From caves to space: the S5Lab student experiments in stratosphere and cave analog missions

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34th UNISEC Virtual Global Meeting – Host: UNISEC-Italy
17 June 2023

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Today's menu

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- S5Lab and nano-satellite announcement
- Part 1: Stratosphere
- Part 2: Caves

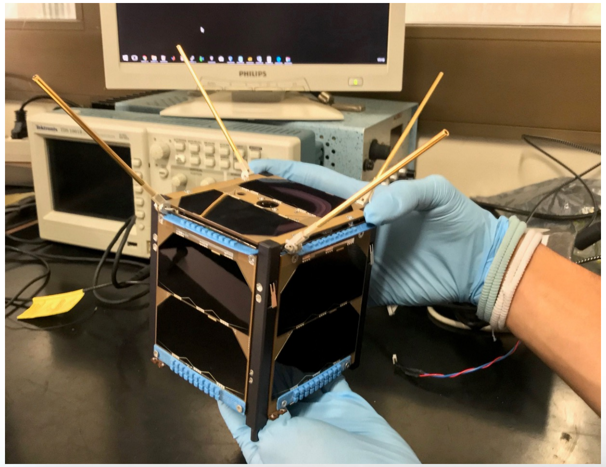
Sapienza Space Systems
and Space Surveillance Laboratory (S5Lab)

❖ Space surveillance

- Optical observation systems
- Data analysis
- Orbit determination
- Attitude Determination

❖ Space systems

- Design, development, operations of space systems
- Stratospheric balloon payloads
- CubeSats
- Support systems for exploration



Involving Aerospace Eng. Students in International Hands-on Education Programmes

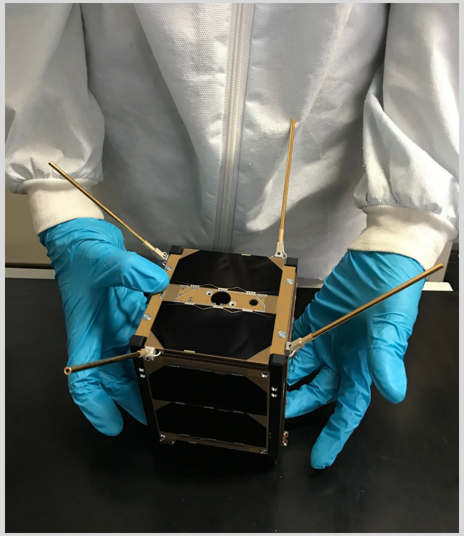
BSc

Balloon Experiments

MSc

Satellite systems and operations

PhD



Leading role in satellite projects

Hands-on space systems projects

❖ Stratospheric Systems

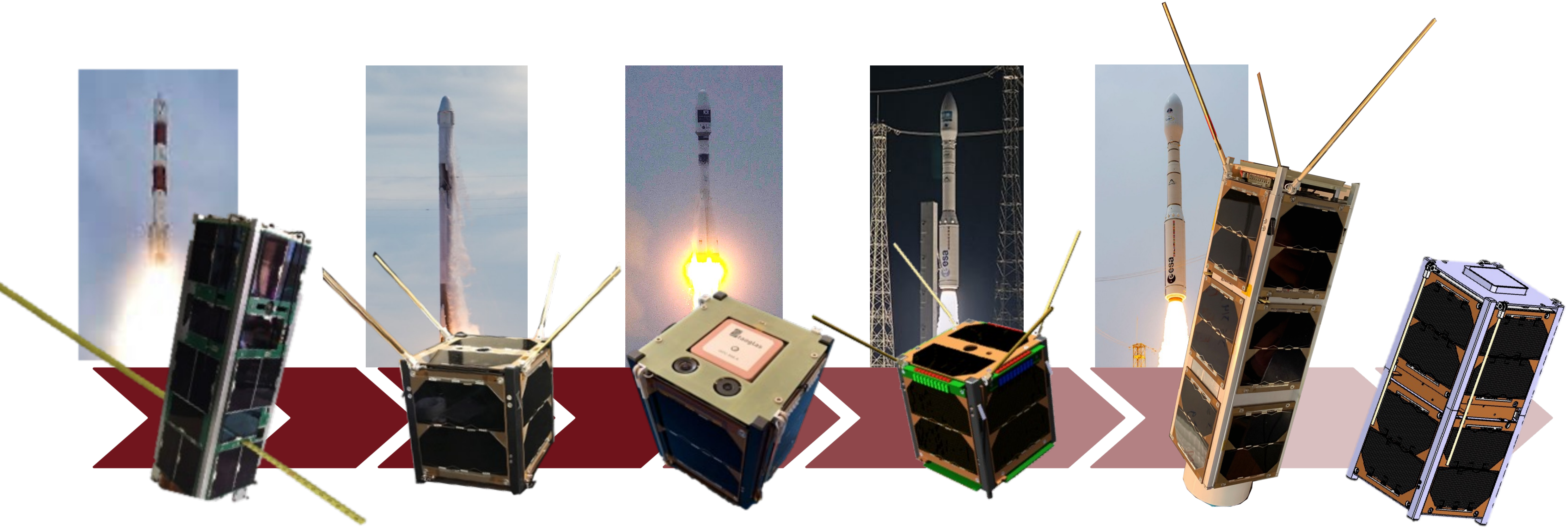
- REXUS/BEXUS Programme:
    - STRATONAV – 2016
    - TARDIS – 2019
    - ROMULUS - 2023
- HEMERA Programme: STRAINS - 2021

❖ Nano-Satellites

- URSA MAIOR (2014- mission concluded)
- 1KUNS-PF (2017- de-orbited)
- LEDSAT (2017- launched on August 17 2021)
- WILDTRACKCUBE-SIMBA (2019 – launched on March 22 2021)
- GREENCUBE (2019 – launched on 13 July 2022)

❖ Other Activities (IGLuna – UNISEC/MIC, Analog Missions with GEA)

CubeSat development Programme at Sapienza S5Lab



URSA MAIOR

2014 – Mission Concluded
Status: Launched on **23 June 2017**

1KUNS-PF

2017 – Mission concluded
Status: Launched on **11 May 2018,**
Deorbited in **Summer 2020**

WILDTRACKCUBE-SIMBA (IKUNS3)

Launched on **22 March 2021**
Status: **operational in orbit**

LEDSAT (IKUNS-B)

Launched on **17 August 2021**
Status: **2017 – Operational in-orbit**

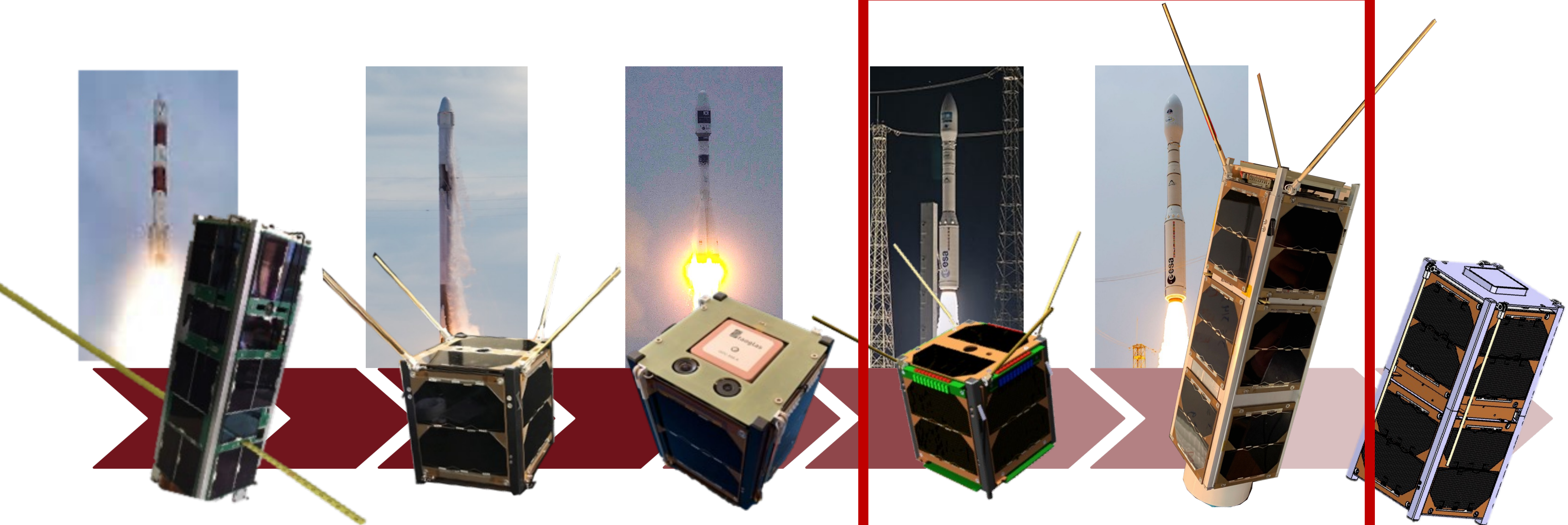
GREENCUBE

Launched on 13 July 2022
Status: **Operational in MEO**

CORAL

To be launched in 2024
Status: **Under development**

CubeSat development Programme at Sapienza S5Lab



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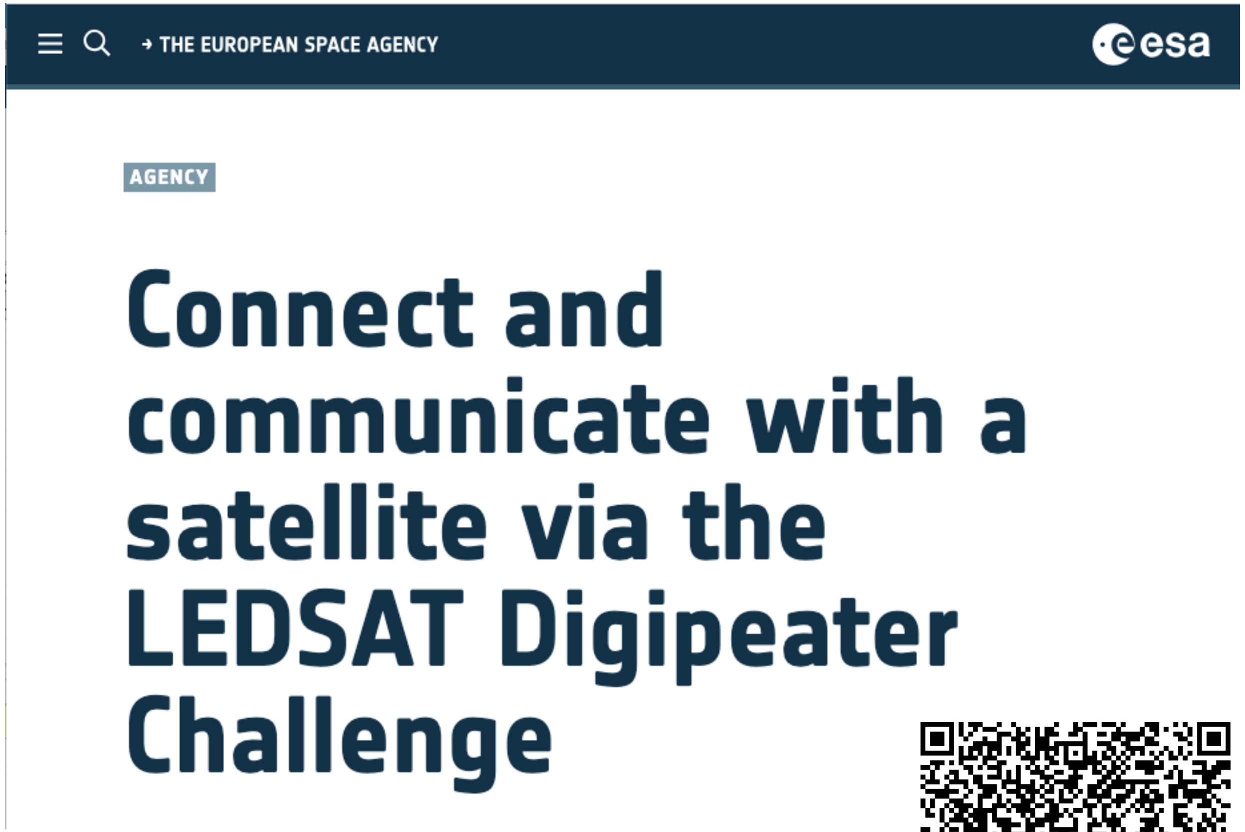
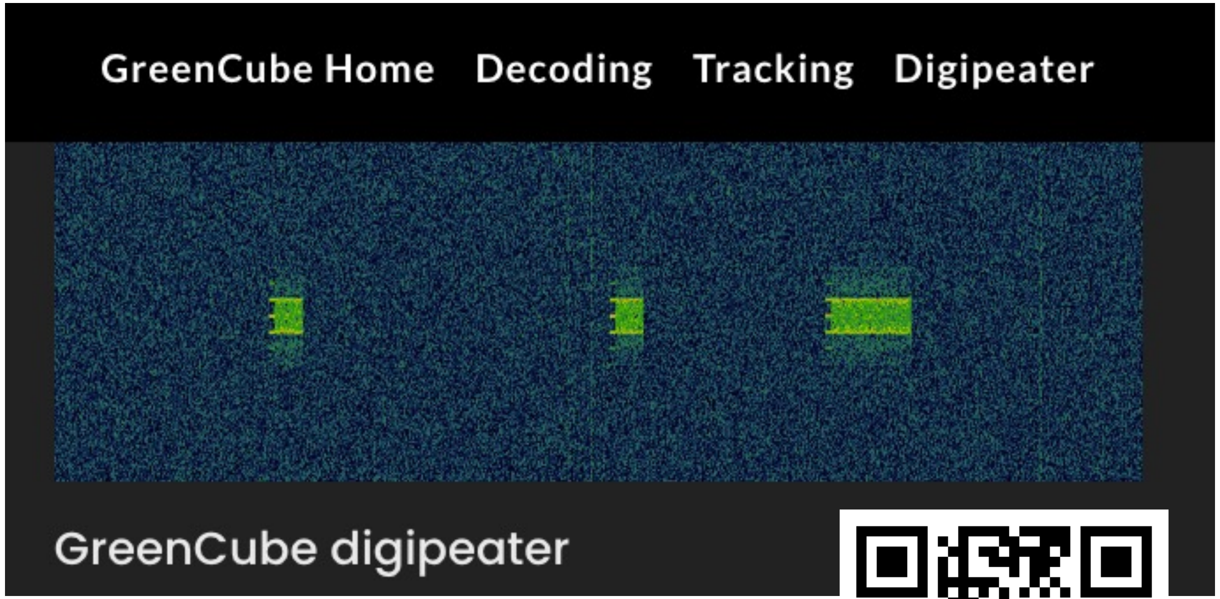
CubeSat digipeaters: announcement



ESA LEDSAT digipeater competition



GreenCube digipeater in MEO

KH6WI Ham Radio @KH6WI_Ham_... · 8h

CQ satellite de KH6WI in BL11. Made my first couple of QSOs on #GreenCube this evening. Will hopefully make some more tomorrow! Hopefully going to get on RS-44 soon as well. #HamRadio #amsat

5 · 3 · 59 · 1.108

鶴島/P @pop_in_jay · 6g

QO-100ペディションに一緒に行こう！
申し込み締め切り6/10←今日じゃん
ココスキーリング島 VK9Cに一緒に行こう
コールサイン VK9QO
AMSAT-DLに存在をアピール
#JAMSATシンポジウム2023

1 · 3 · 311

鶴島/P @pop_in_jay · 6g

11/3-7　パース集合現地解散

2 · 143

Makoto Koyanagi
@JI5RPT

Bill Ward @meteorbill · 08/06/23

In risposta a @S5Lab

Great news. Good luck with the ops. **Greencube** has been a fantastic satellite to use. 📡🛰️

70

Makoto Koyanagi @JI5RPT · 2g

久々の**GreenCube**移動運用準備完了。

5 · 259

Chris VE3FU / VO2AC / VO1FUA /... · 21h

No way I could drive through FN85 without stopping to meet up with John @ve1cwj ! Bonus: I got an IO-117 / GreenCube demo! With any luck I'll be setup for GC the next time I go to VO2. Great to see you again my friend!

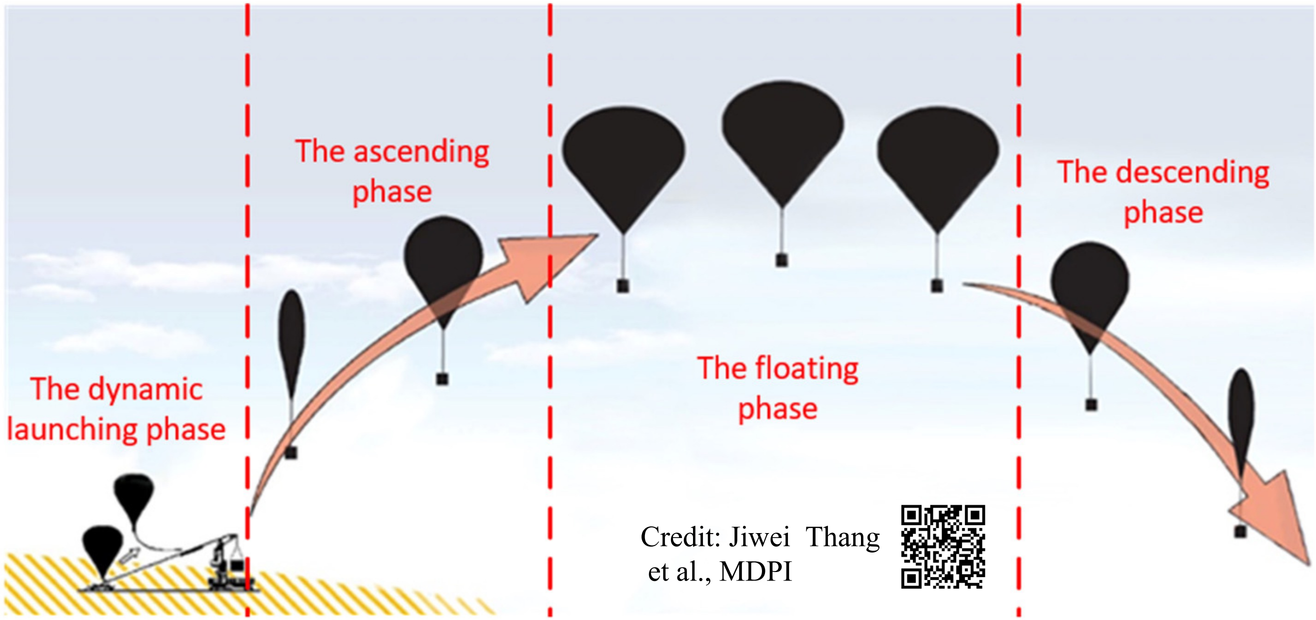
7 · 3 · 61 · 1.421

John, DK9JC 🛰️📡
@DK9JC

Yes Greencube is John's favourite sat 😂😂😂

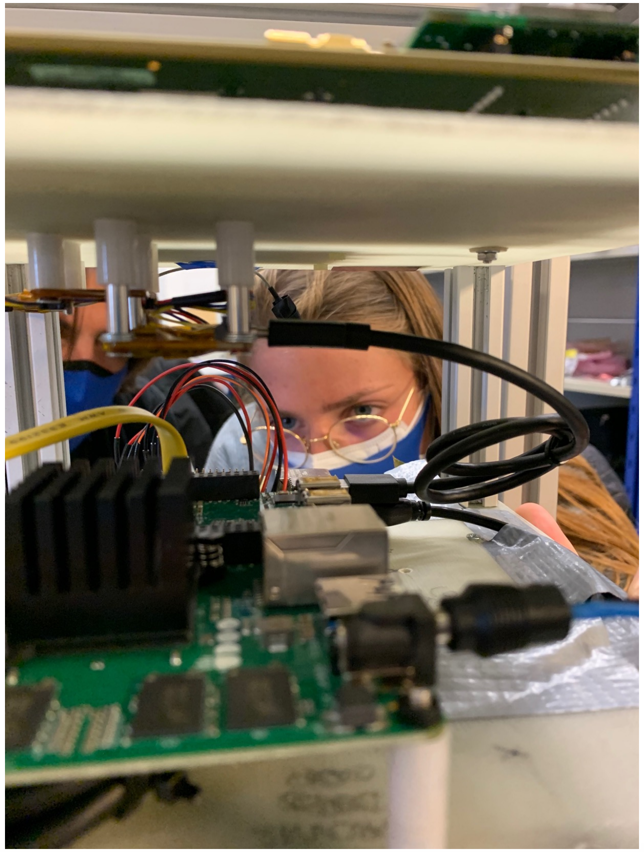
Part 1: Stratosphere

- Stratospheric balloons offer chances a short-time experimentation in near-space
- Apogee and float altitudes can vary upon 25-40 km of altitude
- A typical mission time can vary between 3-4 hours and several weeks
- The thermal environment is conditioned by lower variability and in general lower surface temperatures than LEO
- The vibrational environment is very mild
- Experiments are in general recovered after balloon cut-off
- Typical experiments within large balloon launch infrastructure (SSC in EU) can be around 50-cm Cubes with 15-30 kg of mass, small balloon can be handheld and launch CanSats



Credit: Jiwei Thang et al., MDPI

Stratospheric experiments for University students: why?



- From a technical point of view, there is plenty of scientific investigations to be carried out in stratosphere;
- Stratosphere is a good test bed for new mission profiles, including high-altitude/suborbital aviation, and a decent simulation terrain for space experiments and technologies with low TRL

- From a student perspective, learning through stratospheric experiments development represent a great chance due to several features:
  - Experiments are bigger, meaning you can see and put your hands in without being a mature user of pliers and small connectors (as in CubeSats)
  - Experiments are way cheaper than satellites, meaning it's (almost) no harm when something breaks

- International Programmes in stratospheric research can help students in practicing their soft skills within an International framework

Experiment development heritage at S5Lab: REXUS/BEXUS Programme and HEMERA

❖ **REXUS/BEXUS Programme (Rocket/Balloon Experiments for University Students)**

- Realized under a bilateral Agency agreement (SNSA/DLR) + ESA
- Call for new student experiments each year (all ESA countries), with 10 months between selection (December) and launch (late October)

❖ **HEMERA H2020 Research Infrastructure**

- Realized under the European Commission funding, coordinated by CNES
- The Italian experiments received support from ASI
- Participated in the 2018 call for a flight opportunity in 2020 (then postponed to 2021 with COVID outbreak)

Stratospheric experiments Programme

STRATONAV

BEXUS 22/23

2016

- Demonstration of the «old» VOR nav. system in stratosphere
- Six students participating to the hands-on part
- First steps in SDR technology exploitation

TARDIS

bexus 28/29

2019

- Follow-up: demonstrating VOR and interpreting the data on-board with SDRs
- Ten students participating,

STRAINS

HEMERA

2021

- Research Programme: demonstrating novel tracking techniques
- 13 students and research fellows involved in development and launch campaign
- Supported by ASI

BEXUS 32/33

ROMULUS

SAPIENZA S5LAB

2023

- Exploitation of SDRs for GNSS Radio Occultation in stratosphere
- 12 students, 2 coming from STRAINS have leadership roles

STRAINS

Stratospheric Tracking Innovative Systems

A HEMERA EXPERIMENT AIMED AT TESTING PASSIVE RF-BASED TRACKING SYSTEMS FOR STRATOSPHERIC AND INNOVATIVE HIGH ALTITUDE AIRCRAFT AND SPACECRAFT

Proposed by

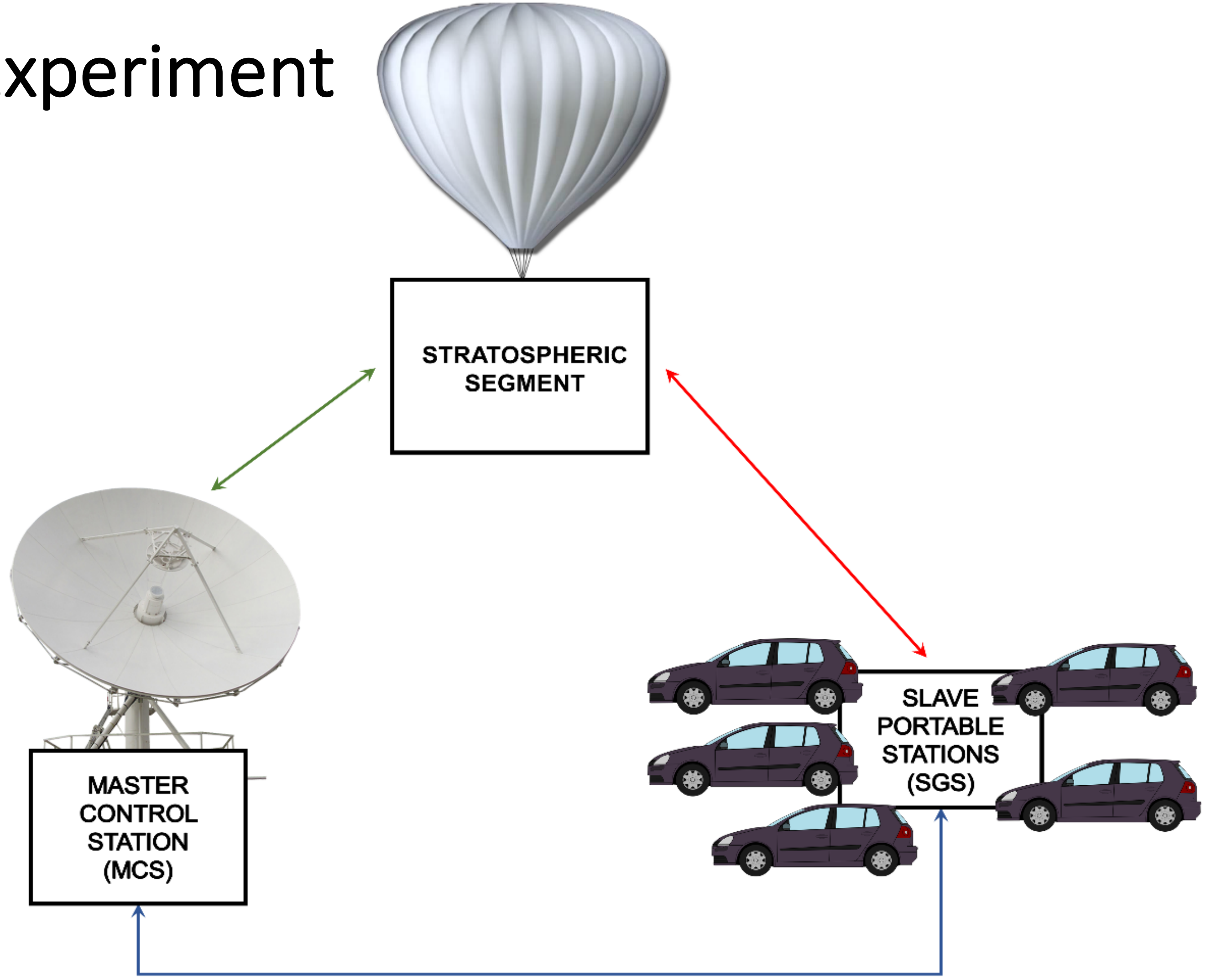
SAPIENZA UNIVERSITÀ DI ROMA

ALTEC

Supported by

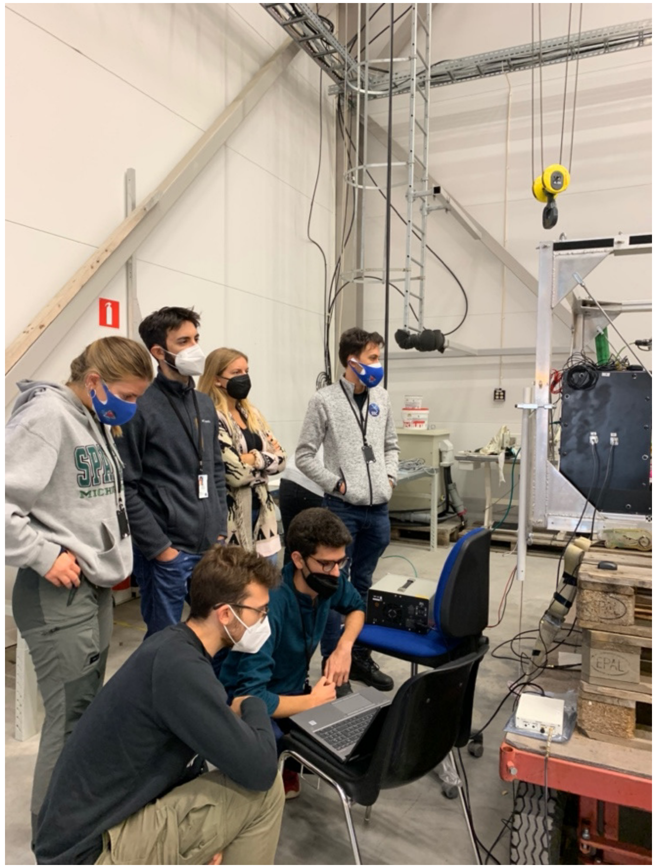
ASI Agenzia Spaziale Italiana

STRAINS Experiment

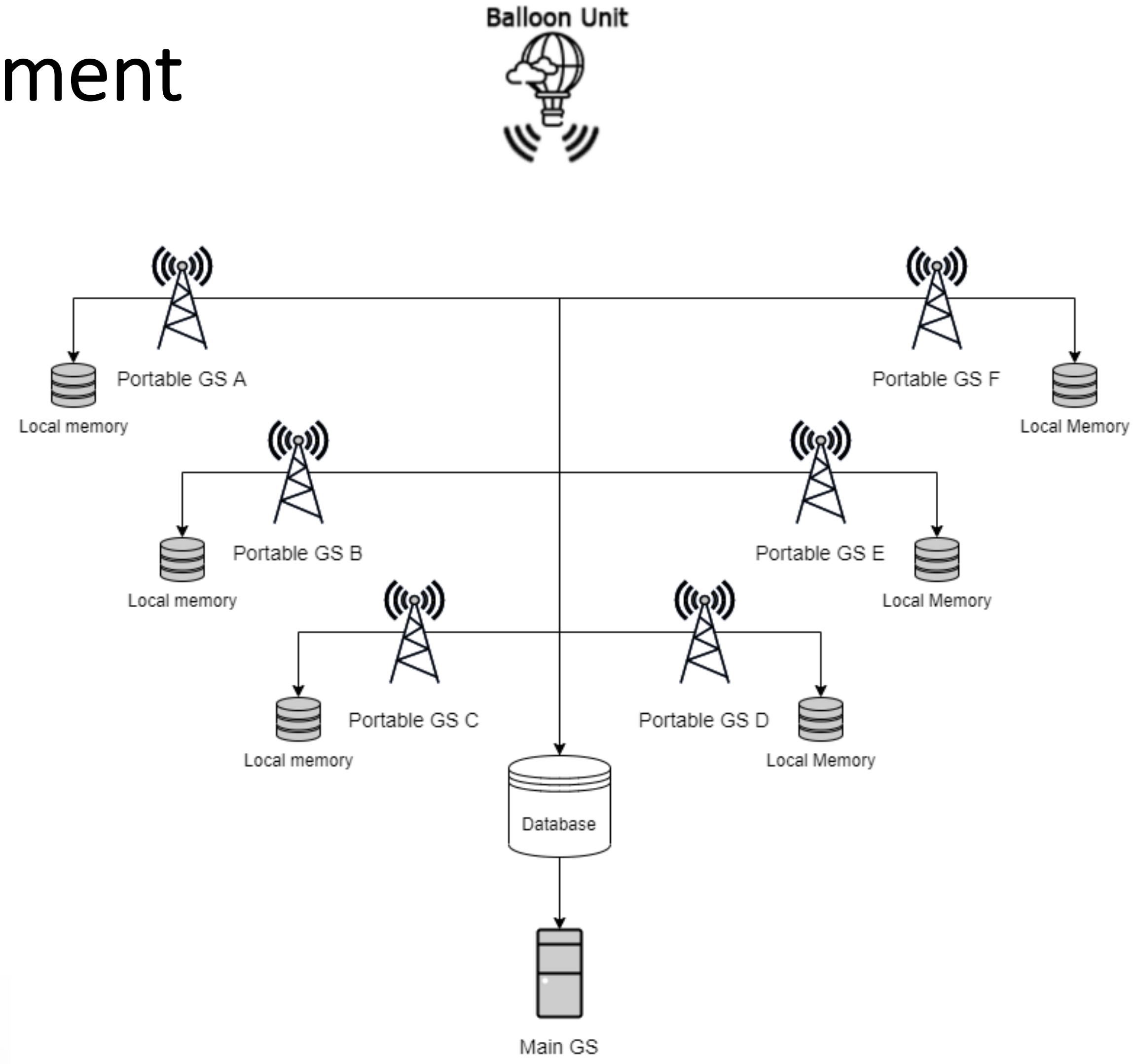


Stratospheric Segment

- A box of 30 x 30 x 50 cm approximately
- Two transmitters enabled in UHF and S-band
- Internal power storage and distribution
- Housekeeping and telemetry link enabled through the balloon system



STRAINS Experiment



STRAINS teams (A to F)

Team A: Addis Abeba	Alessandra Graux, Gaetano Zarcone
Team B: Beirut	Linda Misercola, Emanuele Bedetti
Team C: Caracas	Luigi di Palo, Federico Curianò
Team D: Dakar	Luca Collettini, Clara Di Nunzio
Team E: Esrange (localizzato al centro di controllo)	Paolo Marzioli, Niccolò Picci, Riccardo Garofalo
Team F: Fuji	Lorenzo Frezza, Andrea Gianfermo

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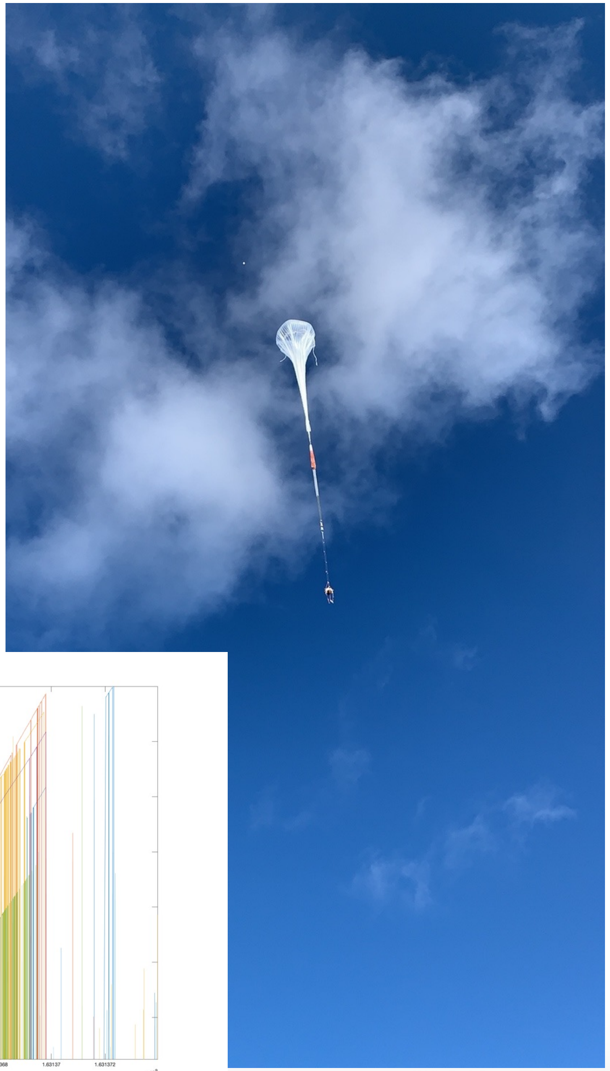
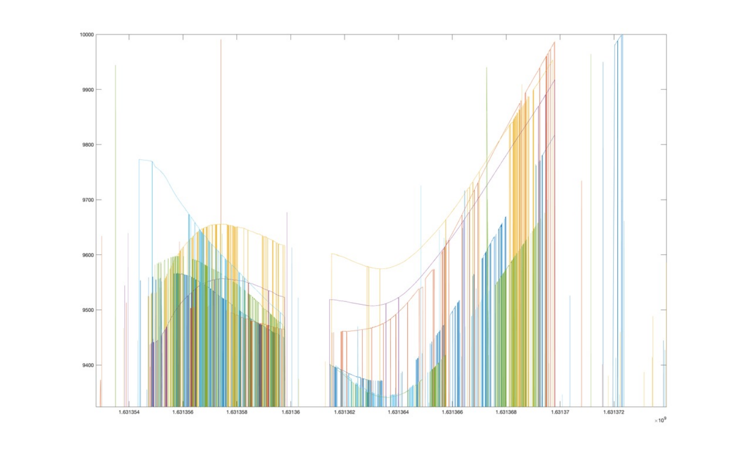
STRAINS Launch

- STRAINS was launched at 9.53 UTC on 11 September 2021 from the Esrange Space Center in Kiruna, Sweden
- During the 9-hour flight the experiment and ground segment managed to gather around 40 000 telemetry packets to be converted in navigation measurements
- Data showed very consistent precision, with a slightly better performance from the UHF segment than S-band due to synchronization difficulties





STRAINS Experiment – Preliminary results in brief

40 000 measurements collected by the ground stations

Perfect functionalities of the experiment from switch-on to cut-off (when we commanded automatic shutdown)

No criticalities during launch campaign – all nominal work proved good management of the testing campaign

Lesson learned: transitioning from student ballooning to stratospheric research (and back…)

- Out of 14 participating students and research fellows to the STRAINS Experiment, 8 were previously involved in a BEXUS stratospheric experiment developed at Sapienza S5Lab (**STRATONAV**, **TARDIS**)
- The participation in HEMERA revealed how fundamental skills were already acquired by the STRAINS teams in terms of:
  - Team work and team spirit;
  - Technical skills (mainly concerning the payload) and interface design with a “known” platform

The two “new” students joining the HEMERA experiment are now leading a new BEXUS experiment, taking advantage of the lessons learned

R.O.M.U.L.U.S.

Radio Occultation Miniaturized Unit for Leo and Upper Stratosphere

GNSS Radio Occultation 1/2

Atmospheric **refraction bends** GNSS signals

Measuring the bending of the signal's path enables the retrieval of atmospheric properties (e.g. **density**, **temperature**, ...)

GNSS-RO soundings are daily used for **weather forecasting**

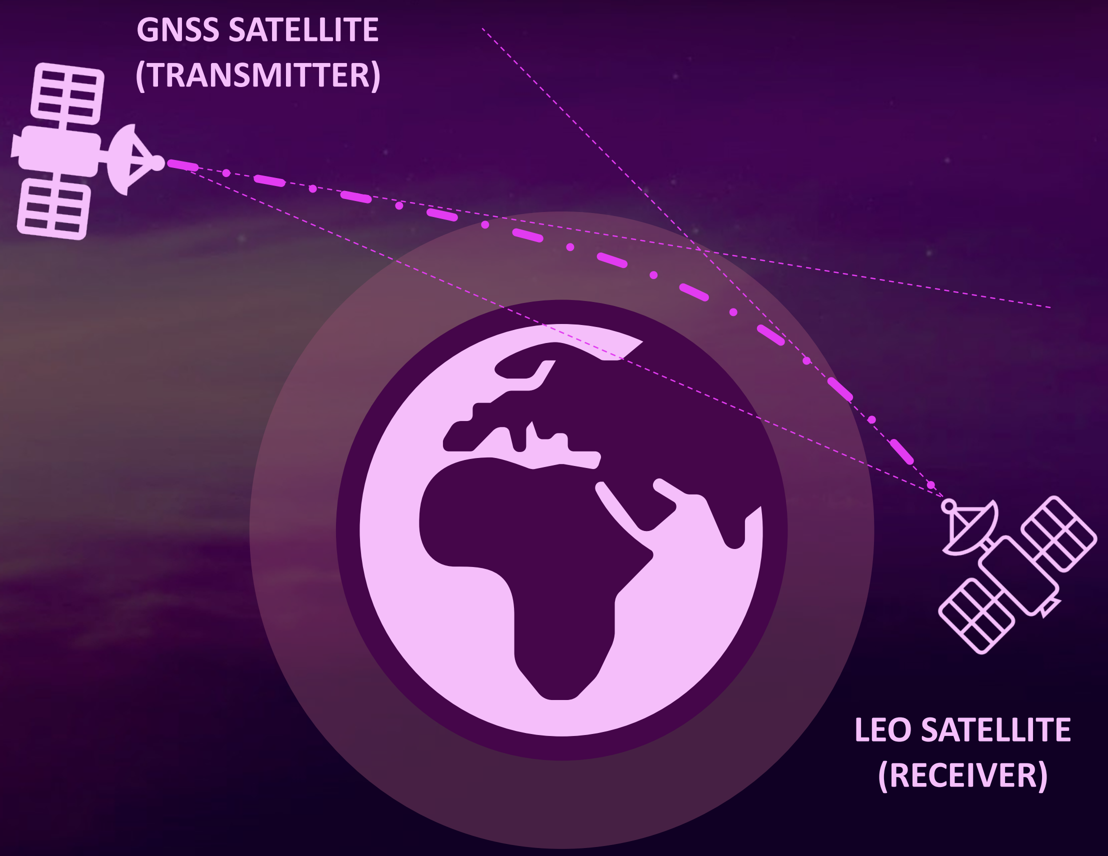
GNSS Radio Occultation 2/2

GNSS SIGNALS

PHASE AND DOPPLER

SIGNALS PATH BENDING

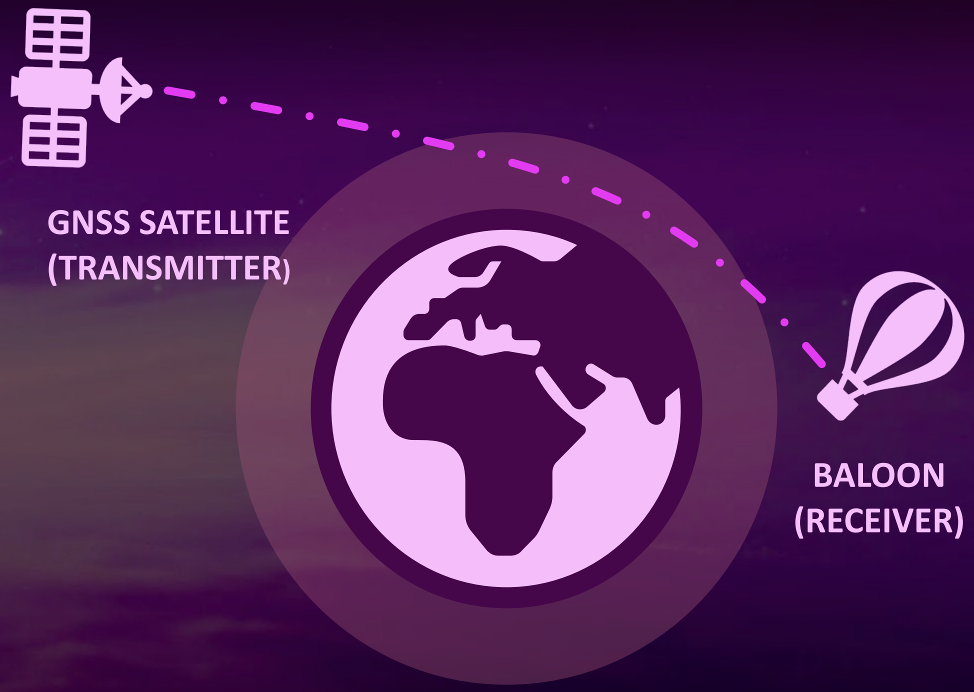
ATMOSPHERIC PROPERTIES

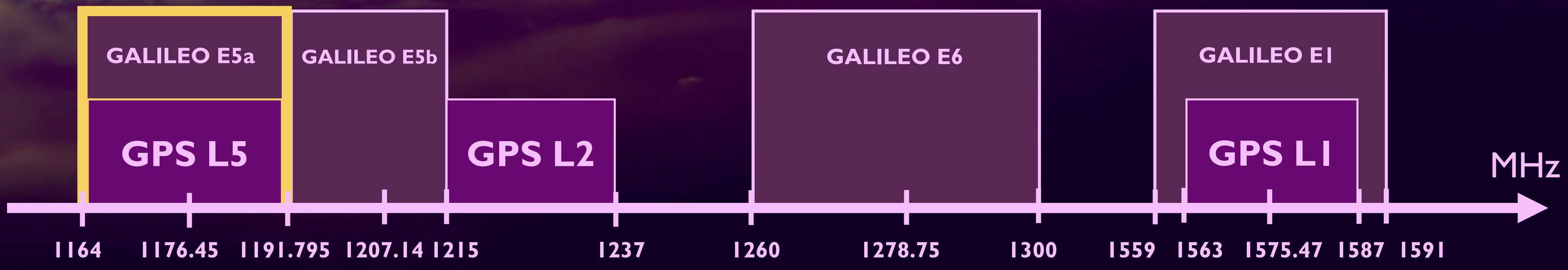


Objectives

- Test a small-scale system for balloon-borne **GNSS-RO** based on a **Software Defined Receiver**

- Investigate the advantages of **Galileo** and **GPS** signals in the **L5 band** for Radio Occultation





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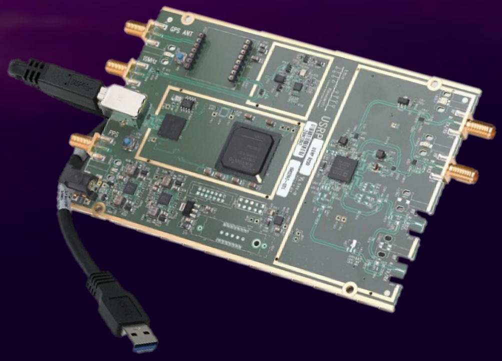
… and why a Software Defined Receiver?

- **Low-cost**
- **Simplified hardware**
- **Flexibility** in the operating frequency
- **Raw RF samples storage** for **post-processing**
- Possibility to apply different algorithms for signal tracking



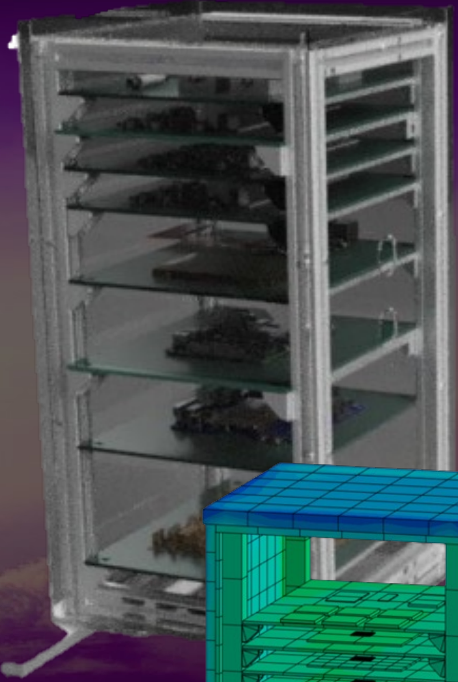
Timeline of the Experiment

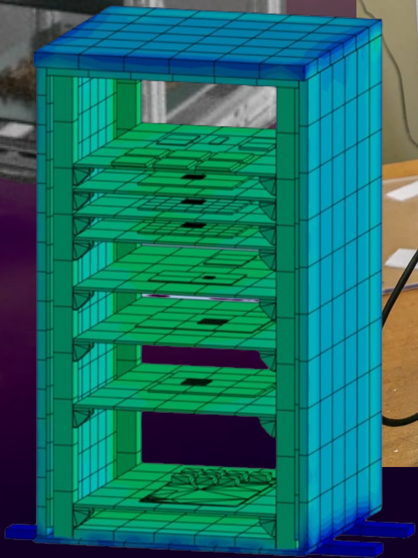
SELECTION WORKSHOP ✅
(November 2021, S5Lab facilities)
PRELIMINARY DESIGN REVIEW ✅
(February 2022, S5Lab facilities)
CRITICAL DESIGN REVIEW ✅
(May 2022, ESA-ESTEC)
INTEGRATION PROCESS REVIEW I&II ✅
(September '22 & March '23, S5Lab facilities)

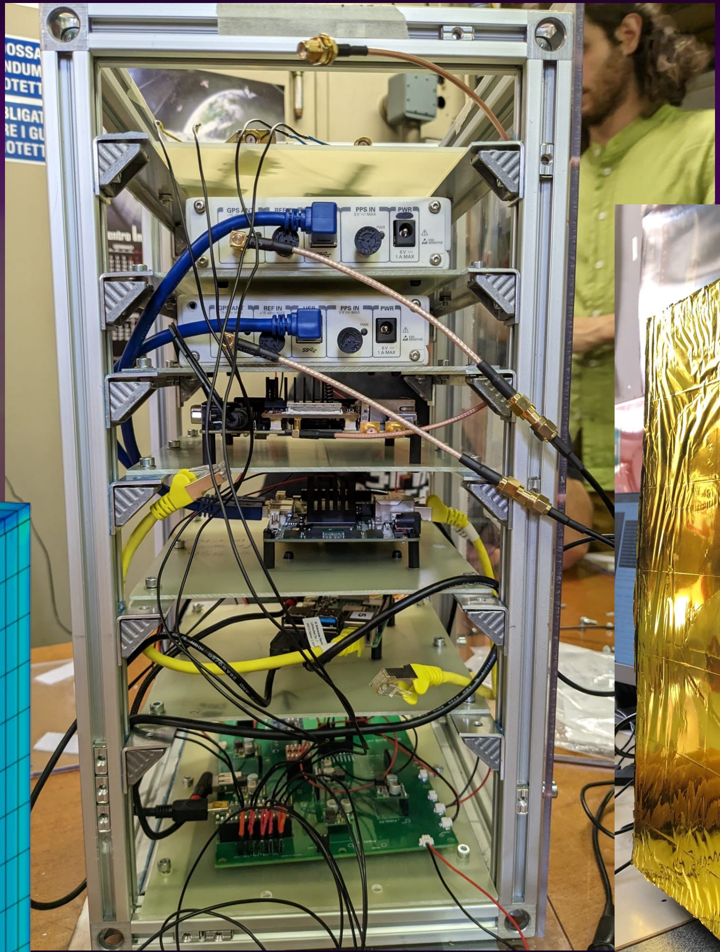
Upcoming:
EXPERIMENT ACCEPTANCE REVIEW
(26 June 2023, S5Lab facilities)
LAUNCH CAMPAIGN
(September 2023)

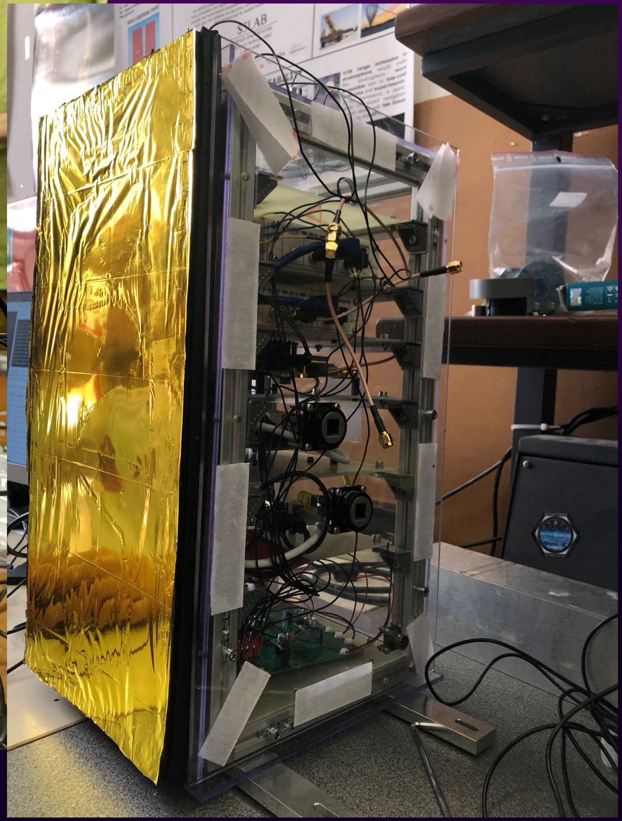
NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
2021		2022												2023								

The ultimate aim – from mock-up to reality

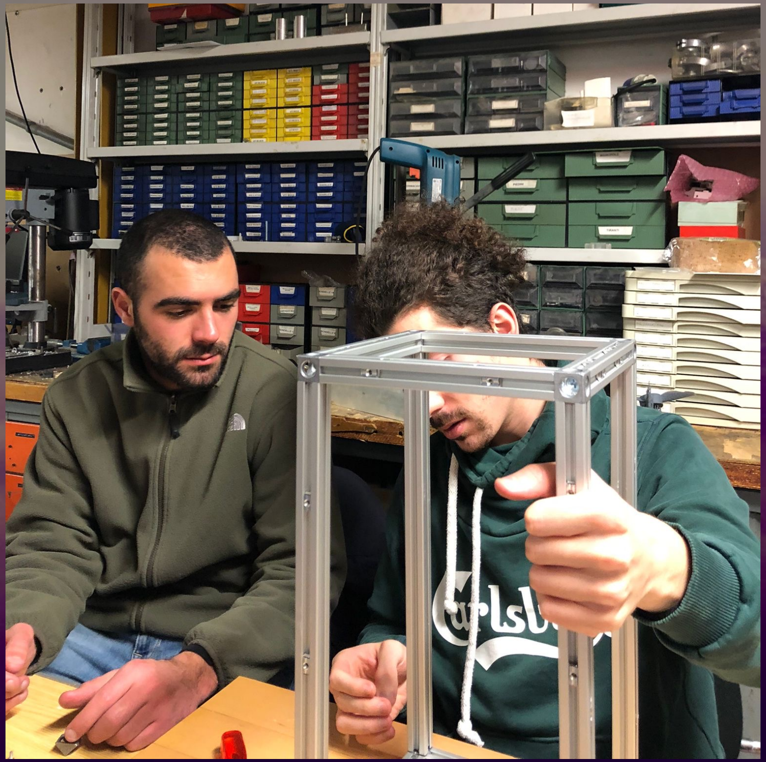








A lot of fun, hard work, outreach and presentations…



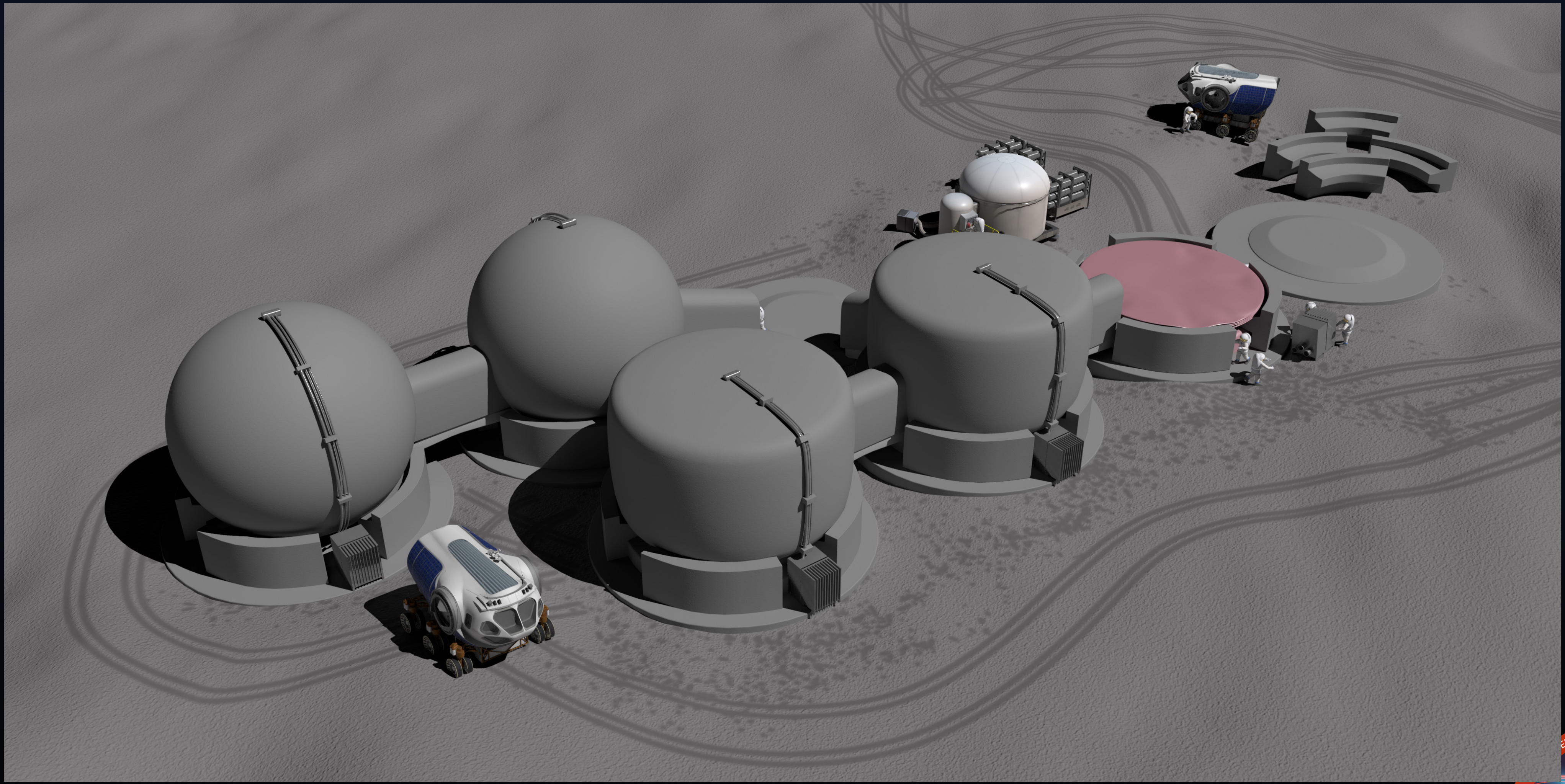
...with some very special meet-ups (w/ Astronaut Paolo Nespoli)

Part 2: Lunar analog missions

GEA – Gruppo Esplorazioni Analoghe

- S5Lab – Sapienza Space Surveillance and Space Systems Laboratory
- GS – CAI (Club Alpino Italiano) of Rome

How do you imagine and envision lunar bases?



Source: Aerospace.org

How they will likely be:

Source: ESA, Politecnico di Milano

How they will likely be:

Source: NASA/JPLTech

GEA: Analog Exploration Group

GEA is a **speleology Analog Mission** conducted in caves

- Extreme and unfriendly environments
- Interesting for exploration activities
- Speleological progression must respect different security procedures (such as the use of instruments and the knowledge of descending techniques)

GEA Concept Mission

Main Goal of GEA

- Establish an analog infrastructure, managed by **researchers and students**
- Recruitment and training of **12 speleonauts**
- Participating in a **real analog mission of 72 h**
- Living in a challenging environment
- Developing their own small scale experiments

GEA: Speleology Training

First steps in caving progression

- The students and researchers in GEA have been learning caving progression techniques in Spring 2022
- The techniques are necessary to operate safely in the extreme environment

GEA: Mission Organization

- Recruitment of **12 speleonauts**, with a **50% share of women** involvement in the mission
- **Two teams of six astronauts**: three men and three women for each one. Back-up team of 4 astronauts, with other 4 speleonauts to be trained every fall
- **A team of at least five mission controllers** that will manage the Mission Control Center (MCC)
- A team of at **least five speleology instructors**
- **First 24h test under preparation: foreseen for July 2023**
- **First 3-day analog – end of 2023**

How to choose the «perfect» cave?

❖ Underground environment hidden from the Sunlight

- To alterate the cyrcadian cyle
- To simulate the future colony on Moon and Mars
- To promote the isolation from the external world

❖ Cave shall be close enough to the surface

- To ensure the crew safety in case of danger
- To guarantee the functioning of telecomunication system

❖ Cave dimension shall be large enough

- To transport potentially large instruments
- To support the simultaneous operations of 12 people

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gea.
GRUPPO ESPLORAZIONI ANALOGHE

1° Lesson Learned: Psychology

Physical and mental challenge

- Recognize fear and anxiety to proceed in a confined and extreme environment
- Capacity to endure the mental and physical stress (panic, fatigue,…)
- Necessity to get out of the comfort zone and to go beyond the personal limits
- Awareness of being isolated and not being able to receive prompt help

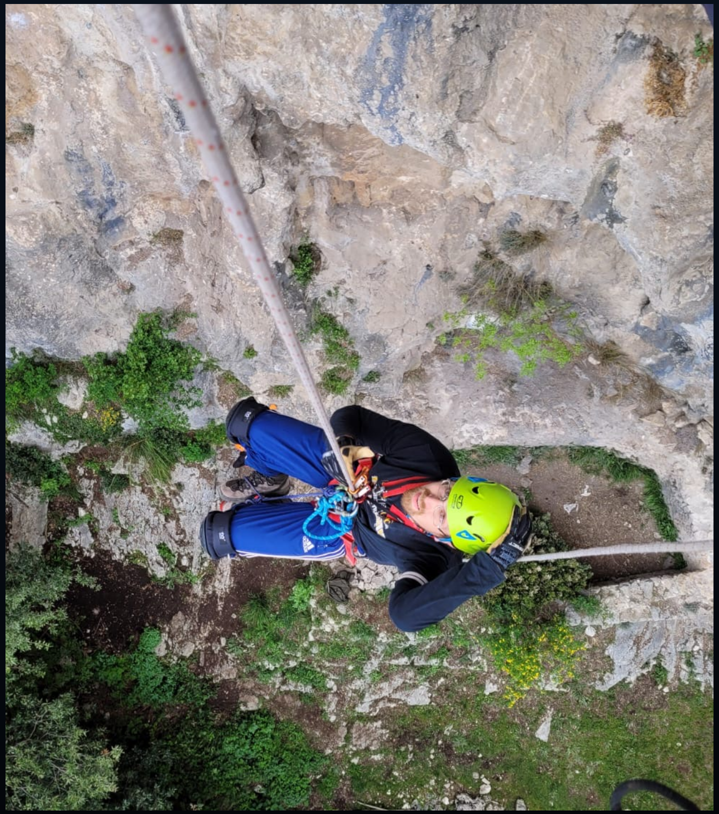
Forced co-existence and cooperation

- Opportunity to do team building
- Increase of team work quality
- Facing and solving the possible disagreement

2° Lesson Learned: Use of Caving Tools

Training on rock walls

- Knowing new instruments, such as abseil device, croll and caving handle
- Acquiring familiarity and confidence with caving tools
- Learning how to ascend and descend on rock walls
- Learning how to walk in an hostile and dark environment
- Improving the ability of horizontal and vertical progression

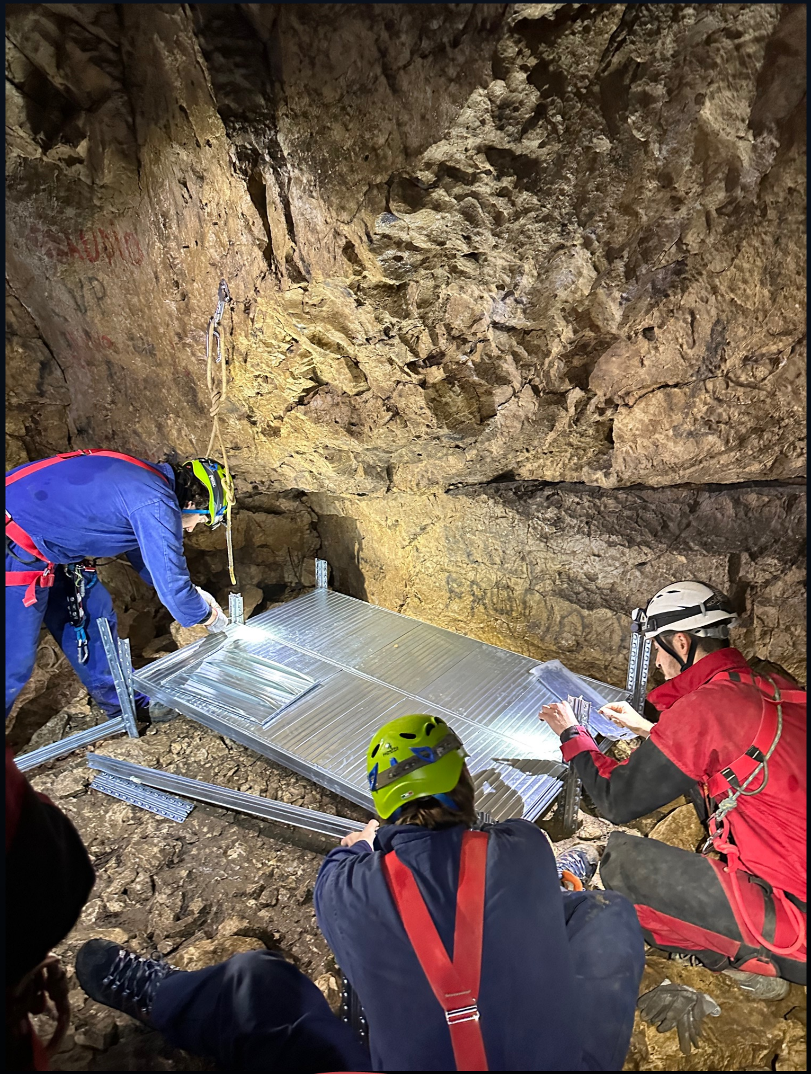


3° Lesson Learned: Environment Setting Up

Cave Management

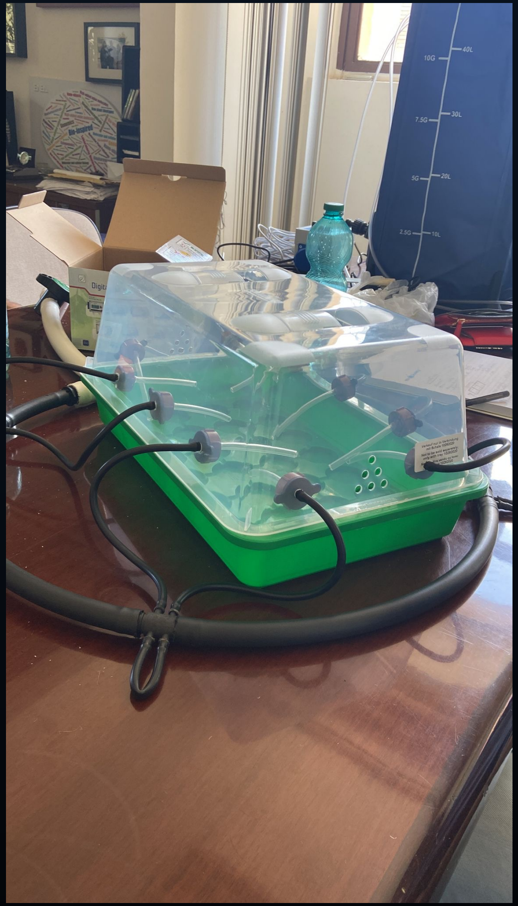
- Appropriate number of “room” to place the experiments and to live for three days
- Learning the logistics difficulties for primary needs
- Difficult transportation of the experiment payload in caves, in particular through narrow areas
- Necessity of an electrical source to generate power inside the cave to support all the activities
- Suitable distance from the cave’s entry, to guarantee a working communication with the MCC

Recent advances: habitat rehearsal



Recent advances: Communication & Sensors

Recent advances: Plant cultivation & science



This automated cultivation system is being mounted in a cave by Lorenzo **in this precise moment…**

Last but not least...

@sapienza.s5lab

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