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Astronomical and space-based systems engineering

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Abstract. The Master's degree "Outils et Systèmes de l'Astronomie et de l'Espace" (OSAE, "Astronomical and Space-based Systems Engineering") is intended for students interested in Astronomy and Space technology. Students undergo a comprehensive training in partnership with international-level laboratories and with leading private companies. The degree provides physicists with a wide range of skills, appropriate for those whose intention is to participate in subsystems, equipment and engineering systems, and also for future project managers, working in the aerospace industry or similar technological industries or in national and European agencies. The 1-year course is given in collaboration with national and international institutions, laboratories and industries. It includes an extended training period (5 to 6 months) and a theoretical and practical specialization given by university and industrial teachers. It benefits from the network of laboratories associated with the Astronomy and Astrophysics doctorate school of the Île-de-France.

Keywords. Master's degree, Space, System, Engineering, Instrumentation, Numerical techniques

1. Introduction

The techniques used today for astronomy and space projects are complex systems pushed to the highest performance levels. They are conceived in research laboratories with international support, carried out with strong industrial partnerships and executed by national and European agencies, e.g. the French National Centre for Space Studies (CNES), the European Space Agency (ESA) and the European Southern Observatory (ESO). The conception and the operation of these systems, together with contacts between engineers, researchers and industrialists, offers exceptional training possibilities in a high-technology and advanced international context (Fig. 1).

The Master's degree "Outils et Systèmes de l'Astronomie et de l'Espace" (OSAE, "Astronomical and Space-based Systems Engineering") is intended for students in physics, applied physics, technology, electronics, computer science, materials science etc., interested in astronomy and science or space technology. This short course (1 year) is given in collaboration with national and international institutions, laboratories and industries. It includes an extended training period (5 to 6 months) and a theoretical and practical specialization given by university and industrial teachers. The full description of the educational resources is given in Section 2.

The Master's degree is associated with the doctorate school in Astronomy and Astrophysics. About 30 laboratories (CNRS, CEA, the Paris Observatory, Universities, ONERA) in the Île-de-France region, as well as national and international institutions (CNES, IRAM, ESO, ESA/ESTEC) participate in this school; in addition, the degree Astronomical and Space-based Systems Engineering includes private industry. Students are presented with a complete training in partnership with international-level public and private laboratories. The rôles of each partner are elaborated in Section 3.

The degree trains physicists for a wide range of skills, appropriate for those whose intention is to take responsibility for subsystems, equipment and engineering systems, and also for future project managers, working in the aerospace industry or similar technology industries or in national and European agencies. Specialized industries, equipment producers, small subcontracting firms and laboratories from the public sector, are also possible outlets. Skills and jobs are described in Section 4.

Finally, in Section 5, we summarise our experience.

2. Educational resources

2.1. *Organisation*

The 1-year course is divided into three parts: the core syllabus and the specialization in Semester 1 and the training period in Semester 2. The core syllabus and the specialization include courses, practical work and projects. The specialization "computational physics" is directed towards digital techniques, programming tools, signal processing and simulations, the other specialization "instrumental techniques" focusses on the methods for pushing instrumentation to the highest performance levels in the constrained environments of large telescopes and space missions. A training in the conception of complex systems for space or ground-based instruments is delivered in the core syllabus.

In addition, students lead and develop practical projects. All together, the different modules introduce the many subjects necessary first to observe an astronomical object, than to process the data (Fig. 2).

Table 1 describes the resources of the modules taught in Semester 1.

- The "computational physics" specialization includes advanced programming tech-

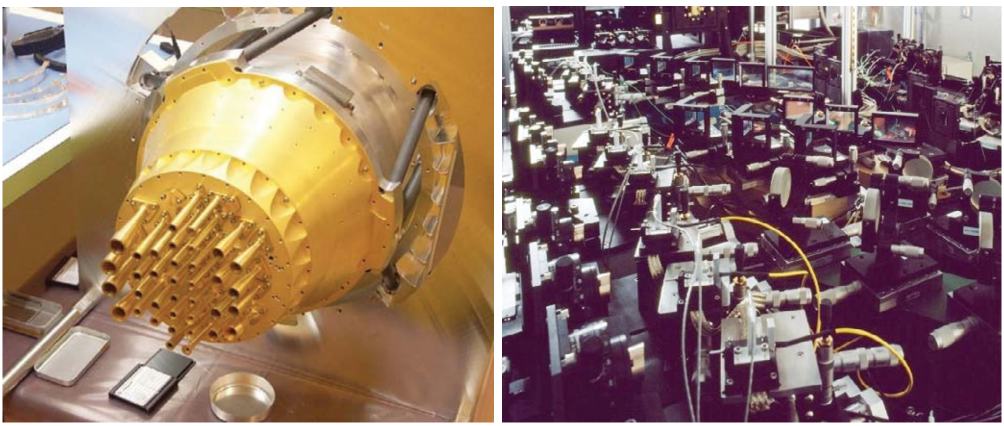

Figure 1. (*Left*) High Frequency Instrument (HFI) for the focal plane of the ESA Planck mission; (*Right*) Amber interferometer at ESO/VLTI. The goal of the Master's degree "Astronomical and Space-based Systems Engineering" is to train physicists whose intention is to take responsibility for the conception, the development, the operations and the exploitation of such instruments.

Table 1. First semester

Core syllabus	Specializations	
	Instrumental techniques	Computational physics
- Signal detection	- Guided and active optics	- Digital processing
- Data processing, automation	- Microwaves, radars and applications	- Structure calculations (mechanical, vibration)
- Structure calculation	- Sensors, microelectronics	- Data acquisition and processing
- Systems and projects	- Thermical, cryogenics	- Filtering. Wavelet transform
- Industry	- Space environment	- Object oriented programming
- Practical work in instrumentation		- Electronics and programming onboard
- Computing science		
- Astronomy		
- English language		
- Project		

niques, civil engineering software, user interfaces, a complete training in the use of software, data acquisition and processing.

• The "instrumental techniques" specialization includes training in signal detection (sensors, optics, and electronics) under very demanding conditions for space projects or large observatories.

• During the 5 to 6-month long training period, students work in industry, space agencies, foreign laboratories or observatories (Table 2).

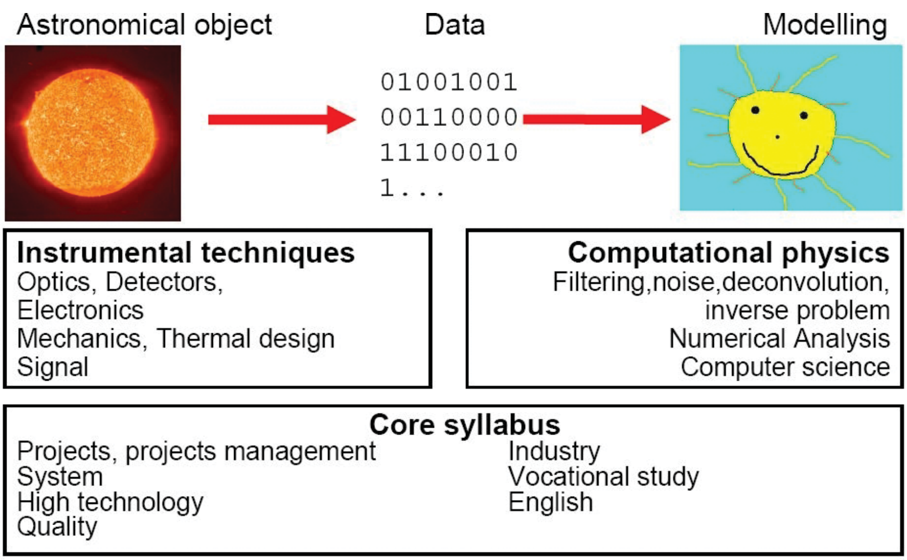

Figure 2. The philosophy of the Master OSAE: the different modules give a detailed view on each step necessary to observe an astronomical objet (specialization in instrumental techniques) and to process the data (specialization in data processing). All of these steps developed in detail during each specialization period are first introduced during the core syllabus.

Table 2. Second semester: training period

Examples of training periods in industry		
- Setup of an optical bench	EADS, Toulouse	France
- Radiometric test bench for APS and CDD detectors	SODERN	France
- Modeling and design of a deformable mirror	REOSC/SAGEM	France
- Characterization of a C-MOS detector	EADS, Toulouse	France
- New technology mirrors	Imagine Optics, Orsay	France
- Calibration of an infrared detector	Alcatel, Cannes	France
...		
Examples of training periods in space agency, foreign laboratory or observatory		
- Trade-off study for instruments, rovers and operations for lunar polar landers	ESA/ESTEC	The Netherlands
- Design and testing of a focal plane coupler prototype for the SPICA-ESI mission	RAL, London	UK
- Development and test a client-server platform for a Matlab code that computes seismic travel time sensitivity kernels	MPI, Lindau	Germany
- Automatic procedure to monitor the alignement of the delay line rails	ESO/VLTI	Chile
- OHANA: study phase of the first baseline	Ohana	Hawaii, USA
- Post processing of VIRTIS-M data and characterization of the optical bench tools	Galileo Avionica Firenze	Italy
...		

2.2. *Specific lectures*

Lectures specific to the Master's define its spirit. They are all based on special skills of the laboratories involved in the Master's, including space-borne but also ground-based

Table 3. Fact sheet

Opening	2000
Core syllabus	380 hr
Specialization	150 hr
Training course	5-6 months
Candidates per session	$\simeq$ 18
- withdrawals before the examination	3 %
- success at the exam	98 %
Education completed with a PhD in instrumental or numerical engineering	15 %
Placement rate as engineer	$\simeq$ 85 %
Median time before placement	2 months
Median time before a rolling contract	2.5 years
Engineer in the industry	62%
Engineer in agencies, laboratories or observatories	38%
Web site (in French + page in English)	`http://osae.obspm.fr/`
Web site of the association of the OSAE students	`http://www.osae.fr/`

Values averaged over 7 groups of students, having graduated in the years 2001-2007.

projects. We manage to introduce multiple aspects in each lecture: for example, adaptive optics gives the opportunity to study in detail optics, mechanics, automation and systems.

- The "System and space project" module presents the specific characteristics of the organization of space projets. It introduces the development in different phases, as well as the concept of a system, the systems approach, the functional analysis techniques.
- The "Object oriented programming" module is proposed as a project for the modeling of a complex system (e.g. the detection chain of adaptive optics). The module is organized in a collaborative environment: each sub-group is in charge of a part of a subsystem; a student acts as a project manager.
- The "Project study" is a personal contribution to a Phase 0 or Phase A project. With this module, students undergo a detailed analysis of a subsystem selected among the critical subsystems of the project.
- The training period, in industry, space agency, foreign laboratory or observatory is oriented towards system approach (Table 2). Long duration is profitable for efficient contributions.
- A 2-day visit of a space technology center (ESTEC, Fig. 3) or a large ground-based facility (Nançay Radio Telescope) gives the opportunity to discover the facilities for the integration and tests of space-borne or ground-based projects.

Further informations on the degree are given in Table 3.

3. Partners

The degree benefits from the experience and skills of the partners which are involved in the most recent and largest projects in astronomy (e.g., CoRoT, Planck, Herschel, Mars Express, Rosetta, JWST, Bepi Colombo, NAOS/VLT, OHANA, VISIR/VLT, ...). Due

Figure 3. OSAE students visiting ESTEC, the European space research and technology centre.

Table 4. Main partners

Universities supporting the Master's		
Observatoire de Paris	Meudon	
Université Pierre et Marie Curie, Paris 6	Paris	
Université Denis Diderot, Paris 7	Paris	
Université Paris-Sud, Paris 11	Orsay	
Space laboratories involved in the Master's[♭]		
IAS, Institut d'Astrophysique Spatiale, Université Paris-Sud	Orsay	France
LESIA, Laboratoire d'Études Spatiales et d'Instrumentation en Astrophysique, Paris Observatory	Meudon	〃
LPP, Laboratoire de Physique des Particules, École Polytechnique	Palaiseau	〃
SAp, Service d'Astrophysique, CEA	Saclay	〃
Observatories, National and International Agencies*		
CFHT	Mauna-Kea	Hawaii
CNES, Centre National d'Études Spatiales	Toulouse	France
ESA/ESTEC, European Space Research and Technology Centre	Nordwijk	The Netherlands
ESO, European Southern Observatory	Garching	Germany
	La Silla, Paranal	Chile
IRAM, Institut de Radio-Astronomie Millimétrique	Grenoble	France
ONERA, Office National d'Études et de Recherche en Aéronautique	Chatillon	France
Industry*		
AER	Chevilly-Larue	France
Astrium satellites	Toulouse	France
Carlo Gavazi Space	Padova	Italy
CILAS	Orléans	France
EADS Space transportation	Les Mureaux	France
Imagine Optics	Orsay	France
SAGEM/REOSC	Saint-Pierre du Perray	France
SESO	Aix-en-Provence	France
SODERN / EADS	Limeil-Brevannes	France
Thalès Alenia Space	Cannes	France
...		

[♭]Major contribution in bold font.
*Partners involved via teaching or training.

to the nature of these projects, the partnership brings together laboratories, agencies and industrialists (Table 3). The rôle of the partners are, depending on the case, similar or complementary. Research and development are conducted everywhere. Phase 0 work occurs mainly in the laboratories; phase A work too, in close interaction with the agencies. Further phases are supervised by the agencies, with most of the realizations by the industry, but for very unusual devices realized in the laboratories. External experts from industry and agencies participate in the modules. Trainings are favored in the agencies and industries, while a large fraction of them, about one third, occur in an international context (Table 2).

Table 5. Job types of OSAE graduates

Research & Development Engineer	Project Controller
System Engineer	Cost Engineer
Project Engineer	Mechanical Engineer
Product Assurance & Quality Engineer	Thermal Engineer
Test Engineer	Applications Engineer
Qualification Engineer	Software Engineer
Safety Engineer	

The complex interactions between the actors of space and astrophysics have consequences for the careers of the graduates, as is explained in the following Section.

4. Skills and jobs

The objective of the Master's degree, intended to prepare for system engineering, are well met since 85% of the jobs occupied by the graduates of the Master's OSAE are related to engineering in the high-technology domain, in industry, space agencies, space laboratories or observatories. The importance of the rôle of agencies and observatories in the astrophysical and space sector is apparent in the large fraction of graduates working there, about one third (Table 3). A non-negligible fraction of the graduates, about 15%, complete the Master's education with a PhD in instrumental or computational engineering.

The degree, given in an astrophysical context, applies to all high-technology fields, especially when quality plays an important rôle, or when complex systems are involved. The types of most of the jobs occupied by the graduate students are given in Table 5.

Discussions with the graduates and with their employers give the reasons explaining the successful placement of the graduates:

- The Master delivers a multiple set of skills in instrumentation, digital processing and information technology.
- Emphasizing the systems approach yields a highly valued skill.
- Quality and high-technology are naturally associated with space-borne and ground-based projects in astronomy, thus students can apply successfully for jobs in quality and high-technology.

5. Discussion

The 9-year experience of the Master's degree can be summarized by a few statements:

- In France, education of engineers is most often given in Engineer Schools and not at the University. The success of the placement of our students as engineers, hence the success of the degree, shows that the knowhow and skills of the astronomical laboratories and of their partners yields a high performance education. It emphasizes too, if necessary, that astronomy is not only beautiful galaxies and stars, but also a science which stimulates the development of extremely complex systems that works successfully.
- Projects and collaboration between engineers, researchers and industrialists translate easily into a degree where engineers, researchers and industrialists collaborate. This gives a degree allowing a smooth and successful transition from the University to the employment market.
- Training possibilities in astronomy are able to propose exceptional experience in a high-technology and advanced international context. Having participated, for example,

in the test of the alignment and setup of the VLTI delay lines is an invaluable experience that will fully benefit the CV of a young professional.

- Key science in astrophysics comes largely from key projects. Most of the important characteristics of these projects translates into very generic keywords: research and development, complex system, project organization, quality. Early career engineers having benefitted from such an education can apply these skills in all high-technology domains.

Acknowledgements

Being in charge of the Master OSAE is for us a real pleasure, and we warmly thank all of the engineers, professors and researchers involved in this Master's degree. The foresight of many persons allowed its creation in 2000, among whom we should cite Michel Combes, astronomer and former president of the Paris Observatory, Pierre Encrenaz, professor at the Pierre-et-Marie-Curie University (Paris 6) and Pierre Léna, professor at the Denis-Diderot University (Paris 7). The Master's degree benefitted from the support of many other people: we apologise for not mentioning all of them, but we must single out Sonia Akrour for her invaluable rôle presence as the Master's secretariat and administration.