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Memorie della

International Space Station -the Italian scientific utilization

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Abstract. Italy has a privileged two lane access to the ISS, through ESA and through the "*Memorandum of Understanding (MoU) for the design, development, operation and utilization of three Mini Pressurized Logistics Modules (MPLM) for the International Space Station (ISS)*" between ASI and NASA, signed on 9 October 1997. The ISS is a cooperative program between the Governments and Space Agencies of the United States (NASA), Russia (Roscosmos), Canada (CSA), Japan (JAXA) and Europe (ESA). In orbit around our planet, constantly inhabited since 2000, it constitutes a platform in microgravity for scientific and technological experiments as well as for the experimentation of operational solutions for life and for human exploration in Space. ASI, by virtue of the aforementioned MoU, has acquired from NASA the right to use 0.85% of the NASA resources of the ISS (equivalent to 0.6% of the resources of the USOS segment). The ASI therefore promotes the national opportunities for the use of the ISS deriving from the MoU, through the National ISS Utilization Plan periodically updated and agreed with NASA, and the selection of scientific and technological projects through Tenders or in contractual Joint Ventures. Up to now more than 70 experiments have been carried on in different scientific disciplines. A snapshot is provided on the following missions: DAMA (2011, Roberto Vittori), FUTURA (Samantha Cristoforetti, 2015), VITA (Paolo Nespoli, 2017) and BEYOND (Luca Parmitano, 2019).

Key words. ISS, Astrobiology

1. Introduction

Italy has a privileged two lane access to the ISS, through ESA and through the "*Memorandum of Understanding (MoU) for the design, development, operation and utilization of three Mini Pressurized Logistics Modules (MPLM) for the International Space Station (ISS)*" between ASI and NASA, signed on 9 October 1997. The MoU entered in force following the exchange of Minutes between the two respective Governments, on the basis of which ASI provided to NASA 3 pressurized modules (MPLM - Multi Purpose Logistics Module) for the logistics of the ISS. The ISS is a cooperative program between the Governments and Space Agencies of the United States (NASA), Russia (Roscosmos), Canada (CSA), Japan (JAXA) and Europe (ESA). In orbit around our planet, constantly inhabited since 2000, it constitutes a platform in microgravity for scientific and technological experiments as well as for the experimentation of operational solutions for life and for human exploration in Space. The MPLM mod-

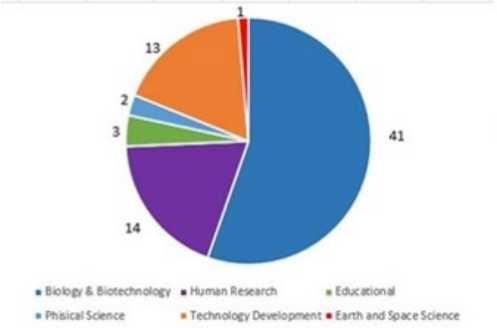
ules were delivered to NASA in 1998, 1999 and 2001 respectively. The first two, Leonardo and Raffaello, made a total of twelve flights to the ISS aboard the Space Shuttle. In February 2010, NASA and ASI considered of interest the permanent installation in orbit of a unit of the MPLM to increase the capacity of the Space Station to host experiments, equipment and materials to support life and operations. Following this agreement, ASI provided, through an assignment to the company TAS-I of Turin which had developed the modules, to modify the Leonardo module to make it compatible with the lifetime in orbit. The new module, called PMM - Permanent Multipurpose Module -, was put into orbit with the STS133 / ULF5 mission on 24 February 2011, and permanently integrated into the ISS infrastructure. In exchange for the supply of MPLM modules, NASA ensures ASI access to use the Station for a portion of its allocations. ASI, by virtue of the aforementioned MoU, has acquired from NASA the right to use 0.85% of the NASA resources of the ISS (equivalent to 0.6% of the resources of the USOS segment). The ASI therefore promotes the national opportunities for the use of the ISS deriving from the MoU, through the National ISS Utilization Plan periodically updated and agreed with NASA, and the selection of scientific and technological projects through Tenders or in contractual Joint Ventures. Up to now more than 70 experiments have been carried on in different scientific disciplines, as shown in the following figure and in the following table.

The MoU gave to ASI also three short duration flights and three long duration flights for ESA Astronauts of Italian nationality; most of such experiments have constituted a scientific complement to some of these missions. In the following paragraphs we will give a snapshot on the following missions: DAMA (2011, Roberto Vittori), FUTURA (Samantha Cristoforetti, 2015), VITA (Paolo Nespoli, 2017) and BEYOND (Luca Parmitano, 2019).

2. The DAMA Mission

It was a short duration mission, the STS-134, from May 16 to June 1 2011. The astronaut Roberto Vittori performed, among the others, the following 12 ASI experiments(Bertolotto et al. , 2012; Mascetti et al. , 2012):

- APE: development of a Space micro vehicle that can be used both indoors and outside of orbiting vehicles (Astronaut Personal Eye). The objective of the experiment was to verify the stability around the roll axis, with 1° of accuracy and with drift less than 1°/min.
- FOAM: aimed to study the possibility of recovering complex geometric shapes of shape memory materials with geometries of different complexity, to test new materials for new actuators, to realize energy sinks, and to realize structures capable of expanding and positioning themselves autonomously.
- IENOS: development of an Electronic Nose, i.e. an artificial sensory system consisting of an array of chemical sensors that compare signals detected using particular recognition algorithms. The goal of the experiment was to simultaneously monitor the air in different environments of the ISS in order to build a map of the air quality during the experimental session and monitor temperature and humidity.
- VIABLE ISS: kept on board the ISS for five years, was aimed at assessing the bacterial and fungal biofilm contamination on different surface Space materials, in order to provide useful information for future Space missions.
- NIGHT VISION: the goal of this experiment was to establish the ability of unicellular algae to withstand cosmic radiation without losing their shielding properties, in order to define a future diet for astronauts.
- BIOKIS: two ASI Space qualified containers, which have previously flown in other missions, in which were housed seven multidisciplinary experiments:
  - Bio-SPORE: aimed to compare how germination and sporulation processes of different strains of Saccharomyces are affected by microgravity.
  - PHOTO-EVOLUTION: aimed to select Chlamydomonas reinhardtii mu-



Sponsored payloads	31
On-board investigations	74
Principal Investigators and Co-PI	> 130
Scientific publications	> 250

Fig. 1. Statistics of Italian experiments on board the ISS

tants tolerant/resistant to both neutron and proton radiation and Space environment.

- HiDOSE: aimed to measure the dose for the experiments in Space biology, using thermoluminescence detectors which efficiently give the dose released by charged particles in low Earth orbit.
- TARDIKISS: investigation of the effects of Space stresses on desiccated but still alive multicellular organisms, *tardigrades*, to test the impact at physiological, biochemical and molecular levels of environmental Space on biological material.
- 3DISS: aimed to assess the radiation dose absorbed during a Space mission on ISS, evaluating the real genetic damage suffered during the Space mission. Cross-correlation of the biological damage was assessed by dosimetric measurements.
- nDOSE: aimed to evaluate the neutron component of the radiation environment (neutrons can be produced as secondary radiation by interaction of primary cosmic rays with spacecraft shielding) within the spacecraft, which is of great importance especially in view of long term Space missions.
- Arabidops-ISS: aimed to investigate the alterations of the gene expression in the model plant species Arabidopsis thaliana related to microgravity conditions, mainly focusing on the ROS genes, with respect to parallel on ground control-experiments.

3. The FUTURA Mission

For the first mission of Samantha Cristoforetti, who was on the ISS from November 23 2014 to June 11 2015, ASI selected a total of 9 investigations(Pignataro et al. , 2015):

- BLIND AND IMAGINED: aimed to understand the sensory motor mechanisms in lack of gravity, through two protocols: MOVE SB (Movement in Orbital Vehicle Experiments Short and Blind) and SHRINK (Space Height Reference In Non-gravitational Kinetics). The deep understanding and the quantification of sensori-motor and perception adaptation is crucial to optimize appropriate countermeasures for long-term Space missions, to deal with the muscular-skeletal system deconditioning. The two protocols share the same payload: Elite-S2, an optoelectronic facility for quantitative human movement analysis already onboard the ISS since August 2007 and exploited for other motion capture experiments with previous crewmembers on board the ISS.
- BONE/MUSCLE CHECK: a study on the salivary markers of metabolic changes during Space missions. Microgravity reduces bone and muscle mass, which is related to

changes in certain substances in the bloodstream and urine; some of these changes can also be detected in saliva samples. Aim of the experiment was to validate whether saliva and/or urine can be used as simple, non-invasive tools to monitor crewmembers' bone and muscle status during a Space mission.

- DRAIN BRAIN: this investigation was both a medical research and a demonstration of an innovative instrument for remote diagnosis and telemedicine. This investigation addressed the cerebral circulation in the human being, specifically the venous outflow mechanisms from the skull, which is one of the major regulators of the brain physiology but very little is known about the mechanisms ensuring blood outflow from the brain in a condition of microgravity. The instrument developed for this research is a strain-gauge plethysmography system, designed to be used on board the ISS both to study cerebral venous return in microgravity conditions and to properly understand the phenomena of physiological adaptation.
- WEARABLE MONITORING: also this investigation was both a medical research and a demonstration of an innovative instrument for remote diagnosis and telemedicine. The goal of this investigation was the validation of a new cloth vest that monitors astronaut autonomic nervous control, heart electrical and mechanical activity, skin temperature and breathing patterns during sleep. The science goals related to the investigation on the sleep quality of the astronauts.
- NANOPARTICLES AND OSTEOPOROSIS: this experiment was related to the crew members' bone density decrease during spaceflight. This decrease is in part caused by the loss of Calcium induced by microgravity-related metabolic changes. This investigation studied a type of nanoparticle made of minerals similar to those found in bones and teeth, which could help counteract bone density loss and accordingly benefit future Space missions.
- CELL SHAPE AND EXPRESSION: the investigation addressed the changes that microgravity causes to living organisms, beginning at the cellular level. It studied how microgravity changes the physical structure of cells, and whether this affects the way they function. Results aimed to provide an experimental model that highlights the relationships among microgravity, cell shape and gene expression, and whether new drugs may be able to counteract these microgravity-induced changes.
- PORTABLE 3D PRINTER: it consisted in a technological demonstration of 3D printer capabilities in Space. The ASI Portable 3D Printer demonstrated an automated 3-D printer producing plastic objects on board the ISS, for a future digital and automated manufacturing facility onboard the ISS, and other future manned spacecrafts or planetary outposts.
- ISSPRESSO: it was a technological demonstration of the capability for preparing an espresso coffee on board the ISS. ISSpresso is part of the Public-Private Partnership program promoted by ASI for the commercial exploitation of the ISS. Within this program, the Agency makes available ISS utilization resources, as crew time, launch mass and volume, to private entities that propose payloads or experiments for the ISS and fund for their development and implementation. The device was an espresso maker for the ISS, which crew members used to prepare tea, coffee, broth and other hot beverages.
- VIABLE-ISS: the experiment brought on the ISS during the DAMA mission was still operational during FUTURA mission.

4. The VITA Mission

The VITA Mission was the third one for Paolo Nespoli, who was on the ISS from July 28 2017 to December 14 2017. ASI appointed for the VITA mission a total of 11 investigations:

- IN SITU BIOANALYSIS: it consisted in the development and testing on the ISS of a simple portable analytical device easily employable by ISS crew members

(Piccirillo et al. , 2017; Carrubba et al. , 2019), in order to collect saliva samples and analyze cortisol level, which is considered a marker of stress level. The device was tested through five different sessions. Future upgrades of the device would allow the analysis of different parameters, in order to let the astronauts check about their general health status.

- AUGMENTED REALITY APPLICATION FOR MAINTENANCE, INVENTORY AND STOWAGE – ARAMIS: it was a technology demonstrator aiming to validate the use of Augmented Reality (Lentini et al. , 2018, 2020), being deployed as an iPad application, to improve and make more efficient the on board operations. The technology demonstration was run by Paolo Nespoli in two different session, the former consisting in performing a maintenance task in Node 2, the latter in a stowage related activity in PMM.
- PERSONAL RADIATION SHIELDING FOR INTERPLANETARY MISSIONS – PERSEO: the experiment was designed to evaluate the effectiveness of a garment fulfilled with 40 liters of water as a personal radioprotection system, easily wearable by the astronaut and aimed at selectively shielding astronaut radio-sensible organs and allowing the crew to exit shelter regions during a SPE to perform emergency activities (Baiocco et al. , 2018; Lobascio et al. , 2018; Baiocco et al. , 2020). The prototype, ad-hoc developed for being worn by Paolo Nespoli, was filled onboard with water from the Potable Water Dispenser, tested for wearability comfort by performing simple activities, and drained after use to the Waste Water System.
- ORTHOSTATIC TOLERANCE: the goal of the experiment was to help developing more effective exercise-based countermeasures to counteract/prevent a major health issue after space flight, the orthostatic intolerance. It consisted of the execution of a pre- and a post-flight orthostatic tolerance test and of the on-board execution of a structured, individually-tailored, treadmill exercise training program, planned on the basis of a pre-flight incremental treadmill exercise test.
- ROOT GROWTH - MUTI-TROP: it was an educational experiment selected after an ASI call, conceived and realized by a high school with the supervision of an academic PI. The experiment aimed to investigate the role of the three main external stimuli (gravitropism, hydrotropism and chemotropism) on root tip orientation and to clarify the interactions between different attractive factors in microgravity conditions.
- THERMAL EXCHANGE – ARTE: a first run of the experiment had already been executed on April 4th 2016, lasting 6 hours; a second run was executed by Paolo Nespoli during the VITA mission. The experiment aimed at on-orbit validation of low-toxicity heat pipe performance for thermal control of future spacecraft, both manned and unmanned. ARTE was operated inside the Microgravity Science Glovebox (MSG).
- ISSPRESSO: the coffee machine brought on the ISS during the FUTURA mission was still on board during VITA mission and it was used by Paolo Nespoli as well, after sending a new set of coffee cartridges.
- ASI BIOMISSION: four selected investigations in the field of cell biology were grouped together due to their commonalities in a single mission:
  - RETINAL LESION STUDY – CORM: the experiment investigated the protective role of Coenzyme Q10 (CoQ10) in retinal lesions, induced by radiations and microgravity in Space environment, in order to Improve our understanding of the effects that radiations and microgravity may have on human retinal cells and to assess the protective effects of CoQ10, related to its antioxidant and anti-apoptotic properties.
  - MUSCLE CELLS – MYOGAVITY: the experiment investigated the molecular, cellular and functional modifications induced by microgravity exposure, both in primary human skele-

tal muscle satellite cells (the muscle's adult stem cells), and in murine muscle cells, overexpressing the insulin growth factor 1 protein (IGF-1).
- OXIDATIVE STRESS – NANOROS: the experiment studied the possible exploitation of cerium oxide nanoparticles (nanoceria) as a countermeasure to skeletal muscle alterations and functional deficiencies caused by the oxidative stress, that is triggered by prolonged microgravity exposure.
- REPROGRAMMING STEM CELLS – SERISM: The experiment investigated the role of the endocannabinoid system in the alterations of bone metabolism, using an innovative cellular model, based on human blood-derived stem cells.

5. The BEYOND Mission

The BEYOND mission wasn't an ASI long duration flight opportunity deriving from the ASI-NASA MoU such as FUTURA and VITA, it was rather an ESA mission. It started on July 20 2019 and ended on February 6 2020. ASI selected six experiments as a scientific complement to this mission: three of them (Acoustic Diagnostics, Amyloid Aggregation and NutrISS) were integrated on board and operated in cooperation with ESA, two (XenoGRISS and LIDAL) were launched through the ASI-NASA MoU, the last one (Mini-EUSO) stem by an Italian/Russian led international cooperation, which required a specific agreement between ASI and ROSCOSMOS.

- ACOUSTIC DIAGNOSTICS: the experiment was aimed at evaluating possible hearing damage by comparing the outcome of several audiological tests performed on the astronauts before and after their mission, and by performing accurate otoacoustic emission (OAE) tests on a monthly base while on board the ISS. For this purpose an innovative system for measuring distortion product otoacoustic emissions was designed, which guaranteed high reproducibility of the test results, exploiting a particular technique for the stimulus calibration in the ear canal, and a high frequency-resolution.
- AMYLOID AGGREGATION: the experiment was aimed to assess if astronauts involved in long-lasting Space missions may have an increased predisposition to develop neurological diseases associated with protein aggregation such as Alzheimer's disease, and to develop novel strategies for the treatment of these neurodegenerative diseases (Casalone et al. , 2019, 2020). These disorders are characterized by the formation, in the brain, of ordered protein aggregates which progressively accumulate into the so-called amyloid plaques and are able to damage neural cells leading to neuropathological lesions and clinical signs. In Alzheimer's disease, the primary component of these protein aggregates is a small protein fragment called Amyloid β peptide (Aβ). 36 jars with peptide Aβ 40, Aβ 42 and a mix of them were filled, in order to study their aggregation and propensity to form insoluble amyloid fibrils in Space over the time.
- NUTRISS: the experiment aimed at tracking and collecting information about body changes during spaceflight, with the ambitious goal of helping the crew to maintain body composition with nutritional advices. To do so, the hardware used on the ISS was a Bio-Impedance Analyzer, capable of assessing changes in body composition; such analyzer was a commercial-off-the-shelf bio-medical device that was Space Qualified by the payload developer. The body mass measurement, also needed for this computation, was carried out just before each session by using the Russian Body Mass Measuring Device.
- LIDAL (Light Ion Detector for ALTEA): it aims at studying the radiation environment in the ISS during the evolution of the solar cycle, allowing: detailed assessment of the radiation environment in the ISS; ISS and transport Models validation; study of the effects of Solar Particle Events in a Space habitat and identification of possible

countermeasures. It is a detector based on scintillators for fast time applications, designed to work paired with three ALTEA Silicon Detector Units (SDU), in order to extend the ALTEA detection capability for the lower Z-part of the radiation spectrum onboard the ISS and to enhance particle discrimination through the measurements of the Time of Flight of the detected ions. It was launched on November 12 2019, and installed and activated for the first time on January 19 2020. It is currently operating nominally in unattended way, and is expected to stay on board the ISS for at least 4 years.

– MINI-EUSO (Multiwavelength Imaging New Instrument for the Extreme Universe Space Observatory): it is an UV optical detector, with a field of view of about 44° and a ground resolution of about 6.1 Km. It is based on an optical system made of two Fresnel lenses with a diameter of 25 cm, and a focal surface made of 36 MultiAnode Photomultiplers, 64 pixels each, capable of single photon detection. The main scientific objectives of the mission are the detection of night UV emissions from the Earth so to build an UV map of the Earth, the search for Strange Quark Matter, the study of atmospheric phenomena such as Transient Luminous Events, the detection of meteors and meteoroids so to contribute to meteor hazard estimation, the observation of sea bioluminescence and of Space debris. It was launched on August 22 2019, and was operated for the first time on October 7 2019. It was used for several observation sessions, is operating nominally, and is expected to stay on board the ISS for at least 3 years.
– XENOGRISS: the ASI scientific complement to this mission included also an educational experiment, like VITA mission, which was selected by ASI after a dedicated call. The experiment payload consisted in a tadpole culture (6 animals) of Xenopus laevis contained in a Xenopus Experiment Unit, contained in the ASI BIOKON facility. The goals were to understand the mechanisms underlying the effect of microgravity upon the processes of growth, repair and regeneration of tissues. A better knowledge of these processes is important in defining protocols for the management of traumatic injuries, wounds and chronic ulcers both in Space and on Earth.

6. ASI support to Italian PIs selected for ESA experiments

Italian researchers can access the ISS also through ESA, as mentioned in the introduction. ESA, however, provides research opportunities on the ISS (and for research on ground) without funding the experiments: this must be done by national agencies. ASI, therefore, issues in turn periodically calls aimed to financially support the national projects already selected by ESA Announcements of Opportunity (AO). The “ESA 2020” call is currently underway, aimed at supporting the Italian researchers selected in the following ESA AOs: AO-16-Bedrest - human physiology using bed rest studies; AO-17-Concordia - medicine, human physiology and psychology using the Concordia Antarctic station; AO-17-IBER - radiation biology using the GSI ground accelerator; “Joint call for ESA-CMSA experiments” - biology, physical sciences and human physiology aboard the International Space Station and the Chinese Space Station; ESA-CORA-IBER - radiation biology using ground accelerators; ESA-CORA-GBF - human physiology, biology (including astrobiology) and physical sciences using ESA’s Ground Based Facilities; ESA-CORA-PF - human physiology, biology (including astrobiology) and physical sciences as part of the ESA program for parabolic flights; ESA-CORA-MAP - human physiology, biology (including astrobiology) and physical sciences using facilities on board the ISS and ground-based.

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