Space & Aeronautics Department

Master SPACE

Earth Observation
Astrophysics
Satellite Technologies

V17 – January 1st, 2016

(LC = Lecture Class ; TC = Tutorial Class ; LW = Lab Work)

Master 1st year – 60 ECTS

Semester 1 (30 ECTS)

Core syllabus (20 ECTS):

11.1 Human, Economic, Social and Juridical Sciences (5 ECTS)

11.2 Introduction to Astrophysics & Earth Observation (2 ECTS) – LC: 20h

Coordinators: Denis Puy – Catherine Prigent

Teachers: *Pham Thi Tuyet Nhung*

General introduction to astrophysics on one side and Earth observation.

11.3 Introduction to Satellite Technologies (3 ECTS) – LC: 30h

Coordinators: *Pham Anh Tuan*

Teachers: *Pham anh Tuan, Hoang The Huynh, Le Xuan Huy*

Space history, space environment, satellite mission, satellite orbit and constellation, satellite subsystems, rocket introduction, ground station, AIT, space applications, system engineering, satellite project and activities, laboratory visit.

11.4 Optical, Infrared and Microwave Imaging Systems (4 ECTS) – LC: 16h ; TC: 16h ; LW: 8h

Coordinators: Gérard Rousset

Teachers: Gérard Rousset, Damien Gratadour, *Jean-Claude Souyris*

- *Radiometry, Planck law and surface properties, diffraction theory. Optical transfer and point spread functions of an optical system, image formation theory of an extended source. Image sampling and sensor scaling. Static and dynamic aberrations, Image array sensors*
- *Antennas. Active and passive microwave imaging systems (radar, interferometric aperture synthesis radar)*

11.5 Signal Processing (3 ECTS) – LC+TC: 15h ; LW: 15h

Coordinator: Damien Gratadour

Teachers: Gérard Rousset, Guillaume Patanchon, Damien Gratadour, *Tran Duc Quynh*

Basics of statistics, Fourier transform, sampling, filters, impulse response, transfer function, convolution, random signals, correlation, power spectrum density, noise

reduction

11.6 Algorithmics and Programming (3 ECTS) – LC: 15h – LW: 15h

Coordinator: Cyrille Rosset

Teacher: Cyrille Rosset

UNIX environment, standard commands, shell. Programming: interpreted vs compiled languages. Basics of programming in Python: loops, conditions, pointers and arrays, functions, input/output. Algorithms

Satellite technologies (10 ECTS)

11.7 Advanced Electronic Systems (4 ECTS) – LC+TC: 16h – LW: 24h

Coordinator: Damien Prêle

Teacher: Damien Prêle

- ***Filters**: Filter parameters, Amplitude responses and Bode plot, Polynomial filter synthesis using Sallen-Key cells. Tutorial and practical work : Active Butterworth and Chebyshev low-pass filters.*
- ***Power supply:** Linear vs switched-mode power supply, DC/DC Buck, Boost and Flyback converters, Feedback regulation - control. Tutorial and practical work : Pulse Width Modulator - PWM, DC/DC Buck converter and regulation.*
- ***Phase Locked Loop:** Phase detector and Voltage Control Oscillator - VCO. Tutorial and practical work : Frequency Shift Keying - FSK demodulation and frequency synthesis.*
- ***Modulation:** Basic of transmitted signals. Amplitude modulation, modulation index, Rectifying and product demodulation. Tutorial and practical work : Modulation with and without carrier transmission. Modulation index measurement. Envelope and product detection.*

11.8 Telecoms and Antennas (3 ECTS) – LC+TC : 28h – LW : 12h

Coordinator: Alain Maestrini

Teacher: Alain Maestrini

- ***Telecoms:** Basics of source and channel coding. Channel capacity. Basics of digital modulation and demodulation. Practical case of transmissions from space instruments*
- ***Antennas:** Basics of guided waves and antenna theory. Antenna pattern, gain, and impedance. Friis formula of radio link budget. Practical antennas and arrays for space instruments. Up and down conversion for signal transmission. Heterodyne detection. Receiver and system equivalent noise temperature.*

11.9 Radiation Thermometry (3 ECTS) – LC: 15h – TC: 15h

Coordinator: Tristan Buey

Teacher: Tristan Buey

Space thermal environment, heat sources, thermal transfer processes (conduction, convection and radiation), heat equation, Fourier's law, black body radiation, Stefan-Boltzmann law, emissivity and absorptivity, Kirchhoff's law of thermal radiation, thermal design and control of satellites, forced convection, introduction to finite element methods

Science from Space (10 ECTS)

11.10 Fundamental in Physics – I (4 ECTS) – LC: 20h ; TC: 20h

Coordinator: Guillaume Patanchon

Teacher: Guillaume Patanchon, Denis Puy

This includes three separate modules:

- *Statistical Physics: thermodynamics, microcanonical ensemble, canonical and grand-canonical ensembles, quantum gas. Goal is to define thermodynamical quantities such as entropy, temperature, chemical potential. Applications : ideal gas, crystals (Einstein model).*

- *Applied electromagnetism: Maxwell equations, propagation of light in continuous media, continuity equations, Fresnel coefficients (to be coordinate with Bachelor program)*
- *Introduction to quantum mechanics*

11.11 Earth and Planetary Sciences (3 ECTS) – LC: 20h ; TC:10h

Coordinator: *Ngo Duc Thanh*

Teacher: *Ngo Duc Thanh*, Sonia Fornasier

General introduction to Earth and planetary geophysics: solid Earth, atmosphere, ocean, continental surfaces ; climate studies and global change; electromagnetic environment of the Earth

11.12 Astrophysics (3 ECTS) – LC: 20h ; TC: 10h

Coordinator: Denis Puy, *Pham Thi Tuyet Nhung*

Teachers: Denis Puy, *Pham Thi Tuyet Nhung*

Stellar physics, exo-planets, galactic physics, cosmology. Objects of astrophysics: stars, galaxies, Universe. Observations: coordinates, distance measurements.

Semester 2 : 30 ECTS

Core Syllabus (11 ECTS):

12.1 Celestial Mechanics and Orbitography (2 ECTS) – LC:10h ; TC:10h

Coordinator: Hubert Halloin

Teacher: Hubert Halloin

- *Celestial mechanics and spherical trigonometry*
- *Time and space reference frames*
- *Two-body problems, Keplerian orbits and osculating parameters*
- *Orbital perturbations and maneuvers*
- *Interplanetary trajectories*

12.2 Space Project Management (3 ECTS) – LC: 20h ; TC: 10h

Coordinator: Emmanuel Hinglais

Teachers: Emmanuel Hinglais, Rodolphe Clédassou

Educational content:

- *Participating as part of a project throughout its life cycle*
- *A 30-hour module is not sufficient to train an operational Project Manager. Course aims to show students how to work within a project early in their professional career how to work within a project, from start to finish. Only after several years of practice can these engineers acquire to manage a project throughout its life cycle*

12.3 Physics of Radiation and Particle Detectors (3 ECTS) – LC:10h ; TC: 10h ; LW: 10h

Coordinator: Eric Nuss

Teachers: Eric Nuss, *Pham Thi Tuyet Nhung*

Description of the radiation and particle interaction processes with matter.

General characteristics of sensors, detectors and measurement chains for astrophysics and space instrumentation

12.4 Numerical Methods (3 ECTS) – LC: 18h ; TC+LW: 18h

Coordinator: Stéphane Jacquemoud

Teacher: Stéphane Jacquemoud

Basic concepts (matrices, Taylor series); differential equations (boundary value problems, partial differential equations); roots of functions (one and two variables); minimization / optimization of multivariate functions (chi2 - least squares method, nonlinear functions)

Satellite technologies (12 ECTS)

12.5 Mechanics of Structures (including PLMCC) (3 ECTS) – LC: 20h ; TC: 20h

Coordinator: Jean-Laurent Dournaux, *Nguyen Manh Cuong*

Teacher: *Nguyen Manh Cuong*, Jean-Laurent Dournaux

Stress and deformations. Constitutive relations, Hooke's law. Choice of materials. Mechanics of continuous media, application to solving a beam subjected to tensile-compression or bending solicitations. Structural dynamics. Thermoelasticity. Buckling. Introduction to finite element modeling

12.6 Workshop on Small Satellites Design (4 ECTS) – LC+TC: 40h

Coordinators: *Le Xuan Huy*, Linda Tomasini

Teachers: Linda Tomasini, *Le Xuan Huy*, Joël Michaud

- *Basic knowledge to design a spacecraft :*
  - *Choice of the orbit (through exercises on heliosynchronism, phasing, rentry)+ programmation (Matlab) of a propagator*
  - *Attitude control (through the programmation of a 3 axis controller on Matlab) and equipment choice on the internet*
  - *RF subsystem sizing (links budgets) and choice of equipments on the internet*
  - *Power subsystem sizing (solar flux, battery, solar array, energy balance exercice) and choice of equipments on the internet*
  - *Thermal subsystem (7 node thermal model on Excel to calculate spacecraft temperature)*
- *2nd part :*
  - *Structure design and analysis (Study design requirements based on rocket environments, material selection, design, structure thermal model, EM, FM, vibration analysis, modal analysis,..)*
  - *Attitude determination for attitude control (requirement analysis, attitude representations, attitude dynamics and kinematics, sensor modelling, attitude determination algorithms numerical simulation and testing, ...)*
  - *Command and Data Handling (requirement analysis, telemetry and command collecting, interface design, development plan, test plan,..)*

12.7 ADCS: Attitude and Orbit Control Systems (3 ECTS) – LC+TC: 30h

Actuators and sensors, dynamics of satellites, kinematic representations (quaternions, rotation matrices and Euler angles), internal and external perturbation torques, rigid and articulated structures, stabilisation techniques and associated performance, stability criteria

12.8 Control Engineering (2 ECTS) – LC: 10h ; TC: 10h

Coordinator: Denis Perret

Teachers: Denis Perret, *Hung Xuan Truong*

Linear systems, transfer functions ; Frequency-domain analysis of linear systems ; Analysis of linear feed back systems ; Analysis of discrete-time signals ; Stability and performance of discrete-time systems ; Discrete-time control systems ; State-space representation of continuous-time systems ; State-space representation of discrete-time systems ; State feedback control

Science from Space (12 ECTS)

12.9 Fundamental in Physics II (4 ECTS) – LC: 20h ; TC: 20h

Coordinator: Isabelle Kleiner

Teachers: Isabelle Kleiner, Ha Tran, Eric Nuss, *Ngoc Hoa Ngo*

- *Introduction to subatomic physics: relativistic kinematics, type of reactions, decay, cross-sections.*
- *Fundamental physics of remote sensing: radiation emission (Planck's law); intrinsic*

properties of matter (complex refractive index, dielectric constant, atomic and molecular spectroscoscopy); scattering (Rayleigh, Mie, non-selective); radiative transfer

12.10 Earth Observation: Methods and Applications I (4 ECTS) – LC: 16h ; TC: 24h

Coordinator: Catherine Prigent

Teacher: Catherine Prigent, Thuy Le Toan

Course provides basic knowledge of the various remote sensing sensor families, including optical, infrared and microwave radiometers, spectrometers, and active sensors such as lidars, radars, SAR, and altimeters. Selected applications (weather forecasting, hydrology, land use change, vegetation monitoring, oceanography, urban areas)

12.11 Image Processing (4 ECTS) – LC: 20h – TC: 20h

Coordinator: Nicolas Delbart

Teacher: *Duc My Vo*

Statistic extraction and image enhancement: histograms, univariate and multivariate statistics, convolution, Fourier 2D, filtering, edge detection. Segmentation: supervised and unsupervised classification, clustering. Inverse problem: multi-linear regression, neural network, bayesien estimation...

12.12 Two-month internship (7 ECTS)

Master 2nd year – 60 ECTS

Semester 1 (30 ECTS)

21.1 Human, Economic, Social and Juridical Sciences (5 ECTS)

21.2 Observational Techniques (3 ECTS) – LC+TC: 30h

Coordinator: Marcello Fulchignoni

Teacher: Cédric Leyrat

Use and performances of different types of space instruments.

21.3 Space and Application Project (3 ECTS) – LC+TC: 20h ; project: 40h over 2-3 months

Coordinator: Benoît Mosser

Teacher: Benoît Mosser

This module aims to train the students to the first phases of definition of a space project.

21.4 Earth Observation Engineering (2 ECTS) – LC+TC: 20h

Coordinator: Linda Tomasini

Teachers: Linda Tomasini, Joël Michaud

Educational objectives are to understand the principles of earth observation space systems engineering in the early design phases

- *To know the main types of earth observation missions*
- *To know how to capture and analyse user needs*
- *To know what an earth observation space system consists of*
- *To know how to identify the driving parameters of an earth observation mission*
- *To understand the iterative process between user needs definition and design*
- *To understand the interdependency between the different elements of an earth observation space system*

Teaching is based on Earth observation missions real case exercises and lectures on topics addressing the different steps of Earth observation engineering process as well as the remote

sensing principles and techniques.

21.5 Earth Observation: Theory and Observation (3 ECTS) - LC+TC: 30h

Coordinator: Thuy Le Toan

Teachers: Nicolas Delbart, Thuy Le Toan

Remote sensing physics and sensors : light-matter interaction, spectroscopy, radiative transfer, radiometry. Remote sensing imagery analysis methods and applications.

21.6 Advanced Astrophysics (3 ECTS) - LC: 25h ; TC: 5h

Coordinator: Daniel Rouan

Teachers: Daniel Rouan, Davide Perna, Pierre Lesaffre, *Nguyen Quynh Lan, Nguyen Anh Vinh*

The Earth is considered a "ground thruth" in the interpretation of the natural processes taking place on the other planets of the Solar system. A short overview on the available knowledge on the extrasolar planets.

21.7 Data Processing and Numerical Simulations (3 ECTS) – LC+TC+LW: 30h

Coordinator: Nicolas Delbart

Teachers: Nicolas Delbart, *Nguyen Thi Hoang Anh*

Data preprocessing and analysis of long images times series (MODIS, VGT) or other archive with matlab, parameters extraction. - Coupling satellite images with external geographic information with GIS software (QGIS). - Neo channel calculation via Principal Component Analysis. - Object extraction via mathematical morphology.

21.8 Spacecraft Architecture (2 ECTS) – TC+LC: 20h

Coordinator: Rodolphe Clédassou

Teachers: Rodolphe Clédassou, Emmanuel Hinglais

- *To understand how the requirements and the constraints of a mission orient the design of a spacecraft.*
- *To design a satellite and its ground segment it is first necessary to express the mission needsand to challenge them against the requirements and the making constraints*

21.9 GNS, Telemetry (2 ECTS) – LC+TC: 20h

Coordinator: Claude Zurbach

Teacher: Claude Zurbach

Introduction to GNSS: the case of GPS - Geodesy and coordinate systems - From orbit to ECEF position - GPS: determining position - Transmission and signal processing - Other GNSS - AMS02: a case incorporating a GPS receiver in a spatial experimentation on ISS.

21.10 The Effect of Ionizing Radiation on the Components (2 ECTS) – LC+TC: 20h

Coordinator: Frédéric Saigné

Teacher: Frédéric Wrobel

Radiation-induced failures in microelectronics pose a growing concern in the aerospace and avionic communities. Incident radiation acting on these devices is mainly due to cosmic rays and their secondary particles produced in the Earth atmosphere. Energetic particles induce various device malfunctions via their interaction with materials in electronic devices. We will present the principles of Monte Carlo simulation tools, which are very useful to establish the transient current shapes and to evaluate the soft error rates.

21.11 Finite Element Method, Control Engineering (2 ECTS) – LC+TC: 20h

Coordinator: Jean-Laurent Dournaux

Teacher: Jean-Laurent Dournaux

Refresher course of Structural Mechanics and Thermal FE modeling principles, symmetries Finite Elements (linear, plate, volume...), theory, presentation and use How to solve problems in linear elasticity (static of dynamic), buckling and thermoelasticity Geometric non-linearities Composites Applications: modelling of a deformable mirror, a supporting truss structure...

Semester 2 (30 ECTS)

21.12 Six-month internship (30 ECTS)