REXUS-BEXUS: PROGETTI STUDENTESCHI PER PALLONI STRATOSFERICI

European Space Agency

Cosa può fare uno studente di ingegneria aerospaziale a PADOVA?

- SVILUPPARE un esperimento in tutte le sue fasi
- COLLABORARE con esperti dell'Agenzia Spaziale Europea
- PARTECIPARE ad una vera missione spaziale

Programma REXUS – BEXUS

INDICE:

- Il programma ***REXUS-BEXUS***
- 2010: L'esperimento **SCRAT**
- 2011: L'esperimento **ARCADE**
- **Proporre** un esperimento: ARCADE
- **Sviluppo** in parallelo
- Passo dopo passo: **fatiche e soddisfazioni**
- I **lanci**
- E ora? **ARCADE-R2**
- **Conclusioni**

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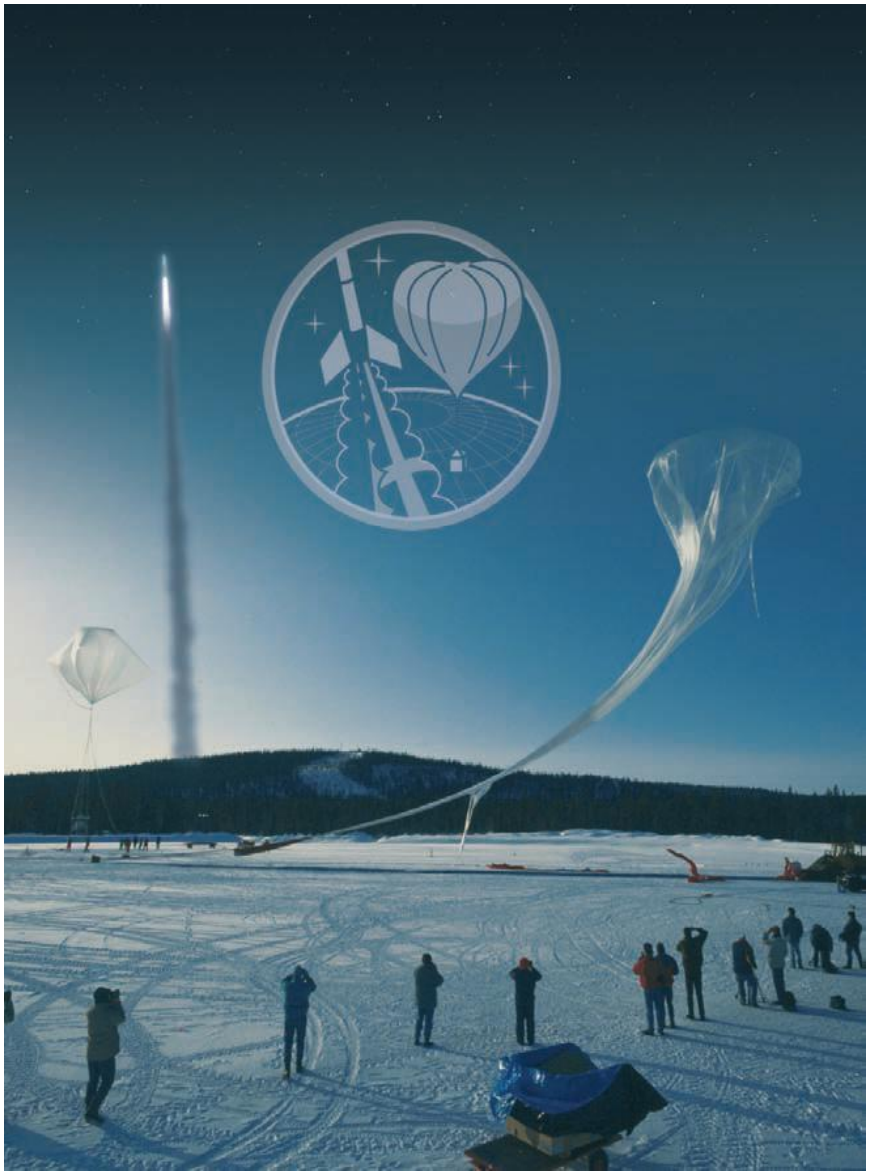


esa

→ REXUS/BEXUS

Rocket and **b**alloon **ex**periments for **u**niversity **s**tudents

ESA 'HANDS-ON' EDUCATION ACTIVITIES

Opportunità per gli studenti:

- Opportunità di lancio di CubeSat
- Voli parabolici (Fly Your Thesis)
- Centrifuga per ipergravità (Spin Your Thesis)
- Torre di caduta (Drop Your Thesis)
- Palloni stratosferici (BEXUS)
- Sounding rockets (REXUS)

Cos'è il programma *REXUS-BEXUS*?

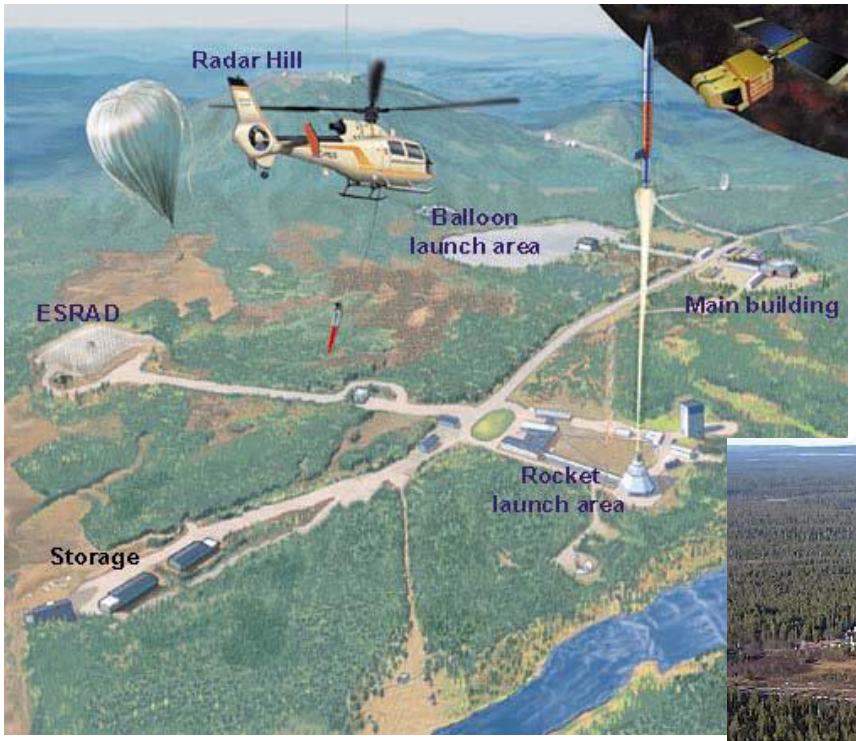
Rockets and Balloons-Borne Experiments for University Students

L'esperienza REXUS-BEXUS

- Un intero ciclo di vita di un esperimento spaziale, dalla progettazione allo sviluppo, alla costruzione, ai test ed infine al volo.
- Il supporto di esperti internazionali
- La partecipazione alla campagna di volo
- Tesi su progetti REXUS - BEXUS

Un'opportunità più unica che rara!

European Space Range ESRANGE



67° N 21° E

oltre il Circolo Polare

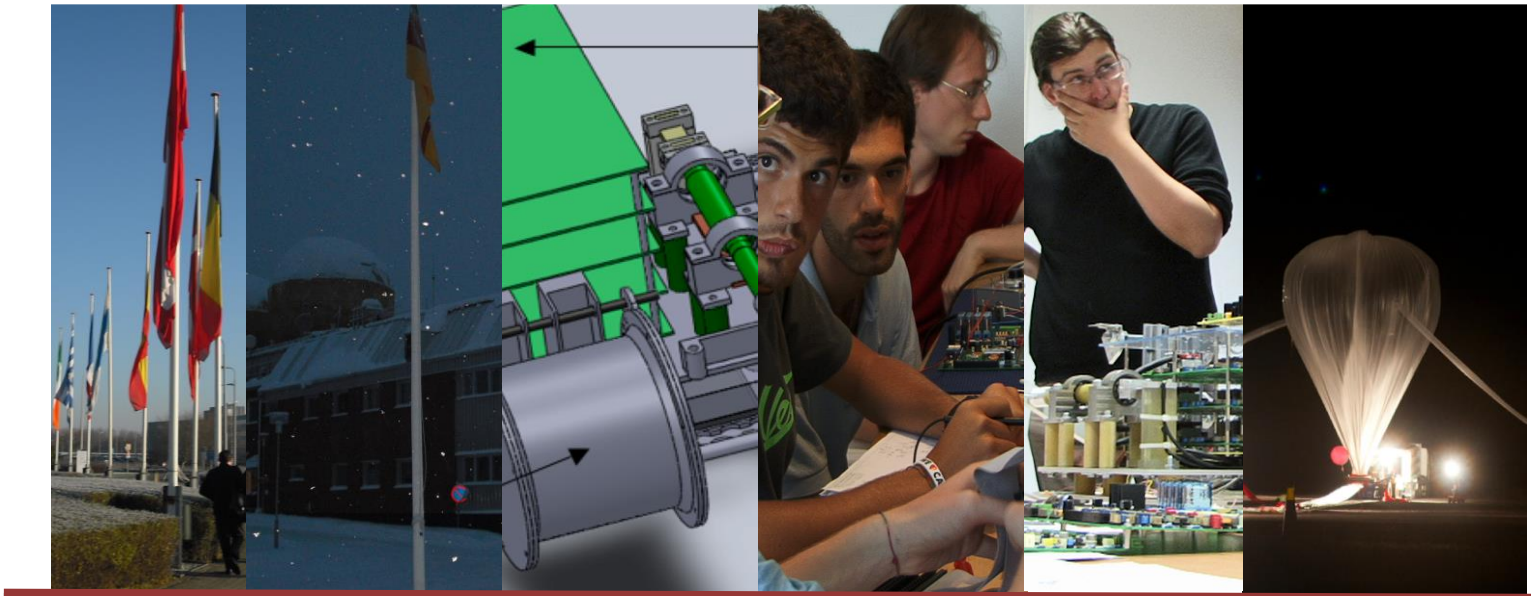
REXUS: Sounding Rocket

- fino a 100 km di altitudine
- 9 min. di volo
- 18 g di max. accelerazione
- 3 min di microgravità

BEXUS: Pallone stratosferico

- fino a 35 km di altitudine
- 2 – 5 ore di volo
- 5 g di max. accelerazione
- Temperature oltre i -70° C
- Pressioni inferiori a 20 mbar

REXUS/BEXUS SCHEDULE



- Selection Workshop — Dicembre
- Preliminary Design Review — Febbraio
- Critical Design Review — Maggio
- Interim Design Review — Luglio
- Experiment Acceptance Review — Settembre
- Flight Campaign — Ottobre

REXUS/BEXUS MILESTONES:

- Selection Workshop → *concetto*
- Preliminary Design Review (PDR) → *prima progettazione*
- Critical Design Review (CDR) → *design congelato*
- Interim Design Review (IDR) → *stato di sviluppo*
- Experiment Acceptance Review (EAR) → *esperimento pronto*
- …campagna di lancio

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S.C.R.A.T.

Spherical Compact Rechargeable Air Thruster

Università degli Studi di Padova – Italia

M. Chiaradia, L. Barilaro, R. Comisso , G. Di Donato, M. Duzzi, L. Olivieri, G. Rodeghiero, M. Cesaro , F. Spagnolo, A. Selmo

OBIETTIVI

- Sviluppare un **cold-gas-actuator** (spinte 10-100 mN)

✓ Controllo d'assetto di piccoli aeromobili

✓ Propulsione di micro veicoli aerei

- Testare l'attuatore durante un volo stratosferico

✓ Performance alle varie quote

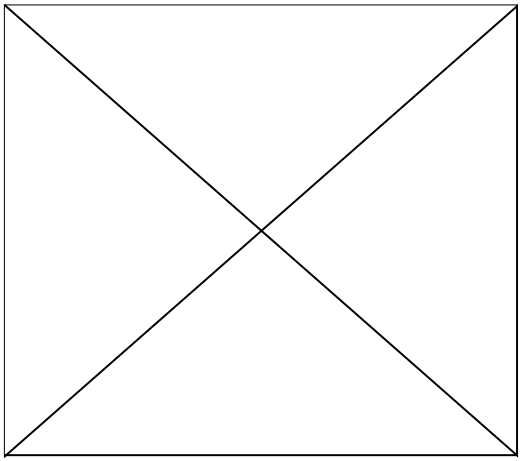
(0..35 km, pressione 3..1000 mbar, temperatura 0..-80° C)

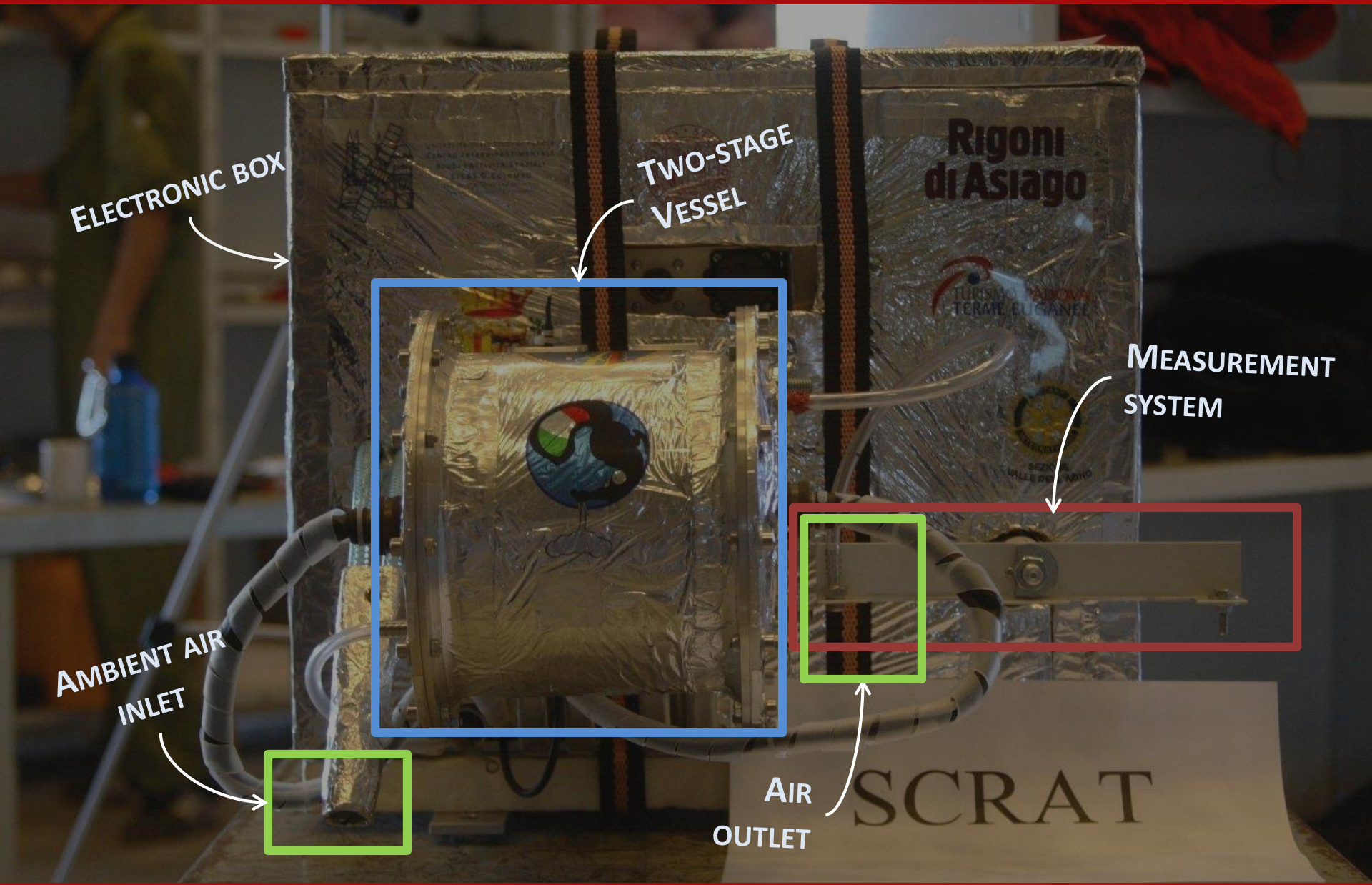
CARATTERISTICHE PRINCIPALI

- **Aria atmosferica come propellente**

➔ Ricaricabile, no combustibile a bordo,

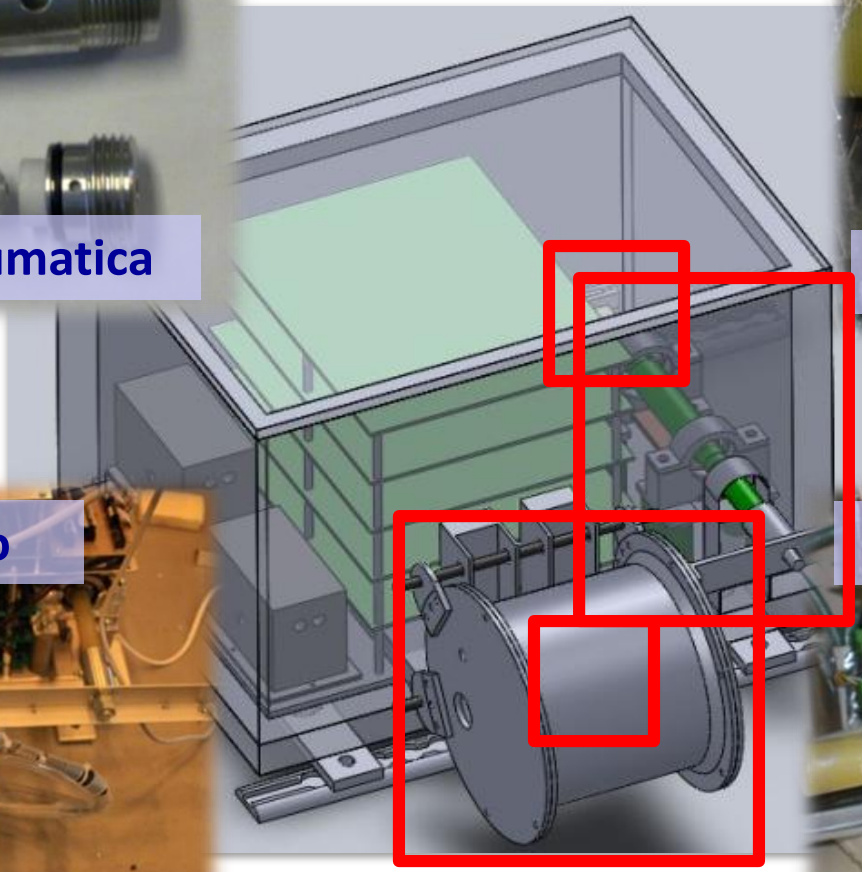
➔ environmental friendly




ELECTRONIC BOX
TWO-STAGE VESSEL
MEASUREMENT SYSTEM
AMBIENT AIR INLET
AIR OUTLET
Rigoni di Asiago
SCRAT

Valvola Pneumatica

Cella d carico

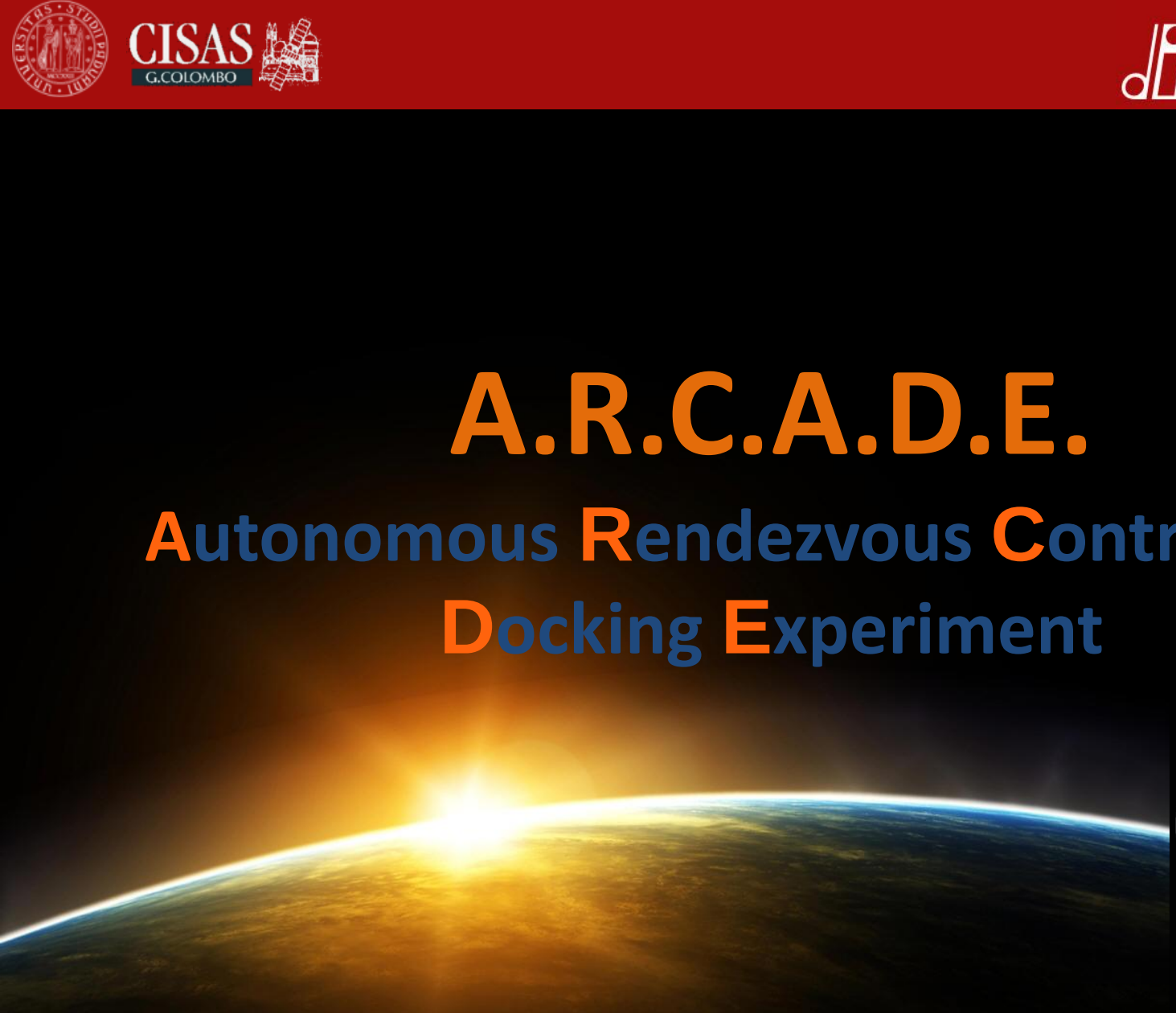


Serbatoio

Trasmissione carichi

A.R.C.A.D.E.

Autonomous Rendezvous Control And Docking Experiment



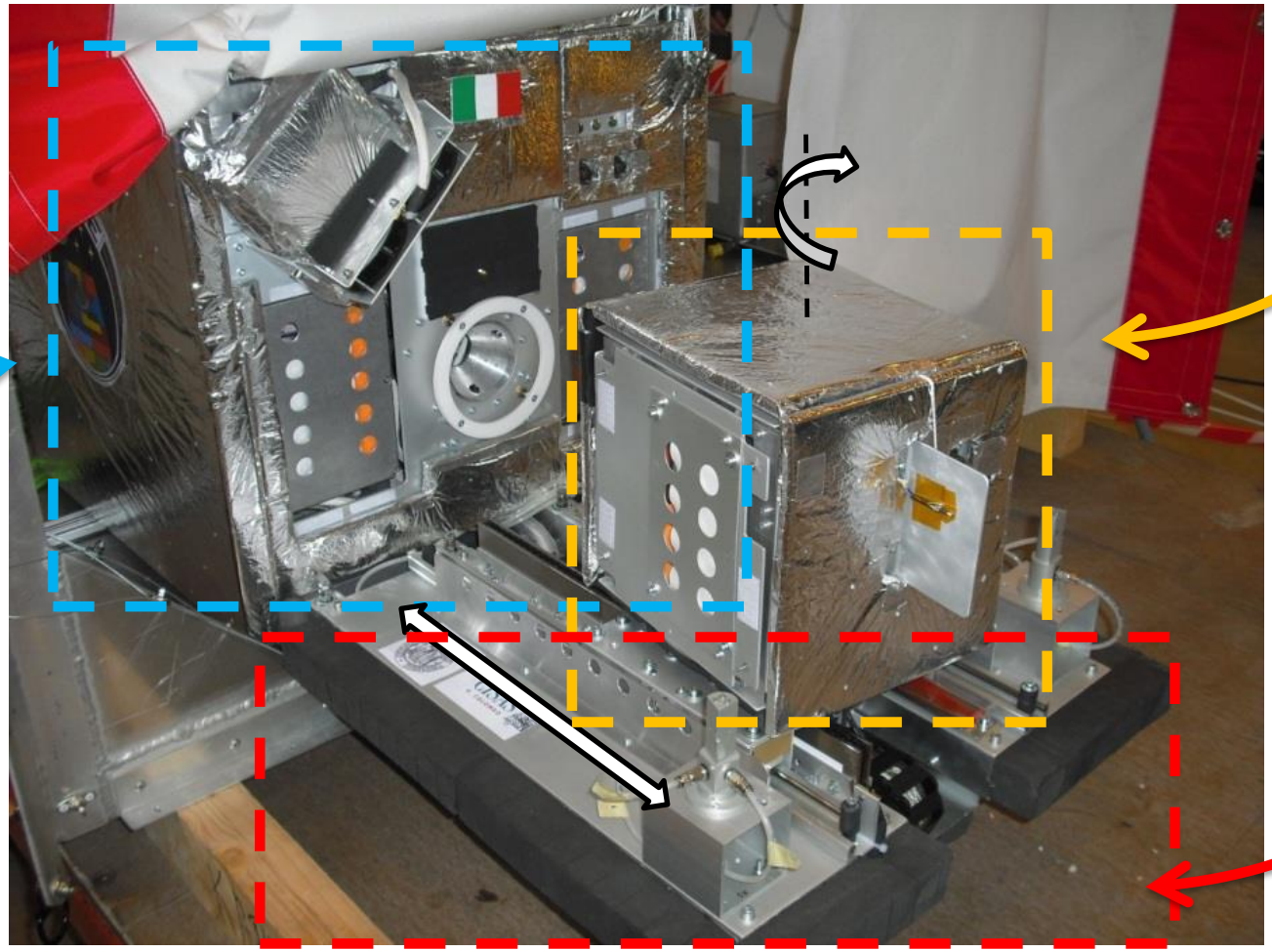
Università degli Studi di Padova – Italia

A. Boesso, M. Barbetta, F. Branz, A. Carron , G. Rodeghiero, F. Sansone , L. Savioli, F. Spinello

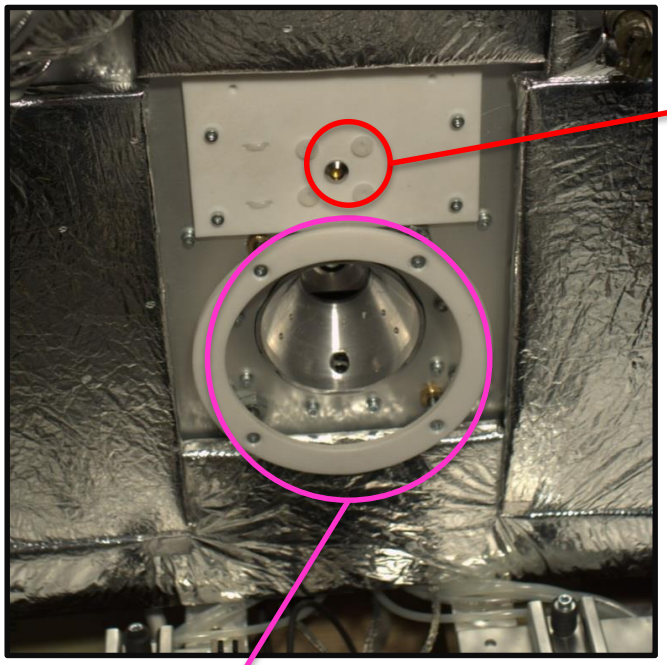
OBIETTIVI

- Sviluppare un set di tecnologie per satelliti o droni atmosferici miniaturizzati e automatici per effettuare:
  - ✓ Controllo d'assetto
  - ✓ Navigazione relativa cooperativa
  - ✓ Docking
- Valutarne le prestazioni sotto l'effetto di condizioni e disturbi atmosferici differenti

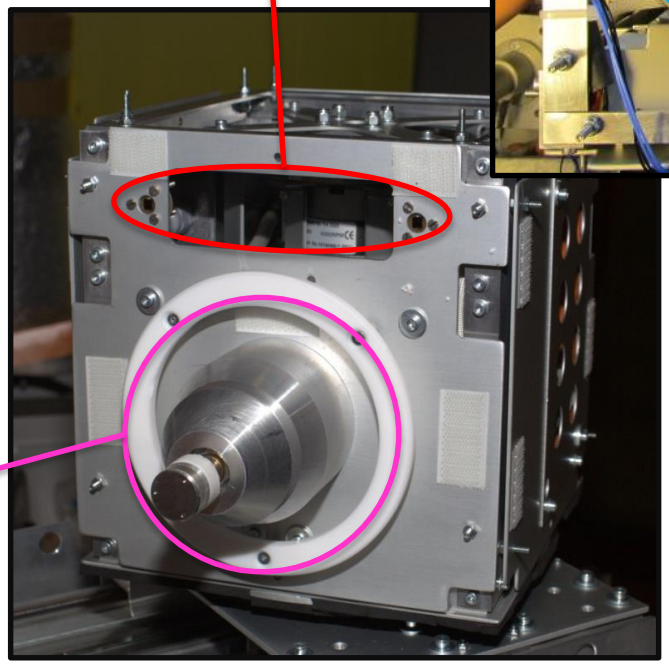
ELEMENTI PRINCIPALI

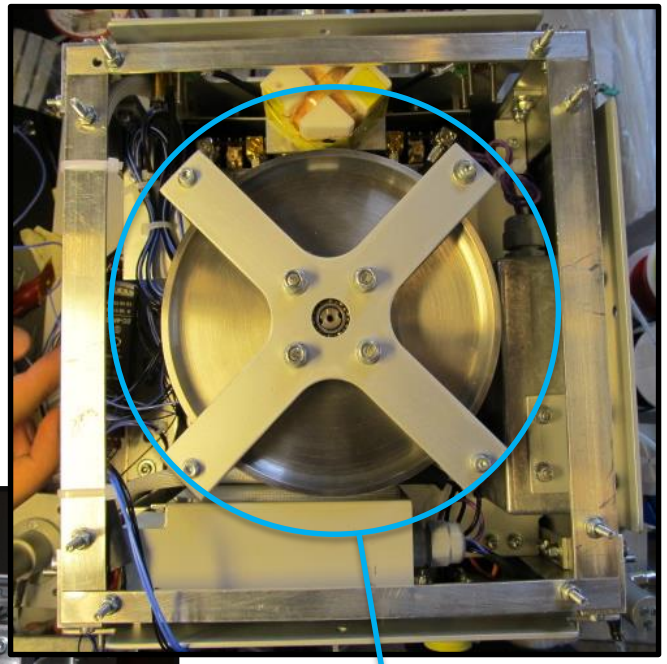


TECNOLOGIE PRINCIPALI



SISTEMA DI NAVIGAZIONE





MECCANISMO DI DOCKING

RUOTA DI REAZIONE

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ARCADE EXPERIMENT: dall'idea al lancio

• CALL FOR PROPOSAL	**Ogni anno: scadenza ~ metà ottobre**
• SELECTION WORKSHOP	Dicembre 2010
• **PRELIMINARY DESIGN REVIEW (PDR)**	Febbraio 2011
• **CRITICAL DESIGN REVIEW (CDR)**	Maggio 2011
• **INTEGRATION PROGRESS REVIEW (IPR)**	Fine luglio 2011
• **EXPERIMENT ACCEPTANCE REVIEW (EAR)**	Fine agosto 2011
• LAUNCH CAMPAIGN	Fine settembre 2011

Call for Proposal: l'idea

Perché non unire le idee per partecipare a un Rexus-Bexus?

Nasce l'idea di ARCADE

Il primo passo: la Proposal

REXUS / BEXUS
Experiment Proposal Form

esa

Full experiment title	Autonomous Rendezvous Control And Docking Experiment (ARCADE)

☐ **REXUS** ☒ **BEXUS**

☐ spinning with 4 Hz
☐ despun with Yo-Yo to about 0.08 Hz

La Proposal: il primo documento (di una lunga serie!!!!!)

- Il team
- Obiettivi scientifici/tecnici
- **Perché un razzo o un pallone?**
- Da dove è nata l'idea
- Descrizione dell'esperimento
- Organizzazione del progetto
- **Outreach**
- Informazioni tecniche

Team Leader, membri (aerospaziali, **elettronici**, automazione, fisici, chimici, biologi, …)

In che modo si raggiungono gli obiettivi: Che dati misurare? Come misurarli? Come analizzarli dopo il volo?

Supporto tecnico, accesso a lab, sponsors

Pubblicità, divulgazione

Meccanica, elettrica/elettronica, necessità particolari e **sicurezza**

Siamo stati selezionati

Dear ARCADE Team,

We are happy to inform you that your experiment proposal has been shortlisted!

We would like to invite you to present your project in more detail at the Selection Workshop between Tues 30 November and Thur 02 December 2010 at ESA's Space Research and Technology Centre (ESTEC) in Noordwijk,

E' iniziata l'avventura

01 - Selection Workshop
Dicembre 2010

ESTEC – Noordwjik
Olanda

ARCADE

Autonomous Rendezvous, Control And Docking Experiment

Team Leader

A. Boesso

Members

F. Branz

F. Sansone

L. Savioli

University of Padova - Italy

TEAM MEMBERS

- **ALESSANDRO BOESSO**

  Docking mechanism, structure, thermal control, system integration

- **LIVIA SAVIOLI**

  Definition of mission operations and data analysis

- **FRANCESCO BRANZ**

  Attitude control

- **FRANCESCO SANSONE**

  Navigation sensors

Non avevamo ancora responsabili di elettronica e automazione!!!

- ARCADE EXPERIMENT
- BACKGROUND & MOTIVATION
- PRELIMINARY DESIGN
- DATA UTILIZATION
- DEVELOPMENT PLAN
- TEAM & SUPPORT
- OUTREACH PROGRAM

- ✓ **ARCADE EXPERIMENT**
- ➢ BACKGROUND & MOTIVATION
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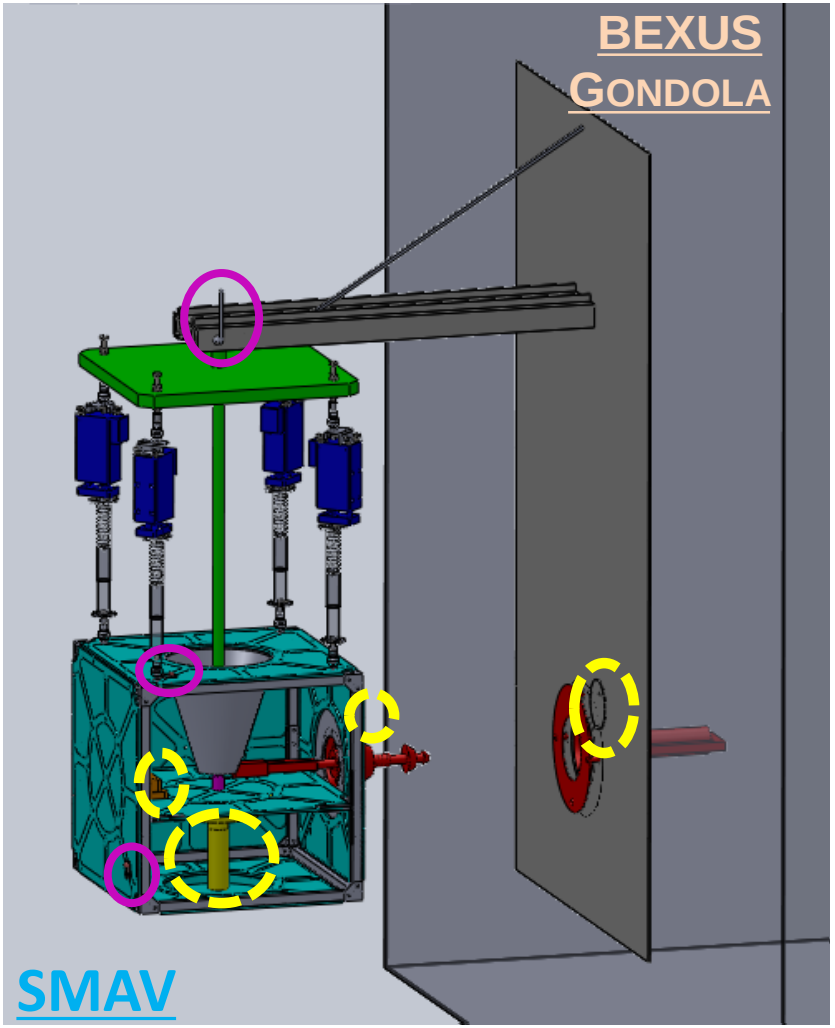
- ➢ OUTREACH PROGRAM

OBJECTIVES

- Demonstrate feasibility of a **small scale docking system**, suitable for both space and aerial vehicles such as **Microsat** and **MAVs**
- Develop alternative solutions for affordable and reliable **relative navigation sensors** and **attitude control systems** for **cooperative vehicles**
- Increase knowledge on **aerodynamic disturbances**, particularly referring to turbulences around coupled vehicles

MAIN FEATURES

- Off-gondola suspended **Small Vehicle** (SMAV)
- **Docking** Mechanism
- **Navigation sensors, attitude control** actuators
- **Pressure and Temperature** sensors



MISSION ACTIVITIES

- Continuous **data acquisition** of external **pressure** and **temperature** during the whole mission, at **different heights,** to evaluate the aerodynamic **disturbances** around **coupled vehicles**

Il perché di un lancio su pallone

- Cyclic **docking and release sequences**, to test both the docking mechanism and the navigation and attitude control system

- ARCADE EXPERIMENT
- ✓ **BACKGROUND & MOTIVATION**
- PRELIMINARY DESIGN
- DATA UTILIZATION
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- OUTREACH PROGRAM

BACKGROUND & MOTIVATION

- Considerable interest in very **small scale vehicle** for both space and atmospheric applications, such as **microsats** and **MAVs**
- Creation of **constellations** of **cooperative spacecraft** to carry out **distributed operations**
- Design of **cooperative aerial** unmanned vehicles to improve existing MAVs capabilities

Autonomous **attitude control, navigation and docking capabilities** are extremely **appealing**

- ARCADE EXPERIMENT
- BACKGROUND & MOTIVATION
- ✓ **PRELIMINARY DESIGN**
- DATA UTILIZATION
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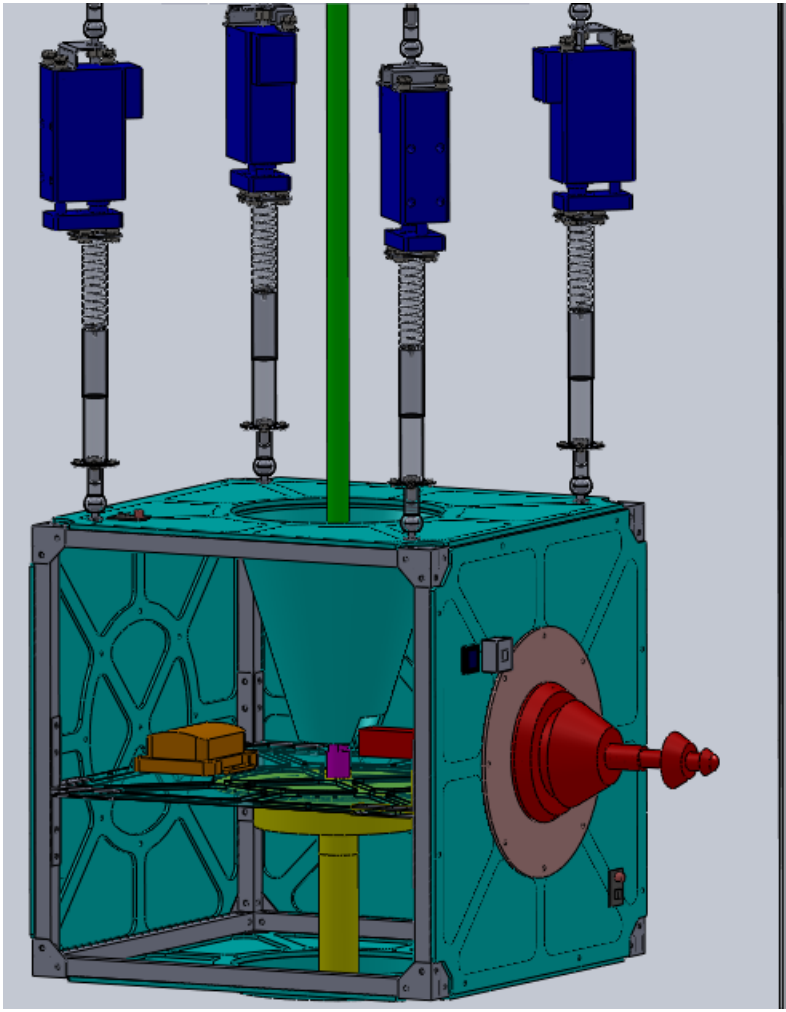
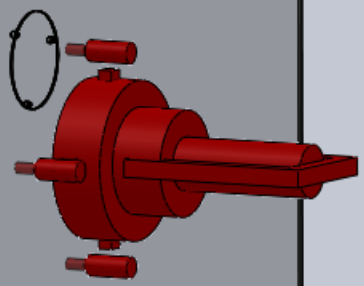
STRUCTURE OVERVIEW



Expected total mass: 10 kg

Envelope:
Lenght: 800 mm
Width: 400 mm
Height: 700 mm



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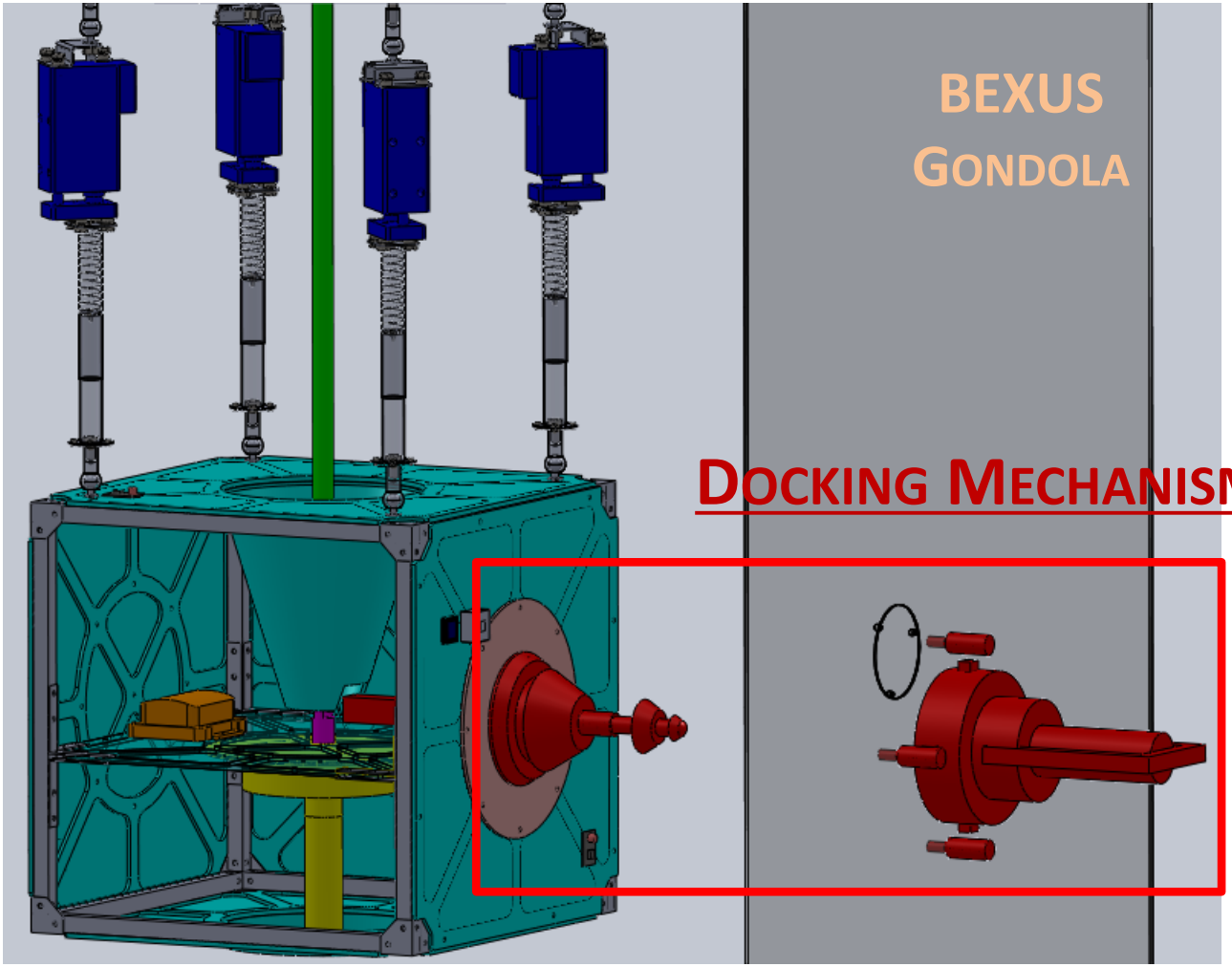

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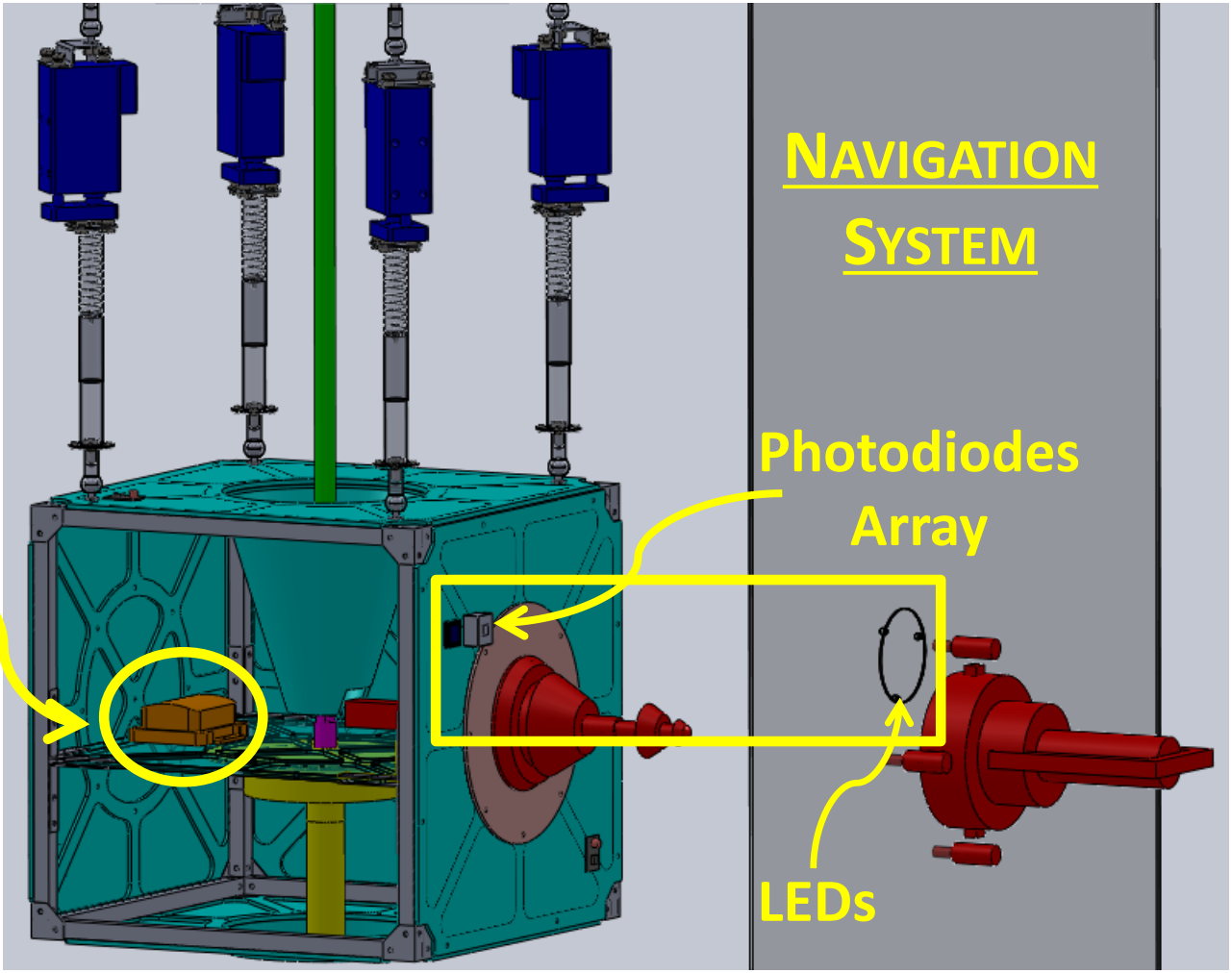

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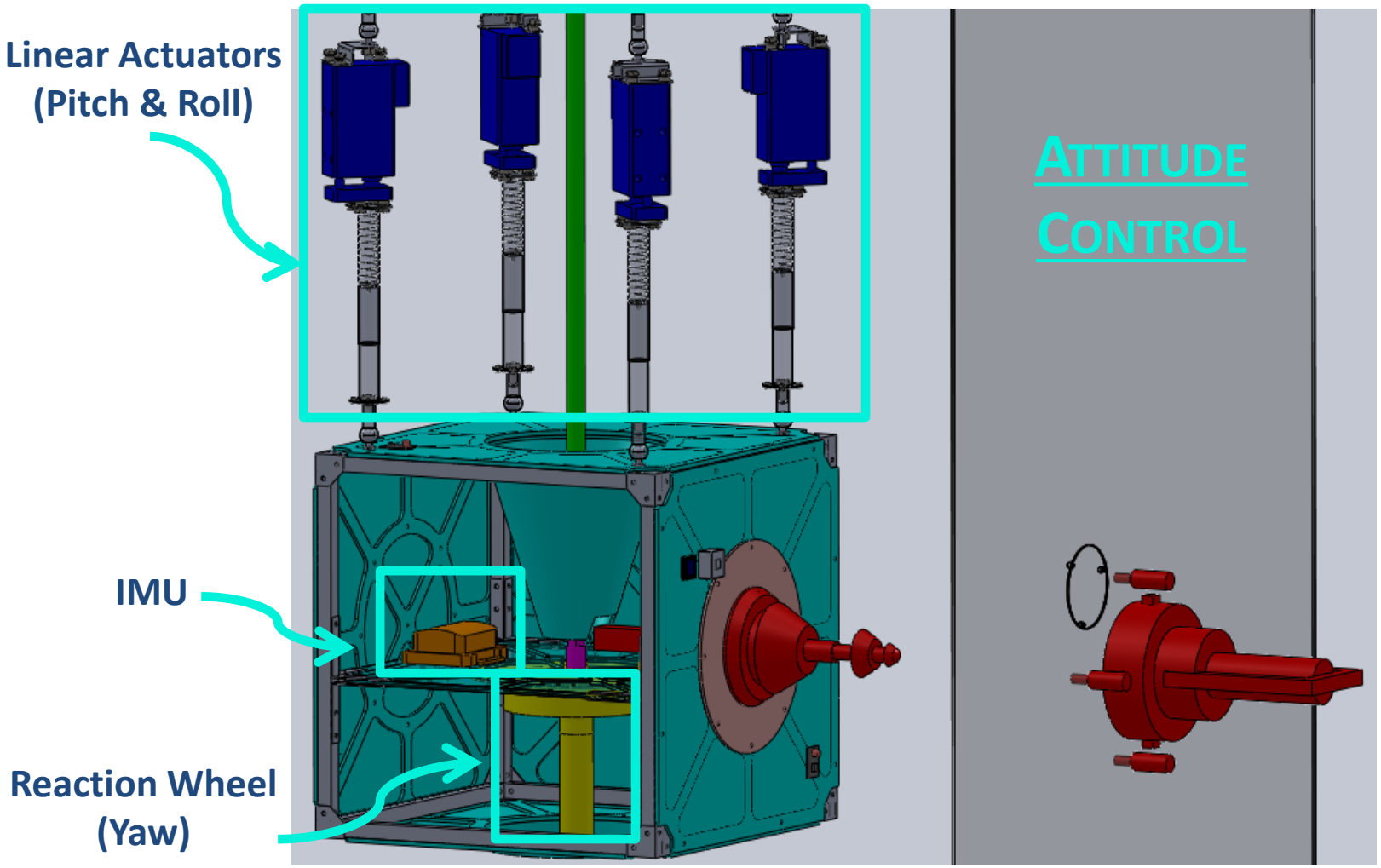
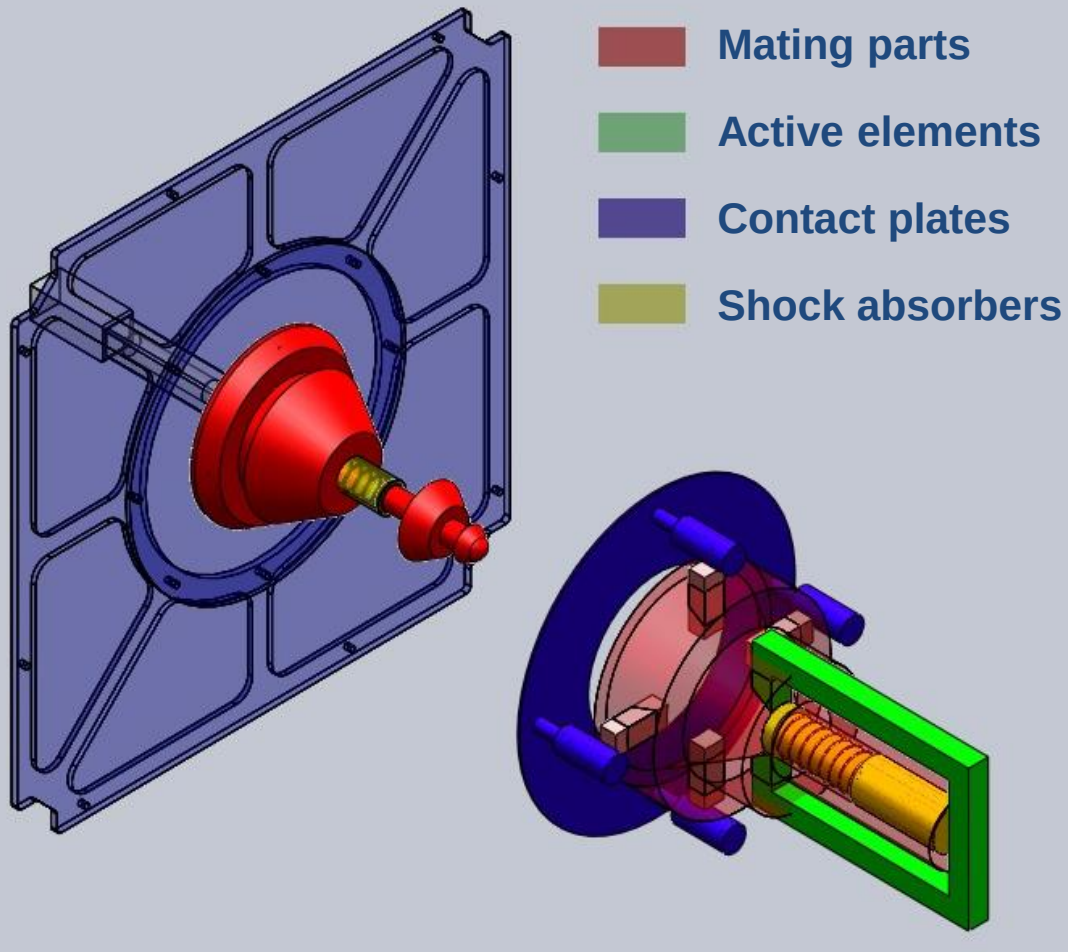


DOCKING MECHANISM (1)



OPERATIONS

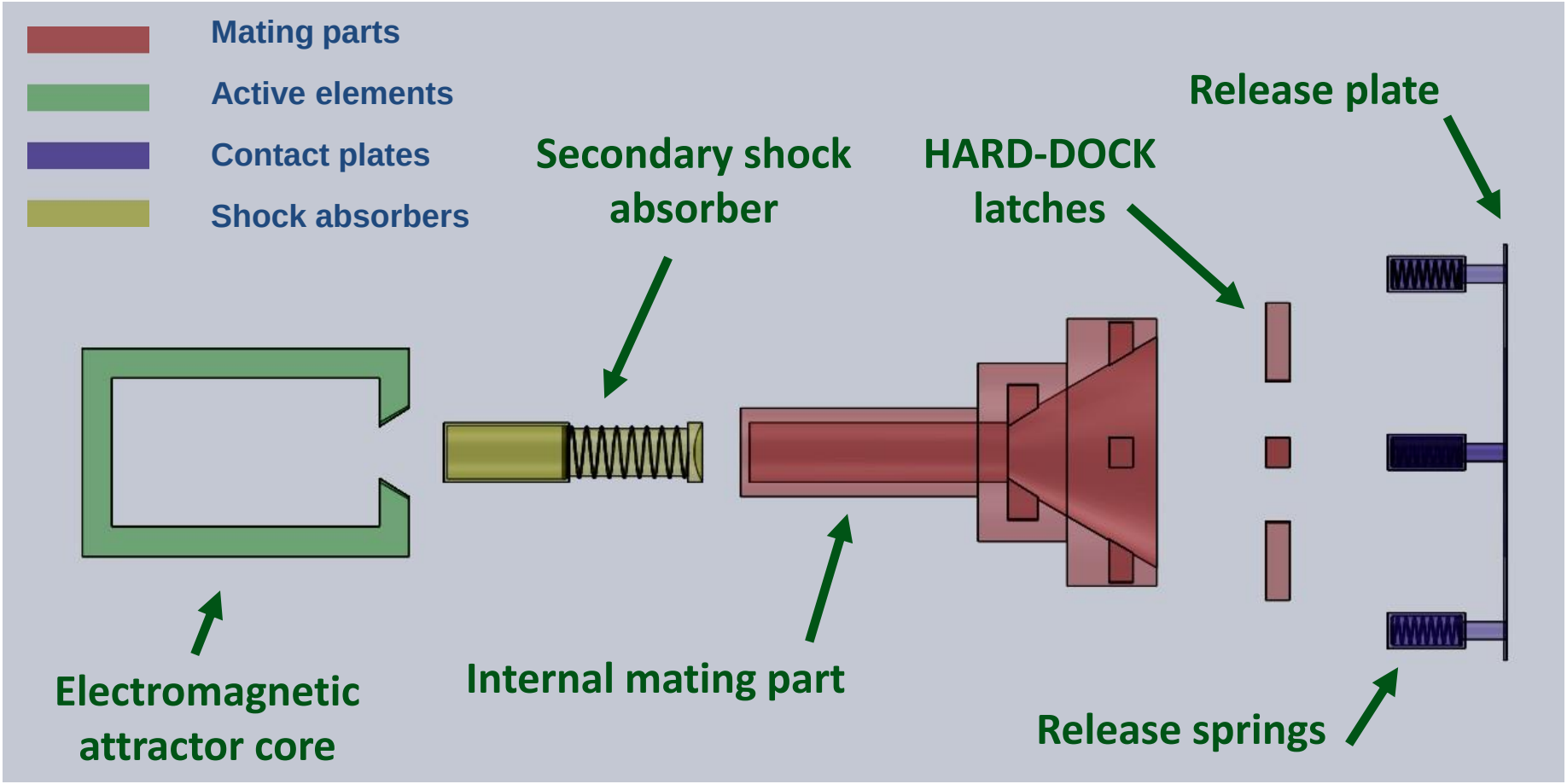
- Magnetic **SOFT DOCKING**
- Passive **HARD-DOCKING** solution
- Elastic RELEASE

MAIN FEATURES

- High misalignment tolerance (±10°, TBC)
- Double shock absorber

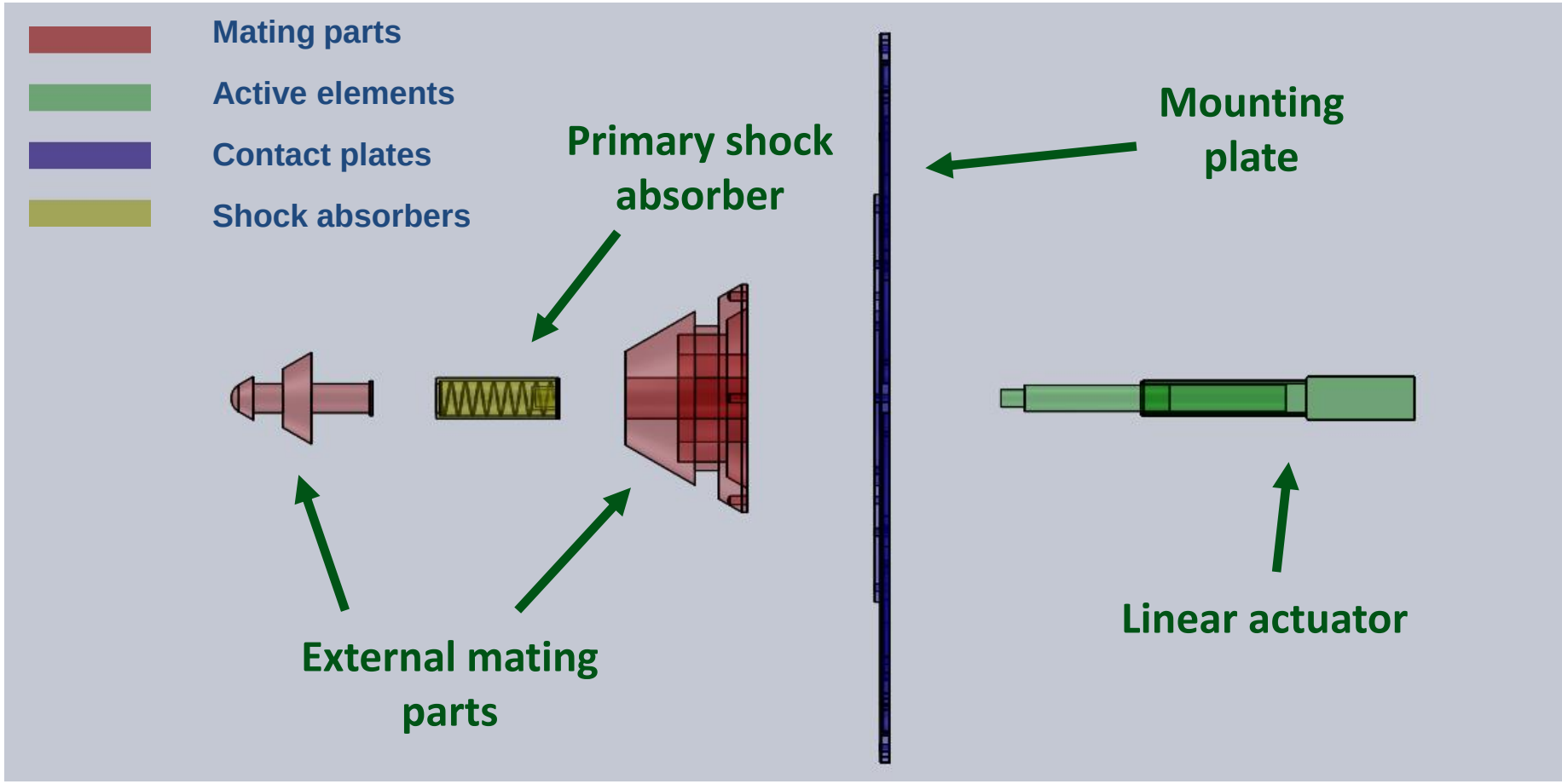
DOCKING MECHANISM (2)

GONDOLA DOCKING INTERFACE



DOCKING MECHANISM (3)

SMAV DOCKING INTERFACE



ATTITUDE CONTROL SUBSYSTEM (1)

GOAL

- **Compensate** external **disturbances** to keep the correct **alignment** required for the docking and release sequence
- Perform the initial yaw **scan manoeuvre** to determine the target position

REQUIREMENTS

- **Torques greater** than external disturbances (NOTE: **gravity torque** due to mass unbalances relative to the center of rotation, do **not allow** the use of **internal actuators** for Roll and Pitch control)
- **High-speed** response: < 1 ms

SOLUTIONS

- Roll and Pitch Axes (X,Y): greater disturbances (gravity) → **External Linear Actuators**
- Yaw Axis (Z): smaller disturbances → **Internal Reaction Wheel**

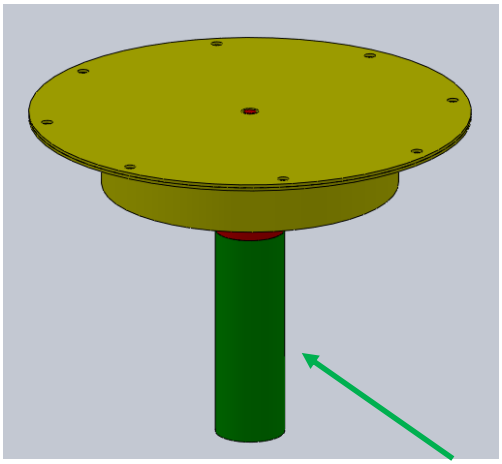
PRELIMINARY DESIGN ALREADY COMPLETED

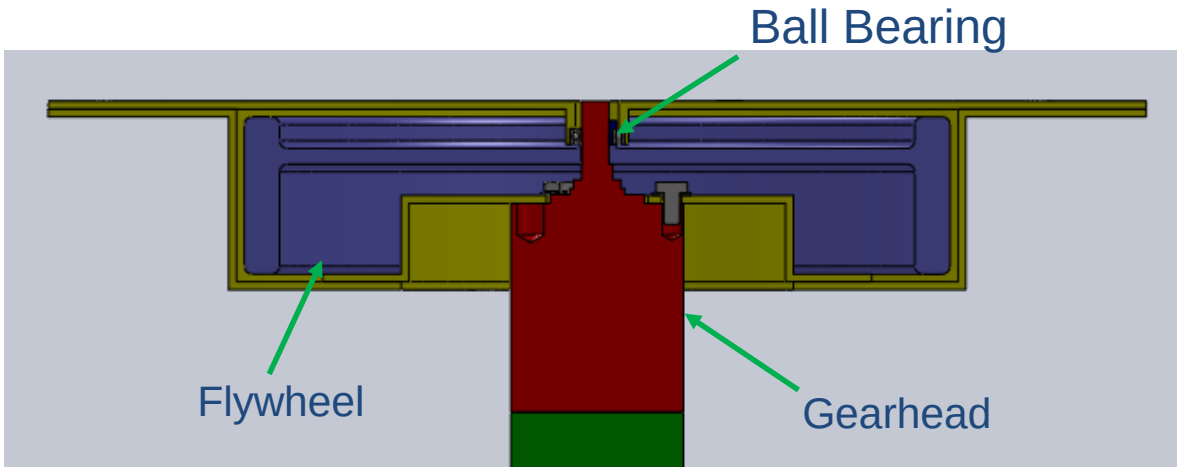
ATTITUDE CONTROL SUBSYSTEM (2)

YAW AXIS: REACTION WHEEL

- The **aerodynamic disturbance** determines the **wheel requirements**
- estimated disturbance frequency of **30 Hz**
- **Self produced**

Reaction Wheel Performances	
Max Torque	54.4×10^{-3} Nm
Max Angular Momentum	69.2×10^{-3} Nms
Speed up to	1700 rpm
Total Mass	530 g





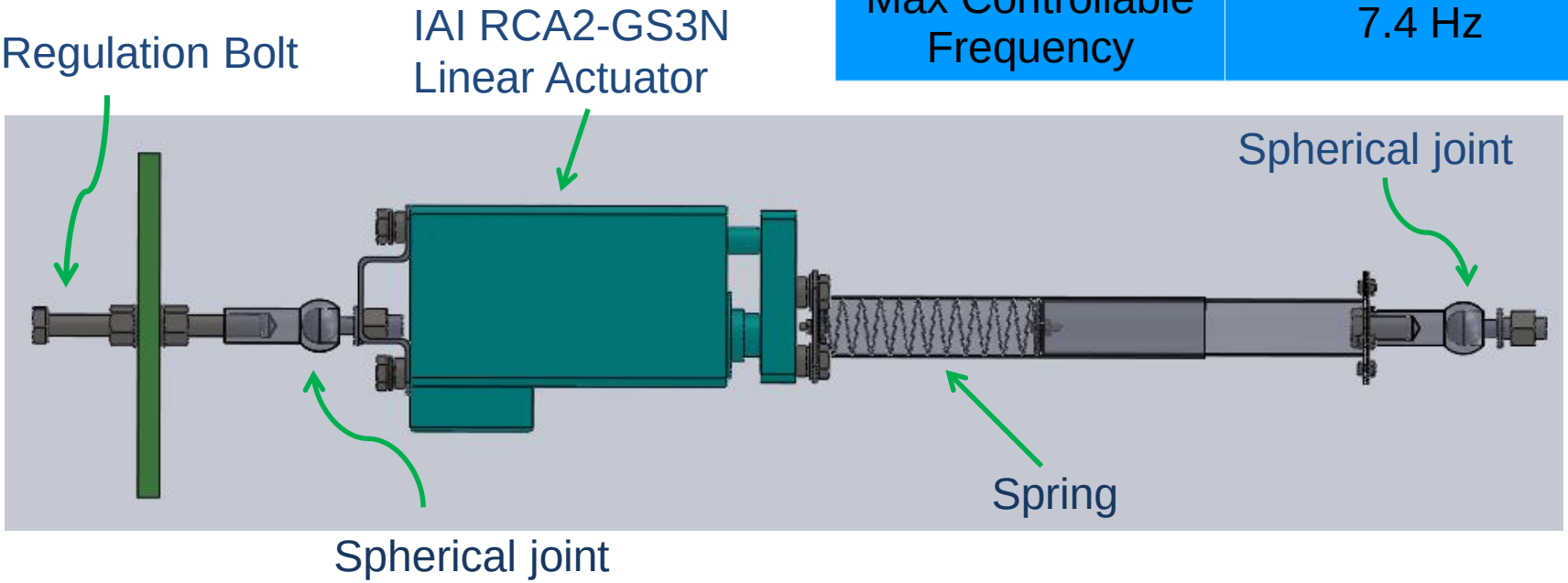
Faulhaber 2250 series brushless DC servomotor

ATTITUDE CONTROL SUBSYSTEM (3)

ROLL & PITCH AXES: LINEAR ACTUATORS

Pitch and roll axes orientation is controlled through **linear actuators coupled with springs**

Linear Actuators Performances	
Max Control Torque	0.29 Nm
Torque Resolution	$5x10^{-4}$ Nm
Max Controllable Frequency	7.4 Hz



NAVIGATION (1)

GOAL

- Determine the **SMAV attitude** and **distance** relative to the docking interface mounted on the gondola

REQUIREMENTS

- **Real time** relative attitude and distance determination
- **Accuracy**:
  - attitude: **< 0.5 deg**
  - distance: **< 1 mm**
- **Reliability**

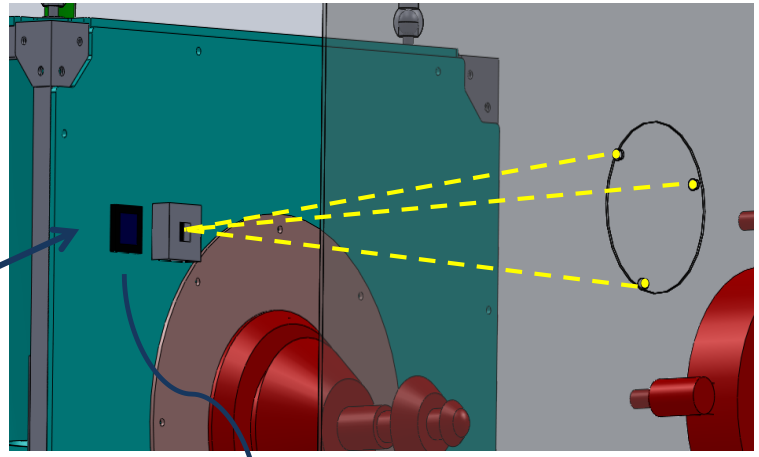
SOLUTIONS

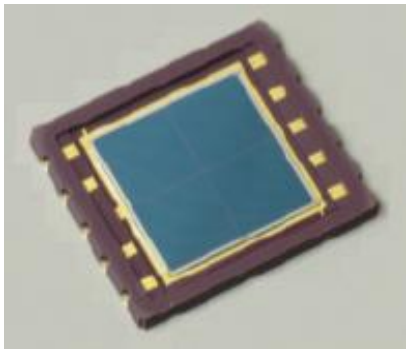
- Infrared (IR) sensors
- Electromagnetic Field (EMF) sensor

NAVIGATION (2)

IR SENSOR

- **2x2 photodiodes array** covered by a **mask** with a square slit illuminated by three simultaneously lit **IR LEDs** on the gondola
- **Differential analog output signals** from each couple of photodiodes
- A fifth, external **single photodiode** works when LEDs are lit in sequence
- Numerical simulations show a **linear output** for both SMAV pitch (θ) and yaw (Ψ) rotations in a **+/- 30° range**
- **Redundant** system

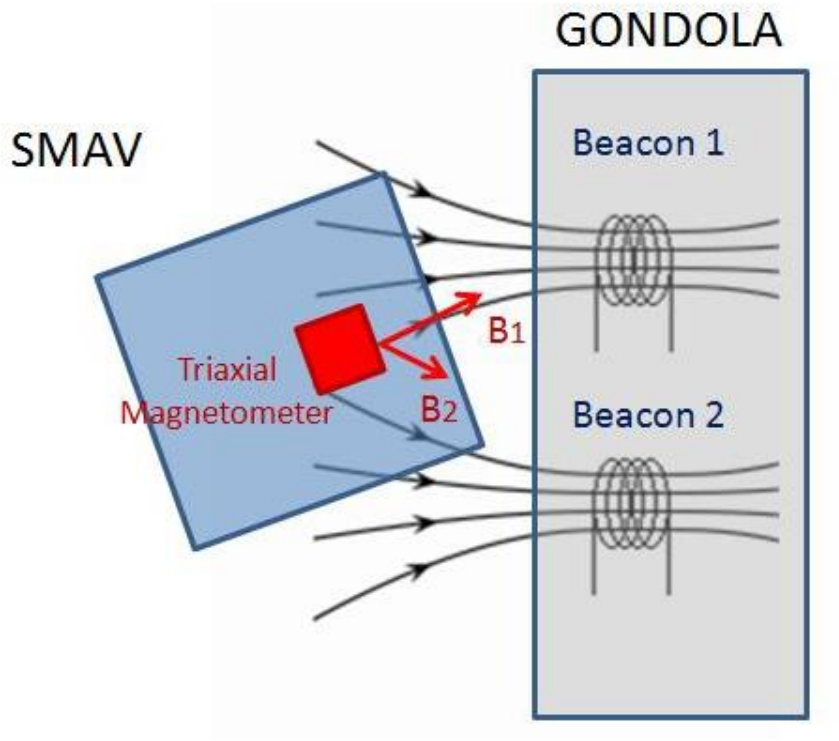




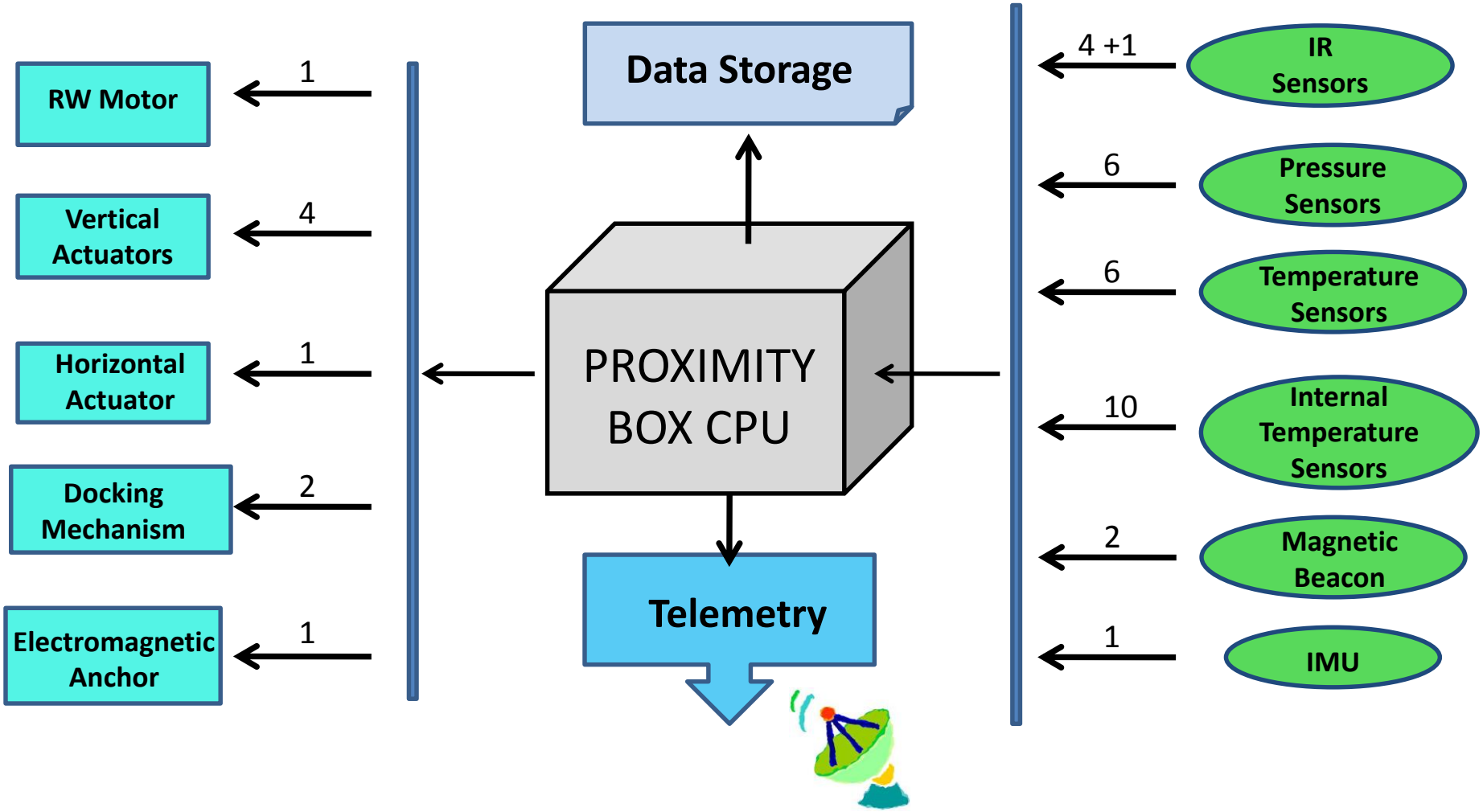
NAVIGATION (3)

EMF SENSOR

- **2 Pulsed magnetic fields** generated from the gondola with **different frequencies** (<MHz)
- **1 Triaxial magnetometer** onboard the SMAV detects the **magnetic fields B1** and **B2 modulated** by both distance and relative attitude
- **SMAV attitude** and **distance** relative to the gondola are determined from **B1** and **B2**
- **Small power** consumption (~ 1 W)



DATA HANDLING (1)

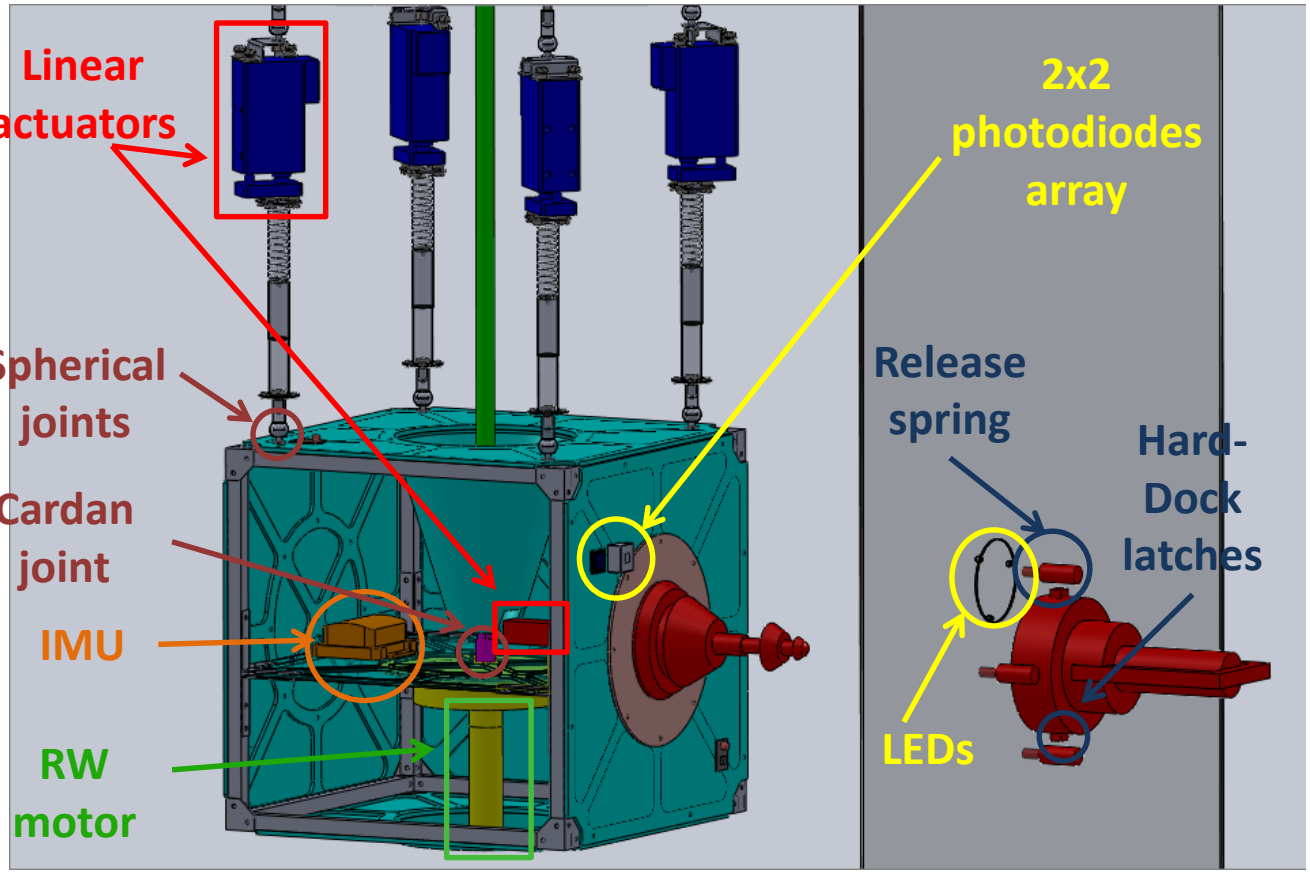


DATA HANDLING (2)

Device	Channels	Sample Rate [Hz]	Data Volume [bit]	Data Rate [kbit/s]
RW Motor	1	1000	16	16
Vertical Actuators	4	1000	16	64
IR Sensors	5	1000	16	80
Load Cells	5	1000	16	80
Magnetic Beacon	2	1000	16	32
Horizontal Actuator	1	10	16	0.16
Docking Actuator	1	10	16	0.16
Pressure Sensors	6	10	16	0.96
IMU	1	10	16	0.16
Internal Temperature Sensors	10	10	16	1.6
External Temperature Sensors	6	10	16	0.96
Docking System	2	10	1	0.02
Electromagnetic Anchor	1	10	1	0.01

Total Data Rate: 345 kbit/s **(safety factor = 1.25)**

THERMAL CONTROL



Thermal insulators and **heaters** will be used where possible;
other critical spots will be reached by **thermal fingers** made by copper wires

POWER CONSUMPTION

DEVICE	POWER [W]
Docking Electromagnet Attractor	5
Magnetic Beacon	1
Magnetic Anchor	3
Vertical Linear Actuators (4)	12 (3x4)
Horizontal Actuator	5
Reaction wheel	10.3 (peak 16.6)
Electronics	4
Docking Linear Actuator	0.5
Heaters	8

Average power

~28 W

Power peak

~41 W (all systems active, but the magnetic anchor and the docking attractor)

- ARCADE EXPERIMENT
- BACKGROUND & MOTIVATION
- PRELIMINARY DESIGN
- ✓ **DATA UTILIZATION**
- DEVELOPMENT PLAN
- TEAM & SUPPORT
- OUTREACH PROGRAM

DATA UTILIZATION

Evaluation of :

- **docking** mechanism and procedure **effectiveness**
- **docking loads**
- **navigation** sensors performance
- **attitude control** system efficiency
- **atmospheric loads** intensity (amplitude & frequency)

- ARCADE EXPERIMENT
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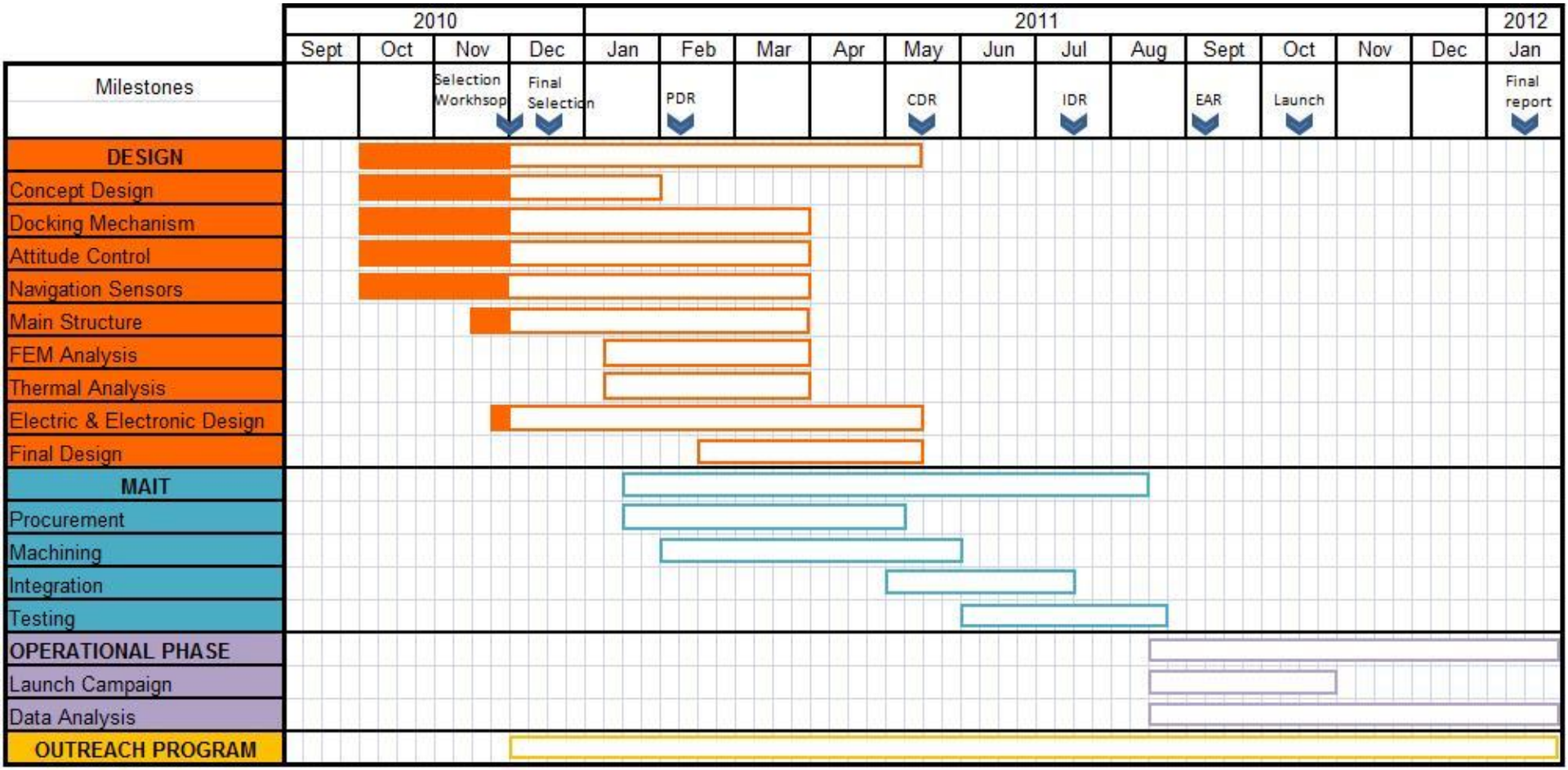
GANTT CHART


2010
2011
2012
Sept
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sept
Oct
Nov
Dec
Jan
Milestones
Selection Workhsop
Final Selection
PDR
CDR
IDR
EAR
Launch
Final report
DESIGN
Concept Design
Docking Mechanism
Attitude Control
Navigation Sensors
Main Structure
FEM Analysis
Thermal Analysis
Electric & Electronic Design
Final Design
MAIT
Procurement
Machining
Integration
Testing
OPERATIONAL PHASE
Launch Campaign
Data Analysis
OUTREACH PROGRAM

COTS

- **IMU**

  (www.microstrain.com, www.xsens.com , www.VectorNav.com)
- **Pitot tubes**

  (www.trimtecsistemi.it)
- **Temperature Sensors**

  (www.farnell.com)
- **Reaction Wheel Motor**

  (www.micromo.com)
- **ADCS Linear Actuators**

  (www.intelligentactuator.com)
- **Photodiode Array and Single Photodiode**

  (www.hamamatsu.com)
- **Triaxial Magnetometer**

  (www.digikey.com)
- **Docking Mechanism Linear Actuator**

  (www.firgelli.com)
- **Load cells**
- **Heaters**
- **Electromagnets**

FROM SCRAT EXPERIMENT

- **PC104**
- **Electric boards for signal conditioning**
- **Electric boards for power management**

NEW PRODUCTS		BACKUP SOLUTIONS
• Reaction wheel	→	✓ Reaction wheel (Sinclair Interplanetary RW - 0.060-28)

• Navigation sensors
  • IR sensor
  • EMF sensor
	→	✓ IMU

• Docking mechanism	→	✓ Magnetic anchor

LOW RISK APPROACH: failure of a component will not affect the other subsystems goal

- ARCADE EXPERIMENT
- BACKGROUND & MOTIVATION
- PRELIMINARY DESIGN
- DATA UTILIZATION
- DEVELOPMENT PLAN
- ✓ **TEAM & SUPPORT**
- OUTREACH PROGRAM

SUPPORT & FACILITIES

Supported by

- Dr. Alessandro Francesconi: Assistant professor of Space Systems, Master Course in Aerospace Engineering
- Prof. Enrico Lorenzini: Full professor of Space Instrumentation, Coordinator of study program in Aerospace Engineering
- Prof. Stefano Debei: Associate professor of Mechanical Measurements, CISAS deputy director
- Prof. Cesare Barbieri: Full professor of Astronomy, Director of the PhD School in Science, Technology and Measurements for Space
- Dr. Antonio Selmo: Electronics Engineering Consultant

Access to

- University workshop for machining and integration
- "CISAS Hypervelocity Impact Facility Laboratory" for full system integration

Further support

- External workshops for critical components

FINANCIAL PLAN

Direct costs

Mechanical parts	Semi-finished (bearings, materials, bolts and scews, etc…)	1.200 €
	Machining (RW, Docking Mechanism, Structure)	5.000 €
Electronic components	Navigation (Photodiodes, LEDs, EMF Sensor, etc...)	4.500 €
	Attitude Control (Linear Actuators, IMU, RW Motor, etc…)	8.000 €
	Docking (Linear Actuator, Electromagnet)	300 €
	Sensors (Temperature, Pressure)	1.410 €
	System (Acquisition Boards, Conditioning Boards, EM Anchor, etc…)	2.200 €
		22.600 €
Travels	Each member not sponsored by the ESA Education Office (whole Project)	2.500 €

* University full support is also provided regarding personnel involved and facilities utilization

Funded by

Center of Studies and Activities for Space CISAS “G. Colombo”
Study Program of Aerospace Engineering
Local SME (Small & Medium Enterprises) involved both in realization and assembling phases

- ARCADE EXPERIMENT
- BACKGROUND & MOTIVATION
- PRELIMINARY DESIGN
- DATA UTILIZATION
- DEVELOPMENT PLAN
- TEAM & SUPPORT
- ✓ **OUTREACH PROGRAM**

OUTREACH PROGRAM

- Websites

  Project website, linked on:

  - University of Padova official website
  - "G. Colombo" Center of Studies and Activities for Space (CISAS) website
  - Padova Aerospace Engineering Student Community official website

- University presentations

  At defined milestones, in:

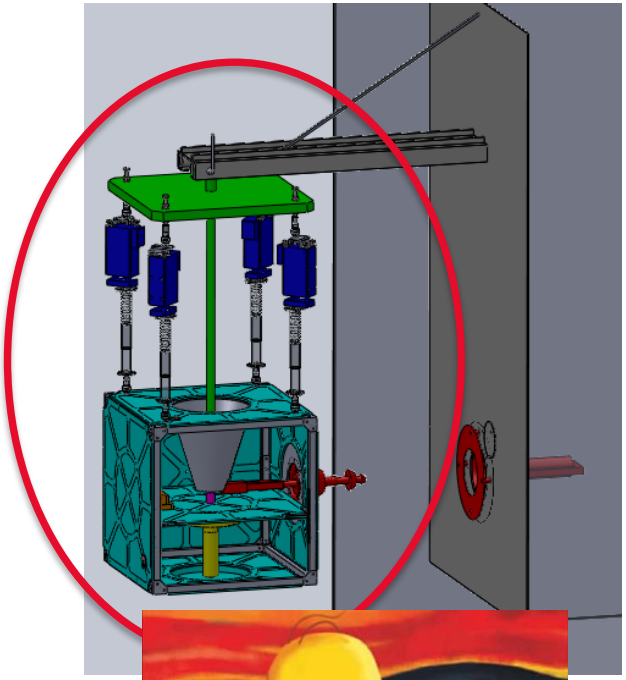
  - the Aerospace Engineering Study Program
  - the PhD School in Science, Technology and Measurements for Space

- Public presentations
- Articles on local newspapers
- Social Networks

Part of the former **SCRAT** team **Outreach Program** for **BEXUS 10-11**: presentation at Valle dell'Agno **Rotary Club** and **Official website**

Selection Workshop: come è andata?

Qualche aspetto dell'esperimento ha preoccupato il panel



Sicurezza: oggetti sporgenti e sospesi, senza appoggio

Obiettivi: 4 gdl

Complessità: tanti sottosistemi da realizzare e implementare nel software

Ridurre la complessità dell'esperimento (2 gdl)

Progettare in modo da assicurare che **nessun oggetto cada** durante il volo (cavi di sicurezza e struttura resistente)

02 – Preliminary Design Review
Febbraio 2011

DLR – Oberpfaffenhofen
Germany

La prima versione del SED

UNIVERSITY OF PADOVA - ITALY

CISAS "G. COLOMBO"

ARCADE

Autonomous Rendezvous, Control And Docking Experiment

PRELIMINARY DESIGN REVIEW (PDR)

Team Leader

A. Boesso

Subsystems Responsibles

M. Barbetta

F. Branz

F. Sansone

Members

A. Carron

L. Savioli

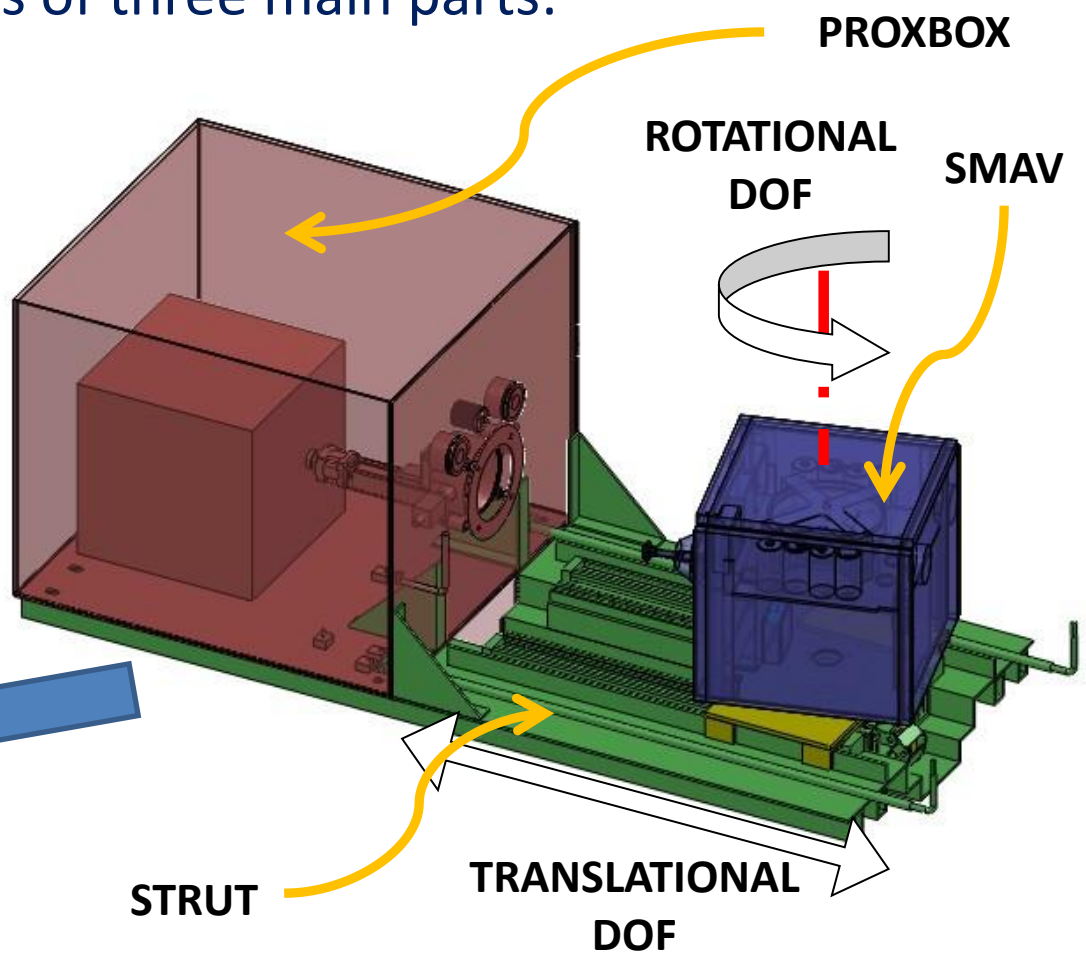
F. Spinello

Nuovi membri

EXPERIMENT OVERVIEW

ARCADE experiment consists of three main parts:

1. An external *SMAll Vehicle*, **SMAV**
2. An on-gondola *PROXimity BOX*, **PROXBOX**
3. An intermediate *STRUcTure*, **STRUT**

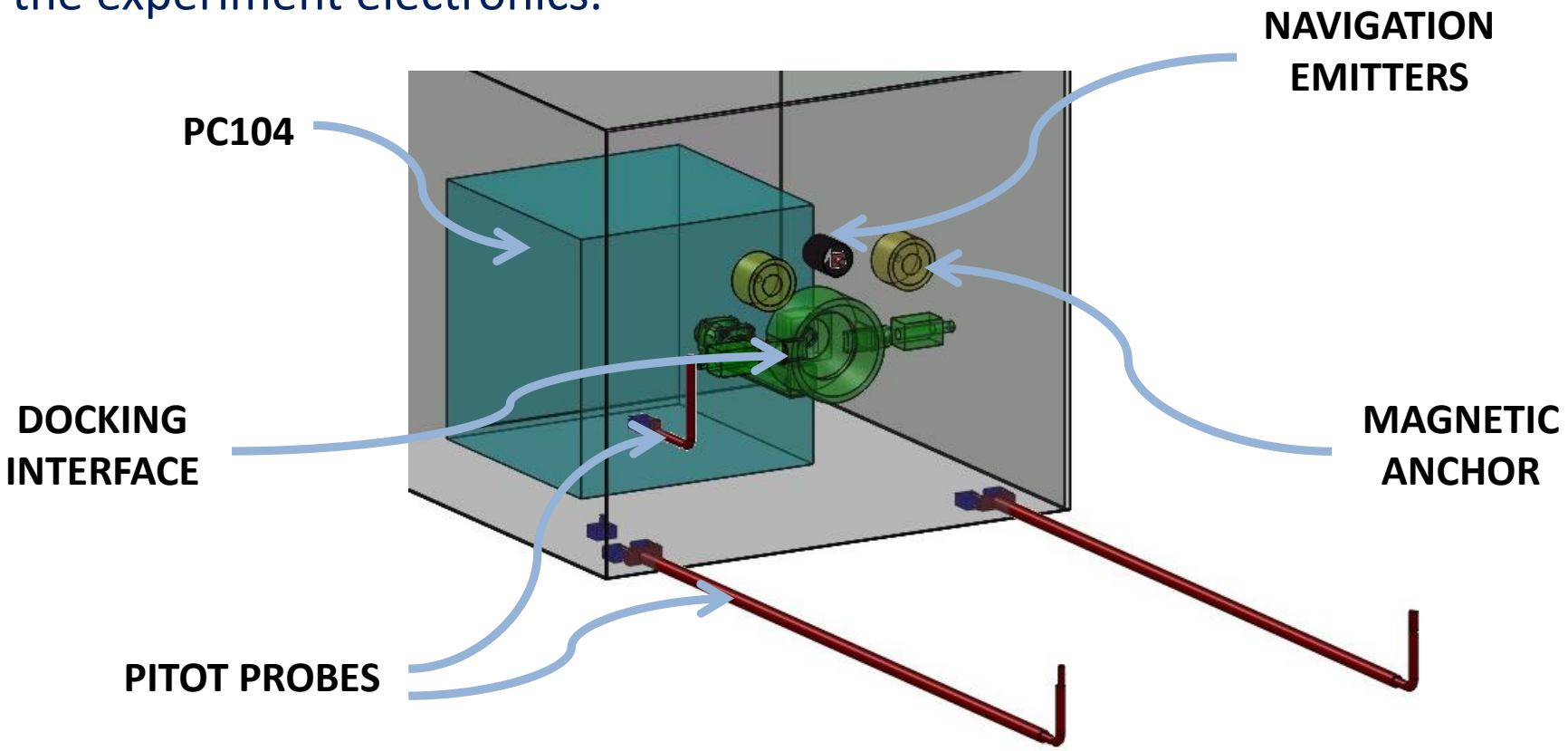


Preliminary total mass:
25 kg

Preliminary dimensions:
Width: **400 mm**
Height: **400 mm**
Length: **900 mm**

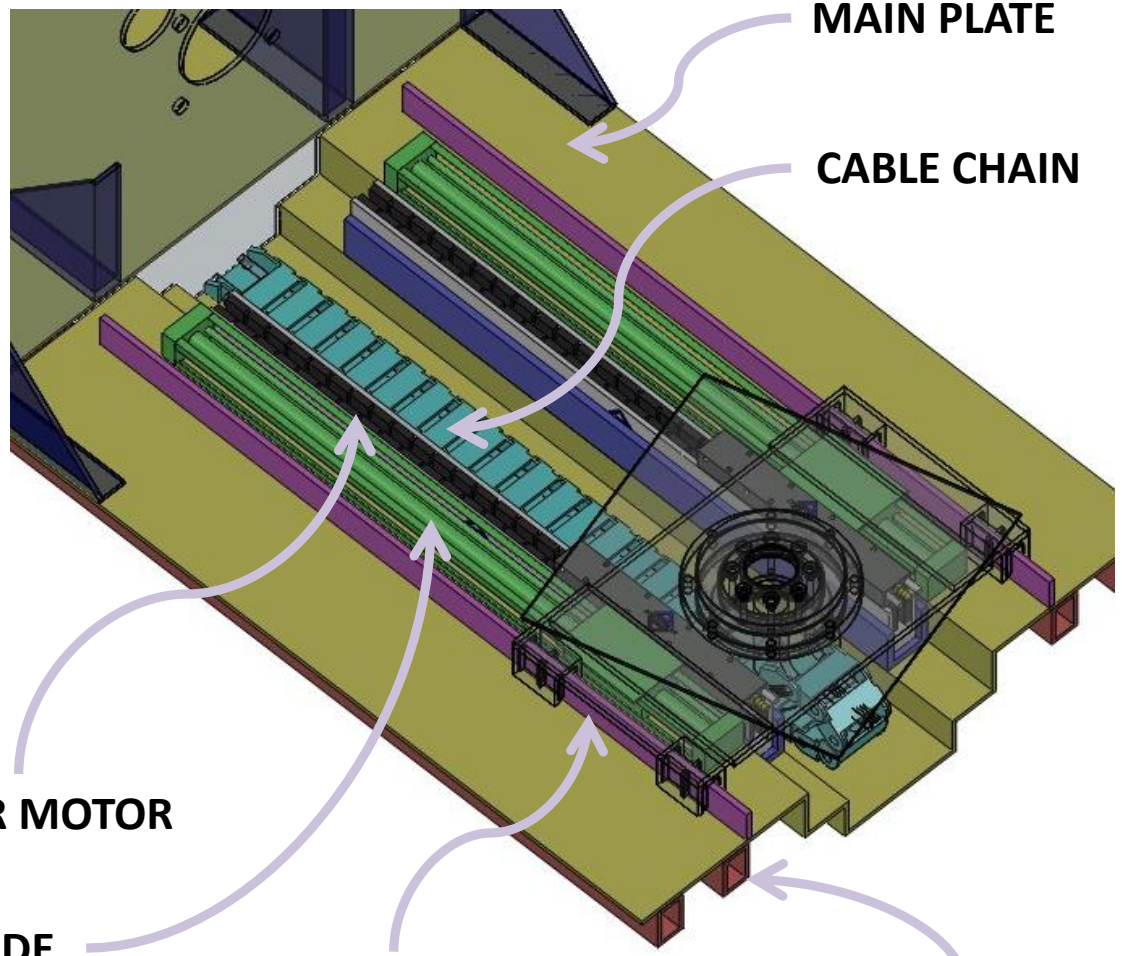
PROXBOX

The **PROXBOX** is a fixed assembly inside the gondola, which contains the parent-vehicle docking interface, the environmental sensors and most of the experiment electronics.



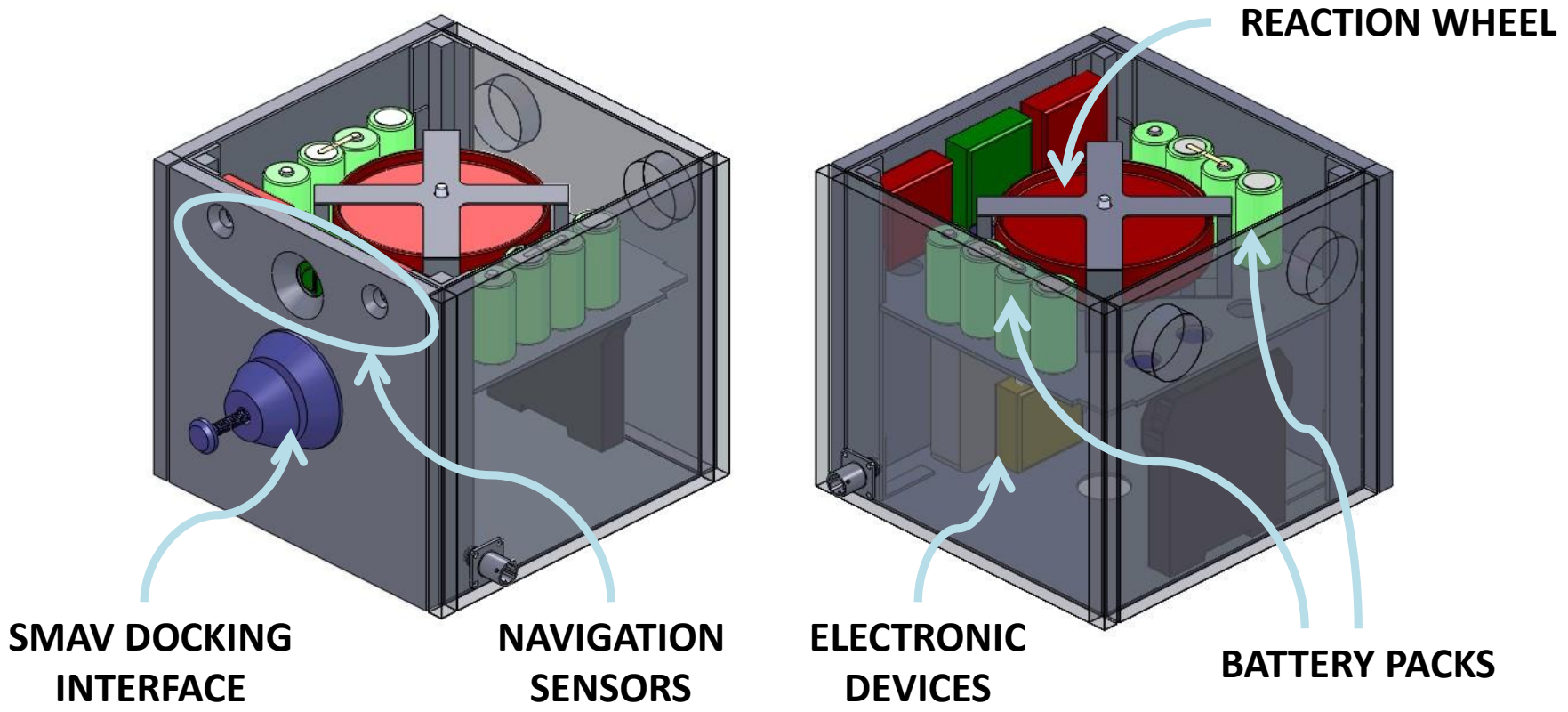
STRUT

The **STRUT** is a rigid supporting structure fixed to the gondola which includes the main plate that support the SMAV and all the devices needed to translate it



SMAV

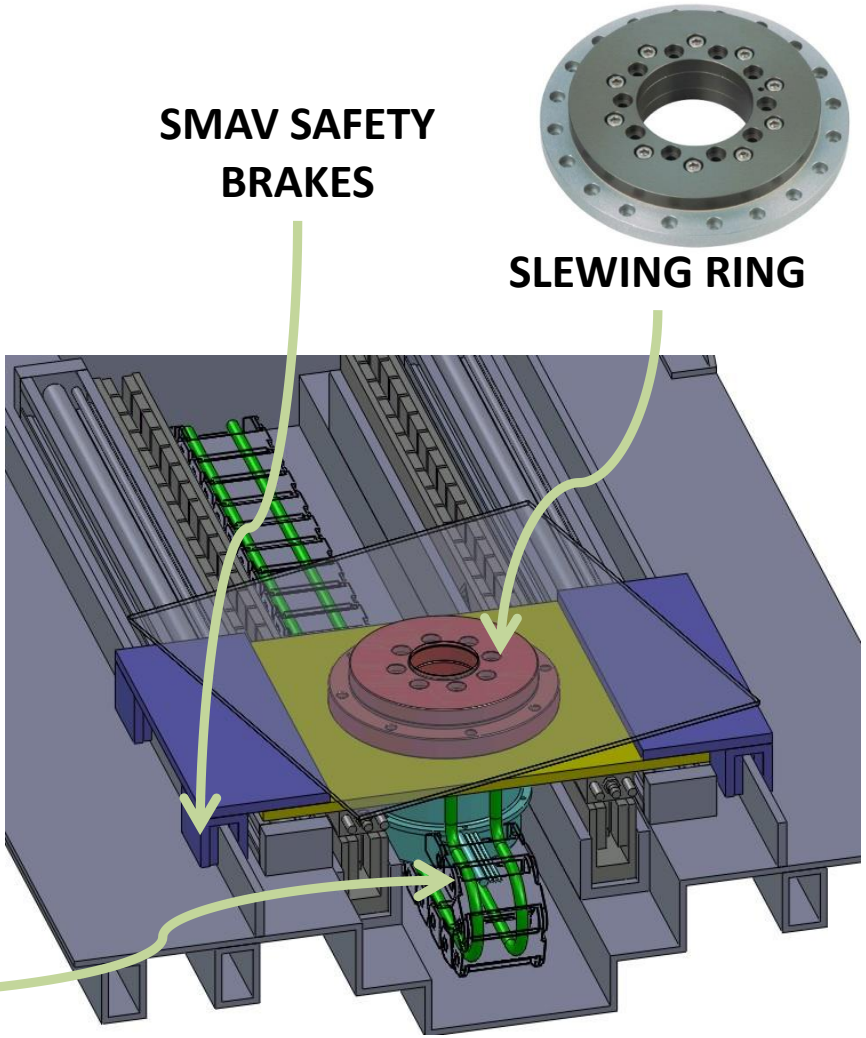
The **SMAV** is a small external vehicle, with navigation, control and docking capabilities.



SMAV-STRUT INTERFACE (SAFETY)

The **SMAV-STRUT interface** is the **most critical junction** of the system.

- A **fully bolted slewing ring** ensure a strong and reliable connection between the SMAV and the linear slider
- **Safety brakes** can block the SMAV at any time
- **Two** additional **steel cable** secures the SMAV assembly to the gondola even in the unlikely case of a linear guide rupture



NAVIGATION

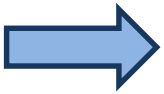
The navigation system determines the **SMAV yaw rotation** and **distance** relative to the docking interface mounted on the gondola PROXBOX.

REQUIREMENTS

- **Min sample rate: 500 S/s**
- **Range: ± 30°** for yaw rotation and **50 to 400 mm** for distance
- **Accuracy: <2°** for yaw rotation and **<5 mm** for distance

SOLUTIONS

- Infrared (IR) sensor
- Electromagnetic Field (EMF) sensor
- MEMS Gyroscope (BACK-UP)

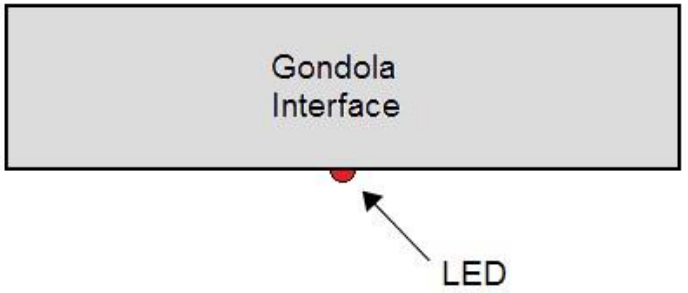


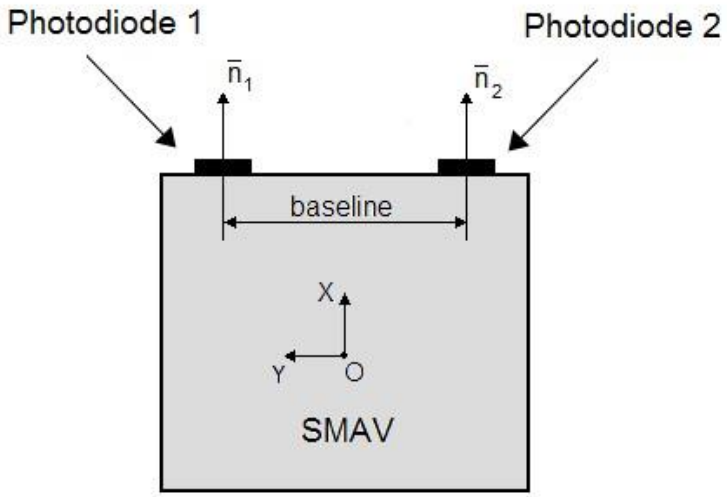
REDUNDANCY

NAVIGATION

IR SENSOR

- **2 separate IR photodiodes** mounted on the SMAV, facing an **IR LED** placed on the gondola outside wall
- IR LED **pulsed** at high frequency (10 kHz)
- The **output current** of each photodiode is **AM modulated** by both the **SMAV-gondola distance** and the IR rays **angle of incidence** on the photodiodes sensitive area
- From the photodiodes output the **sensor logic** calculates the SMAV yaw rotation and distance relative to the gondola **by solving a nonlinear system of equations**

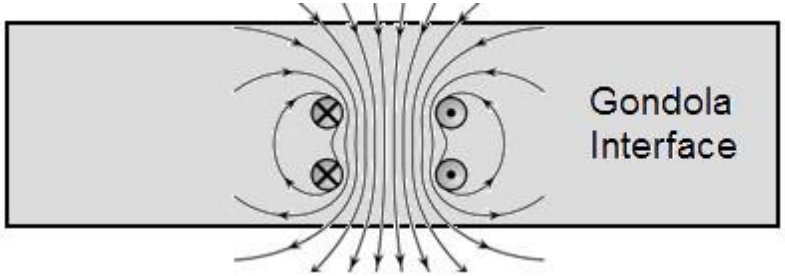


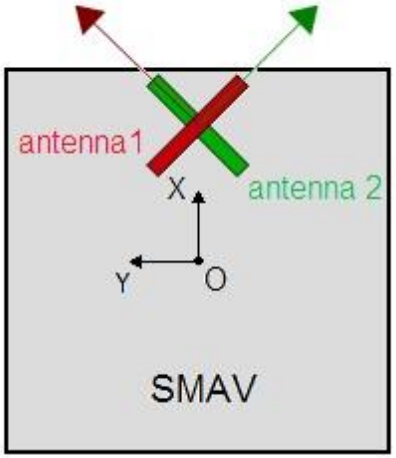


NAVIGATION

EMF SENSOR

- **Pulsed magnetic field** generated from the gondola at high frequency (10 kHz)
- **2 orthogonal antennas** onboard the SMAV detect the **magnetic field components modulated** by both distance and relative attitude, in the SMAV reference frame
- **SMAV yaw and distance** relative to the gondola are determined by the sensor logic, **thanks to a model of the generated EMF**
- **Small power** consumption (~ 1 W)





NAVIGATION

MEMS GYROSCOPE

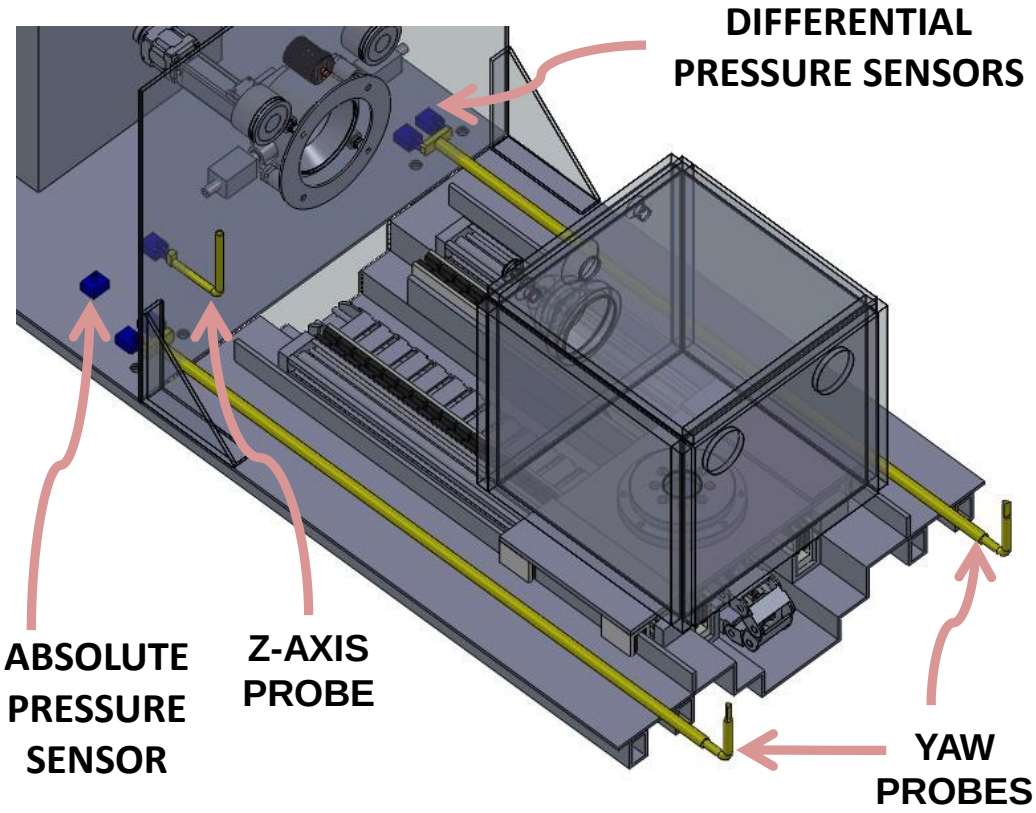
- Based on the **SENSONOR SAR100 MEMS chip gyro sensor**
- **Aligned** with the **yaw axis**
- **Back-up solution**
- Allows to **improve the accuracy** of the attitude and distance estimates in **post processing**
- **Comparison** with the self-made sensors to evaluate their **performance** with respect to a commercial product

ENVIRONMENTAL SENSORS

The environmental sensors collect data on the **external pressure, temperature and wind velocity** in order to fully characterize the external environment around the SMAV

SENSORS

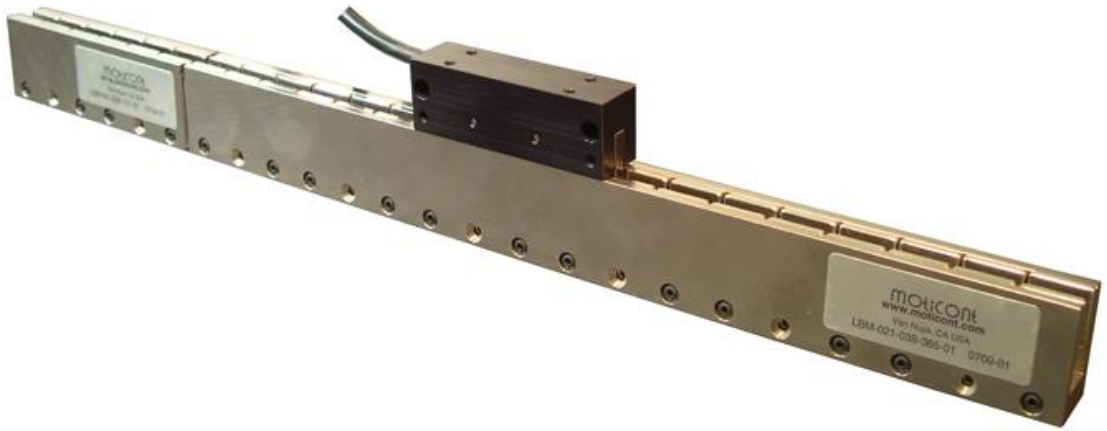
- **1 absolute pressure sensor** to measure the **static atmospheric pressure**
- **2 yaw probes** mounted on the outside plate; **each one is** provided with **3 holes** on the X-Y plane which are connected to **2 differential pressure sensors**
- **1 differential pressure sensor** which takes the difference between the **pressure inside the gondola** and the external **dynamic pressure along the Z axis**
- **External temperature sensors**



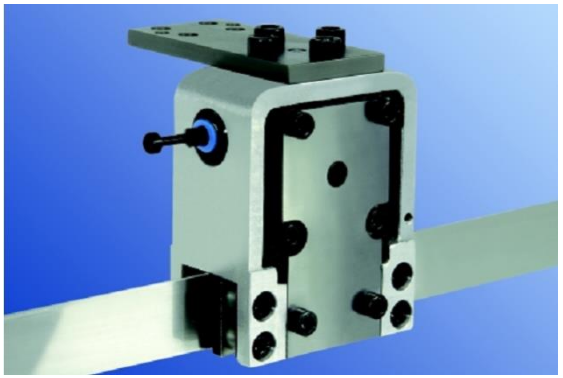
SMAV MOTION CONTROL

The SMAV motion control **manages the yaw rotation** and the **translation** of the SMAV with respect to the gondola.

- A couple of **linear motors** translate the SMAV towards the PROXBOX: this movement is <u>not</u> included in the control feedback loop
- An electromechanical **emergency brake** (TBD) is connected to the SMAV support and acts on a rail on the STRUT



Linear Motor



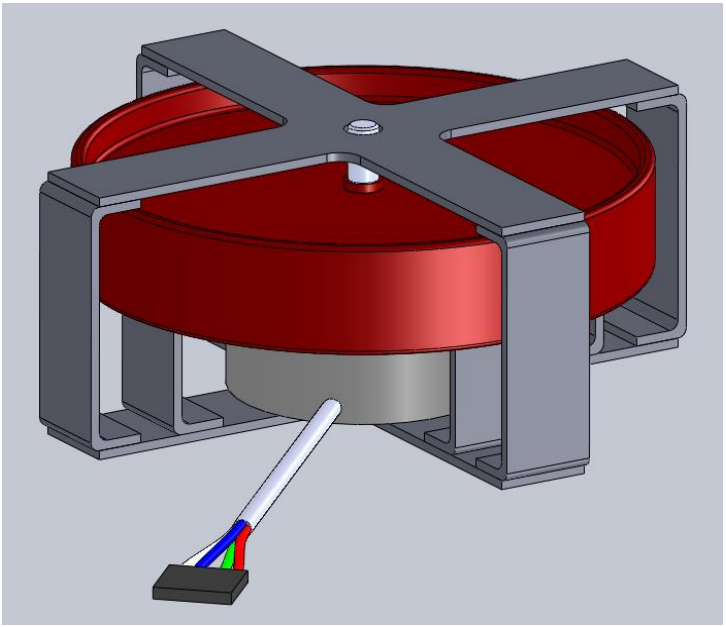
Electromechanical brake

SMAV MOTION CONTROL

- A **self produced** reaction wheel actuates the **yaw axis**
- **External torques** (wind, gondola unbalances) determine the RW requisites
- **Backup** solution: **hollow shaft DC motor** directly connects the SMAV to the STRUT

Reaction wheel performances	
Torque	70 mNm
Angular Momentum	170 mNms
Mass Estimation	850 g

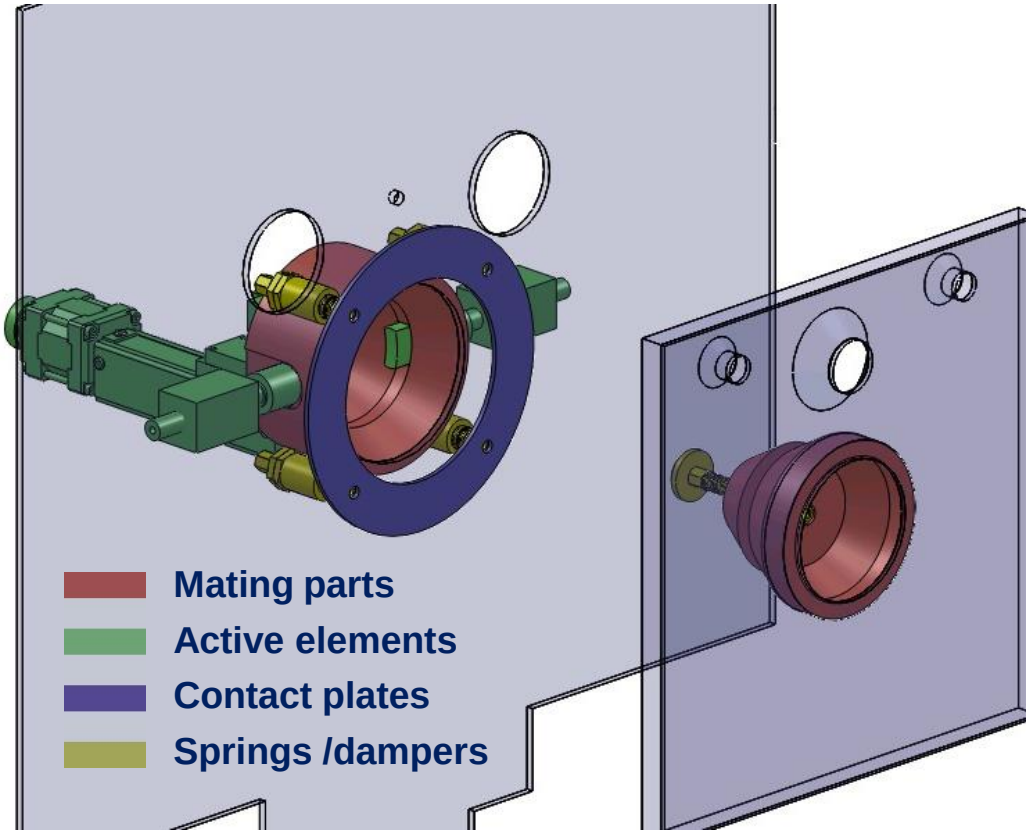
Backup Motor



Custom Reaction Wheel

DOCKING MECHANISM

The docking mechanism **joins the SMAV to the PROXBOX**, providing a **reliable and solid connection** between them.



MAIN FEATURES

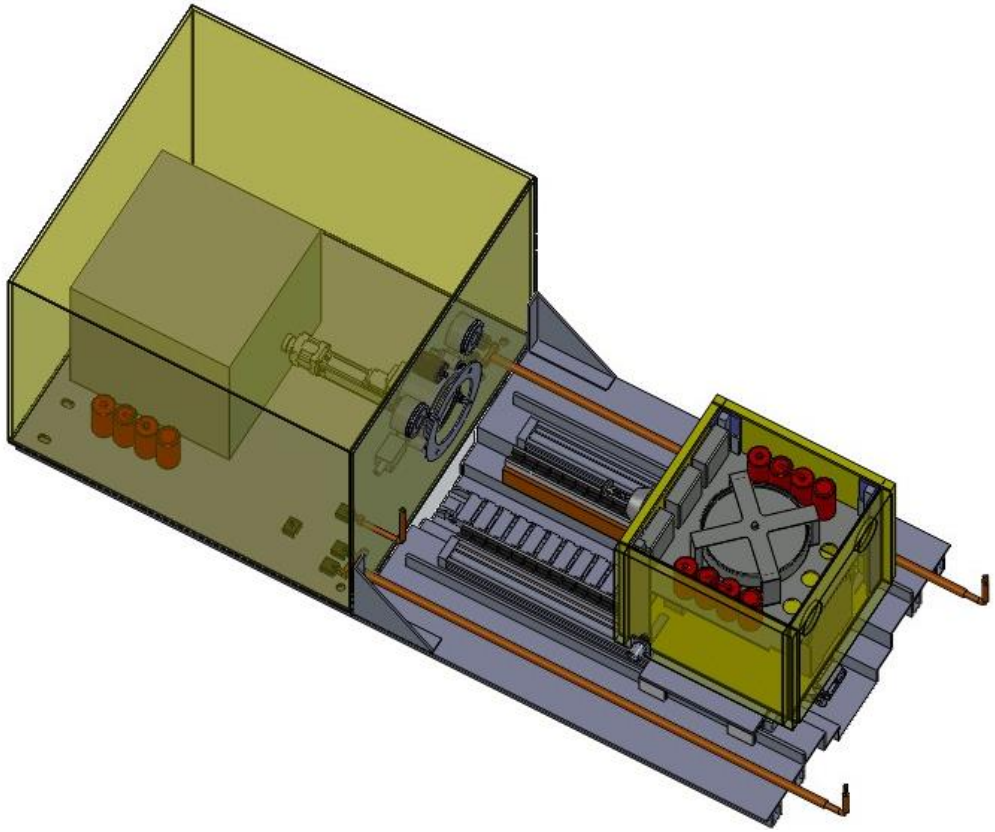
- ±10° misalignment tolerance
- Automatic signaling of HARD DOCKING completion
- High resistance to transversal loads in HARD DOCKING
- Spring damping

THERMAL CONTROL

- Expected external temperature range is 190K ÷ 270K –>

Thermal Control is needed!

- Both the SMAV and the PROXBOX are insulated, as well as the external probes and the linear motors.
- Battery may be actively heated.



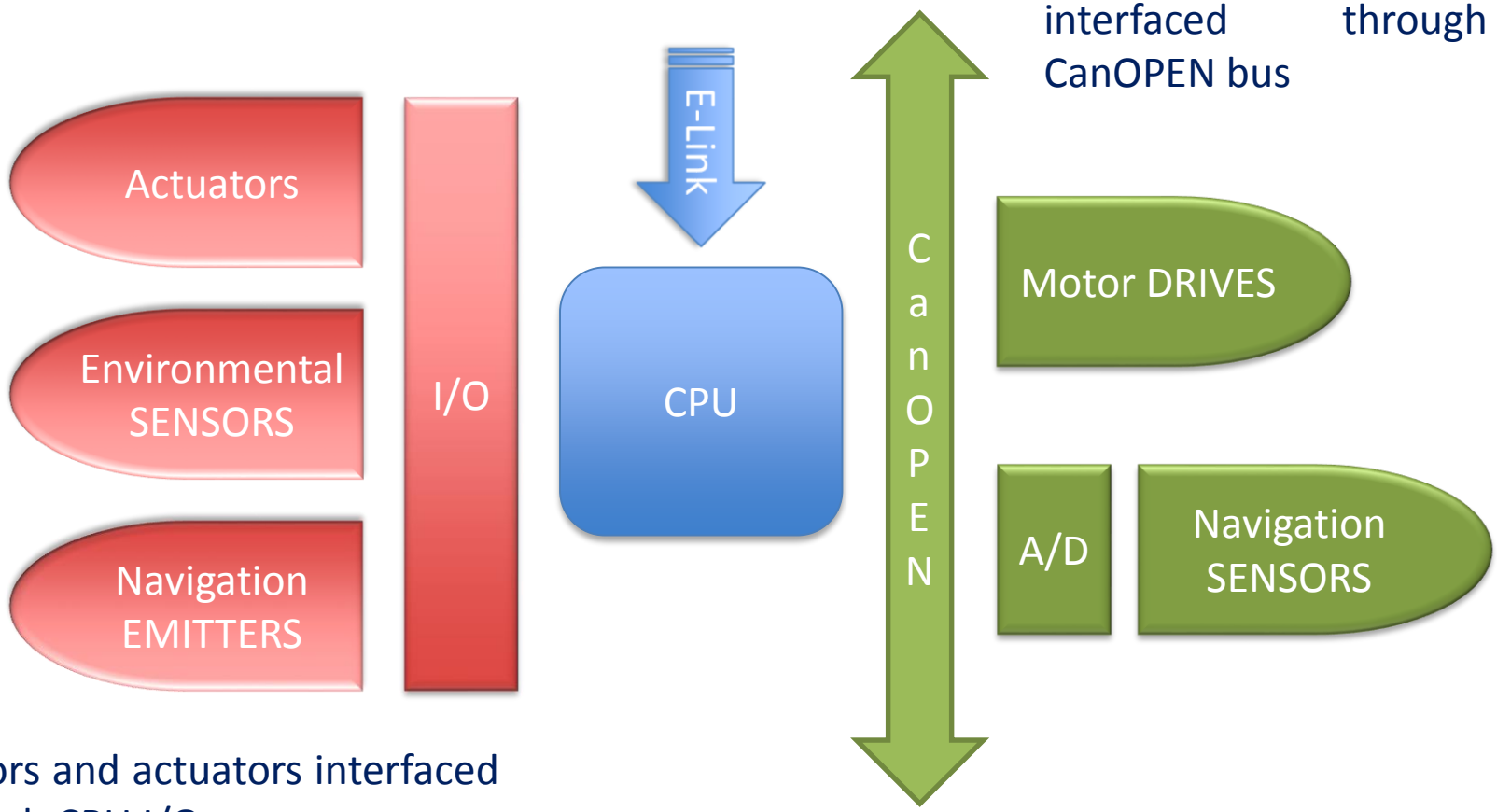
= PROXBOX & SMAV insulation

= external devices insulation

= actively heated devices

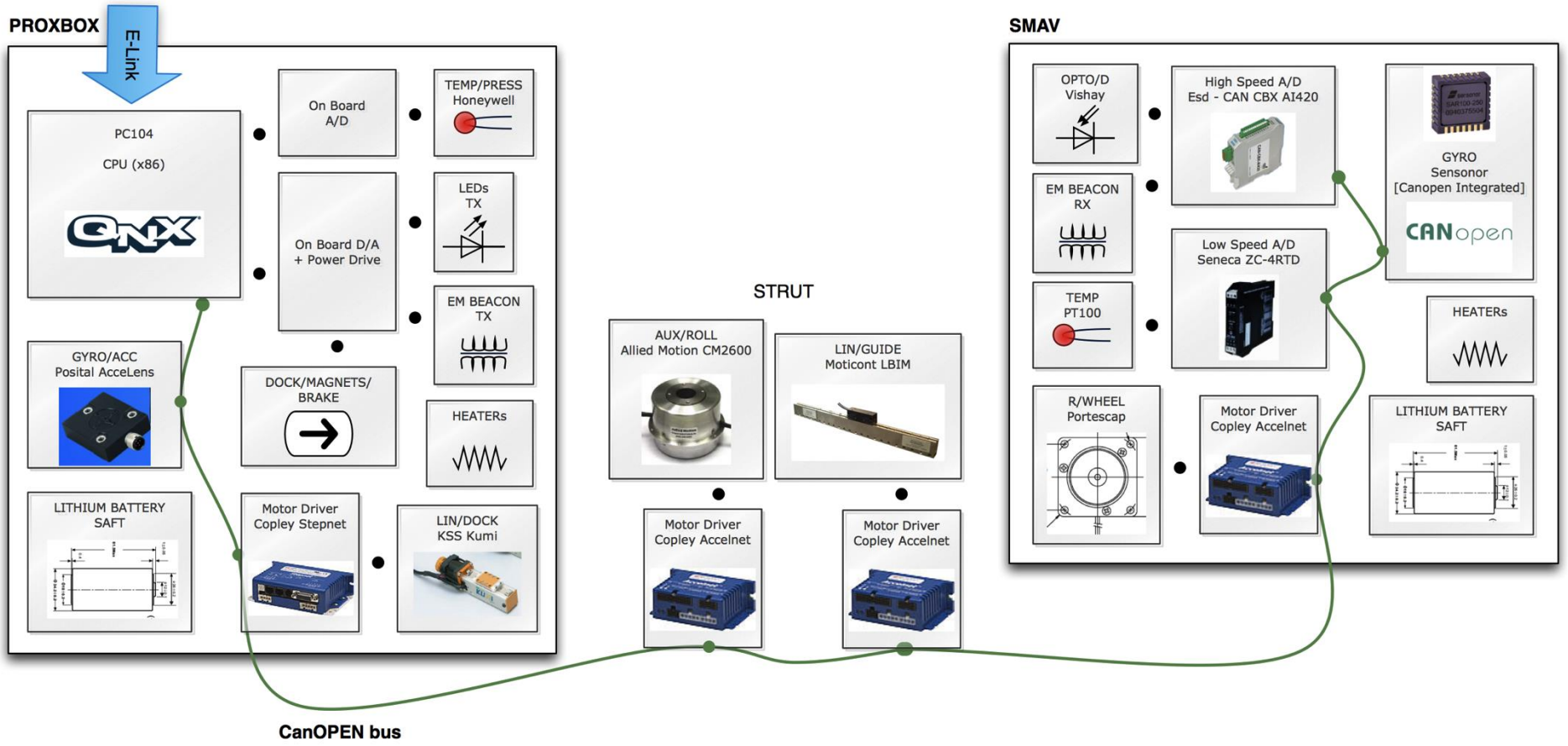
ELECTRONICS

Sensors and actuators interfaced through CanOPEN bus



Sensors and actuators interfaced through CPU I/O

ELECTRONICS



POWER

PRE-FLIGHT

- **PROXBOX**:
  2A @ 24V supply
  umbilical cable

- **SMAV**:
  1.5A @ 24V supply
  umbilical cable

IN-FLIGHT

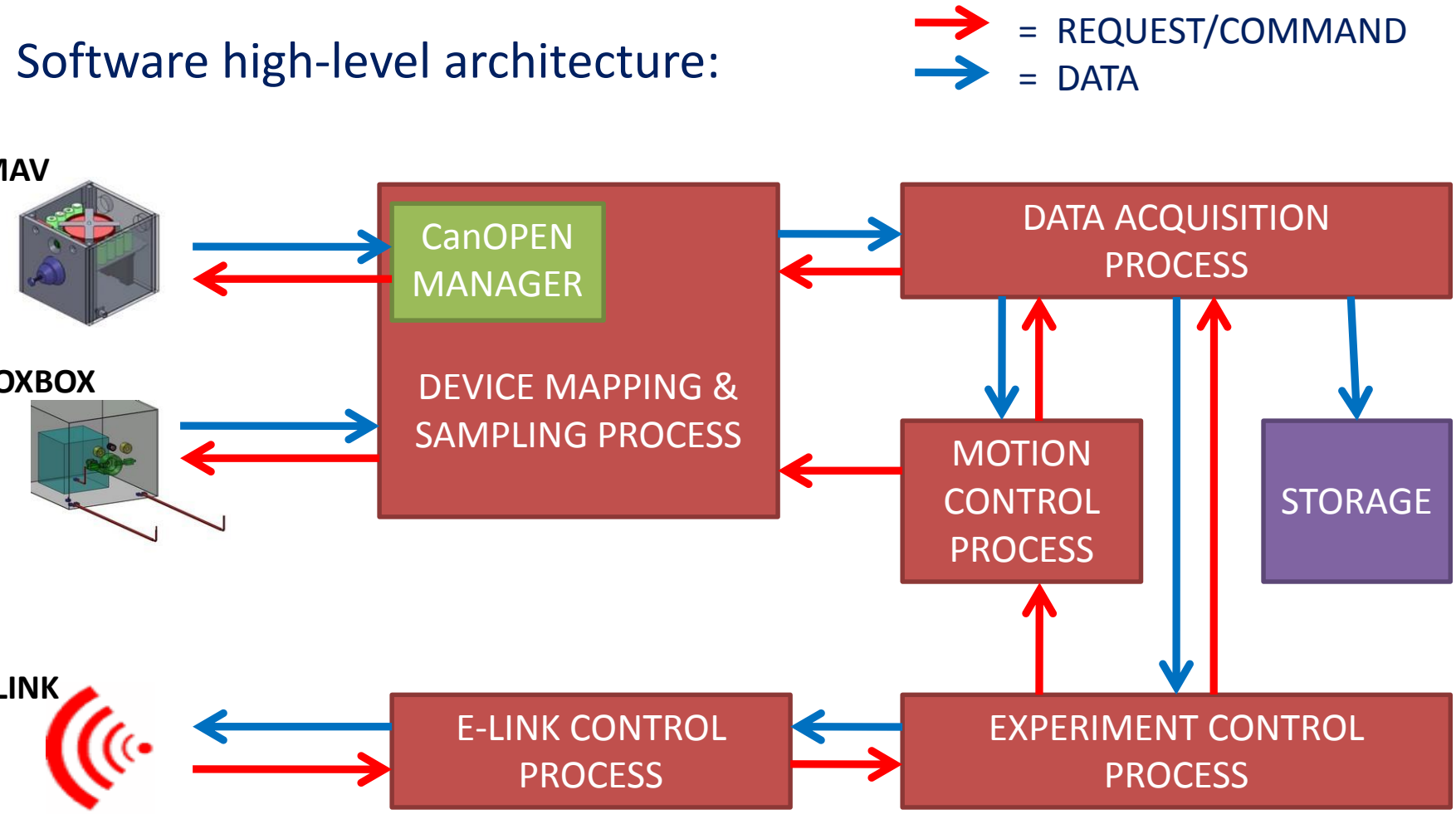
- **PROXBOX**:
  28V 200Wh $LiSOCl_2$
  DC/DC voltage regulation
  Exp. full-power runtime:
  5 hours

- **SMAV**:
  28V 80Wh $LiSOCl_2$
  w/o voltage regulation
  Exp. full-power runtime:
  3 hours

- Software power managing interlock to avoid battery overload

SOFTWARE

- Software high-level architecture:



SAMPLING & DATARATES

Device	Channels	Sample Rate [S/s]	Bits per sample	Data Rate [kbit/s]
RW Motor speed, current	2	1000	16	32
GYRO angle	2	1000	16	32
IR Navigation RX, raw + processed	4	1000	16	64
EM Beacon RX, raw + processed	4	1000	16	64
Internal Temperature sensors	4	10	16	0.64
On-Board Bus TOTAL				**< 200**
Horizontal Actuator position, current	2	1000	16	32
Yaw backup motor position, current	2	1000	16	32
Docking Actuator status	1	10	8	0.08
Pressure Sensors	6	1000	16	96
Inclinometer	2	10	16	0.32
Internal Temperature Sensors	4	10	16	0.64
External Temperature Sensors	2	10	16	0.32
Docking System status, position	2	10	16	0.32
On-Board Bus + Telemetry TOTAL (with 10x decimation)				**< 400 (< 40)**

DEVELOPMENT PLAN

ARCADE Gannt Chart

TESTING

1. COMPONENT/SUBSYSTEM TESTS
   - Navigation system
   - Motion control system
   - Docking mechanism

   …

Vibration facility

2. ENGINEERING TESTS
   - Vacuum
   - Aerodynamic disturbances (wind tunnel)
   - Vibrations

   …

03 – Critical Design Review
Maggio 2011

ESTEC – Noordwjik
Olanda

Il progetto è congelato

UNIVERSITY OF PADOVA - ITALY

CISAS "G. COLOMBO"

ARCADE

Autonomous Rendezvous, Control And Docking Experiment

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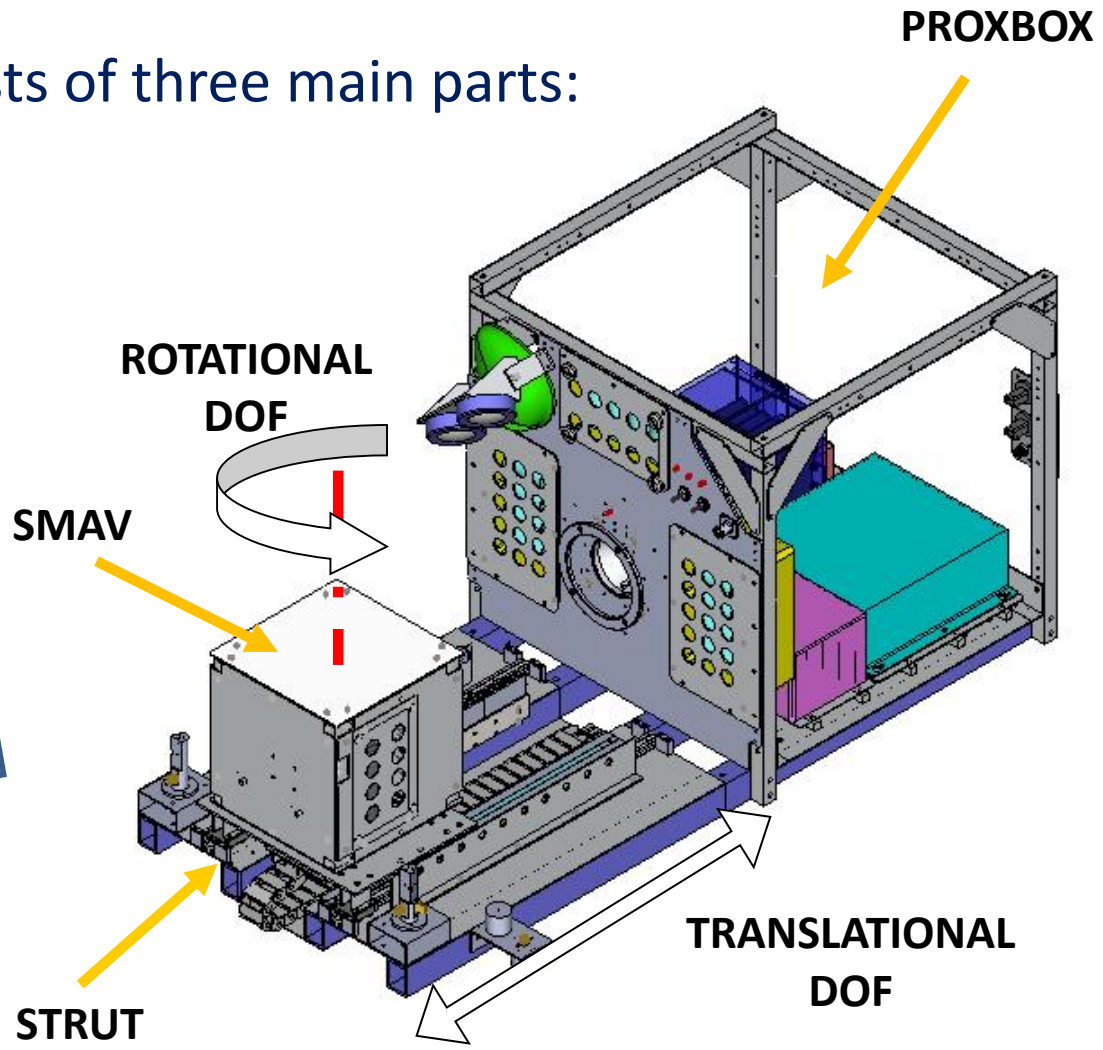
ARCADE experiment consists of three main parts:

1. An external *SMAll Vehicle*, **SMAV**
2. An on-gondola *PROXimity BOX*, **PROXBOX**
3. An intermediate *STRUcTure*, **STRUT**

Total mass:
SMAV: 4.7 kg
STRUT: 7.4 kg
PROXBOX: 15.5 kg
TOTAL: 27.6 kg

Dimensions:
Width: **480 mm**
Height: **500 mm**
Length: **1000 mm**



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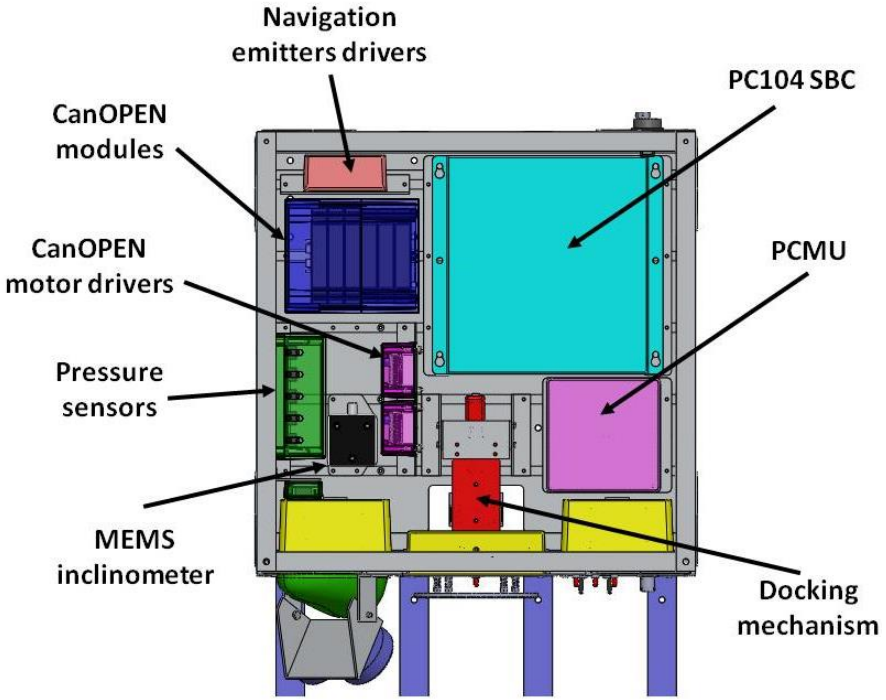
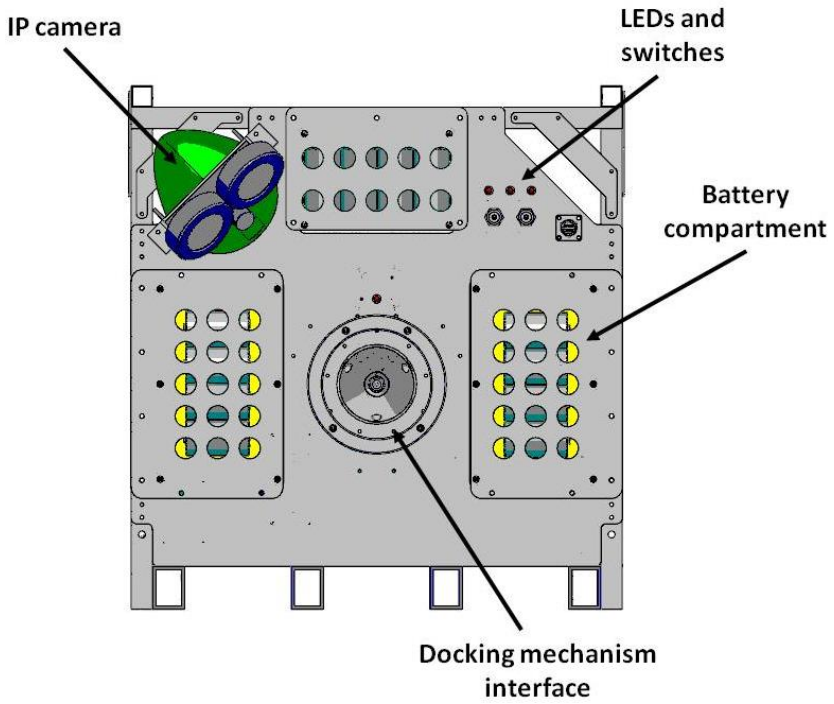


PROXBOX top view



PROXBOX front view

STRUT

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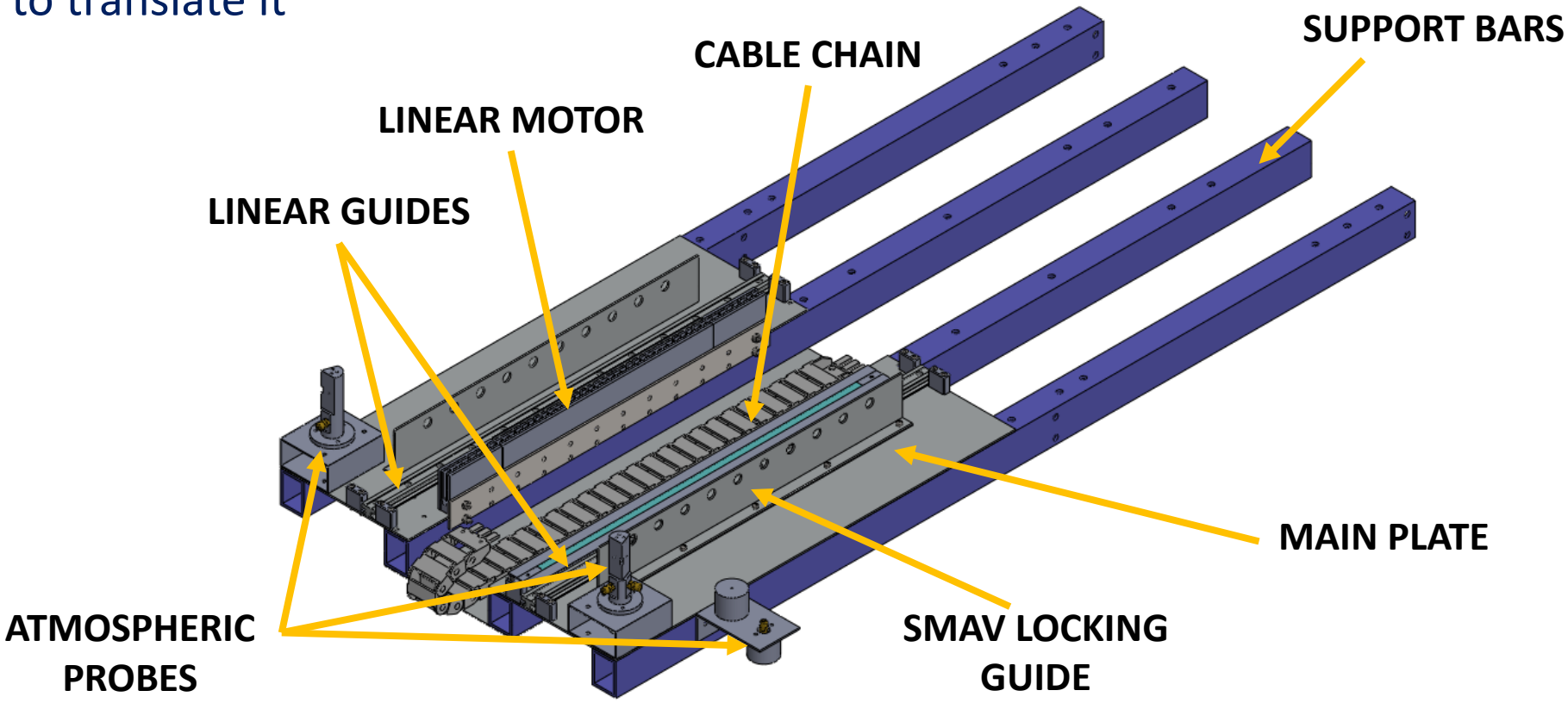

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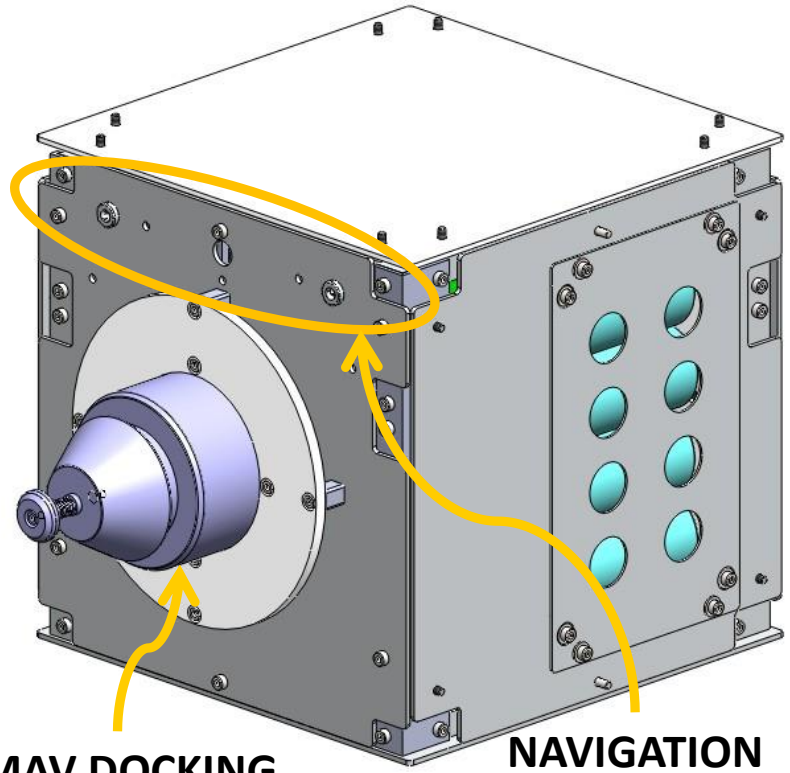

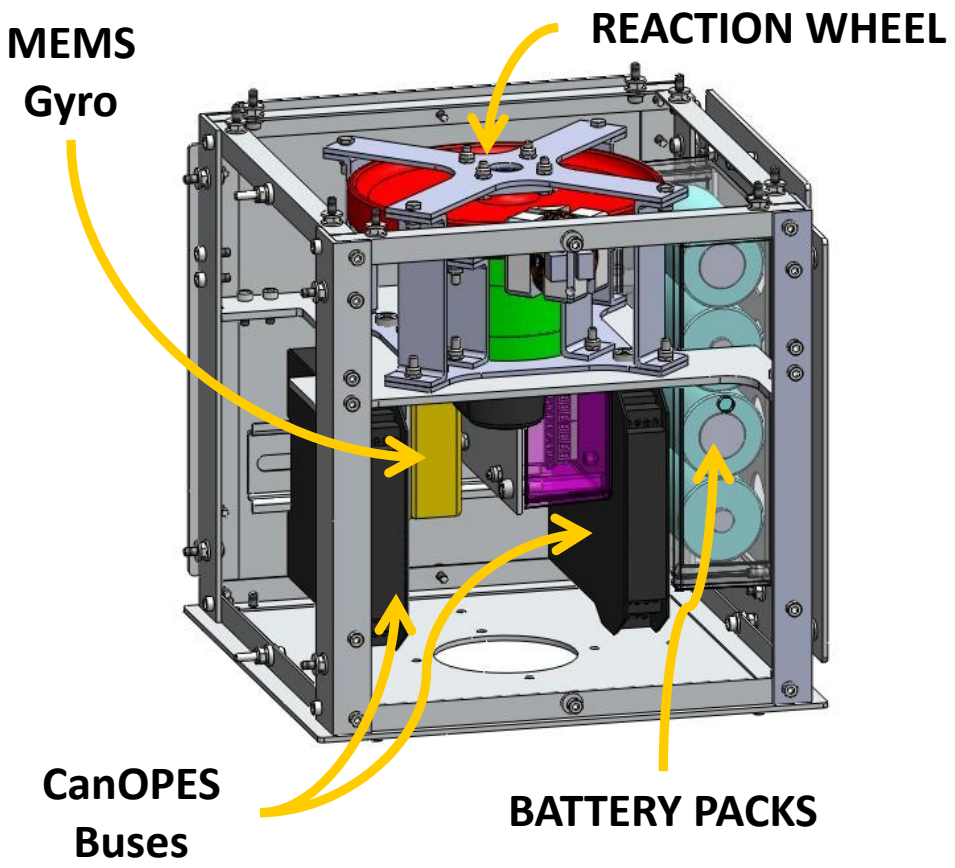

SMAV-STRUT INTERFACE (SAFETY)

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- **Safety brakes** can block the SMAV at any time
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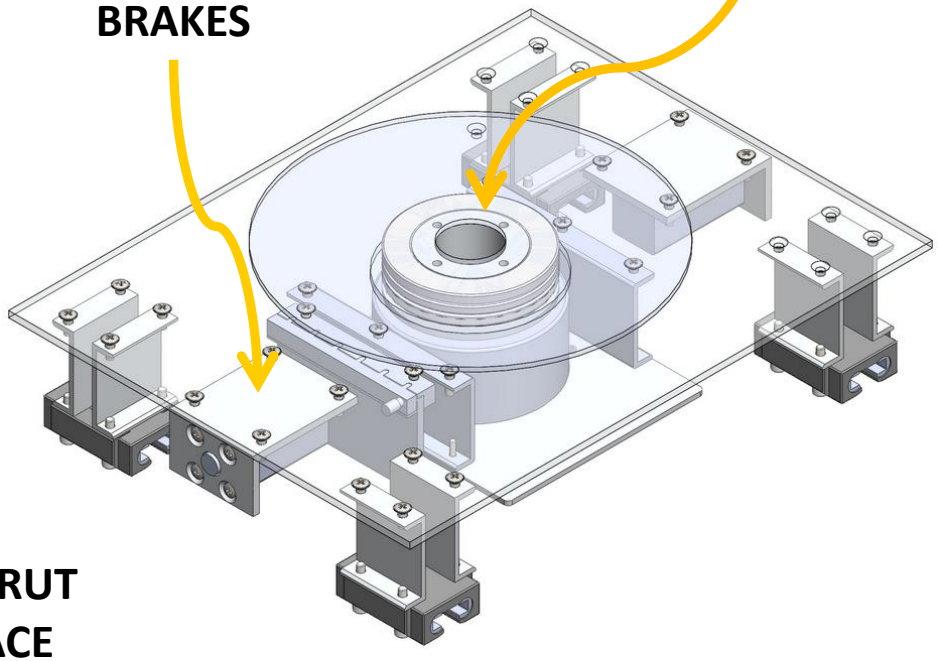
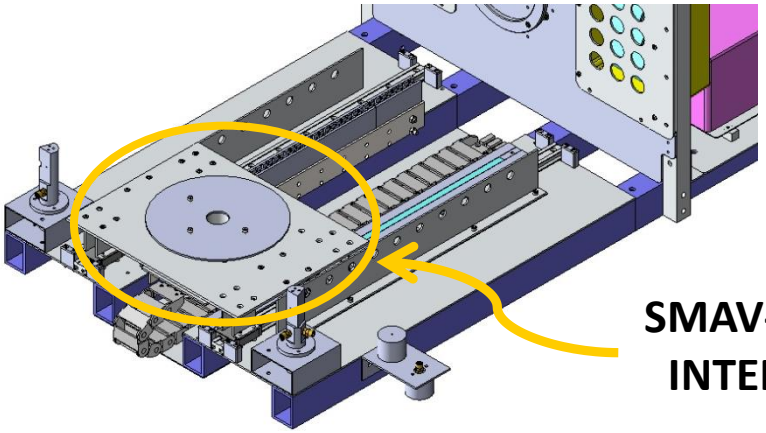
SLEWING RING

SMAV SAFETY BRAKES





SMAV-STRUT INTERFACE

PRE- FLIGHT AND FLIGHT PROCEDURES

1. Pre-Flight Procedures

1. Roll call of the components
2. Inspection for integrity check
3. Mechanical and electronic assembly
4. Functional tests (electronic boards status, CanOPEN network, PC, sensors, Ethernet connection)
5. Box closing
6. GO!

2. Countdown and Flight

Time (h:mm)	Action
T - 0:60	Battery change
T - 0:40	Experiment turn on
T = 0	Lift
T + ~ 1:00	Starting docking sequences
T + ~ 5:00	The experiment stops the operative cycles Stop recording data

OUTREACH PROGRAM

The ARCADE Experiment has an **official website** at:

www.experimentarcade.org

as well as its own **Facebook fanpage**!

ARCADE official website homepage

MiniARCADE at the SPERIMENTANDO 2011

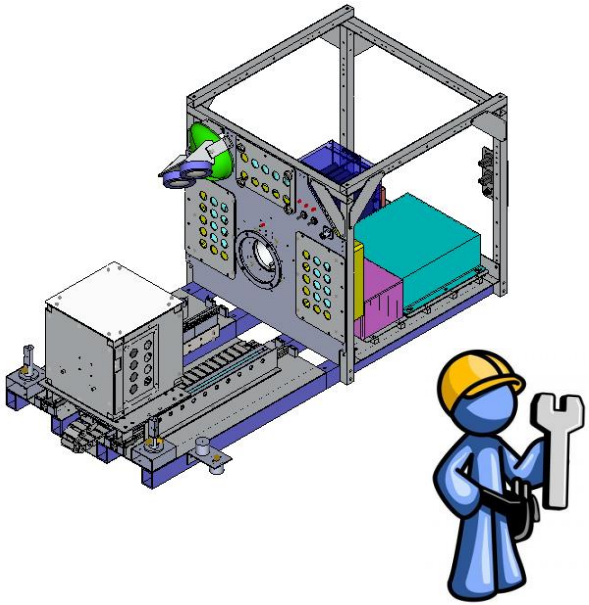
Many **events** have been organized:

- Presentation at the interactive scientific exhibition *"SPERIMENTANDO 2011"*
- Workshops and conferences in local small and medium enterprises

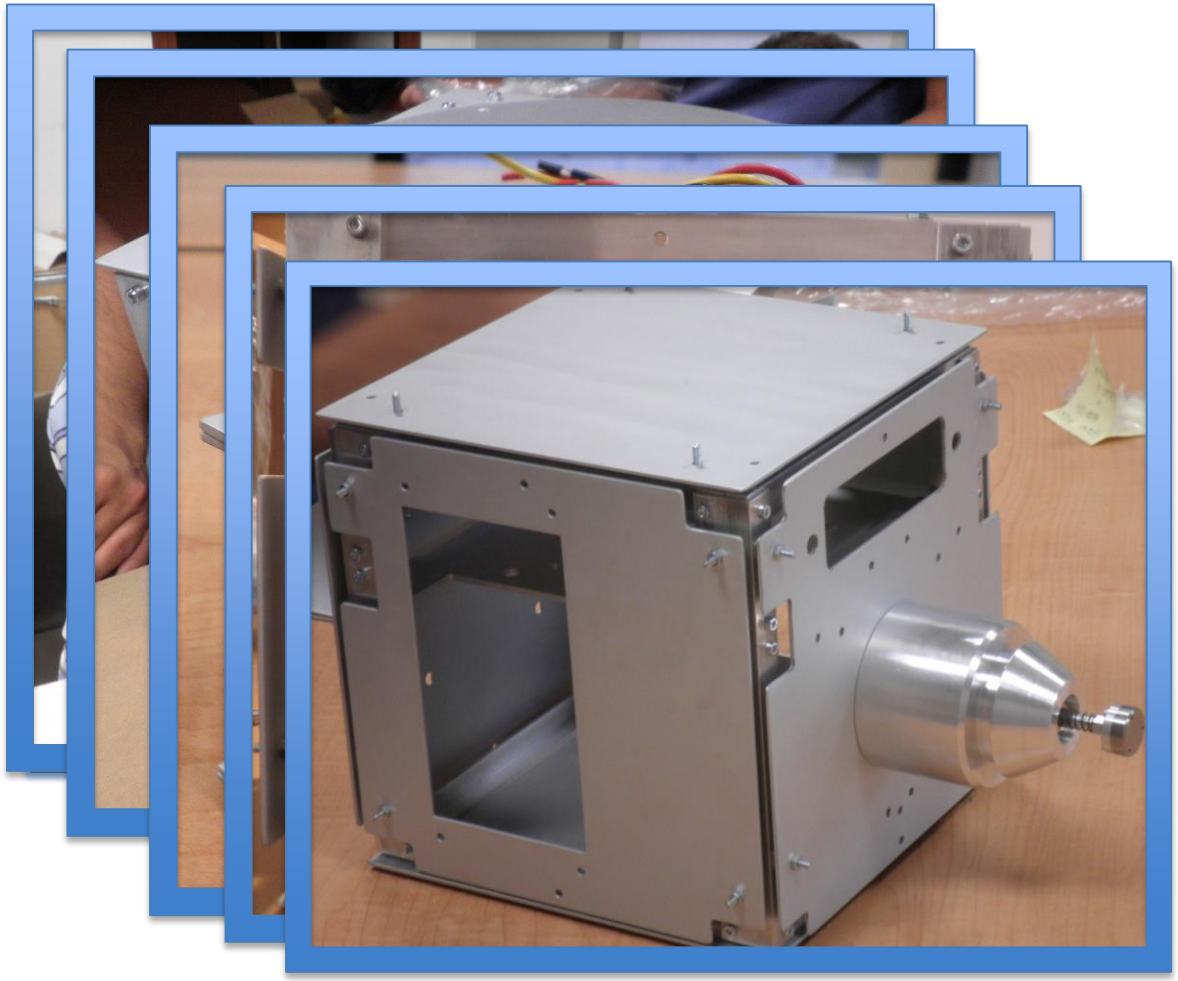
And others are **on schedule**:

- Dinners at ROTARY and ROTARACT clubs
- Presentations at the *Aerospace Engineering Study Program* and at the *PhD School in Science, Technology and Measurements for Space*

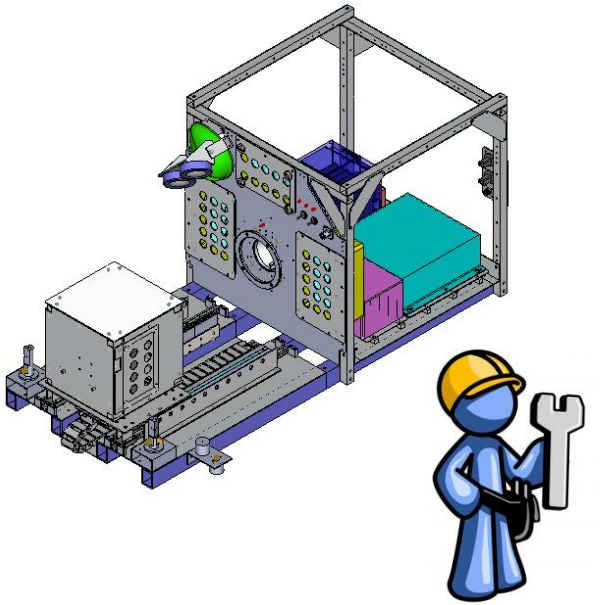
Dal progetto alla costruzione



Lo SMAV



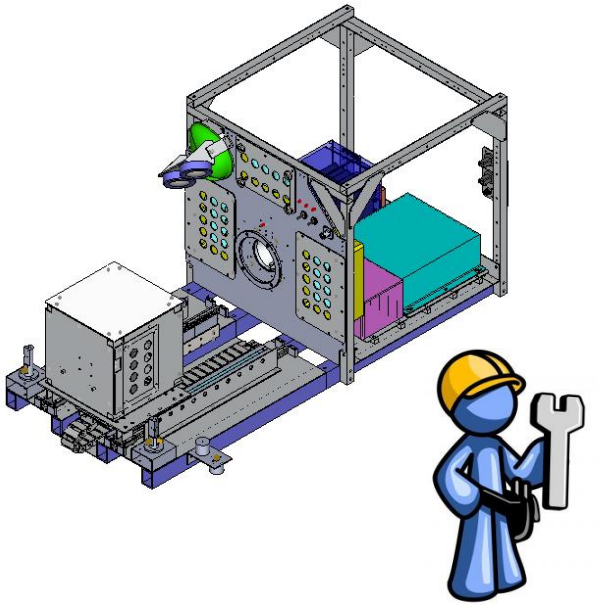
Dal progetto alla costruzione



La STRUT

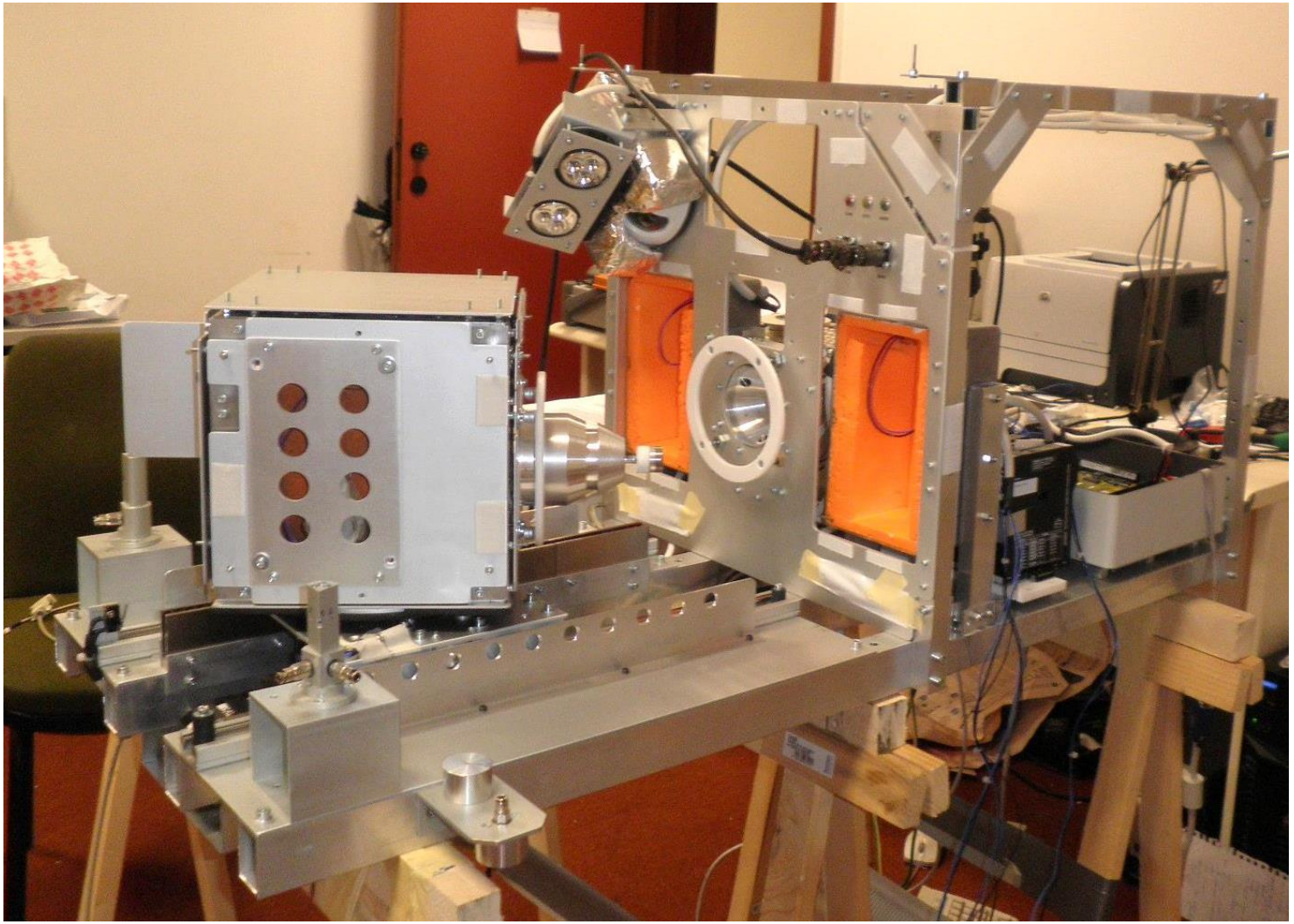
In attesa delle barre originali, abbiamo realizzato una struttura provvisoria!!!

Dal progetto alla costruzione

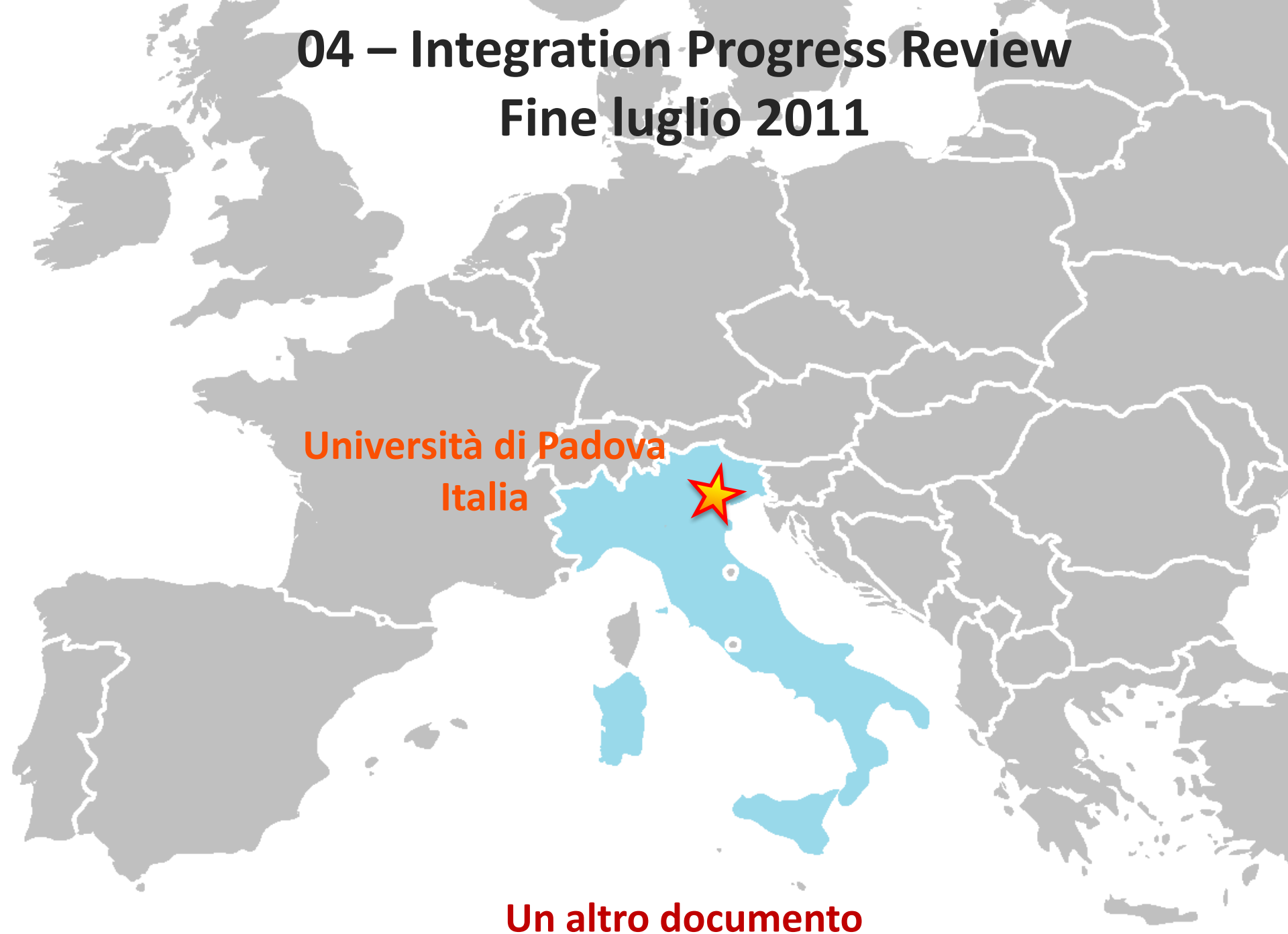


La PROXBOX

Dal progetto alla costruzione

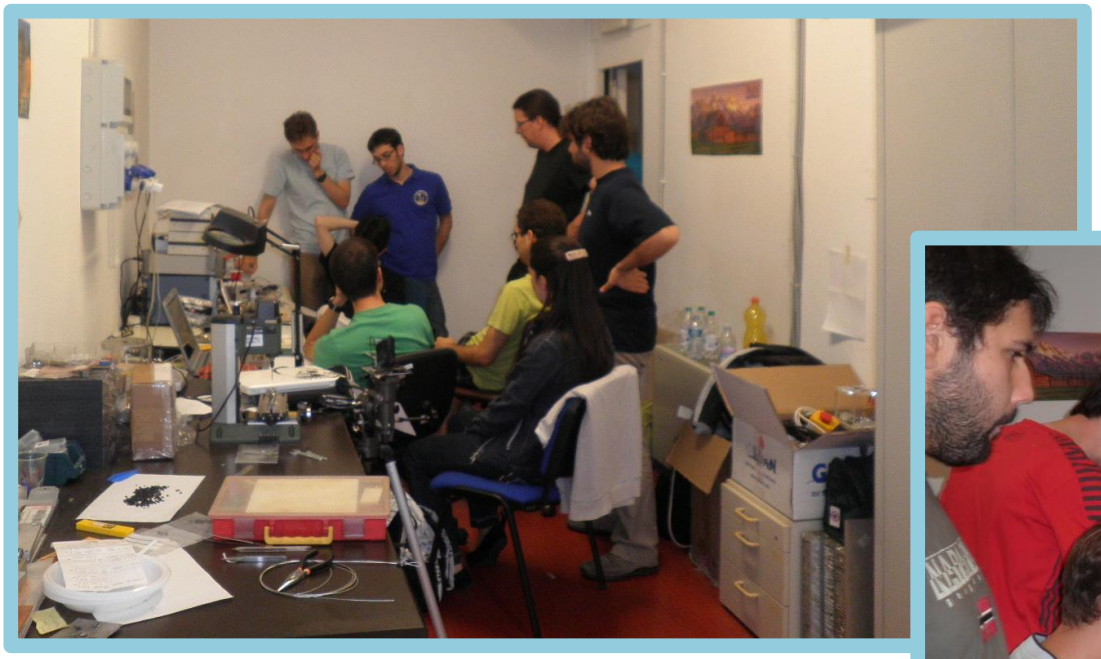


04 – Integration Progress Review
Fine luglio 2011



Un altro documento

IPR: gli esperti del programma Bexus vengono a trovarci per verificare lo stato di avanzamento di ARCADE



Alcuni consigli su come procedere nel nostro esperimento

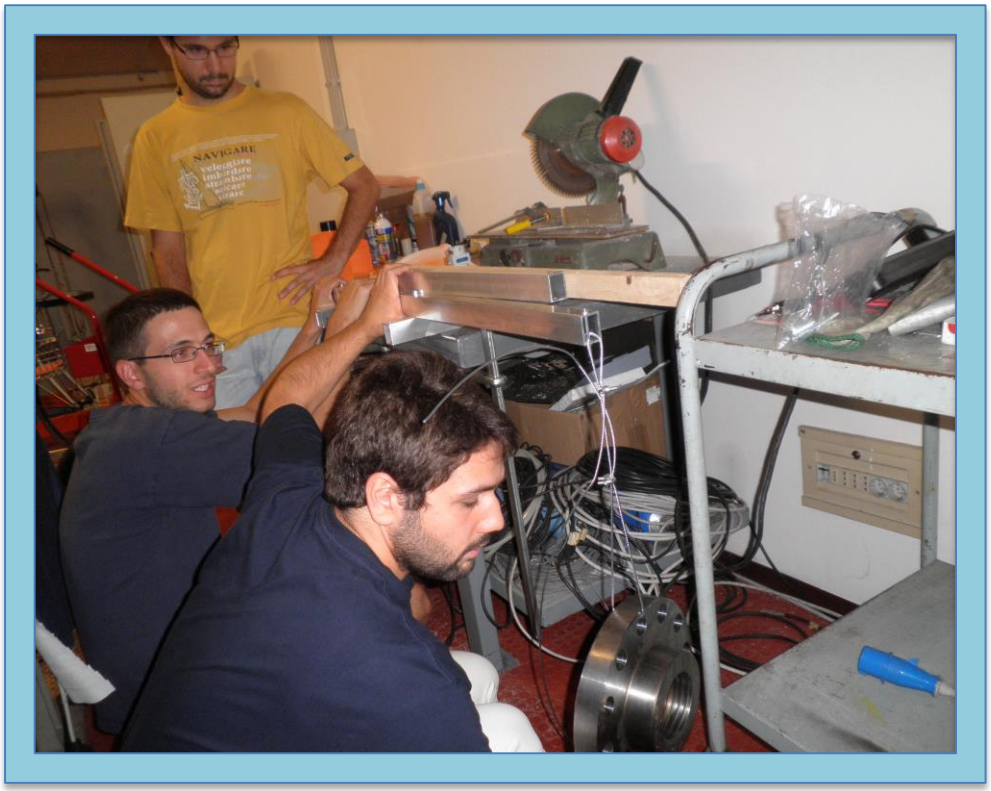
Il lavoro continua: la fase di test

E' una fase importante del progetto: i vari sottosistemi e la struttura devono essere testati per verificare che siano rispettati i requisiti dichiarati

- ✓ **Test strutturali:** la struttura deve resistere a 10g in direzione verticale e 5g in direzione orizzontale

Il lavoro continua: la fase di test

- ✓ **Test strutturali:**



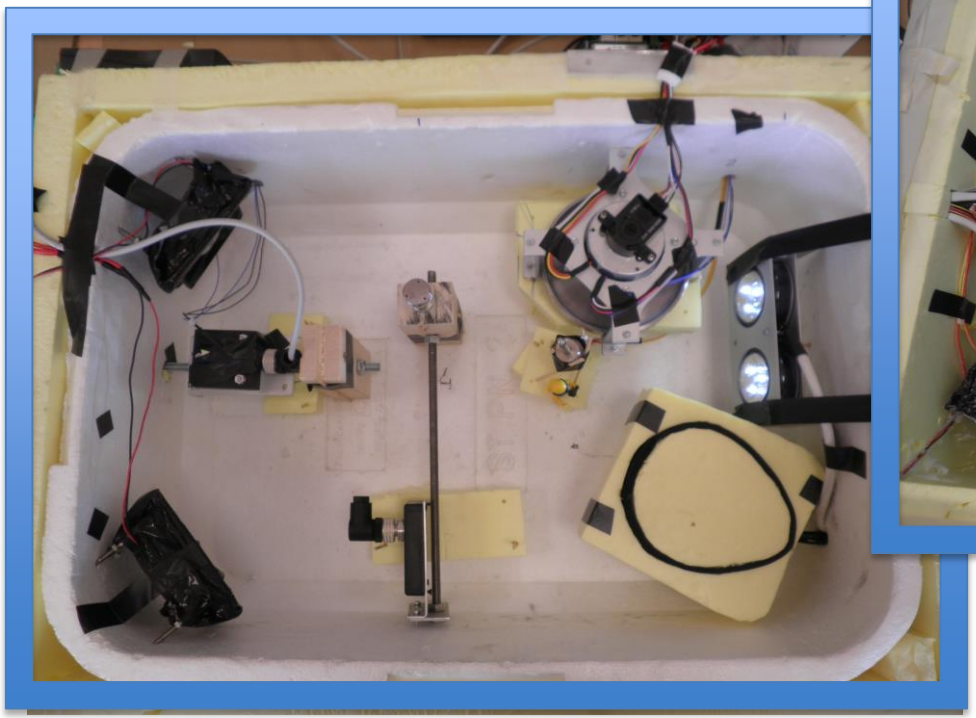
Il lavoro continua: la fase di test

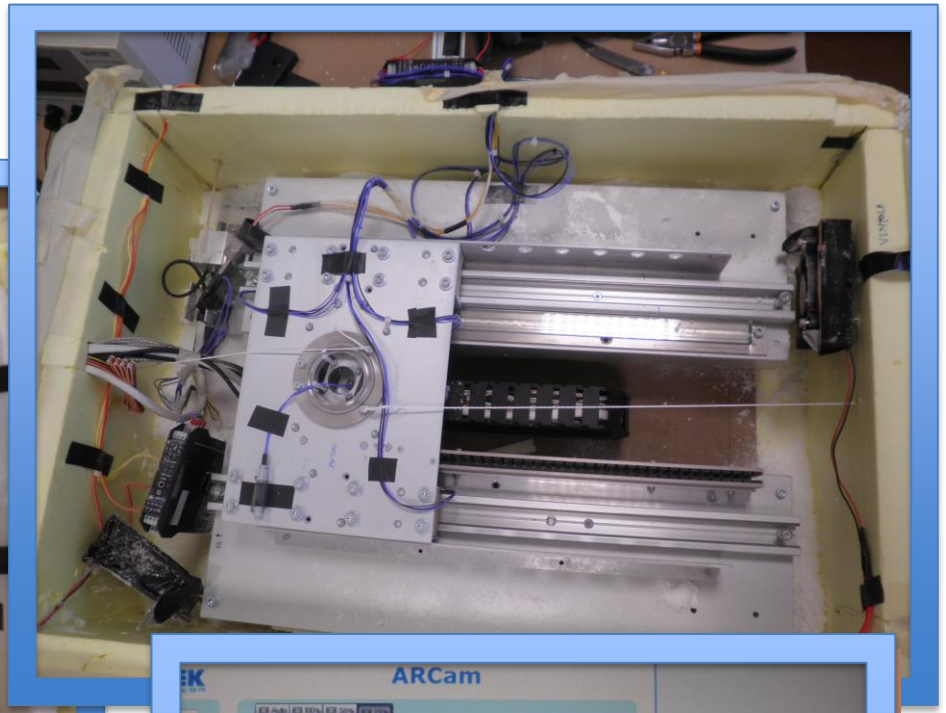
E' una fase importante del progetto: i vari sottosistemi e la struttura devono essere testati per verificare che siano rispettati i requisiti dichiarati

- ✓ **Test strutturali:** la struttura deve resistere a 10g in direzione verticale e 5g in direzione orizzontale
- ✓ **Test termici:** L'esperimento deve funzionare in un range di temperatura compreso tra -90° C e +30° C

Il lavoro continua: la fase di test

- ✓ **Test termici**





Dai singoli componenti…

Uno sguardo all'interno…

Il lavoro continua: la fase di test

E' una fase importante del progetto: i vari sottosistemi e la struttura devono essere testati per verificare che siano rispettati i requisiti dichiarati

- ✓ **Test strutturali:** la struttura deve resistere a 10g in direzione verticale e 5g in direzione orizzontale
- ✓ **Test termici:** L'esperimento deve funzionare in un range di temperatura compreso tra -90° C e +30° C
- ✓ **Test in vuoto:** L'esperimento deve funzionare in condizioni di presine molto bassa (alla quota nominale di 35 km la pressione è dell'ordine dei mbar)

Il lavoro continua: la fase di test

- ✓ **Test in vuoto**

I componenti che riteniamo più sensibili alla variazione di pressione vengono testati nella camera a vuoto

Il lavoro continua: la fase di test

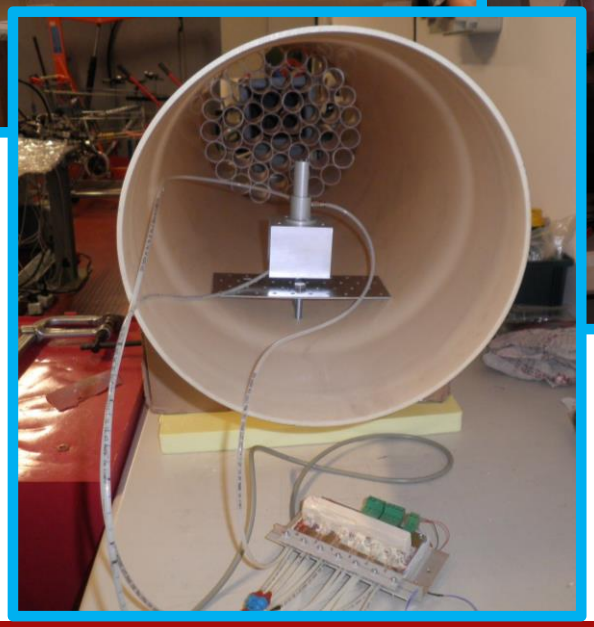
E' una fase importante del progetto: i vari sottosistemi e la struttura devono essere testati per verificare che siano rispettati i requisiti dichiarati

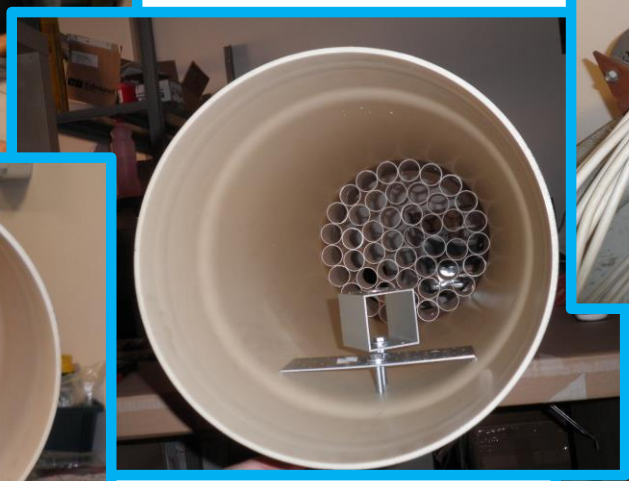
- ✓ **Test strutturali:** la struttura deve resistere a 10g in direzione verticale e 5g in direzione orizzontale
- ✓ **Test termici:** L'esperimento deve funzionare in un range di temperatura compreso tra -90° C e +30° C
- ✓ **Test in vuoto:** L'esperimento deve funzionare in condizioni di presine molto bassa (alla quota nominale di 35 km la pressione è dell'ordine dei mbar)
- ✓ **Altri test:** Sensori di pressione per la misura dei disturbi ambientali

Il lavoro continua: la fase di test

- ✓ **Altri test: sensori di pressione**

Una galleria del vento fatta in casa!!!





05 – Experiment Acceptance Review
Fine agosto 2011

Un altro documento!!!

EAR: gli esperti del programma Bexus tornano a trovarci per la seconda volta…devono dirci se possiamo volare

Controllano a fondo l'esperimento

Il biglietto per il volo

Partenza:
ESRANGE - Kiruna

Arrivo:
30 km slm

Volo:
Bexus - 13

Alessandro Boesso
Marco Barbetta
Francesco Branz
Andrea Carron

Gabriele Rodeghiero
Francesco Sansone
Livia Savioli
Fabio Spinello

Flight Ticket

Si imballa tutto e si spedisce ARCADE

Circolo polare artico

06 – Il lancio
Settembre 2011

ESRANGE – Kiruna
Svezia

Il lancio: il momento è arrivato…si prende il volo!!!!

INDICE:

- Il programma ***REXUS-BEXUS***
- 2010: L'esperimento **SCRAT**
- 2011: L'esperimento **ARCADE**
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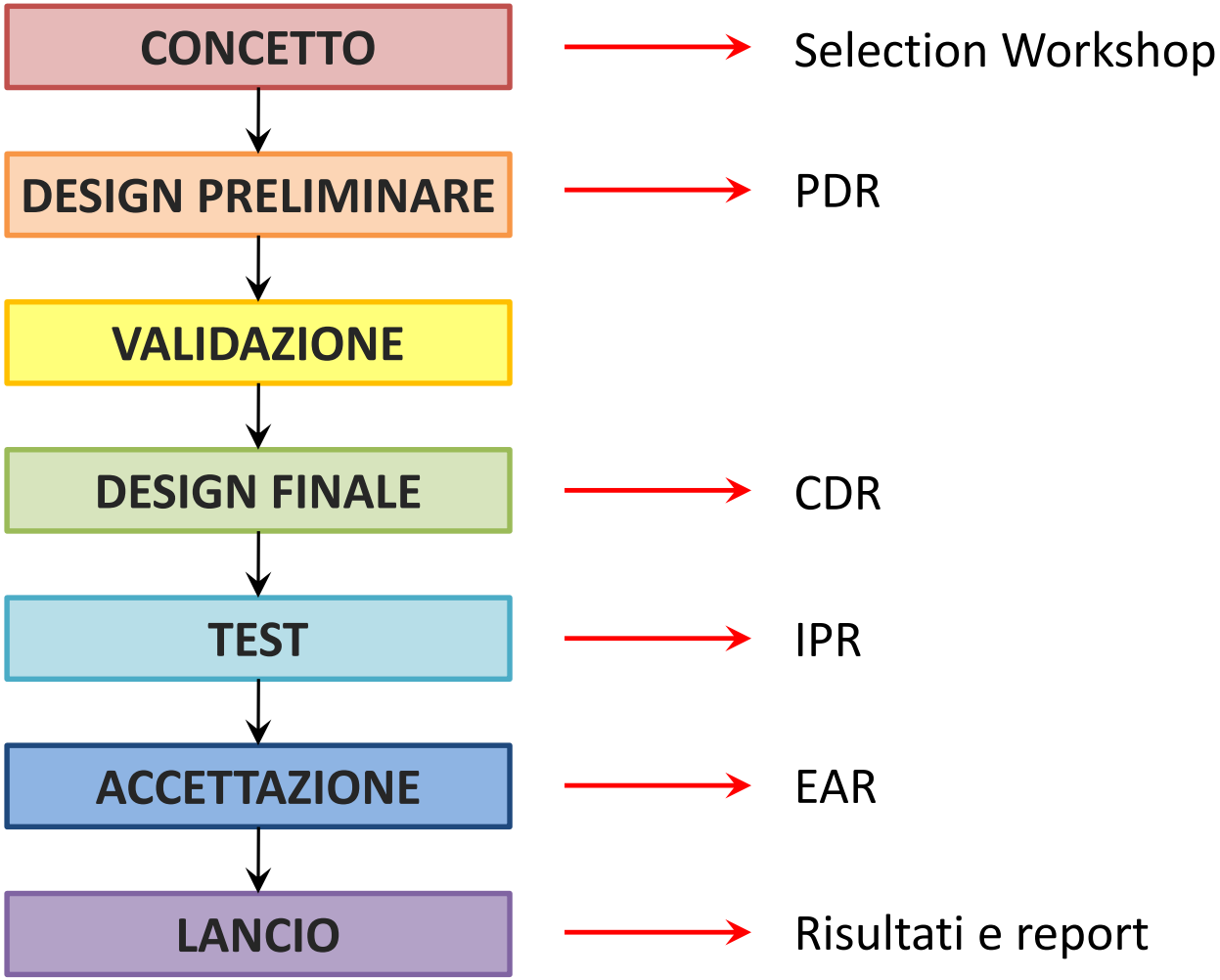
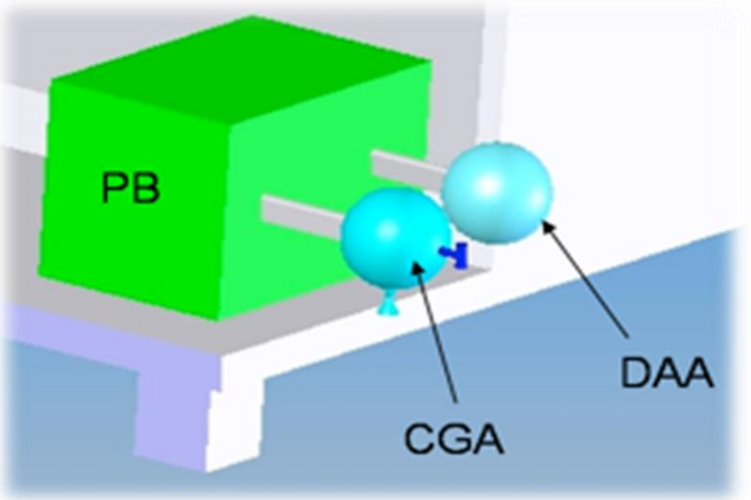
- I **lanci**
- E ora? **ARCADE-R2**
- **Conclusioni**

EVOLUZIONE DI UN ESPERIMENTO



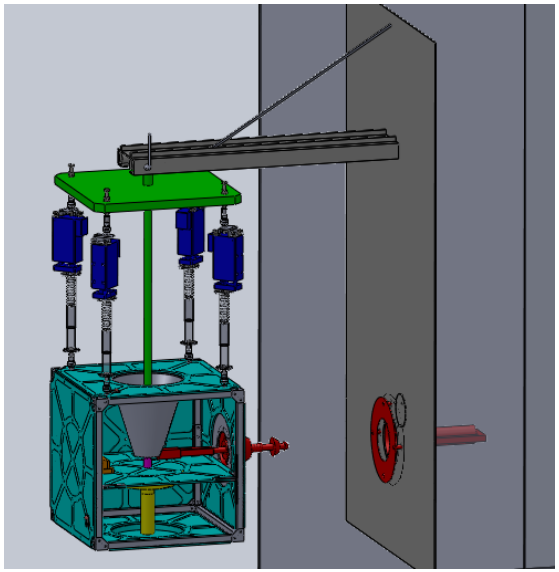
CONCEPT (Selection Workshop)

SCRAT



- **Due serbatoi** (Attuatore e “Dummy”)
- Sistema di misura **flessionale**
- Proximity Box = “scatola chiusa”

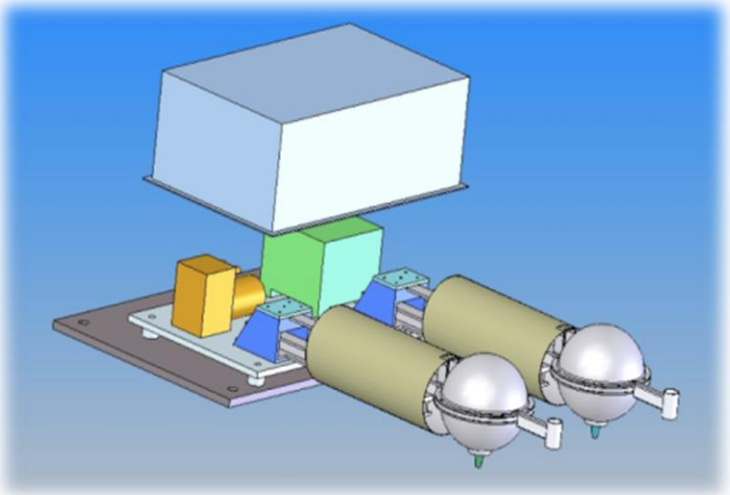
ARCADE



- **4 gdl** (1 traslazione + 3 rotazioni)
- SMAV ‘‘ appeso’’

DESIGN PRELIMINARE (PDR)

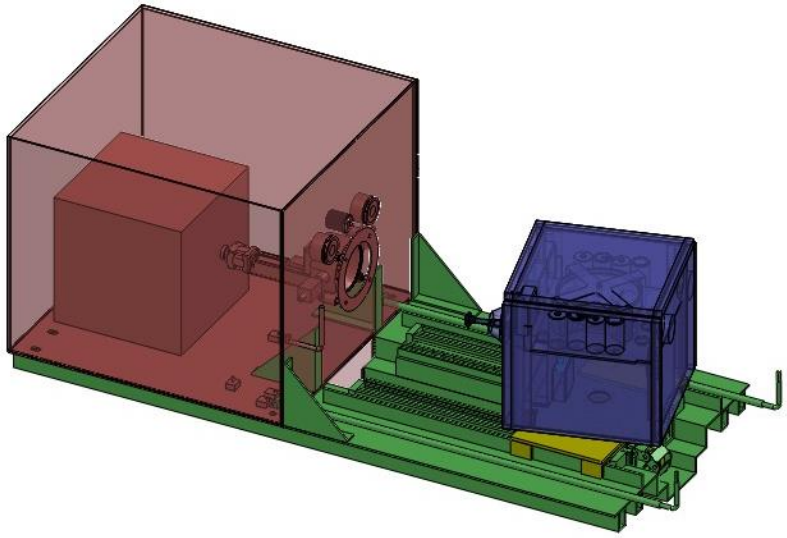
SCRAT



- **Due serbatoi** (Attuatore e “Dummy”)
- Sistema **flessionale** con protezione
- Proximity Box = primo concetto

  (1 compressore, schede elettroniche)

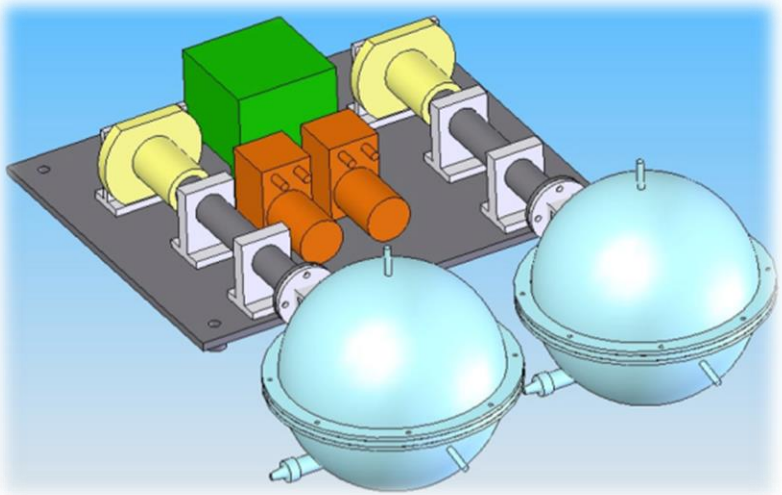
ARCADE



- **2 gdl** (1 traslazione e 1 rotazione)
- Struttura di supporto molto più robusta (maggiore sicurezza)
- Definizione configurazione di ogni sottosistema (navigazione, docking, controllo, potenza, sensori ambientali)

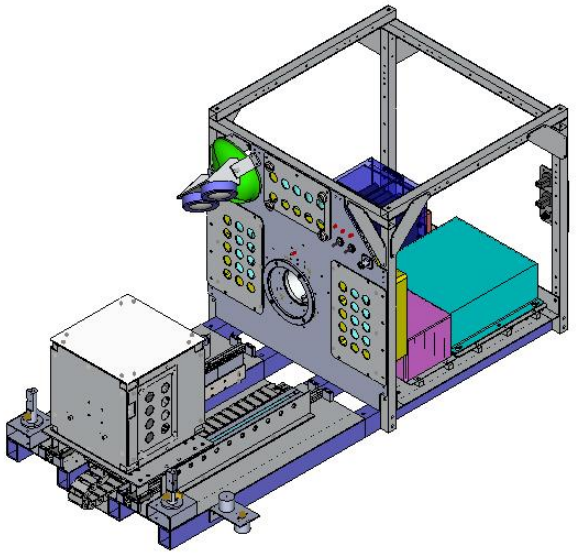
DESIGN FINALE (CDR)

SCRAT



- **Due serbatoi** (Attuatore e “Dummy”)
- Sistema di misura **torsionale**
- Proximity Box: 2 compressori

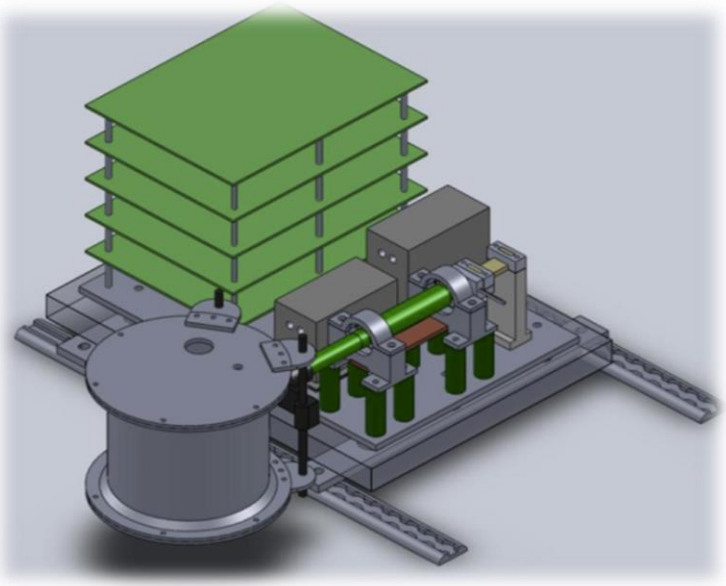
ARCADE



- **2 gdl**
- Design dettagliato di ogni sottosistema

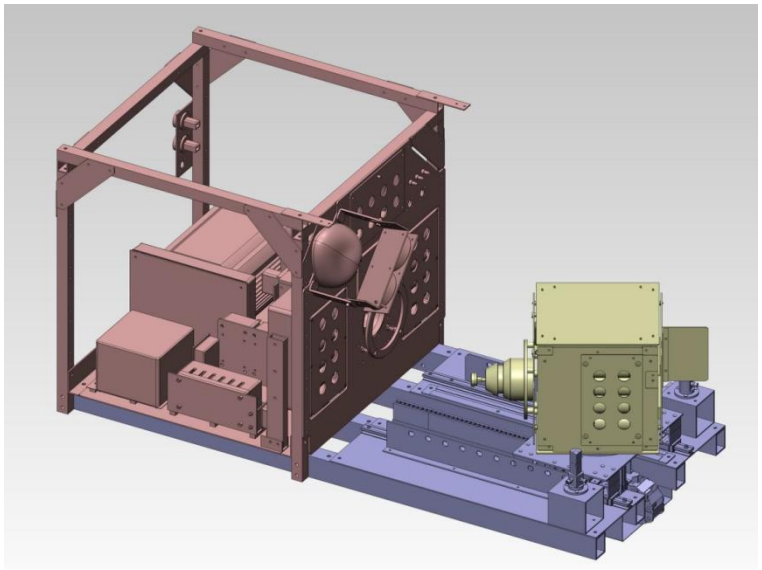
TEST (IPR)

SCRAT



- **Un solo serbatoio**
- Sistema di misura **torsionale**
- Proximity Box = schede elettroniche reali

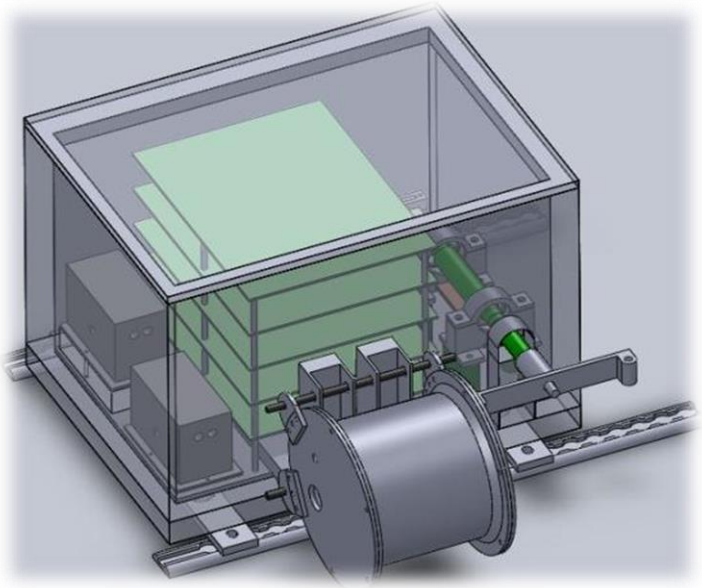
ARCADE



- **2 gdl**
- Design dettagliato di ogni sottosistema
- Aggiunta della pinna dello SMAV

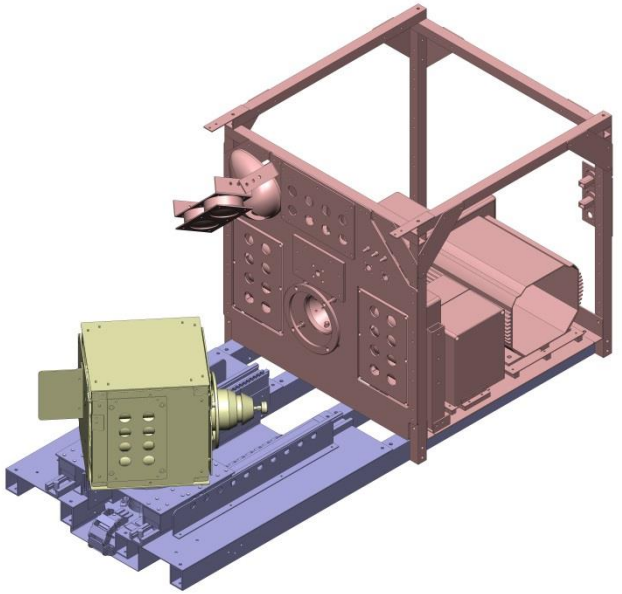
ACCETTAZIONE (EAR)

SCRAT



- **Un solo serbatoio**
- Sistema di misura **torsionale**
- Proximity Box = schede elettroniche reali

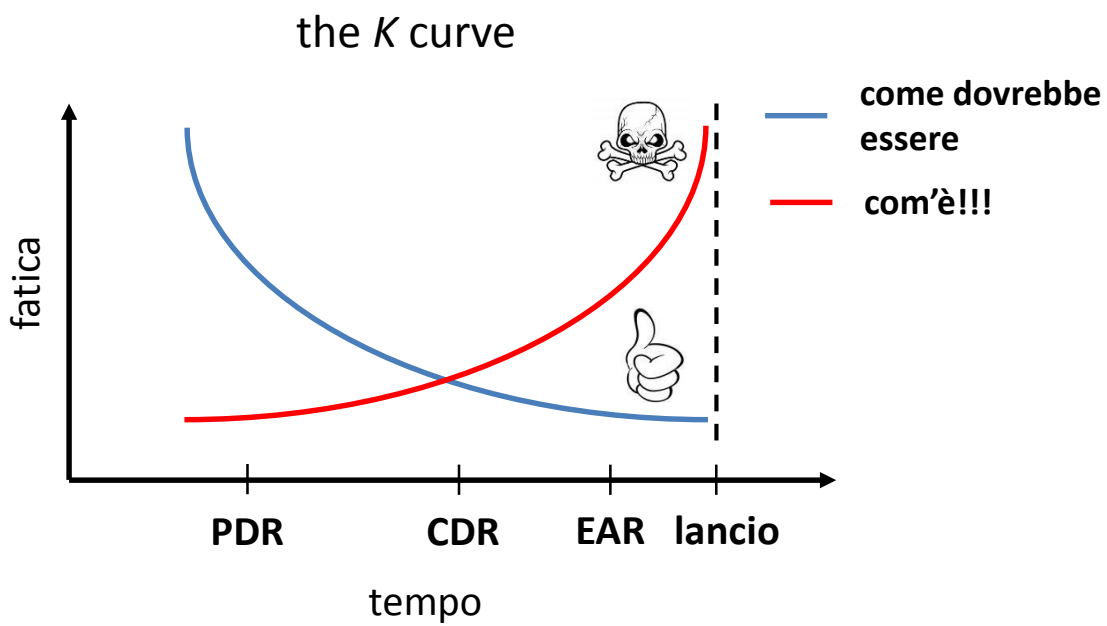
ARCADE



- **2 gdl**
- Design dettagliato di ogni sottosistema
- Nuove guide lineari e relativi carrelli

CONSIDERAZIONI

- Cominciare fin da subito!



- Avere sempre un piano B
- Tanta **esperienza pratica** → TESI SPERIMENTALE
- TANTO lavoro… ma anche TANTO DIVERTIMENTO!

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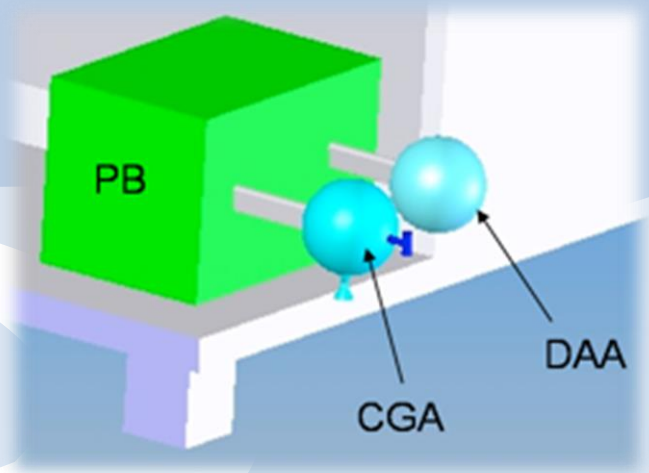
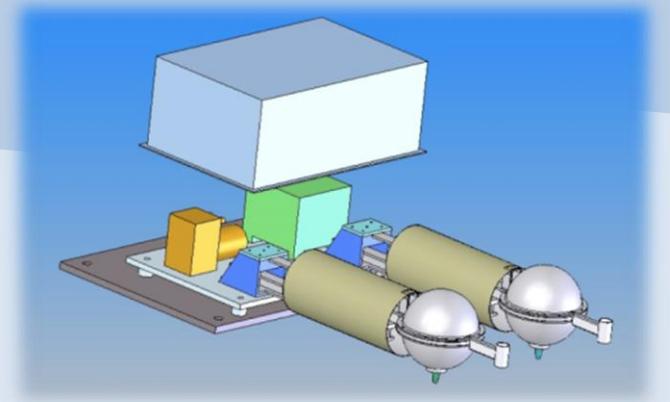
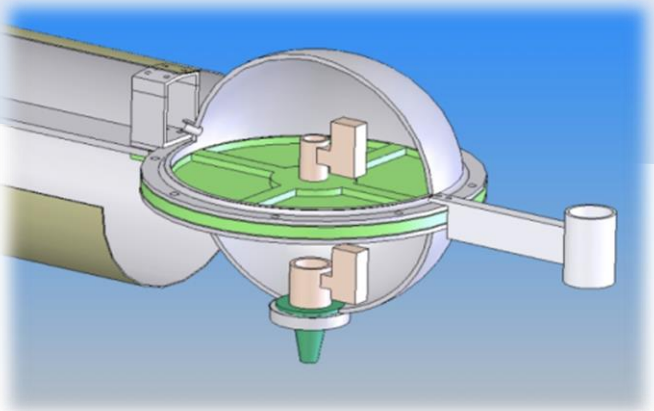
Proposal

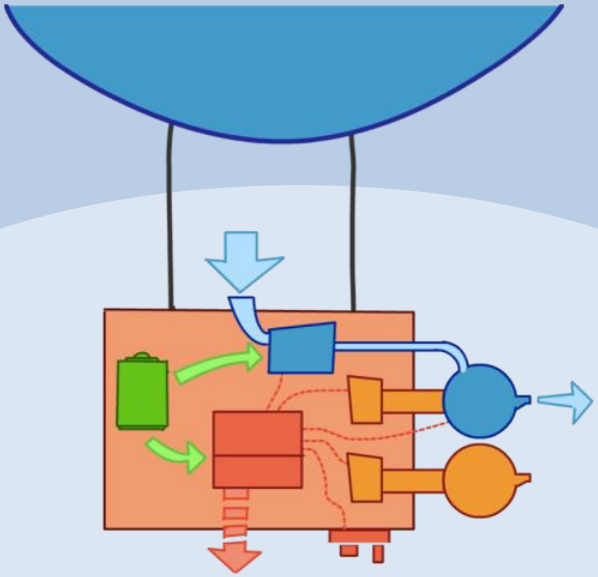


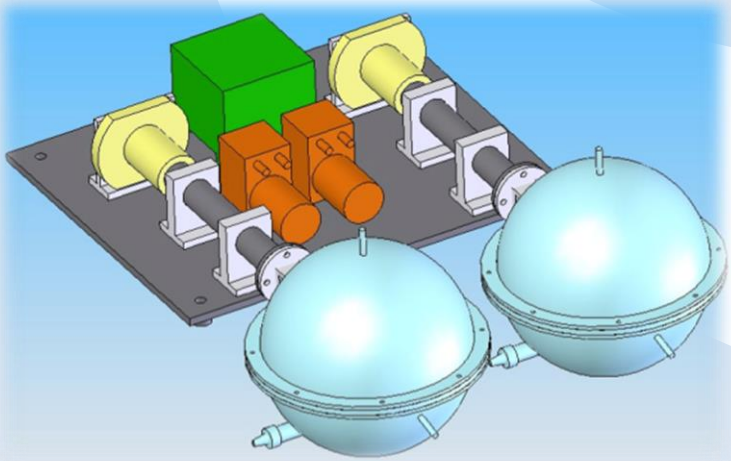
Selection Workshop



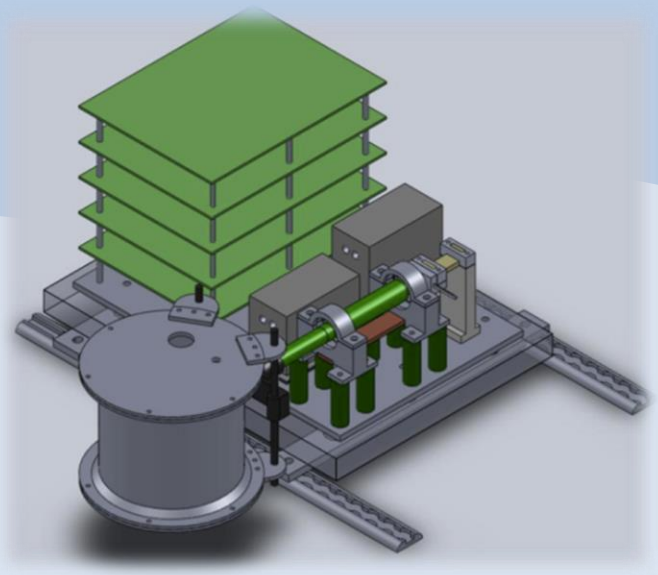


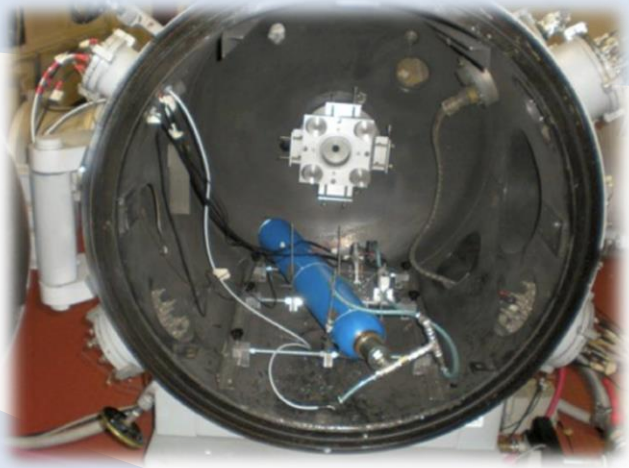
Preparing PDR



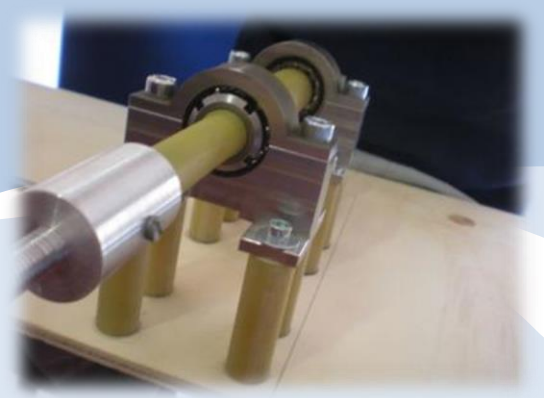


Working For CDR

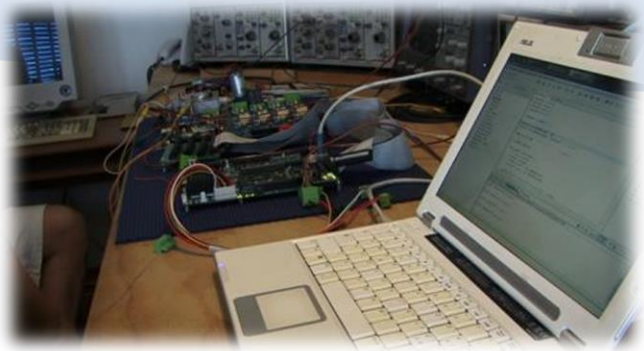


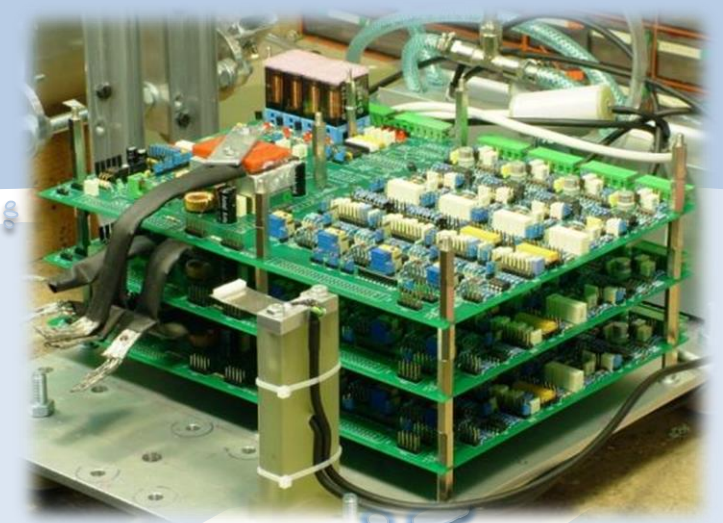


Machining
And First tests

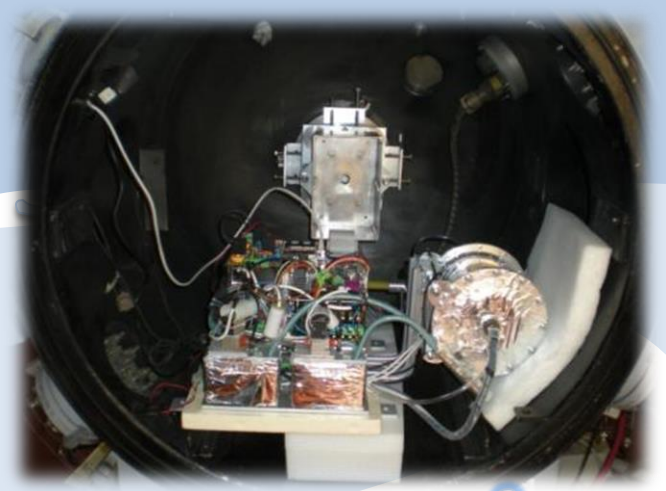


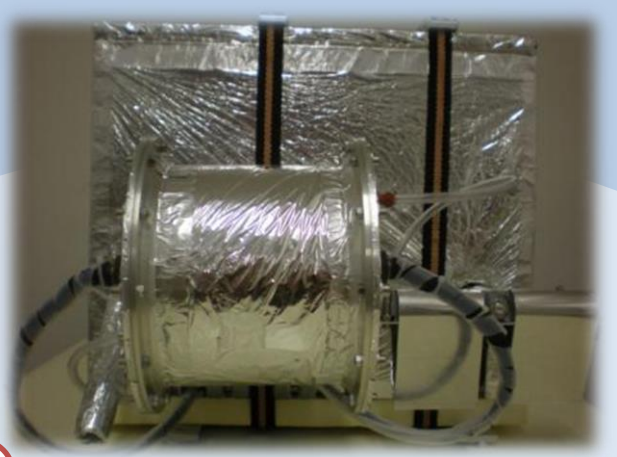
Assembling
And testing





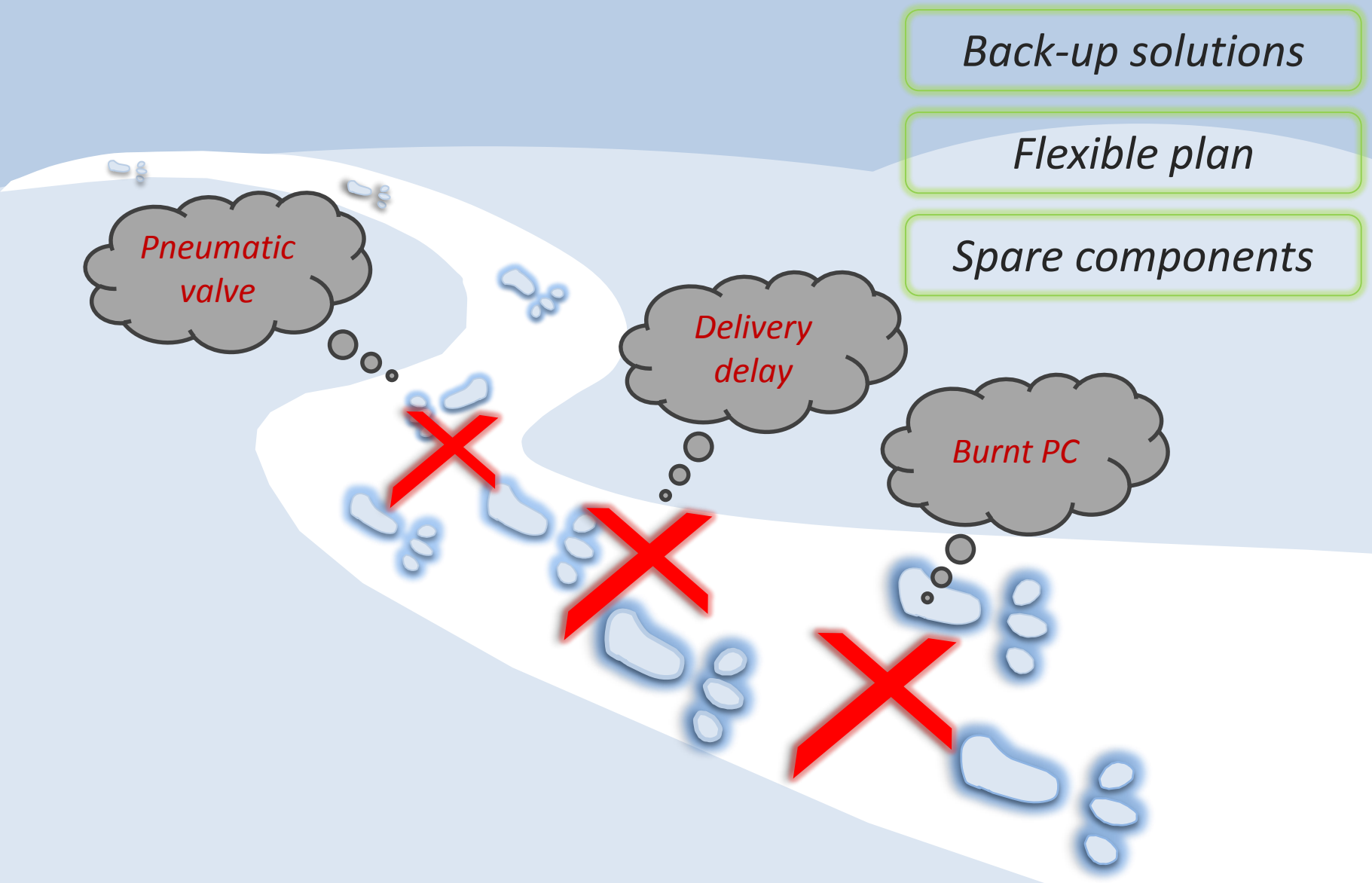
Final Integration

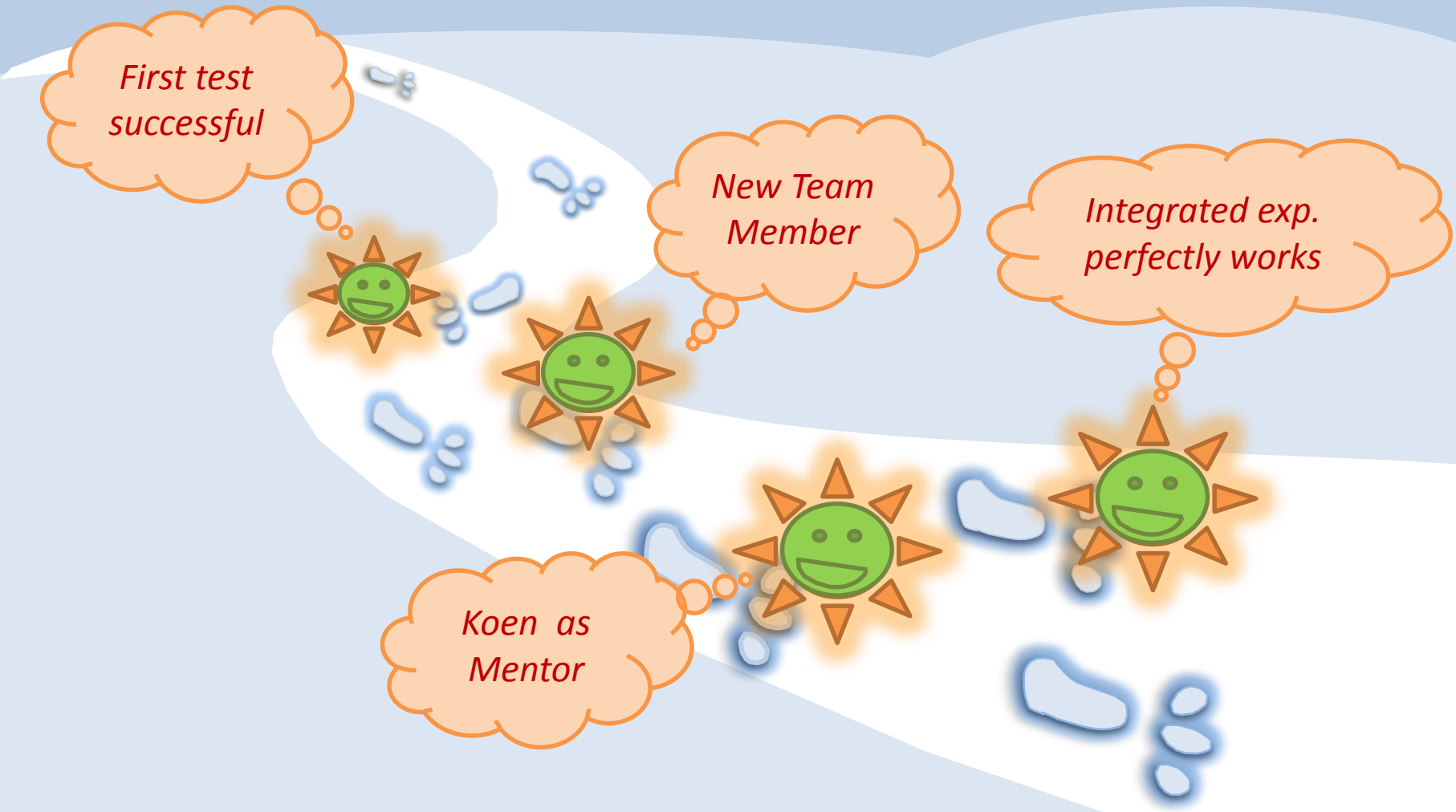




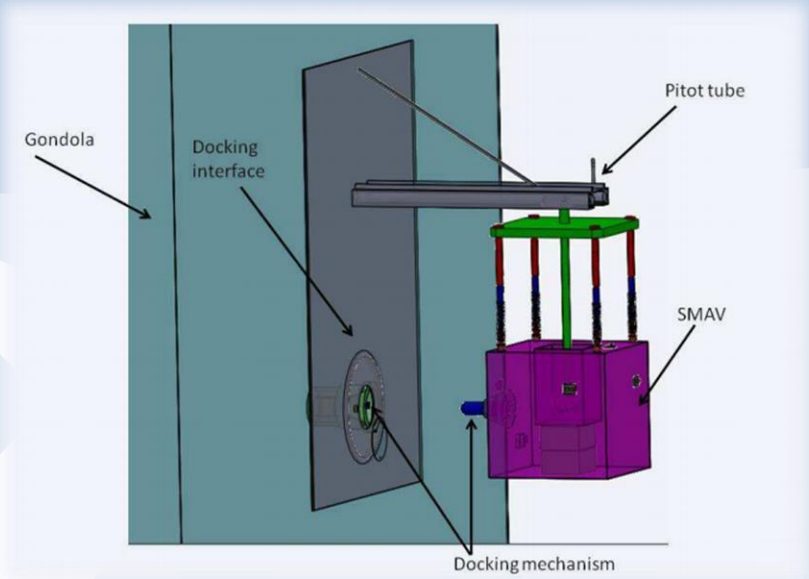
Preparing for launch

Experiment qualified ☺

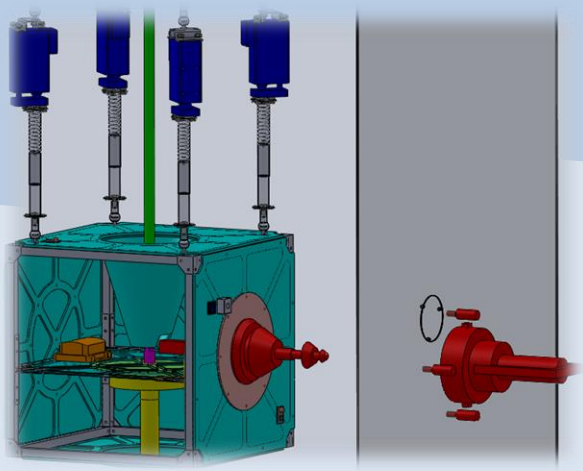

Back-up solutions
Flexible plan
Spare components
Pneumatic valve
Delivery delay
Burnt PC

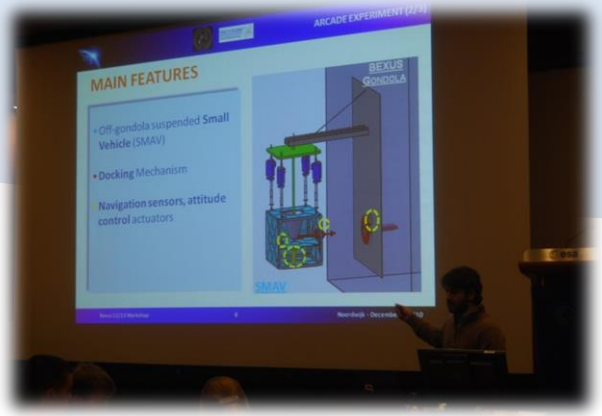

First test successful
New Team Member
Integrated exp. perfectly works
Koen as Mentor

Proposal

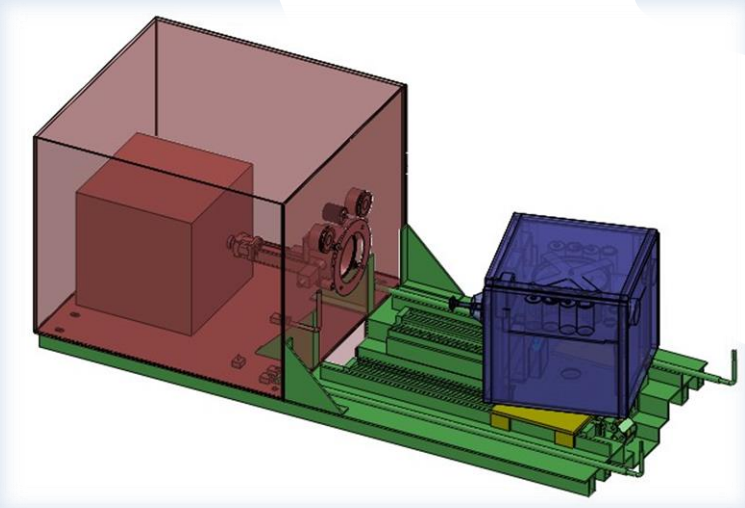

Gondola
Docking interface
Pitot tube
SMAV
Docking mechanism

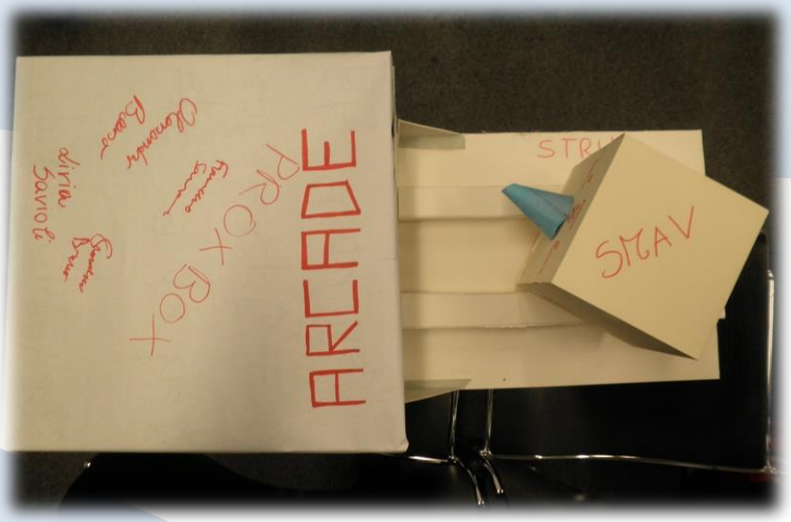
Selection Workshop



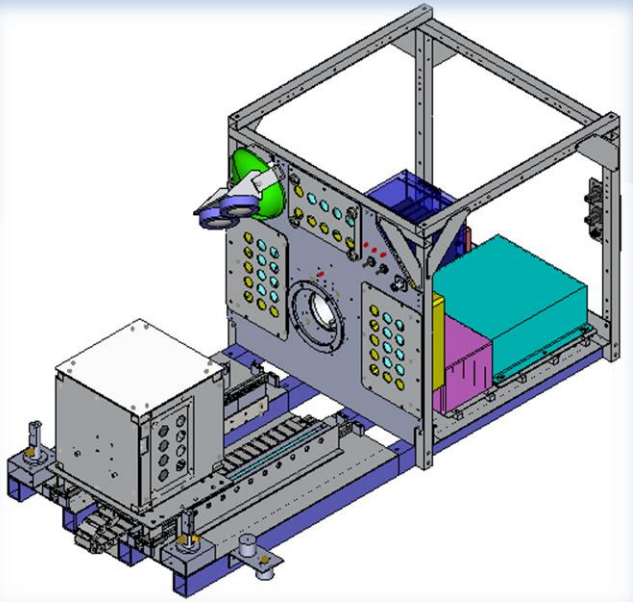


PDR



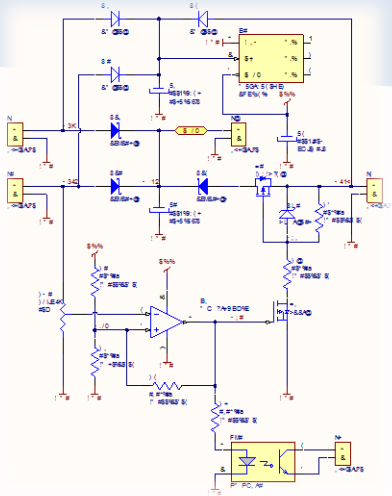


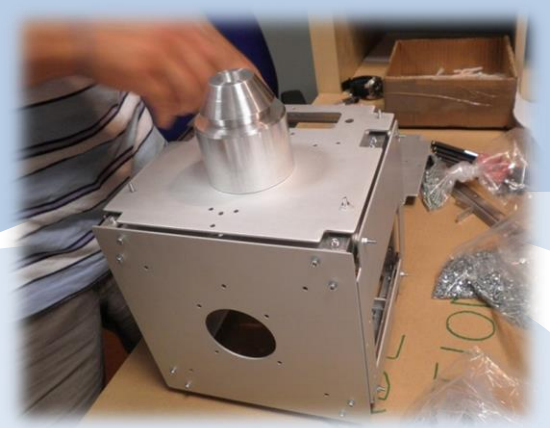
Towards CDR…



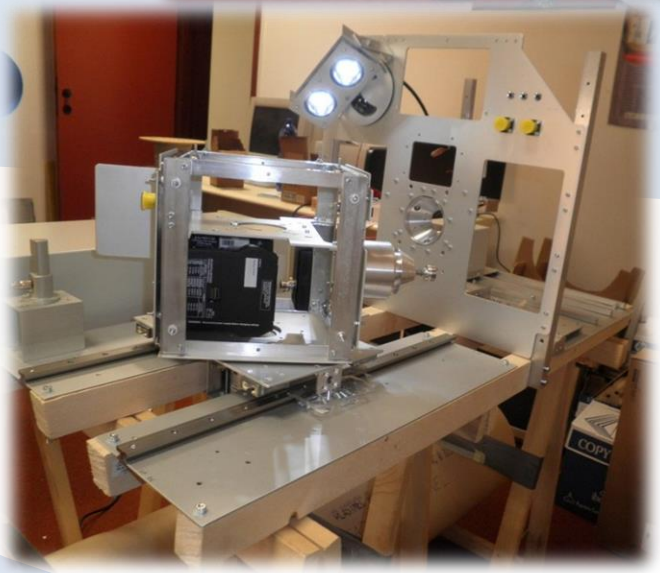

ARCADE EXPERIMENT

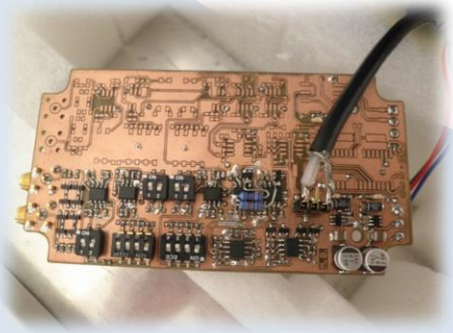

Experiment ARCADE
*** Playing Tetris just a step from space ***
Home
News
Our Mission
Roadmap
Tech
Team
Photos
Contact Us
Site Map
Welcome to the official website of the ARCADE Experiment!
* CURRENT PROJECT PHASE:
Phase B, Advanced Design
* NEXT MILESTONE:
Critical Design Review (CDR)
19-20 May 2011 – ESA/ESTEC
*** LATEST NEWS ***
SEARCH
COUNTDOWN...
RANDOM PICTURES...

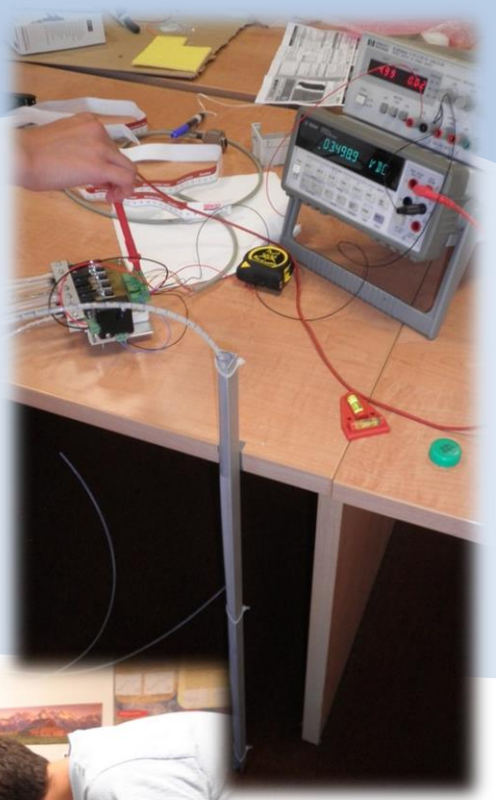




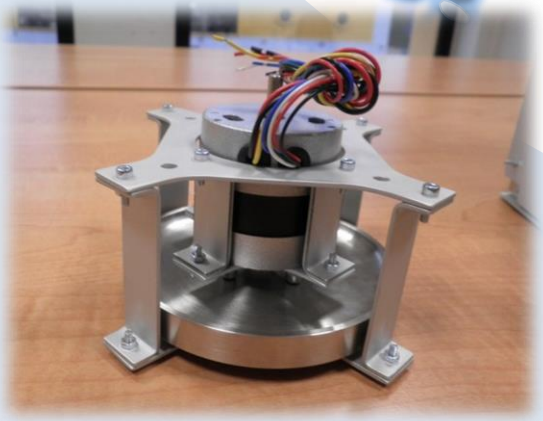
Start assembling and testing…

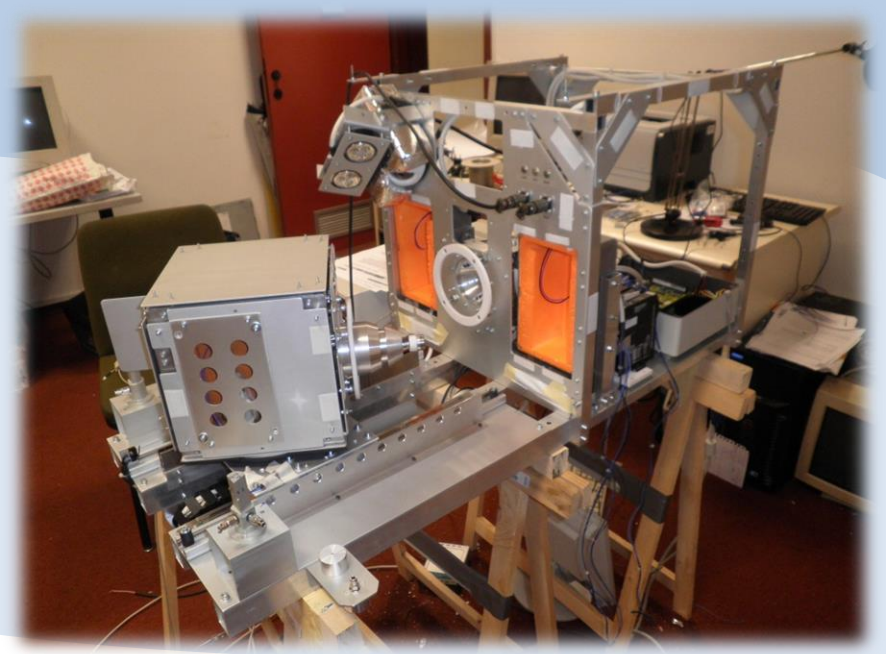




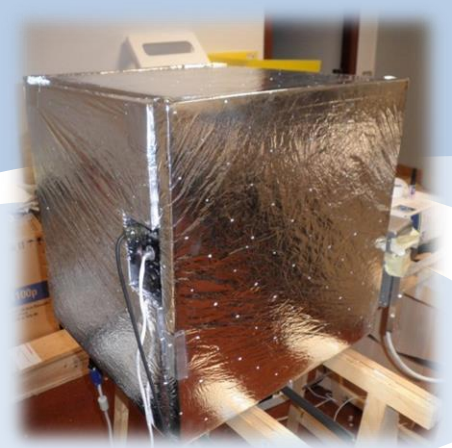


Test test test!

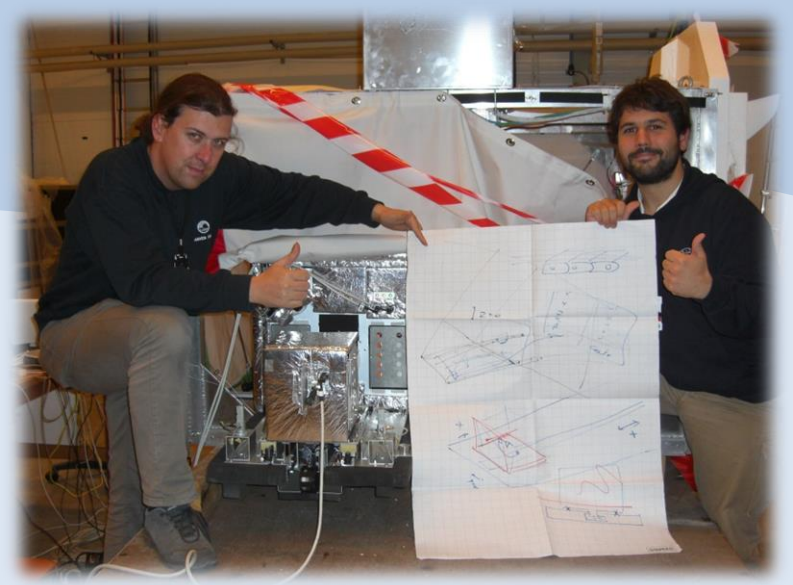




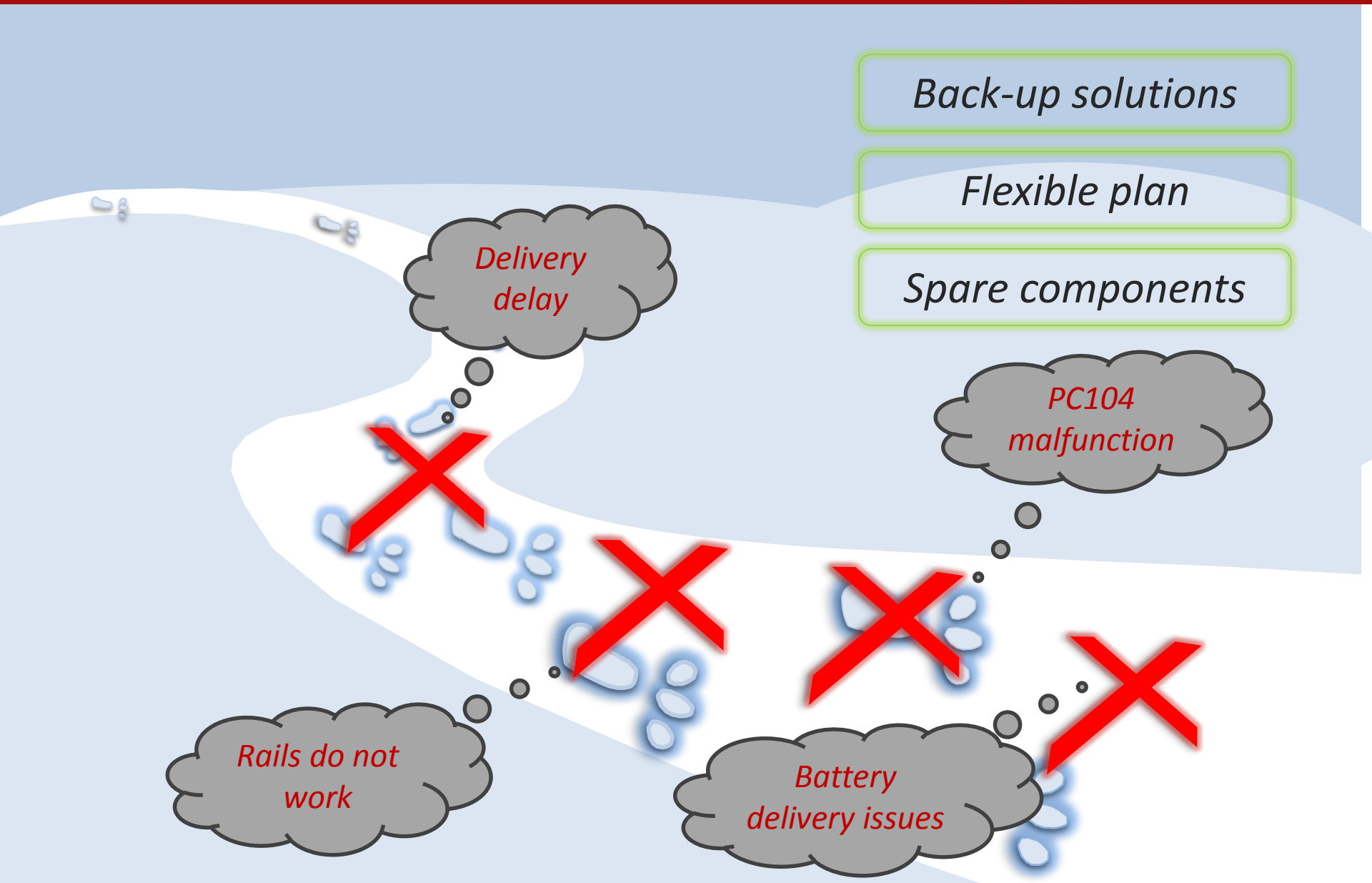
EAR

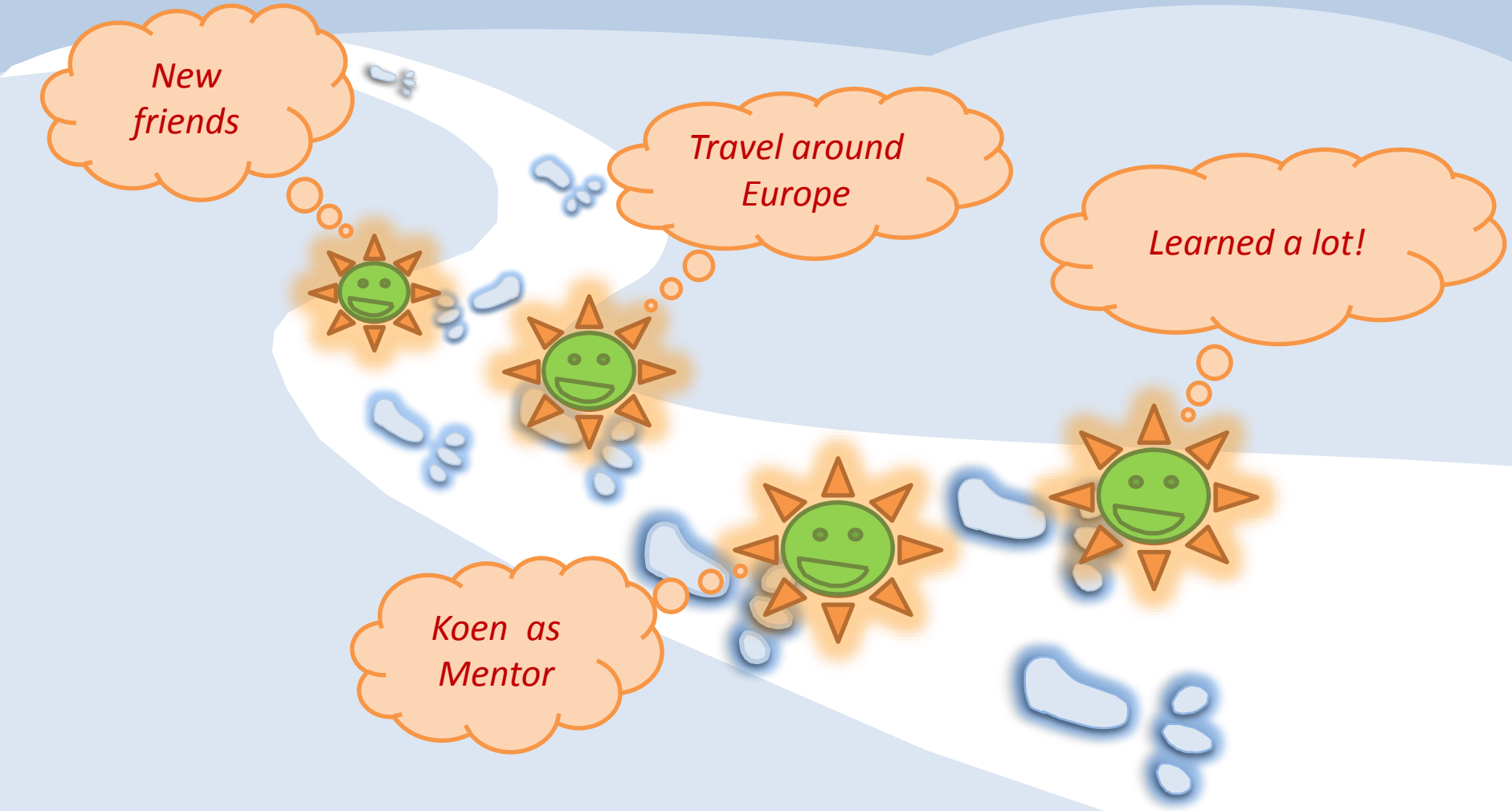


Packing and getting ready for launch campaign



Ready to roll out!!!


Back-up solutions
Flexible plan
Spare components
Delivery delay
PC104 malfunction
Rails do not work
Battery delivery issues


New friends
Travel around Europe
Learned a lot!
Koen as Mentor

L'ESPERIENZA *REXUS-BEXUS*

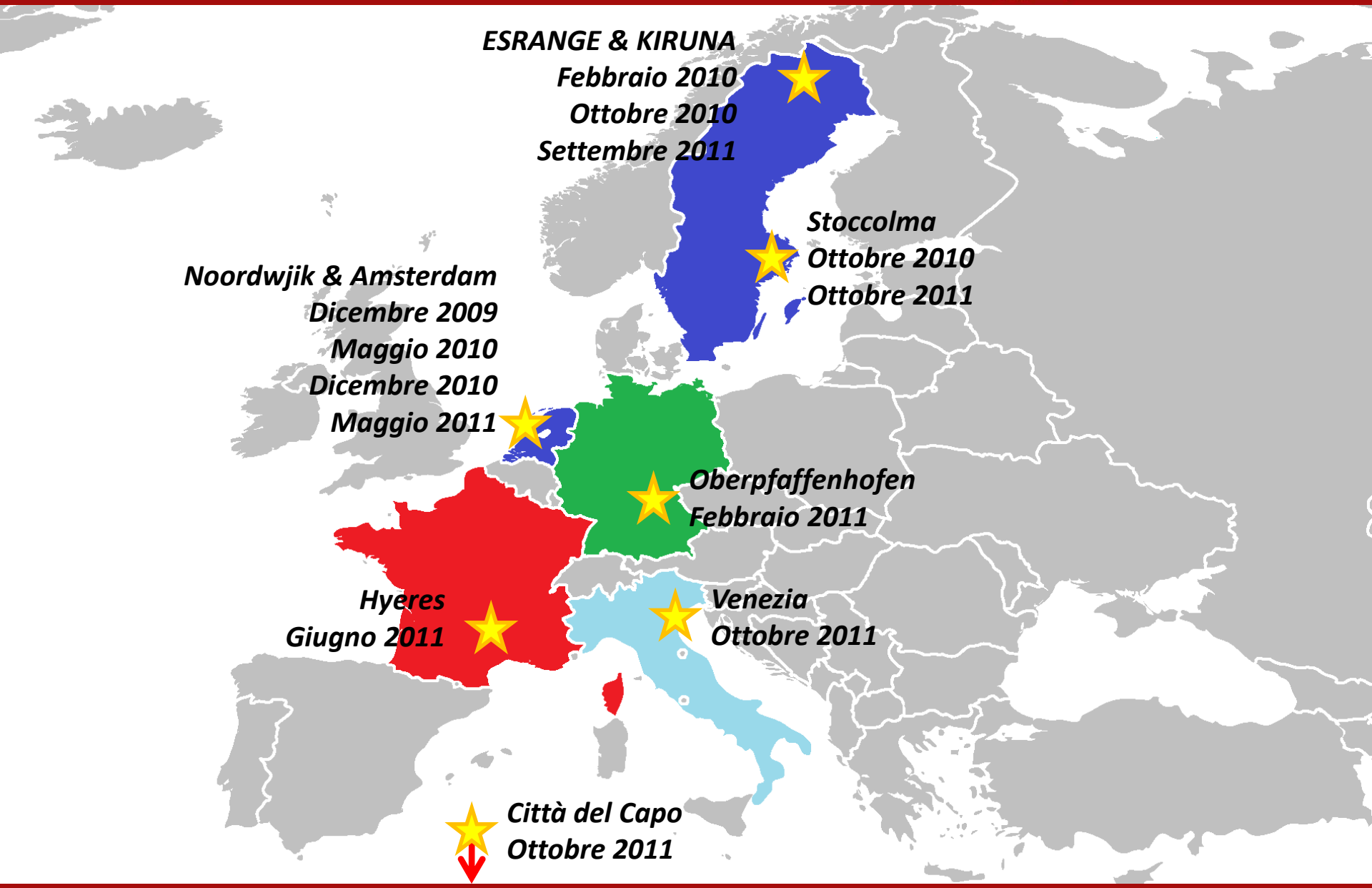
CONTRO	PRO
Meno tempo per i tuoi amici…	*Amici da tutta Europa!*
Sacrificare il tempo libero…	*In giro per l'EUROPA!*
Meno tempo per gli esami…	*Tanta più esperienza nel settore!*
Lavorare anche di notte…	~~*Spuntini di mezzanotte in lab!*~~
Un duro lavoro…	*Una vera missione spaziale!*






YALE


Esrange
esa


ESRANGE & KIRUNA
Febbraio 2010
Ottobre 2010
Settembre 2011
Stoccolma
Ottobre 2010
Ottobre 2011
Noordwjik & Amsterdam
Dicembre 2009
Maggio 2010
Dicembre 2010
Maggio 2011
Oberpfaffenhofen
Febbraio 2011
Hyères
Giugno 2011
Venezia
Ottobre 2011
Città del Capo
Ottobre 2011

NEO-LAUREATO

DOTTORANDI, CISAS

LAVORA, (Germania)

DOTTORANDO, ASTRONOMIA

Matteo

Giulio

LAVORA, (Provincia di BO)

Michele

Lorenzo

Leonardo

LAVORA, (Padova)

Marco

Ruggero

LAVORA, (Provincia di VE)

Gabriele

Federico

LAVORA, (Padova)

Antonio


Esrange

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- Il programma ***REXUS-BEXUS***
- 2010: L'esperimento **SCRAT**
- 2011: L'esperimento **ARCADE**
- **Proporre** un esperimento: ARCADE
- **Sviluppo** in parallelo
- Passo dopo passo: **fatiche e soddisfazioni**
- I **lanci**
- E ora? **ARCADE-R2**
- **Conclusioni**

LA CAMPAGNA DI LANCIO

- Verso fine settembre / inizio ottobre
- Test pre-volo: accensione, radiofrequenze, ecc…
- Procedure di accesso all'esperimento sulla gondola
- Campagne di Lancio:
  - SCRAT
  - ARCADE

SCRAT:

La Campagna di Lancio


Gondola piccola
Gondola grande
SCRAT

Verso il pad di lancio

Ultimo check

Pallone pronto per essere gonfiato

IL COUNTDOWN

- 10:00 pm 8 October: countdown start
- 1:30 am 9 October: SCRAT viene acceso
- 2:30 am: inizio gonfiaggio pallone
- 3:07 am: decollo

FINALLY!

Il pallone prende il volo

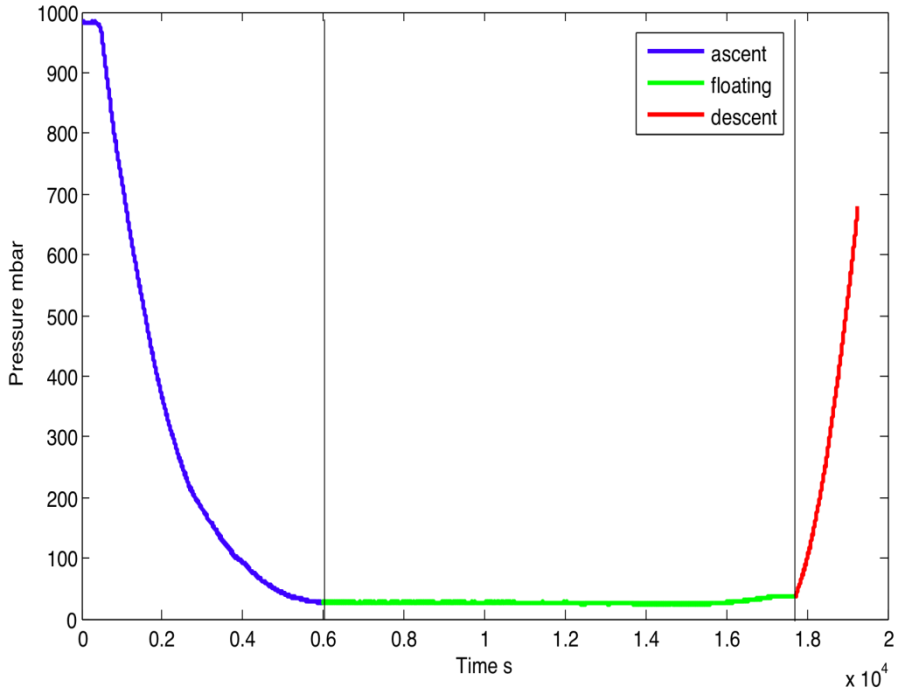
L’ Aurora Boreale accompagna il volo del pallone

Primi risultati alla Ground Station

SCRAT: RISULTATI (1)

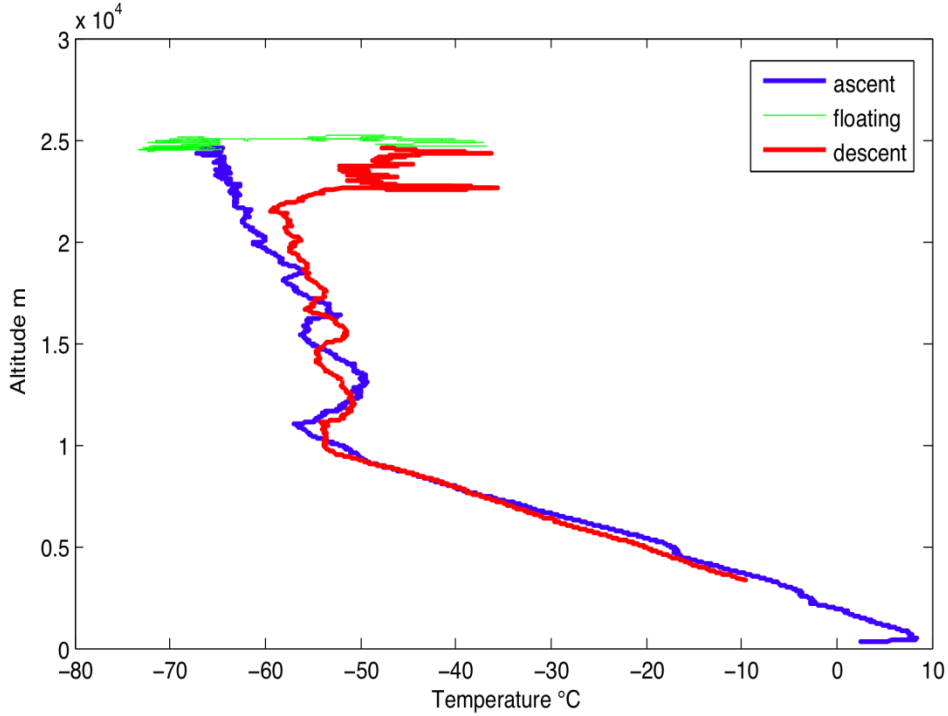
--> Campionamento dell'atmosfera a varie quote

Pressione atmosferica



Pressione minima 23±4 mbar

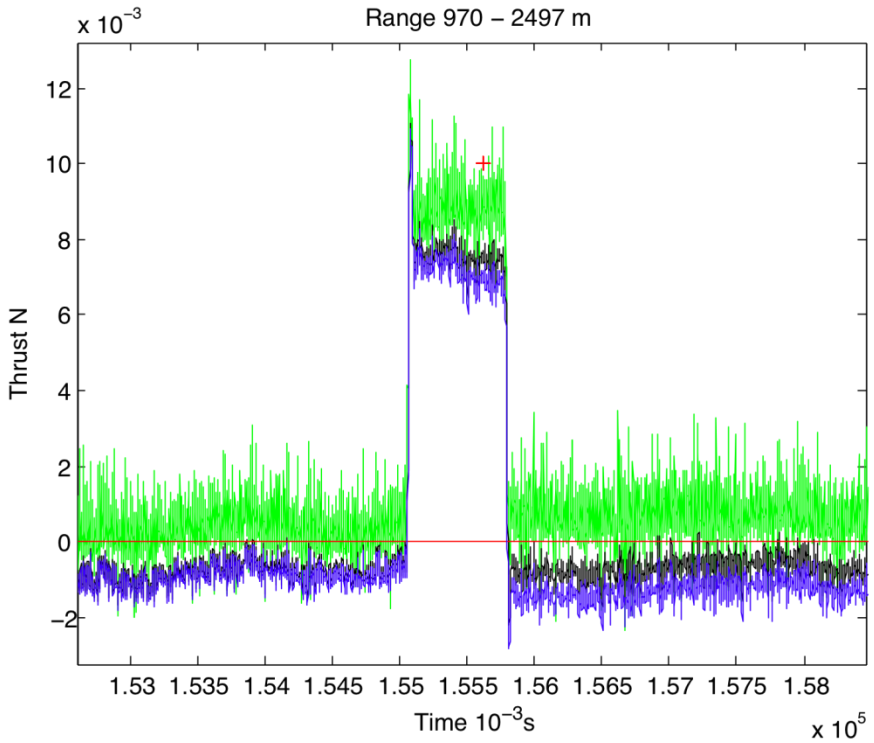
Temperatura atmosferica

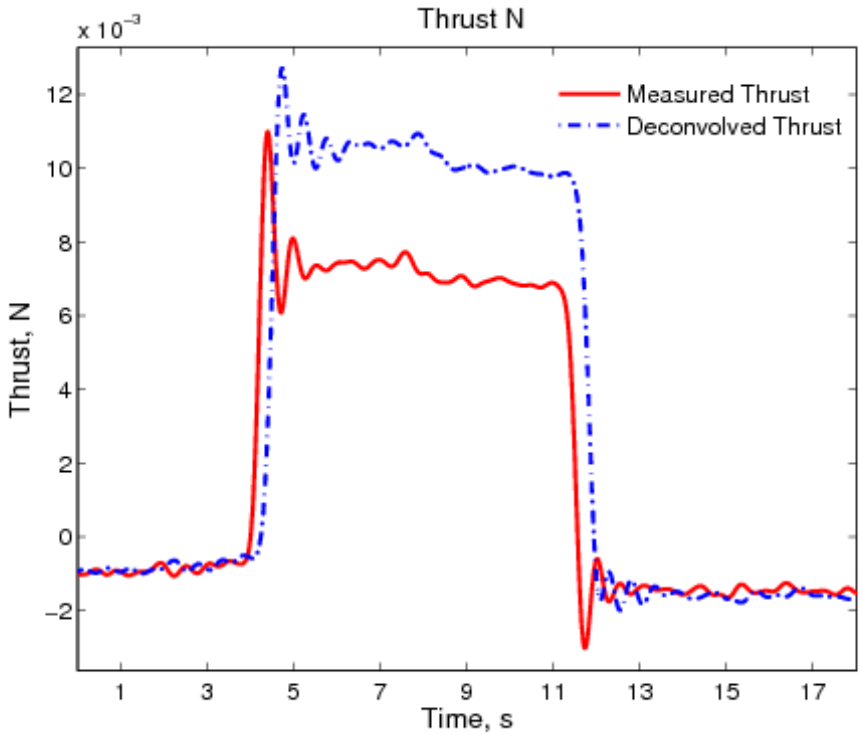


Temperatura minima -71±1 ° C

SCRAT: RISULTATI (2)

--> 101 spinte rilevate, comprese tra 10^{-1} N (al suolo) e 10^{-4} N (20 km)





Dati acquisiti in volo → **Profilo di spinta reale**

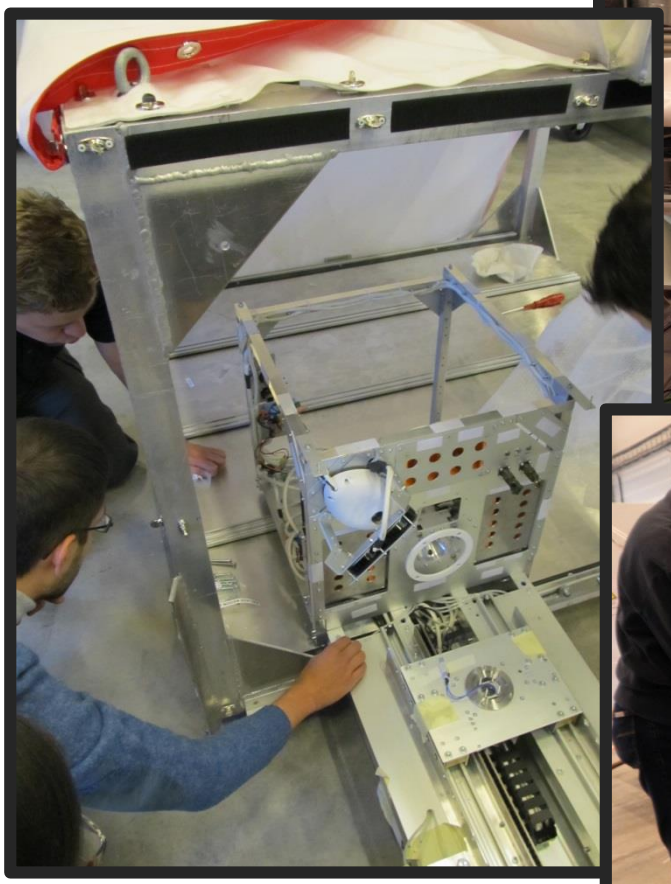
↑

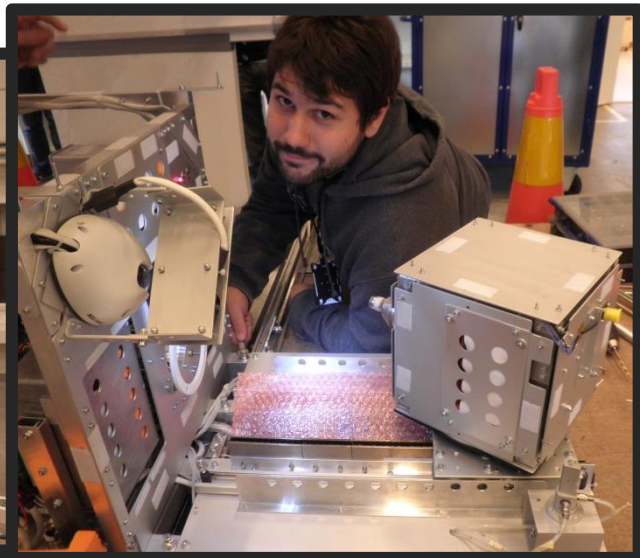
Modello Numerico

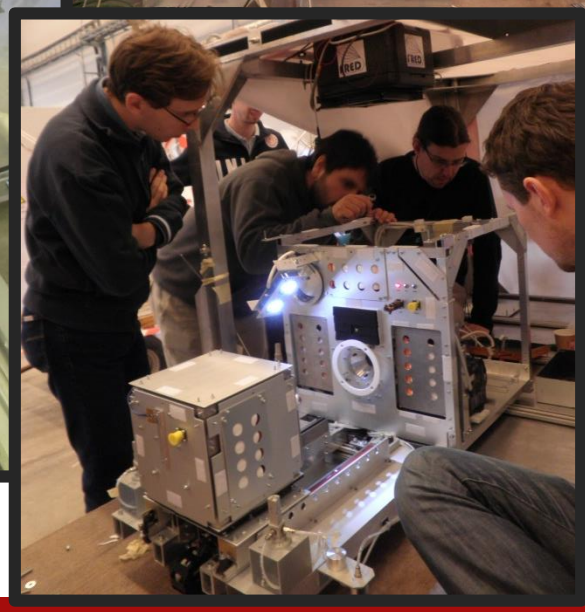
ARCADE

La campagna di lancio

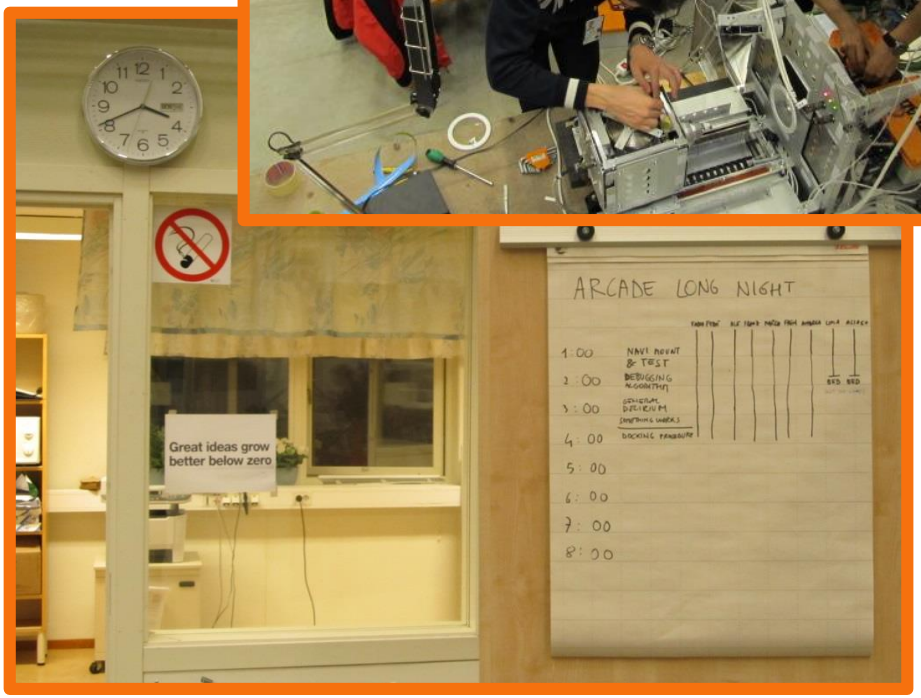
L'esperimento viene montato sulla gondola

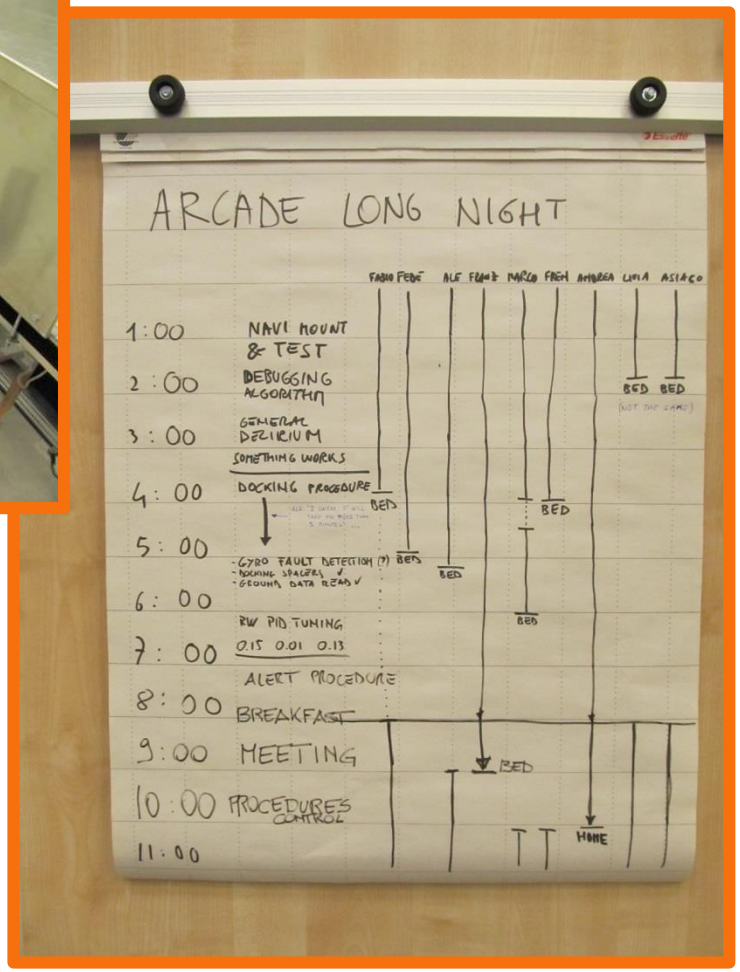






Ci sono da sistemare ancora un po' di dettagli…





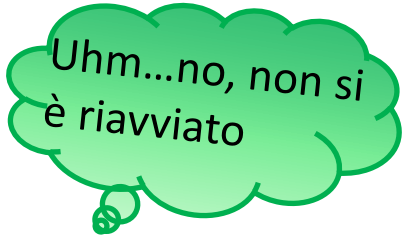
Il giorno è arrivato: il lancio!!!!

Il pallone viene rilasciato

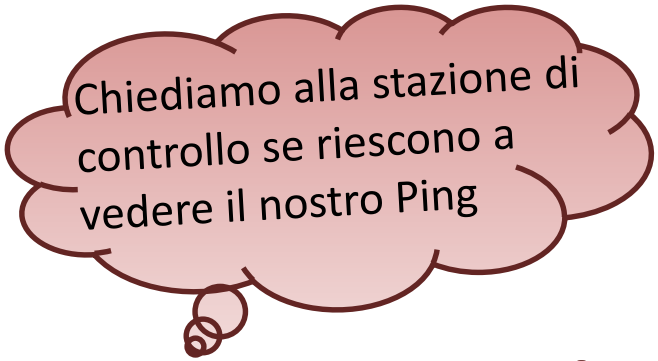
La gondola si solleva

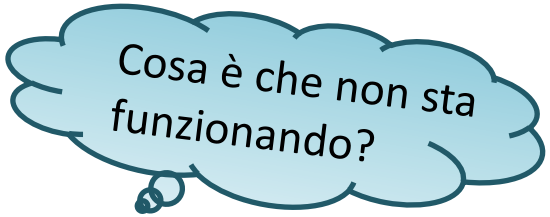
In volo

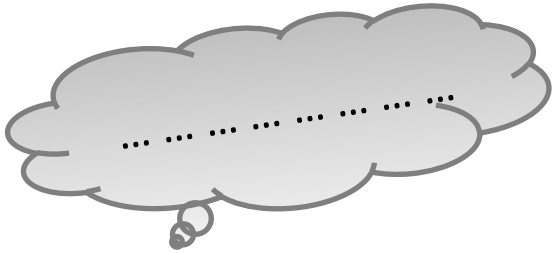
Durante il volo…qualcosa va storto!!!!!



…Il tempo passa e non accade nulla…







T + 5h: cutdown… il volo è concluso!!!

Cosa ci è rimasto…

Nei giorni immediatamente dopo…

Dispiacere

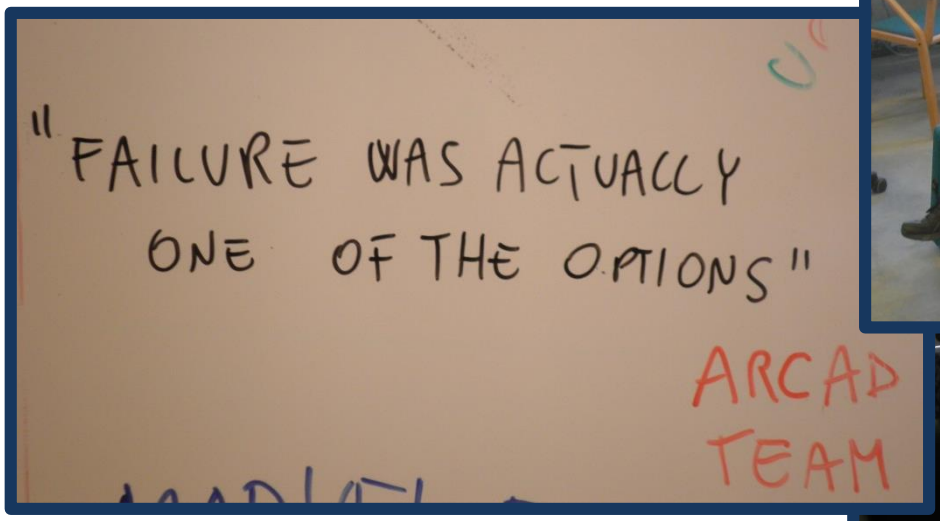
Sconforto

Amarezza

Delusione

Un vuoto dentro

Stanchezza



Cosa ci è rimasto…

Qualche tempo dopo…

Abbiamo partecipato a tutte le fasi di una vera missione spaziale…'in miniatura'

Abbiamo conosciuto esperti delle principali agenzie spaziali europee e instaurato con loro un rapporto sia professionale…


Koen


Mark

Cosa ci è rimasto…

Qualche tempo dopo…

Abbiamo partecipato a tutte le fasi di una vera missione spaziale…'in miniatura'

Abbiamo conosciuto esperti delle principali agenzie spaziali europee e instaurato con loro un rapporto sia professionale… sia umano…

Cosa ci è rimasto…

Qualche tempo dopo…

Abbiamo partecipato a tutte le fasi di una vera missione spaziale…'in miniatura'

Abbiamo conosciuto esperti delle principali agenzie spaziali europee e instaurato con loro un rapporto sia professionale… sia umano…

Abbiamo imparato cose che sui libri non si trovano: lavorare in gruppo, risolvere i problemi, ingegnarsi quando le risorse sono limitate…

Siamo stati in posti in cui forse non saremmo mai andati e visto panorami davvero unici

Un centro dell'ESA

Il DLR, uno dei centri di robotica più all'avanguardia

ESRANGE: una base per lanci in stratosfera e nello spazio

Cosa ci è rimasto…

Qualche tempo dopo…

Abbiamo partecipato a tutte le fasi di una vera missione spaziale…'in miniatura'

Abbiamo conosciuto esperti delle principali agenzie spaziali europee e instaurato con loro un rapporto sia professionale… sia umano…

Abbiamo imparato cose che sui libri non si trovano: lavorare in gruppo, risolvere i problemi, ingegnarsi quando le risorse sono limitate…

Siamo stati in posti in cui forse non saremmo mai andati e visto panorami davvero unici

Abbiamo conosciuto ragazzi da tutta Europa con cui condividere la stessa passione per lo spazio e…

…un bel piatto di pasta per socializzare di più!!!

E ora???

ARCADE-R2

Autonomous Rendezvous, Control And Docking Experiment – R2

Team Leader

M. Barbetta

Ext. support

A. Boesso

Members

F. Branz

A. Carron

L. Olivieri

J. Prendin

F. Sansone

L. Savioli

F. Spinello

Ci riproviamo???

Proposal

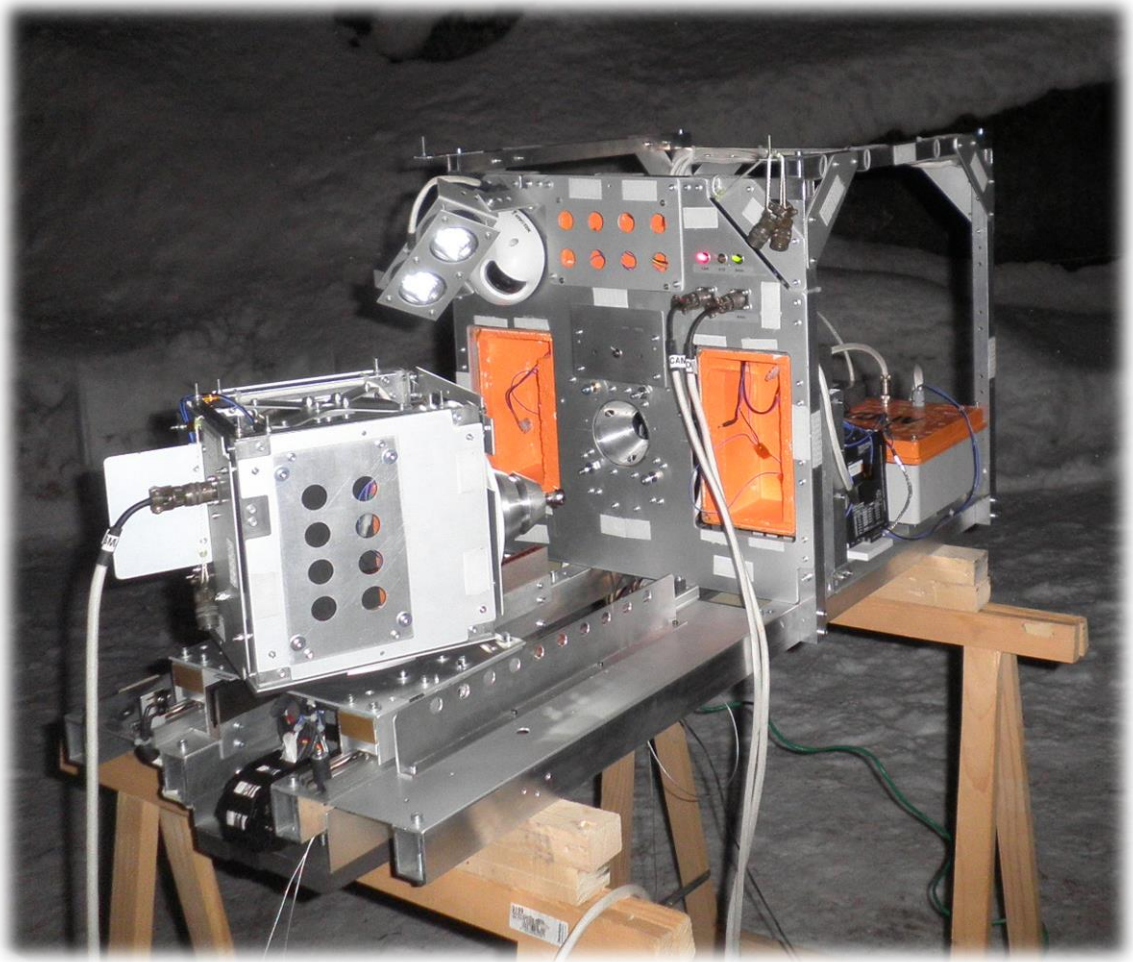
Selection Workshop

PDR

Dobbiamo ridurre la massa!!!

Ci stiamo lavorando

TEST AMBIENTALI A SAN VITO DI CADORE



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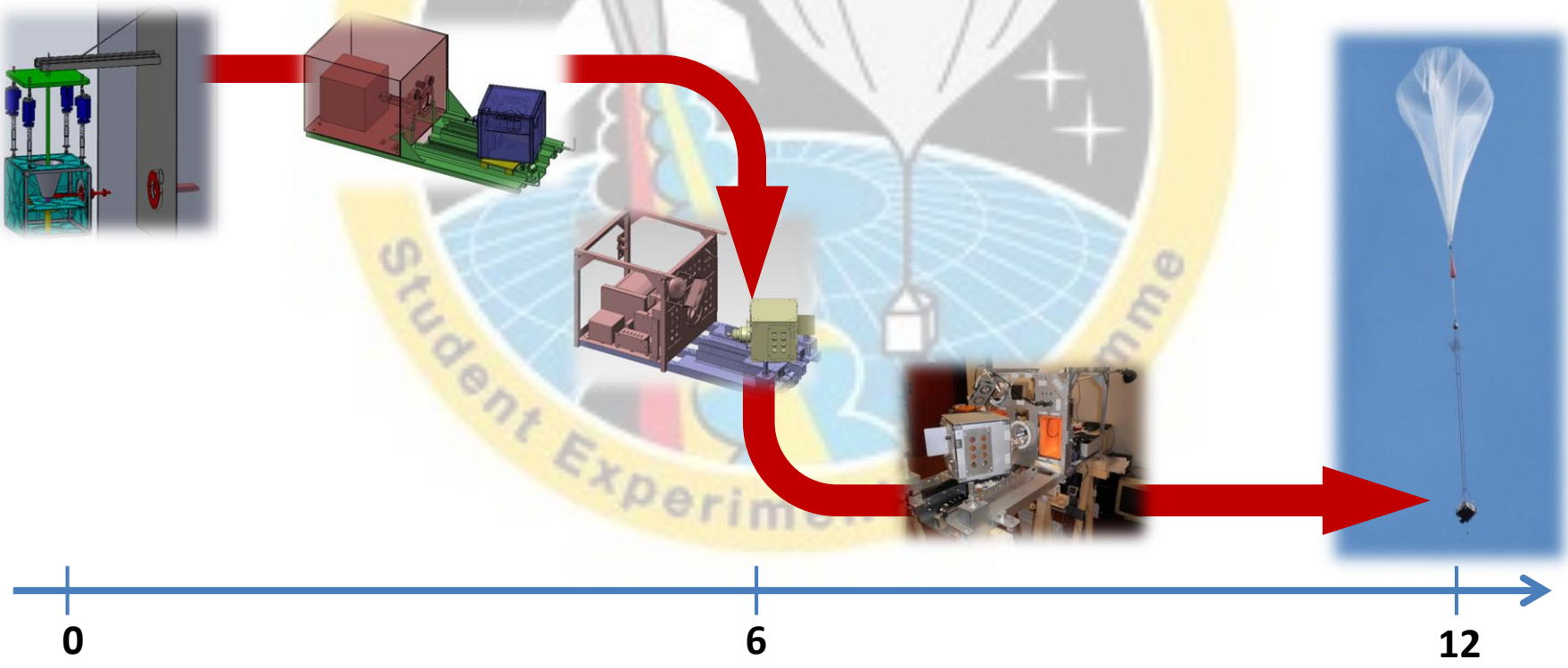
- **Conclusioni**

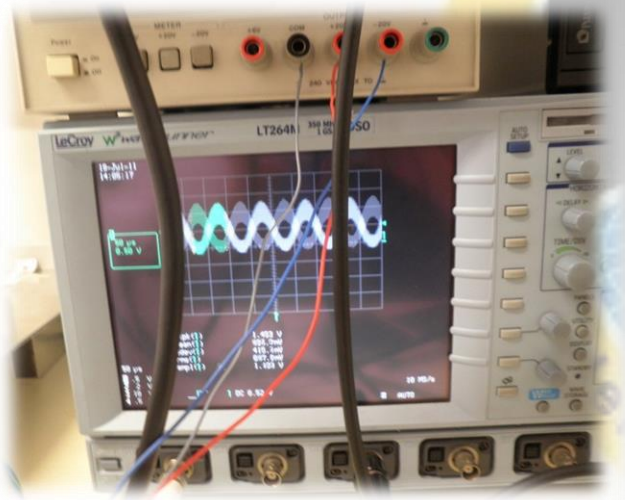
RIASSUMENDO…

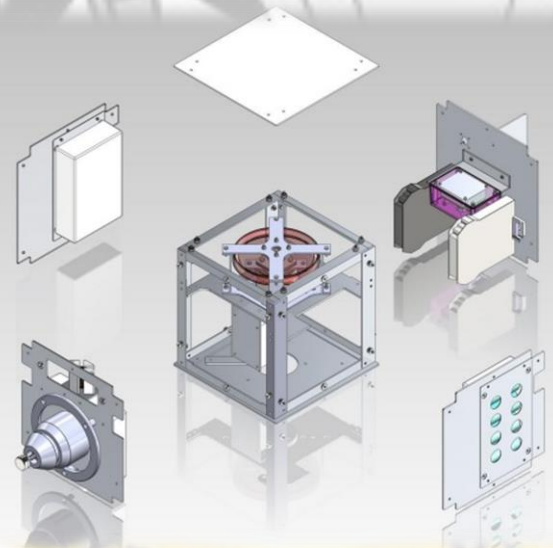
- REXUS/BEXUS è un'***occasione unica*** per partecipare allo sviluppo di un vero ***programma spaziale*** dal concetto al lancio

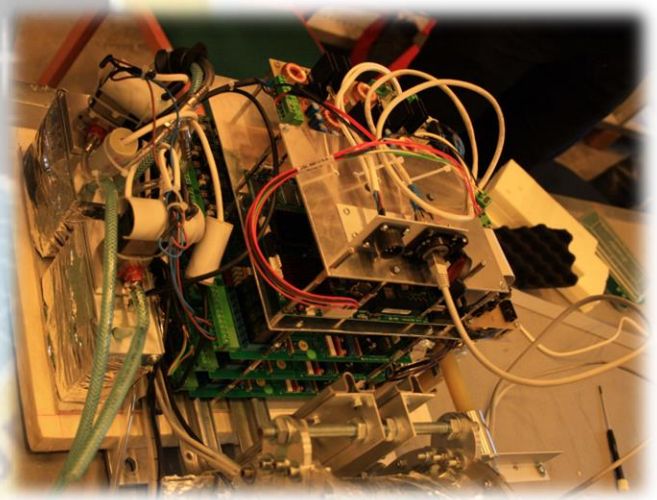


RIASSUMENDO…

- Si imparano cose nuove ***non si trovano sui libri*** e che a lezione non vi diranno







RIASSUMENDO…

- Collaborazione con ***esperti di varie agenzie spaziali*** europee (ESA, DLR, SNSB)

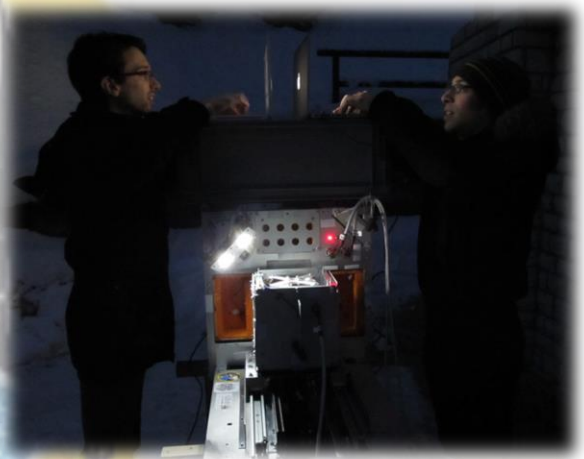
RIASSUMENDO…

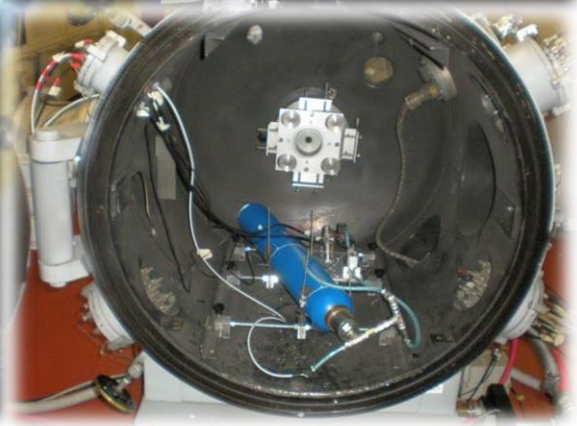
- Si incontrano ragazzi e ragazze ***da tutta Europa***

RIASSUMENDO…

- Tanto tanto **lavoro**…

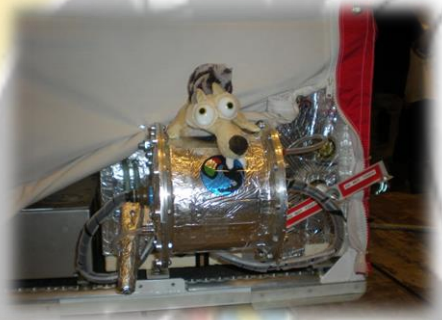




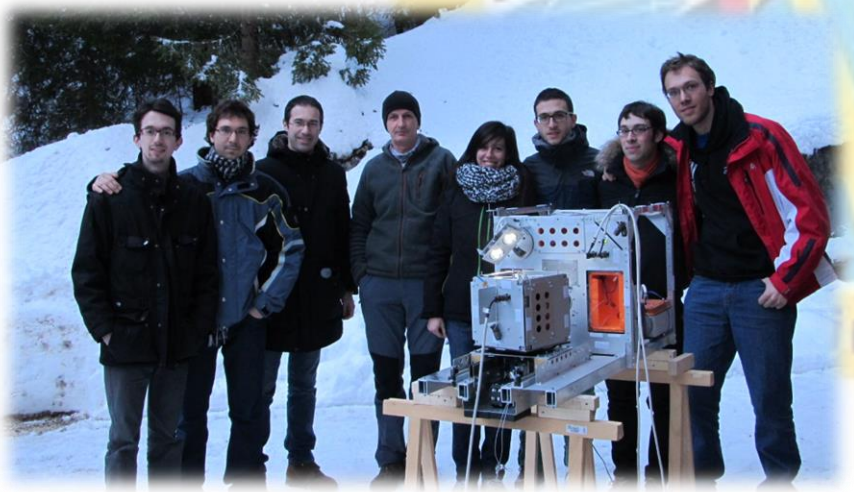


RIASSUMENDO…

- … ma anche ***tanto tanto divertimento***!



REXUS/BEXUS