic bacteria regarding the chlorophyll buildup (green color), oxygen production (air bubbles) and general survivability.

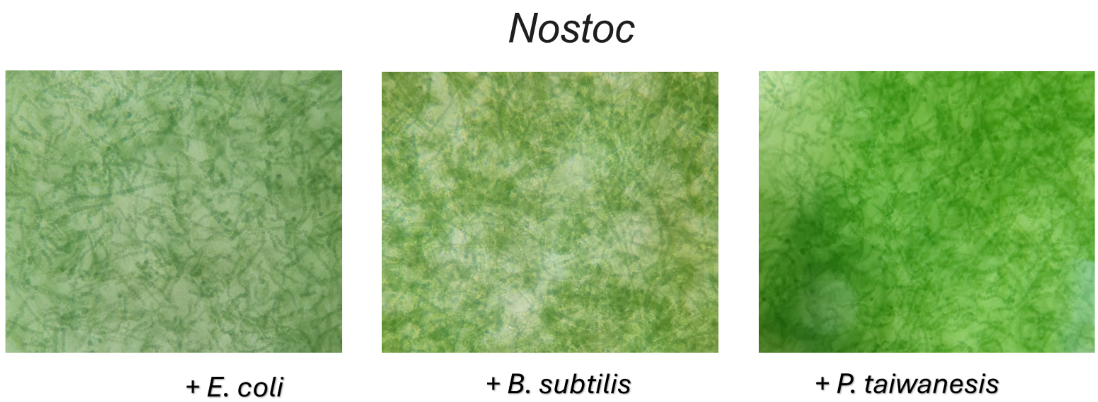


Fig. 4.9-2: *Nostoc sp.* in liquid culture with different complementary heterotrophic bacteria

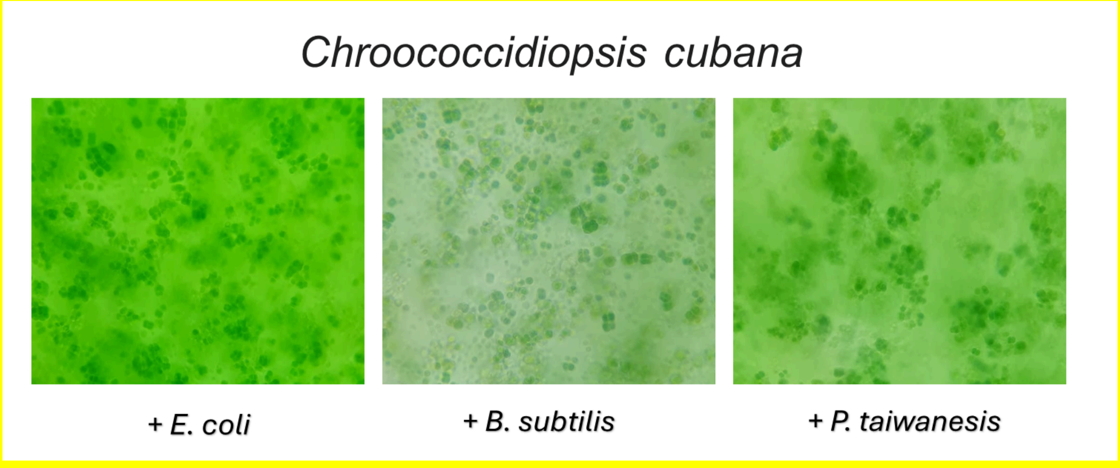


Fig. 4.9-3: *Chroococcidiopsis cubana* in liquid culture with different complementary heterotrophic bacteria

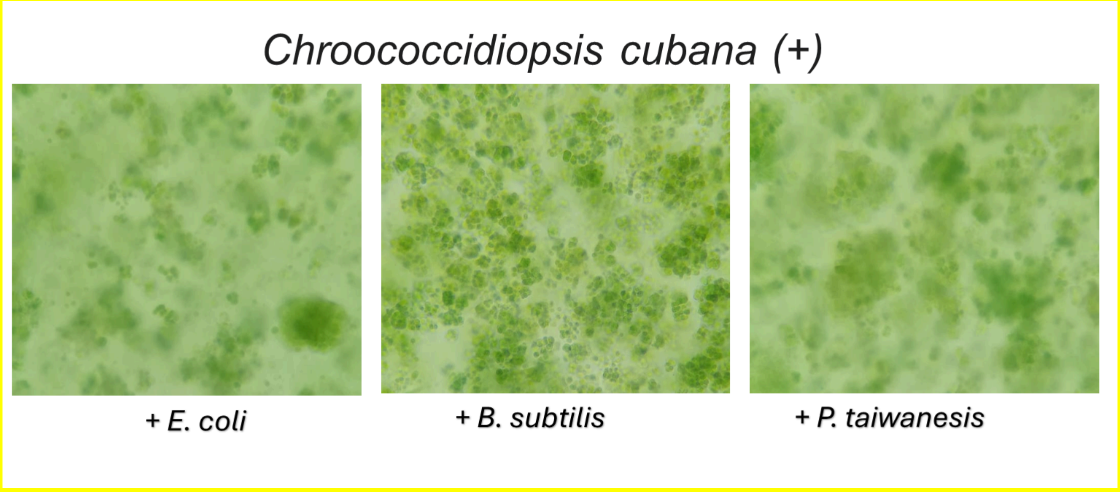


Fig. 4.9-4: *Chroococcidiopsis cubana* in liquid culture in BG11+ medium with different complementary heterotrophic bacteria

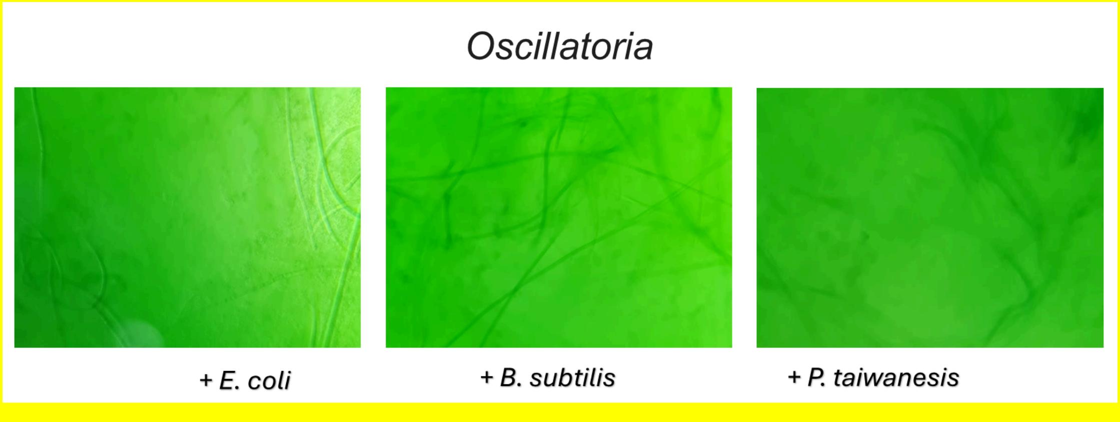


Fig. 4.9-5: *Oscillatoria sp.* in liquid culture with different complementary heterotrophic bacteria

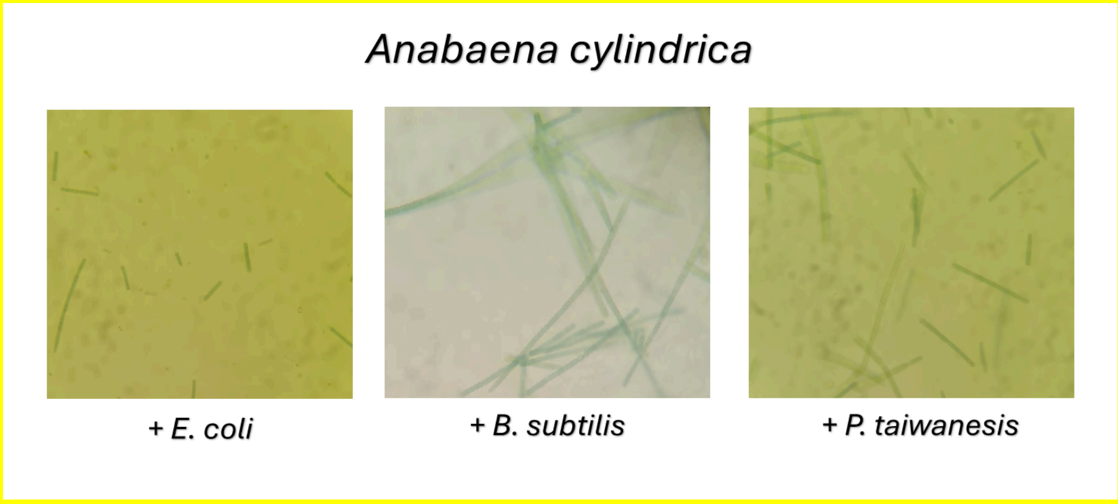


Fig. 4.9-6.: *Anabaena cylindrica* in liquid culture with different complementary heterotrophic bacteria

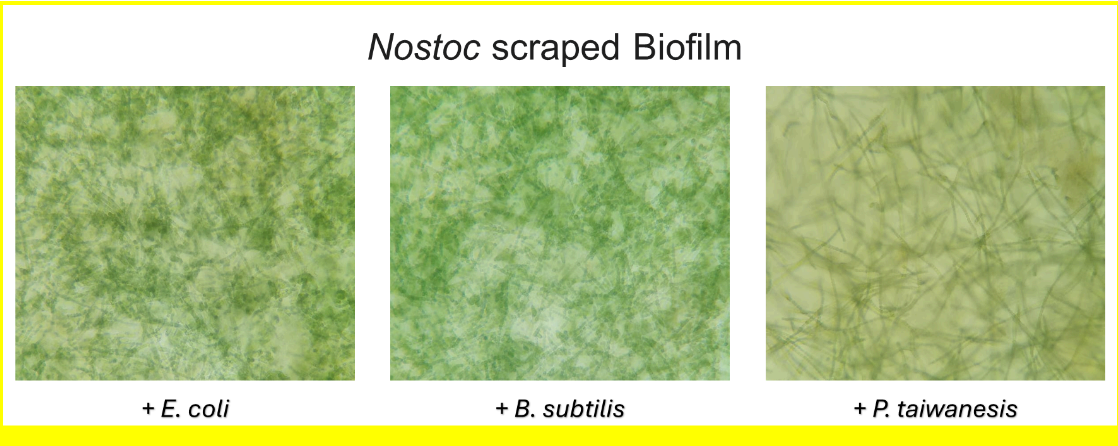


Fig. 4.9-7: *Nostoc sp.* biofilms in liquid culture with different complementary heterotrophic bacteria

Sample Selection:

Nostoc sp. was chosen as the prime flight candidate as it proved to be the most resilient sample in the stated ground setup conditions with a stable biofilm formation time of 3-4 weeks. They were able to sustain changes in daily light periods, direct sunlight and continuous Chlorophyll buildup with all tested heterotrophic complements.

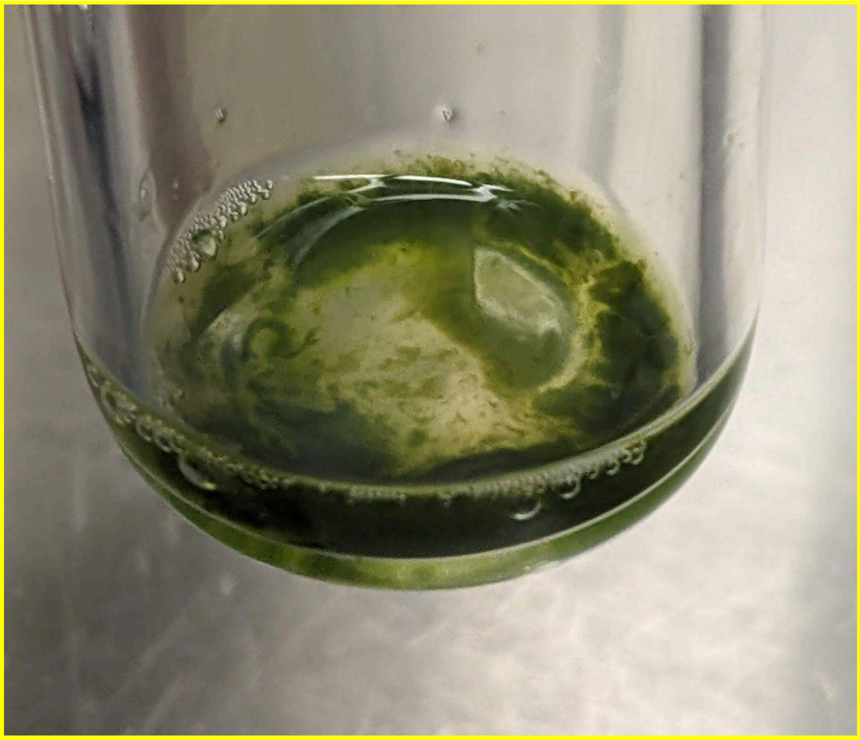


Fig. 4.9-8: *Nostoc sp.* Biofilm selected for flight. The biofilm shows good adhesion to the glass wall, dense biomass, sustained oxygen production (air bubbles) and deep green color indicating sufficient chlorophyll buildup.

Preparation of flight samples:

The following samples were cultivated in 15ml BG11 medium in the experiment glass tubes for 3-4 weeks pre-flight:

1. *Nostoc sp.* with *B. subtilis*
2. *Nostoc sp.* with *P. taiwanesis*
3. *Nostoc sp.* with *E. coli*
4. Pure culture *Nostoc sp.*
5. *Nostoc sp.* with *B. subtilis* from a previous cultivation batch (scraped)
6. *Nostoc sp.* with *P. taiwanesis* from a previous cultivation batch (scraped)
7. *Nostoc sp.* with *E. coli* from a previous cultivation batch (scraped)

One glass tube with BG11 medium and without bacteria is prepared right before launch as a medium control sample.

Samples are reversibly sealed and transported to the facilities in a closed container without access to sunlight to avoid any variability in growth conditions.

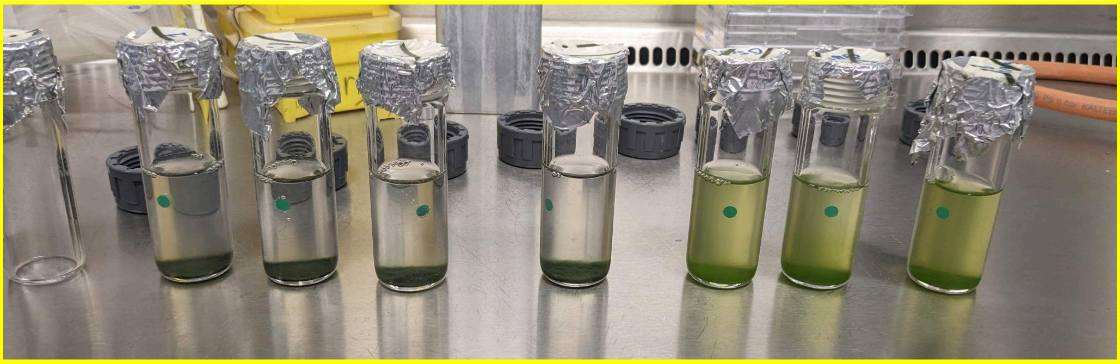


Fig. 4.9-9: *Nostoc sp.* samples in 35ml BG11 medium right before pre-sealing them for transport. The biofilm containing glass tubes are ordered as stated above from left to right.

4.10 Ground Support Equipment

A Laptop with an ethernet port is needed to house the backend and the frontend.

The programming languages used for plotting the data on the ground station will be integrated following the specifications outlined in section 4.8.

4.11 Changes from Former Flight (for Re-Flights only)

SpiCy is not based on former REXUS/BEXUS flight experiments.

5 EXPERIMENT VERIFICATION AND TESTING

5.1 Verification Matrix

Table 5-1: Verification table

ID	Requirement text	Methods	Ref.	Status	Verification Result
F.1	The biofilms shall be exposed to natural sunlight.	I, T, R	Test 14	I - done R - done T - done	Verified
F.2	The experiment shall measure the dissolved oxygen levels in the medium	A, T	Test 1	A - done T - done	Verified
F3	The experiment shall measure the temperature inside the tubes.	A, T	Test 1	A - done T - done	Verified
F.4	The experiment shall measure the temperature outside of the tubes.	A, T	Test 1	A - done T - done	Verified
F.5	The experiment shall measure the temperature of the PCB in the electronic compartment.	A, T	Test 1	A - done T - done	Verified
F.6	The experiment shall measure the UV light entering the module.	A, T	Test 1 &14	A - done T - done	Verified
F.7	The experiment shall save the recorded data of diluted oxygen.	A, T	Test 1	A - done T - done	Verified
F.8	The experiment shall save the recorded temperature data.	A, T	Test 1	A - done T - done	Verified
F.9	The experiment shall save the light transmission data.	A, T	Test 1	A - done T - done	Verified
P.1	The Oxygen sensors shall operate with an accuracy of 0.4 mg/l ± 0.009	R, T	Test 1	R - done T - done	Verified
P.2	The module shall be working within the range of -20 to 50°C.	A, T	Test 1 & 2	A - done T - done	Verified
P.3	The thermal sensors shall operate with an accuracy of <=1°C.	R, T	Test 1	R - done T - done	Verified
P.4	The thermal sensors shall operate with a response time of <=1 seconds	R, T	Test 1	R - done T - done	Verified
P.5	The UV sensor shall measure the incoming UV light with an accuracy of ± 20nm.	R, T	Test 1	R - done T - done	Verified

P.6	The Oxygen sensors shall operate with a sampling rate of <3 seconds.	A, R, T	Test 1	A - done R - done T - done	Verified
D.1	The top side of the module shall allow UV light to pass through.	R, T	Test 14	R - done T - done	Verified
D.2	The tubes shall be hermetically sealed to prevent leakage.	R, T	Test 3	R - done T - done	Verified
D.3	The electronics bay shall be accessible externally.	I, R	-	I - done R - done	Verified
D.4	The tubes inside the module shall have an exposure to natural sunlight for an elevation angle larger than 0 degrees.	A	-	A - done	Verified
D.5	The biofilms shall cover the flat surface of the tubes.	I, R	-	I - done R - done	Verified
D.6	The temperature of the biofilm medium shall be maintained at 25-30°C.	A, T	Test 2 & 6	A - done T - done	Verified
D.7	The temperature of the electronic compartment shall be maintained within the operational temperature range of the hardware components.	A, T	Test 2 & 6	A - done T - done	Verified
D.8	The biological samples shall be S1.	R	-	R - done	Verified
D.9	The experiment shall not interfere with other BEXUS experiments.	A, R	-	A - done R - done	Verified
D.10	The experiment shall withstand the loads during the flight.	A, I, R, T	Test 4	A - done I - done R - done T - done	Verified
D.11	The experiment shall withstand pressure differences during flight as defined in the BEXUS manual.	R, T	Test 2	R - done T - done	Verified
D.12	The experiment shall withstand temperature differences during flight as defined in the BEXUS manual.	R, T	Test 2 & 6	R - done T - done	Verified
D.13	The experiment shall withstand the loads during the landing.	A, I, R, T	Test 4	A - done I - done R - done T - done	Verified
D.14	The experiment shall be compatible with the BEXUS vehicle.	I, R	-	I - done R - done	Verified

D.15	The experiment shall provide an interface for power and LAN.	I, R, T	Test 5	I - done R - done T - done	Verified
D.16	The experiment shall be grounded with the power connector	R, T	Test 5	R - done T - done	Verified
D.17	The experiment shall work within the ambient temperature range of -60 to +30°C.	R, T	Test 2 Test 6	R - done T - done	Verified
D.18	The experiment shall stay within the mass budget of 8kg.	T	Test 7	T - done	Verified
D.19	The experiment dimensions shall not exceed 340x340x300mm.	I, T	Test 7	I - done T - done	Verified
D.20	The electronic system power consumption shall operate within the BEXUS power supply range.	A, R, T	Test 1	A - done R - done T - done	Verified
D.21	The experiment shall operate within the BEXUS voltage supply range.	A, R, T	Test 1	A - done R - done T - done	Verified
D.22	The data rate shall be lower than 50 kb/s.	A, T	Test 8	A - done T - done	Verified
D.23	The electronics compartment shall be accessible independently from the biological experiment.	I, R	-	I - done R - done	Verified
D.24	The sensor data shall be sent to the ground station in accordance to the data rate specified in D.22.	A, T	Test 8	A - done T - done	Verified
D.25	The frontend shall provide a function to evaluate the collected data in the oxygen plot.	A,T	Test 9	A - done T - done	Verified
D.26	The frontend shall provide a function to help evaluate the collected data in the temperature plot.	A, T	Test 9	A - done T - done	Verified
D.27	The system shall store raw data in a database.	A, T	Test 1	A - done T - done	Verified
D.28	The incoming data shall be live plotted on the ground station.	A, T	Test 10	A - done T - done	Verified
D.29	The plot shall check for new data at least every 3 seconds.	A, T	Test 10	A - done T - done	Verified

D.30	The software interface shall visualize the temperature data on the ground station.	A, T	Test 10	A - done T - done	Verified
D.31	The software interface shall visualize the oxygen data on the ground station.	A,T	Test 10	A - done T - done	Verified
D.32	The software of the ground station shall be structured in frontend, backend and database.	R	-	R - done	Verified
O.1	The biosafety protocols for handling the selected biofilms before and after flight shall be followed.	I,R	-	I - done R - done	Verified
O.2	The biofilms shall be cultivated inside of the Esrange laboratory.	I, R	-	I - done R - done	The cultivation was done before the travel - **Verified**
O.3	The biofilms shall be transferred inside of the Esrange laboratory.	I, R	-	I - done R - done	Verified
O.4	The experiment shall operate autonomously, without human intervention	T	Test 1	T - done	Verified
O.4.1	The system shall instantly start running and continue to function when connected to power supply	T	Test 1	T - done	Verified
O.4.2	The system shall instantly shut down when disconnected from power supply on retrieval	T	Test 1	T - done	Verified
O.5	The tube's temperature measurements shall be shared via Downlink with the Ground Station.	A, T	Test 10	A - done T - done	Verified
O.6	The handling of bacteria shall comply with the safety regulations of the facilities they are handled in.	I, R	-	I - done R - done	Verified
O.7	The handling of bacteria shall comply with the rules for international exports posed by the German war weapons control act.	I, R	-	R - done	Verified
O.8	The backend shall ensure continuous data processing and management in the event of receiving invalid requests.	A, T	Test 11	A - done T - done	Verified
O.9	Operational documentation detailing the backend functionality shall be maintained and made available for user reference and system explanation.	R	-	R - done	Verified
O.10	The plot interface shall alert if the temperature data are exceeding the tolerance range according to D.14, D.15.	A, T	Test 12	A - done T - done	Verified

O.11	The software system shall feature a fault detection system.	A, T	Test 13	A - done T - done	Verified
O.12	The system shall support retrieval and export of plotted data for further analysis and reporting.	A, T	Test 1	A - done T - done	Verified

5.2 Verification Plan

Test number	**Test 1**
Test type	a. To verify that all the electronic subsystems are functional b. Verify data handling, storage, retrieval and exporting c. Power consumption measurement d. Overall functioning of the system; from start to shut down
Test facility	University lab
Tested item	*the motherboard, oxygen sensors, thermistors, light sensors and kapton heaters*
Model	Engineering Model (a) Protoflight Model (b,c,d)
Procedure, Test level and duration	a. Making sure all power electronics are working even under load. Test each individual sensor by checking their functionality and performance specifications in varying conditions. Checking stability problems via an oscilloscope. b. Connect all electronic components to sample one tube prototype in required configuration and with the power source, and start measurement and sending of data via the motherboard. Verify if the download container (package) is intact and properly filled with the right data. Additionally, check if the data is stored on the SD card by running it on a computer. c. Measuring the power consumption of the subsystems and comparing it with the expected current draw. Measuring the power consumption of the complete motherboard under various operating conditions to ensure compliance with the BEXUS power supply. d. The system should start as soon as connected to the power supply, and instantly stop when disconnected. Also should restart in case of power failure or data corruption. Qualification test; few hours
Test campaign duration	1-2 days
Test campaign date	June - August 2024
Test completed	YES

Requirements verified	F.2, F.3, F.4, F.5, F.6, F.7, F.8, F.9 P.1, P.3, P.4, P.5, P.6 D.20, D.27 O.4, O.4.1, O.4.2, O.12

Test number	**Test 2**
Test type	Temperature stability in a thermal controlled vacuum (Thermal Vacuum)
Test facility	Thermal vacuum chamber in a lab (ZARM)
Tested item	The entire experiment model
Model	Flight Model
Procedure, Test level and duration	Continuous monitoring of temperature within specified range over a period of couple of hours (exceeding the expected flight duration); Acceptance and Performance test
Test campaign duration	1-2 days
Test campaign date	First week of September with ZARM
Test completed	Yes
Requirements verified	Req ID #P.2: YES Req ID #D.6: YES Req ID #D.11: YES Req ID #D.12: YES Req ID #D.17: YES

Test number	**Test 3**
Test type	Tube sealing integrity/Pressure Testing
Test facility	Vacuum chamber in a lab
Tested item	Sealed tubes
Model	Prototype Model
Procedure, Test level and duration	Subjecting sealed tubes to pressure differential and leakage testing to ensure hermetic sealing for around 5 hours. The tube was subjected to an inside pressure of 0.1 bar, and therefore was tested against an atmospheric pressure of 1bar, and place

	inside a container of water to check for bubbles (indicative of pressure leakage); Acceptance and Reliability test
Test campaign duration	1 day
Test campaign date	Mid-August. 2024
Test completed	Yes
Requirements verified	Req ID #D.2: YES

Test number	**Test 4**
Test type	Static Load Test for structural integrity and gondola fixation
Test facility	Kiruna Dome
Tested item	Final module structure
Model	Flight Model
Procedure, Test level and duration	1. Apply 10 G (10x the mass of the module) to the top of the isolated module 2. Load test on gondola fixture: Apply 10G to top of module fixated to gondola. 3. Load test on bottom of module: Apply 10G on bottom of module while fixated to gondola to simulate force applied by experiment core.
Test campaign duration	1 h
Test campaign date	27th September 2024 (during launch lampaign)
Test completed	Yes
Requirements verified	Req ID #D.10: YES Req ID #D.13: YES

Test number	**Test 5**
Test type	Interface/grounding functionality
Test facility	University Lab

Tested item	*Electronic interface of the module with power connector (Power and LAN connection)*
Model	Prototype Model
Procedure, Test level and duration	Testing the functionality of power and LAN interfaces, including connection and communication; Acceptance test; 30 mins
Test campaign duration	Few hours
Test campaign date	June. 2024
Test completed	Yes
Requirements verified	Req ID #D.15: YES Req ID #D.16: YES

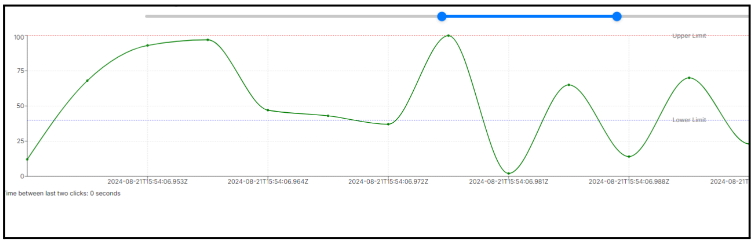
Test number	**Test 6**
Test type	Low Fidelity Thermal testing (system operation under cold and hot case)
Test facility	Hot case: Outside in the sun Cold case: in a freezer/refrigerator
Tested item	Final module structure
Model	Qualification Model
Procedure, Test level and duration	Subjecting the entire experiment setup for the duration of the flight under the sun and in the freezer/refrigerator to simulate the cold and hot conditions and verify hardware functionality under these conditions. System further verified through Test 2 to achieve Flight Readiness Level; Acceptance and Environment test; 4-5 hours each
Test campaign duration	2 days
Test campaign date	Mid-August 2024
Test completed	detailed test results **Hot case:** Not an issue. **Cold case:** Heating is proven to be sufficient at around 15°C for the module in a fridge. This shows the step impulse function in the appended document. We will improve at the isolation by adding more isolation material

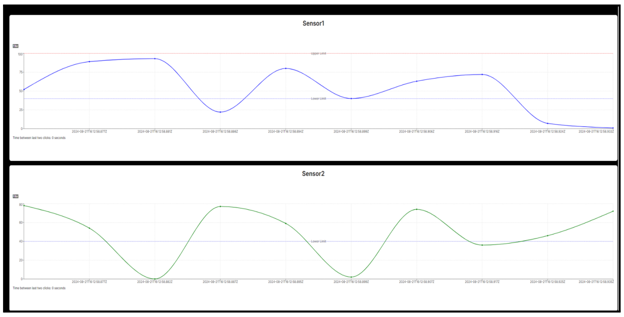
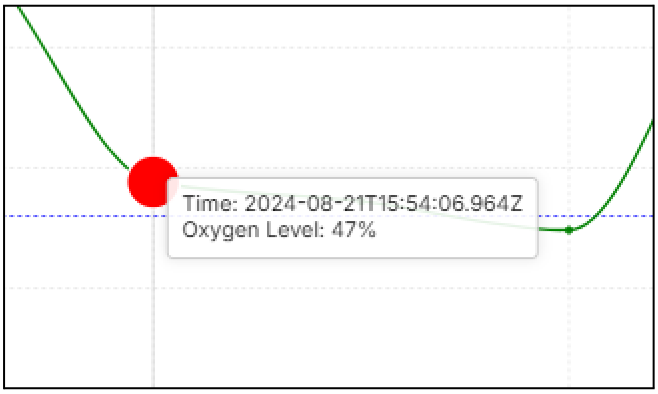
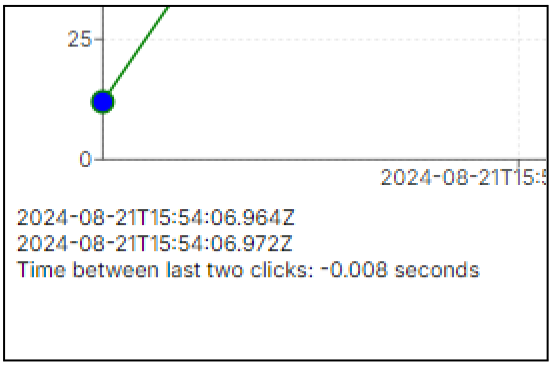
	around the tubes and outside of the module. Moreover, the gaps between the foam structure will be filled with isolation material and taped tightly. Regarding the heating system, we are also able to increase the heating capability significantly by adding an external buck converter. Also: as the drop of temperature of the module is accompanied with a drop of pressure, the lack of air will isolate our module as well, reducing heating requirements significantly. See Fig 4-17 **Update:** ZARM tvac test proved our heating system to be sufficient.
Requirements verified	Req ID #D.6: YES Req ID #D.7: YES Req ID #D.17: YES

Test number	**Test 7**
Test type	Weight and dimensions
Test facility	Electronic scale and measuring tape
Tested item	Final module assembly
Model	Flight Model
Procedure, Test level and duration	Weighing experiment assembly to ensure compliance with mass budget and also measuring the external dimensions of the module to stay within the allotted volume for the experiment on the gondola; Qualification test; 2-5 mins
Test campaign duration	30 mins
Test campaign date	Last week of August. 2024
Test completed	Yes (Table 4.2)
Requirements verified	Req ID #D.18: YES Req ID #D.19: YES

Test number	**Test 8**
Test type	Downlink testing. Interrupt stability, data rate and storage
Test facility	Laboratory setup with data transmission system
Tested item	Data transmission system

Model	Proto flight Model
Procedure, Test level and duration	Measuring the data transmission rate of the experiment system to ensure it is sent to the ground station at lower than 50 kb/s; Acceptance and Performance test; a few hours
Test campaign duration	A week
Test campaign date	July 2024
Test completed	Yes
Requirements verified	Req ID #D.22: YES Req ID #D.24: YES

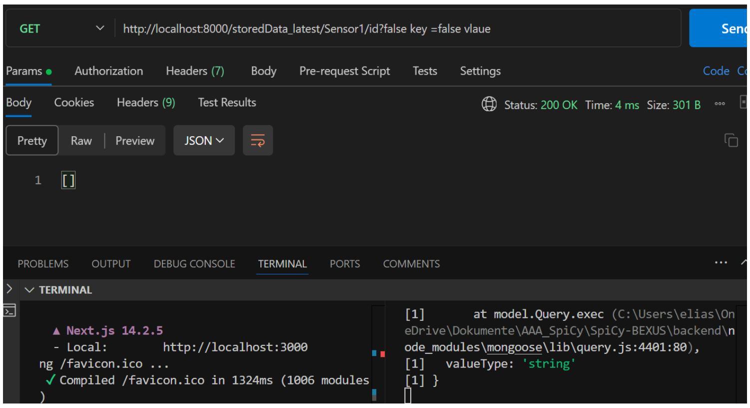
Test number	**Test 9**
Test type	Frontend functionality testing
Test facility	Laboratory setup with software and data visualization tools
Tested item	Frontend software
Model	Qualification Model
Procedure, Test level and duration	Testing the frontend software to ensure it provides functionality to evaluate collected data in oxygen and temperature plot; Qualification and System test; 1-2 hours Use the slider to zoom in on specific data points in the oxygen plot.  Verify the zoom functionality and confirm that only the last 10 points are visible when the slider is deactivated.

	 Tooltip Verification Hover over data points to check that tooltips display accurate data.  Measurement Tool Test Use the measurement tool to calculate and verify the time between two plotted points. 
Test campaign duration	A week
Test campaign date	July 2024
Test completed	YES (with dummy/simulated data)
Requirements verified	Req ID #D.25: VERIFIED

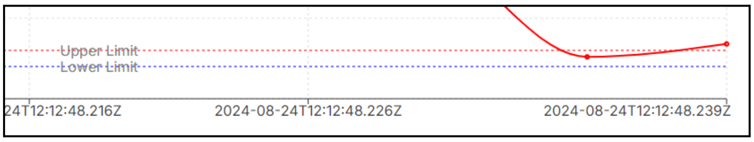
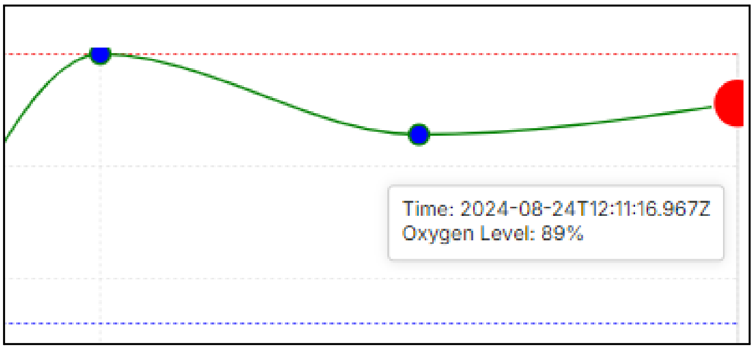
	Req ID #D.26: PARTIALLY

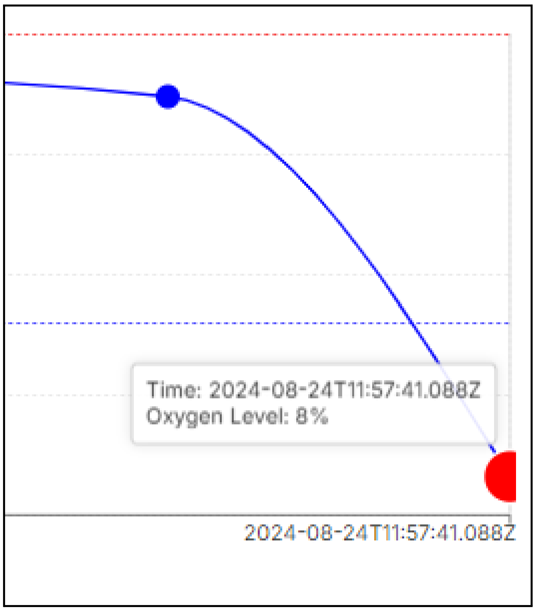
Test number	**Test 10**
Test type	Data downlink, update and visualization testing
Test facility	Laboratory setup with ground station simulation equipment
Tested item	Data visualization system
Model	Qualification/Proto flight Model
Procedure, Test level and duration	Testing the system to ensure it checks for new data every 3 seconds and that incoming data is live plotted on the ground station as required; Enable console logging to capture data checks. 4356 Verify that the system checks for new data every 3 seconds. Calculate time intervals between server responses to confirm compliance. Ensure incoming temperature and oxygen data are accurately visualized in real-time. Cross-check logged data with the data shown in the plots.  Acceptance test; few hours
Test campaign duration	A week
Test campaign date	July. 2024

Test completed	YES (with dummy/simulated data)
Requirements verified	Req ID #D.28: PARTIALLY Req ID #D.29: PARTIALLY Req ID #D.30: PARTIALLY Req ID #D.31: PARTIALLY Req ID #O.5: PARTIALLY

Test number	**Test 11**
Test type	Backend functionality testing
Test facility	Laboratory setup with backend software and simulated invalid requests
Tested item	Backend software
Model	Proto flight Model
Procedure, Test level and duration	Testing the backend software to ensure continuous data processing and management, including handling of invalid requests; Ensure the backend is running normally. Use Postman to send invalid requests (e.g., incorrect data or endpoints). Confirm the backend continues to process valid data without interruption. Check logs for error handling. Record observations to verify backend stability and data integrity.  Acceptance test; 1-2 hours
Test campaign duration	A week
Test campaign date	End of July. 2024
Test completed	Yes

Requirements verified	Req ID #O.8: YES

Test number	**Test 12**
Test type	Alert functionality testing
Test facility	Laboratory setup with plot interface software and simulated temperature data;
Tested item	Plot interface software
Model	Proto flight Model
Procedure, Test level and duration	Testing the plot interface to verify alert functionality for temperature data exceeding tolerance range; Load Out-of-Range Data Input temperature data into the plot, ensuring some values exceed the tolerance limits. Check Alert Response Verify that the plot turns red if the last data point exceeds the upper limit.  Verify that the plot turns green if the last data point is in between the limits  Verify that the plot turns blue if the last data point falls below the lower limit.

	 Acceptance and System test; 1-2 hours
Test campaign duration	Few days
Test campaign date	End of July. 2024
Test completed	YES Partially in Oxygen Plot
Requirements verified	Req ID #O.10: YES

Test number	**Test 13**
Test type	Fault detection testing
Test facility	Laboratory setup with software fault simulation tools
Tested item	Software system
Model	Qualification Model
Procedure, Test level and duration	Testing the software system to verify the functionality of the fault detection system; Acceptance and System test; few hours
Test campaign duration	A week
Test campaign date	Start of August. 2024
Test completed	Yes
Requirements verified	Req ID #O.11: YES

	In case of any small fault, a debug message gets downlinked. Can be fixed with firmware update. For big faults the watchdog is used to reset the electronics.

Test number	**Test 14**
Test type	Exposure to natural sunlight
Test facility	Outdoor test site with access to direct sunlight
Tested item	The glass to be placed on top of module with UV sensor underneath
Model	Engineering Model
Procedure, Test level and duration	Position the glass under direct sunlight with a UV sensor underneath to measure the sunlight that passes through as a qualification test and one of the necessary conditions for the experiment's success. Qualification test; 30 mins
Test campaign duration	A few hours
Test campaign date	Second week of August 2024
Test completed	Yes
Requirements verified	Req ID #F.1: YES Req ID #F.6: YES Req ID #D1: YES

5.3 Verification Results

Verification number	*Test 1 (a, b, c, d)*
Type of test	*a. To verify that all the electronic components are functional* *b. Verify data storage, retrieval and exporting* *c. Power consumption measurement*

	d.Overall functioning of the system; from start to shut down
Facility	*University Lab*
Verified item	*the motherboard, oxygen sensors, thermistors, light sensors and kapton heaters*
Verification description	*a.* *-For the power electronics put a resistor for max current draw across the output and see if the voltage is still stable.* *-For the oxygen sensors test them with a 0% oxygen solution and then with as many other sources of know oxygen levels as can be found in the lab.* *-For the thermistors put Ice in a glass to warm up and measure temperature with the thermistors of the motherboard and also with some calibrated ones. Then compare. (Temperature sweep)* *-The light sensors can be only tested by shining a UV and the sunlight on it and seeing if the data seems to be alright, as we do not have access to an optical lab. They are factory calibrated.* *- Testing if the heaters are working.* *b.* *Running all data acquiring methods in loops and tests with a signal analyser and oscilloscope for data corruption. Writing dummy data in the sd card and seeing if there's any conversion/corruption problem.* *c. disabling all subsystems except one and measuring the power consumption. If disabling is impossible, subtract the known from the unknown.* *D. running the whole experiment and ensure it still work, if:* *-> power gets recycled* *->loses Ethernet link*

	-> sd card goes missing *-> one or more oxygen sensors are missing* *-> one or more thermistors are missing* *-> one or more light sensors are missing* *-> one or more heaters are missing*
Expected results	*a. no significant deviation from the calculated accuracy values for the sensors and no great dividation from the in the data sheets stated values for the power electronics* *b.no data corruption and a healthy sd card* *c.no significant division to the power levels stated in the SED* *d.no complete failure (aka. Blackout or infinite reboot in watchdog) regarding what cable/component gets removed.*
Obtained Results	*Matched expected results. Conversions or corruptions were not recorded.*
Conclusions	The data acquiring systems reliably generates and saves data in a worst-case scenario and thus can be integrated.

For the following tests, as well as those discussed in Section 5.3, the verification results were obtained at the system level rather than for individual subsystems. Some visuals have already been presented in Section 5.2, while the rest were verified during the comprehensive testing of all module systems, including TVAC (Thermal Vacuum) testing and final flight evaluations.The obtained results were as expected and according to the procedures detailed earlier.

Verification number	*Test 4*
Type of test	*Static Load Test*

Facility	*Esrange Dome*
Verified item	*Integrity of module structure and faction to gondola*
Verification description	1. Loadtest on Experiment structure: Experiment mass: 3,86kg Mass of reference man: 70kg  2. Loadtest on Gondola fixture: Experiment mass: 3,86kg Mass of weights: 40kg

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3. Loadtest on bottom of module:

Mass inside experiment (foam box, no aluminium rails): 2.1kg

Pulling force: 30.9kg


</td></tr>
<tr><td>Expected results</td><td>We expect that the experiment module and the fixation to the gondola withstands the static load applied.</td></tr>
</table>

Obtained Results	*The tests were successful. The integrity of the module was retained during the static loads applied*
Conclusions	The cables and connectors can be integrated.

Verification number	*Test 5*
Type of test	*Interface/grounding functionality*
Facility	*University Lab*
Verified item	*Electronic interface of the module with power connector (Power and LAN connection)*
Verification description	*Testing if every cable fits and is easy to connect.*
Expected results	*All is working as expected.*
Obtained Results	*Same as expected results.*
Conclusions	The cables and connectors can be integrated.

Verification number	*Test 8*
Type of test	*Motherboard and tcp server running on a laptop with lan port*
Facility	*University Lab*
Verified item	*Setting up the tcp Server and connecting the motherboard via LAN.* *Testing up downlink via sending of commands/dummy packets. Testing for data corruption and interruptions.*

Verification description	Measuring the data transmission rate of the experiment system to ensure it is sent to the ground station at lower than 50 kb/s
Expected results	*The data is sent to the ground station at lower than 50 kb/s.*
Obtained Results	*Same as expected results.*
Conclusions	The data transmission rate is acceptable.

Verification number	*Test 9*
Type of test	*Frontend functionality testing*
Facility	*Laboratory setup with software and data visualization tools*
Verified item	*Frontend software*
Verification description	***Frontend Data Retrieval:*** ● *Trigger the frontend application to retrieve the newly added dummy data from the database.* ● *Use console logs to track the data retrieval process. Verify that the console logs indicate successful data fetch without errors.* ***Data Plotting:*** ● *Implement the logic to plot the retrieved data on the frontend.* ● *Use console logs to capture the plotting process. Ensure that each data point from the dummy data set is accounted for and correctly mapped onto the plot.* ***Verification of Plot Accuracy:***

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- *Manually inspect the plotted data on the frontend interface to ensure it matches the dummy data.*

Console Log Verification:

- *Review the console logs to confirm that:*
- *Data retrieval from the database was successful and complete.*

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<tr>
<td>Expected results</td>
<td>

The database contains the complete and correct set of dummy data.

The frontend retrieves all the dummy data without any issues.

The data is accurately plotted on the frontend interface, reflecting the expected visual representation.

Console logs confirm the successful completion of each step without errors.

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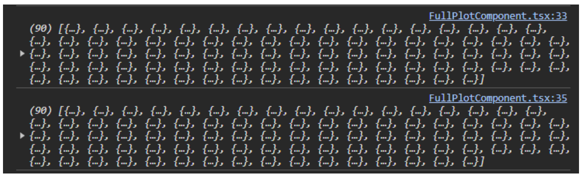
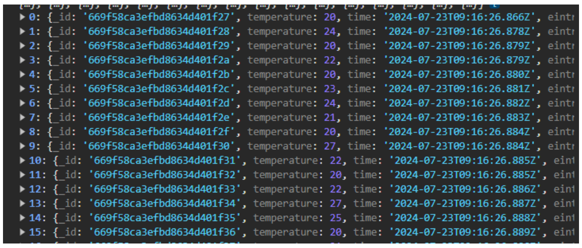
<tr>
<td>Obtained Results</td>
<td>

The dummy data is plotted completely.





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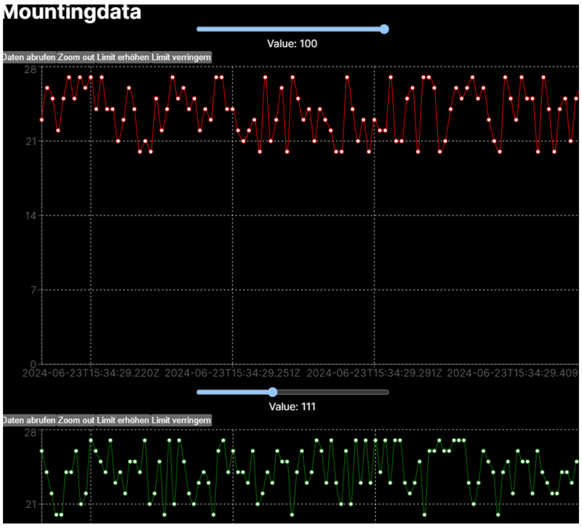
	 *There are no duplicate data points.* *The plot accurately represents the dummy data.*
Conclusions	*Upon successful completion of the above verification steps, it can be concluded that the system correctly handles dummy data from database storage to frontend visualization.*

Verification number	*Test 10*
Type of test	*Data downlink, update and visualization testing*
Facility	*Laboratory setup with ground station simulation equipment*
Verified item	*Data visualization system*

Verification description	*Dummy data is sent to the visualization system.*
Expected results	*The dummy data is visualized correctly*
Obtained Results	*Same as expected results.*
Conclusions	The software reliably sends, receives and visualizes the measured data.

6 LAUNCH CAMPAIGN PREPARATION

6.1 Input for the Campaign / Flight Requirement Plans

6.1.1 Dimensions and Mass

Table 6-1: Experiment Mass and Volume

Experiment mass (in kg):	3.86 kg
Experiment dimensions (for BEXUS) or module size (for REXUS) (in m):	290 x 290 x 306 mm
Experiment expected COG (center of gravity) position:	145 x 145 x 200 mm

6.1.2 Ground and Flight Safety Risks

Table 6-2: Ground and flight safety risks

Risk	Key Characteristics	Mitigation
Glass tubes filled with bacteria and bacterial medium at ground pressure might leak.	Content: Cyanobacterial Biofilms within liquid bacterial medium	Neither bacteria nor medium pose a hazard to human health. Handling of the contents is safe. Tubes are sealed to be leak proof and withstand pressure gradient.
Glass tubing or upper ceiling might break due to impact during landing.	Sharp glass shards	Selection of quartz glass with high stability. If the recovery team detects shattered glass, please proceed with caution. Wear gloves.

6.1.3 Electrical Interfaces

Table 6-3: Electrical interfaces applicable to BEXUS

BEXUS Electrical Interfaces
E-Link Interface: E-Link required? Yes

	Number of E-Link interfaces:	1
	Number of required IP addresses:	TCP_SERVER_IP(169,254,218,4); PAYLOAD_IP(169,254,218,100); *They can be edited in code.*
	Data rate – downlink (max. and average):	472B/s on average, 5KB/s max
	Data rate – uplink (max. and average):	11B/s on average, 162KB/s max (but only if a firmware update should be necessary. This should not be the case)
	Interface type (RS-232, Ethernet):	Ethernet
Power system: Gondola power required? Yes		
	Peak power and current consumption:	35.025 W and ~1,2A
	Average power and current consumption:	4W (averaged over the whole flight, current consumption will be way higher at liftoff) per tube
	Total power and current consumption after lift-off	40Wh
Power system: Experiment includes batteries? No		

6.1.4 Launch Site Requirements

Table 6-4: Launch Site Requirements

Category	Item	Amount	Provided by
Microbiology laboratory	Sterile flow hood	1	SSC
	Serological pipettes 5 mL (sterile)	5	SSC
	Serological pipettes 10 mL (sterile)	5	SSC
	Serological pipettes 25 mL (sterile)	5	SSC

	Window (ideally south/south-west facing)	1	SSC
	Shaker incubator	1	SSC
	Table centrifuge (for Eppendorf tubes)	1	SSC
	Centrifuge for 50 mL vessels	1	SSC
	Photometer	1	SSC
	Pipetting aid (for serological pipettes)	1	SSC
	µL pipettes (10 µL, 50µL, 100µL, 1 mL)	1 of each	SSC
Workstation	Table	1	BEXUS
	Chair	7	BEXUS
	Access to a Lab Power Supply, 0 – 30V	1	BEXUS
	Power extension cord	2	BEXUS
	Whiteboard	1	BEXUS
	Whiteboard marker (multiple colors)	2	BEXUS
	Access to a SMD hot air soldering station	1	BEXUS

6.1.5 Flight Requirements

Table 6-5: Flight Requirements applicable to BEXUS

Optimal altitude	**As high as possible**
Preferred path	**/**
Minimum float time	**1 h**
Ground track length	**/**
Light/dark condition	**Natural sunlight**

To maximize the sunlight elevation angle, the desired flight time is close to noon, which in Kiruna on the 1st of October is at 12:28. Ideally, the window for the flight should be distributed evenly with the noon in between, e.g. 2 hours flight → Launch - 11:28 and Landing - 13:28T. If this is not entirely possible, a launch time after sunrise (06:53 on 1. October) shall be chosen, preferably as close to noon as possible.

UV-A irradiance increases ca. 9 % and UV-B irradiance ca. 18 % per 1000 m altitude under clear skies (Blumthaler, Ambach and Ellinger, 1997; Schmucki and Philipona, 2002). This results in the altitude requirement of “as high as possible”. The higher the UV irradiance the higher the significance of the results of SpiCy.

6.1.6 Accommodation Requirements

Our experiment design shall be mounted on the top of the gondola ensuring that the top part is not covered by any other experiment. Ideally, our experiment is placed away from other experiments that produce outward thermal energy to avoid overheating of our module.

6.2 Preparation and Test Activities at Esrange

Table 6-6: List of planned activities

Time/Day	Main Task	Description	Responsible	Duration [h:m]
3 days before launch	Static load test for the module	Apply static load of at least 10g on the module structure	Tian	1h
2 days before launch	Measure oxygen production of biofilms	Measure oxygen production of biofilms. Confirm expected results.	Ilana, Alex, Fynn	1h
1 day before Launch	Measure oxygen production of biofilms	Measure oxygen production of biofilms. Confirm expected results.	Ilana, Alex, Fynn	1h
	up/downlink	Testing ip allocation and up/downlink communication	Fynn, Elias	Depends on success. 5min to 2h
	Hardware Preparation	Arrive at the launch site and set up equipment and workspace.	All team members	1h
Launch day	Prepare the bio module	Ensure proper sealing of all tubes and insert into rack.	Alex, Tian	1h

	Prepare mechanical module	Prepare the mechanical module, ensuring all connections and attachments are secure.	Tian, Pablo, Fynn	2h
T-5H	Transport the bio module	Transport the bio module to Dome (room temperature).	Ilana, Alex	10 min
	Integrate bio module	Integrate the bio module with the mechanical module and perform a final inspection to verify proper assembly. Verify electronics.	All team members	30 min
	Mount whole box on the gondola	Mount the assembled modules onto the gondola of the sounding balloon and secure them in place.	Tian, Fynn, Alex	10 min
T-4H00	Covering	Cover glass plate of bio module with cling film.	Tian, Ilana	10 min
T-3H30	Comm' check	Communications checked	Fynn, Elias	30 min
	Tests outside Dome	Testing	Tian, Fynn, Alex, Elias, Pablo, Ilana	1h
T-2H00	Nominal functions check	Confirm hat expected sensor data is received	Elias, Ilana, Alex	10 min
T-1H00	Late Access: Remove Covering	Remove covering from module.	Ilana, Tian	2 min
	Nominal functions check	Confirm that expected sensor data is received.	Elias, Ilana, Alex	10 min
	Confirmation	Report ready for inflation.	Ilana	
0	Balloon Release	Launch the sounding balloon with the SpiCy experiment onboard.	BEXUS team	

6.3 Timeline for Countdown and Flight

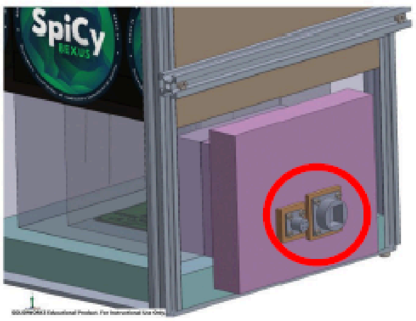
We have no specific timeline for our payload, as it is an uninterrupted continuous experiment. The moment it receives power all measurements / heaters are starting and the moment the battery runs dry it stops.

6.4 Post-Flight Activities

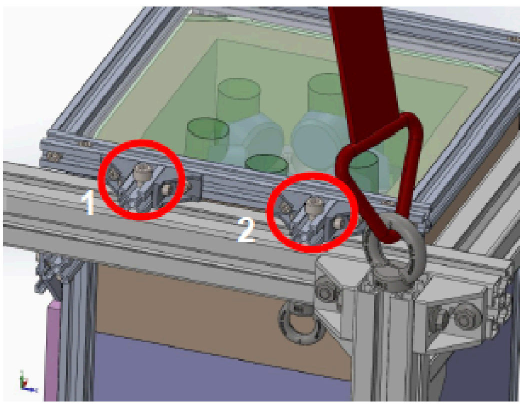
Recovery Instructions:

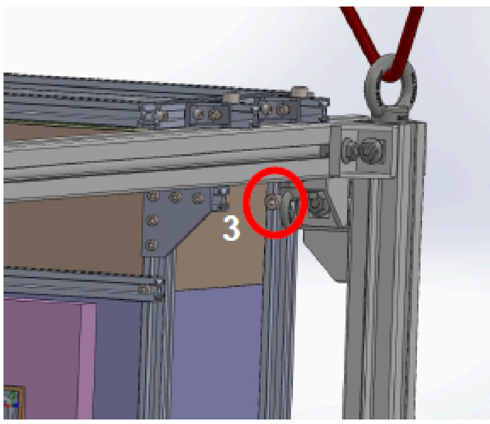
Nominal:

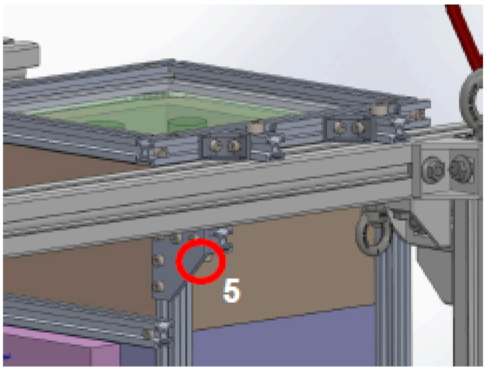
1. Inspect the recovery ground for glass shards.
2. If glass shards visible, wear protective gloves (provided by SpiCy).
3. Unplug power and ethernet connector.

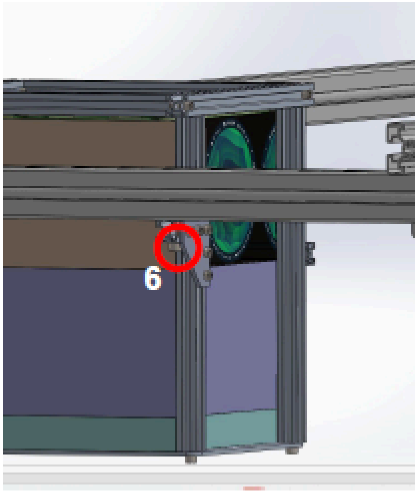


4. Turn gondola so that glass is on top.
5. Unscrew the SpiCy module from the gondola (M8 allen key provided by SpiCy). The screws are only accessible from the top. There are 6 screws in total. The order of unscrewing does not matter.









6. Put whole module into provided bag.
7. Close bag.

Bag:

Not nominal – what if:
Scenario 1: Top glass panel breaks during landing
Impact: Glass shards may pose mechanical hazard to the recovery team. If glass shards are detected, please wear gloves for mechanical protection (specialized gloves are also provided by SpiCy).

Scenario 2: Top glass panel and glass tubes break during landing

Impact: Glass shards as well as bacteria-containing liquid may be covering parts of the module. In addition to wearing gloves to protect from glass cuts, the mechanical team should avoid touching their face, especially eyes and mouth. While the bacteria and their medium are not harmful to humans or environment, allergic reactions to medium contents or bacterial by-products are always possible when handling organisms.

Scenario 3: Gondola lands on the top or top is inaccessible
Impact: Whole module cannot be unscrewed. The gondola must be turned to a side so that the top screws are accessible.

7 Data Analysis And Results

7.1 Data Analysis Plan

Pre-Experiments on Ground:

The first step is the cultivation of our cyanobacteria with different media. The Chroococcidiopsis cubana are grown in BG11+ and BG11 media to find the best growth conditions. The strains Nostoc and Oscillatoria are kept in BG11 media. The growth rate is determined via microscopy and visual indicators such as the color of the culture and the density.

We subsequently cultivate Pseudomonas taiwanensis, E.coli, Bacillus subtilis, Lactobacillus plantarum and Lactobacillus fermentum in their respective media and the minimal medium M9.

The next step is to optimize the combination of cyanobacteria and heterotrophic bacteria. Various combinations and concentrations are evaluated by measuring both oxygen production and biomass growth. The aim is to identify the most effective biofilm composition in regards to their relative oxygen output.

To gain insight into the biofilm composition and especially the matrix composition DNA, RNA and proteins are extracted using the AllPrep DNA/RNA/Protein Mini Kit by QIAGEN. The samples are then stored for a possible later analysis. A western blot analysis is used on the isolated proteins to document the matrix proteins for comparison with the samples extracted after the BEXUS experiment.

Experiment on BEXUS:

The main interrogative is the comparison of oxygen production between the controls, the selected best biofilm candidate and the data already collected in the pre-experiments. The growth rate on BEXUS is compared to the ground data from the pre-experiments.

After the landing, the biofilms are frozen as soon as possible so that DNA, RNA and proteins can be isolated in the lab. A Western blot is performed on the protein samples to compare the matrix composition to the ground experiment.

Final Report:

All the collected data will be integrated into a comprehensive statistical analysis. The parameters will be growth rates, biomass production, oxygen production and matrix composition.

After the final analysis predictions on whether biofilms of cyanobacteria and heterotrophic bacteria are a possibility for oxygen production in space travel will be made.

7.2 Launch Campaign

7.2.1 Flight Preparation Activities

1. Arrival of biological samples in the laboratory. Further cultivation with full spectrum lamp (36W) during module setup. Preparation of biological samples as described in Appendix E one day before first launch.
2. Disassembly of biomodule and placement back into the laboratory setup after first and second unsuccessful launch attempt. This delay altered our experimental setup conditions by transporting the bacteria back and forth from laboratory to Dome multiple times with varying light and temperature conditions.

Fig. 7.2-1: Laboratory setup of biological samples. Due to lack of sunlight in the facilities a 36W full spectrum lamp was employed in ~30cm distance to the circular arranged tubes.

Fig. 7.2-2: Liftup of microbial biofilm mat. Shortly after arrival, some samples show detachment of the biofilm from the bottom of the glass tube and rise up to the top.

After slightly shaking the tubes, the biofilms sank down again, but remained detached from the glass bottom. This effect may be explained by the strong formation of an EPS matrix during biofilm formation with oxygen bubbles trapped inside the microbial mat. After transport in dark for a prolonged period and exposure to the grow lamp, the motile cyanobacterial mat gained buoyancy and moved toward the stronger light source as the indirect sunlight in the laboratory was not sufficient enough.

7.2.2 Flight Performance

Launch Attempts

There were 2 unsuccessful launch attempts until Thursday, 03.2024.

03.10.2024:
After an unsuccessful launch we collected some ground data to analyze. The bacteria were under an aluminum padded foil lid for the whole duration of the

measurement.

04.10.2024

Attempted launch at 15:15. Sun light requirement shortened to minimum 30 min. Sun light at float phase due to wind gusts towards the wests and too high.

Forecast: massive drop of wind between 14:00 and 15:00. Launch might have been possible.

According to the predicted launch time the angle of light is below 8°C during float phase. Prediction is that the angle is too low for direct UV radiation onto samples. Possibility that aluminum reflective material might refract UV light onto the samples.

Launch was not performed on this day.

Failure Analysis

1. Corrupted data points

We observed a small number of corrupted oxygen sensor data points (less than 1%), which was expected due to the use of non-shielded, multiplexed serial communication. This had no impact on our data analysis, as oxygen levels change too gradually for the loss of a few points to make a noticeable difference.

The appended plot shows that data derived from the oxygen sensors, such as pressure and temp_sample_oxy, contained some corrupted values. However, data from other sources, such as Temp_CPU, remained unaffected by the same issue.

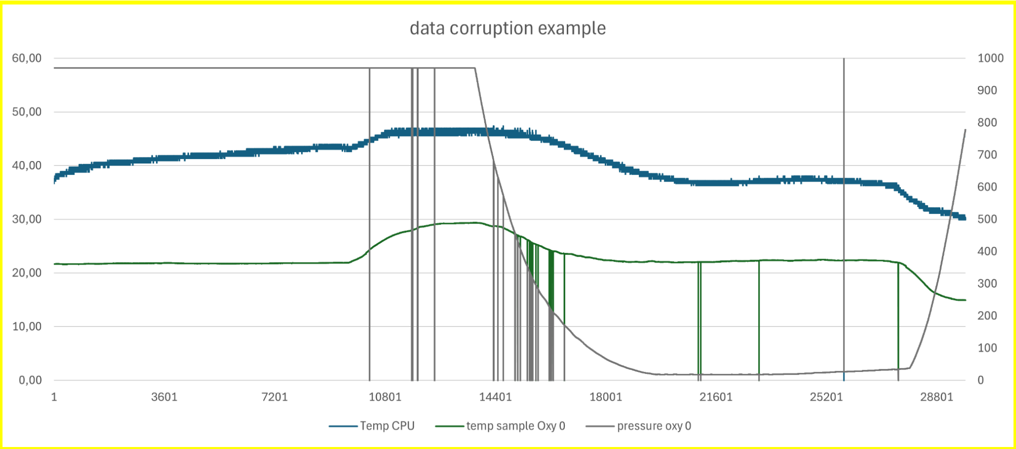


Fig. 7.2-3: Example of data corruption.

2. Temperature and power consumption

During the flight, the temperature inside each tube and power consumption were recorded to study the accuracy of the simulations previously performed.

The maximum altitude of the float phase was 27 km with a temperature of -48°C.

In Fig. 7.2-4, the temperature inside the tubes is displayed. The probes were kept at 20°C before the flight and prior to the launch it was raised up to 27.5°C so the biofilms were at an optimal point for oxygen production.

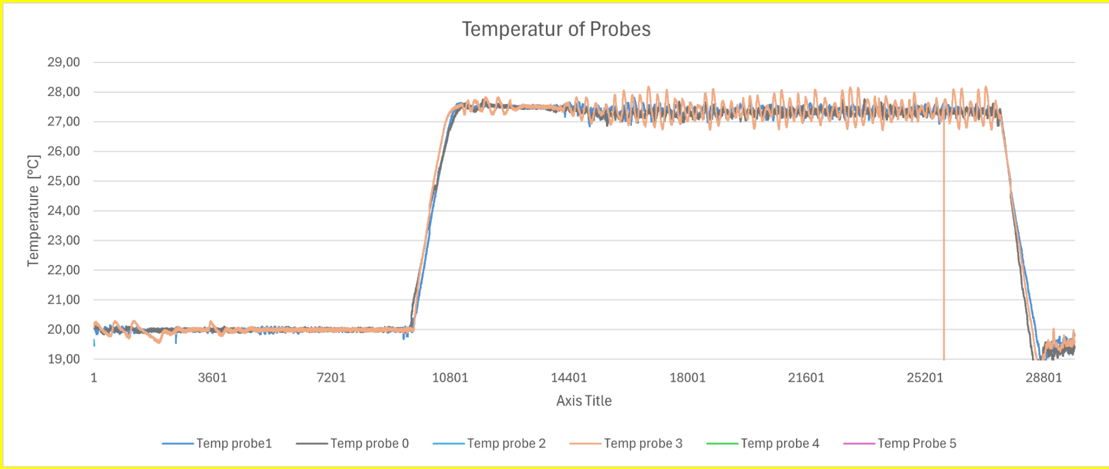


Fig. 7.2-4: Probe temperatures along the flight.

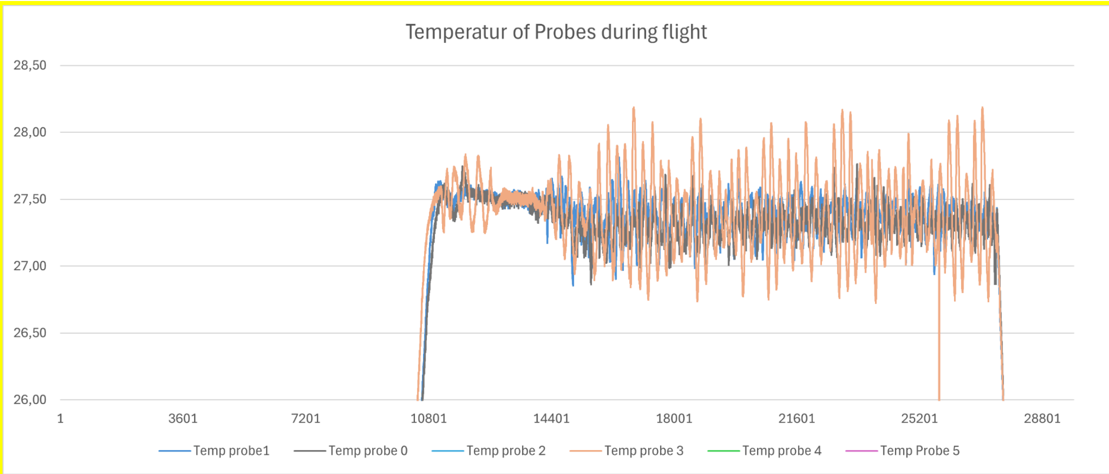


Fig. 7.2-5: Zoom-in of probe temperatures along the flight.

The temperature inside the tubes was kept between 27 and 28°C narrowing down the required range of 5°C to just 1°C.

All the heaters exhibited some oscillation, as it was intentionally programmed to have a faster response than necessary. This was done to ensure the system's stability, even in the event of communication loss or a temperature drop. However, the temperature of probe 3 oscillated more noticeably than the others. While still within the temperature range, this behavior was unexpected given the symmetrical geometry and identical electronics of the tubes.

Attempts to adjust the controller yielded minimal improvement, but no significant changes were made since it was well in the temperature range all the time.

Regarding the power consumption, this experiment used an average of 10.77W and 80.76Wh in total during the ~7.5h from launchpad to cut off. Fig 4-33 illustrates the probe heating power along the flight. Before launch, the power was fixed to 2W per tube for a short period of time to heat them up to 27.5°C. The heating power oscillates significantly with temperature but never reaches the maximum limit of 5W. The average heating power of all the probes is around 2W per tube for the float phase which is similar to the value proposed in the initial analysis. This indicates that the power budget was adequate.

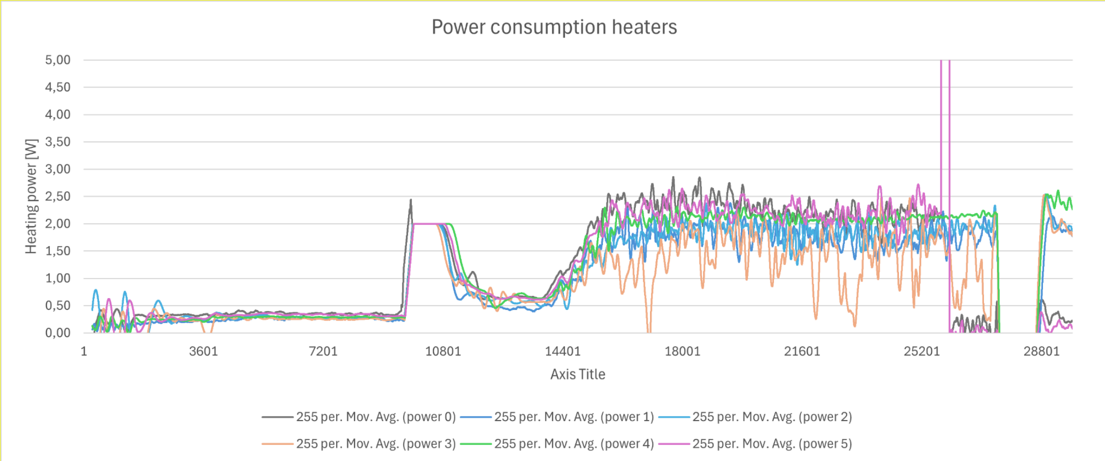


Fig. 7.2-6: Power consumption of heaters along the flight.

The oscillations in heating power might have different reasons:

- Wind over the module surface: the forced convection over the glass surface can have an oscillating effect due to its turbulent behaviour. This turbulent behaviour can increase the heat evacuation in parts of the surface where the speed is higher but it is very difficult to predict with enough accuracy as the movement of the gondola is not prescribed.
- Situation of the probes: although the distribution of the glass tubes is symmetrical, there are two sides on the external side of the gondola and two on the inside. The probes that are placed on the outside are likely to have wider oscillations as there is no dumping effect of the other tubes and the rest of the gondola.
- Cloth over the tubes base: the cloth protecting the electronics from liquid spillage were included in the lower part of the tubes and it is likely that these parts could have modified the dynamic behaviour studied initially.

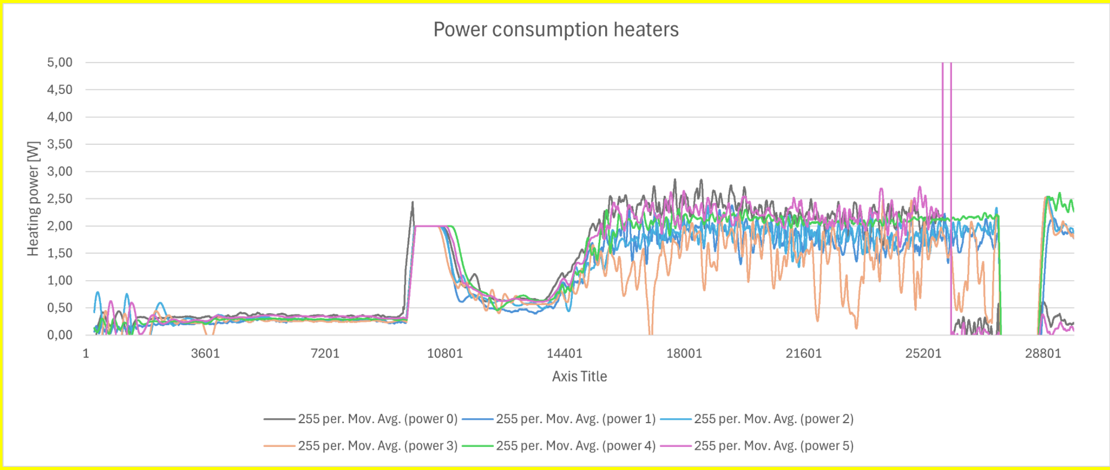


Fig. 7.2-7: Probe temperatures in relation to heating power.

The graph Fig. 7.2-7 illustrates the probe temperatures in relation to the heating power (shown at the bottom). The heating power oscillates significantly with temperature but never reaches the maximum limit of 5W. This indicates that the power budget was adequate.

There was no overheating problem with any of our electronics.

Thermal power considerations which helped achieve our temperature requirements were mainly:

1. Casing (aluminum foil) for preflight activities, radiation is not relevant at this point and axial conduction includes it.
2. Gaps in the foam were sealed last minute before launch with aluminium tape. This decreased the heating power required dramatically, at least compared to the TVAC test. Especially as the launch had winds and TVAC did not.
3. Addition of absorbent material in electronics and around the cap of the tubes.

3. Light measurement

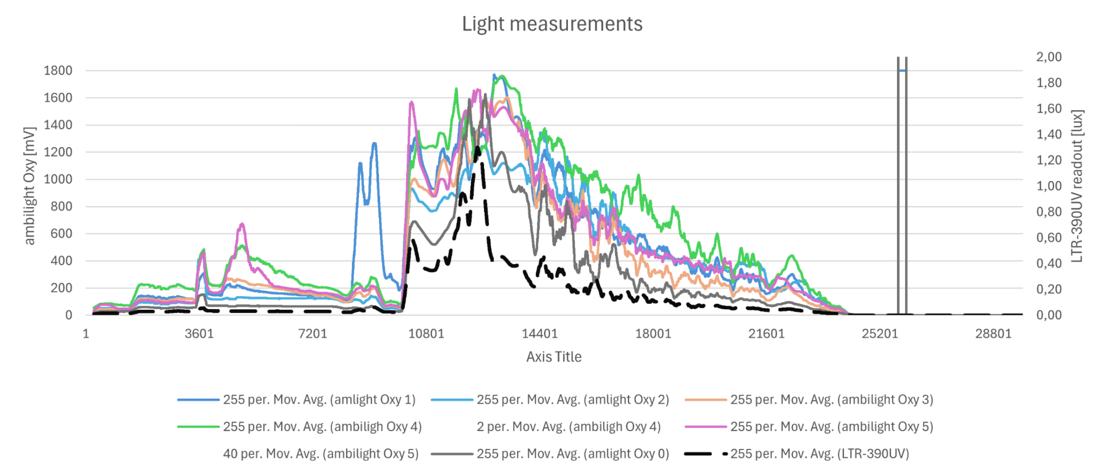


Fig. 7.2-8: Ambient UV light measurements

The ambient UV light measurements from the oxygen sensors showed amplitudes comparable to those of the LTR-390UV light sensor. This suggests that these measurements are at least relatively accurate in terms of their strength.

4. Recovery

The experiment module was not damaged during any time of the flight and recovery operations. The experiment could have flown directly again. Against everybody's expectations even the quartz glass top panel stayed intact.

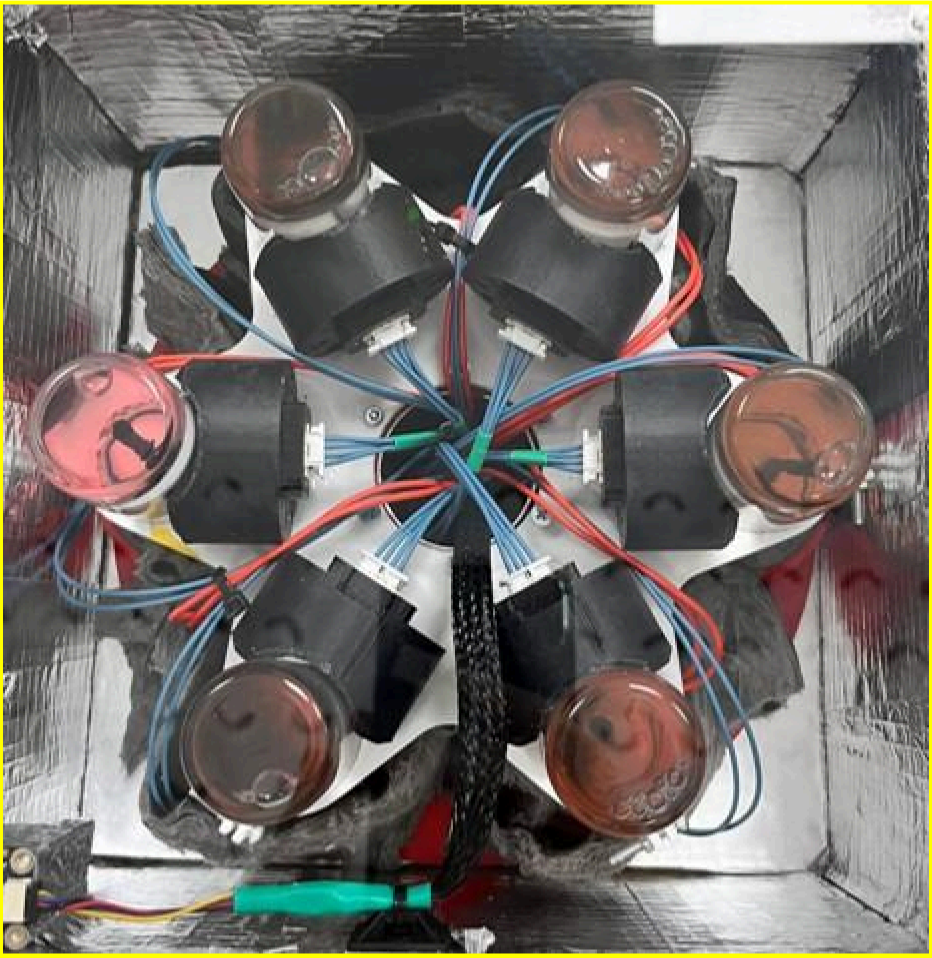


Fig. 7.2-9: Top view of retrieved assembled biomodule.

5. Disassembly and transport to Munich

Check-List before disassembly:

1. Double checking the assignment of every sensor to every probe by individual power on and visual inspection. This was done to make sure no sensor data got assigned to the wrong tube.
2. Readout of the SD card. All stored data there was valid.
3. Compiling the binary SD card data in a .csv file and plotting the data as graphs.

The glass tubes with bacterial probes were taken out of the module and transferred directly into the transport box. They were not opened and kept in the flight configuration since we planned to observe how long they would survive after the flight. The bacteria transport box was taken to Germany via plane with the bio team. In the LMU laboratory they were directly placed under the growth lamp.

The module was not disassembled further. It was placed in the padded and insulated module transport box and shipped to Munich. It arrived in Munich ca. 1 month after the Launch Campaign.

7.3 Results

Cyanobacteria oxygen data and interpretation

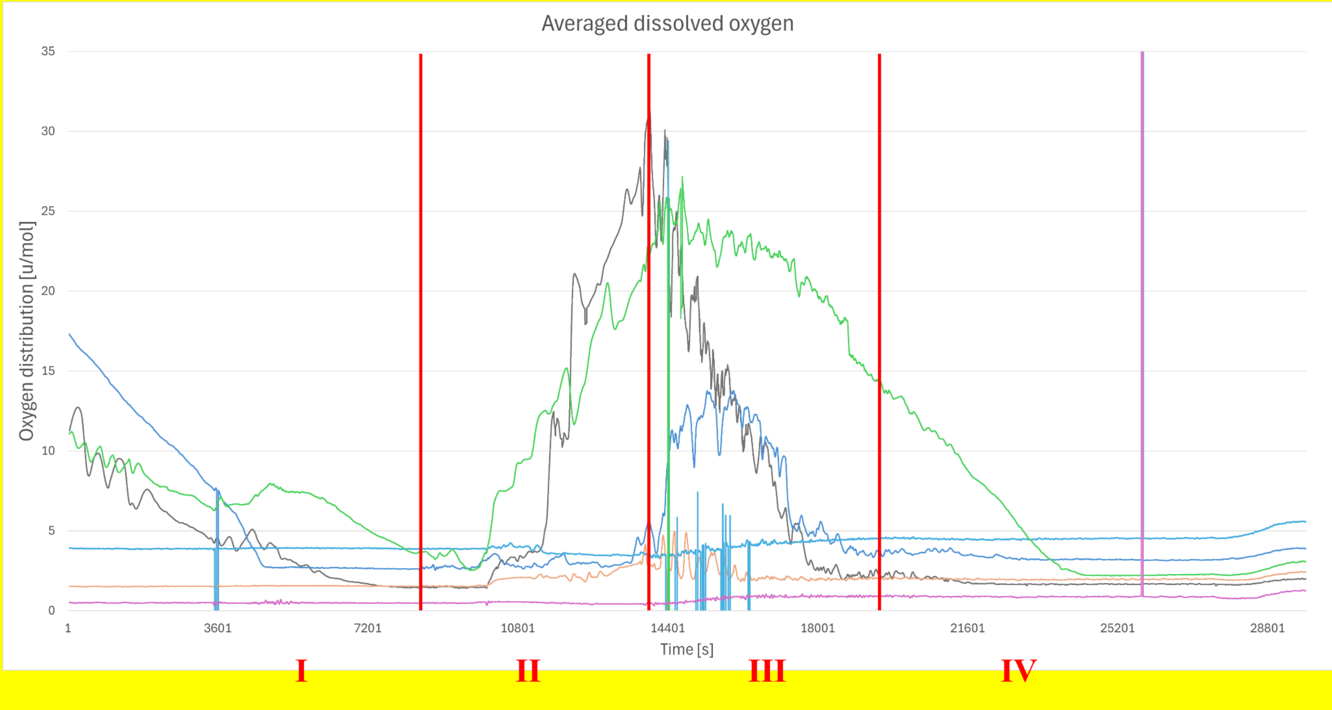


Fig. 7.3-1: Measurement of dissolved oxygen shows significant differences across the samples during flight. Oxygen trends were averaged over 40 time points to account for single corrupted data points.

Samples are indicated by color as follows:

Light Blue: *Nostoc sp.* with *B. subtilis*

Blue: *Nostoc sp.* with *P. taiwanesis*

Green: *Nostoc sp.* with *E. coli*

Black: Pure culture *Nostoc sp.*

Orange: *Nostoc sp.* with *E. coli* from a previous cultivation batch (scraped)

Magenta: Medium control

Samples were not exposed to light during launch preparation (I) and continued to decline in oxygen production. This effect could also be caused by movement of the gondola on the transport vehicle and mounting to the balloon, as abrupt shaking could cause the dissolved oxygen to form bubbles, which the oxygen sensors can not measure.

At late access (II) the light cover was removed shortly before launch. Samples pure culture *Nostoc sp.* (Black) and *Nostoc sp.* with *E. coli* (Green) immediately resumed oxygen production as soon as light was detected (refer to ambient light measurement Fig. 7.2-8). The other samples did not display any significant change in oxygen production, which may indicate a resting state due to stress or the light not reaching the biofilms as they may have sunken down the glass.

Shortly after launch during ascent (**III**) pure culture *Nostoc sp. (*Black*)* immediately stopped oxygen production which rapidly declined. Surprisingly, *Nostoc sp.* with *P. taiwanesis (*Blue) showed increased dissolved oxygen levels right after launch. However, this could have been caused by light reaching the previously sunken biofilm or dissolving of the biofilm into medium and is not directly indicative of a biofilm-related effect.

Most excitingly, sample *Nostoc sp.* with *E. coli (*Green*)* displayed steady oxygen levels, which suggests a continuous production of oxygen despite the changes in altitude, mechanical stresses or increase in light variance during ascent. A slow decline during flight was to be expected, as living conditions are not optimal for any samples in the stratospheric environment and they shut down their metabolism in response.

Also *Nostoc sp.* with *E. coli (*Green*)* maintained steady oxygen production during float phase (**IV**), which can be observed in the delayed drop of oxygen.

The expected reduction of oxygen levels due to cellular respiration by the heterotrophic *E. coli* was not observed, although further research is needed to investigate the presence and function of heterotrophic bacteria in the final biofilms. As indicated in chapter 1.1, heterotrophic bacteria could be vital in sustaining the biofilm, enhancing its initial formation or pre-cultivating the surfaces to allow the cyanobacteria to attach.

As the Medium control sample *(*Magenta*)* did not show any changes in oxygen data throughout the preparation, flight and descent, the oxygen sensors were working properly and the used BG11 medium was not contaminated. The other samples *Nostoc sp.* with *B. subtilis* (Light Blue) and scraped *Nostoc sp.* with *E. coli* (Orange) did not show any change in oxygen data even before flight. This was further analyzed to be very low oxygen data points caused by a missing calibration error due to the multiple assembly/disassembly actions caused by the flight delays.

The biomodule itself and the glass tubes did not show any signs of leakage, contamination or other damages. All biological samples survived the flight and continued to survive back in the laboratory with the exception of the scraped *Nostoc sp.* with *E. coli* from a previous cultivation batch (Orange), which died off 2 weeks after flight.

In conclusion, pure culture *Nostoc sp.* oxygen production dropped immediately and significantly during flight in contrast to complementary cultured *Nostoc sp.* with *E. coli*. This is a first indication towards mediation of resilience in cocultivation and complementary formation of biofilms of cyanobacteria with heterotrophic bacteria.

Future outlook

Current Tests and Experiments

As part of our ongoing research, we are conducting detailed sequencing of *Nostoc* sp. to determine the specific strain we are working with. This foundational step is crucial for understanding its characteristics and potential applications. Additionally, new biofilms are being cultivated under controlled conditions to facilitate accurate oxygen ground measurements. These experiments are essential for interpreting the data collected during the flight and for validating our findings.

To enhance our experimental capabilities, we have partnered with PHIO to utilize their innovative CellWatcher technology. This cutting-edge tool allows for real-time monitoring of *Nostoc* biofilm formation, providing dynamic insights into their development and generating valuable data for our ongoing studies.

Future of SpiCy

Looking ahead, plans are underway to engage students in SpiCy 2.0 and introduce them to the possibilities of conducting their own REXUS/BEXUS experiments. Through dedicated lectures, we aim to inspire the next generation of researchers and promote hands-on involvement in high-impact projects.

To ensure the continuity and growth of the SpiCy initiative, discussions are currently taking place with the dean of the LMU Faculty of Biology about integrating the project into his laboratory. This potential collaboration would provide the necessary infrastructure and support for further advancements.

Moreover, we are actively working on expanding our research with *Nostoc* biofilms to generate data for a comprehensive scientific paper. These additional tests and experiments will deepen our understanding of biofilm dynamics and contribute to broader scientific knowledge in this field.

7.4 Input to Campaign Report

No input to the campaign report is required.

7.5 Lessons Learned

As SpiCy is coming to an end, we would like to reflect on our experience with the program, the team and our environment during the duration of our involvement with REXUS/BEXUS. Apart from the academic, engineering and biological knowledge each of us has gained valuable life lessons and life-long friendships. We would like to thank all of those involved in creating a truly unforgettable experience.

Finding a lab space posed an unexpected challenge, as no professors initially had the resources to assist us. However, this issue is currently being resolved, and a lab space is now available for use. This was made possible after reaching out to the dean and establishing connections with other universities.

Coordinating among the various sub-teams proved to be challenging due to the diverse nature of the subjects involved. Learning to communicate effectively across different specialties was a valuable experience that required time and effort. This problem will also be minimized in the future by implementing the SCRUM methodology. Another reason for communication issues between the sub-teams were unclear requirements. With better requirements, agreed by everyone, it is much easier to work.

The lack of expert knowledge in conducting such projects became apparent during the experimental design phase. To address this, the team engaged in extensive collaboration and sought guidance from external experts, ultimately enhancing the project's design.

Securing grants and sponsors posed a significant hurdle, particularly in the project's early stages. However, the situation has improved, and it is no longer a major concern as the project has gained support from the LMU. As paying travel costs through tax money such as the LMU funds poses bureaucratic difficulties, we continue to look for sponsors in this regard.

Our team acquired proficiency in several novel techniques, including the soldering of QFN components and the cultivation of cyanobacteria. Challenges encountered during our exploration of these methodologies were effectively addressed through insightful conversations with experts. Additionally, we honed our skills by repeatedly practicing these methods.

The outreach team struggled with finding a balance between their own demands and needs, and having to pick the cheapest and quickest way of producing high-quality content. No matter how urgently a scientific project like ours is needed to be given a voice to reach out to the public and potential supporters, especially the financial means amongst our sponsors and ourselves are quite dim, when it comes to not essential experiment-related content. This way, we need to think outside the box of what we learned in sheltered university seminars and shift our design process towards a more flexible and less resource-heavy approach.

Finding a suitable temperature sensor proved challenging due to the varied options available. Testing different sensors is necessary to identify the one with optimal performance.

Defining the requirements for the project presented a challenge. A comprehensive understanding of all necessary components was crucial to ensure the design met expectations. As a team we think that we have now reached a quite clear understanding for the requirements a requirement has on the experimenter.

Simulating the unique experimental environment poses difficulties during the verification process. Overcoming these challenges requires out of the box approaches that we have been developing.

Thorough consideration before conducting experimental tests was essential. Planning and evaluating potential outcomes helped anticipate and address potential issues.

Mechanical design inherently involves multiple iterations to achieve the desired functionality. Each iteration provides valuable insights and opportunities for improvement.

Lessons learned at Launch Campaign:

Every part MUST be labeled and written down manually for everyone to see. This must be also visible without full disassembly of the module. The order of assembly is important.

Background: We did not write down anywhere except on the tubes themselves which sample is measured by every sensor and which tube is where in the module. The labeling of the tubes was not visible without assembly of the whole module. This posed major analysis issues before recovery of the module.

Connected to previous point: Oxygen sensors should also be labeled by sample in groundstation UI (instead of just numbered) so that no guesswork is necessary. Therefore, sensor attribution must be done beforehand.

Summary of the Lessons Learned

The project taught us several valuable lessons, beginning with the unexpected challenge of securing lab space. Initially, no professors had the resources to accommodate us, leaving us at an impasse. However, by reaching out to the dean and fostering connections with other universities, we successfully resolved this issue. Today, a dedicated lab space is available for our work, underscoring the importance of persistence and networking.

Coordinating across sub-teams proved to be another significant challenge, largely due to the diversity of expertise required by the project. Effective communication between specialties took time to develop, but it became a crucial skill for our team. To prevent such difficulties in the future, we have adopted the SCRUM methodology to streamline collaboration. We also realized that unclear requirements further exacerbated these communication issues. Establishing better-defined and mutually agreed-upon requirements not only improved coordination but also laid a stronger foundation for the project.

A gap in expert knowledge became apparent during the experimental design phase, highlighting the need for specialized guidance. By collaborating extensively within the team and consulting external experts, we were able to refine our experimental approach. This experience emphasized the value of seeking diverse perspectives when faced with complex challenges.

Securing funding and sponsorship presented another hurdle, particularly in the project's early stages. With time, support from LMU alleviated many of these concerns. Nevertheless, bureaucratic complications in using LMU funds for travel costs persist, prompting us to actively seek additional sponsors to cover these specific needs.

On a technical front, the team acquired new skills, including soldering QFN components and cultivating cyanobacteria. While mastering these techniques involved overcoming initial challenges, conversations with experts and consistent practice helped us refine our methods. These skills not only advanced the project but also enriched the team’s technical repertoire.

The outreach team grappled with balancing high-quality content production against the constraints of limited resources. Academic seminars had not prepared us for such practical limitations, so we adapted by developing flexible, cost-efficient approaches. This shift required creative problem-solving but proved essential for sustaining our public engagement efforts.

Sensor selection also brought its share of challenges, particularly in identifying the optimal temperature sensor from numerous options. Through rigorous testing, we addressed this issue. Furthermore, lessons learned during the launch campaign underscored the critical importance of thorough labeling and documentation. A lack of visible labeling for tubes and sensors created significant difficulties during analysis, a mistake we now recognize as preventable. Moving forward, we will ensure that all components are labeled clearly and visibly, both on the hardware and within the user interface of the ground station.

Defining project requirements was another area where clarity proved essential. A deeper understanding of the components and their interdependencies emerged as critical to achieving a design that met expectations. Through iterative refinement, we have gained confidence in establishing comprehensive requirements.

Simulating the unique experimental environment posed challenges during the verification process, requiring innovative and non-traditional approaches. By thinking creatively, we developed methods to address these difficulties effectively. Similarly, careful planning before conducting experimental tests helped anticipate potential issues, saving time and resources in the long run.

Mechanical design was another iterative process, where each cycle of refinement provided opportunities for improvement. This iterative approach, though time-intensive, proved indispensable in achieving the desired functionality.

In summary, the project taught us resilience, adaptability, and the importance of meticulous planning and collaboration. Every challenge we faced became an opportunity to learn, ultimately strengthening our team and the project as a whole.

8 Abbreviations and References

8.1 Abbreviations

Add abbreviations to the list below, as appropriate, and delete unused abbreviations.

AIT	Assembly, Integration and Test
ASAP	as soon as possible
CDR	Critical Design Review
COG	Centre of Gravity
CRP	Campaign Requirement Plan
DLR	Deutsches Zentrum für Luft- und Raumfahrt
EAT	Experiment Acceptance Test
EAR	Experiment Acceptance Review
ECTS	European Credit Transfer System
EIT	Electrical Interface Test
EPM	Esrange Project Manager
ESA	European Space Agency
Esrange	Esrange Space Center
ESTEC	European Space Research and Technology Centre, ESA (NL)
ESW	Experiment Selection Workshop
FAR	Flight Acceptance Review
Fig.	Figure
FST	Flight Simulation Test
FRP	Flight Requirement Plan
FRR	Flight Readiness Review
GSE	Ground Support Equipment
HK	Housekeeping
HM	Hochschule München (University of Applied Sciences Munich)
H/W	Hardware
ICD	Interface Control Document
I/F	Interface
IPR	Integration Progress Review
LMU	Ludwig Maximilians University Munich
LO	Lift Off
LT	Local Time
LOS	Line of Sight

Mbps	Mega Bits per second
MFH	Mission Flight Handbook
MORABA	Mobile Raketen Basis (DLR, EuroLaunch)
OP	Oberpfaffenhofen, DLR Center
PCB	Printed Circuit Board (electronic card)
PDR	Preliminary Design Review
PI	Proportional and Integral controller
PST	Payload System Test
RBF	Remove Before Flight
SED	Student Experiment Documentation
SNSA	Swedish National Space Agency
SODS	Start Of Data Storage
SOE	Start Of Experiment
SSC	Swedish Space Corporation
STW	Student Training Week
S/W	Software
T	Time before and after launch noted with + or -
TBC	To be confirmed
TBD	To be determined
TUM	Technical University Munich
TVAC	Thermal Vacuum Chamber
WBS	Work Breakdown Structure
ZARM	Zentrum für Angewandte Raumfahrttechnologie und Mikrogravitation

8.2 References

The document should stick to a single referencing format, with IEEE being preferred.

It is recommended to use a dedicated referencing software or inbuilt tool/add-in to correctly reference material throughout the document.

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Appendix A EXPERIMENT REVIEWS

Preliminary Design Review – PDR

REXUS/BEXUS Preliminary Design Review		Experiment Team:	SPiCY
		Vehicle and Flight number:	BX34
Location: ESRANGE Space Center, Kiruna, SE		Date: 05.02.24	

DLR German Space Agency at DLR · Rymdstyrelsen Swedish National Space Agency · esa · SSC · ZARM

Review Board Members:

Simon Mawn (ZARM, chair)
Merle Cornelius (ZARM)
Steffen Calmer (ZARM)
Sophia Wolters (ZARM)
Michael Becker (DLR)
Esmée Menting (SSC)
Emil Nordqvist (SSC)
Márton Gálbács (SSC)
Gloria Gelosa (ESA)
Koen DeBeule (ESA)
Piotr Skrzypek (ESA)
Leonard Kobow (MORABA)
Tiziano Fiorucci (Alumni)

Experiment Team Members:

Alexander Kubeyk (present)
Ilana Schurmeyer (TL, present)
Alexander Ens
Jacqueline Wiethaler
Jayanth Narra
Eva-Maria Sontag
Tian Lan (present)
Pablo Martin (present)
Nishita Sanghvi
Fynn Gewiese
Sibtain Ali Thepdawala

Summary of Main Actions for the Experiment Team:

1. Define the integration of the box and lid.
2. Design or choose a feed through and test it.
3. Define electrical interfaces.
4. Make sure what you want to do – rework the requirements.
5. Assemble a mass budget.
6. Define the interface to the gondola.

Review Result: pass
Next SED version V2 due to 05 May 2024

Explanation of the Report:
In the following document the board member comments are sorted by the chapters of the SED beginning with SED chapter 2. Comments are divided into RIDs and Remarks:

- ***RID** (Review Items Discrepancy) is the mechanism used to record questions or identified problems and solutions arising from examination of the review documentation and*

Preliminary Design Review - PDR

REXUS/BEXUS Preliminary Design Review	Experiment Team:	SPICY
	Vehicle and Flight number:	BX34
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discussion. They are issues, identified by a reviewer, that are not compliant with a requirement, a review objective or a design goal. A RID will be followed up during the next project steps by the organizers and must be fulfilled by the team in order to pass the review.

- ***Remarks** contain considerations a team should make and recommendations from the board members.*

1 General

1.1 Presentation

REMARK: Much more technical information, include all that in the SED. The reviewers can give detailed feedback on the content of the SED – not so detailed on the content of the presentation.

1.2 SED (editorial)

REMARK: Include more drawings and schematics (less text), this makes it easier and faster to comprehend concepts. Especially in the mechanical chapter: Please provide drawings, cad views etc.
REMARK: Table of content contains wrong page numbers. Add bookmarks to the chapters to have a side panel with the table of contents in a pdf viewer – easier to navigate.
REMARK: Figures split over two pages are hard to read.
REMARK: The current block diagrams are confusing, rework please.

1.3 Science

REMARK: Scientific background is well done.
REMARK: Good and precise mission statement.
REMARK: Good definition of objectives.
REMARK: Suitable medium fluid – explain the hazards?

2 REQUIREMENTS AND CONSTRAINTS

REMARK: REXUS/BEXUS has the preference to sort the requirements by classification.
REMARK: The verification methods in your table are unspecific.
RID: Too little information about measurements (oxygen) and observation (camera).
REMARK: Clear path from mission objectives to requirements on the different levels necessary.

	REXUS/BEXUS Preliminary Design Review	Experiment Team:	SPICY
		Vehicle and Flight number:	BX34
Location: ESRANGE Space Center, Kiruna, SE		Date: 05.02.24	

RID: The five high level requirements are major design requirements. Instead, you should mention what the experiment is doing. Follow up with Koen during STW, take also input from verification presentation from Monday afternoon.
REMARK: At PDR you need an approximate weight.
RID: PAY-001 confusing, should be clear that the function is to observe.
RID: Performance requirement THE4 is a design requirement. Same for some of the operational requirements.
REMARK: POW1 - Power will be provided by gondola.
RID: Missing requirement for measurement and observation (accuracy, range, …) as well as size, withstand external influences, robustness, power and so on.
REMARK: From discussion the team clarified: Sample shall be physical isolated, tubes with oxygen sensor is pressure vessel and should stay and ground level pressure, no pressure difference aimed for.
Add something regarding this to the functional requirements, pressure tight vessel or similar.
RID: The mass is not consistent throughout the SED. At SSW 8 kg were allocated. If you surpass that, make a request. Student team: Currently around 10 kg.
REMARK: THE-001 – "evenly" is not defined. Maybe use gradients or delta T from specific places to make it verifiable.

3 PROJECT PLANNING

3.1 Work Breakdown Structure (WBS)

RID: Workpackages (WP) on electronic and software are missing.
REMARK: Include names and responsible person.

3.2 Schedule

RID: Transfer all WP from WBS to the gantt chart, include milestones and reviews.
REMARK: Think about additional help regarding electronics.
REMARK: The manpower table should give you information about the availability and bottlenecks, think about color coding.

3.3 Resources

REMARK: Put more effort into your budget plan. Have a column for how the costs are covered. Note the state of delivery/manufacturing. Also consider travel expenses, especially if you want to bring more than the sponsored people. Indicate the sponsors for each item.
REMARK: Outreach material not sponsored by DLR/ZARM/ESA.

3.4 Outreach

REMARK: Nice outreach and stickers, the panel looks forward to more content.

3.5 Risks

REMARK: Requirement THE-001, hard to keep the temperature in this range (20-25°C).
REMARK: Reduce TC10 with testing (thermal vacuum chamber).
RID: TC20 - if the risk is acceptable than the severity isn't a 4.
REMARK: SF10 is not rated.
REMARK: "Oxygen might fail" - What are the reasons and what would be your actions?
REMARK: MS20 - Medium risk that they die prior to experiment. Use redundant charge as mitigation technique.
REMARK: High severity for EN10is wrongly allocated, cells don't pose a health risks, reduce the risk level.
RID: Risk level 5 means someone gets insured or the gondola blows up, all you have is 4 at most.
REMARK: If you don't see a risk happening or you don't care about it, don't include it.

4 EXPERIMENT

4.1 Mechanics

REMARK: Clarification for the panel: The outer box cover on top is plexi glas, see through, specimen is in round end of tube that points up.
The tubes are screwed shut, hole in lid for sensor, lid is 20-30 mm diameter, commercial 50 ml tubes. The oxygen production probably doesn't increase the pressure in the tubes.
Experiment need UV, other rays also wished for. The top has to be exposed towards the top.
The main science objective is fulfilled with the sensor data. Another objective needs the heater to turn off (reproduction slower, assess how RNA production changes).
REMARK: Add half cut or exploded view of CAD. Currently everything is see-through which is confusing.
RID: Sketches, technical drawings and CAD views are necessary.
RID: Specify the materials and construction of the outer and inner box.
RID: All plugs (gondola power, E-Link) must be placed into the outer box with easy accessibility.
REMARK: SED still mentions valves.
RID: The mounting to the gondola is missing. Be aware of thermal insulation.

	REXUS/BEXUS Preliminary Design Review	Experiment Team:	SPICY
		Vehicle and Flight number:	BX34
Location: ESRANGE Space Center, Kiruna, SE		Date: 05.02.24	

REMARK: Use different bolds for every integration step – to mount electronics, mount the lid, mount to the gondola (accessible without opening lid!).
RID: In next two weeks: Test if the two plexi sheets let enough radiation for your experiment through.
RID: The sealing is crucial, also look into commercial solutions (e.g. Swagelok) instead of self-made (often fails). Test to the experiment pressure times safety factor, see manual.
REMARK: The total weight should include all parts of your experiment.

4.2 Electronics

RID: Define how to operate the heaters.
RID: Define how to operate the sensors. The connection to controller is missing (analog, I2C, SPI, ...?)
RID: You have identified the main electronic subsystems. But the next step is missing. What's inside subsystems? (Heater, Sensors,...), is required for PDR level
RID: Specify the sensors and the heater. Look into better thermal sensor. Don't use Loca sensors! There is enough money for other sensory.
REMARK: Show block diagrams of the systems.
REMAKR: Define what you have to do and what you get from the sensors etc. They probably provide front end, you have to implement heating control, place sensors correctly (make sure to respect heat conduction). If you include that in the SED we can give you feedback.
RID: Power System Chapter - in this chapter, please specify the power you need (Watt) in a table, not how it will be transformed. The Power supply needs to be described in the electronic section.
RID: Wrong Battery Voltage (18V), not available.
RID: Define the heart of the system as soon as possible, Arduino, microcontroller, ...
REMARK: Update the datalink as you don't plan with the camera anymore.
REMARK: You have much more designed: presentation and hardware shown – include all that in the SED!
REMARK: Don't put nail polish or epoxy on the boards, there are proper conformal coating solutions that let you solder through them (available as easy to use spray).
REMARK: Make sure the Arduino/Pi have a secure connection and is not affected by vibrations. Avoid using shields on top of Arduinos, solder them to a board, otherwise the mechanical strength will not be enough and require you to glue things down or mechanically fix it.
REMARK: For the ground station, the board recommends to write python code directly on a laptop, no extra Arduino.
REMARK: Add the requirement to measure the amount of UV to quantify oxygen production, e.g. specify the wavelengths you are interested in.
REMARK: In section 4.2.1 you specified two electrical interfaces. Does it mean you will use two power inlets? Otherwise just specify one here.

	REXUS/BEXUS Preliminary Design Review	Experiment Team:	SPiCY
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4.3 Thermal

REMARK: The oxygen sensor compensates for the temperature and can provide the temperature itself as well. Another version of the sensor is proposed (approach Koen for details).
REMARK: Make sure to electronics are heated sufficiently. Double wall principle could help. One single box could help by just having one thermal control system.
REMARK: Coolant tube and heater will not work under low pressure environment.
RID: Put more effort into the thermal design.
Define which temperatures are necessary for your experiment and which temperatures the experiment is exposed to.
Calculate the heat production of your components and the power consumption necessary of the heaters.
Define active or passive thermal control.
Consider all thermal heat transfers, transmissions, convection (only in pressure chamber or atmospherically pressure) and thermal radiation (much higher in space).

4.4 Software

RID: Chapter contains to less information. Please describe the process field, the process flow (e.g. Heater Control) and the data flow (e.g. how to acquire sensor data).
RID: The down and uplink rate you provide in Chapter 6 should be reasoned by a calculation in the software chapter.
REMARK: SI based ethernet to communicate with BEXUS is painful. Although their engineer is working on it there is a lot to implement. Use a board with ethernet build in, with IP stack on it. What was presented during the presentation seems to be a good solution.

5 VERIFICATION AND TESTING

5.1 Verification Matrix

REMARK: Mostly A and T used for methods. A is sometimes not applicable. Some should also be I or R. You can also have multiple methods if applicable.
REMARK: Refer to meeting with Koen: New grouping of requirements should give you an easier translation to the verifications.
REMARK: Immediately build test cell and do thermal tests.

5.2 Testplan

REMARK: There will be at least one thermal vacuum test at ZARM.
REMARK: The panel highly recommends further thermal vacuum tests to test your active thermal system.

6 LAUNCH CAMPAIGN PREPARATION

RID: The dimensions are unclear.
RID: Table 6.3, datarate of 400 Kbit/s are too much. Provide a calculation in the software chapter.
RID: Power of 30W but no calculation provided in the power section.
REMARK: Flight and launch site requirements are missing. Include requirements like altitude and time as well as light exposure – when do you need sunrise and for how long daylight?
REMARK: Be careful with the sun being just above the horizon, add the according requirements and investigate a design with plexiglas from the side as well. Be aware that the balloon is on top. Take tilting the experiment into consideration (The gondola is always tuning, about 0.2 HZ but variable). Reflectors are possible, request the necessary space as early as possible.

Critical Design Review – CDR

REXUS/BEXUS Critical Design Review		Experiment Team:	SPICY
		Vehicle and Flight number:	BX34
Location: ESA ESTEC		Date: 15.05.2024	

Review Board Members:

Simon Mawn (ZARM, chair)
Steffen Calmer (ZARM)
Sophia Wolters (ZARM)
Merle Cornelius (ZARM)
Esmée Menting (SSC)
Emil Nordqvist (SSC)
Lars Pepermans (SSC)
Romina Gaudio (SSC)
Maximilian Nürnberger (ESA)
Gloria Gelosa (ESA)
Koen DeBeule (ESA)
Dorota Budzyn (ESA)

Experiment Team Members:

Ilana Schürmeyer (TL, present)
Fynn Gewiese (present)
Sibtain Ali Thepdawala (present)
Elias Eggenberger (present)
Pablo Martin Carillero (present)
Alexander Kubeyk
Jacqueline Wiethaler
Jayanth Narra
Eva-Maria Sontag
Tian Lan
Amanda Clot

Summary of Main Actions for the Experiment Team:

1. Sealing & feed through of the tubes.
2. Update risk table.

	REXUS/BEXUS Critical Design Review	Experiment Team:	SPICY
		Vehicle and Flight number:	BX34
Location: ESA ESTEC		Date: 15.05.2024	

3. Attachment to the gondola.
4. Electrical connector design to the gondola.
5. Power budget (incl. heating).
6. Operations: late access, when, what? Including sensor attachment.

Review Result: pass

Next SED version V3 due to 22.07.2024

Explanation of the Report:
In the following document the board member comments are sorted by the chapters of the SED beginning with SED chapter 2. Comments are divided into RIDs and Remarks:

- ***RID** (Review Items Discrepancy) is the mechanism used to record questions or identified problems and solutions arising from examination of the review documentation and discussion. They are issues, identified by a reviewer, that are not compliant with a requirement, a review objective or a design goal. A RID will be followed up during the next project steps by the organizers and must be fulfilled by the team in order to pass the review.*
- ***Remarks** contain considerations a team should make and recommendations from the board members.*

1 General

1.1 Presentation

-

1.2 SED (editorial)

REMARK: Excellent work on the team presentation, good photos.
REMARK: There is no full experiment block diagram, only a concept overview, electrical connections and an UML-diagramm in the software section.
REMARK: Please include a more detailed mass budget in the SED.
REMARK: Some labels on axes and references are missing in the spectrometer figure (Figure 4.13) and temperature probe plots.
REMARK: Figure numbers missing on temperature probe plots and schematics.

1.3 Science

REMARK: Objective 1 is not scientific but an educational and/or a technical objective.

	REXUS/BEXUS Critical Design Review	Experiment Team:	SPICY
		Vehicle and Flight number:	BX34
Location: ESA ESTEC		Date: 15.05.2024	

REMARK: Good rework of the, good and clear objectives.

2 REQUIREMENTS AND CONSTRAINTS

REMARK: Excellent workover. All RIDs are cleared. Requirements are good now. Some operational requirements could be design and some design (e.g. 2, 28) could be functional.
REMARK: Regarding F.6 – Which property of the light do you want to measure, wavelength, intensity, or both?
REMARK: Regarding P.1 – Issue with the given values and the wording. Is 0.4mg/l the sensitivity/resolution and +/-0.009 mg/l is the accuracy? Then value ranges do not match, usually the accuracy is not smaller than the sensitivity.
REMARK: P.2 is a design requirement.
REMARK: D.20/21 is non-verifiable.
REAMRK: Range for thermal, oxygen, and light sensors are missing, and with that the accuracies.
REMARK: Requirements regarding the BEXUS temperature profile missing.

PDR follow up:
REMARK: REXUS/BEXUS has the preference to sort the requirements by classification. ✓
REMARK: The verification methods in your table are unspecific. ✓
RID: Too little information about measurements (oxygen) and observation (camera). ✓
REMARK: Clear path from mission objectives to requirements on the different levels necessary. ✓
RID: The five high level requirements are major design requirements. Instead, you should mention what the experiment is doing. Follow up with Koen during STW, take also input from verification presentation from Monday afternoon. (✓)
REMARK: At PDR you need an approximate weight. ✓
RID: PAY-001 confusing, should be clear that the function is to observe. ✓
RID: Performance requirement THE4 is a design requirement. Same for some of the operational requirements. (✓)
P.2 is a design requirement
REMARK: POW1 - Power will be provided by gondola. ✓
RID: Missing requirement for measurement and observation (accuracy, range, ...) as well as size, withstand external influences, robustness, power and so on. (✓)

REMARK: From discussion the team clarified: Sample shall be physical isolated, tubes with oxygen sensor is pressure vessel and should stay and ground level pressure, no pressure difference aimed for.
Add something regarding this to the functional requirements, pressure tight vessel or similar. (✓)
Listed not as Fun. Req. but Design Req. D.2

	REXUS/BEXUS Critical Design Review	Experiment Team:	SPICY
		Vehicle and Flight number:	BX34
Location: ESA ESTEC		Date: 15.05.2024	

RID: The mass is not consistent throughout the SED. At SSW 8 kg were allocated. If you surpass that, make a request. Student team: Currently around 10 kg. ✓
REMARK: THE-001 – "evenly" is not defined. Maybe use gradients or delta T from specific places to make it verifiable. ✓

3 PROJECT PLANNING

3.1 Work Breakdown Structure (WBS)

REMARK: Responsible person for the task "Thermal Tests" missing.
REMARK: Figure 3-2 has a bad resolution.
REMARK: Tasks regarding the whole module won't be just for structures, maybe move these to another section.

RID: Workpackages (WP) on electronic and software are missing. ✓
REMARK: Include names and responsible person. ✓

3.2 Schedule

REAMARK: Use the same structure (same main points, same tasks etc.) for WBS, gantt chart, and schedule. For example "1.3. Risks Management" is missing in the WBS and "5. Software" is missing in the Schedule.
REMARK: Include a time header on the second page of Figure 3-4 for readability.

RID: Transfer all WP from WBS to the gantt chart, include milestones and reviews. ✓
REMARK: Think about additional help regarding electronics. ✓
REMARK: The manpower table should give you information about the availability and bottlenecks, think about color coding. ✓

3.3 Resources

REMARK: Name "DLR/ZARM" instead of "ZARM" as sponsor.

3.4 Outreach

REMARK: If the blue captions are links, then they do not work.

REXUS/BEXUS Critical Design Review		Experiment Team:	SPICY
		Vehicle and Flight number:	BX34
Location: ESA ESTEC		Date: 15.05.2024	

3.5 Risks

RID: The given remarks and tips from the PDR panel were not considered in the risks management.
REMARK: Reduce TC10 with testing (thermal vacuum chamber).
RID: MS10 - If the risk is acceptable then the severity isn't a 4.
REMARK: MS20 - Medium risk that they die prior to experiment. Use redundant batch as mitigation technique.
RID: Risk level 5 means someone gets insured or the gondola blows up, all you have is 4 at most. For example in EN10, the cells don't pose a health risks, reduce the risk level or VE10.
REMARK: If you don't see a risk happening or you don't care about it, don't include it, e.g. MS30.
REMARK: The given remarks and tips from the PDR panel were not considered in the risks management

PDR follow up:
REMARK: Requirement THE-001, hard to keep the temperature in this range (20-25°C). X
REMARK: Reduce TC10 with testing (thermal vacuum chamber). X
RID: TC20 - If the risk is acceptable than the severity isn't a 4. X
REMARK: Here, initially MS10 was meant. Still "no action" stated
REMARK: SF10 is not rated. ✓
REMARK: "Oxygen might fail" - What are the reasons and what would be your actions?
REMARK: MS20 - Medium risk that they die prior to experiment. Use redundant charge as mitigation technique. X
REMARK: High severity for EN10is wrongly allocated, cells don't pose a health risks, reduce the risk level. X
RID: Risk level 5 means someone gets insured or the gondola blows up, all you have is 4 at most. X
e.g. VE10,EN10 are not S=5 risks
REMARK: If you don't see a risk happening or you don't care about it, don't include it. X
e.g. MS30

4 EXPERIMENT

4.1 Mechanics

RID: Provide a clear mass budget and a final mass with accuracy +/- 200g.
REMARK: Describe how the foam is connected/fixated to the aluminum profiles. Think about whether you would like some structure to align Styrofoam parts and restrict the x-y movement. Something to slide it in, rods, etc.

REMARK: The foam you choose has to perform in vacuum, select it based on the requirements, PIR might be an option.
RID: You don't explain the heart of you experiment - the sample carrier including the hermetical sealing and the kapton heater.
RID: Concept for sealing of the biofilm tubes is missing. Finish design and test as soon as possible. Test if non-liquid medium like agar could be possible. Include a venting hole in the cap that can be closed. The solution has to feature the cable feed through of the sensors. Overpressure test planned?
REMARK: Be careful with the kapton heaters, they bring a lot of energy with a delay into the probes. Attach the heater carefully, leave no space between the heater and the tube. Describe the placement of the heater in the SED.
REMARK: Detail the attachment to the gondola. The gondola profiles on two adjacent sides at the top are at different heights.
REMARK: Missing justification why the experiment will withstand the loads during a BEXUS flight. Especially see if the quartz glass survives shocks, if you encounter problems increase the damping or support it more.
REMARK: You mention hinges or locks on the glass cover once but no specifics later.
REMARK: Show the plug placements and accessibility.
REMARK: Environment interface of the Styrofoam box unclear: "using a rotation of the axis". Maybe use CAD views to explain geometrics.
REMARK: Do you have any cleanliness requirements on quartz glass top? Perhaps consider implementing a protective cover which is to be removed shortly before launch.

4.2 Electronics

REMARK: Electrical interfaces: description of connectors is missing. For example Power to Mainboard and Sensors to Mainboard. Please describe in more detail, e.g. voltage, current…
REMARK: Wiring of the PCB to the experiment cells is missing. Electrical feed through to the experiment cells is missing.
REMARK: Peripheral components are missing e.g. power converter.
REMARK: Electronics design: description of the schematics missing.
REMARK: Good power system flow chart and description.
REAMRK: Power Budget table is not complete and not time oriented: at the end Wh are needed to compare with the battery capacity. Heating elements not characterized.
REMARK: LDO lost power not accounted for in power budget, nor efficiency of buck converter.
REMARK: The grounding scheme is missing. The whole experiment has to be grounded to the gondola.
REMARK: Maybe add silk screen labels for all the passive components, it will help you in debugging and probing around later.

	REXUS/BEXUS Critical Design Review	Experiment Team:	SPICY
		Vehicle and Flight number:	BX34
Location: ESA ESTEC		Date: 15.05.2024	

German Space Agency at DLR · Rymdstyrelsen Swedish National Space Agency · esa · SSC · ZARM

PDR follow up:
RID: Define how to operate the heaters.//Heater control PCB provided (PWM)
RID: Define how to operate the sensors. The connection to controller is missing (analog, I2C, SPI, …?)//Sensor control PCBs provided, not choosen O sensor yet
RID: You have identified the main electronic subsystems. But the next step is missing. What's inside subsystems? (Heater, Sensors,…), is required for PDR level//done
RID: Specify the sensors and the heater. Look into better thermal sensor. Don't use Loca sensors! There is enough money for other sensory. //done
REMARK: Show block diagrams of the systems.
REMAKR: Define what you have to do and what you get from the sensors etc. They probably provide front end, you have to implement heating control, place sensors correctly (make sure to respect heat conduction). If you include that in the SED we can give you feedback.
RID: Power System Chapter - In this chapter, please specify the power you need (Watt) in a table, not how it will be transformed. The Power supply needs to be described in the electronic section. //done as a power tree
RID: Wrong Battery Voltage (18V), not available. //done
RID: Define the heart of the system as soon as possible, Arduino, microcontroller, …//done

4.3 Thermal

REMARK: Q_{in} vs. Q_{out} calculation is missing.
REMARK: The biofilms are a thermal challenge, show how you are able to stay within the required range, see PDR comment. Be careful with the kapton heaters, they bring a lot of energy with a delay into the probes. See remark in mechanics.

4.4 Software

REMARK: A software overview is missing. The first subsection in software should be an overview, rather than text. You could use or refer to your electronics overview/connections.
REMARK: Do you have different experiment states or will you start measuring immediately? Include in the SED.
RID: The down and uplink rate you provide in Chapter 6 should be reasoned by a calculation in the software chapter.
REMARK: How do you start the program after power on? Client/server needs to be tested for power cycle robustness.
REMARK: How and when do you shut down before the balloon cut off?
REMARK: Consider to provide a manual control e.g. for the heater in case of a malfunction. SED is not clear about autonomous experiment run and manual control possibilities.

REXUS/BEXUS Critical Design Review	Experiment Team:	SPICY
	Vehicle and Flight number:	BX34
Location: ESA ESTEC	Date: 15.05.2024	

PDR follow up:
RID: Chapter contains to less information. Please describe the process field, the process flow (e.g. Heater Control) and the data flow (e.g. how to acquire sensor data).//done, UML design provided to describe data flow
RID: The down and uplink rate you provide in Chapter 6 should be reasoned by a calculation in the software chapter.//no calculation provided

5 VERIFICATION AND TESTING

5.1 Verification Matrix

REMARK: You have no verifications yet. Test components, e.g. the kapton heater.
REMARK: Combine some environmental tests, they take a lot of time. There is a lot possible at the ZARM test.
REMARK: The usage of inspection is mostly incorrect. It is applied if it is only verifiable by looking at it.
REMARK: Try to use more than one method of verification.

5.2 Testplan

REMARK: The thermal vacuum test at ZARM is missing. It will be around August.
REMARK: Test10 is unclear, how to perform this test in a lab? Using a vibration test lab is overkill for BEXUS.
REMARK: Test 11 could be combined with thermal vacuum test at ZARM.

6 LAUNCH CAMPAIGN PREPARATION

REMARK: Launch site requirements are okay. ZARM will bring a soldering station also for SMD.
REMARK: Be aware of any transport regulations to and from Esrange/Sweden.
REMARK: Add flight risk of sealed tube -> pressure vessel.
REMARK: Table 6-3: current consumption missing, give more information in this table. 300 Wh total power consumption is on the high side.
REMARK: Preparation activities: Early arrival is usually not supported. Contact Simon before the next SED and give good arguments.
REMARK: More detailed instructions for the recovery are needed (outer conditions like temp, time, until when do the samples have to be heated, quantify “as soon as possible” and describe reasons/consequences …).
REMARK: Late access could be in a cold environment and includes some walk towards the gondola. You could install the bio module around T-3 h in a warm environment and then have your heating running. Latest access is T-1 h, at this point the access might be hard: gondola hanging up etc.

REMARK: Transportation of bio module and activities after should be in the timeline for flight countdown (Table 6-2).

REMARK: There will be tests at launch campaign, outside and for longer durations. During that power consumption and communication will be tested and all sensors have to be connected like in flight configuration. Be ready to have everything connected at this point.

REMARK: Altitude requirement: write the numbers that you really need, if it is not that important write “as high as possible”.

REMARK: Minimal float time that can be guaranteed is one hour.

REMARK: Light requirement: probably not precise enough for your science. Find out which angle of sun you need for the light to reach the tubes, specify e.g. earliest time after sunrise, time before sunset.

Integration Progress Review – IPR

	REXUS/BEXUS Critical Design Review	Experiment Team:	SPICY
		Vehicle and Flight number:	BX34
Location: TU Munich		Date: 01.08.2024	
German Space Agency at DLR	Rymdstyrelsen Swedish National Space Agency	esa	SSC ZARM

Review Board Members:

Steffen Calmer (ZARM)
Florian Leu (ZARM)

Experiment Team Members:

Ilana Schürmeyer (TL, present)
Fynn Gewiese (present)
Sibtain Ali Thepdawala
Elias Eggenberger
Pablo Martin Carillero (present)
Alexander Kubeyk
Jacqueline Wiethaler
Jayanth Narra
Eva-Maria Sontag (present)
Tian Lan (present)
Amanda Clot (present)

	REXUS/BEXUS Critical Design Review	Experiment Team:	SPICY
		Vehicle and Flight number:	BX34
Location: TU Munich		Date: 01.08.2024	

Summary of Main Actions for the Experiment Team:
1. Detailed description from Sealing & feed through of the tubes.
2. Pressure test of the tubes
3. Attachment to the gondola.
4. Testing PI control loop to stay inside the temperature requirements

Review Result: conditional pass

Next SED version V4 due to 26.08.2024

Explanation of the Report:
In the following document the board member comments are sorted by the chapters of the SED beginning with SED chapter 2. Comments are divided into RIDS and Remarks:

- *RID (Review Items Discrepancy) is the mechanism used to record questions or identified problems and solutions arising*
  from examination of the review documentation and discussion. They are issues, identified by a reviewer, that are not compliant with a requirement, a review objective or a design goal. A red RID will be followed up during the next project steps by the organizers and must be fulfilled by the team in order to pass the review.
- ***Remarks** contain considerations a team should make and recommendations from the board members*

IPR-Agenda
- *Introduction Team, Board, Guests; Welcome*
- *Team Presentation*
  - *15-30 Minutes (stand up or at the table presentation)*
  - *Mechanic, Electronic, Software, Project Planning, Tests*
  - *Experiment status and issues*
- *Discussion*
  - *SED*
  - *Mechanics (interface to the vehicle, thermal, structure, manufactory, accessibility, stiffness, materials, others)*
  - *Electronics (interface to the vehicle, boards, cables, connectors, manufactory, components (actors, sensors), interfaces (bus, I/O, uarts), power management, others)*
  - *Software (states/modes, process flow, data flow, interfaces, implementation, Ground Station)*
  - *Project Planning (status, ordering, manufactory, delivery, availablity of resources, time planning)*
  - *Tests (status, planning, results, configuration, preparation)*
  - *Campaign Preparation (shipping, requirements, special)*
  - *Others*
- *Hardware inspection, photos*
- *Tests*
  - *Communication tests will be performed between Ground Station and Experiment. At least dummy data shall be transmitted. For RX a service module simulator will be used and provided by ZARM.*
- *Tour to rooms, facilities, laboratories if applicable and time left.*

<table>
<tr><td rowspan="2"></td><td rowspan="2">REXUS/BEXUS
Critical Design Review</td><td>Experiment Team:</td><td>SPICY</td></tr>
<tr><td>Vehicle and Flight number:</td><td>BX34</td></tr>
<tr><td colspan="2">Location: TU Munich</td><td colspan="2">Date: 01.08.2024</td></tr>
<tr><td colspan="4">German Space Agency at DLR · Rymdstyrelsen Swedish National Space Agency · esa · SSC · ZARM</td></tr>
</table>

A - Discussion

1 General

1.1 Presentation

REMARK: slides itself were good, to present on a notebook is not state of the art
REMARK: Good presentation of current project state
REMARK: Only part of hardware was shown, no working software or ground control program was presented.

1.2 SED (editorial)

REMARK: issues in some lines – incorrect representation
REMARK: p.65 there are ???? in the equation
REMARK: Page 50 is empty.
REMARK: Page 72, explain what this figure shows.

CDR Follow up:
REMARK: Excellent work on the team presentation, good photos.
REMARK: There is no full experiment block diagram, only a concept overview, electrical connections and an UML-diagramm in the software section.
REMARK: Please include a more detailed mass budget in the SED.
REMARK: Some labels on axes and references are missing in the spectrometer figure (Figure 4.13) and temperature probe plots.
REMARK: Figure numbers missing on temperature probe plots and schematics.

1.3 Science

REMARK: Objective 1 is not scientific but an educational and/or a technical objective.
REMARK: Good rework of the, good and clear objectives.

2 REQUIREMENTS AND CONSTRAINTS

REMARK: Excellent workover. All RIDs are cleared. Requirements are good now. Some operational requirements could be design and some design (e.g. 2, 28) could be functional.
REMARK: Regarding F.6 – Which property of the light do you want to measure, wavelength, intensity, or both?
REMARK: Regarding P.1 – Issue with the given values and the wording. Is 0.4mg/l the sensitivity/resolution and +/-0.009 mg/l is the accuracy? Then value ranges do not match, usually the accuracy is not smaller than the sensitivity.

	REXUS/BEXUS Critical Design Review	Experiment Team:	SPICY
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REMARK: P.2 is a design requirement.
REMARK: D.20/21 is non-verifiable.
REAMRK: Range for thermal, oxygen, and light sensors are missing, and with that the accuracies.
REMARK: Requirements regarding the BEXUS temperature profile missing.

PDR follow up:
REMARK: REXUS/BEXUS has the preference to sort the requirements by classification. ✓
REMARK: The verification methods in your table are unspecific. ✓
RID: Too little information about measurements (oxygen) and observation (camera). ✓
REMARK: Clear path from mission objectives to requirements on the different levels necessary. ✓
RID: The five high level requirements are major design requirements. Instead, you should mention what the experiment is doing. Follow up with Koen during STW, take also input from verification presentation from Monday afternoon. (✓)
REMARK: At PDR you need an approximate weight. ✓
RID: PAY-001 confusing, should be clear that the function is to observe. ✓
RID: Performance requirement THE4 is a design requirement. Same for some of the operational requirements. (✓)
P.2 is a design requirement
REMARK: POW1 - Power will be provided by gondola. ✓
RID: Missing requirement for measurement and observation (accuracy, range, ...) as well as size, withstand external influences, robustness, power and so on. (✓)

REMARK: From discussion the team clarified: Sample shall be physical isolated, tubes with oxygen sensor is pressure vessel and should stay and ground level pressure, no pressure difference aimed for.
Add something regarding this to the functional requirements, pressure tight vessel or similar. (✓)
Listed not as Fun. Req. but Design Req. D.2
RID: The mass is not consistent throughout the SED. At SSW 8 kg were allocated. If you surpass that, make a request. Student team: Currently around 10 kg. ✓
REMARK: THE-001 – "evenly" is not defined. Maybe use gradients or delta T from specific places to make it verifiable. ✓

3 PROJECT PLANNING

3.1 Work Breakdown Structure (WBS)

REMARK: Work package and responsible person regarding software is missing.

CDR follow up:
REMARK: Responsible person for the task "Thermal Tests" missing.

REXUS/BEXUS Critical Design Review	Experiment Team:	SPICY
	Vehicle and Flight number:	BX34
Location: TU Munich	Date: 01.08.2024	

REMARK: Figure 3-2 has a bad resolution.
REMARK: Tasks regarding the whole module won't be just for structures, maybe move these to another section.

RID: Workpackages (WP) on electronic and software are missing. ✓
REMARK: Include names and responsible person. ✓

3.2 Schedule

RID: not all WPs in time, some changes in the timeline from CDR SED to IPR SED
REMARK: some delays caused by ordering

CDR follow up:
REAMARK: Use the same structure (same main points, same tasks etc.) for WBS, gantt chart, and schedule. For example "1.3. Risks Management" is missing in the WBS and "5. Software" is missing in the Schedule.
REMARK: Include a time header on the second page of Figure 3-4 for readability.

RID: Transfer all WP from WBS to the gantt chart, include milestones and reviews. ✓
REMARK: Think about additional help regarding electronics. ✓
REMARK: The manpower table should give you information about the availability and bottlenecks, think about color coding. ✓

3.3 Resources

REMARK: add the sponsor of the Oxgen sensor
REMARK: Name "DLR/ZARM" instead of "ZARM" as sponsor.

3.4 Outreach

REMARK: If the blue captions are links, then they do not work.

3.5 Risks

REMARK: Reduce TC10 with testing (thermal vacuum chamber, etc).
RID: Think of a procedure to perform some sort of leak-test of glass tubes and glued caps.

	REXUS/BEXUS Critical Design Review	Experiment Team:	SPICY
		Vehicle and Flight number:	BX34
Location: TU Munich		Date: 01.08.2024	

RID: The given remarks and tips from the PDR panel were not considered in the risks management.
RID: MS10 - If the risk is acceptable then the severity isn't a 4.
REMARK: MS20 - Medium risk that they die prior to experiment. Use redundant batch as mitigation technique.
RID: Risk level 5 means someone gets insured or the gondola blows up, all you have is 4 at most. For example in EN10, the cells don't pose a health risks, reduce the risk level or VE10.
REMARK: If you don't see a risk happening or you don't care about it, don't include it, e.g. MS30.
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PDR follow up:
REMARK: Requirement THE-001, hard to keep the temperature in this range (20-25°C). X
REMARK: Reduce TC10 with testing (thermal vacuum chamber). X
RID: TC20 - If the risk is acceptable than the severity isn't a 4. X
REMARK: Here, initially MS10 was meant. Still "no action" stated
REMARK: SF10 is not rated. ✓
REMARK: "Oxygen might fail" - What are the reasons and what would be your actions?
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REMARK: High severity for EN10is wrongly allocated, cells don't pose a health risks, reduce the risk level. X
RID: Risk level 5 means someone gets insured or the gondola blows up, all you have is 4 at most. X
e.g. VE10,EN10 are not S=5 risks
REMARK: If you don't see a risk happening or you don't care about it, don't include it. X
e.g. MS30

4 EXPERIMENT

4.1 Mechanics

REMARK: add a fixation of the lid (electronic compartment)
RID: written down procedure for filling and sealing the tubes
REMARK: Provide more detailed information on each component's mass, as well as overall experiment's mass, dimensions and CoG.
REMARK: Provide more detailed explanation including renderings of Experiment setup especially glass tubes and their fixation.

	REXUS/BEXUS Critical Design Review	Experiment Team:	SPICY
		Vehicle and Flight number:	BX34
Location: TU Munich		Date: 01.08.2024	

German Space Agency at DLR · Rymdstyrelsen Swedish National Space Agency · esa · SSC · ZARM

CDR Follow up, still valid:
RID: no actions after CDR, notes almost the same
RID: Provide a clear mass budget and a final mass with accuracy +/- 200g.

REMARK: Describe how the foam is connected/fixated to the aluminum profiles. Think about whether you would like some structure to align Styrofoam parts and restrict the x-y movement. Something to slide it in, rods, etc.
REMARK: The foam you choose has to perform in vacuum, select it based on the requirements, PIR might be an option.
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REMARK: Show the plug placements and accessibility.
REMARK: Environment interface of the Styrofoam box unclear: "using a rotation of the axis". Maybe use CAD views to explain geometrics.
REMARK: Do you have any cleanliness requirements on quartz glass top? Perhaps consider implementing a protective cover which is to be removed shortly before launch.

4.2 Electronics

REMARK: provide schematic flow chart of electrics and data of the experiment.
REMARK: provide table/diagram of experiment harness including connector description.
REMARK: Briefly explain working principle of oxygen sensors.
RID: Selected light sensor is not able to detect UV light and does not meet requirement F.6. Please select suitable sensor.
RID: Test if the experiment can handle battery voltage variation from 32V to 22V

CDR follow up:
REMARK: Electrical interfaces: description of connectors is missing. For example Power to Mainboard and Sensors to Mainboard. Please describe in more detail, e.g. voltage, current…
REMARK: Wiring of the PCB to the experiment cells is missing. Electrical feed through to the experiment cells is missing.

REXUS/BEXUS Critical Design Review		Experiment Team:	SPICY
		Vehicle and Flight number:	BX34
Location: TU Munich		Date: 01.08.2024	

REMARK: Peripheral components are missing e.g. power converter.
REMARK: Electronics design: description of the schematics missing.
REMARK: Good power system flow chart and description.
REAMRK: Power Budget table is not complete and not time oriented: at the end Wh are needed to compare with the battery capacity. Heating elements not characterized.
REMARK: LDO lost power not accounted for in power budget, nor efficiency of buck converter.
REMARK: The grounding scheme is missing. The whole experiment has to be grounded to the gondola.
REMARK: Maybe add silk screen labels for all the passive components, it will help you in debugging and probing around later.

PDR follow up:
RID: Define how to operate the heaters.//Heater control PCB provided (PWM)
RID: Define how to operate the sensors. The connection to controller is missing (analog, I2C, SPI, ...?)//Sensor control PCBs provided, not choosen O sensor yet
RID: You have identified the main electronic subsystems. But the next step is missing. What's inside subsystems? (Heater, Sensors,...), is required for PDR level//done
RID: Specify the sensors and the heater. Look into better thermal sensor. Don't use Loca sensors! There is enough money for other sensory. //done
REMARK: Show block diagrams of the systems.
REMAKR: Define what you have to do and what you get from the sensors etc. They probably provide front end, you have to implement heating control, place sensors correctly (make sure to respect heat conduction). If you include that in the SED we can give you feedback.
RID: Power System Chapter - In this chapter, please specify the power you need (Watt) in a table, not how it will be transformed. The Power supply needs to be described in the electronic section. //done as a power tree
RID: Wrong Battery Voltage (18V), not available. //done
RID: Define the heart of the system as soon as possible, Arduino, microcontroller, ...//done

4.3 Thermal

REMARK: well revised chapter
RID: regarding your strict thermal req. - test the control loop as soon as you can and find more test procedures for harsh enviroments
REMARK: Very detailed description, calculation and simulation of thermal model. However, test the experiment already before the thermal vacuum test at ZARM e.g., in a freezer.
REMARK: Test heat dissipation of electrical compartment before the thermal vacuum test at ZARM.
REMARK: Good PID controlling concept, test extensively before the flight, consider using simple on-off control with hysteresis if PID is not working.

CDR follow up:
REMARK: Q_{in} vs. Q_{out} calculation is missing.
REMARK: The biofilms are a thermal challenge, show how you are able to stay within the required range, see PDR comment. Be careful with the kapton heaters, they bring a lot of energy with a delay into the probes. See remark in mechanics.

4.4 Software

REMARK: clarify which controller you use PI or PID, don't mix it
REMARK: Block diagram/ flow chart for the signal processing

CDR follow up:
REMARK: A software overview is missing. The first subsection in software should be an overview, rather than text. You could use or refer to your electronics overview/connections.
REMARK: Do you have different experiment states or will you start measuring immediately? Include in the SED.
RID: The down and uplink rate you provide in Chapter 6 should be reasoned by a calculation in the software chapter.
REMARK: How do you start the program after power on? Client/server needs to be tested for power cycle robustness.
REMARK: How and when do you shut down before the balloon cut off?
REMARK: Consider to provide a manual control e.g. for the heater in case of a malfunction. SED is not clear about autonomous experiment run and manual control possibilities.

PDR follow up:
RID: Chapter contains to less information. Please describe the process field, the process flow (e.g. Heater Control) and the data flow (e.g. how to acquire sensor data).//done, UML design provided to describe data flow
RID: The down and uplink rate you provide in Chapter 6 should be reasoned by a calculation in the software chapter.//no calculation provided

5 VERIFICATION AND TESTING

5.1 Verification Matrix

CDR follow up:
REMARK: You have no verifications yet. Test components, e.g. the kapton heater.
REMARK: Combine some environmental tests, they take a lot of time. There is a lot possible at the ZARM test.
REMARK: The usage of inspection is mostly incorrect. It is applied if it is only verifiable by looking at it.

	REXUS/BEXUS Critical Design Review	Experiment Team:	SPICY
		Vehicle and Flight number:	BX34
Location: TU Munich		Date: 01.08.2024	

REMARK: Try to use more than one method of verification.

5.2 Testplan

REMARK: many software tests done - good
REMARK: many tests were planned earlier, changing from CDR SED to IPR SED – do not waste any more time
RID: add pressure test for the tubes
REMARK: start the thermal test campaign right now – test the control loop and the thermal behavior of the Styrofoam box
REMARK: Do not rely final experiment design only on thermal vacuum test at ZARM, do smaller test beforehand and verify or revise sub components.

CDR follow up:
REMARK: The thermal vacuum test at ZARM is missing. It will be around August.
REMARK: Test10 is unclear, how to perform this test in a lab? Using a vibration test lab is overkill for BEXUS.
REMARK: Test 11 could be combined with thermal vacuum test at ZARM.

6 LAUNCH CAMPAIGN PREPARATION

RID: finalize the exp mass - not 4-8 kg - 100% margin
REMARK: specify "as high as possible"
REMARK: Written down procedure for recovery and late access
REMARK: revised the WPs at campaign
REMARK: specify which items will provide by you and which items should provide by SSC or ZARM

CDR follow up:
REMARK: Launch site requirements are okay. ZARM will bring a soldering station also for SMD.
REMARK: Be aware of any transport regulations to and from Esrange/Sweden.
REMARK: Add flight risk of sealed tube -> pressure vessel.
REMARK: Table 6-3: current consumption missing, give more information in this table. 300 Wh total power consumption is on the high side.
REMARK: Preparation activities: Early arrival is usually not supported. Contact Simon before the next SED and give good arguments.
REMARK: More detailed instructions for the recovery are needed (outer conditions like temp, time, until when do the samples have to be heated, quantify "as soon as possible" and describe reasons/consequences …).
REMARK: Late access could be in a cold environment and includes some walk towards the gondola. You could install the bio module around T-3 h in a warm environment and then have your heating running. Latest access is T-1 h, at this point the access might be hard: gondola hanging up etc.

REMARK: Transportation of bio module and activities after should be in the timeline for flight countdown (Table 6-2).

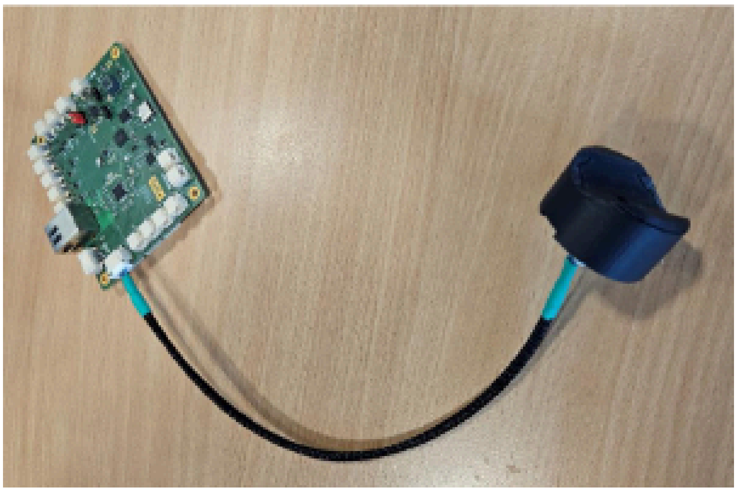
REMARK: There will be tests at launch campaign, outside and for longer durations. During that power consumption and communication will be tested and all sensors have to be connected like in flight configuration. Be ready to have everything connected at this point.

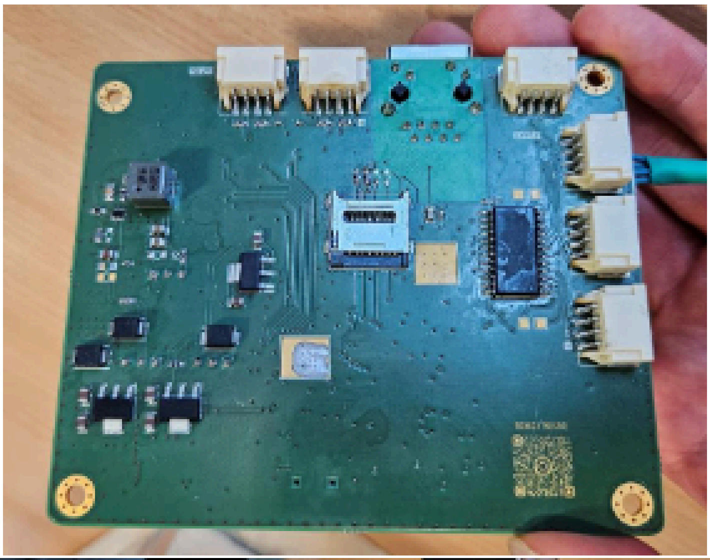
REMARK: Altitude requirement: write the numbers that you really need, if it is not that important write "as high as possible".

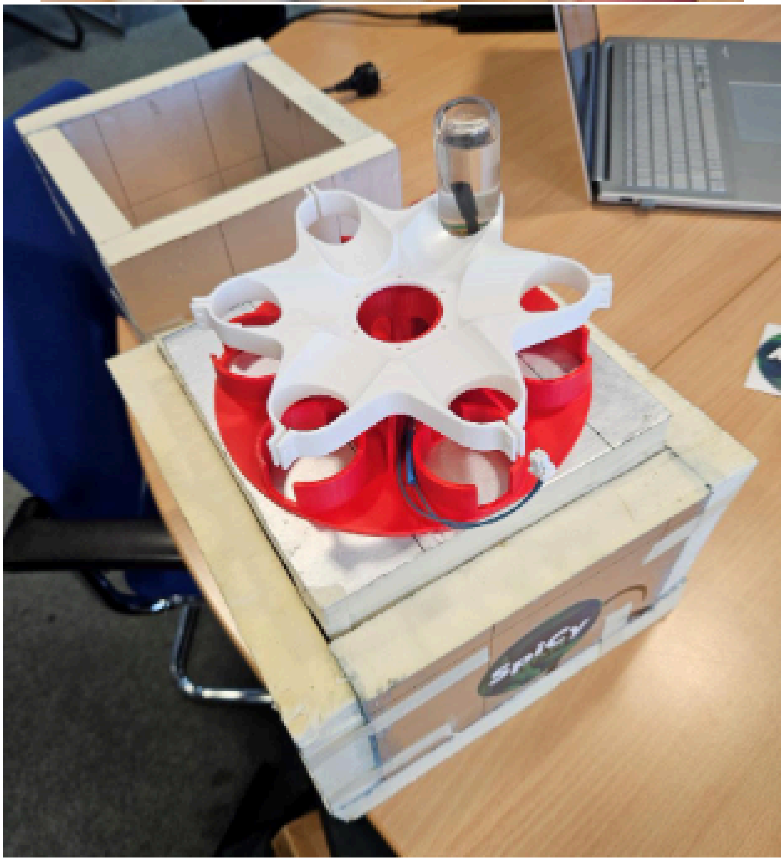
REMARK: Minimal float time that can be guaranteed is one hour.

REMARK: Light requirement: probably not precise enough for your science. Find out which angle of sun you need for the light to reach the tubes, specify e.g. earliest time after sunrise, time before sunset.

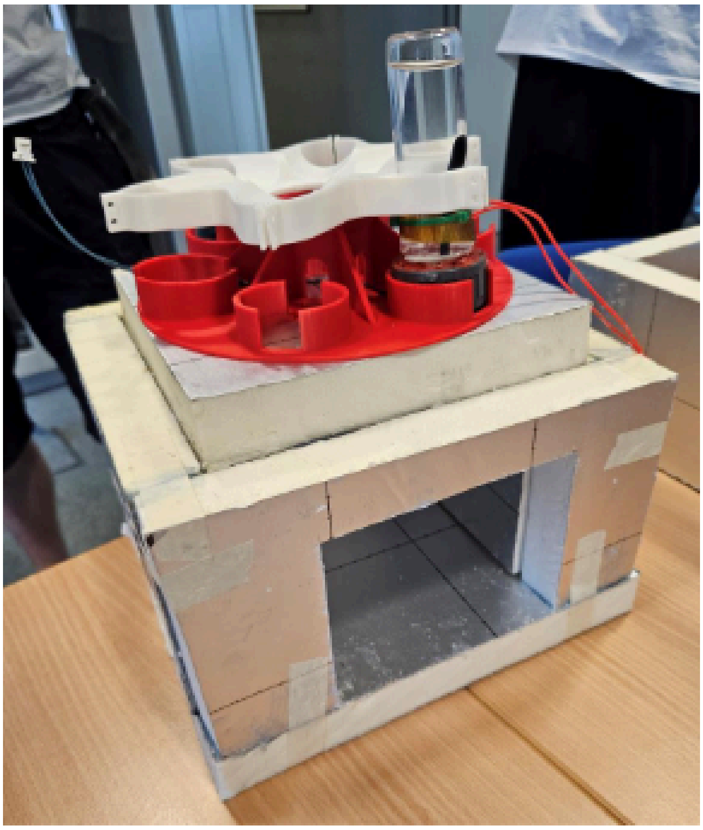
B – Hardware Inspection







	REXUS/BEXUS Critical Design Review	Experiment Team:	SPICY
		Vehicle and Flight number:	BX34
Location: TU Munich		Date: 01.08.2024	



C – Tests

Appendix B – OUTREACH AND MEDIA COVERAGE

B.1 Visual Concept

B.1.1 Color Guide

The following paragraph shall explain the use of colours for all outreach media. We aimed for a palette that enables our visual language and therefore fits both a looser but yet scientifically serious communication on e.g. social media and the means of communication on a more neutral, professional level.

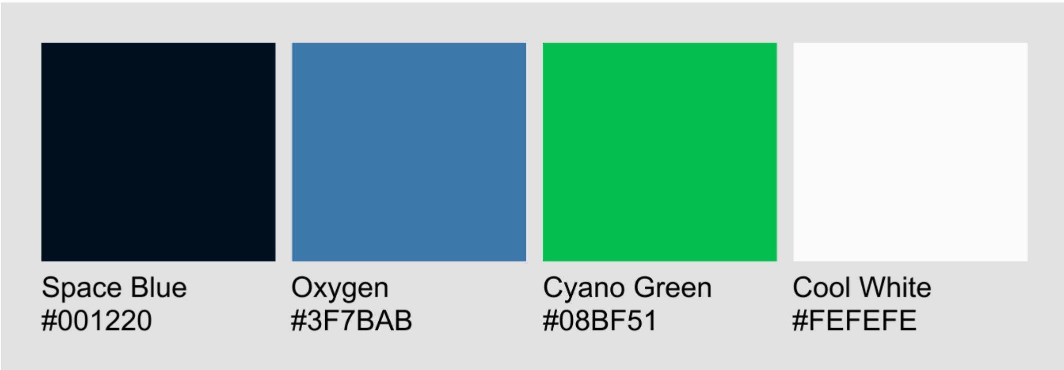


Figure B.1.1: Colour Palette

Space Blue: Primary colour. The dark blue gives the eye some rest. It feels mystic and undiscovered; it represents the view of the space towards which our balloon will fly and all the things being undiscovered for us so far; it is best used as a shadow colour, text colour or for great flats.

Oxygen: Secondary colour. The bright blue shall be used in alternative, brighter layouts if needed. It strongly performs in gradients with the Space blue or Cool White and can be used for decorative elements that are supposed to unobtrusively support the main content; it represents oxygen, air and the view of the sky from afar where our balloon will be in the end.

Cyano Green: Primary colour. This green is a great accent colour and shall also be used in gradients with Space Blue. It feels vivid, exciting and represents the cyanobacteria and life itself.

Cool White: Primary (Text) colour. The white feels neutral and clear and is great for emphasising this by using it in great flats or gradients with Oxygen. Most of all, this is our main text colour since backgrounds are mostly filled with Space Blue; it represents our scientifically and professional approach but shall be carefully used since too much white can cause discomfort amongst the consumer.

B.1.2 Gradients

A major part of the visual language is the use of gradients. They shall either be created within one hue just by raising/lowering brightness of the base colour (or by raising transparency) or be a combination of

a) **Space Blue and Cyano Green** (see Figure B.1-2)
b) **Space Blue and Oxygen** (see Figure B.1-3)

with a) being our predominantly used gradient.

Figure B.1.2-1: Gradient a)

Figure B.1.2-2: Gradient b)

B.1.3 Shapes

To keep the continuity of our visual language and picking up the behaviour of oxygen, air and our project itself as a vividly moving and reshaping substance, we chose long and calming waves as a visual representation of this concept. The waves may vanish at one end, so they are not creating a stiff frame around content and shall be emphasised by a very blurred shade in either pure black (#000000) or whenever possible Space Blue (#001220)

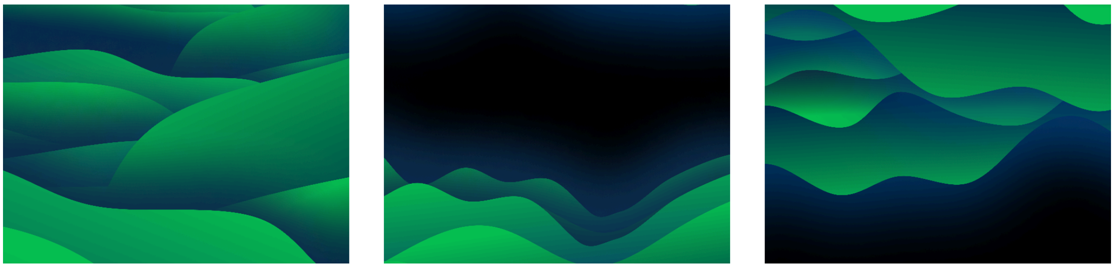


Figure B.1.3-1:Basic shapes - polychrome

Figure B.1.3-2: Basic shapes - monochrome

B.1.4 Typography

We chose ***League Spartan*** as our primary and ***Crimson Pro*** as our secondary font. *League Spartan* is a typeface based on American geometric sans serif from the early 20th century. Its simple and yet very expressive style works both in headings as capitals and body text. *League Spartan* is mainly used in Extra Bold (in body and heading). Exception: For headings or big text you might reduce the weight to “light” at its lowest, if there is a need to highlight other text in the same size. *Crimson pro* is for body only and optional. The predominantly used font shall be *League Spartan*.

B.2 Examples of Use

The following examples are sorted by 1. platform and 2. time. This shall visualise the process of developing our language with time until our latest designs in use.

B.2.1 Logo

The SpiCy logo may be used in the following shapes with the circular one being the predominantly applied version:

Figure B.2.1-1: SpiCy logo in different shapes

However, if the logo is too distracting from other content, apply the word mark instead. Depending on the use case there will be many things to consider like contrast, pictures beneath, spacing, readability and context. Here are examples of possible scenarios and how to use and not to use our logo:

Figure B.2.1-2: The basic SpiCy wordmark logo on different backgrounds.

The basic SpiCy wordmark logo shall not be applied on a bright background. To raise lacking visual contrast, follow the next examples:

Figure B.2.1-3: Use of SpiCy wordmark logo in black

The SpiCy wordmark logo in black shall be applied on bright desaturated and bright coloured backgrounds. Do not use this on darker backgrounds as shown above.

Figure B.2.1-4: Basic SpiCy wordmark logo on gradients and pictures

In case none of the variants shown above provide enough contrast, use a gradient with as mentioned in chapter “B.1.2 Gradients”. If the basic SpiCy wordmark logo is placed on bright pictures always apply a soft luminosity gradient behind the logo or if necessary, combine a very blurred shade together with a blurred ellipse both set to luminosity behind the logo. In case the wordmark logo shall be used on a gradient, the logo must be placed on the darker tone.

B.2.2 LinkedIn

LinkedIn is a secondary outreach platform for our team and was ultimately launched in February 2024. Nonetheless, we planned on implementing it at a later stage if we were in need for more sponsorships or for team members to publicly show engagement and provide the possibility of connecting for further business approaches.

Figure B-2.2-1: Designs for LinkedIn Headers - OUTDATED

Learning: These designs don't work for different reasons:

- The weight of the Font *League Spartan: ExtraLight* is too low
- The white and the green version are too high in contrast
- If used in a twitter or LinkedIn Header, the text is gratuitous

The old design was therefore reworked and applied to our LinkedIn page that has been launched in February 2024:

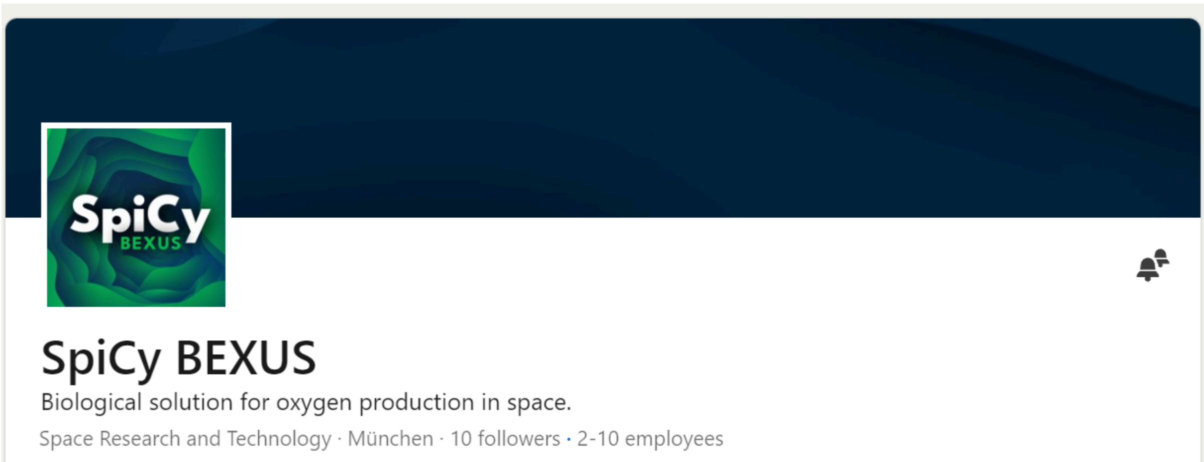


Figure B.2.2-2: LinkedIn Page Header

B.2.3 Instagram

Together with our Website, Instagram is the main platform of communication for us. Before launching the page, the visual concept was the following:

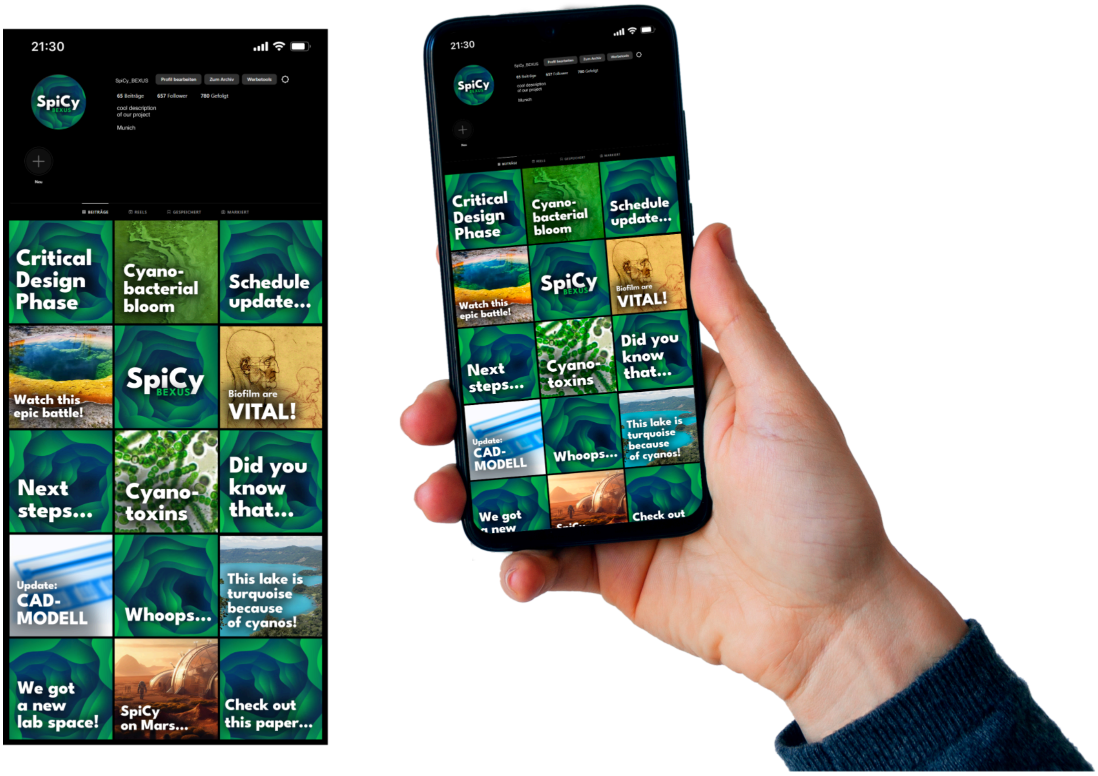


Figure B.2.3-1: SpiCy BEXUS instagram channel - MOCKUP

We started posting on November 27th 2023. For comparison, click here to have a look at our instagram channel.

It is important to us to include as many people as possible and so we pay much attention on using barrier-free tools like alt-texts and screen reader friendly post texts.

SpiCy was given the opportunity to take part in the LMU-Takeover, an instagram channel hosted by the LMU that is temporarily open for invited groups. These groups are picked via an interview with the hosts and can then post about their projects and student life for about one week. The following picture shall give a quick overview about our takeover outline. For more details such as descriptions, comments, more pictures, videos and alt-texts, visit the LMU-Takeover or the SpiCy BEXUS channel.

Figure B.2.3-2: SpiCy's instagram feed after the LMU-Takeover

B.2.4 Website

See chapter 3.4 Outreach Approach

Our Website has the purpose of giving deeper insight into our project and providing information for the science community.

Figure B.2.4-1: Favicons for the Website

To combine easy editing for everyone on the team, even non programmers, and keep the advantages of adding self written code on the website we used "wordpress" as a CMS System. Wordpress is a PHP based Website framework that we host under our own domain: www.spicybexus.de.

The blog entries provide updates, news and technical information about the project.

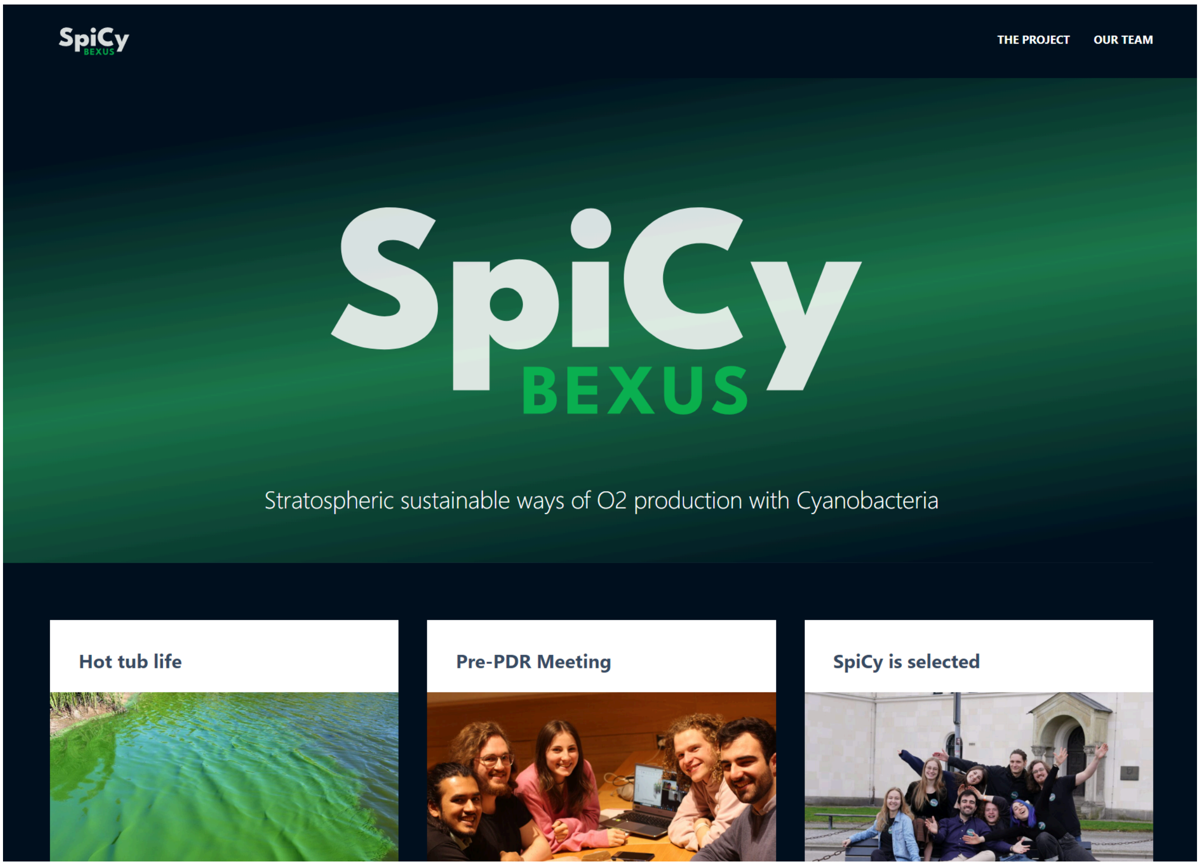


Figure B.2.4-2: SpiCy Website

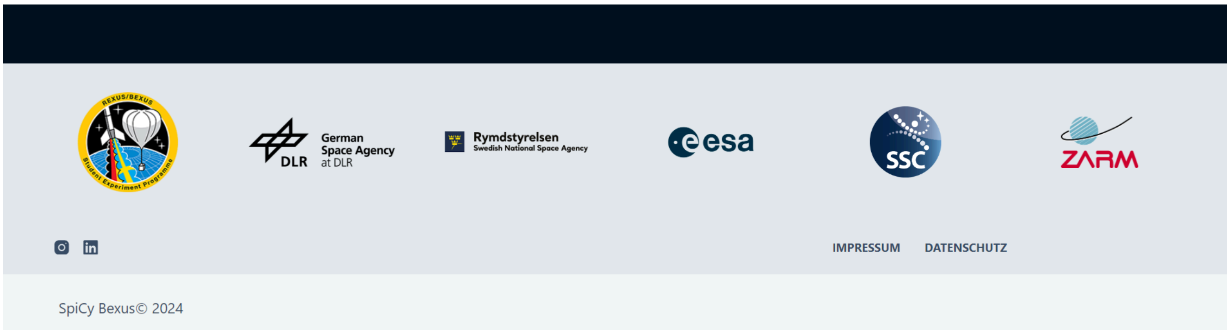


Figure B.2.4-3: SpiCy Website Footer

Along with the website we also set up E-Mail addresses under our domain. For example: info@spicybexus.de or admin@spicybexus.de. The info@spicybexus.de will be used to give one universal Email address to contact our team.

B.3 Analogue Media

B.3.1 Posters

The posters were made for the TUM Spaceday, to give a brief introduction to our project and designed with a call to action, to follow us on social media.

Figure B.3.1: Printed posters before cutting at HM digital printlab

B.3.2 Stickers

To emphasize associations with the REXUS/BEXUS programme and highlight our contact data, we implemented a new sticker design that approaches the current REXUS/BEXUS logo layout but at the same time implements our brands' identificational character within this product.
The following picture shows our current sticker version.

Figure B.3.2: Sticker Layout

B.3.3 Apparel

We printed team t-shirts with our logo, some illustrations and a qr-code for our website. We used a digital textile printer due to the fast production and cost efficiency. The t-shirts were worn by our team members at the TUM spaceday.

Figure B.3.3: T-Shirts in printing process at HM analoge printlab

B.4. Special Events

B.4.1 Space Day

Figure B.4.1: Team SpiCy at the Space Day. In Red: Endorsing professor Dr. Gisela Detrell

B.4.2 Open Day at LMU’s Bio Faculty

Figure B.4.2: Our booth at the Open Day

Figure B.4.3: Some of the button motives that we made

Appendix C ADDITIONAL TECHNICAL INFORMATION

Pyrosience FD-OEM Oxygen Sensors

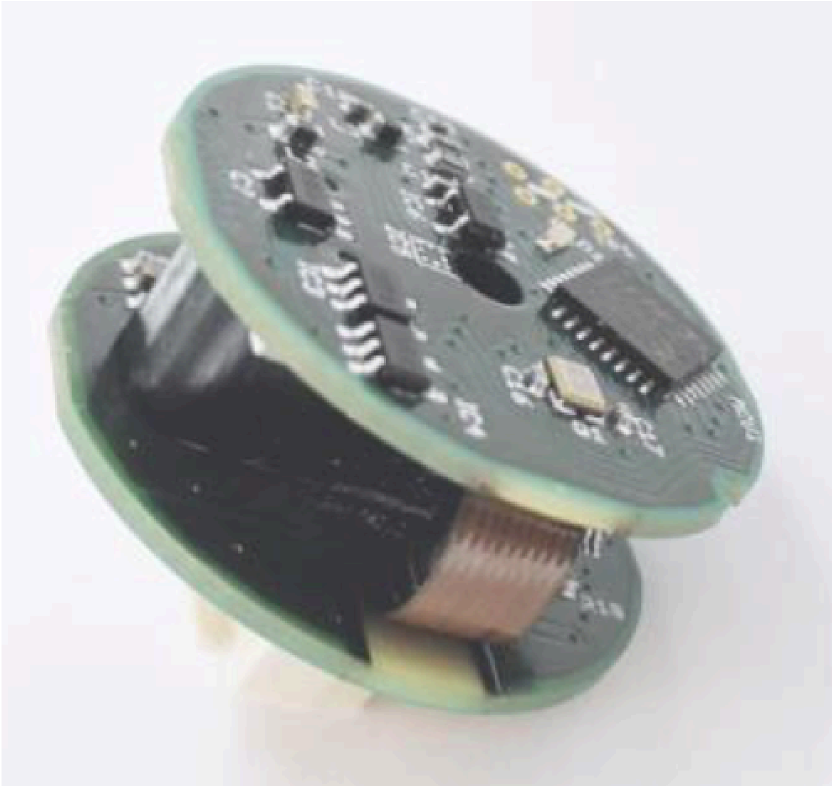


Fig. C-1: FD-OEM sensor

They are basically this sensor just in a different packing.

Biological Laboratory Plan

<u>May:</u>

- 3rd week of May: Oxygen measurement of Cyanobacteria cultures (C. cubana in BG11 and BG11+, Nostoc sp., Oscillatoria sp., Anabaena cylindrica)

- 4th week of May: Ordering heterotrophic bacteria (P. taiwanesis, E. coli, Bacillus subtilis) and preparation of media (LB, M9)

<u>June:</u>

- 1st week of June: Cultivation of heterotrophic bacteria

- 2nd week of June: Combination of Cyanobacteria with heterotrophic bacteria in different ratios (1:1, 2:1, 4:1)

- 3rd week of June: Oxygen measurement of surviving combinations

- 4th week of June: Selection of top candidates and conducting tests (matrix analysis, photosynthesis rate, ...)

<u>July:</u>

- 1st week of July: Combination of Cyanobacteria with 2 heterotrophic bacteria strains

- 2nd week of July: Oxygen measurement of surviving combinations

- 3rd week of July: Selection of top candidates and conducting tests

- 4th week of July: Oxygen measurement of the top candidate in the module

Biological Preparation at the LMU lab in Großhadern:

Tested bacterial strains:

Cyanobacteria:

- *Anabaena cylindrica*
- *Oscillatoria sp.*
- *Nostoc sp.*
- *Chroococcidiopsis cubana*

The *Nostoc sp.* was the only strain that formed consistent biofilms with all three heterotrophic bacterial strains, so this species was selected to be the best candidate for the experiment.

Heterotrophic bacteria:

- *Pseudomonas taiwanesis*
- *Escherichia coli*
- *Bacillus subtilis*

All three strains formed biofilms with the *Nostoc sp.* so all three were selected for the experiment.

Media:

BG11 Media for *A. cylidrica, Oscillatoria sp. and Nostoc sp.:*

1. **200x-Stocksolutions**: autoclave separately

   For 200 ml you need:
   - 60 g NaNO$_3$ [3.5 M]
   - 1.6 g K$_2$HPO$_4$ x 3 H$_2$O [0.035 M]
   - 3 g MgSO$_4$ x 7 H$_2$O [0.06 M]
   - 1.4 g CaCl$_2$ x 2 H$_2$O [0.05 M]
   - 0.24 g Citric acid + 0.24 g Fe-Citrate
   - 1.6 g NaCO$_3$ [0.1 M]
2. **EDTA-Stocksolution:** 100 ml

- 3.72 g EDTA [0.1 M], adjust pH 8.0 with NaOH

3. **Trace elements solution A5+Co:** 100 ml

· H_3BO_3	286 mg
· $MnCl_2$x4 H_2O	181 mg
· $ZnSO_4$ x 7 H_2O	22.2 mg
· Na_2MoO_4 x 2 H_2O	39 mg
· $CuSO_4$ x 5 H_2O	7.9 mg
· $Co(NO_3)_2$ x $6H_2O$	4.9 mg

4. **HEPES-Stocksolution:**

- 59 g / 250 ml è[1 M] pH 7.5 with NaOH

5. **$NaHCO_3$-Stocksolution:** sterile filter it!

- 21 g /250 ml è[1 M]

6. **For 1 l of Cyanobacteria media you need:**

- 5 ml of every stocksolution
- 30 µl EDTA stock solution
- 10 ml HEPES

-> autoclave everything together
-> then add:

- 5 ml $NaHCO_3$
- 1 ml Trace elements solution

<u>BG11+ Media for *C. cubana*:</u>

		[g/L]	[mg/200mL] [mL/200mL]	[ml/L]	
Trace metal Mix	H_3BO_3	2.9	580	<-	
	$MnCl_2$ *$4H_2O$	1.81	362	<-	

	ZnSO4 *7H_2O	0.22	44	<-	
	Na_2MoO_4 *2H_2O	0.39	78	<-	
	$CuSO_4$ *5H_2O	->	2 mL	10 ml	0.8g/100ml Stock Sol.
	$Co(NO_3)_2$ *6H_2O	->	2 mL	10 ml	0.5g/100ml Stock Sol.

Minerals	Volume [mL/L]	Stock Solutions [g/L]	Stock Solution [g/200mL]	
$NaNO_3$	5.0	300	60	Autoclave
$MgSO_4$ *7H_2O	10	7.5	1,5	Autoclave
$CaCl_2$ *2H_2O	10	3.6	720 mg	Autoclave
Na_3-citrate *2H_2O	10	0.6	120 mg	Autoclave
Na_2-EDTA *2H_2O	10	0.1	20 mg	Sterile filtrate

K_2HPO_4 *$3H_2O$	2.0	20	4	Autoclave
Na_2CO_3	2.0	10	2	Autoclave
Fe-NH_4-citrate	2.0	3.0	600 mg	Autoclave
Trace metal mix	1.0	-		Sterile filtrate

Adjust to 1000mL with mQ water and autoclave.

After cooling, add the following filter components

Minerals	Volume [mL/L]	Stock Solutions [g/L]	Stock Solution [mg/200 mL]
Vitamin B12	1.0	0.02	4

M9 Minimalmedia for heterotrophic bacteria:

M9 Salts: for 500mL -> autoclave

- 30g $Na_2HPO_4 \times 2\ H_2O$
- 15g KH_2PO_4
- 2.5g NaCl

Trace Elements: for 200mL

- 1g EDTA(Na)
- Dissolve in water
- pH 7.5
- 166mg $FeCl_3 \times 6\ H_2O$
- 16.8mg $ZnCl_2$
- 2.6mg $CuCl_2 \times 2\ H_2O$
- 2mg $CoCl_2 \times 2\ H_2O$
- 2mg H_3Bo_3
- 0.32mg $MnCl_2 \times 4\ H_2O$
- Fill up to 200mL with water
- Sterile filtrate

Stock Solutions: for 200mL each

- 54.1g $MgSO_4 \times H_2O$ -> autoclave
- 5.9g $CaCl_2 \times 2\ H_2O$ -> autoclave
- 67.5g Thiamine-HCl -> sterile filtrate, store in fridge
- 100g NH_4Cl -> autoclave

- 1M Carbon source -> autoclave

<u>M9 Media:</u> for 500mL

- 50mL M9 Salts
- 500µL $MgSO_4$ x H_2O
- 1mL Thiamine-HCl
- 5mL NH_4Cl
- 5mL Trace Elements
- 10mL Carbon Source
- 500µL $CaCl_2$ x 2 H_2O
- $CaCl_2$ x 2 H_2O has to be put in last

<u>LB Media for *E. coli* and *B. subtilis*:</u>

for 500mL:

5g Tryptone

2.5g Yeast extract

5g NaCl

-> pH 7

-> autoclave

<u>Nutrient Broth for *P. taiwanesis*:</u>

For 500mL:

4g Nutrient Broth (Roth)

-> pH 6.8

-> autoclave

Methods:

The cyanobacteria were first cultivated in their respective media in April 2024. In June 2024 we decided that the cyanobacteria cultures had a high enough biomass to start a cultivation with the heterotrophic bacteria.

Here we first measured the Chlorophyll a of the cyanobacteria with a photometer. 1mL of each culture was pelleted and resuspended in ice cold methanol. This was then incubated in the fridge for 1h. The solution was centrifuged, and the absorbance of the supernatant was measured at 665nm and 720nm. With these readings the amount of Chlorophyll a was calculated: 14.4892 * (A665 – A720) = Chl a [µM] (Bozan et. al. 2022).

Then the OD600 of the heterotrophic bacteria was measured. The bacteria had been cultivated for 24h in their normal media at their optimal growing temperatures:

E. coli: 37°C in LB Media

P. taiwanesis: 30°C in Nutrient Broth

B. subtilis: 30°C in LB Media

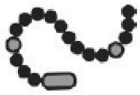
Then 1mL of culture was transferred into M9 Minimalmedia. Where they were cultivated for 48h at optimal growing temperatures.

To cultivate the combinatory biofilms 16µM of Cyanobacteria culture and an OD of 1.5 for the heterotrophic bacteria were used for each approach.

In July 2024 the *Nostoc sp.* was the only strain that formed stable biofilms with each of the heterotrophic bacteria. So, it was decided to send the *Nostoc sp.* with each one of the heterotrophic bacteria on the module. The final biofilms in the glass tubes were cultivated in August 2024. They did however not attach to the bottom of the tubes as we were hoping because the glass was to smooth. A short oxygen measurement was done in September 2024 to confirm that the system works.

Material Safety Data Sheets (MSDS)

Biological Samples



Chroococcidiopsis cubana Active Culture

Product number: DSM 107010

Add to notepad

Selection:

Active Culture

160,00 €

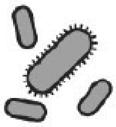
1 To cart

Description

Detailed Price Information Link

CYANO	How to read the following data (Example)
Name:	***Chroococcidiopsis cubana***
DSM No.:	**107010 dsm-107010 dsm107010 dsm 107010 Chroococcidiopsis cubana**
Strain designation:	SAG 39.79
Other collection no. or WDCM no.:	PCC 7433,ATCC 29381,1966/27
Isolated from:	dry soil
Country:	Cuba Pinar del Rio
Nagoya Protocol Restrictions:	There are NO known Nagoya Protocol restrictions for this strain.
History:	<- SAG; SAG 39.79 [2018] <- F. Hindák; 1966/27 [1966]
Genbank accession numbers:	whole genome shotgun sequence: RSCK00000000 16S rRNA gene: AJ344558 16S rRNA gene: JF810080
Cultivation conditions:	Medium 1593, standing culture, 16 hours at 250-300 lux illumination, 8-hours dark period. Transfer interval of 8 weeks, 18°C Complete DSMZ Media List
Summary and additional information:	<- SAG; SAG 39.79 [2018] <- F. Hindák: 1966/27 [1966]. Dry soil, Cuba, Pinar del Rio. Sequence accession no. whole genome shotgun sequence: RSCK00000000, 16S rRNA gene: AJ344558, 16S rRNA gene: JF810080. Phototrophic. It cannot be excluded that the strain produces cyanobacterial toxins that can be dangerous to humans and pets. **DSM 107010 is an axenic culture.** Strain-specific literature (27796). (Medium 1593, 18°C, standing culture, 16 hours at 250-300 lux illumination, 8-hours dark period. Transfer interval of 8 weeks)
Literature:	27796, 40920
Risk group:	1 (classification according to German TRBA)

Fig. C-2: MSDS of Chroococcidiopsis cubana



Escherichia coli Dried Culture

Product number: DSM 5911

Add to notepad

Selection:

Dried Culture ▾

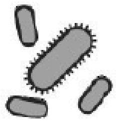
100,00 €

1 | To cart

Description

	Detailed Price Information Link
BACTERIA	How to read the following data (Example)
Name:	***Escherichia coli*** (Migula 1895) Castellani and Chalmers 1919
DSM No.:	**5911 dsm-5911 dsm5911 dsm 5911 Escherichia coli**
Strain designation:	W3110
Other collection no. or WDCM no:	ATCC 27325, K12 W3110
Country:	country of origin unknown
Date of sampling:	before 01.04.1990
Nagoya Protocol Restrictions:	There are NO known Nagoya Protocol restrictions for this strain.
History:	<- ATCC <- J. Lederberg
Cultivation conditions:	Medium 381, 37°C Complete DSMZ Media List
Summary and additional information:	<- ATCC <- J. Lederberg. [K12 W3110]. lambda⁻ F⁻ *mcrA mcrB* IN(*rrnD-rrnE*)1; prototrophic. (Medium 381, 37°C).
Risk group:	1 (classification according to German TRBA)
Supplied as:	Delivery form / Prices: Freeze Dried 100,- € Active culture on request 240,- € DNA 150,- € Price Category for this culture: **1** Freight and handling charges will be added. See price list.
Other cultures:	All DSMZ cultures of the species
	Print data sheet

Fig. C-3: Fig. C-3: MSDS of Escherichia coli (Migula 1895) Castellani and Chalmers 1919



Pseudomonas taiwanensis Dried Culture

Product number: DSM 3263

Add to notepad

Selection:

Dried Culture ▾

100,00 €

1 | To cart

Description

	Detailed Price Information Link
BACTERIA	How to read the following data (Example)
Name:	***Pseudomonas taiwanensis*** Wang et al. 2010
DSM No.:	**3263 dsm-3263 dsm3263 dsm 3263 Pseudomonas taiwanensis**
Strain designation:	25-3
Other collection no. or WDCM no.:	IFO 12996,NBRC 12996
Country:	country of origin unknown
Date of sampling:	before 14.03.1985
Nagoya Protocol Restrictions:	There are NO known Nagoya Protocol restrictions for this strain.
History:	<- IFO <- K. Soda, Inst. Chem. Res., Kyoto Univ. (*Pseudomonas striata* 25-3)
Cultivation conditions:	Medium 1, 30°C Complete DSMZ Media List
Summary and additional information:	<- IFO <- K. Soda, Inst. Chem. Res., Kyoto Univ. (*Pseudomonas striata* 25-3). Listed as *Pseudomonas putida* until 2018. country of origin unknown. Reidentified as strain affiliated with *P. taiwanensis* based on identical 16S rRNA gene sequence with BCRC 17751T (NR_116172, 2018). Overexpresseion of amino acid racemase in *E. coli* for application in an enzyme membrane reactor. Produces amino acid racemase (19310). Application of amino acid racemase in an enzyme membrane reactor. (Medium 1, 30°C)
Literature:	19310
Risk group:	1 (classification according to German TRBA)

Fig. C-4: MSDS of Pseudomonas taiwanensis Wang et al. 2010

SAFETYDATASHEET

UTEX

SECTION 1 - SUBSTANCE IDENTITY AND COMPANY INFORMATION

Product Name: Various Algal Cultures at Biosafety Level 1

UTEX Strain #: Various

COMPANY INFORMATION: UTEX Culture Collection of Algae
205 W. 24th St, Biological Labs 218
The University of Texas at Austin (A6700)
Austin, TX 78712

FOR INFORMATION CALL: (512) 471-4019

SECTION 2 - HAZARDS IDENTIFICATION

GHS Symbol: NA

Signal Word: NA

HMIS Rating:	Health: 0	Flammability: 0	Reactivity: 0
NFPA Rating:	Health: 0	Flammability: 0	Reactivity: 0

Routes of Exposure

Skin Contact: No information available.
Skin Absorption: No information available.
Eye Contact: No information available.
Inhalation: No information available.
Ingestion: May be harmful if swallowed.
Chronic: No Information Found

This substance is not hazardous as defined by OSHA 29CFR 1910.1200 however this product should be handled according to good lab practices, with proper personal protective equipment, proper engineering controls and within the parameters of the purchaser's safety program.

Health Hazards

UTEX recommends that all UTEX cultures be handled by qualified microbiologists using appropriate safety procedures and precautions. Detailed discussions of laboratory safety procedures are provided in Laboratory Safety: Principles and Practice (Fleming et al) and in the U.S. Government Publication, Biosafety in Microbiological and Biomedical Laboratories. This publication is available in its entirety in the Center for Disease Control Office of Health and Safety's web site at http://www.cdc.gov/biosafety/publications/bmbl5/index.htm.

SECTION 3 - COMPOSITION/INFORMATION ON INGREDIENTS

Various Microbial Cultures at Biosafety Level 1

Growing cells shipped in liquid or agar cell culture medium (a mixture of components that may include, but is not limited to: inorganic salts, vitamins, amino acids, carbohydrates and other nutrients dissolved in water).

This substance contains no ingredients at concentrations to be considered hazardous as defined by OSHA 29CFR 1910.1200 however this product should be handled according to good lab practices, with proper personal protective equipment, proper engineering controls and within the parameters of the purchaser's chemical hygiene plan.

SECTION 4 - FIRST AID MEASURES

Ingestion: If person is unconscious seek emergency medical attention; never give anything by mouth to an unconscious person. If the person is conscious wash mouth out with copious amounts of water and call a physician then administer three cupfuls of water. Do not induce vomiting unless directed to do so by a physician.

Inhalation: If person is unconscious seek emergency medical attention, if person is conscious remove to fresh air and call a physician.

Dermal exposure: Immediately wash skin with copious amounts of water followed by washing with soap and copious amounts of water. Remove all contaminated clothing.

Eye exposures: Flush eyes with copious amounts of water for at least 15 minutes with eyelids separated and call a physician.

Notes to Physician: Treat symptomatically and supportively.

SECTION 5 - FIRE FIGHTING MEASURES

General: Wear Self-Contained breathing apparatus in pressure demand, MSHA/NIOSH approved. During a fire, irritating and toxic gases may be generated by thermal decomposition.

Extinguishing Media: Water spray, carbon dioxide, dry chemical powder, Halon (where regulations permit), or appropriate foam.

Autoignition Temperature: N/A

Explosion limits: N/A

Flash Point: Not Available

Specific Hazard(s): Responders should take into consideration the biohazard risk associated with responding to a fire in the area where the material may be stored or handled.

SECTION 6 - ACCIDENTAL RELEASE MEASURES

Use Personal Protective Equipment: Including Chemical Splash Goggles, Chemical Resistant Gloves, and appropriate clothing to prevent skin exposure.

In addition, a Respiratory protection program that complies with OSHA 29 CFR 1910.134 and ANSI Z88.2 requirements or European Standard EN 149 must be followed whenever workplace conditions warrant respirator use.

Patient/Victim: Wash with soap and water. Work clothes should be laundered separately. Launder contaminated clothing before re-use. Do not take clothing home.

Equipment/Environment: Allow aerosols to settle; wearing protective clothing, gently cover spill with paper towel and apply 1% sodium hypochlorite, starting at perimeter and working towards the center; allow sufficient contact time before clean up (30 min).

Note: The use of additional PPE may be necessary for cleaning solutions.

SECTION 7 - HANDLING AND STORAGE

Handling: Handle and store according to instructions on product information sheet and label.

Storage: Keep in properly labeled containers.

SECTION 8 - EXPOSURE CONTROLS/PERSONAL PROTECTION

Engineering Controls: The use and storage of this material requires user to maintain and make available appropriate eyewash and safety shower facilities. Use fume hood or other appropriate ventilation method to keep airborne concentrations a low as possible.

Personal Protective Equipment: Including Safety Glasses or goggles, Chemical Resistant Gloves, and appropriate clothing to prevent skin exposure. In addition, a Respiratory protection program that complies with OSHA 29 CFR 1910.134 and ANSI Z88.2 requirements or European Standard EN 149 must be followed whenever workplace conditions warrant respirator use.

Exposure Limits: No exposure limits for this material have been established by ACGIH, NIOSH, or OSHA. There are no Vacated OSHA PEL for this material.

SECTION 9 - PHYSICAL AND CHEMICAL PROPERTIES

No Information is available for PH, Vapor Pressure, Vapor Density, Evaporation Rate, Viscosity, Boiling Point, Freezing/Melting Point, Decomposition Temperature, Solubility, Specific Gravity/Density, or Molecular Weight.

SECTION 10 - STABILITY AND REACTIVITY

Chemical Stability: No information available.

Conditions to Avoid: No information available.

Hazardous Decomposition Products: No information available.

Hazardous Polymerization: Will not occur.

SECTION 11 - TOXICOLOGICAL INFORMATION

No Information was found in relation to: RTECS, LD50/LC50, Carcinogenicity, Epidemiology, Teratogenicity, Reproductive effects, Mutagenicity, or Neurotoxicology.

Note: The toxicological properties of this substance have not been fully investigated.

SECTION 12 - ECOLOGICAL INFORMATION

No ecological information available.

SECTION 13 - DISPOSAL CONSIDERATIONS

Decontaminate all wastes before disposal (steam sterilization, chemical disinfection, and/or incineration).

Hazardous waste generators are required to determine if a discarded chemical is classified as a hazardous waste according to 40 CFR Part 261.3. In addition waste generators must consult about and comply with all state and local regulations to ensure compliance.

SECTION 14 - TRANSPORT INFORMATION

Land Transport (ADR/RID): Not a dangerous good in sense of this transport regulation.

Inland Water ways transport (ADN): Not a dangerous good in sense of this transport regulation.

Sea Transport (IMDG): Not a dangerous good in sense of this transport regulation.

Air Transport (ICAQ-TP / IATA-DGR): Not a dangerous good in sense of this transport regulation.

DOT Classification: Not a DOT controlled material (United States).

SECTION 15 - REGULATORY INFORMATION

This substance is not listed on the TSCA Inventory. It is for research and development use only.

This substance is not SARA listed.

US Federal Regulations: SARA 313: This product is not regulated by SARA CAA, Section 112, Hazardous Air Pollutants (HAPs) (40 CFR 61): This product does not contain HAPs.

US State Regulations: California Proposition 65: This product does not contain chemicals listed under Proposition 65.

SECTION 16 - OTHER INFORMATION

THE INFORMATION PRESENTED IN THIS DOCUMENT IS BELIEVED TO BE CORRECT BASED UPON DATA AVAILABLE TO UTEX. USERS SHOULD MAKE AN INDEPENDENT DECISION REGARDING THE ACCURACY OF THIS INFORMATION BASED ON THEIR NEEDS AND DATA AVAILABLE TO THEM. ALL SUBSTANCES AND MIXTURES MAY PRESENT UNKNOWN HAZARDS AND ALL NECESSARY SAFETY PRECAUTIONS SHOULD BE TAKEN. UTEX ASSUMES NO LIABILITY RESULTING FROM USING OR COMING IN CONTACT WITH THIS SUBSTANCE.

Safety data sheet Safety data sheet

acc. to Safe Work Australia - Code of Practice

2-Propanol 70 %, pure

article number: **CN09**
Version: **GHS 4.0 en**
Replaces version of: 2021-09-09
Version: (GHS 3)

date of compilation: 2019-04-04
Revision: 2024-01-30

SECTION 1: Identification of the substance/mixture and of the company/ undertaking

1.1 Product identifier

Identification of the substance	**2-Propanol** 70 %, pure
Article number	CN09
CAS number	[67-63-0]
Alternative name(s)	Isopropanol

1.2 Relevant identified uses of the substance or mixture and uses advised against

Relevant identified uses:	Laboratory chemical Laboratory and analytical use
Uses advised against:	Do not use for private purposes (household). Food, drink and animal feedingstuffs.

1.3 Details of the supplier of the safety data sheet

Carl Roth GmbH + Co. KG
Schoemperlenstr. 3-5
D-76185 Karlsruhe
Germany

Telephone:+49 (0) 721 - 56 06 0
Telefax: +49 (0) 721 - 56 06 149
e-mail: sicherheit@carlroth.de
Website: www.carlroth.de

Competent person responsible for the safety data sheet:	Department Health, Safety and Environment
e-mail (competent person):	**sicherheit@carlroth.de**

1.4 Emergency telephone number

Name	Street	Postal code/city	Telephone	Website
NSW Poisons Information Centre Childrens Hospital	Hawkesbury Road	2145 Westmead, NSW	131126	

SECTION 2: Hazards identification

2.1 Classification of the substance or mixture

Classification acc. to GHS

Section	Hazard class	Category	Hazard class and category	Hazard statement
2.6	Flammable liquid	2	Flam. Liq. 2	H225
3.3	Serious eye damage/eye irritation	2	Eye Irrit. 2	H319
3.8D	Specific target organ toxicity - single exposure (narcotic effects, drowsiness)	3	STOT SE 3	H336

For full text of abbreviations: see SECTION 16

b) MSDS Chemicals

Isopropanol 70%

The most important adverse physicochemical, human health and environmental effects

The product is combustible and can be ignited by potential ignition sources.

2.2 Label elements

Labelling

Signal word **Danger**

Pictograms

GHS02, GHS07

Hazard statements

H225	Highly flammable liquid and vapour
H319	Causes serious eye irritation
H336	May cause drowsiness or dizziness

Precautionary statements

Precautionary statements - prevention

P210	Keep away from heat/sparks/open flames/hot surfaces. - No smoking

Precautionary statements - response

P305+P351+P338	IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing
P312	Call a POISON CENTER or doctor/physician if you feel unwell
P370+P378	In case of fire: Use sand, carbon dioxide or powder extinguisher for extinction

Precautionary statements - storage

P403+P233	Store in a well-ventilated place. Keep container tightly closed
P403+P235	Store in a well-ventilated place. Keep cool

Precautionary statements - disposal

P501	Dispose of contents/container to industrial combustion plant

Hazardous ingredients for labelling: 2-Propanol

2.3 Other hazards

Results of PBT and vPvB assessment

Does not contain a PBT-/vPvB-substance in a concentration of ≥ 0,1%.

Endocrine disrupting properties

Does not contain an endocrine disruptor (ED) in a concentration of ≥ 0,1%.

SECTION 3: Composition/information on ingredients

3.1 Substances

not relevant (mixture)

3.2 Mixtures

Description of the mixture

Name of substance	Identifier	Wt%	Classification acc. to GHS	Pictograms	Notes
2-Propanol	CAS No 67-63-0	70	Flam. Liq. 2 / H225 Eye Irrit. 2 / H319 STOT SE 3 / H336		

For full text of abbreviations: see SECTION 16

SECTION 4: First aid measures

4.1 Description of first aid measures

General notes

Take off contaminated clothing.

Following inhalation

Provide fresh air. In all cases of doubt, or when symptoms persist, seek medical advice.

Following skin contact

Rinse skin with water/shower. In all cases of doubt, or when symptoms persist, seek medical advice.

Following eye contact

Irrigate copiously with clean, fresh water for at least 10 minutes, holding the eyelids apart. In case of eye irritation consult an ophthalmologist.

Following ingestion

Rinse mouth. Call a doctor if you feel unwell.

4.2 Most important symptoms and effects, both acute and delayed

Vomiting, Irritation, Dizziness, Drowsiness, Narcosis

4.3 Indication of any immediate medical attention and special treatment needed

none

SECTION 5: Firefighting measures

5.1 Extinguishing media

Suitable extinguishing media

co-ordinate firefighting measures to the fire surroundings!
water spray, alcohol resistant foam, dry extinguishing powder, BC-powder, carbon dioxide (CO_2)

Unsuitable extinguishing media

water jet

5.2 Special hazards arising from the substance or mixture

Combustible. In case of insufficient ventilation and/or in use, may form flammable/explosive vapour-air mixture. Solvent vapours are heavier than air and may spread along floors. Places which are not ventilated, e.g. unventilated below ground level areas such as trenches, conduits and shafts, are particularly prone to the presence of flammable substances or mixtures.

Hazardous combustion products

Carbon monoxide (CO), Carbon dioxide (CO_2), May produce toxic fumes of carbon monoxide if burning.

5.3 Advice for firefighters

In case of fire and/or explosion do not breathe fumes. Fight fire with normal precautions from a reasonable distance. Wear self-contained breathing apparatus.

SECTION 6: Accidental release measures

6.1 Personal precautions, protective equipment and emergency procedures

For non-emergency personnel

Wearing of suitable protective equipment (including personal protective equipment referred to under Section 8 of the safety data sheet) to prevent any contamination of skin, eyes and personal clothing. Do not breathe vapour/spray. Avoidance of ignition sources.

6.2 Environmental precautions

Keep away from drains, surface and ground water. Retain contaminated washing water and dispose of it.

6.3 Methods and material for containment and cleaning up

Advice on how to contain a spill

Covering of drains.

Advice on how to clean up a spill

Absorb with liquid-binding material (sand, diatomaceous earth, acid- or universal binding agents).

Other information relating to spills and releases

Place in appropriate containers for disposal. Ventilate affected area.

6.4 Reference to other sections

Hazardous combustion products: see section 5. Personal protective equipment: see section 8. Incompatible materials: see section 10. Disposal considerations: see section 13.

SECTION 7: Handling and storage

7.1 Precautions for safe handling

Provision of sufficient ventilation.

Measures to prevent fire as well as aerosol and dust generation

Keep away from sources of ignition - No smoking.

Take precautionary measures against static discharge. Due to danger of explosion, prevent leakage

of vapours into cellars, flues and ditches.

Advice on general occupational hygiene

Wash hands before breaks and after work. Keep away from food, drink and animal feedingstuffs. When using do not smoke.

7.2 Conditions for safe storage, including any incompatibilities

Keep container tightly closed.

Incompatible substances or mixtures

Observe hints for combined storage.

Consideration of other advice:

Ground/bond container and receiving equipment.

Ventilation requirements

Use local and general ventilation.

Specific designs for storage rooms or vessels

Recommended storage temperature: 15 – 25 °C

7.3 Specific end use(s)

No information available.

SECTION 8: Exposure controls/personal protection

8.1 Control parameters

National limit values

Occupational exposure limit values (Workplace Exposure Limits)

Country	Name of agent	CAS No	Identi-fier	TWA [ppm]	TWA [mg/m³]	STEL [ppm]	STEL [mg/m³]	Ceiling-C [ppm]	Ceiling-C [mg/m³]	Nota-tion	Source
AU	isopropyl alcohol (propan-2-ol)	67-63-0	WES	400	983	500	1,230				WES

Notation
Ceiling-C Ceiling value is a limit value above which exposure should not occur

Notation

STEL Short-term exposure limit: a limit value above which exposure should not occur and which is related to a 15-minute period (unless otherwise specified)

TWA Time-weighted average (long-term exposure limit): measured or calculated in relation to a reference period of 8 hours time-weighted average (unless otherwise specified)

Relevant DNELs of components

Name of substance	CAS No	Endpoint	Threshold level	Protection goal, route of exposure	Used in	Exposure time
2-Propanol	67-63-0	DNEL	500 mg/m³	human, inhalatory	worker (industry)	chronic - systemic effects
2-Propanol	67-63-0	DNEL	1,000 mg/m³	human, inhalatory	worker (industry)	acute - systemic effects
2-Propanol	67-63-0	DNEL	888 mg/kg bw/day	human, dermal	worker (industry)	chronic - systemic effects

Relevant PNECs of components

Name of substance	CAS No	Endpoint	Threshold level	Organism	Environmental compartment	Exposure time
2-Propanol	67-63-0	PNEC	140.9 $^{mg}/_{l}$	aquatic organisms	freshwater	short-term (single instance)
2-Propanol	67-63-0	PNEC	140.9 $^{mg}/_{l}$	aquatic organisms	marine water	short-term (single instance)
2-Propanol	67-63-0	PNEC	2,251 $^{mg}/_{l}$	aquatic organisms	sewage treatment plant (STP)	short-term (single instance)
2-Propanol	67-63-0	PNEC	552 $^{mg}/_{kg}$	aquatic organisms	freshwater sediment	short-term (single instance)
2-Propanol	67-63-0	PNEC	552 $^{mg}/_{kg}$	aquatic organisms	marine sediment	short-term (single instance)
2-Propanol	67-63-0	PNEC	28 $^{mg}/_{kg}$	terrestrial organisms	soil	short-term (single instance)

8.2 Exposure controls

Individual protection measures (personal protective equipment)

Eye/face protection

Use safety goggle with side protection.

Skin protection

- **hand protection**

Wear suitable gloves. Chemical protection gloves are suitable, which are tested according to EN 374. For special purposes, it is recommended to check the resistance to chemicals of the protective gloves mentioned above together with the supplier of these gloves. The times are approximate values from measurements at 22 ° C and permanent contact. Increased temperatures due to heated substances, body heat etc. and a reduction of the effective layer thickness by stretching can lead to a considerable reduction of the breakthrough time. If in doubt, contact manufacturer. At an approx. 1.5 times larger / smaller layer thickness, the respective breakthrough time is doubled / halved. The data apply only to the pure substance. When transferred to substance mixtures, they may only be considered as a guide.

- **type of material**

NBR (Nitrile rubber)

- **material thickness**

0,4 mm

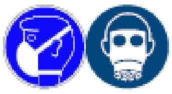
- **breakthrough times of the glove material**

>480 minutes (permeation: level 6)

- **other protection measures**

Take recovery periods for skin regeneration. Preventive skin protection (barrier creams/ointments) is recommended.
Flame-retardant protective clothing.

Respiratory protection



Respiratory protection necessary at: Aerosol or mist formation. Type: A (against organic gases and vapours with a boiling point of > 65 °C , colour code: Brown).

Environmental exposure controls

Keep away from drains, surface and ground water.

SECTION 9: Physical and chemical properties

9.1 Information on basic physical and chemical properties

Physical state	liquid
Colour	colourless
Odour	like: - alcohol
Melting point/freezing point	-89 °C
Boiling point or initial boiling point and boiling range	82 °C at 1,013 hPa
Flammability	flammable liquid in accordance with GHS criteria
Lower and upper explosion limit	50 g/m³ (LEL) - 330 g/m³ (UEL) / 2 vol% (LEL) - 13.4 vol% (UEL) (Isopropanol)
Flash point	12 °C
Auto-ignition temperature	425 °C (Isopropanol)
Decomposition temperature	not relevant

pH (value)	7 (20 °C)
Kinematic viscosity	2.826 $^{mm^2}/_{s}$ at 20 °C
Dynamic viscosity	2.43 mPa s at 20 °C

Solubility(ies)

Water solubility	miscible in any proportion

Partition coefficient

Partition coefficient n-octanol/water (log value):	this information is not available
Vapour pressure	43 hPa at 20 °C

Density and/or relative density

Density	0.85 – 0.86 $^{g}/_{cm^3}$ at 20 °C
Relative vapour density	Information on this property is not available.
Particle characteristics	not relevant (liquid)

Other safety parameters

Oxidising properties	none

9.2 Other information

Information with regard to physical hazard classes:	There is no additional information.
Other safety characteristics:	
Miscibility	completely miscible with water
Refractive index	1.371 – 1.375 (20 °C)

SECTION 10: Stability and reactivity

10.1 Reactivity

The mixture contains reactive substance(s). Risk of ignition. Vapours may form explosive mixtures with air.

If heated

Risk of ignition.

10.2 Chemical stability

The material is stable under normal ambient and anticipated storage and handling conditions of temperature and pressure.

10.3 Possibility of hazardous reactions

Exothermic reaction with: strong oxidiser, Iron, Nitric acid, Strong acid, Aldehydes, Aluminium, Amines,
Danger of explosion: Chlorates, Nitro compound, Hydrogen peroxide, Phosgene

10.4 Conditions to avoid

Keep away from heat, hot surfaces, sparks, open flames and other ignition sources. No smoking.

10.5 Incompatible materials

plastic and rubber

10.6 Hazardous decomposition products

Hazardous combustion products: see section 5. Peroxides.

SECTION 11: Toxicological information

11.1 Information on toxicological effects

Test data are not available for the complete mixture.

Classification procedure

The method for classification of the mixture is based on ingredients of the mixture (additivity formula).

Classification acc. to GHS

Acute toxicity

Shall not be classified as acutely toxic.

Acute toxicity of components

Name of substance	CAS No	Exposure route	Endpoint	Value	Species
2-Propanol	67-63-0	inhalation: vapour	LC50	37.5 $^{mg}/_{l}$/4h	rat
2-Propanol	67-63-0	oral	LD50	5,045 $^{mg}/_{kg}$	rat
2-Propanol	67-63-0	dermal	LD50	12,800 $^{mg}/_{kg}$	rabbit

Skin corrosion/irritation

Shall not be classified as corrosive/irritant to skin.

Serious eye damage/eye irritation

Causes serious eye irritation.

Respiratory or skin sensitisation

Shall not be classified as a respiratory or skin sensitiser.

Germ cell mutagenicity

Shall not be classified as germ cell mutagenic.

Carcinogenicity

Shall not be classified as carcinogenic.

Reproductive toxicity

Shall not be classified as a reproductive toxicant.

Specific target organ toxicity - single exposure

May cause drowsiness or dizziness.

Specific target organ toxicity - repeated exposure

Shall not be classified as a specific target organ toxicant (repeated exposure).

Aspiration hazard

Shall not be classified as presenting an aspiration hazard.

Symptoms related to the physical, chemical and toxicological characteristics

• If swallowed

Data are not available.

• If in eyes

Causes serious eye irritation

• If inhaled

dizziness, fatigue, narcosis

• If on skin

repeated exposure may cause skin dryness or cracking

• Other information

Other adverse effects: Headache, Dyspnoea, Narcosis, Vertigo

11.2 Endocrine disrupting properties

Does not contain an endocrine disruptor (ED) in a concentration of ≥ 0,1%.

SECTION 12: Ecological information

12.1 Toxicity

Shall not be classified as hazardous to the aquatic environment.

Aquatic toxicity (acute) of components

Name of substance	CAS No	Endpoint	Value	Species	Exposure time
2-Propanol	67-63-0	LC50	10,000 $^{mg}/_{l}$	fish	96 h

12.2 Persistence and degradability

Process of degradability

Process	Degradation rate	Time
biotic/abiotic	95 %	21 d

Degradability of components

Name of substance	CAS No	Process	Degradation rate	Time	Method	Source
2-Propanol	67-63-0	biotic/abiotic	95 %	21 d	modifizierter OECD Screening Test	
2-Propanol	67-63-0	oxygen depletion	53 %	5 d		ECHA

12.3 Bioaccumulative potential

Data are not available.

Bioaccumulative potential of components				
Name of substance	**CAS No**	**BCF**	**Log KOW**	**BOD5/COD**
2-Propanol	67-63-0		0.05	

12.4 Mobility in soil

Data are not available.

12.5 Results of PBT and vPvB assessment

Does not contain a PBT-/vPvB-substance in a concentration of ≥ 0,1%.

12.6 Endocrine disrupting properties

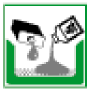
Does not contain an endocrine disruptor (ED) in a concentration of ≥ 0,1%.

12.7 Other adverse effects

Data are not available.

SECTION 13: Disposal considerations

13.1 Waste treatment methods



This material and its container must be disposed of as hazardous waste. Dispose of contents/container in accordance with local/regional/national/international regulations.

Sewage disposal-relevant information

Do not empty into drains.

Waste treatment of containers/packagings

Only packagings which are approved (e.g. acc. to the Dangerous Goods Regulations) may be used. Handle contaminated packages in the same way as the substance itself. Completely emptied packages can be recycled.

Relevant provisions relating to waste(Basel Convention)

Properties of waste which render it hazardous

H3 Flammable liquids

13.3 Remarks

Waste shall be separated into the categories that can be handled separately by the local or national waste management facilities. Please consider the relevant national or regional provisions. Non-contaminated packages may be recycled.

SECTION 14: Transport information

14.1 UN number

UN RTDG	UN 1219
IMDG-Code	UN 1219
ICAO-TI	UN 1219

14.2 UN proper shipping name

UN RTDG	ISOPROPANOL

IMDG-Code	ISOPROPANOL
ICAO-TI	Isopropanol

14.3 Transport hazard class(es)

UN RTDG	3
IMDG-Code	3
ICAO-TI	3

14.4 Packing group

UN RTDG	II
IMDG-Code	II
ICAO-TI	II

14.5 Environmental hazards	non-environmentally hazardous acc. to the dangerous goods regulations

14.6 Special precautions for user

There is no additional information.

14.7 Transport in bulk according to IMO instruments

The cargo is not intended to be carried in bulk.

14.8 Information for each of the UN Model Regulations

Transport informationNational regulationsAdditional information(UN RTDG)

UN number	1219
Class	3
Packing group	II
Danger label(s)	3

Special provisions (SP)	- UN RTDG
Excepted quantities (EQ)	E2 UN RTDG
Limited quantities (LQ)	1 L UN RTDG
Emergency Action Code	2YE

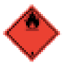
International Maritime Dangerous Goods Code (IMDG) - Additional information

Proper shipping name	ISOPROPANOL
Particulars in the shipper's declaration	UN1219, ISOPROPANOL, 3, II, 12°C c.c.
Marine pollutant	-
Danger label(s)	3

Special provisions (SP)	-
Excepted quantities (EQ)	E2
Limited quantities (LQ)	1 L
EmS	F-E, S-D
Stowage category	B

International Civil Aviation Organization (ICAO-IATA/DGR) - Additional information

Proper shipping name	Isopropanol
Particulars in the shipper's declaration	UN1219, Isopropanol, 3, II
Danger label(s)	3



Special provisions (SP)	A180
Excepted quantities (EQ)	E2
Limited quantities (LQ)	1 L

SECTION 15: Regulatory information

15.1 Safety, health and environmental regulations/legislation specific for the substance or mixture

There is no additional information.

National regulations(Australia)

Australian Inventory of Chemical Substances(AICS)

All ingredients are listed or exempt from listing.

Other information

Directive 94/33/EC on the protection of young people at work. Observe employment restrictions under the Maternity Protection Directive (92/85/EEC) for expectant or nursing mothers.

National inventories

Country	Inventory	Status
AU	AIIC	all ingredients are listed
CA	DSL	all ingredients are listed
CN	IECSC	all ingredients are listed
EU	ECSI	all ingredients are listed
EU	REACH Reg.	all ingredients are listed
JP	CSCL-ENCS	all ingredients are listed
JP	ISHA-ENCS	all ingredients are listed
KR	KECI	all ingredients are listed
MX	INSQ	all ingredients are listed
NZ	NZIoC	all ingredients are listed
PH	PICCS	all ingredients are listed

Country	Inventory	Status
TR	CICR	not all ingredients are listed
TW	TCSI	all ingredients are listed
US	TSCA	all ingredients are listed (ACTIVE)
VN	NCI	all ingredients are listed

Legend

AIIC	Australian Inventory of Industrial Chemicals
CICR	Chemical Inventory and Control Regulation
CSCL-ENCS	List of Existing and New Chemical Substances (CSCL-ENCS)
DSL	Domestic Substances List (DSL)
ECSI	EC Substance Inventory (EINECS, ELINCS, NLP)
IECSC	Inventory of Existing Chemical Substances Produced or Imported in China
INSQ	National Inventory of Chemical Substances
ISHA-ENCS	Inventory of Existing and New Chemical Substances (ISHA-ENCS)
KECI	Korea Existing Chemicals Inventory
NCI	National Chemical Inventory
NZIoC	New Zealand Inventory of Chemicals
PICCS	Philippine Inventory of Chemicals and Chemical Substances (PICCS)
REACH Reg.	REACH registered substances
TCSI	Taiwan Chemical Substance Inventory
TSCA	Toxic Substance Control Act

15.2 Chemical Safety Assessment

Chemical safety assessments for substances in this mixture were not carried out.

SECTION 16: Other information

Indication of changes (revised safety data sheet)

Section	Former entry (text/value)	Actual entry (text/value)	Safety-relev-ant
1.1		CAS number: [67-63-0]	yes
2.3	Results of PBT and vPvB assessment: This mixture does not contain any substances that are assessed to be a PBT or a vPvB.	Results of PBT and vPvB assessment: Does not contain a PBT-/vPvB-substance in a concentration of ≥ 0,1%.	yes
2.3		Endocrine disrupting properties: Does not contain an endocrine disruptor (ED) in a concentration of ≥ 0,1%.	yes
14.8		Emergency Action Code: 2YE	yes
15.1		National inventories: change in the listing (table)	yes

Abbreviations and acronyms

Abbr.	Descriptions of used abbreviations
BCF	Bioconcentration factor
BOD	Biochemical Oxygen Demand
CAS	Chemical Abstracts Service (service that maintains the most comprehensive list of chemical substances)
Ceiling-C	Ceiling value
COD	Chemical oxygen demand
DGR	Dangerous Goods Regulations (see IATA/DGR)

Abbr.	Descriptions of used abbreviations
DNEL	Derived No-Effect Level
ED	Endocrine disruptor
EINECS	European Inventory of Existing Commercial Chemical Substances
ELINCS	European List of Notified Chemical Substances
EmS	Emergency Schedule
Eye Dam.	Seriously damaging to the eye
Eye Irrit.	Irritant to the eye
Flam. Liq.	Flammable liquid
GHS	"Globally Harmonized System of Classification and Labelling of Chemicals" developed by the United Nations
IATA	International Air Transport Association
IATA/DGR	Dangerous Goods Regulations (DGR) for the air transport (IATA)
ICAO	International Civil Aviation Organization
ICAO-TI	Technical instructions for the safe transport of dangerous goods by air
IMDG	International Maritime Dangerous Goods Code
IMDG-Code	International Maritime Dangerous Goods Code
LC50	Lethal Concentration 50%: the LC50 corresponds to the concentration of a tested substance causing 50 % lethality during a specified time interval
LD50	Lethal Dose 50 %: the LD50 corresponds to the dose of a tested substance causing 50 % lethality during a specified time interval
LEL	Lower explosion limit (LEL)
log KOW	n-Octanol/water
NLP	No-Longer Polymer
PBT	Persistent, Bioaccumulative and Toxic
PNEC	Predicted No-Effect Concentration
ppm	Parts per million
STEL	Short-term exposure limit
STOT SE	Specific target organ toxicity - single exposure
TWA	Time-weighted average
UEL	Upper explosion limit (UEL)
UN RTDG	UN Recommendations on the Transport of Dangerous Good
vPvB	Very Persistent and very Bioaccumulative
WES	Safe Work Australia: Workplace exposure standards for airborne contaminants

Key literature references and sources for data

Safe Work Australia's Code of Practice for Labelling of Workplace Hazardous Chemicals (under WHS Regulations).

UN Recommendations on the Transport of Dangerous Good. International Maritime Dangerous Goods Code (IMDG). Dangerous Goods Regulations (DGR) for the air transport (IATA).

Classification procedure

Physical and chemical properties. The classification is based on tested mixture.
Health hazards. Environmental hazards. The method for classification of the mixture is based on ingredients of the mixture (additivity formula).

List of relevant phrases (code and full text as stated in section 2 and 3)

Code	Text
H225	Highly flammable liquid and vapour.
H319	Causes serious eye irritation.
H336	May cause drowsiness or dizziness.

Disclaimer

This information is based upon the present state of our knowledge. This SDS has been compiled and is solely intended for this product.

Bacterial Medium M9

- ## Protocol:

MSDS: M9 medium is self-mixed according to the protocol below. A MSDS of a comparable commercial product is attached.

M9 Minimalmedium Protocol (in German):
M9 Salze: für 500mL -> autoklavieren

- 30g Na2HPO4 x 2H2O

- 15g KH2PO4

- 2,5g NaCl

Trace Elements: für 200mL

- 1g EDTA(Na)

- In Wasser lösen

- pH auf 7,5 einstellen

- 166mg FeCl3-6H2O

- 16,8mg ZnCl2

- 2,6mg CuCl2-2H2O

- 2mg CoCl2-2H2O

- 2mg H3Bo3

- 0,32mg MnCl2-4H2O

- Mit Wasser auf 200mL auffüllen

- Steril filtrieren

Stock Lösungen: je 200mL

- 54,1g MgSO4xH2O -> autoklavieren

- 5,9g CaCl2x2H2O -> autoklavieren

- 67,5g Thiamine-HCl -> steril filtrieren und im Kühlschrank lagern

- 100g NH4Cl -> autoklavieren

- 1M Carbon source -> autoklavieren

M9 Medium: für 500mL

- 50mL M9 Salze

- 500µL MgSO4xH2O

- 1mL Thiamine-HCl

- 5mL NH4Cl

- 5mL Trace Elements

- 10mL Carbon Source

- 500µL CaCl2x2H2O

- $CaCl_2 x 2H_2O$ muss als letztes hinzugefügt werden

Shipping information: 1L will be shipped to Esrange via ZARM. The material within the tubes (300 mL) will be brought to Esrange by the team members via plane.

Amount: Total amount in experiment (flying): 6 x 50 mL = 300 mL, additional 1L spare

Purpose: Nutrient supply for microorganisms.

The bacterial medium will be filled into the tubes and will fly as part of the SpiCy experiment payload.

MSDS Data Sheet of M9:

Page 1/8

Safety Data Sheet
acc. to OSHA HCS

Printing date 03/16/2017 *Reviewed on 03/16/2017*

1 Identification

(Contd. of page 1)

· **HMIS-ratings (scale 0 - 4)**

HEALTH	2	Health = 2
FIRE	0	Fire = 0
REACTIVITY	0	Reactivity = 0

· **Other hazards**
· **Results of PBT and vPvB assessment**
· **PBT:** Not applicable.
· **vPvB:** Not applicable.

3 Composition/information on ingredients

· **Chemical characterization: Mixtures**
· **Description:**
Mixture of substances listed below with nonhazardous additions.
Mixture: consisting of the following components.

· **Dangerous components:**

CAS: 12125-02-9 EINECS: 235-186-4 RTECS: BP4550000	Ammonium Chloride	2.5-<10%

· **Non-Hazardous Ingredients**

CAS: 7558-79-4 EINECS: 231-448-7 RTECS: WC4500000	Sodium Phosphate Dibasic Anhydrous, USP	50-90%
CAS: 7778-77-0 EINECS: 231-913-4 RTECS: TC6615500	Potassium Phosphate Monobasic Anhydrous	10-50%

4 First-aid measures

· **Description of first aid measures**
· **After inhalation:** Supply fresh air; consult doctor in case of complaints.
· **After skin contact:** Generally the product does not irritate the skin.
· **After eye contact:** Flush eyes with running water as a precaution.
· **After swallowing:**
Never give anything by mouth to an unconscious person. Rinse mouth with water. If symptoms persist consult a Doctor.
· **Information for doctor:**
· **Most important symptoms and effects, both acute and delayed** No further relevant information available.
· **Indication of any immediate medical attention and special treatment needed**
No further relevant information available.

5 Fire-fighting measures

· **Extinguishing media**
· **Suitable extinguishing agents:** Use fire fighting measures that suit the environment.
· **Special hazards arising from the substance or mixture** No further relevant information available.

(Contd. on page 3)

(Contd. of page 2)

· **Advice for firefighters**
· **Protective equipment:** No special measures required.

6 Accidental release measures

· **Personal precautions, protective equipment and emergency procedures**
Use personal protective equipment. Avoid dust formation. Avoid breathing vapours, mist or gas. Ensure adequate ventilation. Evacuate personnel to safe areas. Avoid breathing dust.
For personal protection see section 8.
· **Environmental precautions:** Do not allow to enter sewers/ surface or ground water.
· **Methods and material for containment and cleaning up:** Pick up mechanically.
· **Reference to other sections**
No dangerous substances are released.
See Section 7 for information on safe handling.
See Section 8 for information on personal protection equipment.
See Section 13 for disposal information.
· **Protective Action Criteria for Chemicals**

· **PAC-1:**

7778-77-0	Potassium Phosphate Monobasic Anhydrous	9.6 mg/m3
12125-02-9	Ammonium Chloride	20 mg/m3

· **PAC-2:**

7778-77-0	Potassium Phosphate Monobasic Anhydrous	110 mg/m3
12125-02-9	Ammonium Chloride	54 mg/m3

· **PAC-3:**

7778-77-0	Potassium Phosphate Monobasic Anhydrous	630 mg/m3
12125-02-9	Ammonium Chloride	330 mg/m3

7 Handling and storage

· **Handling:**
· **Precautions for safe handling**
Avoid direct contect with skin. Use protective clothing including gloves, lab coat, face/eye protection.
· **Information about protection against explosions and fires:** No special requirements.

· **Conditions for safe storage, including any incompatibilities**
· **Storage:** 15-30 °C
· **Requirements to be met by storerooms and receptacles:** No special requirements.
· **Further information about storage conditions:** This product is hygroscopic.
· **Specific end use(s)** No further relevant information available.

8 Exposure controls/personal protection

· **Additional information about design of technical systems:** No further data; see Section 7.

(Contd. on page 4)

Safety Data Sheet
acc. to OSHA HCS

Printing date 03/16/2017 Reviewed on 03/16/2017

Trade name: M9 Minimal Medium Salts

(Contd. of page 3)

· **Control parameters**

· **Components with limit values that require monitoring at the workplace:**

12125-02-9 Ammonium Chloride	
REL	Short-term value: 20 mg/m³ Long-term value: 10 mg/m³
TLV	Short-term value: 20 mg/m³ Long-term value: 10 mg/m³

· **Additional information:** The lists that were valid during the creation were used as basis.

· **Exposure controls**
· **Personal protective equipment:**
· **General protective and hygienic measures:** Wash hands before breaks and at the end of work.
· **Breathing equipment:** Not required.
· **Protection of hands:**
The glove material has to be impermeable and resistant to the product/ the substance/ the preparation.
Due to missing tests no recommendation to the glove material can be given for the product/ the preparation/ the chemical mixture.
Selection of the glove material on consideration of the penetration times, rates of diffusion and the degradation
· **Material of gloves**
The selection of the suitable gloves does not only depend on the material, but also on further marks of quality and varies from manufacturer to manufacturer. As the product is a preparation of several substances, the resistance of the glove material can not be calculated in advance and has therefore to be checked prior to the application.
· **Penetration time of glove material**
The exact break through time has to be found out by the manufacturer of the protective gloves and has to be observed.
· **Eye protection:** Not required.

9 Physical and chemical properties

· **Information on basic physical and chemical properties**	
· **General Information**	
· **Appearance:**	
Form:	Powder
Color:	According to product specification
· **Odor:**	Indeterminate
· **Odor threshold:**	Not determined.
· **pH-value:**	Not applicable.
· **Change in condition**	
Boiling point/Boiling range:	Undetermined.
· **Flash point:**	Not applicable.
· **Flammability (solid, gaseous):**	Not determined.
· **Ignition temperature:**	
Decomposition temperature:	Not determined.
· **Auto igniting:**	Product is not selfigniting.
· **Danger of explosion:**	See section 10
· **Explosion limits:**	
Lower:	Not Applicable

(Contd. on page 5)

US

(Contd. of page 4)

Upper:	Not Applicable
· **Vapor pressure:**	Not applicable.
· **Density:**	Not Applicable
· **Relative density**	Not determined.
· **Vapor density**	Not applicable.
· **Evaporation rate**	Not applicable.
· **Solubility in / Miscibility with**	Not Determined
· **Water:**	Soluble.
· **Partition coefficient (n-octanol/water):**	Not determined.
· **Viscosity:**	
Dynamic:	Not applicable.
Kinematic:	Not applicable.
· **Solvent content:**	
Organic solvents:	0.0 %
VOC content:	0.0 g/l / 0.00 lb/gl
Solids content:	100.0 %
· **Other information**	No further relevant information available.

10 Stability and reactivity

· **Reactivity** No further relevant information available.
· **Chemical stability**
· **Thermal decomposition / conditions to be avoided:** No decomposition if used according to specifications.
· **Possibility of hazardous reactions** No dangerous reactions known.
· **Conditions to avoid** No further relevant information available.
· **Incompatible materials:** No further relevant information available.
· **Hazardous decomposition products:** No dangerous decomposition products known.

11 Toxicological information

· **Information on toxicological effects**
· **Acute toxicity:**

· **LD/LC50 values that are relevant for classification:**		
12125-02-9 Ammonium Chloride		
Oral	LD50	1300 mg/kg (mouse)
		1650 mg/kg (rat)

· **Primary irritant effect:**
· **on the skin:** No irritant effect.
· **on the eye:** Irritant and potentially harmful
· **Sensitization:** No sensitizing effects known.
· **Additional toxicological information:** Harmful

· **Carcinogenic categories**

· **IARC (International Agency for Research on Cancer)**
None of the ingredients is listed.

(Contd. on page 6)

Safety Data Sheet
acc. to OSHA HCS

(Contd. of page 5)

· **NTP (National Toxicology Program)**

None of the ingredients is listed.

· **OSHA-Ca (Occupational Safety & Health Administration)**

None of the ingredients is listed.

12 Ecological information

· **Toxicity**

· **Aquatic toxicity:**

12125-02-9 Ammonium Chloride		
Oral	LC50 / 96 h	209 mg/L (Cyprinus carpio)
		3.98 mg/L (Oncorhynchus mykiss)

· **Persistence and degradability** No further relevant information available.
· **Behavior in environmental systems:**
· **Bioaccumulative potential** No further relevant information available.
· **Mobility in soil** No further relevant information available.
· **Additional ecological information:**
· **General notes:**
Water hazard class 1 (Self-assessment): slightly hazardous for water
Do not allow undiluted product or large quantities of it to reach ground water, water course or sewage system.
· **Results of PBT and vPvB assessment**
· **PBT:** Not applicable.
· **vPvB:** Not applicable.
· **Other adverse effects** No further relevant information available.

13 Disposal considerations

· **Waste treatment methods**
· **Recommendation:**
Can not be disposed together with household garbage. Do not allow product to reach sewage system.

· **Uncleaned packagings:**
· **Recommendation:** Discard must be made according to official regulations.
· **Recommended cleansing agent:** Water, if necessary with cleaning agents.

14 Transport information

· **UN-Number**	
· **DOT, ADR, ADN, IMDG, IATA**	Not regulated
· **UN proper shipping name**	
· **DOT, ADR, ADN, IMDG, IATA**	Not regulated
· **Transport hazard class(es)**	
· **DOT, ADR, ADN, IMDG, IATA**	
· **Class**	Not regulated
· **Packing group**	
· **DOT, ADR, IMDG, IATA**	Not regulated

(Contd. on page 7)

Safety Data Sheet
acc. to OSHA HCS

Printing date 03/16/2017 Reviewed on 03/16/2017

Trade name: M9 Minimal Medium Salts

(Contd. of page 6)

· **Environmental hazards:**	
· **Marine pollutant:**	No
· **Special precautions for user**	Not applicable.
· **Transport in bulk according to Annex II of MARPOL73/78 and the IBC Code**	Not applicable.
· **UN "Model Regulation":**	Not regulated

15 Regulatory information

· **Safety, health and environmental regulations/legislation specific for the substance or mixture**
· **Sara**

· **Section 355 (extremely hazardous substances):**
None of the ingredients is listed.

· **Section 313 (Specific toxic chemical listings):**
None of the ingredients is listed.

· **TSCA (Toxic Substances Control Act):**
All ingredients are listed.

· **Proposition 65**

· **Chemicals known to cause cancer:**
None of the ingredients is listed.

· **Chemicals known to cause reproductive toxicity for females:**
None of the ingredients is listed.

· **Chemicals known to cause reproductive toxicity for males:**
None of the ingredients is listed.

· **Chemicals known to cause developmental toxicity:**
None of the ingredients is listed.

· **Carcinogenic categories**

· **EPA (Environmental Protection Agency)**
None of the ingredients is listed.

· **TLV (Threshold Limit Value established by ACGIH)**
None of the ingredients is listed.

· **NIOSH-Ca (National Institute for Occupational Safety and Health)**
None of the ingredients is listed.

· **GHS label elements** The product is classified and labeled according to the Globally Harmonized System (GHS).
· **Hazard pictograms**

GHS07

· **Signal word** Warning

· **Hazard-determining components of labeling:**
Ammonium Chloride

(Contd. on page 8)

(Contd. of page 7)

· ***Hazard statements***
Harmful if swallowed.
· ***Precautionary statements***
Wash thoroughly after handling.
Do not eat, drink or smoke when using this product.
IF SWALLOWED: Call a POISON CENTER/doctor if you feel unwell.
Rinse mouth.
Dispose of contents/container in accordance with local/regional/national/international regulations.
· ***Chemical safety assessment:*** *A Chemical Safety Assessment has not been carried out.*

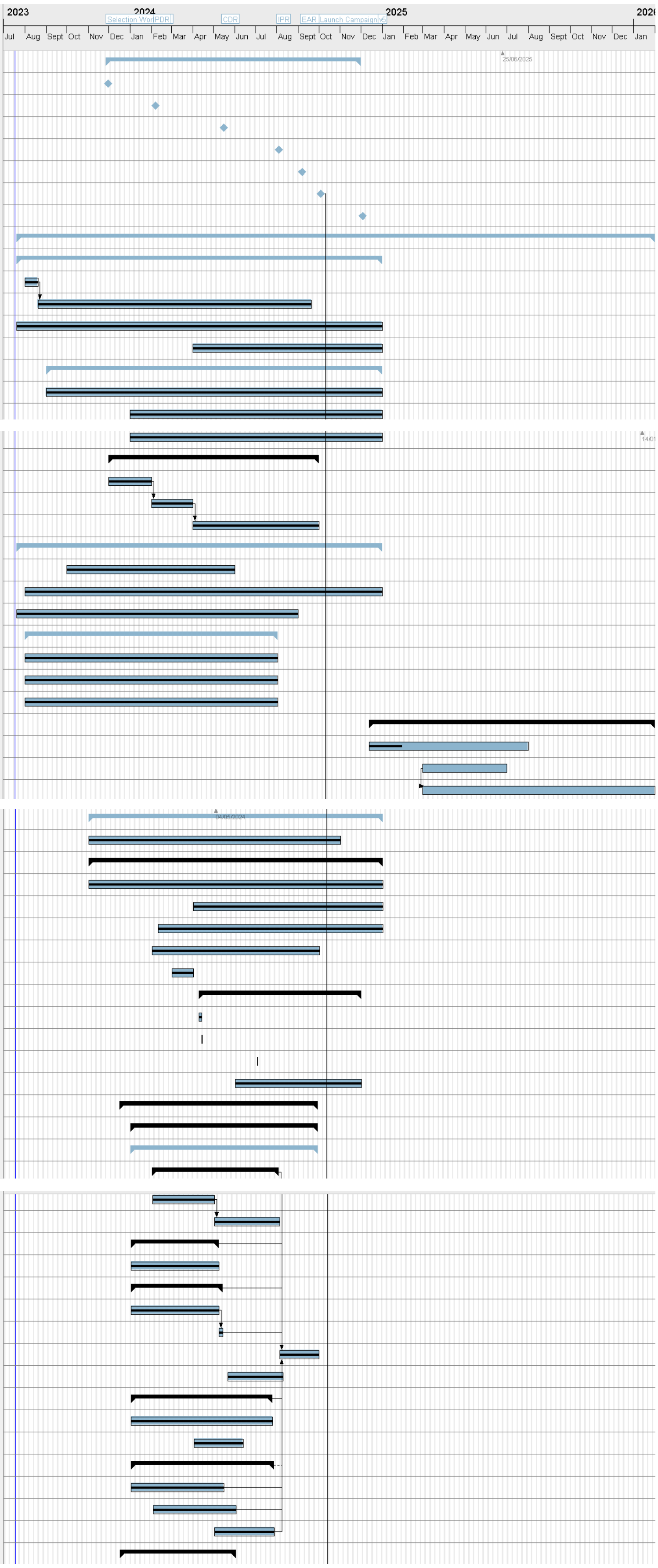
16 Other information

This information is based on our present knowledge. However, this shall not constitute a guarantee for any specific product features and shall not establish a legally valid contractual relationship.

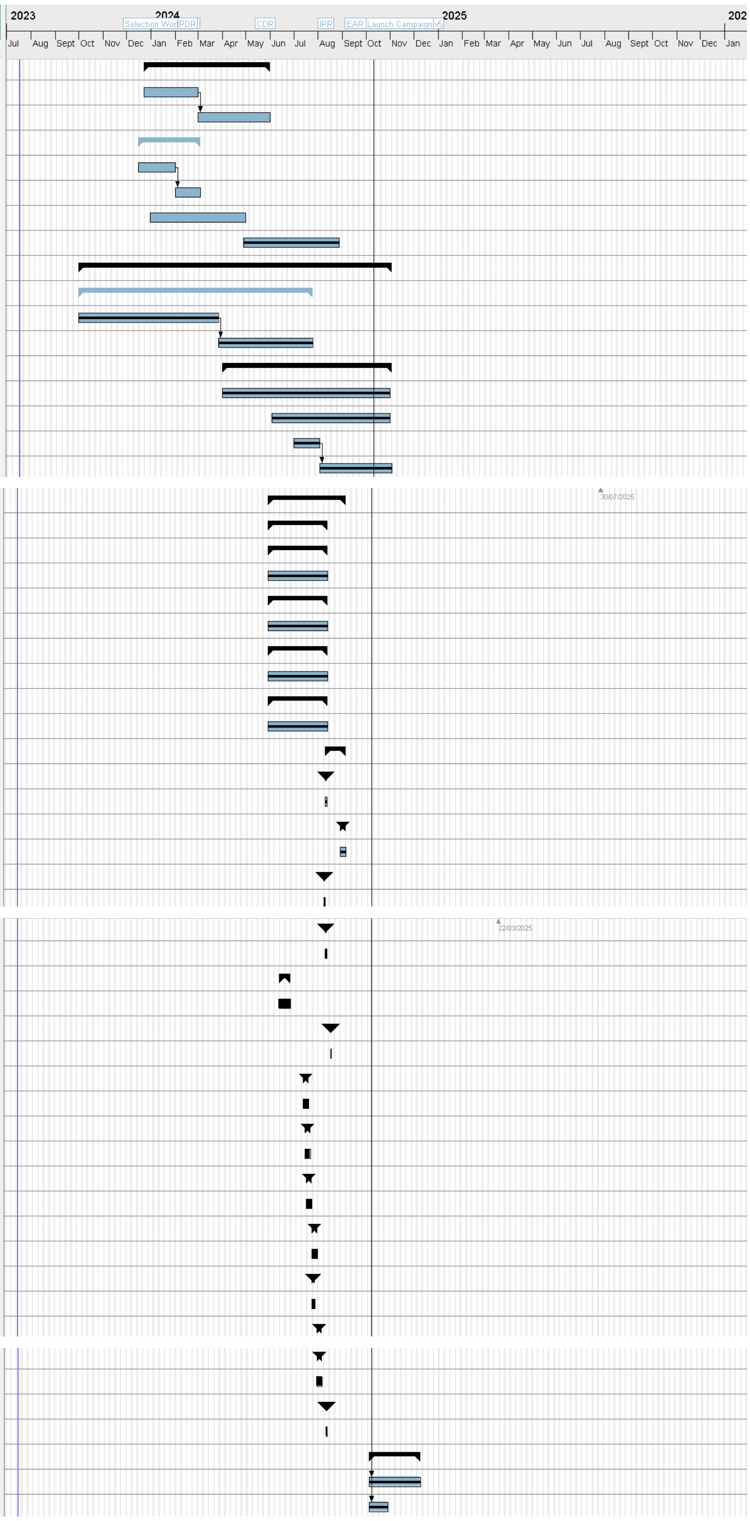
· ***Department issuing SDS:*** *Quality Control Dept.*
· ***Date of preparation / last revision*** *03/16/2017 / -*
· ***Abbreviations and acronyms:***
ADR: Accord européen sur le transport des marchandises dangereuses par Route (European Agreement concerning the International Carriage of Dangerous Goods by Road)
IMDG: International Maritime Code for Dangerous Goods
DOT: US Department of Transportation
IATA: International Air Transport Association
ACGIH: American Conference of Governmental Industrial Hygienists
EINECS: European Inventory of Existing Commercial Chemical Substances
ELINCS: European List of Notified Chemical Substances
CAS: Chemical Abstracts Service (division of the American Chemical Society)
NFPA: National Fire Protection Association (USA)
HMIS: Hazardous Materials Identification System (USA)
VOC: Volatile Organic Compounds (USA, EU)
LC50: Lethal concentration, 50 percent
LD50: Lethal dose, 50 percent
PBT: Persistent, Bioaccumulative and Toxic
vPvB: very Persistent and very Bioaccumulative
NIOSH: National Institute for Occupational Safety
OSHA: Occupational Safety & Health
TLV: Threshold Limit Value
PEL: Permissible Exposure Limit
REL: Recommended Exposure Limit
Acute Tox. 4: Acute toxicity – Category 4

Appendix D Extended Gantt Chart

Name	Begin date	End date
Reviews	27/11/2023	30/11/2024
Selection Workshop	27/11/2023	27/11/2023
PDR	04/02/2024	04/02/2024
CDR	13/05/2024	13/05/2024
IPR	01/08/2024	01/08/2024
EAR (T-Vac)	04/09/2024	04/09/2024
Launch Campaign	01/10/2024	01/10/2024
SED v5	01/12/2024	01/12/2024
1 Project Management	20/07/2023	31/01/2026
1.1 Scheduling	20/07/2023	31/12/2024
1.1.1 Schedule Creation	01/08/2023	19/08/2023
1.1.2 Frequent Meetings	20/08/2023	19/09/2024
1.1.3 Time Management	20/07/2023	31/12/2024
1.1.4 SCRUM Implementation	01/04/2024	31/12/2024
1.2 Documentation	01/09/2023	31/12/2024
1.2.1 Meeting Notes	01/09/2023	31/12/2024
1.2.2 SED Planning	01/01/2024	31/12/2024
1.2.3 SED Final Editing	01/01/2024	31/12/2024
1.3 Risk Management	01/12/2023	30/09/2024
1.3.1 Risk Analysis	01/12/2023	31/01/2024
1.3.2 Risk Assesment	01/02/2024	31/03/2024
1.3.3 Risk Mitigation	01/04/2024	30/09/2024
1.4 Funding	20/07/2023	31/12/2024
1.4.1 Sponsors Acquisitions	01/10/2023	31/05/2024
1.4.2 Budget planning	01/08/2023	31/12/2024
1.4.3 Purchases	20/07/2023	31/08/2024
1.5 Member Recruitment	01/08/2023	01/08/2024
1.5.1 Vacancy Advertisment	01/08/2023	01/08/2024
1.5.2 Recruitement Interviews	01/08/2023	01/08/2024
1.5.3 Onboarding	01/08/2023	01/08/2024
1.6 2SpiCy	13/12/2024	31/01/2026
1.6.1 Recruitments	13/12/2024	31/07/2025
1.6.2 Exp. Planning	01/03/2025	30/06/2025
1.6.3 Mentoring	01/03/2025	31/01/2026
2 Outreach	01/11/2023	31/12/2024
2.1 Presentations	01/11/2023	31/10/2024
2.2 Social Media Man.	01/11/2023	31/12/2024
2.2.1 Instagram	01/11/2023	31/12/2024
2.2.2 LinkedIn	01/04/2024	31/12/2024
2.3 Website	10/02/2024	31/12/2024
2.4 Merchandise	01/02/2024	30/09/2024
2.5 Photography	01/03/2024	31/03/2024
2.6 Event planning	09/04/2024	30/11/2024
2.6.1 Analytica Visit	09/04/2024	12/04/2024
2.6.2 TUM Space Day	13/04/2024	13/04/2024
2.6.3 LMU Faculty of Biology...	03/07/2024	03/07/2024
2.6.4 Team Building Events	01/06/2024	30/11/2024
3 Design and Manufacturing	16/12/2023	28/09/2024
3.1 Mechanical	01/01/2024	28/09/2024
3.1.1 Module Design	01/01/2024	28/09/2024
3.1.1.1 Insulation Material	01/02/2024	02/08/2024
3.1.1.1.1 Selection	01/02/2024	30/04/2024
3.1.1.1.2 Customization	01/05/2024	02/08/2024
3.1.1.2 Sensors	01/01/2024	06/05/2024
3.1.1.2.1 Sensor Selecti...	01/01/2024	06/05/2024
3.1.1.3 Bacteria Tubes	01/01/2024	12/05/2024
3.1.1.3.1 Design	01/01/2024	06/05/2024
3.1.1.3.2 Custom Manu...	07/05/2024	12/05/2024
3.1.1.4 Module Assembly	03/08/2024	28/09/2024
3.2 Ground Station	20/05/2024	07/08/2024
3.3 On-board Computer System	01/01/2024	23/07/2024
3.3.1 Microcontroller	01/01/2024	23/07/2024
3.3.2 On-board data storage	01/04/2024	10/06/2024
3.4 Thermal	01/01/2024	25/07/2024
3.4.1 Heater selection	01/01/2024	13/05/2024
3.4.2 Heating System Design	02/02/2024	31/05/2024
3.4.3 Temperature Analysis	01/05/2024	25/07/2024
3.5 Electronics	16/12/2023	31/05/2024



Name	Begin date	End date
3.5.1 PCB Design	23/12/2023	31/05/2024
3.5.2 Component Selection	23/12/2023	29/02/2024
3.5.3 Prototyping	01/03/2024	31/05/2024
3.5.2 Power System	16/12/2023	03/03/2024
3.5.2.1 Power Distribution ...	16/12/2023	31/01/2024
3.5.2.2 Power Distr. Verifi...	01/02/2024	03/03/2024
3.5.3 Layout	31/12/2023	30/04/2024
3.6 Cable Management	28/04/2024	27/08/2024
4 Biological Samples	01/10/2023	02/11/2024
4.1 Literature Research	01/10/2023	24/07/2024
4.1.1 Prelim. Candidate Sele...	01/10/2023	26/03/2024
4.1.2 Lab Protocol Selection	27/03/2024	24/07/2024
4.2 Wet Lab Cultivation	01/04/2024	02/11/2024
4.2.1 Cyanobac. Cultivation	01/04/2024	31/10/2024
4.2.2 Heterotroph. Cultivation	03/06/2024	31/10/2024
4.2.3 Biofilm Establishment	01/07/2024	02/08/2024
4.2.4 Biofilm Cultivation	03/08/2024	02/11/2024
5 Testing Plan	01/06/2024	07/09/2024
5.1 System Functionality Testing	01/06/2024	15/08/2024
5.1.1 Individual Component ...	01/06/2024	15/08/2024
All components: Test 1a	01/06/2024	15/08/2024
5.1.2 Data Storage and Proc...	01/06/2024	15/08/2024
Data Handling: Test 1b	01/06/2024	15/08/2024
5.1.3 Power Requirement	01/06/2024	15/08/2024
Integrated Circuit: Test 1c	01/06/2024	15/08/2024
5.1.4 Integrated System Fun...	01/06/2024	15/08/2024
Final System Circuit: Test ...	01/06/2024	15/08/2024
5.2 Thermal Requirements	13/08/2024	07/09/2024
5.2.1 Low Fidelity Thermal T...	13/08/2024	14/08/2024
Hot and Cold Case: Test 6	13/08/2024	14/08/2024
5.2.2 Thermal Vacuum Testing	01/09/2024	07/09/2024
Flight Ready Module: Test 2	01/09/2024	07/09/2024
5.3 Tube Sealing	11/08/2024	12/08/2024
5.3.1 Hermetically Sealed T...	11/08/2024	12/08/2024
5.4 Structure/Durability	13/08/2024	14/08/2024
5.4.1 Drop Test: Test 4	13/08/2024	14/08/2024
5.5 Interfacing	15/06/2024	29/06/2024
5.5.1 Electronic Interfacing: ...	15/06/2024	29/06/2024
5.6 Physical Limitations	20/08/2024	20/08/2024
5.6.1 Weight and Dimension...	20/08/2024	20/08/2024
5.7 Communication	16/07/2024	22/07/2024
5.7.1 Downlink and Data Rat...	16/07/2024	22/07/2024
5.8 Frontend	18/07/2024	24/07/2024
5.8.1 Functionality Testing: ...	18/07/2024	24/07/2024
5.9 Data Visualization	20/07/2024	26/07/2024
5.9.1 Downlinked Data: Test...	20/07/2024	26/07/2024
5.10 Backend	27/07/2024	02/08/2024
5.10.1 Functionality Testing: ...	27/07/2024	02/08/2024
5.11 Software Alerts	27/07/2024	30/07/2024
5.11.1 Functionality Testing: ...	27/07/2024	30/07/2024
5.12 Fault Detection	02/08/2024	08/08/2024
5.12 Fault Detection	02/08/2024	08/08/2024
5.12.1 Functionality Testing: ...	02/08/2024	08/08/2024
5.13 Sunlight Exposure	14/08/2024	14/08/2024
5.13.1 Glass Transparency ...	14/08/2024	14/08/2024
7 Post-flight Analysis	08/10/2024	11/12/2024
7.1 qPCR	08/10/2024	11/12/2024
7.2 Western Blot	08/10/2024	31/10/2024



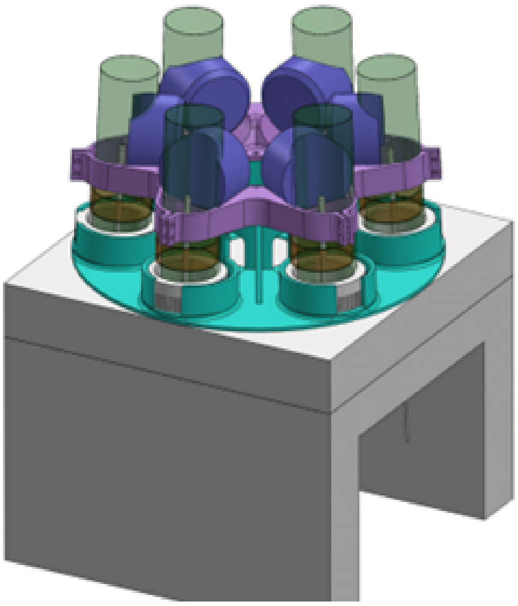
Appendix E CHECKLISTS

Check electronics

1. Check if every plug is occupied except heater 6 and 7 as well as USB
2. Check if battery voltage is ok
3. Check if Vsys is 5V and Vheat is 7.75V
4. Check if sd_card is connected and working
5. Check if tcp_server is connected and working
6. Check perifals with /d in the debug console
7. Send test packet to benchmark connection strength and integrity
8. Check if the OTA firmware update is working correctly. Reflash with usb after.

Assembly of the SpiCy Module

Probe Module

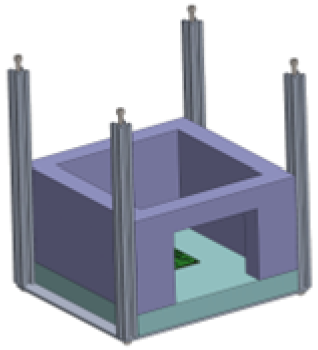


1. Insert micro SD Card & tests if it works
2. Insert of the Tubes in the lower rack holder. It is glued to the foam already
3. Put cables of the heater and thermistors through the center hole
4. Insert upper part of the holder
5. Tighten the screw clamps for the probes (here pink)
6. Connect and put the wires of oxygen sensor through the center hole

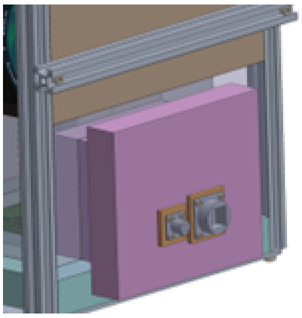
7. Install mainboard and [connect all cables](#)

- battery cable which is already connected to foam plug
- ethernet
- NTC x6
- Heater x6
- Oxygen Sensors x6 (green for Oxy0 | red for Oxy 1-5)
- light sensors x2

Bottom Module

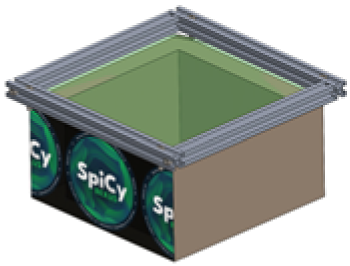


8. Insert Probe Module in Bottom Module



9. Connect Ethernet cable and insert plug
10. Fix plug on the wall with metal stripes

Top Module



11. The top part just needs to be mounted on the lower part and fixed with 4 screws on the corner in the alum profiles.

Assembly of the SpiCy Bio-Tube

1. **Preparation of Components:**

Ensure all components are clean and free of dust, debris, or oil. Move all components to a sterile workbench. Clean the glass tube, 3D-printed plug, nuts, O-rings, cap, and any additional components with isopropyl alcohol.

Inspect the 3D-printed plug for any defects (e.g., cracks or uneven surfaces) that could affect water-tightness. Check the rubber O-rings for any damage or deformation.

2. **Install O-Rings:**

Slide the rubber O-rings onto the nuts of the 3D-printed plug. Ensure they are seated evenly and securely within the designated grooves to create a robust sealing interface.

3. **Insert the Plug into the Glass Tube while it is immersed in the Culture Medium.:**

Immerse the tube entirely under the culture medium. This is to avoid the air-bubbles that could be trapped in the medium. Carefully align the 3D-printed plug with the opening of the glass tube. Slowly push the plug into the tube, ensuring it remains centered and does not tilt. The O-rings should compress slightly against the inner wall of the tube, forming a tight seal.

4. **Secure the Plug with the Cap:**

Tighten the cap gradually. Avoid over-tightening, which could damage the plug or compromise the O-ring seals. Hand-tighten until you feel resistance, then use a wrench or pliers for an additional quarter-turn if necessary.

5. **Leak Test:**

Before operational use, conduct a leak test to ensure the assembly is watertight. Move the filled tubes and monitor for any signs of leakage around the O-rings, plug, or silicone-filled cable hole.

6. **Final Check:**

Verify that all components are securely assembled and no part is loose. Inspect the tubes and ensure the cables are fixed firmly.

7. Operational Setup:

Connect the tube assembly to the required system. Confirm proper alignment and ensure that the glass tube is not subjected to undue mechanical stress. Test the UV sensor, temperature sensor, oxygen sensor and other onboard sensors to ensure it is functional and properly calibrated within the assembly.