University Satellite Design Review at S5Lab

Sapienza Space Systems and Space Surveillance Laboratory

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Tokyo, 13 January 2016

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- **S5Lab Activity**
- University Satellite Development
- S5Lab Facilities
- URSA MAIOR nano-satellite
- IKUNS nano-satellite
- Student satellite design process and review
- Conclusions

S5LabACTIVITY

❖ **University Satellites**

- Mission analysis
- On-board systems/sub-system
- Complete satellite MAIT
- Ground station operations
- Data handling and processing

❖ **Space surveillance systems**

- Optical observation systems
- Data analysis
- Orbit determination
- Active debris removal systems
- Spectral analysis

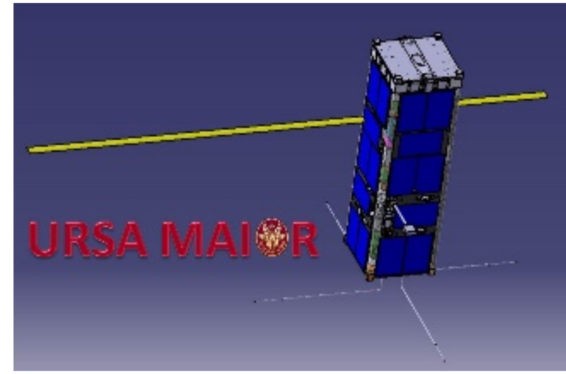
ON-GOING SPACE PROJECTS

- **URSA MAIOR**

  (3U Cubesat, QB50)

- **IKUNS**

  (Italian-Kenyan University Nano Satellite)



- **EQUO**

  (EQUatorial Observatory for space debris)

- **REXUS/BEXUS programme**

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- Lessons Learned (Conclusions)

UNIVERSITY SATELLITES

- It is a **functional spacecraft**, rather than a payload instrument or component. To fit the definition, the device **must operate in space with its own independent means of communications and command**
- **Untrained personnel** (i.e. students) performed a significant fraction of key design decisions, integration & testing, and flight operations
- Teach how to manage resources (budget, mass, power, **<u>time</u>**)
- Teach how to perform group-working

- **The training of people is as important as** (if not more important) **the nominal "mission"** of the spacecraft itself

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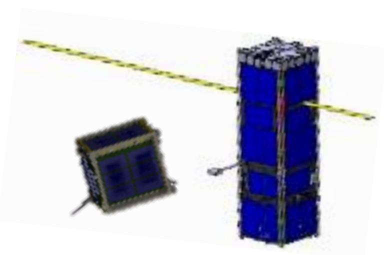
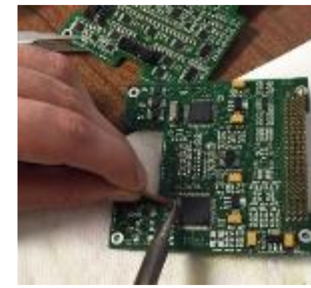
SMALL SATELLITE DEVELOPMENT

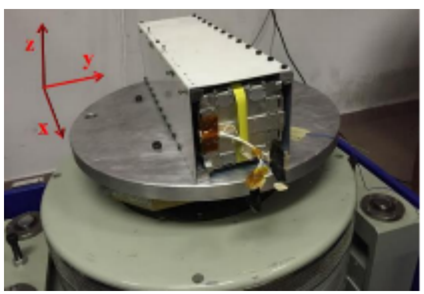
❖ Design



❖ Manufacturing



❖ Testing



❖ Operations

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S5Lab FACILITIES

- **<u>MANUFACTURING</u> (Structure and Electronics)**

Engineering Faculty Machine Workshop

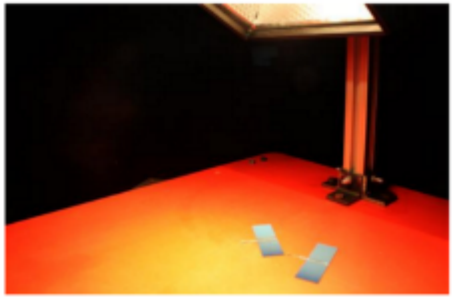
S5Lab Milling Machine

<u>S5Lab Electronic Laboratory and related equipment</u>

S5Lab FACILITIES

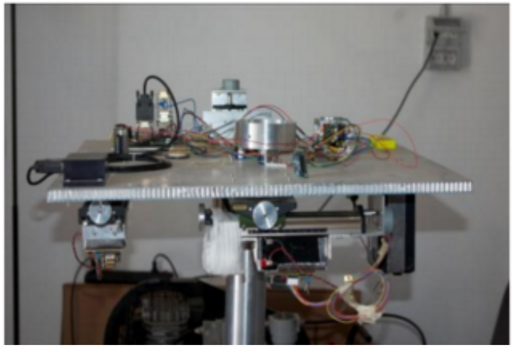
- **TESTING**

Low-Vacuum Chamber



S5Lab Sun Simulator

S5Lab 3D Helmholtz coil system
(Magnetic field simulator)



S5Lab frictionless air bearing system for spacecraft attitude dynamics and control testing

S5Lab 3 DoF ADCS test-bed equipped with
Control Moment Gyros (CMGs)

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S5LAB

S5Lab FACILITIES

- **<u>OPERATION</u>:**

S5Lab Remotely controlled space debris observatory

S5Lab URBE GS

S5Lab GS management facilities

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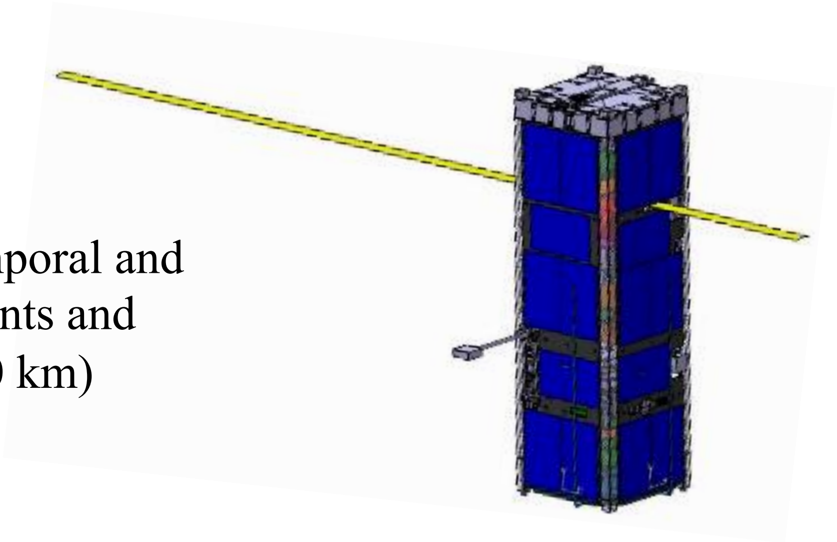
URSA MAIOR

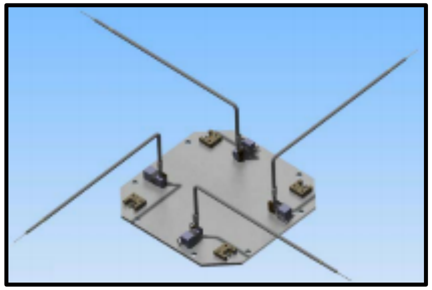
University of Rome la SApienza Micro Attitude In ORbit testing

QB50 Project

QB50 scientific project aims to **study** in-situ temporal and spatial variations of a number of key constituents and parameters in the **lower thermosphere** (400 km) **with a network of 50 CubeSats**

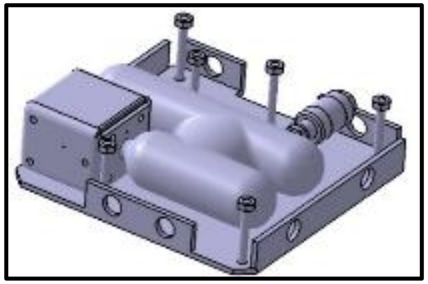


Scientific/Technological Payloads



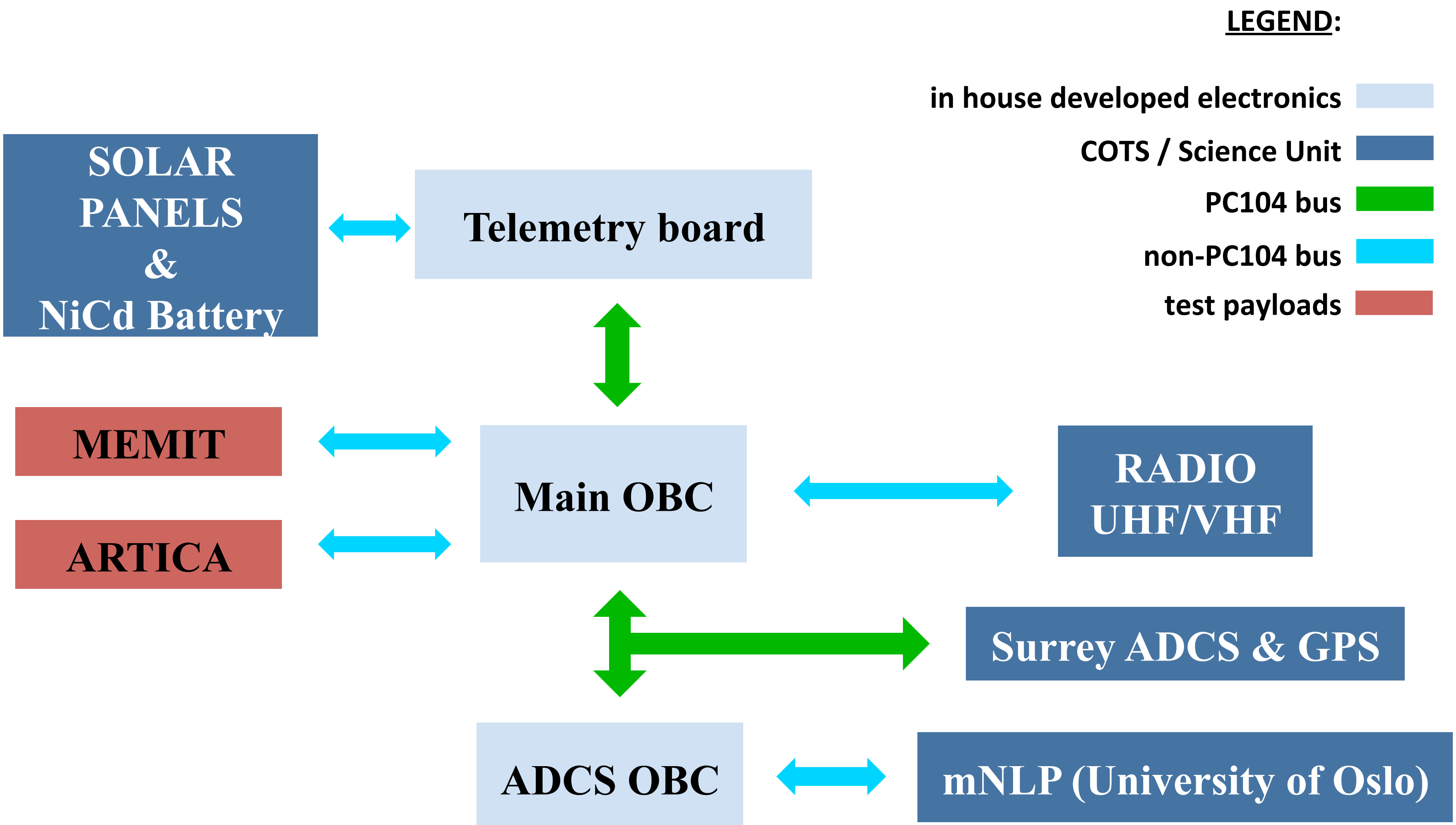
mNLP

ARTICA

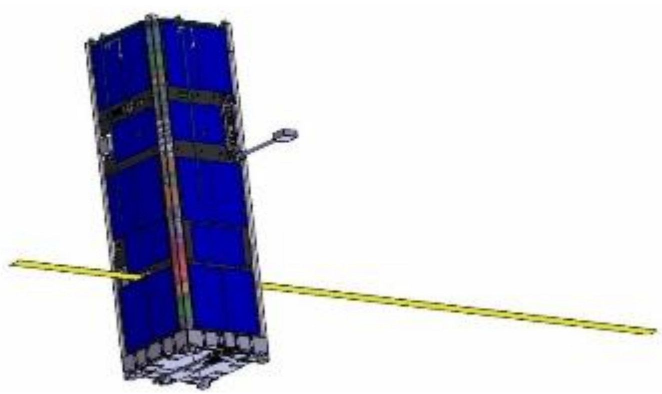


MEMIT

URSA MAIOR Architecture

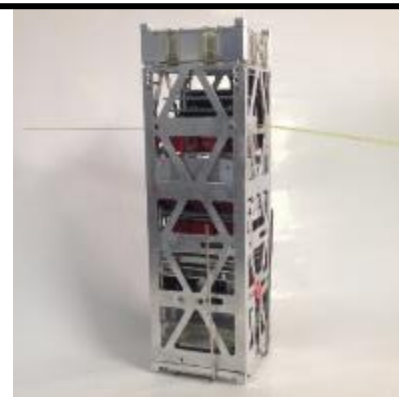


DEVELOPMENT OVERVIEW

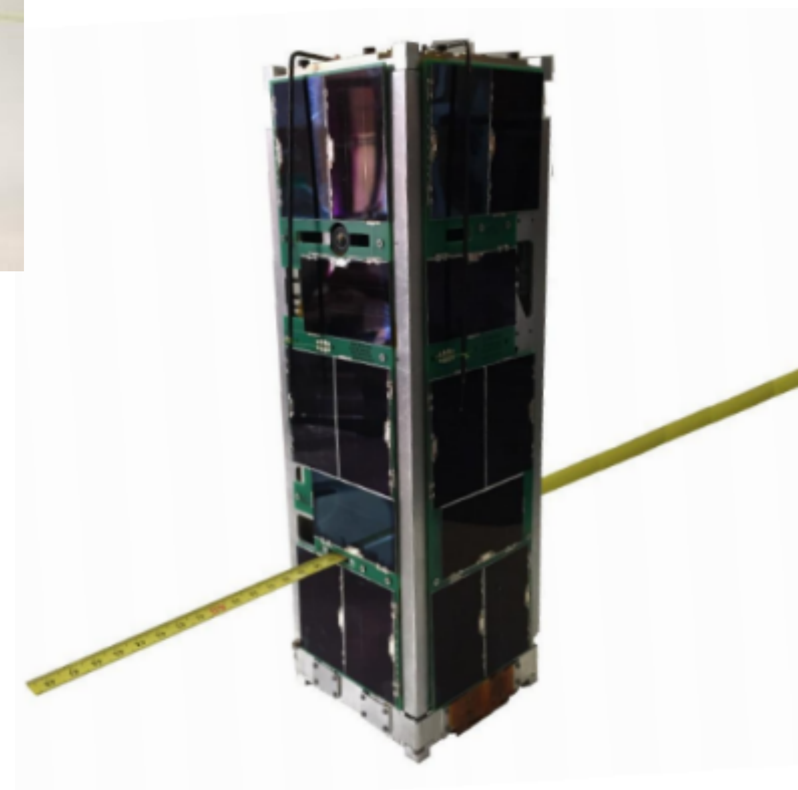


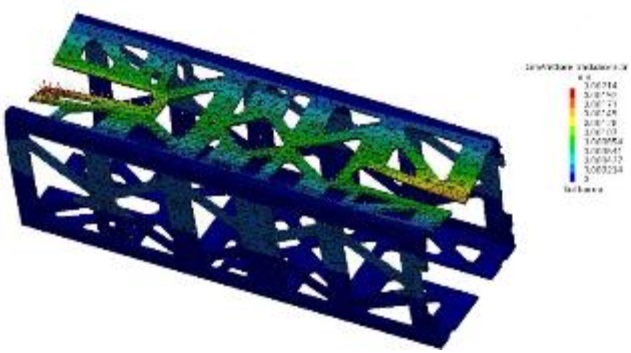
URSA MAIOR CAD

URSA MAIOR 1st Prototype



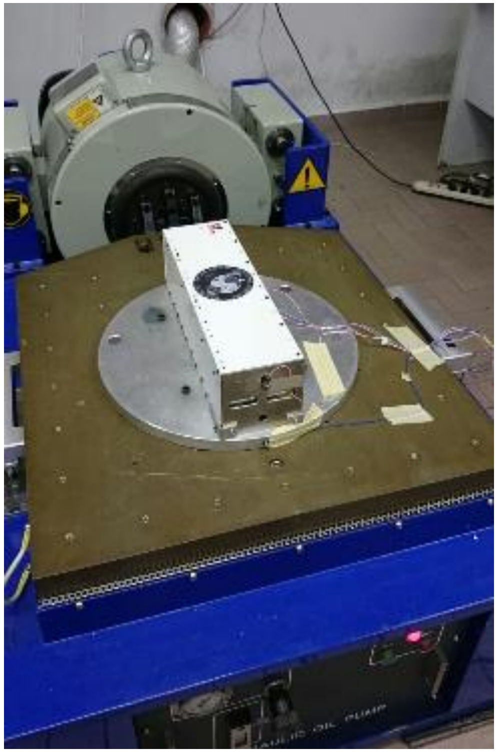
URSA MAIOR Proto-Flight model

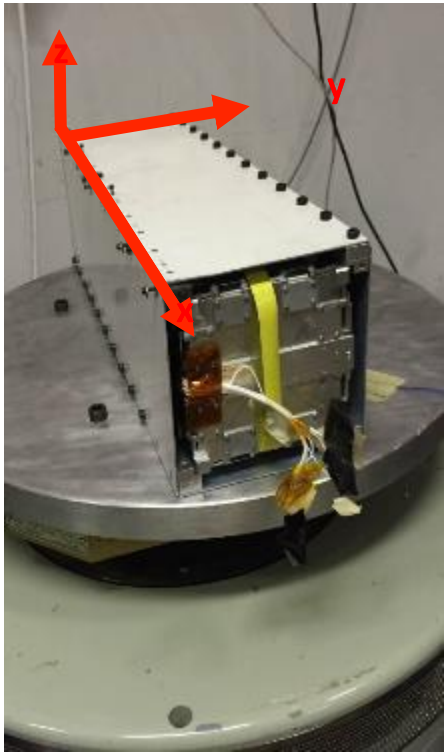




URSA MAIOR FEM

VIBRATION TESTING





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IKUNS

Italian-Kenyan University Nano-Satellite

ASI - Concurrent Engineering Facility

Final Presentation

SAPIENZA, 18-12-2015

Prepared by the ASI-IKUNS CEF Team

ASI - Concurrent Engineering Facility

Team Member Names and disciplines

•*SYSTEM*	*Luca Maioli*
•*MISSION*	*Virginia Notaro , Andrea Di Ruscio , Nicole Segala*
•*PAYLOAD*	*Livio Agostini , Saverio Cambioni*
•*ADCS*	*Emanuele Giovanni Ruà , Michele Gaeta*
•*OBDH*	*Riccardo Corvetti , Matteo Ribet*
•*CONFIGURATION & STRUCTURE*	*Luana Calisti , Eleonora Marotta*
•*TT&C*	*Daouda Coulibaly , Marco Acernese*
•*GROUND SEGMENT*	*Filippo Marchesi*
•*POWER*	*Berardino Lovallo , Laurentiu Constantin Niculut*
•*THERMAL*	*Corinna Cerini , Federica Angeletti & Andrea Gianfermo*
•*COSTS*	*Francesco Ciarla & Davide Nardi*
•*RISKS & PROGRAMMING*	*Vito Lamarca , Veronica Vilona*

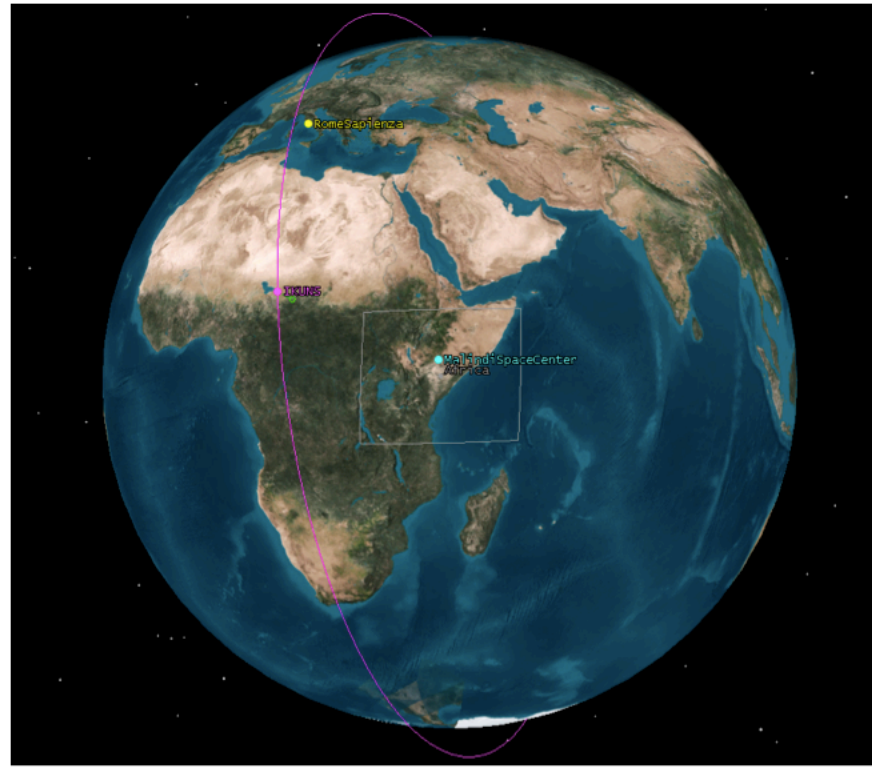
Study Timeline

Day	Month	Weekday	Time-Slot	Activities
23	October	Friday	PM (15:00 -17:00)	Introduction to CEF facility
30	October	Friday	PM (14:30 -18:00)	Definition Mission Requirements
6	November	Friday	PM (14:30 -18:00)	Definition Mission Requirements
13	November	Friday	PM (14:30 -18:00)	Session 1
20	November	Friday	PM (14:30 -18:00)	Session 2
27	November	Friday	PM (14.30 -18.00)	Internal Mid-term presentation
4	December	Friday	PM (14:30-18:00)	Session 3
11	December	Friday	PM (14:30-18:00)	Final Internal Presentation
18	December	Friday	AM (09:30-10:30)	Presentation to “Sapienza”

Mission Analysis: Baseline Design

- Sun-Synchronous characteristics:
  Height: 500 km
  Inclination: 97.4°
  Local time of ascending node: 10:30:00 h
  Period: 98 min
  Maximum eclipse time: 36 min

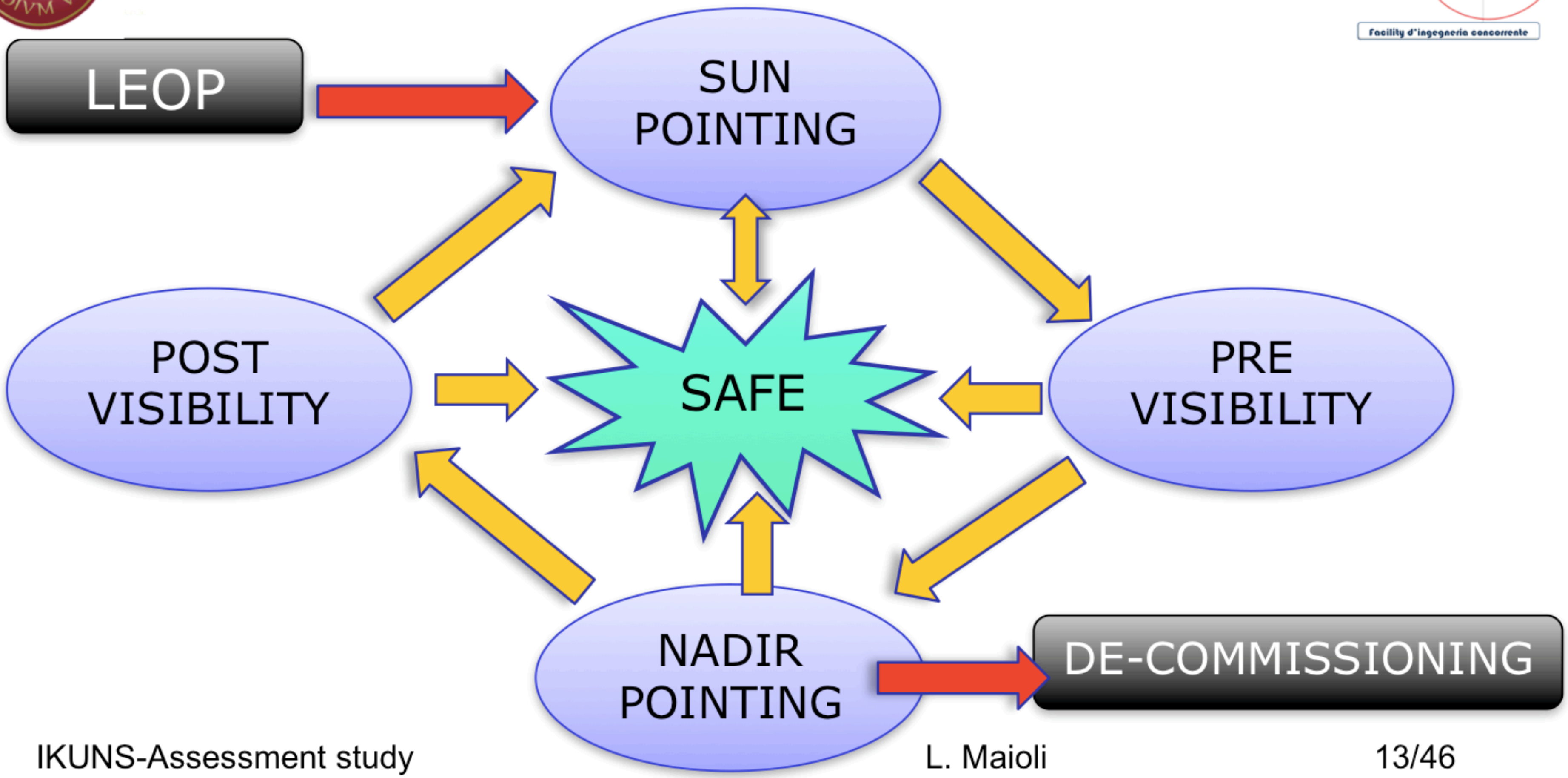
  - **Area of Interest:**
    Eastern Africa

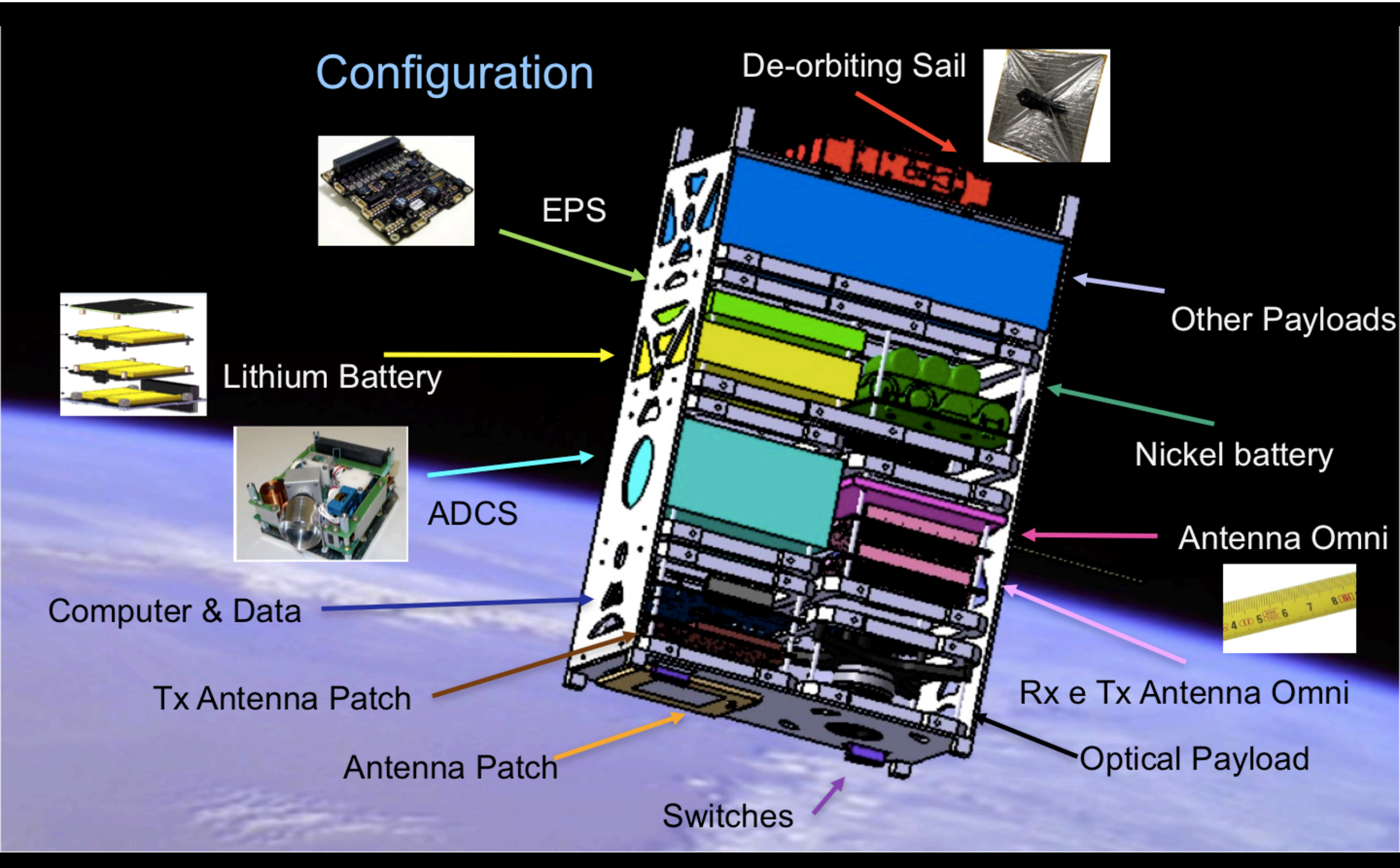


Operative Modes

Mode	Description
LEOP	After the deployment from the launcher, The Cubesat starts de-tumbling phase and contemporary it sends Beacon Signal, until ground stations define its orbit and desired attitude it's achieved .
Sun Pointing	The attitude of the Satellite is Sun Pointing with 6U face in front of the sun. Camera is switched off, as transmitters, while ADCS is in Sun Pointing mode. In this phase OBDH, through internal clock, waits the interval of time (communicated from ground) necessary to reach next visibility time.
Pre-Visibility	ADCS operate the first manoeuvre to reach Nadir pointing from Sun pointing attitude. At the same time, Camera and transmitters are switched on if the window of visibility is with sunlight , instead are switched on only transmitters if the window of visibility is during eclipse phase. Than it's done a check of status of all subsystems
Nadir Pointing	The attitude of the Satellite is Nadir Pointing with the camera and high Gain Antenna pointed toward area of interest: Eastern Africa or Italy. In this phase Telemetry and Payload data are sent to ground station in visibility, and also are received commands for the subsequent orbits. Moreover, if the window of visibility is with sunlight, camera take pictures (maximum 10) and stores them on onboard computer.
Post-Visibility	ADCS operate the second manoeuvre to reach Sun pointing from Nadir pointing attitude. At the same time, Camera and transmitters are switched off if the window of visibility has been with sunlight , instead are switched off only transmitters if the window of visibility was during eclipse phase
De-commissioning	ADCS operate de-commissioning manoeuvre, in which the Cubesat reaches an attitude that permit to the normal of drag sail to be parallel to direction of motion. Camera is permanently turned off, as any other secondary payloads and transmitters. Batteries are discharged and Drag Sail is deployed. At the end, it's turned off ADCS and Power converter.
Safe	Power is removed from non-essential subsystems as payloads; only ADCS and radio reception remain active. Satellite waits command from ground stations through omni-directional antenna to re-establish nominal mode of operation.

Operative Modes




Configuration
De-orbiting Sail
EPS
Other Payloads
Lithium Battery
Nickel battery
ADCS
Antenna Omni
Computer & Data
Tx Antenna Patch
Rx e Tx Antenna Omni
Antenna Patch
Optical Payload
Switches

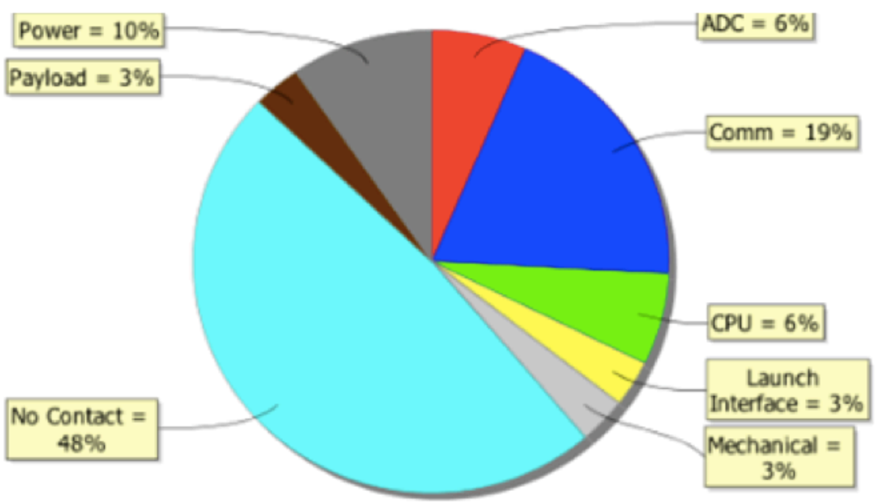
Mass Budget

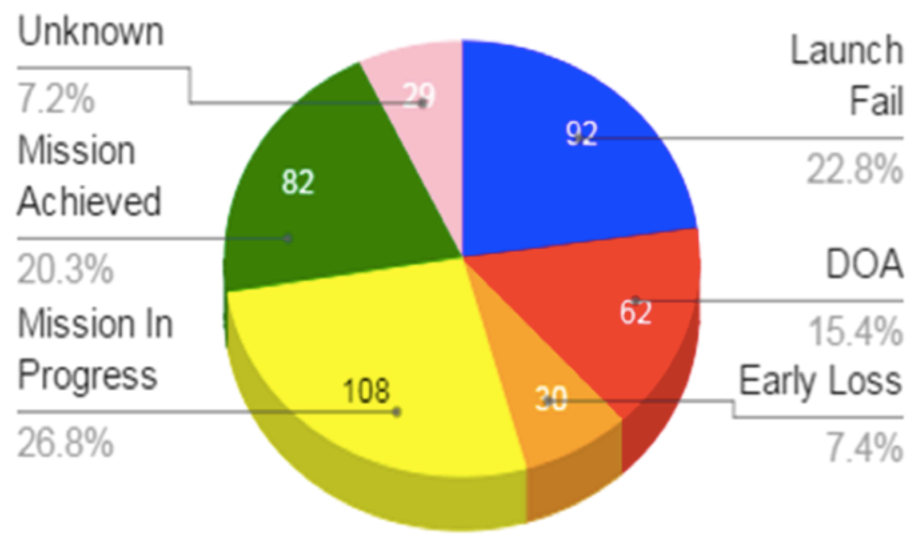
Subsystems	Allocated [kg]	Actual [kg]	Margin [%]
Primary Payload	*0.5*	*0.17*	*5*
Power	*2*	*1.5*	*10*
TT&C	*0.4*	*0.4*	*5*
Structure	*2*	*1.96*	*20*
OBDH	*0.1*	*0.08*	*5*
ACDS	*1*	*0.4*	*5*
Secondary Payload	*3*	*1.5*	*50*
Harness	*0.6*	*0.2*	*50*
Drag Sail	*0.4*	*0.25*	*5*

TOTAL MASS [kg]	
Allocated	10,00
Actual (without margin)	6,46
Actual (with SS margin)	7,92
Actual (with 20% Sys margin)	9,38

Risks

Statistics on CubeSat missions from 2000 to present





Most recurrent failures: **Power and TT&C**

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Typical Space Project Lifecycle and Development Steps

FULL PROJECT LIFECYCLE

- Definition of requirements
- Design and Development
- Build and Integration
- Testing and Verification

- Launch
- Operations
- Data Analysis
- Documentation
- Formal Presentation of Results

STEPS TO A (Hopefully) SUCCESSFUL MISSION

1. Agree on the objectives
2. Define requirements
3. Make a project plan
4. Design
5. Review the design
6. Manufacture
7. Verify requirements are met

8. Launch
9. Operations

S5Lab typical Project Lifecycle

Quick and strongly Iterative Process, including proof of concept prototypes

FULL PROJECT LIFECYCLE

- Definition of requirements
- Design and Development
- Build and Integration
- Testing and Verification

- Launch
- Operations
- Data Analysis
- Documentation
- Formal Presentation of Results

STEPS TO A (Hopefully) SUCCESSFUL MISSION

1. Agree on the objectives
2. Define requirements
3. Make a project plan
4. Design the mission and system
5. Review the design
6. Manufacture
7. Verify requirements are met

8. Launch
9. Operations

S5Lab Nanosat Development Phases

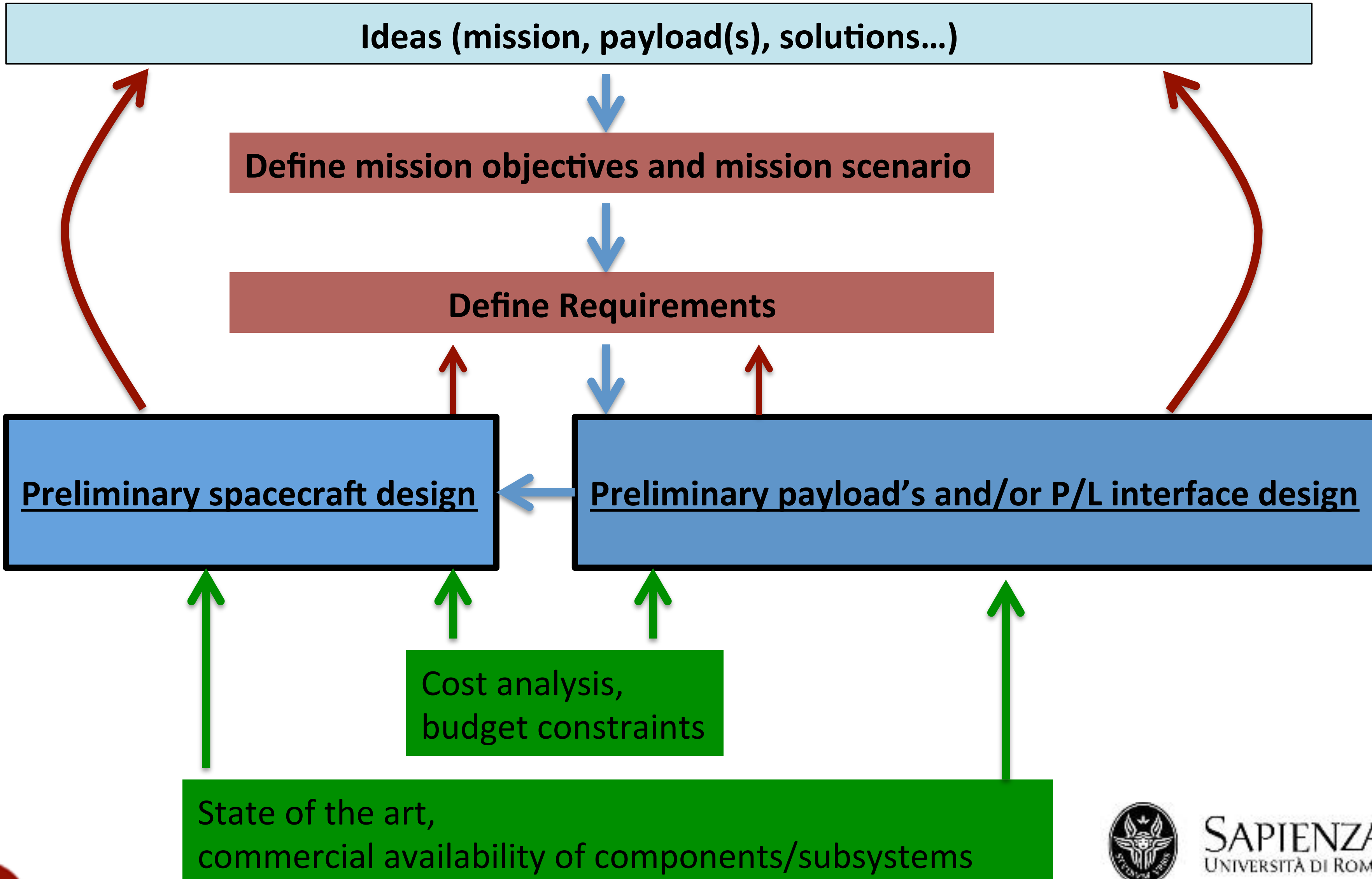
<u>Protoflight approach</u>, due to time and budget constraints

- **Preliminary Design (3 months, typical)**
  - Define: Mission, Payloads, Spacecraft architecture
  - Preliminary: design budgets, CAD drawings,…

- **1st Prototype (4 months, typical)**
  - Detailed system design
  - Build a (preliminary) prototype of the spacecraft, including: structure, electronics, mechanical interfaces to payloads, mechanisms (if any)…
  - Verify electronics, components, low level software routines, interfaces…..
  - Verify harness layout, satellite assembly and integration procedures
  - Testing (Vibration, Thermal)

- **Protoflight (5 months, typical)**
  - Fix errors, select final components, update assembly procedures
  - Develop (high level) software
  - Verify and eventually fix "local" errors
  - Verify assembly and integration procedures
  - Testing (Vibration, Thermal, Thermal Vacuum)

Nanosat Preliminary Design Process



Nanosat Preliminary Design Process

- Mission and payload ideas (Phd, Msc Thesis, Professors)
  - Internal Lab Payloads (e.g. Technical demostration, in orbit testing)
  - External Payloads (e.g. funding agency requirements, scientific cooperation)
- Payload Objective Definition and Design (interface design for external payloads)
- Spacecraft subsystems and system design

HINT:

- Select at least one simple payload to meet minimal success criteria (e.g. contact and telemetry download) and devote the necessary budget to that, <u>using flight-proven hardware</u>.

OUTPUT:

- Mission Scenario
- Electronics Block Diagrams
- Preliminary selection and info on time to delivery of electronic parts/components
  CAD Drawings of the preliminary spacecraft and/or payload
- Cost analysis
- Timeline Planning of the activities

- **DURATION: 1-3 months**

Detailed Design and 1st Prototype

- Detailed system design
- Build a (preliminary) prototype of the spacecraft, including: structure, electronics, mechanical interfaces to payloads, mechanisms (if any)…
- Verify electronics, components, low level software routines, interfaces…..
- Verify assembly and integration procedures
- Testing (Vibration, Thermal)
- Eventually review design based on procurement issues (e.g .discontinued products…..)

OUTPUT:

- **Detailed final design for the <u>Protoflight</u> model**
- **Possibly Working parts and subsystems for the Protoflight model**
- **Conscious and realistic Timeline Planning of activities till launch**
- **<u>Procurement of all parts needed for protoflight</u>**

- **DURATION: 3-5 months**

Proto-flight Model

- Build the spacecraft, including: structure, electronics, mechanical interfaces to payloads, mechanisms (if any)…
- Develop complete flight software
- Develop complete ground software
- Extensive Testing (On-board software along with ground station software, Extensive Functional testing, Environmental Testing, including, Vibration, Thermal, Thermal-vacuum)
- Complete functional testing after environmental testing

OUTPUT:

➢ **Satellite ready for launch**

➢ **DURATION: 4-8 months**

Team Organization

Professors

Daily interaction,
Quick feedback, Fast Decision Making

Phd Students (3 students for URSA MAIOR and IKUNS)
<u>Design responsibility</u>

MSc Thesis (about 10 per year)
Detailed designs, testing procedures, tests,

MSc Course in Spacecraft Design (about 25 students per year)
Design activity, state of the art reviews, mission analysis….)

BSc Thesis (about 15 per year)
Detailed designs, manufacturing, testing procedures, assistant in tests,

BSc Courses in Space Systems and Space Systems Lab (40 students/year)
Detailed tasks (e.g. execution of tests, part design…)

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Make or Buy?

- **If budget allows, "Buy" saves time and improves reliability**

- **However, even if budget allows, one may choose to "Make"**
  - **for education purposes**
  - **to gain experience in a particular field**
  - **to save recurrent cost in future missions**

- **"Make" is obvious when what you need is not on the market**

- "Make" involves a development process which requires design and testing iterations

- **Typical product development at S5Lab when there are items involving a "Make"** :
  - Preliminary design
  - 1st prototype (mock-up)
  - Design refinement and **Protoflight model**

Design process and review at S5Lab

1. At S5Lab the design team is small and typically no external entities are involved in critical design activities, hence we can focus mainly on the **Design process**, more than on the design review.
2. The design team is typically small (up to 10 people), which allows sharing of ideas, problems and solution on a daily basis, mostly in person, to save time
3. **The design is the result of a team work. All decisions are taken together. This minimizes the possibility of errors.**
4. **Exchange o information is fast and "informal". Every team member is updated "real-time" on decisions and design updates**
5. **Tools:**
    - **Mission analysis software (orbit, visibility, attitude, thermal)**
    - **CAD (mechanical and electronics)**
    - **subsystem prototypes**
6. **A formal review is typically not required, since the design is reviewed day by day**

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Lessons learned at S5Lab in University nanosats

1. Do not spend too much time in designing details in the early phase of the project. **Do not pretend to reach the final design based only on paper, CAD drawings, numerical simulations**. As opposite to common sense, **prototypes can save time and efforts,** by giving much more insight into the system and providing inputs for solutions that work.
2. **Design your system from the beginning bearing in mind accessibility and testing. Verify by testing**. Simulations can highlight many aspects, not all.
3. At least **two iterations (including prototypes**) are necessary to reach the final protoflight model
4. Check availability of parts and **procure early**
5. Define a minimum simple task and use fligh-proven hardware for that, so that you can claim a mission success. Complete failure is frustrating.
6. **Keep complexity low.** As a student, don't pretend to develop complex missions in a university curriculum time.
7. Limit formal documentation only to external entities involved (e.g. launch provider). Keep track of the design directly by software (CAD model, PCB layout software....)
8. **Concurrent Engineering Tools** (if available) make the design process easier and systematic. Highly instructive for students

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