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	DESTINY
Full experiment title	Detection of Earthquakes through STratospheric INfrasound studY

☐ **REXUS** ☒ **BEXUS**

- ☐ spinning with 4 Hz
- ☐ despun with Yo-Yo to about 0.08 Hz
- ☐ not of importance for our experiment

Science & Organisation

Team Information	
Student team leader:	**Louis Dubois** French Birth: 21/01/1998 École polytechnique, 2nd year **(1)**, general engineering and scientific studies. Specific courses and interests: mechanics, embedded electronics, cybersecurity. *Expected additional team role: Electronics and computing* **(1):** Students enter the Ecole Polytechnique, a master-level engineering school, after two years of scientific undergraduate

	studies in "*classe préparatoire*". Thus their 2nd year at the École polytechnique is their fourth year of post-secondary education.
Contact information of team leader:	Email address: louis.dubois@polytechnique.edu Phone number: +33 (0) 7 88 36 15 78 Postal address: App. 12.40.10, bât. Joffre, bd des Maréchaux 91120 Palaiseau France
Members of your team:	**Krishan Bumma** French and Mauritian Birth: 27/08/1997 École polytechnique, 2nd year **(1)**, general engineering and scientific studies. Specific courses and interests: physics and chemistry. *Expected team role: Mechanics and thermal design* **Matthieu Jeannin** French Birth: 03/05/1997 École polytechnique, 2nd year **(1)**, general engineering and scientific studies. Specific courses and interests: mathematics, physics, logic and biology. *Expected team role: Physics and fundraising* **Elias Khallouf** Lebanese Birth: 01/01/1997 École polytechnique, 2nd year, general engineering and scientific Studies specific courses and interests: mechanics, thermodynamics, material strength, and transportation. *Expected team role: Mechanics and thermal design, outreach* **Clara Piekarski** French Birth: 02/02/1997 École polytechnique, 2nd year **(1)**, general engineering and scientific studies. Specific courses and interests: physics, mechanics, biology. *Expected team role: Physics and management* **(1):** Students enter the Ecole Polytechnique, a master-level engineering school, after two years of scientific undergraduate studies in "*classe préparatoire*". Thus their 2nd year at the École polytechnique is their fourth year of post-secondary education.

What is the scientific and/or technical objective of your experiment?	We want to **characterize the atmospheric infrasonic noise** to be able to **detect seismic activity.** The objective of our experiment is to prove the effectiveness of a technique using the **propagation of infrasonic waves in the atmosphere** to detect seismic activity. Earthquakes generate **10 Hz frequency** and 1 Pa amplitude sound waves. These waves are then **amplified** during their propagation through atmosphere. Indeed, in the atmospheric model commonly used, the energy of the wave is conserved throughout its vertical propagation. Therefore, since the air density decreases with altitude, the amplitude of the wave increases. This phenomenon eases the detection of infrasound at high altitudes. The final goal would be to use this method on terrestrial planets, in particular **Venus**, to **investigate their internal structure**. It is an **alternative to the use of landers** which are today unable to withstand the temperature (400 °C) and pressure (90 atm) of Venus ground. First, we must **test this technique on Earth**. In order to succeed, we have to study the atmospheric infrasonic background, to be able to discriminate the different sources of noise. We hope to detect the infrasonic fingerprint of nearby perturbations, such as planes. The main difficulty will be to extract a relevant signal from the background noise. The compatibility of our equipment with high altitude conditions must be ensured. We will also examine the possibility of creating a perturbation, with an explosion on ground or a seismic hammer. The team of researchers from ISAE Supaero, JPL and Caltech we are working with already succeeded in detecting such signals using this method at lower altitude **[1]**. **[1]** Geophysical Research Letter, AGU 100, *Detection of Artificially Generated Seismic Signals Using Balloon-Borne Infrasound Sensors*, Siddharth KRISHNAMOORTHY, Attila KOMJATHY https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1002/2018GL077481
Are you planning to fly an existing REXUS/BEXUS experiment?	No.

Why do you need a rocket / a balloon?	To understand the **formation of terrestrial planets** - Mars, the Earth, Venus, and the Moon - and the origins of their differences, it is necessary to **investigate their internal structure**. On Mars and on the Moon, landers have been deployed to probe the ground (e.g. Apollo mission for the Moon, InSight for Mars). However due to the **extreme conditions on Venus' ground**, 400 °C and 90 bars, we are not yet able to design suitable long-lasting landers. Hence, the seismic activity of Venus has yet to be explored. A possible solution would be to **use balloons** to study the propagation of infrasound in the atmosphere. Indeed, at an altitude of 55 km, Venus' atmosphere presents earthly conditions, with a temperature of 0 °C and a pressure of 1 bar. Besides, at such heights, **the detection of infrasonic signals is eased by their amplification**, due to the conservation of energy. Balloons have already been used to analyse Venus' atmosphere within the frame of the Russian Venera program. This experiment on Earth would be **a proof of concept** for a future use on Venus.
What flight characteristics do you require?	● We would like to fly our experiment at **tropospheric** altitude (since at this height the conditions are like those on Venus at 60 km) and at **stratospheric** altitude. ● The longer the flight is, the more data will be gathered, which will improve the characterization of the ambient infrasound noise. However, we estimate that a **two-hour float time** is enough to obtain significant results. ● Our experiment does not require daylight.
Where did you get the idea from?	This experiment is made within the frame of our mandatory second-year scientific team project at Ecole Polytechnique (7 ECTS credits). The **student spatial club** (AstronautiX) of the school presents every year subjects suggested by start-ups, spatial agencies and researchers. This project arises out of the work of the **Venus seismology workshop of the Keck Institute for Spatial Study**, led by Jim Cutts (JPL), David Mimoun (ISAE Supaero), Dave Stevenson (Caltech) and their research teams since 2014 **[2]**. They have already conducted similar experiments at low altitude and obtained significant results at Pahrump, NV. David Mimoun and his team at **ISAE Supaero** were looking for students to join their project of Venusian balloon and run high altitude tests. The five of us were very interested so we contacted him, and he agreed to be our tutor.

	[2] http://kiss.caltech.edu/workshops/venus/venus.html

Describe your experiment	To fulfill our scientific goals, *i.e.* characterize the atmospheric infrasonic noise and use it to detect earthquakes, we will use a **system of four distant barometers**, forming a **triaxial frame**. The phase shifts between the signals received by the different barometers will enable us to select the signals which are effectively propagating from the ground and to determine their spatial origin. To link the phase differences to the location of the origin of the signals, the main box will operate an IMU and a GPS.
What data do you want to measure?	We want to measure **near infrasound pressure variations** (between 5 Hz and 16 Hz) to improve our knowledge of the ambient noise and for location purposes. To do this, we need to know the **position of the sensors**, and the **trajectory of waves** before measurement. We will thus also use an IMU coupled with a GPS and an external temperature sensor. We will manage the internal temperature thanks to another set of heat sensors.
How do you want to take measurements?	Data acquisition will be done by four boxes: one, called the **master box**, will concentrate the measurements of the **three slave boxes**. Each box is built around an 8-bit microcontroller which will operate its different sensors. After gathering all the measurements, the master microcontroller will save them onboard on SD cards, and transmit them to the ground station through the E-Link system.
Describe the process flow of your experiment.	• 90 min before launch: subsystems are started but set to standby • 10 min before launch: data gathering starts • 25 min after the cut off: data storage is stopped remotely, to prevent storage devices from being corrupted • 45 min after the cut off: a timer shutdown all the subsystems. Data acquisition is done continually, with respect to the table 1, and the master collects them at a 1 Hz frequency.

Observable	Sample rate
Pressure	50 Hz
GPS position	1 Hz
Boxes position and attitude	50 Hz
Sound celerity	0.1 Hz

	<table><tr><td>Internal temperature</td><td>0.1 Hz</td></tr></table> *Table 1: data sampling frequencies* Data are transmitted at 1 Hz, in packets gathering all the sensors outputs. This serves as an acknowledge signal, as well as a backup in case of internal failure.
What do you plan to do with your data after the flight?	● Extract and characterize the underlying atmospheric infrasonic noise. ● Locate earthquakes or artificial events generating enough infrasound waves.

Organisation of your project	Responsibilities have been assigned to cover the different aspects of the project, accordingly to the respective fields of interest of the members. ● Louis Dubois: Electronics and computing ● Clara Piekarski: Physics and management ● Krishan Bumma: Mechanics and thermal design ● Elias Khallouf: Mechanics and thermal design, outreach ● Matthieu Jeannin: Physics and fundraising A team of five students from ISAE-Supaero will join our project in February, taking part in the implementation and the tests of our design.
Are you scientifically and technically supported by institutes and/or senior scientists?	The evolution of our project is followed by Jean-Marc Chomaz, professor of Mechanics and co-founder the Hydrodynamics Laboratory at École polytechnique. Our team is supported by David Mimoun and Raphael Garcia, two professors and researchers at ISAE Supaero specialised in planetary science and signal treatment. They both worked on the Insight lander that will land on planet Mars in November 2018. One postgraduate student and one master student at Supaero advise us on modelling and data treatment.
Do you have access to a workshop or a laboratory that meets the fabrication and testing needs of your experiment?	The labs of both engineering schools, ISAE Supaero and École polytechnique, can provide us with the necessary equipment for our tests.
Do you have all the material and equipment that is needed for your experiment? If not, how do you plan to obtain it?	Part of the needed equipment has already been purchased (in particular two barometers and the gyrometer), and we plan to buy the rest through general electronics suppliers for the most part. The other high precision barometers will be purchased from a manufacturer specialized in precision pressure sensors.
How do you plan to finance your expenses?	As we do this experiment in the frame of the mandatory scientific project of our second year at the École polytechnique, we have access to funds provided by the university.

Who else will support you (sponsors, others)?	Since the technology we are working on can be useful for military purpose, namely detecting nuclear explosions from a long distance, we are partially financed by the French Directorate General of Armaments (DGA). We are also looking for sponsors to reduce our expenses.

Outreach Programme	
Describe your outreach programme for before, during and after the REXUS/BEXUS flight campaign.	A website and a Twitter account will present our project to the public and keep it informed of our progress and results.

Experimental Set-up & Technical Information

Mechanics	
Describe your experimental set-up.	The set-up will rely on four boxes: ● 1 master box (see figure 1), containing an Arduino Mega board which controls communications with ground, data storage, and collects the measurements made by all its and the slave boxes' sensors; ● 3 slave boxes (see figure 2) embedding an ATmega328p. Each box embeds a barometer and a thermal regulation system, and the master includes more sensors (see figure 1). The master box will lay on the bottom of the gondola. One slave box will be placed above. It would be best to hook it on the cable above the gondola to detect phase shifts with more precision. If it is not possible, we will use a vertical beam. The two other slave boxes will be hooked to the gondola with two orthogonal horizontal beams (see figure 3 for a 3D illustration). The barometers will be linked to noise-reducing inlets which balance pressure between the inside and the outside of the boxes (see figure 3). We will then treat the collected data to detect and characterize the sources of the different background infrasounds.

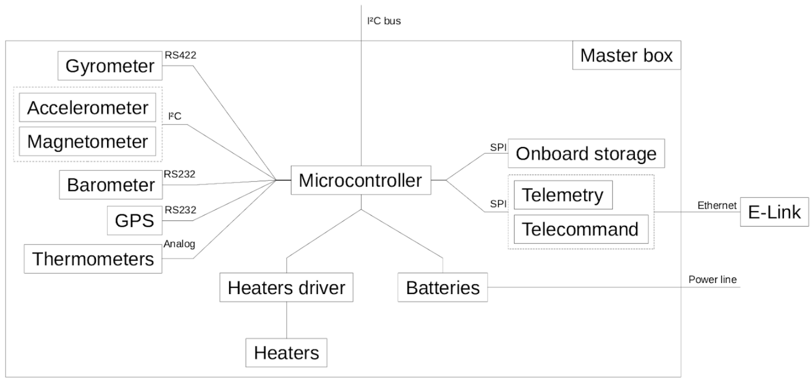

Figure 1: layout of the master box

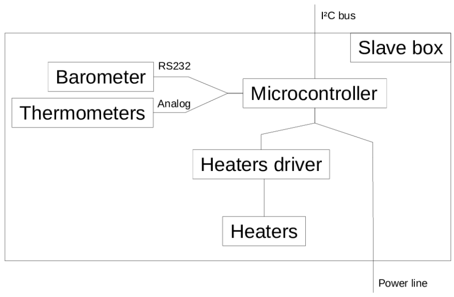

Figure 2: layout of a slave box

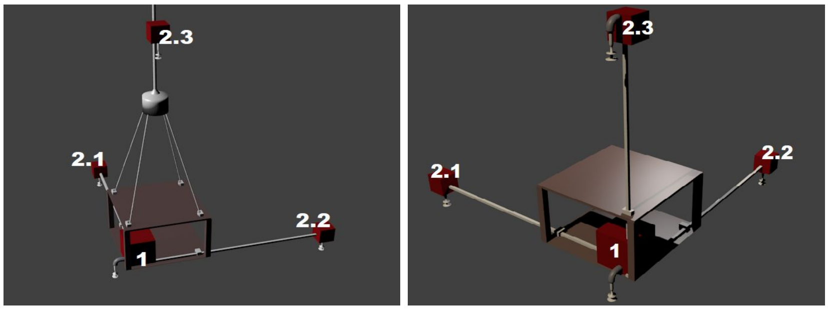

Figure 3: 3D model of our experiment. On the left, the preferred solution (slave 2.3 position is not to scale). On the right, the alternative solution.

1. Main box
2. Slave boxes

Estimate the dimensions and the mass of your experiment (kg and m).	The mass and dimensions of the different components of the set-up are listed in table 2. The experiment will weigh around 15.6 kg if a slave box can be hooked on the cable, around 19.1 kg if not.

<table>
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<table>
<tr><th></th><th>Number</th><th>Mass (kg)</th><th>Dimensions (m)</th></tr>
<tr><td>Master box</td><td>1</td><td>2.1</td><td>0.35×0.35×0.25</td></tr>
<tr><td>Side slave box</td><td>2</td><td>1.0</td><td>0.25×0.2×0.25</td></tr>
<tr><td>Top slave box</td><td>1</td><td>1.5 or 1.0</td><td>0.25×0.25×0.25</td></tr>
<tr><td>Inlet</td><td>4</td><td>0.5</td><td>0.17×0.17×0.3</td></tr>
<tr><td>Beam</td><td>2 or 3</td><td>4.0</td><td>3×0.08×0.04</td></tr>
</table>
Table 2: Components’ mass and dimensions
</td>
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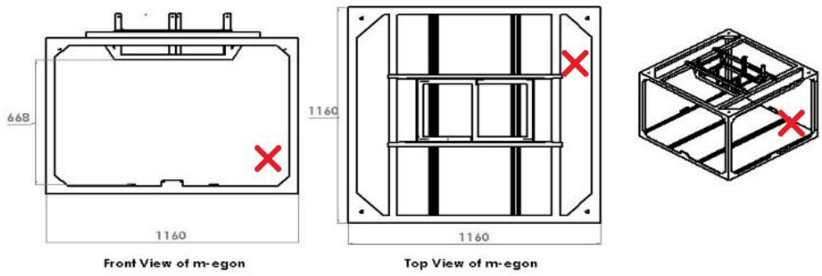
<td>Indicate the preferred position of your experiment:</td>
<td>The inlets attached to the barometers have to be in contact with the air. It would be preferable for our experiment to be placed at the bottom of the gondola. The position of the external boxes can be found in figure 3.


Front view of a gondola   Top view with mounting rails
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<tr><td>Electrics/Electronics</td><td></td></tr>
<tr><td>Will you need the 28 V DC power supply from the REXUS service system or power from the BEXUS gondola, respectively?</td><td>Yes.</td></tr>
<tr><td>Will you need (additional) batteries? What do you need for charging?</td><td>If a slave box can be hooked on the wire linking the gondola to the balloon, it will need to embed additional batteries. Else, no additional battery will be needed.</td></tr>
<tr><td>Estimate the electrical consumption of your experiment (Ah or Wh).</td><td>Data measurement, storage and transmission typically uses 7 W, and at most 11 W. Most of the power consumption comes from the heating system: a first estimate yields a maximum consumption of 55 W.</td></tr>
</table>

	To ensure a 5 h autonomy, the total electrical consumption of our experiment will be below 320Wh.
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:	We will use: ● Uplink to send occasionally commands (see table 3). ● Downlink to send measurements, at a rate of 10 kbit/s.
Provide an event timeline, including the experiment actions during flight, such as timer or telecommand events.	● Pre-launch operations: data storage and transmission, telecommand and sensors tests. ● 1h30 before launch: all the subsystems are powered up. Telecommand listener starts. Sensors are idle. ● 10 min before launch: data gathering, storage and transmission start. ● 25 min after the cut off: data storage is stopped, but data transmission keeps going. The shutdown timer starts. ● 45 min after the cut off: the shutdown timer powers down all the subsystems. During the flight, sensors take measurements according to table 1, and the command signals listed in table 3 can be received. Slave boxes store locally their measurements before sending them at 1 Hz to the master box.

Signal	Action	Typical use
SHUTDOWN	Shuts down all the system	45 min after the cut off
START_SENSORS	Sensors start gathering data	10 min before launch
STOP_SENSORS	Sensors stop gathering data	
START_STORAGE	Data storage starts	10 min before launch
STOP_STORAGE	Data storage stops	25 min after the cut off
MAN_TH_MGMT	Thermal loop is now	In case of thermal

	bypassed by manual commands	loop failure
SET_HEATER	Sets the power of a given heater, requires the thermal loop to be stopped	In case of thermal loop failure
AUT_TH_MGMT	Thermal loop is started	1h30 before launch, or after a recovered thermal loop failure

Table 3: Telecommand signals

Environmental Questions & Safety Issues	
Does the experiment use wireless devices?	Yes, we will use a GPS.
Does the experiment create any disturbing magnetic or electrical fields?	No.
Do you expect to use high voltages in any part of your experiment?	No.
Is the experiment sensitive to light?	No.
Is the experiment sensitive to vibrations?	Yes. If vibrations in the gondola generate infrasounds, it will create additional noise which will need to be suppressed during post-processing.
Does the experiment generate vibrations?	No.

Will you use any flammable, explosive, radioactive, corrosive, magnetic or organic products?	No.
Will you use a laser?	Yes. A fibre optic gyroscope will be used, which securely contains a laser.
Is your experiment airtight? Are parts of your experiment airtight?	The experiment is not airtight, but the barometers' inner transducer is hermetically sealed and evacuated. However, these barometers are certified to operate at low pressure.
Are there any hot parts (> 60°C)?	Yes, our device will contain a heating system to ensure the correct operation of the sensors.
Are there any moving parts? Are the moving parts reachable?	No.
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)?	The booms may unbalance the gondola after the cut off, this could tilt the gondola during the landing.

Additional comments	