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MUSE (Master in Space Systems), an Advanced Master's Degree in Space Engineering

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Abstract

In Spain, and most part of Europe, historically, space engineering education was a small part of a broader aerospace curriculum in aeronautics, dominated by fluid- and structures- focused engineering.

The Spanish universities have entailed a profound renewal within the last years as a result of the European Space for Higher Education implementation. In the case of *Universidad Politécnica de Madrid* (UPM) this change led to the possibility of setting up new official master's degrees (*Masters Universitarios*). One of these new degrees is MUSE (*Master Universitario en Sistemas Espaciales*), the Master's Degree in Space Systems of UPM, which is fully devoted to space systems engineering and technology, and fully focused on the space industry needs.

MUSE is promoted, organized, implemented and run by *Instituto Universitario de Microgravedad "Ignacio Da Riva"* (IDR/UPM) research institute. The main purpose of this master is to share with the students the wide expertise and experience in space research/technology from the IDR/UPM (and other research groups at UPM). At present, IDR/UPM collaborates with several space scientific institutions (ESA, NASA, JAXA, etc.) on different missions, such as Rosetta, Sunrise, Solar Orbiter, ExoMars, JEM-EUSO. Besides, IDR/UPM designed and developed a 50-kg class satellite (UPMSat-1) which was launched in 1995, and is currently developing another two: UPMSat-2 and Lian-Hé (in collaboration with Beihang University, China).

In this regard, MUSE is project-based learning oriented, as it is characterized by a significant amount of practical work by the students, directly linked to IDR/UPM running space projects. This master's degree is designed to reduce as much as possible the initial training required by the graduates once enrolled in a space engineering company.

The aim of this paper is to explain the origin of MUSE master's degree program, its structure, the implementation focus and problems, student characteristics, study cases carried out, and future challenges.

Keywords: Master's degree, space technology, space systems, project-based learning, active learning

Acknowledgment: The present paper is the first one related to Master in Space Systems of the Technical University of Madrid (MUSE). It is dedicated to the memory of Professor José Meseguer, whose vision inspired all people from IDR/UPM to do their best in every challenge he proposed.

"…aunque la vida perdió,
dejonos harto consuelo
su memoria"

Introduction

In 2010, the head of the IDR/UPM Institute, José Meseguer, proposed the staff of the institute a quite serious challenge, to develop an official engineering master program focused on space technology. The aforementioned staff, formed by professors, researchers, technicians and students, reacted according to Professor Meseguer expectations and on May the 24th of 2014, the Master in Space Systems (*Máster Universitario en Sistemas Espaciales* – MUSE) of the Technical University of Madrid (*Universidad Politécnica de Madrid* – UPM) was approved as an official master by the National Agency for Quality Accreditation of Spain (ANECA). This fact is relevant as:

1. This is the first official master's degree developed and organized by a research institute within the UPM and not anyone of the engineering faculties/schools[1].
2. This master represents an academic way to organize the space technology-related research carried out at IDR/UPM Institute, and strengths the Ph.D. activities within the institute.

Space Engineering/Research Activities at IDR/UPM Institute within the Last Decades

It could be said that IDR/UPM Institute inherits a quite large tradition in space research/technology. This activities started thanks to the work of Professor Da Riva and Professor Meseguer in analyzing the effect of microgravity on the liquid bridges in the late 70s at LAMF-ETSIA (Da-Riva & Pereira, 1982; Da-Riva & Ruesga, 1976; Da-Riva, 1981; Meseguer, Sanz, & Lopez, 1986; Meseguer & Sanz, 1985; Meseguer, 1983, 1984; Slobozhanin, Shevtsova, Alexander, Meseguer, & Montanero, 2012), a research group where the more relevant professors of IDR/UPM started their research activities (see Figure 1).

Besides, in 1974 Professors Da Riva, Meseguer and Martínez started working in the preparation of a Handbook on Spacecraft Thermal Control for the European Space Agency (ESA). The first version of the Handbook was issued in 1975, as a result of a collaboration with Dornier System GmbH (Da-Riva, Meseguer, Martínez, & Stroom, 1978). Subsequent work followed with the updating in several items and the amendment of new ones to become the Spacecraft Thermal Control Design Data Handbook, STCDD ESA PSS 03-108.

[1] However, it should be underlined that MUSE is organized in coordination with Aerospace Engineering school (ETSIAE) of UPM.

Figure 1. *Breaking of a Cylindrical Volume Liquid Bridge by Stretching during The Spacelab-D2 Mission (experiment STACO), in 1993*

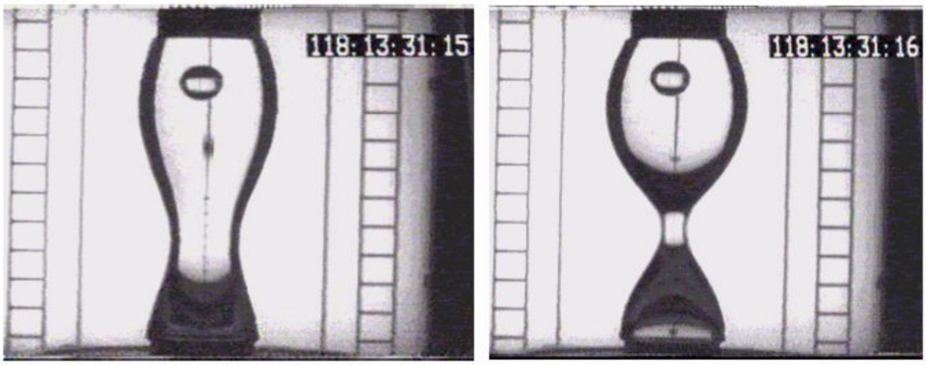
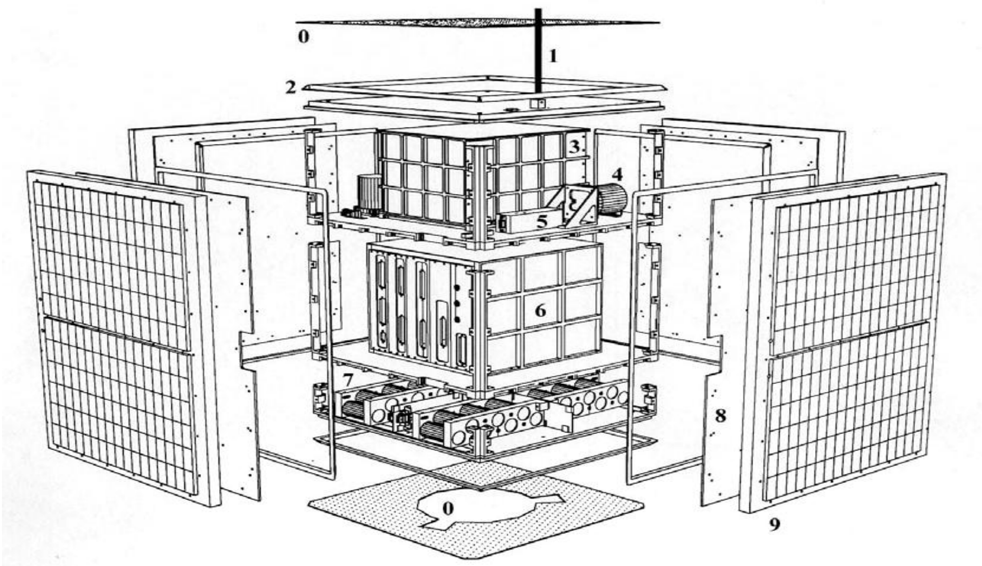


Figure 2. *Sketch of the UPMSat-1*



0- Multilayer Insulation, 1- Antenna, 2- magnetic coils, 3- liquid bridge cell, 4- gyroscopes, 5- magnetometers, 6- electronics box, 7- batteries, 8- side panels, 9- solar panels

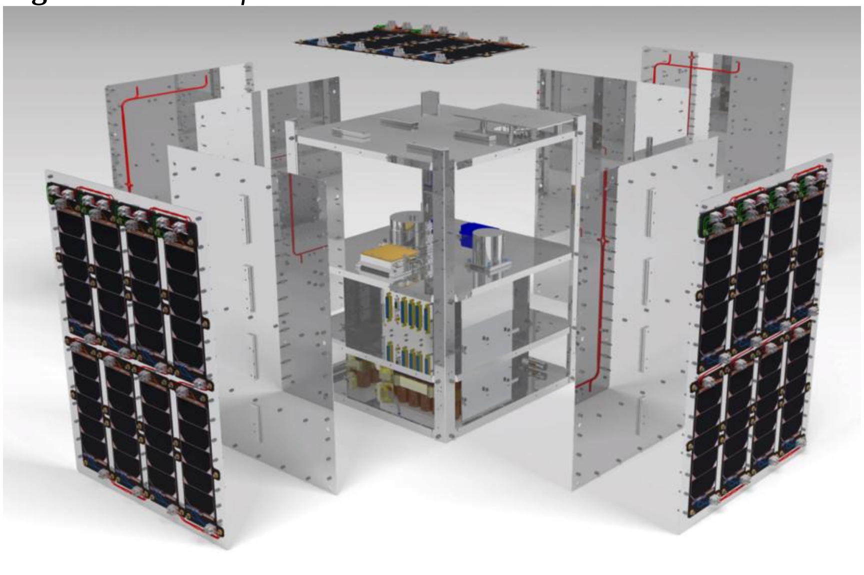
Other relevant examples of space engineering activities developed by the staff of IDR/UPM are:

1. The UPMSat-1, a 50-kg microsatellite designed, developed and constructed under the guidance of Prof. Sanz, who is the present head of IDR/UPM (Meseguer & Sanz-Andrés, 1998; Sanz-Andrés, Meseguer, Perales, & Santiago-Prowald, 2003; Sanz-Andrés & Meseguer, 1996). This satellite was successfully launched in 1995, and represented a joint effort from professors, students and other staff of the Aeronautical Engineering school of UPM (see Figure 2).
2. The CPLM payload (the acronym stands for Liquid Bridge Behavior under Microgravity experiment, in Spanish), designed and

manufactured in the late 90s for the Spanish satellite MINISAT (Sanz-Andrés, Rodríguez-De-Francisco, & Santiago-Prowald, 2001).

3. IDR/UPM team was responsible for the thermal control of the instrument OSIRIS (Optical, Spectroscopic and Infrared Remote Imaging System). This instrument was developed for the Rosetta mission of the European Space Agency (ESA), devoted to the exploration of the 67P/Churyumov-Gerasimenko comet. OSIRIS is a dual infrared camera system consisting in a high-resolution Narrow-Angle Camera (NAC) for the study of the nucleus of the comet, and a Wide-Angle Camera (WAC) designed for recording dust and gas emissions on the surface of the comet (Thomas et al., 1998).
4. IDR/UPM was also responsible for the thermal control of the balloon-borne telescope SUNRISE, which was flown on a balloon at stratospheric altitudes to analyze the structure and the dynamics of the solar magnetic field. SUNRISE can be considered as a precursor of the instrument PHI, which is one of the payloads of the Solar Orbiter mission of ESA (Barthol et al., 2011; Pérez-Grande, Sanz-Andrés, Bezdenejnykh, & Barthol, 2009).

Figure 3. *Sketch of the UPMSat-2*



At present, IDR/UPM Institute is involved in the thermal control subsystem and the structure analysis of the NOMAD payload, which is on board the ExoMars mission. Also, IDR/UPM carries out the same tasks within the consortium responsible for the SO/PHI and EPD payload in Solar Orbiter mission. Both ExoMars and Solar Orbiter are ESA missions (ExoMars in collaboration with Roscosmos).

Furthermore, the UPMSat-2 satellite is at present at the last integration stages at IDR/UPM (see Figure 3). In Table 1 the characteristics of this 50-kg spacecraft are summarized. This is one of the two satellites under development by IDR/UPM as an academic/research challenge, the second one, UNION/Lian-Hé, being the result of a collaboration with Beiang University (Beijing, China).

Table 1. *General Characteristics of the UPMSat-2 Mission*

Mission Life	**2-year**
Orbit	Sun-synchronous: • Noon • Altitude: 600 km • Period: 5828 s
Mass	50 kg
Dimensions	0.5 m × 0.5 m × 0.6 m
Attitude Control	Magnetic: • SSBV and Bartington magnetometers • ZARM Technik AG magnetorquers
Thermal Control	Passive
Power	Based on solar photovoltaic panels and batteries: • 5 body-mounted solar panels (Selex Galileo SPVS-5 modules with Azur Space 3G28C triple junction solar cells) • Li-ion battery designed by SAFT • Direct Energy Transfer (DET)
On board computer and data handling	Based on FPGA (designed by Tecnobit S.L. and programmed by STRAST/UPM)
Launch	2016/2017

Academic Activities at IDR/UPM Related to Space

The related-to-space academic work done until year 2000 by professors of IDR/UPM can be summarized as:

1. Several Ph.D. focused on stability of liquid bridges under microgravity, satellite power subsystem modeling, calibration of scientific instruments in space, etc.
2. Continuous training program on Space Systems Technology, from 1997 to 1999.

From 2000 to 2012, the academic staff of IDR/UPM was involved in several programs related to space technologies organized by the Technical University of Madrid (UPM). They were a quite worthy effort by several engineering schools of the university, to provide a specific master program on space technology/science.

In 2008, the planning to design and develop the UPMSat-2 satellite started at IDR/UPM under the supervision of Prof. Meseguer and Prof. Sanz. Apart from the obvious challenge that such kind of project represents in terms of engineering work, more than 25 Bachelor and Master final degree projects have been carried out related to this project, this academic works being also a challenge for the students, as real responsibilities linked to the UPMSat-2 project were assigned to them. Besides, 4 Ph.D. dissertations on problems regarding UPMSat-2 subsystems have been successfully defended in the last 3 years (with more Ph.D. works being under development at present). Finally, it should be also mentioned that several students from Beihang University are currently doing *stagiares* training periods at IDR/UPM.

Master Programs on Space Engineering and Technology in Spain

Spanish universities offer some programs strictly focused on space technology/science. As far as the authors knowledge, there are four related-to-space technology official programs (approved by ANECA), MUSE being one of them. These programs are summarized in Table 2.

The more relevant differences of MUSE from the other programs are the extension, 120 ECTS instead of 90 or 60, and the orientation, as the present program is fully oriented to technology.

Table 2. *Spanish Master Programs on Space Technologies*

University	Master's program	Total ECTS	Type
UAH	*Ciencia y Tecnología desde el Espacio* (Science and Technology from Space)	60	S, T
UPV/EHU	*Ciencia y Tecnología Espacial* (Space Science and Technology)	60	S, T
UPC	Aerospace Science and Technology	90	S, T
UPM	*Sistemas Espaciales* – MUSE (Space systems)	120	T

UAH – *Universidad de Alcalá* (Alcala University), UPV/EHU – *Universidad del País Vasco* (Basque Country University), UPC – *Universitat Politècnica de Catalunya* (BarcelonaTech), UPM – *Universidad Politécnica de Madrid* (Technical University of Madrid), S – Sscience; T – Technology

The Master in Space Systems (MUSE)

The Master in Space Systems of the Technical University of Madrid is a 120 ECTS (European Credit Transfer and Accumulation System) master program designed to provide a practical, updated and professional approach to space technology.

It is fully harmonized according to the Technical University of Madrid regulations regarding admission of students, organization boards, transfer credits from other university programs, Erasmus program, quality procedures, etc.

Project Based Learning Approach

Together with the normal lessons, quite large part of the master's teaching is carried out through Project Based Learning. This approach was selected as the best educational way in order to force the student to put their knowledge into practice. This methodology basically consists in present to the students real problems that have an open solution (that is, not unique), that make them to take decisions. This normally results into an increased motivation, which is necessary when a large program of 120 ECTS needs to be completed.

Structure of the Master's Program

The Master's program is organized in two years that, depending on the students' necessities, can be extended.

There are 19 subjects, 3 Case Studies and the Final Project of the Master. These 23 study units are classified into 4 different groups:

1. Advanced Mathematics (AM).
2. Space Projects Definition (SPD).
3. Systems Engineering (SE).
4. Spacecraft Subsystems (SS).
5. Case Studies and Final Project (CS-FP).

The subjects tough and the number of credits assigned to each one of them are included in Table 3.

It is important to underline that not only the 3 case studies and the final project are Project Based Learning oriented. Some part of the educational load in a large number of the subjects included in Table 3 is given using this methodology.

Table 3. *Subjects Included in the Master in Space Systems of the Technical University of Madrid (MUSE)*

Group	Subject	ECTS	Learning methodology
AA	Advanced mathematics 1	6.0	L; P
	Advanced mathematics 2	6.0	L; P
SPD	Space environment and mission analysis	4.5	L; P; PBL
	High speed aerodynamics and atmospheric reentry phenomena	4.5	L; P
	Vibrations and aeroacoustics	4.5	L; P
	Space materials	4.5	L; PBL
	Graphic design for aerospace engineering	4.5	L; PBL
SE	Systems engineering and project management	6.0	L; PBL
	Quality assurance	4.5	L
	Space industry and institutions seminars	1.5	L
	Production technologies	4.5	L
	Space integration and testing	4.5	L
	Spacecraft propulsion and launchers	4.5	L
SS	Orbital dynamics and attitude control	4.5	L; P
	Heat transfer and thermal control	6.0	L; P; PBL
	Power subsystems	4.5	L; P; PBL
	Space structures	4.5	L; P; PBL
	Communications	4.5	L; P
	Data housekeeping	4.5	L; P
CS-FP	Case Study 1	3.0	PBL
	Case Study 2	7.5	PBL
	Case Study 3	6.0	PBL
	Final Project	15.0	PBL

L – Lessons; P – Problems; PBL – Project Based Learning

The organization per semester is shown in Table 4. The study load on the students has been tried to be balanced along the four semesters. Nevertheless, changes will be made if required.

Finally, there is one subject, space industry and institutions seminars, in which experts from the industry and official organizations such as ESA or CDTI[1] are invited to give conferences related to their activity.

Table 4. *Time Schedule (in terms of semesters) of the Master in Space Systems of the Technical University of Madrid (MUSE)*

Semester	Subject
Semester 1	Advanced mathematics 1
	Space environment and mission analysis
	Vibrations and aeroacoustics
	Graphic design for aerospace engineering
	Systems engineering and project management
	Space industry and institutions seminars
	Spacecraft propulsion and launchers
Semester 2	Advanced mathematics 2
	High speed aerodynamics and atmospheric reentry phenomena
	Heat transfer and thermal control
	Power subsystems
	Space structures
	Case Study 1
Semester 3	Space materials
	Quality assurance
	Production technologies
	Space integration and testing
	Orbital dynamics and attitude control
	Case Study 2
Semester 4	Communications
	Data housekeeping
	Case Study 3
	Final Project

Admission Procedures

The number of admissions is limited to 20 students each year. This reduced number of admission was stated in order to keep the quality of the education given at maximum standards, bearing also in mind the size of the IDR/UPM research institute.

The admission is regulated by the university official process. There are 2 periods for pre-registration February-April and May-June, in which the students should apply. After each period the Academic Board of the master publishes the list of admissions in the Master's web page. Finally, the registration process is fulfilled each semester by the admitted students within

[1] *Centro para el Desarrollo Tecnológico Industrial* (Centre for the Development of Industrial Technology)

the corresponding period, first period: July (second half) and September (first half); second period: February (first half).

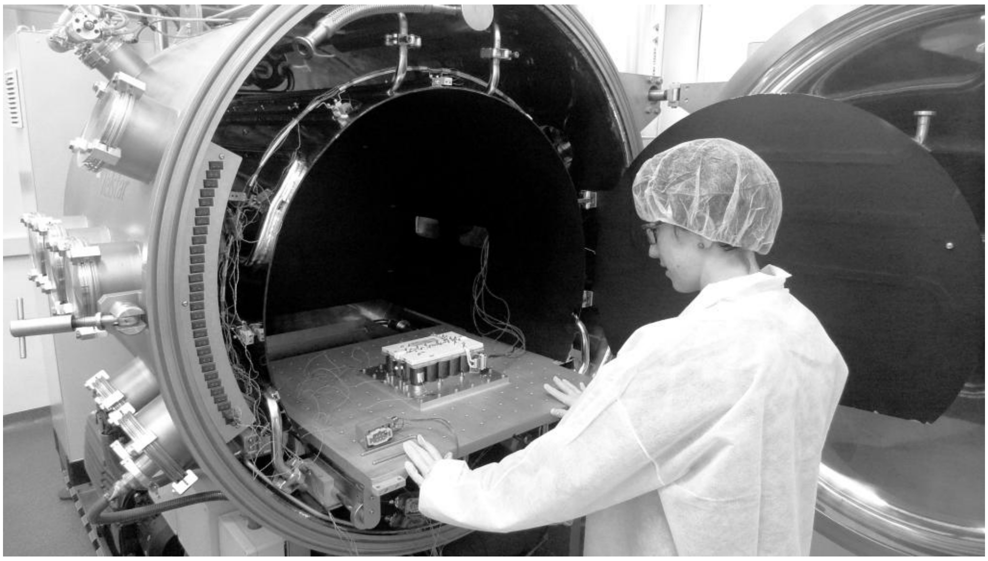
The admission procedure is based on a review of the applicants' background. If after this step the number of candidates exceeds the maximum number of possible admissions a round of interviews would be scheduled. And finally, an exam will be programmed if the remaining candidates are still above the aforementioned maximum number of possible admissions. This exam will be based on the Aerospace Engineering bachelor's degree program of the Technic University of Madrid.

Facilities

The lessons of the Master in Space Systems of the Technical University of Madrid (MUSE) are given at the Aerospace Engineering school of the university (ETSIAE). Some of the laboratory exercises are taught at the facilities of the IDR/UPM Institute located at Montegancedo Campus. These facilities include:

1. A Concurrent Design Facility (CDF). Programed and developed in coordination with ESA, this facility is a quite worthy tool for mission pre-design.
2. A Thermal Vacuum Chamber (TVAC). This facility is currently used for projects carried out for the industry, see Figure 4.
3. Vibration Testing Equipment. Used for satellite parts qualification (UPMSat-2, Lian-Hé).

Figure 4. *UPMSat-2 batteries being tested at the Thermal Vacuum Chamber of IDR/UPM*



Some Lessons Learned

Although this master program has a reduced life (only two academic years, 2014-2015 and 2015-2016), some patterns have been identified.

Background of the Admitted Students

The admitted students come normally from the Aerospace bachelor's degree at the Technical University of Madrid. This background guarantees an adequate path of the students through all Master's program. Additionally, other admitted students have an Aerospace bachelor's degree from other Spanish universities. No special problems have been detected with these students.

Some admitted students with other Engineering Bachelor's degrees or Bachelor's degrees in other fields such as Physics or Informatics, shown certain lacks in certain subjects as "Graphic design for aerospace engineering" or "Vibrations and aeroacoustics". Special tutorial actions are required in these cases.

Finally, this Master program seems to draw attention from other countries students. At present, students from Argentina, Colombia, Ecuador, Venezuela, México, and U.S.A., have applied for a position at MUSE.

Table 5. *Some of the Case Studies Proposed and Carried out by Students of the Master in Space Systems during 2014-2015 and 2015-2016*

Testing of the attitude positioning photodiodes of the UPMSat-2.
Analysis, characterization and testing of the UPMSat-2 Reaction Wheel payload.
Design and analysis of the UPMSat-2 safety transportation box.
Mechanical design of Vibration Testing Facility parts.
Analysis, characterization and testing of the UPMSat-2 magnetometers.
Testing and improvement of the Orbits' module of the Concurrent Design Facility (CDF).
Testing and improvement of the Thermal Control module of the Concurrent Design Facility (CDF).
Harness design for the UPMSat-2.
Thermal analysis of the UNION/Lian-Hé satellite at the CDF.
Orbit analysis of the UNION/Lian-Hé satellite at the CDF.
Analysis and implementation of the ESA CDF core in the CDF of the IDR/UPM Institute.

Case Studies Carried Out

As mentioned in the previous sections, the Project Based Learning methodology is specifically selected for the Case Studies 1, 2, and 3, and the Final Project. A selection of the Case Studies given to the students of the MUSE in the academic years 2014-2015 and 2015-2016, is included in Table 5. These cases were related to the UPMSat-2 project, or new developments for the Concurrent Design Facility or the Vibration Testing Facility.

The level of the works is generally high, this fact being recognized by the industry (Spanish companies within the space industry are normally invited to the dissertation and defense of the Case Studies).

Conclusions

At present, space research/technology/industry represents one of the boundaries for the human knowledge. Besides, it affects different aspects of the society, such as culture, education, business, government, military, etc.

These facts may explain the good perspectives of the Master in Space Systems of the Technical University of Madrid (MUSE). Although, 2015-2016 is the second year of this master program some positive aspects have been identified:

- A significant percentage of the Master's students are interested, or have started, their Ph.D. studies.
- Many students of the Master are receiving fellowships from other departments of the university.
- Some students have been contacted by companies from the space sector even before finishing their degree.

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