Master’s Program Earth Oriented Space Science and Technology (ESPACE)

Department of Civil, Geo and Environmental Engineering, Technical University of Munich
23.03.2018

Bezeichnung: Earth Oriented Space Science and Technology (ESPACE)
Organisatorische Zuordnung: Department of Civil, Geo and Environmental Engineering
Abschluss: Master of Science (M.Sc.)
Regelstudienzeit: 4 semesters / 120 credits
Studienform: Full-time
Zulassung: Aptitude assessment procedure in accordance with current FPSO
Starttermin: WS 2005/06
Sprache: English
Studiengangsverantwortlicher: Univ.-Prof. Dr.techn. Mag.rer.nat. Roland Pail (Program director)

Ergänzende Angaben für besondere Studiengänge: Double-Degree with Wuhan (China)

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1 Goals of the degree programme

1.1 Purpose of the degree programme

With the tremendous increase of satellites it was identified that there exists a knowledge gap between satellite technology and interpretation of acquired data for Earth observation applications. The degree programme intends to train engineers who are able to bridge this gap. It meets the growing demand for globally available satellite data, e.g., GPS and its European equivalent Galileo, TerraSAR-X and TanDEM-X, Sentinels in the frame of EU/Copernicus, and Earth observation satellites like GOCE, GRACE, Cryosat, SMOS, Swarm, etc. For instance, this data is especially interesting for security-relevant applications (e.g., the EU program INSPIRE (INfrastructure for SPatial InfoRmation in Europe) to support in crisis situation response), for the fast growing international market in the field of satellite-supported positioning, navigation and logistics (from Google Maps to vehicle navigation systems for the purpose of routing and guidance), and for issues connected to the impact of global change on the environment and living conditions (e.g., sea level rise, melting ice mass, natural hazards, early warning systems). Upon completion of their studies, students will be able to make direct and important contributions to current topics of paramount importance to society, the economy and science. Accordingly, the need for qualified engineers is high.

The international English-based Master’s degree programme “MSc. in Earth Oriented Space Science and Technology” (ESPACE) was established in 2005. **ESPACE is an interdisciplinary Master’s degree programme positioned at the interface between space technology and the engineering and natural scientific use of satellite data.** ESPACE combines the technical aspects of the satellite and observation systems with scientific and commercial applications. This requires interdisciplinary knowledge beyond the borders of different engineering disciplines such as geodesy, mechanical and electrical engineering, as well as physics, informatics and geosciences.

Typically, tasks of space science and technology are handled in an international framework and at the interface of science and industry with major contributions by national and international space agencies (e.g., ESA, NASA, JAXA), which requires evidently globally interlinked expert knowledge, and which shall be decidedly linked to high-performance German scientific institutions and industry in this field. **Therefore, the ESPACE Master’s programme addresses international students with the goal to educate talented professionals for both the German and the international market.**

The goal of the ESPACE Master’s degree programme is to train students to become experts in the use and development of satellites in the three main areas of Earth system science, remote sensing and navigation. Students acquire fundamental knowledge and competencies in these three fields as a general basis, as well as the interfaces among them in order to be able link technological know-how with practical application. They simultaneously learn the necessary basics of signal processing, sensor technology, orbital mechanics and space technology, so that they are in a position to support planning and development of future missions for the above-mentioned areas. These fundamental competencies shall enable ESPACE graduates to discuss and interact with experts of all relevant fields of Earth-oriented space science in an interdisciplinary environment. Moreover, they acquire and deepen their specialist knowledge in one of the three subjects. Graduates of ESPACE are not only able to interpret, analyse and evaluate satellite data, they also make use of their knowledge to support designing all the phases of the development cycle of a satellite mission, be it the satellite design in terms of payload, instruments, orbit, rocket launch, signal processing or the ground segment. Graduates are therefore experts for satellite missions and their use in Earth observation.
Due to the complexity of the tasks in space and geosciences, which are usually performed in well-organized and functioning interdisciplinary teams consisting of people with different cultural backgrounds embedded in an international structure, students of the ESPACE Master’s programme develop intercultural and teamwork competencies through extensive project-oriented work.

The Munich region has a unique concentration of expertise in the fields of satellite technology, natural science, remote sensing and navigation distributed among the three universities (Technische Universität München (TUM), Ludwig-Maximilians-Universität München (LMU) and Universität der Bundeswehr München (UniBw)), research institutes such as the German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt, DLR) and industry. The international Master’s degree programme Earth Oriented Space Science and Technology (ESPACE) makes use of these favourable conditions to train engineers. Numerous reputed scientists at the above-mentioned institutes and external lecturers from industry and research are involved in the teaching process.

By including numerous scientific institutes and the space industry in the teaching concept, ESPACE makes full use of the potential of excellent scientists, offering also the opportunity of dedicated project work and Master’s theses in close co-operation with, and in many cases even at the location of these institutions. Thus the students become involved in current projects, state-of-the-art technology and science, and daily practice.

1.2 Strategic importance of the degree program

1.2.1 The background of the ESPACE program and its position within the scope of the department’s mission statement

As part of the TUM-wide program innovaTUM, in the early 2000s the Department of Civil, Geo and Environmental Engineering (BGU) has striven to take new strategic direction. The most important goal of this new strategy was to hone the profile of the department in terms of research and teaching within the scope of its mission statement “Building – Infrastructure – Environment – Planet Earth” formulated in 2003. At the same time, the department aimed to further consolidate cooperation with neighbouring faculties and research institutes external to the university.

Against this background, a profile-forming initiative was selected as part of a competition that took place within the department of each of the four core themes named in the mission statement (as well as for an overriding interface topic). As an initiative for the core theme “Planet Earth”, ESPACE was described in an external assessment process within the scope of the innovaTUM program of TUM as “expressly worthy of promotion with few concessions” (Endbericht der Fakultät für Bauingenieur-und Vermessungswesen zu innovaTUM-2008, TU München). The human resources and funding required to carry out the program resulted from this process.

In its mission statement, the BGU department emphasizes the growing impact of global processes in the Earth system on political decisions and also economic, social and technological development. Therefore the central elements of the core theme ‘Planet Earth’ are the global observation of the Earth as a system from space, allowing changes and processes in and on the Earth to be recorded and their mutual interaction demonstrated in models. ESPACE combines the various aspects of the development and analysis of national and international Earth science satellite technologies in a unique manner by linking the expertise available at the department (in particular a number of chairs of the Focus Area “Geodesy”) in terms of the realization, analysis and use of various satellite missions with application subjects (e.g. geophysics, climatology) and complementary engineering subjects (e.g. mechanical engineering, electrical and computer engineering).
1.2.2 Position within the mission statement of the TUM and the guiding principle of the department

Observing the Earth system is a successful research subject at the TUM. The content of the subject matter covered by the ESPACE program is highly relevant to the interdisciplinary core themes environment & climate described in the TUM’s mission statement, because Earth observation with satellites significantly contributes to the monitoring and quantification of global change processes in all relevant sub-components of the Earth system, the determination and visualization of natural hazards as well as early warning systems. Also, the research work on the development of satellite procedures and the analysis of satellite information provide important stimuli for the focal areas of information & communication, as well as mobility & infrastructure.

The TUM specifically concentrates on forging international alliances with leading teaching and research institutes and networking in the fields of science and commerce. The international ESPACE Master’s degree program, one of the first international degree programs instituted at the TUM, fulfills this mission goal and enjoys an excellent reputation both at home and abroad, thanks to the involvement of teaching staff from a large number of scientific institutes, international organizations and the global space industry, as well as guest lecturers from Germany, Europe and overseas. At the TUM, the cooperation afforded via the teaching concept stimulates numerous new, highly innovative research cooperation projects between the participating organizations from which the students also take substantial benefit.

TUM’s mission goal of internationality is fostered, further extended and has been solidly established by the integration of a double Master’s program for especially talented students in cooperation with a university in China - the first of its kind at the TUM. The Double-Master’s Agreement with the Wuhan University, one of the TUM’s partner universities, was launched for the winter semester 2010/11 (see Appendix). The positive acceptance by Chinese students, which have to pass a cooperative German-Chinese entrance selection process to ensure the high quality of candidates, demonstrates the demand for such an international agreement.

The main objectives of the ESPACE program are also in full agreement with the long-term guiding principle of the Department for Civil, Geo and Environmental Engineering “Building – Infrastructure – Environment – Planet Earth” (cf. Fig. 2.1), specifically contributing to the areas “Planet Earth” and “Environment”. ESPACE represents the department’s only international Master’s program in the field “Planet Earth”.

1.2.3 Munich Aerospace

Munich Aerospace is an institutionalized joint organization of the TUM, UniBW, DLR and Bauhaus Luftfahrt (BHL). Among other things, it also pursues the goal of bundling shared competencies in research, teaching and doctoral programs. One of the four main subject areas is geodetic remote sensing. In addition to joint research activities, other focal points of the activities by Munich Aerospace comprise teaching and further training (e.g. Master’s degree programs and graduate schools). By virtue of its international concept and specific cooperation with scientists from several faculties at the TUM and the various cooperation projects with the DLR and UniBW, ESPACE serves as the prototype of a Master’s degree program within the Munich Aerospace industry.

2 Qualification profile

Graduates of the international Master’s program Earth Oriented Space Science and Technology (ESPACE) have solid thematic and methodological competencies in the topics of Earth-oriented space science and technology, being able to perform a quality conscious, responsible and creative approach and having a solid and comprehensive fundament of expert knowledge. Basic competencies are acquired by all students in three core areas: satellite and remote sensing data analysis, space engineering, and satellite application engineering, in order to establish fundamental knowledge of all relevant subjects enabling the graduates to work in a wide range of space sciences.

The focus of the core subject satellite and remote sensing data analysis lies on the development and application of processing methods to satellite-derived data and models. With this core subject, students acquire the methodological competence to apply different processing methods and approaches to practical problems of satellite and space engineering, to select the optimal method for certain practical problems in the field of satellite and remote sensing data analysis, to work with data and process models, to assess the results quantitatively and to interpret the results in the context of space science and technology.

In the core subject space engineering, students acquire thematic and methodological competencies in the field of spacecraft technology (spacecraft design, spacecraft subsystems, launcher systems,
rocket design), orbit mechanics and dynamics, ground segment design, and robotics. Graduates have the basic know-how and competencies required to review state-of-the-art knowledge of space engineering, to systematically expand existing specialized know-how by developing, upgrading and implementing new methods and technologies in the field of space engineering; and they are able to realize and to analyse the interplay among the subdomains of space engineering. They are able to understand and to apply the control principles for orbital, spacecraft attitude and robotic operations, and to reproduce the behaviour of these systems on ground for verification purposes.

The focus of the core subject satellite applications engineering lies on the analysis, modelling and interpretation of satellite and remote sensing data related to the key satellite applications. Graduates have a thorough understanding of the basic components of system Earth and its main geodynamic processes in the Earth’s interior, at the surface, and the global energy budget, and they are able to develop, upgrade and implement mathematical and physical concepts and to apply them for the solution of practical problems in the field of satellite applications engineering, to interpret geophysical, geodetic and geodynamical results, and to put them into the scope of geoscientific concepts. They are able to understand the basic principles and concepts of photogrammetry, remote sensing, geoinformation systems, and satellite navigation, and they are able to apply related methods, to assess and to interpret the results. Graduates have the competence to view processes in their entirety, to connect the expertise acquired in a particular discipline with a more general scope and to derive consequences and guidelines for action on this basis.

These core competencies in the three areas enable ESPACE graduates to have an overview of the most important fundamentals in the field of Earth-oriented space science and technology, to build interfaces and to develop overarching concepts and technologies among them. This interdisciplinary expertise qualifies ESPACE graduates for a wide range of professional profiles both in science and industry.

Beyond their competencies in the three core areas as described above, the main criteria of the qualification are further focused by three selected areas of concentration: (1) Earth System Science from Space, (2) Remote Sensing, and (3) Navigation. Here, students acquire specialized expert knowledge in one thematic field and are trained to acquire in-depth knowledge, to apply related methods, to assess and to evaluate results and to create new methods and technologies in this field.

Graduates selecting a specialization in Earth System Science from Space acquire a profound scientific knowledge of the Earth’s system and its sub-components (ocean, atmosphere, hydrosphere, solid Earth). They are able to link data from Earth observing satellites and geophysical models describing Earth system dynamics, to apply them to record, present and evaluate processes and mass transport in the system Earth, and to evaluate their impact for global change. Graduates specializing in Remote Sensing are able to apply in-depth methods to record, analyse and visualize sensor data of various wavelengths and scales. They are able to evaluate the suitability of ground-based, airborne and space-assisted optical, infrared and microwave sensors for task-specific problems in the field of remote sensing. They have the competence to combine data analysis methods for creating digital city and terrain models, change analysis, and monitoring/forecasting natural hazards. Graduates specializing in Navigation are able to apply and evaluate methods for precise navigation and global surveying using geodetic space procedures and calculate precise orbits using data from GNSS and terrestrial navigation systems. They are able to analyse and solve problems of sensor fusion and integrated navigation systems and related practical applications such as car navigation, aeronautical and space applications.

ESPACE is an international degree program. As such, it involves students from a wide variety of cultural groups. Participants, thus, not only develop theoretical, methodological and technical
skills, but social and intercultural competencies as well. In the course of the program, students develop and practice their intercultural communication skills in specially designed seminar and encouraged to work in project groups. Intercultural competence is essential to work in the field of satellite technology and research, which is generally performed in an international framework at the interface of science and industry, requiring the ability to work effectively with people from different cultural and interdisciplinary groups. By taking part in various projects and seminars, the graduates gain the ability to work in teams, to positively solve conflicts in group dynamics, and to jointly develop solutions and present these accordingly.

Due to the requirement to write scientific project reports and a Master’s thesis, graduates of the ESPACE program are able to define milestones and to meet related deadlines, to problem-solve, and to critically evaluate their own work through self-reflection.

3 Target groups

3.1 Addressees

Admission requirements for applicants are an above-average Bachelor’s degree, diploma or Master’s qualification in a natural or engineering science subject and a very good command of English. No practical experience is required. Generally, the target group is composed of highly motivated candidates with affinity and interest in technical and geoscientific subjects and engineering talent from all over the world, who intend to work in the field of satellite technologies in conjunction with Earth observation.

3.2 Previous knowledge of applicants

The disciplines in which candidates completed their Bachelor's degrees, diplomas or Master's qualifications vary greatly. Exemplary, Fig. 3.1 shows the variety of subjects students have studied before attending the ESPACE programme so far. Bachelor’s degrees, diplomas or Master’s qualifications of students who have attended the ESPACE program thus far. Most common background are Electrical Engineering, Geodesy and Geosciences (about 15% each), but also many ESPACE students held Aerospace Engineering as their previous degree (11%).
The qualification of candidates for the ESPACE program is ensured by means of an aptitude assessment process which examines the specific competence and the ability to work in a methodical, principle-based and scientific manner (details are provided in the study regulations).
This is based on the submitted references and certificates. In addition to the content of the degree held (natural or engineering science subject), one particular point of focus is to check whether the competencies gained in the fields of mathematics, physics and informatics are equivalent to those skills gained in a natural or engineering science Bachelor’s degree taken at the TUM. Students must submit proof of competence in English (e.g. IELTS, TOEFL) with a minimum score of 6.5 (IELTS) or 88 (TOEFL Internet based testing) before they can be admitted to the program. A letter of motivation, two letters of recommendation from professors, and an essay on a scientific subject relevant to the general scope of the degree program need to be submitted together with the application documents. The aptitude assessment process is governed by the FPSO of the degree program and is carried out by an aptitude assessment commission. If there is any doubt about the candidate’s fulfilment of the above-mentioned qualification requirements, the applicant is invited to a video interview. The aptitude assessment process ensures that only qualified candidates are admitted, as is reflected in the very low drop-out figures. Over 90% of those who have taken part in the ESPACE program since it was launched have completed it successfully.

3.3 Target numbers

The target number of number of enrolled students per year is in the order of 30 students a year, because of the size of the available lecture halls, seminar and computer rooms, as well as supervision capacities of the program’s current staff (cf. also Section 4.3).

Since the degree program was launched in the winter semester 2005/06, 1079 applications have been submitted (incl. for the winter semester 2017/18). For further detailed numbers, please refer to Section 4.2.

4 Needs analysis

The following section 4.1 will demonstrate that ESPACE graduates are in great demand at universities, non-university research institutions and in industry. The aerospace technology industry and the fields of Earth system sciences, remote sensing and navigation are employment sectors that will grow in importance in the future. For example, natural catastrophes such as the Sumatra Earthquake (2004), the floods in Pakistan (2010) and the Tohoku Earthquake (2011) are impressive reminders that there is a great need for Earth system sciences research; the primary information sources here are the observations made from space. There is also a great need for globally available data in connection with security-related applications (e.g. for civil defence and humanitarian aid). Likewise, there is a growing international market in the field of satellite-supported positioning, navigation and logistics, all of which indicates that ESPACE graduates have excellent professional prospects (see expert assessment, Appendix).

4.1 Demand for graduates in the labour market

Graduates’ excellent competencies and skills makes the young scientists enrolled in the ESPACE program very sought-after employees. Based on all graduates (about 90) whose employment situation is known to the ESPACE program office, almost 60% of the graduates are working as researchers after completion of the program, either in ESPACE cooperating institutions (36%) or in other research institutions worldwide (23%). About 45% of the graduates go on to complete a PhD. About 41% of graduates continue their professional carrier in industry primarily in the aerospace, energy or automation sectors (e.g. Airbus Defence and Space, RapidEye, OHB-System, SpaceTech,
Sagem Defence, Mitsubishi Power Systems, General Motors, etc.). About two thirds of the ESPACE graduates start their professional career in Germany. Two expert assessments (see Appendix) show that research institutes would like to employ even more ESPACE graduates in the future.

A survey of graduates of the ESPACE Master’s program (see Appendix), performed as part of the quality assessment procedure of the Department of Civil, Geo and Environmental Engineering, revealed that quality of employment significantly increased after graduation from ESPACE.

4.2 Demand from potential students

Since the program was launched in the winter semester 2005/06, over one thousand applications have been received (incl. applications for the winter semester 2017/18). After the aptitude assessment process, 412 students were admitted (incl. applications for the winter semester 2017/18) and 269 students were enrolled (incl. those admitted for the winter semester 2012/13; Fig. 4.1).

The students who enrol in the program come from a wide range of countries (Fig. 4.2). The largest percentages of students come from China (34 %), India (21 %) and Germany (9 %). Consequently, with 91% the rate of participation by international students is very high. The most common reasons why 35 % of the admitted students do not actually take up their space in the program are difficulties relating to finding funding for the course and accommodation, refused visa applications and the decision to take up a different Master’s degree program.

By the end of the summer semester 2017, more than 180 students had successfully completed the ESPACE Master’s program.

Fig. 4.1: Number of applications, admissions, enrolment figures and graduates of the respective program year since the Master’s degree program started in WS 2005/06.
Fig. 4.2: Continents and countries of origin of ESPACE students

The ESPACE degree program was approved in May 2005 so that there was little time to advertise it for the upcoming winter semester 2005/06; nevertheless, 9 students enrolled. Since then, advertising
both at home and abroad has intensified. In particular, a new website was created and the information material (flyer, cf. Appendix) revised. The application figures have also increased thanks to the attendance of ESPACE staff at numerous student information events (e.g. Masterbeurs, Space Technology Education Conference (STEC), Open Day at DLR) and the inclusion of the ESPACE program in the DAAD information brochure. The successful definition and establishment of a professional profile (Satellite Applications Engineering) also led to an increase in the number of applications for the program (Fig. 4.1). The number of applications for the program was razing continuously over the years, and during the last three intakes has been oscillating around 140. The number of admitted students of about 40 per year, shows the intention of ESPACE to select only the top students. Since winter semester 2012/13 the number of admitted students includes also 5-10 candidates involved in the Double Degree program with Wuhan.

4.3 Limiting factors
The target number of number of enrolled students per year is in the order of 30 students a year. Limiting factors are the size of the available lecture halls, seminar and computer rooms, as well as supervision capacities of the program’s current staff.

Fast processing of the applications is essential especially in the case of international degree programs, which all compete globally for the most talented students. Most of these students apply for several degree programs at different universities. Experience has shown that many of these applicants decide in favour of the degree program that offered them a position first, allowing them much more time to take care of their funding, visas and accommodation. This is why ESPACE endeavours to carry out aptitude testing promptly and to inform the applicants of their results as soon as possible. ESPACE aptitude assessment commission recommends applicants from non-EU countries to apply before 15th of March for the following winter semester intake.

Before the applications are assessed by the aptitude assessment commission, the enrolment office checks that all documents have been submitted. This preliminary check also establishes whether the submitted qualifications were granted by recognized universities. Also, the final grades are converted to the German grading system. This service is a great help for the aptitude assessment commission.

As mentioned in Section 4.2, many applicants do not accept their offer of admission. Reasons for this include difficulties with funding their studies and accommodation, refused visa applications and the decision to take up a different Master’s degree program. It is therefore difficult to estimate in advance how many admitted applicants will actually commence their studies. Early notification of admission to the program may be one way to counter this.

4.4 Quantitative target figures
A student enrolment of circa 30 is the goal in the medium term, a figure which matches the department’s resources for the program. Due to increased advertising and the growing number of recommendations by former students, as well as the cooperation projects such as the Double-Master’s program with the Wuhan University, it is realistic to assume that this figure will grow in the near future. There has already been a steady increase in applications over the past few years and the goal of a student enrolment of 29 for the winter semester was achieved (Fig. 4.1). As a result of the cooperation with Wuhan University, 5 to 10 new enrolments are expected as part of the double degree program each year, which makes a yearly student intake of around 30 a realistic goal.
5 Competition analysis

5.1 External competition analysis

ESPACE is an international interdisciplinary consecutive Master’s degree program. There is no degree program with comparable portfolio in Germany.

The degree program is positioned within the scope of the field that examines the observation of the Earth system from space at the TUM. It occupies a strategically important future position at the interface between engineering science and the natural sciences. Also, thanks to its inclusion in numerous external scientific institutions and the space industry, ESPACE is a prototype of a degree program within the Munich aerospace industry (see Section 1.2.3).

ESPACE builds an interdisciplinary bridge between space technology and the engineering and Earth science-related use of satellite data, allowing technical aspects to be linked with applications. In contrast to the conventionally separate degree programs in these fields, such as geodesy, geophysics, mechanical and electrical engineering, aerospace engineering, as well as physics, informatics and geosciences, ESPACE combines this knowledge into one unique degree program. Better suited than students who study these separate fields, ESPACE graduates are able to take a more comprehensive look at decisive positions in the scientific and commercial fields and to mediate between the disciplines. The integration of technology knowledge and application know-how into a single program is particular to the ESPACE program, making it unique in Germany. Moreover, English is the official language of instruction of the ESPACE program, making it attractive to students from around the world. Related Master's degree programs on other space-related topics with different focal points are offered in Toulouse, Strasbourg and at the TU Delft.

By virtue of the high concentration of scientific institutions in the fields of satellite technology, Earth sciences, remote sensing and navigation, and the various companies working in the space industry, there is a high level of interest in the Munich region for the junior scientists trained in the ESPACE program (see also expert assessment, Appendix). Therefore the degree program is ideally positioned at the TUM.

5.2 Internal competition analysis

The ESPACE degree program is primarily run by the TUM Chair of Astronomical and Physical Geodesy (APG), supported by 5 further Chairs of the Focus Area Geodesy Satellite Geodesy, Geodetic Geodynamics, Photogrammetry and Remote Sensing, Remote Sensing Technology, Signal Processing in Earth Observation. The profile of ESPACE is different from all other Master's degree programs run at the TUM.

Its interdisciplinary concept also makes the degree program an ideal supplement to the portfolio of rather more specialized TUM degree programs in these disciplines. In terms of content, there is no competition. The related degree programs (geodesy and geoinformation, aerospace) primarily run by the above-mentioned institutes are much more specialized, and consequently have a different focus and pursue other degree program objectives. Until WS2016/17, there have been no overlaps for applications for ESPACE and these degree programs. Due the fact that since WS2017/18 the M.Sc. Geodesy and Geoinformation (GuG) is offered in English language, a few overlaps for applications to ESPACE and M.Sc. GuG could be recorded. However, this can be attributed to the fact that there are several applicants every year who apply for admission to the various international Master's programs at the TUM. For example, ESPACE competes with the Computational Mechanics (CoMe) degree program that also targets international students with engineering science backgrounds. While there are few overlaps between ESPACE and other English-language degree programs at the TUM,
studying at the TUM is highly attractive for foreign students, which is why they often apply for several programs to increase their chances of admission to the university.

In some subjects there are correlations between ESPACE and other degree programs from different departments at the TUM and LMU. ESPACE lecturers also teach the English-language Master's degree programs Geodesy and Geoinformation (BGU), Environmental Engineering (BGU), Transportation Systems (BGU), Cartography (BGU), Communications Engineering (EI), Geophysics (LMU and TUM) and the German-language Master’s degree programs Electrical Engineering and Information Technology (EI) and Aerospace (MW). Numerous teaching events from the ESPACE program can also be selected as elective subjects for the GuG degree program.

6 Structure of the degree program

ESPACE is a method- and application-oriented degree program. Important elements are technical key components (as required e.g. to plan, design or execute a satellite mission) and special engineering and scientific methods required to evaluate, analyse and interpret satellite data.

The normal program is comprised of 4 semesters (Fig. 6.1). The degree program is taught in English only. The structure of the degree program is as follows:

1) Semester 1 and 2: Basics and fundamentals

In the first two semesters all modules are obligatory, because the students must acquire basic skills in Earth system science, remote sensing and navigation, mathematical and physics-based subjects (numerical modelling, signal processing and microwave remote sensing and estimation theory) as well as lectures in the fields of satellite technology and orbital mechanics (spacecraft technology, orbit mechanics and on-orbit dynamics and robotics) and applied satellite usage (projects in Earth observation and mission engineering). Several modules have the goal to bring the students coming from a wide range of different Bachelor’s programs to the same level of knowledge (confer, e.g., justification of small modules, see Appendix). After these two semesters, students have acquired the competencies concerning the basics of the above mentioned subjects, to identify the links and interfaces among different subjects of Earth and space science, to apply basic methodologies and to assess and interpret scientific and technological results. This is a pre-requisite to fulfill one of the program’s main goals, i.e. that ESPACE graduates are able to work in an interdisciplinary environment and with experts from all relevant fields of Earth-oriented space science and technology.

2) Semester 3: Specialization

In addition to the broad spectrum of competencies acquired during the first two semesters, in the third semester the students can select one of the three areas of concentration, namely (1) Earth System Science from Space, Remote Sensing, or Navigation (Fig.6.2). Thus, they deepen their methodological competencies, are able to develop, upgrade and apply dedicated methods and to gain advanced expertise in one of these three core subjects. The chosen core subject serves as the thematic context for practising and sharpening their methodical competencies in a particular field. In addition to the required module “Spacecraft technology” (8 Credits), students select 3 required elective modules (3 times 6 credits) for each specialization. The 3 areas of specialization and the composition of the corresponding required elective modules ensures the comprehensiveness of students’ profiles. The remaining 8 Credits of the 3rd semester are electives, which offer the opportunity to either sharpen this profile even in more depth, or alternatively to develop a wider profile beyond the main topics of the specialization. As elective modules, the students can take
modules from not selected specializations. This enables them to deepen interdisciplinary knowledge across the specializations. Figs. 6.3 to 6.5 show the complete degree program for the three fields of specialization.

3) Semester 4: Master’s thesis

The fourth and last semester is used to write the Master’s thesis and defend it in a public Master’s colloquium. With the Master’s thesis the competence to perform scientific work independently and to properly document the results are verified.
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<td>Introduction to Earth System Science</td>
<td>Projects in Earth Oriented Space Science and Technology</td>
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<td></td>
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<tr>
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<tr>
<td>30 Credits</td>
<td>30 Credits</td>
<td>30 Credits</td>
<td>30 Credits</td>
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</table>

Fig. 6.1: Overview of the current ESPACE study plan: the table shows the individual modules including the module type and the credits.
<table>
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<tr>
<th>Specialization</th>
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<th>Credits</th>
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<tr>
<td>Atmosphere and Ocean</td>
<td>Photogrammetry</td>
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</tr>
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<td>Navigation Labs</td>
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</tr>
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<td>Type of Module:</td>
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<tr>
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Fig. 6.2: Specialization options in the third semester: An overview of the three areas of specialization with their respective modules. The modules are compulsory modules within the respective specialist field.
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
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</thead>
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<tr>
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<td>6 Credits</td>
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<td>6 Credits</td>
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<td><strong>Introduction to Photogrammetry Remote Sensing and Image Processing</strong></td>
<td><strong>Satellite Navigation and Advanced Orbit Mechanics</strong></td>
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<td>Type of Module: required</td>
<td>Type of Module: required</td>
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<td>6 Credits</td>
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<td>3 Credits</td>
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<td>4 Credits</td>
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<tr>
<td>3 Credits</td>
<td>3 Credits</td>
<td>8 Credits</td>
<td>8 Credits</td>
</tr>
</tbody>
</table>

| 30 Credits                          | 30 Credits                          | 30 Credits                          | 30 Credits                          |

Fig. 6.3: ESPACE degree plan for specialization “Earth System Science from Space”. 
<table>
<thead>
<tr>
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<tbody>
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<td><strong>Introduction to Earth System Science</strong></td>
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<td><strong>Master's Thesis</strong></td>
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<td><strong>Electives</strong></td>
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<td><strong>Applied Computer Science</strong></td>
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<td><strong>30 Credits</strong></td>
<td><strong>30 Credits</strong></td>
<td><strong>30 Credits</strong></td>
</tr>
</tbody>
</table>

---

Fig. 6.4: ESPACE degree plan for specialization “Remote Sensing”.

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20
In addition to regular lectures and accompanying exercises, the degree plan also includes excursions, projects and seminars. These team-building activities serve to promote cohesion within the group, thereby allowing interdisciplinary skills and social competencies to be acquired (e.g. intercultural communication, team work in given projects). At the beginning of the 1st semester, students go on a two-day excursion to the Geodetic Observatory in Wettzell that is run jointly by the Federal Office for Cartography and Geodesy (BKG) and the TUM. This excursion offers an introduction to the degree program and also allows the students to get to know each other. Teamwork is also encouraged by means of several projects that are part of the compulsory and elective program. In particular, this includes the module projects in Earth oriented space science and technology in the 2nd semester that consists of a broad software project on the topics of analysis.

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**Fig. 6.5: ESPACE degree plan for specialization “Navigation”.**
and validation of satellite data (for example sea level observation). A series of seminars in the 2nd semester, during which every student needs to hold a presentation about a given current scientific topic from within the ESPACE environment, not only serves specialization purposes, but it also helps to develop soft skills (presentation techniques, rhetoric, structured style of preparation and work) and thus to strengthen their individual competencies. Also, numerous presentations as part of the specialization modules in the 3rd semester help teach the students how to make presentations, hold lectures and defend their own work. Beyond the degree plan, there are also seminars on the topics of intercultural awareness and culture in a university context (1st semester) and writing techniques for the Master’s thesis (4th semester). The linguistics department of the LMU organises these events specifically for the ESPACE program.

In the Appendix, the implementation of the course time schedule for the first 3 semesters is provided.

6.1 Mobility

ESPACE is an international degree program. Most of the participants therefore come from abroad. Because the program is taught in English, ESPACE events highly interesting for many students that come to the TUM as part of the ERASMUS program.

To encourage mobility among the ESPACE students, the program offers students the opportunity to write their Master’s thesis abroad under the joint supervision of a foreign and TUM lecturer. This is highly popular among the students. In the past, Master’s theses have been completed at the following foreign institutes: European Space Agency, University of Leeds, Ecole Polytechnique (Canada), California Institute of Technology (Caltech)/NASA Jet Propulsion Laboratory (JPL), Universidad Politecnica de Madrid, University of Hawaii.

As of the winter semester 2010/11, there is a Double-Master’s Agreement with Wuhan University (WHU), China, one of the TUM’s partner universities. The agreement, which has been extended in 2015 for another 5 years, governs the TUM’s first Double-Master’s program with a Chinese university. The WHU is the most important university in China in the fields of geodesy and geoinformation. Students who want to take part in the Double-Master’s program need to study for an extra year (three instead of two years), during which at least one whole year needs to be spent at the WHU and one whole year at the TUM. The specialization option in the third year of the program is available at both the TUM and the WHU allowing the students free choice of where to study their specialized subjects. The Master’s thesis (six months) is supervised jointly by professors of both universities. This also strengthens the research cooperation between both universities. Graduates of the Double-Master’s program receive two Master’s certificates, one from the TUM and one from the WHU. The Double-Master’s agreement between both universities that was signed in 2010 governs the process and the curriculum of the Double-Master’s program. The first ten students from WHU are started their studies at TUM in the winter semester 2012/13. Since then, every year continuously 6 to 10 new Double Degree students coming to TUM. In addition, a number of students at TUM decided to purchase the Double Degree and went to Wuhan University for a period of one year.

6.2 Structure

All lectures for the degree program are organised so that they do not overlap within the respective semester. The students can easily attend all compulsory and elective events. The rooms that are used on the main grounds of the TUM are just a few minutes’ walk from each other. All events that take place at the TUM Campus Garching are scheduled for the same day. This means that students do not need to commute between two locations on one day. Detailed course schedules are enclosed in the Appendix. There is enough time between the events for preparation and follow-up. Depending
on the selected specialization, there are some days that are completely free of events from the 3rd semester onwards. These days are available for studying or also for other activities e.g. work as a student assistant or tutor.

7 Organizational set-up and responsibilities

7.1 Organizational set-up

The degree program is run by the Department of Civil, Geo and Environmental Engineering at the Technical University Munich. This department is also responsible for the degree program. Six out of ten Chairs of the Focus Area Geodesy of the Department of Civil, Geo and Environmental Engineering are responsible for the main student teaching load. The Department of Mechanical Engineering (in particular the Chair for Astronautics (LRT)) and the Department of Electrical Engineering and Information Technology Informatics (in particular the Chair of Communication and Navigation) make important teaching contributions. Related letters of intent by the two departments are included in the Appendix.

By including numerous scientists from the TUM, LMU, UniBW, DLR, and industry (e.g. ESA) in the teaching concept, ESPACE makes benefit of the concentrated potential of the Munich region in the fields of satellite technology, Earth sciences, remote sensing and navigation (Fig. 7.1), as it is described in Chapter 2.

The degree program is managed by a Directing Board comprising the six professors of the Focus Area Geodesy that directly contribute to ESPACE (Prof. Bamler, Prof. Hugentobler, Prof. Meng, Prof. Pail, Prof. Seitz, Prof. Stilla). Prof. Pail is the Program Director. Strategic questions of the ESPACE degree program are regularly discussed in an Extended Directing Board, which is comprised of representatives of all contributing institutions. There is also an ESPACE program office in which a program coordinator and academic counsellor and a team assistant take care of all student affairs and the administration.

As part of the Double-Master’s Agreement, Wuhan University (WHU), China, is also involved in training the students that choose this program (see Section 6). Furthermore, the teaching activities for the ESPACE program are linked to numerous research projects at the participating institutions.
Fig. 7.1: Overview of the participation by various organizations in the ESPACE degree program

Links to the websites of the organizational units:

www.espace-tum.de
www.bgu.tum.de/iapg
www.pf.bgu.tum.de
www.lfk.bgu.tum.de
www.dgfi.tum.de
www.lrt.mw.tum.de
www.nav.ei.tum.de
www.dlr.de/caf
www.dlr.de/kn
www.dlr.de/rm
www.unibw.de/nav
www.geophysik.lmu.de

7.2 Administrative responsibilities

ESPACE students are enrolled at the TUM. The admissions procedure, academic counselling, student and examination management of the degree program are organized by the ESPACE program office based at the Chair of Astronomical and Physical Geodesy (BGU).
The program management, the management of the ESPACE study commission and the management of the aptitude assessment commission is the responsibility of the program director. The positive development of the ESPACE program is largely due to the installation of its own program office, which coordinates and manages the program, and also offers academic counselling services. The program office is closely involved in developing the degree program (modularization, FPSO, ensuring the admission requirements are satisfied), advertising (flyers, website, participation in international information events and exhibitions) and various student affairs (counselling, examinations, study handbook).

ESPACE is attached to the geodesy study commission, which is responsible for all 5 study programs hosted at the Focus Area Geodesy. The presence of student representatives also from the ESPACE degree program guarantees that the interest of students and needs of the students are adequately considered and treated. The study commission is chaired by Prof. Thomas Kolbe.

The aptitude assessment commission is managed by the program director. A further university lecturer and the program coordinator are also on the commission. A student representative assumes an advisory role.

The ESPACE examination board is headed by Prof. Hugentobler (FESG, BGU). Other members of the examination board are the program director (Prof. Pail), two additional professor from the BGU department (Prof. Stilla, Prof. Seitz), and one representative from the mechanical engineering department (Dr. Rott, LRT), a representative of the examination office and the secretary of the examination board.

8 Resources

8.1 Human resources

8.1.1 Teaching staff

The largest contribution to the students’ training is made by six chairs of the Focus Area Geodesy (BGU). Many of the teaching events for the ESPACE program are also offered by the Chair for Astronautics (LRT).

One special feature of the degree program is the involvement of many excellent scientists from the institutes in and around the TUM. In the greater Munich district, there is a unique concentration of expertise in the fields of satellite technology, Earth sciences, remote sensing and navigation spread among the three universities (TUM, LMU, UniBw), research institutes (e.g., DLR) and industry. ESPACE taps this potential by involving numerous scientists from the TUM (departments BGU, MW, El), LMU, UniBw, DLR, DGFI and industry (Airbus, OHB) in the degree program coordinated by the BGU department (Fig. 7.1).

DLR’s commitment to the ESPACE teaching concept should be highlighted. The holder of the TUM Chair for Remote Sensing Methods (Prof. Bamler) and the TUM Chair for Communication and Navigation (Prof. Günther) are also the heads of the respective institutes at the DLR and are very closely involved in the ESPACE program. The DLR expressly supports the degree program via its scientific staff and allows the students to take an active part in projects e.g. as part of their Master’s thesis or as student assistants.

The close involvement of experts from various fields of expertise from non-university organizations is one of the outstanding features of the degree program. The degree program profits greatly from this
commitment, however it does not depend upon it for teaching. If there was a drop in the participation of speakers from outside, the events, especially in the compulsory and elective modules, could still be held by competent staff from the TUM.

8.1.2 Further staff
There are two members of staff in the program office responsible for the organization and coordination of the degree program, student affairs and administrative tasks.

8.2 Equipment, rooms
The main lecturing room used by the ESPACE degree program is the seminar room HS 2609. Some lectures within the degree program also take place in the lecture halls HS 0120 and HS 0714. The students of the degree program can also use the APG’s computer room. The CIP pool of the BGU department is also available.

There is a library containing many relevant books for the ESPACE program office that have been procured especially for the degree program. There are enough resources available to complete the degree program successfully.