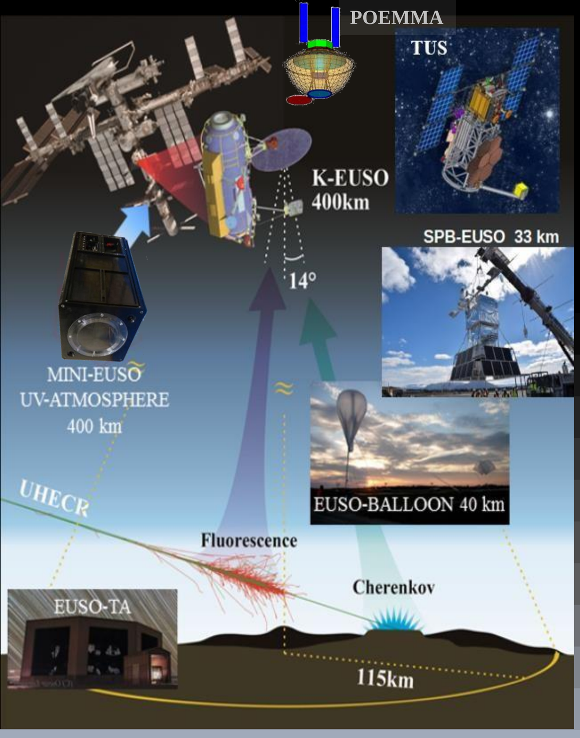
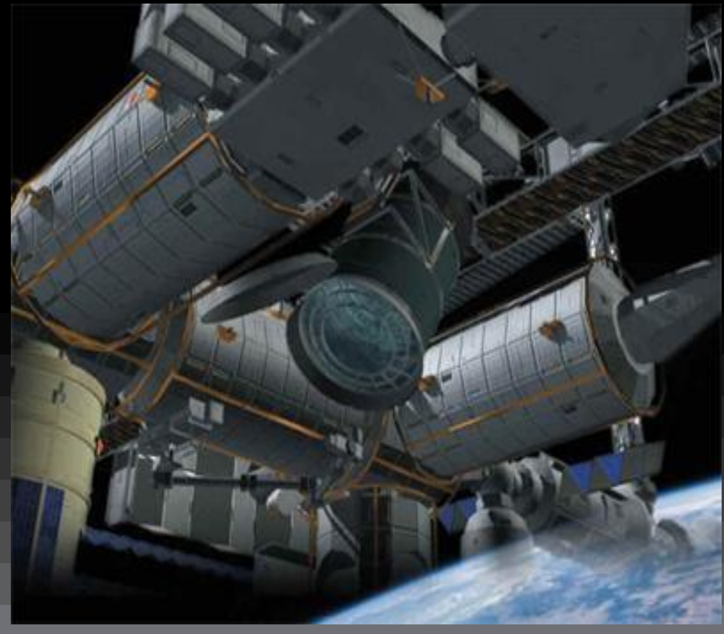


JEM-EUSO on ISS explores the origin of the highest energy particles in the Universe

Mini-EUSO: a new imaging detector on board the International Space Station to study high atmosphere phenomena and cosmic UV emissions



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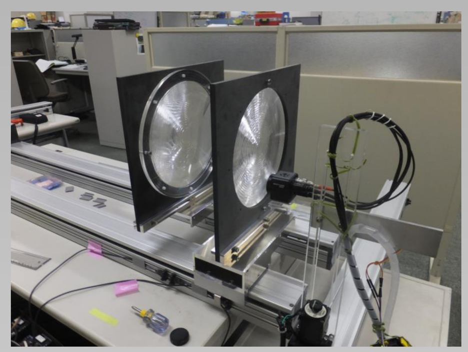
Abstract

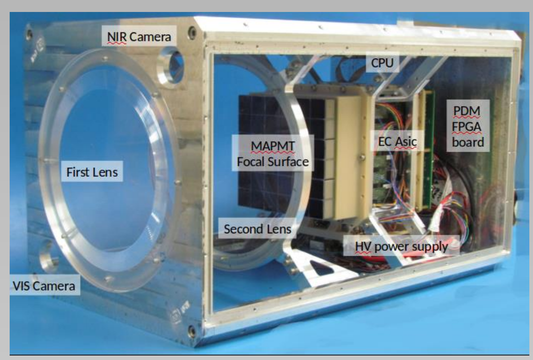
Mini-EUSO is a compact telescope (37 x 37 x 62 cm3) launched on August 2019 with an unmanned Soyuz spacecraft, currently hosted on board the International Space Station. It is accommodated on the Russian Zvezda module, facing a UV-transparent window in Nadir mode. Mini-EUSO is devoted primarily to study Ultra High Energy Cosmic Rays above 1021 eV but also to search for Strange Quark Matter, to observe Transient Luminous Event in upper atmosphere, meteoroids, sea bioluminescence and space debris tracking. Mini-EUSO consist of a main optical system, the Photo Detector Module, sensitive to UV spectrum (300–400 nm) and several ancillary sensors comprising a visible (400–780 nm) and NIR (1500–1600 nm) cameras and a 8 x 8 channels Multi-Pixel Photon Counter Silicon PhotoMultiplier array which will increase the Technology Readiness Level of this ultrafast imaging sensor. The main detector has a super wide-field of view (44°) which allows to map an Earth ground area of 263 x 263 km2 thanks to the optics which comprises two Poly(methyl methacrylate) Fresnel lenses focusing the radiation onto a 36 Hamamatsu Multi-Anode PhotoMultiplier Tubes, each of 64 channels for a total of 2304 pixels with a time resolution of 2.5 microseconds. Mini-EUSO belongs to a novel set of missions committed to evaluate, for the first time, the capability of observing Cosmic Rays from a space-based point of view.

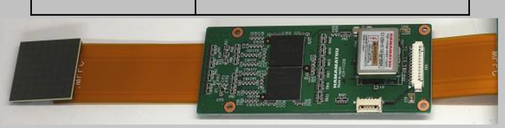
Telescope

Mini-EUSO detector is a 37×37×62 cm^3 volume body which consists of two main subsystem: **Optics** and **Photo Detector Module.** Mini-EUSO optics consists of two double sided PMMA Fresnel lenses which will focus light onto the Focal Surface with a large FoV (44°). The full FS consists of an array of 36 Hamamatsu Multi Anode PhotoMultiplier Tubes each powered by a Cockroft-Walton high voltage power supply board placed inside a ceramic pad and present a BG3 UV filter on the entry window.

FoV/PDM	44° / 2.6×10^2 Km
FoV/pixel	0.8° / 6.11 Km



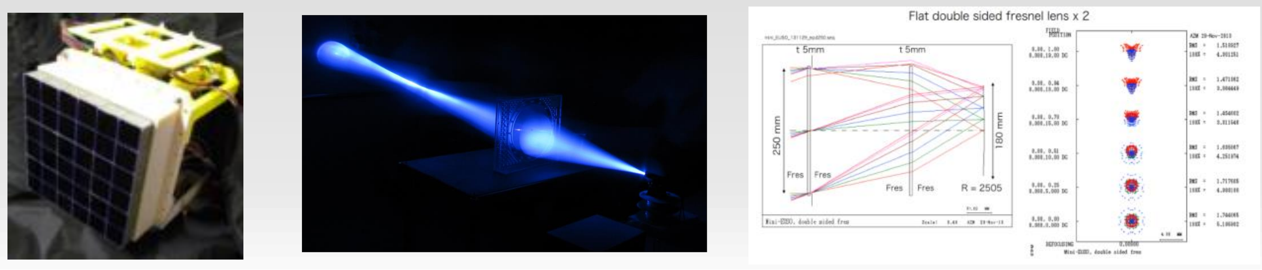




MPPC Hamamatsu module picture.

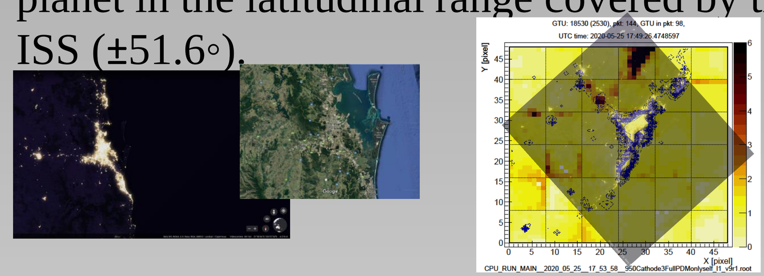
Togheter with FS, the signal and data handling electronics form the PDM chain: 3 Asic boards built on purpose, a Xilinx Zynq XC7Z030 SoC containing a Kintex7 FPGA with an embedded dual core ARM9 CPU processing system and a PCIe/104 form factor CPU. In addition to the main detector, Mini-EUSO contains: two ancillary cameras for complementary measurements in the near infrared and visible range, three single pixel sensor for light and radiation detection and a 64 channels Multi-Pixel Photon Counter SiPM C13365 module provided by Hamamatsu Photonics. An additional Atmel 2560 10-bit microcontroller board is used for ancillary sensor read-out. A three module LVPS (Low Voltage Power Supply) filters and stabilize 27V coming from ISS, providing power for all subsystem and preserving the entire instrumentation from spike or polarization inversion.

Top Left:Mini-EUSO focal surface. **Top Right**: Test bench for double sided Fresnel lenses with laser beam (405 nm) and a CCD camera (Riken, Tokyo). **Bottom Left:** Lens design of Mini-EUSO configuration produced with *Optalix* software. **Bottom Right**: Point Spread Function for different range of field position.

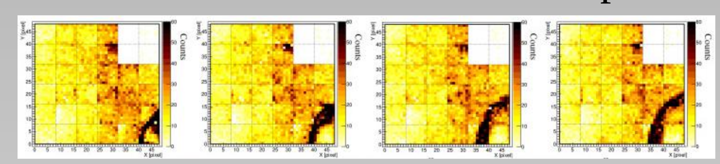


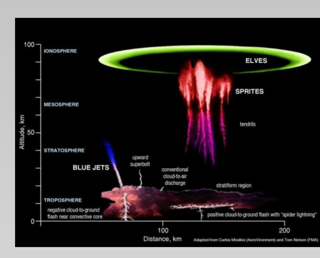
Objectives

- **High resolution UV emission map.** Cosmic and terrestrial UV emissions. Mini-EUSO is providing an accurate map covering all of the planet in the latitudinal range covered by the ISS (±51.6°).



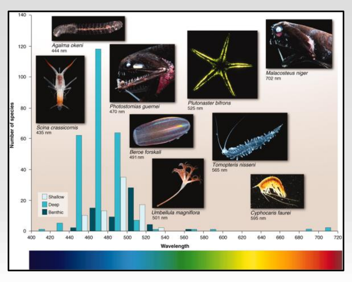
- **Meteor observation** with magnitudes of M<+5. They are detected using off-line trigger algorithms based on photon count and speed.
- **SQM detection**: Mini-EUSO will be able to set a new upper limit on the detection of Strange Quark Matter which can creates a UV signal burning in the atmosphere, that can be discerned from meteor tracks because of the time of flight.
- **Bioluminescence**: large areas of the ocean surface (up to 16000 km^2) sometimes appear to glow during the night for periods of up to several days. The named “Milky sea” condition, is tipically attributed to the fluorescence of phytoplankton colonies
- **Transient Luminous Events (TLEs)** such as blue jets, sprites and elves events that occur in the upper atmosphere: Mini-EUSO has a dedicated trigger algorithm to capture TLEs and other millisecond scale phenomena.





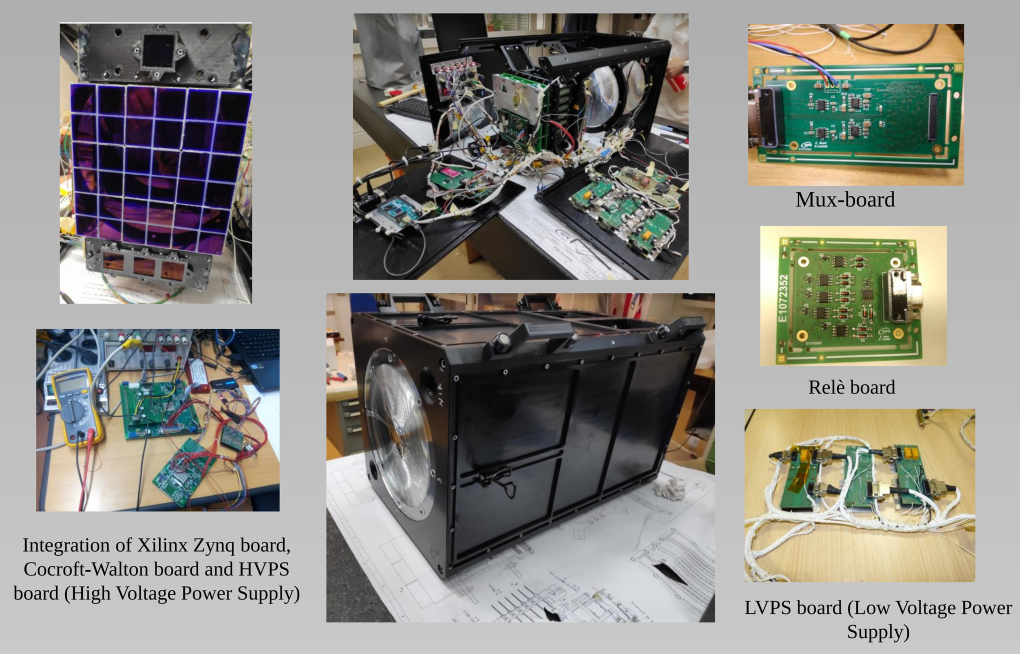
Top Left: Brisbane (Australia) seen by Mini-EUSO. **Top**: Four frame showing an elf developing in atmosphere. **Left**: TLEs size and altitude occurrence. **Bottom**: Origins of Ocean’s bioluminescence.

- **Space debris observation**: Mini-EUSO will be used as a prototype for the detection of space debris during the twilight periods of observation (when debris are illuminated by the sun, but the instrument is in darkness).



Integration and Characterization

Integration took place at Frascati (INFN), Rome (Univ. of Tor Vergata), Paris (APC), Tokyo (Riken), representing part of countries involved in Mini-EUSO project and development.

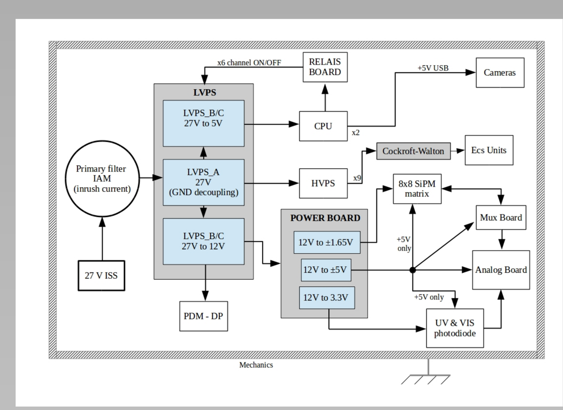


Mux-board

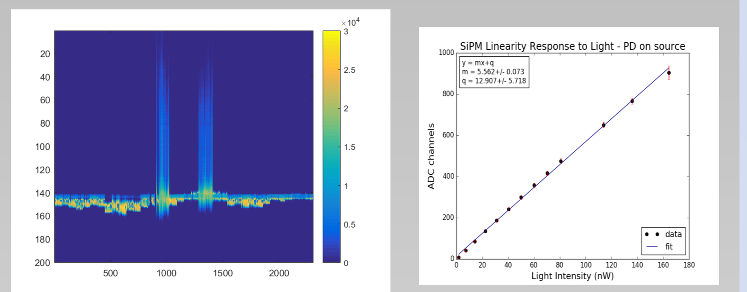
Relè board

Integration of Xilinx Zynq board, Cocroft-Walton board and HVPS board (High Voltage Power Supply)

LVPS board (Low Voltage Power Supply)

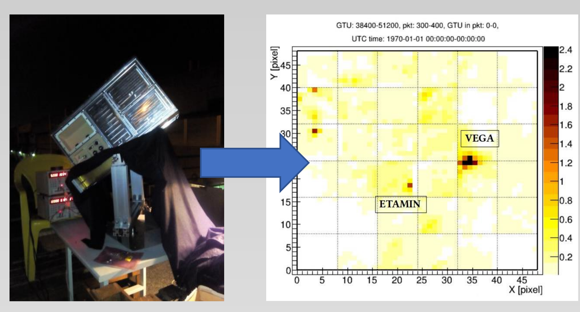


Mini-EUSO functional scheme

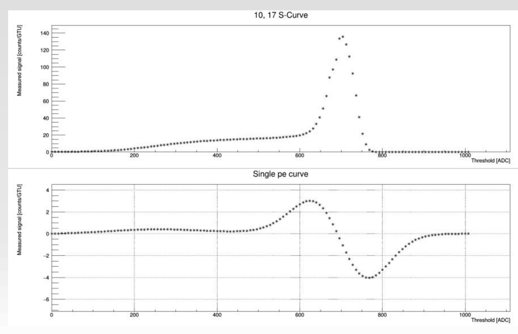


Left: SiPM linear region response to light intensity and pulse.

Qualification at and efficiency tests on the PDM comprising MAPMTs array and SiPM sensors response were performed. Several aspects have been taken into account: properly response of the whole detector; analysis of the Single Pe Counting mode through S-curve analysis; simulation of phenomenon detection efficiency. Most of the work was done through the **ETOS** (Euso TO Screen) scientific software which was expressly generated for all experiments belonging to the JEM-EUSO program. It is the main quick-view and quick-analysis software which operates on the ROOT files generated from the raw CPU data.



Top Left: Detector test in Rome during night time (2019). **Top Right**: Mini-EUSO focal surface quick-view of the same night with ETOS.

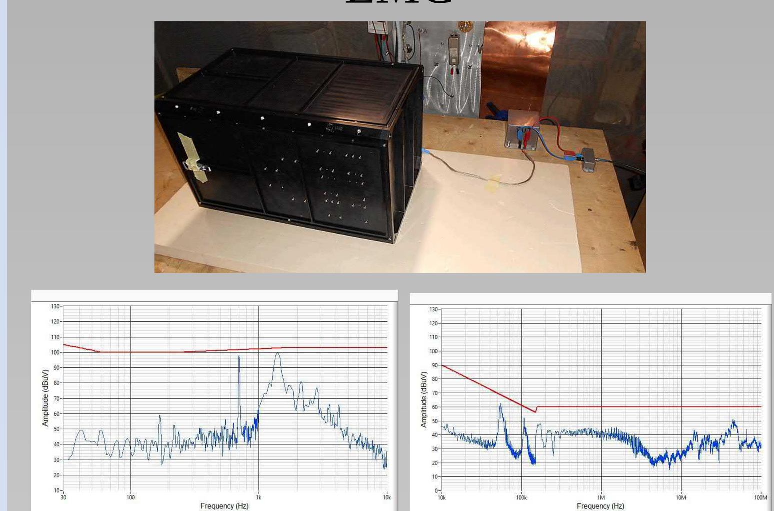


Top : Single pixel S-curve. **Bottom**: S-curve derivative. On x-axis: ADC channel thresholds. On y-axis: PMT pulse’s counts over amplitude threshold. This kind of plot, called S-curve, is intended to calibrate PMTs to have a Single Pixel Photon Count working point, id est, the proper voltage to have one pulse per photon coming. In this case it is visible that our working point falls around 540 ADC value.

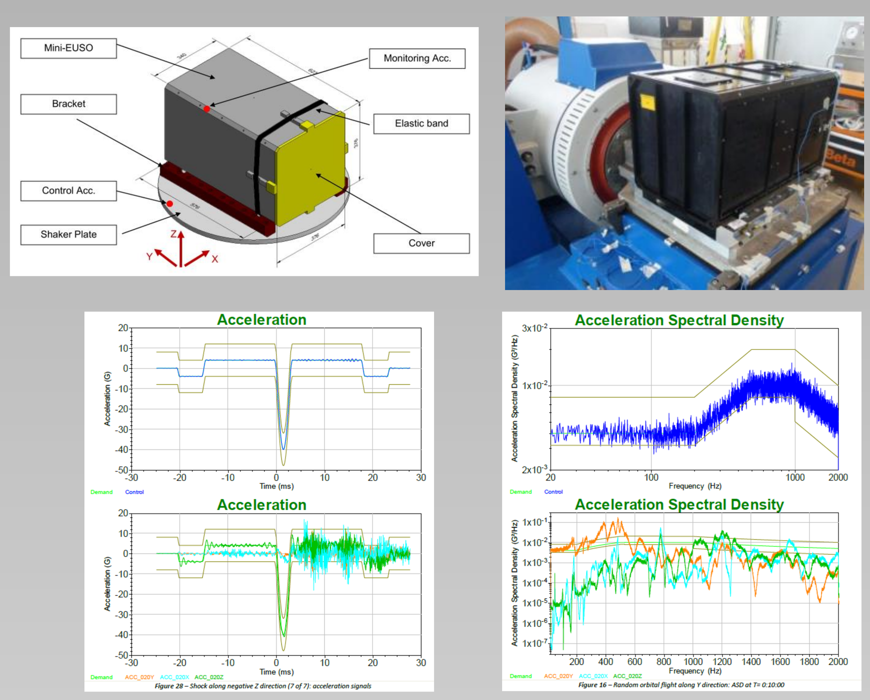
Space Qualification Tests

The General Technical Requirements for Experiment, Equipment and Technical Documents on board ISS required several test to be performed on the instrument as: Electro-Magnetic Interference and Conductive (EMC/EMI); vibration and shock; high/low pressure, thermal and humidity functional tests. Mini-EUSO has successfully undergone all of them.

EMC

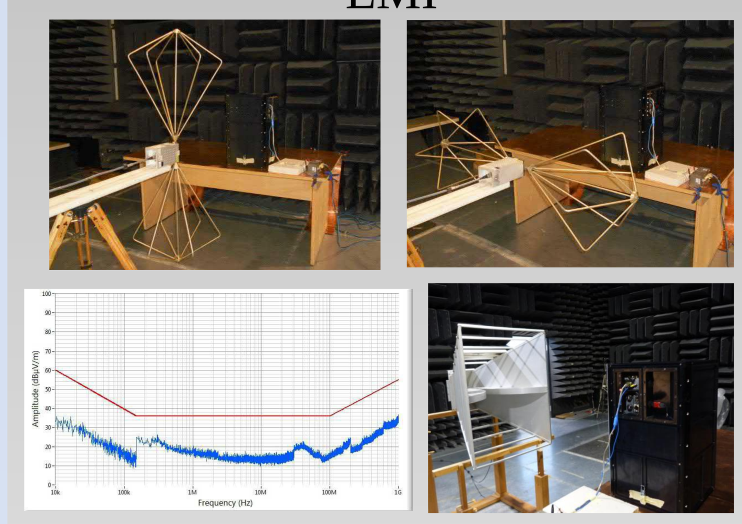


Vibration & shock



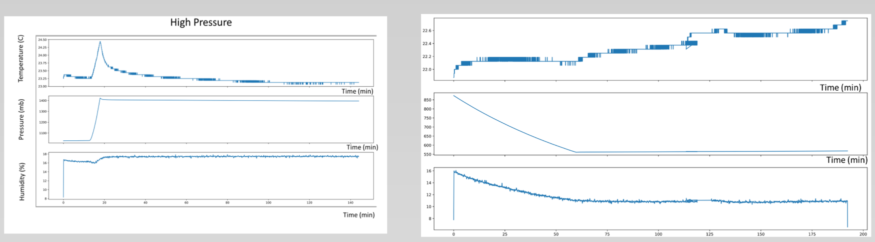
Left. Shock test **Right:** Vibration

EMI



EMC: Mini-EUSO setup during conducted emissions on DC power bus for low and high frequencies**. EMI:** electrical field intensity produced by high frequunecy emissions due to horns polarized horizontally and vertically

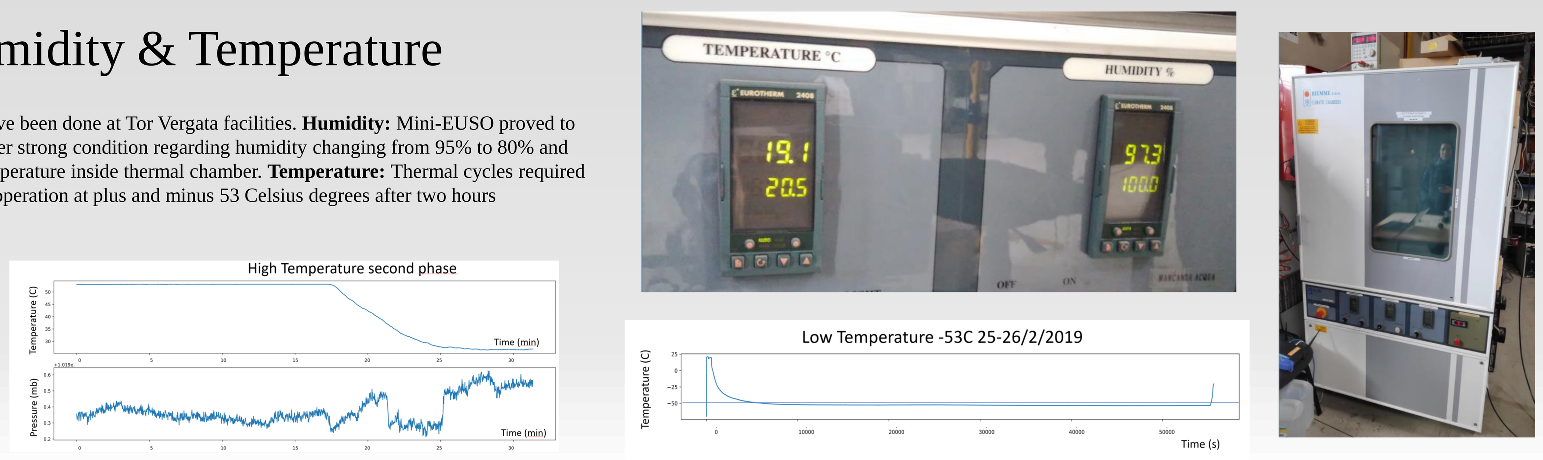
Pressure



Pressure, temperature and humidity during tests inside vacuum chamber**. Left:** After t > 2 h at P >1350mb the pressure has been brought back to P=1028mb and functionality test has been successfully performed **Right:** After t > 2 h at P < 580mb the pressure has been brought back to P=1028mb and functionality test has been successfully performed

Humidity & Temperature

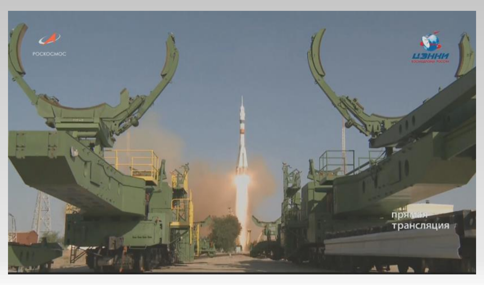
All test have been done at Tor Vergata facilities. **Humidity:** Mini-EUSO proved to work under strong condition regarding humidity changing from 95% to 80% and varying temperature inside thermal chamber. **Temperature:** Thermal cycles required operation at plus and minus 53 Celsius degrees after two hours

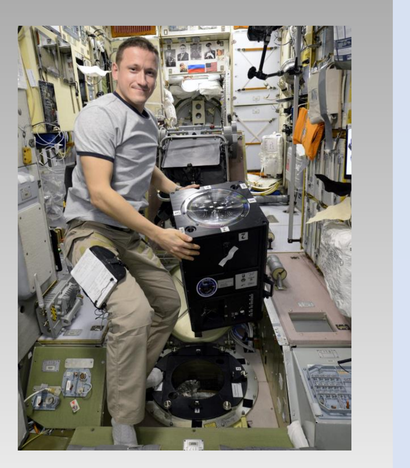


Launch & Accomodation

Mini-EUSO was launched on 22 August 2019 with the unmanned Soyuz MS-14 spacecraft cargo (with robot Fedor). Currently, it is hosted on board the International Space Station, properly on the Russian Zvezda module, facing a UV-transparent window in Nadir mode.

Left: Zvezda module on ISS. The UV transparent windows is located under the panel. **Right: 0**8/22/2019 Launch, Site 31, Baikonur Cosmodrome **Top-right:** Sergey Kud-Sverchkov Cosmonaut mounting Mini-EUSO





JEM-EUSO collaboration 16 Countries, 93 Institutes, 351 people