REXUS/BEXUS

Experiment Proposal Form

Your text should be intelligible to scientists of various fields and engineers with a general scientific background. Before you submit your proposal, please ensure that you have read the **REXUS/BEXUS User Manuals** for more detailed information. The forms and the documents are available at www.rexusbexus.net. To submit your proposal to ESA, please register at www.joinspace.org and download this application form as a Word file. The completed form must be uploaded again before the deadline.

Team/Short experiment name	POLARIS
Full experiment title	POLymer-Actuated Radiator with Independent Surfaces

☐ **REXUS** ☒ **BEXUS**

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

Science & Organisation

Team Information	
Student team leader:	**Davide Paganini** [redacted] M. Sc. Student in Aerospace Engineering University of Padova (Italy) [redacted] Role: EAP actuators design and testing
Contact information of team leader:	Tel. [redacted] [redacted] polaris.unipd@gmail.com (Please contact me here)

Members of your team:	<ins>**Cristian Cacco**</ins> [redacted] Tel. [redacted] M. Sc. Student in Electrical Engineering University of Padova (Italy) [redacted] Role: Electric conversion of Energy, Electric system <ins>**Federico Cipriani**</ins> [redacted] Tel. [redacted] M. Sc. Student in Aerospace Engineering University of Padova (Italy) [redacted] Role: Mechanical design and testing, Fund Rising <ins>**Francesco Cocco**</ins> [redacted] Tel. [redacted] M. Sc. Student in Aerospace Engineering University of Padova (Italy) [redacted] Role: Thermal numerical model <ins>**Riccardo Dalla Vecchia**</ins> [redacted] Tel. [redacted] M. Sc. Student in Aerospace Engineering University of Padova (Italy) [redacted] Role: Electronics (sensor system), System Engineering <ins>**Matteo Zorzan**</ins> [redacted] Tel. [redacted] M. Sc. Student in Aerospace Engineering University of Padova (Italy) [redacted] Role: Structural design and testing, Outreach We had already contacted an electric engineering student and an informatics student to joining the team.

What is the scientific and/or technical objective of your experiment?	POLARIS experiment aims to: • Study the performance of a new concept of heat radiator which can vary its configuration and equivalent thermal resistance, exploiting Electro-Active Polymers (EAP, in this case Dielectric Elastomers) actuators, in variable environmental conditions. • Guarantee, through an active thermal control, the thermal steadiness of a dummy payload whose temperature have to remain within a given operational range. • Verify the correlation between the numerical model used to predict the thermal behaviour of the dummy payload and the measured data, in order to validate the theoretical model and understand the limitations of this radiator concept.
Why do you need a rocket / a balloon?	A stratospheric flight on a balloon allows to perform a realistic test in relevant environment for this new concept of radiator and to collect data on how different ambient conditions (pressure, temperature, winds, solar radiation) affect its performance. This kind of evaluation cannot be easily made in laboratory because such tests would be approximated due to the extreme difficulty of creating random winds and changes of attitude that will expose the radiator to solar and planetary effects. This concept of radiator is intended to operate on planetary probes without an attitude control, exposed to environmental changes; these conditions are close to those the experiment would experience during a BEXUS flight. In other words, a balloon flight will permit to evaluate the radiator in a realistic context, giving an extraordinary opportunity to show its potential for future planetary missions (balloons or rovers on Mars, Venus and Titan).
What flight characteristics do you require?	• We need to flight in stratospheric environment, so the optimal altitude for our experiment is about 20-25 km. We are evaluating the possibility to test the radiator during the ascending phase to simulate different external condition. • We need to float at least one hour and a half, in order to collect a sufficient amount of data. Anyway a longer floating time would be better. • Flying during daytime would be preferable because we want to test the radiator in a complete range of environmental conditions, including solar radiation.

Where did you get the idea from?	Radiators exist in several different forms and every space mission has a particular thermal control system (depending on the function requested to perform). For this reason it is difficult to compare different heat radiators, but anyway it is possible to underline that most of space/planetary missions use passive radiators coupled with devices that allow a semi-active control of the system. These are mostly: • Heaters that dissipate electrical power to warm metal plates (this strongly affects the electric supply budget) • Devices that involve the presence of fluids (need for containment measures to prevent leakage) • Devices that involve the presence of mechanical actuators (need of thermal control for bearings and connections) So the presence of these devices generates several issues, depending on the type. Our radiator concept does not involve any of these devices nor the problems related to them (no typical mechanical actuators as gears , no fluids, low power required) nevertheless it allows an active control of the system varying its equivalent thermal resistance. The simplicity of this concept, along with its high adaptability to variable environmental conditions, makes it suitable for a future use on planetary probes without attitude control (i.e. balloons, airships and rovers). Space exploration requires to reduce the mass, sizes and electrical power demand of spacecrafts and probes; this objective could be achieved through the miniaturization of spacecraft subsystems, but this solution is usually constrained by performance requirements, reliability and other system drivers. Therefore, new ways are to be tested, and one of these is the development of new technologies, such as new kind of actuators. Electroactive polymers (EAPs) are a particular class of polymers, widely studied in the last decade, which show a deformation in response to an electric stimulation; this particular behaviour encouraged new studies to test their potentialities as actuators. These responsive materials are broadly classified as electronic or ionic according to their operational mechanism. Electronic EAPs generally exhibit superior performance relative to ionic EAPs in terms of actuation strain, reliability, durability and response time. Among electronic EAPs, dielectric elastomers (DE) exhibit the most promising properties. The natural ease of preparing and shaping such DE materials, coupled with their low mass and large displacements, show that they have the potential to enable new technologies, like actuators often referred to as artificial muscles. In summary, the advantages of DE actuators are several: • Low density materials (mass reduction, inertia forces reduction) • Limited number of moving parts (reduced complexity, reduced costs, higher reliability) • Possibility of increased redundancy with limited additional economic and weight costs;

	• Direct conversion of electrical energy into mechanical energy, Nowadays the EAP technology is a subject of research at CISAS (Centro Interdipartimentale di Studi e Attività Spaziali, Center of Space Studies and Activities), University of Padova; in this research framework a member of our team, Davide Paganini, wrote his degree's thesis about the space applications of Elecroactive Polymers. The original idea of the experiment was developed with another member of the team, Matteo Zorzan, discussing about his degree's thesis focused on Thermal Control System in spacecrafts. The actual development of the concept has been achieved through the help of the other members of the team, recruited in the University of Padova. Actually the EAP technology for space/planetary applications is still at the beginning and its potentialities have only been investigated theoretically; hence actuators based on EAP have never flown before, neither in upper atmosphere neither in space. However many experimental studies took place in order to investigate EAP in laboratory conditions, as actuators and artificial muscles; the great amount of information resulting from these studies gives us a reliable basis to start from for testing this technology.

Describe your experiment	Our experiment is based on a heat radiator with adjustable equivalent thermal resistance. The radiator is composed by a series of three, square, parallel metallic plates with an equal area, linked together and constrained so that EAP actuators can separate them or put them in good thermal contact. In order to simulate the generation of heat of a dummy payload we will use a metal plate connected to heaters (this solution guarantees the precise knowledge of the generated heat and a simple construction).

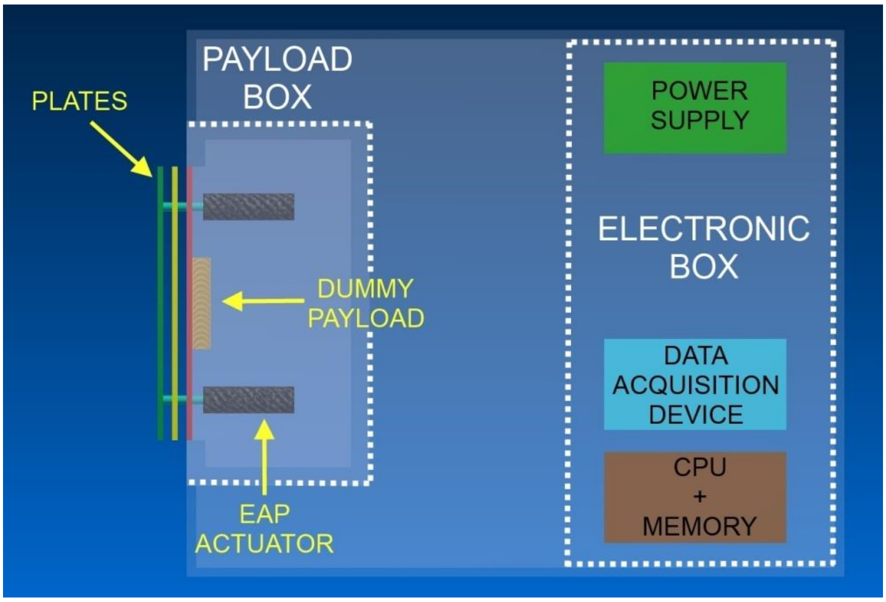


Fig.1: Experiment scheme

In such a context, our experiment set-up consists of two parts:

- On-Board Electronic Box.
  It contains the PC, the electronics, the data acquisition device and the high voltage power supply for EAPs.

- On-Board Payload Box.
  It contains the actuators, the sensors, the dummy payload and the radiating plates (whose last face will be exposed to the environment); it is also thermally insulated from the Electronic Box.

The radiator changes its thermal equivalent resistance by separating the plates. The actuation control changes during the different mission phases. In particular it can be switched between:

- Controlled by the internal CPU, with a programmed time-step.
- Activated by ground command through the BEXUS uplink channel.
- Regulated by the internal CPU to achieve the Payload temperature control.

Due to the very low pressure that characterize the stratospherical environment, the materials choice for the experiment should be done in order to minimize the outgassing. Considering all the experiment components, the elastomeric films of the EAP actuators are the only parts that could be sensible to outgassing. We found results of outgassing tests (http://outgassing.nasa.gov) for several types of acrylic elastomers (3M VHB series 4930 and 4945). The total mass loss percentage remain lower than 1,5% in the ASDM E 595-77/84/90 test. Anyway, since the conditions of the ASDM test (125 °C, 10^{-3} Pa for 24 hr) are much more critical than those

	experienced during a BEXUS flight, we do not expect to reach such outgassing levels; moreover the flight duration is very short compared to the ASDM vacuum tests. The elastomer that we are going to use for the actuators (3M VHB 4910 tape), even if it has not been tested for outgassing yet, is very similar to the two types discussed above. For all these reasons we do not expect sensible performance degradation for the actuators. In any case we will perform extensive vacuum tests on the EAP in order to characterize their behavior in vacuum environments and fill the lack of literature references about this topic.
What data do you want to measure?	We want to measure the payload temperature and the temperature over several spots of the plates. In addition we will measure the external atmospheric conditions, such as temperature, pressure, wind speed and direction. Also, the actual power dissipated by the heater will be monitored. Finally we will measure the force applied by the EAP actuators and the distance between plates.
How do you want to take measurements?	We will use thermistors for the payload temperature and many thermocouples smartly distributed on the external face of the third plate. For the atmospheric conditions, we plan to use many sensors outside the gondola such as thermistors, vacuometers and anemometers. To deduce the force applied we measure the deformations of the rods that connect the plates and the EAP with contact extensometers. Finally, we'll measure the plates relative distance with capacitive transducers.
Describe the process flow of your experiment.	• 30 minutes before Lift Off: experiment initialization. In this phase all subsystems, except high voltage supply, are powered. Start of sensors data storage. • Some minutes after Lift Off all subsystem, including EAP actuators, are powered and tested. • Continuous measurement and on-board storage of environment and plate sensors data (sent also to ground station through BEXUS downlink). • Test of the radiator performance in its two configurations in order to collect meaningful data for its characterization. • Start of the EAPs actuation (PC-controlled) for the active thermal control of the dummy payload. • Cut-Off and experiment conclusion at landing.

What do you plan to do with your data after the flight?	• Concerning the first objective of the experiment, we are going to use the gained data to analyze the temperature profile during the flight. Moreover, we aim to compute the thermal flux through the plates . • We will verify that the payload temperature remains within the requested range. • Compare the gathered data to the expected one from our thermal simulations to obtain a model validation. • Finally we want to estimate the irradiative to convective flux ratio on the external surface. In fact the convective thermal exchange does not have a reliable model in those conditions (e.g., low pressure/density)

Organisation of your project	Although all team members will be involved in every aspect of the mission, since the transversal contribution of both of us will be needed to carry out the program, responsibles have been assigned to the major work packages, according to their personal attitude: • Davide Paganini: EAP actuators design and testing • Francesco Cocco: Thermal numerical model • Riccardo Dalla Vecchia: Electronics (sensor system), System Engineer • Cristian Cacco: Electric conversion of Energy, Electric system • Federico Cipriani Mechanical design and testing, Fund Rising • Matteo Zorzan: Structural design and testing, Outreach In addition, there will be other members expected to join the team as Electronic and Software Responsible.
Are you supported by institutes and/or senior scientists?	We are supported by the University of Padova, in particular by : • CISAS Space Center • DII (Dipartimento di Ingegneria Industriale, Deparment of Industrial Engineering) The professor who follow us during the mission development is : • Prof. Alessandro FRANCESCONI, DII/CISAS, Space

	Systems Moreover, we got the support for theoretical and technical consulting by: • Prof. Pierfrancesco BRUNELLO, DII/CISAS, Thermal Control System • Prof. Giovanni LUCCHETTA, DII, Material Processing Technology • Prof. Mauro ANDRIOLLO, DII, Static Conversion of Electricity • Dr. Lorenzo OLIVIERI, CISAS, Member of Bexus Mission SCRAT and ARCADE-R2 teams • Dr. Francesco BRANZ, CISAS, Member of Bexus Mission ARCADE and ARCADE-R2 teams • Dr. Francesco SANSONE, CISAS, Member of Bexus Mission ARCADE and ARCADE-R2 teams
Do you have access to a workshop or a laboratory that meets the fabrication and testing needs of your experiment?	Thanks to the support of professors from the University of Padova Center of Space Studies (CISAS), we have access to a university workshop for machining and integration of mechanical components. Such workshop will be involved in the realization of the structural part of our system. Moreover, we have access also to a laboratory for testing EAP technology in order to create the actuators. In this location we will put together all the electric/electronic parts of the experiment. In the laboratories we will have the possibility to use a vacuum chamber for preliminary tests and components acceptance at low pressure.
Do you have all the material and equipment that is needed for your experiment? If not, how do you plan to obtain it?	At the moment we need to procure the raw material for the structural part of the experiment and for the actuators. Anyhow raw materials needed are not difficult to source. The university will help us for sensors and electrical/electronic equipment.
How do you plan to finance your expenses?	The University will help us for a part of our expenses, in particular for raw material procurement and electronics necessary for the flight model construction. In case of selection of BEXUS18/19, we will provide to find some funds with a strategy based on conferences and asking to companies interested in sponsorship. Additional financial resources will come from the Aerospace Engineering Study Program. The team can use the previous successful fund raising campaigns experience coming from SCRAT, ARCADE and ARCADE R-2 experiments.
Who else will support you (sponsors, others)?	The main sponsor of our mission is the University of Padova, in particular CISAS ad DII. We will try, if chosen by ESA, to find some funds by asking for support to local companies.

Outreach Programme	
Describe your outreach programme for before, during and after the REXUS/BEXUS flight campaign.	All our activities will be documented and promoted in several ways: • An official logo will be designed for POLARIS and a webpage will be prepared and constantly kept up to date. The webpage will be hosted in the front page of the Space Center CISAS "G. Colombo" website (http://cisas.unipd.it). We will also add a link to the official Industrial Engineering Department of Padova website (http://dii.unipd.it). • A support group will be created on Facebook (https://www.facebook.com/polarisexperiment), an account on Twitter, and advertising videos will be published on YouTube as soon as the activity achieves major advances; • Promotional brochures will be prepared and distributed to both university and PhD students belonging to our Aerospace Engineering Study Program and of the PhD School in Science, Technology and Measurements for Space; • Thanks to the contacts already established by our colleagues who developed the SCRAT, ARCADE and ARCADE R-2 experiments for BEXUS program, we will also have public presentations for local authorities, citations and interviews by local newspapers and broadcasts.

Experimental Set-up & Technical Information

Mechanics	
Describe your experimental set-up.	We have already mentioned that our experimental setup consists on a fully automatic radiator which can vary its configuration, composed by two on-board boxes (see fig.1): • Electronic Box (EB) • Payload Box (PB) The EB contains: • Central Processing Unit (CPU), which analizes the sensors data and controls the EAP actuation • Acquisition Data Device (ADA), which receives raw data from sensors and sends them to CPU. • Power Supply System (PSS), which contains the battery pack and the Voltage booster linked to EAPs The PB, thermally insulated by EB, contains:

- The plates
- EAP actuators
- Dummy Payload (DPL)

EAP actuators are linked to the plates by non-conductive rods. Dummy Payload is directly bound to the first plate and warmed by heaters.

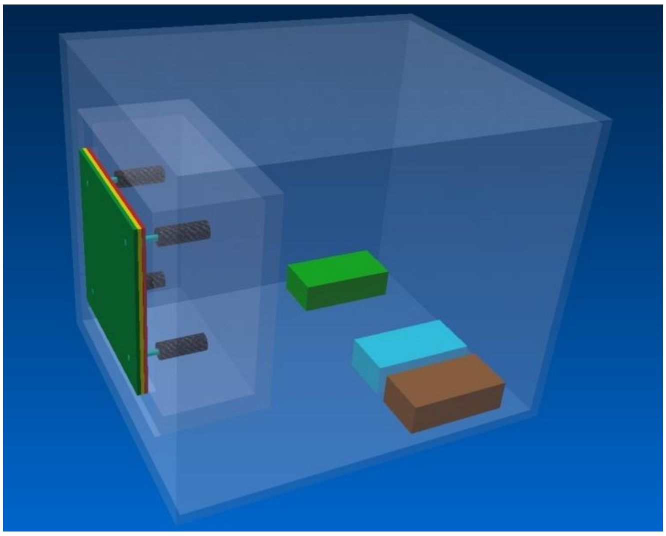
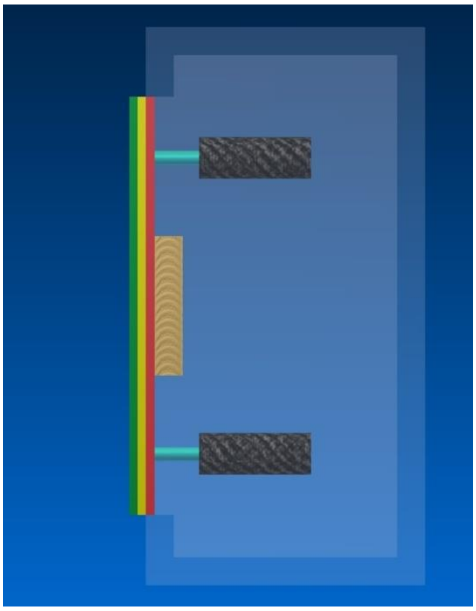
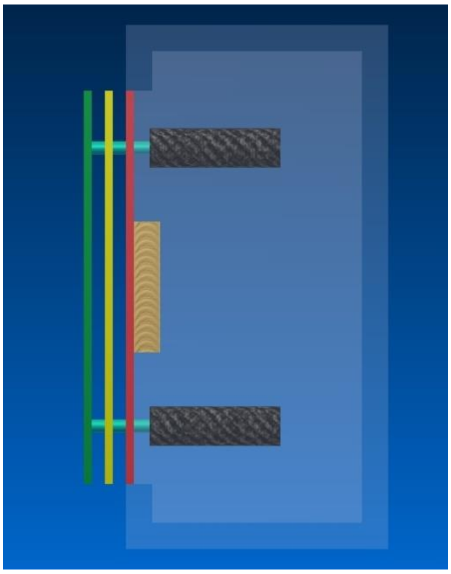


Fig.2: 3D Experiment view

Through a command by PC the system contained in the Payload Box is able to vary its set up in two configurations switchable through the extension of the EAP actuators:

- CONFIGURATION 1 (TIGHTEN PLATES)

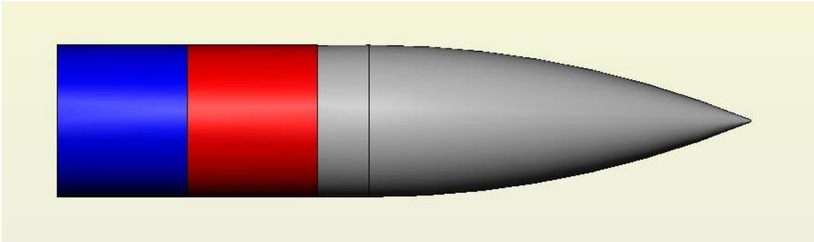
  The three plates are in contact in a way that pressure between them can ensure an adequate thermal conductivity coefficient in order to make them work almost as a single plate, if needed we will provide to insert a Thermal Conductive Interface Pad in order to limit the effects due to irregularity of surfaces. In this case the heat generated by the payload is transferred through the plates mainly by conduction and then radiated to the environment by the last plate. In this case the prevailing thermo-optical property that affects the heat exchange is the last plate one (the coverage and finish of this plate will be chosen so as to obtain a high emissivity and a low absorption factor).

	 Fig.3: Experiment configuration • CONFIGURATION 2 (SEPARATED PLATES) The three plates are no more in contact and the conductive link between the plates becomes mainly a radiative link (this condition leads to an increase of the thermal resistance equivalent between Payload and environment). In this case the heat generated by the payload is transferred through the plates, such as to the environment, mainly by radiation. The thermo-optical properties of each of the 5 faces exposed to the environment strongly influence the efficiency of heat exchange (the coverage and finish of these plates will be chosen to obtain low emissivity, excluding the last one whose property is bounded to the choice made for the first configuration).  Fig.4: Experiment Configuration 2 The switch between these two conditions allows to vary the system equivalent thermal resistance and to control the heat dissipated to the environment.

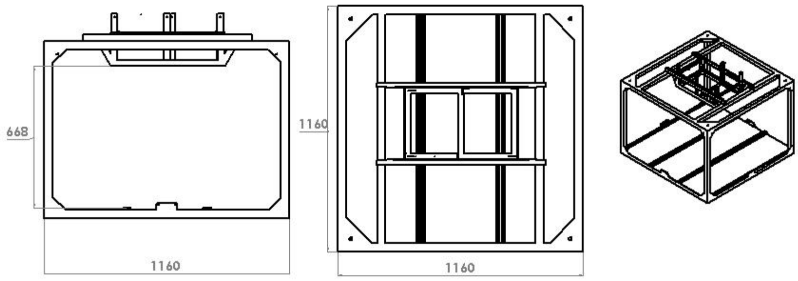
Estimate the dimensions and the mass of your experiment (kg and m).	The estimated experiment total mass will be around 4 kg: • 2,5 kg for the Control Box, cables, PC and High Voltage supply • 1,5 kg for the Payload Box (plates and actuators included) The whole experiment will be contained in a 30 x 30 x 30 cm box.

Indicate the preferred position of your experiment:

REXUS:
Indicate the orientation of your experiment and the preferred position in the rocket: module or nosecone section. Do you need access to the outside environment? Holes? Hatches?



BEXUS:
Define preferred position in the gondola, inside units, external units? Do you need access to the outside environment?



Front View *Top View*

The plates side of the Payload Box needs to be exposed to the external environment; however we do not need any particular position inside the gondola.

Electrics/Electronics	
Will you need the 28 V DC power supply from the REXUS service system or power from the BEXUS gondola, respectively?	We are planning to use a single 28V/1A battery pack.
Will you need (additional) batteries? What do you need for charging?	No.
Estimate the electrical consumption of your experiment (Ah or Wh).	We estimated that the electrical power required by this particular EAP actuators is in the order of milliwatts, due to their highly resistive nature. Considering the worst case scenario (actuators activated for the entire period of flight, 5 hrs of flight) the electrical consumption of such devices should be about 5 mWh. For the acquisition data system and computing devices we estimate that the power consumption should be around 5 Watt for the entire duration of the experiment. For the heaters (used to

	simulate the dummy payload) we estimate that the power consumption should be at most 10 W. Considering all this, it is estimated that the total power consumption is less than 75 Wh for the entire duration of the flight.
Do you use any equipment with high inrush currents? If so estimate the current (A).	No.
Do you need auxiliary power? Do you need a separate umbilical?	No.
Use of uplink and downlink:	Although the experiment timeline will be managed by the on board PC, uplink is foreseen for emergency commands. Raw data generated by sensors will be stored on board with high-frequency sample ratio during the flight. We will use downlink to generate a backup copy of these data with lower rate.
REXUS only: Do you need to use the REXUS TV Channel?	
Provide an event timeline, including the experiment actions during flight, such as timer or telecommand events.	• PRE-LAUNCH OPERATION: ground tests of all experiment subsystems. • T0 - 30 min experiment switch on, start of data sensors storage. Plates are tighten and EAP high voltage supply is OFF. • TAKE OFF (T0) • T0 + 10 min, Functionality test. We test sensors, electronics and power supply. Test of EAPs actuation. • Once in Floating Time (FT0), Start of continuous measurement (and storage) of all sensors signals for testing the radiator performance in its two configurations and to collect meaningful data for radiator's characterization. All electric and electronic devices are ON. • FT0 + 30 min, Start of preliminary control of the dummy payload temperature. • Once achieved the chosen dummy payload temperature, start of the EAPs actuation for active thermal control. Continuous measurement and data storage. • CUT-OFF - 5 min.: EAPs high voltage OFF • CUT-OFF. • Experiment conclusion at landing.

Environmental Questions & Safety Issues	
Does the experiment use wireless devices?	No.
Does the experiment create any disturbing magnetic or electrical fields?	Voltage multipliers have low input current and minimum output current (order of micro Ampere, expected lower levels), so the experiment does not create disturbing magnetic fields. In any case, adequate devices will be chosen to shield the high-voltage components.
Do you expect to use high voltages in any part of your experiment?	Yes. EAP actuators require high voltage to show sensible deformations (In the chosen configuration the voltage is about 4kV). However, we will not deal with typical safety problems related to high voltages because the low electric power levels and the low currents involved do not represent a significant hazard for operators and other experiments on-board. In any case we will use protection devices, such as fuses, highly insulated cables and circuit breakers, to guarantee people and things safety. Due to the high voltages involved and the low pressure that characterize the stratospheric environment, the electric subsystem design must minimize the risks of creating electric arcs. In order not to affect the safety of other experiments and systems inside the gondola, we will use electromechanical power switches, relays and contactors. We will insulate all powered devices (high voltage DC converter, cables, embedded A/D board and on-board PC) with an additional insulation. Furthermore the DC converter chosen for the power supply is guaranteed for higher voltage than the one required for the experiment; we took as reference EMCO G40 miniature DC converters that ensure 3,500 Volts + V_{OUT} (output voltage) insulation (the G40 also guarantees low outgassing issue, NASA approved per ASTM E-595-93). Lately, the metallic plates will be insulated from the actuators with insulating tape to prevent the creation of dangerous potential difference. Anyway we will test every component in the university vacuum chamber to verify the functionality and the safety of all devices
REXUS only: Does your experiment eject anything from the rocket?	
Is the experiment sensitive to light?	Yes, but it is not an issue because daylight would add another thermal load to the experiment, allowing a better characterization of our radiator.
Is the experiment sensitive to vibrations?	No.
Does the experiment generate vibrations?	No.

Will you use any flammable, explosive, radioactive, corrosive, magnetic or organic products?	No.
Will you use a laser?	No.
Is your experiment airtight? Are parts of your experiment airtight?	No.
Are there any hot parts (> 60°C)?	No.
Are there any moving parts? Are the moving parts reachable?	Yes, the EAP actuators move the plates for less than a millimeter. They will be on the external face on the gondola, so they will be easily reachable.
Do you need any pressure systems from EuroLaunch before launch?	No.
Is there any aspect in your experiment which you believe may be viewed as a safety risk by others (regardless of whether you will mitigate this risk in your design)?	Yes, high voltage is a potential safety risk. Appropriate mitigating solutions have already been selected and will be implemented in order to eliminate any danger and make the experiment compatible to a BEXUS flight (see page 16).

Drawings can be inserted below and referenced in the above table.